The William Herschel Telescope

With a primary-mirror diameter of 4.2 meters, the William Herschel Telescope (WHT) is one of the most powerful optical telescopes in Europe. First light was on 1st June, 1987.

The light gathered can be directed to an imaging or spectroscopic camera at any one of four focal stations and observers can switch quickly between three of these during the night. Its state-of-the-art instrumentation together with the superb sky quality of the Roque de los Muchachos Observatory and optimised operation have made the William Herschel Telescope one of the most scientifically productive telescopes in the world. Through continued development of instrumentation, particularly in the field of adaptive optics, the WHT remains at the forefront of astronomical research.

The telescope is scheduled for observing every night of the year. It is used by astronomers based in United Kingdom (48% of the allocated time), Spain (20%) and the Netherlands (18%). 5% of the time is reserved for international collaborative programmes and 9% is allocated to astronomers working at the Instituto de Astrofísica de Canarias. The William Herschel Telescope is part of the Isaac Newton Group of Telescopes (ING) that also operates the 2.5 metre Isaac Newton Telescope and the 1.0 metre Jacobus Kapteyn Telescope. The ING is owned and operated jointly by the Science and Technology Facilities Council (STFC) of the United Kingdom, the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) of the Netherlands and the Instituto de Astrofísica de Canarias (IAC) of Spain. The telescopes are located in the Spanish Observatorio del Roque de los Muchachos on La Palma, Canary Islands at a height of 2350 meters. The internationalised observatory is operated by the Instituto de Astrofísica de Canarias (IAC).

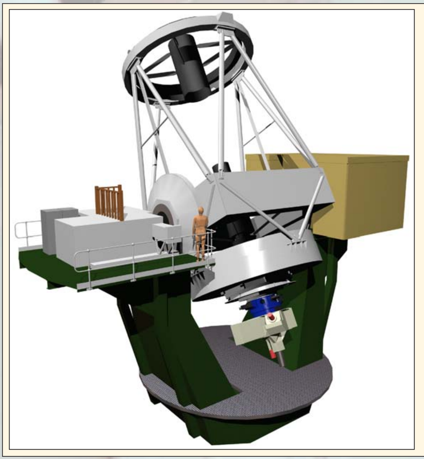
William Herschel

Herschel was born in Hannover in 1738. He emigrated to England at the age of 19, and earned his living there by copying music, composing, conducting and teaching. He began serious astronomical work about 15 years later, producing some of the finest and largest telescopes then in existence and making a number of notable discoveries, including Uranus, the first planet discovered since ancient times. He was also the first to hypothesise the existence of galaxies of stars outside our own. The William Herschel Telescope was named in 1981, on the bicentenary of the discovery of Uranus.

The Dome and the Building

The dome, which weighs 320 tonnes, was completed by the Canadian firm Brittain Steel in 1984. Large fabrications were assembled in Vancouver and shipped to La Palma. The skin of the dome was fabricated on site from 6.3 mm steel plate and the wind shield and shutters were constructed from aluminium alloy. A 35 tonne crane, supported from the arch girder, is built into the upper part of the dome. This was used during the telescope construction, and it still remains in place to remove the mirror for aluminizing and for telescope maintenance.

The dome is onion-shaped, of 21 m internal diameter, and a pair of up-and-over shutters with a windscreen coupled to the lower shutter allows observations down to 12 degrees above the horizon. The dome is supported on a rail set onto a cylindrical concrete building structure which internally is open to ground level. Set on one side of the cylindrical drum is a 3-storey rectangular annex of conventional construction. This contains the mirror aluminizing plant, the operations control room, computer room, dark rooms, workshops, offices and various services. Because no unnecessary activity takes place in the dome there is very little thermal disturbance of the air near the telescope, which greatly improves the chance of achieving perfect 'dome seeing'. This is further facilitated by large extractor fans set into the cylindrical structure.



The Mounting

The alt-azimuth mounting requires about half as much metal as an equatorial design of similar stiffness, but need a computer to calculate many times per second the changes in azimuth and elevation required to track the object observed. The rotation of the field of view as the telescope tracks, common to all alt-azimuth telescopes, is counteracted by rotating the instruments continuously while tracking. The instrument racks rotate with the instruments, but are driven separately, to minimise any jerkiness caused by friction in the cable wrap.

