RIMAS: Testing, and Categorization of Grism Spectral Performance

Joseph Durbak[a], Alexander S. Kutyrev[ab], Sylvain Veilleux[a], Gregory Mosby[b], Gennadiy N. Lotkin[b], Jillian Kunze[a], Kenichi Sakai[bc], John I. Capone[ad], Vicki L. Toy[a], and Paul J. Kuzmenko[e]

[a]University of Maryland-College Park,4296 Stadium Dr, College Park, MD 20742
[b]NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD, 20771
[c]University of Maryland-Baltimore County, 1000 Hilltop Cir, Baltimore, MD 21250
[d]University of Oxford, Parks Rd, Oxford OX1 3PJ, United Kingdom
[e]Lawrence Livermore National Lab., L-183 PO Box 808, Livermore, CA 94551

ABSTRACT

The Rapid infrared IMAger Spectrometer (RIMAS) is designed to quickly follow-up near-infrared (NIR) transient events, gamma ray bursts in particular. One way RIMAS will accomplish this mission is with its echelle spectrograph (R≈4000) that contain the first ruled grisms to be used in cross-dispersed mode for NIR astronomy. These ZnSe grisms were recently fabricated at Lawrence Livermore National Lab. This paper discusses the testing and categorization of the echelle spectrographs containing these grisms by comparing the modeled spectra to experimental spectra. This testing resulted in verification of the echelle spectrograph's quality, resolution, and dispersion. Efforts to develop a data reduction pipeline and upgrade RIMAS's detectors are ongoing.

Keywords: grism, NIR, near-infrared, spectroscopy, immersion grating, echelle, cross-dispersed

1. INTRODUCTION

Rapid infrared IMAger Spectrometer (RIMAS) is a flexible tool for a variety of imaging and spectroscopic studies that require fast reaction, such as GRB afterglows, in the near infrared (NIR).[1] It acquires these observations using the Lowell Discovery Telescope (LDT), a 4.3 m telescope operated by Lowell Observatory in Happy Jack, Arizona.[2]

RIMAS is a fully cryogenic instrument operating along two optical arms one covering H and K bands (HK) and the other covering Y and J bands (YJ). RIMAS is designed for photometry, low resolution spectroscopy ($R \approx 25$), and moderate resolution spectroscopy ($R \approx 4000$). It accomplishes this using a continuously running Gifford-McMahon cryocooler, a dichroic mirror, H, K, Y and J broadband filters, two VPHs, ZnSe grisms with cross-dispersers, and H2RG detectors, shown in Fig. 1. RIMAS is a flexible tool with both imaging and spectral modes available.[1345]

The most notable new step in RIMAS's development is the completion of the ZnSe grisms (Fig. 2) by Paul Kuzmenko at LLNL.[6] Although JWST's NIRSpec,[7] IGRINS,[8] and other ground instruments perform cross-dispersed spectroscopy in the NIR, RIMAS will be the first NIR spectrograph to use ruled grisms in cross-dispersed mode for astronomy. This paper will discuss the first results in characterization of the moderate resolution spectroscopy mode that is accomplished using ZnSe grisms along with VPH grating cross-dispersers.

Further author information: (Send correspondence to Joseph Durbak)
Joseph Durbak: E-mail: jmdurbak@terpmail.umd.edu, Telephone: 1 301 286 4504

Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation IV, edited by Ramón Navarro, Roland Geyl, Proc. of SPIE Vol. 11451, 114515Y
 · doi: 10.1117/12.2561876

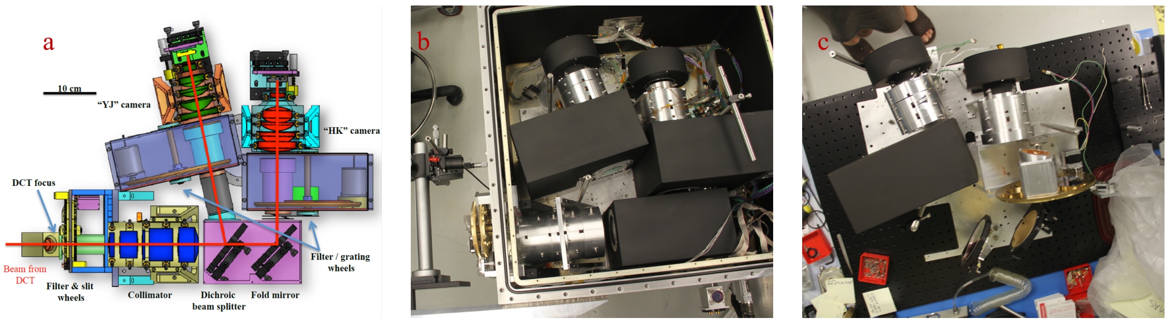

Figure 1. RIMAS instrument (a) annotated model, (b) fully assembled in dewar, and (c) removed from dewar with some baffling removed.

