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CoRoT and the search for exoplanets.

The Italian contribution

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Abstract. The space mission CoRoT (COnvection, ROtation and planetary Transits) will offer the possibility to detect extrasolar planets by means of the transit method. The satellite will observe about 60000 targets in the range 11.0< V <16.0, located in five fields near the equator. The parts of the preparatory work in which the Italian community has been involved are described, with a particular emphasis on the observations to characterize the fields, on the effects of stellar activity and background stars and on the outreach activities. These actions complement those undertaken for the asteroseismologic programme.

Key words. Stars: activity – Stars: planetary systems – Techniques: photometric – Binaries: general

1. Introduction

The satellite CoRoT (COnvection, ROtation and planetary Transits) will perform photometric observations of stars with unprecedented high accuracy. Its goal is twofold: the study of the stellar interiors (the asteroseismic part) and the search for extrasolar planets (the exoplanetary part). The satellite has been successfully launched on December 27th, 2006. The mission has a unique instrument: a 27–cm aperture telescope equipped with two CCDs for each scientific case. The selected CoRoT direction of pointing is a double–cone (the CoRoT eyes) centered at α=6h50m/18h50m (galactic Anticenter/Center), $\delta = 0^o$; the radius of each eye is 10^o. To achieve its goals, CoRoT will continuosly observe five fields for 150 d each (long runs). For a more detailed description of the instrument visit the site `http://smsc.cnes.fr/COROT/`.

Besides a major French participation (75%), the CoRoT mission also involves other european countries: Spain, Austria, Belgium, Germany as well as a participation of ESA. After an initial participation which collected a wide interest in the national community, the Italian Space Agency ASI withdrew the official support to the project. Despite this, a group of

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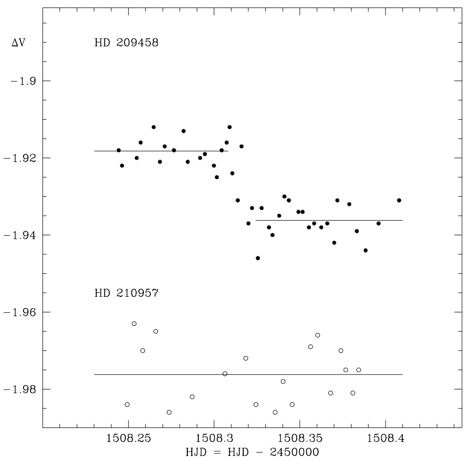

Fig. 1. *V*–band light curve of HD 209458 observed on the night of November 25, 1999 at Merate Observatory. The transit of the planet originates with the dimming in the luminosity of the star; the upper line finishes at the time of the first contact, the lower one starts at the time of the second one. The measurements of the check star, which are arbitrarily shifted, are reported for the purpose of comparison.

researchers still remained active on various aspects. Poretti (2003) described the Italian contribution to the asteroseismologic part. Here we report on the contribution to the exoplanetary part. Four main issues are addressed: the characterization of the stellar content of the exoplanetary fields, the disentangling of the planetary transits from stellar activity, the influence of background stars in the transit detection, the preparatory tools and outreach activities.

2. Stars and planets

In the asteroseismic channel the long–duration and continuous CoRoT survey will result in high–precision photometry, with an expected noise level in the frequency spectrum of 0.7 ppm (parts per million) over a 5 d time baseline for a $V \sim 6.0$ star. This means that CoRoT will be able to detect solar–like oscillations. In the exoplanetary channel, CoRoT will monitor simultaneously up to 12000 stars in each long run in the $11.0 < V < 16.0$ range. Thus, during the expected 2.5–y satellite lifetime, a total of 60000 light curves will be produced at a sampling rate of 8 min. The detection of the extrasolar planets will be performed by measuring the weak decrease of the star flux due to the transit of a planet in front of the star disk. The first observational evidence of this phenomenon has been obtained by Henry et al. (1999) on HD 209458. Figure 1 shows unpublished observations of another transit of that planet, measured some weeks after its discovery with the 50–cm telescope at Merate Observatory. For the brightest stars color information will be available and will help in discriminating single transit events from stellar activity or other artifacts. To get these supplementary and useful data, a dispersive element has been included in the optical path of the exoplanetary channel. In such a way the point spread function of the stellar image is split roughly in three colours.

