Ideas and Suggestions about IRAC Exoplanet Observations

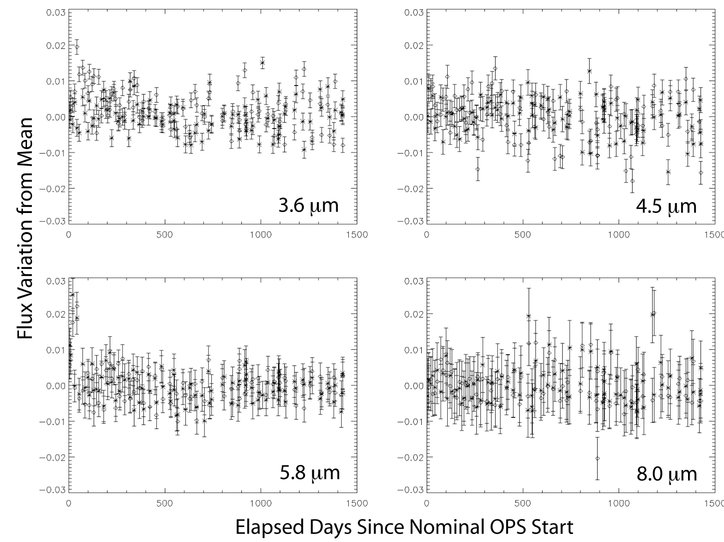
Sean Carey

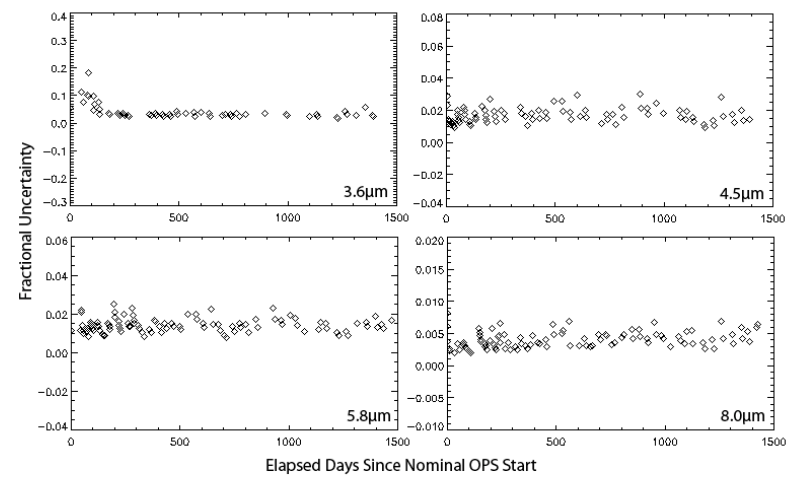
Outline

- Introduction to IRAC
  - *Warm IRAC (A peek at the data!)*
- The Basic Idea or how to get a lightcurve
  - *Centroiding*
  - *Flux measurement Aperture photometry*
- The Devil is in the Details or items to consider for photometry
  - *Pointing constraints*
  - *Pixel-phase effect*
  - *8.0 µm ramp "charge-trapping"*
  - *5.8 µm anti-ramp*
- Observation Planning for the Warm Mission
- Exercises for the Participants

