EPSC Abstracts
Vol. 8, EPSC2013-669, 2013
European Planetary Science Congress 2013

EPSC European Planetary Science Congress

Validation of the smallest *CoRoT* candidates using PASTIS

R.F. Díaz (1), J.-M. Almenara (1), A. Santerne (1, 2), C. Moutou (1), A. Lethuillier (1), M. Deleuil (1), F. Bouchy (1), G. Hébrard (3, 4), and G. Montagnier (3, 4).
(1) Aix Marseille Université, CNRS, LAM (Laboratoire d'Astrophysique de Marseille) UMR 7326, 13388, Marseille, France (rodrigo.diaz@oamp.fr). (2) Centro de Astrofísica, Universidade do Porto, Rua das Estrelas, 4150-762 Porto, Portugal.
(3) Institut d'Astrophysique de Paris, UMR7095 CNRS, Université Pierre & Marie Curie, Paris, France. (4) Observatoire de Haute-Provence, CNRS/OAMP, 04870 Saint-Michel-l'Observatoire, France.

Abstract

The majority of the smallest transiting planet candidates detected by *CoRoT* could not be directly confirmed by a dynamical measurement of their mass. This is due mainly to the faintness of the typical stars observed by *CoRoT* and to the small reflex motion induced by low-mass planets on their host stars. These candidates have traditionally being labeled as "unresolved", and virtually forgotten in the hope that the new generation of ultra-precise spectrographs installed in large telescopes would permit their confirmation. A way out of this problem is to statistically *validate* these candidates. In this talk, I will present PASTIS, the validation tool developed in Marseille that is being used to study the *CoRoT* unresolved candidates.

1. Introduction

To overcome the small odds of planetary orbits being almost perfectly aligned with our line of sight from Earth, ground- and space-based transit surveys have to observe a large number of stars. To achieve this, one option is to observe bright stars over a large region of the sky. This is the strategy adopted by most ground-based surveys [9], and the one that will be adopted by future space missions like TESS and PLATO. The second option is to observe fainter stars over a smaller region of the sky. The only space-based transit surveys carried out so far have adopted this strategy. Therefore, the overwhelming majority of the transiting candidates furnished by the space missions *Kepler* [2] and *CoRoT* [4] are found around faint stars, with typical visual magnitudes above V = 14.

Since false positives are known to plague transit surveys [11], additional observations are usually required to confirm transiting candidates are actually planets. However, the faintness of the targets poses a strong challenge for ground-based follow-up observations, and to radial velocity (RV) measurements in particular. As the precision of the RV measurement scales linearly with the signal-to-noise ratio of the spectrum, the precision obtained on faint stars is degraded. As a consequence, small-mass planets cannot be confirmed by this method.

2. Planet validation and PASTIS

The technique of planet validation consists in accumulating enough statistical evidence for the hypothesis that the candidate is actually a planet to consider it confirmed. In this cases, no mass measurement is possible[1] but the planetary nature of the object is secured. To do this, the planetary hypothesis has to be weighted against the alternative hypotheses of stellar false positives. In a Bayesian framework, this is expressed through the Bayes' factor:

$$B_{\mathrm{pla;FP}} = \frac{p(\mathrm{H_{pla}}|\mathrm{D,I})}{p(\mathrm{H_{FP}}|\mathrm{D,I})} = \frac{p(\mathrm{H_{pla}}|\mathrm{I})}{p(\mathrm{H_{FP}}|\mathrm{I})} \cdot \frac{p(\mathrm{D}|\mathrm{H_{pla}},\mathrm{I})}{p(\mathrm{D}|\mathrm{H_{FP}},\mathrm{I})}\,, \tag{1}$$

which is simply the ratio of the posterior probabilities for two competing hypotheses. Here, H_{pla} stands for the planetary hypothesis, H_{FP} represents a generic false-positive scenario, and D and I are prepositions representing the relevant data and the prior information. If the Bayes' factor is sufficiently large (usually, above 150 [8]) for all conceivable false positive scenarios, and the computed posterior is also greater than the sum of the false positive posteriors, then the planet is considered as validated. A similar philosophy was employed to validate some of the smallest planets detected by *Kepler* [3, 7, 13].

