W. M. KECK OBSERVATORY

Note on OSIRIS Wavelength Calibrations

D. Le Mignant, Oct. 5, 2007

1. Observations and data reduction

In this short note, we report on some on-going analysis of OSIRIS data in an effort to document our wavelength (hence radial velocity) budget error for the kinematics of the Egg nebula (through the H2 2.1218 μm emission line). We have analyzed K-band OH airglow emission lines and we are reporting on some aspects of OSIRIS wavelength calibrations: residuals of the wavelength solution, variation in the spatial dimension of the spectral resolution and some "fringe pattern" in the spatial dimension that may be seen through some narrow emission lines.
The data used for the analysis was recorded on Sept. 3, 2007 UT with the OSIRIS instrument (Larkin et al. 2006) in LGS-AO mode and consist of three data cubes (data set #44, 45 and 47) in Kn2 filter, 100 mas scale. Each of the cube is a 600 second integration, recorded at 09:11, 09:44 and 10:30 UT respectively.
Each cube was reduced using the OSIRIS data reduction pipeline (June 2007, v2.1 release): a master 600 sec. dark was created combining 8 dark frames. The 600 sec master dark was then subtracted from the sky cube in the DRP. No atmospheric dispersion correction was applied to the final cube. We corrected for very noisy pixels (sigma >10 from surrounding pixels) in each final output reduced cube using IDL routines.

2. Thermal and OH airglow emission spectrum

Fig. 1 (left) shows the average of the three spectra extracted from the cubes. The OH airglow lines are superimposed on the thermal background emission. The intensity of the emission from the thermal component doubles from 2.04 to 2.14 microns. We observed intensity variations in the continuum as well as in the OH lines between two sky data sets that were taken 100 min apart. This illustrates and emphasizes the need for estimating and subtracting the continuum and the OH-residuals in the target data cube.

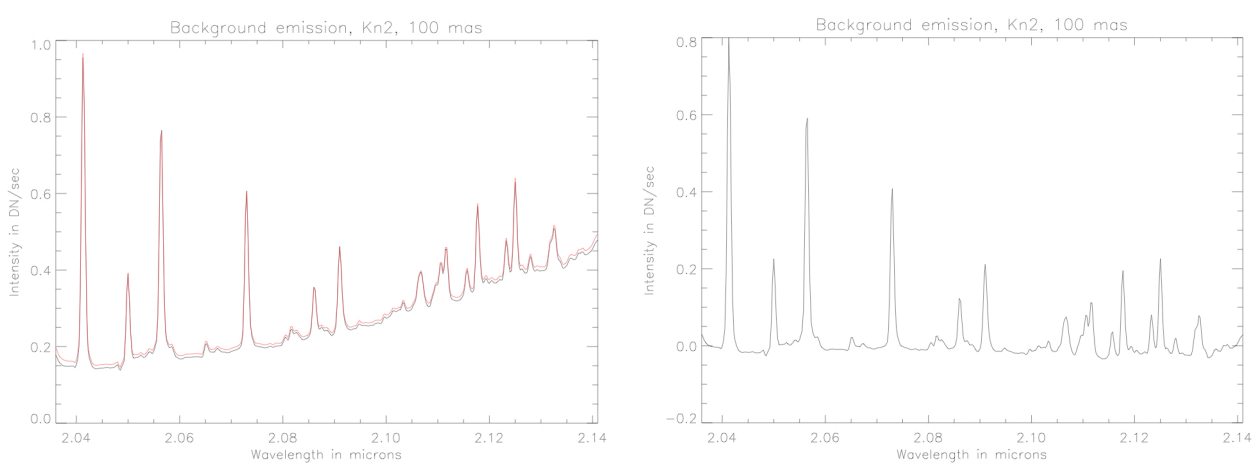

Figure 1: Left: Spectrum of the data set #44 (black line), and data set #47 (red).
Right: Continuum subtracted OH airglow spectrum in Kn2.

The right plot in Figure 1 shows a continuum subtracted spectrum. The intensity ratios for the OH lines used for our spectral calibrations (see Table 1) vary from 1 to 4.

3. Residuals for the wavelength solution

Rousselot et al.[2] (2000) presented a night-sky spectral atlas of OH-emission lines. The line wavelengths are composed from laboratory and are given in vacuum. Oliva & Origlia (1992) also identified OH airglow lines suitable for (air) wavelength calibrations in the near-infrared[3].

