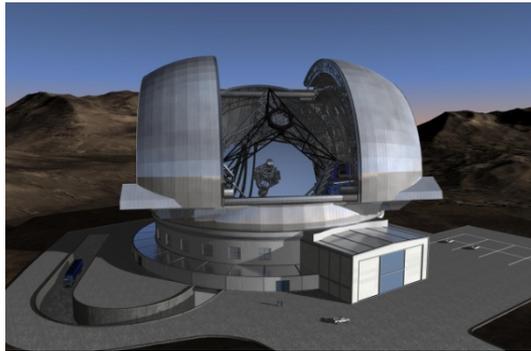




Challenges in Modern Astrophysics: Ground-based facilities



Bruno Leibundgut
(ESO)



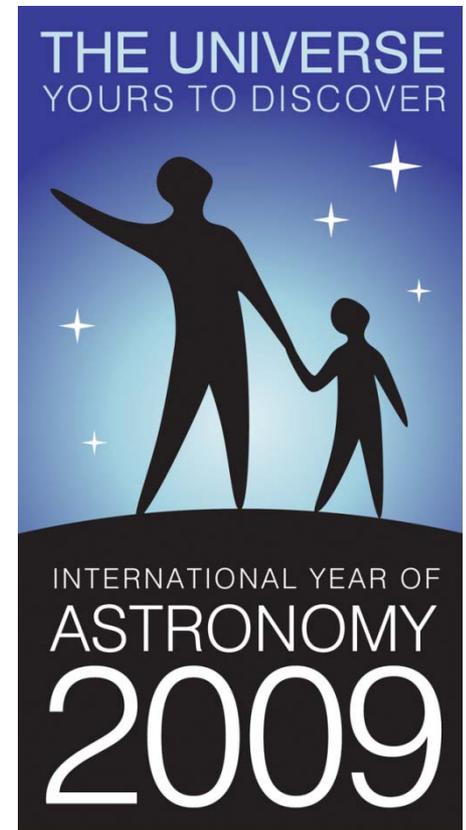
Astrophysics in a Golden Age

- **Full coverage of electro-magnetic spectrum**
 - MAGIC/HESS → Fermi/INTEGRAL → XMM/Chandra/Swift/Rossi XTE → Galex → HST/Gaia → ground-based optical/IR → Spitzer → Herschel → Planck → 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



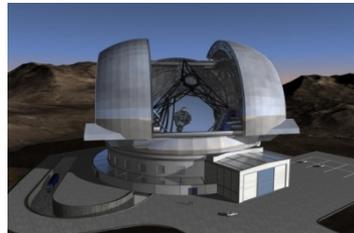
New facilities

VISTA, VST, LOFAR, ALMA



Under discussion

E-ELT, SKA, EST, CTA



European ground-based telescopes

- Spain
 - GTC, WHT, ING, TNG, NOT, MAGIC, Calar Alto, IRAM
 - Solar telescopes
- France
 - CFHT, (Dome C on Antarctica), IRAM
- Germany
 - LBT, HET, SALT, Calar Alto, MAGIC, HESS, APEX, IRAM
- United Kingdom
 - Gemini (North and South), (AAT), UKIRT, WHT, JCMT, eMERLIN
- Italy
 - LBT, TNG, (Dome C)
- International
 - European VLBI Network, LOFAR, ESO



Access to telescopes

- **Most observatories have open access policies**
 - Preference for supporting institutes
- **OPTICON Access program**
 - Access to 4m telescopes is supported by OPTICON funding for successful proposals
 - ESO 3.6m, NTT, Calar Alto, WHT, TNG, and various others
- **Archives!**



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





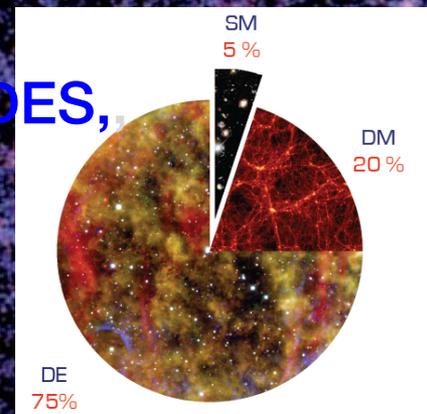
Science themes

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



What matters in the Universe?

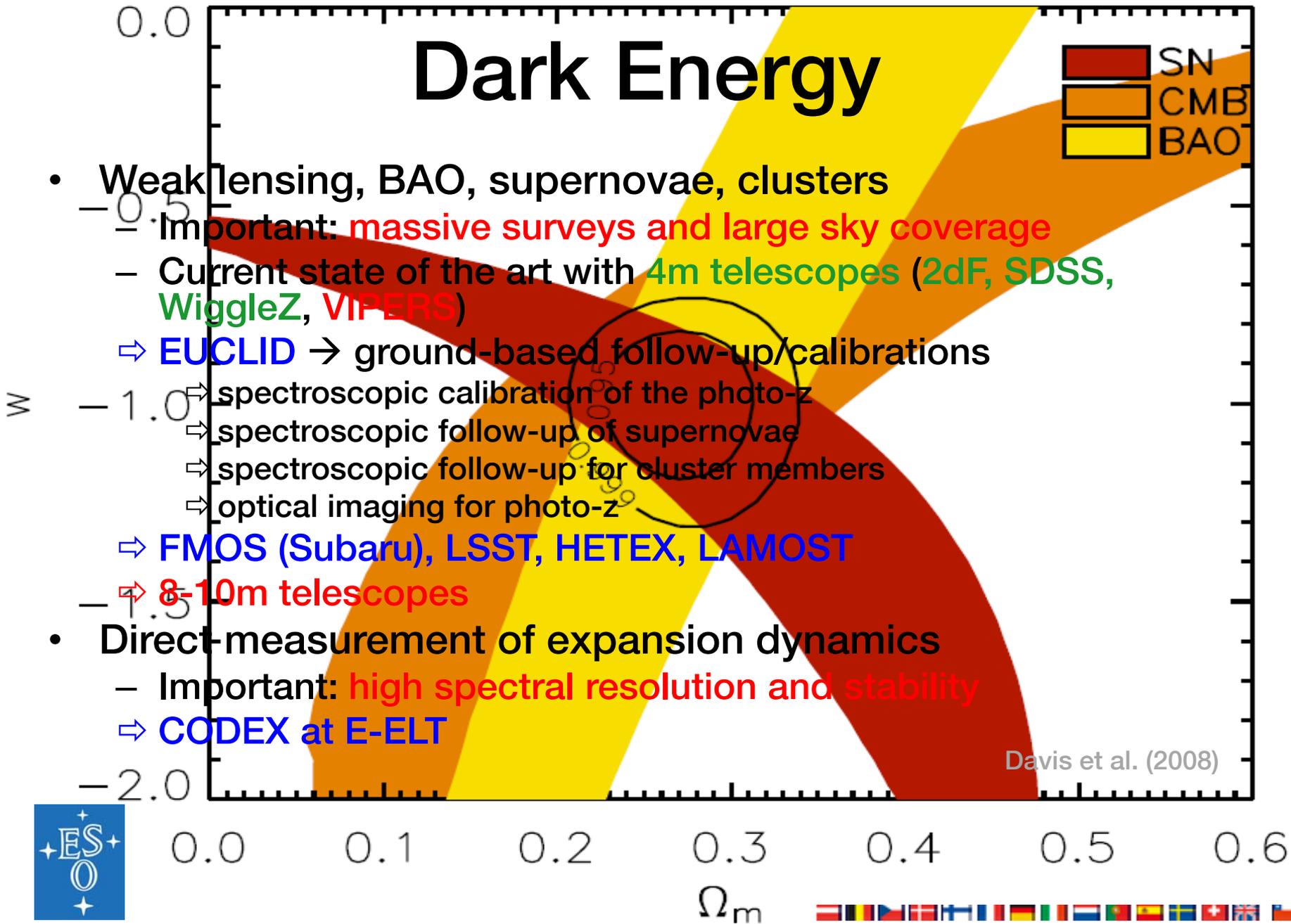
- Characterisation of dark matter and dark energy
 - Requires large samples
 - Multi-year and (often) multi-telescope projects
 - BAO (**SDSS**, **2dF**, **WiggleZ**, **BOSS**, **HETDEX**)
 - Weak lensing (**CFHT-LS**)
 - Supernovae (**SNLS**, **ESSENCE**, **SDSS-II**, **SN Factory**, **LOSS**, **PanSTARRS**, **DES**, **LSST**)
 - Galaxy clusters (**REFLEX**, **NORAS**, **SPT**, **DES**, **eROSITA**, **LSST**)
 - Redshift distortions (**VVDS**, **VIPER**)



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

Davis et al. (2008)

