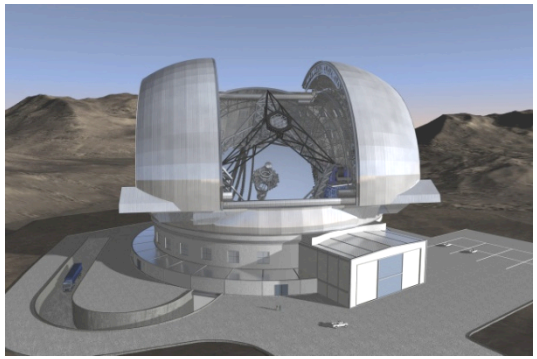
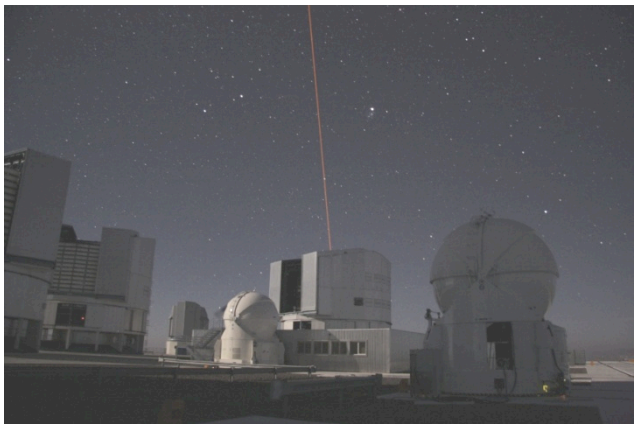
Exciting Astrophysics



Bruno Leibundgut
(ESO)



Astronomy is different …

No direct experiments

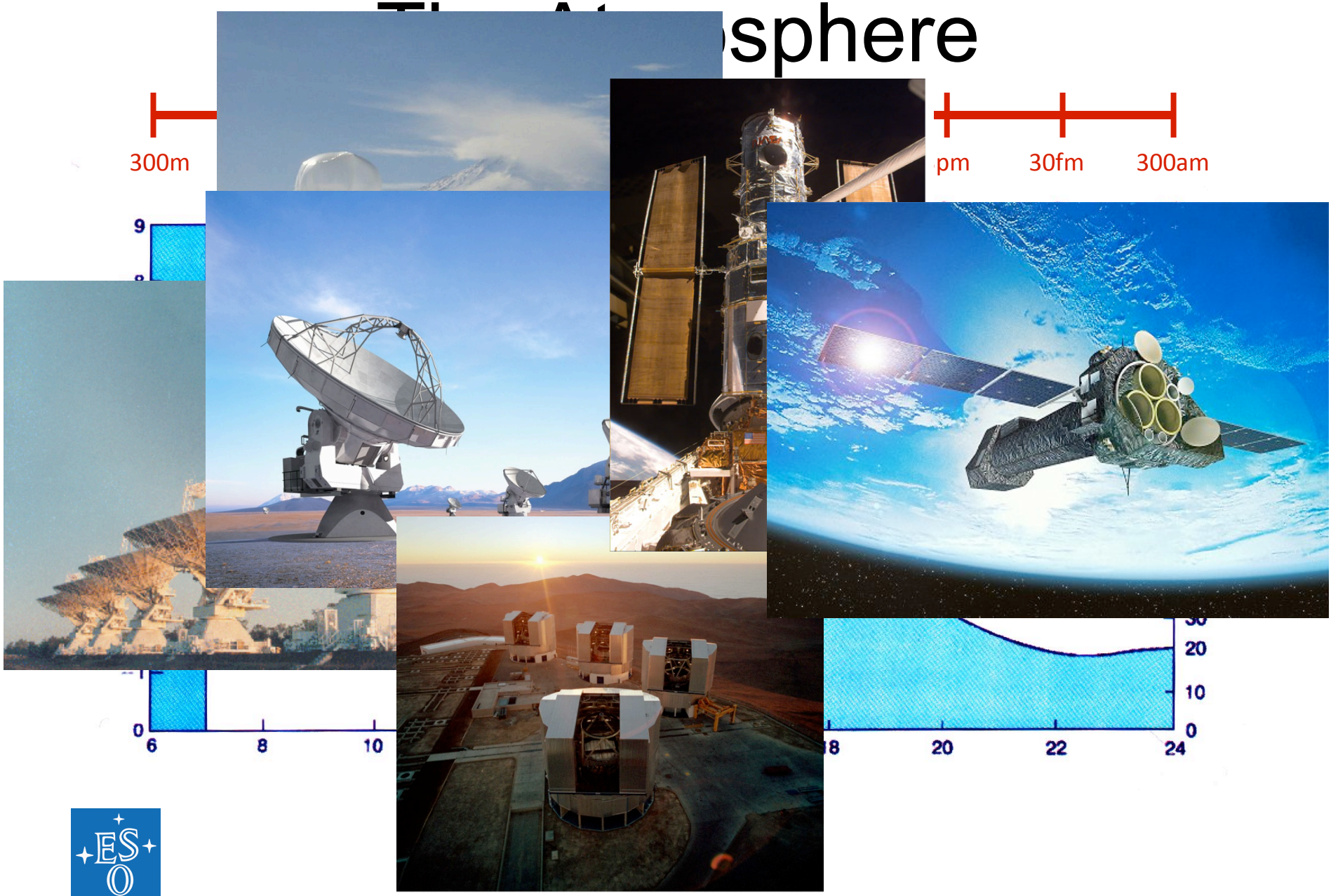
Our Lab is the sky! Very little of the conditions in the universe can be re-created in the laboratory (e.g. densities, scales, temperatures)

Information

Light → electro-magnetic radiation

‘carrier particles’ → neutrinos, cosmic rays

The Atmosphere

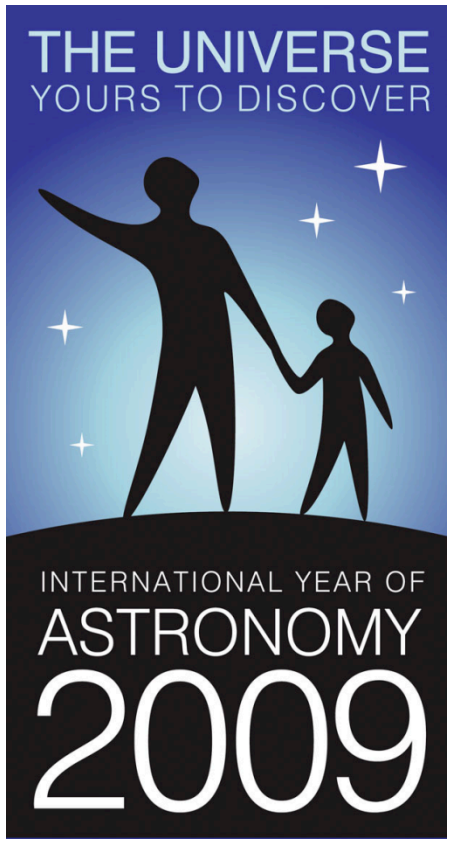


Astrophysics in a Golden Age

- Full coverage of electro-magnetic spectrum
  - MAGIC/HESS/VERITAS (ultra-high energy photons)→Fermi/ INTEGRAL (γ-rays)→ XMM/Chandra/Swift/Rossi XTE (X-rays) → Galex (UV) → HST/Gaia (optical)→ ground-based optical/IR → Spitzer (infrared)→ Herschel/Planck (sub-mm) → IRAM/JCMT/APEX/ALMA → radio telescopes
  - 20 orders of magnitude in wavelength/frequency/energy
  - Large archive collections (e.g. ROSAT, ISO, ESO, HST, MAST)
- Astro-particles joining in
  - cosmic rays, neutrinos, gravitational waves, dark matter searches

Astrophysics in a Golden Age

- International Year of Astronomy
  - Fantastic boost in the public
  - Increased awareness
  - Strong public support
  - Continued interest
    - Connected to the ‘big’ questions
    - Where do we come from?
    - What is our future?



Fantastic opportunities

Already existing ground-based facilities in Europe

Westerbork, Roque de los Muchachos (GTC, WHT, TNG, NOT, ING, MAGIC), Solar telescope on El Teide, Effelsberg, JCMT, La Silla, Paranal, IRAM (Plateau de Bure, Pico Veleta), HESS, MAGIC

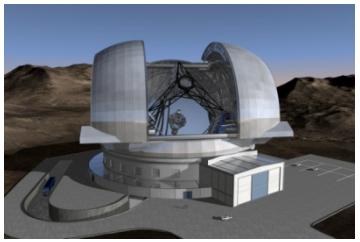
New facilities

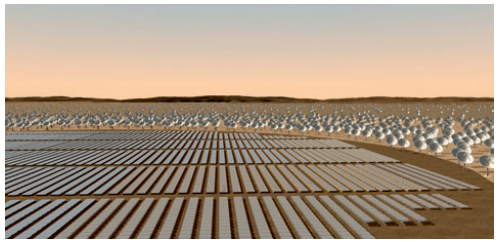
Just started:
VISTA, LOFAR,

To come soon:
VST, ALMA

Under discussion

E-ELT, SKA, EST, CTA





You do not have to observe yourself any longer!

