

The European Extremely Large Telescope and the UK Astronomy Technology Centre

Professor Colin Cunningham Director, UK ELT Programme

The Royal Observatory Edinburgh: 1895



Jantar Mantar: 1724





UK ATC at the Royal Observatory Edinburgh

- Mission "In support of the mission and strategic aims of STFC, to help keep the UK at the forefront of world astronomy by providing a UK focus for the design, production and promotion of state-of-the-art astronomical technology"
- 96 staff scientists, engineers, support
- Focused on strategic role, project delivery of new instruments, and technology development
- Work in supporting universities to deliver science for the UK
- Work closely with the Institute for Astronomy (University of Edinburgh)
- In partnership with Glasgow University in Scottish
 Universities Physics Alliance and Edinburgh and Heriot Watt
 Engineering in the Edinburgh Research Partnership
- Key role in astronomy outreach in Scotland



New Crawford Laboratory









Core technology: Cryogenic Astronomical Instruments for IR & Submm



IRCAM 1 1986





SCUBA 2 2007



What do we do?

- Undertake design studies and construction of new astronomical telescopes and instruments for the world's great observatories:
 - Gemini North on Mauna Kea Hawaii
 - Gemini South on Cerro Pachon Chile
 - ESO VLTs at Cerro Paranal Chile
 - ESO (VISTA Telescope adjacent to Cerro Paranal)
 - ESO E-ELT design studies
 - James Clerk Maxwell Telescope at Mauna Kea Hawaii
 - United Kingdom Infrared Telescope Hawaii
 - Herschel Space Telescope
 - James Webb Space Telescope



Skills

Experience

 ROE been doing facility class instruments since 1980s, world recognition for our engineers and products

Innovation

 demonstrable ability to come up with novel effective solutions in all disciplines to meet scientific goals

Collaboration

- Lead institute with extensive project management & systems engineering experience – or partner
- networks for astronomy and technology

Research

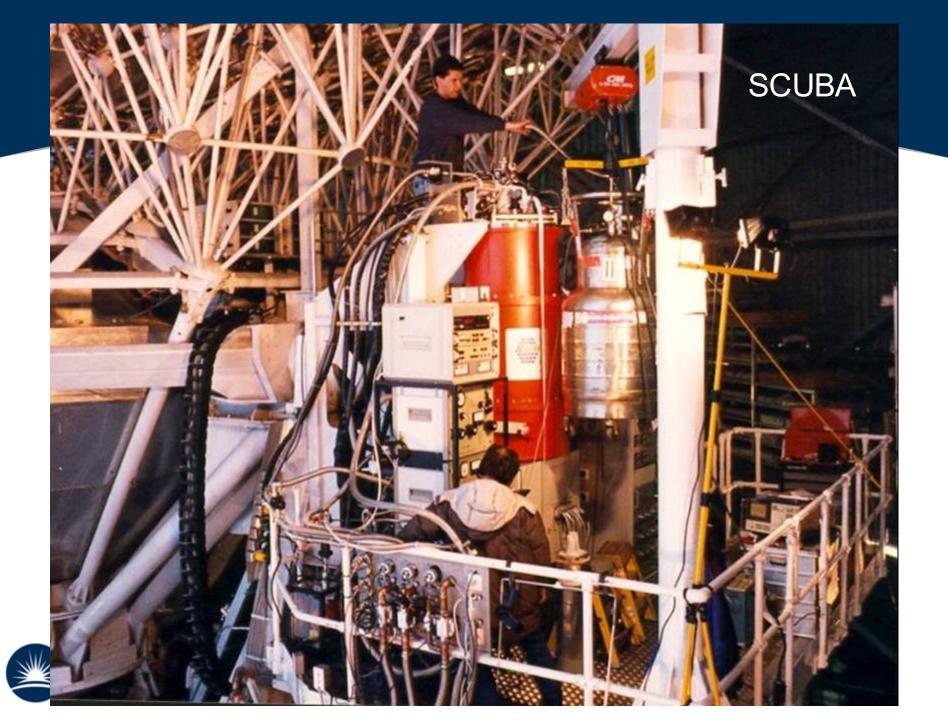
 being co-located with the Institute for Astronomy's top class astronomy research aids engineering understanding and effectiveness



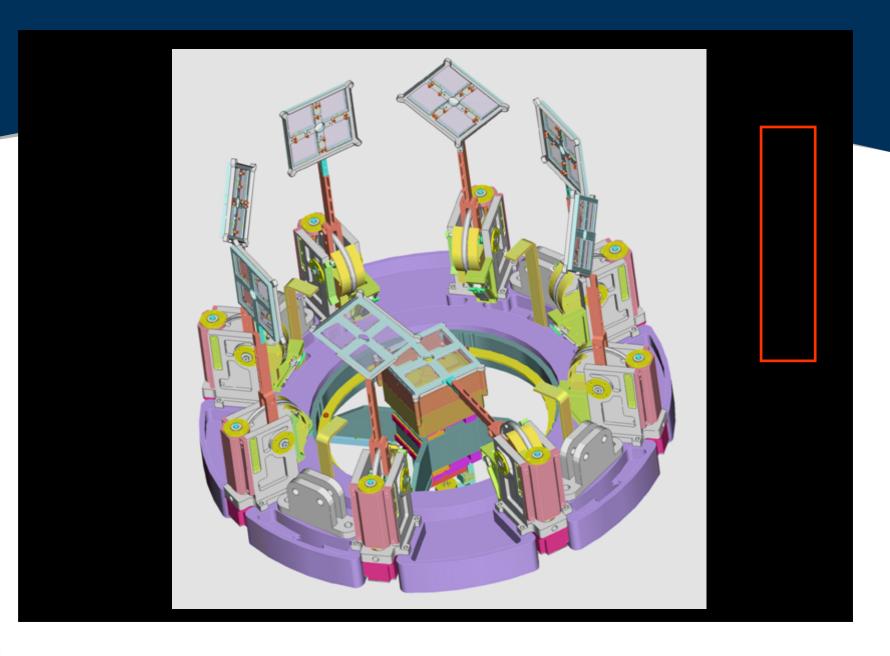
Last 10 years

- SCUBA: delivered to the JCMT in 1996: perhaps the world's most successful ground-based instrument; opened up submillimetre astronomy, key discoveries of SCUBA galaxies and debris disks
- UIST: delivered to UKIRT 2002, 1-5 m imaging, long slit spectroscopy, integral field spectroscopy and polarimetry capabilities Unique cryogenic slicer IFU
- GMOS: delivered to Gemini N & Gemini S in 2001/02; versatile, optical direct imaging, long-slit and multi-object and IFU spectroscopy. Most successful Gemini instruments
- Michelle: mid-IR imaging spectrometer for UKIRT and Gemini, delivered to UKIRT 2001, moved to Gemini N in 2003 – world's best mid-IR instrument.
- WFCAM: wide-field infrared survey camera, delivered
 2004, surveys now underway, world's most powerful infrared camera.

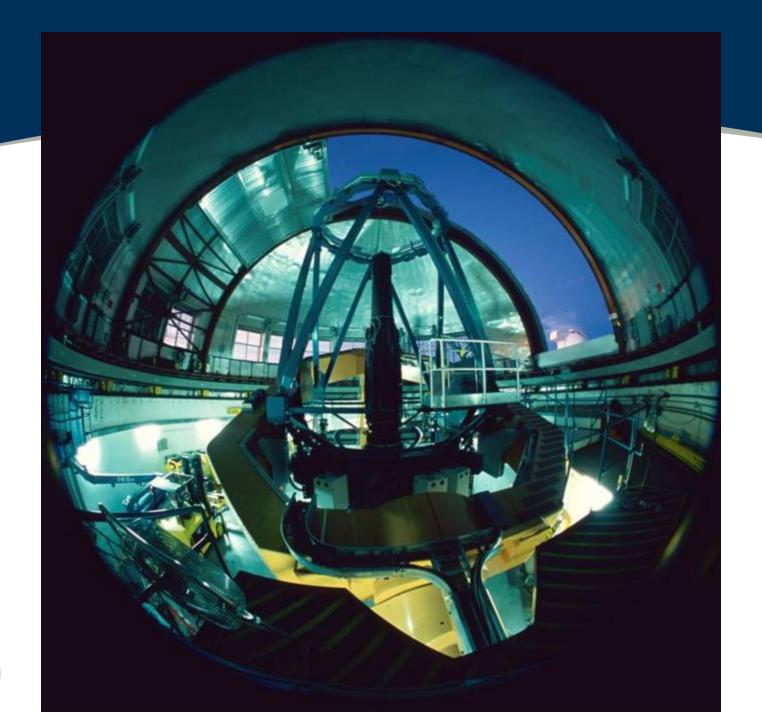








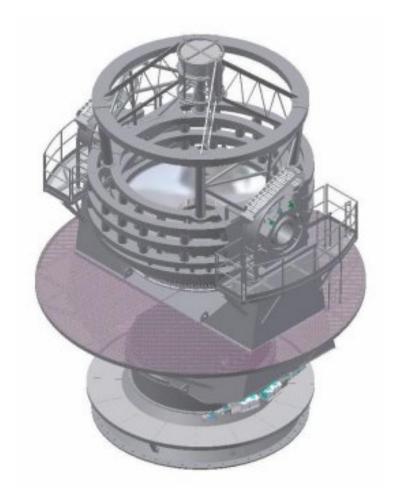






Current Projects: VISTA

- 4m, f/1 primary, optical/IR telescope for Paranal
- Wide-field (1.65 deg) infrared camera (4x4 2k arrays with 67 million 0.34 arcsec pixels) in spring 2008
- UK ATC Prime Contractor, camera produced by RAL/UK ATC







