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Throughput of the Herschel Telescope's ISIS spectrograph

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Abstract

Observations of spectrophotometric standards have been used to determine the throughput of ISIS, its detectors, the WHT, and the atmosphere over La Palma. Factoring out known quantities (the extinction and the efficiency of the diffraction grating and the CCD detector) gives the throughput of the combination of the simple optical elements in the beam. This throughput is different for the red and blue channels of ISIS and, in both cases is nearly a factor of two below the expectation based on fresh reflecting surfaces and clean optical elements.

The observations

The data were taken with ISIS on the WHT, employing the 158 mm^{-1} diffraction gratings. The detectors were EEV-3 on the red channel and GEC-5 on the blue. Observations were made on the nights of 1991 April 3/4 and 4/5. The observers were Robin Clegg and Dave King. Two spectrophotometric standards were observed over a wide range of air masses. A total of 16 observations were made of HZ44 and 23 of Feige 34 (Oke, Ap.J.Suppl. **27,** 21, 1974; Stone, Ap.J. **218,** 767, 1977), at air masses up to 2.1. One the first night, a slit of width 9 arcsec was used in 2 arcsec seeing. The slit was not vertical, but the computed maximum image shift between 3200 A and 5500 A would at most have been 1.1 arcsec, which is negligible by comparison with the slit width. No dichroics were used.

Reduction and supplementary data

The reduction of the spectra (by Janet Sinclair) followed a well-trodden path. The steps were

1. extraction of the spectra and sky subtraction;
2. wavelength calibration;
3. correction for CCD gain (electrons per ADU);
4. conversion into AB magnitudes and comparison with published data;
5. estimation of extinction by a linear fit with airmass;
6. calculation of count rates extrapolated to zero airmass; and
7. determination of the throughput of the entire system.

Most of these reductions were done using FIGARO programs, but some had to be done manually or by specially-written programs. The reduction was checked by manual calculation at a single wavelength.

The determination of the extinction is the subject of a separate Note. Both nights however were of acceptable photometric quality and the extinction is well measured for both. After correction to zero airmass, the data therefore take the form of the simple ratio of photons in at the primary aperture to counts ('ADU') recorded at the detector.

The efficiency of the gratings was measured by Mike Lowne at Herstmonceux, and these data are reproduced as Figure E7 of the La Palma Users' Guide. Measurements were made separately for light polarized along and orthogonal to the grating rulings. Not surprisingly, at this low ruling frequency, the efficiencies for each polarisation were the same to within 3 per cent.

The efficiency of the detectors is known from measurements by Paul Jorden. In the case of GEC-5, these data are about three years old but are much more recent for EEV-3.

Data on the reflectivity of the coatings were provided by David Jackson.

System efficiency

For general interest, we quote here the Oke AB magnitudes giving 1 photon sec^{-1} A^{-1}. These figures are rather contingent; they include detector and grating efficiencies and are for one air mass given the extinction we measured. The nights were however typical, the response of the gratings is broad in wavelength, and the detectors appear to be representative of coated CCDs.

Wavelength	3500	4000	5000	5000	6000	7000	8000	9000	10000
AB	15.9	16.1	16.3	16.5	17.5	17.5	17.1	16.0	14.2

Comparison with expectations

Factoring out the colour-dependent terms of atmospheric extinction, and detector and grating efficiency, should give a throughput for the telescope and ISIS optics which (for each channel of ISIS) varies only slowly with wavelength. This is a useful quantity to know because it is a single number which is the same for all observers; the system efficiency can be calculated by each observer for their particular configuration, using tabulated data in the Users' Guide.

The results are given in the Figure; the blue channel shows a fairly flat throughput. The red channel's data are also fairly flat, except for a few unexpectedly low points shortward of 5000 A. For these the grating efficiency was extrapolated from the available data, an extrapolation which would be expected to be accurate given the wide blaze profile of the grating. Absorption by water vapour varies rapidly with time and may be responsible for the two high points longward of 9000 A. The efficiency of the CCDs is low here, however, and the measurements in the laboratory of the chips' response may be inaccurate because of the low signal levels that result.

