Herschel Calibration Report for HUG#9.

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To Herschel User's Group #9, 18-19 June 2015.

Outline of Presentation

1. General Items Regarding Calibration
2. Calibration Models
3. Pointing Updates
4. PACS Instrument Calibration
5. SPIRE Instrument Calibration
6. HIFI Instrument Calibration
7. Spectral Cross Calibration
8. Point Source Catalogue
9. Conclusions

1. Some General Items Regarding Calibration

- **Herschel Calibration Steering Group** had two more meetings. The last one 7-8 May 2015. There will be one more meeting (by telecon).
- **Change of Calibration Team Lead**. Tony Marston ceases to be instrument and calibration scientist team lead at the end of June 2015. New team lead will be David Teyssier.
- Herschel calibration **special edition** of *Experimental Astronomy* journal (refereed --- produced in July 2014). Contains 18 papers.
  - Overall more than 40 calibration papers for all instruments exist in refereed papers. More are still planned.
  - Will appear as part of the legacy documentation.
- Archive Products
  - Updates – typically along lines of HUG suggestions – have been made in several areas, including improved standalone products.
- **Herschel Point Source Catalog Working Group**
  - Feasibility studies for PACS and SPIRE completed.
  - Working group now in full swing (HSC, NHSC, Konkoly – major contributors).
  - Extraction techniques designed. Test fields under analysis. Quality control starting.
  - End of year for internal catalog production. Hope to release first version in early 2016.
  - Possible extensions being discussed for later editions including full bandmerging.

2. Calibration Model Updates

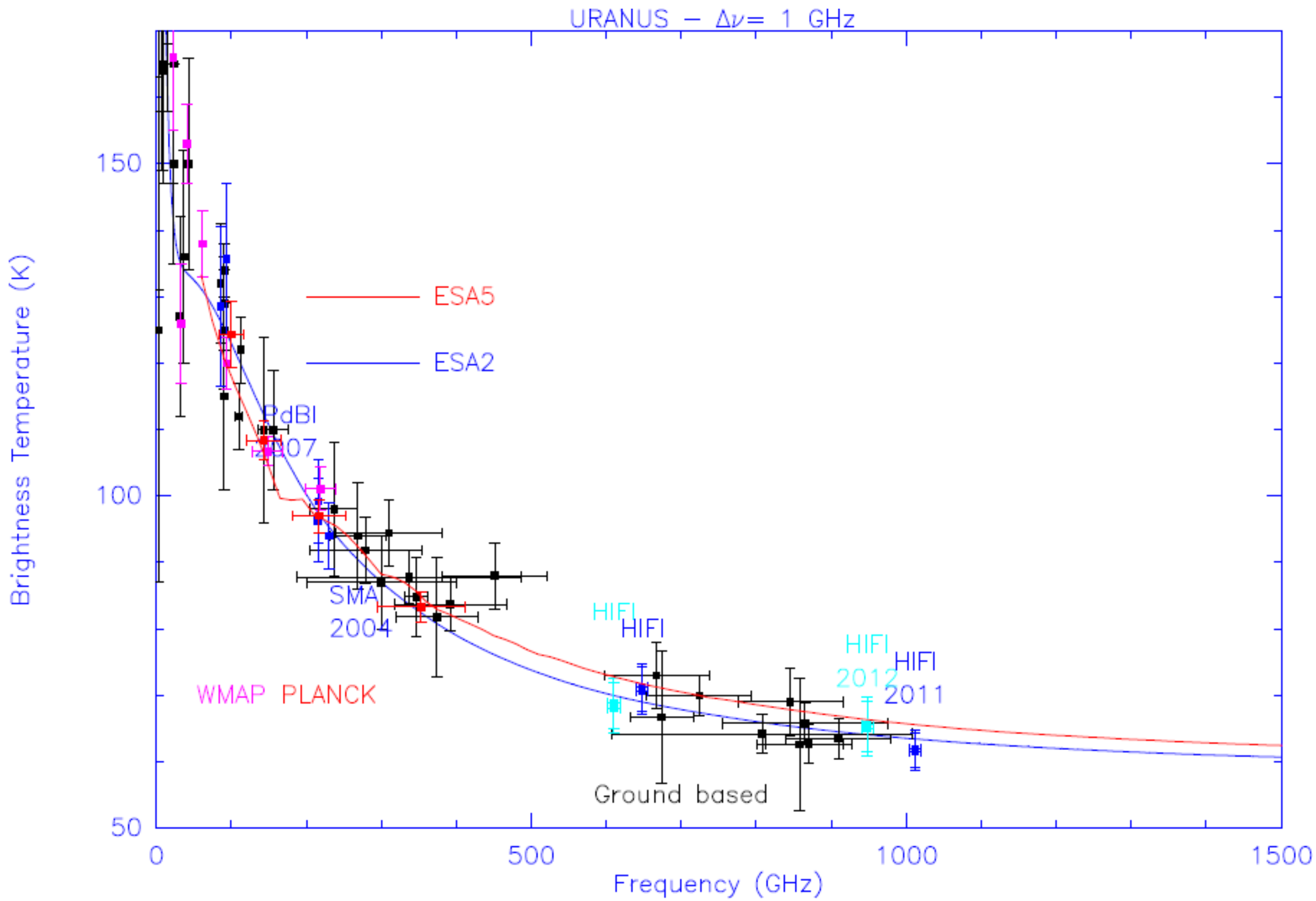
Planetary Models:

- Basically done – but new Uranus model available (Glenn Orton) which has some issues with PACS data – one more go around.
  - Note: Glenn just got a NASA science merit award for his Uranus models!!!
- No changes to PACS/SPIRE planet models being used in their calibration trees.
- All bar recent models are in the calibrators section of HIPE. BUT it is now intended that they be placed separately in the archive and have more extensive web pages in the near future.

Asteroid Models:

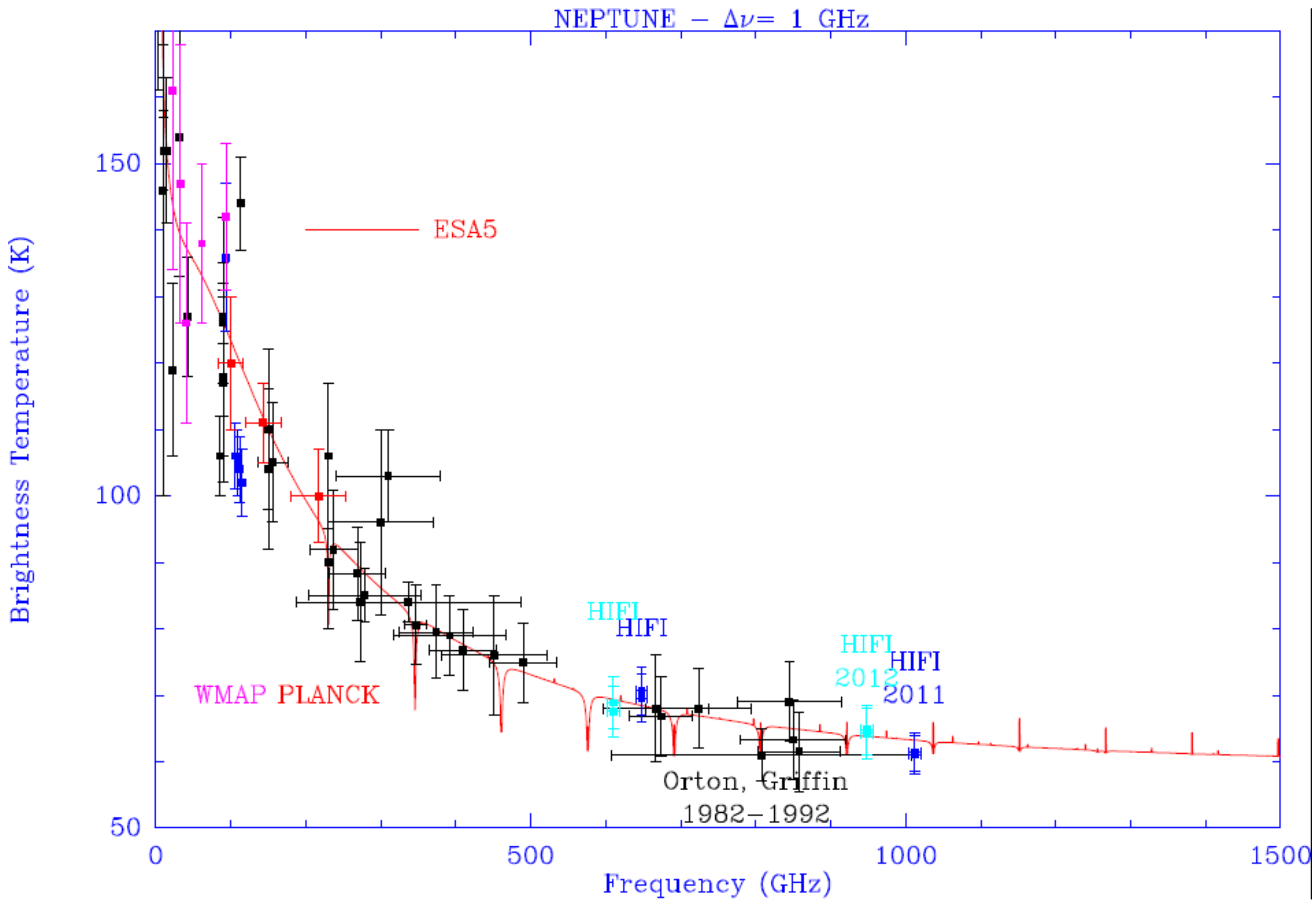
- Four prime calibrator asteroids now available Thomas Mueller, with updated models based on Herschel data feedback.
- These 4 are the only ones with updated models since launch.
- Models now being used by SOFIA, ALMA, APEX…. for calibration purposes.

Uranus model – start to end



- Blue model at launch
- Red model we finish with.
- ~+4% in SPIRE range and +2% in PACS range.