IR Camera





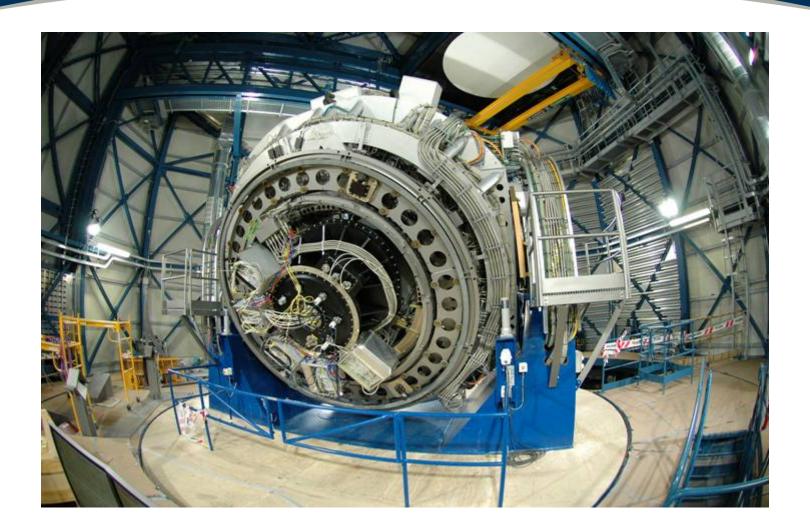
16 x 2kx2k Arrays













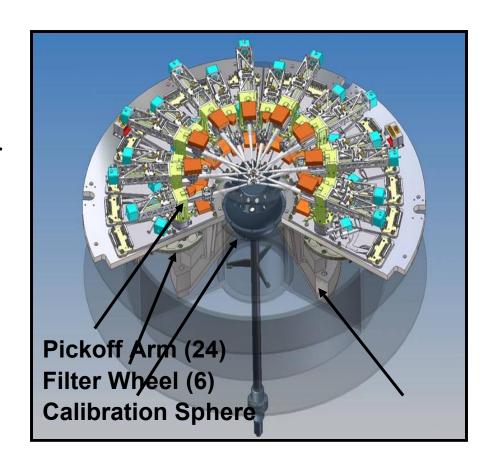




KMOS for ESO VLT



- Near IR Multi-Integral Field Spectrometer for the VLT, has 24 cooled patrol arms with IFUs giving a patrol field of 7.2 arcmin diameter
- IFUs use image slicing, have FoV of 2.8x2.8" with sampling at 0.2 arcsecs
- Feed three cooled spectrometers at spectral resolution of 4,000





KMOS

KMOS is being designed and built by:

- Max-Planck Institut f
 ür extraterrestrische Physik
- The Universitätssternwarte München
- UK ATC (Prime Contractor)
- University of Durham (PI)
- University of Oxford
- University of Bristol

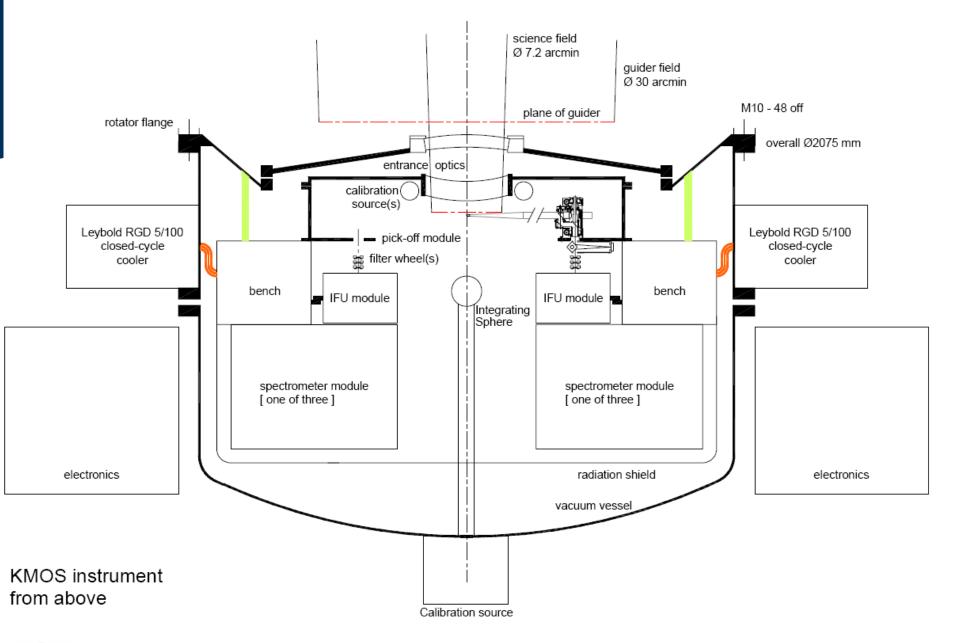




Top Level Scientific Drivers

- Investigate the physical processes which drive galaxy formation and evolution over redshift range 1<z<10.
- Map the variations in star formation histories, spatially resolved star-formation properties, and merger rates
- Obtain dynamical masses of well-defined samples of galaxies across a wide range of environments at a series of progressively earlier epochs

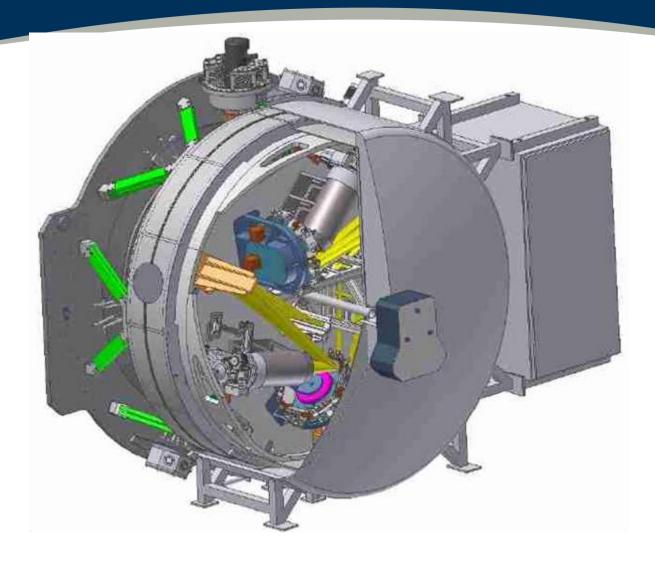






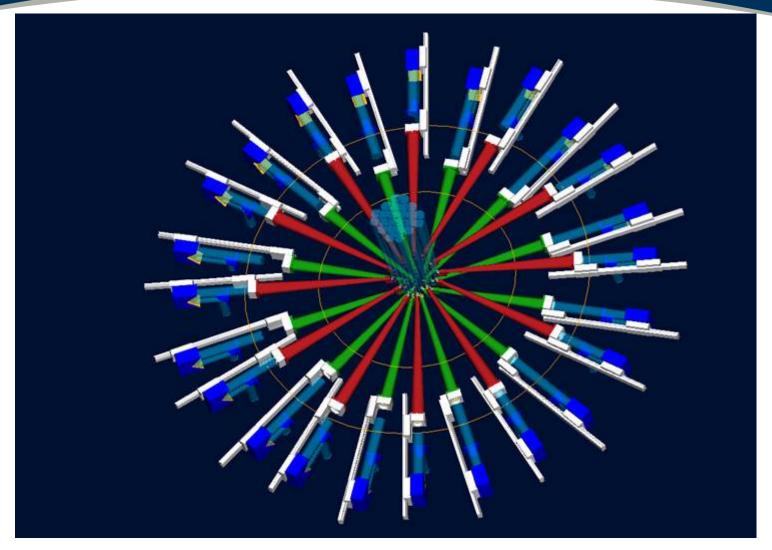


Spectrometers



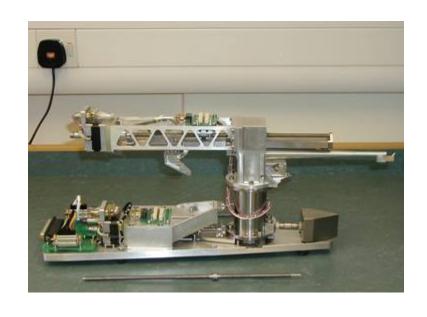


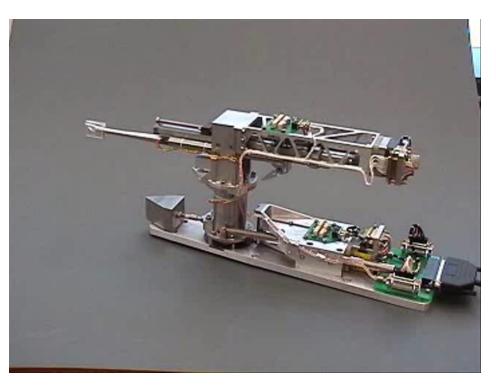
Arms set to survey a contiguous field





KMOS - prototype pick-off arm







SPIRE

- Beam steering mirror for SPIRE for the Herschel Space Observatory (PI: Matt Griffin, Cardiff)
- Delivered in 2004 and now in flight instrument







SPIRE BSM Technologies

- Operates at 4K and sustains 50G loads
- 4 mW power
- Flex pivots
- Superconducting voice coil actuators
- Permanent magnets
- Magneto-resistive sensors

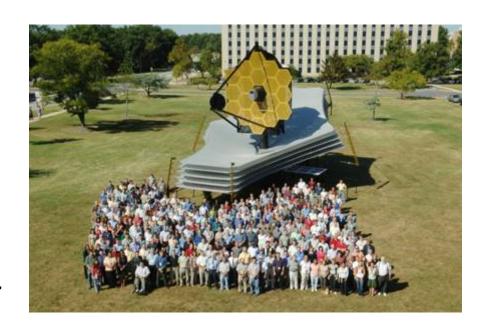






JWST - MIRI

- Mid-infrared (5-28 m) imager/spectrometer/ coronagraph for the JWST due to be launched in 2012+
- UK ATC Prime Contractor for the European Consortium and European PI
- Industrial Project Manager: EADS Astrium UK
- Imaging: 2 x 2 arcmin fov 0.15 arcsec/pixel Spectroscopy: R ~ 1500 0.15 arcsec/pixel and 2.3 x2.3 arcsec fov image slicer



