Pan-STARRS 1 Photometry and Astrometry Calibration Status

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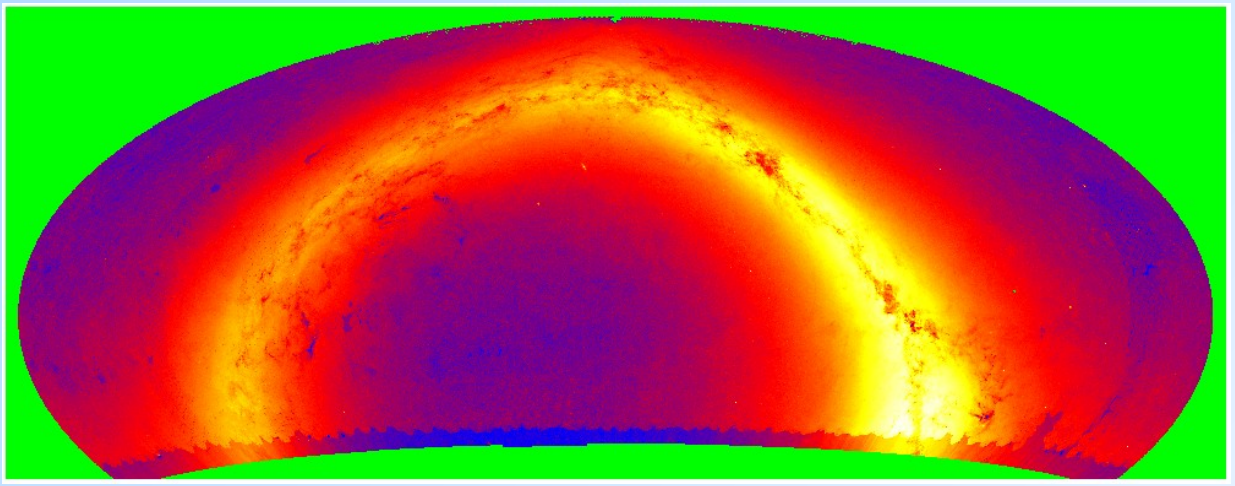
Pan-STARRS 1: a 1.8m survey telescope (1.4Gpix & 7deg² F.O.V.)

PS-1 on Haleakala



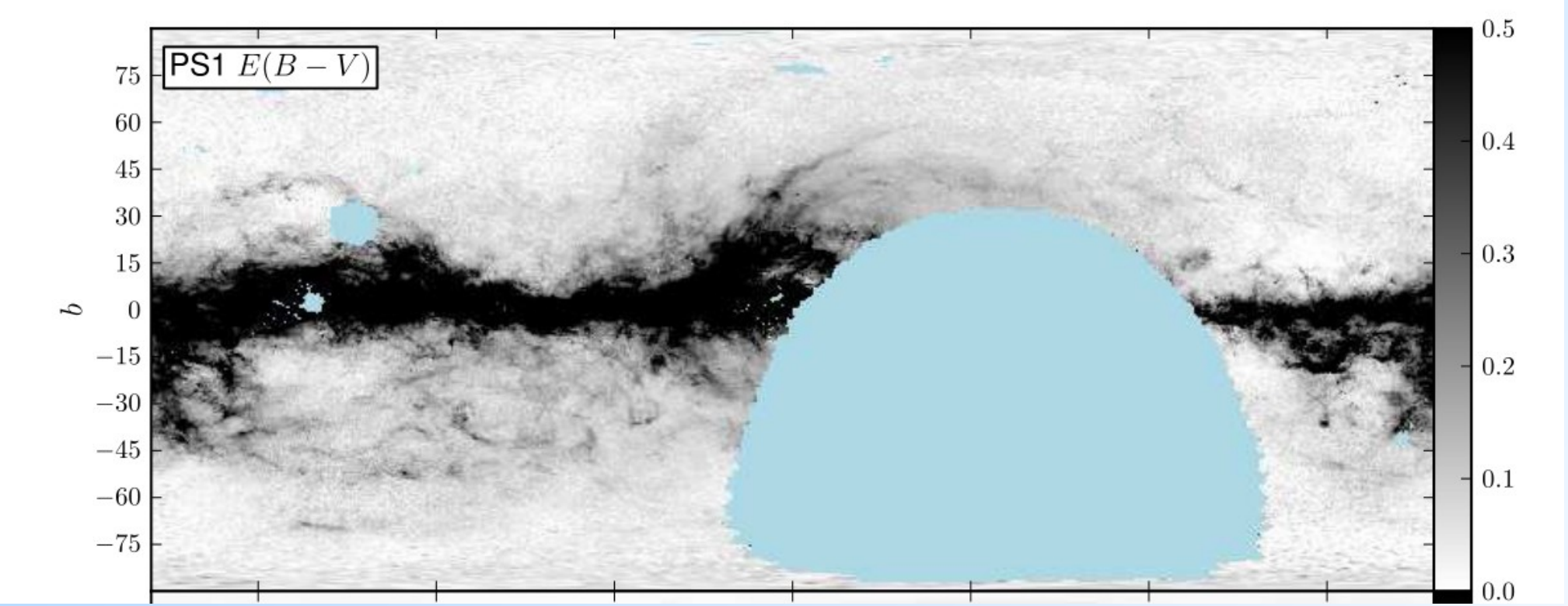
PV1 sky density @ i = 20.0

PS1 Survey Mission:

- 5/2010 – 4/2014
- Release to public (MAST): 4/2015 (PV3)
- PV2 stats:
  - 60B chip detections
  - 13B stack detections
  - 7.9B chip 'objects' (grouped detections)
  - 2.8B stack objects
- PV3 processing ongoing (complete ~ Jan 2015)

Precision Photometry Uses: Dust Maps

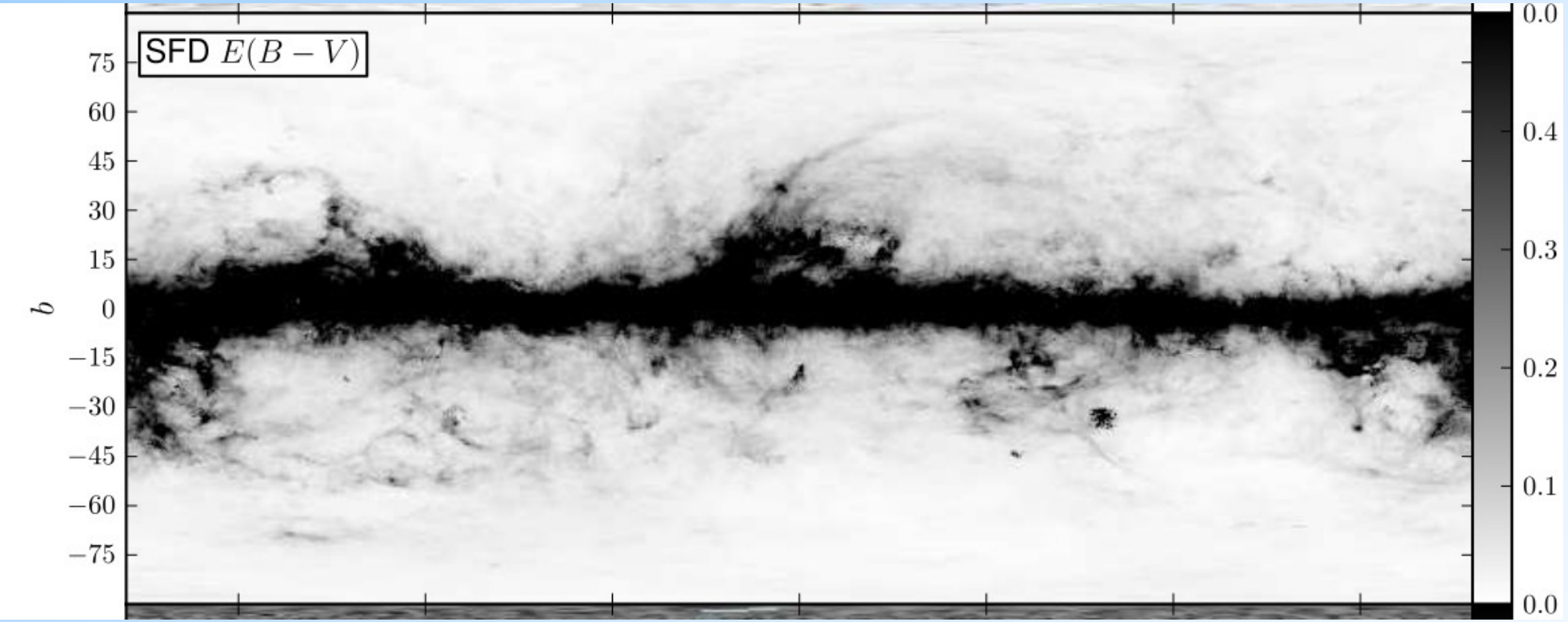
- Schlafly et al (2014) measure E(B-V) trends in lines-of-site



