BIG TELESCOPES

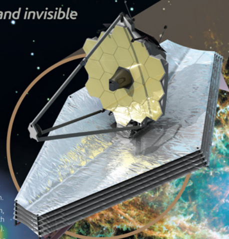
On the ground and in space, a global family of giant telescopes – present and future – is designed to gather visible and invisible light from across the Cosmos

Science & Technology Facilities Council

A rainbow is the spectrum of colours that make up visible light. But there are other types of light that our eyes can't see. The full range of light is called the electromagnetic spectrum. Each research telescope is designed to detect light from a specific part of this spectrum, helping astronomers to understand more about the story of the Universe.

- The cool radiation left over from the Big Bang, known as the Cosmic Microwave Background, is detected by instruments detecting microwaves.
- Hundreds of exoplanets have been discovered using telescopes detecting visible and infrared light.
- We know that black holes exist because X-ray telescopes reveal the hot material around them.

All light travels as waves, from long radio waves to short X-rays. The Earth's atmosphere blocks some of the wavelengths and lets others pass through. That is why we have some telescopes at sea level, others on mountain tops and some in space.

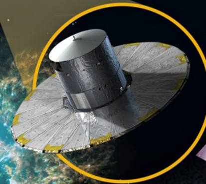


JWST
(James Webb Space Telescope)

JWST will be the largest telescope in space. Its mirror will be cooled by a sunshield that is half the size of a football pitch.

Location: 1.5 million kilometres from Earth, held at a point where the gravities of the Earth and Sun balance (called L2).

Launch date: 2018.

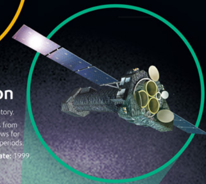


Gaia

Gaia is a space mission designed to chart in 3D 1 billion stars in our Galaxy. Its camera is the largest flown into space and it is protected by a sunshield that is half the size of a tennis court.

Location: 1.5 million kilometres from Earth at L2.

Launch date: 2013.



XMM-Newton

XMM is the most advanced X-ray observatory.

Location: 7000 to 114,000 kilometres from Earth, in an elongated orbit that allows for long observation periods.

Launch date: 1999

ALMA
(Atacama Large Millimetre Array)

ALMA is a giant array of 66 antennas observing at millimetre/submillimetre wavelengths.

Location: at 5000 metres in the Atacama desert, Chile.

'First light' was in 2011, fully operational by 2014.

SKA
(Square Kilometre Array)

SKA will be the world's largest radio telescope.

Location: at sites in Southern Africa and Australia.

'First light': early designs are being tested, phase 1 fully operational by 2020.

E-ELT
(European Extremely Large Telescope)

The E-ELT will be the world's largest optical/infrared telescope with a mirror 39.3 metres across.

Location: Cerro Armazones in the Atacama desert, Chile.

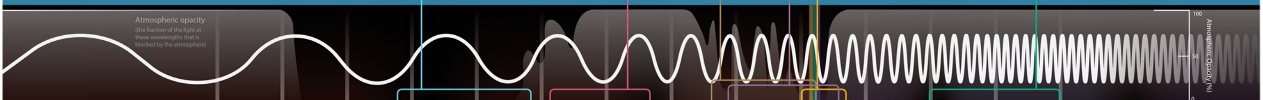
'First light': construction due to start in 2014, operational by 2022.

Left to right: the famous Crab nebula seen in radio waves, visible light and in X-rays

384,400km

690km

sea level



WAVELENGTH	1 km	100 m	10 m	1 m	10 cm	1 cm	1 mm	100 µm	10 µm	1 µm	100 nm	10 nm	1 nm	0.1 nm

Radio | Microwaves | Infrared | VISIBLE LIGHT | Ultraviolet | X-rays | Gamma-rays

RELATIVE SIZES	row of houses	average height of a person	flea	tip of a needle	bacterium	molecule	atom	atomic nucleus
TEMPERATURE OF A SURFACE EMITTING AT THAT WAVELENGTH	0.01K (-273°C)			100K	5000K	30,000K		30,000,000K
APPLICATIONS	fm/am radio	mobile phones	lasers/scanners	silicon chips	medical imaging	nuclear power		

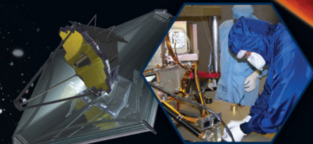
WHY DO WE NEED BIG TELESCOPES?

On 26 July 1609, the Englishman Thomas Harriott was the first astronomer to use a telescope to make drawings of the Moon. Four months later, Galileo did the same thing. Their spyglasses were a couple of centimetres or so in diameter. For more than 400 years, astronomers have been using ever larger telescopes to gather light from fainter and more distant objects in the Universe. The new generation of optical and infrared telescopes have reflecting mirrors many metres across.

Combining the light waves from many detectors massively increases the sharpness of an image. This is why both SKA and the ALMA consist of large arrays of receivers spanning a wide area.

