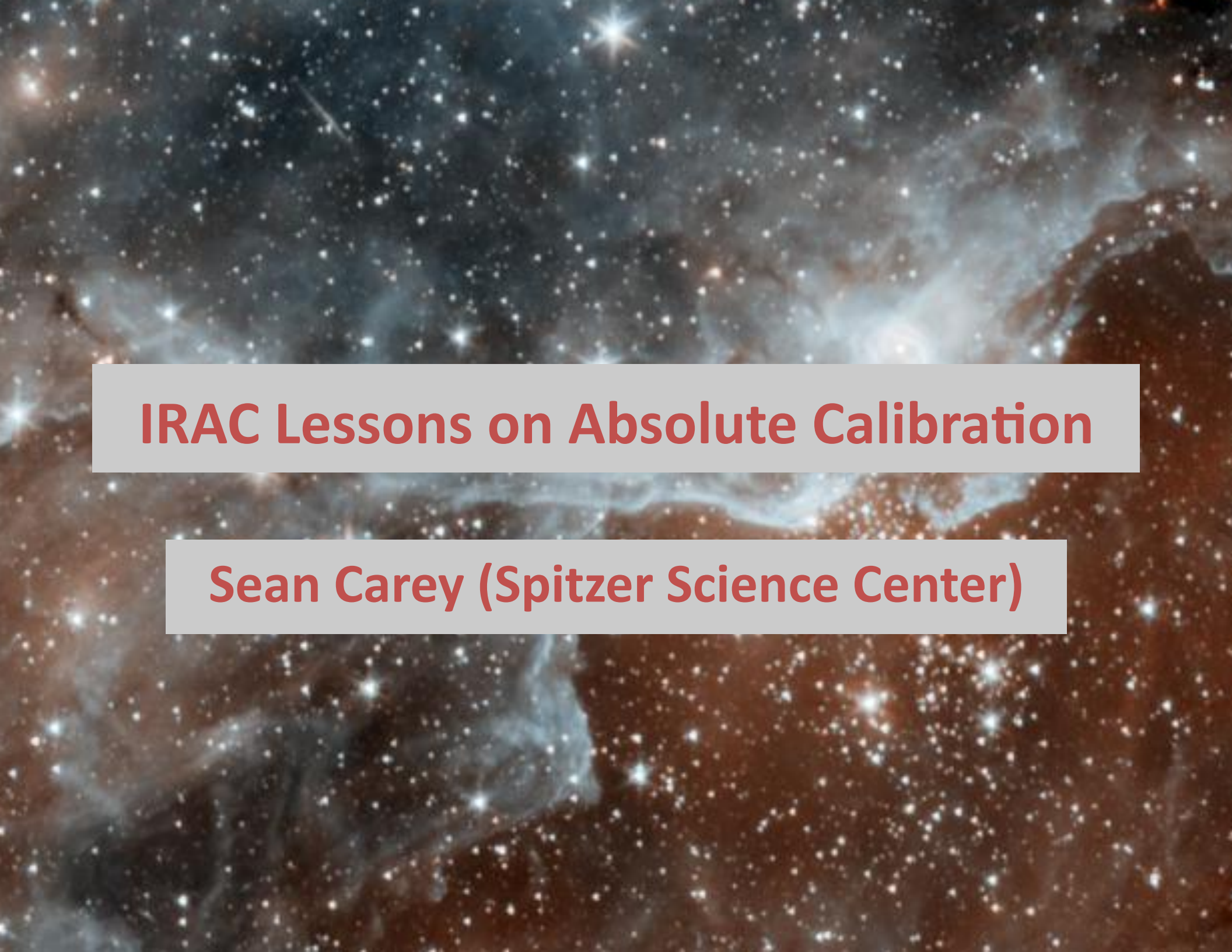

IRAC Lessons on Absolute Calibration

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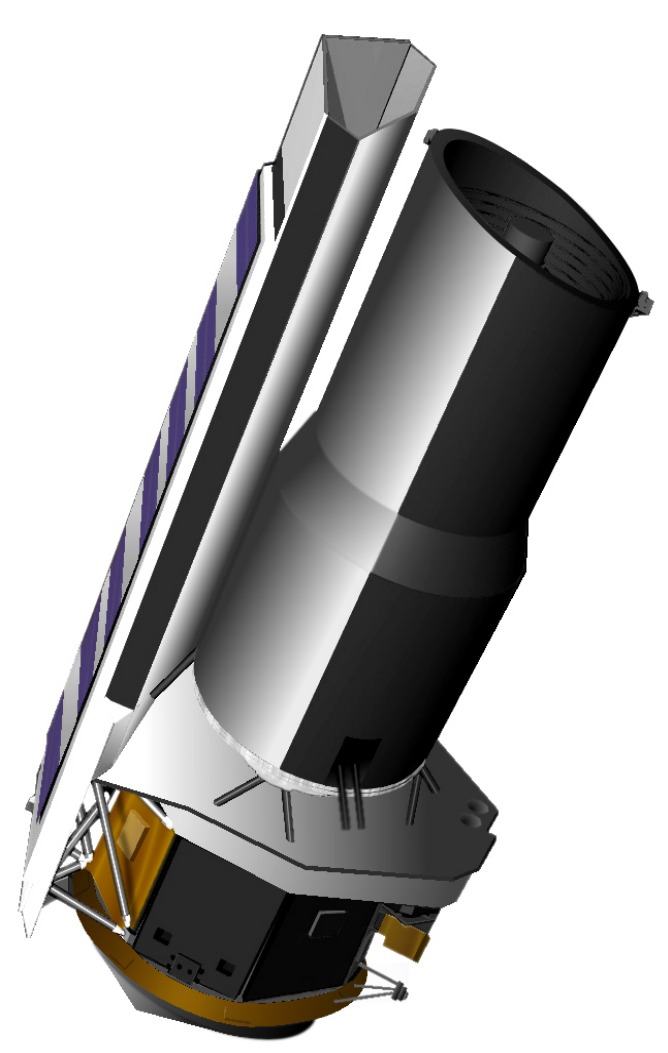
Introduction to Spitzer

