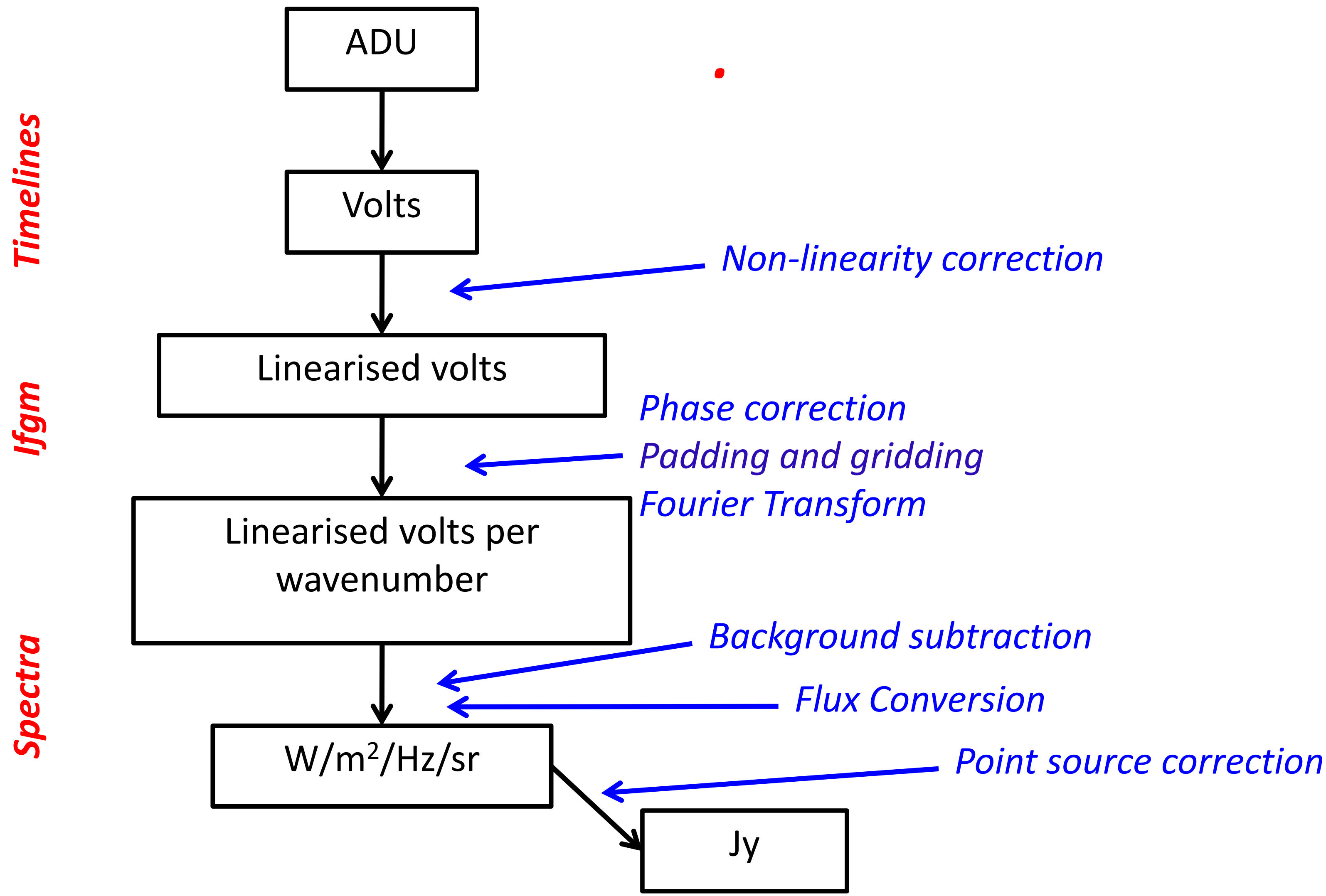
SPIRE FTS Flux Calibration Overview

Bruce Swinyard
Ed Polehampton
Trevor Fulton
Ros Hopwood

UCL/RAL/Lethbridge

On behalf of FTS group

Current FTS Flux Calibration Scheme



Flux Calibration Equations

$$I(\sigma) = R_{tel}(\sigma)\,[V(\sigma) - M_{tel}(\sigma)\,/R_{tel}(\sigma) - M_{inst}(\sigma)\,/R_{inst}(\sigma)]$$

I(σ) is the source **intensity** in units of W/m^2/Hz/sr
R(σ) is the **RSRF** in units of (W/m^2/Hz/sr)/(V cm^{-1})
V(σ) is the **spectrum** in units of linearised voltage
M(σ) is the **model** for this observation of inst., telescope in units of W/m^2/Hz/sr

$$S(\sigma) = C(\sigma)\,I(\sigma)$$

$\Omega(\sigma)\eta_{point}(\sigma)$

S(σ) is the in-beam source flux density in units of Jy
C(σ) is the point source conversion factor

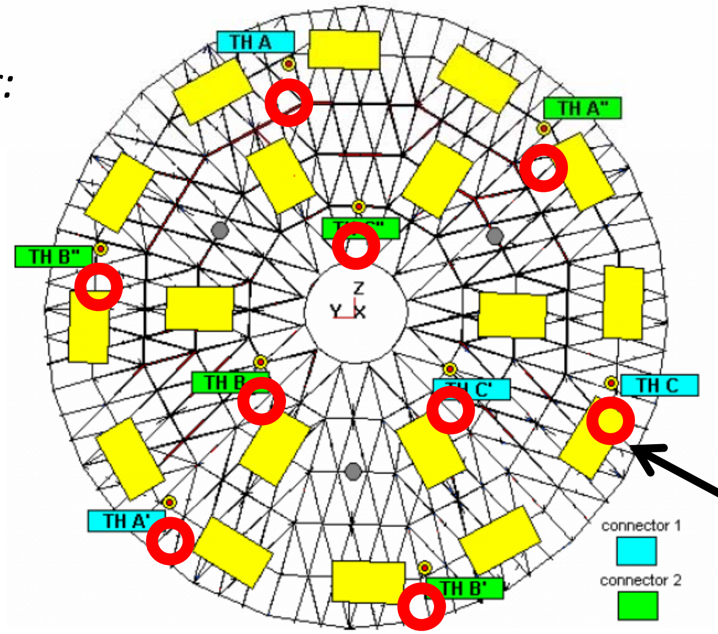
Calibration needed

- Non-linearity coefficients – linearise the voltage in a similar way to photometer using K-values
  - Currently based on model (not on observation)
- Phase correction file – *Ed to provide words*
- Conversion between V/cm^{-1} and W/m^{2}/Hz/sr – i.e. removal of the RSRF & throughput
  - Assume uniformly extended emission
  - Uses model of the telescope
- Account for beam profile and point source coupling efficiency – convert W/m^{2}/Hz/sr to Jy
  - Uses model of Uranus

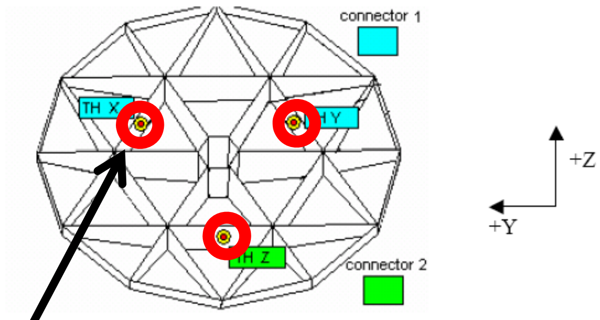
Extended source calibration

We regularly observe a uniformly extended black body
– the telescope!

Primary mirror:



Secondary mirror:



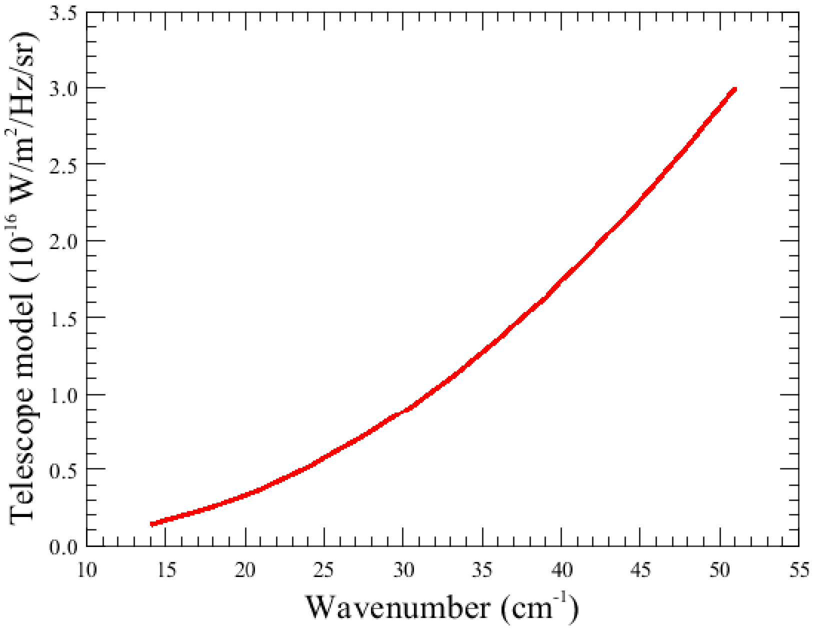
Thermistors

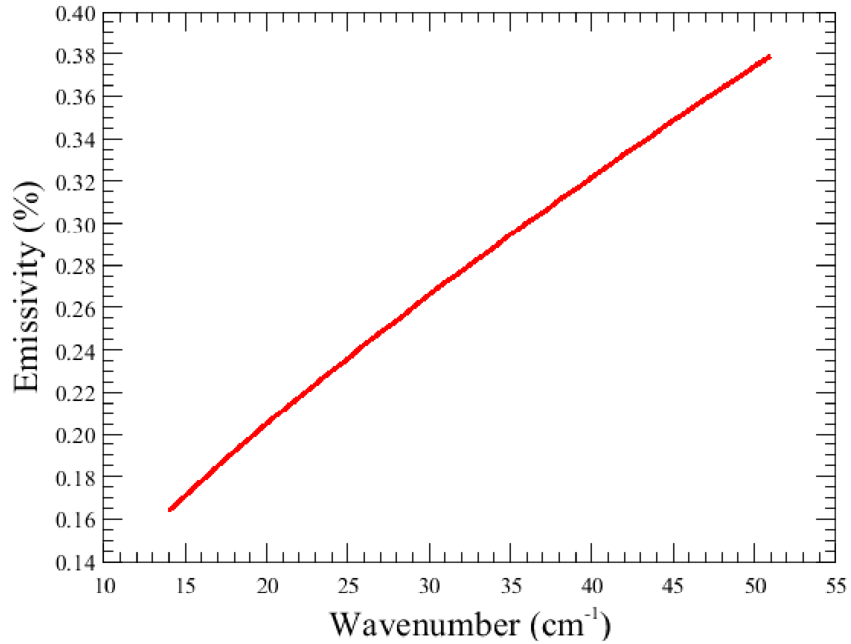
We observe the whole of the telescope – therefore use mean of the thermistors on each mirror to construct model of telescope emission

