EPSC Abstracts
Vol. 6, EPSC-DPS2011-777, 2011
EPSC-DPS Joint Meeting 2011

Transiting exoplanets characterization with the SOPHIE spectrograph at OHP

G. Hébrard (1,2), F. Bouchy (1,2), R. F. Díaz (1,2), C. Moutou (3), A. Santerne (3), and the SOPHIE Team
(1) Institut d'Astrophysique de Paris, France (2) Observatoire de Haute-Provence, France, (3) Laboratoire d'Astrophysique de Marseille, France (hebrard@iap.fr)

Abstract

The SOPHIE environmentally-stabilized echelle spectrograph at Haute-Provence Observatory is widely used for the radial velocity follow-up of photometric surveys for transiting planets detections, including ground- and space-based projects (SuperWASP, HAT, CoRoT, Kepler...). Such spectroscopic observations are mandatory to establish the planetary nature of transiting candidates and to characterize the detected planetary systems. Ground-based spectrographs as SOPHIE will be an essential part for the detection, characterization, and study of planets detected by the future surveys as PLATO and TESS.

1. Introduction

The importance of transiting extrasolar planets has been broadly recognized. In addition to confirm that planets detected through radial velocity (RV) variations were not artifacts due to stellar effects, they allow key studies to be performed. Indeed, transiting planets allow accurate planetary radius, mass and density measurements, atmospheric studies in absorption through transits and in emission through occultations, dynamic analyses from possible timing variations, or obliquity measurements thanks to the Rossiter-McLaughlin effect. The power of these analyses incited numerous search surveys for transiting planets. This results now in a biased population: over the ~ 550 exoplanets currently known, more than 120 are transiting. Most of them were discovered in the five last years and the detection rate is still increasing through ongoing wide-field photometric surveys, from robotic ground-based telescopes and space observatories.

2. The need for RV follow-up

In most of cases, photometric data alone are not able to convincingly conclude to the detection of an extrasolar planet. Indeed, several scenarios implying binary stars could mimic the signature of a transiting planet in a light curve. This includes eclipsing M dwarfs as well as grazing, background or blended eclipsing binaries. Only a small proportion of the candidates identified from photometry actually are transiting planets. The ratio if of the order of 10 % for surveys as SuperWASP or CoRoT; it is likely to be better for Kepler.

Spectroscopy allows the identification of most of the scenarios implying binaries, through RV measurements and line profile-shape analysis. Spectroscopic follow-up is thus mandatory to identify the actual transiting planets among the candidates detected from photometric surveys. They also allow the measurement of the mass of the secured planet and the determination of the parameters of the host star, which are mandatory for the characterization of the system. Finally, extra RV measurements of stars hosting transiting planets allow obliquity measurements and search for additional companions in the systems.

To summarize, RV follow-up of photometric surveys for transiting planets are mandatory in order to:

- establish the nature of the transiting events;
- characterize the mass of the secure planets;
- determine the host-star parameters;
- measure the obliquity of the systems (through Rossiter-McLaughlin effect);
- monitor long-term RV drifts due to multiple systems.

3. SOPHIE follow-up of photometric surveys

SOPHIE is a cross-dispersed, environmentally stabilized echelle spectrograph dedicated to high-precision RV measurements (Bouchy et al. 2009), mounted at the 1.93-m telescope of Haute-Provence Observatory, France. It is implied in the RV follow-up of several photometric surveys.

SOPHIE has been broadly used for the follow-up of SuperWASP candidates. This allowed the detection of the three first planets of this survey (Cameron et al. 2007, Pollacco et al. 2008), followed by a dozen of extra ones. This includes short-period planets with eccentric orbits (WASP-10b and 14b, Christian et al. 2009, Joshi et al. 2009), one of the hottest planets known (WASP-12b, Hebb et al. 2009), an inflated Saturn-mass planet (Bouchy et al. 2010a), or a giant planet on a 7-day period (WASP-38b, Barros et al. 2011). In addition, the planets HAT-P-5b and HAT-P-9b have also been discovered thanks to SOPHIE follow-up (Bakos et al. 2007, Shporer et al. 2009).

CoRoT candidates have been widely followed up with SOPHIE. This allowed the detection of the first CoRoT planet (Barge et al. 2008), of other hot jupiters including ordinary ones CoRoT-2b, 5b or 11b (Alonso et al. 2008, Rauer et al. 2009, Gandolfi et al. 2010) and some on longer periods as CoRoT-4b and 6b (Moutou et al. 2008, Fridlund et al. 2010). SOPHIE also has been used for the identification of promising candidates to be followed up at higher precision with the HARPS spectrograph. This encompasses the super Earth CoRoT-7b (Léger et al. 2009, Queloz et al. 2009) and the long-period Jupiter-mass planet CoRoT-9b (Deeg et al. 2010).

