

A Study of the Radiance of the Fibers on the WIYN Hydra  
Multiple Object Spectrograph & DensePak Array

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INTRODUCTION  
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Fiber optics have been used in astronomical applications since the 1980's, and has allowed a slew of new instruments to be developed. One of the main uses for fiber optics in astronomy is for multi-object spectrographs. An important and potentially critical measurement for any fiber optic device is the radiance of the light exiting the fiber. Since the new generation 10m telescopes almost all have some form of fiber-optic instrumentation, it is desirable to understand and characterize the radiance from fibers in a typical fiber-optic spectrograph.

We present the results of fiber radiance measurement for the MOS/Hydra and DensePak instruments on the WIYN 3.5m telescope located on Kitt Peak, Arizona. With the current Bench Spectrograph using an f/6.7 collimator, we conclude that only 50-70% of the light exiting the fiber foot assembly is collected by the spectrograph. Fiber-to-fiber variations are large, but on average the radiance pattern for the blue MOS/Hydra fibers results in the highest efficiency as about 65% of the light is within an f/6.7 beam. About 55% of the light exiting the red fibers falls within this beam. DensePak fibers generally put about 60% of the light within an f/6.7 beam. The current filter-holder assembly for each of the three fiber cables does not vignette light within the f/6.7 limit. Significant improvement to the overall throughput for WIYN spectroscopy may be achieved with a faster collimator coupled to a field lens placed in front of the fiber ends.

SETUP  
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To do this experiment the Bench Spectrograph was configured to allow direct imaging of the radiance pattern of the fibers. The setup consisted of mounting a fiber cable foot on a movable stage and placing the ends of the fibers 4 inches from the T2KC CCD. The fiber-CCD distance was set taking into account the quartz window of the CCD dewar. This distance was chosen so that light emergent from a fiber within an f/2 beam would be incident on the 2048x2048 CCD (24 micron pixels). The results reported below assume that all of the light transmitted by the fibers is emergent at f/2 or slower. The WIYN telescope has a f/6.3 focal ratio, and for point sources the fiber light output should have exactly this f-ratio. Any deviation from this gives an idea of the imperfections in the fiber optic. We also are interesting in examining the amount of vignetting caused by the filter-holder assembly that is at the toe of the fiber foot.

A 2.004 inch spacer was created at the NOAO shops to allow an exact distance between the foot and the CCD camera to be known. The distance from the fiber output to the end of the foot is known to be 1.418'', and the distance from the front of the dewar to the CCD camera chip is known to have an optical thickness of 0.578". This gives a total distance from output of fibers to screen (the CCD) of 1.418" + 2.004" + 0.578" = 4.00". Knowing this distance and that the pixels on the CCD have a size of 24 microns, we are able to characterize the radiance pattern as a function of the f/ratio.

## METHOD

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Due to the vignetting caused by the filter-holder assembly in front of the fibers, the entire output beam from the fibers cannot be completely seen. To determine the total amount of light leaving the fiber, and its radiance profile it is necessary to recreate the profile from the available information. This is possible by using the IRAF routine ellipse to obtain the light profile as a function of radius. However this routine will not compute at radii where less than half the points on a given annulus are usable. The filter assembly vignetting is rectangular in shape, typically centered on the center of the fiber radiance profile. Hence, we are able to sample and created an elliptical isophote for the inner portion of the profile, but for the outer parts, where less than half of an annulus is formed, ellipse fails to created an isophote.

To overcome this problem, we wrote an IRAF script to double the amount of available pixels by rotating the portion of the beam pattern by 90 degrees, and adding this to the original image. This is done by the following method:

- (1) The center of the beam pattern is found by examining the profile of the radiance pattern.
- (2) The image is then rotated about the center by 90 degrees, and this rotated image is subtracted by the original image.
- (3) All negative pixel values in the subtracted image are replaced by 0, since these are the subtracted pixels from the original image. The subtracted image then contains the outer portions of the original image, with the inner bright portion subtracted out, and the outer portions of the original image set to zero.
- (4) This replaced subtracted image is then added to the original image, therefore creating an image that has the additional information of the outside portion of the profile. Doing this for all the fiber images, we are able to reasonably reconstruct the fiber radiance to fit isophotes throughout most of the image frame.

