Focal reducer for fiber feed Echelle spectrograph

Configuration

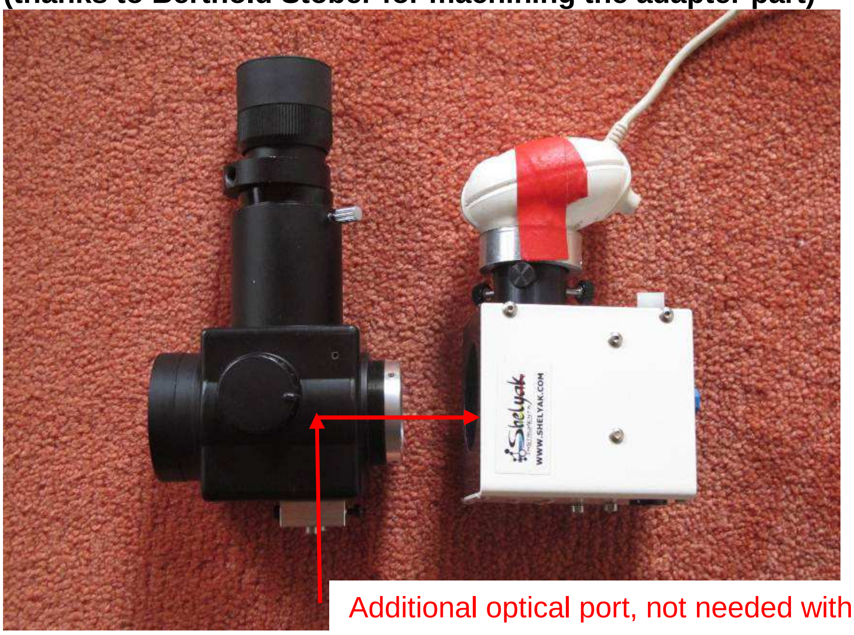
It is well known that the f-ratio of the telescope has to be matched to f-ratio of the spectrograph. In the present case we discuss the combination of a Vixen VC200 telescope (f/9) with a home-made Echelle with an f/5 to f/6 input ratio. The light from the telescope is coupled to the spectrograph with a 50 µm fiber. The coupling on the telescope side is made via a Shelyak fiber guide unit
(http://www.shelyak.com/produit.php?ref=PF0008&id_rubrique=7)
this is also used for guiding. Guiding is done with a Philips Toucam webcam.
The telescope is mounted on a mobile Vixen GPDX mount on a tripod with an FS2 drive and CarteduCiel or TheSky telescope control.
In addition, the same Echelle and guide unit should also be useable on the CEDES 90 cm telescope at Mirasteilas with 9 m focal length:
(http://www.mirasteilas.ch/index.php?option=com_content&task=view&id=34&Itemid=64)

Problem

The field of view of the webcam is only about 3x4’ with the Vixen telescope or about 1’ for the CEDES, which makes finding a star difficult, especially for the mobile Vixen mount if the polar alignment has been done only approximately (I rather spend time on doing spectroscopy than polar alignment). The idea is to install a Flip mirror (http://www.vixenoptics.com/acc/indiv/2680.html) with an eyepiece with reticule for initial alignment and the webcam for fine alignment and guiding. The problem with this is that the Vixen with a fixed main mirror has only a short back focus allowing either the use of a reducer (f/6.4) or a flip mirror, but not both. At present a finder scope is used for coarse alignment on the Vixen telescope.

