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Extra-solar planet studies: the Italian contribution

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Abstract. The search and characterization of extrasolar planets is one of the hot topic of astrophysical research. The italian community is beginning to contribute to this field. Main activities concern: the study of protoplanetary disks; the studies of planet formation, dynamical stability and evolution of their orbits; the search for planets in binary systems using high precision radial velocities acquired with SARG; the search for transiting planets in open clusters; and the participation to the VLT Cheops Planet Finder and the ESA satellites Eddington and GAIA.

Key words. stars: extrasolar planets – stars: circumstellar matter

1. Background

The quest for extra-terrestrial life is one of the major issues for the XXI century science. Life similar to that on the Earth can likely only originate in planets around stars. For astronomy, the first step is a full understanding of the mechanisms that lead to their formation, so that conditions for habitable planets are solidly defined. The first detection of a Jupiter-like planet around a main-sequence solar-type was obtained using precise radial velocity measurements of 51 Peg by Mayor & Queloz (1995). Since then, the number of new extrasolar systems have steadily grown and their nature has been investigated with different observational techniques. More than a hundred giant planets orbiting stars are known at present, with minimum masses derived from Doppler shifts ranging from 0.2 to 10 Jupiter masses. The detailed shape of the transit curve of the planet orbiting the star HD209458 has yielded the first direct measurements of the physical properties of the planet (Charbonneau et al. 1999), while its atmosphere has been probed by measuring the sodium absorption as the stellar light passes through the planetary limb (Charbonneau et al. 2002). Based on our present knowledge, more than 5% of solar-type stars may harbour massive planets and maybe an even higher percentage may have planets of lower masses and larger orbital radii. Comprehensive reviews of the status of extra-solar planet investi-

Send offprint requests to: R.G. Gratton gations are given by Udry et al. (2003) and Marcy et al. (2003).

Notwithstanding the large number of known extrasolar planet systems, their diversity in terms of dynamical properties has raised many questions concerning their origin and evolution. It is matter of debate whether these planets formed according to the conventional core-accretion model for the origin of Jupiter and Saturn (Pollack et al. 1996) or by gravitational instabilities of the protoplanetary disks (Boss 1997, 1998). Important clues can be derived from the detailed studies of the physical properties of the circumstellar disks around pre-main sequence stars. An additional conundrum posed by the new (giant) planets is their orbits, that are in many cases well inside 1 AU from the parent stars. These planets may have originated at larger distances and subsequently migrated inward. Theoretical studies are needed to detail the possible migration processes that account also for the substantial orbital eccentricities of the objects. Note that systems with giant planets in highly eccentric orbit are quite unlikely to host life: hence a clear understanding of the process generating these eccentric orbits is basic in order to understand if the life-friendly circular orbits of the giant planets of the solar system are a rule or rather an exceptional case.

Planetary formation is not limited to single stars but can also occur in the more frequent multiple-star systems. Binary systems and clusters can be considered as laboratories, where we may study the impact of dynamical perturbations on planetary orbits. It is under investigation whether the gravitational perturbations of the binary companion can influence in some way the planetary formation process and the subsequent evolution of the planetary system (Marzari & Scholl 2000; Quintana et al. 2002; Barbieri et al. 2002). Available data indicate that the characteristics of planets in binaries may be different from those orbiting single stars (Zucker & Mazeh 2002). Additional observational data and theoretical modelling may better outline the dynamical properties of binary (or multiple) star systems with planets. Also, the possible existence of planets in dense environments of star clusters is still not a settled question.

The metal-rich nature of stars with planets represents the only link between the presence of a planet and a stellar photospheric feature. However, this relationship has to be strengthened by additional observations and purged by a possible systematic effect related to the dependence of the metallicity of stars in the solar neighborhood on the galactic orbit of the stars (Barbieri & Gratton 2002).

2. Italian activities

The Italian groups involved in the extrasolar planet research field investigates various aspects, working from both a theoretical and observational point of view on topics related to the origin and evolution of extrasolar planets.

2.1. Proto-planetary disks

The group of the Arcetri Observatory studies the evolution of dust and structures of protoplanetary disks around pre-main sequence stars via near and mid IR, as well as radio high spatial resolution imaging and spectroscopy. The goals are to provide constraints on the first stage of planetary formation process, and in particular to investigate the growth of grains in circumstellar disks around pre-main sequence stars (Testi et al. 2001a; Natta et al. 2001, Testi et al. 2003); and to provide a near-infrared low-resolution spectroscopic classification scheme suitable for application to young giant extrasolar planets; this system is based on spectra provided by the TNG/Amici prism (Testi et al. 2001b).

2.2. Dynamics

A necessary step to interpret the observational data on exoplanets is to study the origin and long term evolution of extrasolar planetary systems. Within the 'standard model' for planet formation based on planetesimal accretion, the group at the Padua Department of Physics concentrated on the origin of terrestrial and giant planets in close binary star systems. A crucial parameter for planetesimal accretion is the relative velocity among the planetesimals that determines whether accretion or rather fragmentation dominates their evolution. The gravitational perturbations by a closeby companion star can pump up the orbital eccentricities of the bodies, significantly increase their relative velocity, and then inhibit the formation of a terrestrial planet or core of a gaseous planet.

