**Project Number:** 687378 – SBNAF - RIA

**Project Acronym:** SBNAF

**Project title:** Small Bodies Near and Far

# Periodic Technical Report

# Part B

**Period covered by the report**: from 01/04/2016 to 31/03/2017

**Periodic report:** 1st

## 1. Explanation of the work carried out by the beneficiaries and Overview of the progress

- *Explain the work carried out during the reporting period in line with the Annex 1 to the Grant Agreement.*

- *Include an overview of the project results towards the objective of the action in line with the structure of the Annex 1 to the Grant Agreement including summary of deliverables and milestones, and a summary of exploitable results and an explanation about how they can/will be exploited*[1]*.*

  *(No page limit per work package but report shall be concise and readable. Any duplication should be avoided).*

The SBNAF bench-mark study (2016-2019) addresses critical points in reconstructing physical and thermal properties of near-Earth, main-belt, and trans-Neptunian objects. The combination of the visual and thermal data from the ground and from astrophysics space missions (like Herschel, Spitzer, Kepler-K2, Hubble, and AKARI) is key to improving the scientific understanding of these objects. The development of new tools is crucial for the interpretation of much larger data sets from WISE, Gaia, JWST, or NEOShield-2, but also for the operations and scientific exploitation of the Hayabusa-2 mission. Our approach is to combine different methods and techniques to get full information on selected bodies: lightcurve inversion, stellar occultations, thermo-physical modelling, radiometric methods, radar ranging and adaptive optics imaging. The applications to objects with ground-truth information from interplanetary missions Hayabusa, NEAR-Shoemaker, Rosetta, and DAWN allows us to advance the techniques beyond the current state-of-the-art and to assess the limitations of each method.

In the context of the SBNAF project we derive size, spin and shape, thermal inertia, surface roughness, and in some cases even internal structure and composition, for objects from the near-Earth environment out to the most distant objects in the Solar System. Another important aim is to build accurate thermo-physical asteroid models to establish new primary and secondary celestial calibrators for ALMA, SOFIA, APEX, and IRAM, as well as to provide a link to the high-quality calibration standards of Herschel and Planck. The target list comprises recent near-Earth and main-belt interplanetary mission targets, two samples of main-belt objects (Gaia "mass/perturber sample" & "asteroid calibrator" sample), representatives of the Trojan and Centaur populations, and all known dwarf planets (and candidates) beyond Neptune.

In this first period between April 2016 to March 2017 we developed new tools, web-services, highly reliable calibration and science products for the planetary community. At the same time, we present our scientific results in refereed publications (more than 15 in the first year) and a large collection of conference contributions. All publications are in open access, the various tools, services and products are available on our public web page. Our team combines world-leading expertise in different scientific areas in a new European partnership with a high synergy potential in the field of small body and dwarf planet characterization, related to astrophysics, Earth, and planetary science.

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[1] Beneficiaries that have received Union funding, and that plan to exploit the results generated with such funding primarily in third countries not associated with Horizon 2020, should indicate how the Union funding will benefit Europe's overall competitiveness (reciprocity principle), as set out in the grant agreement.

## 1.1 Objectives

*List the specific objectives for the project as described in section 1.1 of the DoA and described the work carried out during the reporting period towards the achievement of each listed objective. Provide clear and measurable details.*

The main objective of the SBNAF project is to enhance the scientific return from different astrophysics and planetary missions related to small bodies and dwarf planets in our Solar System. We use very different data sets from ground (professional and amateur observations), airborne, and space projects and combine these measurements with newly developed tools and techniques to make the best possible use of those ESA, NASA, and JAXA missions. At the same time, we develop sophisticated web tools, provide calibration products, and establish new scientific data products. The SBNAF activities add scientific value through advanced analysis of the data, leading to a wide variety of scientific publications and higher-level data products for further exploitation by the planetary community. We have already started to provide enhanced data products for upload to ESA archives.

Our team includes world-leading experts in different fields: lightcurve inversion techniques to reconstruct shapes and spin properties of small bodies; handling of infrared data from the ground and from the space, including their reduction and calibration are two of the main areas covered. In the SBNAF team there are also highly experienced observers with world-leading expertise in stellar occultation measurements, as well as photometric and spectroscopic observations; and also experts on thermo-physical modelling. By combining the expertise in our newly formed team, the SBNAF project has specified the following **major objectives**:

- Develop new tools and optimized procedures for the determination of size, shape, spin and thermal properties for NEAs, MBAs, and TNOs, from combined visual and infrared observations, both from space and from the ground.
  - Status Apr 2017: several deliverables are related to this objective, with core information given in "D6.1 Occultation vs. thermal tools"; several publications on NEAs, MBAs, and TNOs address this point; several tools and techniques are available from our public web page;
- Provide expert-reduced maps and fluxes of Herschel measurements in the infrared for feedback to the Herschel Science Archive (HSA) via dedicated studies on small near-Earth and large main-belt asteroids (including calibration observations), and the largest Centaurs and trans-Neptunian objects.
  - Status Apr 2017: new, high-quality products for Herschel NEA and MBA observations have been provided to the HSA, related deliverables are D2.1, D2.2, and D2.3; several asteroid-related calibration products have been provided to the Herschel, ALMA, IRAM, SOFIA, and a few other far-IR/submm/mm calibration teams (D4.1, D4.2, D4.3, D4.6);
- Advance the field of thermo-physical characterization of small bodies by combining disk- resolved asteroid observations from interplanetary missions (Hayabusa, Rosetta, Dawn, NEAR-Shoemaker) with disk-integrated thermal and optical observations from space and ground.
  - Status Apr 2017: work in this context has started (deliverables D6.1; milestone 2), also partly included in NEA and MBA publications, but critical tests and benchmarking are programmed to be carried out throughout the two upcoming years.
- Link the established asteroid-related calibration from Herschel (with data coming also from Planck, Akari, Spitzer and ISO) to ALMA and other sub-mm/mm observatories.

- Status Apr 2017: preparatory work has started by collecting existing thermal measurements from these missions (to be included in the IR database, see D2.5 and D2.6), the focus of the first year was on Herschel and Akari data.

