Herschel Calibration Overview

A.P.Marston

Herschel Science Centre, Instrument and Calibration Scientist Team Lead, ESAC.

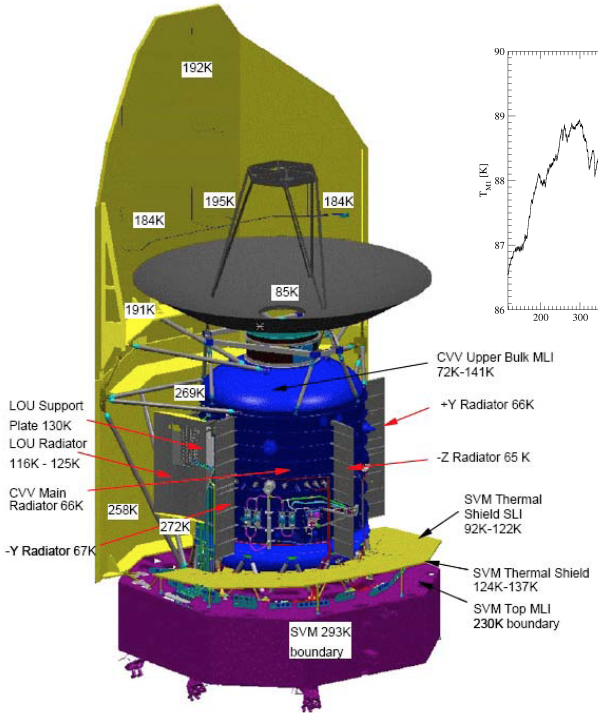
Overview

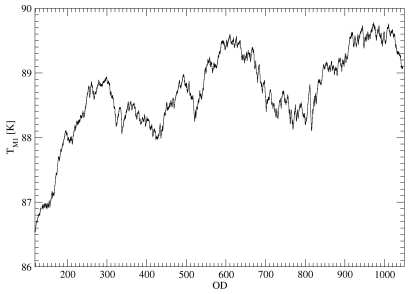
1. Basic telescope and instrumental overview
2. Calibration models
3. Some instrument basics and calibration accuracies
4. Cross-comparison checks
5. Cautionary note – extended sources and flux extraction techniques
   +Upcoming photometric point source catalog (in 2016).
6. Summary
7. Reference Documents

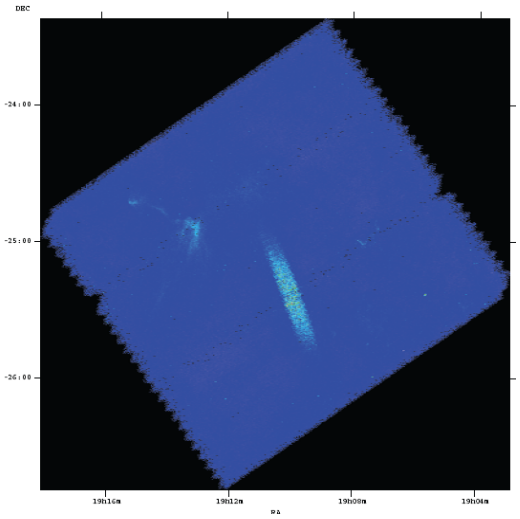
Telescope Basics

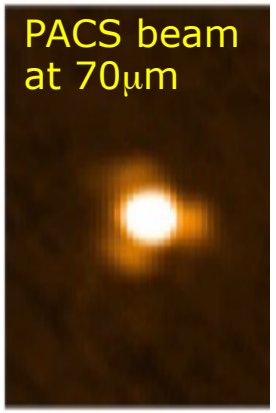
a. SiC mirror. Typically around 85K, but varied over the mission. Brightest object is the mirror! Chopping while observing.

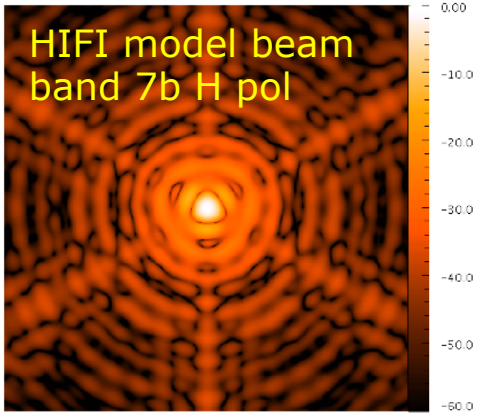
b. Straylight: Predicted from optical models and verified in orbit. Very few cases occurred.











Stray light of Jupiter – appeared where expected. Very few cases in Herschel data.