- Service observing at many telescopes
- Massive surveys publicly available
  - Sloan Digital Sky Survey (SDSS)
  - CFHT Legacy Surveys
  - UK Infrared Deep Sky Survey (UKIDSS)
  - GOODS/COSMOS
  - VST Public Surveys
  - VISTA Public Surveys
  - PanSTARRS (US)
  - Dark Energy Survey (US/European)
  - Large Synoptic Survey Telescope (LSST – US; proposed)
- Large Archives
  - ING, ESO, HST/MAST (US and mostly space)

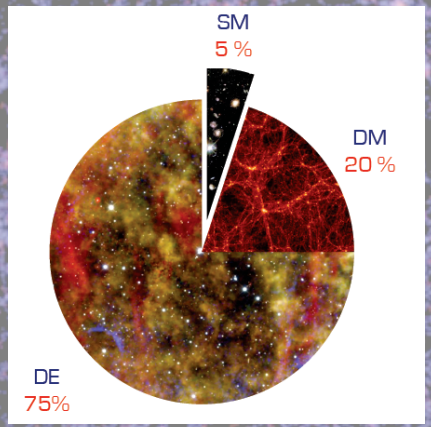
Presentation by Eduardo Gonzalez

Science themes

- What matters in the universe?
- How galaxies form and evolve?
- The Milky Way our Home
- Our own black hole
- How did stars and planets form?
- Planets, planets, planets
- Fashions and other transients
- When opportunity knocks

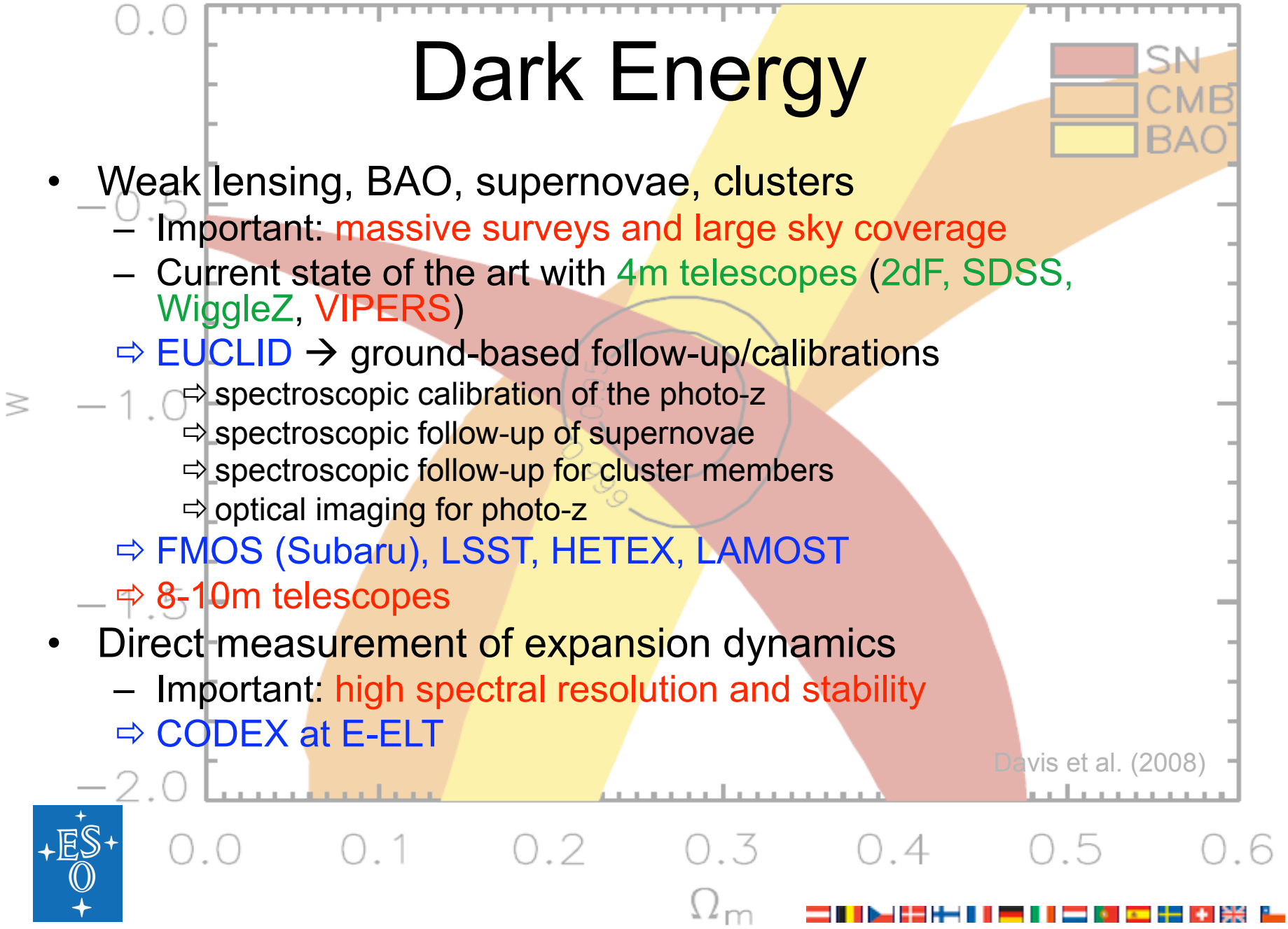
What matters in the Universe?

- Characterisation of dark matter and dark energy
  - Requires large samples
    - sample a large fraction of the universe
  - Multi-year and (often) multi-telescope projects
  - Measure the distribution of matter and the expansion history of the universe
    - Baryonic acoustic oscillations
    - Weak lensing
    - Supernovae
    - Galaxy clusters
    - Redshift distortions



Millenium simulation (Springel et al.)

Dark Energy



- Weak lensing, BAO, supernovae, clusters
  - Important: massive surveys and large sky coverage
  - Current state of the art with 4m telescopes (2dF, SDSS, WiggleZ, VIPERS)

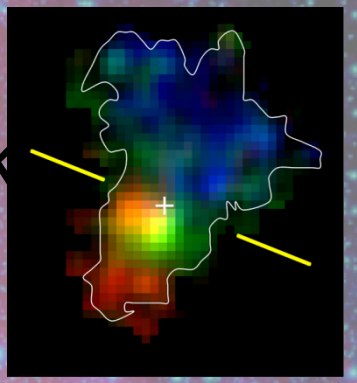
  ⇨ EUCLID → ground-based follow-up/calibrations
    - ⇨ spectroscopic calibration of the photo-z
    - ⇨ spectroscopic follow-up of supernovae
    - ⇨ spectroscopic follow-up for cluster members
    - ⇨ optical imaging for photo-z

  ⇨ FMOS (Subaru), LSST, HETEX, LAMOST

  ⇨ 8-10m telescopes
- Direct measurement of expansion dynamics
  - Important: high spectral resolution and stability

  ⇨ CODEX at E-ELT

How did galaxies form and evolve?



- Characterisation of the Lyman-break galaxies
  - Galaxy population at z>3
- Discovery of compact, old galaxies at z>1
  - "red and dead", "red distant galaxies"
- Characterisation of galaxies at high z
  - Internal kinematics
- Earliest observable stellar agglomerations
  - Ly-α emitters

Millenium simulation (Springel et al.)

