

PERFORMANCE OF THE FOS AND GHRS Pt(Cr)-Ne HOLLOW-CATHODE LAMPS AFTER THEIR RETURN FROM SPACE AND COMPARISON WITH ARCHIVAL DATA

F. Kerber¹, D. Lindler³, P. Bristow¹, D. Lembke¹, G. Nave², J. Reader², C.J. Sansonetti², S. Heap³, M.R. Rosa¹, H.J. Wood³

¹Space Telescope European Co-ordinating Facility, Garching, Germany; ²National Institute of Standards and Technology, Gaithersburg, MD; ³GSFC, NASA, Greenbelt, MD



The Space Telescope European Co-ordinating Facility (ST-ECF) and National Institute of Standards and Technology (NIST) are collaborating to study hollow cathode calibration lamps as used onboard the Hubble Space Telescope (HST). As part of the STIS Calibration Enhancement (STIS-CE) Project we are trying to improve our understanding of the performance of hollow cathode lamps and the physical processes involved in their long term operation. The original flight lamps from the Faint Object Spectrograph (FOS) and the Goddard High Resolution Spectrograph (GHRS) are the only lamps that have ever been returned to Earth after extended operation in space. We have taken spectra of all four lamps using NIST's 10.7m normal incidence spectrograph and a Fourier transform spectrometer (FTS). Combined with pre-launch spectra during ground testing in 1984 and the extensive collection of spectra obtained during the 6,5 years of orbital operation (Apr 1990 - Jan 1997) we have assembled a 20 year history of the spectral output of these lamps. This constitutes a truly unique data base to study time dependent variations in the lamps.

We have also documented the sensitivity of the lamps' performance to optical alignment in the case of lamps that use a MgF₂ lens as entrance window. Our findings represent important lessons for the choice and design of calibration sources and their operation in future UV and optical spectrographs in space.

INTRODUCTION

The two lamps flown on the GHRS and on the FOS are the only calibration lamps ever returned from space after extended use in orbit. All four lamps had been retired to exhibits at museums. In the case of the GHRS the instrument had been disassembled after return and the lamps were on display at the Fiske Planetarium in Boulder, Colorado. The FOS lamps were still inside the instrument which is on display at the National Air and Space Museum in Washington, DC. Courtesy of the HST project and both museums we were able to obtain all lamps on loan, in the case of the FOS this required us to actually open up the FOS and extract the two lamps in a delicate operation.

LABORATORY WORK

All of the laboratory work was done at NIST. In order to cover the full wavelength range of GHRS and in particular the FOS - 115 to 800nm - we used two different instruments. Since we did not have any documentation on the wiring of the lamps we had to establish the correct polarity by trial and error. After a few attempts all four lamps ignited without problems and demonstrated their reliability 20 years after their first use and after a six-year period of hibernation in a museum.

The lamp current was strictly limited to 10 mA in order to match the operating conditions on the spacecraft and to minimize the risk of altering the properties of this unique hardware. In order to preserve the lifetime of the lamps we did not make an attempt to obtain truly deep exposures.

Far UV

- 10.7m normal-incidence vacuum spectrograph (Reader et al. 1990)
- UV sensitive photographic plates (111.5 to 183nm) exposure times 5.5h (GHRS) and 7h (FOS) at 10mA
- Few hundred lines for both GHRS and FOS

Near UV

- The Fourier Transform Spectrometer (FTS) located at NIST's Synchrotron UV Radiation Facility (SURF).
- 155nm (instrumental cut-off) to about 350 (400)nm using two different photomultiplier detectors and a filter.
- Exposure times 4 to 6h at 10mA: GHRS (Pt-Ne) 700 lines, FOS (Pt/Cr-Ne) 1500 lines
- Figure 1 shows an FTS spectrum and the corresponding section from the GHRS archive. A more detailed analysis showed only very limited variation in spectra taken on orbit and after return.

