# Synergies between LOFT/LAD and the E-ELT

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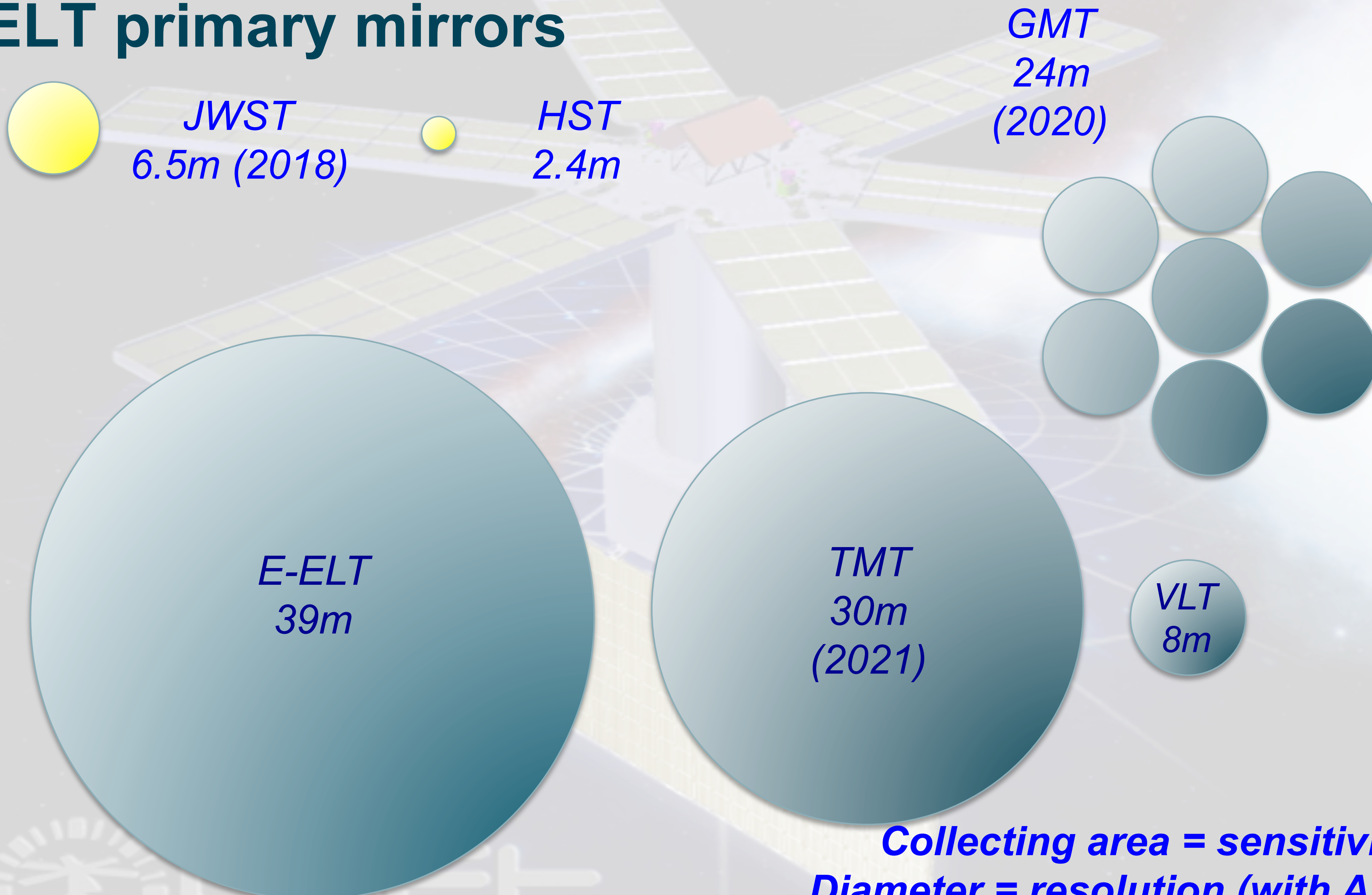
# The European ELT (E-ELT)

- A 39.3m diameter, adaptive telescope
- Approval June 2012, subject to confirmation
- First light early 2020s

Total Cost: € 1082 million (2012)

- Top priority for European ground-based astronomy (ASTRONET)
- Retain European Leadership in the era of ELTs (ESO)

