MW-Gaia WG3 Workshop

Exoplanets in the era of *Gaia*

Porto (Portugal), 18th-20th November 2019

The workshop [Exoplanets in the era of *Gaia*](#) took place in Porto from 18th to 20th November 2019. This was the second workshop of the CA18104 COST Action MW-*Gaia* and the first workshop of the Working Group 3 (WG3).

Scientific motivation of the workshop

With ultra-precise astrometric and photometric observations of more than 1 billion stars, *Gaia* is revolutionizing our view of the Solar System, extrasolar planetary systems, the Milky Way as a Galaxy, distant extra-galactic objects, and many other fields of astronomy. The aim of this workshop was to bring together exoplanet and stellar astrophysicists to discuss how *Gaia* is revolutionizing our understanding of exoplanet formation and evolution, and what are the future perspectives.

The scientific program of the workshop was organized as follows:

- ✓ *Gaia* **and exoplanets**: Overview of the *Gaia* mission; Exoplanet detection with *Gaia*; Overview of Exoplanet research
- ✓ **Exoplanetary systems**: Physical properties of exoplanets and their orbital architecture
- ✓ **Exoplanet surveys**: synergies between *Gaia* and ground-based RV exoplanet surveys
- ✓ **Exoplanet surveys**: synergies between *Gaia* and other ongoing/upcoming space missions and ground-based exoplanet surveys (e.g. Transit, Direct Imaging)
- ✓ **Star-planet connection**: Exoplanet host stars as an instrument to study planet formation and evolution in different environments

In each session there were review and contributed talks, followed by open discussion between the participants.

Day one

Gaia and exoplanets: Overview of the *Gaia* mission; Exoplanet detection with *Gaia*; Overview of Exoplanet research

This very first session of the workshop started with the introductory talk of Nicholas Walton (Cambridge), who gave an overview of the COST action presenting its aim and available opportunities. The session continued with the invited review talks by Berry Holl (Geneva) and Alessandro Sozzetti (Torino) who presented the current status of *Gaia* mission and its potential for detecting exoplanets. The expectations are rather exciting. About 15000 massive jupiters and about 30000 Brown Dwarfs (BDs) are expected to be discovered with *Gaia's* ultra-high precision astrometry. Photometric power of *Gaia* to detect transiting planets is expected to be strong to: ~1000 jupiters and ~9000 BDs for the 5-year mission of *Gaia*. *Gaia* DR3 will already provide non-single star solutions (binaries and perhaps lower mass objects!). The aforementioned large number of newly discovered planets are expected to help us to significantly improve our understanding of formation and evolution of giant planets especially at intermediate orbits. Among many scientific open questions, *Gaia* will help us to answer: What is the actual [Fe/H] limit for giant planet formation? Do low-[Fe/H] stars host longer-period companions? Are more massive planets preferentially found around more massive primaries? Do higher-mass star only host longer-period companions? Are orbital elements distribution of planets in binaries and around single stars the same? How do frequencies depend on binary separation? Many of this questions will be answered thanks to the synergies between *Gaia* and other surveys. As discussed by Antoine Grandjean (Grenoble), synergies between *Gaia* astrometric measurements, high contrast imaging, and radial velocity gives direct constraints on the orbit and on the dynamical masses of sub-stellar companions (planets, brown dwarfs). This masses then can be used to calibrate the evolutionary models. The synergies between *Gaia* and other missions/surveys was discussed in more details during the next sessions.