Schlafly et al (2014), ApJ 789, 15

Precision Photometry Uses: Dust Maps

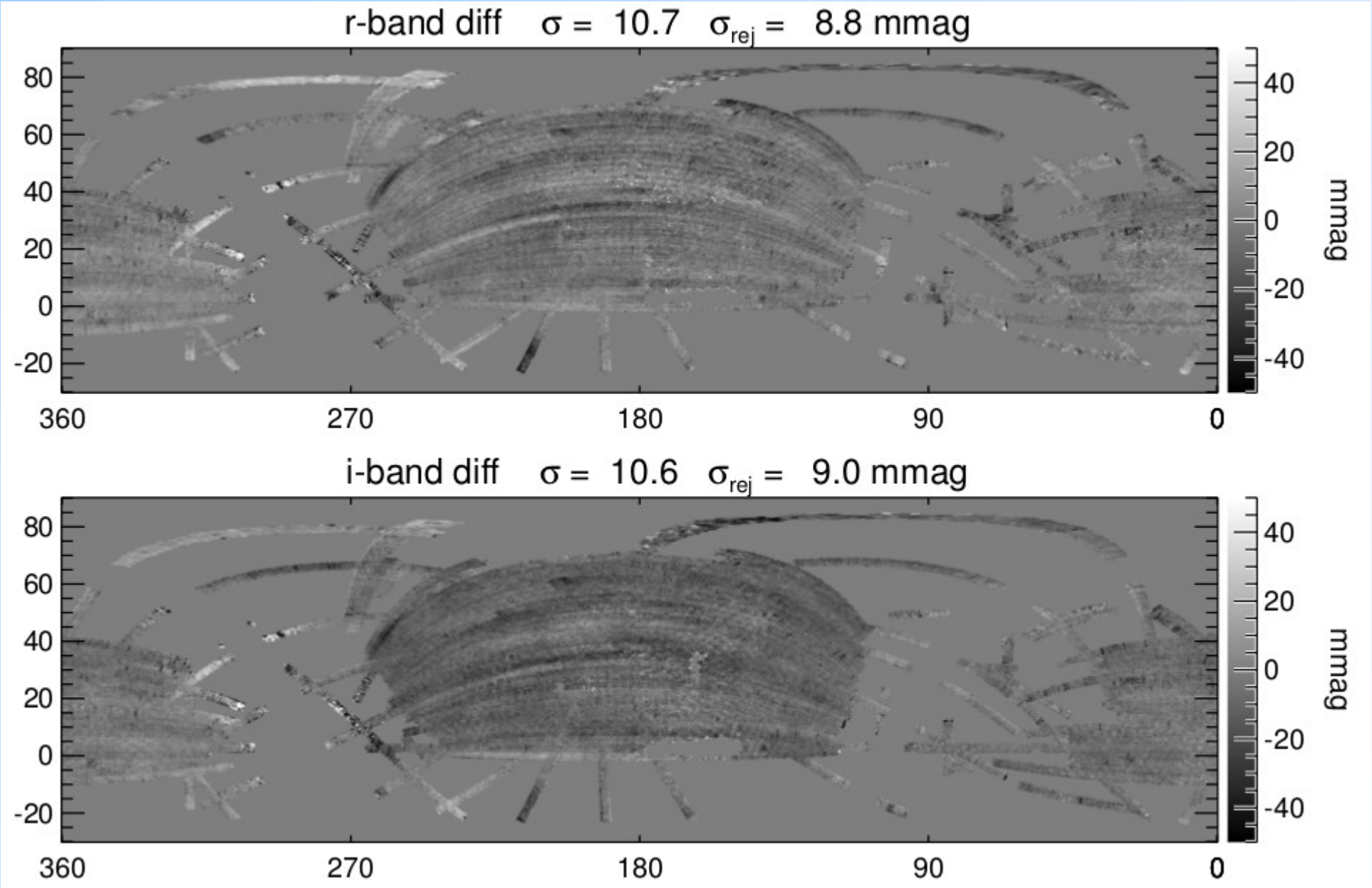
- Schlafly et al (2014) measure E(B-V) trends in lines-of-site
  - Comparison with Schlegel, Finkbeiner, Davis (1998)



Schlafly et al (2014), ApJ 789, 15

Precision Photometry Uses: SDSS Recalibration

- Finkbeiner et al (2014) uses PS1 to improve the SDSS calibration



Precision Photometry Uses: SDSS Recalibration

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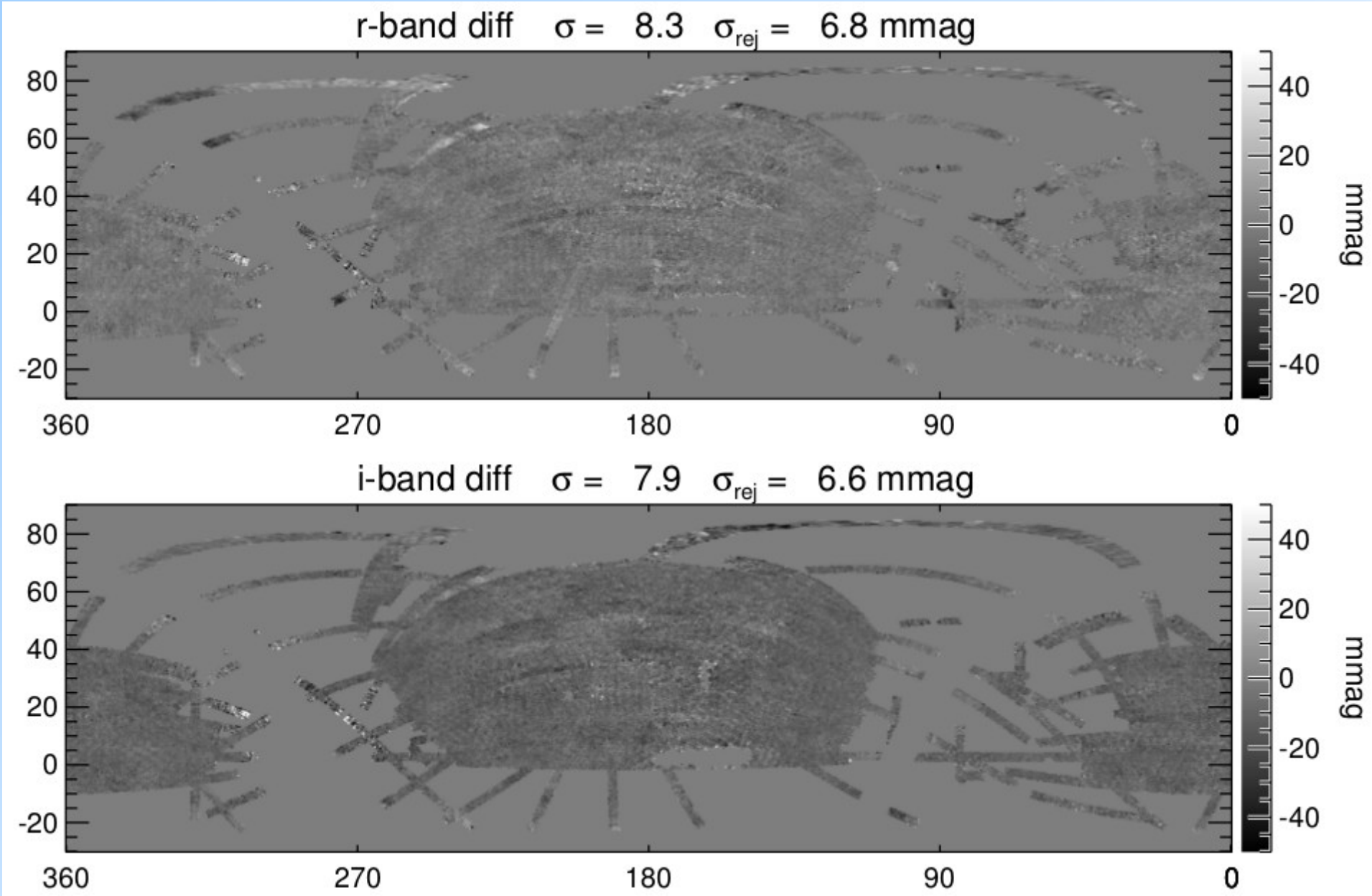
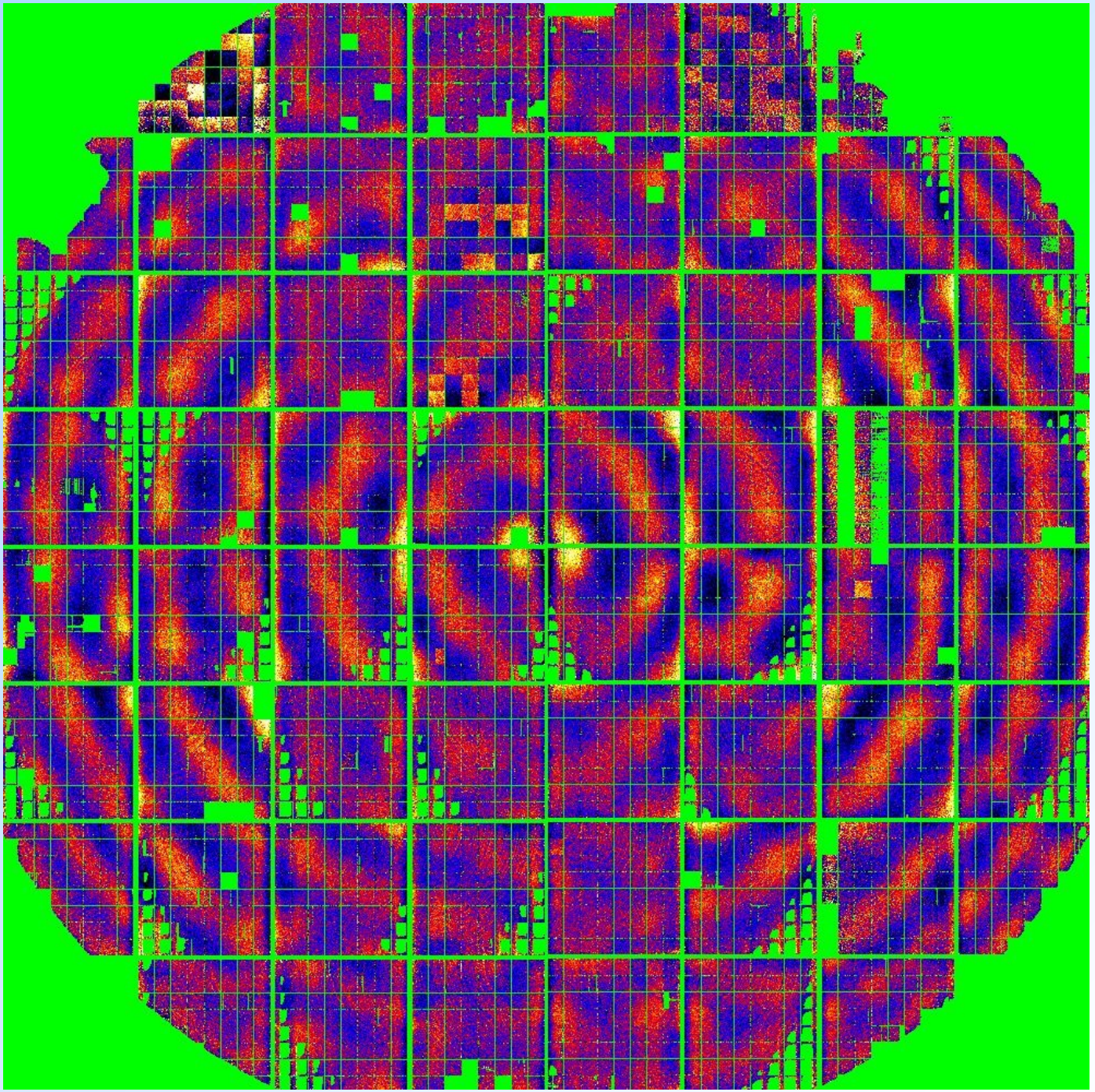


