IN2P3

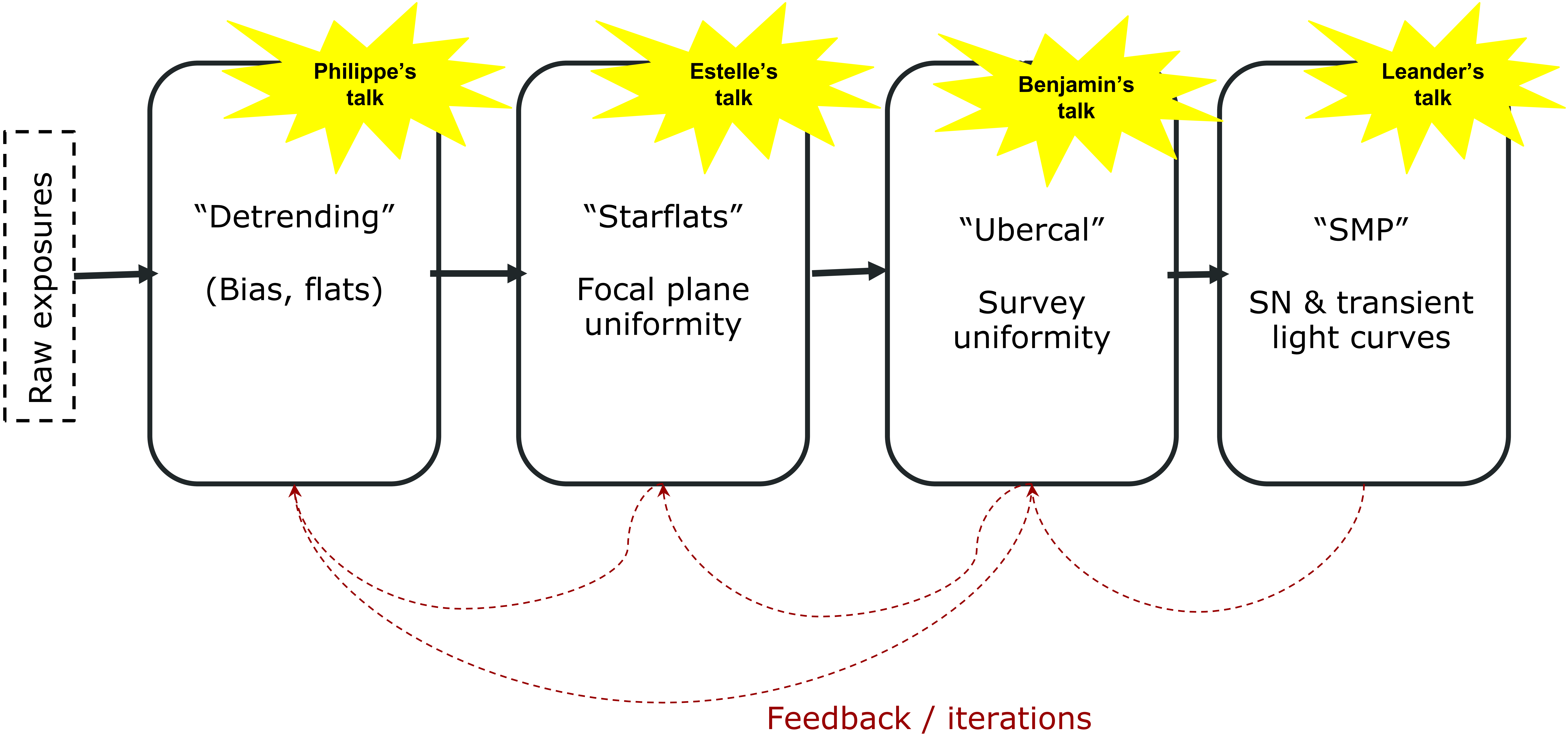
Institut national de physique nucléaire
et de physique des particules

funded by anr

ZTF IN2P3 pipeline: where we are

May 12th 2022

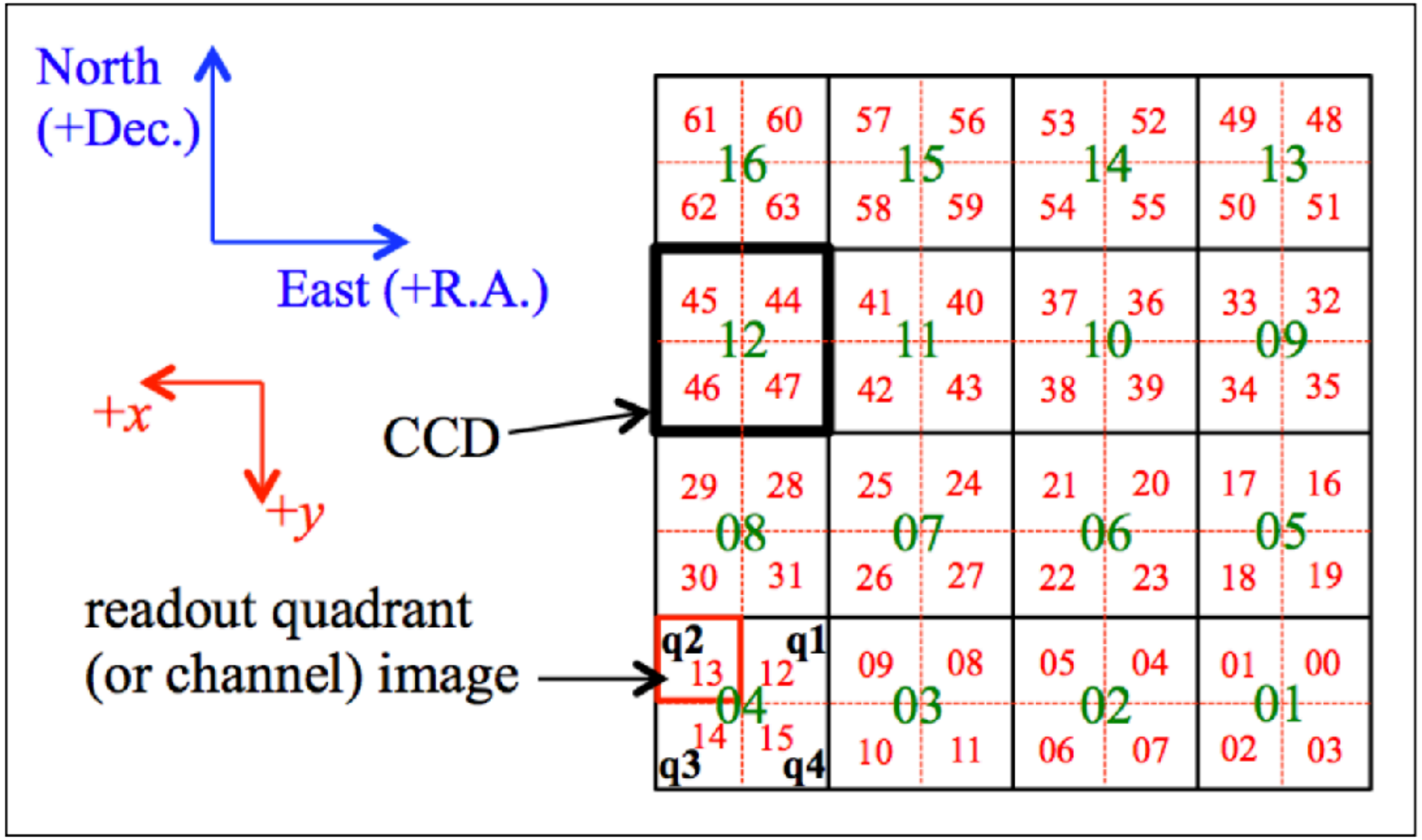
ZTF spring meeting, Paris


Raw exposures
Philippe's talk
"Detrending"
(Bias, flats)
Estelle's talk
"Starflats"
Focal plane uniformity
Benjamin's talk
"Ubercal"
Survey uniformity
Leander's talk
"SMP"
SN & transient light curves
Feedback / iterations

Masterbias & Masterflat

Philippe Rosnet & Philippe Gris

Bias & Flat fielding



$$\frac{\text{Raw image} - \text{Bias image}}{\text{Flat image}} = \text{Science image}$$

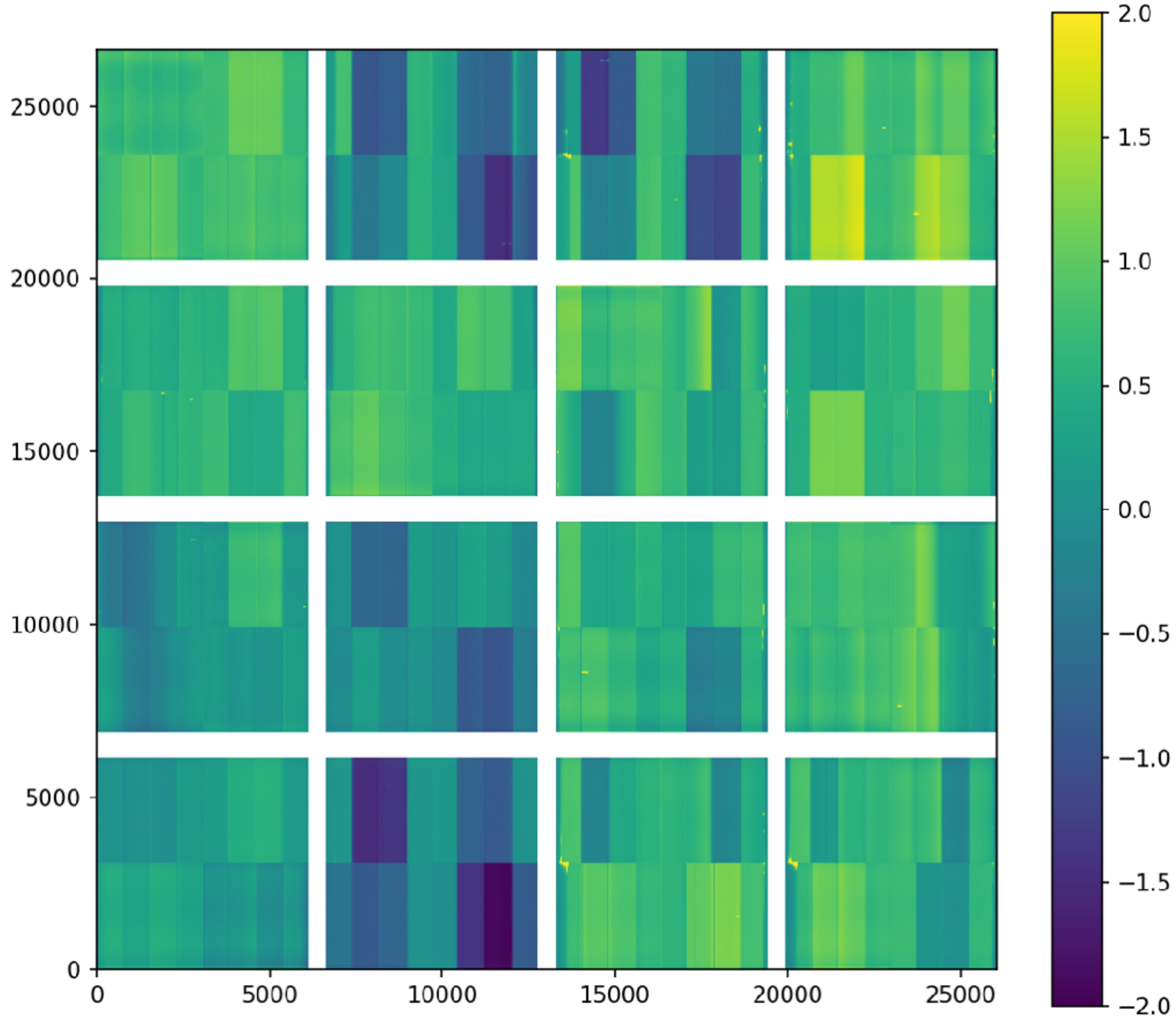
Bias and Master-bias

Bias runs

- Bias frames: exposure time t = 0s, camera's shutter closed (I(x,y)=0)
- Bias runs ~ every day
- 20 runs per day (~5-6 min in total)
- Overscan subtraction included
- Analysis : Y2019

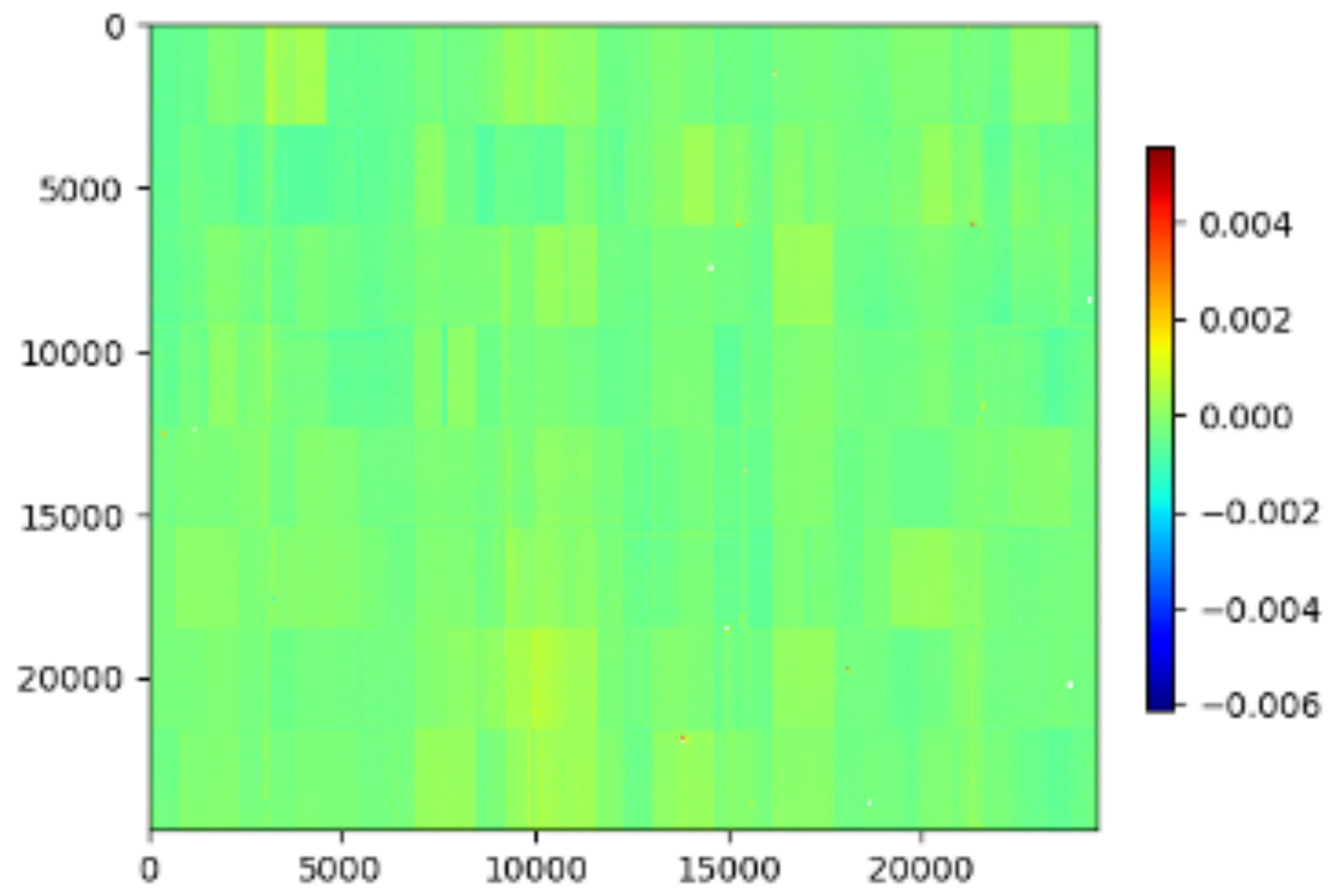
Master bias

- Data from 2019 runs are splitted in 20 days periods
- For each period: master bias are estimated:
  - 3-sigma clipping applied by quadrant
  - mean and sigma for each pixel
- Master bias stability:
  - The first period of 2019 is taken as reference (_ref)
  - All other periods: subtraction of the master bias to the reference

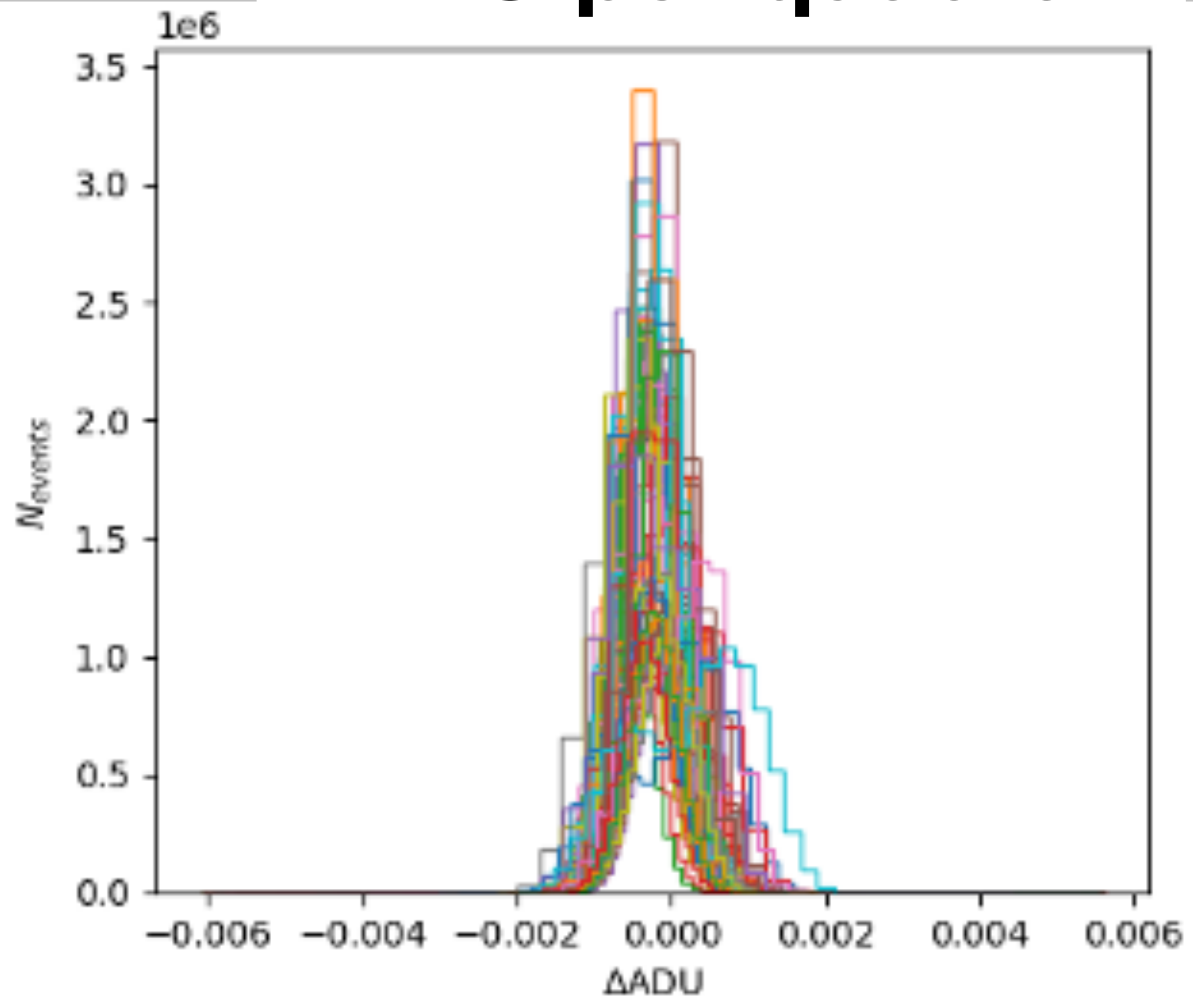


Master-bias stability

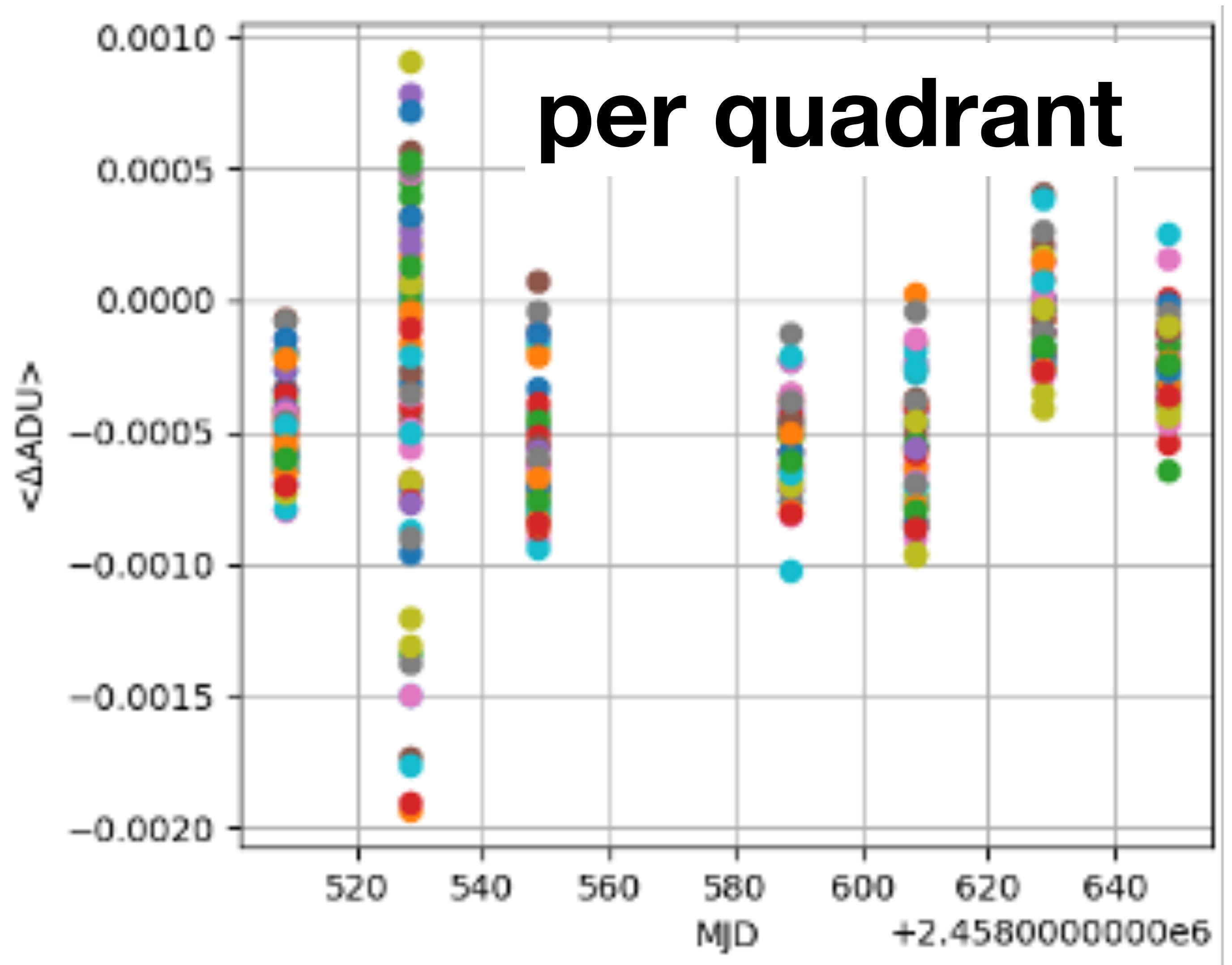
ΔADU mosaic map



ΔADU per quadrant

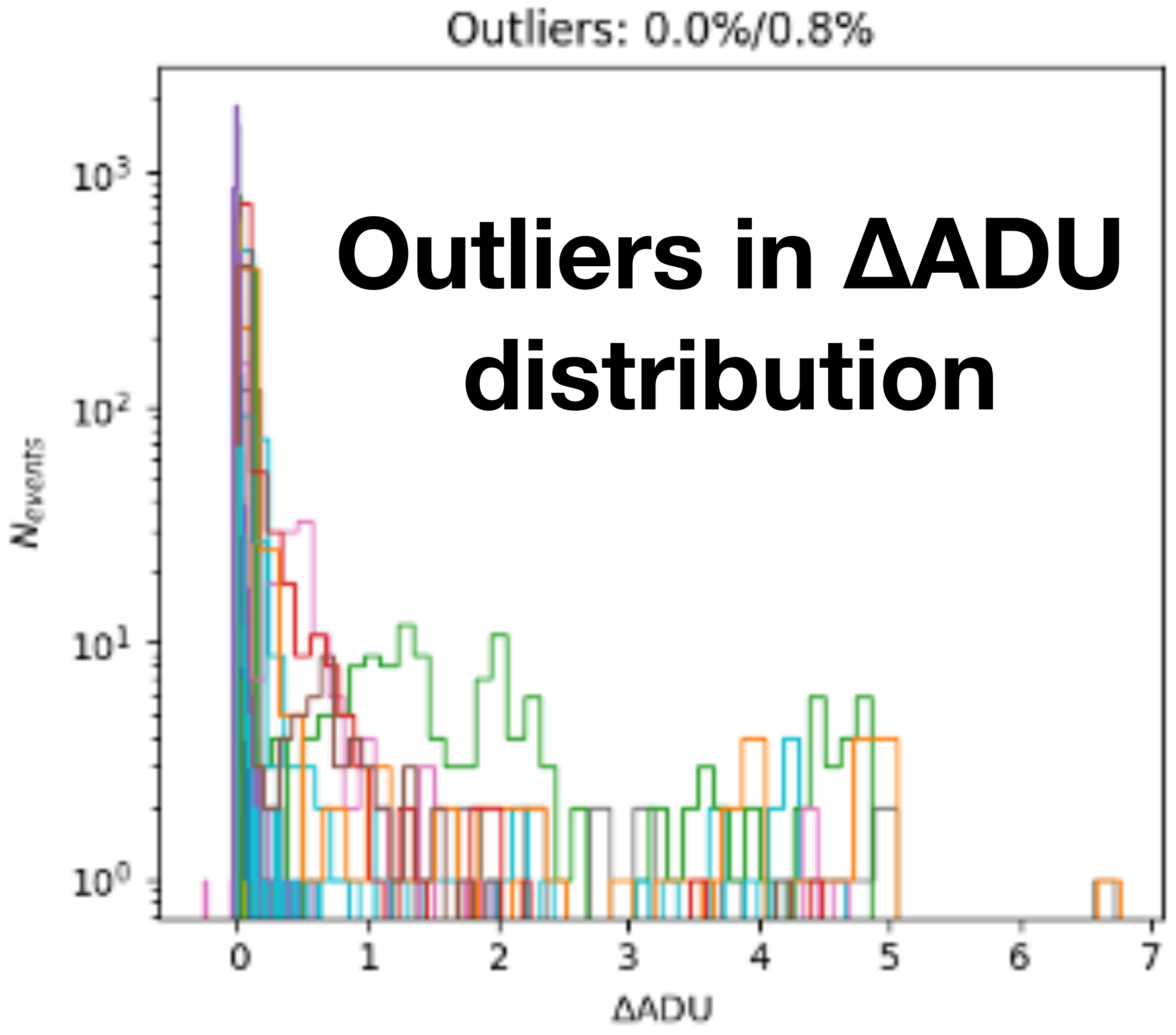


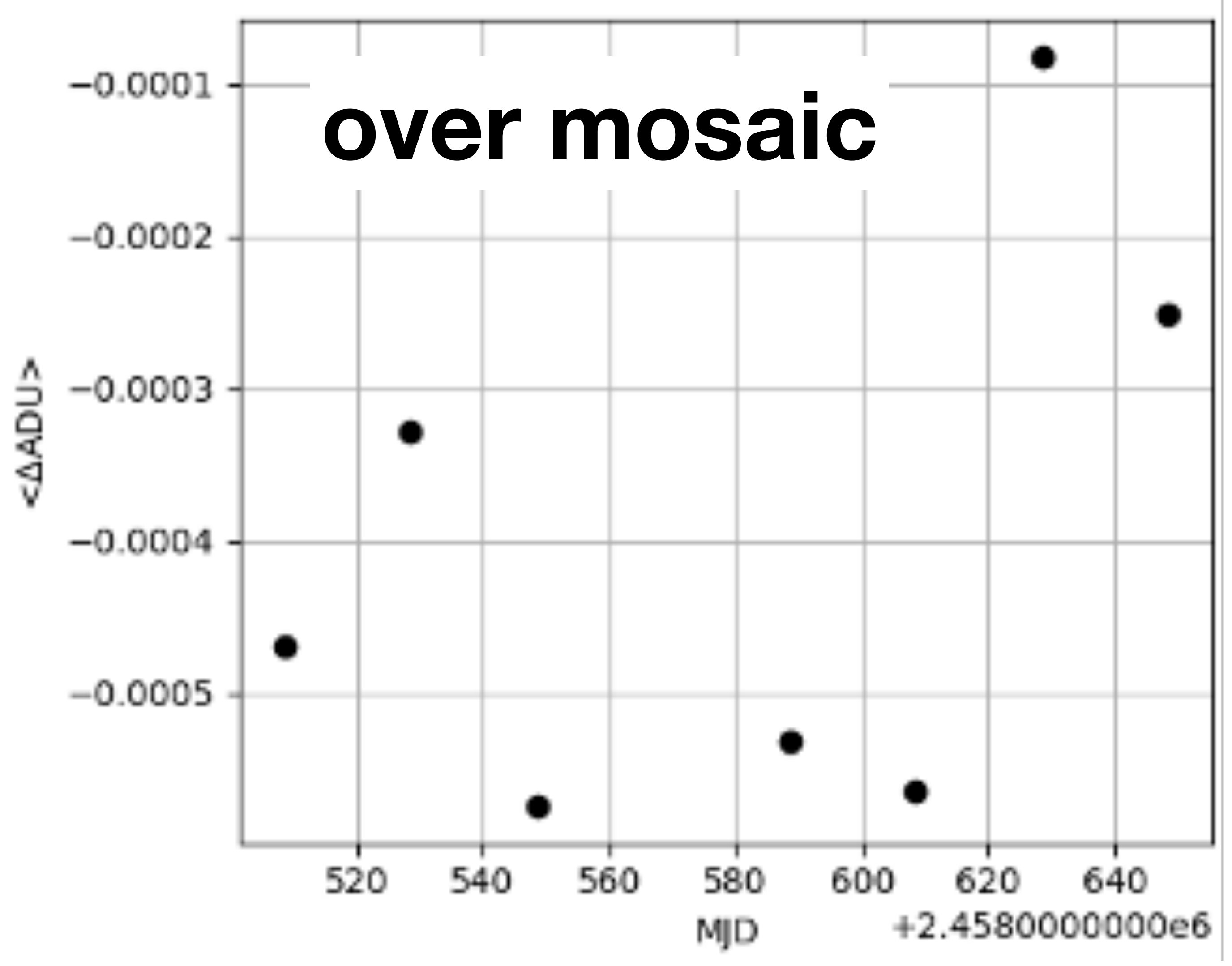
ΔADU mean versus time



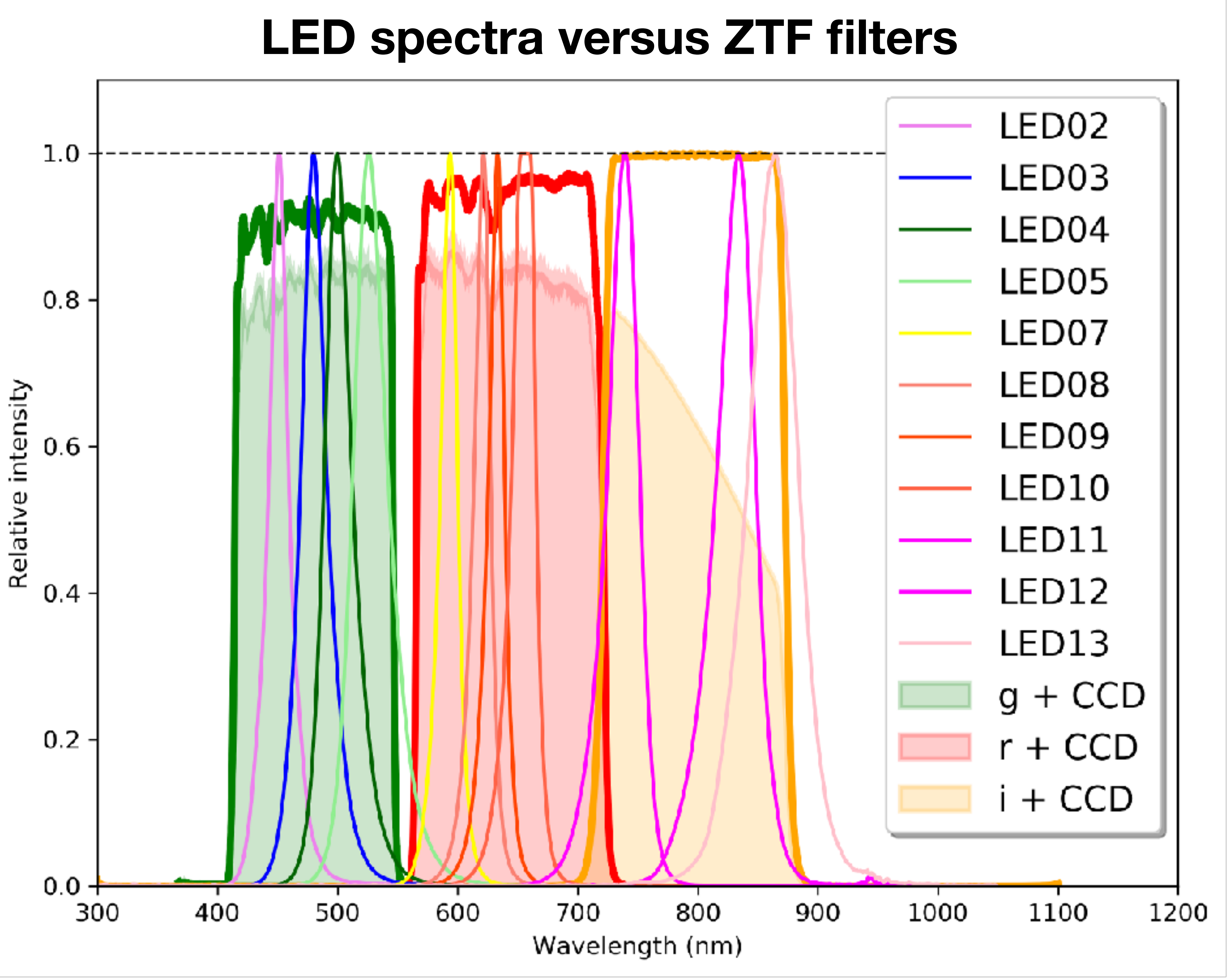
ΔADU = M-bias - M-bias_ref

- Master-bias (20 days) stable at the level of 0.01 ADU
- Outlier < 0.6%
- Full study of 2019 on-going





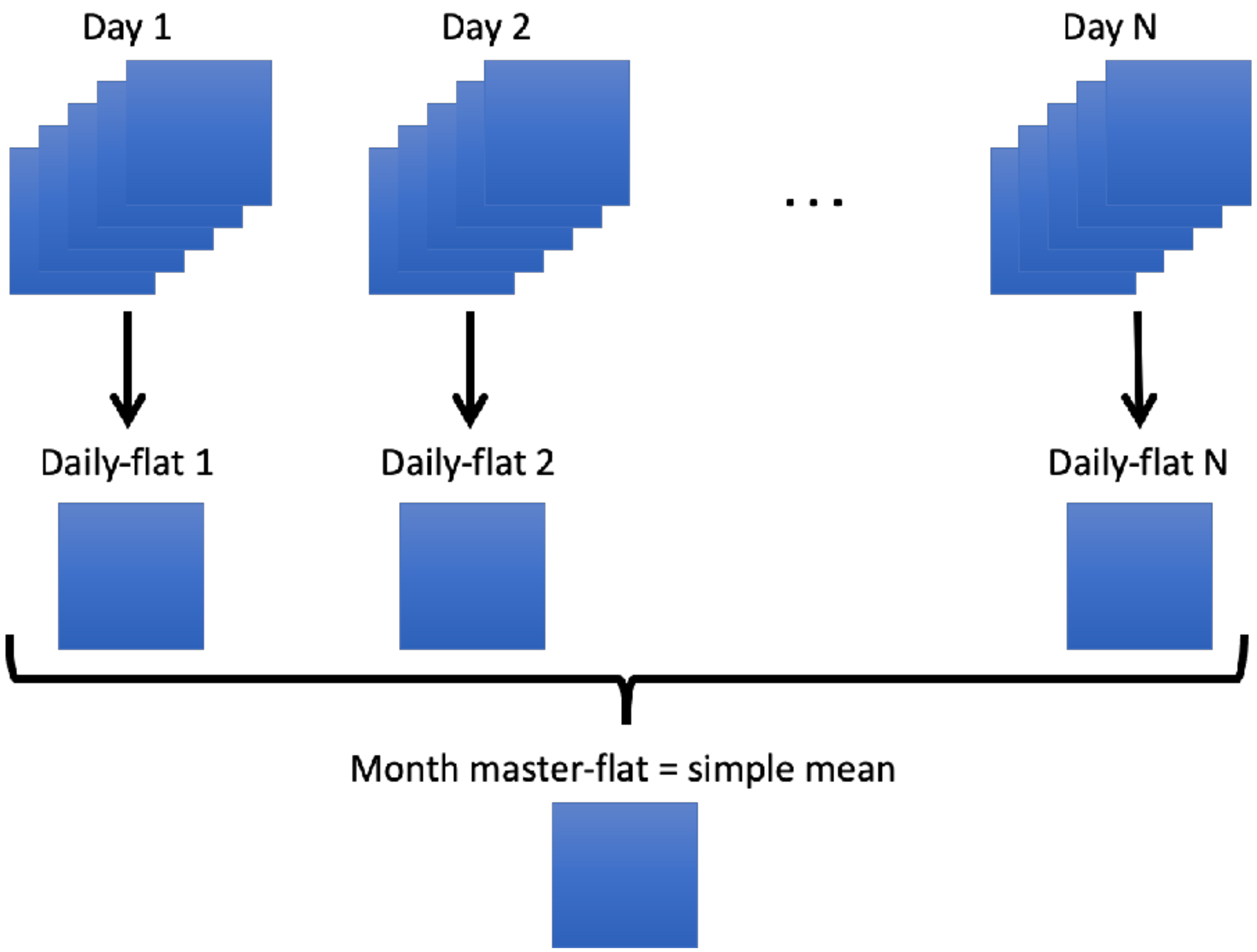
Dome flat-fielding

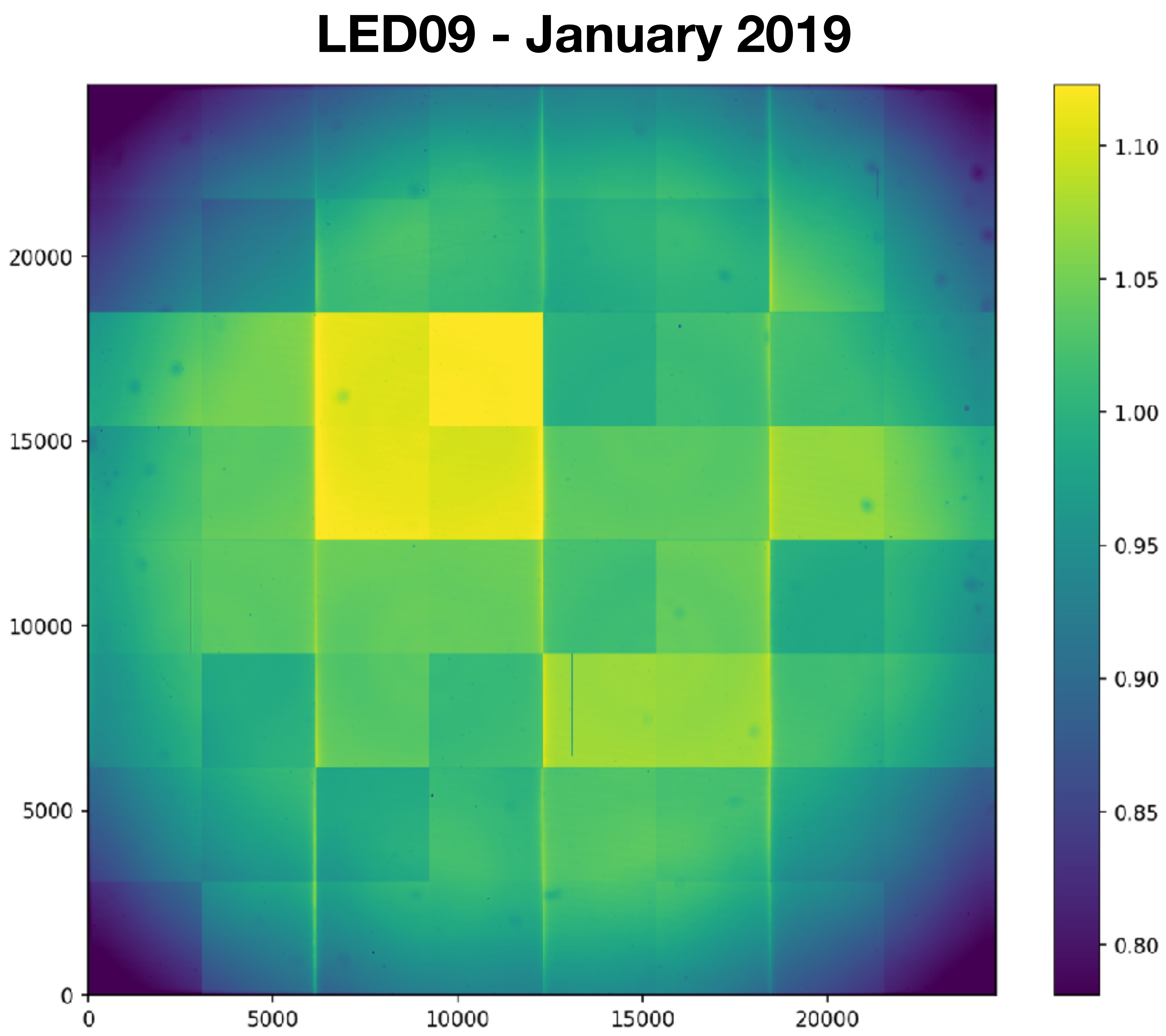


Flat-field illuminator
(32 pulsed LEDs per colour)

