OPTICON JRA2
Fast Optical Detector for AO
Gent - April 2004

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Talk Overview

- Scientific considerations
  - Brief Review of Available Technologies (PN Sensors and L3CCDs/EMCCDs)
  - AO simulations
  - Detector Procurement Strategies
- JRA2 organisation
  - Work packages description
  - Timelines, deliverables…
- Conclusion

Scientific considerations

Goal of the JRA2

- New JRA2 title: " Fast Optical Detectors for AO "
- Goal:define, fabricate and fully characterize the best possible detector working at visible wavelengths for Adaptive Optics (AO) wavefront sensors (first priority).
- For 10m. class telescopes, ELT's taken into account: 256x256 pixels detector appropriate.
- Closely linked to JRA1 : Adaptive Optics
- Closely linked to JRA3 : fast detectors for all applications except AO (see JRA3's presentation by Stefan Wagner)

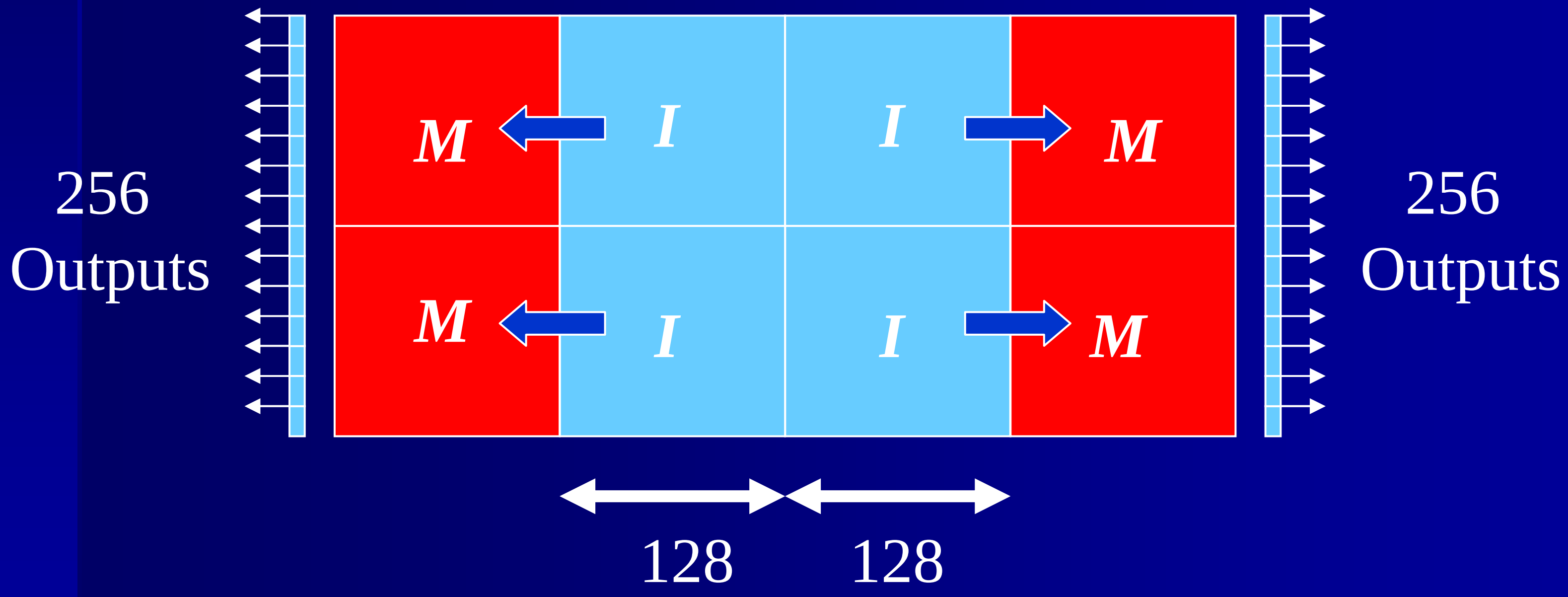
Brief Review of Available Technologies

Detector Availability

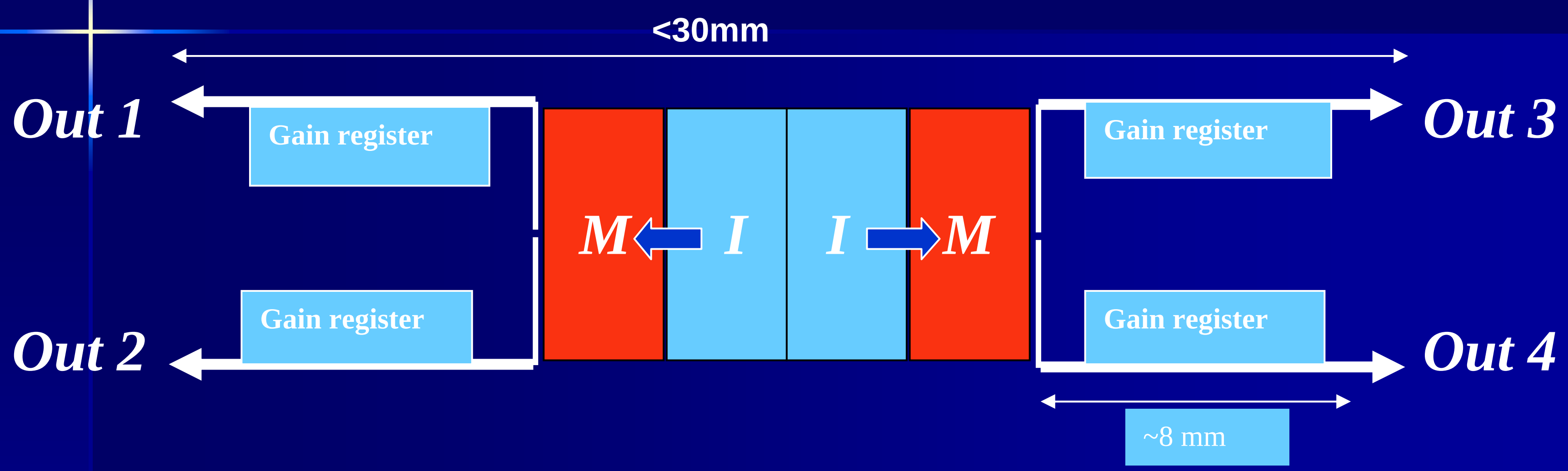
- Development:time frame of 18 months to 2 years.
  →Restricts to conventional CCD already under development
- Either:
  – "Many channels" solution
  – "Minimal channels" solution

Many Channels Solution

- Increase number of channels to decrease required read out speed of output amplifier.
- Use ASIC to multiplex channels down to 8 or 16 to reduce back-end complexity.
- Existing detector:MPE/HLL – Max-Planck-Institut für extraterrestrische Physik Semiconductor Laboratory