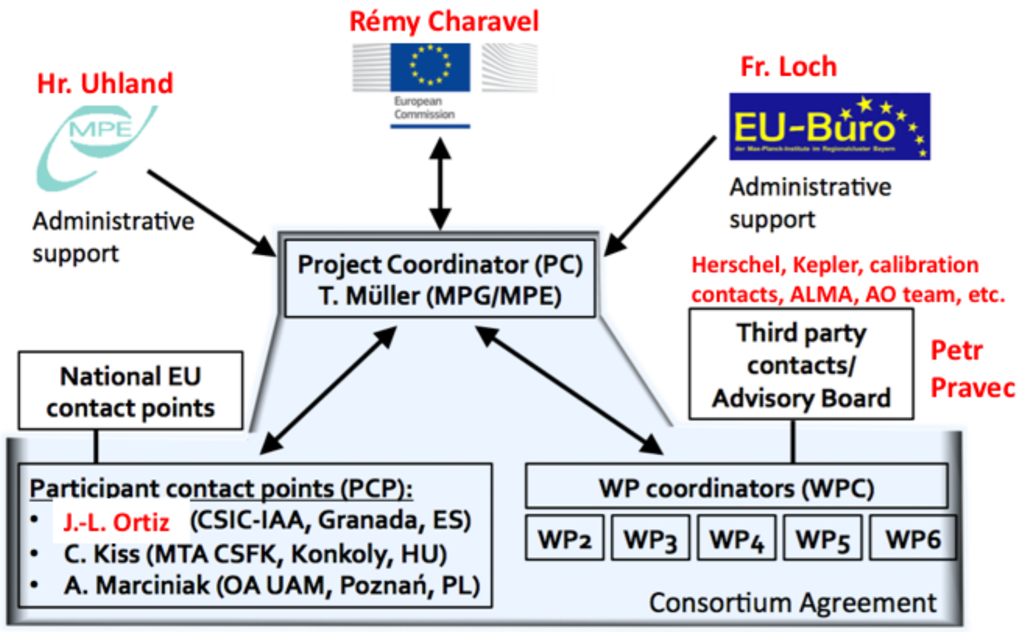
- Setup of a public database for infrared observations of small bodies (selected NEAs, MBAs, Trojans, Centaurs, TNOs) with thermal measurements from all infrared space missions and selected ground-based surveys.
  - Status Apr 2017: an initial setup for the SBNAF IR database has been designed and includes measurements coming from different catalogues (AKARI, IRAS, MSX, and WISE) of several targets on which work already started. This helped us identify early challenges (e.g. different data formats from the various sources, spectra versus spectro-photometry entries) and strategies to overcome them. We are now working on a user interface that allows the members of the consortium to access the data base remotely.
- Establish high-accuracy constraints – object densities, spin parameters, shapes, and thermal properties - of selected single and binary asteroids for testing formation and evolution models of the Solar System.
  - Status Apr 2017: This topic will be on-going for the entire SBNAF period. Preparatory work has begun to establish tools and methods to determine and quantify the reliability of volume information, which will be required e.g. to determine densities when the Gaia mass determinations are released. For the rotational properties there are two aspects: statistical studies on light curves in general (see e.g. the publication by Butkiewicz-Bąk et al. 2017), and the determination of high-quality spin properties for individual objects (see solutions presented in the ISAM service). The initial SBNAF steps have been more focused on shape (and volume) and rotational properties determinations because they are prerequisite to derive thermal properties (thermal inertia, surface roughness, emissivity). Still, because they can also help cross validate shape and rotational properties by assessing the ability of shape/spin solutions to fit thermal data, about half of our publications already feature radiometric studies.
- Enhance the scientific outcome of small body observations of astrophysical infrared space missions (Herschel, Planck, and AKARI) by combining space and ground data.
  - Status Apr 2017: Several of our SBNAF publications contain already Herschel and/or AKARI data. We also have two Herschel-specific and one AKARI-specific catalogue papers in preparation: they will allow a very wide use of small-body observations from these two missions by the planetary community. The Herschel and AKARI data sets include a wide range of scientific aspects, which will be demonstrated in these catalogue publications, but we also plan to do SBNAF-specific studies (in combination with auxiliary data from ground or occultation measurements) to answer some of the key science questions related to NEAs, MBAs, and TNOs.
- Deliver asteroid model solutions for Hayabusa-2, Gaia, ALMA, and other ground-based submm/mm projects.
  - Status Apr 2017: Our Hayabusa-2 related model solution for the mission target Ryugu was recently published (Müller et al. 2017). More Ryugu studies will follow with the availability of new observational data. In the context of Gaia we push for high-quality shape, spin and volume solutions for a range of large MBAs in preparation for the Gaia asteroid mass release in the mid-term future. This includes new lightcurve and absolute photometric measurements from ground, the establishment of new lightcurve inversion techniques, the combinations with other observing techniques (AO imaging, occultations, radiometry) to improve the shape

and spin solutions and to assign size information to these shapes. Radiometric studies related to ALMA and other submm/mm projects have started, but mainly in the calibration context. Very few submm/mm measurements of MBAs and TNOs are currently publicly available, but several collaborations with submm/mm observing teams have started.

- Provide tools, techniques and crucial object properties in support of NEOShield-2, OSIRIS- REx, JWST, and ground-based observations of minor bodies.
  - ➢ Status Apr 2017: Here we can mention the ISAM service to visualize asteroid shape and spin solutions, but also our results on thermophysical model studies of small bodies (here mainly on NEAs) are relevant for NEOShield-2 and OSIRIS-REx. The preparatory work for JWST (some team members are part of the GTO proposals, others are included in an ERS proposals which contains also SBNAF targets) has started and will be followed up during the next two years.

## 1.2 Explanation of the work carried out per WP

### 1.2.1 Work Package 1: Management & Outreach




During the reporting period from April 2016 to March 2017 we encountered no major problems within WP1. The coordination of the SBNAF project is done by the PI (Thomas Müller) in close collaboration with the group leaders of AMU (Anna Marciniak), IAA (Rene Duffard/Jose Luis Ortiz), and Konkoly observatory (Csaba Kiss), since November 2016 also supported by Víctor Alí-Lagoa at MPE (see Figure above). All critical points, questions related to procedures, contracts, financial aspects, etc. were solved with the help of the EU officer, and our national and local EU experts, and by regular interactions between the team members.

The progress in the six WPs is as expected and described in the Grant Agreement No 687378. All deliverables foreseen for the first year (in total 22 deliverables until Mar 31, 2017) have been uploaded to the EU web portal. Four deliverables were late by a few days due to technical reasons or travelling/-conference commitments. One deliverable (D6.1) was delayed by 3 months (in agreement with the EU officer) due to a delay in the hiring process for a critical postdoc position. As part of WP1 we organize regular Webex team meetings of 1-2 hour length every two to three weeks. The meeting minutes and the arising action items are collected, tracked, and followed up on our internal web page. In case of problems, we try to mediate between the team members, the participant contact points, or the WP leaders. Currently, there are no identified risks related to the WP deliverables and milestones.

The biggest workload in WP1 is related to the email/skype/telecon communication between the beneficiaries and the very frequent updates on the internal and public web pages which are the main sources of information for the team members, the EU officer, our external expert, and the public. Via our public web page and Astronomy archives for publications we ensure open access for all tools, public deliverables, documents, and publications. Key observations and generated data products are also available from other archives, like the *Herschel Science Archive* or the *Centre de Données astronomiques de Strasbourg* (CDS). The Solar System and small-body topics are also of great interest to the public and as part of WP1 we foster outreach activities and we offer qualified feedback to media requests.

During the first year, there were two deliverables in WP1 with the following content:

**D1.1 Internal web page (Apr 30, 2016):**
A password-protected, internal web page was set up:

http://www.mpe.mpg.de/~tmueller/SBNAF/sbnaf.html

The web page management is done by the SBNAF PI supported by the MPE/Garching computer system group to ensure security and stability of the system. Input for the internal pages is coming from all involved beneficiaries. The main topics and the purpose of the internal web page are:

- To collect all project-relevant information
- To document all partners & team members & official affiliations
- Store H2020 Compet-05-2015 call & proposal details
- Store Grant & Consortium Agreement
- Link all meeting minutes (webex and in-person team meetings), meeting presentations, pictures, documents & relevant material
- Collect Action Items, including tracking and follow-up
- List all relevant conferences & collect SBNAF conference contributions
- List all SBNAF publications
- Collect auxiliary research documents, papers, links
- Give basic information about target lists
- Provide collections of all outreach activities, press material, outreach ideas

**D1.2 Public web page (May 31, 2016):**
A public web page was set up at:

http://www.mpe.mpg.de/~tmueller/sbnaf

The web page management is done by the SBNAF PI supported by the MPE/Garching computer system group and AMU experts. Input for the public pages is coming from all involved beneficiaries. The main topics and the purpose of the SBNAF public web page are:

- To provide key information for public, external collaborators, potential data users and stakeholders
- To present all partners & team members & official affiliations

