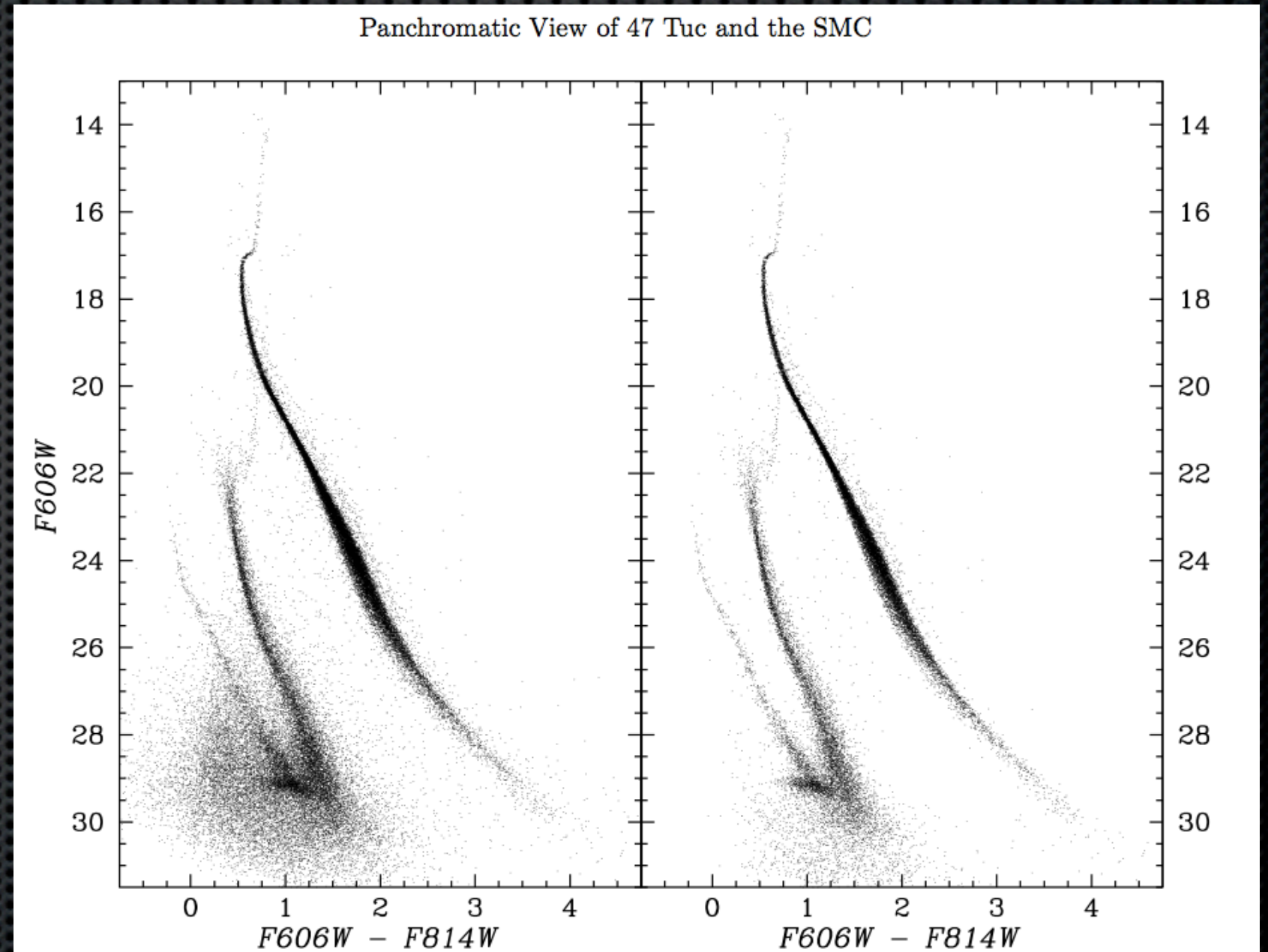


HST Photometry

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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
- ✧ IRAF photometry tasks