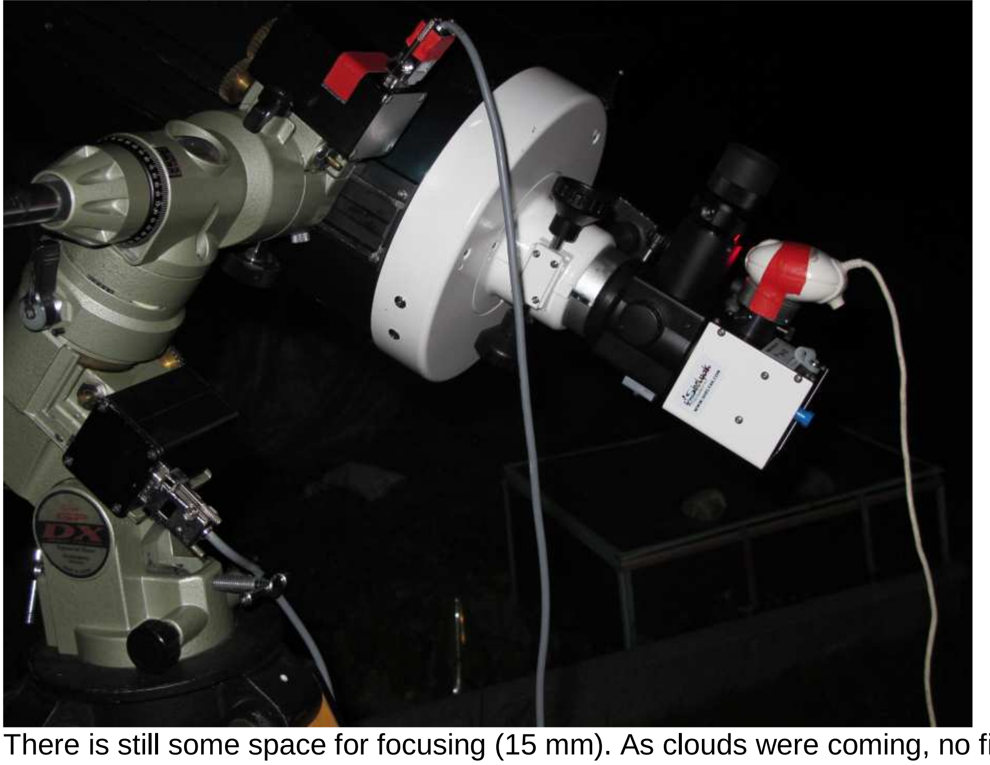
Solution

The problem of insufficient back focus was solved by using a short focal length reducer (F = 108 mm) mounted behind the flip mirror, almost inside the guide unit. The following image shows the flip mirror with reducer inserted via a T2 thread and the fiber guide unit with a female T2 thread before connection. At right the reducer in its T2 connecting adapter
(thanks to Berthold Stober for machining the adapter part)



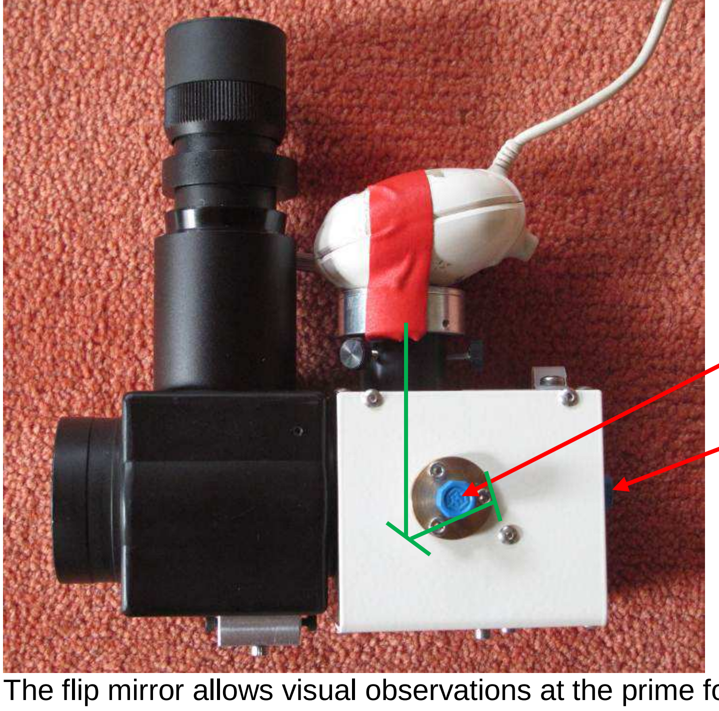
Additional optical port, not needed with Shelyak guide unit

The adapter consists of two parts, a Baader T-ring extension and a barrel which fits inside the adapter holding the 1 ¼" reducer. I used a reducer from Mogg for webcam applications (http://moggadapters.com.au/astro/adapter.asp), but I cannot recommend this product, delivery was slow, the thread in the plastic housing did not fit, however any achromat with adequate focal length should work.
The next image shows the assembled flip mirror with reducer and fiber guide unit mounted to the telescope:



There is still some space for focusing (15 mm). As clouds were coming, no fibers were attached, only the guidecam focused and tested

The assembled unit has the following advantages:



-
- The flip mirror allows visual observations at the prime focus without bending the neck.
- Dust protection 0f guide mirror by lens

- Finding the star in the guide window is very easy after centring and focusing in the eyepiece. The back focus for the eyepiece and guide unit are adjusted so that very little refocusing is required
- The flip mirror can also be used for darks in case the camera has no shutter (this happens also when you forget to move the flip mirror!)
- Over a reflecting foil or mirror on the backside of the flip mirror an additional calibration light can be fed into the optical path (custom made port visible at the bottom of the flip mirror). This was used before I had the Shelyak fiber guide unit and worked quite well. It can also be used for illuminating the fiber or slit for locating it and setting up the guide target.
- With a reduction ratio of 0.66 the same unit works as well on the Vixen and the CEDES and most other Cassegrain telescope with a 2" adapter. Since the CEDES telescope is often used for public demonstrations a quick change from visual observation to spectroscopy is important.

