Instrumental development at the Nordic Optical Telescope

The use of two holographic diffusers to achieve ultra-precise photometry

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Context

Collecting data from the ground as precise as space-based photometry is extremely challenging. Ground-based observations are affected by scintillation, atmospheric effects that change throughout the observing night such as color-dependent absorption of stellar light, cirrus or clouds passing by, telescope tracking errors, and poor flat-fielding. These are first-order effects contributing to the deterioration of astronomical data, manifested in transit light curves as *scatter and correlated noise*. To obtain ultra-high precision differential photometry a new observing technique has been recently developed[1], and recently published (Stefansson+2017,ApJ,848,9). The technique uses holographic diffusers (HDs) as a way to scramble the directions of light that passes through them, spreading the light in many pixels over the CCD but in an homogeneous way, when compared to the defocusing technique (Southworth+2009,MNRAS,396,1023). Instead of the donut-shaped PSF the HDs produce a broad PSF with a *homogeneous illumination that doesn't change with seeing*. Contrary to opaque glass, the HDs do not block or reflect the incident light. Therefore, they provide maximum efficiency. For the Nordic Optical Telescope we have developed two HDs, placed in the FASU filter wheel, to be used in simultaneous with ALFOSC filter wheel. Here we present photometric data obtained with the 0.35 degree HD. The second one, with a diffusing angle of 0.5 degrees, is currently under development.

Test Observations at the Nordic Optical Telescope

The target and basic observing setup

On the night of December 5th, 2017, we observed EPIC247773181 (V = 10.93, α = 05:03:15.38, δ = 24:13:23.98) continuously for 2.55 hours. The star might host an exoplanet candidate. The observations were thus centered around predicted primary transit. The observations were performed with the diffuser placed on FASU, binning 1x1 and the Johnson-Cousins R filter placed in ALFOSC. The diffuser used for the observations was at that time borrowed, and in consequence unfit for FASU. In consequence, the diffuser produced a vignetting of the field of view (see Figure 1) that will not be visible in the future, when the new diffusers arrive to the NOT. Besides the science frames, we acquired bias and flat fields with the diffuser and photometric filters on, in binning 1x1. The exposure time was set to 10 seconds and was kept fixed along the whole observing run. Accounting for readout time, the cadence of the data is 23 seconds.

The data, photometry and results

We reduced the data using standard routines of IRAF (ccdproc, apphot). As usual, we bias and flatfield calibrated all the science frames. For each one of the pre-calibrated frames we computed the airmass corresponding to the center of the field, the full width at half maximum (FWHM), and the centroid positions of all the stars where we measured their photometry. Figure 2 shows the time evolution of these parameters. Although the local seeing drastically changed along the observing run between 1 and 4 arcseconds, the PSF was stable and in most of the cases within 1 pixel (FWHM = 25.55 ± 0.23 pixels, corresponding to the average value and standard deviation). The centroid positions of all measured stars were withing 0.3 pixels. This is not due to the diffuser, but most likely due to the good guiding system of the Nordic Optical Telescope.

For the photometry, we measured fluxes in different apertures and sky rings on the target and two reference stars. We produced several differential light curves using all possible combinations of reference stars, apertures and

