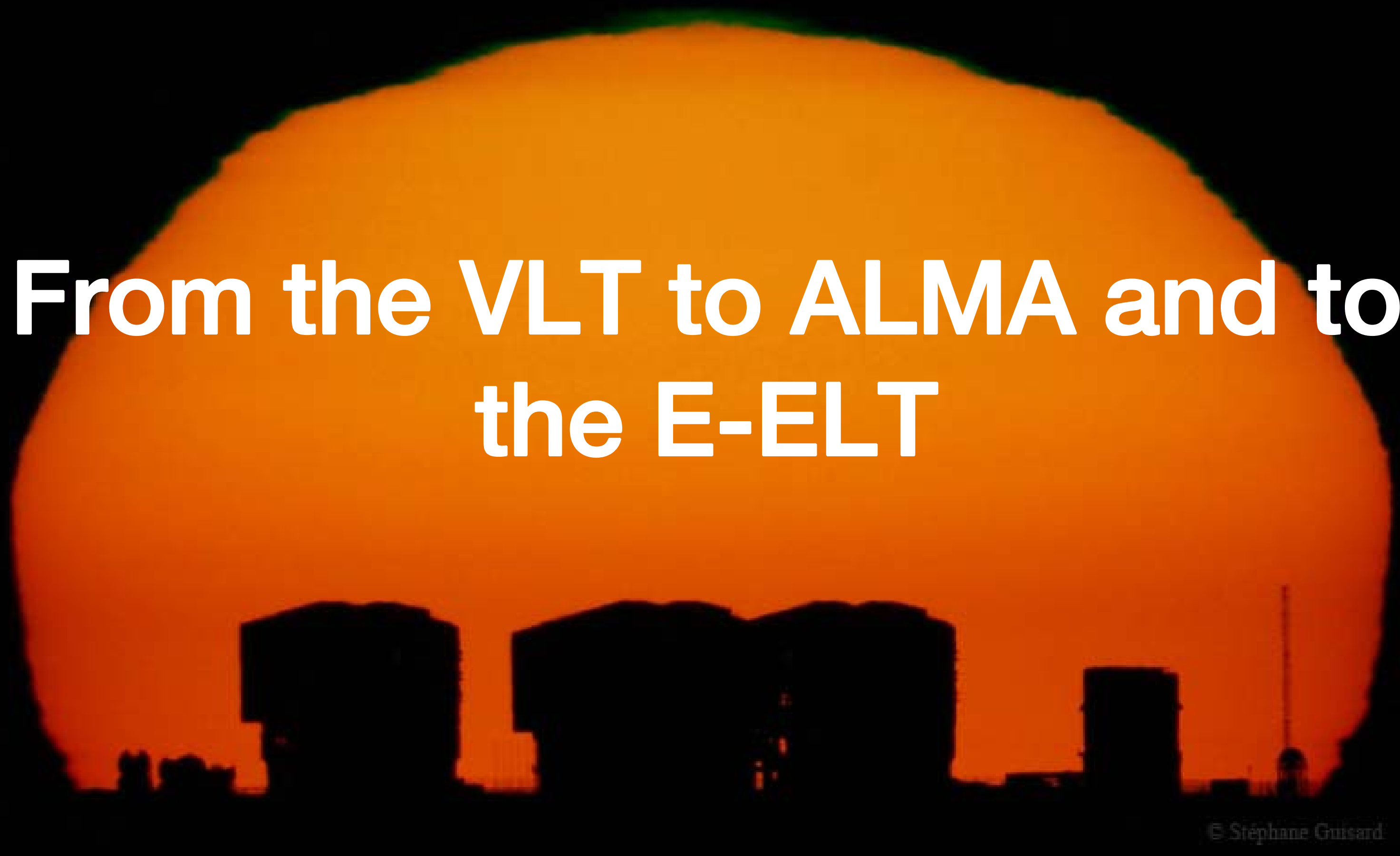
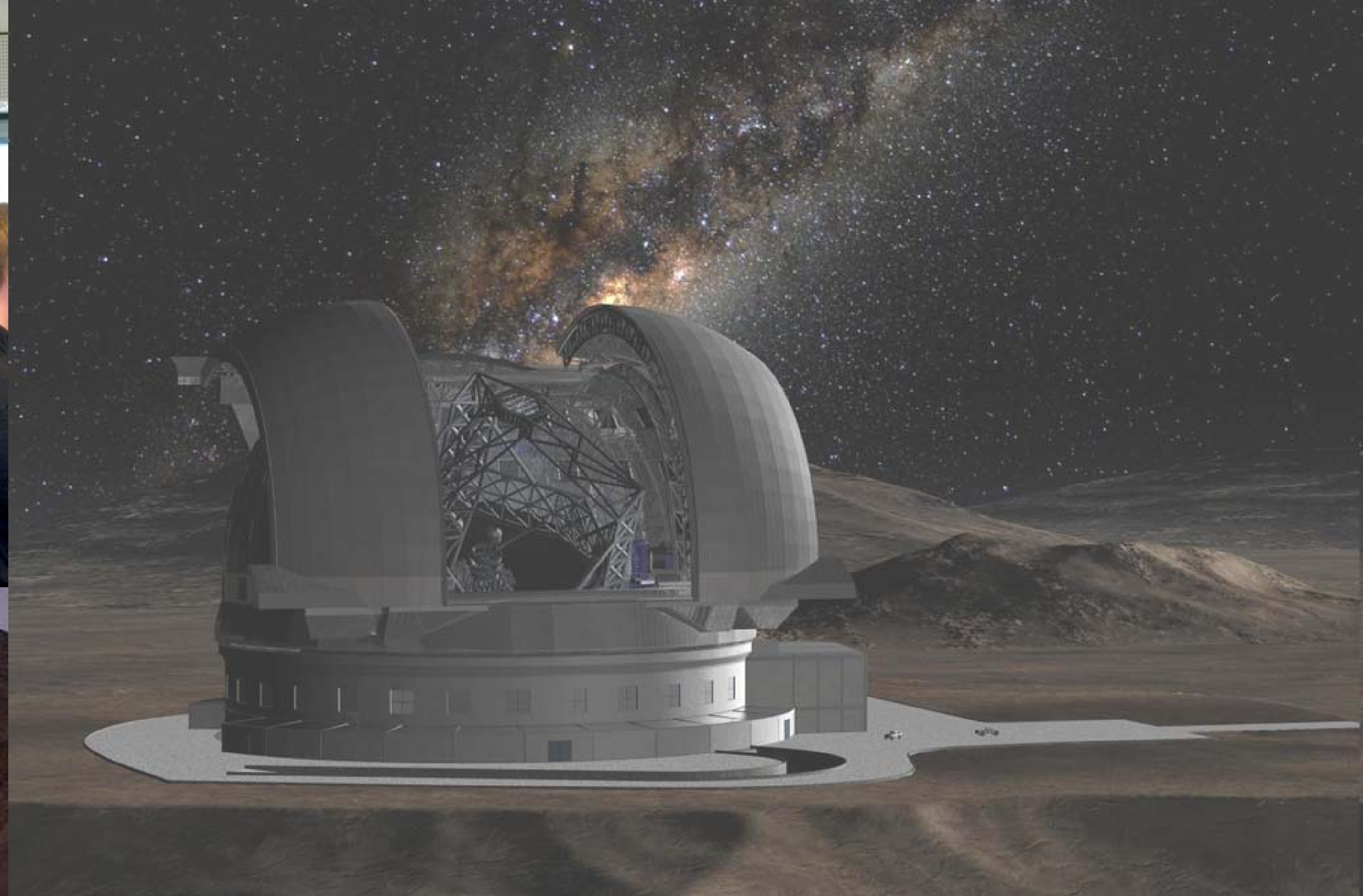
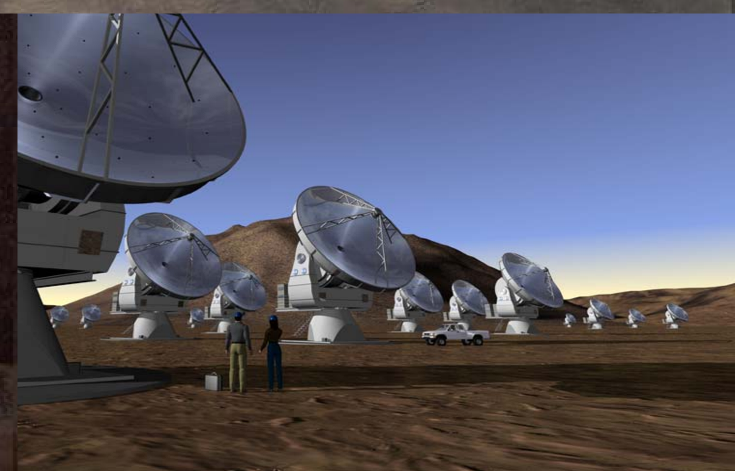
From the VLT to ALMA and to the E-ELT



