Herschel Calibration Report for HUG#6.

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To Herschel User's Group #6, 8-9 April 2013.

Outline of Presentation

1. General Items Regarding Calibration
2. Calibration Models
3. PACS Instrument Calibration
4. SPIRE Instrument Calibration
5. HIFI Instrument Calibration
6. Cross-calibration
7. Pointing
8. Conclusions

1. General Items Regarding Calibration

- Herschel Calibration Steering Group meetings #32, two day meeting 13/14 Dec. Leading to improved planetary calibration models (e.g. still waiting on Neptune ESA4 model for SPIRE-P).
  - Main point was clarification of necessary calibration tasks before launch
  - Also defining needs for post-cryo instrument tests.

- **Special open map-making workshop held at ESAC 18-20 January 2013 (see later)**

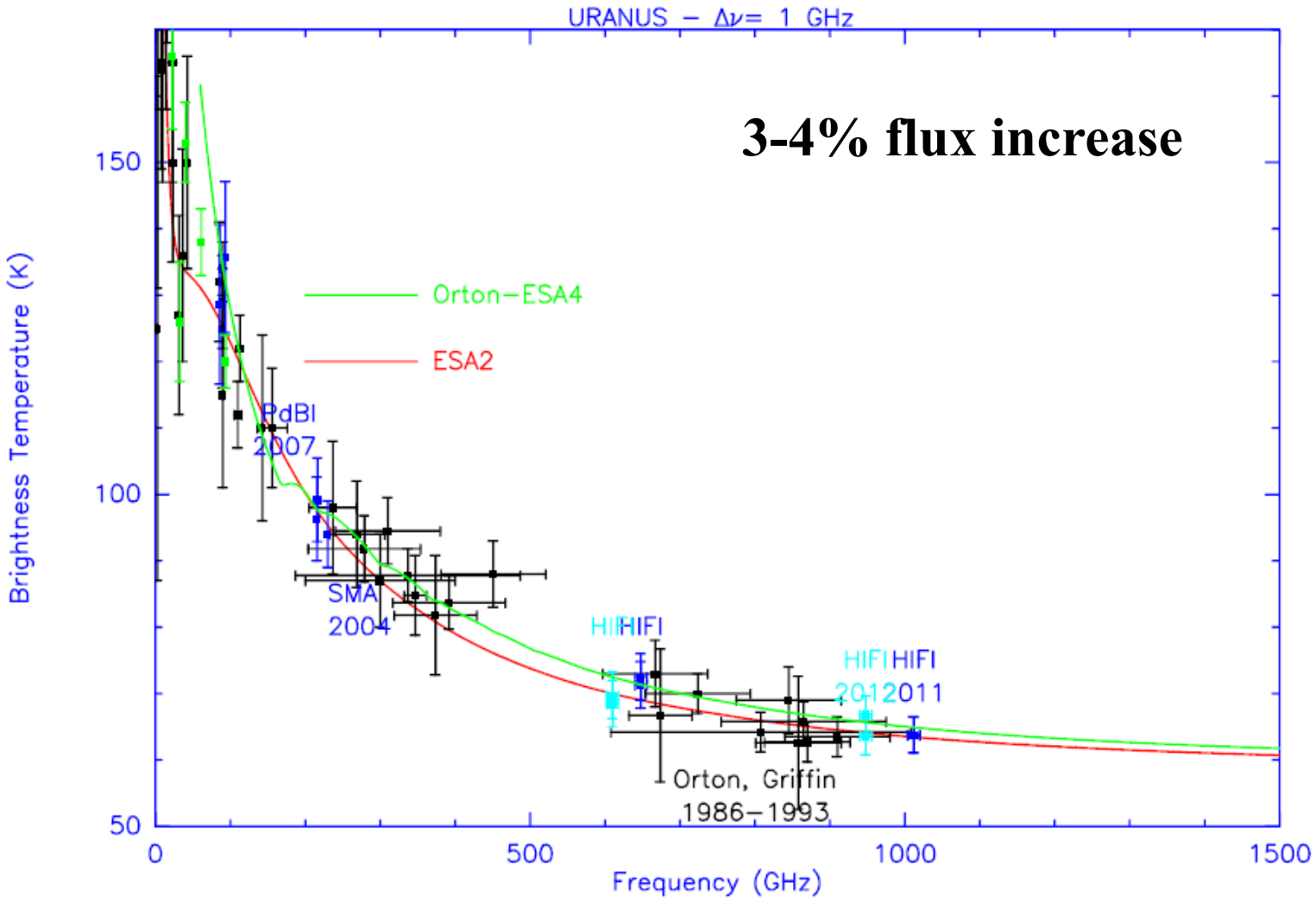
- **Public calibration workshop held 25-27 March 2013. Expect that a number of presentation will be in refereed European journal, Experimental Astronomy. Marston to act as guest editor for a special edition of the journal.**

- **See later for calibration highlights and updates included in HIPE.**

2. Calibration Model Updates

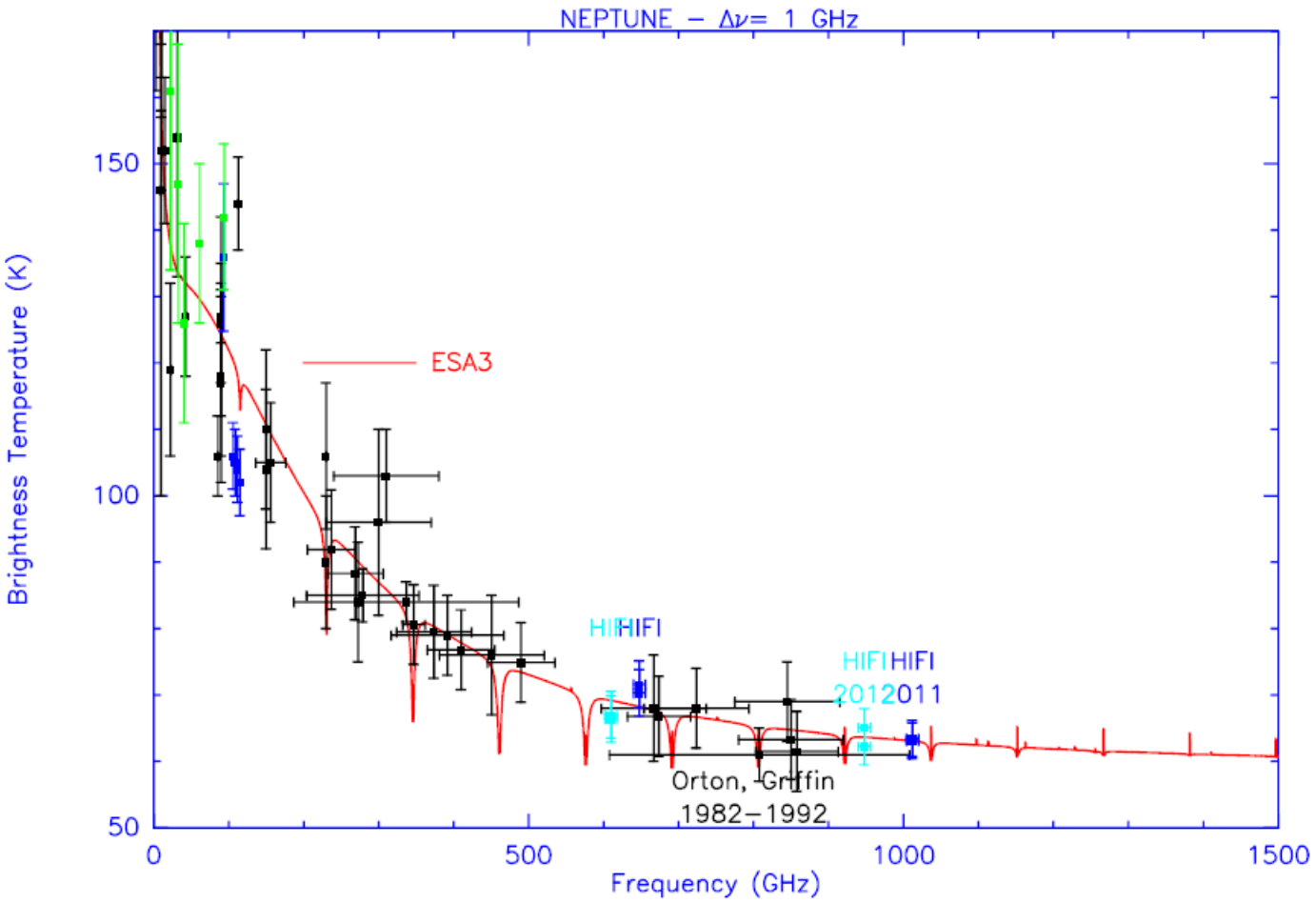
- Calibration of all instruments is done against models of planets (notably HIFI and SPIRE) and stars (notably PACS).
- **Main planetary calibrators** are *Mars, Uranus and Neptune*. **Recent update of Uranus model (ESA4).** Currently given as 5% absolute error.
  - Update for Neptune (ESA4) still pending although an unofficial version to be used by SPIRE in HCSS 11.
  - Includes more feedback of PACS and SPIRE spectral line measurements for constraining planetary atmosphere → 2-3% error?
  - Planetary models (Neptune/Uranus/Mars) are within 2% agreement of each other. HIFI is using Mars as main calibrator – completely consistent with Uranus and Neptune models.
- **Stellar models** are to change, but not much, with improved input parameters (sizes at wavelengths being used and best K band photometry). Still have an absolute level dominated by systematics.
- **Asteroid models** are more secondary calibrators but shown to be good enough that 3-4 being looked as possible future primary calibrators (a **Herschel calibration legacy**).

