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JWST Observations of Jupiter

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1. BACKGROUND

The James Webb Space Telescope (JWST) is the newest space telescope for infrared astronomy. The planet Jupiter is local to the solar system and acts as an interesting yet familiar target for observations with the space telescope. The data taken of Jupiter were released to the public as part of the early release science observations. These data are what are analyzed here.

2. METHODOLOGY

The first step to analyzing a new data set is to understand what was received. For each data fits file, the science images were displayed using a min-max interval and a logarithmic stretch. Initial identifications of features such as rings, Galilean moons, and background galaxies were made. I identified poorly calibrated images, which had many masked pixels. Each filter was accounted for, and the throughput and wavelength ranges of each were found from the NIRCam documentation, and shown in Figure 2. Next, I made cutouts of the images to show the background galaxies, rings, moon, and Jupiter to prominently display the features of the data.

For image analysis, the goal was to create spectra of several features of Jupiter and a background galaxy. The targeted features of Jupiter were its integrated disk, bright central stripe, the storm known as the Great Red Spot, and the stripe of Jupiter that the Great Red Spot is on but without the storm. The selected features are shown in Figure 1. A random galaxy was identified in the background of a wide field of view F225M image at (ra, dec) = (8.424°, 2.104°), which approximately matches the coordinates of galaxy WiggleZ R01J003342275+02064950, identified in the WiggleZ Dark Energy Survey.

The spectra of each feature of Jupiter were taken by first creating an aperture over Jupiter by hand for each feature, as show in Figure 1. Circular apertures were used for the integrated disk and Great Red Spot, while rectangular apertures were used for the stripes. I masked each image by masking the pixels in each image where the data were zero.

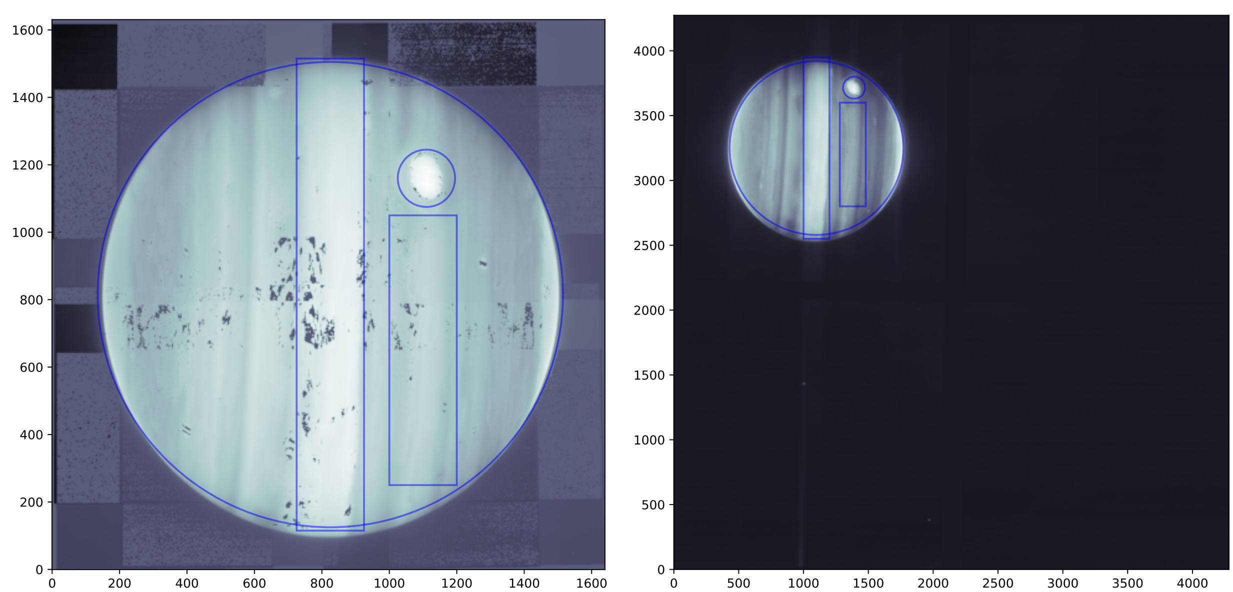

Figure 1. Aperture selections for spectra of features of Jupiter.

