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Extrasolar planet observational studies: the Italian contribution

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Abstract. We review the Italian contribution to observationals studies of extrasolar planets. Various techniques are used, including high precision radial velocities, transits, time delays, and direct imaging. Italian groups participate to some of the most interesting projects of the next decade, including imaging, photometry and astrometry. We will focus our attention on a few of these projects, including results obtained with SARG at TNG, those expected from OmegaTrans at VST, SPHERE at VLT and EPICS at E-ELT, with the PLATO satellite, and with GAIA.

Key words. Extrasolar planets

1. Introduction

Search and characterization of extrasolar planets is one of the major astronomical topic of the last decade. These studies revealed many surprises: planets and planetary systems very different from the Solar System have been discovered. Increasing interest is expected in the coming years, when moving to planets with lower masses, down to Earth-mass planets. This field is attracting more and more the attention of Italian astronomers, and the list of projects now includes searches for and characterization of planets using various techniques. In addition Italians groups are active in various theoretical areas, including the late stages of the growth of planetesimals and planet embryos, and of dynamical evolution and stability of planet orbits. Finally, there is an old tradition in the related area of star formation and disk evolution. While all these researches are of high interest, given the limited space here available, we will focus our attention only to the search for and characterization of planets.

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2. High precision radial velocities

SARG is the high resolution spectrograph of TNG. SARG is a multi-purpose spectrograph; however, it was built with high precision radial velocities as a major goal: it allows high spectral resolution, it was located in a gravity-invariant location below the Nasmyth focus, it was temperature stabilized, and it was equipped with an iodine cell allowing to provide accurate calibration of the radial velocities. Since its commissioning in 2000, SARG has been used for several programs requiring high precision radial velocities, including search and characterization of extra-solar planets, and asteroseismology campaigns.

Due to limitation of time available for programs on extra-solar planets, the SARG team (a collaboration between astronomers at INAF-OAPD, INAF-OACT, Centro Galileo Galilei, and McDonald Observatory) focussed its attention on planets in binary systems. A Long Term Project was realized in the last 8 years. The main goal of the program concerns the investigation of the impact of a quite close stellar companion on the formation and characteristics of planetary systems: this is interesting, because it can set important constrain on the overall frequency of planetary systems and on their dynamical evolution. To this purpose, a sample of about 100 nearly equal mass visual binaries of spectral type F5-K5 were selected from the Hipparcos catalogue; the apparent projected separation ranges from 2 to a few tens arcsec, which implies physical projected separations in the range 100-1000 AU (Desidera et al. 2007b).

Some 15-30 radial velocity measurements have been obtained for all targets, with a typical precision of 4-8 m/s, depending on magnitude (the targets have $7 < V < 9.5$) and spectral type. No sure detection has been obtained insofar, albeit a few stars show clear signs of long term trends indicating the presence of low mass companions (note that the sample was cleaned from obvious spectroscopic binaries). The low success rate suggests that there are indeed less planets in binaries with separation and mass ratios in the range explored, as indicated by comparisons with suitable Monte Carlo simulations (see Bonavita & Desidera 2007). This fits well into the general pattern described by Desidera & Barbieri (2007), who analyzed all available literature data and found that planets are rare (and peculiar) in close binaries (separation a few tens of AU), while they are as common as around single stars for wide binaries (separation > 1000 AU). The bulk of the SARG binary survey is now completed, and various papers are in preparation; observations are continuing only on those targets showing long term trends: some of these might host long period planets.

The second important result of the SARG survey concerns the planet-metallicity connection, found for planets around solar type stars (Gonzalez 1997). This might occur either because planets form more easily in environments more rich in metals, where dust grains are more abundant; or because of infall of metal-rich (rocky) material. This last effect might cause significant alteration of the original surface chemical abundance if the ingestion of the rocky material occurs after formation of the radiative core. The SARG survey is well suited to test this effect: in fact, since the components of the systems are similar each other, very accurate relative abundances (errors as small as ~2%) can be obtained comparing them (Gratton et al. 2001). In almost all surveyed cases, the SARG team obtained nearly identical abundances for the two stars (Desidera et al. 2004, 2006). Stringent upper limits on accretion of rocky materials could be obtained from binaries including late-F or early-G stars, where the convective envelope is tiny. In these cases, the upper limit found is at less than an Earth mass of iron, which is similar to the amount of material suggested to be accreted by the Sun. The only case where a significant abundance difference was obtained includes a blue straggler, suggesting a peculiar evolution (Desidera et al. 2007a).

