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The CoRoT mission's exoplanet program

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Abstract. The CoRoT space observatory was launched at the end of 2006 and has been delivering scientific data from early 2007 until its recent interruption, on 2 Nov. 2012, leading to the discovery of over 30 transiting planets. Here we give an overview over the most relevant results from CoRoT's exoplanet detection program.

1. INTRODUCTION

The advantages of space observations towards planet detection with the transit method, first described by [1], have been recognized long before the first exoplanets have been detected [2, 3]. In parallel, in the early 1990s, a group of french Asteroseismologists began advancing a space mission dedicated to their field. This project, already named "Corot" (for "Convection and Rotation") was preselected in 1994 by CNES for a phase A study [4]. In 1995, the first exoplanets were discovered, whereas delays in the Corot project created to opportunity to add the search for exoplanets as a second major objective in 1996 [5], converting CoRoT's last "T" to "Transits".

CoRoT was constructed under leadership of the French space agency CNES with several international contributors (Austria, Brazil, Germany, Spain and the European Space agency ESA) and launched on 26 Dec. 2006. The acquisition of scientific data began on 18 Jan. 2007 and was initially scheduled to last until April 2010. Given its excellent performance, the mission got extended until April 2013, with an extension for another 3 years having been approved in summer 2012. On 2 Nov. 2012, however, CoRoT stopped acquiring data, presumably due to damage from the impact of highly energetic particles. At the time of writing (Jan. 2013), efforts for its recovery are still going on, with the chances for success however being slim.

The basic payload layout is an afocal telescope with 27 cm aperture, with two sets of CCD detectors in slightly different focal planes, which are dedicated to asteroseismology and to exoplanets, respectively. A bi-prism in front of the exoplanet CCDs permits a measurement of the brighter targets in three colours red, green and blue. In the exoplanet focal plane, about 12000 targets within a field of view of 1.5 deg by 3 deg can be observed simultaneously with a cadence of 32 sec, though most data are downloaded with a cadence of 512 sec [6]. In 2009, the available field of view in both exoplanet and asteroseismology channels got cut to half, due to the failure of one chain of the detector electronics.

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CoRoT pointings consist of "Long Runs" of 2–5 months duration that are primarily devoted to exoplanet detection and to asteroseismology studies, and of 1–6 week long "Short Runs", mostly for its additional science program.

2. RESULTS FROM COROT

Until its failure on 2 Nov 2012, CoRoT observed about 160.000 stars in its exoplanet program, covering an area of ≈ 56 square degrees in 26 pointings. Initial detection algorithms found nearly 4000 lightcurves with transit-like events, of which $\approx 83\%$ became classified as eclipsing binaries in a second stage [7]. The CoRoT Exoplanet Science Team is then undertaking a more detailed analysis of the remaining candidates, often on a case-by-case basis, which led to the rejection of some more cased and the priorizing of the remaining ones (620 to date) according to their planet likeliness. These candidates became then targets for an intense ground-based follow-up program. This program has been the backbone of the work performed by the CoRoT Exoplanet Scientific Team (CEST), which performs spectroscopic [8] (radial velocities and spectral typing) and photometric [9] follow-up observations in over 20 different facilities. Actual observations have been done to date on ≈ 450 candidates, with ≈ 320 observing nights spent for spectroscopy, mostly for RV data, and 200 nights for imaging, mostly for photometric time-series. Of the surveyed candidates, about 60% turn out to be false positives (nearly all them being caused by eclipsing binaries in some configuration with the target star [10]) and $\approx$6% are planets, whereas the nature of the remainder remains unresolved [7]. These unresolved candidates are mostly older ones that are either faint or of low priority, and further observations cannot be justified for them, followed by a smaller group that was observed intensely but with ambiguous results, plus those candidates for which follow-up observations are still going on.

