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The FAST Spectrograph for the Tillinghast Telescope

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ABSTRACT. We describe a high-throughput optical spectrograph that has been in operation at the Cassegrain focus of the 1.5-m Tillinghast reflector since 1994 January. FAST has a 3′-long slit and is typically operated at resolutions between 1 and 6 Å. With a collimated beam diameter of ∼100 mm, FAST (with a 300 lines mm^{-1} grating and a 1″.5-wide slit) offers 4000 Å of spectral coverage at 3 Å resolution. FAST's optics are primarily reflective, are adequately sized to prevent vignetting, and use high-performance coatings. The high measured system peak efficiency of 26% (fraction of light incident on the primary detected at the CCD) demonstrates that the throughput of reflective optics can be quite competitive with that of refractive optics. FAST's structure is constructed from graphite-epoxy composite panels, which have an excellent stiffness-to-weight ratio and low thermal expansion, resulting in low flexure and excellent focus stability.

1. INTRODUCTION

The 1.5-m Tillinghast reflector has enjoyed a scientific productivity that belies its modest size. This productivity has been made possible by focused scientific goals: from 1978 to 1993 the telescope was devoted almost exclusively in dark time to the CfA Redshift Survey and in bright time to stellar radial velocity studies. In dark time, FAST's predecessor, the Z-machine spectrograph, collected approximately 25,000 spectra in its 15 years of life, principally of galaxies with $B < 15.5$ mag.

The Z-machine was created by mounting image-intensified Reticon detectors in place of photographic plates on an existing spectrograph (Latham 1982). Upgrading the Z-machine to use a CCD detector was discussed prior to designing FAST, but the throughput of the Z-machine optics is severely compromised by its inefficient Schmidt-Cassegrain camera design. We decided therefore to design a completely new spectrograph.

Our name for the new spectrograph, FAST, is an acronym for FAst Spectrograph for the Tillinghast Telescope. We believe that FAST has met the expectations raised by its name; currently FAST is acquiring ∼10,000 spectra per year of objects that are typically 1 mag fainter than were accessible with the Z-machine. Redshift surveys are proceeding faster than before, and FAST has attracted many additional observers to the Tillinghast by offering more extended spectral response, 15–20 times higher throughput, greater photometric accuracy, and greater versatility than the Z-machine. Figure 1 is a diagram of FAST with its access panel removed.

2. SCIENTIFIC OBJECTIVES FOR FAST

Given the strong scientific interest in extending the CfA redshift survey, we knew that FAST would be called upon to obtain spectra of large numbers of relatively bright ($R < 16$) galaxies at low redshift for surveys of the structure of the nearby universe. This meant that FAST would need to maintain ∼6–8 Å resolution with a fairly wide slit (∼3″) in order to obtain accurate redshifts while collecting as much light as possible. Efficient redshift surveys also require broad spectral coverage, extending from below [O II] at 3727 Å in the blue to redshifted ($z = 0.15$) Hα at ∼7600 Å in the red. This is about the maximum coverage possible in a single spectral order. A CCD detector allows us to include a long slit, which enables better sky subtraction and more efficient light collection from nearby galaxies.

Other major programs that were foreseen for FAST included: tracking the spectral evolution of supernovae, conducting a spectral survey of nearby galaxies to serve as a benchmark for studies of galaxy evolution, studying galaxy kinematics, surveying the spectra of young stars, and monitoring X-ray binaries and active galactic nuclei. After discussing the requirements for these programs with prospective observers, we arrived at the following design goals for FAST (in approximate order of importance):

1. *High throughput*.—We wished to take maximum advantage of the opportunities offered by a completely new design with an efficient CCD detector.

2. *Spectral resolution*.—Although most programs would be content with ∼6 Å, some programs required resolutions of 1–2 Å FWHM.