The distant universe

- Build up of the Hubble sequence
  - Star forming vs. passive galaxies
    - Important: deep wide-field imaging and massive spectroscopic surveys

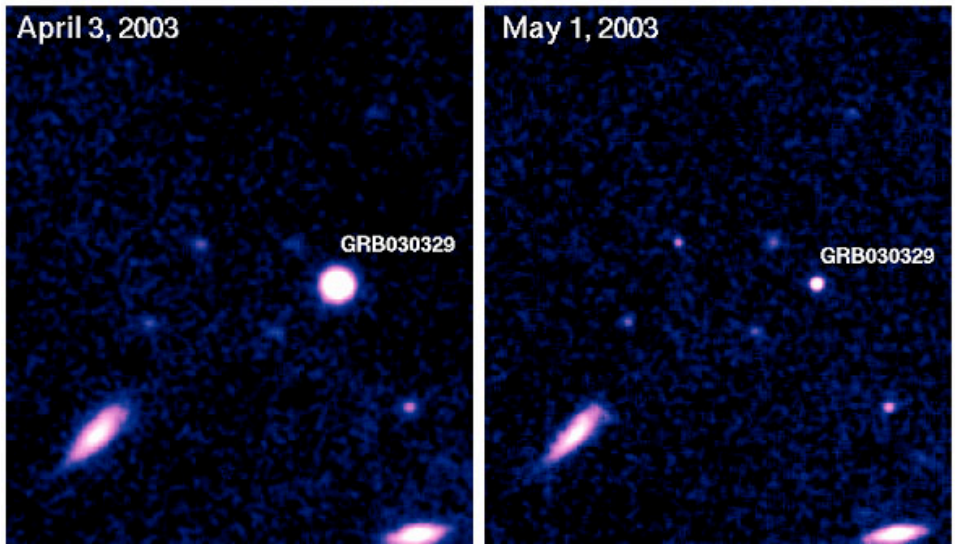
    ⇨ SuprimeCam (Subaru), VST, VISTA, VIMOS upgrade, FMOS (Subaru)
  - Internal physics and morphologies of galaxies at 1<z<3
    - Important: high spatial resolution and spatially resolved spectroscopy

    ⇨ HST, NACO, SINFONI, OSIRIS (GTC), MUSE, KMOS, HAWK-I with AO, JWST, E-ELT
- Objects at very high redshifts (‘first light’)
  - Search for Ly-α emitters, IGM at high z
    - Important: deep surveys, spectroscopic follow-up
    - SuprimeCam (Subaru), X-Shooter, NACO, OSIRIS (GTC), LRIS (Keck), DEIMOS (Keck), HAWK-I with AO, MUSE, KMOS, EMIR (GTC), JWST, E-ELT

Based on Bergeron (2009) Science with the VLT in the ELT Era

Gamma-Ray Bursts

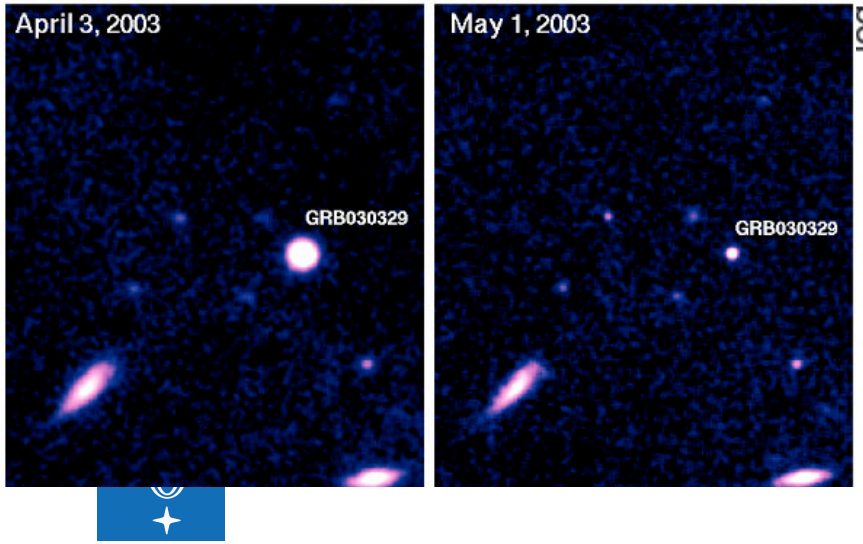
- Identification relied on optical data
  - redshifts, explosion energies, explosion physics
- Cosmological probes
  - the most distant observable stars
  - light houses to measure the intergalactic medium
  - tracers of chemical enrichment?
- Very short duration
  - require special instrumentation and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

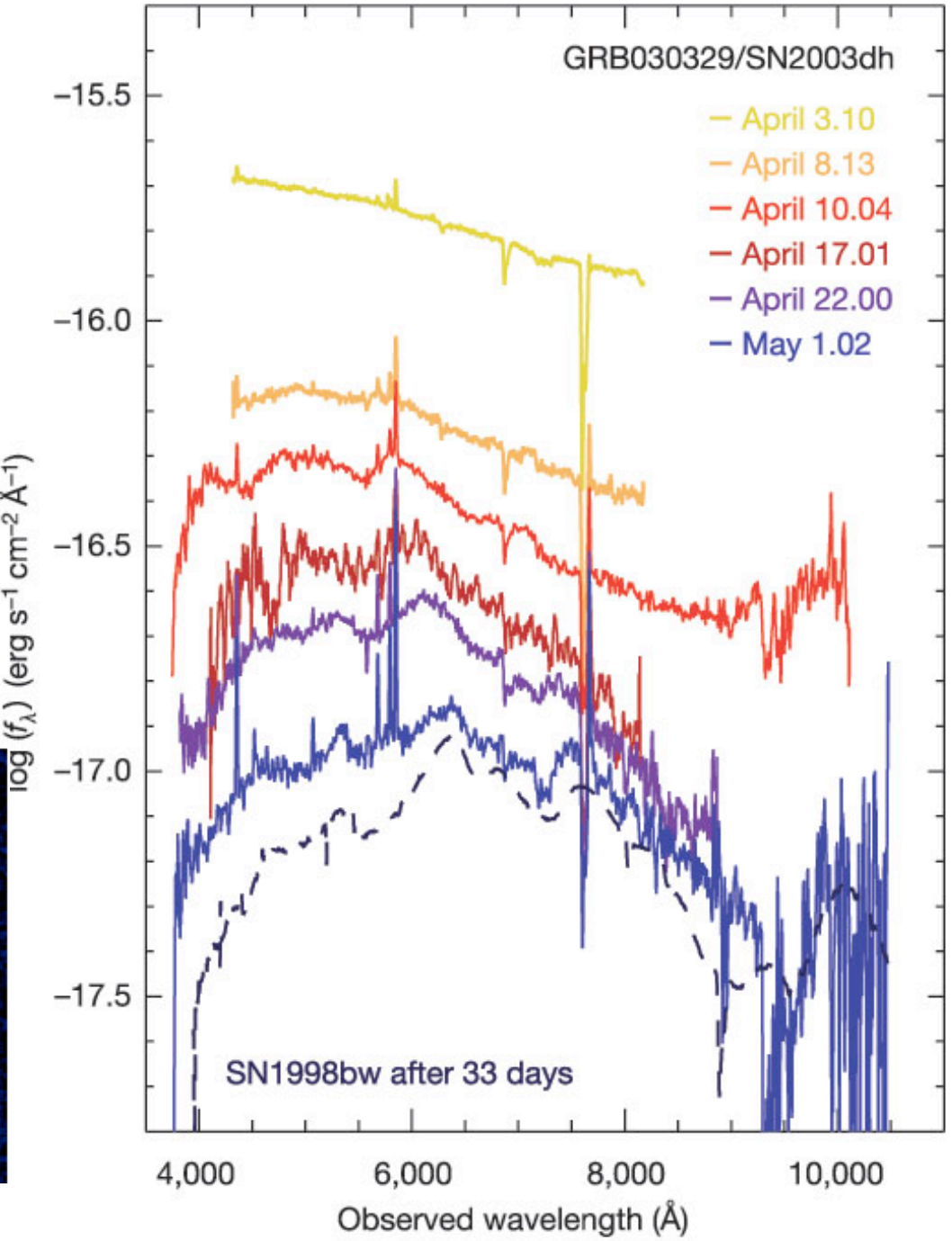


SN/GR

- Spectral signat
  appear in Gam
- GRB 030329/S
  GRB 980425/S

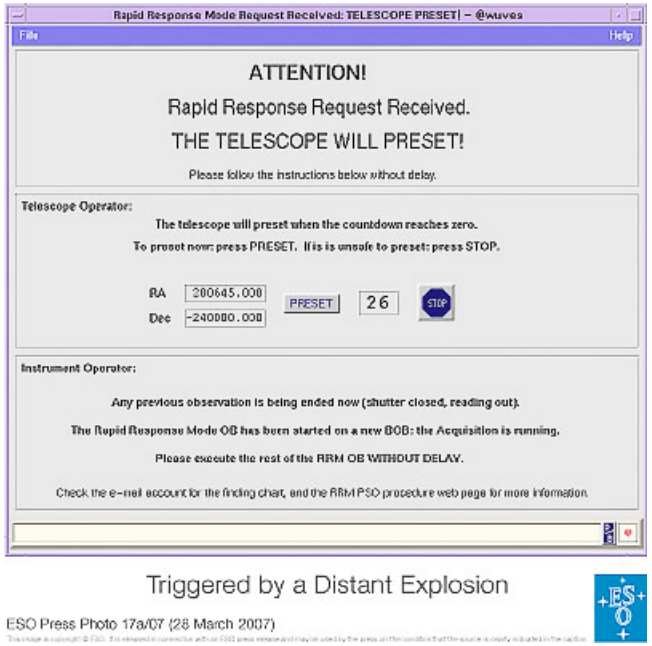
  UVES spectrum
  closest known
  FORS1 and 2 ob