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
  - Currently 14 member states
- Observatories in Chile
  - Optical/infrared: La Silla and Paranal
  - Sub-mm: APEX and ALMA partnerships: Chajnantor
- HQ in Garching and Office in Santiago

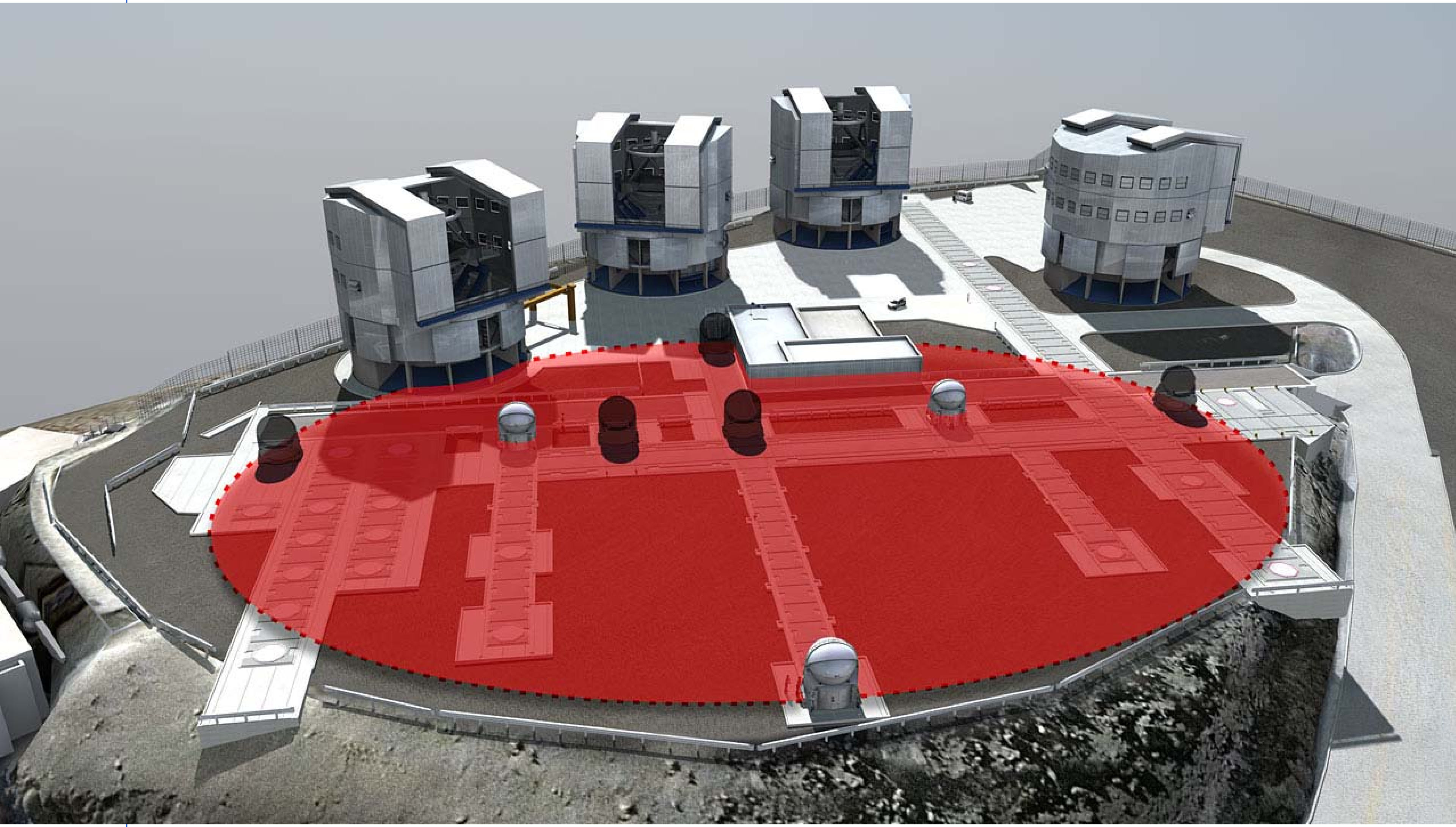


La Silla Paranal Observatory

- Very Large Telescope (Paranal)
  - 9 telescopes operational, one in commissioning
  - 14 instruments in use, 7 in development
  - Instrumentation covers the available optical infrared wavelengths from 300nm to 20µm
  - Angular resolution from seeing limit (0.8 arcseconds) to 50 micro-arcseconds
  - Imagers and wide-field imagers
    - survey telescopes
  - Spectrographs
    - resolution from ~5 < $\lambda/\Delta\lambda$ < 150000
  - Interferometric array (VLTI)
  - Laser Guide Star Facility