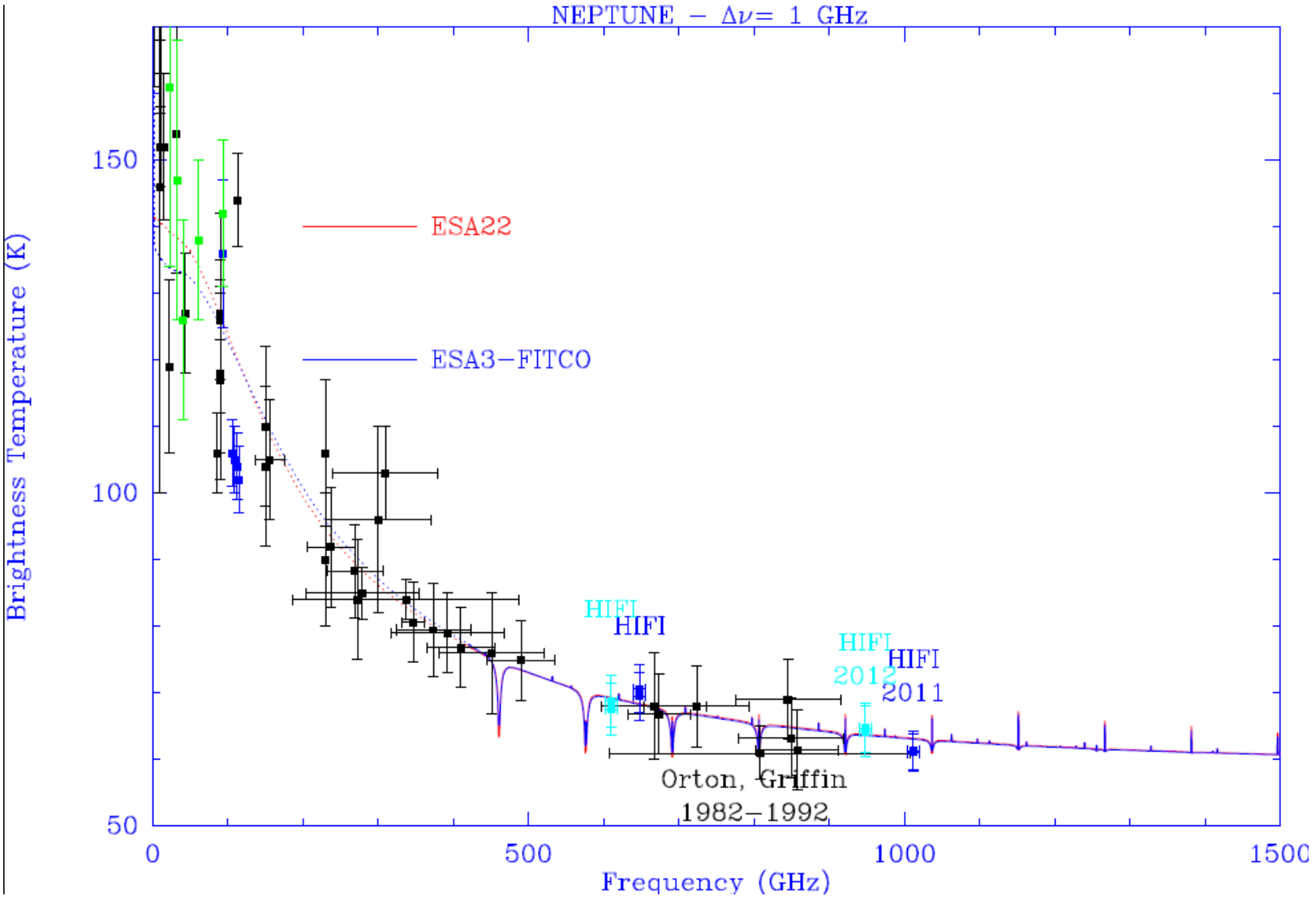
Pointing

1. Over time (and HIPE versions) this has gradually been improved. See http://herschel.esac.esa.int/twiki/bin/view/Public/SummaryPointing for improvements during operations.
2. In post operations - the upcoming bulk reprocessing of the archive we calculate that we have an **absolute pointing accuracy** (1σ) of 1.”2 and an improved representation of the jitter for the whole set of observations in the mission.

Calibration Models

1. **Stars** – MARCS models matching atmospheres of bright F and K stars. Basically blackbodies at longer Herschel wavelengths. **Used by PACS.**
    a. **αBoo**
    b. **αTau**
    c. **αCet**
    d. **βAnd**
    e. **γDra**
2. **Planetary models** – Atmospheric models of planets based on information from flybys and previous IR missions. Incorporated into planetary atmosphere model code. Developed before launch and iterated during Herschel mission (Neptune/Uranus). **Used by SPIRE and HIFI.**