Uranus comparison with Mars

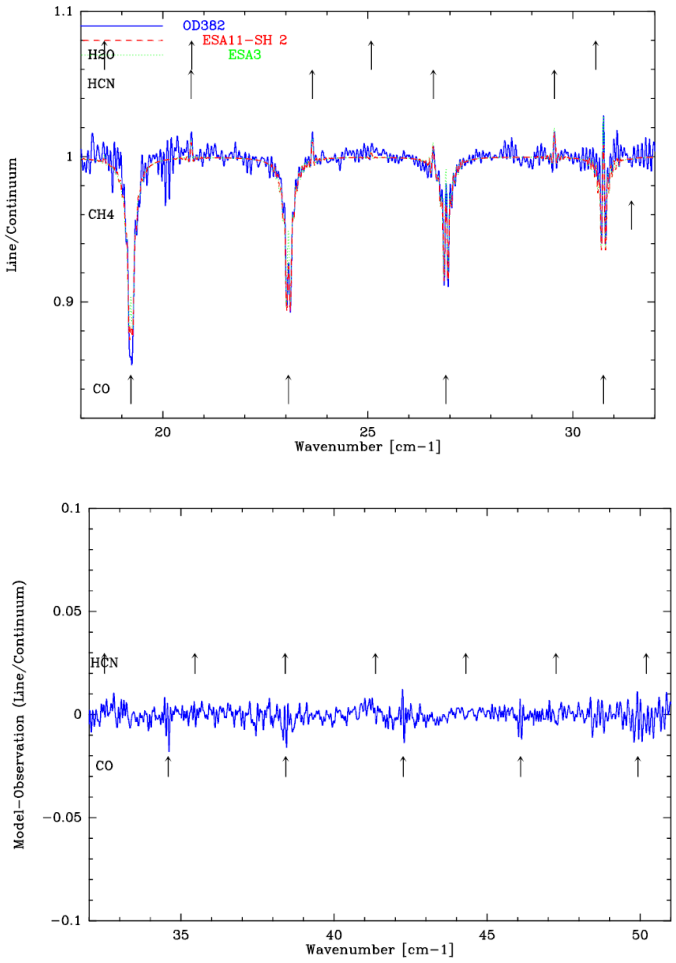


Neptune comparison

Current model used (ESA3)



Neptune model – gained CO line improvement



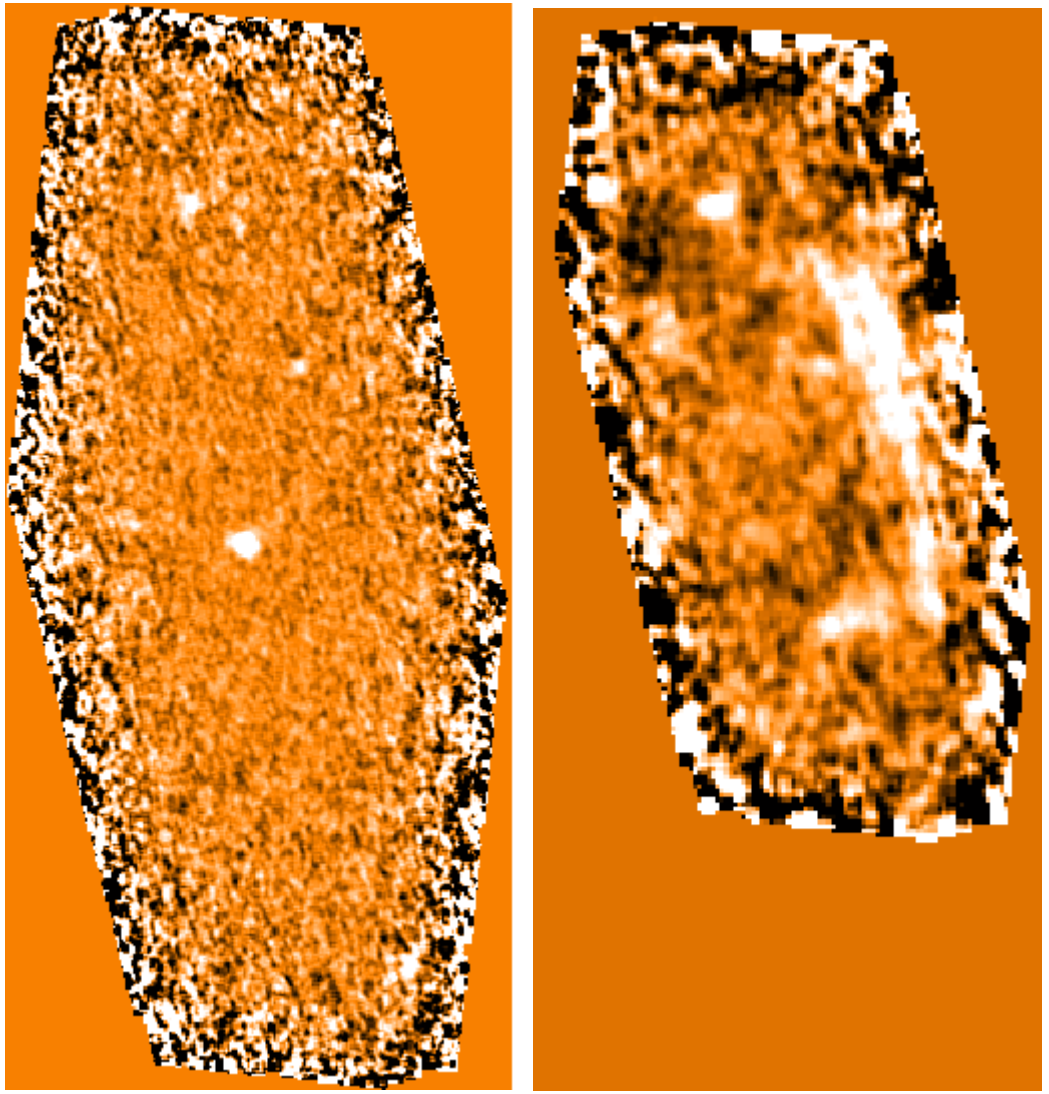
ESA4 model (pending).
Better CO profiles. Some tweaking to come. But flux of final model not very different (<1%) from the one we have been using.

3. PACS Instrument Calibration

- General:
  - Calibration improvements
    - *PACS-P extended emission* – matter being looked at more closely with Spitzer non-linearity info in hand. Now have some info on Spitzer website to warn users.
    - PACS-P fluxes moving towards flux calibration update based on stellar model updates (small).
    - *Mapper comparisons suggest improvements possible/different mapper in pipeline.*
    - With PACS-S there has been a lot of work to reduce the effects of pointing jitter on the overall spectrum
    - Improved pointing accuracy → improved fluxes for PACS-S but not so simple…

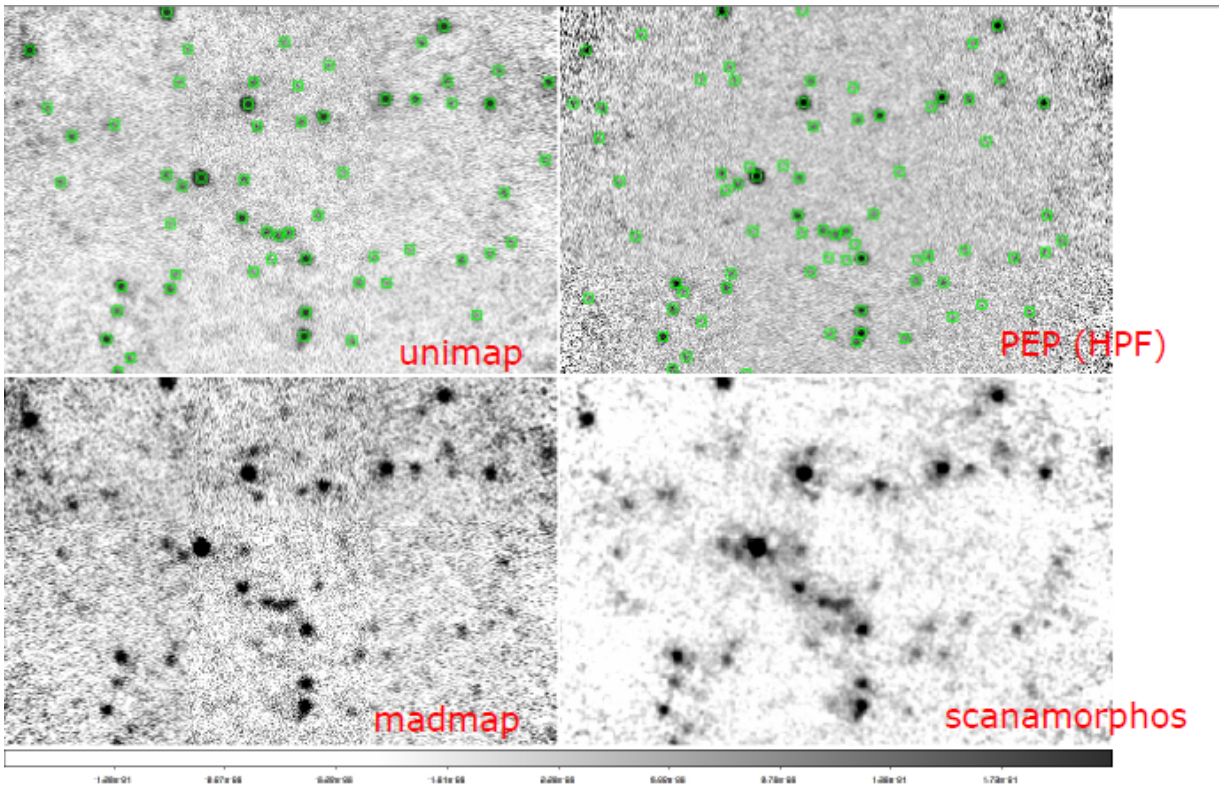
3.1 PACS-P situational update

- PACS-P red array: lost half of the red array. Only a few ODs operated since. Data is fine but reduced area and factor of 1.4 increase in noise for red scans.
- Images show blue (on left) and red (on right) images from PACS mini scan from the same observation.
- Used as-is for the last ODs.