Exoplanetary systems: Physical properties of exoplanets and their orbital architecture

This afternoon session started with the review talk of Lars Buchhave (Denmark) about the statistical properties of exoplanets. In particular, he discussed the dependence of orbital properties (orbital periods and eccentricities) and occurrence rates of different types of exoplanets on the metallicity of the host star. The results suggest that jupiter-analogs (cold giant planets in circular orbits) are mostly found around solar-metallicity

stars, while cold giant planets in eccentric orbits are found to be around metallic stars. It is proposed that in high metallicity environments many giant planets can be formed which will lead to excitement of the eccentricities due to gravitational interactions between planets. This talk was followed by Elke Pilat-Lohinger (Vienna) who spoke about the planetary architectures in binary stars. After discussing the terrestrial planet formation using gravitational N-body simulations an online-tool "SHaDoS" was presented which identifies the location of secular resonances in circumstellar planetary systems. The last two speakers of the day, Solène Ulmer-Moll and Sérgio Sousa (Porto), spoke about "Forecasting exoplanet radii with machine learning" and "The metallicity-period-mass diagram of low-mass exoplanets", respectively. The results of Solène Ulmer-Moll (Porto) suggest that the random forest algorithm constrains the exoplanet radius, with higher accuracy than the previous methods. It derives reliable radii for planets between 4 and 20 $R\oplus$, with a relative error smaller than 25%. Sérgio Sousa presented the SWEET-Cat – The Stellar parameters for stars with ExoplanETs CATalogue, a unique compilation of precise stellar parameters for planet-host stars provided to the exoplanet community. By using the precise parameters from SWEET-Cat he studied the exoplanets with minimum mass below 30 $M\oplus$ and found a correlation in the metallicity-period-mass diagram where the mass of the planet increases with both metallicity and period.

The first day of the workshop finished with one-hour open discussion coordinated by Alessandro Sozzetti (Torino). The discussion touched the topics such as "*Gaia* and exoplanet diversities", "How *Gaia* should help us to understand the orbital 'peculiarity' of Solar System - Cold Jupiter and no close-in super-Earth", and finally the "problems" with *Gaia* performance – currently estimated errors are larger than the formal errors. The general agreement was that DR3 results will be much better.

Day two

Exoplanet surveys: synergies between *Gaia* and ground-based RV exoplanet surveys

The first session of the second they opened Oscar Barragán (Oxford) with his invited talk on "The needle in the haystack: disentangling planetary and stellar activity signals in RV time series". In the presentation he presented different methods (Fourier decomposition, Float Chunk Offset, Gaussian Process, Multi-dimensional GP) to detect planets using Radial Velocity (RV) observations under the presence of stellar activity 'noise'. For each method the "pros" and "cons" have been provided. The main conclusion was that there is no "magic recipe" to disentangle planets from stellar activity signals and one has to treat this problem in a star by star basis. The next two speakers, Nuno Santos and Hugo Tabernero (Porto), described two state-of-the-art spectrographs – ESPRESSO and CARMENES – operating in the visible and visible+nIR wavelengths. ESPRESSO's high and ultra-high resolution, and long-term super-stability allows to reach a 10-20 cm/s precision in RV – enough to detect (if the stellar activity allows) earth-like planets in the habitable zone around sun-like stars. CARMENES's RV precision reaches to 1 m/s level for the visible arm and a bit less for the nIR arm. As stressed by Hugo, CARMENES's nIR spectrograph does well, it is us (researchers) who cannot take the full advantage of this spectrograph, mostly because of the heavy telluric contamination. Afterwards, Domenico Barbato (Torino) presented the first results of their new statistical analysis of cold companions of transiting hot Jupiters based on a 5-yr high precision radial velocity survey conducted with the HARPS-N spectrograph, AO imaging and proper motions taken from *Hipparcos* and *Gaia*. Elisa Delgado Mena (Porto) in her talk also stressed the need to carefully consider the stellar noise when looking for RV planets around evolved stars in open clusters. In particular, she discussed about the different origins of RV variability in these stars. She concluded that long term observations are essential to cover several rotational periods of these giant stars.

