Updates on Survey Uniformity with FGCM… and a bit about reddening

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and the DES Calibrations Crew

LSST/DESC Calibration Workshop

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Introduction

- The Forward Global Calibration Method (FGCM) solves the global calibration problem with a physical model of the atmosphere and instrument
- Please see Burke, Rykoff+18 http://adsabs.harvard.edu/abs/2018AJ....155...41B and my talk in May: (link)
- Will describe progress, further steps, etc.

What is FGCM?

- The “Forward Global Calibration Method”
  - Solve the global calibration problem with a physical model of the atmosphere + instrument
  - Picking up on Stubbs & Tonry (2006)
  - Requires instrument throughput measurements
- Given a set of atmospheric parameters at any given time (under photometric conditions) we can predict the atmospheric extinction as a function of wavelength
  - Also need to know object SED (see e.g., Li+16)
- Once we know the atmospheric extinction, can predict fluxes of all the objects in an exposure

Advantages of FGCM

- Forward model approach always leads to physically possible solutions
  - Allows physically-motivated non-linearities with airmass
  - No gray terms in the model means no runaway solutions
- Uses full range of star colors — increase the s/n and this is useful information!
- Instrumental transmission variations, plus possible evolution of passbands is properly incorporated
- Works best with more overlap in time and space (like übercal), and multiple bands per night is very useful

The Atmosphere Model

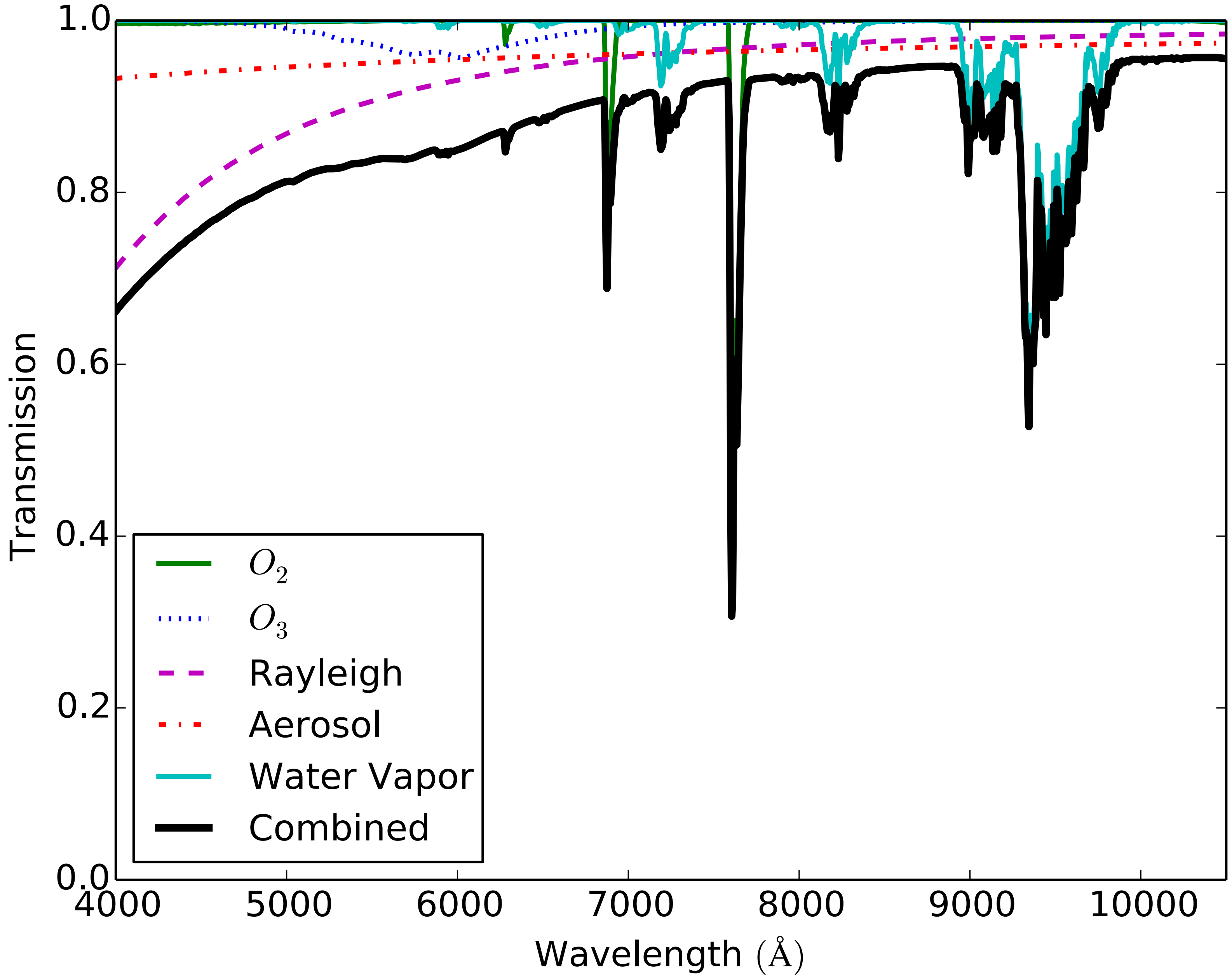
- Atmospheric transmission can be described with a small number of parameters
  - Precipitable water vapor (PWV)
  - Aerosol Optical Depth (AOD) τ and α

$$\tau(\lambda) = \tau_{7750} \times (\lambda / 7750\,\text{Å})^{-\alpha}$$
$$S_\tau(\lambda) = e^{X\tau(\lambda)}$$

  - Ozone (O_3)
  - Given zenith distance and barometric pressure, compute Rayleigh and O_2 using MODTRAN

Atmosphere Constituents

- The FGCM standard atmosphere model



Fit Parameters

- PWV varies linearly through the night
  - Could/should add quadratic term
- A single-constituent aerosol, with optical depth τ_{7750} that varies linearly through the night, and single α per night
- A single value for Ozone each night
- Plus airmass and site-monitored barometric pressure

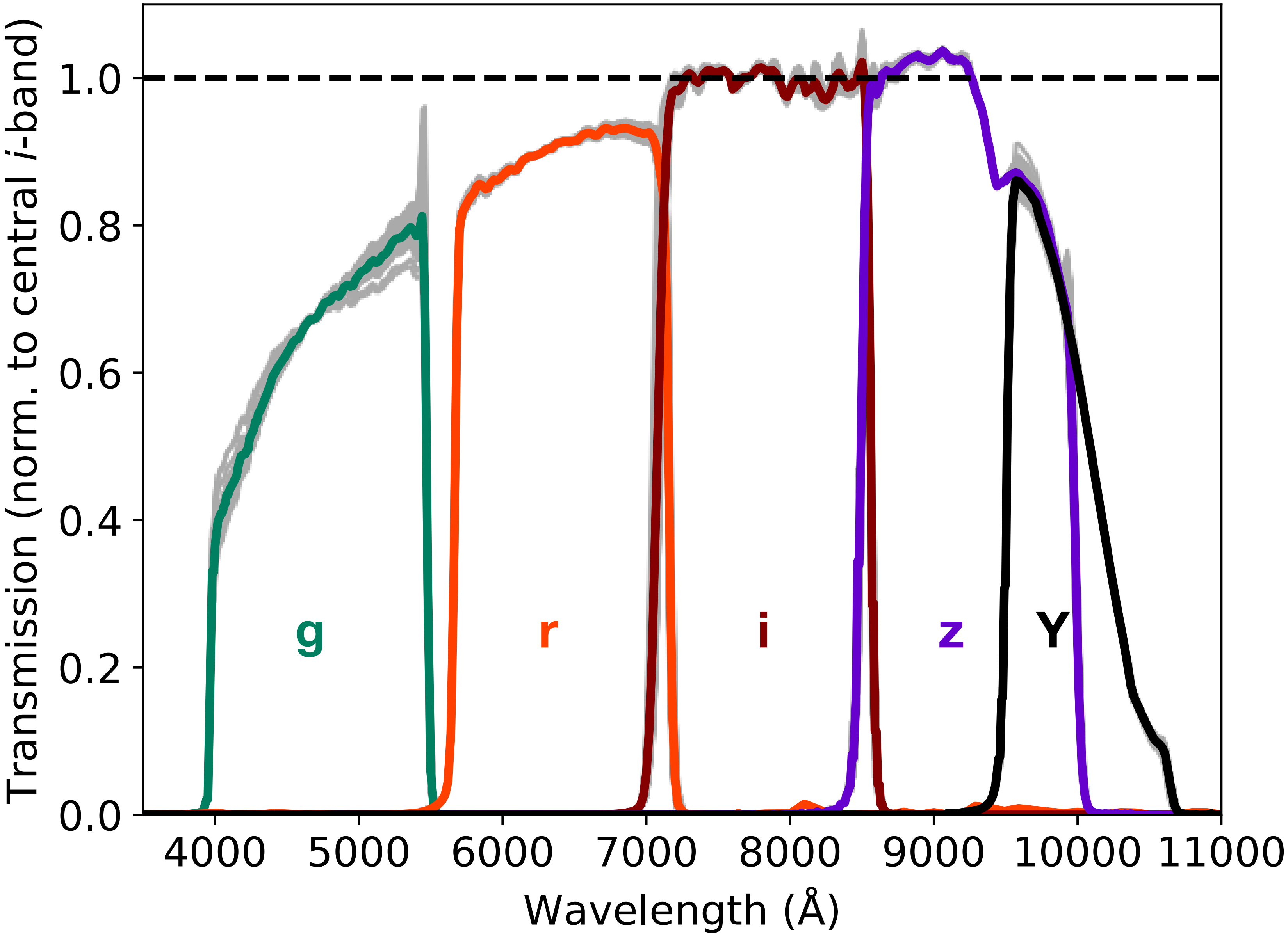
Instrumental Passband

- Instrumental effects (filter variations, anti-reflective coating differences, CCD QE differences) are as big or bigger than atmospheric effects

- Require (at least) CCD-by-CCD scans
  - For DES from the “DECal” system
  - For LSST from the CBP

Filters+CCDs

- From the DECal monochromatic scans
  - g band especially variable from chip to chip