Laser Guide Star Facility

The VLT Interferometer



Top list of ESO science

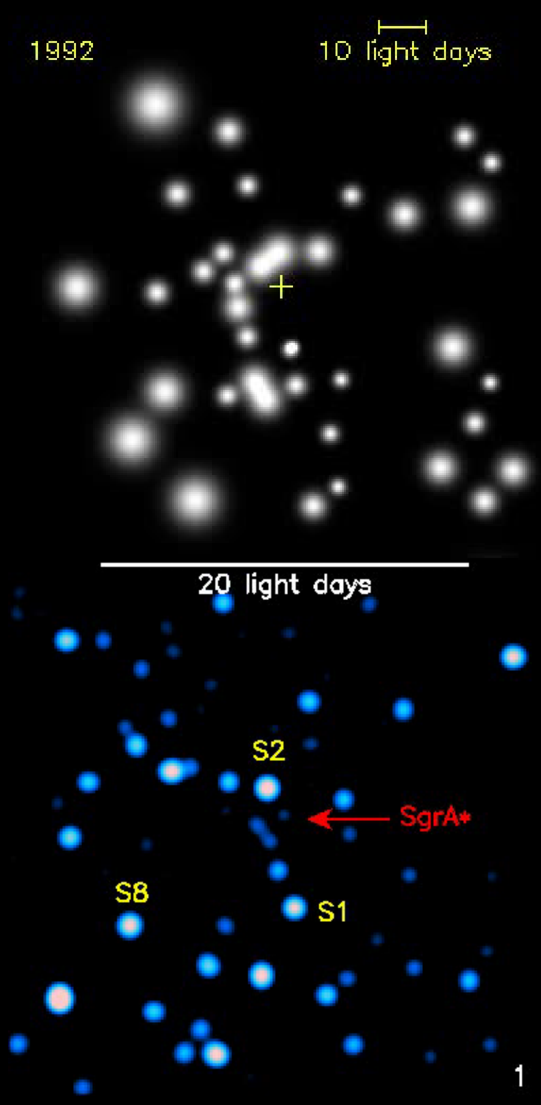
- Galactic Centre
  - Supermassive black hole
  - Measure gravity in its strong regime
- Extrasolar planets
  - Images and spectroscopy
  - Characterise other worlds
- Accelerating Universe
  - Spectroscopy of distant supernovae
- Gamma-Ray Bursts/Supernovae
  - Explosion physics
  - Tracers of the distant universe

Other top science from ESO

- Metal-poor stars
  - Finding the oldest known stars
  - Trace Big Bang nucleosynthesis
- Stellar populations in nearby galaxies
  - Stellar archeology
- Massive galaxies in the distant Universe
  - Formation and evolution of galaxies
- Varying physical constants?
  - Measure the fine-structure constant over time
- Testing the cosmological model
  - Cosmic background temperature

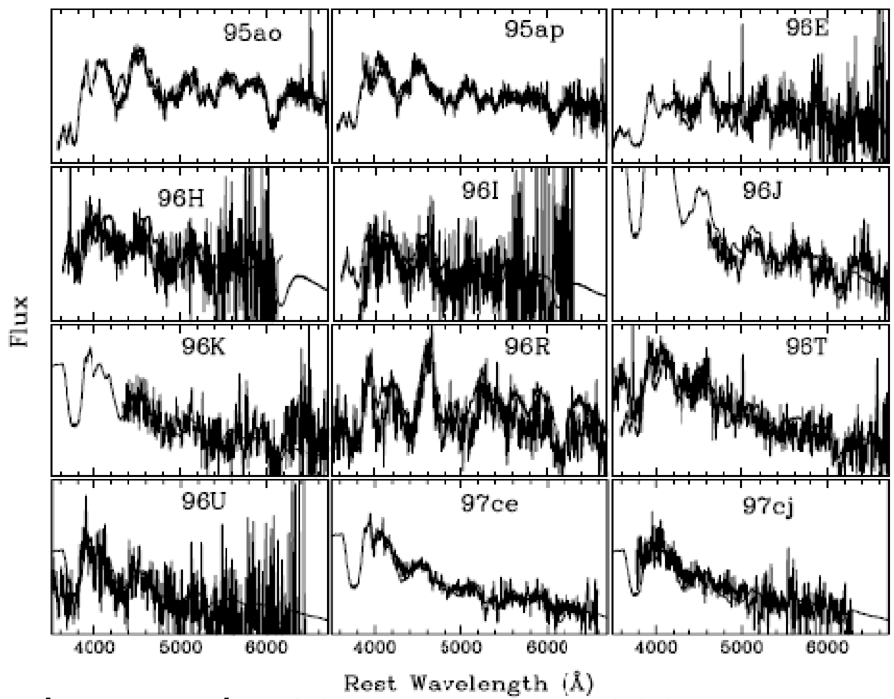
Black hole at the Galactic Centre

- Mass determination through stellar orbits
- Structure around the black hole revealed through flashes
- Coordinated studies with other wavelengths
- Multi-year study
  - use of AO instruments (SHARP on NTT, ISAAC NACO, SINFONI on VLT)

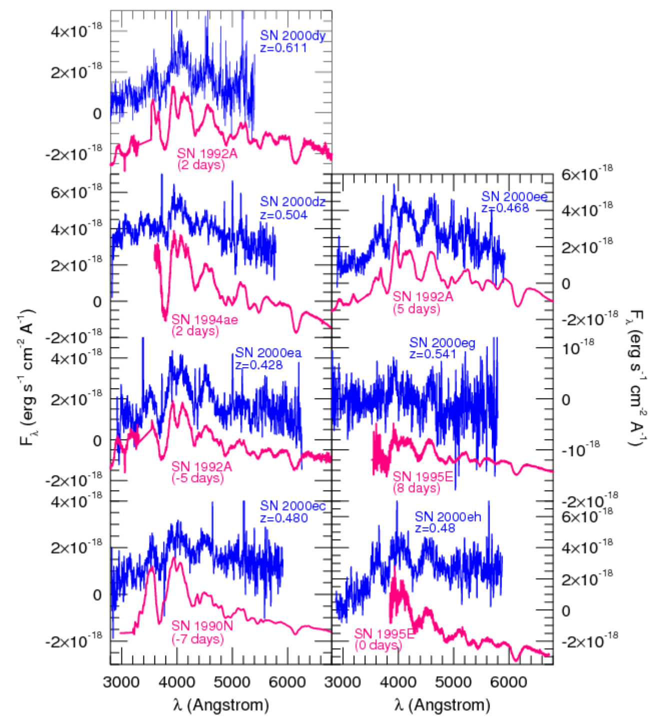


Accelerating Universe

- Contribution of most of the early photometry and spectroscopy of High-z SN Search Team
  - difference between a 4m and a 8m telescope