3. *Long slit*.—Most programs could be carried out with a 1′ slit length, but the spectral survey of nearby galaxies, for example, could make use of slit 5′ long or more. The tiny field allowed by the Tillinghast optics (a spherical primary coupled

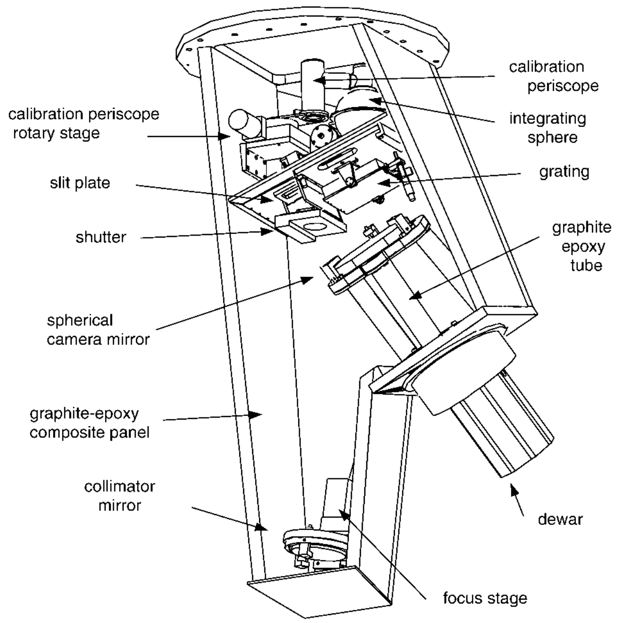

FIG. 1.—FAST spectrograph with its access hatch removed. The calibration periscope is shown in the calibration position where it conducts light from the integrating sphere to the focal plane. The Schmidt corrector plate is hidden behind the spherical camera mirror. The fold mirror (also hidden) is mounted on the flat plate that supports the dewar.

with an ellipsoidal secondary) meant that a corrector preceding the slit would be required.

4. *Broad spectral coverage*.—Most potential FAST users wanted access to the blue, but very few had an interest in wavelengths shorter than 3650 Å. The blue limit is an important decision since it drives the design of the optics and their coatings. At the red end, few users were interested in wavelengths beyond 8000 Å, but the red limit is much less important to the design.

5. *High stability*.—With any variable orientation spectrograph, attention must be paid to the instrument structure if flexure is not to be a problem. Our goal was to limit flexure-induced shifts to 0.2 pixels hr^{-1}, although flexure several times this level is tolerable. In addition, we wished to control thermally induced focus changes so that refocusing during the night would be unnecessary.

6. *Ease of use*.—With an anticipated larger pool of users, many convenience issues that might be forgiven in an earlier generation of instruments would now result in considerable loss of observing efficiency.

7. *Moderate cost*.—Our goal was to build the spectrograph and corrector for a budget of $350,000.

TABLE 1
EFFECT OF COLLIMATED BEAM DIAMETER ON CAMERA DESIGN

Parameter	Collimated Beam Diameter: 100 mm	50 mm
Camera focal length (mm)	350	175
Grating ruling (grooves mm^{-1})	300	600
Full spectral field angle (deg)	6.5	13.0
Camera aperture[a] (mm)	133	108
Camera F.L./aperture	2.6	1.6

[a] For a camera-pupil distance of 225 mm, 3700–7430 Å spectral coverage, 35° camera-collimator angle, and 40 mm detector.

3. SPECTROGRAPH OPTICAL DESIGN

3.1. Basic Design Parameters

The optical design of a spectrograph can be approached from several directions, but one approach is to begin by choosing the detector format and the desired demagnification (which sets the angle on the sky subtended by each detector pixel). Before the FAST project began, John Geary had designed a 512 × 2688 pixel CCD with 15 μm pixels (which was fabricated at the Loral foundry) for a possible Z-machine retrofit. The 40 mm length of this CCD is matched to the format of the original Z-machine Schmidt-Cassegrain camera. Because this CCD was available in quantity and offered a generous format, we decided to use it for FAST.