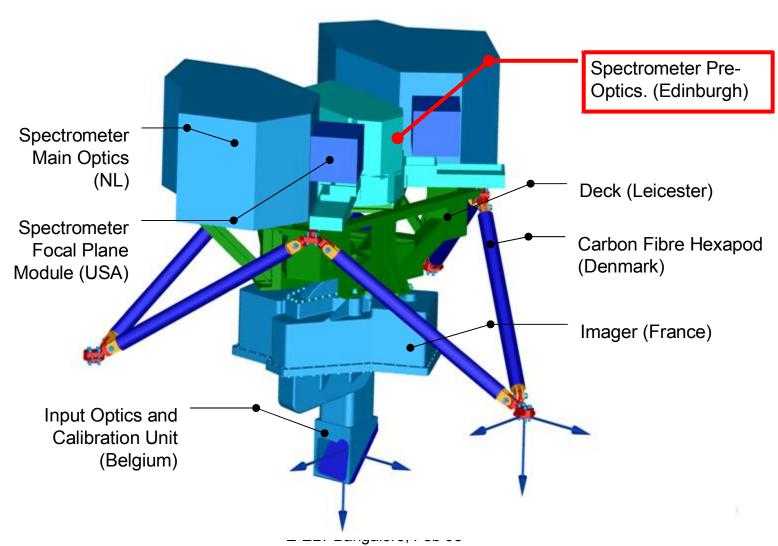


MIRI Science Gains

- Power of MIRI:
 - the thermal background for any groundbased telescope blinds mid infrared detectors
 - prior to JWST, cold telescopes in space have been limited in aperture to 0.85m (Spitzer).
- The MIRI will be more than 10,000 times faster than even a 30-m infrared-optimized telescope on the ground
- More than 10,000 times faster than SIRTF, with the accompanying gain of far higher angular resolution (with a beam a factor of 50 smaller in area than the one for SIRTF at the same wavelengths)
- This unprecedented sensitivity allows the MIRI to make important contributions to all four defining science themes for JWST
 - Detection of the First Light
 - Assembly of Galaxies
 - Birth of Stars and Protoplanetary Systems
 - Evolution of Planetary Systems and Conditions for Life.

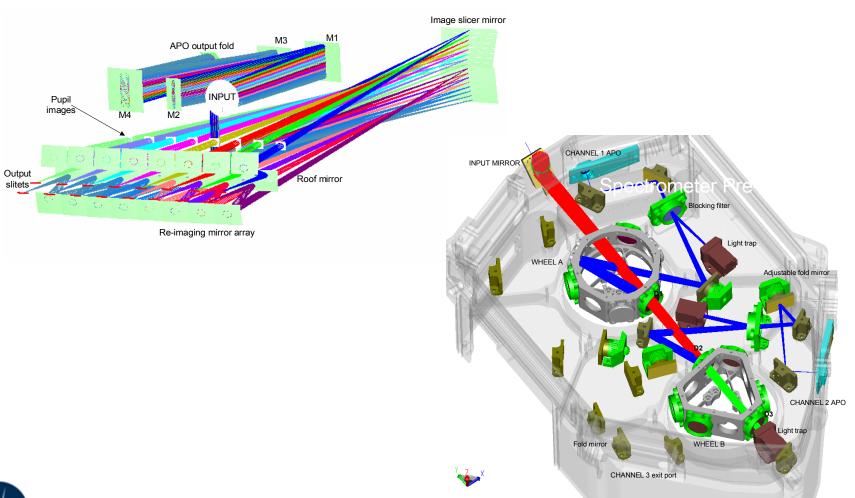


JWST - MIRI



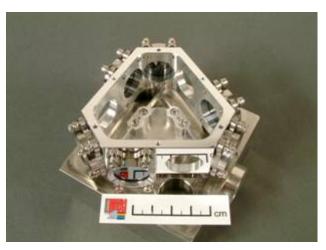


JWST – MIRI Pre-optics

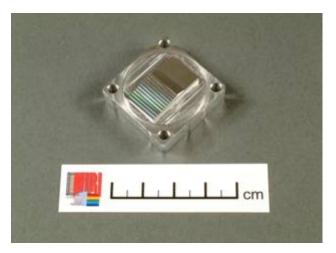




Pre-Optics



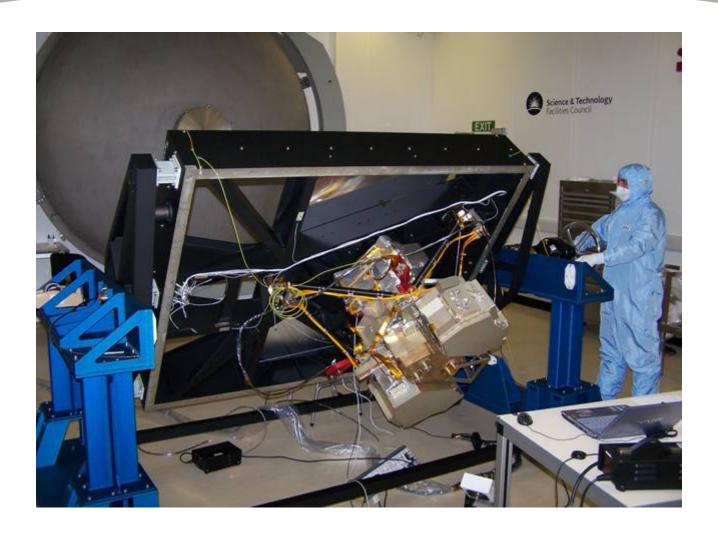








MIRI Testing





SCUBA-2

- Next generation submillimetre wide-field mapping camera
- The world's first submillimetre 'CCD' TES detector with SQUID multiplexer
- High risk, high impact project, £14M.
- UK ATC Prime Contractor with Univ. Edinburgh, NIST, Cardiff, UBC, Waterloo.



SCUBA 2 Extragalactic Surveys

Large-Scale Structure in the Universe

Key Scientific Aims:

 To investigate the nature of the submm galaxy population and their role in the history of structure formation

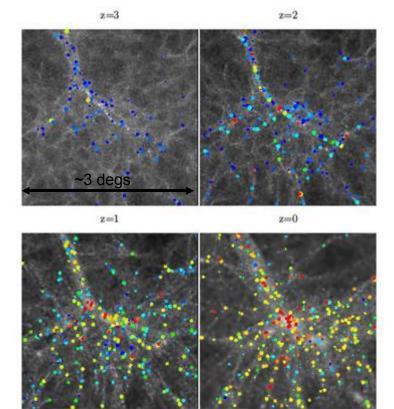
Methodology:

• Ultra-deep surveys of 10's of sq-degrees to the confusion limit at 850µm (unbiased by obscuration)

Key results:

 Measurement of the amplitude and shape of the clustering signal to give insight into the most massive proto-clusters over a whole range of environments

Semi-analytical model of Galaxy Formation





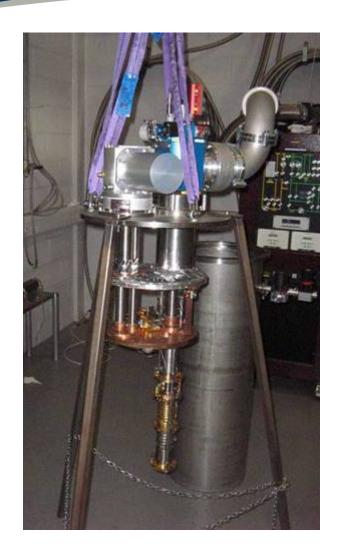


SCUBA2 – reflective optics @ 4K





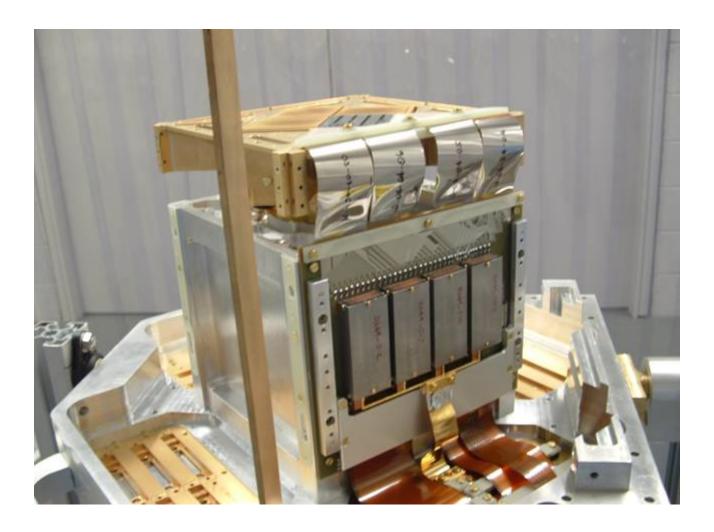
SCUBA2 - dilution refrigerator







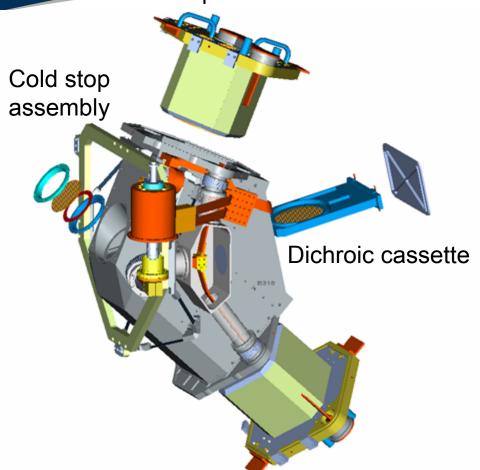
Array assembly





Array Housing @ 1K

Focal plane unit







Focal plane unit

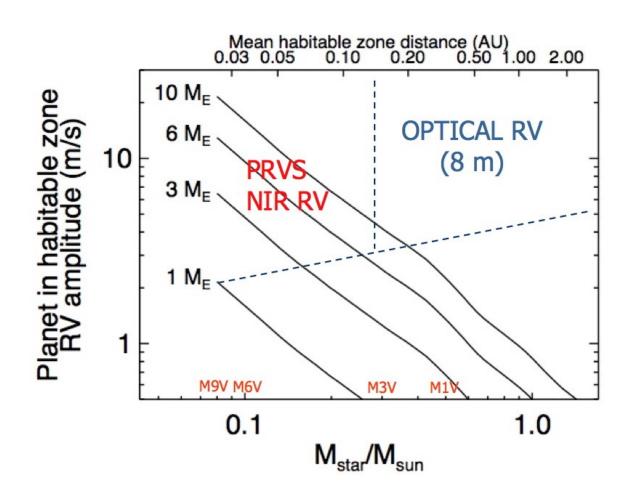
Future Projects

Gemini

- PRVS: Precision high resolution near IR spectrometer with around 1-3m/s stability for radial velocity planet searches
- Negotiating Phase A study as Prime, UK PI, estimate \$7M project
- Penn State and IoA, Honolulu partners

