The Photodetector Array Camera & Spectrometer

ESLAB 2010

Herschel First Results Symposium

A. Poglitsch
for the
PACS Consortium

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- Observing Modes and AOT Release Status
- PACS-relevant Herschel Satellite Performance
- PACS Instrument Characterization Key Results/Issues
  - Spectrometer
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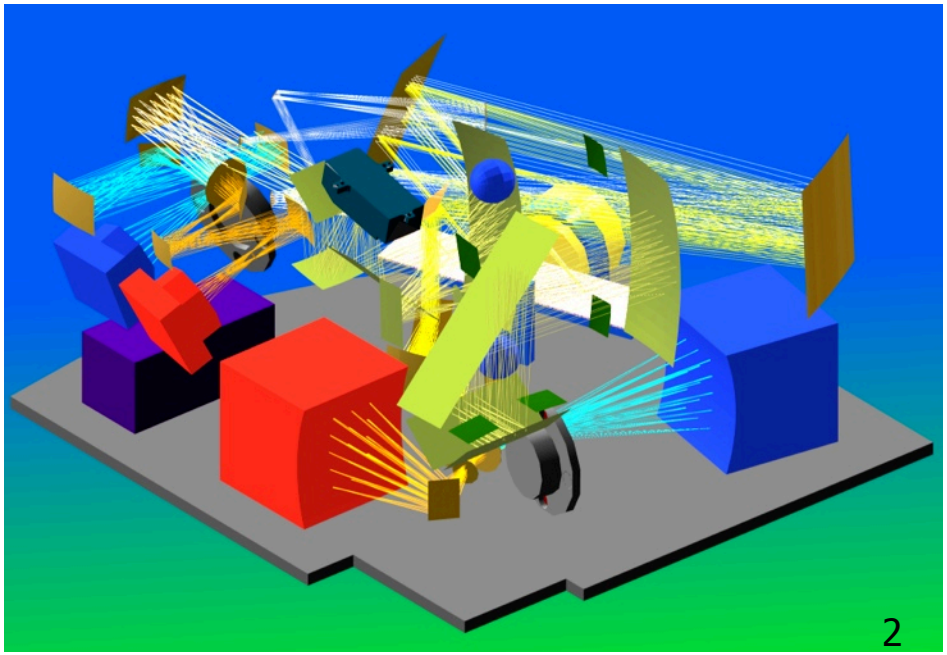
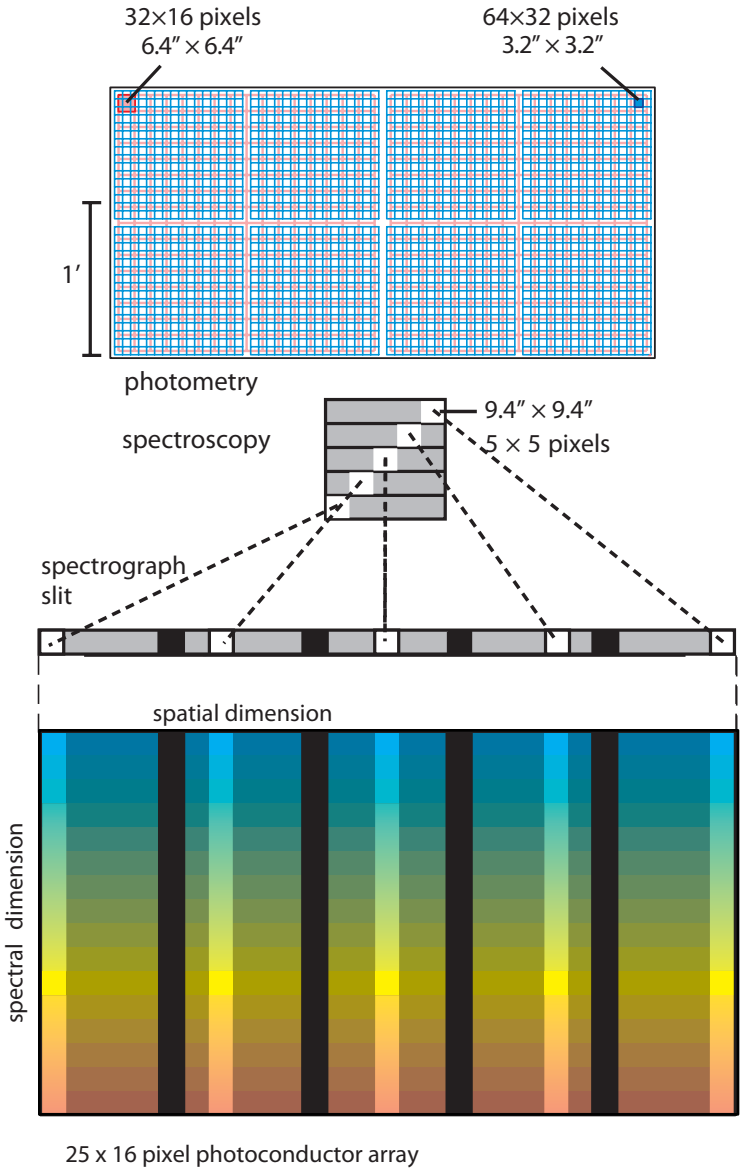
- Outlook and Future Work



Instrument Concept

- **Imaging photometry**
  - two bands simultaneously (60-85 or 85-125 μm and 125-210 μm) with dichroic beam splitter
  - two filled bolometer arrays (32x16 and 64x32 pixels, full beam sampling)
  - point source detection limit ~5 mJy (5σ, 1h)
- **Integral field line spectroscopy**
  - range 55 - 210 μm with 5x5 pixels, image slicer, and long-slit grating spectrograph (R ~ 1500)
  - two 16x25 Ge:Ga photoconductor arrays (stressed/unstressed)
  - point source detection limit 3…20 x10^{-18} W/m^2 (5σ, 1h)



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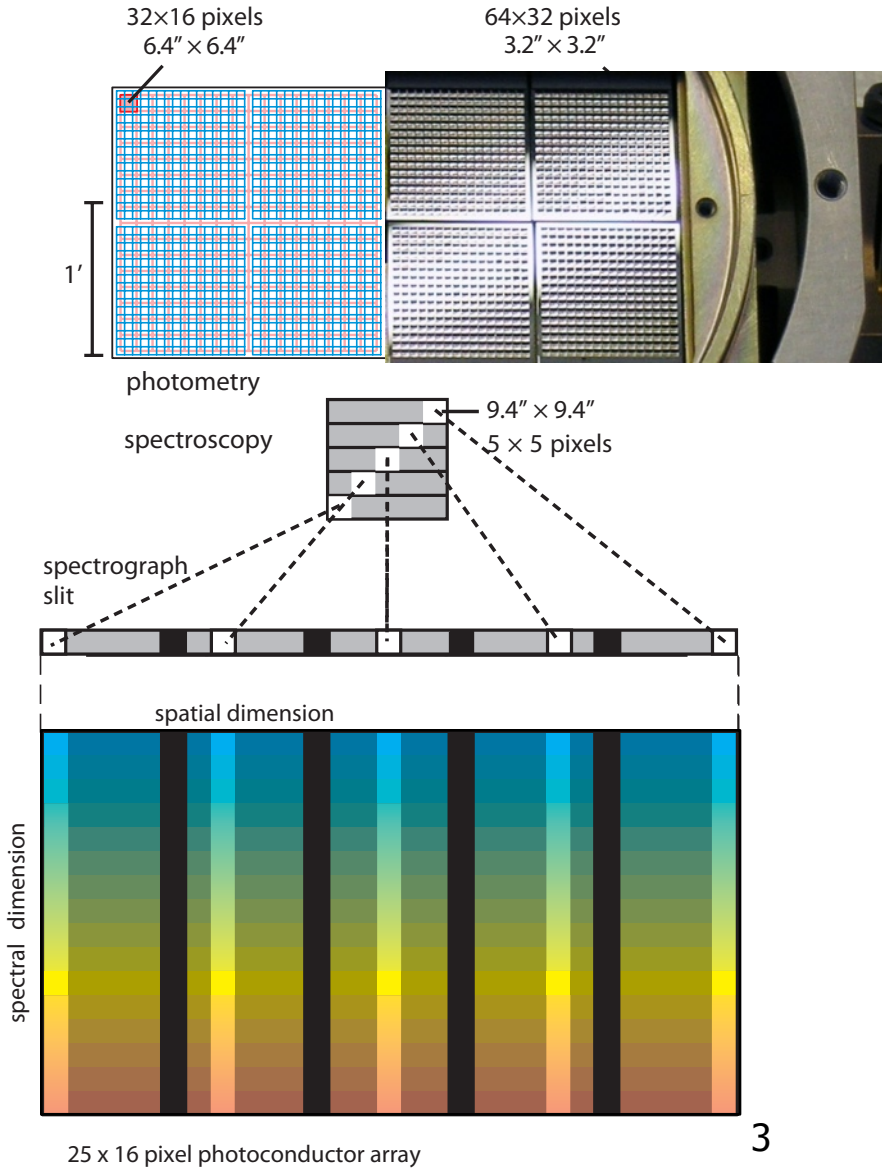

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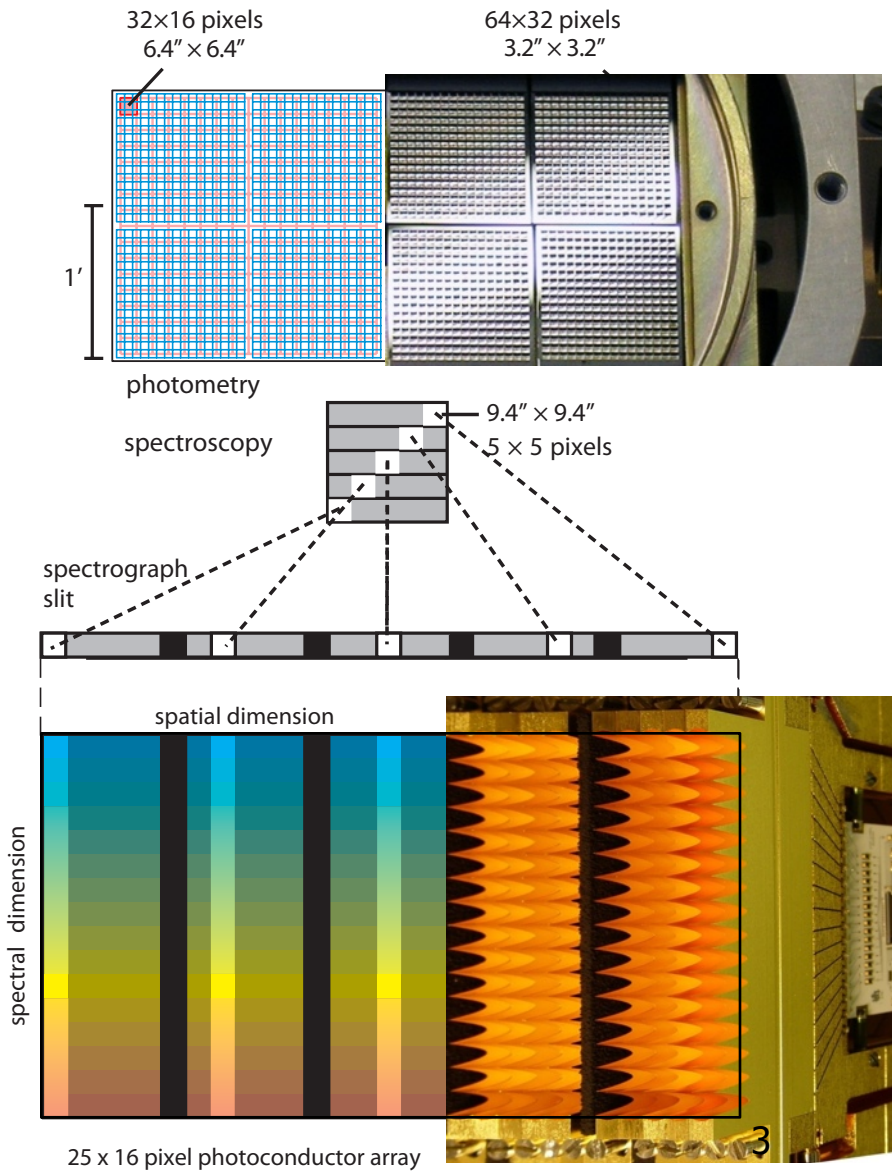
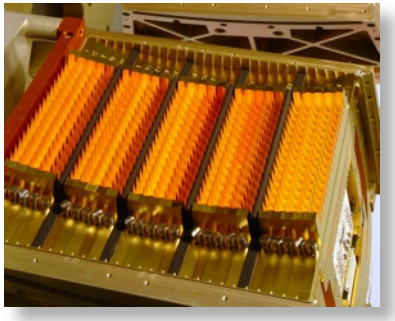
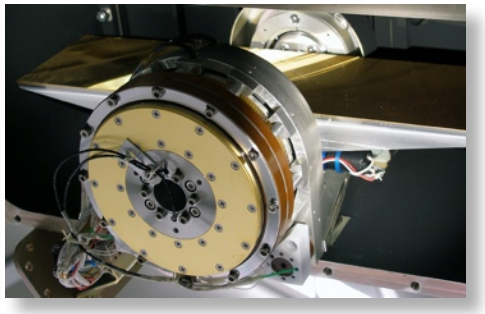
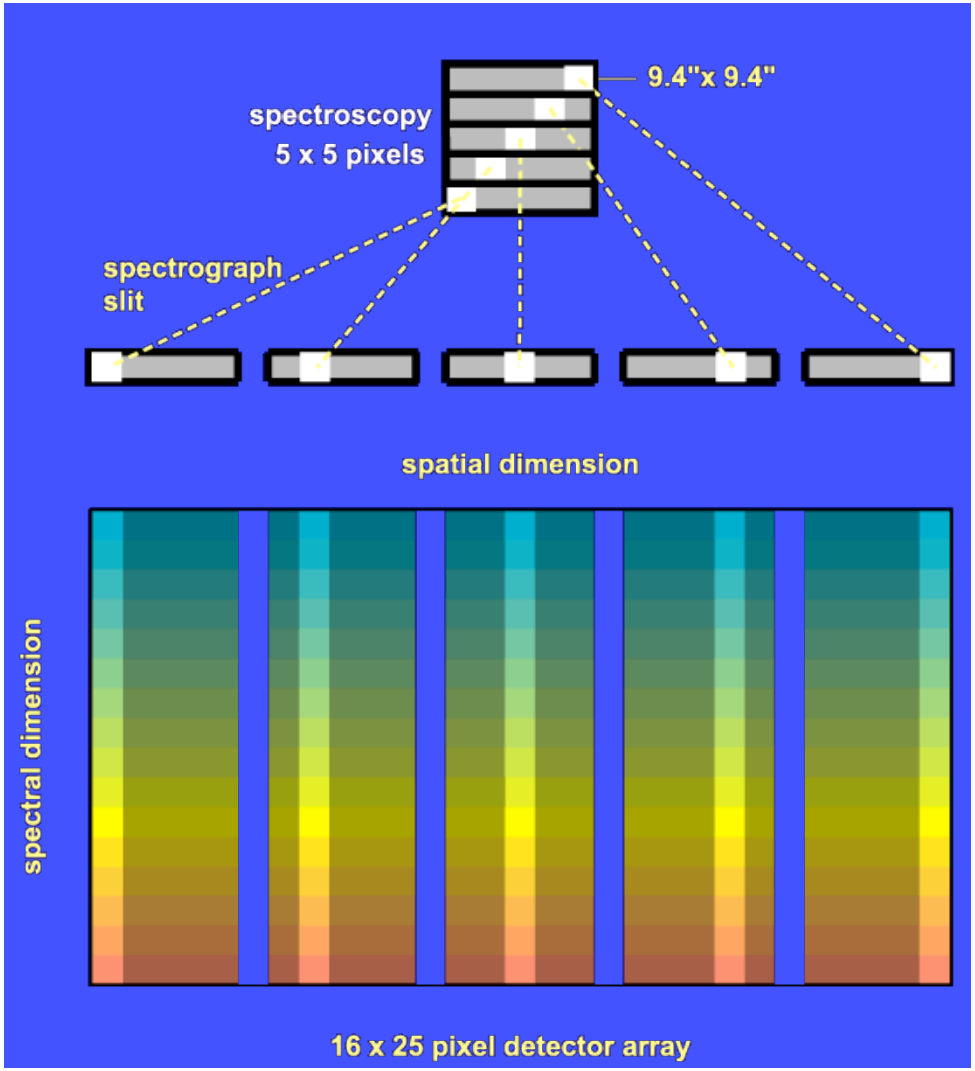


Spectrometer Observing Modes





- **Line Spectroscopy: observation of individual line(s)**
  - Chop/nod or "wavelength switching"
  - Staring or mapping
  - R ~ 1500
- **Range Spectroscopy: observation of extended range(s)**
  - Chop/nod or off position
  - Staring or mapping
  - High sampling or SED mode



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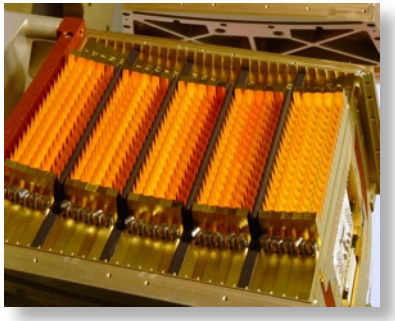

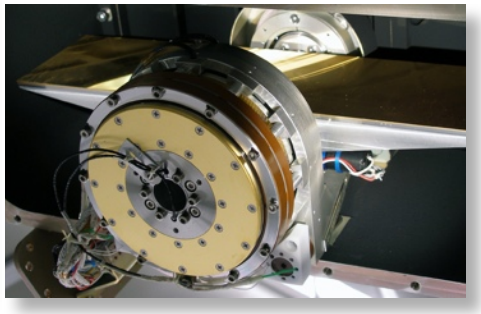

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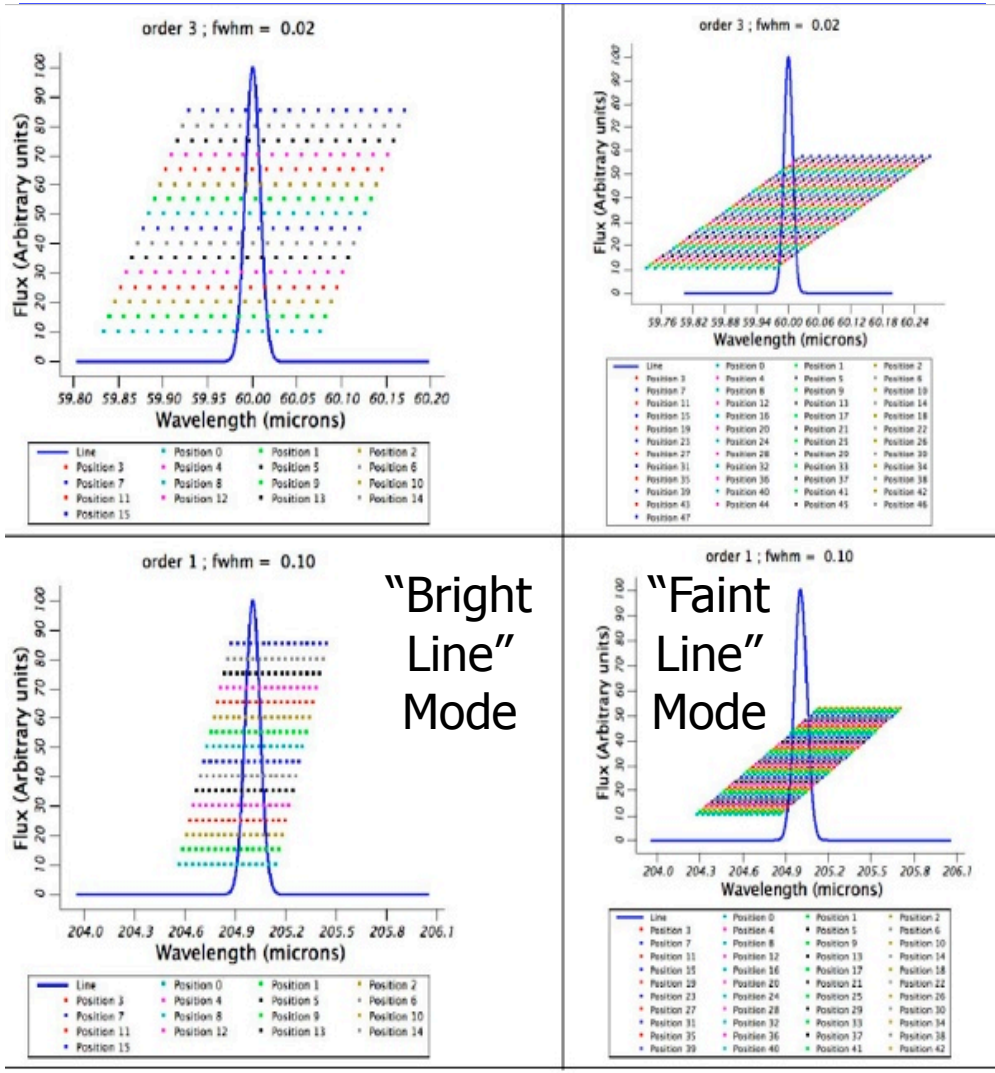
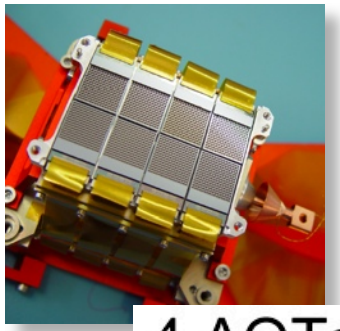
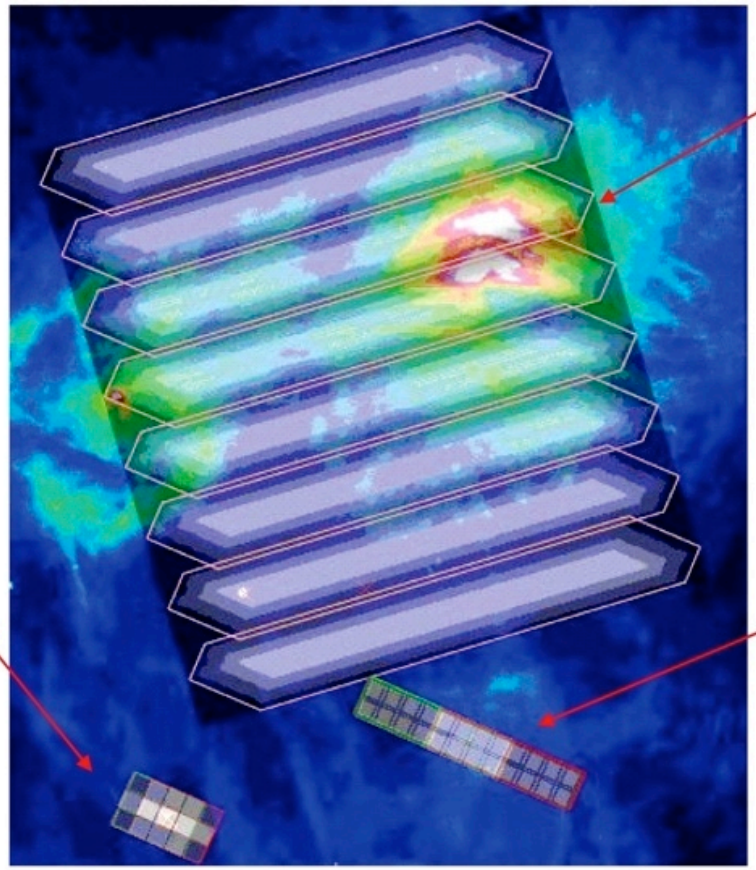