Paris on Sunday

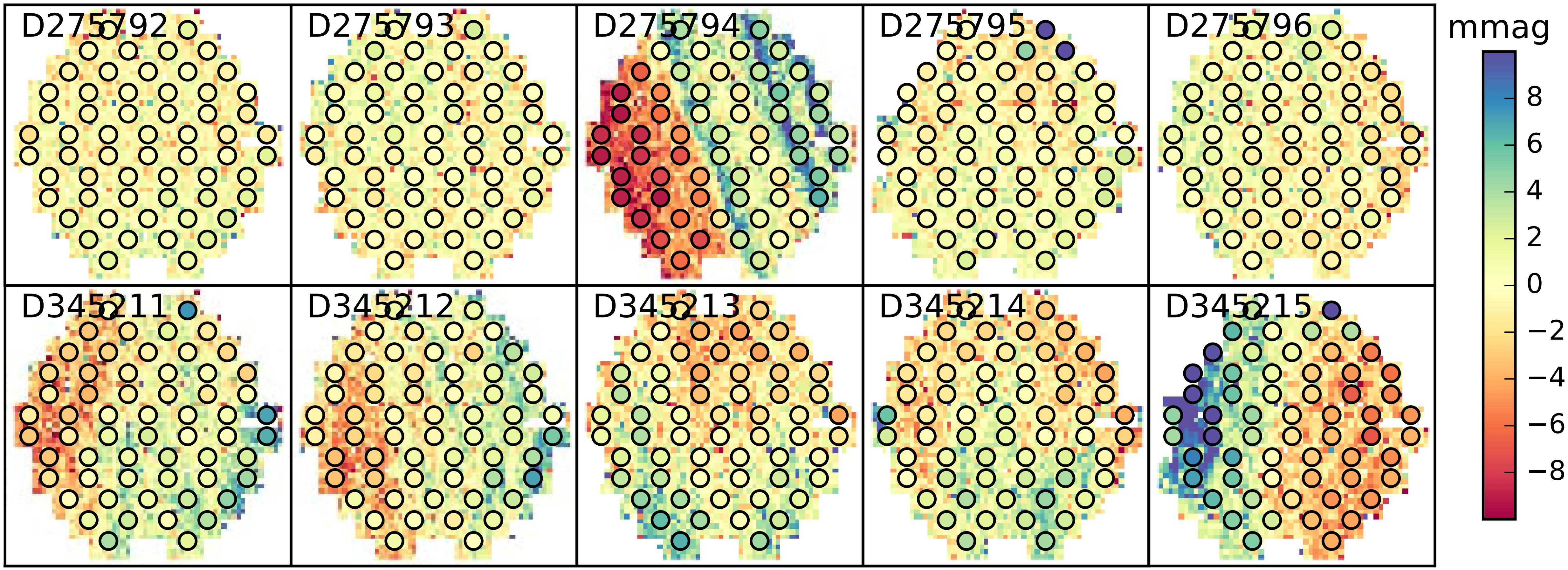
Paris on Sunday

Paris on Sunday

Paris on Sunday

Spatial Residuals

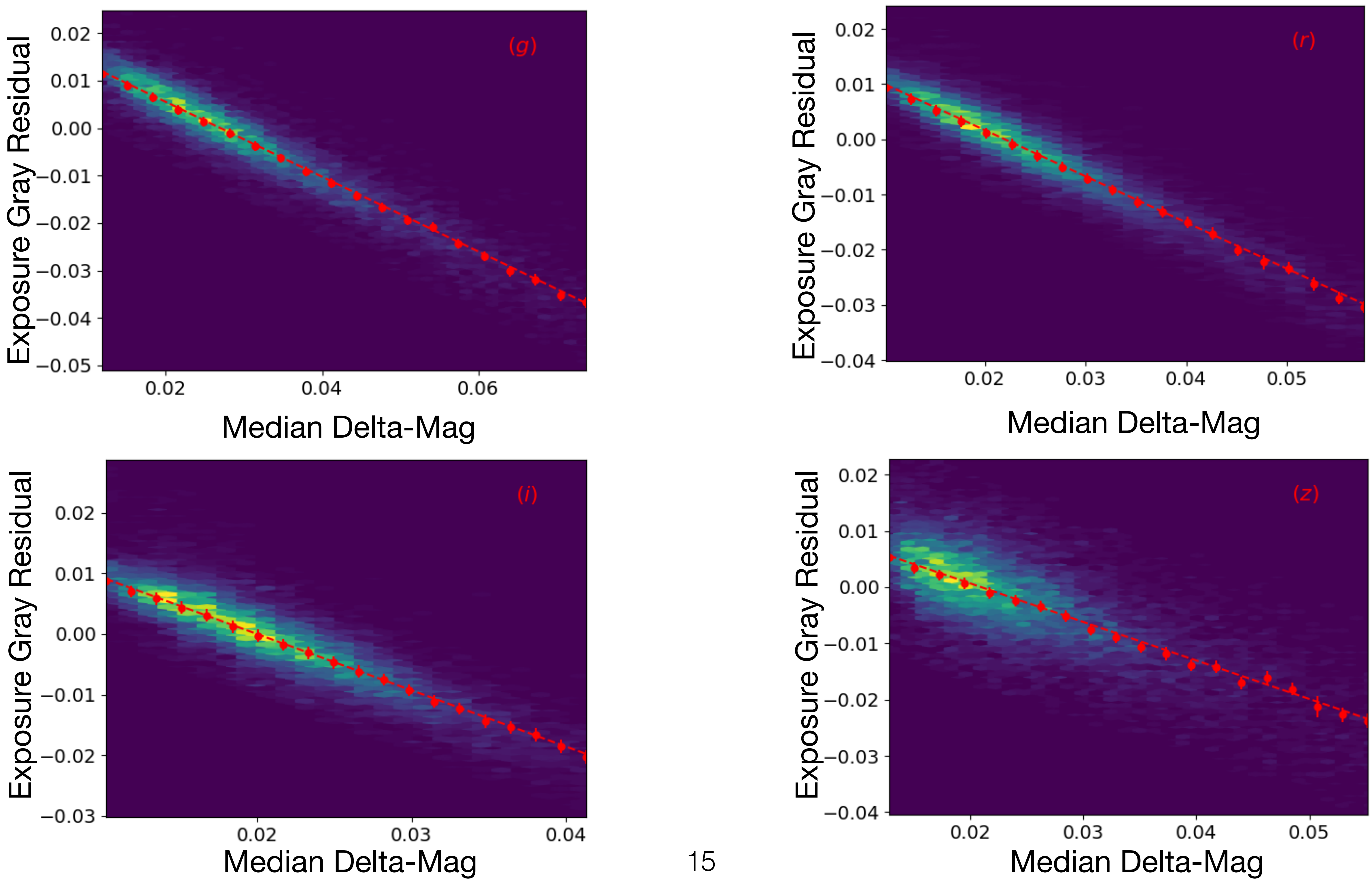
- Each panel is one exposure
- The background are the photometric residuals
- Inside the circles shows the predicted photometric residuals from the aperture correction



Bernstein++18

Aperture Corrections

- Compute median of Aperture mag (8”) - (6”)



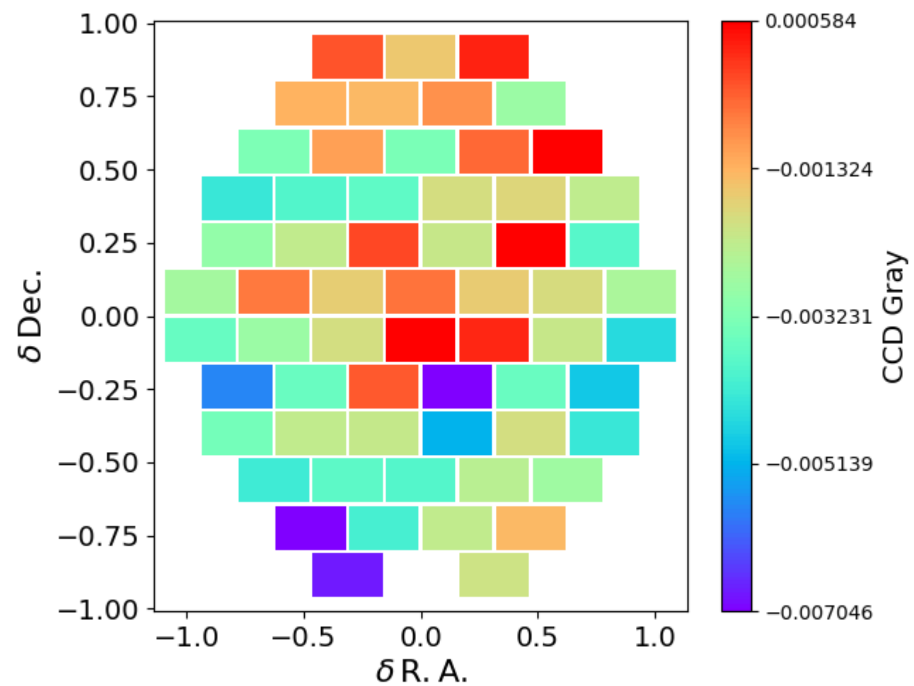
Gary's Conclusion

In summary, we find that *all* of the deviations above $\approx$1 mmag rms from a static response function plus secant airmass law on short timescales are plausibly attributable to spatial/temporal variations in aperture corrections. The A_t statistic measured from bright stars is an accurate predictor of these aperture corrections, so on a typical half-hour stretch of clear-sky observations we can homogenize the exposure zeropoints to $\approx$1 mmag, and if we have sufficient stellar data in an exposure to map out variation of A_t across the FOV, we could reduce any intra-exposure inhomogeneity to similar level.