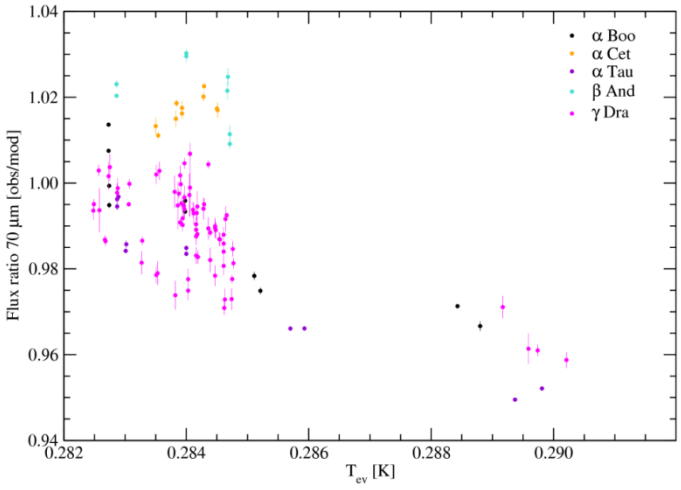
PACS-P Mappers

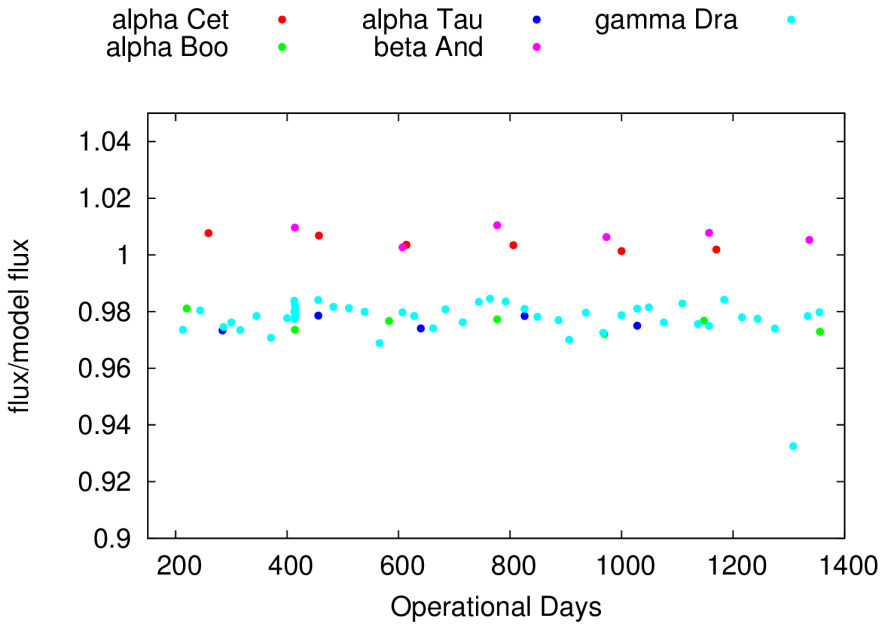
- GLS mappers look to solve several issues. UNIMAP (used by HIGAL) being tested heavily. Good with extended emission and point sources. Change in pipeline?



PACS-P Flux corrections

Corrections for evaporator temperature and mirror changes – effect on calibrator measurements





Sensitivity seen to vary with PACS evaporator temperature. Also effects of changing mirror temperature and emissivity seen! Can be removed (see LHS) for stellar calibrators.

PACS-P flux calibration

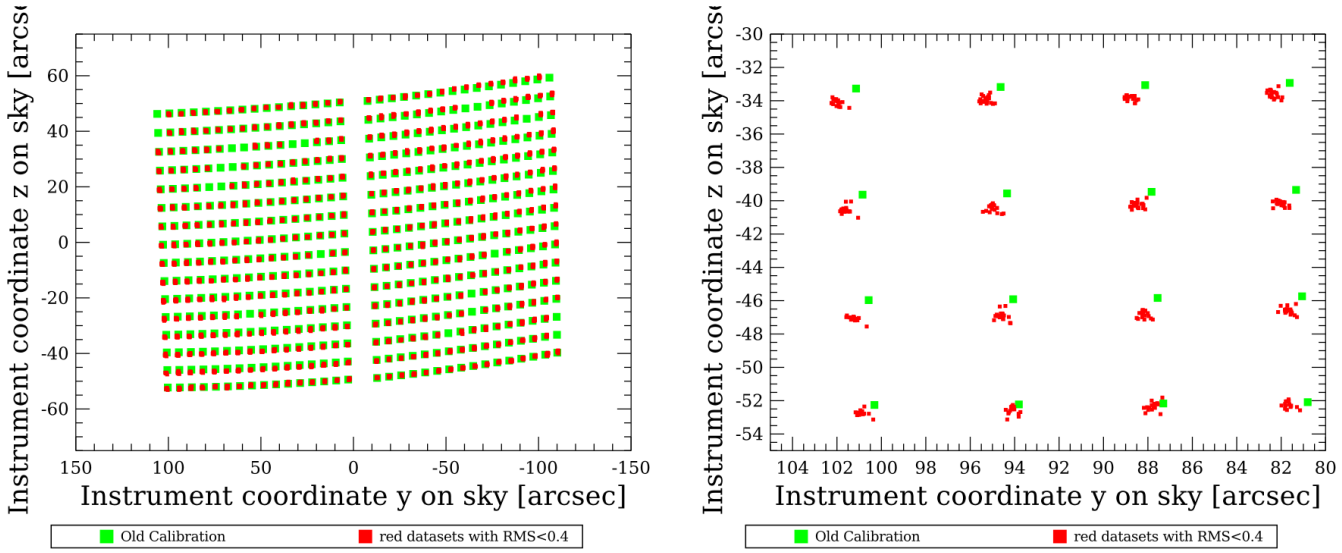
- Blue filter repeatability now at sub 1% level (see RHS).
- Red filter slightly worse.

Current calibration

α Tau	0.976	0.002	0.017
α Boo	0.976	0.003	0.015
γ Dra	0.978	0.004	0.009
α Cet	1.004	0.002	0.004
β And	1.007	0.003	0.007

Mean: 0.982±0.016

PACS-P: Focal Plane Geometry update



- Approx. 1% change since on-ground measurements.
- Will impact PSF and encircled energy functions.

PACS-P Future

- Updated stellar models to be included
  - + corrections for evaporator temperature sensitivity changes and long term mirror changes.
  - Effects are small but that is what we are dealing with as far as calibration is concerned
- Need decision on way forward with mappers – UNIMAP?
  - Consistent point source fluxes across mappers, BUT some better with extended emission and production with error maps, clarity of use etc…
- Pointing updates can improve some cross-like artifacts associated with bright objects in PACS-P maps, notably where maps are combined (scan/x-scan).

3.2 PACS-S Calibration Improvements

Calibration blocks – track response drifts between observations.

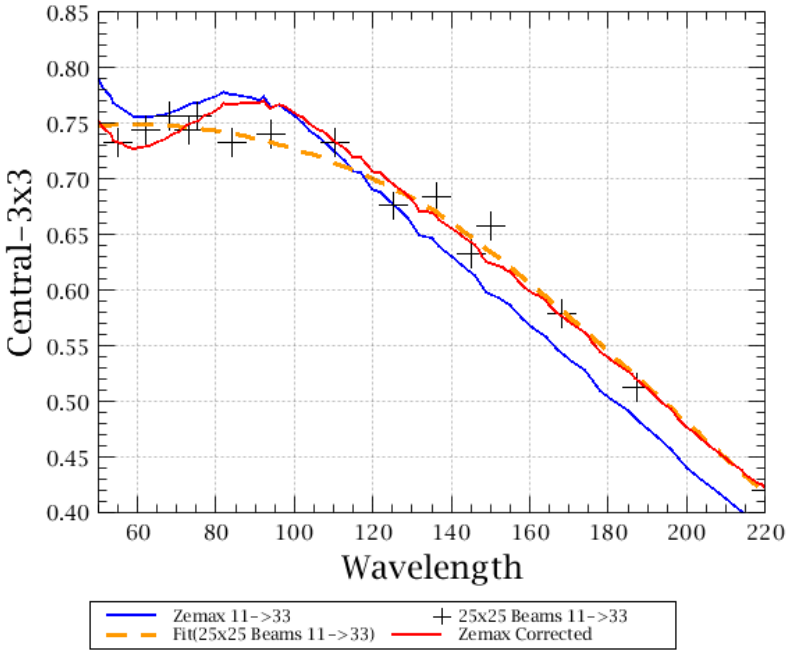
Internal calibration sources calibrated on sky calibrators

→ originally, central spaxel only (hipe 8, cal. set 31)

→ now, central 3x3 spaxels (hipe 10, cal. set 44)

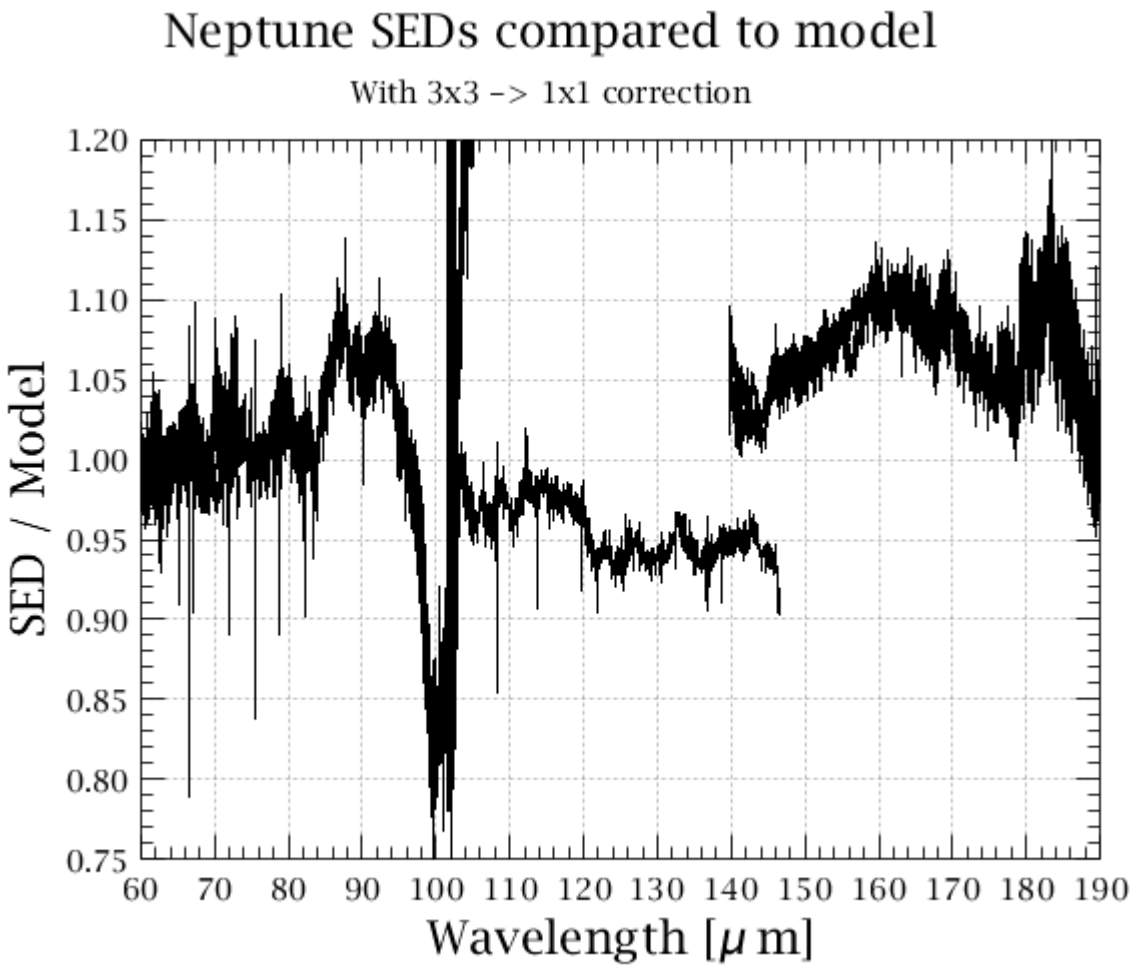
More robust against mispointing – or target offset from nominal centre. Also better extended source calibration (~5%).