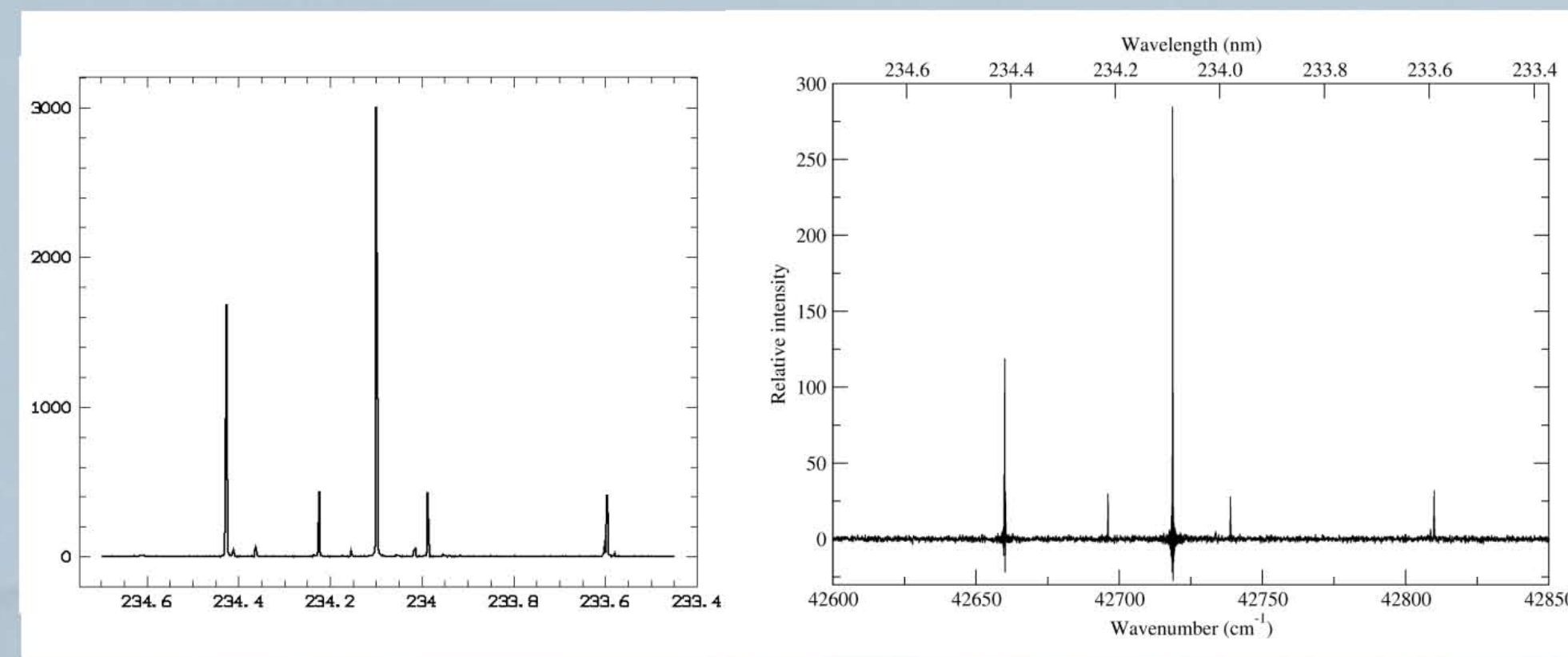


Figure 1: Sample spectrum of GHRS lamp #2. The wavelength range is approximately 233.4 - 234.6nm. The spectrum in the left panel was taken with GHRS during orbital operations in 1994 (mode ECH B). The data was retrieved from the GHRS archive. The right panel FTS spectrum was obtained at NIST in 2003. Line ratios in these spectra are similar for all wavelengths studied.

Analysis of the spectra from different epochs

For the analysis we concentrate on the GHRS spectra because the resolutions of GHRS echelle modes and the FTS are similar facilitating a direct comparison. We have combined spectra from the Instrument Definition Team's pre-launch archive, the orbital archive and the measurements at NIST covering a time base of almost 20 years from 1984 to 2003.