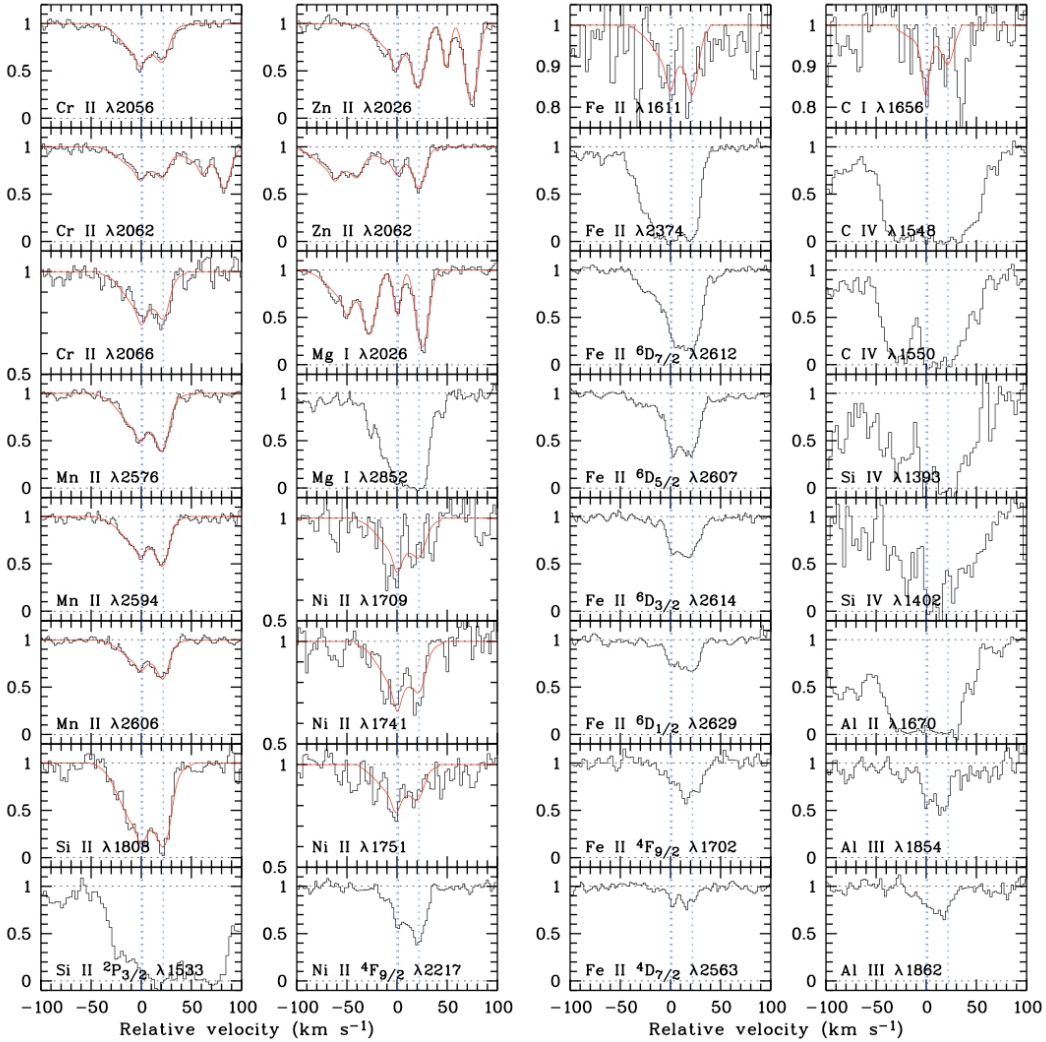
Rapid Response Mode

UVES observations of
GRB 060418
10 minutes
after the initial Swift trigger



Triggered by a Distant Explosion

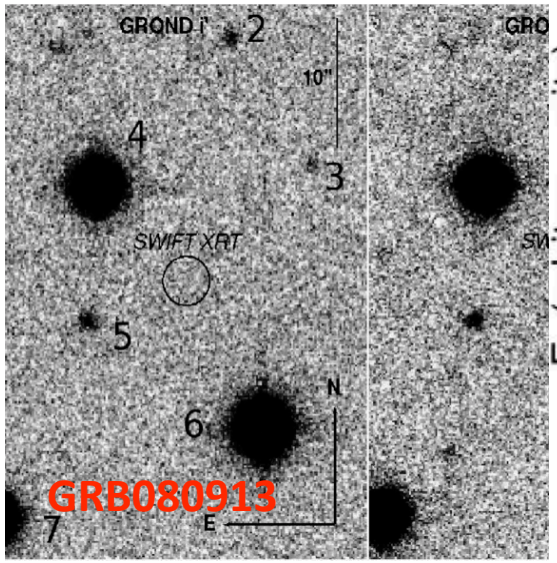
ESO Press Photo 17a/07 (28 March 2007)

