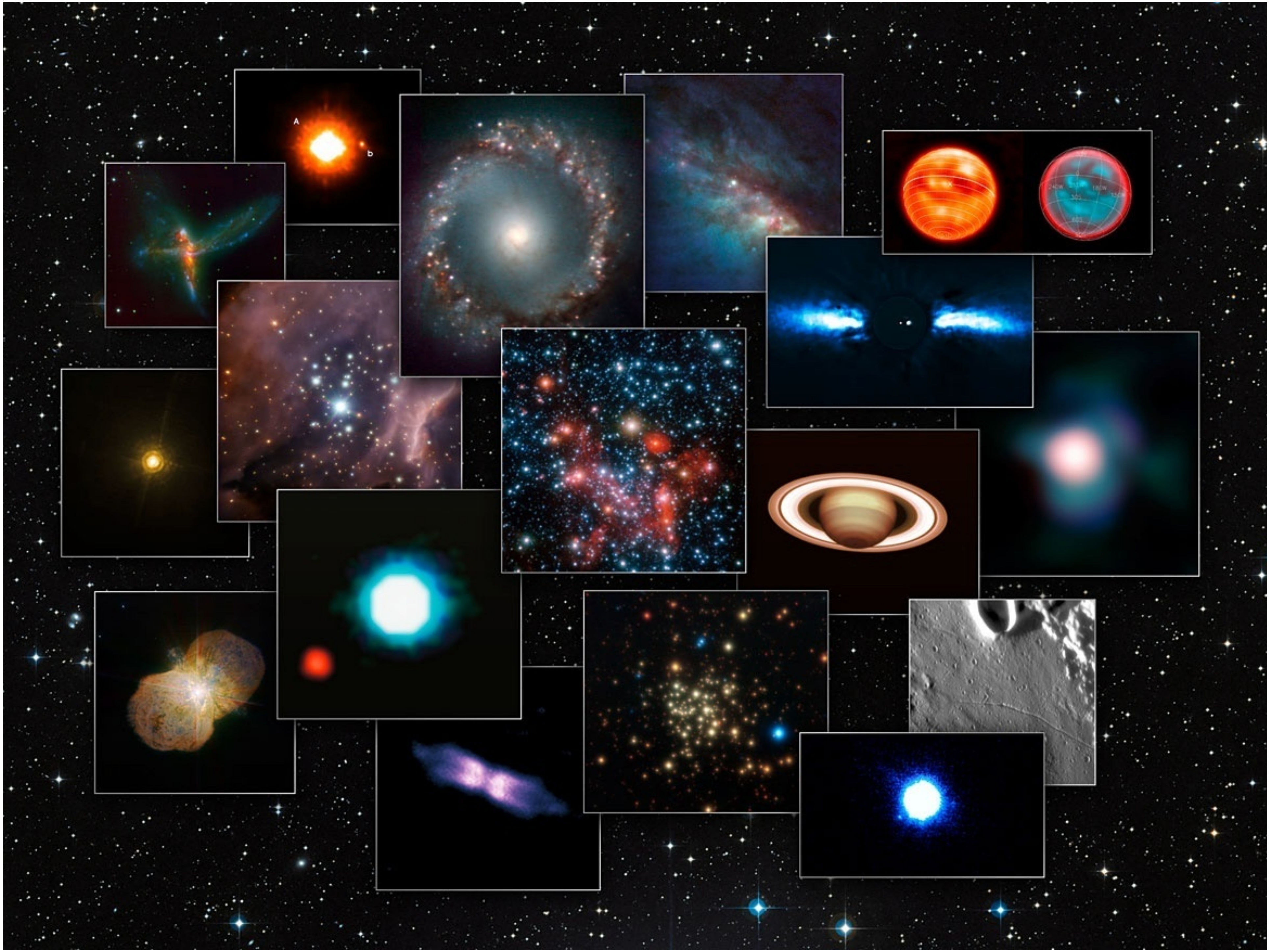
European Southern Observatory

Bruno Leibundgut

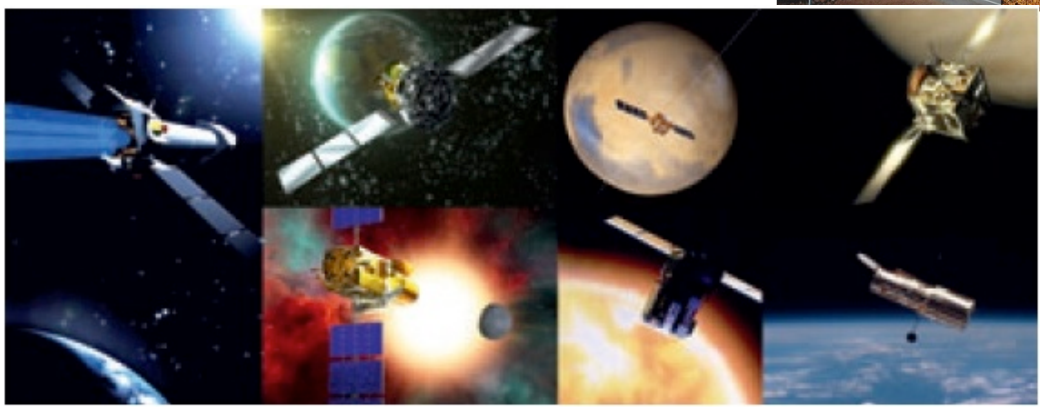

A
b

Earth‘s atmosphere
Shield and Window to the Universe

Astrophysics in a Golden Age

- Full coverage of electro-magnetic spectrum

MAGIC/HESS/VERITAS → Fermi/INTEGRAL → XMM/Chandra/Swift/Rossi XTE → Galex → HST/Gaia → ground-based optical/IR → ISO/Spitzer → Herschel → Planck → IRAM/JCMT/APEX/ALMA/NOEMA → radio telescopes



Astrophysics in a Golden Age

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  - ➢ cover 20 orders of magnitude in frequency/wavelength/ energy

- Astro-particles joining
  - cosmic rays, neutrinos, gravitational waves, dark matter searches

Spectacular Results

- Cosmology with Planck (see François' talk)
- Discovery of Dark Energy
  - Physics Nobel Prize 2011
- Constancy of Fundamental Constants
  - fine-structure constant, proton- to electron-mass ratio
- Exo-planets and planetary systems
- Discovery of pre-biotic molecules
- Nucleosynthesis and stellar explosions

European Southern Observatory

- Mission
  - Develop and operate world-class observing facilities for astronomical research
  - Organize collaborations in astronomy
- Intergovernmental treaty-level organization
  - Founded in 1962 by 5 countries
  - Today 15 member states, Brazil will become 16th
- Observatories in Chile
  - La Silla Paranal: VLT, VLTI, 3.6m, NTT, VISTA, VST
  - Chajnantor: APEX and ALMA partnerships
- Headquarters in Garching and Office in Santiago
- Annual budget of ~140 million €

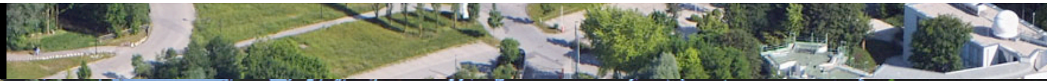
European Southern Observatory

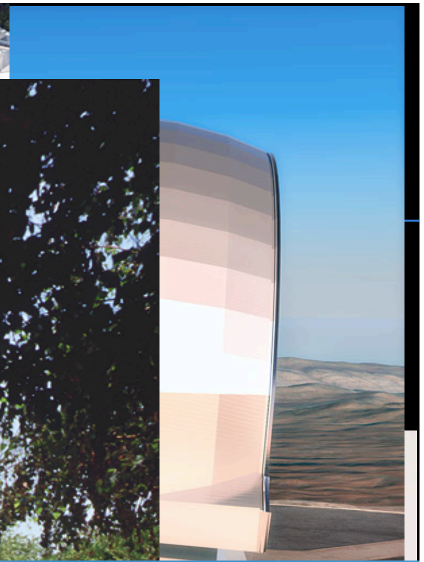
ESO's World

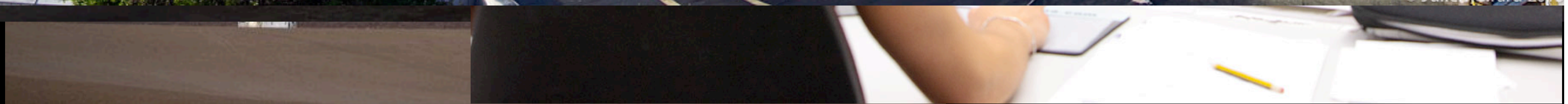
Garching bei München
Chajnantor
Paranal
La Silla
Santiago
Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap001127.html
Astronomy Picture of the Day
2000 November 27
http://antwrp.gsfc.nasa.gov/apod/astropix.html