PV1 Calibration Quality

- Photometry
  - 3pi reliability : (*grizy*) = (8, 7, 9, 11, 12) mmag
  - MD reliability : all filters < 6 mmag
  - per-exposure scatter ~ 10 – 15 millimags
- Astrometry:
  - Per-detection : 18 - 20 mas (1D, depends on chip)
  - Parallax limit (1.5yr) : 3-4 mas
  - Proper-motion limit (1.5yr) : ~5 mas/yr
- PV2 & PV3 calibration underway
  - **can we do better?**
  - **probably --> some improvements to pixel processing help**
  - **what about systematics?**
    - **PS1 / GPC1 tree rings**

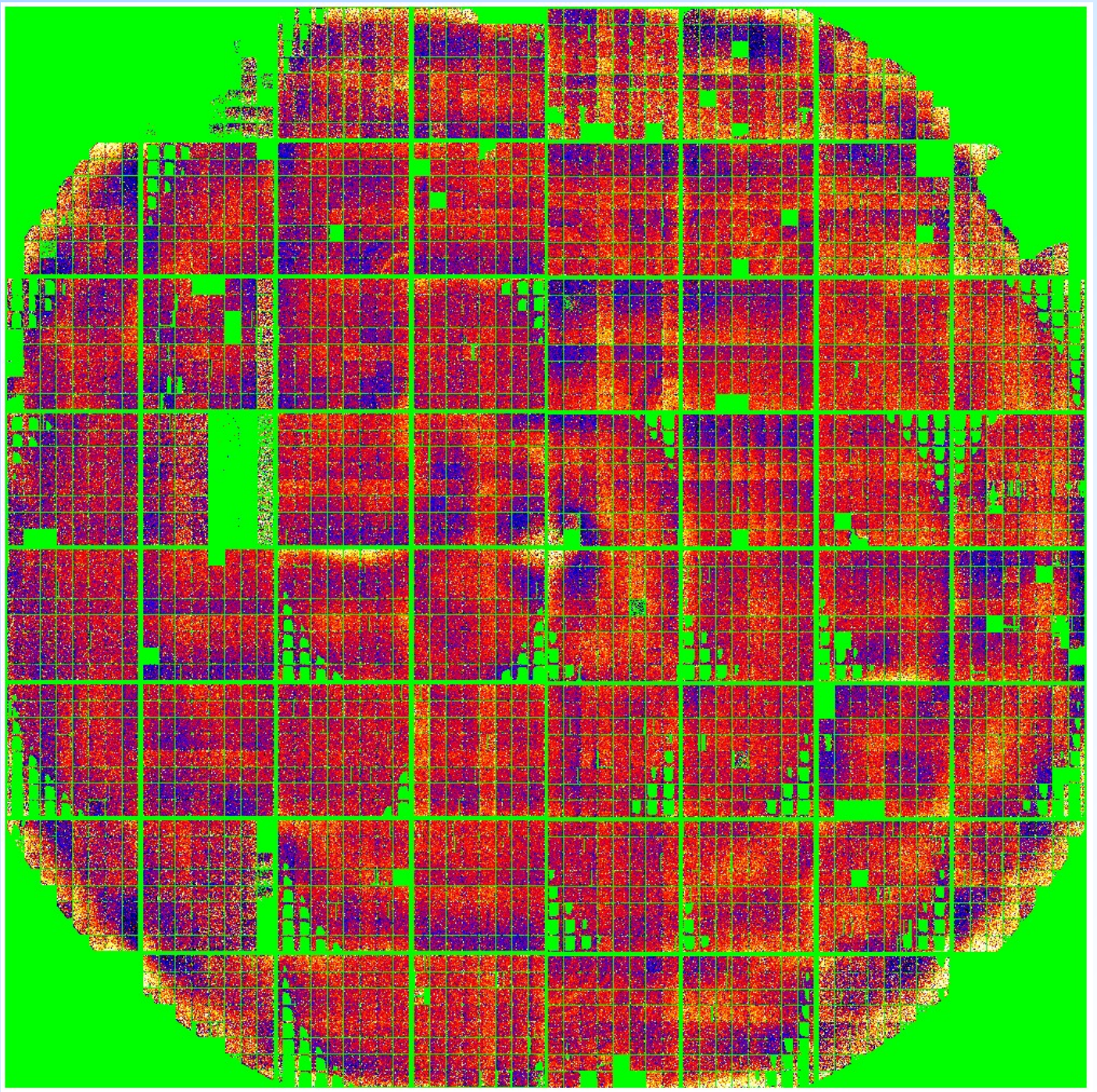
Astrometric Systematics

- mean residuals as a function of camera position
- 20 x 20 pixel bins
- i-band, dX shown
- large-scale structure similar to focal-plane deviations



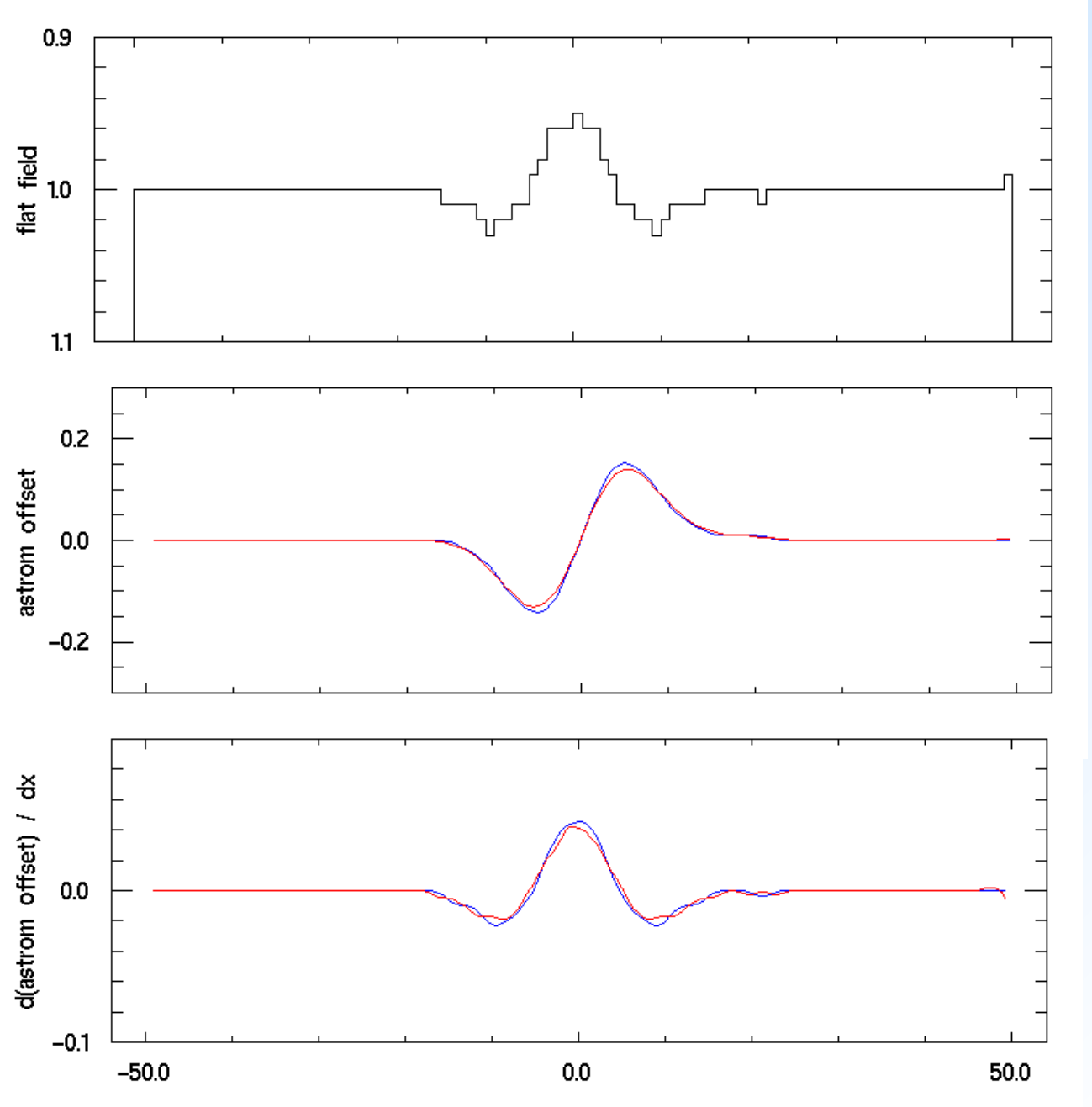
Photometric Systematics : per-exposure residuals