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

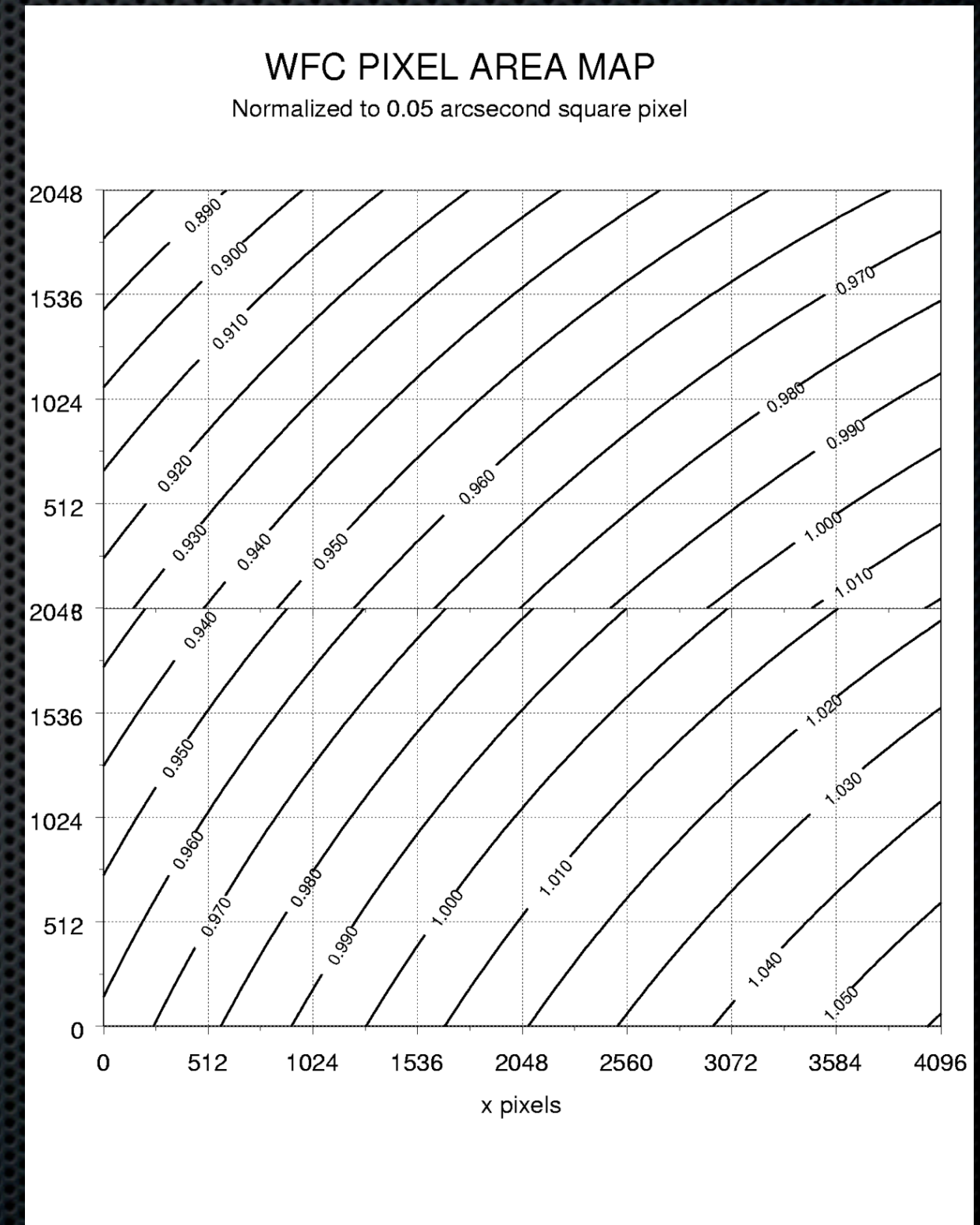
- ✦ CALxxx pipelines calculate and write the sensitivity conversion factor (**PHOTFLAM**) and the ST magnitude scale zero point (**PHOTZPT**) into header keywords in the calibrated data.
- ✦ **PHOTFLAM** is defined as the *mean* flux density F_{λ} in units of $\text{erg cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$ that produces 1 count per second in the HST observing mode.
- ✦ Calibrated images (in 'counts') may be converted to flux ($\text{erg cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$) 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

$$\text{DRZ_flux} = \text{FLT_flux} * \text{PAM} / \text{exposure time}$$

- ✧ 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_{λ})
- ✦ **ABmag** : Magnitude system based on constant flux per unit frequency (reference spectrum is flat in F_{ν})

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 ($\text{erg cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$)
 - 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:
 - $$\begin{aligned} \text{STMAG_ZEROPOINT} &= -2.5 \log (\text{PHOTFLAM}) + \text{PHOTZPT} \\ &= -2.5 \log (\text{PHOTFLAM}) - 21.1 \end{aligned}$$
 - $$\text{ABMAG_ZEROPOINT} = -2.5 \log (\text{PHOTFLAM}) - 21.1 - 5 \log (\text{PHOTPLAM}) + 18.6921$$

From aperture photometry to absolute magnitudes

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

where:

$$\text{zpt} = \text{photzpt} - 2.5 \log (\text{photflam}) = -21.1 - 2.5 \log (\text{photflam})$$

flux = 'counts' in aperture (r=3 for example)