Introduction to IRAC

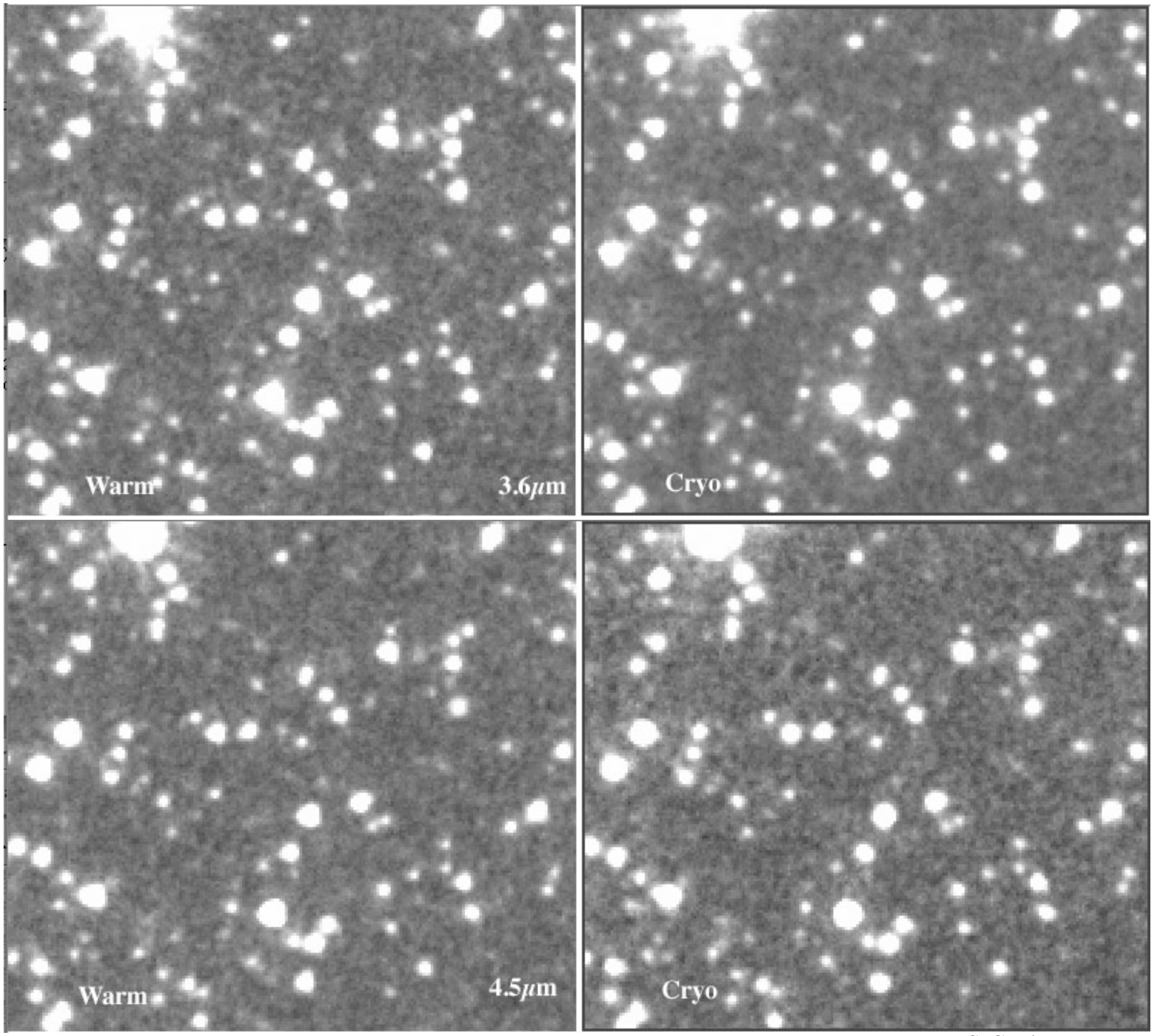
- 4 arrays: 2 fields of view (3.6/5.8 μm), (4.5/8.0 μm)
- IRAC arrays are undersampled
  - *Particularly 3.6 and 4.5 μm*
  - *Must use PRF for profile fitting*
  - *Best current PRF provides 1% photometry*
- Subarrays for high temporal sampling (one array at at time)
- Exceptionally stable
  - ***Thermally controlled to mK***
  - *Well beyond design specification*
  - *Gain maps to < 0.4%*
  - *Photometry repeatable to < 1%*
- Exoplanet observations in photon-limit
  - *Reach 75-80% of theoretical S/N*