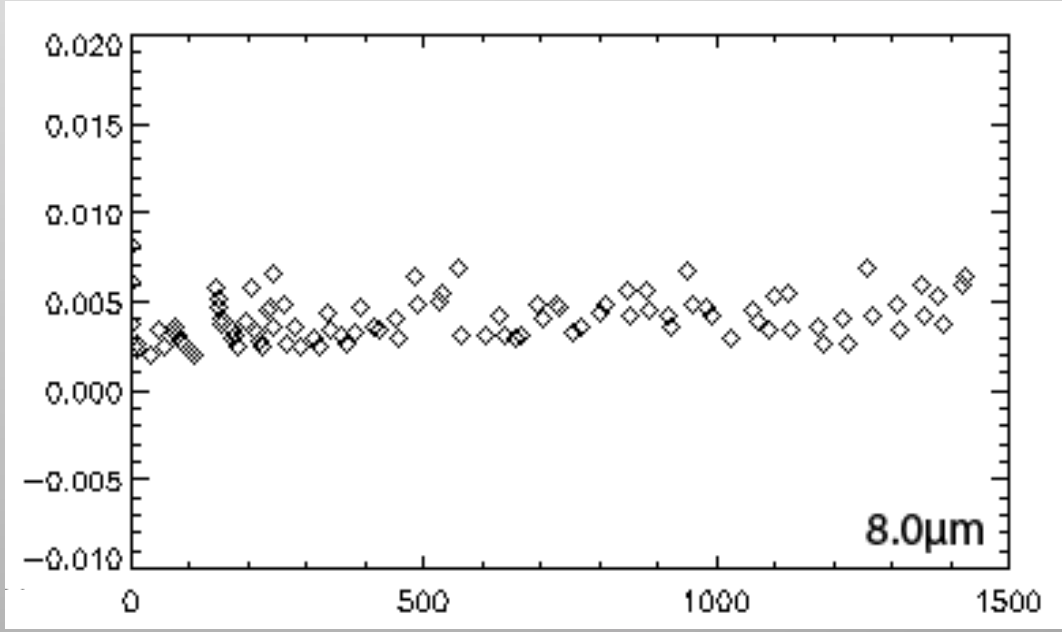
- Launched 25 August 2003
- 0.85m f/12 beryllium primary
- Diffraction limited at 5 μm
- Three science instruments
  - InfraRed Array Camera (IRAC) : mid-IR camera
  - Infrared Spectrometer (IRS): mid-IR spectrometry
  - MIPS: mid to far-IR imager/spectrometer
- Earth-trailing orbit
  - Currently more than 1 AU away
- Passive cooling to < 30K
- Active cooling of primary down to 5.5 K
- Cryogen exhausted May 2009 (>5 yr lifetime)
- Continues in warm mission mode



Basics of IRAC

- 4 arrays: 2 fields of view (3.6/5.8 μm), (4.5/8.0 μm)
  - 256 × 256 InSb and Si:As arrays
  - 1.22 arcsecond pixels (30 μm pitch)
  - IRAC InSb arrays are undersampled
- Sensitive but able to map large areas
  - 5 arcmin FOV
  - <1 e^-/s dark current
  - 20-8 e^- of read noise (Fowler-2)
  - 1-10 mJy sensitivity in 100s
  - 400 hrs to map 220 sq degrees of Galactic plane
- Exceptionally stable
  - **Thermally controlled to ~ 3mK**
  - Gain maps to < 0.4%
  - Photometry repeatable to < 1%

Average fractional uncertainty vs. time for individual flat-field



Days since initial power on

No Worries about Weather?

Solar flare (M1.7) precursor to CME that probably hit Spitzer yesterday

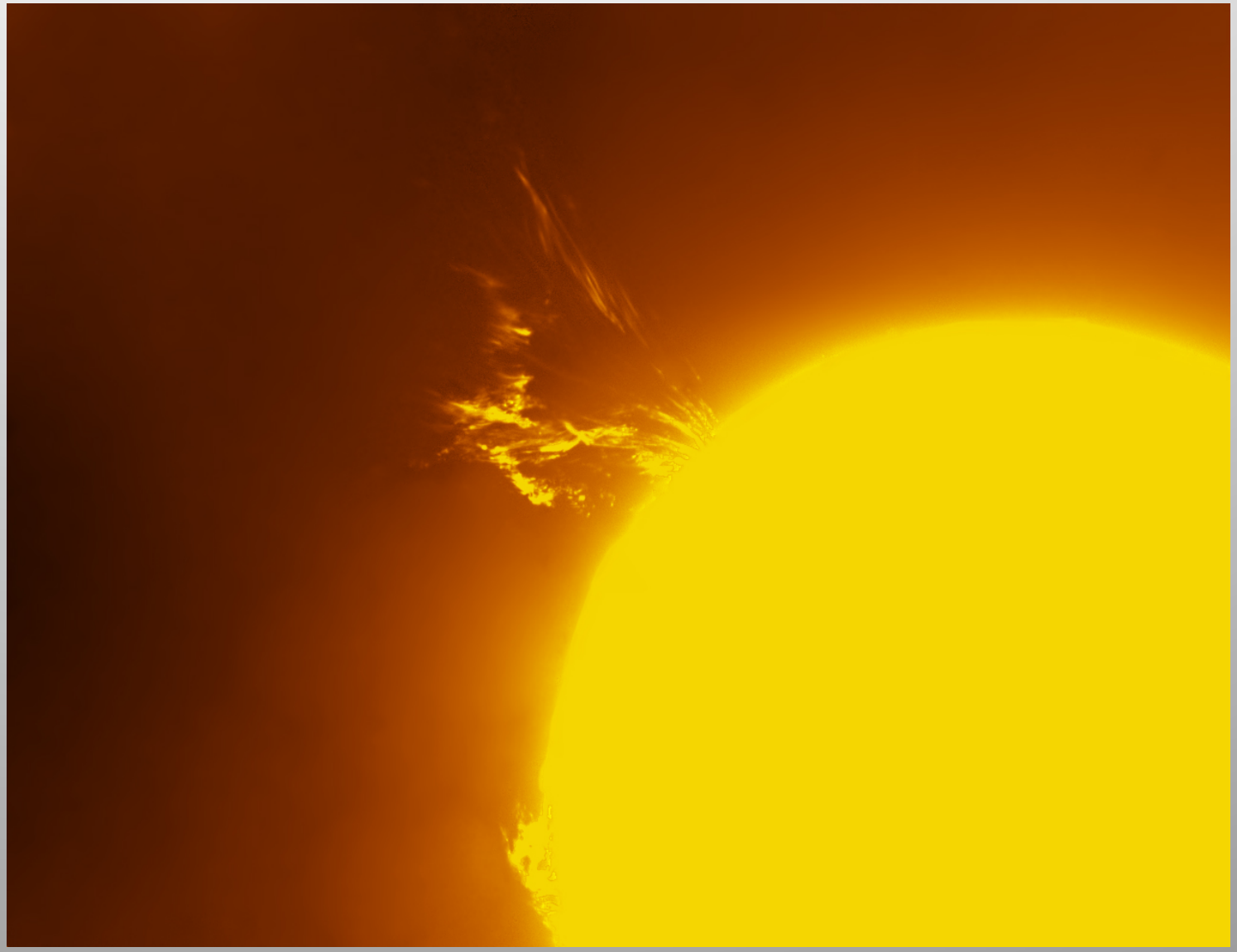
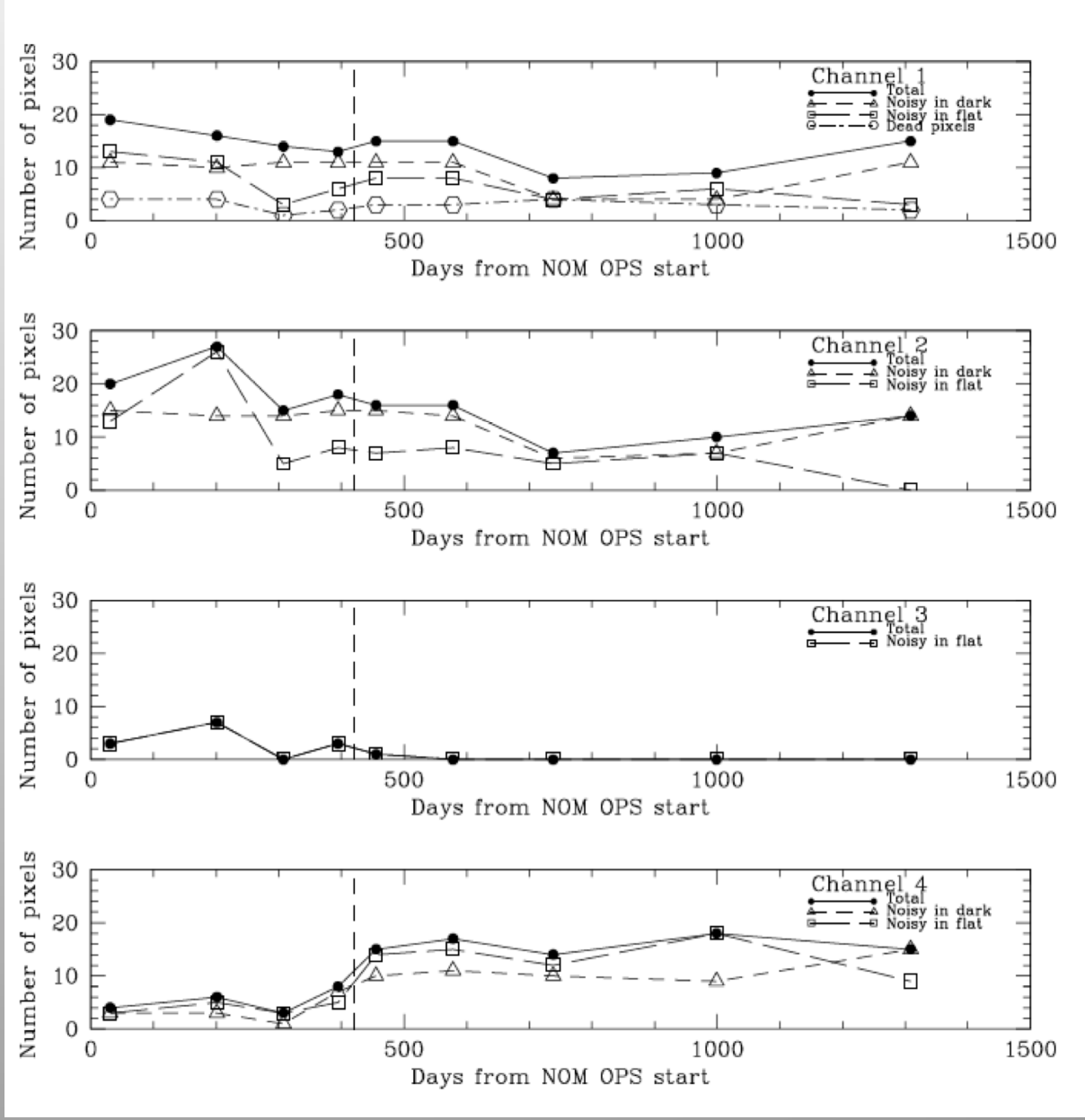