- g-band = stacking of 20 flat-images/day (5 per LED 02+03+04+05)
- r-band = stacking of 20 flat-images/day (5 per LED 07+08+09+10)
- i-band = stacking of 21 flat-images/day (7 per LED 11+12+13)

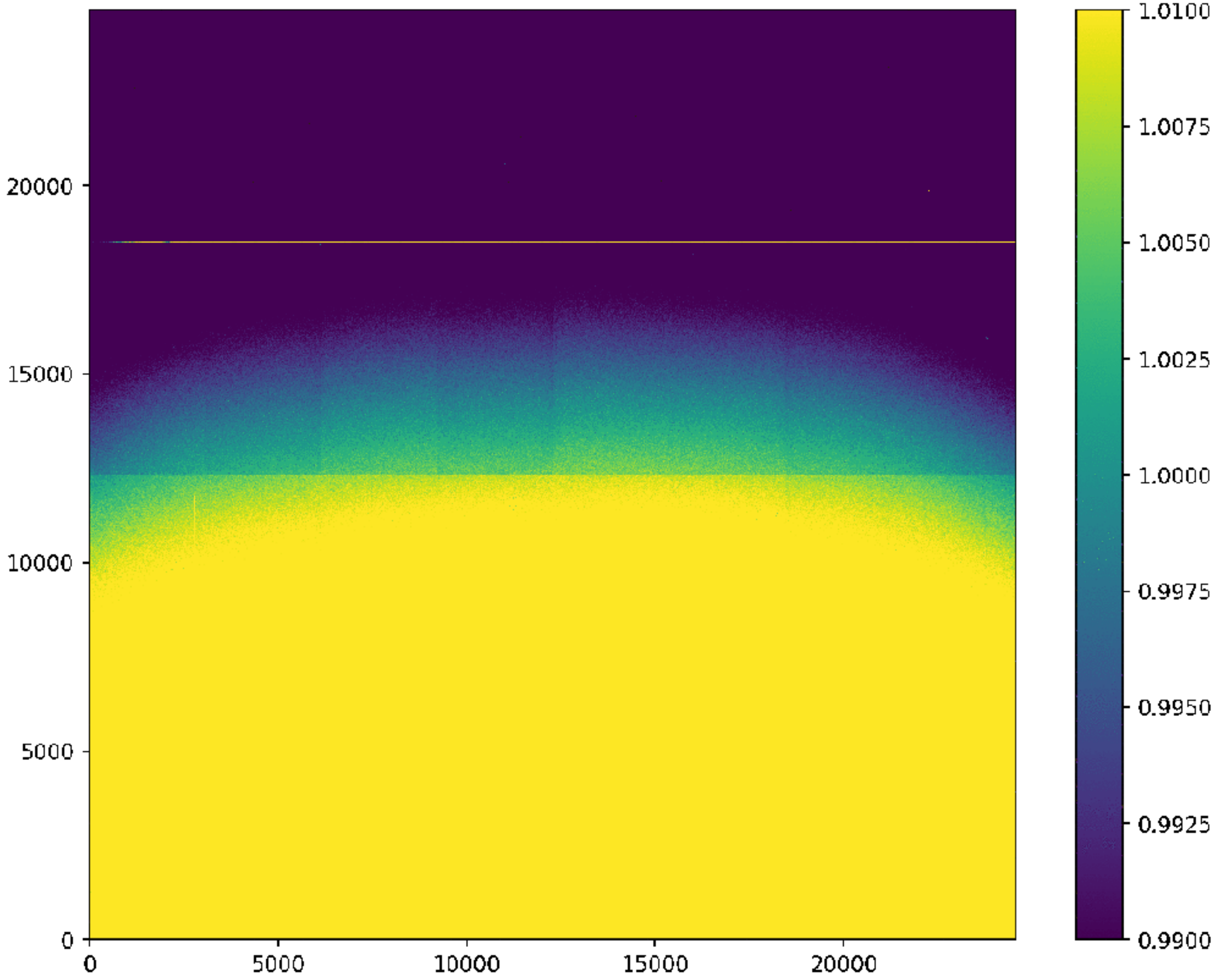
Master-flat processing



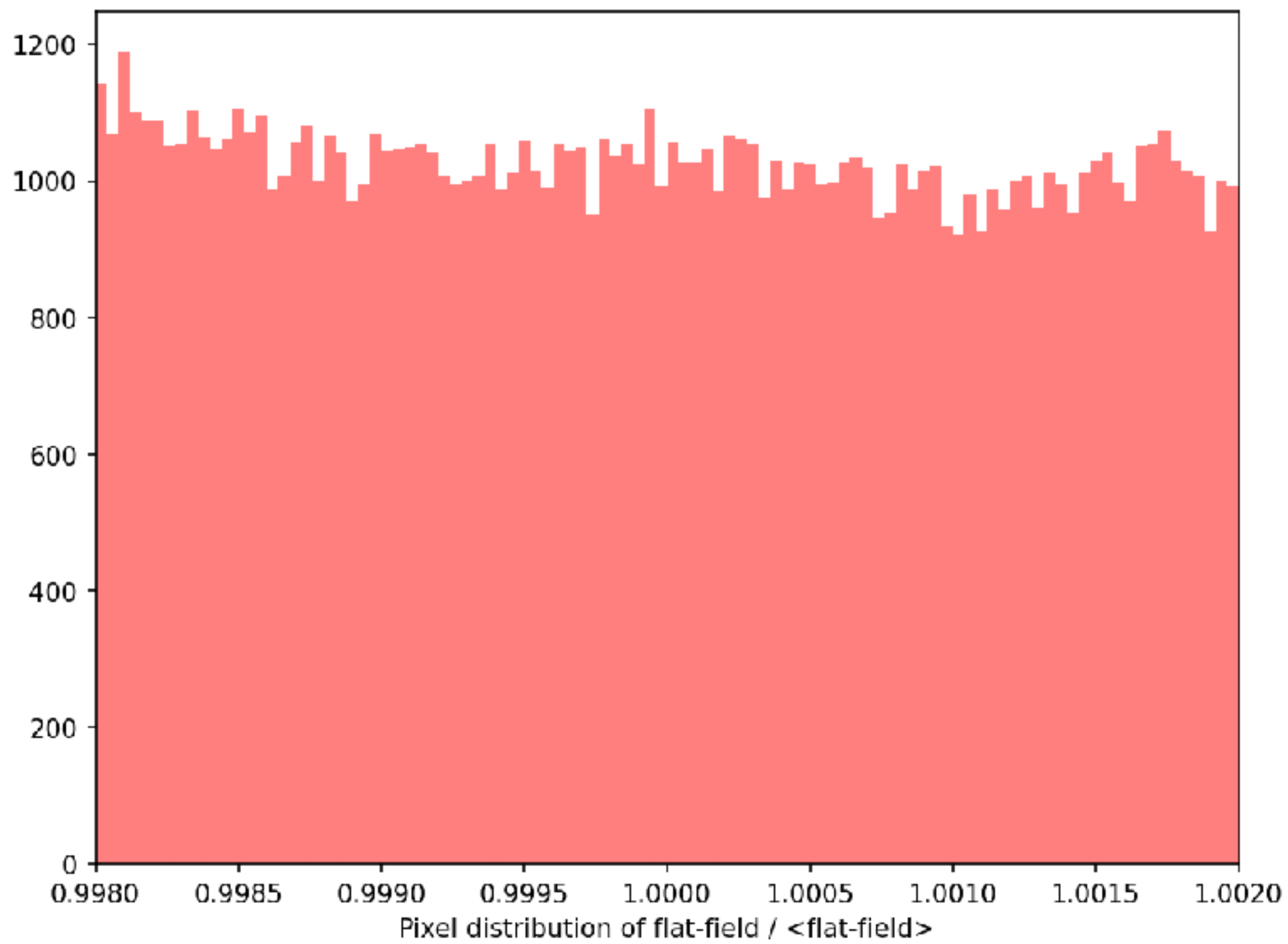


Mosaic master-flat stability

Flat ratio = daily-flat / master-flat



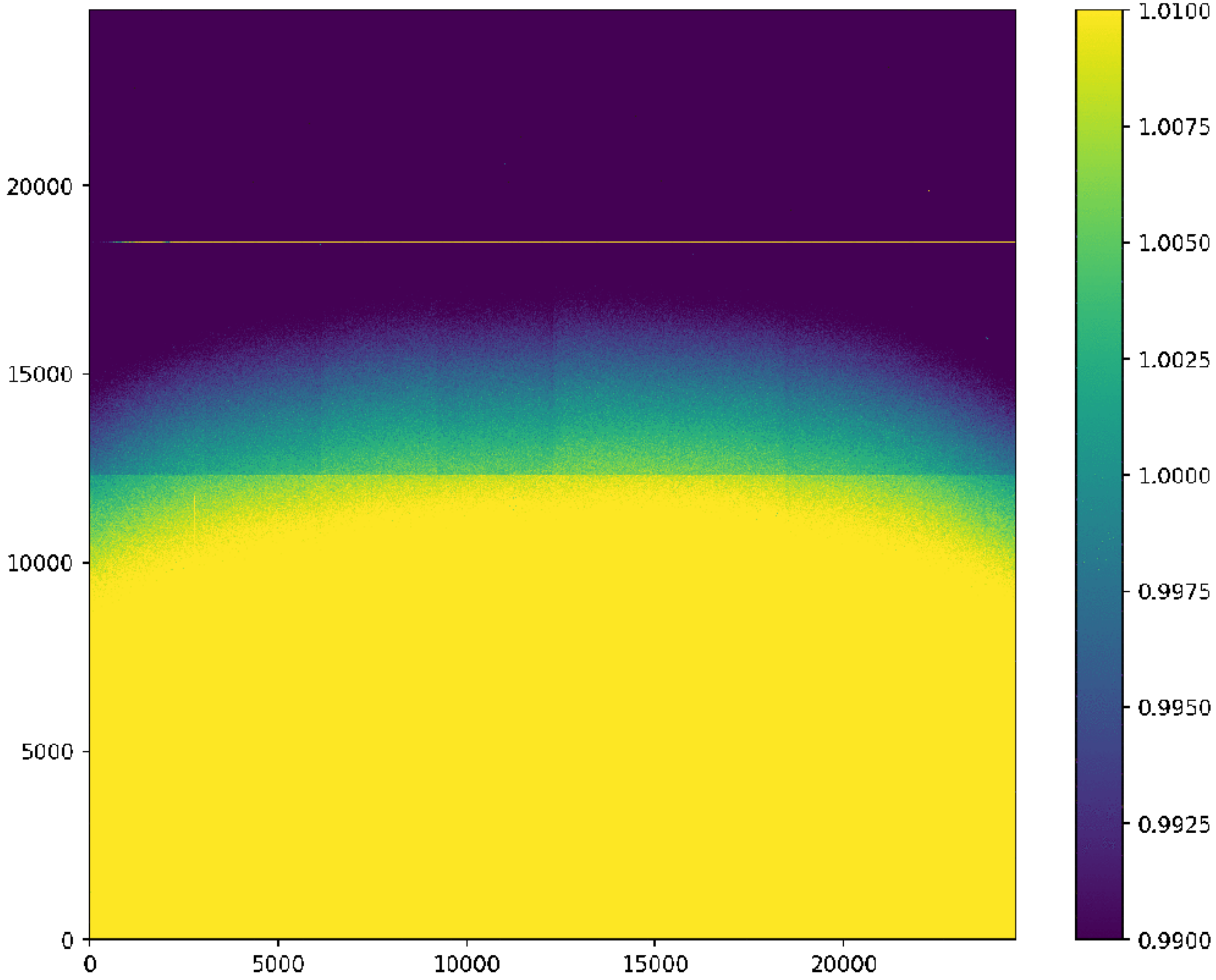
Pixel distribution of flat ratio



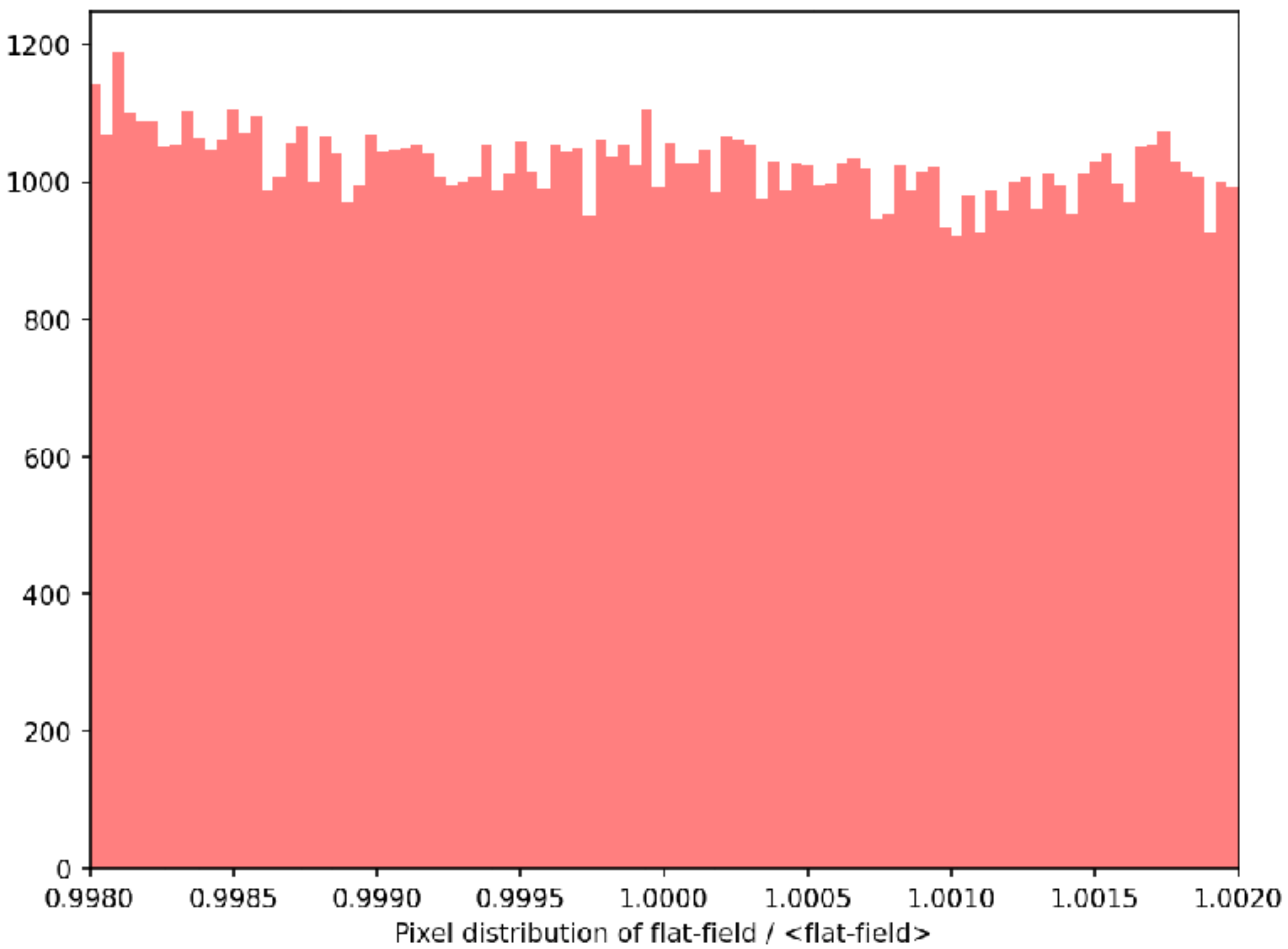
- Bad flat-fields: bad alignment of telescope w.r.t. illuminator
- CCD (16) jumps for one day (January 19)
- Overall stability better than 0.1%

Mosaic master-flat stability

Flat ratio = daily-flat / master-flat

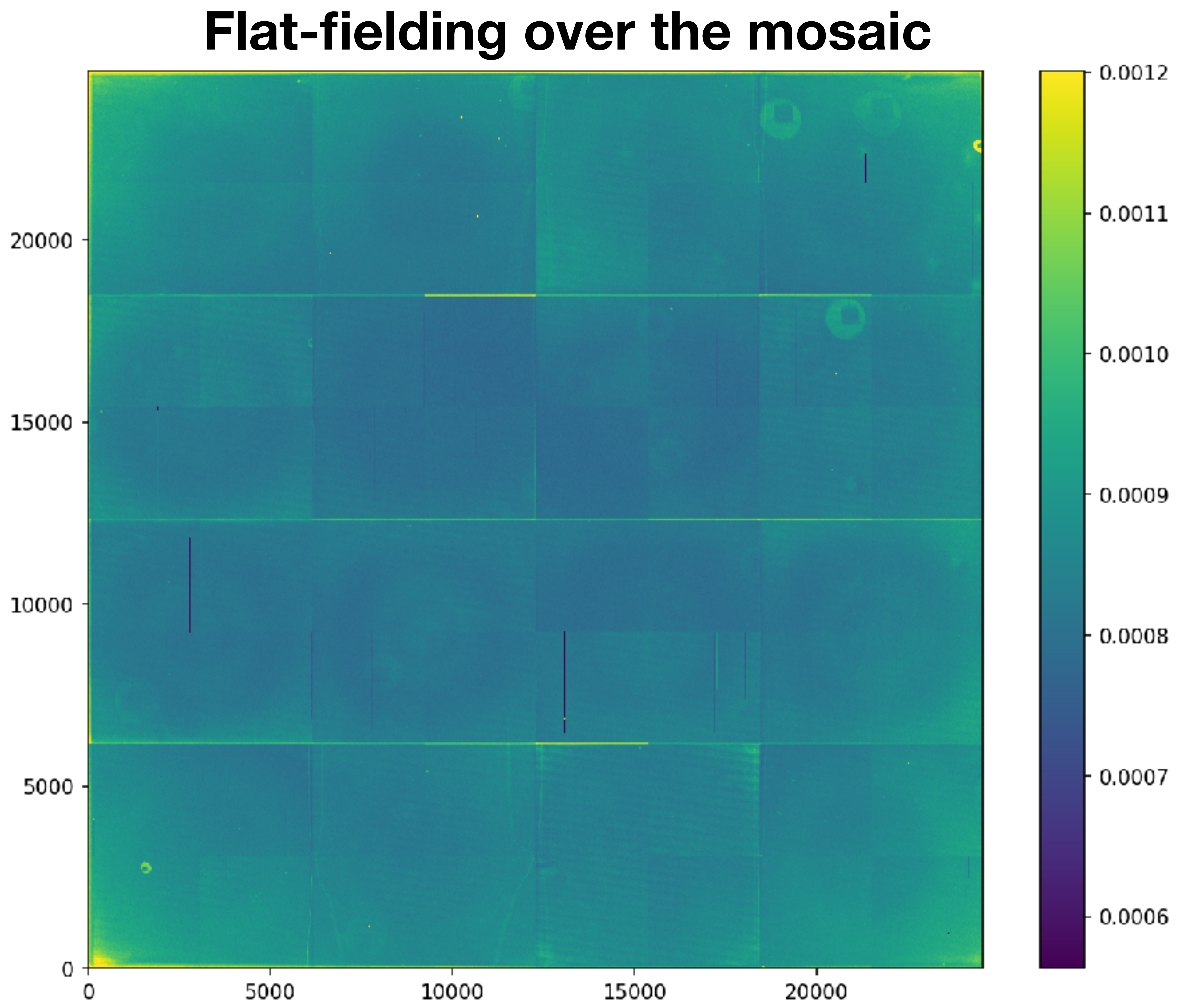


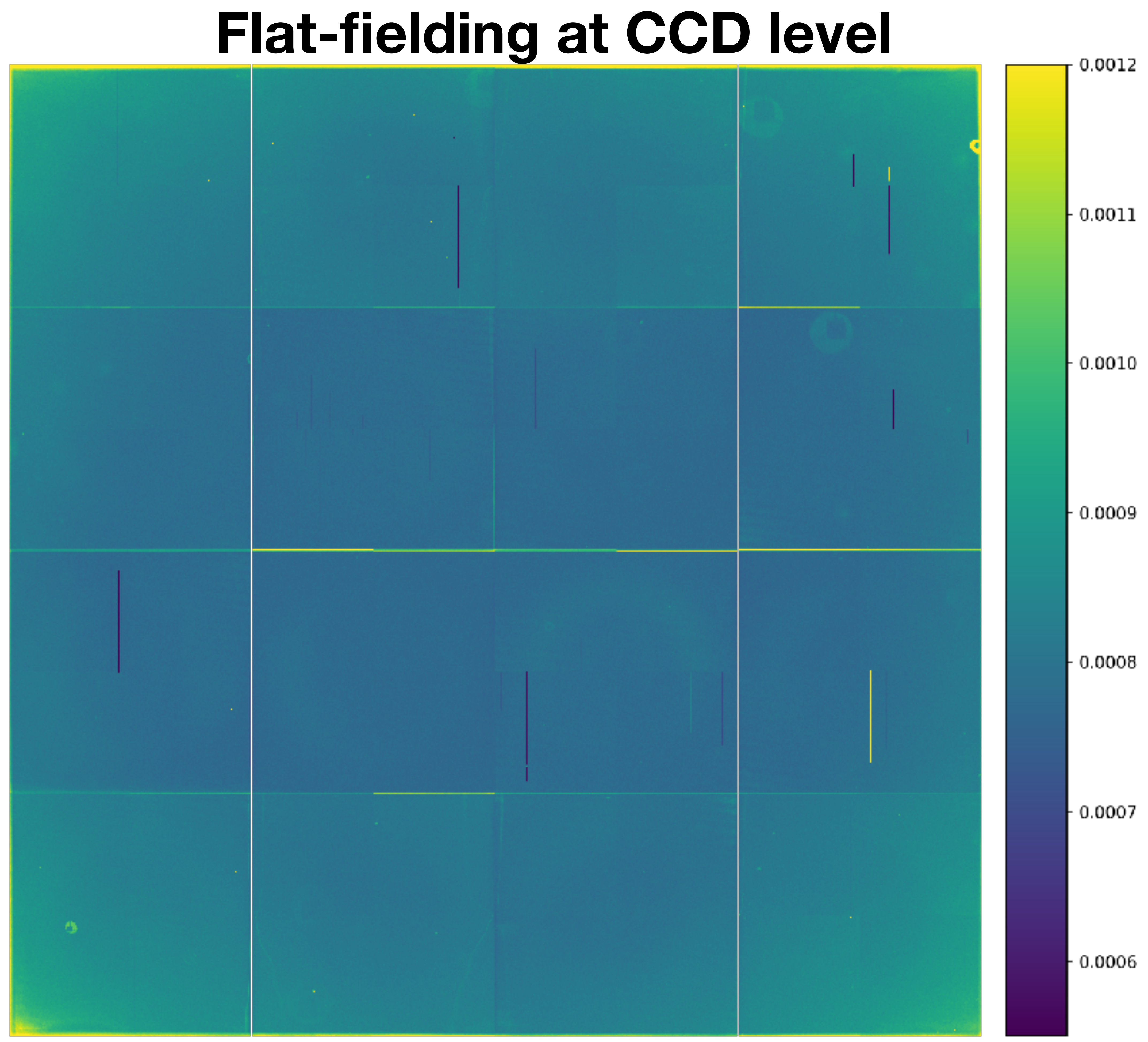
Pixel distribution of flat ratio



- Bad flat-fields: bad alignment of telescope w.r.t. illuminator
- CCD (16) jumps for one day (January 19)
- Overall stability better than 0.1%

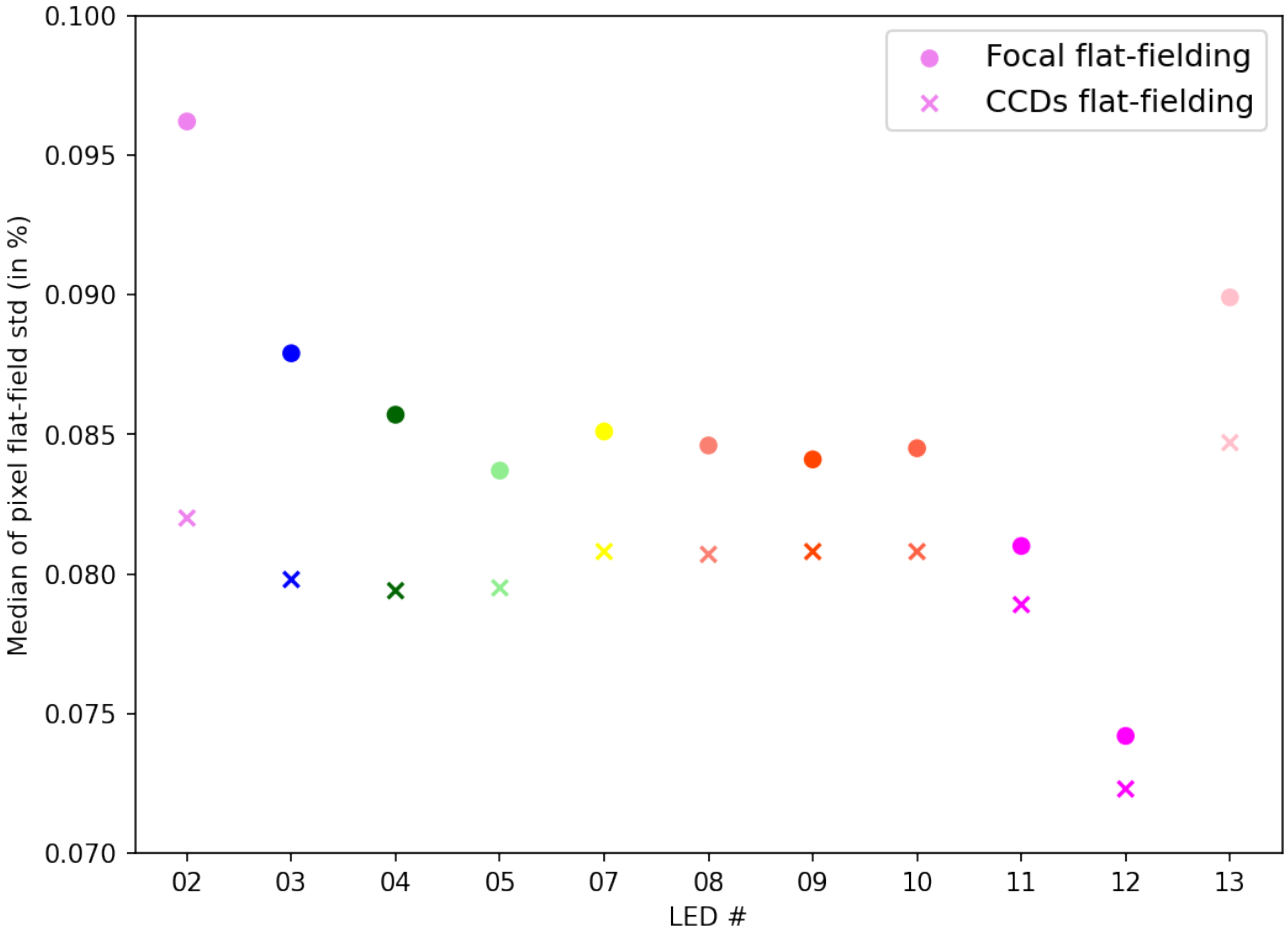
Master-flat residual standard deviation





Residual standard deviation of master-flat $\langle n_i \rangle$ at pixel (i) level: $\sigma_i = \dfrac{\sqrt{\langle n_i^2 \rangle - \langle n_i \rangle^2}}{\langle n_i \rangle}$

Master-flat standard deviation median for LEDs



<u>Conclusions of preliminary study of master-flat</u>

- Flat-field stability better than 0.1% for every LEDs
- Better stability of flat-fielding when performed at CCD level versus mosaic level

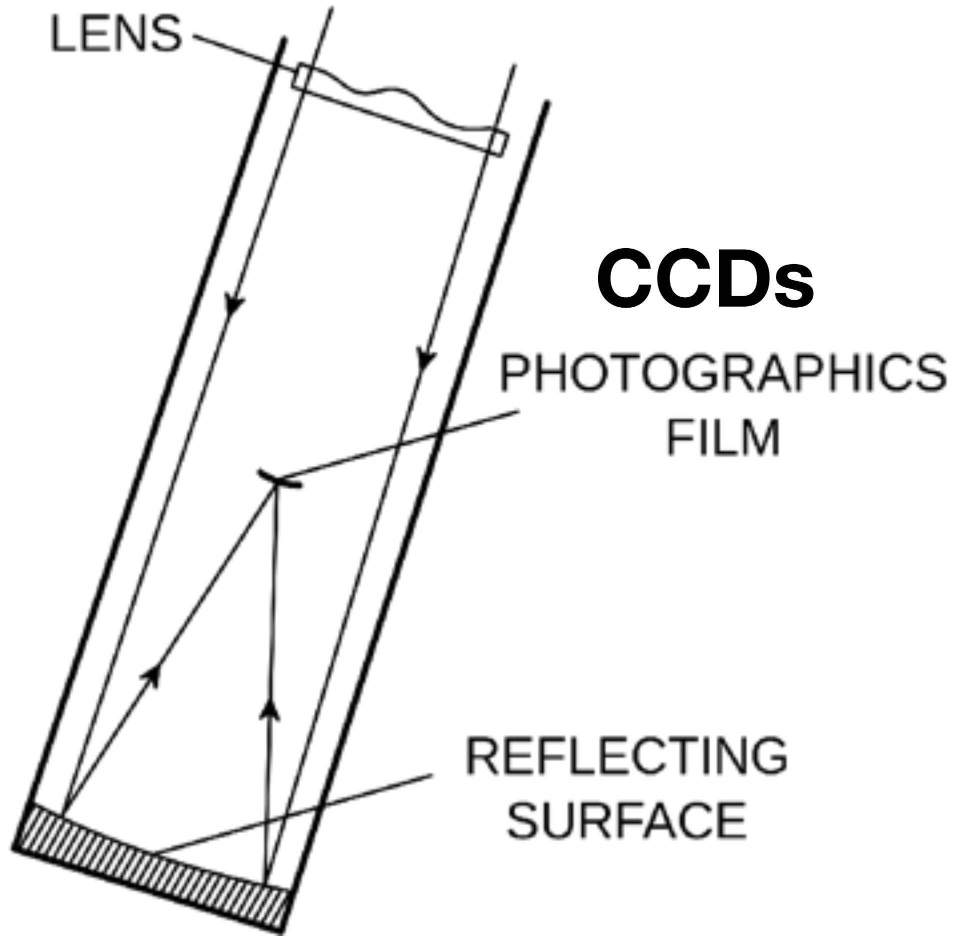
<u>Next step</u>

- Identification of period between interventions
- Processing master-bias and master-flat per period
- Test the new flat fielding procedure using starflats

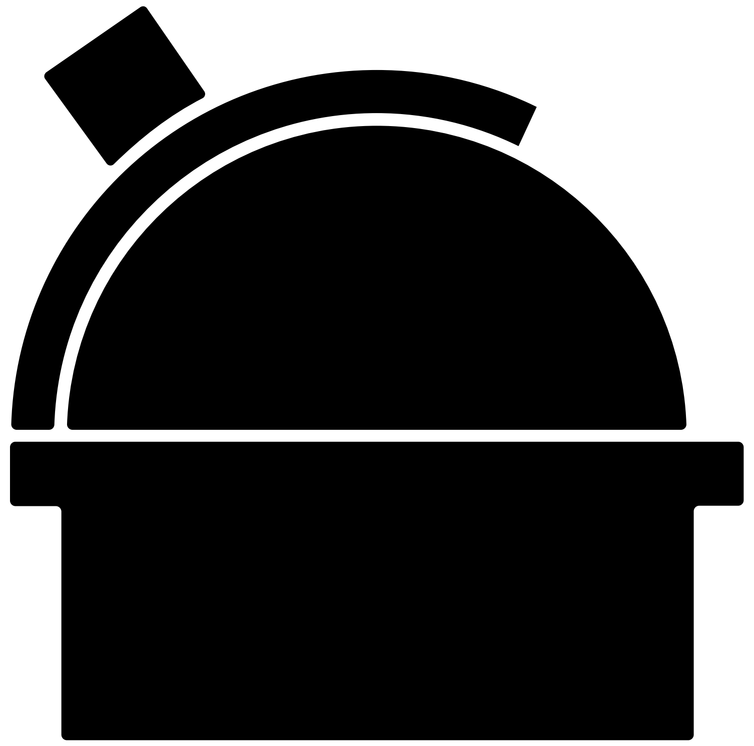
Ubercal

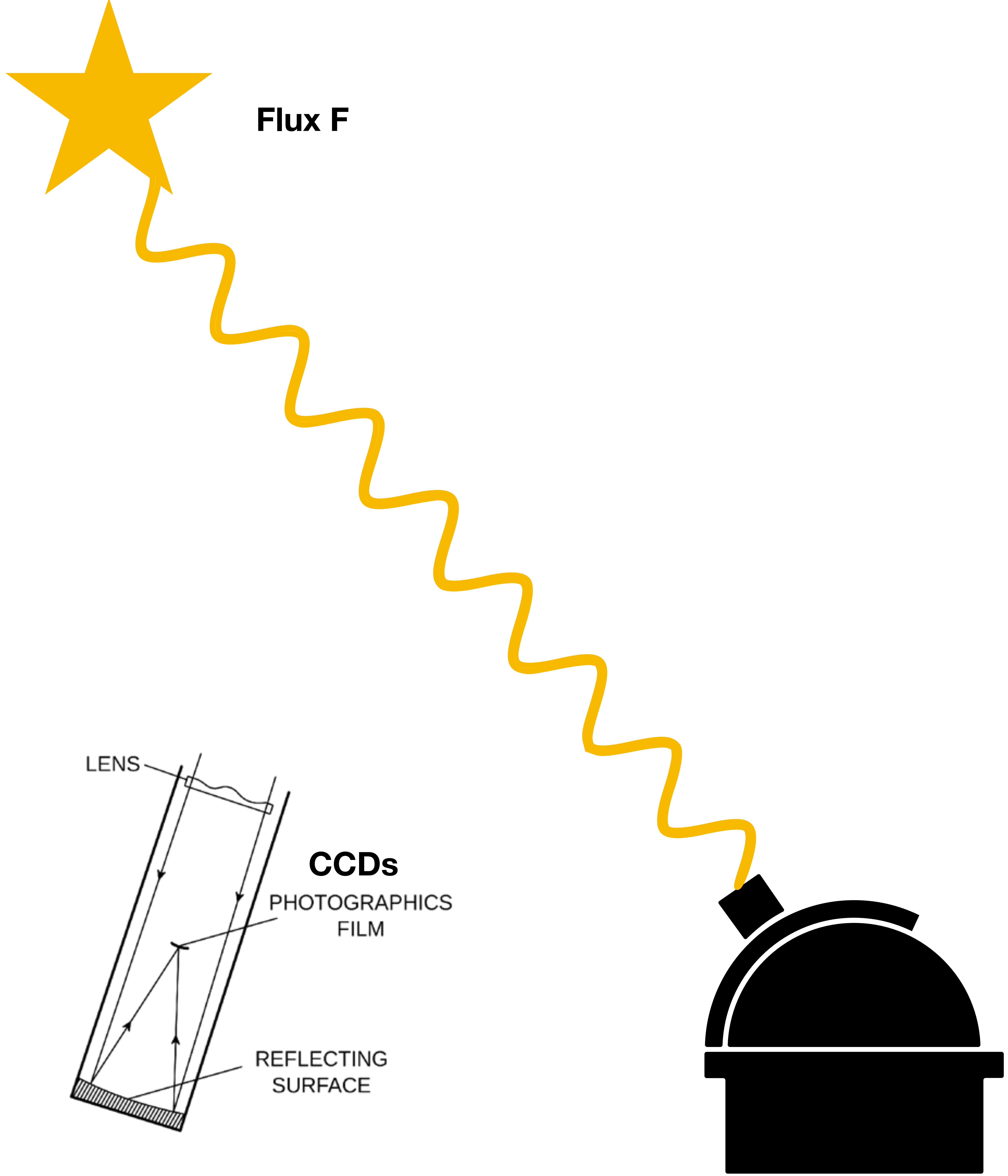
Benjamin Racine, Fabrice Feinstein
+ Julian Bautista, Mickael Rigault, Bastien Carreres, Dominique Fouchez

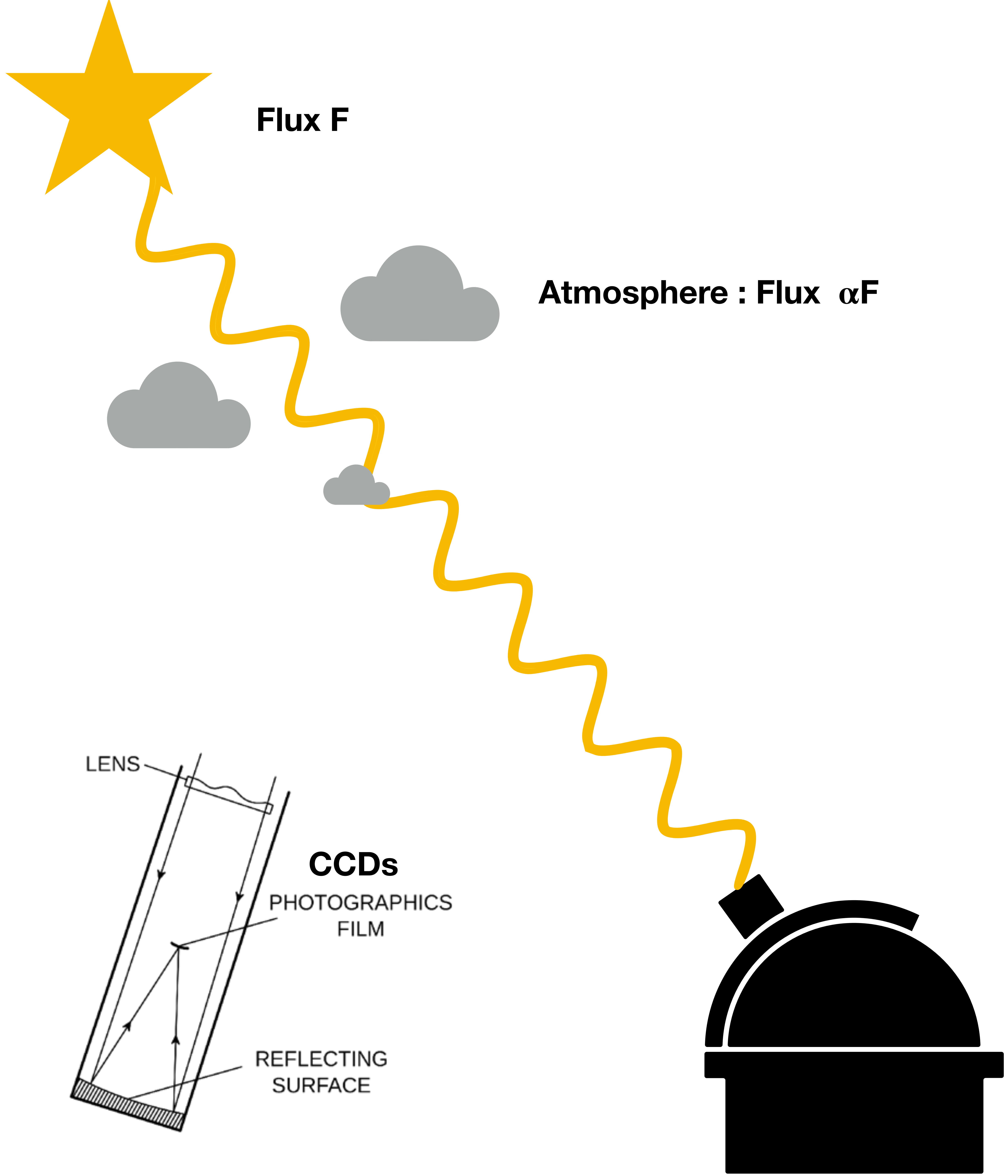
Flux F



CCDs




Flux F
LENS
CCDs
PHOTOGRAPHICS
FILM
REFLECTING
SURFACE


Flux F
Atmosphere : Flux αF
LENS
CCDs
PHOTOGRAPHICS
FILM
REFLECTING
SURFACE


Flux F
Atmosphere : Flux αF
LENS
CCDs
PHOTOGRAPHICS
FILM
REFLECTING
SURFACE
Instrument


Instrument
Flux F
Atmosphere : Flux αF
Mirrors etc. : Flux αβF
LENS
CCDs
PHOTOGRAPHICS
FILM
REFLECTING
SURFACE


Flux F
Atmosphere : Flux αF
Instrument
Mirrors etc. : Flux αβF
Filters : Flux αβγF
LENS
CCDs
PHOTOGRAPHICS
FILM
REFLECTING
SURFACE


Flux F
Atmosphere : Flux αF
LENS
CCDs
PHOTOGRAPHICS
FILM
REFLECTING
SURFACE
Instrument
Mirrors etc. : Flux αβF
Filters : Flux αβγF
Detectors : Flux αβγδF


Flux F
Atmosphere : Flux αF
LENS
CCDs
PHOTOGRAPHICS
FILM
REFLECTING
SURFACE
Instrument
Mirrors etc. : Flux αβF
Filters : Flux αβγF
Detectors : Flux αβγδF
Amplifiers : Flux αβγδεF
+V
-V


Flux F
Atmosphere : Flux αF
LENS
CCDs
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Amplifiers : Flux αβγδεF
+V
-V
Signal
measured
in ADU


Flux F
Atmosphere : Flux αF
LENS
CCDs
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SURFACE
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Filters : Flux αβγF
Detectors : Flux αβγδF
Amplifiers : Flux αβγδεF
+V
-V
Signal
measured
in ADU
$m_{meas} = -2.5 \log (F_{meas})$
$= -2.5 \log (F) - 2.5 \log (\alpha\beta\gamma\delta\epsilon)$

Flux F
Atmosphere : Flux αF
LENS
CCDs
PHOTOGRAPHICS FILM
REFLECTING SURFACE
Instrument
Mirrors etc. : Flux αβF
Filters : Flux αβγF
Detectors : Flux αβγδF
Amplifiers : Flux αβγδεF
+V
-V
Signal measured in ADU
$m_{meas} = -2.5 \log (F_{meas})$
$= -2.5 \log (F) - 2.5 \log (\alpha\beta\gamma\delta\epsilon)$
ZP

+ Frequency dependence
Flux F
Depends on time, elevation, etc
Atmosphere : Flux αF
LENS
CCDs
PHOTOGRAPHICS FILM
REFLECTING SURFACE
Instrument
Dust spots? Aging?
Mirrors etc. : Flux αβF
Dust?
Filters : Flux αβγF
Edges, dust, coating etc.
Detectors : Flux αβγδF
Gain variations etc?
Amplifiers : Flux αβγδεF
+V
-V
Signal measured in ADU
$m_{meas} = -2.5 \log (F_{meas})$
$= -2.5 \log (F) - 2.5 \log (\alpha\beta\gamma\delta\epsilon)$
ZP

Ubercal method for ZTF

What is it ?