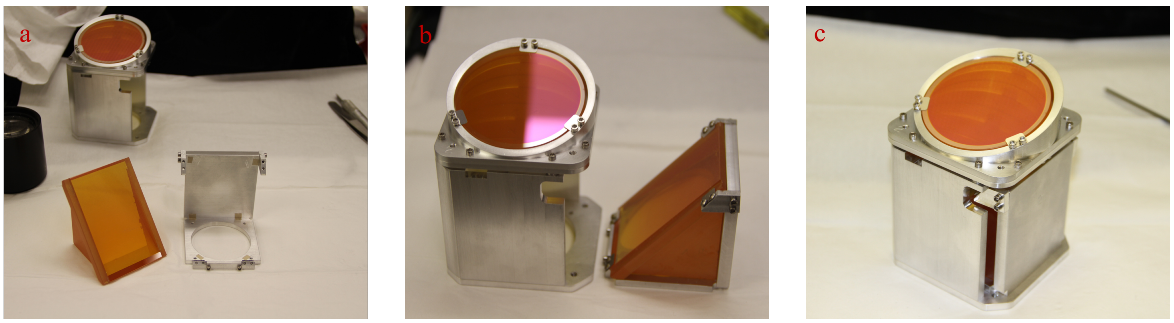

Figure 2. RIMAS echelle assembly. (a) Shows an unmounted grism in the foreground, and mounted cross-disperser in the background. (b)(c) Show a completed echelle assembly.

2. METHODS

Spectral images of thermal sources along with Ar, Xe, Kr, and Hg low pressure gas-discharge lamps[9] were acquired using a 150 micron (1.2 arcsecond) slit with the instrument kept at cryogenic temperatures near 80K (Fig. 3). As can be seen in these images, the detectors have degraded, and have a large dark current, however, we are able to do a few tests despite this issue. The spectral images were inspected for reflected lines by scaling, rotating and translating modeled spectra, and overlaying the modeled and experimental spectra as shown in Fig. 4. One-dimensional spectra were generated from these images using the simple approach of aligning a wavelength map (Fig. 5) generated in Zemax using the transformation parameters calculated in Fig. 4 to determine the wavelength of individual pixels. The result, and comparison to the NIST library spectrum[10] can be seen in Fig. 6. More lamp spectra can be found in Appendix A.1.

3. RESULTS

With RIMAS's degraded H2RG detectors, and a rudimentary data reduction method, a number of characteristics of the grisms can be explored. First, it is confirmed that the echelle spectra are consistent with the theoretical spectra from our modeling as shown in Fig. 4, and that the spectrograph can reproduce the NIST library spectrum,[10] although with different excitations due to the lamp type. A further exploration of the library spectrum comparison can be found in Fig. 7, where the relative error had been quantified. Second, the $\Delta\lambda$, the smallest difference in wavelengths that can be distinguished at a wavelength λ, in the echelle spectrum is noticeably smaller than the R$\approx$300 spectrum that was acquired using the cross-dispersing VPH grating in Fig. 2 without the grism. Although it is difficult to make a precise calculation of R with the current detectors and data reduction method, it is notable that the lines in the images are 2-3 pixels wide as expected, suggesting that R$\approx$4000 as designed. This will likely improve when we have a data reduction pipeline that accounts for the tilt of the slit, and better detectors to improve focusing. Installation of improved detectors, and development of a data reduction pipeline using the IGRINS pipeline[12] is currently underway. Third, the detectors do not allow for a