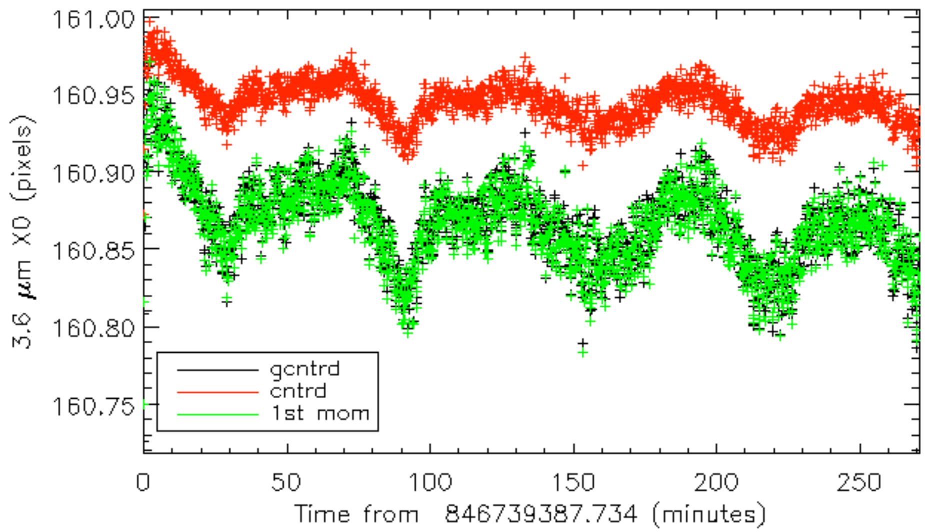
Warm IRAC

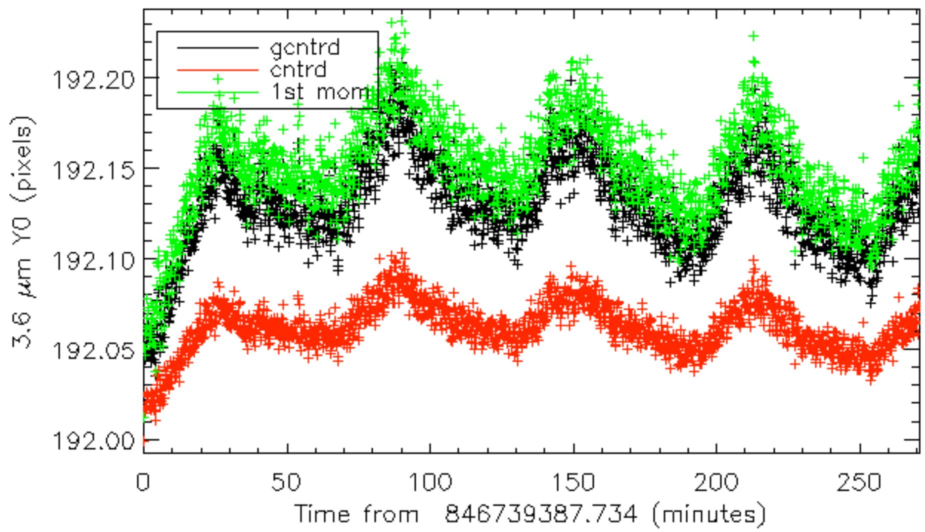
- 3.6 and 4.5 μm only
- Still in characterization phase
  - *Science observations in ~ week*
  - *Calibrations still being developed*
  - *Data to community in ~ month*
- Data looks good
  - *No muxbleed/muxstripe*
  - *Arrays fairly free of hot pixels*
- Small variation in PSF shape between warm and cryo in these images is due to the cryo data being averaged over three epochs



Centroiding and Lightcurves

- Need flux as a function of time
  - *Transits ⇒ Radius determination of planet*
  - *Temperature profile through long term monitoring ~70-100 hour limit imposed by spacecraft observations*
  - *Comparing IRAC passbands / MIPS / IRS ⇒ secondary eclipse ⇒atmospheric properties*
- Aperture photometry robust
- Care needed when optimal weighting
  - *σ^2 ~ Flux is not a good approximation*
- Profile fitting difficult
- Centroiding important and methods do vary
  - *IDL cntr not recommended for undersampled data*
  - *IDL gcntrd not a good model for IRAC PRF also contains bias*

