Report by the ETSRC on
Europe's 2-4m OIR telescopes over the next decade

Background

The ASTRONET Science Vision and Infrastructures Roadmaps concluded that there is an urgent need to define a strategy for 2-4m telescopes at the European Level. Accordingly a panel has been set up to identify how Europe's medium sized telescopes can best contribute to the delivery of the Science Vision and to propose how a suite of existing telescopes can do so cost effectively. This panel will deliver their final report in the first quarter of 2010.

The following membership and terms of reference for the European Telescopes Strategic Review Committee (ETSRC) were agreed on:

Membership

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Terms of Reference

The European Telescope Strategy Review Committee (ETSRC) is appointed by the ASTRONET Board in coordination with the OPTICON Executive Committee to consider the issues listed below.

Its remit is to deliver to ASTRONET, by March 1 2010, a strategy to optimize, in concert with OPTICON, the use of 2-4m class optical/infrared telescopes by the European astronomical community, considering both short- and medium- to long-term timescales.

Special attention should be paid to develop this strategy in close interaction with the telescope owners – especially through the OPTICON Telescope Director's Forum – and with extensive feedback from the community at large.

To fulfil its remit, ETSRC will in particular:

(1) Identify those goals of the ASTRONET Science Vision that are most effectively delivered by 2-4m-class optical/infrared telescopes;

(2) Identify which observational capabilities (site, field of view, instrumentation capabilities and operation modes) are required;

(3) Establish an appropriate balance between the scientific, technological and educational goals of 2-4m class telescopes, taking into account contributions from both larger and smaller facilities;

(4) Among the scientific tasks, consider the appropriate balance between large-scale survey-type efforts, including complementary ground-based programmes in support of European space missions, and free access by individual researchers;

(5) Develop a realistic roadmap, including any necessary technical developments and upgrades, and organisational/financial arrangements, which would enable a set of European 2-4m-class telescopes to deliver the best scientific output for European astronomy in a cost-effective manner;

(6) Analyse major needs and opportunities for collaboration on the global stage, e.g. with the US system proposed by the ReStar committee.

(7) Propose arrangements for open access to all data, e.g. through the Virtual Observatory

It is expected that a similar pan-European exercise will be done around 2015 for 8-10m class telescopes with significant European ownership; ETSRC should where appropriate take into account this further phase in its strategic analysis.

Since the constitution of ETSRC, a second working group has been set up whose remit is to review massive-multiplex wide field spectroscopy options for both 4- and 8-m telescopes, to report in the late summer/autumn of 2010. Cross working group discussion is encouraged.

The chair and co-chair of ETSRC are appointed by ASTRONET, in consultation with OPTICON. The resulting views and recommendations made in this final report are the responsibility of the ETSRC alone.

Jean-Marie Hameury (Astronet) **Gerry Gilmore (Opticon)**

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1 Executive Summary

The heart of this report is a discussion of the most important classes of observational capability that need to be available on 2-4m telescopes over the next 10 years. This amounts to a translation of the Astronet Science Vision, in showing how many (but not all) of the questions posed within it need to draw on data that 2-4m telescopes are best placed to provide. These basic capabilities are grouped as followed: wide-field massively-multiplexed spectroscopy; optical and near-infrared echelle spectroscopy; low-to-intermediate dispersion spectroscopy on individual sparse/rare objects; primarily near-infrared wide-field imaging surveys; optical/near-infra-red time domain photometry.

We also review the importance of retaining the means to train the younger generation of scientists and to support the development of new and/or specialist instrument concepts – a role that cannot realistically be fulfilled by 8-m class telescopes. The business of reconciling the conclusions regarding required observational capabilities with what might actually be feasible is then tackled in two parts: we look at what might be done in the immediate future to simplify the telescope instrument suite and achieve some cost reduction (Table 4 and accompanying figures), and then look at how the landscape should be set in the second half of the decade when new builds/upgrades can come on line (Table 5 and accompanying text). A key feature of this landscape is the construction of a massive-multiplex wide field spectrograph for a 4-m telescope – indeed one in each hemisphere, is the preferred outcome, with an early start in the north desirable.

In our view, for any of the vision to enter the realm of the possible it is critical that barriers between the different nationally-run telescopes are broken down at every level: common operation is needed (particularly in La Palma), a common European TAC is needed, and a framework needs to be established that will allow multi-national consortia to form to construct the required instrumentation. We therefore enter into a discussion of a flexible concept for the operation of a pan-European suite of northern 2-4m telescopes. If this is developed and adopted, this should make it clearer in the future where facility demands are high and where they are falling away.

We end the document with a list of twelve main recommendations.

2 Introduction

2.1 Opening remarks

The panel wishes to note at the outset the general point that it has become ever more vivid as it has carried out its task that astronomy, as an observation-driven discipline confronting phenomena ranging from the very bright (naked eye exo-planet hosts and asteroseismological targets) to the faintest quasars at the edge of the accessible universe, continues to need access to telescopes in all size classes. The technological possibility to build ELT-scale facilities does not mean that the need for e.g. OIR wide field imaging, or first-step spectroscopic identification of brighter objects simply vanishes. In this respect, our subject really is not at all like some other frontier disciplines such as particle physics where it is clear that advances demand a policy of complete facility replacement on decadal time scales.

The 2-4m telescopes support a wide range of research topics and it can indeed be argued that they can offer cutting-edge science – if equipped with state-of-the-art instruments - complementary to that of a single very large aperture telescope. This is especially so, as Europe awaits the launch of Gaia in the summer of 2012 that will produce an avalanche of follow-up needs in the 10–20 visual magnitude range that are the natural realm of operation of the mid-size telescopes. It is also worth noting that there is a rising profile of interest in time domain astronomy, which may involve having the flexibility to respond quickly at OIR wavelength to triggers from e.g. high-energy transients or indeed simply having access to a lot of time on-sky in order to collect ambitious time series. Retaining a broad suite of efficient 2-4m telescopes accessible to Europe's astronomers is – we are sure - crucial for Europe's presence at the astronomical frontier.

2.2 Method of working and organisation of report

In line with the panel's ToR, the approach adopted to the drawing up of a plan for Europe's 2-4m telescopes has been to

- begin by identifying the parts of the Astronet Science Vision that require significant support from these medium-sized facilities,
- proceed to a consultation with the European community of astronomers, via a Web Forum held open for nearly 3 months in the summer of 2009,

- subsequently identify the key classes of observational capability that need to be in place on these telescopes to support the higher priority science over the next 5-10 years
- prepare a plan that distributes these observational capabilities in a fashion that should encourage a more efficient, integrated, pan-European use of these telescopes.
- discuss and propose an operational model that can result in common operation of the telescopes in a flexible way.

In the event, the amount of input via the Web Forum was limited in volume, but in this respect not out of line with the response to the earlier call for input at the time the Astronet Science Vision was being constructed. However, the panel has found much of the input to be very useful, and it is drawn upon in the body of this report. Of particular note were the several responses from across Europe that expressed a concern that streamlining of the 2-4m telescopes should not result in an overly-prescribed, inflexible set of facilities that cannot react to changes in the direction of our science over the coming years that are not yet apparent to 'central planning'. In other words, there is a real perception that 2-4m telescopes need to remain as 'well-found laboratories' enabling innovation, for what at heart is very much a curiosity-driven discipline. We return to this issue in section 4.

Any plan to streamline the existing suite of facilities has ultimately to take into account the present state of the component parts. Observers who regularly use several facilities certainly carry their own views (shaped by experience) as to which telescopes perform well, and which are prone to failures or seem less well maintained. And there are many coffee-room tales about the relative merits of the seeing or weather in different locations. We have, as a panel, collected data from many of the telescope directors on such matters (over the first months of 2009) – but realised, as we did this, that non-uniformities in the way different facilities make their measurements would vitiate definitive judgements in this area. We therefore agree with the contention put to us via the forum that any agreed streamlining plan ought to be preceded by a specialist/technical effort to make properly dispassionate assessments of the readiness of specific telescopes for specific purposes and potential investments.

Finally, as a panel, we have discussed explicitly the observational capabilities that we consider are a struggle for the 2-4m telescopes that are better seen as the remit of the 8-m class. These are:

- Multi-object spectroscopy at NIR wavelengths

- Spectropolarimetry of all but brighter nearby stars and the brightest AGN
- Optical high resolution spectroscopy ($R >> 20000$) of objects fainter than ~ 14

The largest part of this report (section 3) is divided into subsections that each address the most important classes of observational capability that will be needed over the next 10 years. This amounts to a translation of the Astronet Science Vision, in showing how many (but not all) of the questions posed need to draw on data that 2-4m telescopes are best placed to provide. Reflecting what was a non-trivial task, section 3 can be regarded as defining what is a reasonably full set of required capabilities – even if this might be more than can actually be funded at this time.

Section 3 begins with a discussion of wide-field massively-multiplexed spectroscopy: this undoubtedly requires a new investment in one of the northern 4-m telescopes (Section 3.1). Then we move on to echelle spectroscopy where there already is capability in the optical, if not quite yet in the near infra-red (Section 3.2). In Section 3.3, the continuing needs for low-to-intermediate dispersion spectroscopy on individual sparse/rare objects (stars, nebulae, galaxies) are laid out. Whilst wide-field optical survey-style imaging may be seen, internationally, as becoming the preserve of dedicated facilities such as Skymapper, Pan-STARRS and – in due course – LSST, there is still the wide-field near infra-red sky to be considered, which we emphasise in the discussion in Section 3.4. And finally we look at OIR time domain photometry of more modest fields that continues to be a critical need for a number of research fields (Section 3.5).

We review in section 4 the importance of retaining the means to train the younger generation of scientists and to support the development of new and/or specialist instrument concepts – a role that cannot presently be expected of 8-m class telescopes. The business of paring the conclusions of our 'science → instruments' section 3 down to a version of what is actually feasible is undertaken in section 5 – here we present a possible roadmap for the telescopes that assumes no new significant instrument build for any of them is likely before ∼2015. Section 6 gives the background to, and then outlines, a flexible concept for the operation of a pan-European suite of 2-4m telescopes. It is important to note that the proposed framework allows a gradual evolution of the participant facilities that is simply unachievable while telescopes are operated for national groups of users rather than for all of the European Union and Associated States.

We end the main document with a list of our main recommendations (Section 7).

2.3 The list of 2-4m telescopes considered

The telescopes on which we have based our presentation of a rationalised instrumentation plan are as follows:-

In the north:
Observatoire de Haut Provence 1.93m Telescope, France (OHP, 1.93m)
Telescope Bernard Lyot, Pic du Midi, France (TBL, 2.0m)
Liverpool Telescope, La Palma, Spain (LT, 2.0m)
Calar Alto (CAHA) 2.2m Telescope, Spain (CAHA2.2)
Isaac Newton Telescope, La Palma, Spain (INT, 2.5m)
Nordic Optical Telescope, La Palma, Spain (NOT, 2.6m)
Calar Alto (CAHA) 3.5m Telescope, Spain (CAHA3.5)
Telescopio Nazionale Galileo, La Palma, Spain (TNG, 3.6m)
Canada-France Hawaii Telescope, Hawaii, USA (CFHT, 3.6m)
UK Infra-Red Telescope, Hawaii, USA (UKIRT, 3.9m)
William Herschel Telescope, La Palma, Spain (WHT, 4.2m)

In the south:
MPG-ESO 2.2m telescope, La Silla, Chile (MPG-ESO)
VLT Survey Telescope, Paranal, Chile (VST, 2.4m)
ESO 3.6m, La Silla, Chile (ESO3.6)
ESO New Technology Telescope, La Silla, Chile (NTT, 3.6m)
VLT Infrared Survey Telescope, Paranal, Chile (VISTA, 4.1m)

Neither the Rozhen (Bulgaria) nor Aristarchus (Greece) telescopes are included because they are not yet functioning at the level typical of the listed facilities. It is worth noting, however, that the new SMARTS-like operational model considered in section 6 could at an appropriate point be extended to include them. In this sense, these telescopes are not excluded in the long-term, but we reach no conclusions on the role they might play in this report.

2.4 Science Vision goals supported by 2-4m telescopes and their instruments

So as to collect them all in one place, here is the list of Science Vision goals that this panel and forum participants considered can be addressed partially or entirely by observations obtained using 2-4m telescopes.

- A1: Measure the evolution of the dark-energy density with cosmological epoch to search for deviations from a cosmological constant.

- A2: Test for a consistent picture of dark matter and dark energy using independent and complementary probes, thus either verifying General Relativity or establishing the need for a replacement theory.

- A4: Directly detect astrophysically-generated gravitational waves to measure strong-gravity effects, in particular arising from black-hole coalescence.

- A6: Understand the astrophysics of compact objects and their progenitors, particularly the functioning of the supernova explosion and gamma-ray burst mechanisms.

- B2: Detect the first stars, black holes and galaxies, and thus establish the nature of the objects that reionized the Universe and discern the first seeds of galaxies.

- B3: Determine the evolution of the galaxy cluster mass function and constrain the equation of state of the dark energy.

- B4: Make an inventory of the metal content of the Universe over cosmic time, and connect the evolution to detailed models of star formation, and the subsequent metal production and ejection from galaxies by superwinds.

- B6: Measure the build up of gas, dust, stars, metals, magnetic fields, masses of galaxies and thus the evolution of the Hubble sequence with cosmic time and the connection between black-hole and galaxy growth.

- B7: Obtain a comprehensive census of the orbits, ages, and composition of stars in our own Galaxy and the nearest resolved galaxies, aiming to produce a complete history of their formation and subsequent evolution.

- C1: Determine the initial physical conditions of star formation, including the evolution of molecular clouds, and the subsequent development of structure in general, and the formation and mass distribution of single, binary or multiple stellar systems and star clusters.

- C2: Unveil the mysteries of stellar structure and evolution, also probing stellar interiors.

- C3: Understand the life cycle of matter from the interstellar medium to the processing in stars and back into the diffuse medium during the last stages of stellar evolution.

- C4: Determine the process of planet formation, aiming for a full understanding of the timeline for the formation of planets and the chemical evolution of the material that will eventually end up in exo-planets.

- C5: Explore the diversity of exo-planets in a wide mass range from giants to Earth-like, to characterise the population of planetary systems in relation to the characteristics of their host stars.
- C6: Determine the frequency of Earth-like planets in habitable zones and push towards their direct imaging with the long-term goal of spectroscopic characterisation, including the detection of biomarkers in their atmospheres.
- D5: Determine the dynamical history and the composition of trans-Neptunian objects and asteroids, and the rate of large potential impactors in the near-Earth asteroid population; search for complex molecules in comets and study the link between comets and interstellar matter.

3 The main instrument requirements

3.1 Wide-field massive-multiplex spectrographs for 4m telescopes

3.1.1 Summary of science drivers

There are two main research themes that, potentially, would be well-supported by a significant investment in wide-field massive-multiplex spectrographs. These are mainly contained within astronet science vision goals A1 and B7, that are respectively concerned with the evolution of the dark-energy density with cosmological epoch, and with achieving a comprehensive census of the orbits, ages, and composition of stars in our own Galaxy and its nearest neighbours.

To crystallize this a little further: in respect of SV A1, there is a perceived need to address the issue of baryonic acoustic oscillations (BAO), in an effort to better tie down the cosmological parameters – possibly distinguishing dark energy alternatives from those invoking a cosmological constant. One route to do this is via redhift surveys, such as those of the BOSS and WiggleZ projects underway. In respect of SV B7, there is wide recognition that Europe should be backing its investment in Gaia, the ESA cornerstone mission due for launch in early 2012: this project is set to make an enormous contribution to the clarification of the structure and kinematics of the Milky Way and its near neighbours through the measurement of parallaxes and proper motions of all objects down to $V \sim 20$. However Gaia itself is not expected to return the radial velocities of stars fainter than ~16th magnitude, or to provide abundance measurements of sufficient accuracy to perform 'chemical tagging' of the Galaxy's constituent stellar populations.

The optical spectroscopic redshift surveys required for examining how BAO trace the changing Hubble scale with look-back time can be conducted in two ways: by measuring redshifts from [O II] 3727 in emission (out to $z \sim 1.3$), or from the 4000 Å continuum break in e.g. luminous red galaxies ($z < 0.7$). The spectral resolutions needed for this are modest with $R \sim 2000$ being sufficient. The measurement of stellar radial velocities to complement Gaia parallaxes and proper motions demands a precision of 2–5 km s^{-1}: this is readily achieved with resolving powers R of about 5000. Abundance measurements of the precision and scope needed for chemical tagging of stellar populations are much more demanding – $R \sim 30000$ is arguably on the lower boundary of the acceptable spectral resolution range (measurements of e.g. the r-process element, Eu, is usually tackled with $R \sim 50000$ spectrographs). BAO can also be studied via the Lyman-α forest in $z > 2$ QSOs at spectral resolutions in this range.

Below, we divide the needs regarding spectroscopic resolution into two, discussing low-to-intermediate dispersion applications first.

3.1.2 Intermediate dispersion wide field spectroscopy

Both the mentioned applications (BAO, and Gaia radial-velocity faint object follow-up), would seek data over very large sky areas. In the case of BAO, >1000 square degrees is desirable for accessing the near universe, while in principle, at least, Gaia follow-up should approach all-sky in order to sample all distinctive regions of the Milky Way and environs. Some of the existing European 4-m telescopes can already access fields of up to 1 square degree (more than the 8-m telescopes), which makes them worth considering for this work. But of course sensitivity is limited by the aperture and has to be evaluated carefully.

Gaia's RVS will measure stellar radial velocities in the CaII IR triplet region of the spectrum down to ∼16th magnitude. This will leave out of consideration all stars in the $16 < i < 18.5$ range (roughly speaking: faint stars with visual magnitudes of 19-20 are typically very red stars, such that I is often ∼1.5 magnitudes brighter). To fail to explore this magnitude range would significantly limit the volume within which the full kinematics are available. In this fainter range, stars are to be found at surface densities that, within 10 degrees of the mid-plane (a sky area of ∼7000 square degrees), rarely drop much below 10000 per sq.deg, while in the halo the surface densities are an order of magnitude or so lower (but rarely less than 500 per sq.deg). On this basis a multiplex of ∼ 500 per square degree is easily justified.

The time requirement involves estimating the S/N ratio target to be met and either the sky area to be surveyed or the object sample size (whichever implies the larger number of pointings). A reasonable target S/N ratio is in the region of 30, under the assumption that the wavelength grasp is sufficient to provide a good selection of lines for velocity measurement. At $R \sim 5000$, a 4-m telescope, spectrograph and detector combining to give an overall efficiency of ∼8 % could provide such a measurement in the CaII triplet region of an object with $I \sim 18$, in ∼80 minutes of grey time (this figure is consistent with figures using either the ING/WHT/ISIS exposure time calculator at http://catserver.ing.iac.es/signal/, or the VLT/GIRAFFE/MEDUSA equivalent accessible via http://www.eso.org/observing/). In bright time it would be a struggle. At the time of writing it is unclear what is deemed a suitable sample size, and how it should be selected. So here is a strawman to provide a scaling to the problem. *A sample of a million, obtained at a rate of 500 per pointing lasting an hour, would require a large programme occupying a full year.* Making a realistic weather correction, up to 18 months on a 4-m telescope would be needed. This estimate ignores the moon: given that bright time should be avoided, such a programme would be best spread over 3-4 years. The sky area covered in such a survey would be ∼2000 square degrees, for a telescope with a 1-degree field.

With the application of on-chip binning, the same moderate-dispersion wide-field spectrograph could undertake a BAO wide-area survey, in dark time. As well as being able to use a coarser spectral resolution, the continumm S/N requirement can be significantly lower (~ 10), allowing [OII] 3727 emission to be reached in one hour, for galaxies with $R \sim 21$. The Sloan programme, BOSS, to be conducted over the next 5 years is aiming for a limiting magnitude (in a 10000 sq.deg survey of 1.5 million luminous red galaxies) of $i \sim 20$. BOSS has a lead in time, but uses only a 2.5-m telescope, implying that a European 4-m might in principle catch up, and do somewhat better. However, WiggleZ at the 3.9-m Anglo-Australian Telescope has a target of 238000 redshifts obtained from emission lines, and is expected to complete in 2010. The DES (Dark Energy Survey, a mainly USA/UK collaboration) is an example of an upcoming player in this area that aims to exploit photometric redshifts to achieve similar goals. These will benefit from spectroscopic redshift calibration, but it is questionable that a large part of a European 4-m's time should also be committed to this topic.

We now turn to considering whether there is already any European facility in existence that might suit Gaia faint radial velocity work. The short answer to this is 'no' – at least not on a scale that approaches the work-rate just discussed. AF2/WYFFOS on the prime focus of the WHT is perhaps the nearest example, but it offers, in practice, typically rather less than 100 fibres per set-up and its efficiency is a little hampered by its fibre reconfiguration dead-time. Beyond Europe's reach there is HectoSpec on the 6-m MMT (1-degree field, 300 fibres) that comes quite close to the brief just described, but it is in private hands and there is no reason to suppose it will be made over to significant amounts of Gaia follow-up. There is also LAMOST to consider. This new facility built around a 4-m telescope boasts a 5×5 sq.deg field, and 4000 fibres. Whilst these figures are impressive, it has to be borne in mind that the telescope site is a poor one in terms of both seeing and weather – with the consequence that it is unlikely to achieve a limiting magnitude fainter than ∼ 17th. Furthermore the spectrographs' resolving power is presently limited to 2000. In the southern hemisphere, the main wide field spectroscopy facility of note is that of the AAT (now a purely Australian telescope) which accesses a 2-degree field - it is presently executing WiggleZ, and a build is underway to achieve the higher spectral resolution required for chemical tagging (HERMES: see the discussion of $R > 30000$ options, below).

All in all, it appears there is a prima facie case for equipping one of the northern 4-m telescopes with an intermediate dispersion ($R \sim 5000$) ≥1-degree field multi-object spectrograph, with a multiplex of 500 or more. The choice of multiplex (500 versus e.g. >1000) would need to be tensioned between science need and affordability, as defined with respect to the rest of the future 2-4m telescopes programme. The higher S/N Gaia follow-up data flowing from such an instrument, if built, would be well-suited to pipelining straight into a VO database, where it might be exploited to pursue wider science aims as well as to provide a radial velocity harvest. This would become more the case, as the wavelength grasp is increased: at this resolution, it is likely to be in the region of 2000 Å(cf the similar capability that already exists on HectoSpec at the MMT).

For Gaia follow-up, it would be highly desirable to also identify a southern hemisphere counterpart wide field spectrograph of matched capability. There are fewer options for achieving this. One possible route to this would be a redeployment of VISTA – which, without modification, already offers a 1.5-degree field. This only becomes an option after it has completed its NIR survey work. There could be scope for some new-build cost reduction if the same spectrograph design can be minimally adjusted to suit both a northern hemisphere and a southern hemisphere 4-m.telescope. From the perspective of (BAO) galaxy redshift survey work, one hemisphere is sufficient, while the Galaxy and Local Group demands all-sky access.

There will be wider calls on an intermediate dispersion massive-multiplex spectrograph, flowing both from Gaia as a facility attracting interest well-beyond the headline aims of the project and also from groundbased wide-field photometric surveys (IPHAS/UVEX within Europe, Pan-STARRS and Skymapper beyond - and eventually LSST). This would suggest that such an instrument should be operated *p*rimarily as a dedicated survey instrument, but there is no practical reason to close the door to some minority use in a classical responsive mode, which may seed later programmes.

3.1.3 R > 30000 wide field spectroscopy

The science driver for this capability is primarily Galactic archaeology and the need to chemically-tag the many generations of stellar populations making up the Milky Way (and its neighbours).

As a context for the discussion, we need to consider the practical limits on what a high resolution spectrograph on 4-m telescope is capable of achieving. To begin with we turn to available estimates for the performance of HERMES, the new spectrograph in construction for the AAT: at $R \sim 30000$ it is thought likely that an hour's exposure on a 14th magnitude star will yield S/N $\sim$ 100 per resolution element. Comparison with data available via the ETCs for the different modes of FLAMES on the VLT suggests that this amounts to an expected efficiency of somewhere between 6% (i.e. at least 50 percent better than FLAMES+UVES) and 8% (comparable with FLAMES+GIRAFFE+MEDUSA), after correcting for the different primary mirror sizes. The design of HERMES specifically targets 3 (or

4?) 250 Å spectral windows to capture a defined set of lines needed for the desired abundance measures.

