The ESA OGS Spectrograph programme: Exoplanets, minor-bodies and X-ray binaries

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1. Introduction

The ESA Optical Ground Station (OGS) is a 1-m telescope located at Teide Observatory. One of its instruments is a Spectrograph developed at ESA, initially for imaging and spectrometry of comets, later refurbished for extra-solar planet research, and now used too for a variety of research topics of interest to SCI scientists.

The ESTEC Faculty has funded two proposals in 2015-2016 and in 2017, aiming at the observation with the Spectrograph of exoplanet transits, solar system minor bodies, and the validation and calibration of the instrument. The current project also includes the observation in the visible of X-ray binaries.

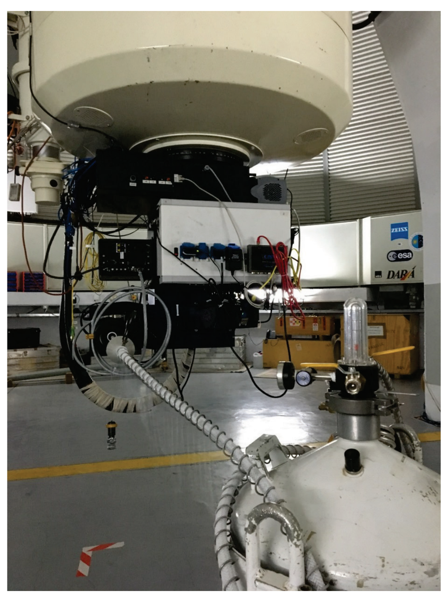


Figure 1: View of the Spectrograph mounted on the OGS telescope, while being filled with liquid nitrogen. The detector array is operated at -100 °C .

2. First results of exoplanet transit observations (2015-2016 campaigns)

The main objectives of the exoplanets observations in these OGS Spectrograph campaigns were (i) to check the feasibility and scientific capability of the instrument for transit observations, and (ii) to follow-up planets discovered by other facilities in order to refine their orbital elements, constrain their physical parameters and search for additional bodies in the system. In total 20 exoplanet transits were observed. Their data have been reduced and the analysis is in progress.

In a first study (Rätz et al., in preparation), OGS follow up observations of CoRoT exoplanets have been combined with observations made at the University Observatory Jena and at the Observatorio de Sierra Nevada (OSN). These observations are of special importance because they took place between five and nine years after the planets' discoveries. For three exoplanets, these observations have allowed corrections of the orbital periods and, therefore, of the mid-transit times of up to 115 minutes (see examples below in Figures 2, 3 and 4). The improvement in the accuracy of the mid-transit times is essential for the planning of observations with large facilities (e.g. JWST).

CoRoT-12 b, a hot Jupiter that orbits a slowly rotating G2V star of *V* =15.5 mag in 2.83 d.

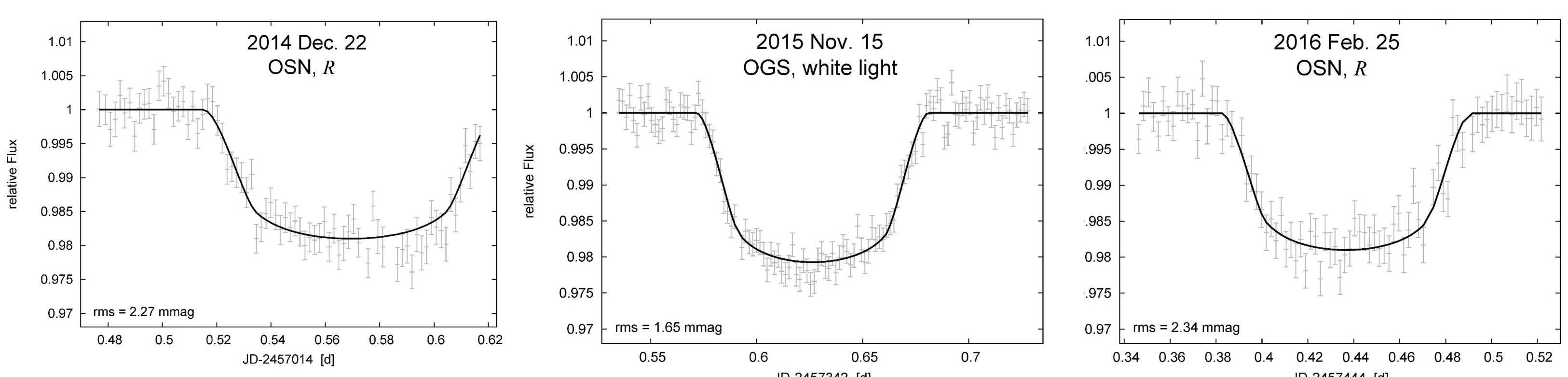


Figure 2: Light curves of CoRoT-12 b with best-fitting model resulting from the simultaneous fit of all CoRoT and ground-based light curves. The date of observation, observatory, filter and the rms of the fit are indicated in each individual panel. These observations allowed for a determination of the orbital period less than a second longer than in previous studies (Gillon et al. 2010) but ~24 times more precise.

