SPIRE
In-Flight Performance

Matt Griffin

on behalf of the SPIRE Consortium

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- University of Sussex, UK

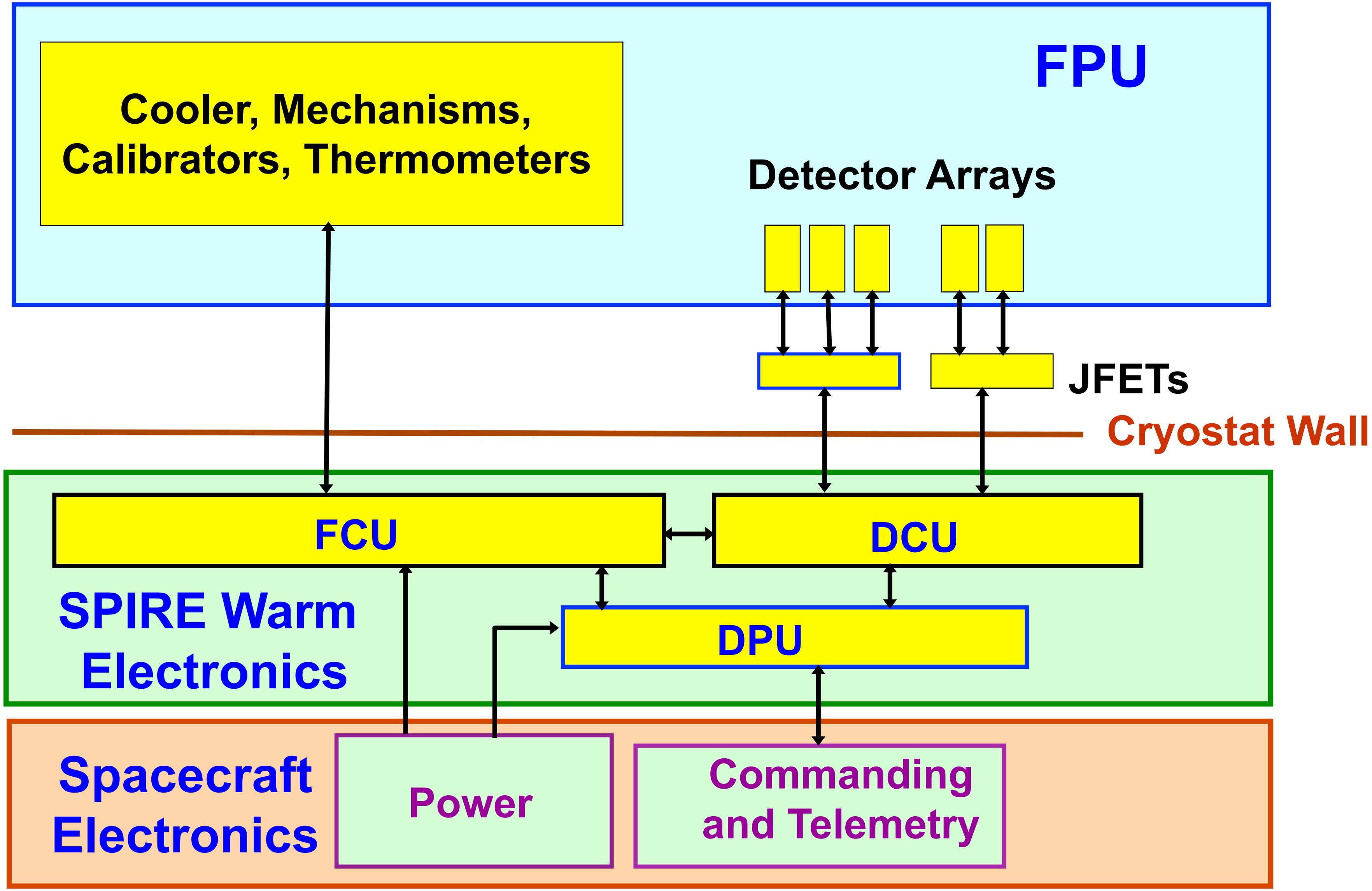
The *Herschel*-SPIRE instrument and its in-flight performance ★

M. J. Griffin[1], A. Abergel[2], A. Abreu[3], P. A. R. Ade[1], P. André[4], J.-L. Augueres[4], T. Babbedge[5], Y. Bae[6], T. Baillie[7], J.-P. Baluteau[8], M. J. Barlow[9], G. Bendo[5], D. Benielli[8], J. J. Bock[6], P. Bonhomme[10], D. Brisbin[11], C. Brockley-Blatt[10], M. Caldwell[12], C. Cara[4], N. Castro-Rodriguez[13], R. Cerulli[14], P. Chanial[5,4], S. Chen[15], E. Clark[12], D. L. Clements[5], L. Clerc[16], J. Coker[10], D. Communal[16], L. Conversi[3], P. Cox[17], D. Crumb[6], C. Cunningham[7], F. Daly[4], G. R. Davis[18], P. De Antoni[4], J. Delderfield[12], N. Devin[4], A. Di Giorgio[14], I. Didschuns[1], K. Dohlen[8], M. Donati[4], A. Dowell[12], C. D. Dowell[6], L. Duband[16], L. Dumaye[4], R. J. Emery[12], M. Ferlet[12], D. Ferrand[8], J. Fontignie[4], M. Fox[5], A. Franceschini[19], M. Frerking[6], T. Fulton[20], J. Garcia[8], R. Gastaud[4], W. K. Gear[1], J. Glenn[21], A. Goizel[12], D. K. Griffin[12], T. Grundy[12], S. Guest[12], L. Guillemet[16], P. C. Hargrave[1], M. Harwit[11], P. Hastings[7], E. Hatziminaoglou[13,22], M. Herman[6], B. Hinde[6], V. Hristov[23], M. Huang[15], P. Imhof[20], K. J. Isaak[1,24], U. Israelsson[6], R. J. Ivison[7], D. Jennings[25], B. Kiernan[1], K. J. King[12], A. E. Lange†[23], W. Latter[26], G. Laurent[21], P. Laurent[8], S. J. Leeks[12], E. Lellouch[27], L. Levenson[23], B. Li[15], J. Li[15], J. Lilienthal[6], T. Lim[12], J. Liu[14], N. Lu[26], S. Madden[4], G. Mainetti[19], P. Marliani[24], D. McKay[12], K. Mercier[28], S. Molinari[14], H. Morris[12], H. Moseley[25], J. Mulder[6], M. Mur[4], D. A. Naylor[29], H. Nguyen[6], B. O'Halloran[5], S. Oliver[30], H. Olofsson[31], H.-G. Olofsson[31], R. Orfei[14], M. J. Page[10], I. Pain[7], P. Panuzzo[4], A. Papageorgiou[1], G. Parks[6], P. Parr-Burman[7], A. Pearce[12], C. Pearson[12,29], I. Pérez-Fournon[13], F. Pinsard[4], G. Pisano[1,32], J. Podosek[6], M. Pohlen[1], E. T. Polehampton[12,29], D. Pouliquen[8], D. Rigopoulou[12], D. Rizzo[5], I. G. Roseboom[30], H. Roussel[33], M. Rowan-Robinson[5], B. Rownd[20], P. Saraceno[14], M. Sauvage[4], R. Savage[30], G. Savini[1,9], E. Sawyer[12], C. Scharmberg[8], D. Schmitt[4,24], N. Schneider[4], B. Schulz[26], A. Schwartz[26], R. Shafer[25], D. L. Shupe[26], B. Sibthorpe[7], S. Sidher[12], A. Smith[10], A. J. Smith[30], D. Smith[12], L. Spencer[29,1], B. Stobie[7], R. Sudiwala[1], K. Sukhatme[6], C. Surace[8], J. A. Stevens[34], B. M. Swinyard[12], M. Trichas[5], T. Tourette[4], H. Triou[4], S. Tseng[6], C. Tucker[1], A. Turner[6], M. Vaccari[19], I. Valtchanov[3], L. Vigroux[4,33], E. Virique[4], G. Voellmer[25], H. Walker[12], R. Ward[30], T. Waskett[1], M. Weilert[6], R. Wesson[9], G. J. White[12], N. Whitehouse[1], C. D. Wilson[35], B. Winter[10], A. L. Woodcraft[7], G. S. Wright[7], C. K. Xu[26], A. Zavagno[8], M. Zemcov[23], L. Zhang[26], and E. Zonca[4]

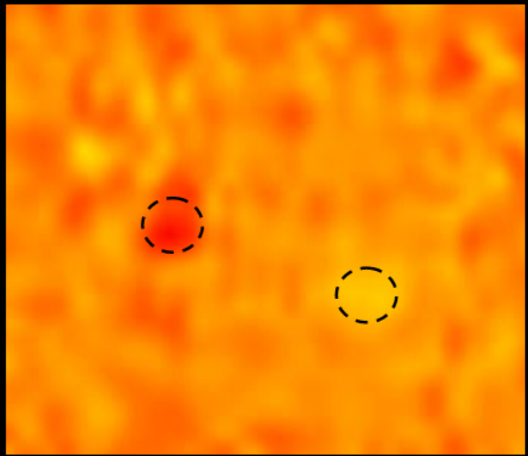
In-Flight Calibration of the *Herschel*-SPIRE Instrument⋆

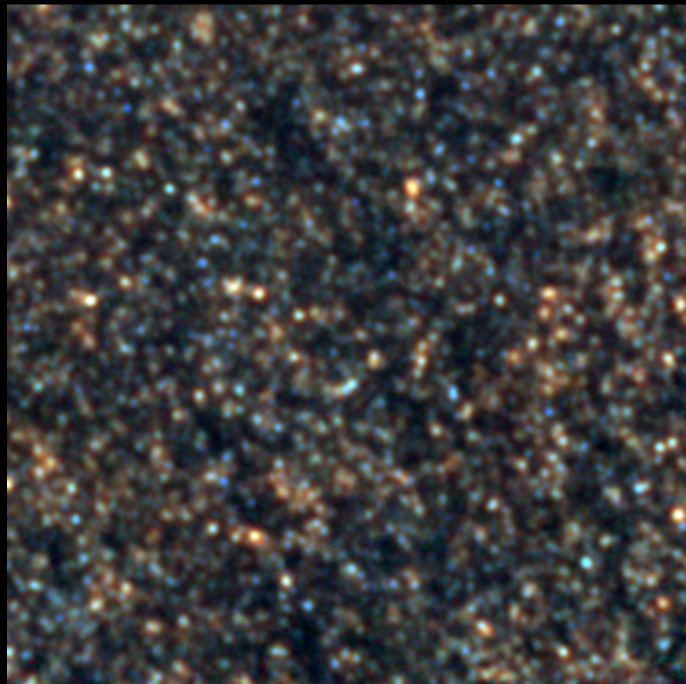
B. M. Swinyard[1], P. Ade[2], J-P. Baluteau[3], H. Aussel[16], M. J. Barlow[4], G. J. Bendo[5], D. Benielli[3], J. Bock[6], D. Brisbin[7], A. Conley[8], L. Conversi[9], A. Dowell[1], D. Dowell[6], M. Ferlet[1], T. Fulton[10], J. Glenn[11], A. Glauser[18], D. Griffin[1], M. Griffin[2], S. Guest[1], P. Imhof[10], K. Isaak[2], S. Jones[14], K. King[1], S. Leeks[1], L. Levenson[12], T. L. Lim[1], N. Lu[13], G. Makiwa[14], D. Naylor[14], H. Nguyen[6], S. Oliver[15], P. Panuzzo[16], A. Papageorgiou[2], C. Pearson[1,14], M. Pohlen[2], E. Polehampton[1,14], D. Pouliquen[3], D. Rigopoulou[1,19], S. Ronayette[1,16], H. Roussel[17], A. Rykala[2], G. Savini[4], B. Schulz[13], A. Schwartz[13], D. Shupe[13], B. Sibthorpe[18], S. Sidher[1], A. Smith[15], L. Spencer[2], M. Trichas[5], H. Triou[16], I. Valtchanov[9], R. Wesson[4], A. Woodcraft[18], C. K. Xu[13], M. Zemcov[11], and L. Zhang[13]

