Highlights of IAU Focus Meeting 10: Synergy of Small Telescopes and Large Surveys for Solar System and Exoplanetary Bodies Research

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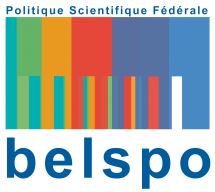

Overview

Preambule

- Preparation of the FM10 and selection of the talks were done by the **Scientific Organizing Committee** that comprises
  - Anatoliy Ivantsov (Royal Observatory of Belgium, Belgium, chair);
  - William Thuillot (Paris Observatory, France, co-chair);
  - Marcelo Assafin (Federal University of Rio de Janeiro, Brazil);
  - Zouhair Benkhaldoun (University Cadi Ayyad, Morocco);
  - David Hobbs (Lund University, Sweden);
  - Myung-Jin Kim (Korea Astronomy and Space Science Institute, Republic of Korea);
  - Anna Marciniak (Adam Mickiewicz University, Poland);
  - Joseph Ryan Masiero (Caltech / IPAC, USA);
  - Bruno Merín Martin (European Space Agency, Spain);
  - Meg Schwamb (Queen's University Belfast, UK);
  - Na Wang (Jinan University, People's Republic of China).

Invited talks FM10-1

- **ExoMiner: A Highly Effective Deep Learning Classifier to Mine Exoplanets** by *Hamed Valizadegan*:
  - Machine classification makes possible to extend human expertise used for detecting exoplanets for large datasets of transit signals.
  - ExoMiner allowed to increase validation of 301 new exoplanets, the total number of known exoplanets by 6.5%, from 4500 to 4800.
- **Enhancing and Optimizing TESS's Scientific Output using Machine Learning** by *Andrew Vanderburg*:
  - The deep convolutional neural network classifier, Astronet, is currently being used in the TESS Quick Look Pipeline to produce the official TESS planet candidate catalog.
  - Radial velocity observations to confirm TESS planet candidates are often limited by astrophysical noise from stellar magnetic activity.

Contributed talks FM10-1

- **MINERVA-Australis: A Southern TESS follow-up machine** by *Rob Wittenmyer*
  - MINERVA-Australis is the world's only fully dedicated set of 4 small telescopes each D=0.7m. Contributed to validation of 30 TESS planets (15%).
  - 85% of 600 TESS small planets still need follow-up.
  - Photometry and RV measurements can mitigate the stellar noise in RV due to stellar activity. It allows to detect smaller planets orbiting more active stars.
- **SPECULOOS: Hunting exoplanets of ultracool dwarfs with 1-meter ground-based telescopes network** by *Sebastián Zúñiga-Fernández*
  - Search for habitable Planets EClipsing ULtra-cOOl Stars aims to perform a transit search on the nearest (<40 pc) ultra-cool (<3000K) dwarf stars. The project is based on a network of 1m robotic telescopes (Cerro Paranal, Tenerife, San Pedro Martir).

Invited talks FM10-2

- **Exoplanet Demographics: Exploring the Multiplicity of Planetary Systems** by *Jessie Christiansen*
  - Multi-planets are common while the systems with a single planet (hot Jupiters) may be the exception.
  - There is a high level of intrasystem similarity using either planet radii or masses for observed multi-planet systems.
- **Characterising the atmospheres of exoplanets using high-resolution transmission spectroscopy** by *Ernst De Mooij*
  - There were discocered 8 stars (WASP-77A b, β Pictoris b, HD209458 b, HD189733 b, GJ1214, 55 Cancri e, KELT-9 b, MASCARA-2b) where transmission spectroscopy for studying planetary atmospheres is being analysed.
  - Spectrophotometry of GJ1214 allows to apply some atmospheric models that contains various mixtures of water and hydrogen.

