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The RATS project

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Abstract. The RATS (RAdial velocity and Transit Search) project is a collaboration among INAF sections of Catania, Napoli, Padova and Palermo the Physics and Astronomy departments of Padua University and ESA. The main goal of the project is to discover at least 10 news planets transiting the host star.

Key words. Stars: planetary systems – Techniques: photometry

1. Introduction

Since 1995, when the Jupiter-like planet 51 Peg b (Mayor & Queloz 1995) was discovered, identification and study of extrasolar planets are one the main goals of the international astronomical comunity. Up to day 136 planetary systems (18 are multiple systems) for a total number of 160 planets are listed in the Extrasolar Planets Encyclopedia (vo.obspm.fr/exoplanetes/encyclo/catalog.php). Most of these planets have been discovered using the radial velocity method however a small fraction of them have been detected thanks to their transit in front of the host star. The detection of transit allows to unveil information that cannot be obtained through the radial velocity analysis that basically gives clues on the geometrical properties of the orbit and lower limit to the mass of the planets. On the other hand the analysis of the transit curve yields almost directly information on the radius, the mass and hence the density of the planet. Unfortunately the geometric probability of a transit is generally low depending on the ratio $R_\star/a$ between the stellar radius and the major semiaxis of the orbit. This means that to have a high probability of detecting a transit one has to sample a large number of

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stars. Furthermore the photometric accuracy of the observations has to be of the order of < 0.01 mag for giant planets transiting a solar type stars and much less < 0.0001 for earth-sized planets. While the first figure is generally achievable using ground based instruments the second one can be obtained only from space. Temporal coverage is one more issue, in fact the ideal coverage would 24 hours that is achievable only from space or through a network of ground based observatories. Last but not least there are several phenomena that can mimic a planetary transit, e.g. eclipsing M dwarves, grazing eclipses, etc. This means that to disentagle these other effects each candidate transiting planet has to be observed spectroscopically. The RATS project is a collaboration among the INAF sections of Catania, Napoli, Padova and Palermo, the Physics and Astronomy Departments of Padua University and ESA whose main goal is the discovery of giant planets transiting solar type stars. The project will have a duration of five years during which the detection of at least 10 new extrasolar planets is expected. Another important goal of the project is to test the strategy of observation, data reduction and archiving of the Eddington ESA mission.

2. Instrumentation

The project will use the telescopes of the Padua Astronomical Observatory at Cima Ekar. In particular the refurbished (Claudi et al. 2005a) Schmidt telescope will be used for the wide field photometric survey while the 182 Copernico telescope equipped with a fiber fed echelle spectrograph will be used for the spectroscopic follow up. As one of the goal of the projects is to test the observational strategy of the Eddington mission, wide field imaging will be performed using one of the CCDs manufactured by e2v for the mission. This CCD will be loaned by ESA to the project consortium in late summer 2005. In the meanwhile we have started the project using two other CCDs. The first CCD camera is the ITANET camera (Gandolfi et al. 2005) which having a field of view too small will be used for the characterization of the stellar field. The second CCD is a 2048 × 2048 SITe device which being a full frame device as opposed to the e2v chip, which is frame transfer, has a lower duty cycle so will be replaced as soon as possible and kept as back up solution. More details on the characteristics of the CCD cameras can be found in Scuderi et al. (2005).

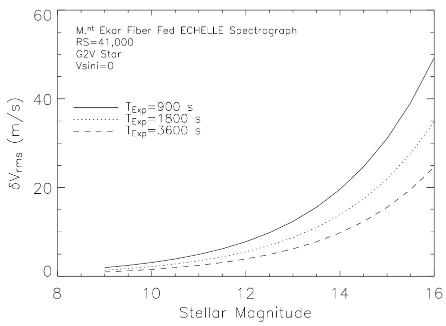

Fig. 1. The precision of radial velocity measurements as a function of stellar magnitude for different exposure times for the echelle spectrograph at Cima Ekar.