exptime = exposure time

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

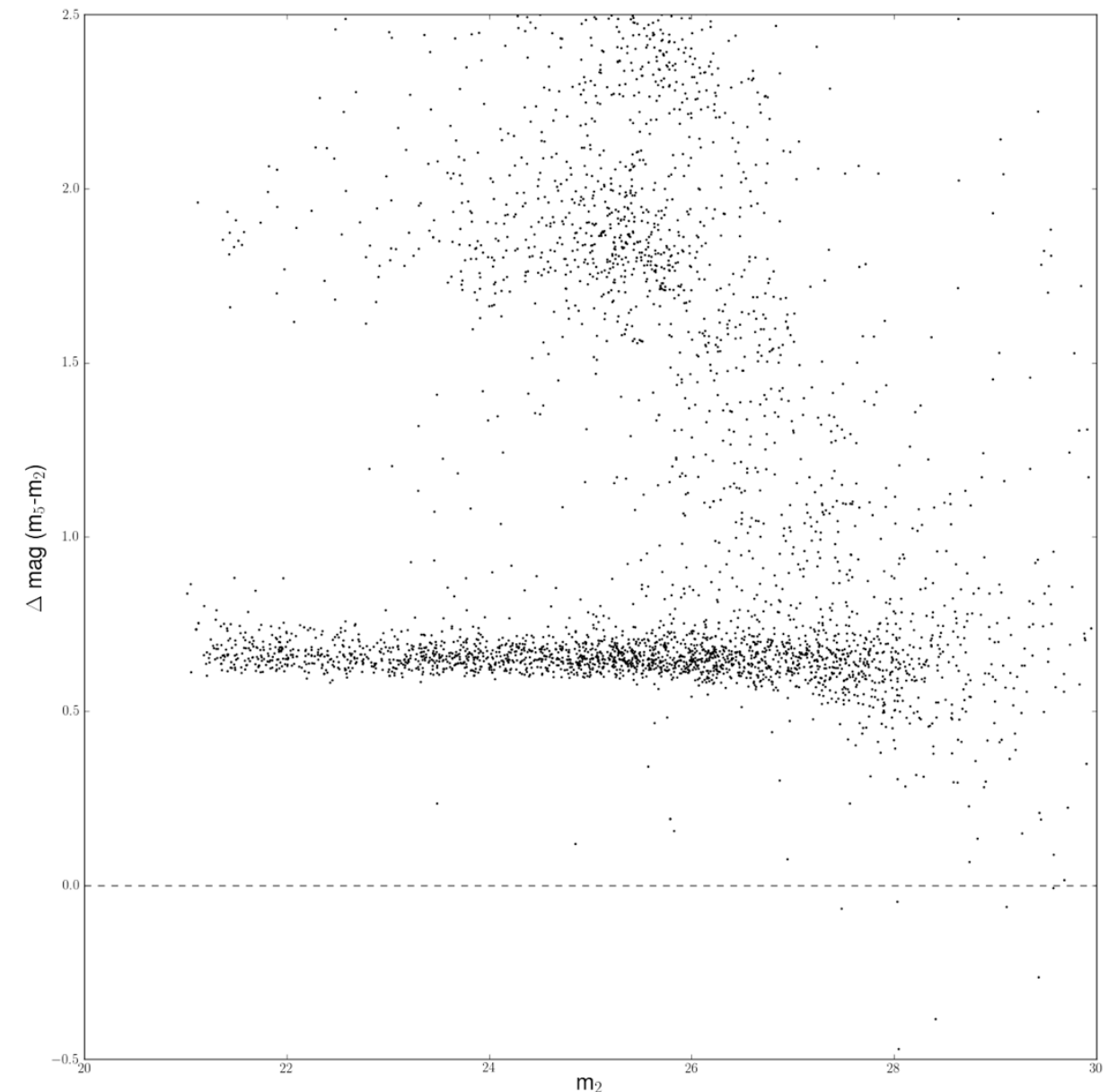
ac05 = apcorr from measured to 0.5"

