# TELESCOPES AND INSTRUMENTATION

## Adaptive Optics at the WHT

Jeremy Allington-Smith, David Buscher, Richard Myers (University of Durham)

June 1999 on the WHT saw two runs with the University of Durham ELECTRA Adaptive Optics (AO) system. The first seven nights were for commissioning various new features and the remainder for service mode AO observing. The new features included the Durham TEIFU integral field unit which can feed WYFFOS with adaptively corrected optical spectra from 500 sky elements simultaneously. This capability will soon be enhanced to 1000 elements (hence TEIFU: Thousand Element Integral Field Unit).

### ELECTRA

Adaptive optics is familiar from CFHT's Pu'eo system and Adonis on the ESO 3.6m and it is also now being introduced on larger telescopes such as Keck and Gemini. The idea of AO is to sense the instantaneous deformations which atmospheric seeing induces on astronomical wavefronts and to correct them in real-time using some form of adaptable mirror. This is illustrated schematically in Figure 1. The light to sense the wavefront distortions must at present come from a relatively bright guide star located within at most an arcminute or so of the science target. In future, however, this limitation will be largely overcome by the introduction of artificial laser guide stars created by resonant scattering of laser light in the upper atmosphere.

ELECTRA is quite a high-order system, having 228 degrees-of-freedom altogether and is designed to operate at short wavelengths, with partial correction available in the optical V, R and I bands as well as correction in the near-IR. In June the two modes available were near-IR imaging with the 1–5 micron 256×256 pixel imager WHIRCAM and optical area spectroscopy with TEIFU.

ELECTRA operates at the GHRIL bench at WHT Nasmyth as illustrated in Figure 2. The optical layout is illustrated schematically in Figure 3. ELECTRA's main subsystems are its adaptive mirror, wavefront sensor (WFS), tip-tilt mirror, calibration unit and computer control system.

