Towards the first transmission spectrum of a gas giant transiting an M-dwarf

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At the forefront of comparative exoplanetology, the atmospheric characterization of transiting exoplanets is revealing the intimate nature of these new worlds. In this exciting context, we are currently conducting a VLT observing campaign on a rare exoplanet specimen, WASP-80b, a gas giant in close orbit around a bright nearby M-dwarf. Even if this planet belongs to the hot-Jupiter population, it is actually more 'warm' than 'hot' with an estimated equilibrium temperature of only 800K. We present here some preliminary results of this program which consists in monitoring four transits of WASP-80b with the FORS2 instrument in multi-object spectroscopic mode in ESO phase 91. Through this approach, our goal is to precisely measure the transmission spectrum of the planet between 740 and 1070 nm in order to constrain the thermal structure and scattering properties of the planetary atmosphere. Furthermore, we will use the water features located around 950 nm to constrain the water mixing ratio in the atmosphere of this peculiar hot Jupiter.

Transit transmission spectroscopy

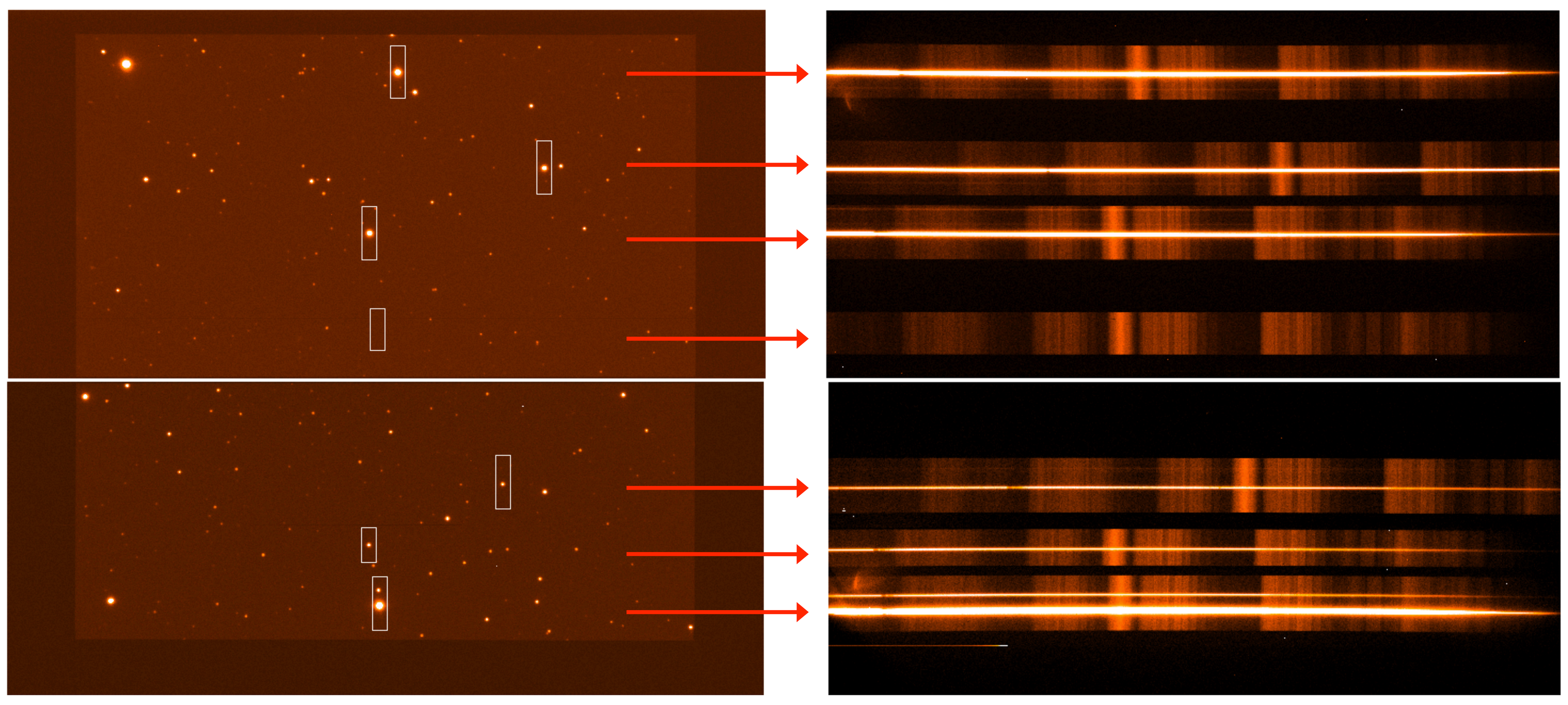
As the light from the host star passes through the atmosphere of the planet during a transit, some wavelengths are absorbed or scattered more effectively by the atmospheric constituents present in the atmosphere, altering the effective planetary radius and hence the transit depth at these wavelengths.