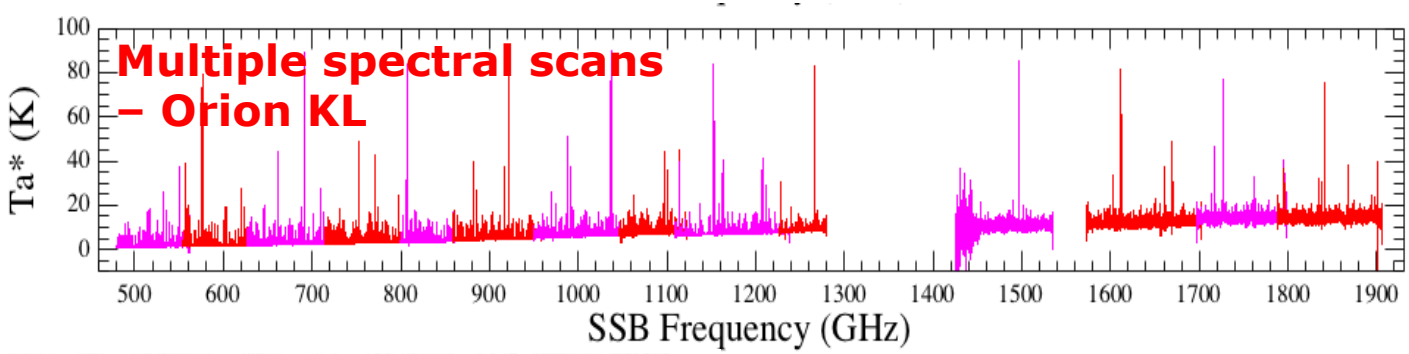
Neptune prime calibrator model

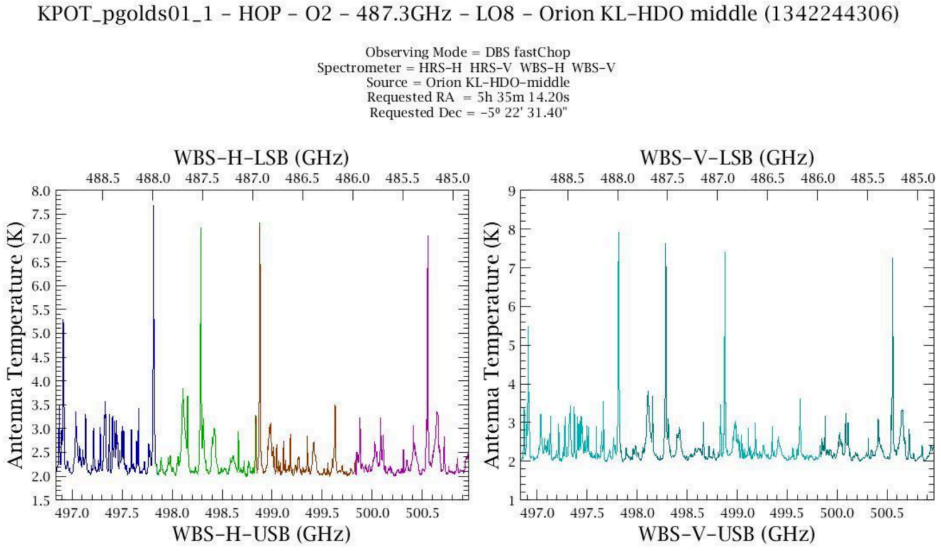


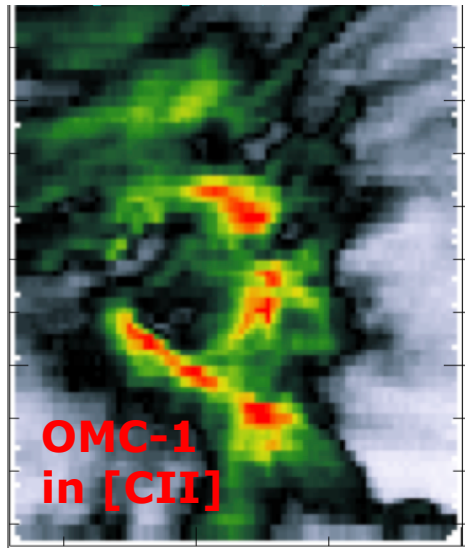
Science Instrument Basics: HIFI

HIFI (Heterodyne Instrument for the Far Infrared)

- 488-1272 GHz (BW = 4GHz) and 1430-1902 GHz (BW=2.4GHz), Heterodyne high-resolution spectroscopy – double sideband. H and V polarizations.
- 0.125-1.1 MHz (0.02-0.6 km/s), beam FWHM, 43” to 11” (at highest, band 7, frequencies)







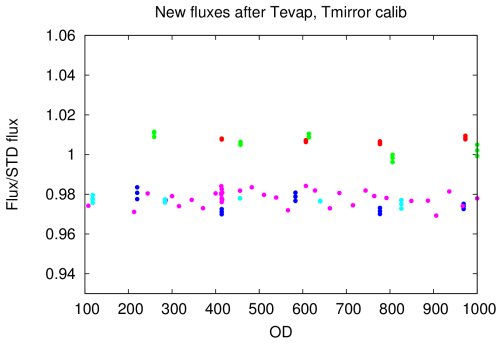
HIFI Extras

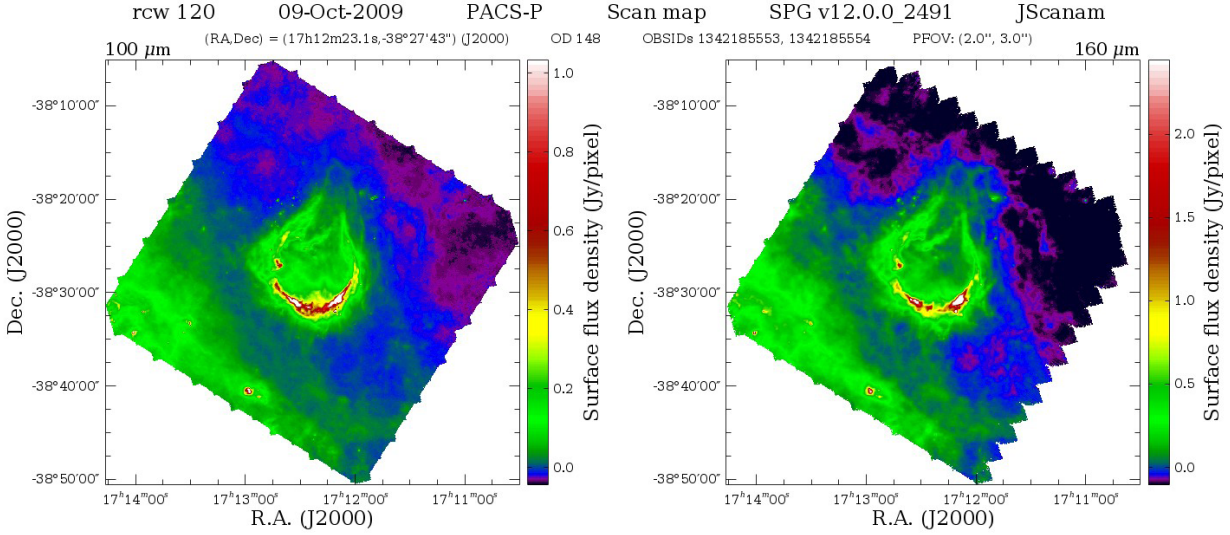
1. Units are antenna temperature (T_A*) derived from a chopper-wheel calibration scheme.
2. Conversion to Jy (or T_{mb}) – task in HIPE software but see note http://herschel.esac.esa.int/twiki/pub/Public/HifiCalibrationWeb/HifiBeamReleaseNote_Sep2014.pdf
3. Calibration accuracy
    a. Line intensity calibration accuracy ~3-20% depending on band
    b. HIFI can measure the continuum too ! (accuracy ~5-50% depending on band)
4. Data readiness:
    a. SPG products can still occasionally suffer from residual baseline artefacts (drift, LO excess noise, spectral spurs)
        – Particularly important to look into for spectral scans and maps