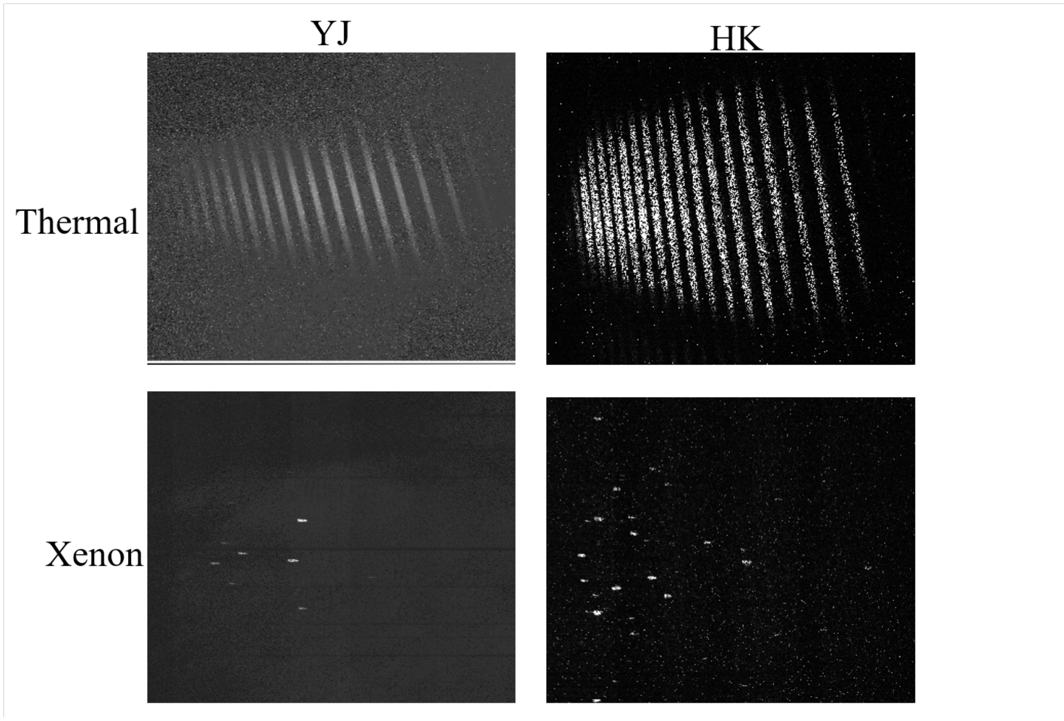

Figure 3. Spectra of a thermal source and a xenon arc lamp in both YJ and HK bands with dark frames subtracted.

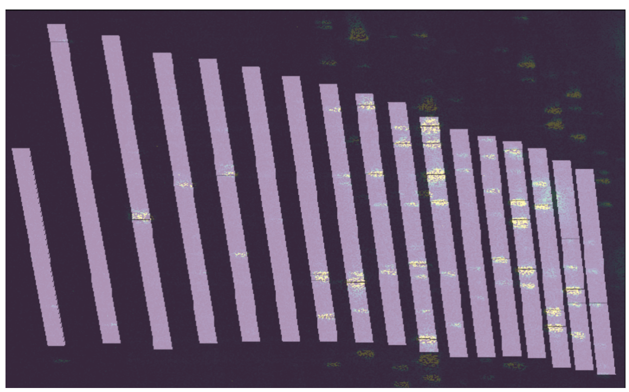

Figure 4. HK krypton arc lamp spectra with modeled version overlaid in order to match the echelle orders.

quantitative analysis, but qualitatively it is confirmed that the grisms produce a high contrast spectrum. There is no evidence of noticeable wings, scattered light or ghosts around even the brightest lines. This confirms the high quality of the grism fabrication. Finally, in Fig. 11 it can be seen that very little light appears outside of the central envelope in the HK spectrum. This shows the blaze angle to consistent with the design. Unfortunately, it is difficult to make the same assessment of the YJ spectrum in Fig. 10 because the quality of the detectors are heavily degraded outside of the central envelope.