- mean residuals as a function of camera position
- 20 x 20 pixel bins
- i-band shown
- central tent
- residual of 2x2 flats



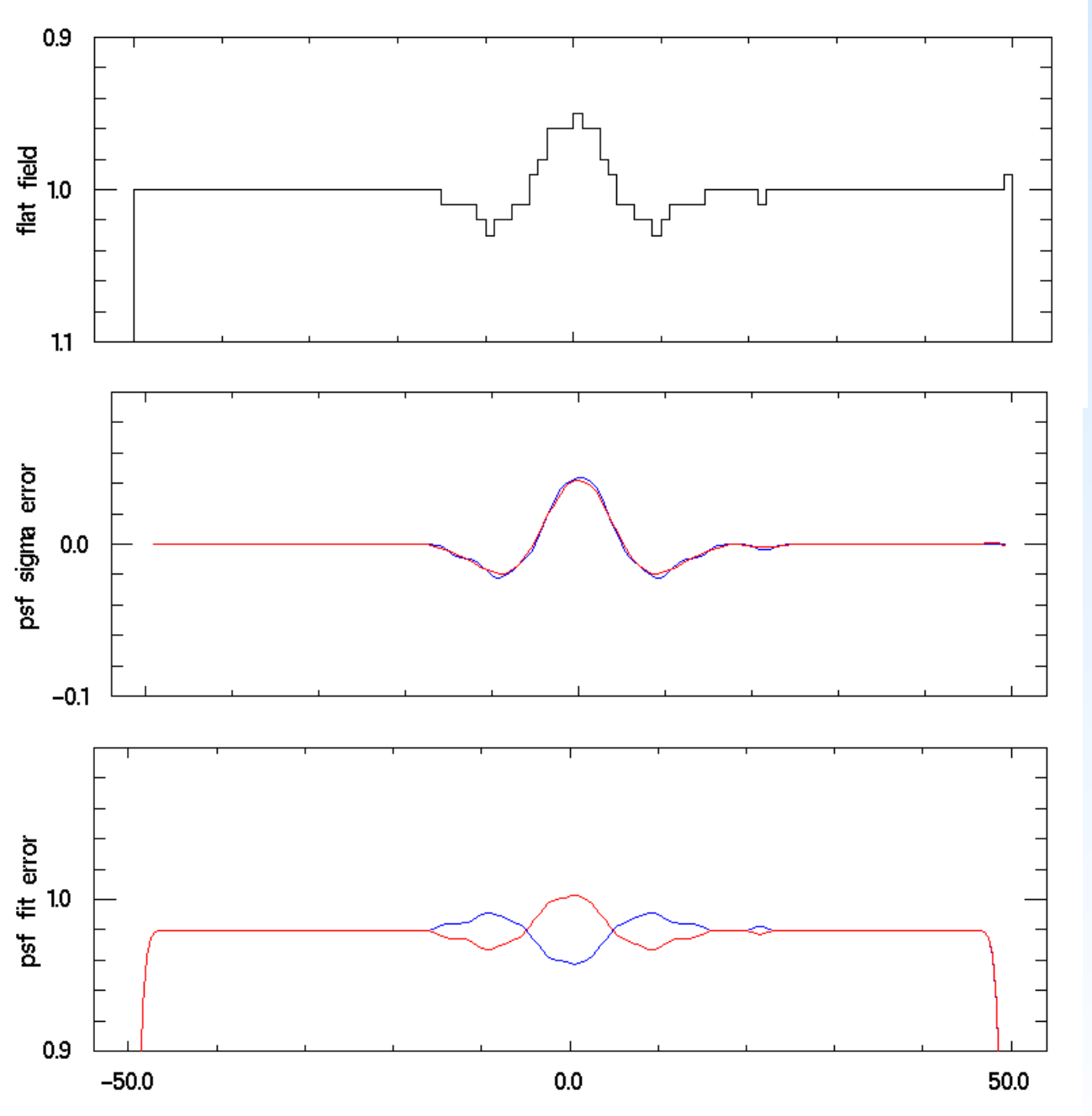
“Classic” Tree Rings : Plate-scale variations

- plate scale -> flat field
- plate scale -> astrometry
- flat-field = grad (astrom)



“Classic” Tree Rings : Plate-scale variations

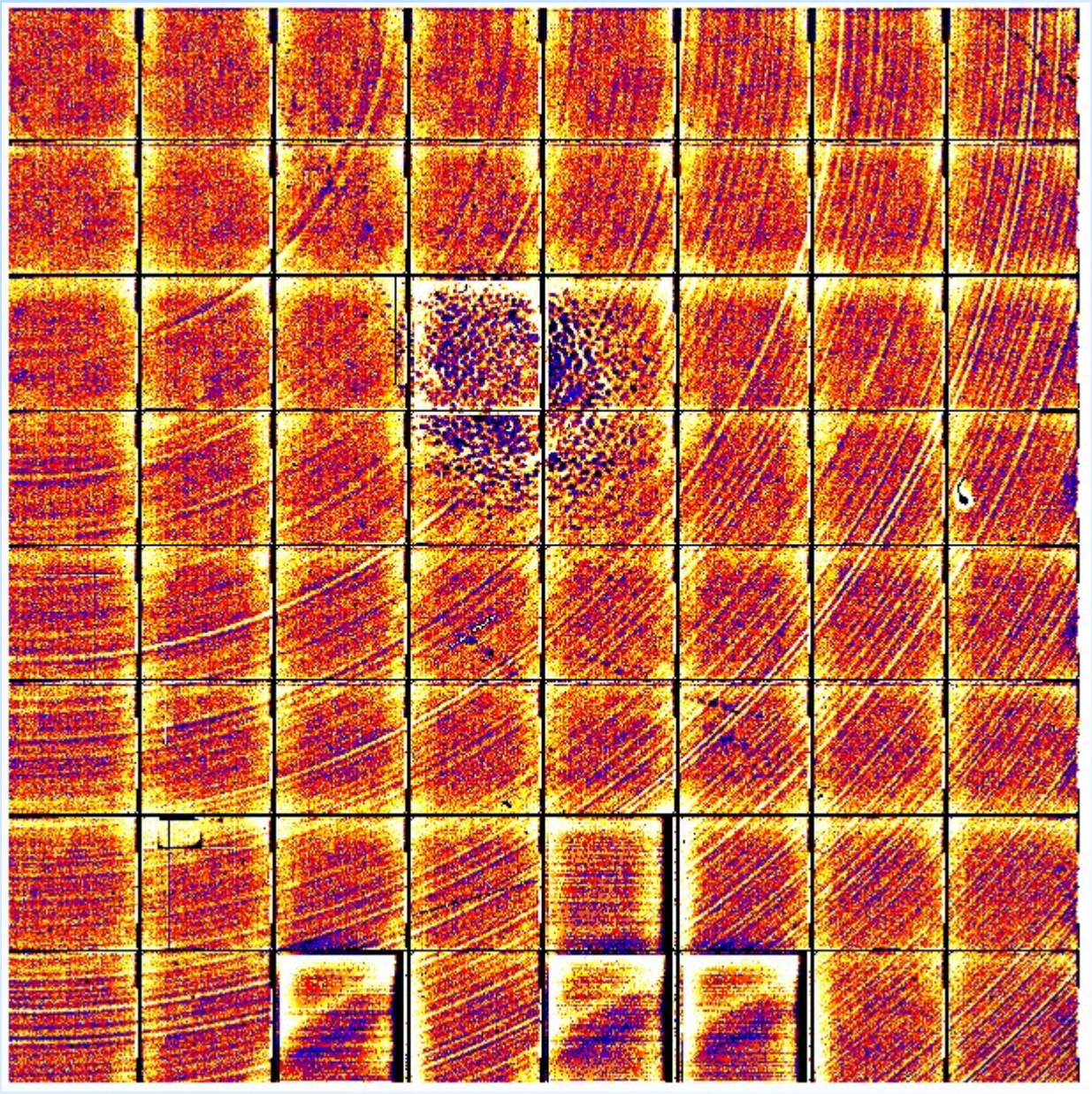
- plate scale -> flat field
- plate scale -> astrometry
- flat-field = grad (astrom)
- plate scale -> psf sigma
- Δpsf sigma = grad (astrom)
- psfmag err = apmag err / 2



GPC1 Tree Rings : Flat Field (after high-pass filtering)