Use of central spaxel information der : in HIPE). See orange curve on graph.



Telescope Background Normalizati

PACS-S SED observation versus Neptune model

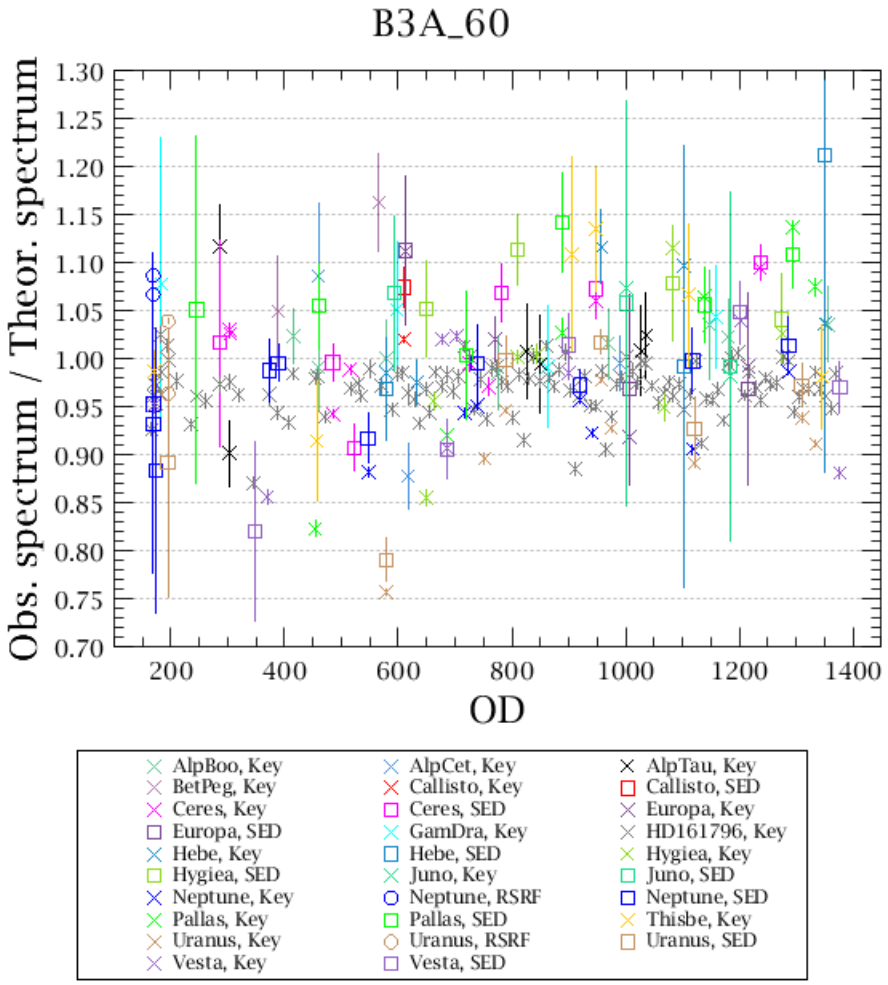


PACS-S: Telescope normalization

- For chopped measurements
  - Telescope visited @every grating position
  - “instantaneous” track of response
- Makes use of the telescope model
- No use of the RSRF needed
- Source measured in 'telescopes ‘
- Telescope calibrated on Neptune rasters
- Now includes mirror ageing effects.

PACS-S: Reproducibility

- Example reproducibility comparing against many calibrator models. Key calibrators marked by crosses (uses 3x3 spaxel extraction).



Reproducibility on source HD169716 (112 obs)

Spectral Band	RMS	Peak-Peak accuracy
B2A (50-70 micrometer)	4 %	+/- 15%
B3A (50-70 micrometer)	4 %	+/- 15%
B2B (70-100 micrometer)	4 %	+/- 15%
R1 (100-220 micrometer)	4 %	+/- 15%

PACS-S: Overall Flux Calibration

B3A_60							
Mode	Modules	N	Mean	Std dev.	Min	Max	Peak-to-peak
Calibration block	Central	136	0.9613	0.1343	0.1629	1.1415	0.9786
Calibration block	Central + correct3x3	136	1.0038	0.0752	0.7718	1.1590	0.3871
Calibration block	3 × 3	136	1.0000	0.0776	0.7573	1.2122	0.4550
Normalization	Central	136	0.9750	0.1335	0.1643	1.1446	0.9803
Normalization	Central + correct3x3	136	1.0148	0.0733	0.7766	1.1560	0.3794
Normalization	3 × 3	136	1.0107	0.0758	0.7819	1.2305	0.4486
B2A_60							
Mode	Modules	N	Mean	Std dev.	Min	Max	Peak-to-peak
Calibration block	Central	134	0.9696	0.1316	0.2144	1.1645	0.9501
Calibration block	Central + correct3x3	134	1.0116	0.0800	0.7657	1.1705	0.4048
Calibration block	3 × 3	134	1.0099	0.0798	0.7695	1.1689	0.3994
Normalization	Central	134	0.9842	0.1274	0.2155	1.1560	0.9404
Normalization	Central + correct3x3	134	1.0233	0.0729	0.7925	1.1577	0.3653
Normalization	3 × 3	134	1.0218	0.0728	0.7955	1.1496	0.3541
B2B_75							
Mode	Modules	N	Mean	Std dev.	Min	Max	Peak-to-peak
Calibration block	Central	134	0.9594	0.1490	0.2202	1.2018	0.9816
Calibration block	Central + correct3x3	134	1.0049	0.0840	0.7659	1.1858	0.4199
Calibration block	3 × 3	134	1.0000	0.0886	0.7701	1.2006	0.4305
Normalization	Central	134	0.9794	0.1472	0.2233	1.1725	0.9492
Normalization	Central + correct3x3	134	1.0238	0.0800	0.7934	1.1947	0.4012
Normalization	3 × 3	134	1.0176	0.0845	0.7968	1.1821	0.3853

- Comparison of Blue SED mode flux cal using telescope (Red SED not so good). normalization/ cal blocks and central or 3x3 spaxel extraction.
- *Mean = mean of flux versus model*. Very consistent
- Overall

σ_{sys} = std.dev/√n = 1%

(not including model uncertainty)

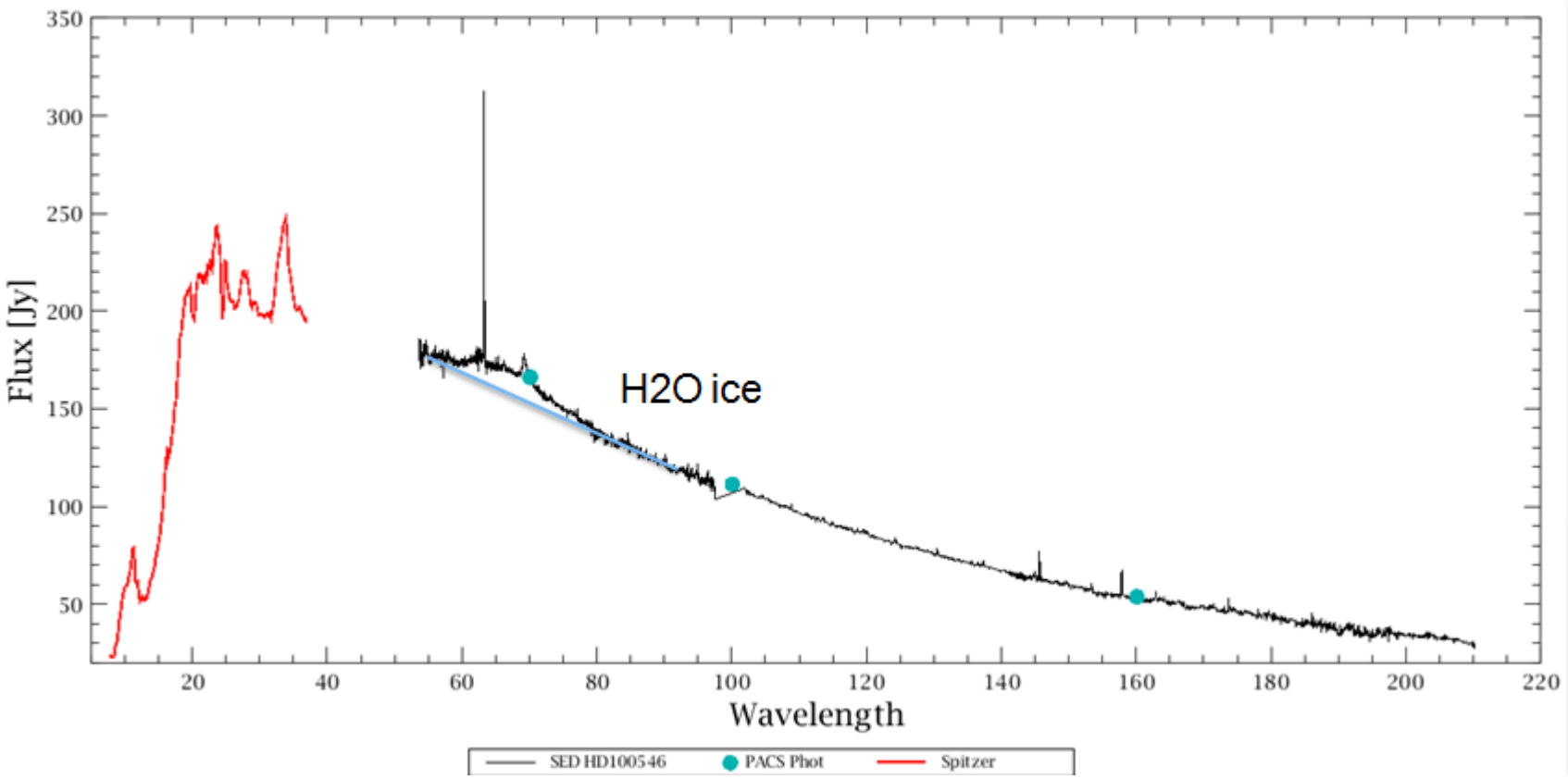
Further PACS-S Cal info

- In-band accuracy : $\Delta \lambda$ vs λkey
  - < 10% in all bands
  - ~10% > 185 μm
- Non-linearity: could be there above 100Jy.