Riess et al. 1998, AJ, 116, 1009



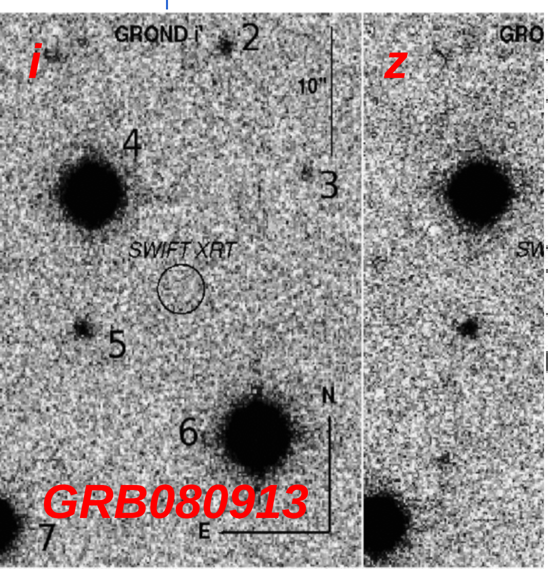
Leibundgut & Sollerman 2001

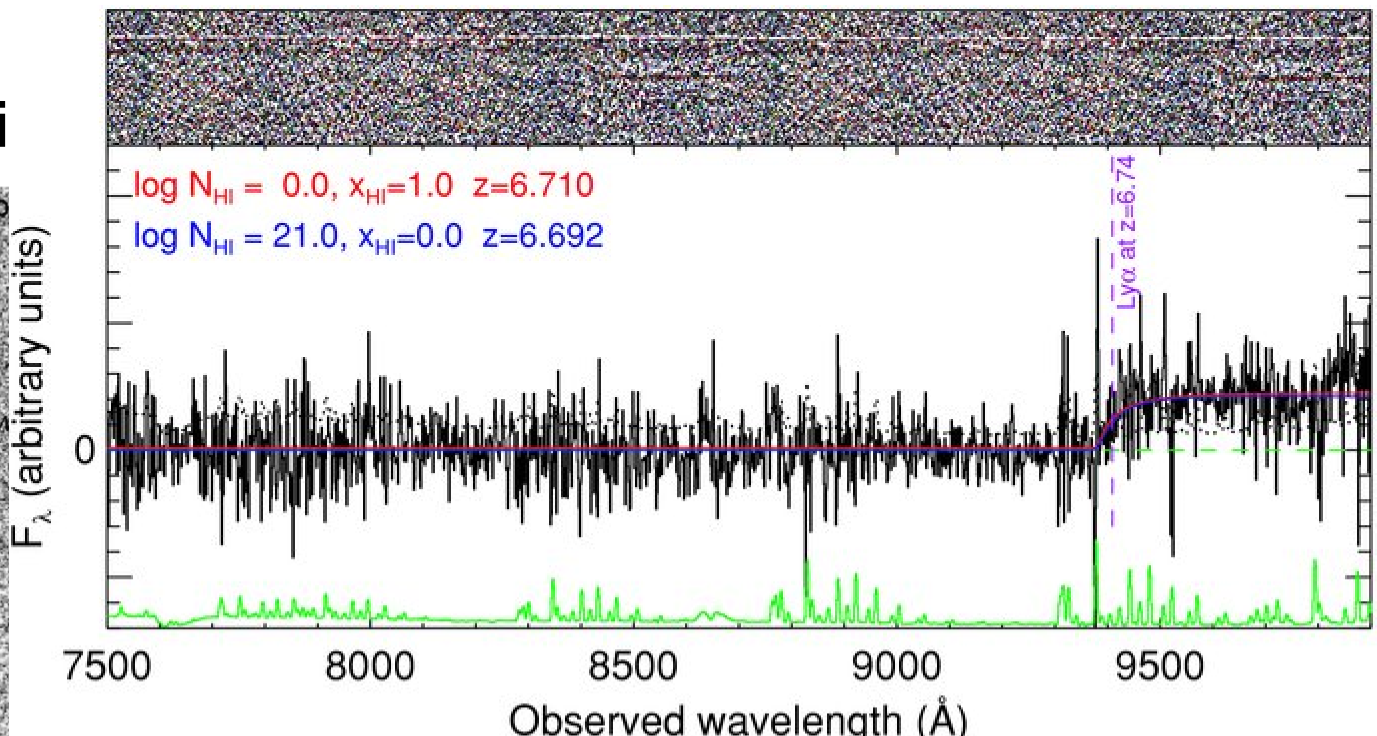
Gamma-Ray Bursts

- Identification relies on optical data
  - redshifts, explosion energies, explosion physics
- Cosmological probes
  - the most distant observable stars
  - light houses to measure the intergalactic medium
  - tracers of chemical enrichment?
- Very short duration
  - required special instrumentation and software to observe adequately