Model of telescope emission

Emissivity of mirrors: $\varepsilon_{Tel} = 0.0336\lambda^{-0.5} + 0.273\lambda^{-1}$

Taken from Fischer et al APPLIED OPTICS Vol. 43, No. 19 1 July 2004

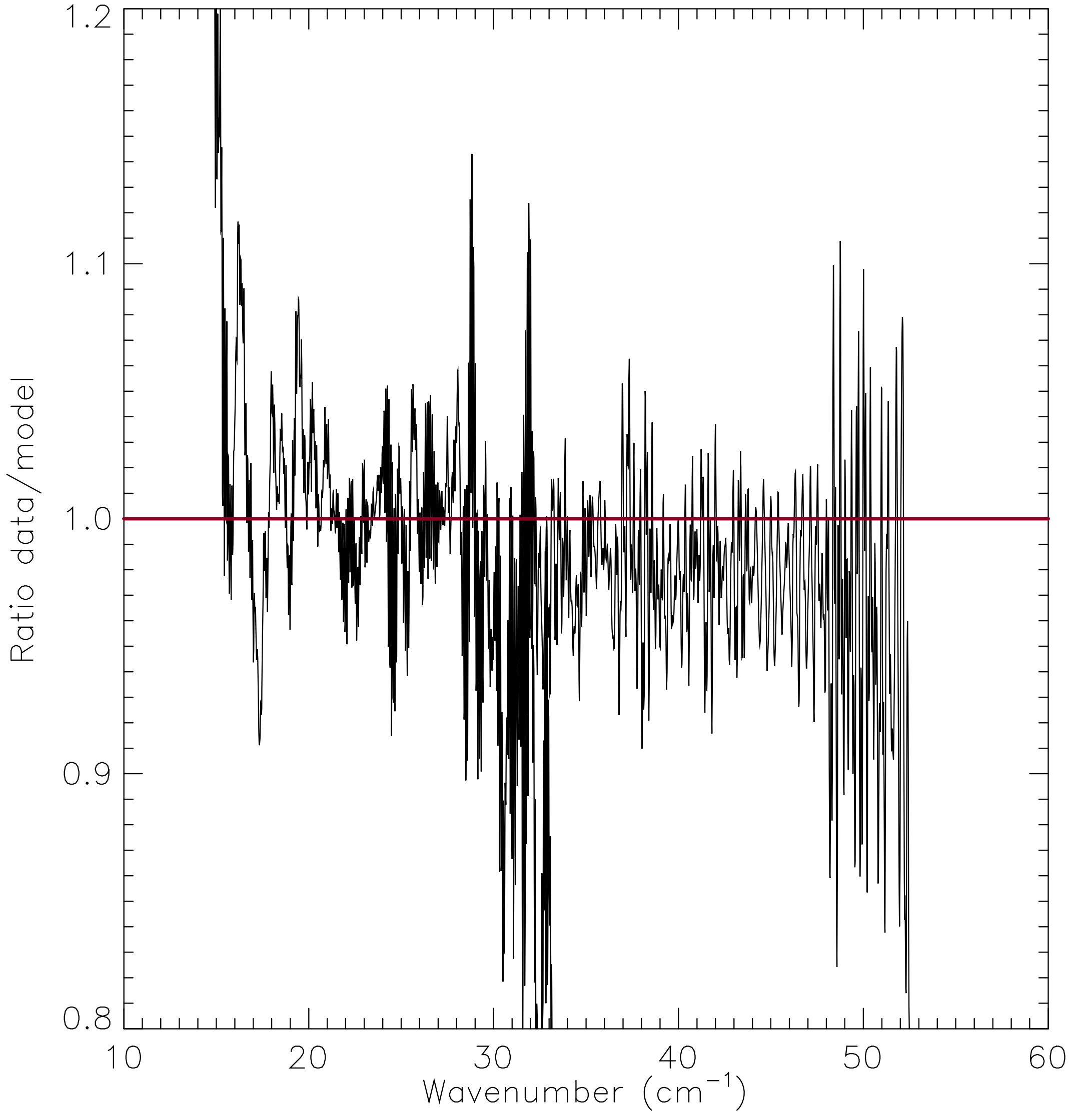




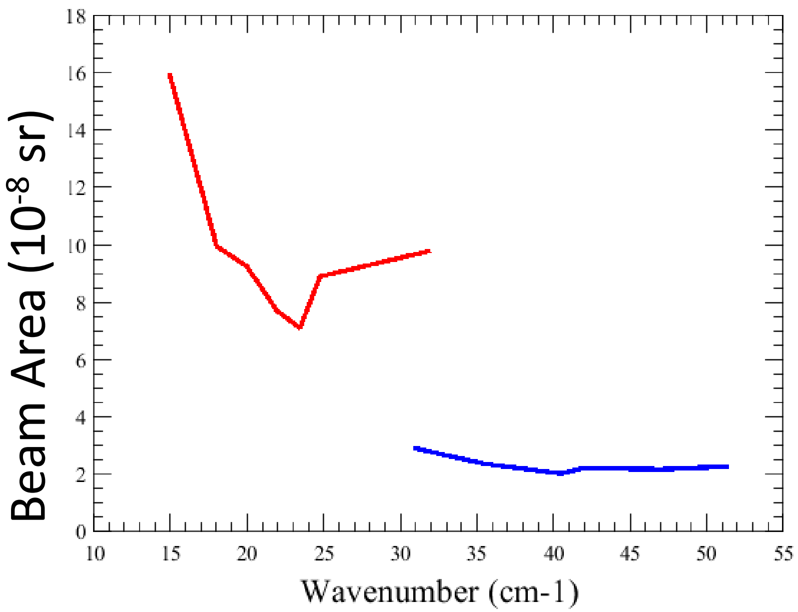
Model of telescope emission using emissivity and temperatures of M1 and M2:

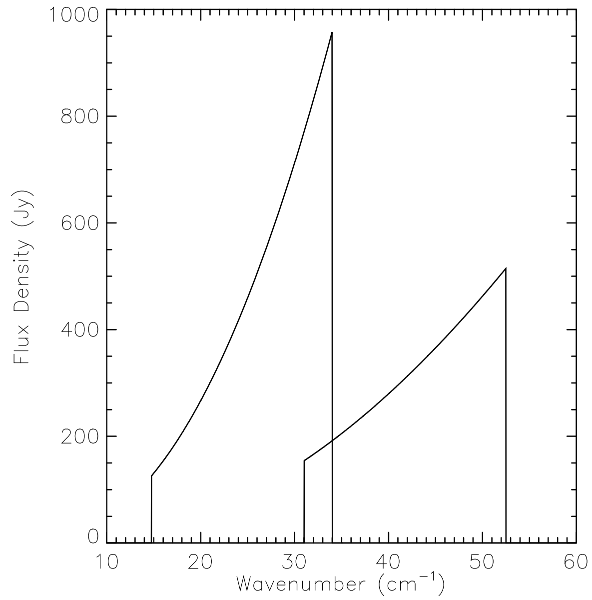
$$B_{\mathrm{Tel}} = (1 - \varepsilon_{\mathrm{Tel}})\varepsilon_{\mathrm{Tel}} B(T_{\mathrm{M1}}, \sigma) + \varepsilon_{\mathrm{Tel}} B(T_{\mathrm{M2}}, \sigma)$$

GO Latest calibrated using telescope only



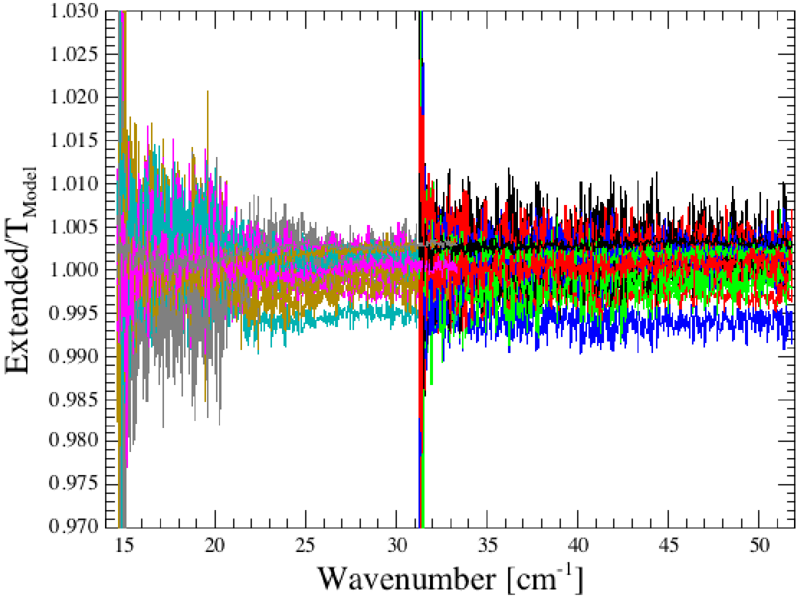
Need to account for the beam



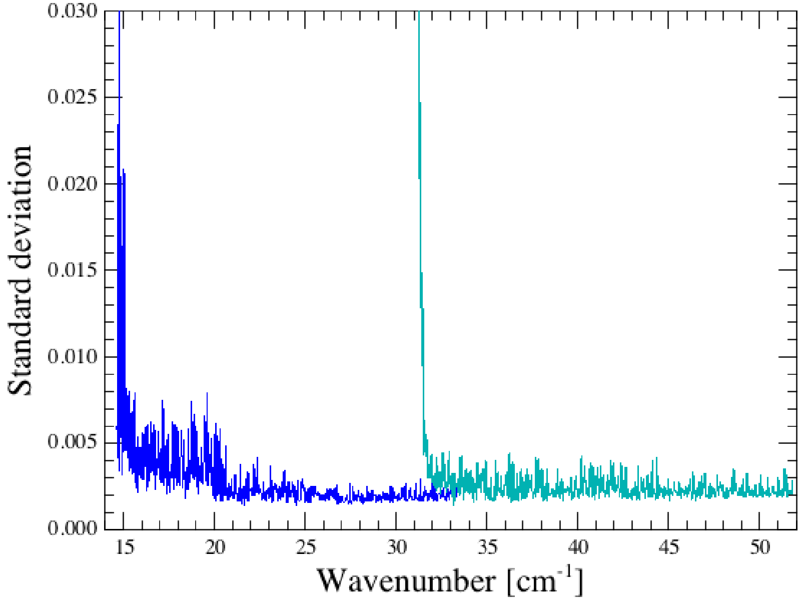


- **The FTS beam is not Gaussian in shape**
  - *for extended sources, significant power comes from a wider area than calculated from the FWHM*
  - *the feedhorns are multi-moded, particularly at the high frequency end of each band*

