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List of Abbreviations

ALMA	Atacama Large Millimeter/submillimeter Array
APD	Avalanche Photo-Diode
ASIC	Application-Specific Integrated Circuit
CCD	Charge Coupled Device
DROID	Distributed Read-Out Imaging Devices
E-ELT	European Extremely Large Telescope
ELT	Extremely Large Telescope
ELT	Extremely Large Telescope
EM-CCD	Electron Multiplying Charge Coupled Device
ESA	European Space Agency
ESO	European Southern Observatory
EU FP7 / FP8	European Union Framework Programme 7 / 8
GRIN	Graded Refractive INdex
GTC	Gran Telescopio Canaria
HET	Hobby-Eberly Telescope
INAF	Istituto Nazionale di Astrofisica (National Institute for Astrophysics)
IR	Infra-Red
ITAR	International Traffic in Arms Regulations
JWST	James Webb Space Telescope
KIDS	Kinetic Incuction Detectors
KOI	Kilometer Optical Interferometer
LAOG	Laboratoire d'Astrophysique de l'Observatoire de Grenoble
LBT	Large Binocular Telescope
LSST	Large Synoptic Survey Telescope
LSST	Large Synoptic Survey Telescope
MCT	Mercury Cadmium Telluride (HgCdTe)
MOEMS	Micro-Opto-Electromechanical Systems
MROI	Magdalena Ridge Observatory Interferometer
NASA	North American Space Agency
NIR	Near-Infra-Red
NOW	Nederlandse Organisatie voor Wetenschappelijk Onderzoek (Netherlands Organisation for Scientific Research)
OPTICON	Optical Infrared Coordination Network for Astronomy
OPTICON KTN	OPTICON Key Technologies Network
Pan-STARRS	Panoramic Survey Telescope & Rapid Response System
QWIP	Quantum Well Infra-red Photo-detector
RAL	Rutherford Appleton Laboratory
ROIC	Read-Out Integrated Circuit
SALT	South African Large Telescope
STFC	Science and Technology Facilities Council
TES	Transition Edge Sensor
UIK ATC	UK Astronomy Technology Centre

UK ATC	UK Astronomy Technology Centre
UV	Ultra-violet
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer

1 Executive Summary

A roadmap of the technology requirements for astronomical instruments has been produced (Figure 1). The roadmap shows the expected progression of ground-based astronomy facilities, the funding resources available and the technological developments which will be required to realise these new facilities. The roadmap highlights the key stages in the development of these technologies.

In some areas, such as conventional optics, gradual developments in areas such as light-weighting of optics will slowly be adopted into future instruments. In other areas, such as large area IR detectors, more rapid progress can be expected as new processing techniques allow larger and faster arrays. Finally, other areas such as integrated photonics have the potential to revolutionise astronomical instrumentation. Adaptive optics technologies are not included in this roadmap.