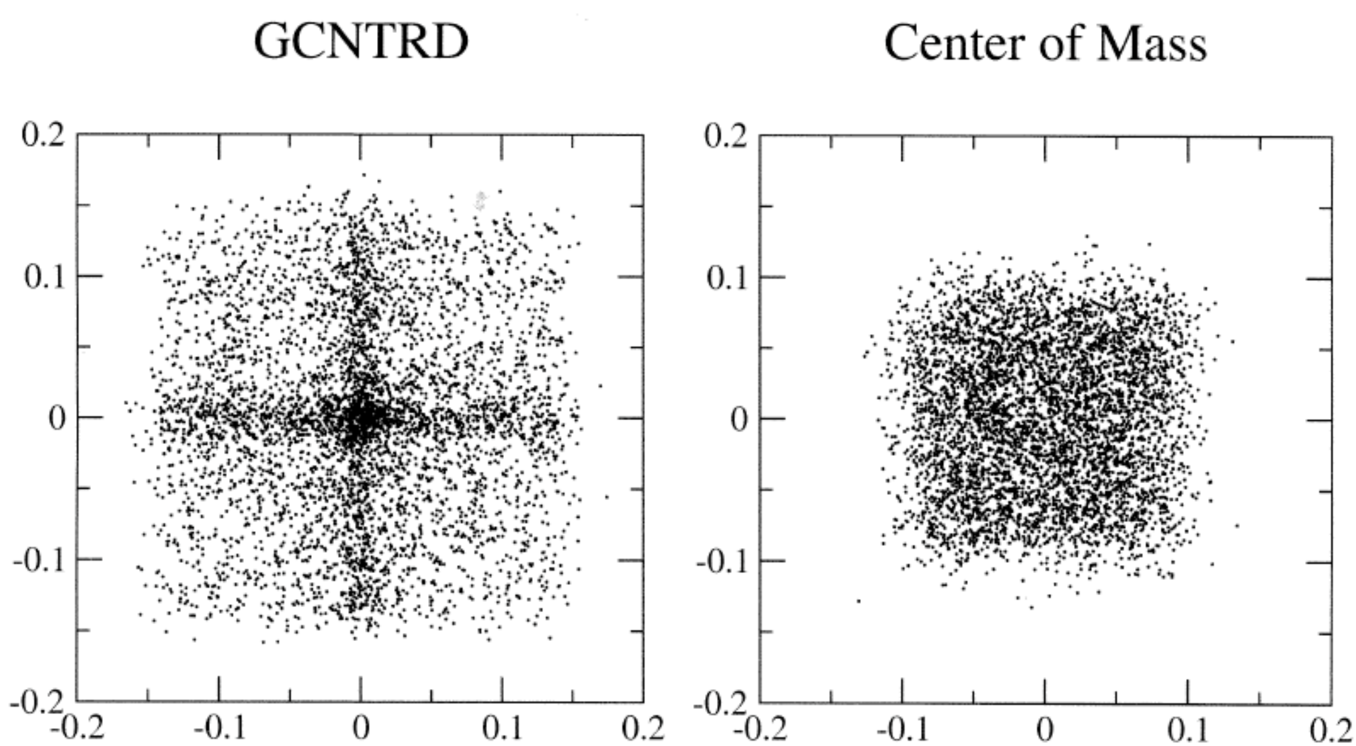




GCNTRD on Synthetic Undersampled Data

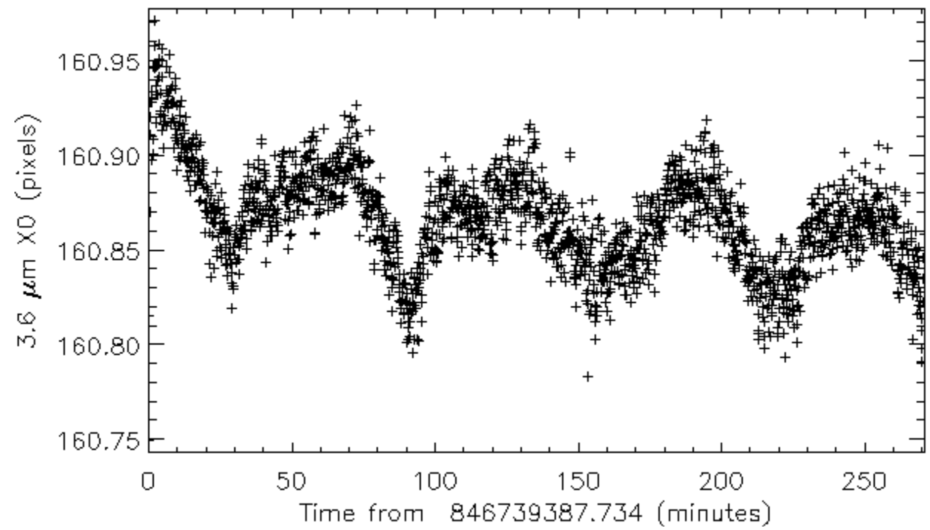
Centroiding accuracy test.

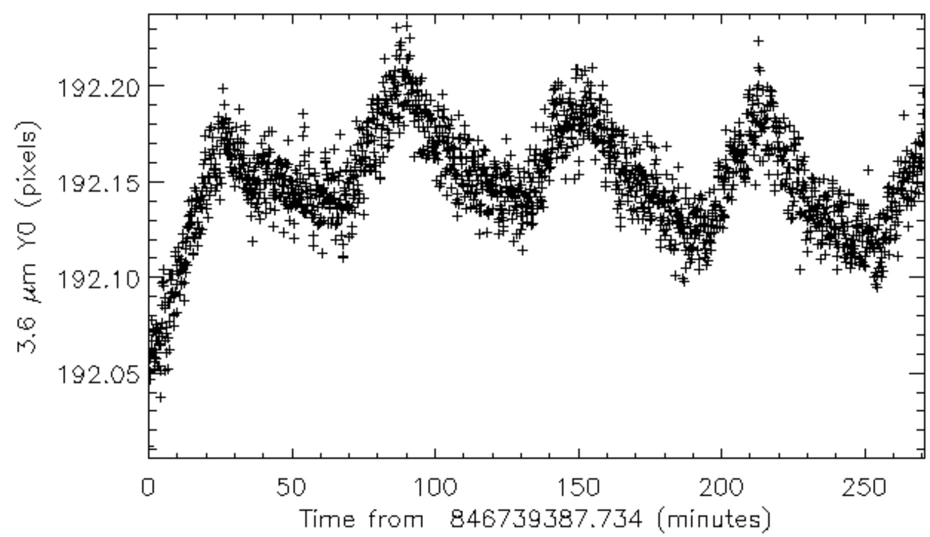
S/N~100 fake sources from GAUSS2D



Pointing Fluctuations Create Systematics

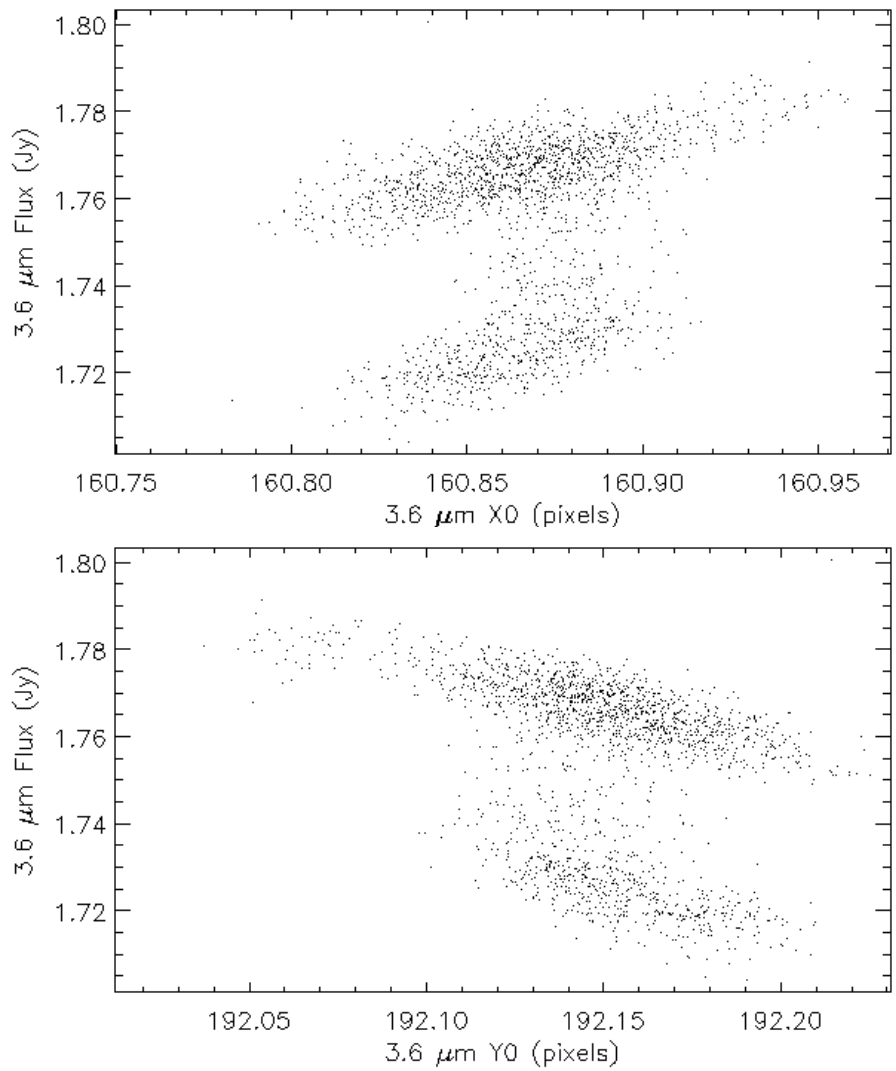
- IRAC observations are fundamentally limited by pointing stability not instrument stability
- All high precision photometric observations facilitated by staring (Morales-Calderón et al 2006)
- Spitzer exhibits a pointing wobble
  - *Period of ~3000 seconds*
  - *Amplitude of ~0.1 arcsecond*
  - *Expansion of startracker to boresight path due to heating*
- Smaller linear pointing drift ~10 μas / s
  - *Will cause source to move off pixel for long duration (10-100 hour) observations*
- Pointing jitter as well ~0.1 arcsecond
  - *Jitter power at all measured frequencies*
- **Pointing system accuracy and stability far exceed requirements**





