Deliverable

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

Topic: COMPET-05-2015 - Scientific exploitation of astrophysics, comets, and planetary data
Project Title: Small Bodies Near and Far (SBNAF)
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WP	**WP4 Asteroid-related calibration**
Del.No	**D4.3**
Title	**Calibration asteroid model predictions**
Lead Beneficiary	MPG
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WP4 Asteroid-related calibration
Objectives: To transport the space-based (Herschel, Planck, Akari) calibration to ground-based and airborne infrared, submm, and millimetre projects with a high demand for asteroids as calibrators.

Description of deliverable D4.3
High-quality model predictions (version 1) for primary calibration asteroids with ground-truth information from interplanetary missions placed on web.

Description of deliverable

I. Introduction

The context for using asteroids as far-IR/submm/mm calibration purposes was presented and discussed in D4.1 and D4.2. Here, we focus on high-quality model prediction of asteroid fluxes (at far-IR/submm/mm wavelengths) for **direct calibration purposes**. These flux predictions (called asteroid **model version 2**) are based on sophisticated models for selected asteroids, and including daily and seasonal variations due to rotation, changing Sun-observer-target distances, phase and aspect angles. Predictions were done for four asteroids (1 Ceres, 2 Pallas, 4 Vesta, and 21 Lutetia), for the time period 2014 to 2020 (also to be used for past ALMA/SOFIA/IRAM/etc. calibation observations). In addition, this deliverable D4.3 includes also specific TPM calculations (FITS files with model SEDs) for all Herschel PACS and SPIRE photometric observations of the asteroids 1 Ceres, 2 Pallas, 4 Vesta, and 21 Lutetia (calibration and science observations; one model FITS file for each OBSID) for direct upload to the Herschel Science Archive. These Herschel model requests include the detailed model and observing parameters, as well as the observation-specific parameters (OD, OBSID, instrument and observing mode) as FITS header keywords. Predictions for more asteroids (also model versions 1 and higher) for direct calibration applications are part of upcoming deliverables and connected to the on-going work (and deliverables) in WP2, WP3, WP4, WP5, and WP6 of the SBNAF project.

II. List of asteroids as new prime calibrators

Müller et al. (2014) presented newly established models for the four large and well characterized main-belt asteroids (1) Ceres, (2) Pallas, (4) Vesta, and (21) Lutetia which can be considered as new prime flux calibrators. The relevant object-specific properties (size, shape, spin-properties, albedo, thermal properties) are well established. The seasonal (distance to Sun, distance to observer, phase angle, aspect angle) and daily variations (rotation) are included in a new thermophysical model setup for these targets. The thermophysical model predictions agree within 5 % with the available (and independently calibrated) Herschel measurements. The four objects cover the flux regime from just below 1,000 Jy (Ceres at mid-IR N-/Q-band) down to fluxes below 0.1Jy (Lutetia at the longest wavelengths). Based on the comparison with Herschel-PACS, SPIRE and HIFI measurements and pre-Herschel experience, the validity of these new prime calibrators ranges from mid-infrared to about 700 μm, connecting nicely the absolute stellar reference system in the mid-IR with the planet-based calibration at sub-mm/mm wavelengths.

Model details are given in Müller et al. 2014.

III. Thermophysical model predictions for calibration purposes

Based on the model solutions given in Müller et al. (2014), we calculated TPM predictions for the time period 2014 to 2020 with high time resolution (1 hour or 15 min, depending on the expected rotational flux changes) for direct calibration purposes. These predictions contain the following information:

- predictions at [micron]: 9993.1, 3747.4, 2606.9, 1998.6, 1499.0, 1303.4, 1153.0, 999.3, 908.5, 832.8, 705.4, 461.2, 374.7, 315.6, 299.8
- corresponding to [GHz]: 30.0, 80.0, 115.0, 150.0, 200.0, 230.0, 260.0, 300.0, 330.0, 360.0, 425.0, 650.0, 800.0, 950.0, 1000.0
- times are given in YYYY MM DD HH MM and reduced Julian Date, with time resolutions of 1 h (Ceres) or 15 min (Pallas, Vesta, Lutetia); times are in the observer's reference system (here: geocentric)
- flux densities are given at the above specified reference frequencies and wavelengths; units: Jy

On special request from the Herschel Science Team, we also prepared flux predictions for these 4 asteroids for the Herschel-specific observing times at PACS & SPIRE photometer reference wavelengths of 70.0, 100.0, 160.0, 250.0, 350.0, and 500.0 micron in two tables, one for PacsPhoto and one for SpirePhoto observations.

