



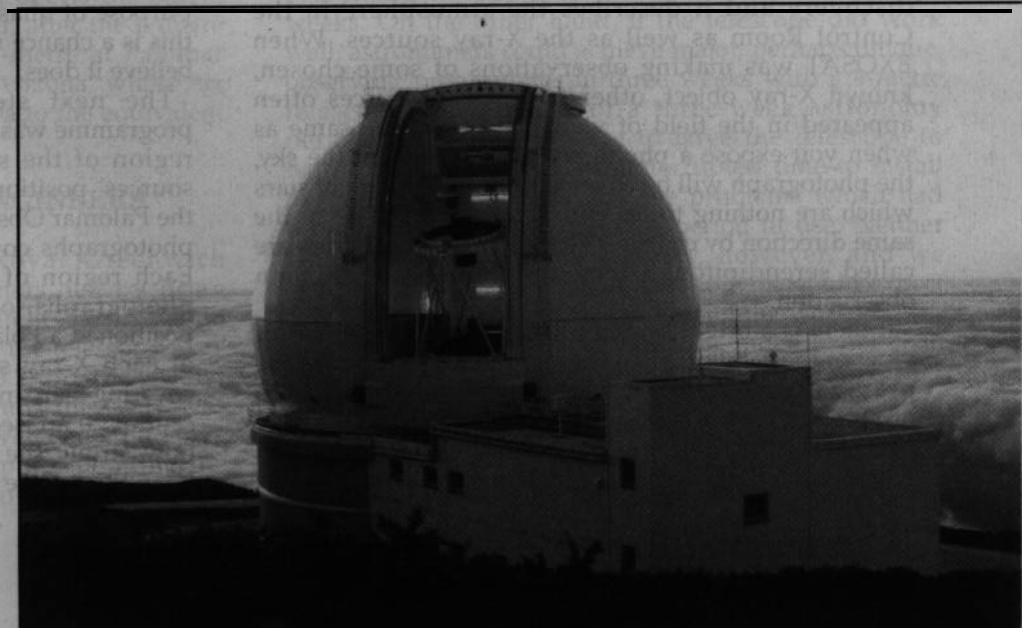
Above: Panoramic view of the Roque de los Muchachos Observatory on La Palma. From left to right can be seen: the rectangular building of the Carlsberg Automatic Meridian Circle, the dome of the William Herschel Telescope, the domes of the Isaac Newton and Jacobus Kapteyn telescopes, and the Swedish Solar Tower.

Left: In the Control Room of the William Herschel Telescope are (left to right) Paolo Giommi, Jeremy Allington-Smith, Paul Murdin and Jon Mittaz. Jon operates the Faint Object Spectrograph, and is looking at a spectrum produced by the instrument.

All photographs in this article courtesy of the Royal Greenwich Observatory and Keith Mason of Mullard Space Science Laboratory.

Right: With the cloud deck below looking like a frozen ocean, the open dome of the William Herschel Telescope glints in the light of the setting Sun.

Facing page: Northern circumpolar star trails over the dome of the 4.2-metre William Herschel Telescope, situated at an altitude of 2,400 metres (7,870 feet) above sea level at the Roque de los Muchachos Observatory on La Palma.



A NIGHT ON THE HERSCHEL TELESCOPE

PROLOGUE

I am writing this article in the Control Room of the William Herschel Telescope on the island of La Palma in the Canary Islands. It is the middle of the night of 1988 February 12/13, and away to my left is the control desk. On the TV monitor screen is the image of a faint star. The telescope has been tracking the star for the last half an hour, and the image of the star's spectrum has just appeared on a colour display. The astronomers in the Control Room drop their papers and converge excitedly around the display.

Jeremy Allington-Smith squats down and peers at the screen: "It's certainly got emission lines," he announces. The astronomers all turn to the data reduction display and Jon Mittaz pecks furiously away at the keyboard. A third display unit flicks into life. 'FAINT OBJECT SPECTROGRAPH', it says, 'Flux in micro-Janskys', 'Wavelength in Angstroms'. A graph springs onto the screen, showing enormous spectral lines. The blue star is obviously a quasar. The tension of anticipation relaxes and the astronomers are obviously pleased with their discovery of a quasar which no-one has ever seen before. But what is its red-shift? The identifications of the lines, the wavelengths at which they appear and the red-shift all have to fit in a consistent story. Keith Mason gazes abstractedly at the spectrum and consults a list of spectral lines. "I don't understand all that mess in the middle, but if the big one on the left is magnesium-II, and the big one on the right is H-beta with oxygen-III beside it, then the red-shift is 0.8," he says; "what are the wavelengths of the Fe-II lines?"