Well tested method (see Padmanabhan et al., 2008) developed for SDSS

A global least-square linear fit of:

- **integrated** star magnitudes
- **variable** instrument parameters: *e.g.* focal plane, zero points variations…
- **variable** atmosphere attenuation: (non-) grey extinction (clouds, dust, …)
- *…we will refine the model*

Why use it ?

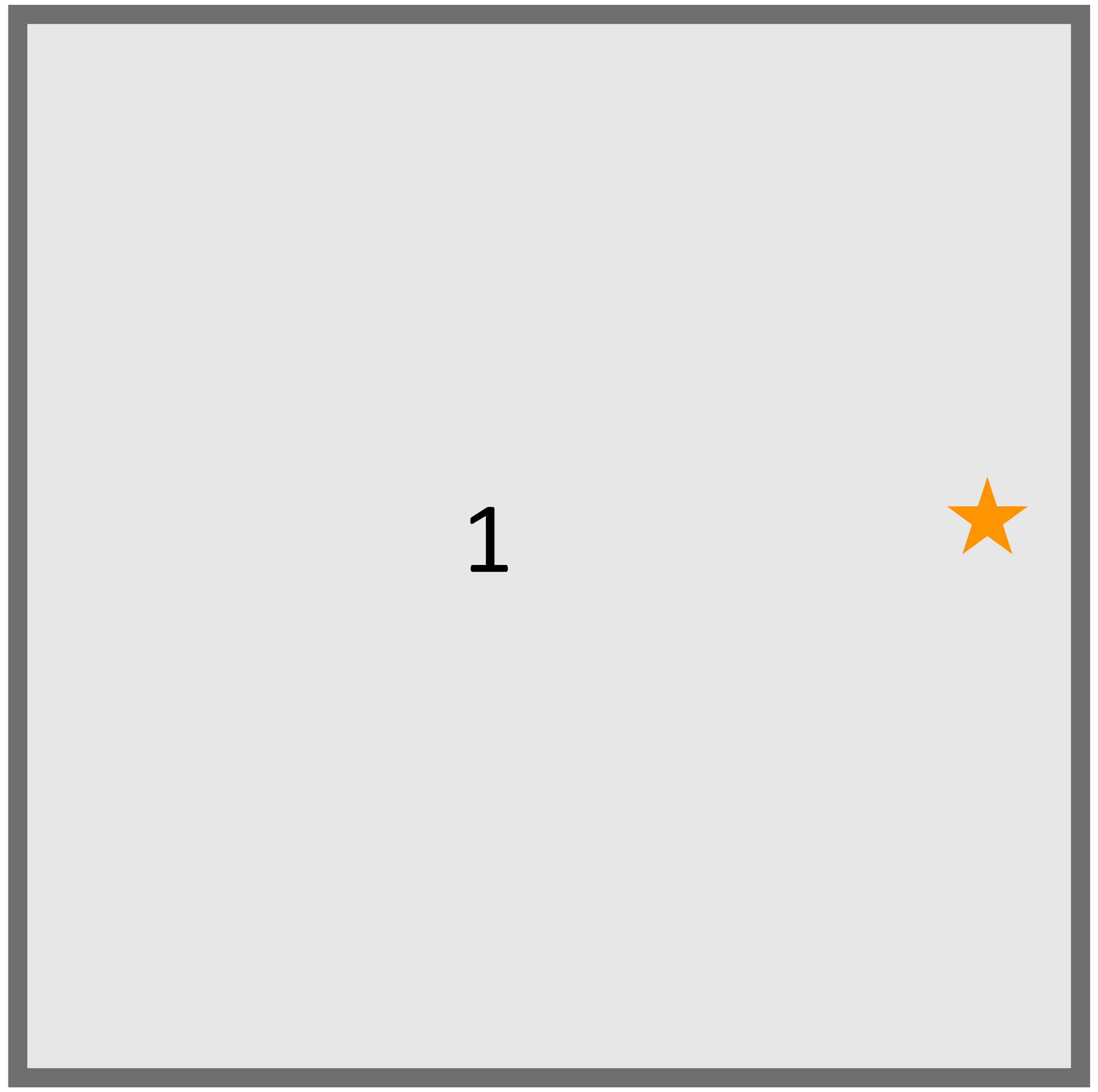
Global rigidity : (RA,dec) and time uniformity—> goal is O(mmag) !!

This is then provided to calibrate the scene modeling

=> Anchoring with few CALSPEC standard stars

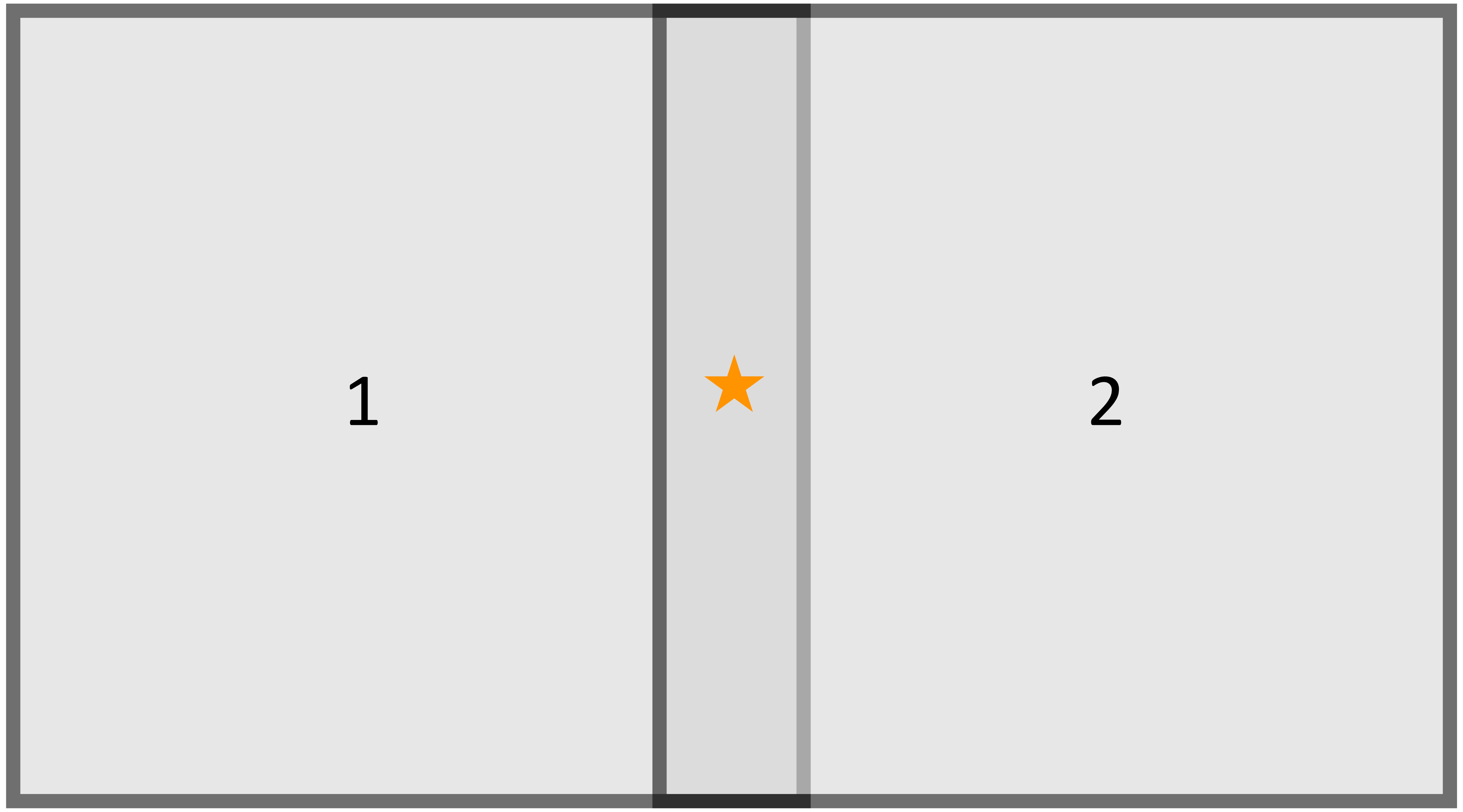
Ubercal method

Ubercal method



$$m_1 + ZP_1 = m_{11}^{obs}$$

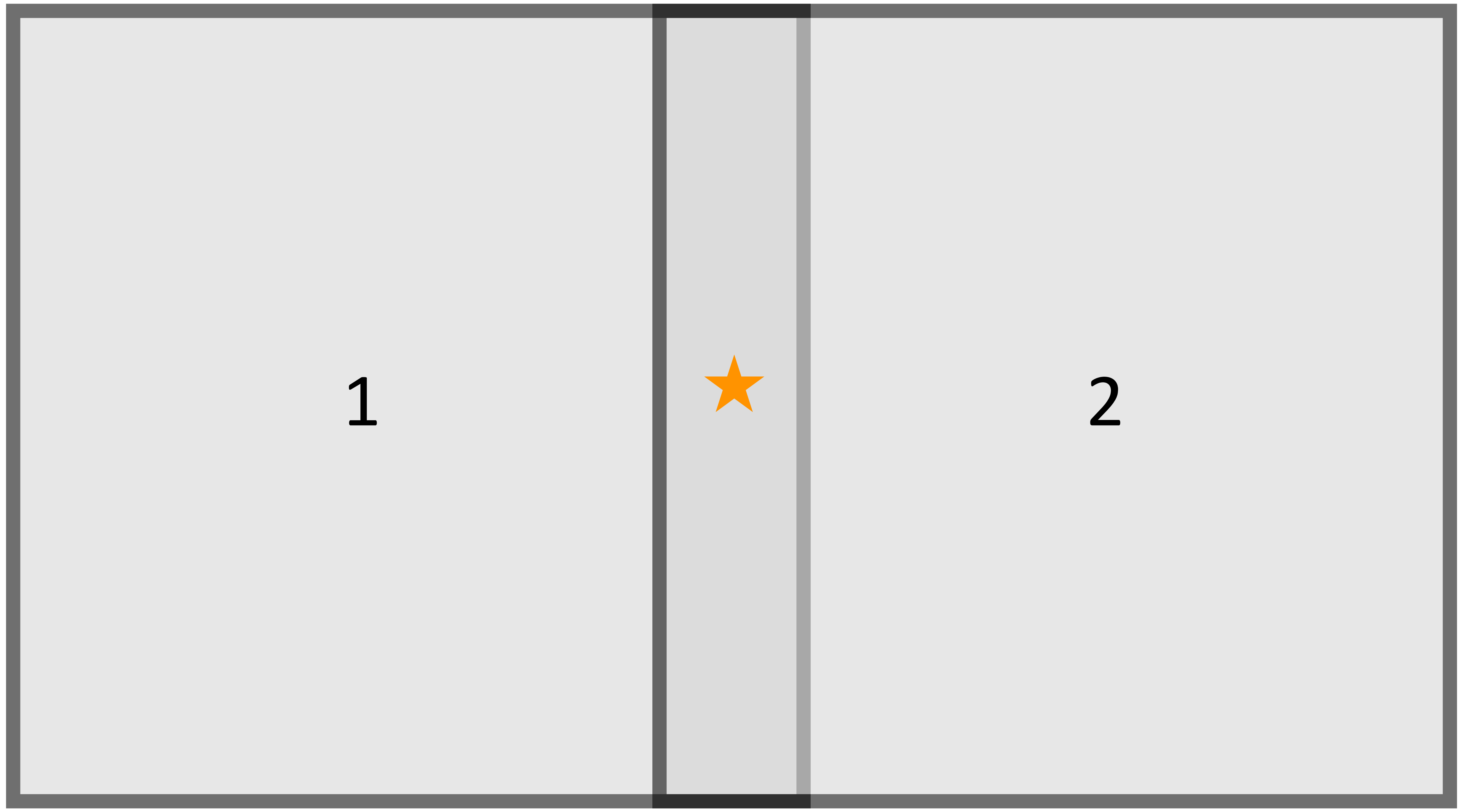
Ubercal method



$$m_1 + ZP_1 = m_{11}^{obs}$$

$$m_1 + ZP_2 = m_{12}^{obs}$$

Ubercal method

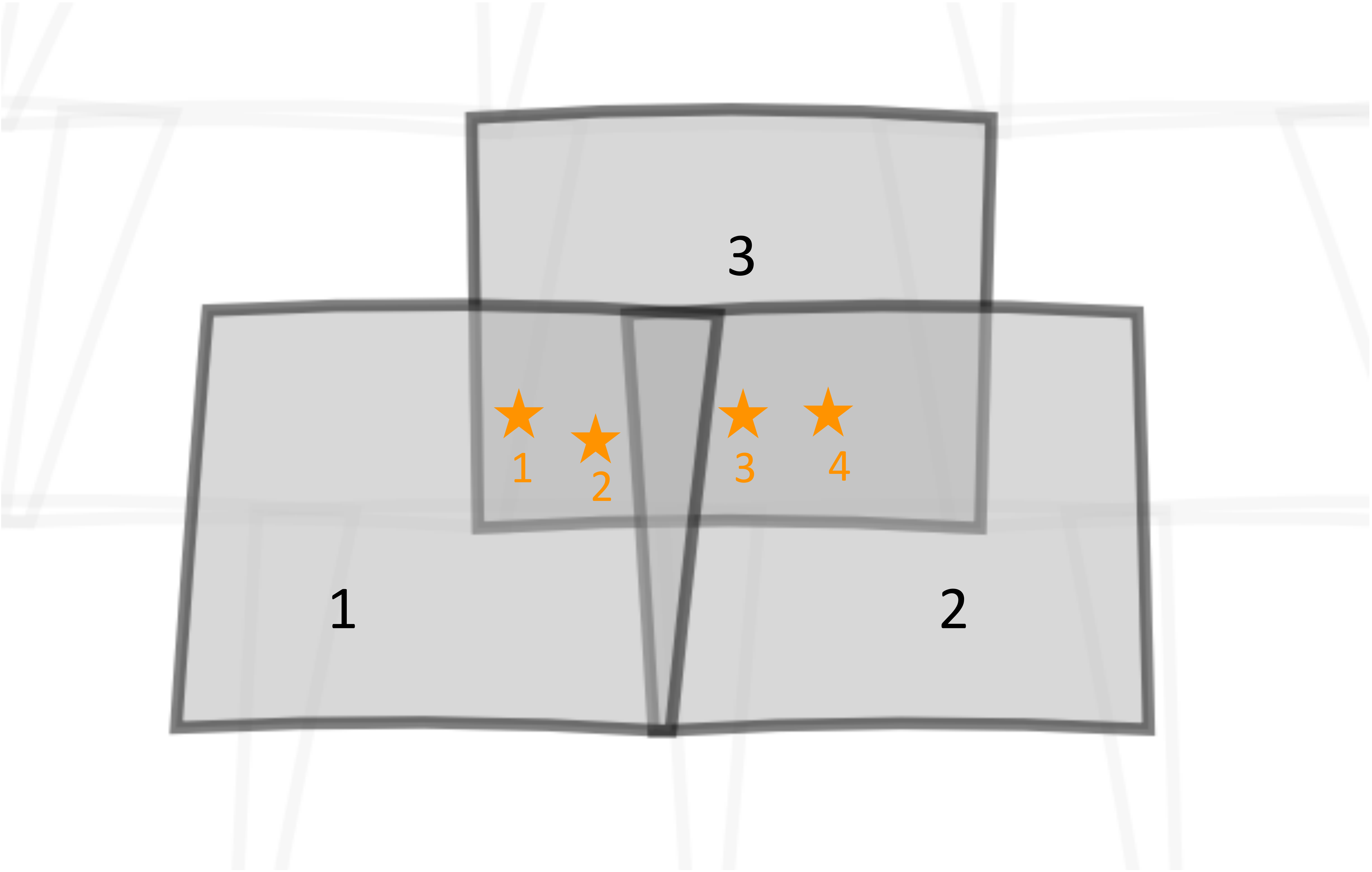


$$m_1 + 0 = m_{11}^{obs}$$

$$m_1 + \Delta ZP_2 = m_{12}^{obs}$$

Fit for relative zero points & star magnitudes

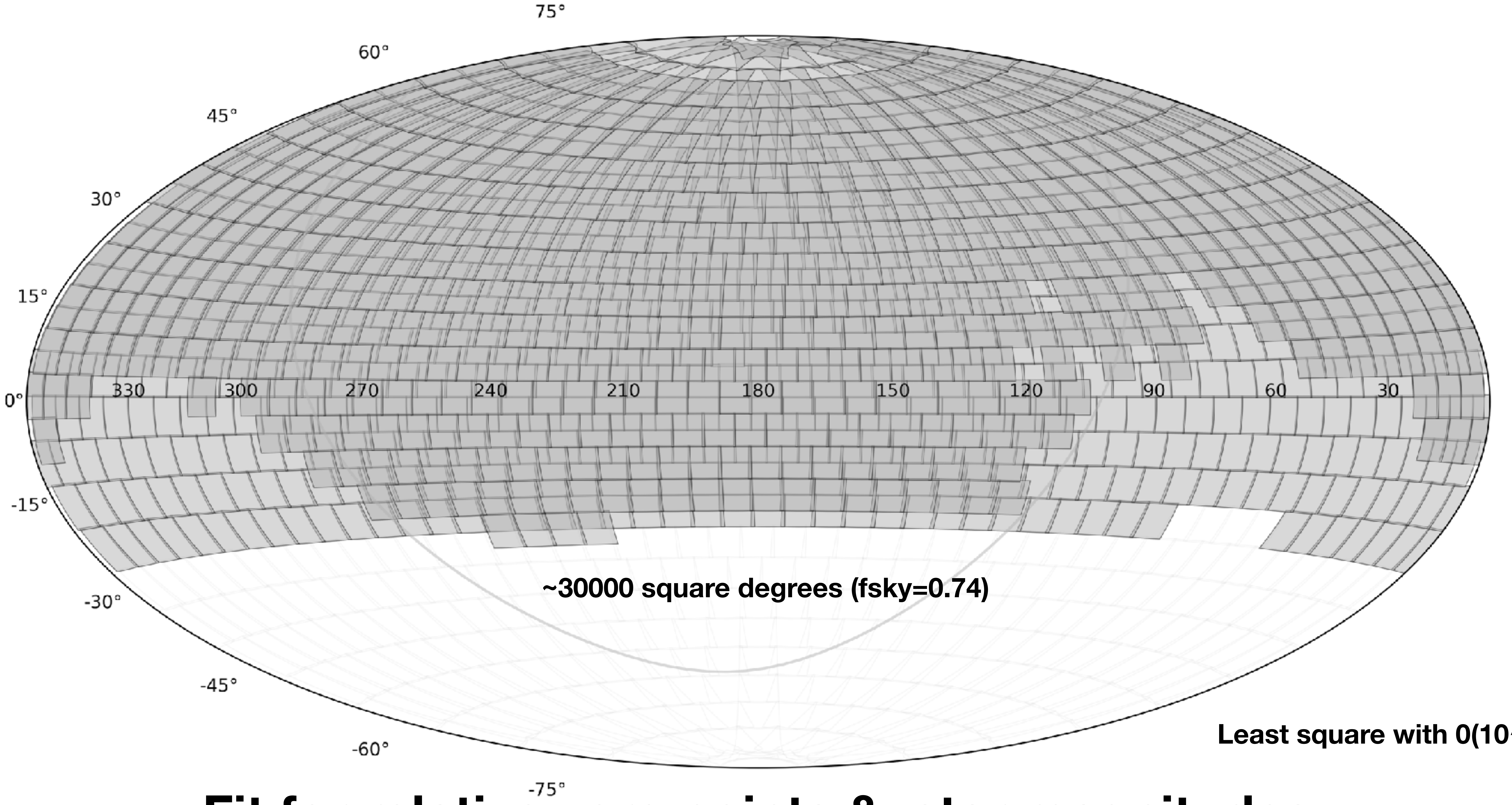
Ubercal method



$$m_1 + 0 = m_{11}^{obs}$$
$$m_2 + 0 = m_{21}^{obs}$$
$$m_3 + \Delta ZP_2 = m_{32}^{obs}$$
$$m_4 + \Delta ZP_2 = m_{42}^{obs}$$
$$m_1 + \Delta ZP_3 = m_{13}^{obs}$$
$$m_2 + \Delta ZP_3 = m_{23}^{obs}$$
$$m_3 + \Delta ZP_3 = m_{33}^{obs}$$
$$m_4 + \Delta ZP_3 = m_{43}^{obs}$$

Fit for relative zero points & star magnitudes

6 month: 2019-03 to 2019-08

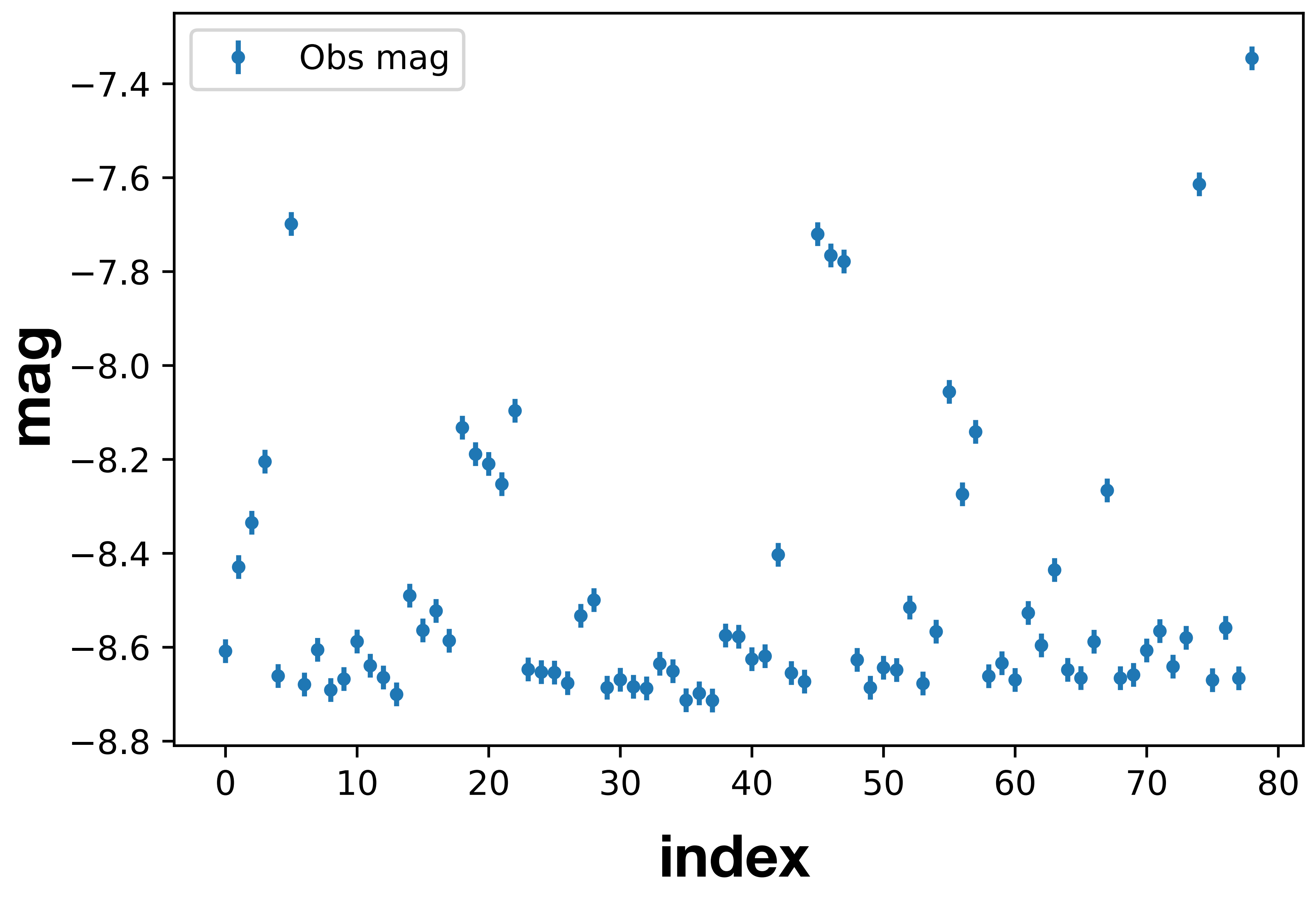


Least square with 0(10^8) lines

Fit for relative zero points & star magnitudes

Result on one star
(79 obs here)

⚠️ **ubercal mags are relative**



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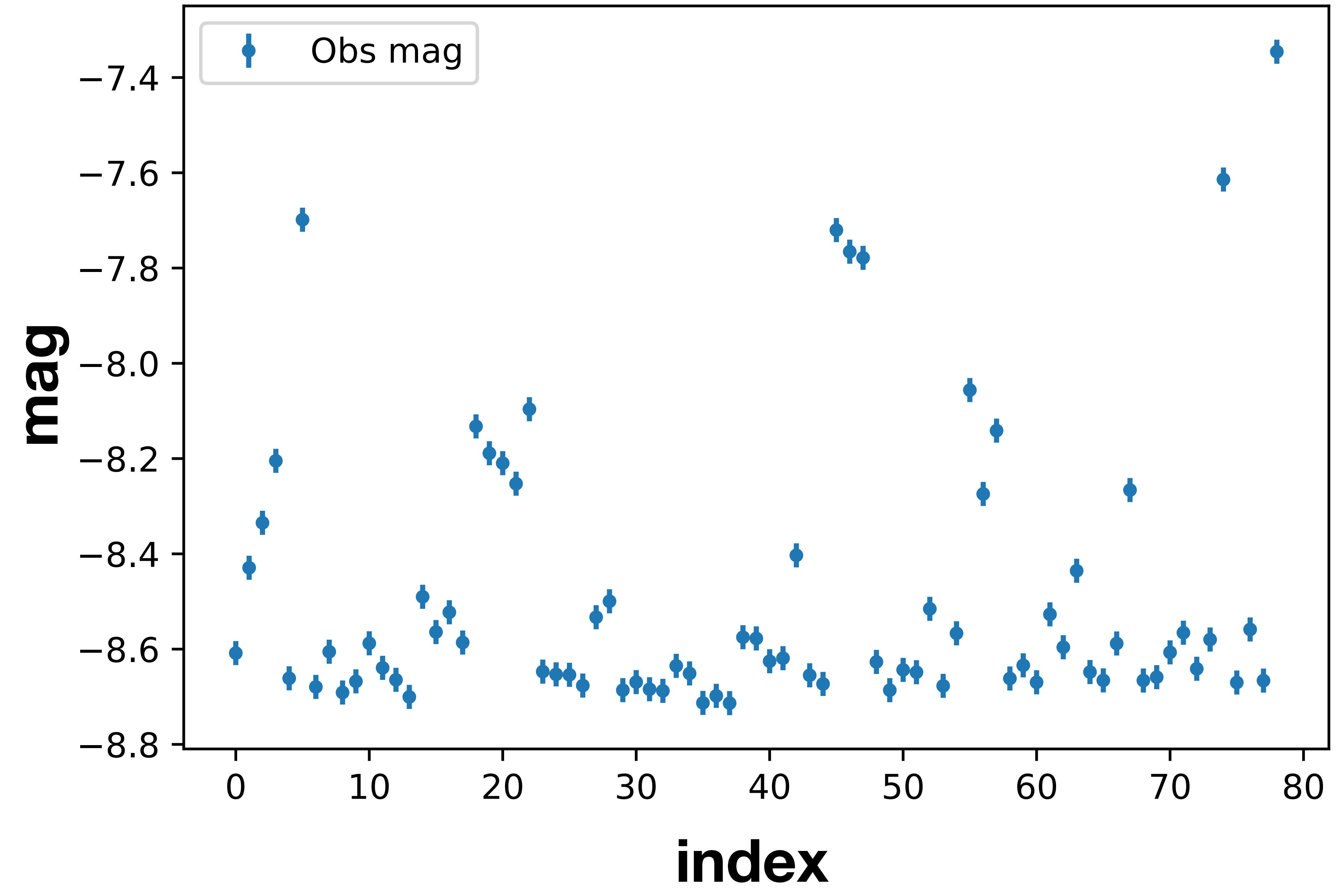

