Summary

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From Interacting Binaries to Exoplanets: Essential Modeling Tools
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Summary of Observational Techniques

Pavel Koubský

Astronomical Institute, Academy of Sciences of CR, Fričova 298, CZ 251 65 Ondřejov, Czech Republic
email: koubsky@sunstel.asu.cas.cz

Abstract. The observational techniques applied to the study of binary stars, brown dwarfs, and exoplanets are summarized in this paper.

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1. Introduction

Nearly two years ago, I heard about this meeting for the first time. And now the remarkable conference is over and I have to attempt to summarize the first portion of it. In the past years, a bunch of meetings devoted to binaries took place. I enjoyed the Dubrovnik meeting in 2003, followed by the Kopal Memorial at Litomyšl in 2004. Two binary meetings were organized in 2006: At the spring meeting on "Solar and Stellar Physics through Eclipses," the participants were lucky observers of the total solar eclipse in the Earth-Moon-Sun system on the coast of southern Turkey; and later the IAU Symposium 240 in was held Prague. In 2009, a very useful conference on binaries was held in Brno. Its scope accented the growing interests in exoplanet research. In this Symposium, the exoplanets have already become a rightful part of a binary meeting. So much information has been presented at this conference that I am very grateful not to have to cover it all, but to leave part to Adam Burrows (especially after I heard and saw his fantastic summary performance!). The synopsis I will try to present does not attempt to be objective. It is much biased and reduced to a personal view with some background comments that I wanted to express. I will limit my summary to some oral papers and a selection of posters.

2. Oral Papers

An extensive of the impact of current and planned telescope systems and new technologies on binary and exoplanetary research was presented by Ed Guinan. It was a prefect overture to the Symposium performed in a lucid, Guinan-like style. At present and in the future, progress in the study of binary stars and exoplanets will rely on instrumentation not originally dedicated to these fields. Despite these limitations, the data available for binaries and exoplanet research are enormous. Astronomers in binary and exoplanetary research are harvesting the data from large surveys like OGLE, ASAS, EROS or MACHO. And the "widest, fastest, deepest" synoptic sky survey: the LSST with the 3.2-billion-pixel camera is under preparation. Ultrahigh precision light curves of binaries observed by the Kepler satellite show effects predicted but never before observed - beaming binaries (Zucker *et al.* 2007). The phase shifts detected from transit-timing variations and transit-duration variations can lead to discoveries of exomoons. Ultrahigh precision spectroscopy (2 ms^{-1}) is now available on HARPS and HIRES spectrographs mounted on 3.6-m and Keck telescopes, respectively. And the possibility to measure Doppler shifts as small as 10 cms^{-1} should appear soon.

We heard about the evolution of big ground telescopes - E-ELT, TMT, space missions like Gaia, but also endangered projects like TESS or (hopefully not) JWST.

Niarchos reviewed the ground-based and space observations of interacting binaries. He discussed the use of data from microlensing and exoplanets surveys for interacting binary research - SuperMacho - extended use of the Blanco 4-m Telescope, which monitored fields in SMC and LMC, and MOA - Microlensing Observations in Astrophysics. Other techniques discussed were the heliospheric imager instrument on board the two solar STEREO satellites and robotic telescopes such as ROTSE. He also mentioned the WSO satellite which in the near future should resume the regular UV spectroscopic observations of nearby stars, including the interacting binaries as was done by the IUE many years ago.

Bonanos presented the use of OGLE/MACHO surveys for detecting eclipsing binaries in the SMC, LMC, and galaxies in the Local Group. The extracted EB are then targets for follow-up observations with 6-10 m class telescopes equipped with multi-object spectrographs which can reach beyond 1 Mpc, capable of going up to the Sculptor or M81 Groups.

The prospects of the Gaia project for binary research were discussed in several talks during the Dubrovnik meeting in 2003. The meetings which followed, Prague 2006 and Brno 2009, mentioned the project only marginally. It was a good decision of the organizers of this Symposium to include the Gaia project again and invite Eyer, one of the key organizers of the project. The ESA Gaia mission will provide a multi-epoch database for a billion objects, including binaries. Gaia is a successor to the Hipparchos satellite which should, besides its higher sensitivity, provide spectroscopic information too; medium resolution spectra in the near infrared region and low dispersion data in two blue and red channels. Each object will be observed by Gaia an average of 70 times during the 5-year mission. It seems that Gaia will be one of several survey projects. One of these is LSST. The 8.4-meter LSST will survey the entire visible sky deeply in multiple colors every week probing the mysteries of Dark Matter and Dark Energy, and opening a movie-like window on objects that change or move rapidly: exploding supernovae, potentially hazardous near-Earth asteroids, and distant Kuiper Belt Objects. Eyer has shown how Gaia and LSST will complement each other in the research on binaries. While the sampling of Gaia is more suitable for periodic objects, LSST will play an important role in monitoring the irregular phenomena.