4. CONCLUSIONS

The first ruled grisms to be used in cross-dispersed mode for NIR astronomy have been fabricated for RIMAS.[6] The grisms were tested in echelle mode with VPH gratings as cross-dispersers by collecting spectra from low pressure gas discharge lamps and thermal sources. Initial tests show that the experimental spectra match the models' predicted dispersion, and resolution. These tests also show no evidence of artifacts such as ghosting and

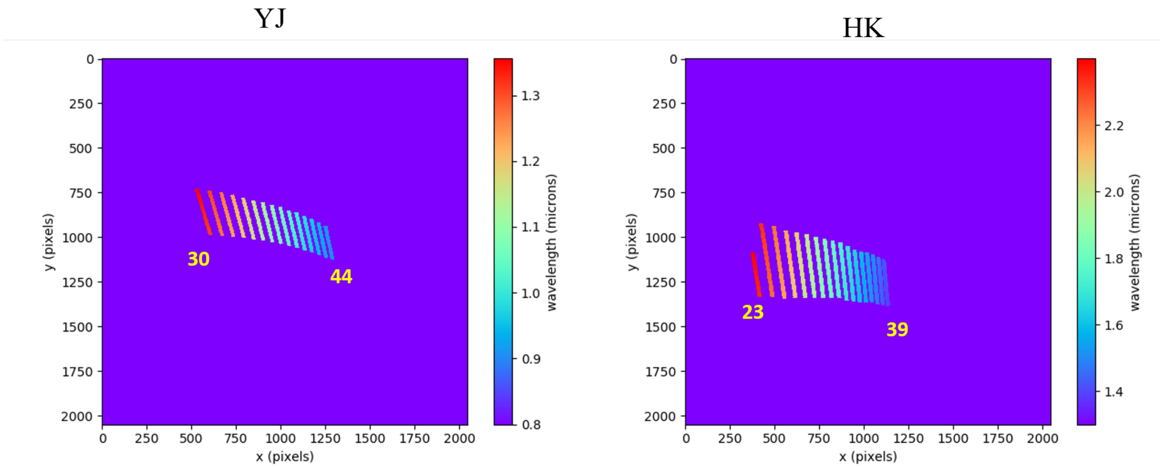

Figure 5. Echellograms for both YJ and HK detectors showing the corresponding wavelength for each pixel location. The limiting orders are labeled, and more information about the wavelengths in each order can be found in Table 1 and Table 2

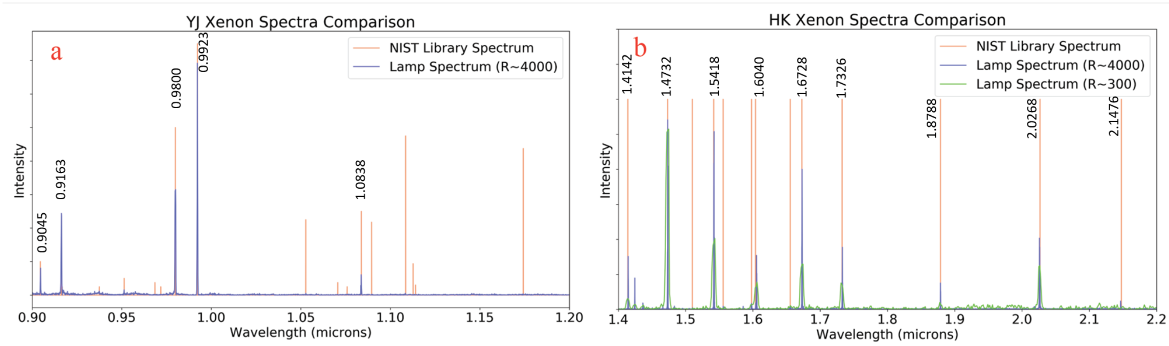

Figure 6. Reduced echelle spectrum of a Xenon lamp shown alongside the NIST library spectrum[10] for reference for both the (a) YJ and (b) HK bands. The HK spectrum also shows the R≈300 spectrum generated using the cross-dispersing VPH grating without the grism present.[11]