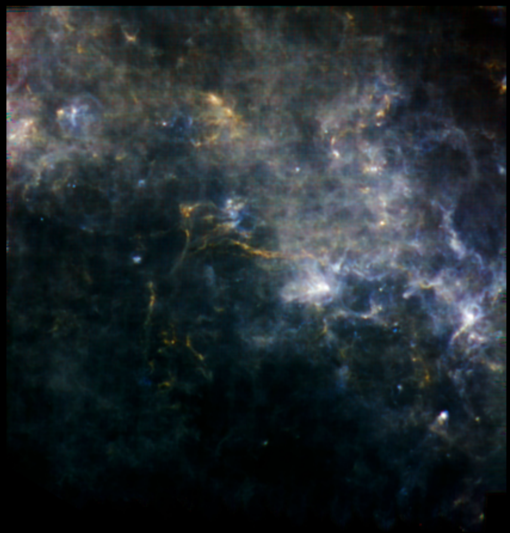
SPIRE Block Diagram

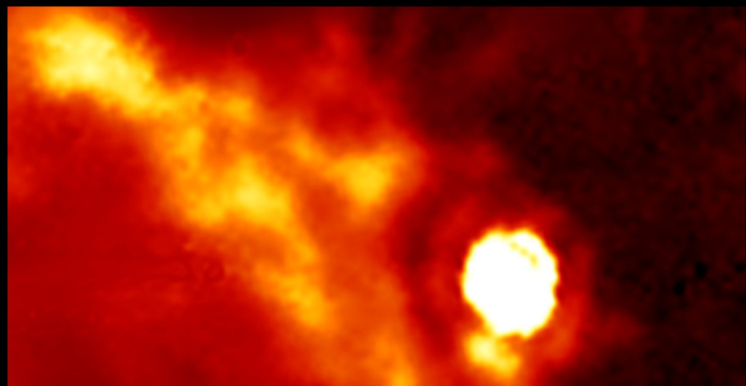


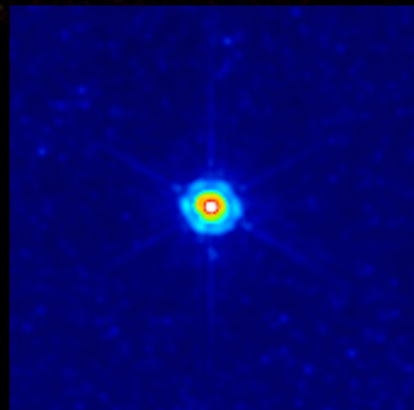
Photometer



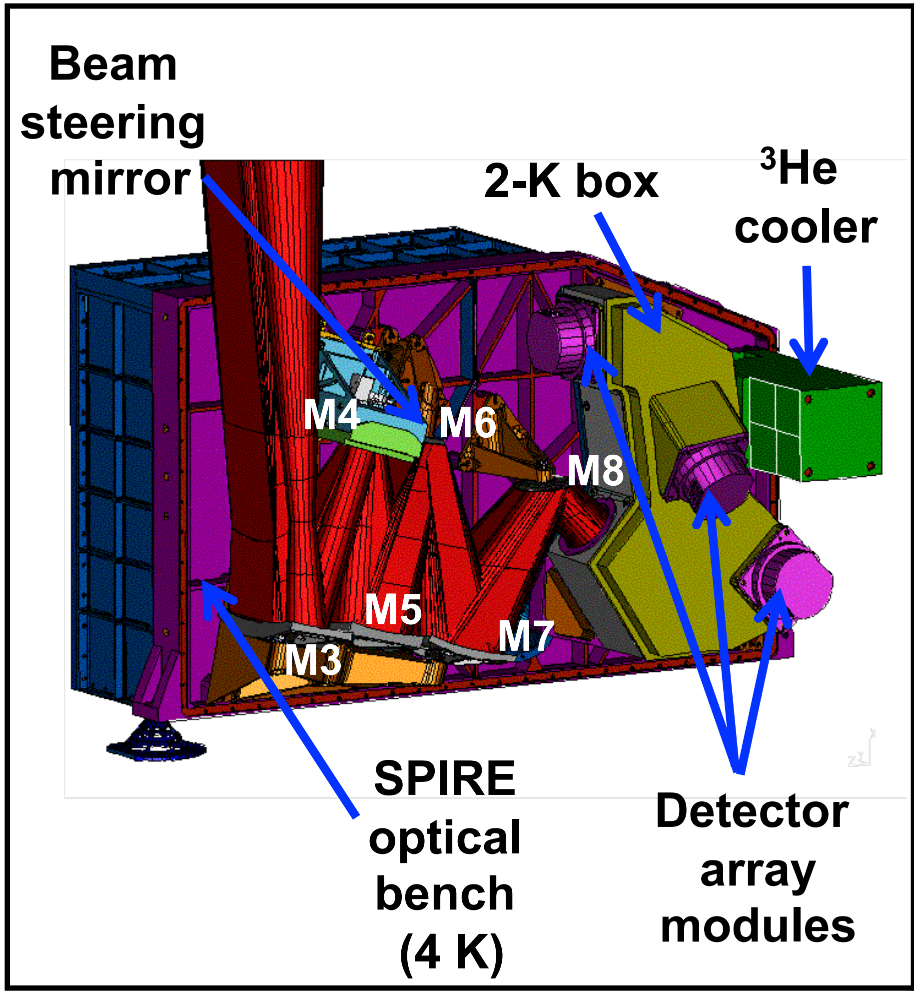


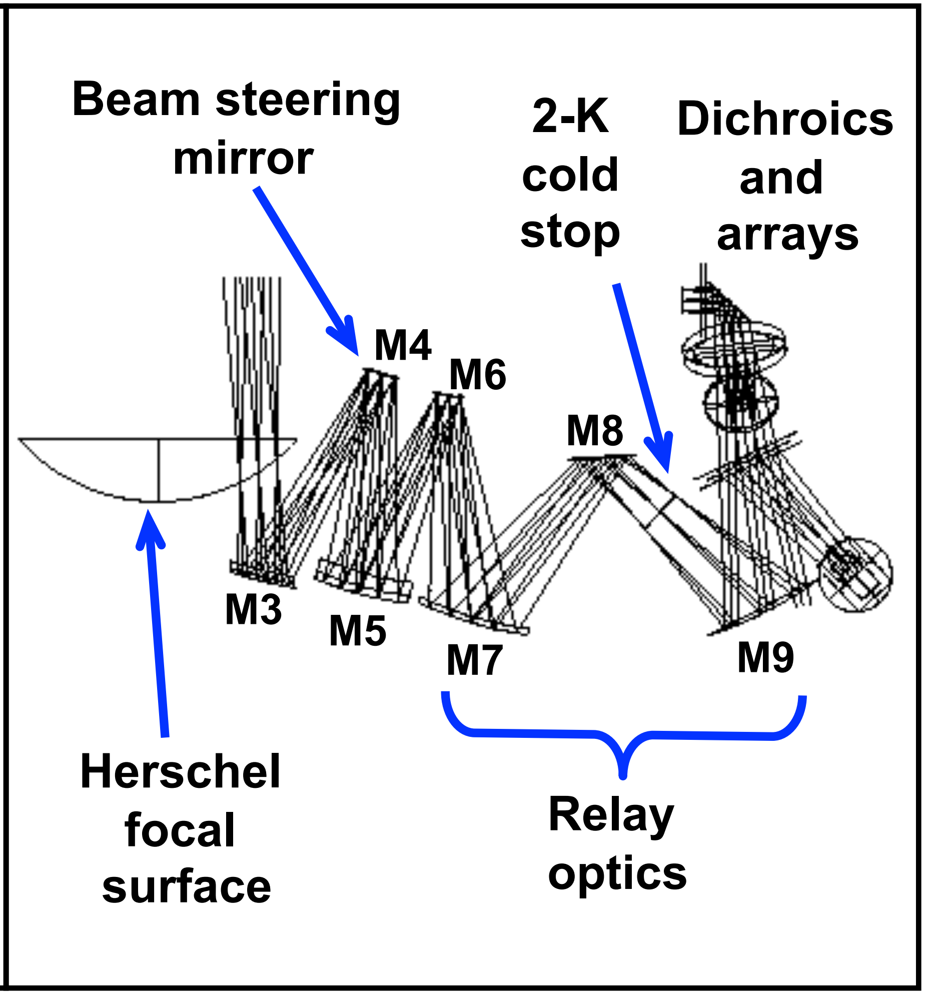






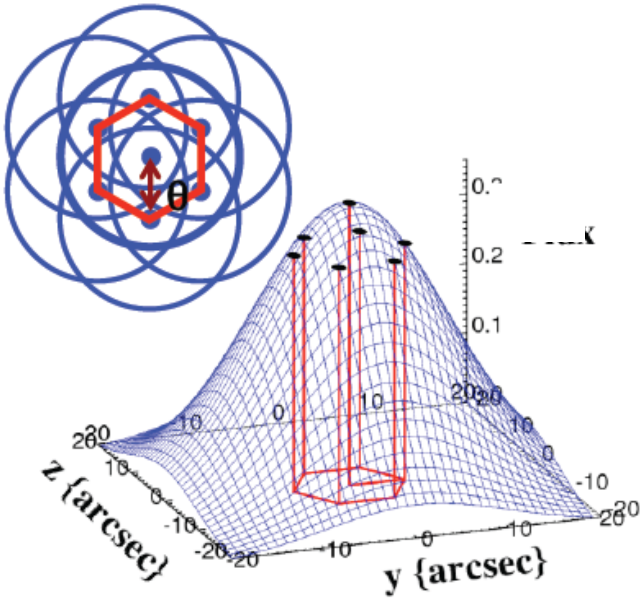
Photometer Layout and Optics



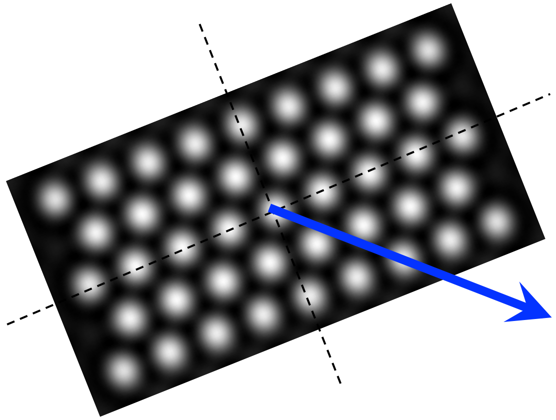


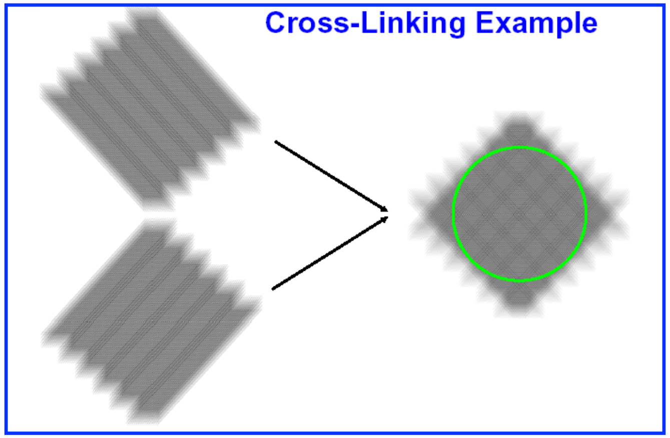
Photometer Observing Modes

Point source: 7-point jiggle



Scan-map





AOT Status: Photometer

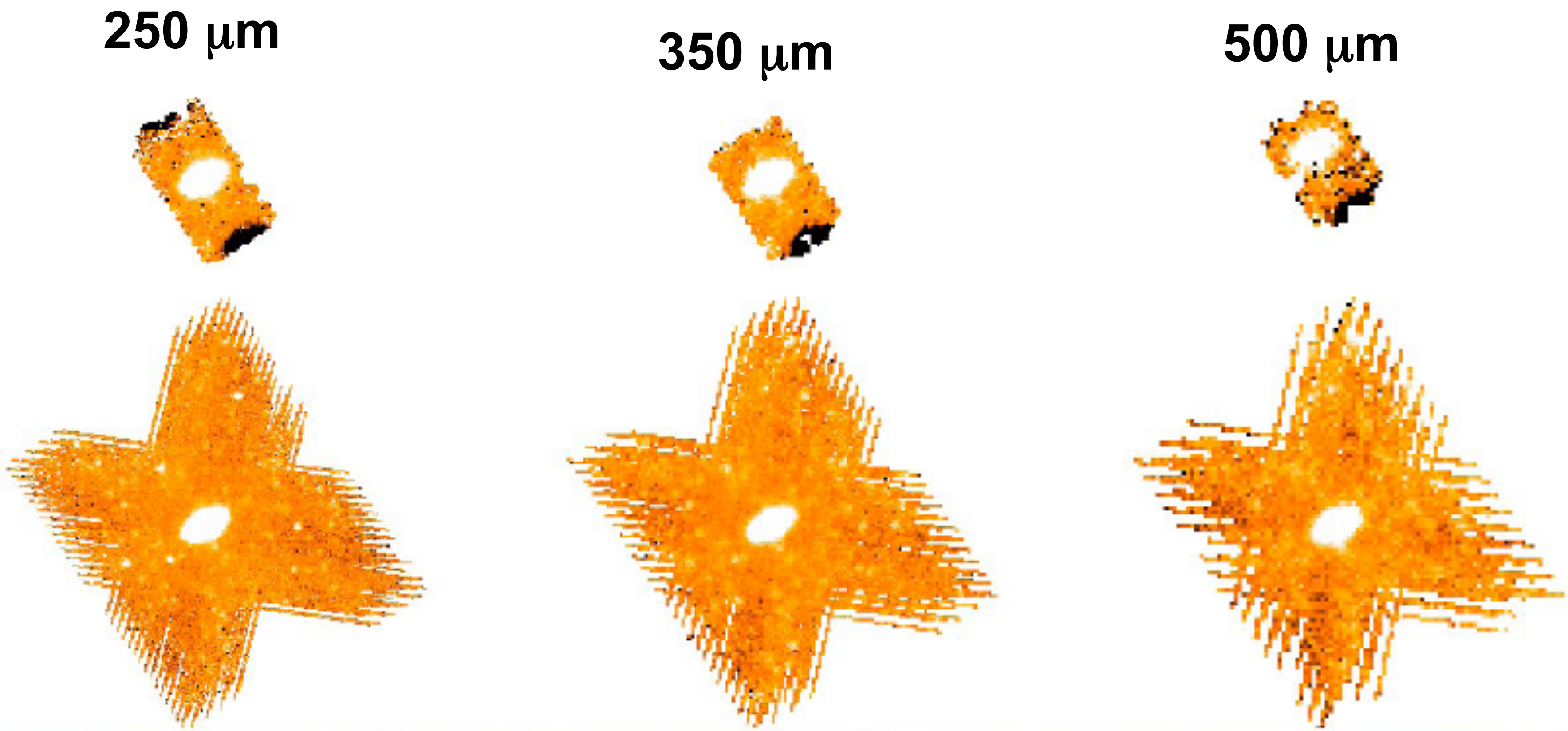
- **Scan Map and SPIRE-PACS Parallel Mode**
  - **Released and widely used in SD Phase**