We can now consider what can be done with a 4-m telescope on stars brighter than 14th magnitude, at how high a resolution, and at how high a time burden. The surface densities of such objects are in the region of 200-700 per square degree within 10 degrees of the mid-plane, dropping to around 100 in the halo. The HERMES instrument will allow around 130 fibres per sq deg (400 altogether) – a figure that makes sense if the aim is to use fibres efficiently in all locations and/or sample the Galactic halo at the same absolute frequency as the plane. With a 2-degree field available, and using their own estimate of the needed exposure time, the HERMES team estimate 400 bright nights will allow them to collect a sample of 1.2 million chemically-tagged stars (a ∼4 year project, that would collect data from ∼1/4 of the southern sky).

It is safe to conclude that to reach fainter than 14th magnitude, at $R > 20000$ on a regular basis, that 8-m telescopes are required. FLAMES already exists as an instrument at the VLT – albeit accessing a more limited ∼0.5-degree field with only 8 fibres for the higher UVES resolution of ∼47000. Despite these limitations, the fact that FLAMES can go appreciably fainter than an instrument on a 4-m implies a competitive advantage at the present time that ought to be exploited over the next few years, to be fully-prepared for the second half of the decade.

Assuming the Australian community goes ahead with HERMES, it is not obvious, a priori, that Europe's community should attempt a venture on the same scale in the southern hemisphere. The existing RAVE consortium pursuing directly related science goals (down to 11th magnitude) is already a collaboration with a major European presence, suggesting that a buy-in to HERMES is a natural avenue to go down. At the same time it would miss an opportunity to invest in European-led Gaia follow-up to explore stellar chemistry not to find away to establish a northern counterpart.

Without a new cash investment in a top-end corrector, there is no access to a northern wide field wider than a square degree. If sampling the halo is important, this can go no faster than can be achieved by a multi-object spectrograph offering 100-150 fibres (this is roughly the actual surface density of stars down to $V \sim 14$ at high galactic latitude – according to the Besancon model, just a handful per square degree would actually *be* halo stars). Looking into the disk/bulge at low Galactic latitude, surface densities of stars down to 14th magnitude of ~ 500/sq.deg are not uncommon, and of course rise strongly to fainter magnitudes.

Members of the Gaia GREAT coalition (Feltzing et al., 2009) have sketched out 2 largescale survey programmes that require $R \geq 20000$ high-multiplex wide-field spectrographs. One of these is a halo survey (Appendix A.1 of Feltzing et al., 2009), spanning up to 5000 square degrees and reaching down to $V \sim 17$ in order to pick up around 50000 halo giants tracing ∼500 streams to 10s of kpc. To reach this magnitude at S/N $\sim$ 40 per spectral resolution element at $R \sim 20000$, via a dedicated programme on a 4-m telescope accessing 1 square degree per pointing, would take 9 years of continuous observing, if the efficiency were to be the same as that of FLAMES+UVES on the VLT. This is so long a timescale as to be impractical. If, instead, the scaling is from either the HERMES@AAT design and claimed performance, or from GIRAFFE@VLT, to a similar instrument on a 4m telescope – assuming a field 2 degrees in diameter – the exposure time per field is no worse than $\sim$ 2 hours, indicating a total time requirement nearer to 2 years (continuously). So, depending on the actually achieved efficiency and field size, this concept changes from being unthinkable to achievable.

The second programme from the GREAT coalition (Appendix A.2 of Feltzing et al., 2009) targets the Galactic disk to the shallower limit of $V \sim 14$, but at higher spectral resolution ($40000 < R < 50000$) and at higher S/N per resolution element (200-250). The aim in this case is chemical tagging as for the HERMES programme, specifically of a volume-limited sample to 2 kpc. Scaling the HERMES numbers up to these more exacting requirements suggests an exposure time per field of $\sim$ 9 hours on a 4-m telescope. Building in some compromises on the way as discussed in the Feltzing et al document, the total programme would need to occupy in excess of 1500 clear nights (or ∼5 years, with continuous access). The total haul in spectra, at a multiplex of 500, would be 0.75 million.

It is clear that high spectral resolution Gaia follow-up is a tough challenge, seriously testing the limits of what may be feasible on a 4-m telescope given the inevitable weather losses. Ambition is presently running high and will need to be carefully compared with what is technically realistic. What is certain at this point is that if a high multiplex $R > 30000$ wide field spectrograph is constructed, (i) it would be best if the field diameter accessed is closer to 2 degrees than 1, and (ii) that such an instrument could be kept extremely busy *just* with Gaia follow-up. For work in the Galactic plane a multiplex of at least 500 per sq.deg. is desirable. Target selection for the two types of programme would have reason to seek to limit the spectral type ranges of the targeted stars more tightly than is needed for radial velocity measurement. Consequently these datasets will be more 'specialist' in nature than those gathered at intermediate dispersion.

If cost scales with the multiplex, a value-for-money argument in favour of a high resolution instrument limited to a multiplex of no more than 100 per sq.degree is that it could also play a role in support of asteroseismology in the Kepler era. Kepler has a 10×10 sq. degree field of view, across which there are likely to be in the region of 30-40 targets per sq.degree down to 12-13 magnitude. These too will need follow-up spectroscopy at $R > 30000$ to determine accurate stellar parameters ($\log g$,

$T_{\rm eff}$, $[Fe/H]$ and $v \sin i$ - see section 3.2.2). It is also plausible that a BAO QSO Lyman-α forest programme would exploit such an instrument: the sky densities of $z < 2.5$ brighter QSOs are not going to be much more than a few tens per square degree.

A further option that might be considered to support chemical-tagging work linked to Gaia, that lies outside the scope of this review, is to investigate a FLAMES-like instrument for Grantecan.

3.1.4 Conclusion

The panel view is that Gaia science (SV B7) is the major driver for considering investment in massively-multiplexed wide field spectrographs for 4-m telescopes. A crucial issue to face before committing to major expenditure of this kind is that of sensitivity: the feasibility of both radial velocity and chemical-tagging surveys will be critically dependent on the end-to-end (telescope × instrument × detector) efficiency that can actually be realised. The rough comparisons looked at here indicate this must be more than 6%, and preferably closer to 8 % (or more).

There are strong scientific arguments for

- an intermediate dispersion ($R \sim 5000$), 500+ multiplex wide-field spectrograph accessing 1 square degree or more, mounted on 4-m telescopes in both the northern and southern hemispheres. These could be used in grey time for Gaia radial velocity work down to I of 18-19, and for BAO redshift surveying in dark time (the latter in one hemisphere only, if it can be shown to be internationally competitive), and more broadly for follow-up of largescale photometric surveys. In the southern hemisphere, a spectrograph might be built for use on VISTA after this facility has completed the greater part of its NIR surveys. In the north, the WHT appears to be the best choice on account of it having the largest available primary mirror.
- a higher resolution ($R \geq 30000$), 100+/sq.deg multiplex instrument on a northern 4-m telescope for Gaia-linked stellar chemistry work. To meet the need in the south, buy-in to the AAT's HERMES also would be the most attractive option in the short term, as this proposed facility appears well-matched to the problem, on account of the AAT's existing 2-degree field. In addition the 8-m VLT FLAMES instrument could also be exploited to start the interested community up a learning curve in the next 2-3 years. A new build using a northern hemisphere 4-m telescope, particularly if aiming for $R > 40000$, will need to pay very close attention to efficiency – this really must be optimised. 8% is desirable if the goals under discussion within the

Gaia community presently are to be achieved on a manageable timescale. If a top-end corrector for one of the 4-m telescopes can be afforded to raise the available field to 2 degrees, or more, Gaia stellar chemistry (and also BAO science) would benefit significantly.

If it is financially attractive, *and* compatible with overall optical efficiency, the option of a single instrument for one northern 4-m should be considered that permits *both* intermediate and moderately-high resolution spectroscopy to be performed ($5000 < R < 50000$). A possible alternative to this, necessarily subject to the same sensitivity caveats, is a spectrograph operating at the 'compromise' spectral resolution of ∼20000 (as explored in the CFHT/GYES concept). Such a telescope could service a possible spread of programmes occupying all moon phases over, potentially, several years and could be run mainly in survey mode – with much, or indeed all, of the data fed directly into a VO database for prompt dissemination to the whole community.

There is, and there will continue to be too much time pressure from across the rest of European astronomy for other types of data collection to permit the luxury of *two* 4-m telescopes equipped for wide field spectroscopy in the same hemisphere.

IDENTIFIED CAPABILITIES:

- 1-1: an optical wide-field spectrograph on 4m telescopes, north and south, delivering R∼5000 for 500+ objects/sq.deg over a field $\geq$ 1 sq.deg
- 1-2: an optical wide-field spectrograph on a northern 4m, $R \geq 30000$ for 100+ objects over a field $\geq$2 sq.deg. It is preferred that this mode is available on the *same* telescope/instrument as 1-1, to be used mainly in bright time.

3.2 R > 40000 echelle spectrographs for 2-4m telescopes

3.2.1 Summary of science drivers

High-resolution echelle spectrographs are required to fulfill important goals associated with the studies of star formation (C1, C4), stellar structure and evolution (C2), the life cycle of matter (C3) and the diversity of exo-planets (C5).

In the context of star formation, these observations are required to characterize and monitor the physical processes at work in young stellar objects, such as accretion/ejection, star-disk interaction and angular momentum evolution. In the context of stellar structure and evolution, these observations are requested for the determination of fundamental parameters (e.g. $T_{\rm eff}$, $\log g$, chemical composition, vsini) as well as seismic properties (mode frequencies, amplitudes, and lifetime) of stars in general and in the context of follow-up of space asteroseismic observations. In the context of the life cycle of matter the observations are required to study physico-chemical processes in interstellar clouds and stars. In the context of the characterization of exo-planet population, the observations are required to enlarge the number and diversity of exo-planets known, to measure the spectroscopic transit of the exo-planet in front of the stellar disk (Rossiter-McLaughlin effect), to follow-up transits discovered both from ground-based and space-based telescopes for mass determination, and, in combination with Gaia astrometric data, to determine the orbital inclination. Also, in this context observations are required to characterize the host stars and to separate true planet detections from blends.

The characterization of young stellar populations in star forming regions and young open clusters offers a unique way to test the predictions of modern star formation theories. For instance, numerical simulations of cloud collapse make detailed predictions regarding the Initial Mass Function (IMF), i.e., the mass distribution of newly formed objects, all the way from the most massive stars down to the fragmentation limit at 3-5 Jupiter masses, the relative number of brown dwarfs to stars, the hierarchy of multiplicity among young stellar systems, the kinematics of stellar populations at birth, the mass distribution and size of their circumstellar disks, etc. In addition, evolutionary models developed for young stars and their disks now predict the average mass accretion rate and disk lifetime, the impact of disk evolution on the stellar mass and angular momentum, the role of star-disk interaction in the driving of powerful jets in young systems, the rate of planetary migration in massive disks, etc. In order to improve our current understanding of the star and planetary formation processes, all these predictions have to be tested against high-resolution spectroscopic observations of complete samples of young stars and brown dwarfs in nearby star forming regions and young open clusters, probing an age range between less than 1 Myr up to 100 Myr, i.e., from birth to the zero-age main sequence.

Physical processes at work in stellar interiors, such as e.g. chemical mixing and segregation, angular momentum transport, or magnetic dynamos, impact on the properties measured at the stellar surface. Deriving the fundamental properties of large and homogeneous (mass, age) samples of stars, and investigating how these properties evolve with time from the PMS to the post-MS, provide clues to the internal processes. On the other hand, the only way to directly probe stellar interiors and test current models for these physical processes is by studying stellar oscillations. Here, however, it is important to distinguish two types of pulsators, namely, classical pulsators, whose oscillations are intrinsically unstable, resulting in relatively large pulsation amplitudes, and the solar-like pulsators, whose oscillations are intrinsically stable, with amplitudes that are considerably smaller. Besides being easier to observe, classical pulsators have the advantage that they cover many difference regions of the HR diagramme, as well as different evolutionary stages. Solar-like pulsators, on the other hand, are much more confined in mass and evolutionary stage, but have the advantage of having very rich, and most often simpler to interpret, oscillation spectra. Hence, these pulsators are unique in the potential they offer to test very specific aspects of the physics of stellar interiors, such as convection, convective overshoot, and diffusion, which are of uttermost importance for studies of stellar evolution in all regions of the HR diagram.

The characterization of the exo-planet population is a fundamental step towards the understanding of the mechanisms behind the formation and evolution of planetary systems, as well as of the conditions that may lead to the presence of Earth-like planets within habitable zones. High-precision radial velocity surveys have made a pioneering contribution to our present knowledge on extrasolar planets and this will continue in the future (supplemented by photometric and imaging methods). Enlarging the sample of extrasolar planets, with particular attention to the ones of smaller mass, remains a key aspect of exo-planet studies. This involves, not only the continuation of current RV surveys, but also their extension to the near-IR, where Earth-like planets in the habitable zone can be searched for around M-dwarfs. Moreover, there are a number of other scientific goals of the utmost importance in this context that need to be pursued. These include, in particular, the characterization of multiple planetary-systems and the determination of the angle between the orbital plane and the rotation axis of the host-star.

A number of the goals associated with the studies referred above can only be achieved with good coordination of the observations in the time domain, which, in turn, requires that the instrumentation is spread over the globe, covering different longitudes (typically a minimum of three), such as to allow continuous observations of the targets. In this respect the science goals can be grouped in three categories, namely:

- Determination of fundamental parameters of stars over the whole HR diagram, including pulsating stars and exo-planet hosts, and spectroscopy of Galactic stars and nebulae to study the physical and chemical processes of the interplay between interstellar clouds and stars. These will generally not require coordination of the observations in the time-domain;
- Short term variability studies, which require continuous observations, on cadences that vary typically from minutes to hours. These include the acquisition of RV time-series to follow-up space-based studies of classical pulsators and to detect and characterize oscillations in bright solar-like pulsators. Also included under this heading are the studies of phenomena which result in spectral modulation over the rotation period of the star, stellar activity, and the various interactions between stars and their environments.
- Long term variability studies, which require observations at different epochs, but not necessarily continuous. These include RV measurements to characterize the exo-planet population and exo-planet systems, and to study long-period pulsators, such as Classical Cepheids.

Some aspects of the science described above can be studied with data acquired with optical high-resolution echelle spectrographs capable of delivering RV measurements with precision of $\sim$ tens of m/s (generally R $\sim$ 50000 instruments). Nevertheless, most science cases either require, or would gain significantly from instruments capable of delivering RV measurements with precision of 1m/s and better. These necessarily highly stable spectrographs are needed both in the optical and in the near-infrared. Moreover, part of the science requires also that a polarimetric mode is available. The required capabilities are detailed below.

3.2.2 Optical high-resolution echelle spectrographs (R $\sim$ 50000)

Science

Instruments of this kind, covering a wide instantaneous spectral range (e.g. $\sim$ 390-900nm), are needed for the determination of fundamental parameters of stars in different phases of evolution, including planet-hosts. This wide simultaneous spectral range is of particular importance for studies of young stellar objects, allowing one to probe all the relevant spectral diagnostics (permitted and forbidden emission lines, Balmer lines, HeI, NaD, CaII, metallic lines – FeI, FeII, etc, [OI], [NII], [SII], etc.) required to determine the star's $T_{\rm eff}$, [Fe/H], and rotation from photospheric lines, the star-disk-wind interaction region (through the analysis of permitted line profiles arising in the hot interacting plasma), and the inner part of the jet (via the forbidden lines). Moreover, detailed characterization of large stellar samples of stars serves as a support for survey space missions, such as XMM and Gaia, and are essential input for studies of planetary systems and for asteroseismic studies, serving as support also to missions such as CoRoT, Kepler, and BRITE.

The follow-up, in RV, of classical pulsators observed in photometry by space missions with asteroseismic programmes will also generally be feasible with $R \sim$ 50.000 and with a RV precision of tens of m/s. The combination of the photometry and the RV time series of classical pulsators, such as β Cep, δ Sct, γ Dor and Be stars, is required to identify the modes of oscillations (i.e., angular degree and azimuthal order), which, in turn, is a fundamental key to the success of asteroseismic studies of these pulsators. We note that multicolour photometry, which can be achieved with smaller telescopes, is often used to attempt to identify the modes of oscillation. However, only the combination of photometry and high-resolution spectroscopy offers a detailed picture of the pulsation velocity field, making this methodology highly favorable, as long as the necessary data (required time-series length, with S/N 200, and adequate integration times) can be obtained. Instruments of this kind, when sufficiently stable to produce RV with precision of only a few m/s, also have an important role to play on the characterization of the exo-planet population and studies of solar-like pulsators. This is particularly important while and where alternatives such as HARPS-like instruments (see next subsection) are not available.

Telescope aperture
Regarding the telescope aperture, spectrographs of $R \sim$ 50.000 at a 2-m telescope are adequate for the determination of fundamental parameters in stars brighter than magnitude ∼12, the typical requirements being S/N∼ 120 in a single exposure, or two exposures with S/N∼ 50-90 (the two exposures having the advantage of a possible detection of binary motions). A significant fraction of the stars to be observed by these instruments are envisaged to be targets of Kepler and Gaia. Three fourths of Kepler current asteroseismic targets are brighter than magnitude ∼ 12, thus 2-m telescopes are likely to suit for the determination of their global parameters. However, in the case of Gaia we may expect a larger range of magnitudes to be covered, which would require larger (4-m) telescopes. Moreover, as most young stellar objects in nearby star forming regions and young open clusters have V∼12-15, high resolution spectroscopy at high S/N to study these objects requires also a 4m telescope (e.g. ESPaDOnS at the CFHT 3.6m). Medium-term monitoring of young stellar objects (e.g. accretion-ejection) and of more mature stars (.e.g star-planet interaction) will require continuous observing campaigns (typically 2-3 measurements per night per target) covering several rotational periods, i.e. from ∼ 2 weeks up to ∼ 2 months, with optimal longitude coverage to avoid phase gaps.

Regarding mode identification in classical pulsators, spectrographs of $R \sim$ 50.000 mounted in 2-m telescopes are adequate for stars brighter than magnitudes

~10. This limitation results from the short integration times involved, which typically need to be about 10% of the shortest oscillation periods (~ an hour). Given that the great majority of classical pulsators to be observed by Kepler are fainter than magnitude ~11, 4-m telescopes equipped with this kind of spectrograph will also be needed in this context. Experience gained, in particular, with the follow up of CoRoT targets shows that typically ~ 30 days of continuous observations are needed for mode identification. As different pulsators have different characteristic oscillation periods, the observing strategy usually involves monitoring 3-4 pulsating stars simultaneously, alternating between them during the night.

Time estimate
Estimating the total number of observing nights required is a complex matter. Nevertheless, one may anticipate that at least ~200 nights/yr over the next 3-4 years will be needed just to derive fundamental parameters for the ~ 4000 Kepler asteroseismic targets (assuming single-object instruments are used). This estimation is based on the S/N requirements stated above and the distribution of magnitudes of the targets. Moreover, with the launch of Gaia, and the need to follow-up selections of Gaia's targets with high resolution spectroscopy, this demand on time can be expected to continue (or increase) until the end of the next decade, just to determine fundamental parameters of stars.

Regarding the monitoring of stars for studies of short- and medium-term variability, we may expect significant amounts of time to be requested, with the additional constraint of a good longitude coverage. For the ground-based follow up of classical pulsators, ~150 nights/yr spread over telescopes at different longitudes are envisaged. This estimation is based on the experience gained with ground-based follow up programs for mode identification in CoRoT targets and on an expectation that ~10 % of Kepler classical pulsators will be followed from the ground for mode identification during the mission. The follow-up programme for mode identification will continue well beyond the expected end of the mission, and similar amounts of observing time may be expected to be needed up to the end of the next decade. Moreover, for the mid-term monitoring of young stellar objects as well as more mature stars a total of ~100 nights/yr is envisaged. This would allow one to monitor a few tens of such stars at high S/N and with a good phase coverage.

Existing facilities and longitude/hemisphere coverage
There are currently six northern 2-4m R~ 50000 instruments in the north, and one in the south that to varying extents match the capability considered here (see 3.2.6 for the list). Given the additional pressure on these instruments that will result, first, from the follow-up of Kepler asteroseismic targets and, later, from the follow-up of selections of Gaia targets, the demand for these instruments will persist.

As part of the science requires continuous observations, consideration of the distribution of these instruments around the globe is also necessary. In that respect, it seems important that these instruments cover a range of longitudes and are offered predominantly through large programmes. Presently, the follow up of classical pulsators for mode identification is done with recourse to large international collaborations which guarantee that the different longitudes are covered by a mixture of public and private telescopes. In order for Europe to continue to lead these studies, in the era of space-based asteroseismic programmes, access to these spectrographs at distinctly different longitudes coverage is highly desirable. Concerning hemisphere, the follow up of Kepler targets will result in larger pressure on northern facilities, CoRoT targets are equatorial, and follow up of BRITE targets will shift the pressure towards the South, due to the higher incidence of hot pulsators in the more metal-rich parts of the Galaxy. Characterization of Gaia targets, on the other hand, will require both northern and southern facilities.

3.2.3 Optical, highly-stable high-resolution echelle spectrographs (R $\sim$ 100000)

Science

Highly stable spectrographs, capable of delivering RV in the optical with precision better than 1m/s are required for the characterization of the exo-planet population and exo-planet systems, including the observation of the Rossiter-McLaughlin effect, the long-term monitoring of planet hosts in search for additional planets, the follow-up of transits detected in ground and space-based programmes, and for combining with future Gaia astrometric data to determine the orbital inclination.

Instruments capable of delivering $\sim$ 1m/s precision RV are also needed to acquire the necessary time-series for detecting and characterising the oscillations of bright solar-like pulsators. Unlike the case of classical pulsators, the stars to be targeted by these instruments for asteroseismic purposes are not those being observed from space (which would be too faint). The scientific justification for observing these stars is based on the unique potential that RV data offer to detect the oscillation modes of lower frequency and the oscillation modes of degree $l = 3$. Without these particular modes, the direct inference of important aspects of stellar interiors (e.g., degree of mixing at the border of convective cores) is seriously compromised. Hence, the emphasis in this case is on observing few bright stars, to obtain the most complete oscillation spectra, that cannot be obtained from photometric time-series, and, hence, are not available in CoRoT or Kepler asteroseismic data.

For young stellar objects, a spectroscopic resolution of order of 3 km/s allows a detailed analysis of the geometry and kinematics of the accretion and ejection flows near the stellar surface. Non-steady accretion/ejection processes occurring on a timescale of a few hours up to a few days are reflected into the changing emission line profiles. Similarly, the magnetic star-disk interaction region, between the inner disk edge and the stellar surface, as well as the base of the wind/jet system, both corotate with the star with a rotational period of ∼1 week. The geometry and physical properties of the interaction region(s) can thus be reconstructed trough Doppler imaging by monitoring the emission line profiles at high spectral resolution over a timescale of a few weeks.

Telescope aperture

Regarding the telescope aperture, while part of the science to be addressed can be pursued with these type of spectrographs mounted on 2-m class telescopes, the trend toward increasing precision in exoplanet studies (aided both by sheer light-gathering power raising S/N, and quality/stability of instruments used) means that the larger 4-m apertures have a clear competitive edge (see e.g. Rauer et al., 2009). The use of larger apertures also enlarges the sample of objects within reach. In the study of young stars, close analysis of accretion disk astrophysics and kinematics is becoming important: this requires observations of YSOs in nearby star forming regions, whose typical brightness is V∼ 12-15. For these, spectroscopy at a resolution of ∼ 100,000 and high S/N (> 50) implies the use of 4m telescopes.

Time estimate and relevant facilities

Generally, the studies described above require large programmes. Therefore, it would be advantageous to have this type of capabilities in partially or fully dedicated telescopes. The single current example of a highly-stable spectrograph capable of delivering the required high-precision radial velocity is HARPS@ESO(3.6m). This is insufficient for fulfilling the goals underlying the studies considered here.

The spectroscopic follow-up of transits discovered in ongoing ground-based transit surveys, such as HATNet and SuperWASP, and the continuation of current RV surveys in search for exo-planets can be expected to require ∼ 100 nights/yr (this excludes US-led Kepler follow-up that has motivated the HARPS-NEF MOU). In addition, asteroseismic studies of solar-like stars require not only significant amounts of observing time with instruments of this kind, but also longitude coverage. As an example, assuming 20 bright targets, each observed continuously for 30 days, over the next decade, we may expect a request of ∼180 nights/yr, or more, spread over instruments at different longitudes. For even better science return, these solar-like stars would need to be observed continuously for longer periods (up to a few years). That requires fully dedicated networks of telescopes. Such networks, of smaller (1-m) telescopes, are being planed for the North and (later) South hemispheres, but even the former is unlikely to be complete before 2015. While the networks are not complete (and, even after completion), 2-4 m European telescopes with instruments of this kind have an important role to play in forming shorter (∼ 2-4 weeks) temporary networks with other telescopes world wide (either it being the first nodes of the dedicated networks, when in place, or other). For that to be possible, it is important that more instruments like HARPS are made available and that they are located at different longitude.