Key Future Items for PACS-S

- Improved beams now formulated (better measurements and pointing jitter corrections).
- At very low flux levels pointing jitter effects come more into play and pointing product improvements will help (see later). *These will also help reduce the continuum fluctuations*.
- Deleaked RSRF for 190-220 micron range shows great promise (disentangling two overlapping orders).

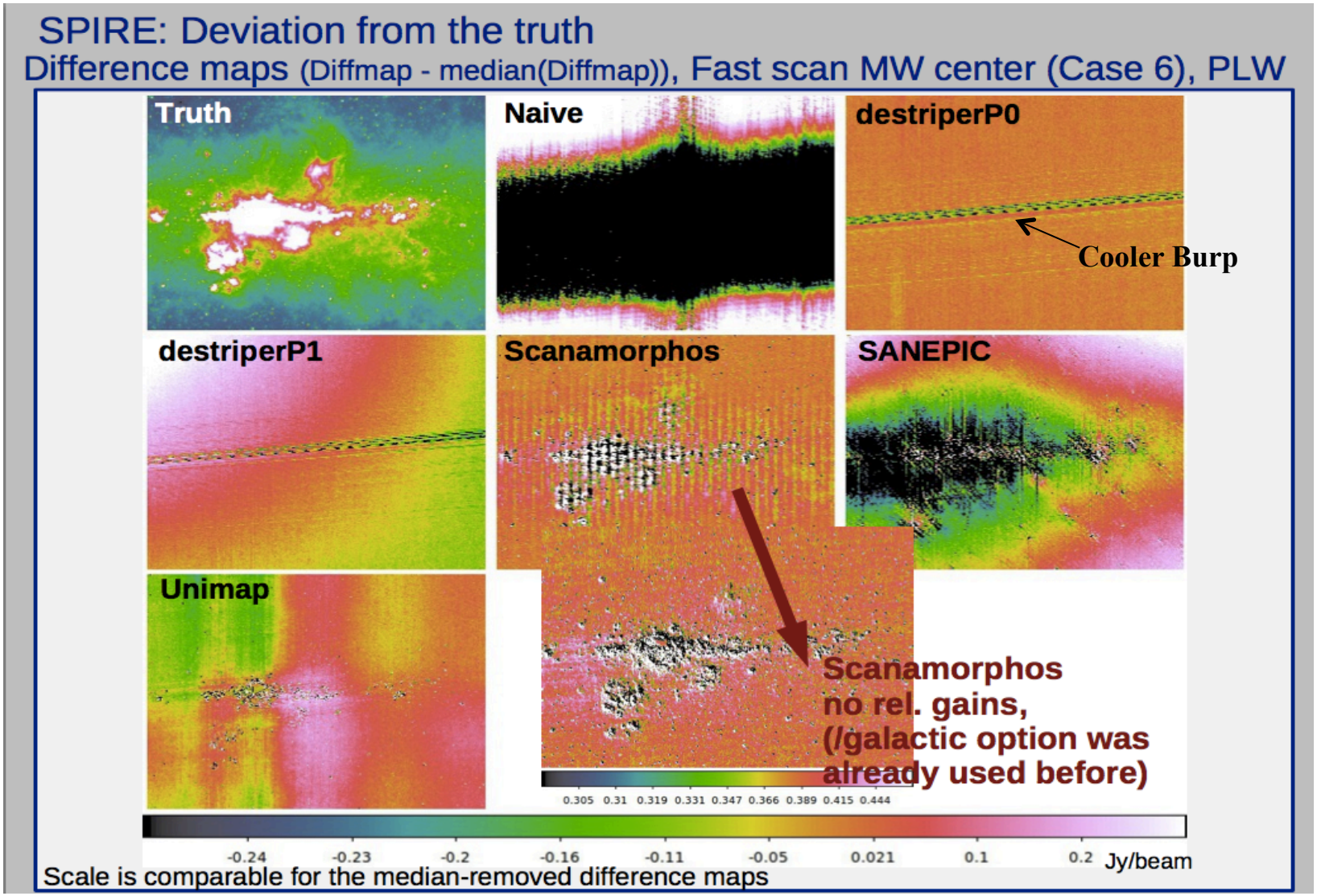
PACS-S: Putting things together – broad lines!



4. SPIRE-P Calibration General

- Mapping workshop suggests current destriper mapping method is as good as any mapper for SPIRE. No intentions to change.
- SPIRE-P beams reassessed, notably in the light of cross-calibration measurements with Planck/HFI → update in SPIRE beam sizes.
- Neptune "ESA4" model being adopted for flux calibration. This will lead to a small change in SPIRE fluxes.
- Above to be contained in HIPE 11.

SPIRE-P Mappers: Deviations from Truth



SPIRE-P Calibration

• Quoted **calibration accuracy is 6%** (4% model plus 2% calibration error). Moving to Neptune "ESA4" model, which is being quoted at 4% (TBC).

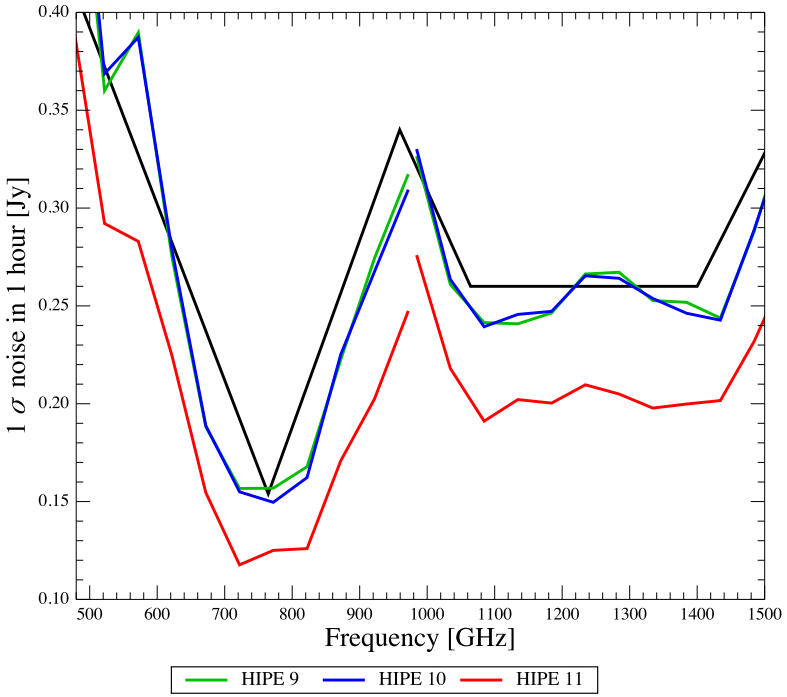
• **Photometric accuracy ~ 1-2%** verified by standard deviation of asteroid and star measurements. Very solid and not changing much now.

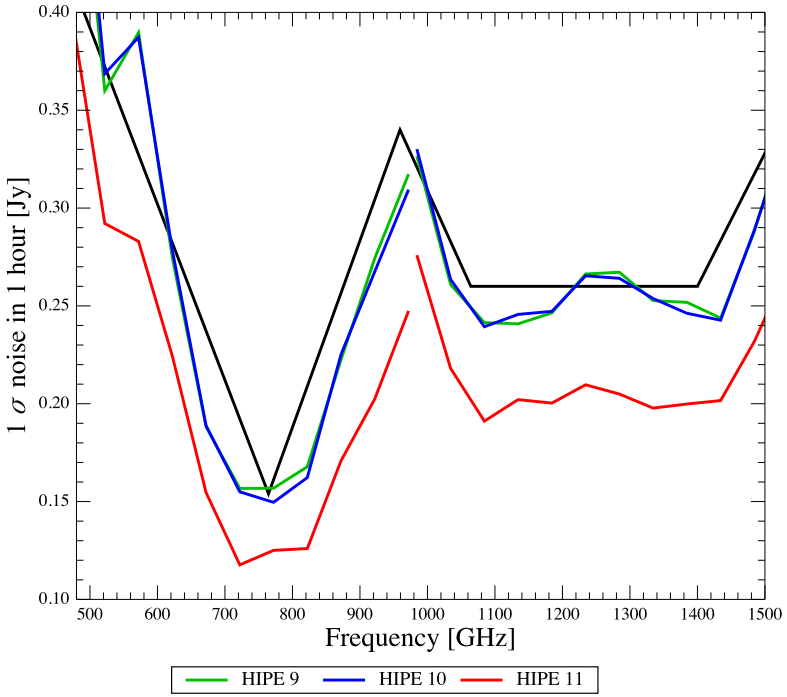
• Flux zero point offsets for SPIRE maps now put into final SPG data as of HIPE 9+, based on Planck/HFI view of the same part of the sky.

- Looking to make used Planck data available with Herschel data
- Full resolution Planck HFI maps in future update
- Work more on colour corrections.

4.2 SPIRE-S Flux Calibration

- Improvements, notably with RSRF, means current extraction (to be seen in HIPE 11) beats HSpot expectations by >20%. HIPE shown in black in the graphs below.