- To describe the H2020 Compet-05-2015 call & SBNAF abstract
- To list scientific publications, public reports
- To present all press releases and press material (images, videos, stories, highlights)
- To collect all public data & calibration products
- To provide information about public model solutions & model predictions
- To describe the newly developed public tools, methods
- To provide links to more specific public pages at partner institutes
- To advertise the SBNAF project to the world

Outlook: WP1 is progressing as expected. The workload for all beneficiaries was high in the beginning and it is still significant close to the bi-annual team meetings, but more relaxed in the periods in between. The next deliverable "D1.3 Mid-term report" was originally foreseen for Sep 30, 2017, but has to be shifted by about one month. Our third team meeting will take place in the beginning of October 2017 and this meeting is considered as crucial for the mid-term report. The goal of D1.3 is to give a mid-term status report of the project and all WPs and deliverables. The results in terms of tools, services, generated products, publications, conference contributions will be summarized. We will also try to identify possible problems and risks for the remaining 1.5 years. D1.3 will also include a listing of past, ongoing and planned outreach activities. We also hope to collect feedback from different external experts, collaborating partners and beneficiaries of our scientific and technical results. The expected new delivery date is October 31, 2017.

### 1.2.2 Work package 2: Infrared observations

The goal of WP2/ Infrared Observations is twofold. First, some tasks in this WP (D2.1, D2.2, D2.3, and D2.4) focus on data obtained with the Herschel Space Observatory and the main goal of these tasks is to produce expert-reduced Herschel data of primary focus targets: (a) of large TNOs (photometric and lightcurve observations); (b) MBAs (science and calibration observations); (c) dedicated NEA observations. A second group of tasks are dedicated to the compilation of a database of infrared observations of solar system targets, collecting infrared data from previous missions (Spitzer, Planck, WISE, Akari, IRAS, ISO, MSX) and published ground- based mid-IR, submm, millimetre observations. In the current 12-months reporting period (Apr 2016 – Mar 2017) three tasks have been completed, as detailed below.

**D2.1 Herschel tools (Sep 30, 2016):**
In this deliverable we provided the final set of tools and methods for the data reduction of moving target observations performed with the PACS photometer instrument of the Herschel Space Observatory. It includes reduction scripts optimized for moving targets that are fine-tuned depending on the object's brightness, apparent motion, and background structures. We perform corrections for positional uncertainty due to telescope pointing and errors in source coordinates (source- and background matching technique) and produce combined data products with background elimination (differential, sky-subtracted, double-differential images). We provided tools for photometry and for the determination of photometric uncertainties.

**D2.2 NEA HSA upload (Dec 31, 2016):**
In this task we produced a set of high-quality data products for Herschel observations of near-Earth asteroids for an upload to the Herschel Science Archive (HSA). These new products are available for the entire scientific community, in parallel to the standard pipeline-processed

Herschel archive data. We describe the Herschel measurements of near-Earth asteroids (NEA), the processing and calibration steps, and present the final products which were provided to the Herschel Science Center (HSC) for an upload of these products to the HSA as User-Provided Data Products (UPDP, see Figure below). The delivery of products (FITS images) for the HSA came also with a product-specific release note. These UPDP are publicly available from the HSA for all registered users. Near-Earth asteroids (NEA) were only observed in very few dedicated small projects, either as part of a Guaranteed Time Programme (GT1 lorourke) or as part of small Director's Discretionary Time projects (DDT lorourke, DDT thmuelle). The NEA target list comprises: 433 Eros, 99942 Apophis, 101955 Bennu (1999RQ36), 162173 Ryugu (1999JU3), 175706 (1996FG3), and 308635 (2005YU55).

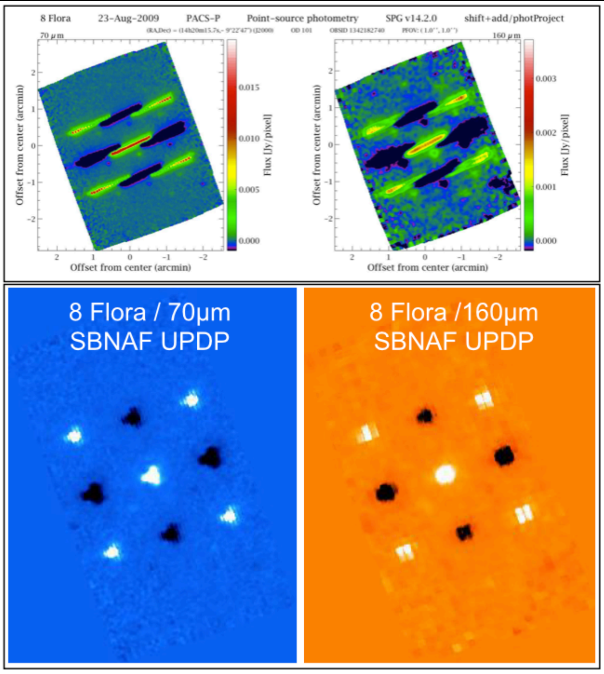
**USER PROVIDED DATA PRODUCTS**

The table below provides access to the currently available User Provided Data Products sorted by release date:

| UPDP Keyword | UPDP Title | Author(s) | Release Note | User Provided Data Products Repository | Related Publications | Latest update | Ingested in HSA ? |
|---|---|---|---|---|---|---|---|
| SBNAF | Herschel/PACS Observations of Near-Earth Asteroids | Kiss et al. | SBNAF Release Note | SBNAF Data<br>SBNAF Postcards | N/A | [07-Mar-2017] | **YES** |

**2.3 MBA HSA upload (Mar 31, 2017):**

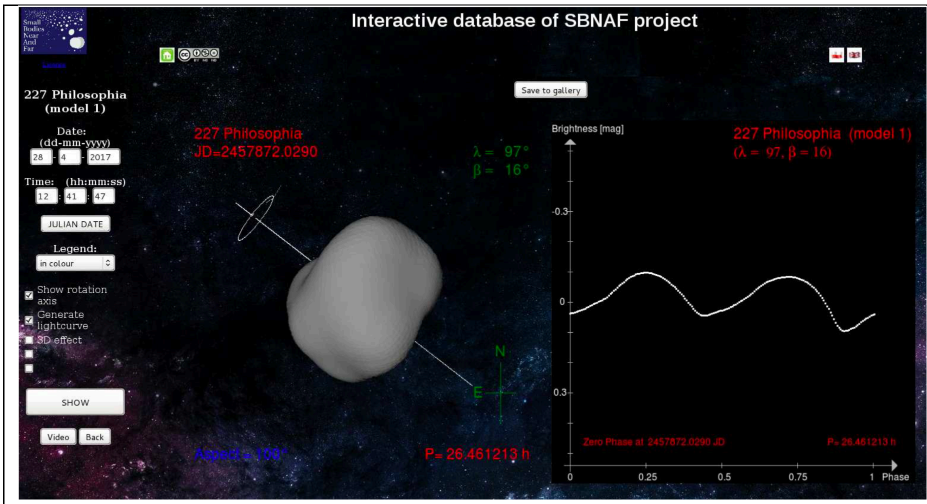
The focus of D2.3 is on Herschel measurements of main-belt asteroids (MBA). Almost all of these measurements are part of the PACS calibration programmes and only very few are related to dedicated science projects. Most of these calibration measurements, as well as all the science measurements, are taken in the standard PacsPhoto observing modes. For SSO-tracked measurements the processing was done in the object's co-moving reference frame. The MBAs are typically bright and even the shortest measurements produce very high signal-to-noise ratios. In general, the default pipeline processing worked out very well and produced reliable products in the HSA. We produced new images only for those cases when the pipeline processing failed, for fainter asteroids, and for specific cases where the pipeline produced suboptimal results. We provided the new MBA images to the Herschel Science Centre (HSC) for an upload to the HSA as User-Provided Data Products (UPDP). The delivery of products (FITS images) for the HSA came also with a product-specific release note. These UPDP are publicly available from the HSA for all registered users. In parallel to D2.3 (and D2.2), we are preparing an A&A catalog paper that will contain all NEA and MBA flux densities derived from the final PacsPhoto images. In this publication we will explain in more details the methods to derive fluxes and error bars, and also discuss quality issues (where applicable), and show the high scientific potential of these measurements. In D2.3 User Provided Data Products have been created for multi-repetition chop-nod measurements of 8 Flora and 18 Melpomene (see below), for the faint main-belt asteroid 2867 Steins and for a set of special measurement when αTau and Vesta were observed in the same field-of-view.