Science Instrument Basics

PACS (Photoconductor Array Camera and Spectrometer)

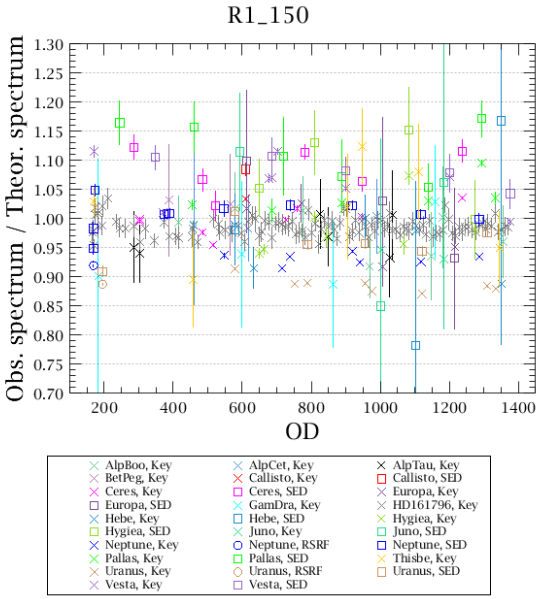
- Photometer at 55–210 μm (3-bands at 70, 100 & 160 microns – 70 or 100 and 160 μm)
- Repeatable to better than 1%!
  - Flux calibration accuracy limited by the stellar model accuracy.

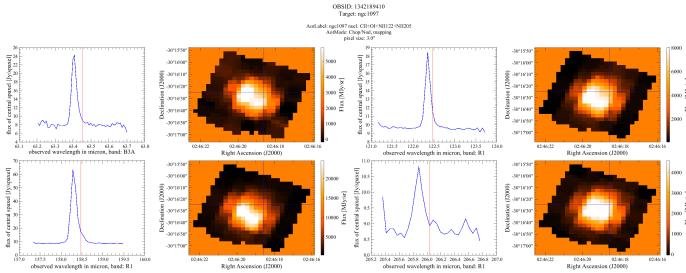




PACS Spectroscopy

- Spectrometer mode (5x5 integral field) from 55 to 220 μm
  - Small BW covering particular lines – can be more than one per observation "line spectroscopy"
  - Larger BW where grating moved to cover range of wavelengths "range spectroscopy"
  - Repeatable within 8% across the spectral band (except red leak area)

