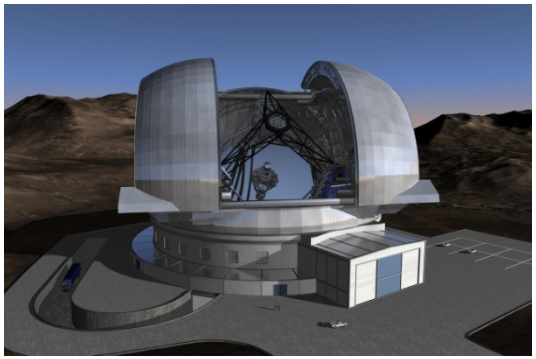
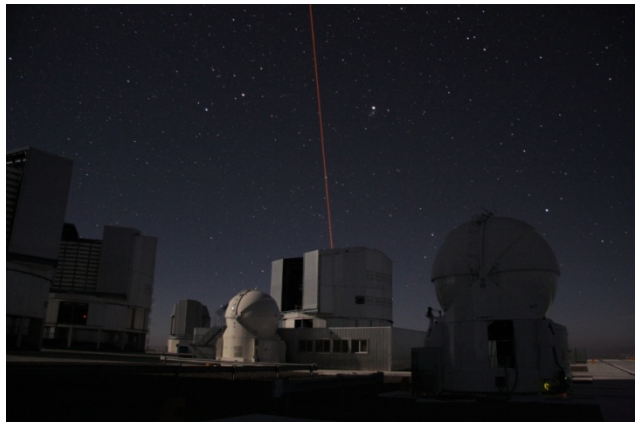
Astrophysics for the Next Decade



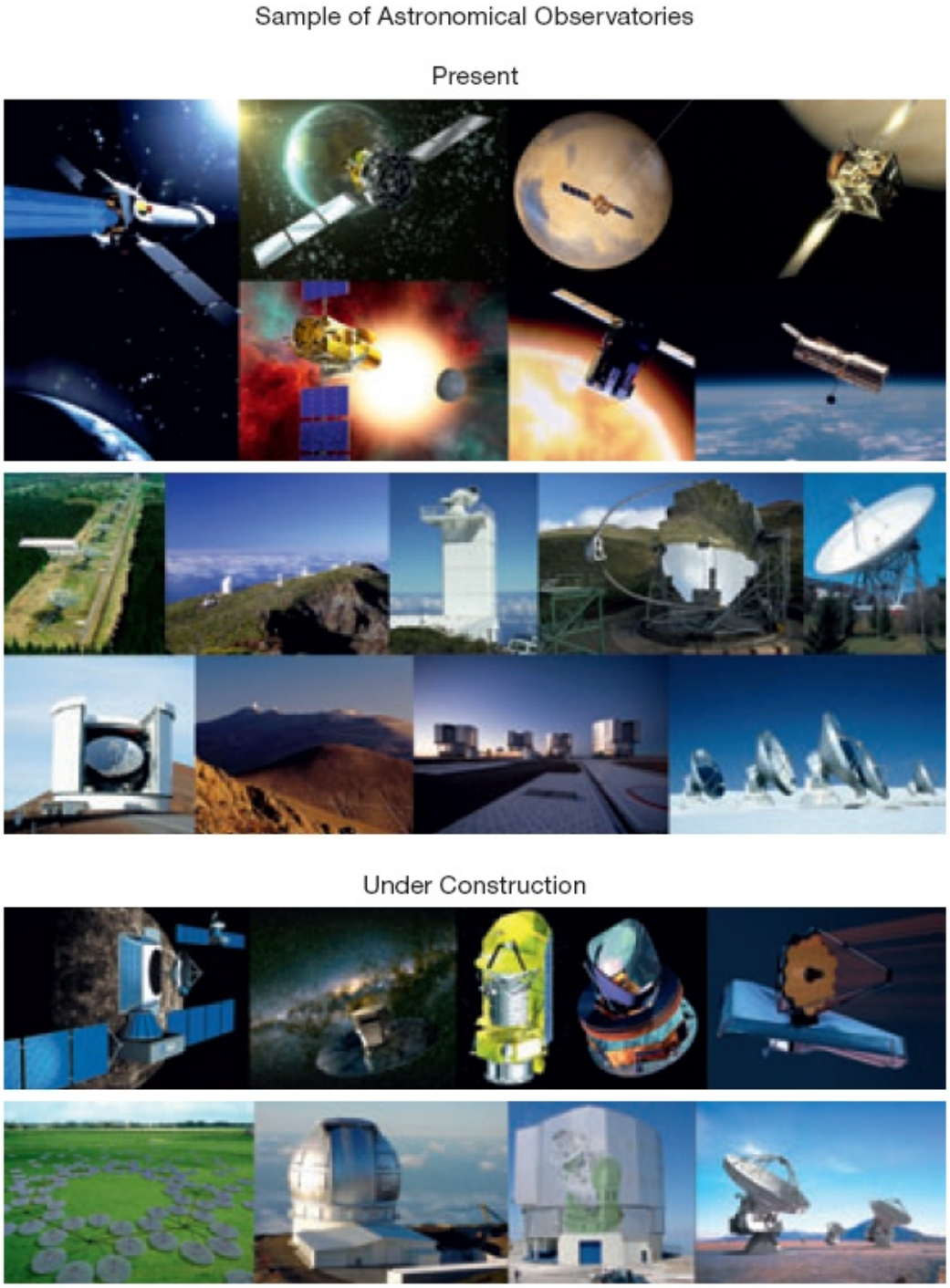
Bruno Leibundgut
(ESO)