The main targets of the exoplanetary mission are bodies having the size of the Earth. Some hypotheses have been made to estimate the number of possible transits due to telluric planets (numbers of young stars with dust discs, radii and distances of the planets from the parent stars, ...). With a photometry optimised up to V=15.5 (expected precision at the 0.1 mmag level) the expected number of detections is (Léger et al., 2000):

1. 25 planets having a radius of 1.6 $R_\oplus$ at 0.3 AU;
2. 40 planets having a radius of 2.0 $R_\oplus$ at 0.3 AU;
3. a few planets of around 2.0 $R_\oplus$ in the "habitable" zone (with the indispensable help of the chromatic information);
4. several hundreds of hot–Jupiters and Uranus–like planets, with detailed light curves.

The two CoRoT programmes are not independent: once a specific asteroseismic target has been proposed (primary target), the corresponding exoplanetary field has to match the requirements for a fruitful search for transits. Moreover, we also need to assure that the stars surrounding the primary target are also interesting for asteroseismology. Therefore, some preliminary investigations of both the asteroseismologic and exoplanetary fields are mandatory. Here we report on two specific and different applications.

2.1. The case study of HD 52265

HD 52265 will be the target of the second CoRoT long run in the Anticenter direction (September 2007–March 2008). It has been proposed for an asteroseismic investigation since it is the only star with an already known planet in the CoRoT eyes (Butler et al., 2000). Transits do not occur since the planet is not on our line of sight. However, the asteroseismic investigation of HD 52265 should allow us a better understanding of the properties of its planetary systems; moreover, considering that HD 52265 has a mass of 1.1 $M_{\odot}$, at the same time removing the observational singularity of our Solar System. The approach to study the parent star to investigate its planetary system could be an important guideline for future space missions and perhaps HD 52265 could constitute an interesting pathfinder.

The characterization of the HD 52265 field resulted in the detection of several pulsators: the δ Sct star HD 50870 (Poretti et al., 2005), the hot Be stars HD 50891, HD 51193, HD 51242 and the cold Be star HD 51404. Therefore, the field has been validated for the asteroseismic programme and looks very appealing.

2.2. The characterization of the exoplanet fields

In order to contribute to the characterization of the exoplanetary field aside HD 49434 and HD 49933, the open cluster Dolidze 25 has been observed. In particular, a photometric (*RI* filters) and spectroscopic investigation has been carried out by using the VIRMOS@VLT instrument (Ripepi et al., 2006). Photometry has been used to select targets for spectroscopy. In total we obtained ~900 spectra with medium resolution (2.5 Å/pixel) and ~600 with higher resolution (0.6 Å/pixel). The spectra have been reduced using the ESO pipeline, and an automatic procedure is going to be applied to obtain the spectroscopic classification for all the investigated objects. This, in turn, will allow us to test the spectral types previously obtained through photometry only. The main goal is to separate dwarf from giant stars in the most reliable way. After such procedure, only the dwarf stars will be selected for additional photometric monitoring.

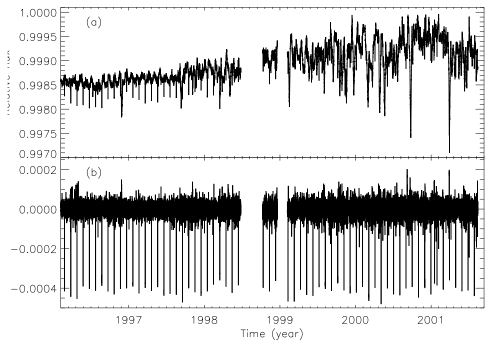

Fig. 2. (a) The transit of an Earth–like planet of radius $R = 2.3R_{\oplus}$ and orbital period of 30.0 d superposed on the total solar irradiance variation; the irradiance values are normalized to the maximum observed in the given time interval; (b) The same time series after subtracting the best fit model light curve computed with the model after Lanza et al. (2003). The transit dips are now clearly visible also during the phases with moderate or high solar activity, whereas they were lost in the irradiance fluctuations during the same phases in panel (a).