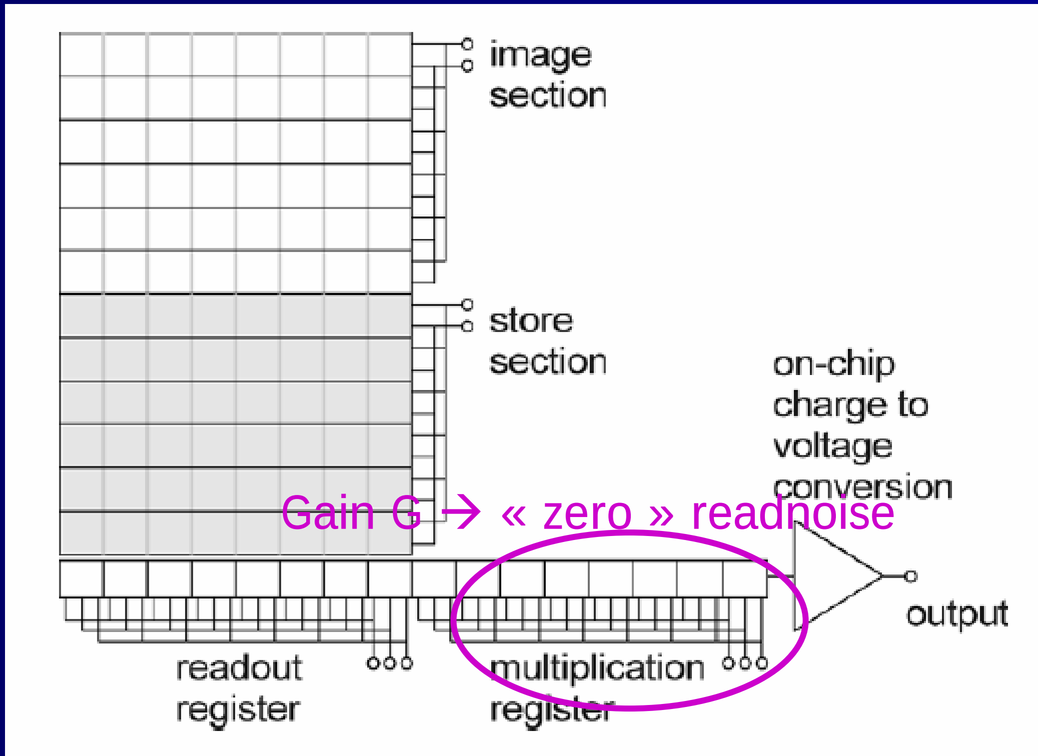
Minimal Channel Solution: EMCCD (or L3CCD from E2V)



- Use special techniques as electron multiplication (EMCCD = Electron Multiplying CCD) to reduce output amplifier read noise at very high readout rates (e.g. L3-Vision of E2V or IMPACTRON of TI).
- Require high speed, high voltage clock drives and high speed signal processing (33Mpix/s for 2 kframes/s).

EMCCDs theory
Electron Multiplying Charge Coupled Device

- EMCCD structure



EMCCDs theory

- Generalized SNR formula for EMCCDs:

$$SNR = \frac{S}{\sqrt{F^2(S + S_{dark} + S_{spurious}) + \frac{\sigma^2_{readout}}{G^2}}}$$

- G = multiplication gain (tunable with a voltage level)
- F = excess noise factor = √2
- If G is sufficient (G>100), readout noise contribution is ~ 0
- Readout noise decreases with G^2

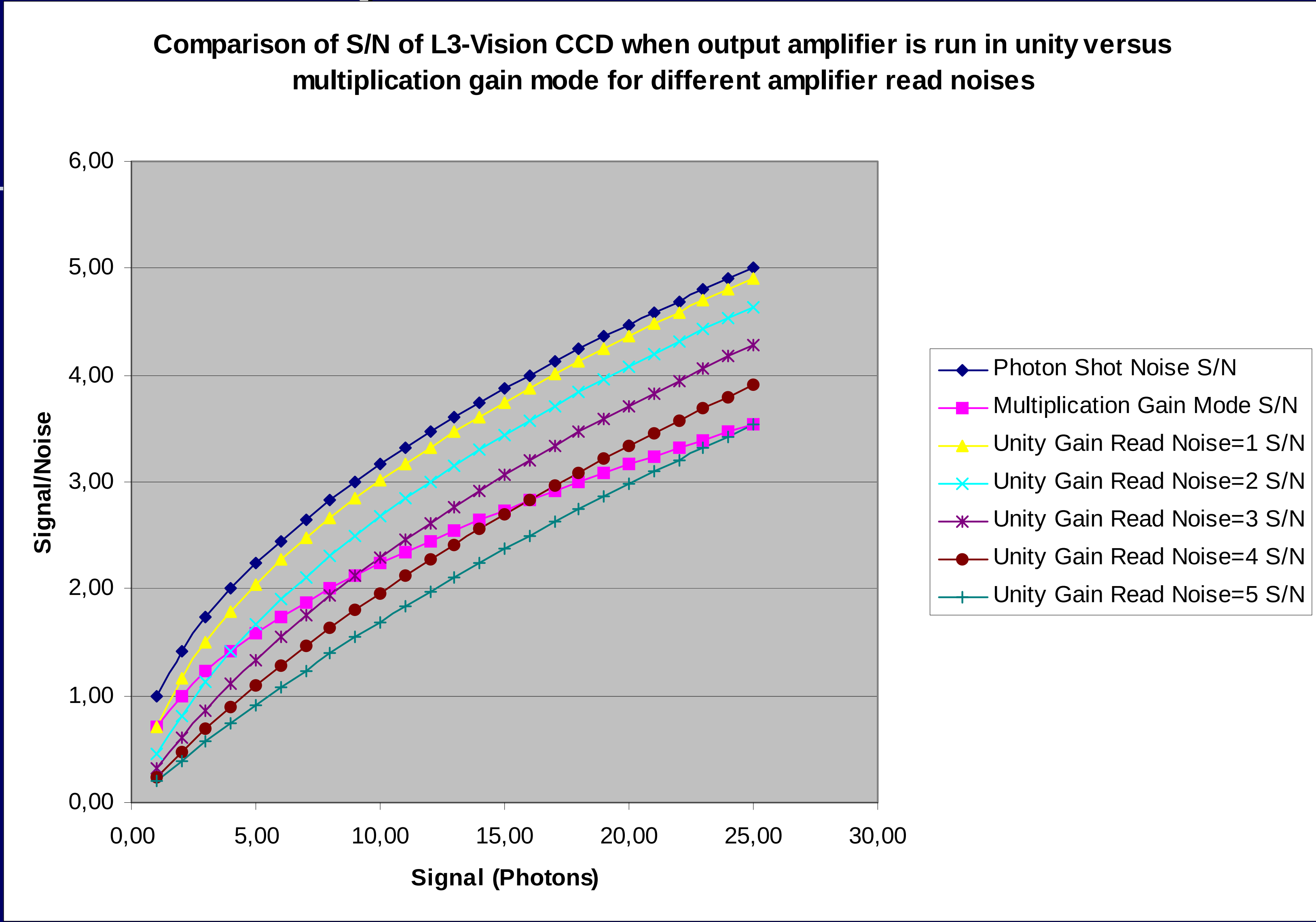
Noise comparison between CCD and L3CCD

- Hypothesis: we assume that the multiplication gain of the L3CCD is high enough to provide a readout noise σ_R close to 0

	CCD	*L3CCD*
Number of e- / pixel	n	n
Readout noise (RMS)	σ_R	~ 0
Total noise (e-)	$\sqrt{n + \sigma_R^2}$	$\sqrt{2}\sqrt{n}$

Excess Noise Factor F

S/N computations



EMCCDs theory

- Possible working modes for an EMCCD:
  - No amplification (G=1)

    the CCD is a normal CCD with high read noise (no interest)

  - Low to medium amplification (1<G<1000)

    Used in AO applications

    The CCD has no readout noise but has excess noise

  - High amplification (G>1000)

    The CCD is used in photon counting mode.
    No readout noise, no excess noise
    possible non linearity at high fluxes

- It's possible to switch between modes at any time!