AC05 = apcorr from 0.5" to infinity

CTE = charge transfer efficiency loss

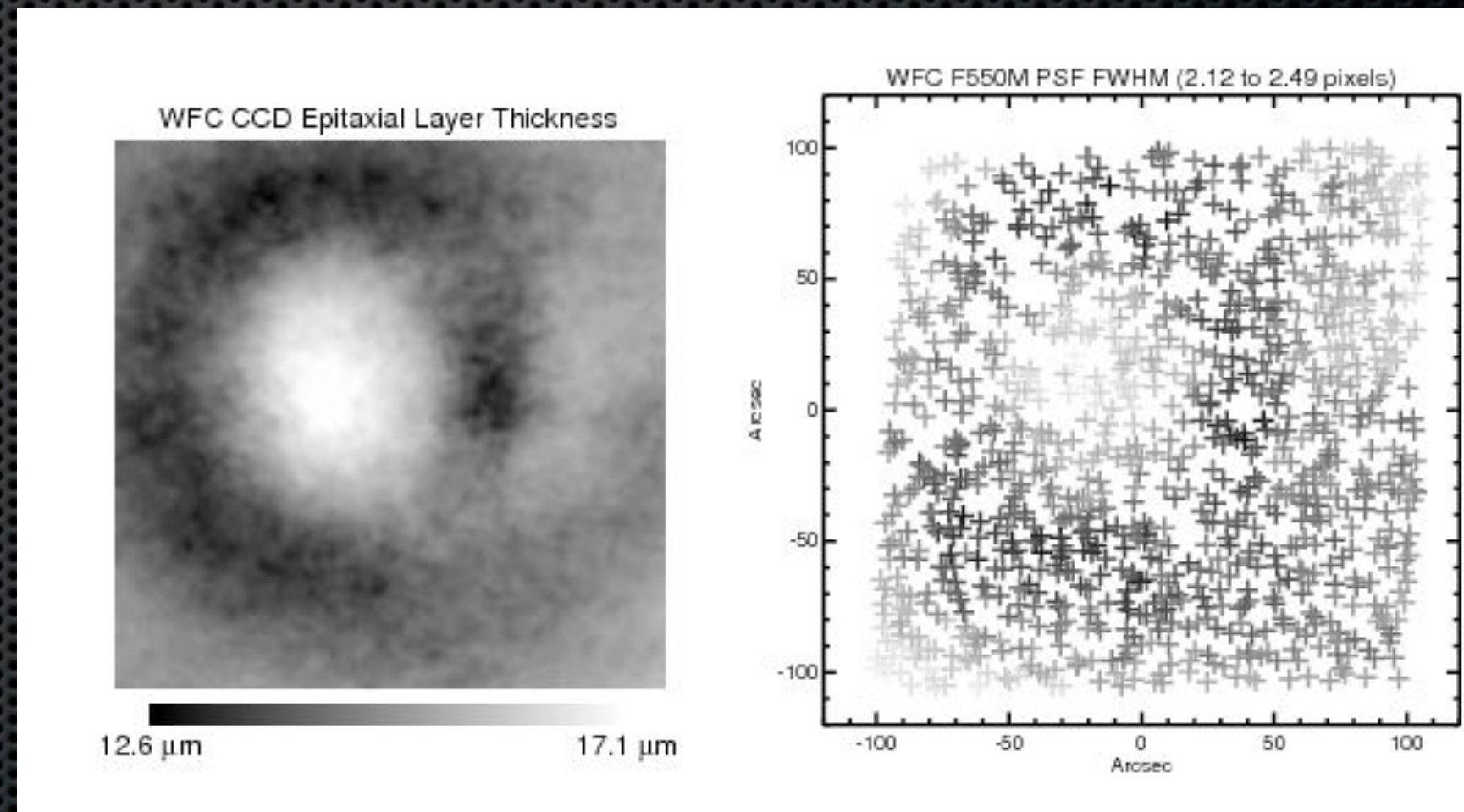
Aperture Corrections

- 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



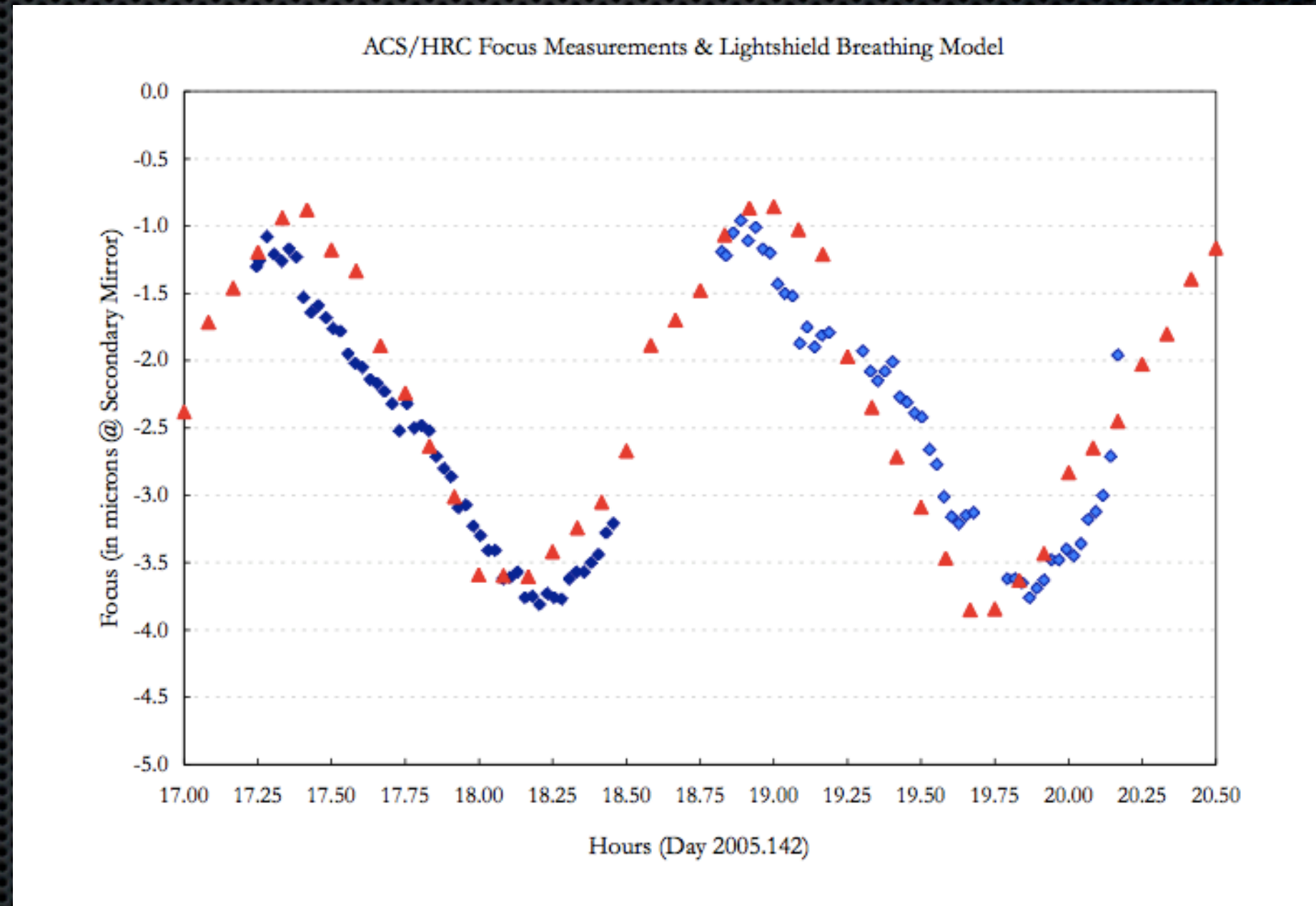
