Deliverable

H2020 COMPET-05-2015 project "Small Bodies: Near And Far (SBNAF)"

Topic: COMPET-05-2015 - Scientific exploitation of astrophysics, comets, and planetary data
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WP	**WP5, Ground-based observations**
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Lead Author	Pablo Santos-Sanz, IAA-CSIC, psantos@iaa.es

WP5 Ground based observations
Objectives: To obtain auxiliary ground-based observations for the SBNAF sample objects: time series (lightcurves), astrometric measurements, stellar occultations and absolute photometry.

Description of deliverable

Observations delivery to MPC, CDS & PDS. Delivery of photometric & lightcurve measurement to the Minor Planet Center, CDS and PDS data archives. In this deliverable are briefly described the observations and data obtained within SBNAF WP5 that are publicly available in the data archives mentioned above. Some of the data obtained within WP5 are also available via different databases, services, and/or open-access papers.

Contents

1 Data available via MPC

From the MPC web page (https://www.minorplanetcenter.net/):

"The Minor Planet Center (MPC) is the single worldwide location for receipt and distribution of positional measurements of minor planets, comets and outer irregular natural satellites of the major planets. The MPC is responsible for the identification, designation and orbit computation for all of these objects. This involves maintaining the master files of observations and orbits, keeping track of the discoverer of each object, and announcing discoveries to the rest of the world via electronic circulars and an extensive website."

When a stellar occultation produced by a Trans-Neptunian Object (TNO) or a Centaur is detected (after a previous very hard work of prediction and refinement of the predictions that sometimes lasts years, plus a difficult coordination of tens of observatories to improve the chance of success) it is possible to determine with high accuracy the astrometric position in the sky of the object. When the ocultation results are published, the very precise astrometry derived from them is submitted to the MPC in a very special format. One of the last batches submitted to MPC by D. Herald, E. Frappa, T. Hayamizu, S. Kerr and B. Timerson included astrometry derived from occultations for 338 events (mainly MBAs, but also few TNO and Centaur). As a general rule, events where there was only one successful observation have an uncertainty of 10's of milliarcseconds -mas- (which is still hugely better than most asteroid astrometry received by the MPC, which is typically 100's of mas). Events where there are multiple chords well distributed across the object have uncertainties of around 1 mas or even less. This occultation-derived astrometry is included in the "Minor Planet Circulars" and is used to improve the orbital elements and the ephemerides of the objects. In the cited batch the astrometry derived from the ocultation by the dwarf planet Haumea is included.This occultation, which also led to the discovery of the first ring around a dwarf planet, was published in Nature within the SBNAF project:

The size, shape, density and ring of the dwarf planet Haumea from a stellar occultation, Ortiz, Santos-Sanz et al. 2017, Nature 550, 219-223; DOI:10.1038/nature24051
https://www.nature.com/articles/nature24051.epdf?author_access_token=bp-7pu-1Y00aV-ScNzBZXNRgN0jAjWel9jnR3ZoTv0Nn2Be8IVdyunt-zYVmzk5LHyladh56RdTs8jAl5MO8qoF5DHEzH9IDHP0EPHZ0V39BYZJpSmPGFY5n0qCsP4I1

More high accuracy astrometry derived from stellar occultations by TNOs/Centaurs observed during SBNAF project has been submitted to MPC and will be submitted to MPC in the near future when papers with new stellar occultations results been published.

MPC is also collecting rotational lightcurves of small bodies (via http://alcdef.org/). All the rotational lightcurves published during the SBNAF project are also availables in this database (e.g. the lightcurve of Haumea

published in the Nature paper just cited above, the rotation lightcurve of the "Halloween Asteroid" 2015 TB145 published during the project, etc).

2 Data available via CDS

All extensive data (e.g. photometric data of rotational light curves of SBNAF targets) obtained within WP5 used to publish a paper are also available via CDS (Centre de Données astronomiques de Strasbourg: http://cdsweb.u-strasbg.fr/). Basic information from this Data Collecting Center directly copied from the CDS web page:

"The Strasbourg astronomical Data Center (CDS) is dedicated to the collection and worldwide distribution of astronomical data and related information.

The CDS hosts the SIMBAD astronomical database, the world reference database for the identification of astronomical objects; VizieR, the catalogue service for the CDS reference collection of astronomical catalogues and tables published in academic journals; and the Aladin interactive software sky atlas for access, visualization and analysis of astronomical images, surveys, catalogues, databases and related data.

