GEOMAGNETIC IMAGE DEFLECTION PROBLEM IN THE FAINT OBJECT SPECTROGRAPH

V. T. Junkkarinen, E. A. Beaver, R. D. Cohen, R. Hier,
R. Lyons, and E. Rosenblatt
University of California San Diego

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In orbit HST data taken with the Red Digicon detector of the Faint Object Spectrograph (FOS) show an image drift correlated with the Earth's magnetic field. This drift occurs because the μ-metal magnetic shield around the Red Digicon does not shield adequately. The amplitude of the drift for a typical orbit is roughly equal to the spectral resolution of the FOS. For data taken with readouts every minute or two, resampling and shifting can be used to remove most of the drift in the spectral direction. The drift will compromise photometric accuracy at high signal-to-noise ratios because the edge of the image of the aperture can drift beyond the diode array in the direction perpendicular to the dispersion. The microprocessor in the FOS can be re-programmed to counter the geomagnetic drift by changing the deflection currents on a time scale of one minute or less. In orbit data from the Blue Digicon show some image drift that does not correlate well with the magnetic field. The Blue Digicon μ-metal shield works better than the red side shield by at least a factor of 3.

I. INTRODUCTION

In the FOS Digicon tubes, photoelectrons are accelerated from the semi-transparent photocathode toward a silicon diode array. The accelerating potential is around 20 keV. To focus the photoelectrons, there is a strong magnetic field parallel to the electric field. The parameters are chosen so that the photoelectrons execute exactly one full gyro-loop in the time it takes to travel from the photocathode to the diode array. The electron motion is basically along the magnetic field lines. If an external field is added to the focus field, then the image shifts by the amount that the magnetic field shifts. There is an additional small motion perpendicular to the total magnetic field that results from the non-parallel component of the electric field. Because each photoelectron completes one gyro-loop, in plasma physics terms, it is only necessary to consider the guiding center motion. For the FOS parameters this $\vec{E} \times \vec{B}$ drift produces a 17 degree rotation of the deflection.

Magnetic shields were designed to prevent external magnetic fields from causing unwanted deflections in the FOS Digicons. The μ-metal shield used with the Red Digicon is less efficient than the design specification by a factor of roughly 10. The original Red Digicon in the FOS was replaced before launch by a tube with a more stable red sensitive photocathode. A spare μ-metal shield and magnetic assembly was installed with the new Red Digicon. The Earth's magnetic field produces a changing external B-field in the Digicon reference frame as HST orbits the Earth. The geomagnetic image drift decreases the effective spectral resolution of the Red side of the FOS and will limit the photometric accuracy available in high signal to noise spectra. We illustrate in this poster paper the nature of this drift and discuss the possible solutions.

II. TALED OBSERVATIONS

The magnetic field deflection problem in the Red FOS Digicon was discovered in calibration data taken with the Target Acquisition Light Emitting Diodes (TALED). These TALED data are intended to accurately map the entrance apertures of the FOS. Each Digicon contains a single 512 diode linear array. The entrance apertures are mapped using the TALEDs by slowly building up a line by line image of the

aperture. The lines are shifted in the "Y" direction by changing a current in the coil attached to the Digicon. Each line in the data is exposed for 10 s and 85 lines are used to cover an aperture pair. Figure 1 shows the A4 (2 X 0.1 arcsec square) aperture pair mapped twice. The apertures, which should appear rectangular, are clearly distorted. The component of the Earth's magnetic field parallel to the diode array changes on a time scale of several minutes as HST moves in its orbit. Since the distortion seen in Figure 1 takes place on a similar time scale, problems with the magnetic shielding of the Red FOS Digicon were suspected.

III. THE B-FIELD

The deflection in the FOS digicons is expected to be primarily correlated with the component of the B-field parallel to the direction of interest. This assumes that the magnetically permeable materials in the FOS, the magnetic shield and the permanent magnets, do not distort the contribution from an external B-field, but merely attenuate it. There is also an $\vec{E} \times \vec{B}$ drift which introduces a 17^{o} rotation so that in the x direction:

$$\Delta_x = C \times (\cos(\theta) B_x - \sin(\theta) B_y),$$

where Δ_x is the x deflection, $\theta = 17^{o}$ and C is a constant which depends on the amount of attenuation provided by the magnetic shield. We use the NSSDC-1 model for the Earth's B-field. A small computer program does the transformations to find the magnetic field components in the coordinate system attached to the Digicon. Figure 2 shows the B field component that produces the deflection in the x direction as a function of time for several orbits. Typically a B field component goes through almost two cycles in a 94 minute orbit.

IV. THE SENSITIVITY COEFFICIENT

The deflection in the Red Digicon is a linear function of the projected (and rotated) B-field. The TALED data include a random offset due to the non-repeatability of the filter grating wheel, which was moved between the observations. Also the high voltage was changed between the observations. The centroid vs. B-field data show not only a random offset but some variation in the sensitivity coefficient beyond that expected from statistical errors. The mean coefficient found is 114 μm gauss $^{-1}$ ± 7. The linear functions fit the aperture centroids with an rms deviation of 1 to 3 μm. For the zero order UM 675 data taken a few months later, a linear function fits the centroid positions with an rms error of 1.2 μm. But the sensitivity coefficient found is 143 μm gauss^{-1} ± 2. This value is significantly different from the value found from the TALED data. The simple model presented above might not be sufficient or some other drifts might be involved. More data will allow us to determine how accurately we can predict the deflection due to the Earth's magnetic field. It is clear from the data that the geomagnetic image drift is the largest component in the Red Digicon image motion. The sensitivity coefficient is somewhere in the range 100-150 μm gauss^{-1}.