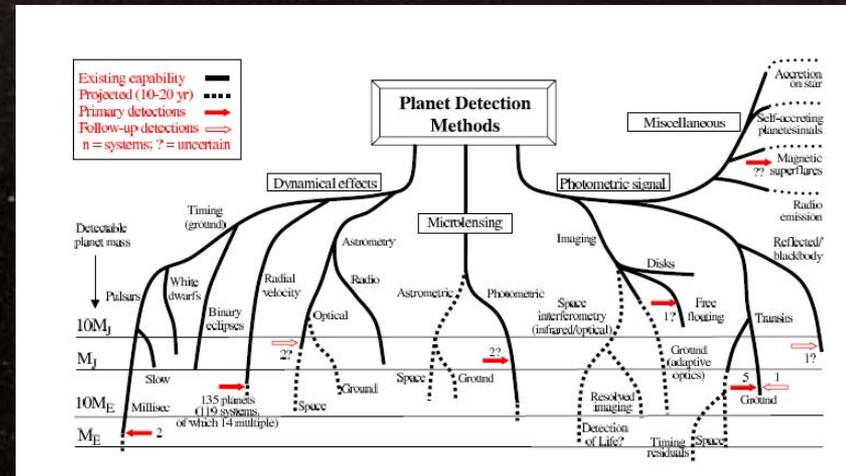
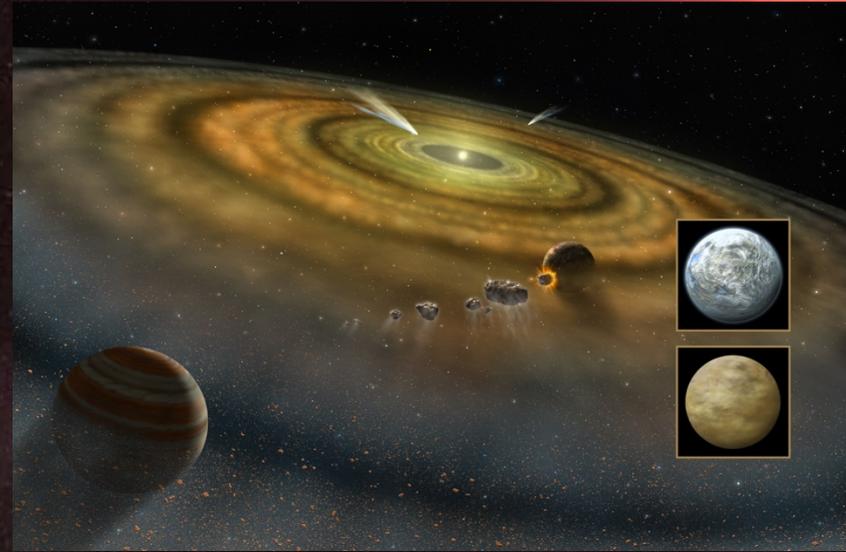


Planets, planets, planets

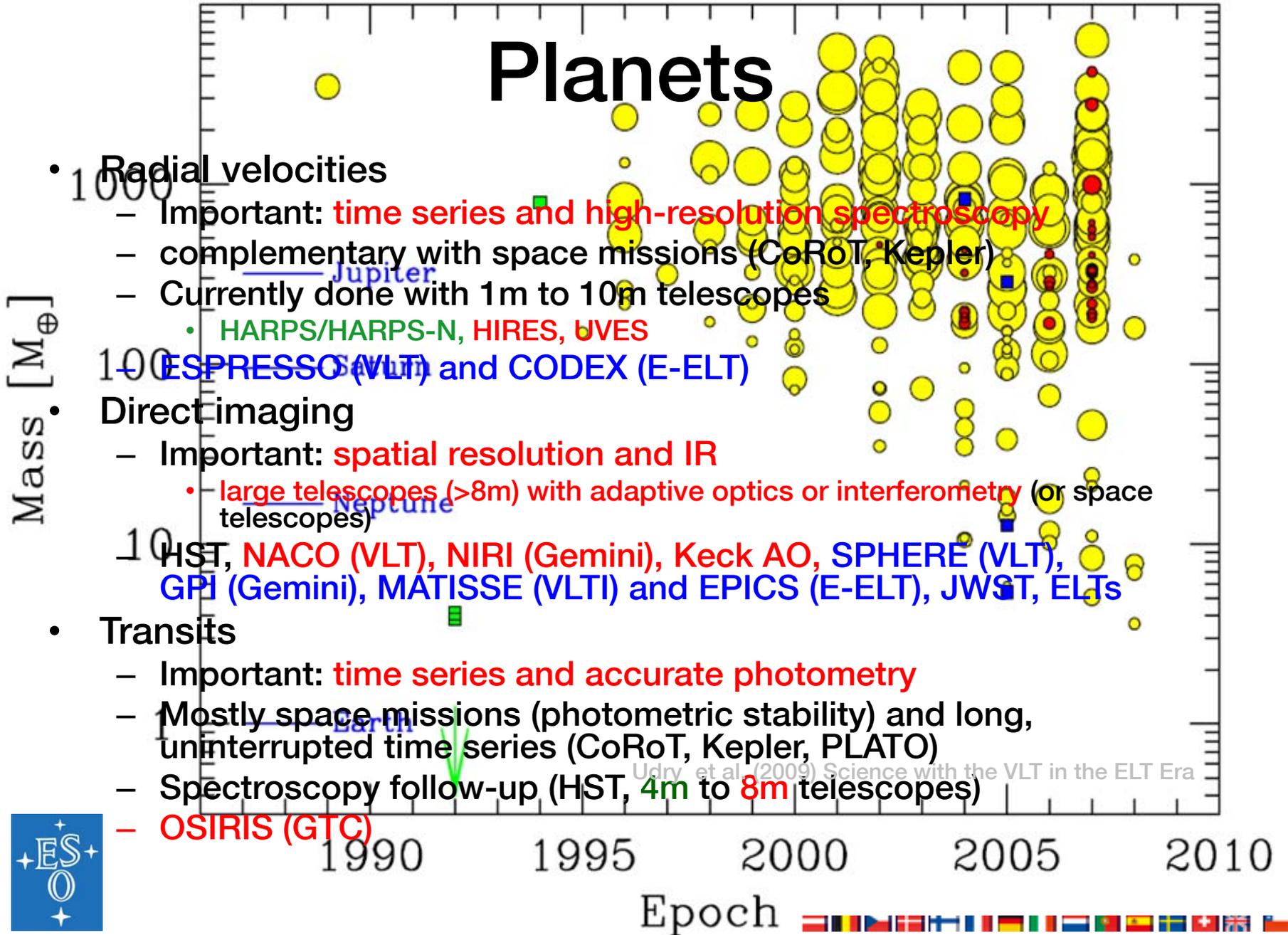
- Planets everywhere
 - Radial velocities
 - Direct imaging
 - Transits

- Characterisation

- Planetary systems, masses, chemical composition, temperatures



Planets



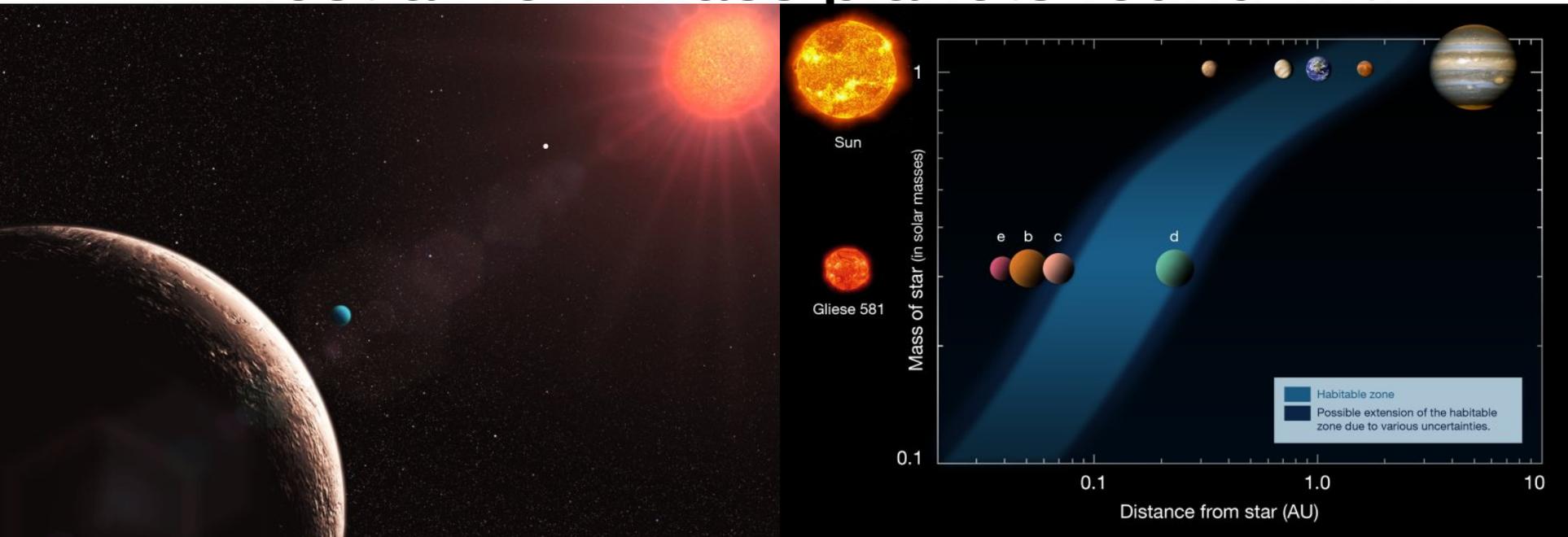
The ESO exo-planet machinery

- **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
- **VLT**
 - highest spatial resolution for follow-up observations of known systems
- **NACO/SINFONI/FORS2**
 - transit measurements
 - atmospheres of exo-planets