Finally, the characterization of the star/disk/wind interaction region in young stellar objects requires monitoring studies over several rotational periods, i.e., 3 or more measurements per target per night over a continuous run of 3 or more weeks. A representative sample of 10-30 accreting young stars could thus be characterized in about $\sim$ 100 nights/yr over 3 years, at high S/N and with an excellent phase coverage.

3.2.4 Near-IR, highly-stable high-resolution echelle spectrograph (R $\sim$ 70000)

Science
Highly-stable, high-resolution spectrographs in the near-IR, capable of delivering RV with precision better than 1m/s are needed to conduct RV surveys of M dwarfs to find Earth-size planets in the habitable zone. Because of their low masses, radii and resultant low effective temperatures, M-type stars are more viable for RV detection of Earth-like planets at near-IR wavelengths.

Instruments of this type are also required to study the dynamics of the inner disc in young stellar objects. The near-IR spectral domain contains a number of diagnostics of the inner disk region around young stellar objects. For instance, the width of CO bandheads in emission (2.3mu) can be resolved at a resolution $>$ 70,000 and provides a direct measurement of inner-disk keplerian motion. Monitoring the variations of their profile might provide the first detections of young hot jupiters still embedded in the inner circumstellar disk. A statistical analysis of complete samples of young stellar objects in star forming regions at high spectral resolution in the near-IR is required to characterize the evolution of the inner discs and and their lifetimes as well as the occurrence and kinematics of powerful molecular jets.

The identification of high mass-ratio binaries, and in particular low mass brown dwarf companions to young stellar objects, will also benefit from spectroscopic monitoring in the near-IR.

Telescope aperture
Regarding the telescope aperture, these instruments need to be set on 4-m class telescopes or bigger to achieve the $\sim$m s^{-1} precision needed for the detection of lower-mass planets. This is also true for the study of young stellar objects at high-enough S/N ratios, as most of these objects in nearby star forming regions have K 9-12. The majority of the observations are to be made through Large Programs and, in fact, will require fully or partially dedicated instruments.

Time estimate and relevant facilities

Concerning the estimate of observing time required, a survey for earth-like planets around M dwarfs may be expected to require $\sim$ 100 nights/yr. Moreover, dedicated observations of complete samples of young stellar objects and their monitoring in the near-IR will require $\sim$ 50 nights/yr over several years. Moreover, if a spectropolarimetric mode is available (see next subsection), these numbers will increase significantly. We thus anticipate good use of an instrument with these characteristics on a fully dedicated telescope, or, alternatively, two such instruments in partially dedicated telescopes (especially if this offers longitude coverage).

NIR spectrographs capable of high-precision RV measurements are still in the development phase and are expected to be functioning after 2012. The first multi-order NIR echelle, GIANO due soon at the TNG 3.6m, offers $20000 < R < 40000$ and is not aimed at planet-finding.

3.2.5 Spectropolarimetry

Science

The magnetic field of stars holds clues to many of their properties, primarily non-thermal activity but also magnetic winds and outflows, magnetospheric reconnection and flares in tight binary systems, magnetically-channeled accretion in young objects and compact ones, and the recent discovery of hot Jupiters inducing enhanced magnetic activity in their host stars reminds of the magnetically interacting Io-Jupiter system. While unpolarized Zeeman analysis revealed the magnetic field of a few spectacular classes of stars with intensities of up to several 10s of kilogauss, the milder field of solar-type stars and indeed of most stars across the HR diagram is best studied through spectro-polarimetry, a technique that yields both the intensity and the topology of the magnetic field at the stellar surface down to a few 10s of gauss. Prime targets are main sequence cool stars, brown dwarfs, young stellar objects, and giants evolving off the main sequence. Large-scale spectro-polarimetric surveys are required to assess the impact of the magnetic field on, e.g., the oscillations of solar-type stars observed with Corot, the chemical composition of main sequence stars observed with Gaia, the interaction of young stars with their disk and the origin of their jets, the fundamental properties of brown dwarfs, the migration process of young planets in magnetized disks, the dynamics of the extended atmospheres of evolved stars, etc.

Time estimate and relevant facilities

Survey-like observations of stars across the HR diagram would by itself justify a fully dedicated bright time instrument on a 4m telescope. Spectropolarimetric monitoring of cool stars and brown dwarfs over several rotational periods (i.e., weeks to months) is needed to investigate the intensity and topology of their surface magnetic fields. A total of 150 nights/yr would provide an in-depth study of stellar magnetism across the HR diagram in about 5 years.

While current spectropolarimeters operating in the optical (e.g. ESPaDOnS@CFHT, NARVAL@TBL) have provided a wealth of new results on stellar dynamos, the extension to the near-IR would open the way to the study of magnetic fields in the coolest and lowest-mass objects such as brown dwarfs, embedded objects such as young stars, and IR-bright targets such as evolved cool stars.

3.2.6 Summary of existing instruments

- At R $\sim$ 50000 the following optical instruments are available. Spectropolarimetric options are noted where they exist.
    - ESPaDOnS@CFHT3.6: optical echelle, also with spectropolarimetric options. Mauna Kea location gives it a strongly contrasting longitude wrt both Chile and the European telescopes.
    - SARG@TNG3.6: optical echelle, offering higher resolution modes also, but not with the same long-term wavelength stability as HARPS or SOPHIE.
    - SOPHIE@OHP1.9: a much sought-after high-stability echelle at this resolution
    - FIES@NOT2.6: a recently built optical echelle, offering more than one resolution.
    - NARVAL@TBL2.0: this echelle is the only other echelle besides ESPaDOnS to offer a spectropolarimetric mode.
    - CAFE@CAHA2.2: a replacement for FOCES (repatriated to the Wendolstein) that is under construction in Spain.
    - FEROS@ESO-MPG2.2: the *only* optical echelle at this resolution available to the European community in the south. Notable for its high throughput.
- Highly stable R $\sim$ 100000 echelle spectrograhs, working in the optical:
    - HARPS@ESO3.6: the only instrument on this telescope running highly successful planet searches and other programmes
    - HARPS-NEF@WHT4.2: this is a private instrument for which time is expected to be purchased at the WHT for 3 (or more) years. The terms of the agreement stipulate it will be available to the ING community as well. Not yet commissioned.

- No NIR echelles with $R \sim 70000$ for deployment on 4-m telescopes are in construction yet. SPIRou@CFHT3.6 is at phase A stage and will provide a resolving power of $R \sim 50000$ and offer spectropolarimetry.

3.2.7 Conclusions

A significant part of the observations to be carried out with high resolution spectrographs will be associated with ground-based follow-up of targets of satellite missions. This will include follow-up of targets of CoRoT, Kepler, and BRITE (under development) missions, which will be most intensive during the first half of the next decade, and follow-up of selections of Gaia targets, starting some time after 2012. Time-series follow-up of variable stars supplied by large-scale groundbased surveys such as OGLE, ASA, and Pan-STARRS will be needed as well, along with studies complementary to transit surveys, like HATNet and SuperWASP. The most relevant parts of the ASTRONET science vision are: C1 through to C5, and B7 (Gaia stellar parameters).

The high priority in this area is for a highly-stable optical $R \sim 100000$ spectrograph in both hemispheres. In the southern hemisphere, this is already available as HARPS on the La Silla 3.6m telescopes. In the north, a new build is may be required to meet this need if HARPS-NEF@WHT (provided as a private instrument, but accessible via TAC allocations) is withdrawn mid-decade. It is anticipated that the demand from asteroseismology, exo-planet and star formation studies for this superior spectral resolution will rise over time, and partly at the expense of the presently more widely-available $R \sim 50000$ echelle spectrographs. Given that asteroseismology, and to some extent, star formation studies, demand longitude coverage, the best location for this instrument would be on Mauna Kea (∼120 deg W of La Silla).

The panel recognizes the importance of retaining enough $R \sim 50000$ optical echelle spectrograph time to respond to the increasing demand for that will result from the European leadership of Kepler's asteroseismic programme and, later, Gaia. Also, we note that while a capability such as a HARPS-like spectrograph is not available in the North, the most stable optical R∼50000 echelles (e.g. SOPHIE) remain the only option for high-profile exo-planet RV studies and solar-like pulsators studies in that hemisphere. It would be advantageous to gradually upgrade part of these instruments to achieve the higher precision offered by, e.g., HARPS, although care should be applied not to lose altogether the possibility of covering a wide instantaneous spectral range (e.g. ∼ 390-900nm). The follow up of Kepler asteroseismic targets, alone, will require more than 350 observing nights/yr, with particular incidence during the first half of the decade. The monitoring of young stellar objects both in unpolarized and polarized light, for star formation studies, is envisaged to require more than 200 observing nights/yr in instruments of this type. Moreover, with the launch of Gaia, the pressure for these instruments is expected to increase further. Consequently, European astronomy needs at least the time equivalent of two fully-dedicated $R \sim 50000$ optical echelle spectrographs in the North. Given the need for long continuous runs it would be advisable to offer the time needed on these instruments on a network of, e.g., 4 international-level telescopes (a mix of 2-m and 4-m) with the possibility *in all telescopes* of requesting time both in the form of shorter queue/classical mode observations and large programmes. Also, the one such instrument on a 2-m telescope in the South needs to be retained for the follow-up of targets from CoRoT, BRITE and Gaia. Finally there is overlap here with the $R \geq 30000$ wide-field spectroscopic capability discussed in 3.1: if this cannot be provided, the demand on analogous single-object echelle spectrographs will remain high for longer.

In addition, it is recognised that an important new frontier, particularly relating to the study of exo-planets, is waiting to be breached at NIR wavelengths: it is in the best interest of European astronomy that *one* $R \sim 70000$ NIR 'planet-finding' echelle spectrograph is built and brought into use on a 4-m in the next few years. Choice of hemisphere is not important.

Most of the science drivers require large programmes on partially dedicated telescopes/instruments. Attention will need to be paid to systems for achieving co-ordination between telescopes offering echelle spectrographs in order to optimize time series.

IDENTIFIED CAPABILITIES:

- 2-1: Optical HARPS-like instrument ($R \sim 100000$) on a 4-m class telescope, North and South. For longitude reasons: CFHT is the preferred northern site.
- 2-2: A network of 4 partially dedicated optical FIES-like instruments ($R \sim 50000$) in the North, with at least 1 in a 4-m telescope, plus 1 such instrument in the South.
- 2-3: 1 NIR high-resolution echelle spectrograph on a 4-m class telescope, with polarimetric mode.

3.3 Low/intermediate dispersion spectrographs for 2-4m telescopes

3.3.1 Summary of science drivers

Spectroscopy at low/intermediate spectral resolution via longslit or IFU instruments is a greatly needed capability in the community for observations of single targets, that are both extended and point-like. The wavelengths accessed range from the atmospheric cut off up to K band. At present there are a number of well-tested instruments performing this task on a range of 2-4m telescopes. For point-like objects, where the goal is identification and/or analysis, it is desirable to use spectrographs able to offer the widest wavelength coverage, while for extended objects it may be at least as important to be able to access a reasonably large sky area. Time domain and time-critical astronomy also call on these spectrographs a lot.

The drivers for multi-wavelength spectroscopy in the next decade are many. For example, the extreme physics of compact objects (SV A6) can be probed. In particular, optical afterglows of GRB can be monitored successfully during the first hours after burst detection. If the simultaneous optical and NIR emission from compact binaries can be studied in combination with X-ray emission it will allow the roles of various components and processes to be determined. It will be possible to separate the contribution of the circumstellar disk from that of the stars and to determine the role of the accretion processes. Multiwavelength observations of supernovae will unveil the nature of the exploding systems and their evolution to the final configuration and the formation of compact remnants. In particular, the physical comprehension of the absolute magnitude vs. light curve shape relation of SNIa and the extinction laws toward them, will add more confidence to the experiments in progress on Dark Energy (SV A1). Our knowledge of the life cycle of matter in the Universe (SV C3) will improve by studying the zoo of objects (SNe, novae, Wolf Rayet stars, planetary nebulae, LBVs, etc.) that contribute both to ongoing nucleosynthesis and to the dispersion and mixing of the newly produced elements (SV B4). Finally, low/intermediate spectroscopy allows the physical mechanisms involved in the overall galaxy formation process (mergers, starbursts, AGN, SN feedback, cooling flows, etc) to be examined critically in the local Universe. This is vital for interpreting the (much less detailed) information being collected for galaxies at high redshifts, in order to build up a consistent picture of the evolution of galaxies through cosmic time (SV B6).

Clearly there will be a continued requirement for long-slit spectroscopy on 2-4m telescopes over the next decade. In order to allow maximum flexibility and science return, wide wavelength coverage at moderate resolution (R 500-1500) is a high priority; we regard coverage of the UV/optical from 0.3 to 1.0μm essential, and simultaneous coverage of the optical to near-IR (0.3 to 2.4 microns) as highly desirable. Presently all available spectrographs on 2-4m telescopes are limited to accessing either the optical or the NIR - not both together. The huge take up of X-Shooter, straight after its commissioning on the VLT, demonstrates a clear interest in complete coverage of the whole optical and NIR window.

2D spectroscopic observations of emission lines in galaxies of the near Universe, preferably by mean of IFU systems spanning fields of 1–2 arcmin, will provide the mapping of the chemical composition of the ionized gas and the metallicity distribution of the different stellar populations. These will constrain chemical evolution models of galaxies thus superseding the present norm of one-dimensional abundance gradients (SV B6). 2D spectroscopy of galaxies will supply the detailed mapping of the star formation rate (SFR) in spatially resolved spiral galaxies through the Hα emission, and the overall kinematics out to the external regions to obtain measures of their dark matter content (SV A2) and the study of very metal-poor dwarf galaxies to understand the cosmological scenarios of galaxy formation (SV B7). In addition, 2D spectroscopy provides a unique way to study galaxy evolution in dense environments such as in nearby/intermediate redshift groups, in clusters, and in AGN (SV B3). It is also the means to investigate the interplay of gas and dust in the interstellar medium of our own and nearby galaxies at maximal resolution (SV C3).

The simpler function of identification, and a wide range of options in time domain astronomy can be well met by more traditional long-slit spectrographs, presently found on both 2m and 4m class telescopes. In the coming Gaia era (SV B7), and on account of other space projects and ground-based photometric surveys, there can be expected to be an increasing need for straightforward spectroscopic identification and follow-up of unusual or transient objects.

3.3.2 Large programs, systematic monitoring, and all-sky survey follow-up

In general, and currently, low/intermediate dispersion spectrographs on 2-4m telescopes are requested for programmes of galactic and extragalactic objects performed in both queue and classical modes, ranging in scale of allocation from small service requests up to less frequent very large surveys.

The likely trend into the future is that more and more of the observing time will be absorbed into *large surveys*, e.g. to understand the evolution, activity and merging of galaxies, to study specific object types within resolved stellar populations, or mass loss and the properties of interstellar matter. Also *systematic monitoring programs* of specific classes of transient, e.g. novae and supernovae, will be requested as the target discovery rates rise and will use low/intermediate dispersion spectrographs on 2- and/or 4-m class telescopes depending on the apparent magnitude range involved.

A number of space and ground-based photometric surveys such as Gaia, Pan-STARRS, Skymapper, are entering into full operation. Specialised instrumentation is very–likely required for the systematic spectroscopic determination of the physical parameters of their targets (cfr. sections 3.1 and 3.2). But in addition, these surveys will provide an increasing flow of unusual or transient objects that, especially, need *rapid spectroscopic follow-up.* As an example, during five years of operation Gaia will discover about 6000 new SNe, 1000 microlensing events, and innumerable classical and recurrent novae, R CrB, FU Ori and asteroids brighter than G=20 mag. 2-4m telescopes equipped with low/intermediate resolution spectrographs are the necessary instruments to begin the scientific assimilation of these sources. On a 4m telescope a spectrograph with resolution of the order of 500-1500 (e.g. EFOSC2 + grism16) a S/N$\sim$ 30 can be reached for a point source of R=20 in 1h. The same S/N can be reached with similar spectrographs on 2m class telescopes for objects 1.5 mag brighter.

3.3.3 RRM/ToO and time domain spectroscopy

It is widely recognized that 2-4m telescopes should be more flexible than the 8m class (whilst the latter remain more heavily over-subscribed) and offer on a more regular basis adjustable scheduling (slow ToO) and overrride ToO for transients. The Rapid Response Mode (RRM), already implemented at the VLT and ESO/MPI 2.2m telescopes, should also be implemented on at least one telescope in the north equipped with a low/intermediate resolution spectrograph in order to trigger observations within seconds after the alert of rapidly variable targets (e.g. GRB OA). For this to be achievable, instruments of this kind should always be available indicating that dedicated facilities of this kind are appropriate.

With guaranteed access to rapid response facilities, the systematic study of several kinds of transients can be carried out efficiently. RRM will allow the capture of the earliest minutes/hours of a significant fraction of the about 100 GRB presently discovered each year. The NIR spectroscopic observation of GRB090423 (z$\sim$ 8.1) Salvaterra et al., 2009) is a noteworthy example of the potential of 4m telescopes in this field. With override ToO it will be possible to catch the earliest phase of the evolution of the about 90 SNe yr^{-1} presently discovered in the local (D $\leq$ 100 Mpc) Universe and to study the outermost layers not affected by the explosion. Then flexible scheduling will allow to monitor the evolution of the most interesting ones with the aim to understand the explosion mechanisms, determine the nucleosynthesis yields and the nature of the progenitors. The same capabilities will be exploited in the follow-up of galactic novae, comets, etc.

Spectrographs on 2m telescopes are important tools for time domain astronomy, most notably for the identification and parameter determination of a broad range of stellar binaries. Only on instruments in this size class is it usually possible to win the larger time allocations needed to properly sample orbital periods running into hours or days (or longer). For this class of programne visiting astronomer mode will often be sufficient, but not when infrequent monitoring is required.

For all the mentioned programs *instrument stability* is a fundamental requirement as it leads to improved instrument characterization, hence to more accurate data. In studies of distant Ia SNe, it is already recognised that systematic error remains a serious stumbling block to further progress. This adds in a very important way to the argument as to why these spectrographs should be permanently installed and available, on at least partly-dedicated telescopes.

3.3.4 Spectroscopy of extended objects

For extended objects the use of long slits (up to about 5 arcmin long) remains essential for detailed high precision spectrophotometry of individual targets. On the other hand, 2D spectroscopy with IFUs, probably fibre-fed for the best use of the full detector area, will provide unmatched, additional capabilities.

Indeed, single aperture or long-slit spectroscopy (like the single-fibre in SDSS) gives limited spatial information on the properties of extended objects. This fact can introduce severe, and hence dangerous, biases in the understanding of these objects. In strong contrast, IFU spectroscopy provides spatial information that is relatively unbiased. IFU observations of nearby galaxies can offer a wealth of information on their stellar populations, star formation and ionized gas properties, as well as kinematics, structure and possible imprints of environmetal effects. Despite this advantage, the small field of view of the available IFUs until very recently (typically below 1 arcmin^2) has meant that spectroscopic mapping of nearby galaxies, covering large angular sizes on the sky, could not be performed in an efficient way, and narrow-band wide field imaging has been used instead. This has been the case, for instance, in the study of the present-day SFR in external galaxies, where 2D spectroscopy can efficiently eliminate previous drawbacks of narrow-band imaging of HII regions: e.g. the contamination of Hα from the [NII]6548,6584 Å doublet, along with systematic errors in continuum subtraction, and also unknowable corrections for absorption in the underlying continuum spectrum. To facilitate these corrections, the contaminating emission/absorption must be fully resolved from Hα which in turn demands sufficient spectral resolution. In contrast, IFU spectroscopy measurements are free of these sources of error. In addition, the clear advantage of using 2D spectroscopy for the study of the structural and kinematical properties of galaxies can not be overlooked.

So far IFU instruments like SAURON (a private visiting instrument at the WHT) have revealed very important information on the stellar populations of early type galaxies. However, the field of view of this instrument is somewhat limited (at most 41 × 33 arcsec^2), allowing mapping of only the central parts of nearby galaxies; this fact together with its specific spectral coverage ($\sim$4700 to $\sim$5400 Å) means it cannot capture the full spatial extent of galaxies throughout the whole optical spectral range. A similar assessment can be made of OASIS, working at the adaptive-optics-dedicated Nasmyth focus of the WHT, which offers an even more limited field of view. In order to perform an efficient 2D spectroscopic study of galaxies in the local Universe a larger field of view is a must. For a galaxy at, for example, the distance of the Coma cluster (i.e. $z \sim 0.023$), 1 arcsec on the sky represents $\sim$0.5 kpc within the galaxy (assuming standard cosmology); therefore, it is clear that an IFU field of view ≥ 1 arcmin in diameter is necessary to carry out an efficient mapping of the full spatial extent of such objects out as far as Coma. An IFU spectrograph presently offering a suitable field of view is PMAS-PPAK attached to the CAHA 3.5m telescope. This instrument provides the spectral coverage of the whole optical range and a field of view of $\approx$ 74”×64”.

Multi object/slit options (with a moderate number of slits), can assist in allowing the study of more separated parts of an extended object or indeed different independent objects (e.g. nearer-by starbursts and/or AGN hosts, or indeed Galactic objects). Therefore, a field of view in excess of one arcmin appears a necessary step to be fulfilled to achieve the proposed science goals. The full optical spectral coverage is a must, with a low to intermediate spectral resolution, working between R=1000 to 5000, which would be required for many studies on the kinematics of nearby galaxies.

3.3.5 Highly multiwavelength spectroscopy

The entire wavelength range, from the atmospheric cut-off ($\sim$ 0.32 μm) to the K band (2.4 μm) is of scientific interest. For the study of high energy phenomena, that are frequently transient in nature or variable, it can be extremely useful to achieve all this coverage and obtain the OIR spectrum in one shot. Another group of targets studied more efficiently in this way would included significantly reddened objects within the Galactic Plane (many Gaia targets, members of young clusters). Looking ahead, it would be an obvious step to replace separate optical and NIR single-object spectrographs of older design by X-shooter type instruments that will allow simultaneous observations of those sources which nowadays have to be studied at different wavelengths on different nights or different telescopes. This evolution will make possible the optimal exploitation of all photons arriving from a given source.

Presently, as a surrogate, NTT and TNG offer on a systematic basis the possibility to switch between optical and NIR instruments placed at separate foci with little overhead. But there are limitations, suffered by these particular instruments, that should be overcome for full exploitation of the OIR spectrum. The short wavelength interval below 0.4 μm is rich in atomic lines presenting important diagnostics, such as OIII, OIV, [NeV], [NeIII] and [OII], as well as the Balmer jump. It requires a combination of both blue-sensitive CCDs as detector, and appropriately optimised optics to enable these short-wavelength lines to be captured well, rather than neglected. The interval $0.7 - 1.0$ μm can be another range of difficulty as it is often affected by heavy fringing in multipurpose single-arm spectrographs aimed at covering the entire optical domain. At these wavelengths are found the the CaII IR triplet lines and others that are increasingly used to characterise red and reddened objects. The CaII triplet can provide a useful tool for stellar kinematics and has been used as a metallicity indicator. In both wavelength domains, twin-armed spectrographs can do better (e.g. ISIS@WHT) - but no such instrument is offered in conjunction with a rapidly deployable NIR spectrograph.

When the time comes to update the low/intermediate resolution spectrographs presently available on 4m telescopes, the possiblity to build a new instrument covering simultaneously the entire optical-NIR domain should be exploited. This amounts to taking the twin-armed spectrograph one step further. Several channels optimized for various domains could be envisaged (e.g. UV-B: 0.32μ to 0.50μ, VIS: 0.50 to 1.0μ, JH: 1.0 to 1.7μ) following the example of X-Shooter at the VLT. Variants on this scheme might make the instrument more simple and versatile. For instance, the spectral resolution can be R=500-1500 (no cross dispersion) in the UV-B and JH arms, whilst still allowing the possibility to reach higher resolution in the VIS arm. Indeed, R$\sim 1000-5000$ is required for many optical studies of nearby galaxies, and hence cross-dispersion in the VIS arm would be desirable. With the NIR arm cut-off at 1.7 μ, the cryogenic cooling need only be applied to the detector (and a few optical elements).