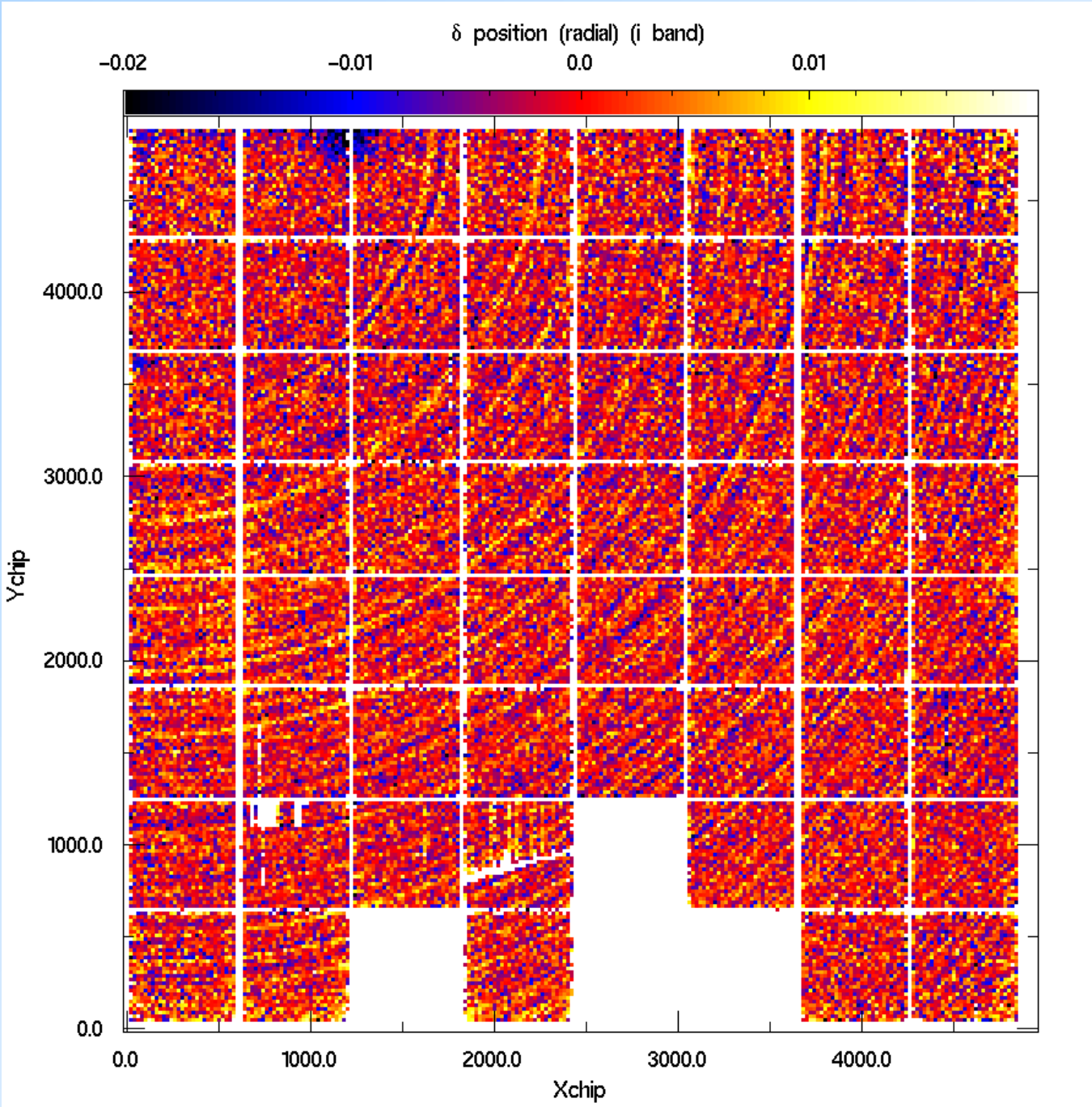
- plate scale -> **flat field**
- plate scale -> astrometry
- flat-field = grad (astrom)
- plate scale -> psf sigma
- Δpsf sigma = grad (astrom)
- psfmag err = apmag err / 2

monochromatic flat @ 630nm



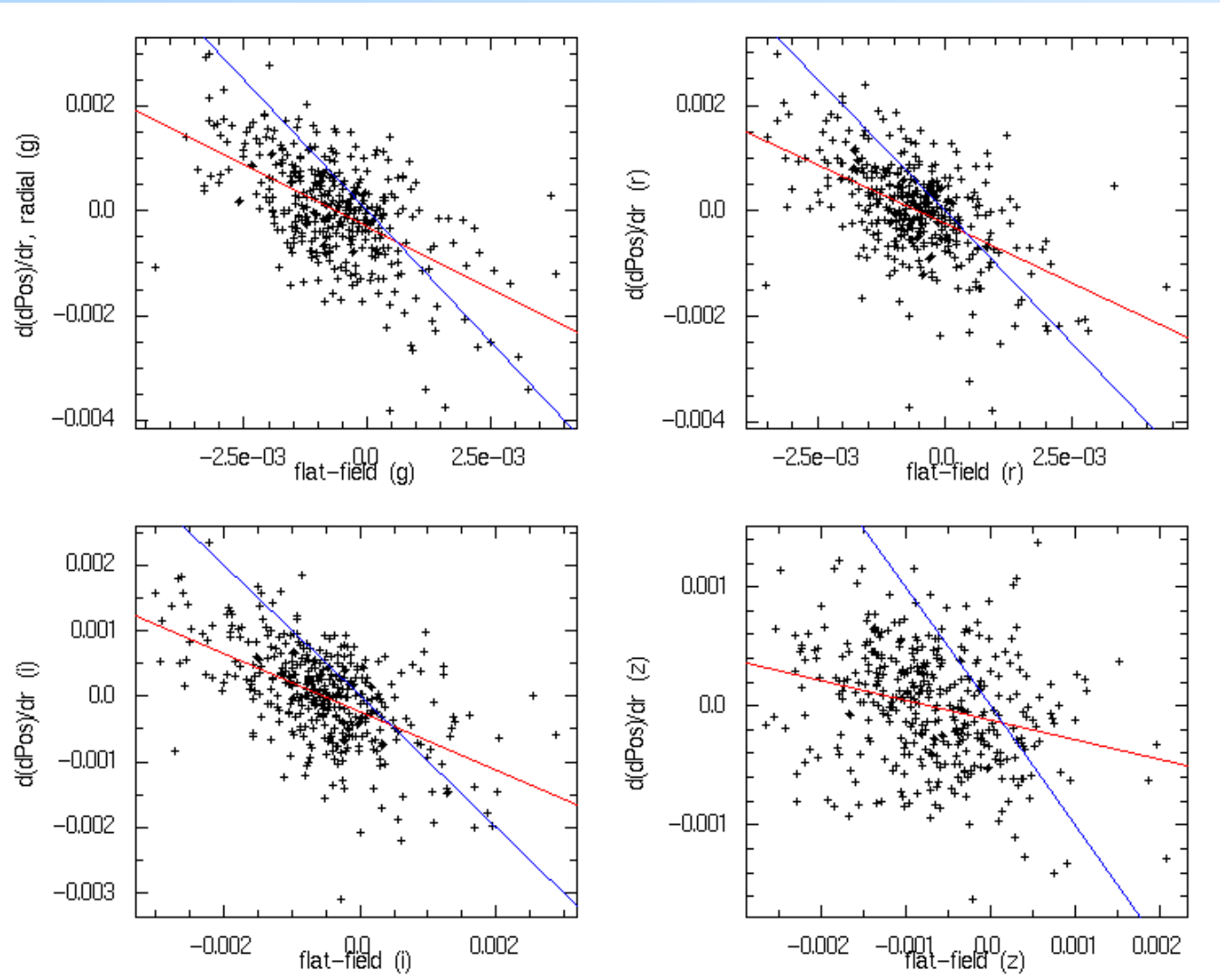
GPC1 Tree Rings : Astrometric Residuals (radial, i-band, XY40)

- plate scale -> **flat field**
- plate scale -> **astrometry**
- flat-field = grad (astrom)
- plate scale -> psf sigma
- Δpsf sigma = grad (astrom)
- psfmag err = apmag err / 2



GPC1 Tree Rings : Flat-field = gradient of astrometry errors

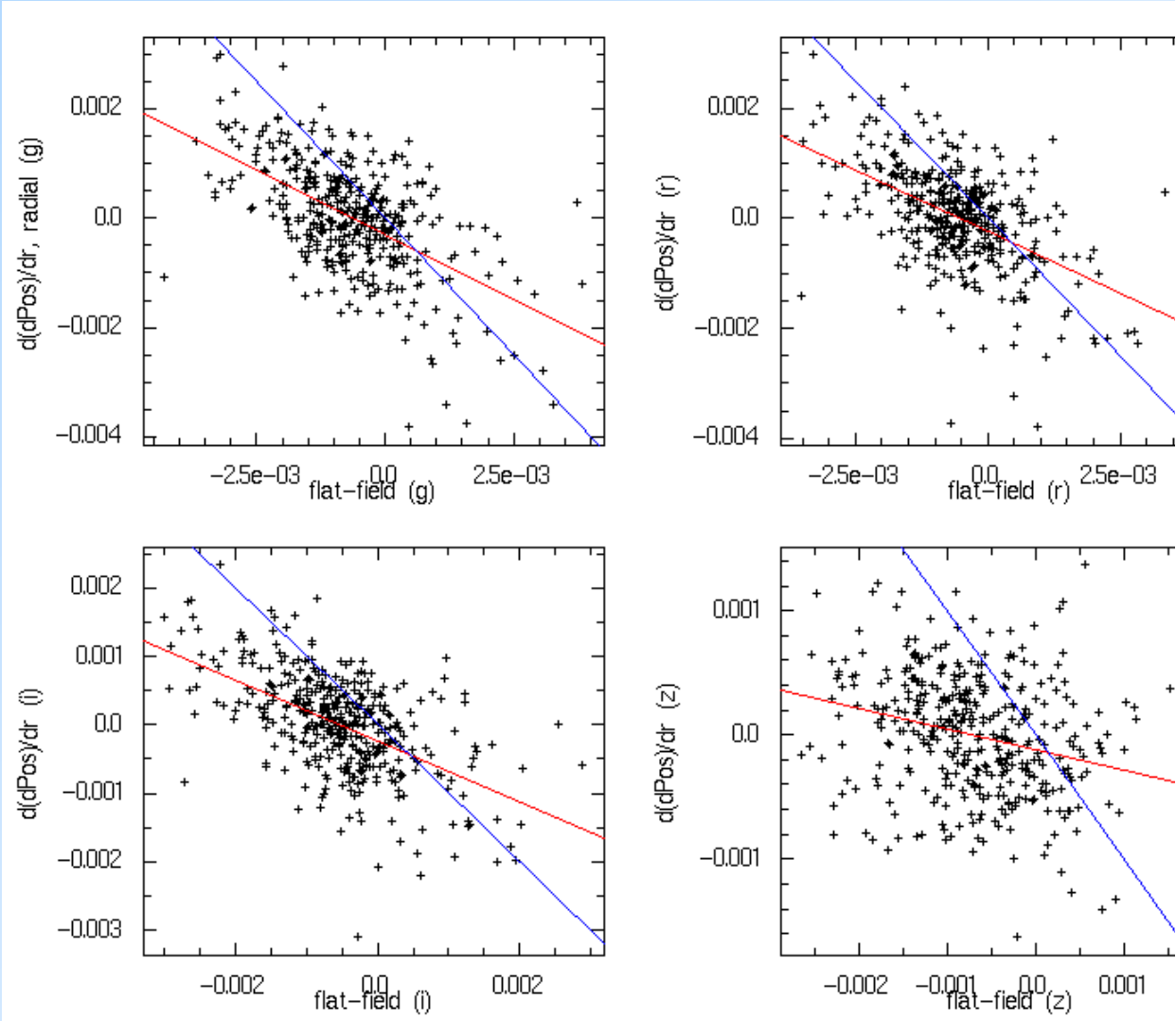
- plate scale -> **flat field**
- plate scale -> **astrometry**
- **flat-field = grad (astrom)**
- plate scale -> psf sigma
- Δpsf sigma = grad (astrom)
- psfmag err = apmag err / 2