Contributed talks FM10-2

- **Using Small Telescopes to Photometrically Determine the Masses of Tatooine Planets** by *William Welsh*
  - Measuring eclipse timing variations is easy to do using small telescope follow-up for finding precession variation, and, thus, masses of exoplanets.
- **Small telescopes and big projects** by *Zouhair Benkhaldoun*
  - Scientific projects, instrumentation at Oukaimeden Observatory located in the High Atlas mountains in Morocco are described.

Invited talks FM10-3

- **Solar System Science opportunities with the Vera C. Rubin Observatory Legacy Survey of Space and Time** by *Siegfried Eggl*
  - Small telescopes can contribute to the LSST science applied for variable or moving celestial sources, validation of sky brightness models.
- **The Gaia Follow Up Network: state of the art and future objectives** by *Federica Spoto*
  - Gaia alerts for Small Solar System Objects can be followed up using small telescopes. These measurements can be useful for linking observations and improving orbits.
  - The required astrometric accuracy is 60/70 mas.
  - By now, there were identified 5808 observations for 175 objects.

Invited talks FM10-3

- **Recycling photons: The uses of archives in solar system searches** by *Stephen Gwyn*
  - The Solar System Object Image Search (SSOIS) at the Canadian Astronomy Data Centre provides search for images of moving objects, allowing precoveries.
  - The user is provided with a list of images containing an object from a variety of telescopes. Initially created to search the CFHT MegaCam archive, SSOIS has been extended to other telescopes including Gemini, Subaru, HST, the ESO and NOAO telescopes, Pan-STARRS and a growing number of other archives.

Contributed talks FM10-3

- **Astrometric bias due to overlapping image profiles in the focal plane and its removal in the positions of near-Earth asteroids** by *Anatoliy Ivantsov*
  - An astrometric bias appears due to position measurements of light sources with overlapping profiles. The image width can be determined by either direct measurements or fitting image profiles and is recommended to be reported to the IAU Minor Planet Center using the ADES format.
  - Astrometric positions of asteroids measured close to the stars are likely biased. These measurements are recommended to be down-weighted or eliminated from the orbit fitting process.

Invited talks FM10-4

- **Searching Solar System and Exoplanetary Bodies the Data Science Way** by *Ashish Mahabal*:
  - Deep Learning with AStreaks developed for identifying moving asteroids, comets, artefacts.
  - Detecting Exoplanet candidates using TESS and deep learning.
- **NAROO: a New Astrometric Reduction of Old Observations** by *Jean-Eudes Arlot* :
  - Digitization of photographic plates with high resolution produces large datasets that can be used for making new much accurate astrometric measurements for the past data.

Contributed talks FM10-4

- **Precovery and risk assessment of the hazardous Near-Earth Objects in large astronomical surveys** by *Teymoor Saifollahi*
  - Description of a pipeline PRECOVERY for extracting images with SSOIS, calculating ephemerides with HORIZONS, analysing $(O - C)$ and identifying NEOs. doing precovery of NEOs. Using SSOIS, HORIZONS for precovery NEOs.
- **Data docking in meteor research** by *Svitlana Kolomiyets*
  - This study is devoted to the experience of dockings in meteor studies. The pros and cons of data stitching in meteor studies will be demonstrated.

Invited talks FM10-5

- **High precision astrometry of Small Solar System Bodies** by *Marco Micheli*
  - Gaia catalogue allows to extract high-quality unbiased measurements of Solar System Bodies, and improve modeling of their orbits.
  - Syntatic tracking as a new astrometric technique that changed the way astrometric observations are scheduled and processed, and the hardware required for data acquisition and its analysis.
- **The Transneptunian Automated Occultation Survey – TAOS II** by *Matthew Lehner*
  - The Transneptunian Automated Occultation Survey (TAOS II) will aim to detect occultations of stars by small (1 km diameter) objects in the Kuiper Belt and beyond.
  - TAOS II will operate three 1.3 meter telescopes at the Observatorio Astronómico Nacional at San Pedro Mártir in Baja California, México. It's description, survey goals, prospects for collaboration are presented.