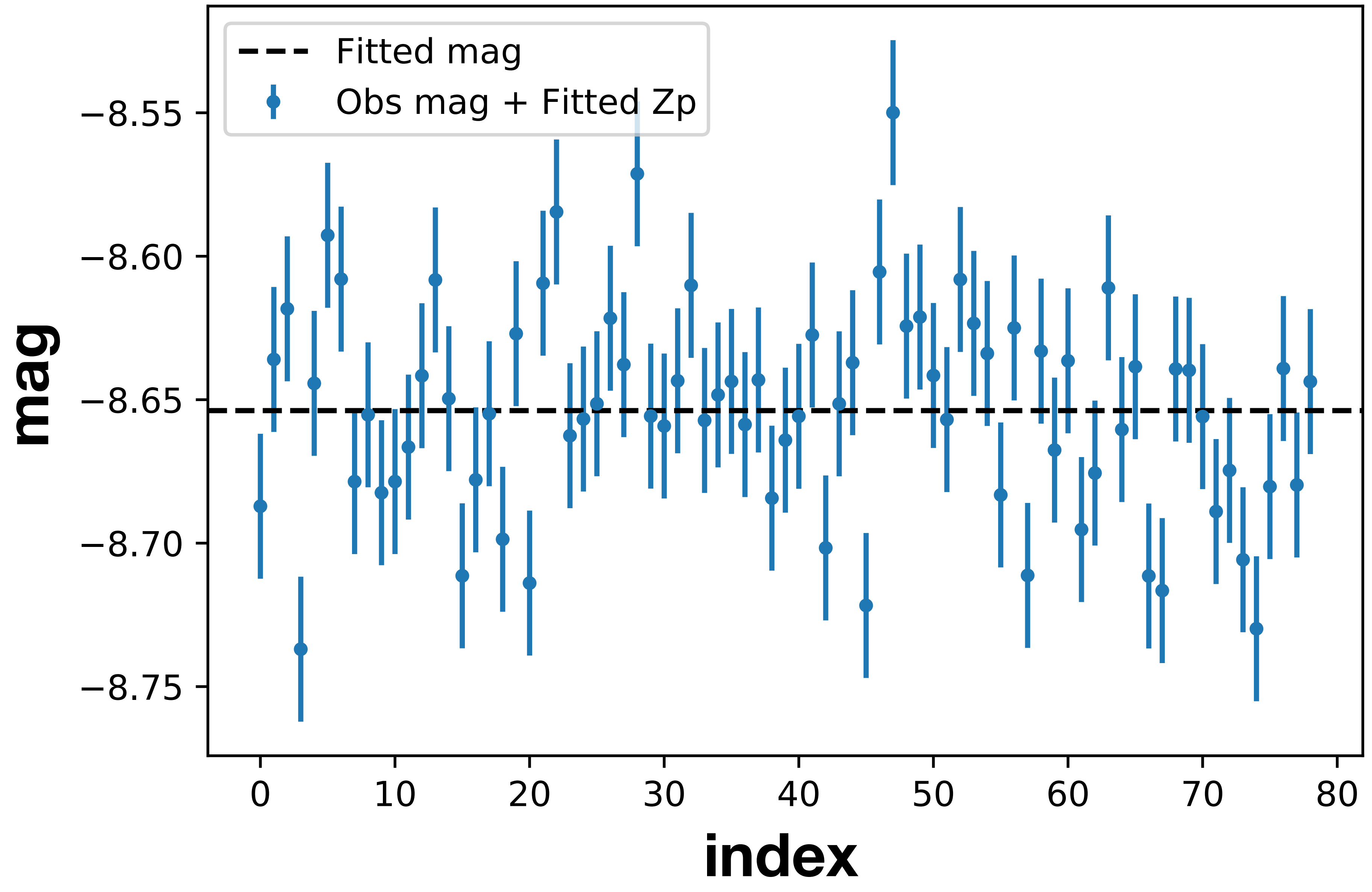

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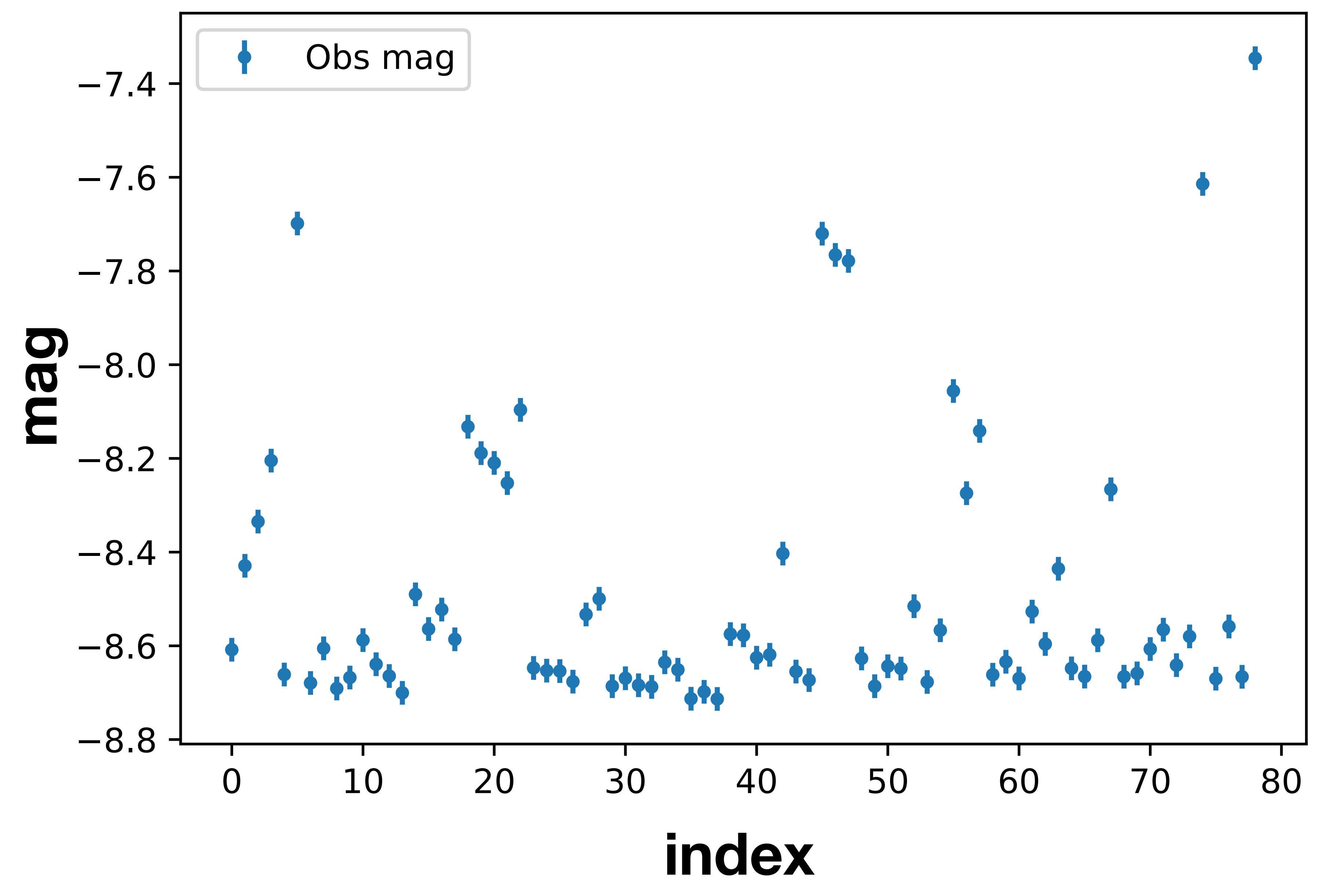
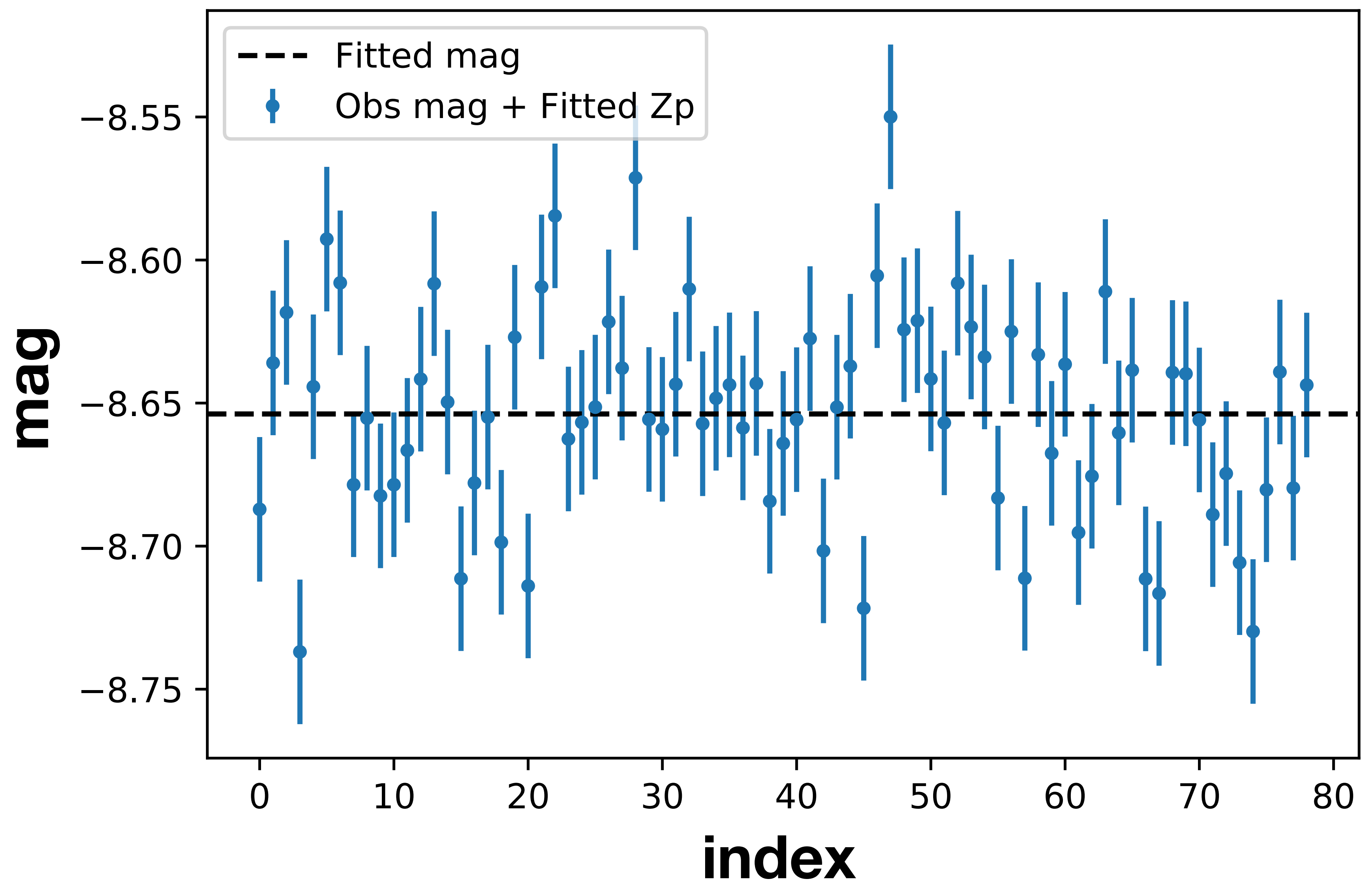
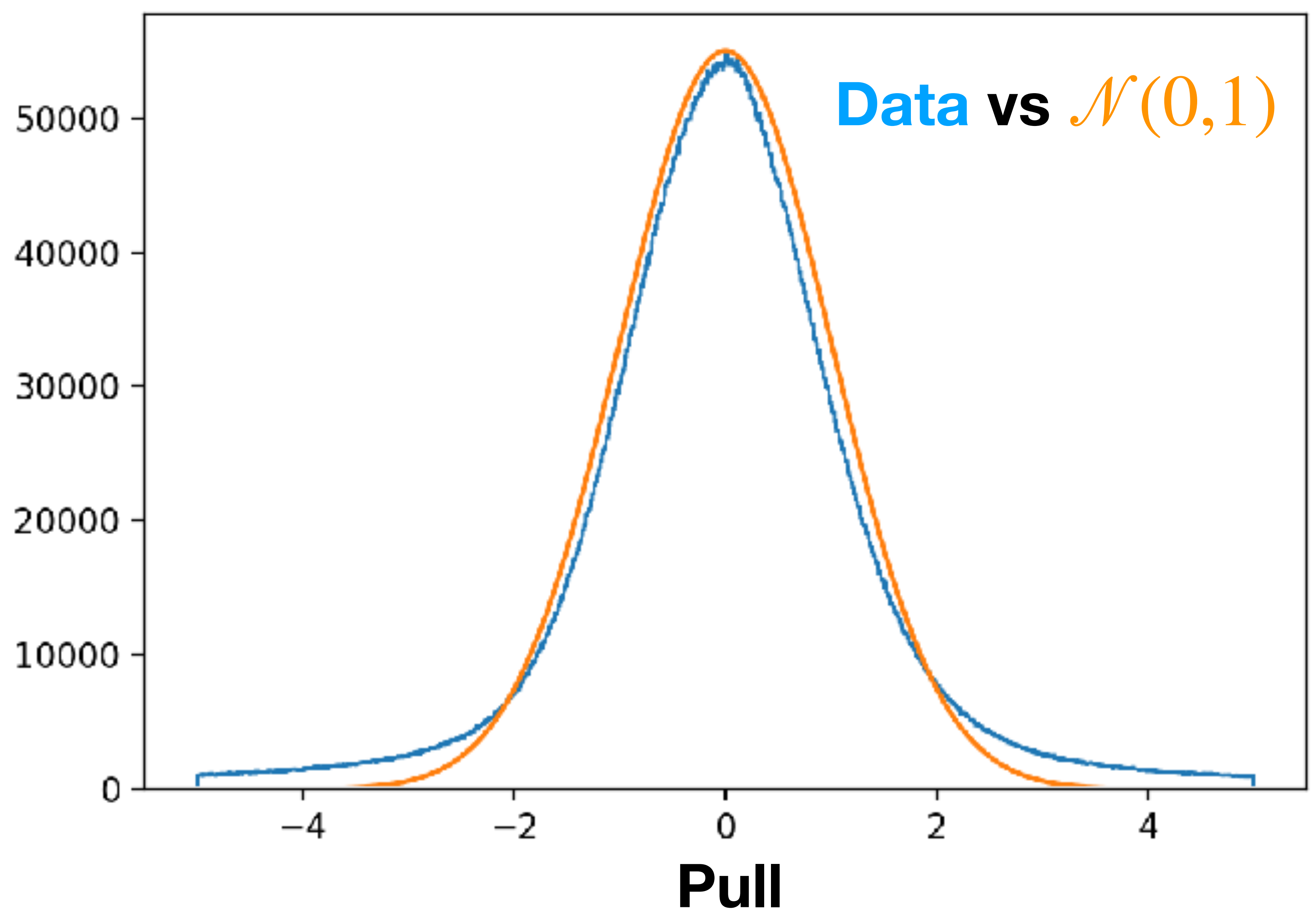
Result on one star (79 obs here)





Result on all stars



Result on one star
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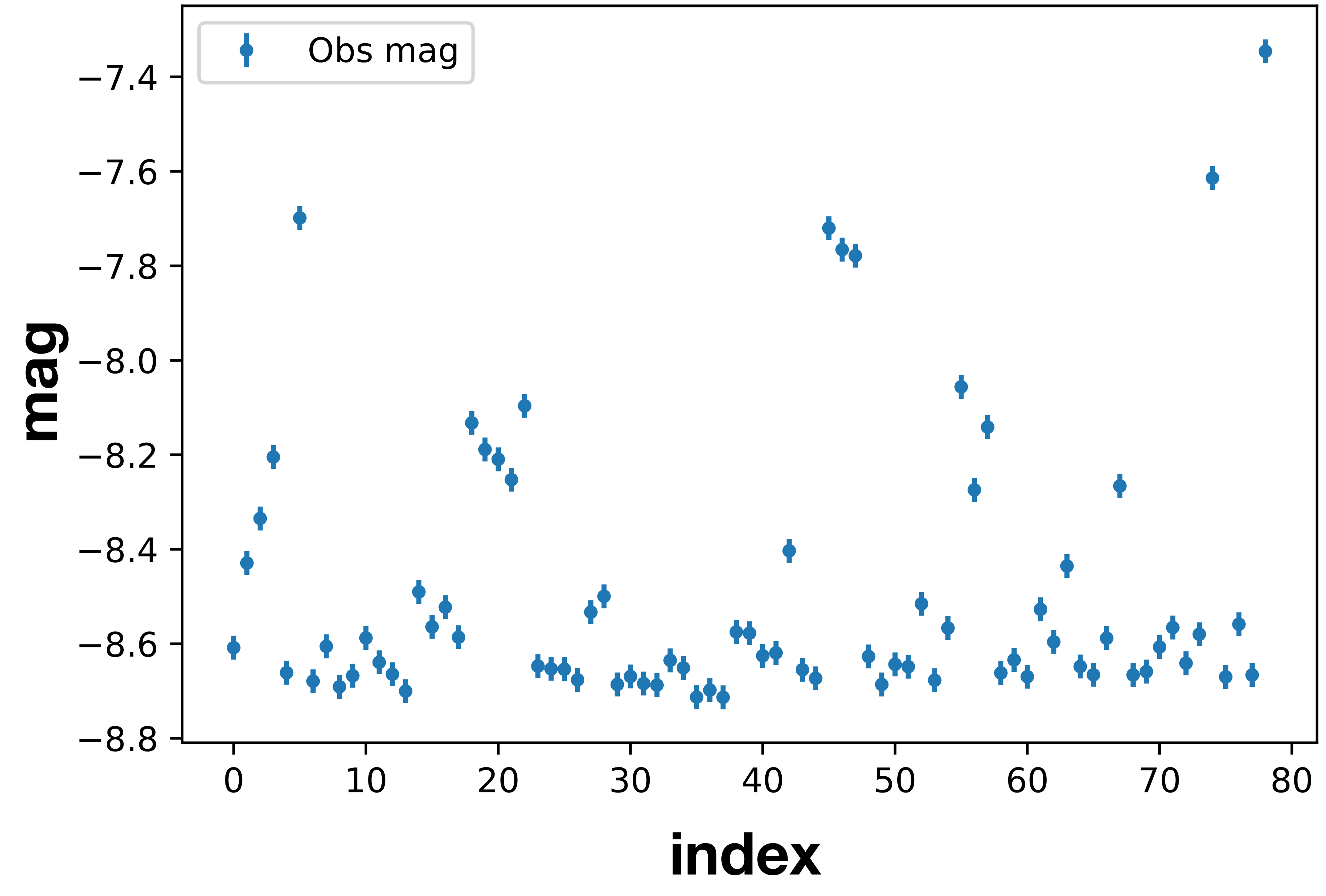
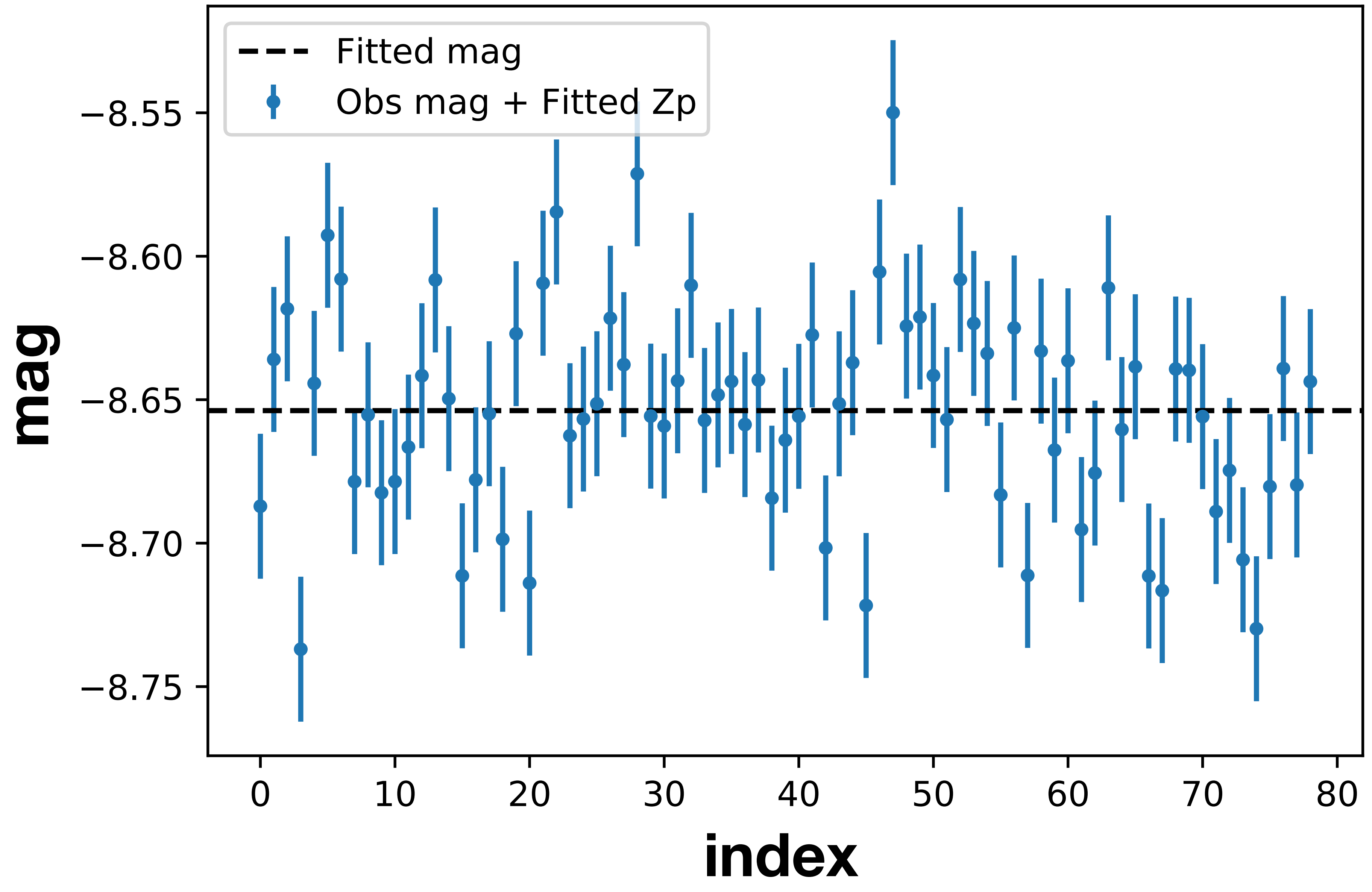
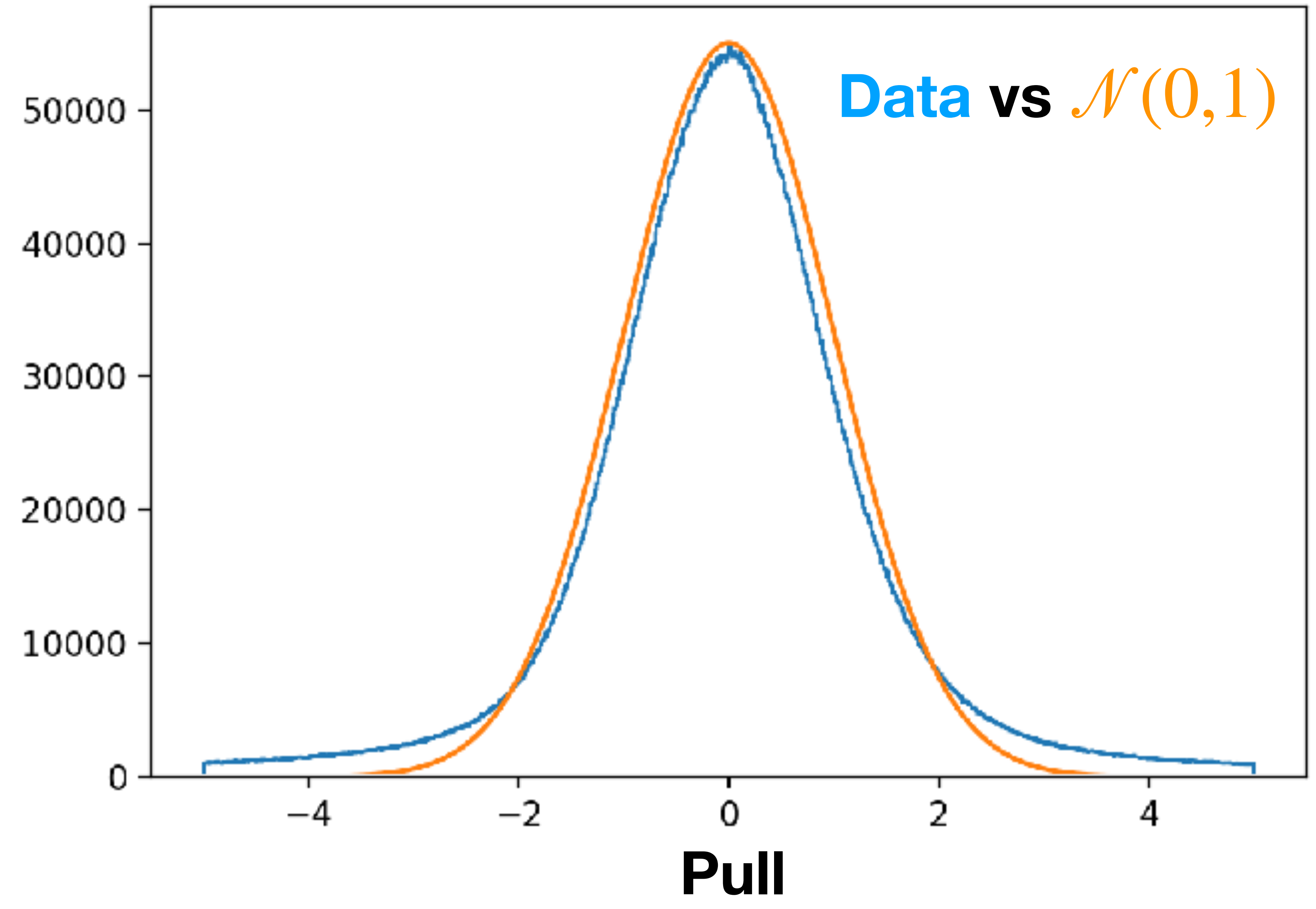




std=0.036

⚠️ **ubercal mags are relative**

Result on all stars



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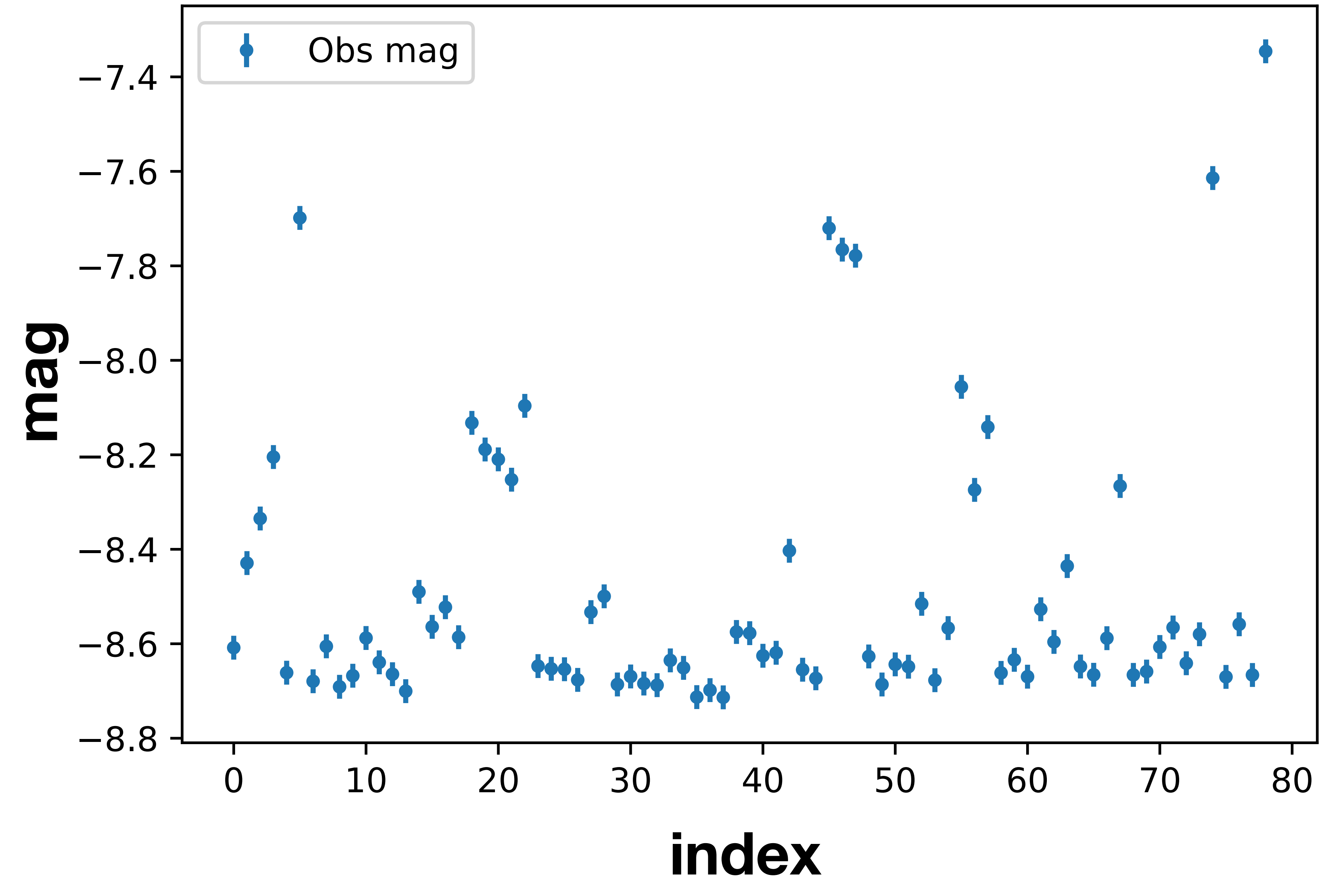
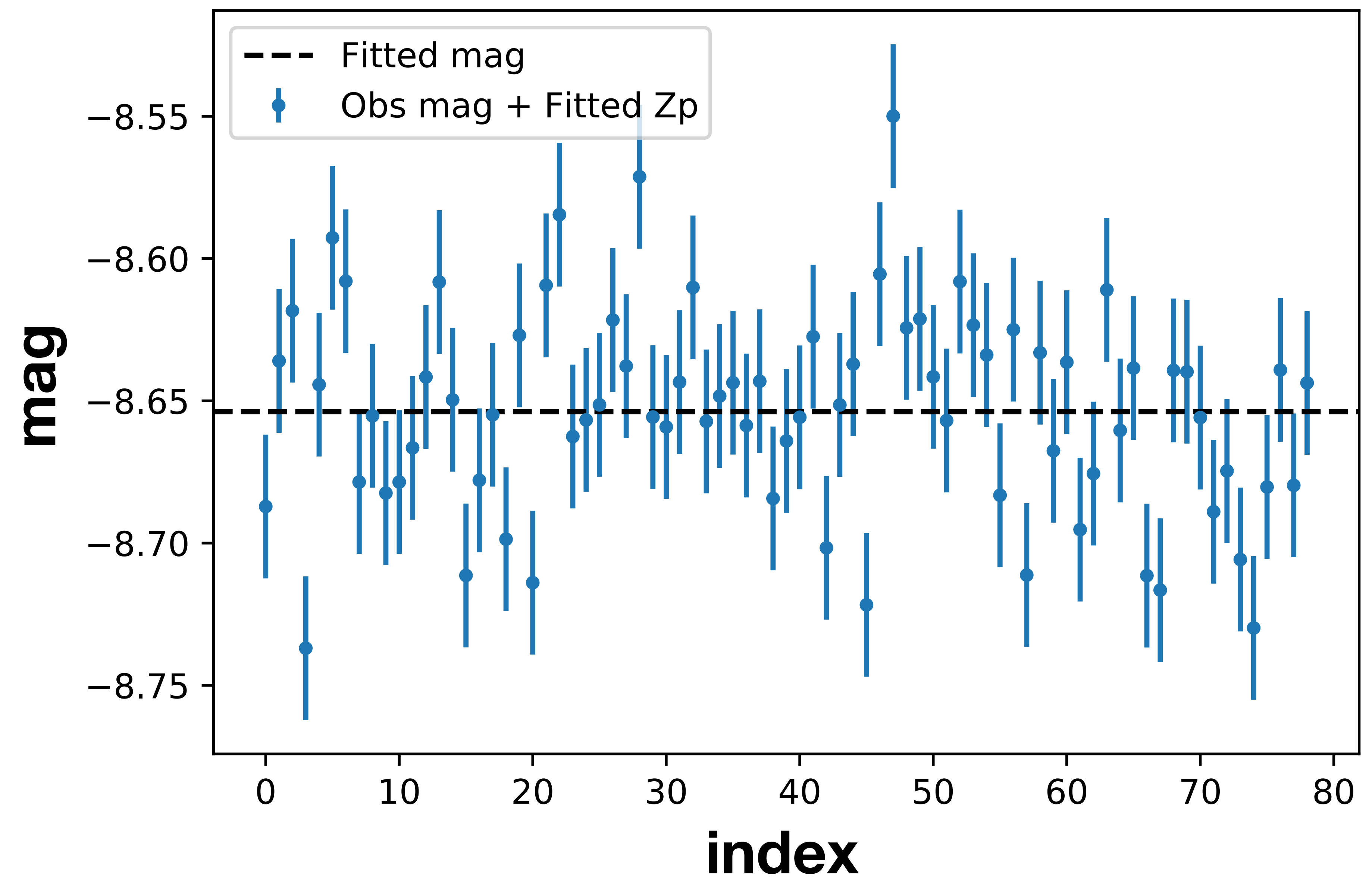
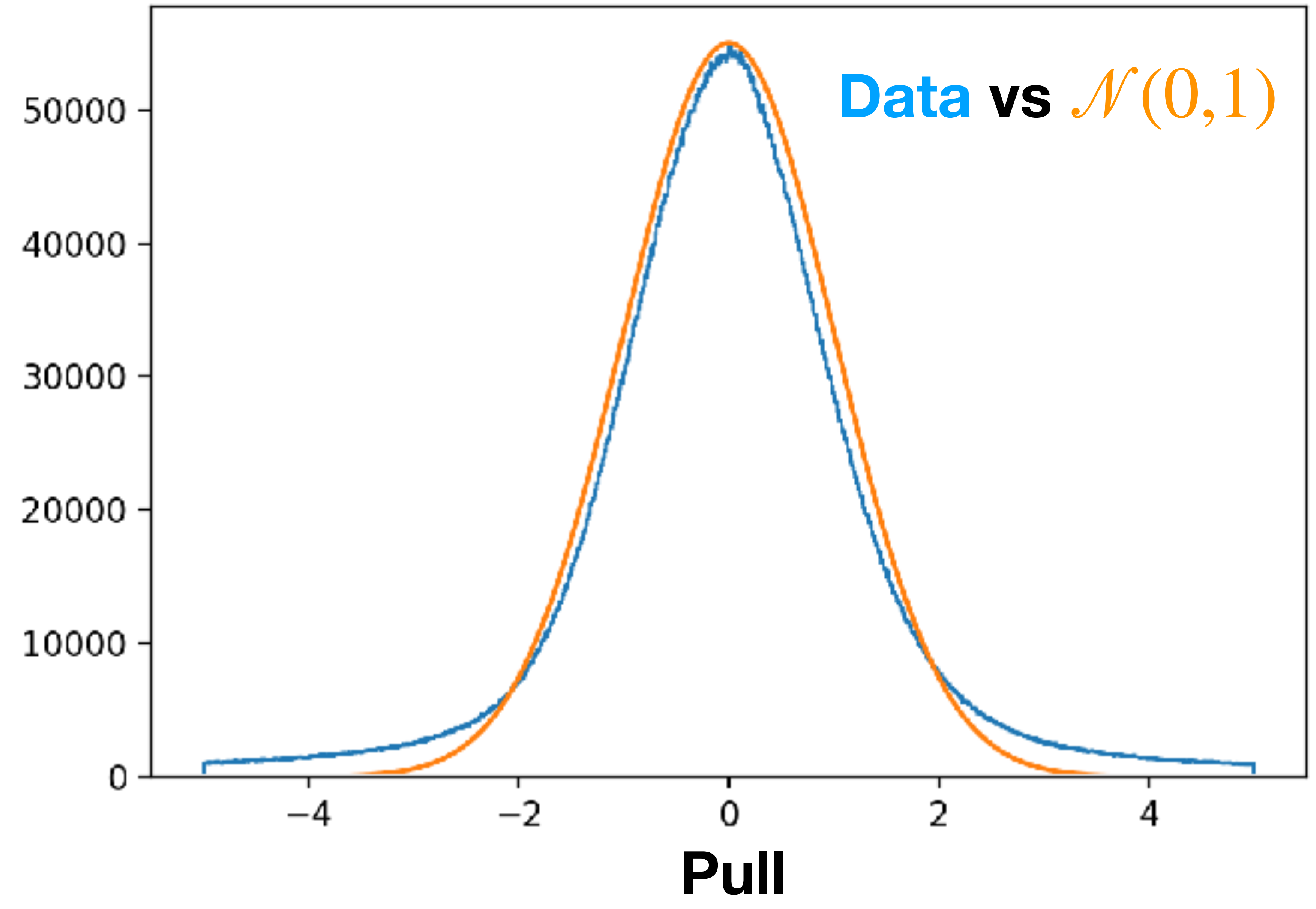
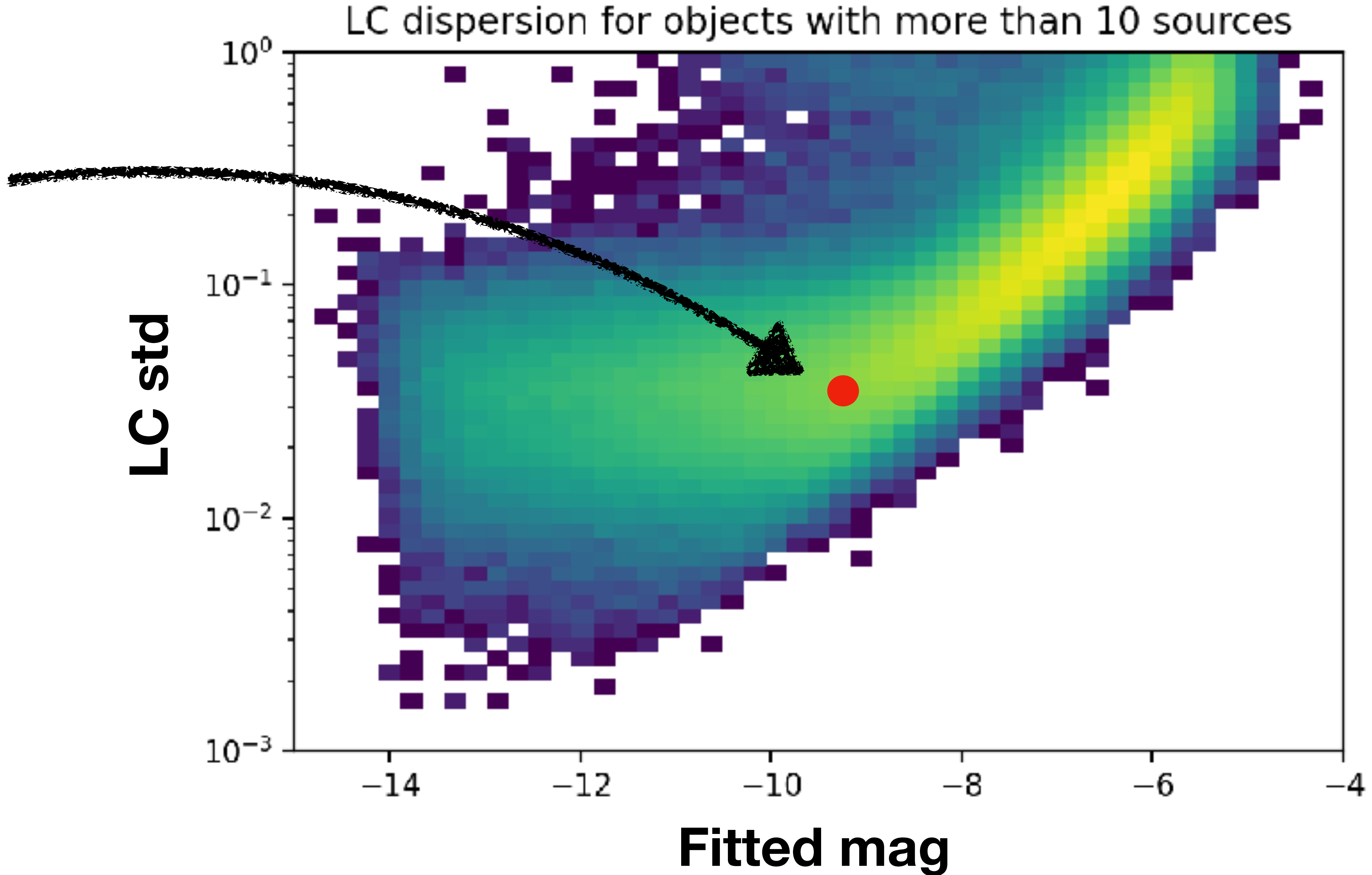




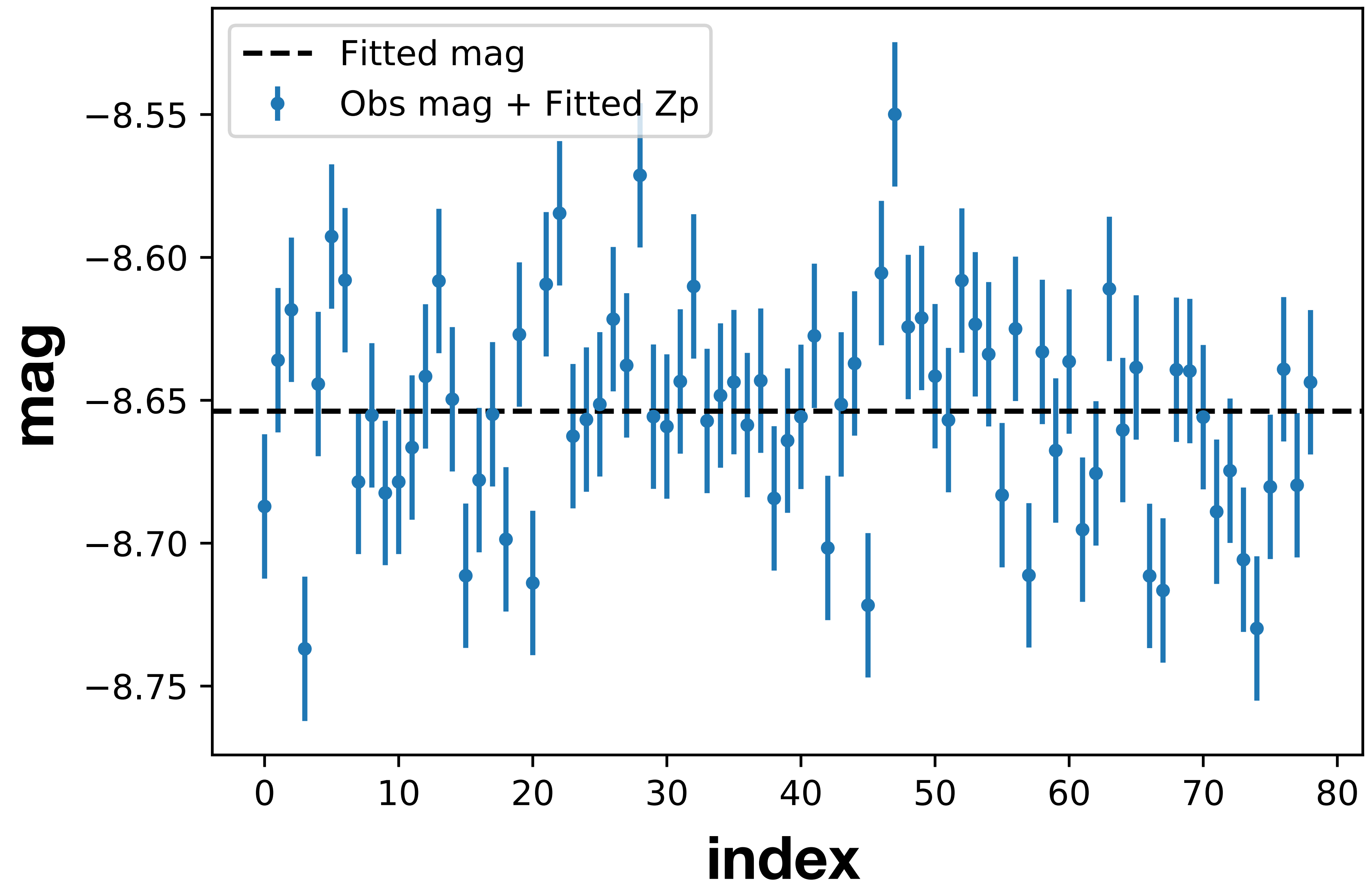
Result on all stars



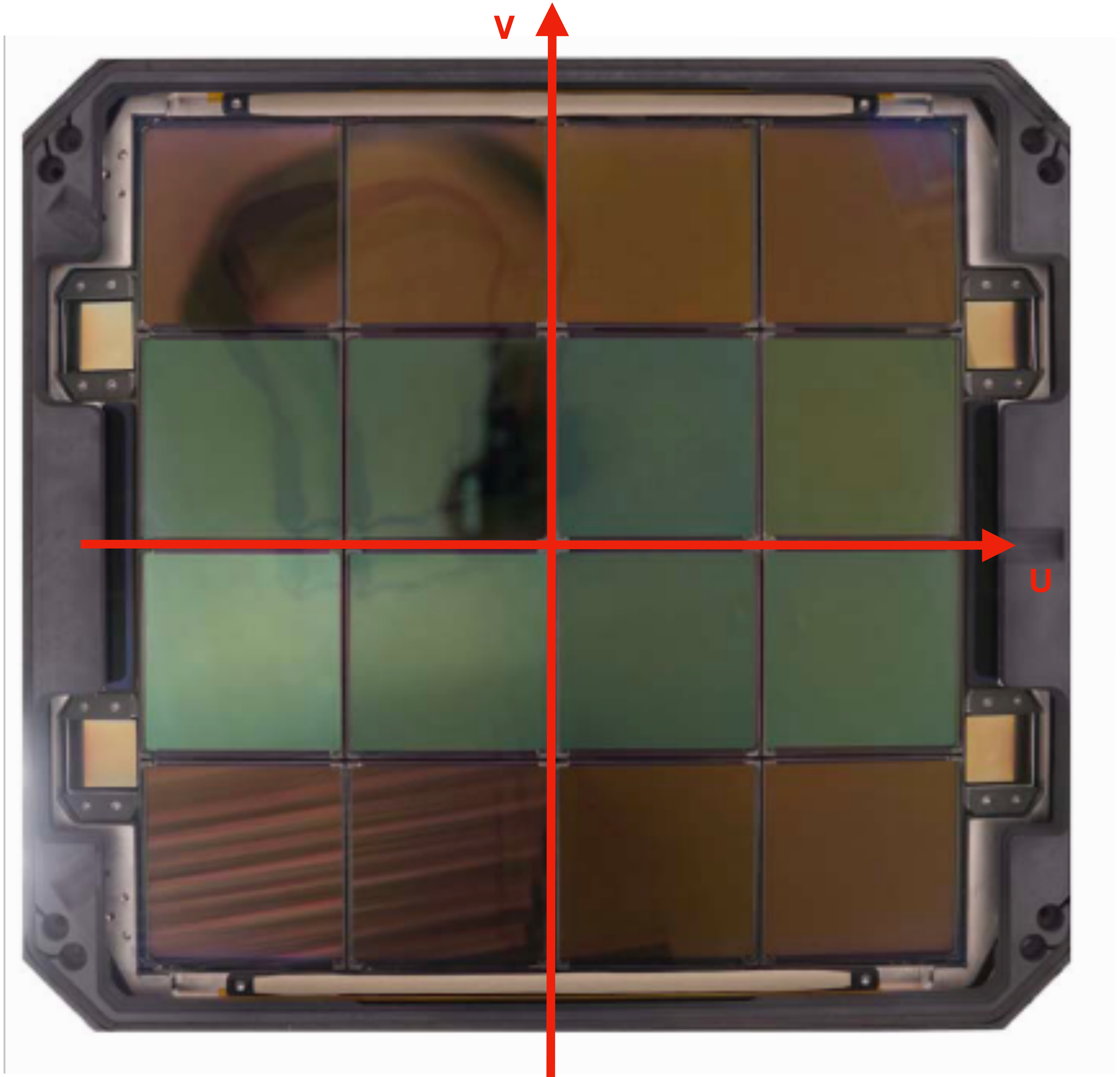
std=0.036



Result on one star
(79 obs here)