We have used Rousselot et al. data to identify the OH lines in our Kn2 band spectra. The lines are OH roto-vibrational P and R transitions. The lines noted with a * subscript correspond to OH lines that consist of an unresolved lambda-doublet separated by more than 0.1 nm: for these we have used the arithmetic mean of the wavelength. The selected calibration lines are listed in Table 1 where the 1st row is the transition and the second row the vacuum wavelength from Rousselot et al. (2000).

Table 1: Wavelength calibrations for the Kn2 band using vacuum OH emission lines from Rousselot et al. (2000).

Transition[2]	8-6 $P_1(3.5)$	8-6 $P_2(3.5)$	8-6 $P_1(4.5)^*$	8-6 $P_1(5.5)^*$	8-6 $P_2(5.5)$	8-6 $P_1(6.5)^*$	9-7 $R_1(2.5)$	9-7 $R_1(1.5)$
λ_{vac} [2] (nm)	2041.268	2049.936	2056.355*	2072.901*	2086.025	2090.957*	2117.656	2124.959
λ_{vac} data	2041.32	2050.00	2056.41	2072.97	2086.11	2091.05	2117.74	2125.02
Res. (nm)	0.05	0.06	0.055	0.07	0.085	0.09	0.084	0.06

The third row lists the average values from the measured central wavelength (using a Gaussian line fit, under the splot IRAF routine) for the sky data sets, after continuum subtraction. The relative error in our method to estimate the central wavelength for the OH emission lines is 0.01 nm. The fourth row of Tab. 1 gives the accuracy of the wavelength solution using the data from Rousselot et al. as a reference.
We find that the absolute wavelength solution from the OSIRIS DRP is very good (1/4 of a pixel), yet slightly overestimates the wavelength in the Kn2 wavelength range by an average of 0.07 nm. Once corrected for this offset, the absolute accuracy for the wavelength solution is better than 3 km/s.

4. Wavelength calibration variations in the spatial dimension.

For a subset of OH lines, we have estimated the mean and the standard deviation over the OSIRIS spaxels for i) the central wavelength, ii) the spectral resolution (here defined by the FWHM of the Gaussian fit) and iii) the integrated flux. We used the IDL routine mpfit (to fit the line profile), wrapped with an IDL routine that reduces the effect of noisy pixels (by using a spatial box average of 2 x 2 spaxels for each spaxel)©. The results are presented in Tab. 2.

Table 2: Wavelength calibrations for the Kn2 band using vacuum OH emission lines from Rousselot et al. (2000).

Transition[2]	8-6 $P_1(3.5)$	8-6 $P_1(4.5)^*$	8-6 $P_1(5.5)^*$	8-6 $P_1(6.5)^*$	9-7 $R_1(2.5)$	9-7 $R_1(1.5)$
λ_{vac} data	2041.32	2056.41	2072.97	2091.05	2117.74	2125.02
σ_λ (nm)	0.02	0.04	0.03	0.03	0.02	0.03
FWHM (nm)	0.81	0.79	0.79	0.86	0.71	0.69
σ_{FWHM} (nm)	0.08	0.07	0.08	0.09	0.06	0.05
Flux (DN/sec)	0.63	0.48	0.34	0.19	0.16	0.16
σ_{flux} (DN/sec)	0.07	0.02	0.01	0.01	0.02	0.02

© The line profile fitting routine mpfit.pro is available from the IDL astro package. The routine o_extract_ap.pro to deal with noisy pixels was provided by T. Do while the general wrapper o_line_mpfit.pro was written by D. Le Mignant. These routines may be available to the OSIRIS user through the Keck web page?

The standard deviation for the estimate of the central wavelength is equal or less than 0.04 nm (1/6 of a pixel) and corresponds well to the value quoted in the OSIRIS Manual by Larkin et al. (2007)[4]. The peak-to-valley (PTV) value for the wavelength shifts equals 0.15 nm (1 pixel). Figure 2 shows the residuals shift for the six selected OH lines.

