Scientific challenges and technological limitations in ground-based astronomy 2:

Instrumentation

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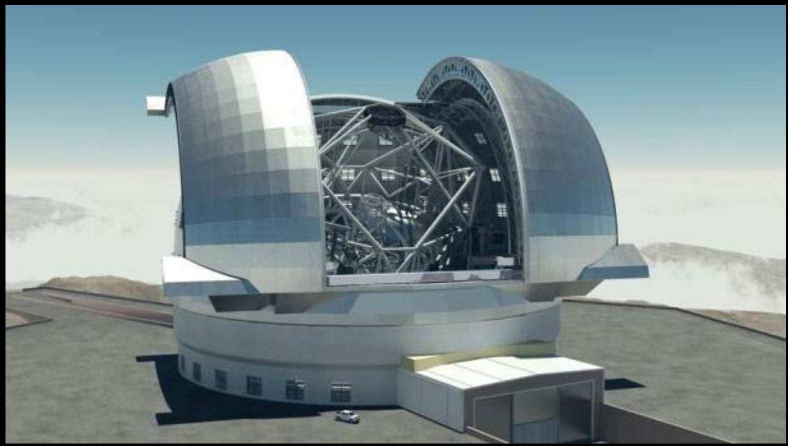
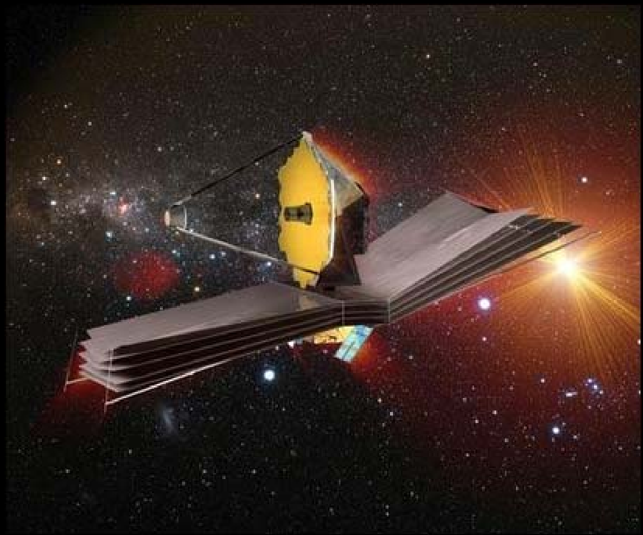
Director, UK Extremely Large Telescope Programme
Chair, OPTICON Key Technology Network

Ground-based Instruments

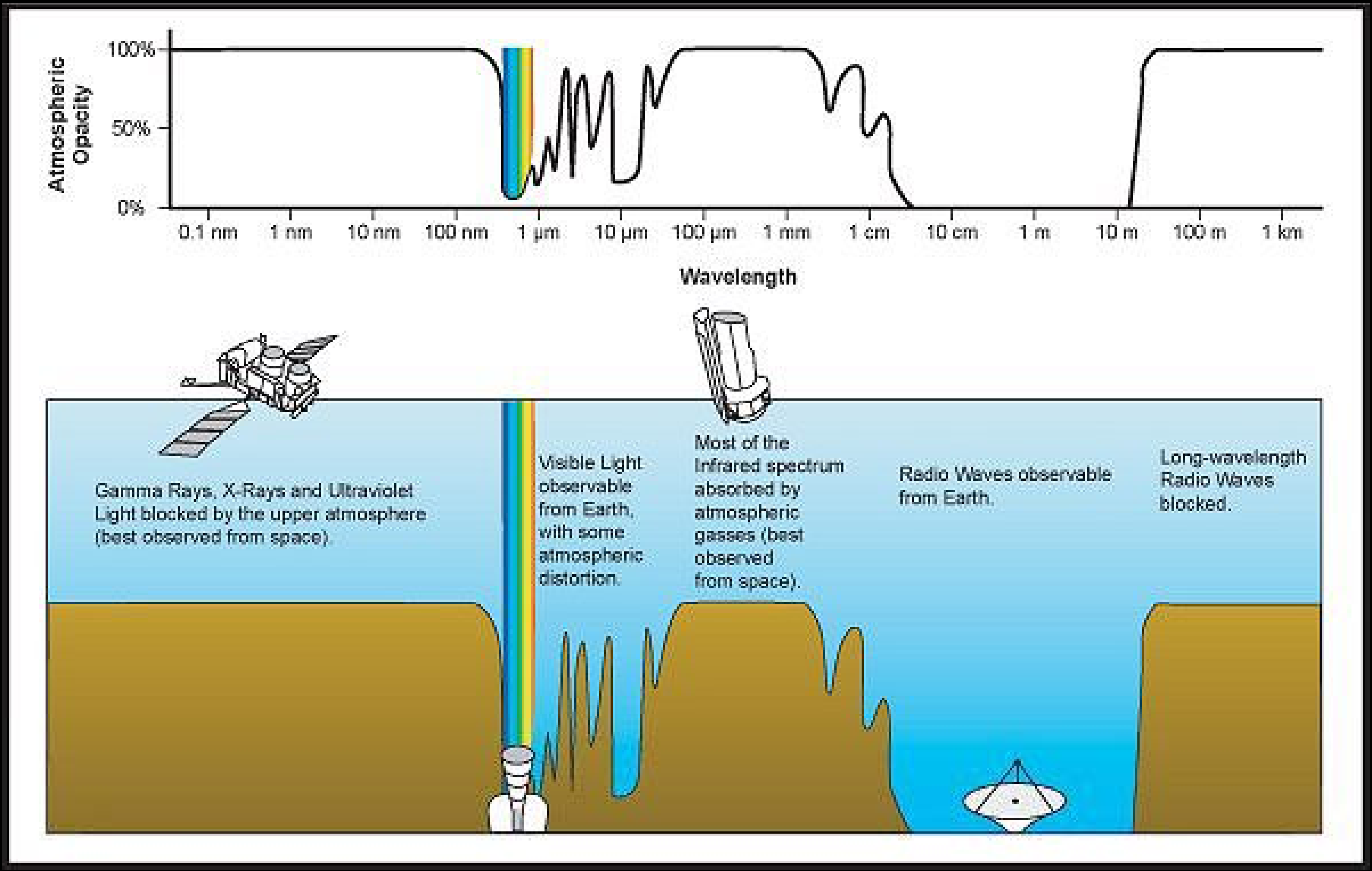
- Technically challenging
  - – But can take more risks than in space
- Still a tendency to be conservative on technology adoption