For each exposure, sources are observed at a specific position on the focal plane (uv coordinates)



Result on one star
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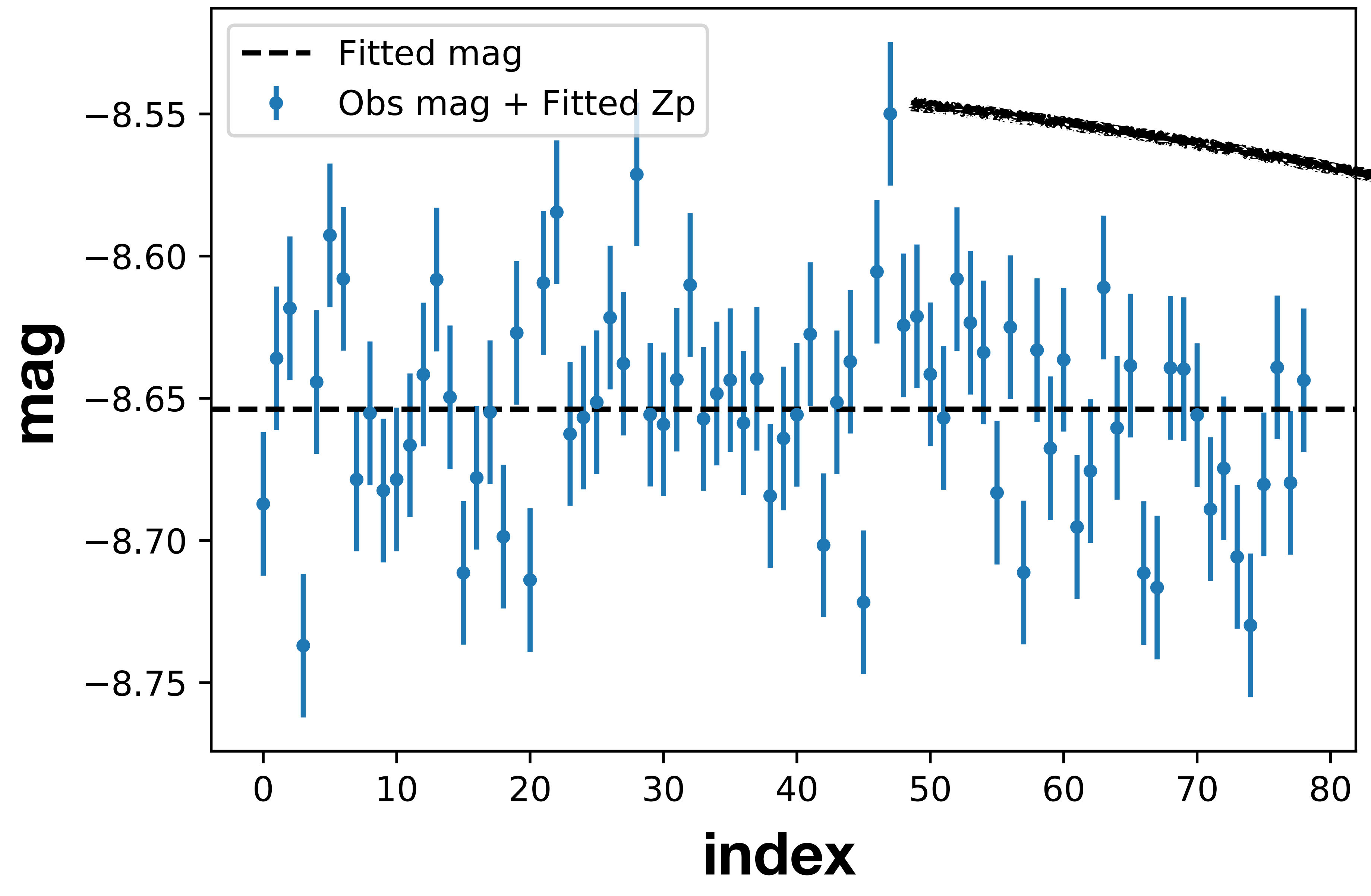

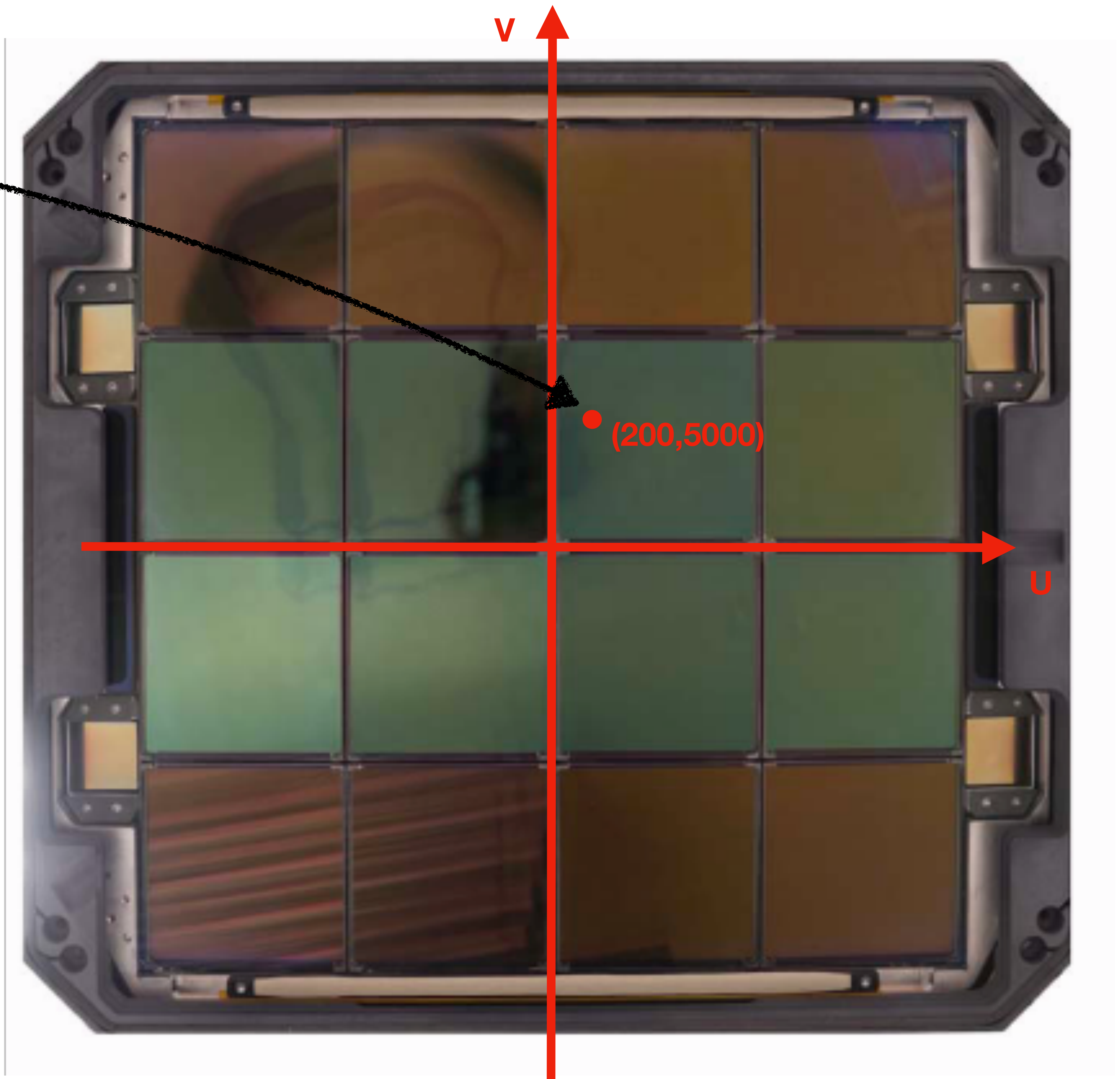

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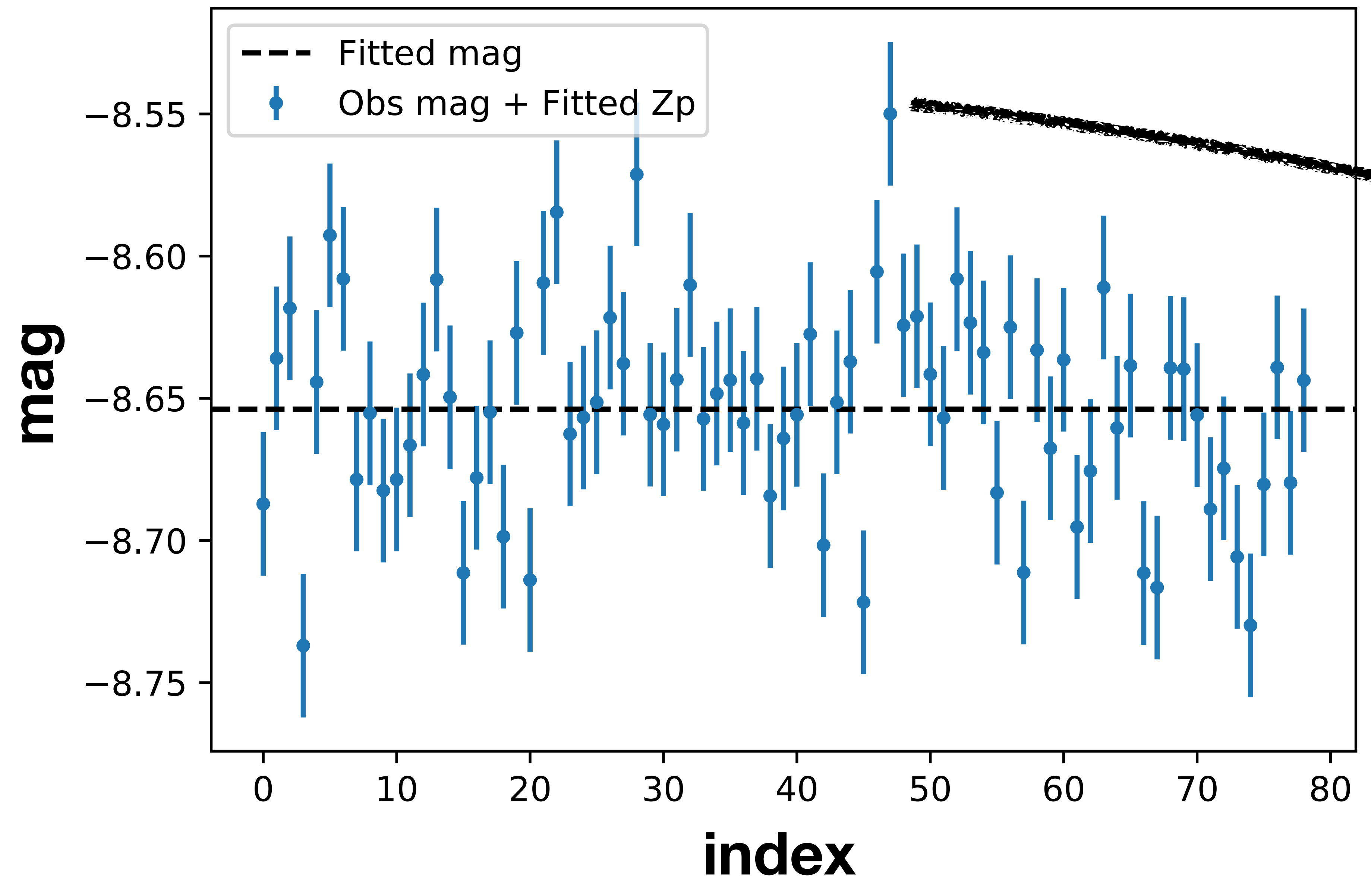
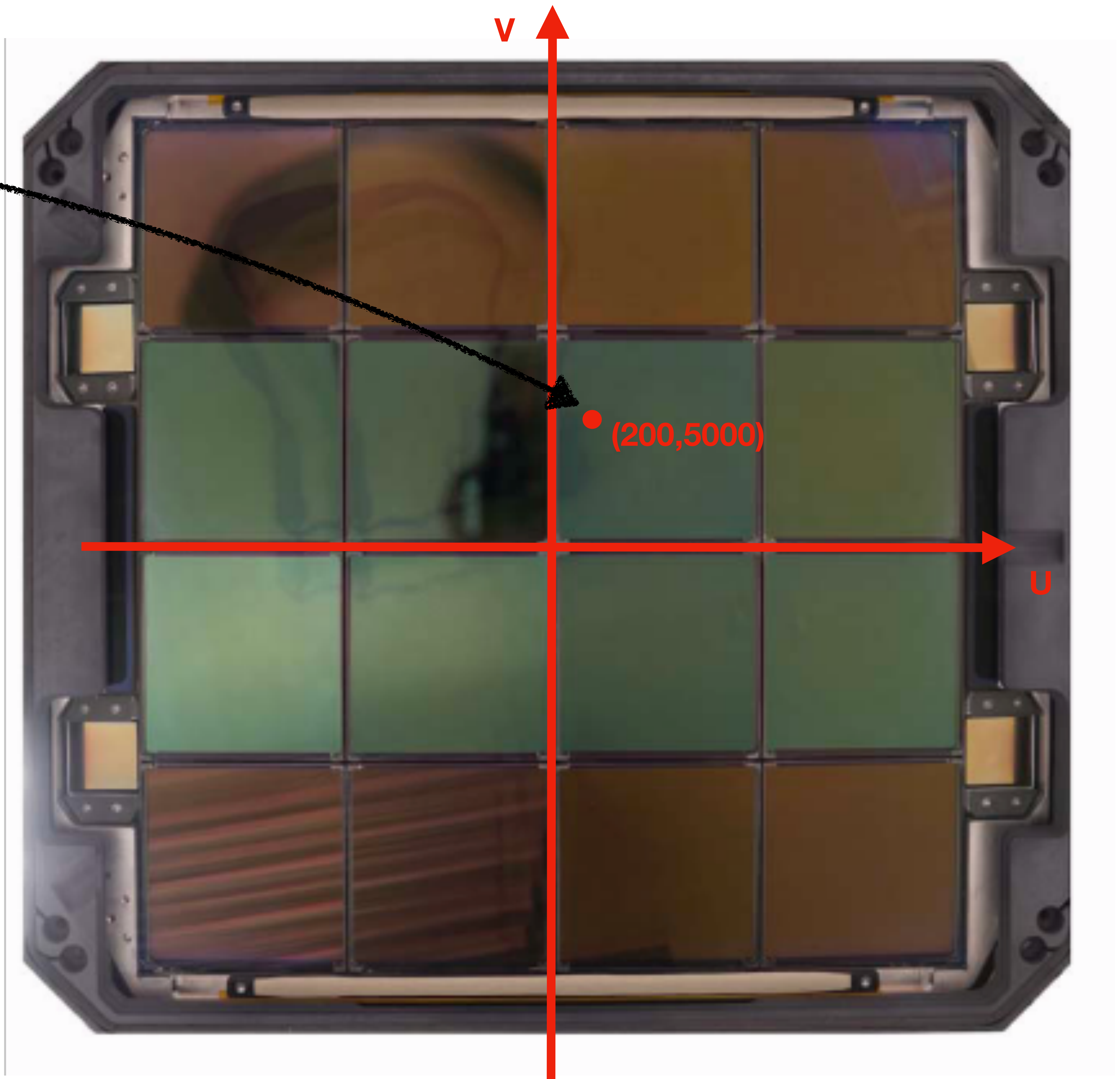
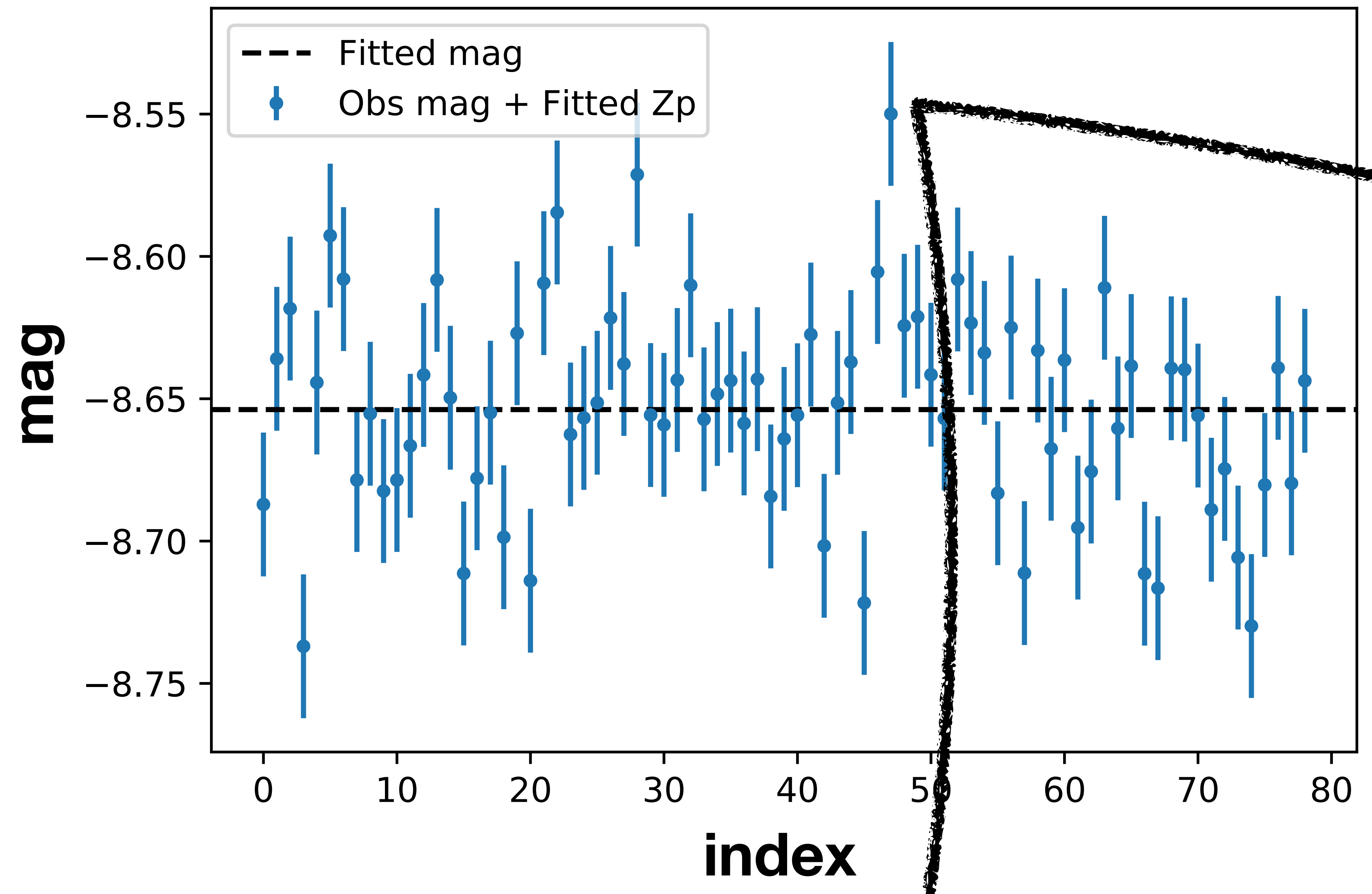




For each exposure, sources are observed at a specific position on the focal plane (uv coordinates)
And in the sky (RA-Dec)

Result on one star
(79 obs here)



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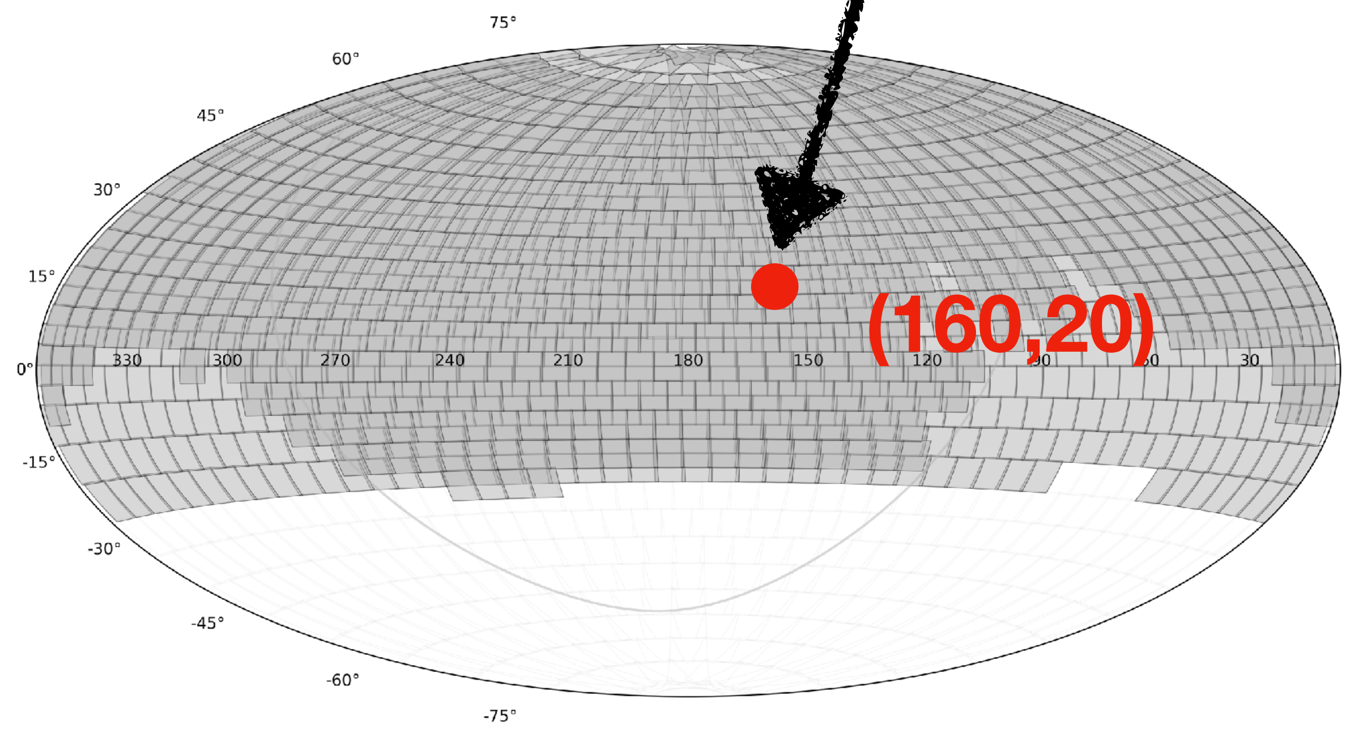
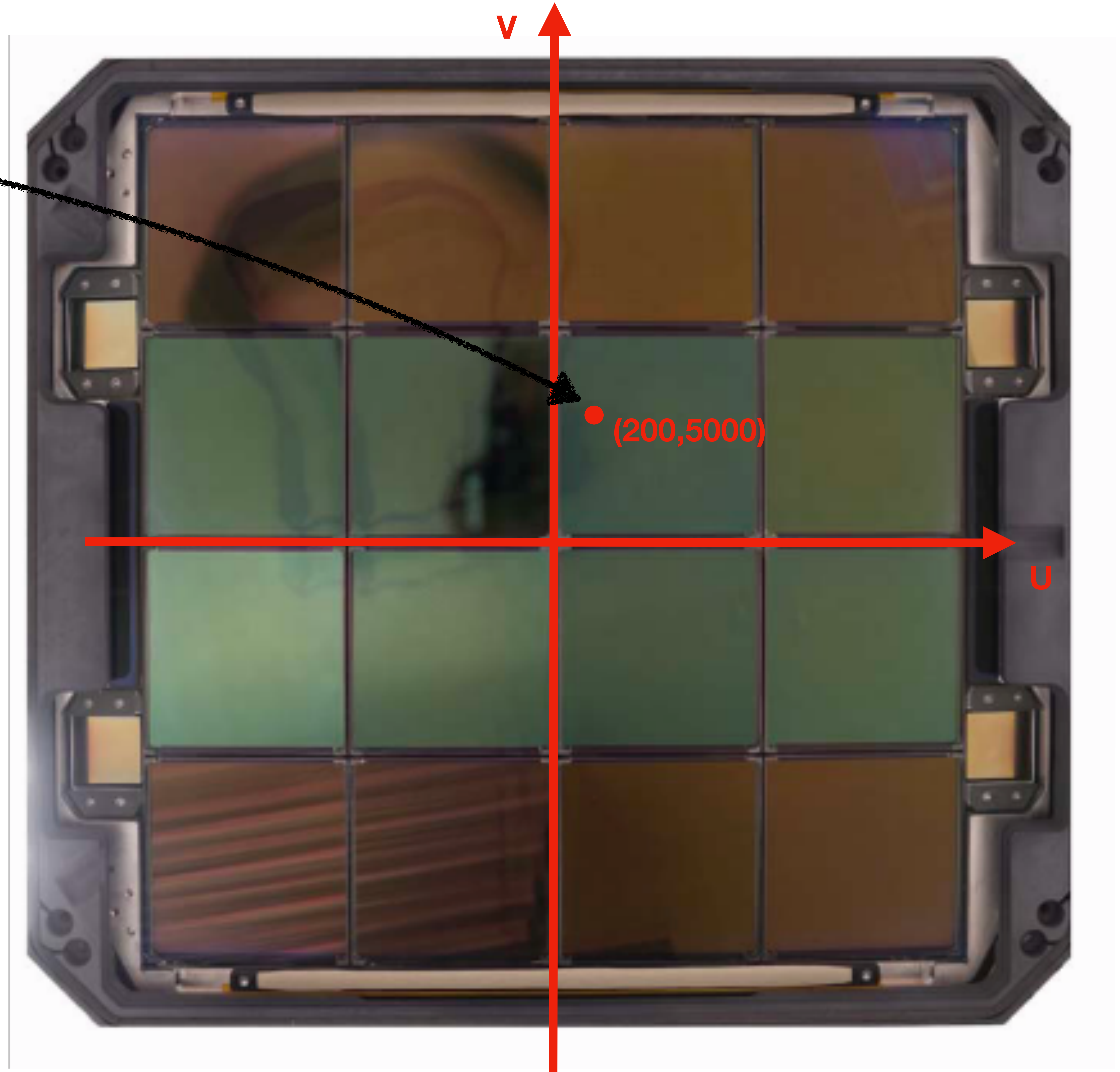
And in the sky (RA-Dec)





Data used

6 month: 2019-03 to 2019-08

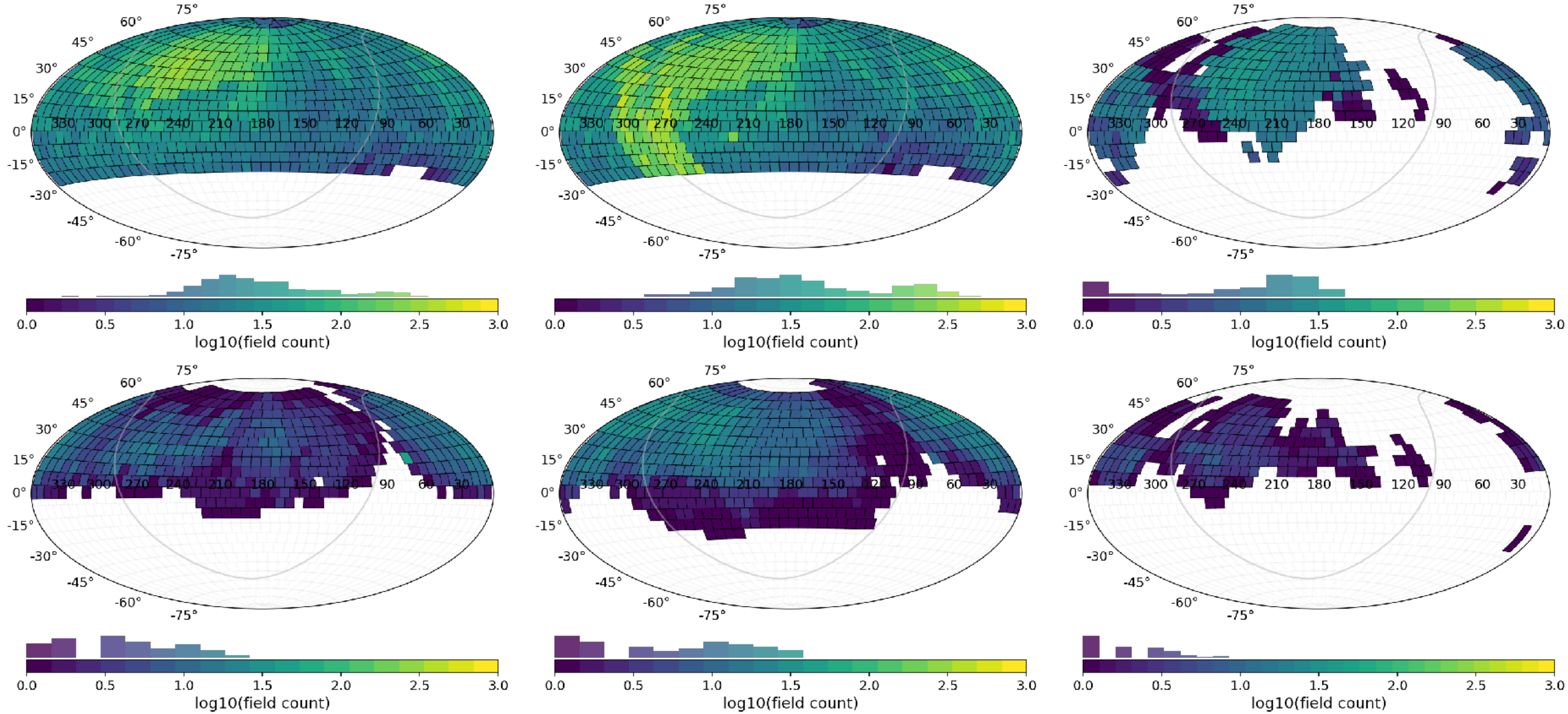
We match detected sources with isolated, non variable stars (Pan-STARR + Gaia)
We perform aperture photometry on the current science images (6pix)
Later will switch to new bias-corrected flat-fielded images

Few cuts:
- **SNR > 5**
- **Pan-STARR g < 19**
- **Remove flagged « bad images »**