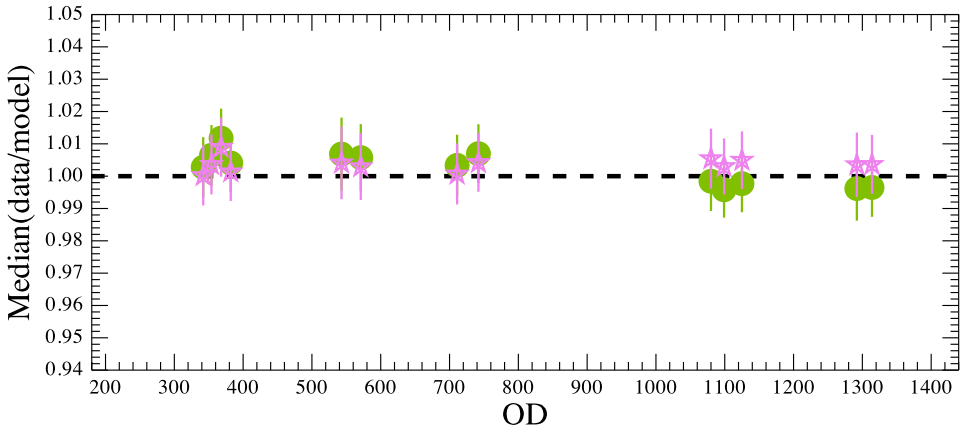


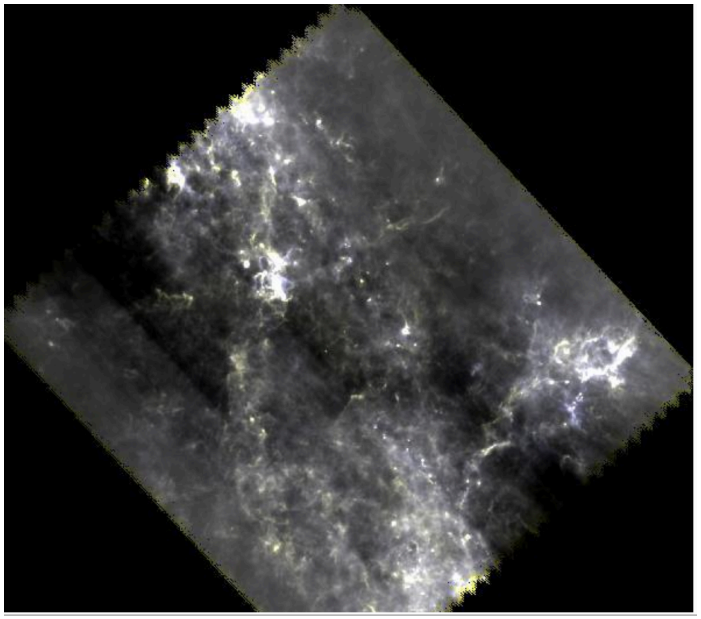


Science Instrument Basics: SPIRE

SPIRE (Spectral and Photometric Imaging REceiver),

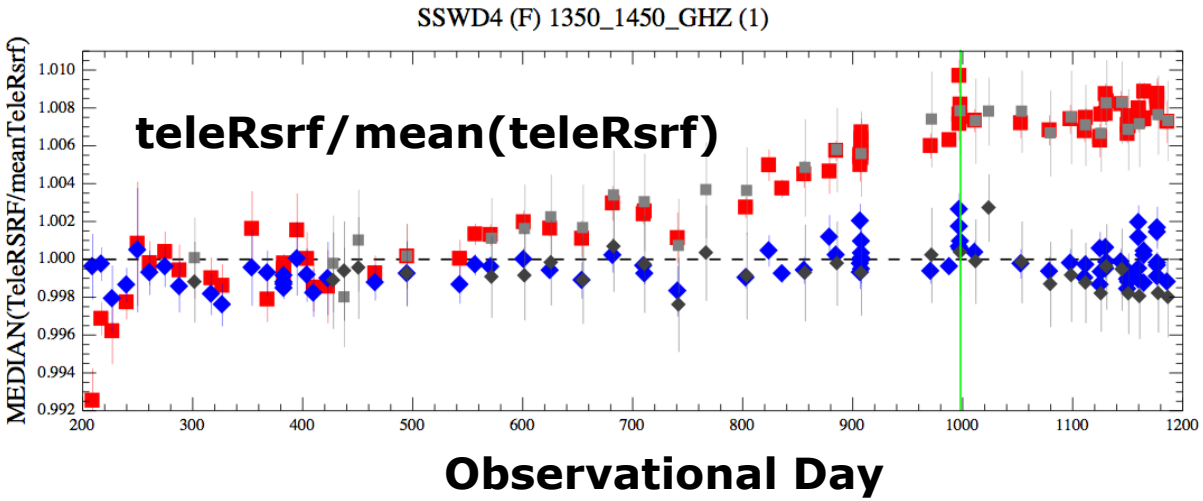
- Photometer at 194-672μm (scan maps of 3 broad bands simultaneously at 250, 350 & 500 μm). Plus parallel mode with 3 SPIRE and 2 PACS bands simultaneously but offset from each other by 15 arcmins!
  - Flux calibration limited by model systematics – 2% repeatability.
  - Flux offset provided by cross-calibration with Planck HFI (see later)





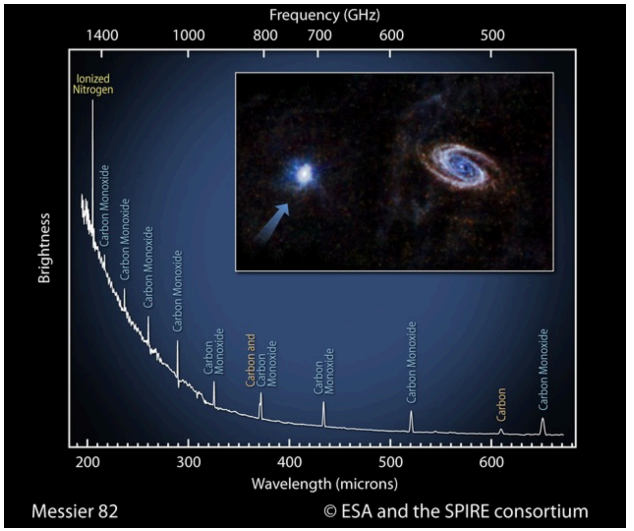
SPIRE spectroscopy

- FTS spectroscopy at 200-670 μm, full bandwidth (simultaneously SSW 944-1568 GHz (318 - 191 μm) and SLW 447-1018 GHz (671 - 294 μm). Three spatial samplings – rasters for > 1 arcmin.
  - Flux calibration +/- 7% with a similar repeatability on cal sources. Includes correction for degrading mirror (also PACS)

