THE ESA/ESO ASTRONOMY EXERCISE SERIES

Student exercises in astronomy using
observations from the
NASA/ESA Hubble Space Telescope
and the ESO telescopes

GENERAL INTRODUCTION

The ESA/ESO Astronomy Exercise Series

Astronomy is an accessible and visual science, making it ideal for educational purposes. Over the last few years the NASA[1], ESA[2], Hubble Space Telescope and the ESO[3] telescopes at the La Silla and Paranal Observatories in Chile have presented ever deeper and more spectacular views of the Universe. However, Hubble and the ESO telescopes have not just provided stunning new images, they are also invaluable tools for astronomers. The telescopes have excellent spatial/angular resolution (image sharpness) and allow astronomers to peer further out into the Universe than ever before and answer long-standing unsolved questions.

The analysis of such observations, while often highly sophisticated in detail, is at times sufficiently simple in principle to give secondary-level students the opportunity to repeat it for themselves.

This series of exercises has been produced by the European partner in the Hubble project, ESA, which has access to 15% of the observing time with Hubble, together with ESO.

The object of the series is to present various small projects that will pass on some of the excitement and satisfaction in scientific discovery to the students. Using elementary geometrical and physical considerations, the students will be able to derive answers that are comparable with the results of much more sophisticated analyses described in the scientific literature.

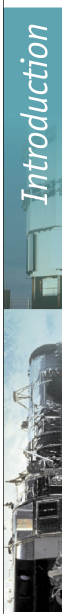
Here we give an overview of the motivation and ideas behind Hubble and the ESO facilities, together with a short description of the telescopes, their instruments and their mode of operation, in sufficient detail to clarify the types of observations presented in the exercises.

The language for the ESA/ESO Astronomy Exercise Series is English. There are several reasons for this choice – it is the language used most often among scientists. Good knowledge and practical experience in the use of this language is a valuable asset for all students, particularly for somewhat technical texts like these.

In modern education it has been recognised that it is important to cross barriers between different subjects and to link them by using inter-disciplinary activities that develop and strengthen several different types of skills. Thus, we recommend that the English text of these exercises may also serve as exercise in the practical use of English. We have provided versions in some of the other ESA/ESO member state languages (see the WWW links on http://www.astroex.org). However, if any effort is made to translate the exercises into other languages we would be glad to learn about this (see the last page of the exercises for contact persons).

All the exercises are constructed with a background text followed by a series of questions, measurements and calculations. The exercises can be used either as texts in traditional classroom format or, as the exercises are quite self-explanatory, be given to smaller groups as a part of 'project work'.

The exercises are intended to be independent of each other and a selection may be chosen to fit the time available. However, we recommend that the relevant parts of the Toolkits are worked through with the students prior to working on the exercises, unless the content is already familiar to them.



[1]National Aeronautics and Space Administration
[2]European Space Agency
[3]European Southern Observatory

The Hubble Space Telescope

The Hubble Space Telescope was deployed from the payload bay of the Space Shuttle ‘Discovery’ on April 26th 1990, sixty-seven years after the potential advantages of carrying out astronomical observations in space, away from the Earth’s atmosphere, were pointed out by the German rocket pioneer H. Oberth. The first serious proposals for a large astronomical space telescope were received by NASA in the early sixties. After a series of feasibility studies, a joint NASA/ESA programme was finally approved and initiated in 1977. With respect to resolution Hubble outperforms all Earth-bound telescopes by a comfortable margin, even though, with a primary mirror diameter of only 2.4 m, it is not a large telescope.