- **Small Map**
  - **Change mode from 64-point jiggle to small scan map**

- **Point Source (Seven-point Jiggle)**
  - **Chopping with SPIRE Beam Steering Mirror**
  - **Telescope nodding**
  - **Now fully evaluated and released**

- **Bright source settings**
  - **Recommended for S_ν > 200 Jy**
  - **Usable for S_ν up to (3.2, 2.4, 1.4) kJy at (250, 350, 500) μm**
  - **Sensitivity penalty factor: (3.8, 3.2, 2.6) at (250, 350, 500) μm**

Reason for change from Jiggle-Map to Small Scan Map



Better data quality and wider coverage for similar observation time

Scan-Map Sensitivity

Pre-launch (HSpot) estimates (instrument noise)

- Nominal scan rate (30"/s)
- One repeat = two cross-linked scans
- For (250, 350, 500 μm)
  - 1-σ for one repeat: (10, 13, 11) mJy in beam

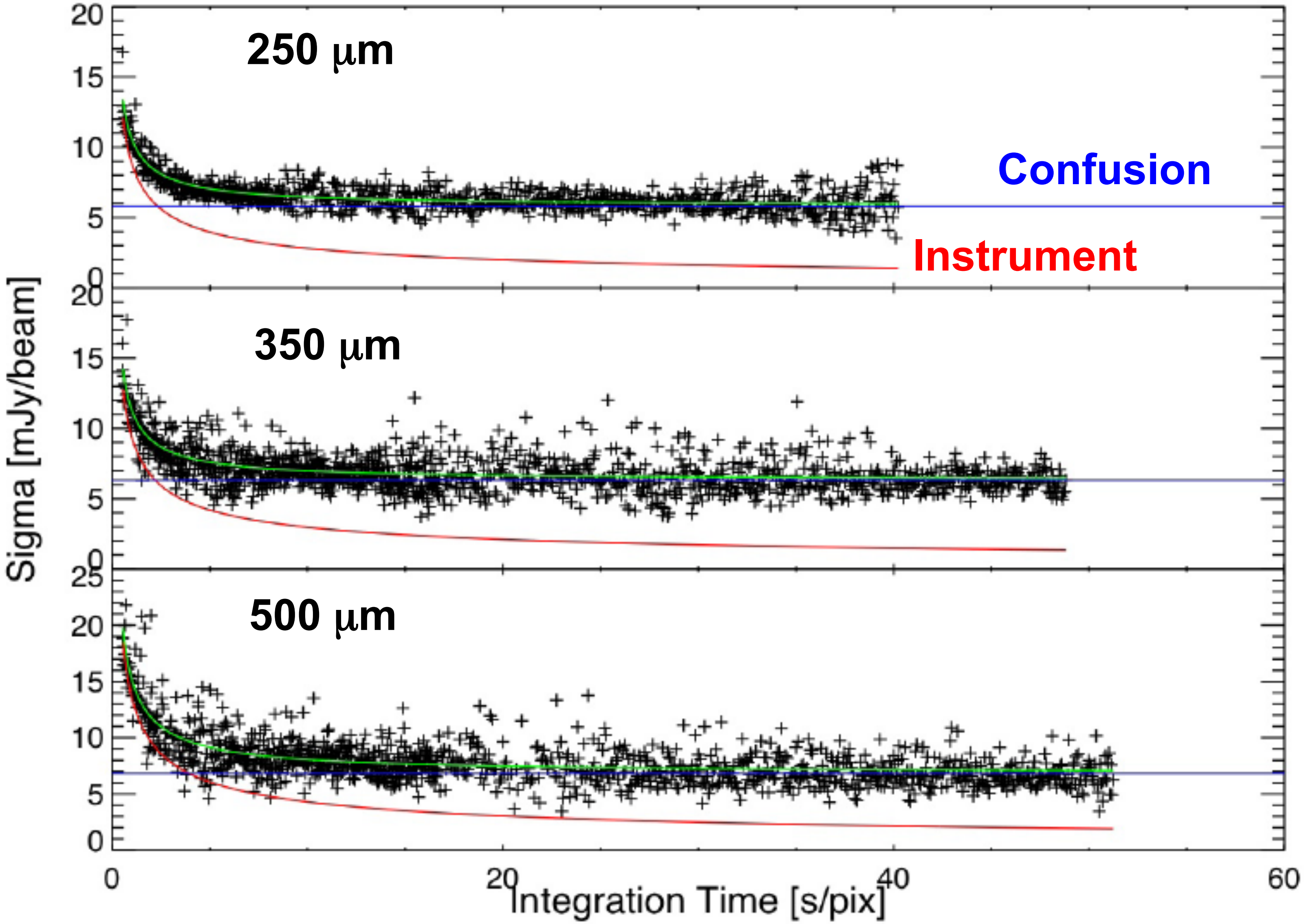
Achieved instrument noise

- 1-σ for one repeat at 30"/s: (9.0, 7.5, 10.8) mJy in beam
- Numbers for 60"/s scale very precisely as sqrt(2)

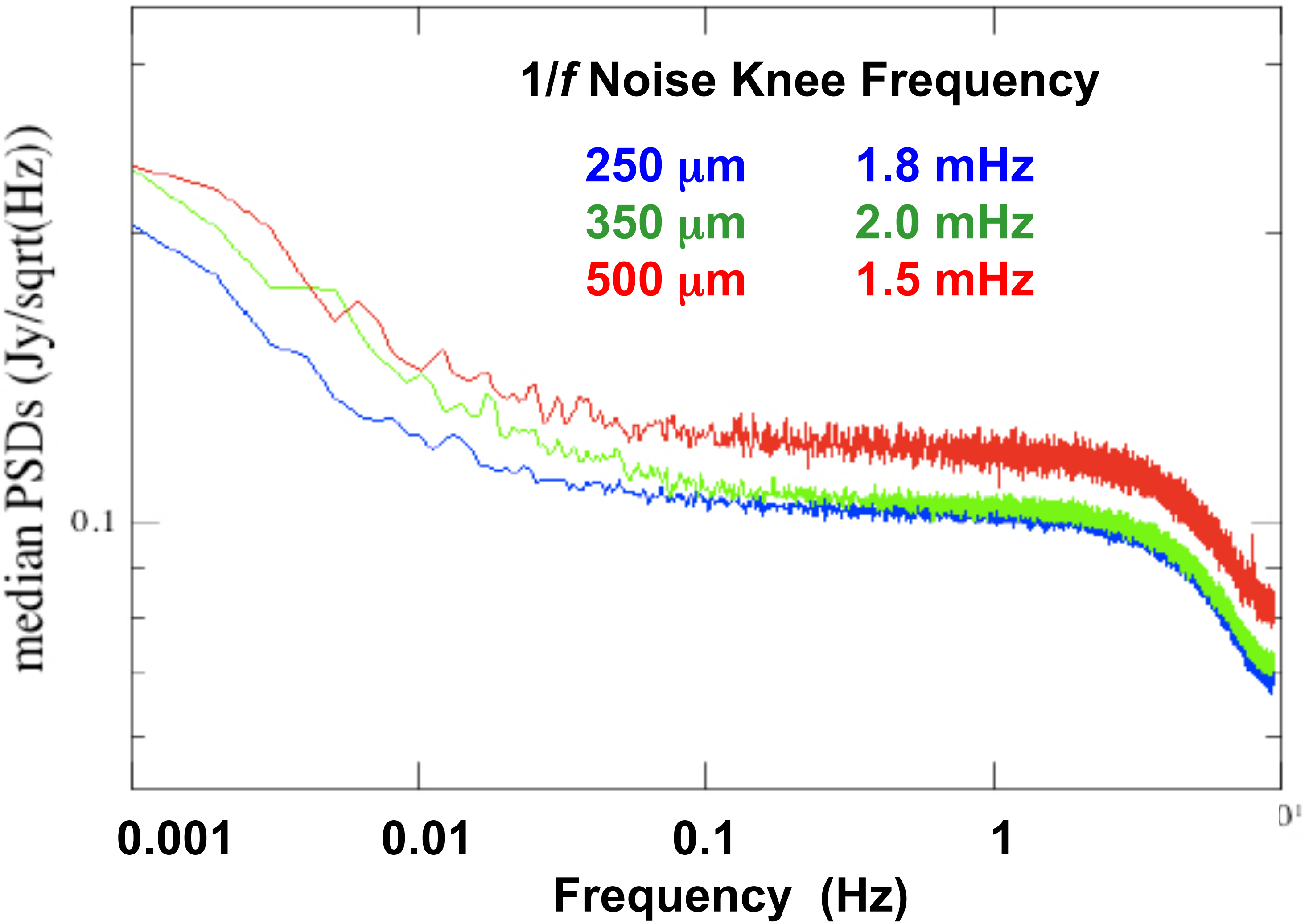
Extragalactic confusion levels

- Measured 1-σ confusion noise for (250, 350, 500 μm): (5.8, 6.3, 6.8) mJy in beam for (6, 10, 14)" map pixels

Instrument and Confusion Noise



Improved Pipeline Temperature Drift Correction (in Development)



Point Source Photometry (Seven-Point Jiggle) Sensitivity

- One repeat
  - A-B-B-A nod cycle
  - 256 sec. on-source; 560 sec. total duration

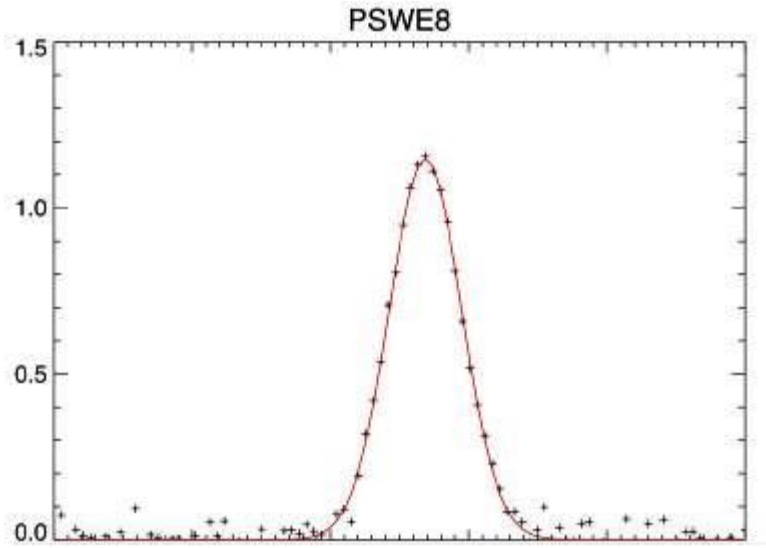
- 1-σ in-beam flux density uncertainty for one repeat:
  - ~ 7 mJy (S_n < 1 Jy) ~ 9 mJy (1 – 4 Jy)
  - Already comparable to confusion limit

- For strong sources S/N limited to ~ 100 by pointing errors

- Chop/nod $\Rightarrow$ differential mode
  - Confusion noise is enhanced
  - Not suitable for sources fainter than ~ 200 mJy
  - Small map will often be a better choice

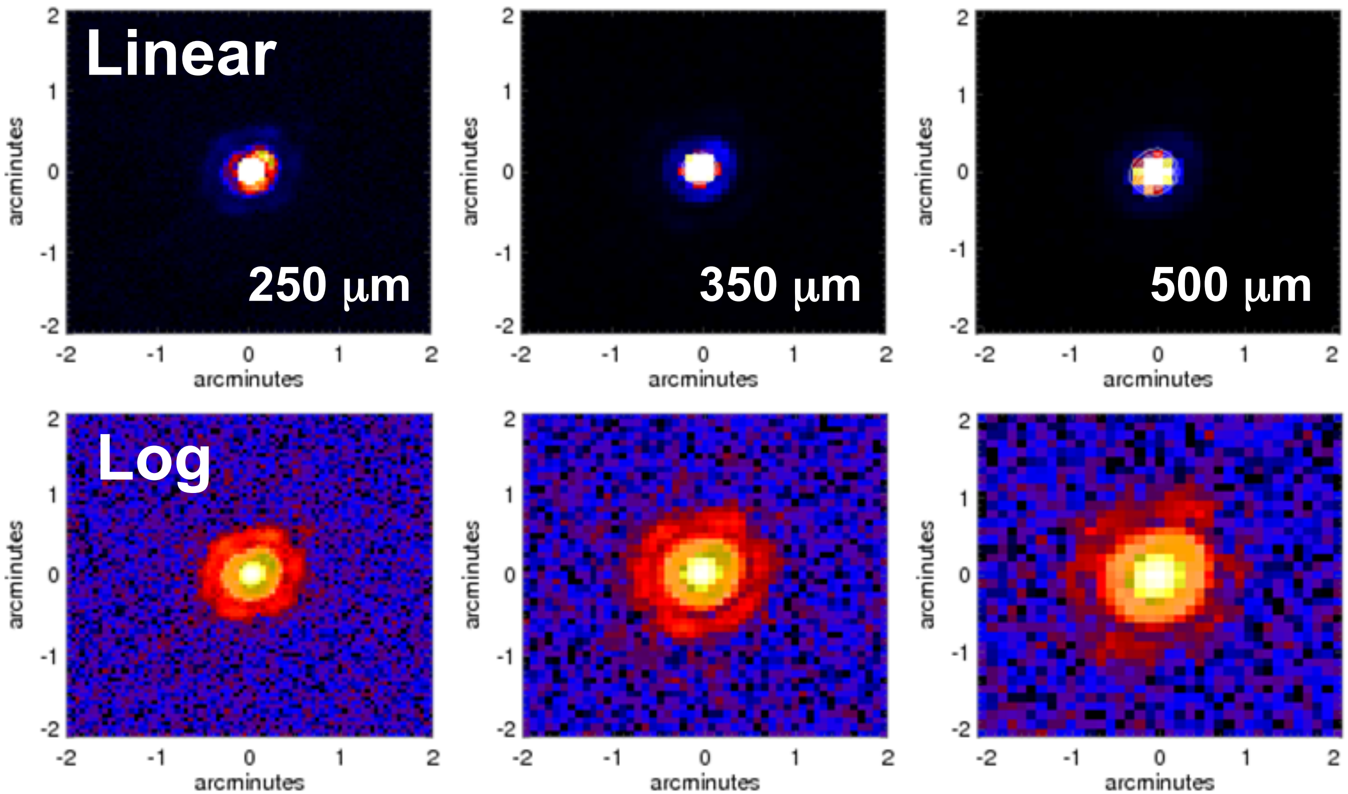
Photometer Beams

Band (μm)	Mean Fitted Gaussian FWHM (arcsec)	Mean Ellipticity
250	18.1	7%
350	25.2	12%
500	36.6	9%