V. FIXING THE DRIFT PROBLEM

a. SHIFTING DATA

Some of the data taken with the Red Digicon can be aligned by using features like the zero-order image. For data that is not self-aligning, the spectra have to be shifted and added (re-registered) using the B-field and an estimate for the sensitivity coefficient. Since typical B-field excursions for long integrations are 0.5 gauss peak-to-peak, the peak-to-peak spectral image motion will be roughly 70 μm. This amounts to 5.6 1/4 step channels (the diode-to-diode separation in the FOS is 50 μm and magnetic deflection is typically used to sample the diode array with 4 steps per diode). The present uncertainty in the sensitivity coefficient and a lack of a complete understanding of the image drifts limits the accuracy of the re-registration. Observations that consist of many short sub integrations (1 to 4 minutes between readouts - 1

or 2 minutes is better than 4 minutes) at present can be re-registered to maintain a typical spectral resolution of 5 channels (1/4 steps) FWHM within 10%. A more accurate model and sensitivity coefficient will allow re-registration to recover the spectral resolution to a few percent. There is always a small loss in resolution in the re-registration process because the channels have a finite width. With 5 channels per resolution element the resolution loss is only about 2% due to the discrete bins.

V. FIXING THE DRIFT PROBLEM

b. REPROGRAMMING THE FOS

Shifting the data after an observation cannot fix the photometric problems produced by the geomagnetic image drift. The FOS Digicon diodes are 200 μm high which is 4 times the 50 μm diode spacing. So the point spread function (PSF) generated by the HST optics and the entrance aperture has more latitude to drift in the "Y" direction. But there is not enough latitude, for example the B field drift combined with the size of the PSF for the 1 arcsec circular aperture (140 μm) are such that sometimes part of the PSF will miss the diode array. This effect is difficult to remove by calibration because the center of the PSF is uncertain - the filter grating wheel shifts by a small random amount every time that it is moved. Estimates of the count rate losses are a few percent - it depends on many factors. These losses will affect photometry especially at high signal-to-noise ratios. They may be the limiting factor since pre-launch estimates for the photometric quality of the FOS were around 1%. These losses also affect spectropolarimetry which involves taking differences of two high signal-to-noise spectra. If one spectrum slightly misses the diode array there will be a false signal. It is desirable to use the Red Digicon because it is more sensitive that the Blue over the wavelengths where both have sensitivity.

The FOS can be re-programmed to counter the magnetic field shift. The projected B-field can be calculated routinely and the FOS microprocessor can apply the correct deflection current to counter the B-field that gets through the magnetic shield. The deflection current can be changed rapidly enough that more of the geomagnetic drift will be removed. This repair strategy is the preferred solution to the geomagnetic drift.

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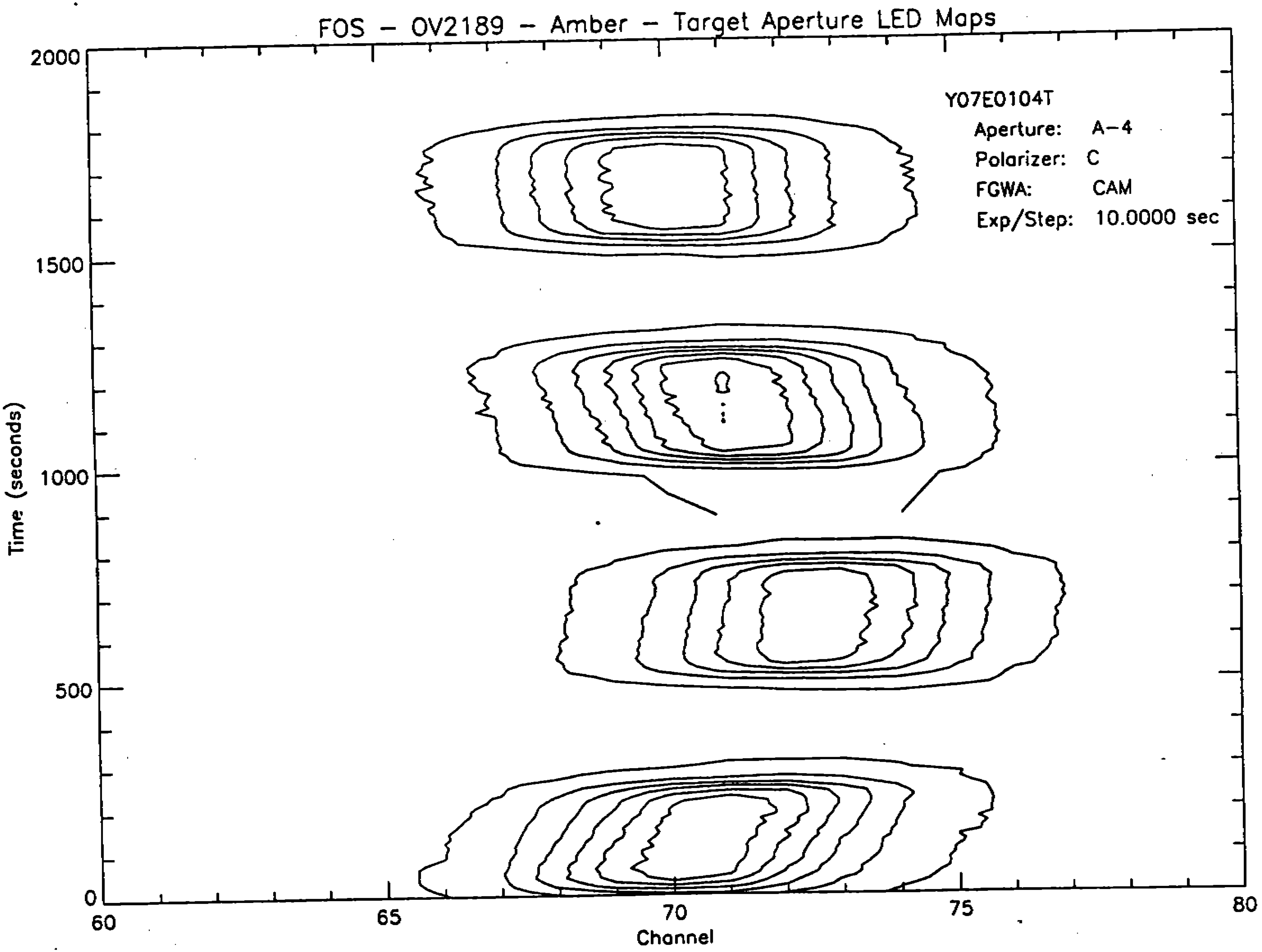