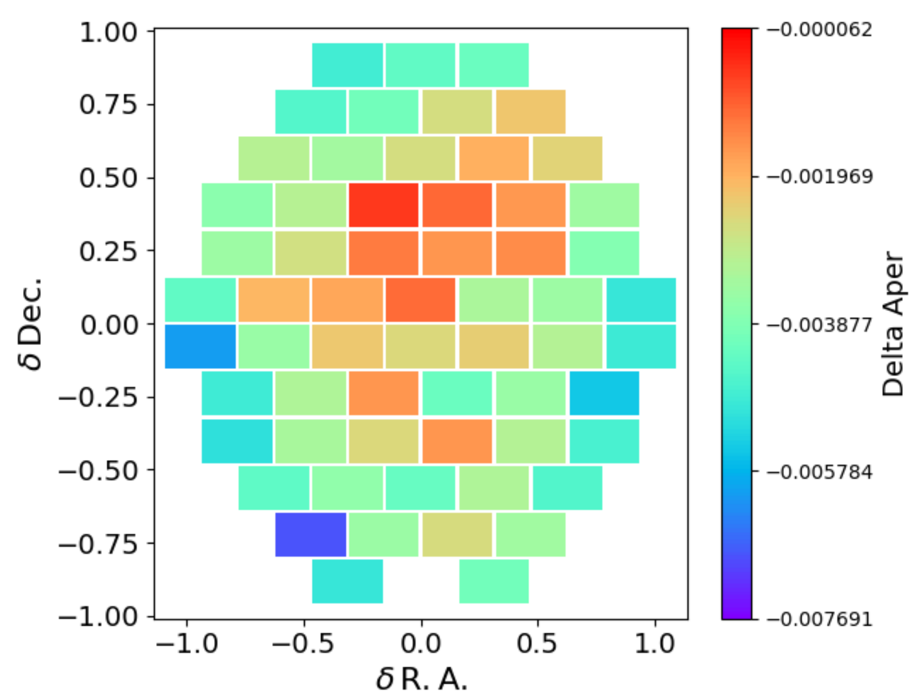
Spatial Variations in Wide-Field

- Comparing predictions to A

A typical exposure



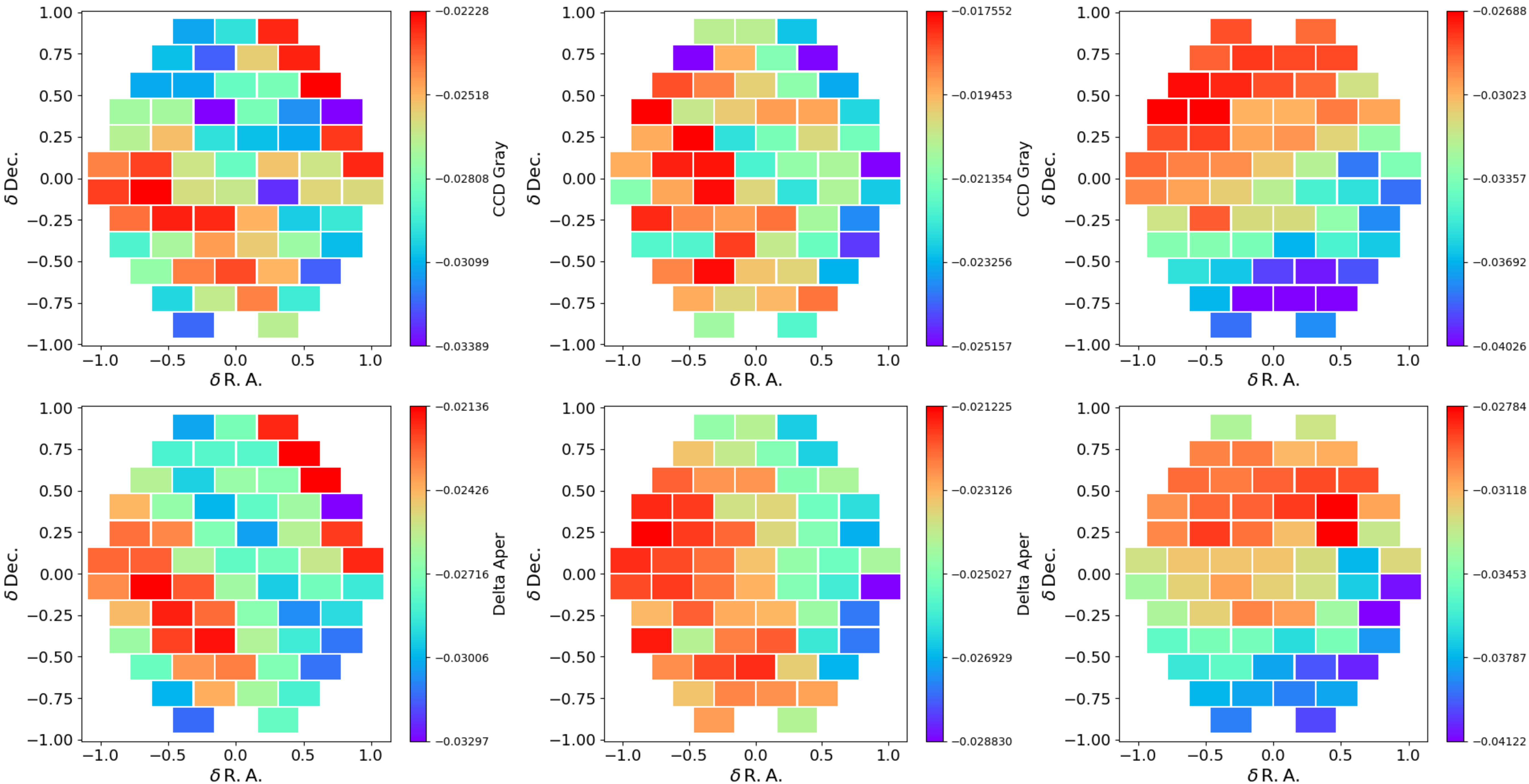
Per-CCD Fit Residual



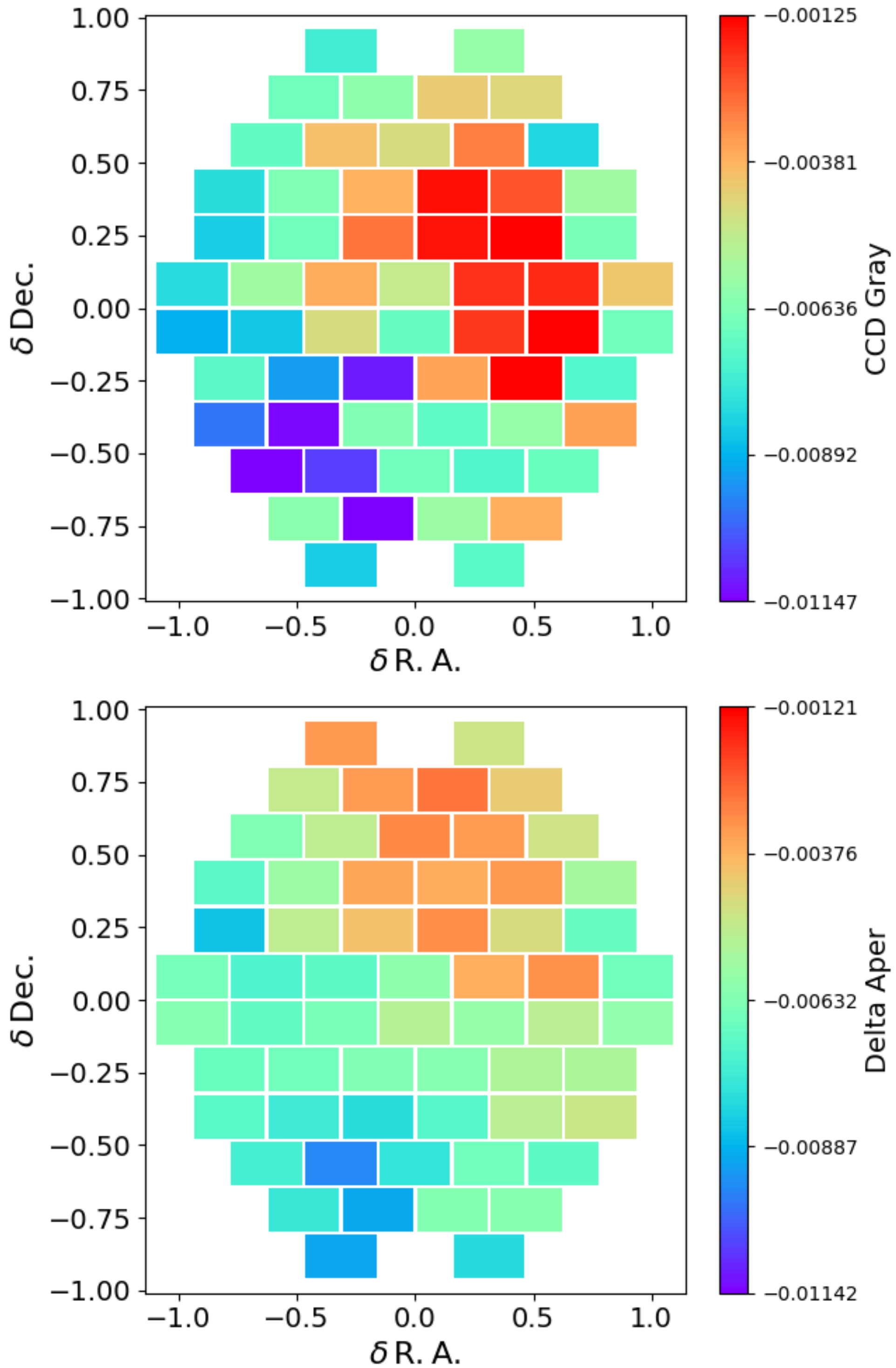
Per-CCD residual predicted from Delta-Aper

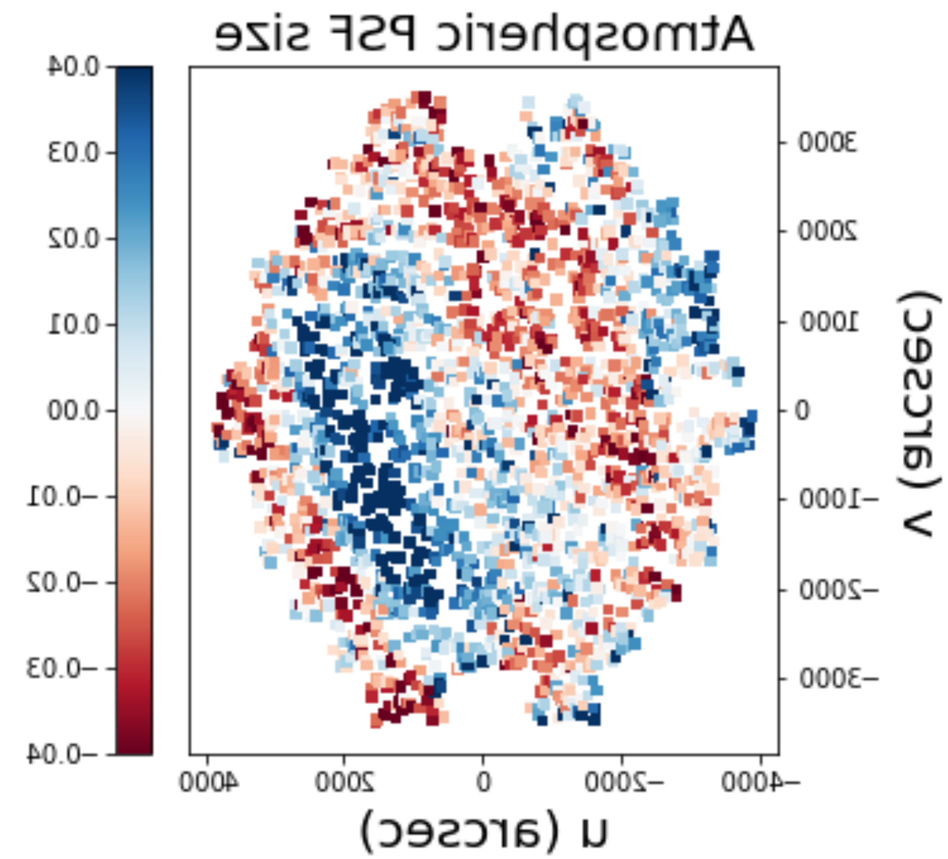
Spatial Variation in Wide Field

- Some less typical exposures (top: measurements; bottom: predictions)



Spatial Variation in Atmospheric PSF

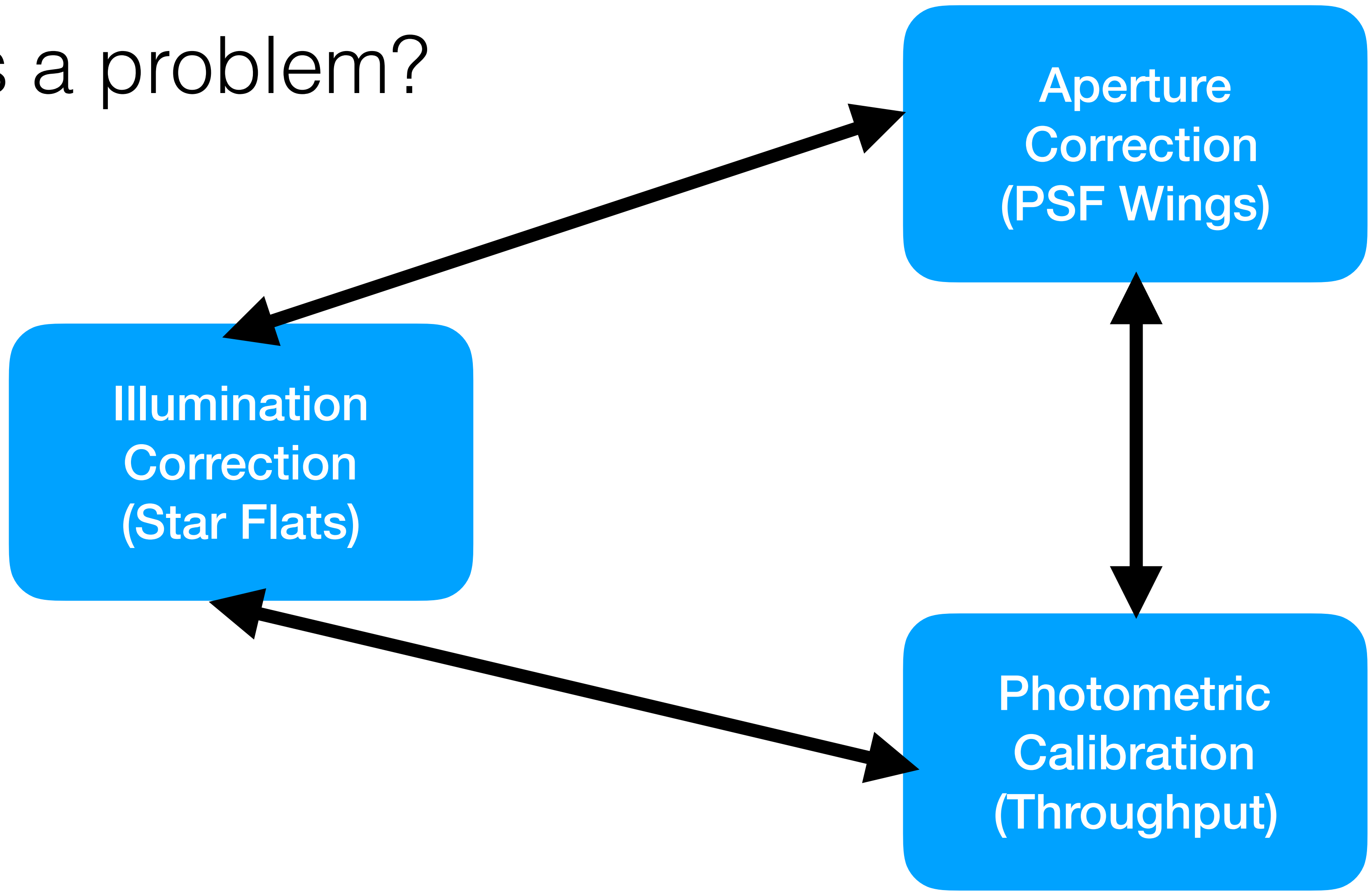




Atmospheric model for PSF size
(see Pierre-Francois' talk next)

Ambiguities in Calibration

- We currently use uncorrected aperture magnitudes as the basis of calibration
- This leads to ambiguities in the sources of variation
- Is this a problem?