The *transit transmission spectroscopy* technique consists in probing this wavelength dependance of the planetary radius in order to study the thermal structure of the atmospheric limb, its cloud coverage, and the mixing ratios of its most spectroscopically active chemical components (e.g. Seager & Sasselov 2000, Brown 2001, Benneke & Seager 2012).

The target : WASP-80b

WASP-80b (Triaud et al. 2013) is a $M_p = 0.55 \pm 0.04\ M_J$, $R_p = 0.95 \pm 0.03\ R_J$ planet recently discovered by the SuperWASP survey (Pollacco et al. 2006). This low-density ($\rho_p = 0.55 \pm 0.04\ \rho_J$) planet transits every 3.07d a nearby (60 ± 20 pc) M0 dwarf. It is a unique object as it is the only known specimen of gas giant orbiting an M-dwarf that is bright enough (I=10.3, K=8.4) for high SNR follow-up measurements.

The small radius ($R_\star = 0.57 \pm 0.02\ R_\odot$) and infrared brightness of the star combined with the low density of the planet make this system one of the most suitable for transit transmission spectroscopy, with an expected amplitude in the transit depth variations of about 300 ppm (assuming a cloud-free atmospheric model and for a strong transition).



Simultaneous observation of WASP-80 and 5 reference stars + one slit on the sky

Observations

Our program consists in observing four transits of WASP-80b with the multi-mode optical instrument FORS2 (Appenzeller et al. 1998) mounted on ESO VLT UT1. Unfortunately, the first transit (2013-06-12) could not be observed because of bad weather. The second transit (2013-06-15) is the one which is presented here. The third and fourth transits will be observed on 2013-07-25 and 2013-07-28, respectively.

FORS2 was configured for multi-object spectroscopy (MXU mode) using a mask with slits positioned on WASP-80 and five other nearby reference stars. The slits had widths of 10 arc seconds to avoid potential differential losses due e.g. to variations in the telescope guiding or in the seeing. About 270 spectra were obtained for all stars, covering a wavelength range of 740-1060 nm for the target, which is well-centered on the chip, and a slightly reduced range of 740-990 nm for the reference star which is the furthest from the center of the chip.

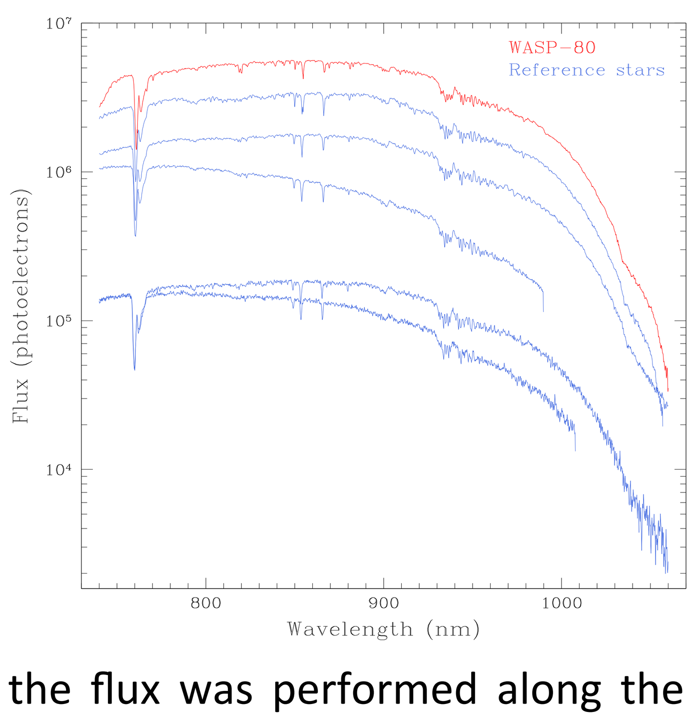
Previous studies (Lendl et al. in prep., Moehler et al. 2010) revealed that the precision could be greatly affected by some inhomogeneities in the transmission of the FORS2 longitudinal atmospheric dispersion corrector (LADC), which consists of two thin prisms with variable distance. To reduce effects on the light curves, we fully closed the LADC and put it in simulation mode.

