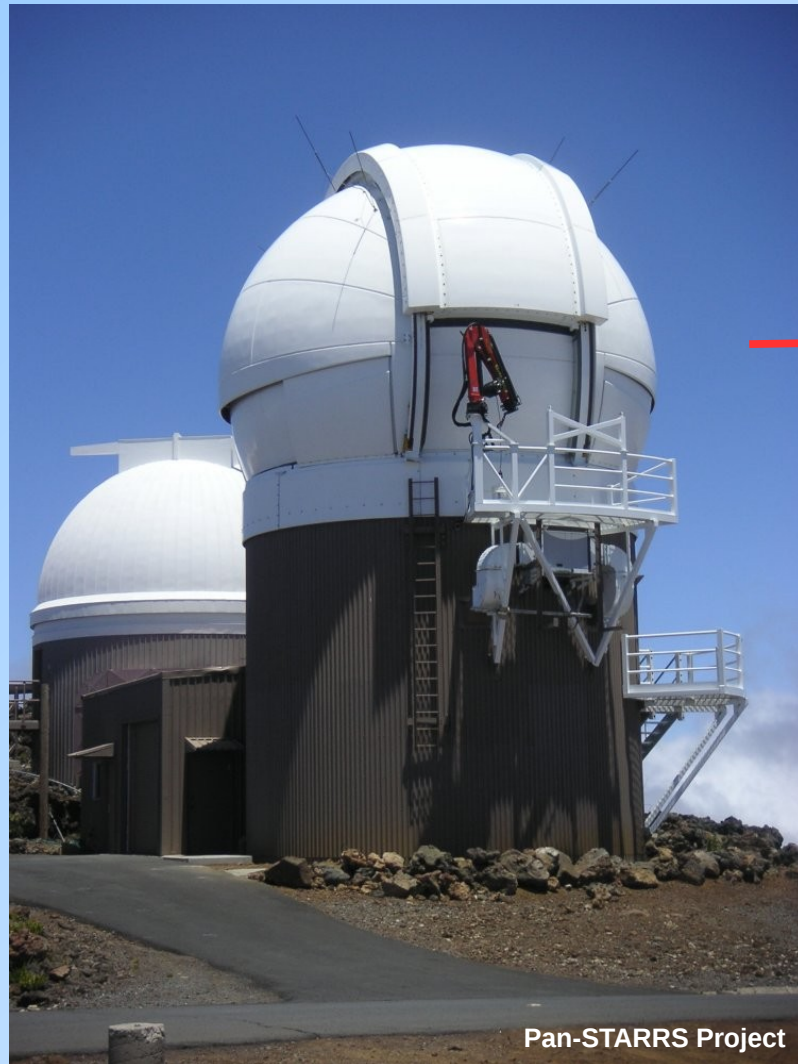# Precision Astrometry and Photometry from Pan-STARRS 1

Eugene Magnier

thanks to
John Tonry
Doug Finkbeiner

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

Pan-STARRS Project

PS-1 on Haleakala

Google

PS1 Survey Mission:
5/2010 – 3/2014

Surveys:
3pi : ~12 / filter
MD : ~500 / filter
others : M31, Solar System, STS

Google

PS1 consortium members

University of Hawai'i · UH Institute for Astronomy · Max Planck Institute for Extraterrestrial Physics · Max Planck Institute for Astronomy · JOHNS HOPKINS UNIVERSITY Department of Physics and Astronomy · Harvard-Smithsonian Center for Astrophysics · Queen's University, Belfast · University of Edinburgh · Durham University Institute for Computational Cosmology · National Central University, Taiwan · Las Cumbres Observatory Global Telescope Network

Photometry Performance

- 3pi reliability : (*grizy*) = (8, 7, 9, 11, 12) mmag
- MD reliability : all filters < 6 mmag
- per-exposure scatter ~ 10 – 15 millimags
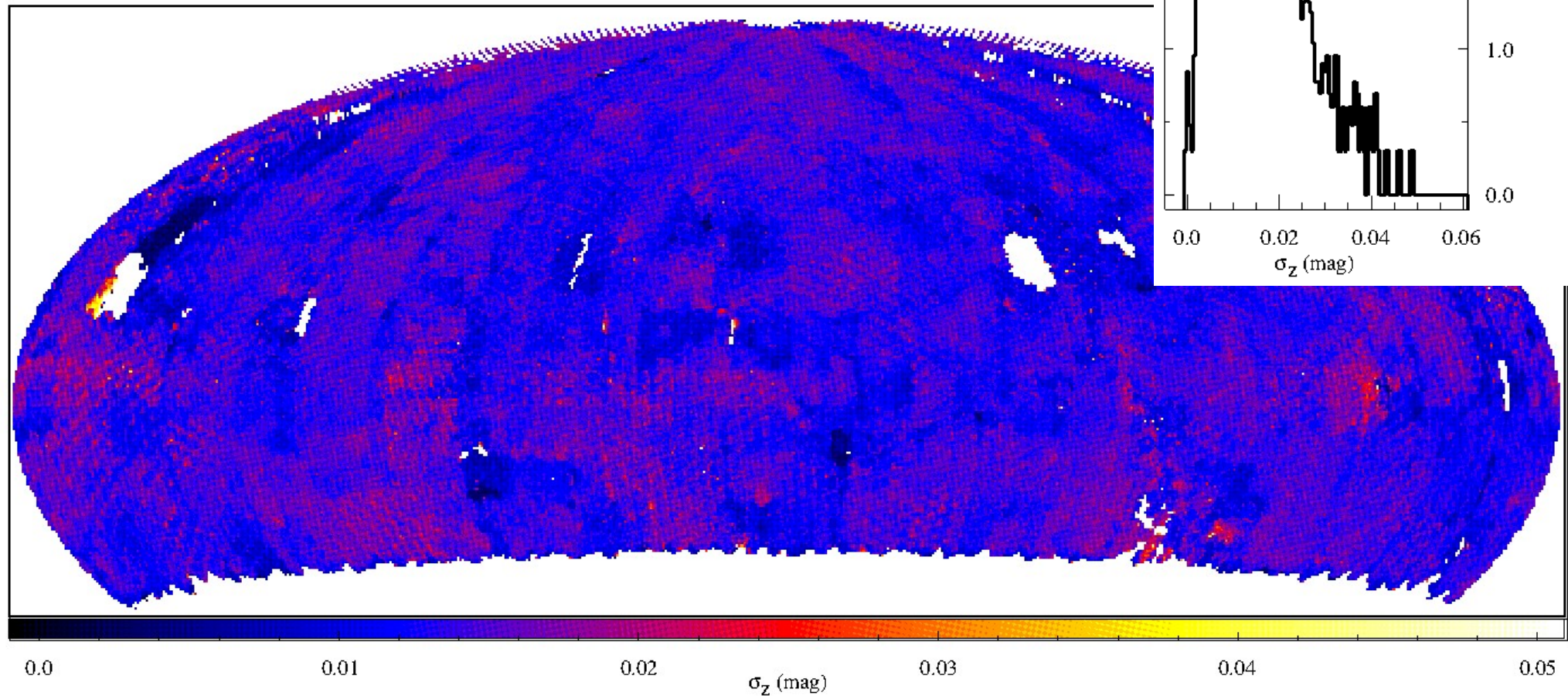
Photometry Performance

- PS1 vs SDSS shows systematic SDSS structures
  - Doug Finkbeiner is working on SDSS recalibration with PS1
  - eBoss will use PS1-based recalibration for target selections
  - In discussion for inclusion in future SDSS DR

SDSS Comparison

r $\sigma = 8.1$

-20   20
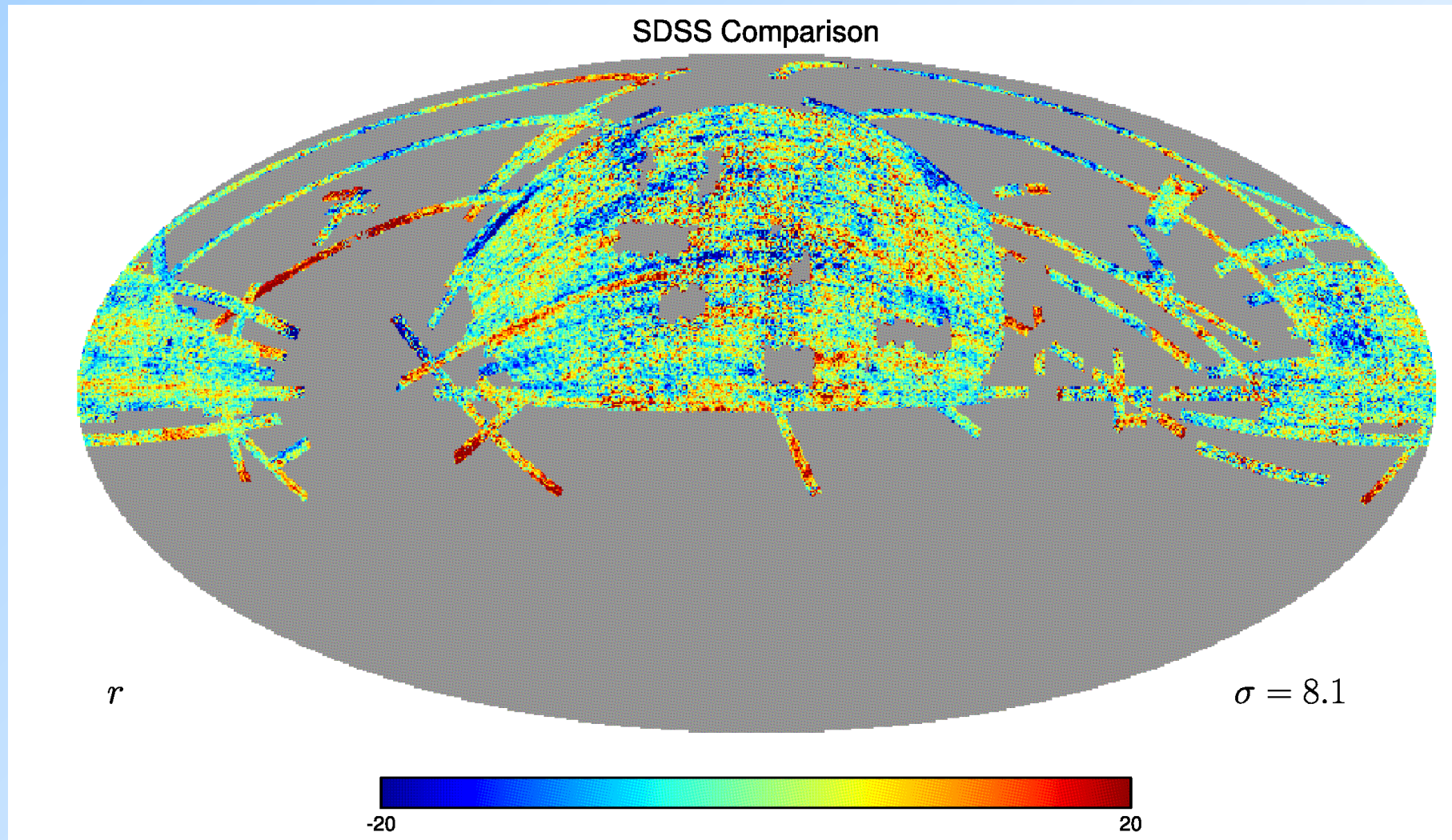
Astrometry Performance

- Per-detection : 18 - 20 mas (1D, depends on chip)
- Parallax limit (1.5yr) : 3-4 mas
- Proper-motion limit (1.5yr) : ~5 mas/yr
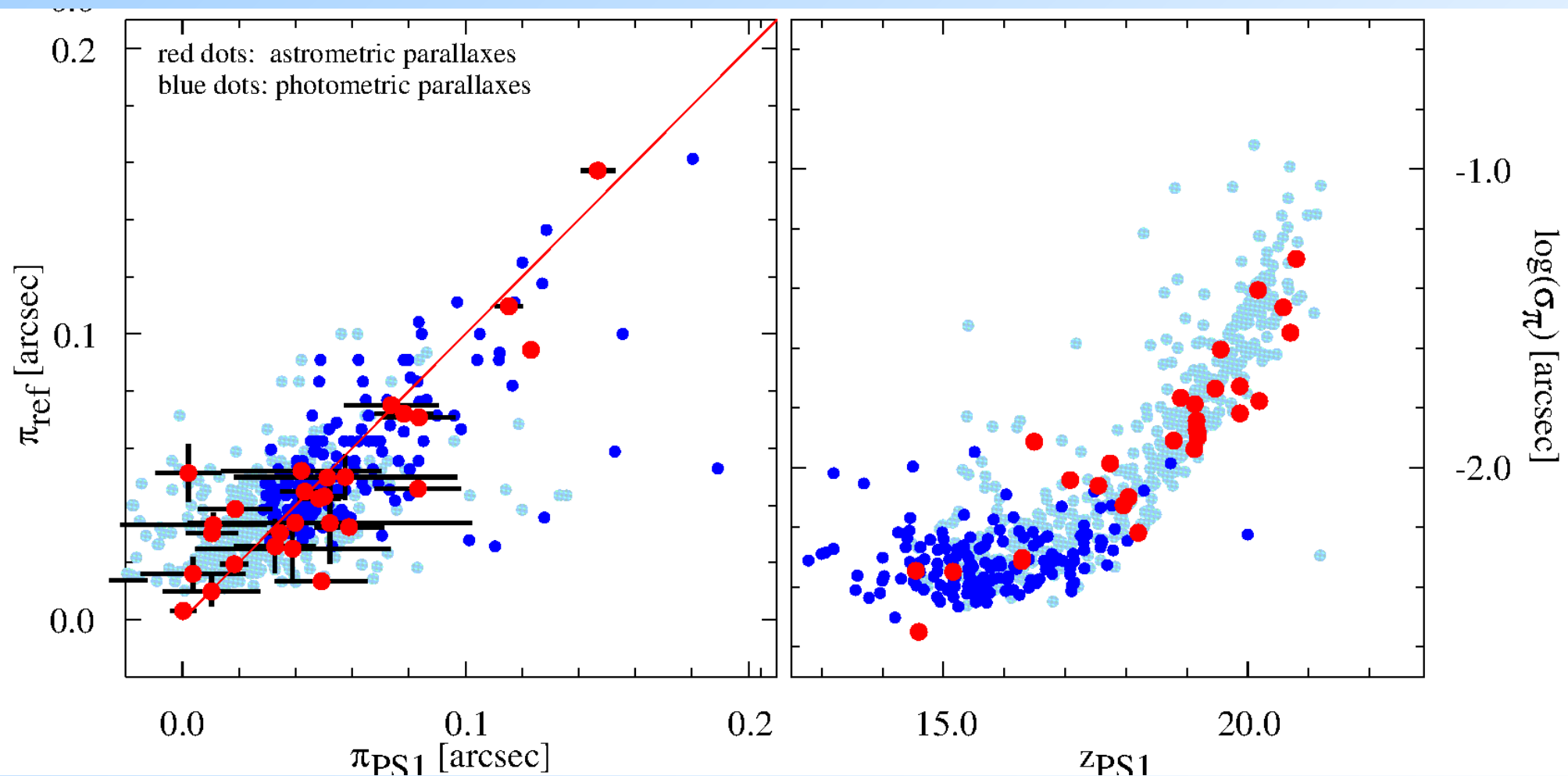
Instrumental Effects

- Bias, Dark, Flat
- Stellar photometric flat
- non-linear darks
- video-dependent dark structure
- persistence
- corner glows
- poor CTE regions
- non-linear response (per cell) at faint end
- non-linear response at bright end
- cross-talk (interchip and intrachip)
- row-by-row bias variations
- 2D PSF variations
- ghosts
- glints