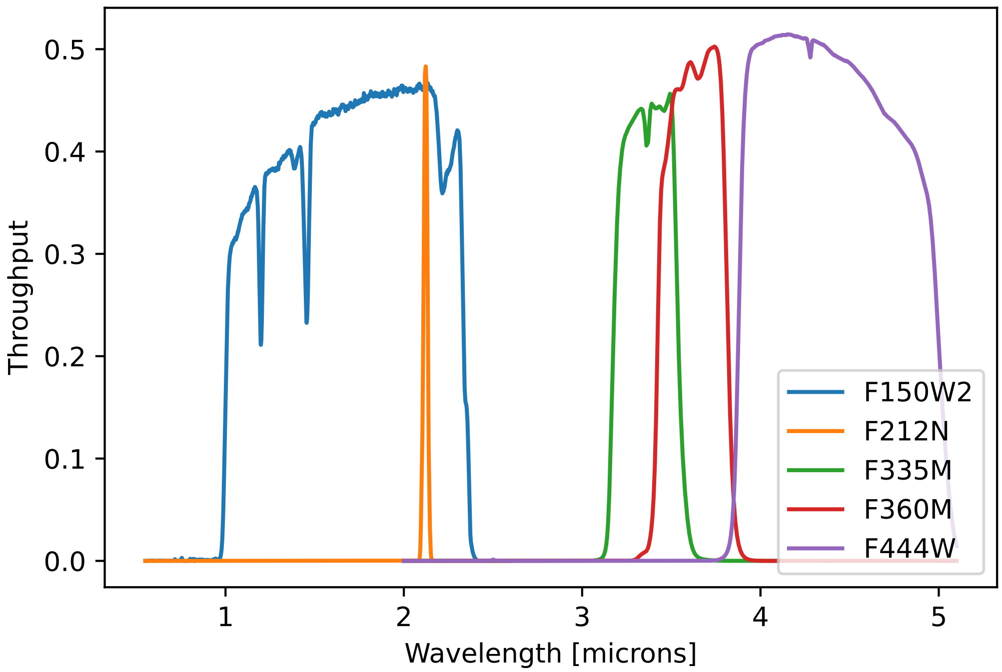

Figure 2. The wavelength coverage and throughput of the filters used in these public release data of Jupiter.

The sum of each aperture was taken using `ApertureStats` from `photutils`. The aperture sum was then converted to flux density by multiplying by the pixel scale, then it was divided by the area overlap between the image and the mask to account for the bad pixels.

The spectrum of the galaxy was found by placing a region over the galaxy by hand using DS9. The region was then opened in python and plotted over the data to ensure that it would be over the correct location. Only the F212N and F335M filters had wide enough field of views to observe background galaxies, so the spectrum only had two points. Cutouts of the data were made to ensure that the galaxy was present within the region. The region was converted into an aperture. The sum of each aperture was taken using `ApertureStats` from `photutils`. The aperture sum was then converted to flux density by multiplying by the pixel scale and dividing by the area overlap with the data.

The wavelengths for the spectra were found by first reading the throughput versus microns table for each filter and plotting it. Next, where the throughput was over zero was used to identify the central wavelengths and widths of the filters. Then, the central wavelengths were used for the wavelength on the spectra for each feature. The widths of each filter were set as the error bars for each point on the spectra.

3. RESULTS

Figure 3 and Figure 4 show the eight images from the early release observations of Jupiter from JWST.

Figure 3 features close-in observations of Jupiter with the F150W2, FF444W and F360M filters. Due to Jupiter being an extremely bright object, the standard calibration done before the data was released masked out much of the disk of Jupiter, the images were over-calibrated.

Figure 4 shows images of Jupiter taken with the F212N and F335M filters. Two images were taken per filter at different epochs, shifting the location of background galaxies and Jupiter's moon. One of Jupiter's moons is circled in the bottom left image, the shorter exposure image with the F335M filter. The bottom right image has several background galaxies circled, although there are many more. The bottom right image also has Jupiter's rings visible.