# ELT primary mirrors

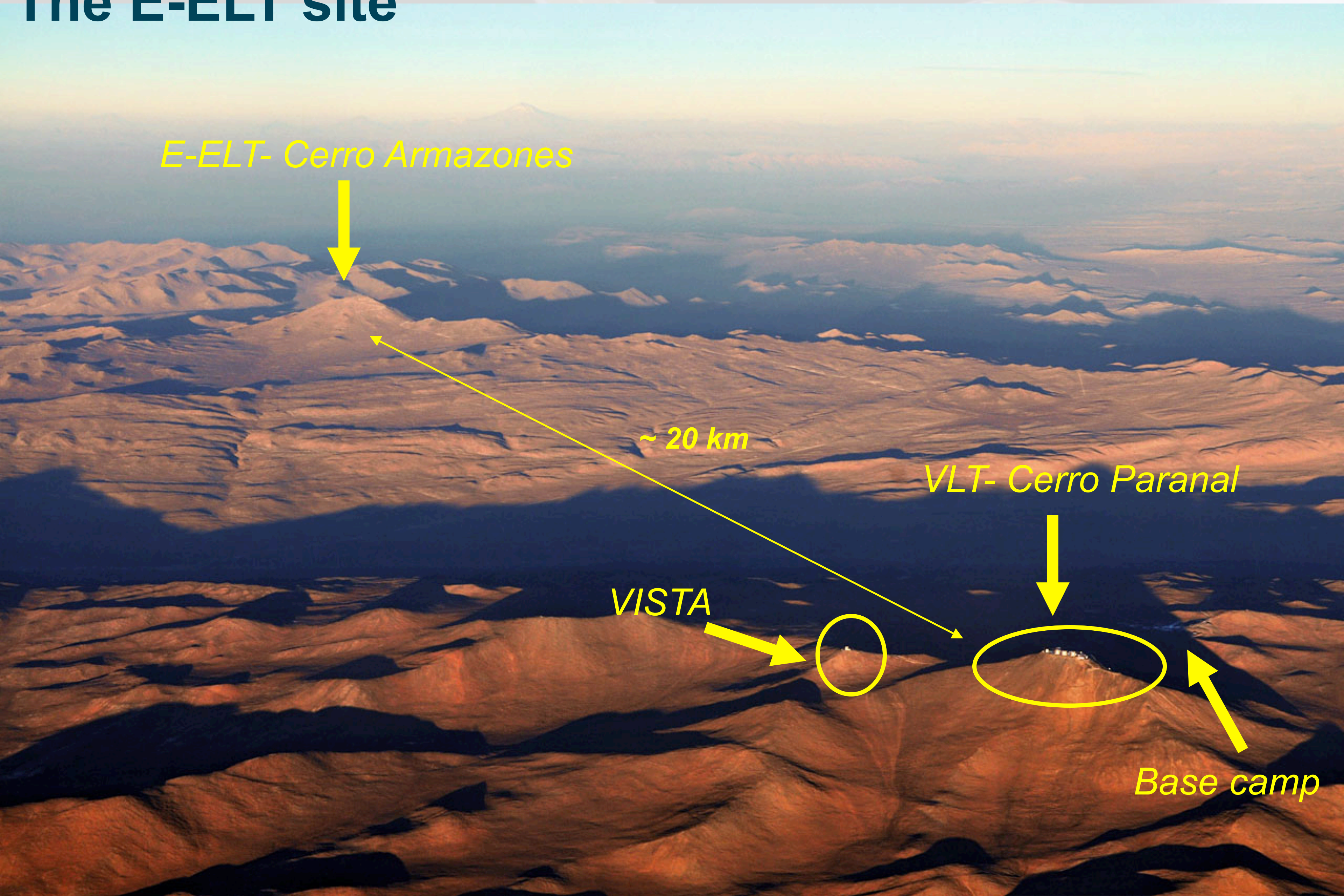



***Collecting area = sensitivity***

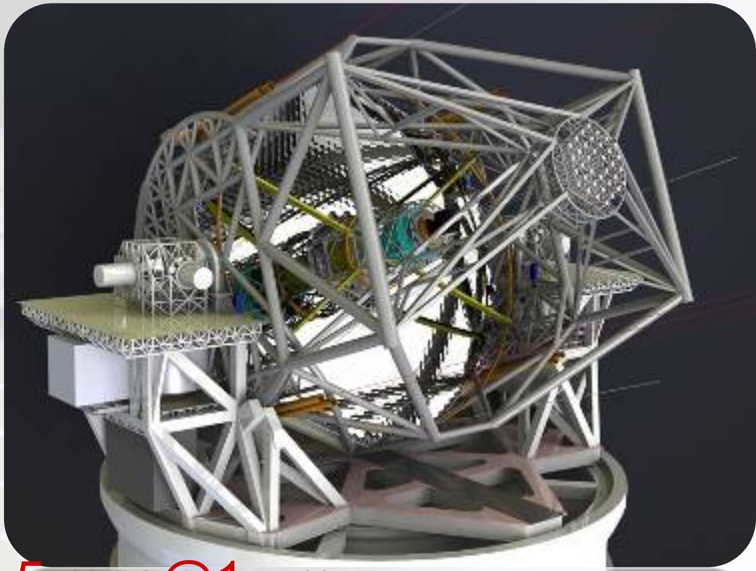
***Diameter = resolution (with AO)***

**Larger collecting area than all major observatories put together!**

# The E-ELT site

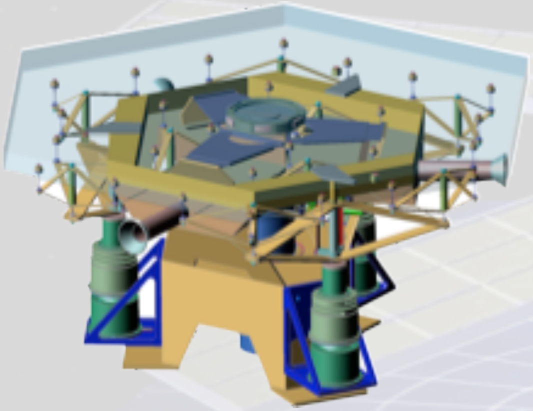


# The Telescope

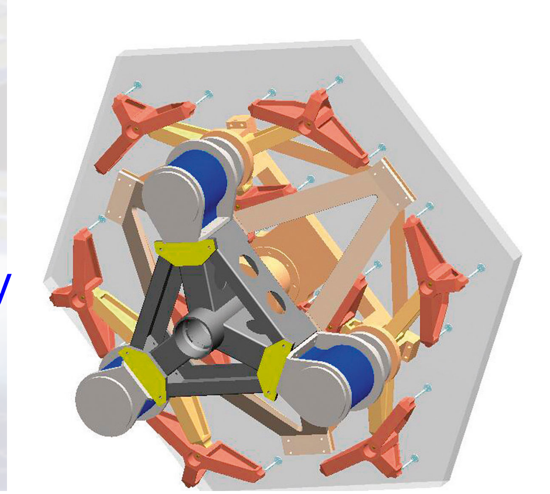


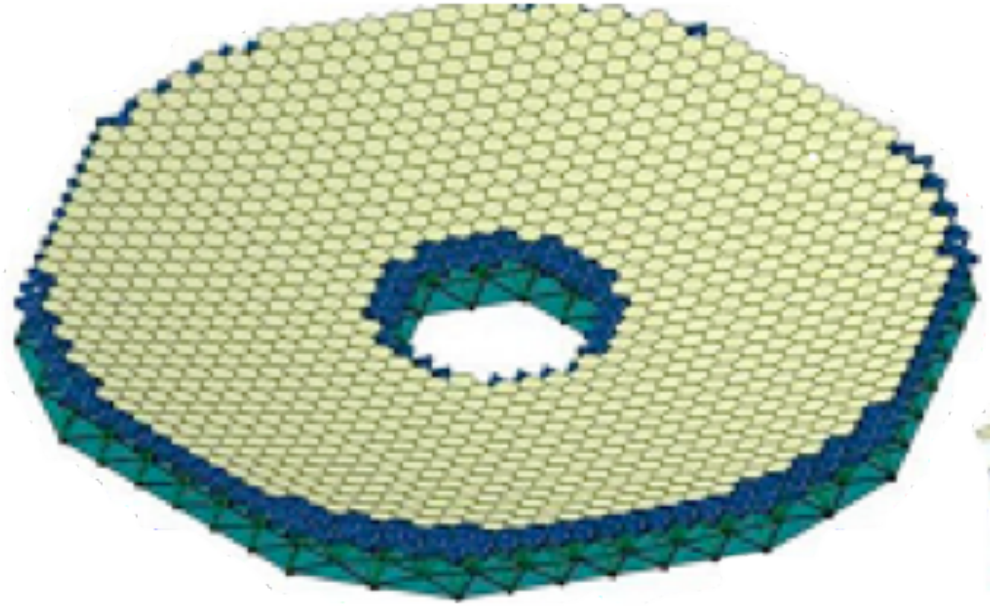
- Nasmyth telescope with a 39m diameter primary mirror
- The primary mirror is a mosaic of about 900 1.45m exagonal segments.
- 10’ field-of-view, 0.2-24 **μ**m, spatial resolution 5 mas@1 **μ**m.
- Nearly 5000 tons of structure
- Two instrument platforms of the size of tennis courts
- Novel 5 mirror design to include adaptive optics in the telescope
- Classical 3-mirror anastigmat + 2 flat fold mirrors [M4,M5]

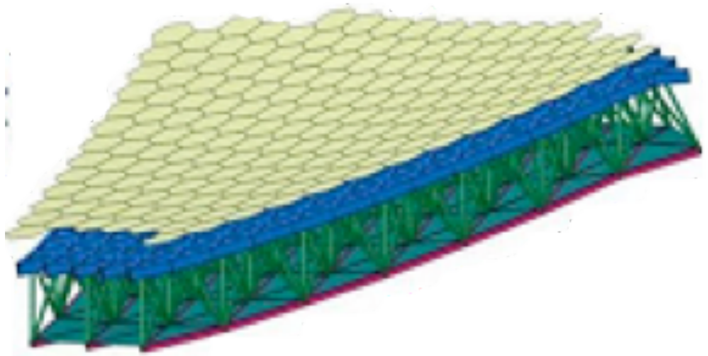
# Primary Mirror



- Real-time software, electronics and mechanics
- Maintain the shape and position of the telescope mirrors
- Compensate for changing gravity as telescope moves around the sky
- Compensates for wind shake on the telescope structure



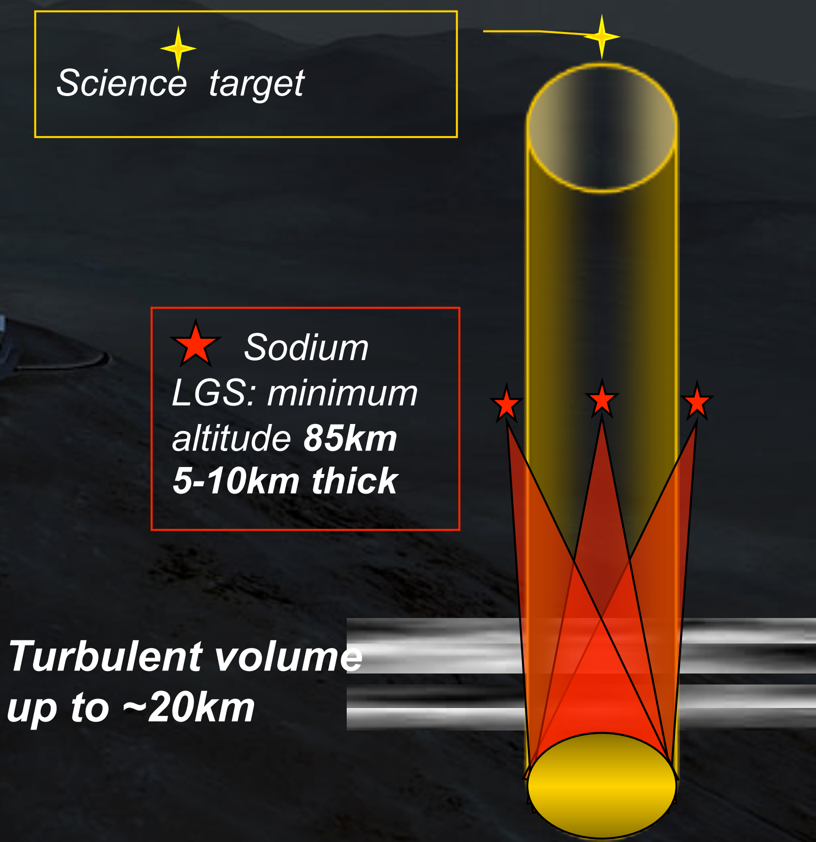




- Partial correction of image wander induced by atmospheric turbulence
- Produces excellent image quality at infrared wavelengths

# Laser Guide Star System

- Six Laser Guide Stars for AO correction
- Outstanding image quality



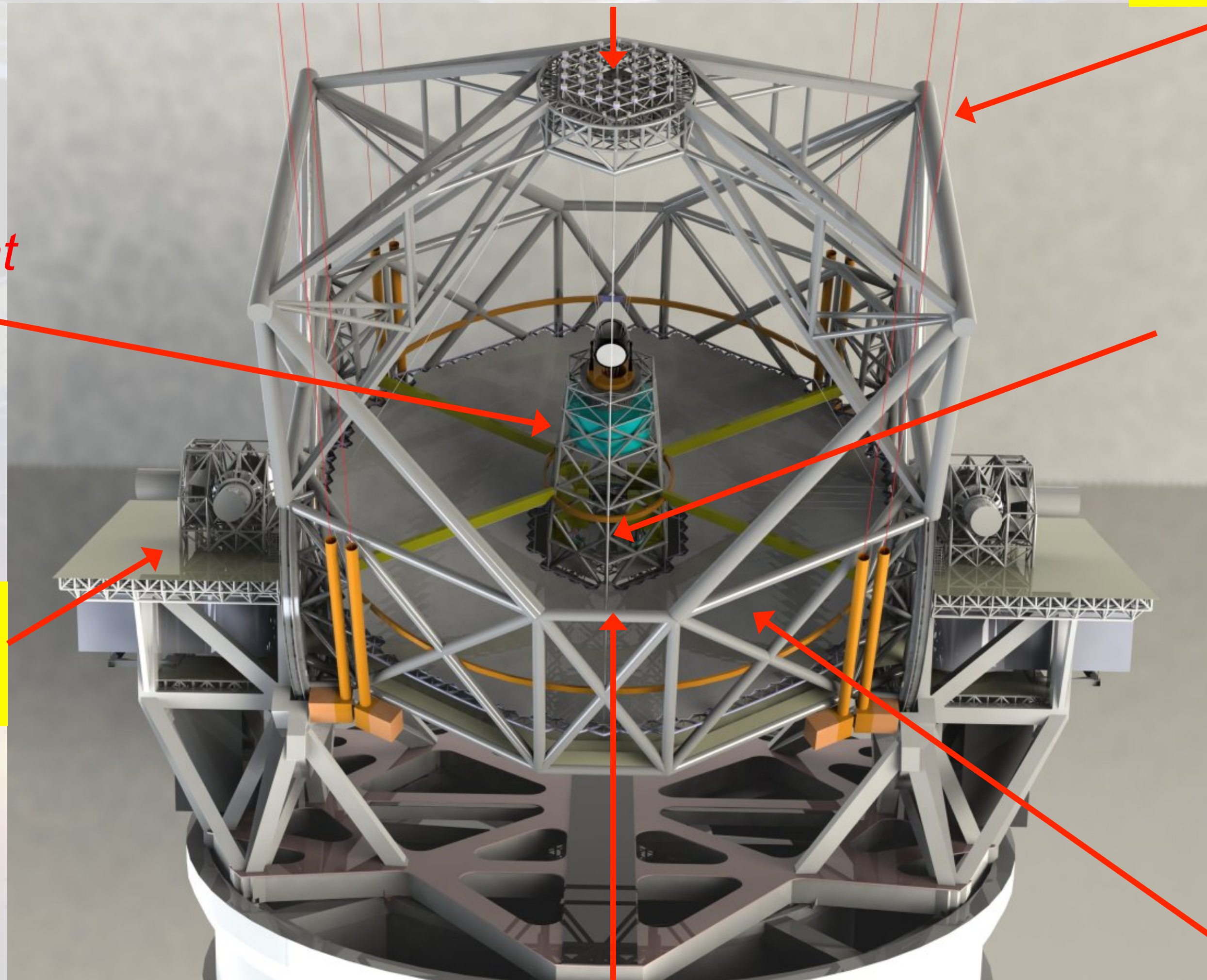

- Adaptive optics needs a bright reference star
- Corrects a patch of sky around the reference
- Not always a natural star nearby
- Laser excites sodium atoms in the atmosphere to create an artificial star