The Koppenhoefer Effect

- bright-end position bias as function of magnitude
- discovered by Johannes Koppenhoefer in STS data
- camera voltages adjusted May 2011 to correct
- bias is only in X-direction
- only affect 2-phase chips (50% of focal plane)
- bias is up to 150-200 mas
- this is *not*
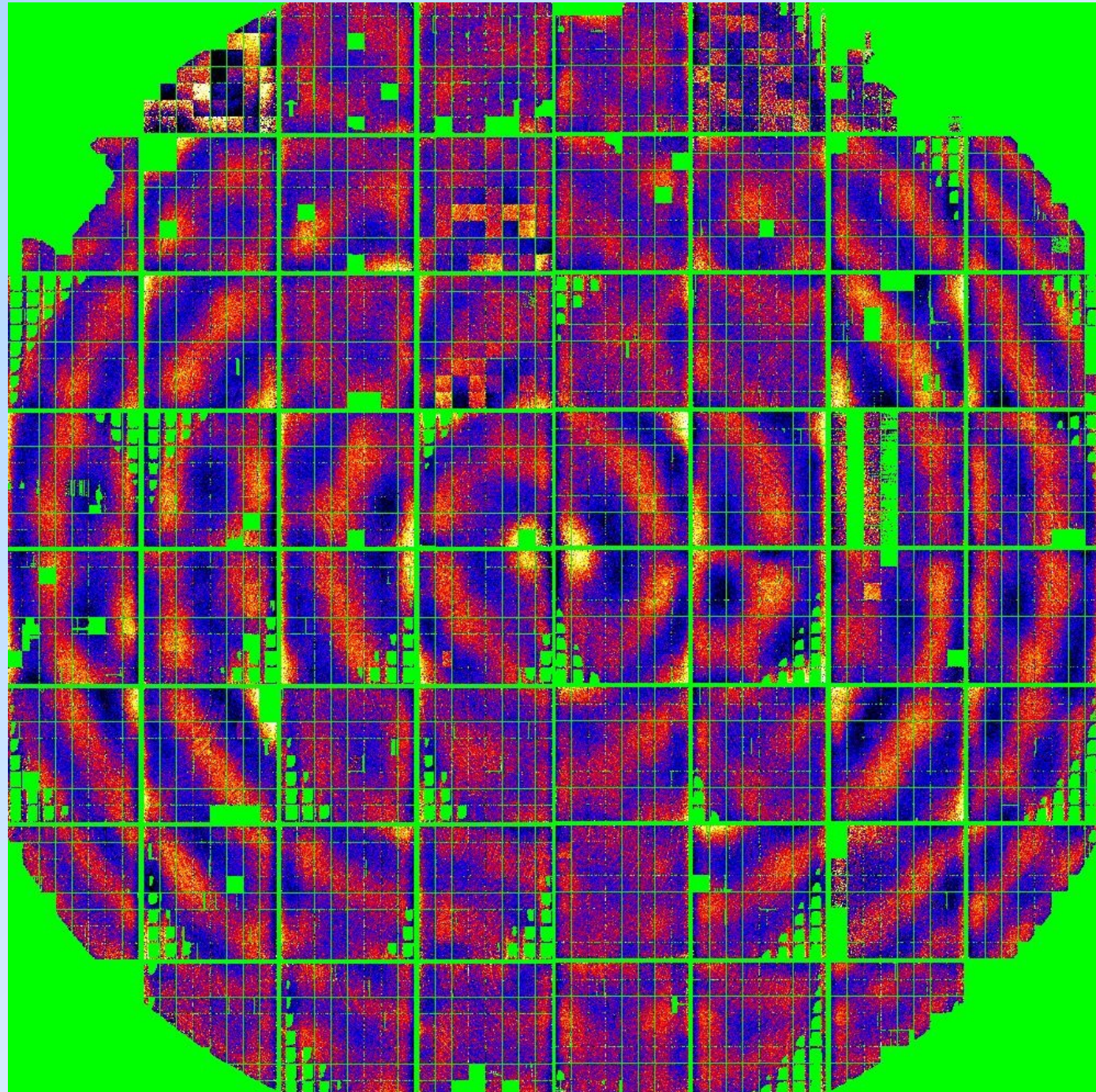 - CTE (wrong direction)
  - saturation (too early)
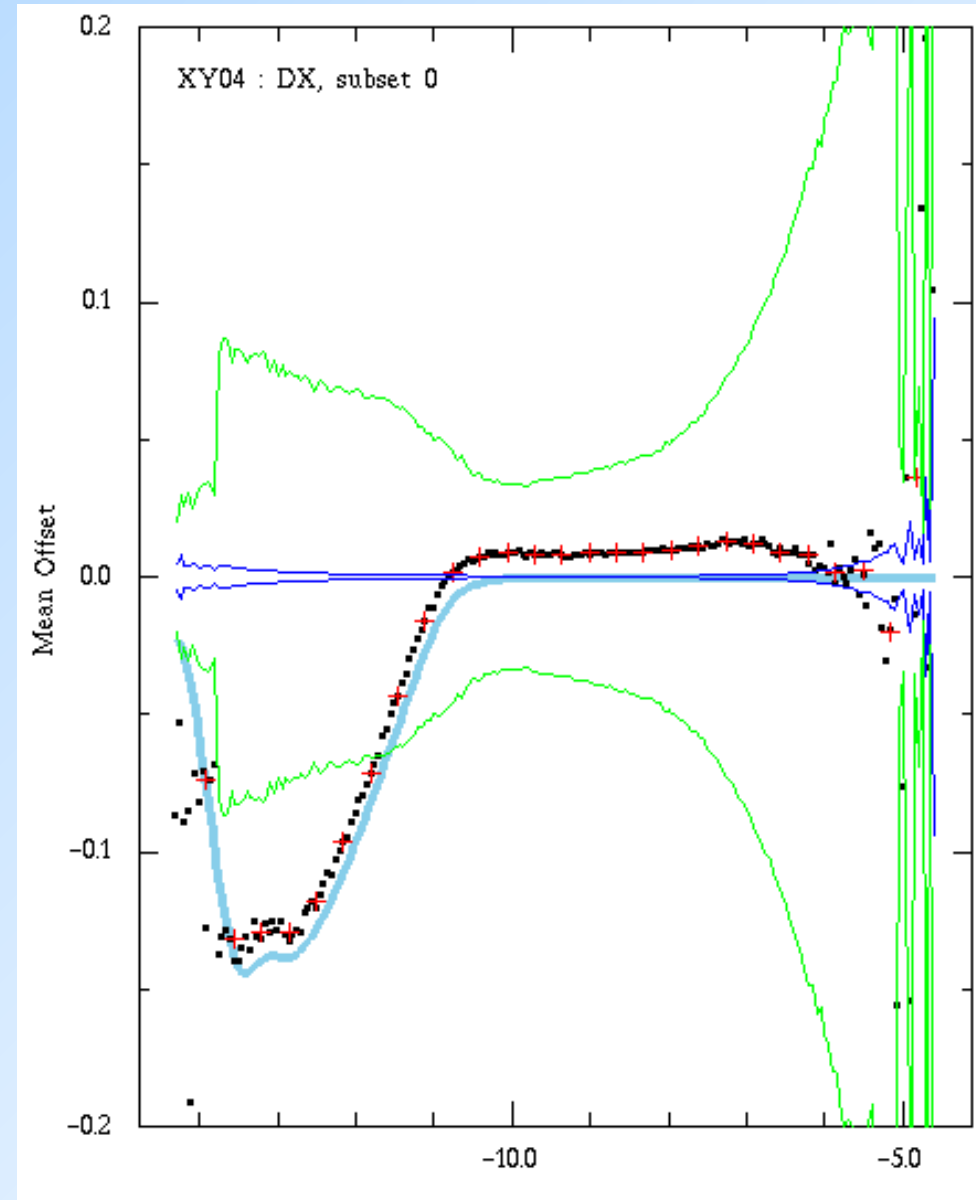
The Koppenhoefer Effect
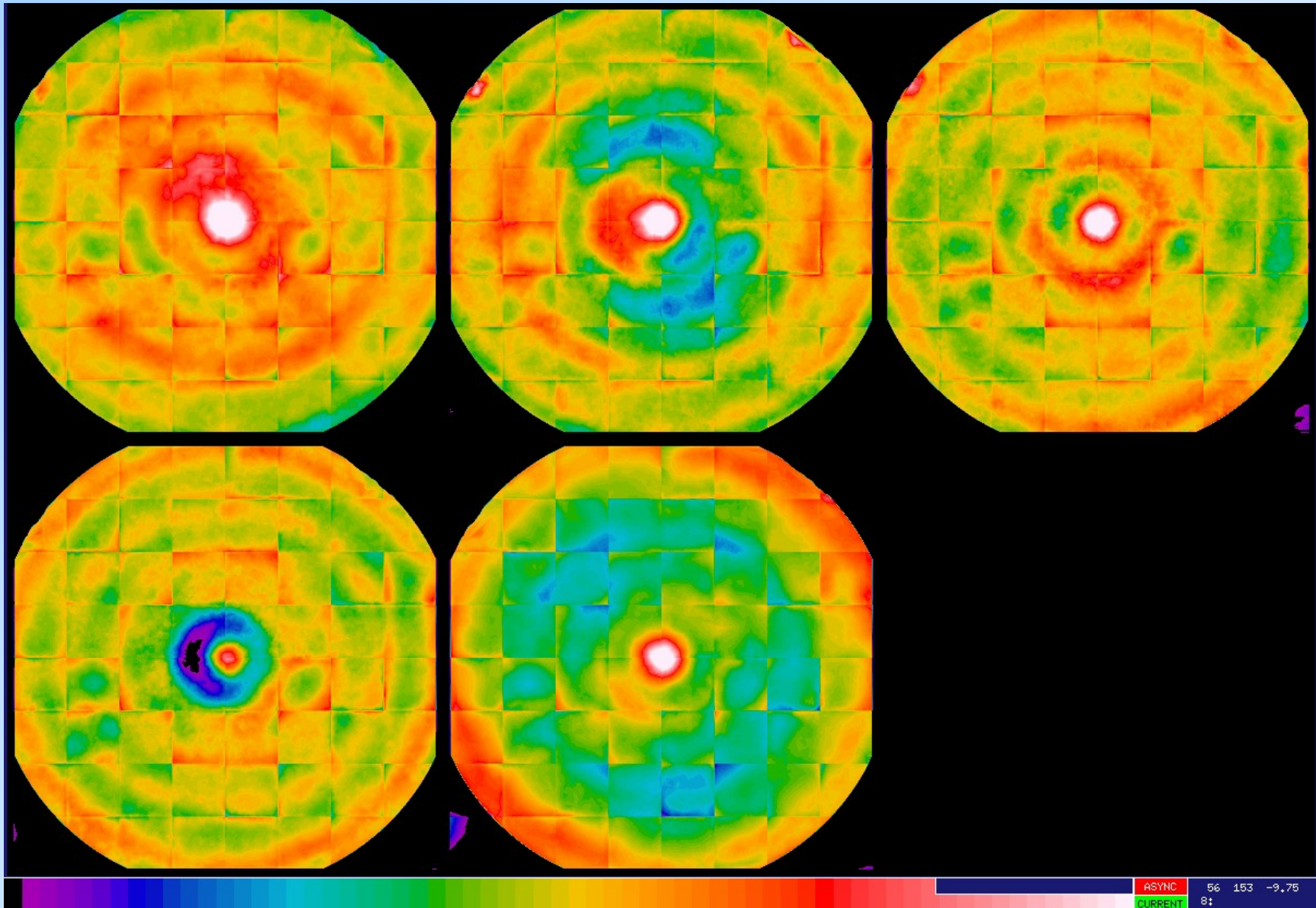
- correction effect on typical errors (25mas -> 18mas)
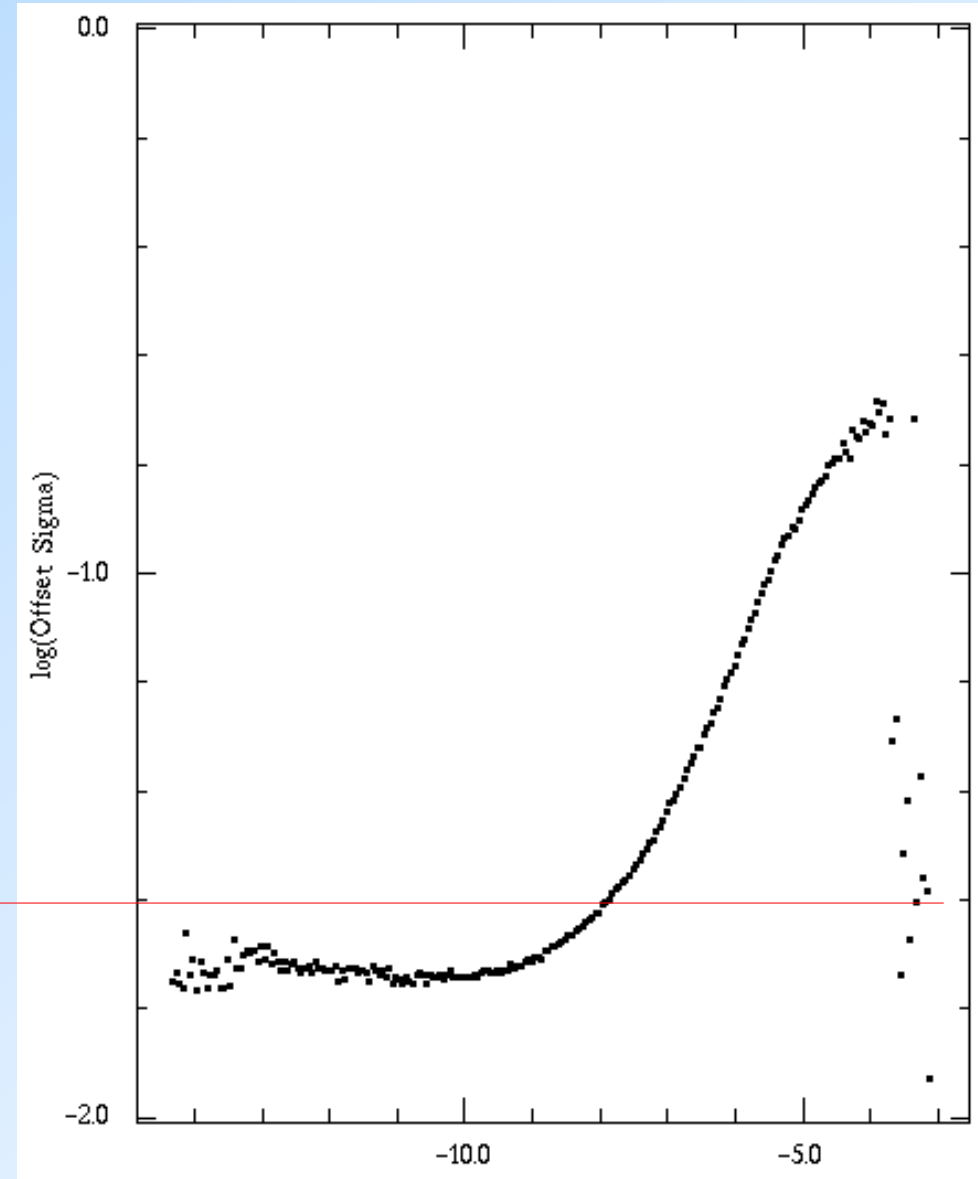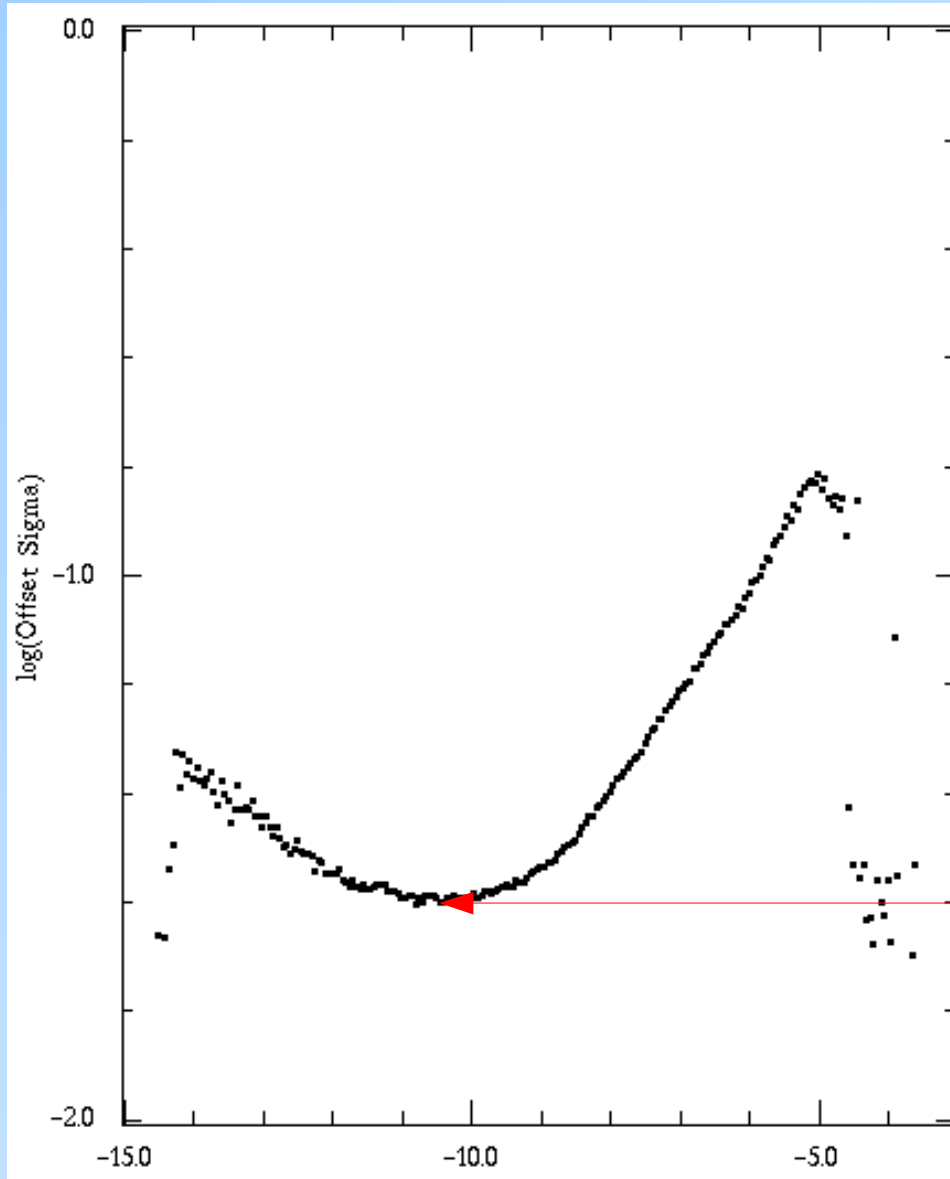
Astrometric Systematics