Searching for other earths

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



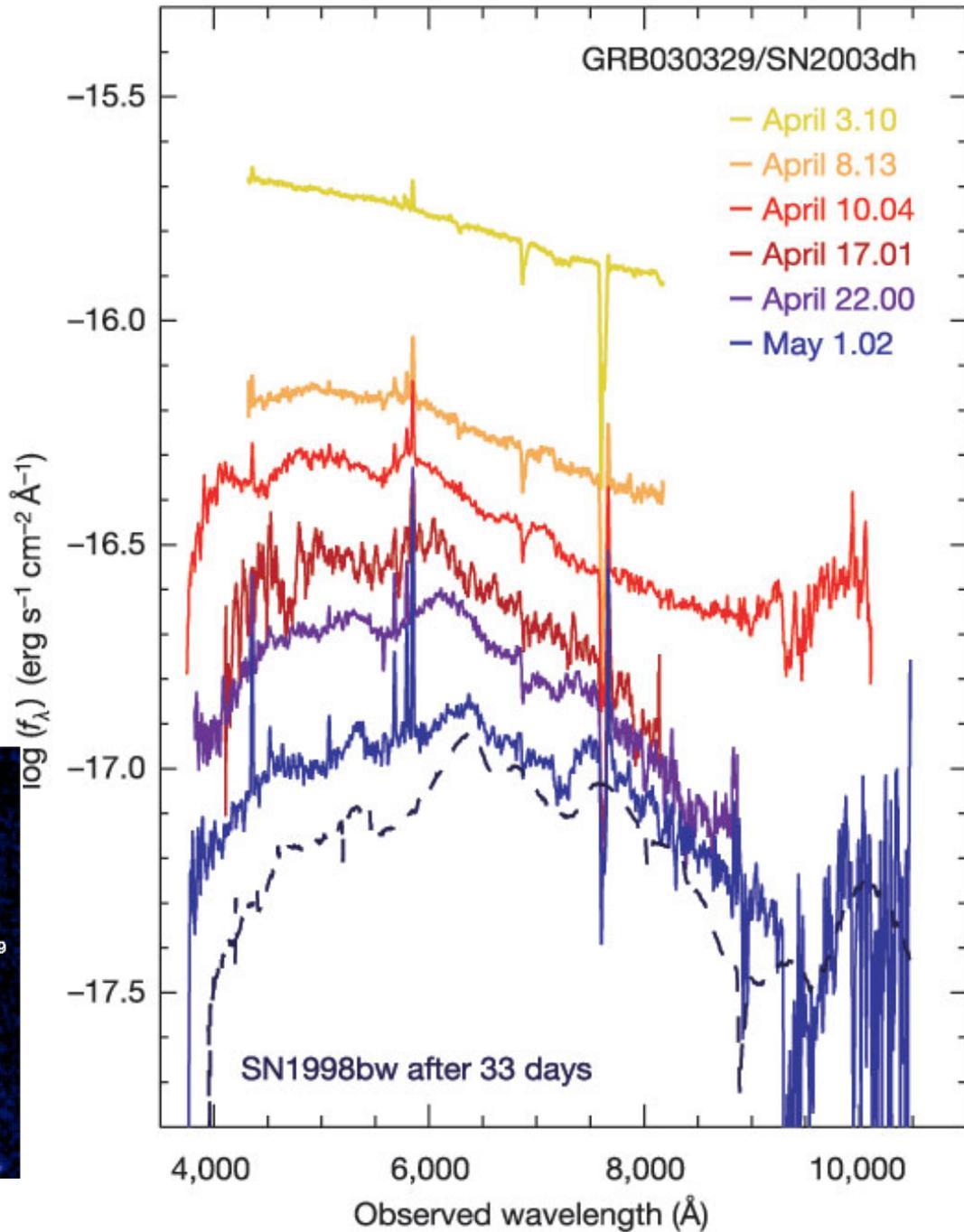
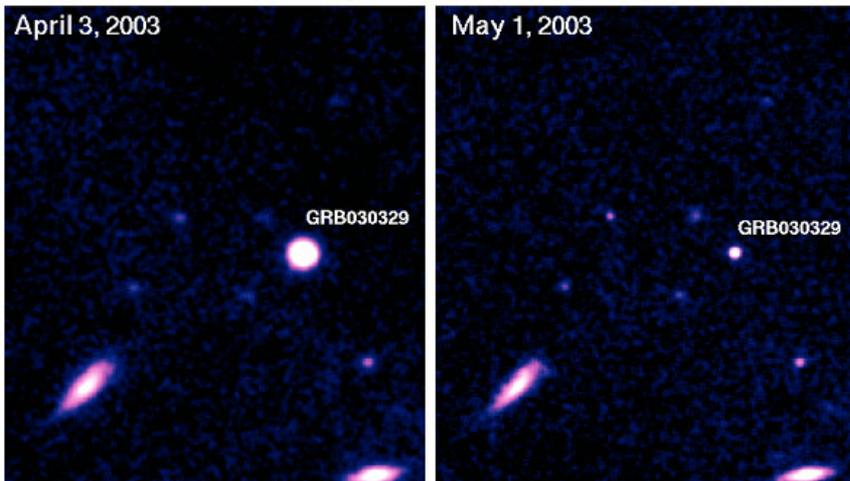
Gamma-Ray Bursts

- 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
 - required special instrumentation and software to observe adequately



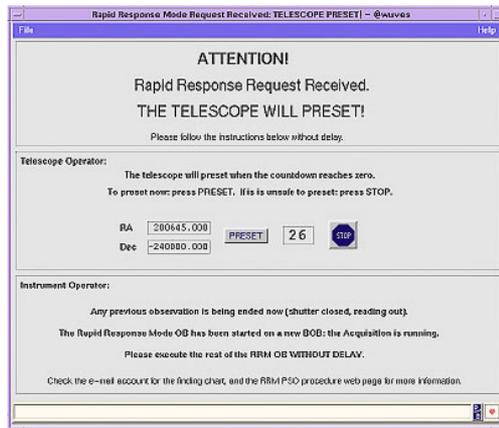
SN/GRB

- Spectral signals appear in Gamma-ray
- GRB 030329/SN 2003dh
GRB 980425/SN 1998bw
UVES spectrum closest known
FORN1 and 2 ok



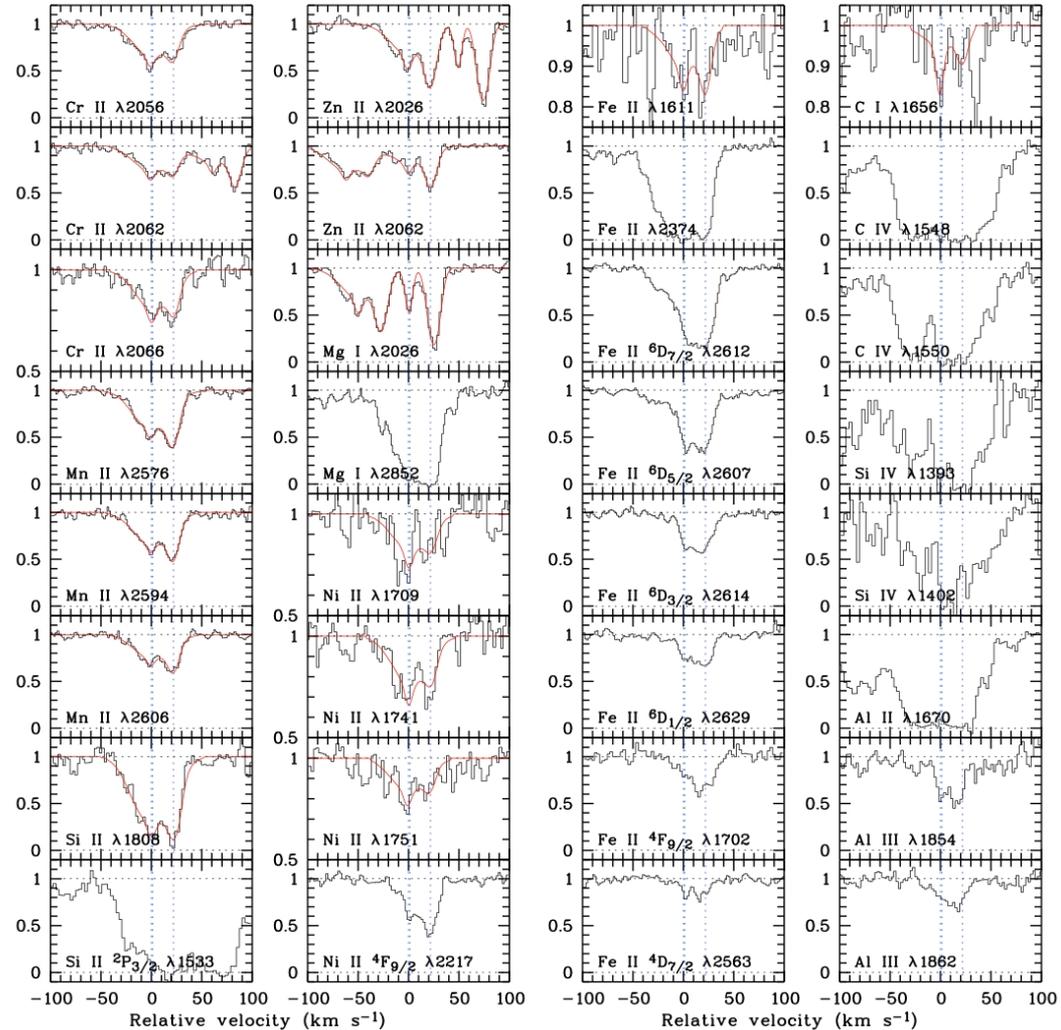
Rapid Response Mode (RRM)

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



Triggered by a Distant Explosion

ESO Press Photo 179/07 (28 March 2007)