For all Herschel PACS & SPIRE photometric and spectroscopic measurements (of these 4 asteroids), we also provided full TPM SEDs covering the entire PACS & SPIRE wavelength range, one TPM FITS file per observation ID (OBSID). These products will be included in the Herschel Science Archive in the near future, connected to the corresponding archive OBSID entries. The FITS files contain also information about the specific object properties and observing geometries in the FITS header, together with the corresponding OBSID, OD, instrument and observing mode.

All calibration products are available on the SBNAF web pages with access for calibration experts from various teams.

IV. Calibration teams & projects: contact points

The following projects and teams have strong interest in the WP4-related work of our SBNAF project:

- Prof. Dr. Takashi Onaka, P.I. of the Infrared Camera onboard **AKARI**, The University of Tokyo
- Dr. Francisco Montenegro, Head of Sciops Group at **APEX** (ESO), Vitacura, Santiago, Chile
- Drs. J. Boissier, M. Krips, R. Neri (**IRAM-NOEMA**); Drs. C. Kramer, S. Leclerc, H. Ungerechts (**IRAM-30m telescope**), Institut de Radioastronomie Millimétrique, Domaine Universitaire de Grenoble, Saint Martin d'Hères, France

- Dr. Erick Young, Director, **SOFIA** Science Mission Operations, SOFIA Science Center, NASA Ames Research Center, Moffett Field CA, USA
- Dr. Anthony Marston, **Herschel** Instrument and Calibration Scientist Team Lead and Chair of the Herschel Calibration Steering Group, Herschel Science Centre, ESAC, Villanueva de la Cañada, Spain
- Dr. Pierre Cox, Director **ALMA** observatory, & Dr. Rüdiger Kneissl, Calibration contact point, Atacama Large Millimeter/submillimeter Array, Llano de Chajnantor, Atacama desert, Chile.

In the calibration context the following contact points have been established:

SOFIA:
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- Carsten Kramer, kramer@iram.es
- Michael Bremer, bremer@iram.fr

Herschel:
- Anthony Marston, tmarston@sciops.esa.int
- Tanya Lim, tlim@sciops.esa.int
- David Teyssier, dteyssier@sciops.esa.int --> new contact point for HSA upload of FITS model prediction
- Glenn Orton, Glenn.S.Orton@jpl.nasa.gov
- Raphael Moreno, raphael.moreno@obspm.fr
- Michael Olberg, michael.olberg@chalmers.se

LMT:
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AKARI:
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- Fumihiko Usui, usui@cps-jp.org

V. Important reference articles in this context

- **Müller et al. (2014), Exp. Astron, 37, 253: Herschel celestial calibration sources. Four large main-belt asteroids as prime flux calibrators for the far-IR/sub-mm range**

- Müller & Lagerros (1998), A&A, 338, 340: Asteroids as far-infrared photometric standards for ISOPHOT
- Müller & Lagerros (2002), A&A, 381, 324: Asteroids as calibration standards in the thermal infrared for space observatories
- Müller et al. (2005), ESA SP-577, 471: The Asteroid Preparatory Programme for HERSCHEL, ASTRO-F & ALMA
- Müller et al. (2016), A&A 588, A109: Far-infrared photometric observations of the outer planets and satellites with Herschel-PACS
- Harris (1998), Icarus 131, 291-301: A Thermal Model for Near-Earth Asteroids
- Lebofsky et al. (1986), Icarus 68, 239-251: A refined 'standard' thermal model for asteroids based on observations of 1 Ceres and 2 Pallas
- Bowell et al. (1989 in R.P. Binzel, T. Gehrels and M.S. Matthews (eds.), Asteroids II, pp 524-556, The University of Arizona Press: Application of photometric models to asteroids
- Kiss et al. (2005), A&A 430, 343-353: Determination of confusion noise for far-infrared measurements