This instrument will provide a new capability, unique for 4m telescopes, that will help to maintain European astronomy at the forefront in several research fields.

3.3.6 Existing facilities

A vast array of instruments is currently offered providing seeing-limited low/intermediate resolution spectroscopy. Many of these instruments have been invaluable workhorses at the respective telescopes where they share the focal planes together with other instruments. Some of these instruments are still highly requested and have been well-maintained - while some begin to show their age (e.g. old design concept, and/or small size detector size). They are:-

- For the optical domain on 4m telescopes:
    - EFOSC2@NTT (also multislit, R=150-5000), *remark: 20yrs old but still performing well, poor UV transmission, some red fringing, the only one in the south. Imaging mode available.*
    - DOLORES@TNG (also multislit, R=500-6000), *good, recently improved with new detectors, low fringing. Imaging mode available*
    - TWIN@CAHA3p5 (R=3000-14000), *A twin-beam spectrograph.*
    - PMAS-PPAK@CAHA3p5 (fibre IFU, R=300-8000), *unique as the only European purpose-built* ~ 1 *arcmin FoV IFU, also has flexibly deployable PPAK fibre bundles*
    - ISIS@WHT (R=2000-15000), *well-maintained with good UV capability, as well as the capability to cover a wide spectral range at intermediate resolution (because dual beam); low fringing in the red arm (optimised deep depletion CCD)*
    - OASIS@WHT (IFU, R=1000-4000), *Has a relatively small field of view*
- for the NIR domain on 4m telescopes:
    - SOFI@NTT (R=600-1500), *high overheads, old detector but good, the only one in the south. Imaging mode.*
    - NICS@TNG (R=50-2500), *old detectors 2x 1kx1k but good, similar to SOFI, useful very low res AMICI prism. Imaging mode.*
    - OMEGA-Cass@CAHA3p5 (R=420 and 1050, used with one of 3 slits) *also an imager, has* $1k\times 1k$ *detector*
    - LIRIS@WHT (R=1000-3000) *recent build, NIR imaging and spectroscopy*

  In store at UKIRT there are two further instruments with spectroscopic capability (CGS4, UIST).
- for the optical on the 2m telescopes:
    - ALFOSC@NOT (R=200-10000), *operation efficient, friendly and reliable, wide lambda range, some red fringing, imaging modes*
    - CAFOS@CAHA2p2 (multislit, R=600-3000), *stable, no fringing, overall good throughput, imaging modes*

  - IDS@INT (R=800-10000 in first order), *easy to use, with wide choice of gratings, red fringing*
  - CARELEC@OHP (R=450-2900 in first order) *long-slit instrument similar to IDS@INT, spanning 3600–10300 Å*
  - FRODOSPEC@LT (fibre-bundle fed, R=2200 $\lambda\lambda$s 3900–9400Å, R=5500 option, entering service 2010)

- for NIR on the 2m telescopes:
  - MAGIC@CAHA2p2 (R=130-260)
  - NOTCAM@NOT (R=2500, 5500; imaging also)

3.3.7 Conclusions

Low-intermediate resolution ($500 < R < 5000$) spectrographs are workhorses for a wide range of science and, as such, are vital in both hemispheres. Their essential role is either to provide IDs and classifications, or to perform quantitative astrophysical analyses (often, but certainly not exclusively, drawing on the methods of nebular astrophysics). The breadth of science involved also implies they are required both on 2m and 4m class telescopes. The most relevant ASTRONET science vision topics fall within: A6, B4, B6, B7, C1 and C3. We foresee a shift toward larger consortium-based programmes over the coming years.

At present, a number of low/intermediate resolution spectrographs are offered at 4m telescopes in the optical, and a lesser number at NIR wavelengths. They cover limited spectral ranges with a single exposure and share the focal plane with other instruments, mainly according to moon phase. Some are rather old and designed according to dated concepts. In the immediate future, it is important to retain the best of them, and to sieze opportunities for upgrades and enhancements (e.g. to reduce red fringing, or raise throughput).

In addition, it is also desirable that low/intermediate resolution spectrographs are: more stable and better characterized in order to guarantee more reliable calibration; available also during new moon (at least one optical spectrograph per hemisphere); offered in override RRM/ToO mode and slow ToO (flexible scheduling) in at least one telescope per hemisphere. Ideally, these requirements favour a scenario in which, in both hemispheres, the equivalent of one 4-m and one 2-m telescope, are truly specialized for low/intermediate resolution spectroscopy.

With respect to the current suite of 2-4m telescope spectrographs at the present time, we conclude that the following capabilities are the natural developments:

- very wide wavelength coverage in a single shot, ideally from atmospheric cut-off to the NIR (cf. sect. 3.3.2). In particular, good sensitivity for $\lambda < 0.4\mu$m and good 'fringe-free' access to the $0.7 - -1\mu$m range are of highest priority. The entire NIR domain (up to 2.4 μm) is also crucial. Should the access of the entire range be impossible for technical or other reasons, every effort should be made to extend the spectral coverage at least up to 1.7 μm. First choice would be to place a combined instrument of this kind at a northern hemisphere 4-m.
- optical IF spectroscopy across fields ≥ 1 arcmin in diameter and multi-slit/object over a larger ($\sim$ 15 arcmin) FoV

With this in mind and noting the currently available instrumentation, a phased programme suggests itself. The first few years of use, would consist mainly of managerial adjustments, that would assure the continued availability of long-slit instruments on both 4-m (N and S) and 2-m (N only), and also access to PMAS-PPAK@CAHA3.5. We note there is no southern 2-m with an instrument in this class. Over the longer term of a ∼5 year timescale, the aim should be that *at least* a northern 4m can perform one-shot optical/NIR spectroscopy in the manner of the VLT's heavily over-subscribed X-shooter, and that increasing the field of CAHA's PMAS-PPAK is considered. In the south, the only provision of this kind is located at the 3.6m NTT, and we are concerned that these are upgraded when it becomes necessary.

IDENTIFIED CAPABILITIES: It is important that the operational structures are in place to support effective RRM/ToO access to intermediate dispersion spectroscopy in both hemispheres.

- 3-1: continued availability of flexible intermediate dispersion spectroscopy, spanning the full optical/NIR range (preferably in "one shot"), on 4-m telescopes in both hemispheres. In the south, two ageing instruments, EFOSC2 and SOFI, on the NTT, are the *only* option, and must be upgraded/replaced. Linked imaging options are desirable.
- 3-2: 1 optical spectrograph with IF with FoV of 1-2 arcmin on a 4m telescope, in at least one hemisphere.
- 3-3: $2 \rightarrow 3$ $500 < R < 5000$ optical spectrographs on dedicated 2m telescopes, $1 \rightarrow 2$ in the north at least (preferably with imaging options).

3.4 Wide field imagers for 4m telescopes

3.4.1 Summary of science drivers

Among the research areas that require coupled optical and NIR wide-field imaging with 4m class telescopes (possibly also 2m class at optical wavelengths), the main ones are QSOs during the reionization era (SV B2), high-redshift galaxy clusters (SV B3), star formation history and evolution (SV B6) and the spatially-resolved study of star and star-cluster formation in the near universe (SV C1). For extragalactic science, the availability of photometric redshifts is mandatory to build large samples of galaxies at intermediate redshift and discover $z > 6$-7 QSO candidates; the NIR wide-field imaging must then be complemented by deep optical imaging.

The SDSS has enabled the first discoveries of bright QSOs at epochs close to the reionization era, $z > 5.7$ (Fan et al., 2001). Subsequent searches including deeper SDSS and CFHT surveys (Jiang et al., 2009; Willott et al., 2009a), led to a sample of about 40 QSOs, large enough to determine the $z \sim 6$ QSO luminosity function. The most distant QSO known today is at $z = 6.43$ whereas the record for Ly-α emitters is 6.96 (Masanori et al., 2006). The number density of QSOs is far too low to fully account for the required ionizing background. Up to now, there are three radio-loud QSOs among the $z \sim 6$ QSO samples. Breaking the $z = 7$ QSO barrier is most important for the following issues: (1) to probe the reionisation era, the transition from a few, isolated HII regions around bright sources (QSOs and starburst galaxies) at early times, through the period of overlap of the ionised regions, to almost complete reionisation of the intergalactic medium at $z \sim 6.0$, (2) to measure the continuing decline of the QSO luminosity function with lookback time and test theories of structure formation, (3) to characterize the first massive structures by searches for neighbouring Lyman break galaxies and Ly-α emitters at the QSO redshifts (with 8-10m telescopes). Radio-loud QSOs at $z > 7$ will be observed with very large radio arrays, such as LOFAR and SKA, to investigate the evolution of the HI content of the universe at early epochs. The high z QSO searches involve wide-field optical (at least i and z bands) and NIR (Y, J, H, and K bands) imaging in at least four filters sampling the continuum bluewards of Ly-α (no flux due to the absorption by intergalactic HI), the Ly-α emission or break, and two others for the continuum redwards of the line. The latter should indeed be probed with two filters to distinguish QSOs (blue continuum) from the far more numerous galactic red 'interlopers' (T dwarfs). The UKIDSS Large Area Survey (LAS) underway on UKIRT (Hawaii) has limiting magnitudes of $Y_{Vega} = 20.2$ and $J_{Vega} = 19.6$. By the end of 2008, the LAS had observed $\sim 10^3$ deg square and identified only four QSOs at $5.82 \leq z \leq 6.13$ (Mortlock et al., 2009) of which two were already in the $z \sim 6$ QSO larger samples of the Sloan Digital Sky Survey (SDSS). No higher redshift QSO has been uncovered whereas two were expected in the redshift range 6.4 – 7.2.

A most significant discovery of the last decade is the recent accelerated expansion of the universe detected in the Hubble diagram for distant type Ia SNe. This acceleration can be attributed to the presence of a significant energy density component. Is the dark energy really the cosmological constant? If yes, the equation-of-state parameter should be equal to $w = -1$. Current constraints from distant SNIa surveys are not tight enough to answer this question. The evolution with redshift of the galaxy cluster mass function traces the growth of linear density perturbations which depends on the baryon mass fraction and w (Rosati et al., 2002). Searches for high-redshift galaxy clusters were first conducted using extensive X-ray surveys (Rosat and later XMM-Newton and Chandra). The discovery and study of galaxy clusters beyond redshift z=1.0 will further constrain cosmological parameters and provide tests for cluster formation scenarios. At these redshifts, the X-ray searches are challenging due to limited survey areas and faint fluxes. A most promising method is wide-field multi-band NIR imaging since the 4000 Å break moves beyond the z band. One of the main goal of the UKIDSS Deep Extragalactic Survey (DXS: 35 deg square down to a detection limit $K_{Vega} = 21.0$) is to measure the abundance of galaxy clusters at $1 < z < 1.5$. Preliminary results show that $z = 1.0 - 1.2$ clusters detected through their X-ray emission (with optical follow-up) are recovered as significant overdensities. Detection in the DXS of a massive supercluster at $z \sim 0.9$ has also been reported (Swinbank et al., 2007). Deeper, smaller area optical and NIR imaging will also be needed for follow-up of the clusters discovered by the redshift independent, Sunyaev-Zeldovich effect (Planck mission and dedicated ground-based submillimeter facilities) and deep X-ray surveys.

Wide-field NIR imaging surveys, including time variability studies, offer a powerful tool to investigate the embedded populations of star forming regions, and address various issues related to star formation theory: age spread, kinematics at birth, mutiplicity, physics and evolution of protostellar envelopes and disks, etc. While Spitzer has discovered a large number of new deeply embbeded objects in nearby star forming regions, Herschel and ALMA will yield even more, identifying the youngest and lowest mass protostars indeed. A full characterization of the embedded population requires follow-up wide-field deep NIR imaging in order to build up their spectral energy distributions continuously from about 1 μm to mm wavelengths, thus providing an estimate of the mass and temperature of the central protostar and its disk/envelope. Ground-based NIR surveys also provide an order of magnitude higher angular resolution than Spitzer and/or Herschel do, respectively 0.5 arcsec at 2 μm (e.g. CFHT WIRCam) vs. 5 arcsec at 75 μm (Herschel), which solves the crowding issue in young stellar clusters, and allows the addressing of the critical issue of protostellar multiplicity as a result of core fragmentation during gravitational collapse. Wide-field NIR monitoring surveys will additionally complement Herschel and ALMA observatories in that they allow the exploration of the time domain. Currently, for instance, several monitoring projects are on-going combining the Spitzer warm mission with ground based NIR, with the aim to investigate the origin of variability in protostars and understand the interaction between very young objects and their circumstellar disks, and how this might affect telluric planet formation in the inner disks. Protostellar variability reflects time variations in the accretion/ejection processes taking place near the central protostar on timescales ranging from hours to days. Rotational modulation on a timescale of about a week provides a unique measurement of protostellar angular momentum – a key issue in star formation theories. Variability may also result from instabilities in the inner disks on even longer timescales of months to years. Repeated observations of embedded young populations across this broad range of timescales are expected to be one of the priorities of the wide-field NIR surveys.

The search for the lowest mass isolated objects in the Galaxy has been one of the most rapidly expanding field in stellar astrophysics in the last 10 years. Hundreds of brown dwarfs have been found, down to masses of a few Jupiter masses in star forming regions, and as cool as $T_{\rm eff} \sim 650$ K in the solar neighbourhood. A whole new chapter of cool atmosphere physics and chemistry has opened with these discoveries, and the first estimates of the lower end of the local IMF have been derived, suggesting that brown dwarfs are nearly as numerous as stars in the Galaxy (though not dynamically significant). The search for these very faint and cool objects requires deep wide-field optical and NIR imaging surveys. While easier to detect in the near-IR, optical follow up is required to assess their nature, and distinguish them from interlopers (e.g. high-redshift QSOs, see Delorme et al., 2008). Looking for high proper motion objects is perhaps the most powerful way to find the faintest and lowest mass objects in the solar neighbourhood, say within several 10 pc. This is attainable through large-scale, deep imaging surveys repeated at several epochs over a timescale of a few years. Complementing Gaia, which will discover the brighter tip of the local brown dwarf population, these studies will provide complete census of extremely low-mass objects in star forming regions, young open clusters, and in the solar neighbourhood, at a time when their spectroscopic follow up will become feasible with the E-ELTs and JWST.

The study of white dwarfs (WDs) is a different research area that uses much the same techniques as do the searches for brown dwarfs. Present within this inherently faint and hence local population will be many thin-disk (pop I) objects, along with less frequent thick-disk and halo (pop II) WDs. WDs can be seen as a relic population bearing the imprint of the star-formation conditions prevailing at the time they arrived on the main sequence: in principle, therefore, we can make inferences about these conditions from the characteristics of the present-day WD population (including e.g. their mass function). For thin-disk objects, this 'inversion' is very complex, given the long time over which the thin disk is believed to have been building. But the same is not necessarily so for thick-disk objects (depending on what the origin of the thick disk really is), while the inversion should be straightforward for halo WDs, since the halo is viewed as having formed rapidly and first. Accordingly we should expect to find a good record of how the first stars formed in the Galaxy from the oldest/faintest pop II WDs – is it indeed true that star formation at high redshift and/or long ago was characterised by no longer typical top-heavy initial mass functions (e.g. Baugh et al., 2005)? To lay hands on this record, a good WD census down to very cool temperatures (or $M_V > 15$), where the halo population becomes dominant, is an absolute requirement.

This view of WDs as a relic population has, in recent times, awoken interest in correcting the long recognised incompleteness of the local WD census, and in taking it deeper. There are two ways in which imaging data can form the basis for WD searches: much of the white dwarf population is relatively blue (mainly because they are unreddened), and they present with significant proper motions. Searches of both kinds are being undertaken, but only the proper motion searches are without bias against the coolest WD population. The state of the art, regarding pop I white dwarfs (see Harris et al, 2006), is that in an SDSS sample of 6000 proper-motion selected stars, only 35 are very cool WDs with $M_V > 15$ – the situation for pop II is of course much worse, and it is also necessary to separate out cool low mass WDs that are the products of relatively recent binary evolution, from the cold, but massive, halo WDs (e.g. Harris et al, 2008). This distinction can be made if SEDs can be constructed from both NIR and optical photometry. Hence, the goal of defining the faint end of the WD luminosity function is best served by a combination of NIR and optical surveying, with a multi-epoch element to provide proper motions. To progress, the sensitivity limit has to be taken a few magnitudes below the present limit of $m_V \sim 19.5$ set, thus far, by proper motion studies reliant on the older-generation photographic surveys.

3.4.2 Required capabilities

Detecting QSOs at $z > 7$ could be achieved with 4m class telescopes and spectroscopic follow-up should then be conducted with 8-10m class telescopes (e.g. with VLT/X-shooter). Predicting the number of $z > 7$ QSOs is quite a difficult task since (i) the number of bright QSOs ($M_{AB} < -26.7$) decreases very rapidly with redshift beyond $z = 3$, (ii) the $z \sim 6$ QSO luminosity function is still not fully constrained. It has recently been attempted by Willott et al. (2009b) who compared their predictions with the on-going, imminent and planned NIR surveys. The VISTA surveys mentioned below should detect 10 to 20 QSOs at $z \sim 7$ and a very few at $z \sim 8$. Observing both hemispheres is thus mandatory to get statistically significant samples, at least at $z \sim 7$.

- survey depth and area

  - Completion of UKIDSS-LAS (4,000 deg square down to $K_{AB} = 20.1$) until May 2012.
  - Proposal in preparation for a possible extension of UKIDSS past May 2012 which depends on continuing UKIRT operations beyond 2012.
  - Start of VISTA-VIRCAM surveys in 2010: VISTA Hemisphere Survey (VHS: 20,000 deg square down to Y_{AB}, J_{AB}, H_{AB}, $Ks_{AB} = 21.2$, 21.2, 20.6, 20.0) and VISTA Kilo-Degree Infrared Galaxy Survey (VIKING: 1,500 deg square down to z_{AB}, Y_{AB}, J_{AB}, H_{AB}, $Ks_{AB} = 23.1$, 22.3, 22.1, 21.5, 21.2, i.e. ~1.2 magnitude deeper than UKIDSS-LAS).
  - Complementary optical surveys and pointed, deep observations: SDSS, CFHT-MegaCam, VST.

Candidate massive clusters/superclusters at $z \sim 1 - 1.5$ or higher can be identified by deep optical-NIR imaging observations (galaxy concentrations, photometric redshifts) and X-ray observations to detect the hot X-ray haloes. Since all rich clusters contain a core population of passively evolving elliptical galaxies, formed at higher redshifts, detection of a red sequence of early-type galaxies reveals the existence of overdensities. These optical-NIR colour searches (with appropriate filters depending on redshift) enable identification of cluster elliptical galaxies as they are redder than all normal galaxies at lower redshifts. The NIR data combined with optical ones will enable an estimate of very accurate photometric redshifts, especially at $z > 1$. This will also be an important step in the observation of baryon acoustic oscillations.

- Existing facilities and on-going surveys

  UKIDSS-DXS and extension of UKIDSS past 2012, VISTA-VIKING, CFHT-WIRCam and complementary optical observations: SDSS, CFHT-MegaCam, VST.

Star formation. A complete census of young stellar populations, down to the lowest mass brown dwarfs, can be obtained in a few nights from wide-field NIR imaging for star forming regions extending over of a few square degrees on the sky, down to a magnitude limit of $K_{Vega} \sim 20$, corresponding to a few Jupiter mass object at an age of 1-5 Myr and a distance of about 100-300 pc. The variability of embedded young stellar objects can be investigated on a timescale of a few weeks from dedicated monitoring studies of nearby star forming regions ($d < 300$ pc) using wide-field NIR imagers.

- Requirements

  wide-field (20 arcmin minimum; 1 square deg ideally), deep: $K_{Vega} \sim 21$ (4m class), time domain (queue scheduling, service observing), both hemispheres to access nearby star forming regions around the galactic plane.

- Existing facilities

  CFHT-WIRCam, UKIRT-WFCam, VISTA

Very low mass stars, brown dwarfs and white dwarfs. Multi-epoch (a few years apart), wide-area optical imaging surveys provide one of the most powerful ways to identify faint, high-proper motion objects within a few 10s of pc from the Sun. Combined optical and NIR imaging surveys can additionally identify more remote very low mass objects based on their colours, and pick out massive pop II white dwarfs. These deep studies, reaching up to $z_{Vega} \sim 24$ and $K_{Vega} \sim 20$ on 4m telescopes, will complement Gaia in measuring the luminosity function of the solar neighborhood all the way from the most massive stars to the coldest brown dwarfs.

- Requirements

  wide-field (≥ 1 square deg), deep: $K_{Vega} \sim 21$, $z_{Vega} \sim 24$ (4m class), time domain (queue scheduling, service observing), both hemispheres to access the whole galactic plane.

- Existing facilities

  CFHT-MegaCam, UKIRT-WFCam, VISTA. UVEX (Groot et al., 2009), a blue-optical survey underway on the INT will provide r' proper motions on a baseline of ∼3 yrs with respect to the ∼complete IPHAS survey (Drew et al., 2005) down to ∼21 magnitude, doing somewhat better for white dwarfs than existing results.

3.4.3 Relevant facilities

There are several NIR wide-field imaging facilities on 4m class telescopes, as well as optical wide-field imaging facilities on 2–4m class telescopes, which provide the required capabilities for galactic and extragalactic surveys. The imagers with smaller field of view are well suited for follow-up of targets discovered with other ground- and space-based (e.g. XMM-Newton, Chandra, HST, Herschel) facilities.

NIR wide-field imagers

- UKIRT(3.8m diameter)-WFCAM: field of view = 745 arcmin^2; 0.4 arcsec/pixel; sensitive from z to K band; non-contiguous pawprint: 4 exposures are needed to cover a contiguous area of 0.75 square degree
- CFHT(3.6m diameter)-WIRCam: field of view = 20 × 20 arcmin^2; 0.3 arcsec/pixel with the possibility to micro-step the image with 0.15 arcsec sampling; sensitive from Y to K band
- CAHA(3.5m diameter)-Omega2000: field of view = 15 × 15 arcmin^2; 0.45 arcsec/pixel; sensitive from z to K band
- CAHA(2.2m diameter)-PANIC: field of view = 31.9 × 31.9 arcmin^2; 0.45 arcsec/pixel; sensitive from z to K band; in construction - alternatively if adapted for CAHA 3.5m: field of view = 16 × 16 arcmin^2 with 0.23 arcsec/pixel
- VISTA(4.1m diameter): field of view = 1.65 deg diameter; 0.34 arcsec/pixel; sensitive from z to K band; non-contiguous pawprint, with one exposure covering 0.60 square degree

Optical wide-field imagers

- CFHT(3.6m diameter)-MegaCam: field of view = 1.0 × 1.0 deg^2; 0.187 arcsec/pixel
- CAHA(3.5m diameter)-LAICA: field of view = 44 × 44 arcmin^2; 0.23 arcsec/pixel; non-contiguous pawprint, with one exposure covering 0.26 square degree
- INT(2.5m diameter)-WFC: field of view = 0.25 deg^2; 0.33 arcsec/pixel
- MPG-ESO(2.2m diameter)-WFI: field of view = 34 × 33 arcmin^2; 0.24 arcsec/pixel
- VST(2.4m diameter): field of view = 1.0 × 1.0 deg^2; 0.21 arcsec/pixel; operations are expected to start the last quarter of 2010

3.4.4 Conclusion

The major science goals that require NIR *and* optical wide-field imaging are searches for QSOs during the reionization era and galaxy clusters beyond $z = 1$ (SV B2 and B3), star formation history and evolution (SV B6) and the spatially-resolved study of star and star-cluster formation in the near universe (SV C1). These wide-field surveys also have a much broader relevance, e.g. for red galaxy populations (luminous IR galaxies, LIRGS, or submillimeter galaxies).

These large-area surveys, that could justifiably expand to being all-sky, require NIR and optical wide-field imagers, one each per hemisphere and in good seeing sites. Telescopes should be of the 4m class, especially for NIR imaging. These surveys are large/long-term projects that require a substantial amount of telescope time (each hundreds of nights). The instrument field of views should be large, optimally 1.0 $\deg^2$ or larger, and the spatial sampling should be adapted to the local seeing (a minimum of 2-3 pixels per FWHM of the average seeing). These facilities must have a secure future over the next decade. Presently Europe has the clear lead in NIR surveying, far surpassing 2MASS in sensitivity.

