## NASA IRTF / UNIVERSITY OF HAWAII

Document #: TMP-1.3.4.2-00-X.doc

Template created on: 15 March 2009 Last Modified on: 31 August 2010

# **ISHELL DESCOPE OPTIONS**

John Rayner



NASA Infrared Telescope Facility Institute for Astronomy University of Hawaii

#### **Revision History**

Revision No.	Author & Date	Approval & Date	Description
Revision 1	John Rayner 11 April 2013		First release



# Contents

1 INTRODUCTION	3
2 CORE SCIENCE	3
3 DESCOPE OPTIONS	4
4 DESCOPED CONFIGURATION	7



# **1 INTRODUCTION**

Feedback from the iSHELL PDR panel recommended investigating instrument descope options as a means to remain within budget and schedule. We start by identifying what we consider to be iSHELL's core science objectives and then consider the impact on these of various descope options. Following this discussion we recommend a descoped instrument configuration.

A wholesale redesign of the instrument is not considered since this will lengthen the schedule. The most viable approach is to remove optical modes that are not needed for core science but with the possibility of upgrades at a later date.

## **2 CORE SCIENCE**

The key science cases developed by the iSHELL science team and from which the high level instrument requirements were derived are given in Table 1 together with the required wavelength range of the spectroscopy (implications for immersion grating), filter required for acquisition and guiding (implications for slit viewer), and whether the target is a point source or extended (implications for slit length).

Key Science Case	Spectroscopy	A&G	Source size
Comets	LM'	K and L (daytime)	extended
Atmosphere of Mars	L	K	extended
Atmospheres of Jupiter and Saturn	LM'	M' acquisition	extended
Jupiter $H_3^+$ Juno mission support	L	<i>nbL</i> acquisition	extended
Atmospheres of hot giant planets	KL	K	point source
RV searches for young planets	K	K	point source
Young binaries and PMS calibration	HK	K	point source
Protostellar envelopes	M'	K	point source
Protostellar evolution	LM'	K	point source
Magnetic fields and rotation	HK	K	point source
Stellar library	JHKLM'	K	point source

#### Table 1. Key science cases from iSHELL Science Team

The IRTF's primary science mission is solar system science. Of the original key science cases clearly comets and the atmospheres of Jupiter, Saturn and Mars must be part of iSHELL's core (indispensable) science investigations. These require an immersion grating optimized for use at LM' and long slits (at least 15" and up to 25" for H<sub>3</sub><sup>+</sup> observations of Jupiter). A descope option is to remove the slit wheel in the slit viewer and used a fixed K for acquisition and guiding. However, the planetary science cases require careful positioning of the slit on the plant and therefore need filters in which the features of interest can be identified (e.g. a *nbL* filter for H<sub>3</sub><sup>+</sup> features on Jupiter, and an M' for hot spots on Jupiter).

The majority of potential iSHELL users will want spectroscopic capability at H and K on point sources. This is where CSHELL is currently mostly used and where low background array performance is critical. iSHELL needs to replace this capability. In addition, important protostellar science at L and M' will be enabled by the high resolving power of iSHELL. Although desirable, there are no strong drivers to include extended objects and J-band science in the core (descoped) science.



A further requirement in the original science case was for the slit viewer to function as a science imager in addition to its primary role for acquisition and guiding. The logic being that imaging photometry would enhance the science return for a subset of programs and help the operational efficiency of the telescope by not having to switch in another instrument for ToO programs needing imaging. This requires a full complement of filters in the slit viewer. However, this is not part of iSHELL's core science.

# **3 DESCOPE OPTIONS**

The current optical configuration of iSHELL is given in Tables 2-6. This assumes the use of two silicon immersions grating: one optimized for LM' and one optimized for JHK. This optimization matches the free spectral range to the width of the H2RG array at about 4.1 µm and 2.5 µm respectively for the most efficient use of the array format. The use of the optimized JHK immersion grating also allows the use of relatively long slits (15") at JHK.