Based on image inspection a reasonable radius was chosen for the ellipse function to create isophotes. The IRAF task "ellipse" was then run for each radius with a flux value determined from the median flux within the a given pixel annulus. Text files were created by this task that gave this flux value as a function of distance from the center of the radiance pattern. To find the total flux value of the profile, the sum of each intensity annulus was added together, in the following manner:  $\text{flux} = \text{sum} (2 * \pi * r * \text{Intensity})$ .

Likewise, the amount of light within each radius was computed by finding the total amount of light within a given radius normalized by the amount of light in the entire recreated radiance pattern.

## RESULTS

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The effect of the vignetting by the filter-holder assembly for 5 red and 5 blue fibers is shown below in terms of the fraction of light that makes it to the collimator. (f refers to dome flats the light source, and s for the images taken with a star in the fiber.)

Red Fibers

Blue Fibers

Slit Position	Fib #	%Pass(f,s)	Slit Position	Fib #	%Pass(f,s)
47	79	*0.79,0.85	48	185	0.87,0.86
48	262	0.70,0.79	49	248	0.82,0.84
49	121	0.81,0.82	50	74	0.85,0.88
50	184	*0.77,0.80	51	8	0.90,0.83
52	55	*0.87,0.86	52	161	0.89,0.89
Averages	---	*0.78,0.82	Average	---	0.87,0.86

\* These numbers are an upper limit on the efficiency, calculated by finding the total flux of the rotated and added images, and comparing with the total flux of the original images. The ellipse routine had difficulty determining several isophotes for these images.

We also investigated the fiber radiance as a function of f/ratio. The incident beam onto the fibers is f/6.3, so theoretically, if there are no imperfections in the fibers, then the light leaving the fiber should be completely contained within f/6.3. With radiance as a function of radius from the center of the profile, we can calculate how much of the light is within the f/6.3 theoretical limit. These results are shown in the following table.

Red Fibers

Blue Fibers

Slit Position	Fib #	%(>f/6.3) (f,s)	Slit Position	Fib#	(>f/6.3) (f,s)
47	79	----,0.46	48	185	0.65,0.71
48	262	0.36,0.41	49	248	0.49,0.54
49	121	0.44,0.46	50	74	0.70,0.76
50	184	----,0.43	51	8	0.68,0.65
52	55	----,0.62	52	161	0.68,0.73
Averages		0.40,0.48	Average	---	0.64,0.68

Defects and/or stresses in the fibers are obviously causing a broader radiance pattern. The collimator is f/6.7, and the accompanying figures graphically shows the amount of light that falls within f/6.7 for a typical blue and red MOS/Hydra fiber. There is a wide variation in the radiance pattern from fiber to fiber with values of from 0.36 to 0.76. This indicates a large variation in the quality of the fibers ability to transmit the incident telescope beam.

We performed a similar experiment on the DensePak fibers, and found similar results for the four fibers tested. The results of this experiment are shown below. Note that fiber 50 was found to have a very broad radiance profile which caused much of the light to be block by the filter-holder assembly.

DensePak Fibers

Fib #	%Pass	%(>f/6.3) (f,s)
17	0.84	0.59
35	0.83	0.55
45	0.90	0.53
50	0.50	0.30

Again, an accompanying figure plots encircled energy as a function of f/ratio. For a typical DensePak fiber, about 60% of the emergent light