PSF spatial variations

- ✧ 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)

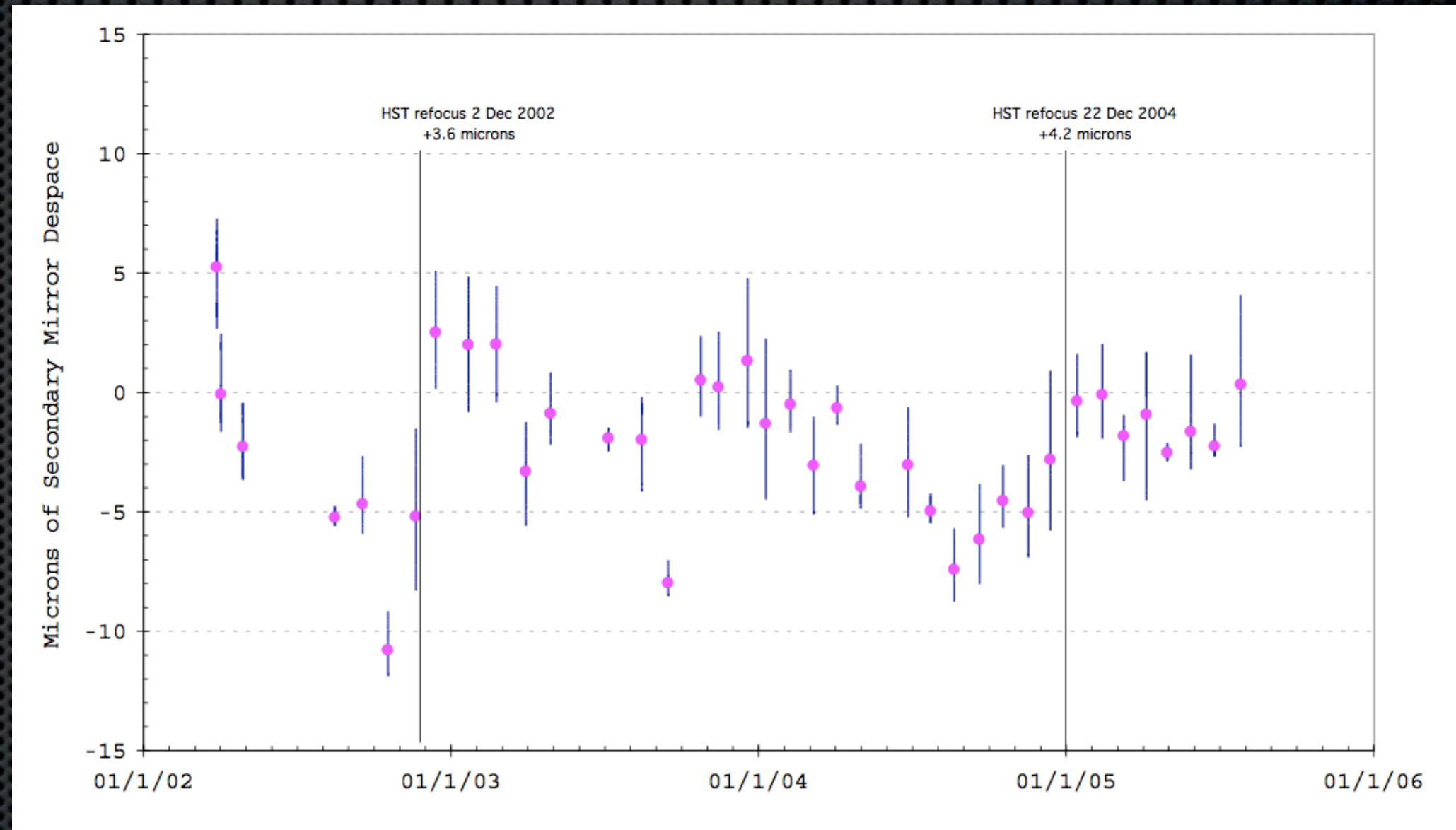
- ✧ HST breathing variations (thermally induced)
- ✧ 1 HST orbit ~90 minutes
- ✧ PSF FWHM varies accordingly