CoRoT-20 b, a compact hot Jupiter that orbits a G2V star of *V* =14.6 with an orbital period of 9.24 d.

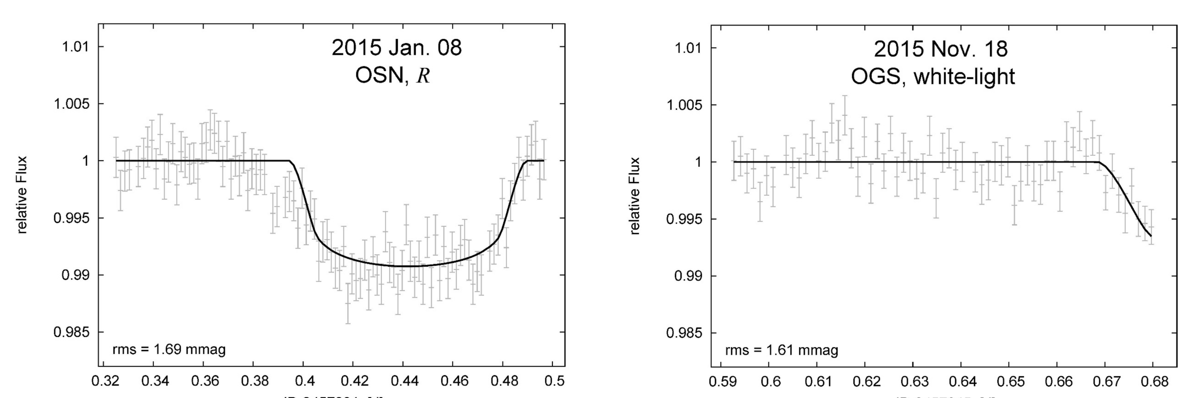


Figure 3: Light curves of CoRoT-20 b with best-fitting model resulting from the simultaneous fit of all CoRoT and ground-based light curves. As can be seen, only the beginning of the transit could be observed with the OGS because of the uncertainty in the planet ephemeris.

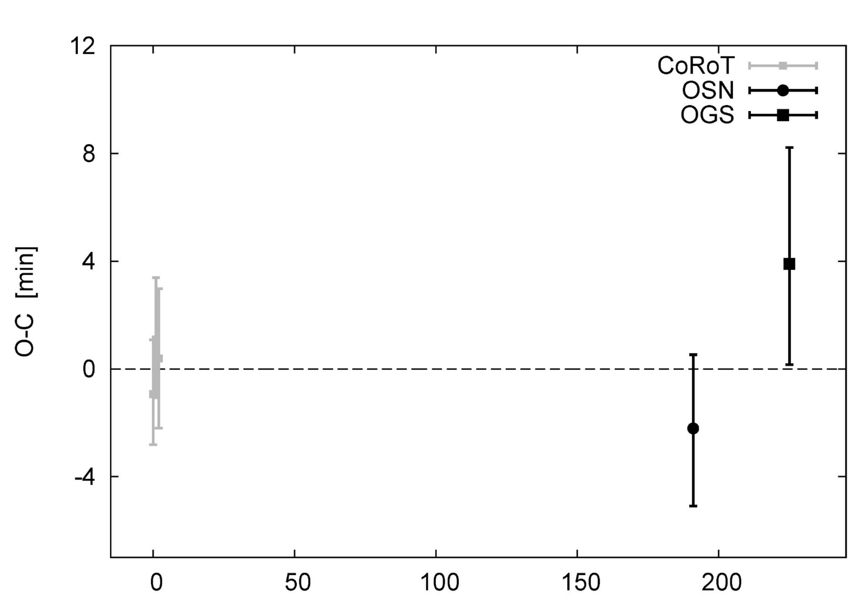


Figure 4:The O–C-diagram of CoRoT-20 b. The dashed line represents the updated ephemeris light curves of CoRoT-20 b with best-fitting model resulting from the simultaneous fit of all CoRoT and ground-based light curves. The orbital period is 29 s longer and 33 times more precise than the one given in Deleuil et al. (2012).

3. Observing campaign in 2017

The first observing campaign of the proposal approved in 2017 consisted of 7 nights, from 2 to 9 October. The observations covered exoplanet transit observations, stellar activity monitoring, both using multi-band photometry, and X-ray binaries observations. It also included test observations to determine the performance of the Hα filter and the capability of the instrument to contribute to the filtering of exoplanet false positive detections.