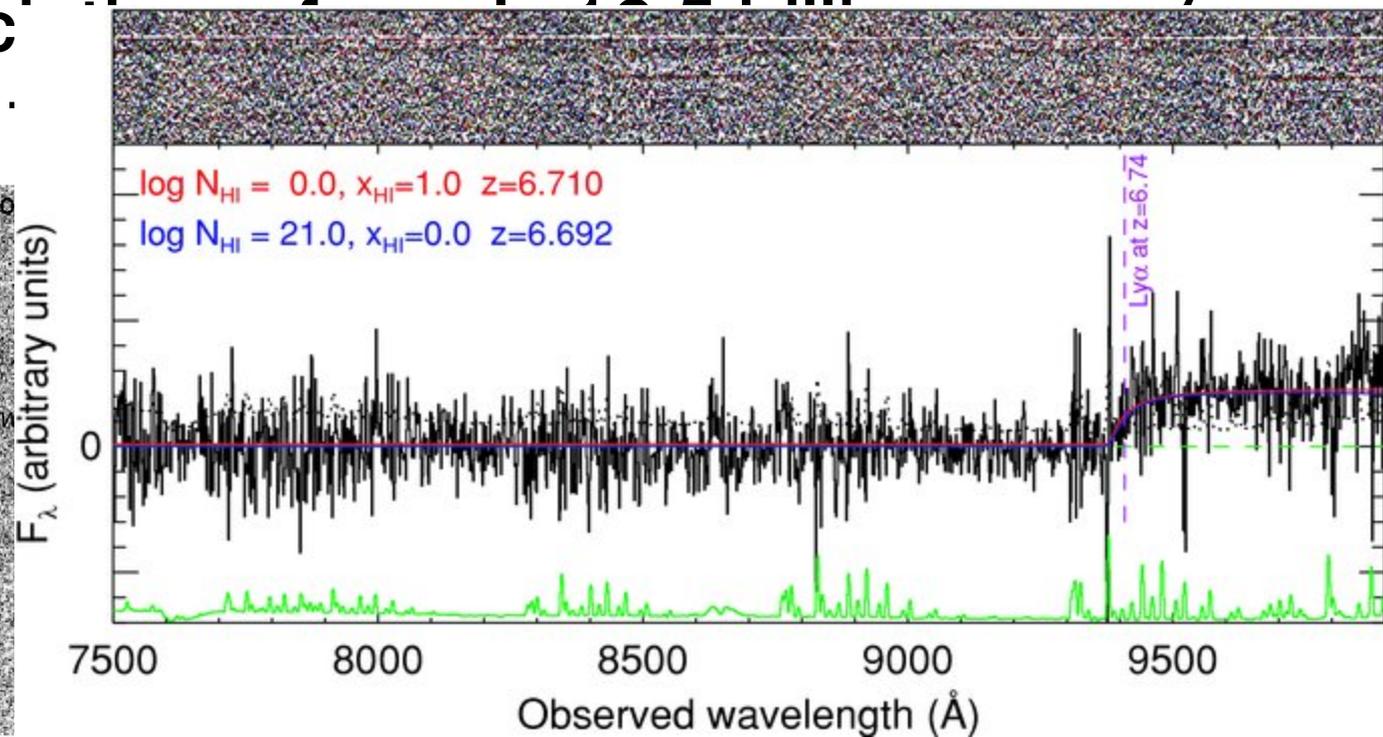
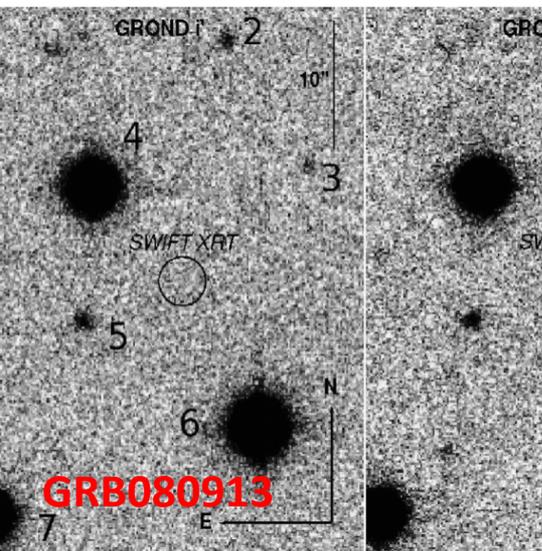


Many metal line systems
at 3 redshifts.
[Zn/Fe] >> QSO abs.



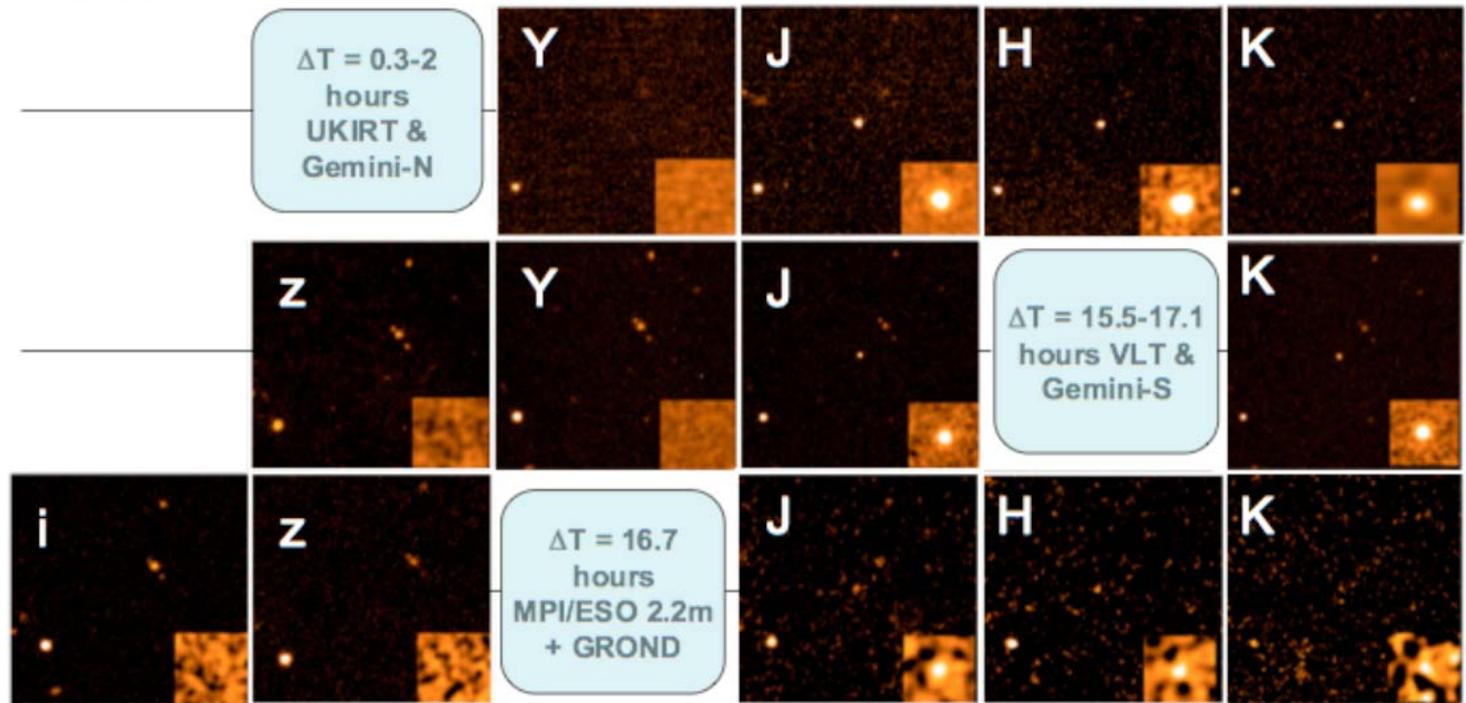
Gamma-Ray Bursts

- Most distant stellar objects ever observed
 - redshifts 6.7 and 8.2 (tentative)
 - lookback time 95% of



Most distant stellar object yet observed – GRB 090423

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

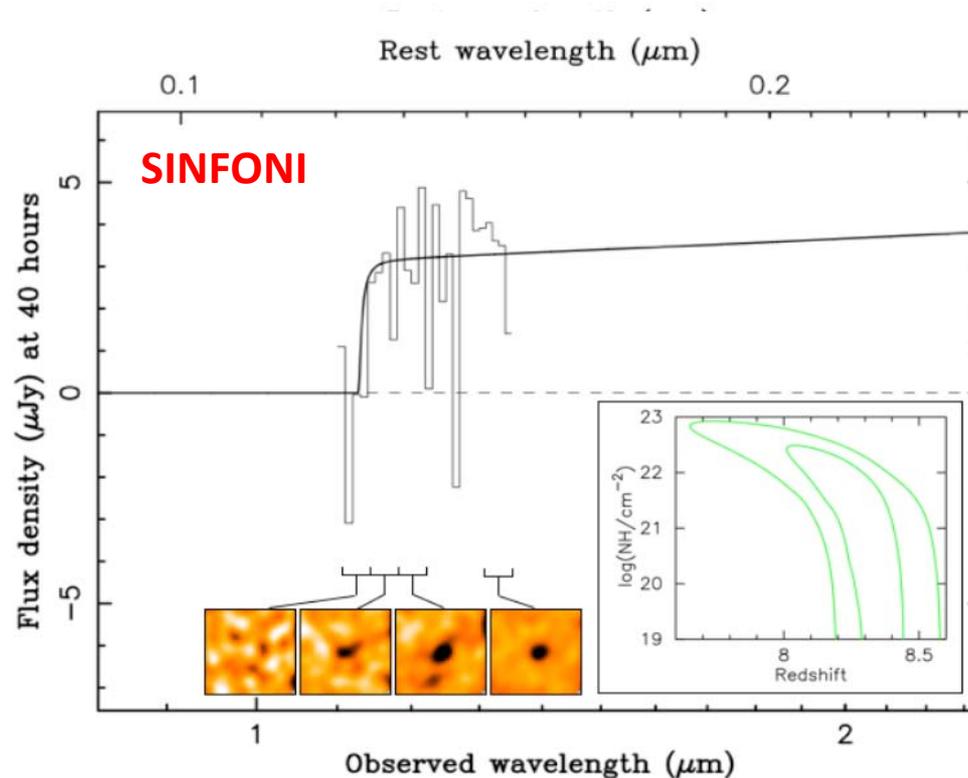


Tanvir et al., Nature submitted



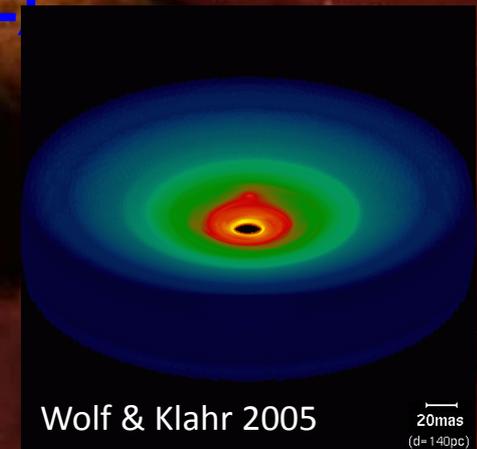
GRB 090423

- Spectroscopy 17 hours after outburst
- Lyman break indicates a redshift of $z \approx 8.2$