Image credit: Jim Lafferty

No Worries about Weather

IRAC array very stable even through several significant solar events (X class flares and associated CMEs)



Calibration Methodology

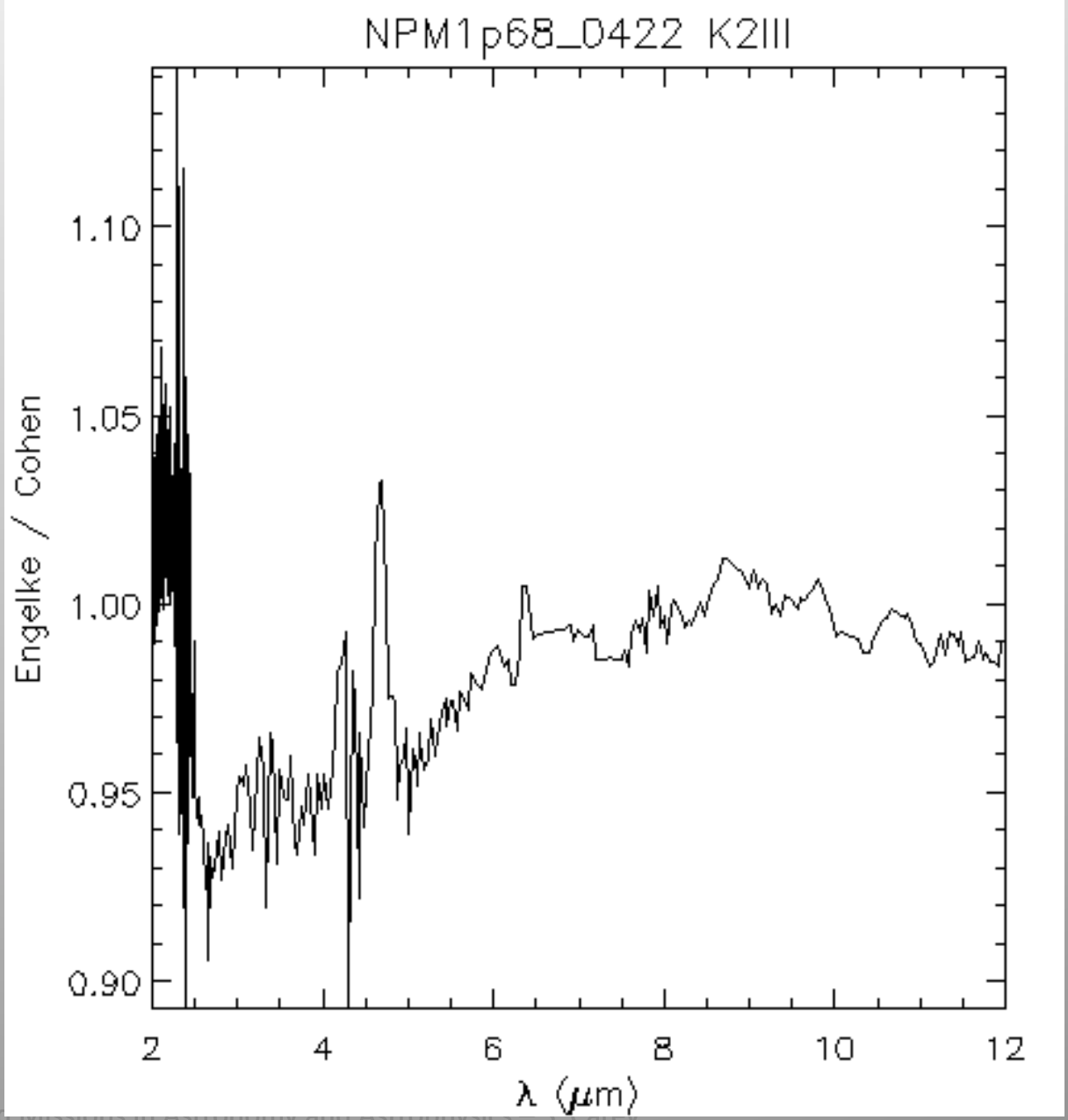
- Calibration factor (DN to Jy) determined by comparison of measurements to calibrated spectral templates

$$C = \overline{\left(\frac{F * K *}{DN_{obs}} \right)}$$

- F* = Flux density @ effective wavelength
- K* = Color correction assuming reference $F_\nu = F_{\nu 0} \times (\nu/\nu_0)^{-1}$
- Primary calibrators used
  - 4 A0V templates (Kurucz models + photometry; Cohen et al. 2003)
  - 5 K0-K2III templates (ISOSWS reduction + photometry from Engelke et al. 2006
- A0V templates use Vega model, KIII templates use Sirius/109 Vir template