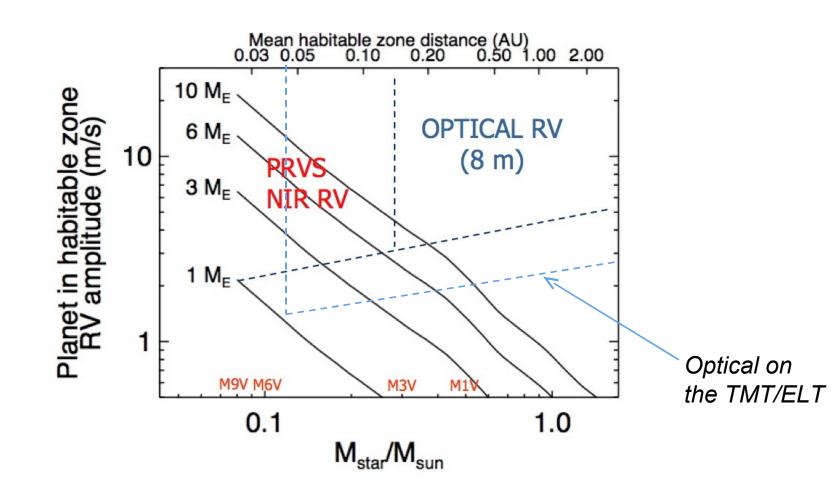


Why near infrared?



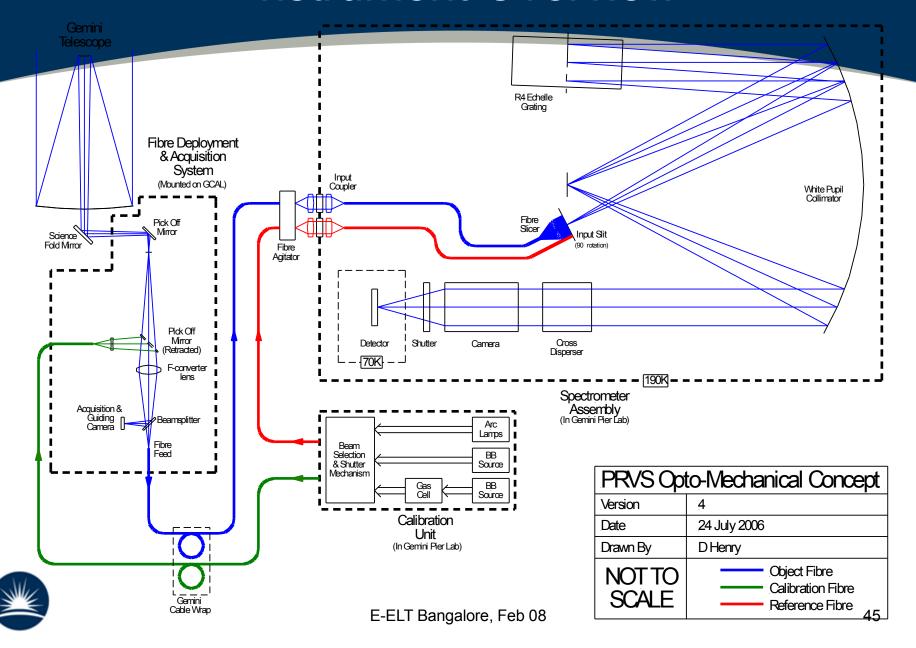


Why near infrared?





Instrument Overview



Achieving 3m/s

- 3m/s RV precision is equivalent to ~0.001 of a pixel
- Large wavelength coverage in single exposure
 - Hundreds of spectral features
- Highly stable instrument
 - Guiding at fibre input
 - Fibre scrambling
 - Fibre agitator reduces modal noise in fibres
 - No other mechanisms (fixed focus, single grating, single filter)
 - Floor mounted instrument gravitationally stable, so no flexure
 - Under vacuum removes effects of pressure and humidity variation
 - Located in Gemini pier lab less than 6K annual temperature variation
 - Temperature stabilisation of spectrograph optical bench ±0.05K over
 24 hours
- Combination of these measures gives <0.1 pixel drift over 1hr integration

Achieving 3m/s

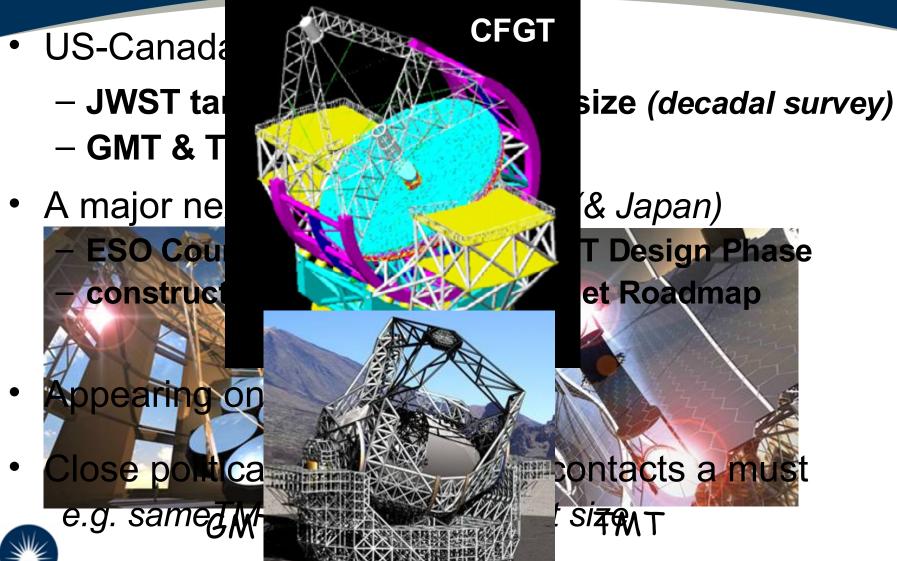
- Calibration needed to increase precision by 2 orders of magnitude to achieve 0.001 pixels
 - Simultaneous calibration via reference fibre tracks drift in wavelength scale over an integration
 - Off line (daytime) calibration via gas cell absolute calibration of wavelength scale
 - Off line measurement of spectral response function (PSF * fibre slit) – mitigates against small changes causing spurious centroid shifts



The European Extremely Large Telescope Project



ELTs International Context



Why an ELT Facility?

- To reach new classes of astronomical objects
 - get even closer to 1st lights (up to Pop III stars?)
 - explore full Galaxy Mass Assembly History
 - dig archeological data on stellar populations (from resolved stellar populations; up to Virgo?)
 - image exo-solar planets (down to Earth-like?)
- To complement other major facilities
 - from radio (LOFAR, ALMA) to γ -rays
 - survey telescopes follow-up (e.g. high-z SN)
- To address the new & unknown

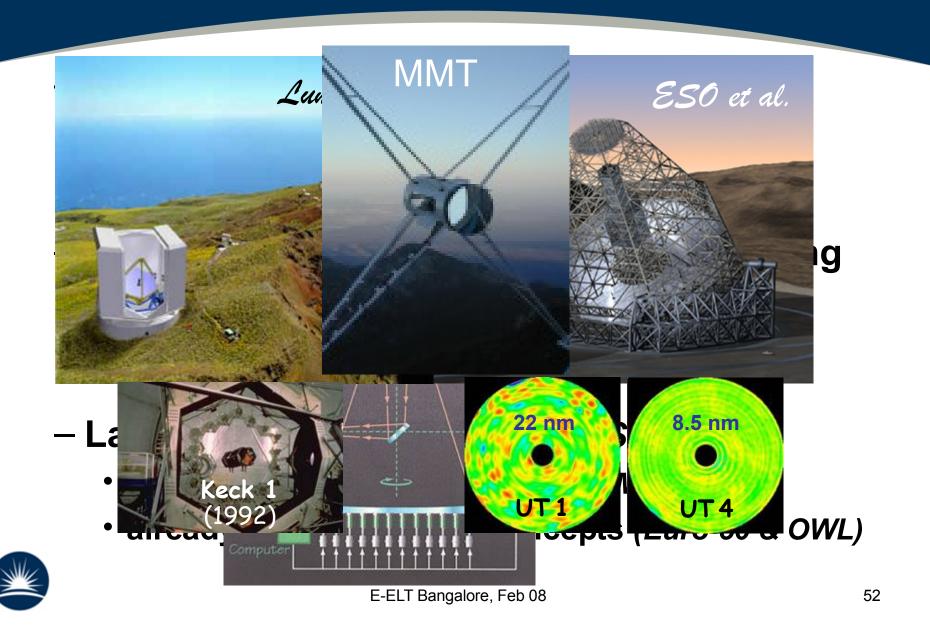
What ELT Facility?