Observa

8 Tel

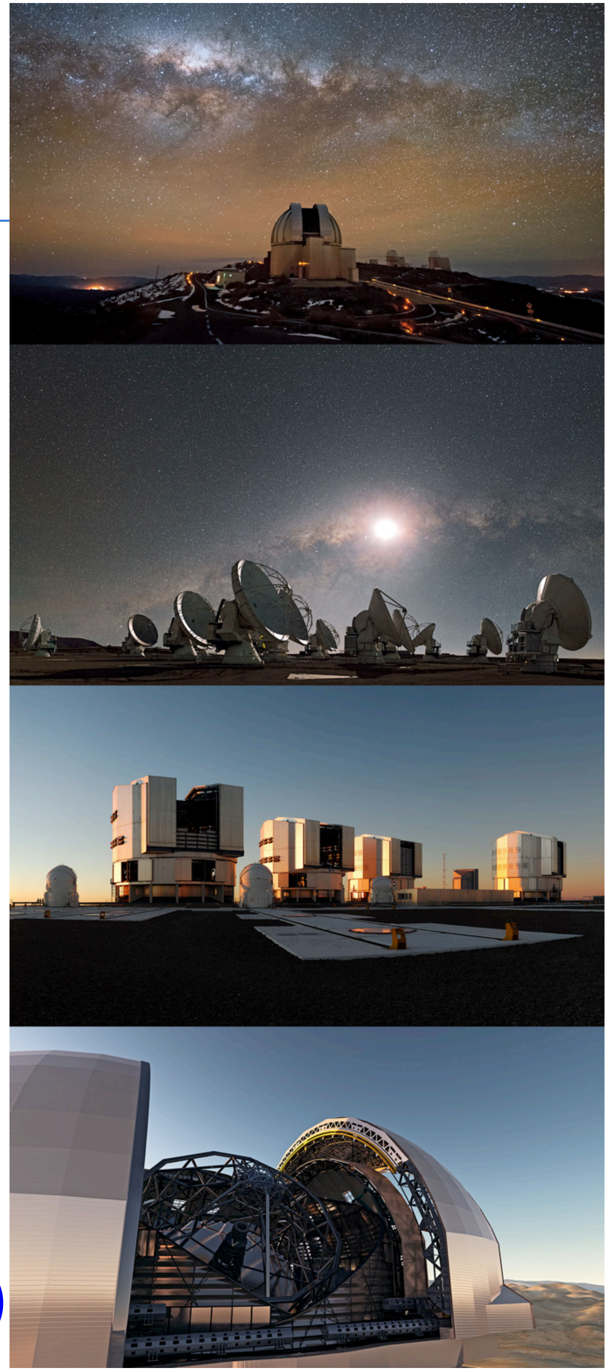


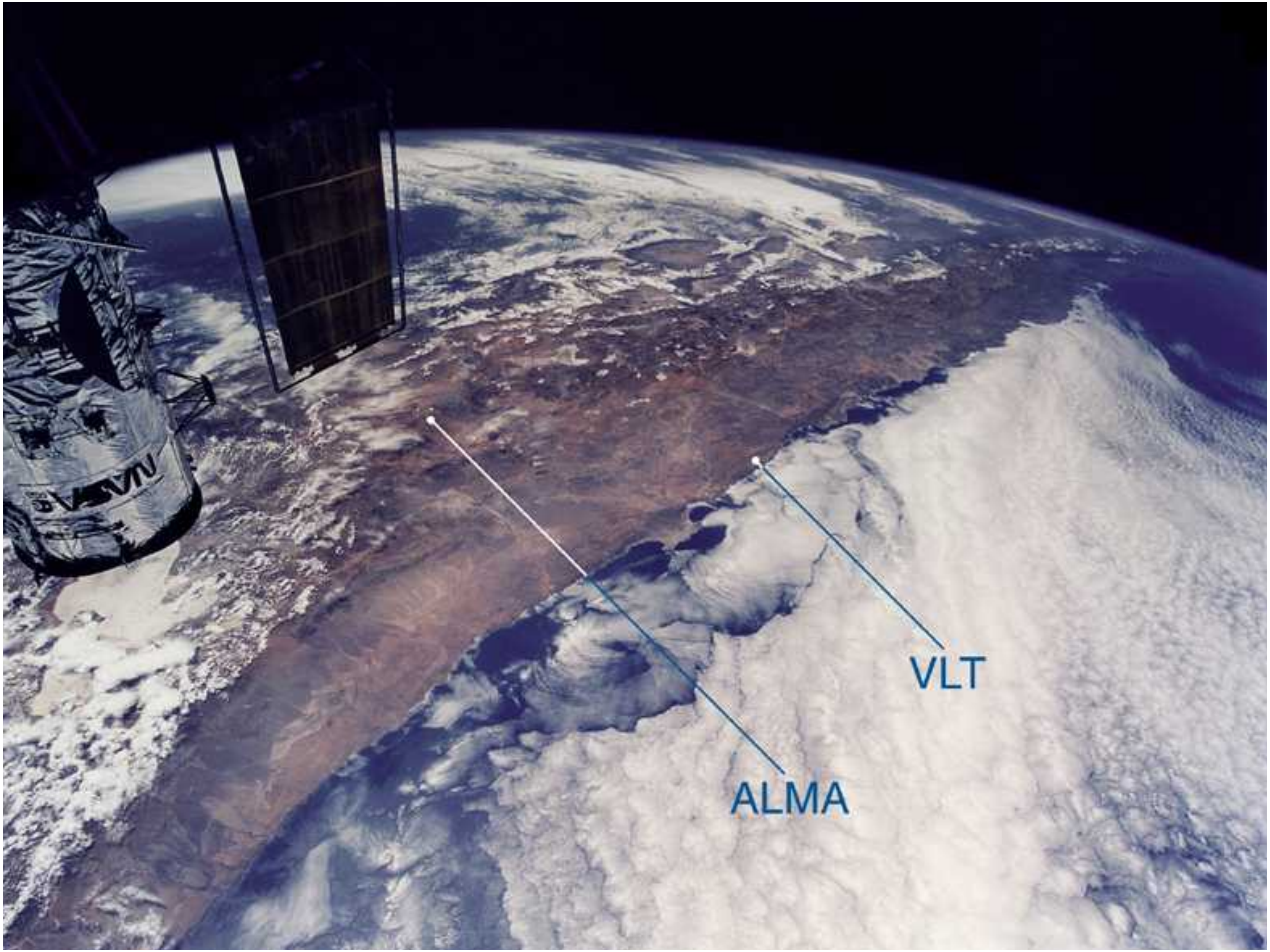




ESO Facilities

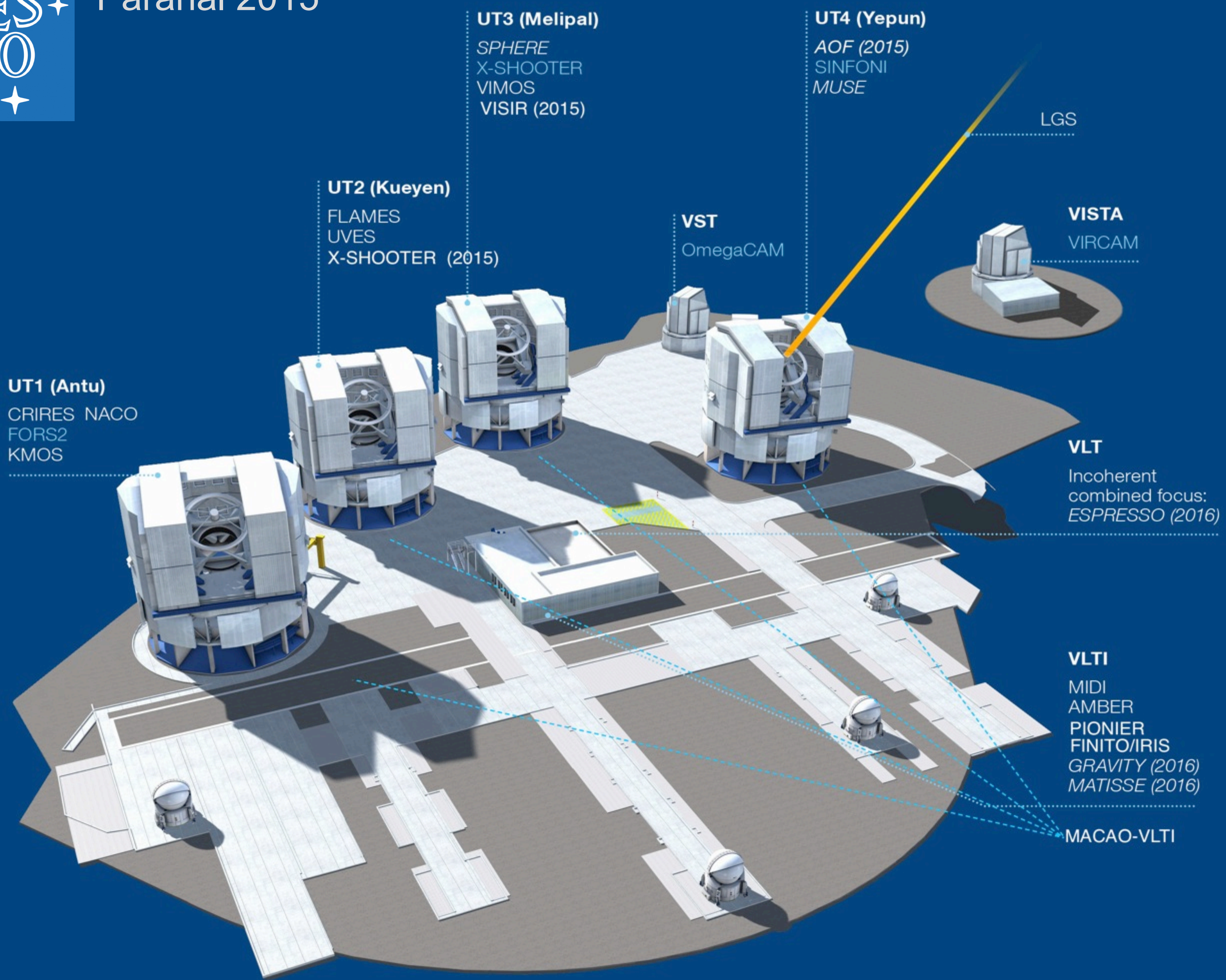
- Optical near-infrared observatories
  - most sensitive to hot black body radiation (T>1000 K)
  - atomic transitions
  - some molecular transitions
  - Very Large Telescope (VLT)
  - Survey telescopes (VISTA and VST)
  - Extremely Large Telescope (E-ELT)
- mm-wavelength observatories
  - cold objects (T<100K)
  - rotational and vibrational transitions in molecules
  - Atacama Large Millimeter Array (ALMA)
  - Atacama Pathfinder EXperiment (APEX)



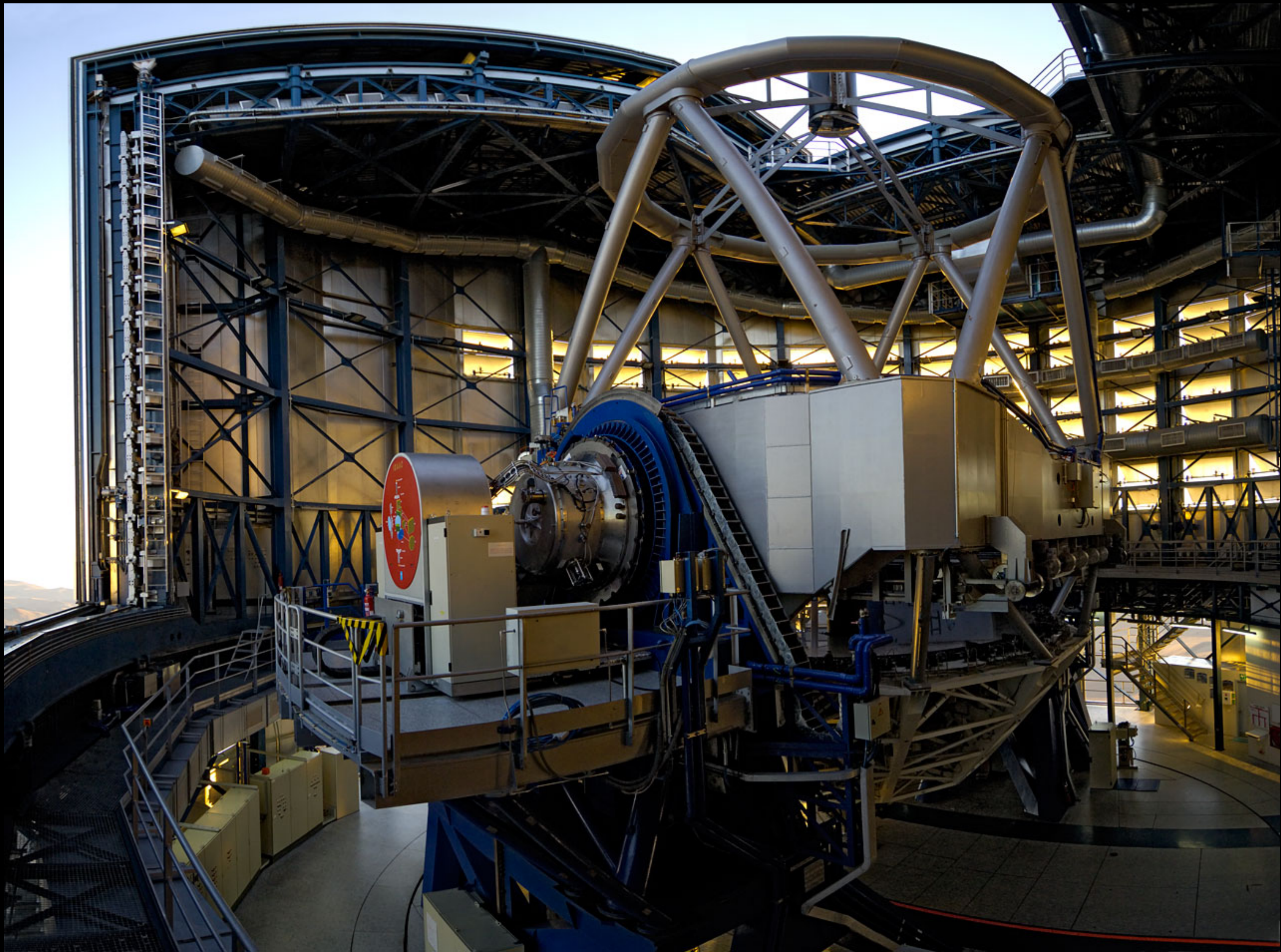

VLT
ALMA


The VLT is the world´s most productive ground-based facility:
more than one scientific paper per day!

