



MULTIPLE MIRROR TELESCOPE OBSERVATORY

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MMT Technical Memorandum 85-4

Subject: Progress Report on Using Etalons for Wavelength Calibration

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INTRODUCTION: The installation of the New Top Box with its comparison lamp illumination scheme has provided us with the flexibility needed to experiment with alternative sources for wavelength and flatfield calibrations. Unfortunately, the wide field of the illumination has caused the projected surface brightness of the Thorium-Argon (Th-Ar) lamp to decrease by a factor of 2.5 from the only-adequate level in the old top box. In an attempt both to alleviate this problem and to provide a better wavelength-calibration source, we are experimenting with using the Edser-Butler bands produced when parallel plates (Etalon) are illuminated with collimated white light as wavelength calibration features. These experiments were begun in the Winter of 1984-5, were not productive until the New Top Box was installed. The purpose of this memo is to report on some recent experiments which we believe demonstrate the promise of using etalons for wavelength calibration.

BASIC DEFINITIONS: For the purpose of this discussion, we consider an etalon to be composed of two flat, partially transmitting mirrors which are parallel to each other. In the case considered here we use an etalon from one of the PEPSIOS triplets (generously loaned to us by Dr. N. Carleton). The etalon is composed of two plates separated by air. Each plate has a partially-transmitting coating on one surface and an anti-reflection coating on its other surface. The latter surface is slightly wedged with respect to the former to avoid forming additional cavities.

When the cavity formed by the two partially-transmitting surfaces is illuminated with a beam of coherent monochromatic light, it will transmit the beam when the optical path length between the surfaces is such that constructive interference occurs. Conversely, illumination with parallel white light produces an output spectrum of fringes with near-constant spacing (the so-called Edser-Butler bands). The condition for constructive interference for a transmitted wavefront is:

$$2nd \cos\theta = m\lambda \quad (1)$$

where:

- n = the refractive index of the medium between the reflecting surfaces,
- d = the spacing between the reflective surfaces,

θ = the angle between the normal to the mirrors and the direction of the incoming radiation,
 m = the order of interference, and
 λ = the wavelength of the light.

From this condition, the free spectral range or fringe separation follows as:

$$\Delta\lambda_{\text{FSR}} = \lambda^2 / 2nd \quad (2)$$

Finally, we define the finesse, F :

$$F = \Delta\lambda_{\text{FSR}} / \Delta\lambda_{\text{BW}} \quad (3)$$

where $\Delta\lambda_{\text{BW}}$ is the FWHM of the fringe.

OPTICAL CONFIGURATION: The etalon and collimated light source are located in the NEMA box on the east wall of the second level instrument lab. This box contains the other comparison sources (with the exception of the Th-Ar and He-Ar lamps) and the termination of the fiber optic feeds to the integrating sphere in the New Top Box.

The filament of a GE type 789 halogen lamp was imaged onto 600 micron pinhole with a 1 inch $f/4$ lens. The light passing through the pinhole was collimated by another $f/4$ 1 inch lens. After passing through the etalon, the light was re-imaged onto the 600 micron end of the fiber with an $f/2$ 1 inch lens.

The parallelism of the etalon plates was established by illuminating them from below with diffuse light from a mercury vapor discharge tube. The adjustable point supports of the etalon were adjusted until the resulting circular fringes remained constant independent of viewing angle. This procedure is difficult to describe but is simple and self-evident in practice.

The alignment of the plates and the parallelism of the collimated beam (resulting from the finite size of the pinhole) were not critical as the maximum achievable finesse was limited by our selection of etalon separation and the instrumental profile of the echelle spectrograph to ≤ 10 .

OBSERVATIONS: The observations reported here were obtained with the MMT Echelle Spectrograph on June 10, 1985. The detector used was the Photon-Counting Reticon mounted on the Old Blue image tube package. The blue cross-disperser (600 gpm) was used. The echelle was set up at a central wavelength of approximately 5180 Å in 109th order for the purpose of the evaluation of the efficacy of the wavelength calibration derived from an etalon integration.