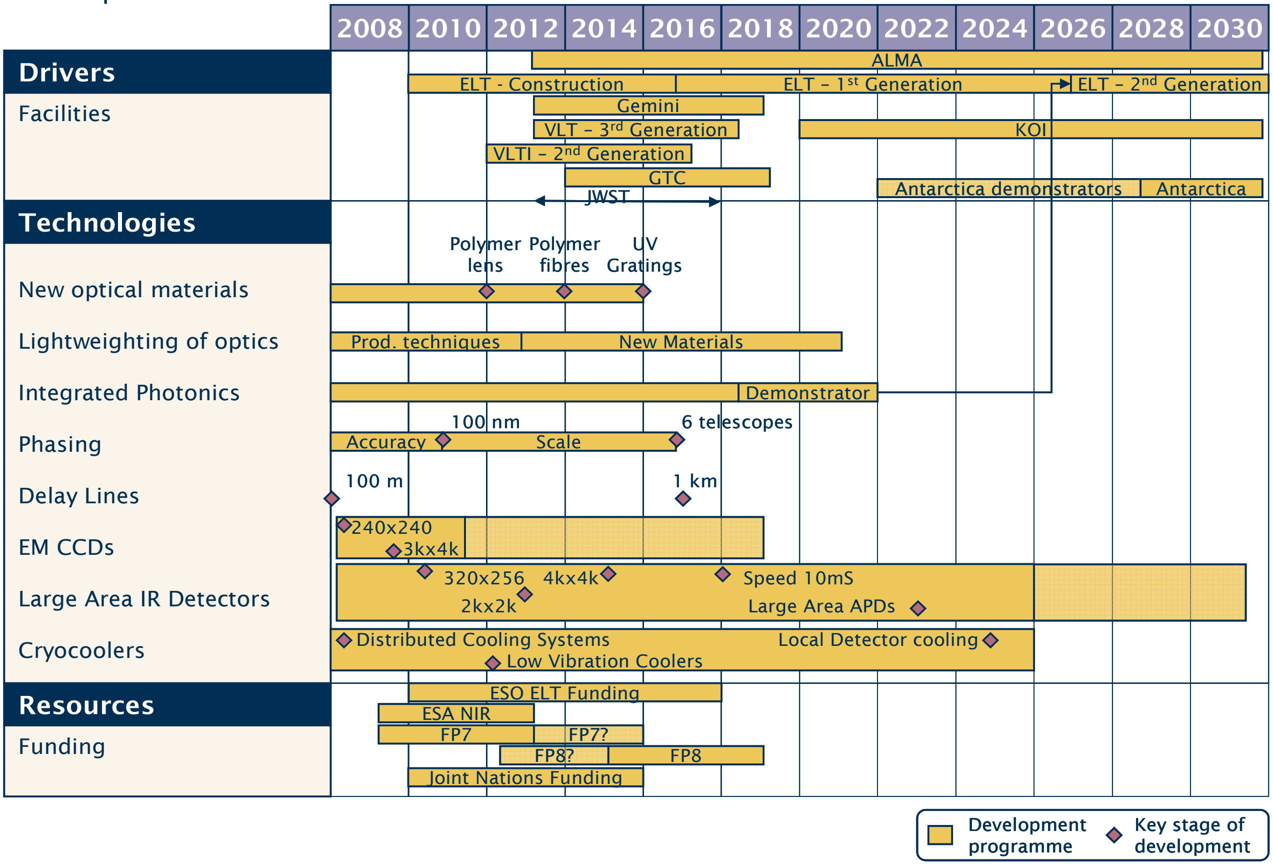

Figure 1 Overview Roadmap

2 Introduction

2.1 Roadmap aims

The aim of this roadmap is to chart the future technology development needed by optical and infra-red ground based astronomy and to provide a useful tool for planning future technology development activities in this field. It highlights the key technologies required for future facilities and the important stages we envisage in their development. It identifies potential funding sources to allow us to develop these technologies, and identifies synergies with developments in space-based astronomy.

The roadmap focuses on technologies for instruments and interferometry, as illustrated in Figure 2. Adaptive optics is not covered in this roadmap, as detailed roadmaps already exist[1] for this area. Solar telescopes are also not included.

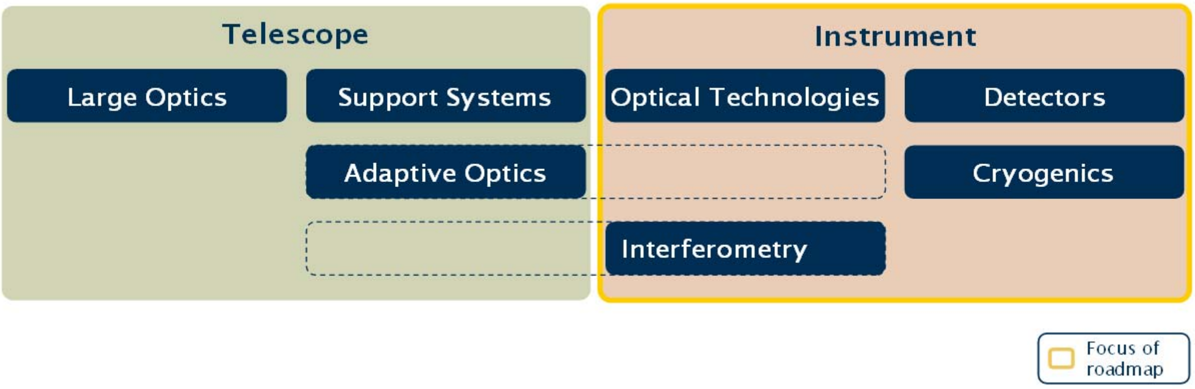

Figure 2 Roadmap focus

The roadmapping project forms part of the OPTICON Key Technologies Network activities. For further details of these activities, the reader is referred to the OPTICON website[2].

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[1] http://www.eso.org/projects/aot/