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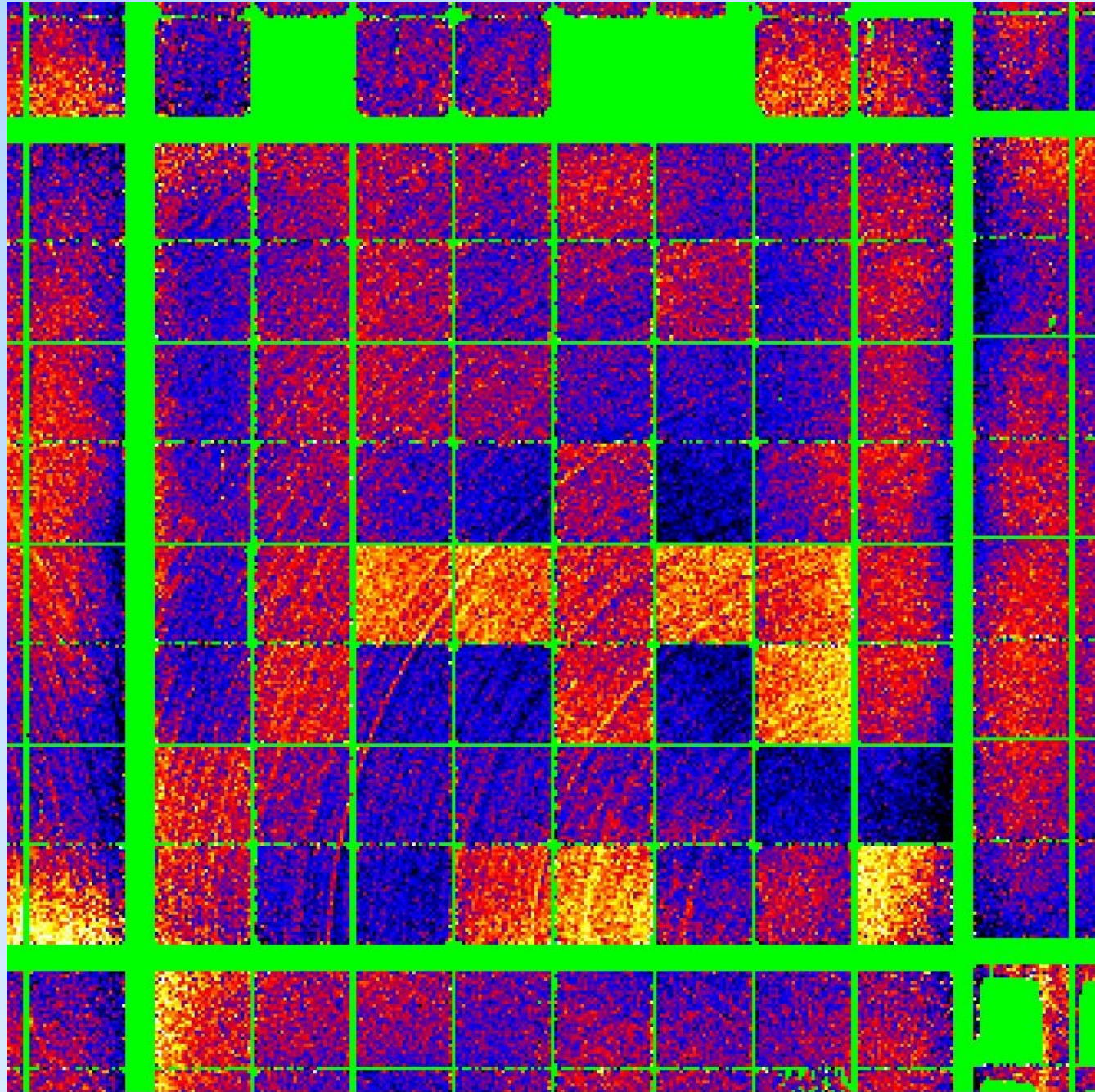- large-scale structure similar to focal-plane deviations

Astrometric Residuals : Large-Scale Circular Pattern

- Similar to focal-plane surface residual
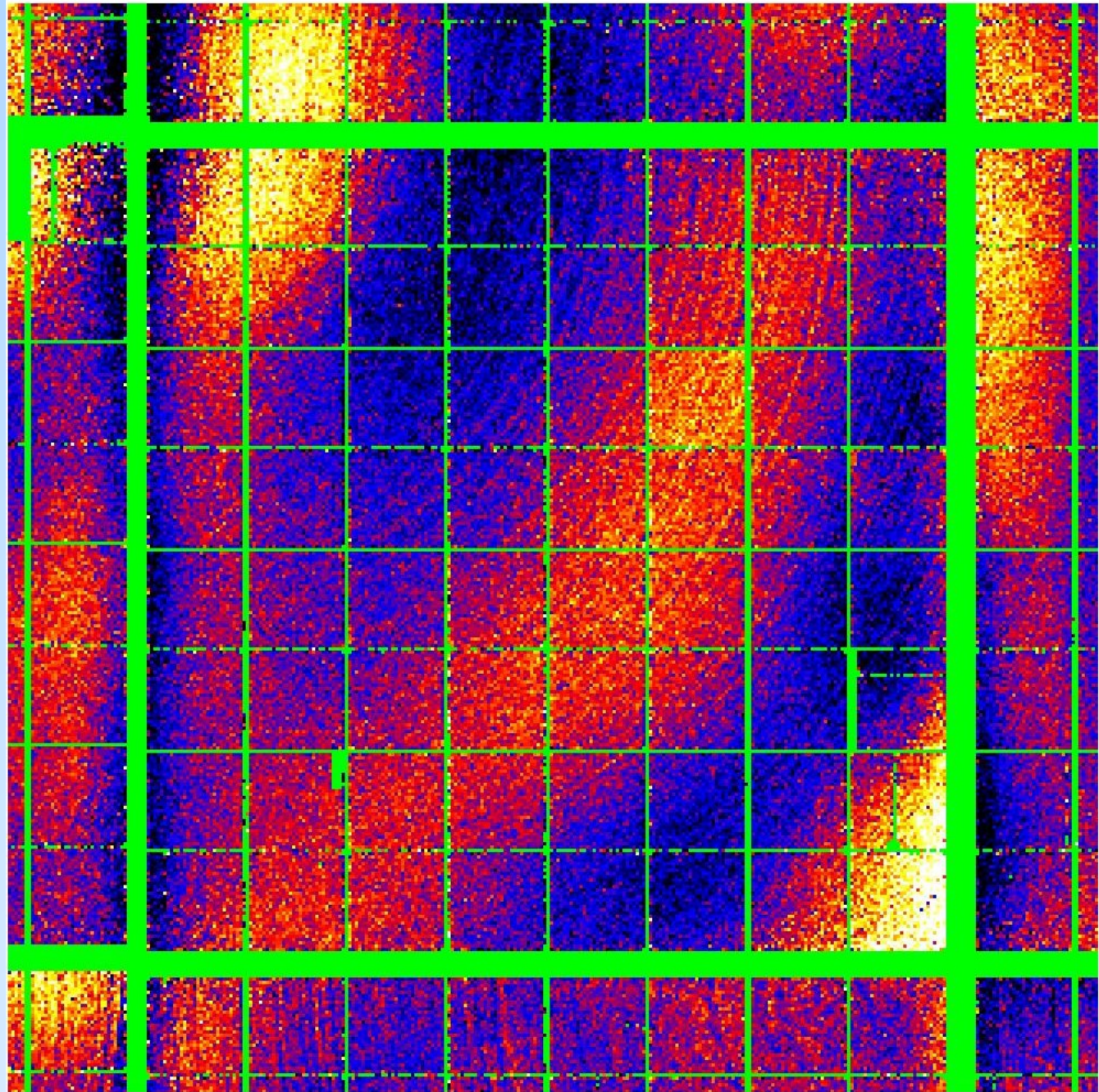- does the trend match in detail (e.g., per filter?)

Astrometric Systematics : Cell-by-cell offsets

- mean residuals as a function of camera position
- other structure quantized per cell.

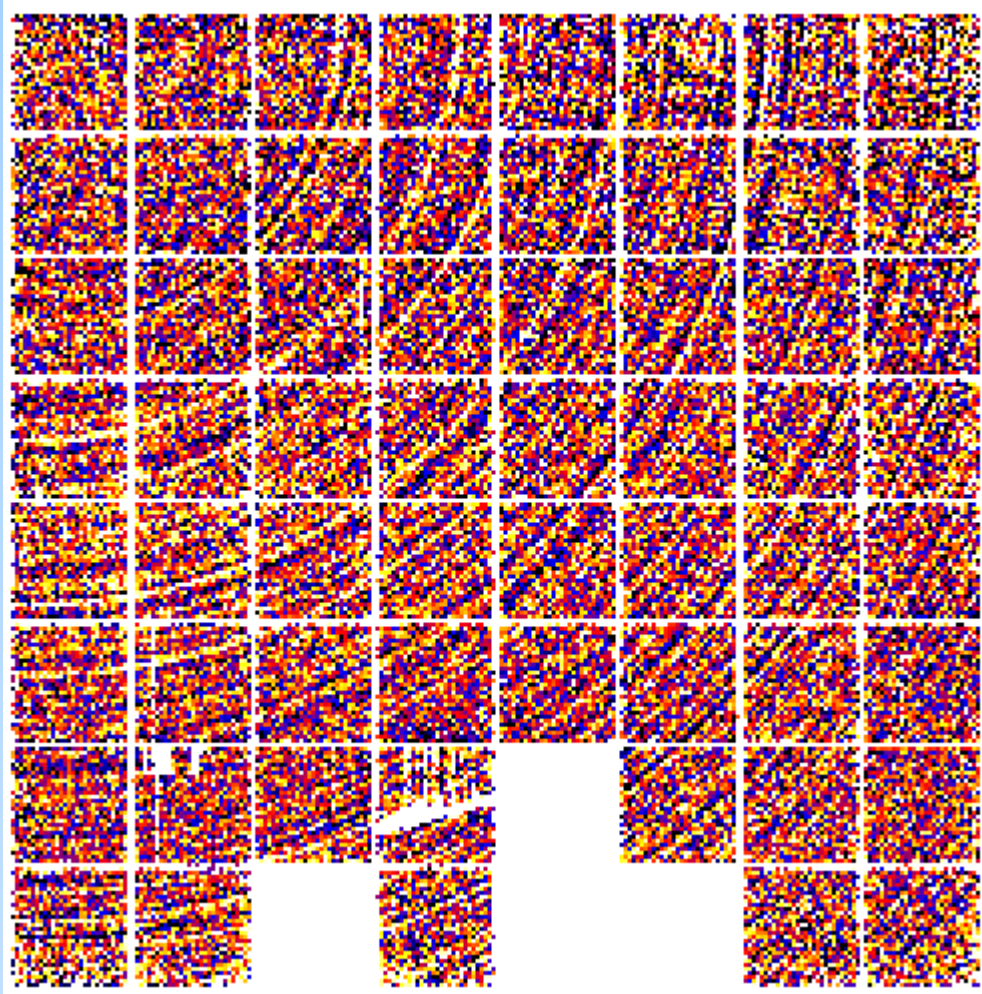# Astrometric Systematics : Tree Rings

- mean residuals as a function of camera position
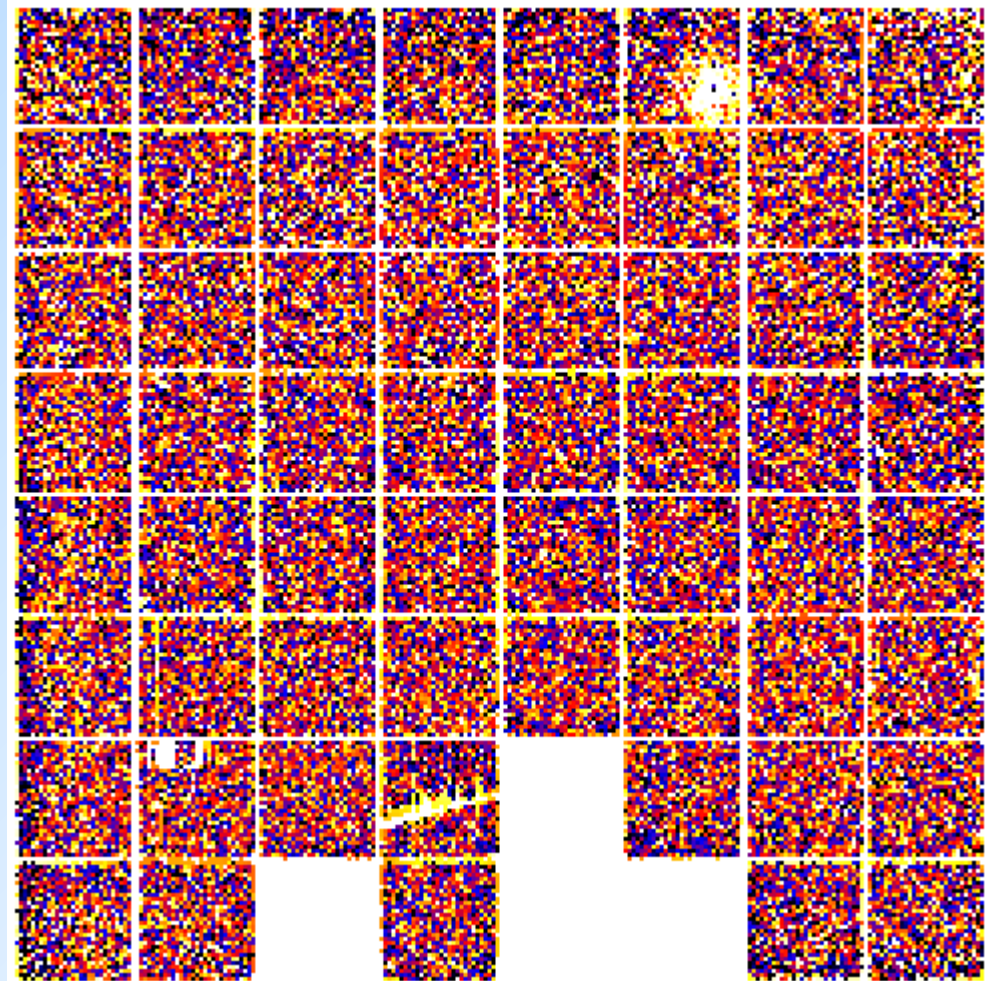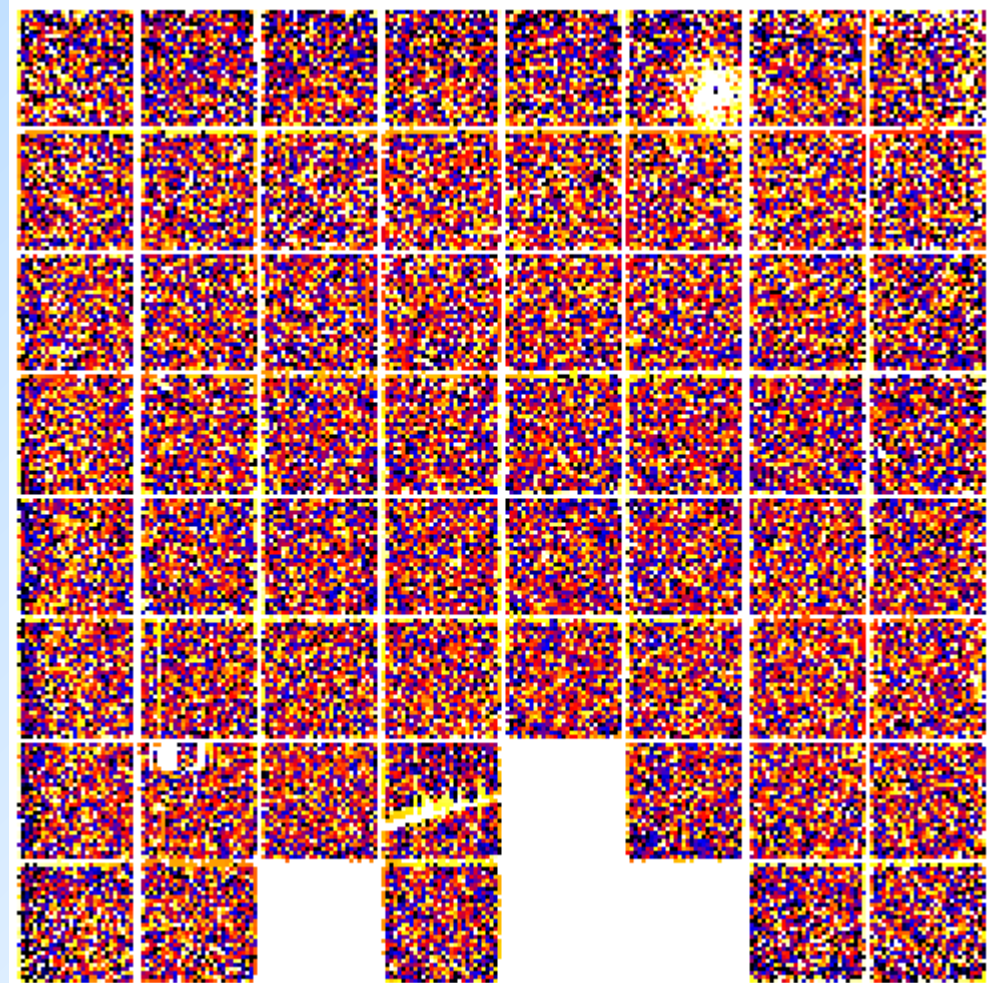- 'tree-rings' (also seen by DES, others)

