Introduction to HST Photometry

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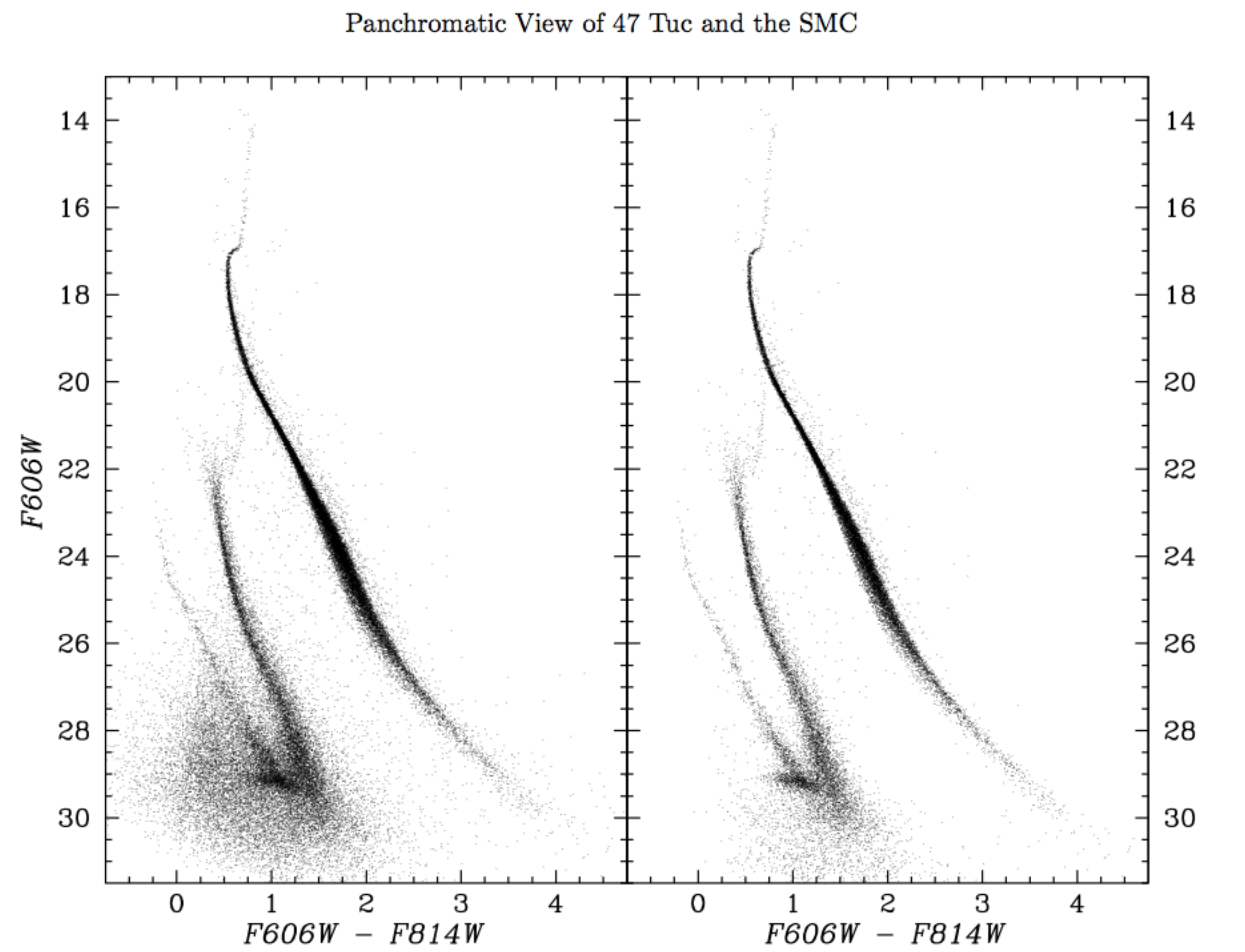


Kalirai et al. (2012, AJ, 143, 11K)

HST photometry

- Converting from counts to flux
- HST photometric systems
- Aperture photometry
- PSF variations & aperture corrections
- Charge transfer efficiency

Converting counts to Flux or Mag

- **Calibrated** HST data in various units:
  - WFPC2 and STIS imaging = DN
  - NICMOS = DN/second
  - ACS = electrons
  - WFC3/UVIS = electrons
  - WFC3/IR = electrons/second
- **Drizzled** data = ‘counts’ per second
  - ** Counts may refer to DNs or electrons per second depending on instrument