Photometer Observing Modes

4 AOTs in photometry channel



Extended source Mapping:

Options are Scan (shown) or chopped Raster

Maximum size 4-deg

3 scan speeds or fixed chopping

Point source photometry:

4-positions

2 chop/nod cycles

Repeat basic cycle to gain more sensitivity

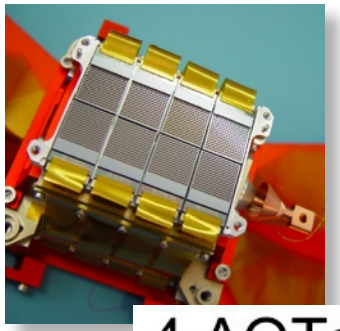
Small source photometry:

Small 2x2 raster

200"x100" FOV

Dither to cover inter-matrix gaps

Dual Band: 70+160 μm
or 100+160 μm



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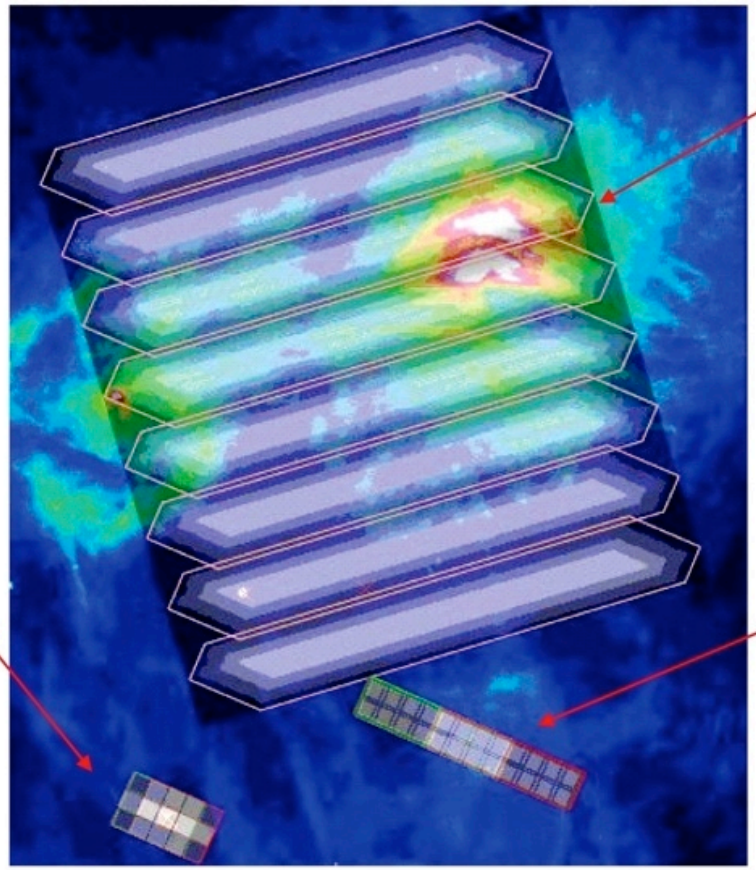

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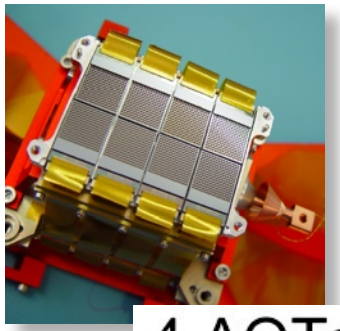

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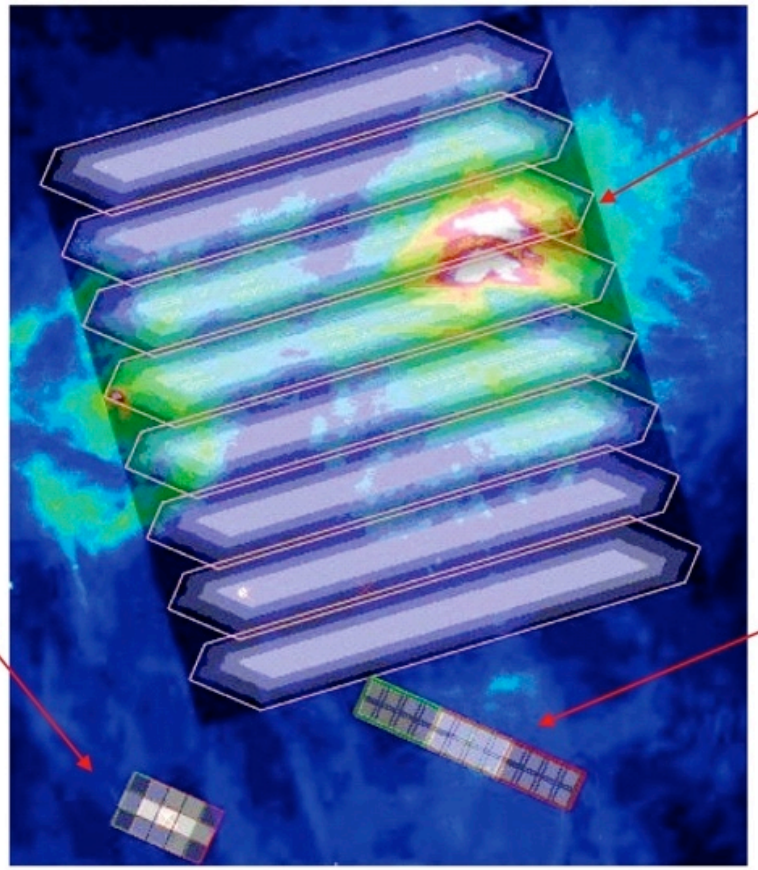

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Sm… raster

…FOV

…ther to …

inter-matrix ga…

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AOT Release Status

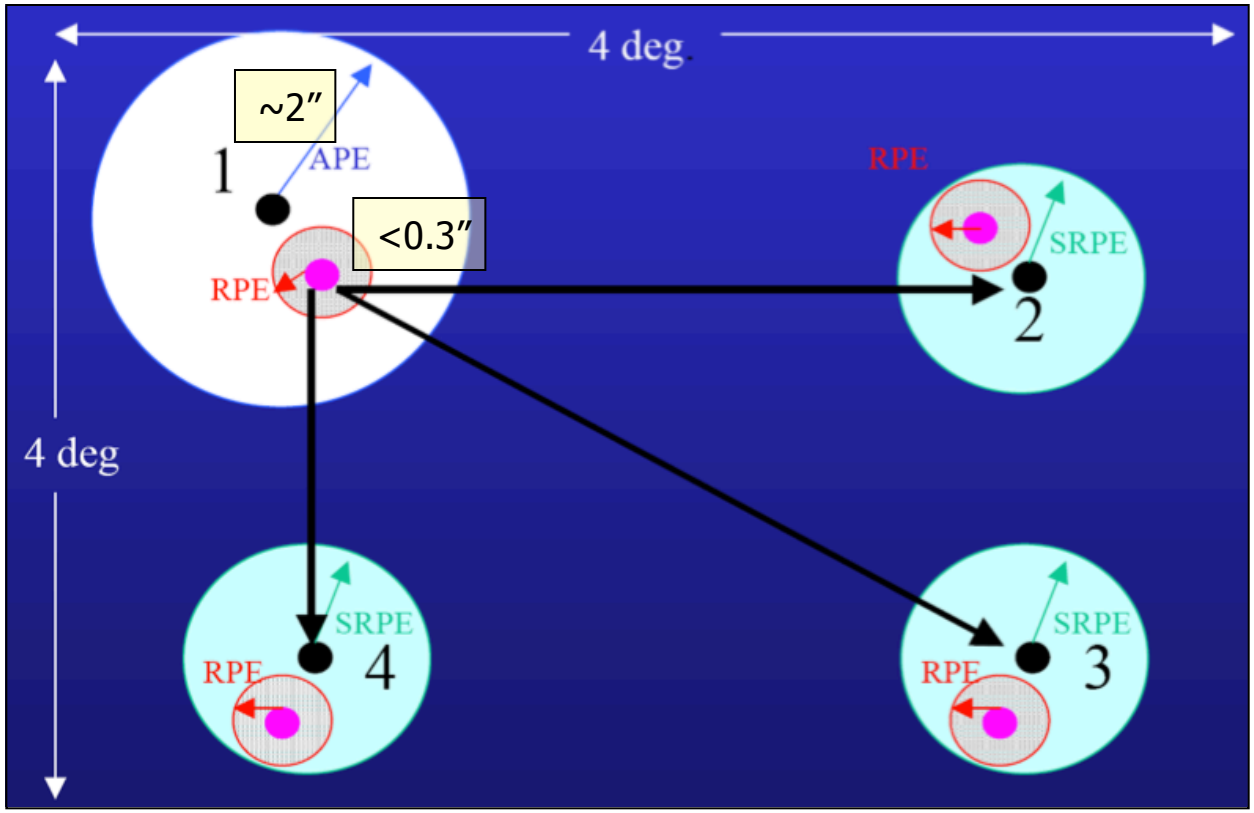
- All photometer AOTs have been released, but with modifications compared to pre-flight
  - scan speed optimization
  - replacement of all chopped observations by scan map mode, except for point source mode
- All spectrometer AOTs have been released, again, with some modifications
  - execution times of AOT "building blocks" have changed
  - wavelength switching modified; imminent (potential) change
- Pipeline versions in HIPE exist for all released modes, except for wavelength-switching line spectroscopy
  - support available from NHSC

Satellite Performance: Pointing

- Pointing Performance:
  - Relative Pointing Error (RPE): Requirement <0.3″ Goal <0.3″
  - Absolute Pointing Error (APE): Requirement <3.7″ Goal <1.5″
  - Spatial Relative Pointing Error: Requirement <1″ achieved ~2″

  - RPE Scanning:
    Requirement <1.2″
    Goal <0.8″

  - Solar Aspect Angle:
    Requirement:
    -30° to +30°
    Actual:
    -20° to +30°



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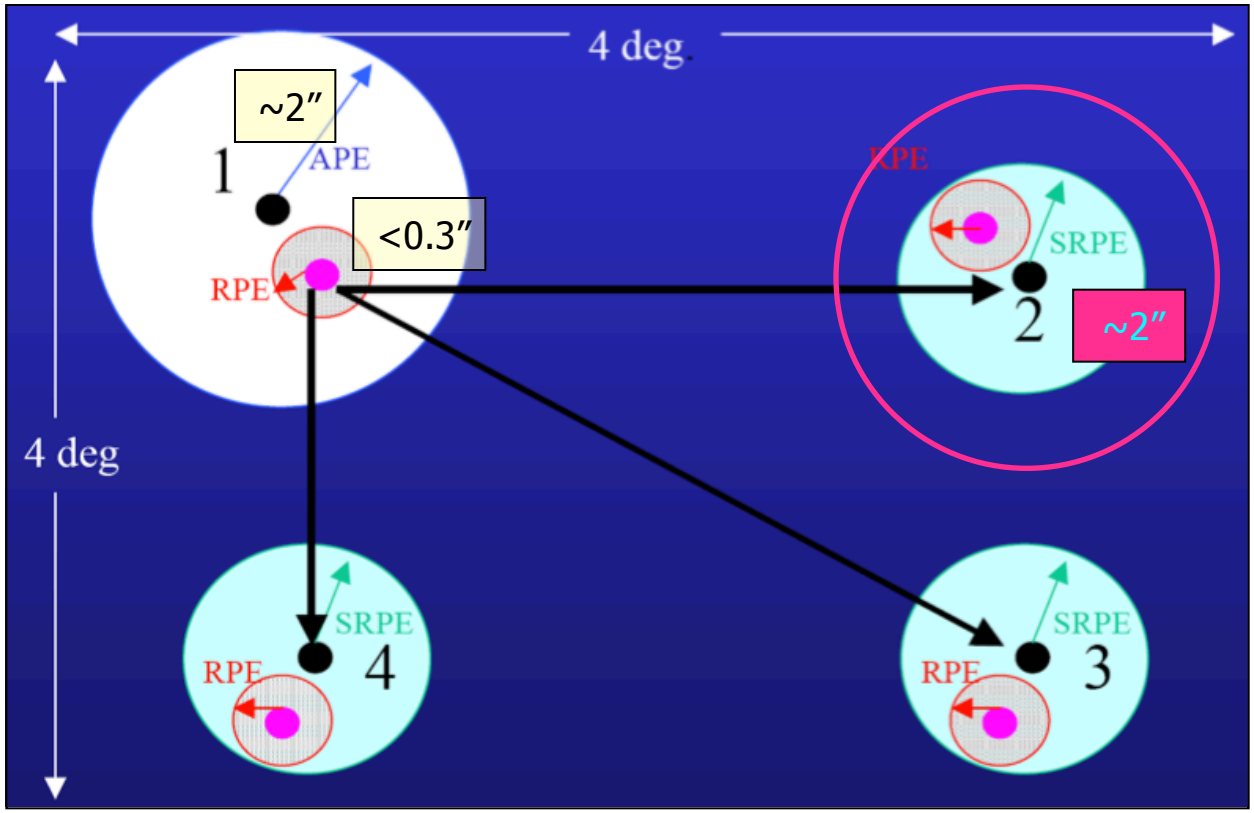
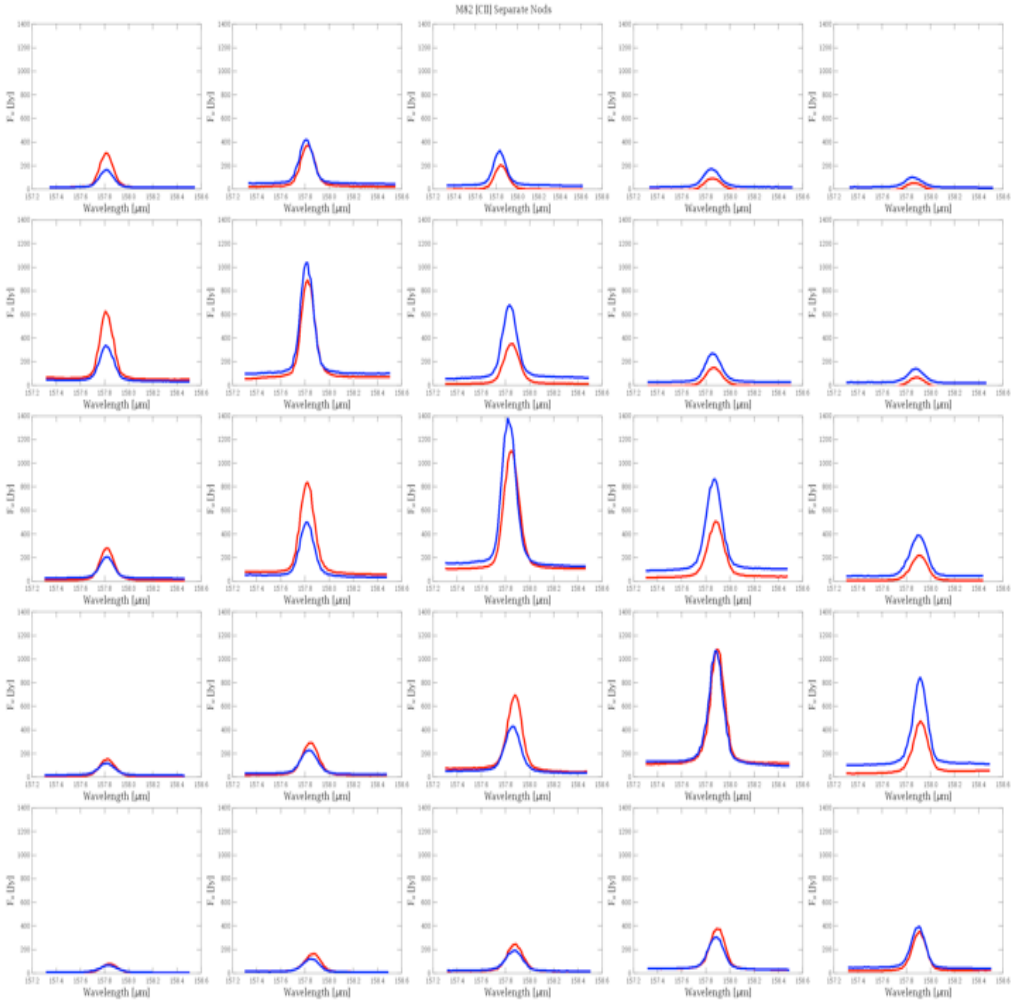


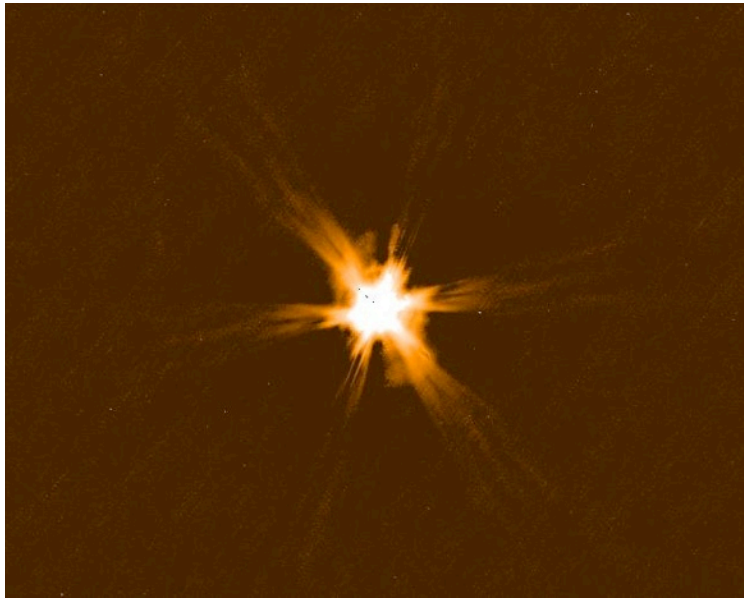
Pointing Match Chop/Nod (Spectroscopy)