The CDS mission is to:

-collect useful information concerning astronomical objects that is available in computerized form
-upgrade these data by critical evaluations and comparisons
-distribute the results to the astronomical community
-conduct research, using these data"

An example of WP5 data collected in CDS is in the paper:

Large Halloween Asteroid at Lunar Distance, Müller, T. G.; Marciniak, A.; Butkiewicz-Bąk, M.; Duffard, R.; Oszkiewicz, D.; Käufl, H. U.; Szakáts, R.; Santana-Ros, T.; Kiss, C.; Santos-Sanz, P., 2017, A&A 598, A63; DOI: 10.1051/0004-6361/201629584
https://arxiv.org/abs/1610.08267

The photometric tables with the rotational lightcurve of the Halloween asteroid (2015 TB145) are available in CDS:
http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/598/A63

The 5 most recent SBNAF papers with data archived in CDS are:

The homogeneous internal structure of CM-like asteroid (41) Daphne, Carry et al. 2019, A&A Volume 623, id.A132, DOI: 10.1051/0004-6361/201833898
https://arxiv.org/abs/1901.01890

(16) Psyche: a mesosiderite-like asteroid?, Viikinkoski, M., Vernazza P., Hanuš, J. et al., A&A 618, L3 (2018).
DOI: 10.1051/0004-6361/201834091
https://arxiv.org/abs/1810.02771

Optical observations of NEA 3200 Phaethon (1983 TB) during the 2017 apparition, Kim, M.-J.; Lee, H.-J.; Lee, S.-M.; Kim, D.-H.; Yoshida, F.; Bartczak, P.; Dudziński, G.; Park, J.; Choi, Y.-J.; Moon, H.-K.; Yim, H.-S.; Choi, J.; Choi, E.-J.; Yoon, J.-N.; Serebryanskiy, A.; Krugov, M.; Reva, I.; Ergashev, K. E.; Burkhonov, O.; Ehgamberdiev, S. A.; Turayev, Y.; Lin, Z.-Y.; Arai, T.; Ohtsuka, K.; Ito, T.; Urakawa, S.; Ishiguro, M., A&A 619 (2018), A123, 8pp.
DOI: 10.1051/0004-6361/201833593
https://arxiv.org/abs/1809.05900

The impact crater at the origin of the 100 Myrs old Julia family detected with VLT/SPHERE?, P. Vernazza, M. Brož, A. Drouard, J. Hanuš, M. Viikinkoski, M. Marsset, L. Jorda, R. Fetick, B. Carry, F. Marchis, M. Birlan, T. Fusco, T. Santana-Ros, E. Podlewska-Gaca, E. Jehin, M. Ferrais, P. Bartczak, G. Dudziński, J. Berthier, J. Castillo-Rogez, F. Cipriani, F. Colas, C. Dumas, J. Ďurech, M. Kaasalainen, A. Kryszczynska, P. Lamy, H. Le Coroller, A. Marciniak, T. Michalowski, P. Michel, M. Pajuelo, P. Tanga, F. Vachier, A. Vigan, B. Warner, O. Witasse, B. Yang, E. Asphaug, D. C. Richardson, P. Ševeček, M. Gillon and Z. Benkhaldoun, A&A 618, A154(2018). DOI: 10.1051/0004-6361/201833477
http://observations.lam.fr/astero/Papers/Vernazza2018.pdf

Asteroid models reconstructed from the Lowell Photometric Database and WISE data, J. Ďurech, J. Hanuš, V. Alí-Lagoa, A&A 617, A57 (2018). DOI: 10.1051/0004-6361/201833437
https://arxiv.org/abs/1807.02083

Using the new GUI of "The SAO/NASA Astrophysics Data System" (ADS) it is possible to search for all the SBNAF papers and within them to search all the papers with data archived in CDS. 14 papers of a total of 68 SBNAF papers in ADS have data archived in CDS (this is around a 21% of our published papers):
https://ui.adsabs.harvard.edu/search/p_=0&q=(full%3A%22687378%22%20cds%20AND%20year%3A2016-2019)&sort=date%20desc%2C%20bibcode%20desc

3 Data available via PDS

Another extensive database container (in addition to MPC and CDS) for Small Bodies observations, data and results is the Planetary Data System (PDS: https://pds.nasa.gov/): "The PDS is a long-term archive of digital data products returned from NASA's planetary missions, and from other kinds of flight and **ground-based data acquisitions**, including laboratory experiments. But it is more than just a facility -the archive is actively managed by planetary scientists to help ensure its usefulness and usability by the world wide planetary science community."

Many of the data and results obtained from observations within WP5 are now available via PDS. A few examples follow below.