The telescope is highly reproducible



“Daily dark” extended spectra (no telescope correction)/telescope model.



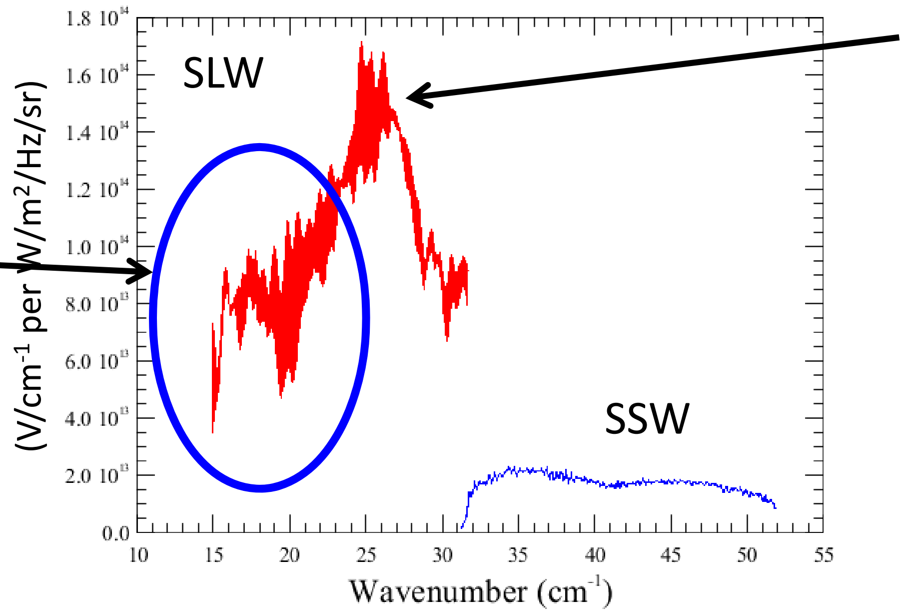
Corresponding standard deviation for all Daily dark extended spectra (no telescope correction)/telescope model ratios

Taken over duration of mission OD189

Instrument Emission

- Emission from the instrument (~4K) is important in the long wavelength band
- Apply a correction to the data using the measured instrument temperature measured at “SCAL” body

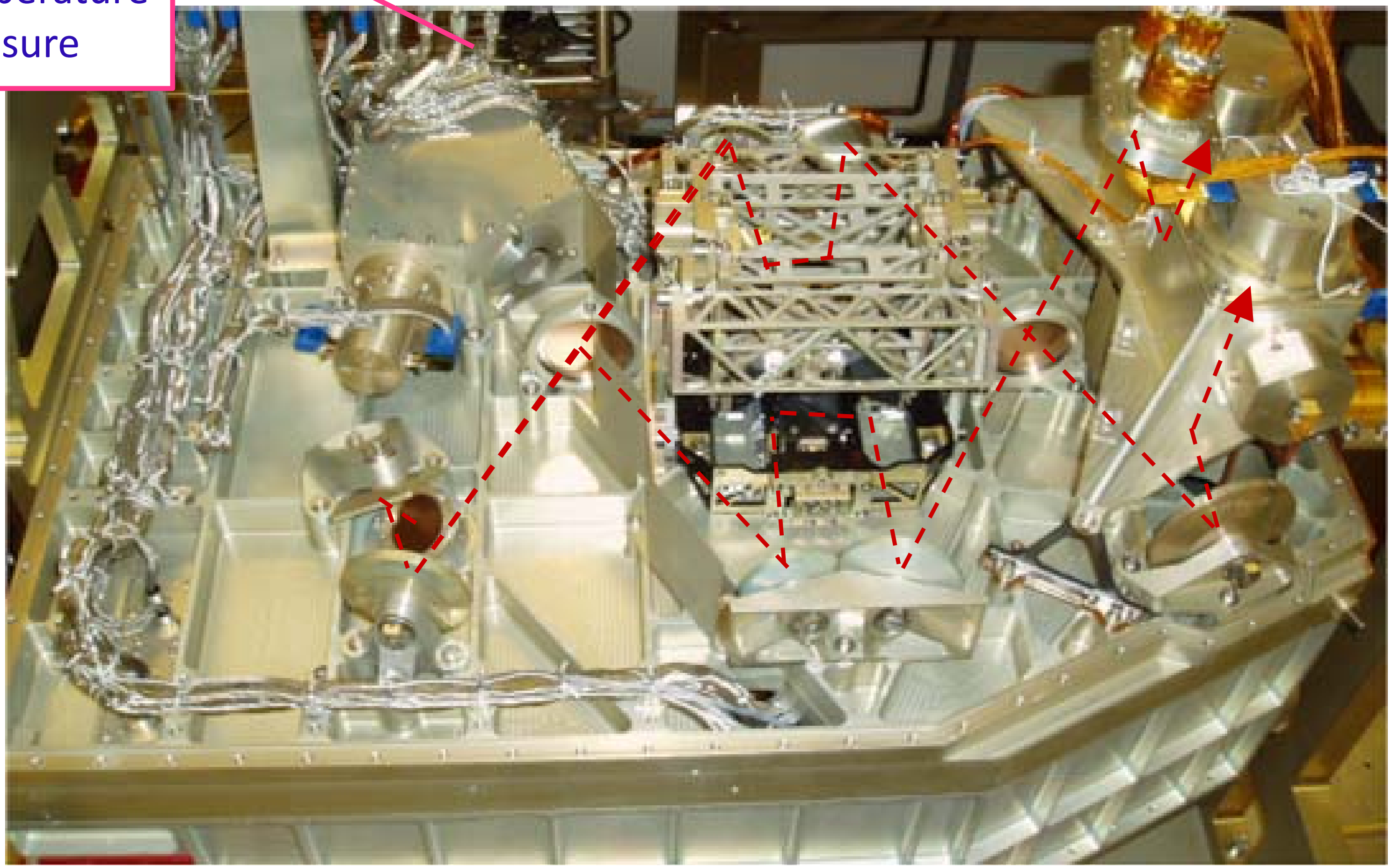
Instrument correction affects long wavelength end



Calibration includes RSRF shape & fringe function

Inside of SPIRE

"SCALTEMP" measures the overall temperature of enclosure



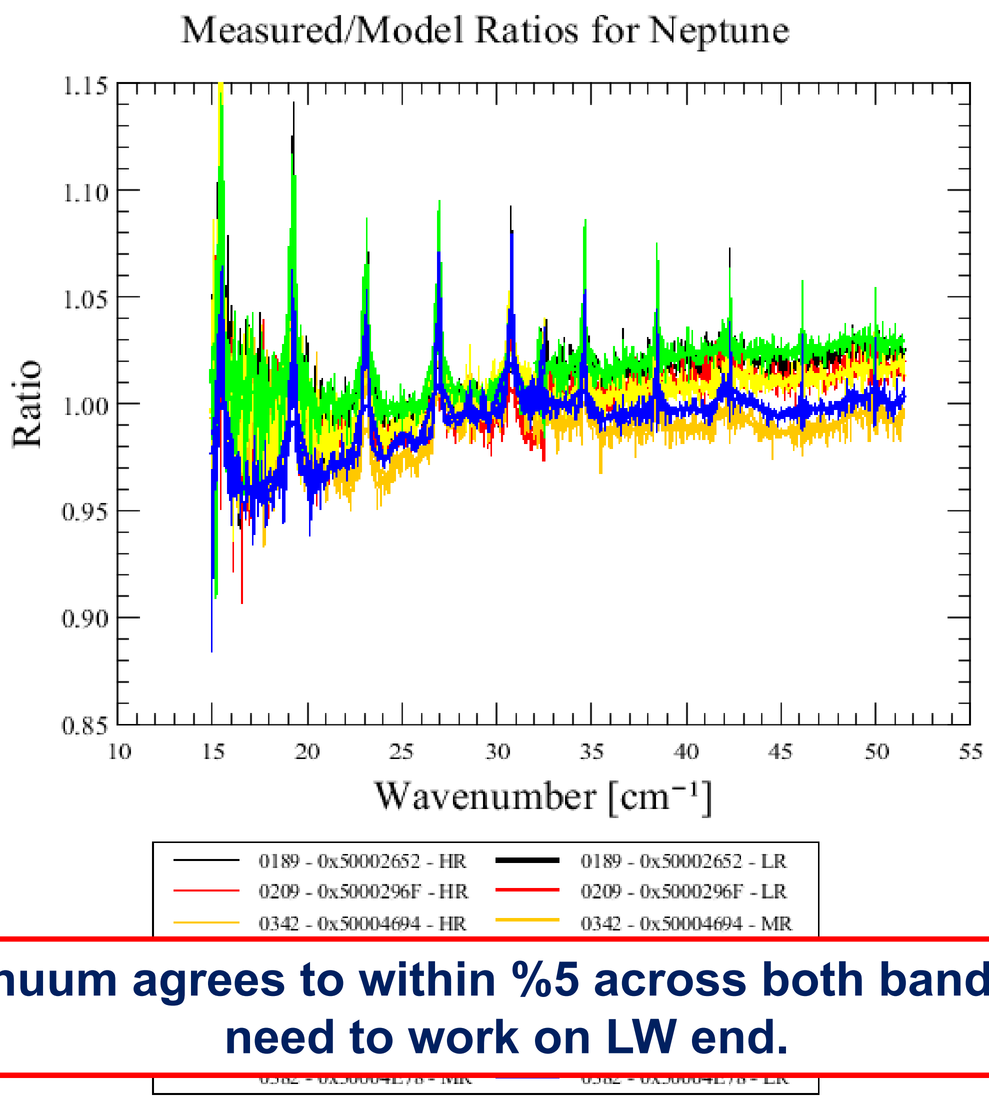
Point sources

- Point sources are observed on the centre detector pair (on axis)
- Calibration derived from Uranus currently being implemented
  - Bright
  - Relatively featureless
  - Official Herschel model from Raphael Moreno (added 10Jy at all wavenumbers & correct for average beamsize)
  - Tested using Neptune model (Herschel primary standard)
- Initial calibration was based on Vesta
- Alternative calibration could be based on telescope