Changes in line intensity ratios:

- Selected regions centered at 185, 263, 315nm (5 - 10nm wide).
- Each band contains more than 15 lines from Ne and Pt.
- Used repeated wavelength calibration for time coverage.
- Each region shows a general intensity decrease over time.
- No significant differences between the individual species have been found.
- This indicates that the conditions in the discharge have not changed noticeably over the years.

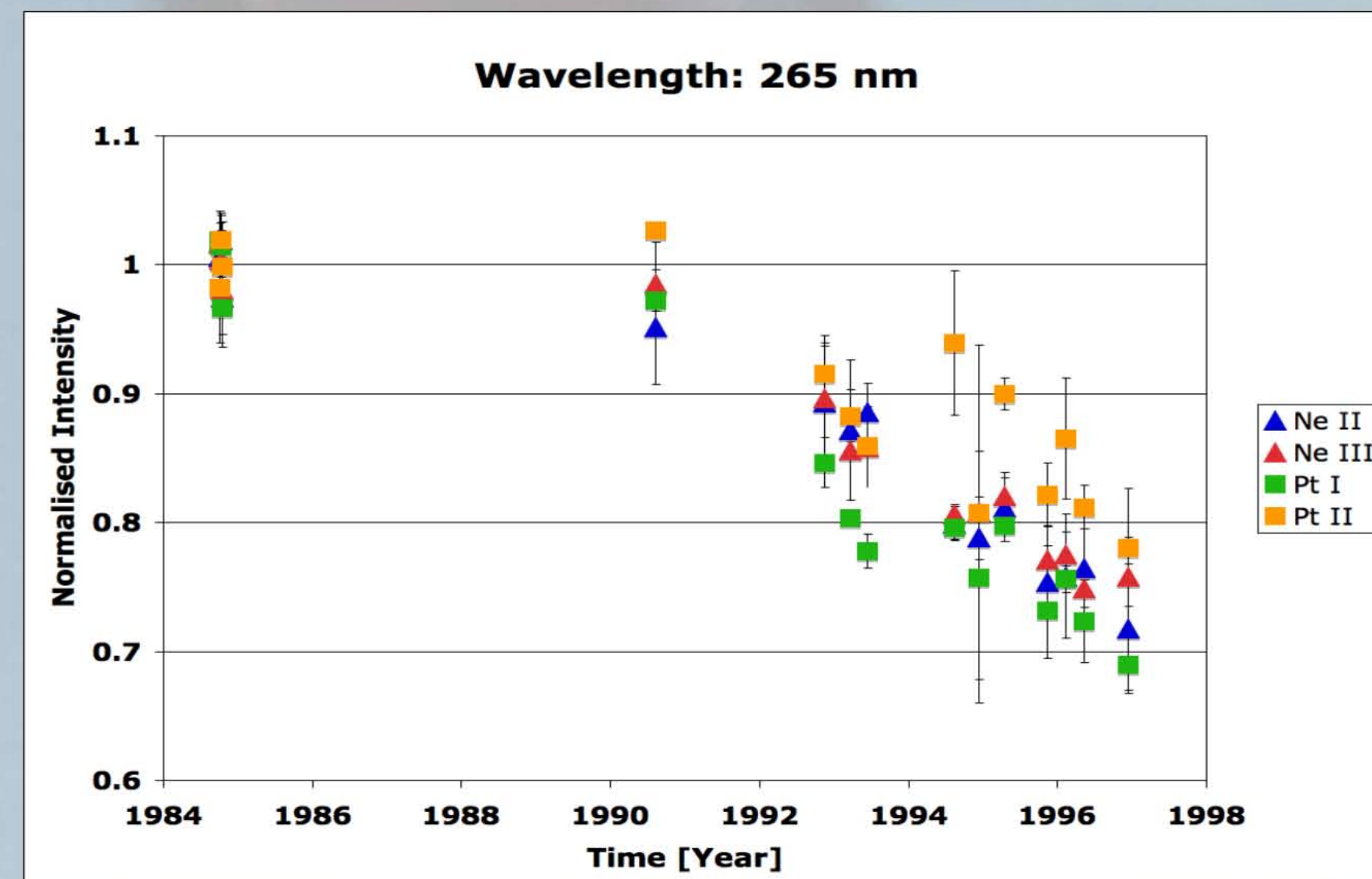


Figure 2: Change of the observed intensities of lines around 265 nm. Lines of a specific element and ionization stage have been normalized to the intensity observed pre-launch and combined into an average for a given epoch.