Seeing further into the past

As we look out into the depths of space, we are also looking back in time. "Large telescopes can look back to when the first stars and galaxies were forming. They can chart how the Universe evolved, learn more about the pervasive dark matter that holds it together, as well as the mysterious dark energy that is rapidly pushing it apart. For the first time, we will be able to create a comprehensive history of the Cosmos, mapping billions of galaxies in amazing detail," says Victoria Bruce who studies distant galaxies at the Royal Observatory Edinburgh.



Alan Pearce at the STFC Rutherford Appleton Laboratory works on one of JWST's instruments, MIRI

Hot and cold

Telescope engineers handle extreme temperatures. Telescopes must operate on mountaintops and in space where they are subject to huge temperature variations. Also, the instruments on some telescopes need to be cooled to ultra-low temperatures so they can detect the faint light – or 'heat' – from distant objects.

Space telescopes like JWST are subject to the extreme heat of the Sun. The Sun-facing side of JWST's giant sunshield will be heated to 85 °C but the shield will cool the telescope, allowing it to operate at -233 °C (40 degrees above absolute zero, or 40K). The telescope's mirror is made from beryllium, a metal that contracts less on cooling than typical materials used on ground-based telescopes.

Infrared and millimetre detectors are sensitive to heat so require ultra-cold surroundings. ALMA has state-of-the-art superconducting cryogenic receivers that cool its instruments to -263 °C (10K).

Exoplanets and alien life

The discovery of hundreds of planets around other solar systems is revolutionising our view of our place in the Universe. Gaia will be able to locate many of the millions of Jupiter-sized exoplanets that likely exist in our Galaxy. The E-ELT may identify Earth-sized planets from the gravitationally-induced wobble of their host stars, and directly image larger planets. SKA will even be able to analyse their atmospheres and look for the characteristic chemical constituents that indicate the presence of life. We may, for the first time in human history, answer the question: "Are we alone?"

Big and small

Engineers designing large telescopes are faced with both large and small-scale challenges.

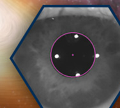
Large heavy optical mirrors are prevented from 'sagging' with a technology called active optics. The E-ELT's huge parabolic mirror will be divided into hexagonal segments whose precise shape is maintained by supporting actuators.

The SKA will use hundreds of thousands of radio telescopes, in three unique configurations, which will enable astronomers to monitor the sky in unprecedented detail and survey the entire sky thousands of times faster than any system currently in existence. The SKA will produce 10 times the data traffic of the global internet.

Far-sighted engineering

Telescope engineers are using their expertise to help people who suffer from a widespread form of sight-loss called age-related macular degeneration (AMD). By 2020, 750,000 people in the UK will be suffering from some form of AMD.

Dave Melotte, at the UK Astronomy Technology Centre, who is leading the project explains: "Our eyes are natural optical machines, just as telescopes are complex optical machines - designed by engineers. AMD occurs when part of the retina deteriorates. When optometrists needed to look at the tiny changes taking place in the retina they came to us. Our engineers are applying their skills in optical, electronic, mechanical, software and systems engineering, just as we do on a telescope engineering project.



Optical systems techniques developed for big telescopes is now being applied to diagnosing degenerative changes in the retina

"I was explaining this project at our annual Open Days, which attracts thousands of visitors. It was amazing to hear how many people are affected by AMD and to feel that we are really making a difference to their lives."

Other applications of telescope technology include:

- X-ray digital detectors called CCDs, developed for XMM-Newton, are already used in medical imaging.
- The advanced adaptive optics developed for E-ELT could improve laser eye surgery and other ophthalmic applications, as well as laser fusion for energy generation.
- SKA and ALMA technology will drive forward advances in telecommunications and signal processing.

The technological solutions developed for large telescopes generate wider spin-out commercial opportunities worth billions of pounds.

Further information

For more about the involvement of UK scientists and engineers with big telescopes
www.stfc.ac.uk/bigtelescopes

The UK is a member of three international telescope organisations:

- European Space Agency
  www.esa.int
- European Southern Observatory
  www.eso.org
- Square Kilometre Array
  www.skatelescope.org

Astronomical and telescope images

Credits: NASA, ESA and ESO

The AMD project is funded by the National Institute for Health Research's Invention for Innovation Programme.

www.stfc.ac.uk

For schools

Schools have access to three mountain-top robotic telescopes that they can use remotely from the classroom:

- National Schools Observatory
  www.schoolsobservatory.org.uk
- Faulkes Telescopes Project
  www.faulkes-telescope.com
- Bradford Telescope
  www.telescope.org

For other telescope-based resources, ideas and support:

- The "Big Telescopes Collection" of on-line resources, in the national STEM e-library
  www.nationalstemcentre.org.uk/elibrary
- ESERO UK, the UK Space Education Office
  www.esero.org.uk

For information on the UK Space Agency, resources for students, teachers and careers in the UK Space sector:
www.bis.gov.uk/ukspaceagency/discover-and-learn

BIG TELESCOPES

SEEING THE UNIVERSE IN ALL ITS LIGHT

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