UCL

# E-ELT Basic Reference Design

M2: 5.6m

Lasers



M4: 2.6m flat adaptive mirror

M5: 3x2.4m flat field-stabilisation mirror

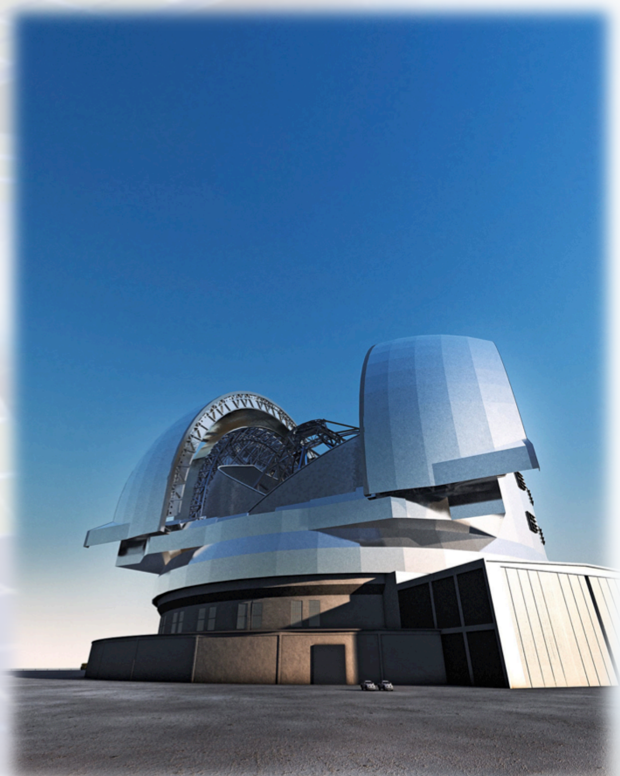
Instrument platform

M3: 4m
Controls f ratio

M1: 42m f/1 aspheric
984 segments

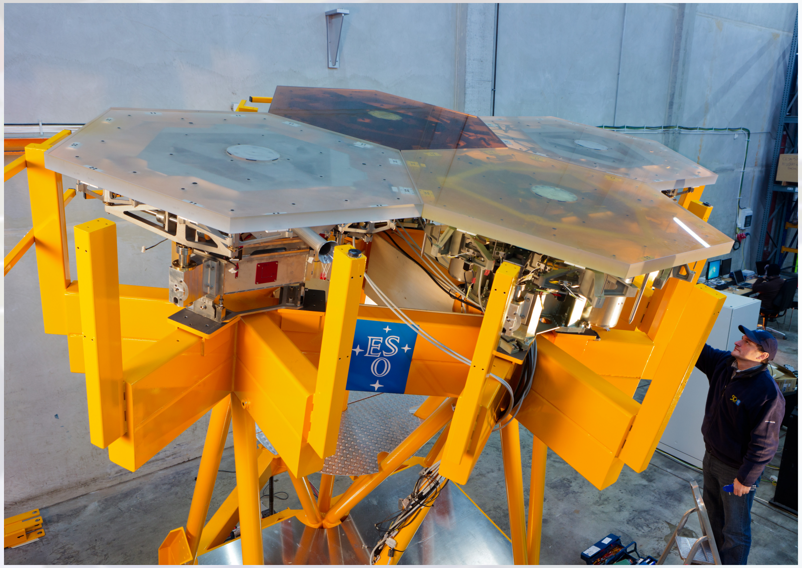
# The European ELT status summary

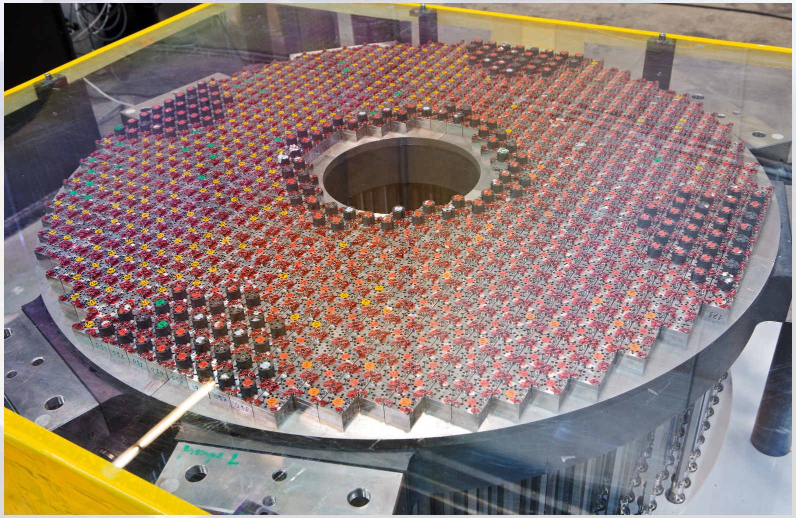
- **Detailed design completed in 2011**
  - Industrial contracts resulting in several fixed-price offers
  - Detailed science simulations: DRM
  - Passed external reviews
- **Dec 2011: Construction proposal published**
- **Dec 2012: approval of the ELT Programme by ESO Council**
- **Now awaiting Brazil to complete ratification procedure**



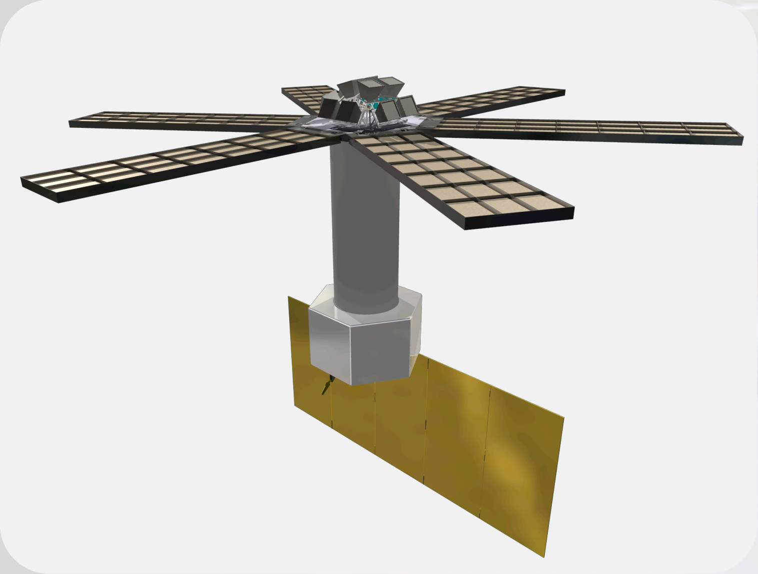
# Current work

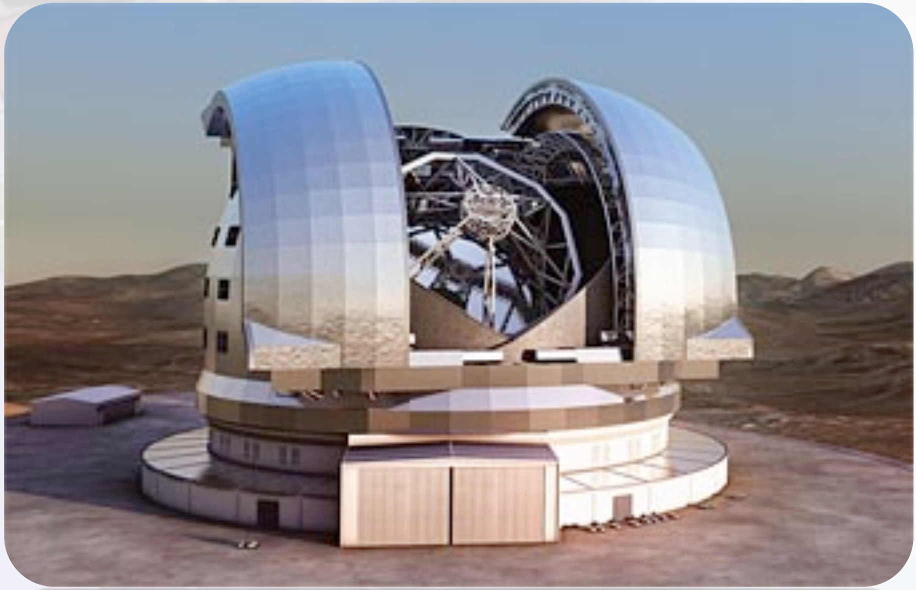
- Preparatory work going ahead
  - detailed design of M4 and access road
- Dome & Main structure specifications
  - Updated & discussed with industry
- Work on prototypes at the Hochbrück warehouse
  - M4 mirror support
  - Primary mirror segments
  - M5
- Work on design of AO systems and interfaces
- Definition of instrument requirements





# LOFT and the E-ELT





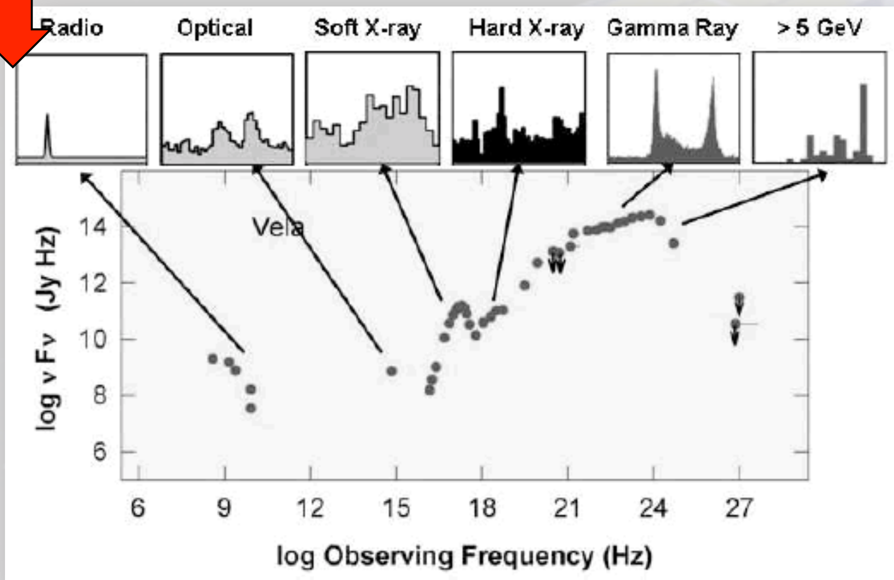
- The E-ELT will not be a survey telescope. Synergy with LOFT/WFM for spectroscopic follow-ups
- Synergy with the LOFT/LAD more obvious – X-ray and optical timing
- The E-ELT large collecting power makes it suitable for optical timing
- Most targets are faint (isolated pulsars V>25)
- Possibility of carrying out observations (e.g. phase-res polarimetry) still difficult at high energies