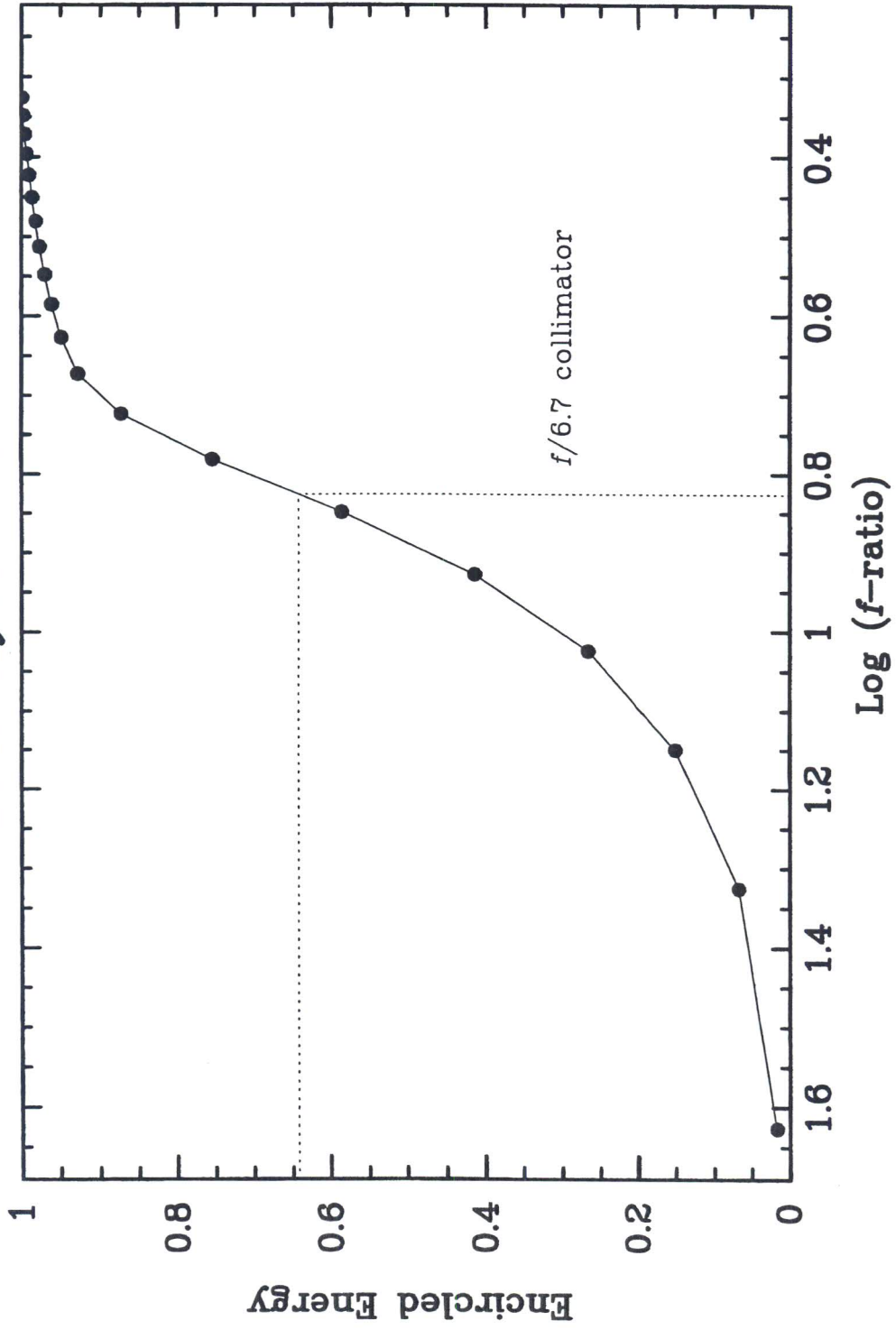
is contained within an f/6.7 beam.