Paranal 2015

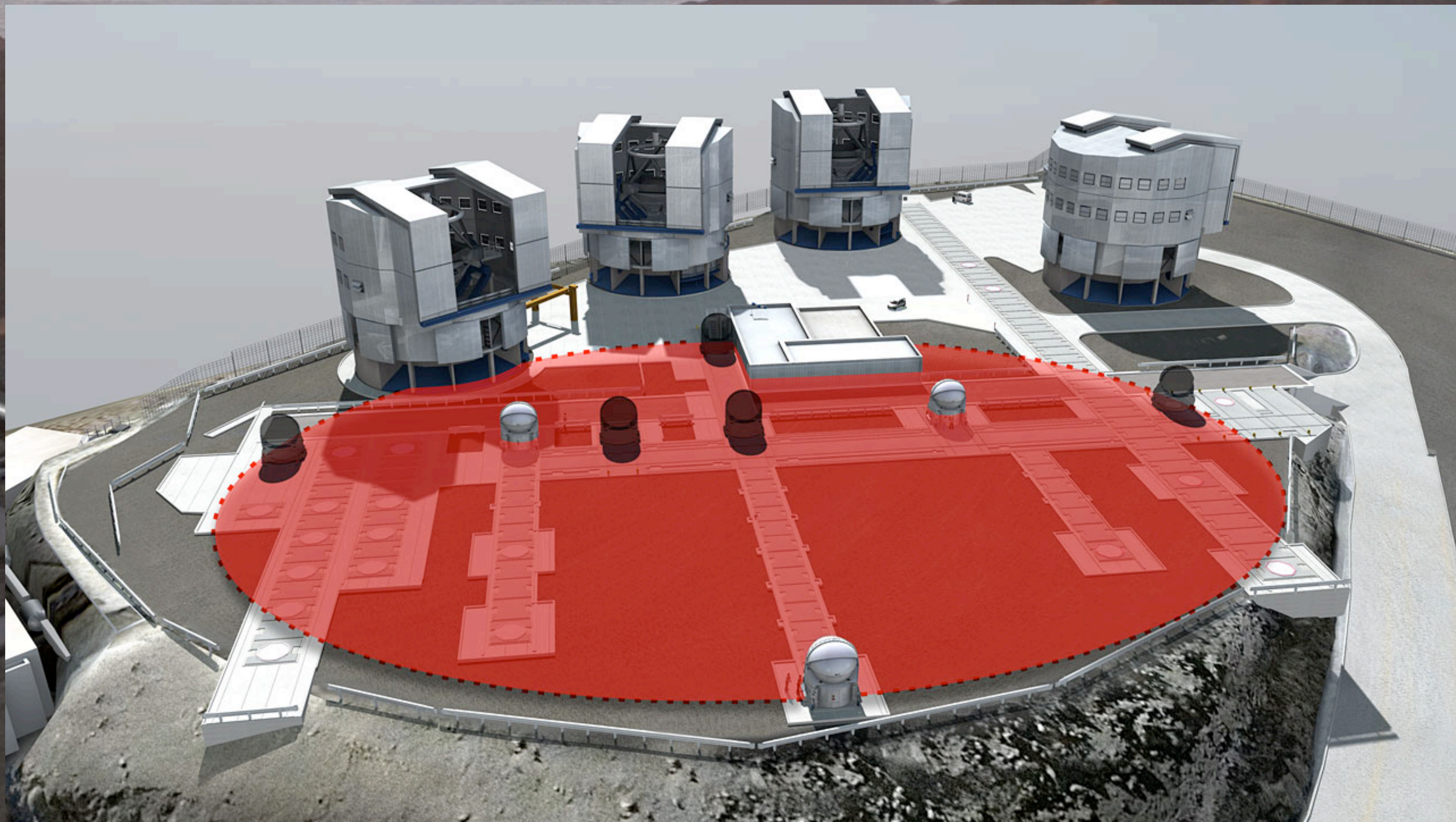


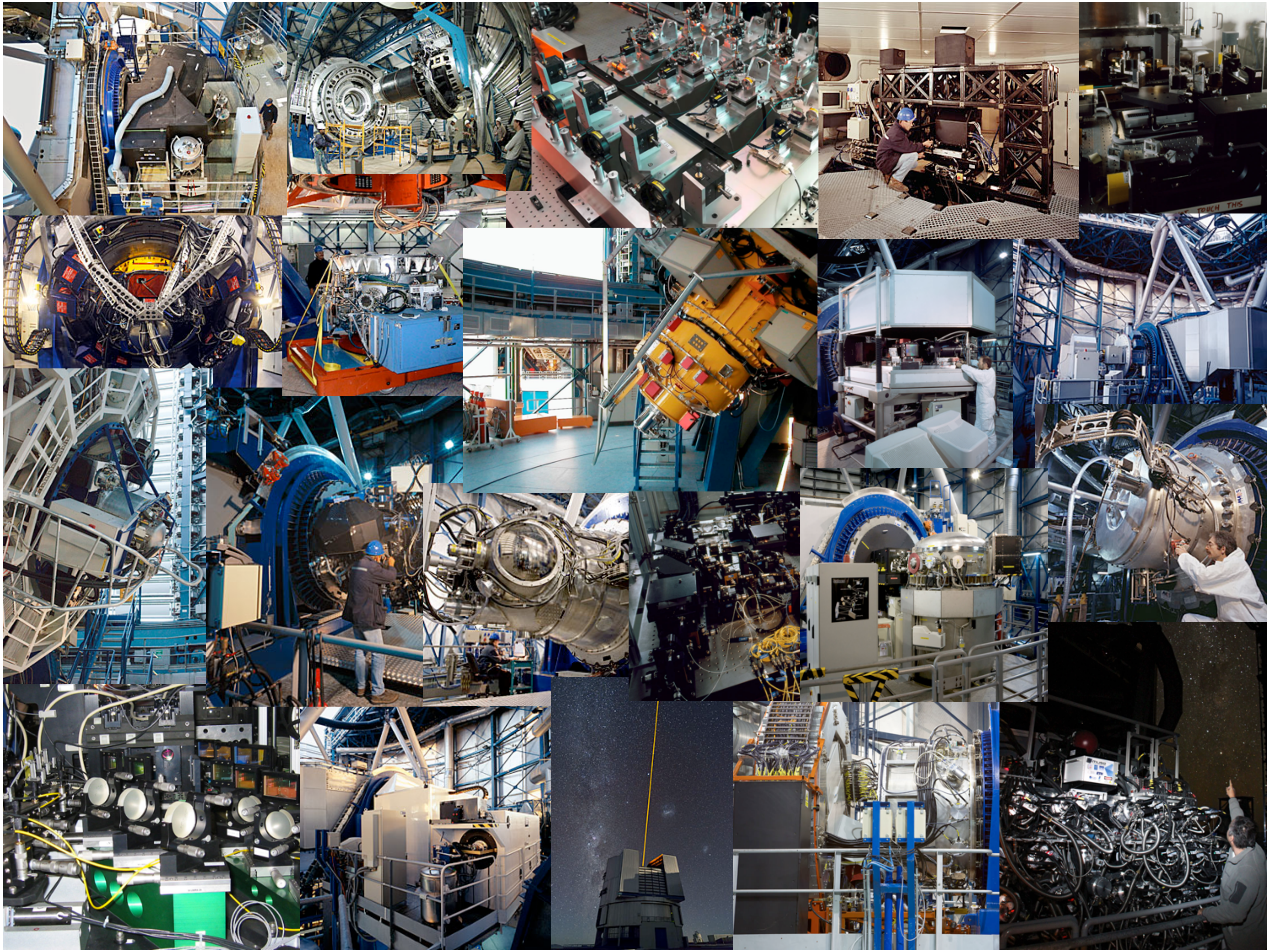
One of the 8m telescopes



VLTI - Very Large Telescope Interferometry

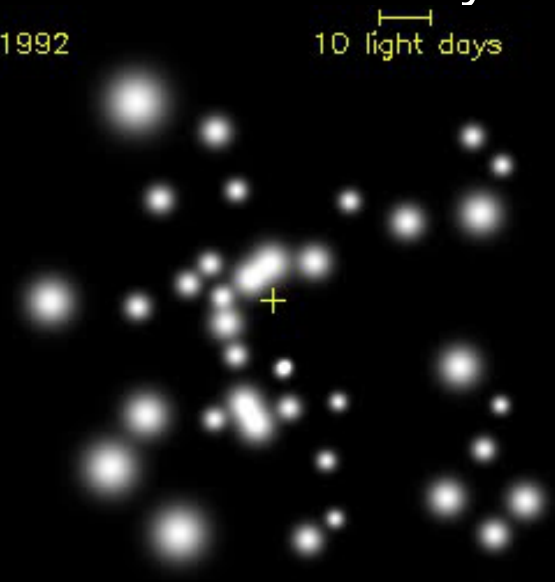
The VLTI is a virtual 100-Meter Telescope

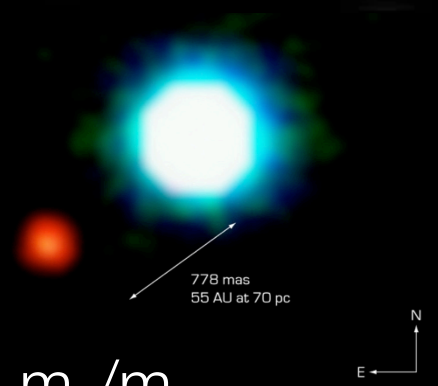




Some Results

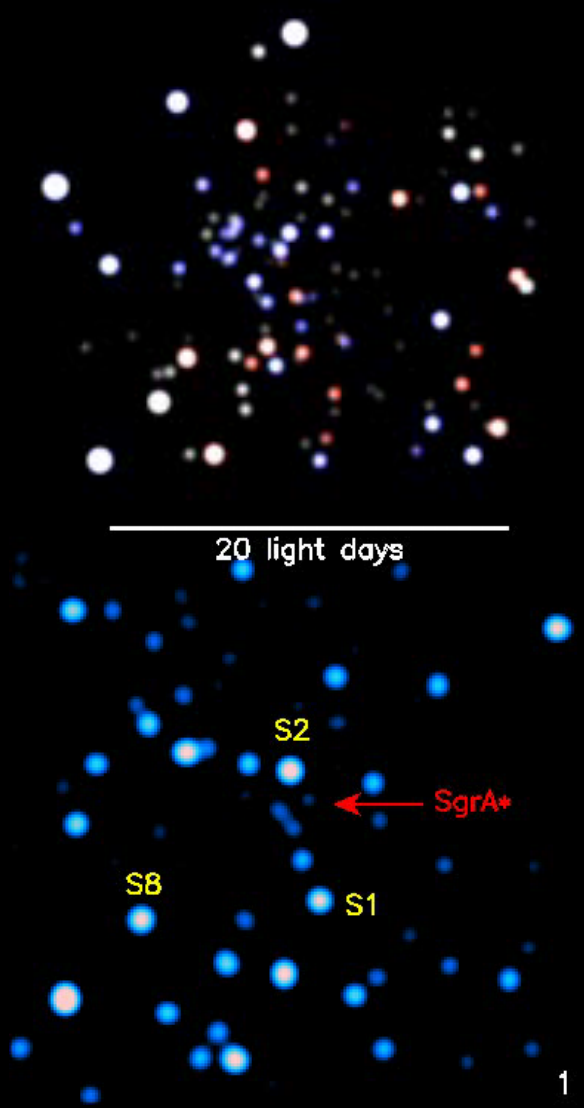
- Supermassive black hole at the centre of the Milky Way
  - test GR in strong gravity
- Discovery of accelerated expansion through supernovae
  - test GR in weak gravity
- Characterisation of exo-planets
  - stability of planetary systems
  - exo-planet atmospheres
  - search for life
- Constancy of fundamental constants
  - no changes of fine-structure constant and m_p/m_e