Figure 5 shows cutouts of the two images taken using the F335M filters, showing many of the background galaxies in the images. The streak across the right image is from diffraction spikes around Jupiter.

Figure 6 shows more cut outs of the data. The left and right images use the F335M filter, and show cutouts of one of Jupiter's moons and its rings. The central image is a cutout of Jupiter using the F212N filter, which is not as effected by over-calibration as the cutouts of Jupiter from Figure 3.

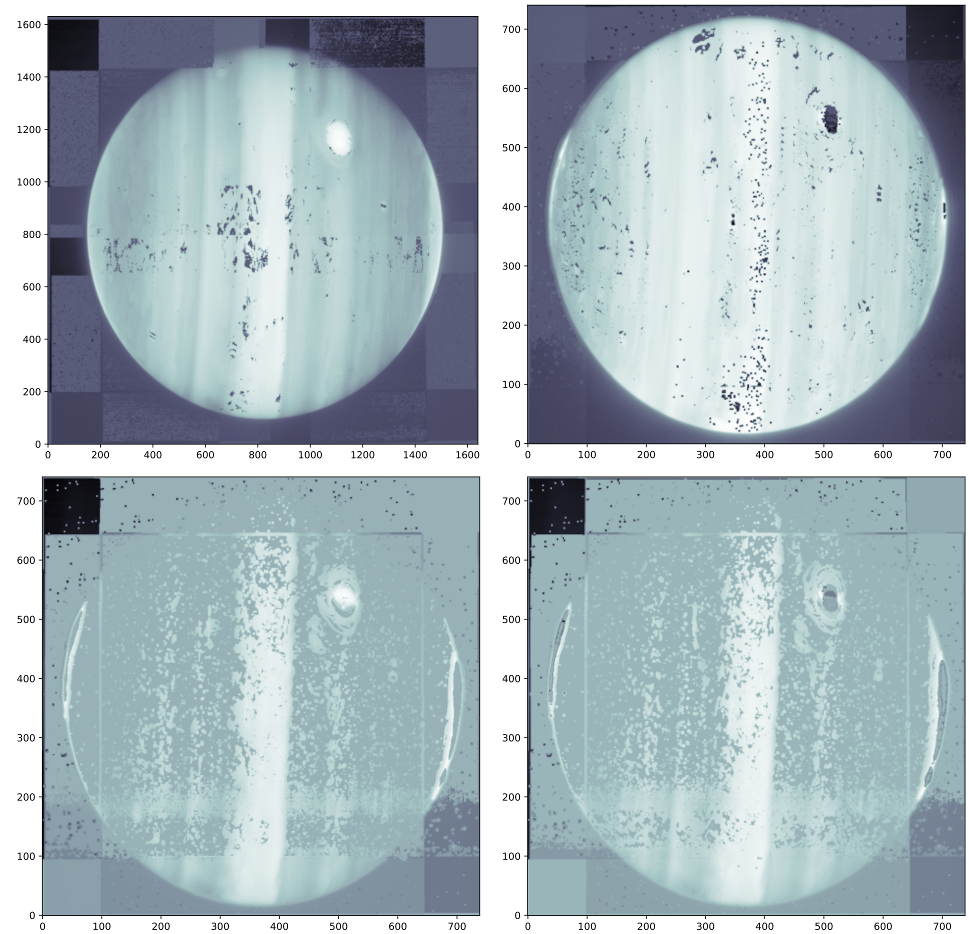

Figure 3. Images of Jupiter with JWST. Top: F150W2 left, F444W right. Bottom: Both F360M. The missing pixels are due to artifacts from running the JWST pipeline on an extremely bright source.

Figure 7 shows the aperture cutouts of the galaxy at (ra, dec) = (8.424°, 2.104°) in the wider field of view images of Jupiter. The left image uses the F212N filter, and the right uses the F335M filter. These cutouts were used to make a simple spectrum of the galaxy, as shown in Figure 8. Only two filters covered enough area to detect background galaxies, which is why the spectrum has few points. Additionally, the background galaxies shifted due to observations of Jupiter happening at different epochs.

