

# Keck AO Workshop

## OSIRIS Tutorial

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### **Using Quicklook2 and Reducing OSIRIS data**

written by Shelley Wright, Anne Medling, and Quinn Konopacky

#### **Getting Started**

This portion of the OSIRIS tutorial follows the talks about “How to plan for an OSIRIS run” and “Introduction to the OSIRIS pipeline.” The aim of these exercises is to get new users familiarized with OSIRIS software tools (Planning GUI, Final Reduction GUI, Quicklook2, and the pipeline), and ultimately to learn how to generate final reduced OSIRIS cubes.

Necessary software packages on your computer for this tutorial:

- OSIRIS Observing Planning GUI (OOPGUI)
- OSIRIS Data Reduction File GUI (DRFGUI)
- Quicklook2 Imaging Software package
- OSIRIS pipeline

#### **Using Quicklook2**

The main purpose of Quicklook v2.2 (QL2) is to provide OSIRIS users with real-time data inspection and a simple means for cursory “quick look” data analysis with 2D/3D FITS files. For the reduction portion of this tutorial we will be opening both raw (2D) frames and reduced (3D) frames for analysis and inspection of the quality of the reductions. QL2 is the image analysis software used at the telescope during your observations, so it is worth our time to spend a few minutes investigating some of the functionalities of QL2.

(1) Go to ql2\_exercise directory

(2) First we would like to open multiple fits files. So click ‘File’ in the QL2 Main Menu, click ‘Options’, and then select ‘Yes’ to ‘Open New Frames in New Windows’.

(3) Open raw frame **s070517\_a038001.fits** and change the color stretch using Min and Max. This is an OSIRIS spectrograph observation of a star in the narrowband (Kn3) 0.035" lenslet scale. You should see the bands of spectra across the detector.

(4) Open raw frame **s070517\_a038002.fits** and change the color stretch with matching Min and Max. This is an OSIRIS spectrograph observation of a pure sky with a matching integration time for the in the narrowband (Kn3) 35 mas mode. Note if you change the stretch even harder all the OH emission lines are even more apparent.

(5) Two common functions that are used on raw 2D frames for OSIRIS are under **'Tools'** -> **'Statistics'** (you can highlight a box region on the frame and get standard deviation, etc. of that region) AND under **'Plots'** -> **'Vertical Cut'** (highlight a rectangular region along the rows of spectra to see the PSF of the raw spectra on the detector). Try using the 'Statistics' box region on the raw sky frame, and use the 'Vertical Cut' along the raw stellar frame to test these functions.

(6) Now open the reduced cube of this star **s070517\_a038001\_Kn3\_035.fits**. Once the frame is open, click on the 'More' button to see more QL2 options. The cube is being displayed as a 2D frame where each spectral slice is being combined by a 'Collapse' method (you may either select 'Median' or 'Average'). You can either collapse the cube with specified wavelength channels (i.e., pixels 20-40) or use the 'Slice' function and look at each spectral channel one at a time or with a specified boxcar.

(7) Two common functions that are used on reduced 3D frames for OSIRIS are under **'Tools'** -> **'Peak Fit'** (i.e., you can highlight a box region surrounding the star and determine the FWHM (x,y) achieved) AND under **'Plot'** -> **'Depth Plot'** (i.e., you can highlight a box region surrounding the star to get a 1D collapsed spectrum). What is the FWHM of the star? This source was observed in Kn3. What feature do you see at spectral channel 180 and what is its wavelength?

(8) Now open the reduced cube of **Titan s050427\_a021001\_datset\_Kn2\_020.fits**. Determine an optimal image stretch (Min and Max) for one wavelength slice. Use the 'Slice' function to slide through the spectral channels. Notice that as you step through the cube towards longer wavelengths that you are able to "penetrate" the upper stratosphere composed mostly of methane and directly see the surface. The bright, continent-like region is believed to have large amounts of water ice, while the dark regions are reservoirs of liquid or solid hydrocarbons. This reduced cube was at the beginning of OSIRIS commissioning, so it was reduced using an older version the pipeline and a different "old" grating.

(9) Use the 'Regions' function and try to collapse over wavelength bins (i.e., 300-350 spectral channels) to create images of both the stratosphere and the surface of Titan. Please see the handouts of a recent paper by Laver et al. (2007), in which the authors use OSIRIS to explore new volcanic eruptions on Titan. You can compare their fully reduced images to the collapsed images you have generated with QL2.