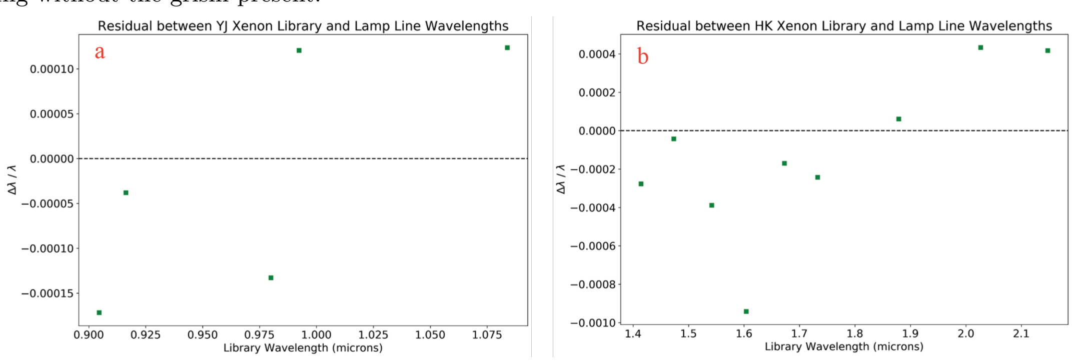

Figure 7. Relative error for Xenon between NIST library spectrum[10] and RIMAS experimental spectrum for both (a) YJ and (b) HK echelle spectra.[11]

scattered light, suggesting high quality grism fabrication. However, both the data reduction pipeline and our detectors need to be upgraded in order to perform a more rigorous tests and analysis. Both of these upgrades are currently under development, and should be completed soon.

APPENDIX A. ADDITIONAL DATA

A.1 ADDITIONAL LAMP SPECTRA

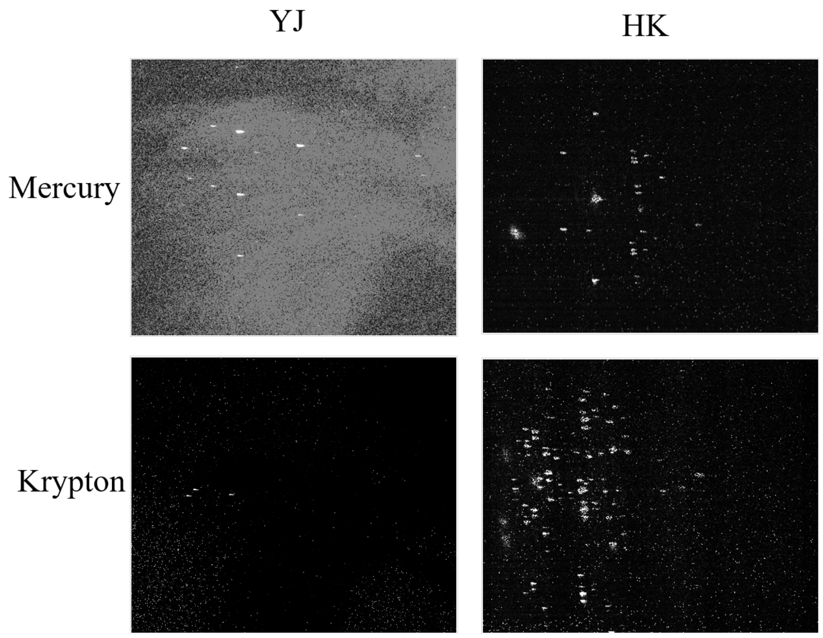

Figure 8. Spectra of mercury and krypton lamps in both YJ and HK bands with dark frames subtracted.