If we wish to sample the sky at about $0\farcs6$ $pixel^{-1}$ with a telescope scale of ∼77 μm $arcsec^{-1}$, we require a reduction of ∼3. The 512 pixels of the CCD then allow a slit length of just over 5′. This turns out to exceed the maximum useful field allowed by the coma corrector discussed below.

The remaining key parameter in the design of a plane grating spectrograph is the collimated beam diameter. A large collimated beam is mechanically undesirable because it results in a bulkier instrument, but it is also optically desirable because, for a fixed reduction, the camera focal length scales with the collimated beam diameter. A longer focal length camera delivers greater resolution for a given grating ruling density and is easier to design because it is slower. In our case, the floor clearance allowed by the asymmetric Tillinghast mount sets an upper limit at a 100 mm collimated beam diameter. Two configurations that offer the same demagnification (3.0), dispersion (1.4 Å $pixel^{-1}$), and spectral coverage (3750 Å) with collimated beam diameters of 50 and 100 mm are compared in Table 1. The optical advantages of the larger collimated beam are obvious, and we adopted a collimated beam diameter of ∼100 mm.

3.2. Optical Design Consultants

The optical design of the spectrograph was performed by Liang Ming and Charles Harmer at the National Optical Astronomy Observatories, under contract to the Smithsonian As-

TABLE 2
OPTICAL PRESCRIPTION FOR THE TILLINGHAST WITH COMA CORRECTOR

Surface	Radius (mm)	Thickness (mm)	Glass	Diameter[a] (mm)	Conic
Object	Flat	Infinity			
Stop	−7625.33	−2834.347	Mirror	1524	−0.00909
2	−2634.74	2834.347	Mirror	390	6.764913[b]
3	155.32	11.461	Silica	111	0
4	255.17	15.075		109	0
5	−410.97	8.187	Silica	108	0
6	Flat	966.579		107	0
Image	Flat			19	

[a] 2′ field radius.
[b] Aspheric, $a_6 = 1.2922 \times 10^{-17}$.

trophysical Observatory (SAO). Liang Ming designed an initial version of the coma corrector that was further refined by Harland Epps at Lick Observatory.

3.3. Coma Corrector Design

Because the designers of the Tillinghast Telescope expected that it would be used only for spectroscopy over a *very* narrow field, and in order to to lower construction costs, it was designed with a spherical primary mirror. With a modified oblate ellipsoidal secondary, such a design can yield a perfectly corrected on-axis image, but it introduces considerably more off-axis coma than a standard Cassegrain configuration. As built, the telescope's (geometric) rms blur diameter is ∼1″ only 35″ off-axis, and it degrades approximately linearly with field angle. Given that the CCD allows a slit length of ∼5′, it was clear that the Tillinghast optics were inadequate for the new spectrograph. The cost of refiguring the Tillinghast optics would be large even without considering the loss of observing time. Instead, we decided to build a coma corrector.

Because the design of the coma corrector is quite sensitive to errors in the prescription of the telescope optics, obtaining this prescription was the first step. An accurate measurement of the primary's focal length was found, but the specifications for the as-built secondary mirror were not available. We were certain that the as-built secondary deviated from the design specifications since the best images are found several centimeters from the design back focal distance. J. Miller and H. Epps at Lick Observatory kindly arranged for us to use the Lick profilometer to measure the figure of the Tillinghast's secondary.

Using these measurements of the secondary, Harland Epps refined the two-element fused silica corrector design developed by Liang Ming. Epps attained a well corrected field about 3′ in diameter. Adding a third element to the corrector offers a negligible improvement in performance. The final design for the air-spaced doublet coma corrector and the telescope optical prescription is given in Table 2. The optical performance of the corrected telescope is given in Table 3.