Images from telescopes on Earth are all affected by distortions introduced as light passes through the turbulent layers of the Earth’s atmosphere. Irrespective of the size of the telescope, this unavoidable ‘blurring’ effectively limits the resolution that typically can be obtained in ground-based astronomical images to about one half second of arc (1 arcsecond = 1/3600 degree). However, in space, light propagates freely (stars do not twinkle) and the limiting performance of any telescope is determined solely by the inherent quality of the optics and the accuracy with which it can be kept pointed at the target during an exposure. Thus, the images taken by Hubble show five times the detail of similar images taken from the ground. The resolution seen in images taken from the ground is roughly equivalent to reading the headlines of a newspaper from a distance of one kilometre, but with Hubble it is possible to read the fine print as well!

It is primarily this dramatic, fivefold improvement in image quality that makes Hubble so special. Hubble not only enables astronomers to study familiar astronomical objects at a much higher level of discernible detail, but also to detect and study hitherto unknown objects several times fainter than those observable from the ground. In this way Hubble has expanded the volume of space that has been observed astronomically.

Telescopes operating in space are also able to collect light radiated by astronomical objects over a much broader range of the electromagnetic spectrum than ground-based telescopes, which are restricted to wavelengths not obscured by the atmosphere (see Fig. 1).

This means that Hubble is not only capable of viewing celestial objects in visible light, but also in the ultraviolet and infrared. The ultraviolet spectral region is of particular importance to astronomers since it contains most of the so-called ‘atomic transitions’ of the common elements. All chemical elements have their own characteristic signature in terms of being able to absorb and emit light of particular wavelengths and it is by identifying these signatures in the spectra of celestial objects that their chemical composition, temperature and physical properties can be determined.

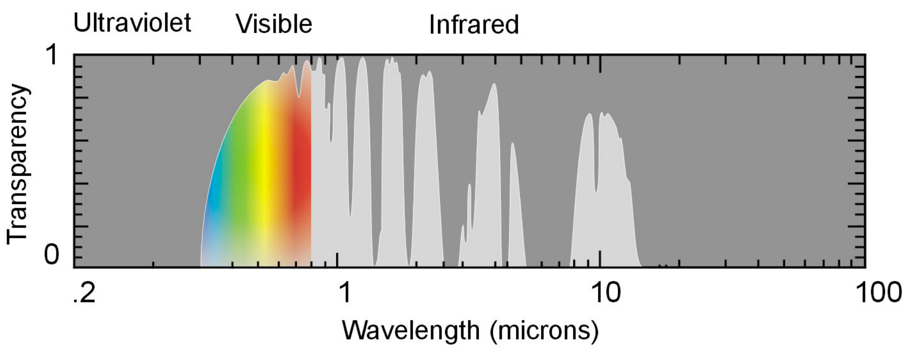
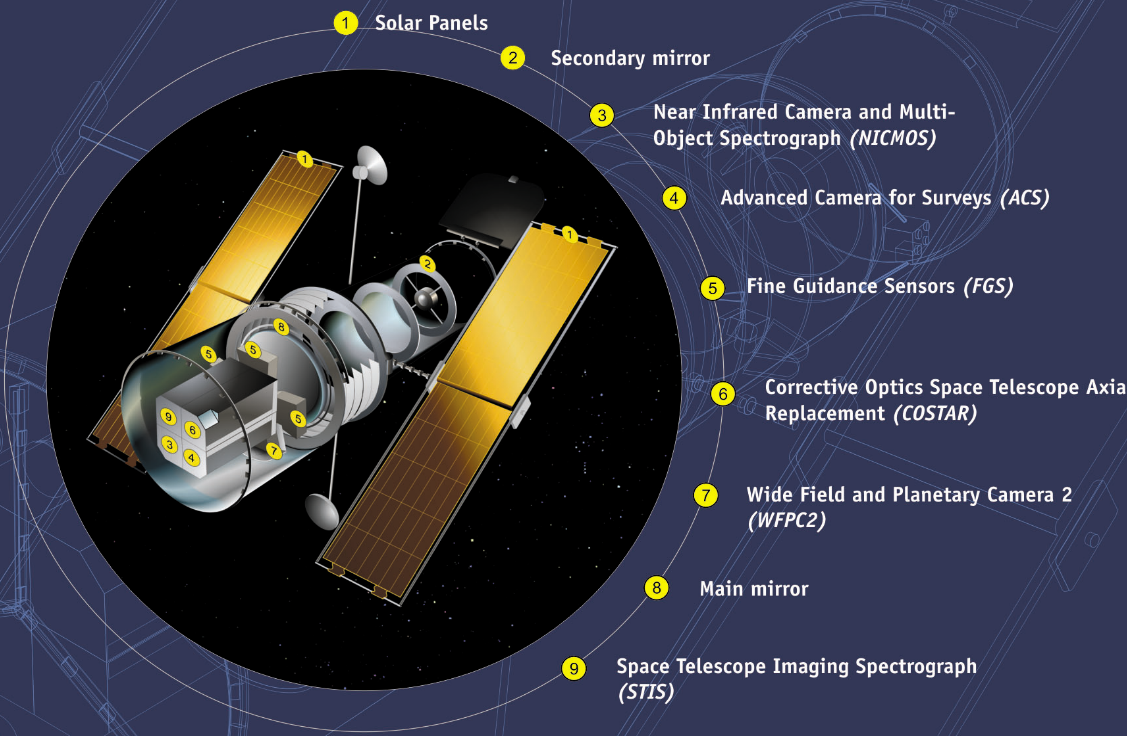