High-level Specs defined in '06 by ESO & its Community

- Multi-purpose facility with "full" sky coverage
 - AO correction over full field (multi-lasers)
 - Instrumentation "friendly" with fast switching
- Optical to mid-IR Facility
 - Full AO correction over 0.85 24 μm
 - (at least) improved seeing over 0.40 0.80 µm
- 42-m baseline size; 6' 10' field



How? – The 3 pillars of wisdom





With the "E"-Community





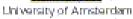
















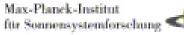


INAF, Padua



















































Service Producted materials of technology Cartest







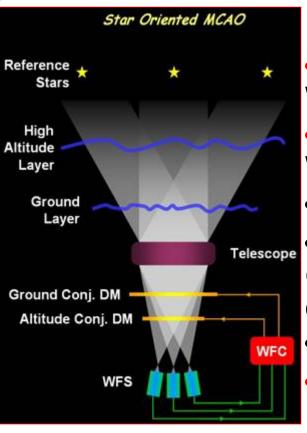




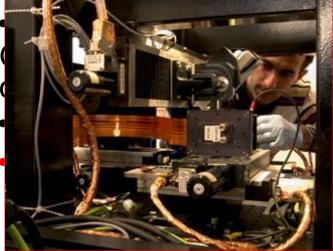


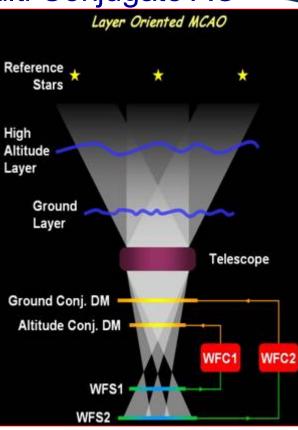
MAD: The GLAO & MCAO demonstrator

Demonstrate Ground Layer and Multi Conjugate Ac



- Star Oriented 3 SH WFSs
- Layer Oriented 8 pyr. WFS
- Study calibration issues



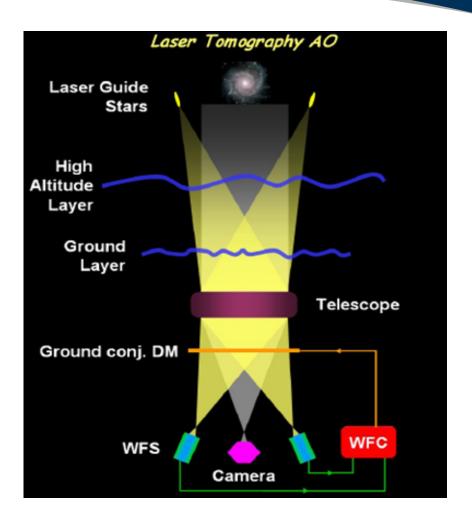






Laser Guide Star Systems







E-ELT AO Development Needs



LTAO (20")

Resolved Stellar Population



MCAO (2')

RSP; Mass Assembly 1st Lights

+ 2 cooled DM _*5k act. eac*h MOAO (8')
1st Lights

+ MEMs
4k act.

"open-loop" Correction

Large DM $(5k^+ act.)$

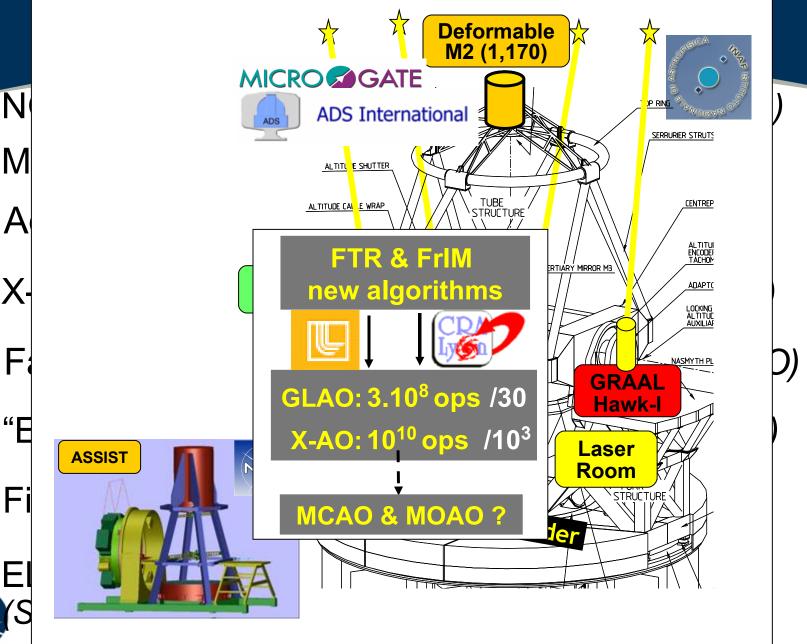
4⁺ LGS (sky coverage)

X-AO (1") Exo-solar Planets

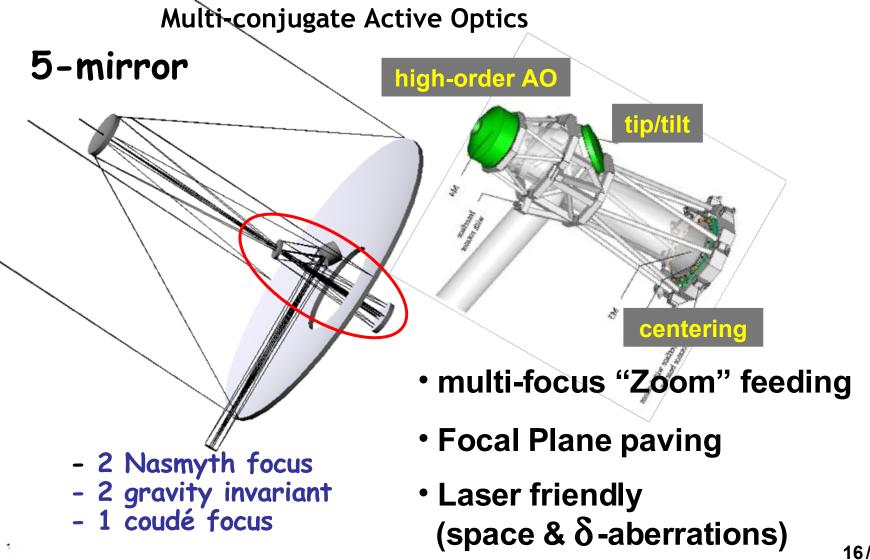
+ MEM 32k+ act.

Differential "Imaging"

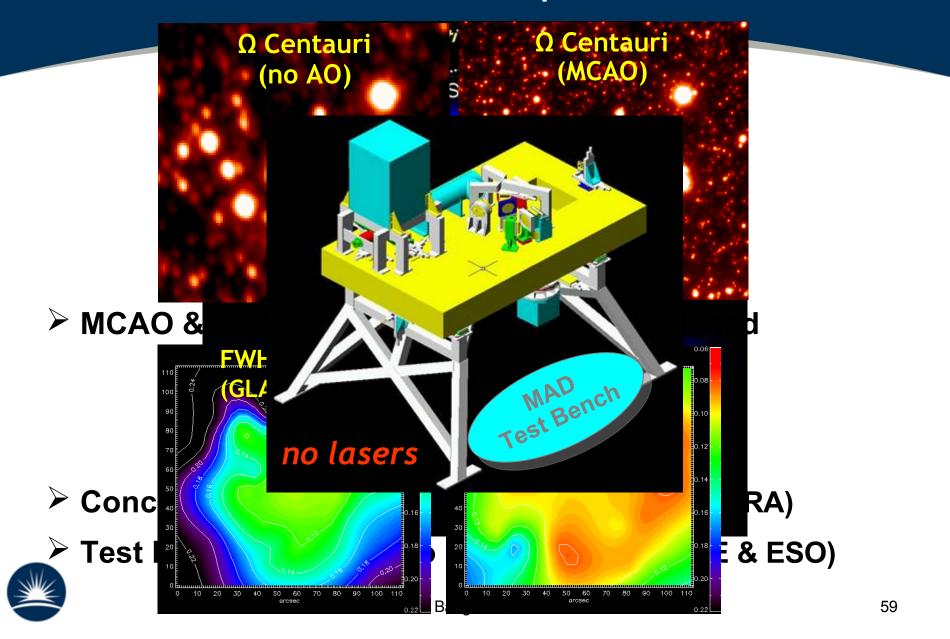
None in hand in 2000!



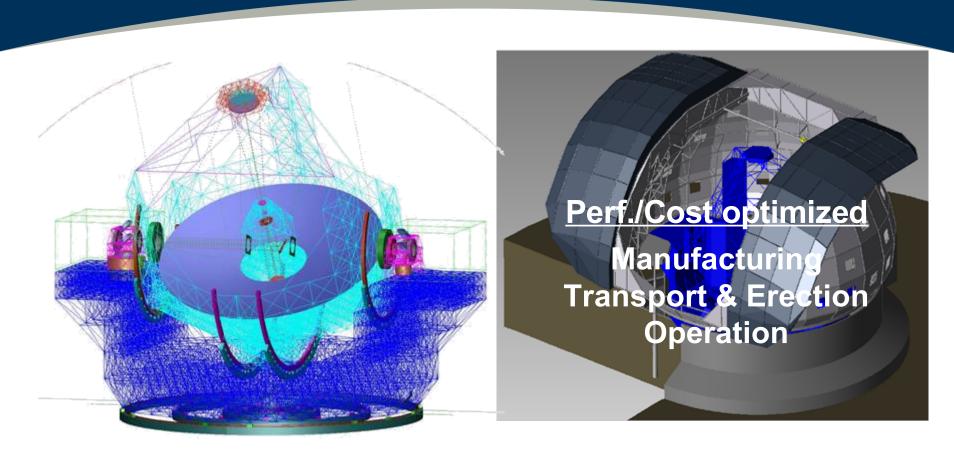
Baseline Optical Design



E-ELT AO: Concept readiness



Baseline Mechanical Design



- 85 x 10³ elements; 27 x 10³ nodes
- 2,1 Hz eigen-frequency
 - 1".4 T/T with 10 m/s wind (predictive corrector)