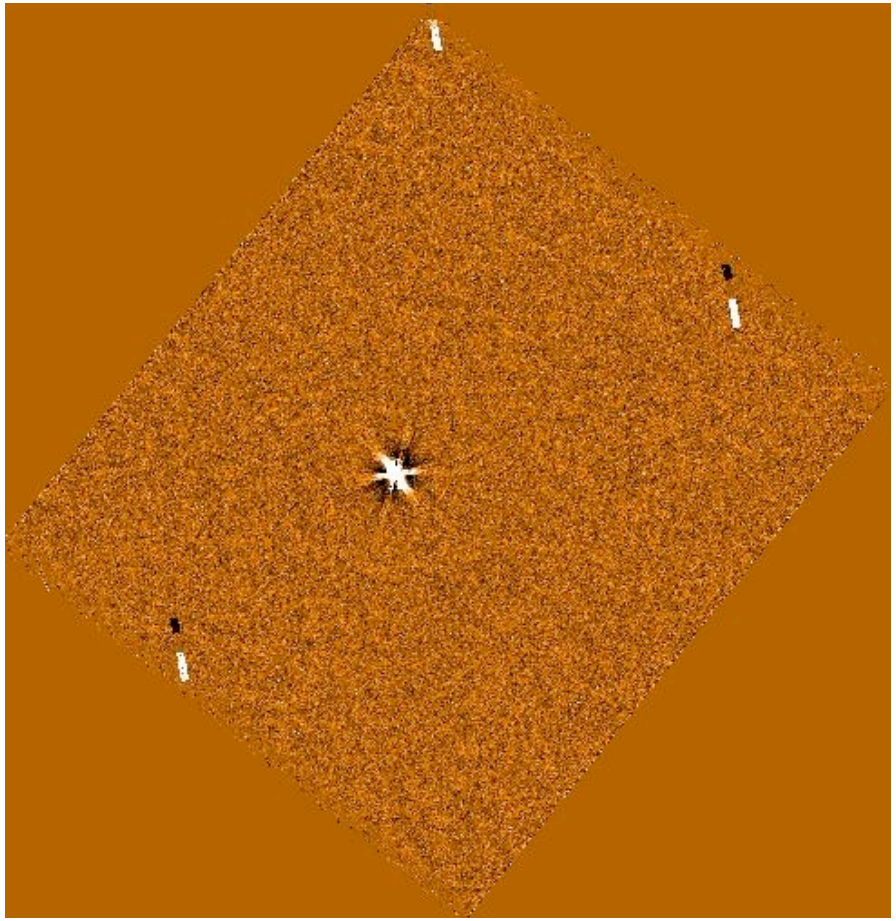
- From (still limited) statistics, no problem for small chopper throw
- With large chopper throw (±3’), APE seems to apply for “Nod A” and “Nod B” individually - sometimes ok, sometimes a problem



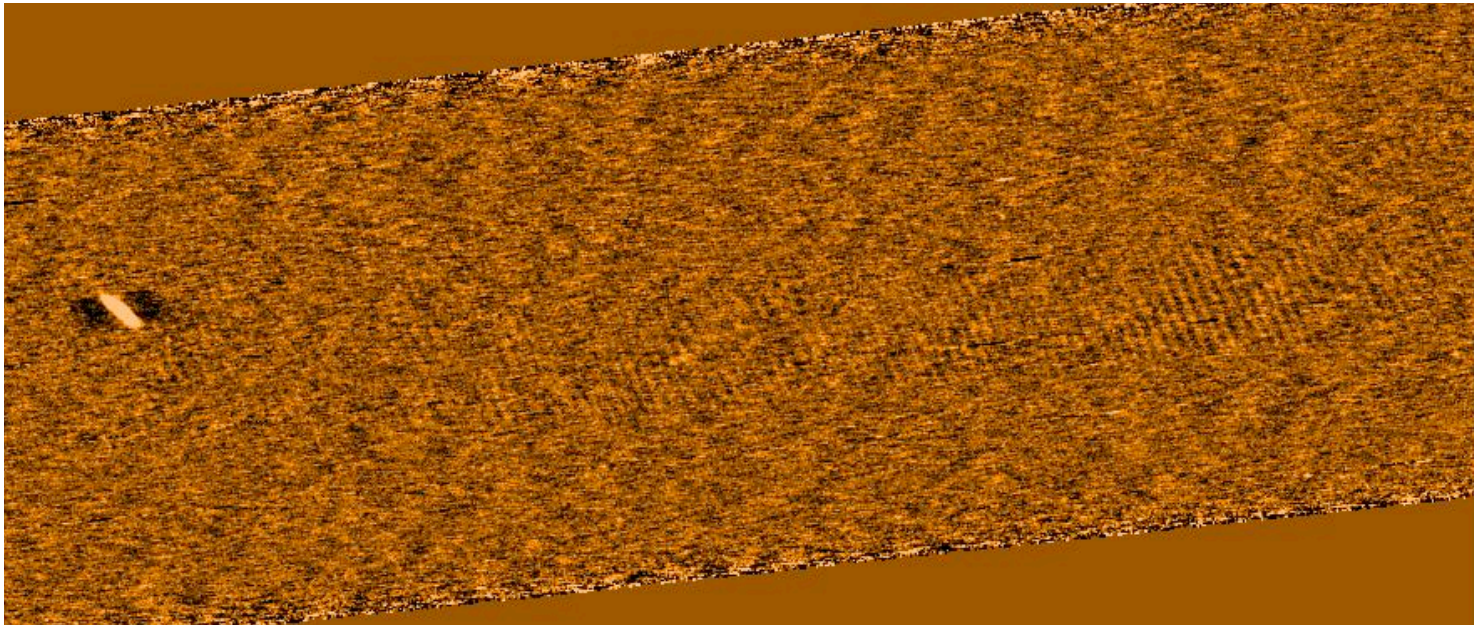
Satellite (+Instrument) Performance (4)

- Straylight
  - Observation of Mars
  - No hint of straylight around boresight



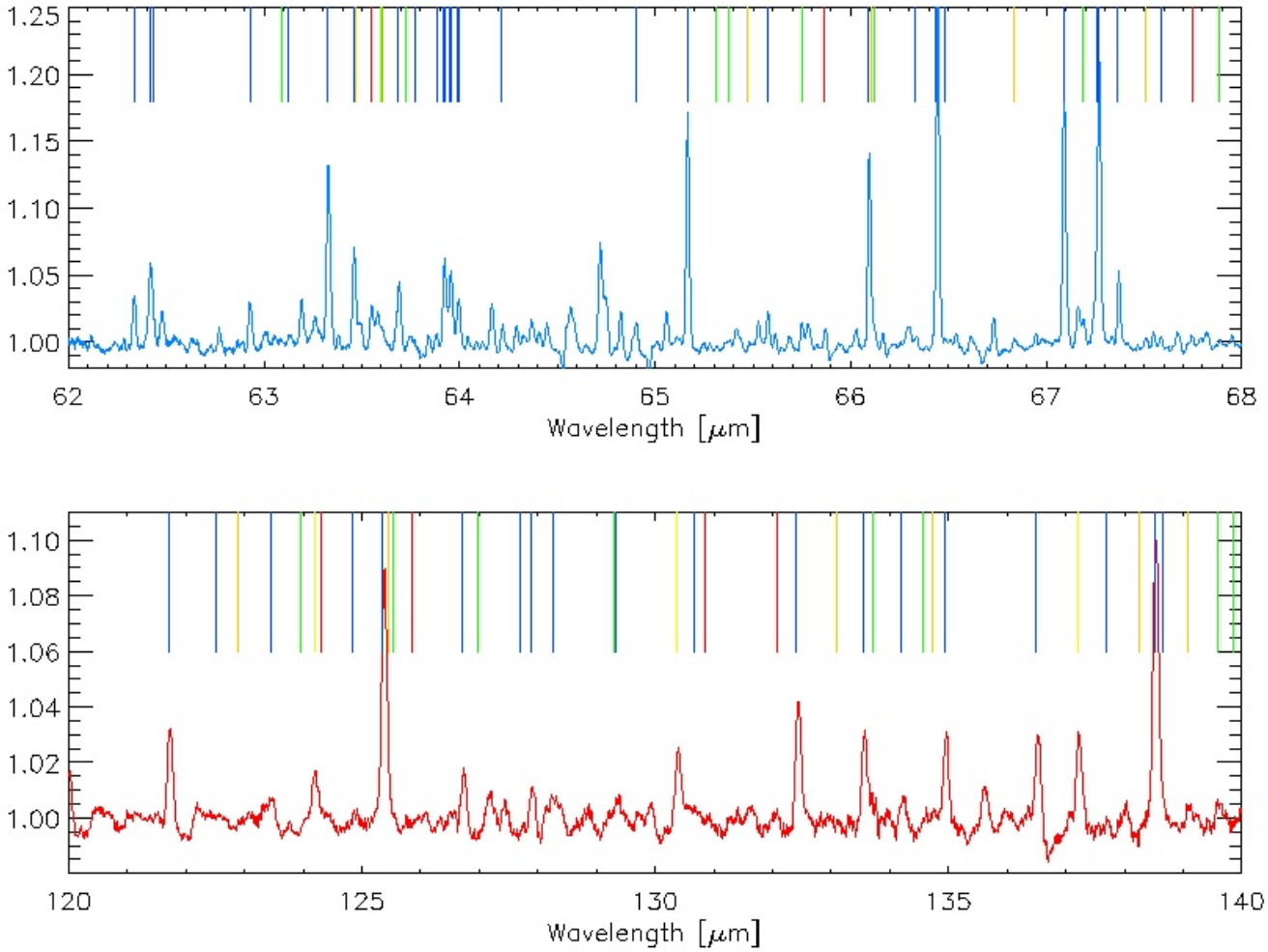


Satellite + Instrument: Interferences



- They affect only the blue photometer
- Amplitude is variable (from faint to severe)
- They are rare (i.e. a large fraction of the observations is unaffected)
- The root cause has not yet been found (solar array?)

Spectrometer Wavelength Calibration



W Hya PACS observation, continuum divided

Velocities corrected to rest frame, strong water lines over-plotted;
$H_2{}^{16}O$=blue
$H_2{}^{18}O$=green
$H_2{}^{17}O$=orange
HDO=red
CO=yellow

Lines from 4 water isotopes are detected.

Wavelength calibration is quite good already, fine tuning to come still

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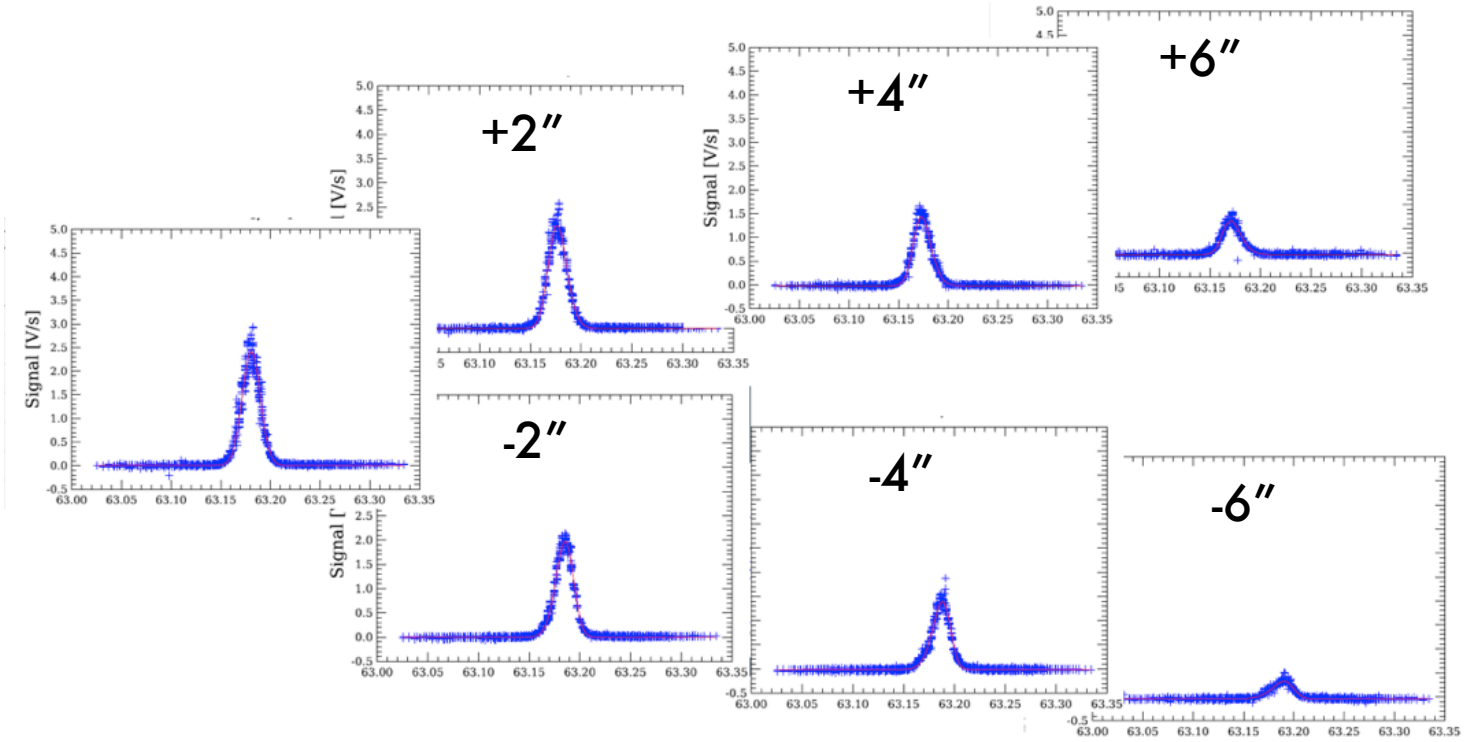
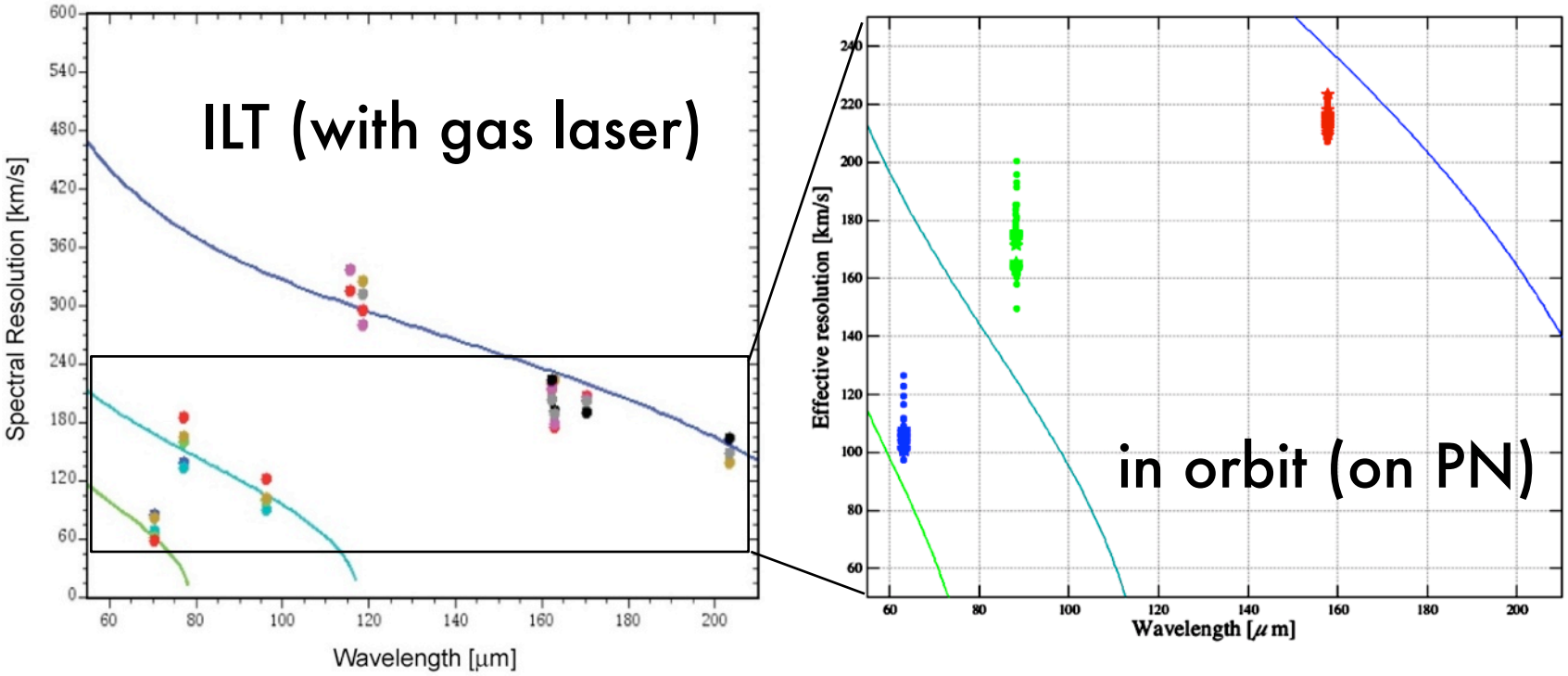


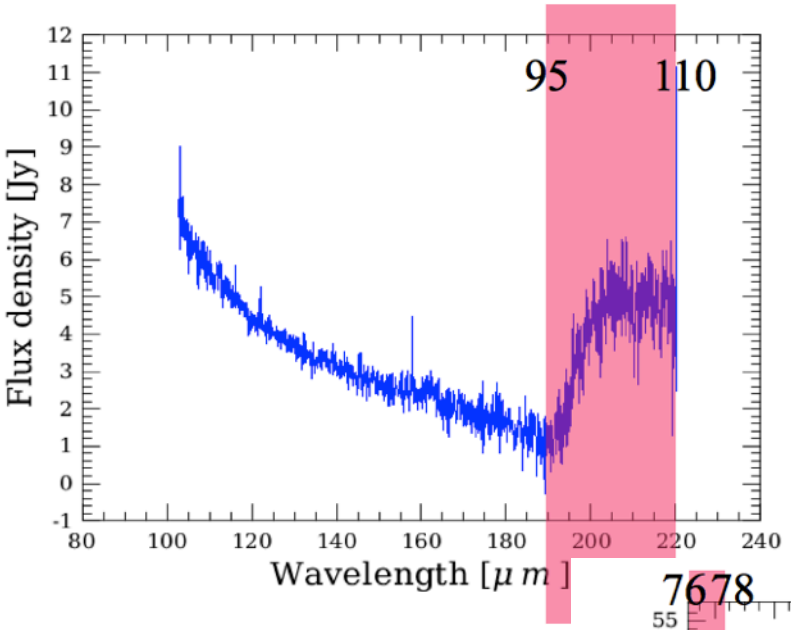
- Wavelength shift + skew with source offset from slit center (cross-slit direction, not along slit)
- Characterization + corrections underway
- Do not over-interpret line shapes in maps