Figure 1: Absorption of radiation by the Earth’s atmosphere
Astronomical objects emit light over a wide range of wavelengths, but only certain wavelengths can penetrate the Earth’s atmosphere. The rest are absorbed and scattered by the atmosphere. The diagram shows the transparency of the atmosphere as a function of wavelength. It can be seen that ultraviolet light is almost totally absorbed or scattered and that a large fraction of infrared radiation is also absorbed.

Hubble Space Telescope



The Instruments

The complement of instruments onboard Hubble – 2 cameras, 2 imaging spectrographs and a set of 3 fine guidance sensors – enable a wide variety of observations to be made.
The second Wide Field/Planetary Camera (WFPC2) is the primary camera on Hubble. It is capable of imaging the sky through a wide range of filters extending from a wavelength of 1000 nm in the near infrared to 115 nm in the ultraviolet.

The Spacecraft

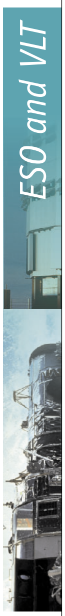
Primary mirror	*Ritchey-Chrétien optics*	*2.4 m*
Total length		*15.9 m*
Diameter (solar panels stowed)		*4.2 m*
Solar panel span		*12.1 m*
Weight		*11,110 kg*
Pointing accuracy		*7 milliarcseconds for 24 hrs*

The Orbit

Altitude (original)	*598 km*
Inclination to the equator	*28.5 degrees*
Mission lifetime	*20 years (until 2010)*

More general and technical information about the NASA/ESA Hubble Space Telescope can be found at the
Hubble European Space Agency Information Centre: **http://hubble.esa.int**

The ESO Very Large Telescope



The ESO Very Large Telescope (VLT) is the world's largest optical-infrared telescope. Initiatives aiming at the realisation of a large European telescope started already in the late 1970s. The basic design of the VLT was thoroughly discussed among European astronomers in the early 1980s. Based on a detailed concept and an associated financial plan for the construction and the subsequent operational phase, the ESO Council gave green light to the VLT project in December 1987.

ESO, an intergovernmental research organisation, was founded in 1962 by Belgium, France, Germany, the Netherlands and Sweden, *"desirous of jointly creating an observatory equipped with powerful instruments in the Southern Hemisphere and accordingly promoting and organising co-operation in astronomical research"*. Since then Denmark, Italy, Portugal and Switzerland have joined. The UK will join in 2002. More recently other countries have also expressed interest in joining ESO.