Paolo Giommi and Gianpiero Tagliaferri exchange grins: this is the 24th quasar which we have discovered in six nights' use of the WHT. Our data are based upon their measurements of the positions of X-ray sources with the EXOSAT satellite. The satellite contained an X-ray sensitive camera and pictures taken with the camera are the ones analysed for X-ray source positions. Paolo and Gianpiero have had to make assessments of the reality of the faint X-ray sources in the X-ray pictures. Twenty photons from a faint source during a 10,000-second exposure with the satellite is not atypical. Their assessments are turning out to be reliable and the positions which they measured are proving accurate.

SERENDIPITY

The X-ray sources which we are identifying are 'serendipitous'. The word means a happy, fortunate discovery and it describes the atmosphere in the Control Room as well as the X-ray sources. When EXOSAT was making observations of some chosen, known X-ray object, other faint X-ray sources often appeared in the field of view. (It is just the same as when you expose a photograph to a galaxy in the sky, the photograph will be covered with the images of stars which are nothing to do with the galaxy but lie in the same direction by chance.) These faint X-ray sources are called serendipitous - they are a bonus to the main observation.

If there is a bright serendipitous source in the field of view of the satellite, then the astronomers who take the picture usually follow it up, but they do not recognise or bother with the faint ones. Paolo and Gianpiero have been analysing these. They are Italian astronomers who work at ESTEC, the technical headquarters of the

European Space Agency, based at Noordwijk in the Netherlands, where the EXOSAT observatory now is. The collection of images which EXOSAT took in its three-year lifetime are archived there, and Paolo and Gianpiero have developed programmes to analyse the archive images to look for serendipitous sources.

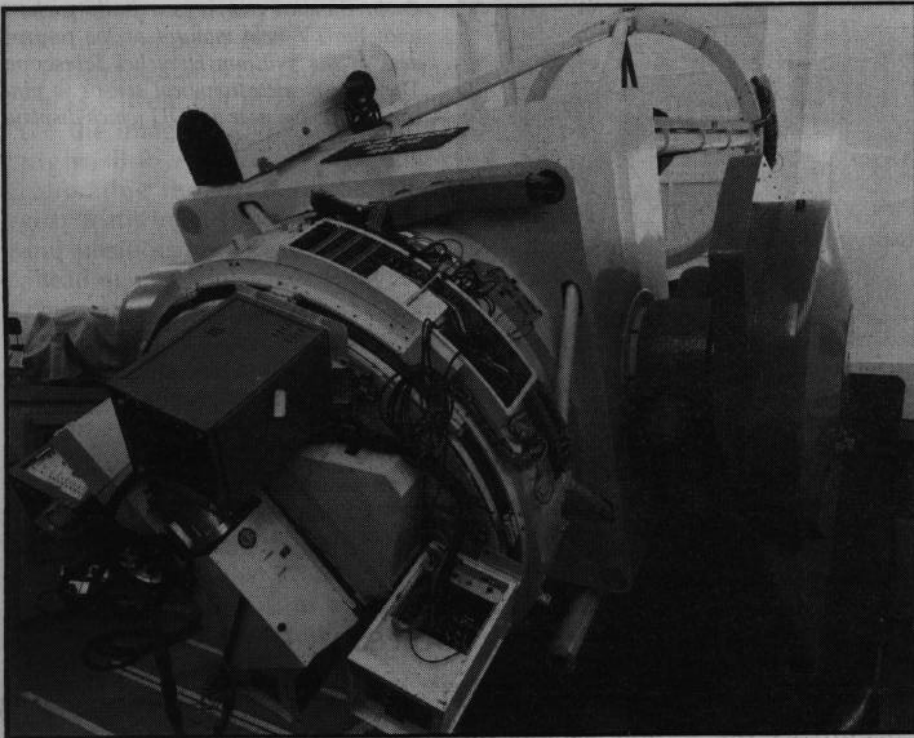
Once you determine the existence of an X-ray source, it is natural to want to find out what it is. It could be a white dwarf at a distance of about 100 light years, or alternatively it might be a quasar at 1,000 million light years. It could also be a more normal galaxy, somewhere in between. Identifying the sources by finding their optical counterparts is clearly essential.