 E-ELT Bangalore, Feb 08

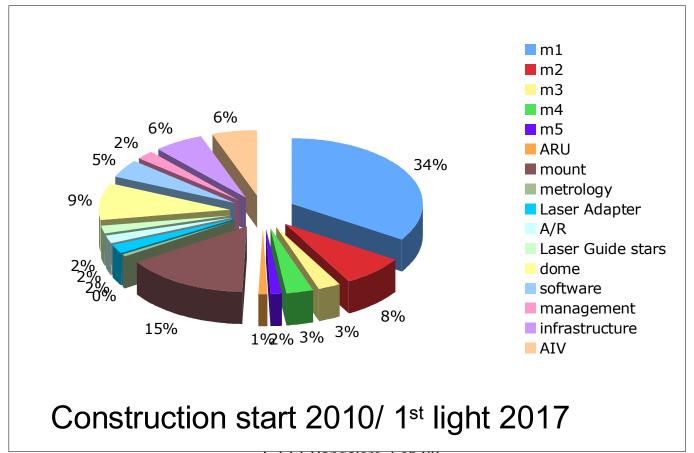
E-ELT non-AO development Status

- Science base (DRM) in development (I. Hook)
- Most Sub-Systems in design/prototype phase:
 - M1 cell + M1 segment prototypes
 - M1 segments sensors & actuators
 - Main Structure & Dome
 - M3-M4-M5 Internal module
 - M2 cell & M2 manufacturing
 - Focal Adapters (including phase sensing)
- Start of 1st gen. Instruments feasibility studies (T₀, EPICS, EAGLE, Codex, NIRI, MIDIR, Innovative)

targeted towards high priority science

E-ELT projected cost

- 807 M€ consolidated cost (incl. 21% contingency)
 - 1st gen. Instruments not included

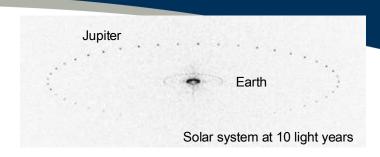


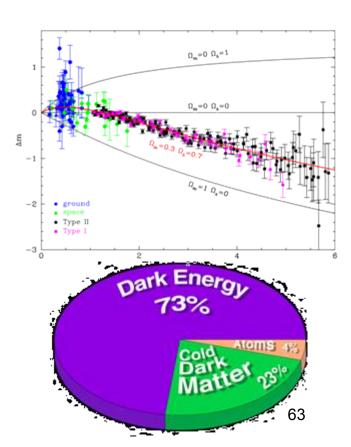


Three Demo Cases defined & evaluated

- Planets in other stellar systems
 - Imaging & Spectroscopy
 - giants & rocky planets (biospheres?)
- Stellar populations
 - In galaxies inaccessible today (ellipticals in Virgo cluster?)
 - Across their whole history
- Cosmology
 - The first stars/galaxies
 - Testing fundamental Physics

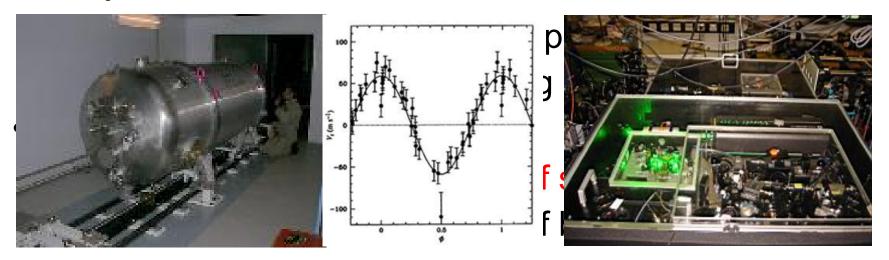






Opening Discovery Space: ultra-precise radial velocities

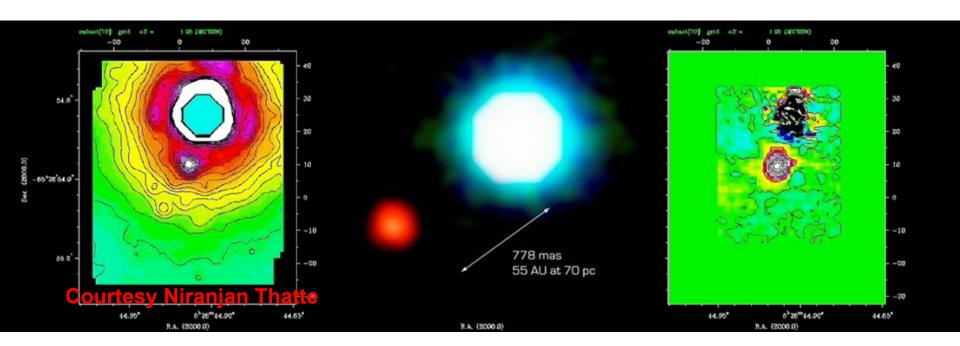
Why?



- How?
 - CODEX (0.4-0.8µm) in coudé Lab (Geneva)
 - absolute calibration thru e.g. a Laser comb (Max Planck Quantum Physics)



Opening Discovery Space: Ultra-high contrast D-L Imaging



- How?
 - Extreme-AO System
 - plus advanced differential techniques

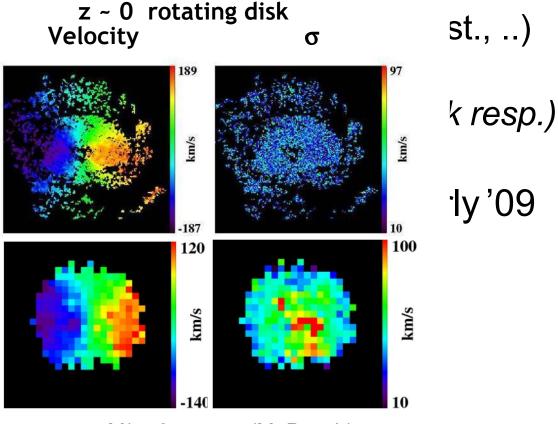
Design Reference Mission

a "full" set of simulated realistic observations

to ass

Comm

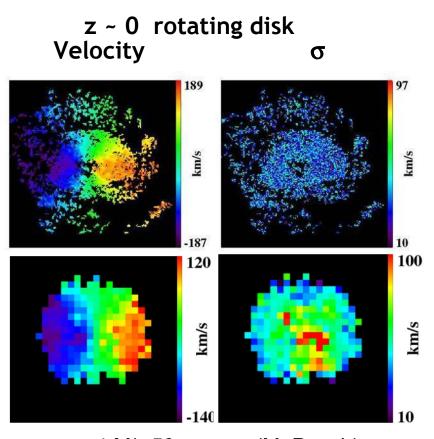
64 Sci

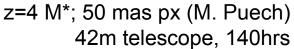




z=4 M*; 50 mas px (M. Puech) 42m telescope, 140hrs

Full Design Reference Mission







DRM: a rough E-ELT assessment

- 10-year program in "Paranal" (weather, AO conditions,..)
- realistic performance (efficiency, AO, Instruments, ...)
- 13,860 hr. total open time (moon phase; AO conditions)
- would complete ~ 20 large programs with:
 - 100s exo-solar planets detected; follow-up study of 10s
 - 10s circum-stellar disks @ 10-50 mas resolution
 - full IMF of 10s of stellar clusters
 - Age/Metal from individual stars in ~ 15 nearby galaxies
 - census of 100s SMBHs in nuclei of galaxies
 - 10³ 2<z<5 L* galaxies characterized
 - 10²-10⁴ very high-z objects
 - Universe expansion, hidden dimension & IGM metallicity

Launch of the E-ELT Program

- ➤ High-level specifications defined by joint ESO-Community Working Groups (May '06)
- Basic Reference Design by Project Office with WGs / Committees advice; endorsed by Community (Marseille, Nov. '06)
- ➤ 3-year, 57.2 M€ Detailed Design Phase launched by Council (Dec. '06)

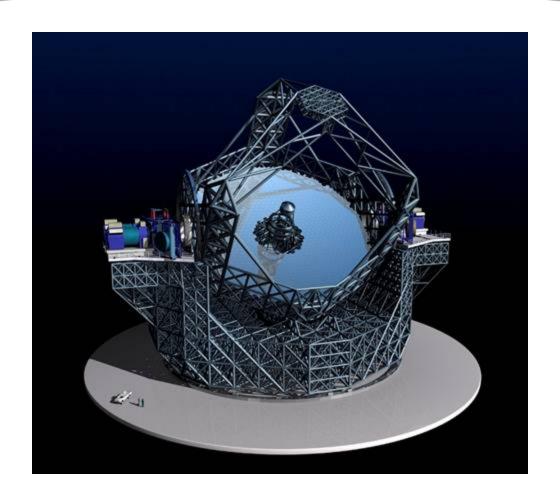


UK ATC Role in E-ELT

- Manage UK R&D Programme
 - Deformable Mirrors
 - Adaptive Optics Simulation
 - Near IR Detectors
- Instruments
 - EAGLE
 - MIDIR
 - HARMONI
- Multi Object Adaptive Optics Test-Bed
- Industry Interface in UK
 - Enclosure, software, Segment Measurements



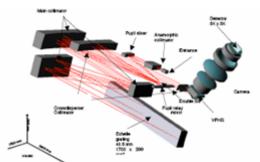
ELT Instrument Studies





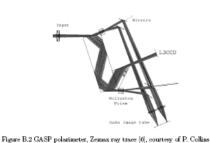
FP6 ELT Design Study: Small Studies Completed & Reviewed

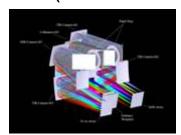




CODEX (HiSPEC Visual)