Fig. 1 - Two maps of the A4(2 X 0.1 arcsec square) aperture pair illuminated by the TALEDs. The distorted shape is due to geomagnetic field deflection.

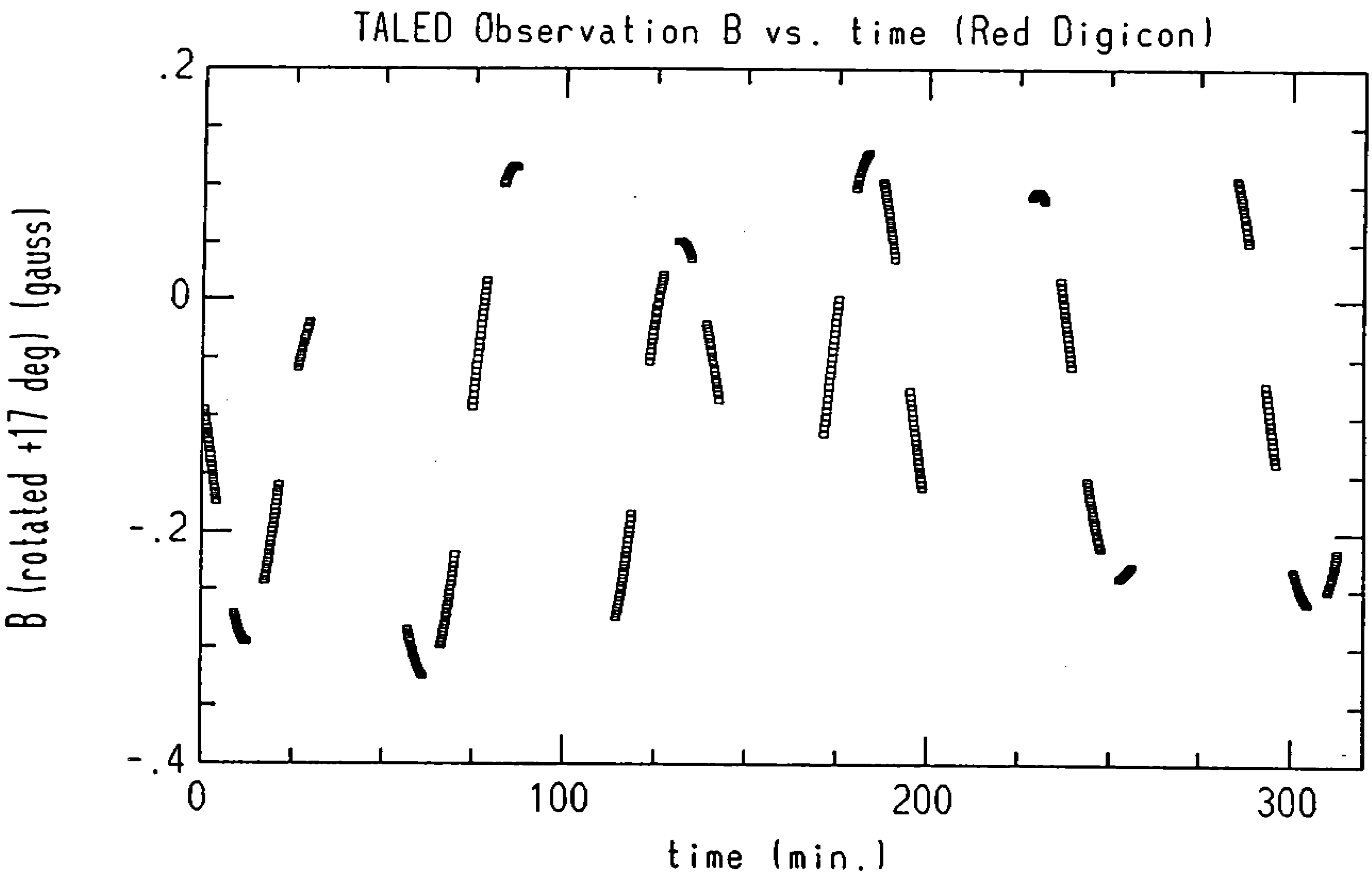

Fig. 2 - The B-field as a function of time during the TALED observations. The B-field component illustrated produces the deflection in the dispersion direction (x).