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
  - Large archive collections (e.g. ROSAT, ISO, ESO, HST, MAST)
- Astro-particles joining in
  - cosmic rays, neutrinos, gravitational waves, dark matter searches

Fantastic opportunities



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?

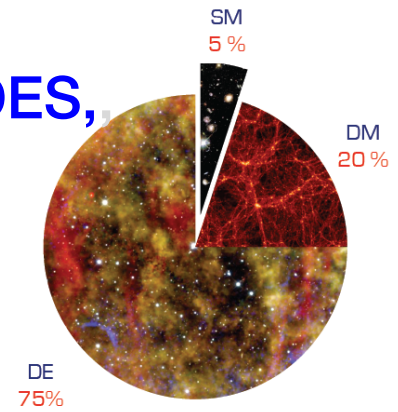

ESA-ESO Working Groups
Report No.3
ESA-ESO Working Groups
Report No.4
A Science Vision for European Astronomy
ASTROPHYSICS AND SPACE SCIENCE PROCEEDINGS
A. Moorwood
Editor
Science with the VLT in the ELT Era
Springer
ASTRONET
The ASTRONET Infrastructure Roadmap:
A Strategic Plan for European Astronomy
esa
BR-247
Cosmic Visio
Space Science for Europe 2015-2025
European Space Agency
Agence spatiale européenne
Report No.2

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 (SNLS)
    - Supernovae (SNLS, ESSENCE, SDSS-II, SN Factory, LOSS, PanSTARRS, DES, LSST)
    - Galaxy clusters (REFLEX, NORAS, SPT, DES, eROSITA, LSST)
    - Redshift distortions (VVDS, VIPER)