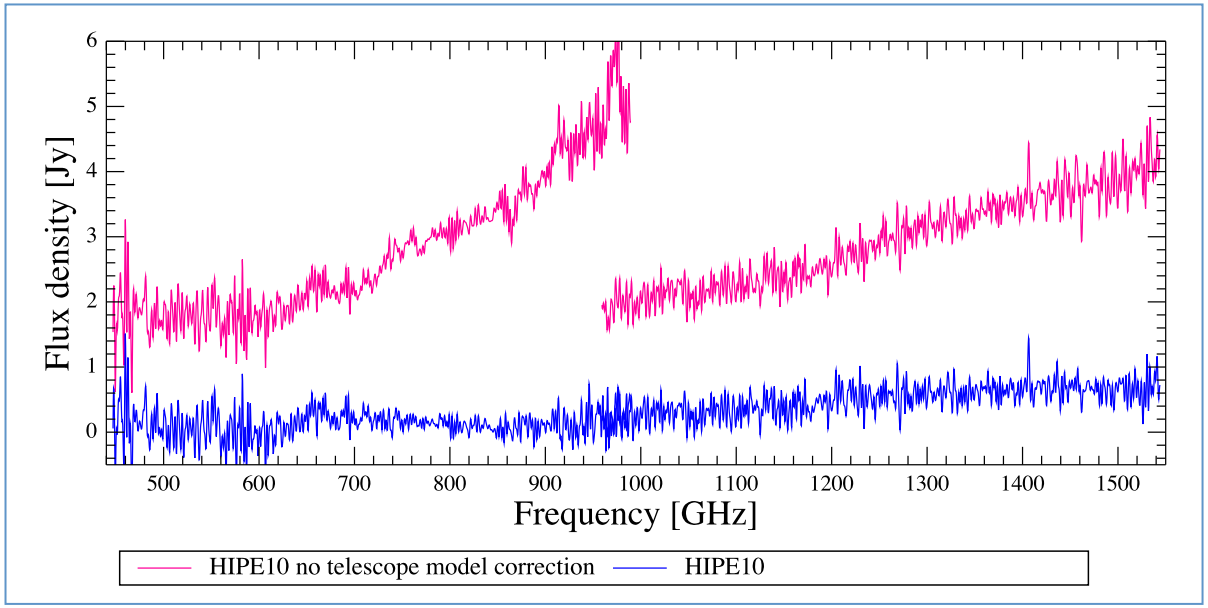




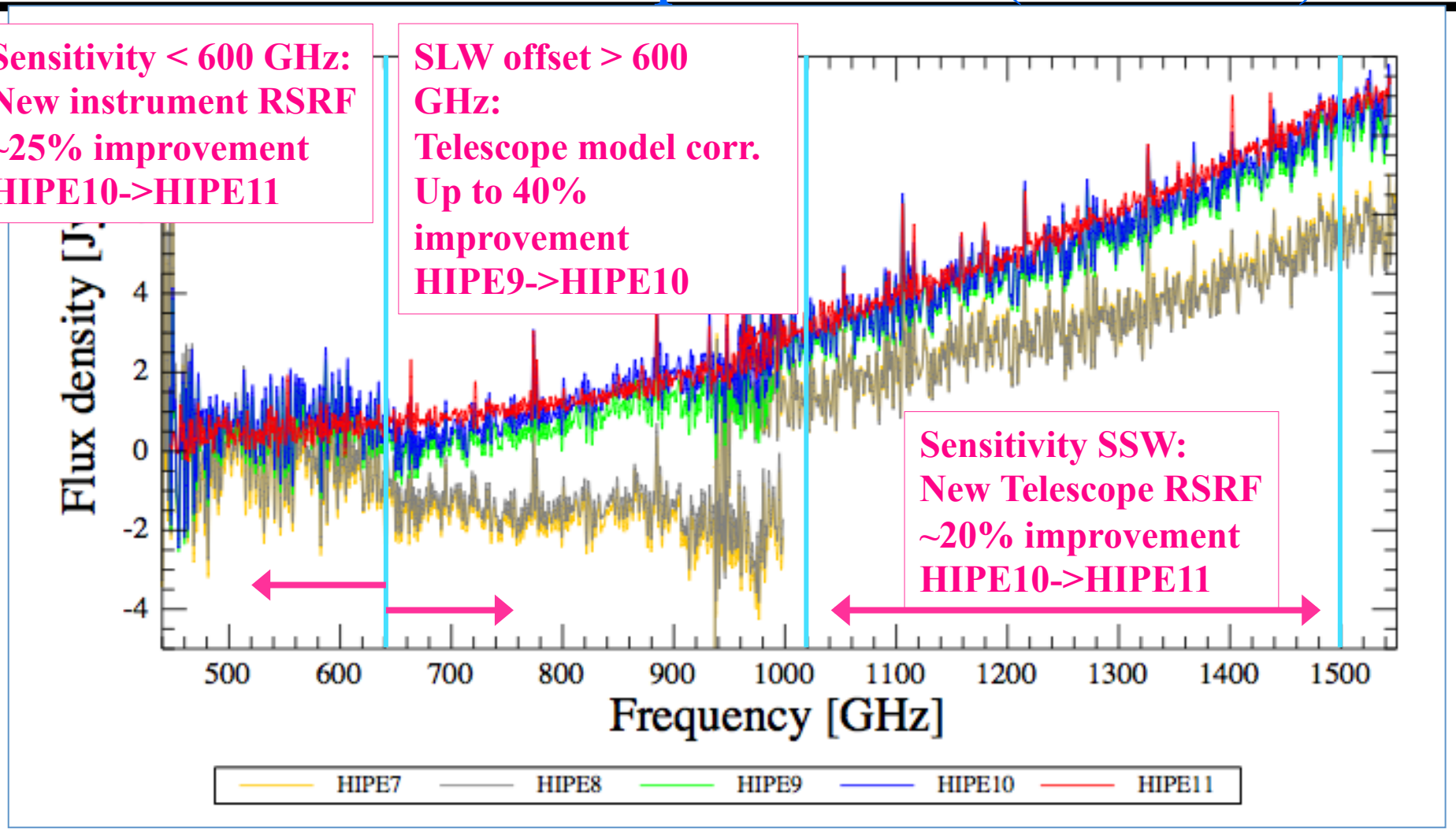
SPIRE-S: Telescope Model Calibration

- SPIRE-S calibrates against a telescope model (in turn flux calibrated against standard) – but evolution means the telescope model needs to be corrected – improves continuum calibration notably.

50-500mJy source seen on OD1032

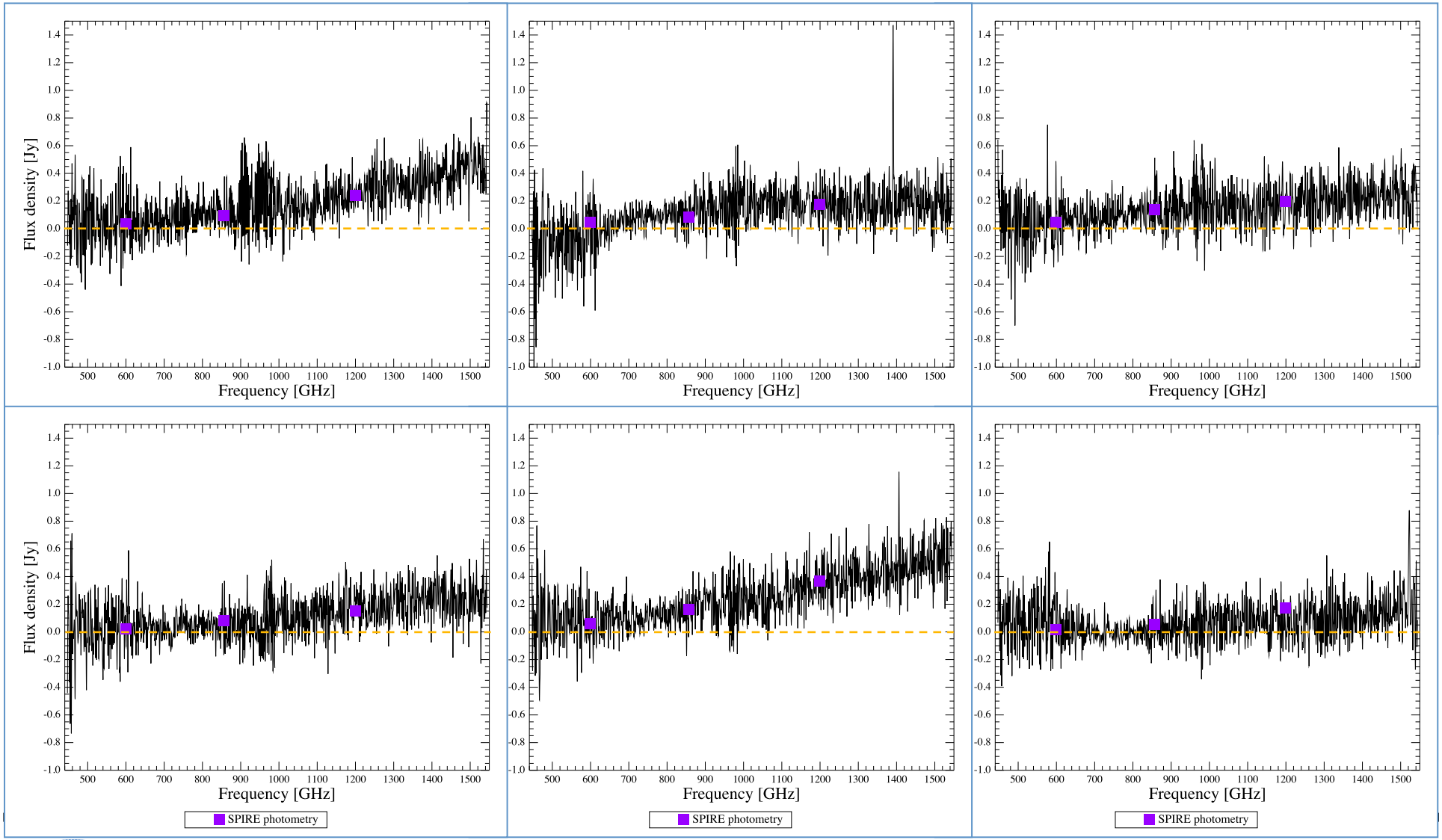


SPIRE-S Overall Improvement (Mkn 231)



- *Bad day (OD290) measurement turned good.*

SPIRE-S vs SPIRE-P: Faint Sources



SPIRE-S: Overall

Continuum offset error improves by:
11% SLW, 8% SSW HIPE10 29% SLW, 20% SSW HIPE11
Sensitivity improves by:
1% SLW, 0.5% SSW HIPE10 23% SLW, 21% SSW HIPE11

Infamous bad days resolved (see Mkn 231 spectrum)