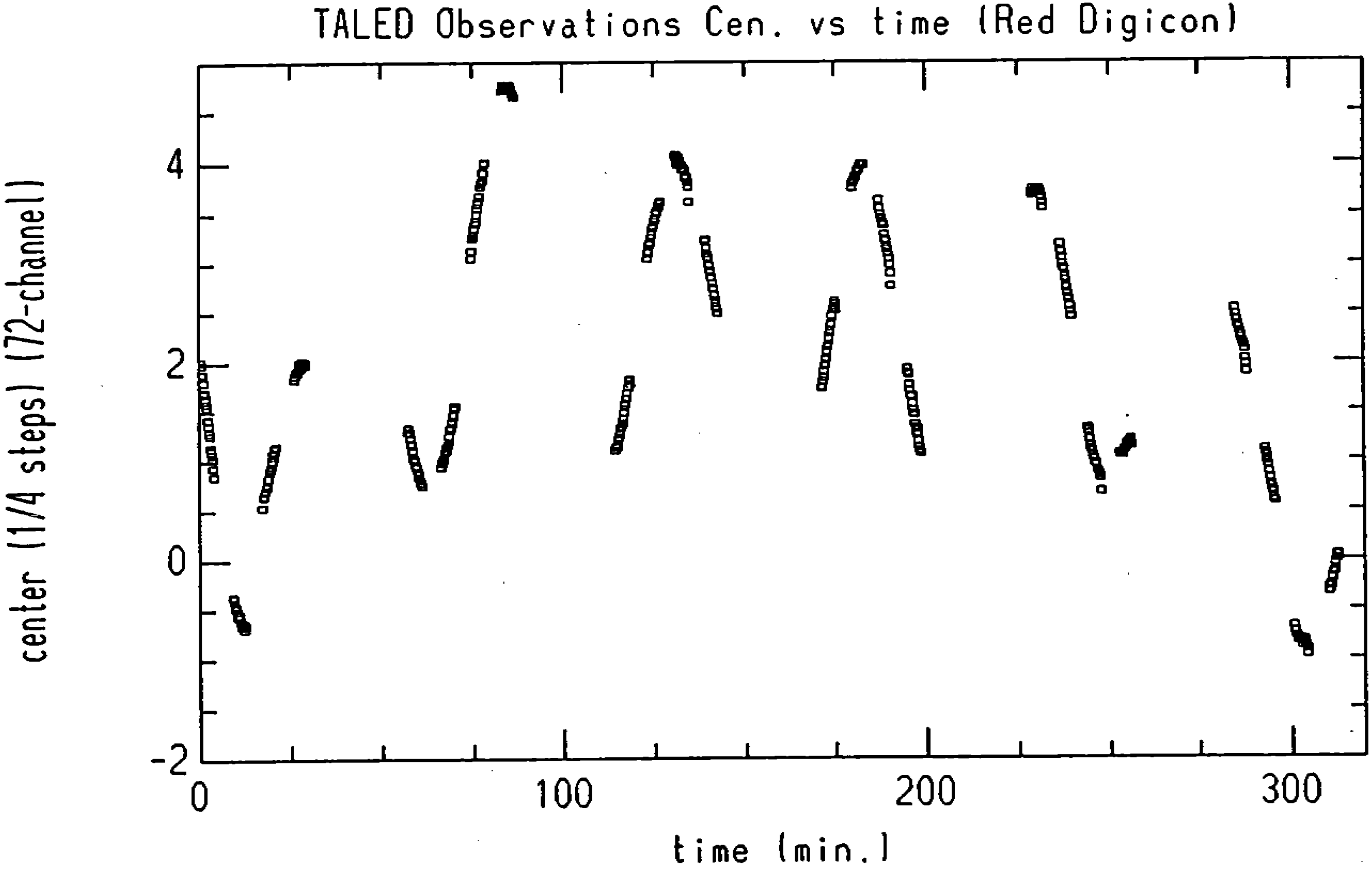

Fig. 3 - The *x* centroid as a function of time during the TALED observations. Note the similarity to the B-field component. The High Voltage was changed and the Filter Grating Wheel was moved in-between the six major sets of data shown.