*UPDP for 8 Flora: PacsPhoto chop-nod observations at 70 and 160 micron before (top) and after (bottom) reprocessing (part of D2.3).*

### 1.2.3 Work package 3: Lightcurve inversion techniques

The main task in the work package on lightcurve inversion techniques is to develop and refine asteroid spin and shape modelling techniques, and to join various types of data for model scaling and validation. Another task is to provide the models with their parameters to the community via the ISAM[2] service (Interactive service for asteroid models, see below).




*Example view of the "orientation" mode of the ISAM service. One of our SAGE models is displayed together with the corresponding lightcurve for the given viewing geometry.*

During the project's first year the main works were performed on collecting and quality assessment of lightcurve data, which resulted in a complete survey of all SBNAF targets in terms of their lightcurves, and an additional sub-list of SBNAF targets that require additional data for precise shape modelling ('Targets_needing_lcs' in the targets webpage: http://asteroidstnos.iaa.es). Future observations were planned for these targets, carefully

[2] http://isam.astro.amu.edu.pl

checking what possible viewing geometries could complete the existing datasets in terms of shape reconstruction.
From this list, on a monthly basis, a set of currently visible targets has been updated and observing campaign has been conducted as a part of WP5. Thanks to the Gaia-GOSA service, many advanced amateur observers have joined the project and are providing valuable lightcurve observations for brighter targets. Most of the targets were successfully observed, with full lightcurve coverage and registered phase angle effects. Resulting composite lightcurves can be found at:
http://asteroidstnos.iaa.es/content/results#overlay-context=content/sbnaf.

The GOSA service has been updated to include predicted stellar occultations by asteroids and organising observers around these rare events (**D3.1 GOSA service upload; Sep 30, 2016**).

A special target of opportunity, the near-Earth Asteroid 2015 $TB_{145}$ called "Halloween asteroid", has been observed for lightcurves during its closest approach to Earth in challenging observing conditions, and have been analysed for period using two different approaches, Fourier analysis and $\chi^2$ fitting. The obtained composite lightcurves have been published by Müller et al. (2017) together with radiometric analysis from ESO VLT-VISIR observations, resulting in determinations of size, albedo, together with thermal inertia and roughness values.
In parallel, the works on developing SAGE algorithm (Shaping Asteroids with Genetic Evolution) were running. The set of allowed shape slopes have been restricted, so that the resulting shapes have less artefacts or unrealistic features. The algorithm has been thoroughly tested on a set of simulated shapes that have been successfully inverted, provided that sufficiently rich datasets were fed into it. This way the possibilities and limitations of the technique were assessed. To complement this work, the SAGE code was also tested on two real cases: asteroid 9 Metis and 433 Eros - two of the key SBNAF targets - (Bartczak & Dudziński, submitted). The resulting shapes were validated against Adaptive Optics images and occultation timing measurements, and also with in-situ images from Near-Shoemaker spacecraft, with very good agreement, reaching the Milestone **MS02 Benchmark study (Mar 31, 2017)**. The models were also compared to models from other techniques.

The works to complement SAGE modelling based on lightcurves with other techniques were started by parallel fitting of radar echoes and lightcurves. An independent method for shape reconstruction data based on radar data was also developed, and tested on a simulated shape of comet 67P.

To quantify the level of trustability of SAGE shapes, the method for creating uncertainty maps was developed. Thanks to it one can see which parts of the model surface are reliable, and which might be uncertain due to insufficient coverage with observations, or too low phase angles. In parallel, the visibility maps were created showing the contribution of each surface element in percentage to the whole observing time. This way further observations can be planned in an optimal way.

Some asteroid models obtained with both convex and nonconvex inversion methods have been tested against radiometric data in full thermophysical modelling, with very promising results: in some cases the mirror symmetry of the pole solutions can be broken, and one of the solutions is often strongly preferred (Marciniak et al. in preparation). Also, the preferred solution for the shape model is usual outcome, with the nonconvex inversion models being preferred over convex models, and both of them over spherical shape approximation. Also, thermal inertia values for long-period targets obtained this way occurred to be substantially higher than average in the Main Belt, confirming the findings of Harris & Drube (2016)

In coordination with the WP4, existing models of calibration asteroids have been evaluated and their trustability as reliable calibration sources has been checked (**D3.3 shape and spin solution for secondary calibrators; Mar 31, 2017**). Asteroids with imperfect models have been put to the target list for lightcurve and occultation observations. Predicted stellar occultations by asteroids with the existing spin and shape models have also been investigated, and targets where the occultations can choose between two possible pole solutions have been identified (**D3.2 Prediction of shape orientations; Mar 31, 2017**). As a part of this work ISAM service has been updated, so now it contains all the models available in DAMIT (models for over 900 asteroids).
In order to share among the team working versions of the models, internal version of ISAM service was created (http://150.254.66.39) and an agreed format of files with shapes has been set, with a proposed universal format of their headers.
A script for format transformations was developed (Mesh Format Converter, available at: https://bitbucket.org/snagaburzum/meshformatconverter/downloads with instructions).
We will promote the usage of such standard shape formats in the community.

### 1.2.4 Work package 4: Asteroid-related calibration

One of the specific challenges in COMPET-05-2015 was listed as follows: "The challenge will however be to allow the European astrophysics community to make the best possible use of those missions by supporting space astronomy observation proposals, using archived data, and making comparisons **(including calibrations)** between different missions, instruments, and between space and ground-based data". WP4 addresses this challenge.
Celestial standards play a major role in observational astrophysics. They are needed to characterise the performance of instruments and are paramount for photometric calibration. Infrared space projects like ISO, AKARI, Spitzer or Herschel have observed a set of asteroids for a wide range of calibration aspects, including band characterisation, filter leak test, verification of relative spectral response, observing mode validation, pointing tests, characterisation of the point-spread-function, and for absolute flux calibration reasons. The asteroids bridge nicely the flux and wavelength gap between planets - typically used for calibration purposes at submm/mm wavelengths - and stars at near- and mid-IR wavelengths.
Asteroids are highly variable in brightness due to their rotation (hour-scale variations), changing distances, phase and aspect angles with respect to Sun and Earth/observer (seasonal variations). These changes are predictable, but require a good knowledge of the physical and thermal properties of the object in question. The goal of WP4 is to transfer the space experiences to ground-based submm/mm observatories and to provide a set of 10-20 asteroids as potential calibrators for a wide range of applications.
The WP4 is closely related to "WP2 Infrared data" where we collect the available thermal measurements, to "WP3 Lightcurve inversion technique" where we try to produce the best-possible shape and spin solutions for the objects in question, to "WP5 Ground-based observations" where we try to obtain missing information for the shape & spin determination (if needed) or occultation observations to scale the shape solutions, but also to "WP6 Synergies" where we test our final solutions against ground-truth information or via other techniques, like AO imaging. The publication by Marsset et al. (2017) on the asteroid (6) Hebe illustrates the interplay between the different techniques. In the context of WP4 we are aiming for: (i) producing reliable (coarse) shape and spin properties with very precise zero

points in rotational phase to be able to phase the object's orientation at any given time; (ii) scaling these shape models either by using occultation, AO, in-situ measurements or by applying radiometric techniques to the most reliable IR data points; (iii) finding solid solutions for the thermal properties (thermal inertia, surface roughness, emissivity) for these large MBAs which are very likely covered with low-conductivity, fine-grained regolith.
WP4 includes many tasks which are handled step by step via a sequence of deliverables:

**D4.1 Observation summary table (Apr 30, 2016):**
This deliverable includes a list of potential asteroid calibrators (all large MBA with Herschel-PACS and/or Herschel-SPIRE observations, plus a few auxiliary objects). For these targets we collected shape solutions, spin properties, size, albedo, and thermal properties. These properties were partly used to make asteroid model predictions for the Herschel mission (model solutions are called "model version 1"). For four objects (Ceres, Pallas, Vesta, and Lutetia) there was more information available and we updated those models (documented in Müller et al. 2014, ExA 37, 253: http://arxiv.org/abs/1311.0628). These models have higher accuracy (~5% absolute flux accuracy for the far-IR/submm range) and they were already provided to many calibration teams worldwide, they are called "model version 2".
The "Observation summary table" includes a list of objects, model input parameters (and origin of numbers), available (thermal and auxiliary) observational data, accompanied by quality judgment from light curve inversion analysis. We also listed our main contact points in the calibration teams of major observatories.
D4.1 is available on public SBNAF page under "Results".

**D4.2 Submm/mm model predictions (Jun 30, 2016):**
This deliverable describes our simple model predictions for 20 well-known asteroids (asteroids with numbers 1, 2, 3, 4, 6, 7, 8, 9, 12, 19, 23, 29, 52, 54, 88, 471, 511, 532, 704) for the time period 2010-2020, at wavelengths of 200, 350, 450,850,1300,3000 micron. The potential users are the calibration experts of ALMA, IRAM, LMT, APEX, ATCA, SOFIA, but also Herschel, Spitzer, and AKARI. The model predictions (model version 0) are in principle only meant for calibration planning purposes, but they can also be used for specific direct calibration applications where model flux accuracy is not crucial.
D4.2 is available on public SBNAF page under "Results".

**D4.3 Calibration asteroid model predictions (Sep 30, 2016):**
This deliverable describes two major aspects:

1. A total of 1433 FITS model predictions (version 1 or 2) for all Herschel asteroid observations (530 individual observations taken in the "PacsPhoto" model, 271 in "PacsSpec" mode; 430 in "SpirePhoto" mode, 194 in "SpireSpec" mode; and 8 in "HifiPoint" mode). In total, these Herschel asteroid calibration observations cover about 360 hours of observing time. This was a large delivery to the Herschel Science Center in ESA. It was accompanied by a formal release note (version 2) which was accepted by ESA. These FITS files and the release note were then implemented in the Herschel Science Archive and they are publicly available to the scientific community (since end of 2016).
2. High-quality TPM predictions at 10 reference frequencies between 30 and 1000 GHz, for primary asteroids for the years 2014 to 2020. These model predictions are accurate on a 5% level in absolute flux and they have a time resolution of 1 hour (for Ceres) and 15 min (for Pallas, Vesta, and Lutetia). These model predictions (model version 2) are meant for direct calibration application, especially in cases where high-accuracy

absolute flux levels are required, but they can also be used for planning purposes.

D4.3 is available on public SBNAF page under "Results" together with all models, FITS files, predictions, release notes, etc.

**D4.6 Selection of secondary asteroid calibrators (Mar 31, 2017):**
This deliverable includes a collection of calibration needs and requirements of ongoing and future far-IR, submm, mm projects. It describes our investigations on the potential use as secondary calibrators for many large main-belt asteroids. We have put our focus on the collection of available object information and thermal IR observations (+ detailed overview table with all available thermal data: IRAS, MSX, AKARI, WISE, PACS/SPIRE, ALMA, Planck, ISO, Spitzer, others).
D4.6 is complemented by "D3.3 Shape and spin solutions for secondary calibrators" which has the focus on the required work related to lightcurves and visual observations in general. It is also complemented by "D5.2 High-precision photometry measurement table" which provided the necessary model input for absolute magnitudes and slope parameters.
D4.6 is available on public SBNAF page under "Results".

### 1.2.5 Work package 5: Ground-based observations

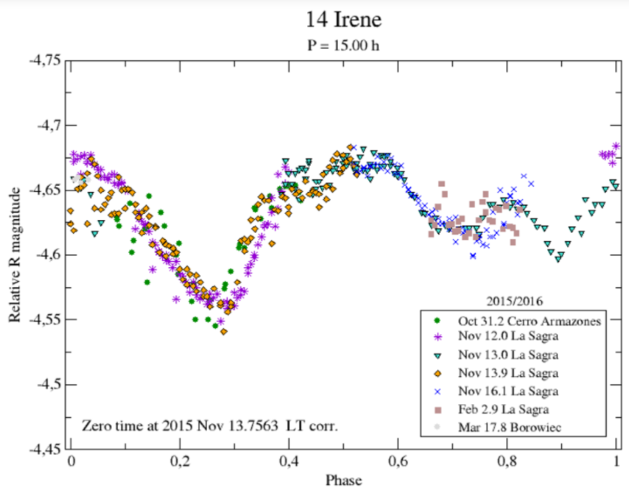
WP5 has the main objective to execute observations from ground-based telescopes with the goal to acquire more data on the targets needed for other work packages. On this particular point the main tasks are to coordinate observations and to produce results on physical properties of near Earth objects (NEOs), Main Belt asteroids (MBAs), Centaurs, and trans-Neptunian objects (TNOs). The main tasks related with the ground based observations performed within WP5 are:

- Astrometric observing campaigns for reliable occultation predictions.
- Refinement of tools and methods for efficient occultation predictions using the last releases of the GAIA stellar catalogue.
- Coordination of world-wide occultation campaigns, preparation and execution of Target of Opportunity (ToO) observing proposals.
- Conduction, analysis, and interpretation of occultation measurements.
- Publication of stellar occultation results of the SBNAF targets from MBAs to TNOs.
- Extraction of existing observations to identify gaps in observational coverage, to plan and conduct additional observations (photometric, lightcurves, stellar occultations, etc).
- Feedback of extracted observations to WP6 for synergy studies, including high angular resolution imaging of MBAs via adaptive optic (AO) observations.
- High-precision photometric measurements as input for WP3, WP4 and WP6.
- Conduction of time series photometry to get rotational information for poorly characterised targets, as requested by WP3.
- Obtaining thermal infrared measurements from the ground (ALMA, IRAM, etc) or airborne-based observatories (like SOFIA) for targets where space infrared data is not available or of poor quality.
- Use existing ALMA observations from calibration programmes to characterise submm/mm properties of reference targets.