TABLE 3
PERFORMANCE OF THE COMA CORRECTOR

FIELD ANGLE (arcmin)	POLYCHROMATIC[a] rms Image (μm)	POLYCHROMATIC[a] rms Diameter (arcsec)
0	54	(0.71)
1.0	49	(0.65)
1.5	61	(0.81)
2.0	95	(1.25)

[a] Wavelengths of 0.365 to 1.0 μm.

3.4. Collimator Design

Given the relatively modest slit length allowed by the coma corrector, an off-axis parabolic collimator appeared to be an attractive choice. A collimator off-axis angle of 8°.5 allows sufficient clearance between the slit assembly and the grating. Schroeder (1987, p. 275) gives an approximate expression for the equivalent blur diameter in arcsec, β, introduced by an off-axis parabolic collimator:

$$\beta = 0.05\gamma\theta .$$

Here γ is the off-axis angle in degrees and θ is one-half the total slit length in arcmin. In our case, with $\gamma = 8^\circ.5$ and $\theta = 1'.5$, $\beta = 0''.6$.

The focal length of the parent parabola of the FAST collimator is 963 mm, producing a collimated beam diameter of 93 mm.

3.5. Camera Design

3.5.1. Folded Schmidt Camera

If we refer to Table 1, we see that we require a camera with a focal length of ∼350 mm. Given our short wavelength limit of 3650 Å and the relatively slow ∼f/3 camera required by our design, a refractive camera offers the highest possible throughput because no central obstruction is necessary. However, we decided to investigate Schmidt designs as well because they are less expensive to design and fabricate. In the end, we adopted a Schmidt camera because the throughput penalty relative to a refractive camera is small.

Initial attempts to design an off-axis Schmidt camera were unpromising, so we adopted a folded geometry. The penalty of the folded design is an additional reflection and central obstruction losses at the fold flat from the hole required to allow light to pass through to the CCD. With our relatively slow camera focal ratio and large collimated beam diameter, these obstruction losses are fairly modest, ∼9%. If we had adopted an unfolded design with an internal focus, the central obstruction losses would have been only slightly lower, at the expense of considerable additional dewar complexity. The optical performance of the folded Schmidt camera is excellent, with typ-

TABLE 4
OPTICAL PRESCRIPTION FOR THE SCHMIDT CAMERA

Surface	Radius (mm)	Thickness (mm)	Glass	Conic	Comment
Object	Flat	Infinity			
Stop	Flat	225.00			
2	Flat	8.00	UBK-7		
3	−34578.22	283.96		0	aspheric, $a_4 = 1.3783 \times 10^{-9}$
4	Flat	−309.86	Mirror		34° fold
5	700.00	333.93	Mirror	0	
6	108.28	8.00	Silica	0	
7	Flat	8.00			
Image	Flat				

ical rms image diameters of 5 μm. The optical prescription of the folded Schmidt camera is given in Table 4, and the image quality with 300 and 1200 lines mm^{-1} gratings is given in Table 5. The pupil anamorphism is 1.06 and 1.33 with the 300 and 1200 lines mm^{-1} gratings, respectively. The effective focal length of the camera is 331 mm, giving a demagnification of 2.91.

Figure 2 is a cutaway view of the fold mirror, dewar, and dewar mounting structure. Part of the back of the fold mirror has been machined away to allow the CCD to be placed close to the front surface of the fold mirror. A larger hole in the fold mirror would be required if the separation between the fold mirror surface and the CCD were increased.

3.5.2. Throughput Comparison of Folded Schmidt and Refractive Cameras

A refractive camera is usually thought to offer considerably higher throughput than a Schmidt camera. The dominant losses from the folded Schmidt camera arise from the three reflections, vignetting at the fold mirror central aperture, and the reflection and scattering losses at the aspheric corrector plate. The dominant losses from the refractive camera arise from the reflection and scattering losses at the glass-air surfaces. Internal absorption in the lenses can be important in the blue, but here we neglect this loss. The relative throughput of the two types of camera depends on the desired field size and the camera speed, but in the case of the relatively slow FAST camera and the modest 3′ field allowed by the Tillinghast Telescope, the folded Schmidt camera offers close to the same throughput as a refractive camera if silver reflective coatings are selected. The relative throughputs of folded Schmidt and refractive cameras appropriate for FAST are summarized in Table 6.