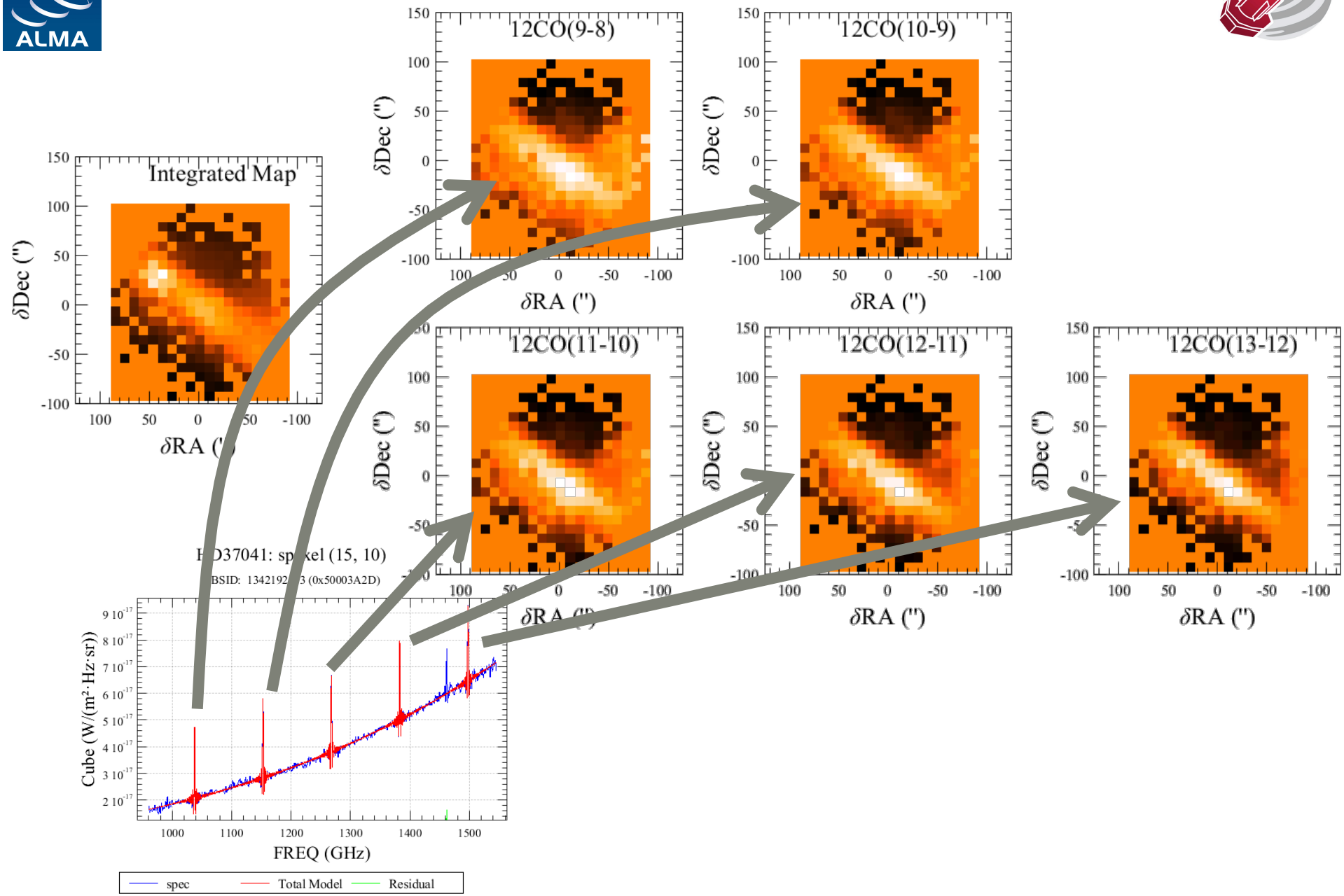


← 0.8%

← corrected

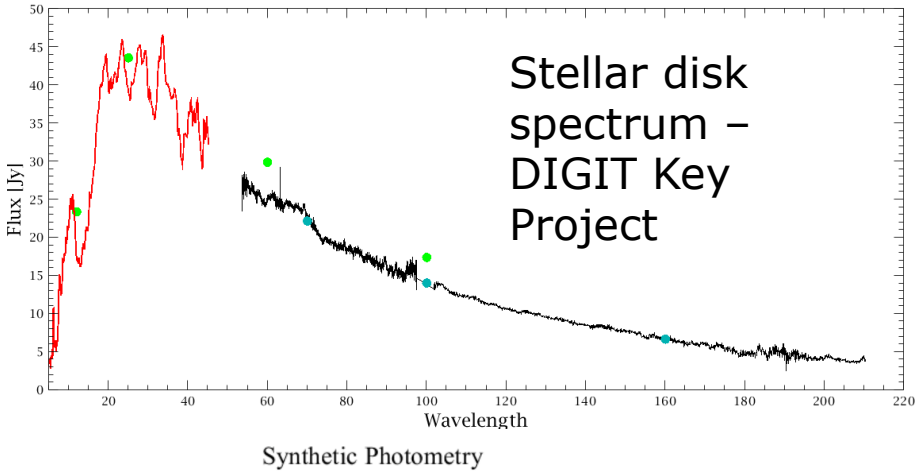


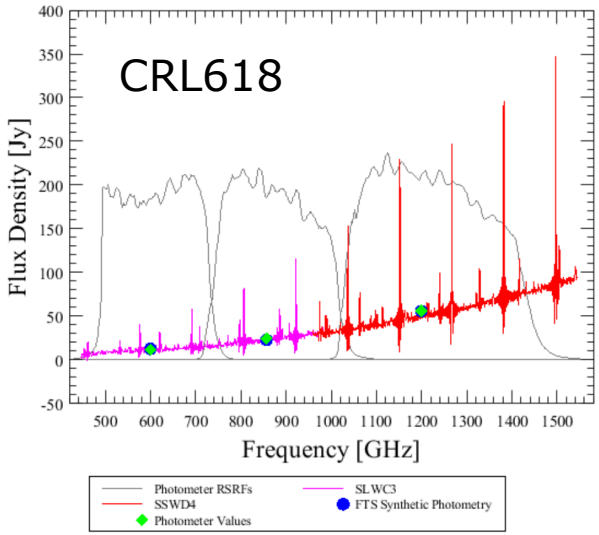
SPIRE Orion Bar Emission Line Maps