Astrometry Residual

- convert dX,dY to dR,dTheta
- subtract a smoothed version (high-pass filter)

radial component   tangential component

Astrometry Residual

- convert dX,dY to dR,dTheta
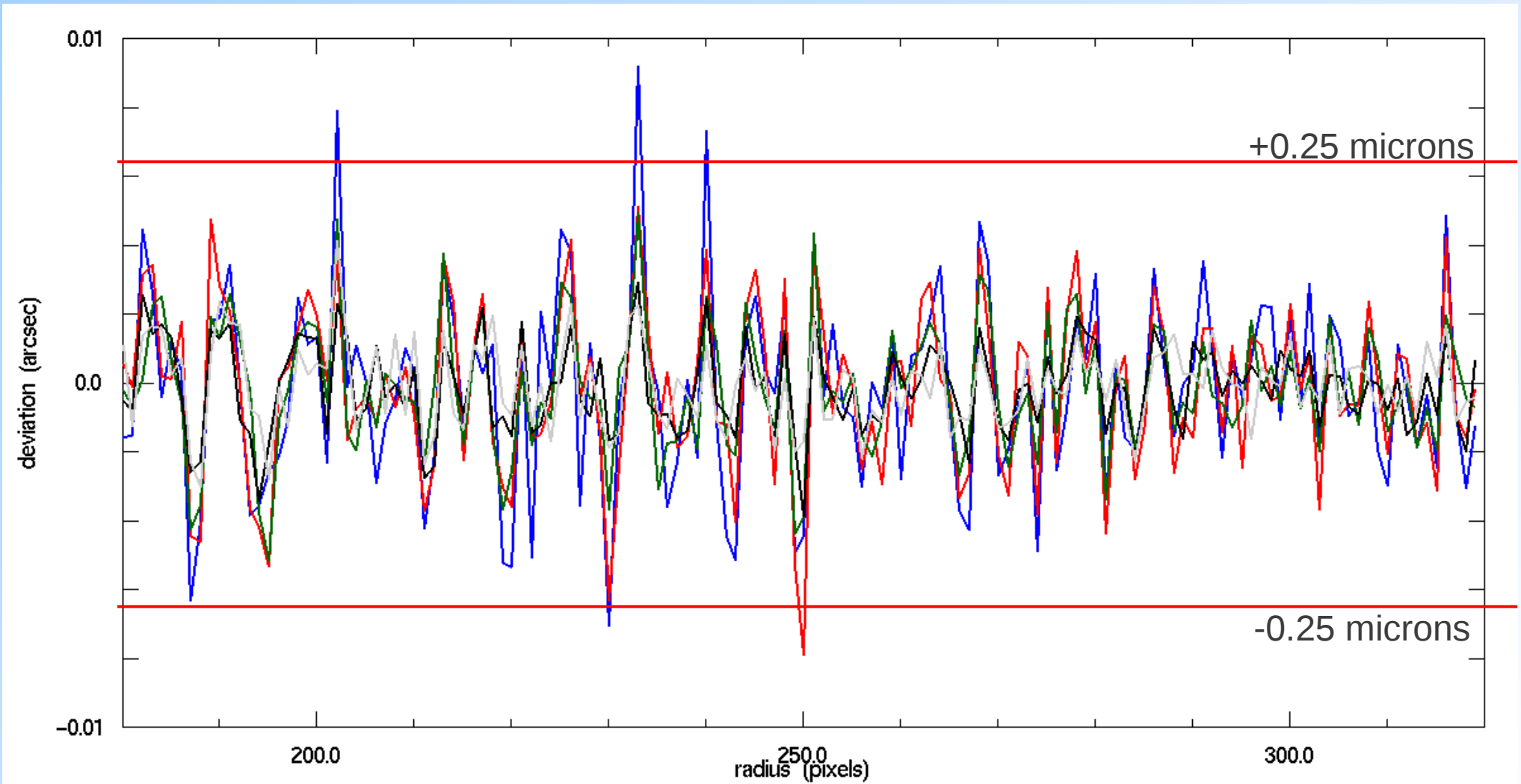- subtract a smoothed version (high-pass filter)
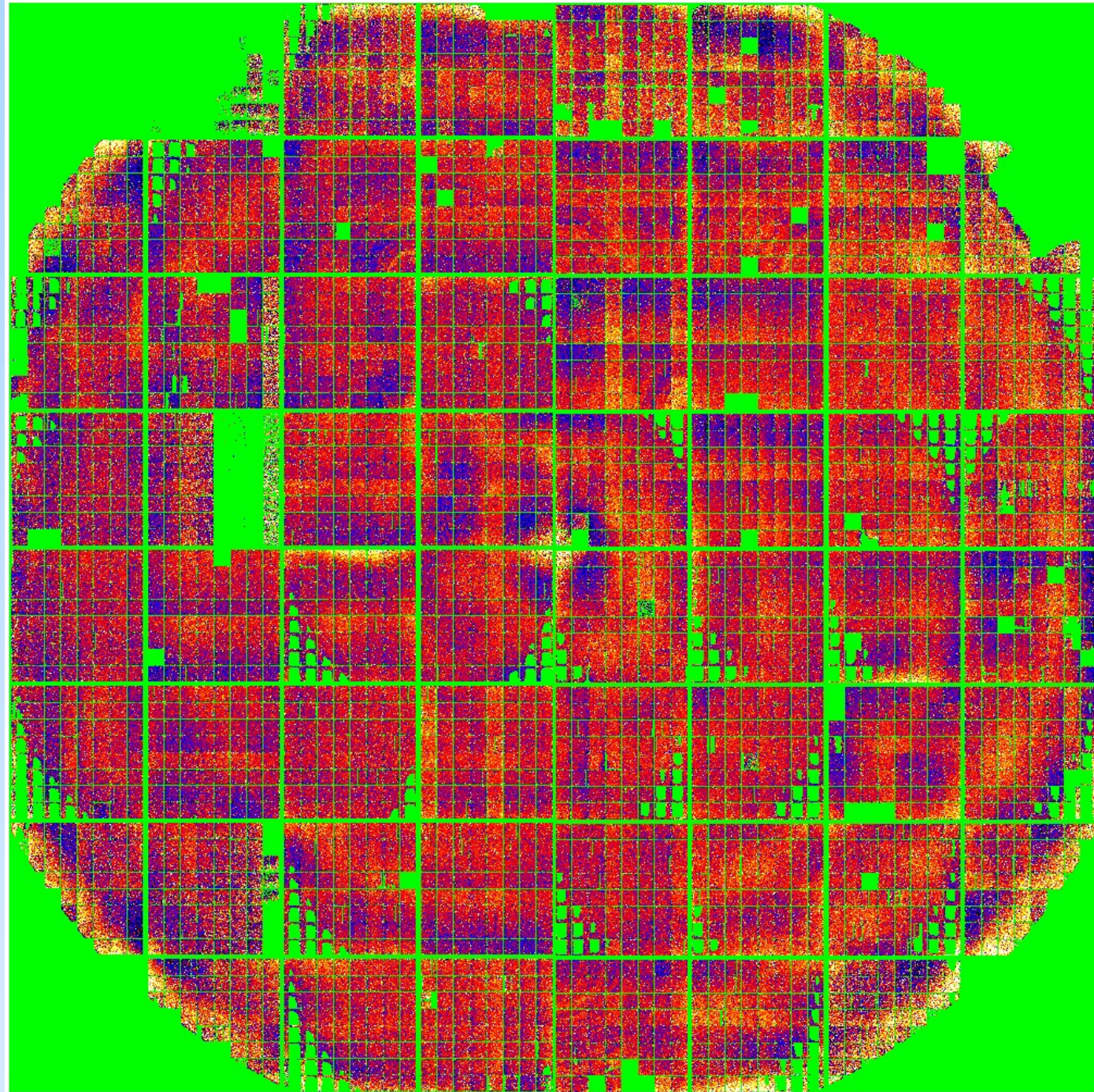
radial component

tangential component

Astrometric Deviations

- *grizy* deviations are correlated, with scaling:
- dR_f / dR_g = (0.50, 0.36, 0.23, 0.21) for f = (*r, i, z, y*)
- (*grizy*) = (blue, red, green, black, grey)

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

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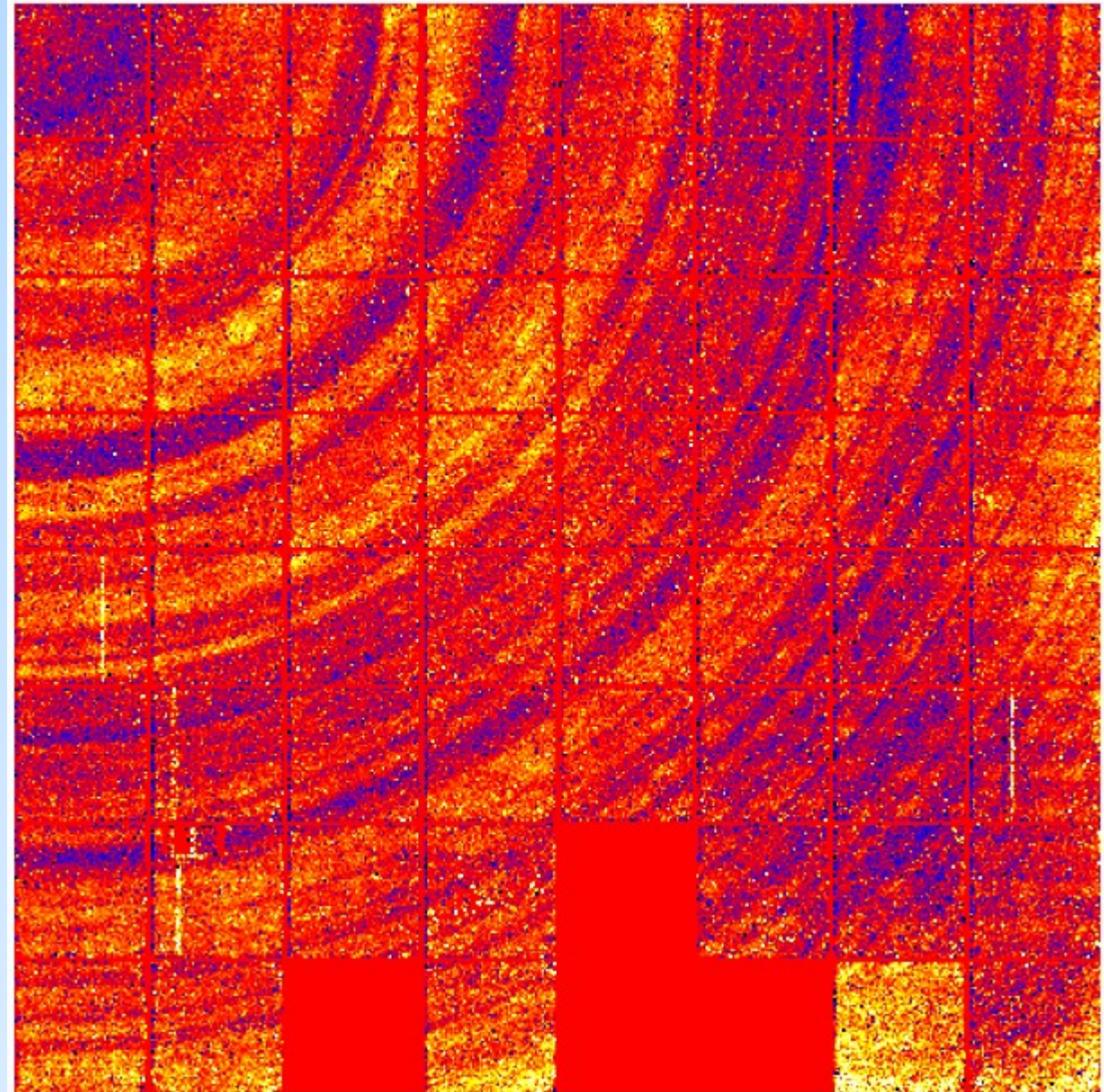- 'tree-rings' also seen
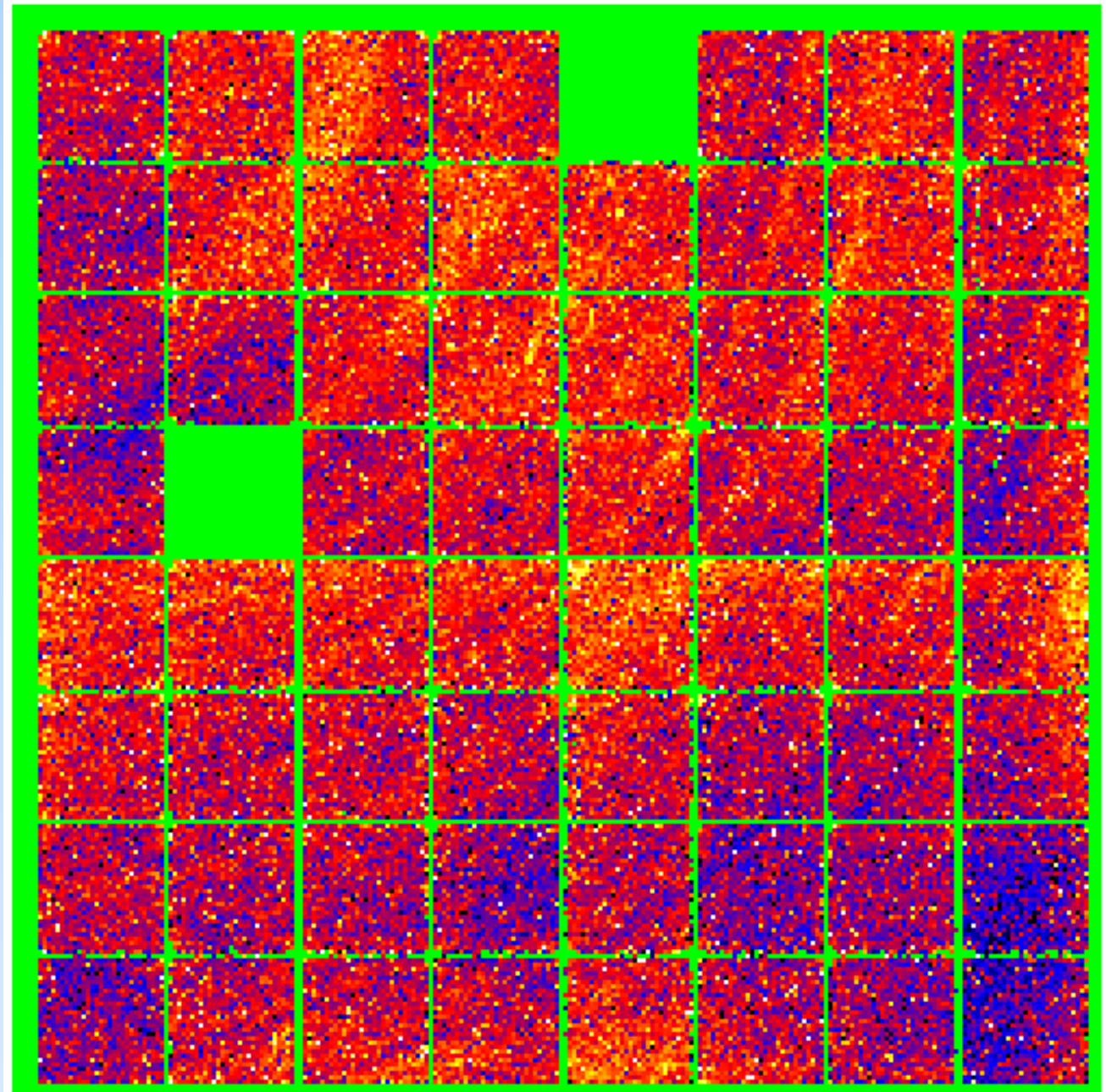
Photometric Residuals : Sample Chip