The telescope weighs about 200 tonnes and flot as on a layer of oil 0.1 mm thick, pumped through six supporting pads. There is so little friction that the telescope can be pushed around by hand. Similar pads support the elevation bearing.

The Serrurier trusses (the white tubes) which support the instruments at Prime and Cassegrain foci ensure that the movements of the primary and the secondary mirrors as the altitude changes, and the truss flexes, are similar, so that the optical properties of the telescope do not change.

Maximum rotations for the mounting are 0–95° from the horizontal and ±270° about East. While observing, however, the accesible altitude is limited to 89.8°–12.0°. The reasons for these limitations are the existence of a zenith blind spot for zenital distances lower than 0.2° imposed by the speed limit in azimuth and that the telescope is partially obscured at elevations below 12° by the dome rail. The telescope takes a maximum of 3 minutes to slew there. It points with an accuracy of about 1 arcsec. The azimuth/elevation encoder readings are related to position on the sky by a 14-coefficient software model. The coefficients describe misalignment of the mechanical and optical axes, flexure of the tube, etc. The 3 most important coefficients of the model are redetermined at the start of each night.

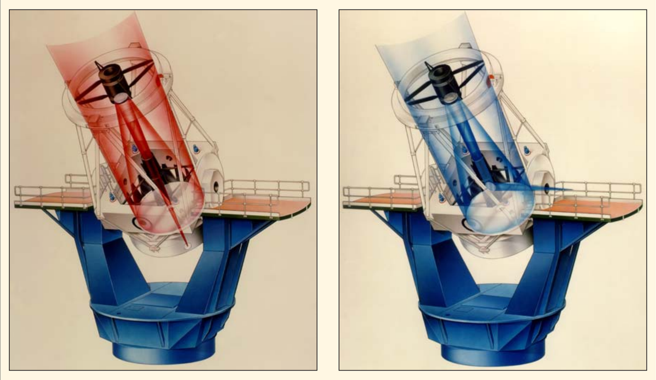
The Optics

The telescope is of classical Cassegrain configuration, with a 4.2-m paraboloidal primary mirror, and a 1.0-m convex hyperboloidal secondary mirror. The fast focal ratio f/3 of the primary mirror allows the telescope to be compact, and thus the dome to be smaller and cheaper. The WHT was originally specified to give on-axis images with FWHM 0.25 arcsec at the Cassegrain focus.

Light can be brought to a focus at any of four foci: Prime (at the top of the telescope), Cassegrain (beneath the telescope) or Nasmyth (the two platforms situated on either side of the telescope). For most observing, light is reflected from the primary mirror to the secondary, then back down through a hole in the centre of the primary mirror to a camera at the Cassegrain focus. Light can also be reflected out to either of the Nasmyth foci via a 500-mm diameter plane mirror in the telescope tube. The effective focal length of the telescope for the Cassegrain and Nasmyth foci is 46.2 m (f/11).

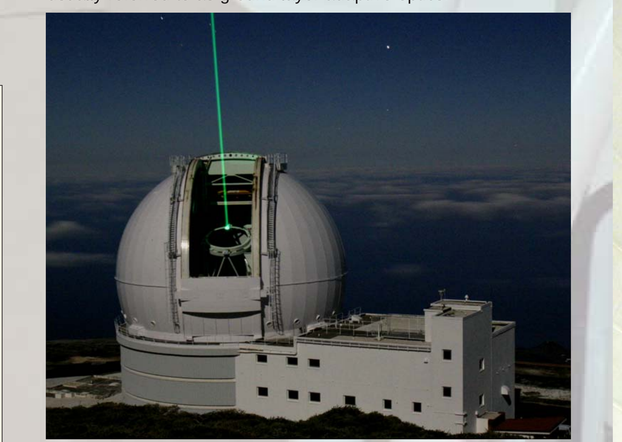
The Nasmyth foci are used to mount cameras which need to be very stable during observing, or to which the observer needs access during observing. At present, the GHRIL laboratory houses an optical table on which can be mounted observers' own instruments, and GRACE laboratory hosts the suite of Adaptive-Optics instruments.