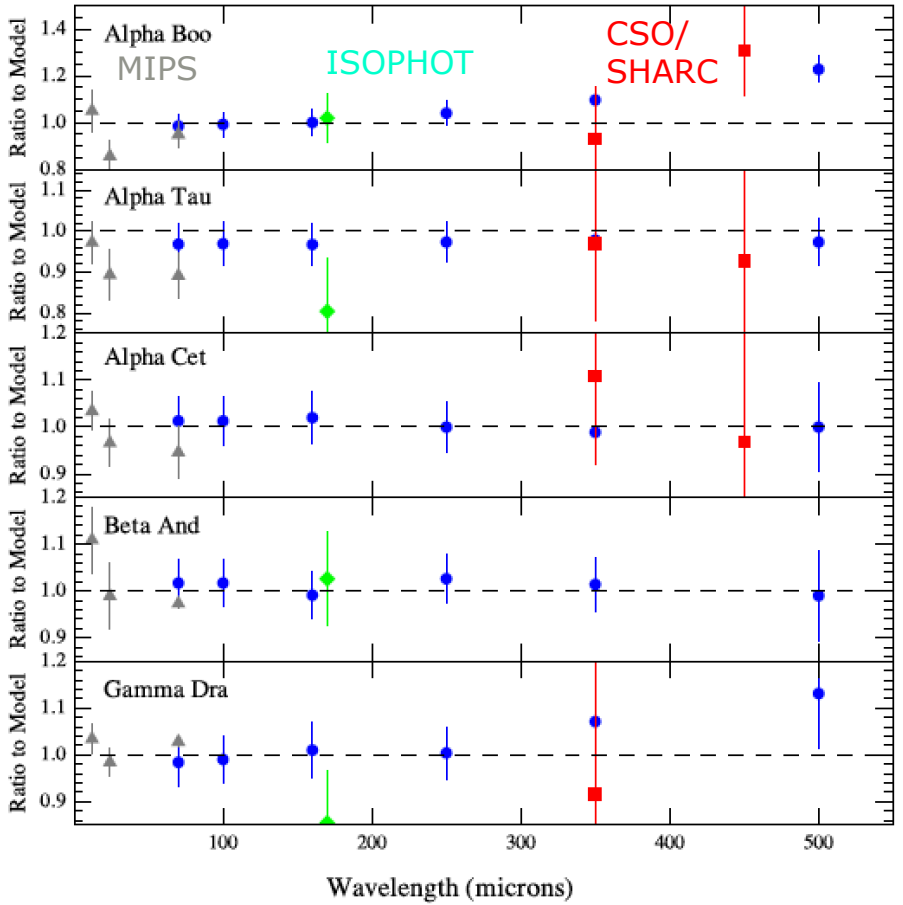


Cross-comparisons Pt.1

1. Photometry versus spectroscopy. Typically within 2% for bright sources.
2. Consistency of PACS and SPIRE photometry (via stellar models). <1%.