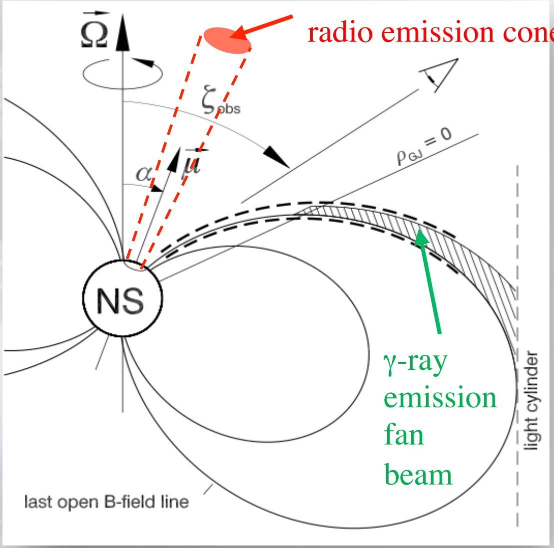
| Name | Year | Age | mag | D(kpc) | $A_V$ | Phot | Spec | Pol | Tim | Astrom |
|---|---|---|---|---|---|---|---|---|---|---|
| **Crab[F]** | **1969** | **3.10** | **16.5** | **1.73** | **1.6** | **UVOIR** | **Y** | **Y** | **P** | **PM** |
| **B1509-58[F]** | **2000** | **3.19** | **26** | **4.2** | **5.2** | **OIR** | | **UL*** | | |
| **B0540-69** | **1984** | **3.22** | **22** | **49.4** | **0.6** | **OIR** | **Y** | **Y*** | **P** | **PM (UL)** |
| *J0205+6449[F]* | *2013* | *3.73* | *27.4* | *2* | *2.5* | *O* | | | | |
| **Vela[F]** | **1976** | **4.05** | **23.6** | **0.23** | **0.2** | **UVOIR** | **Y** | **Y*** | **P** | **PM,PAR** |
| **B0656+14[F]** | **1988** | **5.05** | **25** | **0.29** | **0.09** | **UVOIR** | **Y** | **Y** | **P** | **PM** |
| **Geminga[F]** | **1984** | **5.53** | **25.5** | **0.16** | **0.07** | **UVOIR** | **Y** | | **P** | **PM,PAR** |
| **B1055-52[F]** | **1997** | **5.73** | **24.9** | **<0.72** | **0.22** | **UVO** | | | | **PM** |
| **B1929+10** | **1996** | **6.49** | **25.6** | **0.33** | **0.15** | **UV** | | | | **PM** |
| **B0950+08** | **1996** | **7.24** | **27.1** | **0.26** | **0.03** | **UVO** | | | | |
| *B1133+16* | *2008* | *6.69* | *28* | *0.35* | *0.12* | *O* | | | | |
| *J0108-1431* | *2008* | *8.3* | *27.* | *0.3* | *0.05* | *O* | | | | |
| **J0437-471[F]** | **2004** | **9.20** | | **0.14** | **0.11** | **UV** | **Y** | | | |
| **J1308.6+2127** | **2002** | **6.17** | **28** | **<1** | **0.14** | **O** | | | | |
| **J0720-3125** | **1998** | **6.27** | **26.7** | **0.35** | **0.10** | **O** | | | | **PM,PAR** |
| **J1856-3754** | **1997** | **6.60** | **25.7** | **0.14** | **0.12** | **O** | **Y** | | | **PM,PAR** |
| **J1605.3+3249** | **2002** | **-** | **27.2** | **<1** | **0.06** | **O** | | | | **PM** |
| **RBS1774** | **2008** | **-** | **27.4** | **<0.5** | **0.2** | **O** | | | | |
| **J0806-4123** | **2011** | **>6.5** | **27.9** | **<0.5** | **0.1** | **O** | | | | |
| **SGR1806-20** | **2004** | **3.14** | **20.1** | **15** | **29** | **IR** | | | | |
| **1E 1547.0-5408** | **2009** | **3.14** | **18.5** | **9** | **17** | **IR** | | **Y*** | | |
| **1E 1048.1-5937** | **2004** | **3.63** | **21.3** | **3** | **6.1** | **OIR** | | **UL*** | **P** | |
| **XTE J1810-197** | **2004** | **3.75** | **20.8** | **4** | **5.1** | **IR** | | **UL*** | | |
| **SGR 0501+4516** | **2009** | **4.1** | **19.1** | **~2** | **5** | **IR** | | | **P** | |
| **4U 0142+61** | **2002** | **4.84** | **20.1** | **>5** | **5.1** | **OIR** | | | **P** | |
| **1E 2259+586** | **2002** | **5.34** | **21.7** | **3** | **5.7** | **IR** | | | | |

* phase-averaged

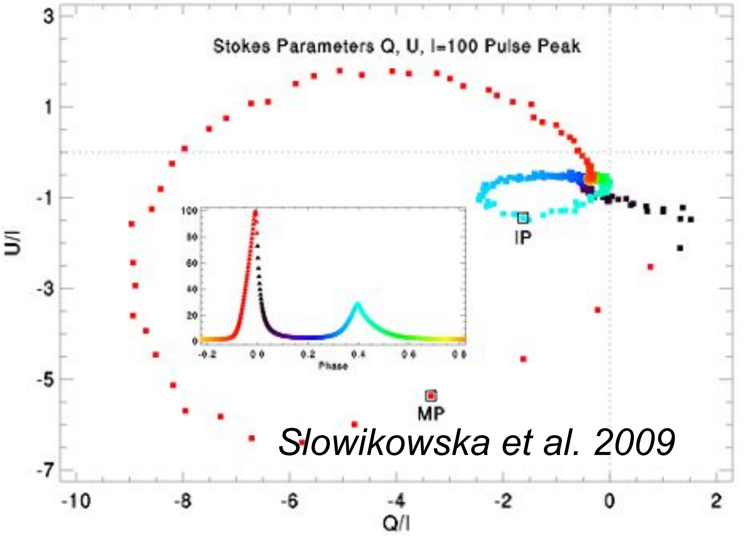
# Pulsar magnetosphere

- Timing at multi-wavelength is crucial to locate different emission regions in the NS magnetosphere from the difference in the pulse profiles and time lags




- LAD light curves for many of the ~150 *Fermi* pulsars



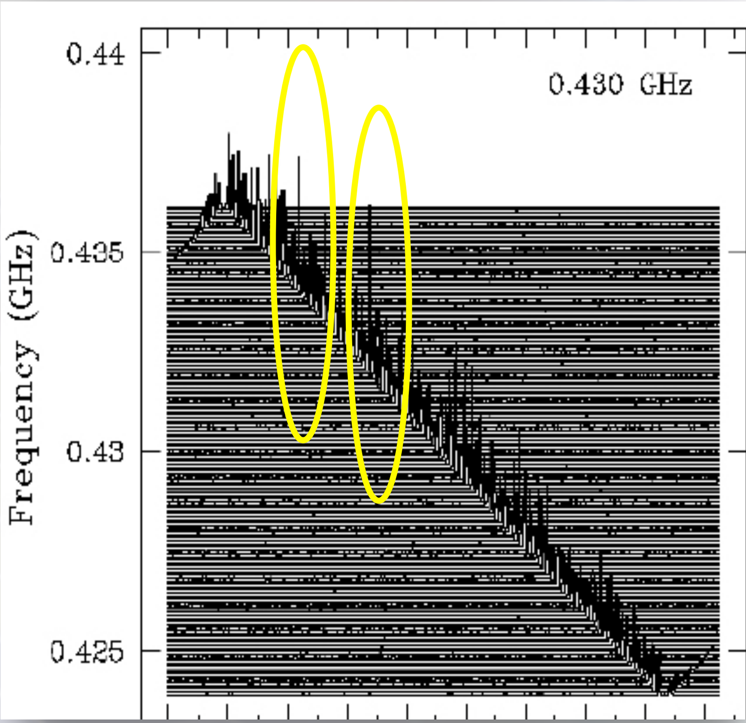

Slowikowska et al. 2009

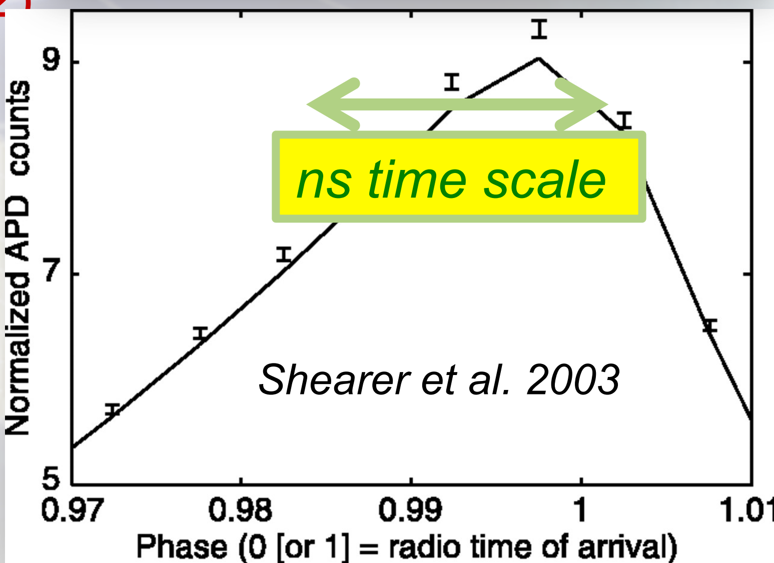
- Optical light curves complement LAD

- Phase-res optical polarimetry, crucial for radio-silent pulsars.