On the assumption that the throughput is indeed independent of wavelength, we obtain average values of about 0.19 for the blue channel and 0.28 for the red. This is very nearly half of what we would expect, calculating the throughput from the following table.

Surface	Red throughput	Blue throughput
Primary	0.85	0.85
Secondary	0.85	0.85
Fold	0.97	0.85?
Collimator	0.97	0.91
Schmidt plate	$(0.98)^2$	$(0.98)^2$
Schmidt mirrors	$(0.97)^2$	$(0.91)^2$
Vignetting	0.92	0.92
Field flattener	$(0.98)^2$	$(0.98)^2$
Cryostat window	$(0.98)^2$	$(0.98)^2$
Total	0.52	0.38

Here 'red' means at 6000 A and 'blue' means at 4000 A. The vignetting in the cameras assumes that the central obstruction in the telescope pupil lies on the central obstruction of the camera, as should be the case for a small anamorphic factor.

The similarity of the discrepancy for both channels suggests that it is not the detector data which are the problem. For instance, we cannot immediately, conclude that the coating on GEC-5 has deteriorated since the measurements in the laboratory. We have also checked the gain of the CCDs (photons per ADU) directly from the data on standard stars. Any continuum source with a reasonable range of counts can be used to check the gain, using a simple statistical model where the observed noise is the combination of photon noise and pixel-to-pixel sensitivity variations. By this method, we measured gains of 0.9 and 1.1 for EEV-3 and GEC-5, whereas the published values (as used in the calculations reported here) are 1.1 for both chips.

A further check, on GEC-5 at least, comes from images taken at the auxiliary A&G focus by Dave Carter. These data date from late September in 1991. The efficiency of the system (telescope, A&G mirror and CCD camera) agrees with theoretical prediction. This is a strong argument that the problem is in ISIS itself.

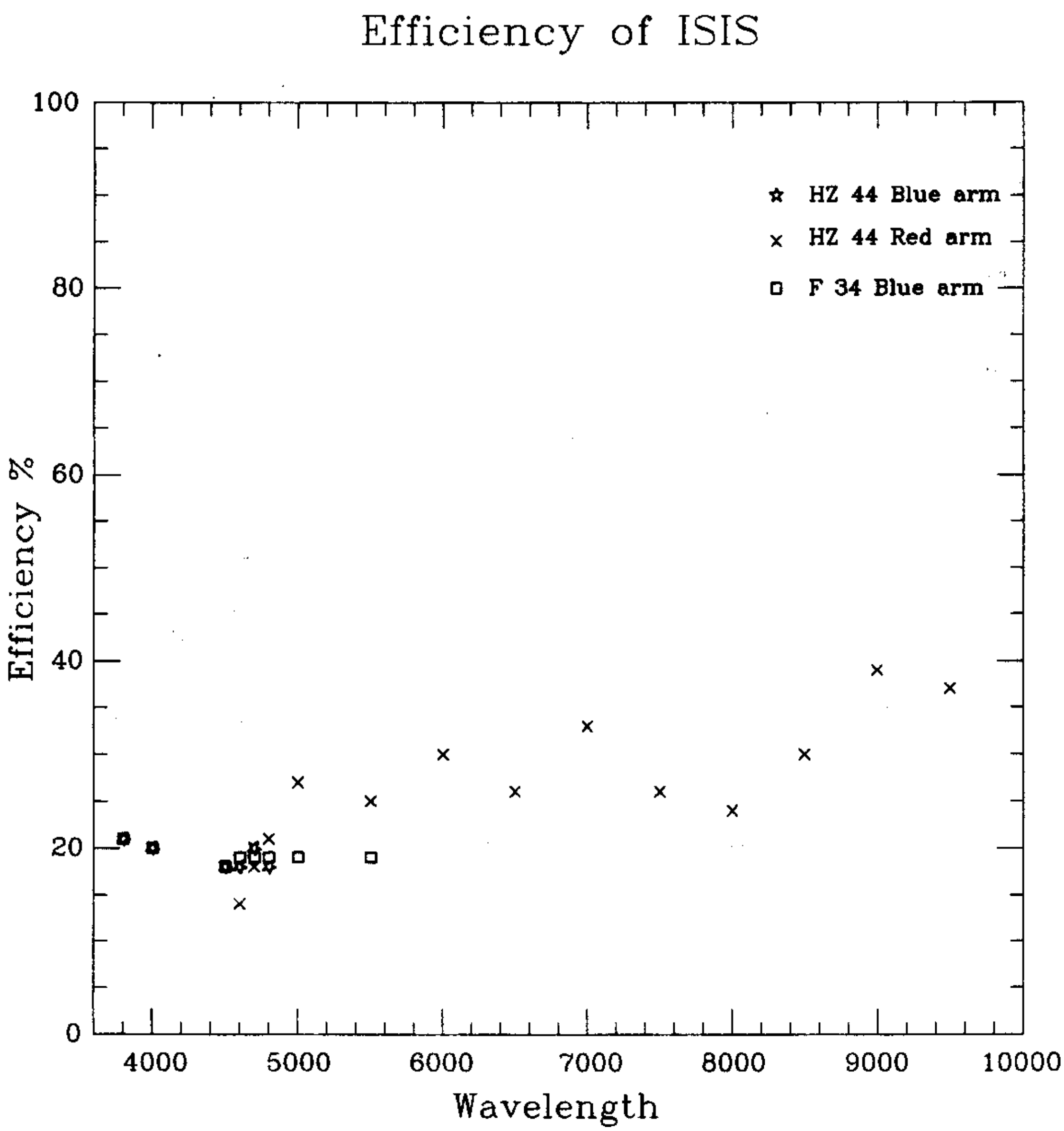
Within ISIS, the gratings do not appear to be the problem. We have one useful check on their efficiency. Using the calibration system, data were obtained for all the gratings and their relative efficiencies determined. These data were in good accord with Lowne's measurements. This shows that, if Lowne's measurements are wrong, they must be wrong by the same factor for every grating. It also shows that there is nothing anomalous about the grating used for the flux measurements.