Use of SARG for asteroseismology campaigns revealed that it is capable of measuring very small variations of the radial velocities. In these cases, nigthly averages over a week have dispersions of about 20 cm/s, which allows to set upper limits of 2 $M_{\rm Earth}$ to planets in very short periods (Benatti et al. 2008). This extreme performances are now being exploited in a program aiming to determine the frequency of Hot Neptunes: this is an extremely hot topic, because in spite of the very low amplitude of the radial velocity curves, several Hot Neptunes have been already discovered, suggesting they are very frequent, maybe more than 10% of the stars hosting an Hot Neptune. Hot Neptunes should then be a very common product of planetary formation, in agreement with some theoretical model (Mordasini et al. 2007). Data are however sparse, preventing any clear statistics: a dedicated survey is then hardly needed. Few spectrographs around the world allow such studies, and SARG is among them. An intensive program requiring some 60 nights/yr for two years is needed. 26 nights were allocated at TNG for AOT17, allowing the program to start. Early results shows that the requested accuracy (1-2 m/s) is being achieved: the only limitation to the success of the program is then tied to the ability to get data for a significant sample of stars fast enough to beat competition.

L. Girardi (INAF-OAPD) and K. Biazzo (INAF-OACT) participate to the very successfull search of planets around Red Giants leadered by L. Pasquini (ESO) (Pasquini et al. 2007). Observing red giants is important because they are typically more massive than solar type stars, and their main sequence progenitors have too few and broad lines for high precision radial velocities. This program uses data gathered at ESO and the German TLS telescopes. It resulted in an unexpectedly large number of detections (e.g. Döllinger et al. 2007). This indicates that giant planets around massive stars ($M > 1.5\ M_{\odot}$) are common ($> 10\%$ of the stars), suggesting a correlation between incidence of planets (or more likely, their mass) and mass of the star. Furthermore, Pasquini et al. (2007) did not find any correlation between presence of planets and metallicity, at variance with results for G-K main sequence stars. This might suggest important differences among planet formation mechanisms in different group of stars.

3. Time delays

Periodic stellar reflex motions due to the presence of orbiting planets can be revealed by examining delays of periodic events. To be useful, these periods must be stable, short, and determined with very high precision. This method lead to the very first detection of extrasolar planets, around the pulsar PSR1257+12 (Wolszczan & Frail 1992). A very interesting result has been recently obtained by Silvotti et al. (2007), who revealed the presence of a planet of 3.2 $M_{\rm Jupiter}$ orbiting V391 Peg, a pulsating B subdwarf. This discovery was unexpected, because the planet should have survived the evolution of the star along the Red Giant Branch.

4. Transits

4.1. Ground based programs

Italian astronomers are active in various groups which look for planet transits. A. Sozzetti (OATO) participates the very successful TReS and HATP surveys. Results obtained are described in his contribution to this meeting. G. Piotto (Univ. Padova) is leadering a group which considers transits in open clusters, in order to understand if planets may form also in dense environments, in spite of the strong UV flux by massive stars during the formation phases, and the frequent dynamical interactions due to close encounters. These searches are usually made using transits, because less telescope time is required. In this case, the main concern is related to the small number of expected detections, because transits are quite rare events and few clusters have enough bright main sequence stars. Metal-rich open clusters are most promising, because we expect planets to be more frequent there due to the planet-metallicity connection. Piotto and coworkers have collected significant time series on two massive and very metal rich clusters, NGC6791 (Montalto et al. 2007) and NGC6253 (publication in preparation). Highly accurate light curves have been obtained with photometric errors of a few thousandths of magnitudes for the brightest stars on the main sequence. No planet candidate has been found in NGC6791. This was disappointing, since 2-3 detections were expected from simulations. The probability that the null detection is simply due to chance coincidence is estimated to be 3-10%, depending on the metallicity assumed for the cluster: this is intriguing, but not yet enough to reach a sound conclusion. Since the number of detected planets is a function of the time coverage, new data might be useful. New observations are scheduled next July. In the case of NGC6253, one good candidate has been found; follow-up observations are scheduled to clarify if this is indeed a transiting planet, and if it belongs to the cluster.