- Main beams very well fitted by Gaussian response
- Individual beam profiles for every detector will eventually be made available

Photometer Beams

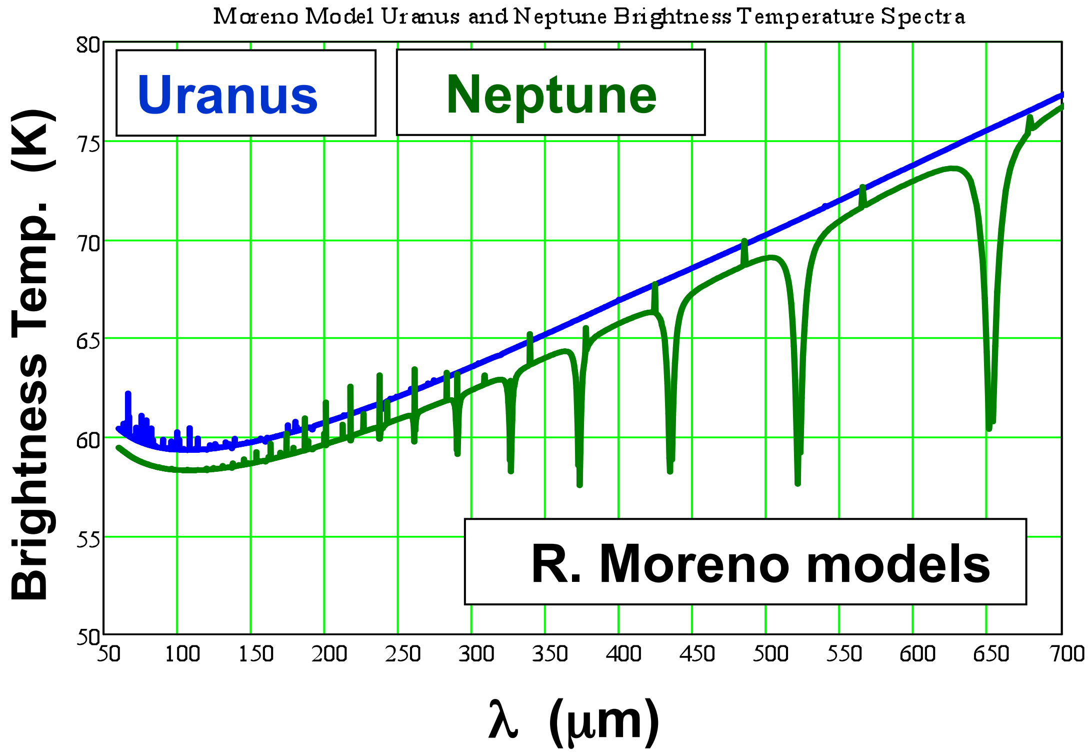


- Interim beam maps available via Herschel Science Centre
  - Based on scan-map AOT observations of Neptune
  - Current beam area estimates: (501, 943, 1923) sq. arcsec.

- Fine-scan observations of Neptune being analysed
  - Above numbers will not change much

Photometer Flux Calibration

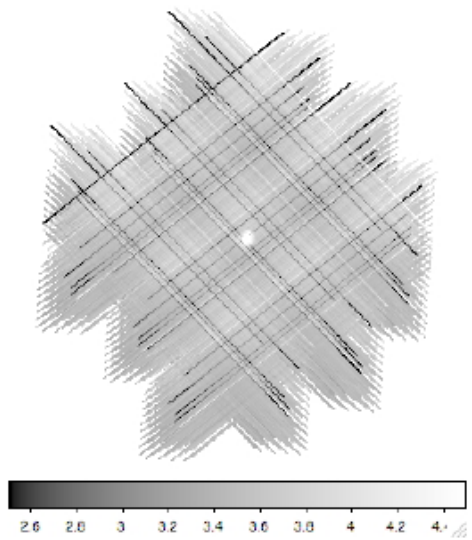
- Primary calibrator is Neptune
- Est. absolute accuracy ± 5 % (correlated over the Herschel range)

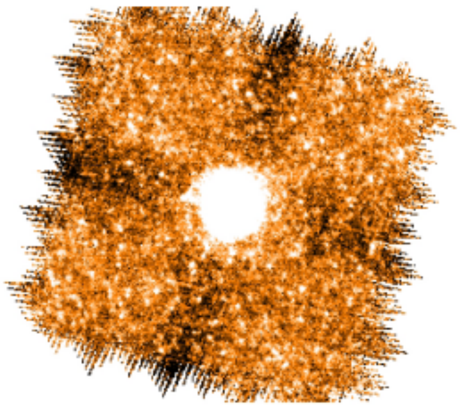


- Current SPIRE pipeline uses interim calibration based on Ceres
- Current overall calibration accuracy ~ 15%
- Neptune observations and non-linearity characterisation
  - Analysis now completed and pipeline to be updated
- Full details of flux calibration scheme will be given in the updated *SPIRE Observers' Manual*

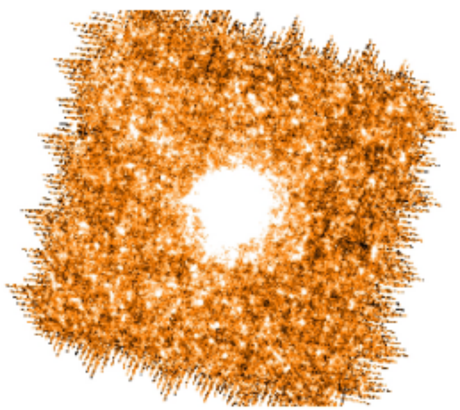
Photometer Scan-Map Pipeline

- **Baseline removal**
  - **Median baseline removal added to L2 processing before the map making stage**
  - **Improved temp-drift implementation will significantly reduce the effects**
  - **Other techniques under evaluation**
  - **De-correlation using thermistor signals over an entire observation has been very successful**





median baseline subtraction

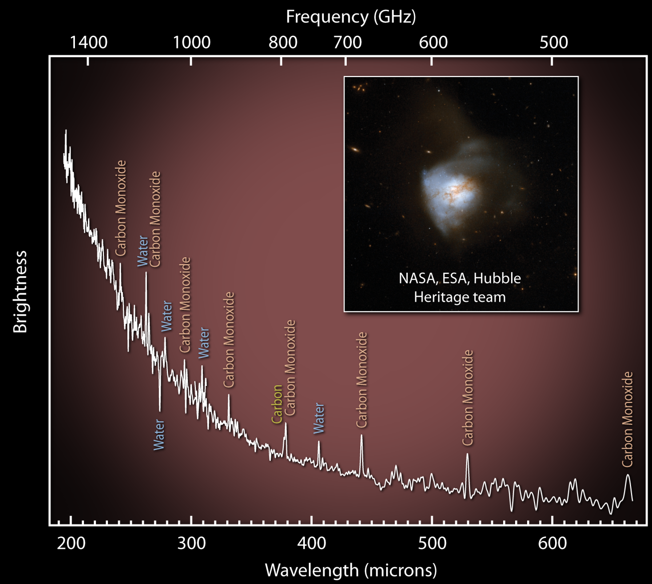


robust linear baseline subtraction per scan

Scan-Map AOT and Pipeline: Future Plans

- Future pipeline enhancements (pre-mapmaking)
  - Incorporation of updated flux calibration
  - Improved baseline removal
  - Glitch replacement
- Mapmaking
  - Possible implementation of MadMap as standard SPIRE mapmaker

Spectrometer



Arp 220

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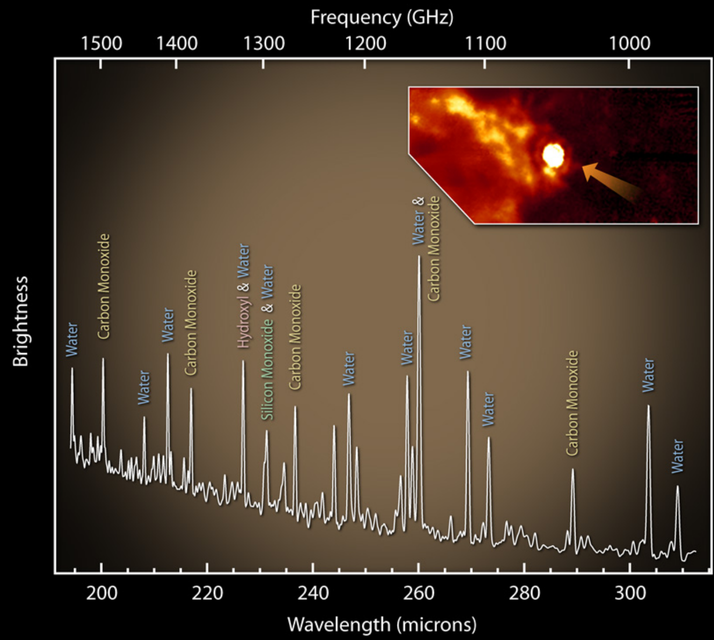