Converting counts to Flux or Mag

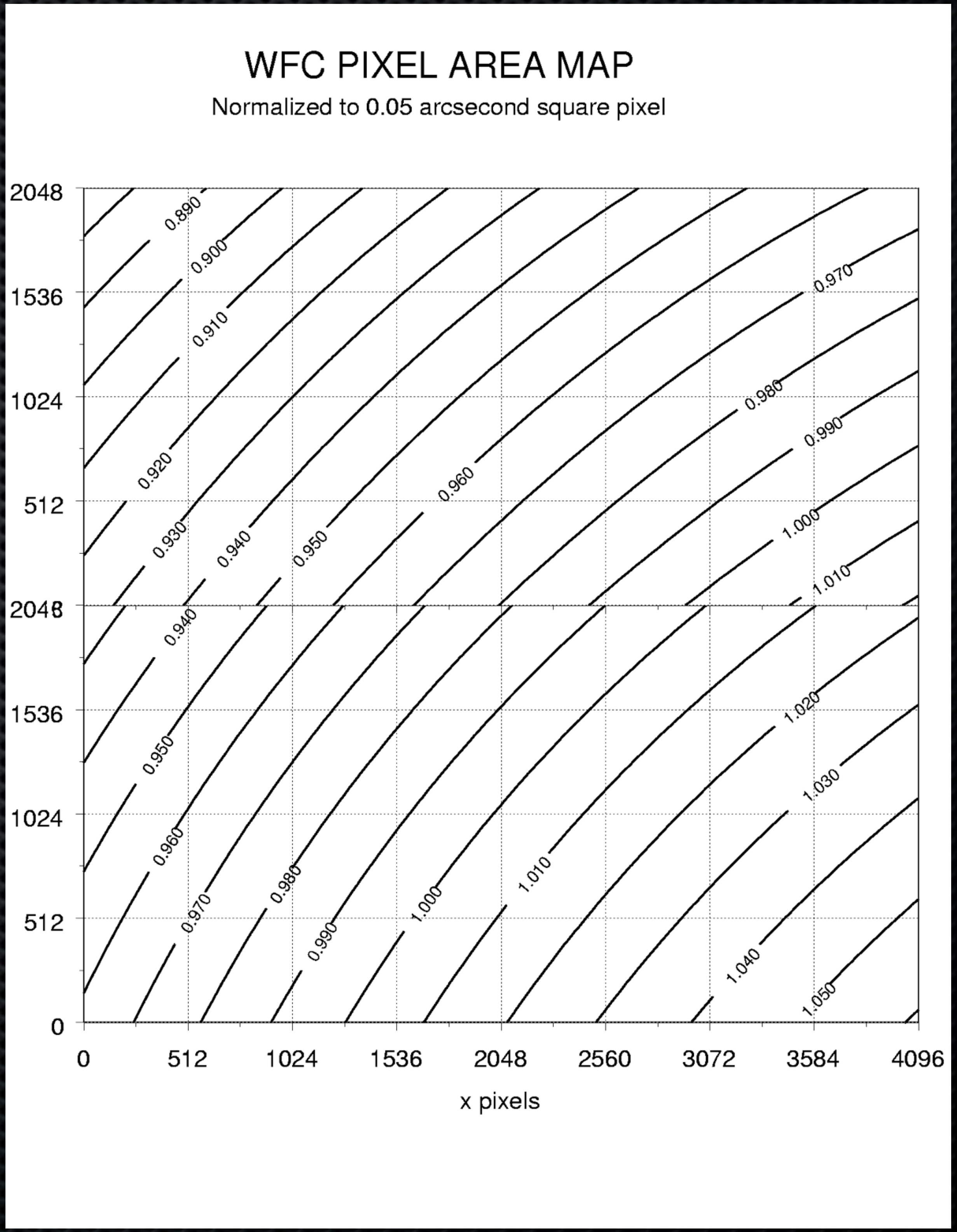
- CALxxx pipelines calculate and write the sensitivity conversion factor (PHOTFLAM) and the ST magnitude scale zero point (PHOTZPT) into header keywords in the calibrated data.
- PHOTFLAM is defined as the *mean* flux density *Flam* in units of erg cm^{-2} s^{-1} A^{-1} that produces 1 count per second in the HST observing mode.
- Calibrated images (in ‘counts’) may be converted to flux (erg cm^{-2} s^{-1} A^{-1}) by multiplying the image by the PHOTFLAM header keyword and dividing by the EXPTIME keyword

Photometry: FLT or DRZ

- ACS zeropoints refer to the drizzled pipeline products (_drz.fits files) which are corrected for geometric distortion
- To perform photometry using distorted (non-drizzled calibrated images), the pixel area maps must be applied

  DRZ_flux = FLT_flux * PAM / exposure time

- DRZ images in cps must be multiplied by EXPTIME and include the background sky or phot errors will be wrong



Photometric Systems

- **VEGAmag** : Standard magnitude system for which Vega has magnitude 0 at all wavelengths
- **STmag** : Magnitude system based on constant flux per unit wavelength (reference spectrum is flat in F_lam)
- **ABmag** : Magnitude system based on constant flux per unit frequency (reference spectrum is flat in F_nu)

The zero points for the last two are set so that Vega has magnitude 0 in both systems for the Johnson V band

Photometric Systems

- Photometric keywords in the image header:
  - PHOTMODE : Observation configuration for photometric calibration
  - PHOTFLAM : Inverse sensitivity (erg cm^{-2} s^{-1} A^{-1})
  - PHOTZPT : ST magnitude zeropoint (=-21.1)
  - PHOTPLAM : Pivot wavelength
  - PHOTBW : RMS bandwidth of filter plus detector
- The header keywords PHOTFLAM and PHOTPLAM relate the STMAG and ABMAG zero points through the formulae:
  - STMAG_ZEROPOINT = -2.5 log (PHOTFLAM) + PHOTZPT