3. Magnetic activity in late–type stars and planetary transit detection

Main–sequence late–type stars have an outer convective envelope that, in combination with a sufficiently fast rotation, becomes the site of hydromagnetic dynamo action (Parker, 1979; Rüdiger & Hollerbach, 2004). The key parameter measuring the efficiency of the magnetic field generation is the Rossby number *Ro*, i.e., the ratio of the rotation period to the convective turnover time at the base of the convection zone. When *Ro* is of the order of the unity, the amplification and modulation of magnetic

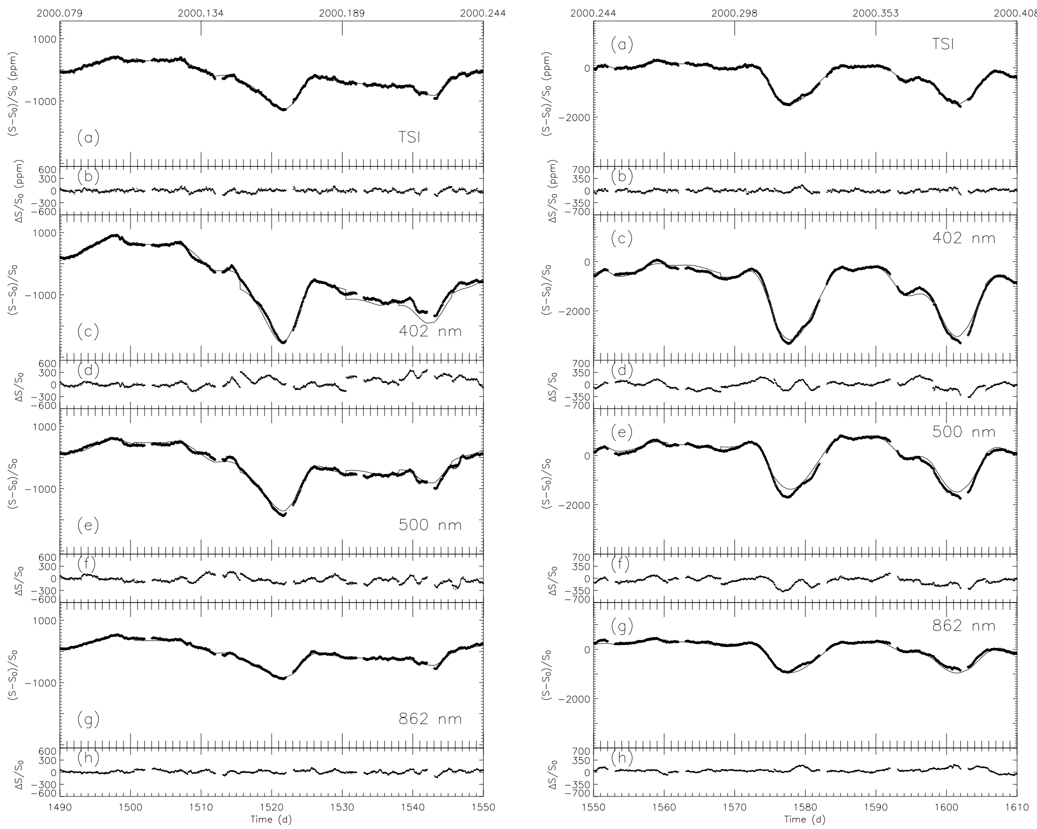

Fig. 3. Two subsets of the time series of the total solar irradiance (TSI) and spectral irradiances at 402, 500 and 862 nm (black dots) with their respective best fits (solid lines) are plotted in panels (a), (c), (e) and (g) for the labeled passbands in the left and the right columns, respectively. The best fits are obtained with the Sun-as-a-star model introduced by Lanza et al. (2004). The fits are usually embedded into the data sequence, except when data gaps are present. The residuals are plotted in the corresponding lower panels (b), (d), (f) and (h), respectively. The time is indicated in days from 1st January 1996 on the lower scale and in years on the upper scale. The data subsets are close to the maximum of cycle 23 and range from 29 January 2000 to 29 March 2000 in the left panels, and from 29 March 2000 to 28 May 2000 in the right panels, respectively.

fields take place and the star displays the typical signatures of solar–like activity. The optical flux is modulated by cool spots and bright faculae in the photosphere which evolve on time scales from a few hours up to tens of days. The active regions with a lifetime comparable to or longer than the stellar rotation period produce the rotational modulation of the stellar flux.