TABLE 5
A. PERFORMANCE OF THE FOLDED SCHMIDT CAMERA WITH A 300 LINES mm^{-1} GRATING

Wavelength (Å)	rms Image Diameter (μm)
3650	9.3
5593	0.3
7559	7.8

B. PERFORMANCE OF THE FOLDED SCHMIDT CAMERA WITH A 1200 LINES mm^{-1} GRATING

Wavelength (Å)	rms Image Diameter (μm)
6064	12.8
6563	1.3
7058	12.5

4. OPTICAL COATINGS

The antireflection coatings on refractive elements and reflective coatings on mirrors must be chosen carefully if the

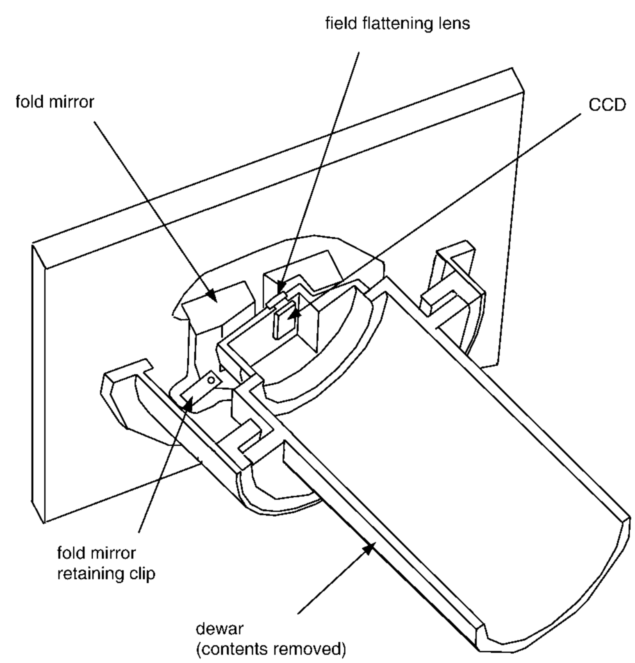

FIG. 2.—Cutaway view of the camera fold mirror, the CCD dewar, and the dewar mounting structure. All the internal parts of the dewar except the CCD have been removed for clarity.

TABLE 6
A. THROUGHPUT OF FOLDED SCHMIDT CAMERA

Loss	Throughput/Surface	Surfaces	Net Throughput
Coated glass/air surface[a] ……	0.98	4	0.92
Silver reflection[b] ……………	0.97	3	0.91
Vignetting at fold mirror ……	0.91	1	0.91
Final throughput ……………			0.76

B. THROUGHPUT OF REFRACTIVE CAMERA

Loss	Throughput/Surface	Surfaces	Net Throughput
Coated glass/air surface[a] ……	0.98	10	0.82
Final throughput ………….			0.82

[a] Reflection loss of 1% and scattering loss of 1%.
[b] Absorption loss of 2% and scattering loss of 1%.