The science team encouraged the use of long slits at *JHK* as it was felt that this would enable better sky and bias subtraction by enabling point source nodding along the slit. Long slits were not required for extended objects since all the key *JHK* science was for point sources. However, aside from sparse sky emission lines sky background is below the level of dark current at a resolving power of 70,000. Also, H2RG arrays appear to be bias stable and so darks and biases taken hours earlier can be usefully subtracted from un-nodded raw data frames. Consequently, the use of short slits is a viable descope option. This means that the *LM'* immersion grating can be used at *JHK* where working in the higher orders required means that short slits (5") must be used (see the optical design documents for a full explanation). As a result the *JHK* immersion grating and the grating selection mechanism can be removed. One disadvantage of this approach is that stray light is not automatically subtracted by nodding along the slit. However, fitting the background along the slit is probably adequate. Also, since the free spectral range at 2.5  $\mu$ m is no longer matched to the span of the array and the array format is not used as efficiently as possible. However, this is compensated for by being able to fit more orders onto the array because of the shorter slit. This descope does require that the WFE of the *LM'* grating be good enough for it work well at *HK*. This is probably the case. The case for including *J* is not as strong.

The original cross-disperser mechanism had space for 12 gratings. This can be reduced to 8 to accomplish the core science and still allow for changes to accommodate an optimized *JHK* immersion grating should it be installed during an upgrade. An upgrade would allow the use of longer slits or one-shot coverage of the *J*, *H* and *K* bands, compared to the proposed descope in which the *H* and *K* bands are each covered in two observations. Five custom cross-dispersing gratings are required in the original design compared to one in the descoped design. At an estimated cost of \$15k per custom grating this is a significant saving. Reducing the number of slots on the cross-disperser mechanism from 12 to 8 allows the wheel to be reduced in size simplifying the design (more space and less mass).

Another significant descope is to reduce the filter complement in the slit viewer filter wheel to just support the core science requirement for acquisition and guiding. Dispensing with this wheel entirely and just using a fixed K filter would affect the core science but is still an option. In the proposed approach the slit viewer filter wheel and the order sorter filter wheel can be reduced in size (to 6 or 7 slots) and be made identical.



Position #	Filter	Notes
1	Blank	
2	Y	1.00-1.10 μm
3	$J_{MK}$	1.164-1.326 μm
4	$H_{MK}$	1.487-1.783 μm
5	$K_{MK}$	2.027-2.363 μm
6	$L'_{MK}$	3.424-4.124 μm
7	$M'_{MK}$	4.564-4.803 μm
8	J + H	Notch
9	H+K	Notch
10	Cont K	2.26 μm 1.5%
11	Cont <i>K</i> + ND 2.0	2.26 μm 1.5%
12	3.454 μm	0.5%
13	3.953 μm	0.5%
14	PV lens + nbL	Pupil diameter 325 pixels, spatial resolution
		3.6 pixels (33 mm on primary)
15	TBD	

## Table 2. Filters in the slit viewer filter wheel.

# Table 3. Slit wheel

Position #	Slit width	Slit length	R
1	0.375"	25.0"	72,000
2	0.75″	25.0"	39,000
3	1.50″	25.0"	20,000
4	4.00"	25.0"	7,500
5	Blank-off/mirror (dark	s/slit-less imaging)	

#### Table 4. Slit dekker wheel

Position #	Slit length	Notes
1	Blank	For darks
2	5.0"	2.79 mm long
3	10.0"	5.57 mm long
4	15.0"	8.36 mm long
5	25.0"	13.93 mm long

Table 5. Order sorter filter wheel

Position #	Filter	Notes
1	Blank	
2	1.05-1.45 μm	J-band XD
3	1.40 <b>-</b> 1.90 μm	H-band XD
4	1.80-2.60 µm	K-band XD
5	2.70-4.20 μm	L/L '-band XD
6	4.50-5.50 μm	M-band XD
7	TBD	
8	TBD	
9	TBD	
10	Open	