    = -2.5 log (PHOTFLAM) - 21.1
  - ABMAG_ZEROPOINT = -2.5 log (PHOTFLAM) - 21.1 - 5 log (PHOTPLAM) + 18.6921

From aperture photometry to absolute magnitudes

$$\text{STMAG} = -2.5 \log(\text{counts}/\text{exptime}) + [\text{photzpt} - 2.5 \log(\text{photflam})] - \text{ac05} - \text{AC05} - \text{CTE}$$

where:

zpt = photzpt - 2.5 log (photflam) = -21.1 - 2.5 log (photflam)

counts = sky subtracted total counts in aperture (r=3 for example)

exptime = exposure time

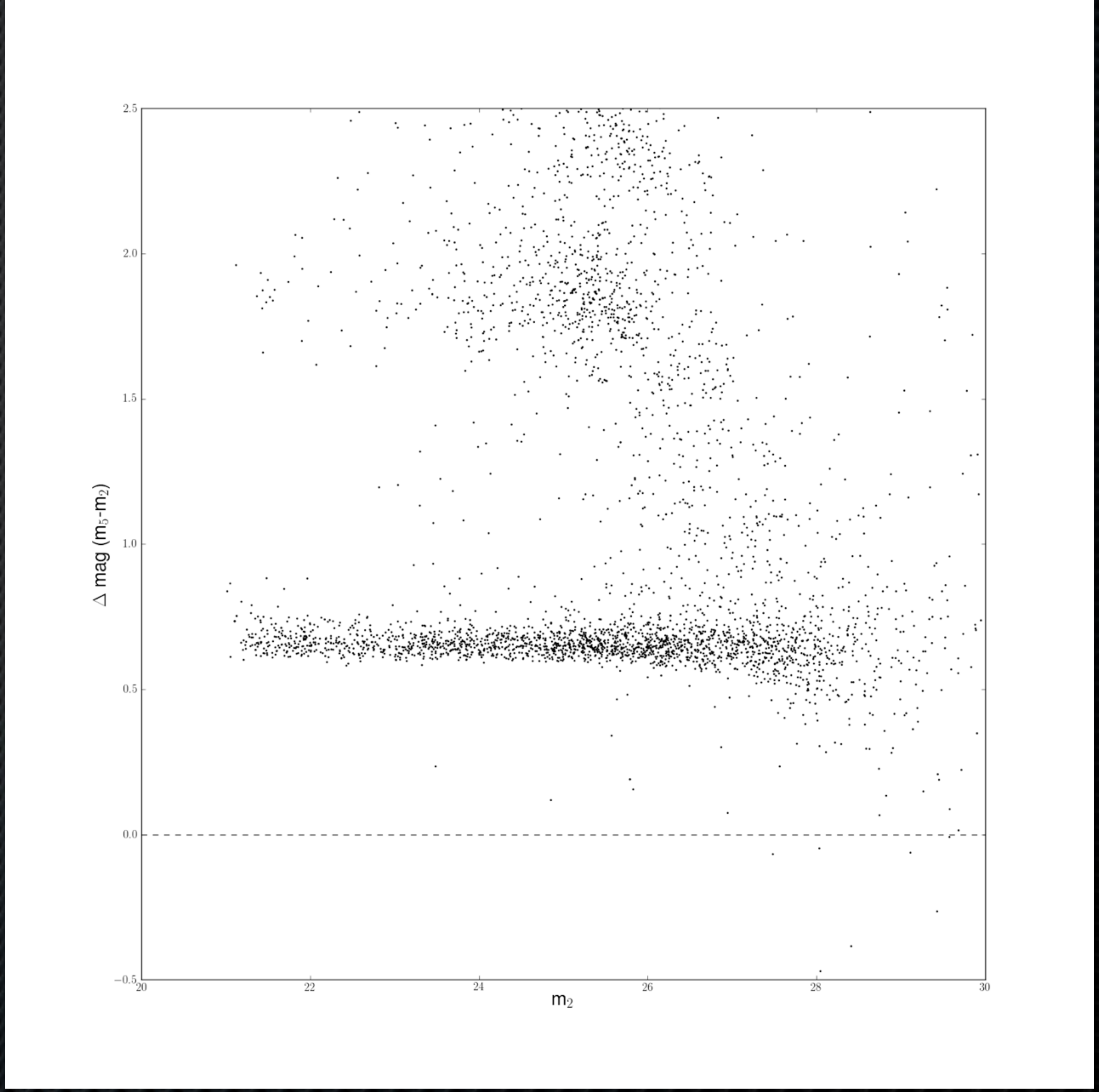
photflam = inverse sensitivity (erg s^{-1} cm^{-2} A^{-1} DN^{-1})

ac05 = apcorr from measured to 0.5”