SOME DETECTIVE WORK

Foggy ESTEC lies on the coast below sea-level and is over-shadowed by a large and, one hopes, strong dyke, on the other side of which is the North Sea. From there the story moved to the Mullard Space Science Laboratory, in a country house on a hill-side in Holmbury St. Mary, overlooking the Surrey countryside in southern England. It is part of University College, London, where Keith Mason leads a group of astronomers studying X-ray sources. Jon Mittaz is a graduate student there. Keith and his colleague Graziella Branduardi-Raymont (with the two of whom I have enjoyed working for 15 years), arranged a collaboration with the ESTEC astronomers to identify the EXOSAT sources.

The motives of the two groups are not quite the same. The ESTEC astronomers want to classify all the X-ray sources which they are finding with EXOSAT, using the optical identifications. This helps them determine the properties of X-ray sources in general. The MSSL astronomers are using the X-ray characteristics to pick out interesting quasars. EXOSAT was sensitive to soft (low energy) X-rays which, in quasars, according to the most widely accepted theory, come from the heated innermost regions of the disk of gas accreting onto the central black hole. (Many readers of this magazine will understand that there are a lot of assumptions built into this last sentence, but this is not the article to go into details!) So the MSSL astronomers think they are getting as close to black holes as they conceptually can, by studying quasars which have been selected because they have X-ray emission. When Keith, Graziella and I used the Isaac Newton Telescope a couple of years ago we found more quasars than we expected, working with a special EXOSAT deep exposure taken for the purpose of quasar-hunting, and we want to find out if this is a chance result, or has the significance which we believe it does.

The next step in the EXOSAT identification programme was to chart the stars which lie in the same region of the sky as the X-ray sources. The X-ray sources' positions were superimposed on prints from the Palomar Observatory Sky Survey (POSS), an atlas of photographs covering the whole of the northern sky. Each region of the sky is represented by a pair of photographs, one red and one blue. Jon accurately positioned a Polaroid camera on the precise coordinates of each X-ray source and took pictures of the area, covering 5 arc minutes. The X-ray source lies within the central 20 arc seconds or so - the accuracy depends on how strong the source is, and whether its image lay near the centre of the field of view of the EXOSAT



The cluster of instruments at the Cassegrain focus of the 2.5-metre Isaac Newton Telescope at the Roque de los Muchachos Observatory. It was with this telescope that Keith Mason, Graziella Branduardi-Raymont and the author found more quasars than expected a couple of years ago, when using a special EXOSAT exposure taken for the purpose of quasar hunting. The recent work on the Herschel Telescope was organised to establish whether this has some significance or if it was just a chance result.

camera, or off to the side where there are distortions. Usually there are several stars and galaxies in the central area of each X-ray source position. At most, only one of these is the optical counterpart of the X-ray source.

One initial clue as to which is the true identification is the colour of each star. X-ray stars are often quasars or white dwarfs - and these are blue. Blue stars are rare; most stars are cool and yellow, or red - interstellar reddening only makes stars redder. If you compare the blue and red photographs of the pair, the blue stars are relatively stronger in the blue photograph than the red stars; conversely, the red stars are stronger in the red photo. Keith and Jon paid special attention to any blue stars which they discovered in the region, of the X-ray sources, in the expectation that the blue stars were the prime candidates for the X-ray source identifications.

The blue colour is indicative but is not enough. What is really needed is the spectrum of the stars. However, the stars are faint - a typical quasar identified this way is 18th magnitude and some are as faint as 22nd magnitude. Only the biggest telescopes can take spectra of stars this faint. And that, of course, is where the William Herschel Telescope, (WHT) comes in. With its 4.2-metre mirror, the Herschel telescope is the fourth largest optical telescope in the world, after the 6-metre telescope at Zelenchukskaya, the 5-metre at Palomar and the Multi-Mirror Telescope in Arizona, whose six smaller mirrors sum in collecting area to the equivalent of a single 4.5-metre mirror.