Very recently, Barbieri et al. (2007) have discovered a planet transiting the 9th magnitude star HD17156, a result obtained with the decisive contribution of Italian amateur astronomers. This discovery was exciting because HD17156b is the longest period (21.2 d) and most eccentric ($e = 0.67$) known transiting planet. The high eccentricity might be an indication that the planet did not migrate to its current location by the usual mechanism of interaction with the disk usually invoked to explain Hot Jupiters. If its peculiar orbit is due to strong interaction with a 3rd body, then the orbit might be not coplanar with the stellar rotational plane. This can be determined exploiting the Rossiter-McLoughlin effect from high precision radial velocities taken during the transit. Early results by a Japanese group suggested a large inclination. However, much more precise data obtained using SARG (Barbieri et al. 2008) clearly indicate that the orbit of planet is roughly coplanar with stellar rotation.

Two other significant projects should be mentioned. RATS (RAdial velocities and Transit Search) is a collaboration between various INAF observatories (Padova, Catania, Capodimonte, Palermo), the Padova University (Astronomy and Physics Dept.), and ESA, with the goal of searching giant planet transits and performing the follow-up spectroscopic characterization. The search uses the Schmidt telescope at Cima Ekar, with a CCD covering a 1 square degree field of view. The program suffered under funding, which caused significant delays. Data acquisition is now starting. RATS is open to collaborations with amateurs for follow-up observations.

OmegaTrans is a transit survey approved for GTO bright time on VST. The PI is R. Saglia (MPE Garching), and Italian participation is supported by the Capodimonte and Padova Observatories. OmegaTranS will make use of the Omegacam CCD camera on VST, which is expected to become operational at early 2009. OmegaCAM is a 1 square degree wide field, optical 16k×16k camera. It consists of 32 low-noise array built by a consortium of Dutch, Italian, and German institutes. During its first season, the observing strategy of OmegaTrans uses 3 weeks of bright GTO time to monitor 4 densely populated star fields towards the galactic disk at low declination. Cycle time will be approximately 8.5 minutes, with 20 sec. exposures - targeting about $\sim 200,000$ F,G, and K dwarf stars at R=13.5-17.5 for at least 1000 epochs during the first observing season.

4.2. Space programs

The French-ESA satellite CoRoT (COnvection, ROtation and planetary Trantis), succesfully lauched on December 2006, is performing high-precision photometry, with the goals of searching for planetary transits and studying stellar oscillations. A few planets have been discovered in first year of scientific operations. Even without formal participation, after the ASI withdrew the official support to the project, several italian researchers of Brera, Catania, Roma and Napoli observatories are contributing to the project, mostly in the field of target characterization and the study of the role of stellar magnetic activity for detection of transiting planets. The italian contribution to the COROT mission is described in more detail by Poretti et al. (2007).

The main European future project on transits is PLATO (PLAnetary Transits and Oscillation of Stars), a satellite proposed for ESA Cosmic Vision and approved for Phase A. The PI of this project is Català (LESIA, France). Italian participation includes astronomers of Brera, Catania, Padova and Capodimonte Observatories, and Catania and Padova Universities. The PLATO mission concept is still in development: the basic idea is a 3-year continuous monitoring of a first single field, followed by at least two additionals years on a second field, complemented by one year of step and stare monitoring of additional fields for up to 3 months each. The payload will include 28 identical small telescopes (pupil of $\sim$ 100 mm), each one equipped with four 4k×4k CCDs. PLATO should be able to monitor some 100,000 stars of $V < 11$ with a $< 3 \times 10^{-5}$ noise in 1 hr, and 4 times more stars of $V < 14$ with twice this error. This should allow to detect sub-earth-size planets around solar type stars down to V=11, and earth-size planets around stars down to V=14. The satellites will also target oscillations. PLATO will outperform the NASA satellite Kepler (launch foreseen next year) by at least a factor of four.

5. Astrometry with GAIA

Astrometry is a very interesting technique for planet detection, because it allows to determine the full planet orbit and its mass. GAIA (launch foreseen in 2011) is one of the ESA Cornerstone satellites: it is a survey instrument which will provide high precision astrometry (at some tens μarcsec accuracy), photometry and spectroscopy of some 10^9 stars down to $V \sim 19$ over its planned 4 yr lifetime. GAIA has very interesting potentials for detection and characterization of extra-solar planet systems. Casertano et al. (2008) discussed its performances in this area. GAIA sensitivity is maximum for giant planets around the snow-line, where it is expected not only to recover the great majority of those long period planets already detected by radial velocities, but moreover to provide several thousands new detections, allowing extremely good statistics to be obtained. However, due to the small astrometric signal, GAIA will not detect rocky planets; furthermore, the lifetime of the satellite is too short for revealing planets on long period orbits (> 10 yr).