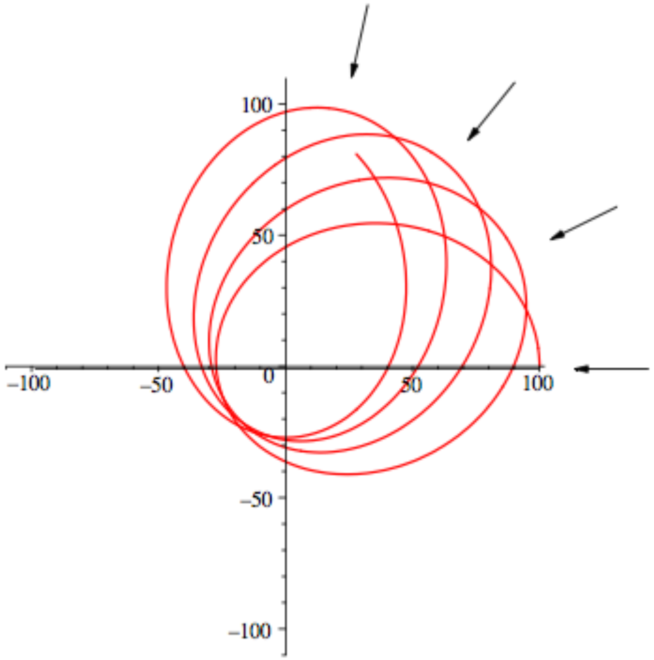
Black hole at the Centre of the Milky Way

- Mass determination through stellar orbits (about 40 known)
  - $M \approx 4 \cdot 10^6 M_\odot$
- Structure around the black hole revealed through flashes
- Post-Newtonian effects predicted for the next passage of star S2
  - direct test of GR in the strong field



Galactic Centre

- Pericenter shift probes the nature of the black hole
  - measure post-Newtonian effects



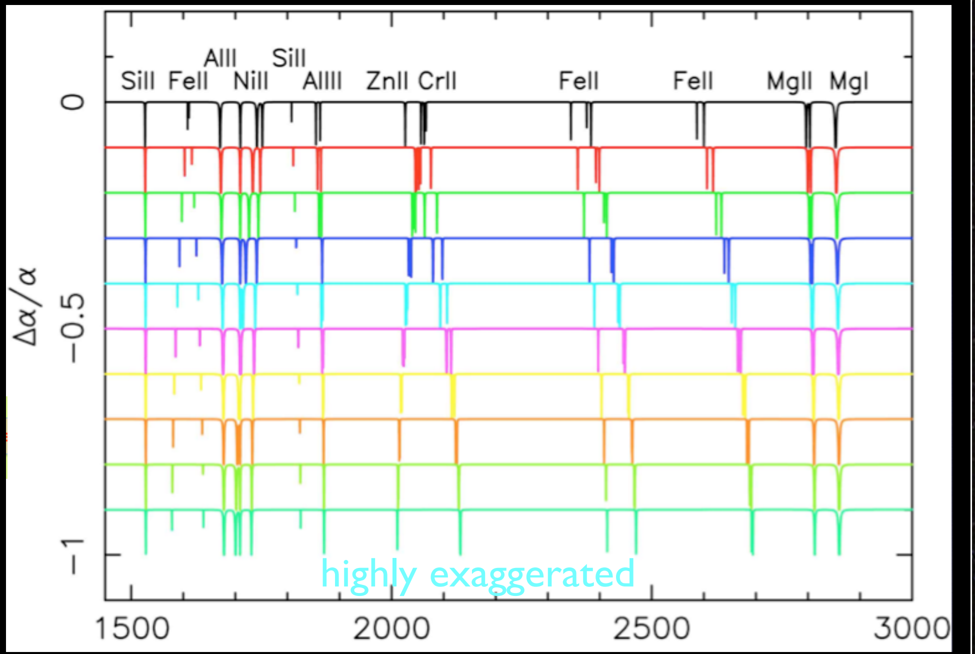
$$\Phi = -\frac{G\,M}{r} + f\,\frac{G\,M\,l^2}{c^2\,r^3}$$

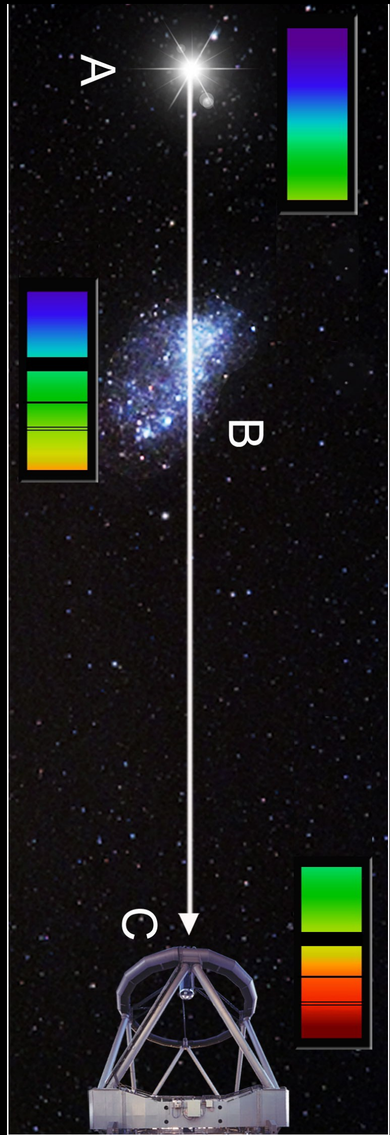
Higher order terms necessary to take into account GR in the strong gravity regime
GRAVITY at VLTI aims at constraining them

Cosmology with high resolution

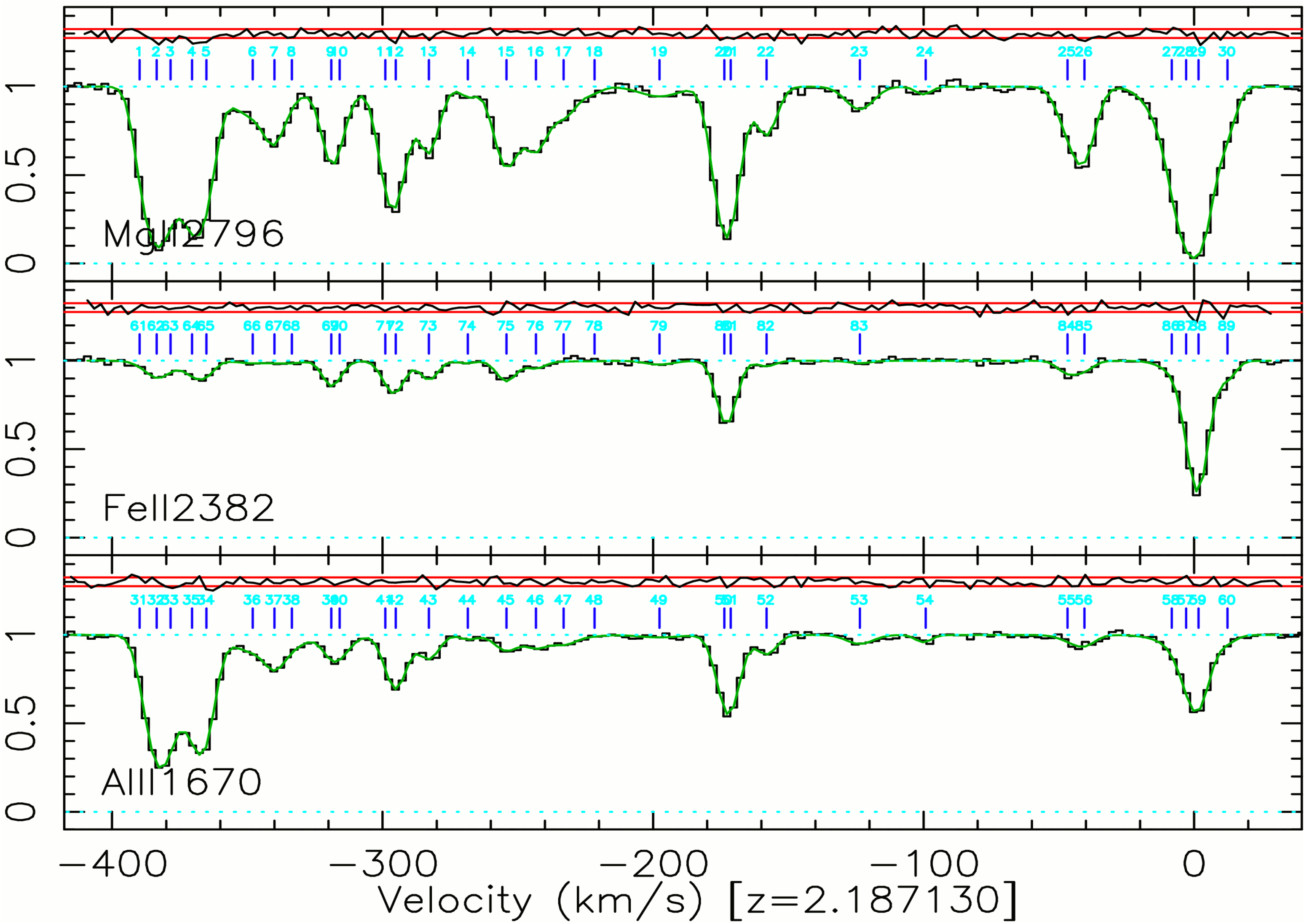
- Measure absorption lines of intervening galaxies towards quasars
- Determine line shifts due to changing fine structure constant