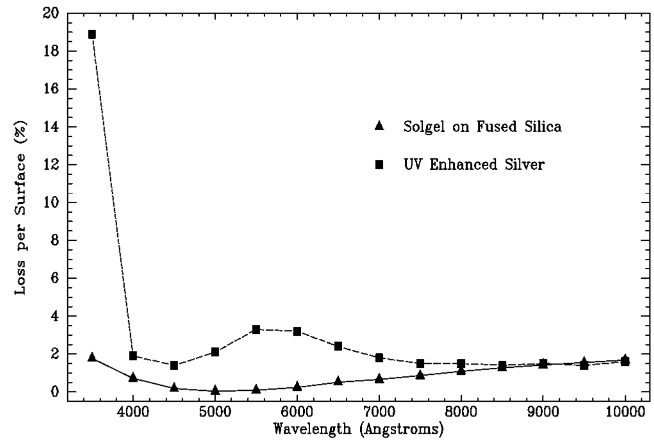

FIG. 3.—Loss from each reflective and refractive surface exclusive of scattering losses. The refractive elements are fused silica or UBK-7 antireflection coated with Solgel, and the reflective elements use silver overcoated with multiple dielectric layers for protection from tarnishing and to enhance the UV reflectance.

maximum thoughput is to be attained. FAST has eight glass-air surfaces (four in the coma corrector and two each in the corrector plate and the dewar window/field flattener) and three mirrors in its optical train.

The refractive elements in FAST are fused silica, with the exception of the UBK-7 Schmidt corrector plate. Both fused silica and UBK-7 have low refractive indices so that standard MgF_2 quarter wave coatings perform rather poorly. However, an excellent quarter wave antireflection coating can be made from Solgel. The performance of the selected Solgel coating is shown in Figure 3. Traditional Solgel coatings are quite soft, but techniques have been developed for hardening them, and these hardened coatings can be cleaned if care is taken. We have obtained our Solgel coatings from Cleveland Crystals in Cleveland, Ohio.

It has long been known that silver coatings are more reflective than aluminum coatings at wavelengths longer than ~4000 Å, but the lifetime of silver coatings has been a problem. Various overcoats have been developed to protect silver coatings, and multilayer overcoats can be used both to protect the silver from tarnishing and to boost the reflectivity of the coating below 4000 Å. After contacting numerous coating vendors, we found a desirable UV-enhanced silver coating from Newport Thin Films in Chino, California. The performance of the Newport Thin Films coating is also shown in Figure 3. We have tested the lifetime of this coating and found it to exceed 2 years when left unprotected in a telescope chamber. In the more protected environment of a spectrograph, the coating life is expected to exceed 3 years.

5. MECHANICAL DESIGN

As discussed in § 2, our goal was to achieve high stability, with gravitationally induced image shifts of less than 0.2 pixels (3 μm) per hour of tracking, and no refocusing required to compensate for nightly temperature changes. A large collimated beam diameter was selected for high optical performance, but the resulting large instrument size meant that meeting the flexure goal with the Tillinghast's instrument weight limit of 135 kg would be challenging. Convenient access to the grating and slit was an additional important constraint.

5.1. Structural Design

5.1.1. Main Structure

After studying various alternatives, a monocoque structure made from a graphite-epoxy composite emerged as an attractive option. Unfortunately, composite structures are usually prohibitively expensive to design and fabricate. Our limited budget forced us to consider how we might use standard composite products to build the FAST's structure.

Albany International Research in Mansfield, Massachusetts suggested that we make a box from flat graphite-epoxy composite panels joined with custom graphite-epoxy corner brackets. Flat composite panels of this type are produced in large quantities for airplane floors. The panels used in FAST's structure have a 25 mm thick aluminum honeycomb core and 6 mm thick graphite-epoxy face sheets. Custom graphite-epoxy corner brackets were too costly so we substituted stainless steel brackets.

The brackets are bonded to the panels with structural adhesive and bolted through the panels. The bonded panels form a box structure that tapers from the mounting flange to the collimator mirror. One long side of the box is removable for access, and all optical and mechanical components are attached to the remaining (fixed) portion of the box. Attachments to the composite panels are made with bonded-in stainless steel threaded inserts. To keep the instrument weight down while keeping costs under control, aluminum plates bolted to support

TABLE 7
FAST SPECTRAL COVERAGE (GRATING CENTERED AT 5500 Å)

Grating (lines mm^{-1})	Spectral Coverage (Å)	Dispersion (Å $pixel^{-1}$)	Pixels $Arcsec^{-1}$ (along dispersion)
300 ………	3940	1.47	1.64
600 ………	2000	0.75	1.55
1200 ……..	1000	0.38	1.37

brackets are used where complex or machined mounting interfaces are required.