AC05 = apcorr from 0.5” to infinity

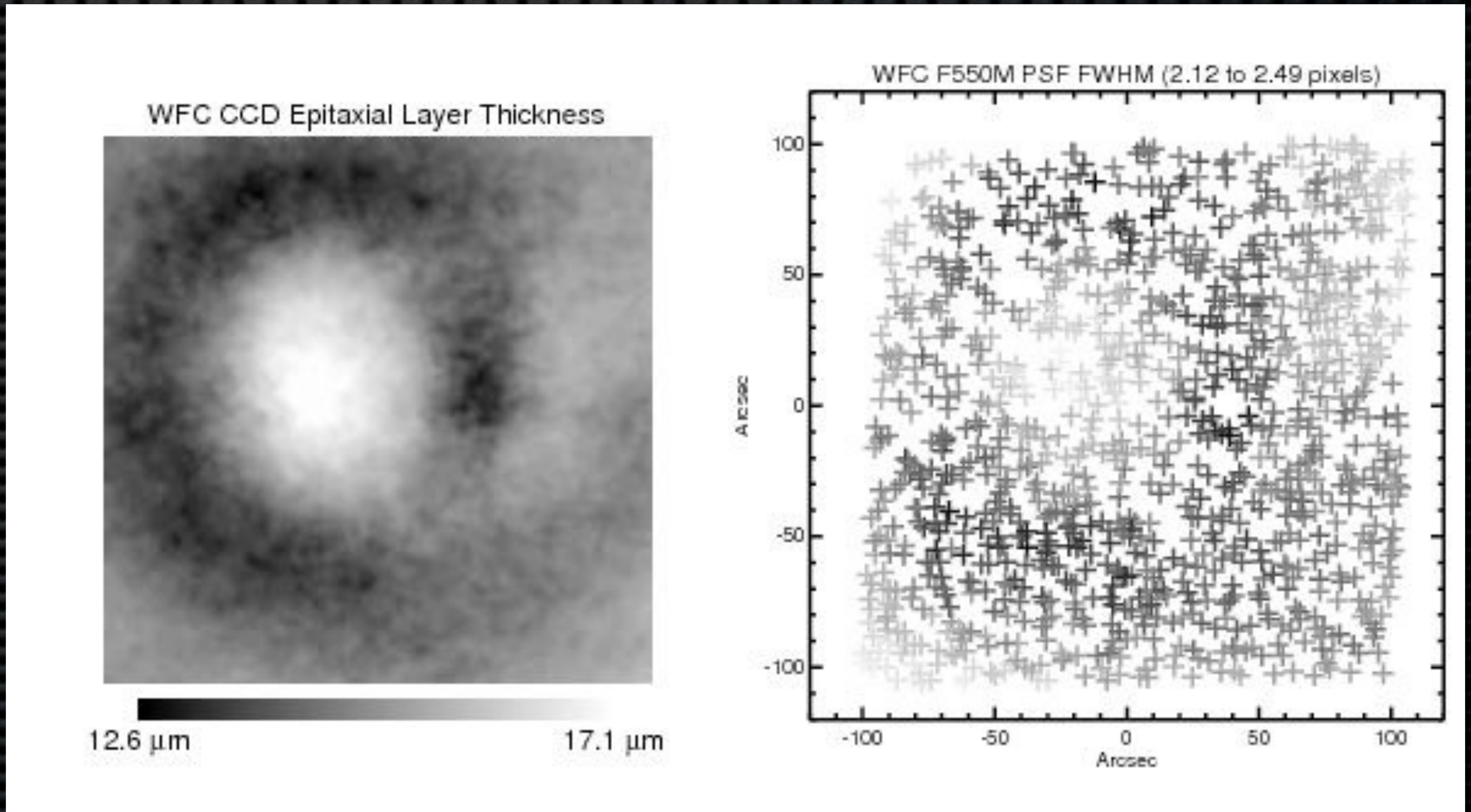
Aperture Corrections

- The two most popular photometric techniques, aperture photometry and PSF-fitting, are usually performed by measuring the flux within a small radius
  - reduces errors due to flat-fielding and background variations
  - increases the S/N
- This measurement must be tied to the total count rates by applying an aperture correction
- This correction can be a major source of systematic errors in the calibration
- Accurate aperture correction are a function of time and location on the chip
- Aperture corrections should be derived for each frame
- Encircled energy curves should be used to estimate aperture corrections when it is otherwise impossible to determine such corrections directly from the image