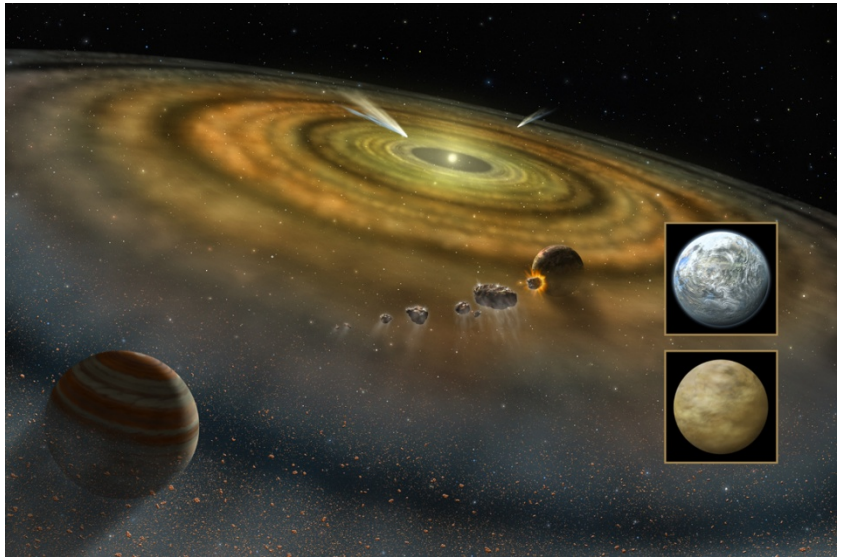
Dark Energy

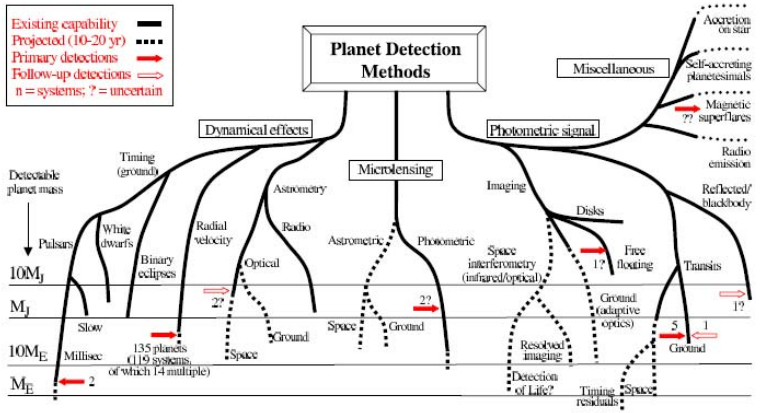
- Weak lensing, BAO, supernovae, clusters
  - Important: massive surveys and large sky coverage
  - Current state of the art with 4m telescopes (2dF, SDSS, WiggleZ, VIPERS)
  - ⇨ EUCLID → ground-based follow-up/calibrations
    - ⇨ spectroscopic calibration of the photo-z
    - ⇨ spectroscopic follow-up of supernovae
    - ⇨ spectroscopic follow-up for cluster members
    - ⇨ optical imaging for photo-z
  - ⇨ 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





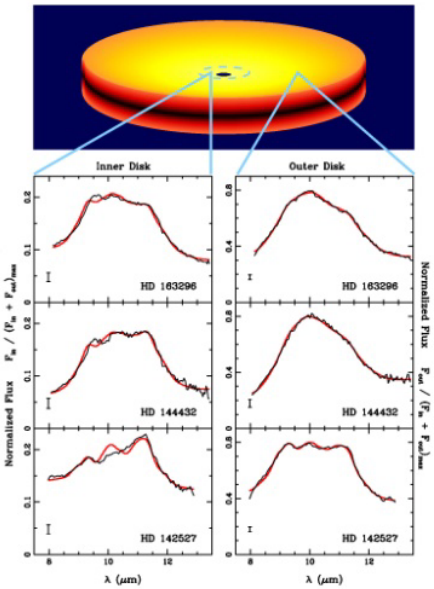
Planets

- 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

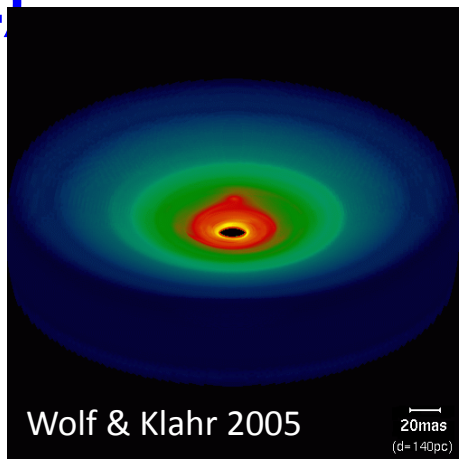
How did stars and planets form?