2.1. PASTIS

PASTIS stands for Planet Analysis and Small Investigation Software, and is a tool to rigorously estimate

[1] Usually, RV observations provide only an upper limit to the mass of the transiting object.

the Bayes' factors relevant to the problem of planet validation. PASTIS models the light curves, radial velocity variations [12] and spectral energy distributions of almost all conceivable false positives and of transiting planets. To do this, it relies on state-of-the-art stellar evolution and atmospheric models (e.g. [1, 6]), and on models of the Galactic interstellar extinction. It self-consistently takes into account all available data to compute the evidence ratio (the second term in the right-hand side of equation 1). This is coupled with models of the Galactic structure and populations [10] to compute the remaining term, the prior ratio.

Thanks to an efficient Monte Carlo Markov Chain algorithm used to sample from the posterior distribution of the models and to the use of the importance sampling technique [14] to compute the evidence of each model, PASTIS provides a precise and rigorous estimation of the Bayes' factor with a minimum of computation time [5].

3. The *CoRoT* unresolved cases

The *CoRoT* mission has provided hundreds of transiting planet candidates. For little less than 200 of them, their nature remain unknown. As mentioned above, this is usually do to the faintness of the star, that impedes ground-based confirmation. In Fig. 1 the fractional depth of these candidates is plotted as a function of their orbital period. The targets that have undergone some sort of complementary ground-based observations (around half of them) are plotted as gray circles.

For comparison, the confirmed *CoRoT* planets are plotted as red circles. Some of the unresolved transiting candidates are among the smallest ones detected by *CoRoT*. Validating them will increase the scientific harvest of the mission and help populate a region of parameter space where only scarce constraints on the mass of the objects exists. Additionally, it will allow for a precise determination of the planet occurrence rate in the two Galactic regions probed by *CoRoT*, which is currently hindered by the existence of these unresolved candidates.

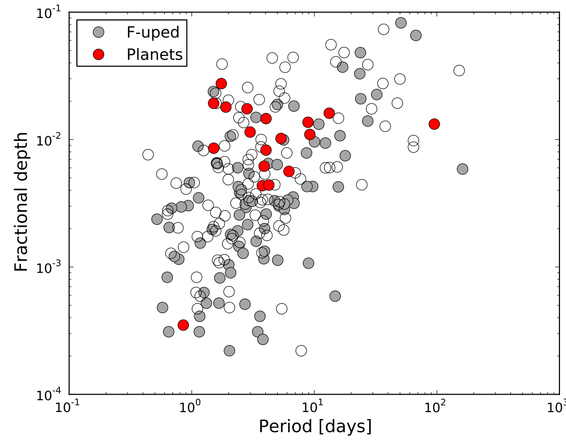

Figure 1: Fractional depth and period of the *CoRoT* unresolved candidates. Filled circles represent candidates for which additional ground-based observations have been performed. The red dots are some of the planets discovered by *CoRoT*. It can be seen that some of the unresolved cases are among the smallest transits detected by the mission.

References

[1] F. Allard, D. Homeier, and B. Freytag, *Royal Society of London Philosophical Transactions Series A*, vol. 370, pp. 2765–2777, June 2012.

[2] W. J. Borucki, D. G. Koch, G. Basri, et al. *ApJ*, vol. 728, 117, Feb. 2011.

[3] W. J. Borucki, D. G. Koch, N. Batalha, et al. *ApJ*, vol. 745, 120, Feb. 2012.

[4] M. Deleuil, et al., in preparation.

[5] R.F. Díaz, et al., in preparation.

[6] A. Dotter, B. Chaboyer, D. Jevremović, et al. *ApJS*, vol. 178, pp. 89–101, Sept. 2008.

[7] F. Fressin, G. Torres, J. F. Rowe, et al. *Nature*, vol. 482, pp. 195–198, Feb. 2012.

[8] Robert E Kass and Adrian E Raftery, *Journal of the american statistical association*, vol. 90, no. 430, pp. 773–795, 1995.

[9] D. L. Pollacco, I. Skillen, A. C. Cameron, et al. *PASP*, vol. 118, pp. 1407–1418, Oct. 2006.

[10] A. C. Robin, C. Reylé, S. Derrière, and S. Picaud, *A&A*, vol. 409, pp. 523–540, Oct. 2003.

[11] A. Santerne, R. F. Díaz, C. Moutou, et al. *A&A*, vol. 545, A76, Sept. 2012.

[12] A. Santerne, et al., in preparation.

[13] G. Torres, F. Fressin, N. M. Batalha, et al. *ApJ*, vol. 727, pp. 24, Jan. 2011.

[14] M. Tuomi and H. R. A. Jones, *A&A*, vol. 544, pp. A116, Aug. 2012.