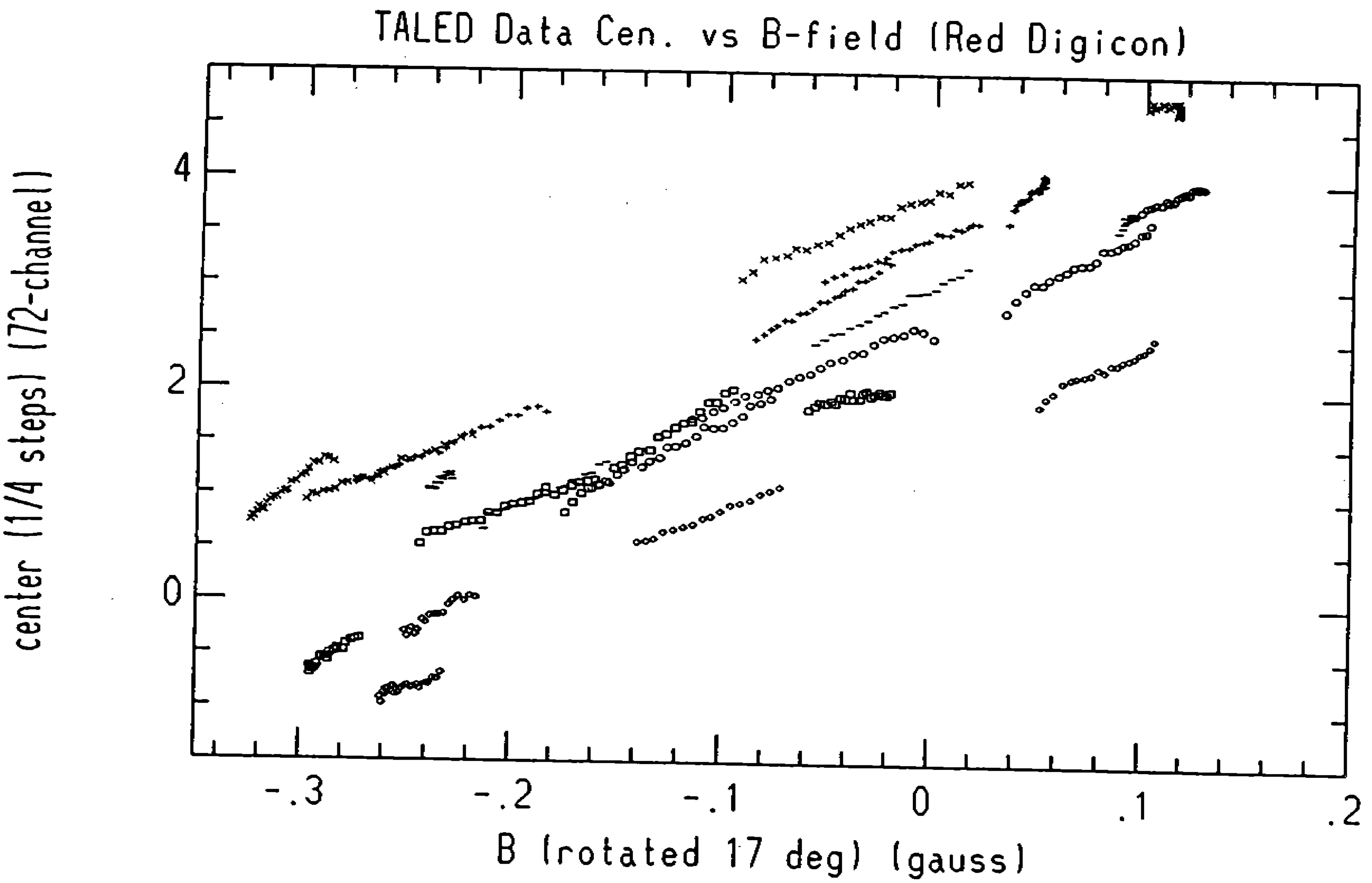

Fig. 4 - TALED data from Figs. 2 and 3 shown as *x* centroid versus B-field. Each of the six major data sets is plotted with a different symbol. The zero point offsets between the six data sets are probably due to a non-repeatability in the filter grating wheel.

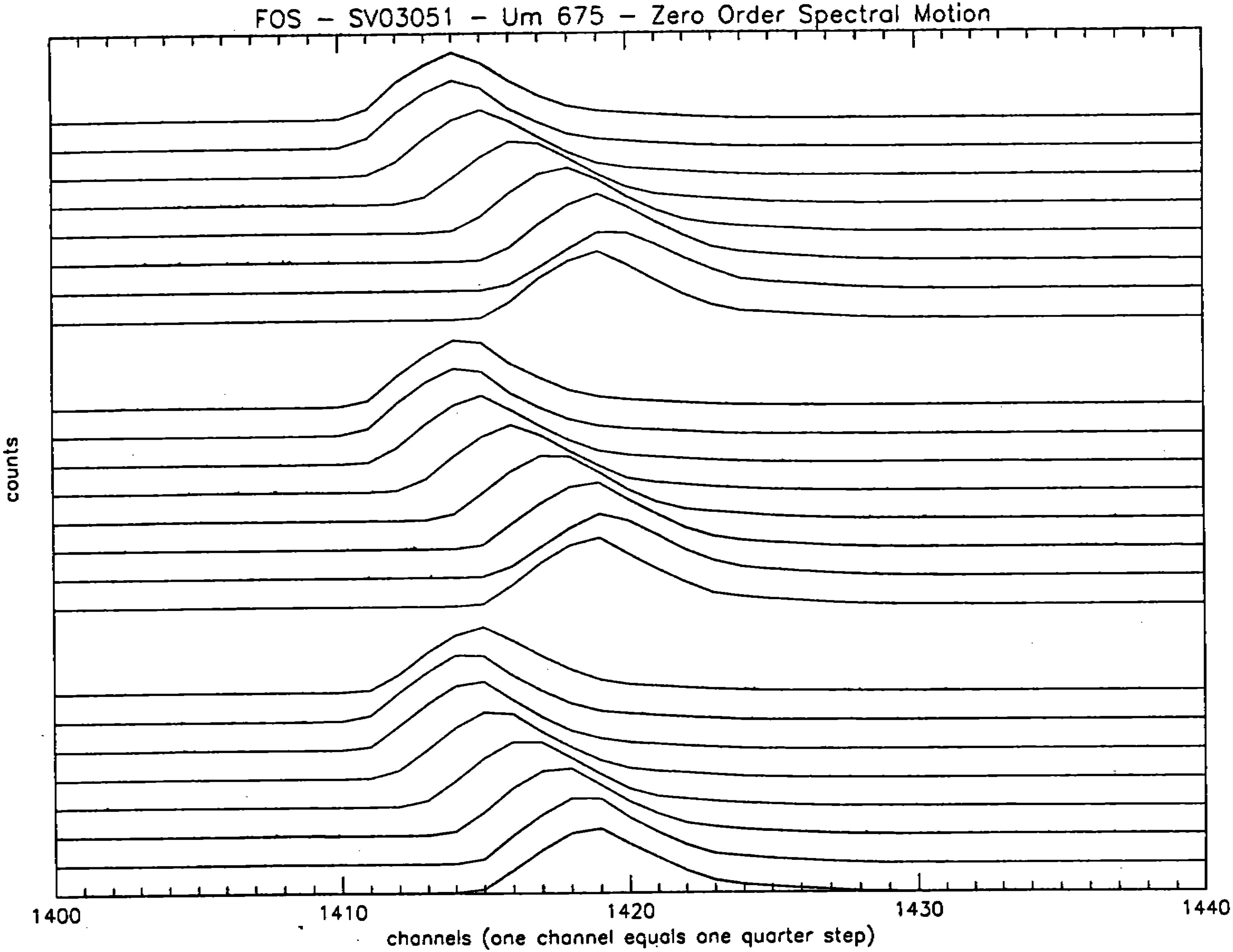

Fig. 5 - The zero order image recorded with the low resolution spectrum of UM 675 (a z = 2.148, V = 1.74 QSO) shows the geomagnetic image defl[illegible]. Each of the three 2000 s integrations was split into 8