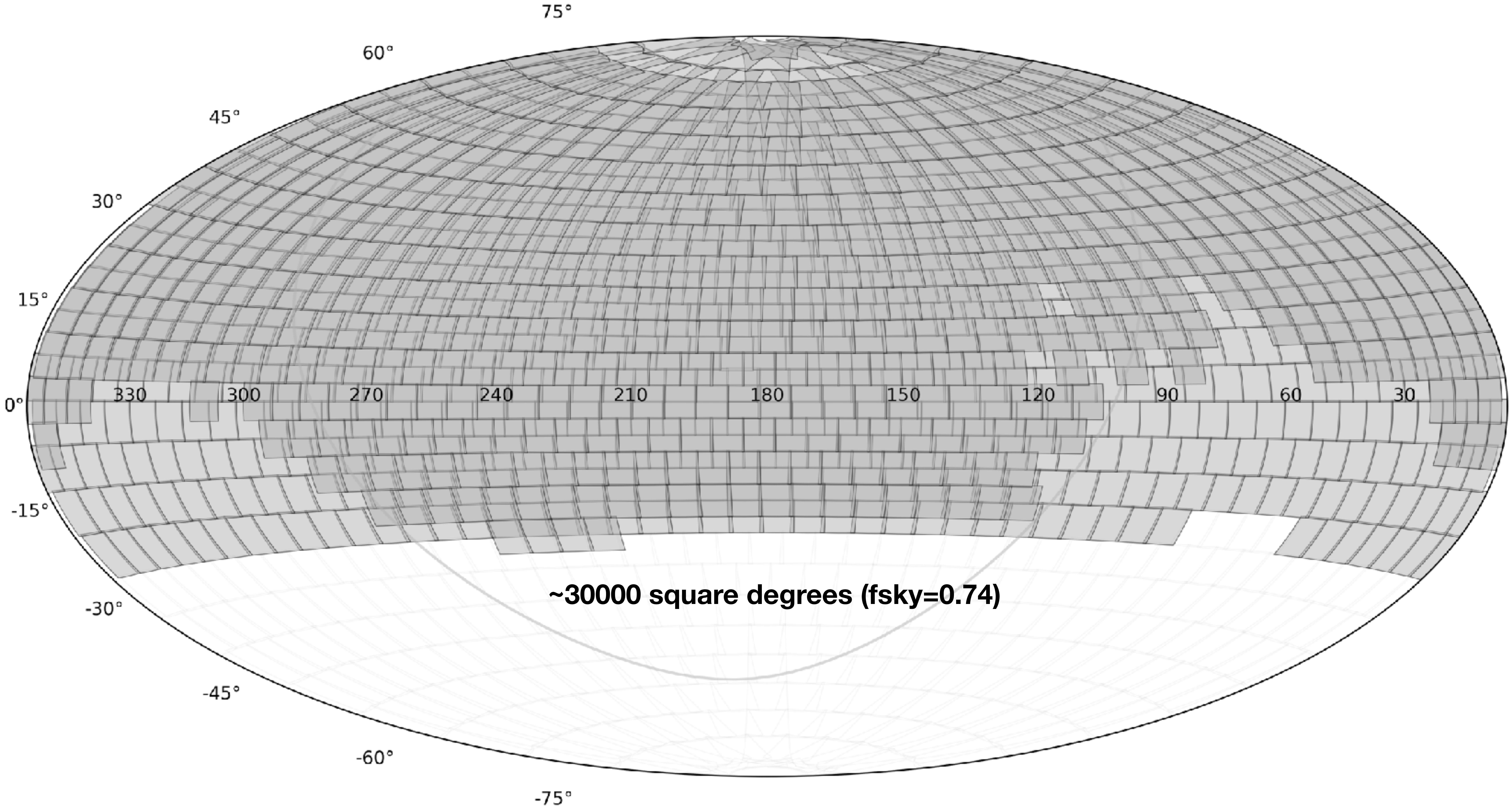
all ra
dec > -30

6 month here: 2019-03 to 2019-08

ZTF-g **ZTF-r** **ZTF-i**

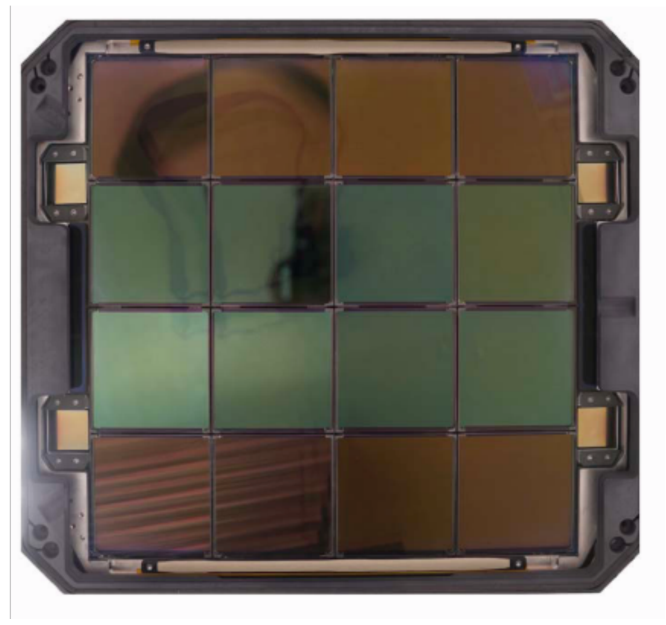


6 month: 2019-03 to 2019-08



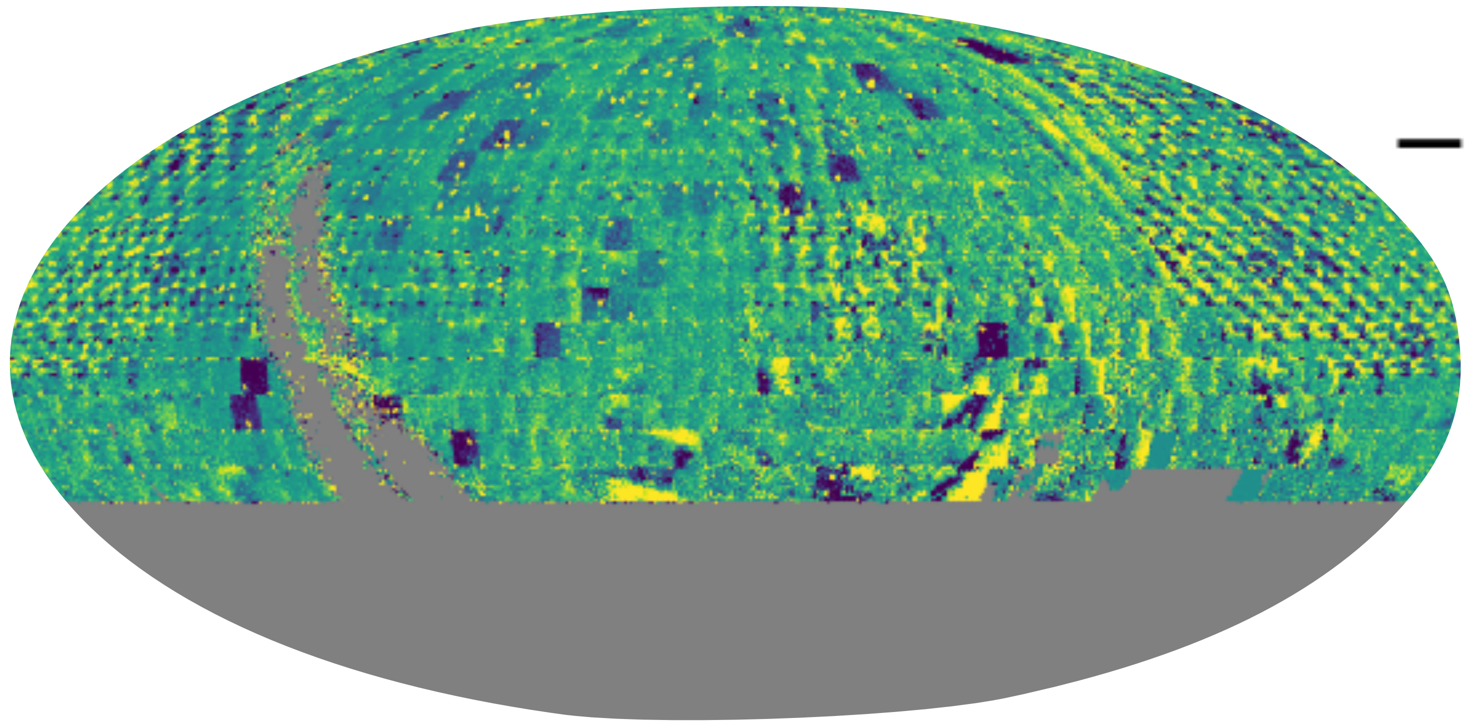
0
90
60
30

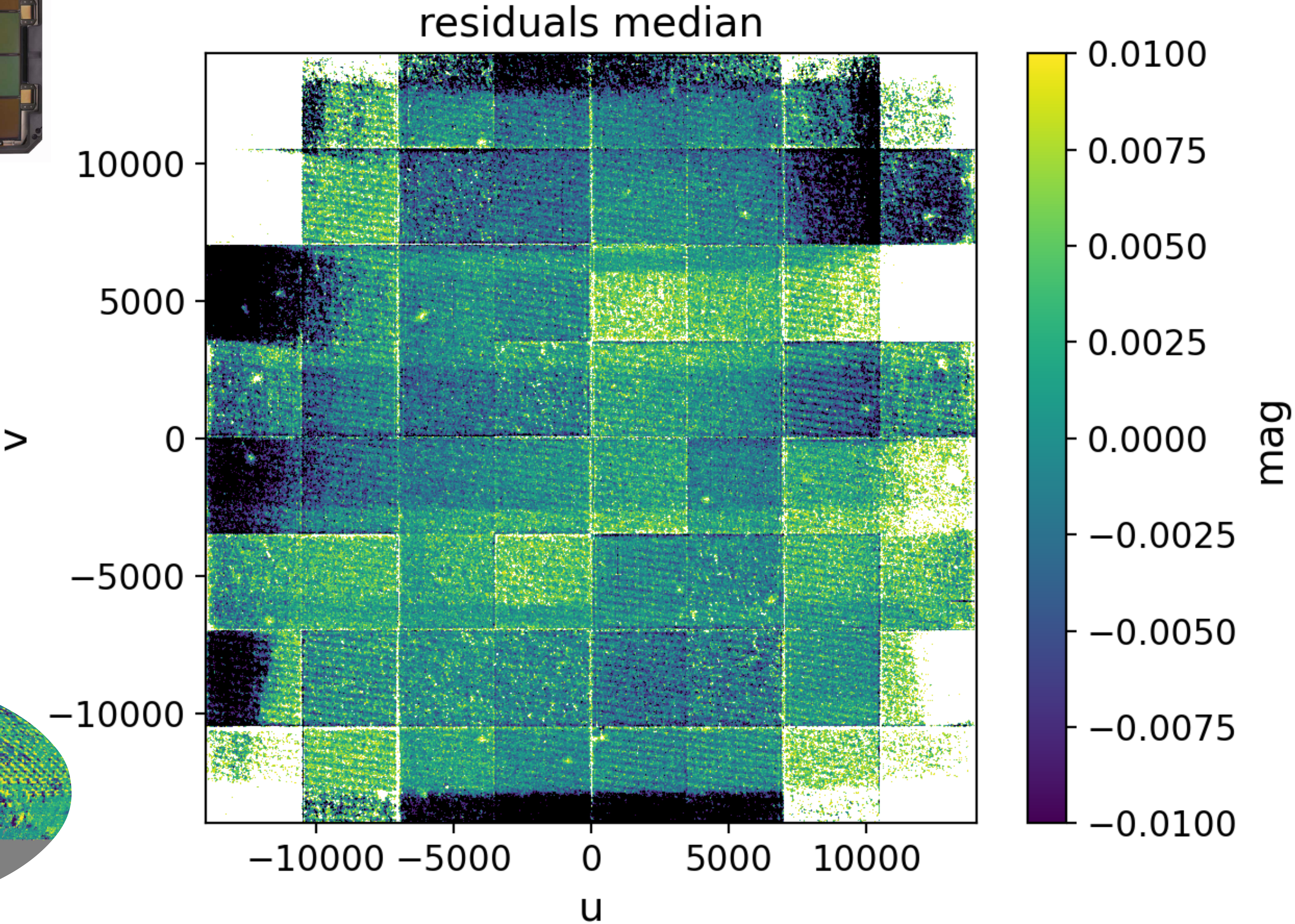
ZTF-g



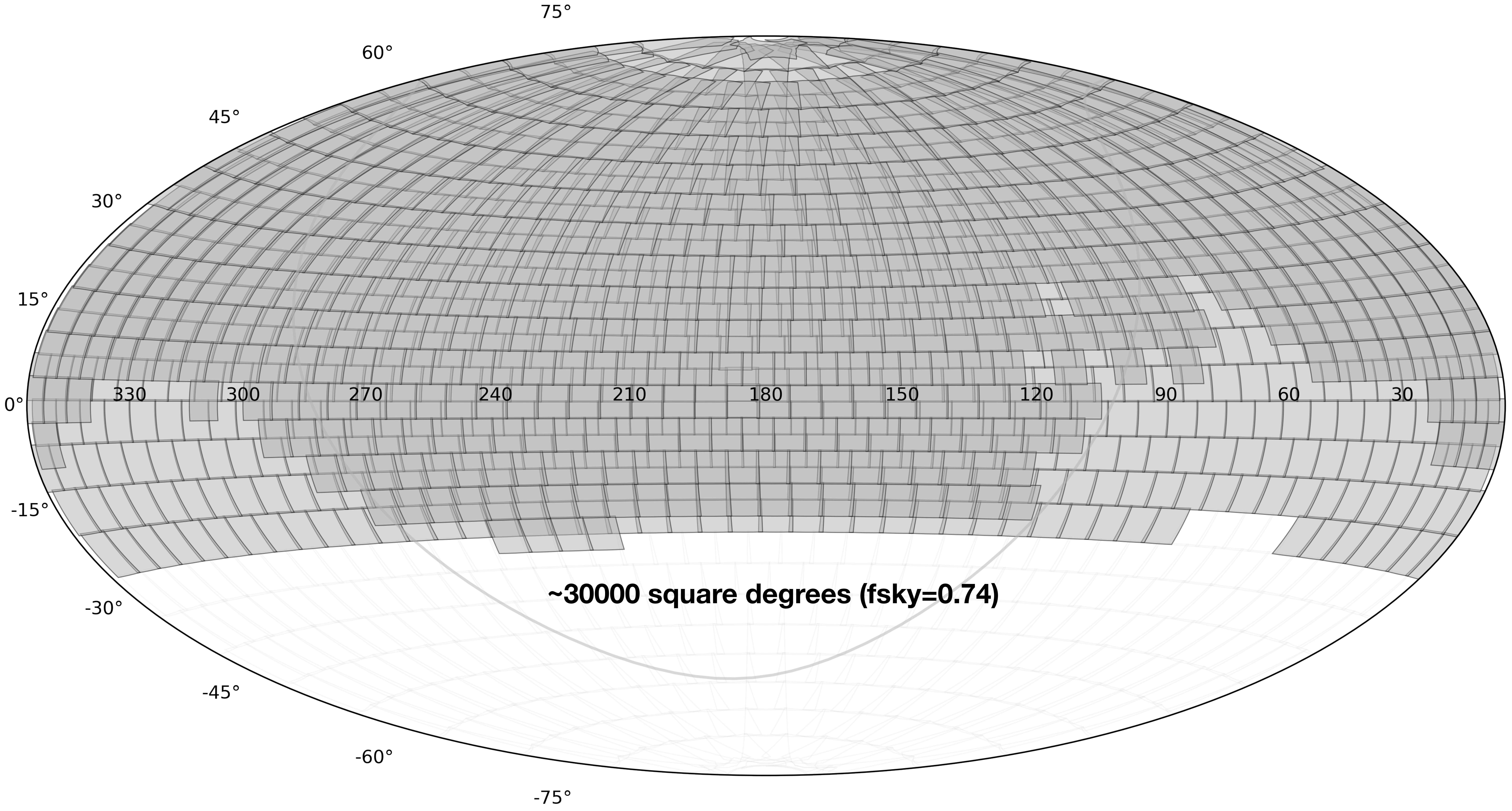
Fit
1 zero point
per exposure

We see large quadrant to quadrant variation





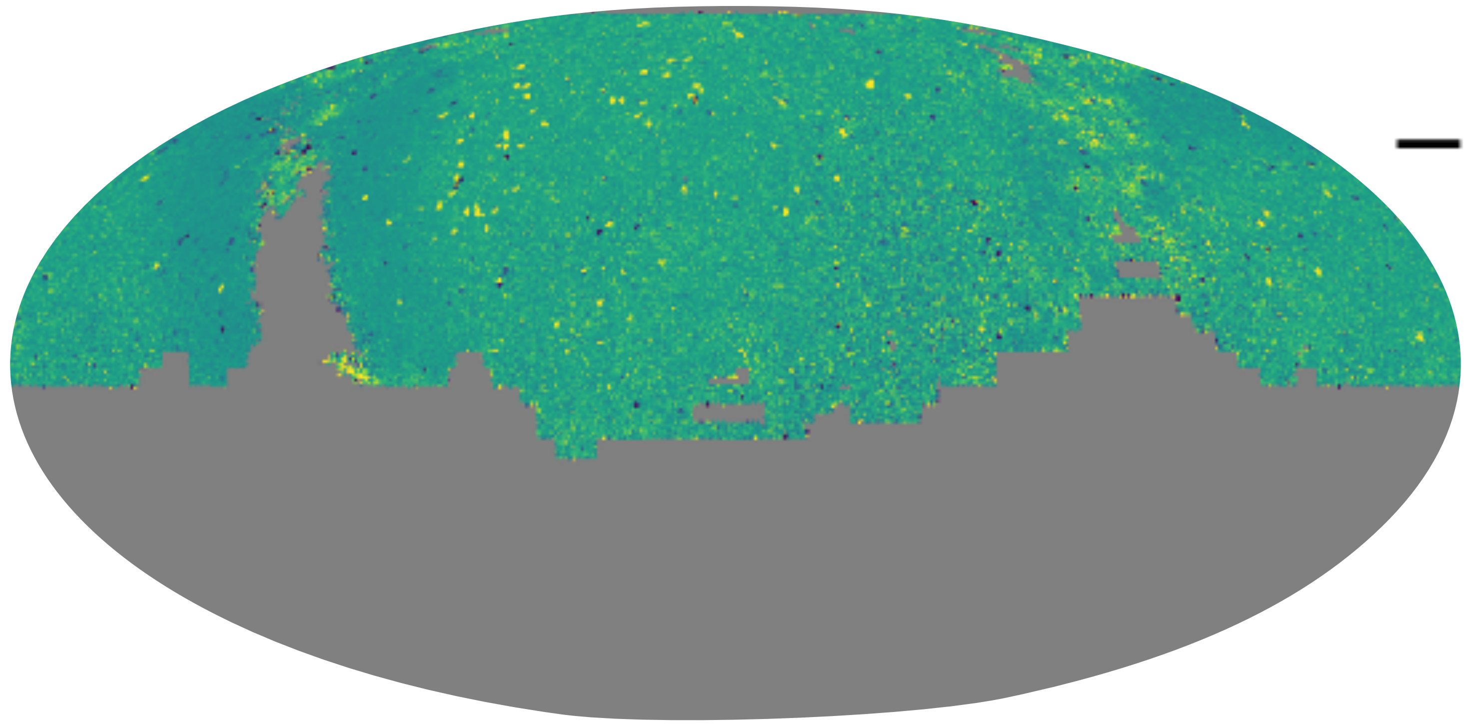
6 month: 2019-03 to 2019-08

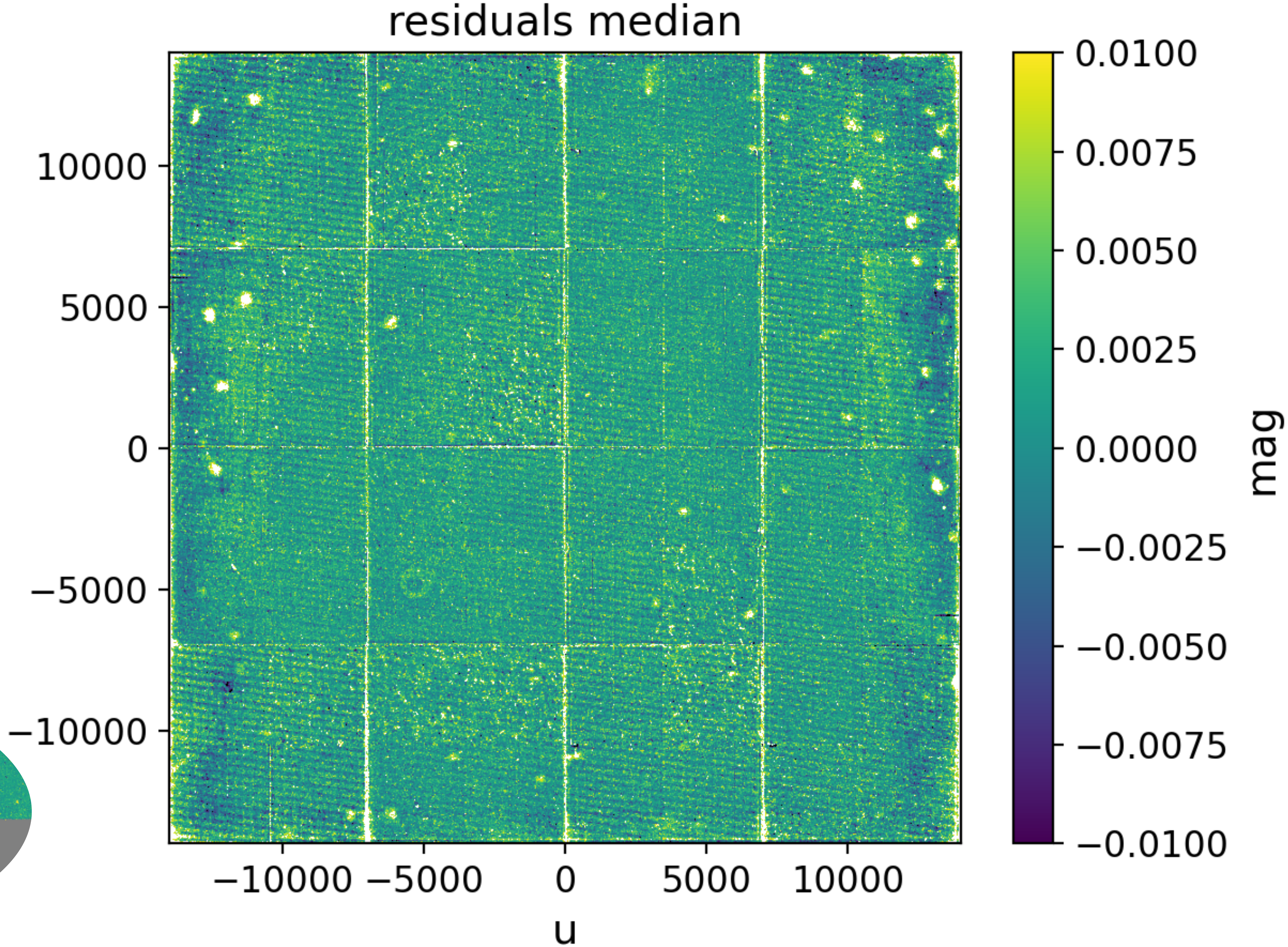


ZTF-g

Fit
1 zero point
per quadrant
(if secondary pointing)

Much flatter residuals

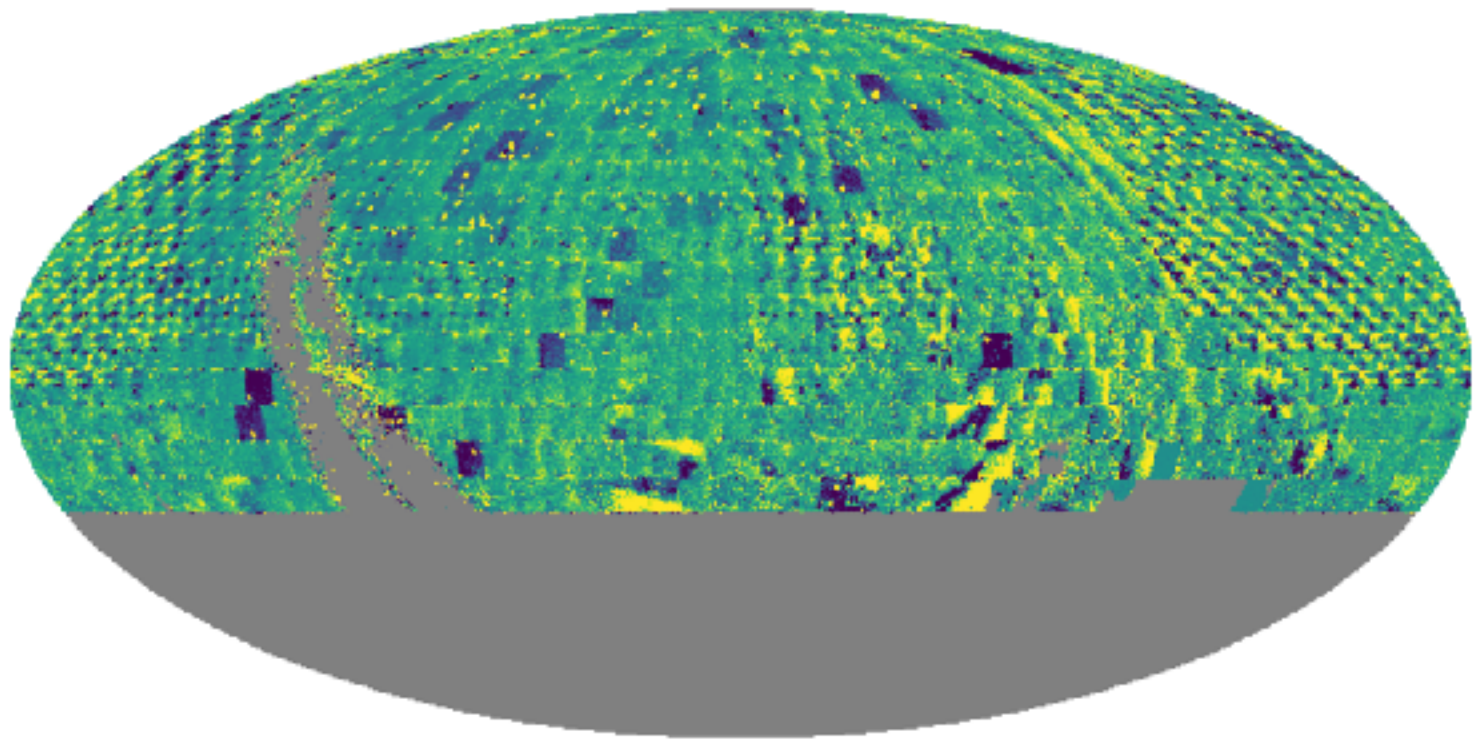


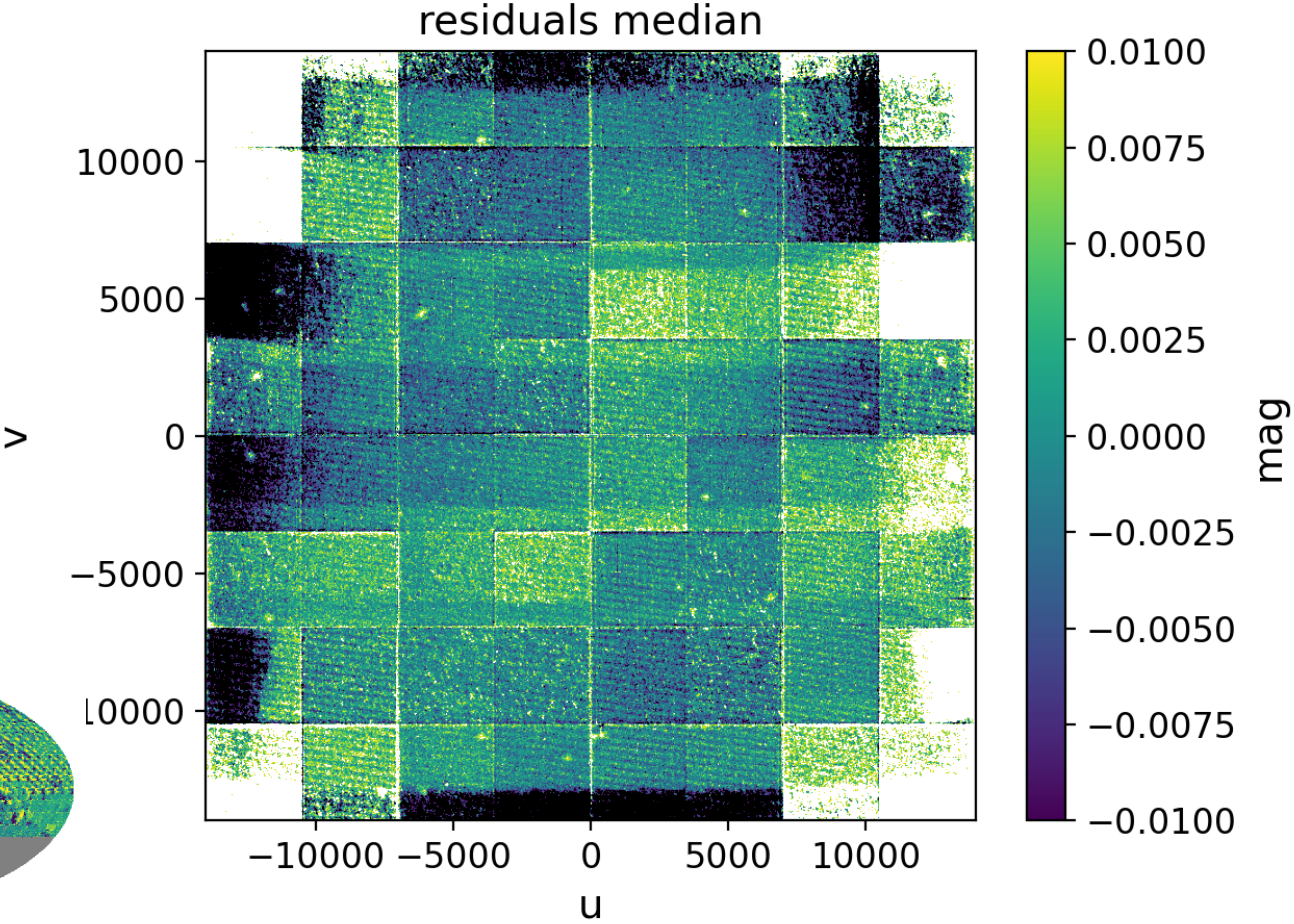


ZTF-g

Fit
1 zero point
per exposure

We see large quadrant to quadrant variation

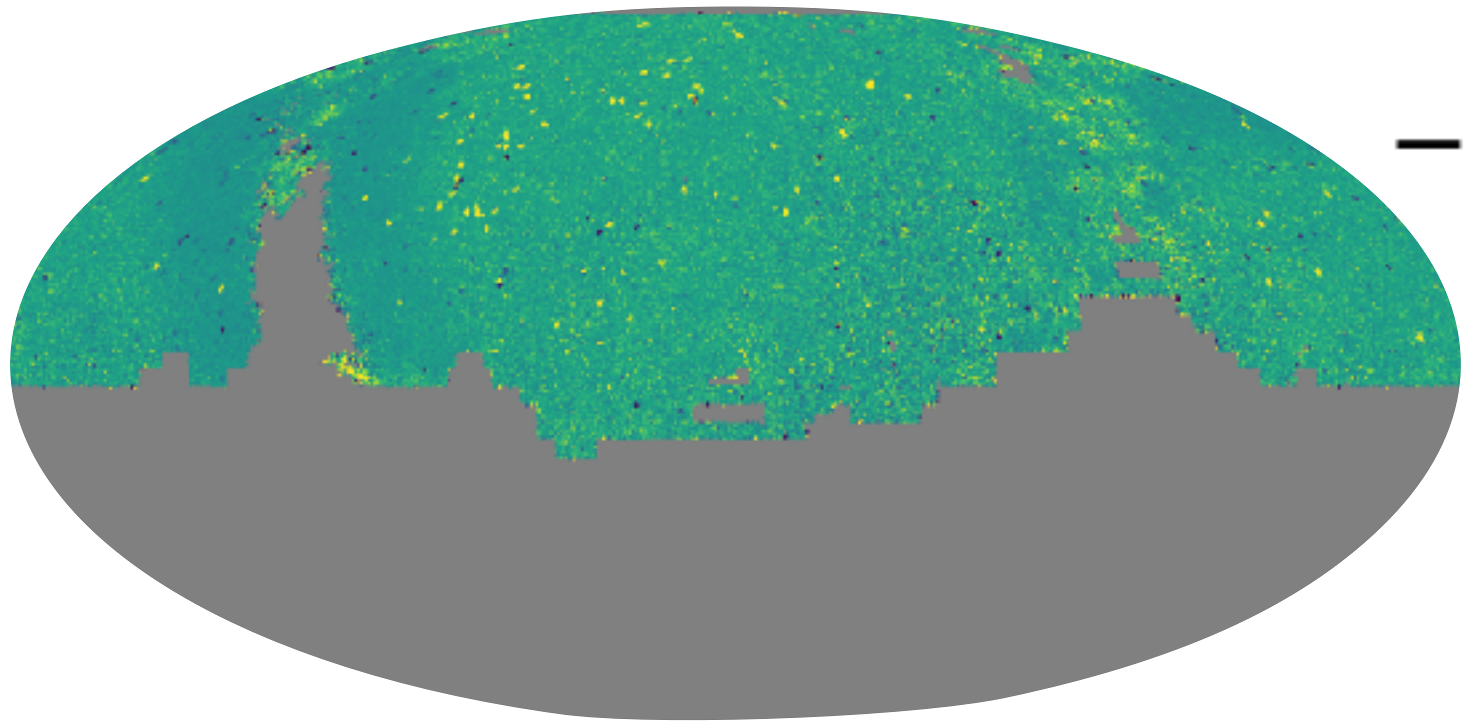


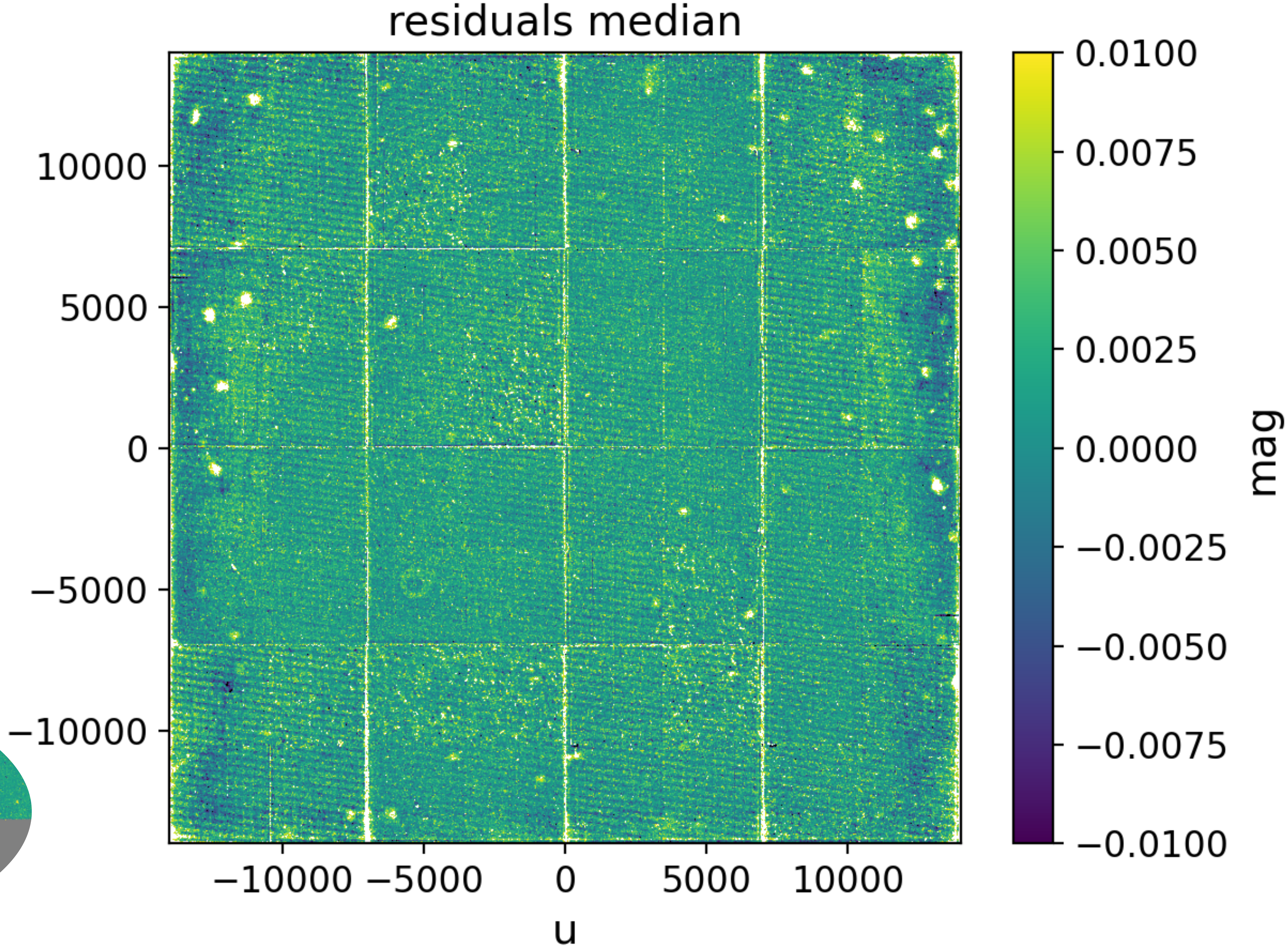


ZTF-g

Fit
1 zero point
per quadrant
(if secondary pointing)