$$\alpha = \frac{e^2}{\hbar c}$$

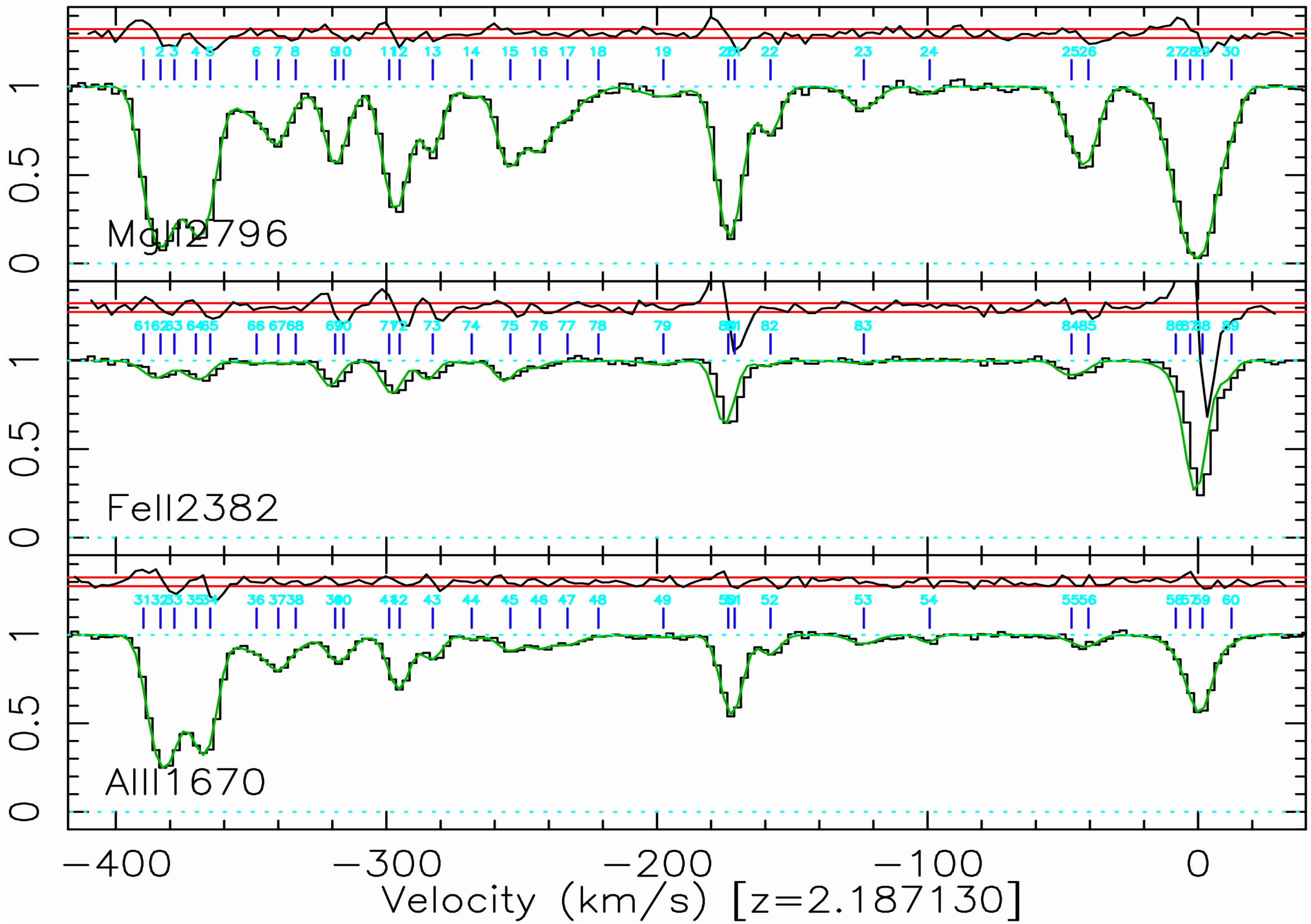




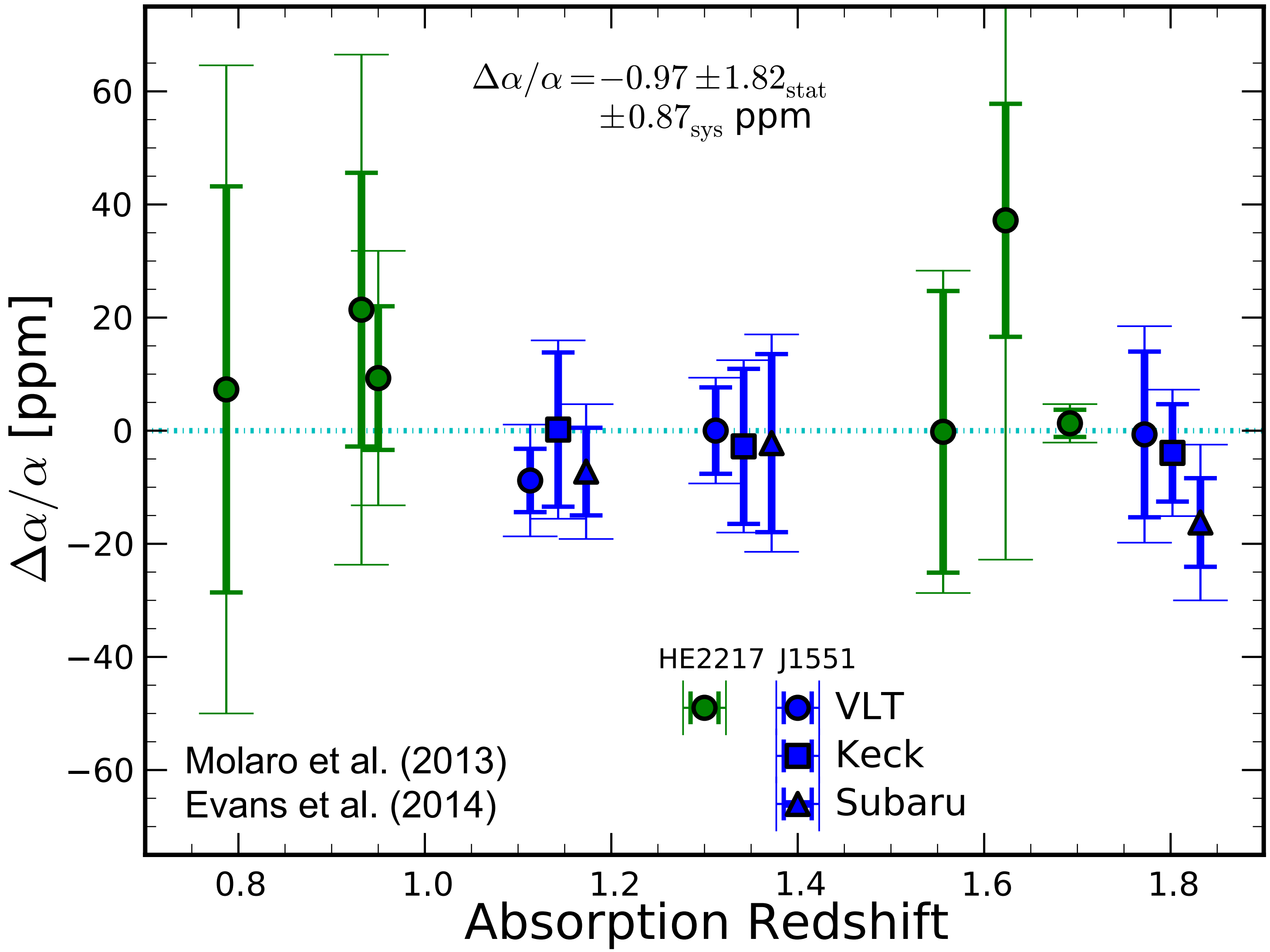
VLT/UVES absorber: $\Delta\alpha/\alpha=0$