Optical calculation

That the device works properly some simple calculations in geometrical optics are necessary. For a more complete discussion of matching a telescope and spectrograph to a fiber I recommend to study the pages of the CAOS group (http://spectroscopy.wordpress.com/category/optical-fibres/).
For the calculation of the distances we need the lens equation which relates focal length f, distance of original focus to lens d1 and resulting image distance from lens d2 (see sketch below):

$1/f = 1/d2 – 1/d1$ (1)

The reduction factor is calculated as:

$R = d2/d1$ (2)

For a desired reduction factor R one has to eliminate d1 or d2 from the above equations. This gives the mounting position of the lens

$d2 = (1 – R)*f$	distance of lens to fiber input hole in guide mirror	(3)
$d1 = (1/R – 1)*f$	distance of lens from original focus	(4)

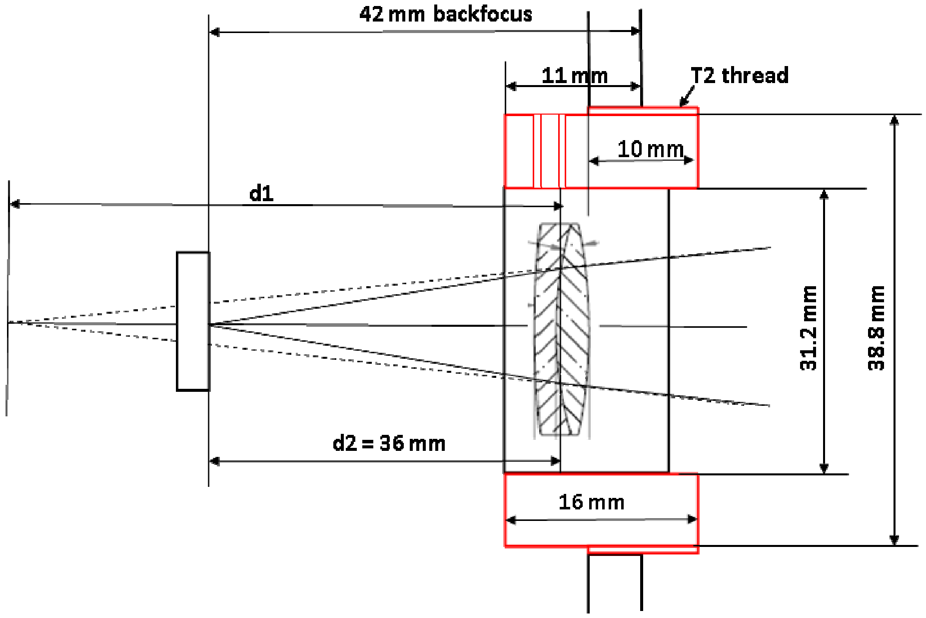
From this one obtains the shortening of back focus introduced by the reducer as:

$d1 – d2 = (R + 1/R - 2)*f$ (5)

These equations can be solved for given focal length and desired reduction factor. In the present example, reduction from f/9 to f/6, R = 2/3, focal length f = 108 mm (estimated)

(1, 2)	R=2/3, f=108	starting point, focal length chosen to fit mechanical restraints,
(3) →	d2 = 36	lens is within guide unit.
(4) →	d1 = 54	this distance is used for eyepiece position.
(5) →	d1 - d2 = 18	back focus is reduced by 18 mm, there is still some tolerance