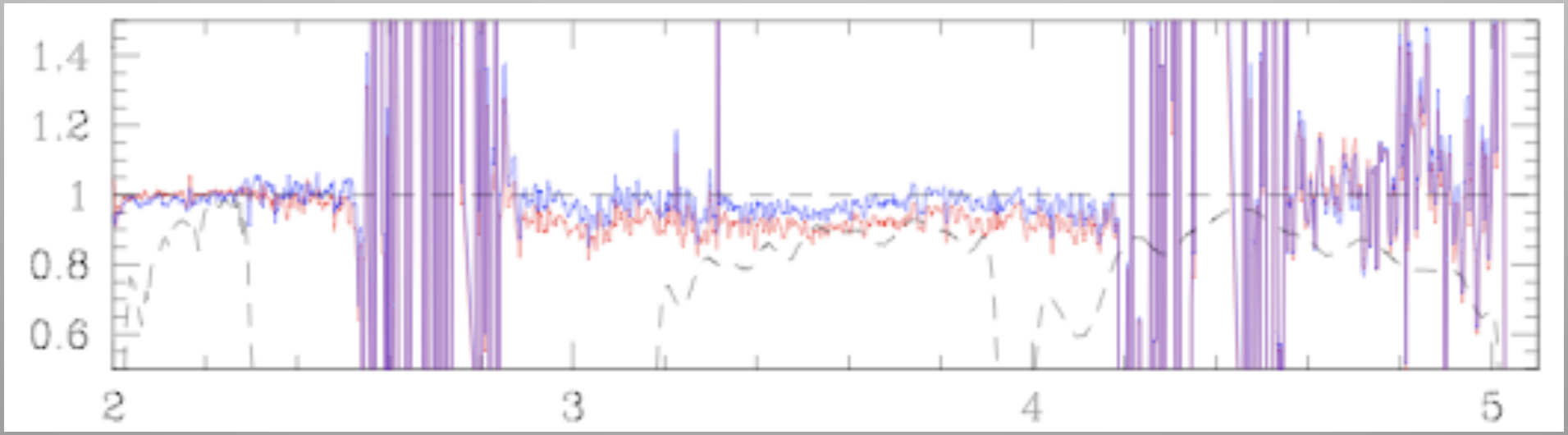
IRAC AV / KIII Calibration Offset

- In Reach et al. (2005) difference between Predicted/ Observed between AV and KIII calibrators was **7.3%**, **6.5%**, **3.6%** and **2.1%** for 3.6, 4.5, 5.8 and 8.0 μm
- Improved reduction of ISO spectra produced better templates



Engelke / Cohen Comparison

- IRTF SpecX data of NPM1p68.0422 (K2III) calibrator for IRAC
- Red is ratio of spectra / Cohen template
- Blue is ratio of spectra / Engelke template



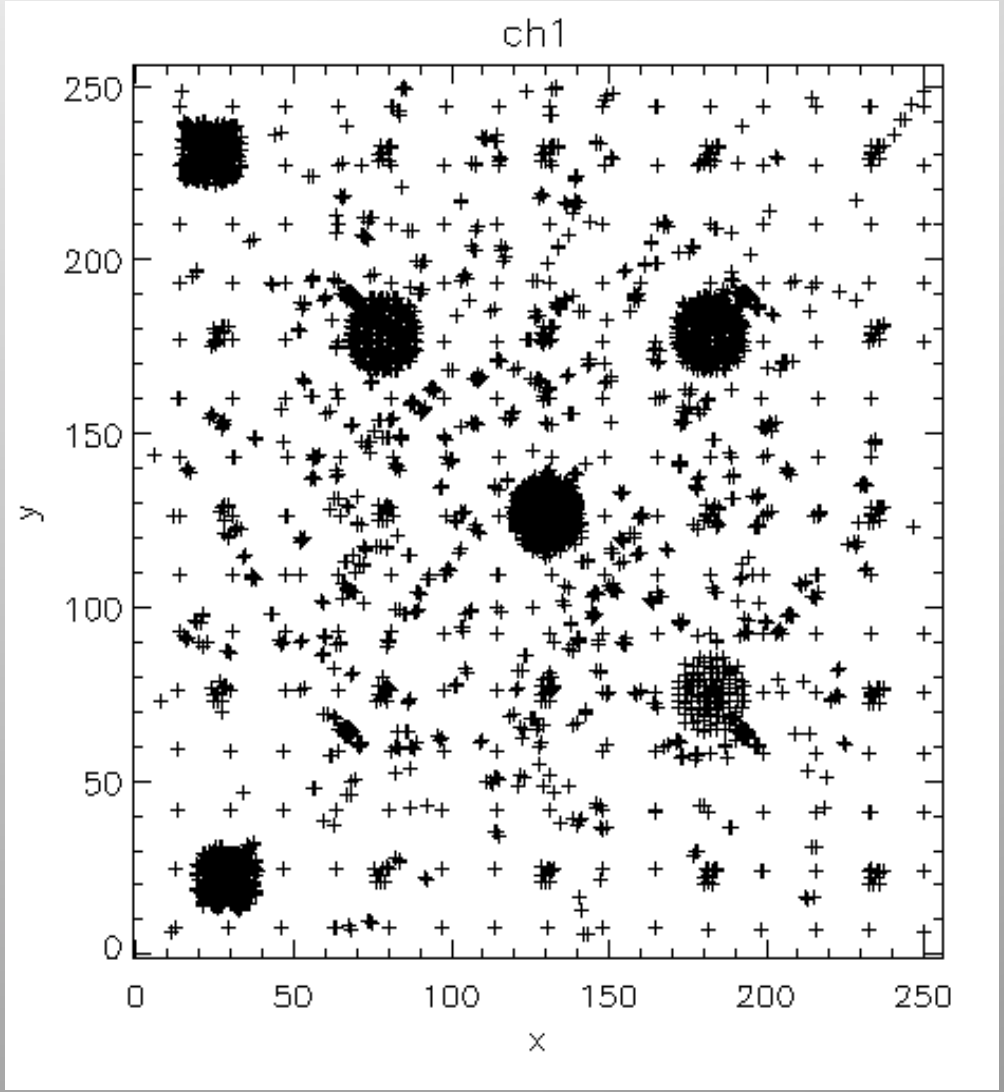
μm

Photometric Systematics and Absolute Calibration

- Use calibrators to solve for systematic variations
  - Array-wide
  - Intrapixel
- Solve both variations simultaneously with per-star flux conversion factor
- Correct photometry for systematics, then solve primary calibrator network for flux conversion factor
- Assume that measurement errors per star goes as $N_{obs}^{-0.5}$, $N_{obs} > 500$: this error effectively disappears
- Assume that error in flux conversion goes as $N_{star}^{-0.5}$, $N_{star} = 7$