[2] http://www.astro-opticon.org/

2.2 Existing Roadmaps

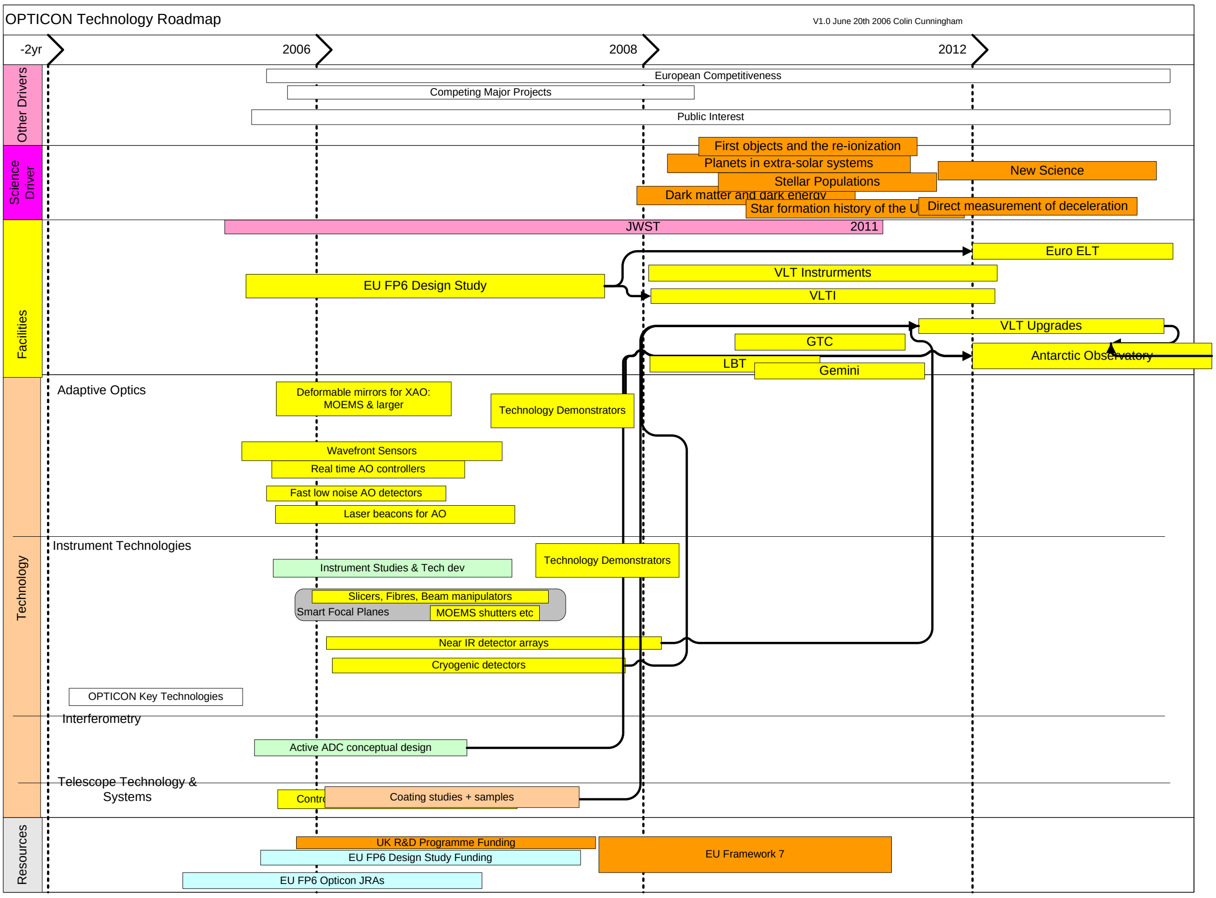

Figure 3 Previous OPTICON roadmap

Several roadmaps are available which are relevant to the current field of optical and infra-red ground-based astronomy instrumentation. These include the previous OPTICON KTN roadmap shown in Figure 3. Other relevant roadmaps include the NASA Advanced Telescope and Observatory Roadmap[3], the ASTRONET Infrastructure Roadmap[4], the ESO Adaptive Optics Roadmap, and ESA's Cosmic Vision[5]. Note: The ASTRONET Infrastructure Roadmap identified adaptive optics, fibre optic beam transport & integrated optics as key technologies for future development.

2.3 Roadmapping process

The information contained in this roadmap was gathered through a workshop, hosted at the UK ATC in Edinburgh, followed by selected interviews to gather additional information on key areas. The workshop followed a three-step process was followed to gather the information for producing this roadmap. This process is illustrated in Figure 4. The first step was to identify the drivers and resources which guide which the development of future facilities and instrumentation, together with the enabling funding sources. The second step was to identify the key technologies which have a role in making these developments. Once these have been

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[3] Feinberg and MacEwen (Chairs), NASA Capability Road Map (CRM) 4 Advanced Telescope and Observatory (ATO) (2005), http://universe.nasa.gov/workshop/documents/Advanced_Telescopes_Tech_Portfolio_2005.pdf

[4] Bode, Cruz and Molster (Eds.), The ASTRONET Infrastructure Roadmap: A Strategic Plan for European Astronomy (2008), ISBN: 978-3-923524-63-1

[5] Bignami et al., Cosmic Vision: Space Science for Europe 2015-2025 (2005), ISBN 92-9092-489-6

identified, the required technology developments can be charted, and this serves to highlight the key technologies which will enable new instrumentation.

The contributors to the workshop and interviews are show in Table 1. Interviews were held to address areas which were not covered in sufficient detail during the workshop.

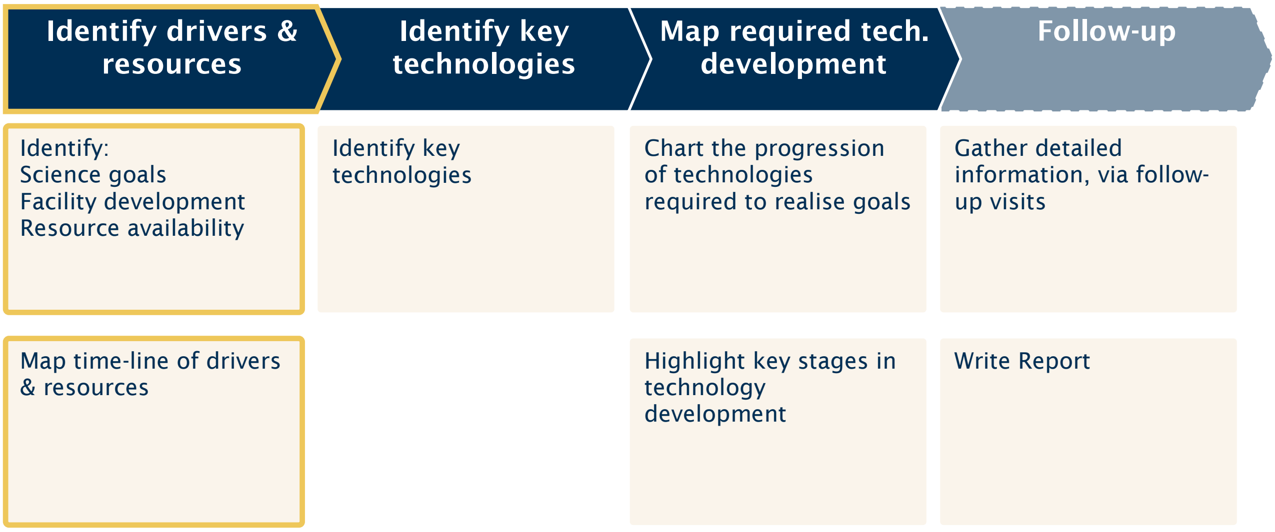

Figure 4 Roadmapping process

Contributor Name	**Affiliation**	**Workshop**	**Interview**
Jeremy Allington-Smith	Durham University		✓
Colin Cunningham	STFC - UK ATC	✓	
Gavin Dalton	STFC - RAL	✓	✓
Tim Gledhill	University of Herefordshire	✓	
Pierre Kern	LAOG	✓	See note[6]
Didier Martin	ESA	✓	✓
Frank Molster	NOW	✓	
Suzanne Ramsay	ESO	✓	
Lars Venema	ASTRON	✓	
Martyn Wells	STFC - UK ATC	✓	
Adam Woodcraft	STFC - UK ATC	✓	
Fillipo Zerbi	INAF-Brera	✓	