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), VLT (MATISSE), JWST, ELTs**
 - **ALMA** will be the champion for this field



The Milky Way

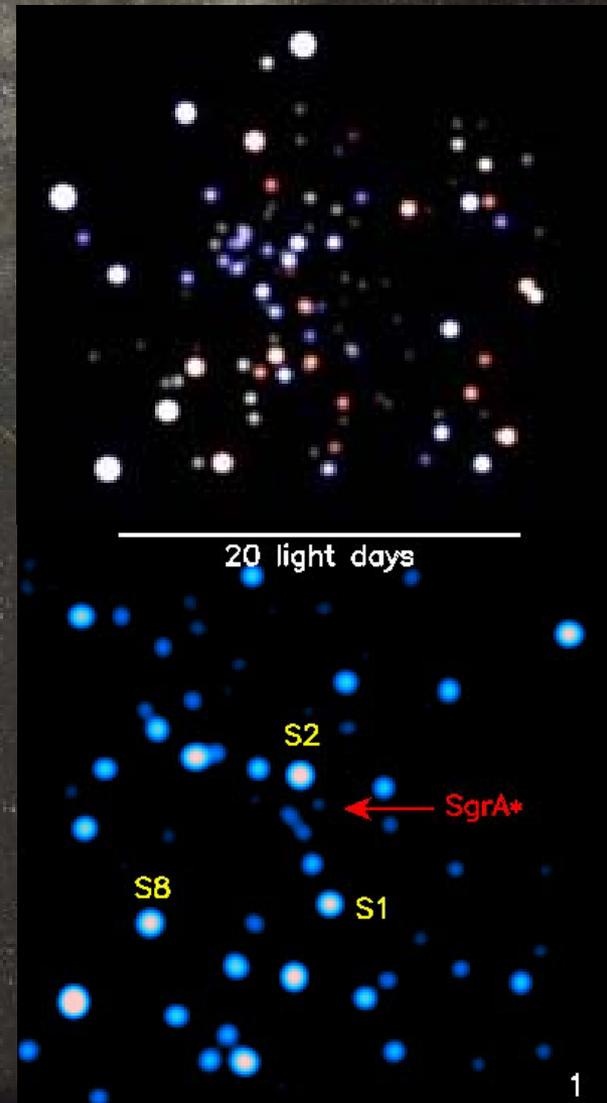
- Radial velocity study of 14000 F and G stars over two decades years
- This photometry and Hipparcos parallaxes

- Spiral arms
 - Gas flows, stellar distribution
- Bulge composition, Galactic Centre
- Distribution of massive stars



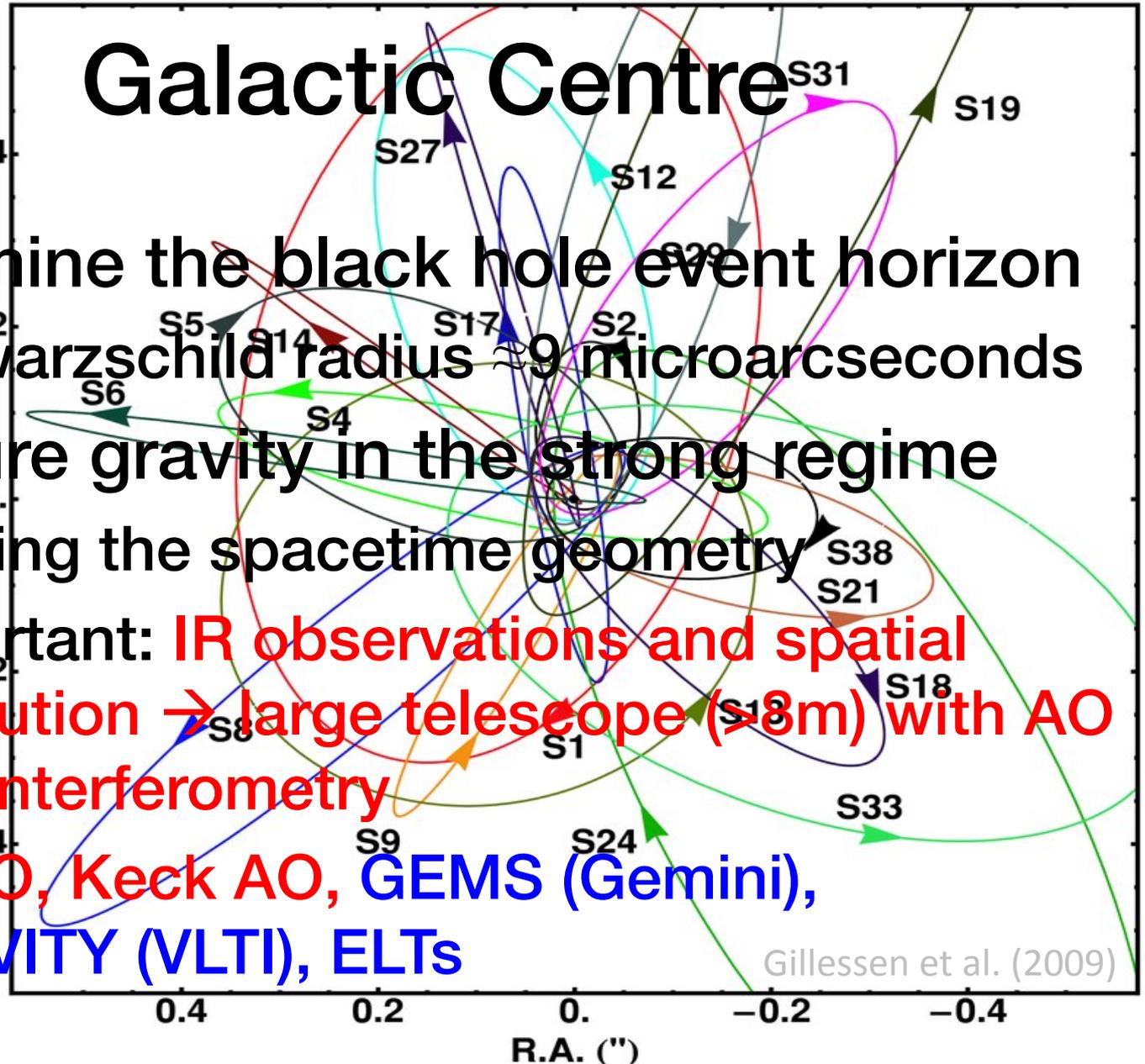
Our own black hole

- Mass determination through stellar orbits
- Structure around the black hole revealed through flashes
- Coordinated studies with 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 \rightarrow large telescope ($>8\text{m}$) with AO and interferometry
 - NACO, Keck AO, GEMS (Gemini), GRAVITY (VLTI), ELTs

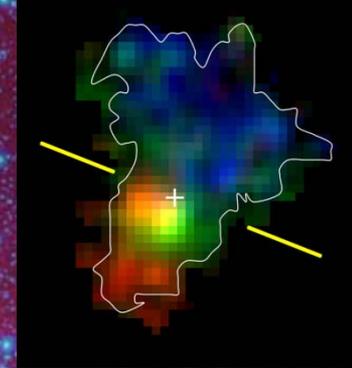


Gillessen et al. (2009)



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



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



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

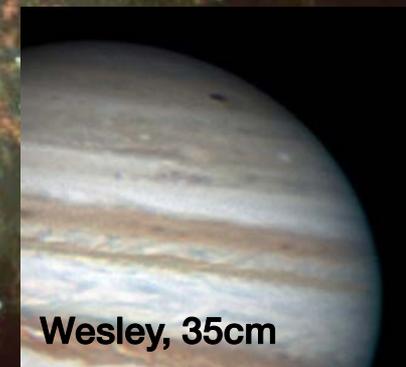
- Near-Earth objects

- Solar system event

- Spots on Jupiter

- Volcano eruption on Io?

- Formation of new large spot on Jupiter?



Wesley, 35cm



Role of 2-4m telescopes

- Workhorses of optical/IR astronomy
 - Distributed resource
 - Access at the university level
 - Many national telescopes
 - Access for many astronomers
 - Develop specific strengths
 - E.g. time series, large samples
 - Examples of successful the 4m telescopes over the past decade
 - AAT/2dF, CFHT/Legacy Survey, ESO 3.6m/HARPS, WHT/SAURON and PN.S