Lallo et al. (ISR TEL 2005-03)

PSF variations & HST focus (long term)

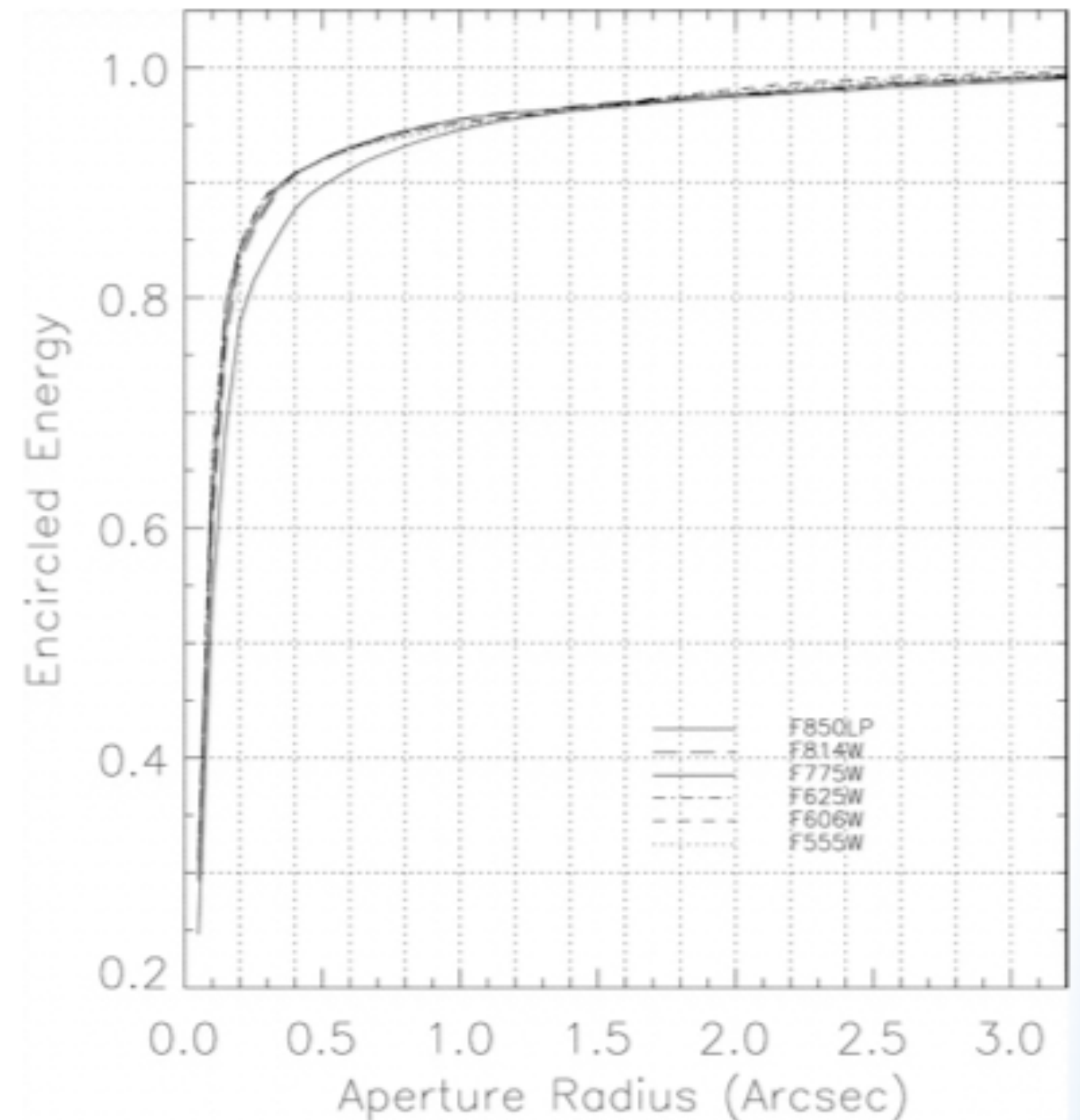
- ✧ HST long term focus variations due to separation of primary and secondary mirror
- ✧ Telescope is refocused periodically



Lallo et al. (2005)