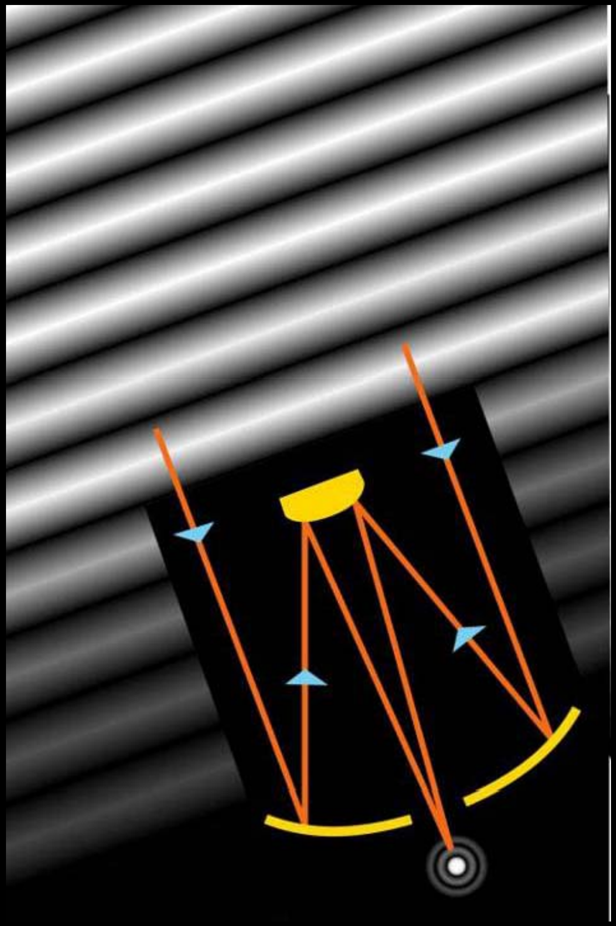
Technical Limitations: Atmosphere

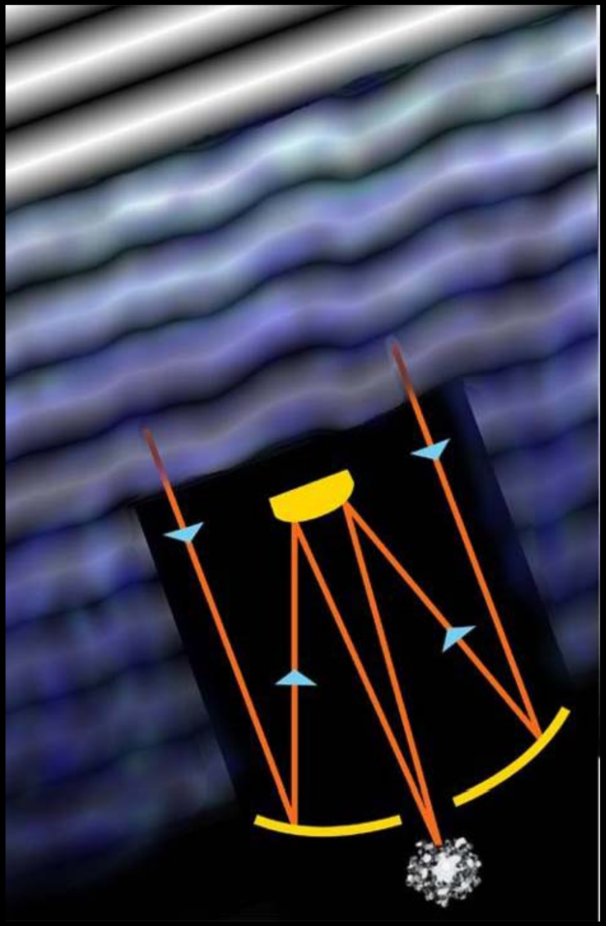
Absorption



Technical Limitations: Atmosphere

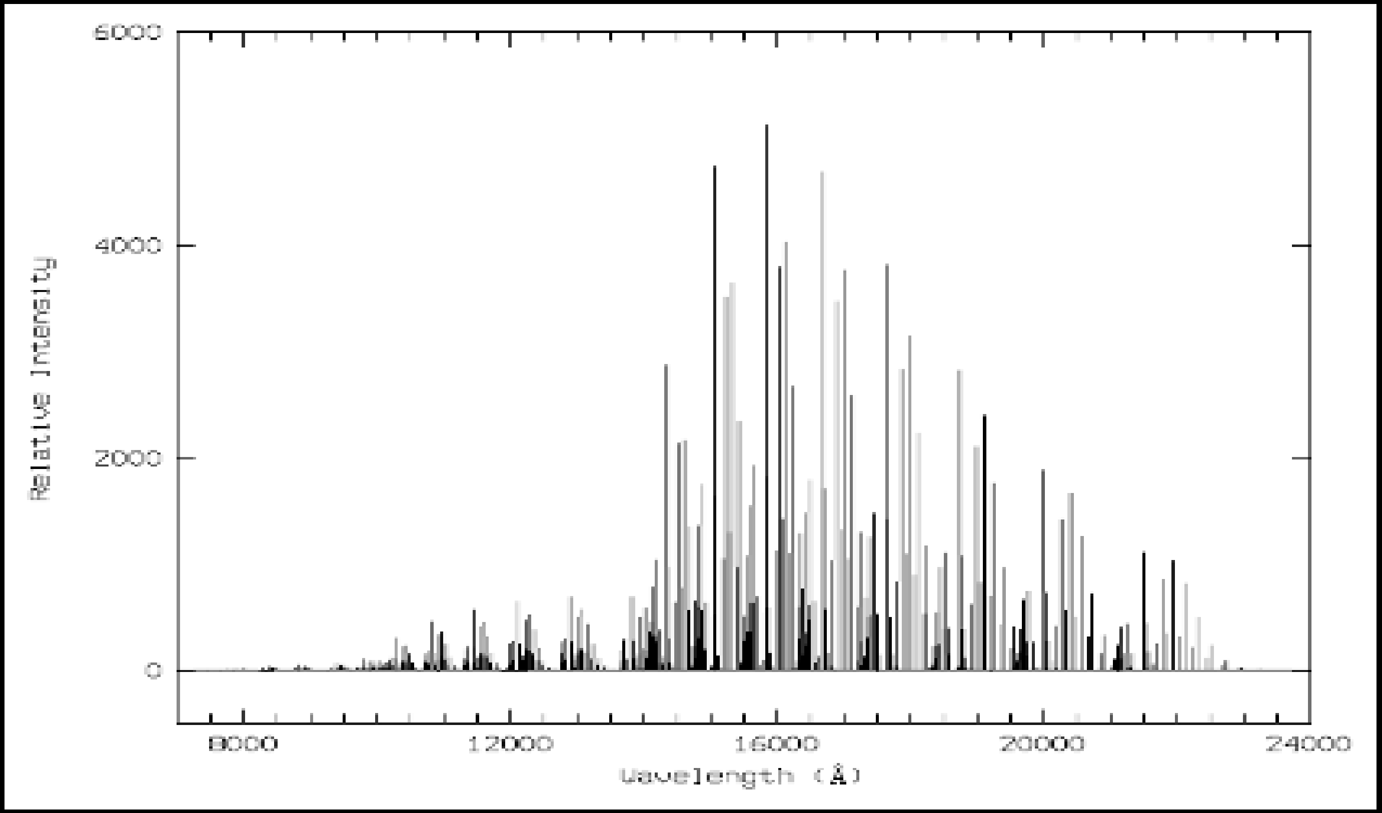
Turbulence





Technical Limitations: Atmosphere

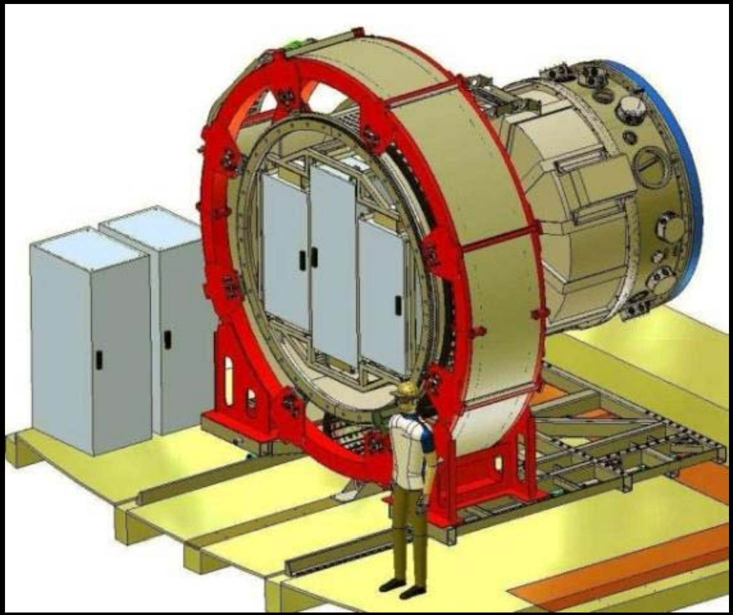
OH Emission Lines



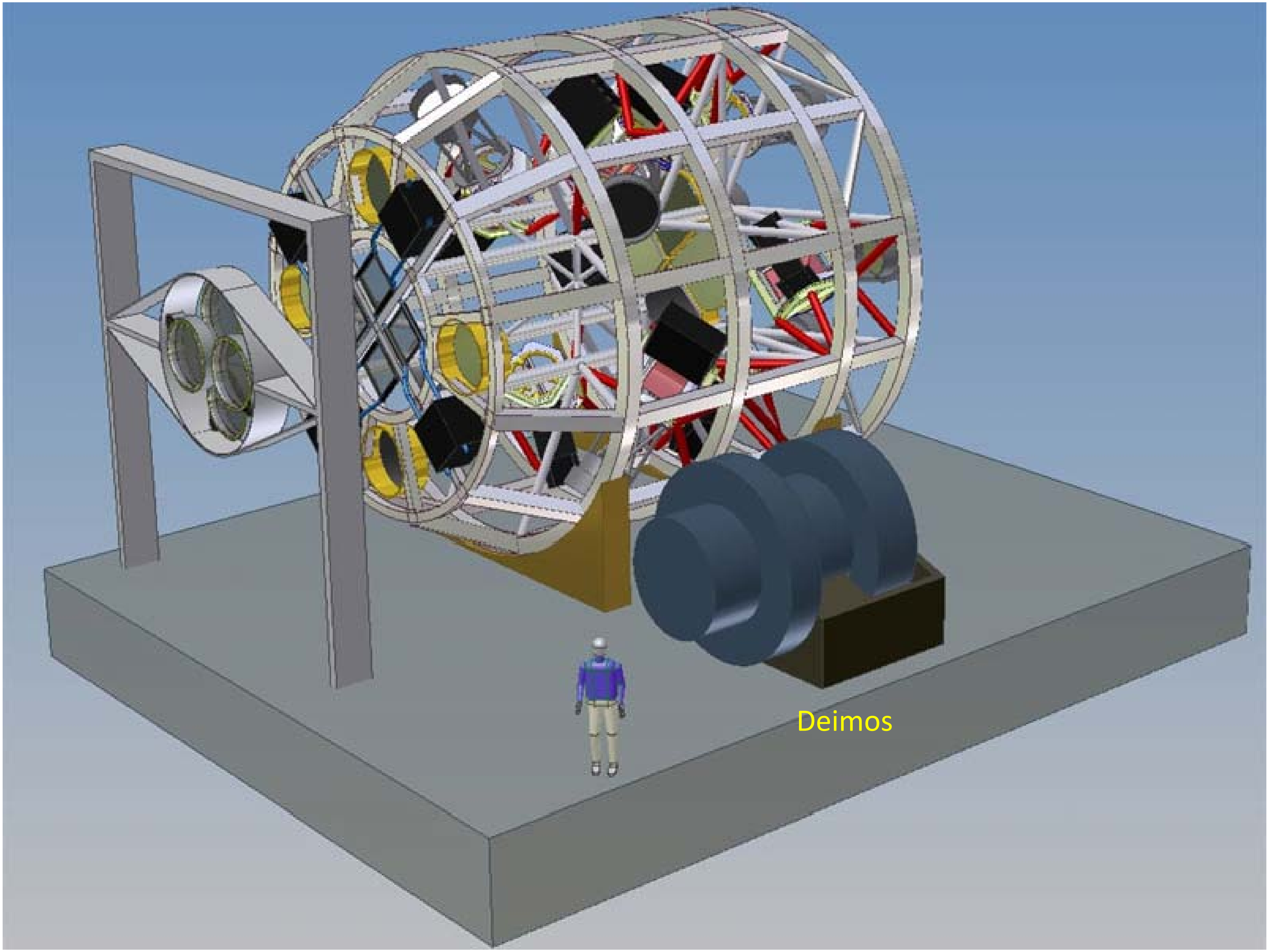
Night sky near-IR spectrum
P Rousselot et al,
*Astron. & Astrophys. **354**, 1134 (2000)*

Technical Limitations: Instrument size and stability

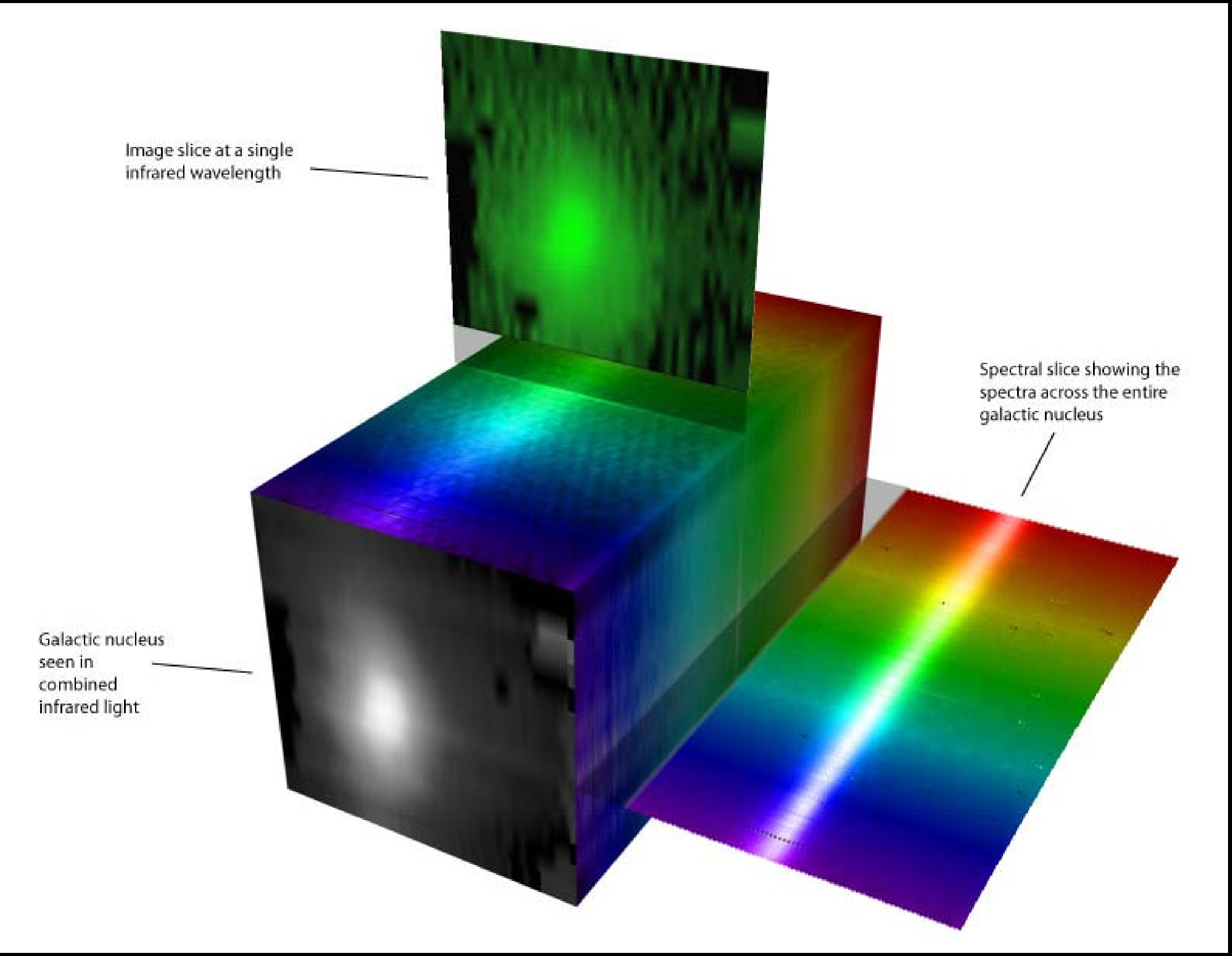
UKIRT: IRCAM 1 1986



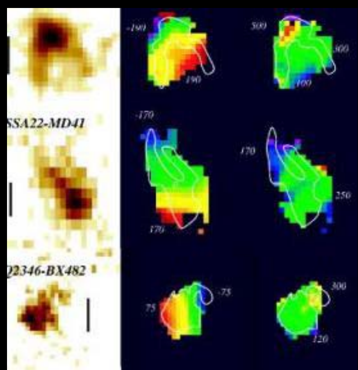
VLT: KMOS 2011

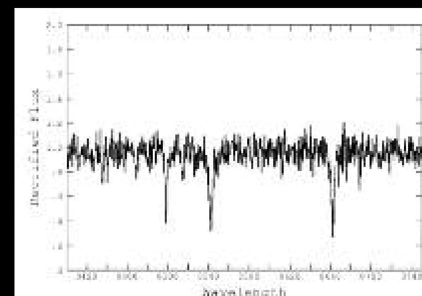

Deimos

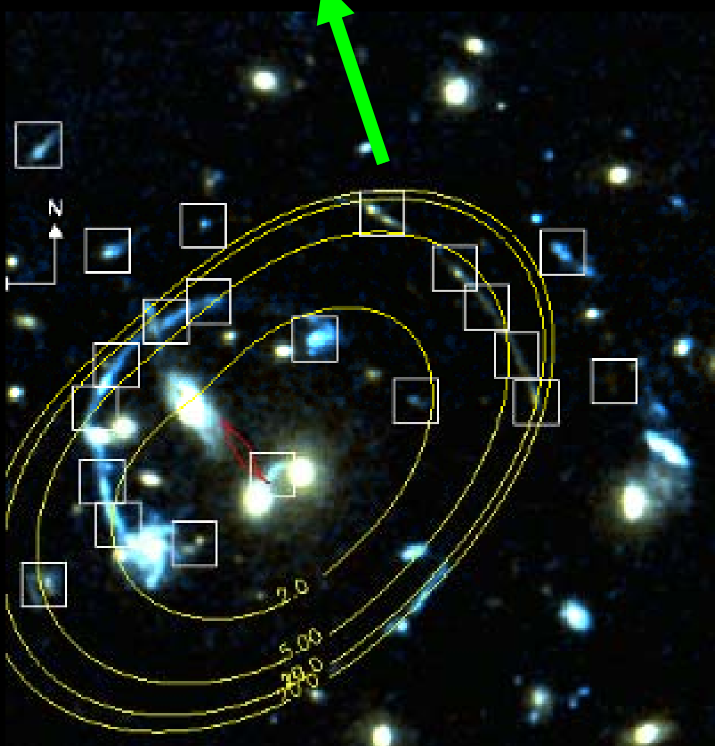
Critical Requirement: 3D and Multi-object spectroscopy