The WP5 is in charge of all those observations and we concentrate in the observations of optical lightcurves of the selected SBNAF objects. The observations were done basically using the following telescopes:

- 40cm telescope at La Sagra Observatory in Spain.
- 80cm telescope at La Hita Observatory in Spain.
- 1.5m telescope at Sierra Nevada observatory in Spain.
- 1.5m telescope based at the Bosque Alegre Observatory, in Argentina.
- The 60cm and 1.0m telescopes at Piszkesteto Mountain Station, in Hungary.
- The 40cm telescope at Borowiec Observatory, in Poland.
- The 80cm telescope at the OAdm telescope in Spain.
- The 0.25 BEST and 0.15m VYSOS-6 telescope at Cerro Armazones, in Chile.
- The I64 observatory under the Gaia-Gosa collaboration in UK
- The 40cm Albox Observatory telescope in Spain.
- The 20cm Anunaki observatory, in Spain.

Using some of the above telescopes, we also were able to obtain high accuracy astrometry from images to refine the prediction of the shadow path for a predicted stellar occultation. After one or two observations, the selected occultation was discarded in some cases, as the shadow miss the Earth. For the cases were the shadow were identified to be on a telescope dense region on Earth (Europe, Japan, USA, Argentina, Australia, New Zealand) the prediction was refined and the observers (amateurs and professionals) were alerted. Professional telescope time was asked in the case it was possible (VLT in Chile, Casleo in Argentina, IAC-Canary Island Observatories in Spain) and observations were done.
In the year of the reporting period we observed several positive stellar occultations by MBAs, Centaurs and TNOs and we presented them in international conferences or we published them (or are in the process to publish) in scientific journals.
On the lightcurve observations to obtain rotational properties, we used the above telescopes to obtain more than 500 hours (plus another several hundred hours from the partner institutes in Poznań and Konkoly observatory), on SBNAF target observations. From those lightcurves, the refinements of the rotational period and amplitude were achieved, and the data were included in the shape inversion models (WPs 3 and 6).




*An example of a rotational lightcurve obtained within WP5. The figure presents the combination of observations to obtain the rotational period of 15.00 hrs of (14) Irene. Peak-to-peak amplitude is also derived from the lightcurve. These rotational lightcurves are needed to refine and constrain the shape models obtained by means of lightcurve inversion techniques within WP3, which is also relevant for finding the object's size and possibly also its density (WP6).*

For the specific case of the NEA 2015 TB145, observations were also done at the VLT at mid-infrared wavelengths. Optical lightcurves were acquired during the fly-by of the asteroid as well.

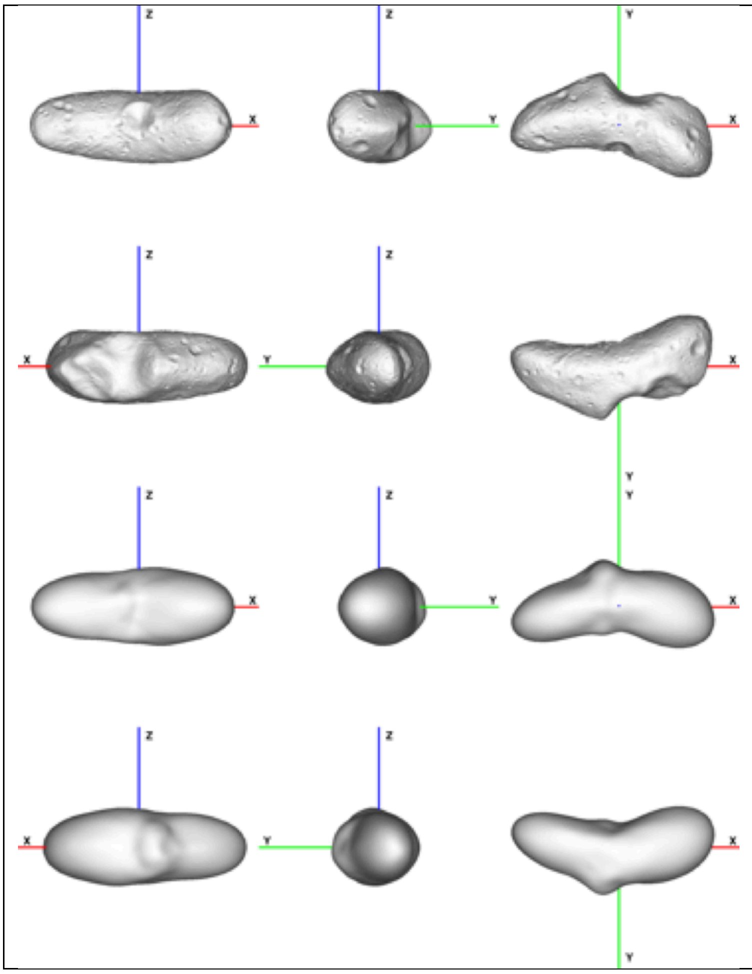
Published papers with data obtained within WP5

- Assessment of different formation scenarios for the ring system of (10199) Chariklo, Melita et al. 2017, A&A, accepted Feb 8, 2017.
- "TNOs are Cool": A Survey of the Transneptunian Region. XII. Thermal light curves of Haumea, 2003 VS2 and 2003 AZ84 with Herschel Space Observatory-PACS, by Santos-Sanz et al., A&A, accepted Apr 19, 2017.
- Physical properties of centaur (54598) Bienor from photometry, by Fernandez-Valenzuela et al. 2017, MNRAS 466, 4147.
- Results from a triple chord stellar occultation and far-infrared photometry of the trans-Neptunian object (229762) 2007 UK126, by Schindler et al. 2017, A&A 600, A12.
- Results from the 2014 November 15th multi-chord stellar occultation by the TNO (229762) 2007 UK126, by Benedetti-Rossi et al. 2016, AJ 152, 156.
- 2008 OG19: a highly elongated Trans-Neptunian object, by Fernandez-Valenzuela et al. 2016, MNRAS 456, 2354.
- Hayabusa-2 Mission Target Asteroid 162173 Ryugu (1999 JU3): Searching for the Object's Spin-Axis Orientation, by Müller et al. 2017, A&A 599, A103
- Large Halloween asteroid at lunar distance. Müller et al. 2017, A&A 598, A63.
- Small Bodies: Near and Far (SBNAF), by Müller et al. 2016, COSPAR 2016, B0.4-72-16 (ADS)
- The long-wavelength thermal emission of the Pluto-Charon system from Herschel observations. Evidence for emissivity effects, Lellouch et al. 2016, A&A 588,2L (ADS & arXiv:1601.05606)
- Small Bodies Near and Far (SBNAF): a benchmark study on physical and thermal properties of small bodies in the Solar System, Müller et al. 2017, Advances in Space Research, submitted Feb 22, 2017
- Discovery of a satellite of the large trans-Neptunian object (225088) 2007 OR10, by Kiss et al. 2017, ApJL 838, L1 (ADS & arXiv:1703.01407 & DOI: 10.3847/2041-8213/aa6484)

### 1.2.6 Work package 6: Synergies from ground and space

The main goal of this work package (WP) is to make scientific exploitation of the different techniques and tools used and developed in the other work packages in combination. To that end, it is required to benchmark the different approaches against ground truth information and to inter-compare the techniques that provide complementary information in order to identify their strengths and weaknesses and define strategies to combine them to overcome their limitations. In this sense, it is also crucial to appropriately quantify errors, which is especially complicated in the case of three-dimensional shape models.

The objectives of the first four deliverables (D6.1-D6.4) thus constitute initial steps towards the gathering of relevant information and model input (such as shape models of targets with ground truth observations) and setting up a common repository and framework for all SBNAF members, who come from different backgrounds and fields of expertise following different conventions. The works carried out in the context of deliverable D6.5 are more focused on the comparison of shape models against ground truth pertinent to the milestone M02, but also to subsequent phases of the project. In particular, deliverables D6.6 and D6.7, due in within the time frame for the second period report (moths 18 and 24, respectively), are focused on the use of thermal tools to reject ambiguous shape/spin solutions and on the establishment of a system to assess shape/spin models' quality.