[1] http://sites.psu.edu/astrowright/2014/04/18

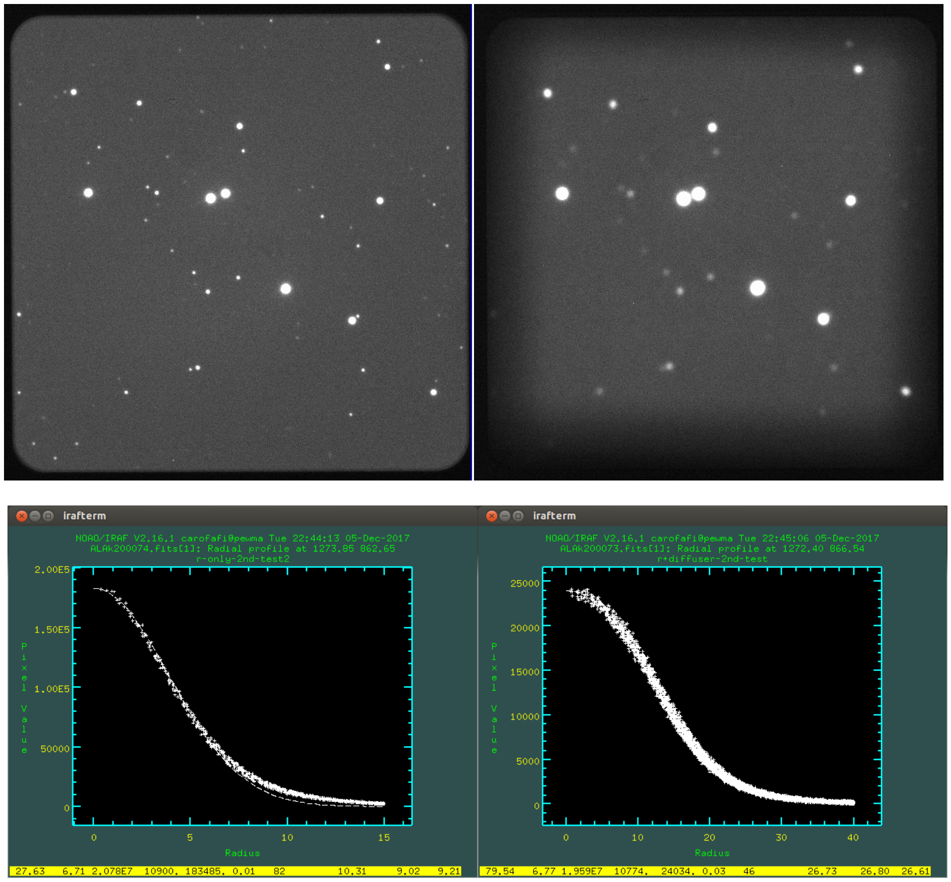

Figure 1: *Top:* Field of view around EPIC247773181 without (*left*) and with (*right*) the diffuser. Note the vignetting area on the right-side image. *Bottom:* radial profiles of EPIC247773181 taken without (*left*) and with (*right*) the diffuser on. Note the increase in radius and the decrease of pixel value.

sky rings, and chose the combination of parameters that minimized the point-to-point scatter of the light curves. Figure 2, *right*, shows a raw transit light curve. This is, not corrected for systematics. The airmass trend is clearly visible. Overall, the achieved photometric precision is **0.8 parts-per-thousand at a cadence of 23 seconds (10 seconds exposure)**.

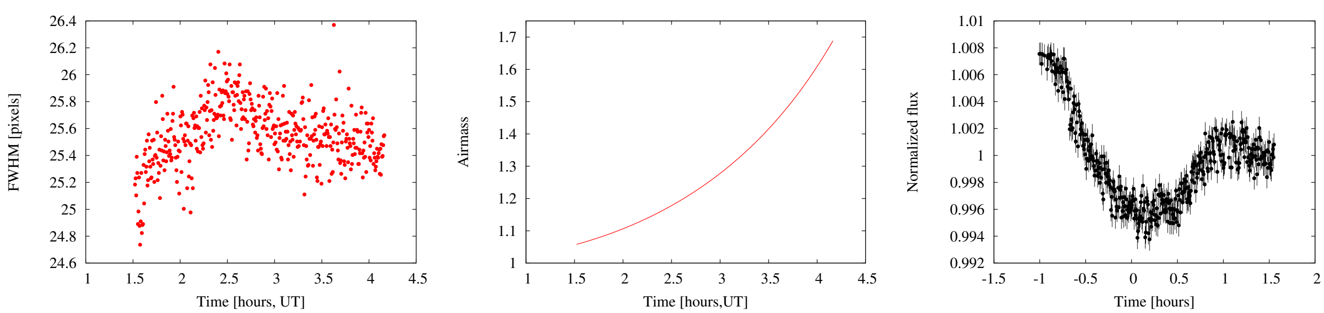

Figure 2: Time-dependent changes of the FWHM (*left*) and airmass (*center*) obtained from all the measured stars in the field. *Right:* transit photometry.