Figure 9 shows the spectra of the features selected using the apertures shown in Figure 1. Each point was made by taking the aperture sum and averaging over the unmasked area. The top left spectrum is of the whole integrated disk of Jupiter, made by placing a circular aperture over the whole disk. The top right spectrum is of the Great Red Spot, which was selected by placing a circular aperture over the storm. The notable differences in the F360M points is due to the storm being masked out in one image and not the other. The bottom left spectrum is of the central band of Jupiter. The bottom right spectrum is of one of Jupiter's other stripes, specifically the band along the same stripe as the Great Red Spot, but with the storm not included.

4. CONCLUSION

The immediate issue was that the close-in cut outs of Jupiter were missing pixels due to over-calibration. Features such as Jupiter's Great Red Spot and poles tended to be missing, which contribute to the planet's total flux. With enough time, the holes in the data could be fixed by interpolating over them to create a more whole set of images and more accurate flux measurement. The multiple exposures per filter could have been combined to make an average flux measurement. The spectrum of the galaxy could be used to find its spectral index. More spectra of background galaxies could have been made. The spectra of a galaxy and several features of Jupiter were found an plotted. The spectrum of the galaxy was simple, but well behaved, and could be used to find its infrared spectral index. The spectra

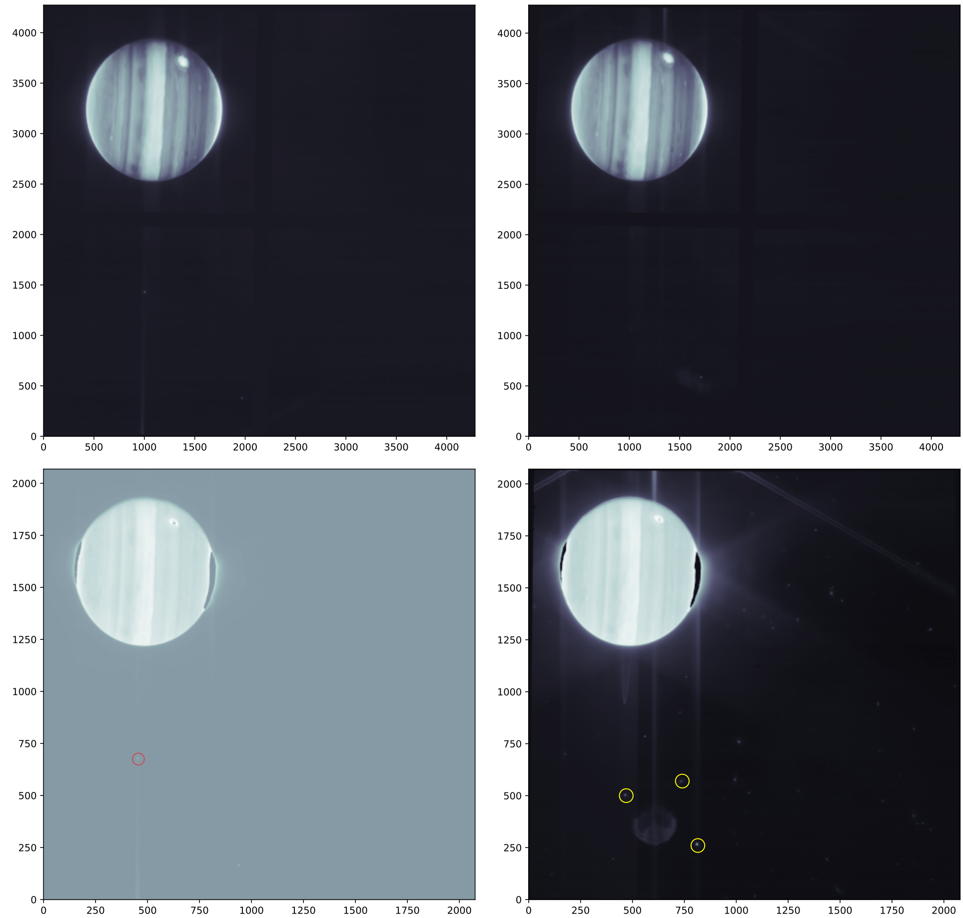

Figure 4. Images of Jupiter and surroundings with JWST. Top: F212N. Bottom: F335M. The red circle in the bottom left image identifies the location of one of Jupiter's moons. The yellow circles in the bottom right image identify some of the visible galaxies.