Table 1 List of Contributors

2.4 Scientific Goals

The scientific goals for infra-red and visible ground based astronomy form the driving force for future instrument development. The current scientific goals of the community were discussed during the workshop, and have been catalogued through several other works. Most importantly,

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[6] Due to time constraints, it was not possible to conduct the planned interview

ASTRONET has compiled a comprehensive science vision for astronomy[7], which details the specific scientific goals to be addressed. Other studies which outline the scientific goals for relevant areas of astronomy include the ESA Cosmic Vision[8] and the science case for the E-ELT[9]. These studies, as should be expected, all detail almost identical scientific goals:

- Exoplanets
- Galaxy Formation
- Black Holes
- Star & Planet Formation
- First Objects
- Dark Matter & Energy
- Astrobiology
- The Solar System
- Stellar Populations

The general consensus from the workshop was that future instrumentation must be capable of addressing several of these areas. It was not envisioned that these goals would alter dramatically over the next 20 years, save for the inherently unpredictable impact of new discoveries which may be expected to come from facilities such as ALMA and the JWST. These can be expected to open up entirely new areas of astronomy.

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[7] de Zeeuw and Molster (Eds.), A Science Vision for European Astronomy (2007), ISBN: 978-3-923524-62-4

[8] Bignami et al., Cosmic Vision: Space Science for Europe 2015-2025 (2005), ISBN 92-9092-489-6

[9] Hook (Ed.), The Science Case for the European Extremely Large Telescope: The next step in mankind's quest for the Universe (2005)

3 Roadmap

The technologies which were considered to be the most important to the success of the planned facilities were included in the graphical roadmap below.