To date, 22 substellar objects discovered by CoRoT have been published, of which 20 are clearly planets, one is a brown dwarf (Corot-15b with a mass of $63\mathrm{M_{jup}}$ [11]) and one (Corot-3b) is in the intermediate range between planes and brown dwarfs [12]. These planets cover the entire range in the mass-radius plane of the currently known transiting planets (Fig. 1). Most of the planets are of the "Hot Jupiter" variety, but they are among the best-characterized ones, due to the high precision of their light-curves and the thorough ground-based observations. Also, several of them have some "special feature" that makes them interesting. Of special mention among giant planets are:

- Low-density inflated giants (e.g. Corot-1b, 4b, 5b, 12b, 16b); of which some have relatively long periods; e.g. Corot-4b has a period of 9.2 days [13].
- Hot Jupiters (e.g. Corot-1b, 3b, 6b, 18b) that orbit stars with low metal content, which is contrary to the usual metallicity relations found by RV searches.
- Several of the giants are rather massive with $> 3\mathrm{M_{jup}}$ (Corot-2b, 14b, 18b, 20b), with Corot-3b having a mass ($21.6\mathrm{M_{jup}}$) [12] that makes its assignment between planets and brown dwarfs ambiguous. The density of some of these cases is also very difficult to explain with current planetary formation models; e.g. Corot-20b with a mass of $4.24\mathrm{M_{jup}}$, a radius of $0.84\mathrm{R_{jup}}$, and an inferred density of $8.9 \pm 1.1\,\mathrm{g\,cm^{-3}}$ would require a dense core with about 1000 Earth masses [14].
- The massive planet Corot-2b shows a beautiful beating pattern in its light-curve, caused by stellar activity [15], which made it into a prototypical case for some similar planets later discovered by Kepler.
- The first temperate transiting planet that is truly Jupiter-like was also discovered by CoRoT. This is Corot-9b with a nearly circular period of 95 days and an expected surface temperature of 250 K and 430 K [16].

Lastly, there are four small planets: Three Saturn-like ones (Corot-8b [17] and the planetary system consisting of Corot-24b and c [18]), and the first confirmed terrestrial planet, Corot-7b with a radius of about $1.7\mathrm{R_{earth}}$ [19]. This planet has probably been the most important discovery by CoRoT, being the first planet that is definitively not gaseous. With its expected surface temperature of > 3000 K it has

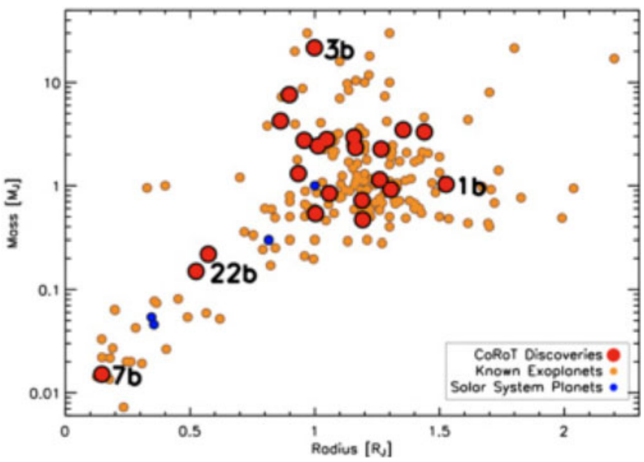

Figure 1. Masses and radii of published CoRoT planets, in comparison to the known planet population. Figure credit: T. Pasternacki.

become the prototype for a new class of "Lava-Ocean" planets [20], that is, short-periodic planets with a bound rotation, where the star-facing side is an ocean of molten Lava.

Only a very cursory overview about the detected planets could be given here; more detailed overviews of the exoplanet findings of CoRoT can be found in [21, 22]. Several more detected planets are currently in various stages of analysis and publication, rising the count to a total of 33 planets in 32 systems. Of course, not only the planet discoveries are important, but also the subsequent interpretive work and further follow-up observations. In fact, over 80% of the currently ≈ 250 refereed publications on CoRoT-Exoplanets are such "further works", most of them being contributions by the wider community not directly being involved in the mission. With the likely end of the active phase of the CoRoT satellite, the focus of the scientists involved in the mission will also change from discovery to a deeper analysis of the planets found. To some extent, this change in paradigm had already occurred before the instrument failure. Some of the last observing runs had been overlapping with previously surveyed areas, in order to permit the re-observation and deeper analysis of known planets; among them Corot-7b, with the new data currently being revised. Continued ground-based surveying of the known planets, searches for events that have been missed in the existing Corot data, and the reduction of the still considerable list of unresolved candidates will likely provide work for several more years and help to establish the legacy of CoRoT as the first space mission that undertook a search for extrasolar planets.

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