Calibration Accuracy (point source)

- Systematic uncertainty due to Uranus model compared to Neptune (multiplicative)
- Initial Vesta calibration: 15-20% (SSW) and 20-30% (SLW) estimated uncertainty
- Uranus calibration more accurate & lower noise
- Compared multiple measurements of sources to look for consistency
- We can also use the telescope as a calibrator to do an independent check

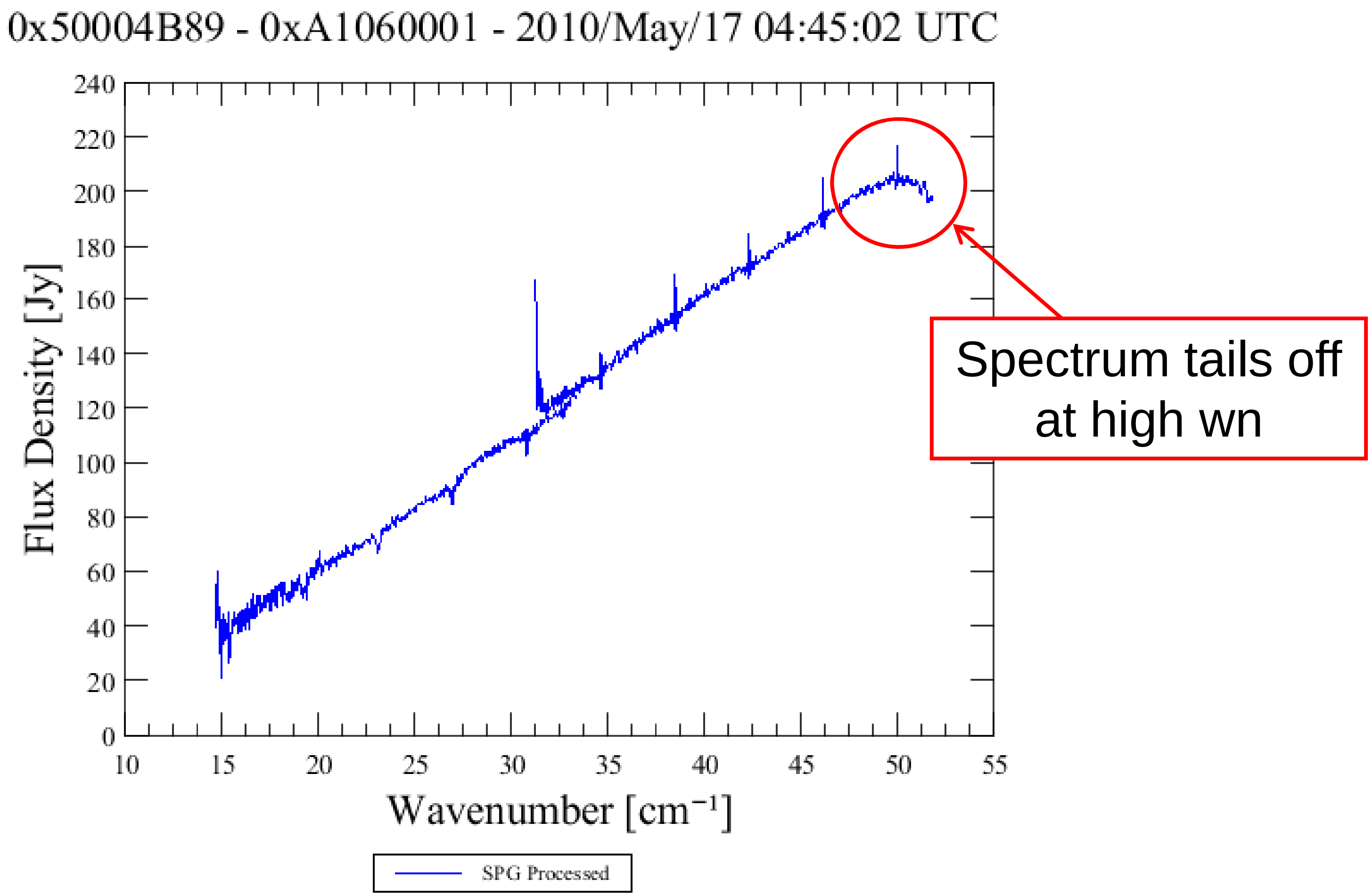
Neptune calibrated with Uranus

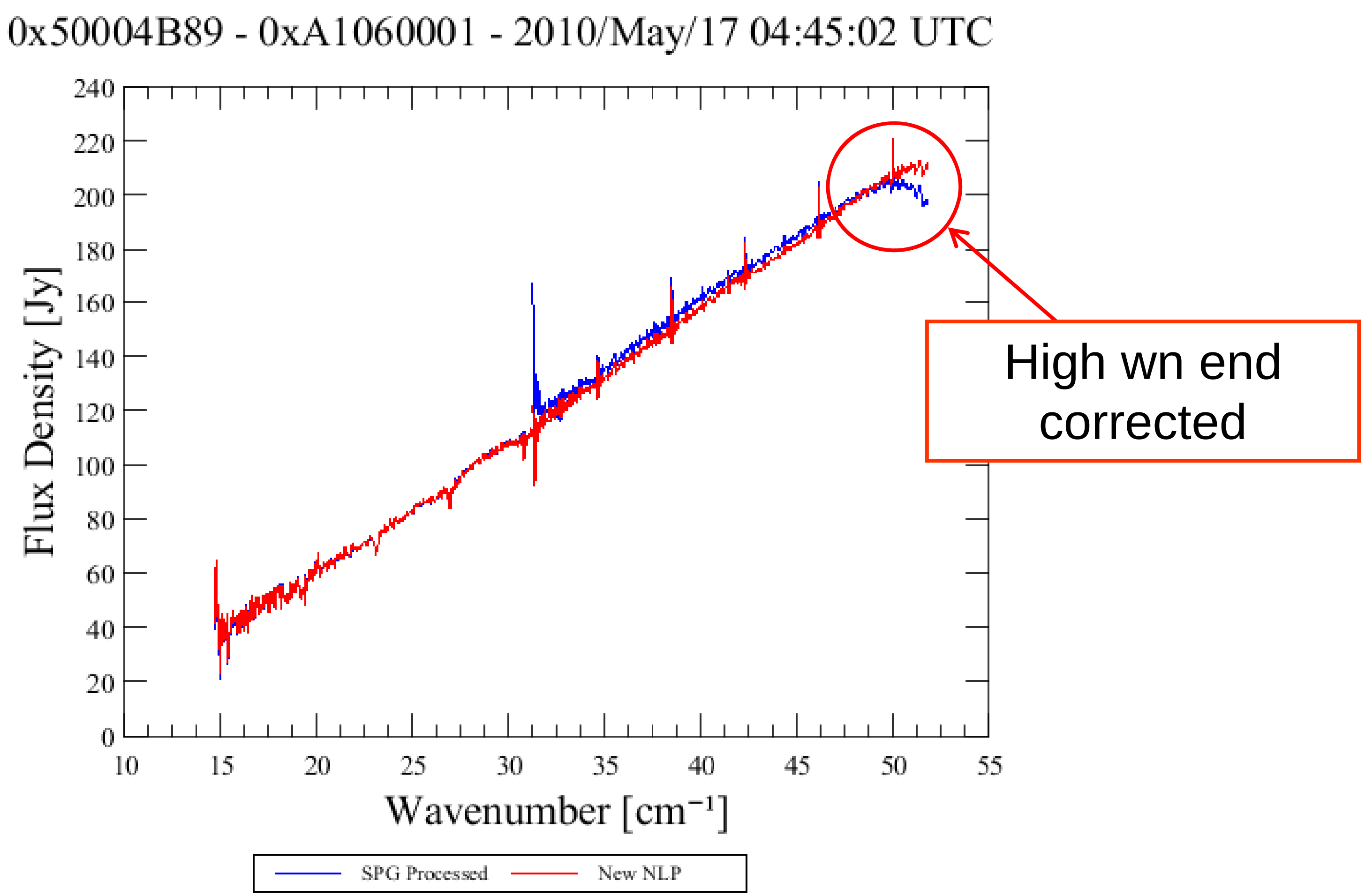


Continuum agrees to within %5 across both bands. Still need to work on LW end.