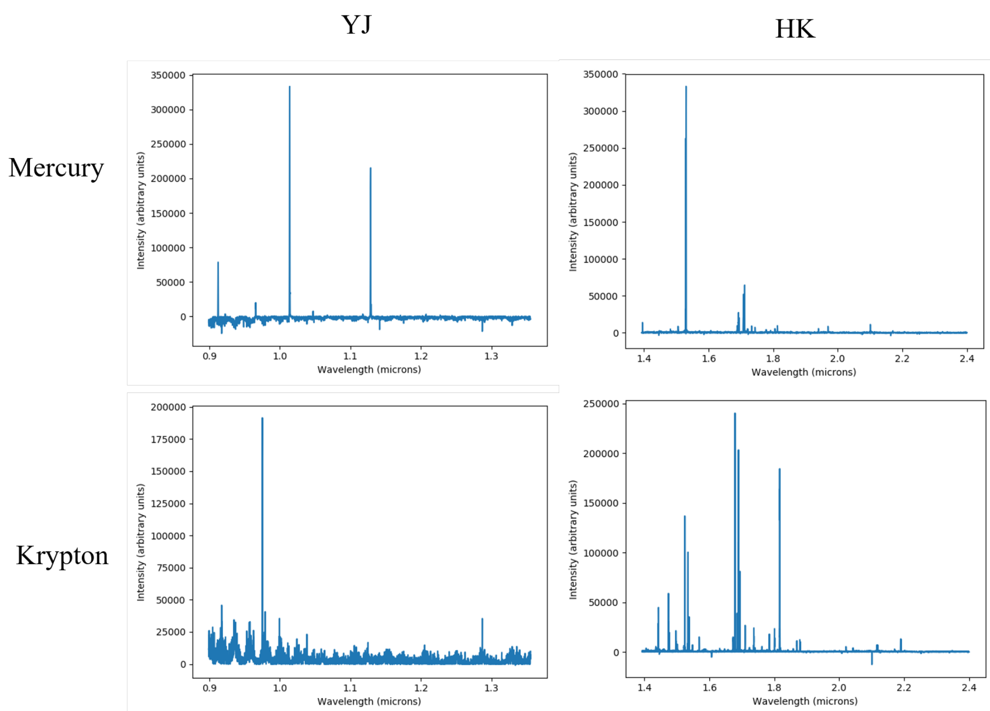

Figure 9. Reduced spectra of mercury and krypton low pressure gas discharge lamps generated from the images in Fig. 8 using the wavelength maps in Fig. 5

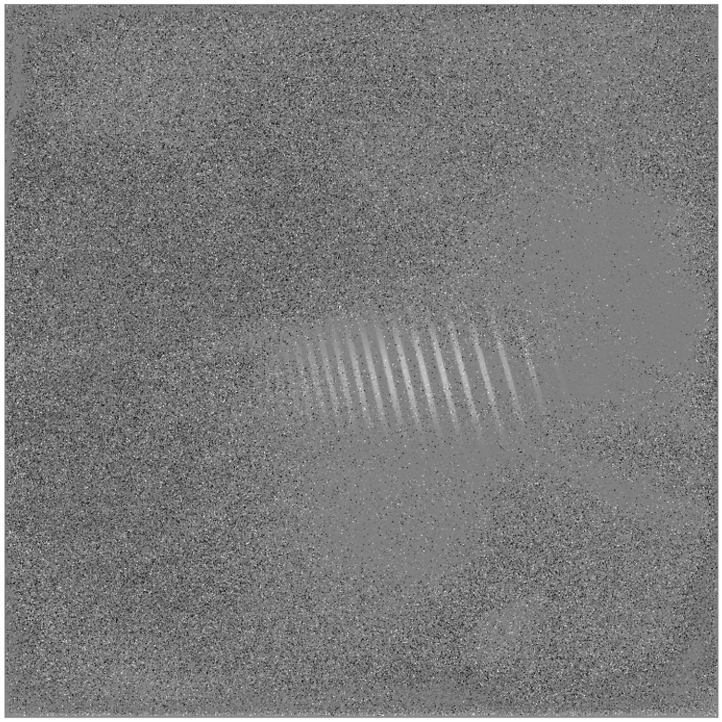

Figure 10. Spectrum of thermal source on the YJ detector, showing the full array.

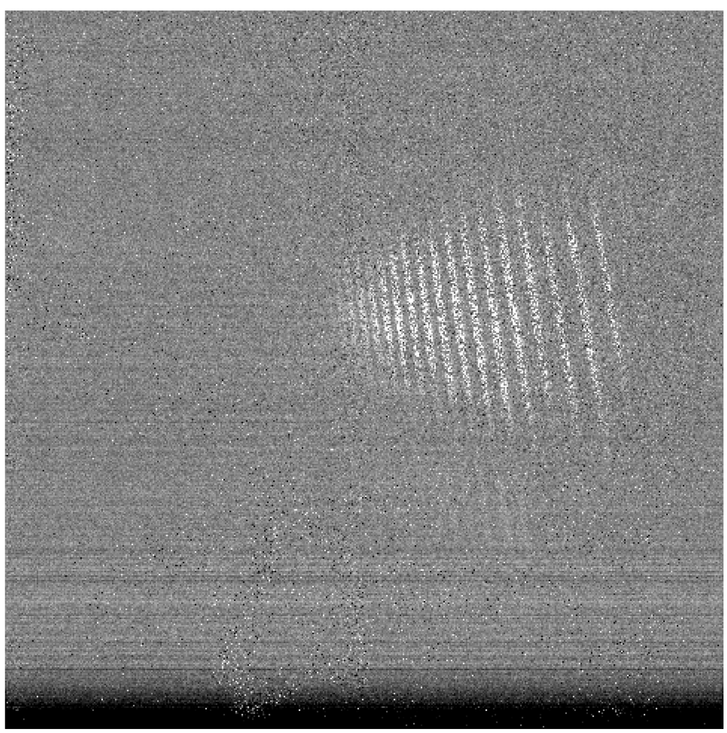

Figure 11. Spectrum of thermal source on the HK detector, showing the full array.