VY Canis Majoris

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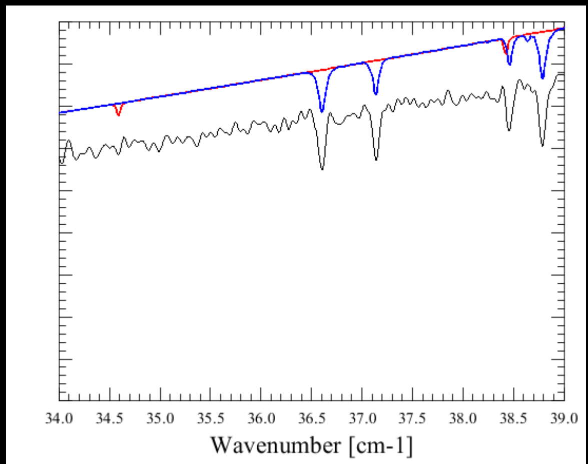
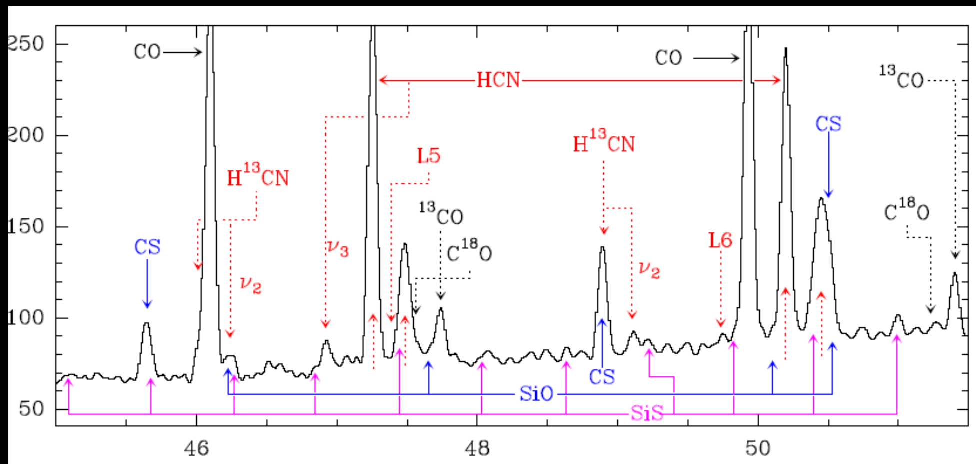
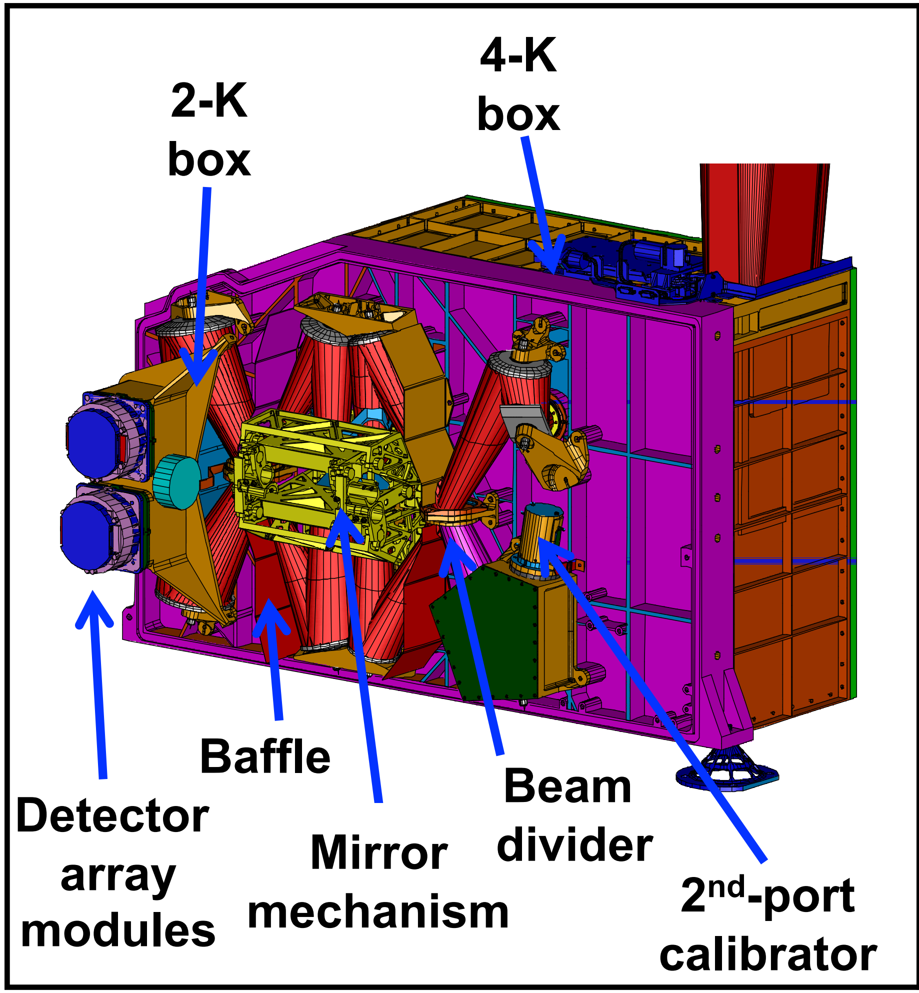
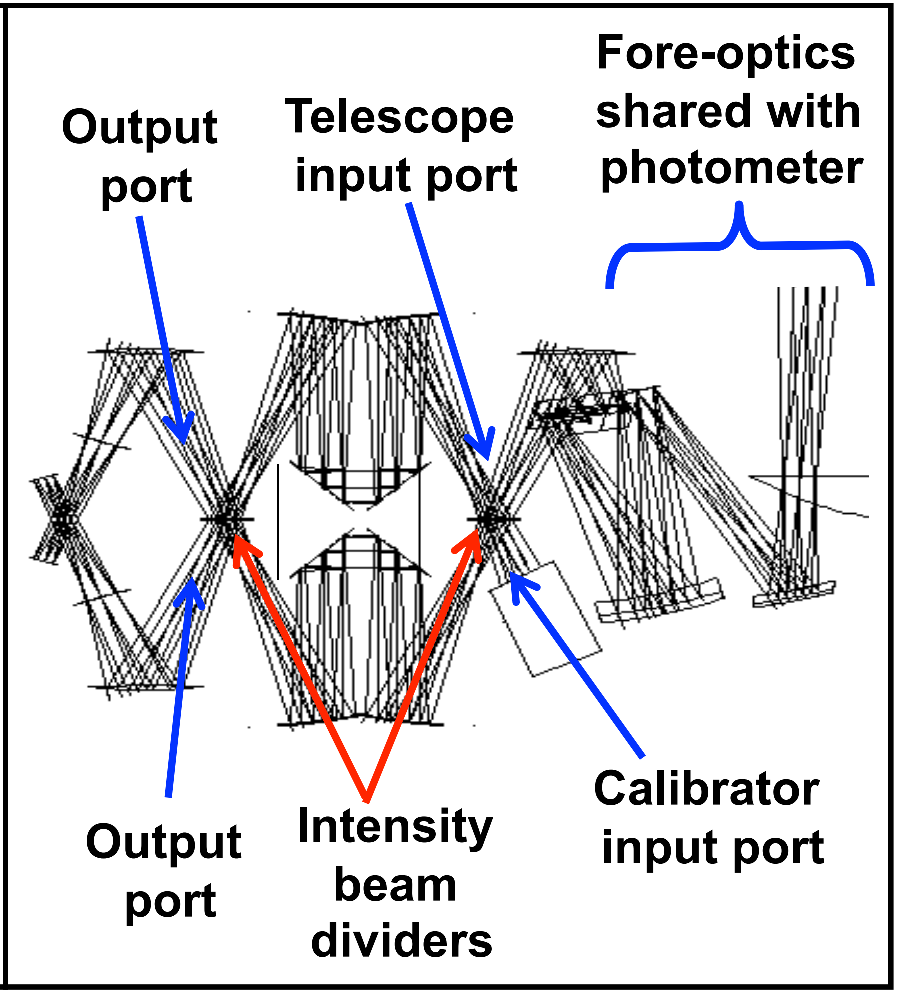