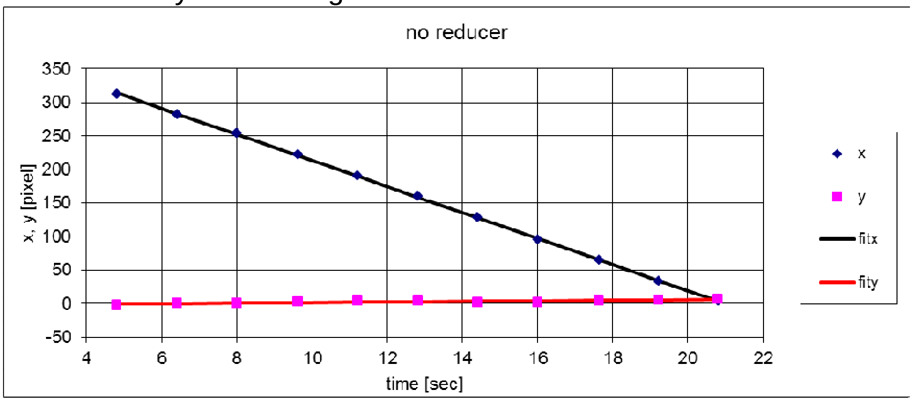
for focusing.
Since the reducer is used close to specified reduction factor, it should also give a good image over the full field of view. For a standard achromat, which is designed for a parallel input beam, the imaging quality over a larger field of view might not be optimal, but it is certainly very good on axis where it is needed for spectroscopy.

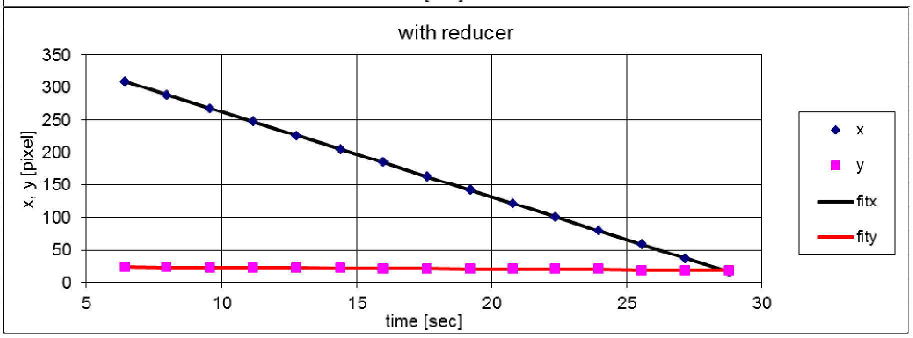


Sketch of the reducer with critical dimensions (not to scale)

First tests

In order to see if the assumptions and calculations had been correct, the image scale was checked. Since the webcam did not allow long time exposure I could not image a star field and do an astrometric reduction. Therefore the scan speed was measured, with a bright star (Spica) traversing the image, with the telescope drive motors stopped. The speed in pixels/sec was measured with the guide function of IRIS (http://www.astrosurf.com/buil/us/iris/iris.htm), with telescope drive off. This produces a file of star positions (x, y) as a function of time, from which the scan speed in pixels/sec can be determined by a linear regression:





Some data for the analysis of the IRIS data files

	Vixen no reducer	Vixen reducer	Comments
x0	407.43	393.01	Intercept from regression

x1	-19.41	-13.07	slope from regression
y0	-2.72	25.14	Intercept from regression
y1	0.39	-0.22	slope from regression
rms error of fit [pixel]	**1.73**	**0.75**	Bad seeing, wind
(x^2+y^2)^0.5 [pixel/sec]	19.41	13.08	Diagonal movement
rad	57.2958	57.2958	Radian to deg conversion
pixel size [mm]	1.12E-02	1.12E-02	2x2 binning
Spica delta [°]	11.2333	11.2333	Declination
cos delta	0.9808	0.9808	
star speed [arc sec/sec]	14.7126	14.7126	
image scale [arc sec/pixel]	**0.7578**	**1.1251**	
focal length guide cam [mm]	**3048**	**2053**	
magnification guide cam *	1.6973	1.6973	Previous measurement
focal length at fiber input	**1796**	**1210**	
f-ratio	**8.98**	**6.049**	
reduction R		**0.674**	Instead of 0.666 as designed

*It can be noted that a correction factor for the magnification of the transfer optics of the guide camera has been used, which had been determined earlier by comparing the prime focus of the telescope with the guide focus. The reduction factor R = 0.674 was as desired, the lens misplaced by about one mm. This is not surprising, the lens was assumed as thin and placed only approximately inside the barrel.
After these experiments clouds came in, so no spectra have been taken yet with this reducer.

Conclusion

A compact focal ratio adapter has been built which fits within the tight back focus of the Vixen telescope and permits together with the flip mirror easy acquisition of targets and guiding with a cheap webcam. The idea can be adapted to other telescopes, guide units and spectrographs easily. The required equations for the design are given.

My garden observatory. Older image, without flip mirror, separate PC for guiding and telescope control. At present everything is running on a single PC shown at left (telescope control, guiding and spectra acquisition running under Windows XP). The second PC is connected via TightVNC wireless connection to check progress of acquisition from the living room.