- Photometric Residuals (3pi)
- Similar to tree rings
- S/N is not great
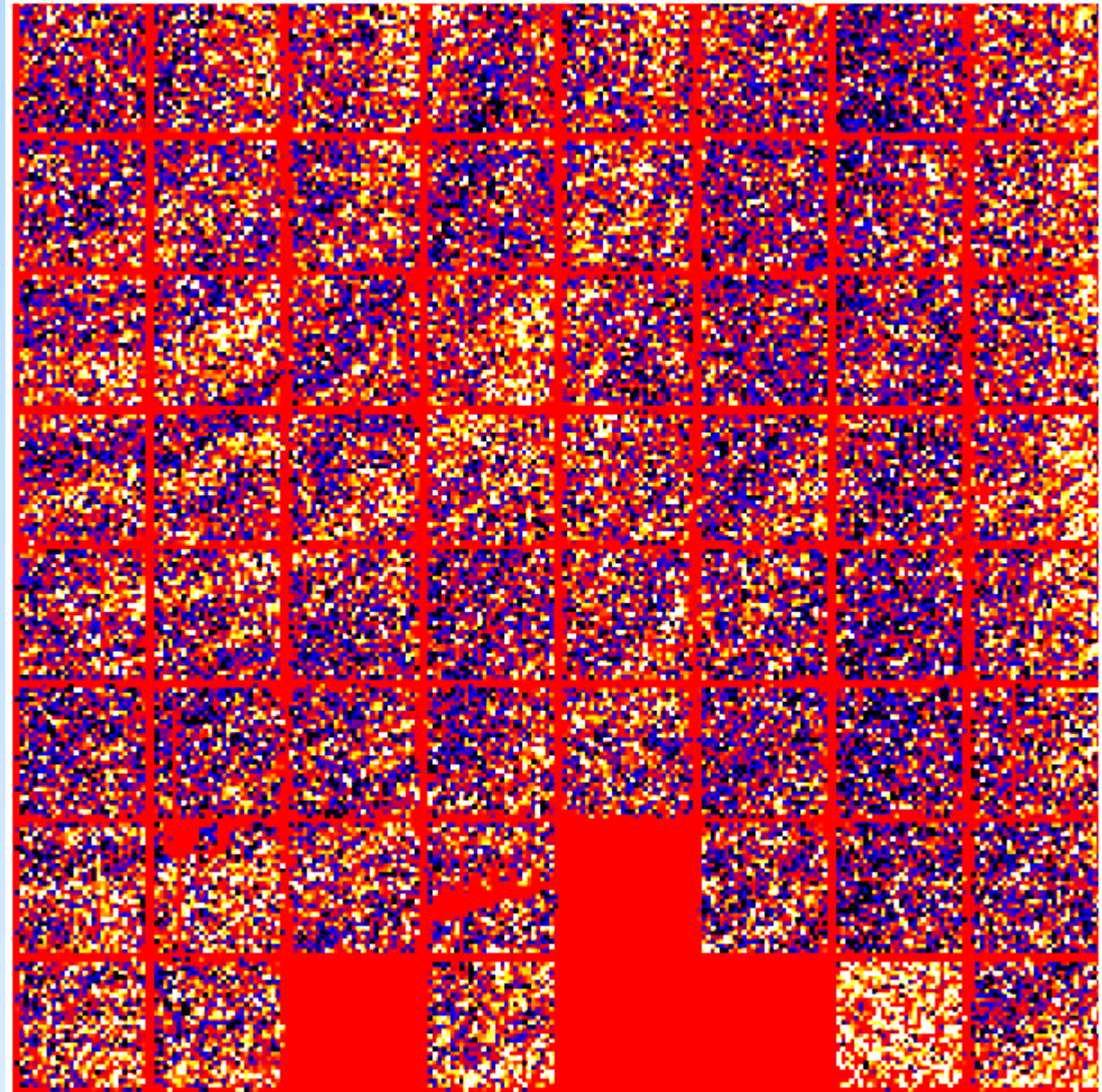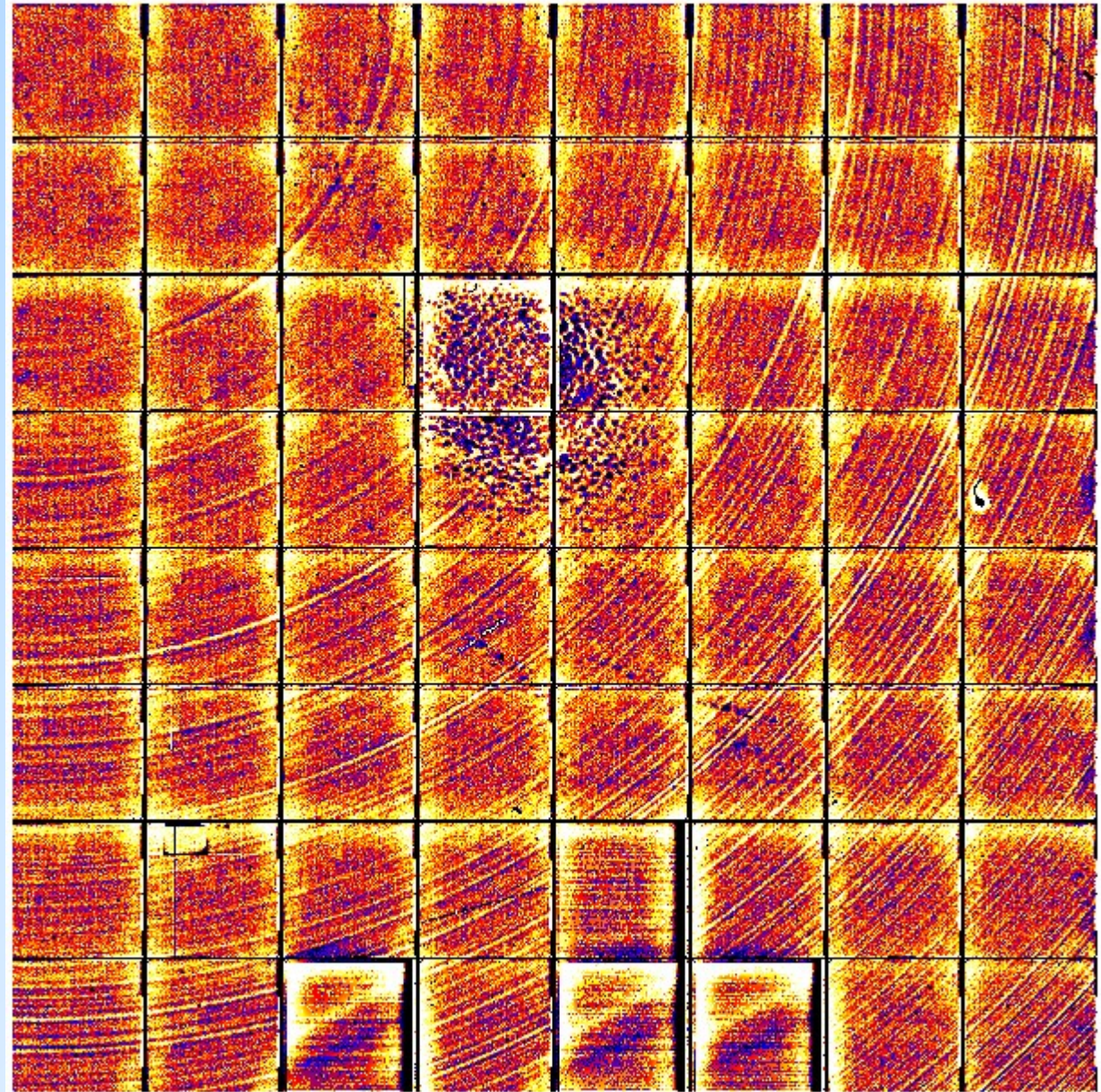
Photometric Residuals : Sample Chip

- Photometric Residuals (MD)
- From D. Finkbeiner
- Pattern matches 3pi
- S/N is much higher
- Is this a Jacobian Effect?
  - astrometric effect moves stars but squeezes flat-field light
  - residuals are imprint of over/under correction in the flat field?

Photometric Residuals : Sample Chip
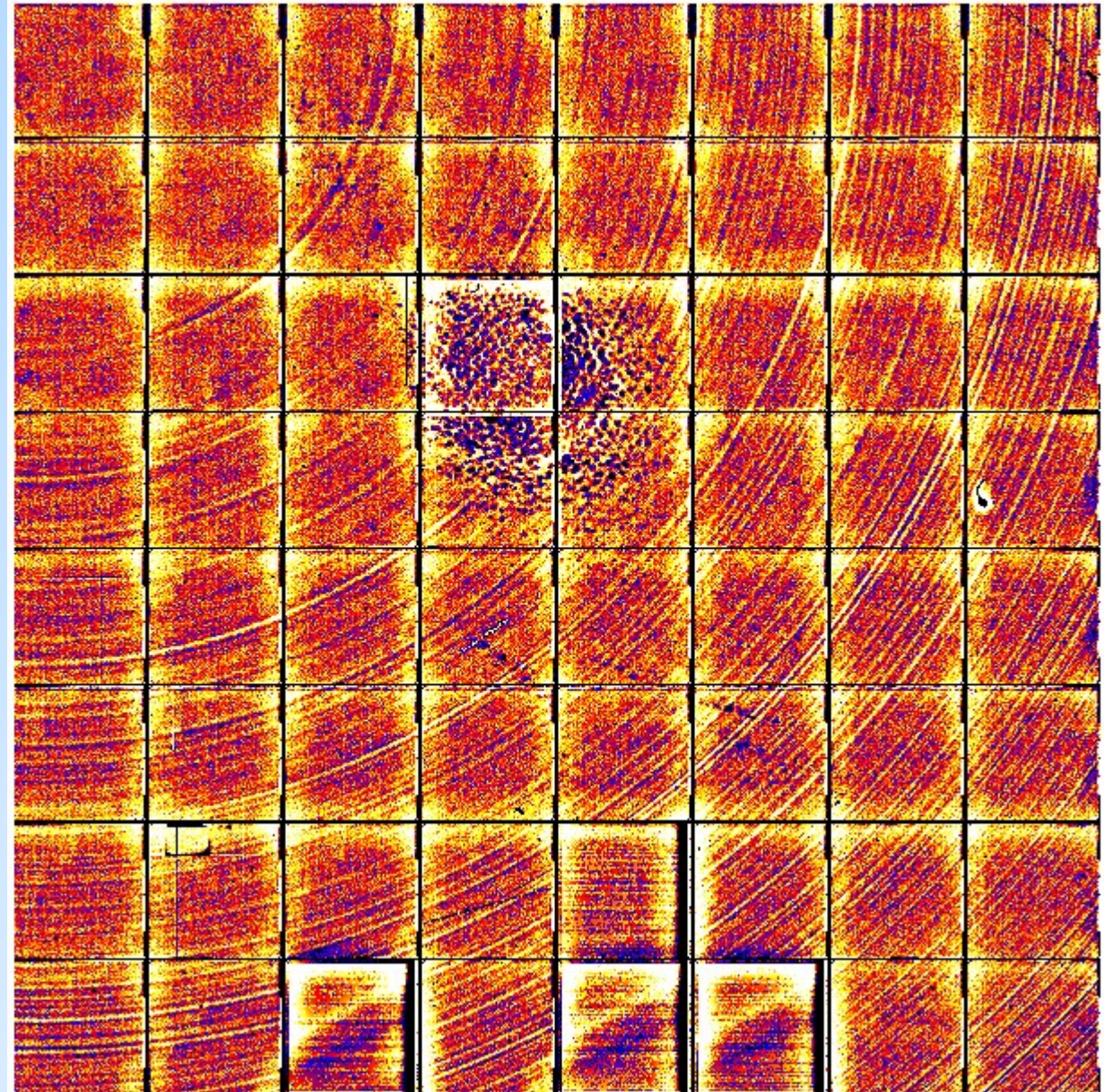
- Flat-field shows the rings