## **Reducing OSIRIS data**

We will be reducing two objects within this workshop: an extragalactic OSIRIS LGS-AO observations of the nearby spiral-barred galaxy NGC 7479 and a stellar OSIRIS LGS - AO observations of a close binary pair, 2MASS+21402.

*PLEASE NOTE: Both of these observational sets have been kindly donated by the PIs for use for this workshop only. Please do not distribute these data sets further or use them for scientific investigations without first contacting the PIs directly (NGC7479: Larkin/Wright, 2Mass\_object: Ghez/Konopacky). Thank you for your understanding!*

### **PART 1A: NGC7479 Reductions**

(1) We will start with reducing the NGC 7479 dataset. Begin by opening the README file in the ngc7479 directory for a summary of the observing logs. Open the first object raw frames (set 53) with QL2 and determine an optimal stretch for viewing both images.

(2) Open the ODRFGUI, and set up the reduction for set 53 using the “basicARP\_drfTemplate”, where frame 1 is the object and frame 2 is the sky frame. Make sure the correct rectification matrix is selected for ‘Extract Spectra’ module.

(3) Use QL2 to open reduced Kn3 100 cube of NGC7479 to make sure everything looks okay. These short integration frames (60seconds) were taken at the telescope to ensure centered pointing.

(4) Now using the ODRFGUI, reduce set 54, 56, and 57 (Kn3 035) using the “basicARP\_drfTemplate”. Note that there is only one sky frame for these three on source frames (set 54, frame 2).

(5) Use QL2 to open all reduced Kn3 035 cubes to ensure that all reduced frames look good, then use “cubes\_mosaic\_drfTemplate” to combine the three frames together. Select a ‘Combine\_Method’ for the “Mosaic Frames” module. See the description of the OSIRIS manual to select the optimal combine method. Once you have mosaicked all three frames together, view the new cube with QL2.

(6) Now reduce the telluric star (HD 203856) observations that were taken for these observations (set 49) using the “basicARP\_drfTemplate”, and open the reduced cube within QL2 to verify that the observations of the telluric star are centered. Using the 'Depth Plot' feature, check that the spectrum of this star looks reasonable and is not saturated. (Note: It is very important that you check for saturation on the raw data frames BEFORE reduction!!). Telluric features are usually corrected with observations of an A0V star that is reasonably bright in the infrared. Care should be taken at the telescope to make sure these observations are NOT saturated (i.e., don't close DM loops and use short integrations).

(7) Now create a 1D spectrum of the telluric star using the “cubes\_telluric\_extract\_drfTemplate”. Using SIMBAD, look up the exact spectral type of this telluric star HD 203856 to input the correct Effective Temperature for this star in the ‘Divide Blackbody’ module.

(8) QL2 does not open 1D fits frame. So using IDL, read-in 1D spectrum created for the telluric star and plot the telluric spectrum.

```
IDL > spec = readfits('file_1d.fits')
```

```
IDL > plot, spec
```

(9) Divide your 1D telluric spectrum into the reduced mosaiked cube of NGC 7479 using the “cubes\_telluric\_correct\_drfTemplate”

**Now you have a final reduced OSIRIS cube of NGC 7479 ready for analysis!**

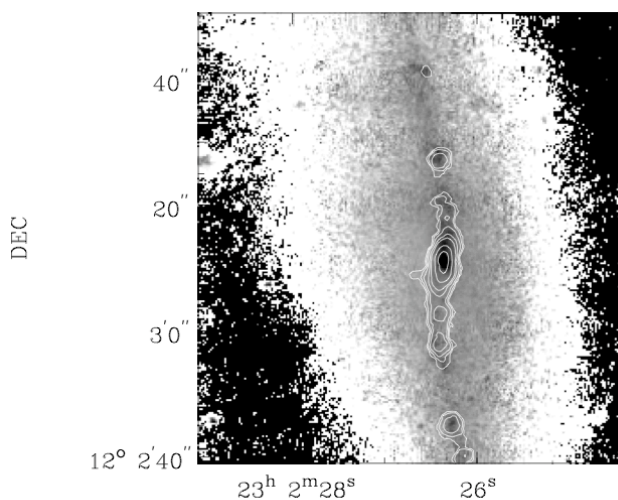
NOTE: Another way to reduce your data would be first to create the 1D spectrum extracted telluric observations, then use the “fullARP\_drfTemplate”, and then use “cubes\_mosaic\_drfTemplate” for mosaicking frames. And you could have potentially used the “telluricARP template” (instead of reducing your telluric star using basicARP and then using cube\_telluric\_extract)

## **PART 1B: Analyzing Emission Lines with OSIRIS and QuickLook2: The Case of NGC 7479**

Integral field spectroscopy is a powerful tool for measuring and mapping emission and absorption features in nearby galaxies. Not only does this allow one to distinguish where certain lines come from, but differing dynamical regions can be resolved.