3. Magnitude interval selection

We have already noticed that to detect a planetary transit we need high photometric accuracy and also that we need a spectroscopic follow up to confirm that the photometric variation is indeed due to a planet transit. This last requirement limits the range of magnitudes that we can sample during the survey. In fact, the limiting magnitude to reach a precision in the radial velocity measurements of 10 m/s using the echelle spectrograph at the Copernico Telescope in one hour exposure is (see) about 14. On the other side the minimum magnitude is set by the observational strategy. A 15 seconds exposure (as foreseen for the Eddington mission) at the Schmidt of Cima Ekar taken in integrated light easily saturates a star with visual magnitude of 13. The solution adopted to avoid CCD saturation is to defocus the telescope. However, one has to guarantee high S/N ratio for the weakest magnitude and also an adequate number of stars per square degree with brightest magnitude. We found that $m_V = 9$

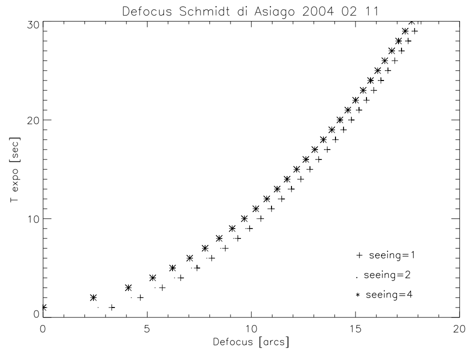

Fig. 2. Variations of telescope defocusing (see text for explanation) with exposure time for a star with $m_V = 9$ for different values of the seeing.

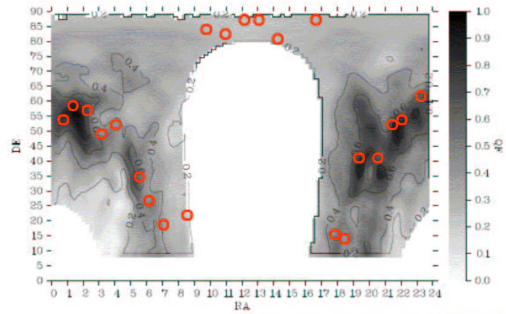

Fig. 3. The distribution of the fields according to the quality factor QF. Darker areas corrsponds to higher QF. Circles represent those fields that have the highest value of QF at each hour of RA

is a good compromise between the number of target stars and the necessary defocus. The $FWHM$ of a stellar image can be considered as the convolution of seeing, diffraction and, in our case, defocusing:

$$FWHM^2 = seeing^2 + airy^2 + defocus^2 \quad (1)$$

Figure shows an example of calculation of defocusing for a star with $m_V = 9$. To avoid troubles with CCD saturation we put a limit to the signal that can be collected at a given exposure time in a CCD pixel, in particular:

$$S_{pix} \leq 0.75 \times FullWell - S_{sky} \times t_{exp} \quad (2)$$

where S_{sky} is sky background per pixel per second. Dividing the star total flux by S_{pix} one obtains the number of pixels over which to spread the signal. Multiplying this quantity for the pixel sky projection one obtains the area A which is related to the $FWHM$ of the stellar image (assumed to be a gaussian) by the following expression $A = \pi FWHM^2$. Using then equation one can calculate the amount of defocusing. Once the exposure time has been set the defocusing depends on the seeing, on the sky background and on the characteristics of the CCD.

4. Fields selection

The selection of the stellar fields that will be the target of the survey has been performed using the following criteria. First of all each of the fields has to be observable for at least 8 hours during the night which for the Cima Ekar observing site means $\delta \geq 13°$. Second to maximize the number of stars per square degree we will observe close to the galactic plane, that is $-40° \leq b \leq 40°$. Finally we divided the sky in areas of 1 square degree and define for each of this area a factor of merit, QF:

$$QF = f(N/N_{max})(Nb_{max} - Nb)/Nb_{max} \quad (3)$$

where N is the number of stars in the selected area, N_{max} is the maximum number of stars in a field, Nb is number of stars with V magnitude lower than 9 and Nb_{max} is the maximum number of stars that can be tolerated in a field before staring to have problem with CCD saturation, f is a normalization factor. From this analysis, whose results are shown in figure , we selected three fields.

