Preliminary analysis of exoplanet XO-2 b observed with HST NICMOS

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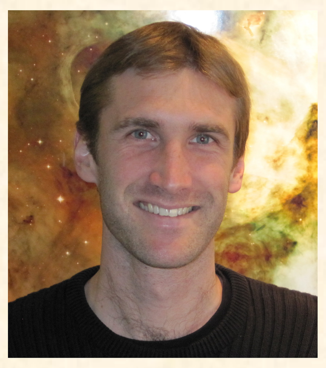
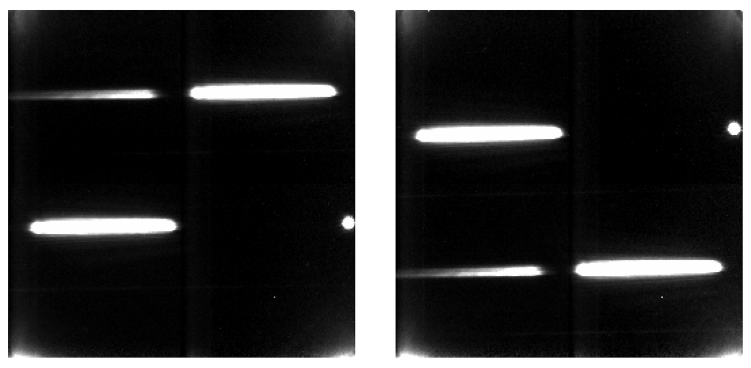


We present the on-going photometric and spectroscopic analysis of the transiting planet XO-2 b, from HST NICMOS. Three transits of the planet have been observed. The field of view contains not only the XO-2 star but also a second star of very similar properties, which we use as a comparison star. We first perform a white-light photometric analysis of the data, and derive a high signal to noise transit lightcurve. We then build the spectrum of the system. A careful derivation of instrumental parameters allows a clear identification of correlations. Removing these correlations should yield the spectrum of the planet. In the context of a debate about planetary spectra obtained with NICMOS, this study provides new information about the analysis of NICMOS data and other similar data.

1) Observations

XO-2 has been observed with HST NICMOS during 3 visits, on November 2, 2007, December 11, 2007 and February 12, 2008. Each visit is centered on a transit, and is composed of 5 HST orbits. Each orbit contains typically 68 images of 32 s. In total, 1006 images were acquired (for a duration of 9 hours). We used the G141 filter, with a spectral range from 1.08 to 2.0 µm. In addition to XO-2, a companion star is present in the field of view. Both have a K0 V spectral type and a magnitude J = 9.7. The position of both stars on the CCD is the same in the 1st and 2nd visits, whereas they are placed differently in the 3rd visit (figure 1). Note that the 0th order of one star is present, as well as a faint 2nd order spectrum.

Figure 1: Image of XO-2 from NICMOS, for the 1st and 2nd visit (left), and 3rd visit (right). The field contains 2 stars, XO-2 (upper star) and a companion of very similar properties (lower star).



2) Measure of instrumental parameters

Whether an accurate spectrum can be obtained from NICMOS data is currently a topic of controversy. As pointed out by Deroo et al., an good instrument model is of critical importance to analyze NICMOS data. Thus, our first analysis aims at understanding the influence of instrumental effects on the final spectrum. We thus determine several parameters of the 1st order spectrum for both stars, in particular the position in x and y, the angle, and the FWHM. The variations of these parameters during the 1st and 2nd visits are shown in figure 2, and are comparable to those found in other NICMOS data (Swain et al. 2008). These variations are of about 0.3 px in x, 2 px in y, 1° in angle and 0.5 px in FWHM in each visit. Combined to the different responses and wavelengths of the pixels, and to the transmission variations of the dispersive element, these parameters are likely to influence the spectrum.