The observations of the solar disk-integrated irradiance show that the amplitude of the flux modulation due to the surface brightness inhomogeneities is of the order of 2000 – 3000 ppm around the maximum

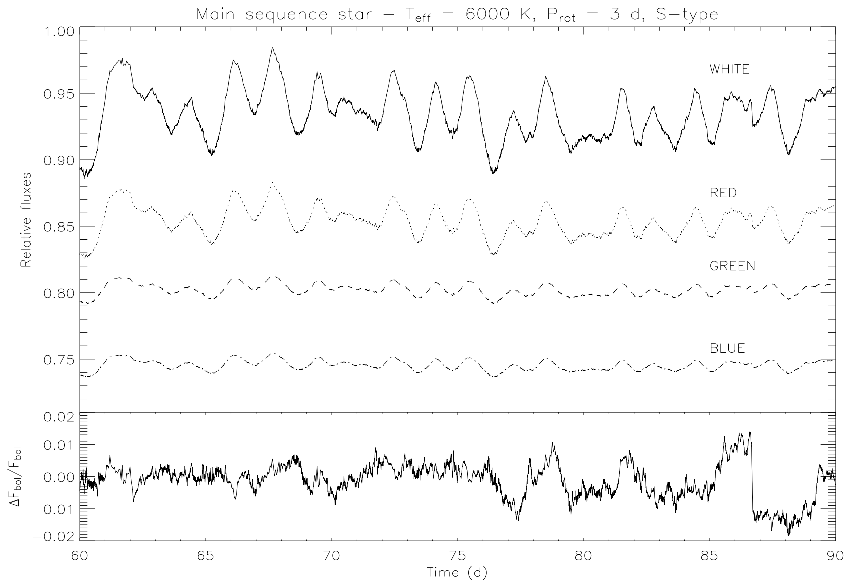

Fig. 4. *Top panel:* A sample of the synthetized light variations in the four CoRoT passbands for a main–sequence star with $T_{\rm eff}$ = 6000 K, log g = 4.5 (cm s^{-2}), a rotation period of 3 days and with spots dominating the light variations. Different linestyles refer to different passbands: solid – white channel; dotted – red channel; dashed – green channel; dash-dotted – blue channel. The mean values of the red, green and blue passband fluxes have been shifted up in order to plot them on the same scale. *Lower panel*: The short–term relative variations in the white channel that were superposed on the rotationally modulated variations to obtain the light curve in the upper panel. The short–term variations in the other passbands were obtained from those in the white channel by scaling the red, green and blue channels, by factors of 0.923, 1.095, 1.199, respectively (Lanza et al., 2006).

of the 11–yr cycle (Fröhlich & Lean, 2004). The detection of Earth–like planetary transits requires the observation of flux dips with amplitudes of the order of 100 ppm. This implies that solar–like activity introduces a severe limitation for the detection of Earth–like transits across the disks of stars similar to the Sun or with a higher level of activity (Aigrain & Irwin, 2004).

In the framework of the preparatory work for the CoRoT mission, we built models of the variability of the Sun as a star. They are based on a discrete distribution of active regions plus a uniformly distributed background whose area and coordinates vary with a time scale of 14 d in order to reproduce the modulation of the total as well as spectral solar irradiances at 402, 500 and 862 nm (Lanza et al., 2003, 2004). Such a model allows us to fit the solar variation giving residuals of the order of 100–200 ppm for the total irradiance which may significantly improve the detection of planetary transit (Figs. 2 and 3). Moreover, the model can be applied to scale the solar variability to the case of younger, more active stars to produce simulated light curves (Fig. 4) which will be used for testing different detection algorithms for the CoRoT mission, i.e., the so-called CoRoT Exoplanet Blind Tests 1 and 2, described by Moutou et al. (2005); Lanza et al. (2006) and Moutou et al. (in preparation).

The model described above as well as those applied to stars with a high level of magnetic activity (Messina et al., 1999; Lanza et al., 2002) allow us to derive information also on the stellar rotation period, the level of activity and the kind of hydromagnetic dynamo operating in a given star. The level of activity determines the average UV and X–ray stellar fluxes (Messina et al., 2003) which are important to model the chemistry of exoplanet atmospheres. On the other hand, close–by Jupiter–sized exoplanets may affect stellar rotation and magnetic activity through tidal as well as magnetospheric interaction (Saar et al., 2004; McIvor et al., 2006).

Modelling the light curves obtained by CoRoT will allow us to obtain information on the area variation and surface distribution of stellar active regions which will disclose the dependence of magnetic activity on fundamental stellar parameters, that is presently not known for stars with an activity level comparable to that of the Sun.