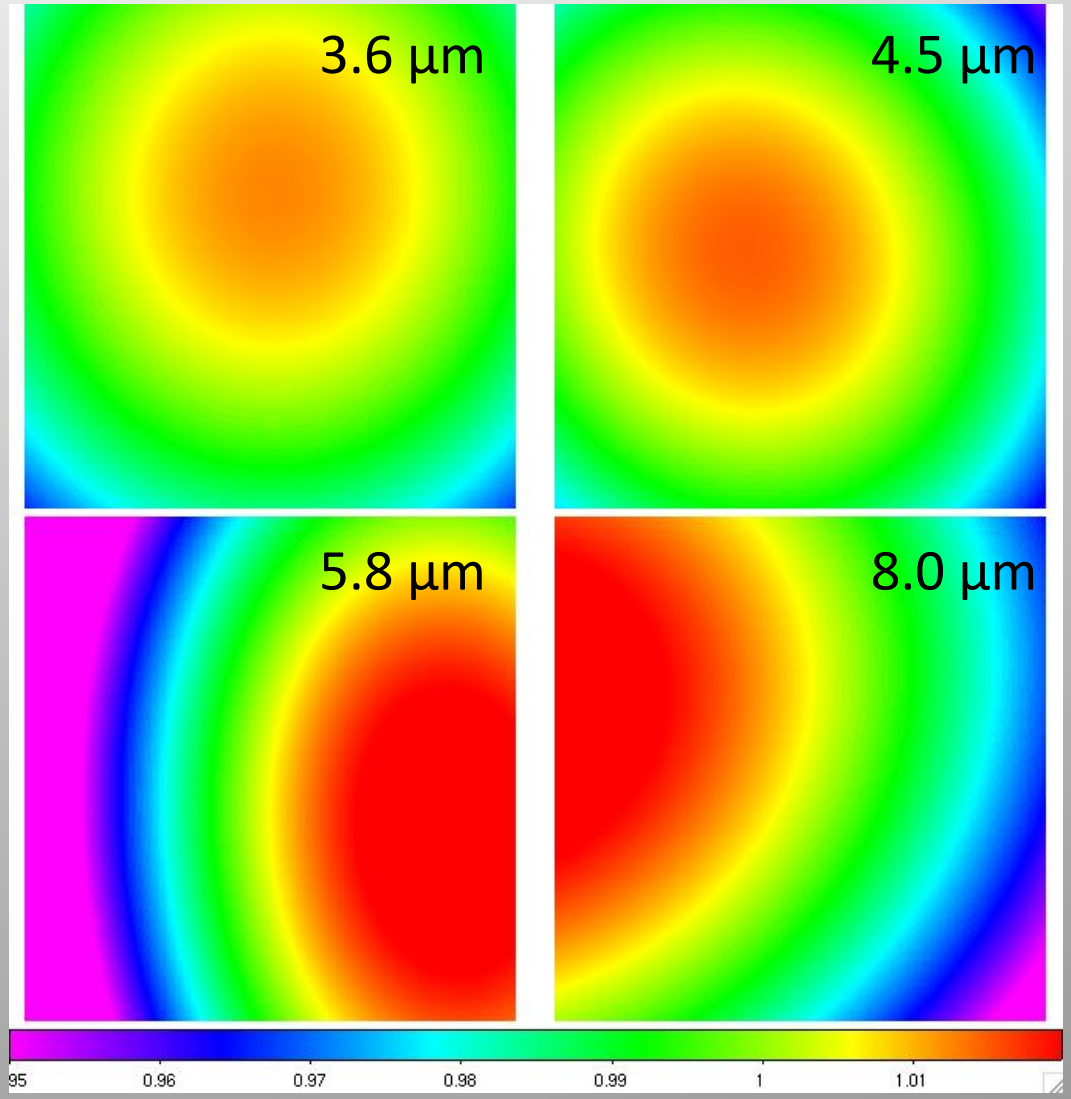
Mapping the Arrays

- Regular grid across array
- High density sampling for PRF
- Sparse random sampling to check for higher frequency structure
- Multiple phases on many pixels

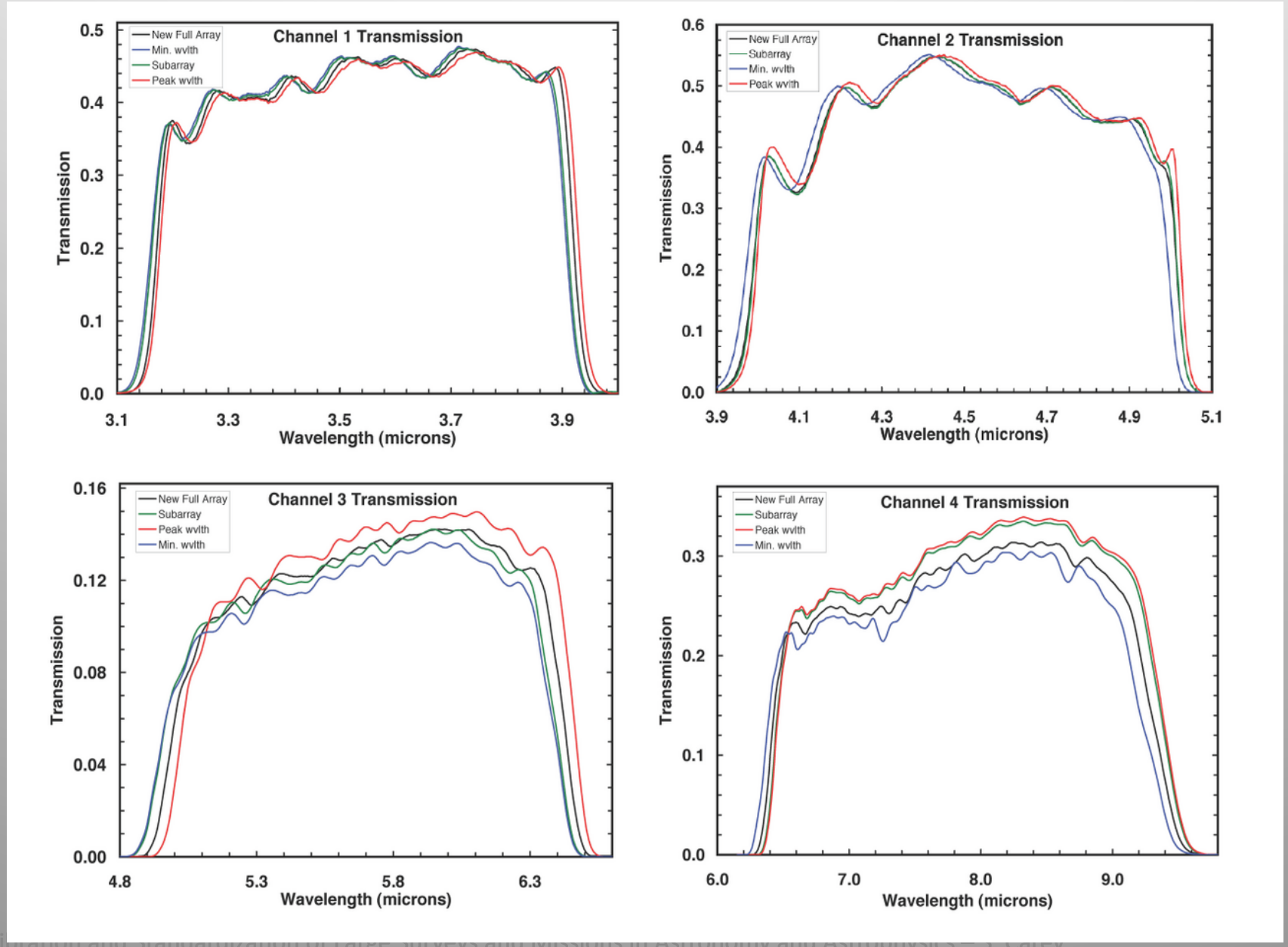


Array Location Dependent Correction

- Photometry varies due to change in filter bandpass as light is incident with different angles (paths) through filter
- 30° variation in angle for 5 arcmin FOV
- 10% effect across array
- Change in pixel solid angle ~1% effect
- Photometric variation for stars (R-J sources in IRAC bandpasses) is amplified due to use of Zodiacal light as flat-field