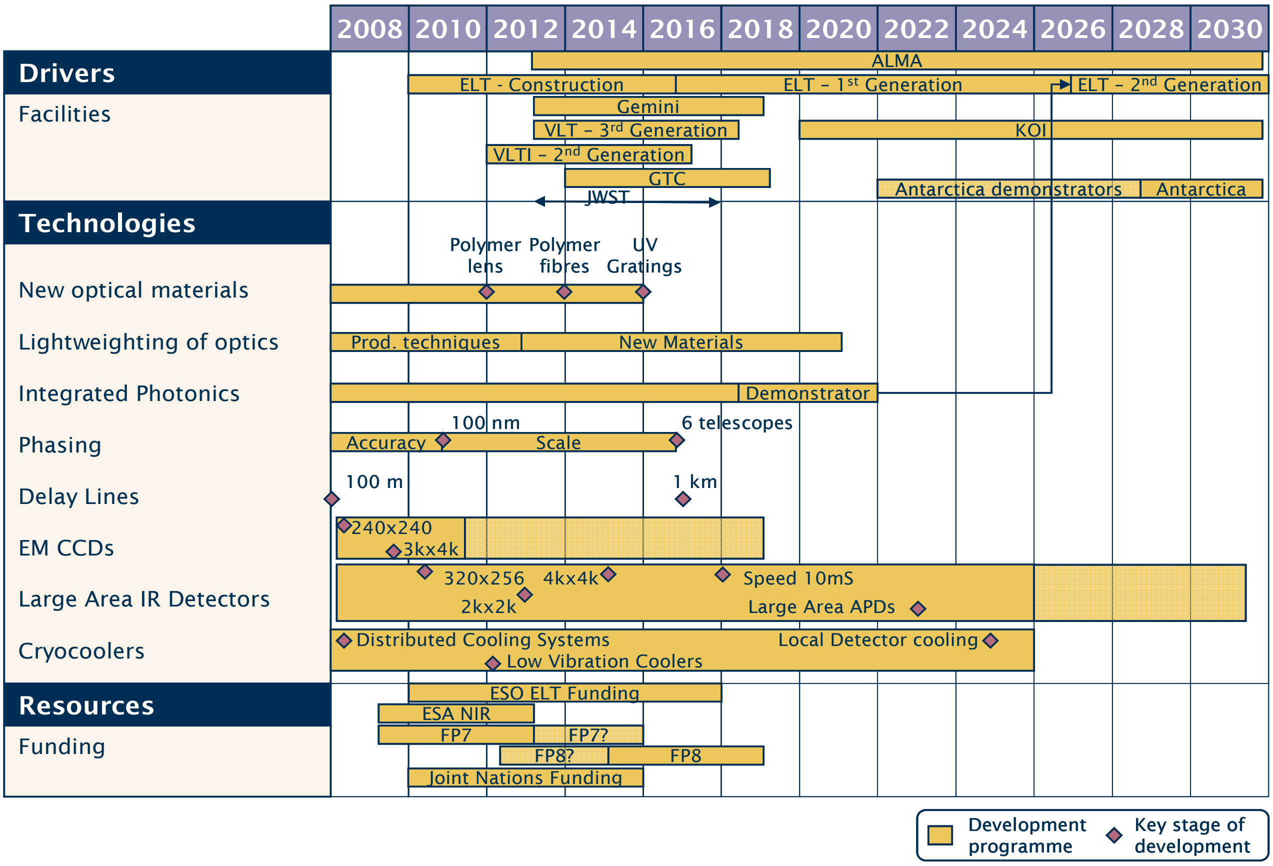

Figure 5 Overview Roadmap

3.1 Facilities

The developments in telescope facilities will have a major impact in driving instrument development. In the short term, current facilities will directly impact the instruments which they are paired with, guiding any technology development which is required. Looking further ahead, future facilities such as the E-ELT will require a whole new instrument suite to fully exploit the capabilities of the telescope. These will have even more demanding technological requirements, and will drive technology development over long timescales.

This section details the major facilities to which European countries have significant access. A more detailed overview of these facilities can be found in the ASTRONET Infrastructure Roadmap[10]

3.1.1 Current facilities

Although current facilities already contain suites of instruments, there is the potential for new instrumentation as part of a facility upgrade path.
The major facilities which Europe currently has access to are shown in Table 2.

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[10] Bode, Cruz and Molster (Eds.), The ASTRONET Infrastructure Roadmap: A Strategic Plan for European Astronomy (2008), ISBN: 978-3-923524-63-1

Facility	Opportunity
VLT	Third generation instruments
VLTI	Second generation instruments
Gemini	Second and Third generation instruments
GTC	Second generation instruments

Table 2 Key existing major facilities and opportunities

Other facilities to which Europe also has access are shown in Table 3.

Facility
SALT
LBT
Subaru
HET
4m telescopes
Pan-STARRS
Chara array
MROI

Table 3 Additional existing facilities

3.1.2 Future facilities

Key future facilities where Europe is expected to play a major role are shown in Table 4.

Facility	Opportunity
E-ELT	First and second generation instruments
KOI	Construction and instruments
Antarctic Observatory	Construction and instruments

Table 4 Key future facilities and expected opportunities

Europe may play a role in the additional future facilities shown in Table 5

Facility
Special purpose small telescopes
Other ELTs
LSST

Table 5 Additional future facilities

3.2 Resources

Resources available for European technology development for instrumentation were identified during the workshops. The major funding sources are shown in Table 6.

Funding Source
National government funding
ESO ELT funding
ESA Near IR detector development
EU FP7 programmes
EU FP8
EU Research Council
Joint Nations Funding
Private Funding / Charity

Table 6 Funding sources

3.3 Instrument Technologies

3.3.1 Optical Technologies

Optical technologies form a key part of any instrument for optical and IR astronomy. Relevant technologies range from system level, e.g. multi-object spectroscopy, to the component level, e.g. reflective and refractive optics. There is a general drive towards larger optics, which allow greater resolutions (spectral and spatial) or a wider field-of-view, but this is counterbalanced by the larger mass of these optics. Larger optics require improvements in manufacturing techniques, while novel materials have the potential to reduce the mass. Finally, novel approaches, such as integrated photonic devices, have the potential to alter the existing landscape, by achieving high resolutions without extremely large optics.

The workshops focused on the component-level technologies, for two reasons. Firstly, it was perceived that it was impossible to discuss the requirements of the systems level technologies without knowing the exact goals of the instruments where they would be found. One way to approach this impasse in the future could be to research the trends which have developed in historic instrumentation, and thereby to extrapolate to future requirements. Secondly, it was perceived that the systems level technologies would simply integrate the best available mature component technologies. This is a natural consequence of minimizing the risk of constructing an instrument.

3.3.1.1 Multi-Object Spectroscopy

Multi-object spectroscopy is a system-level technology which allows one to simultaneously obtain spectra of multiple objects. There are three approaches currently in use; multi-slit systems, fibre-based systems and pick-off mirrors.

Multi-slit systems use either laser cut masks, or micro-opto-electromechanical systems (MOEMS) to select objects from a complex field. The whole field is imaged onto a spectrometer, resulting in separated spectra from each object. General improvements allowing larger optical fields to be imaged will be of interest, such as larger optics. Digital micro-mirror arrays would allow masks to be generated in situ, and are currently under active development (optical characterisation is ongoing, and qualification expected to commence Q3 2009) at ESA for the EUCLID mission.

Fibre-based systems image the optical field onto multi-mode fibres, which are placed at selected locations either manually or automatically. These fibres then transmit the light to a spectrometer, so that spectra are obtained from each object. The fibres are either placed manually or by robotic means. Advances in fibre technology, described below, will benefit these systems.

Pick-off-mirror systems use small mirrors in the image plane to select objects of interest from the field, sending the images to separate spectrometers.

3.3.1.2 Integral Field Spectroscopy

Integral field spectroscopy is a system-level technology which allows selected regions of the optical field to be reformatted so that spectra can be taken simultaneously of each spatial element of the field. Three designs can be used to achieve this: Fibres or fibre-bundles, lenslet arrays, or image slicers. Of these, image slicers are currently believed to be the key technology, as this allows efficient smaller instruments.

Fibre-bundles will benefit from advances in fibre technology, lenslet arrays from the manufacture of plastic optics and image slicers from optical processing techniques.

3.3.1.3 Fourier Transform Spectroscopy

Fourier transform spectroscopy is a system-level spectroscopy which varies the length of an optical cavity to separate the frequency components of an image over time. This allows a spectrum to be obtained. Although this technology is used in some space instruments, it is of limited use for terrestrial astronomy.