Line sources:
Error on line flux < 6.0%
Spread on line velocity < 7 kms^{-1}

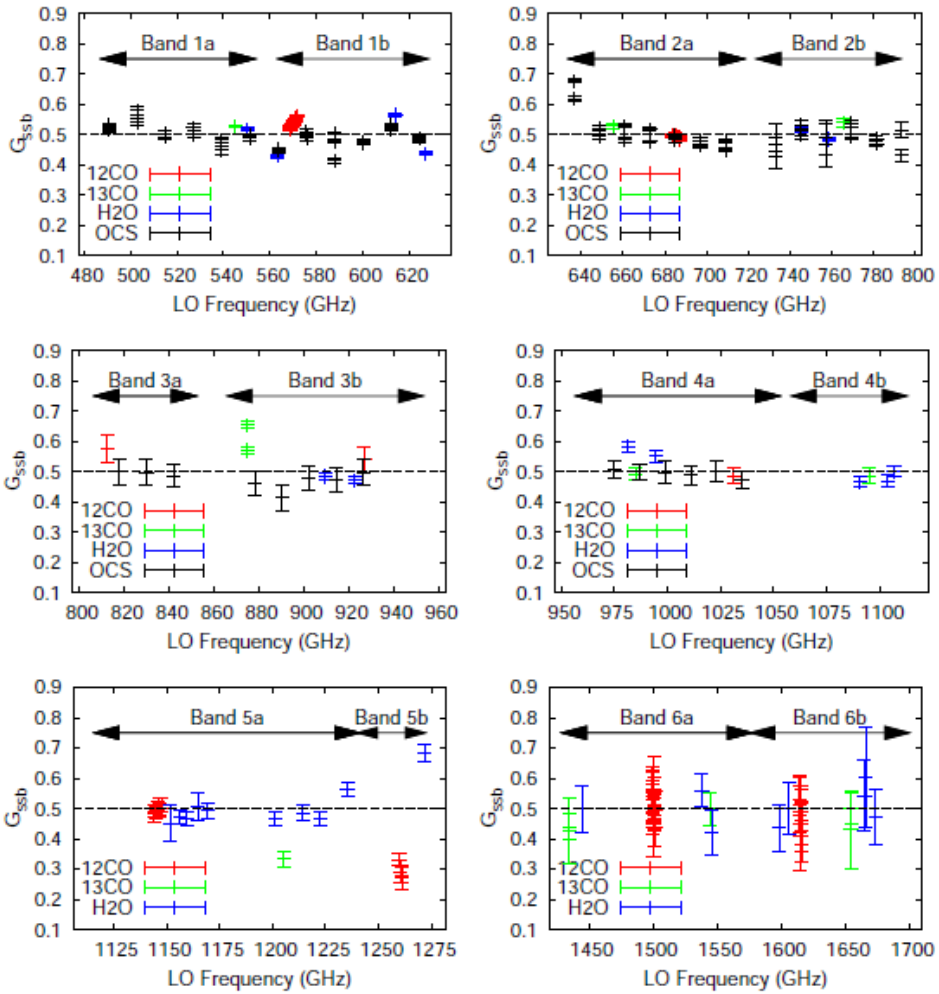
Absolute flux calibration assessment is hampered by pointing offset
For observations with low pointing offset, agreement with the model is 1%
Pointing corrected data:
Uranus: $\mu = 1.0 \pm 0.01$ Neptune: $\mu = 2.3 \pm 0.01$ SLW & 1.0 ± 0.02 SSW
μ = ratio of observation to model.
Future work: Fabulous new RSRFs into HIPE11
Pointing offset correction & temperature based flux correction into HIPE12
Off-axis detectors & mapping

5. HIFI Instrument Calibration

- **General:**
  - V polarization comb has lasted to the end of the mission (just about).
  - Nearly whole mission on redundant electronics
  - Still got SEUs to contend with, but handled with standard procedures. Occasional loss of science time.
  - Impurity in upper part of band 3b corrected. This leads to a "correction" for measurements made with impure settings in the past (see sideband ratio discussion).

HIFI Instrument Calibration: Sideband Ratio Update

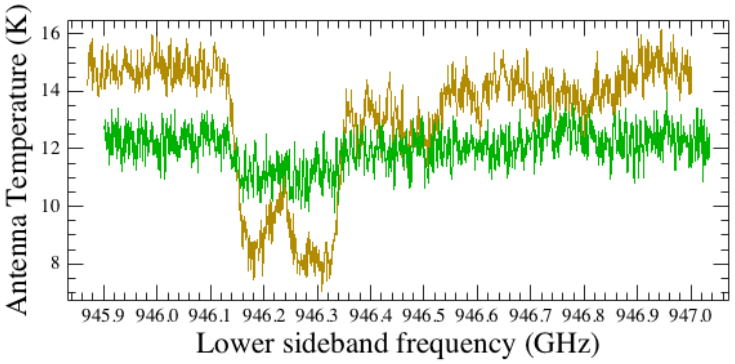
- Full corrections needed for on-ground measurements (see Ph.D. thesis, R. Higgins, NUI). Results shown on RHS.
- But non-optimal setup for ground tests – so have been using other sources of information.
- One problem – it is known that SBR can change over small LO ranges, e.g. around CO 5-4 line. Need to get such fine detail into the HIFI calibration.
- *Need upgrade to allow better info in pipeline cal. No changes since last meeting.*



HIFI Sideband Ratio: Next steps

- It is known that the sideband ratio will change across the IF band. It is also known how this should change. *To be included in HIFI pipeline processing.*
- There exist a limited number of frequency areas where HIFI is sensitive to signal outside of the sole **LSB and USB ranges**
- This results in leak lines and an improper side-band calibration due to the contribution of the leaking range – we call this ***Impurity***
- • In SBR term, this translates into a flux loss (in both **USB and LSB calibration),** that can be estimated if a purified detector is used
- We have estimated this correction factor for the following areas:
  - Band 5a between 1231 and 1236 GHz (loss between 5 and 50%)
  - Band 3b between 951 and 953 GHz (loss up to 90%)

In Sgr B2

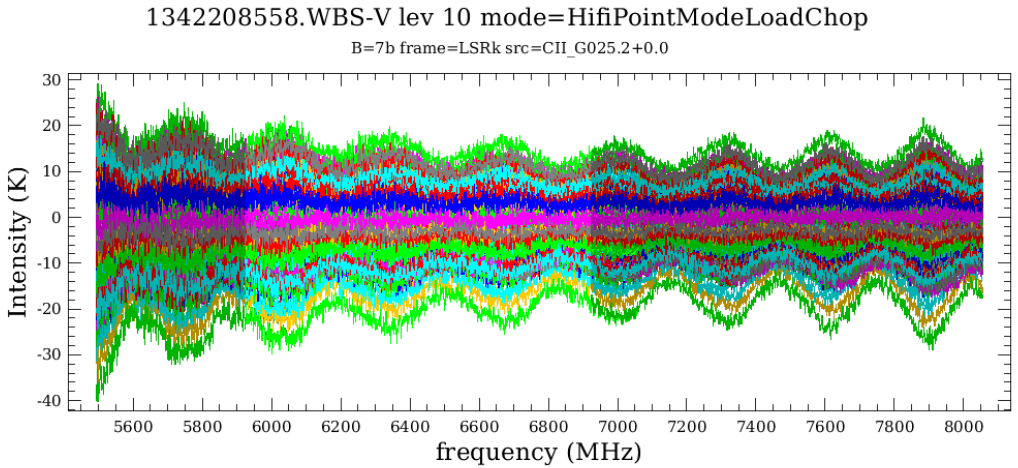


HIFI Sideband Ratio: Next Steps Cont.

- Fill in gaps from ground test data with more in-flight info.
- Use Bayesian statistics based decon algorithm to potentially fill in the frequency gaps.
- Goal is to reach 2% error for sideband ratio (unclear for bands 3 and 4).

HIFI standing waves

- Ambitious attempt to do a full optical model to understand the source and strength of the standing waves remaining in the HIFI system.
- Intent is to model then remove them from observations.
- Early models show promise, but much testing.
- Band 6 and 7, HEB electrical standing waves: looking to create a database of electrical standing waves for matching and removal of these effects. Most time is just to set up the database of these!

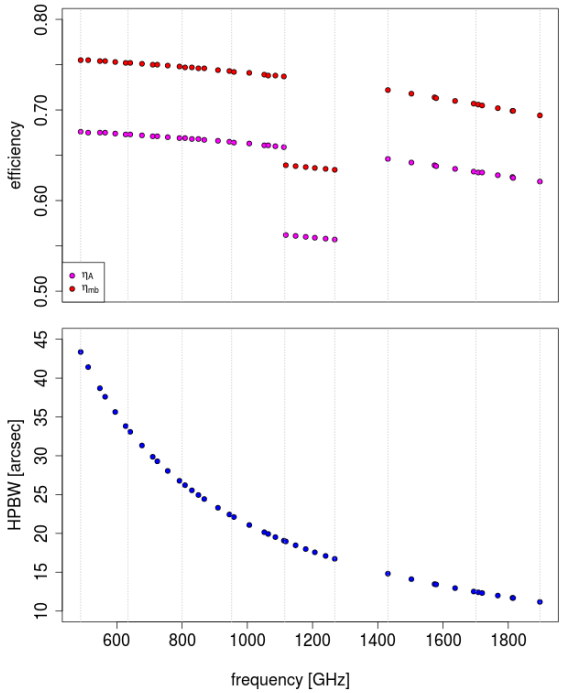


HIFI Calibration: Beam pattern and efficiencies

Overall approach consists in propagating the ILT model (including post-launch telescope model) to the sky, and compare all four beam measurement runs consistently – **NOTE** that this is NOT a fit but a pure forward projection problem

On the mid-term, the goal is to deliver synthetic beam maps as calibration files – probably not feasible before the POPS phase. Need to go beyond gaussian beams.

Measurements much more accurate and efficiencies and beam widths in much better shape.
In band 5 an extra optical component used drops the efficiencies.
Good to ~5% so far.



6. Cross-Calibration

- Main contribution is confirmation that line fluxes in 190-220 micron wavelength region of PACS gives consistent fluxes with HIFI.
- This confirms the use of the updated RSRF derived for this region of order overlap.

