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DOCUMENT

Release notes: Herschel Planetary Calibrator Models

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Reference	**HERSCHEL-HSC-DOC-2125**
Issue	**1**
Revision	**0**
Date of Issue	**17 January 2017**
Status	**For release**
Document Type	**Release note**
Distribution	**HSC, SAT**

European Space Agency
Agence spatiale européenne

APPROVAL

Title Release notes: Herschel Planetary Calibrator Models	
Issue 1	Revision 0
Authors D. Teyssier, Anthony Marston	Date 17 January 2017
Approved by: P. Garcia-Lario	Date

CHANGE LOG

Reason for change	Draft Issue	Revision	Date
First version of document	1	0	17 January 2017

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1 INTRODUCTION

This release note provides a short description of the planet models for Mars, Uranus and Neptune, which were used as prime calibrators during the Herschel mission. In all three cases, the models are available for the particular dates applicable to dedicated Herschel observations of those planets. On top of that, for Neptune and Uranus, various versions the calibration models used in the Herschel mission are made available as Ancillary Data Products from the Herschel Science Archive. In the case of Mars, the model is also available via an on-line tool outside of ESA.

The following note is expanded on in the calibration model website[1] where model flux values for particular observing days when the calibrators were measured are directly available, together with additional detailed information on inter-comparisons between planet models and their consistency with stellar models (used as prime calibrators for the shorter PACS wavelengths). All files provided in the framework of this Ancillary Data Product can also be fetched from the Herschel long-term repository area at http://archives.esac.esa.int/hsa/legacy/ADP/PlanetaryModels/.

2 MODEL OVERVIEW

2.1 Mars

This was the main model used for HIFI calibration. It was used to measure and model the beam of HIFI also (see Jellema 2015, Ph.D. thesis, U. Groningen, The Netherlands).

Data used for calibrating the HIFI beams that included predicted Rayleigh-Jeans temperature maps for the Mars observations are included at the following link:

http://archives.esac.esa.int/hsa/legacy/ADP/PlanetaryModels/Mars/HIFI_Mars_Maps.zip

Details about the concerned observations and applicable model parameters are given here:

http://archives.esac.esa.int/hsa/legacy/ADP/PlanetaryModels/Mars/HIFI_Mars_Maps_Summary.xlsx

Flux calibration is based on the on-line model of Lellouch & Moreno and originally presented for use with Herschel in February 2008. **Note that distances used in the model are**

[1] http://www.cosmos.esa.int/web/herschel/calibrator-models

distances from Earth – adjustment would need to be made for Herschel-Mars distances as compared to Earth-Mars distances.

The approximate error on the fluxes for the final model is ~5% absolute (peak-to-peak)**.** The model is available as an on-line tool at.

- http://www.lesia.obspm.fr/perso/emmanuel-lellouch/mars/

A description of the model is provided here

- http://www.lesia.obspm.fr/perso/emmanuel-lellouch/mars/description.html

The archive provided as Ancillary Data Products contains models constructed for Herschel observations of the dates of particular observations made by the Herschel science instruments.

2.2 Uranus

Uranus was the main planet model used for the calibration of the SPIRE spectrometer (FTS), since Neptune was too faint (see below). Several versions of the model were made over the lifetime of the mission as feedback from Herschel observing and cross-comparisons enabled more precise information to be included in the atmospheric model**.** Uranus models are based on the Uranus atmosphere modeling and based on fluxes from various missions including flyby missions. The ultimate model used by the SPIRE spectrometer team was labelled ESA4 and produced by Glenn Orton (JPL).

- ESA2: Uranus model at launch. No feedback from Herschel observations (bootstrapping) possible before this date (Moreno).
- ESA3: Unused.
- ESA4: Includes Spitzer data for constraining the continuum, but no lines (Orton; also see **Orton et al, 2014, Icarus 243, 471**)
- A model labelled ESA5 was later prepared as a revision of the ESA4 model to account for spillover radiance outside the Spitzer IRS slit. Note however that this model poorly fitted the PACS range and was therefore not used for the PACS calibration (see also **Mueller et al. 2016**, **A&A 588, A109**). As such the Herschel Calibration Group did not officially endorse it. Please get in touch directly with Glenn Orton (Glenn.S.Orton@jpl.nasa.gov) in case you want to get access to this model.