Role of 8-10m telescopes

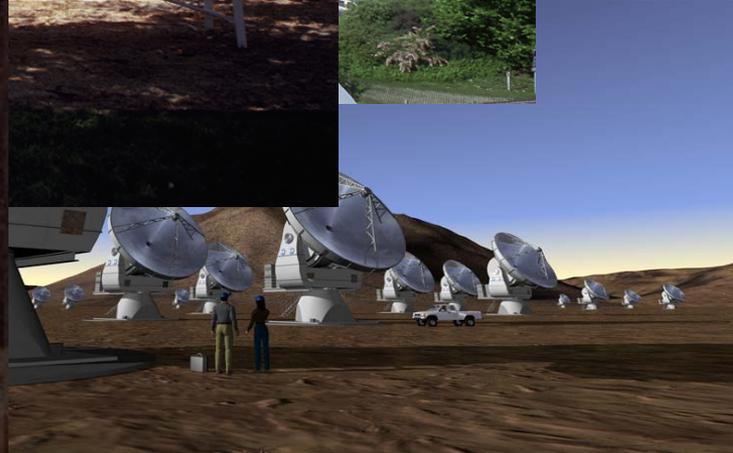
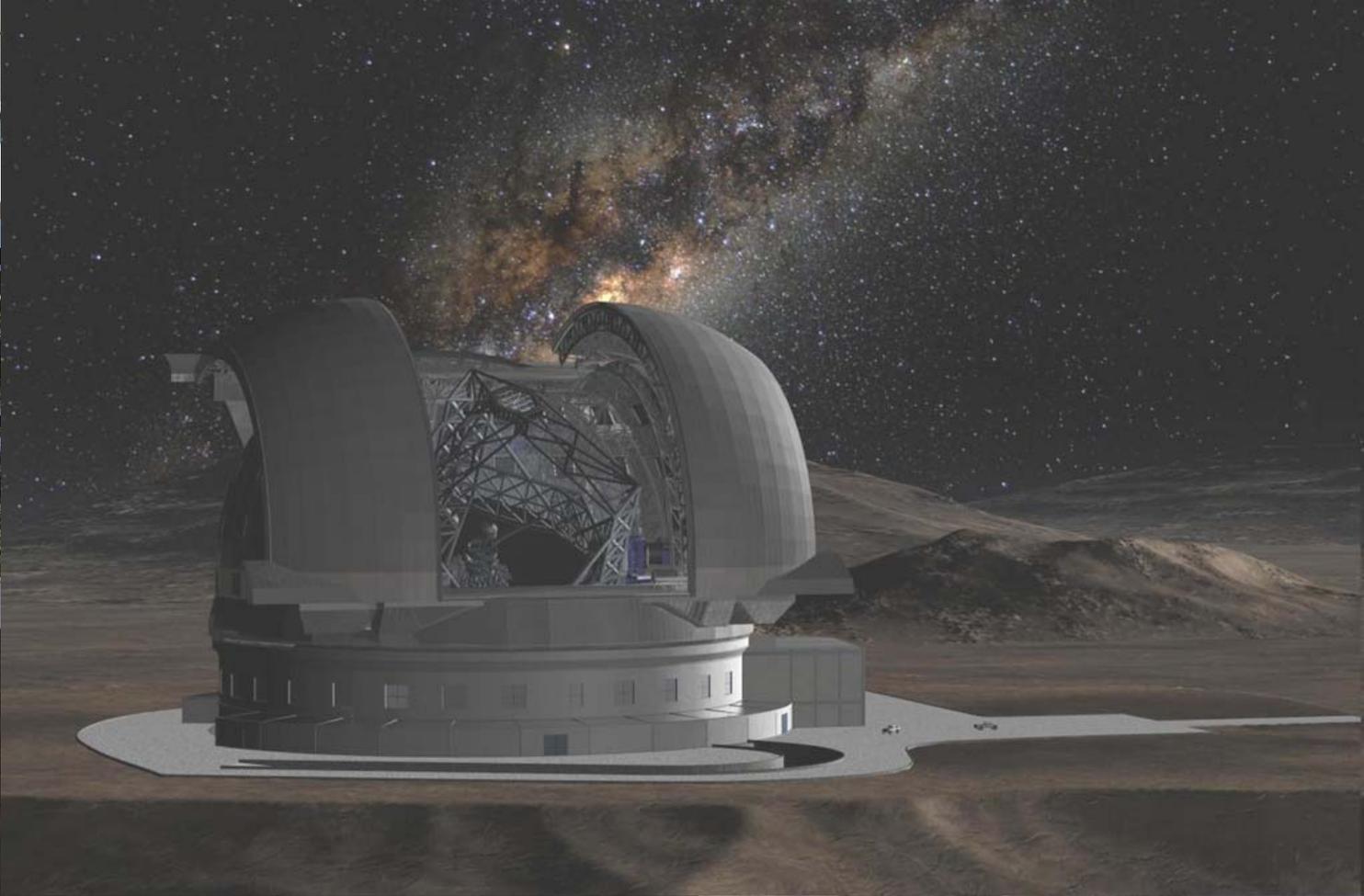
- **Workhorses of optical/IR astronomy**
 - **Distributed resource**
 - In general have an open access policy
 - **Access for many astronomers across all regions**
 - **Currently cover all observational parameters**
 - **In the future develop specific strengths**
 - E.g. time series, wide-field spectroscopy



ESO's program

- **La Silla Paranal Observatory**
 - Continue operations of these southern telescopes
 - Implement second generation instruments (VLT/VLTI)
 - Key surveys with VST and VISTA
 - Long-term programs for unique science on La Silla
 - Prepare for ALMA science with APEX
- **Deliver ALMA on time and budget**
- **Design world-leading E-ELT and secure funding for construction and operations**





ESO's world

ESO's sites

Paranal
La Silla
Santiago
Chajnantor

Garching bei München

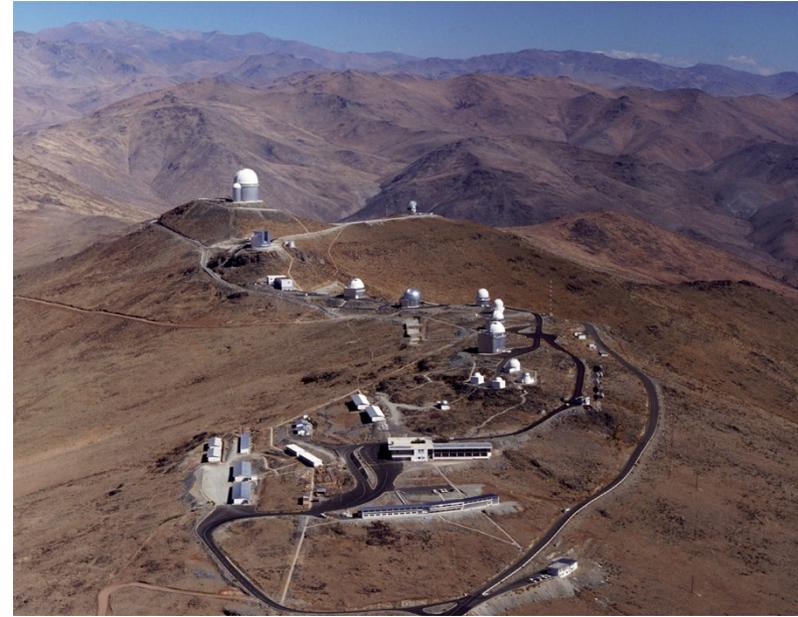
La Silla Paranal

- VLT
 - Continue operations with new instruments
 - FORS2, ISAAC, UVES, FLAMES, NACO, SINFONI, CRIFES, VISIR, HAWK-I, VIMOS, X-Shooter, KMOS, AOF, MUSE, SPHERE
 - MIDI, AMBER, PRIMA, GRAVITY, MATISSE
- La Silla
 - Continue operations with long-term programmes
 - HARPS, EFOSC2, SOFI, visitor instruments
- APEX
 - Covers sub-mm and mm wavelendths 0.3 to 3 mm
 - SHFI (Swedish Heterodyne Facility Instrument), LABOCA, SABOCA, APEX-SZ, CHAMP+, FLASH



La Silla

- **Medium-size telescopes**
 - 3.6m: HARPS for exo-planet searches
 - 3.5m NTT: EFOSC2 & visitor instruments
 - 2.2m in partnership with **MPG**
- **Small telescopes**
 - Closed/funded externally



La Silla: 5 Operational Instruments

3.6m



HARPS



NTT



SOFI



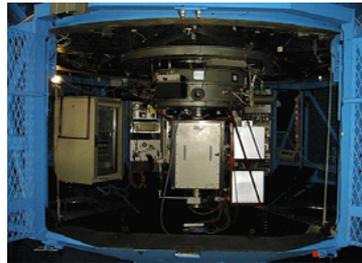
2.2m



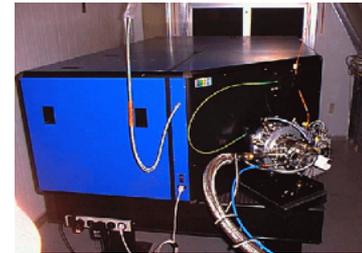
WFI



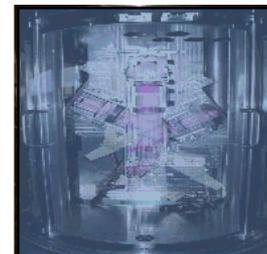
EFOSC2



FEROS



GROND



Access to La Silla 3.6m and NTT

- Through the OPTICON Access program non-ESO member state astronomers can get their observing costs reimbursed
- Simply apply to ESO under this program
- So far, this channel has not been used very successfully → very few proposals!