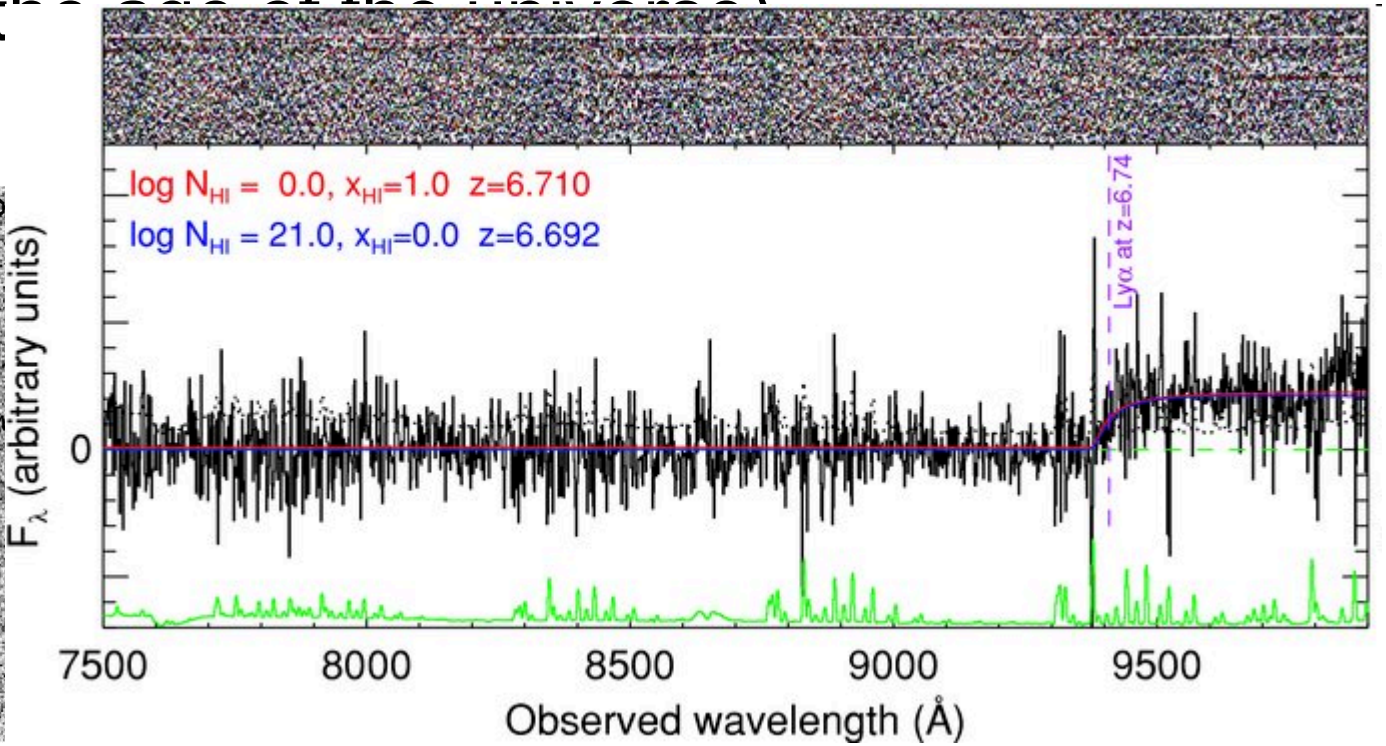


Many metal line systems
at 3 redshifts.
[Zn/Fe] >> QSO absorbers

Gamma-Ray Bursts

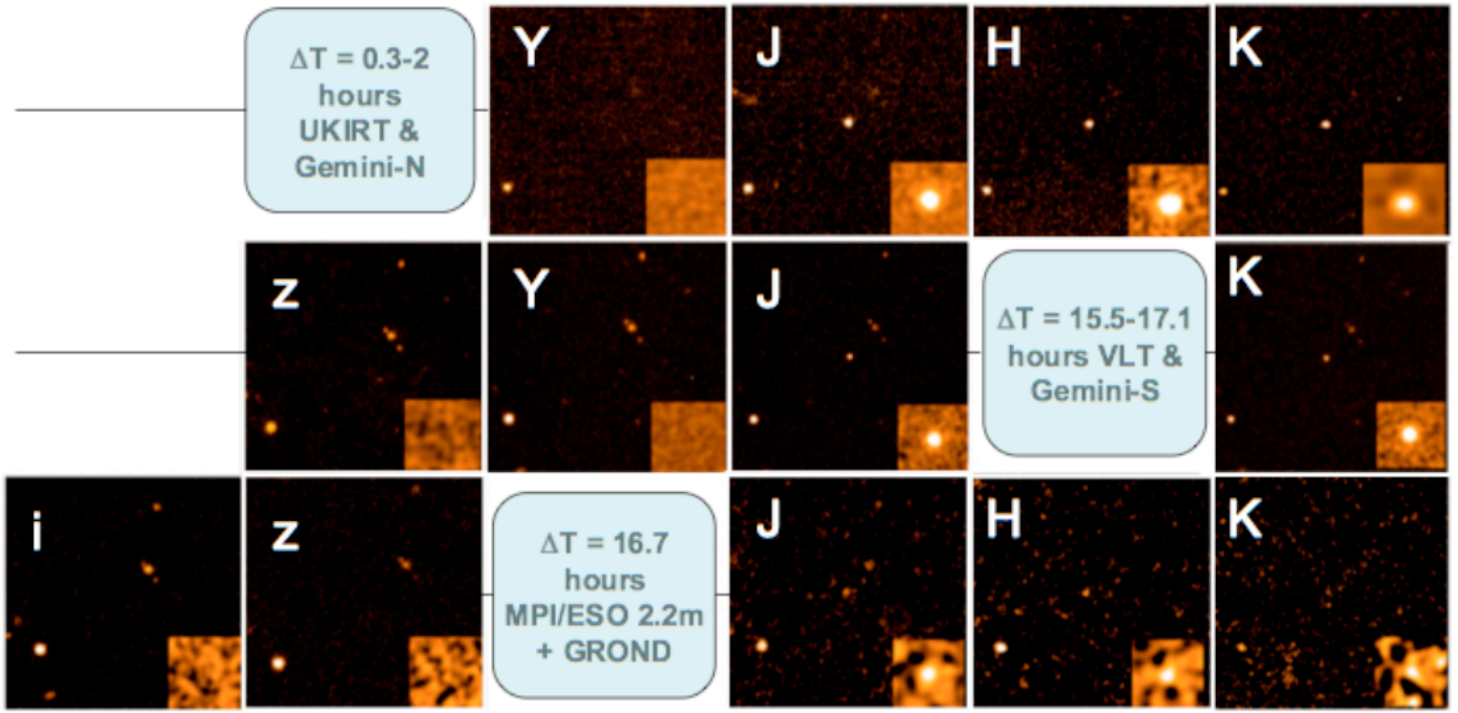
- Most distant stellar objects ever observed
  - redshifts 6.7 and 8.2 (tentative)
  - lookback time of nearly 12.5 billion years (or 95% of t[illegible])





Most distant stellar object yet observed – GRB 090423

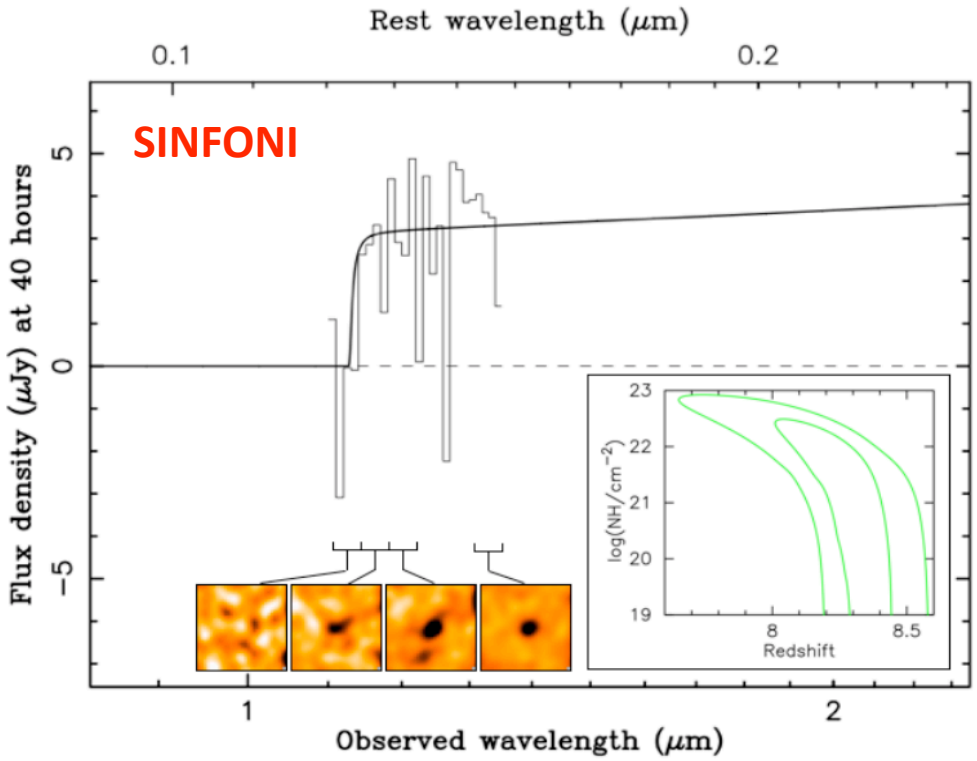
- Optical drop-out, bright in the near-infrared