The unvignetted field of view at Prime focus is 40 arcmin. The effective local ratio of the primary mirror with corrector is f/2.8.

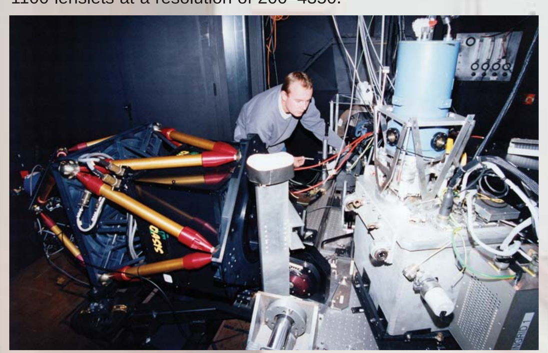


Left: Light path through the telescope to the Cassegrain focus. Right: the same for one of the Nasmyth foci.

Ground-layer Laser Adaptive optics System (GLAS): The Rayleigh laser system GLAS is designed to work in conjunction with existing Adaptive-Optics equipment and ancillary instrumentation and infrastructure. A 25W pulsed laser is projected to 15km altitude from a launch telescope mounted behind the secondary mirror. The somewhat low altitude implies that turbulence nearer the ground is best illuminated, and hence this is usually referred to as ground-layer adaptive optics.



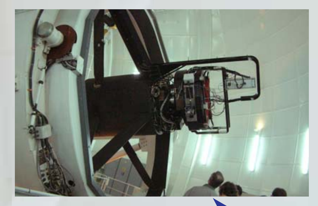
GRound based Adaptive optics Controlled Environment (GRACE): A dedicated structure designed to facilitate the routine use of adaptive optics (AO), using ING's AO instrument suite. It also allows for the use of laser guide stars. The core AO instrument is the Nasmyth Adaptive Optics for Multi-purpose Instrumentation (NAOMI), and it feeds the Isaac Newton Group Red Imaging Device (INGRID), 0.04 arcsec/pixel, yielding a total field of view of about 40x40 arcsec; the Optimized Stellar Coronograph for Adaptive optics (OSCA), mask sizes 0.2–2.0 arcsec in conjunction with INGRID; and the Optically Adaptive System for Imaging Spectroscopy (OASIS), an integral field spectrograph which covers an area of the sky from 3 to 10 arcsec approximately imaged onto 1100 lenslets at a resolution of 200–4350.

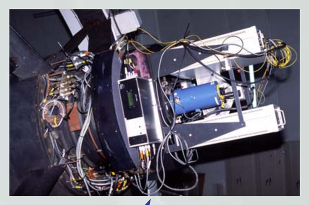


Outside the WHT, a Robotic Differential Image Motion Monitor (known as RoboDIMM) is intended foremost to provide a real-time guide to seeing conditions and it allows observers to decide when to move to the AO programme queue.

Acquisition and Guiding Unit: Mounted on primary-mirror cell turntable, to stabilise image orientation by de-rotation, and it includes acquiring cameras, autoguiders, field mirror in/out to select either the auxiliary port camera (AUX), field of view 1.8 arcmin, or the instruments mounted at the straight Cassegrain focus.

Automated Fibre Positioner (AF2): Robotic fibre-positioner to place up to 150 fibres at positions over a field of 1 degree diameter. Feeding WYFFOS spectrograph at 26 meters away in Nasmyth 1 focus, AUTOFIB-2 works as a multi-object spectrograph at a resolution of 2000–10,000.





Prime Focus Imaging Platform (PFIP): It mounts a deep-imaging camera consisting of a mosaic of two CCDs that cover 16 arcminutes on sky.

Top-end ring: It rotates for secondary mirror and cell to be removed, replaced by prime-focus corrector and instrument.