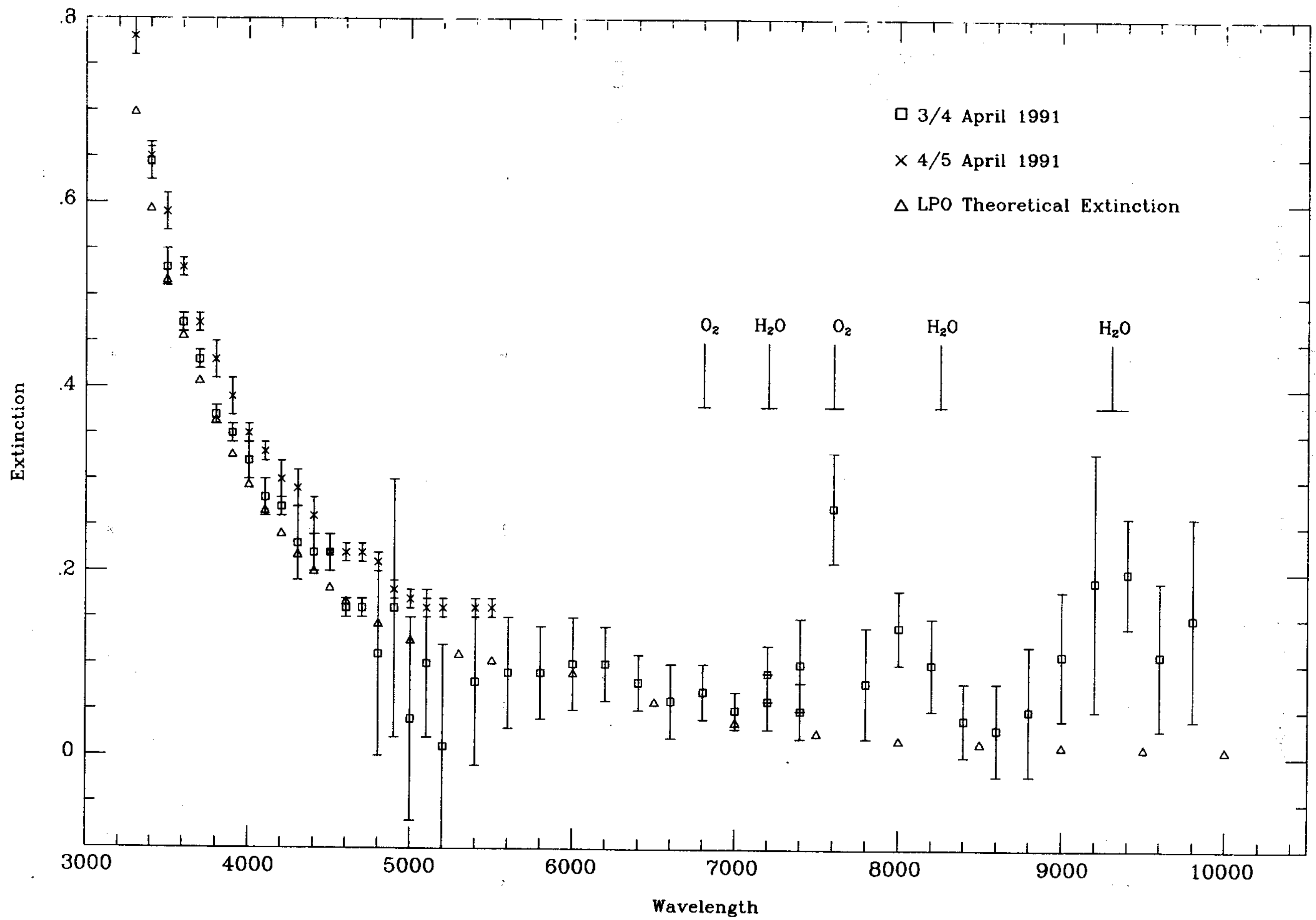
Polarisation effects need to be considered. The two folds in each channel (the main fold, and the camera fold) are orientated with respect to each other in a way that would be expected to suppress the intensity of light polarised in the plane of incidence. A simple check was made during the commissioning of the imaging polarimetry mode of ISIS. In this mode, the grating is replaced by a flat mirror and the geometry is such that we would expect the system polarisation to be roughly the square root of the level with the grating in; the reasoning is that the low-ruling grating reflects each polarisation equally, whereas as the mirror will suppress the plane of polarisation that is enhanced by the reflections at the fold and the camera. The test was done by using fully-polarised light, generated by the calibration system and the A&G box's polaroids. The plane of polarization was rotated with the half-wave plate and the intensity emerging from ISIS was recorded on a CCD. The lamp was extremely stable in its output during this test. No systematic fluctuations in output were seen; there were changes at the 5 per cent level which most probably result from pupil effects at the retarder plate, which is not properly normal to the beam. We therefore conclude that ISIS is equally sensitive to all planes of polarization, to within 10 per cent.