6. High contrast imaging

6.1. SPHERE

Italian astronomers are deeply involved into the two major ground-based European projects for high contrast imaging of extra-solar planets, SPHERE for VLT (competing with the GPI project on Gemini) and EPICS for the E-ELT.

Direct imaging offers unique opportunities for detecting and characterizing extra-solar planets. On ground-based 8-10 m telescopes, the niche of direct detection mainly concerns the definition of outer parts of the systems (from the snowline outward, 3-40 AU) crucial to understand formation mechanisms of planetary systems. In fact, undirect methods are not efficient at large separations: radial velocity signal is very small, transits and microlenses are too rare, and astrometry is too slow. Direct detection is efficient for young giant planets if contrast is $\sim 10^6 - 10^7$ at 0.1-0.5 arcsec from the star, which is expected to be feasible with SPHERE (and GPI), improving by almost two orders of magnitude over current instrumentations, which allowed only to put upper limits at large separations (see e.g. Nielsen et al. 2007). Furthermore, direct detection observations provide (low resolution) planet spectra, and then first order characterization of the atmospheres of extra-solar planets.

SPHERE is the Planet Finder for VLT, with the goal of direct detection of extrasolar planets. The consortium (P.I. J.L. Beuzit, LAOG) includes groups in France, Italy (Padova, Catania, Capodimonte, and Brera Observatories), Germany, Switzerland, and Netherlands. The project has passed Preliminary Design Review (fall 2007); Final Design Review is expected at the end of this year, and commissioning at VLT during fall 2010. The SPHERE Concept includes a Common Path, featuring a high order extreme Adaptive Optics system (SAXO) and an array of coronagraphs, which reduce the wavefront error and the diffraction pattern; and three different scientific channels, which allow differential imaging, boosting contrast by at least a further order of magnitude: a dual band differential imager (IRDIS), an Integral Field Spectrograph (IFS), and a polarization analyzer (ZIMPOL). The Italian group (which contributes about 17% of the total FTE's) is responsible for the IFS, the Instrumental Control Sofwtare, and has important responsibilities in the science group.

The science Objectives of SPHERE include direct detection of photons from extrasolar giant planets and the exploration of the mass-period distribution over a range complementary to radial velocity surveys (1-20 $M_{\rm Jupiter}$, 1-1000 years). To this purpose, the guaranteed time (260 nights) will be mostly used for a large survey of stars in different bins of mass and age. In addition, SPHERE will allow first order characterization of the atmosphere (clouds, dust content, methane, water absorption, effective temperature, radius, dust polarization) for those some tens of planets that are expected to be discovered.

6.2. EPICS

Even more ambitious goals, including detection of rocky planets in the habitable zone and of old giant planets near the snow line, are within reach if contrast as large as $\sim 10^9$ are achieved. This is the goal of EPICS, an instrument project for the direct imaging and characterization of extra-solar planets with the European ELT, currently in its Phase A. Similar to SPHERE, EPICS will include an eXtreme Adaptive Optics (XAO) system, a Diffraction Suppression System (or coronagraph), and a speckle suppression system, similar to that designed for GPI. The planned Scientific Instruments include Integral Field Spectrographs, a Differential Polarimeter (E-POL, similar to ZIMPOL), and a new instrument based on speckle coherence.

EPICS is in the conceptual design phase, which is expected to terminate at end 2009. The Consortium (PI M. Kasper at ESO) includes ESO, many French, English, German, Swiss and Dutch Institutes; Italy is represented by Padova Observatory, with a rôle similar to that in SPHERE. The most ambitious science goal of EPICS concerns terrestrial planets in the habitable zone. This is very difficult: there is some chance of success for the $\sim$ 70 accessible M dwarfs closer than 10 pc; note that the habitable zone at 10 pc is at 15 mas, probably beyond the inner working angle of EPICS. In addition, rocky planets inwards of the habitable zone (similar to Venus) can probably be discovered by EPICS for the about 100 G, K and M stars within 10 pc. EPICS offers unique opportunities for studies of giant planets. For what concerns young self-luminous gaseous planets in star forming regions or young associations, EPICS can achieve good resolution even for star forming regions at $\sim$ 150 pc. Young planets at > 3 AU can be detected, yielding very important observation to understand planet formation. Quite challenging observations will be mature giant planets at orbital distances between $\sim$ 5 and 15 AU in the solar neighbourhood ($< 20pc$): in this case EPICS may focus on planets that have been discovered by radial velocity searches, for which spectral characterization should be possible. This is very important to understand giant planets atmosphere composition and structure.

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