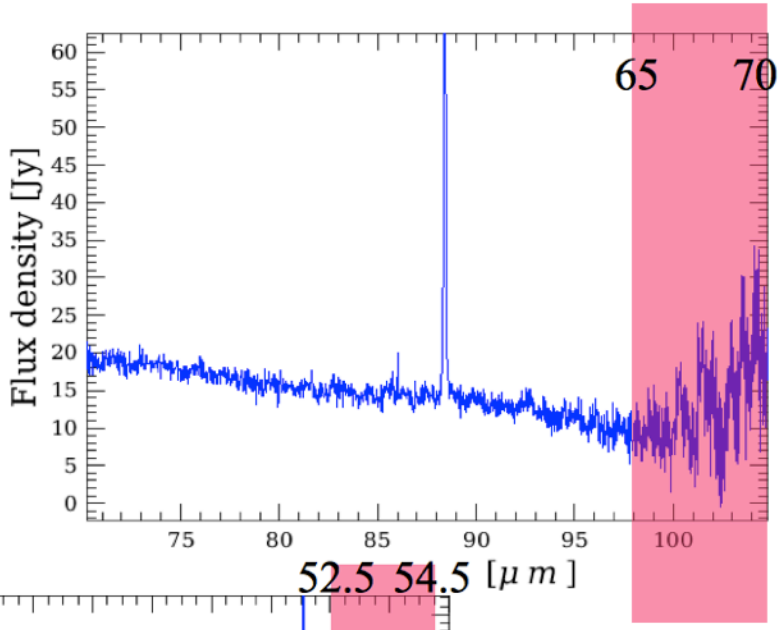
Spectrometer Spectral Resolution

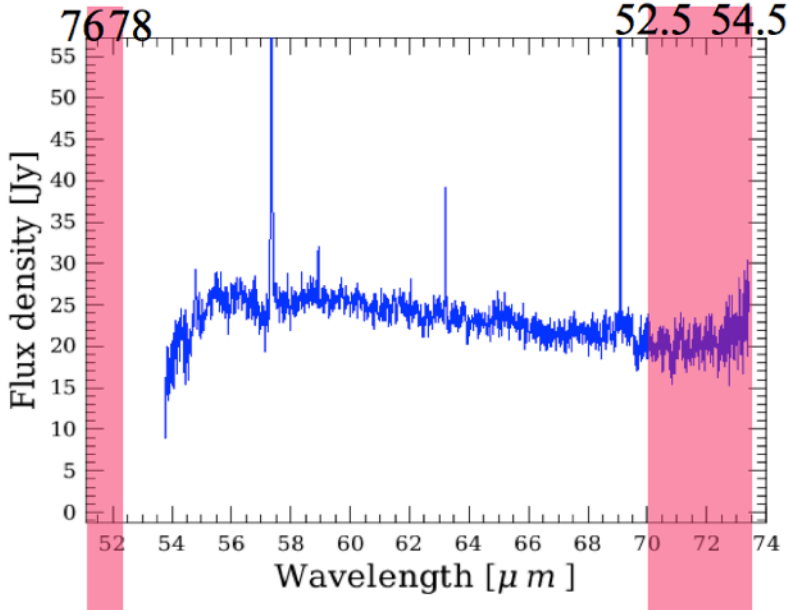


- Measured resolution in fair agreement with lab test and calculated resolution

Spectrometer "Problem Zones" - Leakage







Spectrometer Sensitivity

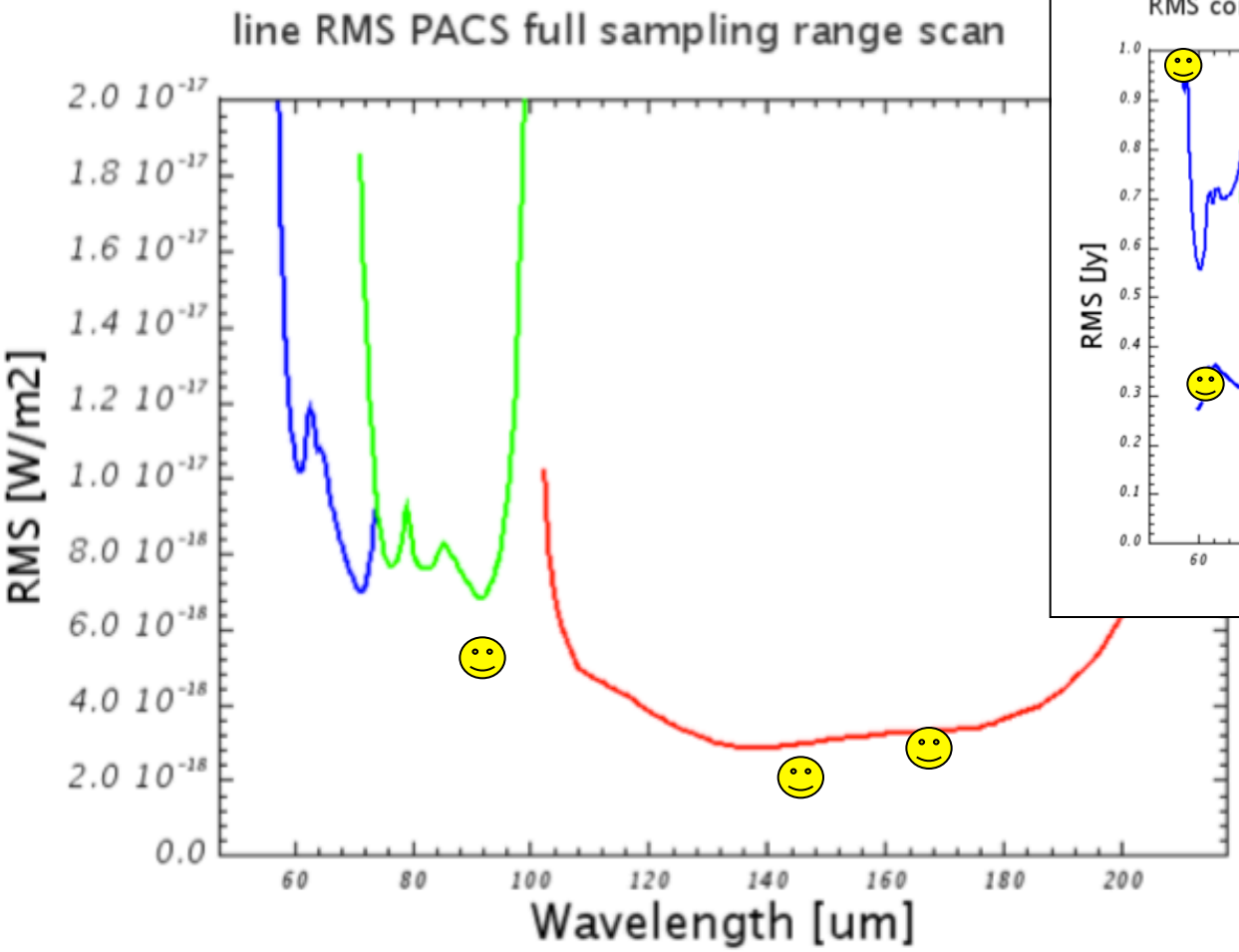


Fig.: 3.14 from PACS Observers Manual
= HSPOT sensitivity

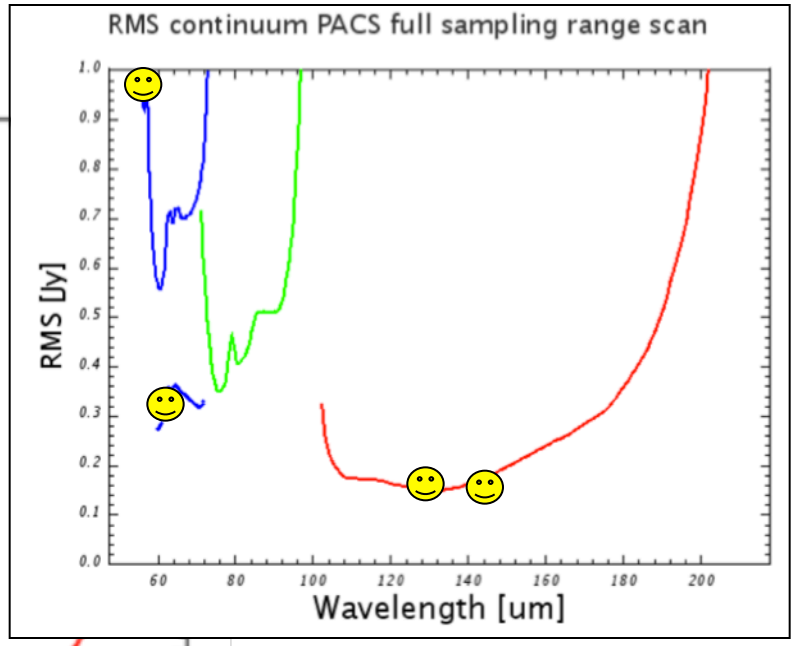
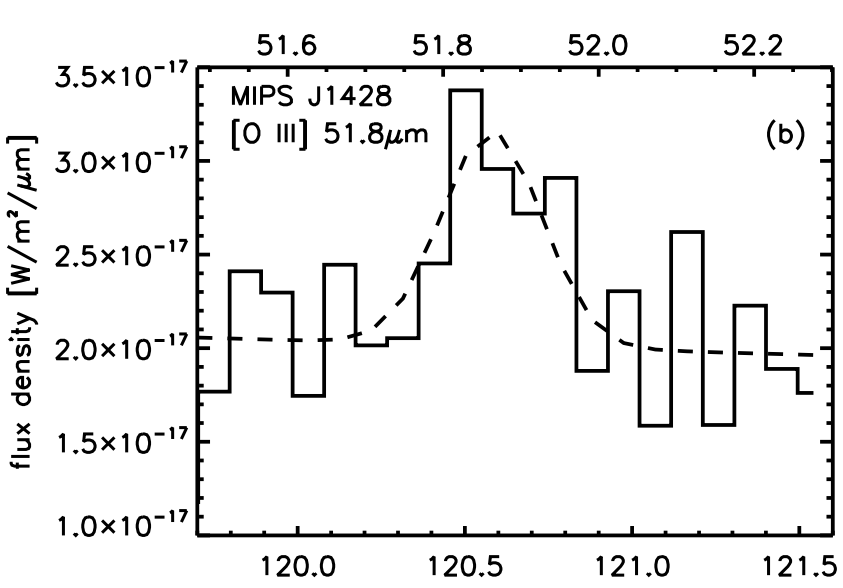


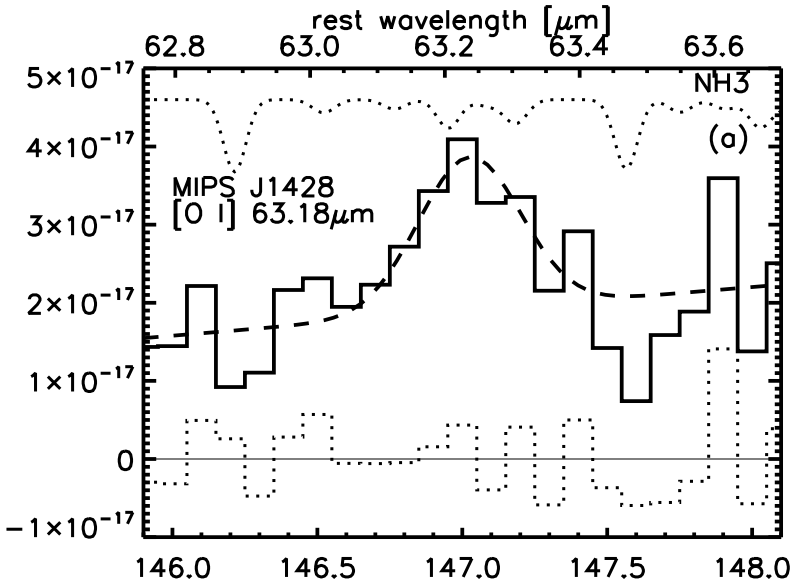
Fig.: 3.13 from PACS Observers Manual

Recalculated 1σ sensitivities from actual exposure time to HSPOT exposure (~450sec per 1nod and 1up-down).

Spectrometer Sensitivity: Deep Integration

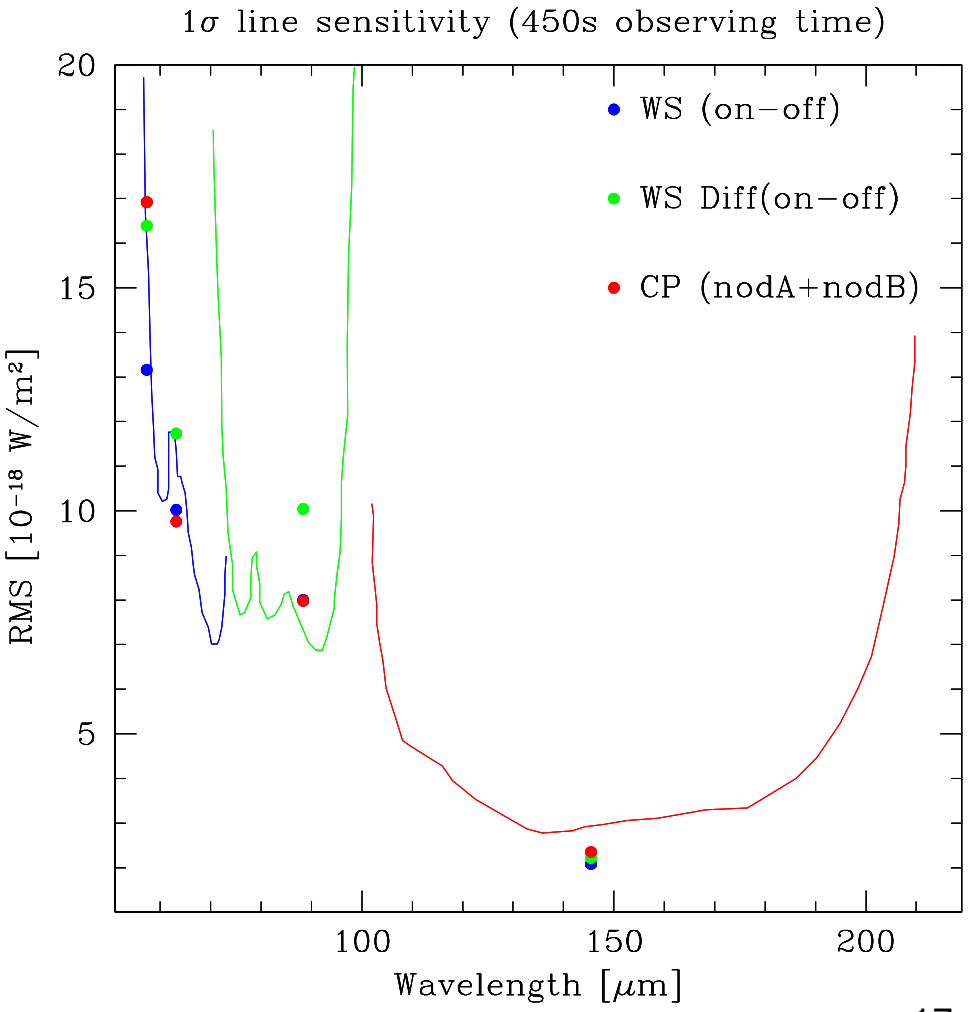
Source	line	OD	OBSID	$n_{rep} \times n^{a}_{cyc}$	**aor duration** [sec]	flux[b] [10^{-18}W/m^2]	continuum flux density [mJy]
MIPS J1428	[O III] 52	205	1342187779	2×7	**5348**	3.7 (0.8)	117 (35)
F10214	[O III] 52	179	1342186812	10×4	**24827**	0.9 (0.3)	445 (130)





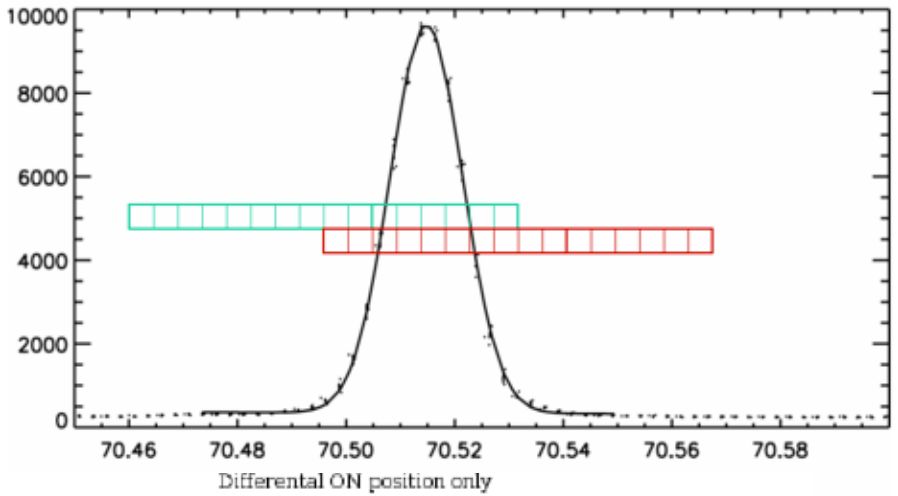
Chop/Nod vs. Wavelength Switching

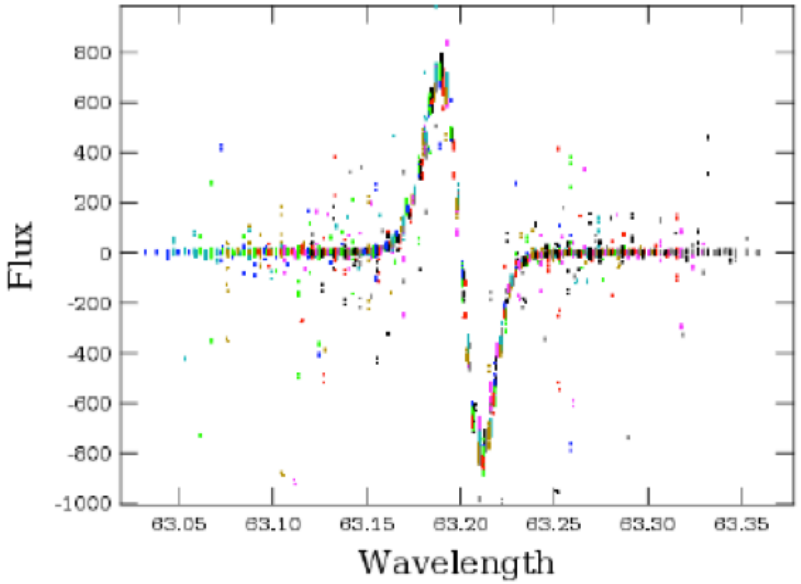
- No major degradation from wavelength-switching [for not too faint sources]
- Pipeline (will) provide(s) different "demodulation" techniques



Wavelength Switching Scheme

- Pre-launch: Modulate between on-line and off-line in spectral domain
- Improved wavelength switching strategy (smaller jumps in flux on detectors):
  - Modulate with step of a fraction of the FWHM
  - Use differential profile
- Might be replaced with continuous scan