-Data of TNO and Centaur Diameters, Albedos, and Densities are available in PDS link
https://sbn.psi.edu/pds/resource/tnocenalb.html

In this site, for example, are available some of the data included in the next SBNAF papers (and others):

Physical properties of centaur (54598) Bienor from photometry, Fernández-Valenzuela, E.; Ortiz, J. L.; Duffard, R.; Morales, N.; Santos-Sanz, P., 2017, MNRAS 466, 4147F; DOI: 10.1093/mnras/stw3264
https://arxiv.org/abs/1612.02626

2008 OG19: a highly elongated Trans-Neptunian object, Fernández-Valenzuela, E.; Ortiz, J. L.; Duffard, R.; Santos-Sanz, P.; Morales, N., 2016, MNRAS 456, 2354; DOI: 10.1093/mnras/stv2739
https://arxiv.org/abs/1511.06584

"TNOs are Cool": A survey of the trans-Neptunian region. XII. Thermal light curves of Haumea, 2003 VS2 and 2003 AZ84 with Herschel/PACS", P. Santos-Sanz, E. Lellouch, O. Groussin, P. Lacerda, T. G. Müller, J. L. Ortiz, C. Kiss, E. Vilenius, J. Stansberry, R. Duffard, S. Fornasier, L. Jorda, A. Thirouin, A&A, 604, A95 (2017); DOI: 10.1051/0004-6361/201630354
https://arxiv.org/abs/1705.09117

"TNOs are Cool": A survey of the trans-Neptunian region. XIII. Statistical analysis of multiple trans-Neptunian objects observed with Herschel Space Observatory, A&A 608, A19 (2017), Kovalenko, I. D.; Doressoundiram, A.; Lellouch, E.; Vilenius, E.; Müller, T.; Stansberry, J.; ResearchGate; DOI: 10.1051/0004-6361/201730588
https://www.researchgate.net/publication/320171353_TNOs_are_Cool_A_survey_of_the_trans-Neptunian_region_XIII_Statistical_analysis_of_multiple_trans-Neptunian_objects_observed_with_Herschel_Space_Observatory

-Lightcurves of Main Belt Asteroids (MBAs) published in SBNAF papers are also available in the PDS database in
https://sbn.psi.edu/pds/resource/lc.html

Some SBNAF papers for which lightcurve data are included in PDS are:

Photometric survey, modelling, and scaling of long-period and low-amplitude asteroids, A. Marciniak, P. Bartczak, T. Müller, et al., A&A 610, A7 (2018); arXiv; DOI: 10.1051/0004-6361/201731479
https://arxiv.org/abs/1711.01893

Thermal properties of slowly rotating asteroids Results from targeted survey, Marciniak et al. 2019, submitted to A&A in January 2019

-Results from stellar occultations by TNOs / Centaurs published in SBNAF papers are also available in the PDS database following the link
https://sbn.psi.edu/pds/resource/occ.html

Some examples archived in PDS are the results from stellar occultations by the Centaur Chariklo or the dwarf planet Haumea:

The structure of Chariklo's rings from stellar occultations, Bérard, D., Sicardy, B., Camargo, J.I.B., Desmars, J., Braga-Ribas, F., Ortiz, J.-L.; Duffard, R.; Morales, N.et al.., AJ 154, 144, 21pp (2017); DOI: 10.3847/1538-3881/aa830d
https://arxiv.org/abs/1706.00207

Size and shape of Chariklo and its rings reflectivity from multi-epoch stellar occultations, Leiva, R.; Sicardy, B.; Camargo, J. I. B.; Ortiz, J.-L.; Desmars, J.; Bérard, D.; Lellouch, E.; Meza, E.; Kervella, P.; Snodgrass, C.; Duffard, R.; Morales, N. et al., AJ 154, 159, 23pp (2017); DOI: 10.3847/1538-3881/aa8956
https://arxiv.org/abs/1708.08934

The size, shape, density and ring of the dwarf planet Haumea from a stellar occultation, Ortiz, Santos-Sanz et al. 2017, Nature 550, 219-223; DOI:10.1038/nature24051
https://www.nature.com/articles/nature24051.epdf?author_access_token=bp-7pu-1Y00aV-ScNzBZXNRgN0jAjWel9jnR3ZoTv0Nn2Be8IVdyunt-zYVmzk5LHyladh56RdTs8jAl5MO8qoF5DHEzH9IDHP0EPHZ0V39BYZJpSmPGFY5n0qCsP4I1

4 Data available via other databases/services

-Stellar occultation predictions
Thousand of astrometric observations with different telescopes in different observatories have been performed within WP5. These observations have been intensively used to predict stellar occultations and to refine the predictions. Part of these predictions are included in the SBNAF deliverables D5.1 'Occultation candidates for 2016', D5.2 'Occultation candidates for 2017' and D5.3 'Occultation candidates for 2018'. An important part of these astrometric observations have also been used to refine the ERC Lucky Star project predictions published in http://lesia.obspm.fr/lucky-star/predictions.php in the framework of the international collaboration on stellar occultations (Paris group, Rio group and Granada group).