Table 1: Summary of the 2017 proposal first campaign

Night (October)	Targets	Type of object	Observation
2	Qatar-4 b CoRoT-14 b	Exoplanet Exoplanet	Transit, multi-band photometry B,V,R Transit, multi-band photometry B,V,R
3	BD+37 426 HAT-P-29 b SwiftJ0243.6 X-Per	Stellar standard Exoplanet X-ray binary X-ray binary	Hα filter photometry (test) Transit, multi-band photometry B,V,R Spectroscopy Spectroscopy, Photometry
4	KIC11805150 KELT-7 b	Active Kepler star Exoplanet	Multi-band photometry B,V,R Transit, multi-band photometry B,V,R
5	KIC6025466	Active Kepler star	Multi-band photometry B,V,R
6	WASP-33 b WASP-75 b	Exoplanet Exoplanet	Transit, multi-band photometry B,V,R Transit, multi-band photometry B,V,R
7	WASP-28 b	Exoplanet	Transit, multi-band photometry V,R
8	K01140.01 SwiftJ0243.6 WASP-77 A b	Candidate exoplanet X-ray binary Exoplanet	Transit, multi-band photometry V,R Spectroscopy Transit, multi-band photometry B,V,R

3.1 Multi-band transit observations

Photometry of planetary transits in several visible wavelengths may provide first hints on the nature of the planetary atmosphere. In particular, in a cloudless atmosphere, visible multiwavelength observations allow us to measure the Rayleigh slope of the planet's reflected light, and therefore to derive the atmosphere mean molecular weight (Benneke & Seager 2012). Multi-band photometry also allows us to study the stellar activity, and to determine the planet and orbit parameters with high precision.

During the October 2017 campaign, we observed several exoplanet transits quasi-simultaneously in the B, V, and R bands. We have confirmed the capability of the OGS Spectrograph to carry out this type of observations with enough S/N for planets with $R_{planet}/R_{star} > 0.08$ and $V < 15.2$.

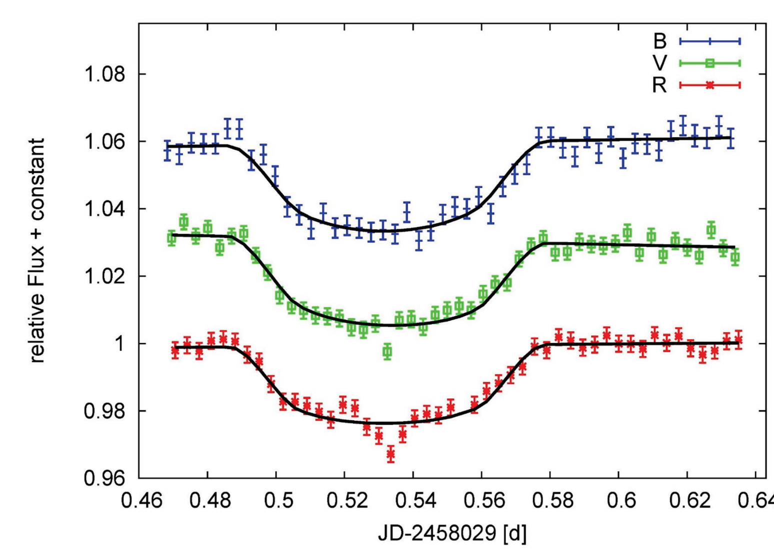


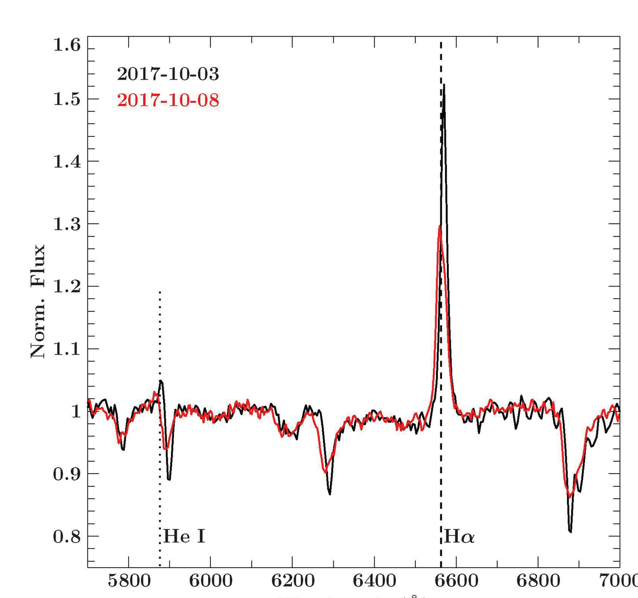
Figure 5: The transit of Qatar-4 b observed by the OGS Spectrograph in the B, V, and R bands, with the fit represented by a black line. Sequences of three consecutive exposures, each exposure made with a different filter, were obtained across the complete transit allowing us to have quasi-simultaneous multi-band photometry.