In the southern hemisphere, instrumentation at the VISTA and VST telescopes fully satisfy the requirements.

In the north, UKIRT (NIR) and CFHT (NIR and optical) fully meet requirements also, but their operations must continue beyond 2012 and 2015, respectively. There are ambitious, needed or planned, surveys. The extension of UKIDSS-LAS (currently 4,000 deg square at completion of the survey) to cover the entire sky visible from UKIRT is crucial for the $z \geq 7$ QSO search, as planned for VISTA-VHS. The preliminary agreement between CFHT and the Pan-STARRS1 Science Consortium (PS1SC) foresees a comprehensive U-band survey to be carried out at CFHT that it is planned will be combined with PS1 data. There could also be new forefront instrumentation for these telescopes, as the proposed optical imager IMAKA at CFHT which is currently in a R&D phase. The goal of this imager is to achieve exquisite image quality over the largest possible field of view, with a FWHM of not more than 0.3 arcsec (obtained with ground-layer adaptive optics) over a square degree field in the optical domain. Sharper images will increase sensitivity depths and reduce confusion noise in crowded fields. Among the main science aims of IMAKA are $z \geq 7$ galaxy searches (complemented by deep NIR imaging), high redshift supernova cosmology, weak lensing and galaxy and stellar evolution.

At NIR wavelengths, alternatives in the north could be the Omega2000 NIR imager at the CAHA 3.5m telescope, although it has a smaller field of view and coarser sampling than UKIRT-WFCAM. The PANIC imager under construction for the CAHA 2.2m telescope has a large field-of-view (30×30 arcmin^2) but a coarse sampling. This camera would have a better sampling if adapted to the CAHA 3.5m telescope, but this option does not seem to be currently considered. Another attractive possibility is a new NIR imager using the full field of view at the prime focus of WHT or CAHA 3.5m telescope. NIR wide-field imagers at these sites will enable observations beyond the +60 declination limit of UKIRT to reach important star-forming regions (e.g. a large part of the Perseus Arm) and key extragalactic targets such as M81 and M82. These observations will supplement those carried out at UKIRT, CFHT and VISTA, and enable all sky coverage, north and south, down to 4-5 magnitudes fainter than 2MASS.

IDENTIFIED CAPABILITIES:

- 4-1: Wide-field ($\geq$1 deg^2) NIR imager on a 4m-telescope, North and South
- 4-2: Wide-field ($\geq$1 deg^2) optical imager on a 4m-telescope (preferred) or 2m-telescope, North and South

3.5 OIR time-domain photometry

This section focuses on imaging and photometry that can be accomplished by optical/NIR cameras built around single detectors accessing more modest sky areas in the region of a few arcminutes. In tandem with medium to high-resolution spectrographs (sections 3.3 and 3.2), such imagers are required to address a broad range of questions in stellar evolution (C2), and also in planet formation (C4), and the diversity of exoplanets (C5). High precision imaging techniques can also identify perturbations due to Earth-size planets in already discovered planetary systems (C6). Time domain observations performed by medium-size telescopes establish the *basic input data* of both variable-star astronomy and also for extrasolar planet research. The instrumentation is of modest cost compared with e.g. wide field spectrographs, and mostly exists, but it is obviously and critically important that the on-sky time to exploit them remains available over the next 5-10 years.

Characterization of the exoplanet population along with that of their host stars is a fundamental step toward understanding the mechanisms behind the formation and evolution of planetary systems. These are also the necessary steps to understanding the conditions that yield Earth-like planets within habitable zones. Telescopes of the 2–4m-class can contribute significantly to the solution of the most important current problems concerning extrasolar planets (e.g., the incidence rate of multi-planetary systems; their degree of coplanarity; relative inclination of the stellar spin and planetary orbital axes; exoplanet albedo and atmosphere composition, and interior structure; planet migration). In addition to the follow-up on targets supplied by the current satellite missions (CoRoT and Kepler) in searching for extrasolar planets, ground-based facilities play key roles in characterizing the many bright candidates detected via transits measured by small telescope systems (e.g., HATNet and SuperWASP) and via radial velocity searches (e.g., the HARPS consortium, the California Planet Search team).

Studying stellar pulsation is the *only* way to collect information on the internal structure of stars. Multi-mode variables (including those with solar-type, stochastically-excited oscillations) enable us to map the envelope, and, in the case of deep gravity modes, even regions close to the bottom of the envelope. In addition to acquiring information on stellar structure, variable stars are valuable assets in establishing the cosmic distance scale, and as a means of determining interstellar reddening. An example of testing stellar evolution photometrically is given by examining the dependence of the HRD blue-loop of Cepheids on the treatment of convection, nuclear energy production rate and chemical composition (see Cordier et al., 2003). Problems in stellar pulsation in the past have led to improved physics, e.g. the revision of opacities in the 1990s was stimulated by long-standing difficulties in this area (see Simon , 1982; Seaton , 1993; Iglesias and Rogers , 1996). Many intriguing questions remain to be answered in this field (e.g., understanding the Blazhko effect; the origin of multimode large-amplitude pulsations; the convection-pulsation interaction).

In addition to the extrasolar planets and pulsating stars, there is a plethora of various time-domain questions to be pursued on $2-4$ m-class telescopes. These include variability studies on scales from the size of the Solar System to the distant quasars. We note as an example at the near, small-scale end of this range, the need for time series photometry in characterizing the shape and rotational properties of asteroids, monitoring NEOs after the detection by larger telescopes and observing stellar occultations of TNOs and KBOs (SV D5, see Bickerton et al., 2008, who used the 1.8 m telescope at DAO). There is a particular opportunity for this, in the Gaia era, when accurate event predictions will make these kinds of observations feasible.

In the far universe, the aim of prompt, fast monitoring of GRB optical afterglows is to study the flux and decline rate to get information on the energetics, on the aperture of the beam, hence on the central engine (SV A6). For them RRM is needed. Nearby SNe, instead, need ToO at early stages when they can also be observed with 2m telescopes, and queue mode at late time with both 2m and 4m instruments depending on the phase. The aim is to describe the whole multiwavelength evolution and to determine the whole energy budget which, in turn, provides insights on the size of the exploding star, the mass of the envelope and the total radioactive yield produced during the explosion. Other extragalactic studies that could be mentioned needing OIR time-domain photometry include various types of variables in dSph galaxies (e.g. Poretti et al., 2008, using WFI@ESO-MPG2.2) and QSO variability research (e.g. Ojha et al., 2009, using the SMARTS-consortium telescopes) and the work of Goicoechea & Shalyapin (2010), who used RATCAM@LT.

Finally, there is a continuing need also to pursue the problem of binary star evolution, particularly in the late stages leading to SNIa (SV A6), and also to use binaries as a means to measure accurate stellar masses and radii (SV C1, sometimes in support of e.g. VLT interferometric work). Since binary periods can be anything from hours to weeks or more, and even individual eclipses may be quite long-lasting in eclipsing systems, there is nothing for it but to set aside a significant tranche of time to collect the needed data: the data-taking might be continuous or better scheduled as regular monitoring observations. The important work to be done includes, on the one hand, the characterisation of low-luminosity stars in order to better understand the low mass end of the IMF, and on the other, the collection of large samples of compact binaries as tests of population synthesis and estimates of space densities, that in turn test our uncertain ideas about the progenitors of Ia SNe, and set constraints on sources of gravitational wave radiation (SV A4).

More generally, ground-based OIR time-domain photometry not only provides the opportunities for vital supplementary observations of targets traced by current (MOST, CoRoT and Kepler) and future (Gaia, BRITE) satellite missions, but also support the detailed studies of the many exciting variables supplied by large-scale surveys (ASAS, and OGLE, in the recent past, IPHAS/UVEX presently, Pan-STARRs, SkyMapper and LSST over the next decade). We note that access to $1-2$ m-class telescopes have also been requested, via the Web Forum, to provide data for the Ground Based Optical Tracking (GBOT) programme that are necessary to reach the desired astrometric accuracy of Gaia. Specifically, imaging data are needed on a nightly basis throughout the several years of Gaia operation. Strictly speaking this last is a service role, rather than the direct pursuit of science – it is a curious feature of long-standing ESA policy that this kind of support is requested, rather than directly paid for to assure its delivery.

3.5.1 Remarks on the classes of required capability

To characterize the various capabilities needed to pursue the science goals described above, we note the following. For interesting variables discovered by space- and ground-based surveys, multicolour time series photometry is needed to aid mode identification in the case of pulsators, to confirm and characterise exo-planet transits, or to determine basic orbital properties in the case of binary stars. The timescales in question may be short, but can also be quite prolonged requiring long time allocations. We separate these as two distinct capabilities below: namely, technically more demanding precise fast photometry and time-intensive longer monitoring (able to use more straightforward cameras).

In exo-planet science the near-infrared domain is important also, as a third capability – particularly for the accurate determination of planetary orbital parameters and atmospheric properties via high precision photometric follow up of occultation events. Less demanding, but still important topics the ones related to classical variable stars, including the ones targeted by the VISTA survey and those in the early phase of stellar evolution (YSOs and other pre-main-sequence stars). Fourth and finally, the prompt photometric detection and follow-up of transient events (most notably GRB, SNe and novae) is another clear area of need.

3.5.2 Precise/fast-rate OIR photometry

Current interest in precise planet and host star characterization have led to an impressive improvement in the accuracy of the photometric (or more strictly, of the relative flux) measurements. With Orthogonal Transfer CCDs one can perform on-chip tip-tilt correction due to the isoplanatic angle/phase changes, together with PSF shaping to aid more accurate photometry (see Howell et al. , 2003, for the description of OPTIC@UH2.2). We note that these techniques are being used in several large imaging programmes, such as Pan-STARRS (Tonry et al., 2008), the One Degree Imager, or ODI, at the WIYN telescope (Harbeck et al., 2009) and the imager planned for PILOT (a 2.4 m telescope located at Dome C on the Antarctic Plateau; Saunders et al., 2008). The application of fast (~ 1 s) frame transfer detectors not only allows us the effective observation of rapid astrophysical phenomena (see the short ingress of eclipsing dwarf novae observed by ULTRACAM at the WHT, e.g. Copperwheat et al., 2010), but helps also in avoiding both image saturation and resorting to image degradation via excessive defocusing.

Internal (relative) photometric accuracies at or just below the mmag/min level are beginning to be realised at several facilities. For example, transit events of HAT-P-3 measured by Gibson et al. (2009) with RISE@LT2.0 in a wide-band (500–700 nm) filter yielded 1.3 mmag/min accuracy on the average. As a further instance, the $V = 12.7$ mag host star of the transiting planet WASP-10b was measured by OPTIC@UH2.2 (Johnson et al., 2009) and an accuracy of 0.55 mmag/min was reached in the z' band. This level of accuracy, namely 1.0–0.5 mmag/min, is making ground-based photometric data comparable to those collected in space and enables us to detect Neptune and even Earth-size planets around solar-type stars (see Colón and Ford, 2009). At optical wavelengths, this goal of precision can be reached for medium bright (i.e., $V < 13$ mag) stars using 2 m-class telescopes – presuming that they are equipped with the type of detectors discussed above and the accompanying data reduction pipeline utilizes all the advantages of the instrumentation. When fainter objects are to be followed up or, or when even higher overall accuracy is needed, higher aperture telescopes could be advantageous (see, e.g., the factor of two stronger variability limit imposed in a survey of DA white dwarfs by UltraCam@WHT4.2, vs. SAAO1.9, Kurtz et al., 2008).

Finally, concerning the important case of moderate field-of-view near diffraction-limited imaging, the very short exposure time and the high sensitivity enabled by electron multiplying make it possible to filter out atmospheric image motion. This is less expensive but about as effective as what is achieved by conventional adaptive optics. With Lucky Imaging, atmospheric disturbances can be cured/avoided by selecting near diffraction-limited images from a large number of short-exposure ones (see the binary survey by LuckyCam@NOT of Law et al. (2008) or the imaging of the binary extrasolar transit host stars by AstraLux@CAHA2.2 of Daemgen et al. (2009)).

3.5.3 Light curve acquisition and monitoring on longer timescales

The instruments needed for this are already plentiful, straightforward in concept, and inexpensive to build or upgrade: what is required is a sufficiently large CCD in the focal plane capturing both the target of interest, and sufficient neighbouring stars to serve as comparison objects. And of course there needs to be a sufficient set of commonly-used filters. In many cases these can be the same instruments as described in the section above, but this capability can also be accessed via the alternative mode of use of a number of low-to-intermediate dispersion spectrograph (as in CAFOS@CAHA and ALFOSC@NOT). The main point is that the need for photometry of this kind is still essential to enable progress in a number of high-profile research areas.

In most instances 2m telescopes are well-suited to this role (able to reach down below 20th magnitude, depending on the time resolution required), and can be maintained at low cost when sharing a site with a larger telescope. This situation already applies at CAHA and also in La Palma where the NOT and INT are located. A significant part of the role of the Liverpool Telescope is to facilitate monitoring, but would not be able to shoulder Europe's entire need for sky time on its own, and would struggle to accommodate many long continuous time series.

The pressure on 4m telescope time remains high enough that it makes little sense to plan for very long photometric campaigns or monitoring programmes on them. But there are occasions when only 4m telescopes offer the required accuracy at the target brightness levels – as examples of this, there are many interesting variables in distant galaxies and in nearby dSphs, whose study requires time-series acquisition on faint objects (mentioned in Sect. 3.5.1.), and monitoring of fading GRB/SNe may need access to this aperture. It is therefore appropriate to retain some imaging capability on the 4-m telescopes.

Lastly, we remind that much of what was said in 3.3 on RRM/ToO spectroscopy applies with equal force to RRM/ToO OIR photometry: it is a matter of identifying stable, well-characterised photometric instruments, and setting up the mechanisms to achieve prompt and appropriate access.

3.5.4 NIR time series photometry with 4-m telescopes

Secondary eclipse observations of extrasolar planets have been nearly routinely performed by the Spitzer infrared satellite. Ground-based observations have been successfully attempted also from the ground by 8-10m-class telescopes (e.g. Gillon et al., 2009), and quite recently by 4m-class ones. The infrared emission of CoRoT-1b has been successfully measured in the K-band by Rogers et al. (2009) with

NICFPS@ARC3.5 telescope at Apache Point Observatory. The occultation of the planet TrES-3b was observed by de Mooij and Snellen (2009) with LIRIS@WHT4.2. There are also preliminary reports on similar measurements made with WIRCam@CFHT (see Croll et al., 2009). These successful attempts show that 4 m-class telescopes are well-suited to the measurement of the K-band emission of extrasolar planets, even though the expected signal relative to the host star is very faint (of the order of few times 0.1%). The general importance of these measurements has been stressed already above. A specific example that demonstrates the impact of the occultation measurements is the case of HAT-P-13c, the long-period outer planet of a system with a transiting inner component. Because planet "c" is, so far, non-transiting, we have only a lower limit for its mass: however, according to Batygin et al. (2009) its mass can be accurately fixed (even if it really is non-transiting) once we have a more accurate measurement on the eccentricity of the inner planet. This goal is easily achievable by an occultation measurement in the NIR.

Obviously, as it is also noted in Sect. 3.5.1., NIR time series photometry has a very wide applicability in other area of research (from variability of YSOs to the pulsations of red supergiants). We refer to Sect. 3.4 for the instrumental background on wide field NIR imaging as the source of time series photometry of clusters and galaxies.

3.5.5 Existing facilities:

High precision, fast optical cameras:

- RISE@LT2.0, RATCam@LT2.0 *(RISE is a frame transfer camera allowing the measurement of low S/N signals on short time scales. RATCam is a low-noise 2K×2K back-illuminated camera. Both have been used very successfully to conduct precise photometry on individual targets.)*
- IO@LT2.0 *(A replacement for the above pair of instruments, offering smaller pixels, and accessing an increased 10×10 arcmin^2 field. Being commissioned. Also has a NIR arm which, if furnished with a detector can replace SupIRCam - see below)*
- LuckyCam@NOT2.6, AstraLux@CAHA2.2 *(These are working in frame transfer mode and equipped with EMCCDs enabling them to perform subsecond frame taking. So far they have been mainly used for imaging close to the diffraction limit.)*
- UltraCam@WHT4.2 *(High-speed triple-beam 1K×1K CCD camera, used for observing rapidly varying objects. Private instrument, that has also been used on other telescopes, including the NTT and VLT.)*

Other optical cameras:

- BUSCA@CAHA2.2 *(Optical imager, offering 4 Stromgren colours simultaneously, 12×12 arcmin^2 field, 0.176 arcsec pixels.)*
- MOSCA@NOT2.6 *(High resolution optical imager, 0.217 arcsec pixels 2×2 binned, 4 2K×2K CCDs, 7.7 arcmin field.)*
- MOSCA@CAHA3.5 *(Optical imager at RC focus, with an 11 arcmin field and 0.33 arcsec pixels. Grism and multislit spectroscopy also.)*
- ACAM@WHT4.2 *(Permanently mounted Cassegrain optical imager, with an 8 arcmin field and 0.25 arcsec pixels. Offers spectroscopy with* $R \sim 450$ *and* ~ 900*.)*
- See also Section 3.3.6 for time-domain photometric applications of other focal-reducer instruments offering spectroscopy (e.g., DOLORES@TNG, ALFOSC@NOT, CAFOS@CAHA).

NIR imagers on 4-m telescopes:

- LIRIS@WHT4.2 *(NIR imager and intermediate-resolution spectrograph, with only some applications so far for time series photometry.)*
- UFTI@UKIRT3.8 *(Imager with 1K×1K CCD, with applications in accurate time series photometry. In storage presently.)*
- See also Section 3.3.6 for SOFI@NTT, NICS@NTT.

For completeness we also mention NIR imagers located on 2-m telescopes:

- NOTCam@NOT2.6 *(Also mentioned in section 3.3.6, this is a combined imager/spectrometer spanning 0.8–2.5μm, offering imaging on two scales - respectively 0.234 and 0.078 arcsec/pixel.)*
- SupIRCam@LT2.0 *(A J,H imager. 1.7 arcmin field, 0.413 arcsec pixels.)*

3.5.6 Conclusions

The highest-profile science drivers in time-series observations are the search for *extrasolar planets* (SV C4, C5) and stellar interiors probed by *stellar seismology* (C2). Other applications arise in areas as diverse as A4, A6 and D5. The required photometric capabilities amount to the following:

- Coverage of both hemispheres, to assure a match to running/upcoming satellite experiments and ground-based surveys, and – ideally – a spread in longitude.
- Partially/fully dedicated instrument/telescope usage with remote control, or, preferably in *automated* operation.[1]
- Both optical and NIR detectors. The extension to NIR is especially important for exoplanets.
- Precise (sub-mmag/min) photometry based on modern CCD technology.
- Continued access to focal reducer instruments able to offer both spectroscopy and imaging modes (see 3.5.3 above), for less demanding time series work – to free up high precision instruments for what only they can do.

The ideal hosts of the above instrumentation would be a network of 4 telescopes: two of them of 2 m-class, equipped with modern optical imagers at contrasting longitudes, and one in each hemisphere and, distributed similarly, two 4 m-class telescopes offering NIR (and, if possible, optical) imaging capabilities.

A broad range of access modes is needed, particularly on 2m-class telescopes, due to the large number and variety of interesting targets. For individual event observations that can be covered in one night (typical of short-periodic transiting planets) simple one-off time allocations are viable, whereas for longer events (e.g., long-periodic planets, multiperiodic variables) we need some form of monitoring achieved through collaborative arrangements or by flexible time allocation algorithms. And of course RRM/ToO options have to be available.

We now provide some rough total time estimation. First, we take an example from the study of exo-planets: if systematic study of transit timing variation is targeted, then, due to the increasing number of known transiting extrasolar planets there is at least one event per night, each typically needing $\sim 4-5$ hours on-sky time. Approaching these events selectively, picking only the most promising/interesting targets and/or focusing on the derivation of accurate planet parameters, ~ 50 new targets per year might be chosen, each requiring three transit observations. Adding 30 occultation observations yields a *minimum* total request of 1000 hours/yr (∼4 months/yr). Other programmes drawn from other research areas (pulsating variables, eclipsing binaries, transients, compact binaries, small bodies in the Solar System) will consume widely varying amounts of time involving different patterns of use. This will include light curve acquisition for mostly periodic variables and time-critical capture of transient events and eclipses. Given the many active research

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[1] We note that presently it is only the LT that offers robotic operation – a very important asset both for producing higher science value and lowering costs and human intervention.

fields involved, it is easy to see the total time requirement would most probably exceed that just estimated above for exo-planets alone.

IDENTIFIED CAPABILITIES:

- 5-1: fast-frame (tip/tilt correcting) 5-10 arcmin FOV optical imager on a 2m telescope, North and South, at contrasting longitudes, → precise (<1 mmag/min) photometry.
- 5-2: 5-10 arcmin FoV NIR imager on a 4m telescope, North and South, at contrasting longitudes, → 5-10 mmag/min NIR photometry.
- 5-3: 5-10 arcmin FOV standard optical imager on a 2m telescope for classical time domain works at 1%/min accuracy.

4 Wider considerations relevant to the health of European astronomy

As well as directly supporting the specific science goals identified in the ASTRONET Science Vision document, the 2-4m telescopes provide an infrastructure that is crucial for the long-term health of the European astronomy community. As a panel we see three very important aspects to this – all of which were brought up by contributors to the web forum. These are: (1) the continuing need for flexible telescope access that allows novel ideas to be tested out, and underwrites an invigorating breadth of science ; (2) the opportunity for new instrument concepts to be tried out in visitor mode; (3) hands-on experience of observing with modern telescopes that is a critical part of the training of the next generation of astronomers. A fourth new element that needs to be considered, also, is how to make a reality of Europe-wide collaboration over the construction of new instruments for non-ESO telescopes, and also for the collective exploitation of data obtained. We comment on these issues in turn.

4.1 Flexible telescope access for observers

Due to their extreme over-subscription rates, it is difficult to successfully apply for time on 8m telescopes for high-risk/high-gain science projects that are genuinely innovative. With their lower over-subscription rates and broad suites of common-user instruments, the 2-4m telescopes currently provide the capacity necessary to support the higher risk projects. Although some increased specialisation in the use of 2-4m telescopes is inevitable, it will be important over the next decade to maintain sufficient breadth and flexibility across the complete suite available to European astronomers to allow the early exploration and demonstration of new, emergent ideas. If this kind of access becomes difficult-to-impossible, our subject risks a fall into centralist 'safe science' that unduly favours retreading the successes of the recent past.

One contributor to the ETSRC web forum, endorsed by others, put it this way:

> There is undoubtedly a great need for very high-quality surveys with 2-4m class telescopes... However, it is crucial that two world-class 4m facilities (one for N and one for S) be dedicated to high-quality classical optical/IR observations using a wide range of instrumentation and with time awarded through peer-reviewed competitive application. This is based not only the wide range of science which is best carried out on such telescopes and the training it provides for young scientists, but

> also to allow scope for small-scale innovative highly ambitious projects (high-risk, high-return).

These remarks also anticipate the question of training which we return to below

A different take on this issue places the emphasis on what might be described as artificial barriers of process, nationality and - of course - resource restrictions:

> 2-4m telescopes can often carry out scientific programmes that are more and more "forced" to be proposed for execution at larger telescopes, either because of telescope or instrument (un) availability, or allocation rules. This unjustifiably and expensively increases pressure on larger telescopes, whilst making it harder for these programmes to make a case. Programmes of this kind never cease to exist, as they include monitoring programmes as well as the follow-up of unpredictable (bright) events.

It is worthy of note that the desired flexibility does seem to be more often thought of in terms of classical peer-reviewed access to 4-m class telescopes offering a broad range of state-of-the-art instruments. This panel does not see it as by any means essential that this broad range should all exist on one and the same 4-m telescope per hemisphere – it can be spread across a suite. It should be remarked that there is quite wide acceptance of the notion that 2-m telescopes are more appropriately viewed as specialised facilities supporting surveys and/or time-domain astronomy. Specialisation can become a feature of 4-m telescopes too, but the community is vocal about this still meeting a broad need.

4.2 Fostering innovation: visitor instruments

The support provided by 2-4m telescopes for niche instruments is important in three main respects. First, by allowing astronomers to be creative and bring their ideas to fruition on a short timescale, the direct scientific rewards are high. Second, the possibility of rapid deployment of small-scale instruments directly supports technical innovation in instrument groups. Third, the 2-4m telescopes can act as direct test-beds for technologies that can be deployed on future ELTs. Such opportunities are not so readily available on 8m telescopes: these are heavily over-subscribed; have long lead-in times for major common-user instruments; and provide relatively limited access to visitor foci.