		01000 a.op		- <b>F</b>						
Exp. name (Mode)	Wavelength coverage (µm)	Orders Covered	XD (line/mm)	Blaze wavel. (µm)	Blaze angle (deg.)	Order sorter (µm)	Slit length (arcsec)	XD tilt (degrees)	XD size (mm)	Custom grating?
J	1.15-1.35	279-237	800	1.25	29.9	1.05-1.45	5.0	39.4	40x40	Yes
Н	1.50-1.80	211-176	530	1.67	25.7	1.40-1.90	5.0	35.2	40x40	Yes
K	1.97-2.52	160-125	290	2.19	18.5	1.80-2.60	5.0	28.0	40x40	Yes
J1	1.15-1.26	280-255	1200	1.2	46.0	1.05-1.45	10.0	56.0	55x40	No
J2	1.25-1.35	255-236	1200	1.2	46.0	1.05-1.45	15.0	61.5	55x40	-
H1	1.50-1.66	211-191	847	1.67	45.0	1.40-1.90	10.0	51.6	50x40	Yes
H2	1.60-1.75	198-181	847	1.67	45.0	1.40-1.90	15.0	55.0	50x40	-
H3	1.68-1.83	188-173	847	1.67	45.0	1.40-1.90	15.0	57.1	50x40	-
K1	1.84-2.03	171-156	720	1.90	43.1	1.80-2.60	15.0	54.1	50x40	No
K2	2.02-2.18	156-144	720	1.90	43.1	1.80-2.60	15.0	58.9	50x40	-
K3	2.12-2.34	148-135	600	2.16	40.4	1.80-2.60	15.0	51.6	50x40	No
K4	2.32-2.52	135-125	600	2.16	40.4	1.80-2.60	15.0	56.4	50x40	-
L1	2.80-3.10	184-167	450	3.14	45.0	2.70-4.20	15.0	51.3	50x40	Yes
L2	3.02-3.30	171-157	450	3.14	45.0	2.70-4.20	15.0	55.0	50x40	-
L3	3.14-3.42	164-151	450	3.14	45.0	2.70-4.20	15.0	57.3	50x40	-
L4	3.28-3.67	157-141	360	3.70	42.0	2.70-4.20	15.0	48.5	50x40	No
L5	3.65-4.01	141-129	360	3.70	42.0	2.70-4.20	15.0	53.5	50x40	-
L6	3.84-4.18	134-124	360	3.70	42.0	2.70-4.20	25.0	56.2	50x40	-
M1	4.55-5.27 s	113-98	210	5.0	31.7	4.50-5.50	15.0	40.4	40x40	No
M2	4.55-5.271	113-98	210	5.0	31.7	4.50-5.50	15.0	40.4	40x40	No

#### Table 6. List of cross dispersers and spectral formats available in iSHELL

By removing filters and gratings as proposed the estimated savings are about \$100k. In addition there will savings in effort by removing the *JHK* immersion grating, the grating selection mechanism, and simplifying the OS and SV filter wheels. The only other reasonable descope measure is to replace the SV filter wheel with a fixed *K* filter but at the cost of the core science of iSHELL.

There are no other viable descopes apart from fundamental changes like reducing the resolving power to make the instrument smaller or removing the foreoptics at the cost of performance and operational efficiency (no cold stop or rotator). These would changes would also lengthen the schedule which is not an option.



# **4 DESCOPED CONFIGURATION**

The proposed descoping measures are summarized as follows:

- 1. Remove *JHK* immersion grating
- 2. Remove grating selection mechanism
- 3. Reduce number of grating positions in XD wheel from 12 to 8
- 4. Reduce number of slots in SV filter wheel from 15 to 7
- 5. Reduce number of slots in OS filter wheel from 10 to 7
- 6. Make OS and SV filter wheels identical

Tables 7-11 list the proposed descoped mechanism configurations.

Table 7. Filters in the slit viewer filter wheel.