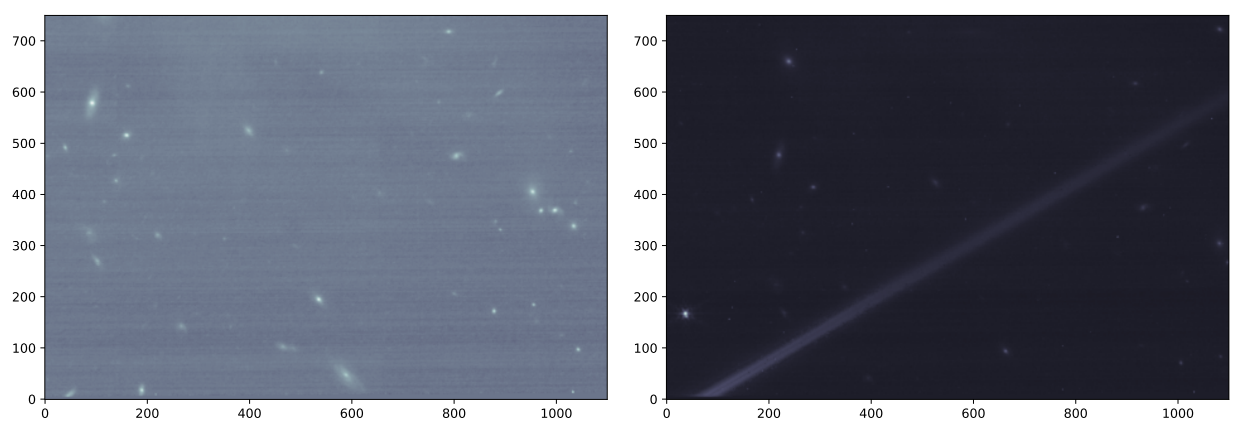

Figure 5. Cutouts of galaxies from the two the F335M images.

of Jupiter did not have a familiar shape, but showed some variation depending on which part of the planet was targeted for photometry. Overall, these data of Jupiter have good quality, and only slightly degraded by over-calibration.