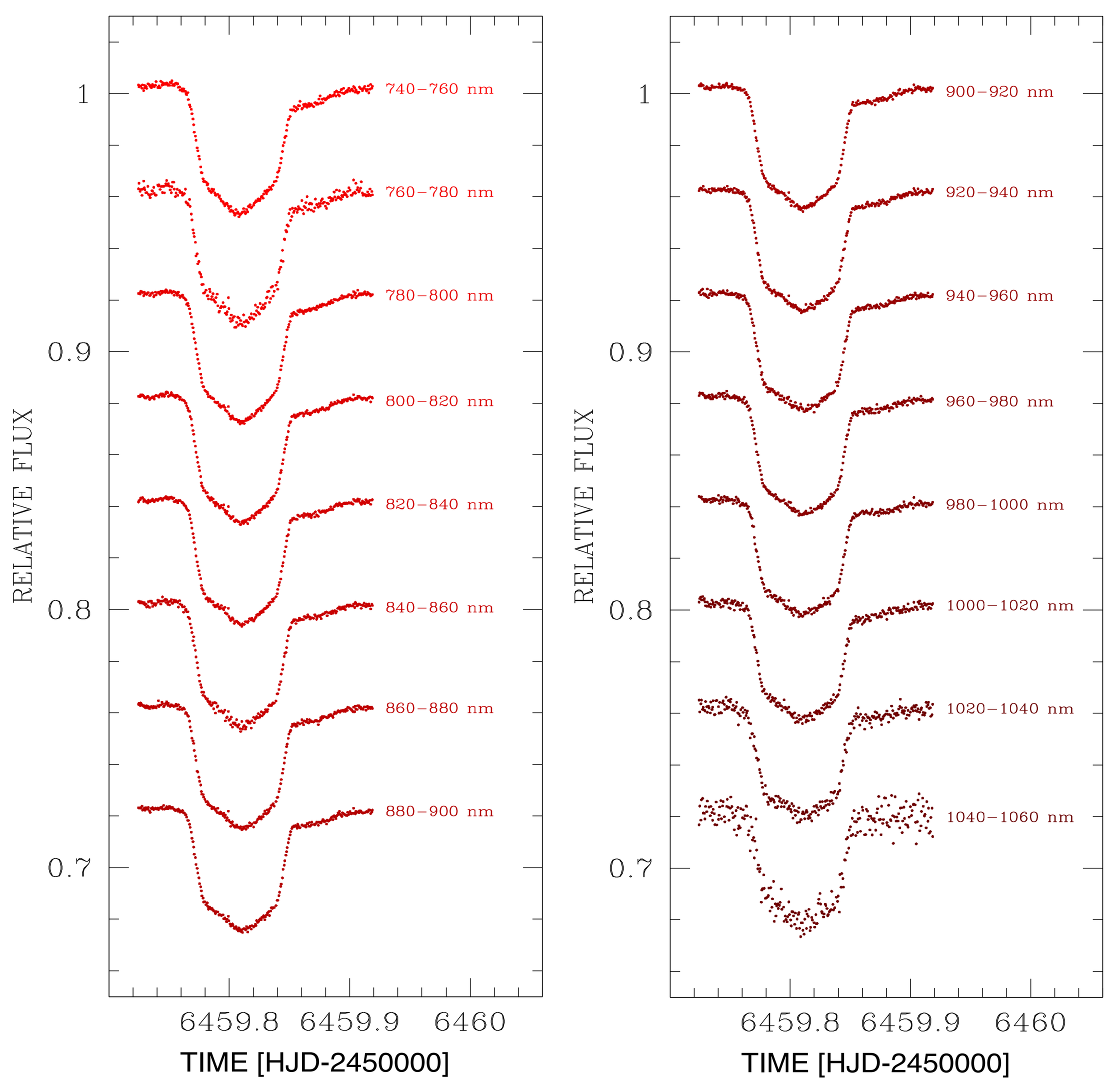
Data reduction

We performed the data reduction using an IRAF pipeline specifically developed for this purpose. After bias and flat field corrections, we determined the wavelength calibration of the spectra based on spectra of an emission lamp that were obtained using a copy of the science mask with slit widths set to 1 arc second. A third-order polynomial model was adopted for the wavelength solution. The dispersion was about 0.81 Å/pixel.

Then, the optimal extraction algorithm (Horne 1986) was used to extract one-dimensional spectra (as the ones presented on the right) and their corresponding uncertainties for each star. To summarize, at each pixel in the dispersion direction, the center of the spatial profile was determined and a variance-weighted sum of the flux was performed along the spatial axis within a chosen aperture. At this stage, the background was subtracted based on estimates obtained in regions separated by 6-10 arc seconds from the stellar spectra. The cosmic rays were also rejected and replaced by interpolated values derived.

Finally, the spectra were binned over wavelength to obtain sixteen 20nm-width spectrophotometric light curves for WASP-80 and the reference stars. The transit light curves presented on the right were then obtained by combining the fluxes of the reference stars into one comparison signal and dividing it from the flux of WASP-80.