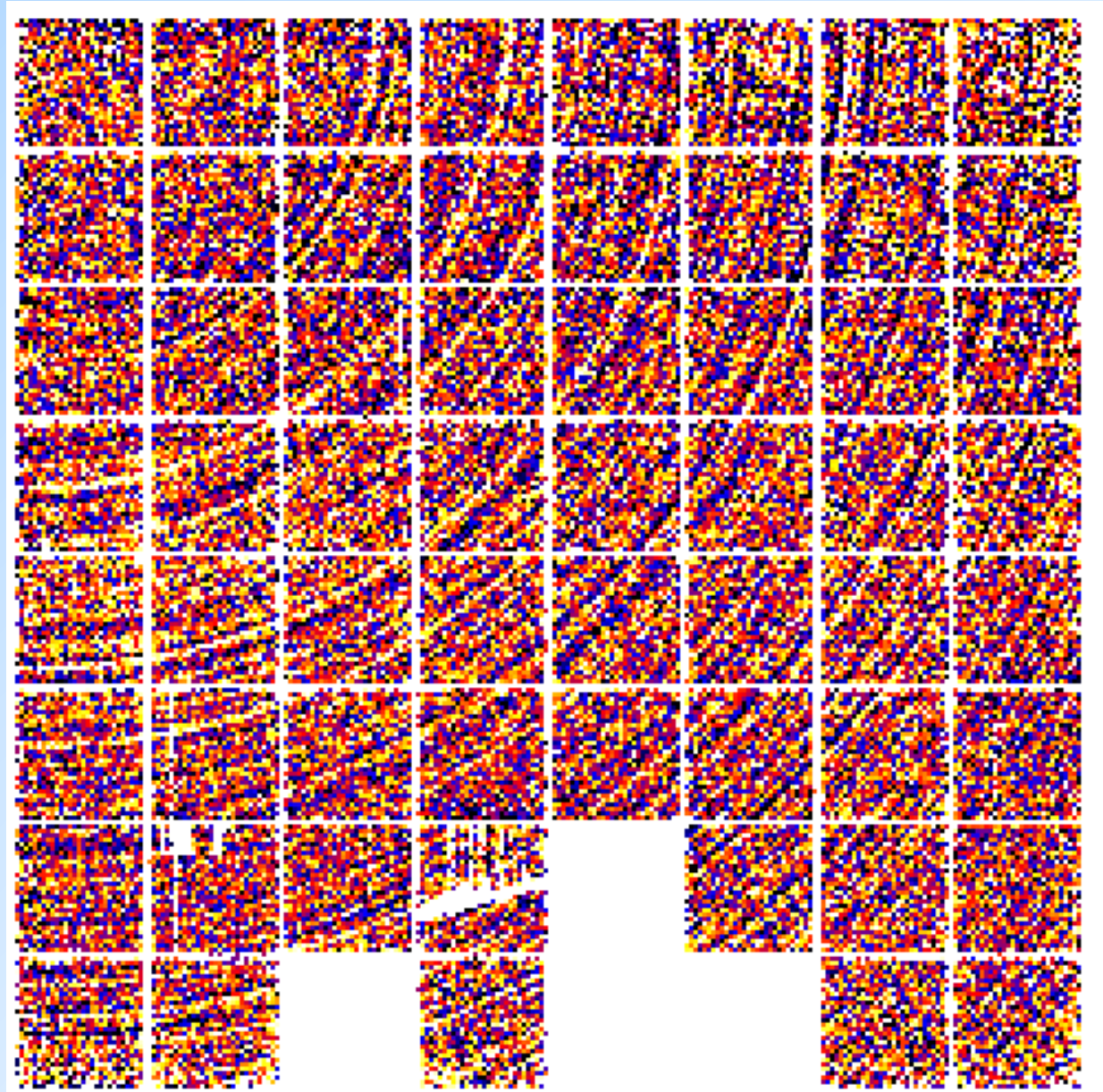monochromatic flat @ 630nm

Photometric Residuals : Sample Chip

- Flat-field shows the rings
- **But wait!**
  - **flat field looks like astrometric residuals**
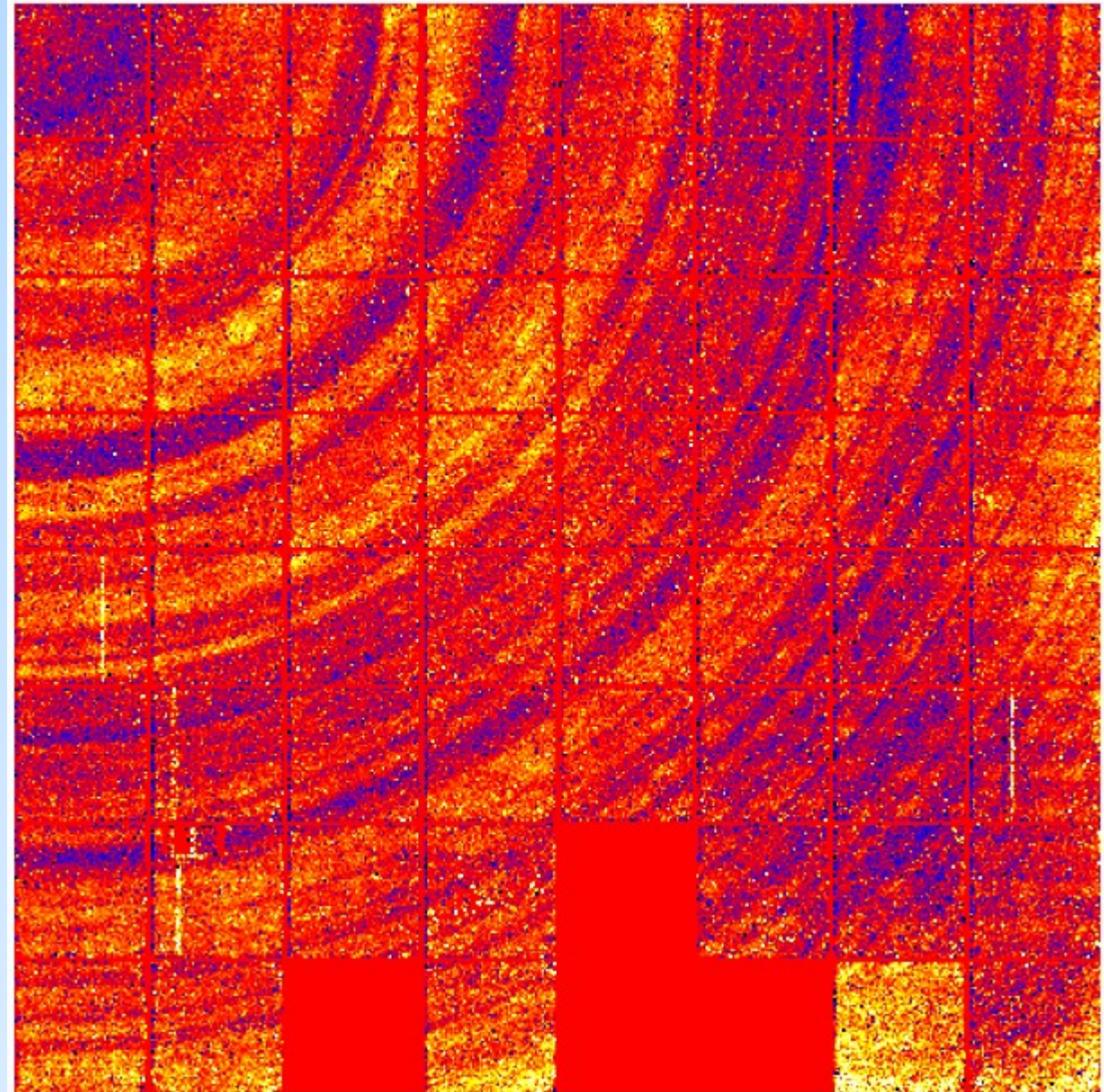
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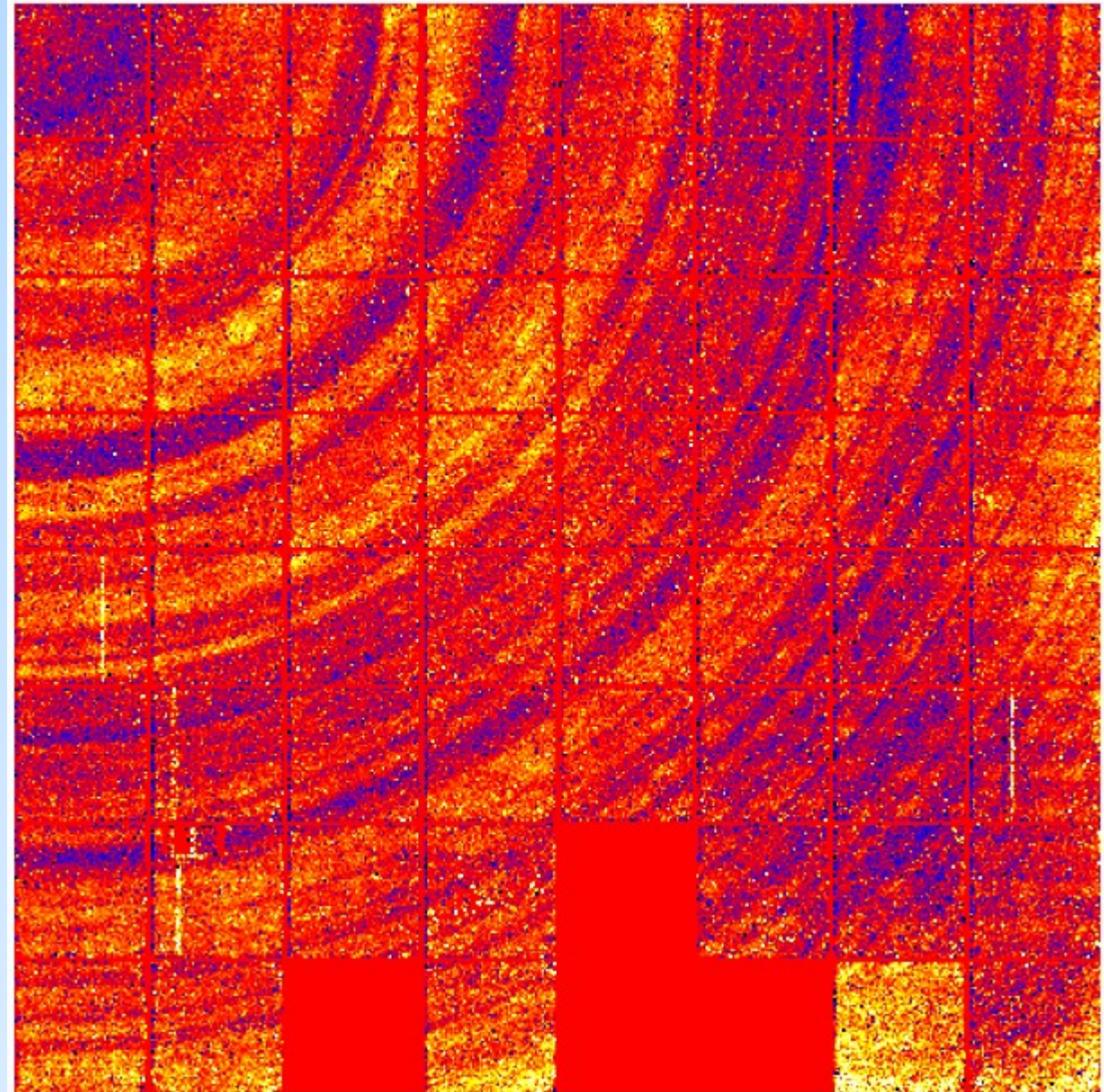
Photometric Residuals : Sample Chip

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  - **not like photometric residuals**

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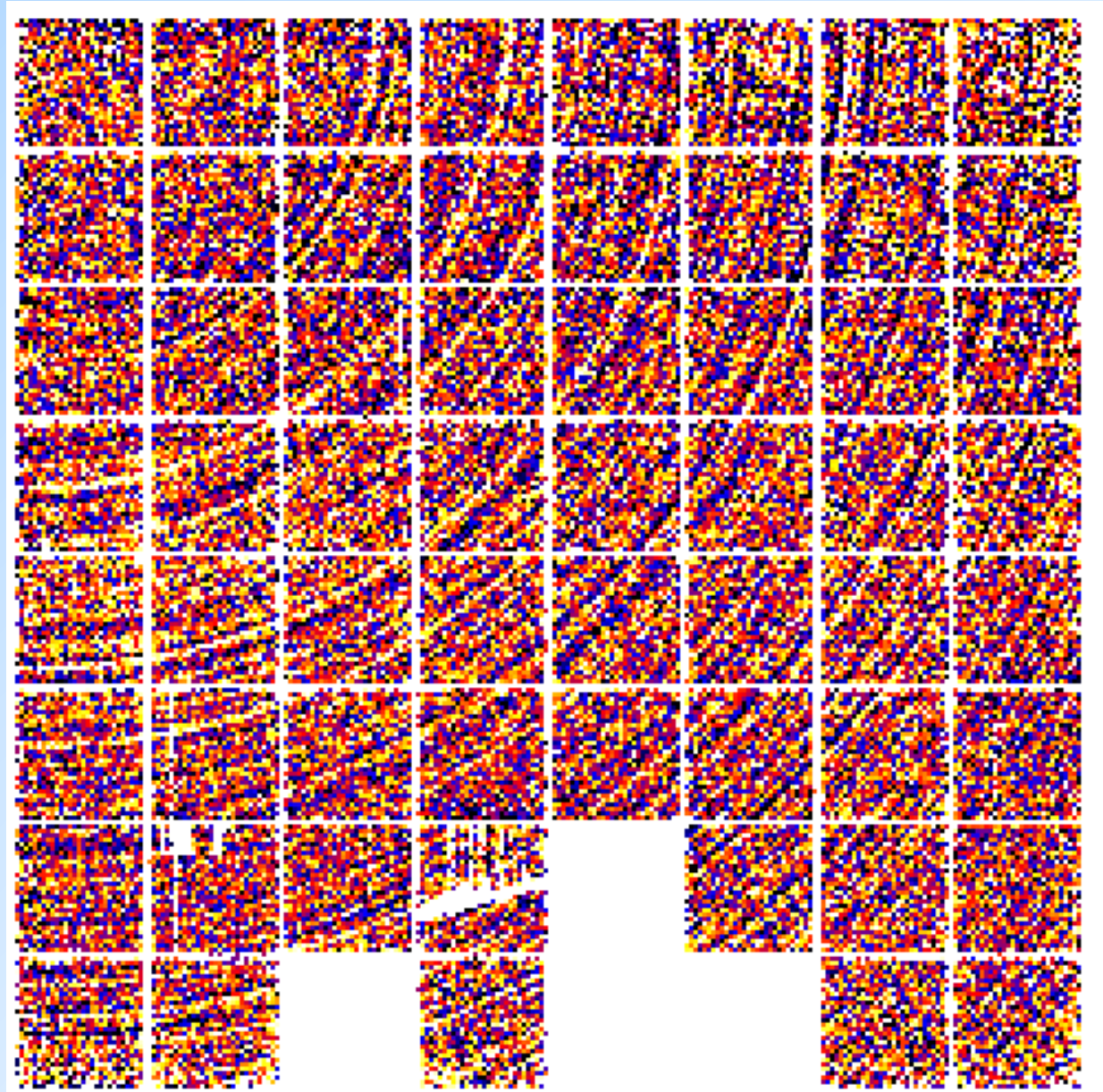 - **not like photometric residuals**
- **Also we see:**
  - **dR ~ grad dM**
- **But Jacobian effect wants**
  - **dM ~ dR**

Photometric Residuals : Sample Chip

- Flat-field shows the rings
- **But wait!**
  - **flat field looks like astrometric residuals**
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- **Also we see:**
  - **dR ~ grad dM**
- **But Jacobian effect wants**
 - **dM ~ dR**

Summary

- PS1 is achieving good astrometry & photometry
- There is room for improvement
  - static systematics
  - finer spatial modeling of PSF variations
  - finer spatial modeling of astrometric corrections
  - stellar density is the ultimate limiting factor
- Tree-rings show up in astrometry and photometry
- We do not really understand the tree rings...

Backup Slides Follow:
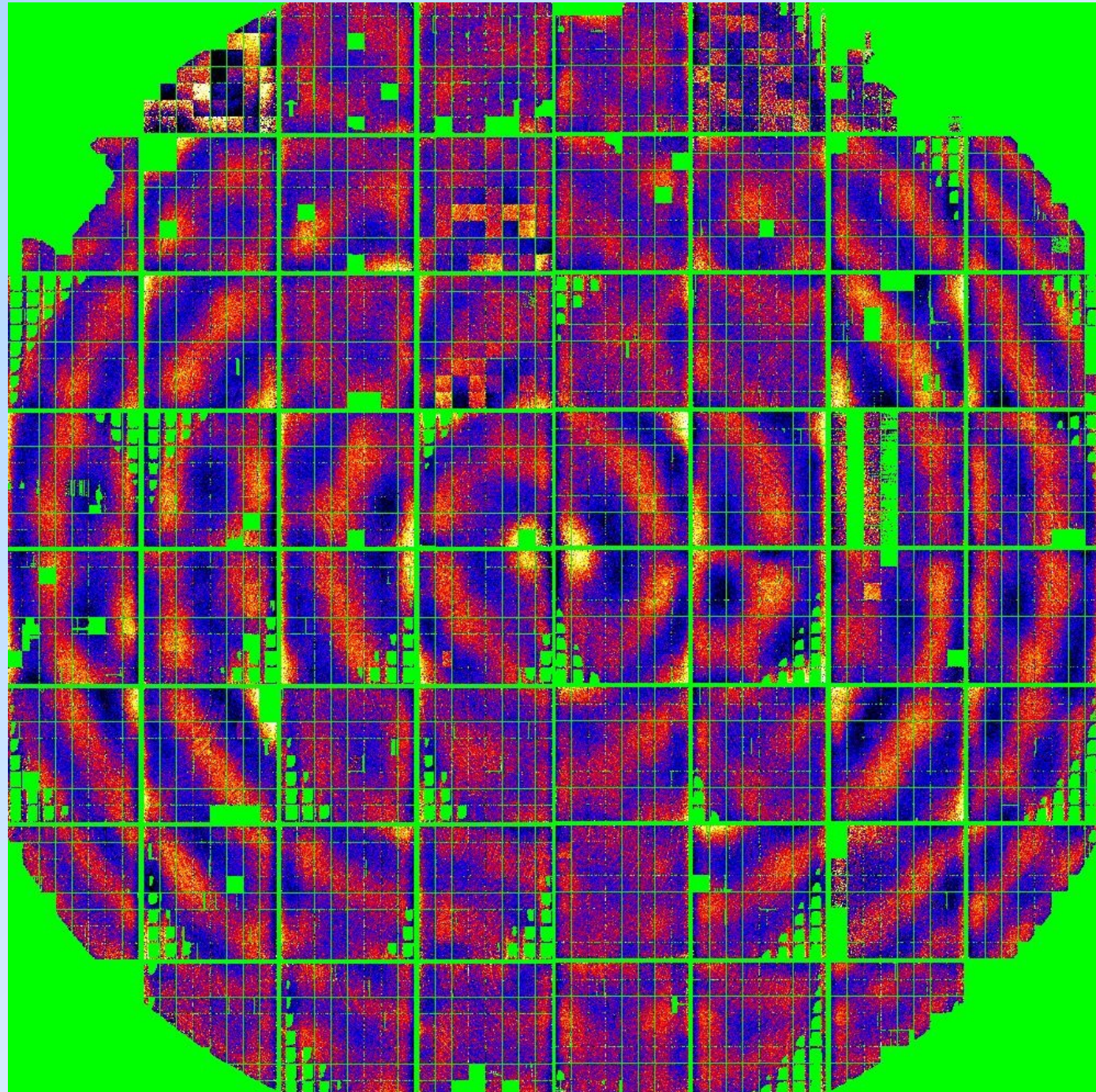
- Astrometry and the atmosphere
- Spatial Sampling

Finer Sampling

- PSF modeling and astrometric correction need references
- Limit of spatial sampling is stellar density
  - 1000 deg^{-2} -> ~6 arcmin
  - 10,000 deg^{-2} -> ~2 arcmin