Final Neptune Model

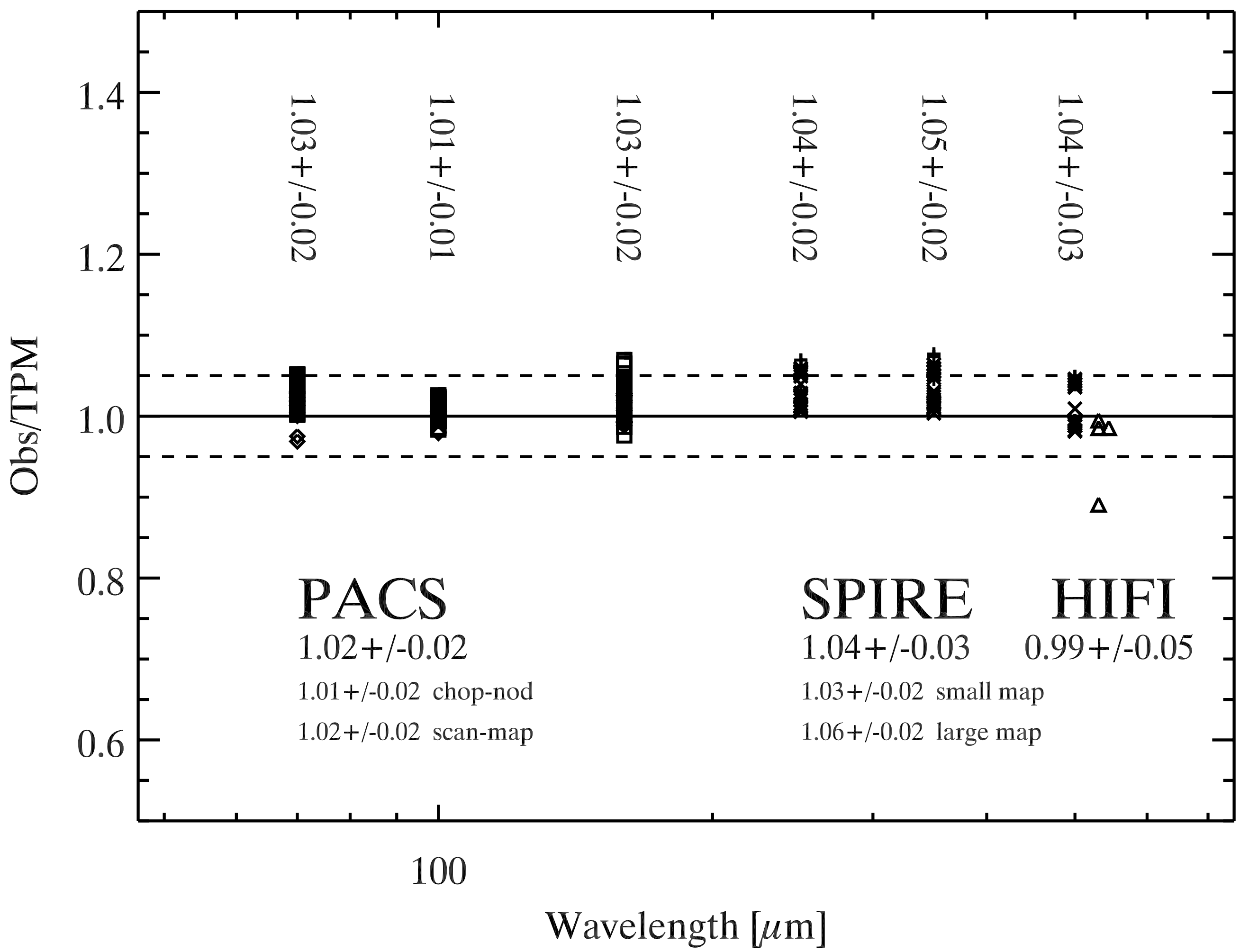


Final planet models limited by thermal structure knowledge. ~3-5%.

Relative calibration Neptune/ Uranus <2%.

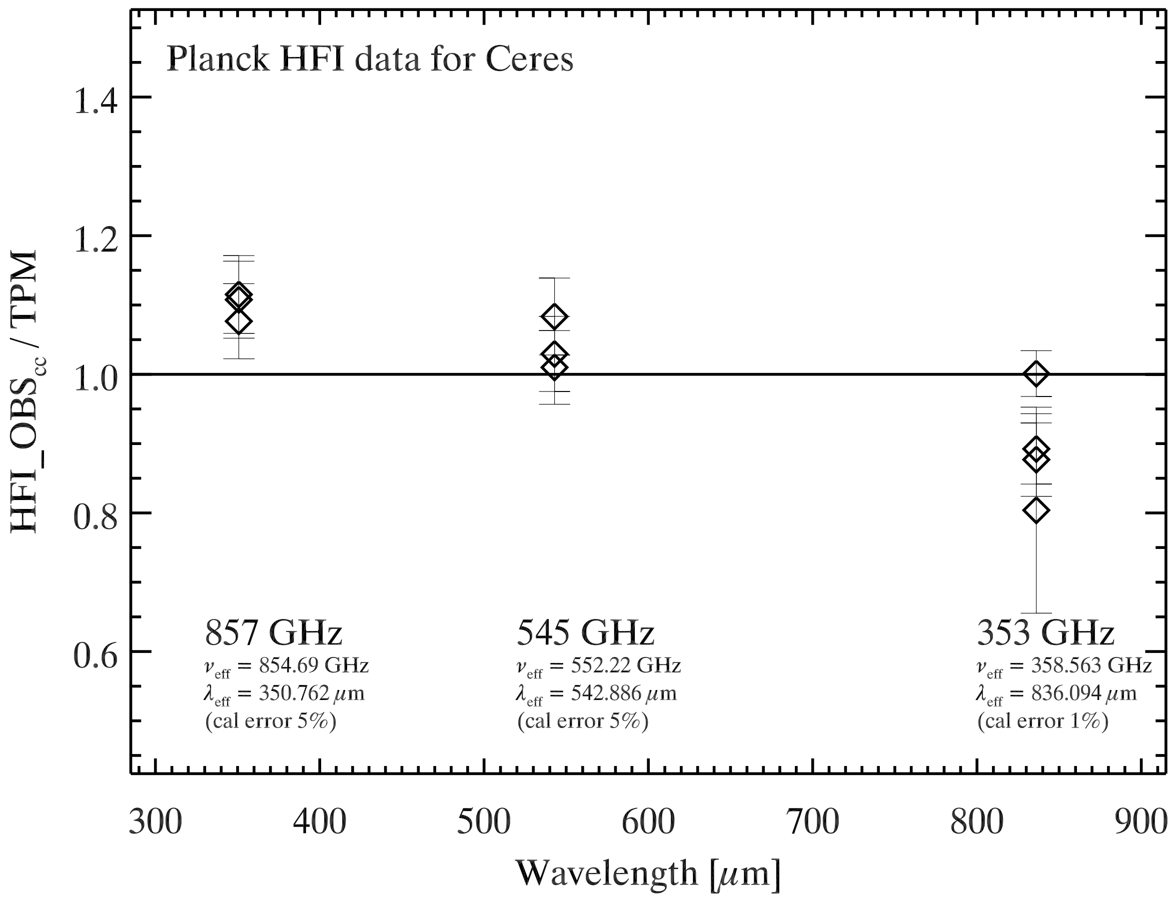
(used by SPIRE)

Asteroid Models: Ceres

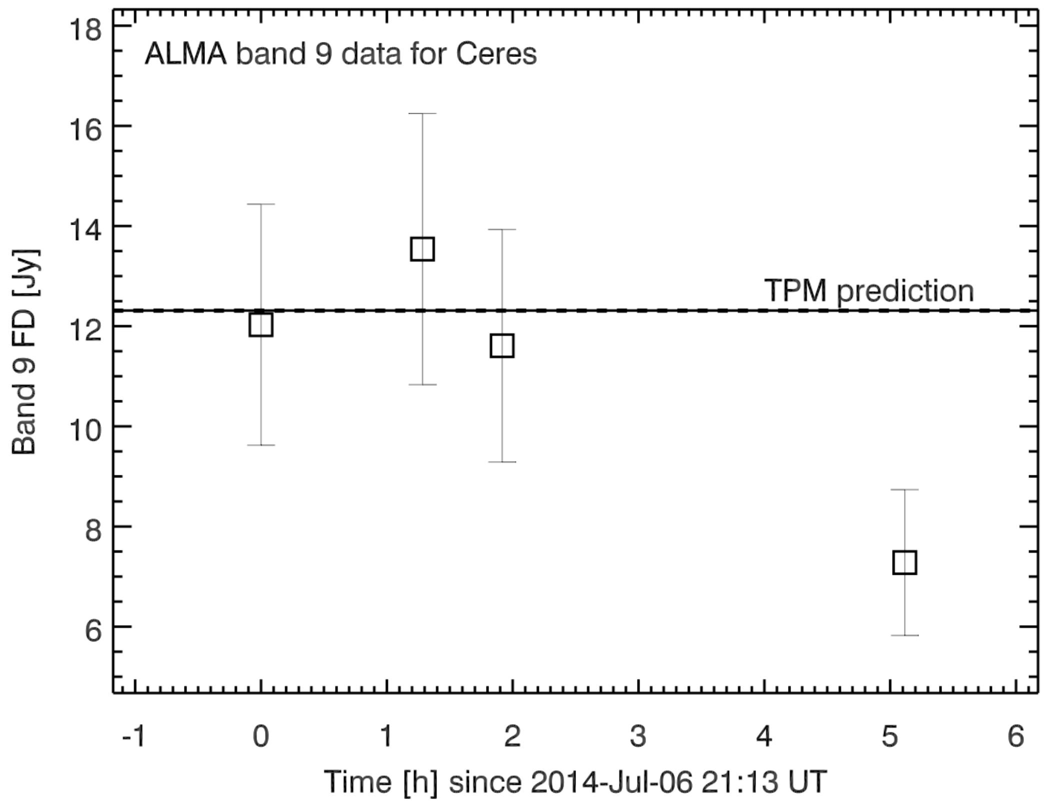


Asteroids: Ceres Planck Measurements

Simultaneous Planck/ Herschel observations made during the mission.