Gamma-Ray Bursts

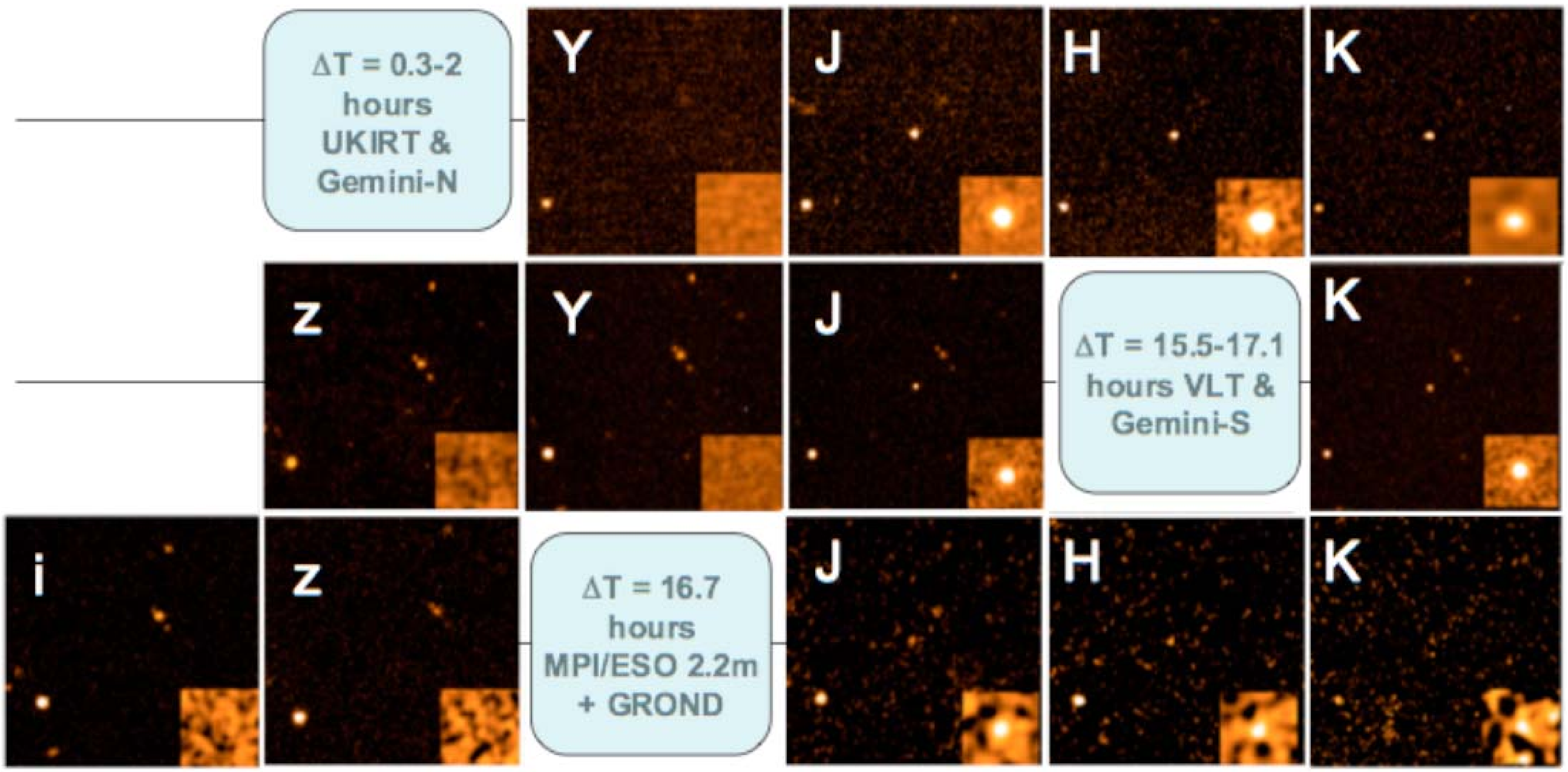
- Most distant stellar objects ever observed
  - redshifts 6.7 and 8.2 (tentative)
  - lookback time of nearly 12.5 billion years (or 95% of the age of the universe)
- VLT equipped with rapid response mode
  - allows
    detecti





Most distant stellar object yet observed – GRB 090423

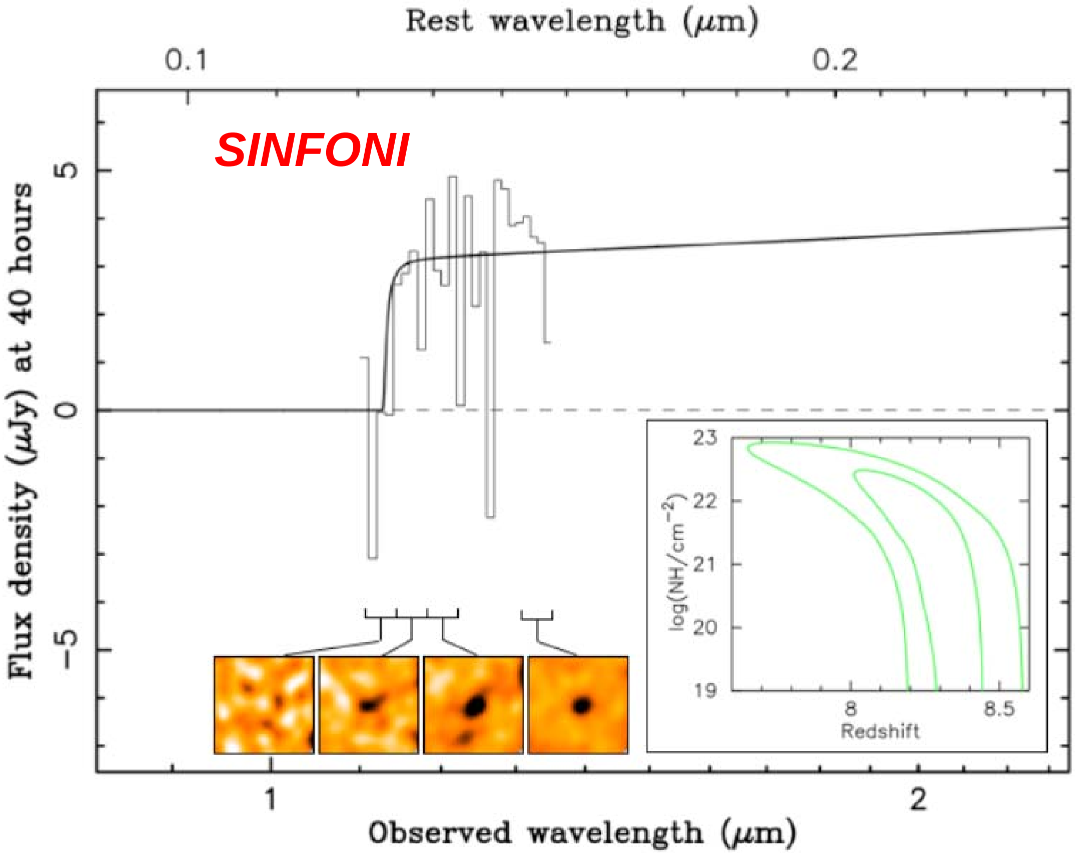
- Optical drop-out, bright in the near-infrared
- Rapid decline