SOPHIE is also used for the follow-up of Kepler objects of interests. This led to the confirmation of the low-mass white dwarf KOI-74b (Ehrenreich et al. 2011) and to the detection of several new transiting giant planets (Santerne et al. 2011)

4. Spectroscopic transits

Thanks to the Rossiter-McLaughlin effect, spectroscopic observations of a star during the transit of its hosted planet gives informations on the obliquity of the system, i.e. the angle between the planetary orbital axis and the stellar rotation axis. This effect occurs when an object transits in front of a rotating star, causing a distortion of the stellar lines profile, and thus an apparent anomaly in the measured RV of the star. The shape of the disturbed RV curve allows one to determine the obliquity, or more specifically its sky-projected value λ. Such measurements could give crucial clues on the history and dynamics of planetary systems (Moutou et al. 2011).

Between 2000 and 2008, spectroscopic transits have been measured for a dozen of extrasolar systems, including some with SOPHIE (HAT-P-2 and CoRoT-2, Loeillet et al. 2007, Bouchy et al. 2008). All these measurements shown aligned, prograde orbits ($\lambda \simeq 0^\circ$), as expected for planets that formed in a protoplanetary disk far from the star and that later migrated closer-in.

However, a first case of misaligned system was reported by Hébrard et al. (2008) in the XO-3 system. The SOPHIE observations secured during a transit of this massive planet only shown a blue-shifted anomaly, instead of the feature expected in case of aligned system. The second case of misaligned system was also reported thanks to SOPHIE observations: simultaneously with the detection of the transiting nature of the long-period, eccentric planet HD 80606b, Moutou et al. (2009) shown that $\lambda \neq 0^\circ$ in this system. This result was refined thanks to the observation of another transit of this planet, simultaneously with SOPHIE and Spitzer (Hébrard et al. 2010).

Since then, other misaligned systems were detected with SOPHIE (Moutou et al. 2011), including retrograde ones (Hébrard et al. 2011). These surprising results, as well as those obtained with other spectrographs, suggest that some close-in planets might result from gravitational interaction between planets and/or stars rather than migration due to interaction with the accretion disk.

References

Alonso, R., Auvergne, M., et al. 2008, A&A, 482, L21
Bakos, G. A., Shporer, A., et al. 2007, ApJ, 671, L173
Barge, P., Baglin, A., et al. 2008, A&A, 482, L17
Barros, S., Faedi, F., et al. 2011, A&A, 525, A54
Bouchy, F., Queloz, D., et al. 2008, A&A, 482, L2
Bouchy, F., et al. 2009, A&A, 505, 853 (and EO1)
Bouchy, F., Hebb, L., et al. 2010, A&A, 519, A98
Cameron, A., Bouchy, F., et al. 2007, MNRAS, 375, 951
Christian, D., et al. 2009, MNRAS, 392, 1585
Deeg, H. J., Moutou, C., et al. 2010, Nature, 464, 384
Ehrenreich, D., et al. 2011, A&A, 525, A85
Fridlund, M., Hébrard, G., et al. 2010, A&A, 512, 14
Gandolfi, D., Hébrard, G., et al. 2010, A&A, 524, A55
Hebb, L., et al. 2009, ApJ, 693, 1920
Hébrard, G., Bouchy, F., et al. 2008, A&A, 488, 763
Hébrard, G., Désert, J.-M., et al. 2010, A&A, 516, 95
Hébrard, G., Ehrenreich, D. et al. 2011, A&A, 527, L11
Joshi, Y. C., et al., 2009, MNRAS, 392, 1532
Léger, A., Rouan, D., et al. 2009, A&A, 506, 287
Loeillet, B., Shporer, A., et al. 2007, A&A, 481, 381
Moutou, C., Bruntt, H., et al. 2008, A&A, 488, L47
Moutou, C., Hébrard, G., et al. 2009, A&A, 498, L5
Moutou, C., et al. 2011, arXiv1105.3849 (and PD3/EO9)
Pollacco, D., et al. 2008, MNRAS, 385, 1576
Queloz, D., Bouchy, F., et al. 2009, A&A, 506, 303
Rauer, H., Queloz, D., et al. 2009, A&A, 506, 281
Santerne, A., et al. 2011, A&A, 528, A63 (and EO7)
Shporer, A., Bakos, G., et al. 2009, ApJ, 690, 1393