Asteroids: Ceres with ALMA



Asteroids: Overall Dispersion of Measurements

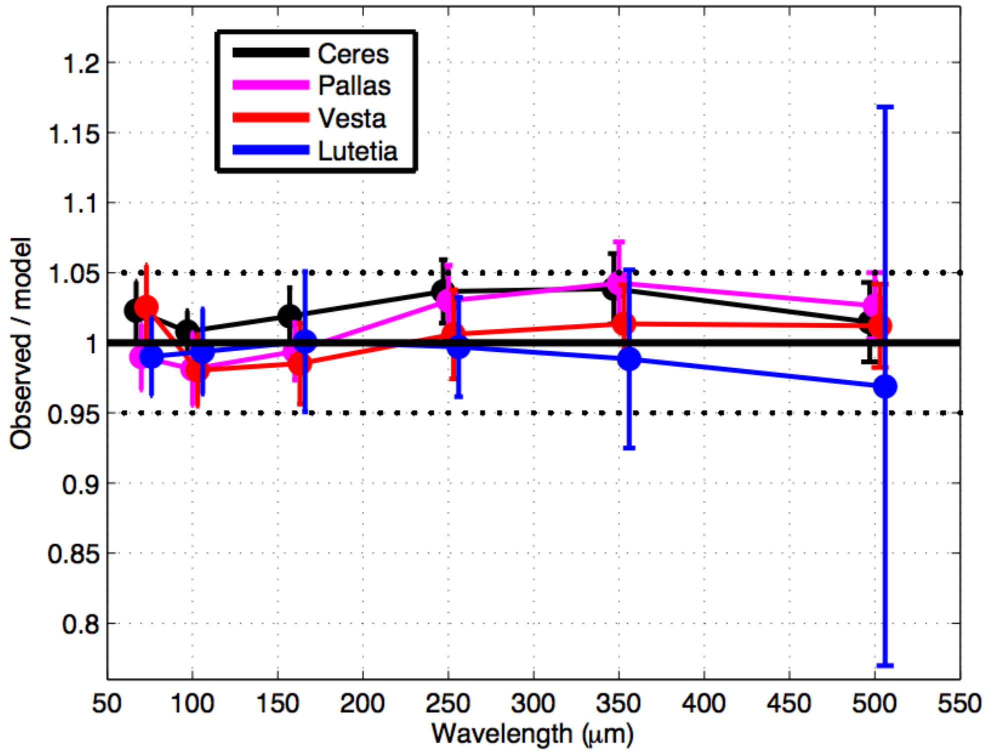
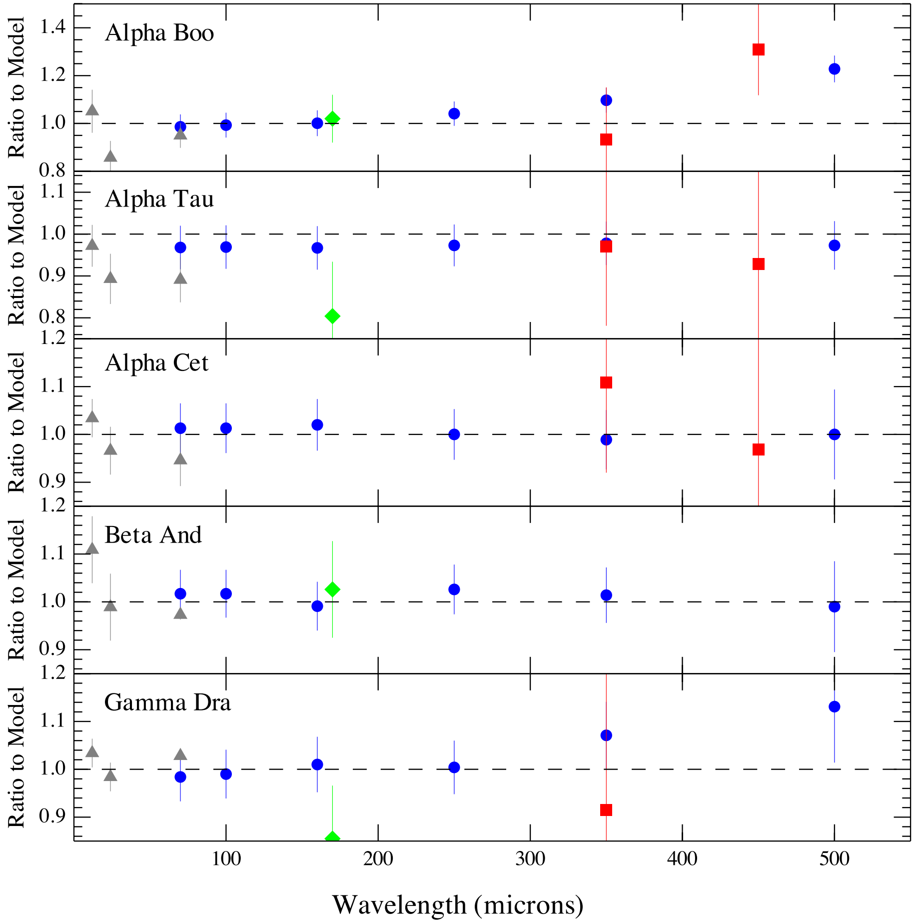


Fig. 10 Dispersion in the ratios of measured-to-model fluxes for the four asteroids as a function of wavelength. The weighted mean ratios are shown with errorbars reflecting the absolute flux calibration of individual measurements as well as the variance of the sample.

Stellar Calibrators

- MARCS models of 8 stellar calibrators not updated since launch.
- 5 used as prime calibrators by PACS.
- Herschel data shows the excess of flux to model is present at SPIRE wavelengths for four of 8 Decin the stars. More usable in PACS range.
  - α Boo,
  - β Peg,
  - β Umi
  - γ Dra.

Fiducial Stars: Comparisons of Observations with models



The ratio of the Herschel fluxes with each model (blue circles). NOTE: SPIRE did NOT use these for calibration – so independent.

Also plotted are the ratios from

Spitzer-MIPS (grey triangles)

ISOPHOT(green diamonds) and

CSO (red squares)

Fiducial Stars: Some further conclusions

- Comparing the 250 μm results with the PACS ratios: (excluding α Boo), the difference between SPIRE and PACS gain calibration is 0.4 ± 1.4%.
- Assuming there are no systematic issues with the models, the agreement with the model in all three bands of SPIRE for α Tau, α Cet and β And indicates that the relative Neptune based calibration of SPIRE is better than 3% at fluxes down to 90 mJy.

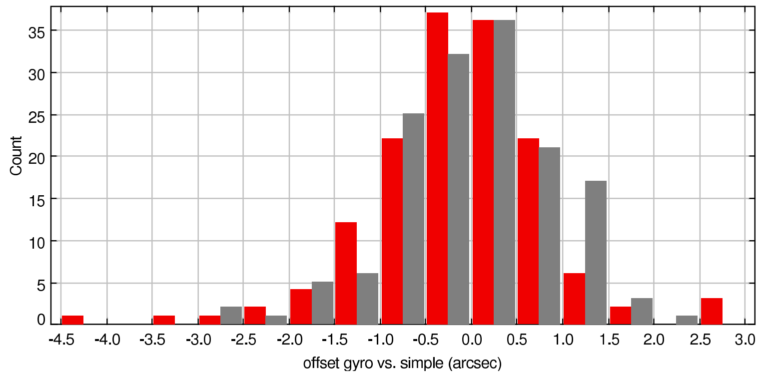
3. Pointing Updates

- **Gyro-based attitude reconstruction in reprocessing with HIPE 13:**
  - To overcome the relatively poor estimation of the high-frequency changes in S/C attitude (too heavily filtered)
  - The gyro-based attitude reconstruction combines the STR attitude measurements with the output of gyroscopes (GYR)
  - Much greater weight to the the measurements made by the GYR
  - STR data provide an absolute reference and account for GYR drift
  - The HCSS 13.0 software is based in the tools provided by the PACS ICC with some additions/improvements
  - Available in the SPG (AUX) and also as a user task (toolbox).
- *Net result is better estimate of objection motion in PACS-S integral field during observation – can correct for flux losses.*
- *Potential improvements in PSFs and positions (flux loss estimates for spectrometers.*

Pointing Update Results

- Tested more >1000 observations to judge effects before including in HIPE 13 bulk reprocessing. Report is available on S/C part of the Herschel web.
  - Quality metrics for reconstruction (used by HIFI to reject certain poor reconstruction cases).
  - Overall at 1.”2 APE for the mission.
  - More importantly have better handle on motion of telescope (e.g. watch object versus jitter correction during a PACS observation).
  - Some low-level issues revealed.
  - Jitter reduction by as much as a factor of 3 but further checks ongoing to confirm this number (relative pointing efficiency, RPE).

Pointing differences HIPE 12 to 13 for observations in first half of the mission



Pointing in HCSS 14+?

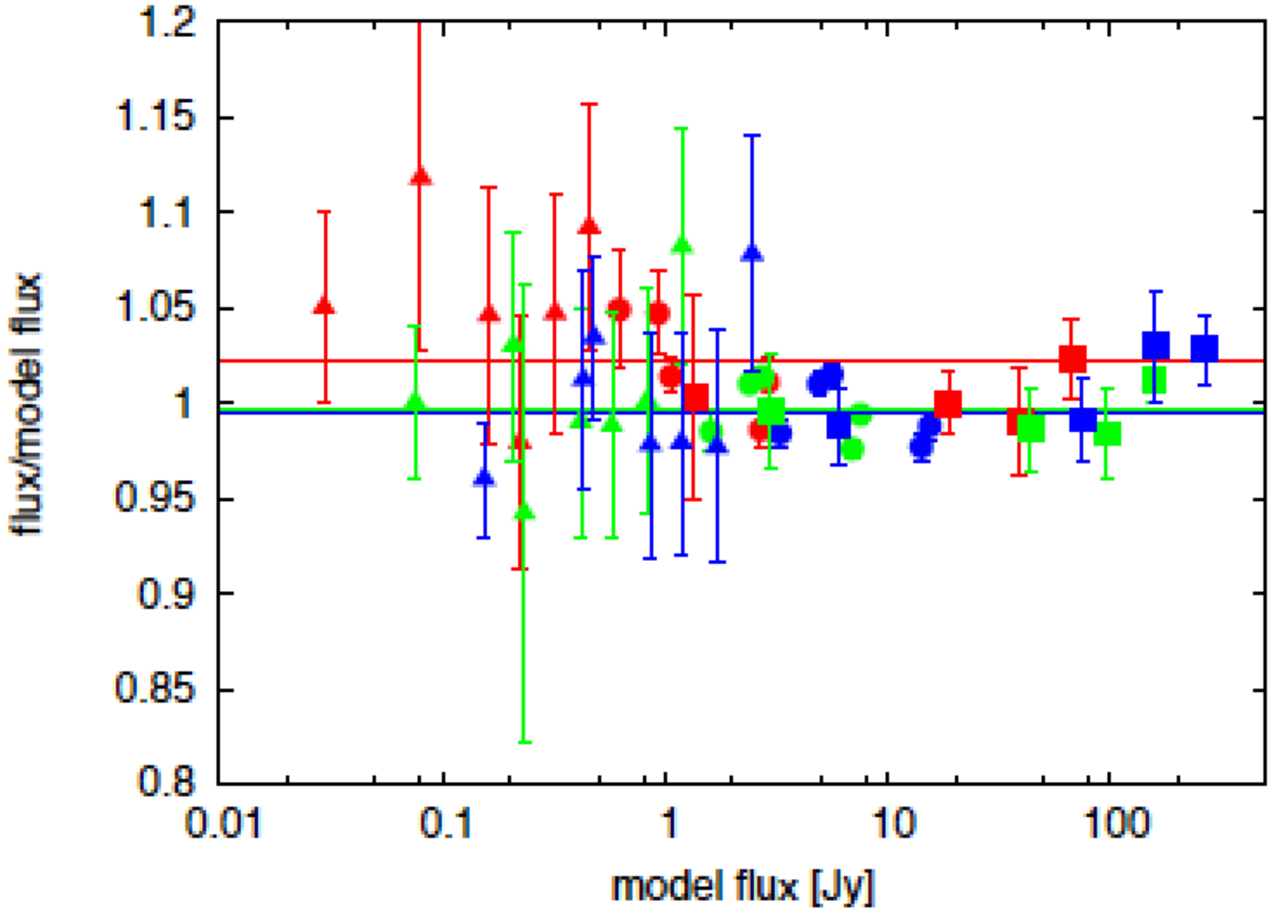
- We are studying how to address the thermo-elastic impact of the pointing **in 'warm' attitudes** where there was solar heating:
  - Early attempts, using naïve approximations, gave good results in extreme cases.
  - Now we are trying to do a proper modeling
- **Interlacing:** the current gyro-based reconstruction algorithm only uses up to 9 guide stars. For a large part of the observations, interlacing was enabled so we have additional information in TM that is not used. An algorithm to be devised to use the whole set of data.