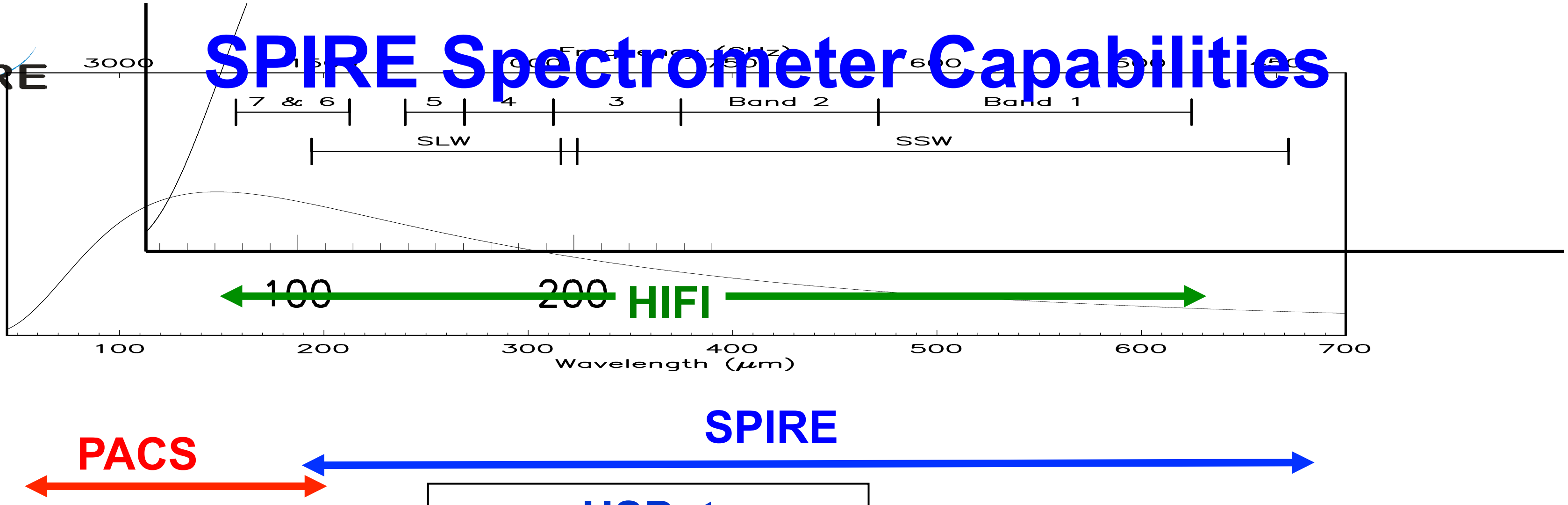


Fourier Transform Spectrometer (FTS) Layout and Optics





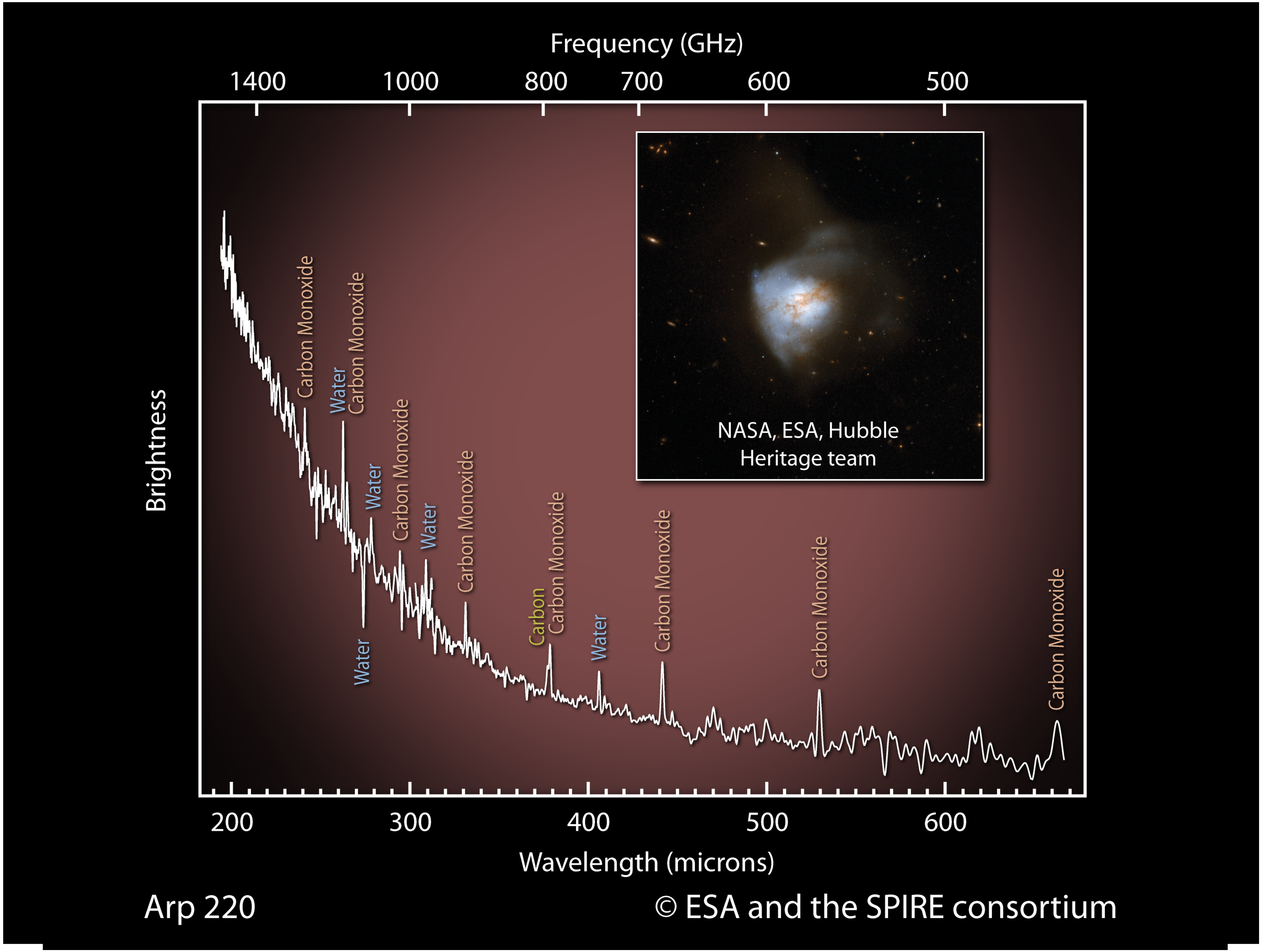
SPIRE Spectrometer Capabilities

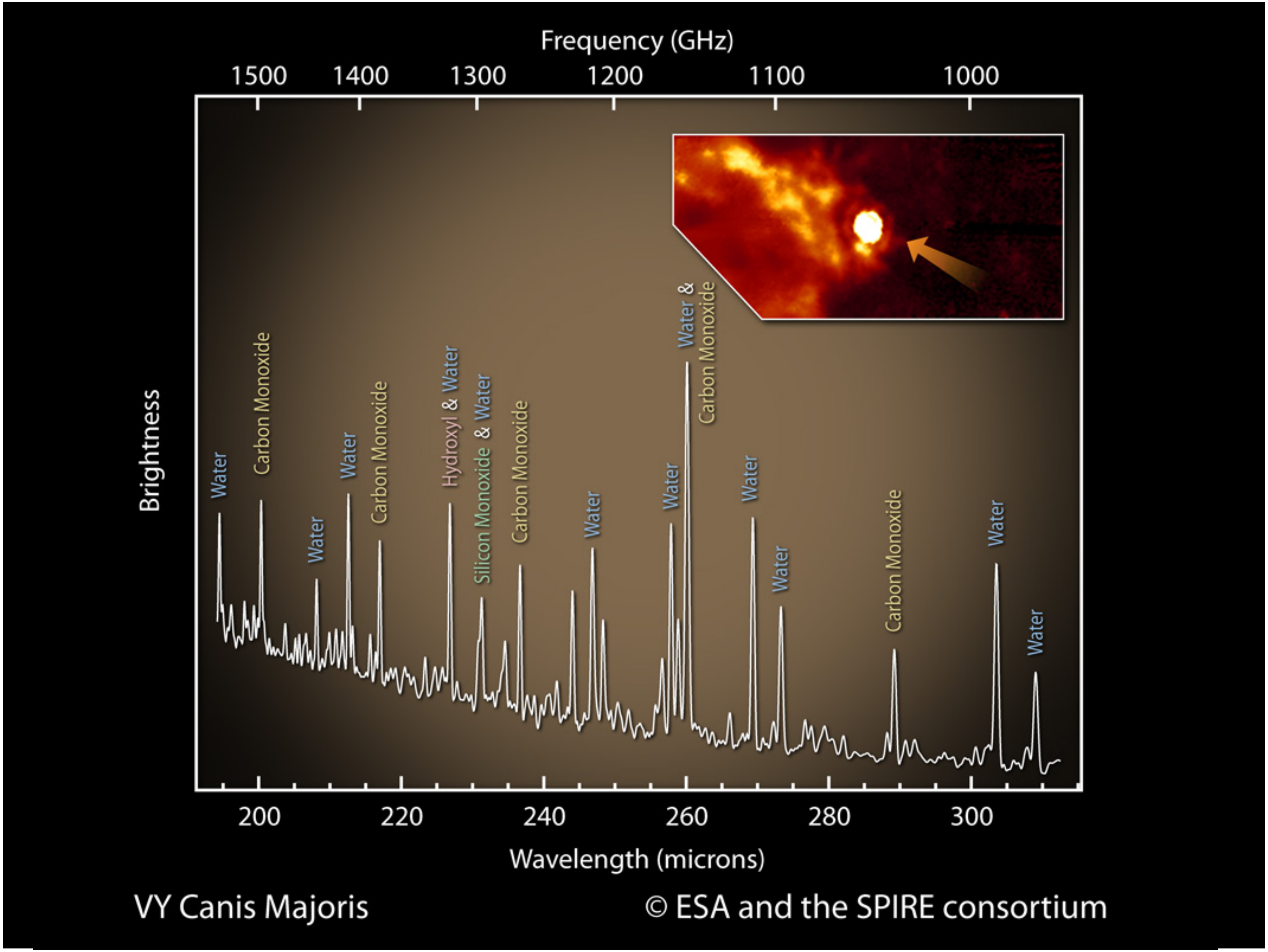


HSPot
194 – 671 μm
51.5 – 14.9 cm-1
1545 – 447 GHz

Achieved:
193 – 685 μm

- **Entire range covered simultaneously**
  - **Small variations from detector to detector**
- **Continuum measured as well as spectral lines**
- **Adjustable spectral resolution : $\Delta\nu$ (H, M, L) = (1.2, 7.2, 25) GHz**
- **Frequency calibration accurate to < 1/20 resolution element**


Frequency (GHz)
1400
1000
800
700
600
500
Brightness
Carbon Monoxide
Water
Carbon Monoxide
Water
Carbon Monoxide
Water
Carbon Monoxide
Water
Carbon
Carbon Monoxide
Water
Carbon Monoxide
Carbon Monoxide
Carbon Monoxide
NASA, ESA, Hubble
Heritage team
200
300
400
500
600
Wavelength (microns)
Arp 220
© ESA and the SPIRE consortium



Frequency (GHz)
1500
1400
1300
1200
1100
1000
Brightness
Water
Carbon Monoxide
Water
Water
Carbon Monoxide
Hydroxyl & Water
Silicon Monoxide & Water
Carbon Monoxide
Water
Water
Water & Carbon Monoxide
Water
Water
Carbon Monoxide
Water
Water
200
220
240
260
280
300
Wavelength (microns)
VY Canis Majoris
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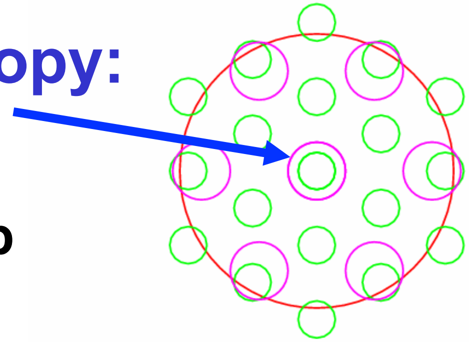
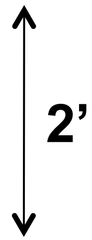
Spectrometer Observing Modes
(all now released)

Point source spectroscopy:

Also provides a sparse map

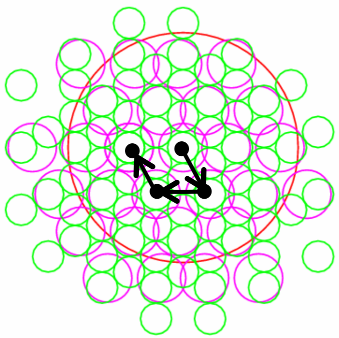


2 beam spacing



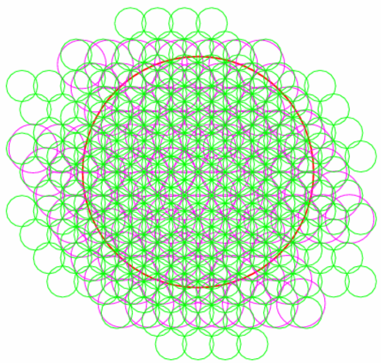
Spectral mapping:

Intermediate image sampling



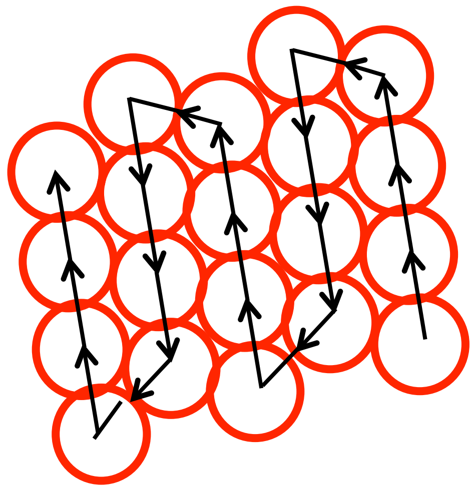
1 beam spacing
(4 jiggle positions)

Full image sampling



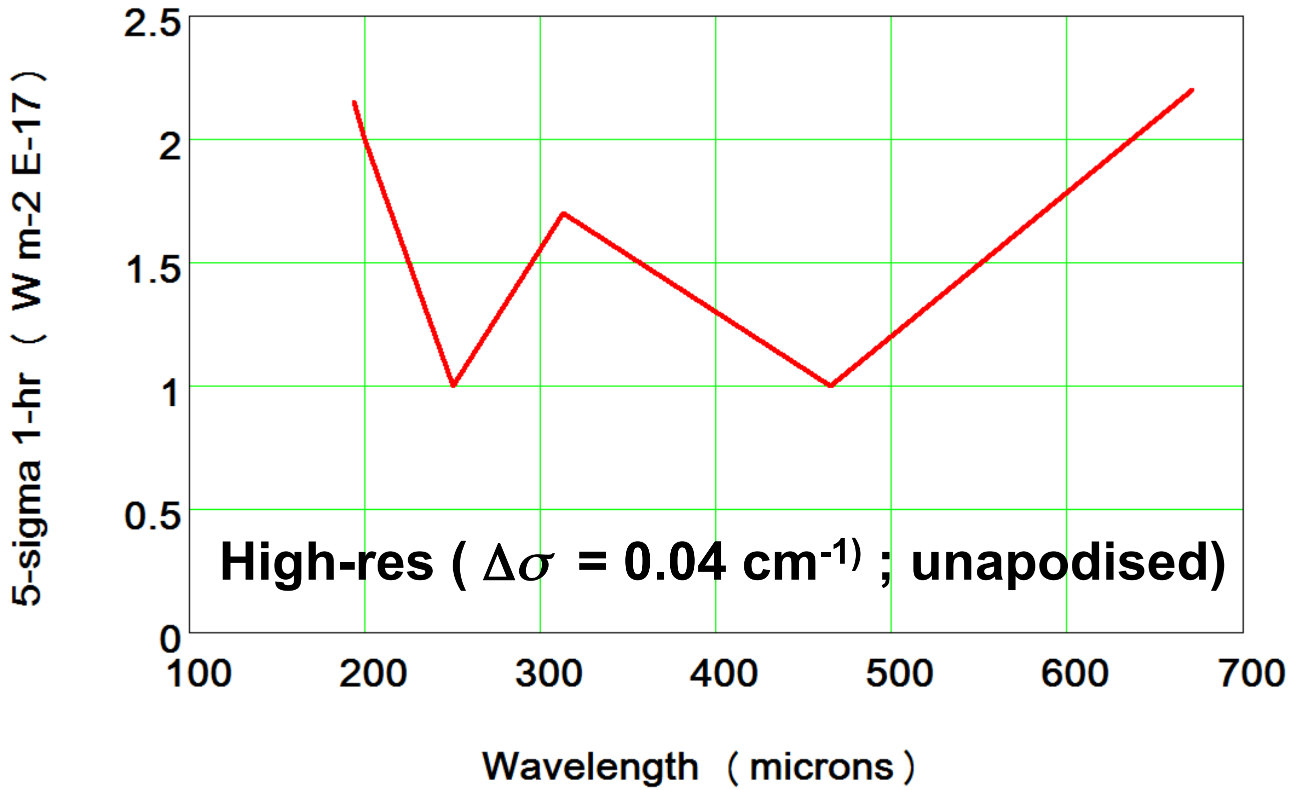
1/2 beam spacing
(16 jiggle positions)

Raster mapping for larger fields:



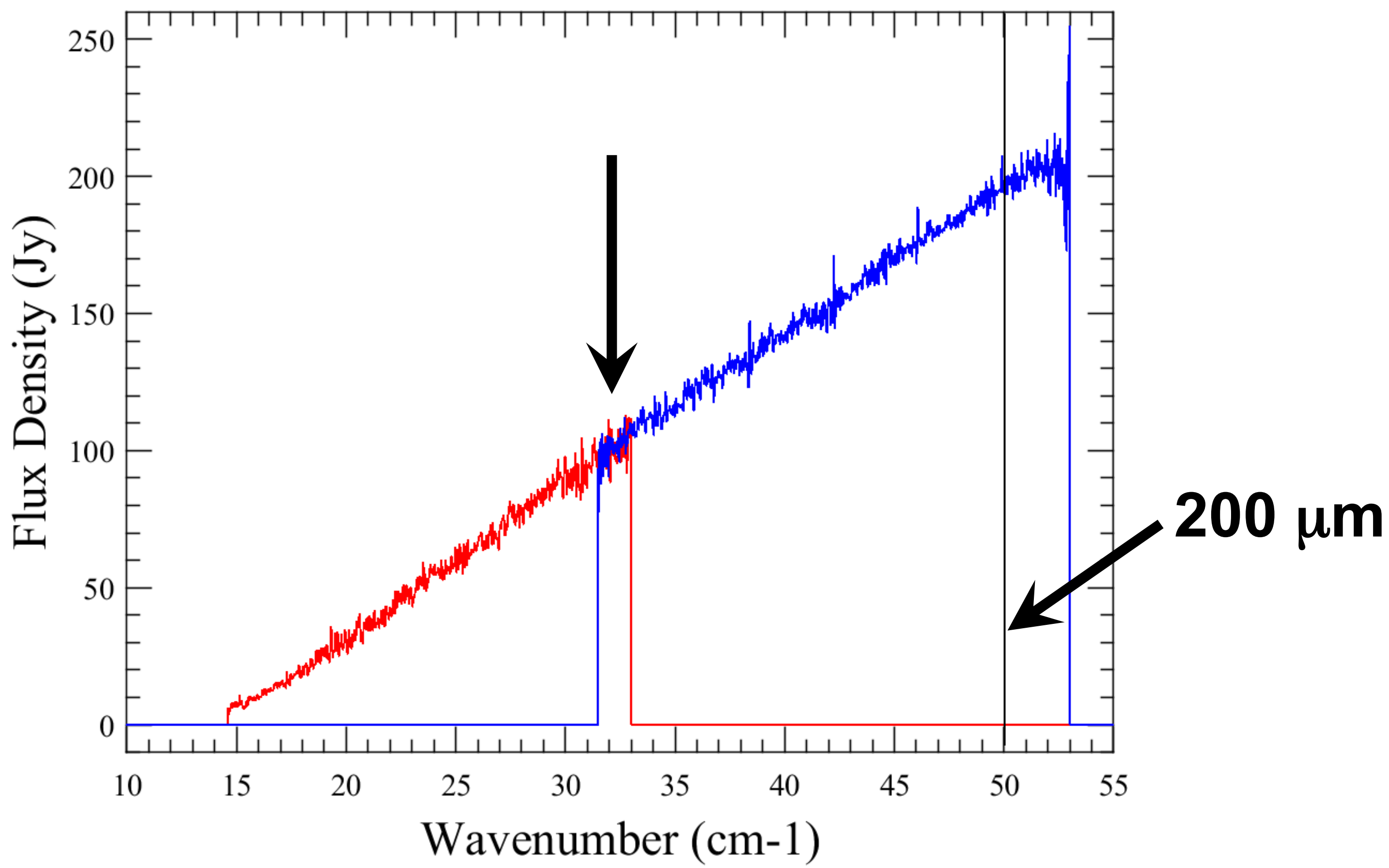
Spectrometer Sensitivity

- **Better than pre-launch estimate (~ 3 x 10^{-17} W m^{-2} 5 σ 1 hr)**
- **Current best performance (based on Uranus calibration) requires careful expert data processing but will be implemented in automatic pipeline**