*Views of the NEAR-based 3-D shape of (433) Eros and the model based on SAGE (Bartczak & Dudziński, submitted to MNRAS).*

**D6.1 Occultation vs. thermal tools (Jan 31, 2017)** was conceived to identify synergies between stellar-occultation and thermal-infrared data towards the reconstruction of three-dimensional properties of bodies (shape, spin orientation, rotation period, and accurate volume). Different works and approaches are scattered across the literature but no common guidelines have been defined. In D6.1, we provide a table to show how some key strengths and weakness of stellar occultation versus thermal data and thermal tools are complementary to each other. This will be a helpful reference when analysing these types of data in combination as we collect them. We also distinguished four sets or categories related to different degrees of available information for main belt asteroids (either 3-D shapes are already available or not) and trans-Neptunian objects (either the rotational period is known or not) and what kind of scientific exploitation can be expected in such circumstances.

We collected the three-dimensional shape, spin pole orientation and rotation period of the four primary calibrators Ceres, Pallas, Vesta, and Lutetia for **D6.2 Shape and spin solutions for primary calibrators (Nov 30, 2016)**. This ground-truth information is important for WP4 (flux predictions for mm and sub-mm missions) and for benchmarking and scientific exploitation purposes. With this goal in mind, we also included a small discussion about some scientifically relevant physical properties of each one of these targets, three of which have been visited by spacecraft.

**D6.3 In-situ object properties (Dec 31, 2016)** compiles all physical and thermal properties relevant for modelling and carrying out scientific studies of a selection of objects visited by spacecraft. We selected main belt asteroids Ceres, Vesta, Lutetia, and Gaspra, and near-Earth asteroids (NEA) Eros and Itokawa. Table 1 constitutes a great resource for the most up-to-date relevant information as well as an invaluable set of references selected from the vast literature produced based on space missions. We have not included all objects visited by spacecraft because not all of them have available ground-truth information as complete as our current selection to offer great benchmark and/or scientific prospects. This list is nonetheless still open, since the partial coverage of other interesting targets (e.g. Ida) may be complemented during our project if compelling windows of observation are found or additional data may be made available (two on-going mission targets, NEAs Bennu and Ryugu, will be reached before the end of our project).

**D6.4 Gaia asteroid list (Jan 31, 2017)** defines and compiles the state of the art of the so-called "Gaia perturbers" (GP), a set of large main belt asteroids for which it will be possible to infer masses based on the unprecedentedly accurate Gaia astrometry (the values will be published in 2020). It will be thus important to determine the shape and size of these GPs reliably, since these will lead to bulk density values. These, in turn, would provide crucial information on these bodies' internal structures and porosities. We created a table containing information about already existing models (which were assigned a quality code defined in the deliverable), catalogued photometric observations, and availability of thermal data from space. This helps to define strategies towards enhancing our knowledge of these bodies, based on which we have prepared a short list of targets (24 asteroids) to be included in our SBNAF observation campaign, with the aim of deriving a high-quality model using the SAGE technique. Next, we aim to calibrate (in size) the models obtained by means of direct measurements (stellar occultations, adaptive optics) and thermal models.

**D6.5 Ground-truth shape models (Mar 31, 2017)** contains several elements. We briefly introduce the context for the work carried out by Bartczak & Dudziński (submitted), which provides a comparative study of non-convex models derived from light-curve inversion using the SAGE algorithm and ground truth-based models of asteroids Eros and Metis (see Figure above). They propose quantitative strategies to assess 3-D shape uncertainties, also based on the light-curve inversion results of synthetic shape models (more details in the summary of WP3). This directly addresses the goals defined in the milestone MS2 and constitute a key step towards a quality system for shape models (MS8, due date March 2018).

With this continuing goal in mind, we also compiled shape-related information of targets coming from ground-truth observations, such as spacecraft targets and stellar occultation. Despite the fact that it involves some modelling, we decided to consider adaptive optics (AO) observations and shape models as ground truth because of their increasing availability, which can contribute to the benchmarking and shape, spin, and period quality assessment goals of WP6. We also enumerated in D6.5 several other works submitted or close to submission that are directed towards some of the goals mentioned above.

Apart from the addition of AO information to the scope of this WP, it is worth mentioning the work on retrieving Kepler-K2 data, especially helpful in the modelling of very long-period bodies because it spans timescales of days and provides uninterrupted light curve coverage (which is impossible from the ground due to the limited duration of the night). Moreover, ALMA data from the science demonstration and calibration programmes are available for a few main belt asteroids, and will be available for trans-Neptunian objects thanks to the participation of members of SBNAF (or collaborators) in on-going scientific programmes. Finally, we have devoted work on the modelling of radar data (a poster discussing a novel approach was presented at the ACM2017 in Montevideo, Uruguay; Dudziński et al.), as it may be an especially valuable additional source of information for near-Earth asteroids, for which stellar occultations are not amenable.

### 1.3 Impact

*Include in this section whether the information on section 2.1 of the DoA (how your project will contribute to the expected impacts) is still relevant or needs to be updated. Include further details in the latter case.*

In our initial project description we identified ten areas where we expected impacts by SBNAF-related work. Scientific output, tools and services expected for the reporting period have been delivered, such as studies in support for on-going planetary mission targets (Ryugu and Bennu), Herschel expert-reduced data products, calibration-related flux predictions for Herschel, ALMA, SOFIA, APEX, etc., production of new shape and spin solutions for MBAs, procedures to test, validate and scale shape solutions or more accurate stellar occultation predictions (phasing in Gaia results) and successful occultation observations. These actions have been collected in the deliverables summarised in this document and/or in a large list of publications in scientific journals, which is the major medium through which scientific impact is materialised.

On basis of our target sample we identified open points and a range of specific scientific questions which we want to address in the SBNAF project (Table 1.1 in the SBNAF proposal). Some of these questions are already discussed, and partly answered, in the SBNAF-related publications. In the context of the near-Earth asteroids (NEAs) we published the following articles:

- 02/2017: Spectral and rotational properties of near-Earth asteroid (162173) Ryugu, target of the Hayabusa2 sample return mission, Perna et al.
- 02/2017: Large Halloween Asteroid at Lunar Distance, Müller et al.
- 03/2017: Hayabusa-2 Mission Target Asteroid 162173 Ryugu (1999 $JU_3$): Searching for the Object's Spin-Axis Orientation, Müller et al.
- 02/2017 (accepted): Sizes and albedos of Mars-crossing asteroids from WISE/NEOWISE data, Alí-Lagoa et al.
- 2016: In-space utilisation of asteroids (ASIME 2016 White Paper), Graps et al.
- Statistical analysis of the ambiguities in the asteroid period determinations, Butkiewicz-Bąk et al., (MNRAS submitted Mar 2017)
- Shaping Asteroids with Genetic Evolution (SAGE), Bartczak & Dudziński; (MNRAS submitted May 2017).