E2V L3-Vision technology (EMCCD)

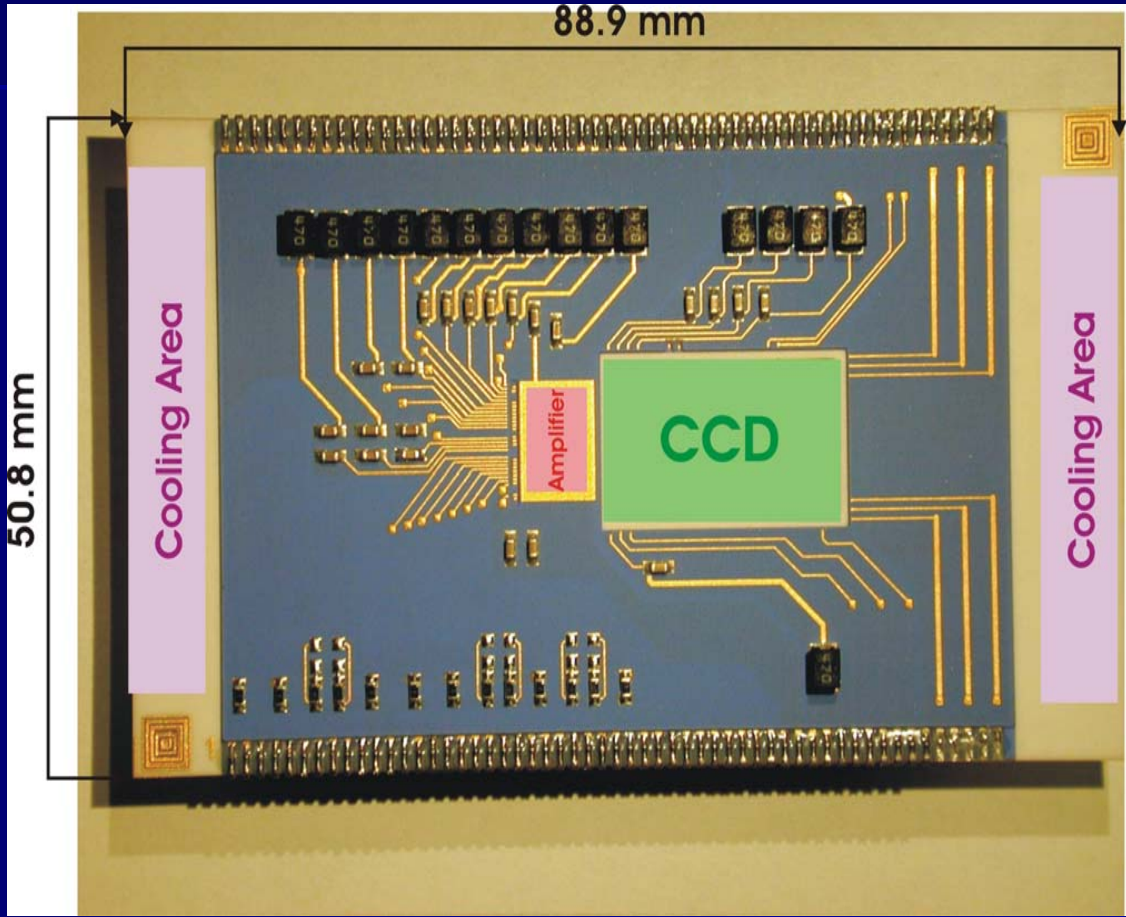
- E2V is pushing L3-Vision technology and reluctant to look at alternatives.
- E2V is commercial company that will deliver detectors that satisfy requirements.
- E2V has a relatively good reputation on delivering detectors on time.

MPE/HLL PN-Sensors

- Common research facility of Max-Planck-Institut für Physik in Munich.
- Provide commercially not available silicon detectors for particle physics and X-ray astronomy mainly for space applications.
- Work by best effort.
- Specialize in
  - Fully depleted **PN-CCDs** as opposed to more common **MOS** scientific CCD.
  - Large pixel size: 36μm to 300μm
  - Thick device with high red Quantum Efficiency (90% from 450nm to 1000nm) and very low (no) fringing.
  - Fast readout + low noise by having one amplifier per column.
- Success – detectors for XMM-Newton X-ray Telescope
- Advanced talk of collaboration to develop detector for ESO
- Link with the JRA3