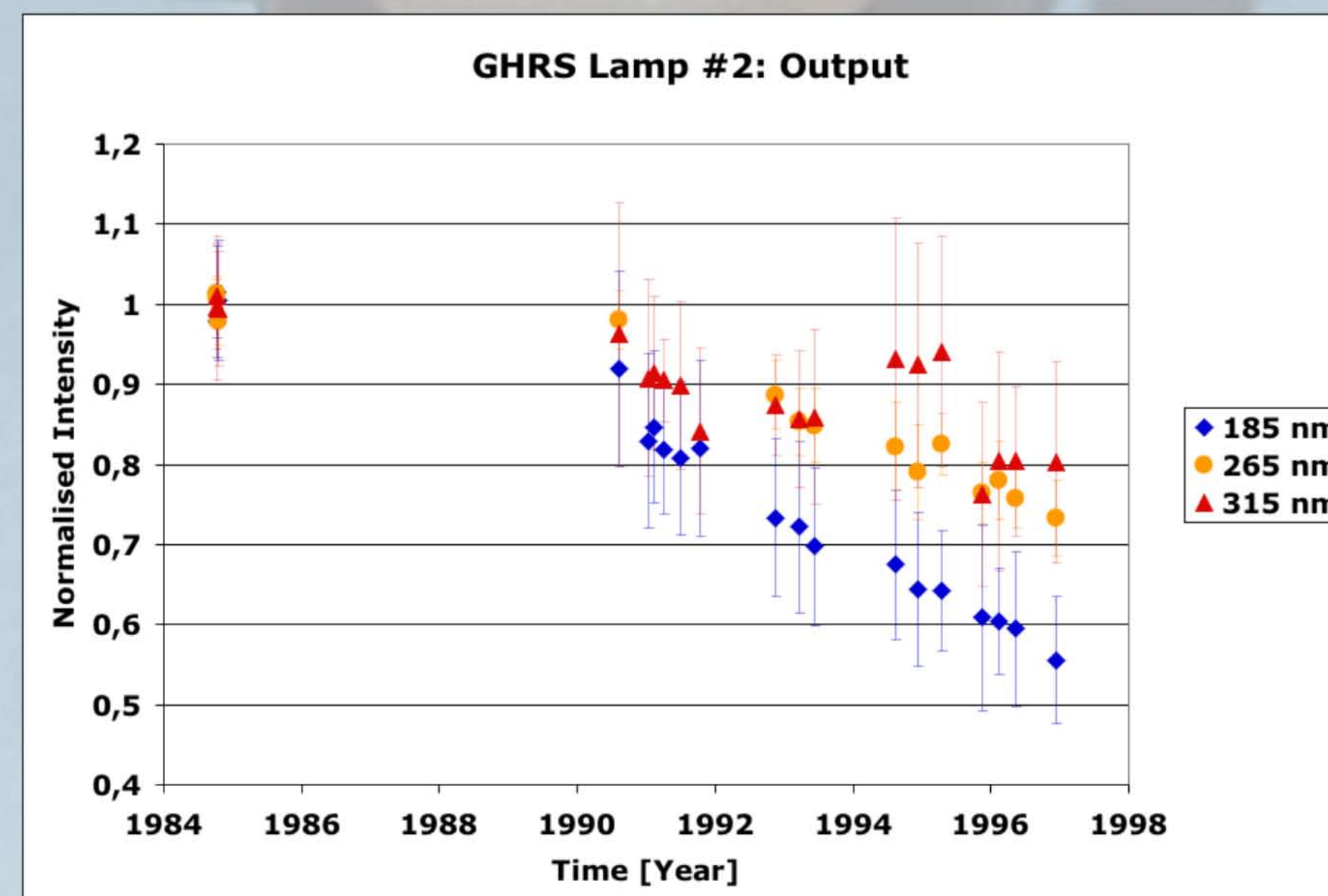


Figure 3: Change of the observed intensities of lines in three selected small (5-10nm) wavelength bands distributed over the GHRS spectral range. Based on the finding that no major differences between elements and ionization stages exist (Fig. 2) we have normalized all lines to the intensity observed pre-launch and combined into an average for a given epoch. The shortest wavelength shows a decrease of 45% in intensity while longer wavelengths show smaller losses.

Change in intensity is wavelength dependent

- 185nm: 45% decrease
- 265nm: 25% decrease
- 315nm: 15% decrease but no single slope
- Accumulated operating time for lamp #1: 10h, for lamp #2: 50h
- In contrast: accelerated aging tests in the lab show limited change after more than 1000h

To further elucidate the situation we made comparisons with other calibration exposures available from the GHRS.

Flat Field Lamp:

- Xe discharge lamp, with major emission at 147nm
- Directly illuminates detector without dispersing or imaging optics
- 15% decrease over 6.5 years at roughly constant rate

External calibration source: Standard star μ Columbae

For flux calibration photometric standard stars were regularly observed. We have compiled a number of observations of μ Col over the complete orbital lifetime of GHRS.

- Flux is constant over time at the 5 - 10% level
- Installation of CoStar introduced change
- CoStar provides highly improved point spread function (PSF) mimising slit losses
- CoStar adds two reflective surfaces to the optical path
- These two effects have different relative importance at different wavelengths
- CoStar results in net losses at short and net gains at longer wavelength (Fig. 4)