Modeling Magnitude Errors

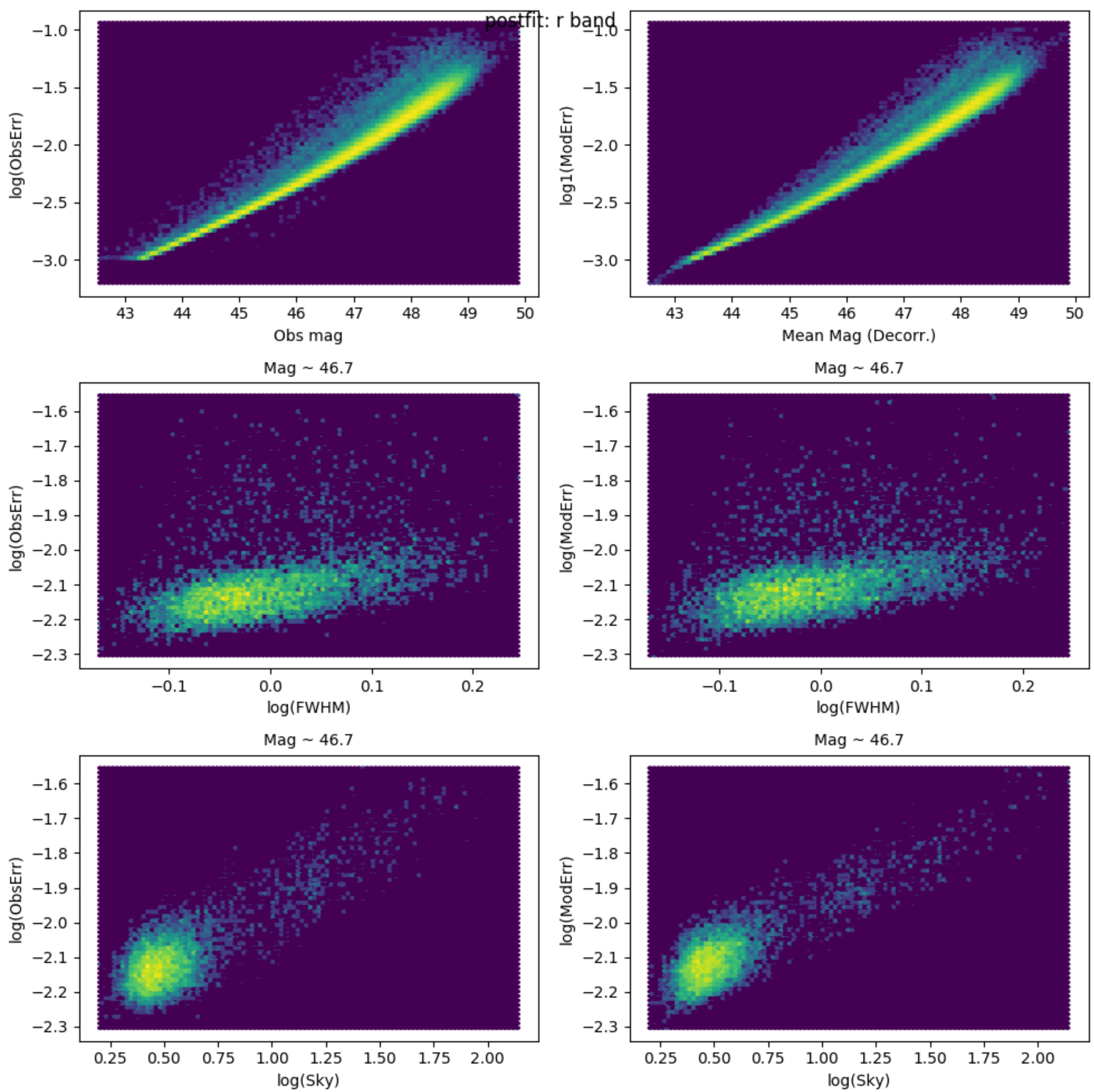
- The FGCM computation for chi2 uses the quoted photometric errors (as comes out of the pipeline)

$$\overline{m_b^{\mathrm{std}}(j)} = \frac{\sum_i m_b^{\mathrm{std}}(i,j)\sigma^{\mathrm{phot}}(i,j)^{-2}}{\sum_i \sigma^{\mathrm{phot}}(i,j)^{-2}}$$

$$\chi^2 = \sum_{(i,j)} \frac{\left(m_b^{\mathrm{std}}(i,j) - \overline{m_b^{\mathrm{std}}(j)}\right)^2}{\sigma^{\mathrm{phot}}(i,j)^2}$$

- This can be biased near the faint end because of fluctuations.
- We can predict the magnitude error empirically given the sky brightness, seeing, and knowledge of the true magnitude + local transparency

Modeling Magnitude Errors

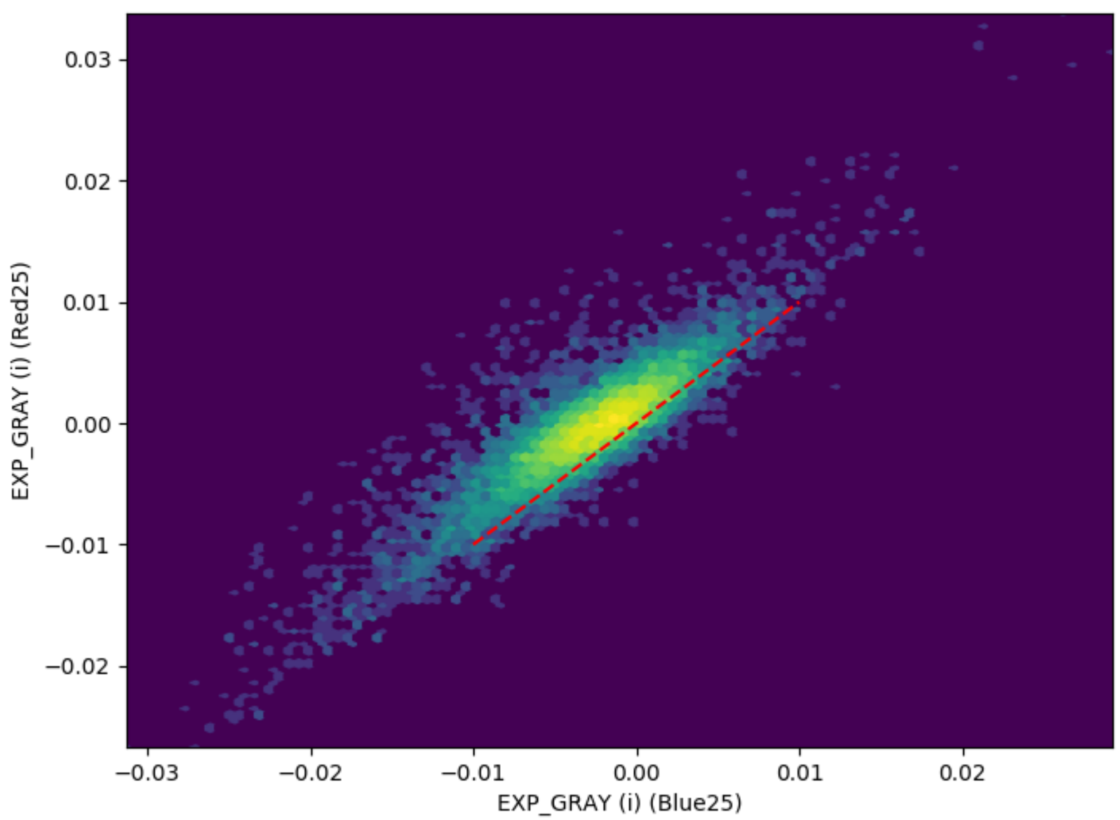


Modeling Magnitude Errors

- Look at gray residuals per exposure for red vs blue stars

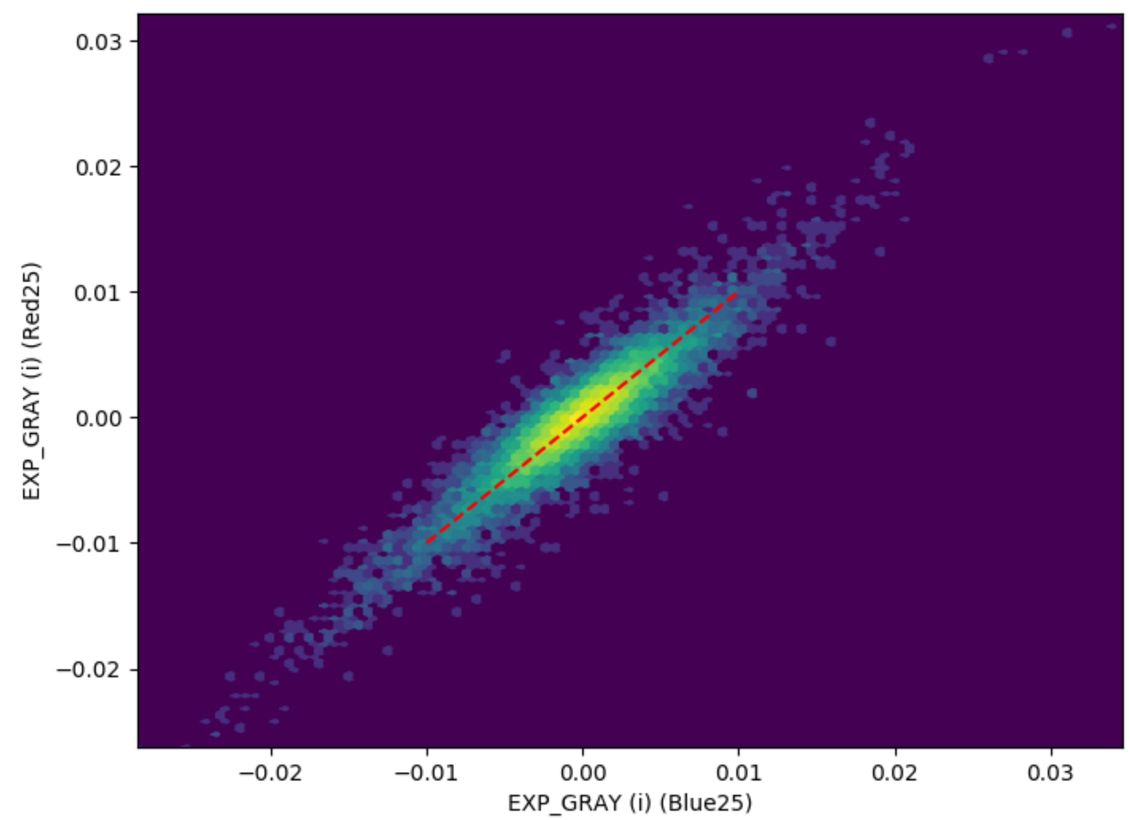
Exposure Residual (red stars)

No error modeling



Exposure Residual (blue stars)

With error modeling



Exposure Residual (blue stars)

Gaia Flux Excess

- Before I look again at the uniformity compared to Gaia, let's look at the uniformity of Gaia internally
- Gaia DR2 suggests using the "flux excess" which is $(flux_{BP} + flux_{RP}) / flux_{G}$ ($>\sim 1$) to cut bad objects