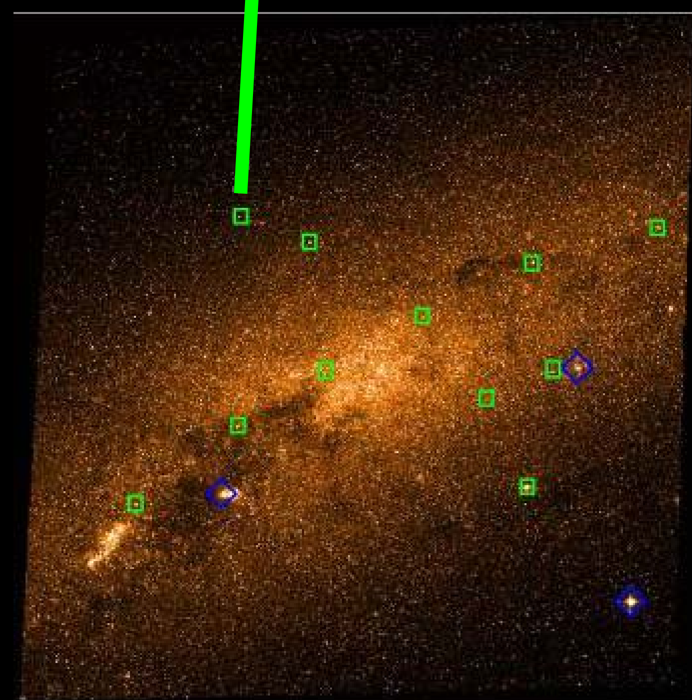


Critical Requirement: 3D and Multi-object spectroscopy

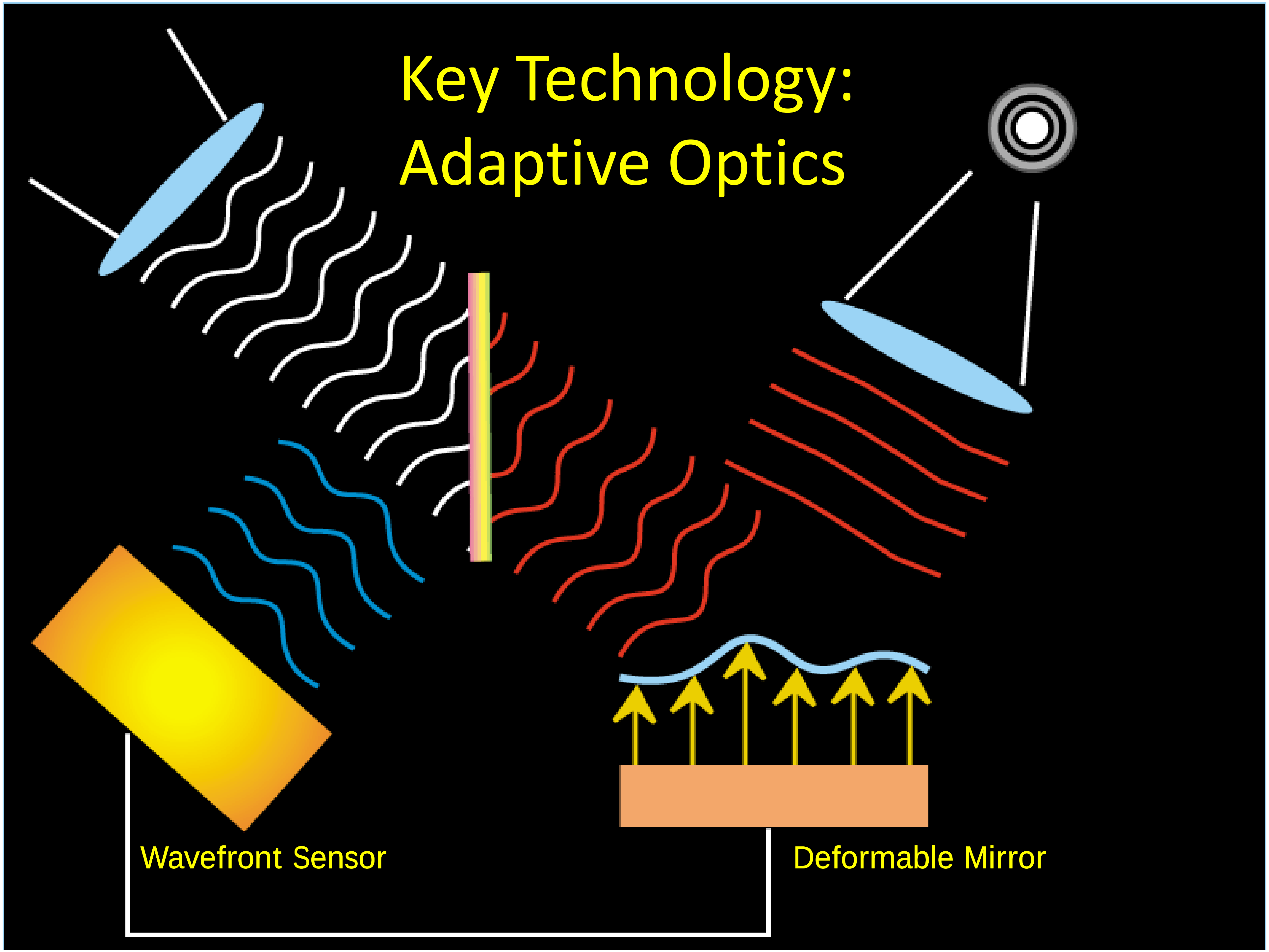






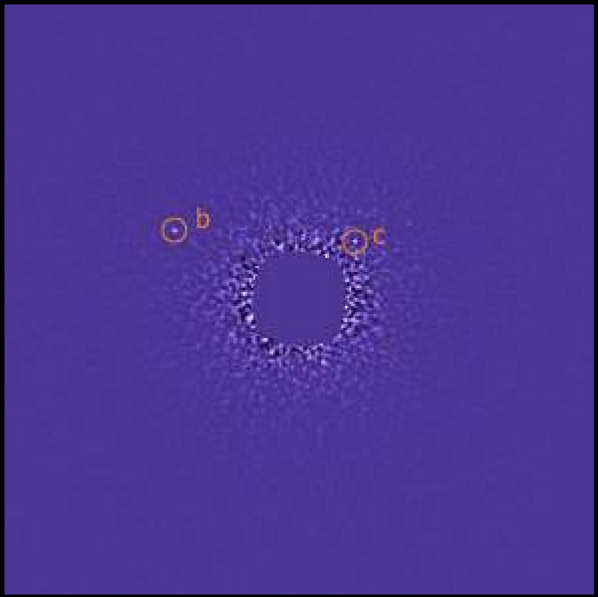


SOLUTIONS


Key Technology:
Adaptive Optics
Wavefront Sensor
Deformable Mirror

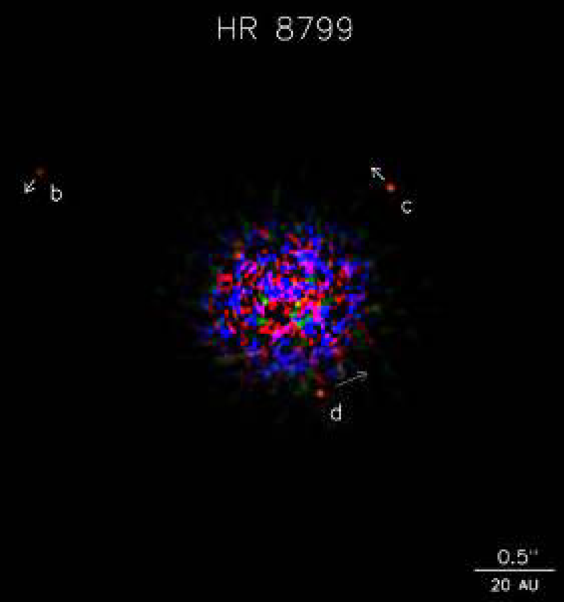
Impact of Adaptive Optics: exoplanets

HR 8799: 140 light years away, 1.5 times the size of our Sun and five times more luminous



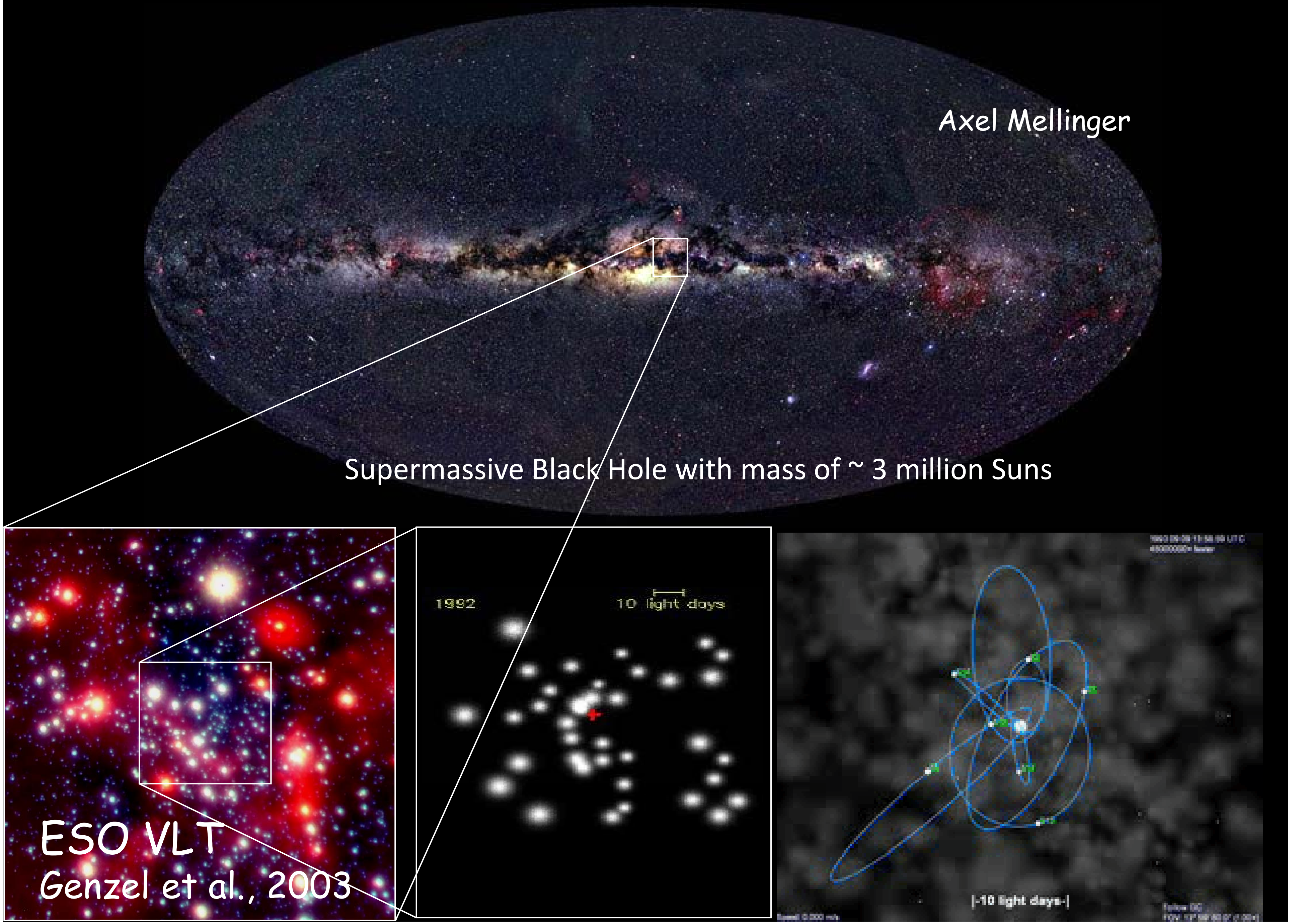
Gemini North adaptive optics image shows two of the three confirmed planets