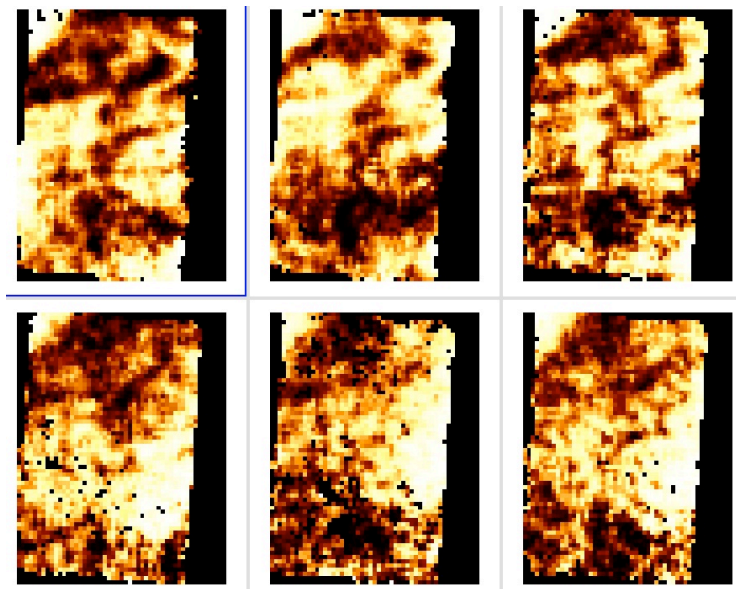

Figure 2: Residual shifts for the wavelength solution. The wavelength values follow the order from Table 2, namely, from left to right and top to bottom: 2041.32, 2056.41, 2072,97, 2091.05, 2117.74 and 2125.02 nm. The rms for the shifts is less than 0.04 and the PTV less than 0.15.

The spectral resolution through the Kn2 band has been estimated from the FWHM of the OH lines and is less than 0.8 nm, leading to a spectral resolution ($R = \lambda/FWHM$) between 2,500 and 3,000 (increasing with wavelength?).

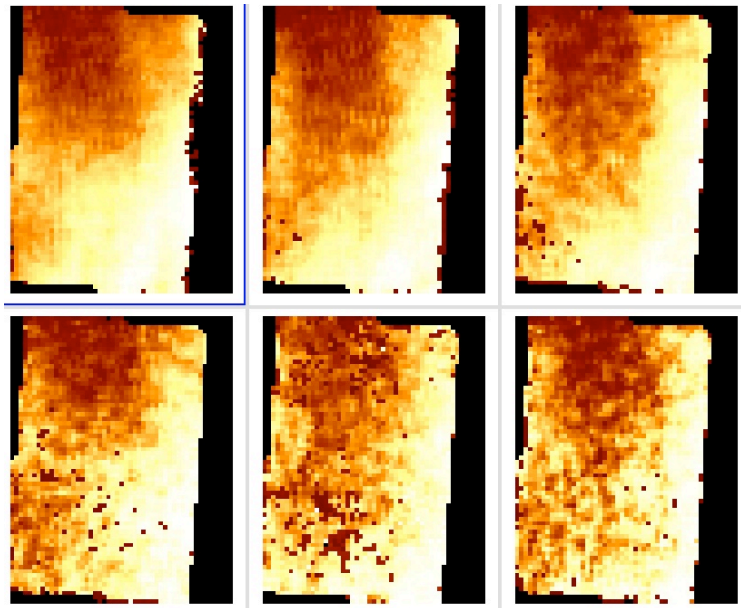

Figure 3: FWHM for the selected OH lines. The wavelength values follow the order from Table 2, namely, from left to right and top to bottom: 2041.32, 2056.41, 2072,97, 2091.05, 2117.74 and 2125.02 nm. The FWHM are indicated in Table 2. The rms for the FWHM is less than 0.09 and the PTV equals to 0.25.

The integrated flux through the Kn2 band has been estimated for each of the OH lines and is tabulated in Tab. 2. The standard deviation for the flux remains at less than 1% of the total flux in DN/sec. We show in Fig. 4 the flux variation for each OH line, using a histogram equalization scale. The fringe pattern is quite obvious for the four OH lines closer to the edge of the Kn2 filter: 2.041, 2.056, 2.118 and 2.125 μm. The PTV for the fringe pattern is ~0.20 of the max intensity. Some fringe pattern may be present for the other OH lines. S. White and J. Larkin® suggested that the fringes are created by a Fabry-Pérot effect.