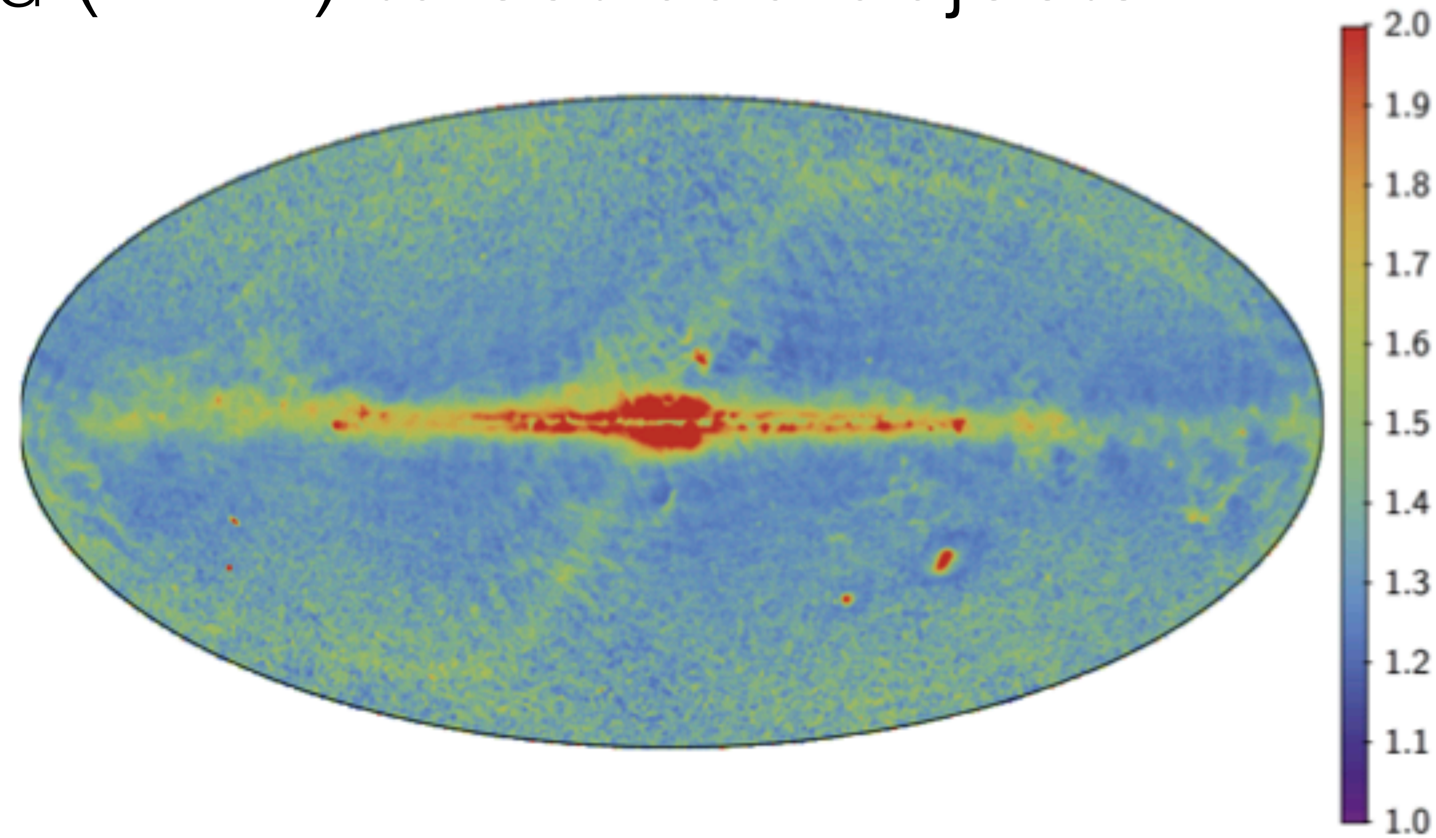
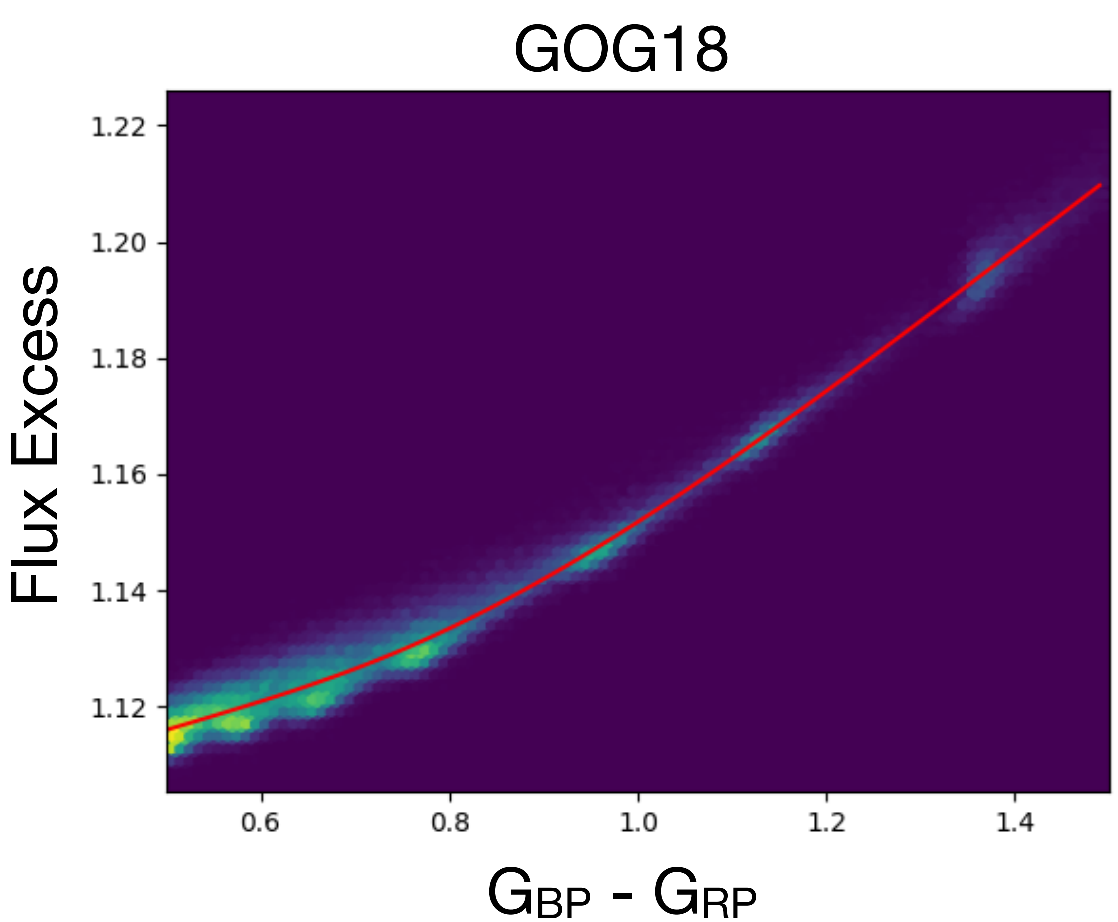
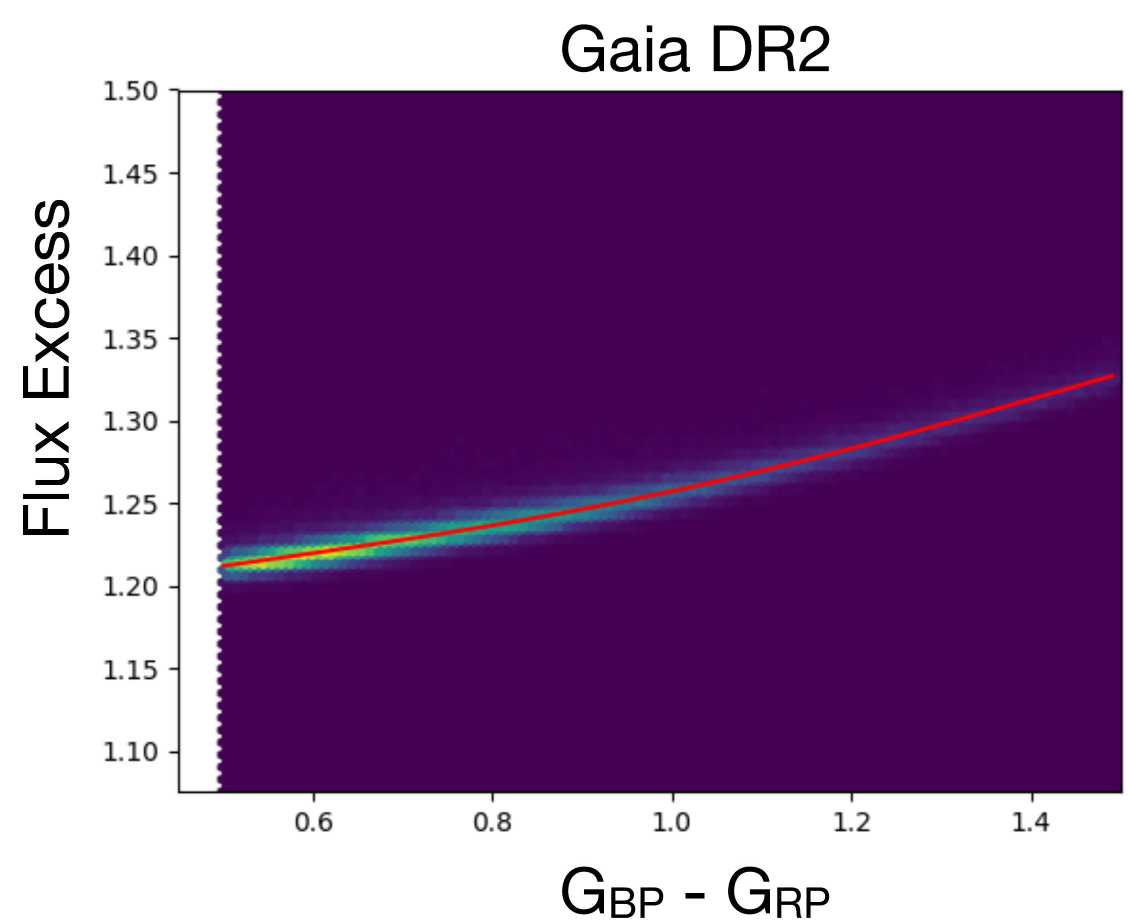


Fig. 18. Median flux excess in galactic coordinates for a random set of sources.

Gaia Flux Excess

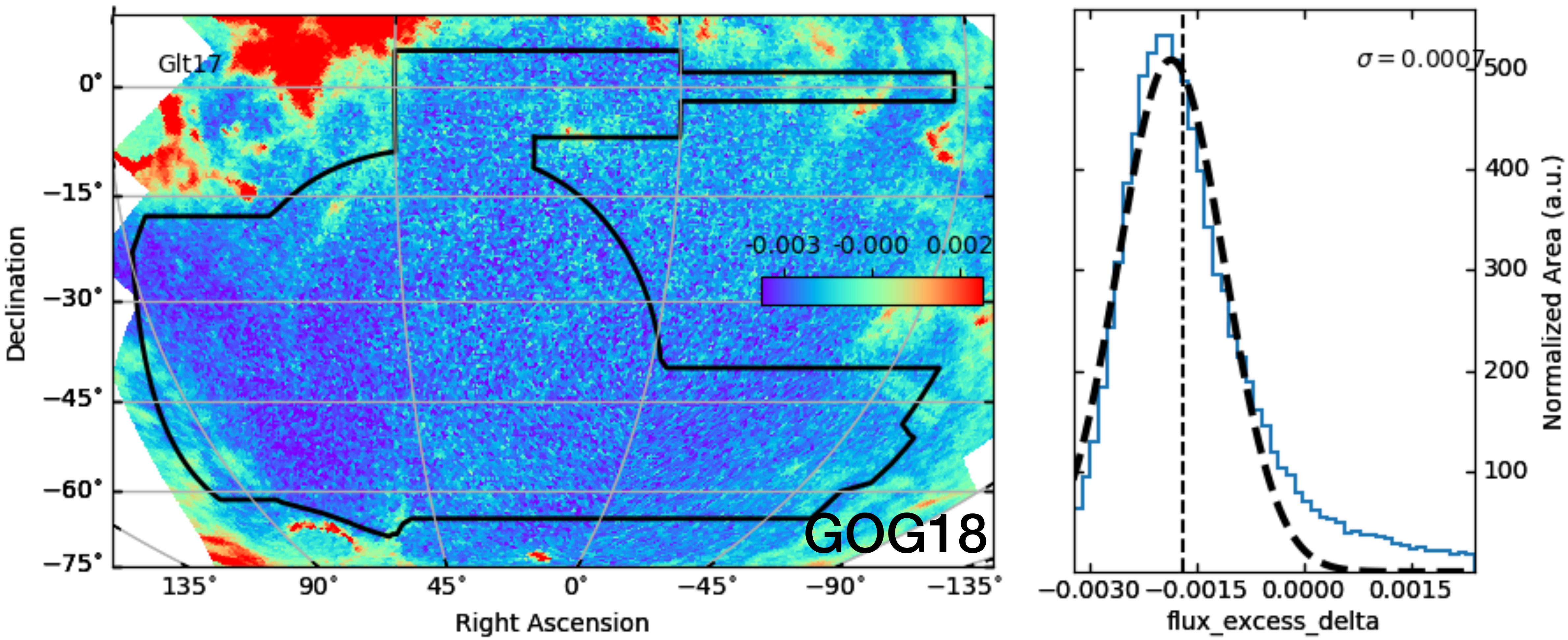
- We can calibrate the flux excess as a function of Gaia color for both Gaia Object Generator (GOG18) and Gaia DR2
  - GOG18 is supposed to give realistic errors for the full Gaia survey