3.3.1.4 Atmospheric Dispersion Correction

Atmospheric dispersion correction is a system-level technology which removes the distortions introduced by light propagating through the atmosphere at non-zenith angles. These distortions are dispersive and refractive. Current systems use matched pairs of prisms of up to 300mm in size. Larger sizes of optics (up to 1m) will allow corrections over a larger field.

3.3.1.5 Reflective and refractive optics

These optics are a part of any optical instrument. While many optics are commercially available, there are serious issues with the production of large optics over 1m. In particular, blanks for the IR in this size are difficult to obtain. Generally, reductions in the mass or cost, or improvements in the speed of manufacture would be beneficial. For small optics, the reproducibility is a key issue.

Technologies which could impact the manufacture of these optics include processing techniques (e.g. for aluminium surfaces), light-weighting, the development of new optical materials which allow better replication, and GRIN (Graded Refractive Index) lenses.

3.3.1.6 Dispersive optics

Dispersive optics spatially separate light according to its wavelength. Current technologies are gratings, volume phase holograms and prisms. Efficiency for gratings is currently limiting in the UV and thermal IR (aim is to achieve >80%), but not in the visible. Larger effective sizes will allow better spectral resolution, and this can be achieved either through larger gratings, or by embedding the gratings in a medium of higher refractive index.

Improved replication and better fabrication of grating mosaics will be beneficial.

3.3.1.7 Polarization Optics

Polarization optics alter the polarization of light, or separate and combine polarizations. Currently, telescope designs degrade the polarization information of the incoming light. Compensatory optics could potentially correct this, as could better telescope design. Size is a key issue for large birefringent optics as they are difficult to manufacture. Novel birefringent materials would be of great use. Polarization gratings are a relatively new technology which can achieve high efficiencies.

3.3.1.8 Optical Coatings & Filters

Optical coatings are used to coat surfaces with either metallic or dielectric coatings to produce a reflective surface, or a wavelength selective element. Filters may additionally use a frequency selective absorptive element. Coatings for extreme angles of incidence are difficult to produce. Increased size, efficiency and wavelength range together with improved temperature stability and reduced coating distortion effects would be beneficial. This could be achieved through novel manufacturing methods or novel materials.

3.3.1.9 Active Optics

Active optics consist of optical surfaces which can be moved or deformed on timescales greater than 1s. Current technologies are not currently limiting, but improvements in actuator density and stroke, or increases in the size and speed would be beneficial.

3.3.1.10 Integrated On-Chip Spectrometers

A miniaturised complete spectrometer on a chip would enable great simplification and increased functionality of multi-object instruments, and is seen as the key novel technology for instrument design. Current designs plan to collect the light from objects of interest in multi-mode fibres, and send these to an integrated photonic device. This device would convert the multi-mode input to single-modes, pass each of these through a spectrometer and detect the signal on a single integrated linear array.

It may also be possible to suppress OH emission in the single mode stage, using Bragg gratings. Development is targeting 2018 for inclusion in the Second Generation ELT instruments.

3.3.1.11 Optical Connections

Optical connections allow switching between many optical channels, each contained in fibres. Ideally, one would like to send any combination of input in *n* fibres to any combination of *m* output fibres (*n>m)*. Telecoms technologies can already do this for single-mode systems, but this needs to be extended to multi-mode for it to be applicable for astronomy.

3.3.1.12 Fibres

Optical fibres can be used to transport light efficiently. Current systems are efficient in the telecoms wavebands, but less efficient outside this region. Improvements in wavelength range, cryogenic properties and larger core sizes would be beneficial. Photonic crystal fibres could be a key technology, as they introduce no dispersion.
Multimode fibres cause a degradation in etendue on transmission, as a single mode input is converted to a multimode-output through scattering processes.

3.3.2 Interferometry

This section is incomplete, due to insufficient time to fully discuss the topic during the workshop. A meeting is planned with P. Kern to gather additional information on this section.

3.3.2.1 Beam Transport & Delay Lines

Collected light is transported over long baseline distances from the telescopes, and through a delay line. Current systems use free-space transmission combined with active optics for 100m baselines. Future systems could be fiber based, and will need to work over 1km baselines. This currently poses a major technical challenge

3.3.2.2 Control Systems, Metrology & Phasing

Path distances are accurately measured and controlled to around 100nm over distances of 200m. Four telescopes can currently be co-phased. Future systems will require the same accuracy over 1km distances, and will involve six telescopes.
More details are required.

3.3.2.3 Detectors

Fast detectors are required for interferometry.
More details are required.

3.3.2.4 Beam Combination

More details are required.

3.3.2.5 Spectral Coverage

More details are required.

3.3.3 Detectors

In the period 1975 to 1990 developments in astronomical technology and the resulting, observations and science were dominated by the increasing linearity, size and sensitivity (as well as the reducing cost) of Charge Coupled Devices (CCDs). In the last couple of decades attention has switched to other wavelengths and in particular the Infrared with perhaps the most important development thread being the desire for “CCD-like” IR detector arrays. There is also a wide variety of possible developments of superconducting devices which can measure the energy of incoming photons.

3.3.3.1 CCDs

Charge Coupled Devices operate by incoming photons promoting electrons between energy bands in suitably doped silicon. The energy band gap corresponds to a wavelength of 1.1 μm and therefore CCDs cannot be used at higher (MIR) wavelengths.