Tanvir et al., Nature submitted

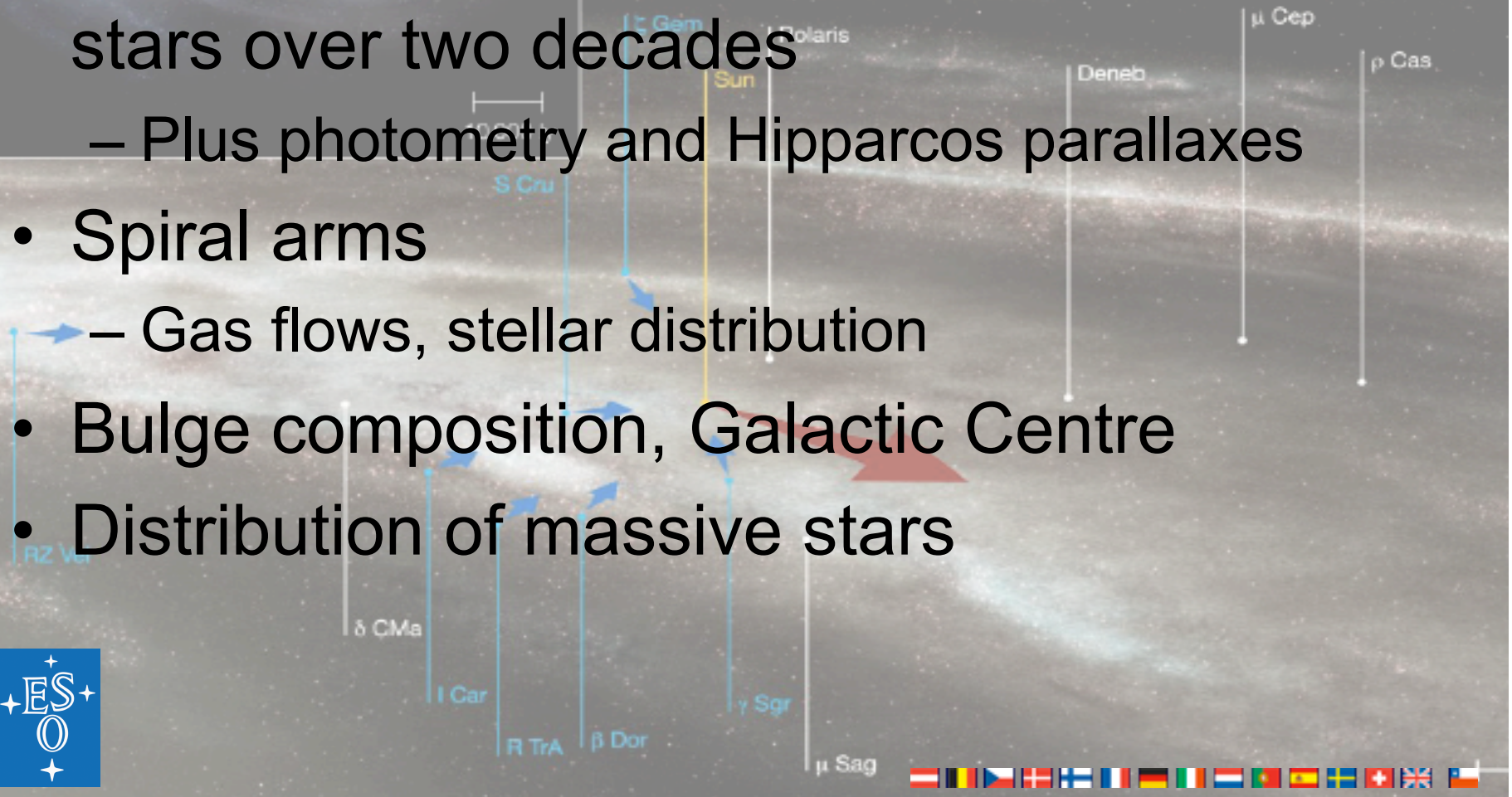
GRB 090423

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



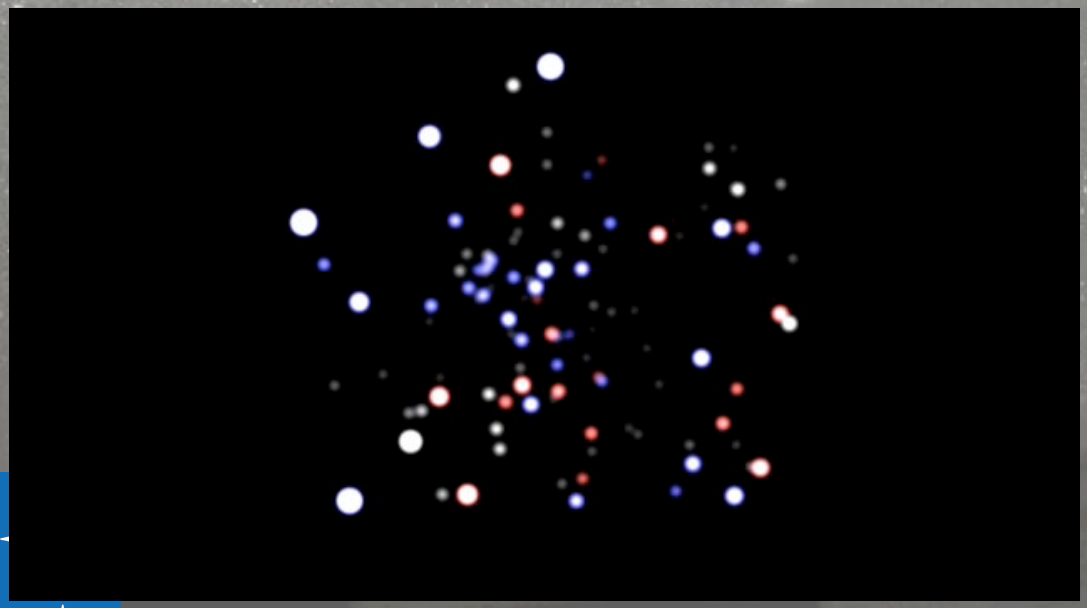
The Milky Way – our home

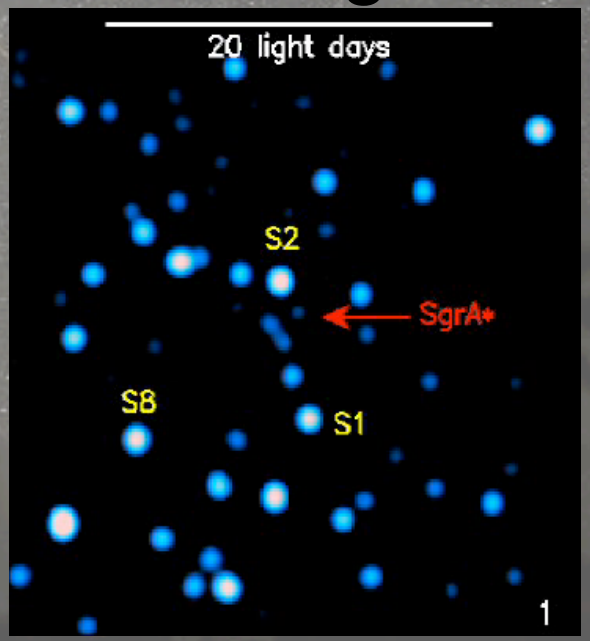
- Radial velocity study of 14000 F and G stars over two decades
  - Plus photometry and Hipparcos parallaxes
- Spiral arms
  - Gas flows, stellar distribution
- Bulge composition, Galactic Centre
- Distribution of massive stars



Our own black hole

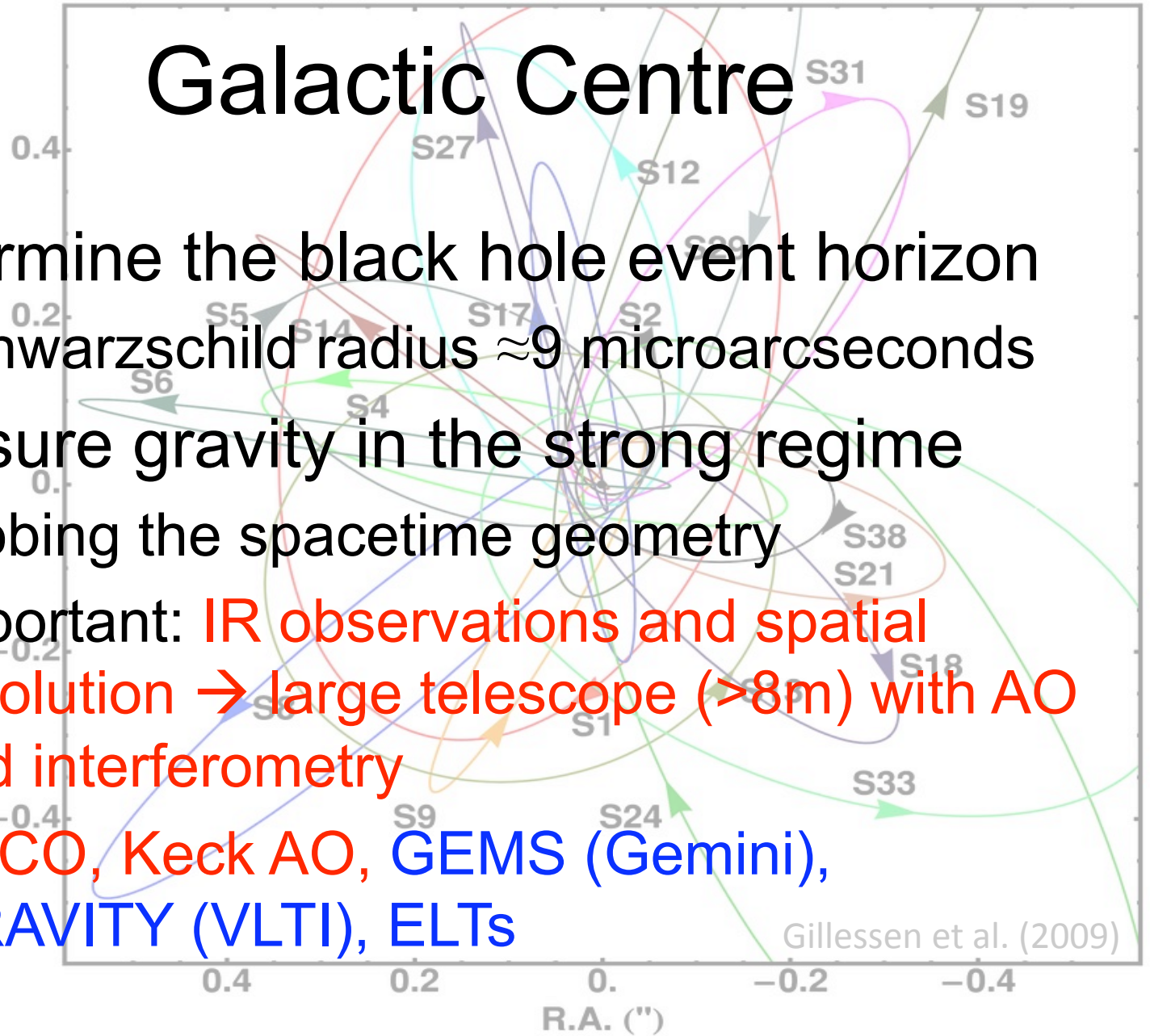
- Mass determination through stellar orbits
- Structure around the black hole revealed through flashes
- Coordinated studies at other wavelengths