Additional exposures bearing on the minimum wavelength at which the existing etalons can be used were also performed. Briefly, the results of these tests can be summarized by saying that the coatings on the current etalon plates are adequate for wavelengths longward of about 4500 Å. Shortward of about 4000 Å, the etalons are probably useless due to poor finesse resulting from the degraded reflectivity of the PEPSIOS etalon surfaces.

Two integrations were needed to perform a wavelength calibration. Figure 1 presents a plot of a 15 minute integration obtained through the etalon. The mean line width of the fringes is 7.2 pixels, comparable to those of unblended comparison lines implying that the finesse of the etalon is sufficiently high that the fringes are unresolved by the spectrograph. Figure 2 presents a 6 minute Th-Ar exposure obtained immediately before the etalon integration. Both observations were made with no filters in the Top Box though an open pupil mask.

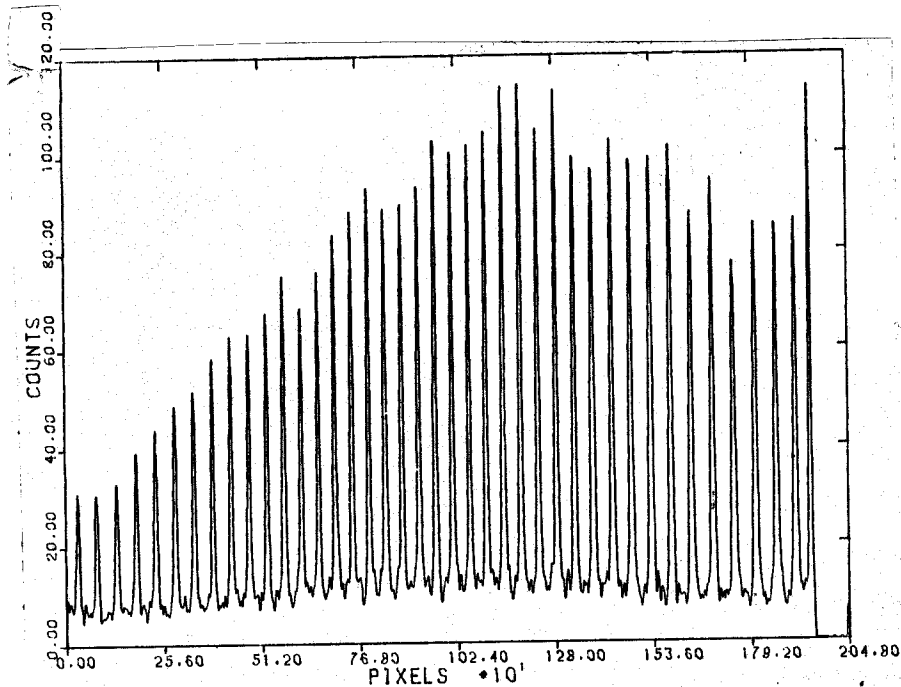


Figure 1. Spectrum of the fringes produced by illuminating the etalon with collimated white light.