Of the current generation of 4m telescopes, the WHT provides an excellent example of how the flexibility to support visitor instruments can lead to high scientific gains and technical innovation. Over the last decade significant fraction of the WHT time has been allocated to a number of innovative visitor instruments including SAURON, PNS, and ULTRACAM; more recently the WHT has also been used as a test bed for laser guide star adaptive optics experiments. The high-profile science produced by the visitor instruments on the WHT is competitive with that produced by any 8m telescope, and some of the instruments and techniques have subsequently been deployed on the larger telescopes. Astronomy is a technology-led discipline. Therefore it is important to to ensure that 2-4m telescopes continue to be used to support technological innovation in instrument groups.

To underline both this specific need, and indeed the broader retention of flexibility in the use and application of existing 'general purpose' instruments, we provide this direct quote of a contribution to the ETSRC web forum from a post-doctoral scientist, of the younger generation:

> This flexibility to try new things should be maintained, beyond the goals identified in the current road maps. This implies access to general purpose instruments in both hemispheres. It also requires that these facilities have the support to do experiments with these instruments outside of their normal operation; the option for groups to try new optical components or experimental detectors, and the staff expertise not only to get the best out of the instruments in normal operations but to be able to creatively solve problems and enable new modes. It is also important that there exist options for entirely new experiments (i.e. visitor instruments on telescopes). Finally, there should be access routes to the 'specific experiment' sort of instrument for people wanting to do different science than the original design, where a new capability is identified.

These remarks were echoed by other forum contributors bringing out the importance of maintaining a short distance between (mainly university) instrumentation groups dispersed across Europe and opportunities to properly test new instrument concepts, or to adapt instruments already in place. For many nations, the option to exploit either regionally or privately-funded telescopes in this manner simply does not exist.

4.3 Educating the next generation

As the 8m telescopes have moved increasingly to queue styles of observing, the opportunities for visitor mode observing have significantly diminished. The impact of this, from the training point of view, extends beyond lowered awareness of the basic mechanics of how data are obtained, into less appreciation of e.g. the role of weather in data quality, methods of calibration and the options for instrument setup. Furthermore, astronomy is entering an era in which more and more use is made of already-pipelined survey and archive data, making it more and more common that graduate students do not have to confront the steps involved in data extraction, including the propagation of observational error and the origins of systematic effects. Yet a knowledge of these matters based on experience are important ingredients in the business of the successful design and selling of observing programmes. Accordingly, we must confront the question of how the next generation of observational astronomers will gain direct hands-on experience and be trained in observational techniques.

Clearly, the 2-4m telescopes are eminently well suited to this training role, mainly on account of their less extreme oversubscription. A number of schemes that use 2-m telescopes to train young astronomers are already in place.

The ETSRC panel has received, via the web forum, a succinct proposal in this regard, from Michel Dennefeld who is able to draw on his experience as the coordinator of the Europe-wide NEON schools. The text below has undergone some minor editing just to make it even more succinct:

> There is a definite need for training in observing techniques, including data reduction. This cannot be done on larger telescopes (pressure factor too high), but should now be done on the 2m, where the pressure is going down. But it requires these 2m telescopes to remain available, and to be, equiped with competitive research instruments.
>
> From my experience, a "real research run" is essential (as opposed to smaller university telescopes where you do standard (and boring...) exercises: you are "in conditions", motivation and concentration is maximum (you do "only that"), and you have direct and permanent contact with the experienced astronomers during a few days/nights. You get the basic "starter" experience for your career! You do this training in basics: imaging/photometry with CCD's (can be done with even smaller telescopes) and low dispersion spectroscopy (visible, or near IR) High dispersion spectroscopy with echelle gratings should come later as it is more complicated - you need first to master the basics in spectroscopy (2D flat fielding, large wavelength coverage issues with distorted wavelength calibration and response curves, etc...). So, to do a good training with, at the same time, an interesting research programme, you need a 2-m for spectroscopy. You do the training with a real research program (given by the tutor, or it can be your own programme), giving publishable results!
>
> Some of the observatories do this already for their national (or regional)

> graduate students: Haute-Provence at the 1.93m, NOT with the Nordic School, Rozhen for the SREAC school. I would argue for organising this more generally at the European level, as one, significant bonus we found out with the NEON schools (running now for more than 10 years) is that the students appreciate particularly being in groups of various nationalities and origins – besides the fact of being within a real research environment: this is the seed for future collaboration.
>
> So we should set-up a network of 2m telescopes usable for research training, with high quality, basic instruments: CCD cameras, and low-dispersion general purpose spectrographs (EFOSC type instruments would be ideal, because you can do with them all you want: long-slit, multi-object, Fabry-Perot, polarimetry, etc...and imaging!). Specific training in more specialised techniques would then be done on request, for smaller groups of participants, on other telescopes equiped accordingly (e.g. IFU, AO, high-precision velocity, etc...). Telescopes suitable for this training (on a Europe-wide, coordinated network) are essentially those we use for the NEON schools! These are: CAHA 2.2m, LaPalma INT 2.5m and NOT 2.5m, OHP 1.93m, to which can be added the Asiago 1.82m, the Rozhen 2m (needs to be better equipped) and the greek Aristarchos 2.5m (once it has some suitable instrumentation) THESE TELESCOPES NEED TO REMAIN AVAILABLE with modern instrumentation!

The panel strongly endorses the general principle of what is proposed here, if not necessarily every detail. The point about access to modern instruments is critical – the aperture of the telescope, less so.

An additional point worthy of mention is that some 2-m telescopes provide a less formal training in requiring observers to work unaided by a telescope operator - after an initial introduction by a local astronomer familiar with the telescope/instrument. Such a 'sink-or-swim' approach is very cheap to implement, if not without some modest risk. In recent years this has been the normal mode of operation of the INT in La Palma, and of the CAHA 2.2m, to the benefit of many graduate students. It should also be acknowledged that it can amount to a very low-cost telescope operational model, to the benefit of all.

Related to the above, and providing even more in-depth training are the 1-year (typically graduate) student placements offered both by the ING and NOT. Again this is inexpensive and also adds to operational support of these facilities. This practice should certainly continue, and see some expansion.

4.4 Achieving "End-to-End" European integration

Several of the most important scientific topics described in the ASTRONET Science Vision and in this document cannot be addressed properly by national projects, but would be much better served by concerted effort at the European level. Perhaps the most immediately obvious example is the systematic collection of spectroscopic data complementing the Gaia surveys, which requires: (1) a coordinated strategy involving telescopes ranging in size from 2m up to the 8m class; (2) the construction of one or several new spectrographs surpassing current instruments in one or more of field-of-view, multiplex factor and wavelength grasp; (3) the design and execution of large survey programs along with the data reduction and archiving; (4) the analysis of the data with large state-of-the-art libraries of model atmospheres; (5) the integration of the results with other information available directly from Gaia; and (6) the scientific harvest and interpretation in the context of the structure and evolution of the Milky Way. Challenges of similar scope are posed by the follow-up of data from large photometric surveys from space (e.g., Kepler and Plato) and from the ground (Pan-STARRS and LSST).

Providing the resources for international consortia that can address outstanding questions on this scale clearly requires coordination between the national funding agencies during all phases of the project. For instrument teams, there is a need for funding mechanisms that will enable them to join consortia building instruments for the most suitable telescopes across national boundaries. Observatories must be prepared to consider proposals for surveys requiring perhaps hundreds of nights even when their national constituencies may only be a minority among the beneficiaries; this may require the creation of compensating schemes between the funding agencies. Finding the resources needed to participate in such multi-national programmes is particularly acute for those countries that currently do not operate national observatories. Most of these difficulties do not occur for projects using ESO facilities exclusively, but solutions for the other telescopes need to be devised.

5 Rationalising instrumentation on Europe's 2-4m telescopes

5.1 Requirements and the present status, compared

Tables 1 and 2 bring together the capabilities we have respectively identified for spectroscopy and imaging that are needed over the next decade, and sets beside them the existing and planned instruments that at least in a crude sense satisfy these needs.

Table 3 takes this a further step by: (i) identifying the capabilities of Tables 1 and 2 that are incompletely met, or not met at all, that would entail significant new capital investment; (ii) identifying a possible timescale or path to remedy. We pick up these issues in section 5.3.

For convenience, here is a complete list of all the capabilities written down in section 3, for reference when viewing the tables.

- 1-1: an optical wide-field spectrograph on 4m telescopes, north and south, delivering R$\sim$5000 for 500+ objects/sq.deg over a field $\geq$ 1 sq.deg
- 1-2: an optical wide-field spectrograph on a northern 4m, $R \geq$30000 for 100+ objects over a field $\geq$2 sq.deg. It is preferred that this mode is available on the *same* telescope/instrument as 1-1, to be used mainly in bright time.
- 2-1: Optical HARPS-like instrument ($R \sim$ 100000) on a 4-m class telescope, North and South. For longitude reasons: CFHT is the preferred northern site.
- 2-2: A network of 4 partially dedicated optical FIES-like instruments ($R \sim$ 50000) in the North, with at least 1 in a 4-m telescope, plus 1 such instrument in the South.
- 2-3: 1 NIR high-resolution echelle spectrograph on a 4-m class telescope, with polarimetric mode.
- *Note re the following 3 capabilities:* it is important that the operational structures are in place to support effective RRM/ToO access to intermediate dispersion spectroscopy in both hemispheres.
- 3-1: continued availability of flexible intermediate dispersion spectroscopy, spanning the full optical/NIR range (preferably in "one shot"), on 4-m telescopes in both hemispheres. In the south, two ageing instruments, EFOSC2

and SOFI, on the NTT, are the *only* option, and must be upgraded/replaced. Linked imaging options are desirable.

- 3-2: 1 optical spectrograph with IF with FoV of 1-2 arcmin on a 4m telescope, in at least one hemisphere.
- 3-3: 2 → 3 $500 < R < 5000$ optical spectrographs on dedicated 2m telescopes, 1 → 2 in the north at least (preferably with imaging options).
- 4-1: Wide-field ($\geq$1 deg^2) NIR imager on a 4m-telescope, North and South
- 4-2: Wide-field ($\geq$1 deg^2) optical imager on a 4m-telescope (preferred) or 2m-telescope, North and South
- 5-1: fast-frame (tip/tilt correcting) 5-10 arcmin FOV optical imager on a 2m telescope, North and South, at contrasting longitudes, → precise (<1 mmag/min) photometry.
- 5-2: 5-10 arcmin FoV NIR imager on a 4m telescope, North and South, at contrasting longitudes, → 5-10 mmag/min NIR photometry.
- 5-3: 5-10 arcmin FOV standard optical imager on a 2m telescope for classical time domain work at <10 mmag/min accuracy.

Table 1: Identified spectroscopic capabilities for the next decade, compared with existing and planned instruments of similar characteristics.

Capability		Comparable instruments	
ID & hemisphere/aperture		Existing	Coming/Planned
1-1: R 5000 optical WFMOS	N/4m	WHT 4.2/WYFFOS	CFHT 3.6/GYES[1]
	S/4m		
1-2: $R > 30000$ optical WFMOS	N/4m		
	(S/4m)		(AAT 3.9/HERMES)
2-1: highly stable $R \sim 10^5$ optical echelle	N/4m		WHT/HARPS-NEF[2]
	S/4m	ESO 3.6/HARPS	
2-2: $R > 40000$ optical echelle	N/both	CFHT 3.6/ESPaDOnS TNG 3.6/SARG NOT 2.6/FIES TBL 2.0/NARVAL OHP 1.9/SOPHIE	CAHA 2.2/CAFE[3]
	S/2m	MPG-ESO 2.2/FEROS	
2-3: $R \sim 70000$ nir echelle (with spectropolarimetry)	either/ 4m		TNG 3.6/GIANO[4] CFHT 3.6/SPIRou[1,5] CAHA3.5/CARMENES[6] UKIRT 3.8/UPF[6]
3-1m: $500 < R < 5000$ opt+nir spectroscopy	N/4m	TNG 3.6/DOLORES+ NICS WHT 4.2/ACAM+LIRIS[7] WHT 4.2/ACAM+ISIS[8] CAHA 3.5/TWIN[8]	
	S/4m	NTT 3.6/EFOSC2+SOFI	
3-2: $500 < R < 5000$ $\sim$ 1-2 arcmin IFU	either/ 4m	CAHA 3.5/PMAS-PPAK	
3-3: $500 < R < 5000$ 2-m optical spectroscopy	N/2m	NOT 2.6/ALFOSC INT 2.5/IDS CAHA 2.2/CAFOS OHP 1.9/CARELEC	LT 2.0/FRODOSPEC[9]
	S/2m		

Notes: 1: phase A status 2: temporary private instrument 3: in construction 4: first light 2010 5: $R = 50000$, with polarimetry, FDR 2012? 6: concept studies for respectively $R = 85000$ and $R = 70000$ echelles 7: to $R \sim 1000$ 8: optical up to 1 micron 9: entering service 2010

Table 2: Identified imaging capabilities for the next decade, compared with instruments of similar characteristics that either already exist (column 2) or are planned (column 3).

Capability		Comparable instruments	
ID & hemisphere/aperture		Existing	Planned
4-1: wide-field nir imager	N/4m	UKIRT 3.8/WFCAM	
		CFHT 3.6/WIRCAM	
		CAHA 3.5/Omega2000	
		CAHA 2.2/PANIC[1]	
	S/4m	VISTA 4.1/V-IRCAM	
4-2: wide-field optical imager	N/either	CFHT 3.6/MegaCam	CFHT 3.6/IMAKA[2]
		INT 2.5/WFC	
		CAHA 3.5/LAICA	
	S/either	MPG-ESO 2.2/WFI	VST 2.6/OmegaCam[3]
5-1: fast/precise opt. imager (5-10 arcmin field, mmag precision)	N/2m	NOT 2.6/LuckyCam	
		WHT-INT/UltraCam	
		CAHA 2.2/AstraLux	
		LT 2.0/RISE	
		LT 2.0/RATCAM	LT 2.0 IO[4]
	S/2m		
5-2: time-domain nir imager	N/4m	WHT 4.2/LIRIS	
		(UKIRT 3.8/UFTI)	
	S/4m	NTT 3.6/SOFI	
5-3: as 5-1, with 1% accuracy for optical time domain	N/4m	WHT 4.2/ACAM	
		TNG 3.6/DOLORES	
	S/4m	ESO 3.6/EFOSC2	
	N/2m	NOT 2.6/ALFOSC	
		CAHA 2.2/CAFOS	
	S/2m		

Notes: 1: Being built for 2.2m - adaptable to 3.5m?, 2: design concept, not ready before 2017, 3: VST commissioning now expected second-half 2010, 4: optical arm of this OIR imager, to replace RATCAM/SupIRCAM is approaching commissioning.

Table 3: A list of identified capabilities that are incompletely/not met, requiring action. Suggestions for remedies and associated timescales are given in column 3.

Capability		Explanation	
ID & hemisphere/aperture		problem	timescale/remedy
1-1: $R \sim 5000$ optical wide-field spectrograph	N/4m	WHT/WYFFOS multiplex + unvignetted field inadequate	~2015 on a 4-m
	S/4m	none available	new VISTA sp'graph after nir surveys
1-2: $R > 20000$ optical wide-field spectrograph	N/4m	not available – needs 2-deg corrector	gain early S experience (below); combine with 1-1 capability
	S/4m	(as north)	AAT/HERMES buy-in and/or VLT/FLAMES use preparatory to new build
2-1: highly stable $R \sim 10^5$ optical echelle sp'graph	N/4m	HARPS-NEF private and temporary	alternative from end of MOU (CFHT pref.)
2-3: $R \sim 70000$ nir echelle (with spectropolarimetry)	either/4m	closest matches SPIRou, CARMENES not confirmed	~2015: support SPIRou or CARMENES
3-1: $500 < R < 5000$ opt+nir spectroscopy	S/4m	ageing EFOSC2,SOFI: prospect of **no** 2-4m sp'graph of the class in the south	upgrade needed by 2015
	N/4m	no northern son-of-X-shooter	new build for 2015+
4-1: wide-field nir imager	N/4m	northern cameras have < 0.25 deg^2 FoV UKIDSS loss	1 deg^2 camera on 4-m from 2015

5.2 Initial rationalisation, 2012 – 2015

On the next page, in Table 4, we present a possible simplified instrument suite for the northern hemisphere that could be implemented within the next 2 years. Where an instrument is associated with a capability as primary, we view these as the lead options for this capability.

First it will be important to play to the strengths of the different sites in the north, to ensure the best value for the money invested. For example, the top of Mauna Kea represents an excellent infrared site, capable also of excellent seeing in the optical. It is therefore well-suited to all infrared work, high-quality optical imaging and photon-hungry spectroscopic applications that can take advantage of good seeing. In contrast, the least number of photometric nights per year are to be had at Calar Alto – by a small margin, at the lowest altitude of the 3 main northern sites – which would argue that, on the whole, it is better to concentrate there on spectroscopy. In PMAS-PPAK the CAHA 3.5m has a globally unique capability that should continue to be supported, and a popular echelle that is being replaced.

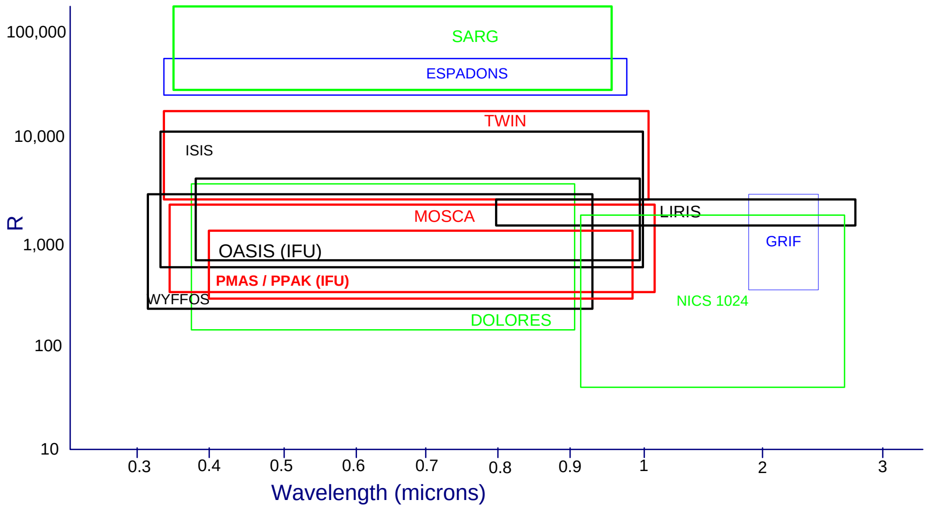
La Palma's site characteristics fall in between these two extremes, but clearly offers an opportunity of economy of scale (5 2-4m telescopes) and is home to the largest telescope in this mid-range (the WHT 4.2m), as well as the 10.4-m GTC. The two 4-m telescopes in La Palma should be operating with clearly complementary instrumentation by mid-decade, as should the three 2-m facilities (which in the case of the LT is already specialised). A strong recommendation of this report is that uniting and simplifying the operation of this group of telescopes is now urgent.

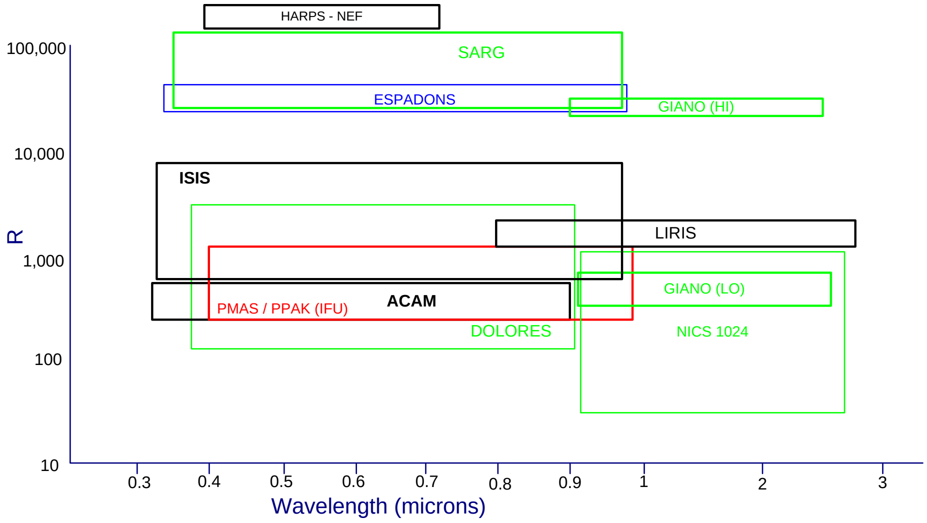
The southern hemisphere telescope suite is assumed to continue as already operated by ESO - and so is omitted from Table 4.

The four pages after Table 4, contain updates of figures originally prepared by Michel Dennefeld that set out to illustrate how the 4m and 2m northern telescopes respectively cover the OIR domain in terms of resolving power (spectroscopy) or field size (imaging) and wavelength coverage (both modes). On each page, the present (upper panel) is compared with the slimmed-down suite laid out for ∼2012 in Table 4 (lower panel) – both primary and backup instruments are shown. The boxes representing the domain of operation of the instruments are necessarily approximate and illustrative, rather than precise. In an Appendix, analogous figures are shown in which the content of the lower panels is reduced to primary instruments only.

Table 4: A streamlined 2-4m telescope instrument set, up to∼2015. With the exception of the NOT where we see FIES and ALFOSC as equally important instruments, the column ordering represents a priority ordering (1 highest).

