

Astronomy

Sebastian Egner European Southern Observatory (ESO) 2021-06-07





Scientific mysteries





Constituents of the Universe



The standard model of cosmology (ACDM) has turned out to be very mysterious!

Universe energy density is within 0.5% of that required for a spatially flat spacetime.

Observed Mass: ~5% of the mass-energy is in stars, galaxies, hot & cold gas.

Dark Matter (DM):

~25% of the mass-energy acts as an attractive gravitational source but has never been seen.

Dark Energy / Cosmic Constant Λ : ~70% of the energy density acts as a repellant force.



Constituents of the Universe



Formation of Galaxies





At the center of our Milky Way galaxy:

Supermassive black hole (4 million solar masses)

Orbital period 16 years

> 20 billion kilometres = 120 × Earth–Sun ₌ Size of the Solar System

> > Maximum speed > 25 million km/h

Orbit of S2

Closest approach . 19 May 2018















Black Hole M87



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Chandra: X-ray EHT: sub-mm

Black Hole M87





Gravitational waves from BH mergers (LIGO)



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https://www.youtube.com/watch?v=TWqhUANNFXw



Exoplanets

"As of 28th January 2021, there are 4,341 confirmed exoplanets." Wikipedia. In 1995 this was zero.





Planet Formation



HL Tauri

Young disc of material from which a solar system will form.

How to form planets from such a disk of gas & dust?

How will the planets evolve in such a disk?



Evolution of the System Earth

- Creation of elements heavier than Helium?
 - Details of fusion in super-nova / red giants?
 - Re-collapse of cloud after explosion?
- Formation of solar system?
 - Meter-barrier?
 - Stability of the sun?
 - Late heavy bombardment?
 - Water on Earth?
- Role of our Moon?
 - Concentration of heavy elements in Earth?
 - Magnetic field strength & stability?
 - Plate tectonics?
 - Tides?
 - Stability of Earth rotation axis & climate zones?
- Mass extinctions?
 - Role of Jupiter?
 - Gamma-ray bursts / supernovae?













Emergence of Life

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Exoplanet Life

- Requires studying planet atmospheres and surfaces.
- Requires isolating the reflected planetary light from that of the central star.
- Requires high-contrast imaging techniques such as adaptive optics, phase masks.







HOW TO ANSWER THESE QUESTIONS?





- "European Southern Observatory"
- Intergovernmental research organization for ground-based astronomy.
- Mission: "Provide state-of-the-art research facilities to astronomers and astrophysicists".
- Founded: 1962
- Member States in 2019: 16
- Annual budget: ~360 M€
- Staff members: ~700











Astronomy as a science

- Astronomy is not a normal experimental science. Unfortunately.
 - The objects of research are beyond our reach.
 - > A little like experimental physics
 - Building the specialized equipment required to investigate and test a theory.
 - > A little like botany
 - What is out there? Taxonomy.
 - > A little like archeology / forensic
 - Studying the fragments and evidence of events which are long gone.
 - > A little like psychology
 - You only find what you are searching for.

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Telescopes & Instruments

Telescope: Collect photons

Instrument: Analyse photons

8m Telescope on Paranal in Chile





Collecting Photons



Collected Photons: $N \sim D^2 \cdot T_{exp}$

To reach a given SNR:

 $T_{exp} \sim D^{-2}$



Angular Resolution



Image of point-source in the focal plane is the Fourier power spectrum of the Aperture



Angular resolution



D=305m $\lambda = 30$ mm $\Theta = 24$ arcsec





 $\begin{array}{l} D=8.2m\\ \lambda=1 \text{ micron}\\ \Theta=0.03 \text{ arcsec}\\ \text{Seeing: } 1.0 \text{ arcsec} \end{array}$

D=12m $\lambda = 1 \text{ mm}$ $\Theta = 21 \text{ arcsec}$



Large Telescopes

Combing the two effects for bright sources:

- > More photons due more collecting area.
- > Sharper image due to larger aperture diameter.





Angular Size & Resolution





Human Eye

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Very Large Telescope

AN OF STATE

4x 8m telescopes (UT's)4x 1.8m telescopes (AT's)2x Survey TelescopesSeveral smaller telescope



Angular Size & Resolution







Tiny temperature variations within our atmosphere create unsharp images.



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Adaptive Optics

Measure & correct distortions to the image caused by the atmosphere in real-time







Adaptive Optics

Create artificial "Laser Guide Stars"





Angular Size & Resolution







Optically combine light from the telescopes

Very Large Telescope Interferometer



Angular Size & Resolution







Atacama Large Millimeter Array











Angular Size & Resolution





Angular Size & Resolution



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Extremely Large Telescope: ELT





First-Light: 2026

- Primary Mirror: 39m diameter
- 798 hexagonal segments, 1.45m hexagonal











Angular Size & Resolution





More to come tomorrow

Suzanne Ramsay:

"Instrumentation for ground-based optical/IR astronomy."

Gie Han Tan:

"Advanced Technology for Modern Radio Telescopes."







Thank you for your attention.