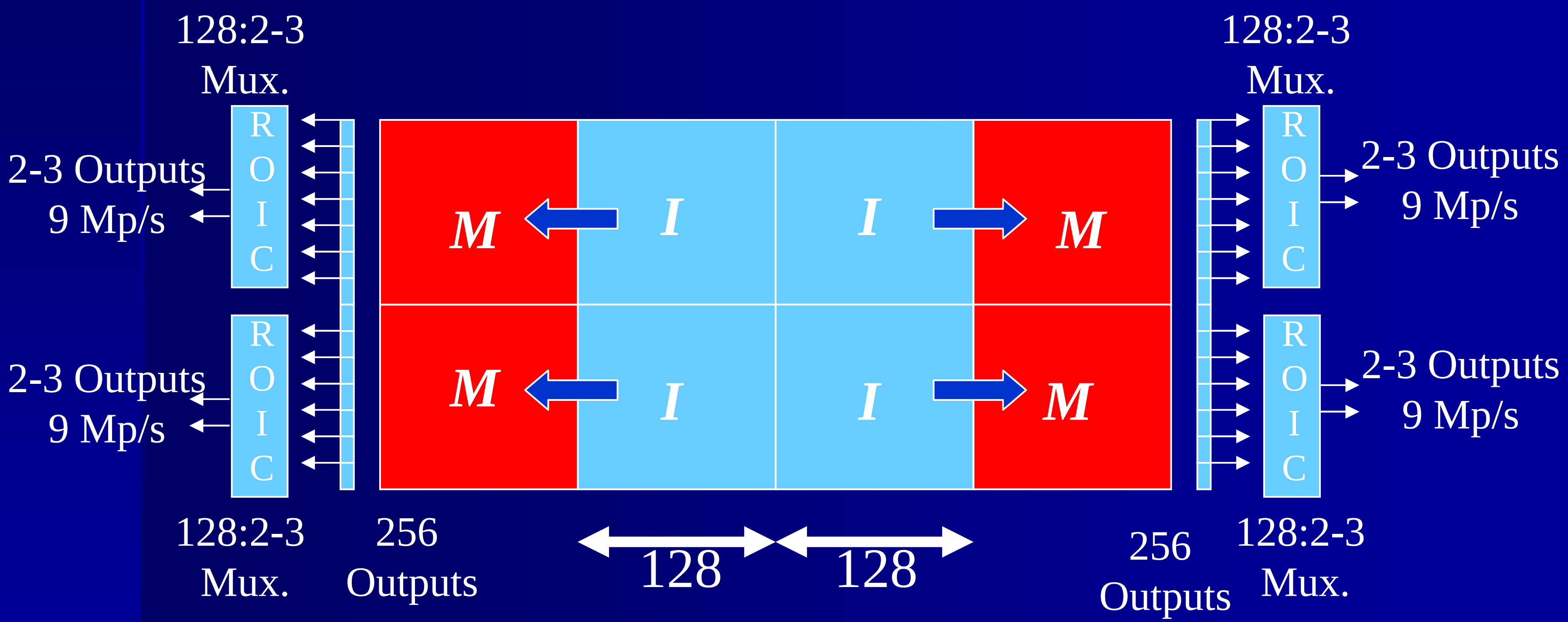
Current MPE Detector

- 256x256.
- 51 μm^2 pixel.
- 500 μm thick.
- Frame transfer PN-CCD device.
- 256 outputs.
- 2 ROIC (128:1 output MUX).
- 500 kframes/sec.



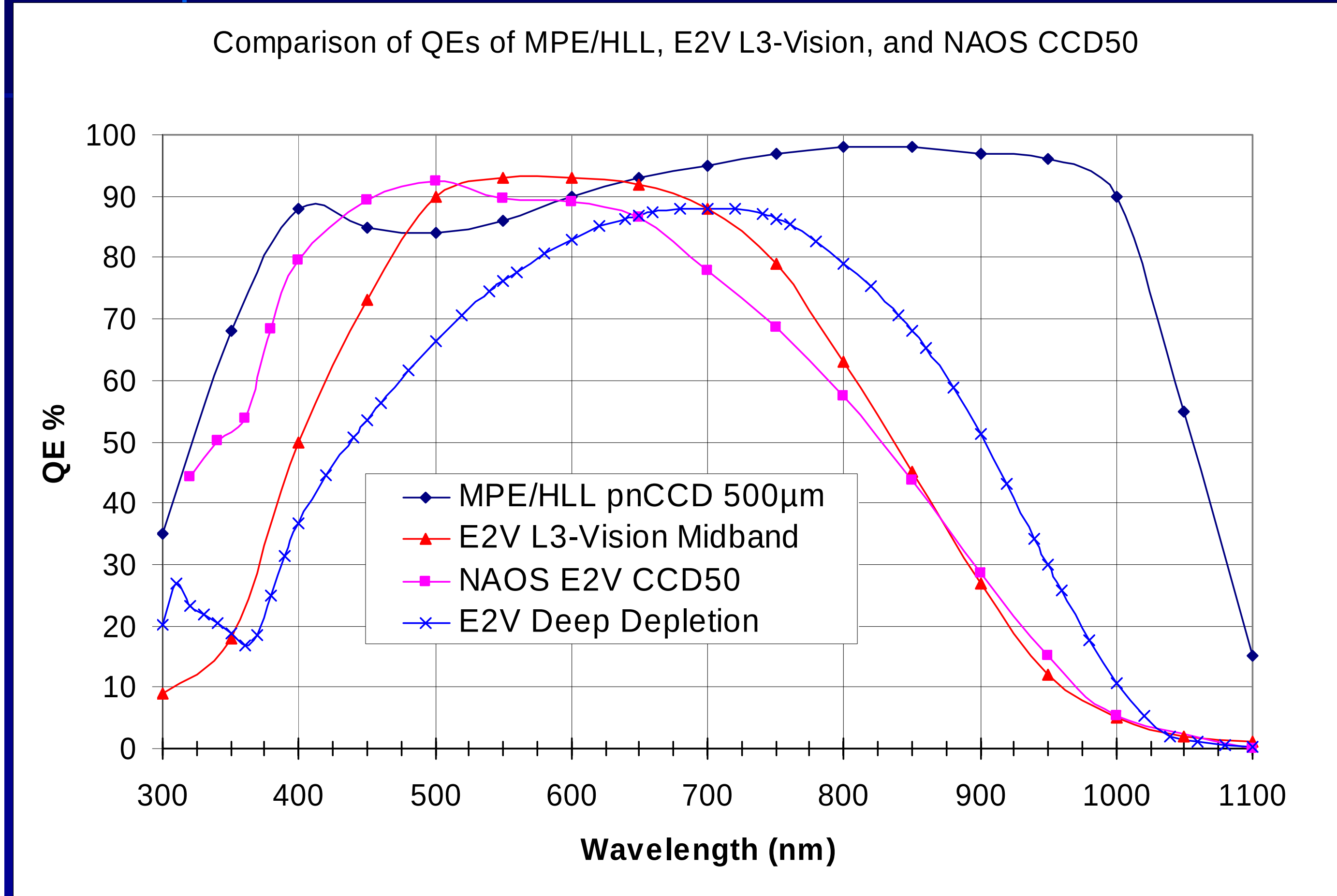
MPE/ESO Collaboration Detector

- 256x256, 51μm^2 pixel, 450μm thick, split frame transfer PN-CCD device.
- 512 outputs, uses four ROICs for goal frame rate of 1500frames/sec at 4e RON and 1000frames/sec at 3e
- This development is apart from the JRA2 but has close links with the JRA2 activity