A COMPROMISE WITH THE ENGINEERS

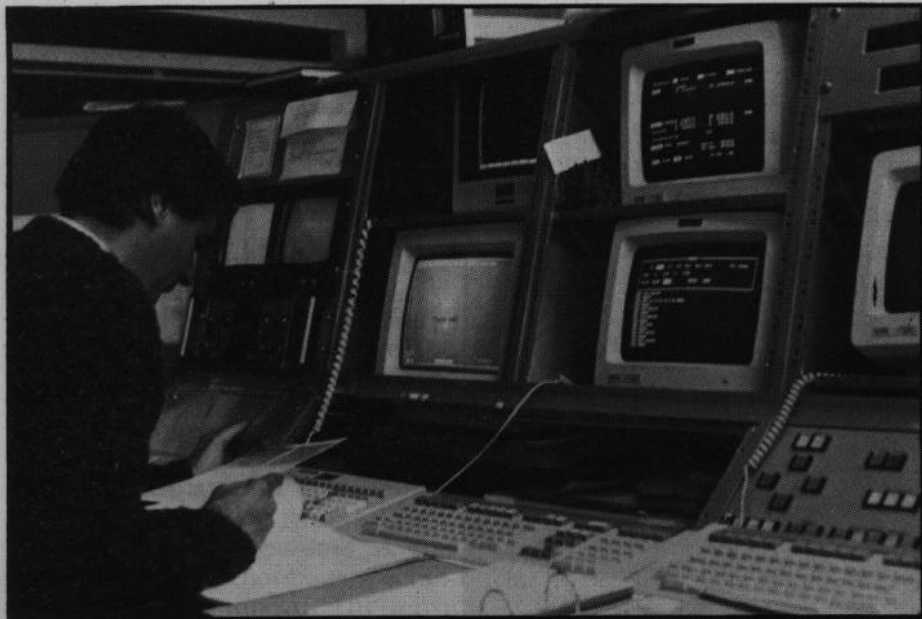
The WHT was completed by Royal Greenwich Observatory engineers and scientists, led by Brian Mack, in June 1987, seeing its first-light -star image on the first of the month. Full details of the telescope were given in *Astronomy Now* Vol 1, No.2, pp 17-25, July-September 1987. Within three months the WHT was operational, with its optics aligned well enough to give round images, and its control computer pointing the telescope with sufficient accuracy to pick out a given

star and track it well enough to keep the star on the telescope axis. It is unusual to get a telescope of this complexity commissioned so fast, but this was a deliberate policy of the RGO Director, Alec Boksenberg. The WHT is a scientific instrument, intended to generate science. The aim was to get astronomers using the telescope as quickly as possible, so as to get the most out of it at the earliest opportunity. Moreover, it is not necessary that everything has to be there on day 1, if the telescope does some basic things, like point and track, with good images at one focus, then the additional functions can be added later. At the same time, a complex telescope takes up a lot of tuning up. It is even the case that - I am obliged to make an admission which will not astonish anyone - some things do not work first time. Engineers need access to the telescope to complete it over the next year, at least. So a balance has to be found between astronomy and engineering.

For the WHT the plan for the first year was like this: some groups of astronomers were to be allowed to use the telescope for periods of three weeks. This is a long time to observe, and at RGO we thought that, given this amount of time, astronomers would be tolerant if not everything worked well throughout the whole three weeks. On the other hand, if the telescope did work well, astronomers could achieve major, perhaps unique, observing programmes in three weeks with a 4-metre telescope: At the end of a three-week astronomy period, the engineers were to have the telescope to work on, getting a long, uninterrupted time to install new features, and really fix the problems which had been identified in the previous period of use. Neither side was to have it exclusively, however, and we cautiously estimated that the astronomers would expect to spend half their time on commissioning work.

Actually the plan has worked out much better than we expected, and the telescope has come together remarkably cleanly. By August 1987 the first instruments were being installed on the telescope. These were chosen to be the ones which were most tolerant if the telescope was not performing well.