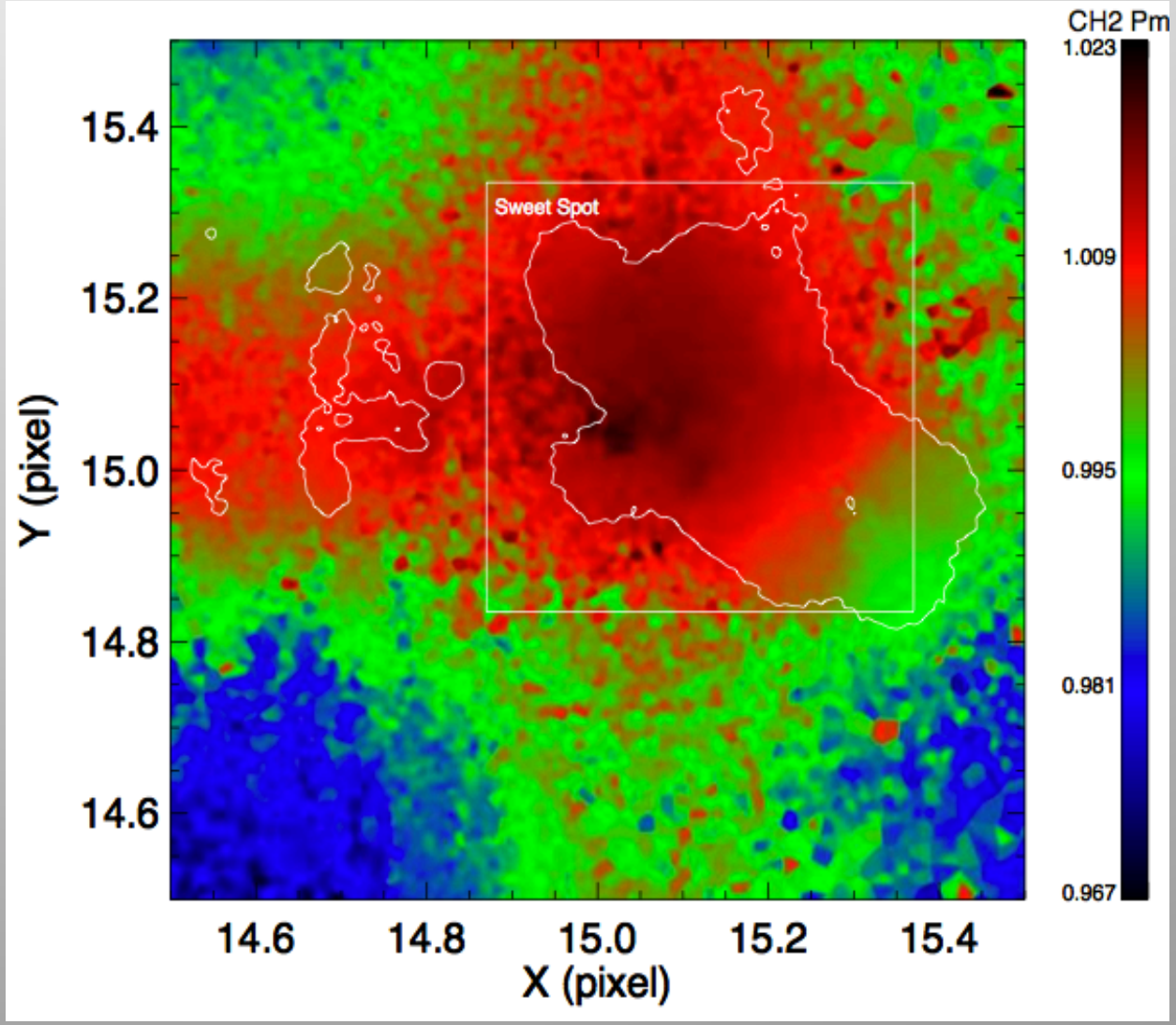


Array Location Dependent Correction

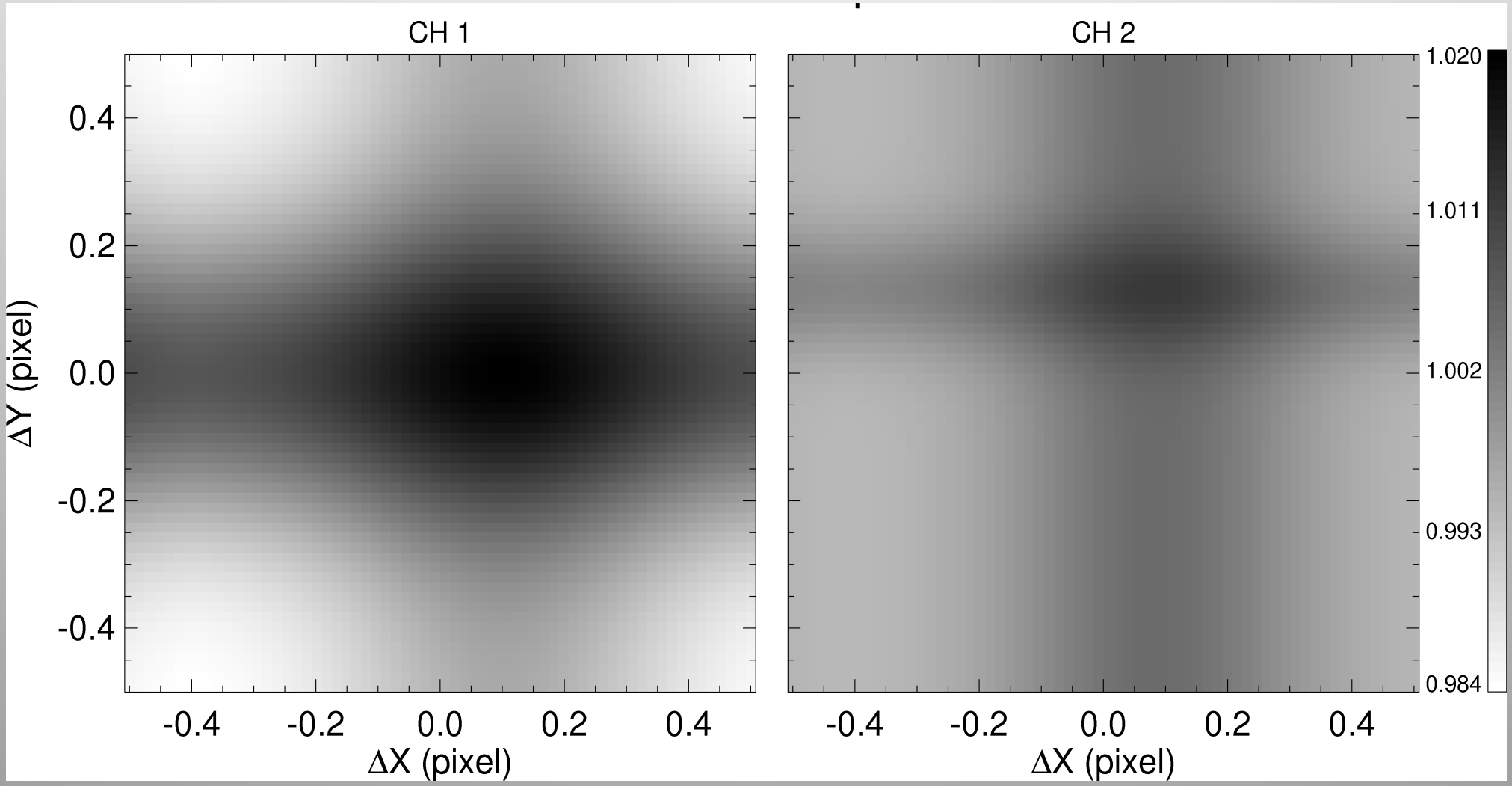


Intrapixel Photometric Variation

- Observed flux of source on InSb arrays depends on position relative to pixel center
- Function of variation in pixel gain and undersampling of PSF
  - 4% and <1% effect in cryogenic mission
  - 7% and 4% effect in warm mission
- Trending of intrapixel variation is limiting factor in exoplanet light curve precision
  - Best current precisions are 30-50 ppm