Position #	Filter	Notes
1	Blank	
2	$K_{MK}$	2.027-2.363 µm (guide)
3	$L'_{MK}$	3.424-4.124 µm (daytime comet acquisition)
4	$M'_{MK}$	4.564-4.803 μm (Jupiter acquisition)
5	continuum K	2.26 µm 1.5% (guide)
6	3.953 µm	0.5% (H <sub>3</sub> <sup>+</sup> acquisition)
7	PV lens + $nbL$	Pupil diameter 325 pixels, spatial resolution
		3.6 pixels (33 mm on primary)

#### Table 8. Slit wheel

Position #	Slit width	Slit length	R	
1	0.375"	25.0"	72,000	
2	0.75″	25.0"	39,000	
3	1.50″	25.0"	20,000	
4	4.00"	25.0"	7,500	
5	Blank-off/mirror (darks/slit-less imaging)			

#### Table 9. Slit dekker wheel

Position #	Slit length	Notes
1	Blank	For darks
2	5.0"	2.79 mm long
3	10.0"	5.57 mm long
4	15.0"	8.36 mm long
5	25.0"	13.93 mm long



Table 10.	Order	sorter	filter	wheel

Position #	Filter	Notes
1	Blank	
2	1.05-1.45 μm	J-band XD
3	1.40 <b>-</b> 1.90 μm	H-band XD
4	1.80-2.60 μm	K-band XD
5	2.70-4.20 μm	L/L'-band XD
6	4.50-5.50 μm	M-band XD
7	spare	

Table 11. List of cross dispersers and spectral formats available in iSHELL

Exp. name (Mode)	Wavelength coverage (µm)	Orders Covered	XD (line/mm)	Blaze wavel. (µm)	Blaze angle (deg.)	Order sorter (µm)	Slit length (arcsec)	XD tilt (degrees)	XD size (mm)	Custom grating?
Spare 1										
Spare 2										
H1	1.50-1.69	350-308	720	1.90	43.1	1.40-1.90	5.0	44.6	50x40	No
H2	1.61-1.82	323-289	720	1.90	43.1	1.40-1.90	5.0	47.6	50x40	-
K1	1.95-2.26	265-229	497	2.25	34.0	1.80-2.60	5.0	41.0	50x40	No
K2	2.24-2.53	231-205	497	2.25	34.0	1.80-2.60	5.0	45.8	50x40	-
L1	2.80-3.10	184-167	450	3.14	45.0	2.70-4.20	15.0	51.3	50x40	Yes
L2	3.02-3.30	171-157	450	3.14	45.0	2.70-4.20	15.0	55.0	50x40	-
L3	3.14-3.42	164-151	450	3.14	45.0	2.70-4.20	15.0	57.3	50x40	-
L4	3.28-3.67	157-141	360	3.70	42.0	2.70-4.20	15.0	48.5	50x40	No
L5	3.65-4.01	141-129	360	3.70	42.0	2.70-4.20	15.0	53.5	50x40	-
L6	3.84-4.18	134-124	360	3.70	42.0	2.70-4.20	25.0	56.2	50x40	-
M1	4.55-5.27 s	113-98	210	5.0	31.7	4.50-5.50	15.0	40.4	40x40	No
M2	4.55-5.271	113-98	210	5.0	31.7	4.50-5.50	15.0	40.4	40x40	No

The resulting spectral formats are illustrated in Figures 1-11. (See the OCDD for original spectral formats).





Figure 1. Exposure H1 (see Table 5), slit length 5", 720 line per mm grating. The box indicates the H2RG array.





Figure 2. Exposure H2 (see Table 5), slit length 5", 720 line per mm grating. The box indicates the H2RG array.





Figure 3. Exposure K1 (see Table 5), slit length 5", 497 line per mm grating. The box indicates the H2RG array.