VLT/UVES absorber: $\Delta\alpha/\alpha=10^{-4}$



Currently no change detected

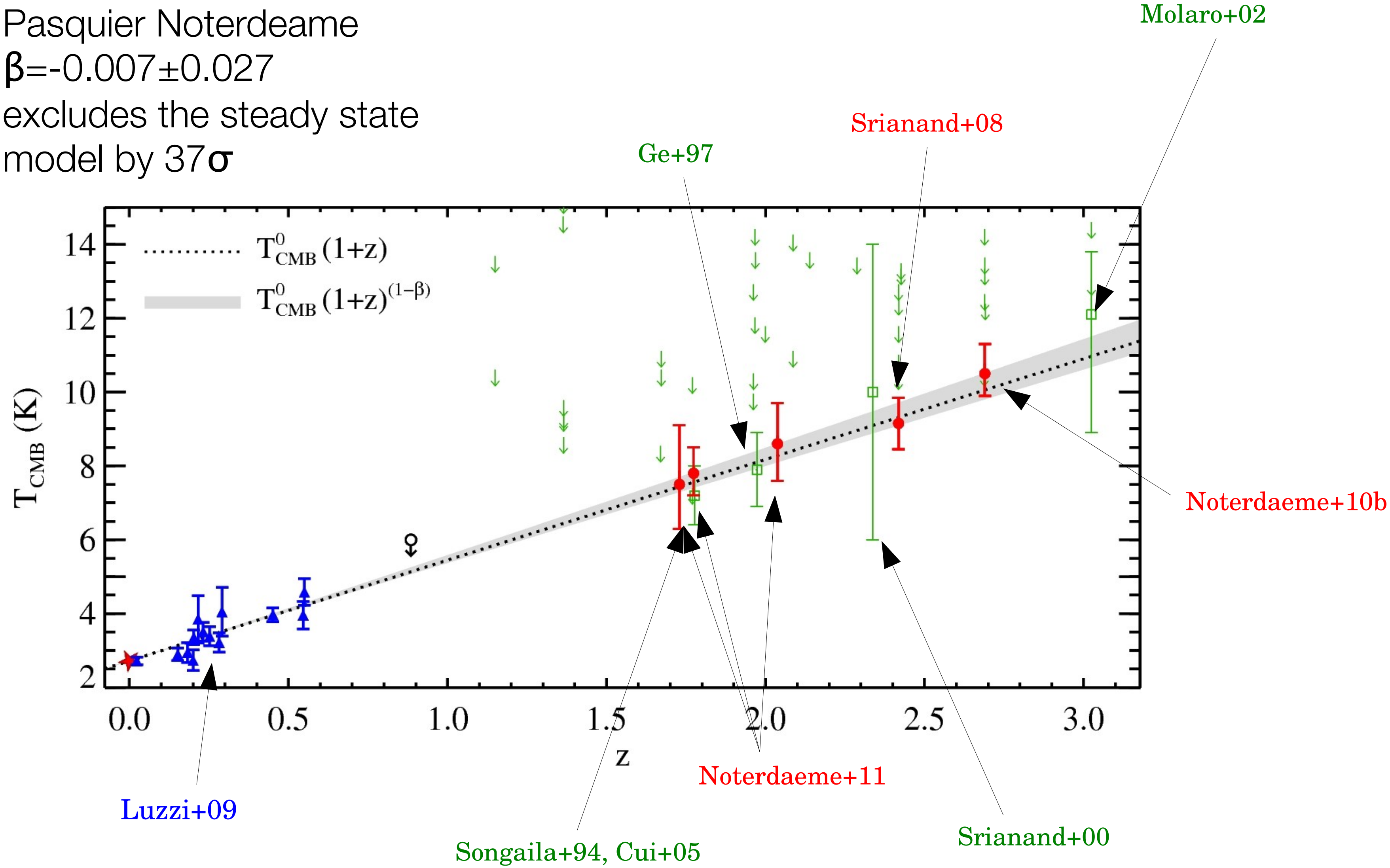


Temperature of the CMB

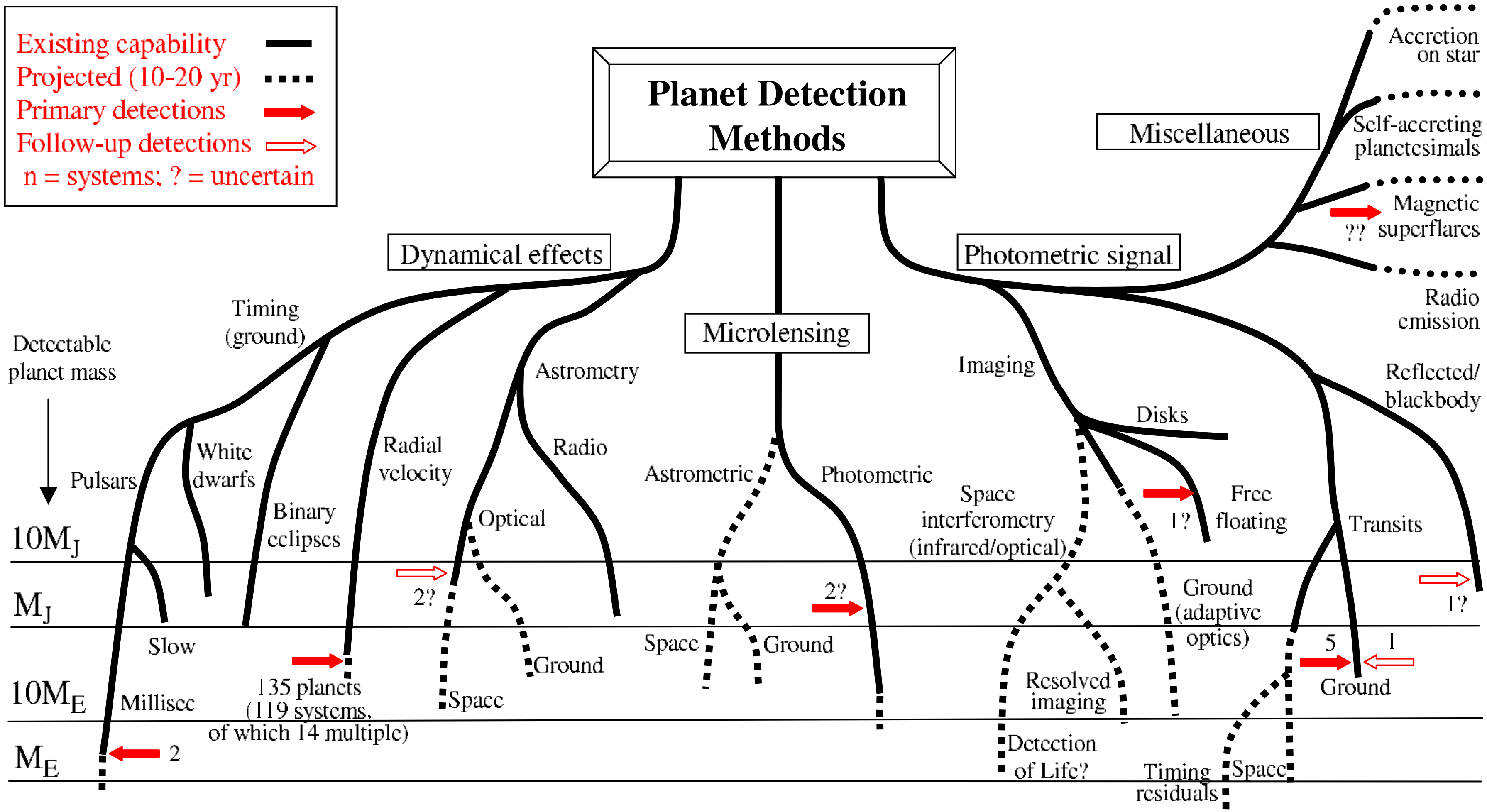
- Adiabatic expansion of the universe predicts
  - $T_{CMB}(z)=T_0(1+z)$
    - deviations would indicate violation of equivalence principle or non-conservation of photons
- Direct excitation of interstellar molecules
  - Measure rotational transitions of CO as absorption line at different redshifts
    - excitation energy close to the CMB temperature

Temperature of the CMB

Pasquier Noterdeame
β=-0.007±0.027
excludes the steady state model by 37σ



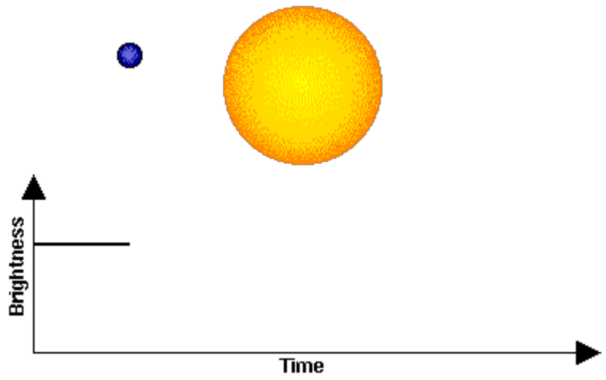
Planets, planets, planets



Perryman et al. 2005

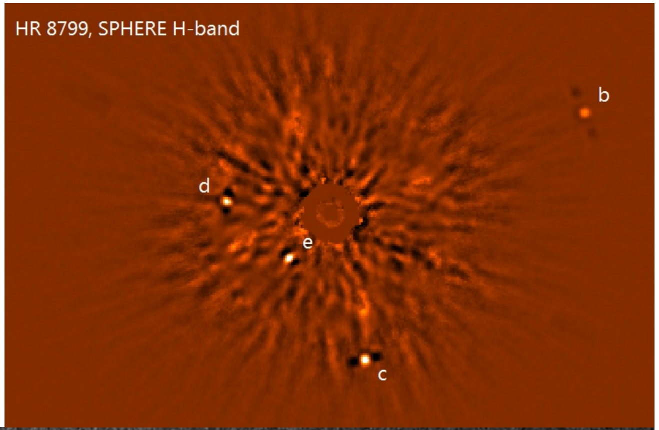
Exo-Planets

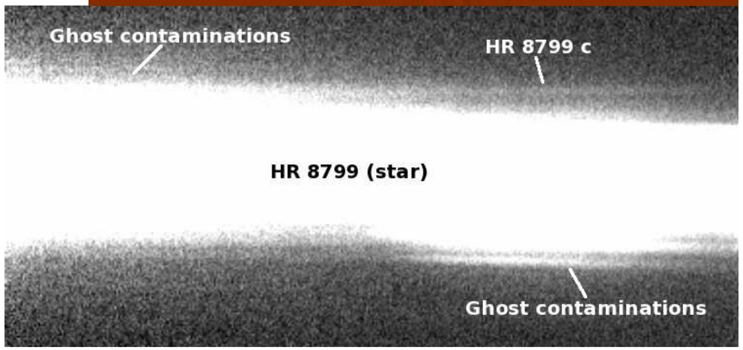
- Emphasis is shifting
  - most discoveries expected through transits
  - characterisation of atmospheres
  - discovery of Earth-like planets
  - characterisation of hot Jupiters
- Requires different instruments
  - Many global ongoing surveys
    - Next Generation Transit Surveys (NGTS – Paranal)
    - dedicated telescopes hosted at ESO sites (e.g. Swiss Euler)
    - future space missions (TESS, CHEOPS, PLATO)
  - Continued radial velocity surveys
    - masses through the combination with the transits
  - Atmosphere characterisation

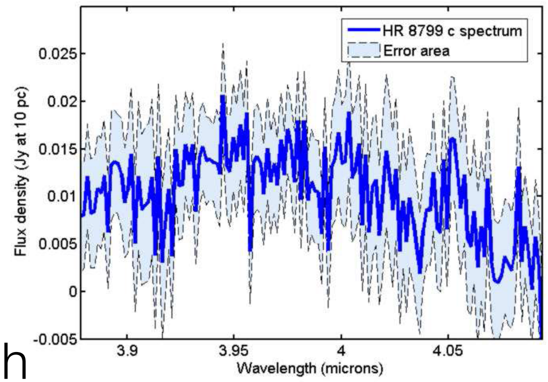


The ESO exo-planet machinery

- High-resolution spectrographs
  - HARPS at 3.6m telescope
    - best radial velocity machine at a 4m telescope, extremely stable spectrograph
  - ESPRESSO at VLT in the future
- Adaptive Optics cameras
  - NACO/SPHERE
    - imaging, direct detection
- Adaptive Optics spectrographs
  - NACO/SINFONI/FORS2
    - atmospheres of exo-planets
- Interferometry
  - highest spatial resolution for follow-up observations of known systems
- Infrared high-resolution spectrographs
  - CRIRES+, NIRPS
    - spectroscopy of atmospheres
    - low mass host stars → Earth mass planet search

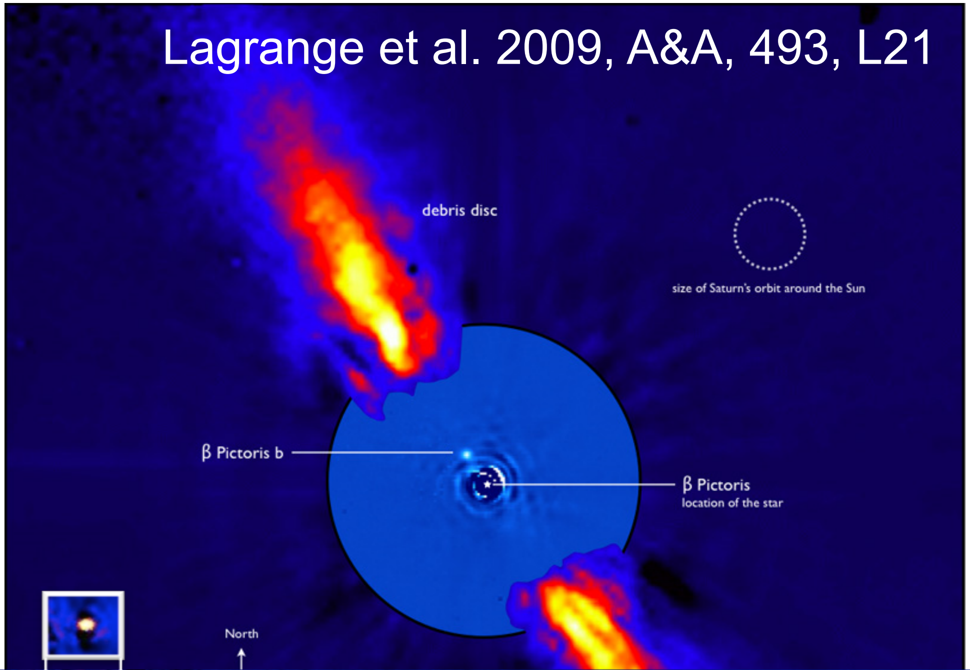


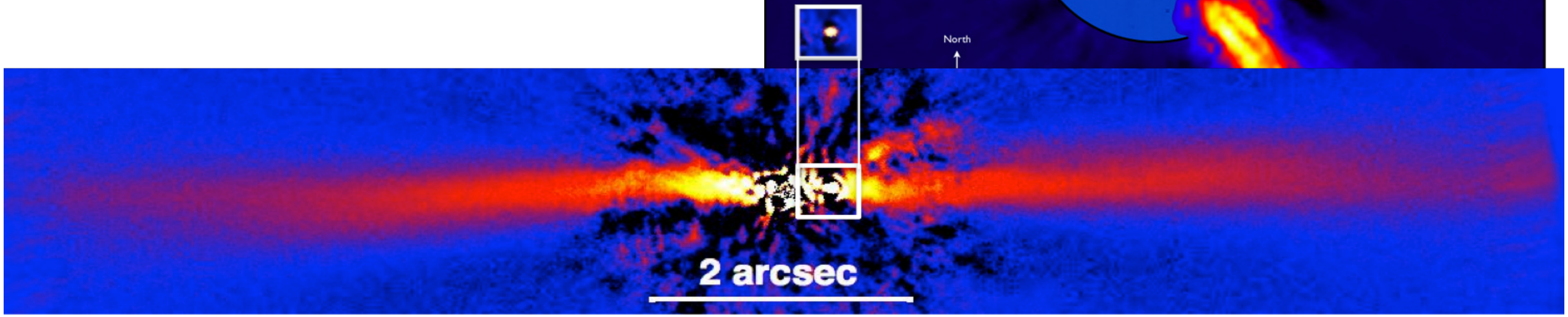




β Pic planet

- Planet (~10 M_{jup}) within the massive dust disk
- Orbit only a few AU
- NACO imaging
- SPHERE imaging
  - planet – star separation
    - ~350 mas