In addition to their excellent stiffness-to-weight ratio, graphite-epoxy panels offer a coefficient of thermal expansion that is less than half that of steel and less than a quarter that of aluminum. As a result, the focus is quite stable with temperature. Slow seasonal focus changes are encountered as the graphite-epoxy panels absorb and release moisture, but these are small and require only a single focus session per observing run.

FAST's structure was manufactured by Albany International Research for about 15% of the project cost. It weighs ~80 kg and has performed to expectations at the telescope.

5.1.2. Schmidt Camera Support

Graphite-epoxy composites solved another structural design problem in the Schmidt camera. The spherical camera mirror is located at an awkward angle with respect to the main structure, far away from the fixed sides of the structure. The solution was to use three graphite-epoxy tubes to join the mirror mount to the main dewar mounting plate. These tubes offer the high stiffness-to-weight ratio and low thermal expansion of the main structural panels, are easily machined, and are relatively inexpensive. Similar tubes are widely used for high-performance sporting goods.

5.2. Optical Mounts

The fabrication tolerances of FAST's composite structure are comparable to those achieved in woodworking shops, ~1 mm. Each optical mount requires sufficient adjustment range to accommodate those tolerances. In order to allow us to optically align the spectrograph at the CfA, disassemble it for shipping to Arizona, and reassemble it without realignment, each mirror mount was built in two sections. A removable section of the mount remains with the mirror after initial alignment. This section is pinned to the fixed portion of the mount at two locations so that each mirror can be removed for safe shipment and replaced at the original location. For convenience, the holes that receive the mounting pins are machined in a small plate that can be adjusted with respect to the mount and then securely locked down. In practice, the spectrograph was easily reassembled at the telescope, and it remained in excellent alignment and focus following reassembly.

6. CALIBRATION AND SLIT VIEWING OPTICS

The calibration optics are built into the spectrograph. A rotary stage holds a small periscope system that guides light from an integrating sphere to the focal surface. A He-Ne-Ar lamp provides wavelength reference lines and a halogen bulb provides continuum light for flat-fielding. An achromatic lens in the periscope places the exit pupil of the calibration illumination at the same location as the telescope's exit pupil. The wavelength offsets between light incident from the telescope and light incident from the calibration optics are observed to be less than 0.1 pixel.

Light reflected from the polished slit jaws is collimated and passed through the spectrograph case with fold mirrors. The jaws are inclined at 20° with respect to the input beam. A small TV camera with a GEN-III image intensifier front end is used for guiding. The available field is about $2' \times 3'$. The output from the guide camera is fed to a frame integrator that can average up to 128 successive video frames, subtract background, and adjust the image scaling. With this system 18th magnitude stellar objects are easily visible.

7. GRATING AND SLIT SELECTION

FAST uses (oversized) 128 × 154 mm gratings. We currently have 300 and 600 lines mm^{-1} gratings blazed at ~4800 Å, and a 1200 lines mm^{-1} grating blazed at ~5700 Å. Five fixed slits with widths of 1″, 1.″5, 2″, 3″, and 5″ are available. Slit and grating changes are manual, but as a result, simple yet stiff grating and slit mounts could be used. We avoided building a grating turret or slide because of space, weight, and budget constraints. Grating tilts can be quickly adjusted with a manual digital readout micrometer.

The resolution and spectral coverages achieved with the various grating and slit combinations are summarized in Table 7.