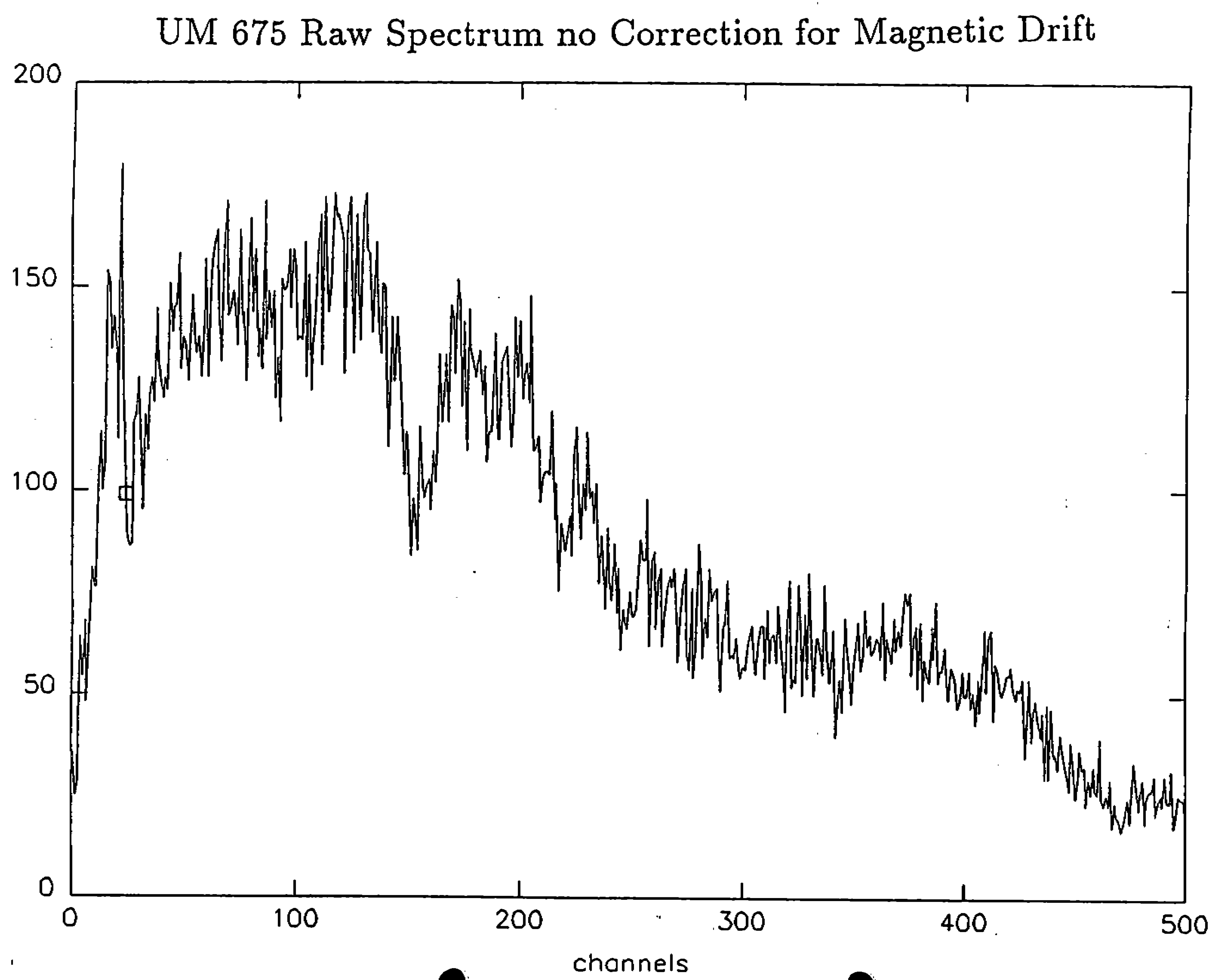

Fig. 7 - The 6000 s raw spectrum of the OS[illegible] 1 675 before shifting and adding to remove the effects