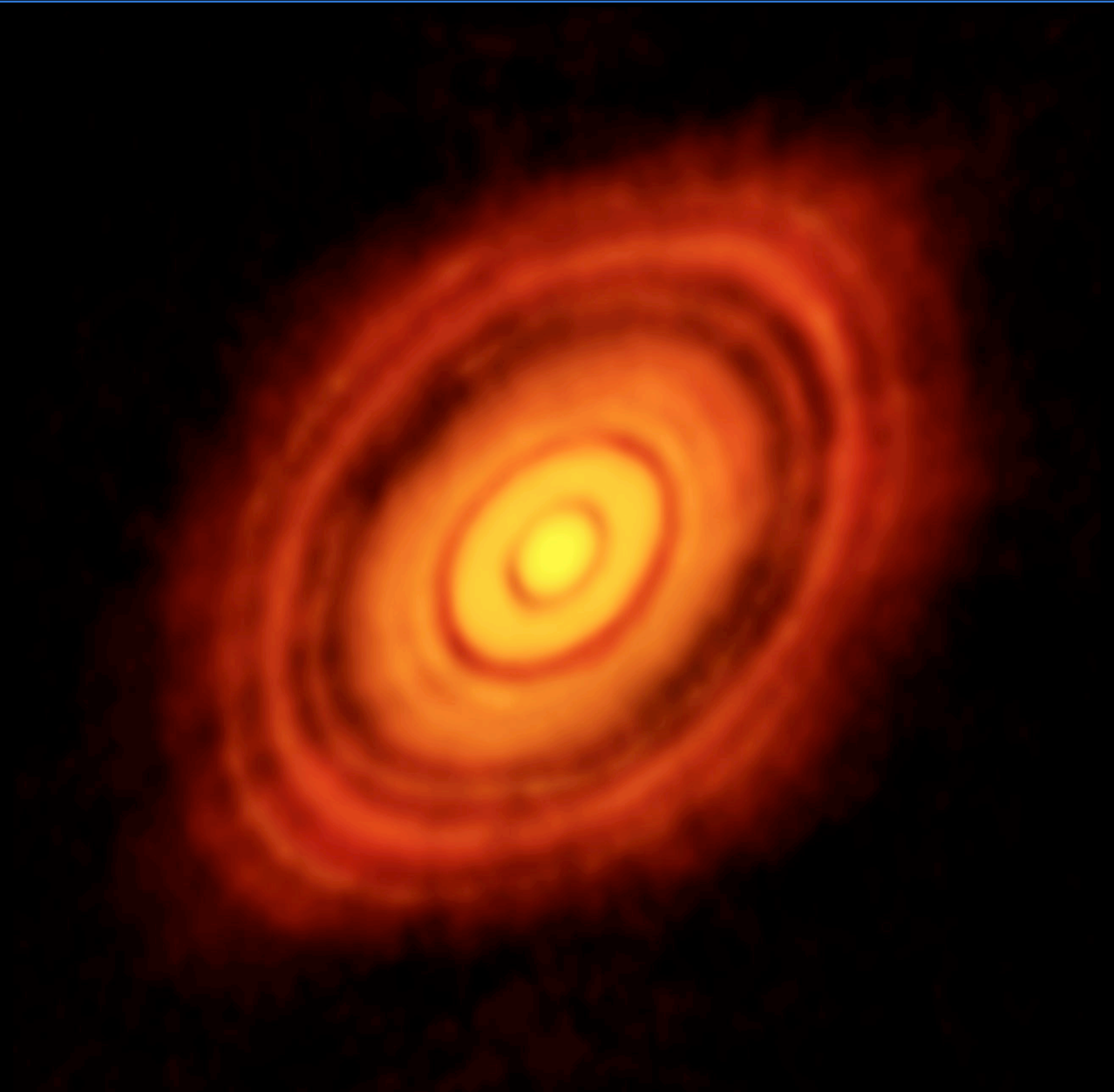




ALMA

- Observe the cold universe
  - wavelengths from 300 µm to 1.3 mm (1 THz to 200 GHz)
- Global Partnership
  - Europe (ESO), North America (USA/NSF and Canada/NRC), East Asia (Japan/NINS, Taiwan/NSC/ASIAA, South Korea/KASI)
- 66 antennas located at 5000m altitude
  - 50 12m antennas
  - 12 7m + 4 12m antennas (compact array)

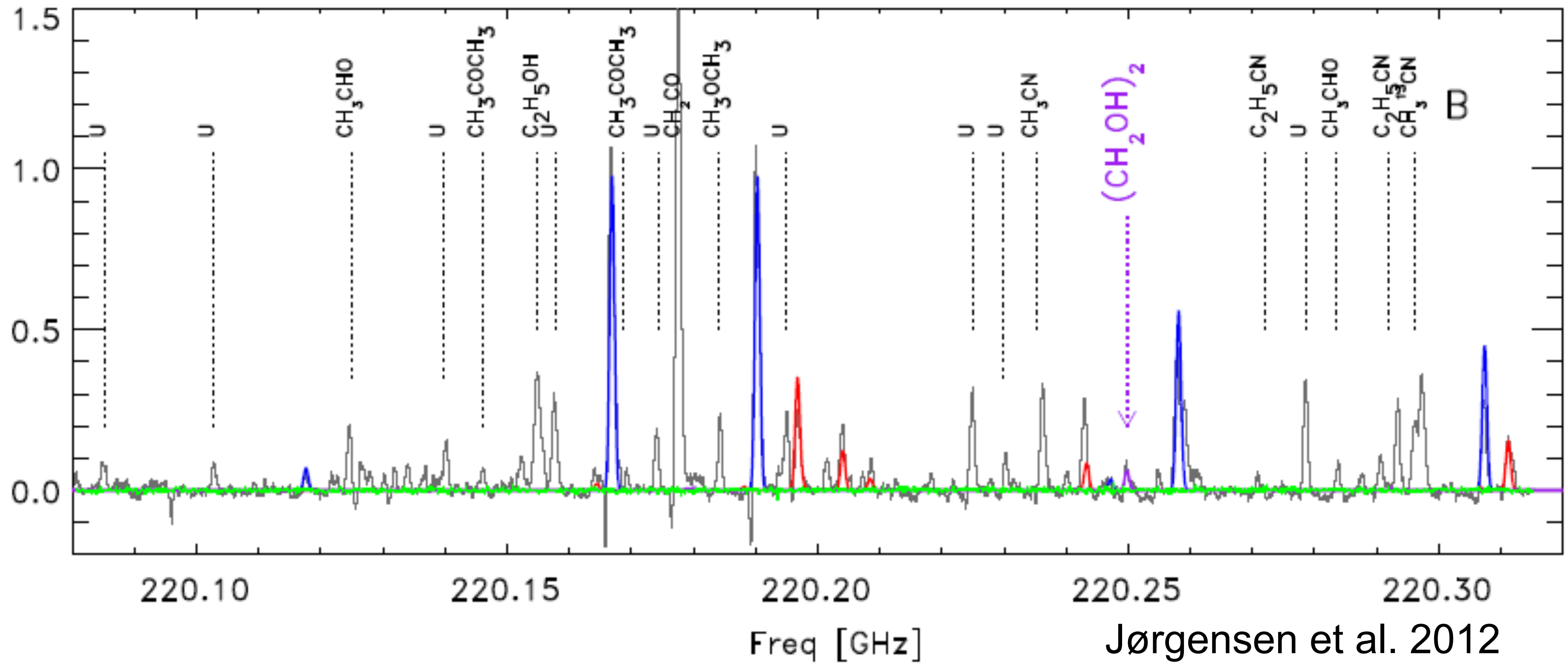
HL Tau



ALMA

Complex molecules in space

- Detection of sugar molecule
  - glycolaldehyde $HCOCH_2OH$ and several alcohols
    - e.g. methyl formate, ketene (CH_2CO), trans-ethanol (t-C_2H_5OH)
  - Class 0 binary proto-star with about solar mass

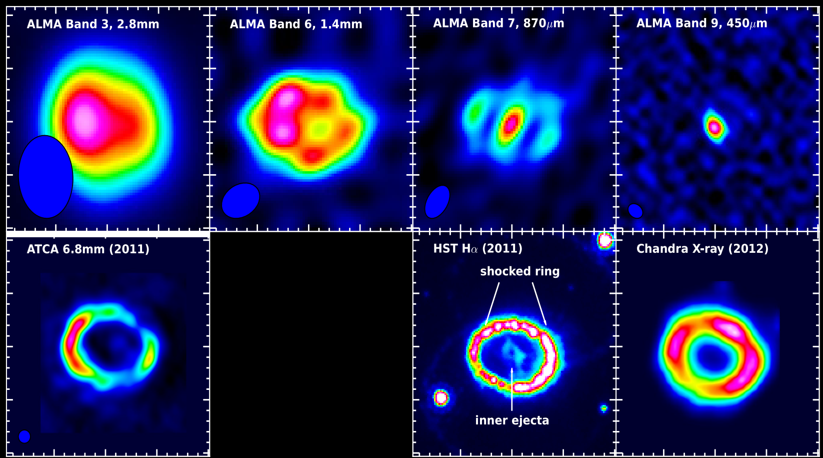


Jørgensen et al. 2012

SN 1987A
an example of a multi-wavelength study

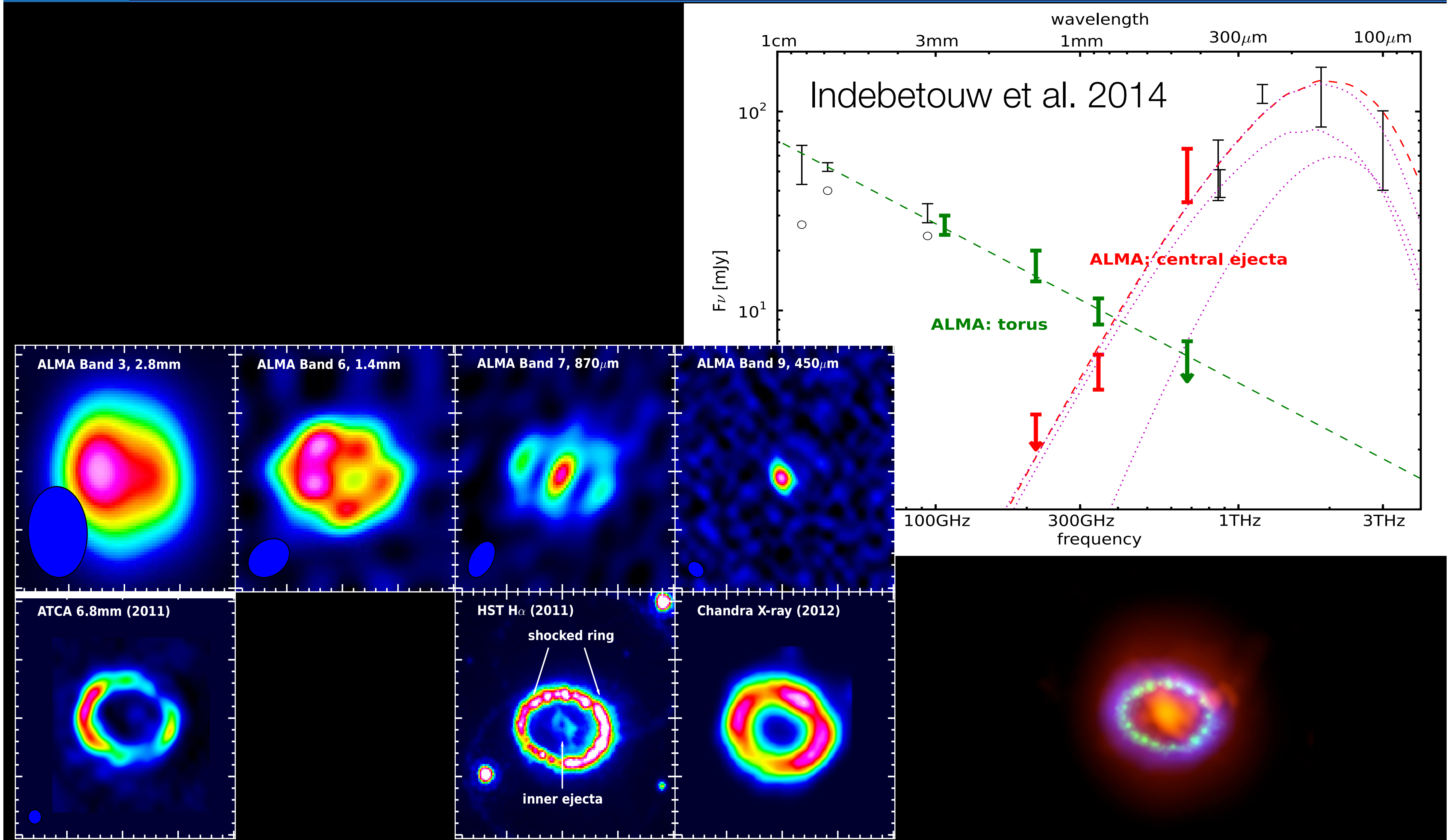
- Neutrino source at explosion
- Follow-up observations for 28 years
  - HST, VLT, Chandra, XMM/Newton, ATCA