NGC 7479 is a barred spiral galaxy (Seyfert 2) at  $z=0.00794$  (Haynes et al. 1998). Ionized hydrogen is plentiful – indicating regions of star formation.

Millimeter observations (Laine et al. 1999) have mapped the kinematics of CO emission; showing CO along the dust lane that follows the bar as well as a distinct circumnuclear disk. This disk was shown to have a rotation speed of 245 km/s at 1”.



You have OSIRIS images taken in Kn3 at the 0.035” scale. Open your final reduced cube in QuickLook2 and use the ‘Depth Plot’ tool to examine the spectra. Identify the most prominent feature or features.

You will see a strong Br $\gamma$  emission line dominating your spectra. Step through the wavelength slices around this emission line. Since wavelength space is also radial velocity space, make inferences about the dynamics you are seeing. In your depth plot, you may want to use the line fit tool on individual lenslets to quantify the radial velocities you are seeing. If the nominal wavelength of Br $\gamma$  in this galaxy is 2.1385  $\mu\text{m}$ , what are the radial velocities in km/sec at lenslet locations [24, 38], [24, 38], and [28,34]?

## **PART 2A: 2MASS+21402 Reductions**

(1) Begin by opening the README file in the 2mass\_binary directory for summary of the observing logs and open all raw frames (set 24, 25, 26) with QL2. There was no pure sky taken for these observations; instead, the source was nodded up and down along the detector. These observations were taken at a time when one of the 32 readouts of the detectors was out (note that quadrant on the detector in the raw frames?). Therefore, the observers were unable to nod easily up and down using the whole field of view of the detector.

(2) Each nod pair is typically used as a sky for the “Subtract Frame” module. Determine which combination of pairs are best used to clear the source from itself for each frame for the 180 second integrations (i.e., set26 – set24) and use the “basicARP\_drfTemplate”

(3) Use QL2 to ensure all three of the Kbb 035 reduced cubes look fine, then use the “cubes\_mosaic\_drfTemplate” to combine the three frames together.

(4) Now reduce the telluric HD 194324 (set 33) using the “basicARP\_drfTemplate” and then extract the telluric star into a 1D spectrum using “cubes\_telluric\_extract\_drfTemplate”.

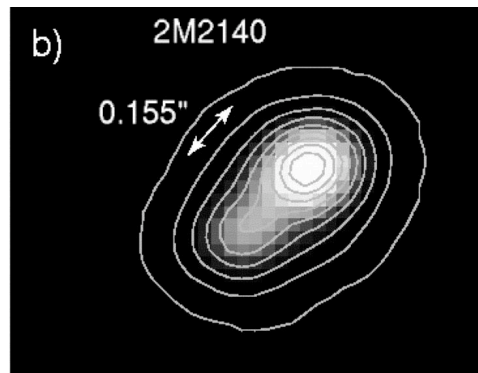
(5) Check the 1D spectrum of the telluric star observations

(6) Divide your 1D telluric spectrum into the reduced mosaiked cube of 2Mass+21402 using the “cubes\_telluric\_correct\_drfTemplate”

**Now you have a final reduced OSIRIS cube of 2Mass+21402 ready for analysis!**

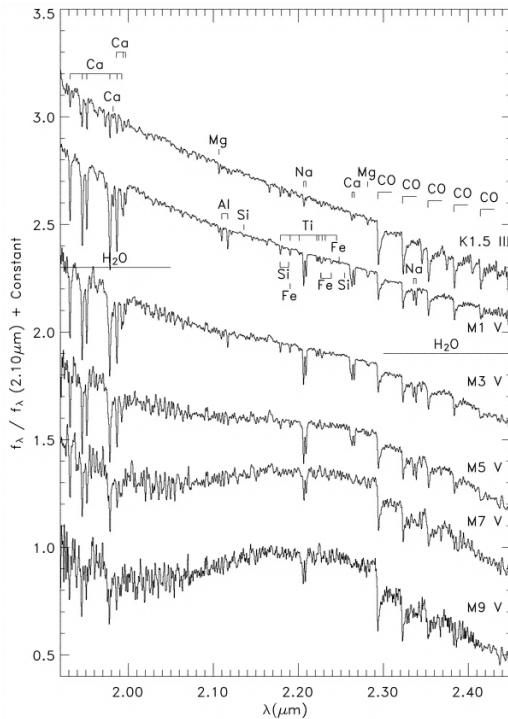
**PART 2B: Using OSIRIS to spectrally classify binary sources:**  
**The case of 2MASSW J2140293+162518**