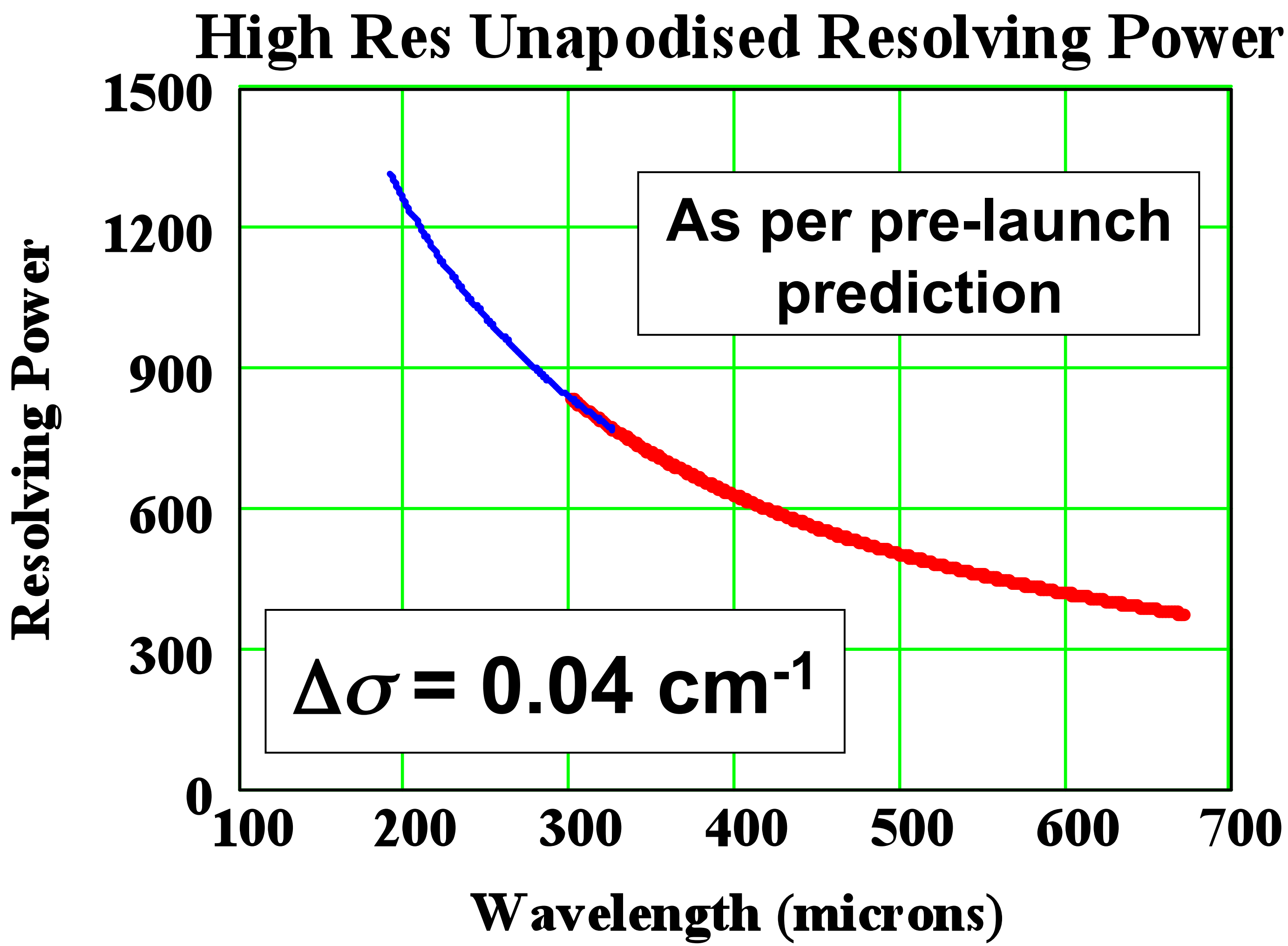


Overlap Between Bands

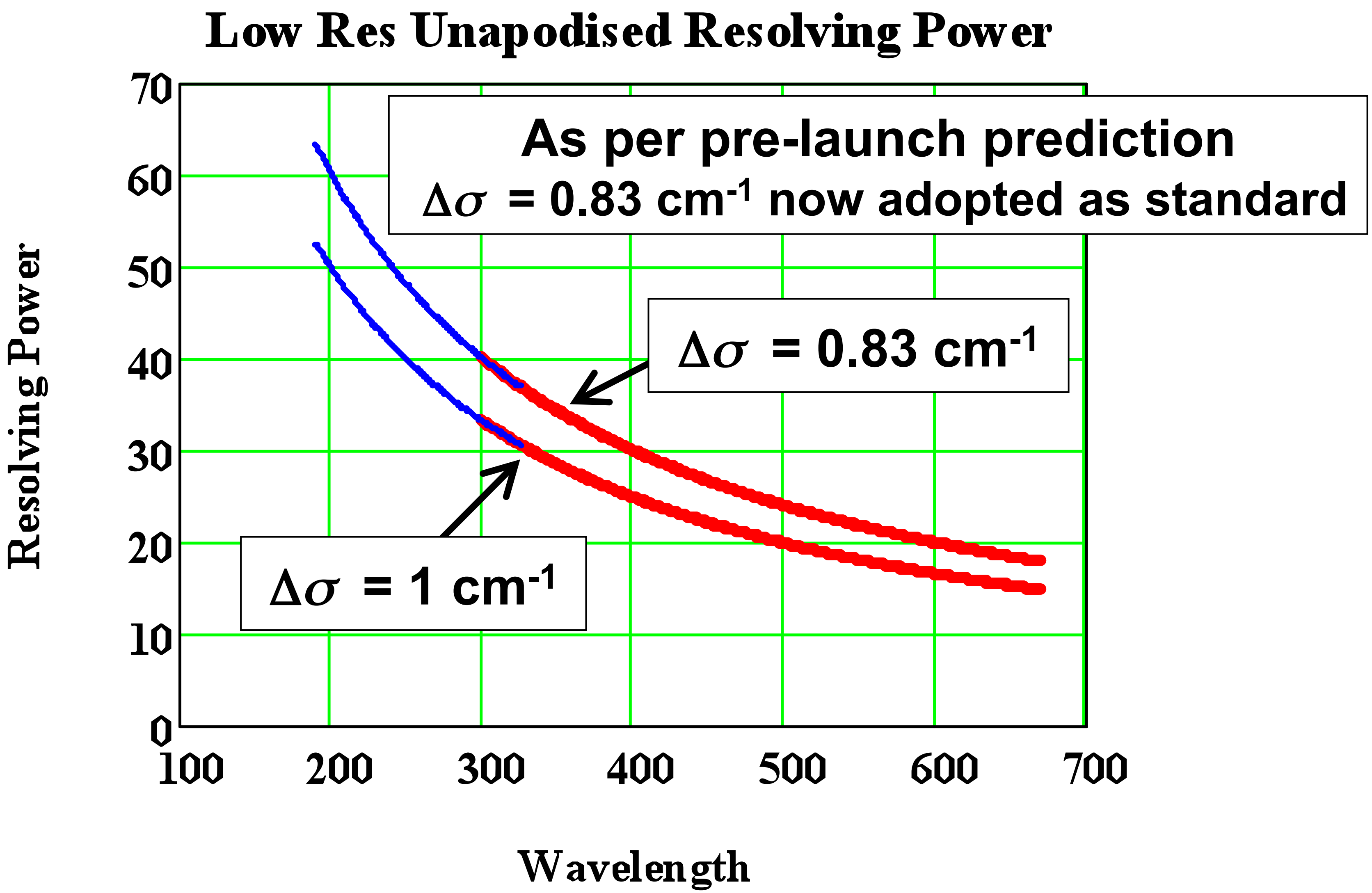
- Good agreement in overlap region for point sources
  - Beamsize difference will affect extended sources
- Short-wavelength overlap for cross calibration with PACS



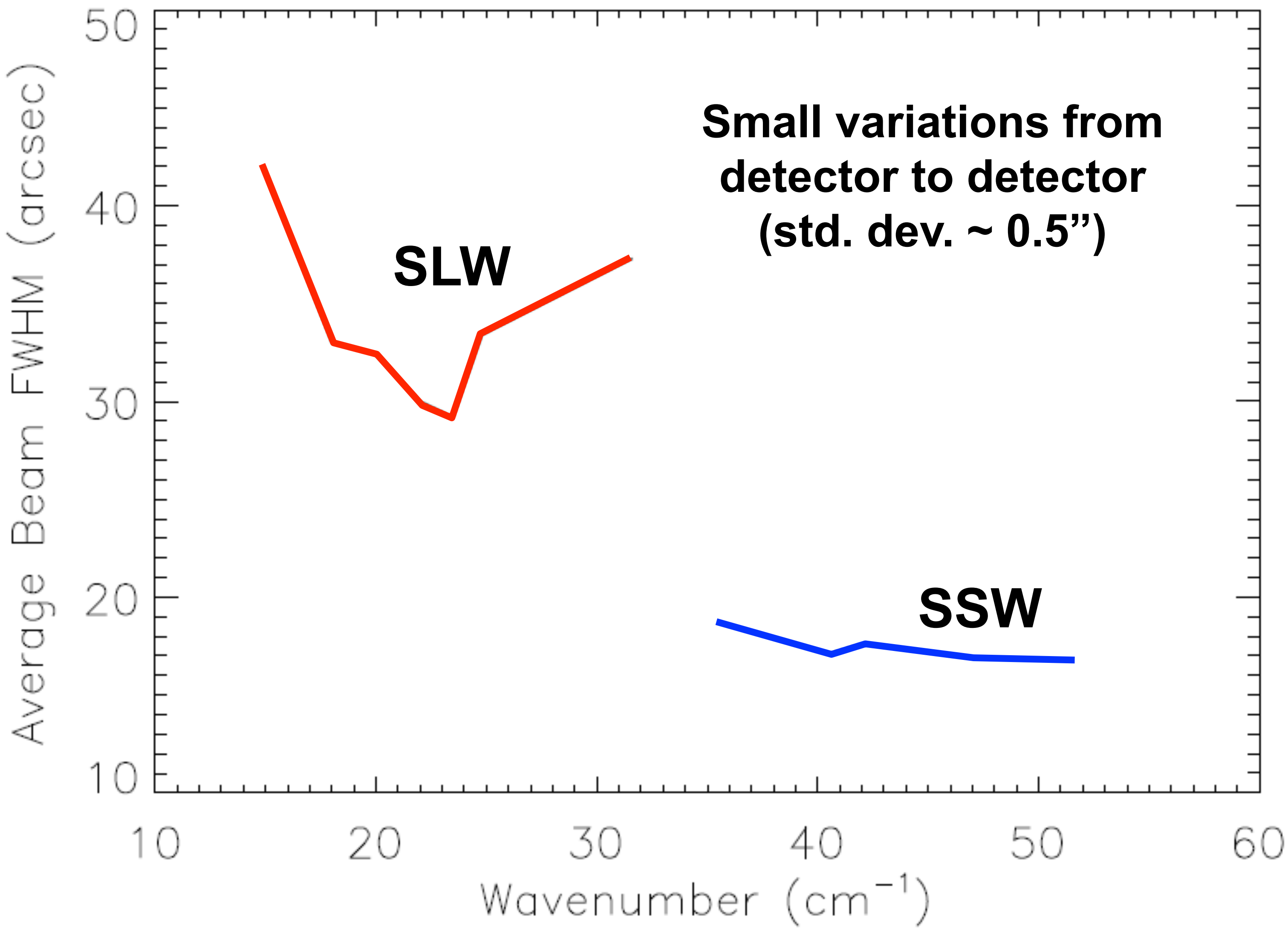
Resolving Power



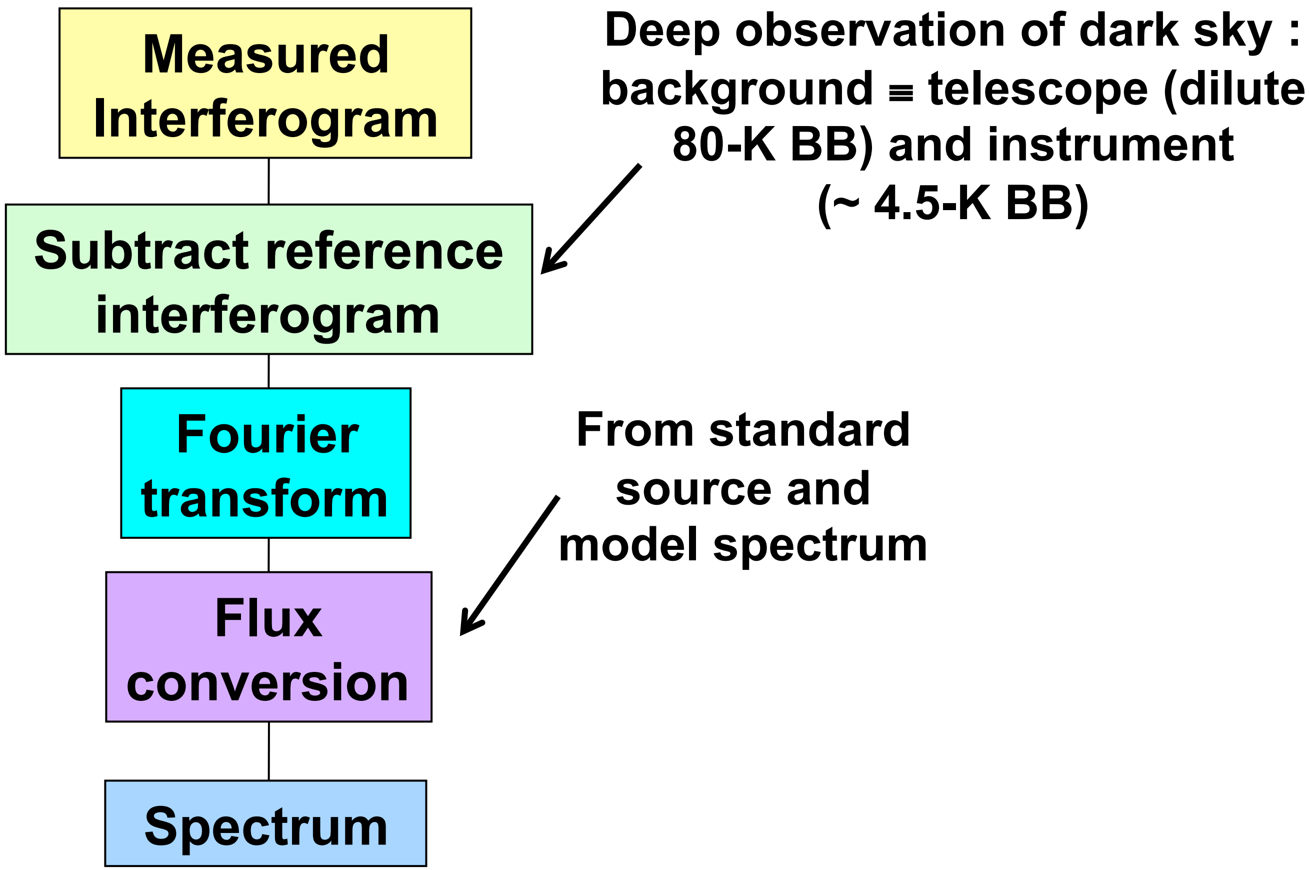
Resolving Power



Spectrometer Beam FWHM vs. λ



Spectrometer Data Processing



Standard calibrators: Point source: Uranus
Extended emission: the telescope itself

