Back Focal Distance versus Image Quality
Trade study for UH 2.2-m Bent Cassegrain Port

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1 Introduction

The SNIFS instrument is to be mounted at one bent-Cassegrain port of the University of Hawaii 2.2-m telescope. The distance from the mounting flange to the nominal best focus is 82 mm according to Andrew Pickles (the UH 2.2-m scientist). This distance imposes severe constraints on the design of SNIFS, including the placement of the pick-off optics for the spectrograph and the filter bolt and dewar assembly for the imager. The secondary focus range can accommodate a flange-to-focus distance as large as 400 mm, therefore, a study was conducted to determine the image quality for larger back focal distances. The maximum image degradation accepted was 0.3 arcseconds in the FWHM, which would result in less than 20% degradation for seeing of 0.5 arcseconds.

2 Telescope Optical Parameters

The nominal optical parameters of the UH 2.2-m main Cassegrain focus are listed in Table 1. Note that the location and size of the bent-Cassegrain folding mirror are not yet known so are not included.

Table 1: UH 2.2-m Optical Specifications

Element	Location (mm)	Curvature Radius (mm)	Conic Constant	Diameter (mm)
Primary	0.0	-12344.5	-1.0535	2220
Secondary	-4648.98	-4198.1	-3.604	660
Focal Plane	5552.68	flat	N/A	N/A

This configuration reproduces the nominal focal ratio of f/10.15 (giving f/10.14) and effective focal length of 22500 mm (giving 22501 mm). The aperture stop is located at the primary mirror. The distance from the face of the primary mirror to the focal plane is 903.7 mm. Using the mirror thickness of 291 mm given in the UH manual, the distance from the back of the mirror to the focal plane is then 612.7 mm. Unfortunately the UH manual doesn't prove this distance, but instead gives a distance of 313 mm from the back of the mirror cell to the nominal focus. My calculation and the quoted back focal distance agree if the mirror cell thickness is 300 mm (which seems plausible).

Even though the folding mirror is not included — preventing calculation of the true flange-to-focus distance for bent-Cassegrain within the ray-trace program — the change in image quality with a change in flange-to-focus distance can still be studied. This is accomplished by associating the back focal distance of 903.7 mm for the main Cassegrain focus with the 82 mm flange-to-focus distance at the bent Cassegrain port. Both back focal distances will increase in direct proportion as the secondary mirror is moved.

3 SNIFS imager field of view

It is expected that the SNIFS imager/guider will contain two 2k x 4k CCD's, with 15 micron pixels, mounted side by side. One chip will be used for imaging and the other will be used for guiding. For LBL devices, there will be a gap of 3 mm between the CCD's. Thus, the imaging/guiding area is roughly 61.4 x 64.4 mm. Assuming that the spectrograph pick-off mirror is on the optical axis, but the CCD's are offset 5 mm from the array center towards the center of the imager CCD, the furthest corner of a guider CCD will be at 48 mm from the optical axis. This corresponds to a field angle of 442 arcseconds = 7.4 arcminutes = 0.123 degrees.

4 Point Spread Function Computations

4.1 Case 1: Focal length fixed at nominal value

The CODE V optical design program was used to calculate the point spread function for different back focal distances and field angles. The effective focal length was constrained to preserve the nominal focal length of 22500 mm. I stepped the secondary mirror from the nominal position towards the primary mirror in increments of 1 mm. I calculated the image quality with and without a field-flattening lens for the dewar window. The main result is that the natural focal plane is curved (with a radius of about 1570 mm), so a field-flattening lens dewar window (13 mm thick, placed 5 mm in front of the imager focal plane) is needed to allow use of a large flange-to-focus distance.

The results of the calculations are given in Tables 2 & 3. The first column is the distance of the focus behind the primary mirror (since for these calculations I couldn't include the fold mirror). Assuming that the nominal focus in the first column (903.8

Table 2: No dewar window

BFL	Flange Distance	Mean RMS Diameter Field Angle		100% EE Diameter Field Angle	
		On-axis	6 arcmin	On-axis	6 arcmin
(mm)	(mm)	(micron)	(micron)	(micron)	(micron)
903.8	82	14	23	17	50
917.7	96	14	27	19	60
932.0	110	15	31	22	77
946.2	124	18	35	25	80
960.6	139	21	39	36	92
974.9	153	25	44	47	103
989.4	168	29	49	59	114

