CHIRON efficiency

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Version 2. March 28, 2011
file: prj/bme/chiron/commissioning/efficiency.tex

1 Estimated CHIRON efficiency

In this Section, the estimate of the total efficiency of CHIRON is updated, taking into account the measured eficiency of the prism and grating.

Table 1: Estimated efficiency of the spectrometer at 530 nm

Sub-system	Element	Eff.
Telescope		**0.675**
	Atmosphere	0.90
	Two Mirrors (0.885x0.86)	0.75
Fiber link		**0.535**
	Diagonal M3	0.98 (vendor data)
	Seeing ($2''$, hole $2.7''$)	0.715
	Re-image (4xVIS0°)	0.98
	Fiber + FRD	0.78
Spectrograph		**0.377**
	Re-imager (4xVIS0°)	0.98
	CFA	0.96
	Collimator mirror	0.96
	Echelle	0.60
	Prism	0.74
	Triplet+fold	0.96
	Flattener	0.98
Detector		**0.85**
Total		**0.116**

2 Measurements on the sky

CHIRON efficiency near 550 nm has been estimated for the first time in January 2011. However, these estimates are useless because the CCD gain was not known even approximately. Here we report the results from March 9/10, 2010. On that night, the sky was clear and the seeing was good.

The calculations were performed by the program `images/flux.pro`. It takes a small segment of the order just to the left of the CCD center, at [2021:2069,1816:2176] in raw un-binned coordinates (the binning is then accounted for), subtracts the over-scan, integrates in the X-direction and plots the resulting scan. The median value of this scan is taken as the continuum-flux measure, in ADU/pixel. It is assumed that the gain is 2.59 el/ADU in the fast mode and 2.39 e/ADU in the normal mode. When the stellar V-magnitude is given at input, the program calculates the efficiency E,

$$E = \frac{F}{F_0 10^{-0.4V} S \, \Delta\lambda}. \quad (1)$$

Here F is the flux [photons/s/pixel]. We use the constant $F_0 S \Delta\lambda = 3.43E5$ [photons/s] – the flux of a $V = 0^m$ star above atmosphere per $\Delta\lambda = 0.0202$Å pixel. The telescope collecting area $S = 1.7 \cdot 10^4$ cm^2.

Table 2: Efficiency measures on March 9/10, 2011

File	Star	Binning	V	t_{exp}	Flux F, ph/s	E, %
52	Canopus	1x1S	-0.72	5	2.37E4	3.6
55	Canopus	1x1F	-0.72	5	3.67E5	5.4
56	Canopus	4x4F	-0.72	0.5	3.52E4	5.2
73	HD 56593A	3x1S	6.72	30	236	2.9
74	HD 56593A	3x1S	6.72	300	2.6E3	3.2
75	HD 56593C	4x4F	9.53	600	2.4E3	4.5
163	HD 128620	4x4F	0.01	300	2.3E4	4.4
164	HD 128621	4x4F	1.33	2	1.28E4	4.1
165	HD 128620	3x1S	1.33	3	3.7E3	3.2
166	HD 128620	3x1S	0.01	2	9.1E3	3.5

Table 2 gives the signal level F in photons per second per pixel and the calculated efficiency E. The binning mode also indicates whether the pure fiber (F) or slicer (S) was used. All these spectra were taken without iodine cell. We conclude that the CHIRON efficiency without slicer is 4-5%, with slicer 3-4%.

3 Measurements of the components

3.1 Spectrograph transmission

Spectrograph transmission at 532 nm was measured by A. Tokovinin on January 5, 2011. A narrow laser beam was directed backwards from the CCD to the fold mirror, APO, prism, etc. The flux was measured with the Newport instrument. The baseline flux is measured at point A after the field flattener (its transmission is not included). Further points down the beam are B (before the prism), C (after the prism), and D (after the echelle, central order).

The results are:

- Total D/A=0.406
- Flattener+APO B/A=0.96

- Prism C/B=0.74
- Echelle D/C=0.57

The echelle transmission is somewhat less than measured previously (0.65), maybe 532 nm is slightly off the blaze peak. The un-coated prism transmits less than expected, possibly because of some scattering in the glass. Overall, however, the spectrograph transmission is not bad.

Optical elements not included in these measurements (flattener, CFA, re-imaging lenses) are accounted for in Table 1, leading to the total spectrograph transmission of 0.38.

3.2 Checking the fiber

Light loss in the fiber link is the prime suspect of the low efficiency. The fiber could be mis-aligned or broken. The transmission of the fiber cable #1 at 650 nm was previously measured and found to be 0.80 (at F/5 input and F/4.4 output).

The alignment of the fiber with the hole in the FEM mirror has been checked several times. It was found to be correct and stable.

On January 27 2011 the telescope was pointed to HR 2326 (Canopus) and the light cone emerging from the fiber on the spectrograph end was examined and photographed. It had a well-defined uniform circular illumination with F/5 divergence, with some fainter halo around caused by the FRD. We concluded that the fiber is well-aligned w.r.t. the incident light cone. This has been confirmed the next day by shining a bright red laser light through the fiber at the spectrograph and observing the output cone on the pupil aperture in FEM, well-centered.