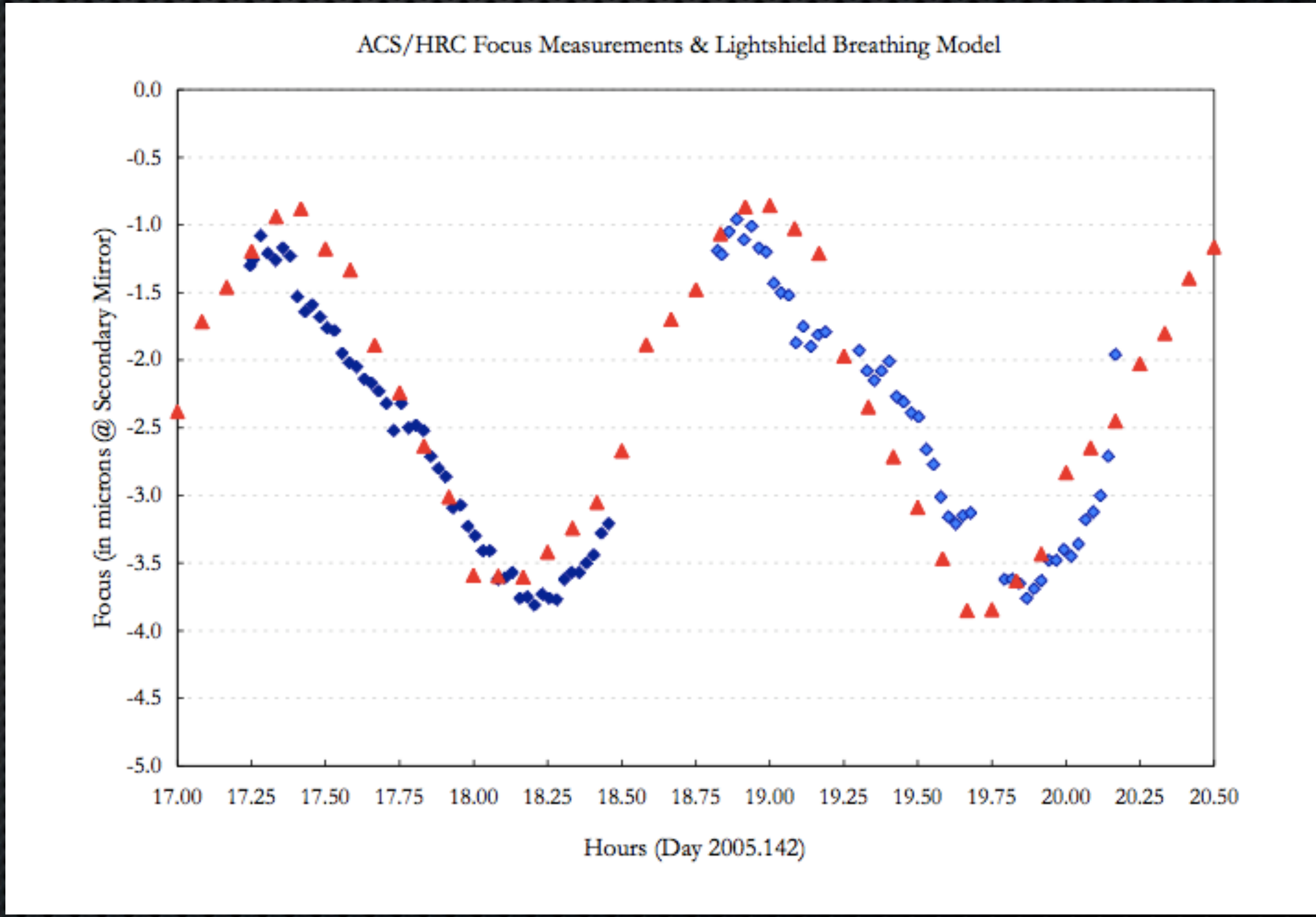
PSF spatial variations

- Spatial variations across the detector FOV arise from combination of defocus, coma, astigmatism, and charge diffusion
- Time variations occur from focus changes and spacecraft jitter during the exposures



PSF variations & HST focus (short term)