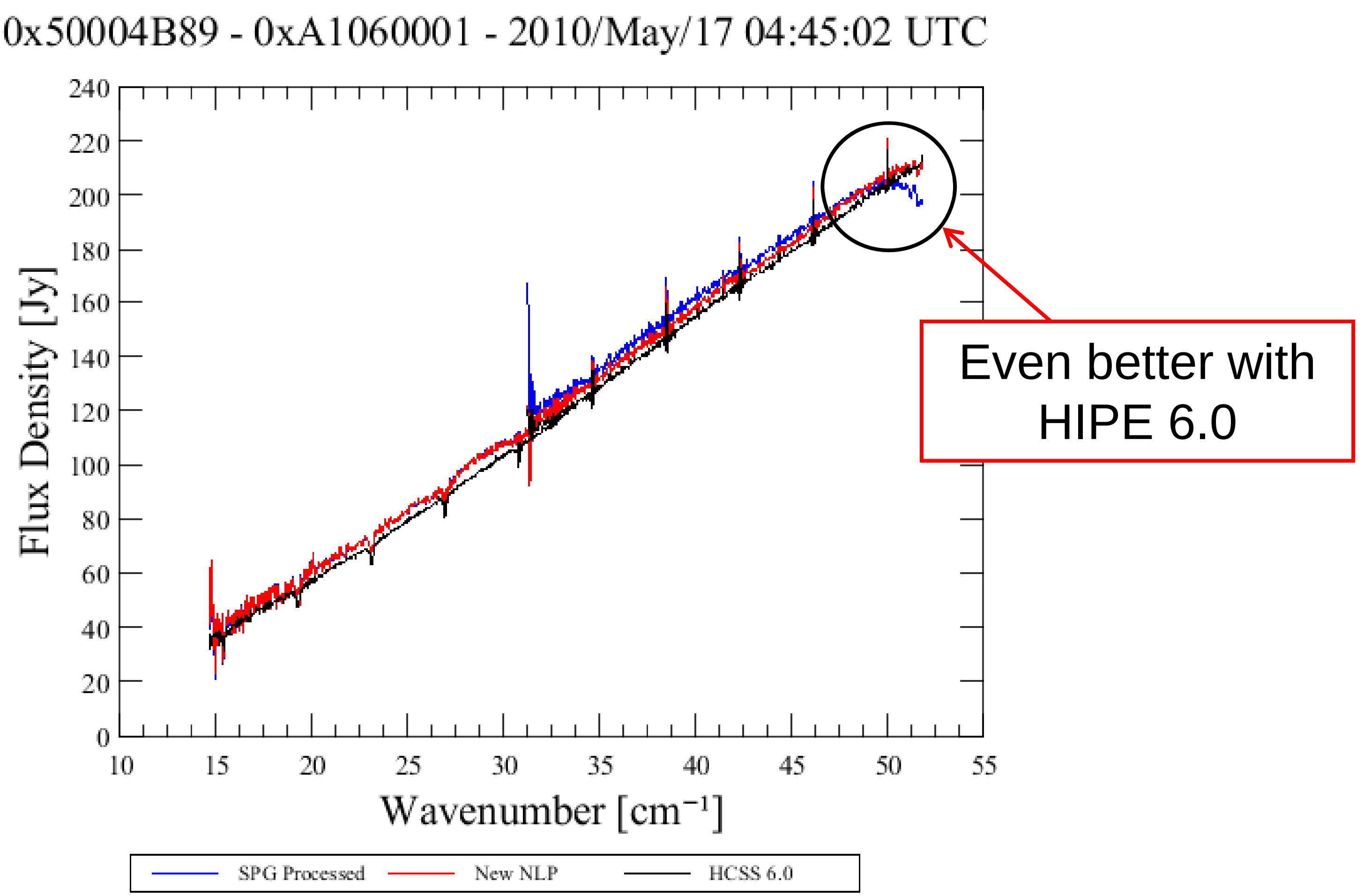
An aside – New pipeline correction steps for Phase Correction

- A new method of phase correction is proposed to improve the spectral shape coming from pipeline products
- Next few plots show the improvement this will bring
  - Version 5 – Nominal Calibration product
  - Version 5 – Specialized Calibration product
  - Version 6 – No Calibration product required


0x50004B89 - 0xA1060001 - 2010/May/17 04:45:02 UTC
Flux Density [Jy]
Wavenumber [cm⁻¹]
SPG Processed
Spectrum tails off at high wn
0
20
40
60
80
100
120
140
160
180
200
220
240
10
15
20
25
30
35
40
45
50
55



0x50004B89 - 0xA1060001 - 2010/May/17 04:45:02 UTC
Flux Density [Jy]
Wavenumber [cm⁻¹]
SPG Processed
New NLP
High wn end corrected

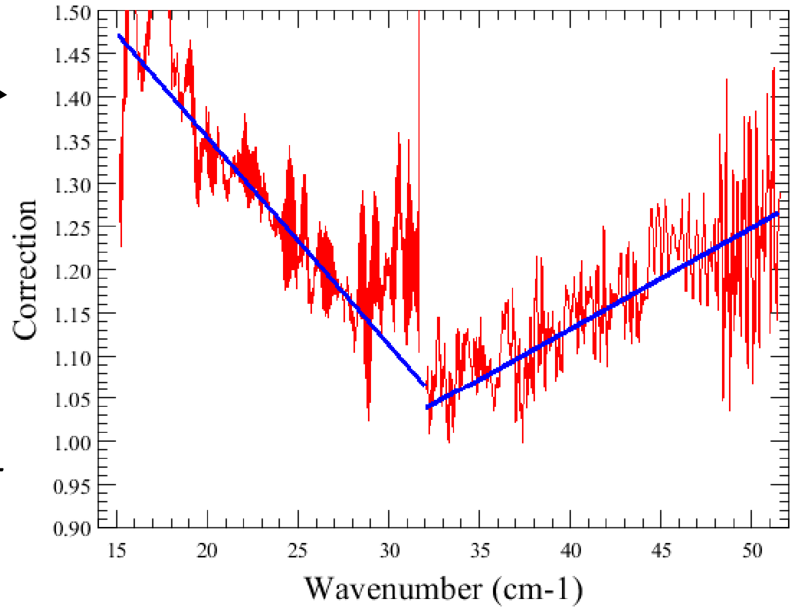


Recommendation: Replace the current pipeline step with that described here.

Calibration Accuracy (extended)

- Check against point source calibration using measured AΩ, and calculated η_{point} (to convert to Jy)

Remaining difference with Uranus calibration



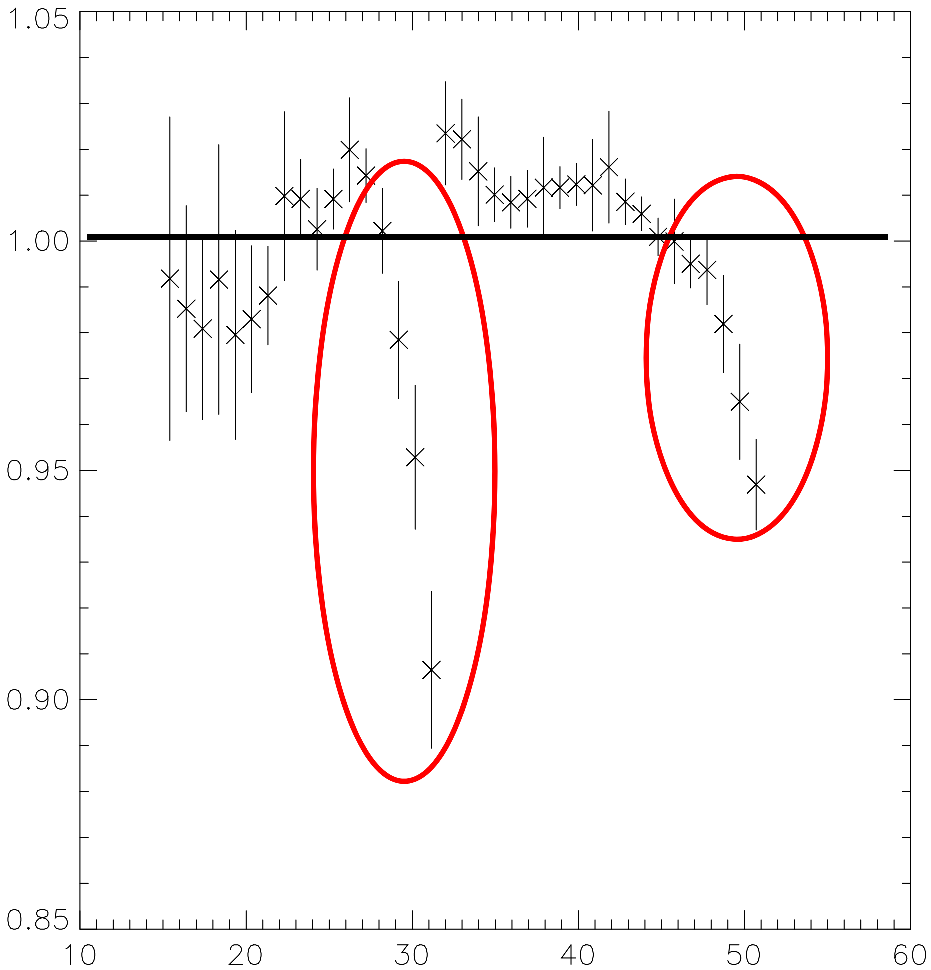
Assume this is due to:

- *coupling efficiency of the extended source*
- *wavenumber dependence of A*
- *vignetting*
- *also difference in fringing between point and extended source*
- *Can also remove slope*