4. PACS Instrument Calibration: general

- PACS-P
  - Evaporator temperature correction tested and implemented
  - MadMAP replaced by Unimap in standard pipeline – proper error maps potentially available in the future rather than standard deviation maps.
  - Level2.5 and level3 (partially) products are introduced in the Observation context. Combining maps.
  - PACS (and SPIRE) **point source catalog working group (chair: Luca Calzoletti)**
- PACS-S
  - Telescope model updated – evolution of telescope mirror. Used as a reference measurement during PACS-S observations. Model being put into the HCSS build as a resource for users.
    - Reminder: telescope mirror used for flux reference.

	HPF	Unimap	JScanam
blue	0.9948 +– 0.0167	0.9996 +– 0.0162	0.9992 +– 0.0169
green	0.9958 +– 0.0162	1.0036 +– 0.0176	1.0038 +– 0.0164
red	1.0214 +– 0.0266	0.9974 +– 0.0165	1.0124 +– 0.0184

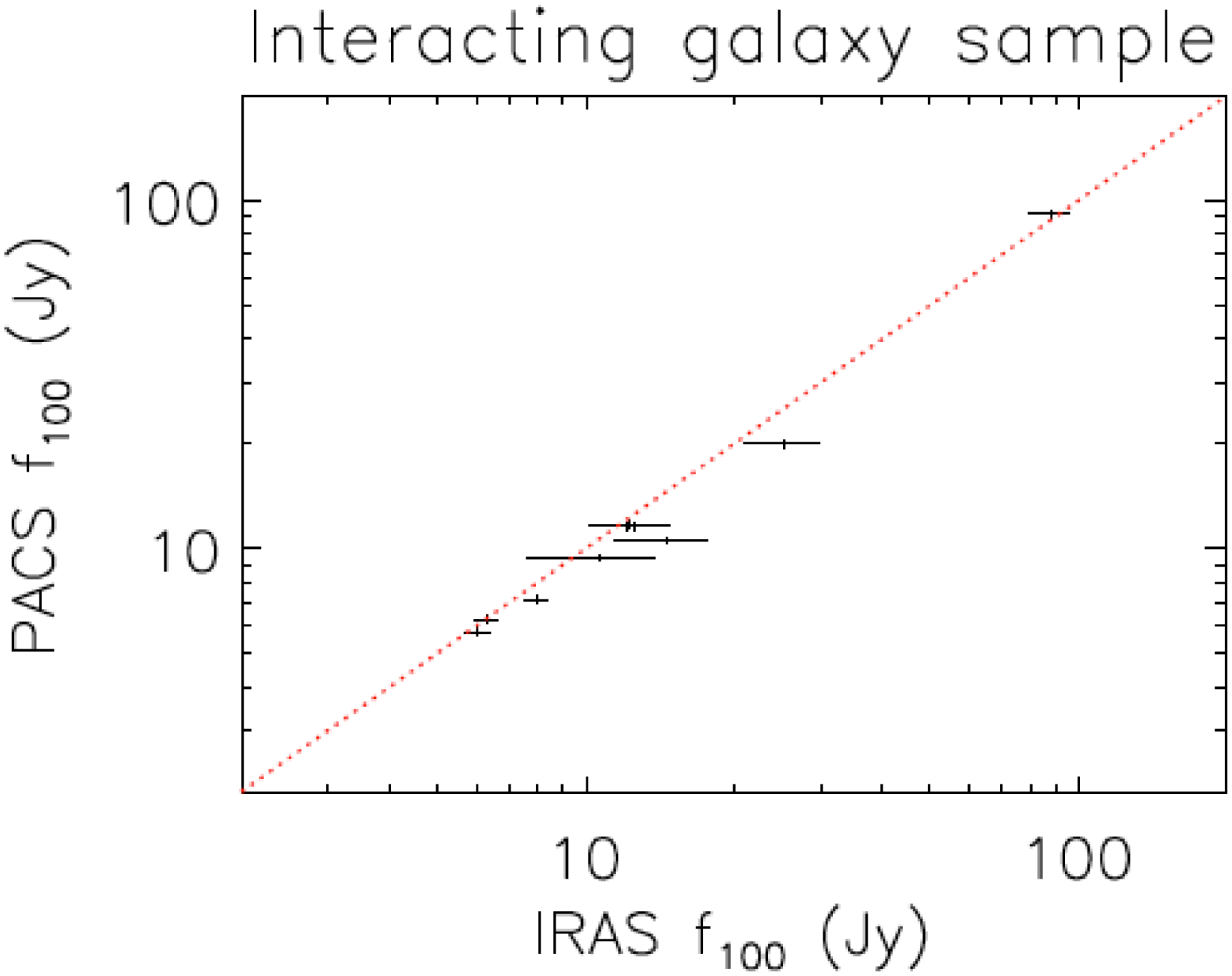
PACS-P Flux extraction: Small red excess?



PACS-P Error Budget

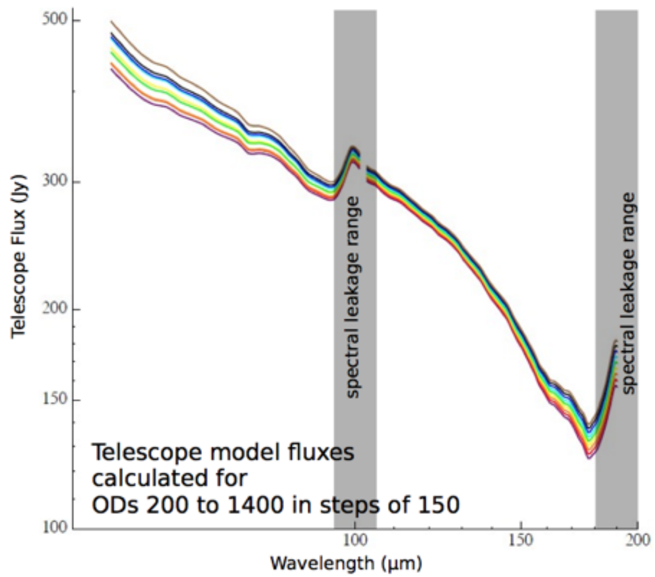
- **Absolute calibration** ~5-7% (+ < 2%)
  - accuracy of the standard fluxes: 5%
  - colour correction: 1-5%
  - non-linearity correction uncertainty (only bright sources): < 2%!
- **Relative calibration (reproducibility)** < 1% at 70 and 100; < 3% at 160 (assuming standard minimap setup)
  - flat fielding uncertainty: negligible residuals due to the use of many pixels)
  - pointing jitter: affecting a PSF width hence the correction of the EEF (depends on aperture size): < 0.3%
  - evaporator temperature correction residuals: < 0.2%
  - variation in telescope background (response change):~0.5%
  - DA conversion: negligible
  - distortion correction uncertainty: < 0.5%
  - map making method: < 0.5%

PACS-P Extended Emission



PACS-S: Calibration Updates

- Update of the time-dependent background model for Telescope Background Normalization (TBN) of flux
  - Smooth Fischer et al. model known to badly represent PACS background & its evolution
  - Replaced by empirical model built from Ceres & Pallas observations
  - Flux calibrated to the entire set of celestial calibrators (stars and asteroids)
    - o Less dependent on systematics from Pallas & Ceres models
    - o consistent with calBlock + RSRF



PACS-S Calibration Cont.