ESO operates two state-of-the-art observatories, Paranal and La Silla. Cerro Paranal, a 2635 m high mountain (24 deg 37 min S, 70 deg 24 min W), is located in the northern part of Chile, 12 km from the Pacific coast, 130 km south of Antofagasta, 1200 km north of Santiago de Chile, and 600 km north of La Silla. This site is located in one of the driest areas of the world, the Atacama Desert. As bad weather is the major enemy of Astronomers, ESO performed extensive climatic studies before choosing Cerro Paranal as the VLT site. Here there are up to 350 clear nights per year.

The VLT consists of four 8.2 m Unit Telescopes (UT); this measure indicates the diameter of the four main mirrors. The secondary and tertiary mirrors are much smaller. As light passes through the Earth's atmosphere, images are distorted: this is why the stars twinkle. The Adaptive Optics System has been developed to correct this unwanted effect, so that the images recorded by the telescope become as sharp as if the VLT were in space.

The VLT is equipped with many different high-tech astronomical instruments. All four 8.2-m telescopes were in operation by the end of 2000. Many exciting scientific results have already been obtained.

Three 1.8 m Auxiliary Telescopes (AT) are being built. It is possible to use each UT on its own or, when the AT's are finished, to combine all the telescopes into the VLT Interferometer (VLTI). The VLTI will have the same image sharpness as a telescope 200 metres in diameter. The first observations with the VLTI took place in 2001.

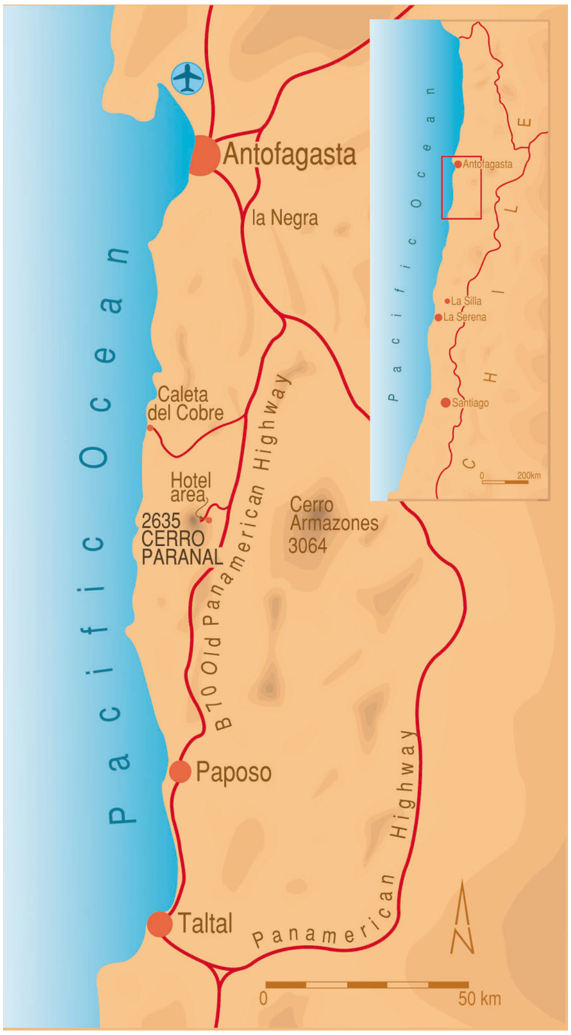


Figure 2: Map of Chile
The locations of ESO's two observatories in Chile, La Silla and Paranal, are indicated.

ANTU and FORS

Construction work at Cerro Paranal began in 1991 and six years later, in 1997, the first of the four mirrors arrived at its final destination. After the installation, first light with ANTU (UT1) took place as scheduled, on May 25–26, 1998. ANTU means “The Sun” in the Mapuche Language. The other three giant telescopes had “first light” in March 1999, January 2000 and Setember 2000, respectively.