~3,000 objects / degree^2
i = 20.0

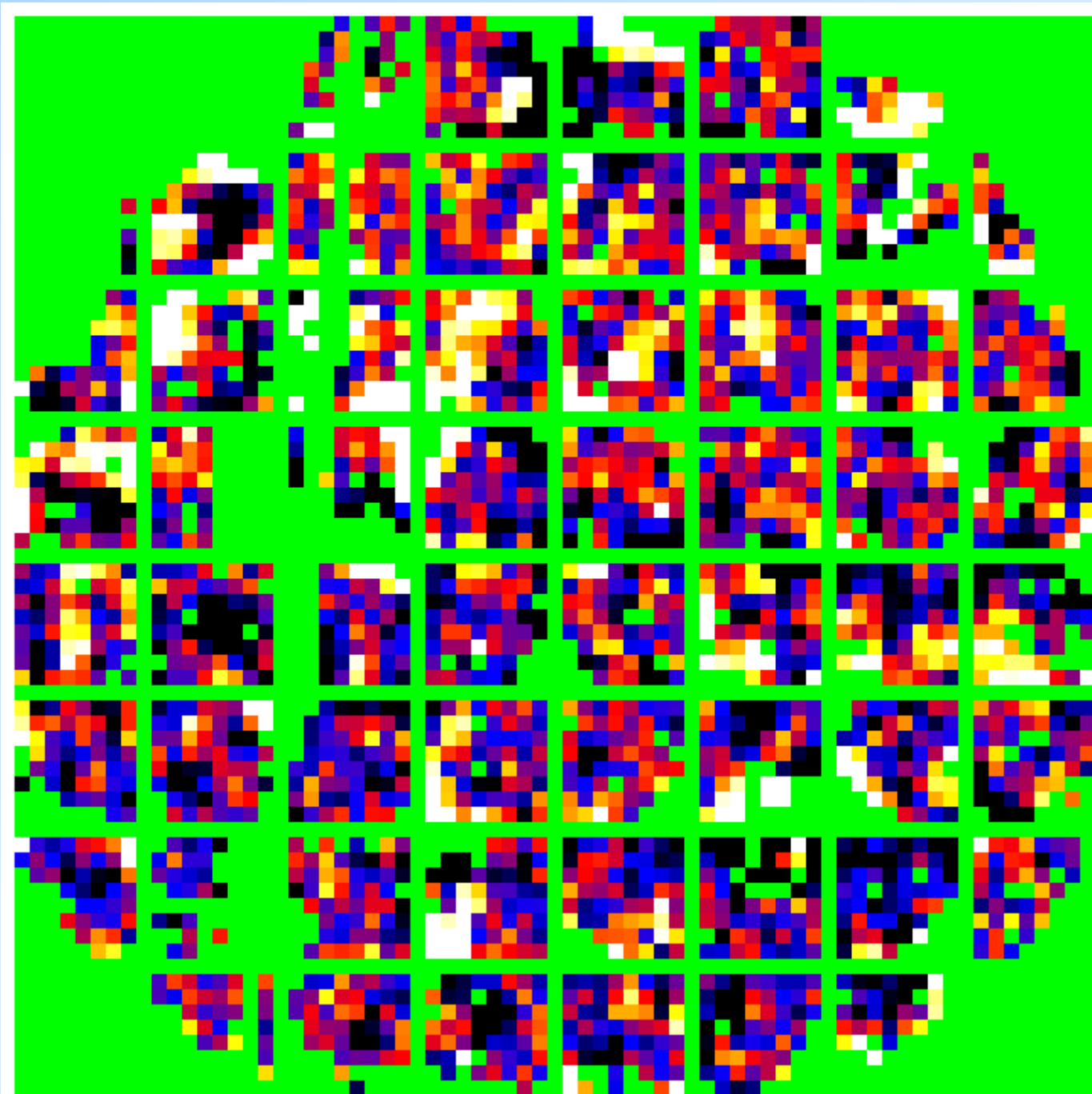~3,000,000 objects / degree^2
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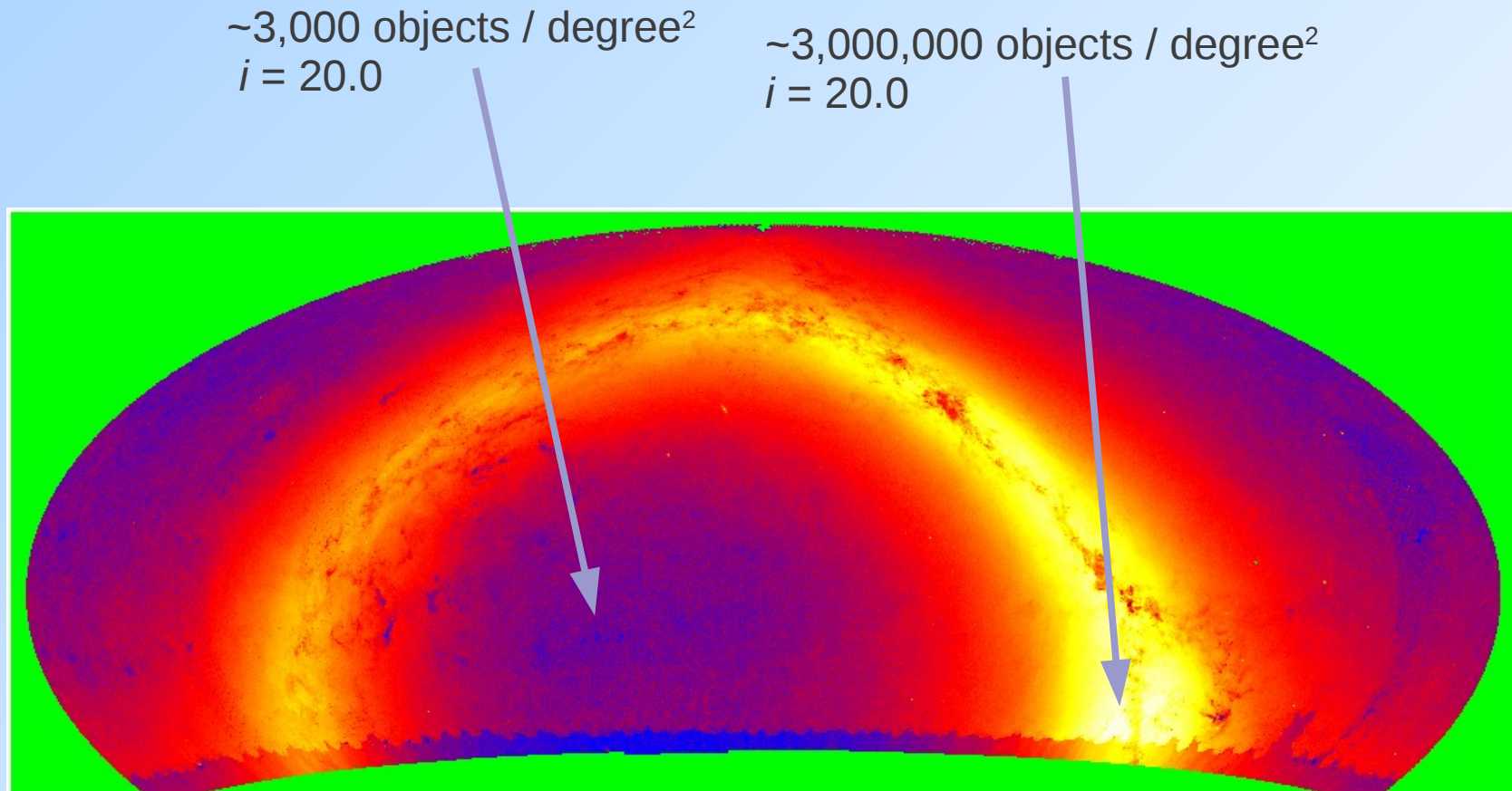
Astrometric Systematics

- mean residuals as a function of camera position
- constant systematics contribute ~ 5 mas
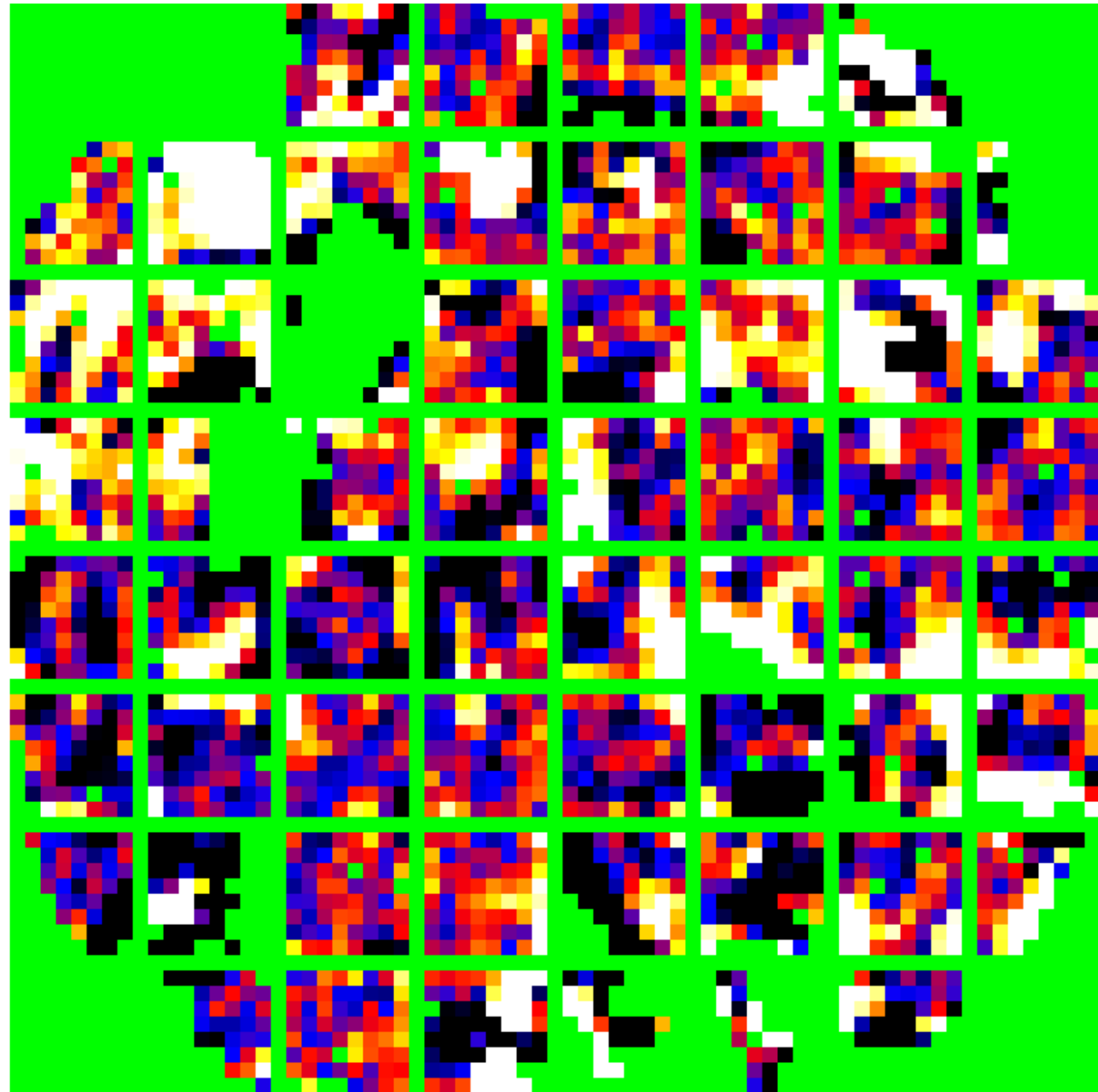- **overall systematics are ~ 20 mas**
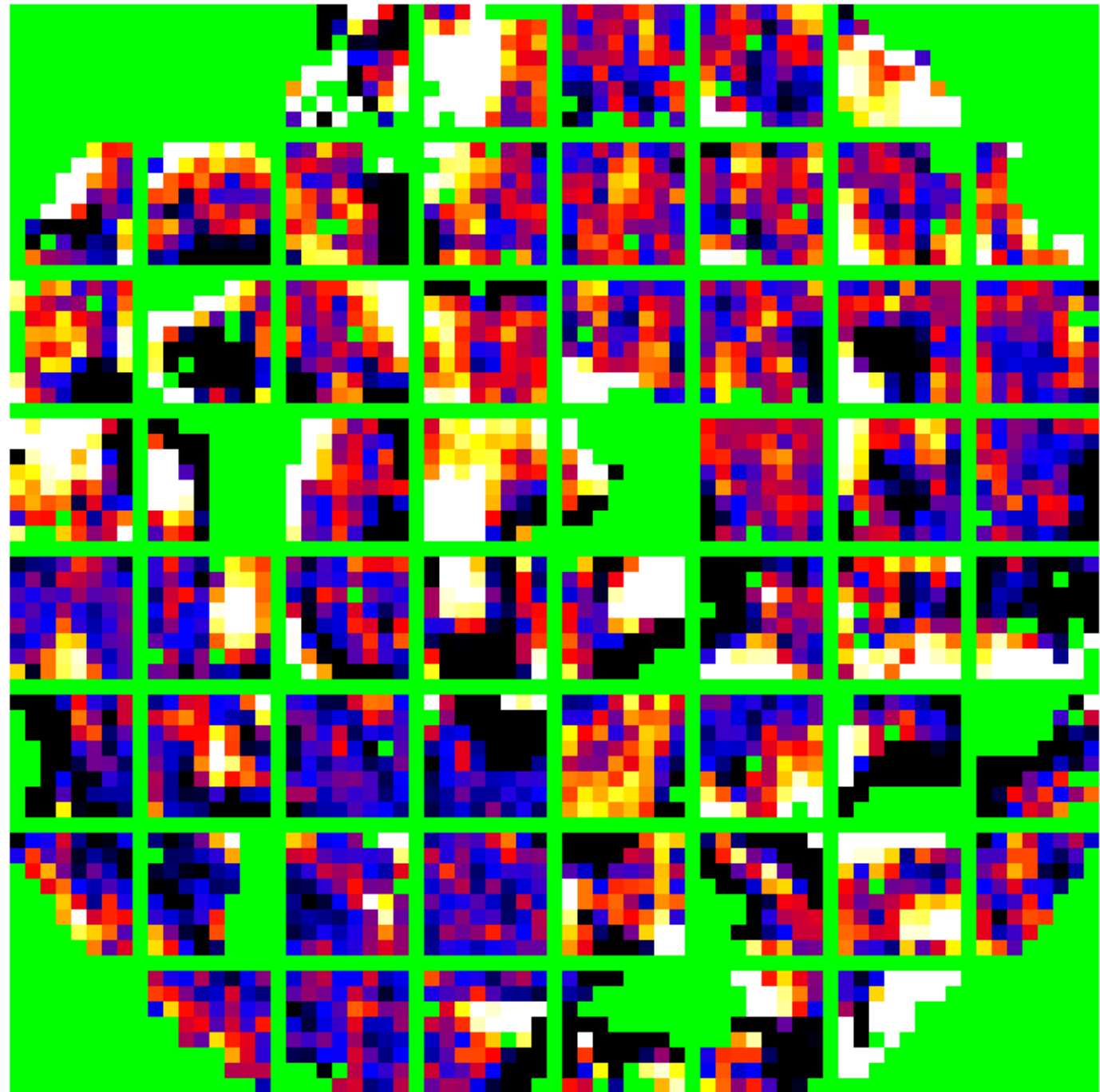- **what is the source?**