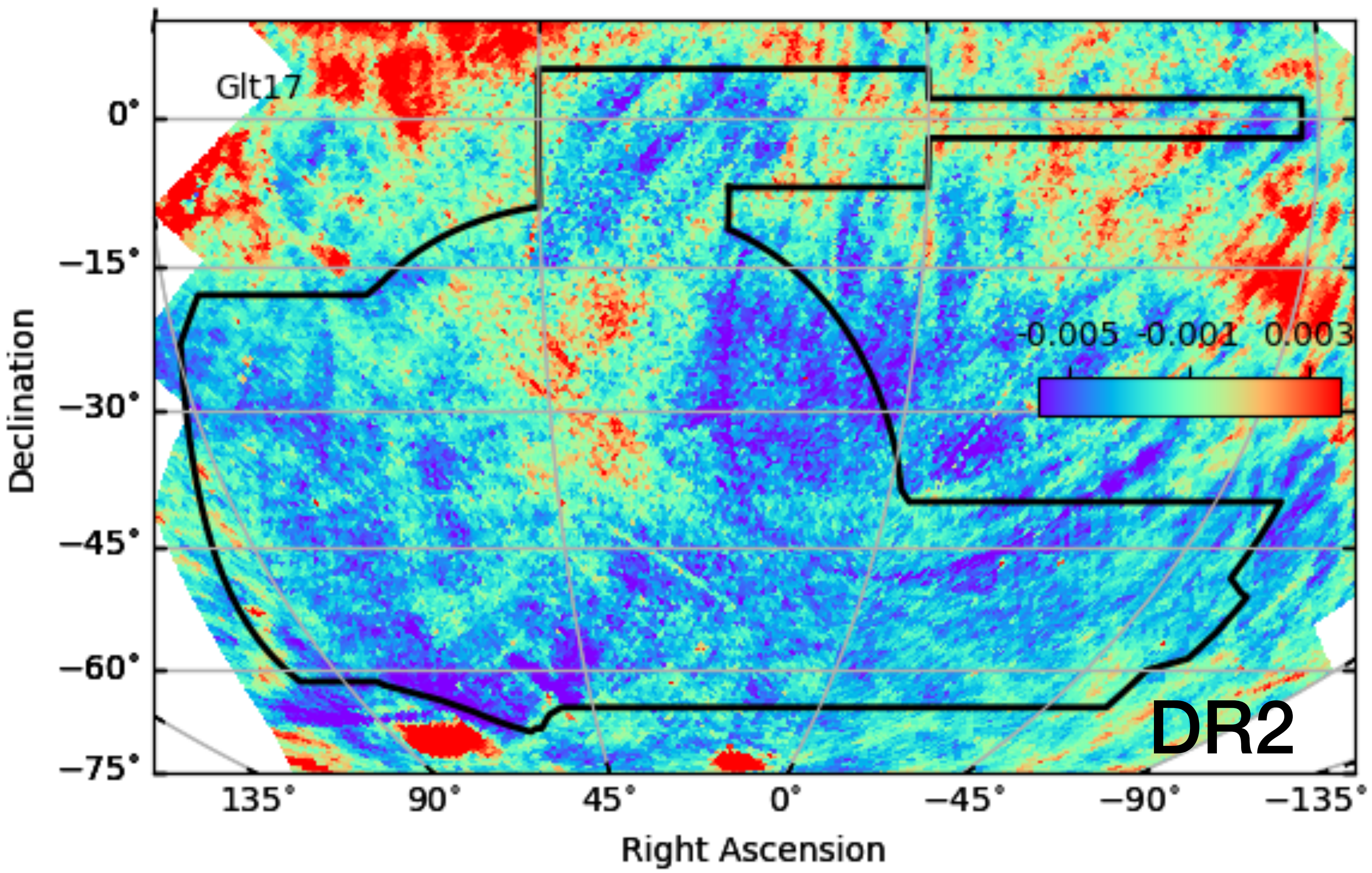
Median Flux Excess Map

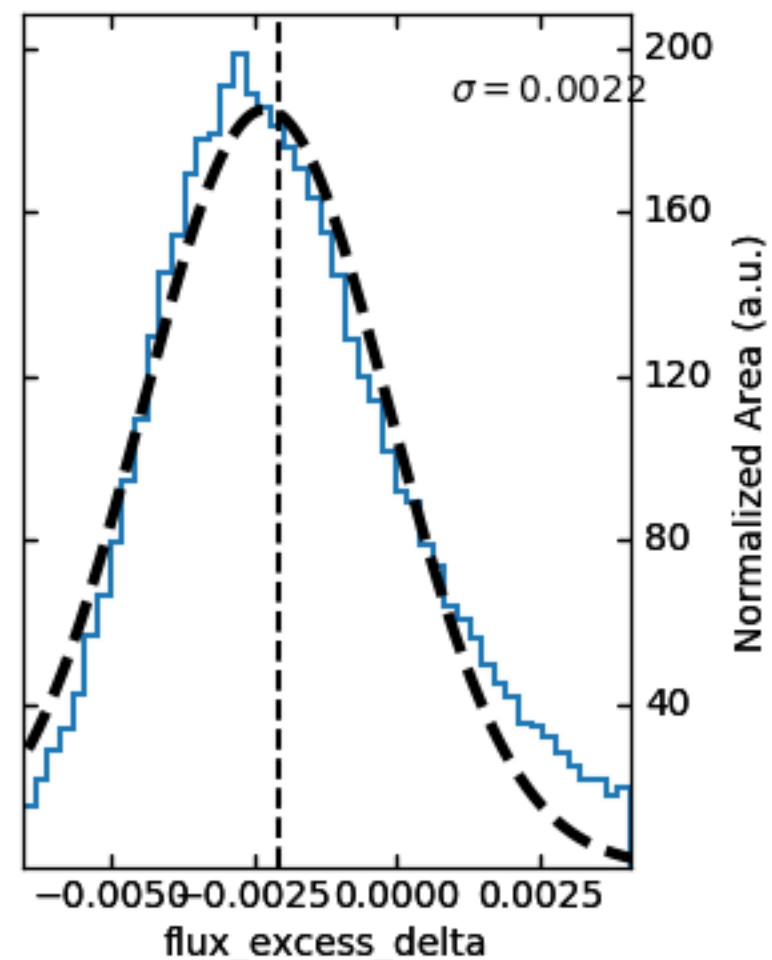
- Look at the median flux excess as a function of position for GOG18



Median Flux Excess Map

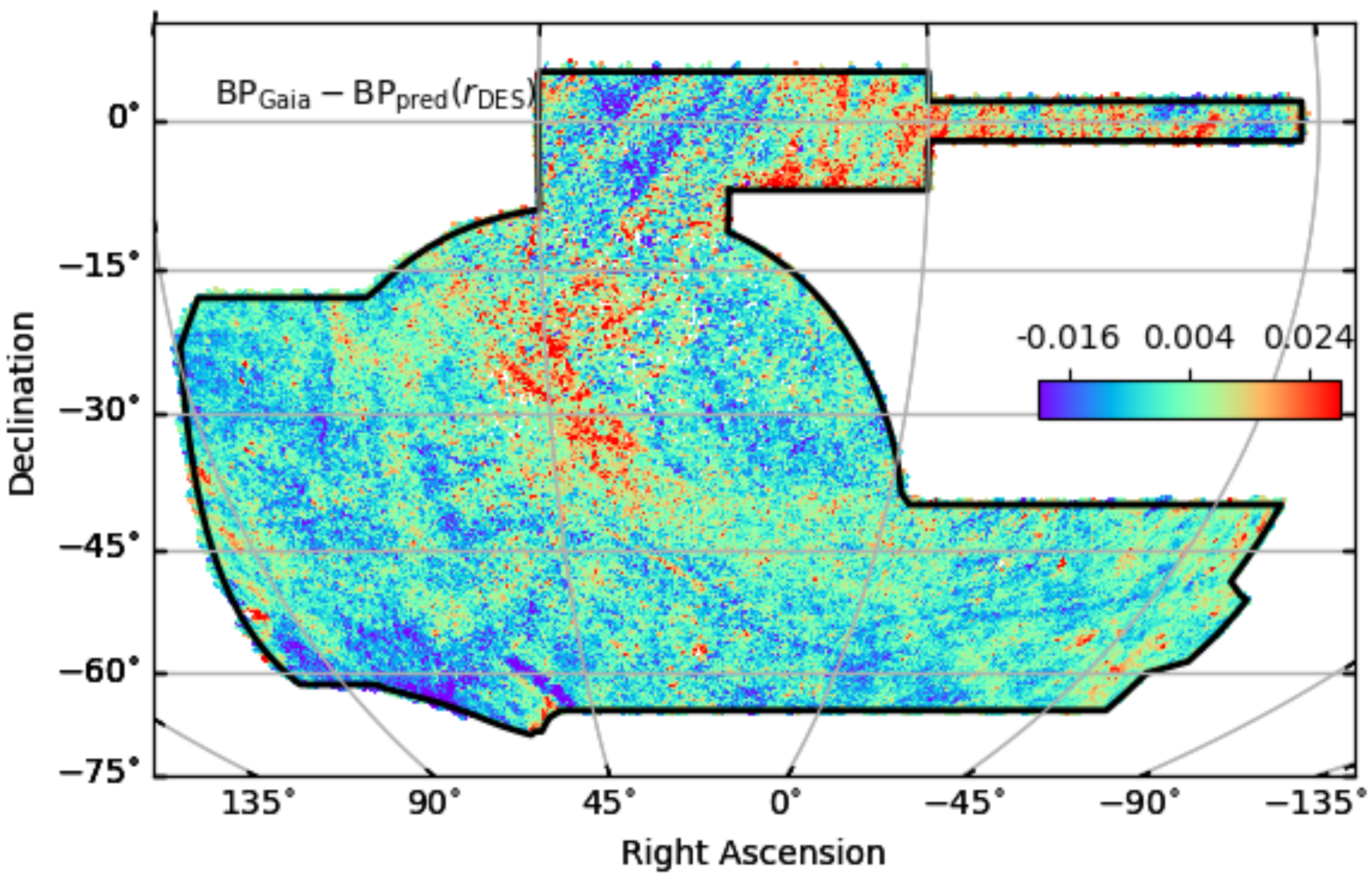
- Look at the median flux excess as a function of position for Gaia DR2