- calBlock + RSRF scheme remains important (no TBN) for
  - o Unchopped (no telescope measurements to normalize to)
  - o Spectral lines in red-leak > 190 µm (e.g. CO 13-12, NII)
  - o Useful to assess off-source contamination

- Calibration accuracy unaffected:
  - • 4% RMS in all bands (15% pp)
  - • In band accuracy 10%, with possible improvement thanks to pointing offset correction

PACS-S Products

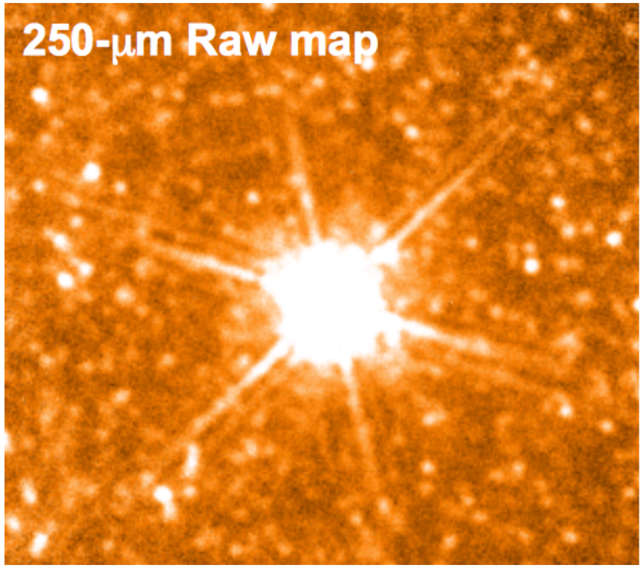
- In HCSS 13. Consistent products set across modes.
  - Includes standalone product with **rebinned cubes of equidistant frequency/wavelength and ra/dec.** ***(HUG recommendation)***
  - ASCII table of rebinned cube *(HUG recommendation)*

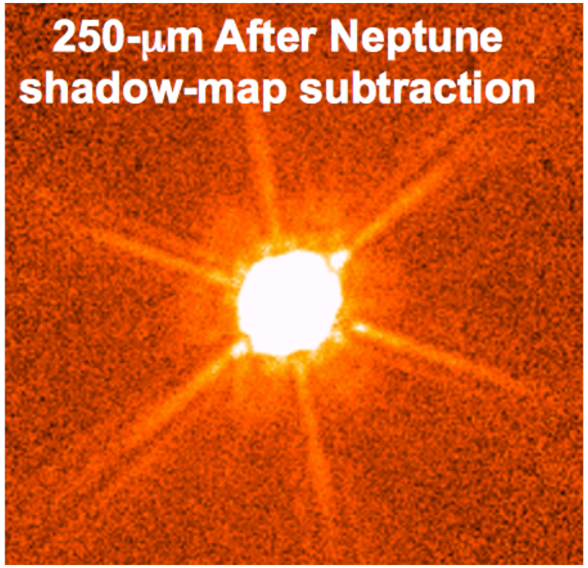
- Flux correction available in HIPE to handle the case of **marginally extended sources** (< 25” ~ 3x3 spaxels)

- **Also see DP discussion of products science readiness.**

5. SPIRE-P Calibration Updates in PostOps

- Beams
  - Beam profile maps improved using **shadow observations** of Neptune
  - The **radial beam calibration product** updated for new beams.
  - **Colour correction products** have been updated for new beams.
  - A **new "fine" beam map** is provided for each band with 1" pixels. The "nominal" maps are also available with pixel sizes of 6", 10" and 14" for PSW, PMW and PLW.

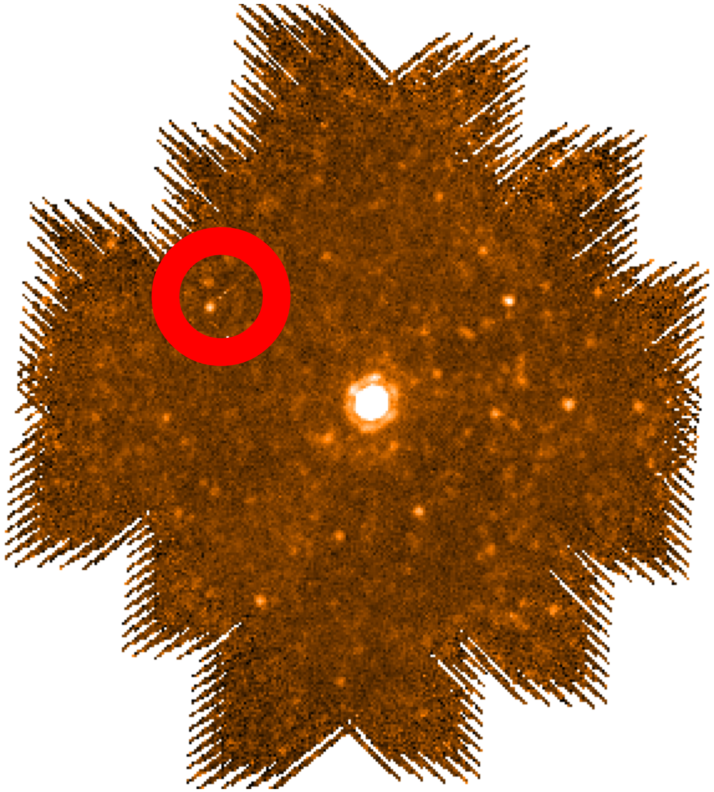




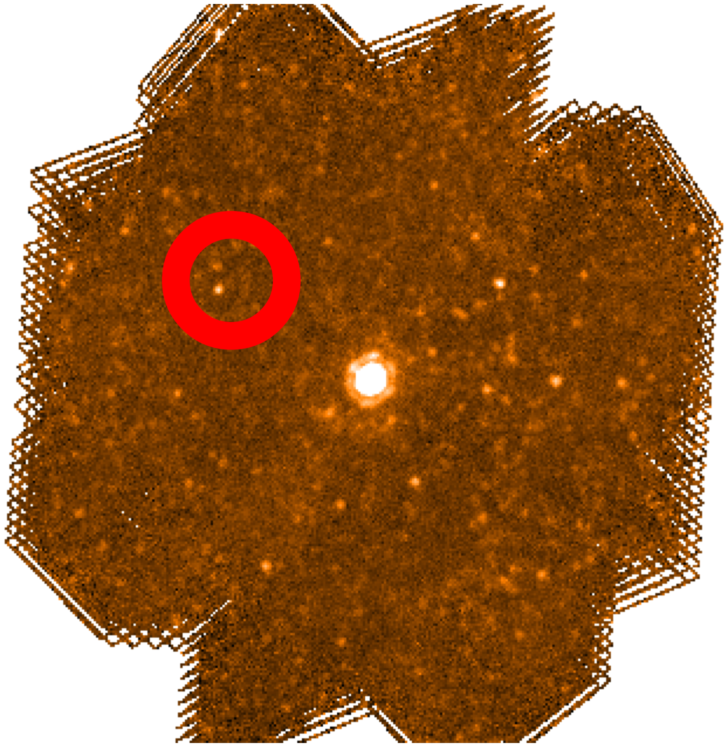
SPIRE-P Calibration Updates

- **Drift Correction**
  - The parameters in the temperature drift calibration product that are used to perform **cooler burp** correction have been updated to improve the correction.
- In HIPE 13, **a 2-Pass Pipeline** has replaced the standard pipelines for Large, Small and Parallel modes.
  - The 2-Pass Pipeline runs iteratively on the data to produce optimally cleaned timelines.
  - The first pass is run with minimal tasks (e.g. no FT tasks). **Glitches are detected and flagged using 2nd level deglitching outlier detection**.
  - The full pipeline is then run using all the standard tasks.

2-Pass Process & turnaround data scan data inclusion



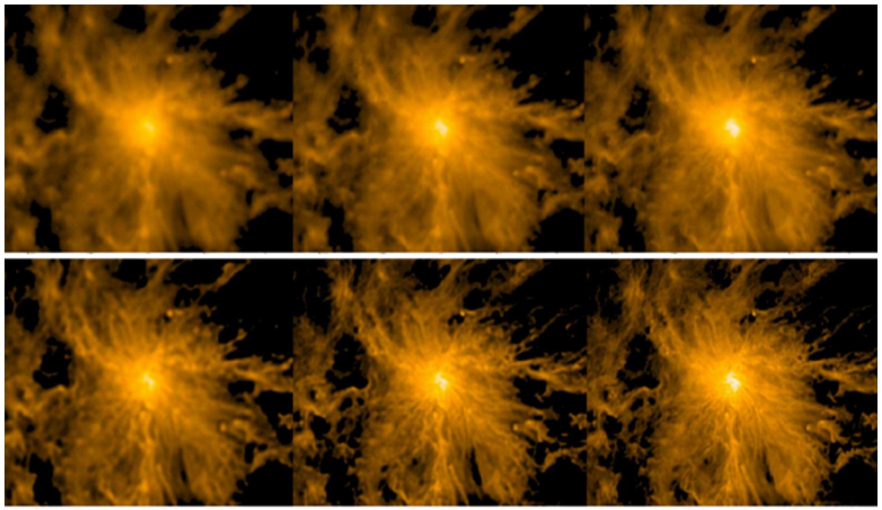
HIPE 12.1



HIPE 13.0 – no tail up and to right of main source in circle.

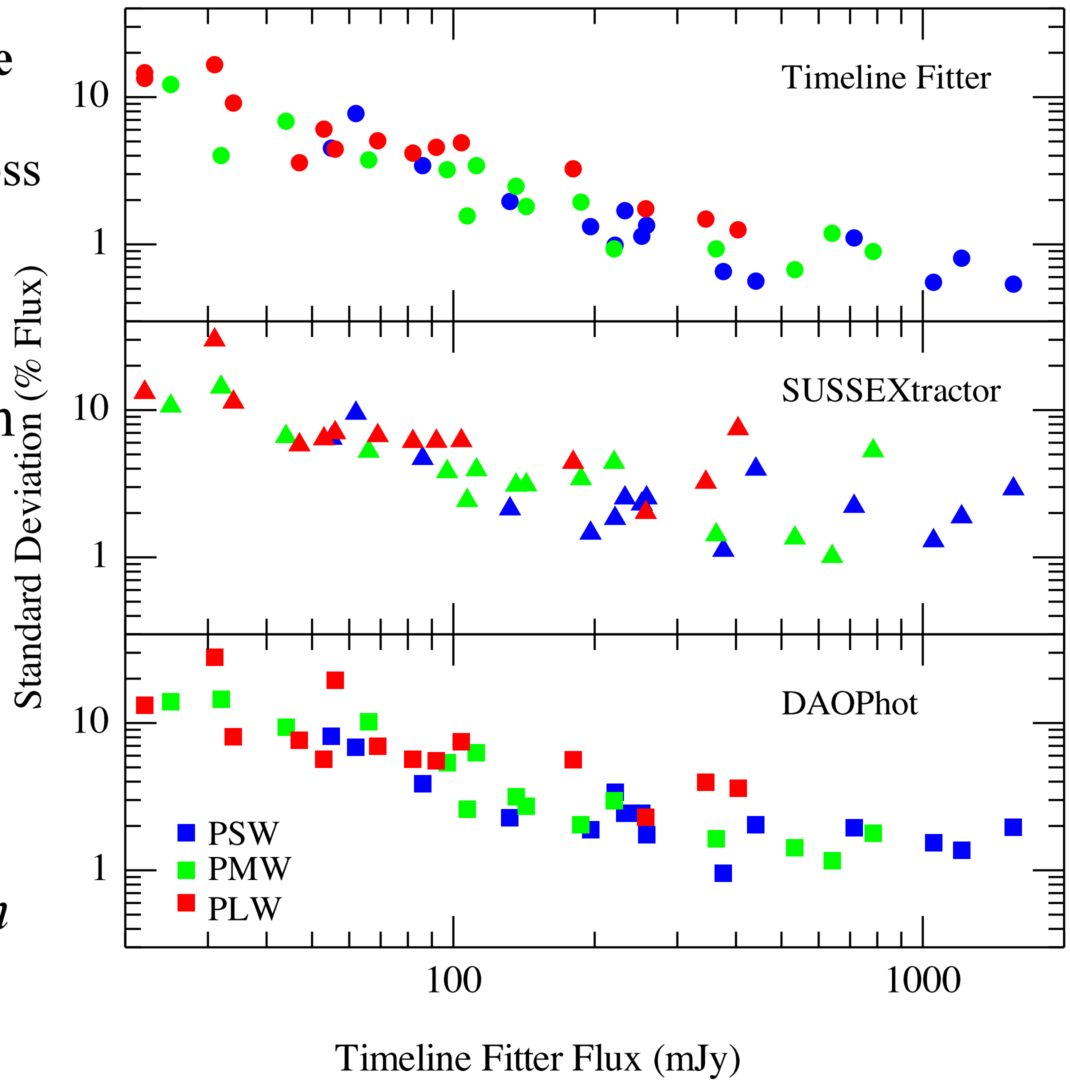
Further SPIRE-P Updates

- **Super-resolution:**
  - Script in HIPE for users.
  - Looking to make a standard product in HCSS 14, but validation to occur.
  - Possible resolution enhancement of max. factor of 3. Below shows iterative sequence to higher resolution.