Astrometric Systematics : per-exposure analysis

- choose dense fields
- find mean astrometric offsets in cells for each exposure
- we have dX and dY astrometric offsets
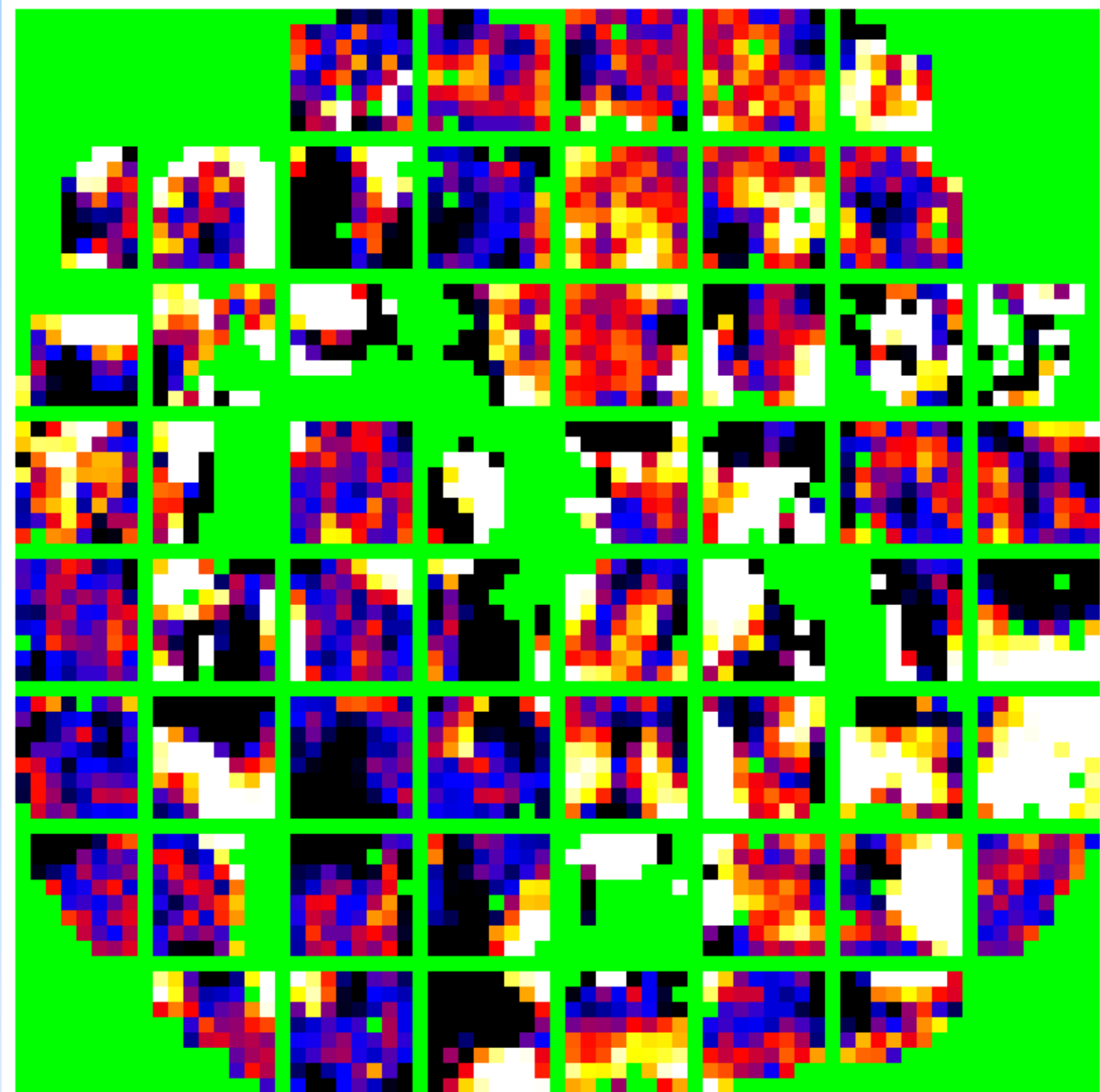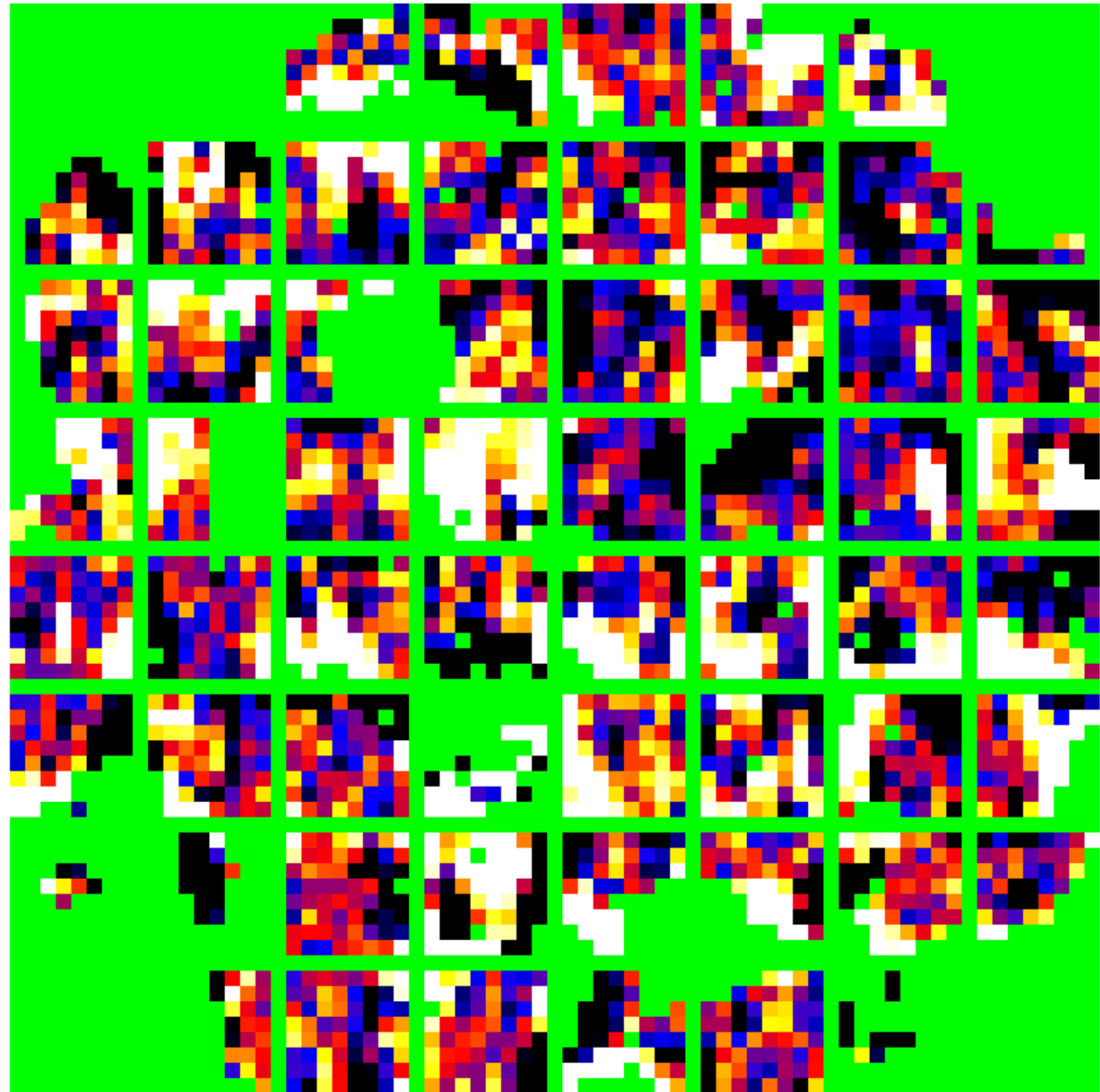
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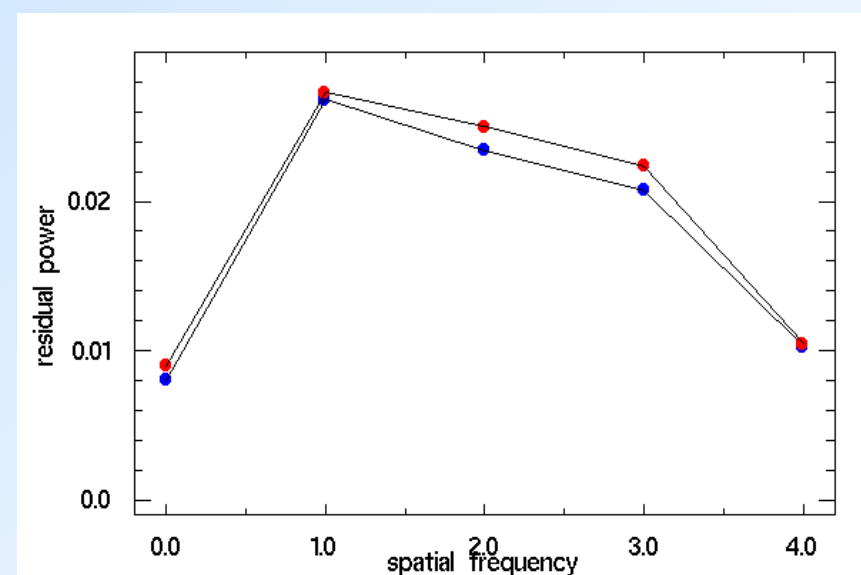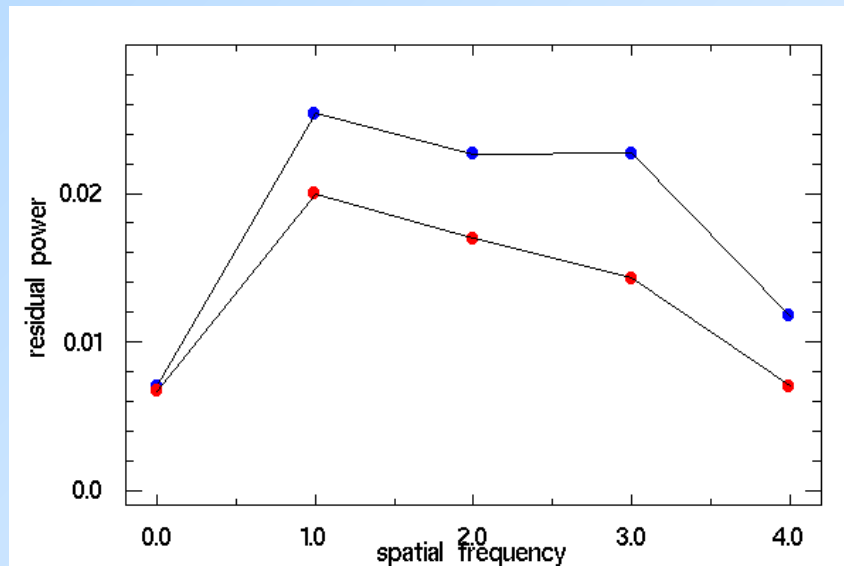- we have dX and dY astrometric offsets
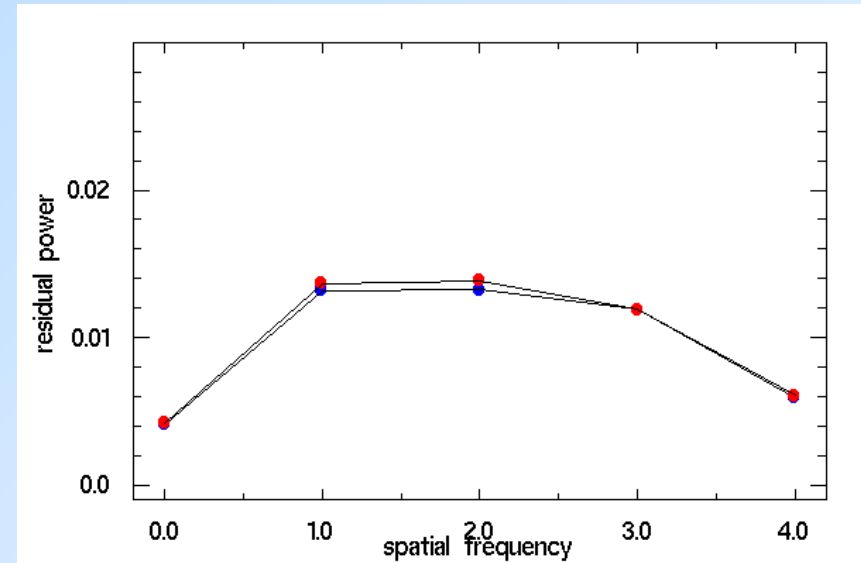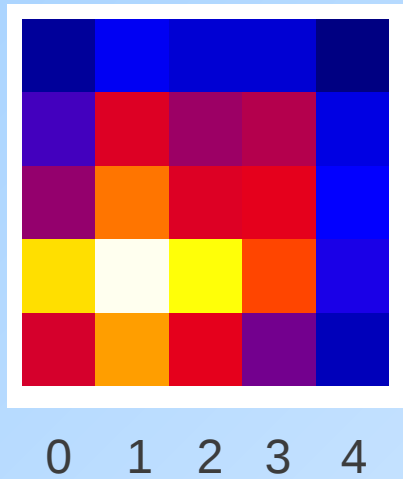
Astrometric Systematics : FFT of per-exposure data

- FFT of data per chip
- sum of power
- not coherent over camera
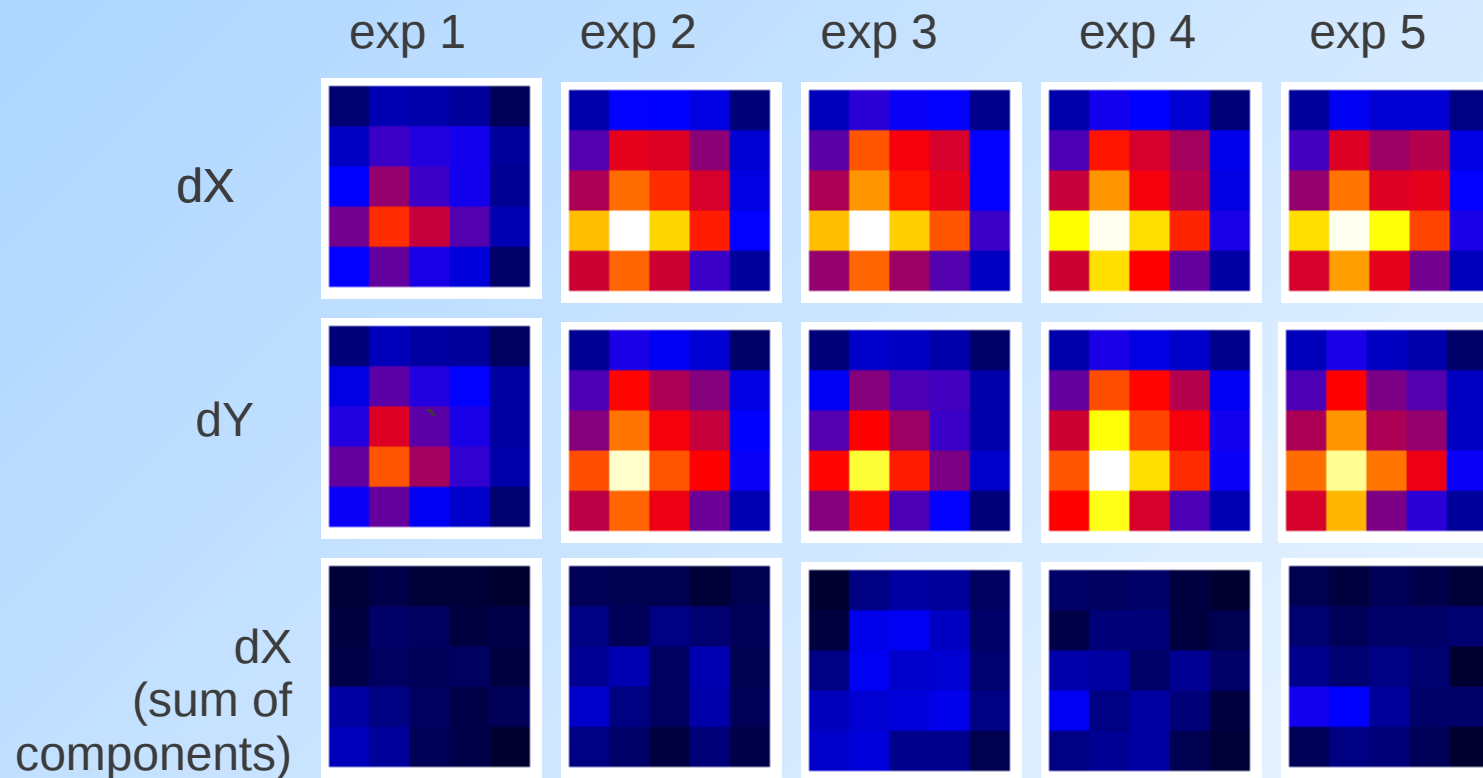
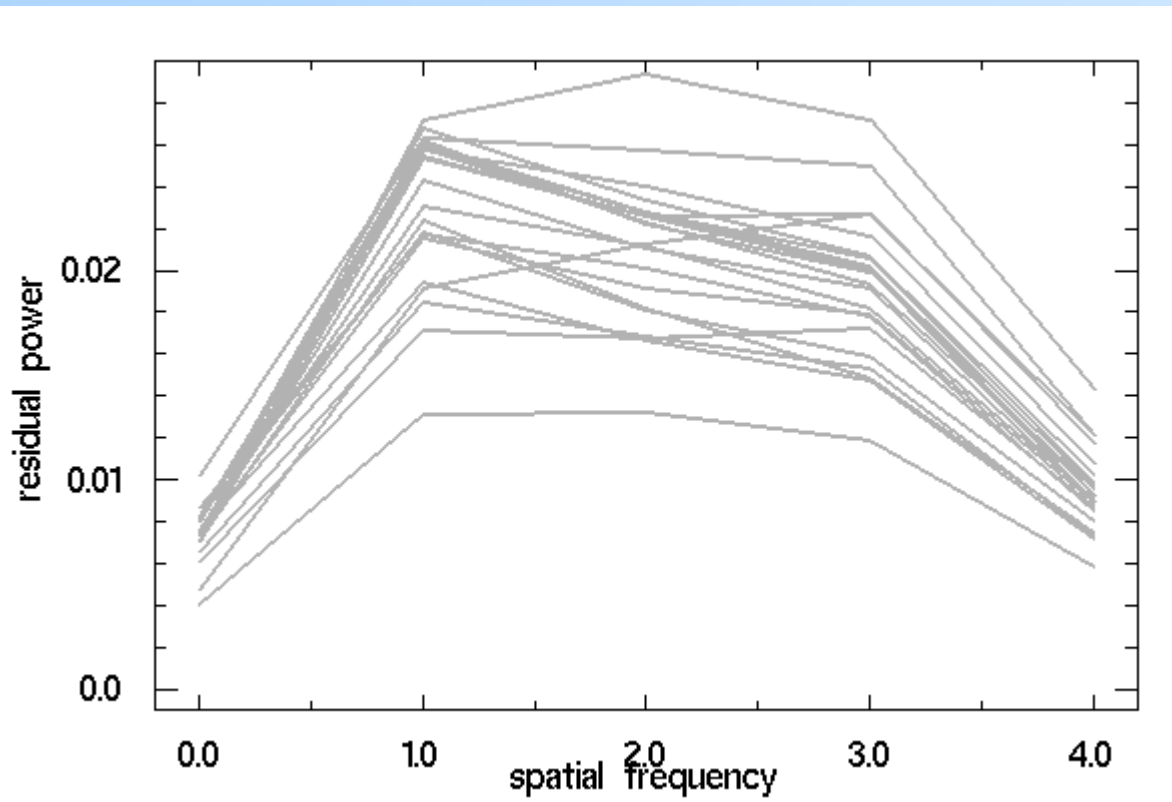# Astrometric Systematics : FFT of per-exposure data

- sum the power (in quadrature) in annuli
  - residual power (N) = sum (F <= N) − sum(F < N)

Astrometric Systematics : Significant Spatial Frequencies

- power distribution varies from exposure to exposure
- **FFT interpretation of sigma seems OK**
- **correction at 4x4 or 6x6 cells per chip would improve model**
- **correction at 8x8 cells yields diminishing returns**
- **correction @ 4x4 requires 160 stars / chip (~1000 / deg²)**
- **correction @ 6x6 requires 360 stars / chip (~3000 / deg²)**

residual power for 21 exposures

camera vs implied sigma