Maceroni gave a talk on the impact of CoRoT and Kepler satellites. Since its launch, at the end of 2006, the CoRoT space mission has acquired continuous and high accuracy photometry of a hundred thousand stars in several long (150d) and short (30d) runs. Hundreds of new eclipsing binaries have been discovered and photometry of unprecedented accuracy is becoming available. The CoRoT Public N2 data archive provides an open access to the CoRoT data one year after their delivery to the CoRoT Co-Is, following the CoRoT data policy. Kepler uses a photometer developed by NASA to continuously monitor the brightness of over 145,000 main sequence stars in a fixed field of view. The data collected from these observations will be analyzed to detect periodic fluctuations that indicate the presence of exoplanets that are in the process of crossing the face of other stars. Kepler Q0, Q1, Q2 data are now public data. Thanks to CoRoT and Kepler, excellent photometry research topics such as asteroseismology of EB components are quickly developing, and very fine phenomena like Doppler boosting (van Kerkwijk *et al.* 2010) have been unambiguously detected.

Peters' talk was devoted to the use of various databases in binary star research. She stressed the power of existing databases for data ranging from the gamma ray region to the infrared. She showed some examples of discoveries of secondary components to some

Be binaries, discoveries enabled by the extended use of existing databases of spectroscopic data. One example: the detection of a hot subdwarf companion to the Be star FY CMa (Peters *et al.* 2008). With some amount of nostalgia, she recalled the International Ultraviolet Explorer as a "discovery machine" in the 1980s. There is a good chance that a new, advanced IUE would appear. The hope is called the World Space Observatory for the Ultra-Violet (WSO-UV), a satellite, which will carry a 1.7-m telescope equipped with spectrographs and camera for the ultraviolet region of the spectrum (Kappelmann *et al.* 2009). The satellite, which was developed in the former Soviet Union in late 1980s under the name Astron, is to be launched in 2015.

Queloz described the state of exoplanet research sixteen years after the discovery of 51 Peg b with the 1.93-m telescope/ELODIE instrumentation (Mayor & Queloz 1995). Since the time of the Elodie spectrometer, much better techniques are available: high precision spectrometers securing spectra with high signal-to-noise ratio and resolution up to 100,000. Now a large population of multiple planetary systems is known. A new paradigm on the formation, structure, and composition of planets is emerging, wider that we had anticipated from the knowledge of the Solar System. Among 500 known exoplanetary systems, Queloz pointed out some very interesting observations: HD 69830 around a K0 star in the constellation Puppis, located at a distance of 12.6 parsecs, has three detected planets of approximately Neptune mass, traveling in orbits of low eccentricity, with a narrow debris ring reminiscent of the Asteroid Belt. This system is remarkable for at least two reasons: it is part of the small group of known exoplanetary systems without any known gas giants, and belongs to a still smaller group with a field of colliding debris that produces warm dust. A multi-planet system orbiting the star HR 8799 now contains four bodies and a debris disk. The four planets were discovered the old-fashioned way: they were directly imaged.

Pasternacki presented a homogeneous reanalysis of the currently known CoRoT-exoplanets. This way, the refined planetary and stellar parameters are to be obtained. A preliminary result suggests that hot stars may be more active than solar-type stars.

Allers talked about brown dwarfs in binaries. Brown dwarfs were predicted in the 1970s, and called then black dwarfs. The first brown dwarfs were discovered in 1988. Now, about 1000 BDs are known. Binary brown dwarfs provide a unique opportunity to empirically determine fundamental parameters, which can be used to test model predictions.

Konacki gave an interesting review on detecting and characterizing exoplanets in binary systems. In principle, there are two methods to detect circumbinary planets: ET eclipse timing and precision RV techniques. At the present time, circumbinary planets represent 10% of the exoplanet population. Two projects were presented in the talk: SOLARIS – to commemorate the outstanding Polish writer Stanislaw Lem and his novel, and TATOOINE – a wild acronym for The Attempt To Observe Outer-planets In Non-single stellar Environments (Konacki *et al.* 2009). SOLARIS should use a network of robotic telescopes to carry out precision photometry of a sample of eclipsing binaries, while TATOOINE uses the best high resolution spectrographs and a novel iodine cell-based approach to determine radial velocities.

Stee gave a very nice summary of results from interferometric observations of binaries and multiple systems. He focused on three interferometers working in the visible and infrared regions - VLTI, CHARA and NPOI. Ten binary orbits and five images of binaries have now been obtained from interferometric studies. In several cases, the distance, brightness ratio of the components, masses of the primary and secondary, effective temperatures, and limb darkening were derived. The results he has shown confirm his statement that interferometry is a mature technique now; but the number of objects observed clearly show that interferometry is not a commonly used method. The explanation

is obvious: while there are hundreds of telescopes to be used for binary research, there are less than ten interferometers capable of studying binaries.