Slit length (arcsec)= 5.0							
XD order = 1 XD blaze angle (deg)=34.00 XD blaze wavelength (micron)=2.250 XD blaze (micron)=0.1071	2 15010 -						
XD tilt $(deg) = -9.50$	2.15919	<b>\$</b>	2. (6370	240		2 16819	
XD rotation (deg) = $-0.00$	2.17698		.17260	2390		2 17714	
SIG blaze angle (dea)=71.57	2.18599		2.18157	238		2.18613	
SIG ruling (lines/micron)= 0.012500	2,19508	^	2.19061	237		2.19521	
	2.20424		2.19974	236		2,20440	
	2.21348		2.20894	<b>Q</b> 35		2.21364	
	2.22280		2.21822	234		2.22296	
	2.23220	~	2,22/58	233		2.23234	
	2.24169	V	2.24055	♦ 232		2.24183	
	2.25125		2.24000	231	$\diamond$	2.25139	
	2.26091		2.25010	230		2.26106	
	2.27064	0	2,20080	229		2.27080	
	2.28046		2.2/565	228		2.28062	
	2.29037 📢	, vv	2(28000)	♦ 227		2.29051	
	2.30037		2.29545	♦ 226		2.30053	
	2.31046		2.30550	225		2.31062	
	2.32064		2.31553	224		2.32080	
	2.33091		2.32586	♦223		2.33107	
	2.34128		2.33617	222		2.34144	
	2.35174	<b>\$</b>	2.34659	221		2.35187	
	2.36229	C	2.35709	220		2 36243	
	2 37295		236070	219 众		2 37308	
	2 39370	_	2.37840	218		2.37300	
	2,36370		2.38920	<b>0</b> 17		2.36366	
	2.39455		2.40010	216		2.39469	
	2.40550		2.41111	215		2.40566	
	2.41656	<b>\$</b>	2 42222	2100		2.41672	
	2.42772	0	2 13313	214		2.42785	
	2.43899		2.40040	213		2.43914	
	2.45036		2.444/5	210		2.45052	
	2 46184		2.45618	211		2,46200	
	2 47343		2.46772	210		2 47359	
	2.47545		2.47837	209		2.47539	
	2,48514		2.49113	200		2.48530	
	2.49696	$\diamond$	2 50300	200		2.49712	
	2.50889		2.50500	207		2.50902	
	2 52094		2.51499	206		2 52110	
	2.52331	<b>♦</b>	2.5270	205		2.52110	
	2.53311		2 5 3 9 3 3	001		2.53324	
	2.54540		2 55169	204		2.54553	
	2.55781		2.33108	203	\$	2.55797	
	2 57035		2.56416	202		2 57049	
	2.37035	٥	2.57676	204		2.37048	
	2.58301		0.500.40	20()		2.58317	
	2.59580		2.38948	200		2 59593	

Figure 4. Exposure K2 (see Table 5), slit length 5", 497 line per mm grating. The box indicates the H2RG array.



				2.00227		
Slit length (arcsec)=15.0	2.68907			200000	L193	2,68920
XD order = 1 XD blaze apple (dep)=45.00	2.70295	П		2,05009	192	2.70308
XD blaze wavelength (micron)=3.140 XD ruling (lines/micron)= 0.4504	2.71698			2.71004	191 🗖	2.71711
XD gamma (deg)= -0.00 XD rotation (deg)= -3.25	2,73116			2.72415	190 🗖	2.73132
SIG blaze angle (deg)=71.57 SIG ruling (lines/micron)= 0.012500	2,74549			2.73840	189	2.74562
	2.75997			2.75281	188 🔲	2.76013
	2.77461			2,76737	187	2.77477
	2.78941		<u>v</u>	2,78209	186	2.78954
ٳ	2.80437			2,79697	185 🔷	2.80450
	2.81950	П		2,81202	184	2.81966
	2.83479		<u> </u>	2,82782	183 🗖	2.83492
	2.85025			2.84260	182	2.85041
	2.86588		<b>\$</b>	2.85815	181 🗖	2.86601
	2.88169			2,87387	♦180 🔲	2.88182
	2,89768		\$	2,88976	179 🔷	2.89784
	2.91384			2.90584	178	2,91400
	2 9 30 20			2.92210	177 🗖 🗖	2 03032
	2,55020			2,93854	176	2.50002
	2.310/3			2.95518	175	2.54000
	2.90340	<b>\$</b>	>	2.97200	174	2.90302
	2.98038			2.98902	173	2.98054
	2.99750			3.00624	172	2.99766
	3.01482			3.02367	172	3.01495
	3.03235			3 04129	171	3.03247
	3.05008			7.05017	170 🗖	3.05024
	3,06802	٥		5.05915	1690	3.06815
	3.08618			3.07718	168	3.08630
	3 10456			3.09545	167 🗖	3 10472
L	7.10710			3.11394	166	0.10172
	3.12316			3.13265	165 🗖	3.12332
	3.14199			3 15160	100	3.14211
	3.16105			5.15100	164	3,16117
	3 18034			3,17078	163	3 19046
	5.10054			3,19019	1620	5.10040
	3.19988			7 00005		3.20000
	3.21966			3.20985	161	3.21982
				3.22975		