A.2 2D IMAGE PARSING TABLES

Table 1. Wavelength range for each order on the YJ echellogram in Fig. 5.[11]

	YJ Band	
Order #	**Starting Wavelength (μm)**	**Ending Wavelength (μm)**
44	0.898	0.919
43	0.919	0.941
42	0.941	0.964
41	0.964	0.9875
40	0.9875	1.013
39	1.013	1.039
38	1.039	1.067
37	1.067	1.0957
36	1.0957	1.127
35	1.127	1.159
34	1.159	1.194
33	1.194	1.231
32	1.231	1.27
31	1.27	1.3111
30	1.3111	1.3556

Table 2. Wavelength range for each order on the HK echellogram in Fig. 5.[11]

	HK Band	
Order #	**Starting Wavelength (μm)**	**Ending Wavelength (μm)**
39	1.3922	1.4283
38	1.4283	1.466
37	1.466	1.507
36	1.507	1.549
35	1.549	1.593
34	1.593	1.64
33	1.64	1.691
32	1.691	1.7456
31	1.7456	1.803
30	1.803	1.864
29	1.864	1.929
28	1.929	1.999
27	1.999	2.074
26	2.074	2.154
25	2.154	2.2439
24	2.2439	2.339
23	2.339	2.4

Table 3. This table contains the the information used to compare the NIST library,[10] the models generated from Zemax, and the experimental data for the YJ spectrograph.[11]

Library Wavelength (µm)	**Library Intensity**	**Lamp Wavelength (µm)**	**Lamp Intensity**	**xmodel (pixel #)**	**ymodel (pixel #)**	**xlamp (pixel #)**	**ylamp (pixel #)**
0.9045	400	0.9047	160939	1378	868	1278	974
0.9163	500	0.9163	487403	1356	974	1257	1085
0.9168	100	-	-	-	-	-	-
0.9375	100	-	-	-	-	-	-
0.9513	200	-	-	-	-	-	-
0.9685	150	-	-	-	-	-	-
0.9718	100	-	-	-	-	-	-
0.98	2000	0.9801	629744	1251	992	1146	1100
0.9923	3000	0.9922	1383916	1231	909	1126	1013
1.0528	900	-	-	-	-	-	-
1.0707	150	-	-	-	-	-	-
1.0759	100	-	-	-	-	-	-
1.0838	1000	1.0837	121163	1085	1031	973	1137
1.0895	870	-	-	-	-	-	-
1.1085	1900	-	-	-	-	-	-
1.1127	375	-	-	-	-	-	-
1.1141	120	-	-	-	-	-	-
1.1742	1750	-	-	-	-	-	-

Table 4. This table contains the the information used to compare the NIST library,[10] the models generated from Zemax, and the experimental data for the HK spectrograph.[11]

Library Wavelength (µm)	**Library Intensity**	**Lamp Wavelength (µm)**	**Lamp Intensity**	**xmodel (pixel #)**	**ymodel (pixel #)**	**xlamp (pixel #)**	**ylamp (pixel #)**
1.4142	80	1.4146	75655	1364	988	1119	824
1.4732	200	1.4733	270531	1322	892	1074	722
1.51	100	-	-	-	-	-	-
1.5418	110	1.5424	253981	1273	1072	1021	918
1.5557	150	-	-	-	-	-	-
1.5979	250	-	-	-	-	-	-
1.604	100	1.6055	77016	1228	922	973	764
1.6555	125	-	-	-	-	-	-
1.6728	5000	1.6731	200015	1180	1044	925	888
1.7326	1650	1.733	88595	1137	1092	879	940
1.8788	860	1.8787	37602	1036	951	768	788
2.0268	2300	2.0259	101740	933	1004	656	845
2.1476	140	2.147	11868	850	1149	571	1050
2.2624	90	-	-	-	-	-	-
2.3286	110	-	-	-	-	-	-

REFERENCES

[1] Capone, J., Content, D., Kutyrev, A., Veilleux, S., Moseley, S., and Gehrels, N., "RIMAS - Optical Design Development of the Imager/Spectrometer for the Discovery Channel Telescope," in [*American Astronomical Society Meeting Abstracts #219*], *American Astronomical Society Meeting Abstracts* **219**, 446.14 (Jan. 2012).