- ~7 Jupiter-mass planet orbiting at about 70 AU
- ~10 Jupiter-mass planet orbiting the star at about 40

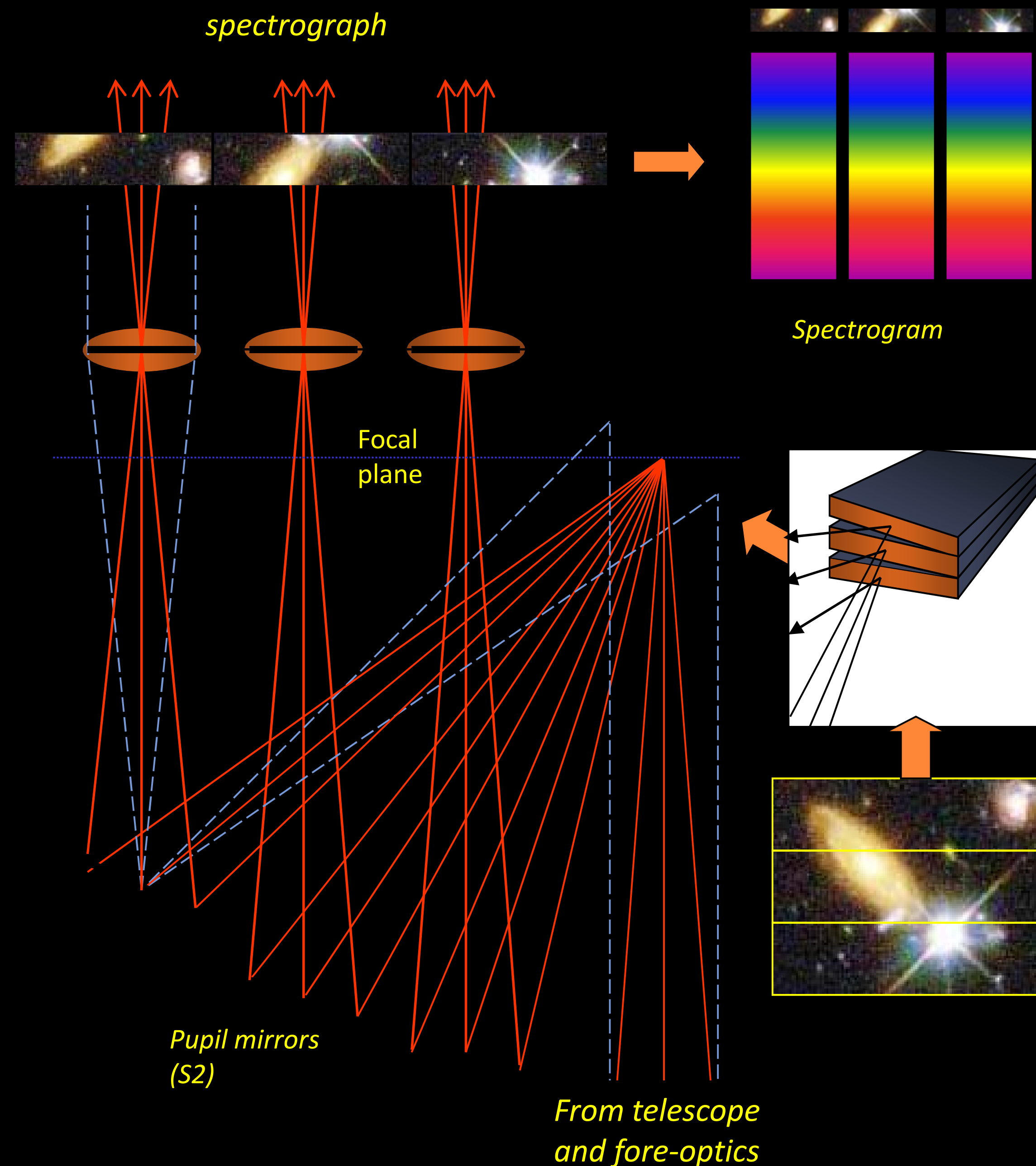


Keck AO follow-up AO image showing a third planet!

Adaptive Optics: The Galactic Centre



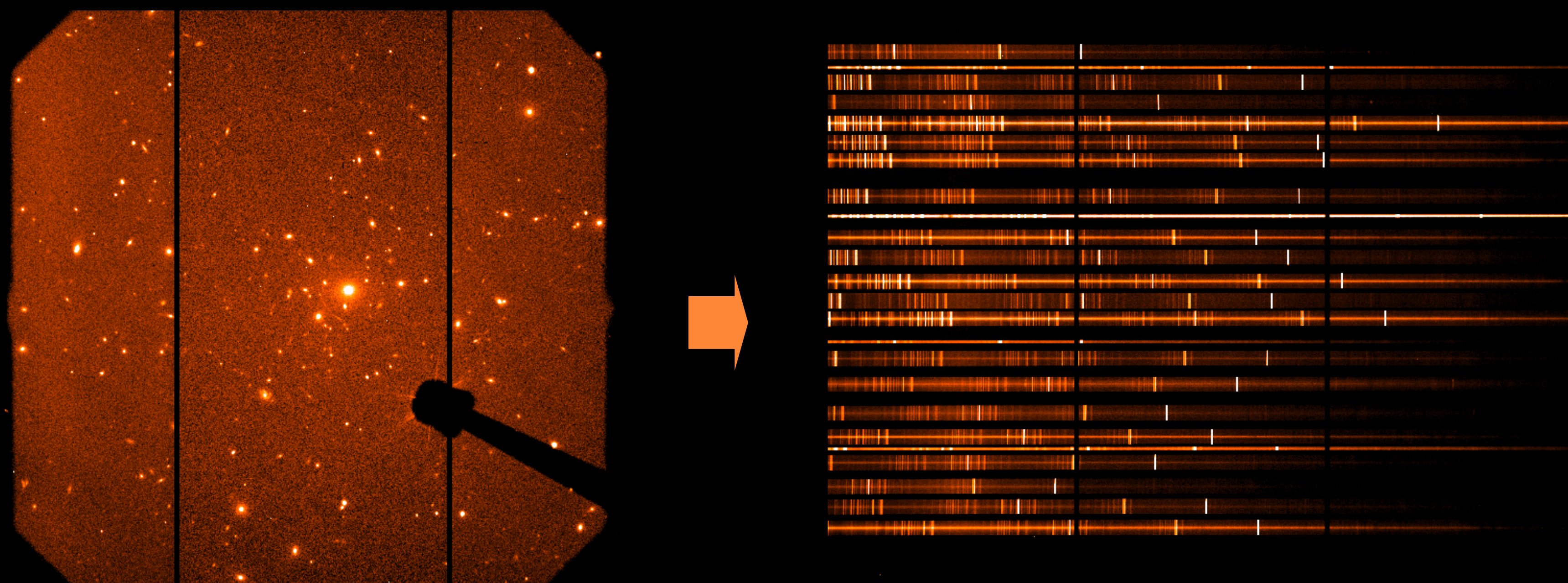
Integral Field Spectroscopy: Image Slicer



Jeremy Allington-Smith

University of Durham

Multi-Object Spectroscopy

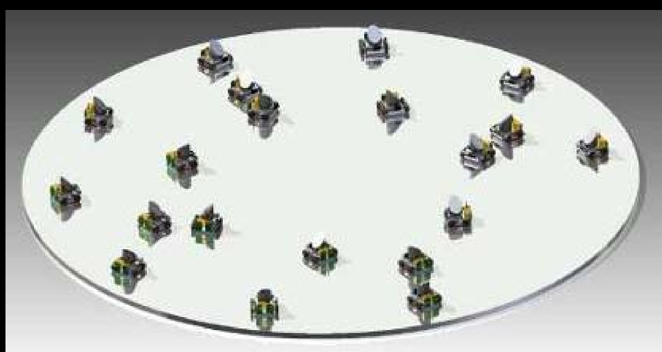


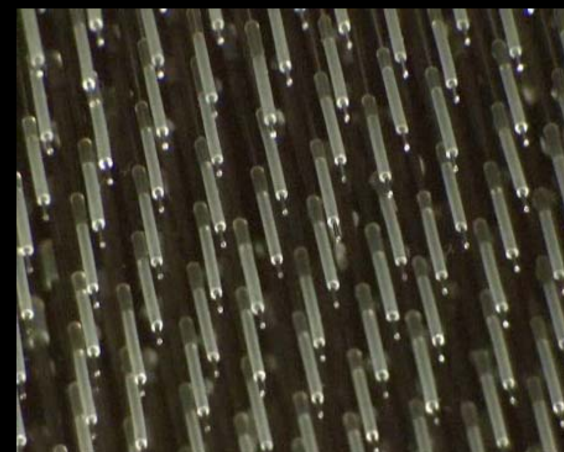
Key Technology: Smart Focal Planes

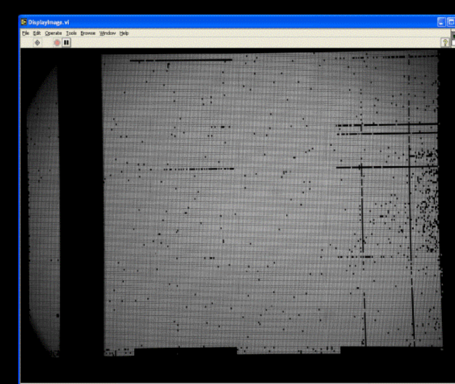
VLT KMOS: Pick-off arms

Object Selection Technologies

Smart Focal planes – fibres, robots, micro-mirror arrays

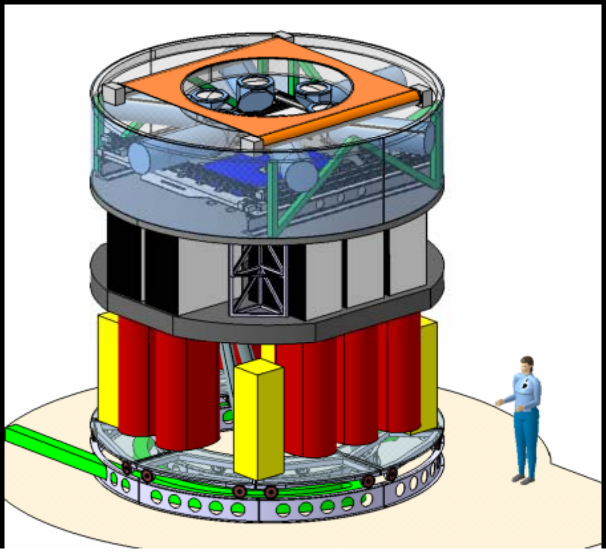


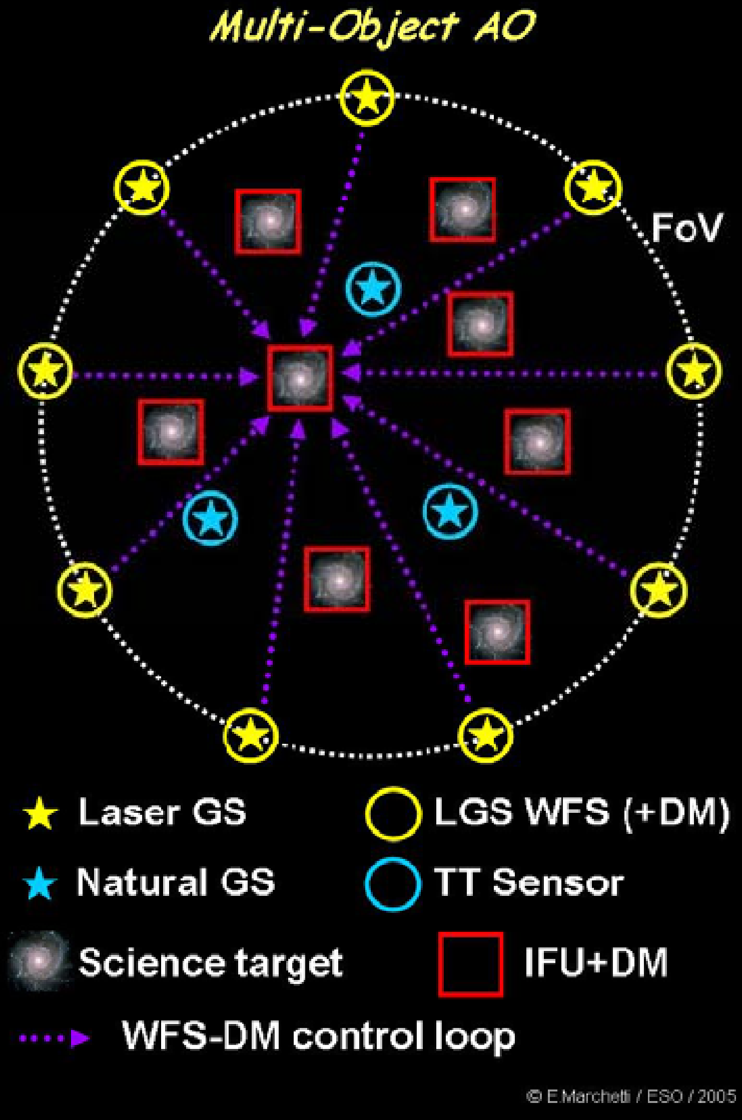


E-ELT: EAGLE Adaptive Optics

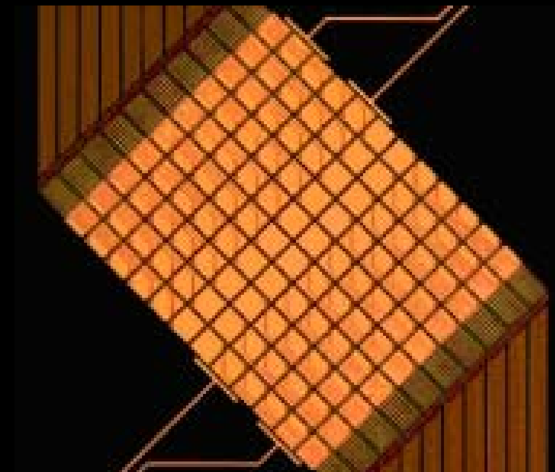
- Multi-Object Adaptive Optics (MOAO)
- Correct small sub-fields across a 5 arcmin field
- Extensive MOAO research in the UK and France