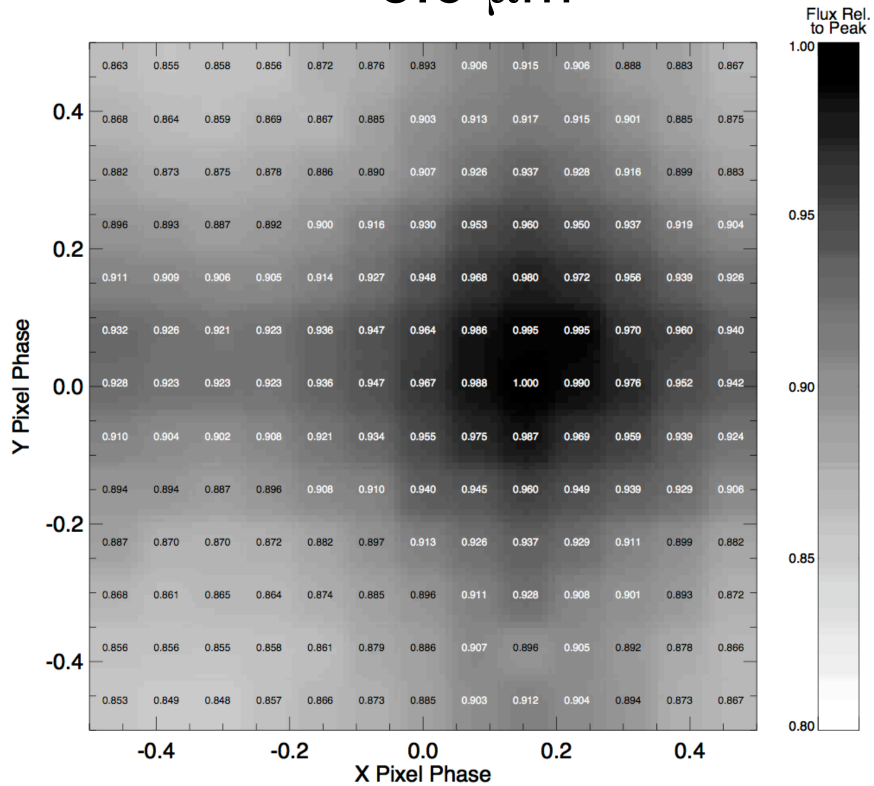
Pixel Phase Effect

- Variation in photometry as a function of source position relative to center of a pixel
  - *Reduced responsivity/ dead spots at pixel edge*
  - *Common to InSb and HgCdTe detectors*
  - *More significant for undersampled arrays*
- ~4% variation in 3.6 μm photometry
- ~1% variation in 4.5 μm photometry
- Appears to vary from pixel to pixel
- Best practice is trend from data
  - *Usually have to fit transit/eclipse simultaneously to have enough data*
  - *A functional form in both Δx, Δy gives best results (e.g. Désert et al. 2009)*
  - *No clear functional form to use, let the data be your guide*