The very low mass (VLM, where VLM sources have  $M_{\text{tot}} < 0.2 M_{\odot}$ ) source 2MASSW J2140293+162518 (2MASS+21402) was discovered to be binary by Close et al. (2003) using the Gemini-Hokupa'a curvature sensor AO system. The discovery image is shown below. The secondary (bottom left) is clearly fainter in this K band image than the primary (top right).

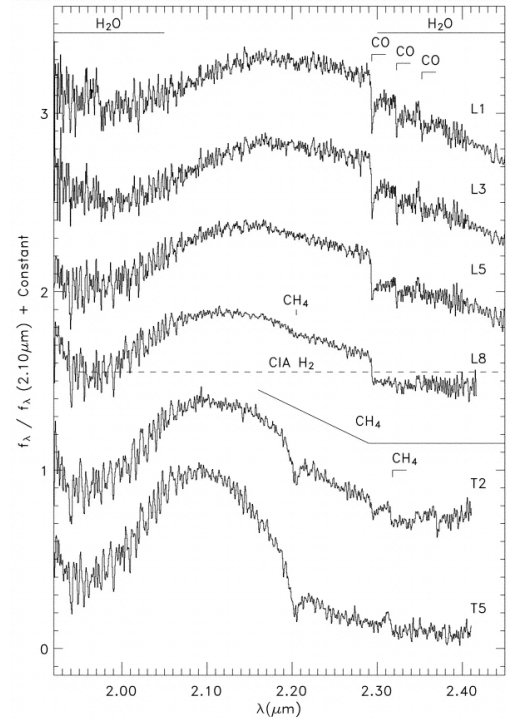


At the time of this discovery, spectral typing of individual components of tight binaries was extremely difficult, and possible almost exclusively from space-based instruments like STIS (as this source is too faint for NGS AO). However, space-based slit spectroscopy for very close binaries is also problematic because their tight physical separation ( $\sim 3$  AU) results in significant orbital motion that can make proper alignment on a slit very difficult. The advent of OSIRIS and the laser guide star system transformed our ability to easily and effectively obtain spatially resolved spectra of these types of systems.

When no spatially resolved spectra are available for VLM binaries, spectral types are estimated using pre-determined color or magnitude relationships, all of which have significant intrinsic scatter. Close et al. (2003) classified the components of 2MASS+21402 as an **M9 $\pm$ 1** (primary) and an **L2 $\pm$ 1** (secondary) using this type of relation. Obtaining medium-resolution spectra is a much more effective means of classification. Most initial classification is done almost entirely “by eye” by comparing morphologies to previously existing spectral libraries (**as shown below**) and looking for obvious spectral features.



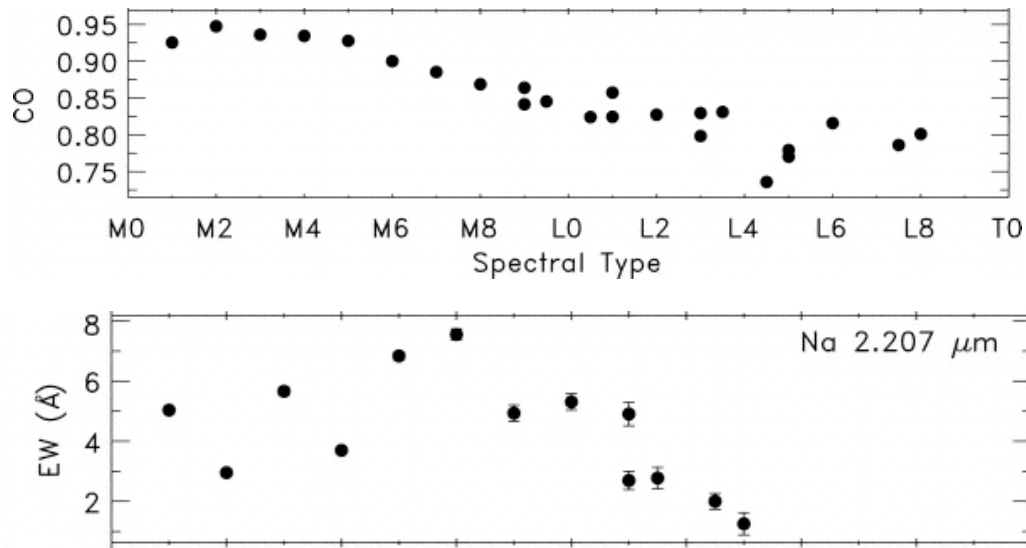
SPEX K-band spectral sequence (Cushing et al. 2005)