Paranal





VLT Instruments

Instruments Operational on the VLT/I

ANTU

ISAAC



KUYEN

FLAMES



MELIPAL

VISITOR



YEPUN

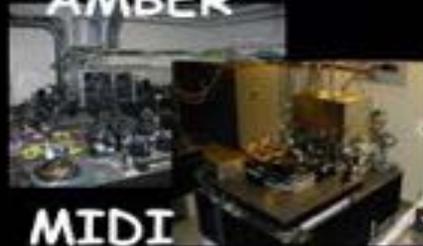
HAWK-I



2xFORS



AMBER



VISIR



SINFONI



MIDI

CRIRES



UVES



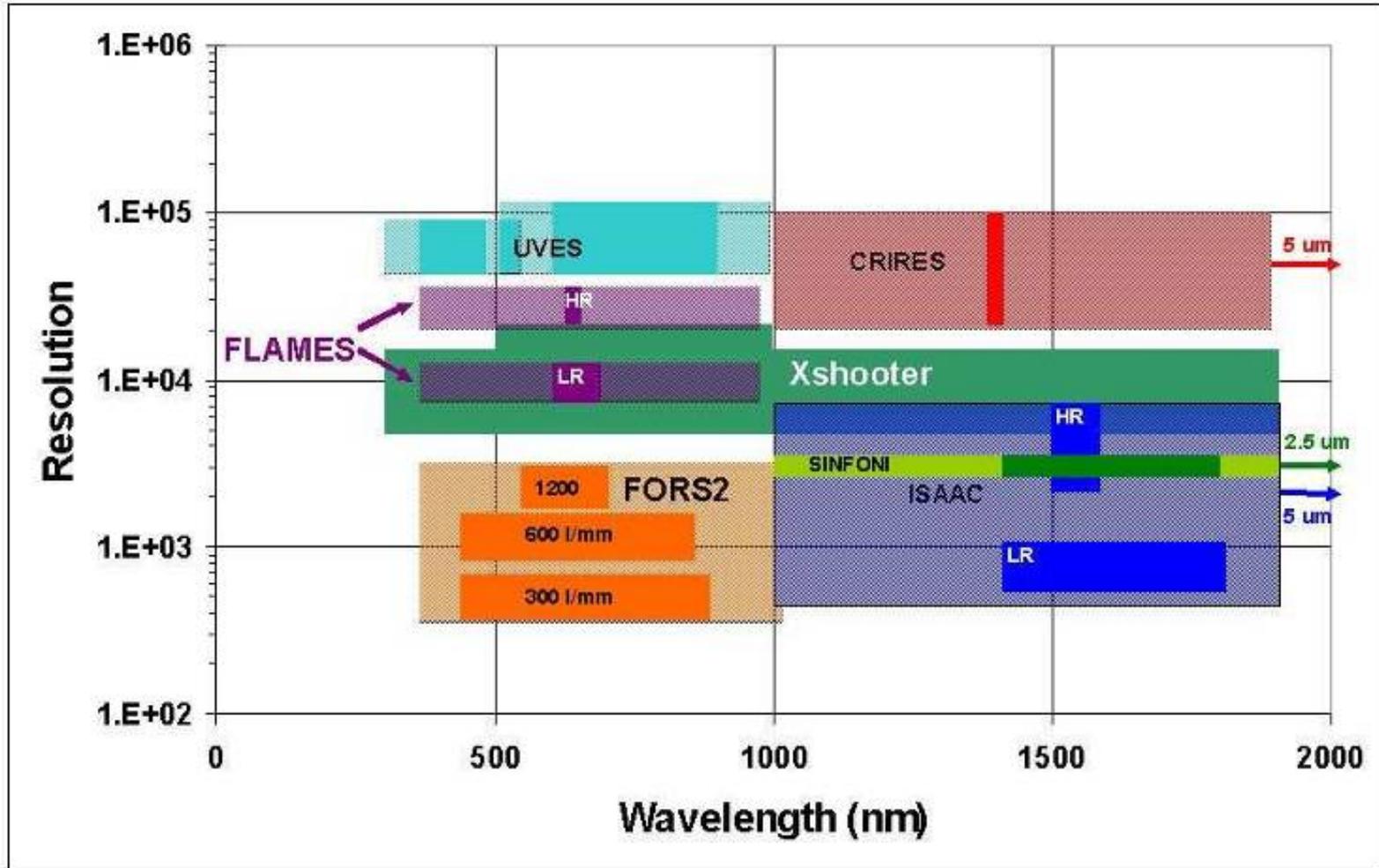
VIMOS



NACO



VLT/I Spectral Resolution



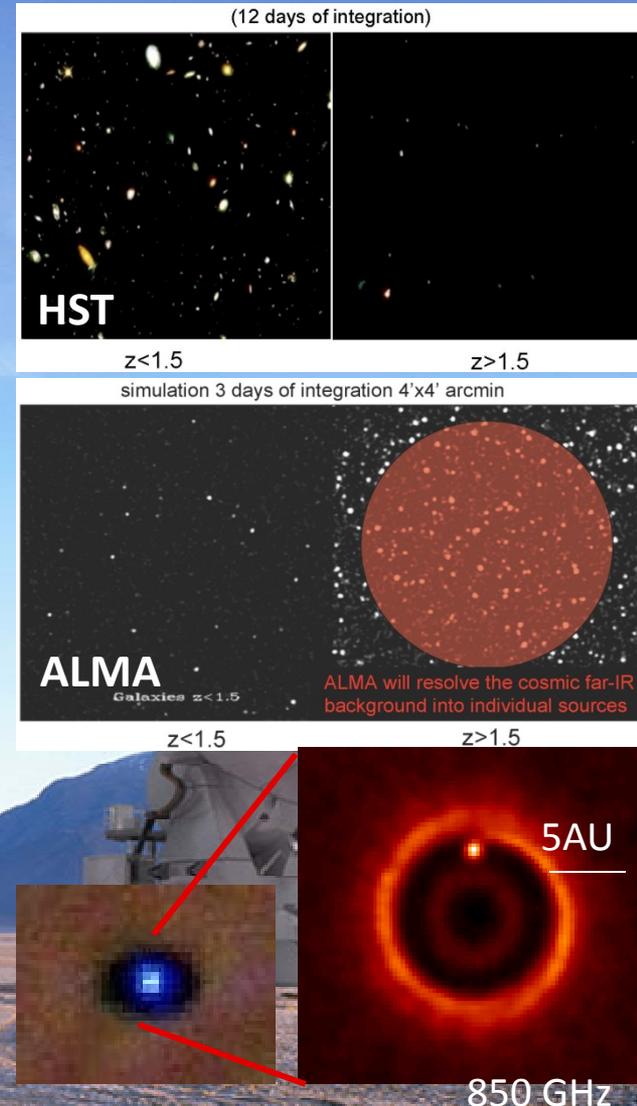
Very Large Telescope Interferometer



ALMA

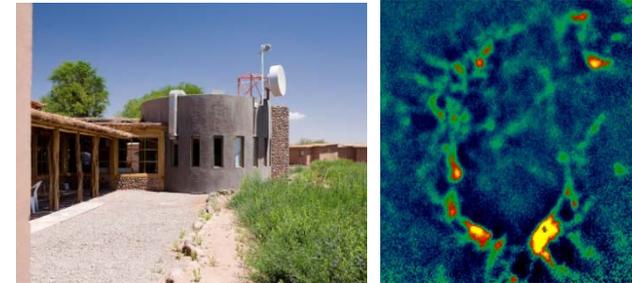
In Search of our Cosmic Origins

- 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)
 - 16 km max baseline (< 10 mas)
 - 30-1000 GHz (10–0.3mm), up to 10 receiver bands



Chajnantor

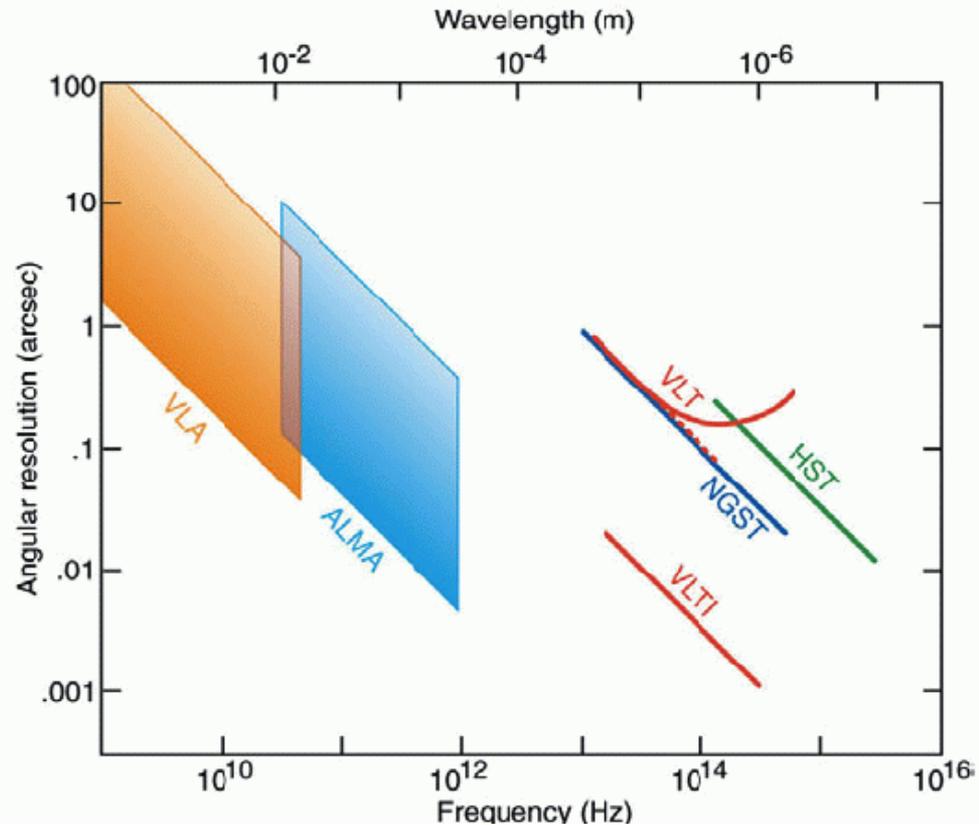
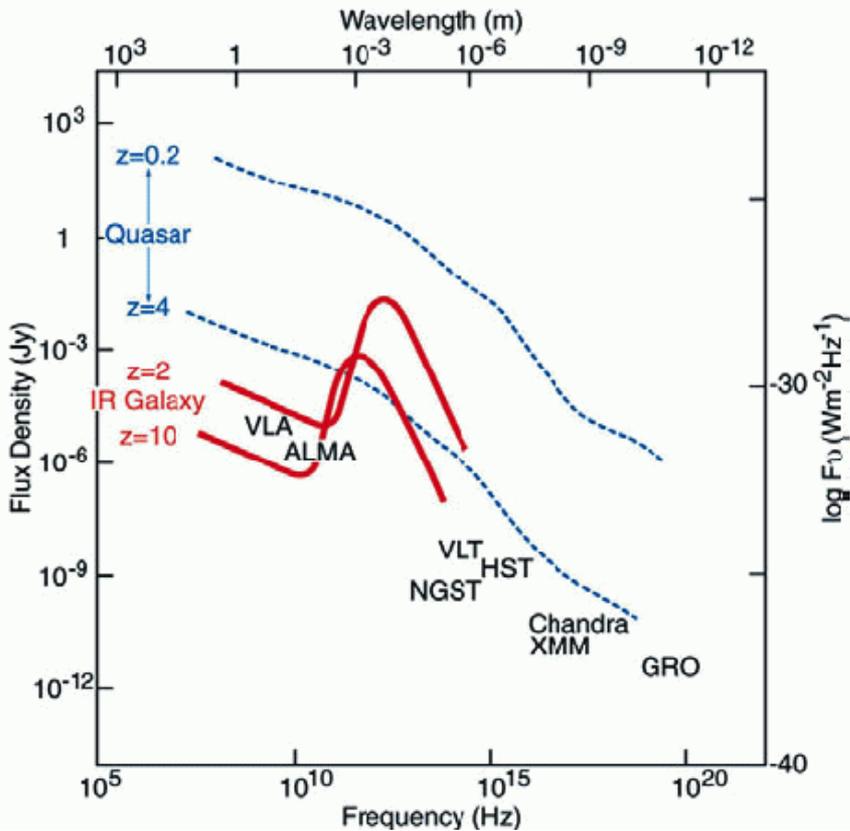
- **APEX**
 - 12m sub-millimeter antenna, operated by ESO @ Sequitur
 - MPG (50%), Sweden (23%) and ESO (27%)
- **ALMA**
 - Transformational science
 - 66 antennas at 5050m
 - Operations support at 2950m
 - Global partnership with North America East Asia & Chile