Disruptive Technologies: Detectors

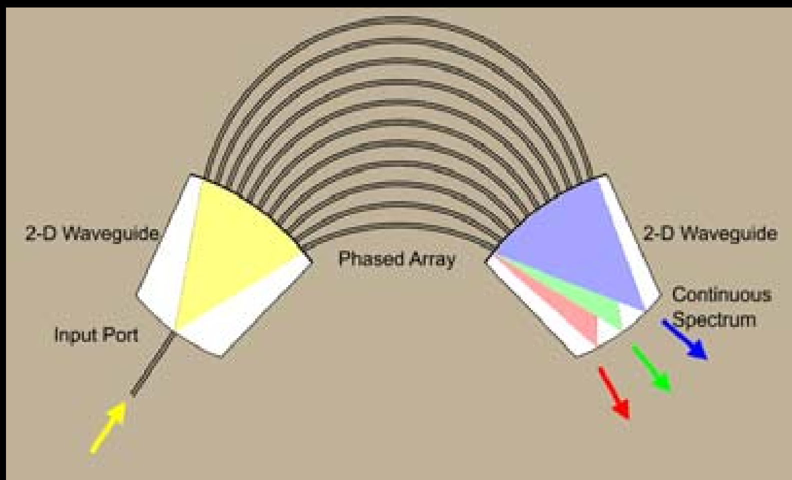
- Generally limited to intensity measurement
- Energy resolution would be great:
  - R (Eg λΔ/λ)>100
- Technology maturity and performance scales inversely with wavelength eg Visible (CCDs), NIR, Far-IR/THz

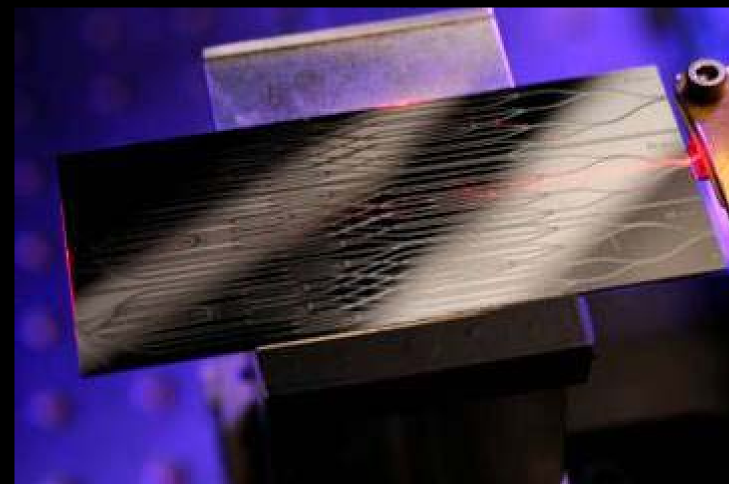


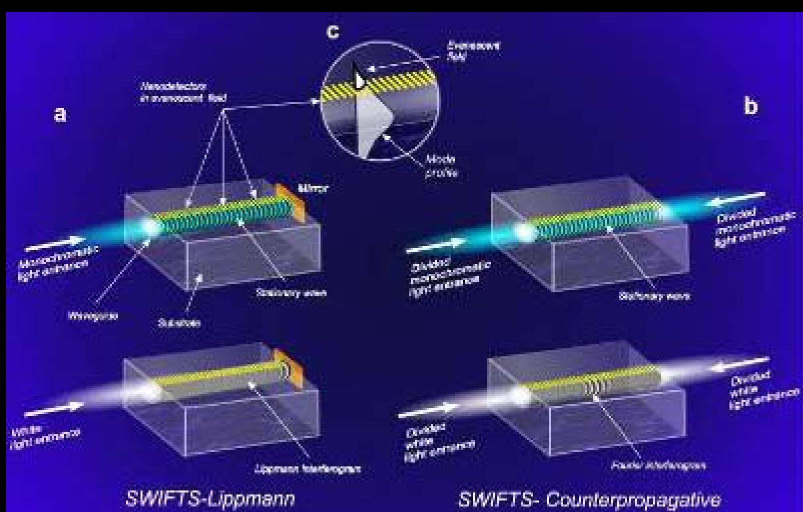
ESA S-CAM: Superconducting Tunnel Junctions

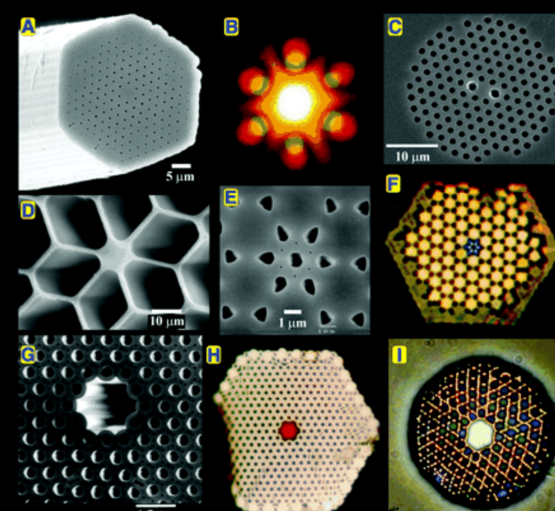
SCUBA2: Arrays of Transition Edge Superconducting Devices

Disruptive Technologies: Astrophotonics

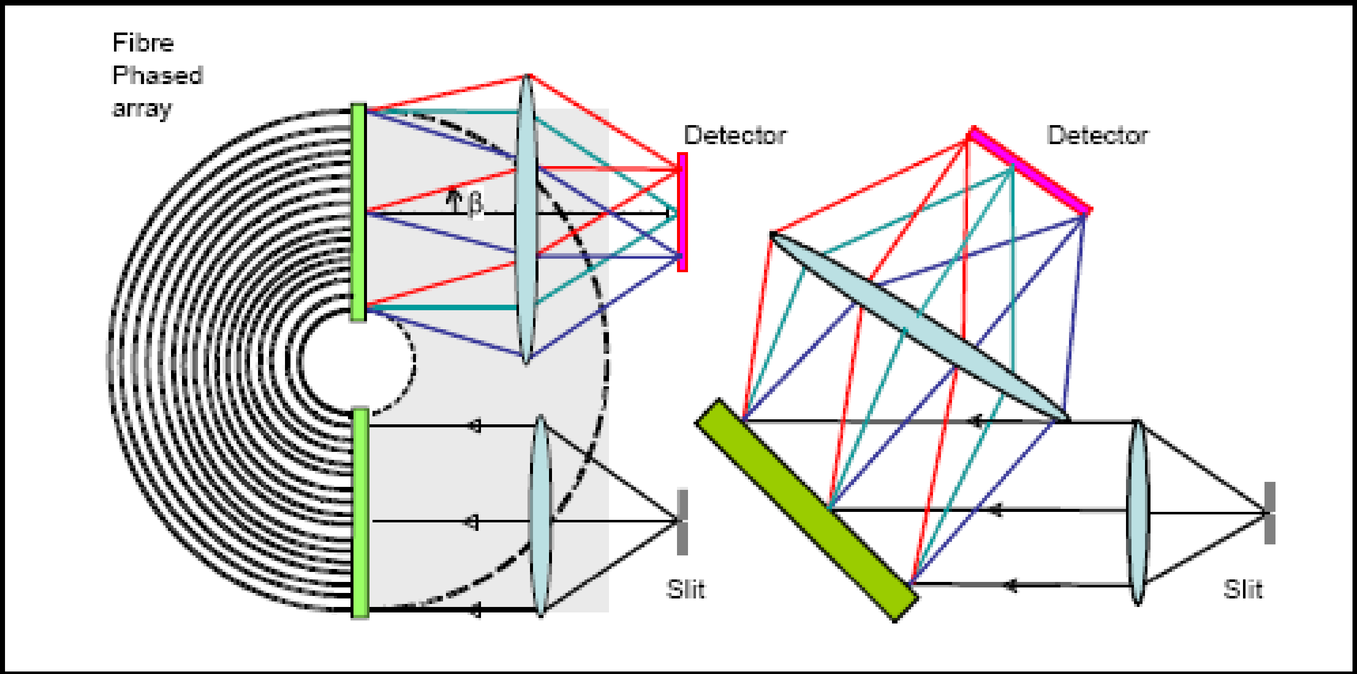








Fibre v. conventional spectrometer



The fibre array spectrometer has 5x the spectral resolution of the conventional dispersive spectrometer – or is 5x smaller

Robert R. Thomson, Ajoy K. Kar, and Jeremy Allington-Smith Vol. 17, No. 3 / OPTICS EXPRESS

Integrated Spectrometer

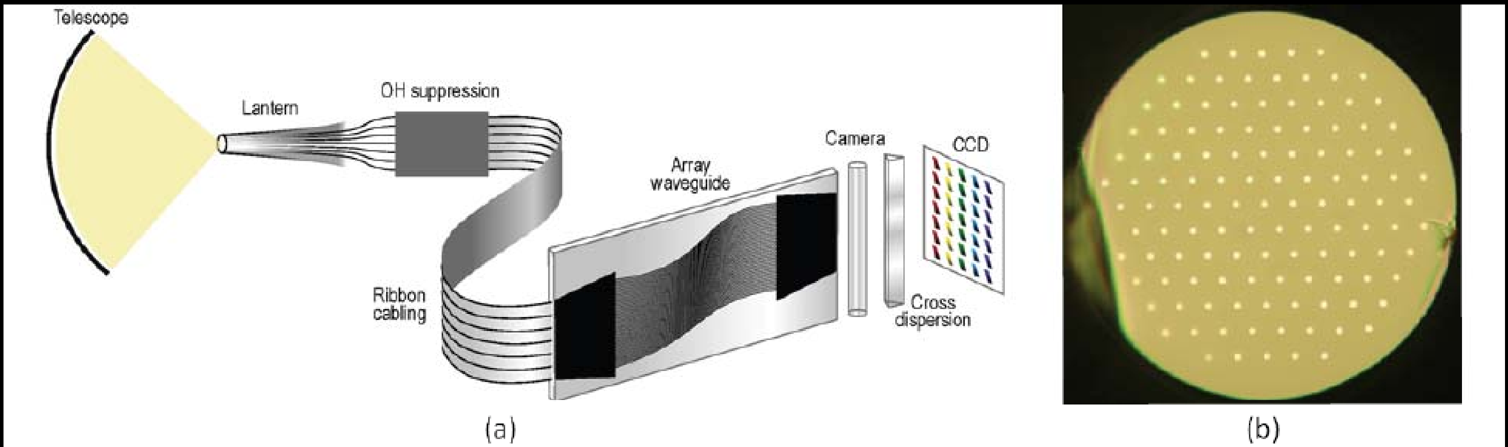
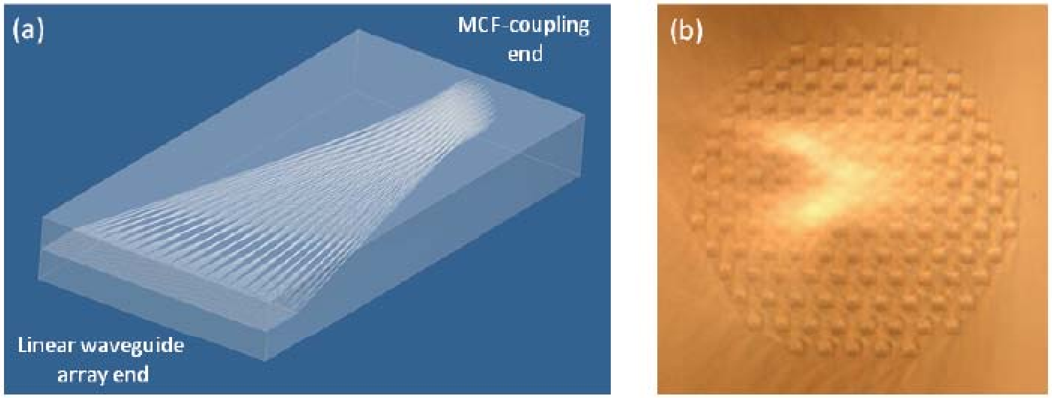


Figure 1 (a) Schematic diagram of the first Photonic Integrated Multimode Micro Spectrograph (PIMMS#1). (b) Transmission mode micrograph of the 120 core multicore fiber. The field of view of (b) is ≈ 240 × 240 μm.