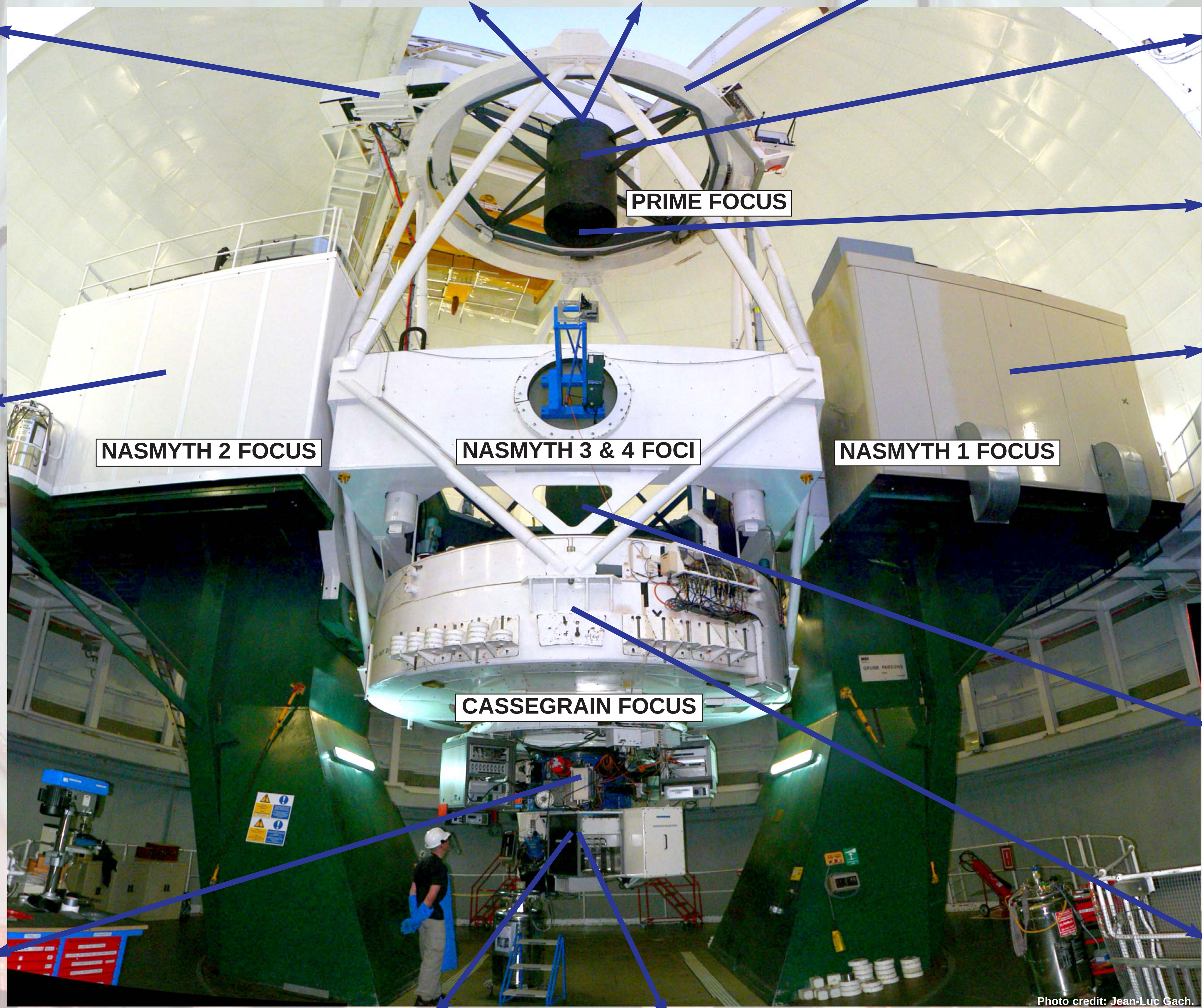
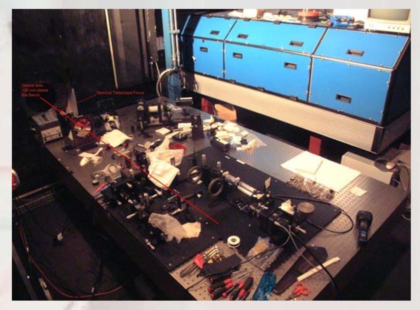


Photo credit: Jean-Luc Gach.

Prime-focus assembly: It includes a field corrector over 40 arcminutes, and an atmospheric-dispersion corrector.