4. Planet detection and background binaries

Another very serious problem for planetary transit detection will arise from the contamination by background eclipsing binaries (Bebs). The CoRoT exoplanet program essentially performs aperture photometry on a crowded stellar field. In spite of the masks, conceived to optimize photometry and to limit contamination from nearby stars, a contribution of faint background objects to the light curve of the target is unavoidable (Maceroni & Ribas, 2006). The high frequency of false alarms from Bebs was already experienced in the OGLE planetary transit search: only five true planets out of 177 alarms were confirmed by follow–up observations (Udalski et al., 2004), a result in agreement with the theoretical estimation of Brown (2003).

We need to test the ability of detrending the lightcurves from instrumental and environmental biases and of eventually detecting planets in the specific context of CoRoT. Therefore, a complex simulator has been realized (Auvergne & al., 2003) to reproduce instrumental noises and to produce the first light curves for the exoplanet channel. The simulator was used to generate a sample output of 1000 lightcurves, hiding 20 transiting planets and 20 other types of variable objects of similar amplitude (Bebs, binaries with grazing eclipses, other variables); such a sample was used in a first blind test (BT1) to estimate the detection threshold of CoRoT (Moutou et al., 2005), i.e. the minimum detectable planet radius depending on the period and parent star. It served as well to test the efficiency of the various detrending/detection methods developed by the different teams who will work on the real data.

The results of BT1 allowed to derive an empirical "detection curve", expressing a lower limit of transit depth for detection as $d \simeq 10^{-3}n^{-1/2}$, where d is the depth and n the number of transits during the run. For instance a planet orbiting a G0V star should be detected if $R_{pl} \geq 2-4R_{\oplus}$ (for $P_{orb} = 3-50$ d). Besides, it was directly confirmed that Bebs will be in practice the only source of false alarms: the only cases of misidentification by all teams, and therefore not method–related, are from eclipsing binaries.

A more refined blind test (BT2) is now in progress with the purpose of analyzing the problem of Bebs and of estimating the type and amount of necessary follow–up observations. Many cases could be discriminated just by detailed analysis of the folded lightcurve (on the basis of color behavior of the transit and by detection of a secondary minimum). The BT2 light curves were produced using the same complex simulator used in BT1, but polluting events, whose statistics has been estimated using the Corotlux tool (Guillot et al., 2006), have been included. To provide lightcurves in the three color "bandpasses" of CoRoT, Corotlux uses the Besançon galactic model (Robin et al., 2003), real observations of the CoRoT fields (to estimate the number of stars of different type in each field) and the expected binary frequency and distribution of orbital elements (Moutou et al., in preparation). A first result is that in one long run in the CoRoT Anticenter field a mean number of ~ 80 candidate planets is expected, with about 80% of alarms cleared by follow up photometry and 10% by follow–up spectroscopy (Pont, 2006).

Fig. 5. Starting menu of the "Dal cuore delle stelle ... ai pianeti abitabili" multimedia flash project.

5. Outreach activities

We are taking care of outreach activities related to the CoRoT mission and to the research on extrasolar planets.

5.1. CoRoT mission

A multimedia product (Macromedia Flash) illustrating the CoRoT mission and its science objectives was developed in French at the Observatoire de Paris. We have edited and translated the project in Italian and published it on the web site of Catania Observatory (http://www.ct.astro.it/gass/CD-CoRoT/corot.swf). The multimedia project, titled "Dal cuore delle stelle ... ai pianeti abitabili" [1], allows the user to explore the following subjects (Fig. 5):

1. the space mission;
2. the instrument;
3. the observational technique;
4. the CoRoT sky;
5. the science project;
6. the history of the project;
7. the involved people and institutions
8. a section with background information, from basic definition to the physics of oscillations and stellar evolution.

Each of the above subjects is a starting point to the exploration of several sub–subjects, as well as it is possible to access to pop–up insights by clicking on highlighted words. Our aim is to put this multimedia product on CD–ROM support and distribute it to schools and to the general public during education and outreach activities regularly carried out in the INAF Observatories involved in the CoRoT projects.