Invited and contributed talks FM10-5

- **Understanding asteroids from their spectra. Asteroid taxonomies: benefits and limitations** by *Julia de León*
  - Future advances are expected so far due to
    - Mean spectrophotometric spectra of 60,000 asteroids binned in 16 wavelengths from 0.35 μm to 1.06 μm published by Gaia DR3 (June 2022).
    - Classification of asteroids to be done using artificial neural networks and deep learning.
- **Search for M-type dominated asteroid families** by *Ivan Slyusarev*
  - There were found 6 M-type dominated asteroid families (Baptistina, Brasilia, Eria, Tina, San Marcello, 1993 FY12).
  - A new criterion is proposed for separation of M-type asteroids using "a* - albedo" plot. M-type asteroids are located in the plot within $-0.2 < a* < 0.05$ and albedo $0.1 < p_V < 0.35$.

Contributed talks FM10-5

- **Composition and activity of comets with TRAPPIST telescopes** by *Said Hmiddouch*
  - TRAPPIST (for TRAnsiting Planets and PlanetesImals Small Telescope) is a set of two twin robotic telescopes with a diameter of 60 cm installed at La Silla ESO Observatory and the Oukaimeden Observatory (Morocco) in 2016.
  - The telescopes were used for observing two comets C/2020 M3 (ATLAS) and C/2017 K2 (PANSTARRS) and deriving production rates for dust and different molecules with respect to OH and CN.

Invited talks FM10-6

- **Asteroid photometry and its interpretation** by *Josef Ďurech*
  - Inversion of asteroid photometry is based usually on a convex form assumption asteroids. Detailed non-convex models with surface features can be reconstructed when disk-integrated photometry is combined with disk-resolved data.
  - Accuracy of photometry data has to be sufficient for applying the comprehensive models.
  - The comprehensive models get benefit from combination of various independent data, e.g. photometric and thermal infrared data for getting size and thermophysical parameters. Sometimes it is possible to interpret changes in the linear rotational model as the YORP effect.
- **Significance of shapes and spins in the thermophysical modeling of asteroids** by *Eric MacLennan*
  - Application of thermophysical models (TPM) as analysis tools for the interpretation of thermal IR observations in the studies of asteroid surfaces.
  - TPM analysis techniques that do not rely on a priori shape and spin information.

Invited talks FM10-6

- **Asteroid Polarimetry in the Gaia Era** by *Alberto Cellino*
  - Polarimetric data are useful to identify dynamical family interlopers.
  - A relation is proposed between albedo and the slope of the linear portion of the phase-brightness curve:

$$b = (0.013 \pm 0.002) - (0.024 \pm 0.002) \log p_V$$

  - If the previous hypothesis is valid, one can derive the albedo of many thousands of asteroids from Gaia observations, even without knowing the absolute magnitude.

Contributed talks FM10-6

- **Light curve survey of the asteroids with KMTNet** by *Hee-Jae Lee*
  - The Korea Microlensing Telescope Network (KMTNet) consists of D=1.6 m telescopes. An ecliptic plane survey with 25 min cadences has begun in the second half of 2019 provided photometric data for 40,000 asteroids per year. 3,000 of those have got confirmation of their rotational periods.
  - A statistical analysis of spins and shapes is provided.
- **Synergy of Small Telescopes for Asteroid (6478) Gault Observations in Tajikistan and Slovakia** by *Gulchehra Kokhirova*
  - Quasi-synchronous observations of the asteroid (6478) Gault at two different telescopes confirmed signs of cometary activity.

Conclusions

- Machine and deep learning are used frequently in classification and detection exoplanets using large sets of parameters and data.
- While large surveys produces homogeneous data over greater area of sky, small telescopes can be the suitable instruments for follow-up various objects suspected in either variability or motion.
- While there are plenty possibilities for calibration of small telescope measurements, the Gaia data releases provide the most accurate ones, and, thus, are highly recommended.
- There are observational programmes for small telescopes which are opened for collaboration today (Gaia Follow-Up network, LSST contribution programme, other observational networks).