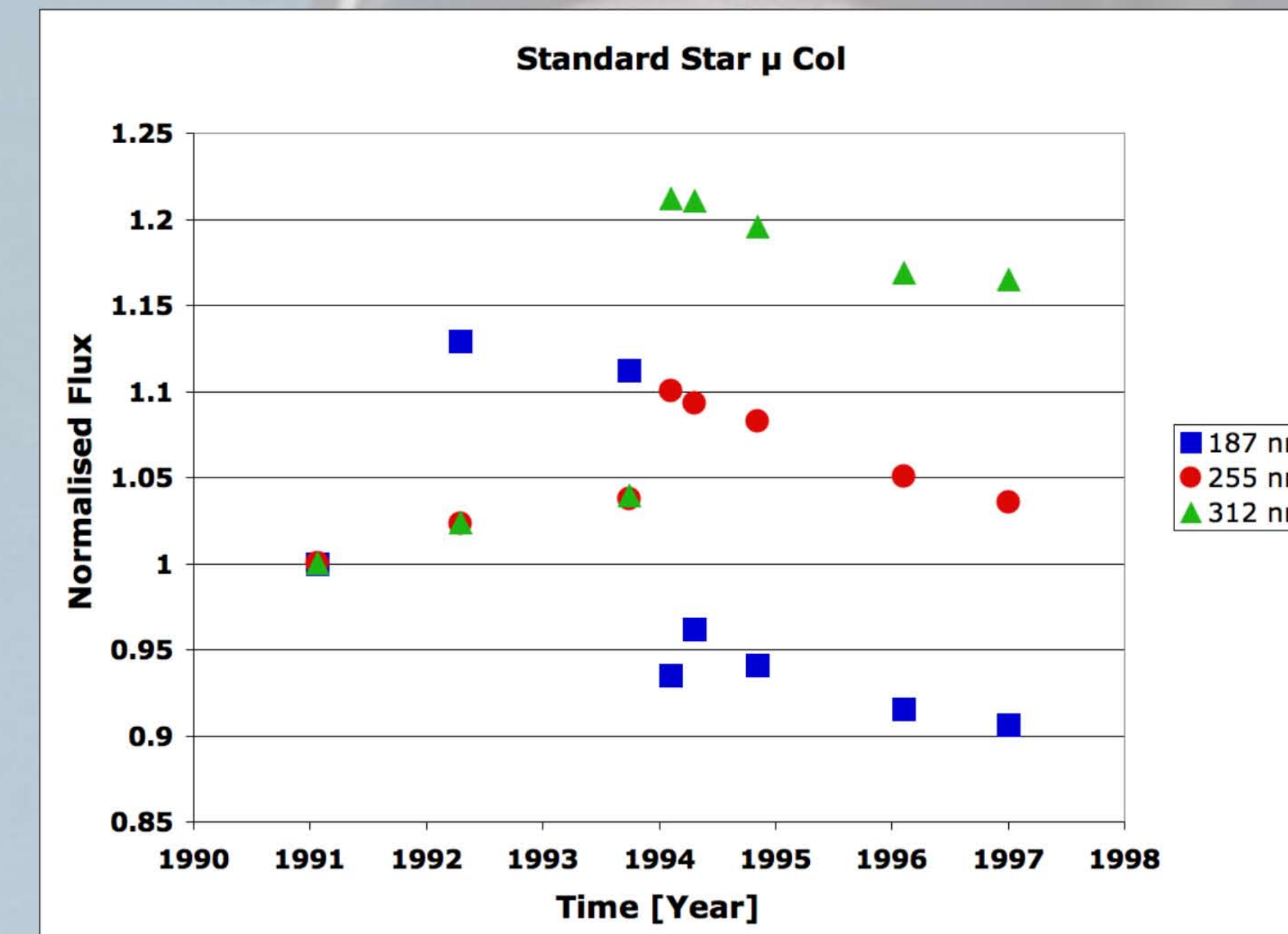


Figure 4: Observations of the standard star μ Col during GHRS orbital operations. Three wavelengths closely corresponding to the wavelength bands observed with the spectral lamps (Fig. 3) have been plotted. Except for a step introduced by the addition of CoStar (details in the text) the fluxes show no more than a 5% variation over time.

GHRS optical layout and interpretation of the observed behaviour of the lamps:

- External source (standard star) stable to about 5% over 6.5 years
- Flat field lamps (147nm) -15% decrease in intensity
- Conditions in discharge of Pt-Ne calibration lamps are stable
- Light from calibration lamps undergoes two reflections before entering slit
- Observed wavelength dependent loss of 15- 45% probably caused by optical elements or lamp's window