HISPEC IR



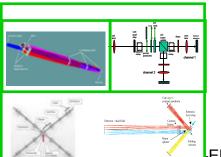


MIDIR



HiTri

Planet Finder - EPICS



Wavefront Seasons

Sheeding Mirrors

Prince Tubercopy

Front Tubercopy

Front Tubercopy

Front Tubercopy

Front Tubercopy

Front Tubercopy

Front Tubercopy

WFSPEC

& Innovative Instrument Designs



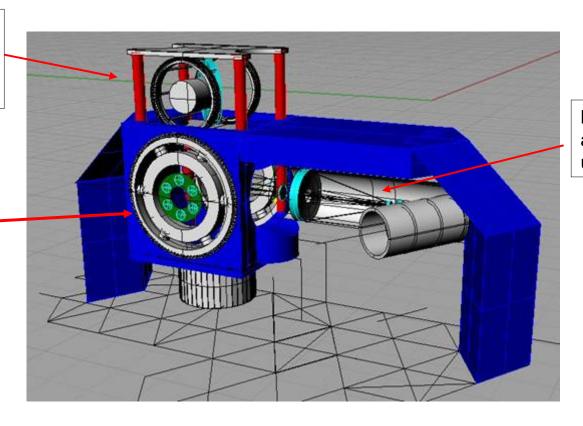
ELT Bangalor

OBSERVATORY – INSTRUMENT INTERFACES

GLAO and MCAO adapters at Nasmyth focus A

Feeding unit for coude, MCAO or gravity invariant focii, retractable

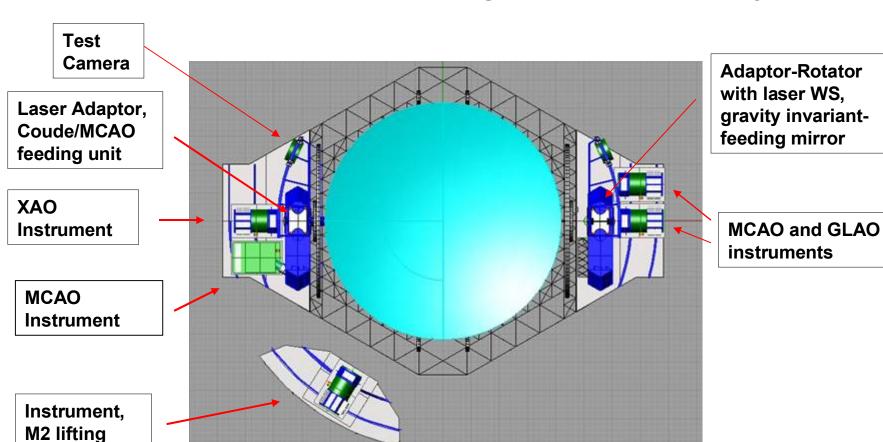
Adaptor:
active optics
natural star
sensors, laser
WFS,
up to 7' science
field with
GLAO, DL at
center



MCAO module, 2 adaptive mirrors, up to 2' DL field

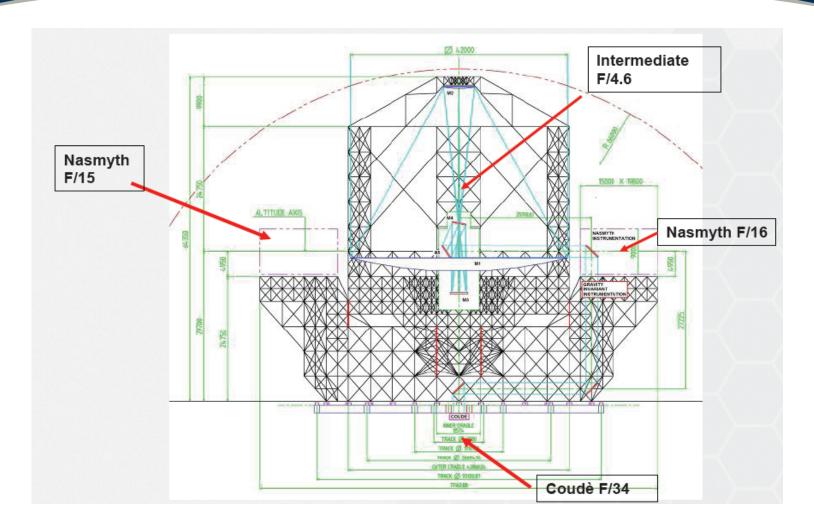
OBSERVATORY – INSTRUMENT INTERFACES

Multi-instrument test configuration at the Nasmyth focii



platform

Issue: Gravity variant platforms





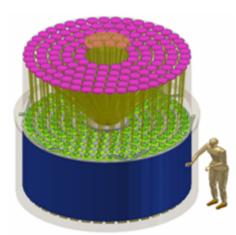
OPTICON Smart Focal Planes

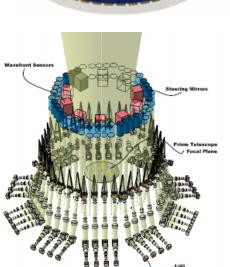
The Smart Focal Planes Team	
Laboratoire d'Astrophysique Marseille	France
Centre de Recherche Astronomique de Lyon	France
Instituto de Astrofisica de Canarias	Spain
UK Astronomy Technology Centre	UK
Centre for Advanced Instrumentation, University of Durham	UK
Institute of Astronomy, University of Cambridge	UK
Anglo Australian Observatory	UK/Australia
ASTRON	Netherlands
TNO-TPD	Netherlands
CSEM SA	Switzerland
Observatories of Padua & Milan	Italy
Reflex SRO	Czech Republic
LFM, University of Bremen	Germany

- 'Smart Focal Planes are devices that enable the efficient sampling of a telescope focal plane to feed spectroscopic and imaging instruments'
- Motivation: Put Europe in a leading position for developing instruments for the next generation of giant telescopes by developing technology to enable Smart Focal Planes



Multi-object Multi-IFU Spectrometers: WFSPEC & MOMSI in FP6 ELT design study

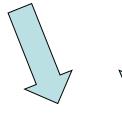






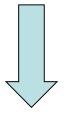




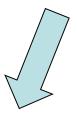




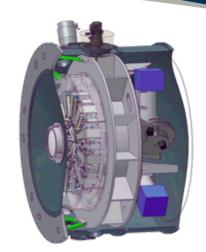


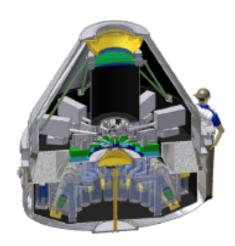








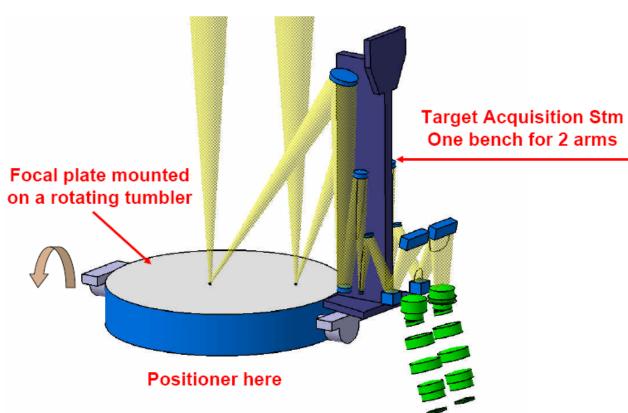






EAGLE

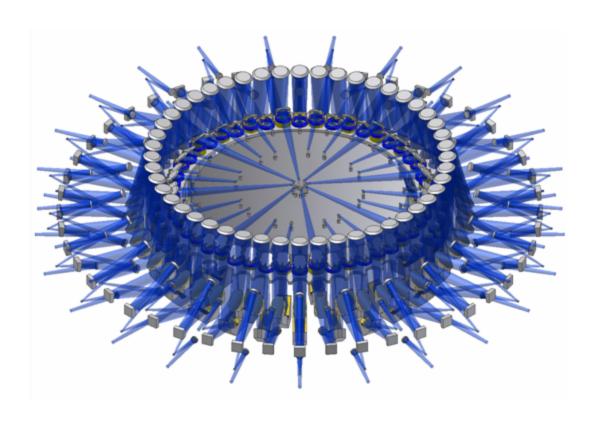




EAGLE Instrument being studied for E-ELT by a UK & French team



EAGLE Concept





Pick-off Mirror Technology







Star-picker



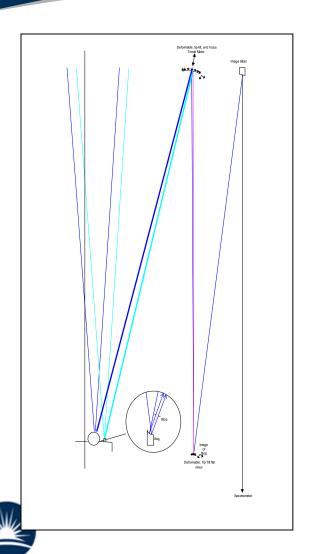


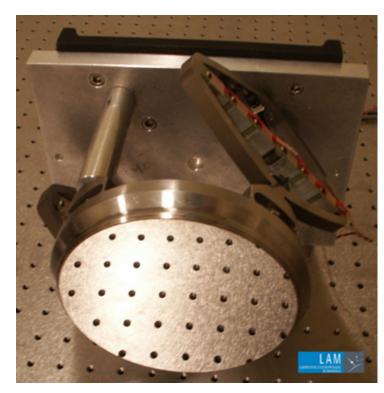


- Positions Pick-Off Mirrors to 5 micron repeatability
- 100 repositions per hour will be improved
- Joint Opticon Project: UK ATC, Astron & CSEM



Cryogenic Active Mirror





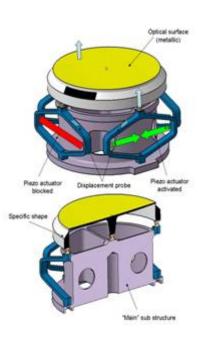
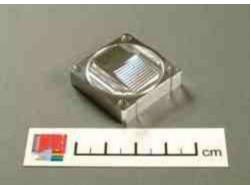


Image Slicers

- Invented by Ira
 Bowen in 1938, but
 only now coming
 into use as optical
 fabrication
 techniques make it
 possible
- Now possible to replicate using electroforming
- Sub 10nm rms surfaces needed – still only possible with glass slicers