Secondary mirror: Convex hyperboloid of Zerodur, 1.0m diameter. For Cassegrain and Nasmyth foci.

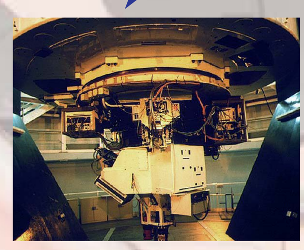
Ground-based High Resolution Laboratory (GHRIL): A light-tight room covering Nasmyth-1 platform, including an optical bench on which experiments can be conducted and private instruments set up. GHRIL houses permanently the Wide-field Fibre Optic Spectrograph (WYFFOS), a spectrograph optimised for input from optical fibres. It covers wavelength range 3500–11,000 Å at a resolution of 2000–10,000.



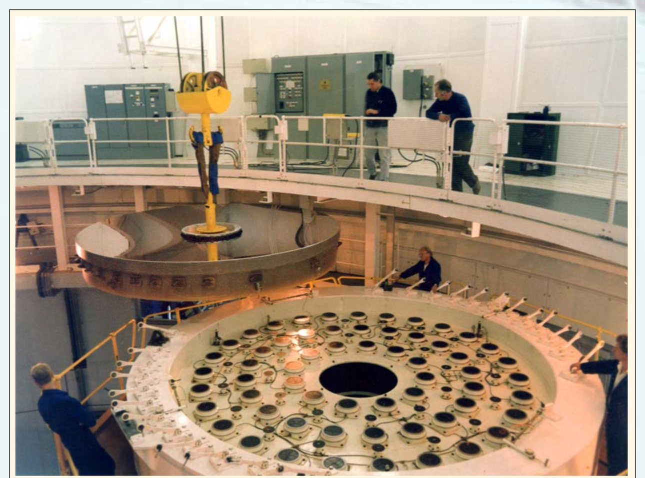
Nasmyth flat: Made of Cervit material, 0.6×0.4m, introduced into beam at 45° to select Nasmyth foci.

Primary mirror and mirror cell: Cervit, 4.2-m diameter concave paraboloid mirror, mounted on an axial flotation system of 64 roll-diaphragm seals with independently-controlled gas pressure, together with axial radial-support system plus defining links.

Intermediate dispersion Spectrograph and Imaging System (ISIS): A slit-spectrograph with a field of view 4×0.9 arcmin. It consists of two arms optimised for red and blue, resolution 2000–10,000 and wavelength range 3000–11,000 Å, for general-purpose polarimetry and spectrophotometry, of both extended and stellar objects.



Long-slit Intermediate Resolution Infrared Spectrograph (LIRIS): A near-IR imager/spectrograph, covering a wavelength range 8000–25,000 Å. In imaging mode it yields a field of view of 4.3x4.3 arcmin, and a resolution of 1000–3000 for spectroscopy. It is also capable of multi-object spectroscopy, coronography and polarimetry.



The Primary Mirror

The 4.2-m primary mirror is made of a glass-ceramic, Cervit, with zero-coefficient of thermal expansion. It weighs 16.5 tonnes and the diametre of the central obstruction is 1.21 m.The mirror surface is figured to better than 1/50 wavelength on a scale of a few cm, and to better than half a wavelength over larger scales. The mirror surface is aluminium and when fresh reflects about 85% of the light falling on it. The primary mirror suffers particularly from exposure to the elements (humidity, pollen, dust, etc.) and it is realuminised once every two years. This involves removing the mirror cell from the telescope, lowering the mirror to the ground floor, washing off the old surface with caustic soda and resurfacing in a large vacuum tank.

The primary mirror of the WHT has sophisticated axial and transverse support systems. The axial support system consists of two subsystems: an axial flotation system made up of an array of pneumatic cylinders ('belloframes') employing roll-diaphragms as seals, together with a pumping system providing the gas pressure needed to support the full mirror weight; and an axial defining system which locates the mirror in its correct position at three points around the mirror edge ('load cells').The mirror is supported in a transverse direction by mechanical weighted levers coupled by link arms to brackets connected to the edge of the mirror ('axial definers') in much the same way as a conventional push-pull radial support system.