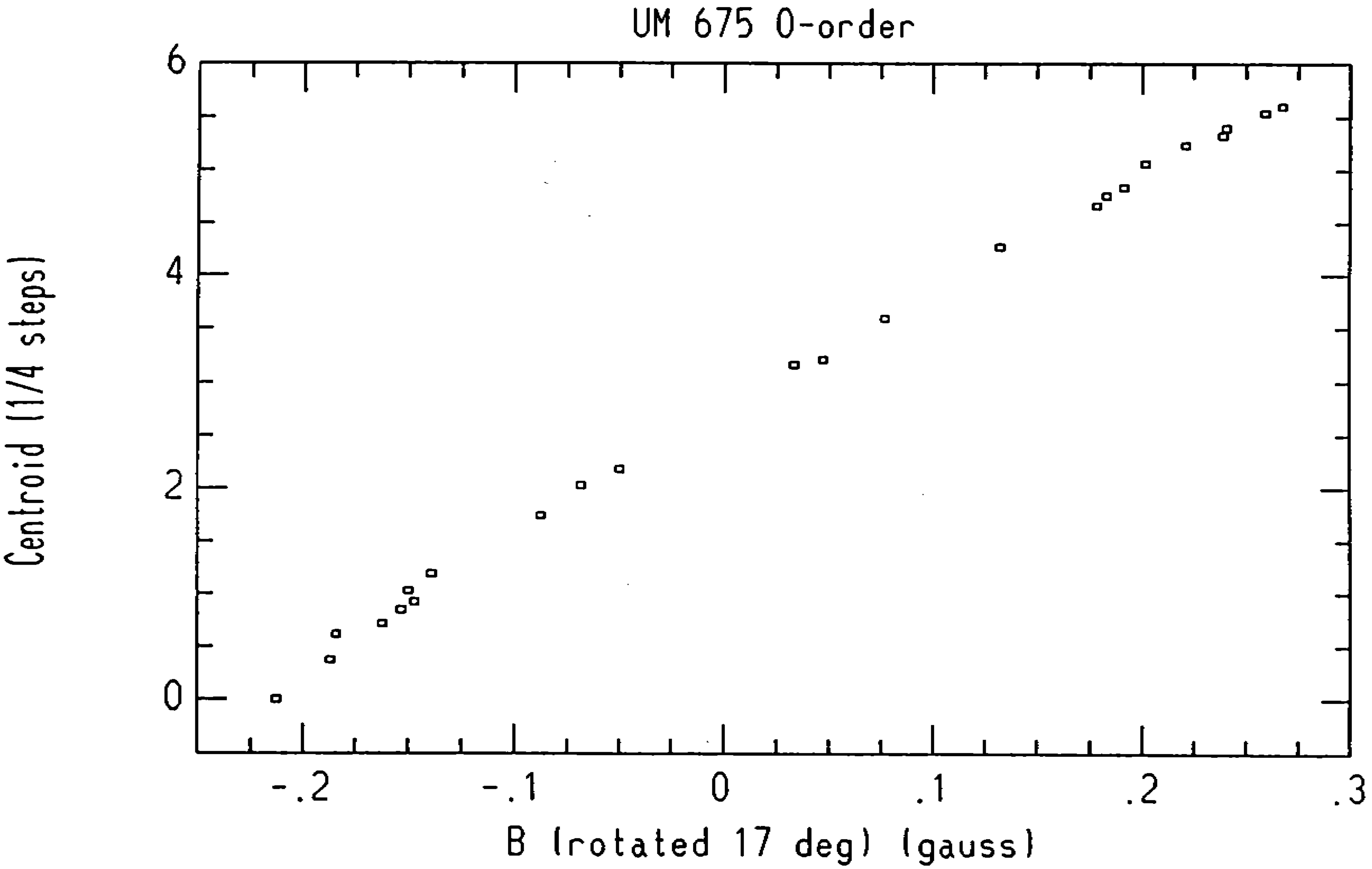

Fig. 6 - The correlation between the centroid of the zero order image for the UM 675 and the B-field. The centroid axis is in 1/4 steps (1420.301 - channel number).