In the context of MBAs (and Trojans) we published the following articles:

- 11/2016: Uninterrupted optical light curves of main-belt asteroids from the K2 Mission, Szabó et al.
- 00/2017: Shape Models and Physical Properties of Asteroids (Assessment and Mitigation of Asteroid Impact Hazards, Astrophysics and Space Science Proceedings, Volume 46), Santana-Ros, et al.
- 02/2017: The heart of the swarm: K2 photometry and rotational characteristics of 56 Jovian Trojan asteroids, Szabó et al.
- Asteroid shapes and thermal properties from combined optical and mid-infrared photometry inversion, Ďurech et al., (A&A submitted in April 2017)
- 3-D shape of asteroid (6) Hebe from VLT/SPHERE imaging: Implications for the origin of ordinary H chondrites, Marsset et al., (A&A submitted in April 2017)

- Thermal Infrared and Optical Photometry of Asteroidal Comet C/2002 CE10, by Sekiguchi et al., (Icarus, submitted Feb 2017)

In the context of TNOs we published the following articles:

- 01/2016: James Webb Space Telescope Observations of Stellar Occultations by Solar System Bodies and Rings, Santos-Sanz et al.
- 03/2016: 2008 OG19: a highly elongated Trans-Neptunian object, Fernández-Valenzuela et al.
- 04/2016: Nereid from space: rotation, size and shape analysis from K2, Herschel and Spitzer observations, Kiss et al.
- 05/2016: Large Size and Slow Rotation of the Trans-Neptunian Object (225088) 2007 OR10 Discovered from Herschel and K2 Observations, Pál et al.
- 12/2016: Results from the 2014 November 15th multi-chord stellar occultation by the TNO (229762) 2007 UK126, Benedetti-Rossi et al.
- 03/2017: Results from a triple chord stellar occultation and far-infrared photometry of the trans-Neptunian object (229762) 2007 UK126, Schindler et al.
- 03/2017: Discovery of a satellite of the large trans-Neptunian object (225088) 2007 $OR_{10}$, Kiss et al.
- 04/2017: Physical properties of centaur (54598) Bienor from photometry, Fernández-Valenzuela et al.
- 02/2017 (accepted): Assessment of different formation scenarios for the ring system of (10199) Chariklo, Melita et al.
- 04/2017 (accepted): "TNOs are Cool": A Survey of the Transneptunian Region. XII. Thermal light curves of Haumea, 2003 $VS_2$ and 2003 $AZ_{84}$ with Herschel Space Observatory-PACS, by Santos-Sanz et al.
- "TNOs are Cool": A survey of the trans-Neptunian region. XIII. Characterization of multiple trans-Neptunian objects observed with Herschel Space Observatory, by Kovalenko et al., (submitted to A&A, Feb 2017)

The first-year public deliverables and publications contribute substantially to the expected impacts. In addition, some of the NEA publications will also be relevant for projects like NEOShield-2 and for small-body exploitation and mining projects. The JWST-related work started recently and it will be one of the focus projects for the second year.

New elements in the SBNAF project were (i) the phasing in of Kepler-K2 lightcurve observations of MBAs, Trojans, Centaurs, and TNOs; and (ii) the collaboration with AO imaging experts for the characterization of MBAs. Both aspects will have significant impact in the field of small-body and TNO research.

## 2. Update of the plan for exploitation and dissemination of result (if applicable)

*Include in this section whether the plan for exploitation and dissemination of results as described in the DoA needs to be updated and give details.*

No update of the original plan is needed.

The SBNAF team is very active in producing outreach material (youtube videos, posters, 3-D asteroid shape models, flyers, articles in public/amateur astronomy journals, etc.). The various topics on small bodies are presented in many public events, like the “Asteroid Day” (every year on June 30), the Marie Skłodowska-Curie action “European Researchers Night

(NIGHT)" (every year on the last Friday in September), public open-door institute days, public talks in the context of astronomical events like the Perseid Meteor shower or eclipses, or in public lectures/seminars either given at the institute premises, scientific fairs, schools, or in public places like town halls or shopping malls. Some of our technical and scientific work was also used for press releases and public articles, with the highest-impact topic being related to the very large size of the trans-Neptunian object "2007 OR10" and the discovery of a moon.

The SBNAF outreach material and also the press releases are presented in English and available worldwide from our public web page. The SBNAF public talks and articles are usually presented in one of the four SBNAF languages (Polish, Spanish, Hungarian or German) and reach the local and regional population.

In the small-body research community there is the tradition that the International Astronomical Union (IAU) names asteroids (based on recommendations from peers) after scientists working in the field of small-bodies research. Recently, during an official ceremony of the important "Asteroids, Comets, Meteors 2017" conference in Montevideo/Uruguay, four SBNAF team members were honored with the asteroid names "(10470) Bartczak", "(10471) Marciniak", "(10472) Santana-Ros", and "(10678) Alilagoa". The corresponding press release was picked up my many newspapers and journals.

| | |
|---|---|
| | *QR code for our public web page* |

The SBNAF project is meanwhile very well visible from Google searches: We tested "SBNAF" searches from different places in Europe and typically 9 out of the 10 first Google hits are related to our project.

## 3. Update of the data management plan (if applicable)

*Include in this section whether the data management plan as described in the DoA needs to be updated and give details.*

Not applicable. We did not participate in the pilot project on "Open Research Data in Horizon 2020" and therefore no "Data Management Plan" was required.

## 4. Follow-up of recommendations and comments from previous review(s) (if applicable)

*Include in this section the list of recommendations and comments from previous reviews and give information on how they have been followed up.*

Not applicable.

## 5. Deviations from Annex 1 and Annex 2 (if applicable)

*Explain the reasons for deviations from the DoA, the consequences and the proposed corrective actions.*

### 5.1 Tasks

*Include explanations for tasks not fully implemented, critical objectives not fully achieved and/or not being on schedule. Explain also the impact on other tasks on the available resources and the planning.*

Currently, we do not see any significant changes for the tasks described in the six different work packages.

### 5.2 Use of resources

*Include explanations on deviations of the use of resources between actual and planned use of resources in Annex 1, especially related to person-months per work package.*

*Include explanations on transfer of costs categories (if applicable).*

Not applicable. The funding distribution between the four beneficiaries does not require any changes right now. However, small changes with respect to the original plan occurred:

1. MPG/MPE: no changes required
2. MTA CSFK/Konkoly observatory: there is a small discrepancy between the planned budget and the spent money for the first year. About 10k€ have been spent less on salaries (employing lower-cost employees than foreseen to replace one person on maternity leave), but more money was spent on travelling. Overall, the workload (and the related deliverables) for the first project year required more manpower and travel costs, but this will be compensated by spending less in the second and third year. The extra cost in equipment is due to the fact that the VAT (for computers) was originally planned as extra cost.
3. CSIC/IAA/Granada: The travel budget for the first year was exceeded, but this will be compensated by travelling less in the second and third year.
4. UAM/Poznań: The purchase of the computer cluster was delayed due to administrative reasons by almost one year.

#### 5.2.1 Unforeseen subcontracting (if applicable)

*Specify in this section:*

*a) the work (the tasks) performed by a subcontractor which may cover only a limited part of the project;*
*b) explanation of the circumstances which caused the need for a subcontract, taking into account the specific characteristics of the project;*

c) *the confirmation that the subcontractor has been selected ensuring the best value for money or, if appropriate, the lowest price and avoiding any conflict of interests.*

Not applicable. No subcontracting was done in the first year. It is also not foreseen to do subcontracting in the following years.

### 5.2.2 Unforeseen use of in kind contribution from third party against payment or free of charges (if applicable)

*Specify in this section:*

d) *the identity of the third party;*
e) *the resources made available by the third party respectively against payment or free of charges*
f) *explanation of the circumstances which caused the need for using these resources for carrying out the work.*

Not applicable. No paid in-kind contributions from third parties was needed in the first year. In kind contributions are also not foreseen in the following years.

| HISTORY OF CHANGES | | |
|---|---|---|
| VERSION | PUBLICATION DATE | CHANGE |
| 1.0 | 15.07.2015 | Initial version |
| 1.1 | 08.08.2016 | Corrections for MSCA. |