CCDs already offer the astronomer high quantum efficiency, linearity and large array sizes so it seems unlikely that there are many fundamental developments to be made in this area, although cost reductions are always in demand. Array sizes of around 6kx4k are already possible and going to much bigger arrays is likely to produce yield issues that would adversely affect cost.

However there are some niche developments (described below) of interest.

Electron multiplication CCDs (also known as EM CCDs or L3CCD) contain a gain register in which the number of electrons is increased by means of impact ionization. This is useful for detection at low light levels (at higher light levels the stochastic nature of the multiplication process effectively reduces quantum efficiency). In principle this register could be added to any size or geometry of CCD, the main issue is cost.

It would be convenient for certain telescope geometries to have a curved detector to be used in a curved focal plane. With current technology it is estimated that a 5m radius of curvature might be possible. Curvature (say approx 300mm concave radius of curvature) would be required to be useful in most telescopes.

3.3.3.2 IR detector arrays

Because of the 1.1 µm cut-off in Silicon most IR detector arrays use a detector wafer constructed from some other semi-conductor and Indium bump bonded to a Silicon Read-Out integrated Circuit (ROIC). This “hybridisation” is necessary to make use of the conventional (Silicon based) solid state electronics in the readouts. The problem with hybridisation is that differential thermal contraction can cause high stresses when the detector is cooled. In addition it is suspected that the bonding process itself can introduce internal stresses which may be responsible for reliability issues. The semi conductor most commonly used for the detector is Mercury Cadmium Telluride, HgCdTe, also sometimes known as MCT or Mer-Cad-Tel. The MCT is normally grown onto a substrate of Cadmium *Zinc* Telluride and this can limit the size of array which can be produced.

The main issues facing European astronomy are the ability to source detectors within Europe and the size of the detector available.

Currently the main suppliers of IR detectors to Astronomy are Teledyne Scientific Imaging, based in the US and to a lesser extent Raytheon also based in the US. This is of concern to European funding organisations such as ESA (who have a formal policy of sourcing within member states where possible) and ESO (who also try to source within Europe). As future space and ground based telescopes are likely to need significant numbers of IR arrays there is a strong desire to develop a European manufacturer. This would also ensure continuity of supply which could be threatened by any change or reinterpretation to the ITAR regulations, since the detector technology used by Astronomers is essentially the same as that used by the military. ESA are making a considerable investment (€8M over the next 4 years) into IR detector and readout controller development in Europe, the aim being to develop European suppliers as well as addressing the size limitations.

The ability to create larger arrays is important since the alternative of creating “mosaics” has several limitations as the required detector sizes get larger. Currently array sizes of around 2k x2k are possible from US sources but not yet from Europe. Firstly however good the design there will always be gaps between the arrays, this is not a great problem for imaging since the telescope can simply be moved but it creates problems for spectroscopy. Secondly the complexity and cost of wiring, integrating and individually characterising many arrays can become prohibitive. Thirdly the mechanical positioning of large numbers of arrays in a mosaic can be challenging, for instance a flatness specification of ~10-20 µm can be difficult to achieve. Sizes up to at least 4k×4k are required.

In an attempt to address the above two issues the following technologies are being developed: Selex (European) are using a Gallium Arsenide substrate to grow the MCT onto and QinetiQ (European) are developing a way to grow MCT islands directly onto the Silicon ROIC. This latter non-hybridised approach could bring benefits in persistence, cost and reliability but the fill factor needs to be improved.

For many years it has been suggested that the drive to produce ever faster processors might lead the microprocessor industry to start using Gallium Arsenide (which allows a higher transistor switching speed) or other semiconductors. Were this to be the case then it might open up the possibility of a CCD (with detector the same material as ROIC) which operates at IR wavelengths. However currently “Moore’s Law” is being maintained with the use of Silicon and there is not sufficient resources to develop a new semiconductor technology for Astronomy alone.

3.3.3.3 Energy Sensitive Detectors

There are several superconducting devices operated at other wavelengths which measure the photon energy allowing a spectrum to be built up. They can also be used for photon counting in certain circumstances. These are difficult to use at IR wavelengths as currently R~30. Improvement to R~200 would effectively mean a solid state low loss spectrometer.

Possible technologies include:

TES (Transition Edge Sensors) is currently the best candidate. ESA have demonstrated R~25 at 500 nm but as R is proportional to √E it will be harder to get good resolution at longer wavelengths.

KIDs (Kinetic Induction Detectors) are not currently available under 20 microns however they have potential for the future, especially for longer wavelengths. They consist of a series of resonant cavities, when a photon is absorbed it changes the resonant frequency and the signal on resonance peak changes. Many cavities can be read simultaneously, as they are detuned from each other.

Nanowires are currently at a very early stage of development but they may be of use in the future.

3.3.3.4 Fast APDs

Avalanche Photodiodes are high gain photo detectors. Faster APD arrays would enable high time-resolution spectrometry and polarimetry.

3.3.3.5 Multi-band QWIPs

Quantum Well Infrared Photo-detectors operate by having incoming photons excite electrons to a higher energy band within a quantum well. They have a very narrow spectral response. Multi-band QWIPs give greater spectral range by integrating several QWIP stacks into a single array structure. Multi-band QWIPs exist now but have not been used for astronomical devices. It may be possible to develop these by 2014.

3.3.3.6 Single Photon / Photon Counting Devices

Possible technologies include:

Single-Photon Avalanche Diodes or **SPAD**s can be used for photon counting. This has been explored in the QuantEYE concept study.