# Giant pulses in radio pulsars

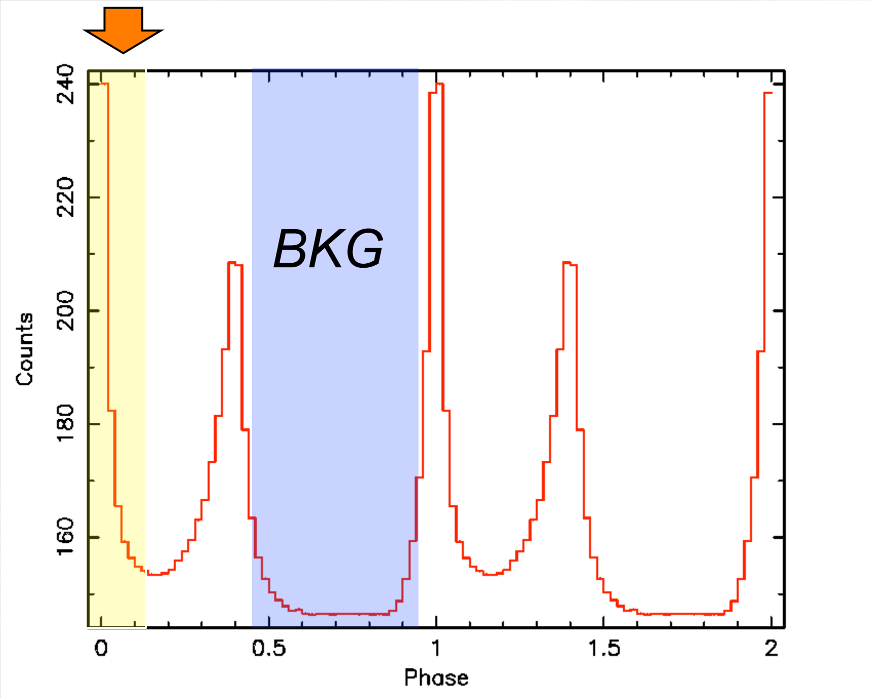
- Giant Pulses are erratic variation of the peak-to-peak pulse intensity (few %)
- So far only observed in radio (~10 pulsars) and in the optical for the Crab pulsar (Shearer et al. 2003; Collins et al. 2012)
- Optical GPs linked in time with Radio GPs (coherent vs. incoherent radiation)
- Not yet observed in X-rays (Bilous et al. 2012) and gamma-rays (Lewandowska et al. 2011).
- Some of the best candidates (B0540-69 & J0537-6910) are very faint or undetected in radio - Possible targets for the LAD
- B0540-69 is also a well known optical pulsar

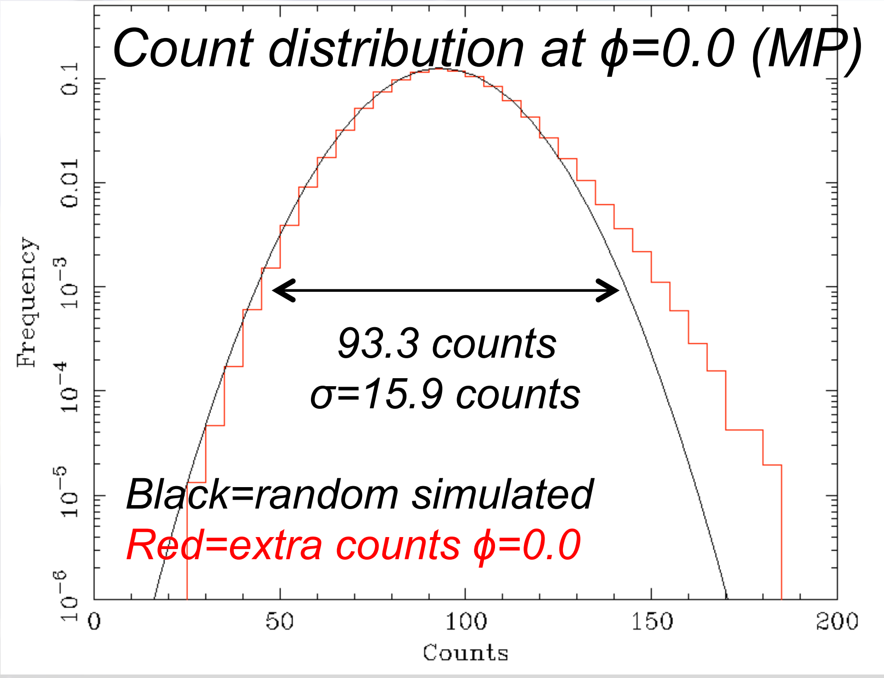


# LAD detection of Giant pulses

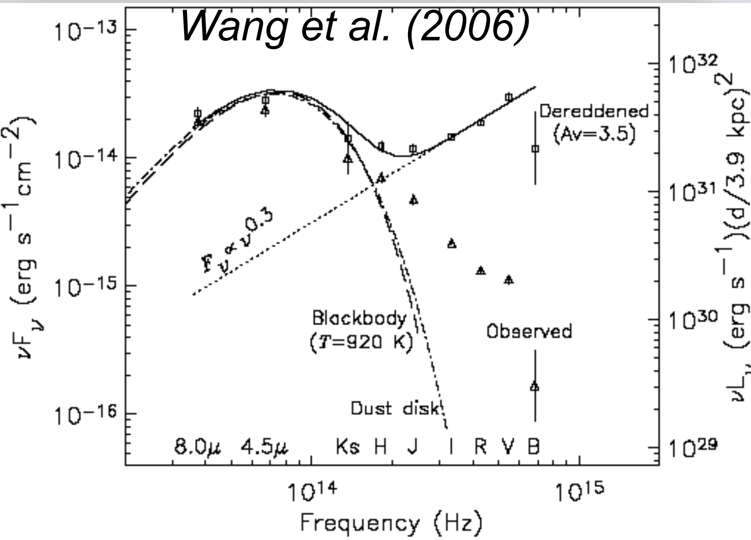
- Detectability of GXPs for Crab and B0540-69 (10 ks)
- 303000 light curves (50 bins) with random counts in one period
- Crab: GXP detected for a >34% flux increase at $\phi$=0.0 (> 32 counts).
- B0540-69 (500x fainter; 10 bins): GXP detected for a 20x peak flux increase



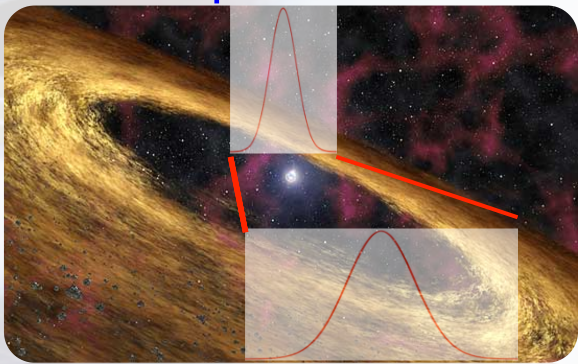



# Debris disks around NSs

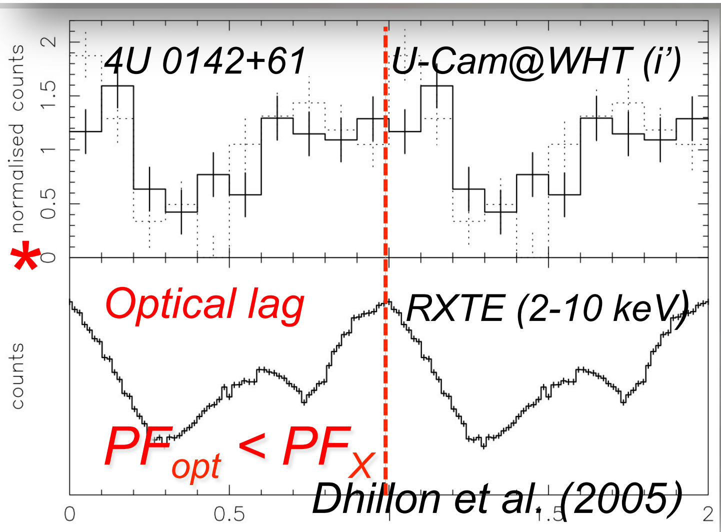
- Evidence for post-SN debris disks around isolated NSs from optical/IR observations. Crucial for SN explosion models

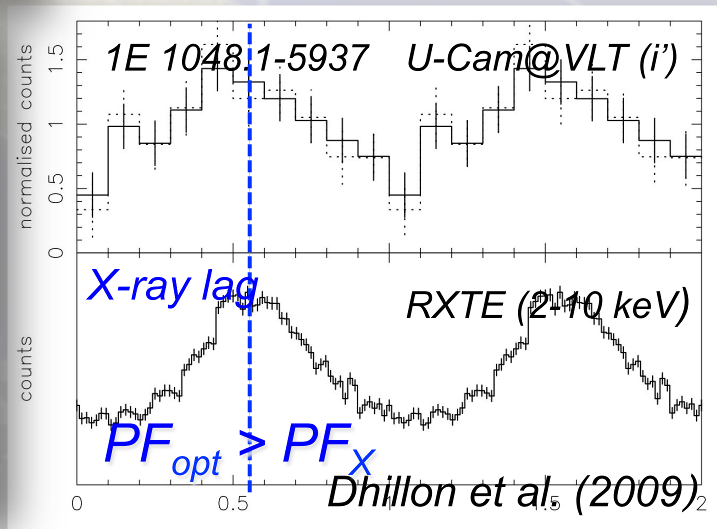



- First evidence found for a magnetar



- Presence of debris disks via X-ray and optical timing (pulse reprocessing)
  - Pulse smearing: $PF_{opt} < PF_X$
  - Phase shift: $\Delta\varphi_{opt,X} > 0$