Galactic Centre

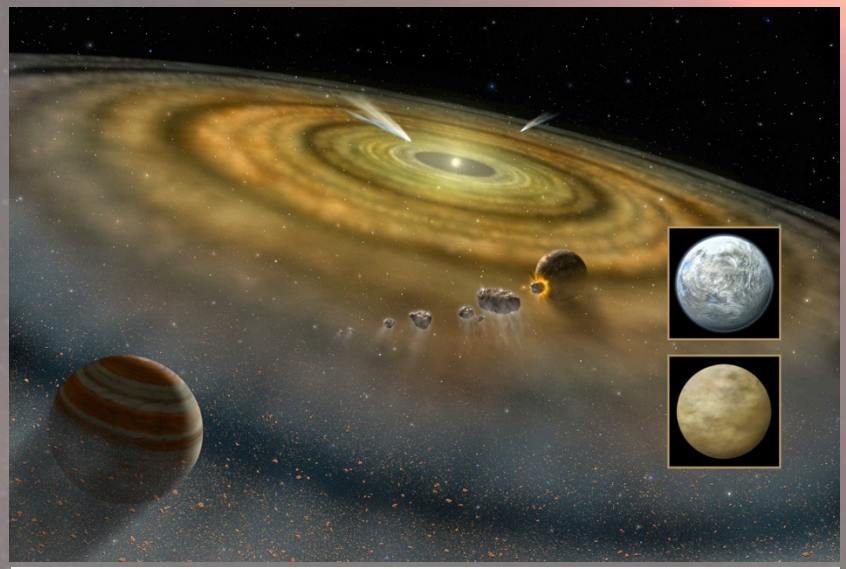
- Determine the black hole event horizon
  - Schwarzschild radius ≈9 microarcseconds
- Measure gravity in the strong regime
  - Probing the spacetime geometry
  - Important: IR observations and spatial resolution → large telescope (>8m) with AO and interferometry
  - NACO, Keck AO, GEMS (Gemini), GRAVITY (VLTI), ELTs

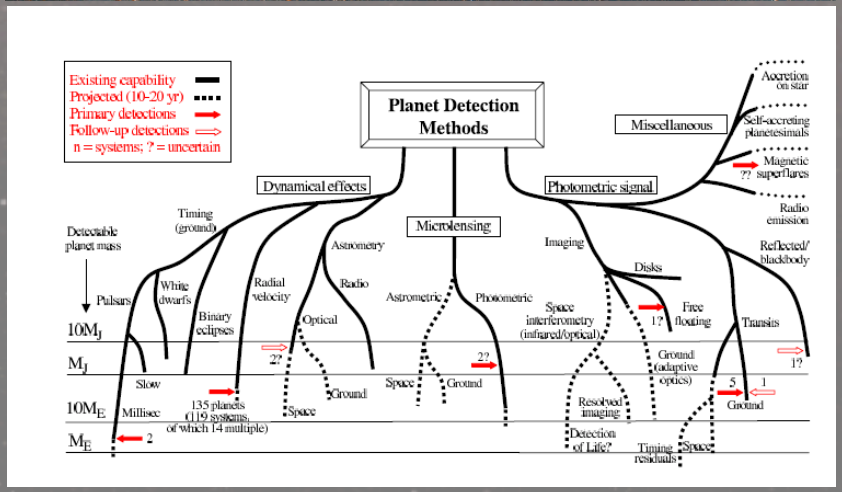


Gillessen et al. (2009)

Planets, planets, planets

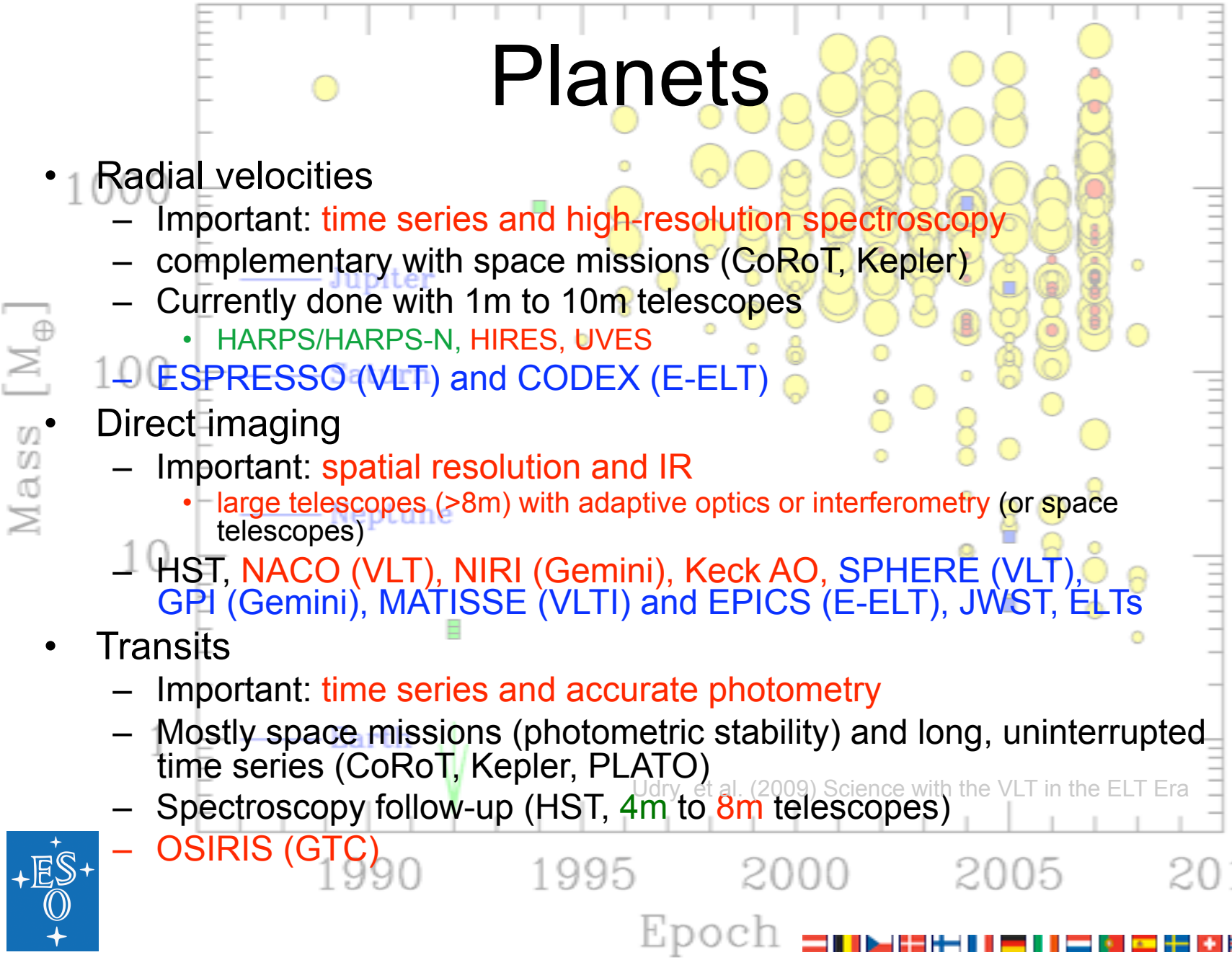
- Planets everywhere
  - Radial velocities
  - Direct imaging
  - Transits
- Characterisation
  - Planetary systems, masses, chemical composition, temperatures





Planets

- Radial velocities
  - Important: time series and high-resolution spectroscopy
  - complementary with space missions (CoRoT, Kepler)
  - Currently done with 1m to 10m telescopes
    - HARPS/HARPS-N, HIRES, UVES
  - ESPRESSO (VLT) and CODEX (E-ELT)
- Direct imaging
  - Important: spatial resolution and IR
    - large telescopes (>8m) with adaptive optics or interferometry (or space telescopes)
  - HST, NACO (VLT), NIRI (Gemini), Keck AO, SPHERE (VLT), GPI (Gemini), MATISSE (VLTI) and EPICS (E-ELT), JWST, ELTs
- Transits
  - Important: time series and accurate photometry
  - Mostly space missions (photometric stability) and long, uninterrupted time series (CoRoT, Kepler, PLATO)
  - Spectroscopy follow-up (HST, 4m to 8m telescopes)
  - OSIRIS (GTC)