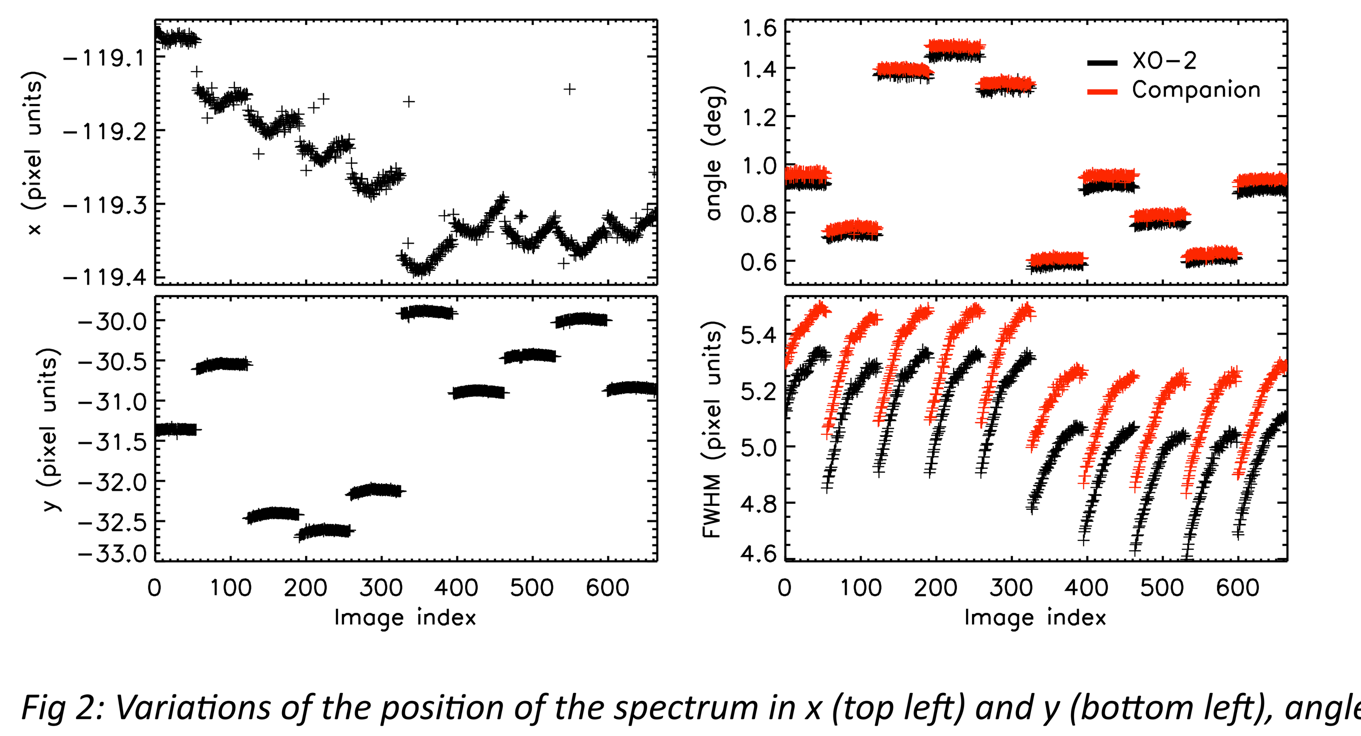
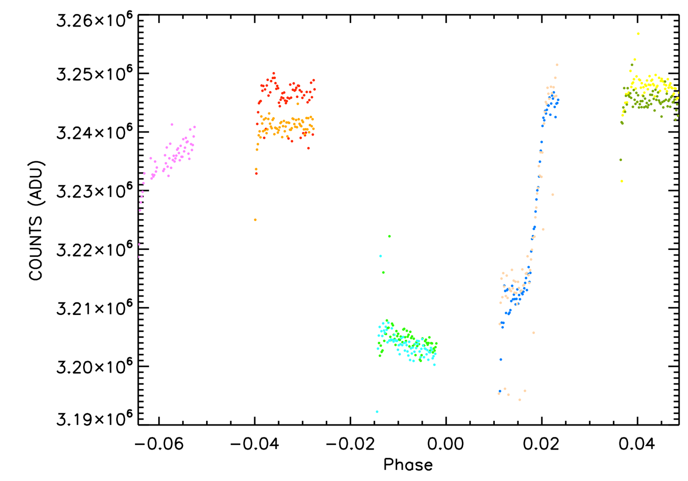


Fig 2: Variations of the position of the spectrum in x (top left) and y (bottom left), angle (top right), and FWHM (bottom right), for XO-2 (black) and the companion (red). The x and y variations are computed from the only 0th order present on the images, and are thus the same for both stars. The angle is relative to the horizontal direction, and the FWHM is measured in the vertical direction (perpendicular to the dispersion).

3) White-light analysis

We build the white-light photometric transit curve for each visit. From the raw image, bad pixels are corrected. A wavelength-dependent flat-field is built for each star: we use the position of the spectrum derived in section 2, the reference position of the star from a direct image (*i.e.* taken without the dispersive element), and the NICMOS dispersion relation to derive the wavelength at each pixel. The response of each pixel in each image is then obtained from flat-fields taken at different wavelengths. We also correct for the electronic phase variations (see Burke et al. 2010). Finally, the flux is summed over the entire spectrum. Although further calibration is needed, we obtain for example a point-to-point precision of 411 ppm for XO-2 and 448 ppm for the companion, for the 3rd visit. Thus, the high signal to noise ratio of NICMOS data will allow an accurate derivation of the planet and star parameters.