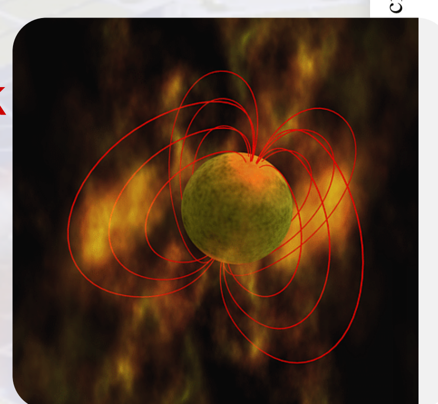



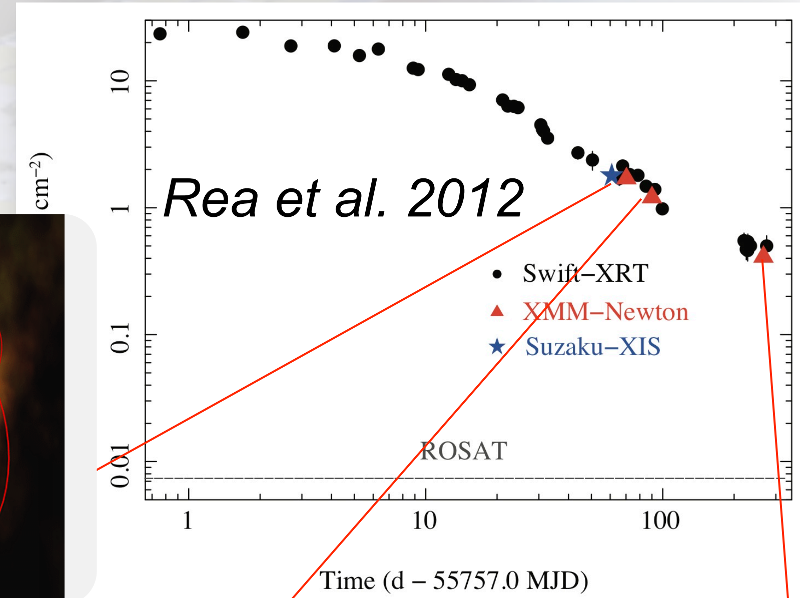

*Unclear evidence from current observations*

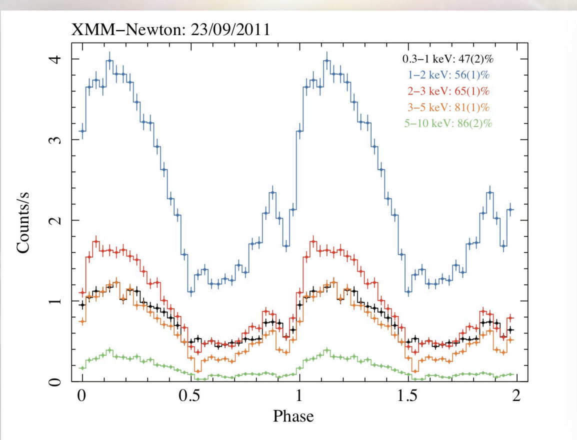
** Observations not simultaneous !*

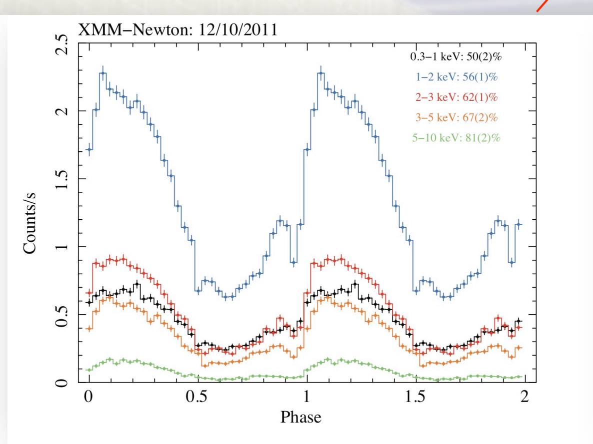
# X-ray Outbursts in Magnetars

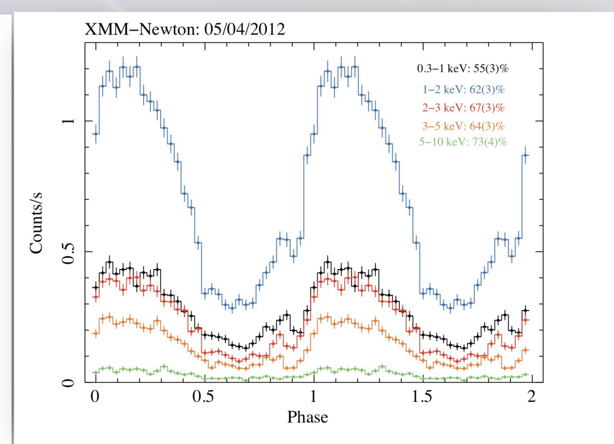
- Many detected and studied by WFM + LAD
- Light curve changes after an event
- Multi-λ timing crucial to track twists in the magnetic field
- Phase-resolved optical polarimetry would be crucial to track changes in the magnetic field properties





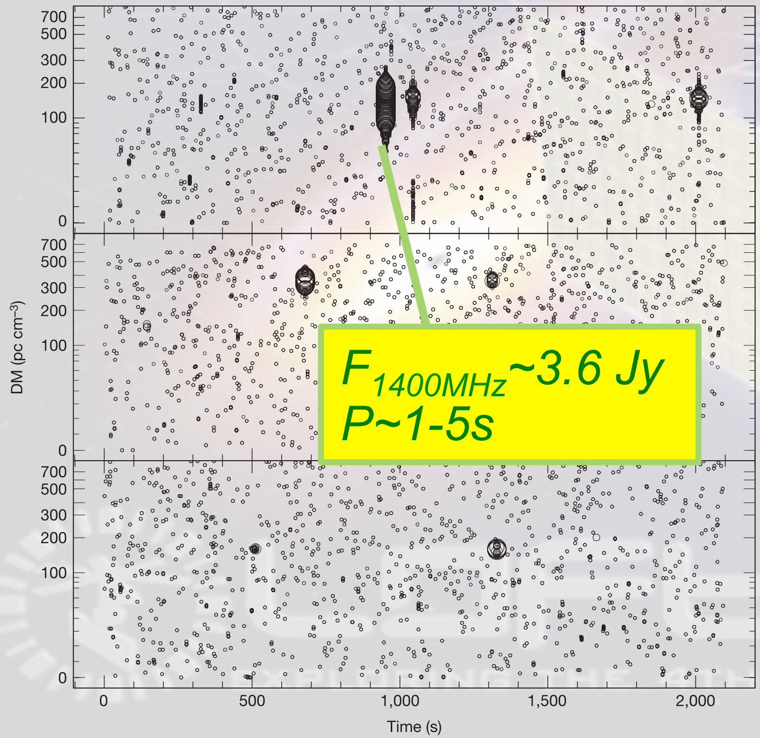



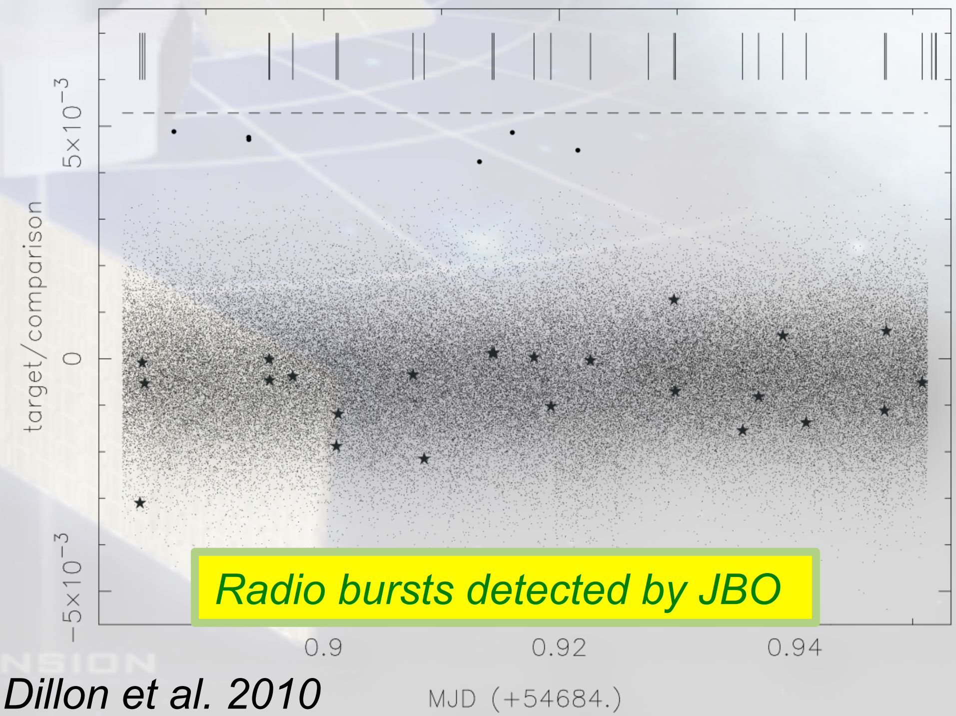
# Radio bursts in Rotating Radio Transients

- X-ray pulsations from one RRAT only (RRATJ1819-1458; McLaughlin et al. 2007). More from the LAD. Optical/IR pulsations/bursts can help understanding RRATs' nature.

- No steady optical/IR ctp. IR candidate for J1819-1458 (Rea et al. 2010)
- If no steady ctp, long integrations would wash out the optical/IR bursts

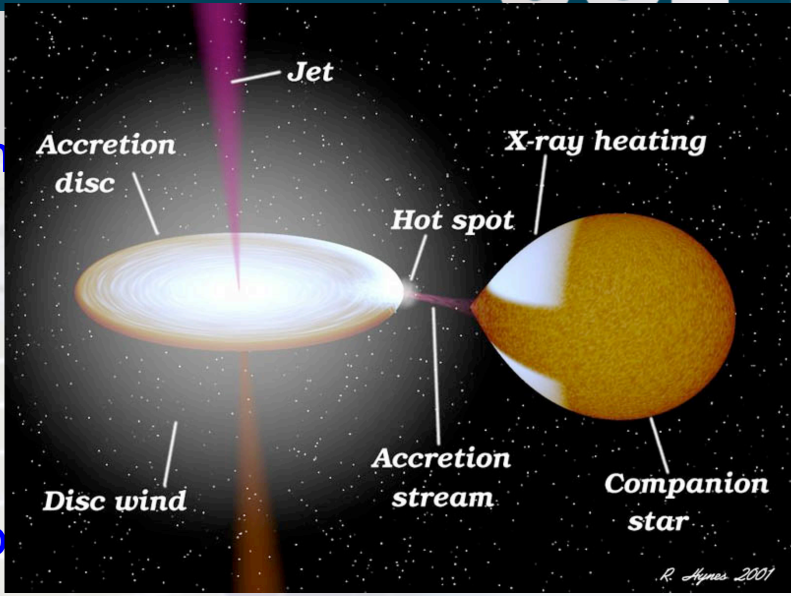
- Search for optical pulsations/bursts from RRATJ1819-1458 negative