The Aluminizing Plant

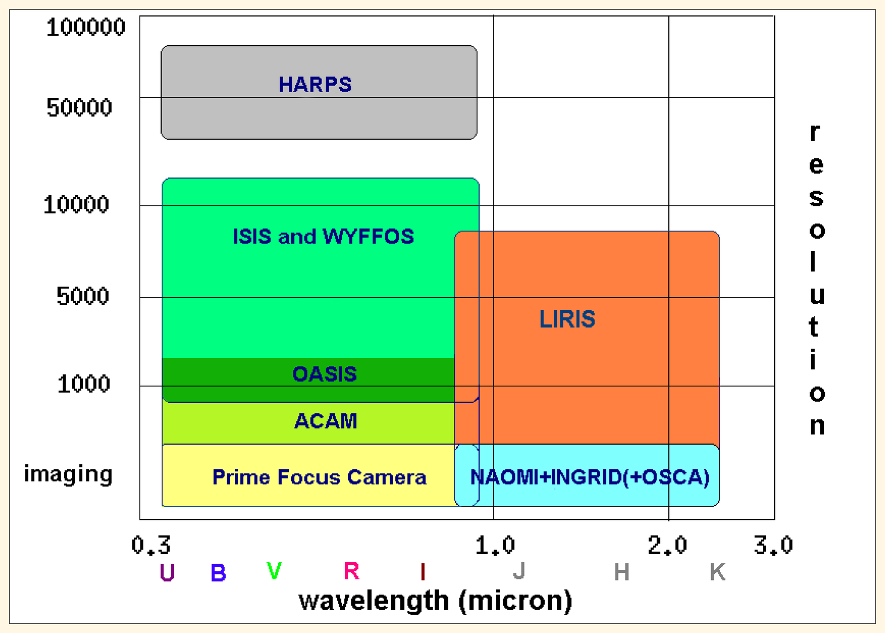
The plant was produced by Balzers of Liechtenstein who subcontracted the large vacuum vessel to Grazebrook Limited, a UK firm. During the aluminizing process, a total of 63 g of aluminium is evaporated, 3.5 g being desposited on the 13m² surface of the primary mirror to create a reflective surface 100 nm thick. Mirrors are aluminized once every two years approximately.

The Control Room

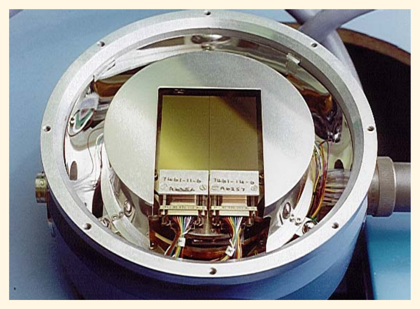
The control room is located on the second floor of the annex building. It houses the front ends of the observing systems: the telescope control, the instrument control, and the data acquisition. The first one is the responsability of the telescope operator, while the other two are operated by the support astronomer or the visiting astronomer.

The Instrumentation

The William Herschel Telescope is a general-purpose facility, instrumented to allow a wide range of astronomical observations, from the optical wavelengths to the near-infrared, and covering both imaging (with different fields of view and spatial resolutions) and spectroscopy (with different acquiring methods and spectral resolutions).



This plot gives an overview of the present and future common-user capabilities of the WHT. Axis x shows wavelength in microns; axis y shows spectral resolutions. The overlapping areas are decoupled when acquiring methods (slit, multi-object or integral-field) or spatial resolutions (seeing dominated or adaptive-optics corrected) are taken into account.



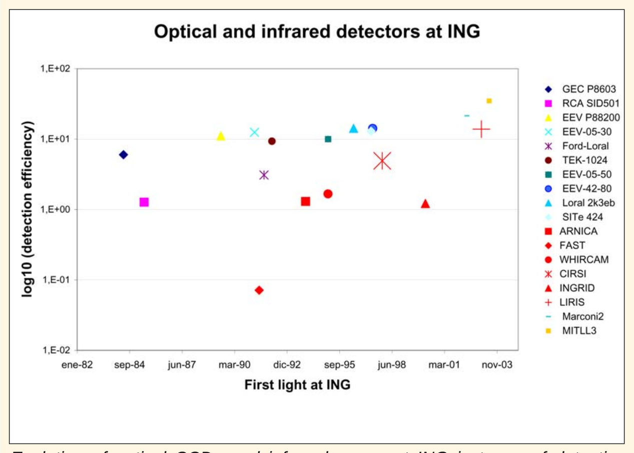
The Detectors

The mainly used detectors at the WHT are the optical CCDs and the infrared arrays. Other technologies like photomultipliers or superconductivity have also been tested or used for specific purposes.