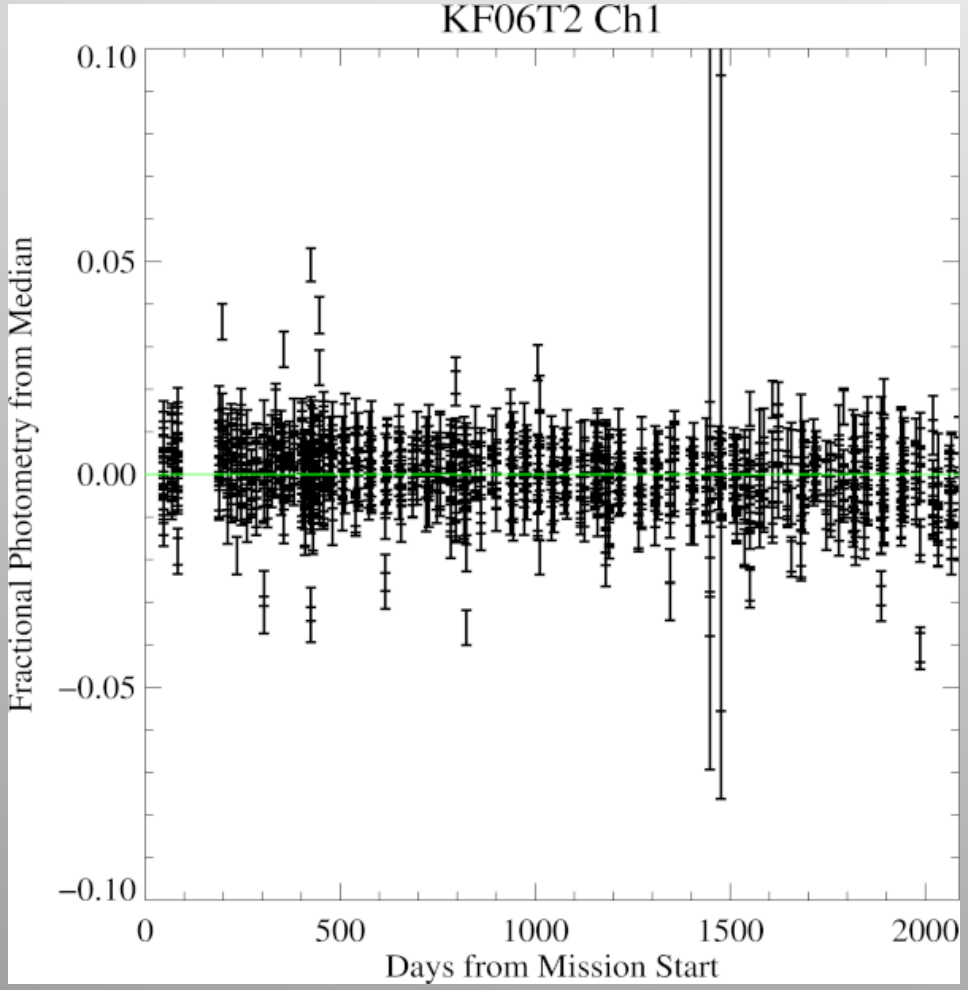


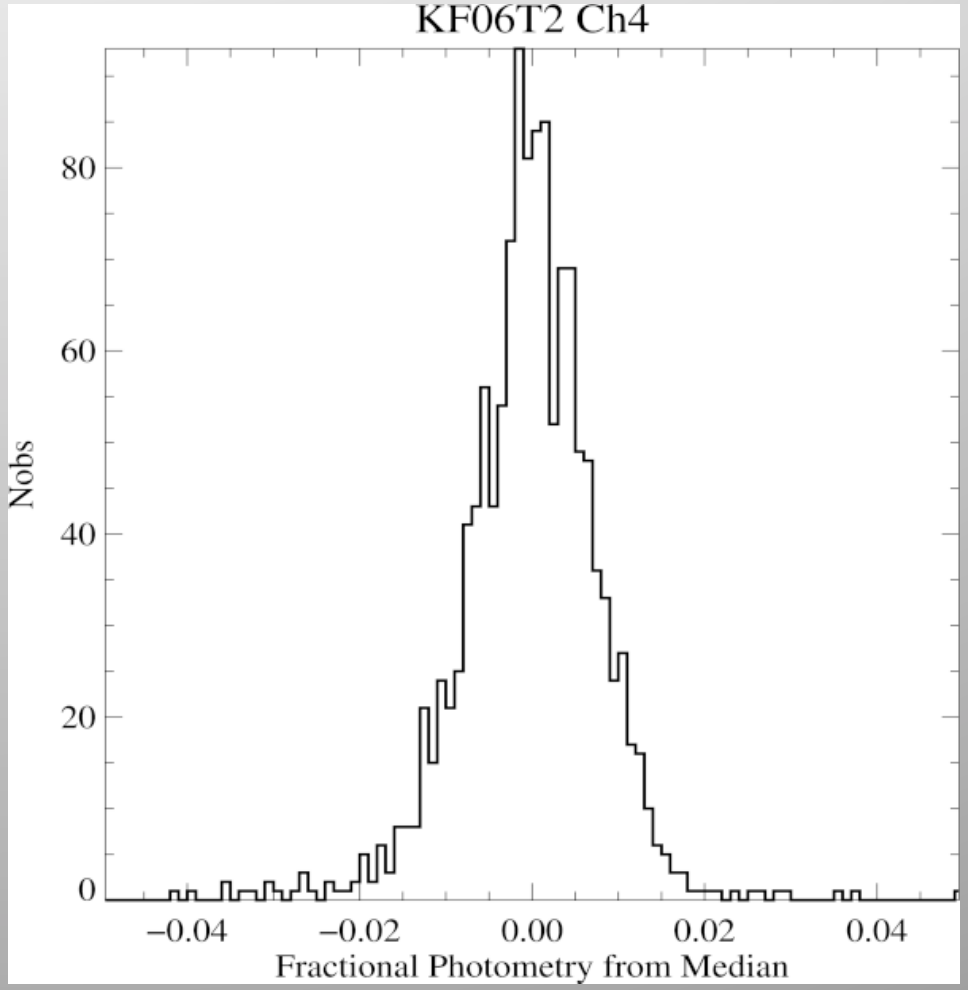
Cryogenic Intrapixel Response



- Two-dimensional pixel-phase functions

Photometric Stability





Accuracy of Photometric Calibration

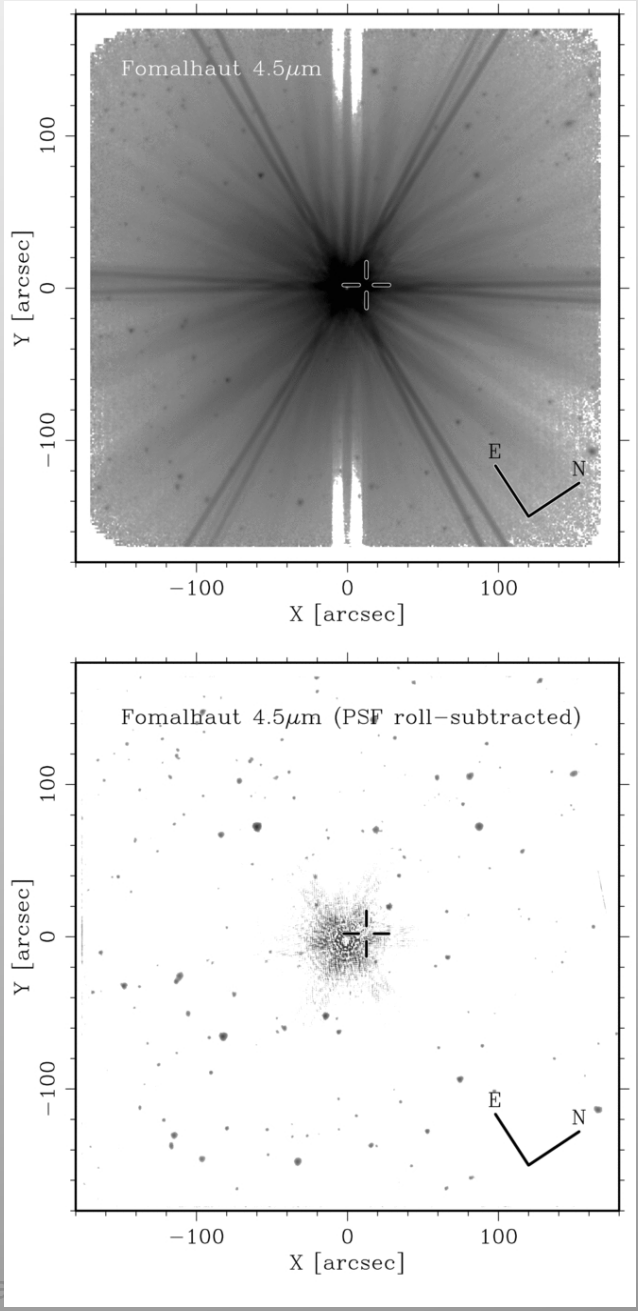
Band	σ_m	σ_{zero}	A-K bias	Calspec bias
3.6	0.6%	1.5%	-1.79%	0.4%
4.5	0.5%	1.5%	-1.25%	-0.3%
5.8	0.6%	1.5%	0.48%	-3.9% (-0.3%)
8.0	0.6%	1.5%	-1.39%	-1.2% (-0.7%)

σ_m: measurement uncertainty
σ_{zero}: assumed Vega uncertainty
A-K < 0 implies K star derived cal factor is lower
(): Calspec bias without WD measurements

- A/K discrepancy larger than uncertainty of average
- Calspec bias = measured - predict
  - WD measurements at 5.8 & 8.0 μm are problematic
- Rieke (2008) 8 μm bias +1.5%
- Differences between different calibration schemes at limit of their uncertainties
  - Systematics in zero point/ fundamental calibration not well understood

Future Work to Improve Absolute Calibration

- Observations of fundamental calibrators
  - Sirius
  - 109 Vir
  - Vega