AO simulations

Comparison of Quantum Efficiency (QE) for PNCCD/L3CCD

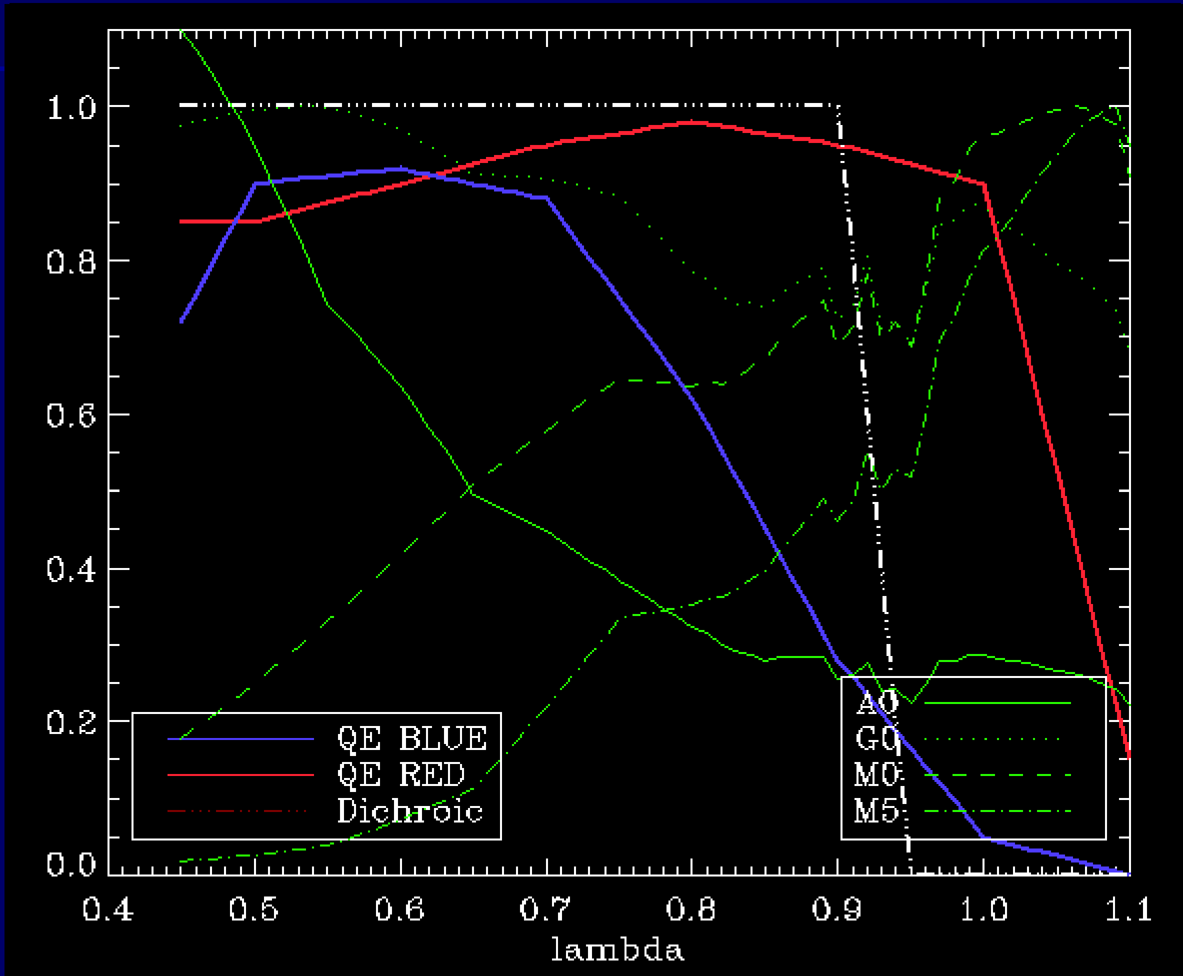


- MPE/HLL much better response expected in red (to be confirmed, optical measurements not done)

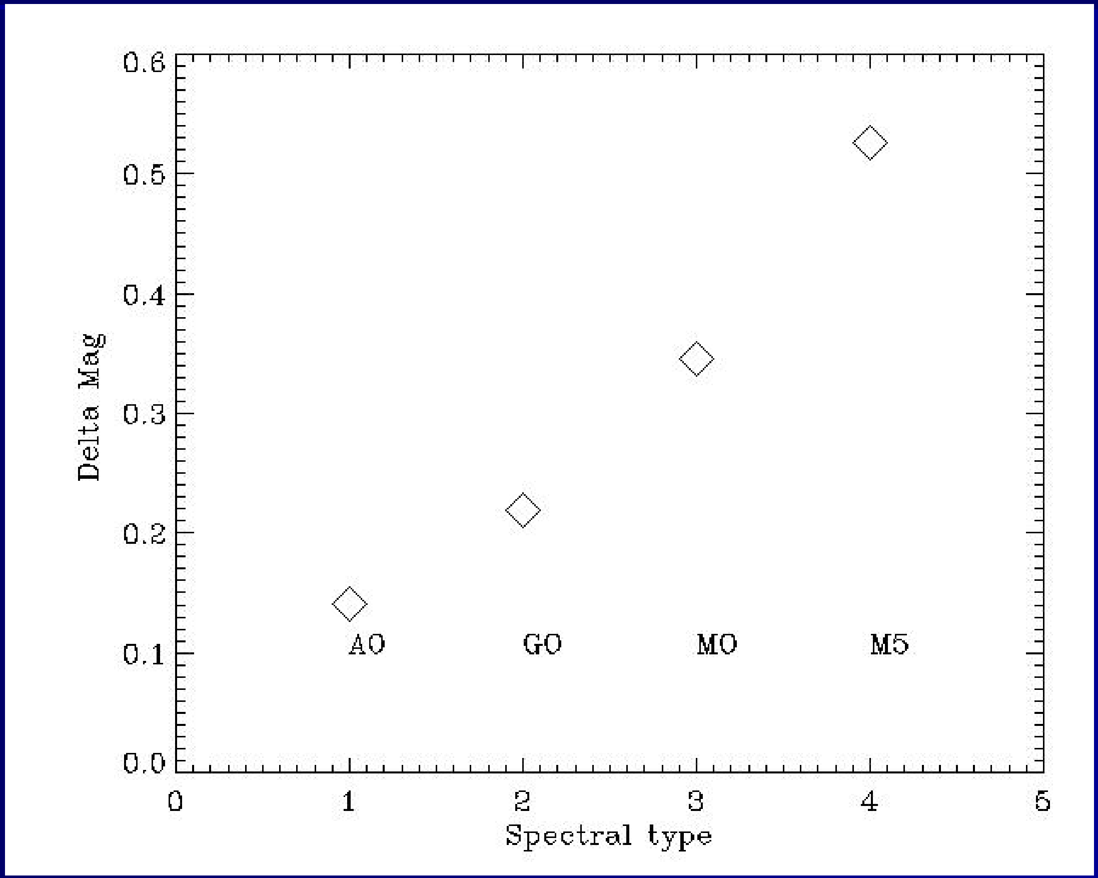
Impact of QE curve: assumptions

- AO range = 0.45 - 0.95 microns
- QE spectral response: 2 test cases « blue » and « red »
- Independent study of spectral response and RON cases (no correlation?)
- Various target spectral types

Quantum Efficiency effects



Magnitude gain of « red » vs. « blue »