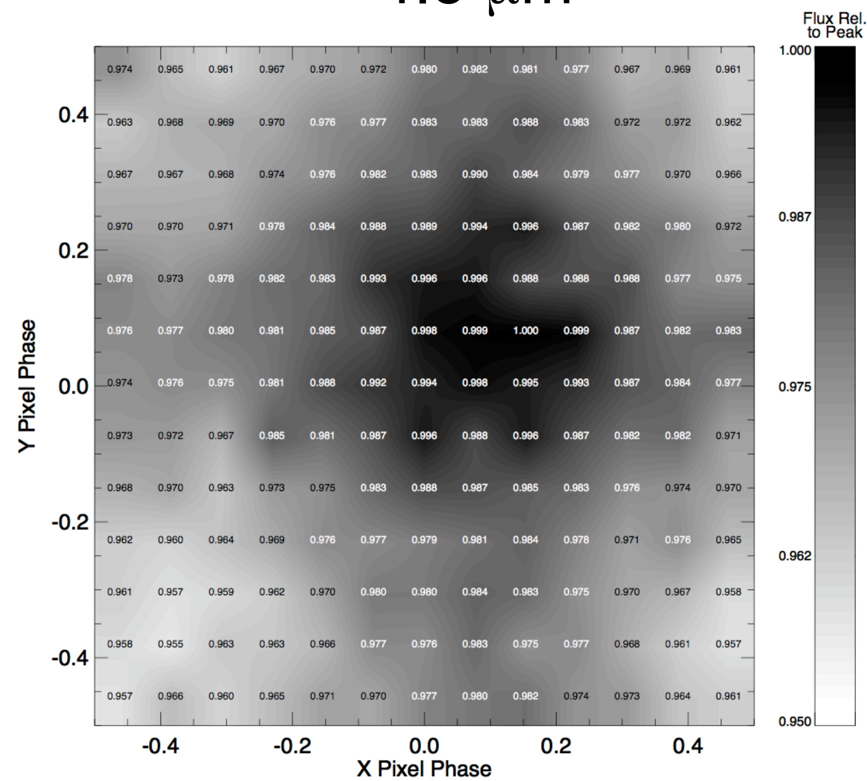


Warm Spitzer Pixel Phase Measurements

3.6 μm



4.5 μm



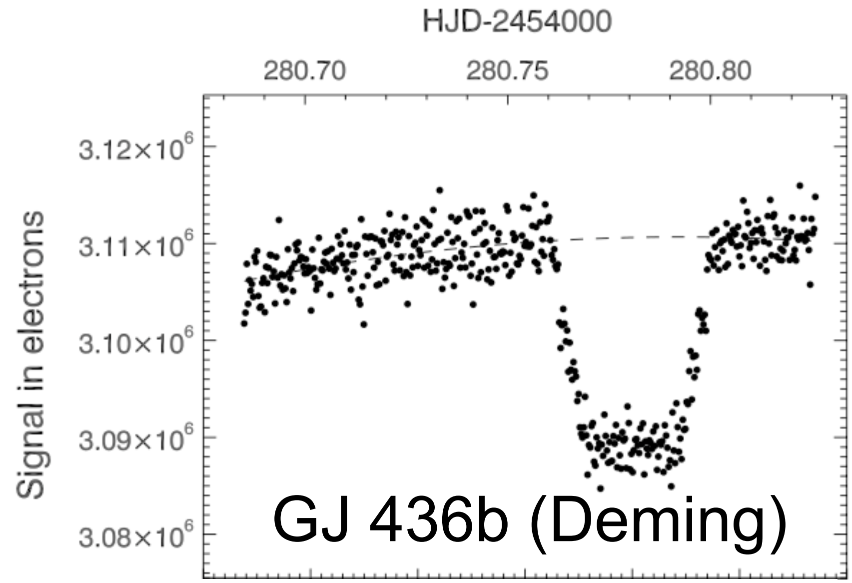
Pixel phase is still present and is being mapped. The effect may be more significant but this analysis is preliminary and uses a rapidly reduced linearity correction.

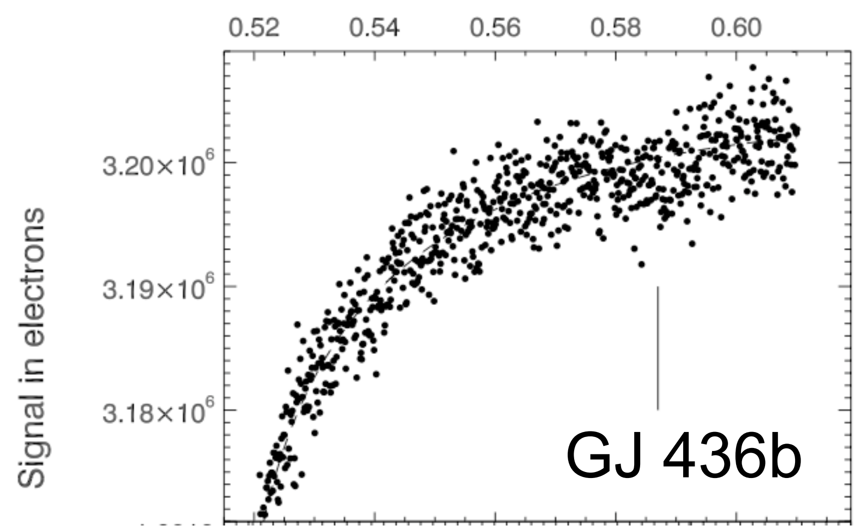
8.0 μm Ramp – "Charge Trapping"