Tanvir et al., Nature submitted

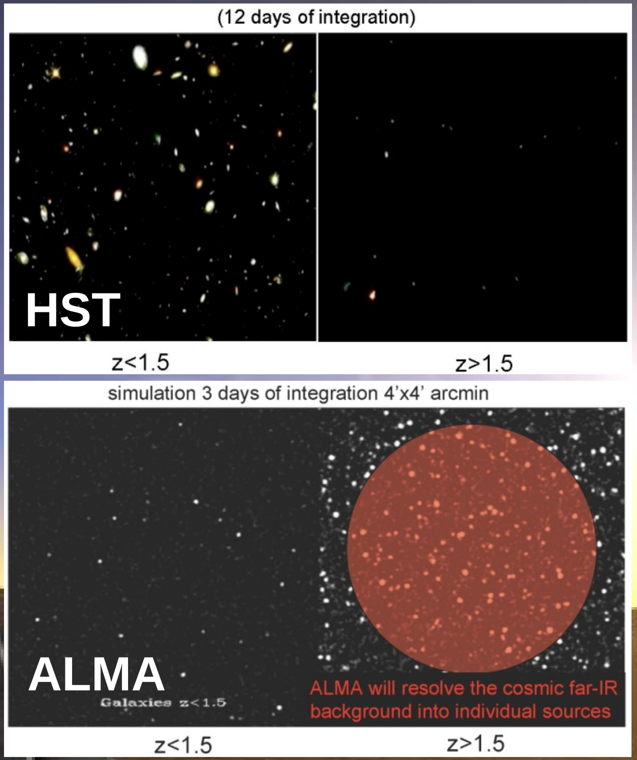
GRB 090423

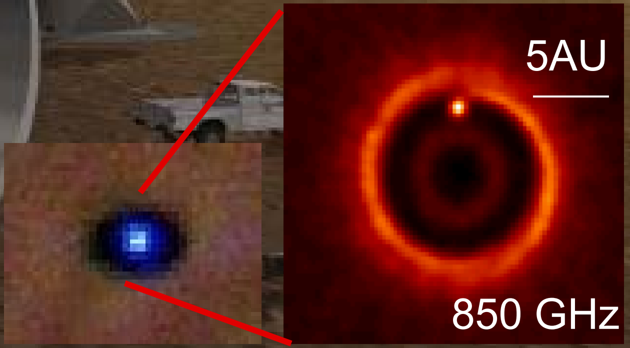
- Spectroscopy 17 hours after outburst
- Lyman break indicates a redshift of z≈8.2



Atacama Large Millimeter Array

- Global project with Europe, North America and East Asia as partners
- Science requirements
  - Detect CO and [CII] in Milky Way galaxy at z=3 in < 24 hr
  - Dust emission, gas kinematics in proto-planetary disks
  - Resolution to match Hubble, JWST and 8-10m with AO
  - Complement to Herschel
- Specifications
  - 66 antennas (54x12m, 12x7m)
  - 14 km max baseline (< 10mas)
  - 30-1000 GHz (10–0.3mm), up to 10 receiver bands

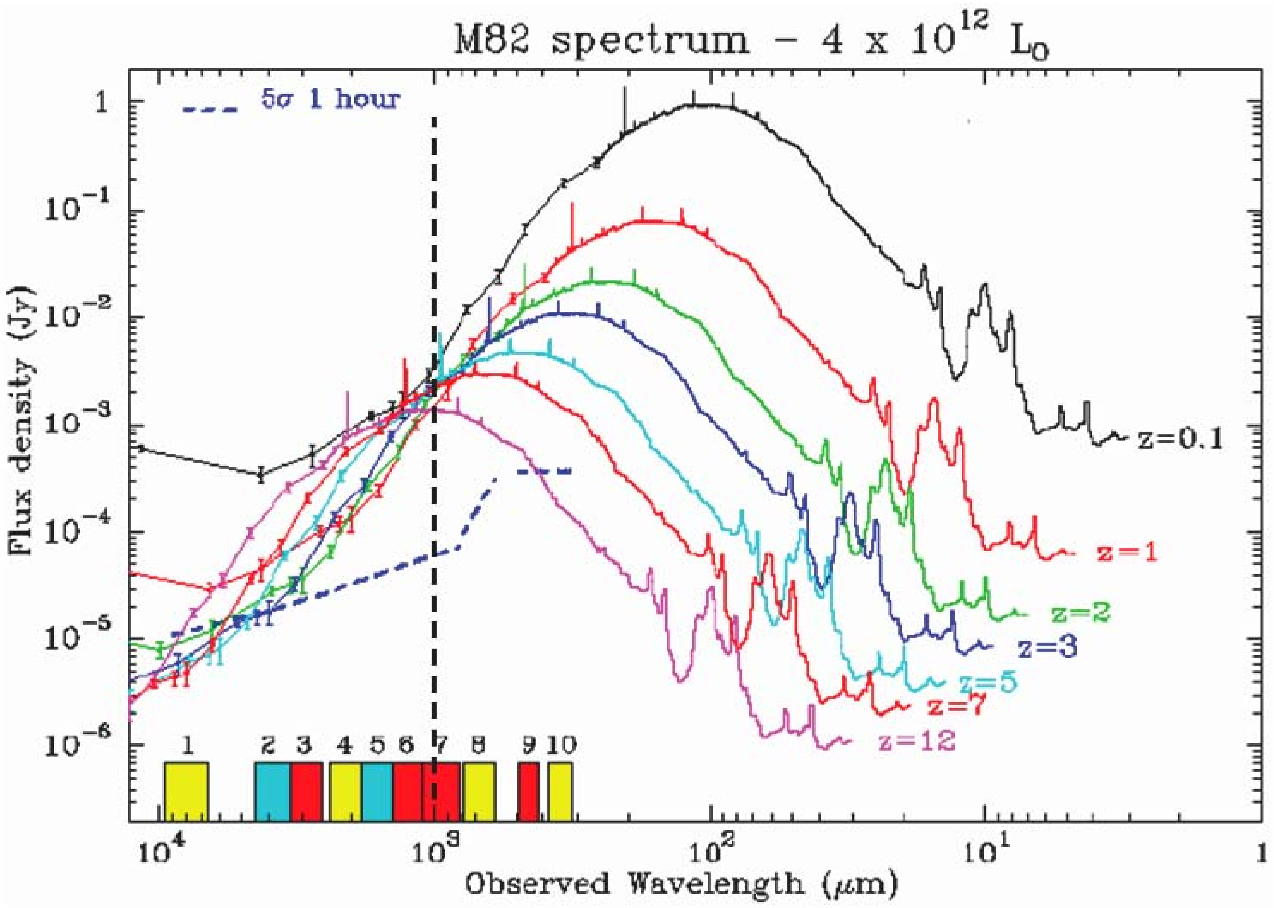




ALMA

- ALMA will explore the cold universe
  - typical gas temperatures` 10 K < T_{gas} < 500 K
  - molecular astrophysics
- ALMA has great capabilities to observe the distant universe
  - 'inverse' K-correction
  - detection of the cold gas in distant galaxies as tracers of star formation
    - [C II] 157μm is the strongest coolant in most galaxies
    - CO amongst the most abundant molecules in the universe
  - Sunyaev-Zeldovich effect directly measurable