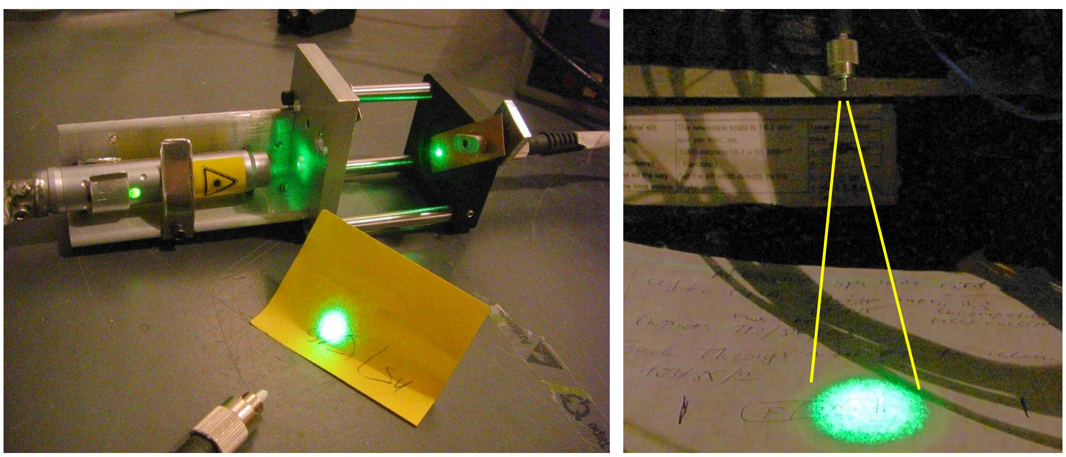

Figure 1: Left: the device used for fiber-transmission measurement consists of a green laser pointer and FC fiber collimator with a 0.9-mm aperture. Right: light cone emerging from the fiber cable #1 at the telescope when the output is connected to the test device.

On January 28 2011 we checked the integrity of the installed fiber cable #1 by comparing it with another cable #3. The cable #3 was provisionally placed to connect FEM with CHIRON, it was aligned in FEM. Quartz exposures were taken with the regular cable, then with the new cable, and again with the regular one. The flux with cable #3 was 0.6 times less than with the regular cable #1.

The likely reason is that we did not align the beam from cable #3 on the CHIRON collimator, and that the substitute cable has a slightly inferior quality.

On February 4, 2011, the transmisison of the fiber cables was checked again. We used a test device asembled from the green laser pointer and a fiber collimator, with elements of 30-mm ThorLabs cage in-between (Fig. 1). The laser illuminated fiber collimator F230FCA (focus 4.5 mm). A 0.9-mm hole placed in the beam in front of the collimator produced a well-defined beam with divergence $F/5.4$, as confirmed by direct measurement. Fiber cables #2 and #3 were connected and their transmisison was measured with the Newport power meter. The 1-cm aperture of the power meter was centered manually at 5 cm distance from either fiber connector or fiber exit, to evaluate the transmisison at $F/5$ divergence. The relative accuracy of these measurements is not high (possibly 0.1). It is limited by the stability of the laser, by approximate method of power measurement, and by the spatial non-uniformity of the Newport power sensor.

The results are 81% for cable #2 and 83% for calbe #3, in good agreement with previous measurements.[1]

The combined transmission of the cable #3, FOB and CFA was evaluated by placing the power meter in the divergent beam leaving the CFA. The result is 75%.

Finally, we connected the output end of the actually installed fiber cable #1 with the test device and obseved the beam emerging at the telescope (the cable was disconnected from the FEM). The output cone has a full divergence $F/3.2$, estimated by projecting the output light on a white paper (Fig. 1, right). The full power emerging from the fiber equals the input power (to whithin measurement uncertainty). This tells us that the fiber cable #1 is not damaged. There is possibly some focal-ratio degradation (FRD), but is cannot be quantified without more accurate centering of the input beam in the fiber.

3.3 Telescope

The reflectivity of the telescope mirrors has been measured in 2010[2]: 0.885 for M1 and 0.86 for M2. The primary mirror is regularly washed.

4 Discussion

Considering the transmisison of the prism, the expected efficiency of CHIRON should be around 12%. We actually measured the efficiency of 5% without image slicer, 4% with the slicer. The discrepancy by a factor 2.5 means that CHIRON reaches about 1 magnitude brighter than expected. However, there is substantial gain compared to the previous echelle.

The light loss in the current prism without AR coating is taken into account; a relative improvement by 10% is expected with a coated prism. The fact that CHIRON spectral resolution is around $R = 90\,000$ instead of 80 000 tells us that the fiber image is smaller than planned, hence the FRD is higher. For the same reason the image slicer “eats up” another 20% of the light. It is obvious from the images of the sliced fiber that the fiber does not fit into the 3-slice format and that the 4th slice is chopped off.

[1] A. Tokovinin. Characterization of the new fiber cables for CHIRON. Internal report, Dec. 2, 2009.

[2] D. Holck, J. Subasavage, SMARTS mirror reflectance, ACTR-doc-291-v5, December 2, 2010

Existing spectrometers at Lick, Keck, and DuPont telescopes have efficiency on the order of 8%, even without fiber link. Their designers took care of the optics and coatings just as we did (if not better), and yet the light is lost somewhere. The new PFS spectrometer at Magellan claims a peak efficiency of 23% with a wide slit.[3] However, their zero point ($V = 19^m$ gives 1 ph/s/Å) leads to an efficiency of 12% if we use the formula (1).

It is conceivable that currently we under-estimate the CHIRON efficiency. A spectrophotometric standard star should be observed for a better measurement, and a more accurate data reduction with true spectrum extraction should be done.

[3] See http://users.obs.carnegiescience.edu/crane/pfs/specs.php