Much flatter residuals

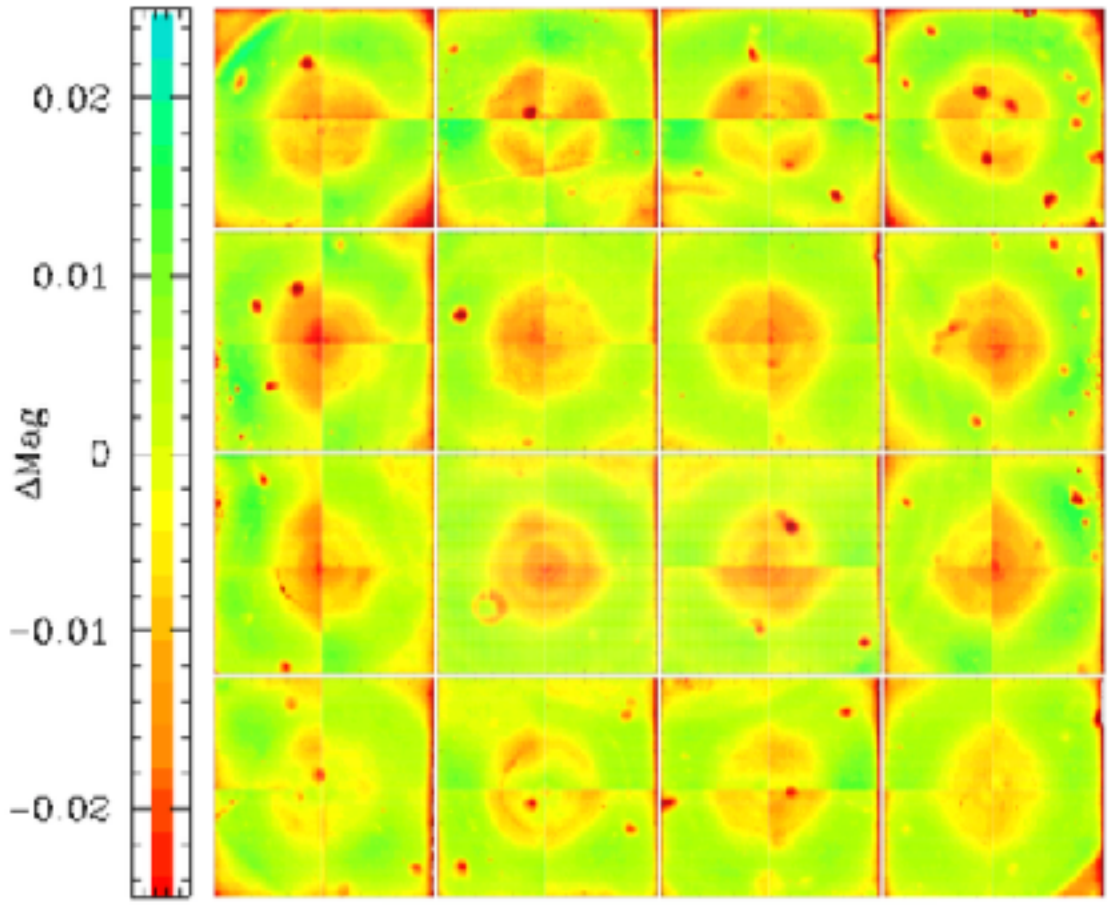


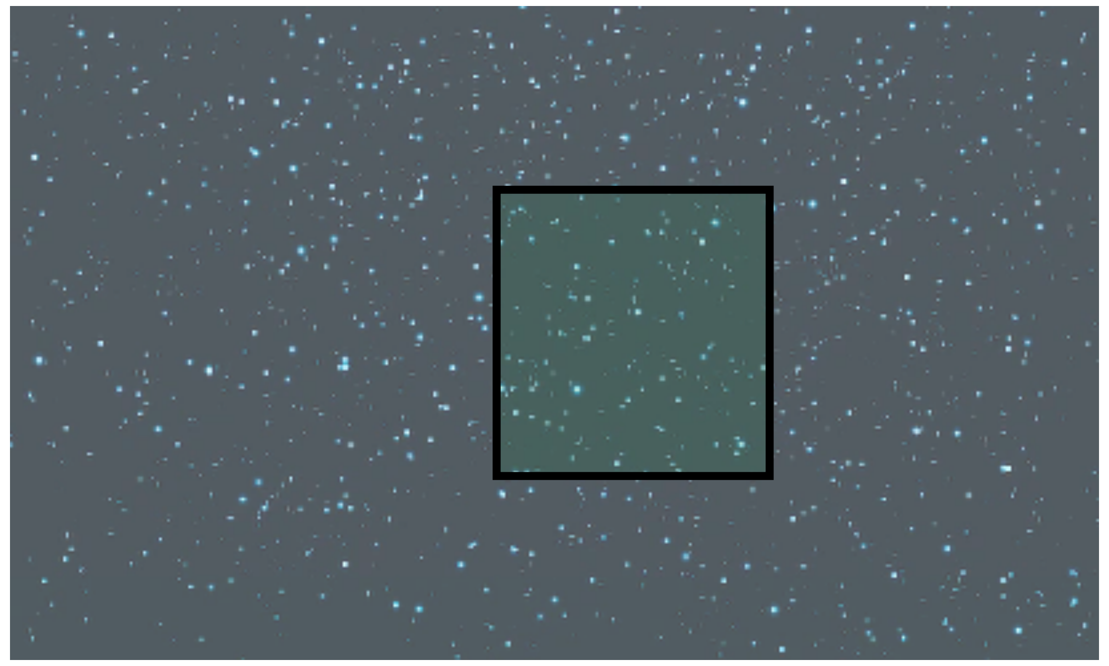


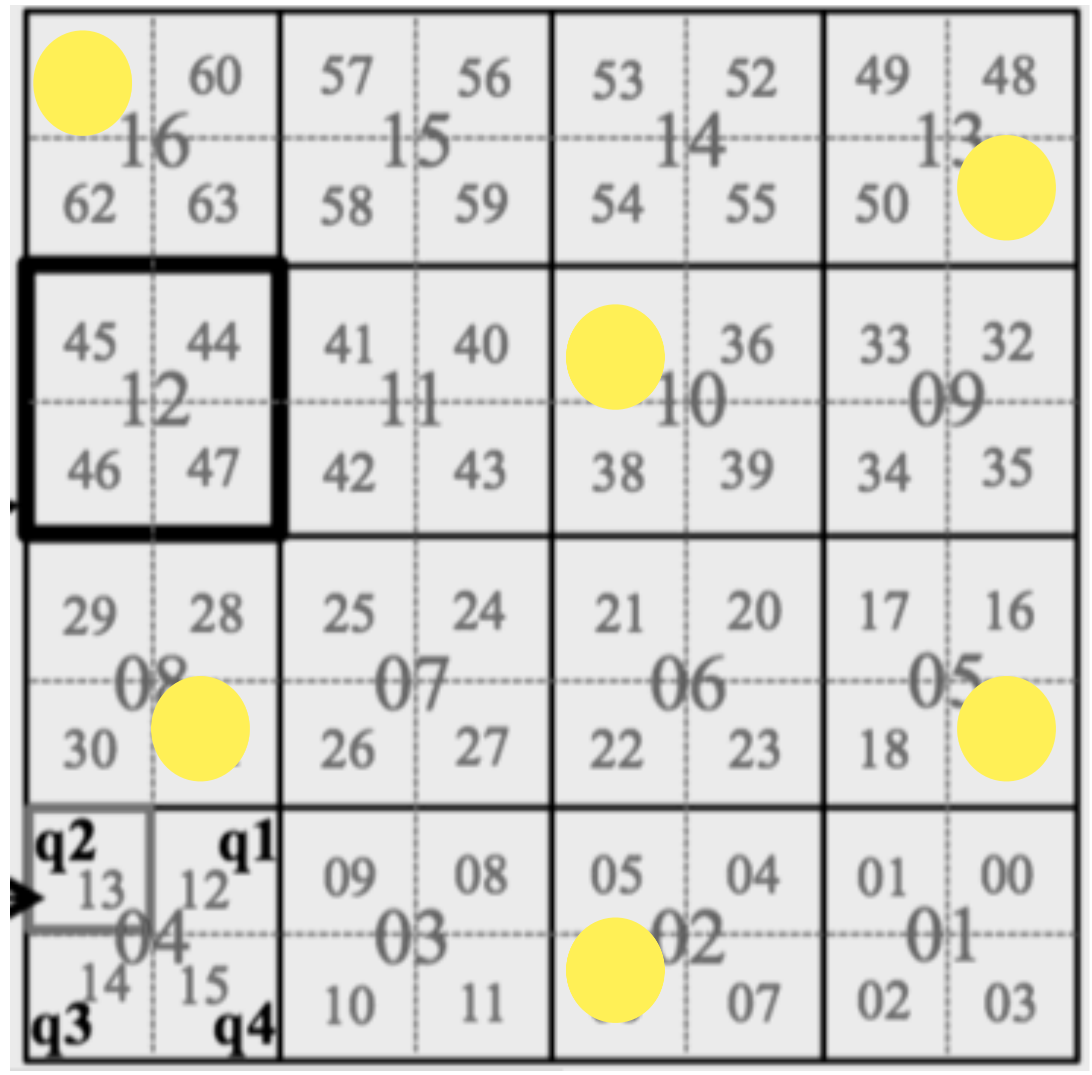
Starflats

Estelle Robert, Nicolas Regnault

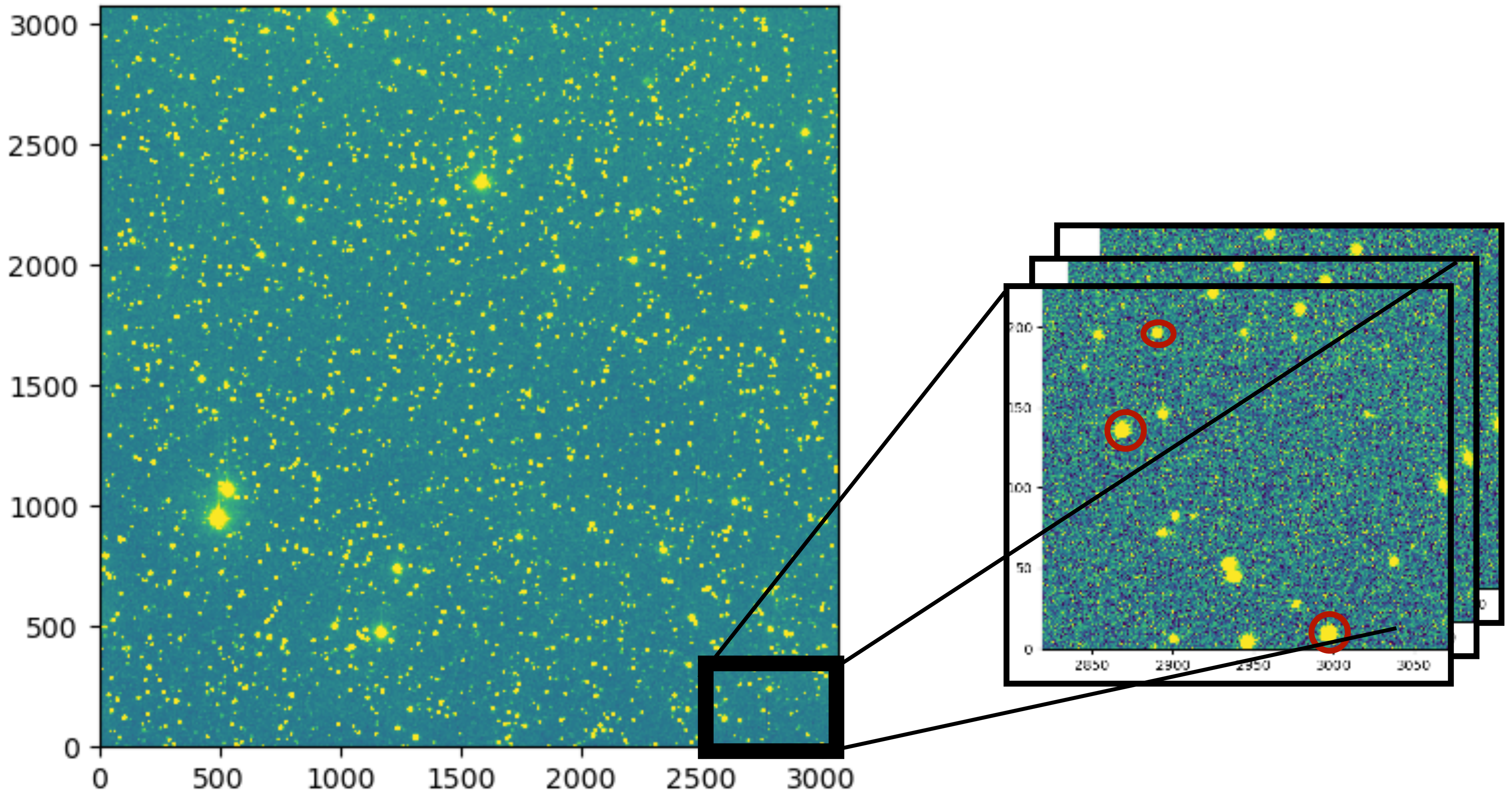
Starflat procedure





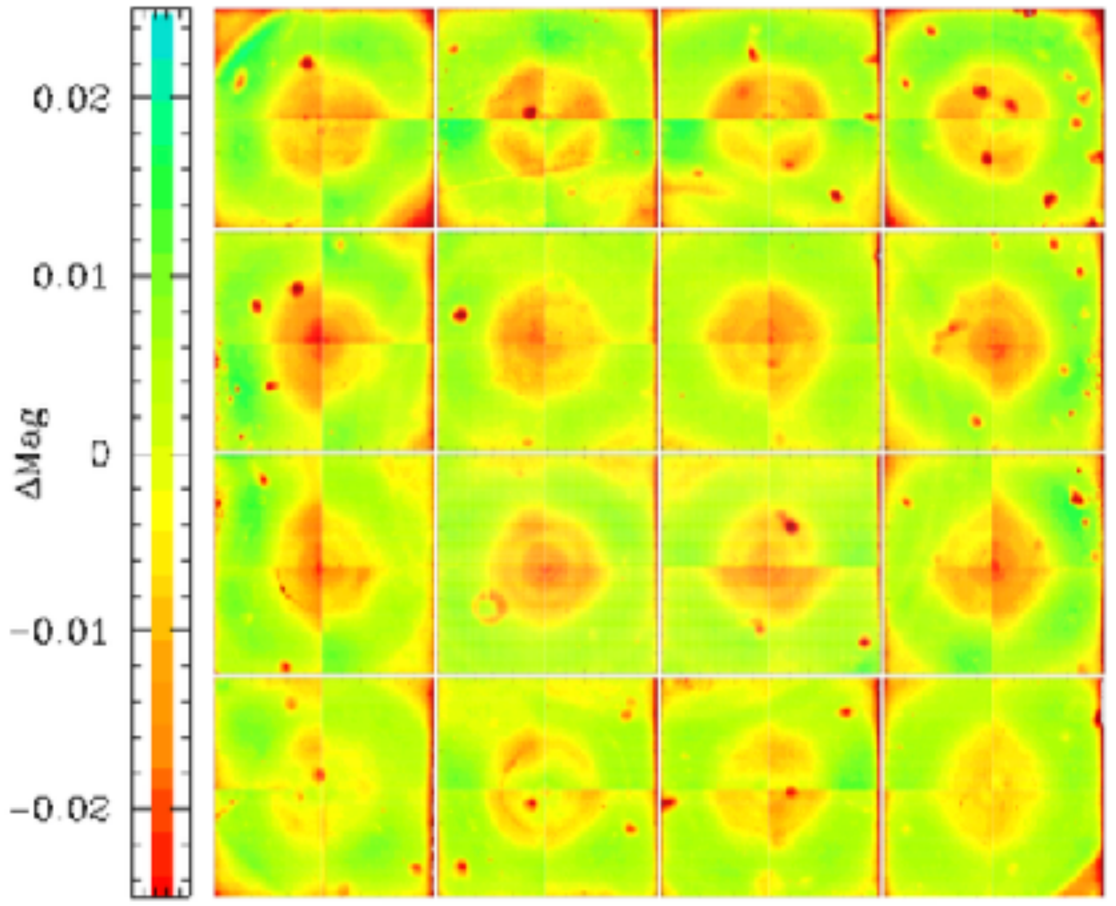


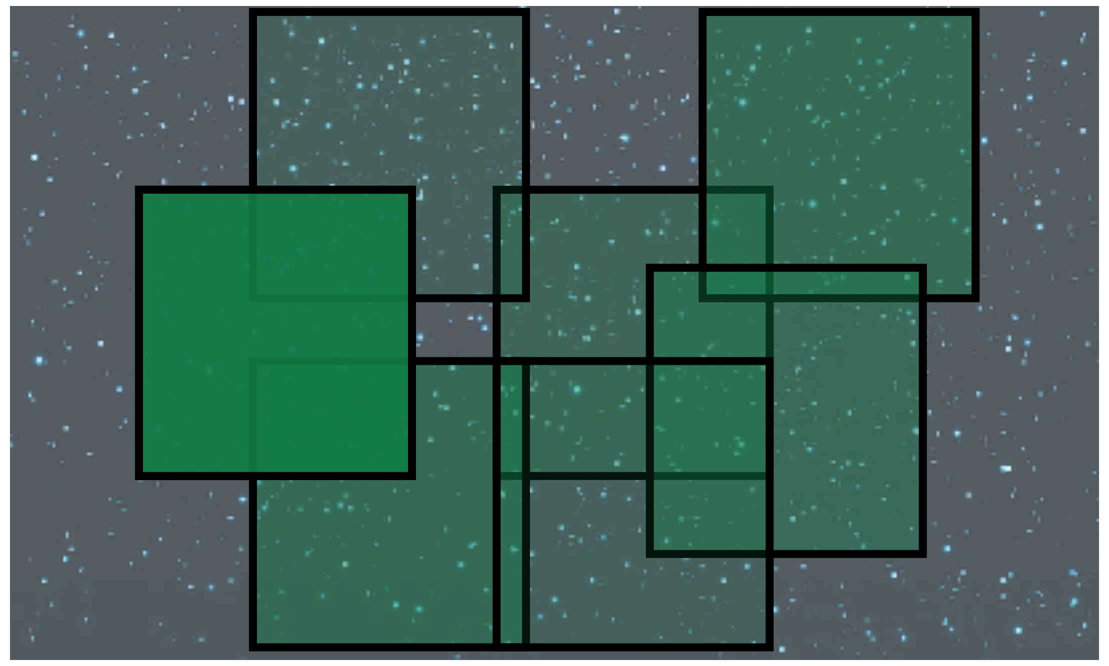
1 ZTF quadrant

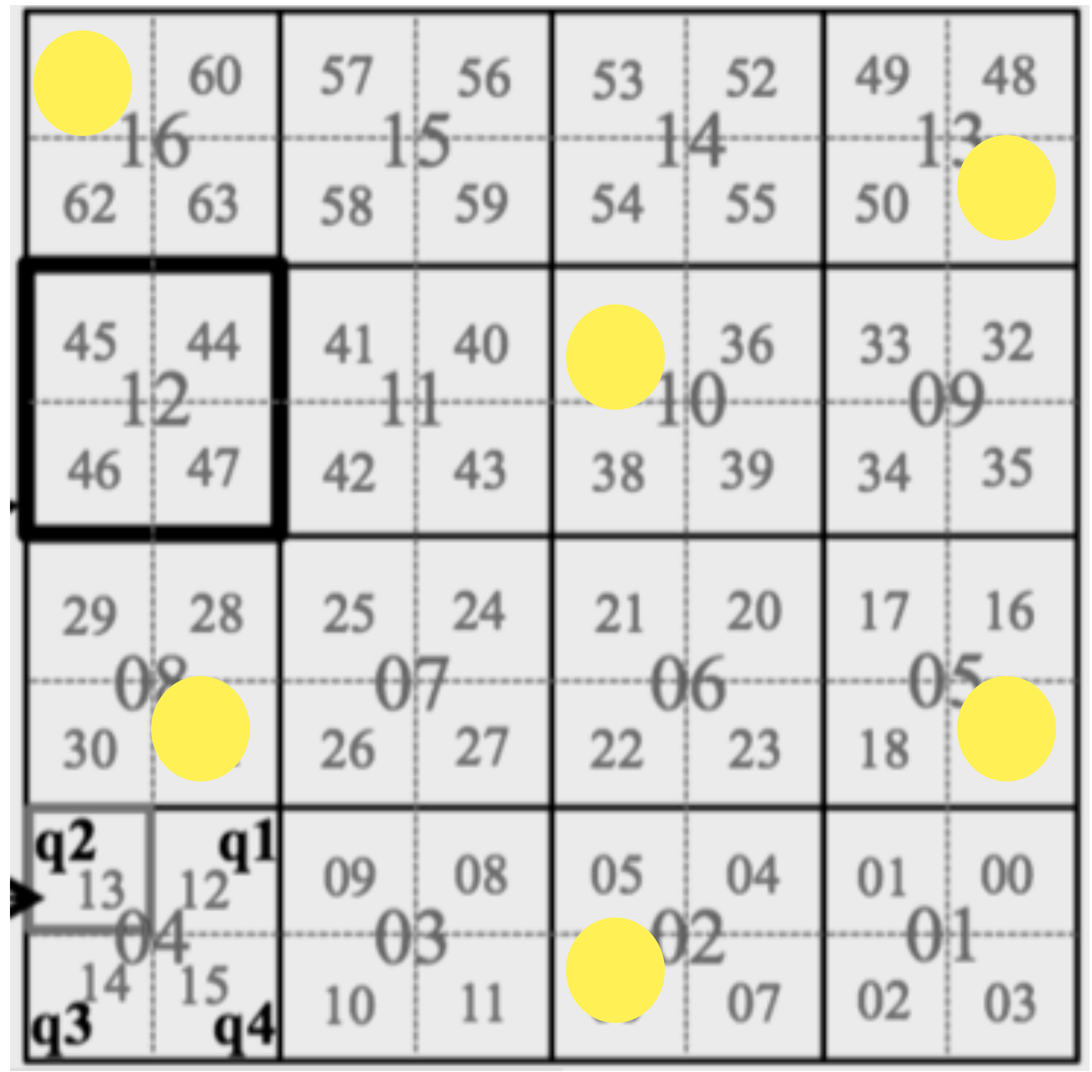


Starflat : flux variation of a star depending on its position on the camera

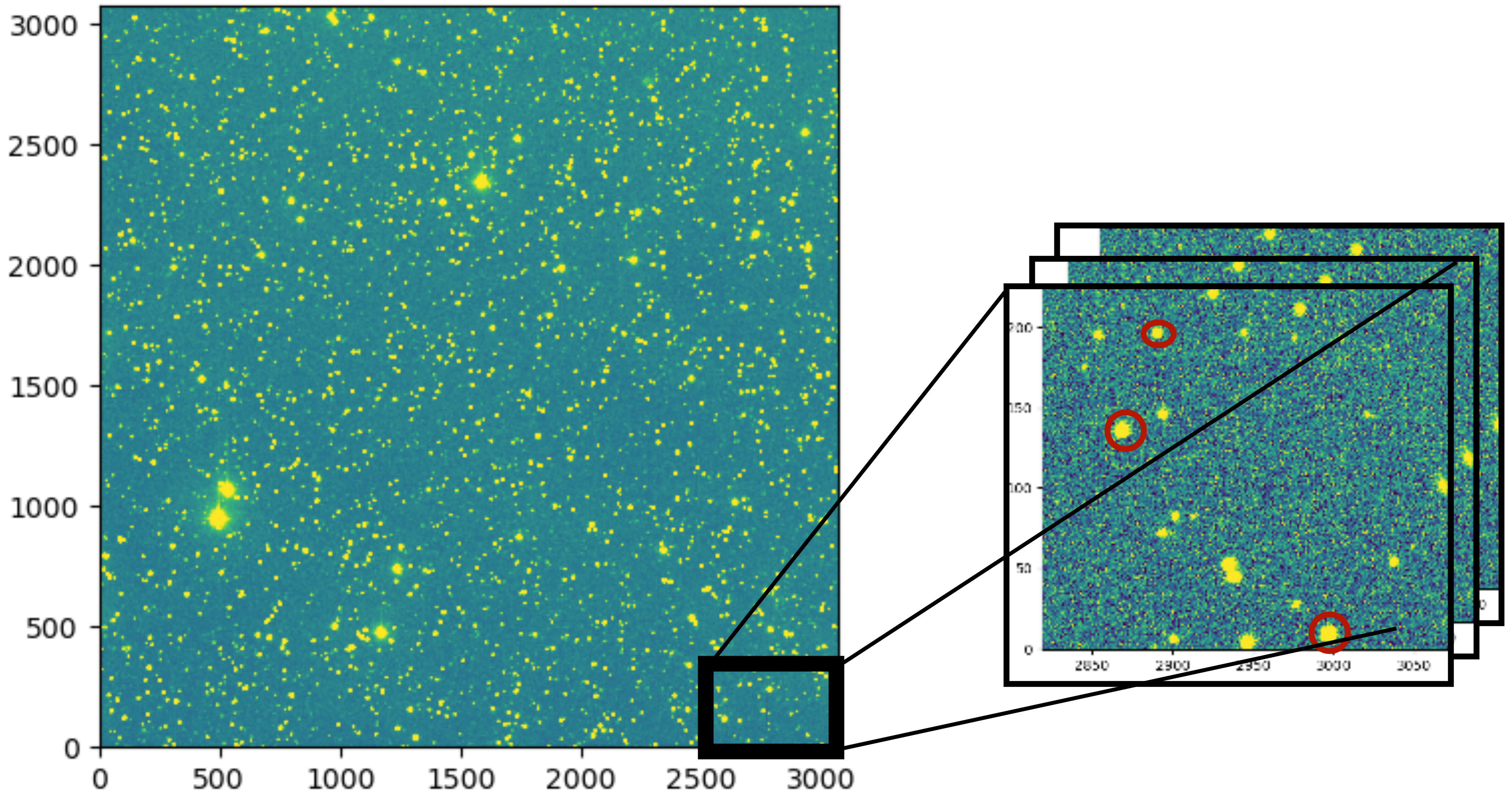
Starflat procedure





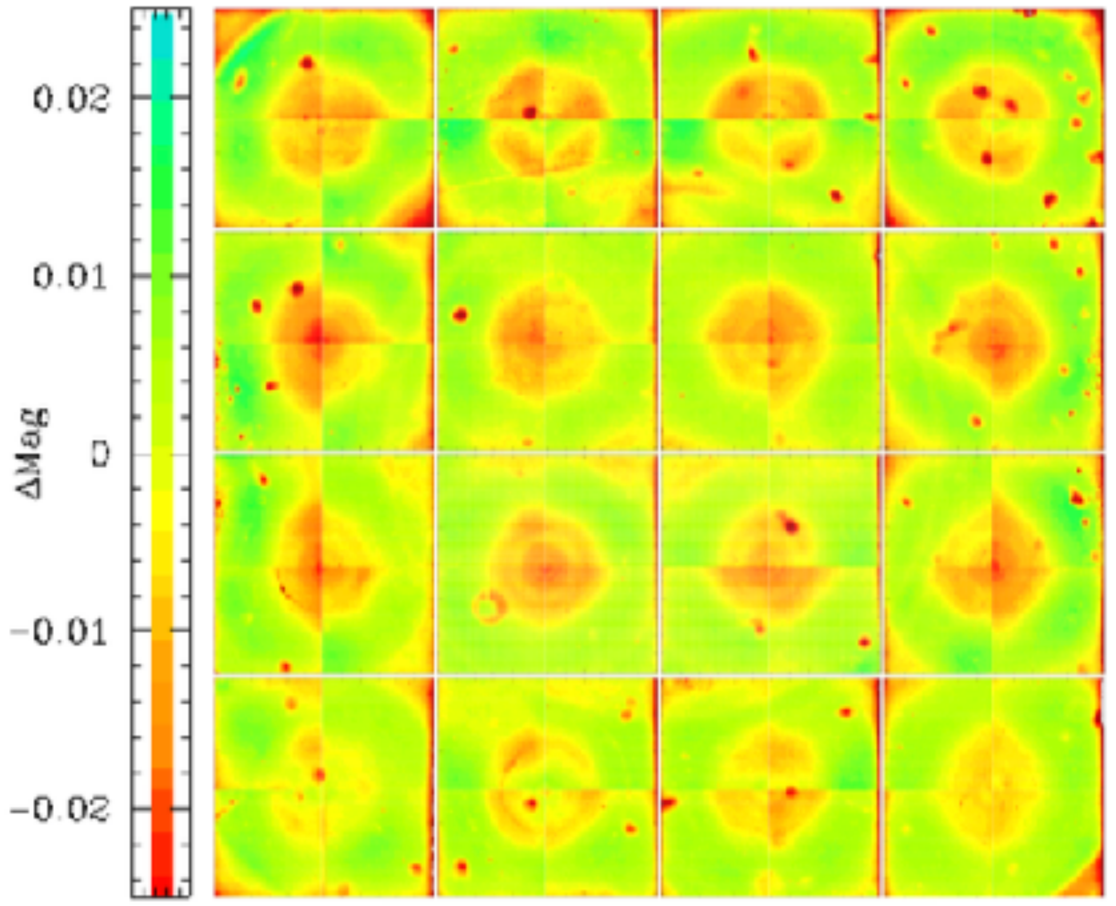


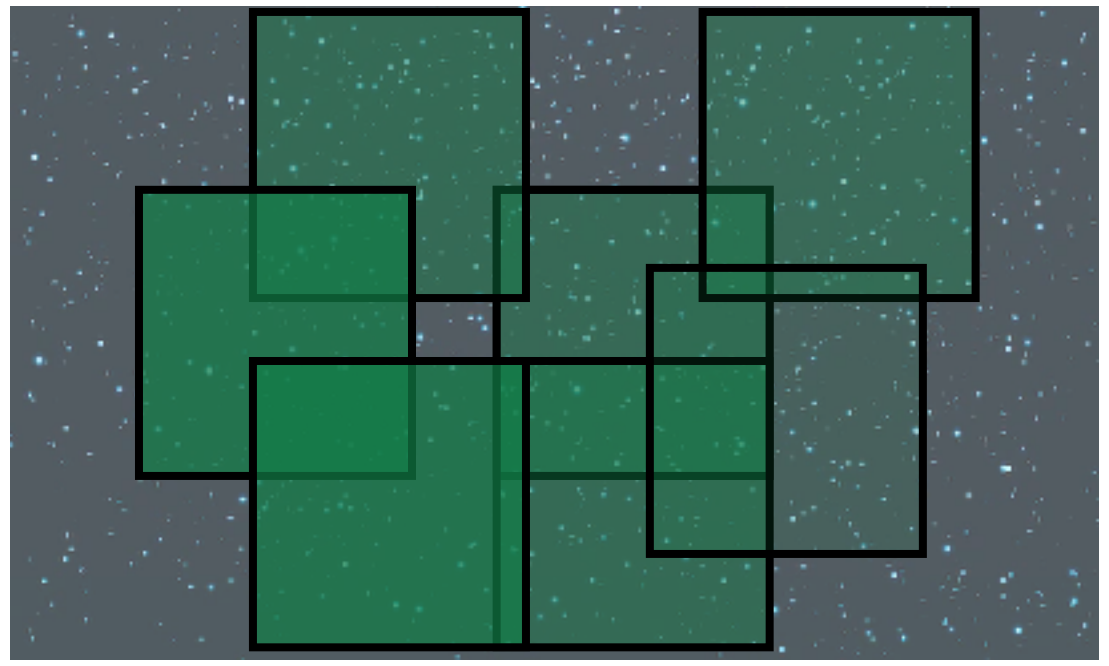
1 ZTF quadrant

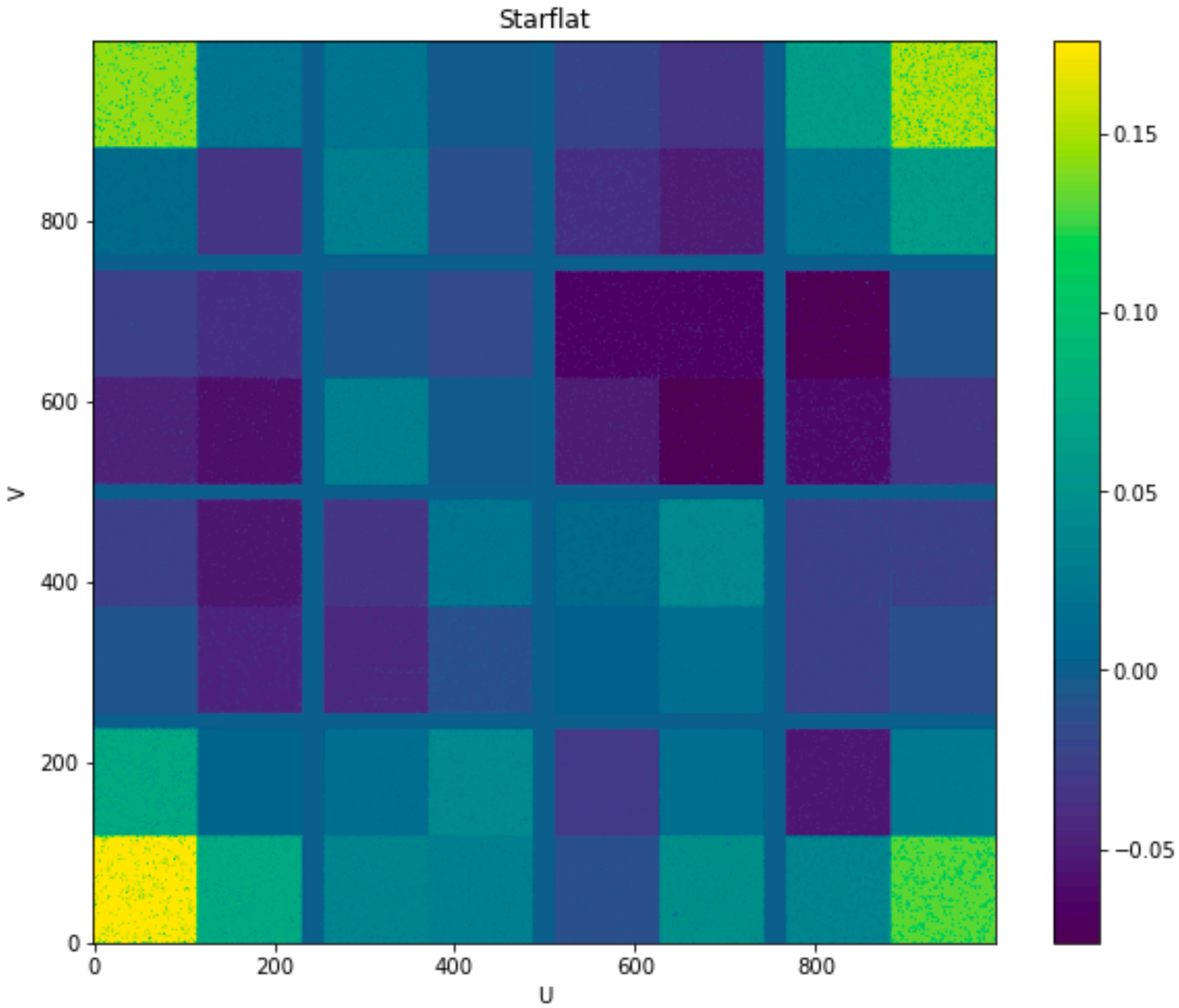


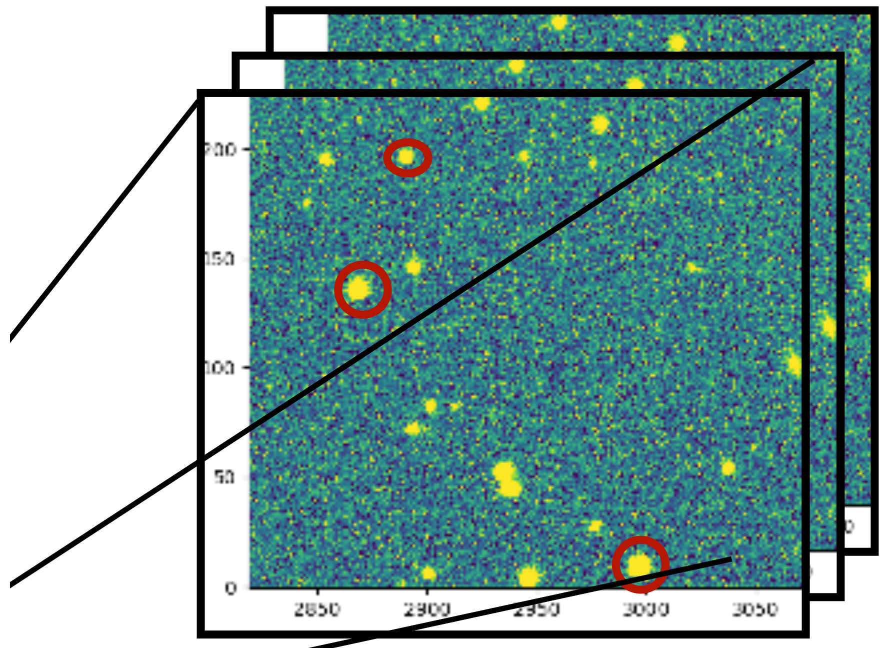
Starflat : flux variation of a star depending on its position on the camera