#### CONCLUSIONS/THE FUTURE

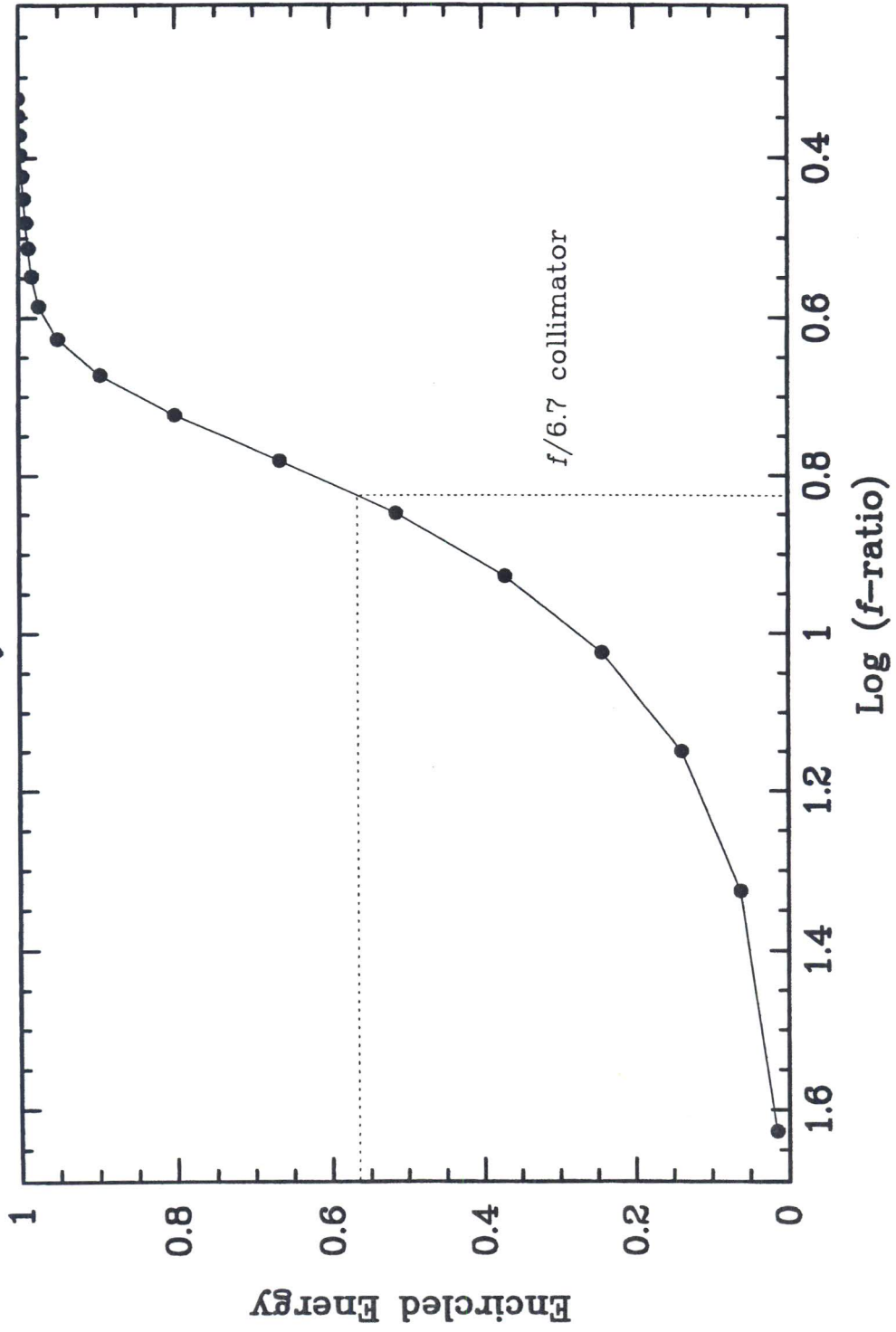
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It is well known that the transmission ability of fibers varies significantly between different fibers. We find this to be true and from our experiment and conclude that for the red fibers less than 50% of the light is within the f/6.3 limit which is predicted for perfect radiance. The number for the larger blue fibers is about 68%, somewhat better. It is not known if the radiance profiles increase with time as might be expected from wear and use and the resultant fiber imperfections. However, it might be worth repeating this experiment in a few years to determine if there is any time dependence in the fiber characteristics. Outside of replacing the fiber cables with new ones that may have a more concentrated radiance pattern, efficiency of the Bench Spectrograph may be improved to some degree by employing a field lens or a combination of a field lens and a faster collimator.