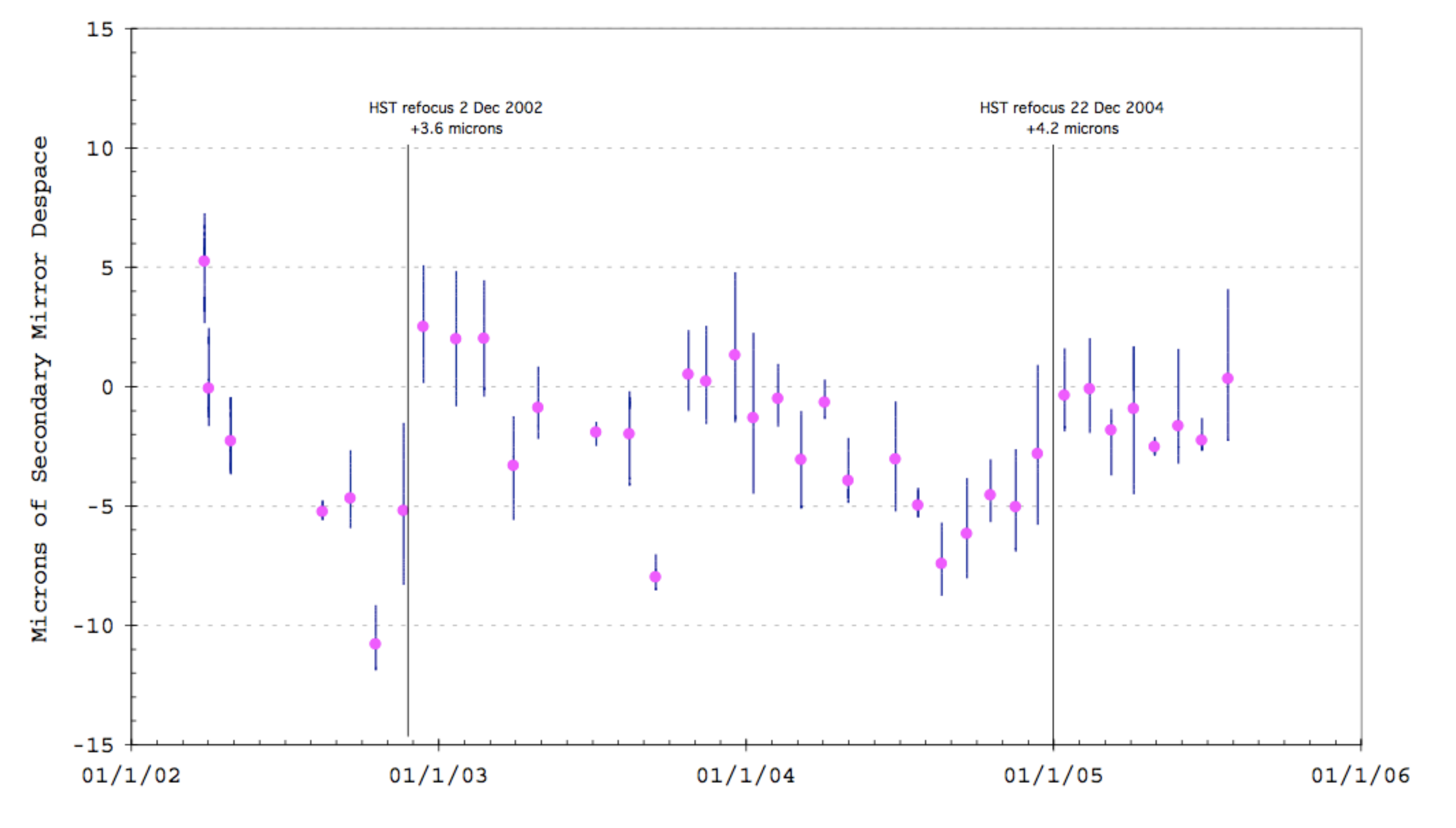
- HST breathing variations (thermally induced)
- 1 HST orbit ~90 minutes
- PSF FWHM varies accordingly



Lallo et al. (ISR TEL 2005-03)

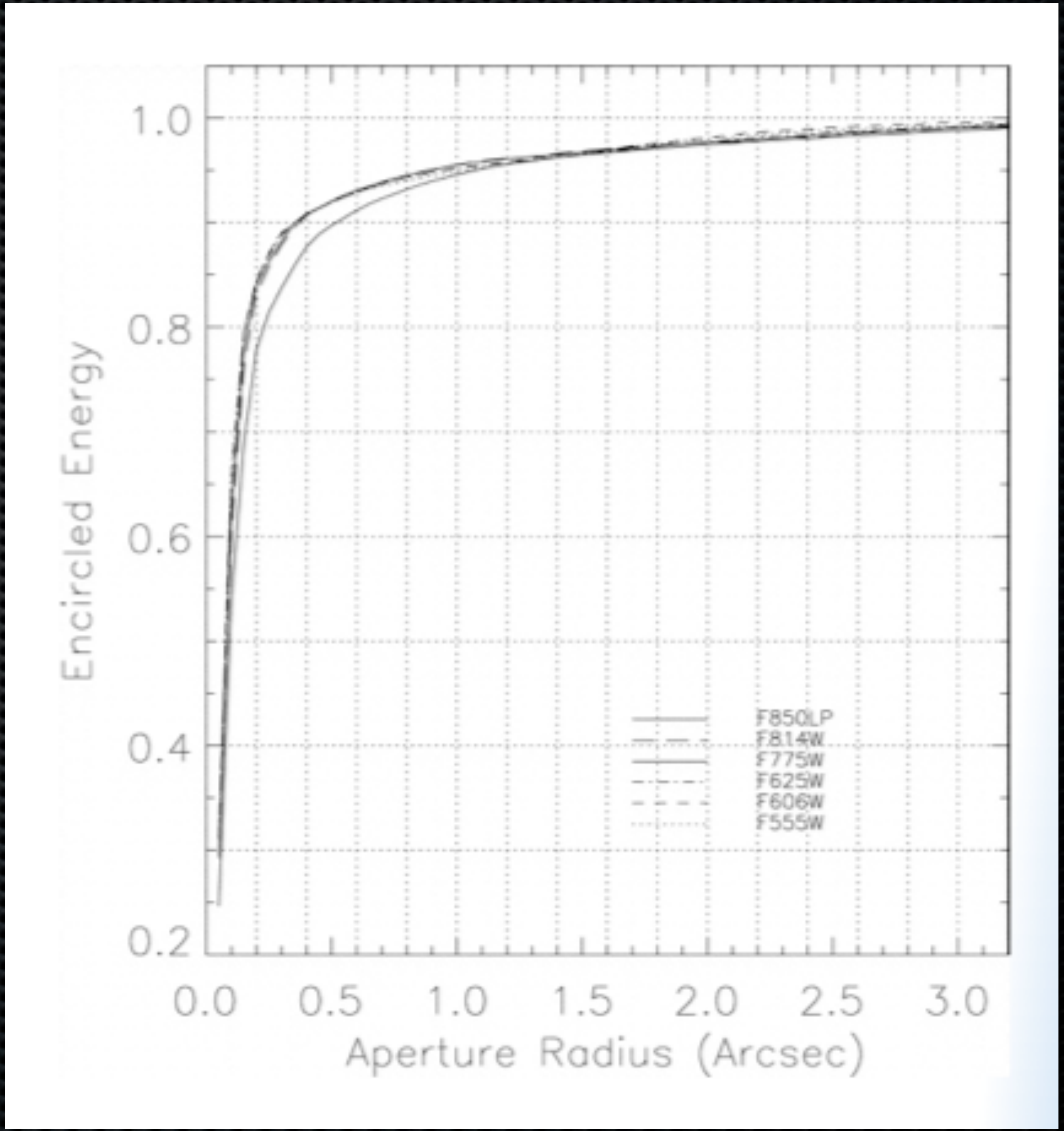
PSF variations & HST focus (long term)