This group addressed the dynamical questions concerning the migration of giant planets in exoplanetary systems by gravitational scattering (Marzari & Weidenschilling 2002) and the possible metal enrichment of stars by infall of planets on the convective envelope of the star. The group also studied planetesimal accretion and orbital stability of terrestrial planets and giant planet cores in binary systems (Barbieri et al. 2002). In particular, the origin of the planet detected in the γ Cep system is investigated. This is by far the system with the closest companion star located at $a = 21.36$ AU on a highly eccentric orbit ($e = 0.44$). Preliminary results show that the planetesimal dynamics is strongly perturbed by the secondary star and that only large values of the protoplanetary disk density, as in Bodenheimer et al. (2000), allows an 'in situ' formation of the detected planet. The gas drag coupled to the perturbations of the star causes an alignment of the orbital pericenters that lead to low collisional velocities. A critical aspect of the planetary formation in γ Cep is the migration of the planet during the giant impact phase when large planetary embryos collide to form its core. During this stage the core tends to migrate inwards by scattering the other protoplanets. According to our simulations the core drift stops preferentially at 1 AU from the star, while the observed

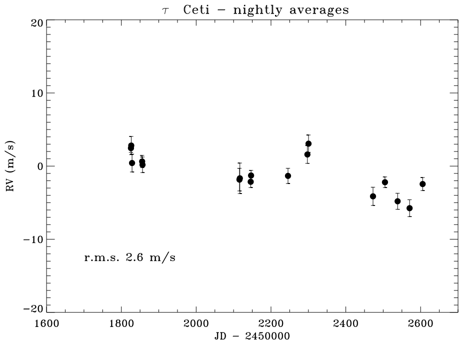

Fig. 1. Radial velocities for τ Cet

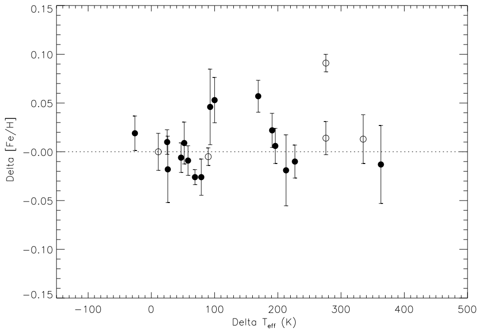

Fig. 2. Differences in the metallicty values for components of binary systems as a function of the difference in temperature. Open symbols are from Gratton et al. (2001); filled ones are from Desidera et al. (2003b)

planet is located at $a = 2.15$ AU. The estimate of the stability limits for planetary orbits in the γ Cep system was also refined by using the Frequency Map Analysis method (Laskar et al. 1992, Laskar 1993a,b) tuned by long term numerical integrations with the Hierarchical Jacobi Symplectic integrator (Beust, 2003) designed to integrate multiple stellar systems. The outer borders of the stable region ranges from 4 AU for low eccentricity orbits to 2 AU for highly eccentric orbits.

2.3. The SARG extrasolar planet search

These theoretical studies are complemented by the TNG long-term project

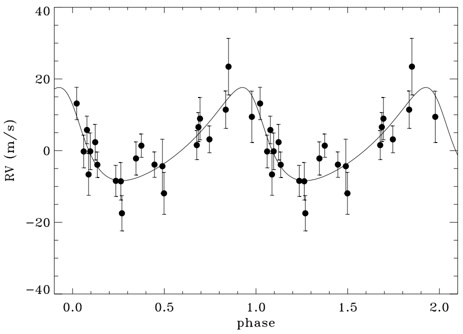

Fig. 3. Radial velocity curve for HD219542B. Superimposed is the best keplerian solution

searching for extrasolar planets using the high resolution spectrograph SARG at the TNG, by the Padova, Catania and Teramo Observatory groups, in collaboration with M. Endl (Texas). The observational sample includes 50 visual binary systems (separation of a few arcsec). The selected binaries have main sequence components of nearly equal mass. The program uses the SARG spectrograph (constructed by the same group), equipped with an absorbing cell. The high precision radial velocities are obtained using AUSTRAL developed by Endl and coworkers (Endl et al. 2000). The program is completed by an extremely accurate analysis of the differences in chemical composition between the two components, with errors as small as a few per cent, that allows to show the existence of even very small differences in the chemical composition between the two components of the observed systems.

Figure 1 shows the radial velocity curve obtained for the bright reference star τ Ceti, which is supposed to have a constant radial velocity. The internal errors of our measures (about 1.4 m/s) represent one of the best results obtained insofar in this kind of investigations.