5.2. The extrasolar planets encyclopaedia

The extrasolar planets encyclopaedia (http://exoplanet.eu) is a working tool

[1] From the stellar core ... to habitable planets

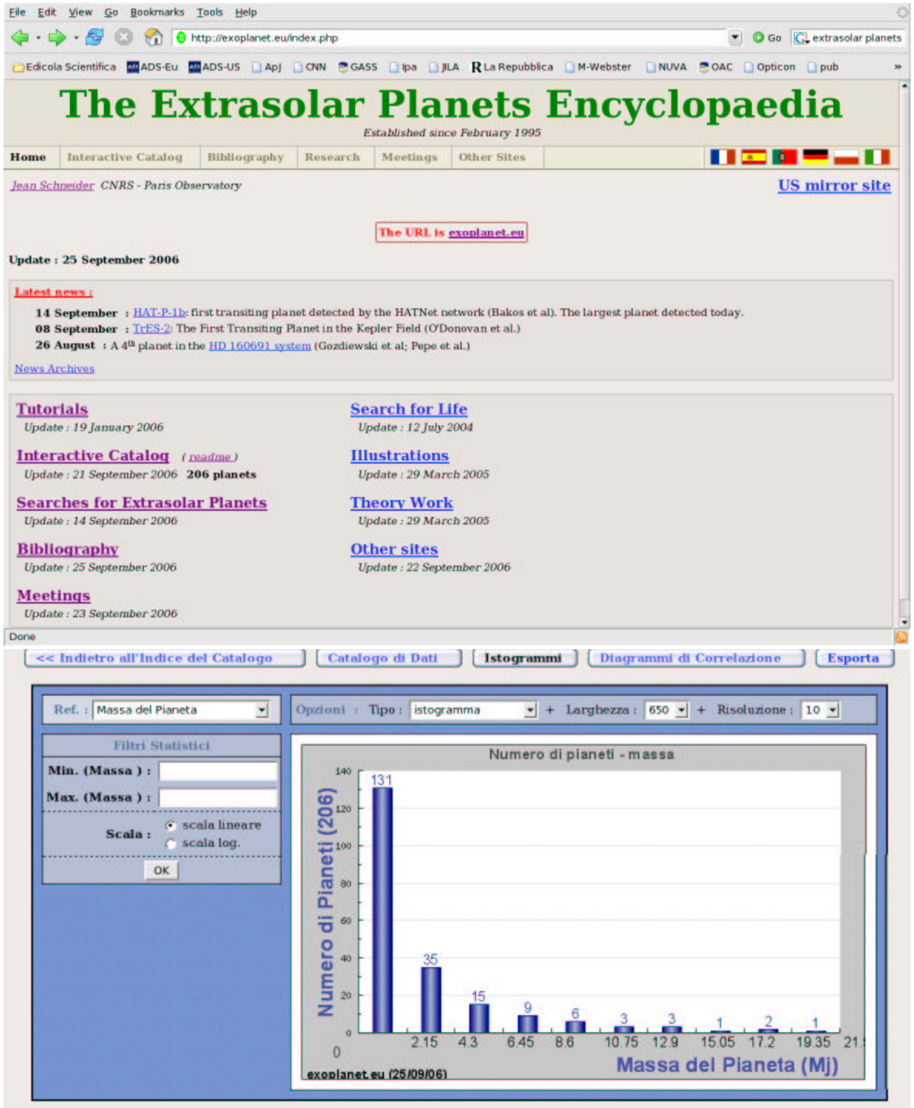

Fig. 6. *Top panel*: Homepage of the extrasolar planets encyclopaedia (http://exoplanet.eu). *Bottom panel*: Distribution of extrasolar planet masses. This is an example of the histograms and correlation diagrams that can be build from the interactive catalog of the extrasolar planets encyclopaedia.

providing all the latest detections and data announced by professional astronomers, useful to facilitate progress in exoplanetology. It has been established and maintained by Jean Schneider of the CNRS – Paris Observatory since February 1995. From the homepage (Figure 6, top panel) it is possible to access an interactive catalog of all known extrasolar planets, and to update information on bibliography, meetings, ongoing research programs and future projects. Finally, links to related sites are provided.

The catalog gives access to interactive tools to perform statistical analysis, such as the possibility to build histograms (Fig. 6, bottom panel), and to correlate couples of different parameters. The site can be viewed in several languages: English, French, Spanish, Portuguese, German, Polish and Italian, allowing the general public and amateur astronomers to easily access high level scientific information in the field. We have provided the Italian translation and collaborate to the continuous update of the Italian version of the site (http://exoplanet.eu/index.it.php).

6. Conclusions

We showed how the Italian contribution to the CoRoT space mission has allowed a quantitative evaluation of instrumental and stellar effects in the planetary transit detection and a more careful evaluation of the stellar content of some specific stellar fields. Also considering the full spectroscopic characterisation of the targets and the precise photometric evaluation of the stellar variability in the CoRoT fields (Poretti, 2003), the Italian researchers provided original and useful inputs to the scientific profile to the mission.

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