5. Observational Strategy

From stellar counts one finds that the number of stars per square degree with $9 \leq m_V \leq 14$ and spectral types F,G,K is about 200 (Claudi et al. 2005b). With three fields selected and a CCD field of view of about 0.8° the total field of view covered by the survey would be 2.4°. This means that the total number of possible candidates is about 480 stars. The probability of having a hot Jupiter is about 1% while the probability of observing a hot Jupiter transit is 10% so in total the probability to observe a transit is 0.1%. This number has to be reduced by a factor that take into account the observing conditions (temporal coverage, duration of transit, period of transit etc). In particular the probability of observing a transit during a night is $P_t = \Delta T/T_{orb}$ where Δt is the total observing time and T_{orb} is the orbital period. The total probability of detecting a transit observing the same field for n nights is then:

$$P = 1 - (1 - P_t)^n \tag{4}$$

Using typical numbers for observing conditions at Cima Ekar $\Delta t = 4.2h$, $n = 40d$, and $T_{orb} = 4d$ one obtains $P = 0.83$ which gives us a total probability of detecting a transit of 0.083%. This yields 0.4 transit per year and a total number of detected transits during the survey of 2. This number can be increased only increasing the sky coverage of the survey. The idea is to have for each of the fields selected a number of different but adjacent pointings. This solution has a drawback. In fact, for each true transit detection the number of expected false alarms varies between 6 and 60 (Brown 2003). This has an impact on the spectroscopic follow up in terms of pressure on the echelle spectrograph. In figure we have plotted the pressure on the Copernico telescope as a function of the observing nights for different numbers of pointings. Assuming that the maximum acceptable value of night sharing on the Copernico telescope is 40% of the total nights the number of pointings compatible with this limit is about 7. An increase in the sky coverage by a factor of 7 will increase the number of detected transits per year to 2.8 and the total number to 14. Having several adjacent pointings will have an impact on the observational duty cycle too, because one cannot observe continuously the same field but one has to move among adjacent subfields. For 7 subfields assuming a 4×15 seconds exposure time for each pointing, 5 seconds to go from one pointing to the next and 30 seconds to go back to the first pointing yields a total duty cycle interval of about 10 minutes, that should give a fair sampling of the transit curve. We did not include the CCD readout time in the overheads because the Eddington CCD is frame transfer so the readout is done during the exposure.

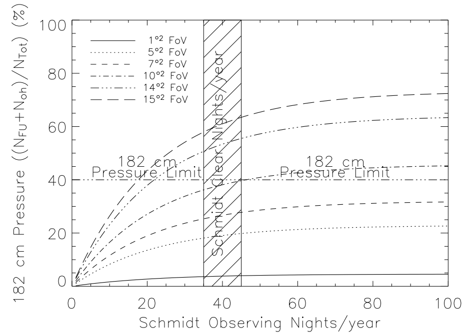

Fig. 4. The percentage of necessary spectroscopic follow up time as a function of the number of observing nights per year at Cima Ekar for different numbers of pointings.

6. Conclusions

RATS is a five year long program whose goal is twofold: 1) to discover at least ten new extrasolar planets using the transit method; 2) to test the observational, data reduction and archiving strategy of the ESA Eddington mission. The new discoveries are expected to give insights in the mechanism of planetary formations, in the properties of the environmental conditions, the hot Jupiter problem. Parallel science in the fields of stellar variability (pulsating stars, magnetic activity, eclipse variables etc) and spatial variability (minor bodies of the solar system) will be pursued.

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