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Paolo Giommi compares a findings chart with the TV field monitor at the control desk of the William Herschel Telescope. The interim meteorological sensor (a pine cone) is visible near a VDU which displays data from the telescope.

GETTING THE TEAM TOGETHER

The instrument which we have on the telescope now is the Faint Object Spectrograph (FOS) built by the University of Durham and the RGO. It is unlike a conventional astronomical spectrograph in that it has no versatility at all - you point it at a star and expose its detector (a Charge Coupled Device) to the whole spectrum, and you see everything between 3,400 Angstroms and 10,000 Angstroms, that's it. The power of the idea behind the FOS is that, being so simple, it can be made incredibly efficient. We are taking spectra of stars at the 20th magnitude in half an hour. The FOS is especially efficient in combination with the WHT. In December 1987, a group of astronomers were snapping spectra here at a peak rate of one every 4 minutes, and determined the redshifts of 1,500 galaxies in their observing run.

In 1986 no-one knew how effectively the WHT would be working in 1988. It was September 1986 when Keith Mason got together with Paolo Giommi and I to propose the X-ray source identification scheme for one of the three-week observing slots. We wanted to use the FOS and we invited Jeremy, who built it, to join in. We needed his expertise on this superb instrument to ensure the programme's success. He had worked at MSSL before moving to Durham.

We were successful in our application, and scheduled to use the WHT in February 1988. Part of our team assembled at the Roque de los Muchachos Observatory on La Palma during the day before our run began, to try to learn about the mechanics of operating the telescope. Lorella Angelini from ESTEC, and Graziella and Mark Cropper from MSSL would arrive later to relieve some of us in the middle of the three-week run. We were happy to discover how simple the whole telescope was to use, and how easy it was to concentrate on the astronomy. This was just the plan conceived by WHT project scientist Charles Jenkins. When you are seated at the control desk it is impossible to know that there is a telescope next door - the telescope and the vast dome rotate remarkably quietly. Only the displays tell you that the telescope is moving. Paolo and Gianpiero feel quite at home in the control room - it is just like a satellite observatory, the only difference being that the 'satellite' is just 20 metres away.

FIRST FIND YOUR STAR

So now, a week into the observing run, we are working one by one through the list of 100 X-ray sources, obtaining spectra of the several selected stars near each one. Jon has measured their positions to the accuracy that the telescope requires. Each star has been given a name and we keyed the stars' Right Ascension and Declination coordinates into the computer at the beginning of the week. When we want to set the telescope on a star, we name it, and the computer converts its coordinates into the position in the sky to which the telescope must be pointed at that time.

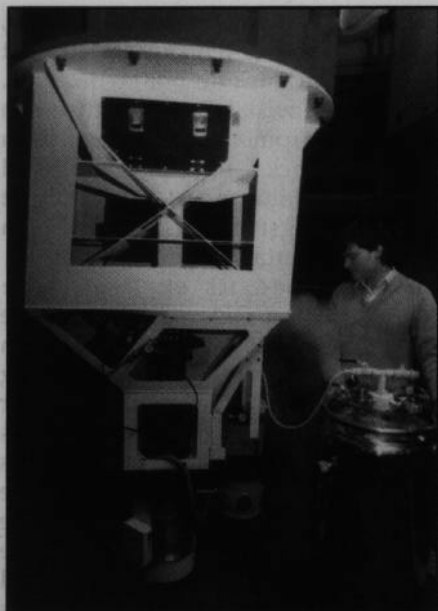
The WHT is an altazimuth mounted telescope, so the Right Ascension and Declination must be converted to Altitude (elevation) and Azimuth (bearing from true north); corrections for precession and refraction by the Earth's atmosphere are automatically applied. Already there is, written into the computer program by RGO astronomer Robert Laing, a model of the telescope's main imperfections - small misalignments of the axes and flexure under gravity of the telescope tube. Because of the altazimuth design the computer model is very simple; this is one reason for the WHT's accuracy.

The telescope slews to the named star and stops. The telescope already points better than any telescope that I know. The stars all come within 3 arc seconds of the centre of the TV screen (r.m.s. 1.6 arc seconds).