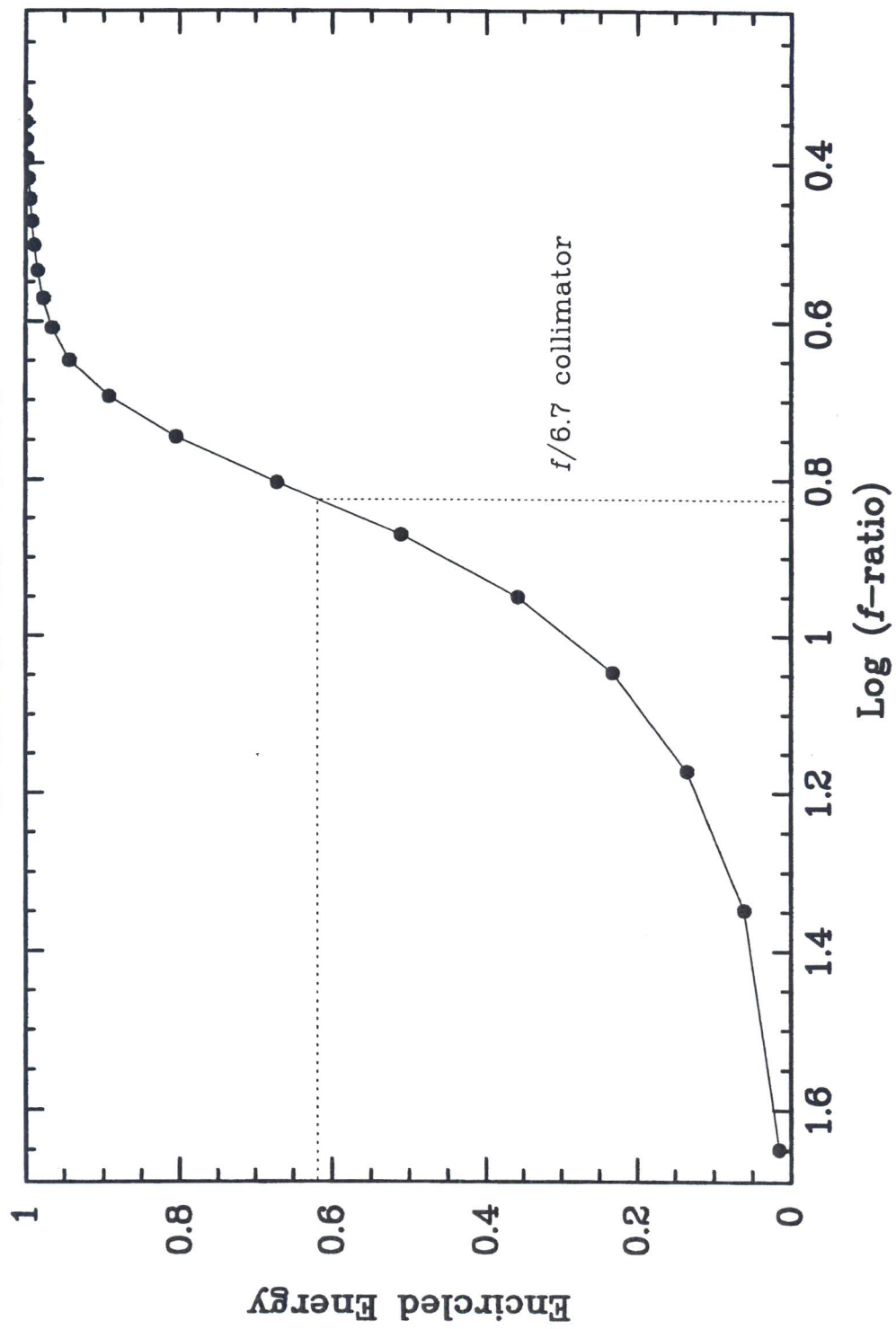
# Blue Hydra Fiber



# Red Hydra Fiber



# DensePak Fiber



# Results and Conclusions from the MOS/Hydra Fiber Radiance Test

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- Filter holder assembly vignettes  $\sim 14\%$  and  $\sim 18\%$  of the light of a star emergent from the blue and red fibers, respectively.
- However, none of this light would make it through the spectrograph with the current  $f/6.7$  collimator.

**CONCLUSION:** With the current collimator, the filter holder assembly is NOT introducing a loss into the system (indeed, it actually baffles light that would increase the scattered light in the system).

- A significant amount of light emerging from a fiber falls outside of the  $f/6.7$  beam defined by the collimator.
- Initial analysis indicates that the fiber radiance distribution leads to a  $\sim 30\%$  and  $\sim 50\%$  loss for the blue and red fibers, respectively. (Note that the spectrograph was designed for the  $f/8$  beam delivered by the 4m, not the  $f/6.3$  beam delivered by WIYN.)
- Fiber-to-fiber variations are large. For example, 5 blue fibers near the center of the slit assembly show between  $\sim 50\%$  and  $\sim 75\%$  of the light falling within  $f/6.7$ .