GPC1 Tree Rings : Plate Scale -> Flat-field & astrometry errors

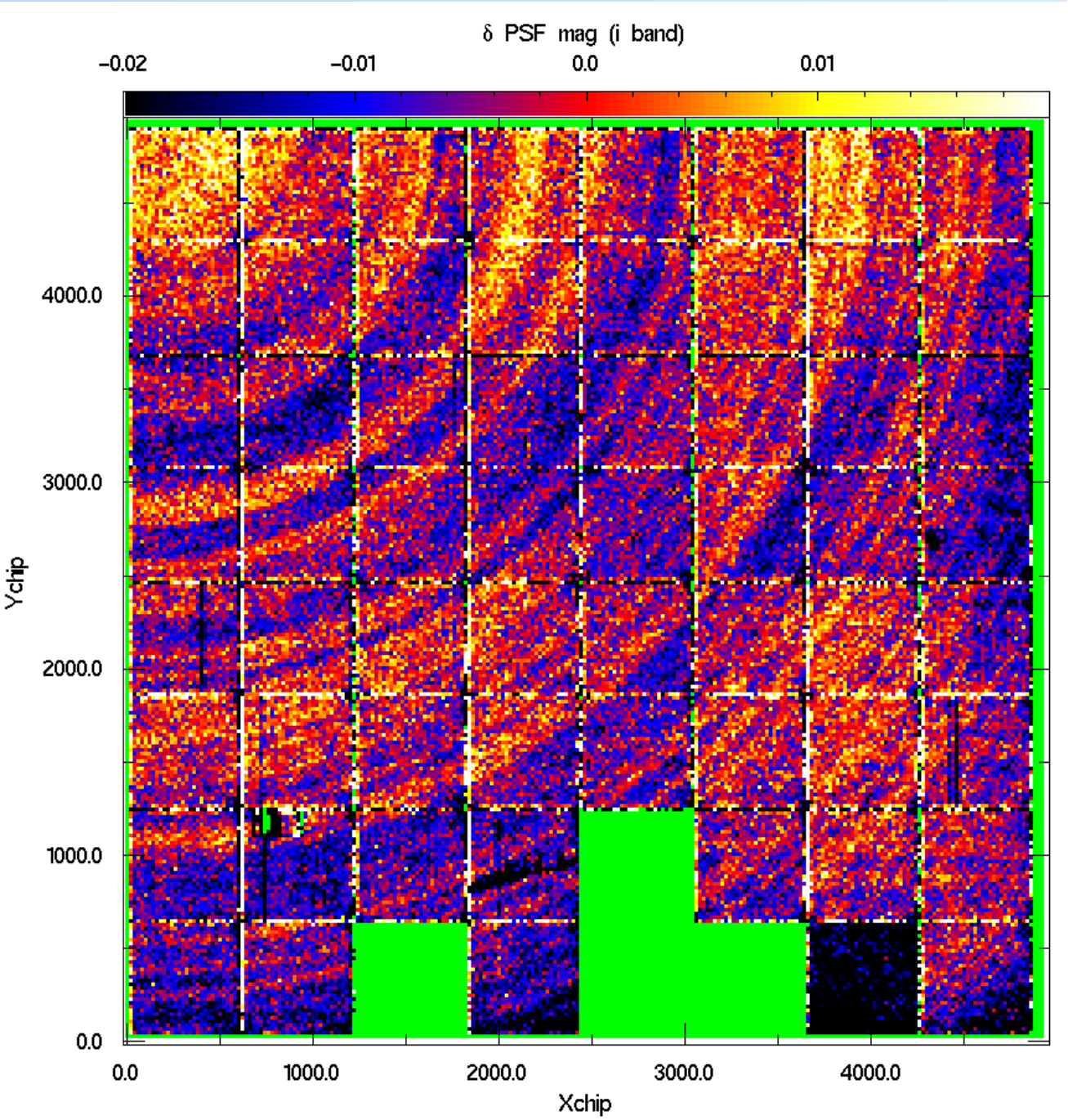
- **plate scale -> flat field**
- **plate scale -> astrometry**
- **flat-field = grad (astrom)**
- plate scale -> psf sigma
- Δpsf sigma = grad (astrom)
- psfmag err = apmag err / 2

- **NOTE amplitude of**
- **astrometry error:**
- **4 mas peak-to-peak in GPC1**
- **(vs 15 mas in DEC)**



GPC1 Tree Rings : PSF magnitude residuals

- **plate scale -> flat field**
- **plate scale -> astrometry**
- **flat-field = grad (astrom)**
- plate scale -> psf sigma
- Δpsf sigma = grad (astrom)
- **psfmag err = apmag err / 2**



GPC1 Tree Rings : Aperture magnitude residuals

- **plate scale -> flat field**
- **plate scale -> astrometry**
- **flat-field = grad (astrom)**
- plate scale -> psf sigma
- Δpsf sigma = grad (astrom)
- **psfmag err = apmag err / 2**

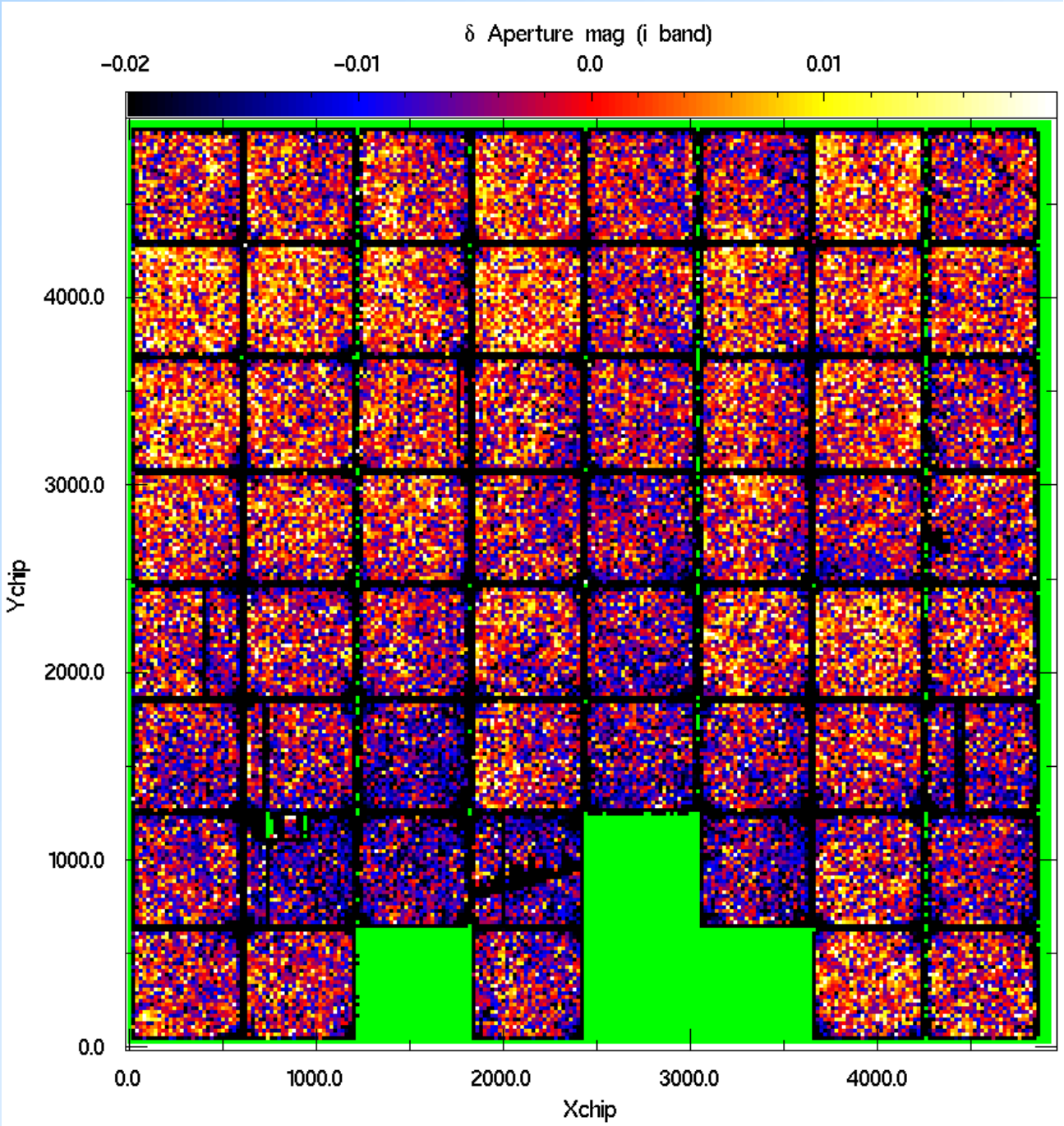


Image Shearing (σ^2_{major} - σ^2_{minor} : i-band, XY40)