Figure 3: White-light photometric lightcurve of XO-2, for two different visits. Each color stands for an HST orbit. The typical precision is 400 ppm for one visit (excluding the 1st orbit). Further calibration between visits is needed.



4) Correlations in the spectrum

The 1st order spectrum is spread along 111 columns, each one accounting for a given wavelength (the actual resolution is however set by the defocused FWHM). In this first approach, we look at the columns individually. Correlations with instrumental parameters are searched for in the lightcurve of each column. The second star, not subject to any transit or variation, is extensively used to track for systematics.

We find for all columns a strong correlation with the position of the spectrum in x (figure 4). We interpret this as the effect of the transmission variations of the dispersive element. We decorrelate by removing a 3rd order polynomial to the lightcurve, and reduce the noise from 1% to 0.3% in the spectrum per column. Second, a correlation with the FWHM appears, and a correction lowers the noise to 0.1% in the spectrum. Further correlations are under investigation.

This process allows a characterization of the noise sources of the NICMOS instrument. However, a joint decorrelation with all parameters will be performed to derive the spectrum of the planet.

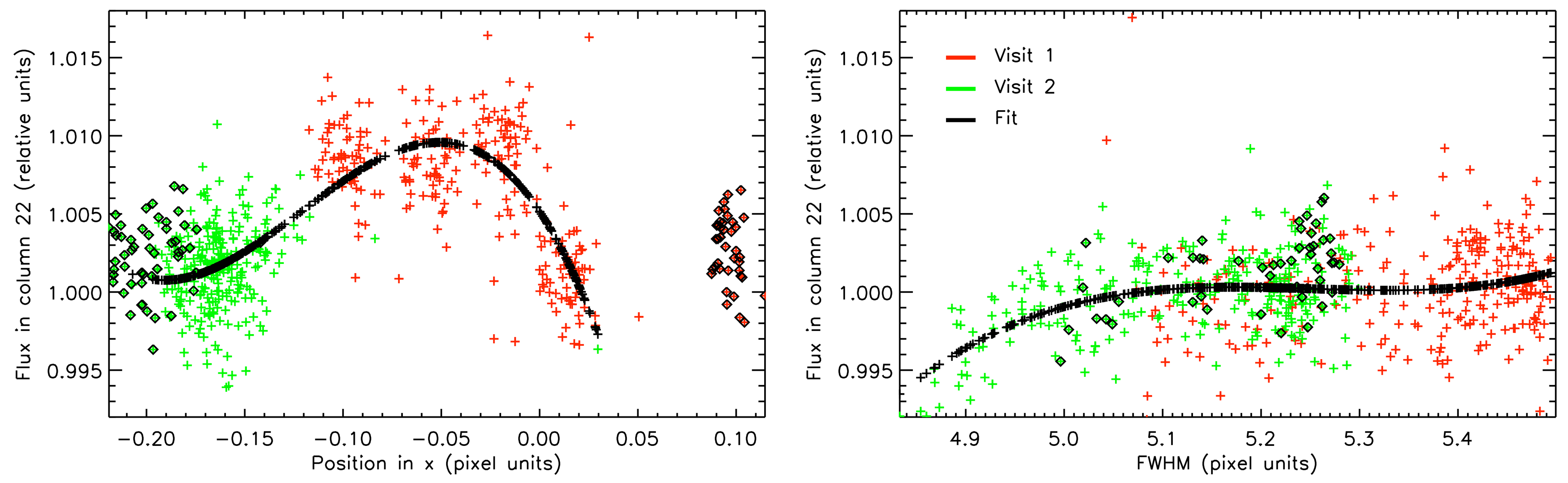


Figure 4: Example of correlations of a single column lightcurve with instrumental parameters. Visit 1 is in red, visit 2 in green, and the fit in black. Diamonds represent the 1st HST orbit of each visit, not used for the fit. The most important correlation is with the x position of the spectrum (left). Then, a correlation with the FWHM appears (right).

Conclusion

The white-light photometry of XO-2 NICMOS observations yields a 411 ppm precision lightcurve, and will allow an accurate determination of the star and planet parameters. When building the spectrum of both stars, clear correlations with the position of the spectrum in x and with the FWHM appear. Other correlations are under investigation. Removal of those identified correlations is fundamental to ascertain the validity of results obtained from NICMOS data. Simultaneous work on both XO-2 and the companion star provides a further validation of the method.

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