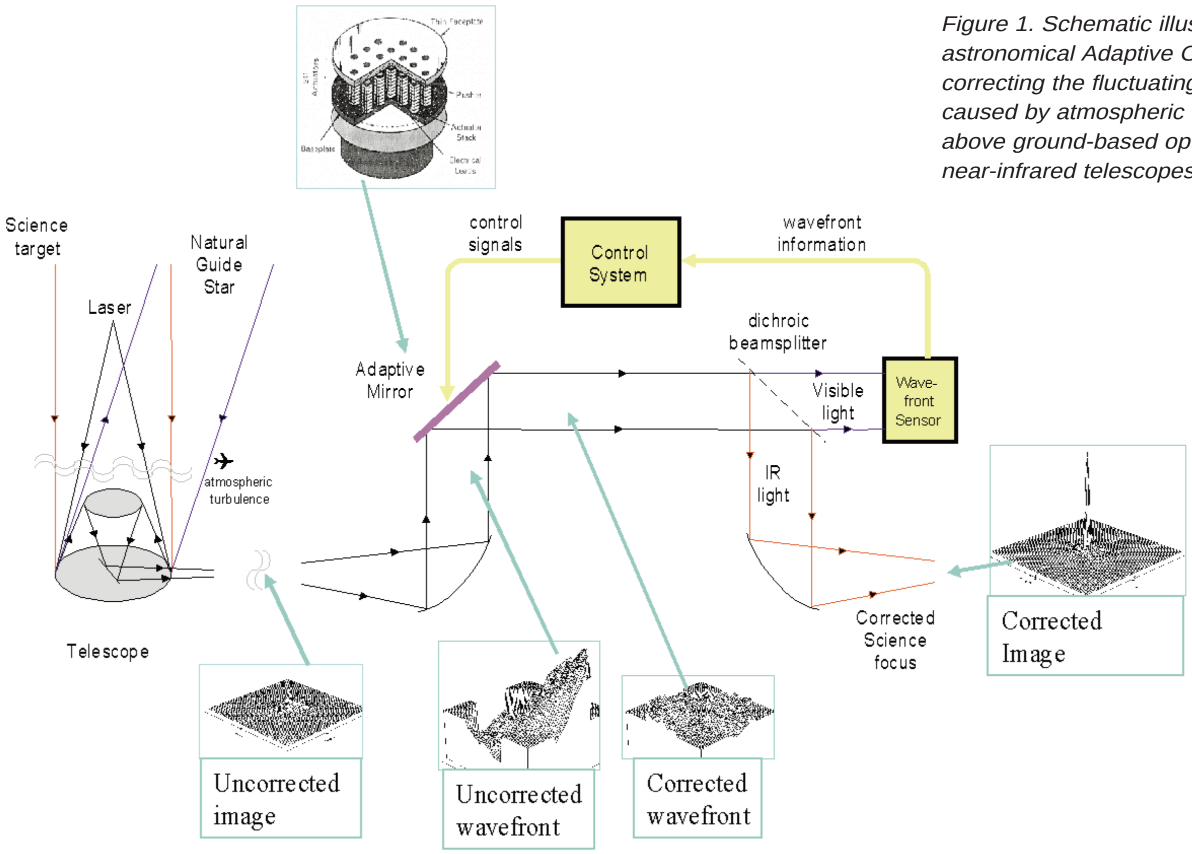



*Figure 1. Schematic illustration of astronomical Adaptive Optics for correcting the fluctuating aberrations caused by atmospheric turbulence above ground-based optical and near-infrared telescopes.*

The adaptive mirror was built by TTC in San Diego. It has 76 segments each of which can tip, tilt and piston (hence 228 degrees of freedom) under computer control and is equipped with strain-gauge position feedback which ensures a linear response to wavefront correction commands.

The WFS is a Shack-Hartmann sensor which uses a camera built at RAL and based on an 80×80 pixel EEV CCD-39. This camera can read out up to 2 million pixels per second from each of four readout ports. These signals are processed by an array of eight Digital Signal Processors (DSPs) in order to produce wavefront reconstruction commands which are then passed to an additional bank of eight DSPs. This second back uses digitised feedback from the adaptive mirror strain-gauges to accurately place the required wavefront correcting figure on the mirror.

Near-IR seeing correction with ELECTRA is illustrated in the 'before' and 'after' correction images of Figures 4a and 4b. The service mode AO data will be reduced by the requesting observers but an early indication of the subarcsecond detail available is illustrated in the raw image of a planetary nebula in Figure 4c.