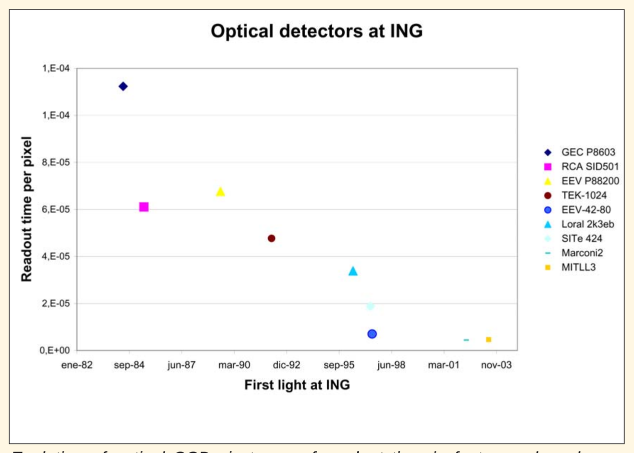
A CCD is an array of photosensitive elements, each one of which generates photoelectrons and stores them as a small bucket of charge. When requested, the elements form a bucket brigade; each row of charges is passed from element to element down the columns and horizontally along the final row to be measured in turn and recorded digitally.

Infrared arrays are very different in technology and operation to the CCD detectors visible astronomers are familiar with. Each device is actually two systems joined together in a hybrid array. An infrared detector material (HgCdTe) converts the infrared photons into electrons, this charge is stored in a separate readout circuit made from conventional silicon devices.

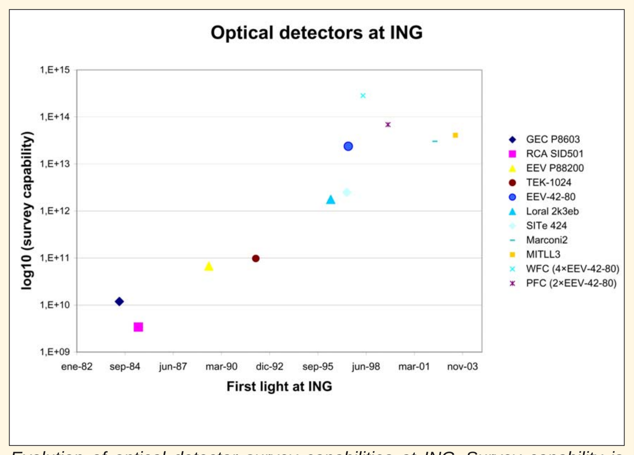
The accompanying plots show how the detector technology used at ING has developed in terms of detection efficiency, readout speeds and survey capabilities .



Evolution of optical CCDs and infrared arrays at ING in terms of detection efficiency, defined as Peak Quantum Efficiency (%) / Typical Readout Noise (e^-).



Evolution of optical CCDs in terms of readout time in fast speed mode per pixel.

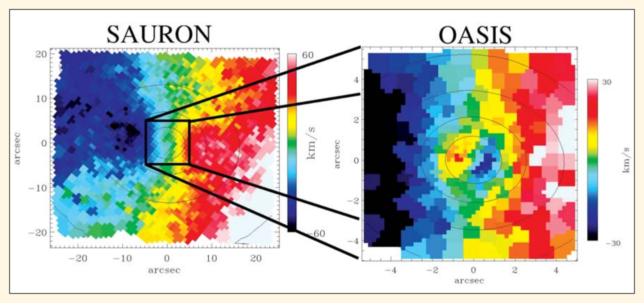


Evolution of optical detector survey capabilities at ING. Survey capability is defined as (PQE×pixels^2)/($\sigma_{readout}$×$T_{readout}$). PQE is percentual Peak Quantum Efficiency, $\sigma_{readout}$ is typical readout noise in e^-, and $T_{readout}$ is readout time in slow speed mode.