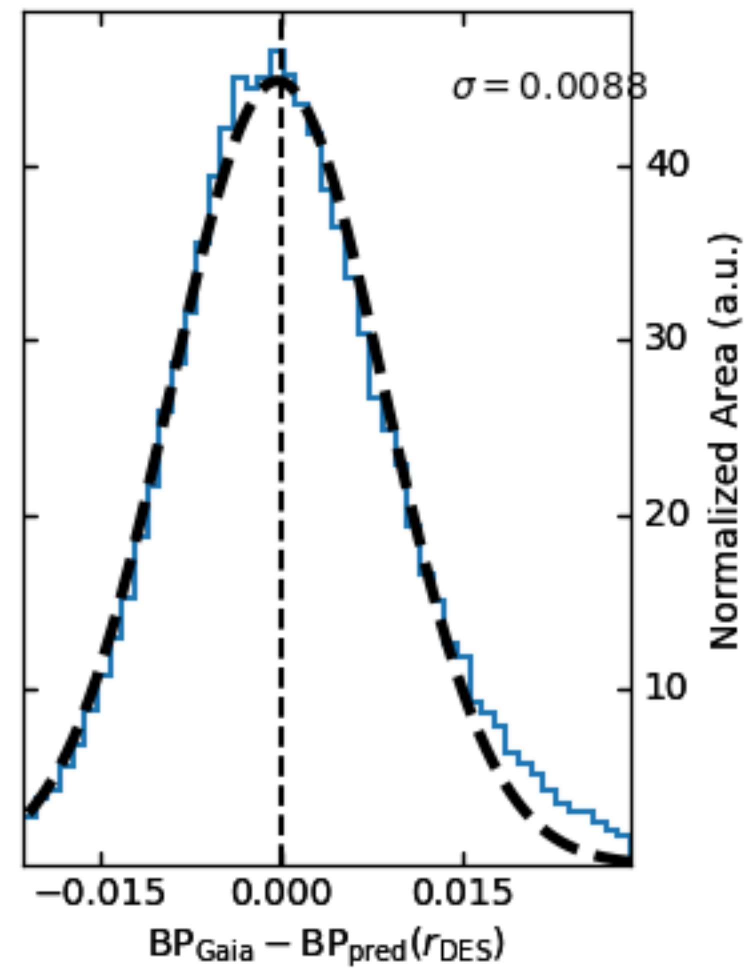




Gaia BP and DES r

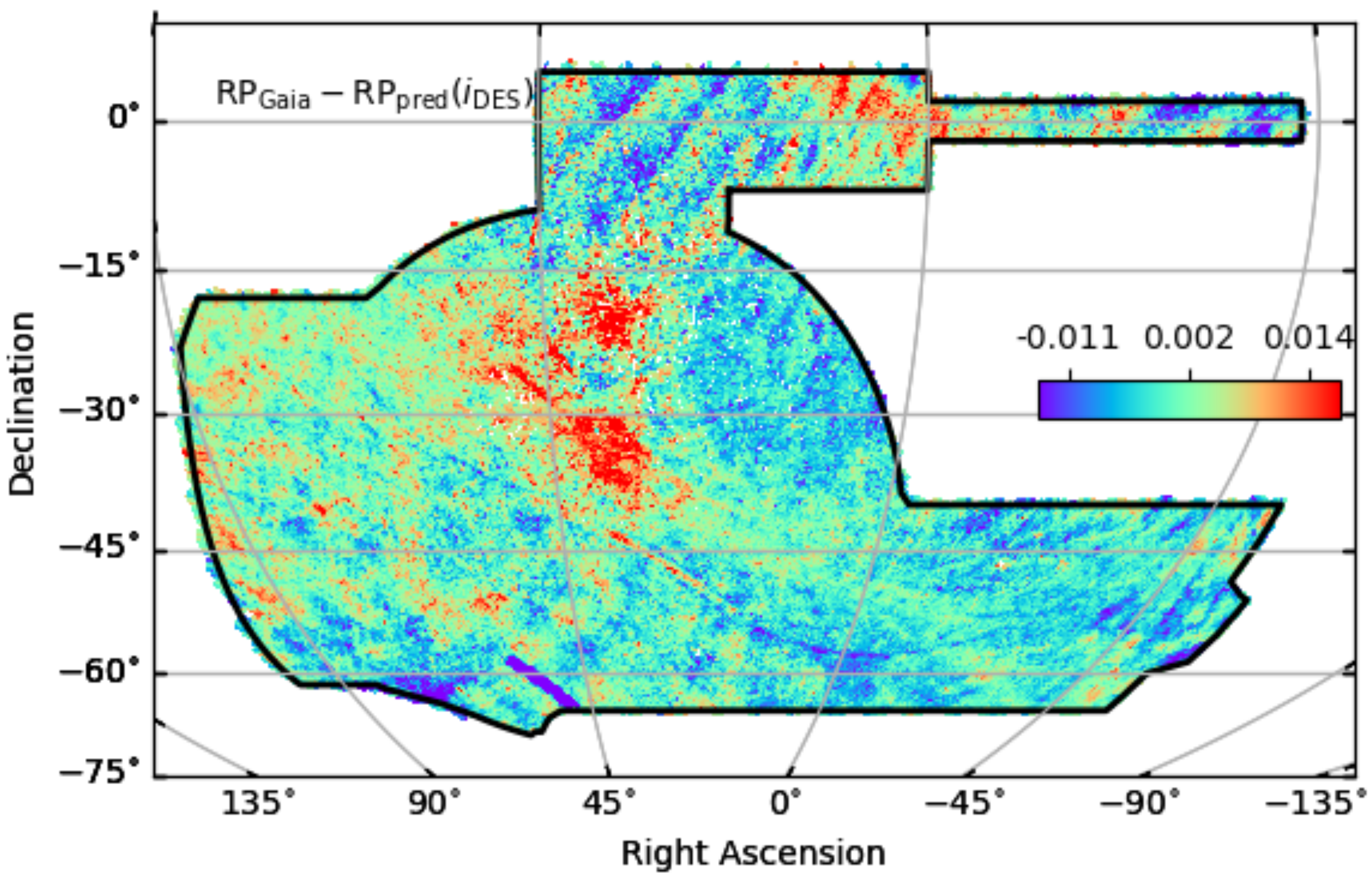
- Offsets are highly correlated with internal Gaia offsets

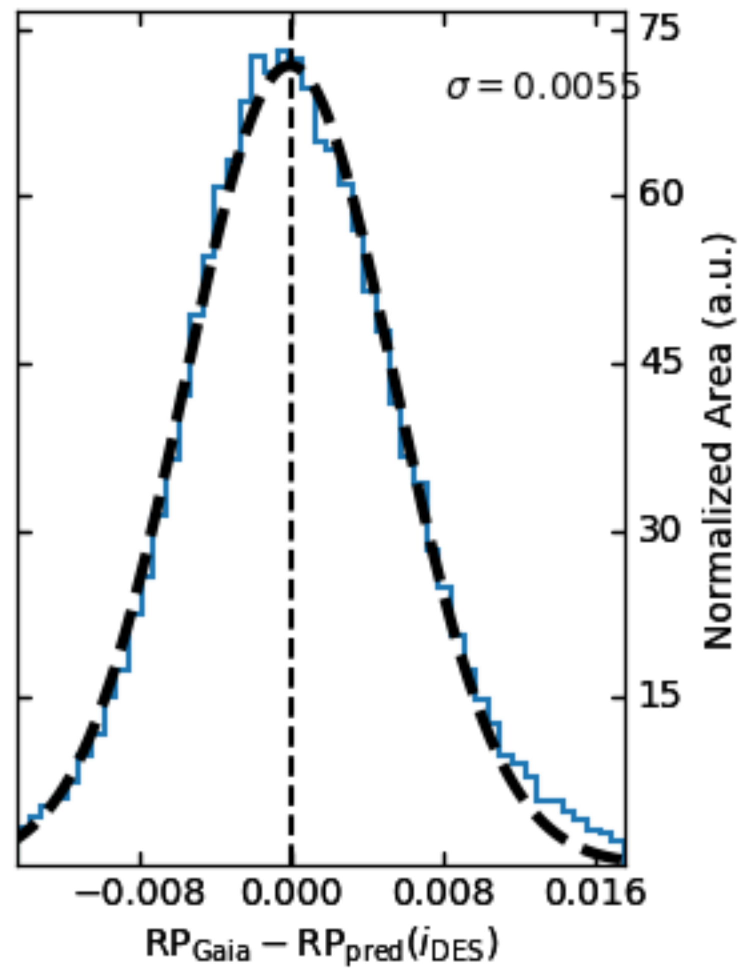




Gaia RP and DES I

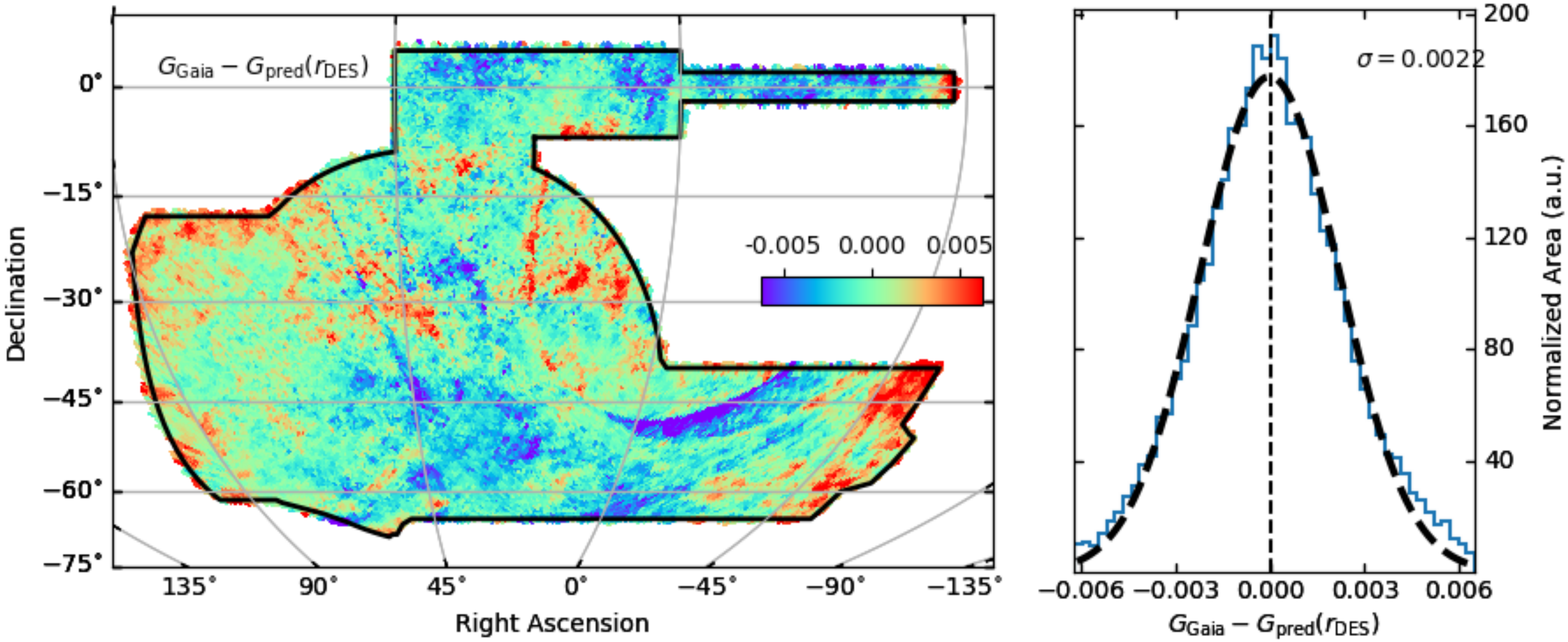
- Offsets are highly correlated with internal Gaia offsets





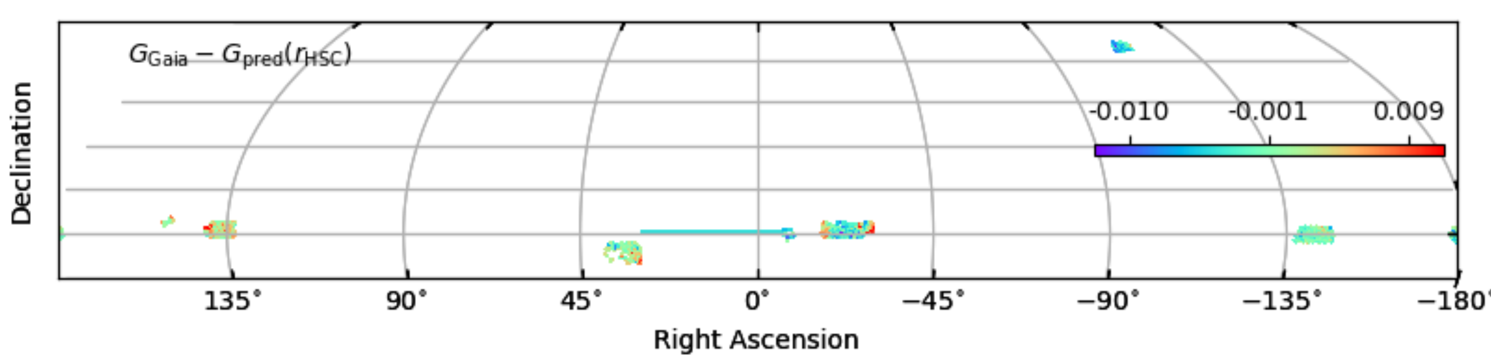
Gaia G and DES r

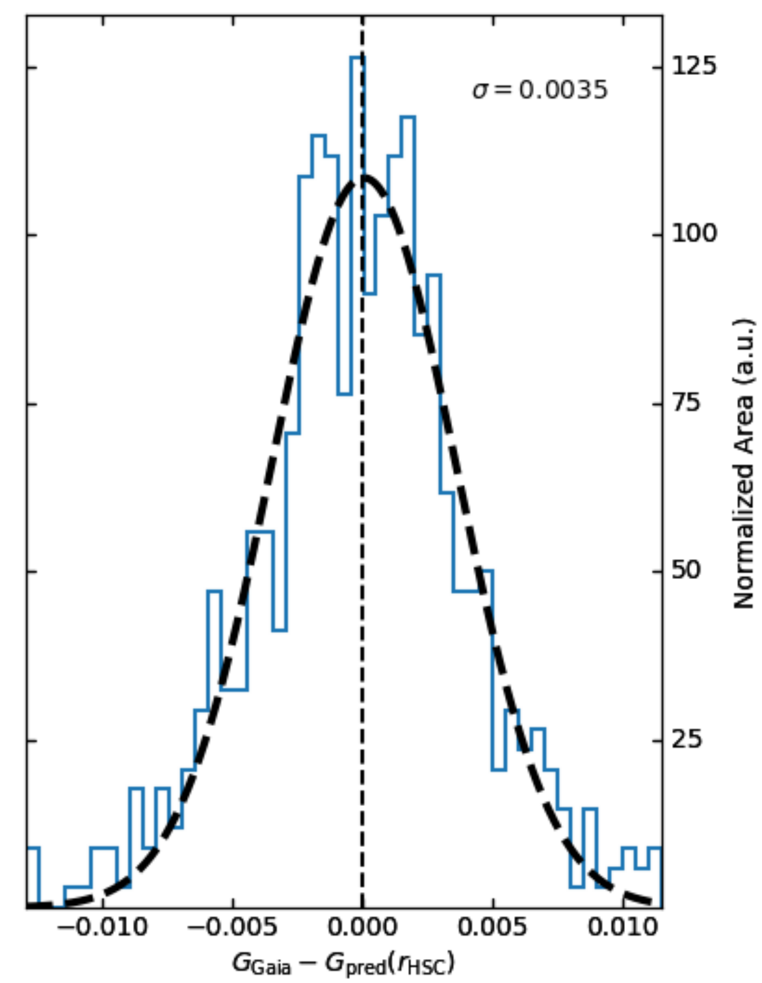
- Latest comparison plot between Gaia G and DES r + g-r + r-i + i-z (best SED transfer)
- 2.2 mmag uniformity (low Galactic latitude)



HSC PDR1 Uniformity

- ~4 mmag in r-band after comparing to Gaia DR2
- Though some systematics between widely separated fields