Therefore apply it as correction to beam area:

$$\textbf{beamArea} = (A\Omega/A_{eff})\ast \textbf{correction}$$

Neptune RM ESA3 compared to measurement OD189

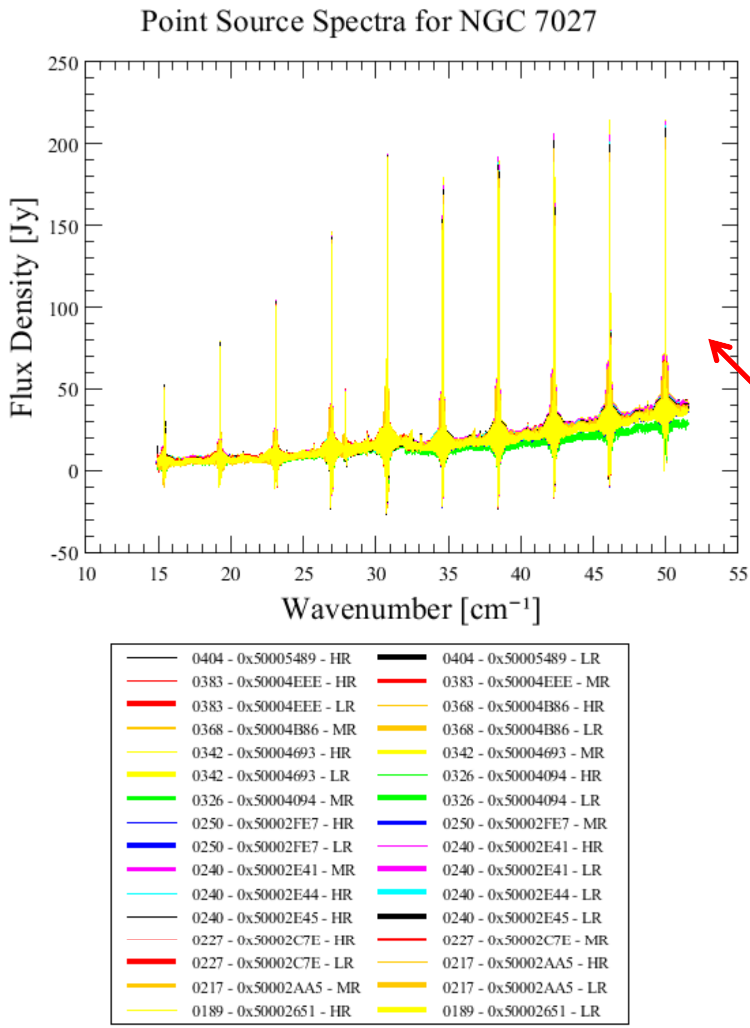


Calibrated only using telescope and telescope model plus point source correction from Uranus

Latter only removes ringing – binned anyway

New phase correction not applied

Spectrometers measure lines!



Outlier on OD326 was flagged previously as being the result of pointing errors on that day

Line Fit Results – NGC7027

Line	Rest Centre (cm^{-1})	FWHM (cm^{-1})	δFWHM (cm^{-1})	%	Amplitude (Jy)	δAmp (Jy)	%
CO(4-3)	15.3787	0.04780	0.00022	0.47%	45.7	2.0	4.4%
CO(5-4)	19.2222	0.04772	0.00011	0.22%	63.8	2.3	3.6%
CO(6-5)	23.0651	0.04778	0.00003	0.06%	91.7	4.3	4.7%
CO(7-6)	26.9070	0.04784	0.00005	0.10%	134.1	4.6	3.4%
CO(8-7)	30.7479	0.04778	0.00003	0.07%	178.5	4.3	2.4%
CO(9-8)	34.5877	0.04776	0.00003	0.05%	156.7	10.4	6.7%
CO(10-9)	38.4261	0.04776	0.00002	0.03%	167.7	13.3	7.9%
CO(11-10)	42.2631	0.04777	0.00003	0.05%	172.8	14.6	8.4%
CO(12-11)	46.0984	0.04773	0.00002	0.04%	170.2	15.5	9.1%
CO(13-12)	49.9320	0.04779	0.00005	0.11%	164.3	13.9	8.5%

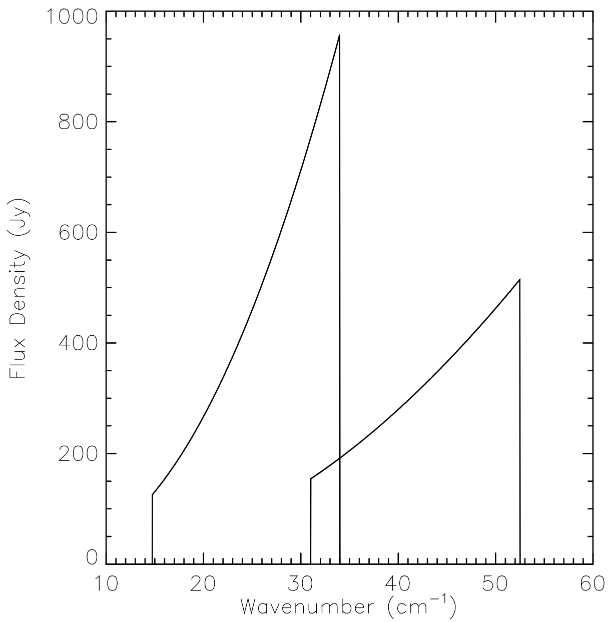
Fitted Average:
0.04777 ± 0.00003

SPIRE OM:
0.0480 ± 0.0002

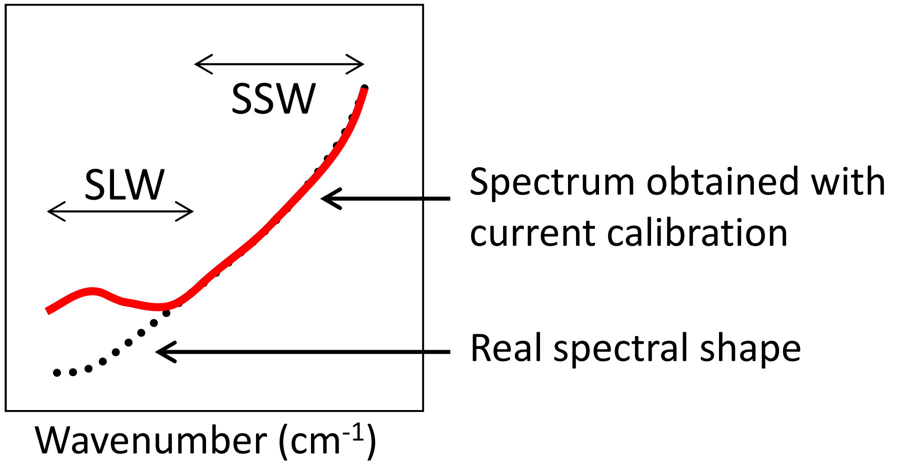
Reference Subtraction

- Reference subtraction leads to systematic uncertainty – additive term due to temperature variations between reference & source observation

Typical spectrum of the telescope

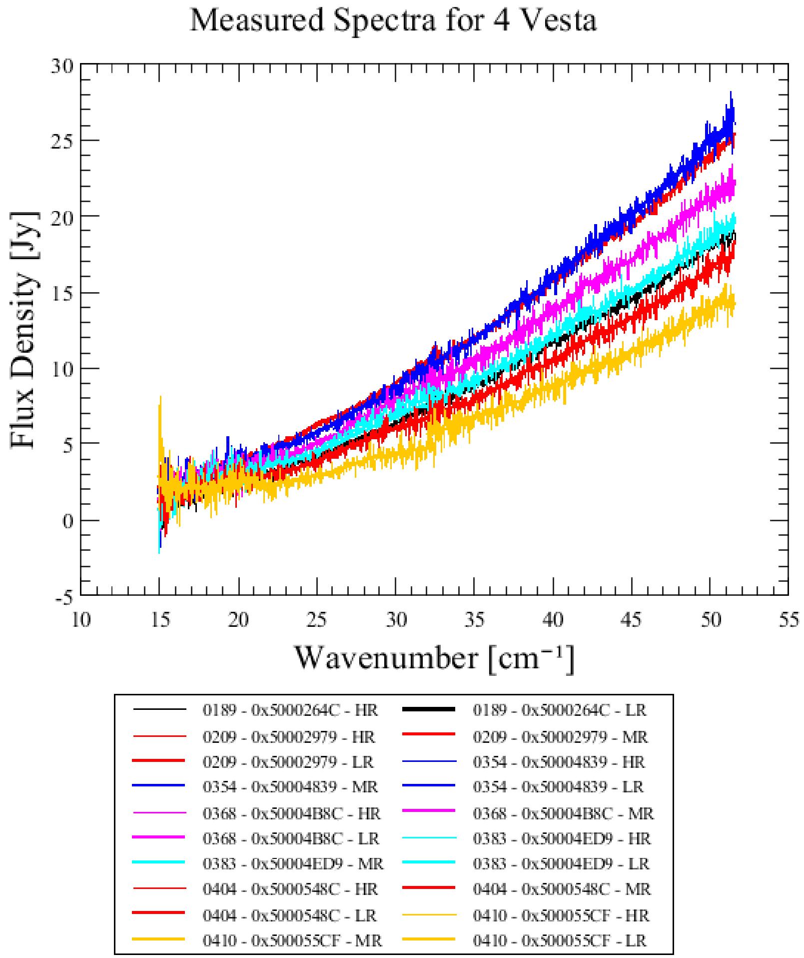


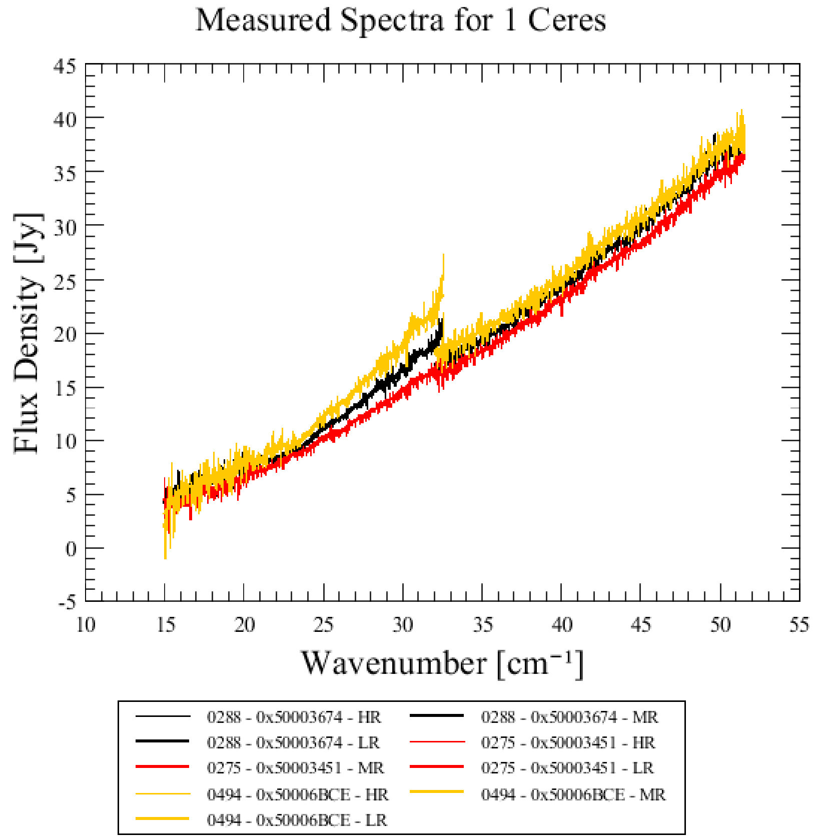
Limits the faintest sources we can observe