We gingerly turn up the gain of the intensified TV camera which looks up the telescope. We have to do this carefully in case there are bright stars in the field of view (we know that there are none on our charts, but we might have made a mistake in the coordinates we keyed in). In a 4.2-metre telescope, bright stars are so dazzling that they can destroy the TV tubes, and a stern notice by the gain knob reminds us of this. The TV image is digitised by a small microprocessor system and displayed. Within a minute we can see not only the star which we know is on the Palomar Sky Survey, but several that are too faint to appear on the 30-year old photographs - they are magnitude 21 or so. We have, in fact, chosen one of the blue stars, which does not appear on the red print at all. Here it is clearly visible.

There is no conventional handset on the WHT to move the star to the slit: instead there is a keyboard like a home computer. We type 'HANDSET', and then we

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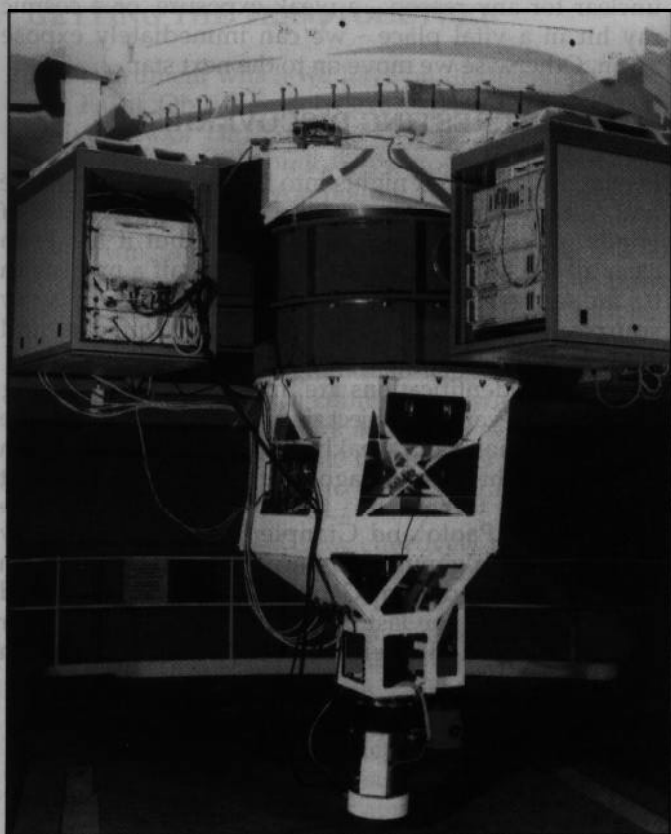


Above: Star images reflected off the spectrograph faceplate. A black rectangular slot, its ends marked with ink on the monitor screen, is the light which passes into the spectrograph. A pink broken cross marks the central axis of the telescope. When the telescope points to a star, it appears in the central gap of the cross.

Above left: Jon Mittaz fills the red dewar of the Faint Object Spectrograph with liquid nitrogen (clouds of condensation and frost are an accompaniment to this twice-a-night excitement). The liquid nitrogen cools a Charge Coupled Device (CCD) inside the spectrograph camera (shiny container at bottom). The open frame structure is where the main spectrograph will later be installed.

Left: The Faint Object Spectrograph, constructed jointly by the University of Durham and the Royal Greenwich Observatory, at the Cassegrain focus of the Herschel Telescope.

Below: The dome of the William Herschel Telescope, pictured the day after an ice-storm at the Roque de los Muchachos Observatory.



cataclysmic variable star, caught by chance in a flare during the blue POSS exposure, and infrequently visible. We will re-visit the region of this X-ray source from time to time throughout our run on the William Herschel Telescope, to see if Gepu comes back.

In the meantime we have two dozen quasar spectra to look at, quasars which are unknown to everyone except us, and were secret from everyone including us until we turned this fine telescope skywards in the clear La Palma nights. ■

Dr. Paul Murdin, well known for his many books, articles and broadcasts, is a regular contributor to Astronomy Now. He is head of the Royal Greenwich Observatory's Astronomy Division at Herstmonceux and has been heavily involved in the installation and commissioning of the William Herschel Telescope. He was awarded the OBE in the New Year's Honours List for his many services to the science of astronomy.