The approximate error on the fluxes for the final model is ~5% absolute (peak-to-peak)**.**

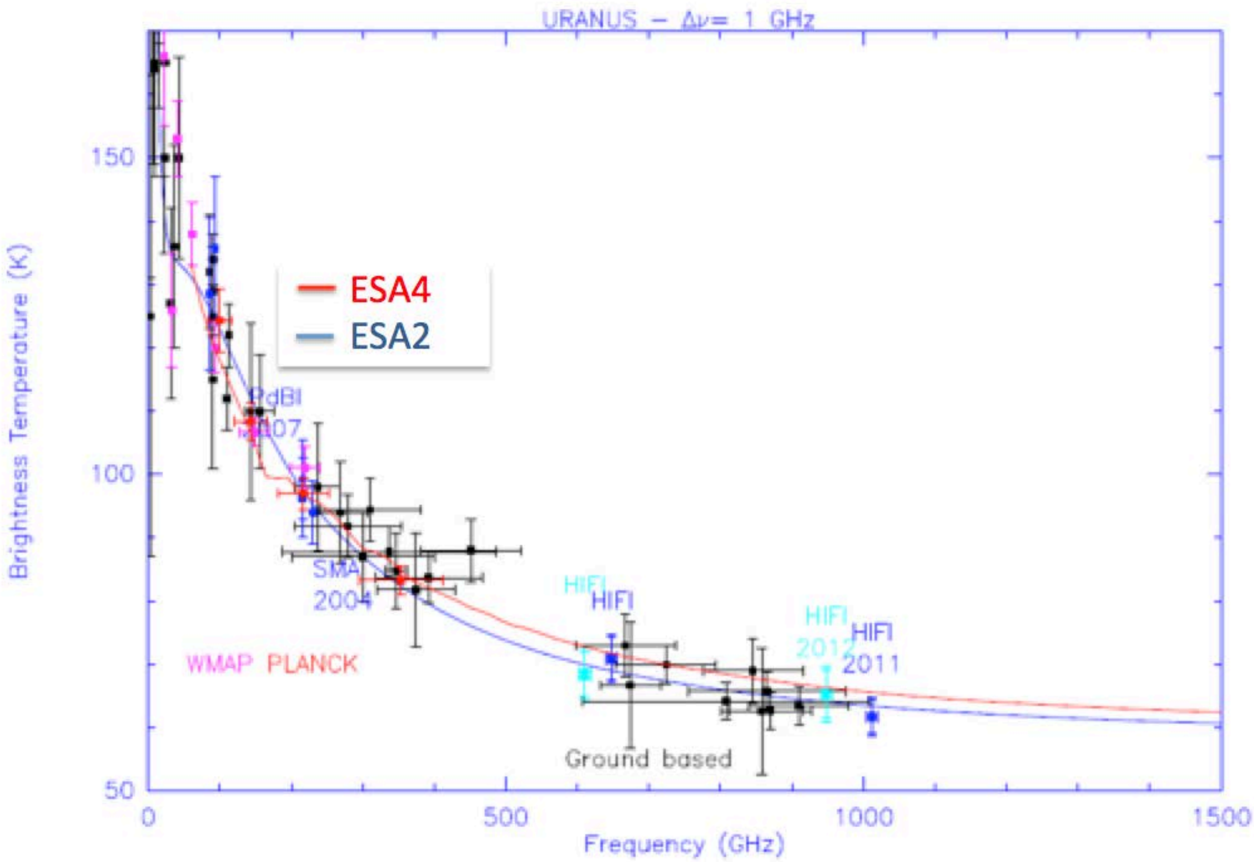

Figure 1: Uranus ESA2 and ESA4 models with various space-based and ground-based measurements shown for comparison. Two sets of near contemporaneous Uranus-Mars measurements by HIFI in 2011 and 2012 are also shown. Planck measurements were made contemporaneous to Herschel planet measurements for PACS and SPIRE throughout the mission overlap periods of Herschel and Planck.

Later model information was compared to Planck (a simultaneous mission with Herschel) and WMAP results. Quasi-Contemporaneous Uranus and Mars measurements by HIFI allowed for an accurate comparison to the Mars calibrator used by HIFI, which show consistency well within the error bars (~2%).