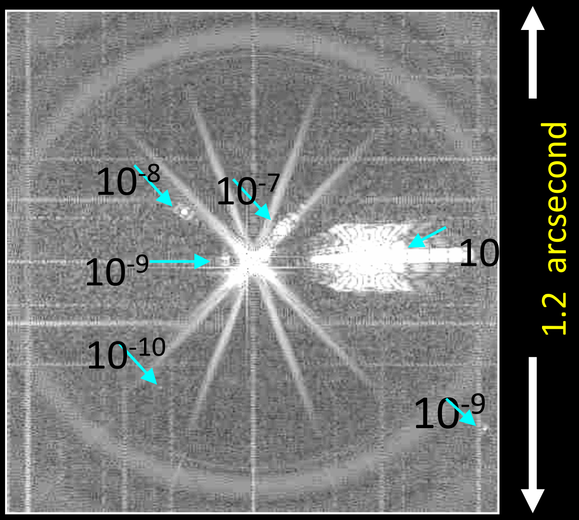
PIMMS: Joss Bland-Hawthorn (Sydney)



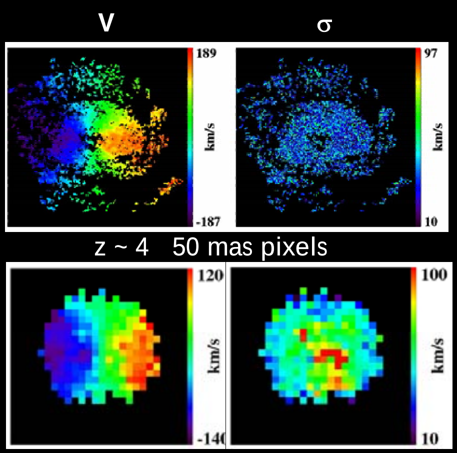
Direct-write waveguides: Robert Thomson (Heriot-Watt)

Summary: Scientific challenges

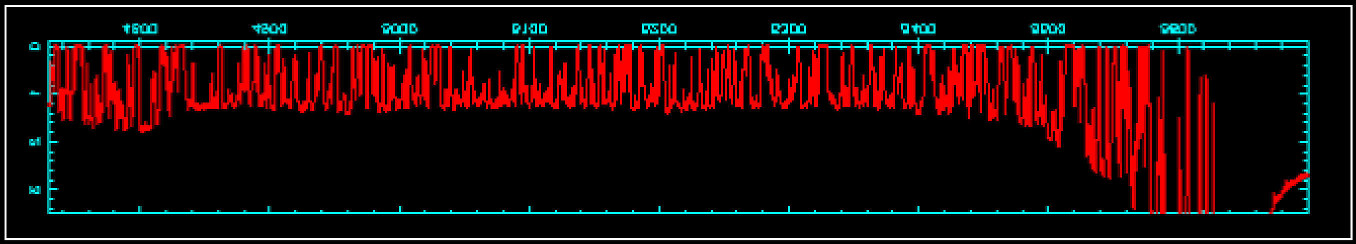
- Direct detection of a “Super Earth”



- Understanding of galaxy formation in the early Universe



- Direct measurement of the expansion rate of the Universe



Summary: Technology Limitations

- Energy-sensitive Detectors
- Real-time computing
- Deformable Mirrors
- OH-line suppression
- Object selection
- Beam combiners in interferometry
- Spectrometer size and hence stability

Multidisciplinary character of KETs

- Cross-links with military, environment and biomedical applications
  - Adaptive optics in the eye
  - Adaptive optics for laser optimisation
  - Adaptive optics for free-space communication
  - Earth observing – multi-spectral imaging
  - Skin Cancer detection – multi-spectral imaging

European “windows of excellence”

- Adaptive Optics
- Smart Focal Planes
- Image slicers
- Interferometry
- Detectors
- Astrophotonics

Promising/demonstrated mechanisms

- ERA-net: ASTRONET astronomy roadmapping
- FP7 OPTICON Optical and IR Astronomy
  - Joint Research Activities
  - Key Technology Network
- FP7 RADIONET – Radio Astronomy
- FP7 ARENA – Antarctic Astronomy
- UK Knowledge Transfer Networks
  - Electronics, Sensors and Photonics
- Open Innovation in the UK
  - Daresbury and Harwell Science and Innovation Campuses
    - International Space Innovation Centre (ISIC)
    - Hub & spoke model

end

Additional Material

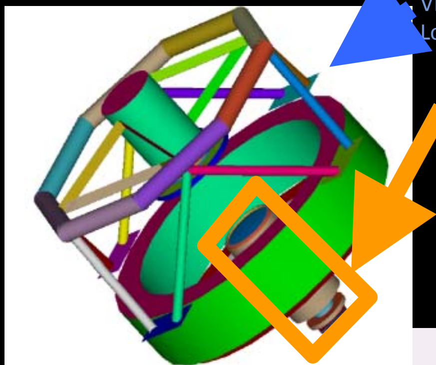
Cameras: VISTA

IR Camera for the VISTA Telescope

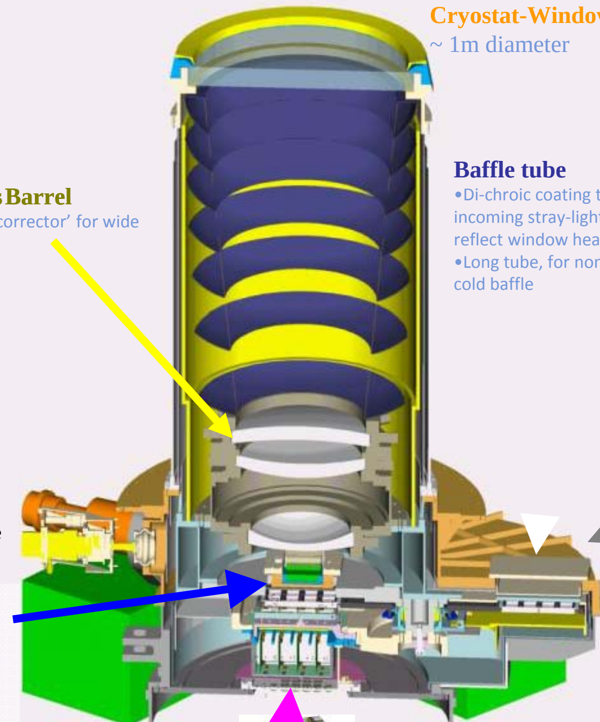
- VISTA telescope: Largest dedicated IR survey in the world – 4m class
- Location is ESO's Cerro Paranal site in Chile

IR Camera

- At focus of F/3 telescope.
- Field of view 1.65 degrees.
- Up to 7 spectral bands.
- M ~ 20 at Ks wavelength (2 microns) in 15 minute exposures.
- Pixel size : 0.34 arcsecs
- Cold front baffle, cryostat length ~2.5m
  – for low background, to be similar to telescope (self-emissivity, ~4% in Ks-band)



VISTA Telescope with the IR Camera



Cryostat-Window
~ 1m diameter

Baffle tube
•Di-chroic coating to absorb incoming stray-light (2um), but reflect window heat.
•Long tube, for non-re-imaged cold baffle

Lens Barrel
'field corrector' for wide FOV

Filter Wheel - 1.4m diameter
Up to 7 science filter arrays
Utility filters
High-order sensor optics

Closed Cycle Coolers x3

Auto-guider & Wave-Front Sensors Telescope & camera aberrations, flexures corrected by Active Optics
Low order: movement of M2.
High order: actuators in M1 cell

Science detectors focal plane array
4 x 4 Raytheon VIRGO detectors
2048 x 2048 pixels each

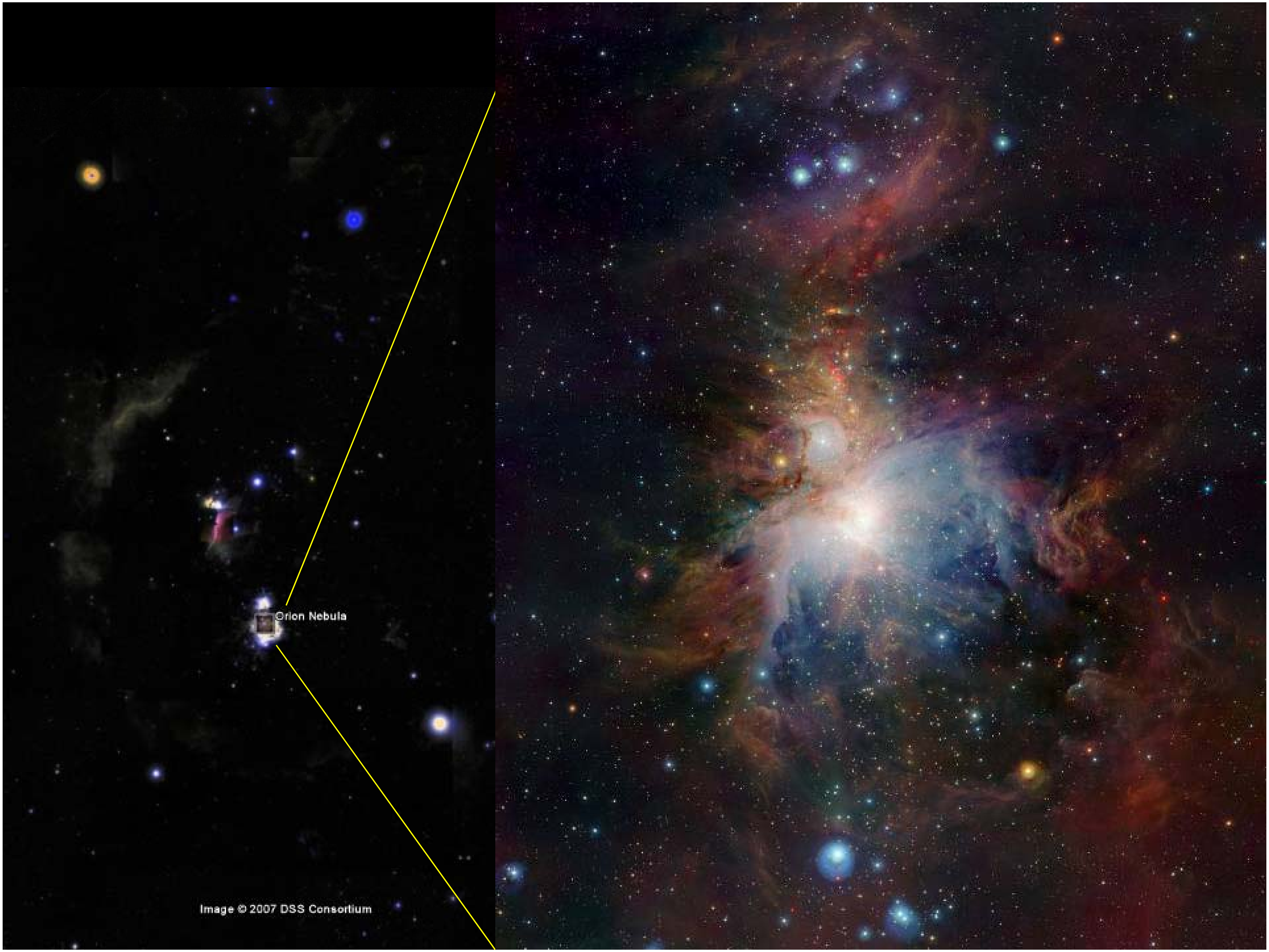
Science & Technology Facilities Council
UK Astronomy Technology Centre