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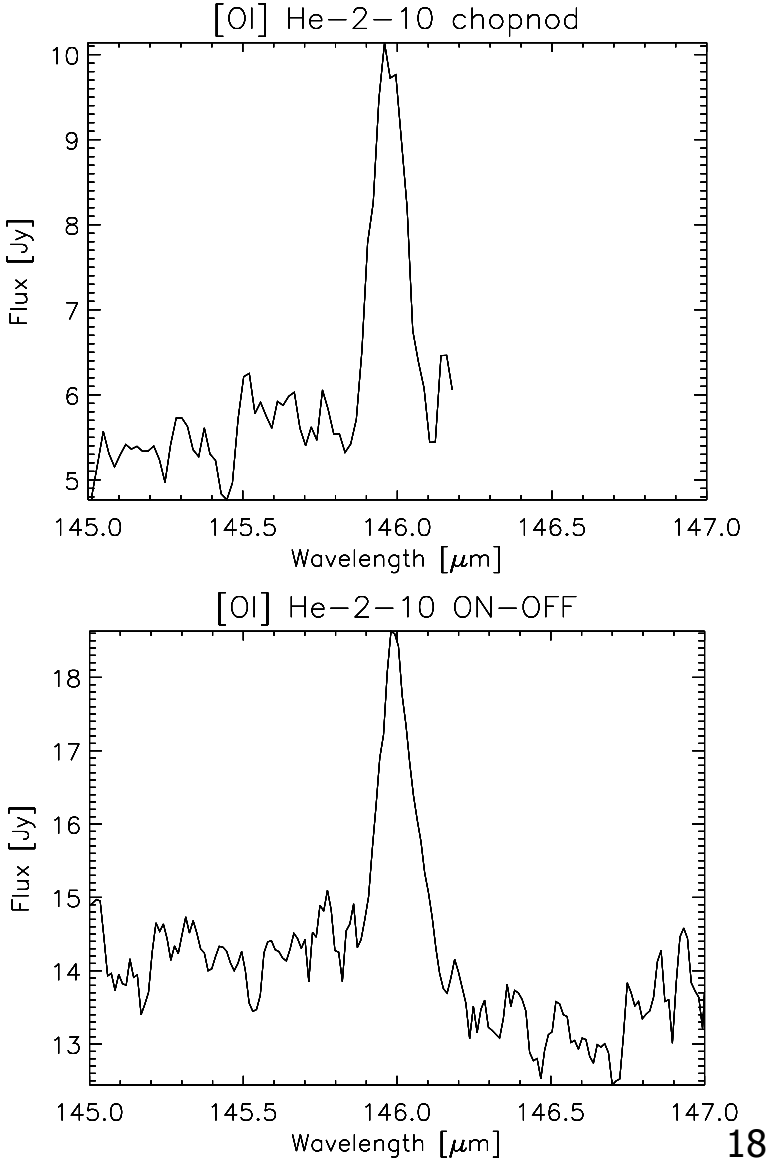
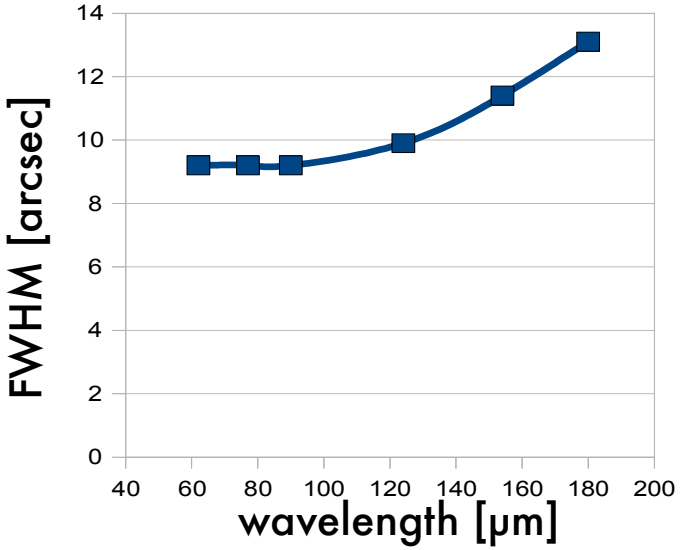
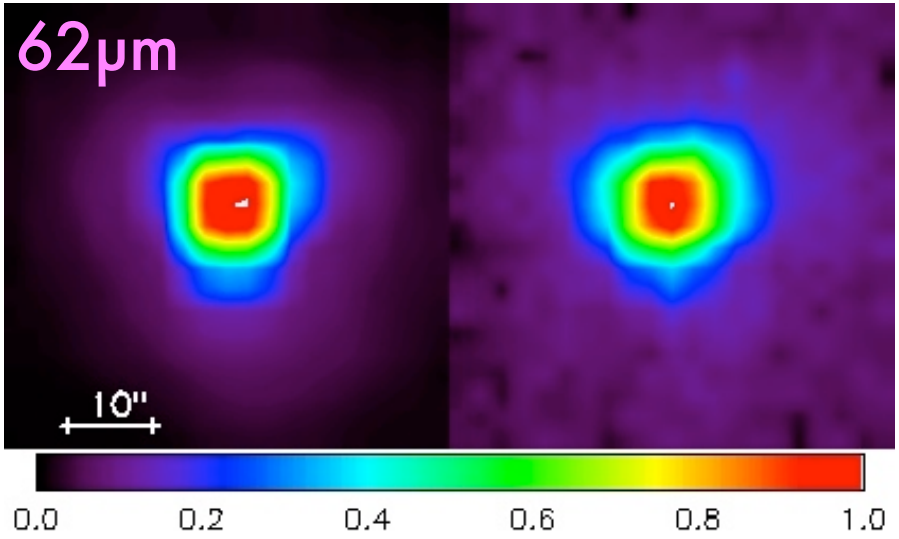
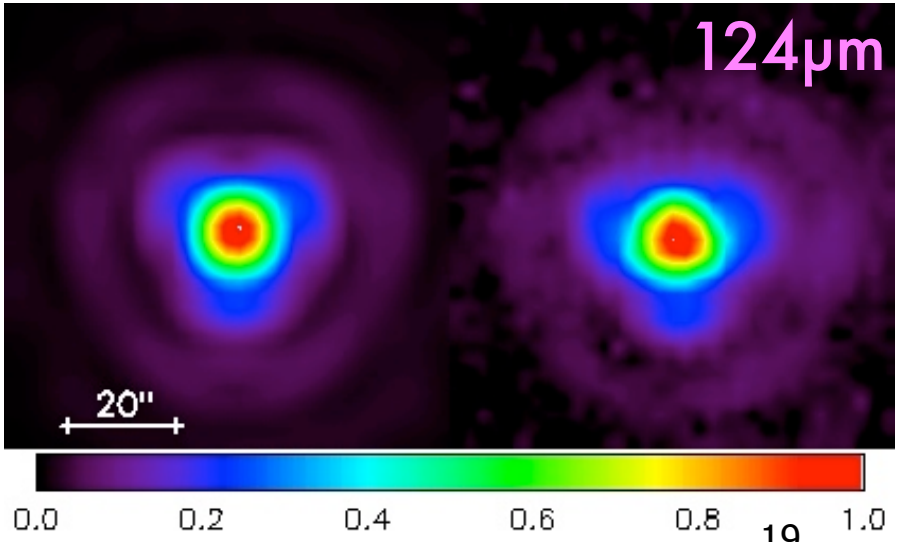


Spectrometer PSF

- Modeled/measured at 62μm and 124μm /on Neptune
- "Trifoliate" structure, also seen in photometer

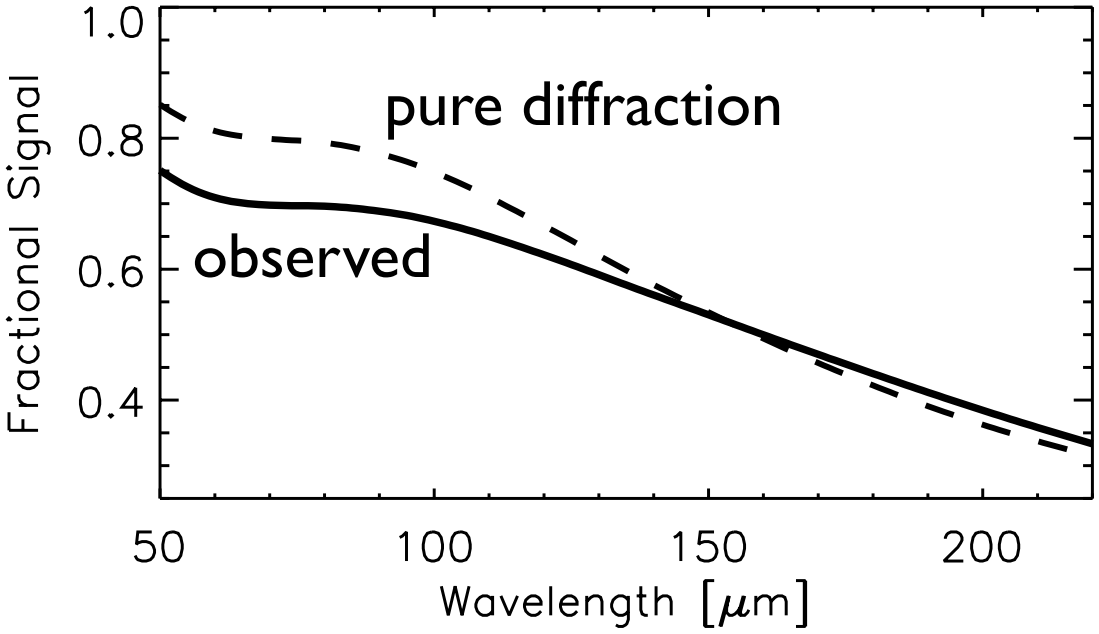






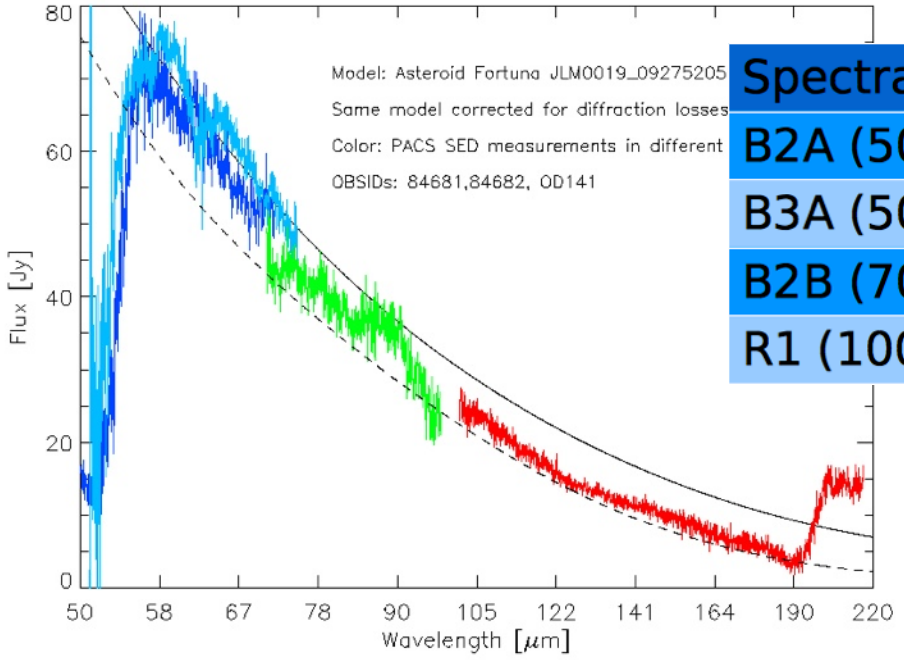
Spectrometer "Beam Efficiency"

- Fraction of PSF seen by (centered!) 9.4"x9.4" spatial pixel varies with wavelength
- Point source correction table available in HIPE



Spectrometer Flux Calibration (1)

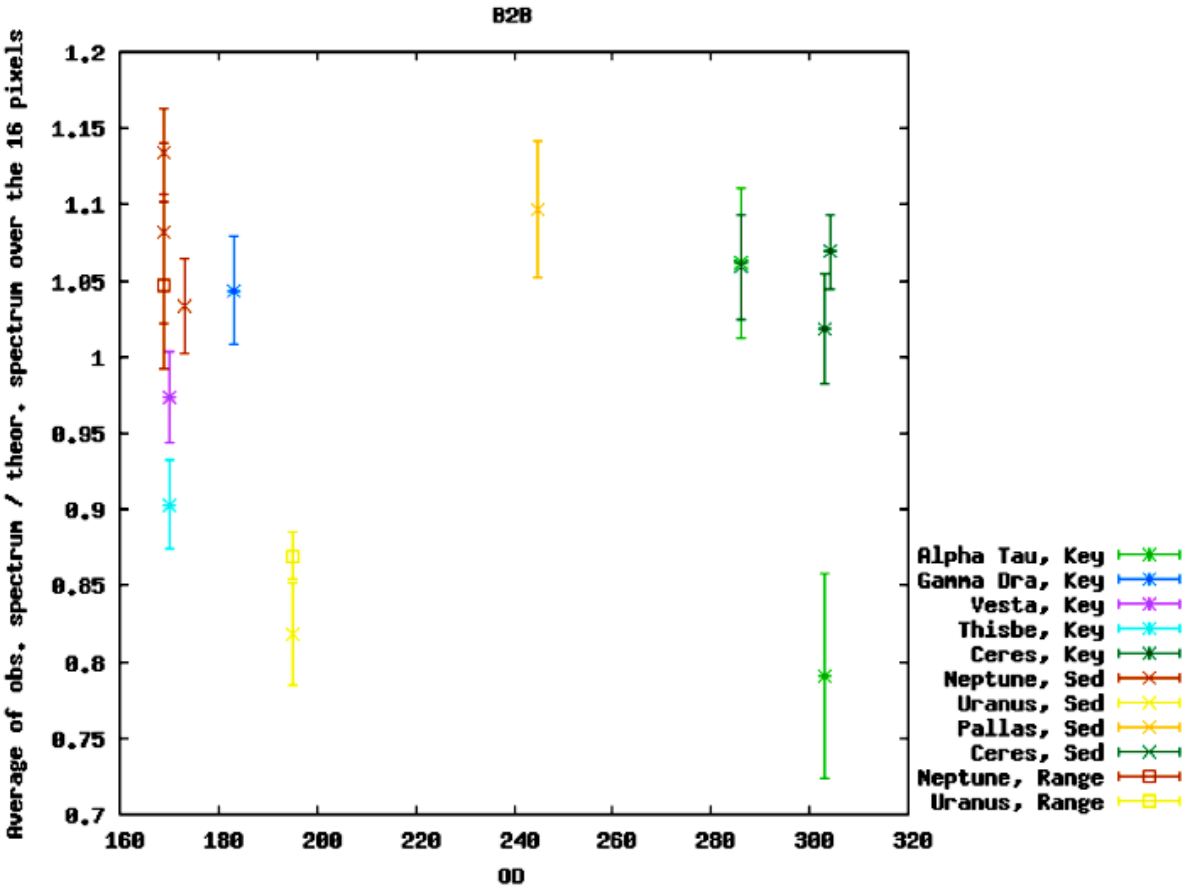
- Pipeline uses nominal absolute and relative spectral response from ground tests
- In-orbit measurements of flux calibrators (asteroids, Neptune, Uranus, fiducial stars) give first correction factors to ground calibration, yielding a 30% absolute error



Spectral band	Correction factor
B2A (50-70um)	1.3
B3A (50-70um)	1.3
B2B (70-100um)	1.3
R1 (100-220um)	1.1

Spectrometer Flux Calibration (2)

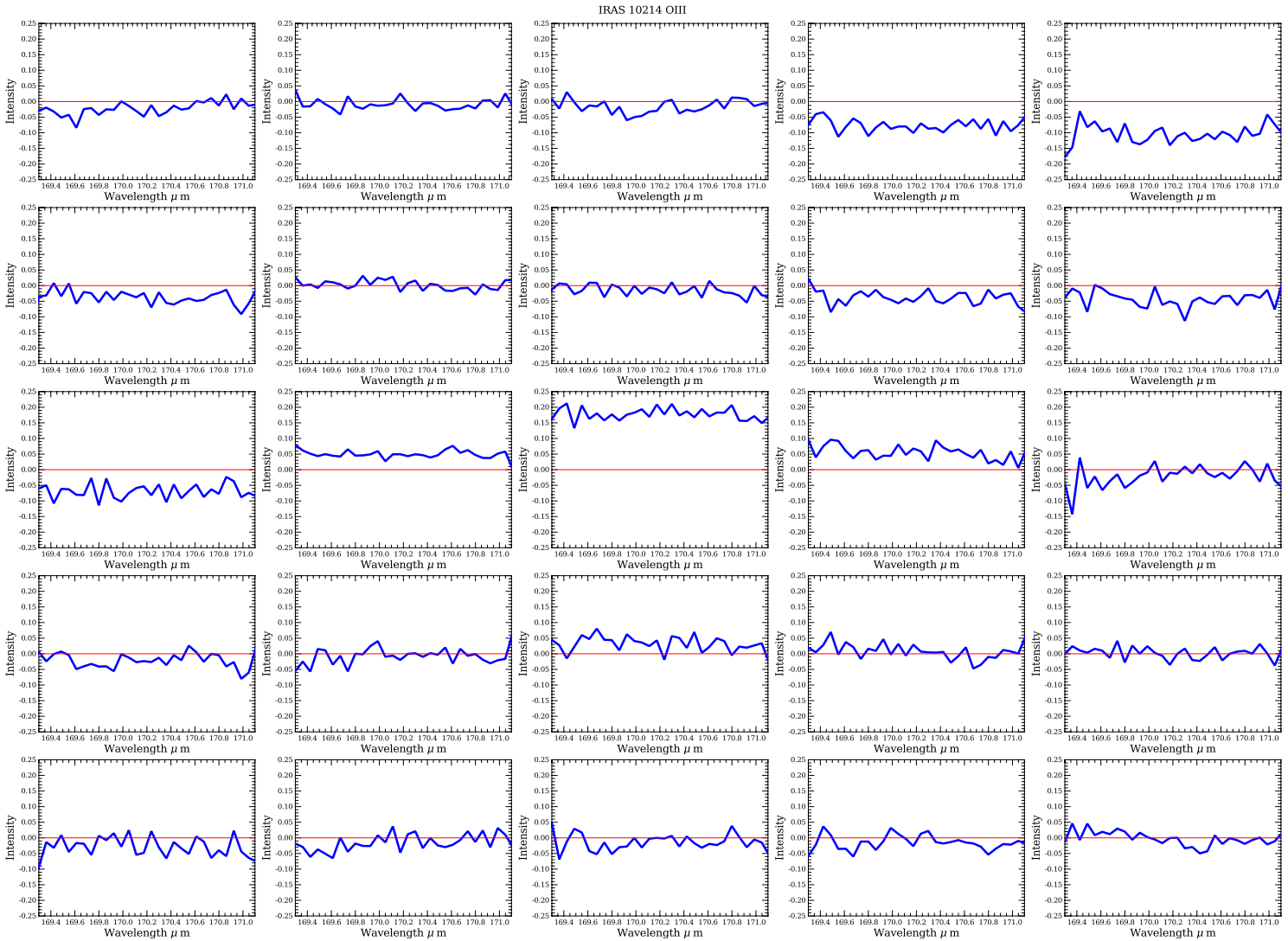
- Use of internal calibration block under test [compensation for detector drifts]
- Example: observed/model for different sky calibrators in band B2B



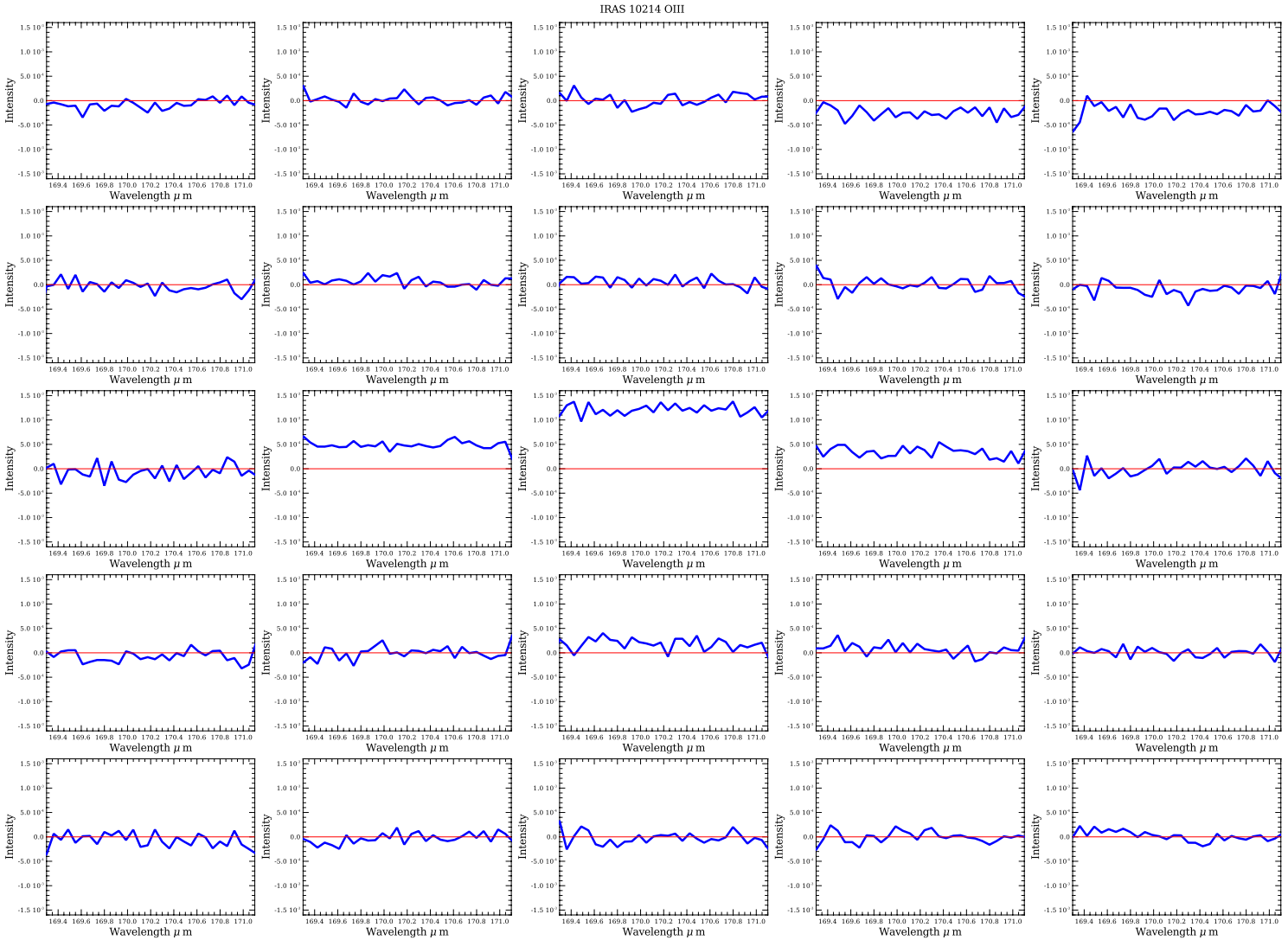
Spectrometer Flux Calibration (3)

- Default: Use of "Relative Spectral Response Function", measured on ground for each detector
  - gives absolute flux density (Jy), within ~20...30%
  - does not compensate for (short-term) time-variability of detector response (CR hits, memory effects)
  - may result - for faint sources - in insufficient cancelation of telescope background
- Alternative for faint sources: "Normalization"
  - ("left" - "right")/0.5("left" + "right")
  - continuously uses telescope background as calibrator
  - works only if source ~ fainter than telescope!
  - presently no absolute flux density - fraction of telescope background; update planned