- Change in effective gain for 8.0 μm staring observations
  - *Removal of traps in detector material which capture photons thereby reducing measured flux*
  - *Traps are long-lived and cross-section is small ⇒ not seen in normal observations*
  - *Related to but different from long term residual images at 8 μm*
- Number of traps dependent on previous observation history
- Can mitigate ramp by removing traps prior to observation ⇒ pre-flash
  - *> 2000 MJy/sr extended blob for 30 minutes*
- Gain change (G) should have functional form of

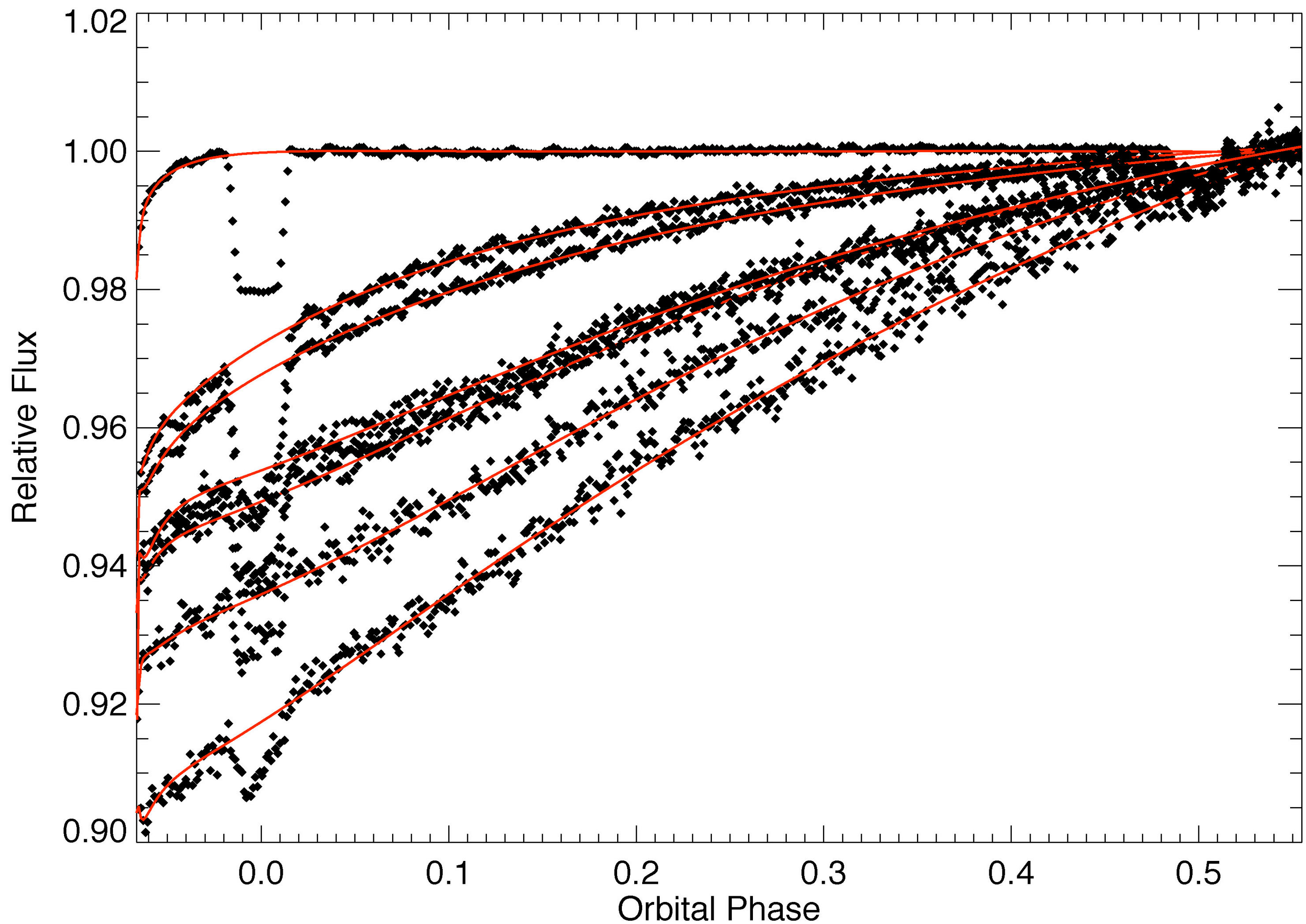
$$G = (N_0 - N_{pre})(1 - e^{-CF})$$

where N is number of traps, F flux of star, and C has all the physics
  - *Best to correct on pixel by pixel basis*
  - *Linear for low flux values*