Durham University

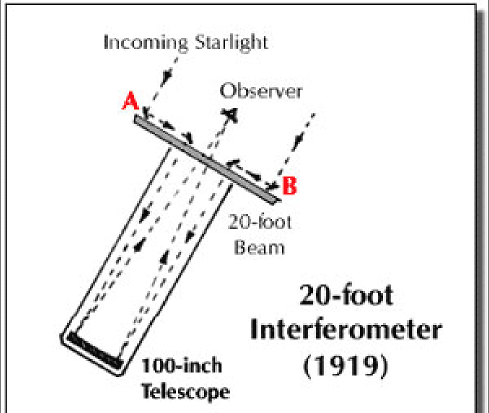
Science & Technology Facilities Council
Rutherford Appleton Laboratory

Further information: www.roe.ac.uk/atc/projects/

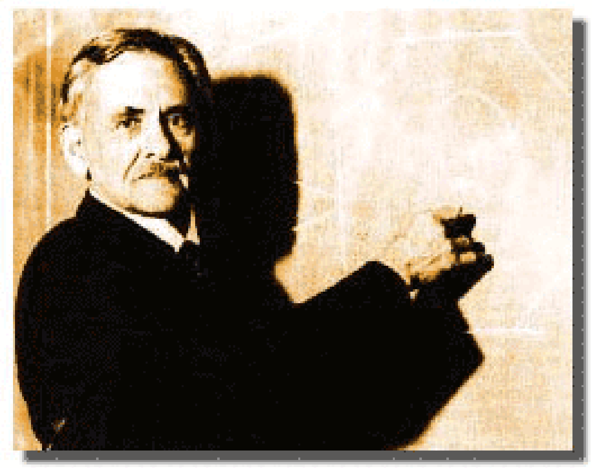
Poster prepared by: IR Camera team, contact A K Ward or M Caldwell


Orion Nebula
Image © 2007 DSS Consortium

Key Technology: Interferometry



Small mirrors on the 20-foot beam directed light into the telescope. The effective diameter of the telescope has now become the distance between mirror A and B.



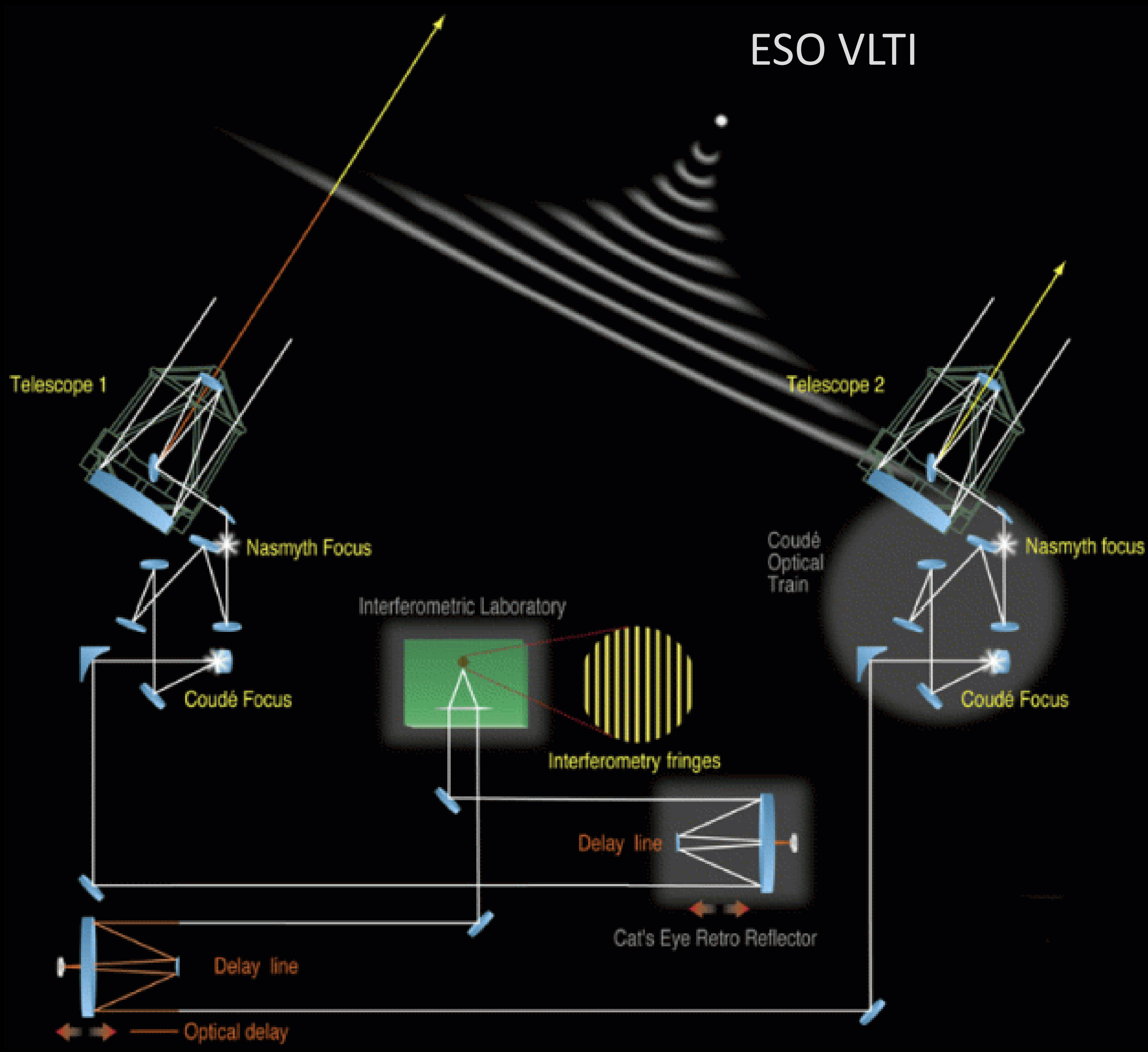
Albert Michelson

The 20-foot beam on top of the 100-inch Hooker Telescope on Mt. Wilson in Southern California.

ESO's VLTI

Very Large Telescope Interferometer

ESO VLTI



Telescope 1
Telescope 2
Nasmyth Focus
Nasmyth focus
Coudé Optical Train
Interferometric Laboratory
Coudé Focus
Coudé Focus
Interferometry fringes
Delay line
Cat's Eye Retro Reflector
Delay line
Optical delay

Key Technology: waveguide beam combiners

- Planets at earth-like temperatures brightest between ≈ 5 μm and 30 μm
- Use Ultrafast Laser Insciption to enables 3D mid-IR waveguides
- Robert Thomson (Heriot Watt, UK) with Pierre Kern (LAOG, France) and Lucas Labadie (IAC, Spain)

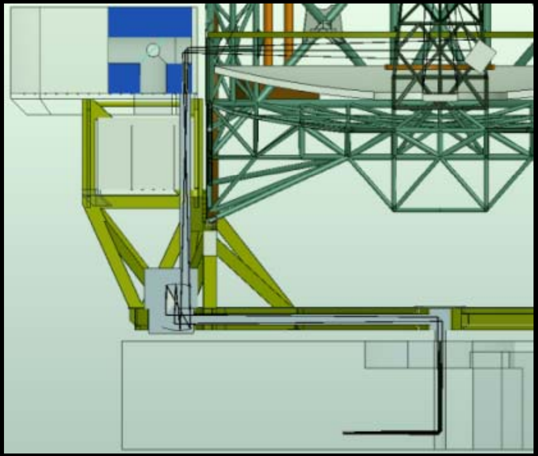
Planar three-telescope beam combiner
P. Haguenauer et. al., Proc. SPIE 4006, 1107 (2000)

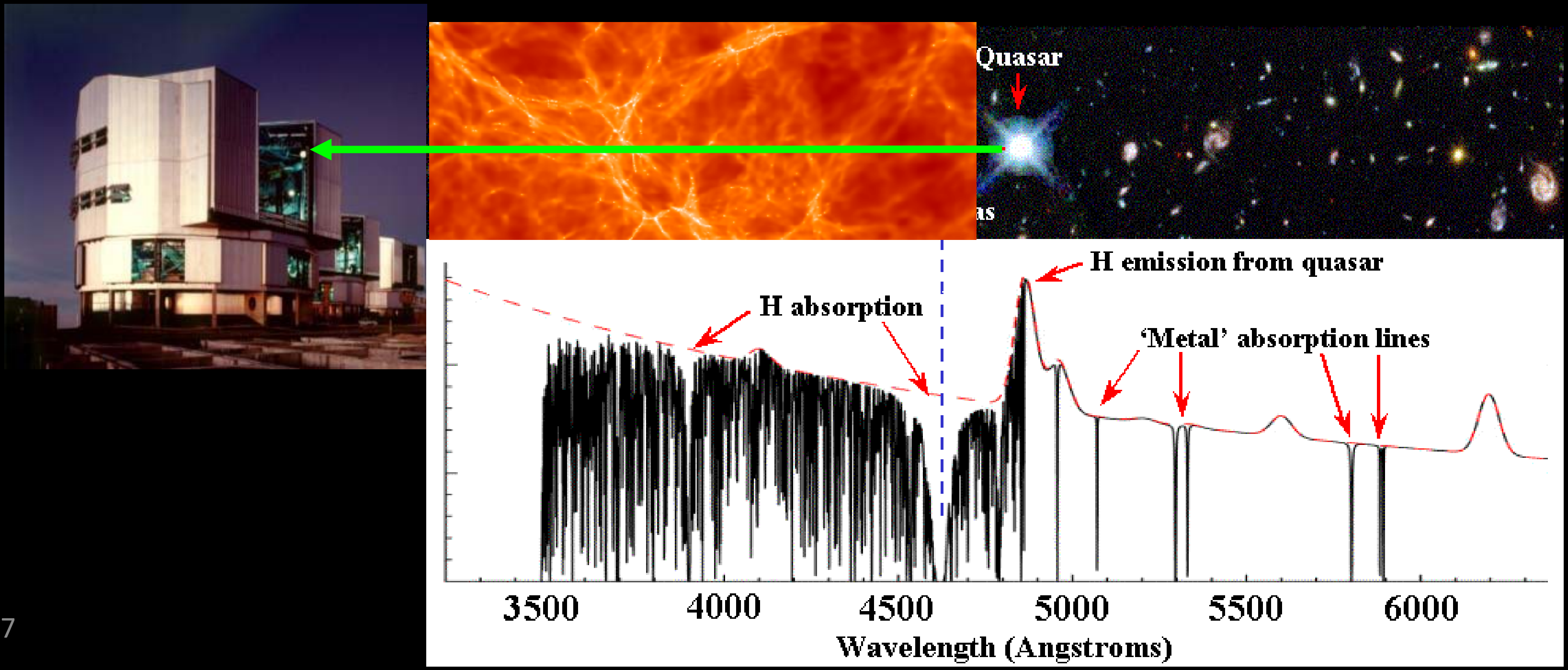
Four-telescope beam combiner
P. Kern, Opt. Express 17, 1976 (2009)

CODEX

Dark Energy accelerating the expansion of the Universe?