SPIRE-P Error Budget & Flux Extractors

- Calibration uncertainties:
  - **± 4% absolute from Neptune model** (this uncertainty is systematic and correlated across the three bands)
  - **± 1.5% (random)** from Neptune photometry
- Extended emission calibration
  - In addition to the above uncertainties, there is an **additional ±1%** due to the current uncertainty in the measured beam area
- For lower fluxes, random component uncertainty increases – see right (*paper in advanced draft, Lim et al*).

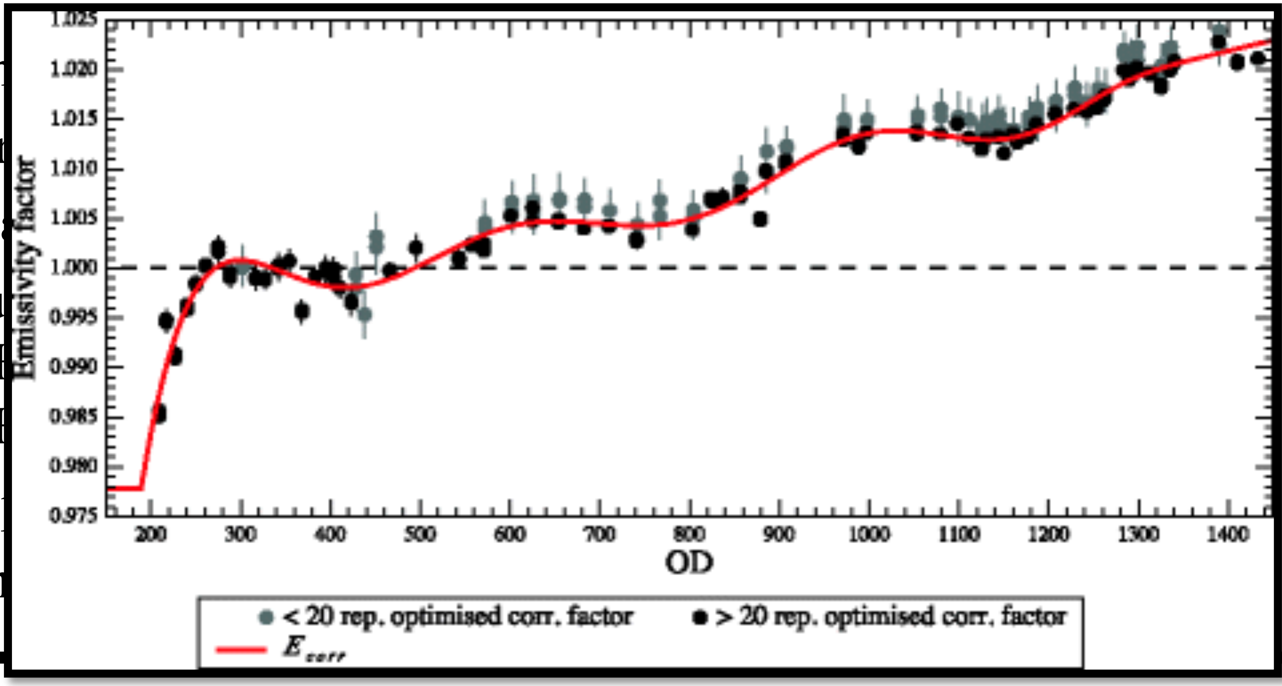


SPIRE-S: Calibration updates

- Wider bands in HIPE v12.1+
- Point-source calibration updated with the pointing offset of Uranus, since HIPE v12.1+
- All spectra are now in LSR frame, since HIPE v12.1+
- Maps use vignetted detectors too, from HIPE v12.1+ on.
- Treatment for semi-extended source is available from HIPE v12.1+
- Much improved observation context structure (response to HUG) in HIPE v13
- Fixed processing of sources during very cold instrument, in HIPE v13

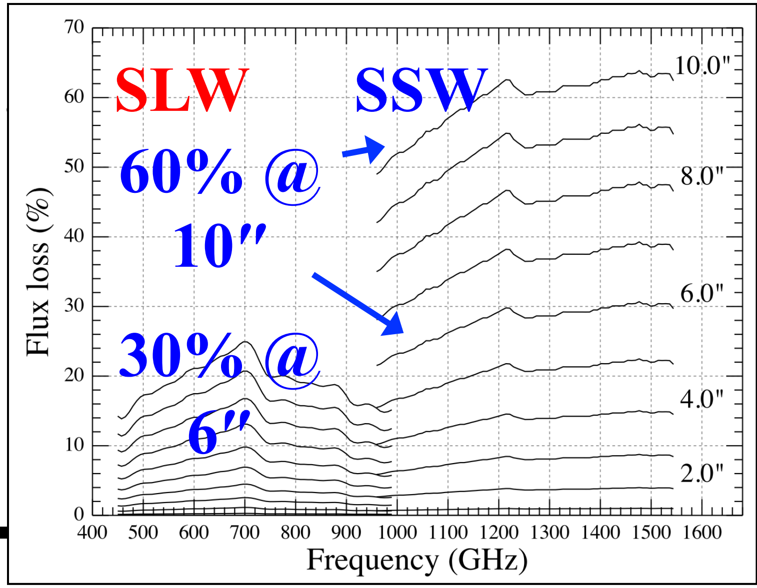
SPIRE FTS Extended Source Calibration & Errors

- Extended calibration using the Herschel telescope emission:
  ➔ spectra in W/m^2/Hz/sr
  More details in Swinyard et al. (2014)
- Beam maps from Neptune, Makiwa et al. (2013)
- Telescope model: using the temperatures of primary and secondary mirrors, M1 and M2, + emissivity model + emissivity correction (Hopwood et al. 2013).
- Calibration uncertain
  - Systematic uncer
  - Statistical repeat
  - Additive continu
    3.4×10^{-20} W/m^2/
    1.1×10^{-19} W/m^2/
  - Spectral maps re
  - **Total: 1% exten**



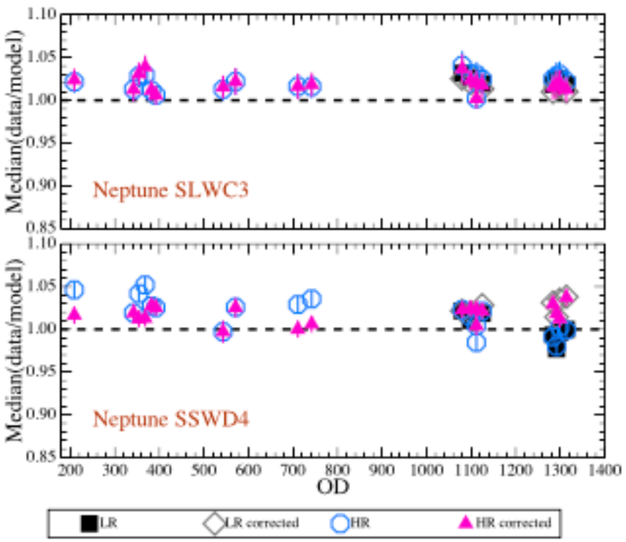
SPIRE FTS point source

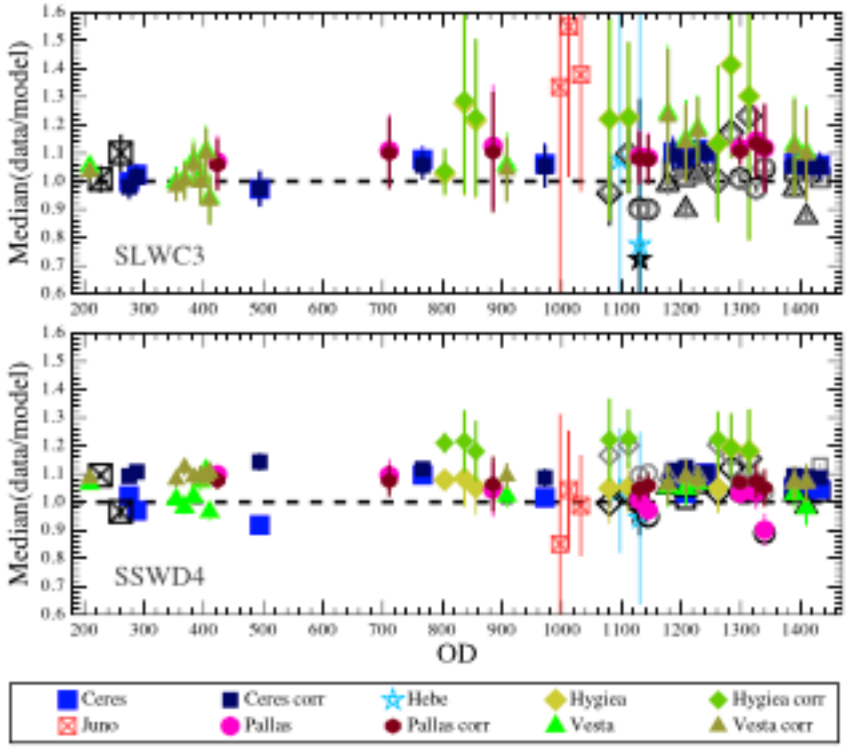
- Point source calibration using Uranus ESA-4 atmospheric model (Orton et al. 1986, 2014) ➔ spectra in Jy
- Conversion factor Cp(v) to go from extended calibrated to point source calibrated.
- Calibration uncertainties: **total 6%**
  - Absolute systematic uncertainty from Uranus model: ±3%
  - Statistical repeatability for Uranus and Neptune: ±1% (consistency of Uranus ESA-4 and Netune-ESA4 models used by SPIRE for FTS and SPIRE-P calibration).
  - Additive continuum offsets: 0.4 Jy (SLW)
  - Herschel pointing (See figure)
- Detailed study of calibrators:
  - Hopwood et al. (2015)