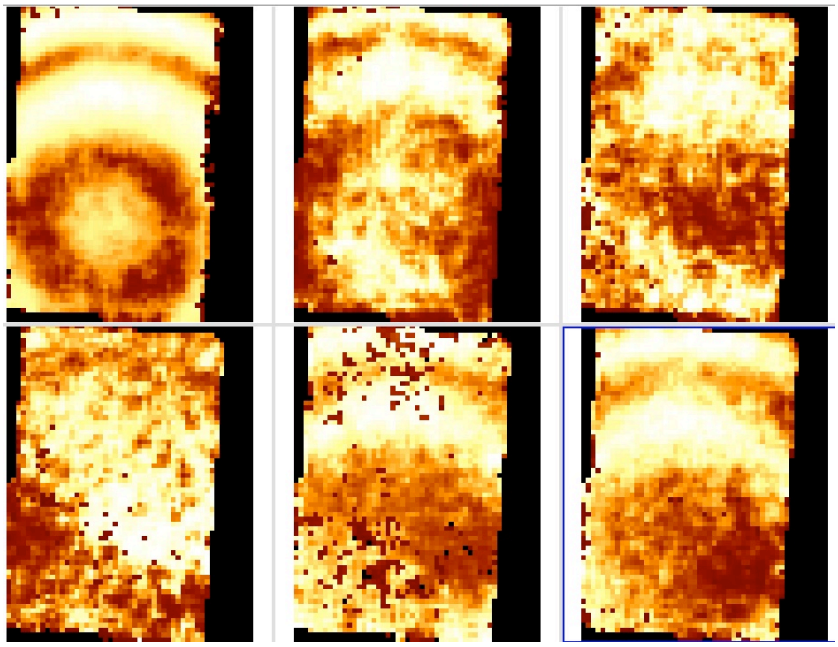

Figure 4: Integrated flux for the selected OH lines. The wavelength values follow the order from Table 2, namely, from left to right and top to bottom: 2041.32, 2056.41, 2072,97, 2091.05, 2117.74 and 2125.02 nm. The flux values are indicated in Table 2. The rms for the flux is less than 1% of the total flux. The images are displayed using a histogram equalization. The PTV value for the fringes is 0.20 of the maximum intensity.

5. Conclusions

We have analyzed the wavelength calibrations for OSIRIS in the Kn2, 100 mas configuration in an attempt to document the velocity incertitude for the astronomical H2 emission line. We have found that i) as suggested by many, we need to correct for the residual thermal and OH airglow emission in the object data cube, ii) the absolute wavelength solution has an average wavelength offset of 0.07 nm with an average error of 0.02 nm (~ 3 km/s), iii) the spatial wavelength shifts remain very small, below 0.04

® From J. Larkin (09/25/2007): I think Shelley's suggestion of a Fabry-Pérot effect is correct. Your line at 2.0412 microns is right at the edge of the Kn2 filter at very close to the 50% power point of the filter. So the filter is a very effective optical cavity so the transmission at those wavelengths has an angular dependency. It's in a collimated space, but of course different field points are passing through the filter at different angles (all rays from a single field point are going through at the same angle which is why the interference is so noticable). So they will have variable transmission as a function of angle in collimated space, which corresponds to variable transmission as a function of position in the focal plane. The same thing happens in slit spectrographs and cameras but most people either don't look closely at the emission lines from the sky at the extremes of the filter, or in imagers the effect is swamped by the majority of light from the middle of the filter. In all instruments it can have a scientific impact that most people overlook. At least OSIRIS lets you find and characterize it easily.

nm (velocity centroid accuracy ~ 6 km/s), and don't need to be adjusted for, iv) the spectral resolution is close to 3,000 for the H2 line (FWHM = 0.7 nm or ~100 km/s).

We thank T. Do, J. Larkin, S. Wright, J. Lyke and R. Campbell for their time, comments and help.

6. References

1. J. Larkin et al., 2006, New AR, 50, 362
2. P. Rousselot et al. 2000, A&A, 354, 1134-1150
3. E. Oliva & L. Origlia, 1992, A&A, 254, 466
4. J. Larkin et al. 2007, OSIRIS Manual
5. T. Do 2006, "OSIRIS Wavelength Rectification Notes"