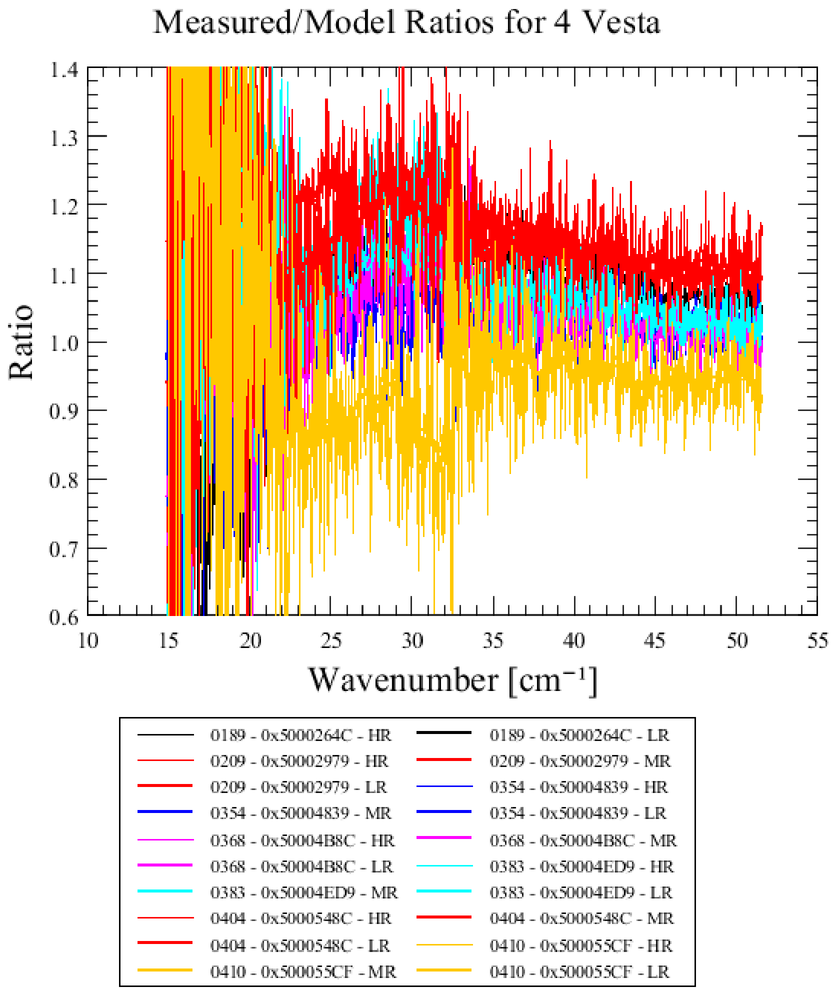
Aim is to correct this using measured instrument temperatures

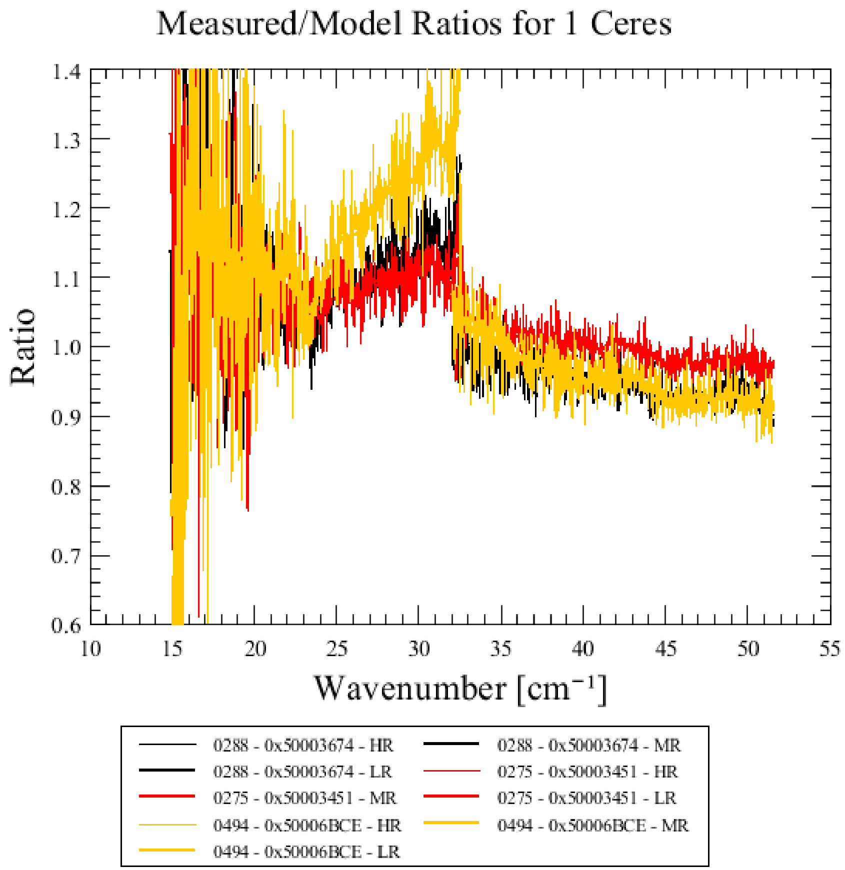
An illustration – Asteroids Fluxes





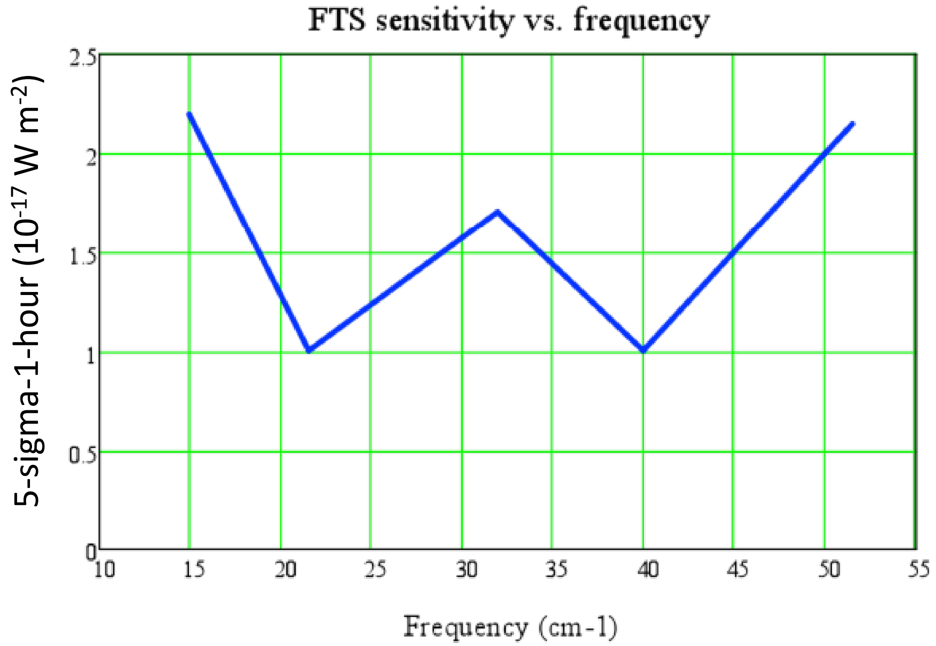
An illustration – Asteroids
Ratios to TM models