[2] Jacoby, G. H., Bida, T. A., Fischer, D., Horch, E., Kutyrev, A., Mace, G. N., Massey, P., Roe, H. G., and Prato, L. A., "Instruments at the Lowell Observatory Discovery Channel Telescope (DCT)," in [*American Astronomical Society Meeting Abstracts #229*], *American Astronomical Society Meeting Abstracts* **229**, 155.02 (Jan. 2017).

[3] Capone, J. I., Content, D. A., Fox, O. D., Gehrels, N. A., Kutyrev, A. S., Lotkin, G. N., Moseley, S. H., Robinson, F. D., Toy, V. L., Veilleux, S., and Vogel, S. N., "The development and analysis of cryogenic optical systems for the rapid infrared imager/spectrometer," in [*Cryogenic Optical Systems and Instruments 2013*], Heaney, J. B. and Kvamme, E. T., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **8863**, 88630D (Sept. 2013).

[4] Capone, J. I., Content, D. A., Kutyrev, A. S., Robinson, F. D., Lotkin, G. N., Toy, V. L., Veilleux, S., Moseley, S. H., Gehrels, N. A., and Vogel, S. N., "Cryogenic optical systems for the rapid infrared imager/spectrometer (RIMAS)," in [*Ground-based and Airborne Instrumentation for Astronomy V*], Ramsay, S. K., McLean, I. S., and Takami, H., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **9147**, 914736 (July 2014).

[5] Kutyrev, A., Toy, V., Veilleux, S., Capone, J., Robinson, F. D., Lotkin, G. N., Moseley, S. H., Gehrels, N., and Vogel, S. N., "RIMAS - rapid reaction near infrared imager-spectrometer," in [*American Astronomical Society Meeting Abstracts #223*], *American Astronomical Society Meeting Abstracts* **223**, 148.01 (Jan. 2014).

[6] Kuzmenko, P. J., Little, S. L., Kutyrev, A. S., and Hunter, M., "Machining of ZnSe grisms for the Rapid Infrared Imager Spectrograph (RIMAS): effect of diamond crystal orientation," in [*Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation III*], Navarro, R. and Geyl, R., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **10706**, 1070659 (July 2018).

[7] Posselt, W., Holota, W., Kulinyak, E., Kling, G., Kutscheid, T., Le Fevre, O., Prieto, E., and Ferruit, P., "NIRSpec: near-infrared spectrograph for the JWST," in [*Optical, Infrared, and Millimeter Space Telescopes*], Mather, J. C., ed., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **5487**, 688–697 (Oct. 2004).

[8] Moon, B., Wang, W., Park, C., Yuk, I.-s., Chun, M.-Y., and Jaffe, D. T., "Immersion grating mount design for IGRINS and GMTNIRS," in [*Modern Technologies in Space- and Ground-based Telescopes and Instrumentation II*], Navarro, R., Cunningham, C. R., and Prieto, E., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **8450**, 845048 (Sept. 2012).

[9] "Typical spectra of oriel instruments spectral calibration lamps," (Aug 2012).

[10] Kramida, A. and Ralchenko, Y., "Nist atomic spectra database, nist standard reference database 78," (1999).

[11] Kunze, J., *Calibration and Data Simulation for RIMAS, the Rapid Infrared Imager - Spectrometer*, Undergraduate thesis (2020).

[12] Sim, C. K., Le, H. A. N., Pak, S., Lee, H.-I., Kang, W., Chun, M.-Y., Jeong, U., Yuk, I.-S., Kim, K.-M., Park, C., Pavel, M. D., and Jaffe, D. T., "Comprehensive data reduction package for the Immersion GRating INfrared Spectrograph: IGRINS," *Advances in Space Research* **53**, 1647–1656 (June 2014).