Figure 5. Exposure L1 (see Table 5), slit length 15", 450 line per mm grating. The short wavelength limit (about 2.80 µm) is set by the need to keep orders separated by at least 10 pixels. The box indicates the H2RG array.



	0.00700				1/9		0.00704
Slit length (arcsec)=15.0	2.89768			2.90584 🔥	178		2.89784
XD order = 1 XD blaze angle (deg)=45.00 XD blaze wavelegath (micron)=3.14	2,91384			2.92210			2.91400
XD ruling (lines/micron)= 0.4504 XD tilt (deg)= -9.50	2.93020			0.07954	177		2.93032
XD rotation (deg)= $-0.00$	2.94673			2.93034	176		2,94686
SIG ruling (lines/micron)= 0.012500	2.96346	-	A	2.95518	175		2,96362
	2,98038	~	•	2.97200	174		2,98054
	2 00750			2.98902	173		2 00786
ſ	2,99730	U		3.00624	172		2.99700
	3.01482			3,02367	171		3.01495
	3.03235			3.04129			3.03247
	3.05008			3.05013	170		3.05024
	3,06802	٥		3.03913	1690		3.06815
	3.08618			3.07718	168		3.08630
	3.10456			3.09545	167 🗖		3.10472
	7 10710			3.11394	166		7 10770
	3.12316			3,132 <mark>6</mark> 5	165		3,12332
	3.14199			3,15160			3.14211
	3,16105			7 17079	164		3.16117
	3,18034			3.17078	163		3,18046
	3.19988			3.19019	162 🗆 🔷 💠		3.20000
	7.01000			3.20985	161		7.01000
	3,21900			3.22975	100		3.21982
	3.23969			3 24991			3.23984
	3.25997		-	3,24331	159		3.26008
	3 28051		U	3.27032	158		3 28062
	0.20001			3.29099	157		0.20002
l	3.30131	\$		7 31107			3,30147
	3,32239			3,31193	156		3.32250
				3.33314	155		
	3,34373			7 35460		-	3.34389
	3.36536			0,00402	154		3.36552
				\$37639	953		
	3.38727				100		3.38743
				3.39845	152		
	3.40947						3.40963

Figure 6. Exposure L2 (see Table 5), slit length 15", 450 line per mm grating. The box indicates the H2RG array.



length (arcsec)=15.0	3.03235		3.02367	171			3.03247
order = 1 blaze angle (deg)=45.00 blaze wavelength (micron)=3.140	3.05008		3.04129	170			3 05024
ruling (línes/micrón)= 0.4504 tilt (deg)= -9.50 gamma (deg)= -0.00	3 06802	A	3.05913	1690			3 06815
notation (deg)= -2.80 blaze angle (deg)=71.57 pulses (liges (micron)= 0.012500	3.08618	~	3.07718	168			3 086 30
	3 10456		3.09545	167	]		3 10472
	3 1 2 3 1 6		3.11394	166			3 10330
Г	3.14100		3.13265	165	1		3.14211
	3.16105		3.15160	164			316117
	3.10103		3.17078	163			3,10117
	3.18034		3.19019	162>		-	3.18046
	2,19988		3.20985	161			3.20000
	3,21966		3.22975	160			3.21982
	3.23969		3.24991	159			3.23984
	3,25997		3.27032	159			3.26008
	3.28051		3.29099	150			3.28062
	3.30131	\$	3.31193	457			3.30147
	3.32239		2 22244	L156			3.32250
	3.34373		3,33314	155			3.34389
	3.36536		3.35462	154			3,36552
	3 38727		\$37639	\$53			3 38743
	0.00727		3.39845	152			5.567 15
	3.40947		3.42080				3.40963
Ļ	3.43197			151			3.43212
	3.45476		3.44344	150			3.45492
			3.46640	149			
3	5.47787		7.107.11	, 14			3,47803
	50129		3.48966	148			3 50140
			3.51324				0.00140
3	.52504			147			3.52515