The most interesting results concern the system HD219542. For this system, the differential chemical abundance analysis showed a significative offset in chemical composition between the two components, the primary being more metal-rich than the secondary (Gratton et al. 2001). A similar analysis on 21 other systems (Desidera et al. 2003b) shows that this is the most exceptional case of abundance differences between the two components (see Figure 2). Differences significative at about 2 σ have been found for two other systems. The abundance differences between the two components of HD219542 are weakly correlated with the condensation temperature of the various chemical elements, suggesting the ingestion of about 4 earth masses of rocky material. However, this last conclusion needs to be strengthened by more observations. On the other hand, the radial velocities (Desidera et al. 2003a) do not show any evidence for a planet around the primary: the upper limits are already significative enough to exclude a system like 51 Peg. A Saturn-like planet orbiting at a distance from the star similar to that of Mercury from the Sun is compatible with our observations for the secondary (see Figure 3). The probability that such a planet indeed exists is rather high (statistical test show a significativity of about 97%); however it is not possible to exclude at present that the observed signal is due to activity. If confirmed, this would be the first extrasolar planet discovered by an Italian group.

2.4. Planets in open clusters

In parallel to the SARG survey, a photometric monitoring of old, super-metal rich open clusters is performed in a collaboration between the Padova Astronomy Department and Astronomical Observatory (Piotto et al. 2003). The aim is to estimate the frequency of stars with planets by the transit method, providing costraints on the planetary formation in metal-rich stars. The effectiveness of gravitational encounters between stars of a cluster in disrupting planetary systems (and prevent its formation) may eventually justify a poor statistics in extrasolar planet detection.

2.5. Polarization

Finally, a group at Padova Astronomy Department is also studying in a systematic way the polarization properties of stars with and without planets (Tamburini et al. 2002): this study is intended to provide basic data to the hypothesis (drawn from a smaller sample) that the planet formation efficiently removes the original dust.

3. New instrumentation for extrasolar planet researches

Italian groups interested in extrosolar planets are actively participating to the design of various instruments devoted to search, detection and characterization of extrasolar planets.

3.1. CHEOPS: a Planet Finder for the VLT

Direct detection of habitable planets, and possibly of signs of life on them, is one of the main goal of astrophysics (see e.g. the Origin program by NASA). Achievement of this goal will require observations from space. However, giant planets might perhaps be discovered from ground. ESO has included a Planet Finder among the instruments proposed for the Second Generation at VLT. One of the two groups who answered this call is the CHEOPS project, leadered by M. Feldt at MPIA of Heidelberg, which includes various Italian institutions, under the coordination of Padua Observatory. The main goal of CHEOPS is the detection and characterization of planetary systems similar to our own, with giant planets in the outer regions. In fact, stars with giant planets in such external orbits may be good candidates for harbouring terrestrial planets in the habitable zone. CHEOPS may probably discover giant planets in different phases of their evolution. In fact, during the on-going contraction and accretion phases, the internal luminosity of giant planets exceeds the reflected light contribution by several orders of magnitude. This raises the possibility of detecting young planets around the closest young stars, in spite of their relatively large distances. The phase A study of CHEOPS will end within autumn 2004; if the project will be approved, observations are planned to start in 2008, three years before the JWST will be launched.

The direct detection of extrasolar planets is extremely difficult even with 8 m telescopes, due to the large intensity ratio (a typical value being 10^8) between the light from the star and that from the planet. From ground, the main difficulty is related to the presence of speckles (and related noise) due to the atmospheric turbulence. An adaptive optics system able to provide a high Strehl ratio is mandatory. Furthermore, CHEOPS will exploit differential techniques, considering subtraction of images characterized by an ideally identical speckle pattern, but where the planet signature is present/absent. CHEOPS considers two different strategies: one based on simultaneous acquisition of narrow band images obtained by means of an Integral Field Spectrograph (IFS); and the second based on quasi-simultaneous polarimetry, where images obtained with different polarization angles are acquired at a rate faster than the rate of variation of the atmospheric turbulence. The Padua Astronomical Observatory has responsibility for the design and construction of the IFS (co-PI: M. Turatto).

3.2. Eddington

Eddington is an ESA mission which has two primary science aims: to produce data on stellar oscillations necessary to understand stellar structure and evolution and characterize habitable - as well as other types of - planets around other stars (Favata 2002). The planet finding will be conducted with the method of transit detection. Eleven italian institutes will be involved in the Eddington Project with different aims. In particular the scientific interest of Italian community includes (i) partecipation in the search for habitable planets; (ii) partecipation to the asteroseismological observations and data analysis; (iii) interest in the "parallel science" results; (iv) partecipation in the development of the software for on board and ground – based data analysis; and (v) ground based observations in support of the mission. Eddington will be launched in 2007 just some months before its major competitor: Kepler (recently approved by NASA). Europe then, and Italy in particular, with the Eddington mission aims to be the first in the rush for the ambitious goal to find Earth twins.

3.3. Gaia

The astrometric group at Osservatorio Astronomico di Torino is involved in the design and characterization of NASA and ESA astrometric satellites SIM and GAIA, and in particular in the definition of the requirements for detection of extrasolar planets by means of astrometric perturbations (Sozzetti et al. 2002; Lattanzi et al. 2002). SIM and GAIA will be launched at the beginning of the next decade. Thousands of extrasolar planets with periods in the range from a few days to a few years could be discovered with these satellites, and full orbit could be determined for a substantial fraction of them.

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