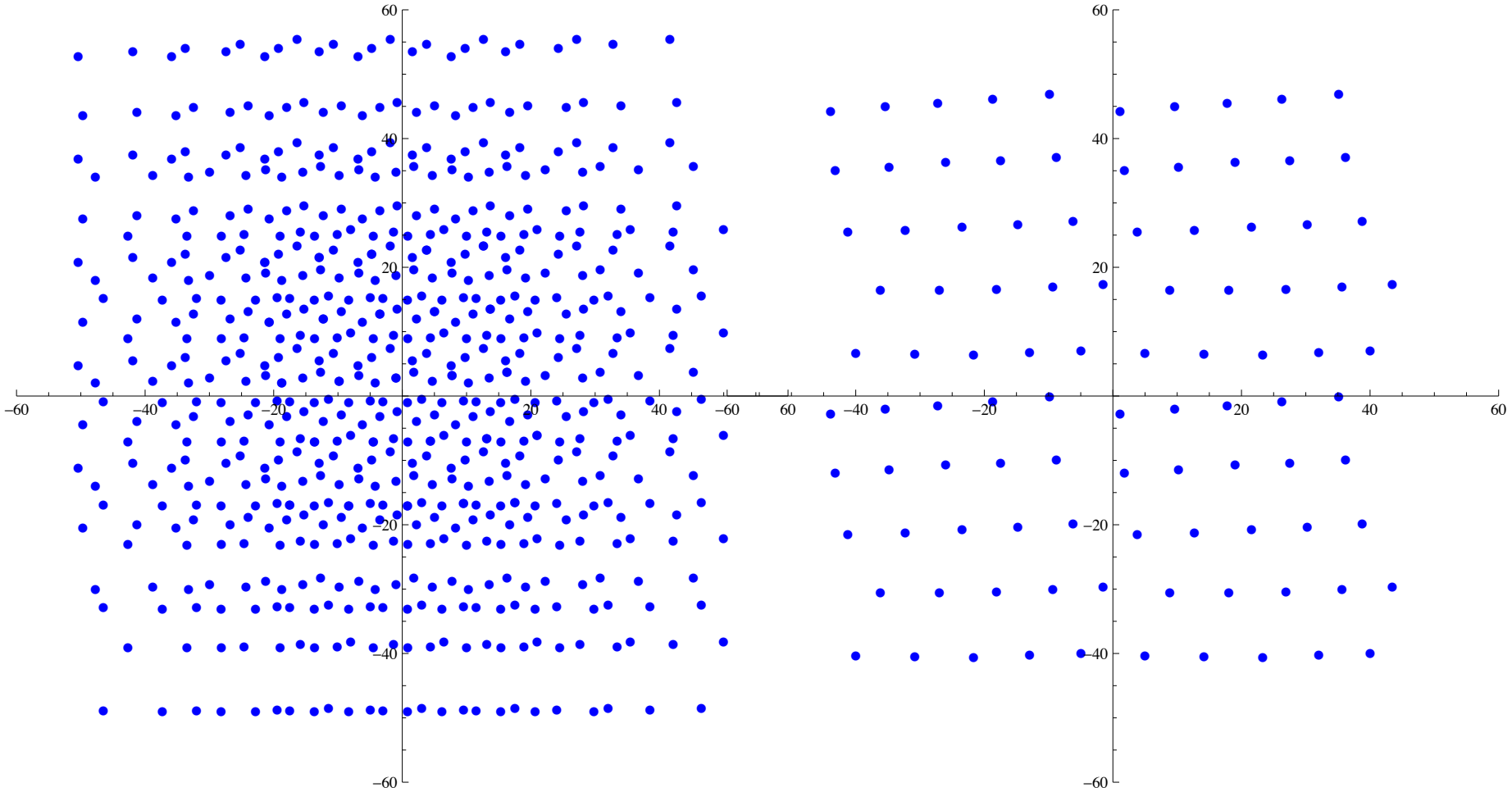
RSRF vs. “Normalization” for Faint Source



RSRF vs. “Normalization” for Faint Source

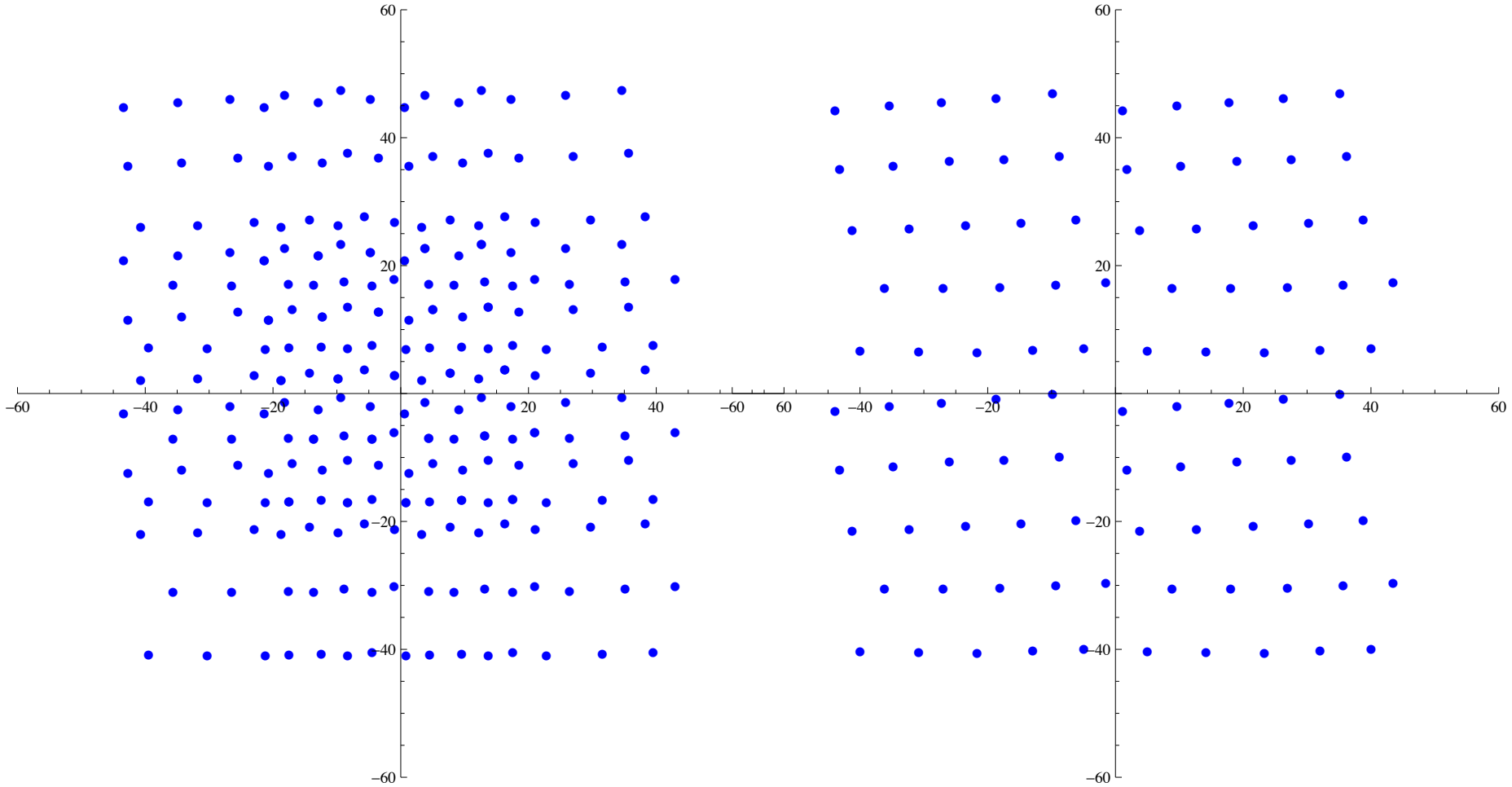


Extended Spectral Line Maps



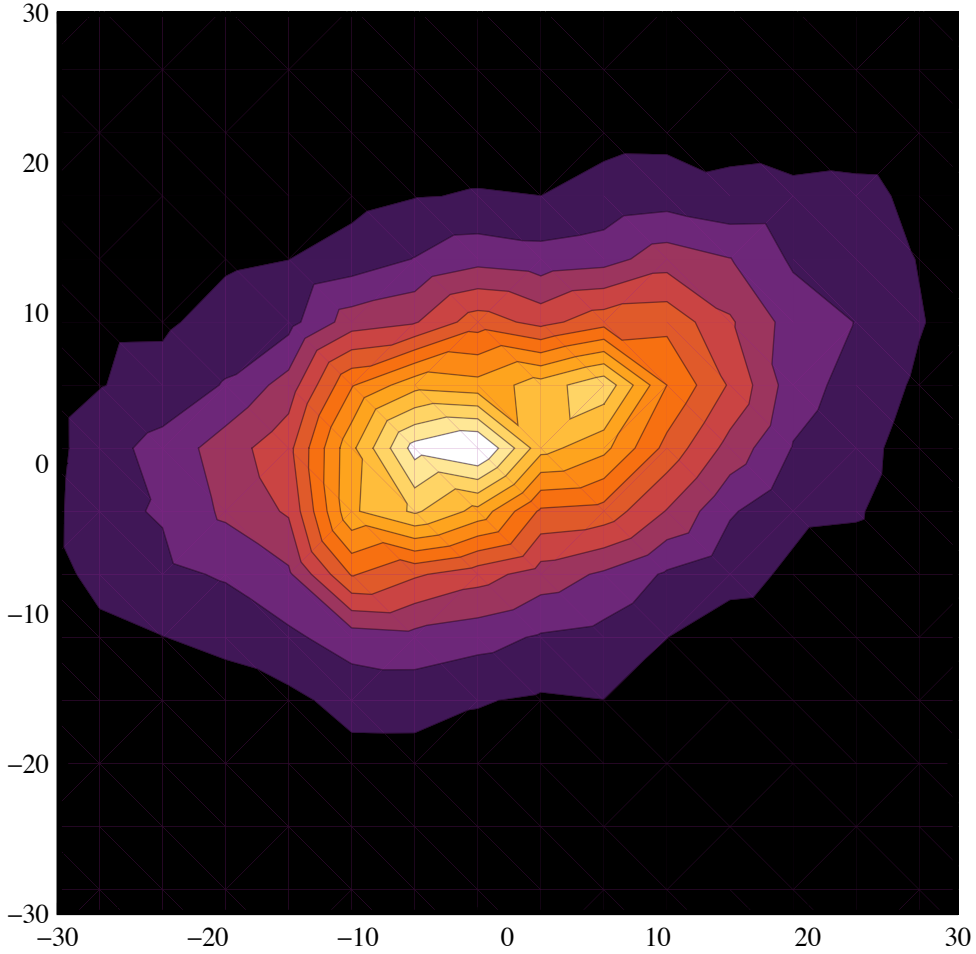
5x5 “oversampling” (short-λ) vs. 2x2 “tiling”

Extended Spectral Line Maps

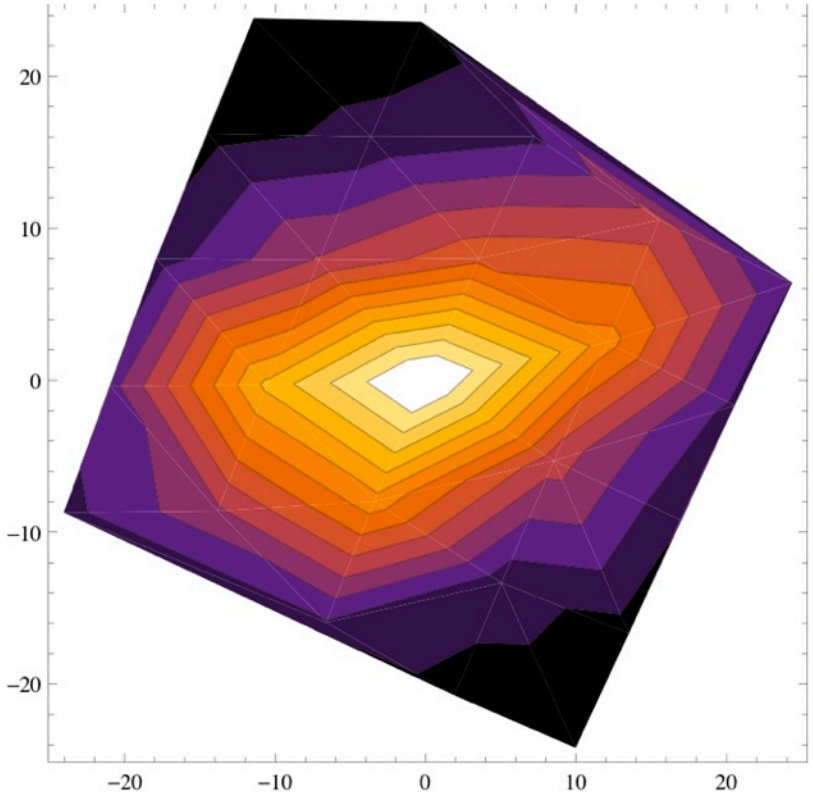


3x3 “oversampling” (long-λ) vs. 2x2 “tiling”

Snapshot vs. Mapping



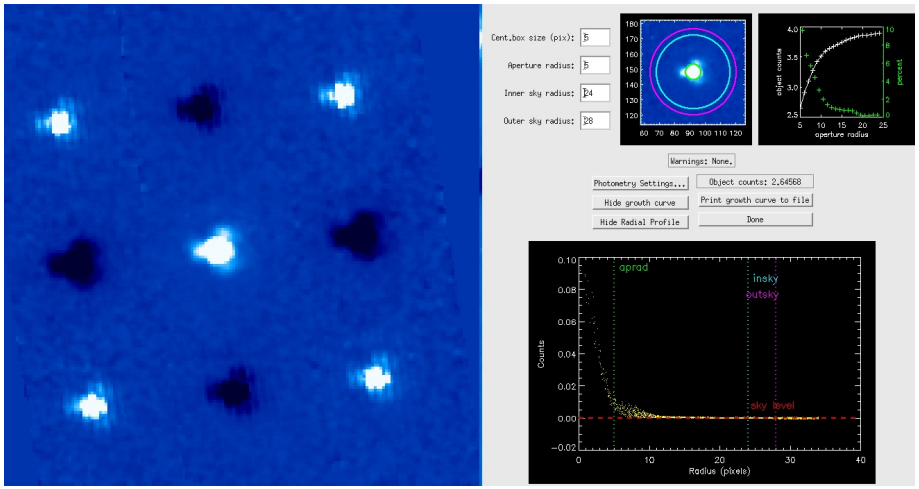
M82 [O I] 63μm

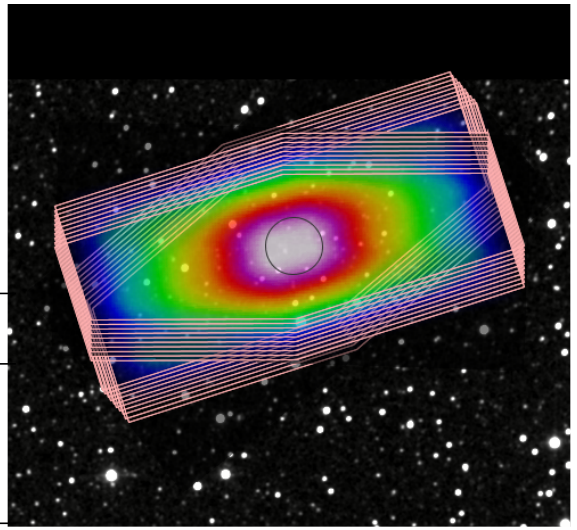


Map reconstruction under construction (in HIPE)

Photometer: "Point Source" Mode(s)

- Chop/nod Point Source mode is delivering very precise photometry for sources above ~50 mJy
  - For faint sources, S/N and background subtraction degraded
- For optimum sensitivity (S/N) and background removal on faint sources, new "Mini-Scan Map" mode recommended as better alternative





instrumental	bgr. conf.		total 5-σ	Note
0.77 mJy	$\geq$ 0.03 mJy	$\times$5	$\geq$**3.9 mJy**	instr. limited
0.82 mJy	$\geq$ 0.5 mJy	$\times$5	$\geq$**4.8 mJy**	instr./confN limited
1.17 mJy	$\geq$ 1.8 mJy	$\times$5	$\geq$**10.7 mJy**	confN limited

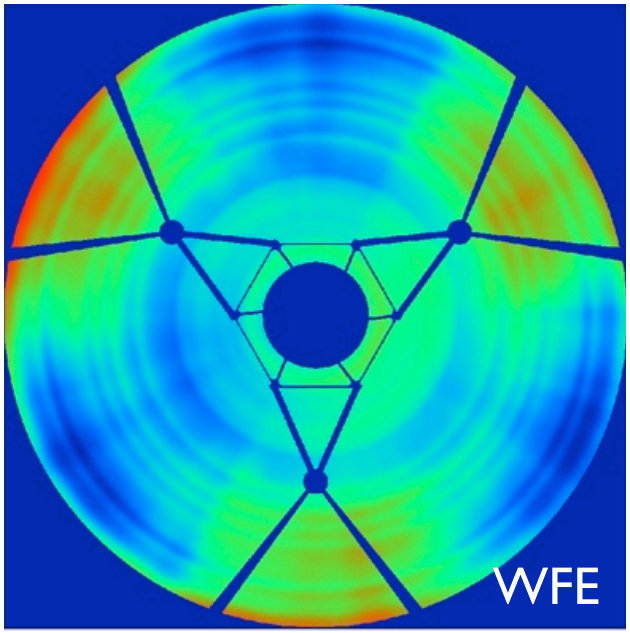
Photometer: Flux Calibration

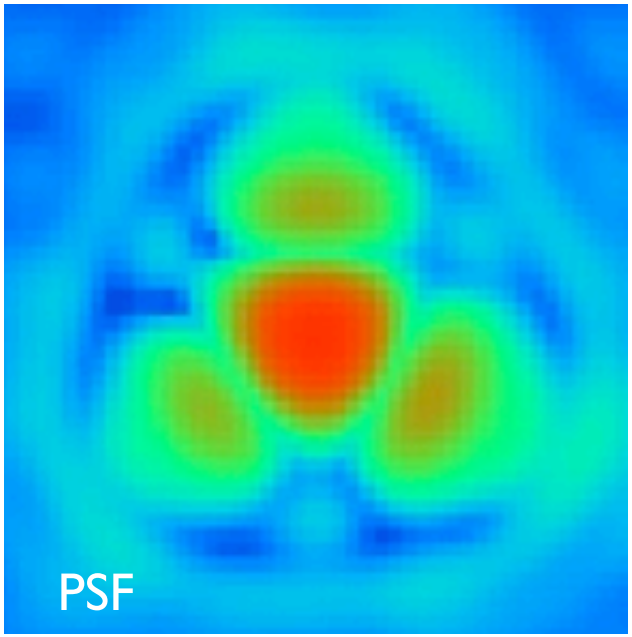
- Flux calibration is converging; best in chop/nod
- Absolute fluxes, based on primary (stars) and secondary (asteroids, planets) standards highly consistent and reproducible
  - The star γ Dra was observed in blue band 10×, in green band 4× and in red band 14× during the mission phase from OD 108 and OD 320. The scatter between all observations (on basis of a 10'' aperture radius in all 3 bands) is (*peak-to-peak*): 8% in blue, 5% in green and 13% in red.