Figure 7. Exposure L3 (see Table 5), slit length 15", 450 line per mm grating. The box indicates the H2RG array.



	3.12316				100		3.12332
Slit length (arcsec)=15.0	3,14199			3.132 <b>6</b> 5	165 🗖		3.14211
XD blaze angle (deg)=42.00 XD blaze wovelength (micron)=3.700 XD ruling (lines/micron)= 9.3617	3.16105			3.15160	164		3,16117
XD tilt (deg)= -9.50 XD gamma (deg)= -0.00	3.18034			3,17078	163		3.18046
SIG blaze grigle (deg)=71.57	3,19988			3.19019	162> 🗖 🔷 🔇		3.20000
SIG ruling (liñes/mičřon)= 0.012500	3.21966			3.20985	161		3.21982
	3 23969	U		3.229 <mark>75</mark>	160		3 2 3 9 8 4
	3.25997			3.24991	159		3,26008
Г	7.08051			3.27032	158		3.08060
	3.26031			3.29099	157		3,20002
	3.30131	۵		3.31193	156		3.30147
	3.32239			3.33314	155		3.32250
	3,34373			3.35462	155		3.34389
	3.36536			\$ 376 30	154		3.36552
	3.38727			ecore.	\$153		3.38743
	3.40947			3.39845	152		3.40963
	3,43197			3.42080	151		3,43212
	3 45476			3.44344	150		3 4 5 4 9 2
				3.46640	149		3.43432
	3.47787			3.48966	148		3.47803
0.2	3,50129			3.51324	140		3,50140
3	3.52504			3 5 3 7 1 5	147		3.52515
3	54911	0		0.00710	146		3,54926
3	.57351			3.56139	145		3.57362
	50825			3.58596	144		3 50841
	.55025		<	3.61088	143		3.33041
3.	62335			3.63615		L	3.62351
3.	64880			7 664 70			3.64896
3.	67461			3.00176	141		3.67477
L	70080			3.68778	140		7 70000
υ.,ι		[	2	3.71416	130		3.70090
3.7	2736	♦			LBBI		3.72746
3.7	5431			V3.74091	138		3.75447
	×			3.76806	1.37		
3.7	8166			7 70561			3.78176
3.80	0941			3.79361	136		3,80951
				3.82357	135	-	
3.83	3758 🔲 🗖				100	U	3.83768

Figure 8. Exposure L4 (see Table 5), slit length 15", 360 line per mm grating. The short wavelength limit (about 3.28 μm) is set by the need to keep orders separated by at least 10 pixels. The box indicates the H2RG array.