Qatar-4 b is a hot Jupiter that orbits a K1V star of B = 14.7 mag in 1.8 d.

3.2 X-Ray binaries

We observed the new X-ray transient Swift J0243.6+6124 with the GrismBB during two nights (3 and 8 October). From X-ray observations it was known that the accreting object in this source is a slowly rotating neutron star, however, the stellar type of the mass donor was not yet identified. In our spectra we clearly detect a strong Hα line. While the line profile could not be resolved, the detection of the line allows us to classify the optical companion as a Be star with a significant circumstellar disk. This disk provides the reservoir for the accreting material onto the neutron star.

These observations show that the throughput and resolution of the OGS Spectrograph grism is suitable to study and monitor the stellar activity of Be-X-ray binaries. Future observations will allow us to observe a sample of these systems, and correlate their optical spectra with their X-ray.



OGS Spectrograph observation of the X-ray transient Swift J0243.6+6124, showing the variability of the Hα line. We measure an equivalent width of 11.0 Å (first night, black) and 9.5 Å (second night, red). The variability might indicate that the neutron star has accreted a fraction of the circumstellar disk, which was therefore smaller during the second observation.

4. Next steps

The next steps for this project are:

- Continue the analysis and publication of the 2015-2016 campaigns observations
- Reduce and analyse the data of the 2017 campaign
- Carry out a second observing campaign in the beginning of next year with the same objectives as the first one, and the addition of pilot Ca-II filter observations of Sun-like stars in open clusters
- Fix the leakage of the Hα filter and make test astronomical observations in preparation for future programmes
- Continue monitoring of circumstellar disk size and activity of bright Be-X-ray binaries

Appendix: Ca-II and Hα filters

As part of the 2017 campaign, we made on-sky calibration observations to evaluate the performance of the Spectrograph Hα filter, and found a significant leakage at longer wavelengths. We had identified a similar problem with the Ca-II filter after performing tests at an ESTEC optical lab (thanks to Mathijs Arts and Zoran Sodnik, Optics Laboratory of the Optics Section, TEC-MMO). The leakage has been fixed by adding a blocking filter, a solution that we also plan to implement for the Hα filter. Figure 7 (left) shows the measurements of the transmission of the Ca-II filter, where it can clearly be seen that the filter also transmits at wavelengths higher than 450 nm. In addition, the specification stated that the transmission peak should be at 393.4 nm with 2 nm FWHM, while the test showed that the peak is at 395 nm with 3.4 nm FWHM.

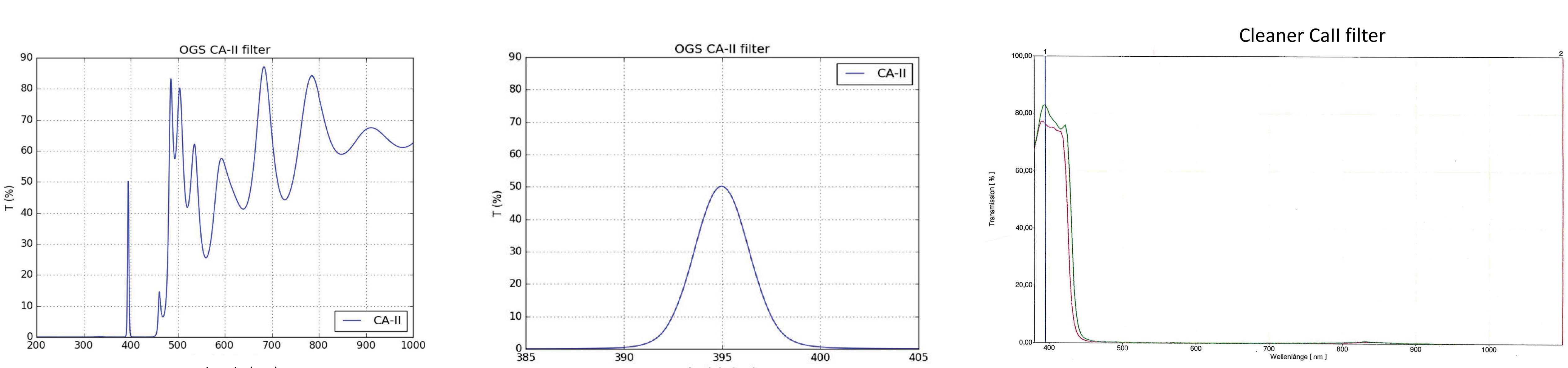


Figure 7: Laboratory measurements of the Ca-II filter (left and centre panels), and the new filter that will be used as cleaner (right panel).

References

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