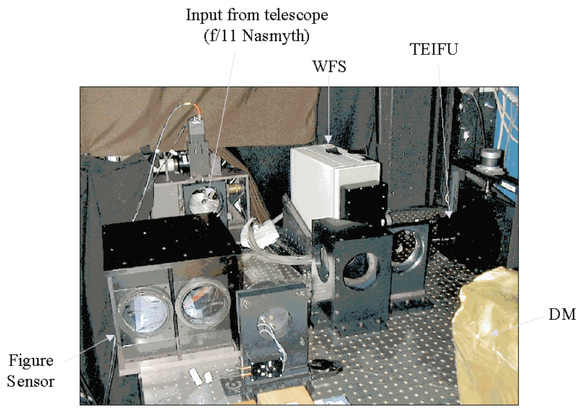



*Figure 2. Schematic layout of ELECTRA at GHRIL (WHT).*

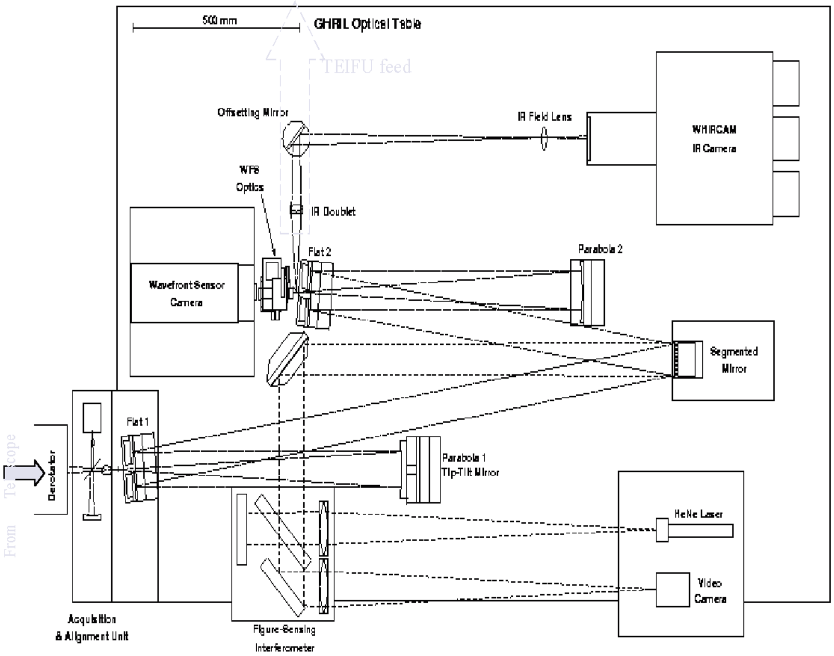
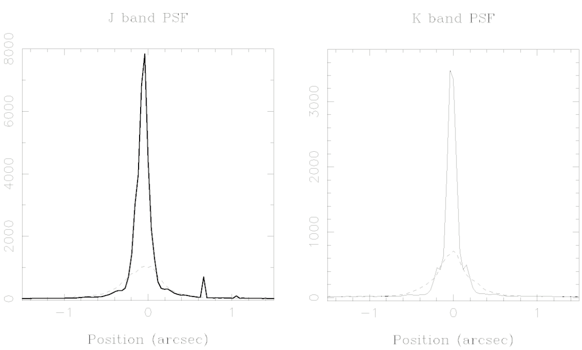
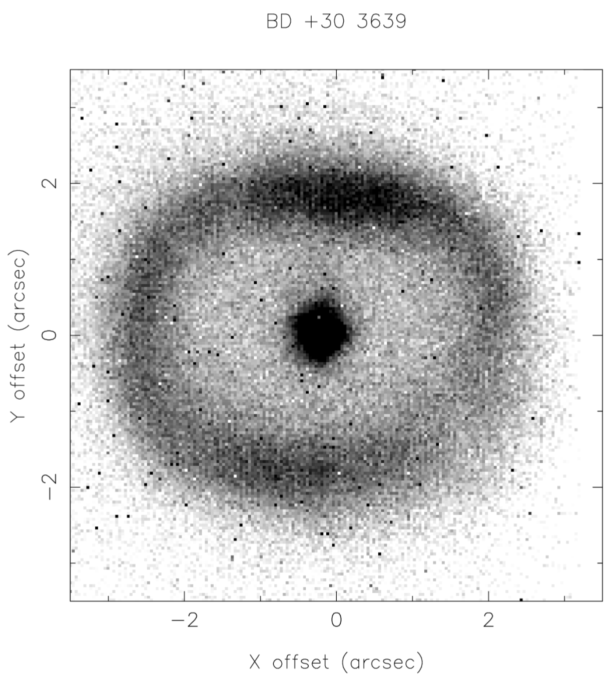



*Figure 3. Schematic layout of ELECTRA at WHT/GHRIL.*

*Figure 4. (a) ELECTRA K-band image before and after correction (b) ELECTRA J-band image before and after correction (c) Raw WHIRCAM image of planetary nebula taken with ELECTRA AO. The core of the central star image has an angular size of <0.2 arcsec, but the ring appears not to have any structure on scales smaller than ~0.5 arcsec.*



## NAOMI

ELECTRA is a complete AO system in its own right but has also been the means of developing the real-time control system of NAOMI (Nasmyth AO for Multiple Instrumentation). Unlike ELECTRA which is always supported by a team of at least two staff from Durham, NAOMI is an ING facility which will be permanently available at the WHT and will integrate fully with the instrumentation and telescope. It also has a more sophisticated guide star pick-off method than ELECTRA and will ensure optimum IR imaging with simultaneous correction at an optical port over a wide range of guide star separations. It is designed to work with considerably fainter guide stars and also has an upgrade path for working with a laser guide star.

The opto-mechanical and system software components of NAOMI are approaching completion at the UK Astronomical Technology Centre in Edinburgh. These components will then be shipped to Durham for final integration with the adaptive system in October of this year. The complete system will then be commissioned on the WHT commencing in April next year, after which the system will be available to the community. Judging by the volume of service proposals to use ELECTRA we anticipate a healthy uptake.

## TEIFU

The TEIFU system will be available for use with both ELECTRA and NAOMI. It is a lenslet-fibre areas spectroscopy system with consequently very high spatial fill-factor. A schematic illustrating its mode of operation is given in Figure 5. At present it feeds WYFFOS in the 300–1000 nm wavelength range and has a single field with 28×18 elements each with an angular extent of 0.25 arcseconds. In future it will have two separate fields with 1000 elements in total. These fields will have variable separation for simultaneous object and sky observation and will be available at three different image scales:

| | | | |
|---|---|---|---|
| *Sampling:* | 0.125 | 0.25 | 0.50 arcsec |
| *Field:* | 2×(3.5×2) | 2×(7×4) | 2×(14×8) arcsec$^2$ |

In future TEIFU will also benefit from a new long camera on WYFFOS giving better sampling. TEIFU will also be adapted for operation in the near-IR.