	Obs/Mod-ratio		
Band	with β Peg	without β Peg	Remarks
blue	0.97 ± 0.04	0.97 ± 0.03	18/17 observations
green	0.99 ± 0.03	0.99 ± 0.02	13/12 observations
red	1.01 ± 0.04	1.01 ± 0.04	31/29 observations

Photometer: PSF

- Remarkable agreement between predicted PSF, derived from measured/constructed telescope WFE map, and *central peak* of observed PSF
- Analysis of PSF "outskirts" should confirm (or not) the apparent (somewhat low) Strehl ratio or/and transmission (from point source flux calibration)





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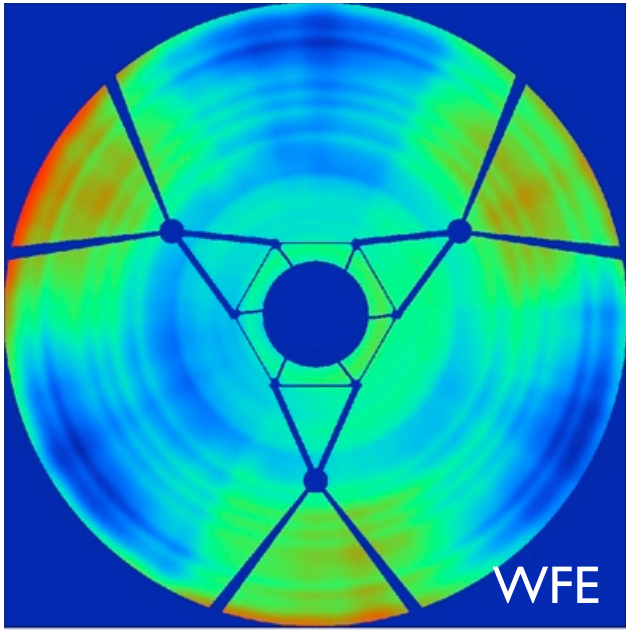

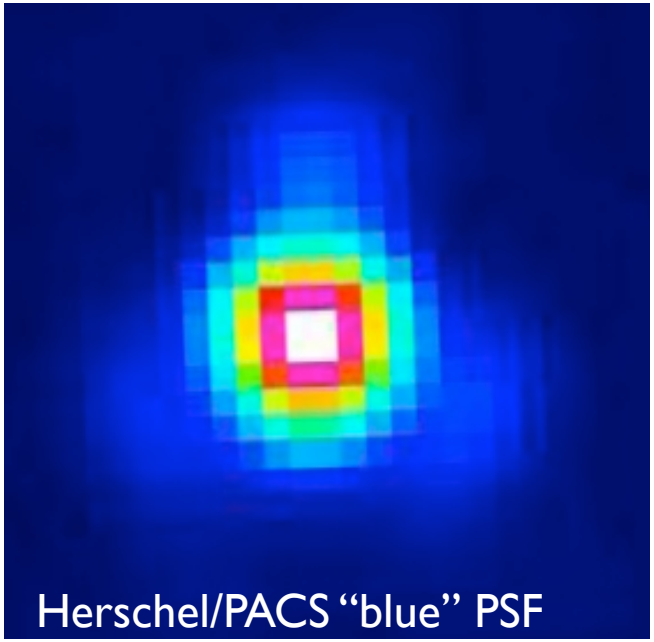

Core scaled to peak, Vesta

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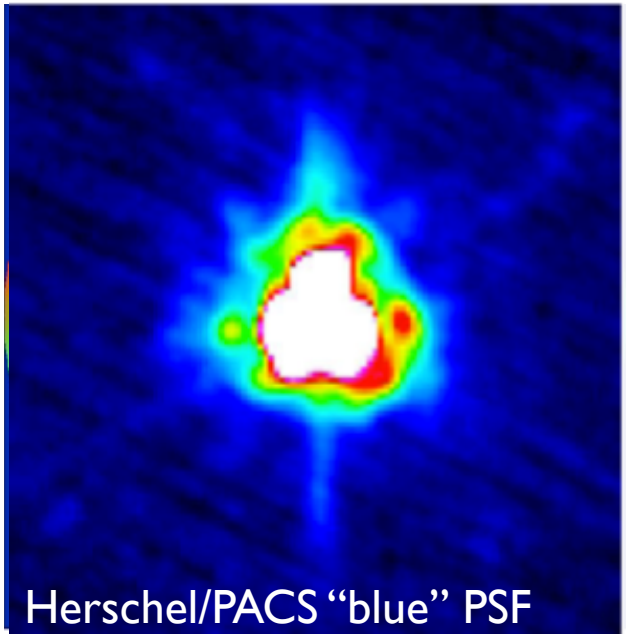
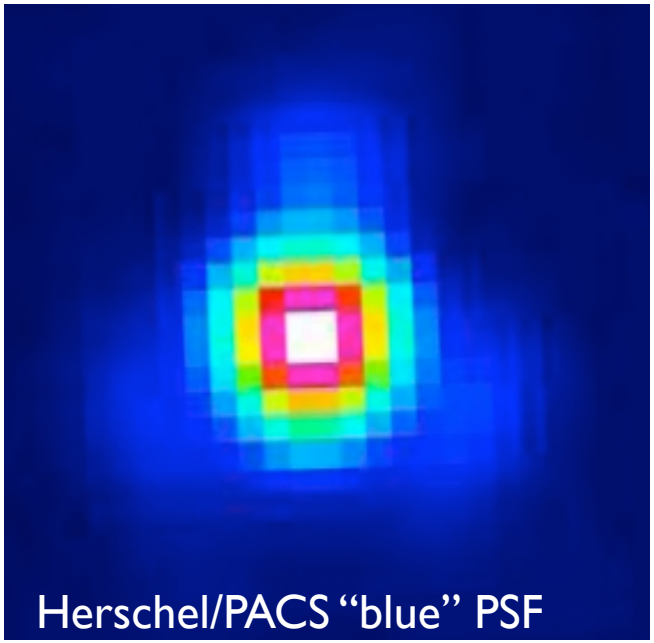


1% peak cut, wide range, Vesta



Core scaled to peak, Vesta

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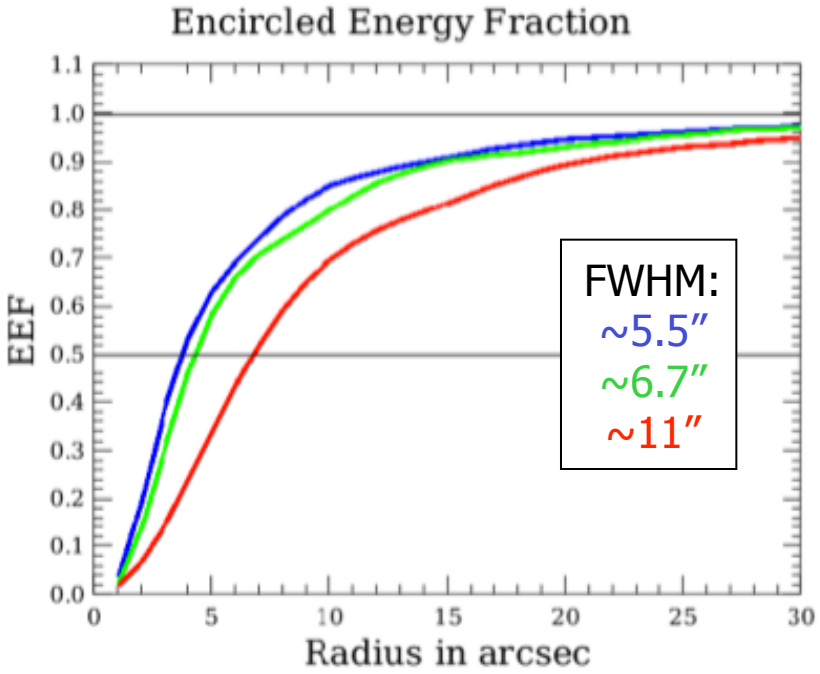
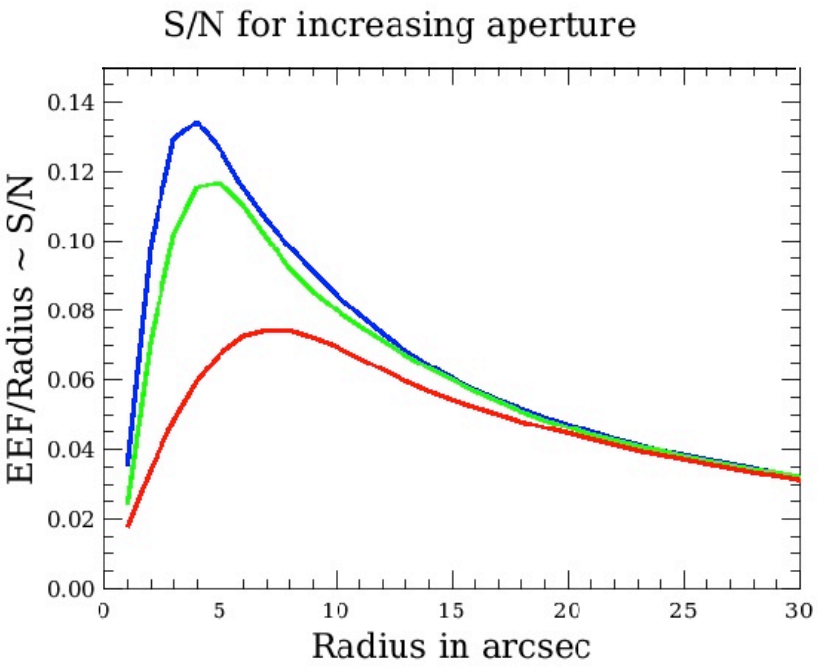
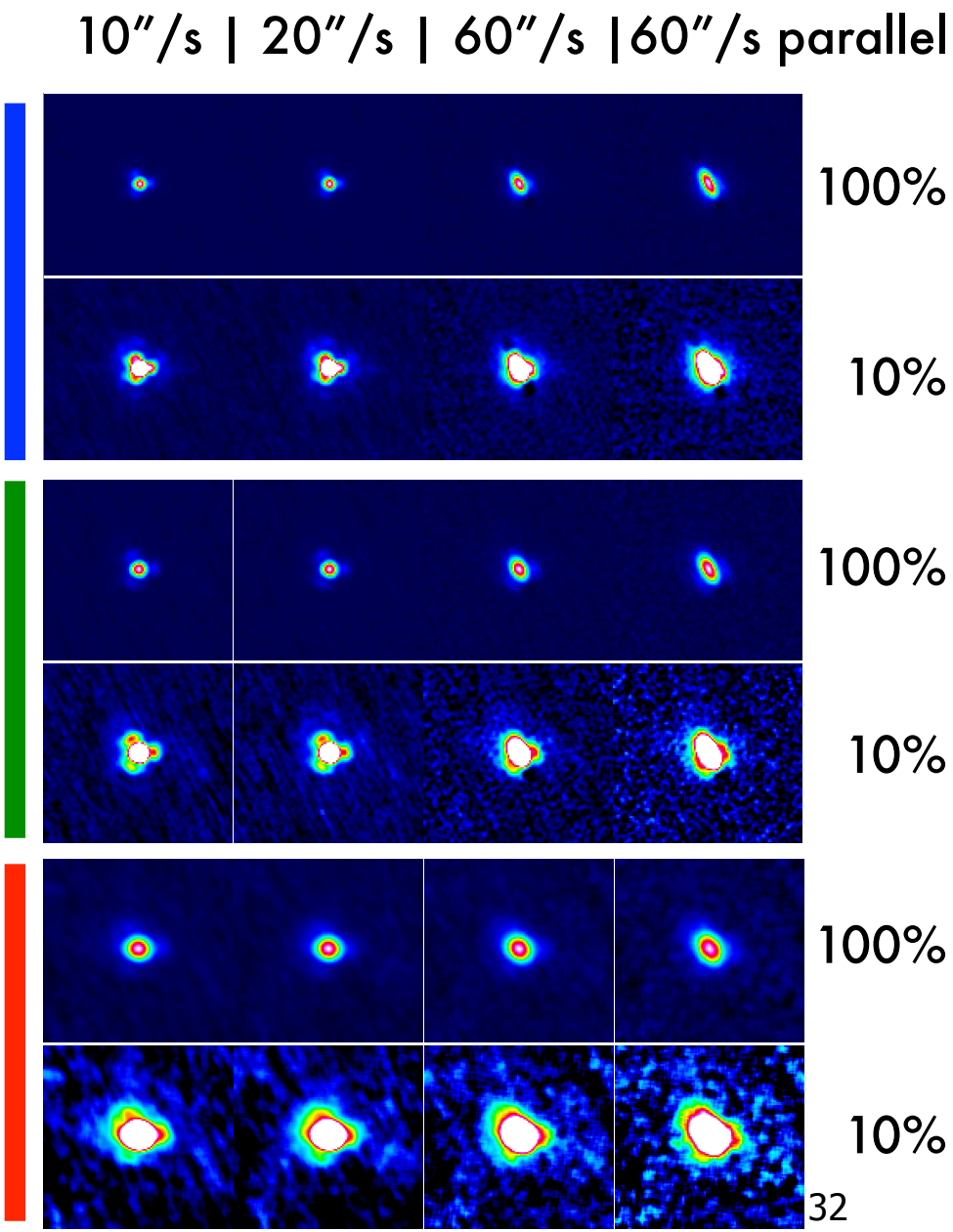




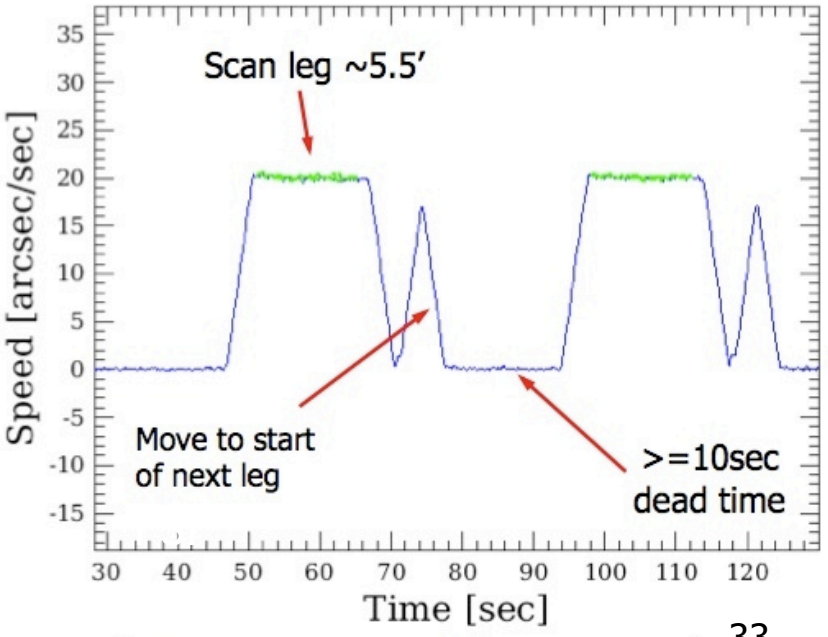
Photometer PSF and Scan Speed

- 10″/s and 20″/s PSFs nearly identical
- 60″/s is showing the expected elongation
- Effect further enhanced by frame-averaging in parallel mode

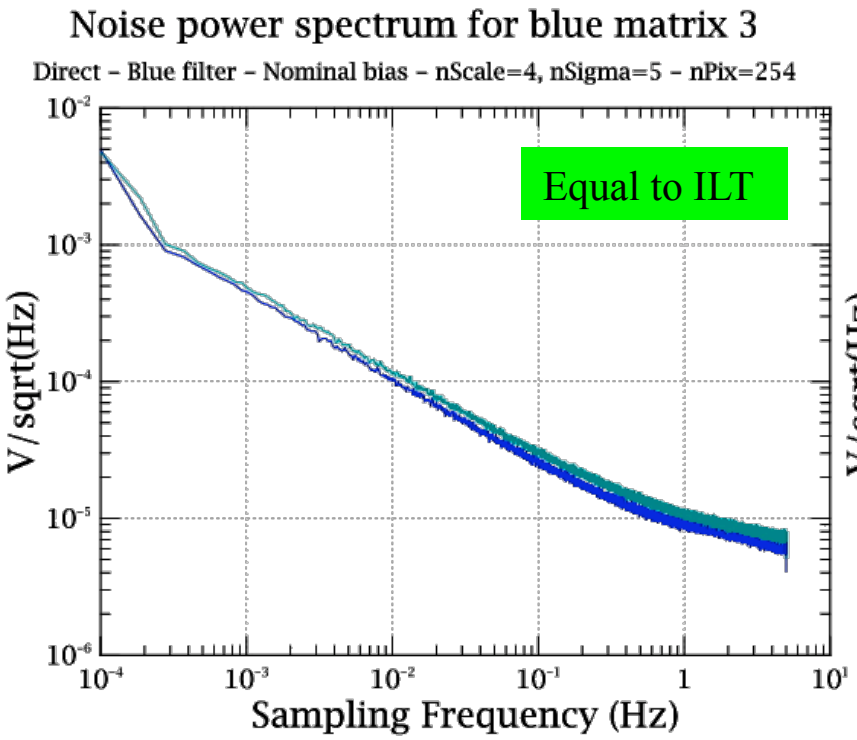


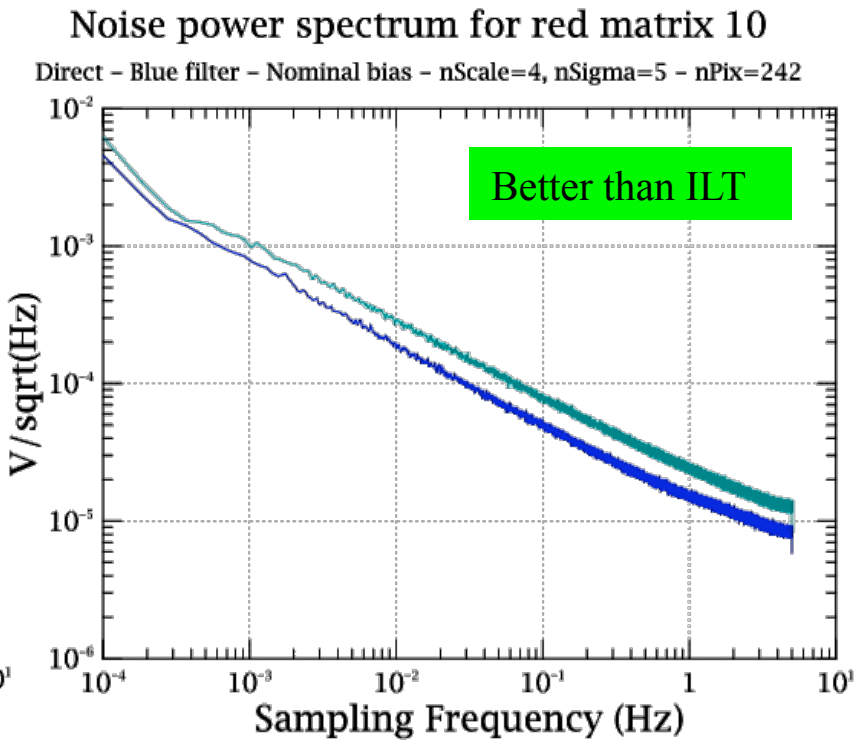
Photometer: Scan Map Sensitivity

- Most "deep" observations originally used for sensitivity evaluation were performed with "slow" scan speed (10"/s)
- Evidence for significant improvement in sensitivity by going to "medium" scan speed (20"/s)
- This is the official recommendation for scan maps now, at the cost of higher overhead. (Data processing might still improve, observing will not.)
- Reduction of the overhead: Each turn costs ~17s, of which only ~5s are "real". Extra dwell time has been removed as of OD221.