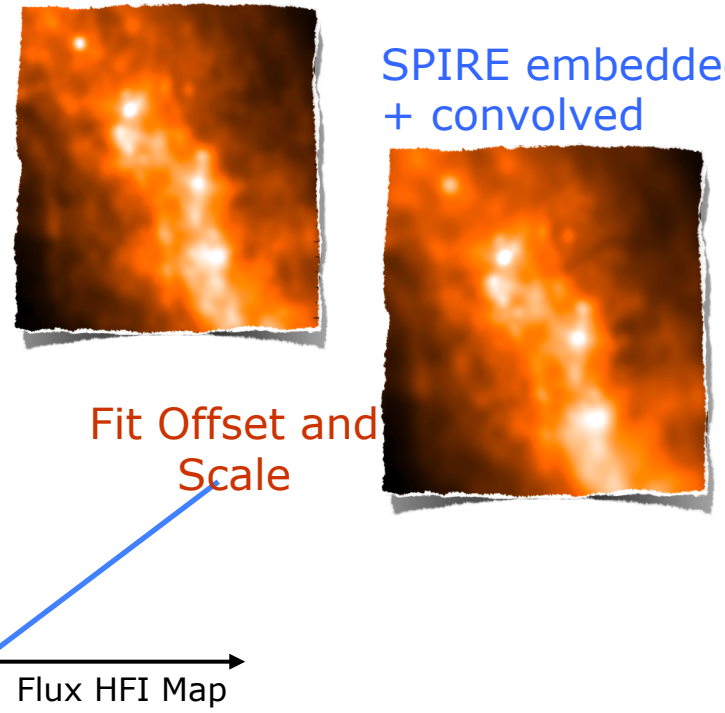


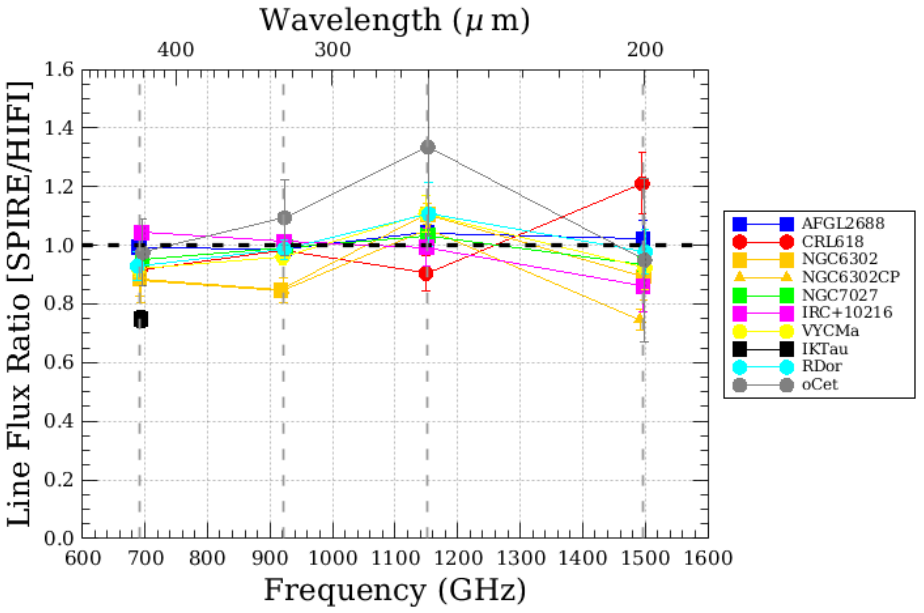


Cross-comparisons Pt 2

1. SPIRE and HFI/Planck photometry. Working group was set up for this during the mission. Consistency is within 2% at 350 and 500 microns and nearer 5% at 250 microns (extrapolation to waveband with no HFI equivalent)
2. Consistency of spectroscopy across instruments

Planck simulated colour-corrected map





Caveats

1. Be aware that many sources are not point sources – small extended sources should be treated with care for spectroscopy. Current software for Herschel allows better spectral corrections (SPIRE and PACS).
2. Care with flux extraction – different extractors can give notably different results.
3. “Standardized” extraction being used in a forthcoming Herschel Point Source Catalog (in 2016). PACS and SPIRE only.

Summary

1. Limitations on absolute calibration come from calibration models (~ 4-5%)
2. Repeatability on calibrators for photometers is excellent, 1-2%
3. Spectroscopy has good calibration to within 7-8% across the instruments – for bright objects.
4. Consistency between Spec/Phot and between instruments is good
5. SPIRE photometry is in agreement to less than 0.5% with PACS photometry and of a similar order compared to Planck HFI measurements.
6. Asteroid, planetary atmosphere calibrators majorly improved by comparison to Herschel data over the mission.
7. Pointing improvements since the beginning of the mission → 1.”2 (1σ).

Reference Documents

Documents

(Instrument documentation: http://www.cosmos.esa.int/web/herschel/home go to Documentation tab.)

1. HIFI:
    a. HIFI calibration webpage: http://herschel.esac.esa.int/twiki/bin/view/Public/HifiCalibrationWeb
    b. de Graauw et al. 2010 "The Herschel-Heterodyne Instrument for the Far-Infrared (HIFI)", A&A 518, L6
    c. Roelfsema et al. 2012 "In-orbit performance of Herschel-HIFI", A&A 513, A17
    d. Mueller & Jellema 2014 "The HIFI Beam: Release Note for Astronomers", http://herschel.esac.esa.int/twiki/pub/Public/HifiCalibrationWeb/HifiBeamReleaseNote_Sep2014.pdf
    e. HIFI Observers' Manual, http://herschel.esac.esa.int/Docs/HIFI/pdf/hifi_om.pdf
2. SPIRE:
    a. SPIRE calibration webpage http://herschel.esac.esa.int/twiki/bin/view/Public/SpireCalibrationWeb
    b. The SPIRE Handbook, volume IV of the Herschel Explanatory Supplement.
    c. Calibration of the Herschel SPIRE Fourier Transform Spectrometer, Swinyard et al., 2014, MNRAS 440, 3658
    d. Systematic characterisation of the Herschel SPIRE Fourier Transform Spectrometer, Hopwood et al., 2015, MNRAS, in press (arXiv: 1502.05717).

Documents Cont.

e. Observing extended sources with the Herschel SPIRE Fourier Transform Spectrometer, Wu et al. 2013, A&A, 556, 116

f. Griffin, M. J., 2013, MNRAS, 434, 992
Flux calibration of broad-band far-infrared and submillimetre photometric instruments: theory and application to Herschel-SPIRE

g. Bendo, G. J. et al., 2013, MNRAS, 433, 3062
Flux calibration of the Herschel-SPIRE photometer

h. Pearson, C., et al., Experimental Astronomy, Volume 37, Issue 2, pp.175-194
SPIRE point source photometry: within the Herschel interactive processing environment (HIPE)

3. PACS

a. PACS calibration webpage:
http://herschel.esac.esa.int/twiki/bin/view/Public/PacsCalibrationWeb

b. In-flight scientific capabilities of the PACS instrument:
The Photodetector Array Camera and Spectrometer (PACS) on the Herschel Space Observatory, Poglitsch et al., 2010, A&A, 518, L2

Documents cont.

c. PACS photometer calibration:
http://herschel.esac.esa.int/twiki/pub/Public/PacsCalibrationWeb/Balog_ExpAstr_2013.pdf

d. PACS spectrometer calibration:
http://herschel.esac.esa.int/twiki/pub/Public/PacsCalibrationWeb/PacsSpectroscopyPerformanceAndCalibration_v2_4.pdf