The characterisation of TEIFU has been very pleasing showing around 50% throughput with an rms fibre-to-fibre uniformity of 6%. An example set of TEIFU spectra from the galaxy 3C327 is shown in Figure 6.

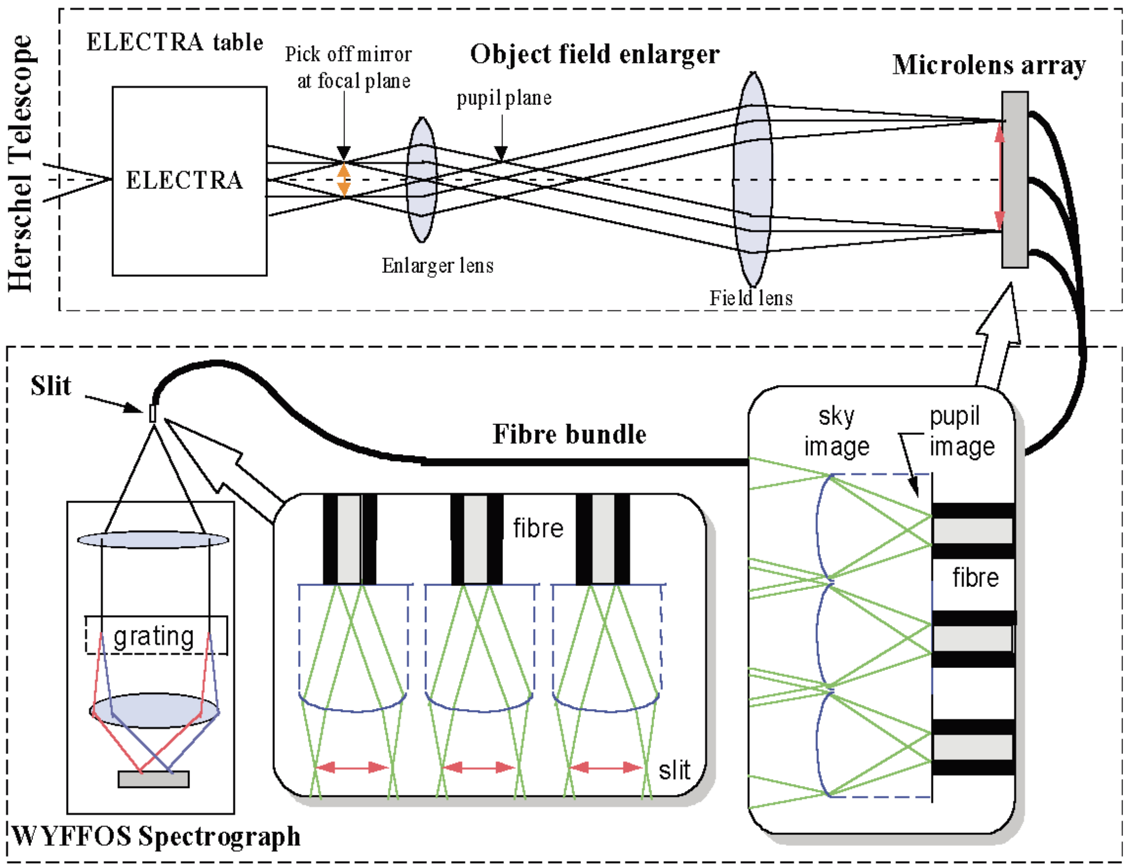



*Figure 5. Principles of Operation of TEIFU.*

## Acknowledgements

We would like to thank all AO and TEIFU staff at Durham without whom nothing would exist at all, Dr. Nick Waltham's CCD group at RAL for their great work on the WFS, all ING staff involved in the run for their invaluable help, and, in particular, Andy Longmore at UKATC (who would be a co-author if he were not currently observing elsewhere!) for his crucial contribution throughout. Funding was kindly provided by PPARC, the Royal Society Paul Instrument Fund (which funded the WFS) and the University of Durham. ¤

Jeremy Allington-Smith
(J.R.Allington-Smith@durham.ac.uk)