- Photometry from wing fitting method of Marengo et al. (2009)
  - 1% photometry
- Tie to subarray using observations of η Corvi
- Zero magnitude template of Engelke et al. (2010)



Fomalhaut Subtraction Marengo et al. (2009)

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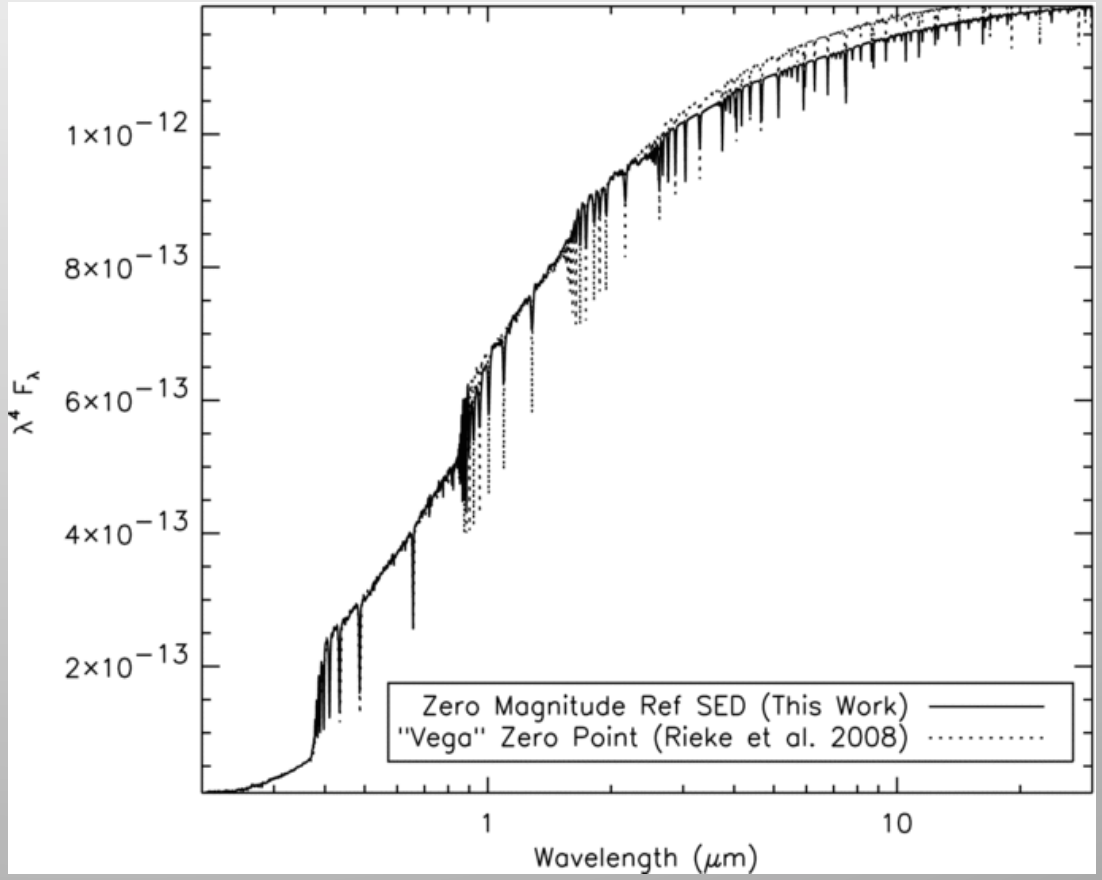

Zero Mag Reference of Engelke et al. (2010)

Spitzer Cycles 9-10 and Beyond

- Cycle 9 call to be released first week of May
  - Senior Review Panel recommended operating Spitzer through 2016, Spitzer funded through 2014
  - Exploration science (>500 hours) and large programs (>100 hours) solicited first, proposals due early August
  - Smaller proposals due towards end of October
  - Expect to take ~7800 hours of science/year
- Spitzer hardware will operate with no degradation beyond 2016
  - Decreased downlink rate (due to distance from Earth) is being offset with improved on-board data compression
  - Current engineering analysis suggests no issues through 2020
- Contact us (SSC) directly for calibration programs