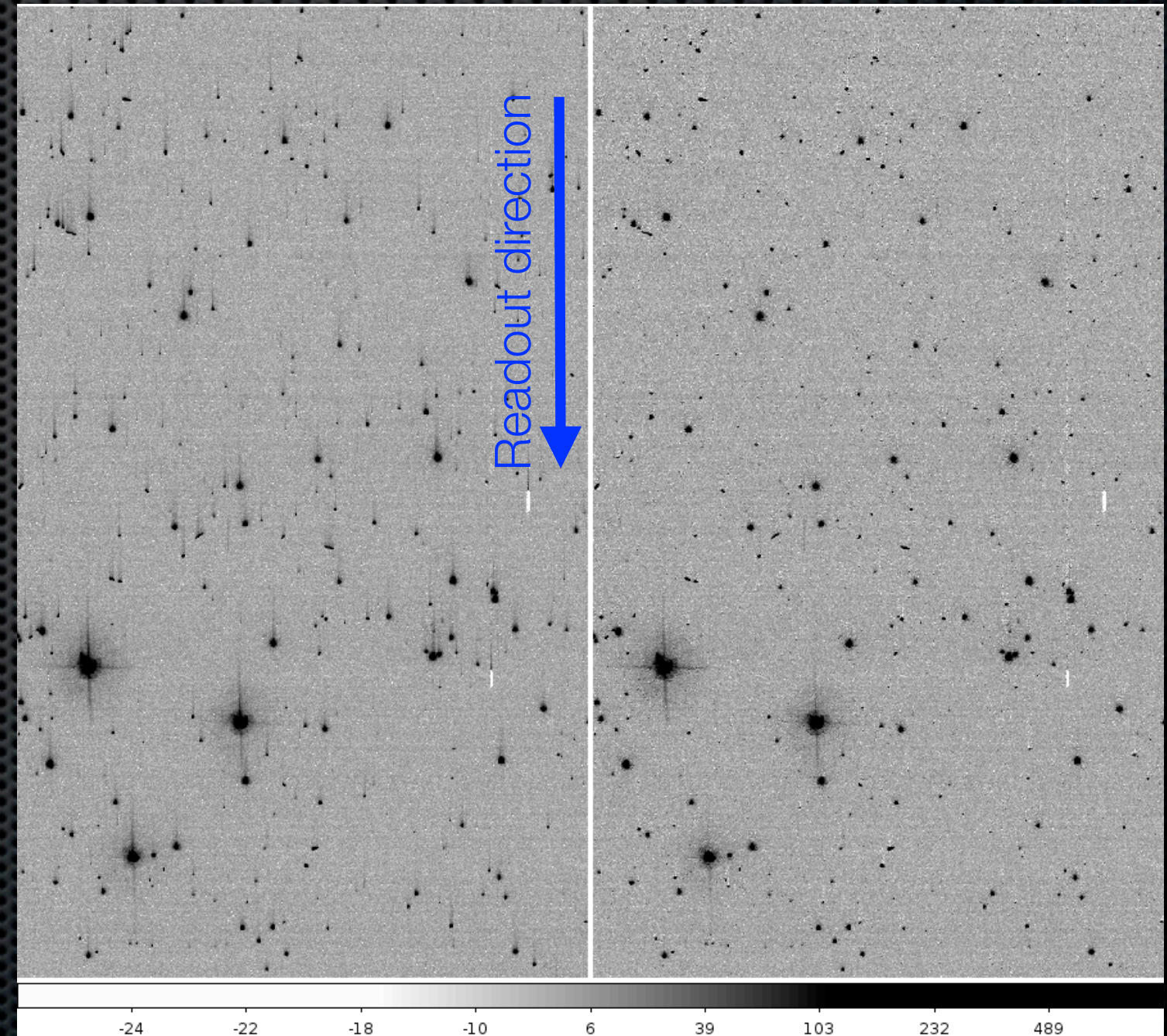
Aperture corrections

- ✧ 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)