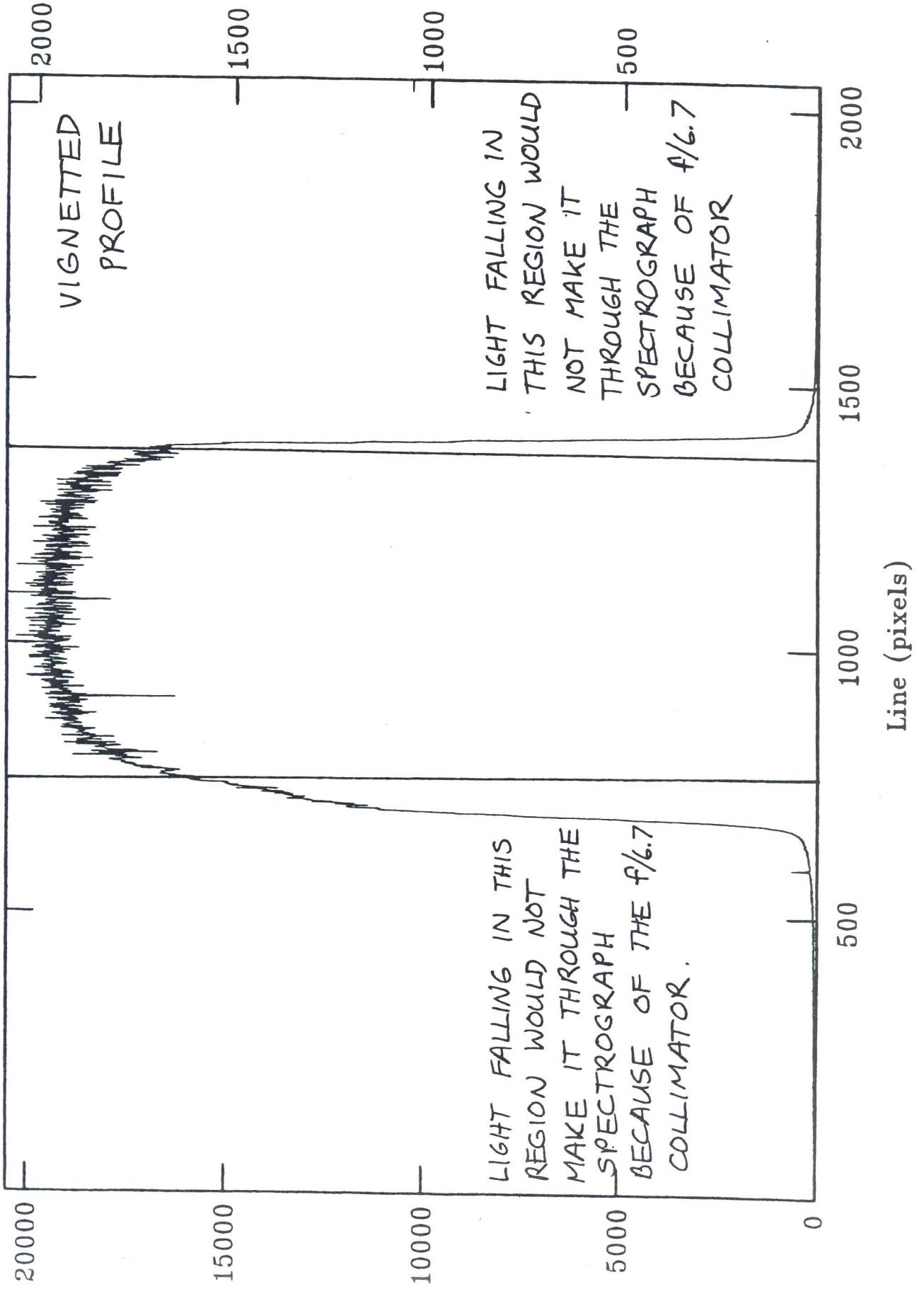
## CONCLUSIONS:

Spectrograph throughput may be improved by:

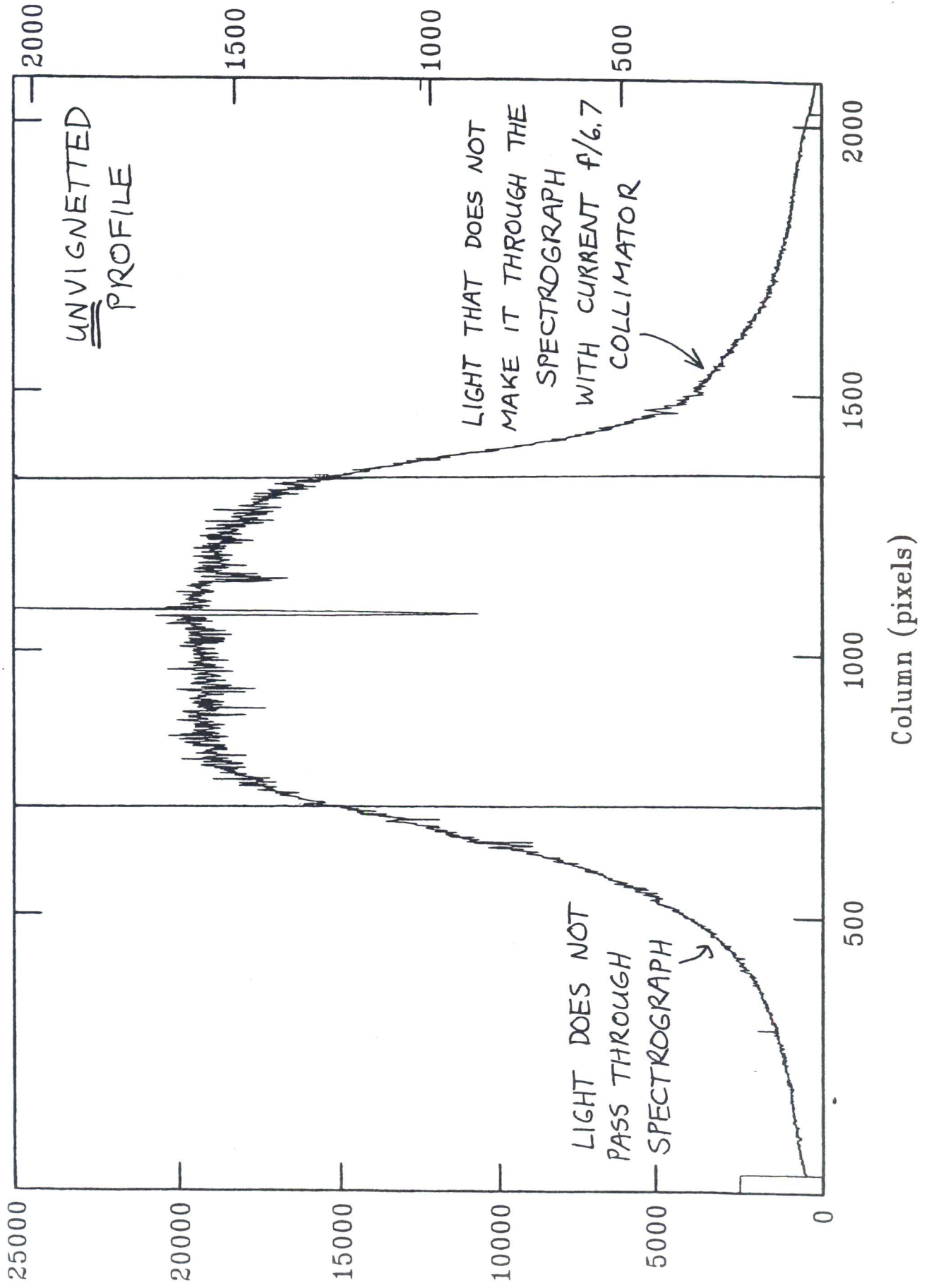
- Investigating and correcting possible stresses in the current fiber cables that result in a broadened beam profile.
- Employing a faster collimator.  
This modification may be less costly than the one above, but comes with the price of introducing larger aberrations and a degradation in the resolution of the spectrograph.