- HST long term focus variations due to separation of primary and secondary mirror
- Telescope is refocused periodically



Lallo et al. (2005)

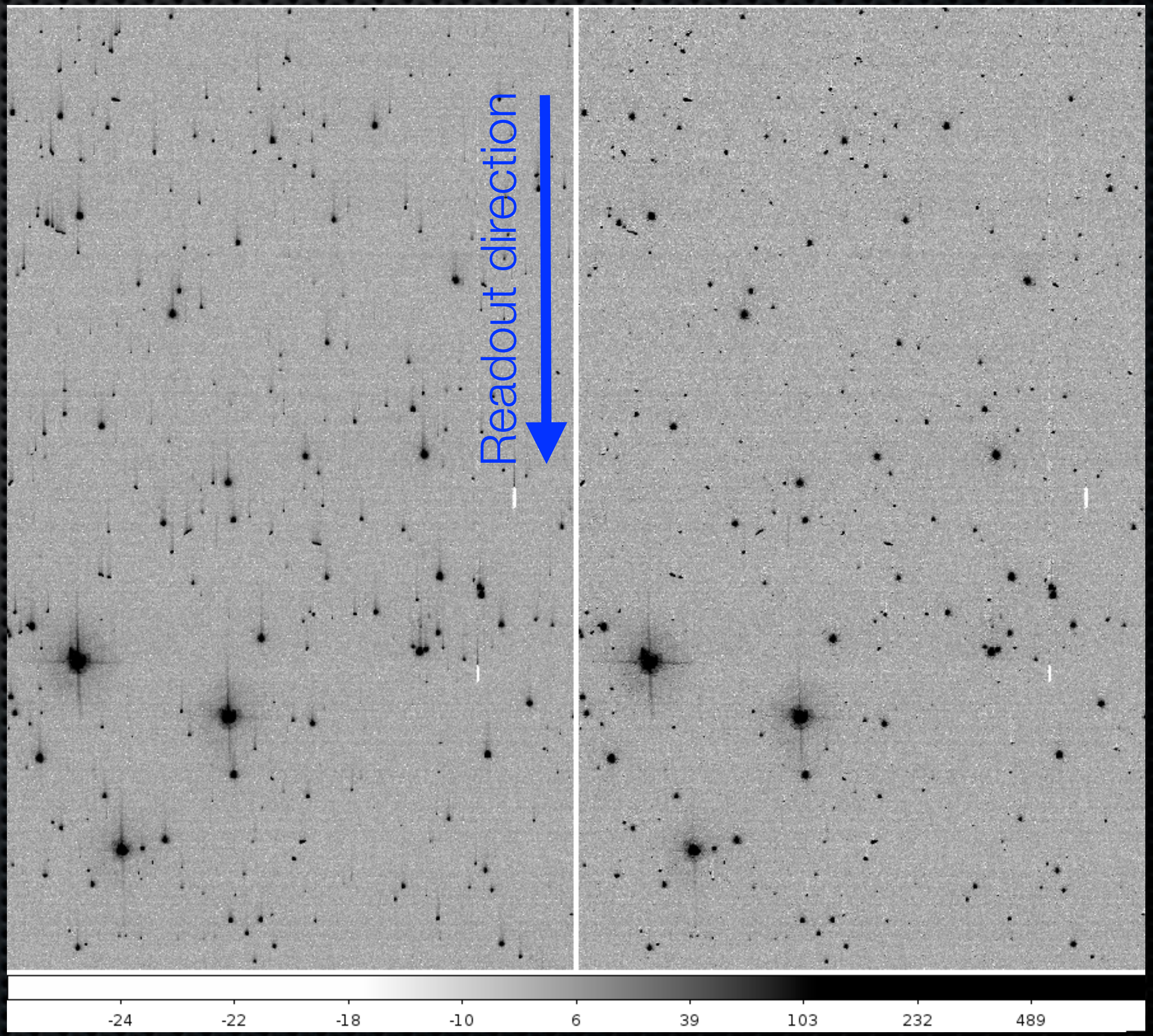
Aperture corrections



- Encircled energy profile (the fraction of total counts as a function of aperture radius)
- Computed using high S/N observations of standard stars

Charge transfer efficiency (CTE)