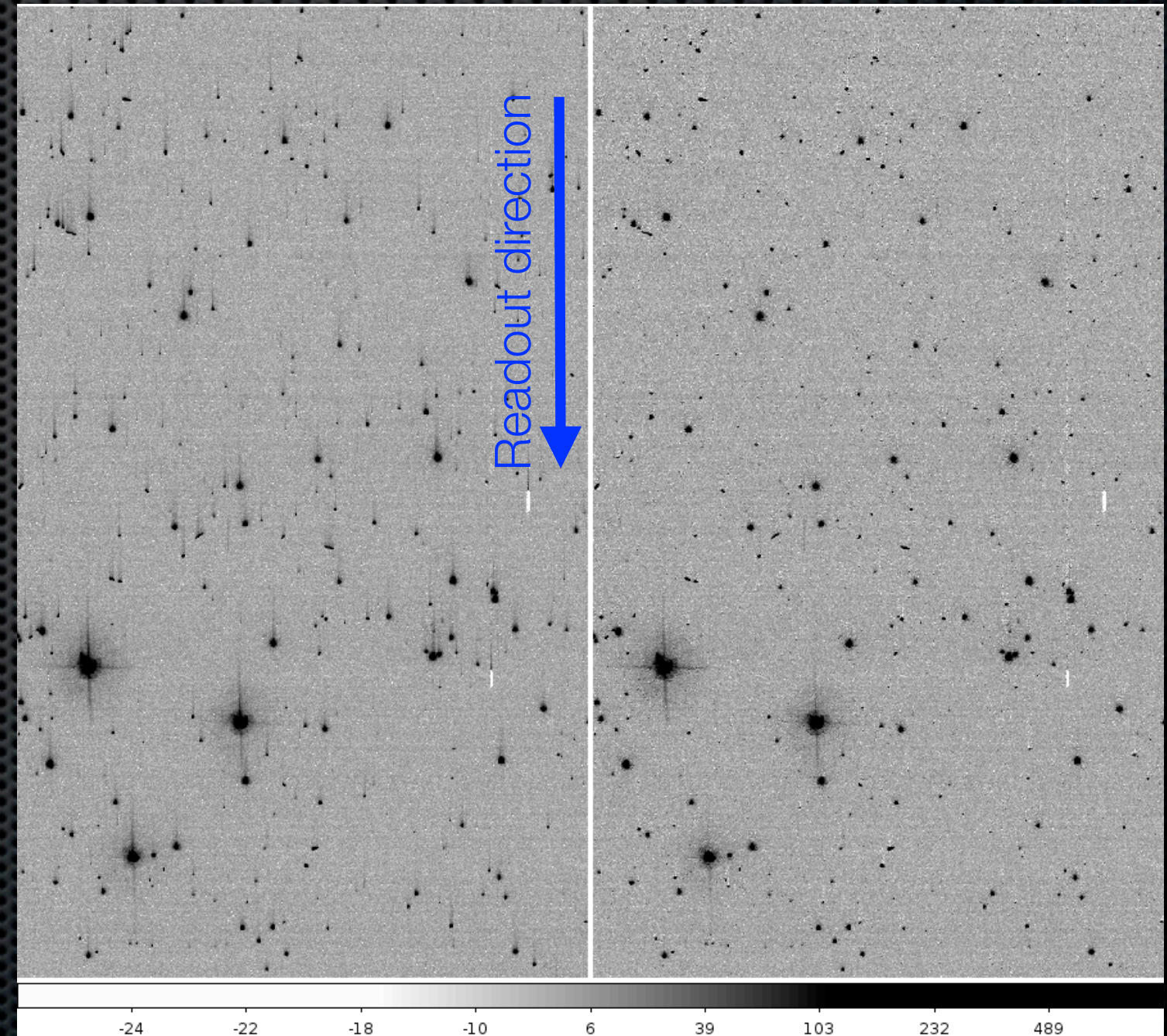
- All CCDs flown in the harsh radiation environment of space suffer degradation of the charge transfer efficiency
- During transfer of charge from one pixel to the next, defects in the silicon can result in traps that grab electrons for a short time and spontaneously release them
- The effect of CTE 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 only)

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
- ✧ Only available for ACS/WFC full frames



Pixel based correction (ACS only)

Photometric CTE correction formulae

- ✧ Can only be used on point sources
- ✧ ACS/WFC formula (Chiaberge et al. ACS ISR 2009-01):
 - ✧ $\Delta\text{mag} = 10^A \times \text{SKY}^B \times \text{FLUX}^C \times Y/2000 \times (\text{MJD}-52333)/365$
 - ✧ $A = -0.15 (\pm 0.04)$ $B = -0.25 (\pm 0.01)$ $C = -0.44 (\pm 0.02)$
- ✧ WFC3/UVIS formula coming soon.....

Useful photometry tasks in IRAF

- ✦ apphot : Aperture photometry package
- ✦ daophot : Stellar PSF photometry for crowded fields
- ✦ isophote : Fitting elliptical isophotes
- ✦ imexamine : Simple photometry measurements
- ✦ imstat : Image pixel statistics

Aperture photometry with IRAF

PACKAGE: apphot or daophot

TASK: phot

- (datapars = "") Data dependent parameters
 - (sigma = 0.0) Standard deviation of background in counts
 - (ccdread = "") CCD readout noise image header keyword
 - (exposure = "") Exposure time image header keyword
- (centerpars = "") Centering parameters
 - (calgorithm = "centroid") Centering algorithm
 - (cbox = 5.0) Centering box width in scale units
 - (maxshift = 1.0) Maximum center shift in scale units
- (fitskypars = "") Sky fitting parameters
 - (salgorithm = "mode") Sky fitting algorithm
 - (annulus = 10.0) Inner radius of sky annulus in scale units
 - (dannulus = 10.0) Width of sky annulus in scale units
- (photpars = "") Photometry parameters
 - (apertures = "3.") List of aperture radii in scale units
 - (mag = 25.0) Zero point of magnitude scale
- (mkapert = no) Draw apertures on the display