-Stellar occultations results by TNOs/Centaurs
In this web page (http://occultations.ga/results/), results on stellar occultations by TNOs and Centaurs are collected. The page is maintained by the Rio group, which is part of the international collaboration on stellar occultations by TNOs/Centaurs composed by the Paris group, the Rio group and the Granada group (IAA-CSIC). Thanks to this wide collaboration we are world leaders on the prediction, observation and detection of stellar occultations by TNOs/Centaurs.

From October 2009 -when the 1st stellar occultation by a TNO, apart of Pluto, was recorded- to March 2019, 70 stellar occultations by TNOs / Centaurs have been detected (43 by 24 TNOs, and 27 by 5 Centaurs) and we (the international collaboration on occultations) have participated in more than 90% of them!

During the SBNAF project (31st March 2016 – 31st March 2019) hundreds of stellar occultations by TNOs/Centaurs have been predicted and refined (this means thousands of astrometric observations performed to do this task). After these refinements we have selected around 4-5 occultations per month, and finally we have observed around 1-2 stellar occultations per month. It is important to note that to obtain a multi-chord stellar occultation by a TNO or Centaur a minimum of 15-20 observatories are needed (e.g. 50 observatories were involved in the very recently and successful stellar occultation by the TNO Huya on 18th March 2019 to obtain around 20 chords, this is a 'record' regarding the number of chords for this kind of occultations!). The work to contact, manage and coordinate such a number of observers (and to collect and analyze all the data after the occultation) is really hard and very time consuming.

We have observed more than 60 stellar occultations during the SBNAF project obtaining 26 positive detections. This means that the ambitious Milestone 12 (MS12: '25 successful TNO occultation measurements to be reached in month 36 -31 Mar 2019-') has been reached on time. It is expected that astrometric data obtained from most of these occultations will be provided to MPC in the near future. More information about all these occultations is in our password protected SBNAF targets web page http://asteroidstnos.iaa.es/content/results#overlay-context=content/sbnaf.

-Interactive Service for Asteroid Models

The Interactive Service for Asteroid Models (ISAM: http://isam.astro.amu.edu.pl/) is maintained by the Adam Mickiewicz University in Poznań (Faculty of Physics, Institute Astronomical Observatory). ISAM service enables:

'-to display an asteroid orientation as seen from Earth at any date
-to generate lightcurves
-to animate the rotation
-3D views
-shape and lighting analysis'

Lightcurves of MBAs obtained within WP5 has been used and 'injected' in ISAM to obtain/refine asteroid models.

-Infrared database

One of the deliverables of the SBNAF project is a public Infrared (IR) database that collect all available IR data of Small Bodies from different large space missions like IRAS, Spitzer, Herschel, AKARI, WISE, etc. Some auxiliary data included in the database are obtained within WP5.

Detailed information about the IR database can be read in deliverable 'D2.6 IR database (public)'. The IR database is now publicly accessible at https://ird.konkoly.hu/. Also deliverable 'D2.5 IR database (internal)', which is public, contains information about the IR database.

-Herschel Science Archive / IRSA Archive
Expert-reduced Herschel data of NEAs, MBAs and TNOs have been uploaded to the Herschel Science Archive (HSA: http://archives.esac.esa.int/hsa/whsa/). This is described in detail in deliverables 'D2.2 NEA HSA upload', 'D2.3 MBA HSA upload', and 'D2.4 TNO HSA upload'. These data uploaded to HSA are also available in the NASA/IPAC Infrared Science Archive from JPL (IRSA: https://irsa.ipac.caltech.edu/frontpage/).

- Finally, note that these and others SBNAF 'Products & Tools' and 'Services' are available via the following public link:
  http://www.mpe.mpg.de/~tmueller/sbnaf/results.html

5 Data available via open-access published papers

Of course, many of the data obtained within WP5 are available via the open-access SBNAF published papers, that can be consulted in our public web page:
http://www.mpe.mpg.de/~tmueller/sbnaf/science/publications.html

A quick search in ADS also can be used to obtain most of the SBNAF papers (68 results, at date 4 April 2019) , including also most of the open-access links to the articles:
https://ui.adsabs.harvard.edu/#search/p_=0&q=(full%3A%22687378%22%20AND%20year%3A2016-2019)&sort=date%20desc%2C%20bibcode%20desc

6 Outlook

It is expected that more SBNAF data and results obtained within WP5 will be added to MPC, CDS, PDS or the other databases/services detailed in this document when papers based on these data be published (soon). There are also several papers "submitted" which include the SBNAF acknowledgement.

33 papers (around 49%) of a total of 68 SBNAF papers found using ADS (at date 4 April 2019) include *external data products* linked to CDS and to other data archives like SIMBAD, ESA, ESO, Herschel, ALMA, NED, MAST, etc.