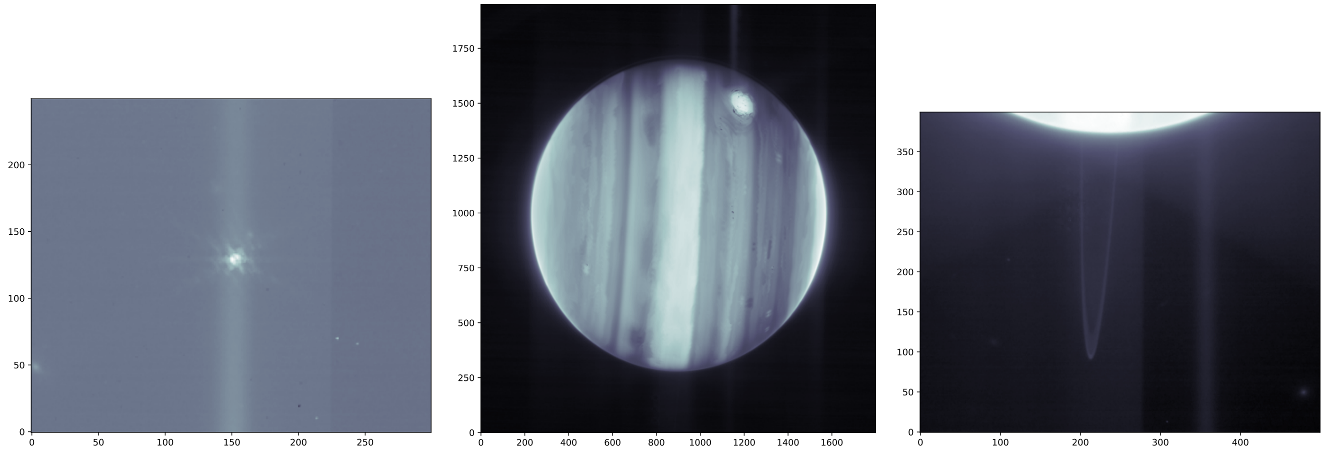

Figure 6. Features around Jupiter. Left: Cutout of Jupiter's moon in F335M. Center: Zoom in of Jupiter with minimal missing pixels in F212N. Right: Jupiter's rings in F335M.

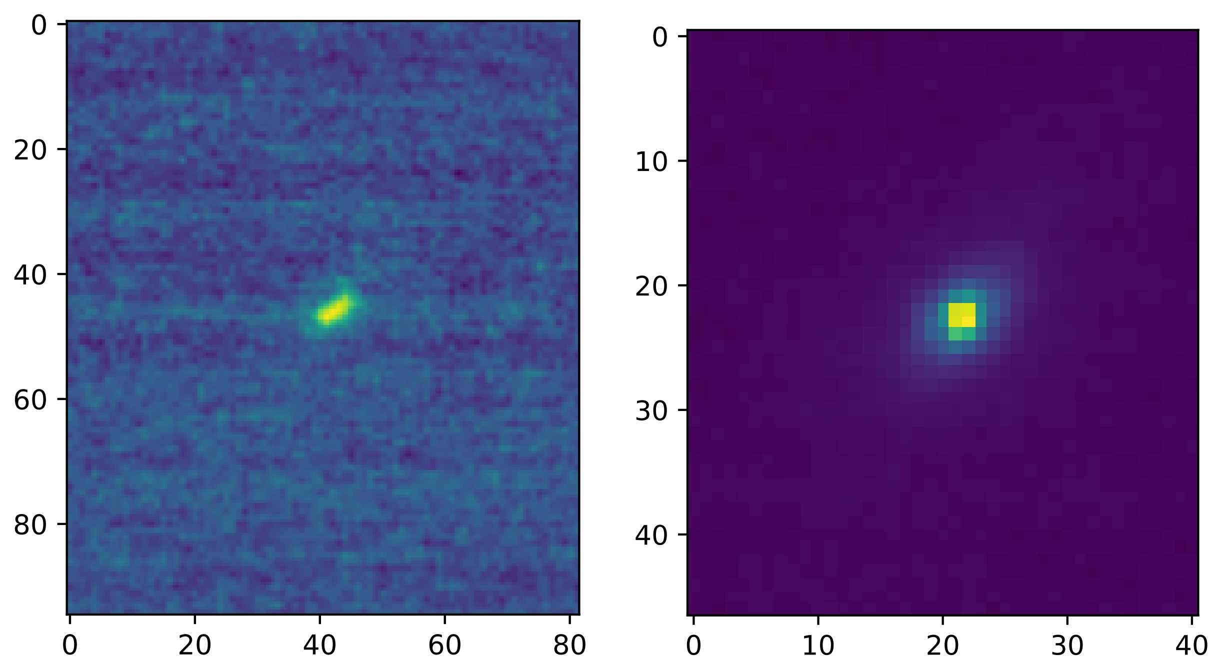

Figure 7. Cutouts of galaxy (ra, dec) = (8.424°, 2.104°). Left: F212N, Right: F335M.

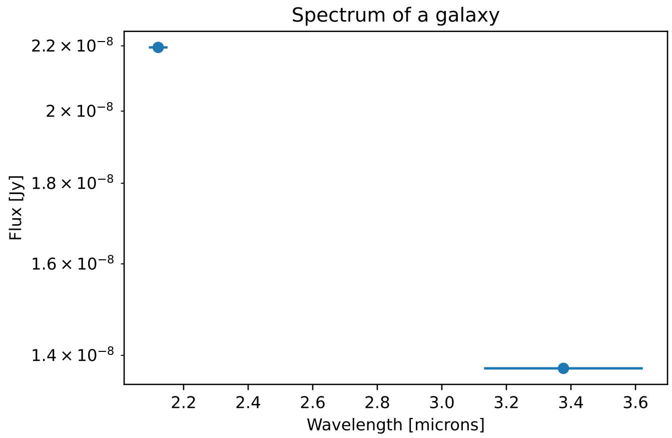

Figure 8. Spectrum of the galaxy selected in Figure 7.