Present and Future Developments

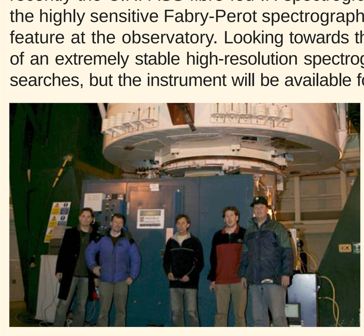
The main areas of development of new common-user instruments and enhancement of existing instruments focus on adaptive optics (AO) in order to maximally exploit the good seeing at the observatory. Turbulence in the air above the telescope smears out the images obtained with it (in the same way that the view of the bottom of a swimming pool from outside is smeared by ripples on the surface of the water). This smearing amounts to about 1.0 arcsec, or 0.5 arcsec under exceptionally calm atmospheric conditions. AO are moving components, such as deformable mirrors, placed in the path of the light before it reaches the camera, to counteract the optical effects of the turbulence. The deformations needed are of the order of microns and the shape of the mirror is changed hundreds of times per second. They are deduced by analysing part of the incoming light from a star.

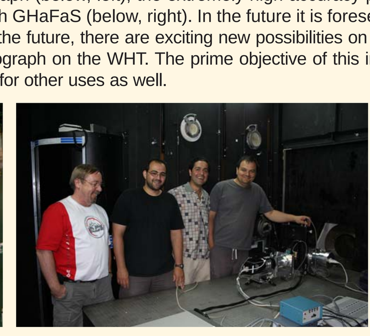
The existing AO instrument suite offers unique scientific capability of high spatial resolution spectroscopy in the visible wavelength range. The fraction of sky available for natural guide star AO is however limited to around only one percent, thus hampering wide application of AO observations. For reason of resolving the above limitation on sky coverage, a Rayleigh laser beacon, GLAS, will really open the field of high spatial resolution imaging and spectroscopy. Building on ING's experience and infrastructure in the field of adaptive optics and laser guide stars, and in collaboration with a large number of European institutes, ING is seeking European funding for the WHT to become an AO/LGS-technology test bed facility for future extremely large telescopes. Below it's an example of the science OASIS in conjunction with NAOMI can do.

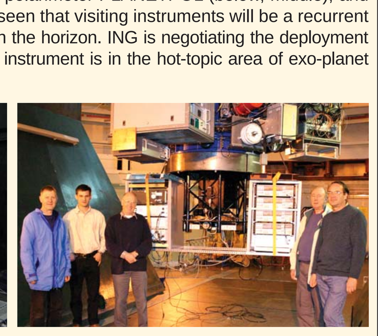


AF2/WYFFOS is the multi-object, wide-field, fibre spectrograph. Recently, its 150 optical fibres have been replaced by smaller fibers of 1.6 arcsec diameter. Object light is transmitted along fibres 26 metres in length to the Wide Field Fibre Optical Spectrograph (WYFFOS), whose camera was upgraded to longer focal length and a mosaic of two CCDs. These recent modifications make AF2/WYFFOS an efficient spectroscopic survey instrument unique in the Northern Hemisphere.

The WHT serves as a popular platform for visiting instruments such as the SAURON intergral field spectrograph, the PNS Planetary Nebula Spectrograph, the tripple-beam high-speed camera ULTRACAM, the SCAM super conducting tunnel junction detector, and most recently the CIRPASS fibre-fed IR spectrograph (below, left), the extremely high-accuracy polarimeter PLANETPOL (below, middle), and the highly sensitive Fabry-Perot spectrograph GHaFaS (below, right). In the future it is foreseen that visiting instruments will be a recurrent feature at the observatory. Looking towards the future, there are exciting new possibilities on the horizon. ING is negotiating the deployment of an extremely stable high-resolution spectrograph on the WHT. The prime objective of this instrument is in the hot-topic area of exo-planet searches, but the instrument will be available for other uses as well.







Authors: Javier Méndez, Chris Benn and René Rutten
Isaac Newton Group of Telescopes
4th August, 2007