Valtchanov et al. 2014

Consistency of SPIRE FTS Measures

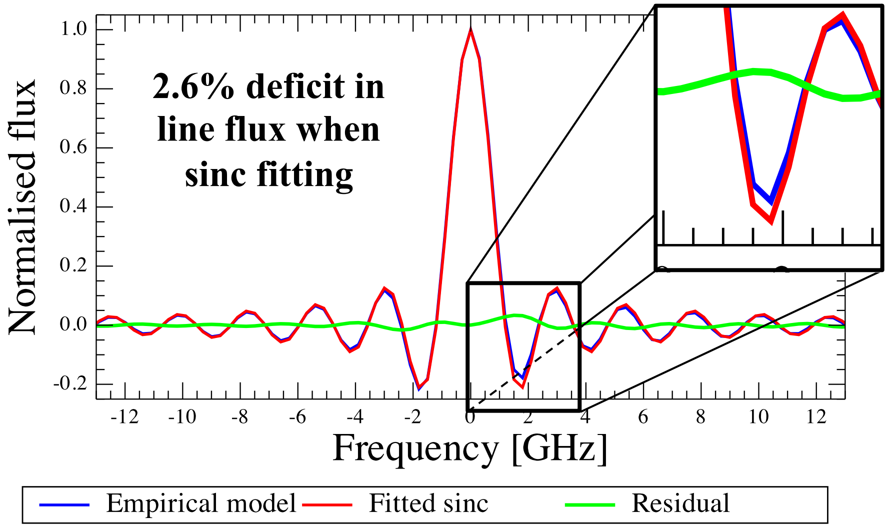




After pointing correction – within 5% of models for planets and asteroids models over the operational days (OD) of the mission

SPIRE-S: Key remaining Issues

- Line Sinc Functions:
  - SPIRE FTS lines are not pure sinc functions. There is a 2.6% deficit on one side of the function which is likely caused by a small deficiency in the working of the interferometer mechanism



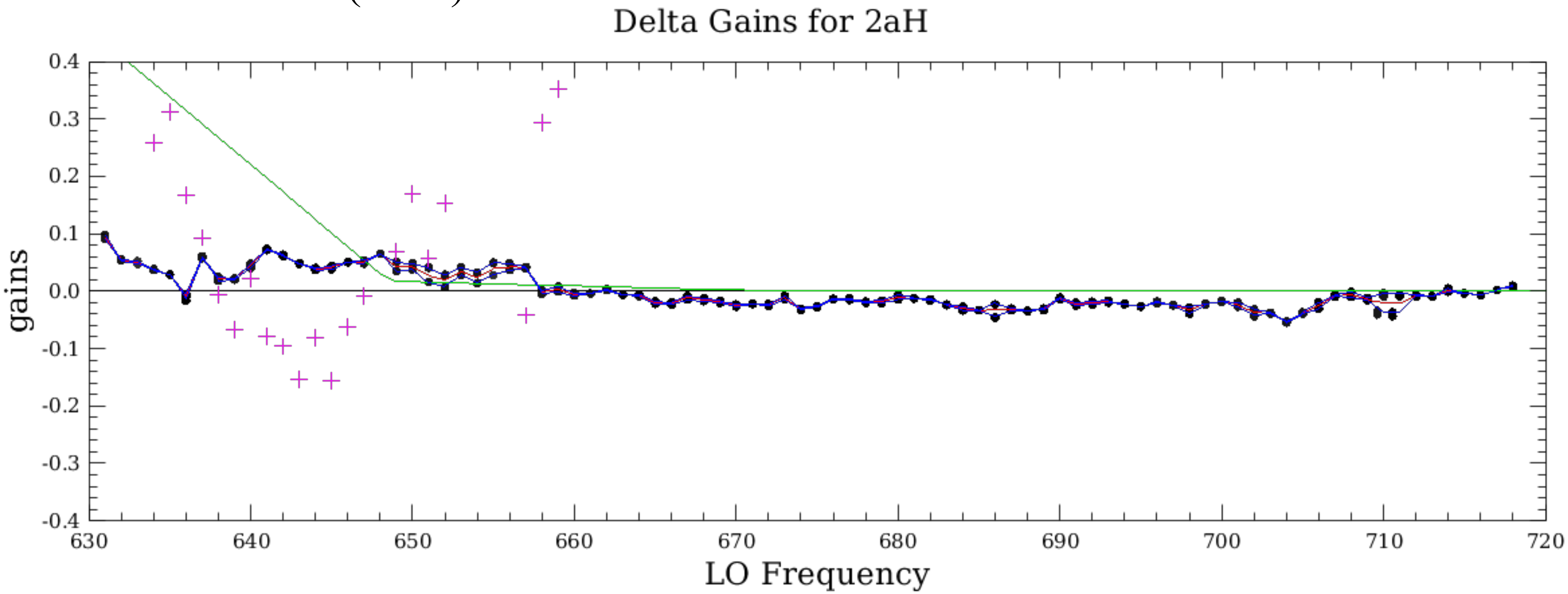
- LR calibration:
  - "bumpiness" in first several scans – depends also on resolution of scan before. Analytial and empirical approaches need to be applied.
- Correct Semi-extended source fluxes:
  - Requires use of SECT tool in HIPE. Likely provide as HPDP set of data in the archive.

6. HIFI Cal: Electrical Standing Waves in Bands 6 and 7

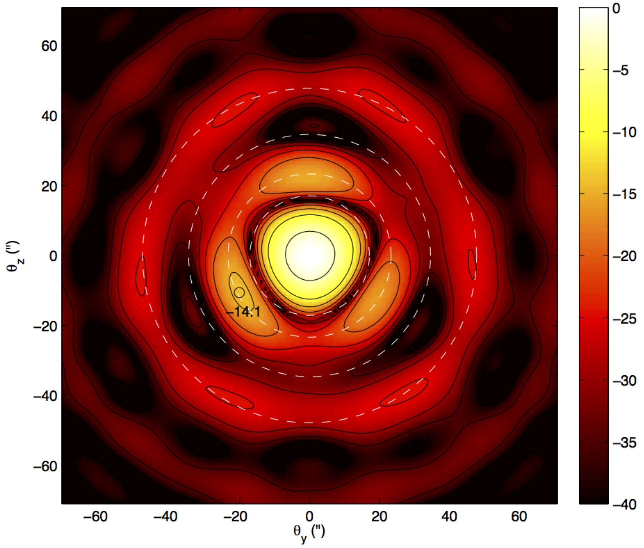
- Part of the HIFI pipeline in HIPE 13:
  - Allows correction for any observing mode
  - Uses a large data-base of (emission-free) OFF positions spanning a wide range of Electrical Standing Wave (ESW) shapes
  - Discussed at last HUG meeting.
- First solutions applied via HIFI pipeline in 13.0
  - correction applied via calTree
  - metric for improvement developed and under investigation
- 1808 point spectra inspected
  - 40 obsids identified as poor corrections based on existing ESW models.
  - available in latest HIFI calTree
- **TODO**
  - add 40+ obsids to existing ESW models suite
  - HIFI maps - expert reduced data products will focus on ESW correction results

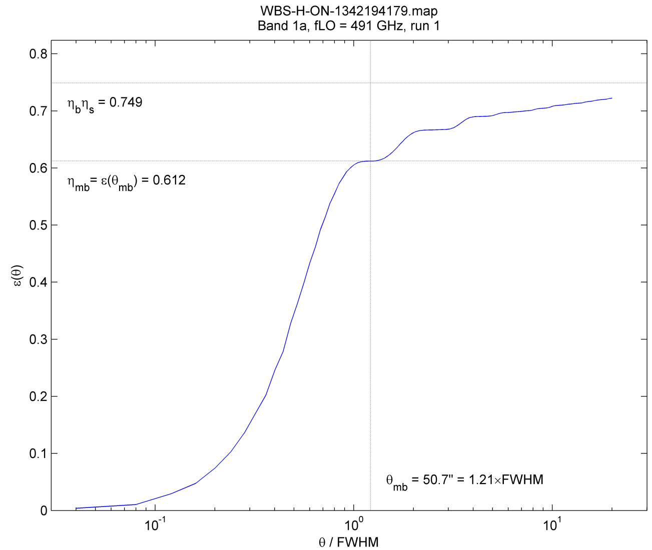
HIFI Instrument Calibration: Side-band ratio

- Coming to fruition. New deconvolution technique applied to data across the mission as well as gas cell data (see below) has produced significant advances that will show as modified sideband ratios in the HIFI calibration tree used in HIPE 14+.
- Production of observation contexts from gas cell campaign for ingestion into archive (HSA) almost done



Beam maps and encircled energy fraction diagrams /info from release note of September 2014. Available from instrument web pages.



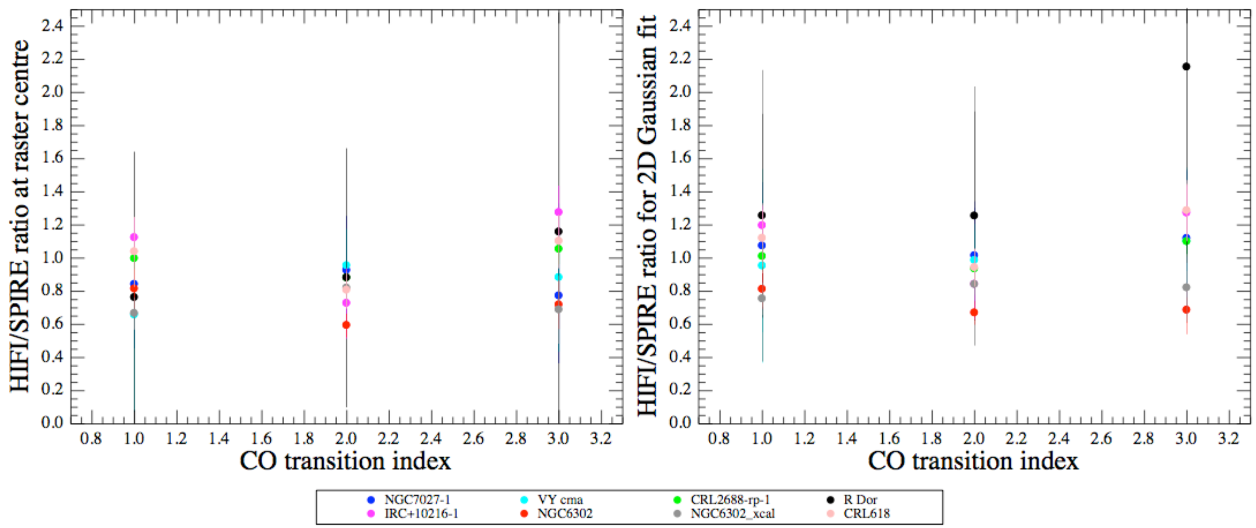


Updated efficiency values (although normal assumption of Gaussian main beam is clearly not true). Noted at last HUG meeting.