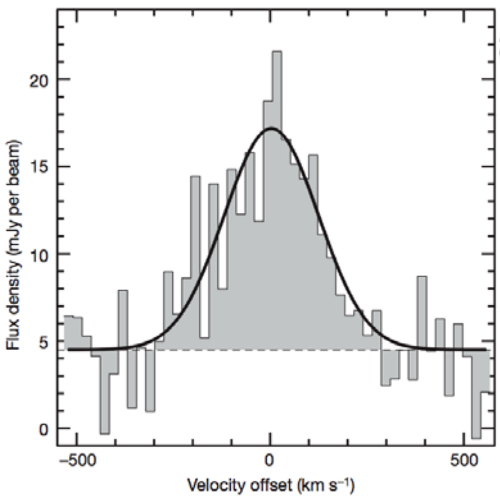
K-corrections due to redshift



- In the (sub-)millimeter the inverse K-correction compensates for the distance as redshift increases

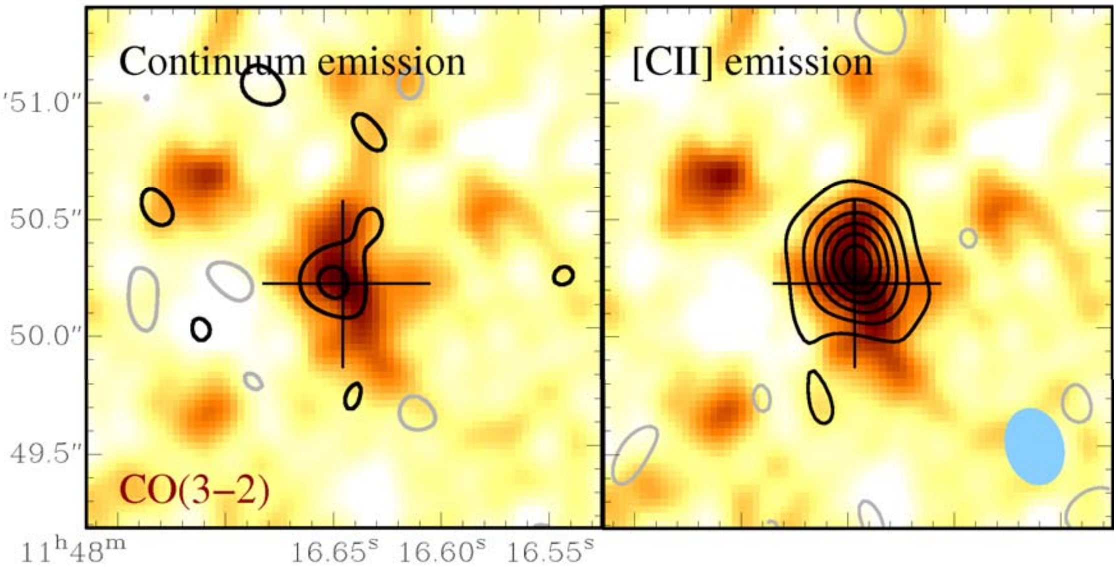
Starburst at z=6.4

- Detection of [C II] in the distant universe



Maiolino et al. 2005

Walter et al. 2009



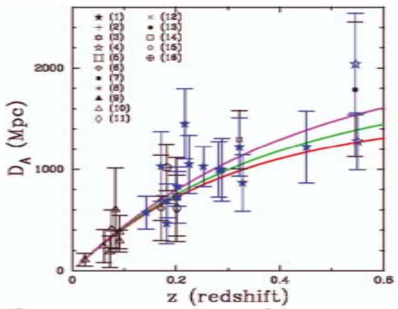
FIR continuum *[CII]*

➢ [CII] size ~ 1.5 kpc => SFR/area ~ 1000 M_o yr^{-1} kpc^{-2}

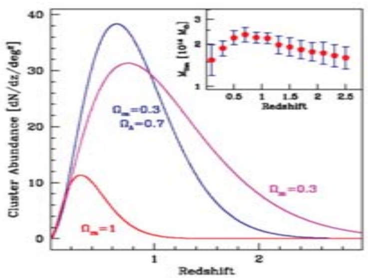
Astrophysical relevance

Galaxy clusters

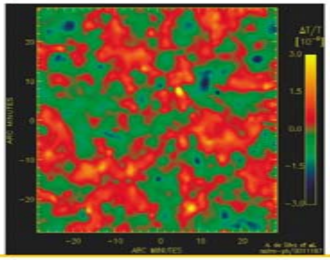
Hubble diagram



Cluster counts/masses

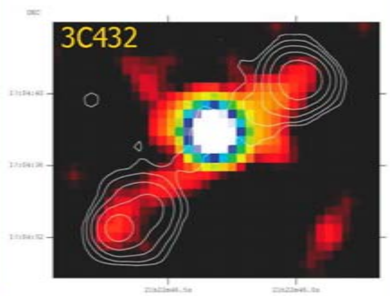


Cluster velocities



AGN jets/cavities

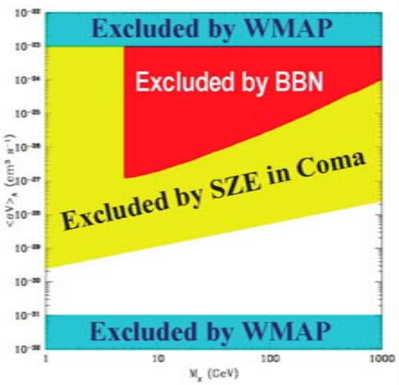
$T_{CMB}(z)$



$$\frac{\Delta T}{F_{IC}} \propto (kT_{CMB})^{-3}$$

DM nature

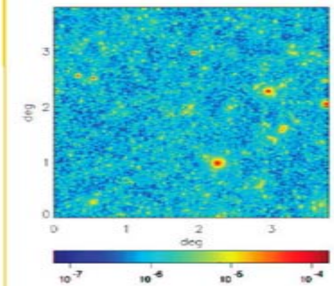
SUSY DM



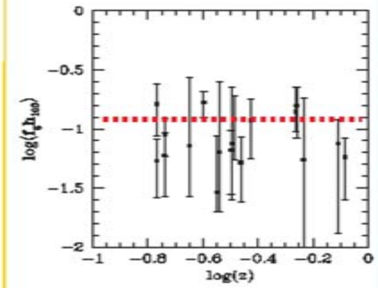
Non-SUSY DM

- MeV DM
- sterile ν
- …

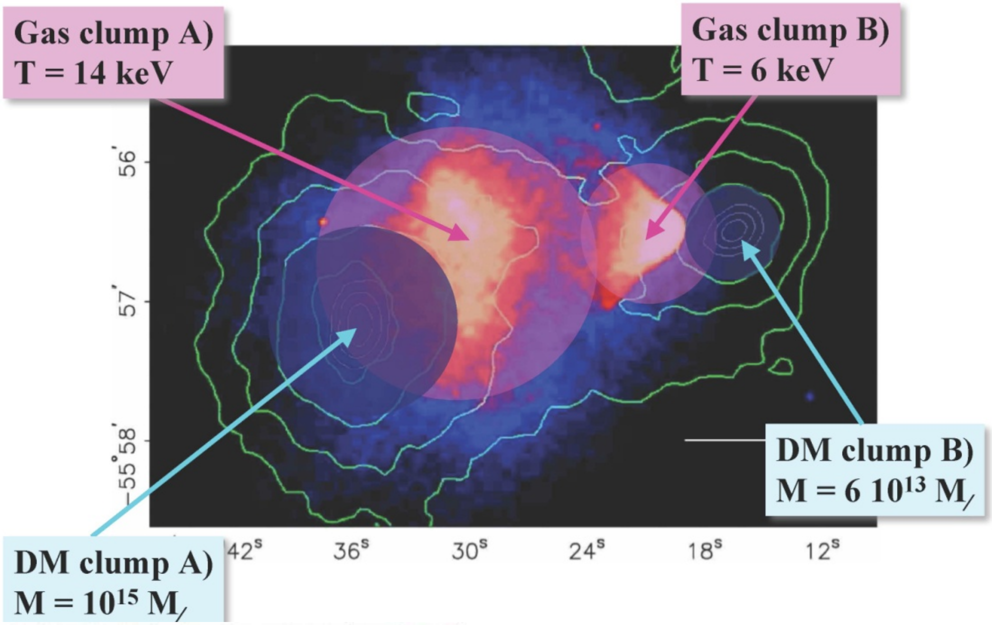
WHIM

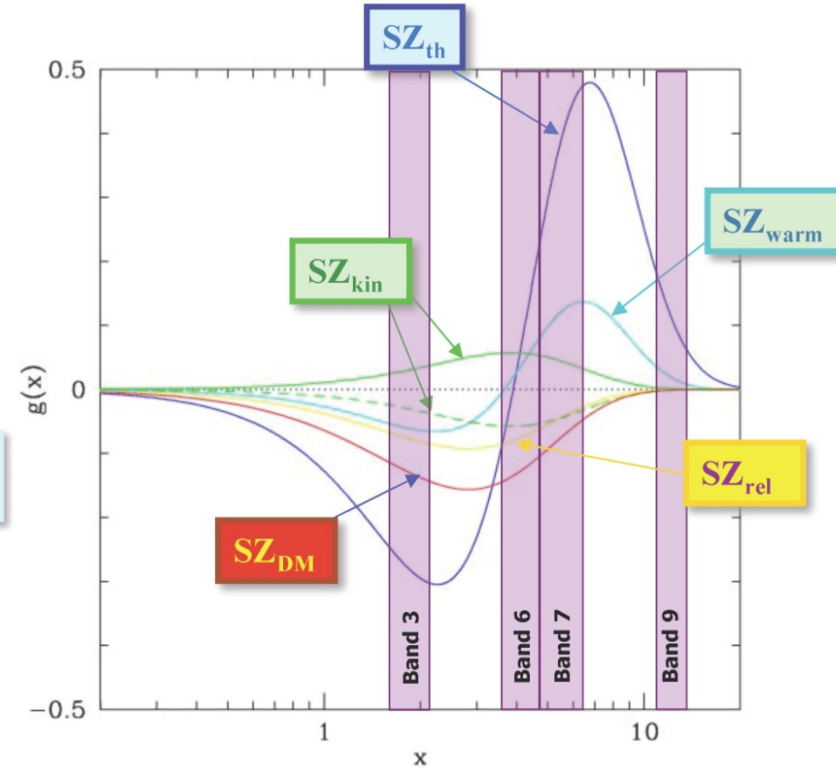


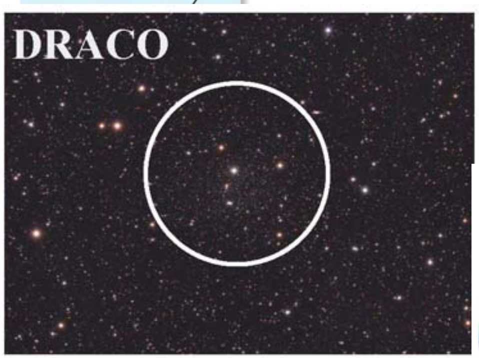
Baryon fraction



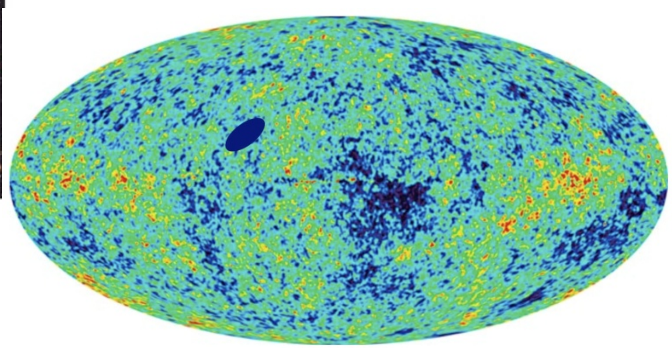
Observing the Sunyaev-Zeldovich effect with ALMA







low surface brightness galaxies



- Observing Dark Matter signatures in SZ effect with ALMA

ALMA 2013

E-ELT

- Detailed design study