- **plate scale -> flat field**
- **plate scale -> astrometry**
- **flat-field = grad (astrom)**
- **plate scale -> psf sigma**
- **Δpsf sigma = grad (astrom)**
- **psfmag err = apmag err / 2**

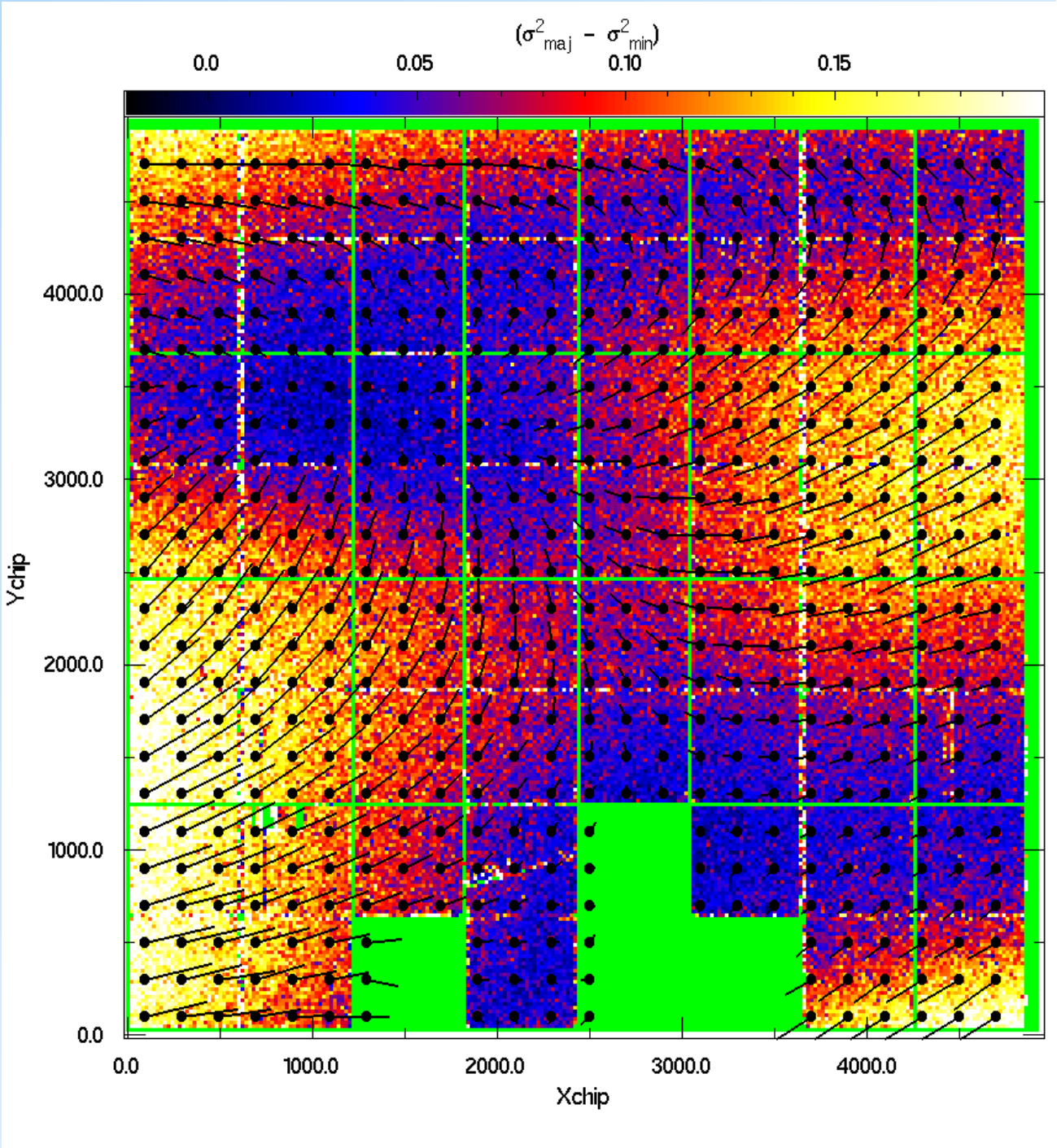
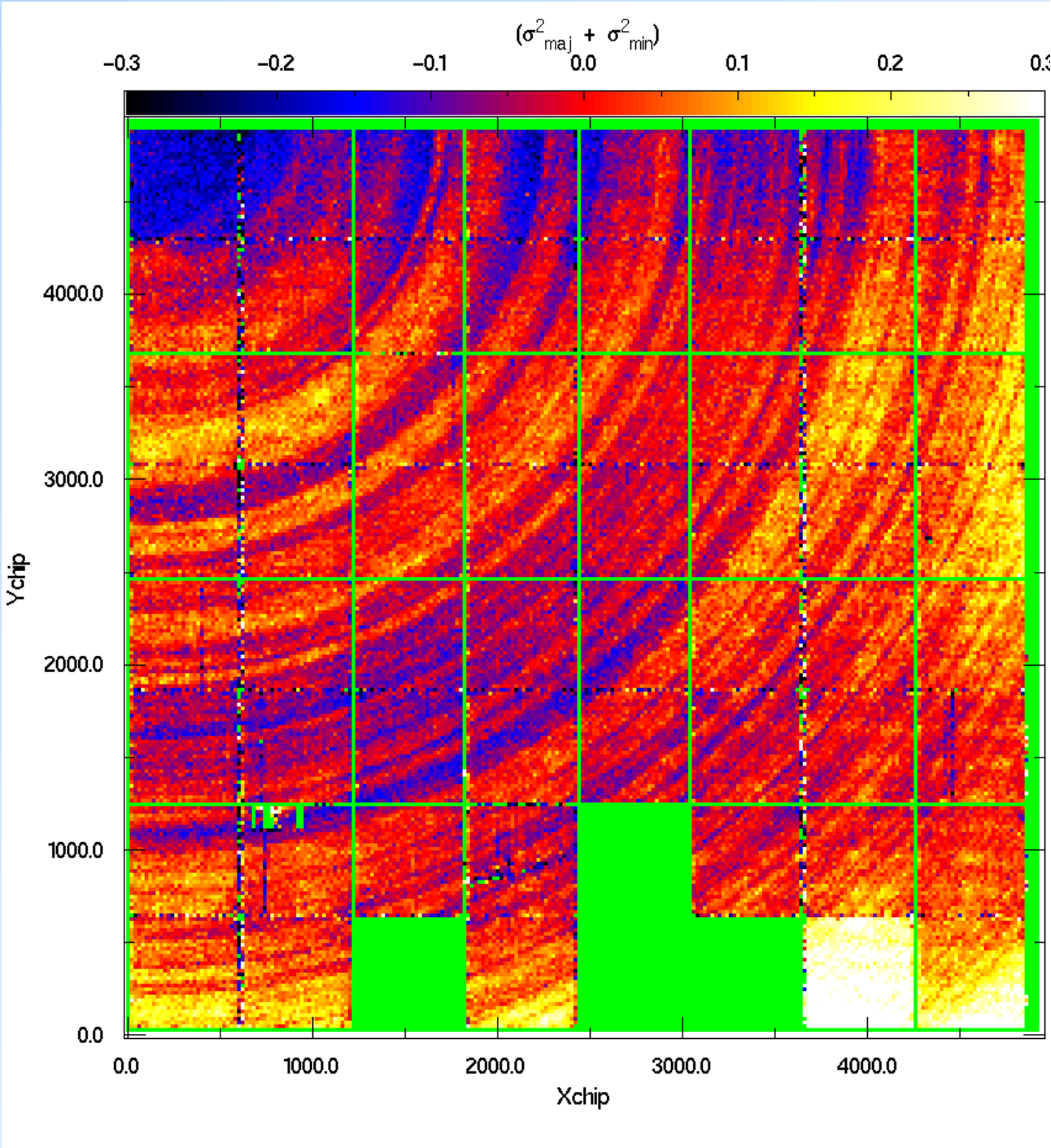