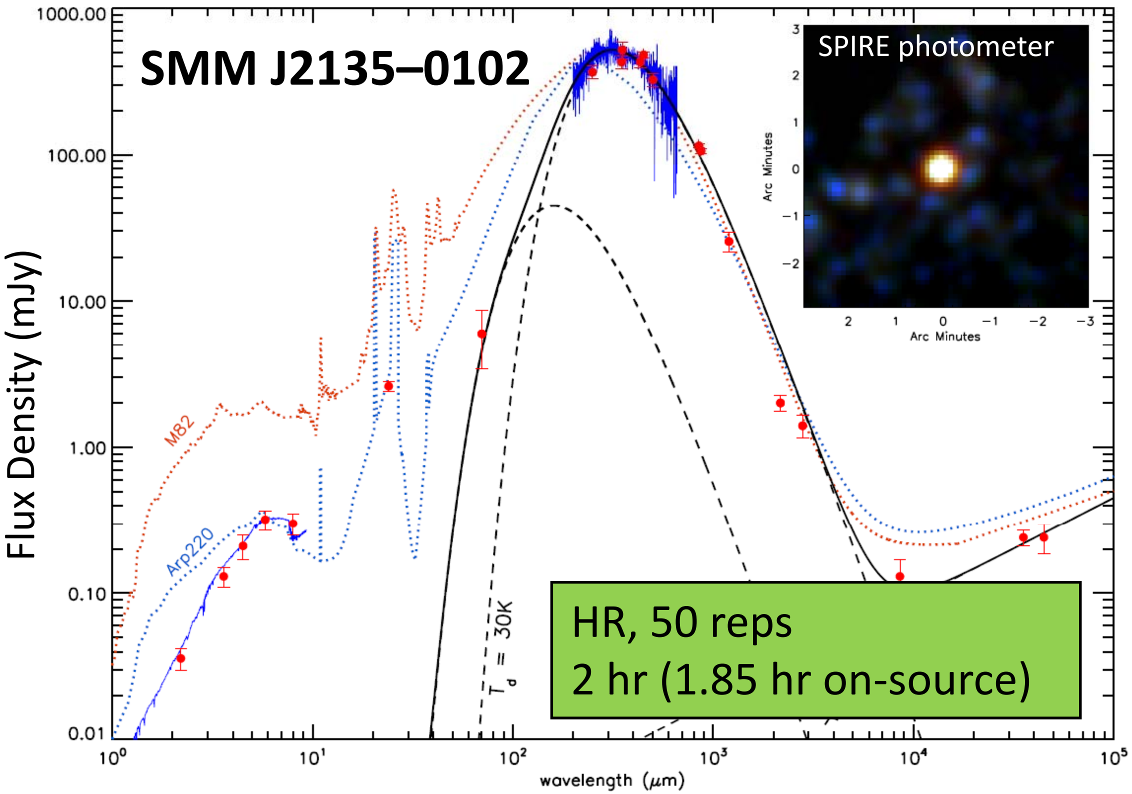
Noise & Sensitivity

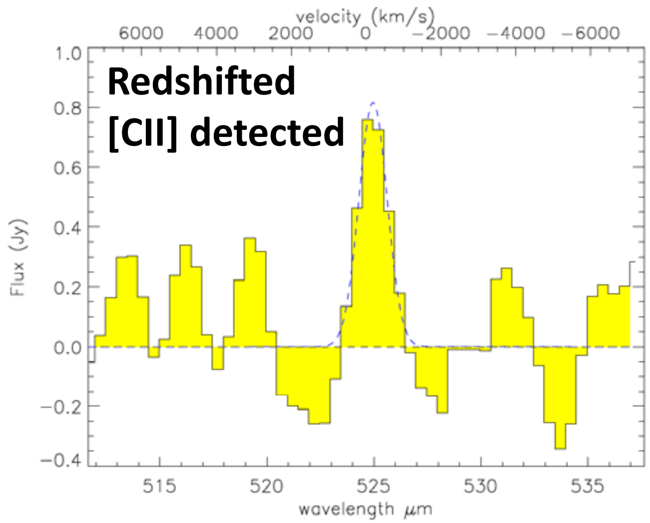
- Typical High res. FTS sensitivity (*5σ 1hour*) achieved with Uranus calibration:
  - 1 – 2 × 10^{-17} W/m^2 *(integrated line at high resolution)*
  - 0.8 – 1.7 Jy *(continuum noise at high resolution)*



Faint targets..

Faintest target so far: lensed z=2.3 galaxy (***Ivison et al. 2010***)



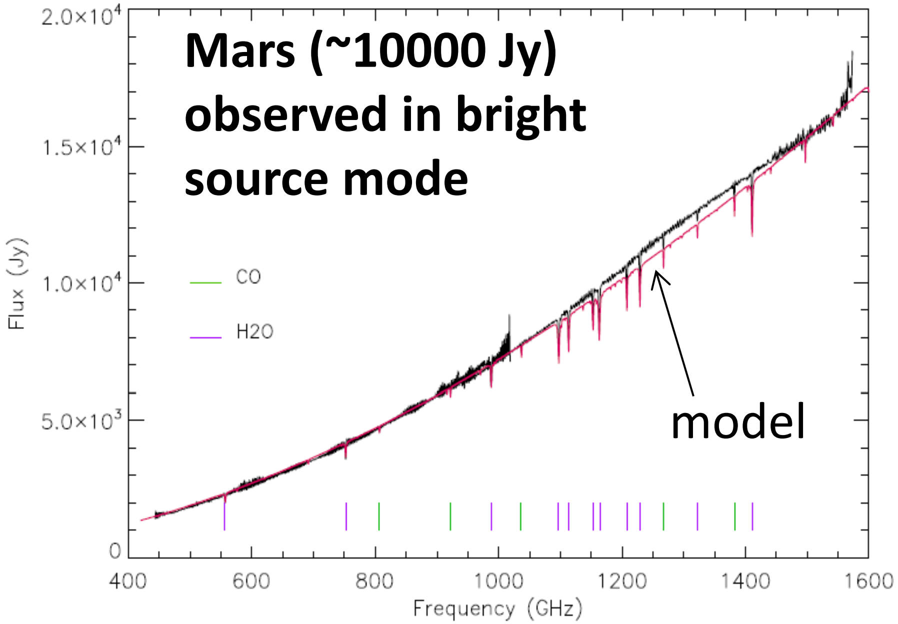


- Continuum ~300 mJy
- Photometer map important for absolute flux calibration

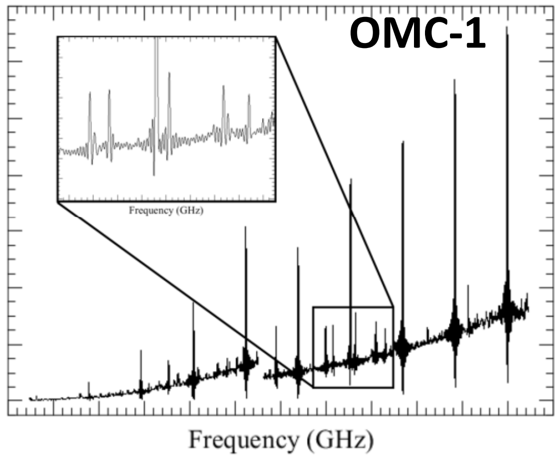
Herschel imaging and spectroscopy of a bright, lensed submillimetre galaxy at z=2.3, **Ivison et al. 2010**

Bright targets..

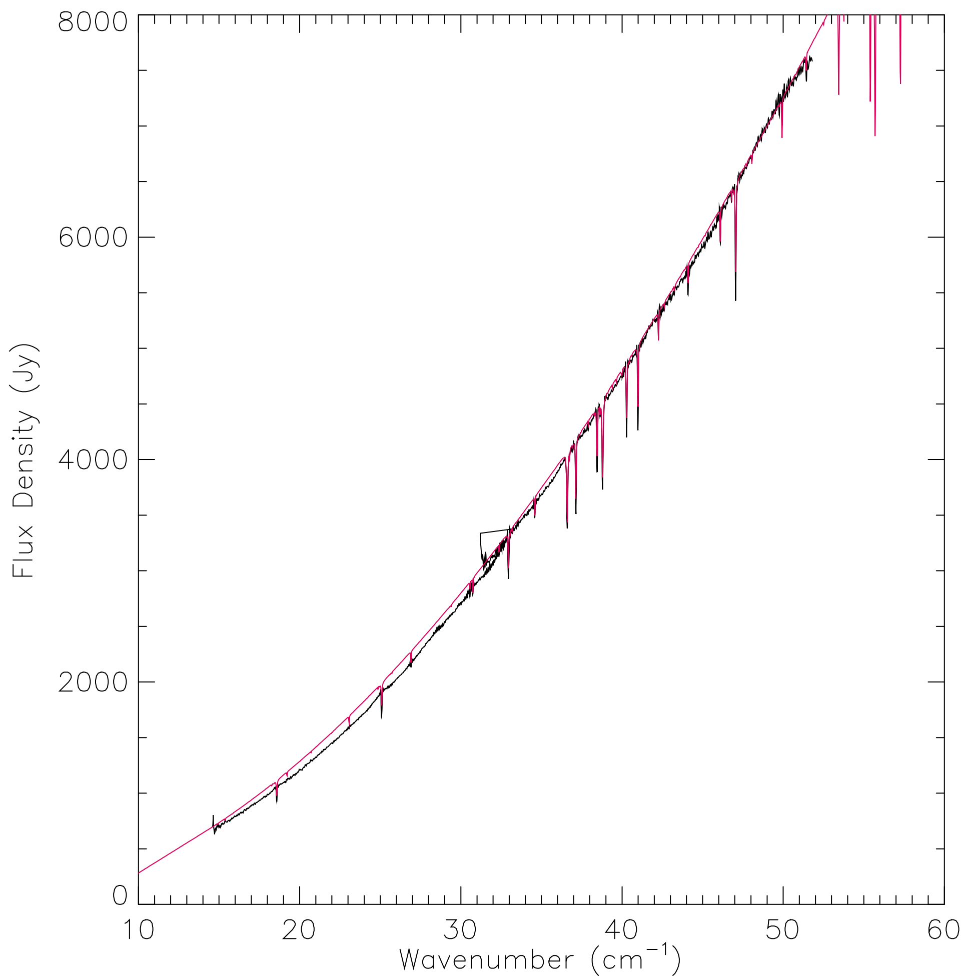
- We have optimised bright source mode using a combination of "dephasing" and increasing the bias
- Bright source mode: lower responsivity - reduces clipping but at the cost of reduced sensitivity
- Appropriate for sources of brightness greater than ~175 / 55 Jy for SSW, SLW



Tests to optimise bright source mode using Orion



Mars OD404 – special processing

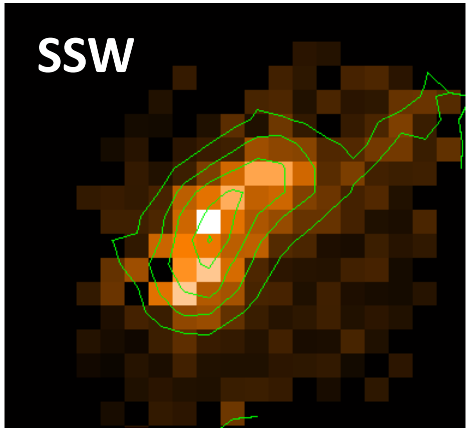


Convert to detector temperature
Apply gain derived from ratio of PCAL flash in bright/nominal mode.
Standard v5 pipeline to create Interferograms
Standard v5 pipeline to FT, but with prototype phase correction
Standard instrument correction
Subtract background in calibrated Jy using dark from the day of the observation

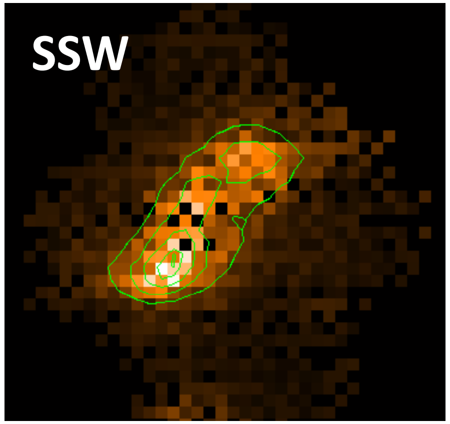
Model from Sidher (using RADTRANS) from OD176 scaled by square of apparent diameter

Mapping

Sparse (38" pixels)



Intermediate (19" pixels)



Full (9.5" pixels)

- Flux calibration depends on jiggle position
- Holes in map due to naive gridding & dead detectors
  (HIFI gridding algorithm could also be used)