

EXOPLANET DETECTION CAPABILITY OF COROT. P. Bordé¹, D. Rouan¹, and A. Léger², ¹Laboratoire d'Études spatiales et d'Instrumentation en Astrophysique, FRE2461, 5 place Jules Janssen F-92195 Meudon Cedex, Pascal.Borde@obspm.fr, ²Institut d'Astrophysique Spatiale, UMR8617, Université Paris XI, F-91405 Orsay.

Introduction: In the continuing search for exoplanets, the next challenge to take up is certainly the detection of Uranus to Earth-like planets. This goal will be within reach of the space mission COROT [1,2] to be launched in 2005. COROT will continuously monitor five stellar fields, during 150 days each, to measure the lightcurves of 6,000 to 12,000 dwarfs with a very high photometric precision. Exoplanets orbiting in an almost edge-on plane will periodically transit in front of their parent star, inducing a characteristic signature in the recorded lightcurve [3]. The depth of a dip due to a single transit is in the ratio of the radius of the planet to that of the star, and the duration τ of the event depends on the orbital parameters of the planet, but will remain inferior to ≈ 15 hours for COROT targets.

The aim of this work is to evaluate the detection performances and characteristics of COROT. We utilize the model of the stellar population of the Galaxy developed at Besançon Observatory [4] to generate a synthetic stellar field with statistical properties (visual magnitude and spectral type distributions) similar to those of the future target fields. Then, a virtual planet is attributed to every star, and we compute the number of expected detections using a S/N (signal to noise) criterion based on a simple cross-correlation technique [5] that takes into account the instrumental parameters of COROT. We study the influence of the magnitude and the spectral type of the parent star on the number of detections, as well as the impacts of the stellar variability and of the crowding effect.

Detection criterion: Our point here is not to develop a refined detection method as it was done recently by [6], but merely to estimate the performances of COROT. Our treatment of the lightcurves begins by removing the long term stellar variations with a high-pass filter. The data are then averaged over a trial value for τ to increase the S/N, and cross-correlated with a noise-free signal that has the shape of a comb with k teeth, k being the trial number of transits. The transit search consists in computing a set of cross-correlation products $C(\tau, k, \phi)$ to explore the parameter space of transit duration, period and phase of the first transit (ϕ). A detection is said to occur if C happens to be greater than a threshold fixed by the desired confidence level. Assuming a gaussian statistics for C with a standard deviation σ_C , we find that the number of false detection

falls below one for the whole mission if $C \geq \beta \sigma_C$ with $\beta=7$. In terms of S/N, this criterion reads

$$\frac{S}{N} \geq \frac{\beta}{\sqrt{k}}, \quad (1)$$

or

$$R_p \geq R_* \left(\frac{\beta \sigma_n}{\sqrt{k} N_e} \right)^{1/2} \quad (2)$$

where R_p is the planet radius, R_* the stellar radius, σ_n the standard deviation of the noise affecting the lightcurve and N_e the number of photo-electrons collected during τ . Our simulations take into account the read-out noise, the background noise (zodiacal light) and the stellar variability noise set at the solar value (≈ 50 ppm rms after filtering of SOHO data [7]).

Synthetic stellar field: Centered around the Galactic Anticenter ($l_{II}=210^\circ$, $b_{II}=0^\circ$), it covers 3.5 deg^2 and contains 16,000 B2 to M2 dwarfs with visual magnitudes between $V=10.5$ and $V=16.5$. The number of dwarfs roughly follows a geometric progression with a ratio of ≈ 2.3 , and the sample is dominated by spectral types F7-G2. As this synthetic field, located in one of the two selected directions for the mission, seems to be in good agreement with preliminary stellar countings on the sky, it serves as a fiducial field for the purpose of our simulations. In the remainder of this work, we assume that COROT will observe five fields with the same statistical properties as this one.