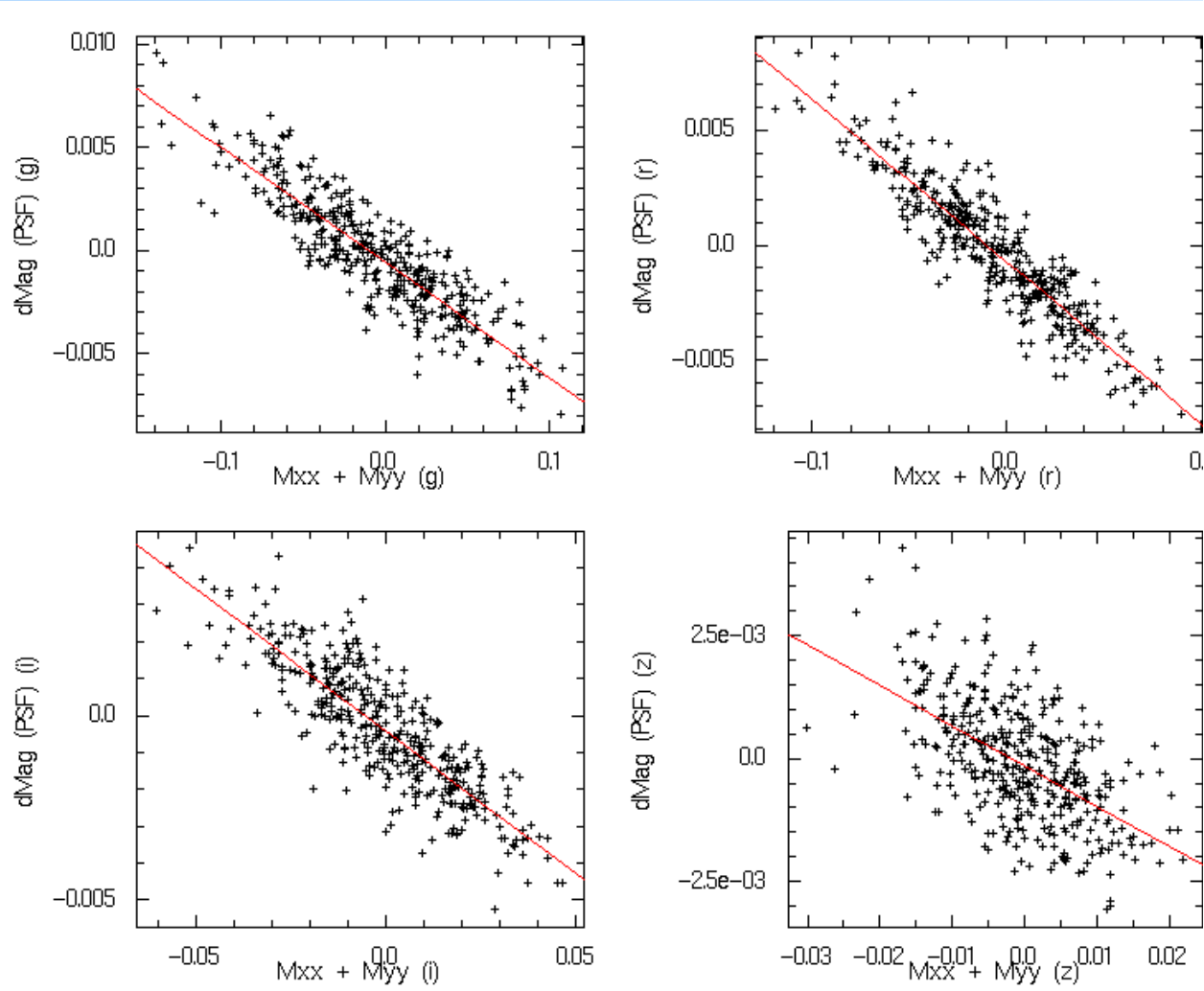
Image Smearing ($\sigma^2_{major} + \sigma^2_{minor}$: i-band, XY40)

- **plate scale -> flat field**
- **plate scale -> astrometry**
- **flat-field = grad (astrom)**
- **plate scale -> psf sigma**
- **Δpsf sigma = grad (astrom)**
- **psfmag err = apmag err / 2**



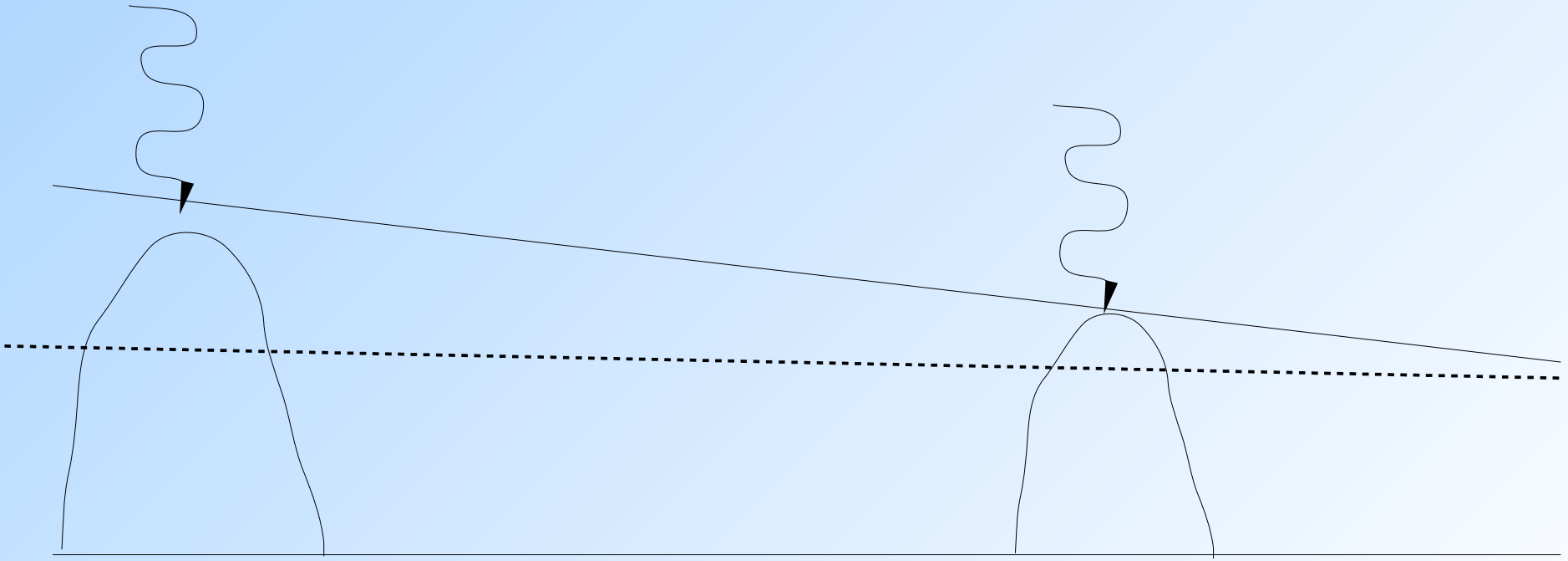
PSF magnitude residuals : correlations between filters

- **plate scale -> flat field**
- **plate scale -> astrometry**
- **flat-field = grad (astrom)**
- ~~**plate scale -> psf sigma**~~
- ~~**Δpsf sigma = grad (astrom)**~~
- ~~**psfmag err = apmag err / 2**~~
- **psf smear -> psfmag err**
- **grad(smear) -> astrom err**



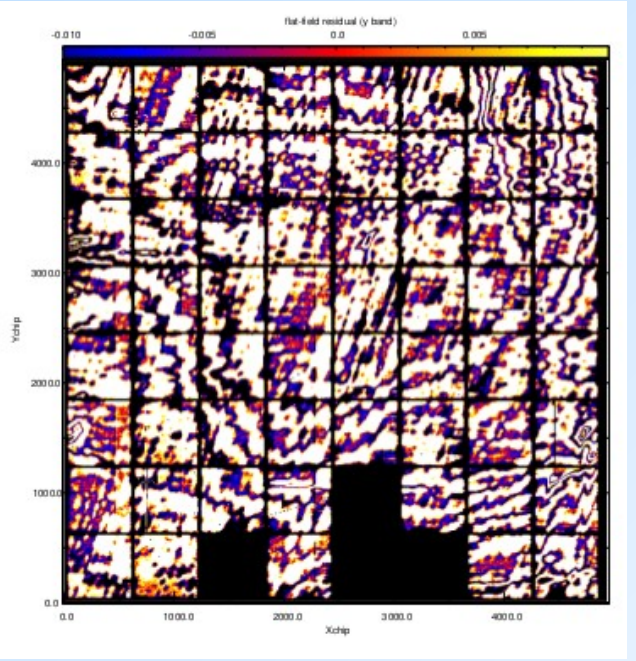
GPC1 Tree Rings : Causes?

- charge diffusion?
  - g-band smearing as an example:
  - $\sigma^2 \sim 0.05$ pixel^2 -> $\sigma \sim 2.2$ microns
  - mean charge diffusion ~ 3 microns
  - diffusion σ^2 ~ conversion depth [or E(z)]
  - if *floor* is 3 microns, range corresponds to 50% variations in depth!
  - for 5 micron variations in depth (1/15), floor is ~8.5 microns



GPC1 Tree Rings : Causes?

- focus variations?
  - $\sigma^2 \sim 0.05$ pixel^2 -> $\sigma \sim 2.2$ microns
  - beam is f/4 -> 8.8 micron variations in depth
  - inconsistent with fringe patterns



Conclusions

- GPC1 has a new and exciting type of tree ring effect!
- circularly symmetric smear -> PSF photometry errors
- related to (weaker) plate-scale variations (traditional tree rings)
- no good model for physical cause
  - charge diffusion implies implausibly large depth variations
  - focus variations implies implausibly large thickness variations
- affects the PSF in quadrature
  - cannot be taken out as multiplicative correction to the mean
  - include in the PSF model or per-exposure measurements
  - may now be the dominant term in PS1 photometry!

Filter	psf photom res vs smear	∂ smear / ∂ radius vs ΔR_{off}	$\partial \Delta R_{off} / \partial$ radius vs Δflat
g_{P1}	-0.056	-0.066	-0.47
r_{P1}	-0.071	-0.073	-0.45
i_{P1}	-0.077	-0.095	-0.45
z_{P1}	-0.082	-0.078	-0.17