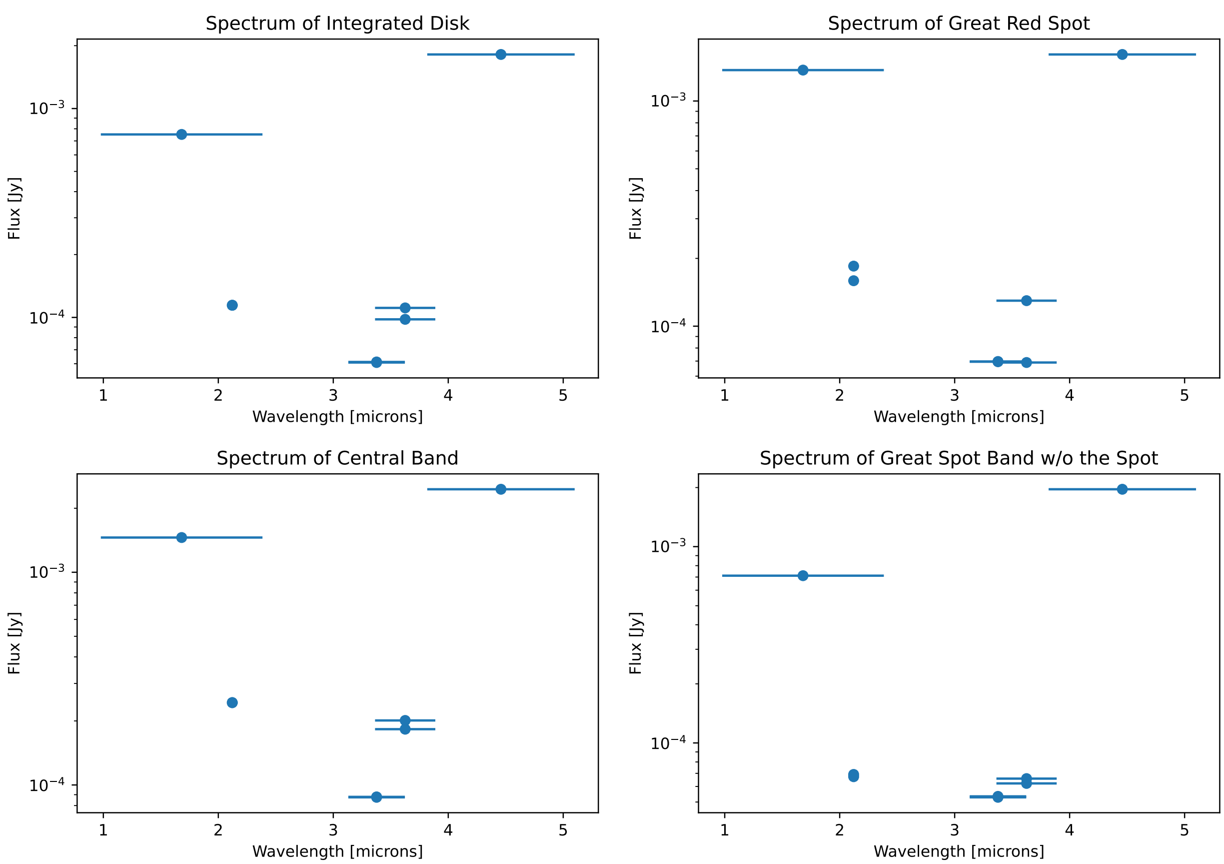

Figure 9. Spectra of different features of Jupiter. Top: Integrated disk left, Great Red Spot right. Bottom: Central band of Jupiter left, right band of Jupiter on same stripe as the Great Red Spot. The horizontal error bars are the widths of the filters.