					3.48966	148				
length (arcsec)=15.0 order = 1	3.50129	)			3.51324				3.50140	
blaze angle (deg)=42.00 blaze wovelength (micron)=3. ruling (lines/micron)= 0.3617	700.52504				3.53715	147	[	3	3.52515	
gamma (deg)= -9.50 rotation (deg)= -0.00 rotation (deg)= -2.00	3,54911		۵		3 561 39	146			3,54926	
blaze angle (deg)=71.57 ruling (lines/micron)= 0.0125	50 <b>ð.573</b> 51				7 68506	145			3.57362	
	3.59825				3.58596	144			3.59841	
	3.62335		-	0	3.61088	143			3.62351	1
	3 64880	-		-	3,63615	142			3 64896	6
					3.66178	141			7.0717	-
	3.67461				3.68778	140			3.6747	<i>'</i>
	3,70080				3.71416	170			3.7009	0
	3.72736	\$		(	3.74091	1281			3.7274	-6
	3.75431	٥			7 70502	138			3.7544	47
27.	3.78166				3,76806	137			3.7811	76
	3.80941	-			3,79561	136			3,809	51
					3.82357	135				
-	5.83758				3.85195	134			3.857	68
: 3	.86617				3 88076	1,04			3.866	532
3	.89519		~		0.000	133			3.89	534
3	92465		· · ·	<b>\$</b>	3.9100 <mark>0</mark>	132			3.92	475
					3.93969	131				
3.	95457				3.96984				3.95	467
3.	98495					130		E	3.98	3511
44	11581			U	4.00046	129			40	1500
					4.03156				4.0	1330
4.0	4715			•		128			4.0	4730
	7900			•	4.06314	127			4.0	7000
4.0	1099				4.09524				4.0	/908
4,1	1133				L	126			4.1	1142
					4.12784	105				
4.14	4420					125		٥	4.	14429
					4.16098					

Figure 9. Exposure L5 (see Table 5), slit length 15", 360 line per mm grating. The box indicates the H2RG array.





Figure 10. Exposure L6 (see Table 5), slit length 25", 360 line per mm grating. The short wavelength limit (about 3.81 µm) is set by the need to keep orders separated by at least 10 pixels. The box indicates the H2RG array.



									_	
Slit length (arcsec)=15.0 4.246	05	_		4.22888	122			4.248	514	
XD order = 1 XD blaze apple (deg)=31.704.281	14	— — <b>—</b> —		4,26367	121			4,28	129	
XD bloze wovelength (micron)=5.0 XD ruling (lines/micron)= 0.4.5088	00 31			4,29905	120		<u>ہ</u>	4.31	689	
XD gamma $(deg) = -0.00$ XD rotation $(deg) = -0.00$ 4.3530	8			4,33502	119			4.35	5323	
SIG blaze angle (deg)=71.57 SIG ruling (lines/micron)= 0:0929	do			4.3/160	118			4.39	3005	
4.42750	D			4,40881	117			4,4	2758	
4,46568				4.44667	116			4,4	6576	
4.50453				4.46316	115			4.5	50460	
4.54406				4.32437	114			4.	.54421	
4.58430				4.06426	113			4	.58445	
4 62526				4.60485	112			4	.6254	
4.66696	000			4.64619	111			4	4.6670.	5
4.70943		_		4.68827	110				4.7095	8
4.75268	_	<u> </u>		4,73113	109				4.7528	3
4.79674		~		4,77479	108			0	4,796	89
4 81163				4.81926	107				4 841	79
4.04100				4.86457	106				4.04	70
4.88/3/				4.91075	105				4.88	/52
4.93398				4.95782		-			4.93	404
4,98150			Ø	5 00590	104				4.98	165
5.02995			-	5.00560	103				5.0	3010
5.07935				5.05473	102				5.0	7941
E 10021				5.10463	101		1			0070
5.12974				5.15552	100				5.	2979
5,18115				5 20745	100				5	18120
5.23360				5,20745	99				5	.23375
E 0074 E				5.26044	98					
5.28713				5.31452						.28/28
5.34177					9/				-	5.34181
5 30755				5.36973	96		C			5 30770
0.09700				5.42611						5.55770
5.45452					95					5.45455
		-		5.48369	94					
5.51271				5.5/251						5.51286
5.57216				5.5+251	93					5.57219

Figure 11. Exposures M1 (black box) and M2 (blue box) (see Table 5), slit length 15", 210 line per mm grating. The short wavelength limit (about 4.55 µm) is set by the need to keep orders separated by at least 10 pixels. The boxes indicates the



H2RG array. To cover the full FSR two exposures are required with two different XD gratings (same grating in different slots but with different tilts in the dispersion direction).