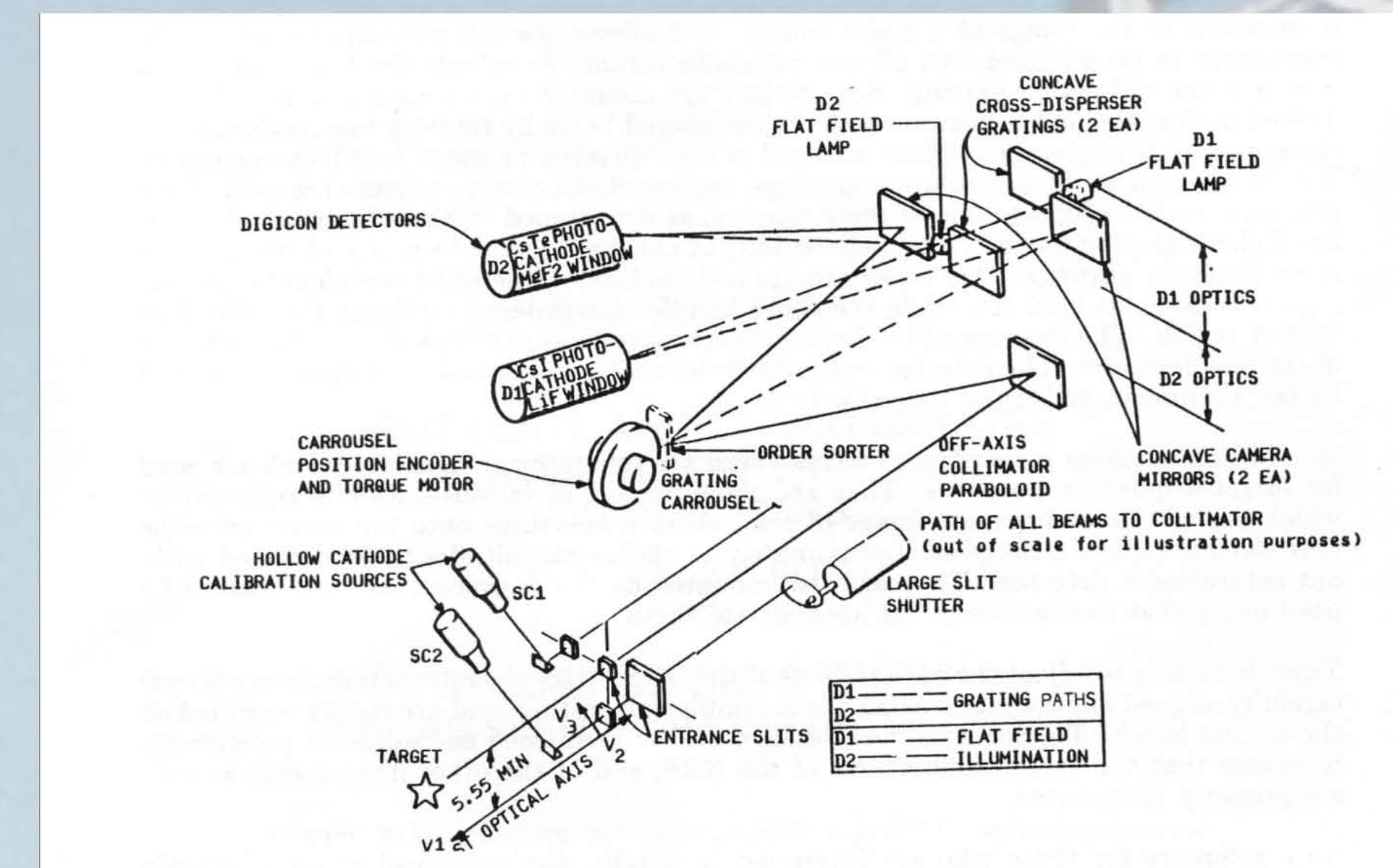


Figure 5: Schematic drawing of the GHRS optical system.

Alignment for UV calibration lamps with a MgF₂ lens:

- MgF₂ window for transmission down to 115nm
- Mg F₂ has wavelength dependent index of refraction that strongly increases below 150nm
- Singlet lens to focus light on slit introduces sensitivity to alignment
- Alignment in the UV is required in order to obtain good spectra (Fig. 6)
- Improper alignment can result in loss of factor ten or more at wavelength below 150nm
- FOS blue side lamp was not well aligned rendering the calibration spectra useless below about 135nm.