FITS tables of the models are provided in the following link, together with specific information per calibration obsid for PACS and SPIRE and SPIRE-P in-band fluxes per obsid/date:

http://archives.esac.esa.int/hsa/legacy/ADP/PlanetaryModels/Uranus/Obsid_specific_models/

Values provided in the models assume an effective diameter of 3.5 arcsec as seen from Earth, assuming a distance of 2.977792 x 109 km and a radius for Uranus at 1 bar of 25264.3 km.

Since the flux depends on (radius/distance)^2, assuming the radius is constant then fluxes observed will depend on the Herschel - Uranus distance, d_{HU}, at the time of the observation.

- Flux = $(2.977792 \times 10^9/d_{HU})^2$. model flux
- or, Flux = (diameter (in ")/3."5)^2 .model flux
- The diameter of Uranus during the mission is available here. The first column is the operational day number, followed by the year, month, day and apparent sizes of Uranus and Neptune.
- The apparent, Herschel-centric sizes of the planets can also be obtained for any time/day from **JPL Horizons (http://ssd.jpl.nasa.gov/horizons.cgi): using the Herschel Space Observatory [500@-486] as the viewing point from within the solar system.**

In all cases, the format of the model files is FITS tables, with four columns in each of them:

- Frequency -- with name "Wave"
- Brightness temperature, T_b -- with name "T_b"
- Rayleigh-Jeans temperature, T_{rj} -- with name "T_rj"
- Flux in Janskys -- with name "Flux"

Figure 1 shows a comparison between ESA2 and ESA4 models (effectively beginning and end of mission models) which illustrate the fact that the models show ~+2% increase in model flux at PACS wavelengths and up to ~+4% increase in flux in the SPIRE/HIFI range going from ESA2 to ESA4.

2.3 Neptune

Nepture was the main model used in the SPIRE photometer. It was also checked and used for the HIFI calibration (see cross-calibration section below). The initial atmospheric model was gradually updated as Herschel data (predominantly spectroscopic lines) pin down more precise atmospheric conditions over the course of the mission. The final model used by SPIRE was ESA4. ESA5 is a slightly better fit but fluxes, compared to the ESA4 model, have no noticeable differences within the SPIRE spectral range.

- ESA2: This is the launch version of the Neptune atmospheric model from Moreno based on original flyby and ground-based data.

- ESA3: This version is the initial update following early Herschel observations and evaluation of pre-existing information. Early incorporation of PACS spectroscopic information, e.g. HD line and mid-IR measurements which constrained the thermal structure of Neptune and improved model output flux accuracy by ~1-2% (see also **Feuchtgruber et al., 2013, A&A, 551, A126**).
- ESA4: Second update based on improved models incorporating (especially) CO emission line measurements from SPIRE
- ESA5: Final model with reduced errors due to improved Herschel and Planck information.

FITS tables of the models are provided at the following link, together with specific information per calibration obsid for PACS and SPIRE and SPIRE-P in-band fluxes per obsid/date:

http://archives.esac.esa.int/hsa/legacy/ADP/PlanetaryModels/Neptune/Obsid_specific_models/

The approximate error on the fluxes is ~5% absolute (peak-to-peak).

Values provided in the models assume an effective diameter of 2."3 arcsec as seen from Earth, assuming a distance of 4.412237 x 10^9 km and a radius for Neptune at 1 bar of 24599.8 km. Since the flux depends on $(\text{radius}/\text{distance})^2$, assuming the radius is constant then fluxes observed will depend on the Herschel–Neptune distance, d_{HN}, at the time of the observation:

- Flux = $(4.412237 \times 10^9/d_{HN})^2$. model flux
- or, Flux = (diameter (in ")/2."3)^2 .model flux
- Like for Uranus, the diameter of Neptune during the mission is available here.
- The apparent, Herschel-centric sizes of the planets can also be obtained for any time/day from **JPL Horizons (http://ssd.jpl.nasa.gov/horizons.cgi: using the Herschel Space Observatory [500@-486] as the viewing point from within the solar system.**

In all cases, the format of the model files is FITS tables, with four columns in each of them:

- Frequency -- with name "Wave"
- Brightness temperature, T_b -- with name "T_b"
- Rayleigh-Jeans temperature, T_{rj} -- with name "T_rj"
- Flux in Janskys -- with name "Flux"