Expected detections: In the prospect of exobiology, we introduce the reduced orbital distance, $a_r = a/(L_*/L_\odot)^{1/2}$, defined so that a planet at $a_r = 1$ AU would receive as much flux from its star (L_*) as the Earth from the Sun (L_\odot). If preferred, it is equivalent to use the effective temperature of a blackbody $T_p(K) = 278/(a_r)^{1/2}$. Assuming that every star has a planet of a given radius orbiting its star at a given reduced distance, we derive the detection curves displayed on Figure 1. A first result of these computations is that terrestrial planets ($R_p \approx 1-2 R_{\text{Earth}}$) are within reach of COROT provided they are close enough to their stars ($a_r \leq 0.2$ AU), i.e. rather hot and not in the inhabitable zone ($a_r \approx 1$ AU). Besides, since there is no significant gain from R_p equals 5 to 10 R_{Earth} , the instrument reaches its full potential for planets that have half the size of Jupiter.

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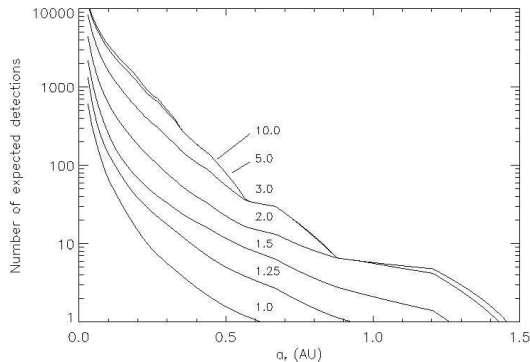


Figure 1 : Number of expected detections for the whole mission vs. the reduced orbital distance for different planet radii (expressed in unit of R_{Earth}).

In order to get an estimate of the total number of planet detections for the whole mission, one has now to integrate over the orbital distance. This can be done provided a law has been chosen for the planet orbital distribution. We have contemplated two cases:

- (i) a uniform orbital distribution: the planet probability density vs. a_r is constant beyond 0.03 AU (the shortest reduced orbital distance observed to this date), and normalized to one planet per AU per star;
- (ii) an “observed” distribution: the planet probability density vs. a_r is derived from the actual sample of detected exoplanets orbiting their stars in the range $0.03 \leq a_r \leq 1.5$ AU [8], also normalized to one planet per AU per star. This distribution strongly peaks at $a_r \approx 0.05$ AU. Although this sample is clearly biased toward small orbital distances, the precision of radial velocity surveys implies that it is almost complete for giant planets ($M_p \geq 1.4 M_J$) within the first AU, the relevant zone for COROT. Off course, we have no indication that small planets abide by the same orbital distribution as giant ones.

Because the “observed” distribution puts more weight on short orbital distances, it appears as much more favorable for COROT (Table 1). One may consider that these two laws establish a lower and an upper limit to the total number of expected detections.

Stellar variability and crowding: Since we have modeled the stellar variability using the Sun, usually considered as a “quiet” star, it is worth investigating the impact on the detection efficiency of a variability higher than solar. If this noise is increased to 10 times the solar value, half of the small planets ($R_p \leq 2 R_{\text{Earth}}$) are lost, but almost no effect is seen for the giant plan-

ets. However, if the stellar variability were 100 times the solar value, no small planets could be detected at all. This problem might be partly overcome with a proper combination of the colored channels extracted from the dispersed stellar PSF [2,9].

A last important effect is due to crowding: the number of background (BG) stars of all luminosity classes increases typically by a factor ≈ 2.3 with the magnitude V . As a consequence, the photometry of a target star is likely to be polluted by the flux of a BG star that may be variable. Using data from the Geneva group and the Hipparcos mission [10,11], we have crudely estimated the variability statistics for dwarf and giant stars. Monte-Carlo simulations with stellar distributions computed with the Besançon model and for 85-pixel photometric masks, reveal that $\approx 10\%$ of the detections could be lost because of crowding.

R_p (in R_{Earth})	uniform distribution	“observed” distribution
1.0	14	73
1.25	31	147
1.5	58	275
2.0	133	596
3.0	331	1382
5.0	605	2330
10.0	665	2545

Table 1 : Total number of expected detections for the whole mission for different planet radii and two hypotheses on the orbital distribution of planets around their parent stars. The extra variability induced by the crowding effect is expected to cause a loss of $\approx 10\%$ in the detections quoted here.

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