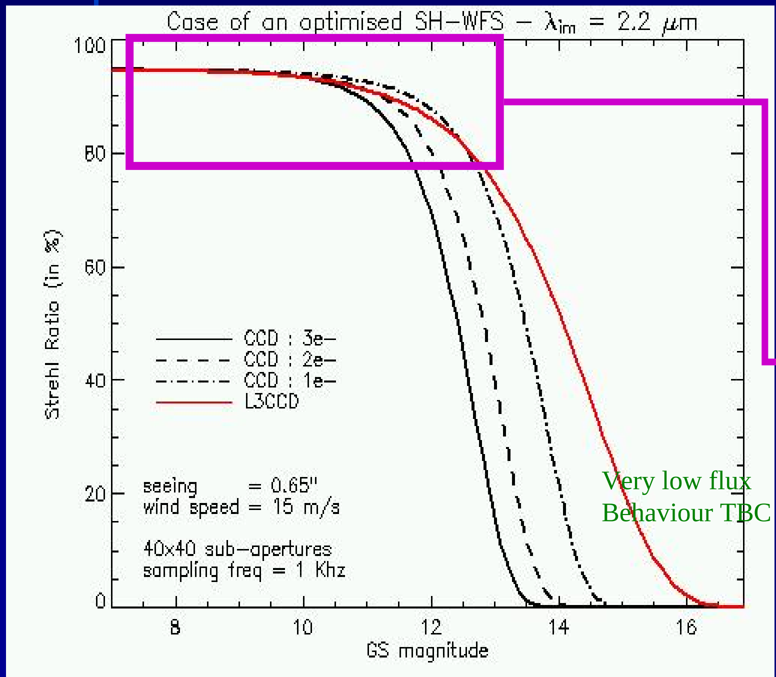
Effect of Noise on WFS measurements

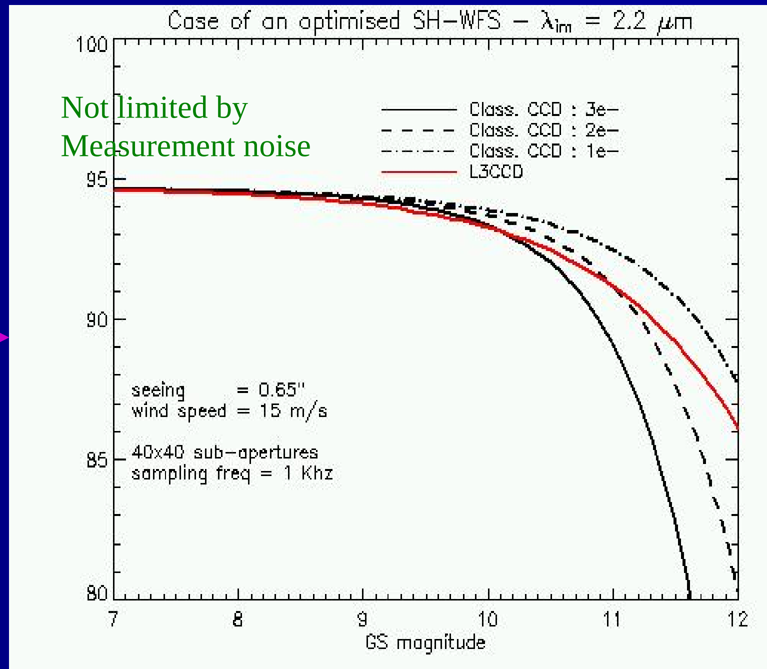
- Shack-Hartmann WFS :
  - Wavefront estimation from sub-aperture PSFs
  - Noise effects on wavefront estimation :
    - Photon noise : $\sigma^2_{\mathbf{phot}} = \alpha / \mathbf{n_{ph}}$ ⇨ Optimisation of QE
    - Detector noise : $\sigma^2_{\mathbf{detec}} = \beta\, (\mathbf{ron} \ / \ \mathbf{n_{ph}})^2$ ⇨ Reduction of RON
- Pyramid WFS
  - Wavefront estimation from 4 quadrant intensity subtractions
  - Noise effects : same evolution than SH-WFS

Strehl Ratio: Comparison CCD / L3CCD Impact on XAO performances

For XAO main goals: CCD > L3CCD only if RON < 2e- , and on a narrow magnitude range

For wider use: L3CCD better or not far behind





- **Seeing = 0.65'', wind speed = 15 m/s**
- **40x40 sub-apertures - 1 kHz frame rate**

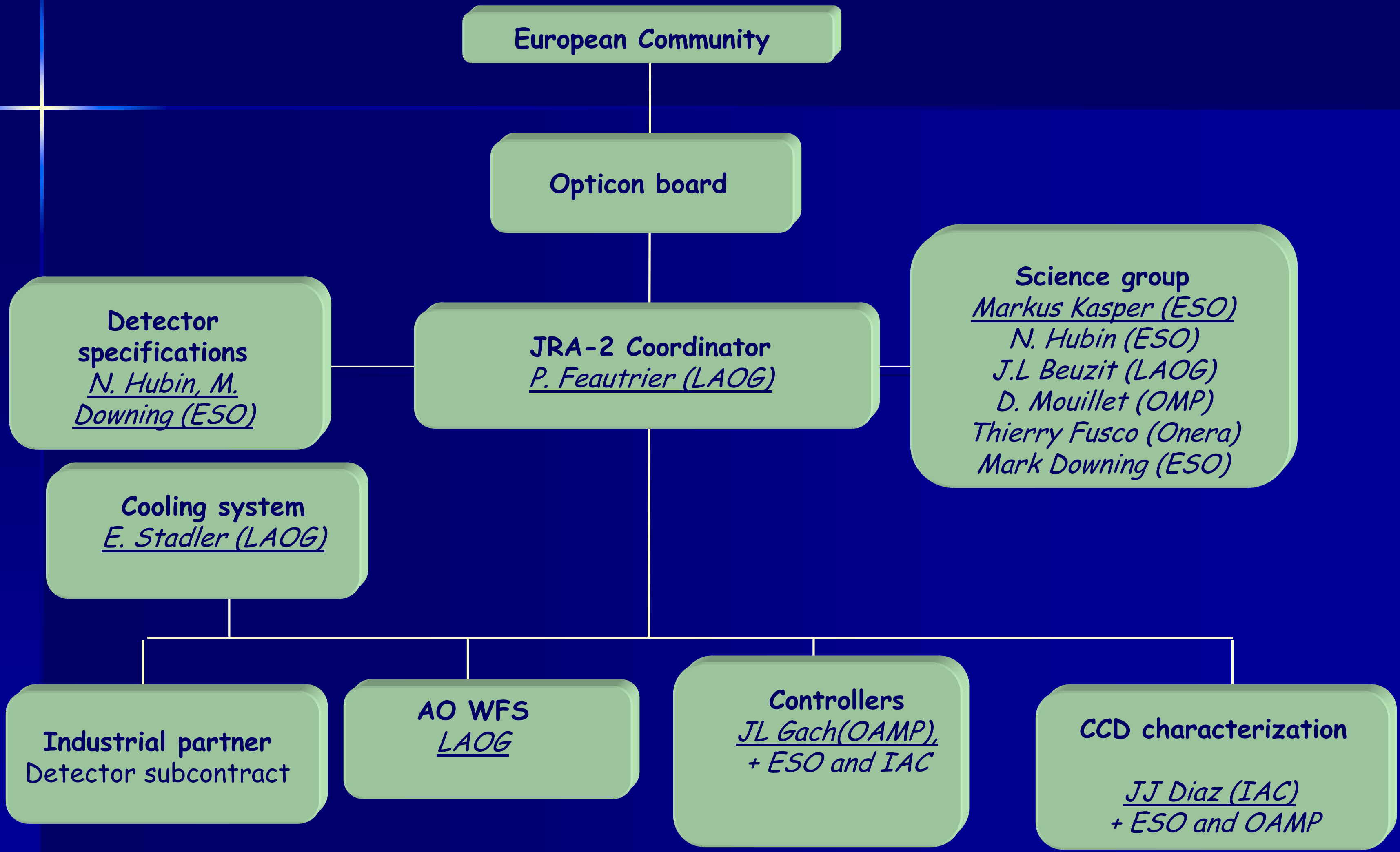
Detector Procurement Strategy

Detector Procurement Strategy

- Our Risk Level should remain Low , we need to deliver results
- Best Effort Detectors
  - Example: MPE/HLL and MIT/LL
  - Only interested in producing devices not available from commercial manufacturer
  - Cannot respond directly to Tender Documents
  - Potential to obtain a more unique device with better performance
- Commercial Company
  - Example: E2V
  - Deliver devices that meet requirements or do not get paid
  - Higher probability in obtaining a device, however device will be more conservative
- ESO already negotiating contract with best effort manufacturer MPE/HLL
- Need to compose and distribute Tender Document
- Should include minimum specifications + goals specifications