- Star formation shrouded in dust
  - Transition from absorbing cloud to self-luminous object
- Planetary and debris disks as cradles for planets
  - Chemical composition of disks
- Observations
  - Thermal IR, sub-mm and mm observations
  - Importance of spatial resolution



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

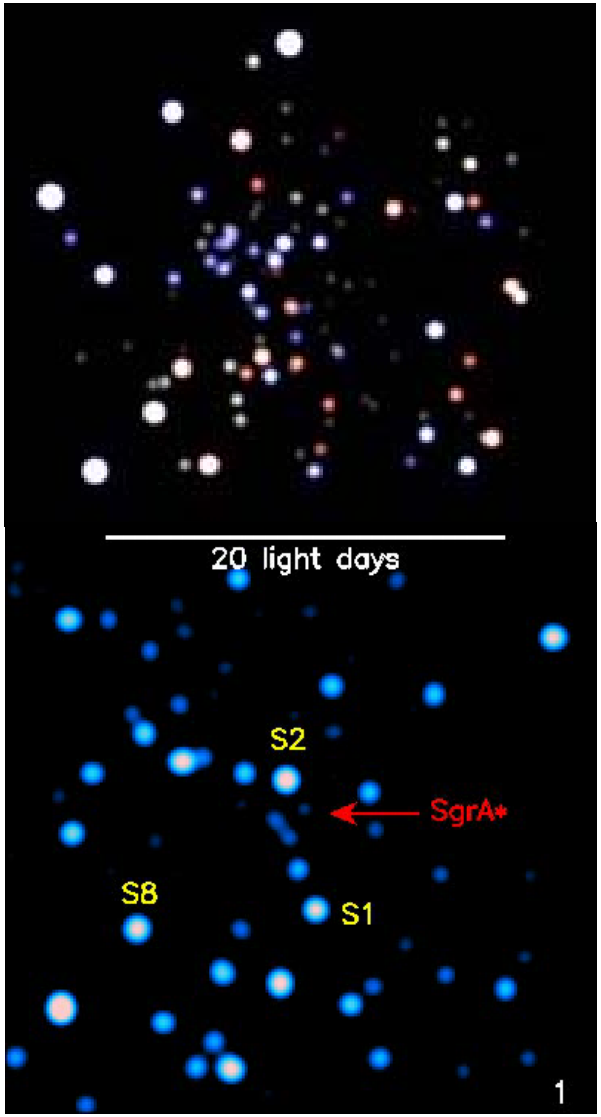


The Milky Way – our home

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

Our own black hole

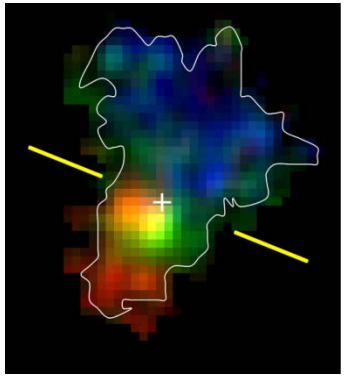
- Mass determination through stellar orbits
- Structure around the black hole revealed through flashes
- Coordinated studies with other wavelengths



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 → large telescope (>8m) with AO and interferometry
  - NACO, Keck-AO, GEMS (Gemini), GRAVITY (VLTI), ELTs

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
    - ⇨VST, VISTA, VIMOS upgrade,
  - 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
    - X-Shooter, NACO, OSIRIS (GTC), HAWK-I with AO, MUSE, KMOS, EMIR (GTC), JWST, E-ELT