Other data taking during the imaging polarimetry run are not as satisfactory. Observations of a spectrophotometric standard, taken with the blue channel, gave a throughput of the spectrograph which was 90% of expectation. This result was derived by a careful integration of the spectrum of the standard across the Harris V filter that was used, taking into account the change in sensitivity of the CCD across the bandpass. However, an extinction had to be assumed, and was taken to be 0.2 mag airmass^{-1}. This discordance is worrying.

Is it likely that the spectrograph is simply dirty? There are 12 surfaces involved, excluding the grating; if each introduced attenuation by the same factor f, then an overall loss of a factor 2 would require f to be $2^{1/12}$, or 1.06. This may seem small, but its effect would be for a typical air-glass surface to have a throughput of 0.92 rather than the 0.98 we expect. It would also mean that half the light entering the spectrograph would be scattered in random directions.

However, the available evidence is clear that the loss is occurring in ISIS itself not in the telescope, gratings, or detectors.


Efficiency of ISIS
HZ 44 Blue arm
HZ 44 Red arm
F 34 Blue arm
Efficiency %
0
20
40
60
80
100
4000
5000
6000
7000
8000
9000
10000
Wavelength


3/4 April 1991
4/5 April 1991
LPO Theoretical Extinction
O2
H2O
O2
H2O
H2O
Extinction
.8
.6
.4
.2
0
3000
4000
5000
6000
7000
8000
9000
10000
Wavelength