Astrophysics for the Next Decade

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(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?
Research themes

- Similar for most observatories
- Defined in several community:
  - Astronet Science Vision and Roadmap
  - ESA Cosmic Vision initiative
  - National decadal reviews
  - Special publications
  - ESA-ESO working group reports
- Specific fields (e.g. Connecting quarks with the Cosmos)
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)
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 $\approx 9$ microarcseconds

• Measure gravity in the strong regime
  – Probing the spacetime geometry
  – Important: IR observations and spatial resolution $\rightarrow$ 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

<table>
<thead>
<tr>
<th>Telescope diameter</th>
<th>In operation</th>
<th>Construction or Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>d&gt;10m</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>7m &lt; d &lt; 10m</td>
<td>9</td>
<td>LSST</td>
</tr>
<tr>
<td>5m &lt; d &lt; 7m</td>
<td>6</td>
<td>JWST</td>
</tr>
<tr>
<td>3m &lt; d &lt; 5m</td>
<td>16</td>
<td>VISTA, LAMOST, Lowell</td>
</tr>
</tbody>
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- 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
• **Science requirements**
  – Detect CO and \([\text{CII}]\) 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