SN 1987A in 2013
Indebetouw et al. 2014



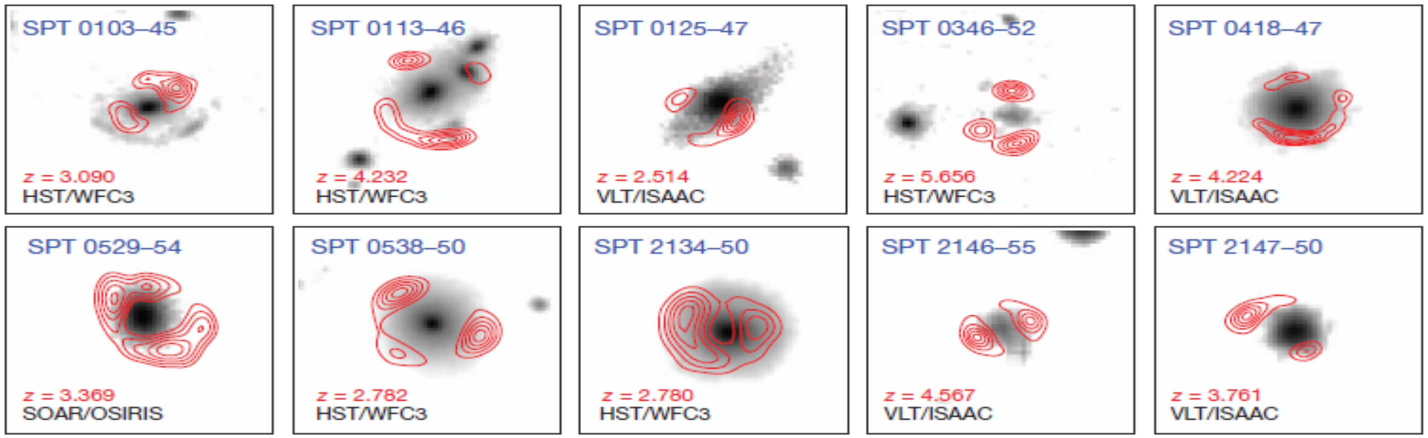
HST - Fransson et al. 2015

SN 1987A


wavelength
1cm
3mm
1mm
300μm
100μm
Indebetouw et al. 2014
10^2
10^1
Fν [mJy]
ALMA: central ejecta
ALMA: torus
100GHz
300GHz
1THz
3THz
frequency
ALMA Band 3, 2.8mm
ALMA Band 6, 1.4mm
ALMA Band 7, 870μm
ALMA Band 9, 450μm
ATCA 6.8mm (2011)
HST Hα (2011)
shocked ring
inner ejecta
Chandra X-ray (2012)

Distant galaxies with ALMA

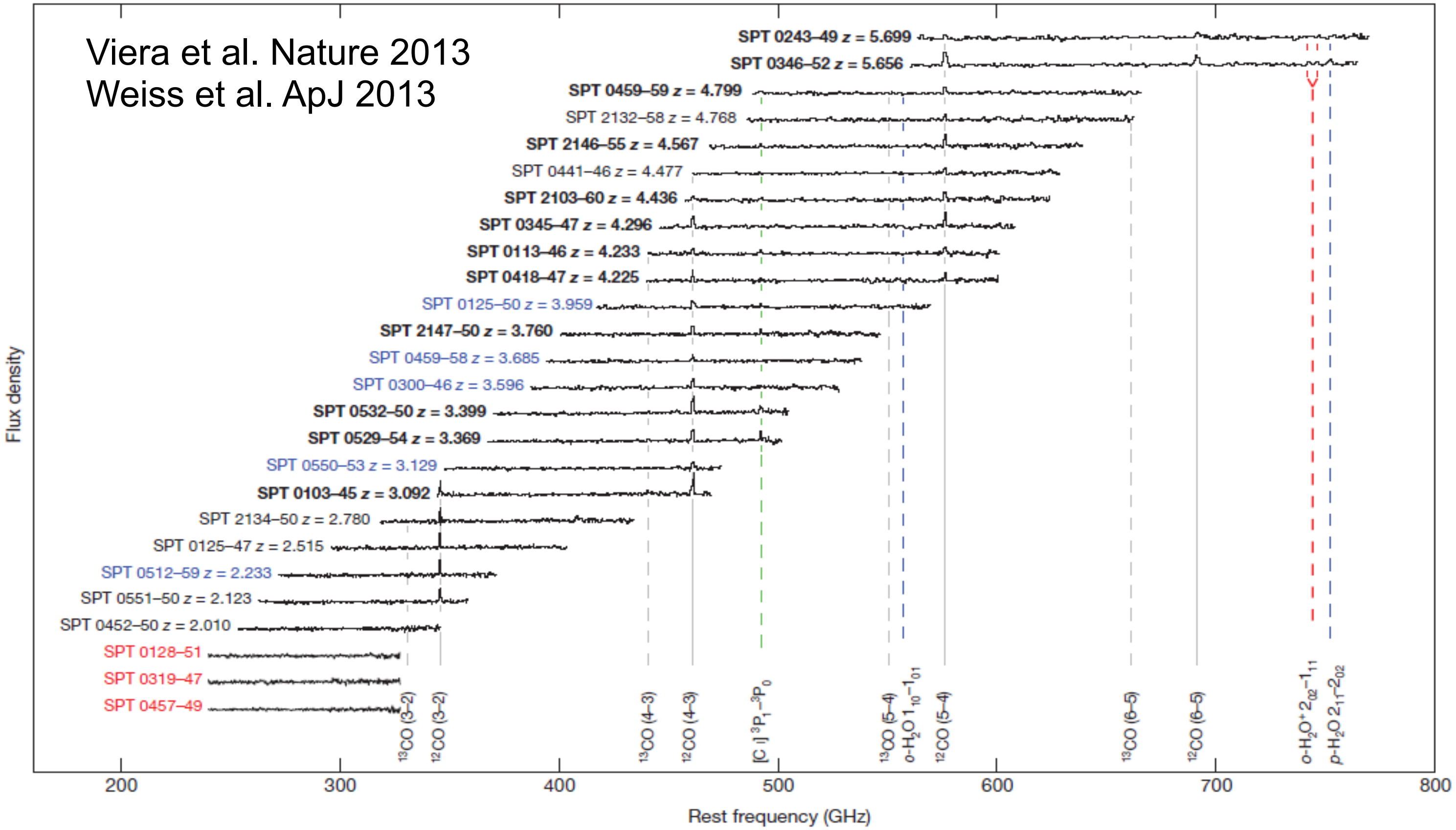
- Follow-up of mm sources discovered with the South Pole Telescope (SPT)
  - Detected many high-redshift galaxies (<z>=3.5)
  - 860μm ALMA imaging (Cycle 0 – 16 antennas)
    - 47 candidates → several clearly lensed sources
    - Integration times 1 minute
    - 2 objects at z=5.7 with high star formation rate > 500 $M_{\odot}$ yr^{-1}



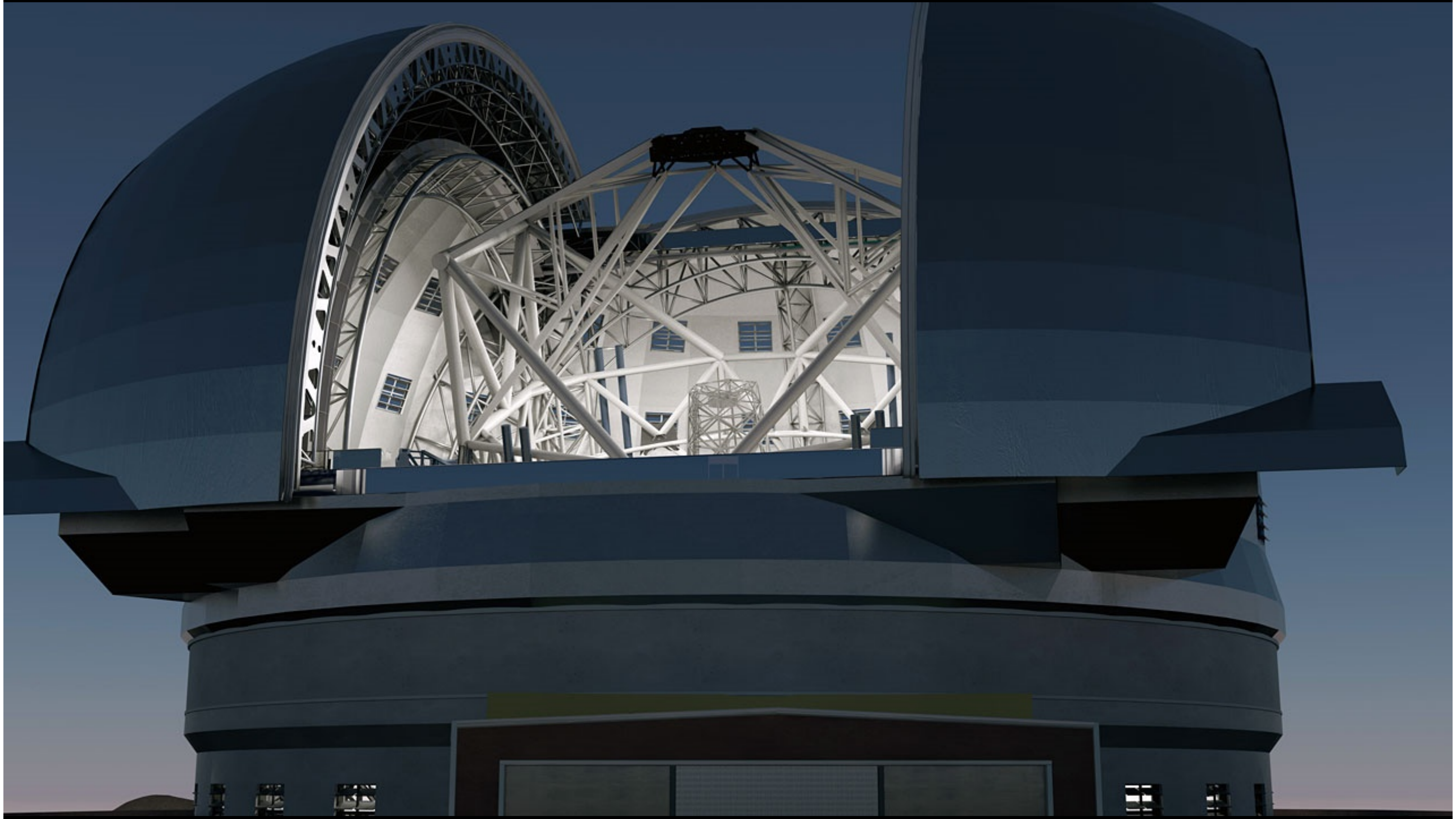
Viera et al. Nature 2013; Hezaveh et al. ApJ 2013

Distant galaxies with ALMA

- Secure redshifts for many sources
  - ALMA 3mm spectroscopy
  - Integration times about 10 minutes
    - Lines detected of ^{12}CO, ^{13}CO, CI, H_2O



ESO's next project - E-ELT



Cerenkov Telescope Array

- Southern array potentially to be placed near Paranal/ Armazonas