By using the depth plotting features of QL2, you should be able to easily extract R~4000 K-band spectra for each component of this binary system and get a good idea of the general morphology. Look for obvious spectral features and overall continuum shape and compare them by-eye to the spectral sequence shown above.

Again, these are K-band spectra and among the most prominent features in the K-band are the CO bandhead, which starts at 2.29  $\mu\text{m}$ , and a sodium doublet at 2.206  $\mu\text{m}$  and 2.209  $\mu\text{m}$ . While CO remains strong throughout the M and L spectral types, the sodium doublet decreases in strength with later spectral types, effectively disappearing around L0, as is shown in the equivalent width plots below (Cushing et al. 2005). If sodium is present in the spectrum of a very low mass object, it is likely that the source is of the M spectral type, and not the L spectral type. Look for the presence of sodium lines in both components. Use QL2 for rough estimates of the line strength of the CO bandhead and the sodium doublet. For instance, the first line in the CO bandhead region can be fit with a Gaussian in QL2 and the depth can be roughly compared to the plot below. With the spectral morphology, sodium lines, and CO strengths, one should be able to get a rough estimate of the spectral types of these two sources.

**Given the OSIRIS data and the above information on spectral classification, were the initial Close et al. (2003) spectral type estimates correct?**



Cushing et al. (2005)

### **PART 3: Investigating the Scaled Sky Routine with NGC7479**

This new “Scaled Sky Subtraction” module implements (mostly) the OH-line-suppressing scaled sky subtraction algorithm from Davies (2007, MNRAS). The basic idea is that the various OH lines that make up the sky background arise from certain families of vibrational transitions. While the intensity of the skylines can vary unpredictably throughout the night, the lines within a given family tend to fluctuate up and down together. Thus one can look at the brighter skylines and determine, for each transition family, the ratio between the OH lines in your science data cube and the OH lines in a sky cube. Then one can apply multiplicative scaling factors to the lines in your sky cube, in order to minimize the residuals in the final subtracted cube. The scaling ratios are applied to the entire sky data cube, rather than to an extracted spectrum, such that any spatial or wavelength variations in the sky lines across the cube will still be accurately matched and cancelled out in the sky subtraction. Interested users should refer to Davies (2007) for a detailed description of the algorithm.

Not only does this provide superior sky subtraction to the conventional direct subtraction, it also allows a small number of sky frames to be re-used to reduce a much larger number of science frames, hence improving observation efficiency. Davies reports that he is able to use a single H band sky frame for over an hour of science data, or a single K-band sky frame for an entire night for SINFONI data. Thus far, testing with OSIRIS data shows very good results as well.

Usage:

In order to use this module, you must first make a reduced sky cube that can be scaled, then subtracted. The overall steps are as follows:

- a) make a master dark frame, from several raw dark frames.
- b) reduce a sky frame into a sky cube, using the master dark. Save this sky cube to a FITS file.
- c) reduce the object frame to a cube using the same master dark, and subtract the scaled sky.

You will primarily be following the steps from Part 1A for NGC7479, but will first need to make a combined dark 2D frame (“super dark”) that will be used for the “Subtract Frame” module, and to make a reduced sky 3D cube subtracted by the “super dark”.

- (1) First make a combined dark frame with the three dark frames in the ngc7479 directories “combine\_skies\_darks\_drfTemplate” (note that if you want to use the scaled sky routine you need to take dark frames with matching integrations either the afternoon or morning of your observational run)
- (2) Now create a reduced cube of the single sky exposure for NGC7479 using the combined dark created in Step 1 for the “Subtract Frame” module
- (3) Now follow the steps in Part 1A, but instead of using “basicARP\_drfTemplate” for the NGC7479 individual reductions use “fullARP\_drfTemplate” using the Scaled Sky Subtraction module and Dividing by the 1D spectrum of the telluric you’ve already created

Although we don’t see much gain for using the scaled sky routine on this source since it’s a narrowband in the K-band, we do see a significant gain using this module in the H-band where we are dominated by a plethora of OH sky emissions.