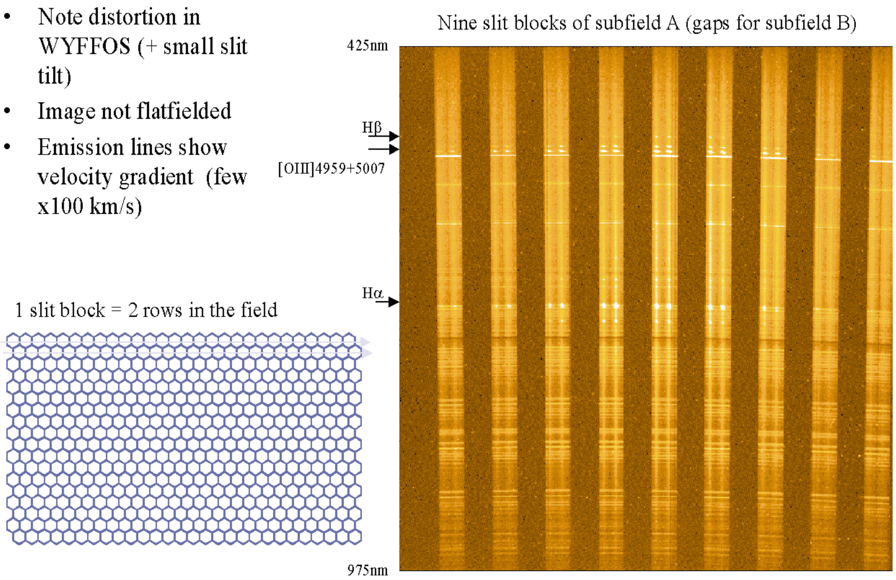



*Figure 6. 3C327 raw TEIFU spectra.*

# INGRID: A New Near-IR Camera for the WHT

## Chris Packham (ING)

The new near-IR camera to be operated at the WHT is now nearing completion ready for its commissioning date, now set for January 2000. INGRID (the Isaac Newton Group Red Imaging Device) was designed and partially built by the RGO and finished at the ING during the last year.

At INGRID's heart is a 1024×1024 pixel HgCdTe array developed by Rockwell International Science Centre and the University of Hawaii, which features good sensitivity from 0.8 to 2.5μm. The sensitivity of the Hawaii array is very competitive compared with that of a standard optical CCD from a wavelength of 0.8μm as shown in Figure 1. INGRID will typically be mounted at the folded Cassegrain focus near-IR port of the WHT, opposite to the optical auxiliary port imaging CCD camera, to provide a plate scale of 0.25 arcseconds per pixel to give a field of view of 4.27×4.27 arcminutes. This will allow rapid changes between optical to near-IR imaging facilitating colour mapping. INGRID will also be used in conjunction with NAOMI (described by Jeremy Allington-Smith et al. in this newsletter) as the imaging camera. With NAOMI, the pixel scale is 0.04 arcseconds per pixel in order to exploit the high resolution NAOMI can provide at near-IR wavelengths.

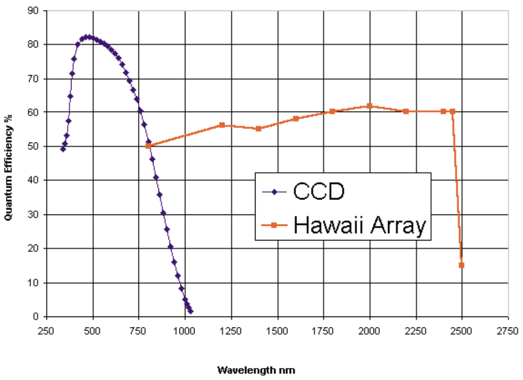



*Figure 1. Quantum Efficiency of a Hawaii Array compared to that of a CCD.*

Current members of the INGRID team include Gordon Talbot (project manager), Chris Packham (project scientist), Paul Jolley, Kevin Dee and Bart van Venroy (mechanical), Simon Rees & Mathieu Bec (software), Peter Moore (detector), Sue Worswick (optics) and Andrew Humphrey (librarian). The ATC and the IAC also provide valuable help as does Keith Thompson, the ex-RGO project scientist.

At the time of writing we are preparing to enter the performance and science verification stage. We envisage this stage to take around three months for precise characterisation and alignment of all elements of INGRID. Some initial verification has already been successfully achieved but many hurdles remain to be overcome. Shortly after the commissioning phase the ING will offer several nights of service time earmarked for INGRID observations to allow rapid science exploitation of the unusual capabilities INGRID can deliver. Please watch the INGRID's WWW for more information on this:

http://www.ing.iac.es/IR/INGRID/ingrid1_home.htm

The main design criteria for INGRID is excellent optical quality ready for the integration with NAOMI. The optics are all-refractive in design and are split into two parts. The camera is placed within the cryostat to minimise thermal background, and requires an alignment accuracy of 20μm between the four lenses. As ING will offer INGRID at two focal station, two warm collimators are available which enable a change of focal station without thermally cycling the cryostat. In order to