8. PERFORMANCE

8.1. Throughput

At wavelengths between 4500 and 8000 Å FAST is among the most efficient astronomical spectrographs now available. The measured throughput of the spectrograph and telescope combination with a 5″ slit and the 300 lines mm^{-1} grating is plotted in Figure 4. The throughput in Figure 4 was measured in 1996 January after 2 years of operation (and dirt accumulation!). Subsequently, a better CCD UV flood and recoated telescope optics have substantially improved the throughput below 4500 Å.

8.2. Flexure and Thermal Stability

The measured flexure slightly exceeds the design goal of 0.2 pixels hr^{-1} of integration (or corresponding 15° change in elevation angle): we measure an average of 0.3 pixels. We have traced this flexure to the collimator focus stage, but we have

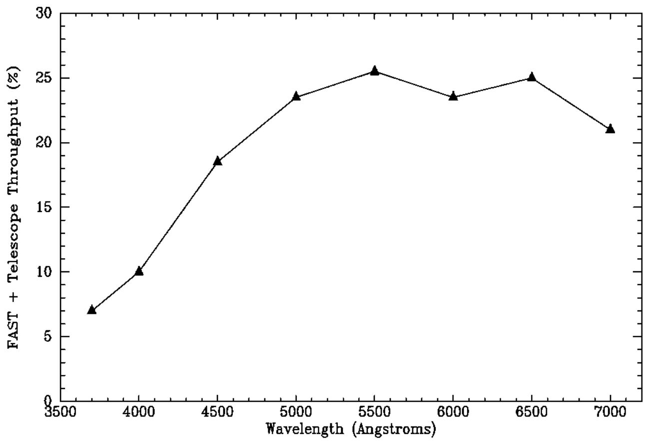

FIG. 4.—Measured throughput of the telescope and spectrograph combination, defined as the ratio of electrons detected at the CCD to photons incident on the primary mirror. A 5″-wide slit was used to observe two flux standards in 1996 January after 2 years of operation. The independently measured atmospheric extinction was removed.

not replaced the stage because observers have been content with the present performance.

Because the spectrograph contains a mixture of materials, temperature changes can introduce slight tilts in optical components with a corresponding shift in the position of spectral features. We measure a shift of 0.2 pixel $°C^{-1}$ of temperature change. Typical temperature changes at the Whipple Observatory are less than 0.2 °C hr^{-1} (excepting the first hour after the dome is opened), so this temperature sensitivity is unnoticeable in practice.

8.3. Productivity

FAST has proven to be an effective and reliable instrument. After 2.5 years of operation, FAST has acquired ∼25,000 spectra, equalling the Z-machine's output in its 15 years of operation. The comparison is even more impressive when one considers that the objects observed with FAST are typically 1 mag fainter.

The authors would like to thank Margaret Geller for her continuous encouragement and Irwin Shapiro for funding FAST. Charles Hughes, our dedicated and highly skilled instrument builder, cannot be thanked sufficiently for his superb and tireless effort in building FAST. Joe Zajac did an outstanding job of designing and installing FAST's electronics. David Brown skillfully performed the detail design and drafting, and Bill Davis carried out the critical finite element analyses of FAST's structure.

We are grateful to Susan Tokarz, Doug Mink, Michael Kurtz, John Roll, and Bill Wyatt for their fine work in assembling the FAST data reduction pipeline. Susan Tokarz has efficiently and carefully reduced nearly all the FAST spectra. Scott Kenyon, as chairman of the Time Allocation Committee, has done an excellent job of ensuring that FAST is used efficiently. Perry Berlind and Jim Peters, who have used FAST the most, have observed with an impressive efficiency. Bastiaan van't Sant, Lou Boyd, and Ted Groner, the technical team at the Whipple Observatory, have done an admirable job of preparing for, installing, and maintaining FAST. Dianne and Charles Harmer provided a very helpful tutorial on spectrograph alignment. Andrew Szentgyorgyi lent a much appreciated helping hand during busy phases of FAST's assembly and test.

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