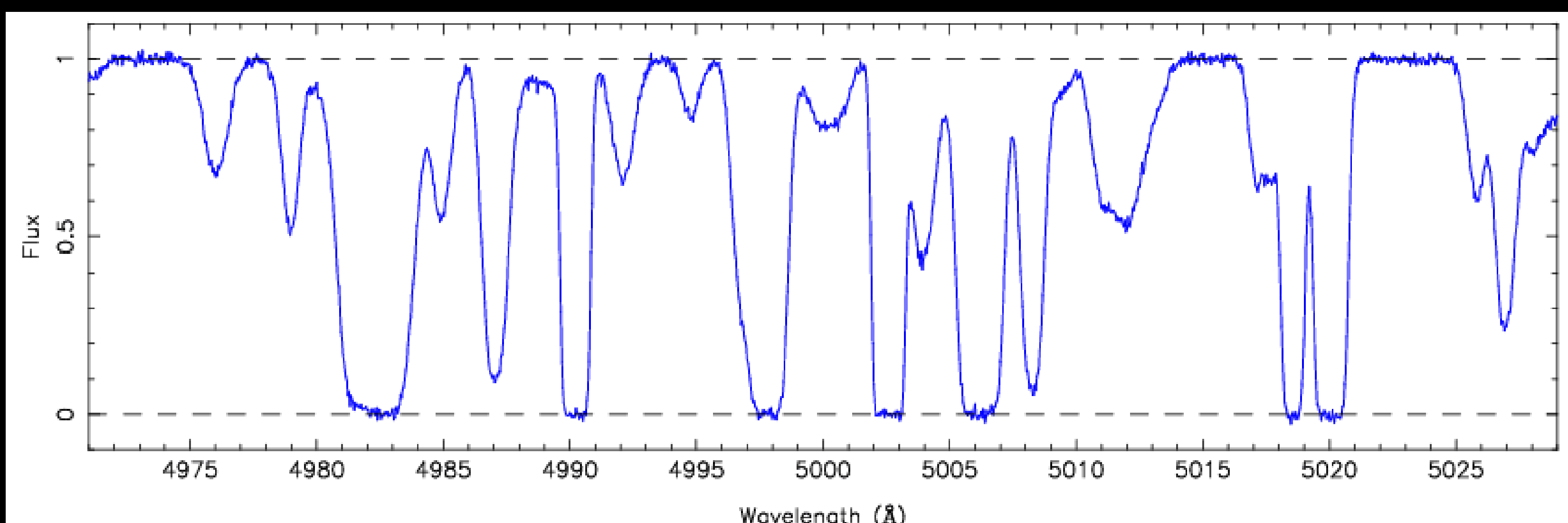
- E-ELT can measure acceleration **directly**, in real time
- Fundamentally different probe
  - dynamical vs geometrical – current measurements rely on supernova ‘standard



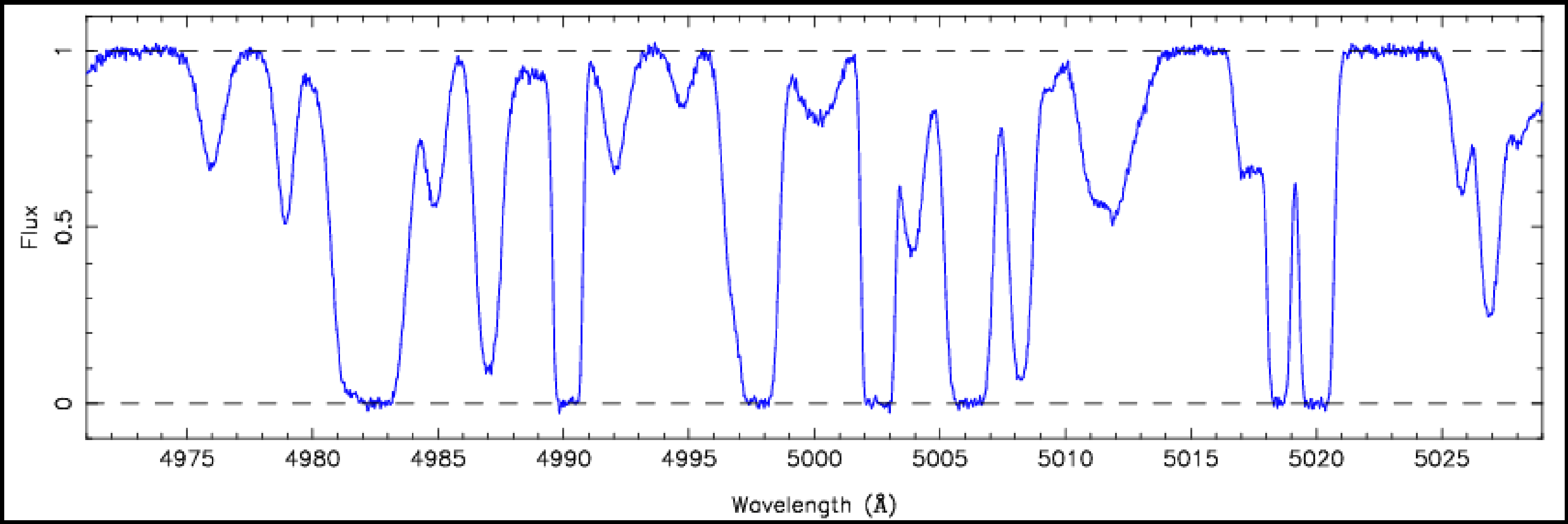


by John Webb

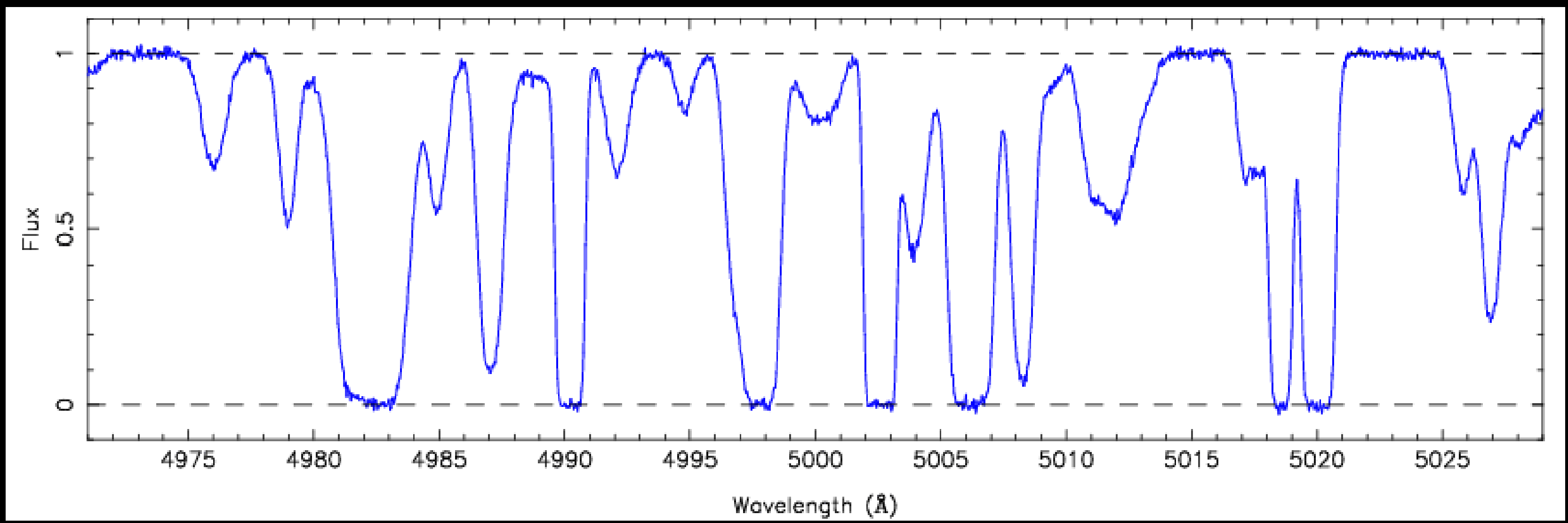
Measuring Cosmic Dynamics



Measuring Cosmic Dynamics



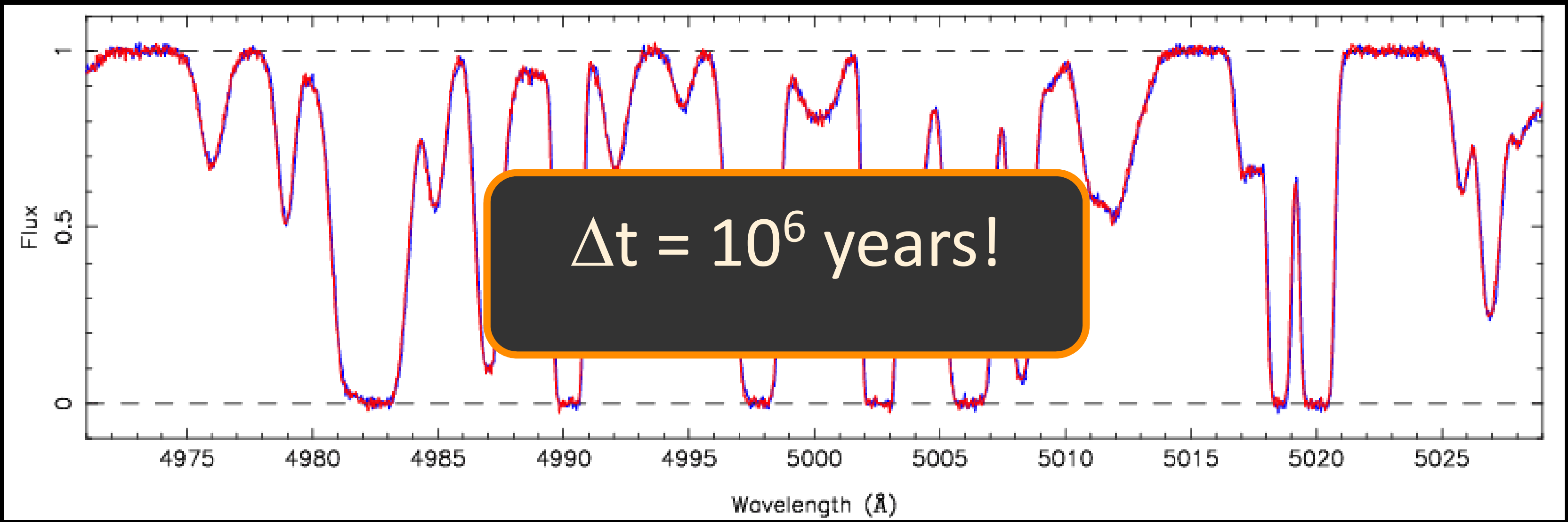
Measuring Cosmic Dynamics



Measuring Cosmic Dynamics

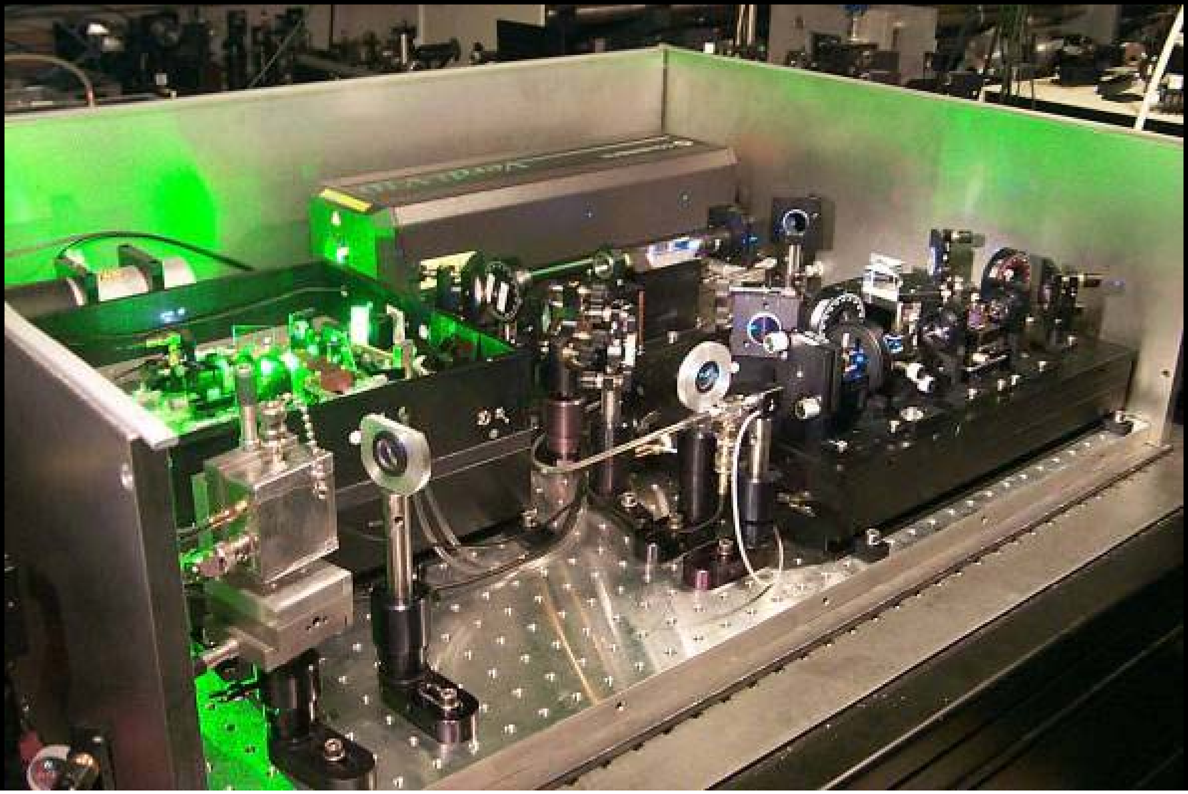
Measuring the redshift drift requires:

- E-ELT
- High-resolution, extremely stable spectrograph: CODEX
- ~20 yr long spectroscopic monitoring campaign.



Frequency Comb

the frequency comb:



Thomas Udem (MPQ)