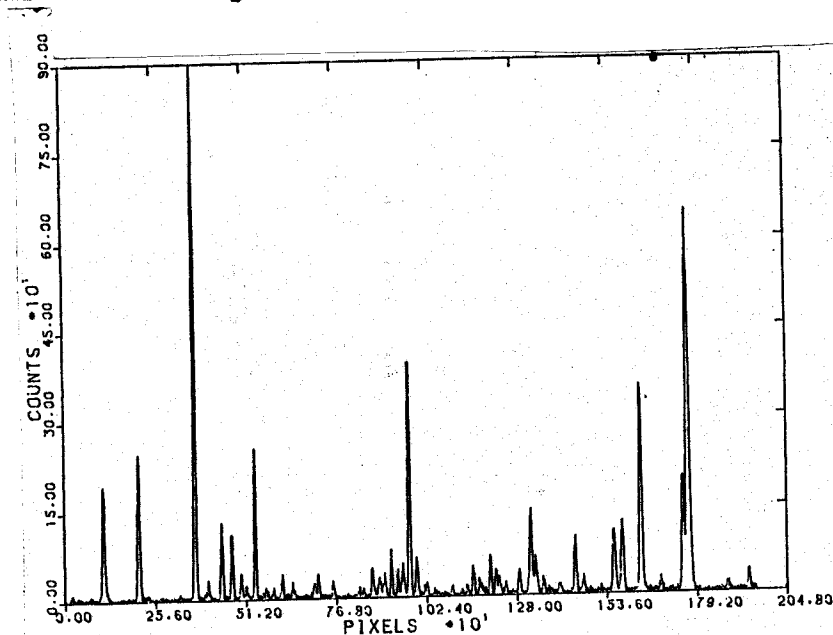


Figure 2. Th-Ar exposure in 109th order of the echelle.

ANALYSIS PROCEDURE: In order to evaluate the quality of wavelength solutions provided by the etalons, these data were reduced using both IRS and the SAO reduction software. Both systems use polynomials to approximate the relation between pixels and wavelength, though the conventions used in naming the pixels and specifying where a pixel begins are different between the two systems. The game plan in wavelength calibration, of course, is to determine the polynomial coefficients by some appropriate means. Typically 5th to 7th order polynomials are used. Calibration by means of an etalon exposure requires that two additional parameters be determined: m , the order of an arbitrarily chosen fringe, and $2nd \cos\theta$, twice the effective plate spacing.

The determination of these parameters could be carried out simultaneously by a suitable least-squares technique. In these tests, however, we chose not to develop new software routines but rather to avail ourselves of existing routines, and our analysis procedure is described below.

The first fringe visible at the short wavelength end of the scan was denoted order m . The direction of increasing λ corresponds to decreasing order numbers. Four strong Th-Ar lines were selected as wavelength fiducials. The fractional fringe of these lines relative to fringe m , Δm , was calculated by interpolating between the fringes which bracket each line. The information so-derived is presented in Table 1 below. Two of these lines were used to calculate the value of m by noting that $\lambda_1(m - \Delta m_1) = \lambda_2(m - \Delta m_2)$. Since m must be an integer, the nearest integral value of m so-calculated was then used. In this case, $m = 3806$.

Each Th-Ar line then gives an estimate of the product $2nd \cos\theta$. These estimates are subject to the accuracy with which the interpolation of Δm can be performed. Therefore, a value was calculated for each of the four lines and the arithmetic mean of these estimates was used. These are presented in Table 1.

Table 1.
Th-Ar Lines Used in Analysis

Wavelength	Pixel (IRS convention [*])	Δm	$2nd \cos\theta$
5154.24	209.17	-3.4927622	1.9599034 mm
5176.96	976.23	-20.1788321	1.9599044
5195.81	1633.67	-33.9140449	1.9599041
5199.16	1768.51	-36.3478339	1.9599025

mean = 1.9599036 mm

* The first pixel is called pixel 1 (not pixel 0), the pixels begin at their leading edge.

With these estimates of m and $2nd \cos\theta$, we can then use equation (1) to find the wavelengths of all of the fringes, use these to construct a wavelength table or catalog and proceed with the wavelength calibration in the normal way, and apply these solutions to the Th-Ar exposure to evaluate our performance.

RESULTS: As noted above, the analysis was conducted using existing software in both IRS and the SAO reduction routines. The data were Hanning smoothed three times before the fits were performed. Experimentation with the smoothing showed that this did not increase the line widths significantly and resulted in an improvement in the residuals of about 10% with respect to fits performed on unsmoothed data.

The results are summarized in Table 2 wherein we present the residuals in pixels and Angstroms, σ_p and σ_λ ; the minimum and maximum pixels and wavelengths; and the maximum unfit region in pixels and Angstroms, Δp_{max} and $\Delta \lambda_{max}$. In addition we present the results of a fit to the Th-Ar exposure using only the SAO software.