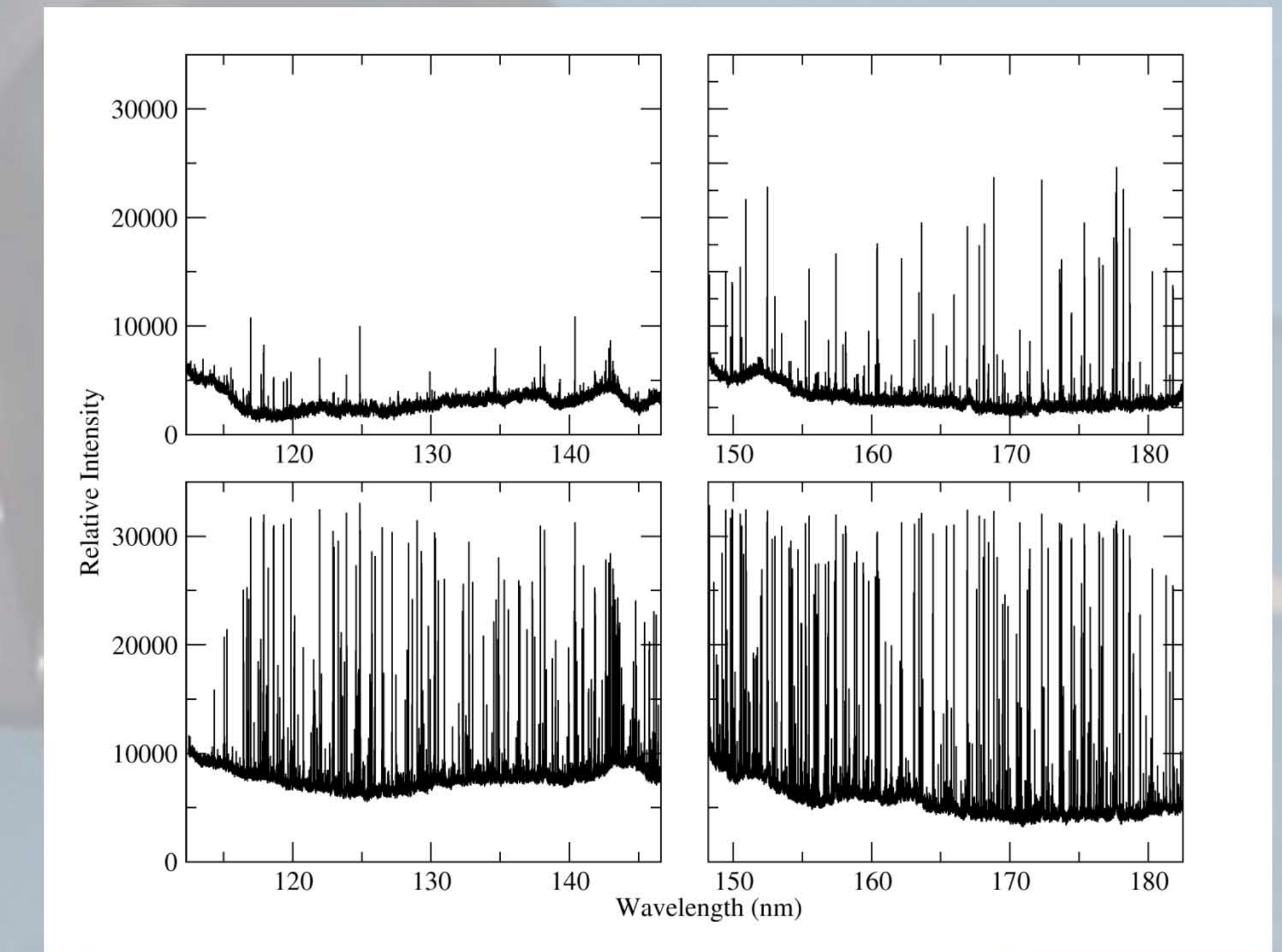


Figure 6: The spectrum of a FOS lamp after alignment in the visible (upper panel) and after alignment in the UV (lower panel). The dramatic increase in the line intensity at shorter wavelengths illustrates the strong sensitivity to alignment that results from use of a single element MgF₂ lens.

Summary:

- We have assembled a unique data set spanning a period of 20 years consisting of spectra taken before launch, during operations in orbit and after return of the four GHRS and FOS lamps.
- The lamps still work perfectly after 20 years and the conditions in the discharge seem to be rather constant in time confirming that hollow cathode lamps are very reliable and stable sources for wavelength calibration.
- This stability is confirmed by accelerated aging test of lamps similar to GHRS, FOS and STIS with operating times well in excess of 1000h, see Fig 3 in poster #
- The data show some change in the intensities as observed over time. Careful analysis suggests that these can be attributed to optical components in the light path, specifically two reflective prisms or possibly the lamps' window.
- Hollow cathodes have been previously suggested as secondary radiometric standards for monitoring of such changes in the optical path, further investigations to this end are recommended.
- MgF₂ singlet windows introduce chromatic alignment sensitivity that can lead to severe light loss if the lamps are not properly aligned. Proper procedures for alignment in the UV are essential.

Good pre-launch calibration is essential, but when in doubt...



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