Photometer Noise Spectra

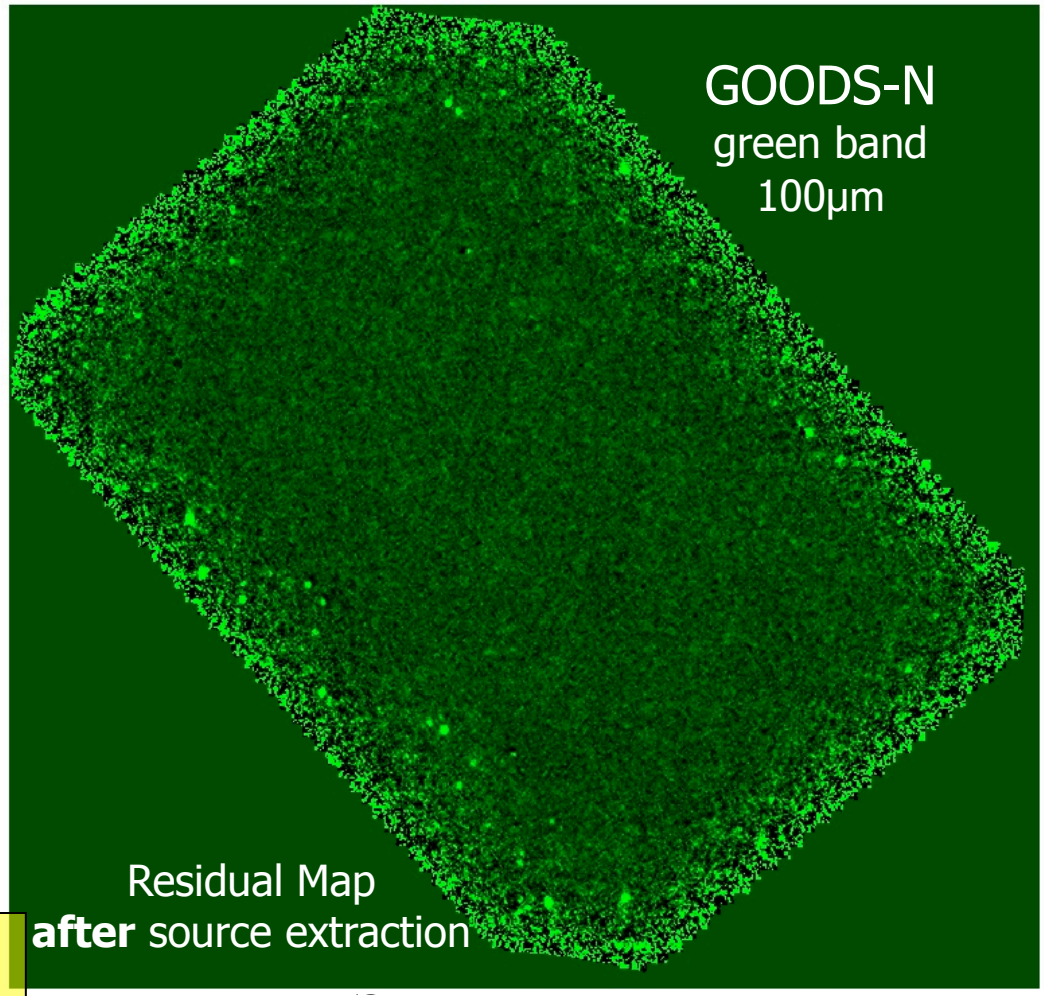




- Noise in the PACS bolometers is essentially $1/f^{1/2}$ over the whole accessible bandpass
- We see excess background/straylight in orbit at long wavelength end, compared to pre-launch conditions

Photometer: Scan Map Sensitivity Analysis

- Comparison of PEP 30h scan map [10'x15'] against pre-launch HSPOT prediction
- Present reduction of GOODS-N/S data:
- Blue : 5σ = 3.7 mJy
  Green: 5σ = 5.0 mJy
  Red : 5σ = 9.5 mJy
- Improvement going from slow to medium scan speed has materialized



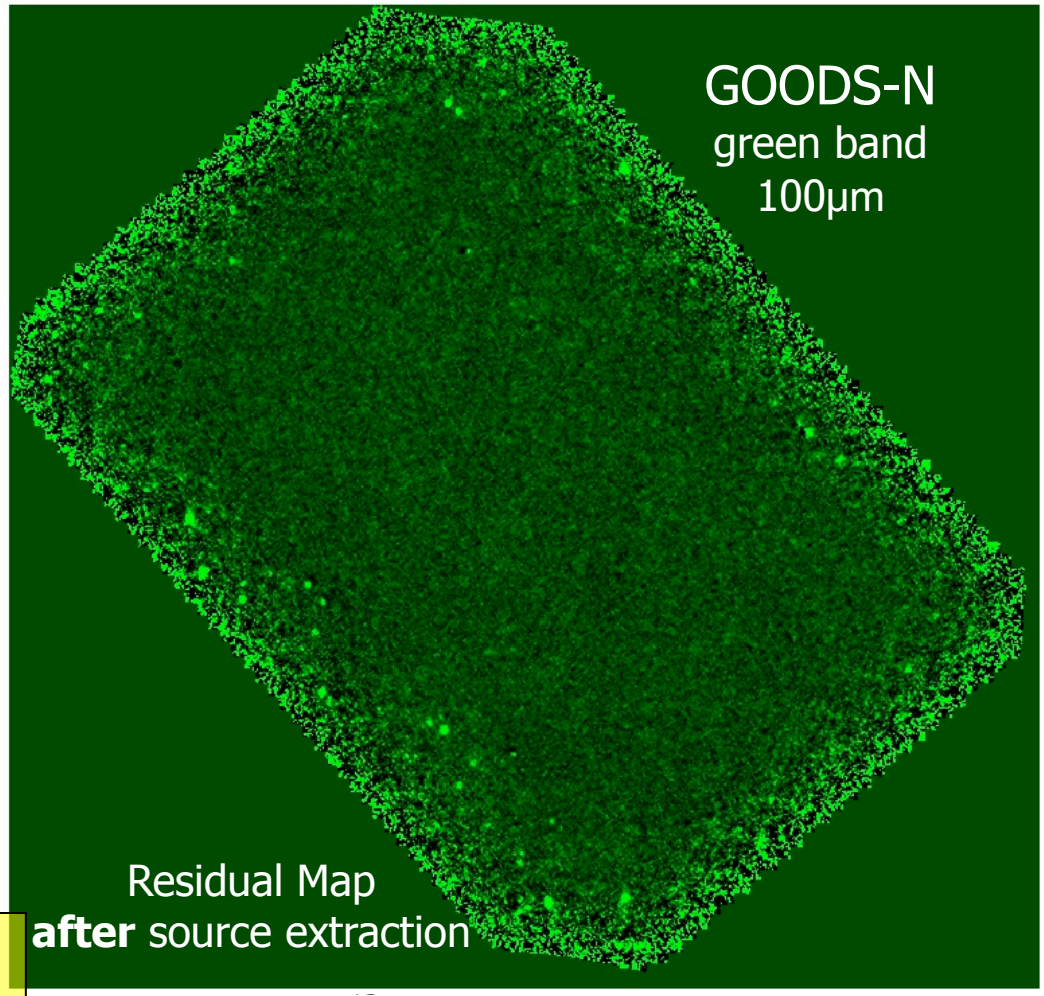
10000 random aperture extractions (R = 1.35 x HWHM)

Photometer: Scan Map Sensitivity Analysis

- Comparison of PEP 30h scan map [10'x15'] against pre-launch HSPOT prediction
- Present reduction of GOODS-N/S data:

+13% • Blue : 5σ = 3.7 mJy
+24% Green: 5σ = 5.0 mJy
+67% Red : 5σ = 9.5 mJy

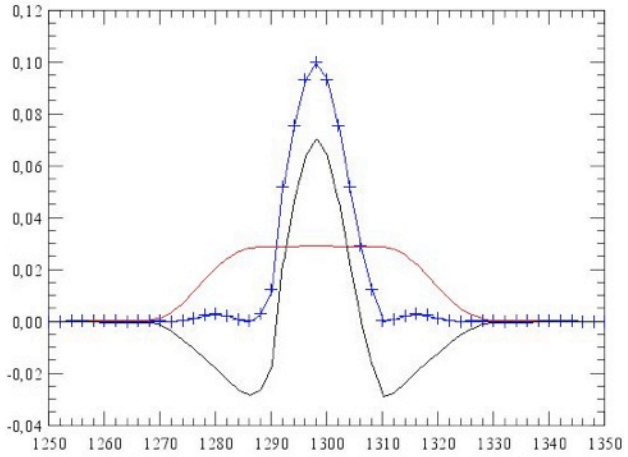
- Improvement going from slow to medium scan speed has materialized

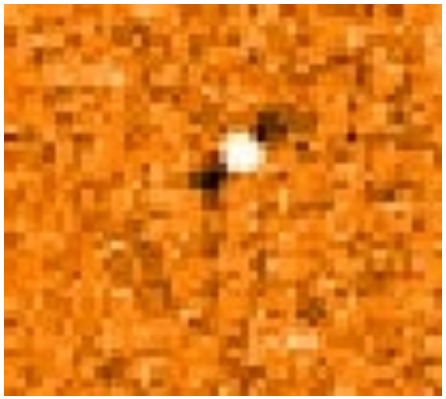


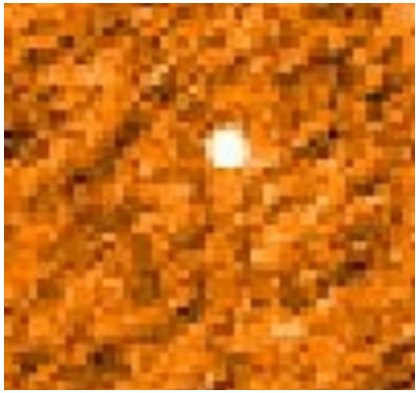
10000 random aperture extractions (R = 1.35 x HWHM)

Scan Map Reconstruction

- PACS is presently using
  - "high pass" filtering + drizzle (MPE): best for point sources
    - Non-linear high-pass method creates artifacts around (bright) sources - can be eliminated by masking of such sources during filtering
    - Mask to be deactivated in final map-making steps!





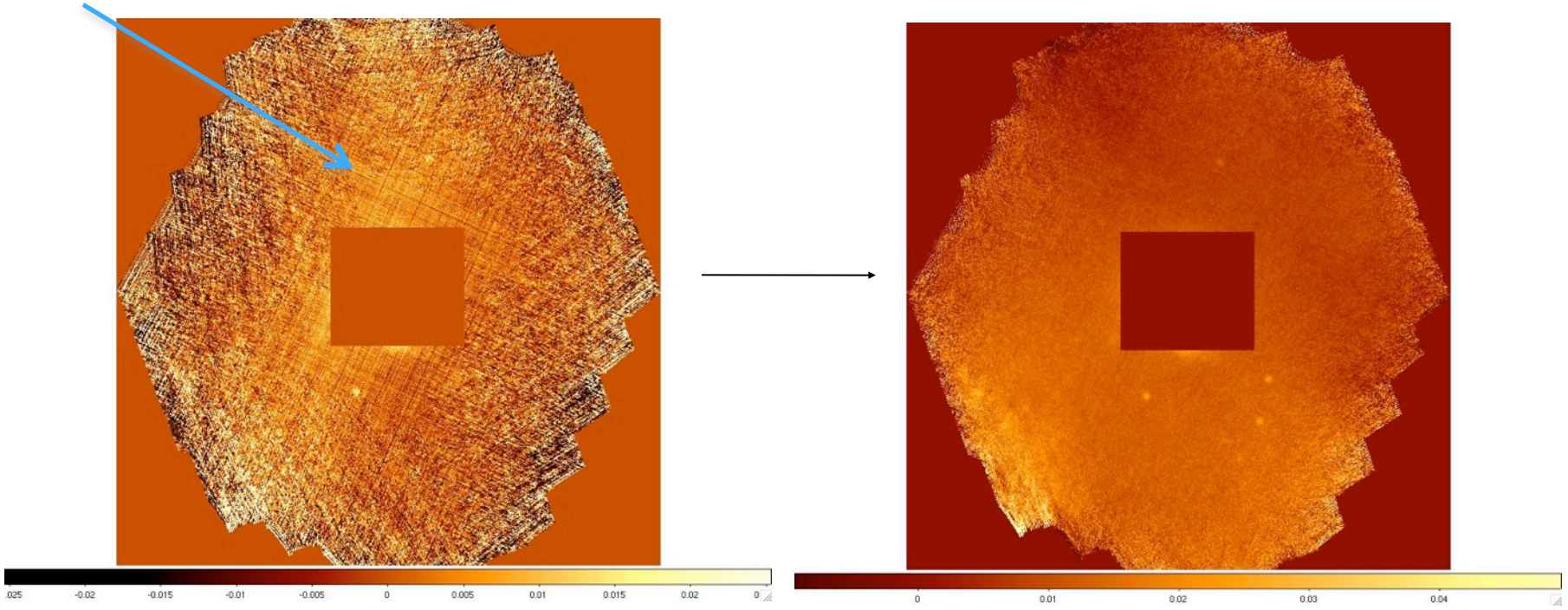


  - MADmap (NHSC): needed for extended structures

What Can MADmap Do?

1/f
"striping"

Corrected

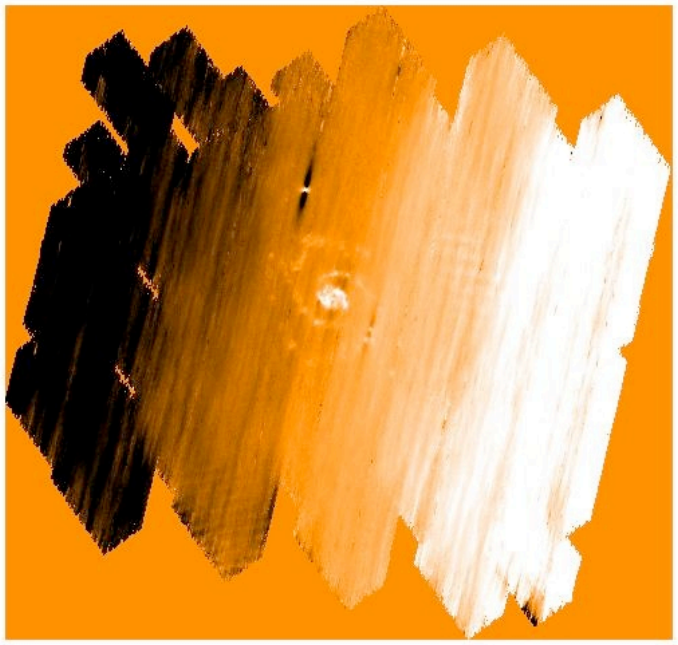


MADmap is designed to remove 1/f noise effects!

What MADmap Won't Do for You

- Global signal drifts.
  - The MEDIAN signal level of the PACS bolometer array varies systematically in a correlated fashion from start to the end of observation.
  - No thermistors to correct for it as SPIRE

Correlated monotonic drift in the signal over the duration of the observation.



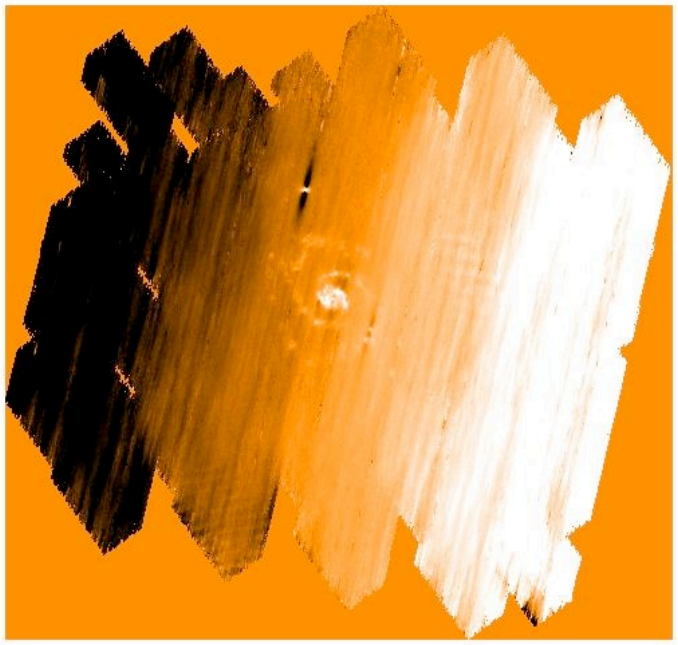
What MADmap Won't Do for You

- Global signal drifts.
  - The MEDIAN signal level of the PACS bolometer array varies systematically in a correlated fashion from start to the end of observation.
  - No thermistors to correct for it as SPIRE

Mitigated by fitting and subtracting baselines.

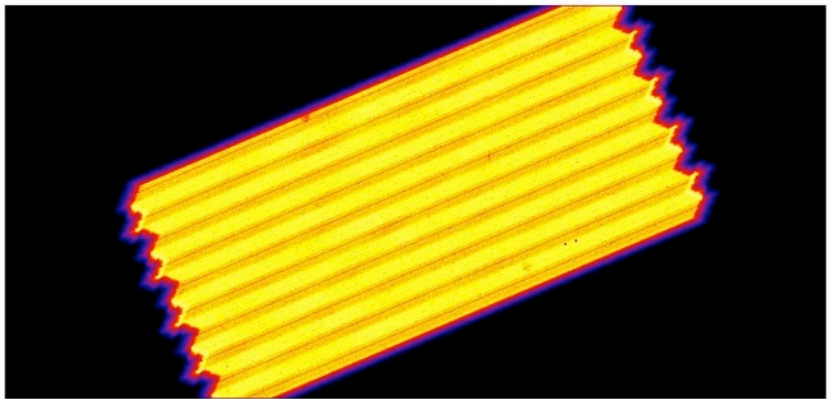
3 different options are available for baseline fitting.

Correlated monotonic drift in the signal over the duration of the observation.



Parallel Mode

- Calibration blocks interleaved every hour
  - in parallel to PCAL flashes
  - nuisance because of transients effects
  - suppressed starting with OD228
- Homogeneity
  - initially unsatisfactory



-42.4 degrees

42.4 degrees (magic angle)

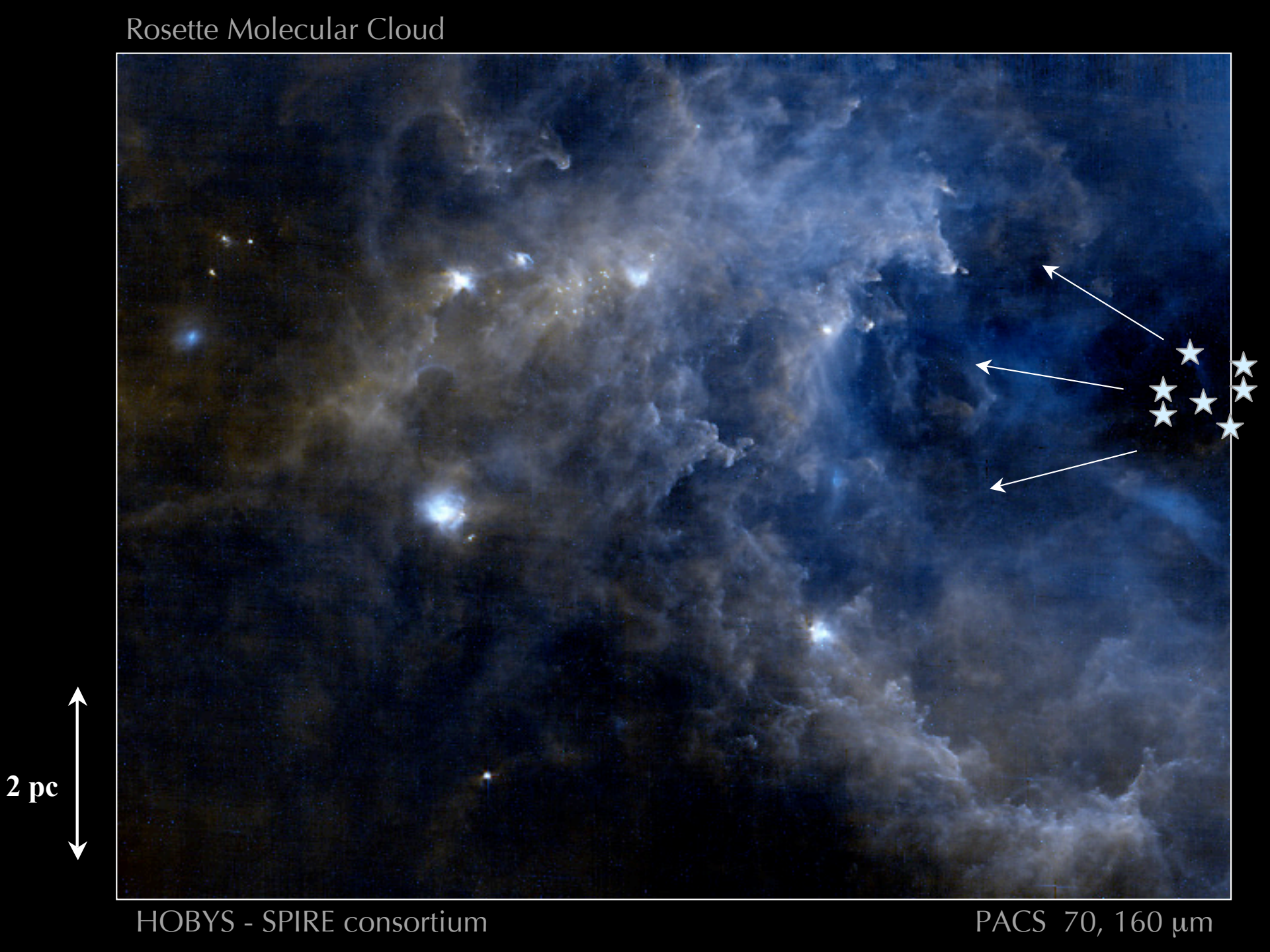
Parallel Mode

- Calibration blocks interleaved every hour
  - in parallel to PCAL flashes
  - nuisance because of transients effects
  - suppressed starting with OD228
- Homogeneity
  - initially unsatisfactory
  - meanwhile modified, coverage homogeneous to <20%

(do we have a figure to illustrate this?)

Outlook and Future Work

- Decision on final implementation of unchopped/ wavelength switching spectroscopy imminent
- Data processing within HIPE is improving continuously, but don't expect publication-ready results to drop out of the standard pipeline!
- Optimization (for PACS) of MADMap implementation should receive high priority. Alternative algorithms may further improve maps of extended sources
- Final flux calibration in spectroscopy (including "telescope normalization" method) is urgent issue
- Spectral line mapping / full 3D data cube reconstruction is work in progress


Rosette Molecular Cloud
2 pc
HOBYS - SPIRE consortium
PACS 70, 160 μm