DROIDs (Distributed Read Out Imaging Devices) are position and energy sensitive Superconducting detectors. At its simplest a DROID consists of a1-D linear absorber with a TES at each end. When a photon strikes the absorber the sum of the TES signals gives the energy of the photon and the difference gives the position. This can be extended to a 2-D surface with readouts at corners. Thus you can get large area detectors without the requirement for separate readouts for each pixel.

Quantum Dots are a young technology with potential in photon detection.

3.3.4 Cryogenics

3.3.4.1 Cryocoolers

Whether cryogen immersed, circulation or dry all cryogenic systems require a cooler. Vibration from the cooler can cause significant problems with instruments on the telescope. Future developments could include: use of low vibration coolers (such as Pulse Tube Refrigerators); a distributed cooling system to decouple the cooler from the instruments; and eventually direct cooling of the detector and wiring itself (although this would depend on the wavelength as often thermal background noise can be dominant).

3.3.4.2 Cryostats

Cryostats normally consist of a cryogen vessel, and a vacuum vessel containing multiple layers of radiation shielding. The main areas identified where technology could bring improvements are the thermal radiation rejection and a reduction in the mass of the cryostat.

Thermal Radiation Rejection could be enhanced through the use of: Baffles, Dichroic reflectors or Filters

Reduced mass might be achieved by looking at cryostat design features from other technology areas.

3.3.4.3 Cryo-Materials

Current knowledge of material properties at cryogenic temperatures is patchy. As instruments get bigger and more complex, and time and money get tighter then it is going to be increasingly important to draw on a systematic set of material data which has been validated offline. The current approach of using “tried and tested materials” or trying to determine behaviour as part of the design validation runs the increasing risk of failure or large delays.

Establishment of reliable metrology is a prerequisite to such a study (for example using position encoders).

Properties of: Adhesives, Thermally isolating supports, Thermal contacts and Piezo’s would all be of interest

It would be important to share this information perhaps via a database

3.3.4.4 Cold Electronics

There is a lot of complexity, mass and heat-load present in instrument systems because of the necessity to have complex bulky control electronics at room temperature. The development of cheap, compact, low power (chip based) control electronics operating at cryogenic temperatures would allow location close to the detector minimising wiring connections and mass. This becomes increasingly important as instruments get larger. Ready ~ 2014

The compact controllers might be in the form of a single chip ASIC (application-specific integrated circuit) or a slightly larger “matchbox” of discrete components which would nonetheless be compact enough to be mounted close to the detector.

3.3.4.5 Cryo Mechanisms

The development of cryogenic mechanisms draws on a wide variety of technologies including lubrication, metrology, position sensing. A long term goal might be to enable micro-robots that can work at low temperature moving optics and detectors around the focal planes. Finding motors and power sources for such an application would be key technological challenges.

Drive technologies to be investigated include Harmonic Drives, Direct Drive Motors, Gears, and Ultrasonic Motors. Power sources should also be considered for instance batteries at low temperature or inductive powering.

3.3.4.6 Wiring

Instrument malfunctions are often traced to wiring problems and therefore it seems likely that reliability could be improved by developments in this area.
Required developments include: robust, reliable and flexible interconnects (such as multi-channel woven ribbon) and perhaps a replacement for current low temperature board to chip bonding.

3.3.5 System

3.3.5.1 Mechanical Structures

Mechanical structures are required to support the optics. Conventional materials such as metals are currently used. Increasing instrument size and complexity mean that the mass of supporting structures are increasing. Reductions in mass (using novel materials or designs) will reduce costs, and allow larger instruments. Thermal compensation is also a key issue.

3.3.5.2 Simulation

As astronomical systems become increasingly complex it is becoming increasingly important to be able to accurately model these systems and to simulate their performance during the design phase. In the past large safety factors were used in the mechanical design of these systems. however as the required accuracies and physical sizes increase this becomes impractical, and active and adaptive compensation methods must be used and analysed during system design.

The development of models that can accurately model the image quality of astronomical instruments and its complex interplay with environmental factors such as wind, atmosphere fluctuations, cooling system vibrations and thermal effects; may be a limiting factor in future facilities.

4 Future Work

4.1 Continuation of the Key Technology Network

The Key Technology Network will continue under the auspices of the extended OPTICON project in its FP7 phase.

Initially the intention is to focus on those areas which were not well covered in this document and to elaborate on specific topics of interest. The KTN will also be collaborating more closely with ESA (Cosmic Vision) and ASTRONET.

4.2 Suggestions for OPTICON KTN workshops

A key recommendation arising from the roadmapping exercise was that workshops specialising in particular areas should be held. Possible topics include:

- Cryogenic materials workshop (Held 4/5 December in Italy)
- Best Practice in Mechanisms
- Position Sensing, Metrology & Phasing
- Systems Modelling & Simulation
- Novel Materials in Instrument Design
- Long Baseline Interferometry
- Polarisation Issues for the E-ELT
- Small Deformable Mirrors
- IR Detectors Workshop (in one year)

4.3 Contacts

For general OPTICON Key Technology Network enquiries please contact Colin Cunnigham (crc@roe.ac.uk).

For enquiries relating to the Roadmap please contact Dave Melotte (djm@roe.ac.uk) or Robert Pfab (rjp@roe.ac.uk).

Optikeytec Web is a web-based collaboration area for the Framework 6 OPTICON Key Technologies Network to obtain a login please follow the instructions given here.

5 Acknowledgments

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