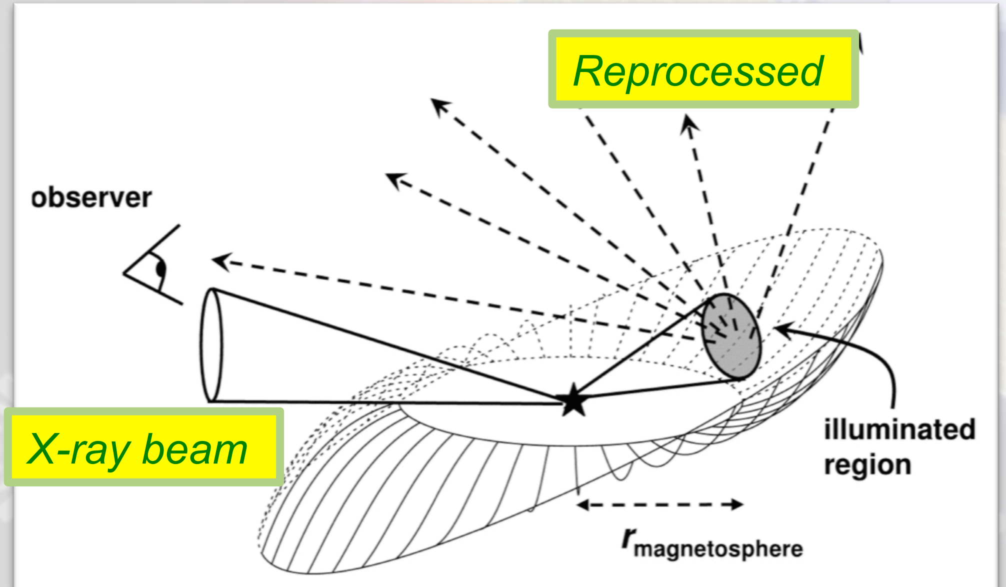



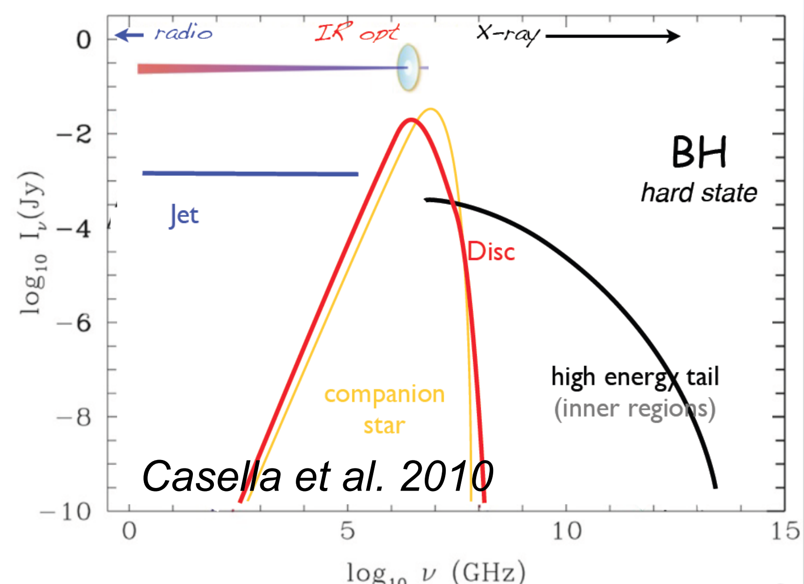

Dillon et al. 2010

# NS and BH Binaries

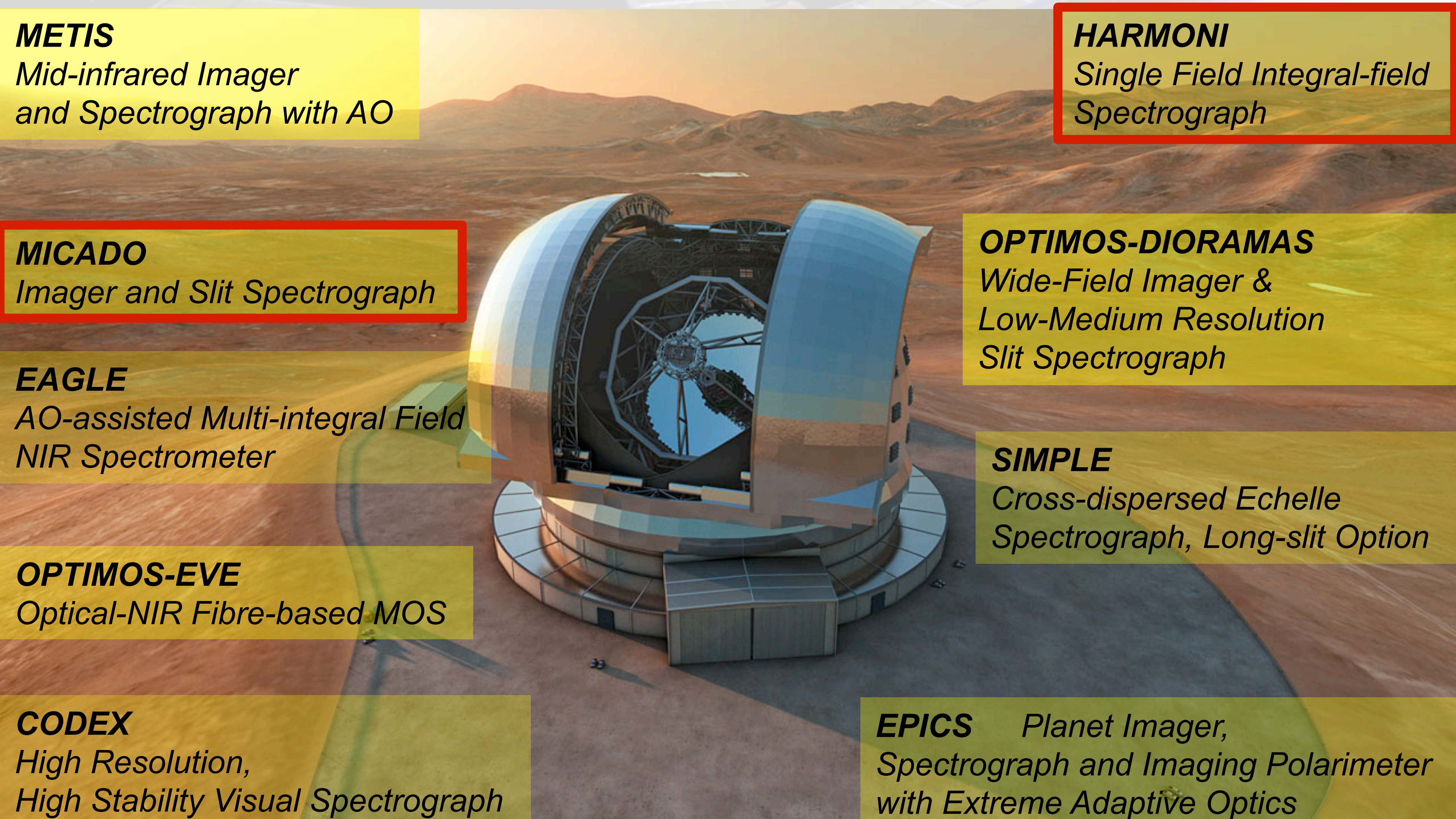



- X-ray ms/s pulsations and QPOs detected in NS/BH binaries + erratic variability. Direct probe the motion of matter close to NS/BH
- Optical/IR variability probe different parts of the accretion disk. Structure (warps), albedo geometry, disk inclination, radius
- Companion star irradiation. Jet formation and instabilities



# PHASE-A Instrument Studies



***METIS***
*Mid-infrared Imager and Spectrograph with AO*

***HARMONI***
*Single Field Integral-field Spectrograph*

***MICADO***
*Imager and Slit Spectrograph*

***OPTIMOS-DIORAMAS***
*Wide-Field Imager & Low-Medium Resolution Slit Spectrograph*

***EAGLE***
*AO-assisted Multi-integral Field NIR Spectrometer*

***SIMPLE***
*Cross-dispersed Echelle Spectrograph, Long-slit Option*

***OPTIMOS-EVE***
*Optical-NIR Fibre-based MOS*

***CODEX***
*High Resolution, High Stability Visual Spectrograph*

***EPICS*** *Planet Imager, Spectrograph and Imaging Polarimeter with Extreme Adaptive Optics*

# High Time Resolution Astrophysics at E-ELT

- **Contributions to the E-ELT Science Case on HTRA**

- With sub-minute and sub-second resolution, can study
  - *Extreme physics (e.g.  pulsars, neutron stars, black holes)*
  - *Identification of rapidly varying sources from other wavelengths*
  - *Stellar phenomena, GRBs, transits and occultations*