Management and organisation

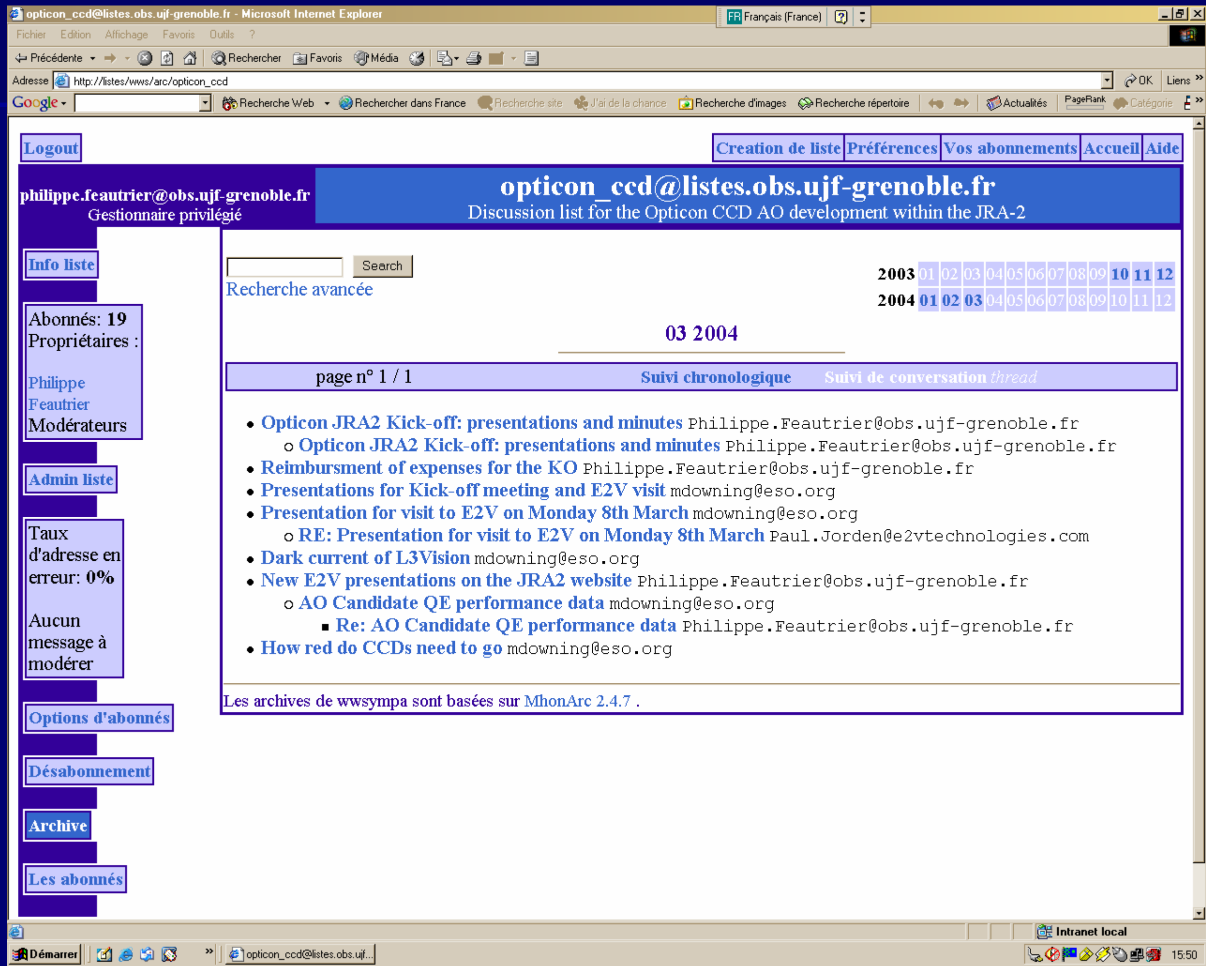
JRA-2 organisation



The JRA2 mailing list:

opticon_ccd@listes.obs.ujf-grenoble.fr

- Saved archives
- Private list
- Discussions, information…



The JRA2 web site:

http://www-laog.obs.ujf-grenoble.fr/JRA2/

- Presentations, minutes.
- List of participants
- Documents…
- Private site, public section still to develop
- Common templates with Opticon FP6 website to be considered

The Work Packages

WP1 : management

- Kick-off: 8 March 2004
- One progress meeting every 9 Months
- Coordinate the JRA activities
- prepare the key specifications for the other WPs
- monitor the WPs
- organize study and design reviews
- prepare the regular reports and detailed work plans for the OPTICON management
- Web-site responsibility

WP2: science group, detector specification, design and fabrication

- Detector Specification Leaders: Norbert Hubin and Mark Downing (ESO).
- Will be in close loop with the science group.
- Inputs:
  - Simulation results from Science Group which looks at two or three test cases to determine requirements.
- Description:
  - In close collaboration with the Science Group, compose the detector specifications and Call for Tender document. Monitor progress of detector development.
- Deliverables:
  - Detector specification document, Call for Tender document, Tender Results and detector progress reports, and Detectors!

WP2: science group activity

- Inputs:
  - Requirements from up-coming instruments such as VLT-PF and MUSE.
- Description:
  - Determine detector specifications by doing simulations and looking at high level requirements of up coming VLT and other instruments.
- Deliverables:
  - Simulation results and detector specifications.

WP3: Controller

- OAMP (Marseille) is the leader
- Inputs:
  - Detector type, detector specifications and operating modes of the detector.
- Description:
  - Design, manufacture and test a detector controller to characterize and optimize the performance of the chosen detector. Controller should not limit the performance of the detector.
- Deliverables:
  - An operating controller that has sufficient performance to characterize the detector and to be transportable to run stand-alone at IAC.
- Should take into account the operation on existing facilities.

WP4: Cooling system

- LAOG is the leader
- Inputs: Detector package and detector operating requirements.

- Description:
  - Design and manufacture a test cryogenic system to safely mount , cryogenically cool and temperature stabilize the detector.
- Deliverables:
  - Cryogenic system including detector head together with cryostat wiring.