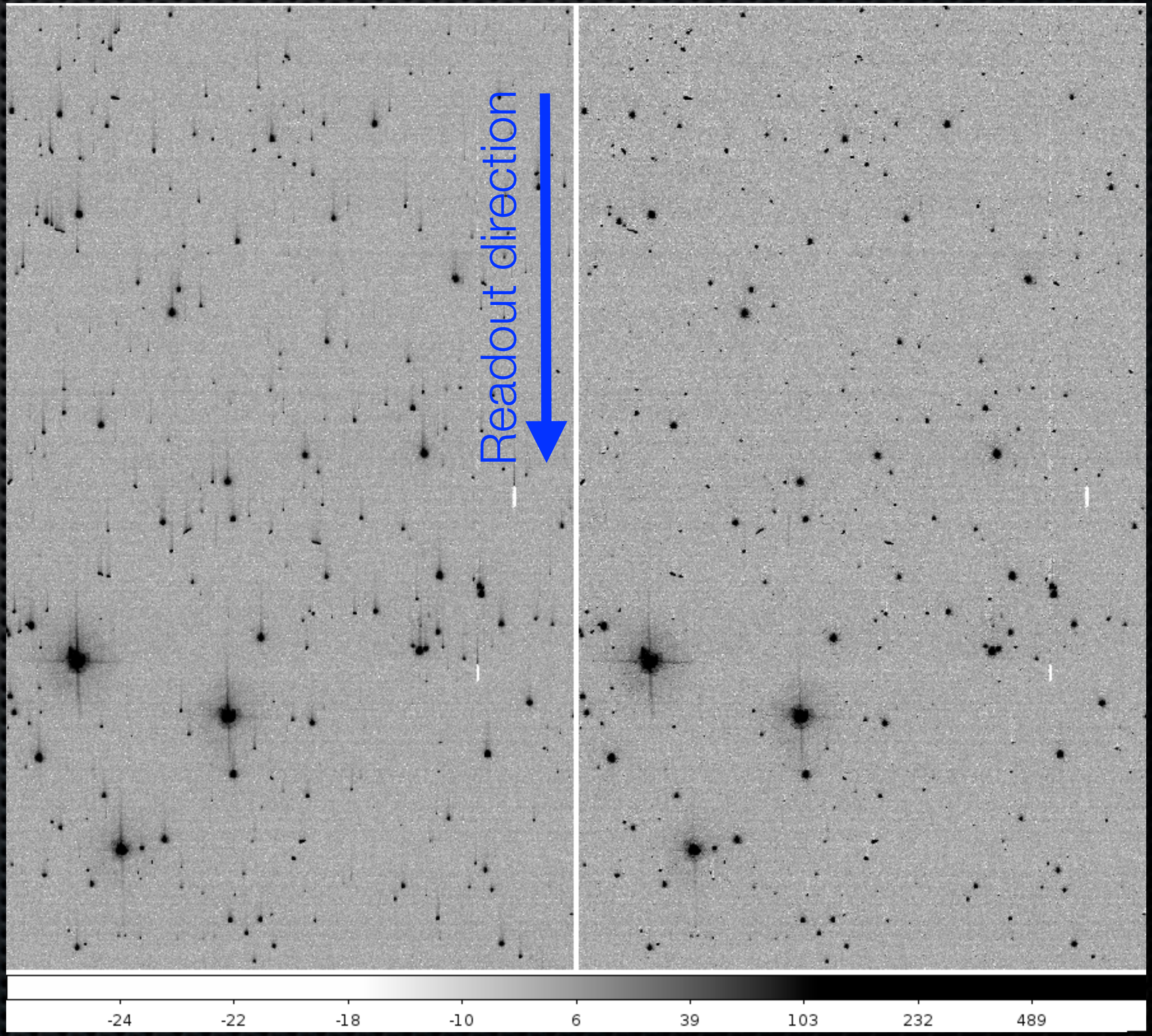
- All CCDs flown in the harsh radiation environment of space suffer degradation of the charge transfer efficiency
- During transfer of charge from one pixel to the next, defects in the silicon can result in traps that grab electrons for a short time and spontaneously release them
- The effect of CTE degradation is to reduce the apparent brightness of sources
- CTE degradation can lead to:
  - photometric inaccuracies (brightness depends on chip position)
  - astrometric shifts (PSF shape is elongated)
  - decrease in S/N (brightness is reduced and deferred charges increase noise in background)



Pixel based correction (ACS)

Pixel based CTE correction

- Pixel based CTE corrections work directly on images
  - flux put back where it came from
  - astrometry fixed
  - background noise amplified far from amps
  - Available for ACS/WFC and WFC3/UVIS full frames



Pixel based correction (ACS)

Photometric CTE correction formulae

- Can only be used on point sources
- ACS/WFC formula (Chiaberge et al. ACS ISR 2012-05):
  - Δmag (Y, t, SKY, FLUX) = [p1 Log(SKY) Log(FLUX) t + p2 Log(SKY) Log(FLUX) + p'1 Log(SKY) t + q1Log(Flux) t + p'2 Log(SKY) + q2Log(FLUX) + q'1 t + q'2] * Ytran / 2000