Table 3: Custom fused silica dewar window

BFL	Flange Distance	Mean RMS Diameter Field Angle		100% EE Diameter Field Angle		Window Curvature
		On-axis	6 arcmin	On-axis	6 arcmin	Radius
(mm)	(mm)	(micron)	(micron)	(micron)	(micron)	(mm)
908.3	82	6	10	15	23	-520
922.2	96	11	13	26	34	-520
936.4	110	14	16	33	41	-521
950.7	124	19	20	43	50	-524
965.0	139	23	24	52	59	-529
979.3	153	28	29	62	69	-535
993.7	167	32	33	72	80	-542

mm or 908.3 mm) is equivalent to the optimal flange-to-focus distance of 82 mm for the Cassegrain side port, I then calculated the increase in the flange-to-focus distance as the secondary was moved; this is reported in the second column. I then determined the image quality on-axis and at 6 arcminutes off-axis. Two image quality metrics are used — the root-mean-square diameter (reported in columns 3 and 4) and the 100% encircled energy diameter (full-width-to-zero, reported in columns 5 and 6). The image metrics are quoted in microns; to convert to arcseconds, divide by 109 microns per arcsecond. The last column of Table 3 gives the required radius of curvature for the dewar window; the sense is that the window is concave upwards.

For this case I did not count the extra 4.5 mm resulting from the window in determining the back focal distance relative to the nominal 82 mm. Thus, in any realistic situation, the focal plane of the imager will be located about 4.5 mm further back than the quoted "Flange Distance."

Note that the change in back focal distance with each 1 mm change in secondary location is 14.3 mm. This is exactly 10× larger than reported in the UH manual (page 24). I believe that the UH manual is incorrect in this regard because at the quoted rate of 39/27 micron per micron and quoted focal plane range of 685 mm, the secondary would move by 474 mm, or almost half a meter, which is excessive.

4.2 Case 2: Floating focal length

I also explored the possibility of allowing the effective focal length to float. In doing so, I found that the image quality improves if the focal length is allowed to increase slightly (by less than 4%) from the nominal value. An increased effective focal length also pushes back the location of the optimal focus by 86 mm compared to the cases presented above. This would make access to a near-optimal focus easier for SNIFS. However, it must be remembered that if the quoted nominal focal length of the UH 2.2-m is not really 22500 mm this added focal length already may be accounted for in the nominal flange-to-focus distance of 82 mm quoted by Pickles.

With this caveat, in Tables 4 & 5 I present the image quality for changing back focal distances. I conservatively assume that the best focus corresponds to the nominal flange-to-focus distance of 82 mm, but note that the absolute back focal distance (column 1) is considerable larger than in Tables 2 & 3. The additional last column of each table lists the optimized focal length.

Table 4: Floating focal length & Flat dewar window

BFL (mm)	Flange Distance (mm)	Mean RMS Diameter Field Angle		100% EE Diameter Field Angle		Effective Focal Length (mm)
		On-axis (micron)	6 arcmin (micron)	On-axis (micron)	6 arcmin (micron)	
964.9	39	22	18	45	30	22657
979.3	53	20	19	35	30	22696
993.9	68	17	20	25	35	22736
1008.4	82	16	22	18	45	22776
1023.2	97	16	24	20	54	22816
1037.9	112	17	27	24	63	22856
1051.8	125	19	31	27	72	22896
1066.4	140	22	35	31	82	22936
1081.1	155	25	39	35	93	22978
1095.8	169	29	43	46	102	23019

Table 5: Floating focal length & Field-flattening dewar window

BFL (mm)	Flange Distance (mm)	Mean RMS Diameter Field Angle		100% EE Diameter Field Angle		Window Curvature Radius (mm)	Effective Focal Length (mm)
		On-axis (micron)	6 arcmin (micron)	On-axis (micron)	6 arcmin (micron)		
965.4	53	9	12	20	31	-514	22917
979.7	68	5	9	10	22	-511	22961
994.1	82	1	8	1	14	-509	23005
1008.6	97	4	9	10	18	-508	23049
1023.1	111	9	12	20	28	-509	23092
1037.6	125	13	16	30	37	-510	23136
1052.2	140	18	20	40	47	-513	23178
1066.8	155	22	24	51	57	-517	23220
1081.5	169	27	29	61	66	-523	23261
1096.2	184	31	33	71	78	-530	23302

5 Conclusion

By employing a field-flattening dewar window the RMS image diameter across the SNIFS imager/guider field can be kept below 0.3 arcseconds (33 micron / 109 micron per arcsecond = 0.3 arcsecond) for flange-to- focus distances of up to 184 mm. At this distance the 100% encircled energy diameter from geometrical ray tracing is slightly more than 0.7 arcseconds. Thus, no image degradation will be noticeable at the 20% level unless the natural seeing is less than 0.5 arcseconds (and the image degradation will be only 10% for 0.7 arcsecond seeing) as long as a flange distance of less than roughly 184 mm is maintained. Since a longer focal length may push the flange-to-focus distance further out than the nominal value, SNIFS may be able to work at the optimal focus for that longer focal length without any image degradation whatsoever.