Exoplanet surveys: synergies between *Gaia* and other ongoing/upcoming space missions and ground-based exoplanet surveys (e.g. Transit, Direct Imaging)

The afternoon session of the second day started with the invited talk by Mariangela Bonavita (Edinburgh) who (remotely) spoke about the current and future efforts aimed at exploiting the emerging synergy between astrometry and direct imaging. This synergy will help to develop a framework to obtain the most precise model-independent measurement of the mass of directly imaged young giant planets. In her talk "Weighing young giants: tracing a path to precise dynamical masses for directly imaged exoplanets", she explained how to directly detect and characterize young giants in the outermost regions of planetary systems. It seems that *Gaia's* astrometric measurements are accurate enough to constrain the masses of the imaged companions (which was not possible before e.g. with Hipparcos). Maksym Lisogorskyi (Hertfordshire) in his talk explained how to use PEXO (Precision EXOplanetology) as a global modelling framework for nanosecond timing, microsecond astrometry, and µm/s radial velocities. This tool simultaneously models the classical and relativistic effects for Solar System and the Target System. This was followed by Paolo Giacobbe's (Torino) talk on the detection and characterization of giant planets combining *Gaia* astrometry, radial velocities and transit information. K2 mission detected large number of mono-transit planet candidates with transit duration of several hours. To confirm the planetary nature of these signals one needs to look at the astrometric data from *Gaia* which can provide useful mass upper limits or actual astrometric detection, particularly in the regime of orbital separations 1-4 AU, for which *Gaia* achieves maximum sensitivity. The session ended with the talk of Ozgur Basturk (Ankara) who presented the observation facilities in Turkey that can be used for exoplanet sciences. In Turkey they have several facilities and some are soon-to-come. They are open for collaboration.

After-presentations discussion of the second day was led by Shay Zucker (Tel Aviv) and was focused on two main important points: what are the main limitations for the RV precision and can we use the *Gaia* observations to estimate the upper mass limits of planets not-detected by *Gaia*. It was concluded that although it is still possible to improve the methods of the RV determinations of stars, a real breakthrough is expected only if/when we understand the physics that is behind the impact of stellar activity on the formation and profiles of spectral lines. The discussion also led to a conclusion that *Gaia's* detection and non-detections of planets will help us to significantly improve our understanding of giant planet formation and evolution, and to estimate the occurrence rates of massive planets.

Day three

Star-planet connection: Exoplanet host stars as an instrument to study planet formation and evolution in different environments

The last day stared with the invited talk of Tiago Campante (Porto) who gave a review on the synergy between asteroseismology and exoplanet science. He explained that asteroseismology can provide high precision mass and age determination for planet host stars. At the same time asteroseismology needs improved luminosity to constrain the models. It was interesting to realize that the radii determined from *Gaia* in general is in good agreement with the asteroseismic ones. After this talk, Jacob Hamer (Baltimore) demonstrated that hot-Jupiters are tidally destroyed while their hosts are on the main sequence. He found that stars hosting hot-jupiters are younger than the stars without hot-Jupiters. Interestingly, ultra-short period (P < 1d) planets do not show the same effect as hot-Jupiters. The main limitation (discussed after the talk) was that he uses stellar

velocity dispersion as a proxy for age. Dolev Bashi (Tel Aviv) gave a nice review on the exoplanet formation in the galactic context. He used Kepler-*Gaia*-LAMOST sample to study the occurrence rate of small-sized planets and its dependence on [Fe/H] and total velocity (Vtot - galactic space velocity) of the stars. The results suggested that planets are located in some favoured regions in the [Fe/H]-Vrot diagram: around metallic stars and in case of low-[Fe/H] planets tend to appear more around high Vtot. The latter trend is not easy to explain. Later on, Vardan Adibekyan (Porto) spoke about the dependence of the occurrence rate of different planets on the host star metallicity. He showed that it is still not clear whether there is a correlation between low mass planets and metallicity or not. The results are sensitive to the samples considered. It was also shown that stars hosting super-massive planets (Mp > 4Mjupiter) tend to appear around less metallic, but massive stars than field stars.