Note that if a faster collimator is used, the filter holder assembly will have to be modified so that vignetting by the assembly does not become significant.

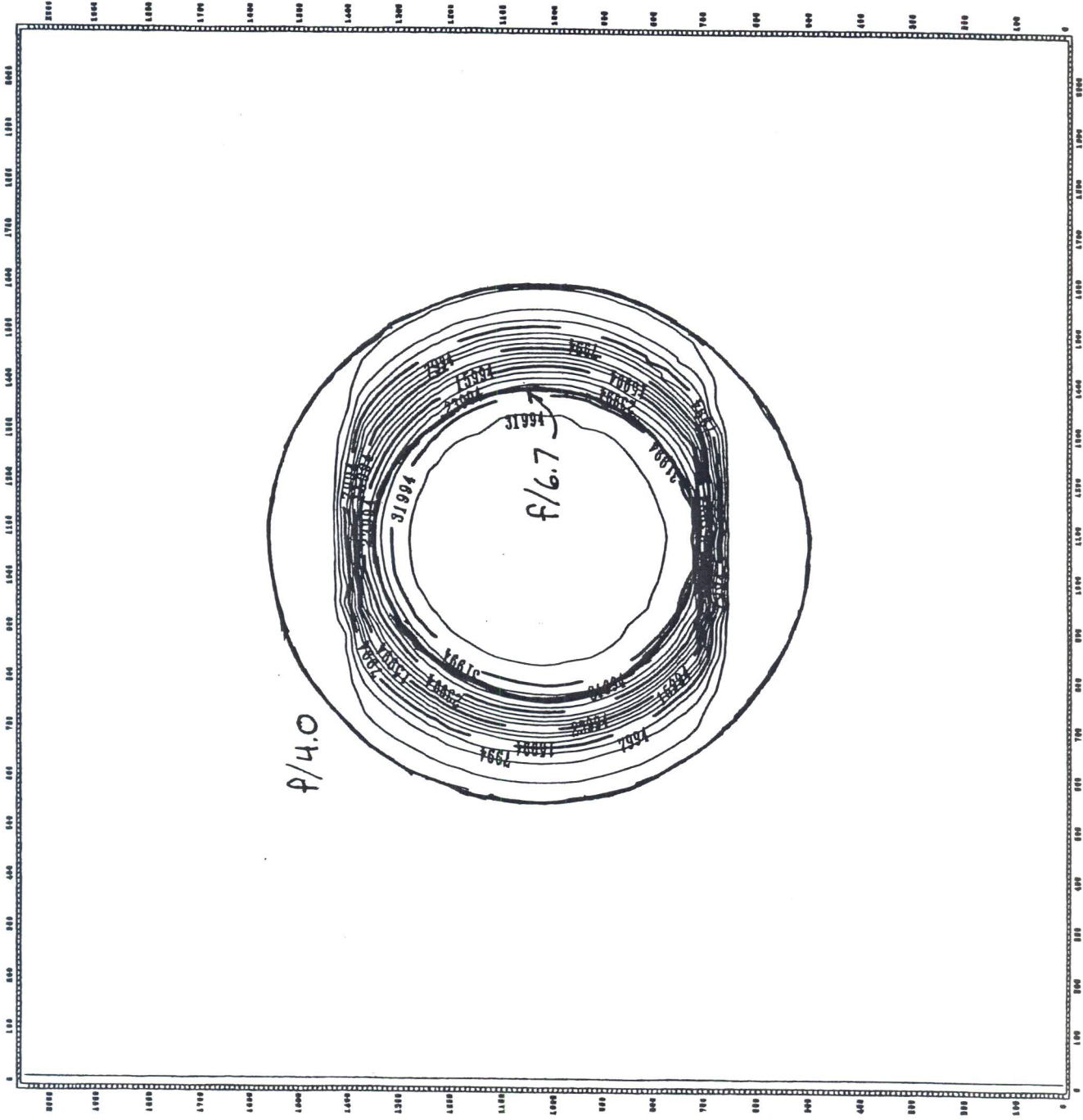
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f8bs: f8b bs6791



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