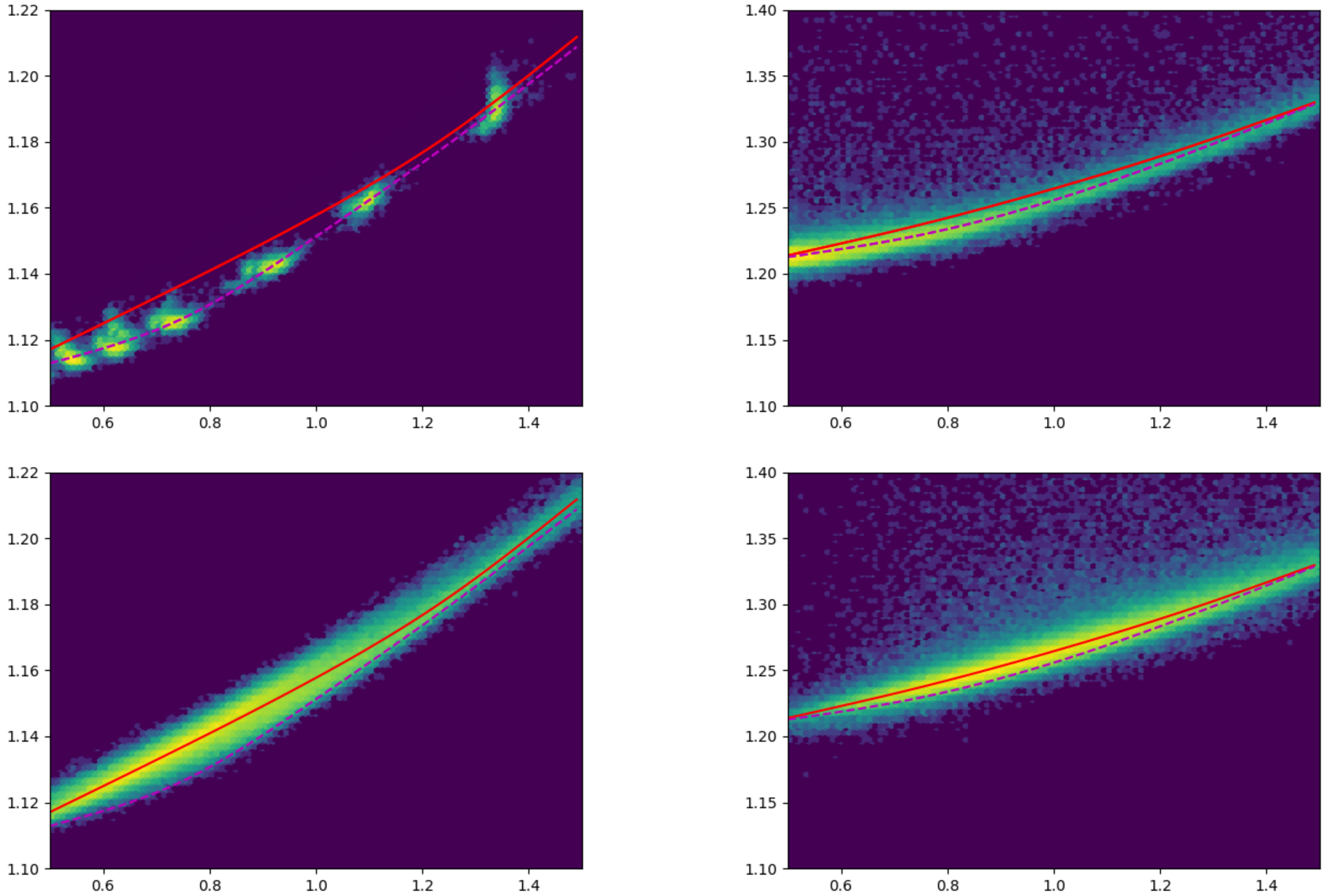
About that Reddening…

GOG18

DR2

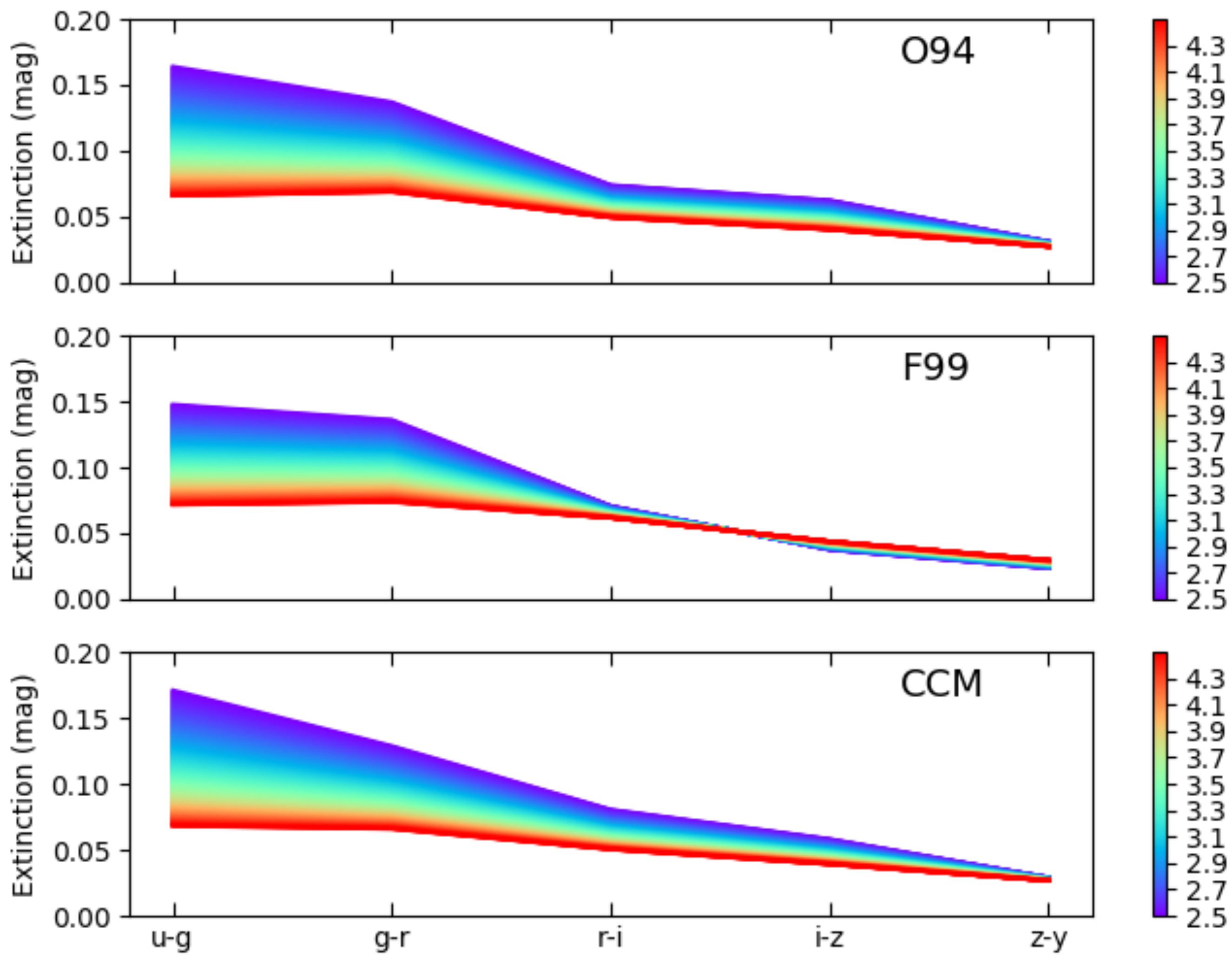
Low Reddening

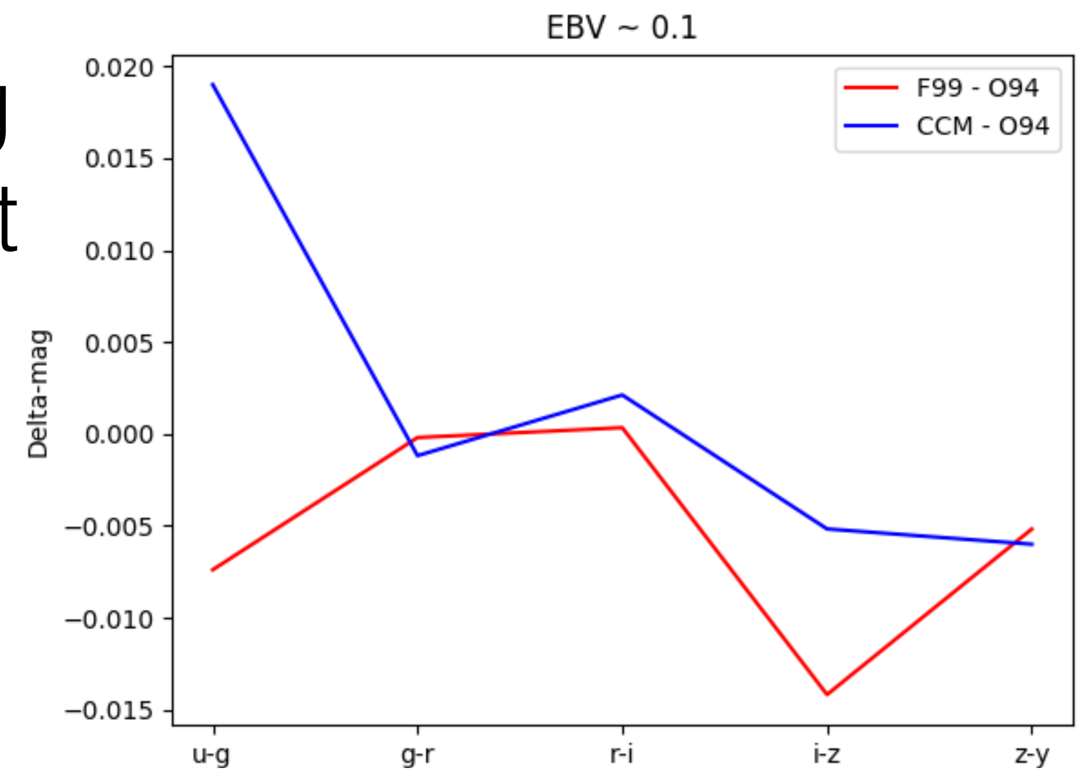
High Reddening

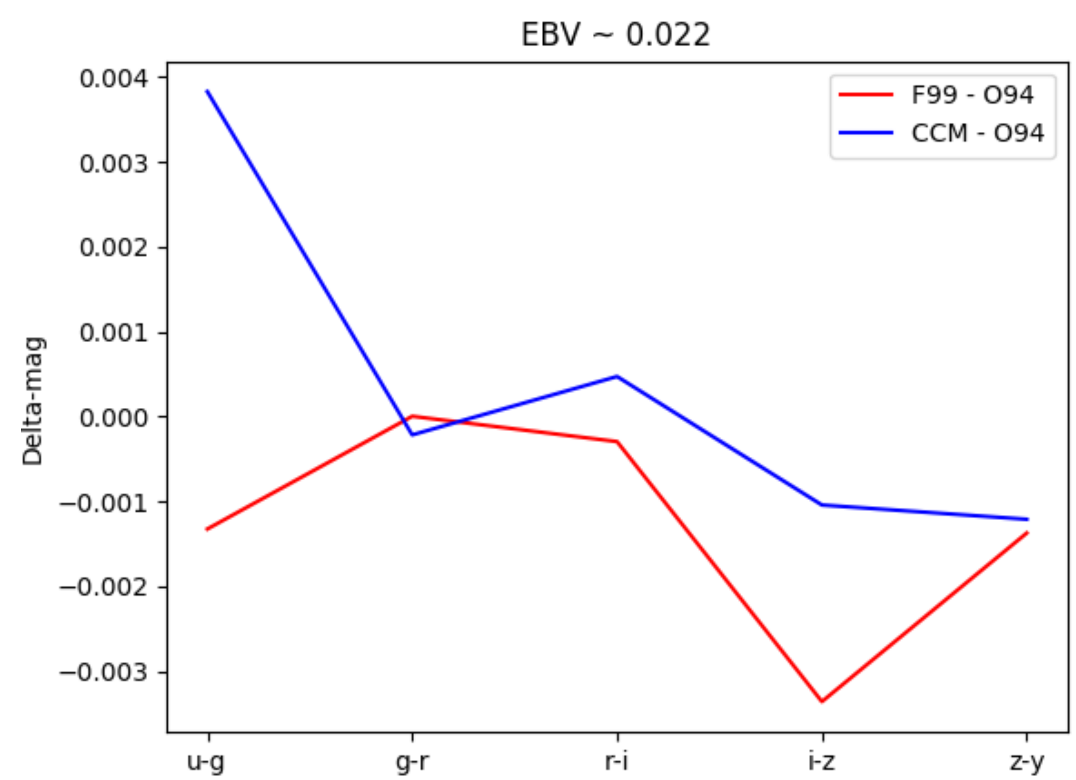


And the Reddening Law!

- Comparing reddening laws shows issues at the >mmag level (depending on amount of reddening)







Discussion

- This is a grab-bag of issues to get below the 5mmag uniformity level (that I know about…)