After these invited/contributed talks, Ana Ulla-Miguel (Vigo), Alan Alves (Aveiro), and Nicolas Unger (Geneve) presented their posters in short talks. Ana Ulla-Miguel spoke about the stellar cosmic rays and potential exoplanet habitability explaining that the cosmic rays can be bad for habitability of planets. Alan Alves explained that resonance trapping is a natural outcome of planetary migration processes due to planet-disk interactions. In particular, he explained the dynamics of the 3:1 planetary mean-motion resonance on the example of HD60532 b-c planetary system. Finally, Nicolas Unger showed the results of the re-analysis of the radial velocities data of HD40307 with the evidence estimator PolyChord: a Bayesian interface to determine number of existing planets. Alexandre Correia (Coimbra, "Exoplanets and the Cradle of Life with the SKA") and Ema Valente (Coimbra, "Dynamics and Habitability of Multi-Planet Systems") also presented their results but only in poster forms.

The workshop ended with a discussion and wrap-up led by the chair of the action Nicholas Walton (Cambridge). We briefly discussed the main questions that have arisen during the last session and continued with more general discussion about the potential of *Gaia* for exoplanet research, and how to be prepared for the *Gaia* DR3 and DR4. Nicholas Walton reminded the audience the structure of the Cost Action, opportunities it provides and the upcoming events organized within the action.
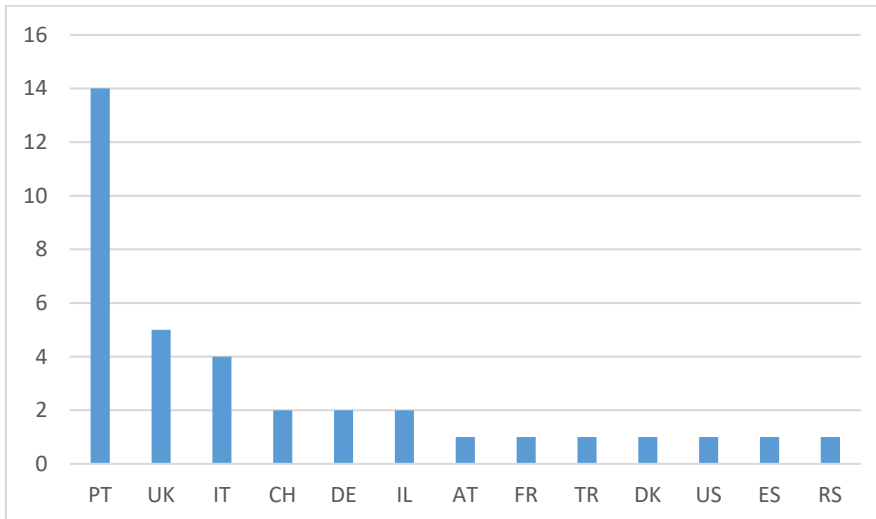
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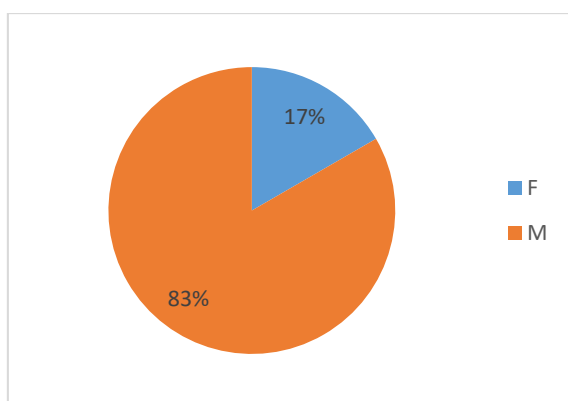
The workshop was attended by 36 researchers (one remotely), 17% of them female.

The SOC and LOC both had a 33% of female researchers (3 out of 9).

From the total, 14 participants (39%, including invited speakers) had financial support by the COST Action.

There were researchers from 13 different countries: Europe (mostly Portugal), the United States, Israel and North Macedonia.

There were 26 presentations. All female participants presented something while only 55% of male participants did. There were 6 Invited talks (only 17% female, as one had to cancel), 15 Contributed talks (20% female) and 5 Posters (40% female).

Regarding career stage there were 11 PhD students and 7 Early Career Researchers (47% of young researchers).

Report prepared by Vardan Adibekyan and Lola Balaguer-Núñez.