Table 2.
Results of Wavelength Calibrations

A. IRS Results								
Order of Fit	σ_λ	σ_p	P_{min}	P_{max}	λ_{min}	λ_{max}	$\Delta\lambda_{max}$	Δp_{max}
All 40 fringes:								
5th	0.0196	0.42	30.67	1909.81	5149.51	5202.82	1.38	52.46
7th	0.0122	0.67	30.67	1909.81	5149.51	5202.82	1.38	52.46
Center 38 fringes:								
5th	0.0104	0.36	80.12	1860.11	5150.86	5201.44	1.38	52.46
7th	0.0091	0.31	80.12	1860.11	5150.86	5201.44	1.38	52.46
B. SAO Results								
Order of Fit	σ_λ	σ_p	P_{min}	P_{max}	λ_{min}	λ_{max}	$\Delta\lambda_{max}$	Δp_{max}
Center 38 fringes:								
5th	0.01	0.55	79.36	1859.52	5150.86	5201.44	1.38	52.46
Solution using 26 Th-Ar lines:								
5th	0.01	0.43	108.10	1767.07	5151.61	5199.16	4.4	160.4

As is seen from Table 2, the residuals to the fits are of order 0.40 pixels ($<.01 \text{ \AA}$). In the SAO reductions, the wavelengths in the tables are specified only to two decimal places and in IRS the wavelengths are read from the catalog as single precision numbers. Furthermore, the uncertainty in finding the centers of the fringes is about 0.5 pixels. These two factors lead us to believe that the limit to the accuracy of the solutions in both cases is of order 0.01 \AA .

To test for the presence of systematic problems, we subsequently applied the solutions derived from fits to the fringe positions to the Th-Ar exposure and determined the wavelengths of the Th-Ar lines. The rms differences between the measured positions and the catalog positions were less than or of order 0.01 Å for both reduction systems.

We point out one of the obvious advantages of using the etalon fringes as wavelength references. The size of the largest unfit region is small regardless of the wavelength at which one is observing and fringes are available over virtually the entire sensitive length of the detector.

PROSPECTS FOR THE FUTURE: It is our preliminary conclusion that since the solution determined from the uniformly spaced lines of the etalon is indistinguishable from that determined from a superbly exposed Th-Ar spectrum and since the etalon fringes are nearly uniformly spaced, independent of the wavelength region under investigation, that the use of etalons for wavelength calibration of the MMT Echelle Spectrograph is extremely promising. Those aspects yet to be pursued include:

1. Thermal and Mechanical Stability. The calibration procedure applied here makes no assumption about the long-term stability of the etalon as the Th-Ar and etalon integration were performed nearly simultaneously. Such stability is not required if two reasonably spaced comparison lines are measurable from a Th-Ar exposure made contiguously with the etalon exposure. If, however, only one such line is available or if the etalon fringes alone are used to provide wavelength calibration, such stability must be understood. We have not yet begun to investigate this question. We expect that it will be possible, if desired, to isolate the etalon from vibration and thermal changes.

2. Illumination Level. We need to investigate alternative illumination schemes which will provide more light without degrading the finesse of the etalon to an intolerable level. The current illumination scheme and choice of etalons is adequate for the MMT Spectrograph with echellette grating in the 8th through 12th orders. This is due to the fact that the fringes are only half as wide as they are for the echelle and the fact that the spectrograph is a factor of 2-3 faster in achieving a given number of counts per Å. However, we could use an increase in the illumination level by roughly a factor of five for use with the echelle.

3. UV and Blue Response. The coatings on the PEPSIOS etalons are inadequate shortward of about 4500 Å. We need to investigate new coatings for use in the blue and UV for use with the MMT Spectrograph and the Multi-line readout.

4. Custom Etalons. The current selection of etalons have spacings which are too wide for use at spectral resolution less than about 40 km/sec. We would need etalons with narrower spacing for use with MMT Spectrograph or FOGS at low resolution.