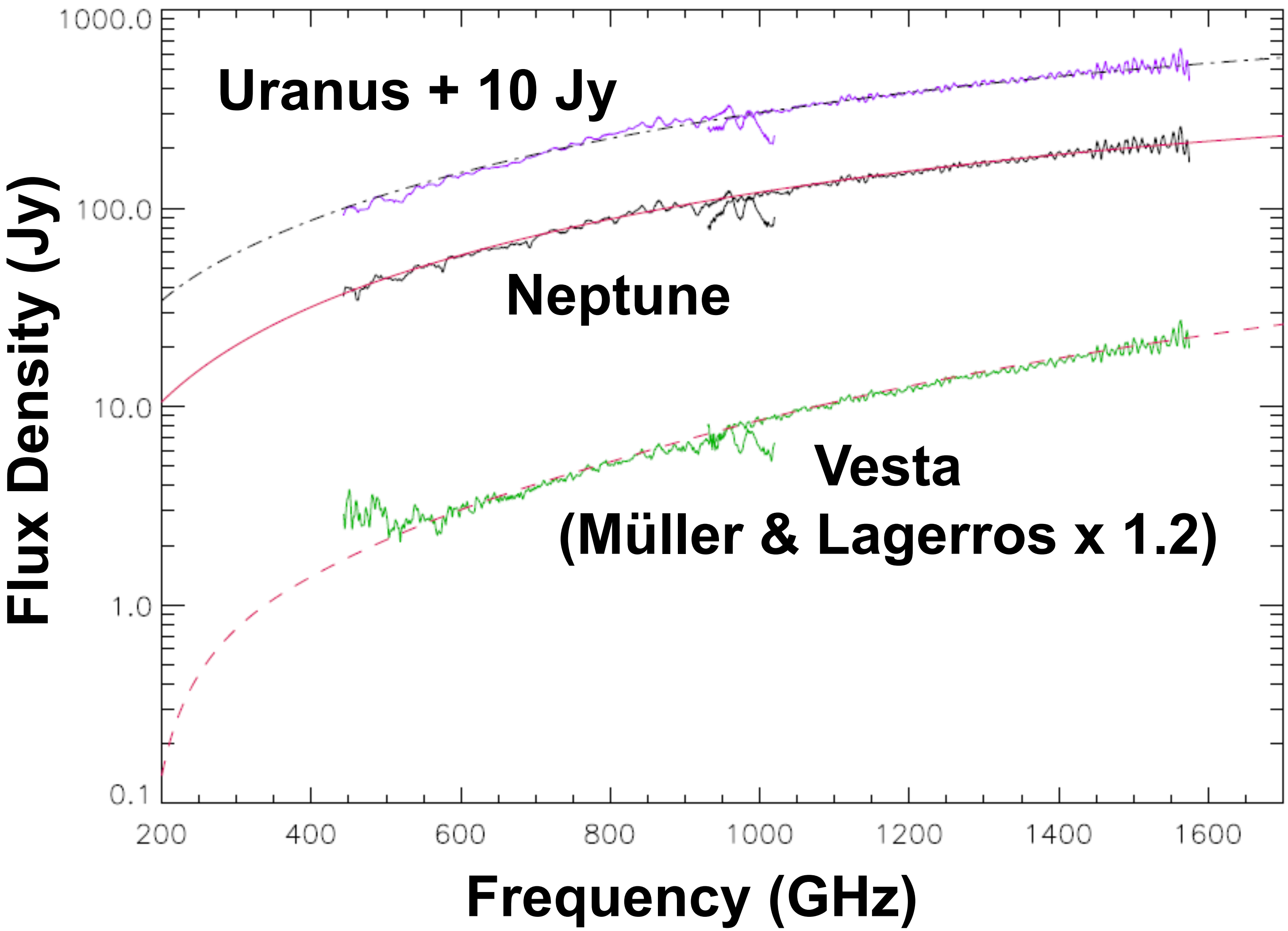
Spectrometer Data Processing

- Noise currently integrates down as $N_{Reps}^{1/2}$ for up to ~ 2500 s (~ 20 repeats) in high-res mode, then more slowly

- Weak targets down to sub-Jy level possible
  - Expert analysis is currently needed to achieve best calibration and instrument background subtraction on faint sources
  - Recommendation to include complementary photometer map (quick)

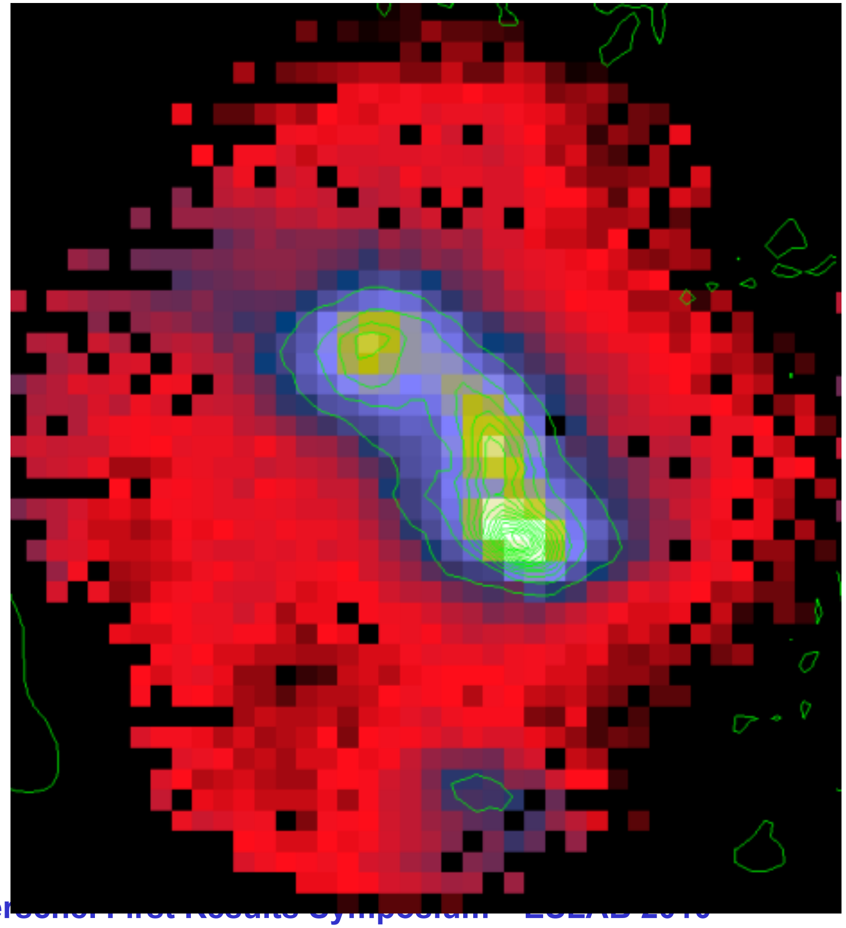
- Very bright targets (e.g. Orion, Sgr B2, Mars) possible using bright source mode
  - Not formally released at present (will be soon)
  - Provisional cross-over level ≡ Neptune (~ 60/180 Jy for SLW/SSW)

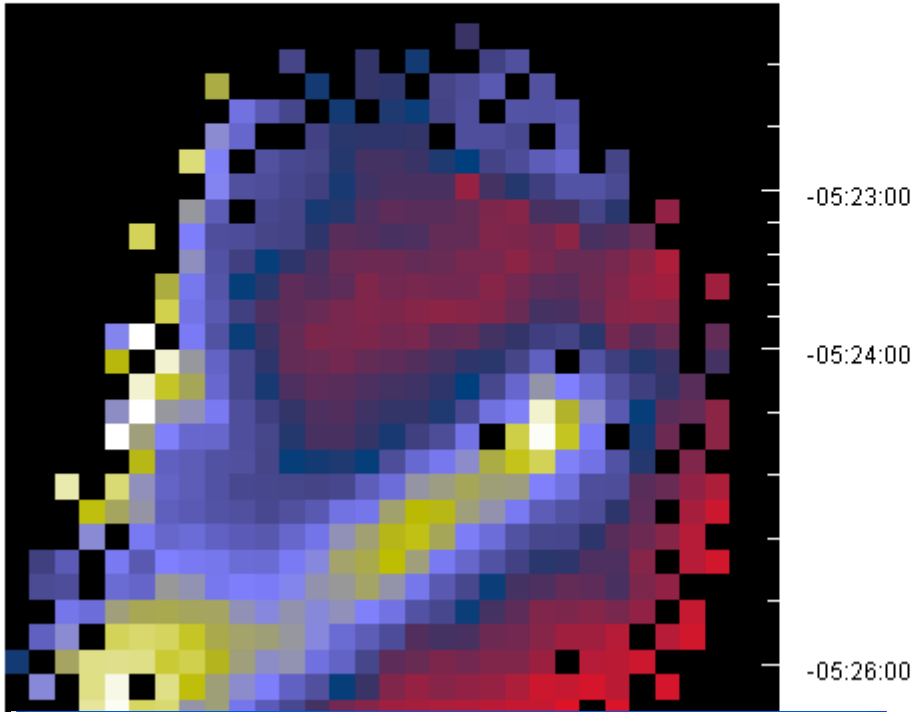
Spectrometer Flux Calibration: Current Status

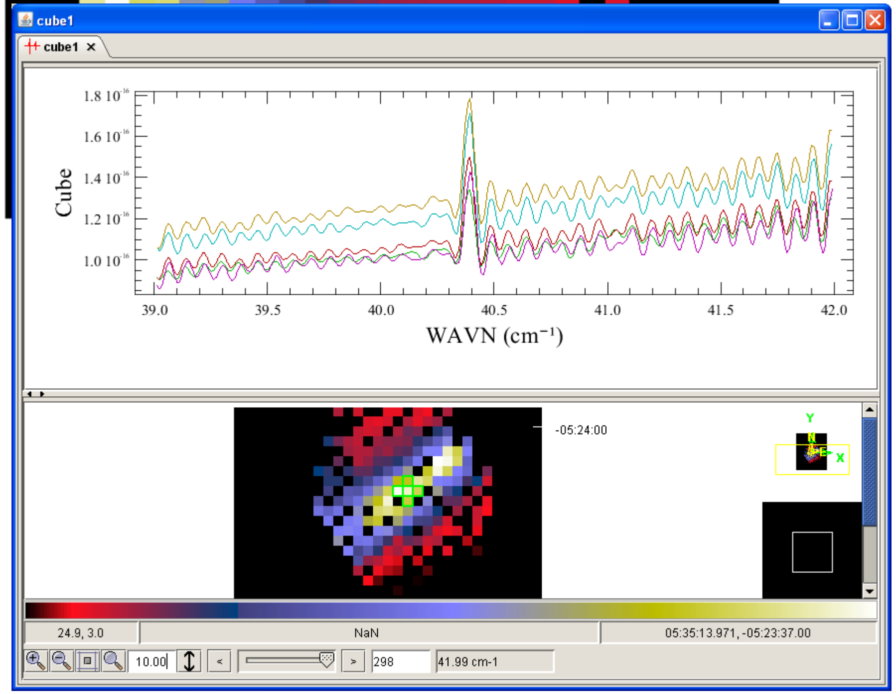


Spectral Maps

Rich data products:
- **Hundreds of pixels**
- **~ 1000 independent spectral elements per pixel**







Conclusions

- SPIRE is fully functional with performance matching or exceeding pre-launch estimates
- Current pipelines are already producing very high-quality data, and further improvements are being made
- Flux calibration is already very good and will be further improved
- Future work will concentrate on
  - Further improving pipeline products and calibration
  - Supporting observers