We saw fine pictures of systems like β Lyr or υ Sgr based primarily on data from the VEGA instrument on CHARA; but in the case of β Lyr, a nostalgic reminiscence of the old GI2T was presented (Harmanec *et al.* 1996). As a masterpiece of the interferometric technique, a detection of the close faint exoplanet companion to HD 59717 was presented. Duvert *et al.* (2010) using the AMBER/VLTI instrument in the K band, detected the 5-mag fainter companion of this star at a distance of 4 stellar radii from the primary. This is one of the highest contrasts detected by interferometry. We hope that exoplanets may be detected this way in the future. A giant planet in the well known system β Pic has now been detected in two IR photometric bands, giving the possibility to better estimate its spectral type, atmospheric parameters, and mass (Bonnefoy *et al.* 2011).

Serabyn's talk was focused on observations close to binary stars using vortex coronography, visible-wavelength adaptive optics, and nulling interferometry. He showed images of a debris disk in HD 32297 obtained using phase-mask coronagraphy on the 1.6m well-corrected subaperture on the 5m Palomar Hale telescope. The image clearly demonstrated the benefits of operating in the extreme adaptive optics regime with a coronagraph able to reach a very small inner working angle. Another example of the progressive new technique was the image of exoplanets in the system of HR 8799 (evidently a very popular object among the high angular resolution people) taken in infrared light with Palomar's Hale Telescope. The image was captured using a 1.5-meter-diameter portion of the Hale telescope's mirror.

Hinkley described the use of several new dedicated observing platforms geared toward high contrast imaging of binaries, brown dwarfs, and exoplanets: The Gemini Planet Imager adaptive optics instrument for the Gemini South telescope, VLT- SPHERE project to gain at least one order of magnitude with respect to the present VLT AO facility NACO, project 1640, and PALM 3000. He showed the image of the ζ Vir system (M dwarf orbiting an A3V star), secured with the coronographic integral field spectrograph (Project 1640). He described the PALM 3000, a high order adaptive optics system at Palomar, which uses 3388 actuators. First light was in summer 2011.

Schmidt talked about the methods of estimating masses of sub-stellar companions around young stars. The observations were secured with the VLT Adaptive Optics (AO) instrument NACO and AO integral field spectroscopy with SINFONI obtained to deduce the physical parameters of the companions.

3. Posters

I have selected five posters from the numerous and diverse collection of posters.

An interesting application of ultra-precise photometric data was presented in the poster by Kiss and Derekas, a discovery of a unique triply-eclipsing triple system HD 181068. The original discovery was published in Science in April 2011.

Whittaker showed interesting results from the twin STEREO satellites, primarily devoted to solar research. The stellar photometric data from onboard imaging cameras were suitable for planetary transit searches and a number of new eclipsing binaries were found.

Hadrava was invited to present a talk on his disentangling code KOREL; such a presentation was deeply missed in some previous binary meetings. It was an excellent and very ripe presentation (the first version of the code has been more than 15 years old now). Hadrava's talk was complemented by a number of posters. Here are the two most interesting.

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Škoda presented VO-KOREL, a web service exploiting the technology of the Virtual Observatory to run the most recent version of KOREL. It was one of the most interesting mini-talks at the conference.

The poster by Chadima *et al.* which showed the results of the spectroscopic study of ϵ Aur, brought a clear warning that disentangling codes both in lambda and the Fourier domain cannot be treated as a black box machine.

And finally: a technique which could mean an important jump in the efficiency of ground-based astronomy and astrophysics. Mkrtichian *et al.* presented a poster on daytime Doppler spectroscopy. They showed nice results of daytime spectroscopy used for astroseismology of bright stars.

4. Last Thoughts

During the first Panel Discussion, Virginia Trimble warned that the HST successor James Web Space Telescope is endangered and mentioned the actions of astronomers to save this centerpiece of U.S. space astronomy for the next two decades. She used this example to call on (European) astronomers to struggle for any threatened project.

The history of efforts to save telescope projects is probably as old as modern astronomy. One example is closely connected with the site of this Symposium and with its dedication. The largest telescope in former Czechoslovakia is a 60-cm Zeiss reflector that was installed in a place called Stará Ďala in southern Slovakia in 1927. This was an important step for the development of astrophysics in Czechoslovakia realized by Dr. Bohumil Šternberk (1897 – 1983). Before the outbreak of WW II when the borders of European states started to change again, it was necessary to move the telescope to the inland of Slovakia. It was Dr. Šternberk who succeeded in saving the telescope for the astronomical community. The 60-cm telescope was later erected at a new observatory at Skalnaté Pleso. As we heard during the Opening Ceremony, the building of the Observatory was initiated by Antonin Bečvář (1901 – 1965), whose anniversary is commemorated by this Symposium. The telescope was very extensively used, partly devoted to binary research, until 1977. Since 1994, the refurbished 60-cm telescope has been used at Modra Observatory of Comenius University in Bratislava. One of the projects run by the telescope is the study of exoplanet transits.

At the end, warm thanks and applauses are addressed to the Scientific Organizing Committee, led by Mercedes Richards and Ivan Hubeny, and the Local Organizing Committee, led by Theo Pribulla and Ladislav Hric, who prepared this memorable meeting.

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