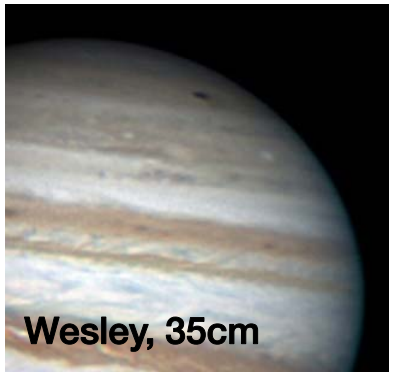
Based on Bergeron (2009) Science with the VLT in the ELT Era

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?



The telescope landscape

- There are many large optical and infrared telescopes

Telescope diameter	In operation	Construction or Planned
d>10m	4	
7m < d < 10m	9	LSST
5m < d < 7m	6	JWST
3m < d < 5m	16	VISTA, LAMOST, Lowell

- 3 telescope planned with d>20m

Role of 8-10m telescopes

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

Complementarity

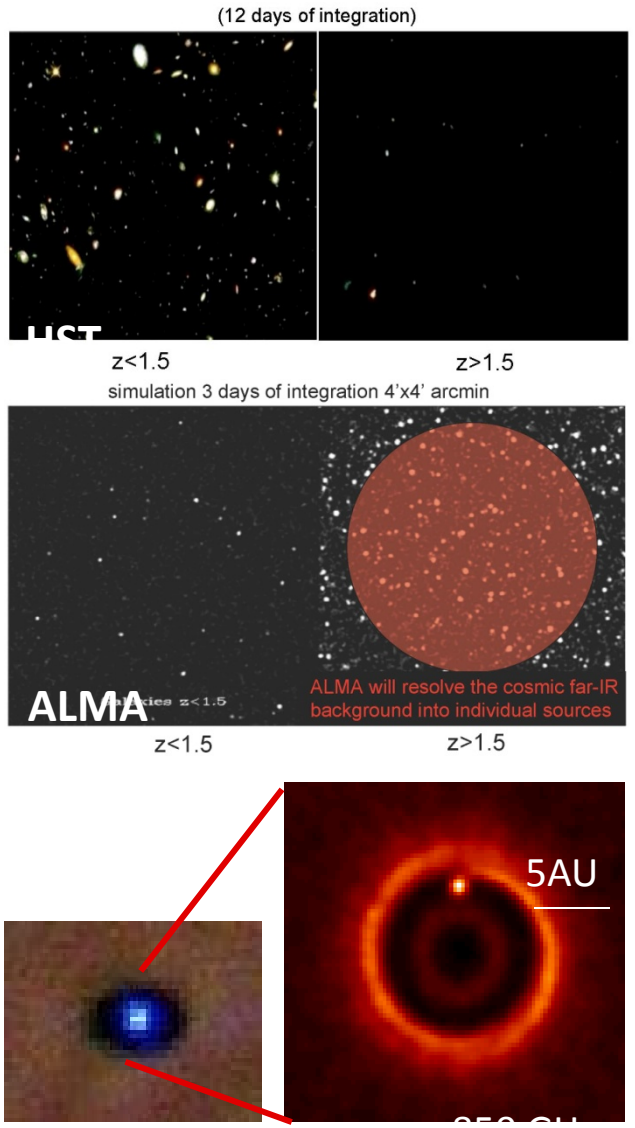
- Follow up of imaging surveys
  - UKIDSS, VST, VISTA, LSST/PanSTARRS
  - ESA Cosmic Vision → EUCLID/PLATO
- Follow up of sources detected at other wavelengths
  - Herschel, Fermi, XMM/Chandra, JWST, eROSITA
- ALMA/SMA follow-up/complement

La Silla Paranal

- VLT
  - Continue operations with new instruments
    - FORS2, ISAAC, UVES, FLAMES, NACO, SINFONI, CRIRES, 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

ALMA

- 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



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