Detector Packaging

- Application requires compact, low weight solution
- Peltier cooling produces most compact system with minimal support equipment.
- E2V
  - have experience and can produce Peltier cooled device but low JRA2 budget may require internal solution.
  - L3vision CCD have low enough dark current to enable Peltier cooling
- MPE/HLL
  - no experience with Peltier cooled package
  - we need to develop package
  - First, need to know whether dark current is low enough to allow Peltier cooling ~ 12 months for results

Work Package 5: detector test

- IAC is the WP responsible
- MPE contract is outside the JRA but the JRA is interested in the results of this contract.
- Inputs:
  - Detector type, detector specifications, and detector controller.
- Description:
  - Characterize and if possible optimize the performances of the detector. Compose a detector test plan. Compose a list of available tools and tools that are required.
- Deliverables:
  - Detector Test Plan, tools required, Detector Test Report.

Detector Test:Parameters To Measure

- Critical Parameters
  - Read noise (RON) vs read out speed (bias for RON and flats for gain)
  - Cosmetics (bias, darks and uniform flats for bright and dark pixels) (low level flats for pocket pumping)
- Less critical parameters
  - QE (uniform flats at different wavelengths and calibrated photodiode)
  - Dark Current (darks)
  - PSF (point source)
  - Smearing (test pattern)
  - Charge Transfer Efficiency
  - Crosstalk between channels (test pattern)
  - Linearity (flats)
  - Full Well (flats)
  - Fringing (flats with narrow optical bandwidth)
  - Detector surface flatness (surface measurement device)

Work Package 5: AO tests

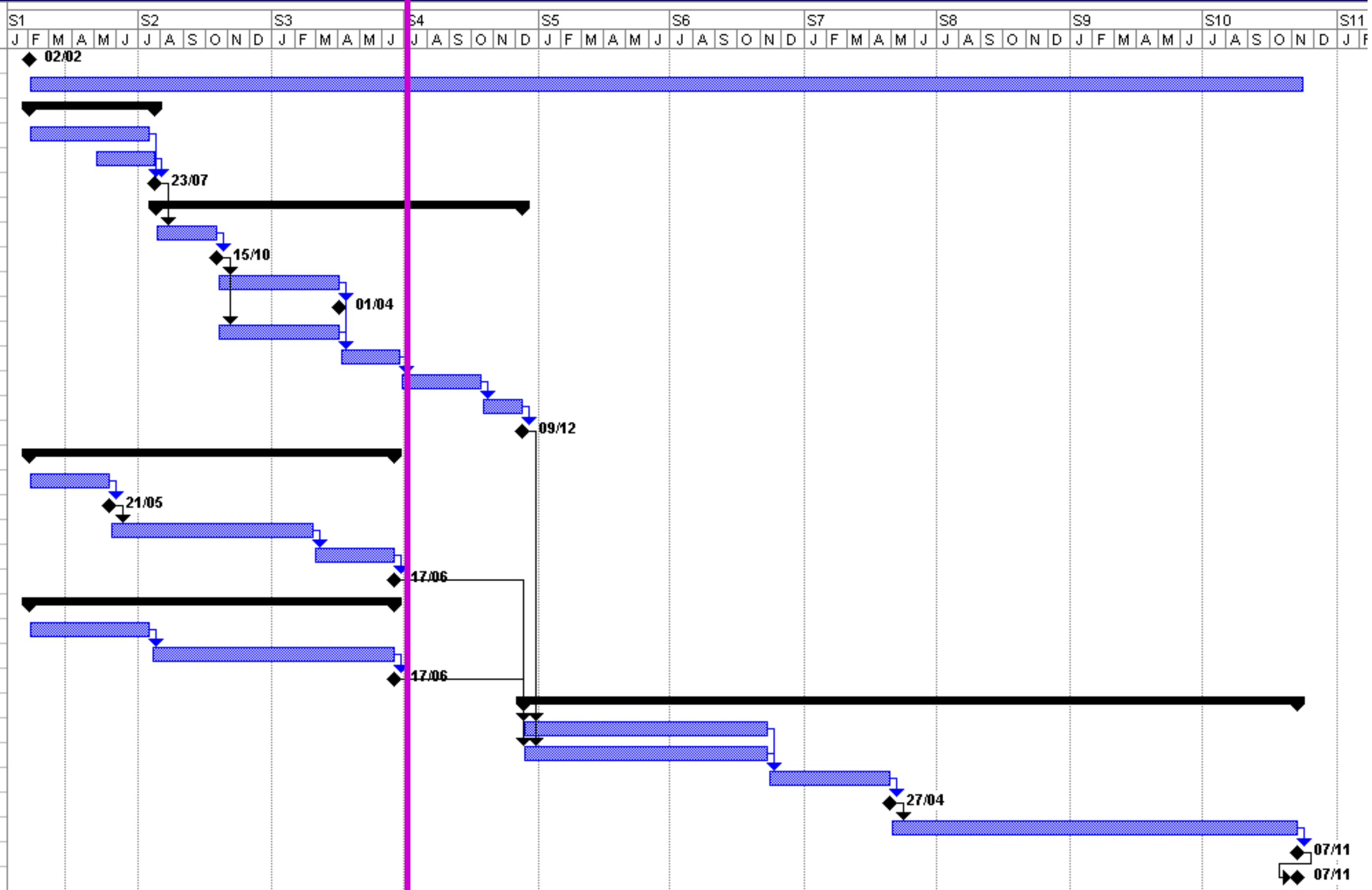
- best effort activity
- closely linked to the JRA1 and the AO test bench facility
- Probably difficult to finish this activity before the end of the FP6
- Possibility to use the measured performances of the fabricated detector inside AO simulations.

Timelines, Milestones, Deliverables

Timelines

18 Months

N°		Nom de la tâche
1		Start JRA2
2		WP1 : managment
3		**WP 2:Concept design**
4		M1: Science group discussions
5		concept discussion
6		M2: Concept design review
7		**Detector Manufacuturing**
8		Detailed design
9		M3: Detailed design review
10		Demonstration devices manufacturing
11		M4: Demonstration device delivering
12		Test facilities
13		M5: Frontside devices test
14		Backside devices manufacturing
15		Backside devices test
16		M6: detector delivering and acceptance
17		**WP 3: Controller manufacturing**
18		M1: Controller conceptual design
19		M2: Controller design review
20		Controller manufacturing
21		Controller test
22		M3: Controller delivering and acceptance
23		**WP 4: Cryogeny**
24		M1: Cryogeny design
25		Cryogeny manufacturing
26		M2: Cryogeny delivering and acceptance
27		**WP 5: L3CCD for AO evaluation**
28		M1: Complete detector test in laboratory
29		M2: AO wavefront sensor manufacturing
30		M3: AO Det. performances evaluation
31		M4: AO WFS acceptance for AO tests/simus
32		AO CCD tests on sky/simulations
33		D1: test report delivering of the AO results/simus
34		End JRA2



Conclusions

- Interesting and challenging development
- Should be very useful for the astronomical community in the years to come where low RON + fast detectors are needed.
- Funding may be an issue: real detector cost is uncertain, trade-offs between specifications and available budget might be necessary…

Many Thanks For Listening