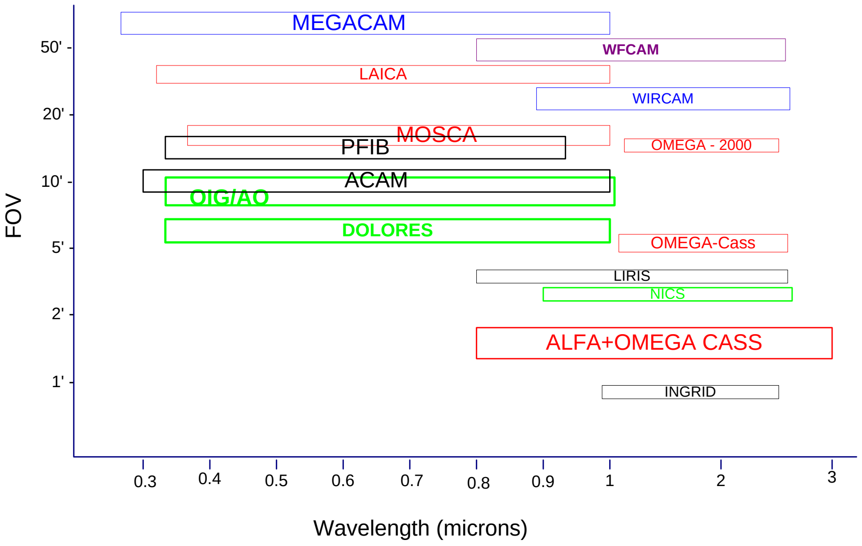
Location			Capability addressed		
Telescope	Aperture	Instrument	Primary	Back-up	Comment
Mauna Kea					
CFHT	3.6m	MegaCam	4-2		
		ESPaDOnS	2-2		
		WIRCAM		4-1,5-2	
UKIRT	3.8m	WFCAM	4-1,5-2		
Southern France					
OHP	1.9m	SOPHIE	2-2		
		CARELEC		3-3	
TBL	2.0m	NARVAL		2-2	
Calar Alto					
CAHA	2.2m	CAFE		2-2	not commissioned
		CAFOS		3-3,5-3	
		PANIC		4-1	
CAHA	3.5m	PMAS-PPAK	3-2		
		Omega2000		4-1,5-2	
		LAICA		4-2	
La Palma					
LT	2.0m	IO	5-3	5-2	RRM/ToO
		RISE	5-1		RRM/ToO
		FRODOSPEC		3-3	RRM/ToO
INT	2.5m	IDS	3-3		
		WFC		5-3,4-2	
NOT	2.6m	ALFOSC	3-3,5-3		RRM/ToO
		FIES	2-2		
		LUCKYCAM		5-1	
		NOTCAM		5-2	
TNG	3.6m	DOLORES+NICS	3-1,5-3		RRM/ToO
		SARG	2-2	2-1	
		GIANO		2-3	$R \sim 30000$ only
WHT	4.2m	LIRIS/ACAM	3-1,5-2		
		HARPS-NEF	2-1		private
		ISIS/ACAM	3-1,5-3		optical only


Spectroscopic Instruments on 4m Telescopes - 2010

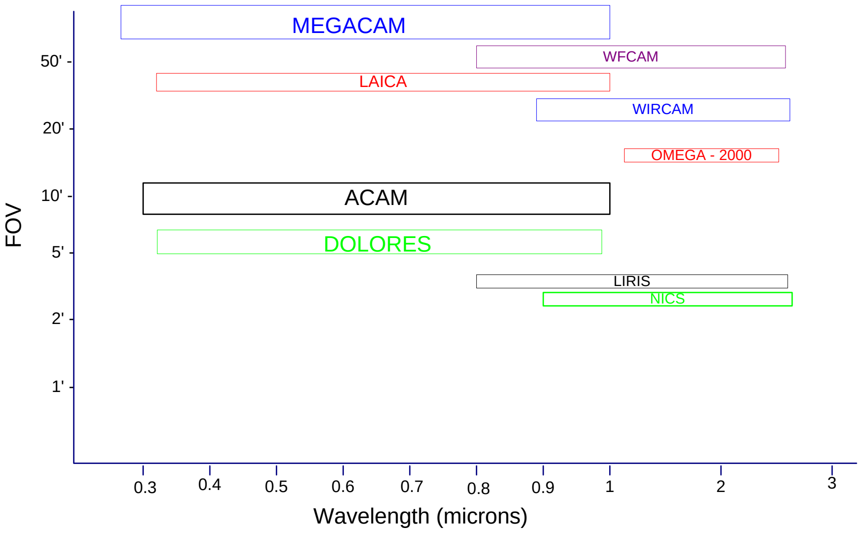

Spectroscopic Instruments on 4m Telescopes – 2012+ optimal suite

- Colour coding: WHT: Black TNG: Green CAHA: red CFHT: Blue

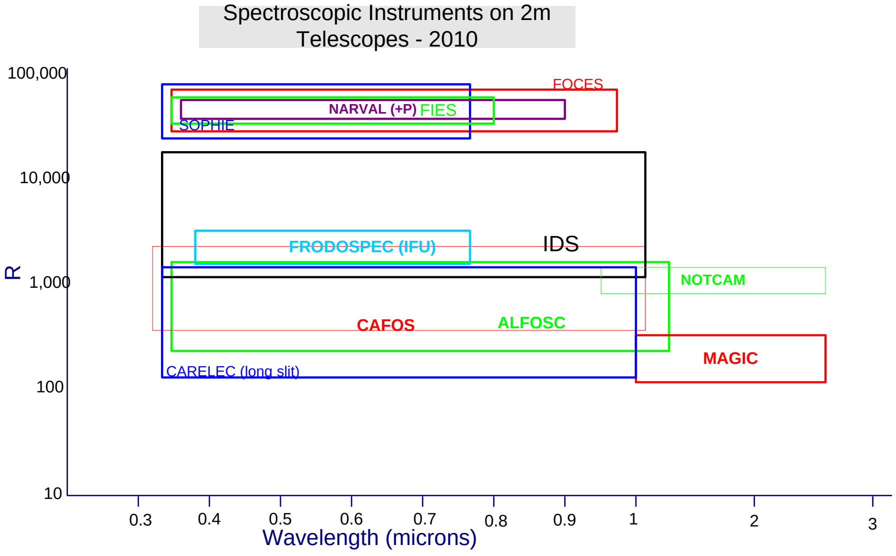
Imaging Instruments on 4m
Telescopes – 2010



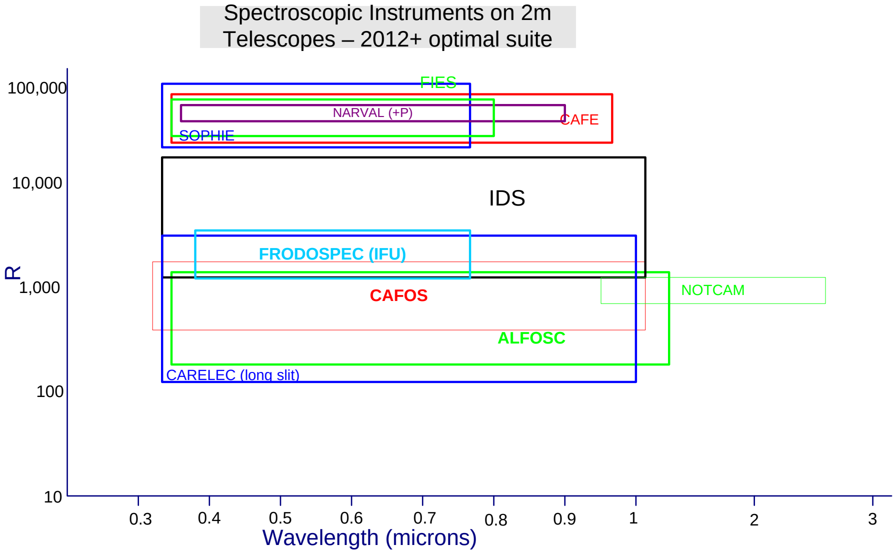
Imaging Instruments on 4m
Telescopes – 2012+ optimal suite



- Colour coding: WHT: Black TNG: Green CAHA: red
  CFHT: Blue UKIRT: Violet



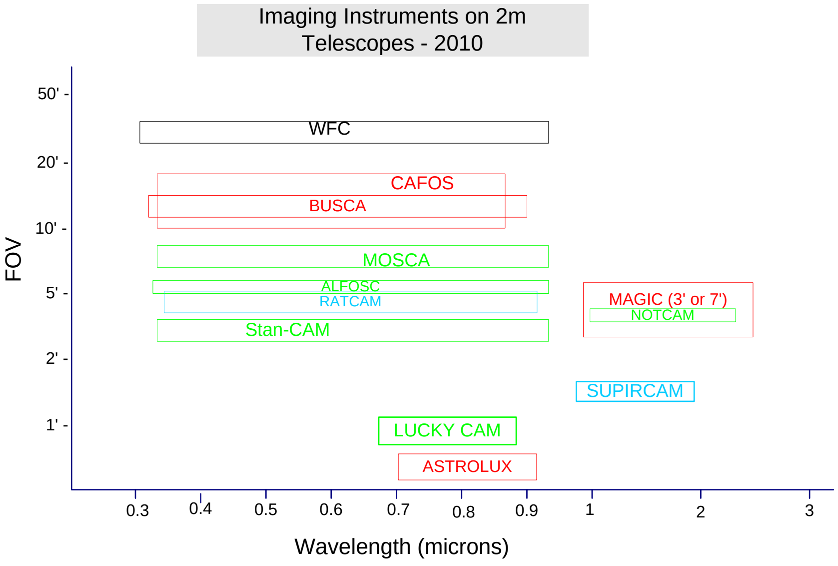
Spectroscopic Instruments on 2m Telescopes - 2010

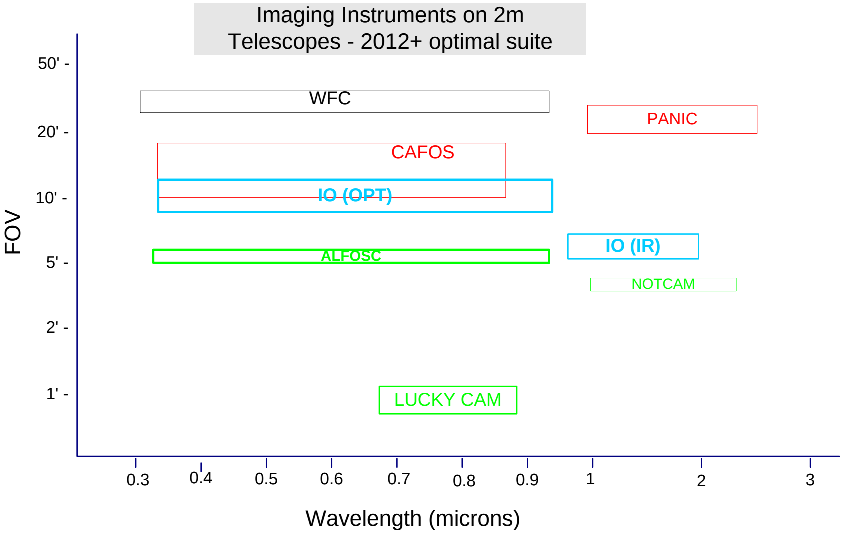


Spectroscopic Instruments on 2m Telescopes – 2012+ optimal suite

- Colour code: INT: Black CAHA: Red NOT: Green
  OHP: Blue TBL: Violet LT: Light Blue

Not shown: RISE (LT) Fast Readout Transit Camera in ‘V+R’ Filter


Imaging Instruments on 2m Telescopes - 2010


Imaging Instruments on 2m Telescopes - 2012+ optimal suite

- Colour code: INT: Black CAHA: Red NOT: Green OHP: Blue TBL: Violet LT: Light Blue

Not shown: RISE (LT) Fast Readout Transit Camera in V+R’ Filter

5.3 From 2015 on

The first phase of rationalisation will need to be followed by some further reorganisation mid-decade to begin to deal with the upgrading and clear new additions indicated in Table 3. How this may be achieved is outlined by Table 5 – in which some of the instruments of Table 4 are identified as needing replacement, or upgrading. Instruments listed as 'Instrument 1' are what we see as the top priority function of each telescope (except where noted as otherwise). Those picked out in bold type are entirely new builds.

A significant feature post-2015, it is hoped, will be the commissioning of a northern massively-multiplexed wide-field spectrograph (discussed in 3.1). This is an important investment, of very broad interest across the European community. The fact that the CFHT is shared between one European and two non-European partners, argues against placing such an instrument there as it could only be operated for the benefit of our community's science for a fraction of the total available time. It would not be enough. We envisage a nearly or entirely dedicated 4-m, mainly carrying out surveys in support of Gaia science, wholly in European control. Among the panel membership, the majority favourite for this role is the WHT because sensitivity appears to be a significant issue, and this telescope is best able to maximise this since it offers 30-40 percent more collecting area than the alternatives.

This leaves the question of the Mauna Kea site, more generally. Further investment in imaging at CFHT, as would be realised by two of the entries in Table 5, is viewed as highly appropriate to the wide field of this telescope, as well as its location. The panel would like to see WFCAM continue to be operated at UKIRT for long enough to allow the UKIDSS survey to reach at least its originally-stated goals. To fill the gap and maintain European leadership in NIR imaging beyond this point, we have identified 3 possible northern options in Table 5 - one of these would be to upgrade the field of WIRCAM at CFHT. If the operational model of section 6 can be applied successfully in keeping UKIRT open, a valuable follow-on use of this telescope (after UKIDSS) would be for an optical, and/or a NIR, very high resolution echelle.

We also see a need to renew some important instrumentation. We are very concerned about the stated lack of ESO funds for assuring the continued operation of EFOSC2+SOFI on the NTT: if these instruments fail (not so unlikely), there will be no more intermediate dispersion spectroscopy at all on a European-operated southern mid-size telescope. If the TNG is to fulfill the same specialised role in the north, then an upgrade path for DOLORES+NICS is also needed.

We have considered the mix of roles of the three La Palma 2-m facilities. The LT has been specialised but is gaining a new spectrograph, while the well-invested NOT already has many good instruments – leaving the minimally-supported INT. This potentially threatens an imbalance for the future of excessive pressure on the NOT and LT (if open to a wider community than now). To solve this, a redistribution of load to allow the INT to take a portion of it should be investigated. To spread the load would require either an instrument relocation or an upgrade, in order that the now ageing IDS (spectrograph) can be superceded. This would allow the NOT more time for FIES programmes and for imaging applications, the LT more capacity for time-domain photometry and RRM/ToO spectroscopy, while the INT takes on (i) spectroscopic surveying, at very low operational cost, supporting Gaia and ground-based photometric surveys (ii) longer time series spectroscopy unsuited to the LT's scheduling patterns.

In anticipation of the operational model discussion of the next section, we note that the La Palma 2-4m telescopes represent the natural core to the proposed consortium of northern telescopes, in which as much as possible of the available time is internationalised and overseen by a European TAC and Board. It is therefore particularly important to get the balance of instruments in La Palma right and we propose that the priorities in Table 5 offer one plausible realisation of this aim. The need is probably at a level that it will be sufficent to bring in the continental European sites (CAHA, OHP and Pic du Midi) *partially* into the same scheme. These sites do offer important instrumentation for which some Europe-wide access is needed. In this regard, SOPHIE and PMAS-PPAK are the outstanding existing instruments supporting important science areas.

Table 5: Possible instrument suite (existing, upgraded, **new**) beyond ∼2015.

Capability	Instrumentation		
ID & aperture	Instr 1	Instr 2	Instr 3
Mauna Kea			
CFHT 3.6	WIRCam upgraded to 1deg^2 FoV?^{1}	**SPIRou**, **GYES** selection end 2010	**IMAKA** if selected/feasible
UKIRT 3.8	useful OIR high res^n spectroscopy site (e.g. **HARPS-N**)		
Southern France			
OHP 1.9	SOPHIE	CARELEC	
TBL 2.0	NARVAL		
Calar Alto			
CAHA 3.5	PMAS-PPAK	**CARMENES** if selected, **if not →**	**1 deg^2 NIRCam**?^{1}
CAHA 2.2	CAFE	CAFOS	PANIC
La Palma 4m telescopes			
TNG 3.6	DOLORES+NICS or new **Xshooter-type**	GIANO	
WHT 4.2	**WFMOS**	HARPS-NEF buy-in after end MOU?	**1 deg^2 NIRCam**?^{1}
La Palma 2m telescopes			
INT 2.5	IDS (upgrade/replace)		
LT 2.0	IO	RISE	FRODOSPEC (RRM/ToO role)
NOT 2.6	FIES	ALFOSC	NOTCAM
ESO southern telescopes			
VISTA 4.1	NIR Camera	**WFMOS** after completion IR surveys	
ESO 3.6	HARPS		
NTT 3.5	EFOSC2+SOFI upgraded		
VST 2.5	OmegaCam		
MPI-ESO 2.2	FEROS	GROND^2	

Notes: 1: For the siting of a 1 deg^2 FoV NIR camera we give three alternatives. See text.
2: GROND is an imaging instrument with several dichroic beam-splitters which feed light into three NIR channels and four visual channels, each equipped with its own detector.

6 Operational model(s)

6.1 The lessons of recent experience

We should first distinguish between ’over-capacity’ and ’under-resourcing’, for these require different responses. Over-capacity is usually solved by closures and mergers until demand and supply are in balance. Under-resourcing when the available capacity is still required or even lacking creates pressure for cheaper, leaner delivery, possibly even with standards moving towards the least acceptable rather than the best available. Astronomers measure demand, and hence required capacity, by subscription pressure. While recognising that, to some degree, applications chase available time, an over-subscription ratio in the region of 2.5–3 is generally considered healthy and one below 2 as poor. Thus, when tough decisions are required on an individual basis, it might be worth considering a sensible threshold of demand which indicates ’international competitiveness.

Assuming that the existing facilities pass this threshold of demand, and thus we are resource poor, then the likely savings from operational changes need to be considered. Several agencies have been trying to drive down the operational costs of their facilities for some time and in some cases, the UK for example, they do not believe that further savings are possible without significant organisational/operational changes. There has been much speculation on the magnitude of possible savings, but in practice they may be relatively small and not enough to be game-changing. In many cases quantifying these would require more detailed input from the facilities. A few examples are

(1) *Specialising facilities to operate a single instrument.* This is often considered as a cost saving measure but in practice it is not clear how much can be saved. UKIRT adjusted its operations from a four instrument (3 general purpose Cassegrain instruments plus 1 survey camera) to a single instrument operation in 2008 but many site related, infrastructure type costs are unaffected by this. Staff numbers were reduced only slightly by the change so the overall savings, while real, were modest and were offset by a significant reduction in capability. The INT went from two instruments to one for a period and yet even at a time of considerable financial restraint the ’missing’ instrument (the IDS) was eventually re-commissioned due to astronomer demand and the failure of a comparable instrument to arrive on another telescope in time to take up that demand.

(2) *Time swapping between facilities (often related with 1)* Another often mooted, but seldom implemented scheme, time swapping has had limited success in

the medium sized telescope arena. Time swaps between ING and TNG were attempted to reduce the number of instruments to be supported at WHT but seldom rose above a level of a few nights per semester. Bringing the broadly comparable facilities, a 3.5m and 2m telescope, at CAHA into a tripartite scheme never succeeded. Reasons for this general failure to implement time swapping are unclear, but a fear of being reliant on another facility over which you have no control for part of your national capabilities is probably one. Another is the difficulty of equating capabilities and costs at very different sites, is a 3.5m at Calar Alto the same as a 3.5m in La Palma as a 3.5m on Mauna Kea? If not what is the appropriate metric (clear nights, median seeing, cost per hour, aperture?) and how should it be weighted?

There are some examples of time swapping. The 8m on Mauna Kea have entered into some apparently well-developed schemes. At the other end of the scale a group of US university run telescopes in the 0.6-1.5m range at Cerro Tololo were incorporated into a federation called SMARTS (http://www.astro.yale.edu/smarts/). Interestingly, both of these successful schemes involve facilities of comparable sizes on the same site, thus removing at least one, and maybe more, of the major variables from the mix. SMARTS also benefits from the presence of a larger facility from which technical support can be provided on an a la carte basis.

(3) *Changing the user experience.* What we now call medium sized telescopes were flagship facilities for two decades. As such they were well resourced and aimed to deliver a high quality service to their users. Downtime was minimised, time lost to faults was key judge of operational performance. High quality professional support was provided by telescope operators and technical staff, often around the clock, to maximise the amount of productive time on the sky. Users expected this service and staff saw it as their job to provide it. However in the 8m era this level of support is no longer affordable. The lesson from the airline industry is clear. It seems that, if the price is low enough, or some other benefit high enough, people will adjust their expectations. Therefore some services currently offered could be removed or downgraded. These might include:
Telescope operators.
Access to support scientists at night
Replacement of full time support scientists by less well qualified staff (PhD Students)
No on call technical support
No technical support (ie repairs) at night or weekends.
No sea level support for travel/accommodation/data reduction/data tapes
No short runs/changeovers at weekends or holidays
Allowing the telescope to stand idle during periods of statistically bad weather.

Several combinations and variations of these options have already been tried at, for example, ING and La Silla.

A variation on this theme is to end the principle, operated by at least some agencies, that high quality projects from non-national users are scheduled and supported out of national allocations on the assumption of a "quid pro quo" in allocations on another country's facilities. In a resource-poor environment such largess is no longer affordable, especially with regard to countries which have no equivalent infrastructures. A new regime of charging such users (or their sponsors where foreign policy issues were relevant) would thus be required. The costs charged would have to be real operational costs making at least some contribution to upgrades and longer term issues, not just the marginal costs (power, staff) of operating for a few extra hours.

(4) *Flexible scheduling (a la UKIRT + JCMT)* Flexible and service mode observing as practiced at CFHT and Gemini using full time staff can be efficient, but is expensive. In contrast, the JAC has developed a practical operational mode which combines features of classical, service and flexible scheduling. Much observing is done by visiting astronomers who are allocated relatively long (about 7 day) summit runs. These observers are expected to carry out programmes matched to the conditions which, from time to time, may not be their own projects. The observing sequences are preloaded as schedulable blocks similar to UKIRT 'execs' or ESO 'OBs' which can be queued in the observing software and executed more or less automatically. The switch over points can be based on conditions (seeing, water vapour) or on RA range available provided clear guidelines are available. Using visiting observers, rather than observatory staff, saves on staff costs at the observatory and having long runs minimises other support costs. Of course some of this is achieved by moving those costs to another institution, but this mode can increase flexibility. The JAC model also offers potential training opportunities to visiting observers who arrive in company with a more experienced astronomer. Although this model can be applied to general purpose observing, this scheme seems to work best when the number of instruments is fairly small and the projects are fairly large so that consortia can develop in house expertise over a period of several years (eg the UKIDSS survey). A requirement for this to work is well documented and supported observation preparation/queuing/online data reduction software. Provided such a move does not require disproportionate investments in new software or hardware upgrades to ensure reliability, this model may become quite attractive if telescopes move to long term, large survey projects using a few instruments (e.g. the CFHT legacy surveys and projects like RAVE and UKIDSS).

(5) *Sharing of support staff* Another mechanism that seems logically obvious but often hard to implement is the sharing of support staff, usually technicians, between observatories so that full complement of skills is not required at several facilities on the same site. This clearly works for organisations like OHP, CAHA, JAC and ING when two or more telescopes are part of a group with a single controlling authority. Similar schemes in LPO and Hawaii have been less successful when the sharing is attempted across organisational boundaries. This may be due to the radically different nature of each facility, concern about priorities when several facilities require the same resource, different accounting systems and employment conditions. In a new environment in which all facilities are not supported to the same level, issues about work prioritisation may become more tractable, but bi- and tri-lateral resource sharing will always be hard to manage without a single overarching ethos and management.

(6) *Sharing of base facilities* Here again the story is not one of success. Mauna Kea supports about a dozen telescopes and has almost as many sea level offices. Keck and CFHT are based in one town while 75km away Gemini, UKIRT+JCMT, CSO, Subaru and UH share a single street address but have five different buildings. Each of these requires receptionists, secretaries, cleaners and infrastructure maintenance. In La Palma there was a move towards a more rational approach when TNG, NOTSA and ING rented several floors of a single building. This allowed internal adjustment of the offices to match demand as ING started to shrink, but at some point a few years ago the TNG team moved to their own dedicated building. In the same timeframe the IAC developed a custom-built base in La Palma, the CALP, but its final size was such that the other observatory teams declined to move into it.

(7) *Common Time Allocation Processes* Several of Europe's medium sized telescopes began as consortia and, over time, the sizes of these consortia have tended to grow. As a consequence some telescopes have several TACs allocating time in a single semester. In the case of WHT this includes PATT, NWO, CAT and the ITP international time. In almost all cases these committees use different ways to publicise their calls for proposals, have different proposal tools with different deadlines, request slightly different information from the proposers and then run separate TACs and write the results into different databases. Each telescope must then balance these multiple ranked lists by merging them according to various national shares. They repeat this process every 6 months. This must be hugely wasteful.

6.2 Current OPTICON actions

Over the last two years OPTICON has developed, using EC funding, a flexible observing proposal tool called NORTHSTAR This is based on a tool developed at ASTRON for the radio community and so already offers potential for code sharing and maintenance across disciplines. NORTHSTAR can support proposals to a single telescope (and is already doing so at UKIRT and at JCMT), for several telescopes under the control of the same agency (TBL and OHP) and even multiple telescopes of different agencies (the full up OPTICON version which has just been deployed for a call in 2010B, see: http://proposal.astro-opticon.org).

NORTHSTAR also has a TAC process element which can extract proposals from the proposal database, send them to a list of TAC members and external experts, collate the results, produce ranked ordered lists of proposals, accept feedback from the TAC and distribute the outcomes to the users. This is all done from a single database and many operations are handled automatically once the required identification of TAC members and referees has been entered. This tool is being used to support OPTICON calls for trans-national access which, significantly will go to a single TAC drawn from 7 different national communities. In the short term this involves yet another TAC and yet another tool to allocate a small number of nights. However the strategic opportunity to open this tool to any telescope which wishes to use it is already available, since almost all of the telescopes in the ETSRC review are already included in the OPTICON tool. Adding a few more telescopes simply requires some extra configuration files.

Consolidating a number of small TACs into one, combining the nights available in to a multi-telescope pool and using NORTHSTAR for the entire process could offer various efficiencies at several levels. Moderating the results over a period of several semesters to ensure national shares proportional to resources committed to the combined network would be possible. The pooled approach would also open the possibility of adjusting the various national contributions to the network in response to national demand and priorities. Significantly it also allows third parties to enter the pool for a fixed but relatively short period via some agreed contribution which might be staff, instrumentation or simply cash.

Purely market driven approaches in which the resources follow the demand (voucher systems) have been tried at other sorts of facilities and were not successful, since the level of income at each facility fluctuated unpredictably. This created difficulties with long term planning. However, some kind of demand-driven system with a (say) two year financial buffer in which income for year 3 was derived from demand in year 1 might be a way of smoothing out this problem.

6.3 A new model for 2012?

One could imagine a world in which some of the present suite of medium sized telescopes will be combined into a single, "SMARTS/OPTICON" like operational structure to carry out distinct but complementary missions.