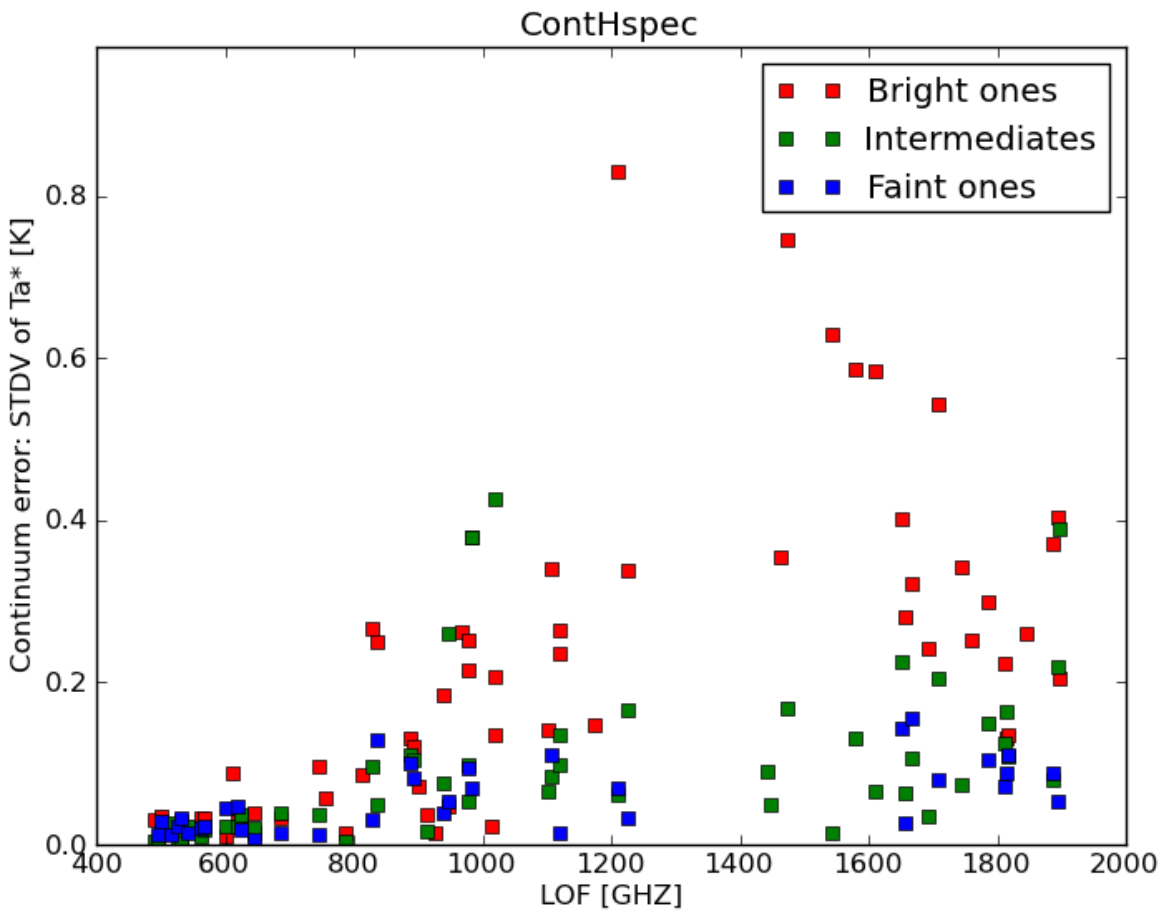
HIFI Calibration: Continuum Assessment

- Continuum not guaranteed accurate for HIFI observations (originally) but generally appears to be consistent.
  - Mars continuum measurement reports indicate consistency. Nov 2014
  - Other flux levels for objects (incl within science programmes) and solar system objects still being investigated.
  - Initial internal report April 2015 is promising. But continuing.

Fair agreement with SPIRE continuum



Continuum noise sources under debate



HIFI and Spectral Line Lists

- Spectral line identification is common to the three Herschel instruments.
- The following catalogue products have been defined:
  - **Spectral Line List product** will be the output of automatic extraction tools, and interactive tools (TBD). Lines are defined using a 3 parameter model (e.g. Gaussian) with a position, a width and an amplitude.
- **NB: Source List product** is aimed at holding relevant information on the properties of sources extracted from Herschel images.
- The spectral line list product will be the output of automatic extraction tools, and interactive tools. In HIPE? Use for higher data products? [TBD]
- For now – task for user is available for **line identification**.

http://herschel.esac.esa.int/hcss-doc-13.0/load/pdd/html/catalogueprods.html

HIFI Error Budget

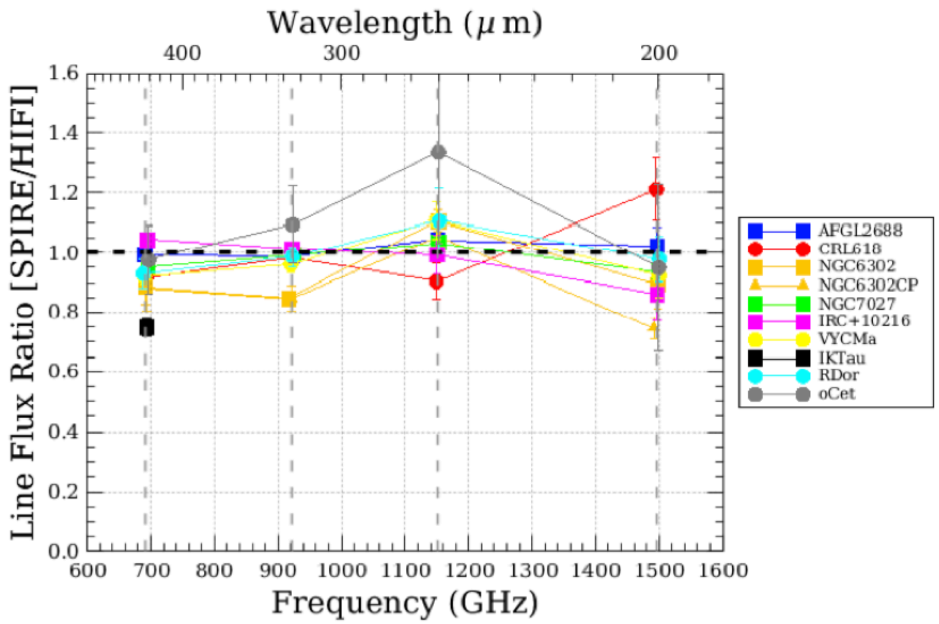
- Ongoing workpackage to complete the job properly, but current status given below.

	HIFI mixer band			
Error source	1 & 2	3 & 4	5	6 & 7
Hot load coupling	< 1	< 1	< 2	< 2
Cold load coupling	< 1	< 1	< 1	< 1
Hot load temp	< 1	< 1	< 1	< 1
Cold load temp	< 1	< 1	< 1	< 1
Planetary model	< 5	< 5	< 5	< 5
Pointing	< 1	< 3	< 4	< 8
Beam efficiency	< 2	< 2	< 2	< 2
Sideband ratio	3 – 4	4 – 6	4	3 – 4
Opt. standing waves	4	4	3	3

7. Spectral Cross Calibration

- Draft paper created but on hold (maternity leave of first author).
- Consistency of measurements through the mission.
- Complex – few bright line point sources.
- But agreement is reasonable so far between instruments.

CO line comparisons between SPIRE and HIFI



8. Point Source Catalogue Overview

- Will look at all SPIRE-P and PACS-P observations and will extract point sources for all objects detected in the fields.
  - A bit like the Hubble source catalog.
- Potentially 2 million sources.
- Currently separated by band (3 SPIRE and 3 PACS bands).
- Feasibility studies done (check of algorithms/techniques done and agreed to go ahead.
- Looking at first delivery around end of 2015/beginning of 2016.
- To be provided in the archive and linked to observations via obsid.

Point Source Catalogue Progress

- *PACS/SPIRE PSC Coordination Meeting in Feb at IPAC. Catalogs for PACS and SPIRE will look similar and are now defined*
- Reduced full SPIRE scan map dataset (few exceptions) to Level 2 and Level 2.5
- Created a repository @ NHSC of PACS and SPIRE high-Level maps (without duplications)
- First test of the PACS pipeline on UPDP (PEP). Looking for a ‘more structured’ test case (Rosette, Gould belt, nearby galaxies). Not yet E2E test but csv files of extractions generated. Relational Postgres database with source ingestion scripts for SPIRE created at IPAC.
- **Performed point source extraction on representative datasets (160 obsIds)**
- SPIRE: Position corrections for representative dataset through stacking on WISE sources
- List of 2MASS large galaxies with semi major axis > 1’ obtained from NED (regions of complexity to be treated specially).

9. Conclusions

- Calibration improvements now just about complete for instruments and being propagated to the products. Tidy-up in HCSS 14.
- Absolute photometer errors limited by calibration models. We are looking into the errors of extraction (also needed in the point source catalog production) and some of these are reported here.
- Cross-calibration with Planck is done (papers making slow progress). Cross-calibration for photometers indicate gains are good to better than 1%. Spectral line measurements are consistent but need care – no point sources have emission lines!
- Systematics: better understood – including in calibration models
- Error budgets: not complete but getting more complete. Also better errors for lower flux sources (rather than just on the calibration sources).
- Pointing:
  - Gone about as far as we can. Some last tweaks that will affect quality of some observations somewhat. Couple of small possible updates.
- Point Source Catalog creation for PACS and SPIRE. This is a major activity for the next year or so and will create a catalogue of about 2 million sources. Probably extend to bandmerging.