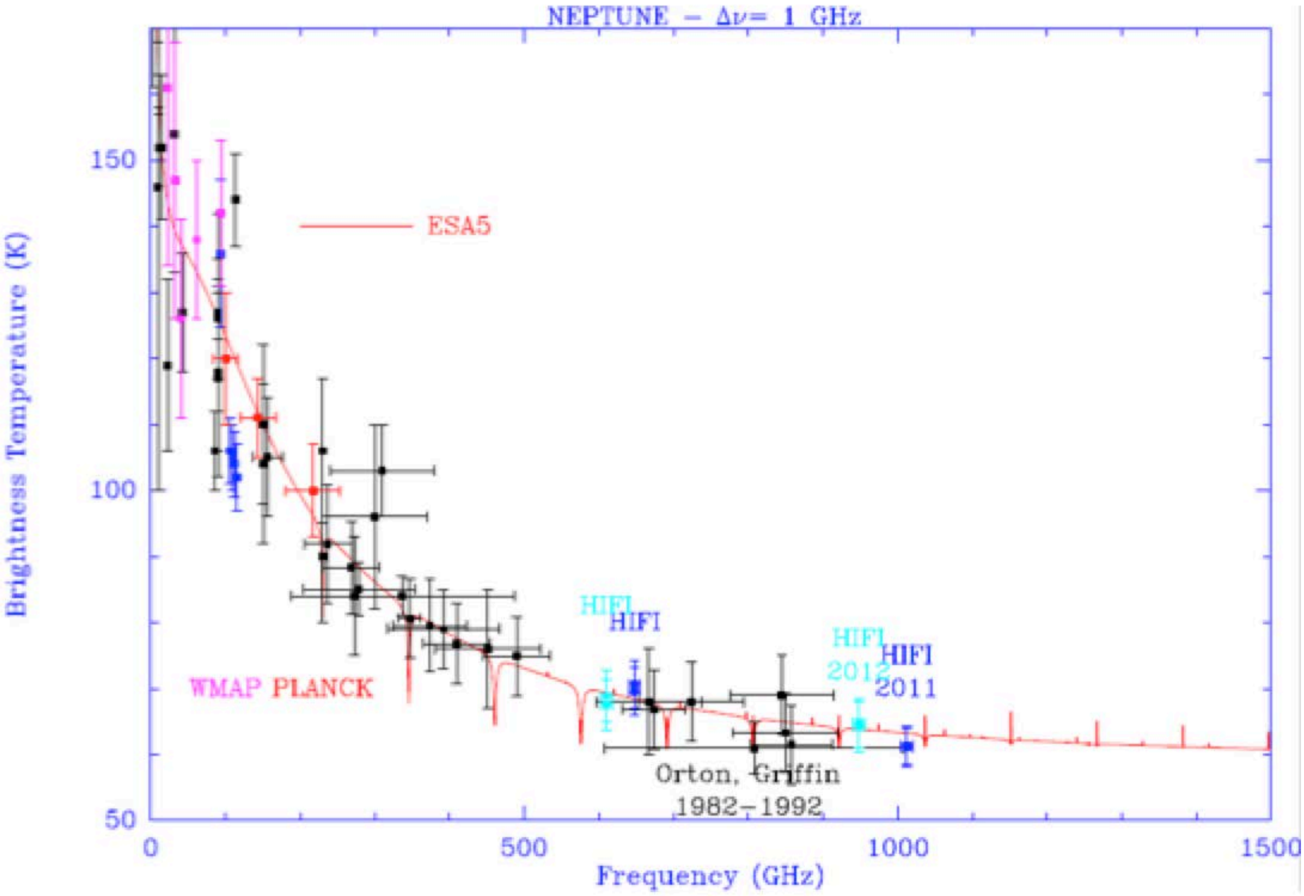

Figure 2: comparison between the Neptune ESA5 model and various ground and space-based data. Two sets of near contemporaneous Neptune-Mars measurements by HIFI in 2011 and 2012 are also shown. Just as for Uranus, Planck measurements were made contemporaneous to Herschel planet measurements for PACS and SPIRE throughout the mission overlap periods of Herschel and Planck.