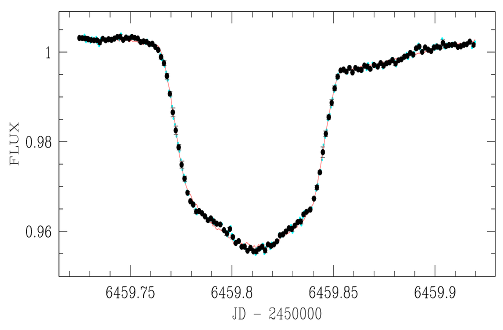




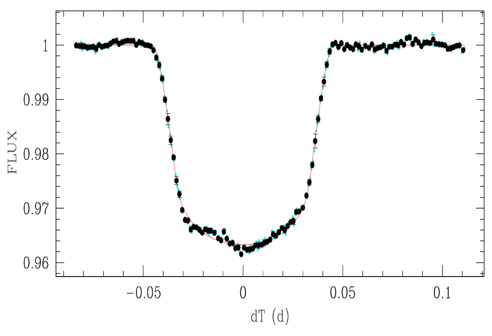
First modeling

The analysis of the light curves is currently in progress. It will consist in fitting a transit model to all the spectrophotometric light curves simultaneously, requiring agreement in the system parameters for all the curves but allowing a different transit depth for each curve. For that purpose, we will use the Markov Chain Monte Carlo (MCMC) code described in Gillon et al. 2012. During the procedure, the modelisation of the photometric baseline will be of first importance in order to correct the light curves for any external (astrophysical, instrumental or environmental) factor that could have affected them. As illustrated on the figures below, some tests have already been done in that direction. However, further investigation on the baseline modelisation is still needed.

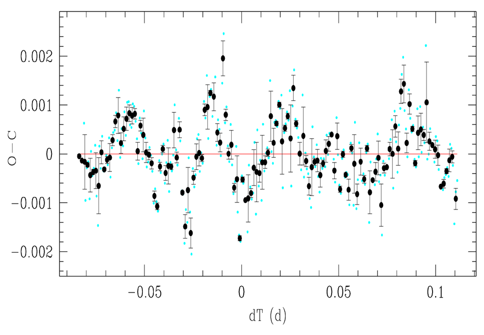
Initial transit light curve obtained for the bin 880-900 nm



Division by a baseline model including dependencies on the parallactic angle in order to correct for the remaining LADC effect



As can be seen on the residuals of the fit, the curve is still affected by an unknown additional external parameter



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