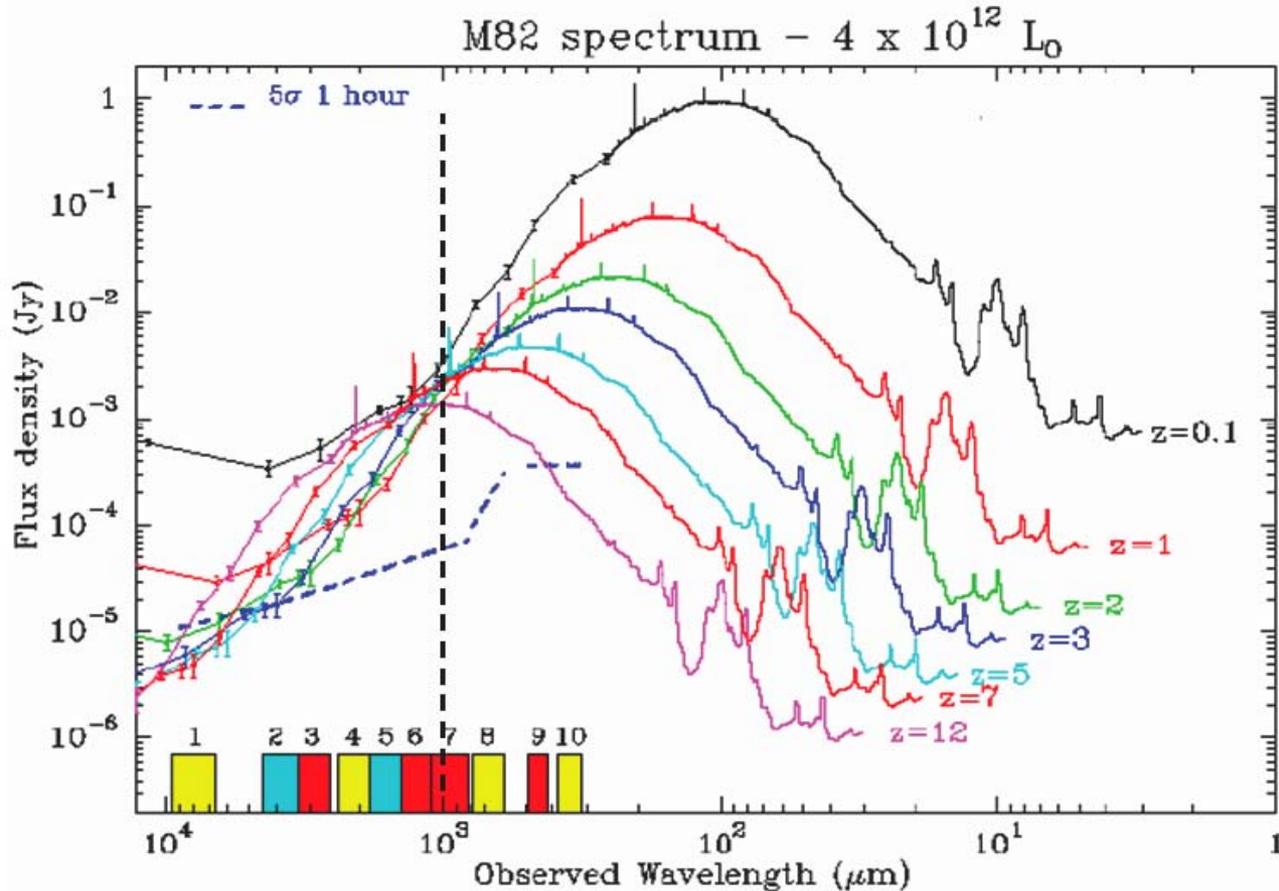
First antenna at 5000m



Sensitivity and Resolution



History of Galaxies



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



ALMA Science

- Star Formation, Proto-planets in nearby disks
- Astrochemistry
- Interstellar medium (Galaxy, Local Group)
- High-redshift deep fields
- *+130 projects in first 3yrs – DRSP 2.1*
 - <http://www.eso.org/sci/facilities/alma/science/drsp/>

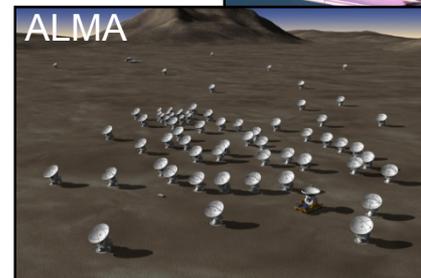
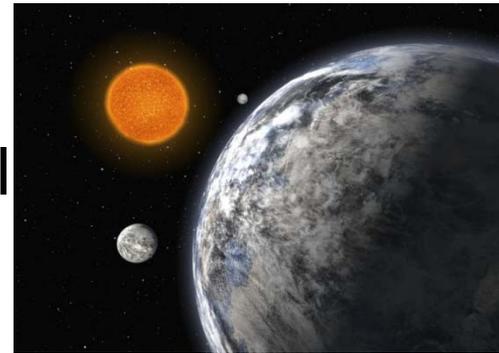


E-ELT

- Detailed design study
 - Baseline 42m primary mirror
 - Adaptive optics built-in
 - Industry 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

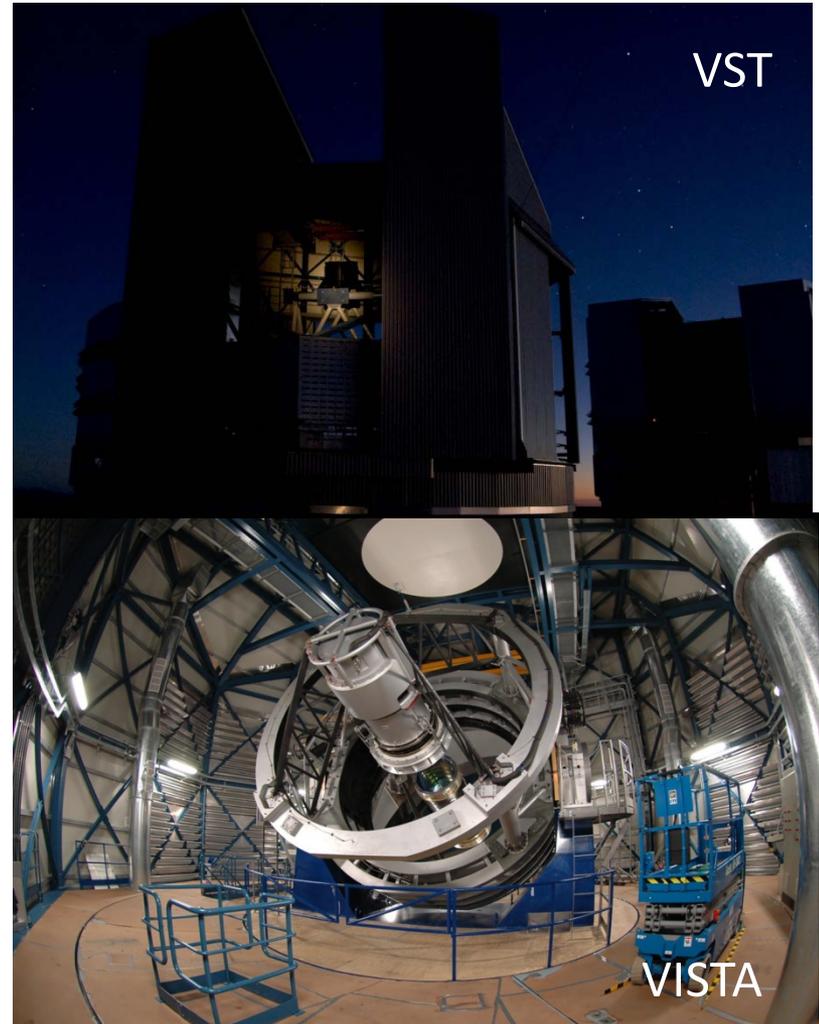
The Science

- **Contemporary Science:** Exoplanets, planet formation, resolved stellar populations beyond the Local Group, Black Holes, the physics of high redshift galaxies, the expansion of the universe, ...
- **Synergies with other top facilities:** ALMA, JWST, survey telescopes, SKA, ...
- **Discoveries:** opening new parameter space in spatial resolution and sensitivity, ...



The Survey Telescopes

- **Under construction**
 - VST 2.6m for optical
 - Completion in 2010
 - VISTA 4.1m for infrared
 - Currently in science verification
- **Science**
 - Multi-year program of large public surveys
 - Coordinated by ESO
 - Develops European survey capability



ESO Archive

- **The ESO data archive**
 - is a rich source of excellent data
 - abstracts of previous proposals available
 - data public one year after they have been delivered to the PI
 - great way to compete with your competitor, if they got observing time
 - easy retrieval and selection of calibration data



Get involved

- **Participate in ESO activities**
 - get to know the organisation better
 - active interactions with ESO people
- **Have a lively scientific exchange with the (European) astronomical community**
 - conferences, workshops
 - regularly publish your results



European Extremely Large Telescope