The VLT UTs have so-called alt-azimuth mounts. In such a mount the telescope tube moves around a horizontal axis (the elevation axis). The two bearings, which support the tube, are mounted on a fork rotating around a vertical axis (the azimuth axis) thus enabling it to point over the entire sky.

On September 15, 1998 FORS1 (FOcal Reducer and Spectrograph), mounted on ANTU, saw first light and immediately began to obtain some excellent astronomical images. FORS1 and the other VLT instruments have opened a wealth of new opportunities for European Astronomy.

FORS1, with its twin (FORS2), is the product of one of the most thorough and advanced technological studies ever made of a ground-based astronomical instrument. The FORS instruments are “multi-mode instruments” that may be used in several different observation modes. For example, it is possible to take images with two different image scales (magnifications) and spectra at different resolutions may be obtained of individual or multiple objects. Thus, FORS can first detect the images of distant galaxies and immediately make recordings of their spectra so that the type and distances of the stars in the galaxies can be found.

More information about the ESO VLT can be found at: http://www.eso.org.

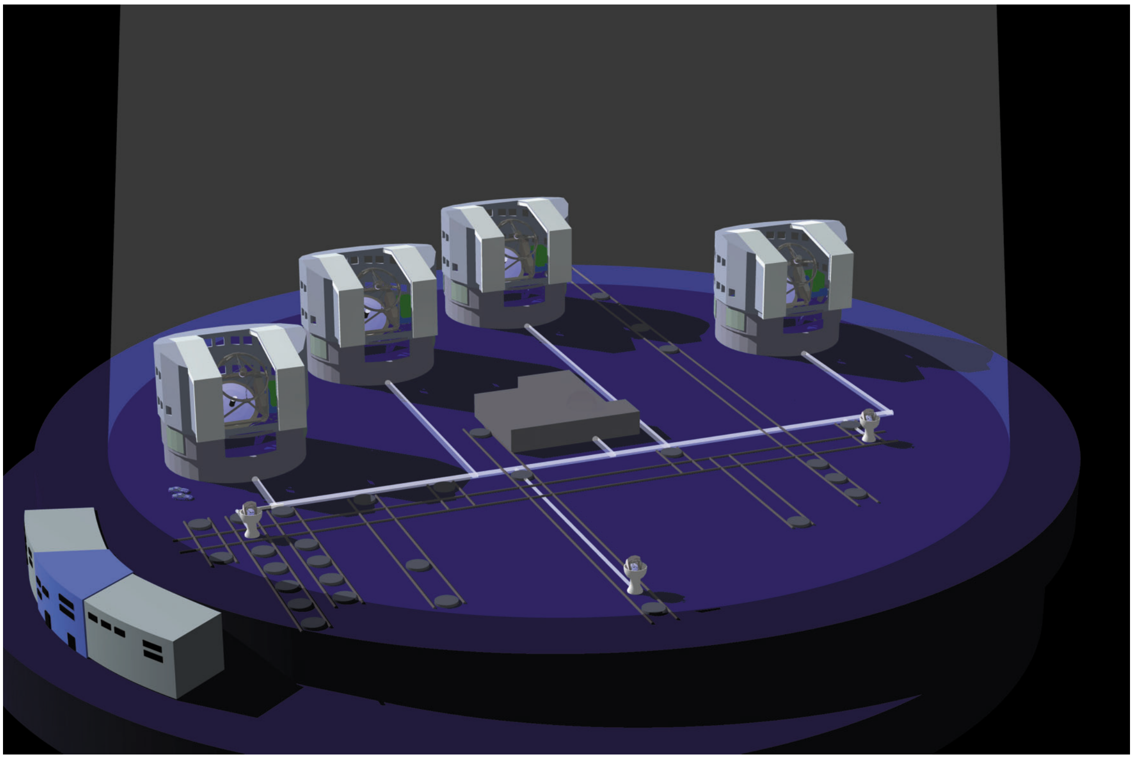


Figure 3: A schematic view of the VLT Interferometer

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