  - Baseline 42m primary mirror
  - Adaptive optics built-in
  - 8 instrument studies and 2 adaptive optics modules → selection of the first generation of instruments (~ 6 instruments)
  - Community strongly engaged
  - Study complete in 2010
- Project
  - Builds on *entire* expertise at ESO *and* in the member states
  - Construction 2011-2018
  - Synergy: JWST/ALMA/SKA

Science cases for the E-ELT

- Observe Earth-like planets in the habitable zone
  - characterisation, e.g. atmosphere
  - observe planetary systems
- Measure the dynamics of the cosmic expansion
  - see Joe Liske's presentation
- Measure any evolution in the value of the fine-structure constant α
  - also Joe's talk
- Observe the stellar population (individual stars) out to the Virgo cluster
- Explore the high-redshift universe
  - 'first objects'

ESO telescopes have plenty to contribute to cosmology

- The La Silla Paranal Observatory continues to be upgraded
  - Second generation instruments (VLT/VLTI)
  - Key surveys with VST and VISTA
- Key science themes:
  - strong gravity → black hole in the Galactic Centre
  - distant universe → galaxy formation, first stars
- ALMA provides access to the cold stages of matter
- E-ELT will open the possibility to directly measure
  - dynamics of cosmic expansion
  - address the constancy of the fine-structure constant