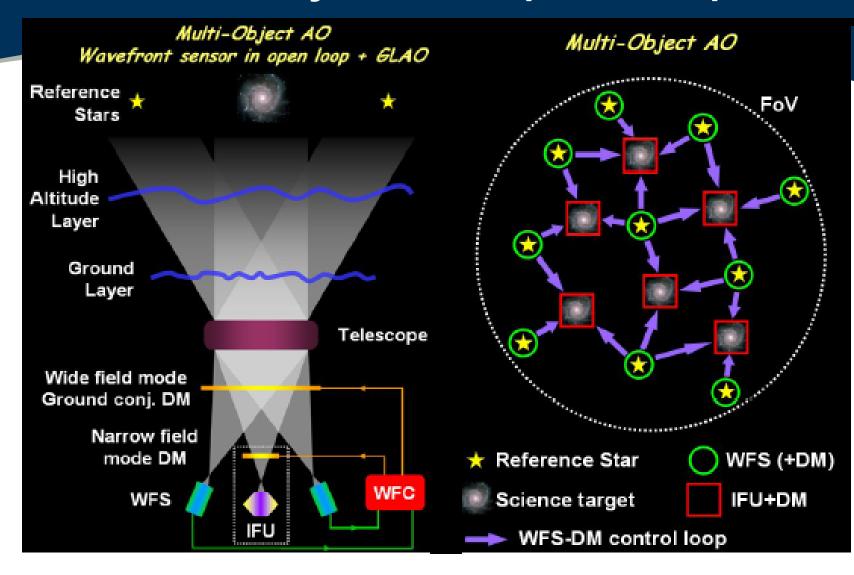








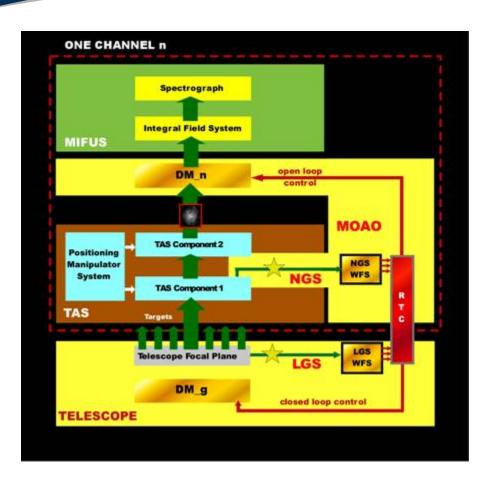
Multi Object Adaptive Optics

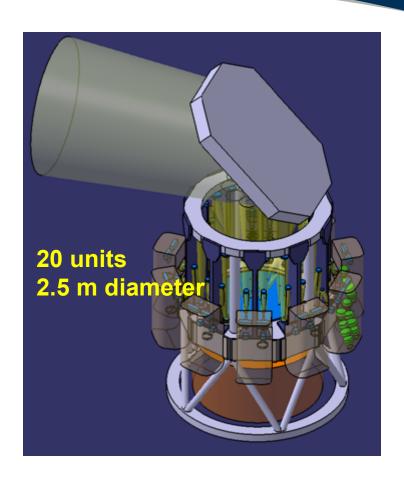




ESO 84

EAGLE







World Observatory?

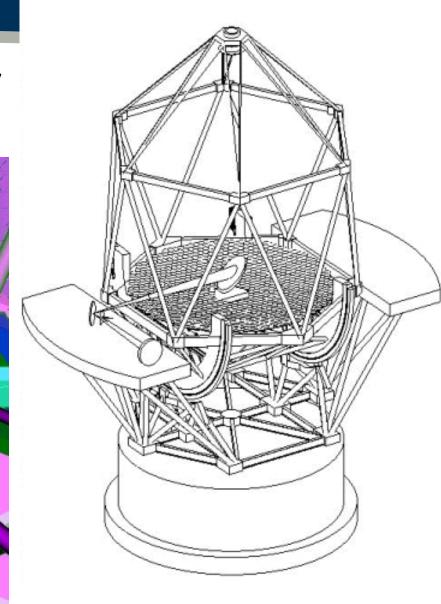
- ESO has new partners:
 - UK, Spain, Czech Republic
 - Others possible
- What about Asian ELT partners?
 - Japan may join TMT, but perhaps not if it goes to Chile



Japan

30m 3-aspheric mirror

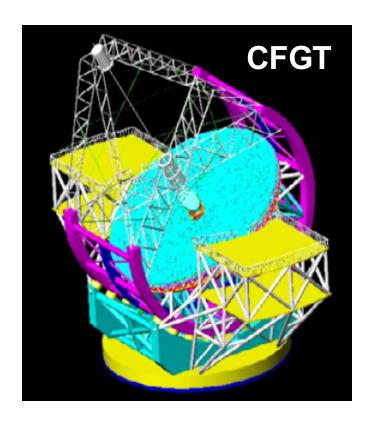
10 arcmin field



eb 08

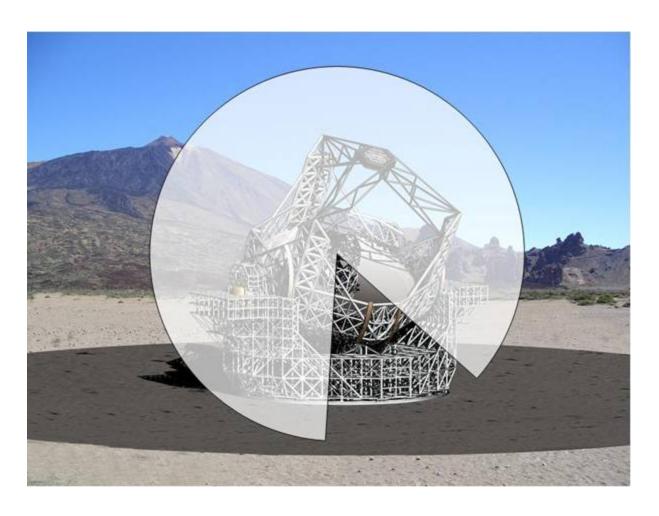
China

- CFGT Chinese Future Giant Telescope
- 30m modified Ritchey-Chrétien
- Wide field 20 arcmin
- Seeing limited fibrefed MOS





Indian ELT?





Planets orbiting other stars	Star formation history across the Universe
Planetary environments of other stars	Dark Matter
Solar system: planetary weather	Dark Energy
Solar system: complete census of small bodies	First objects and the reionisation of the Universe
Resolved stellar populations	High redshift intergalactic medium
Massive Black Holes demography	THE UNEXPECTED

Additional Info

Presented to the Community at the E-ELT meeting in Marseille, to STC and Council in 4Q 2006

High Priority Instrument Batch: candidates for 1st generation

INSTRUMENT	OBS. MODES	FOCUS / AO *	WAV. RANG E. (ILM)	FIEL	PIXEL SIZE (mas)	Δλ / λ	PROMINEN T SCIENCE	REF. STUDY
DL, NIR Imager	imaging	Nasm./LT AO,	0.9-2.5	>30"	4	wide, n.	~ all	ONIRIC A @
Narrow Field Spectrograph	spectroscop y	Nasm./SC AO ,	0.6- 2.5	1"/ 10":	20/50	3000, 20000:	~ all	Not studied
High Resolution Vis	spectroscop y	Coude/ GLAO	0.4 -0.8	Point source	=	150000	C2, C7	CODEX
Planetary Imager	imaging, spectroscop	Nasm/ EXAO	0.6- 1.75	~2" V ~4" H	>= Nyquis	>15	S3, S9	EPICS
NIR MOS	Spectrosco py	Grav. Inv./ MOAO	0.8-2.5	>= 5'	30 - 50	3000, 10000:	C4, C10	WFSPEC, MOMSI
NIR MOS ,DL	Spectrosco py	Grav. Inv.	0.8- 2.5	>30"	10 - 30	3000, 20000	G4, G9	MOMSI
MIR Imager	imaging (+limited spectroscop	Nas or IF/ SCAO or LTAO	3-20	30"	6 - 20	w-n bands,	S3, S9, S5, G9, C10	MIDIR

^{*} Minimum Strehl or EE to be specified; +: from Science WG Report http://www.eso.org/projects/e-elt/publications.html

Presented to the Community at the E-ELT meeting in Marseille, to STC and Council in 4Q 2006

Fishing Pond: instruments concepts still to be investigated for the 42m, or not yet firmly associated to prominent science cases

INSTRUMEN T	OBS. MODES	FOCUS/ AO	WAV. RANGE	FIELD	PIXEL SIZE (mas)	Δλ / λ	SCIENCE CASE	REF. STUDY
Wide Field NIR Imager	Imaging	Nasmyth/ GLAO, LTAO	0.8 – 2.5	> 5' x 5'	50	Wide,narr ow bands	C4,C10,S5,G 4	ONIRICA @ OWL
High Time Res. Imager	Fast photometry	NASMYTH/ GLAO, SCAO	0.4 - 0.8	2 times (2" x	tbd	Wide, narrow bands	Photon stat., rapidly varving	QUANTEY E @ OWL, HTRI
High Res. IR	HR spectrosco	coude/ SCAO,LTAO	0.8 – 1.8 (5)	<1"	tbd	150000:	S9, G4, G9, C7	HISPEC
High Res. MIR	HR spectrosco	Nasmyth/SCAO,L TAO	3 – 20:	2":	tbd	50000:	S9, G9, C7,	MIDIR
Polarimeter *	Imaging, spectrosco	IF, Nasmyth? / GLAO, LTAO:	0.35- 0.8	tbd	tbd	W-n bands,LR	S9,C7,	No study
MOS Visual	MR spectrosco	Nasmyth/ GLAO	0.35 – 1	~ 6' x 6'	100:	1000- 15000:	C10, C4,G4	No study
Wide Field Visual	Imaging	Nasmyth/ GLAO	0.35- 1	~7' x7'	50-100:	Wide bands	C10, C4,G4	No study
Sub-mm Imager	Imaging	Nasmyth/ tbd	350-450- 850	5'	1- 2.5"	Wide Bands	C10	SCOWL, SCELT

^{*:} Polarimetry can be included as an observing mode in other instruments, if required by their respective science cases