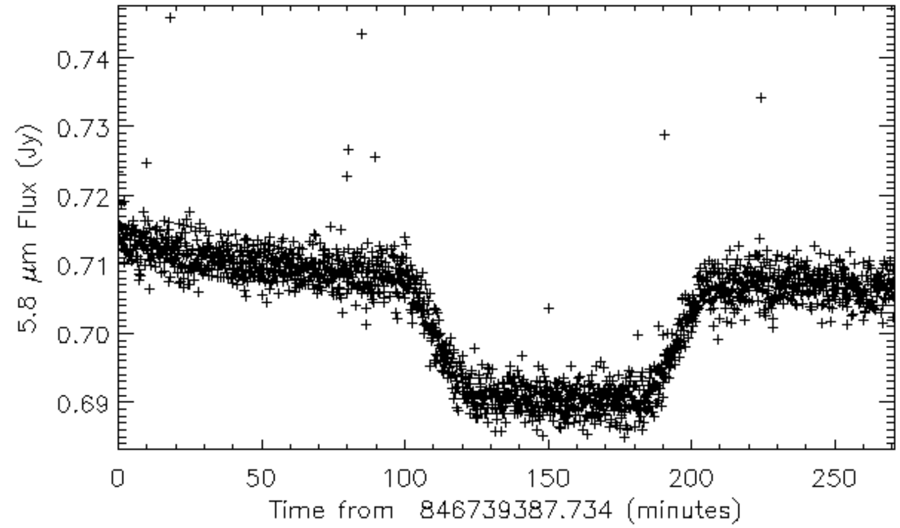


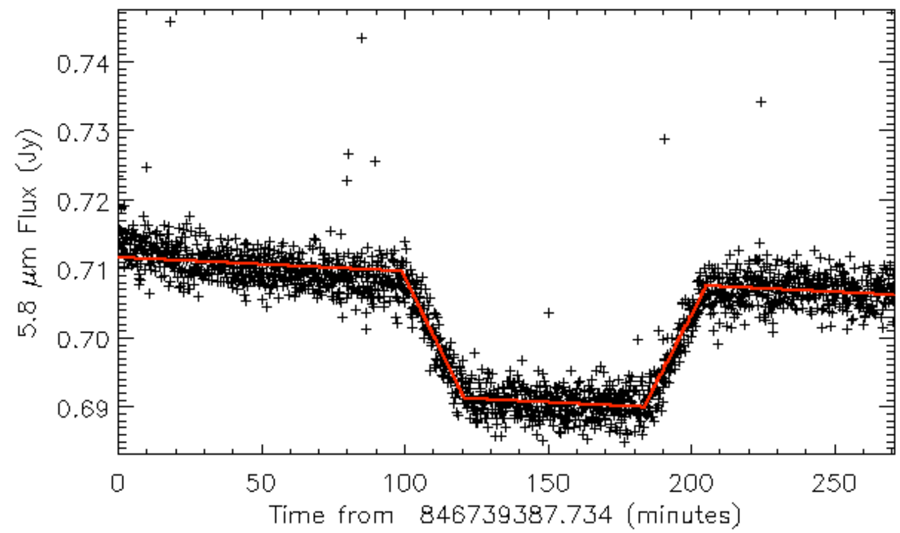
Correction for HD 189733b
(Knutson et al 2008)

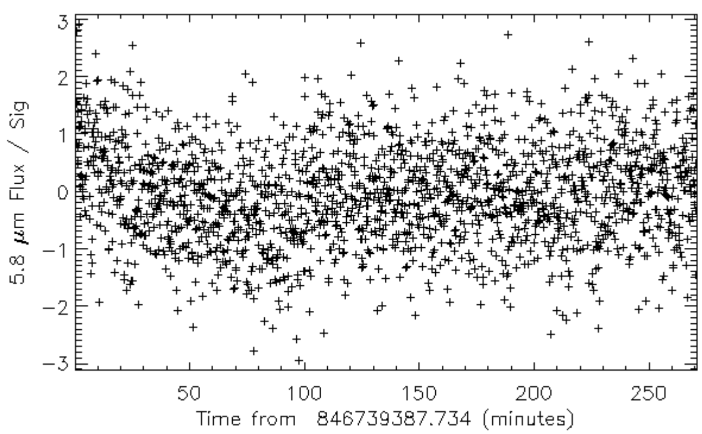


5.8 µm Anti-Ramp

- Decrease in effective signal at 5.8 µm
  - *Cannot be charge trapping*
  - *Probably a persistence effect in the readout multiplexers*
  - *No physical model exists*
  - *Less analysis done as 5.8 µm data taken later*
- Need to trend using data
  - *Be careful not to overfit effect*
  - *But do look for weak trends*
- Appears to be a thresholding behavior
  - *Do not see anti-ramp at low flux levels*







Warm Mission Observation Planning

- Same strategy as cryo exoplanets
  - *Maximize S/N by using longest frametime that does not saturate*
  - *Offset source by ½ pixel if close to saturation for available frametimes*
- Upgrades to Consider
  - *Take data only in prime field-of-view*
  - *Use 2 second subarray for higher throughput*
  - *Place target on photometric pixels (currently in definition)*
- Performance should be very similar to Cryogenic mission
  - *But more time for observations with IRAC*
  - *And more experience reducing data*

Exercises for the Audience

- Cryogenic data
  - *Reduce all data sets uniformly*
  - *Consider transit/eclipse timing*
  - *Generate pixel-phase map using existing data*
- Post-cryo observations
  - *How low can you go? Will S/N go as time$^{0.5}$?*
  - *Is intrinsic planet/stellar variability or instrument systematics the limiting factor*
  - *How about residual flat-field errors, it's there, but hasn't impacted data as yet*