Public Surveys.

A number of surveys (including long term, multi-target projects which are not necessarily 'mapping') are likely to be required/in progress in the 2010-2015 period. These include but are not limited to Gaia follow-up, planet searches and imaging to generate targets for larger telescopes. All of these have wide European interest and will inevitably attract, indeed require, large consortia to carry them out. The survey programmes will be solicited and reviewed on a pan-European basis and the successful ones will receive large allocations (of order 200-300 nights) to be executed over a typically 2-3 year period. These will be carried out by a number of the existing telescopes each potentially carrying one or two surveys for which its capabilities are best suited. The surveys will be matched so that instrumentation at each facility is reduced to the smallest viable subset to conduct the surveys in question. The observing will be done by a combination of resident staff and visiting consortium members. The resident staff may be either full-time observatory staff inherited from the existing operations teams or consortium nominees employed on fixed term appointments to support specific surveys.

It is not proposed that these facilities are necessarily fully devoted to survey programmes as that would imply an inflexibility that we are trying to avoid. Time not required for surveys (for example wrong RA ranges, wrong moon or other conditions) would be available for regular proposals, but only using the specified instrument suite fitted for the survey programmes. This is the practice adopted at the CFHT, ESO 3.6m and UKIRT, where PI projects are still allowed provided that they do not impact the key survey programmes.

Open Access PI Projects.

Despite the power of the 8m, and the long term legacy of surveys, there will remain a demand for shorter individual projects. These will encompass projects such as those that simply do not require the collecting power of expensive 8m telescopes; time domain astronomy at all scales from GRBs through variable phenomena like novae and planetary astronomy; long term synoptic monitoring, high risk-high return pathfinder observations and 24hour "whole Earth" monitoring.

To support the demand for PI projects, and compensate some communities for what may be perceived as, and actually be, a drastic reduction of their national open-access time, some of the existing high quality and flexible facilities can be devoted to open access, ie small PI projects.

These will be allocated via single trans-national TAC to ensure national balance and a consistent scientific standard. This suite of telescopes will also be available to support innovative visitor instruments for science and engineering tests/proof of concept prototypes required for larger facilities.

Dedicated Facilities

Some telescopes may not be required for either the pan-European survey or small PI led projects. These might be profitably employed as dedicated facilities operated independently by well-resourced groups having a specific scientific objective requiring specialist instruments and/or long allocations which do not fit within the European networks described above. These would be transferred to the ownership of these groups.

6.3.1 Resource balancing

The whole network would be run by a single consortium, to maximise economies of scale.

Each member will contribute to the consortium either in cash, in kind or a mixture of both. In-kind contributions could be in the form of:

(1) telescope time by making available time not required for national use.

(2) engineering, astronomical or administrative support at either the observatory site or elsewhere.

In-kind contributions in the form of support might allow more efficient use of technical and administrative resources at locations where several consortium telescopes are located. By moving all the facilities into a single organisational structure, the priority and cultural issues which have inhibited resource sharing could be reduced. The ability of smaller agencies to contribute in-kind contributions, such as staff or software, in return for observing time would open access to new comunities and provide training and knowledge exchange opportunities.

In return for these contributions the consortium members would receive an agreed fraction of the time on the entire suite of telescopes (both for survey and general purpose projects) in the network. Whether this fraction would be based on a principle that all telescopes are equal and a night was a night wherever it was scheduled or that there was some weighting is TBD. Weighting could be applied based on telescope size, visitor vs staff executed service mode, survey or PI-led or a variety of other criteria. Outside organisations unable to provide in-kind contributions would simply invest cash in return for an agreed share of time. For example if EC trans-national access funds are available, the EC would be a “cash only” member. National agencies, or even individual institutions, without their own infrastructures could also enter on a “cash only” basis. When partners contributed time to the observing pool, some of the cash invested by these ’cash only’ members would flow back to these partners to offset their operational costs in the way that EU Trans-national access money does in FP6/FP7.

Note that the participating organisations need not all be European, provided they brought along a worthwhile resource, all would be welcome. While formal commitments from each participating organisation would be needed, these might be for only a few semesters at a time, and would be in the form of MoUs rather than international treaties, making constant adjustments of the consortium possible as national interests and resources change with time. If and when insufficient resources are attracted to support all the facilities in the consortium, those in least demand can be temporarily removed from use. In the consortium model, this reduces capacity to match demand while not forcing any particular partner “out of the game” which would be the result of closing a national telescope to its own community.

At the cost of some efficiency, allocations could be made by each member running their own TAC process and then somehow merging the results. An agreed software standard would facilitiate this. However, the single TAC model is preferred by the ETSRC panel – this would be based on scientific merit moderated by the available member shares in that allocation period. This moderation might take place over several semesters, as with HST, to ensure fairness in the long term.

Given the complicated ownership, treaty and site tax obligations of the agencies involved, none of this would be simple to organise but it can start with a small number of partners and evolve organically. However, with an agreed vision and the will to deliver it, the rest is just details.

6.3.2 Conclusions

(1) Economies of scale based on shared services or time swapping work best within a single management structure.

(2) Operations support should be consciously driven down from best possible to the minimum required to deliver the mission.

(3) A common TAC process is being explored by OPTICON which may smooth a path towards wider integration.

(4) Specialising some facilities to large projects for a large fraction of their time will exclude some national groups who will need access to other general purpose facilities curently operated by other communities.

(5) Bringing some or all of the facilites into a loose confederation which allows small partners to enter and leave without the administaive burdens of international treaties may be a way forward and the economies of this should be investigated.

7 Recommendations

(1) If efficiencies in the operation of the 2-4m telescopes is to be achieved by reducing the number of instruments on each telescope and eliminating unnecessary duplications between them *it is essential* that they are brought together both in terms of access (common European TAC) and operations.

(2) For this reason, work towards a common European TAC is a central recommendation of the ETSRC panel. Three separate allocation streams can be envisaged: large projects; classical visiting observer and/or queue allocations; RRM/ToO time-critical programmes. A science oversight panel, reporting to a telescope-consortium management board, might work out the splits between these streams. The panel does envisage that large programmes will take up a half or more of the available nights, and that this share can be expected to rise as the decade progresses.

(3) At minimum, the management and operation of the relevant La Palma telescopes discussed in this report should be combined to produce a merged OIR 2-4m telescopes observatory that will be better placed to offer high-level expertise and to retain high-quality staff, whilst realising efficiency savings.

(4) The operational model discussed here, in section 6, does not require that all telescopes are on the same site, and so it can in principle be extended to include all non-ESO operated telescopes. The feasibility of a SMARTs-like consortium should be investigated via ASTRONET through the establishment of a steering group involving both interested national funding agencies and science representatives. In time, this would evolve to become the management board. The key question needing an early answer is whether there are in fact sufficient partners willing and able to invest in such a scheme at a level that would significantly reduce the financial pressures on the existing telescope funders.

(5) A technical implementation group, built around 2-3 full-time-equivalent mid-career staff with wide direct observational experience across the 2-4m telescopes, could usefully prepare the way for coordination of all European northern telescopes that are presently run independently. They would report to the initial steering group. Appraisals of the technical readiness of telescope operation and instruments likely to be continued, and of seeing statistics from actual imaging data, should be made before a new streamlined pattern of instrumentation is confirmed. To achieve this has been beyond the resources available to the ETSRC panel who, of necessity, have had to rely on non-uniform observatory self-reporting.

(6) This panel is reporting at least six months ahead of the Astronet Wide Field Spectroscopy Working Group, investigating options for massive-multiplex spectrographs on both 4-m and 8-m telescopes. In advance, we note that the case for such an instrument on *one* 4m telescope specialised for the purpose in each hemisphere is an appropriate response particularly to the upcoming Gaia mission. More than one build per hemisphere would be very costly and unbalance European astronomy.

(7) Options for a rationalised suite of telescopes/instruments were presented in section 5, and an operational model was discussed in section 6. Theproposed pan-European scheme is characterized by a significant reduction in the instruments deployed, and an approach to operations that will allow market-testing of thefacilities supported within the global system. Up to now, this market-testing has been obstructed by largely impervious national boundaries.

(8) Procedures will need to be put in place that will facilitate the formation of consortia across national boundaries to build instruments for northern telescopes. We have also identified a need for an upgrade to instrumentation on the ESO NTT that might be funded through this same process.

(9) Visitor instruments should continue to be encouraged. Because of its scale, as a group of 5 2-4m telescopes, a combined La Palma observatory would be best able to support this and, indeed, would be invigorated by it. The telescopes operating within one structure will offer opportunities for flexibility that will make it easier to respond positively to visitor-instrument requests.

(10) Training opportunities, typically on 2-m telescopes, remain essential and should access modern instrumentation. An economic way to support this is as for e.g. the ING and NOT who both offer very successful student placement schemes, lasting a year. Also, where there is no telescope operator, observers – who are very often graduate students – learn to deal with all aspects of data acquisition. These approaches realise operational efficiency, cost-savings, at the same time as they offer training. As a concept it also aligns well with encouraging survey consortia to replace some/all of the functions of staff astronomer support. Good documentation is critical for this to work well. It is important, also, to set aside time for formal graduate schools, and for some outreach.

(11) A website that serves as a one-stop shop for interested astronomers seeking basic information on the suite of instruments offered at the 2-4m telescopes should be constructed by the technical implementation group and maintained thereafter. There were several requests for this placed on the Web Forum. It should go beyond a simple list of links, to give a first impression of the available options regarding different types of spectrograph and imager that would warrant closer inspection for the planned observations.

(12) Finally, a striking submission to the panel via the Web Forum was a note of the need for long-term purely operational support for Gaia, in the form of nightly imaging of the satellite itself for the entire duration of the mission (see 3.5, page 50). That this access is not directly purchased by ESA is remarkable. For many years, NASA has directly invested in ground-based facilities to support its missions and science goals – at least as far as mission operations support is concerned, the logic is irrefutable. We propose that ESA's policies in this regard would certainly bear a fresh look.

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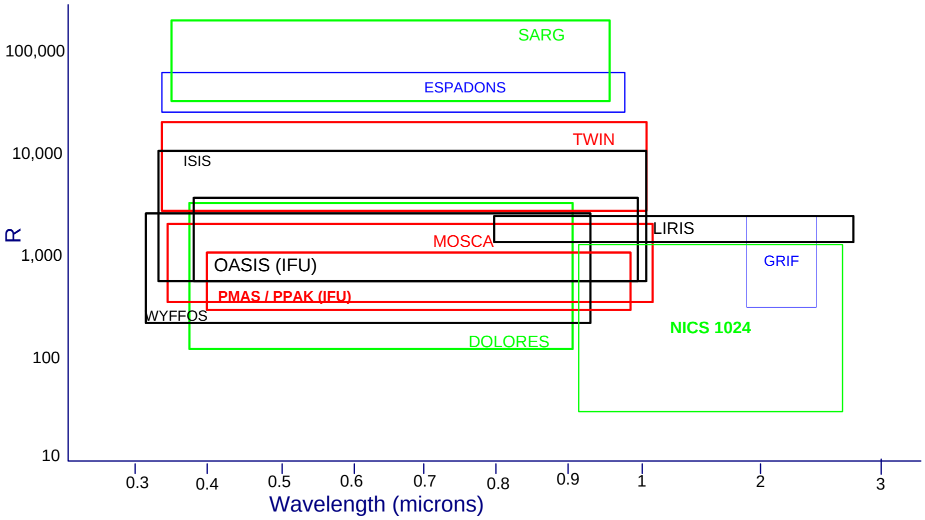
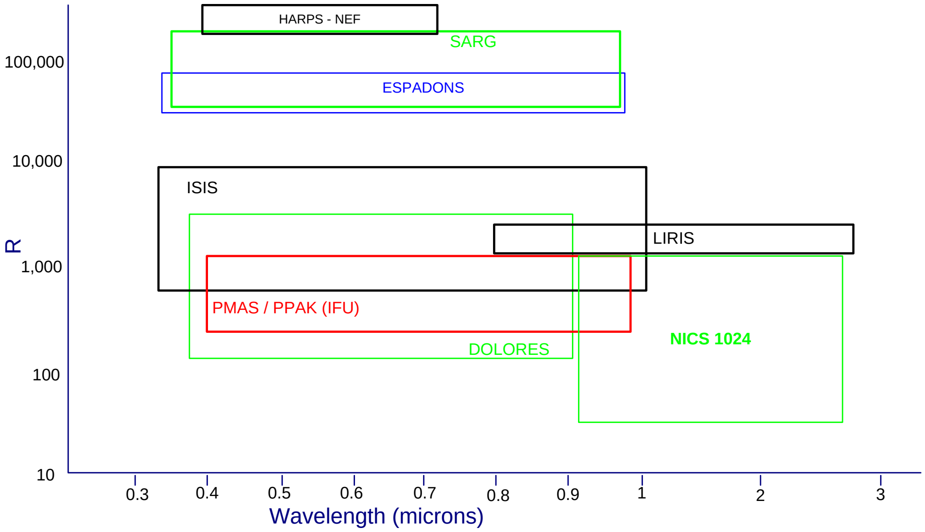
Appendix: Further ∼2012 instrument diagrams

The following figures are a further supplement to those following Table 4 (section 5.2). As for the in-text figures, these set out to illustrate how the 4m and 2m northern telescopes respectively cover the OIR domain in terms of resolving power (spectroscopy) or field size (imaging) and wavelength coverage (both modes). In these diagrams, the status quo (upper panel) is compared with the suite reduced to the primary instruments, only, listed in Table 4 for ∼2012 (lower panel).

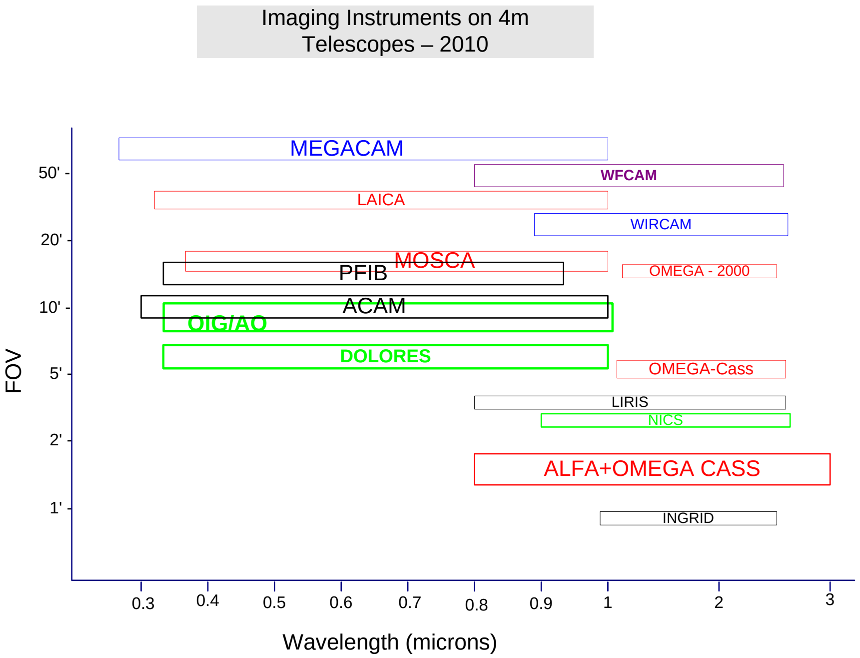
Spectroscopic Instruments on 4m
Telescopes - 2010

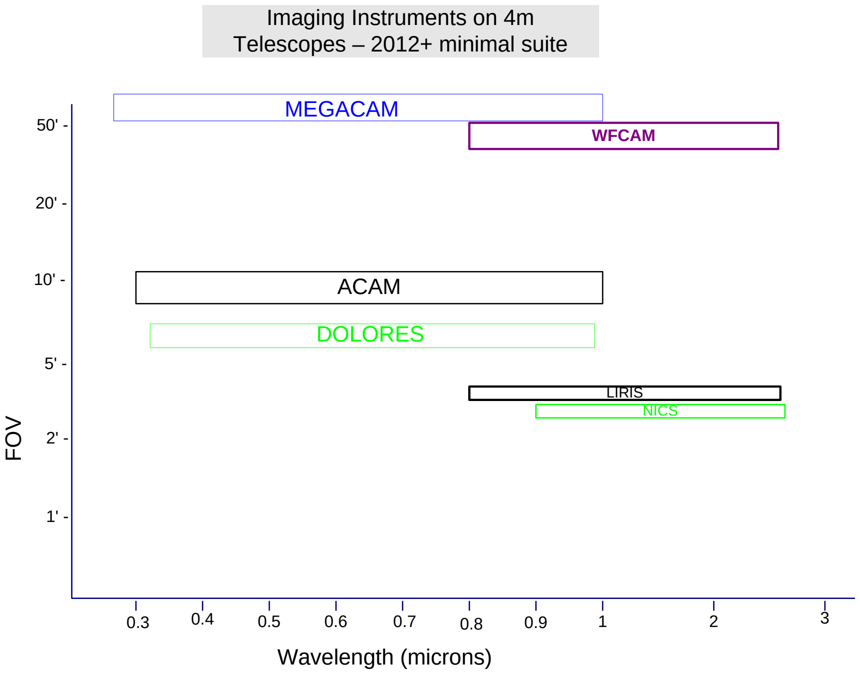


Spectroscopic Instruments on 4m
Telescopes – 2012+ minimal suite

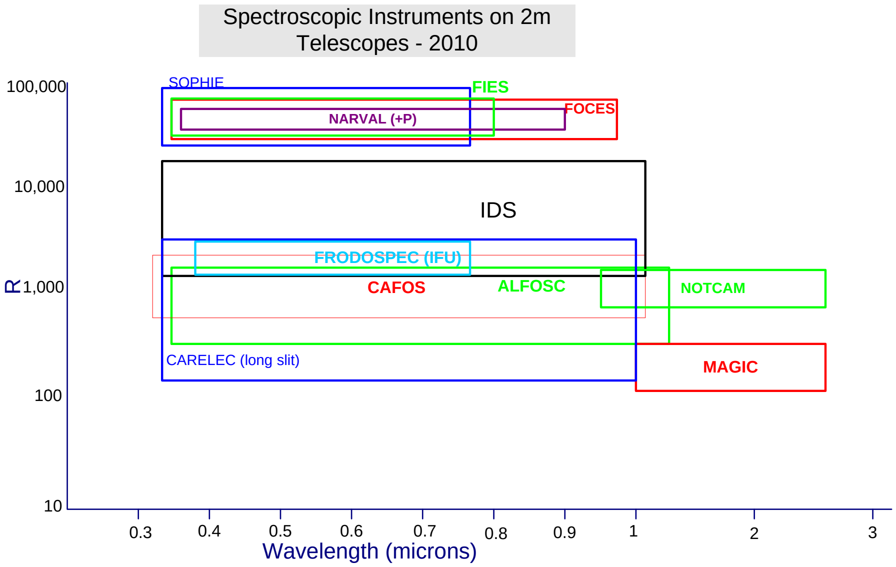


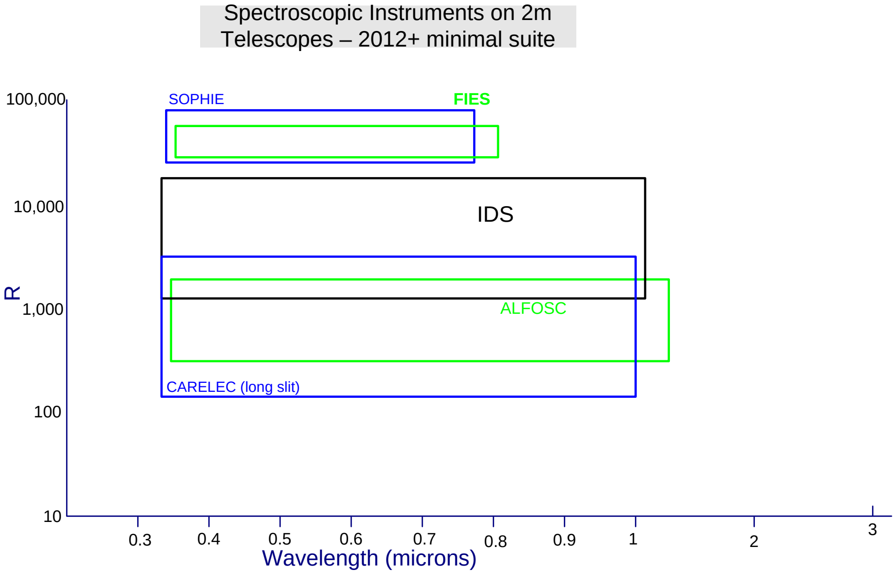
- Colour coding: WHT: Black TNG: Green CAHA: red
CFHT: Blue UKIRT: Violet


Imaging Instruments on 4m Telescopes – 2010


Imaging Instruments on 4m Telescopes – 2012+ minimal suite

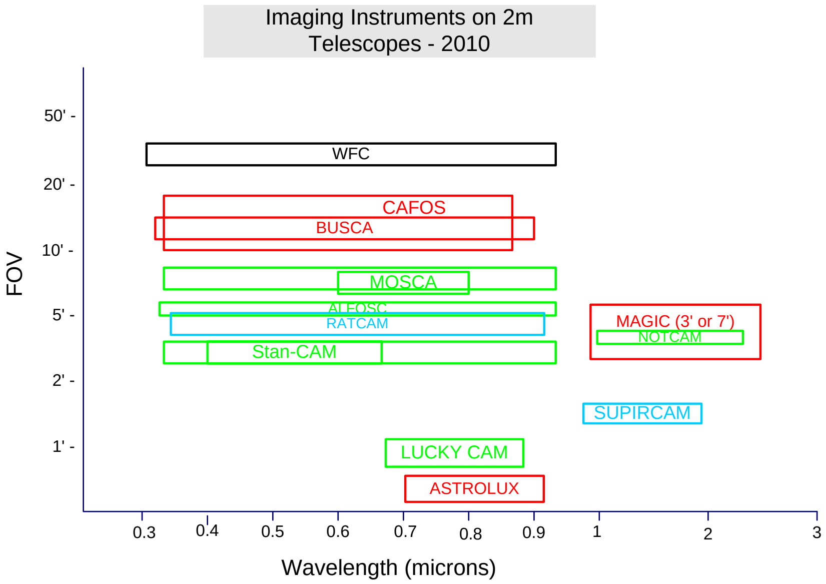
- Colour coding: WHT: Black TNG: Green CAHA: red
  CFHT: Blue UKIRT: Violet

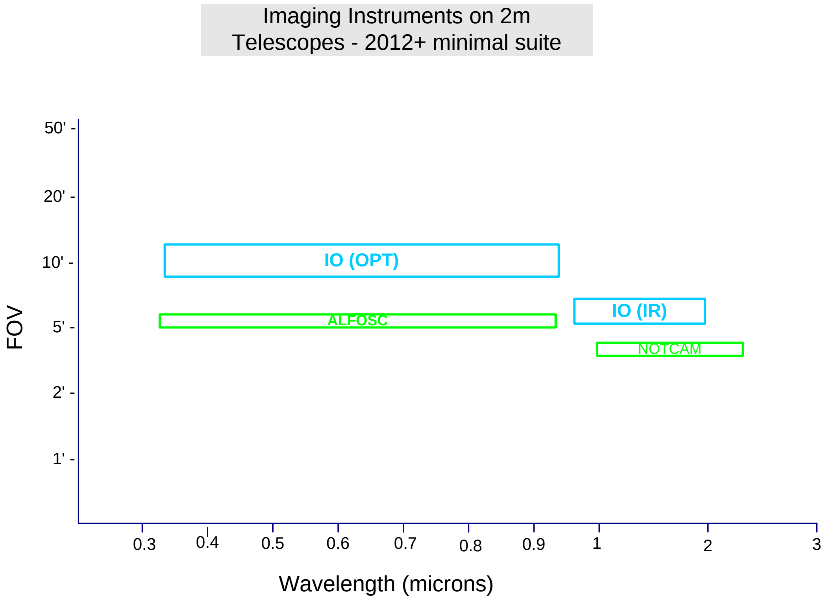




- Colour code: INT: Black CAHA: Red NOT: Green
  OHP: Blue TBL: Violet LT: Light Blue

Not shown: RISE (LT) Fast Readout Transit Camera in ‘V+R’ Filter





- Colour code: INT: Black CAHA: Red NOT: Green OHP: Blue TBL: Violet LT: Light Blue

Not shown: RISE (LT) Fast Readout Transit Camera in V+R' Filter