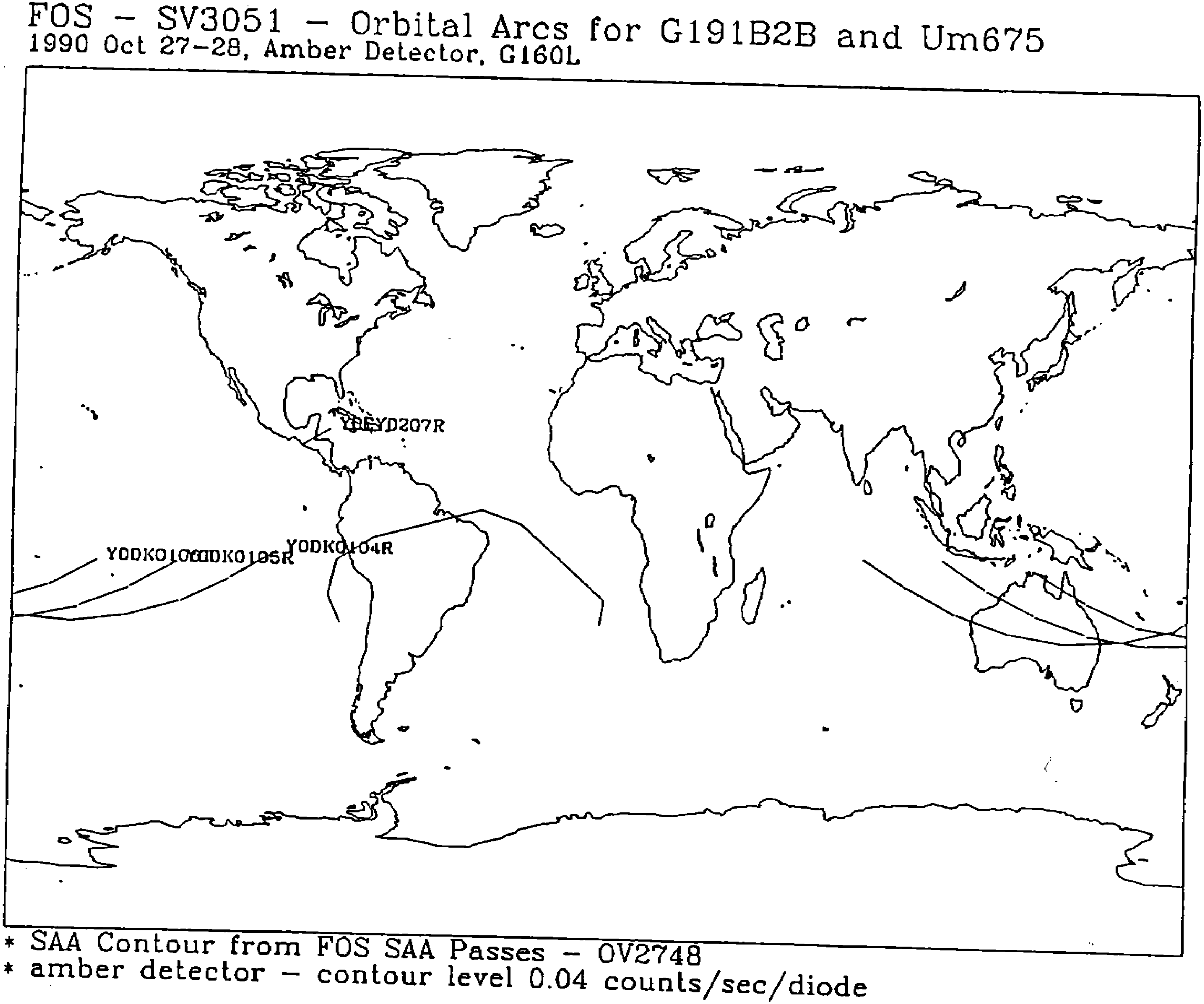

Fig. 9 - The location of the HST during the UM 675 (0150-202) observation. The observation was split into three orbits with 2000 s of integration per orbit.

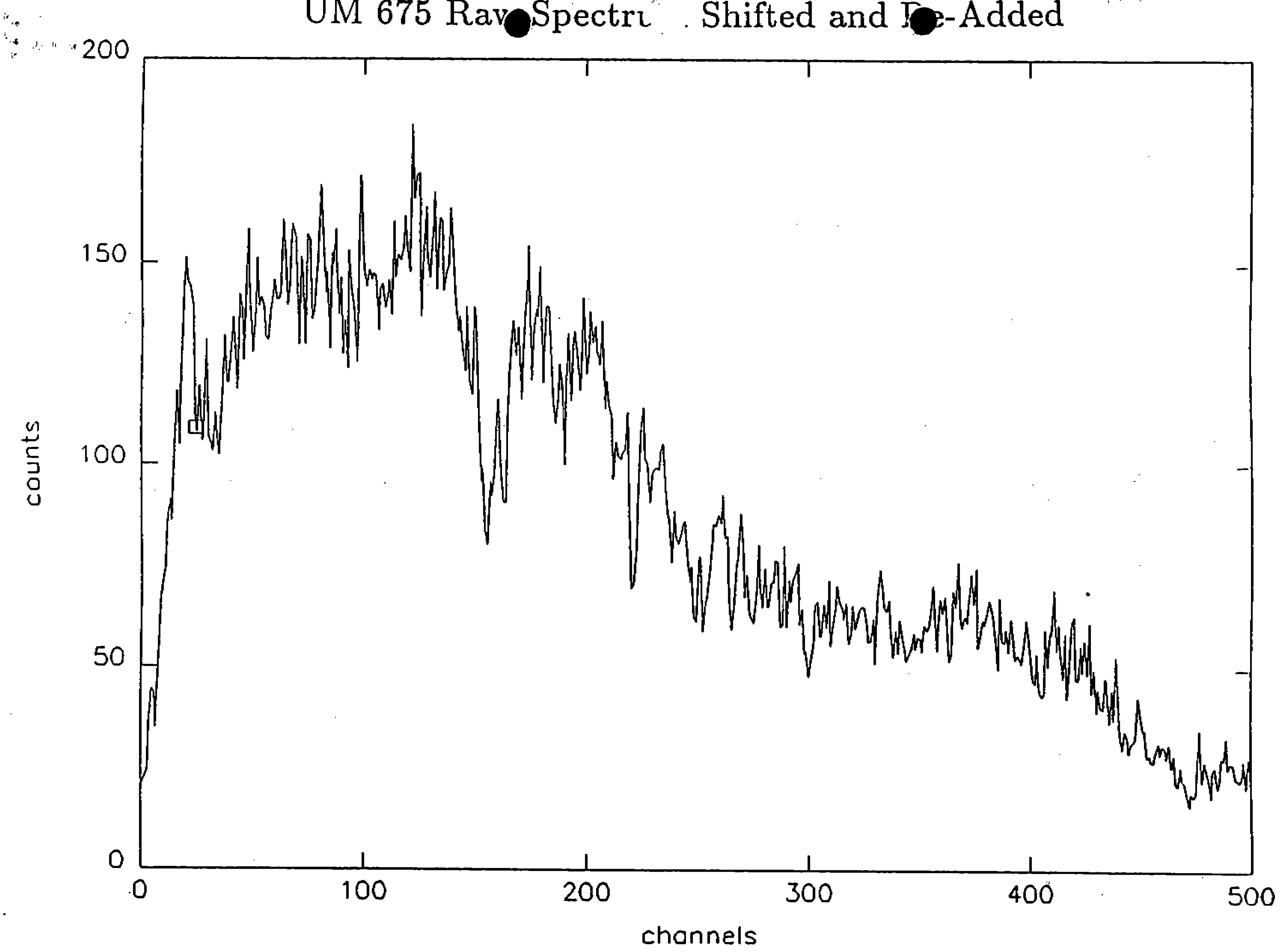

Fig. 8 - The raw spectrum of the QSO UM 675 after shifting and adding to remove the effects of the geomagnetic deflection. The location of the zero order image was used to calculate the shift. Note that re-registration produces some smoothing. Several spectral features are sharper after re-registration.