(note that the continuum shape is not corrected for in the region, just the lines)

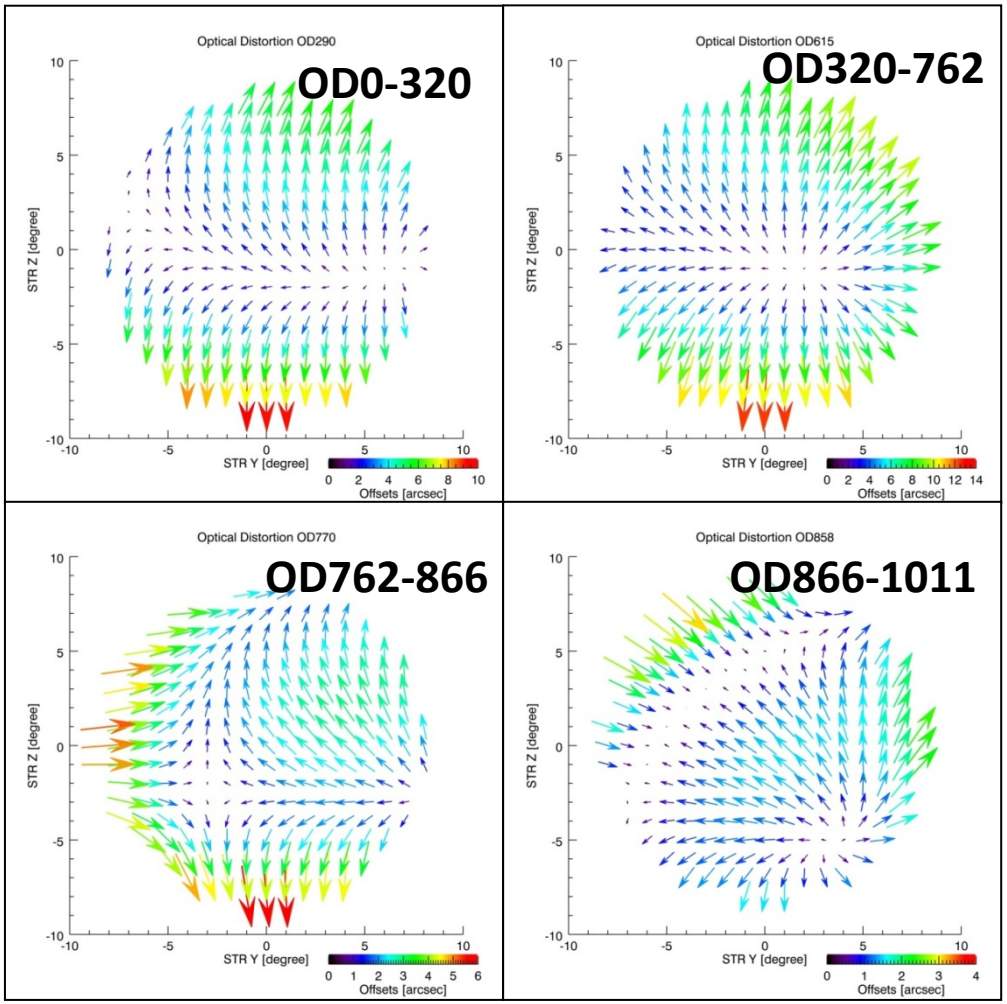
Also now have cross-cal with Planck/HFI included in SPIRE-P pipeline. Provides accurate offsets to the zero level of SPIRE-P maps.

7. Current Pointing Performance

- Pointing performance information is available on the website at http://herschel.esac.esa.int/twiki/bin/view/Public/SummaryPointing
- Generally pointing around ~1.”1. However now can see some notable variations from mild heating of STRs from indirect sunlight over periods of a few hours (previously thought okay). More restricted in view for final part of the mission but effects remain – may be improved by special pointing products where known.

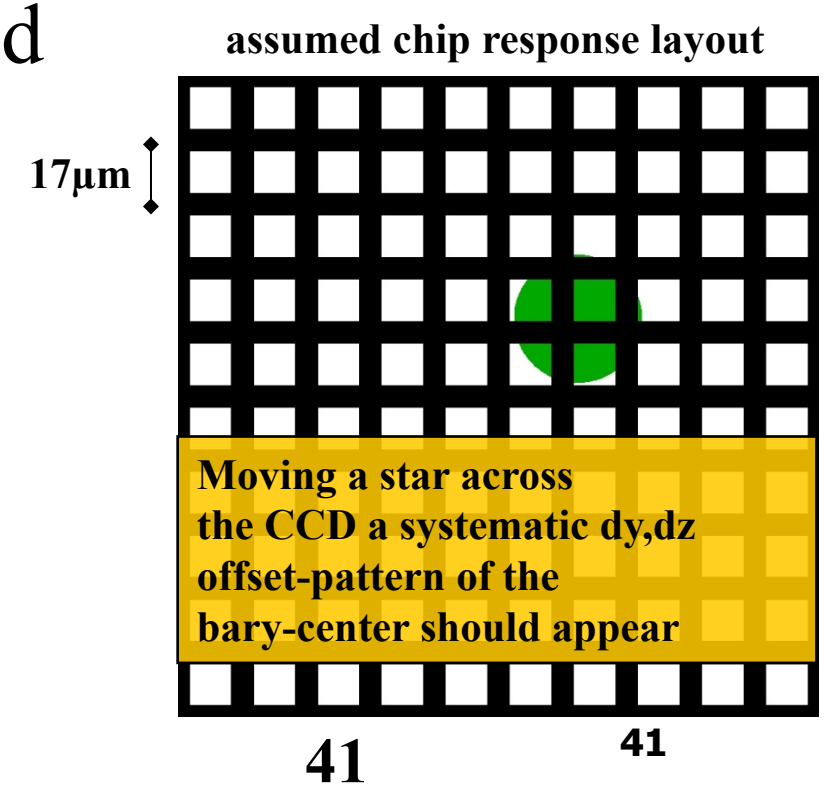
Future Pointing Updates

- Startracker distortion corrections for all phases of the mission. Removed afer OD1011



Removal of sub-pixel structure

- Due to insensitive borders of pixels in the STR affecting centroiding.
- Variations mapped



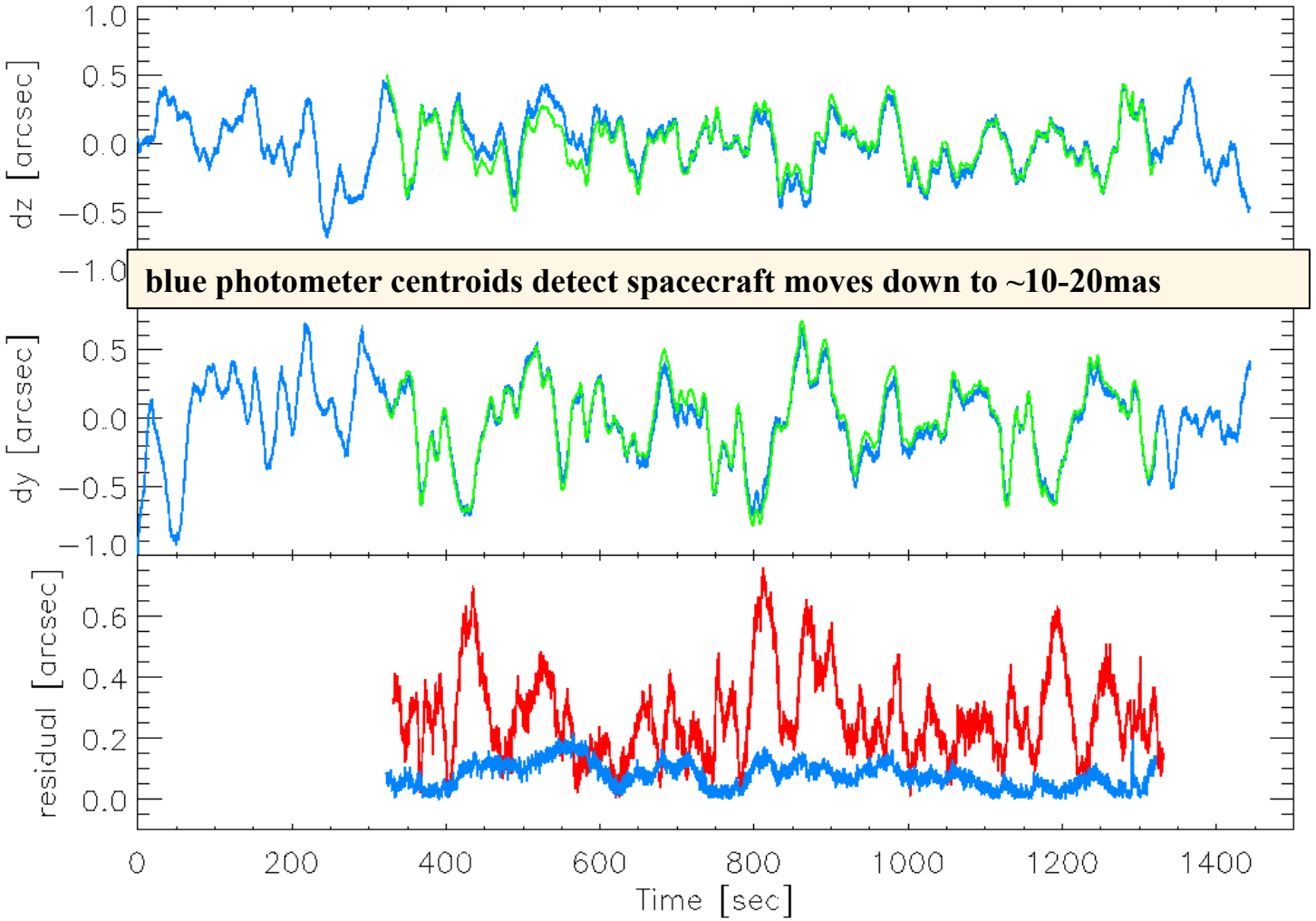
Bad tracking stars removal

- 73 stars removed from catalogue on board. Needs to be applied in reconstruction of any pointing products.

Spacecraft jitter determination

Use gyro info (blue) and compare to object movement seen by PACS (green).

Predicted relative pointing reduced by factor 3 (lower plot in blue versus currer pointing product i red)



8. Conclusions

- Calibration improvements steadily being made for all sub-instruments. Quantum jump at calibration workshop, more to come in postops.
- Absolute photometer errors limited by calibration models. Feedback of Herschel data to models → Go to ~3% errors. But not yet. Possibly at 4% now for planets, or approaching that. Stellar models not going to change in any substantial way.
  - Improved methods for science information extraction coming into place (better RSRFs, pointing effects reduction etc.)
- Asteroid models → updates to 4 that can now be considered prime calibrators (~5%). A Herschel legacy
- Cross-calibration with Planck now complete (1st iteration) and in SPIRE pipelines. Possible use of full resolution Planck/HFI data in the future + papers!
- Pointing:
  - now at the point where corrections for STR distortions in all eras of the mission is possible and hopefully will be in HIPE 11 bulk reprocessing.
  - Gyro corrections to determine jitter and therefore effects on flux calibration and map reconstruction, in the works.