Udry, et al. (2009) Science with the VLT in the ELT Era

The ESO exo-planet machinery

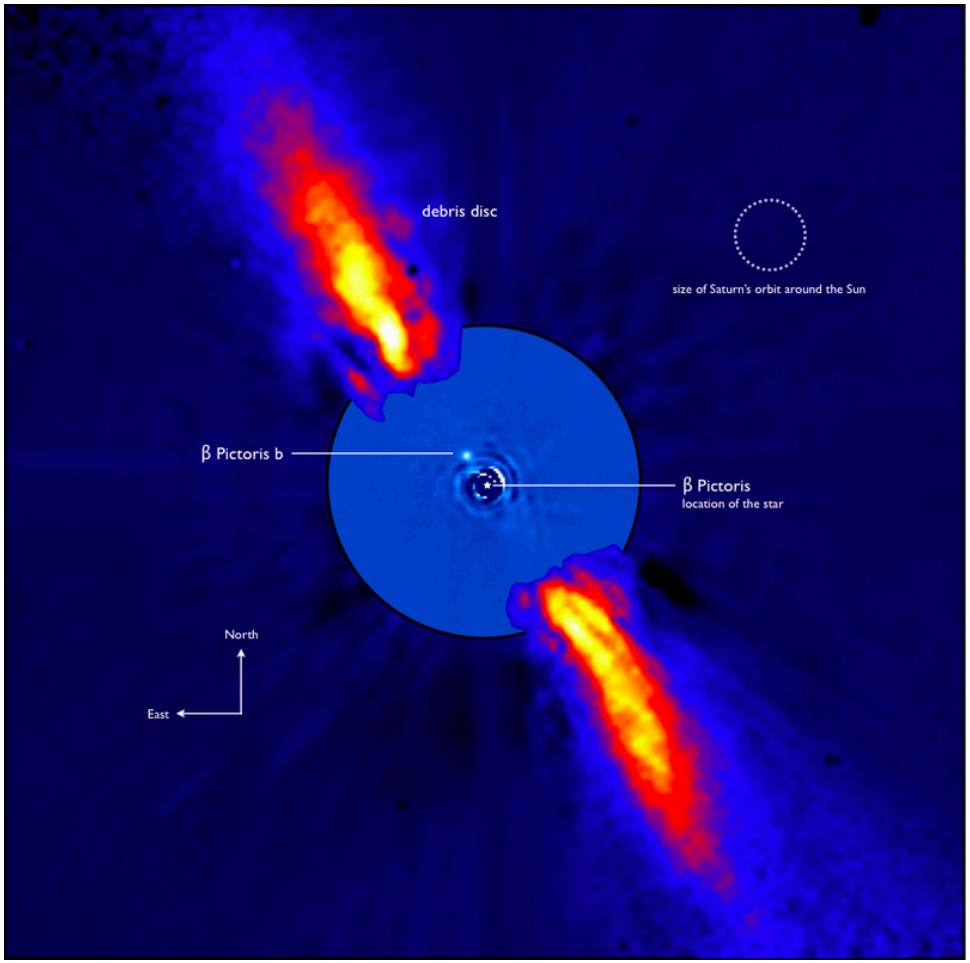
- HARPS at 3.6m telescope
  - best radial velocity machine at a 4m telescope (supported by UVES on VLT)
  - extremely stable spectrograph
  - fast pipeline → nearly immediate results
- NACO
  - adaptive optics system on an 8m telescope
- VLTI
  - highest spatial resolution for follow-up observations of known systems
- NACO/SINFONI/FORS2
  - transit measurements
  - atmospheres of exo-planets

A planet with 1.9$M_{\oplus}$ and one in the habitable zone

Mayor et al. 2009

β Pic planet

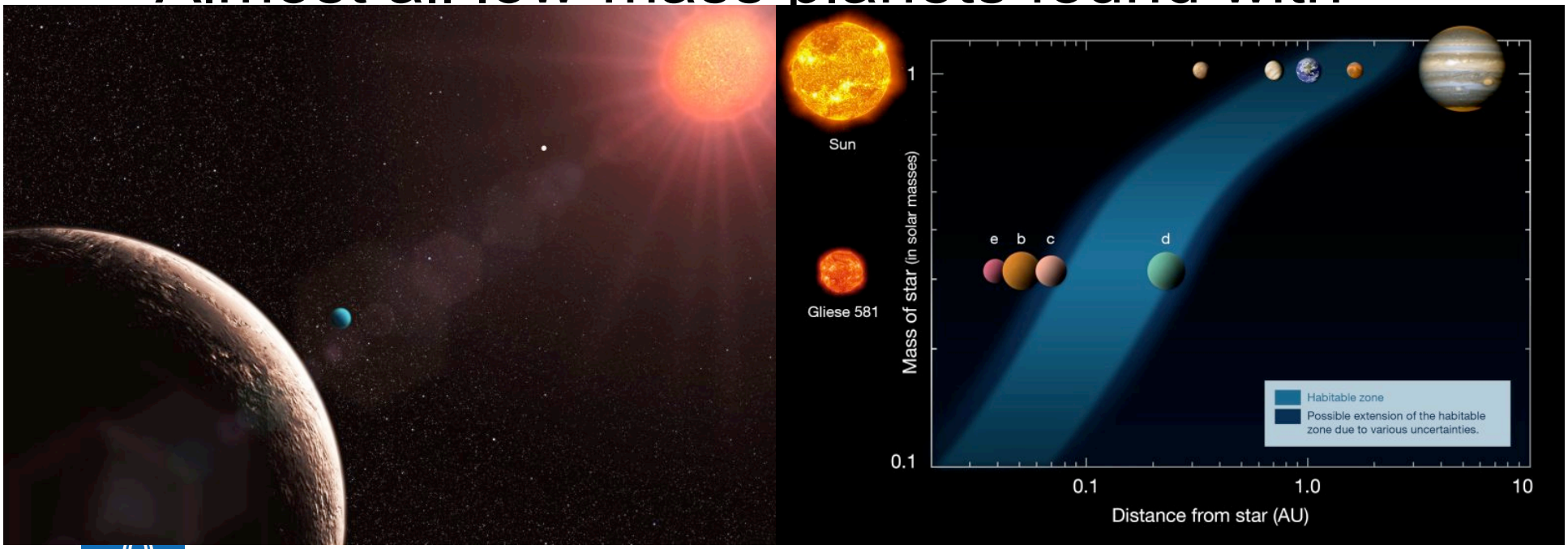
- Planet within the massive dust disk
- Orbit only a few astronomical units



Lagrange et al. 2009, A&A, 493, L21

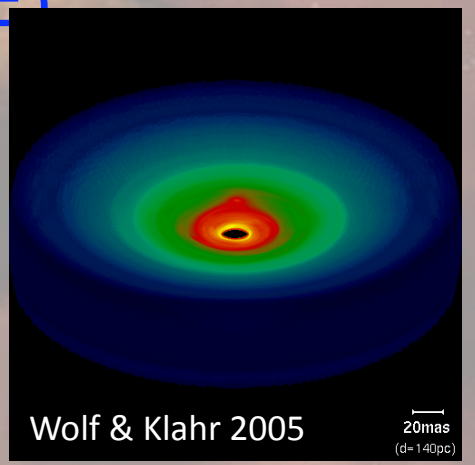
Searching for other earths

- HARPS is the most successful planet finder right now
- Almost all low-mass planets found with



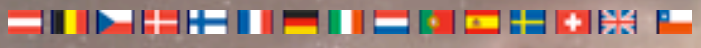
Star and planet formation

- Observing the warm cores of molecular clouds
  - Important: spatial resolution and large wavelength coverage
  - IR observations with large (>8m) telescopes, CanariCam (GTC), VLTI (MATISSE) JWST, ELTs
  - ALMA will be the champion for this field



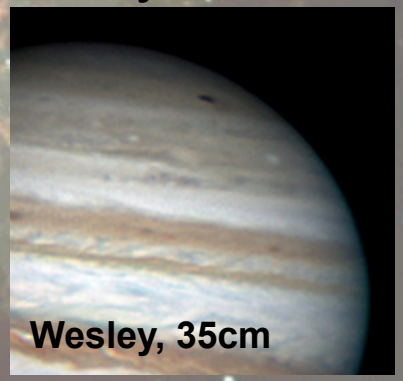
Fashions and other transient phenomena

- ESO top ten cited papers are all supernovae and GRBs
  - This is more a sign of fashion than sound physics
- AGNs – topic of the 4m telescopes
  - Topic for 8m telescopes?
- Metal-poor stars – originally 8m (e.g. First Stars programme)
  - And now?



When opportunity knocks

- Unique objects
  - SN 1987A
    - One in a century object?
  - Comets
    - Hale-Bopp, Hyakutake, 73P/Schwassmann-Wachmann 3, Shoemaker-Levy 9, Halley
  - Near-Earth objects
  - Solar system event
    - Spots on Jupiter
    - Volcano eruption on Io?
    - Comet impact on Jupiter?



Questions for the coming years

- nature of dark energy
- nature of dark matter
- when and how did the universe become transparent
  - what caused this transition
- how did galaxies form
- what is the connection between galaxies and black holes
- how do stars and planets form

An exciting future

- New telescopes
  - LOFAR
    - open up completely new parameter space
  - VISTA/VST
    - survey telescopes to map large fractions of the sky
  - ALMA
    - start in the coming years
  - E-ELT
    - to be constructed in this decade
- New missions (ESA's Cosmic Vision)
  - EUCLID
    - map the IR extra-galactic sky
  - PLATO
    - detect earth-like planets