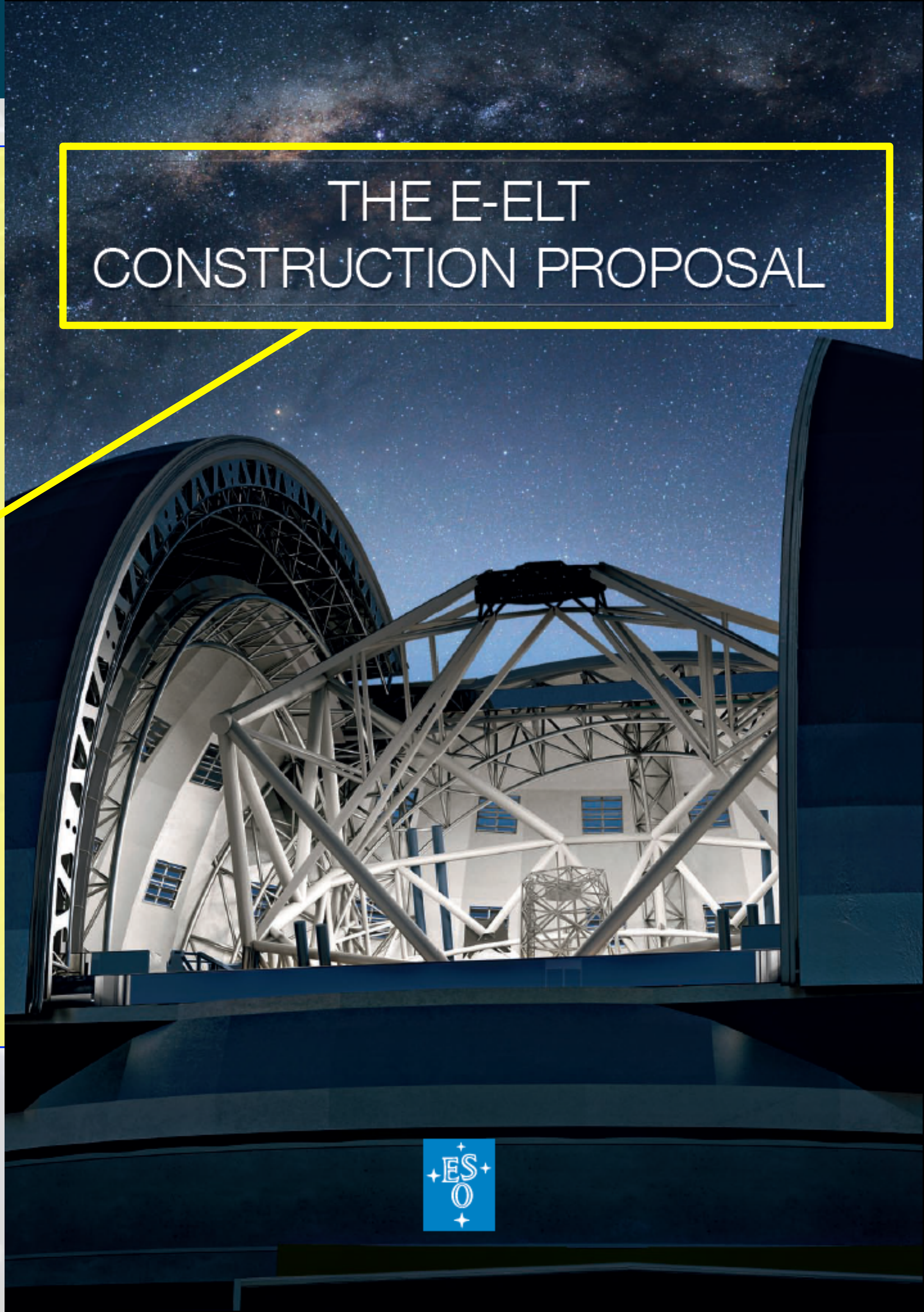
- **SWG supportive of HTRA science case**
  - Made draft resolution (to the project):
  - Continue to explore implementation within “existing” instruments
  - Keep open the possibility of a visitor focus in future (after 1st Gen?) for specialised instruments

"The (E-ELT) Science Working Group also recommended the inclusion of more specific modes, such as spectro-polarimetry and **high time resolution astronomy**.

Allowing for visitor instruments would further enable the E-ELT to react to **important emerging niche science**.

A **visitor port** will therefore be available for at least the first six to eight years of telescope operation."

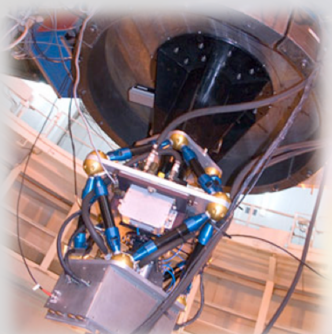
**From 2013 the HTRA WG is part of the Opticon E-ELT Science WG**

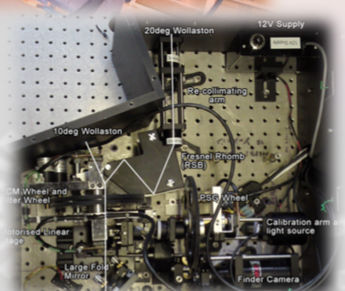


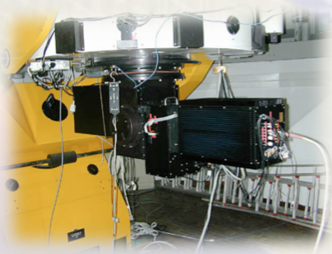
# Current HTRA Instruments

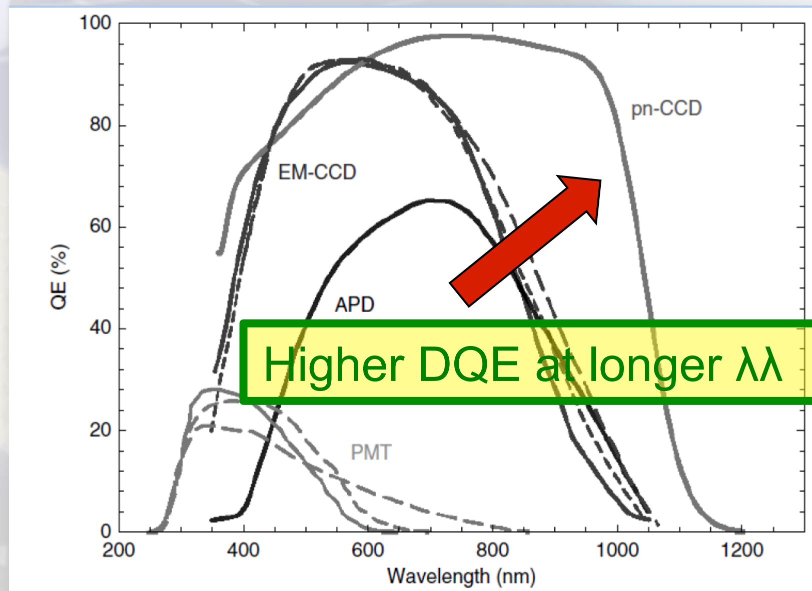
- Visitor instruments only. Successful. Portable. Tested at different telescopes

| Instr. | Det. | Owner | Res. | Type | Ref. |
|---|---|---|---|---|---|
| U-Cam | CCD | Warwick/Sheffield | 5ms | imager | Dhillon et al.2007 |
| U-Spec | emCCD | Warwick/Sheffield | 1ms | spectrograph | Dhillon et al.2007 |
| OPTIMA | SPAD | MPE | 4 μs | photocounter/polarimeter | Kanbach et al. 2008 |
| GASP | SPAD | Galway | 1 ns | imager/polarimeter | Kyne et al. 2010 |



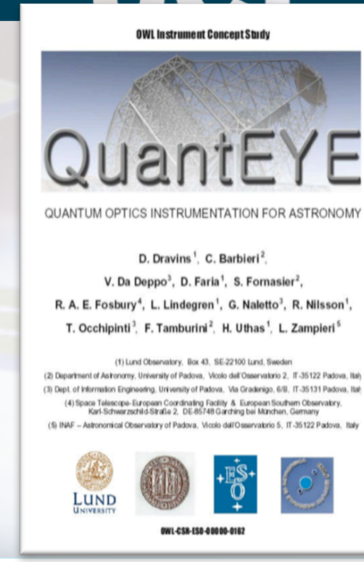




# A Quantum Eye for the E-ELT

- *QuantEye:* pilot study for the *OWL* 100m telescope concept, based on quantum detector technology
- Two prototypes built: *AQuEye*@Asiago 182cm (Barbieri et al. 2009) & *IQuEye@NTT* (Naletto et al. 2009)
- SPAD (Single-Photon Avalanche Diodes) detectors
- Multi-band light curves (0.1 ns time resolution)


OWL Instrument Concept Study

QuantEYE

QUANTUM OPTICS INSTRUMENTATION FOR ASTRONOMY

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OWL-CSR-ESO-00000-0162

**Equeye: the ESO Quantum Eye**

**A proposal for the highest in the world time-resolution single-photon photometer for the VLT as a precursor for a quantum photometer for the E-ELT**

Submitted by: Cesare Barbieri[1] as P.I
and by: Giovanni Bonanno[2], Dainis Dravins[3], Roberto Mignani[4], Giampiero Naletto[1], Erez Ribak[5], Andrea Richichi[6], Andrew Shearer[7], Luca Zampieri[2] as Co.I.'s

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| | | Time-Scale Now | Time Scale ELT era |
|---|---|---|---|
| Stellar flares and pulsations | | Seconds/ minutes | 10-100ms |
| Stellar Surface Oscillations | White Dwarfs<br>Neutron Stars | 1-1000 $\mu s$<br>- | 1-1000 $\mu s$<br>0.1 $\mu s$ |
| Close Binary Systems accretion & turbulence | Tomography<br>Eclipse in/egress<br>Disk flickering<br>Correlations (e.g. X & optical) | 100ms++<br>10ms+<br>10ms<br>50ms | 10ms+<br>$<$ 1ms<br>$<$ 1ms<br>$<$ 1ms |
| Pulsars | Magnetospheric<br>Thermal | 1 $\mu s$-<br>100ms | ns<br>ms |
| AGN | | Minutes | Seconds |

- VLT prototype *(EQuEye)* proposal to be for post-Phase A instrument
- Not just photon counting, also **phase-res spectroscopy** and **phase-res polarimetry**
- New dimension in time-domain astronomy
- EQuEye @ E-ELT would be a powerful companion to the LOFT/LAD

# Conclusions

- The universe at sub-s time scales is still largely unexplored in the optical domain.
- Possibilities of synergies with the LOFT/LAD in the study of compact objects
- Complement synergies with future radio and high-energy observing facilities
- Possibility of exploiting potentials of optical time-resolved polarimetry and spectroscopy
- Time-domain astronomy at sub-s time scales satisfies the fundamental E-ELT rationale of opening up new parameter space. Positive feedbacks from the E-ELT SWG.
- Optical community is developing instrumentations for observations in the sub-s time domain

# Faster Deeper : Expanding Astronomy in Time and Sensitivity with ELTs

May 13-16 2014

NUIG, Galway (Ireland)


## SOC

| | |
|---|---|
| Isobel Hook | *(INAF Rome/University of Oxford)* |
| Andy Shearer | *(National University of Ireland Galway)* |
| Vik Dhillon | *(University of Sheffield)* |
| Aga Słowikowska | *(Kepler Institute of Astronomy University of Zielona Góra)* |
| Roberto Mignani | *(UCL/MSSL, INAF-IASF Milan)* |
| Ric Davies | *(MPE, Garching)* |
| Roger Haynes | *(Leibniz-Institut für Astrophysik, Potsdam)* |
| Suzie Ramsay | *(ESO)* |

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