Starflat procedure







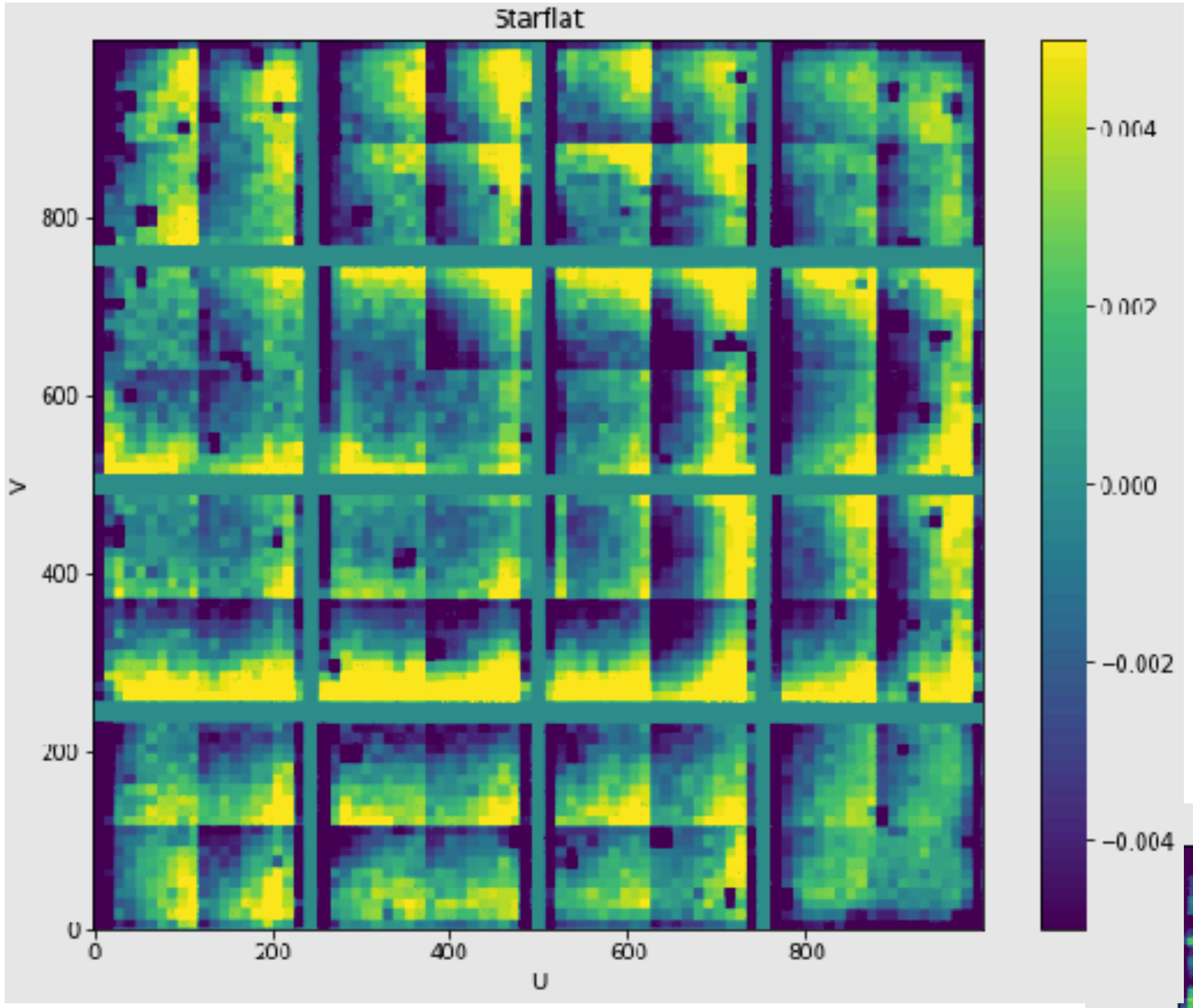


Starflat : flux variation of a star depending on its position on the camera

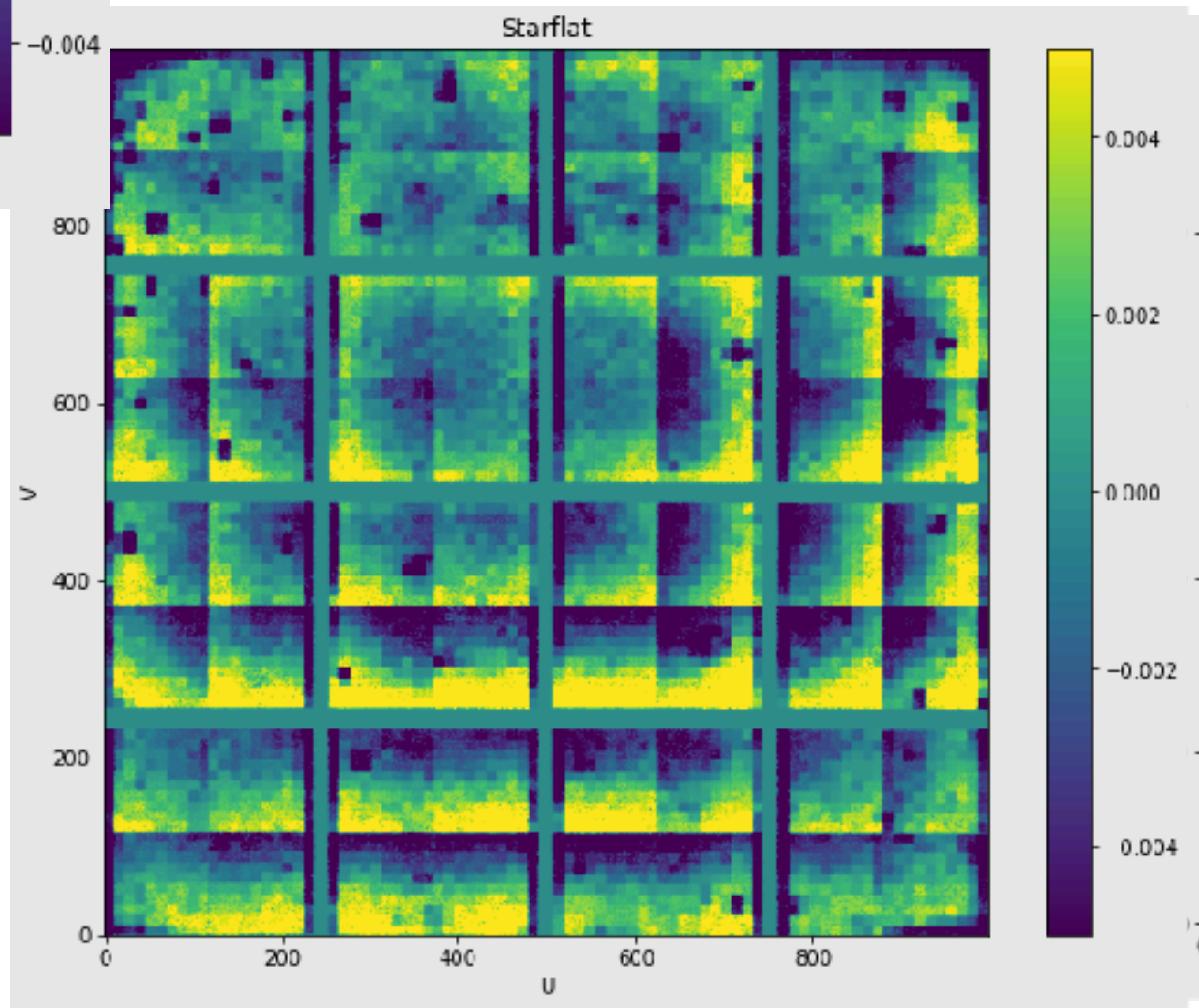
Gain subtracted: superpix = 10*10

g band
aperture photometry

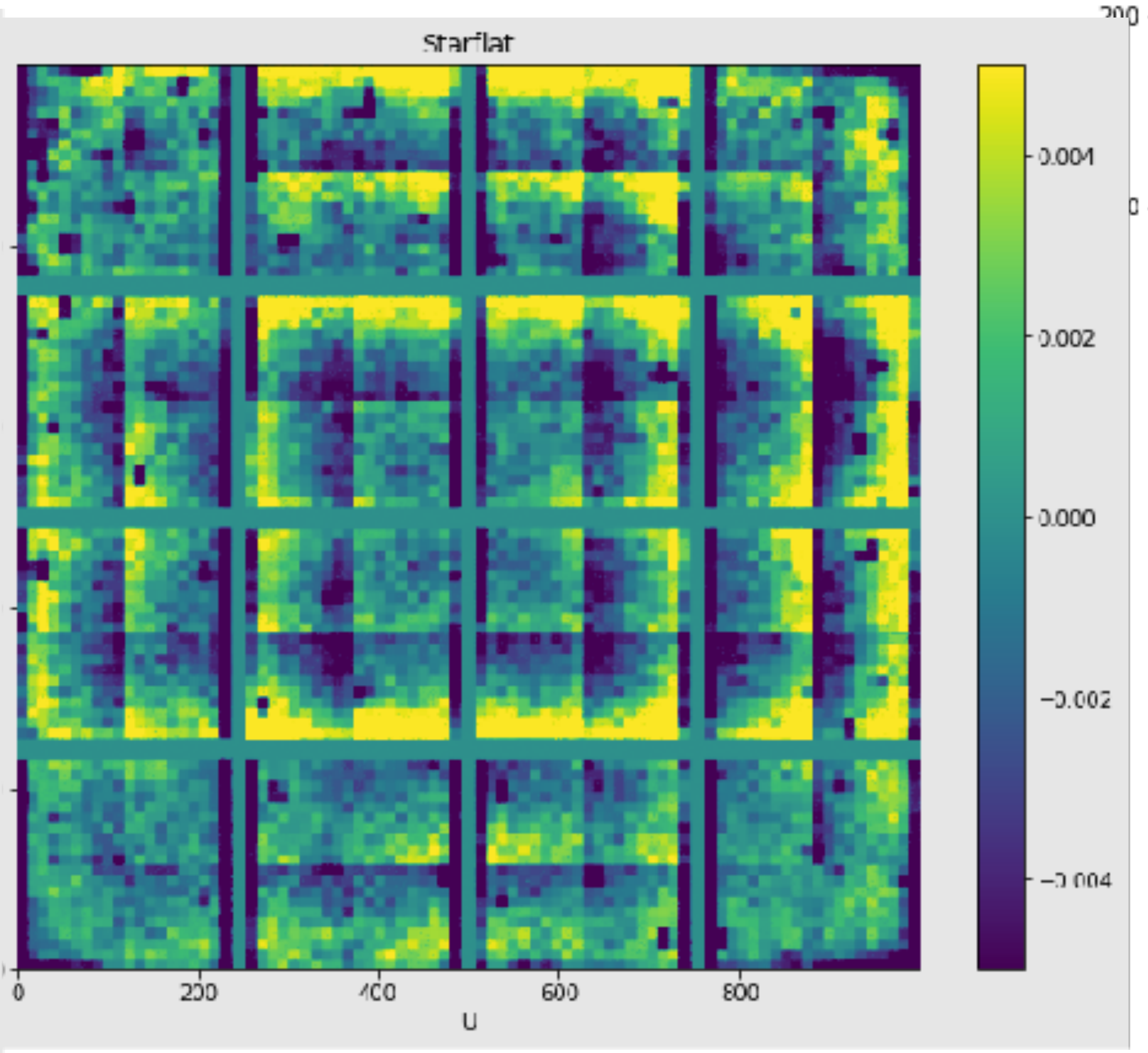
$$m_{ADU} = m + \delta ZP(x)$$



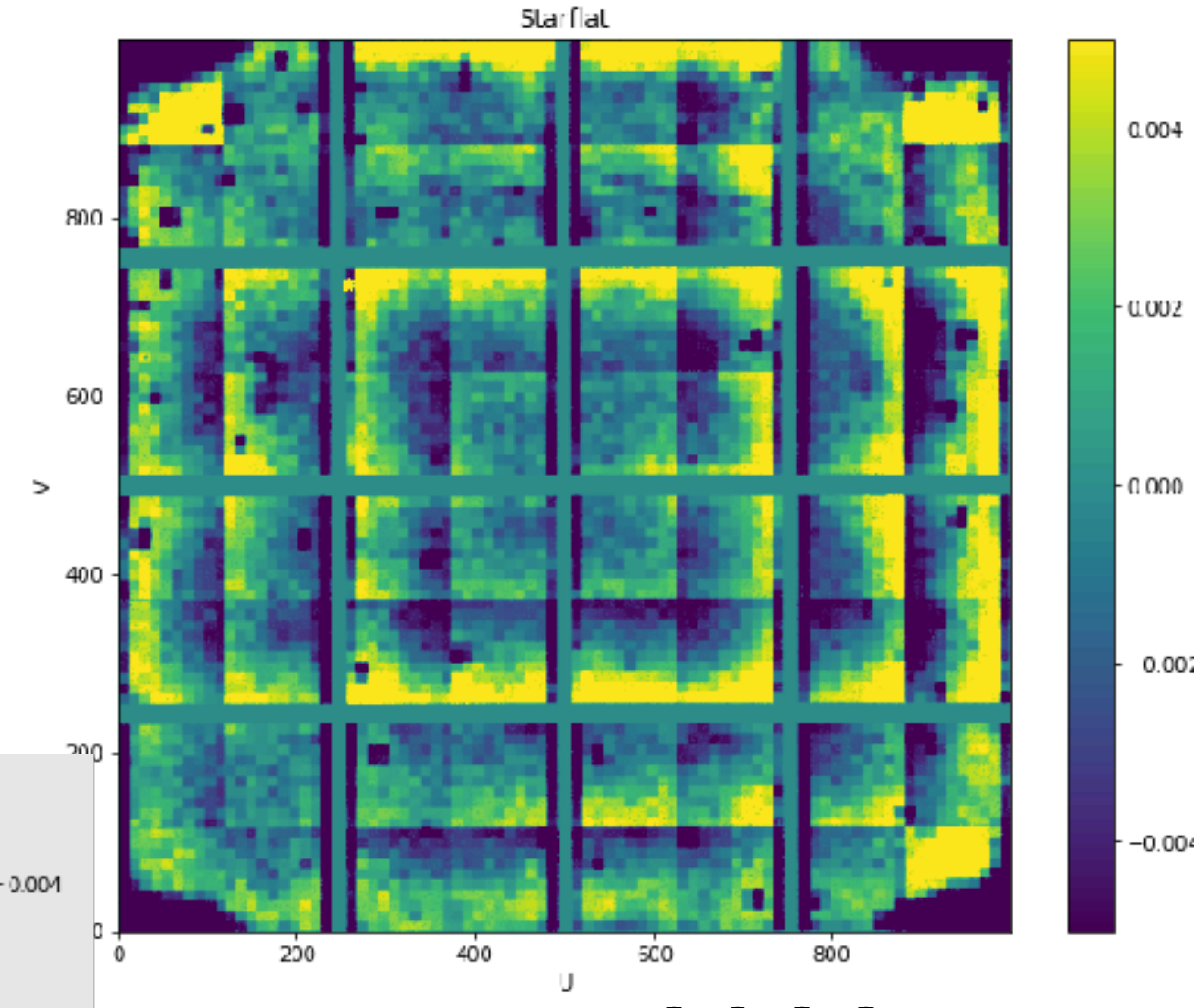
2018



2019



2021

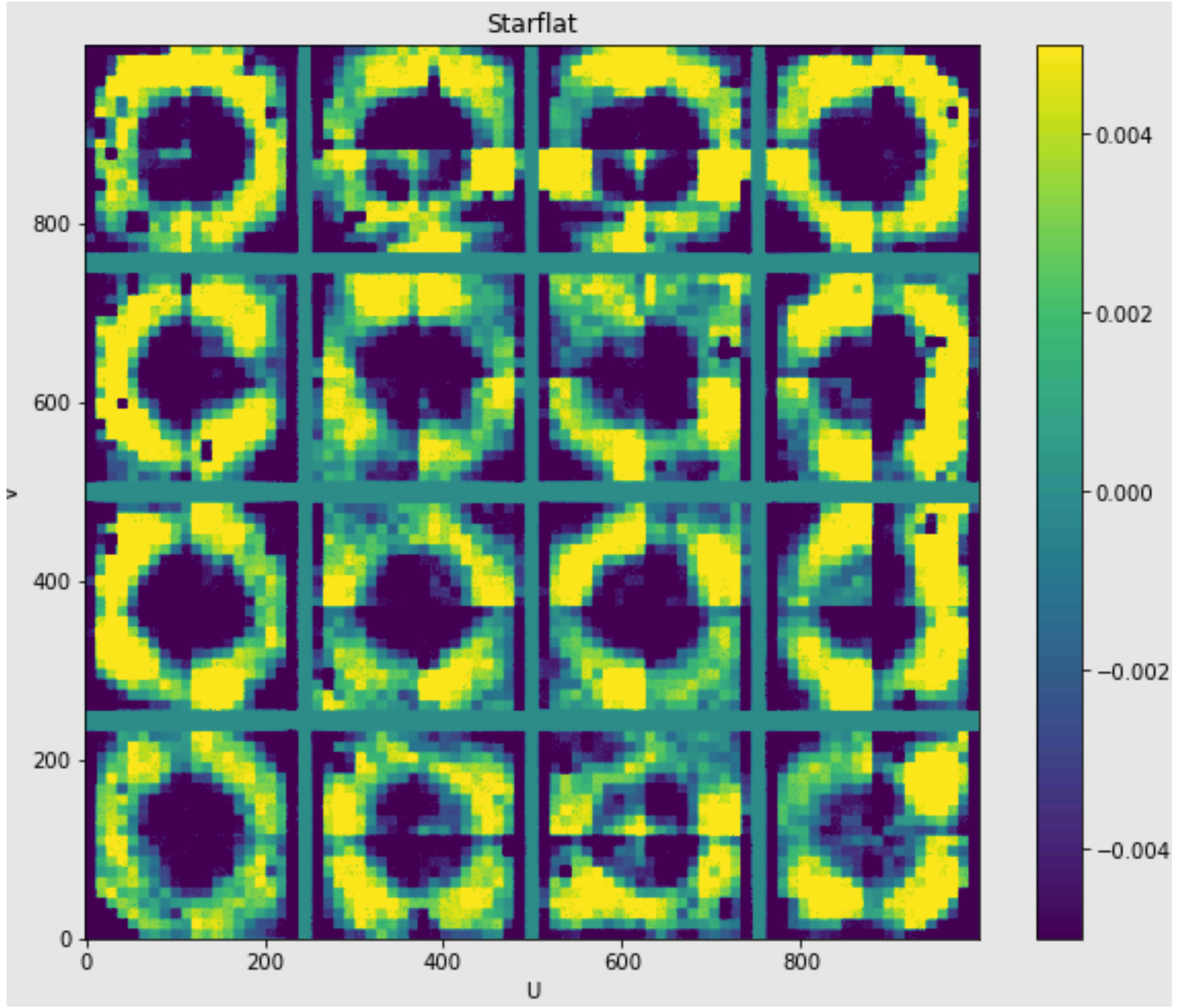


2022

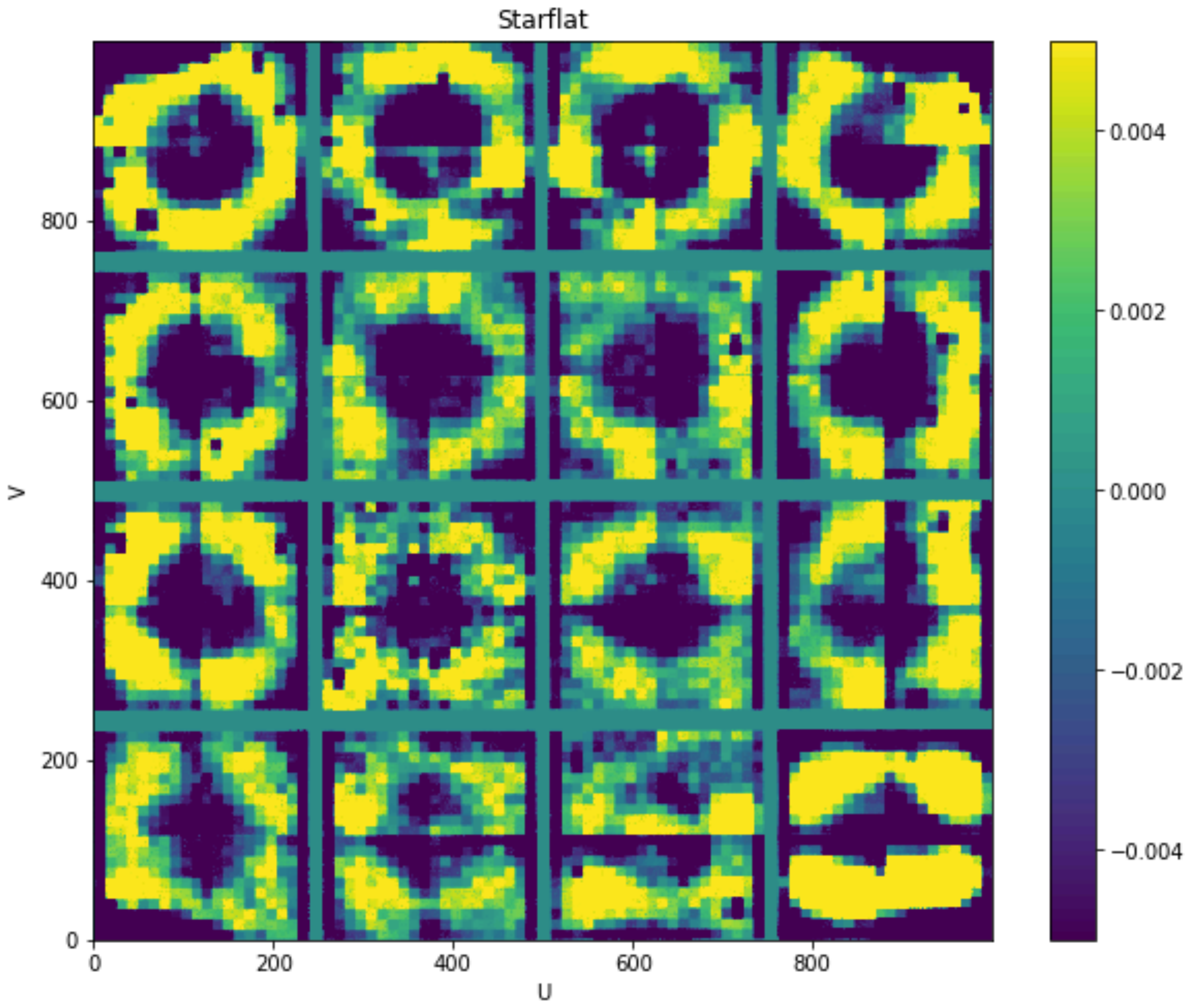
Gain subtracted: superpix = 10*10

g band
ZTF PSF

$$m_{ADU} = m + \boxed{\delta ZP(x)}$$



2021

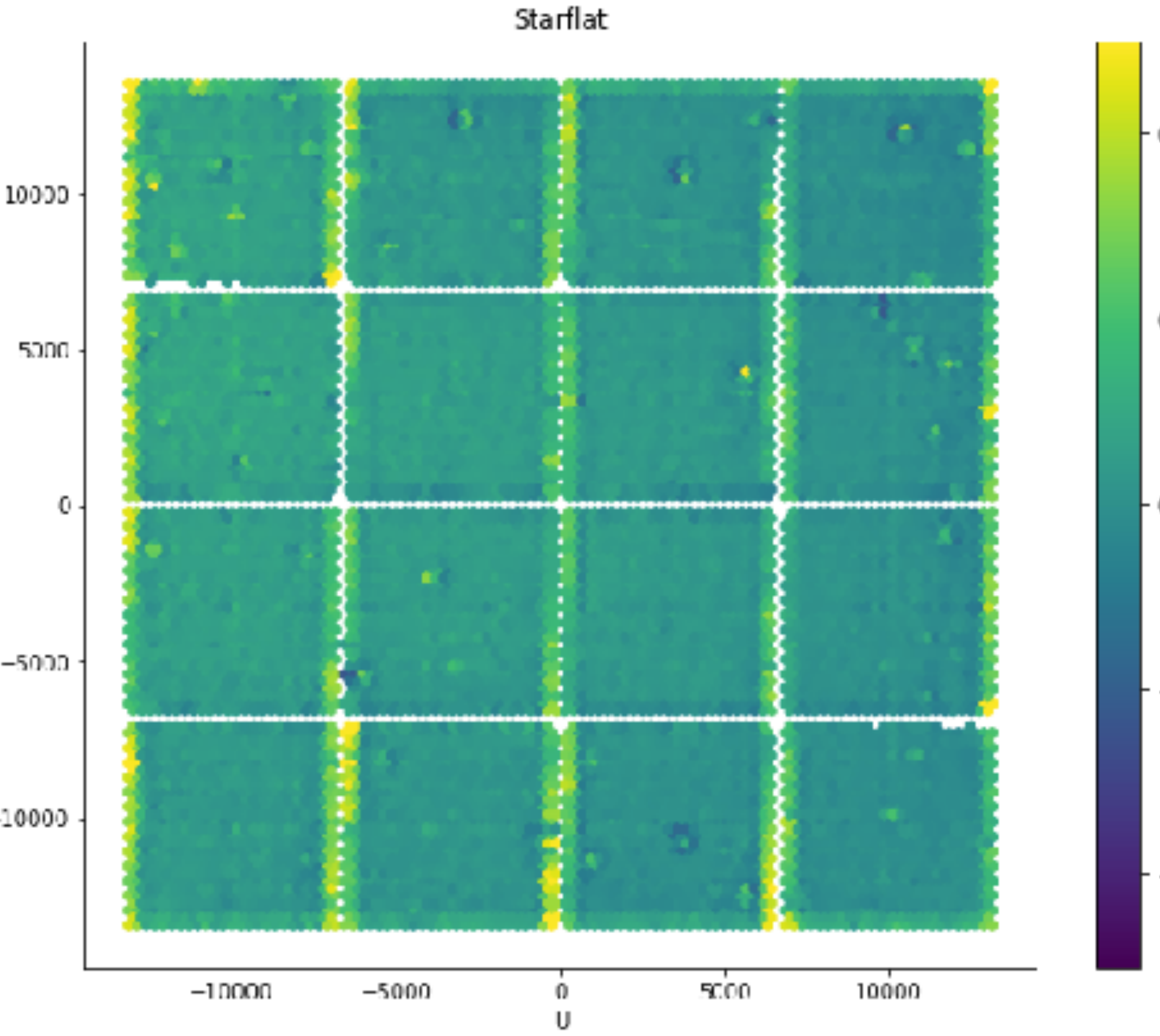


2022

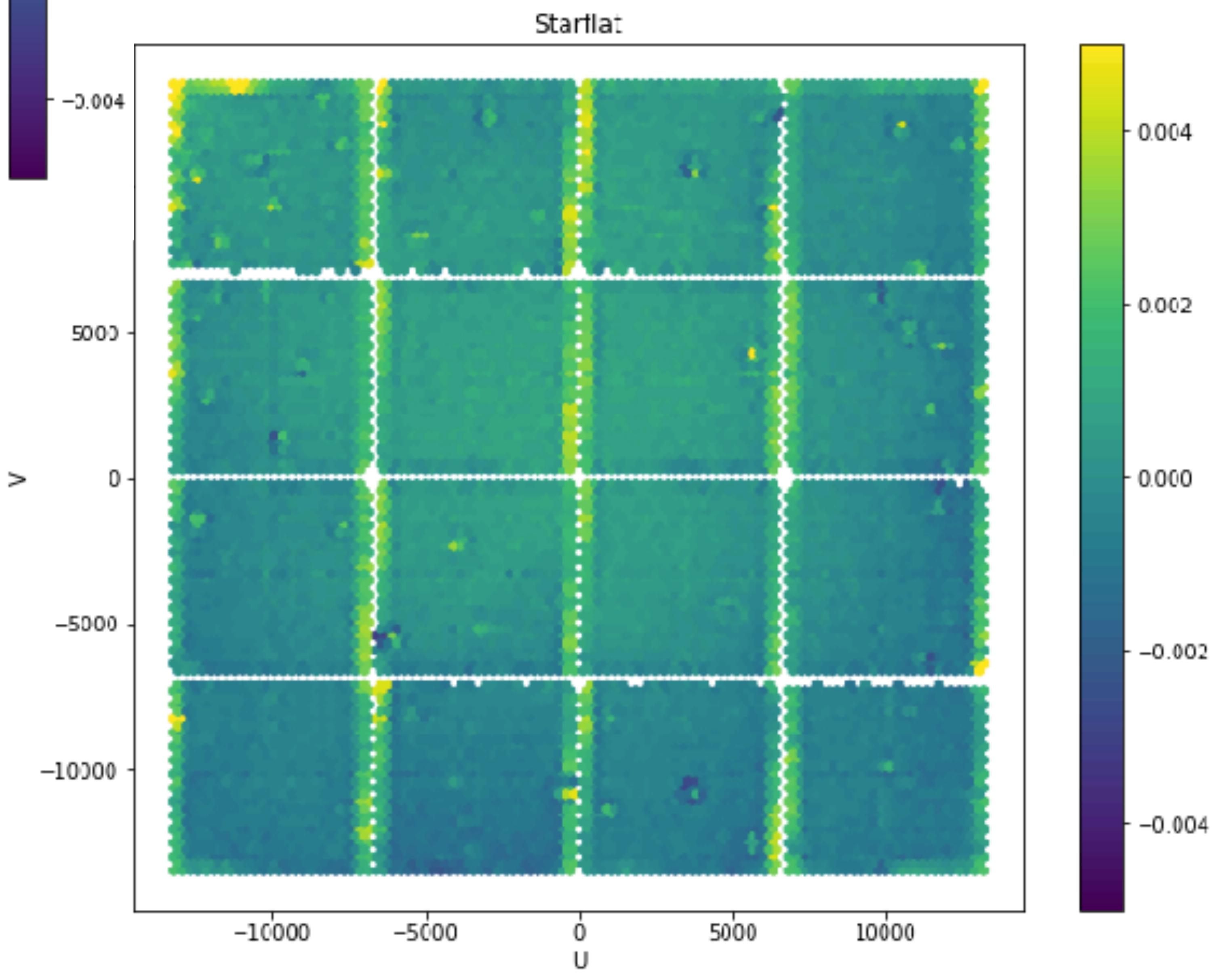
After iteration, gain subtracted: superpix = 10*10

g band
aperture photometry

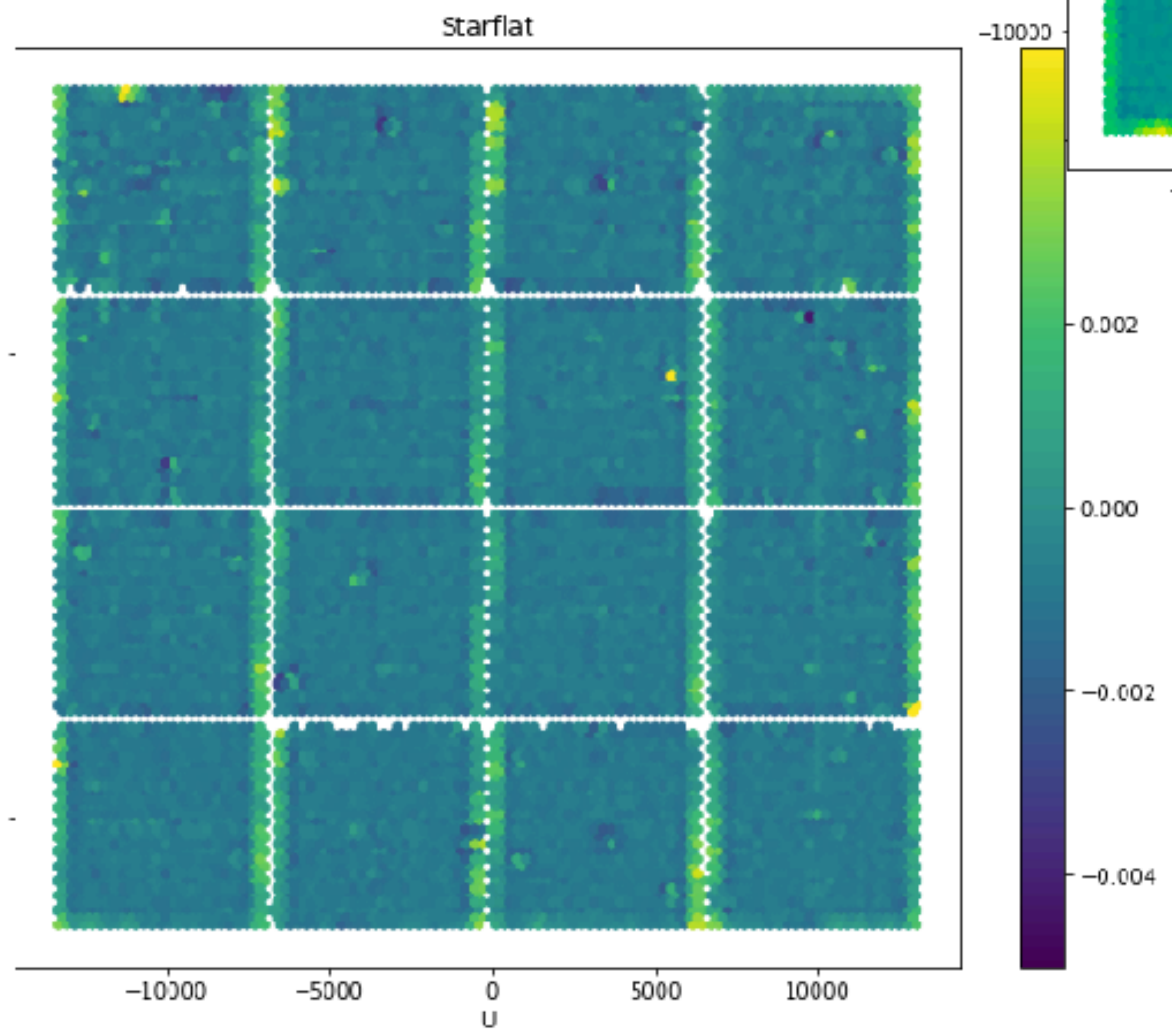
$$m_{ADU} = m + \delta ZP(x)$$



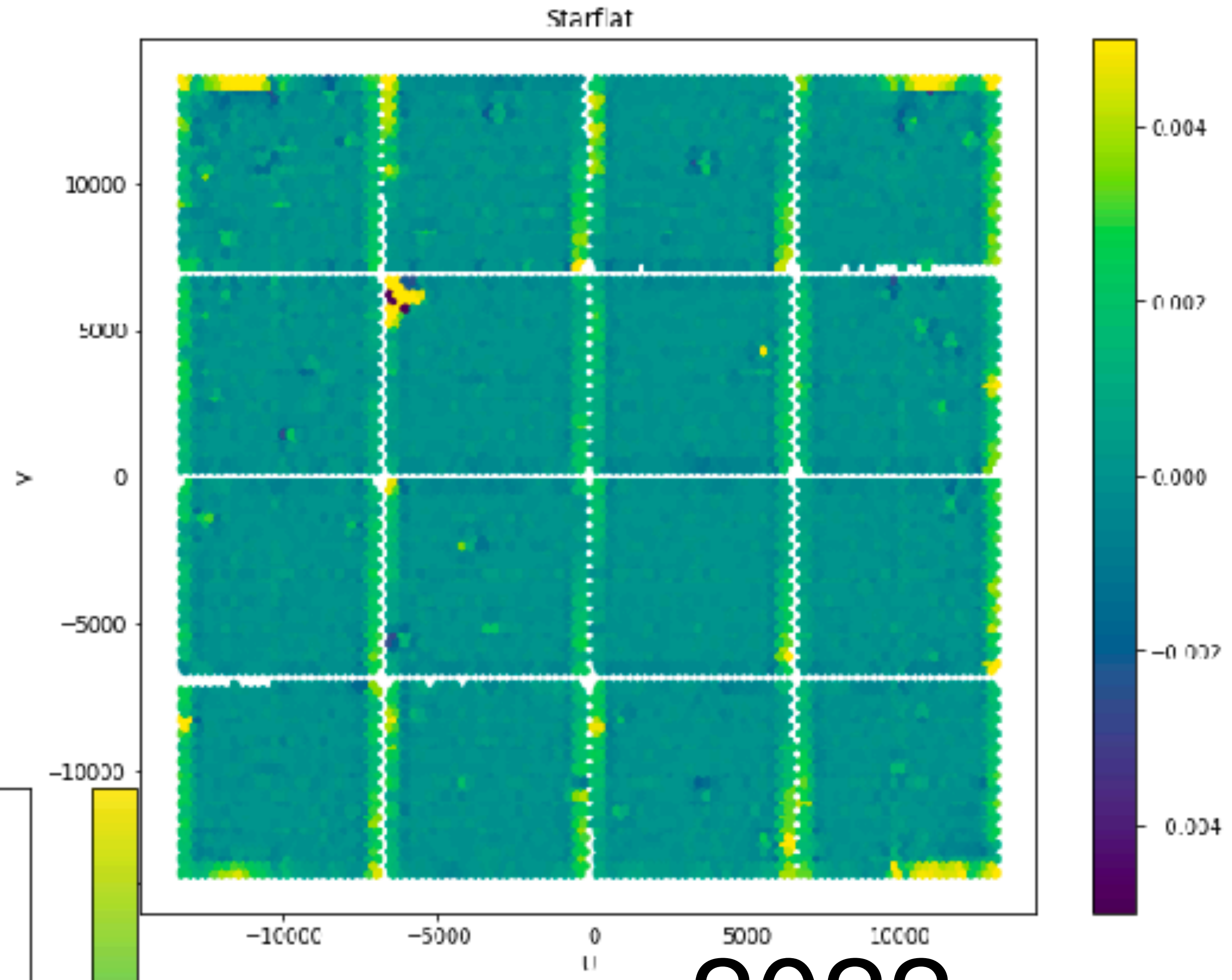
2018



2019



2021



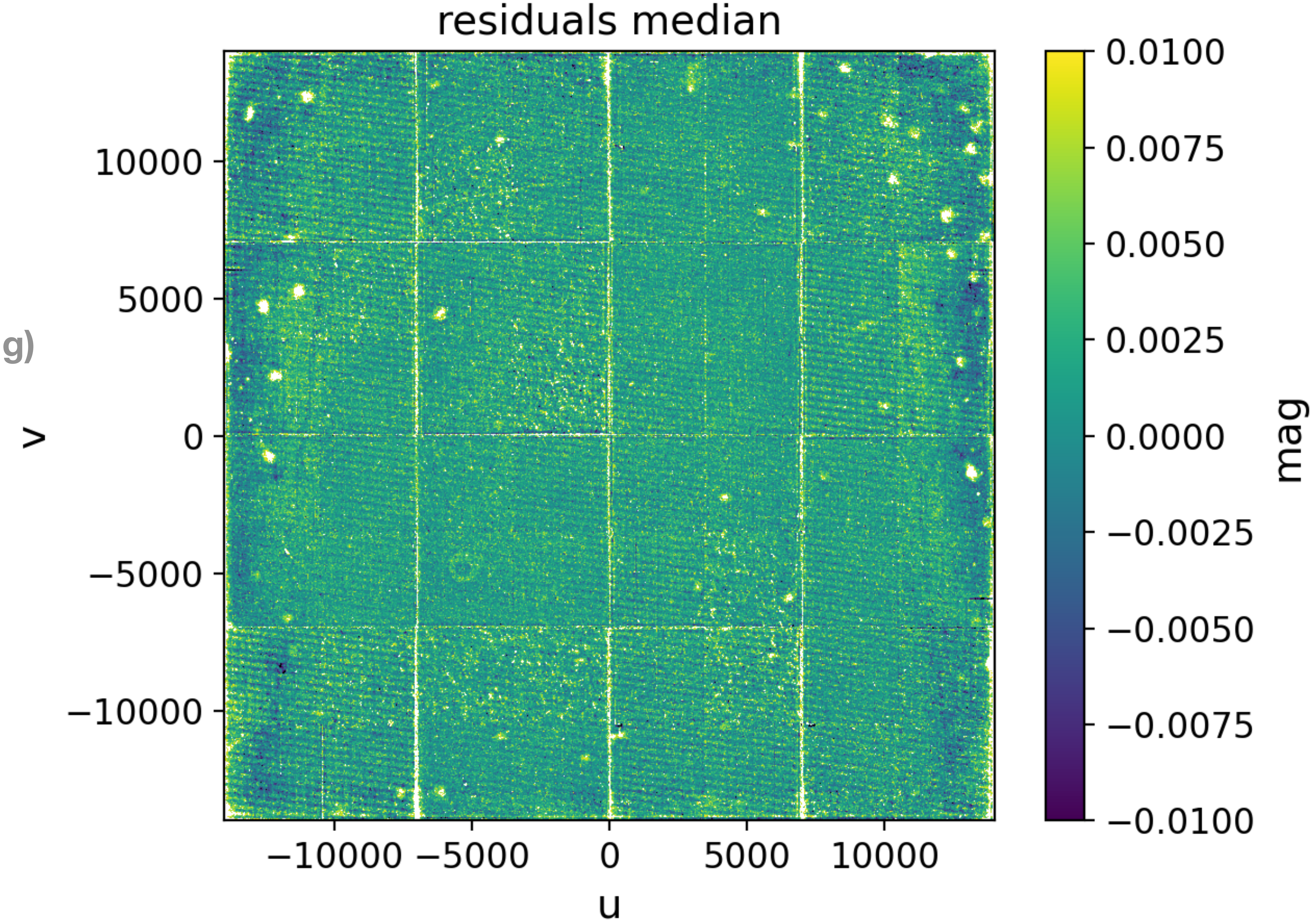
2022

Back to ubercal

ZTF-g

Fit
1 zero point
per quadrant
(if secondary pointing)

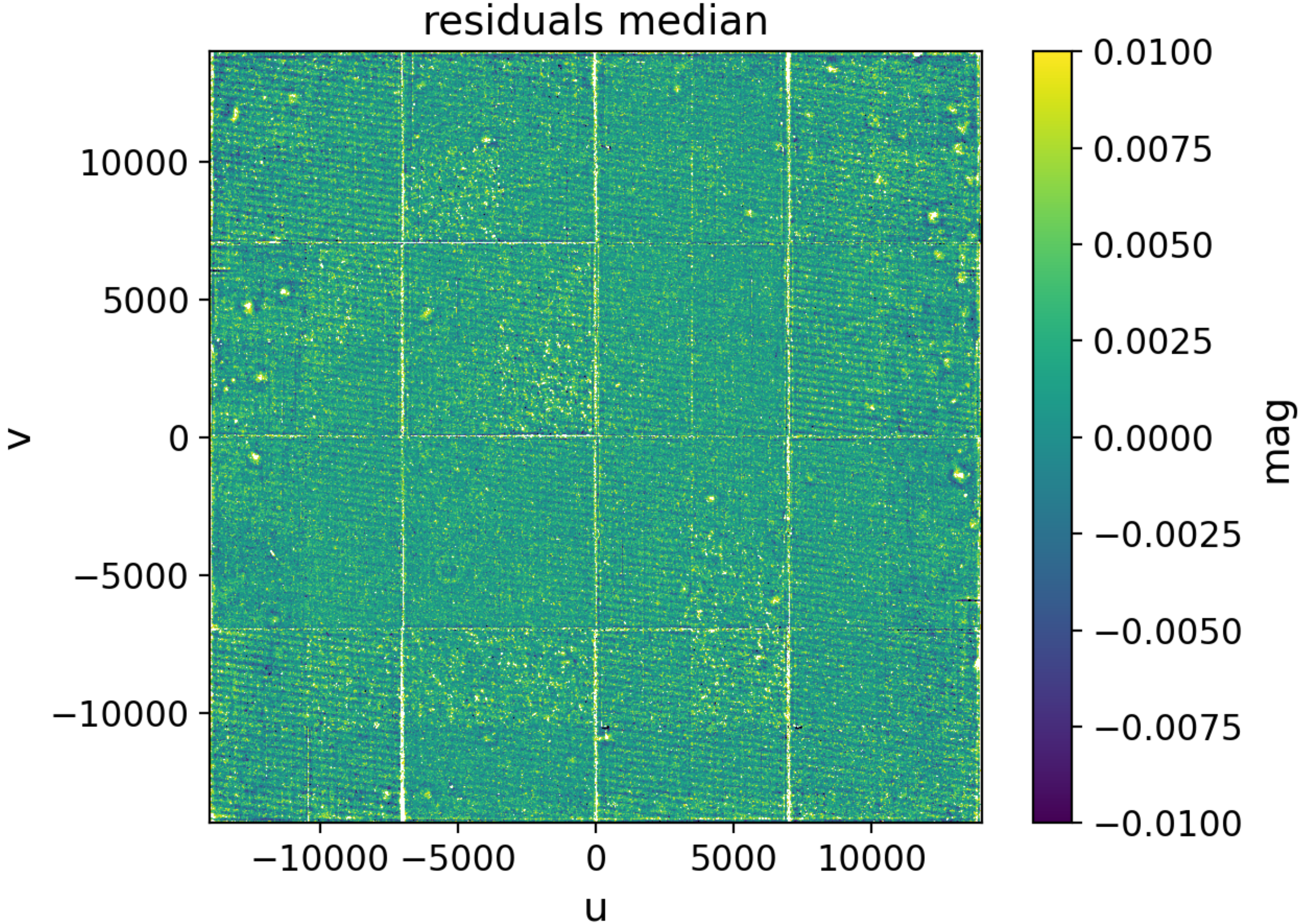
Much flatter residuals

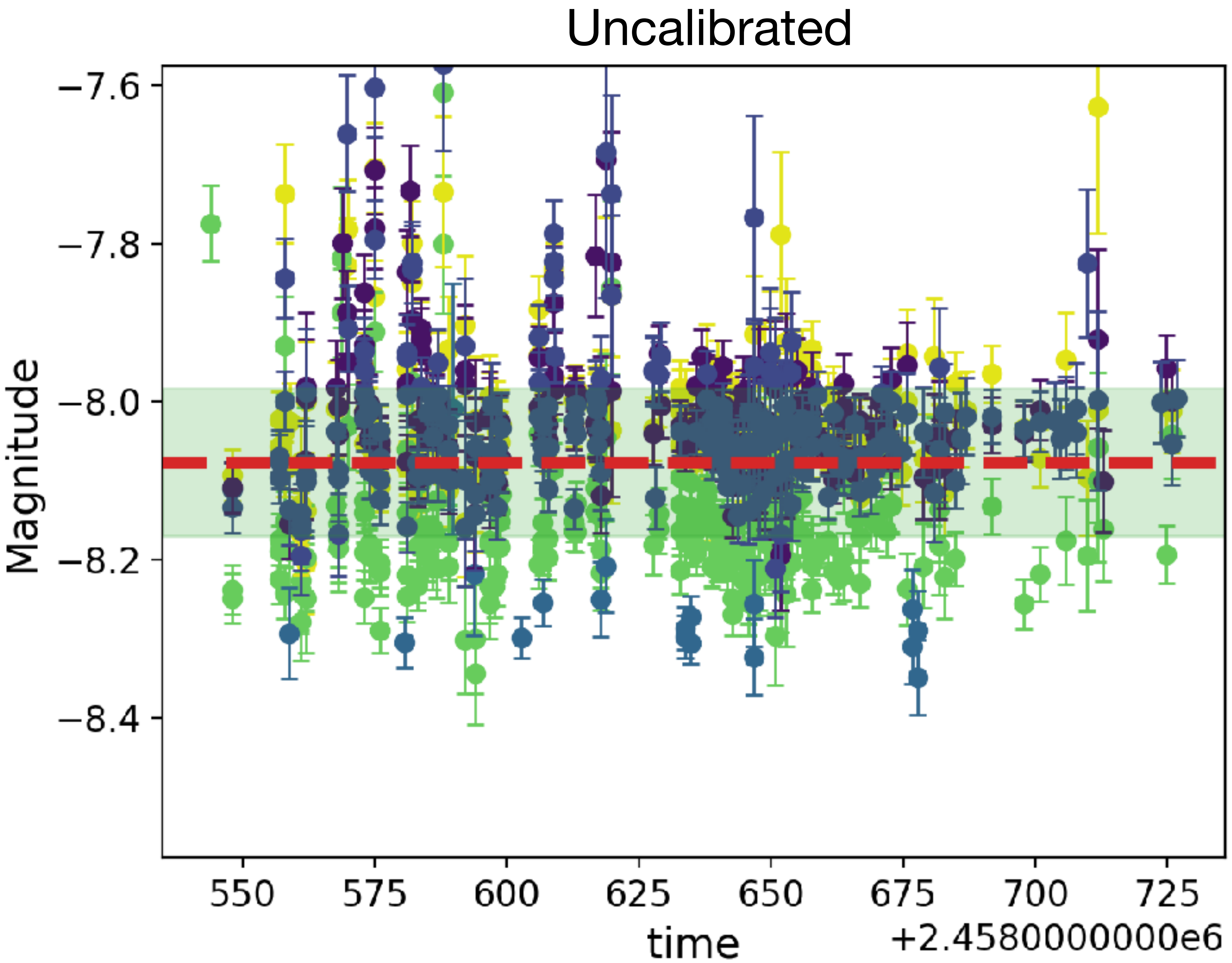


ZTF-g

Fit
1 zero point
per quadrant
(if secondary pointing)
With starflat correction

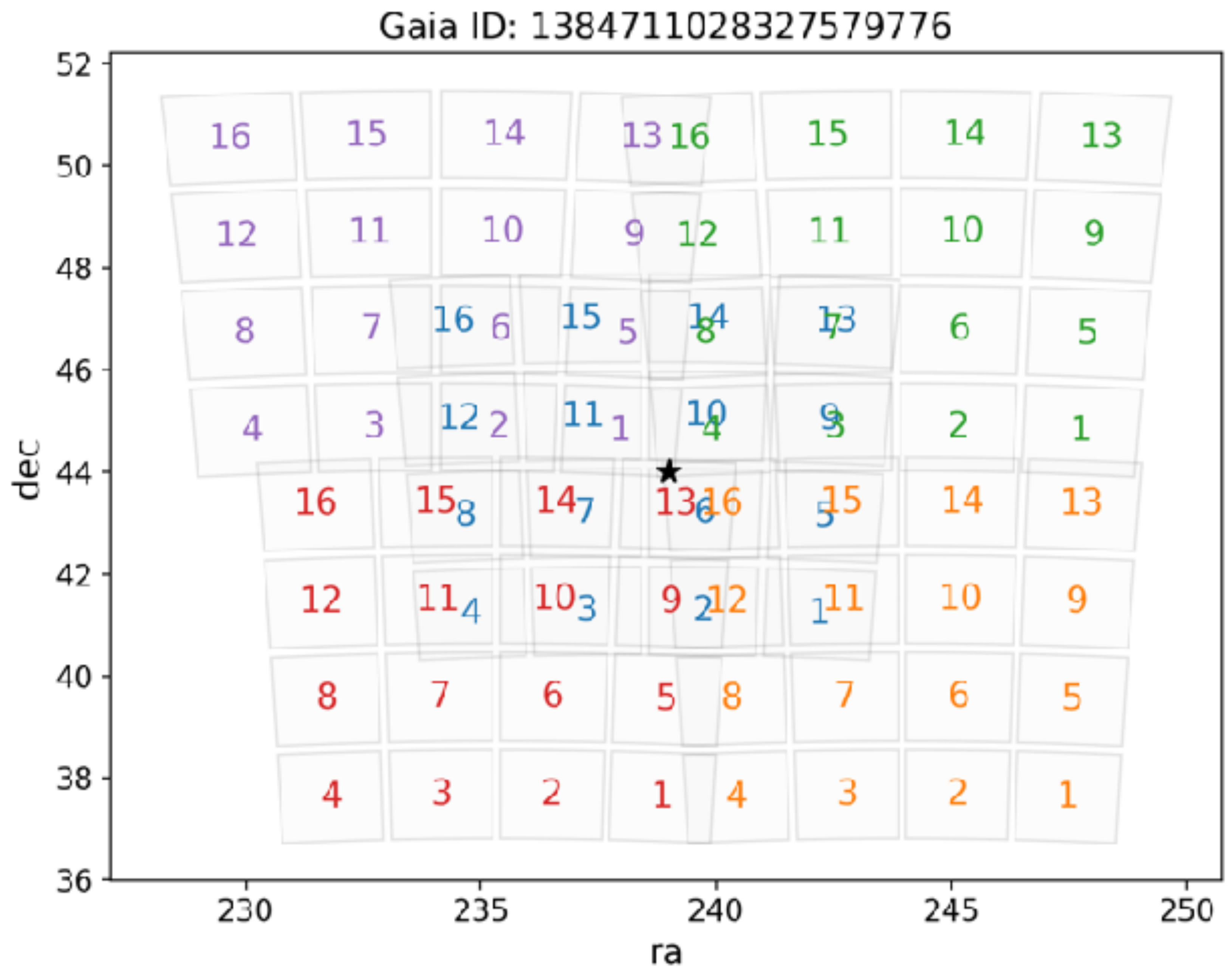
Even flatter residuals

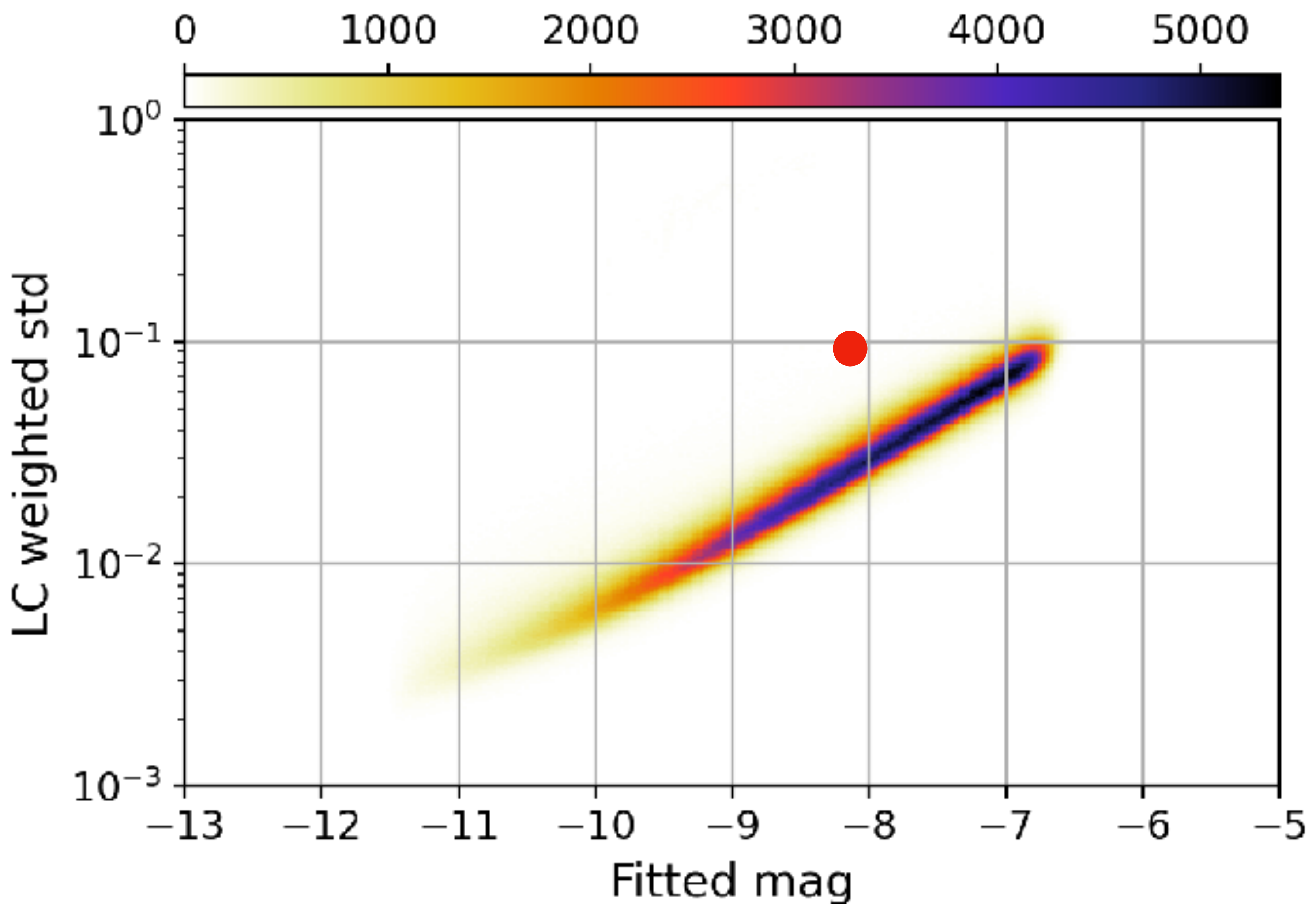


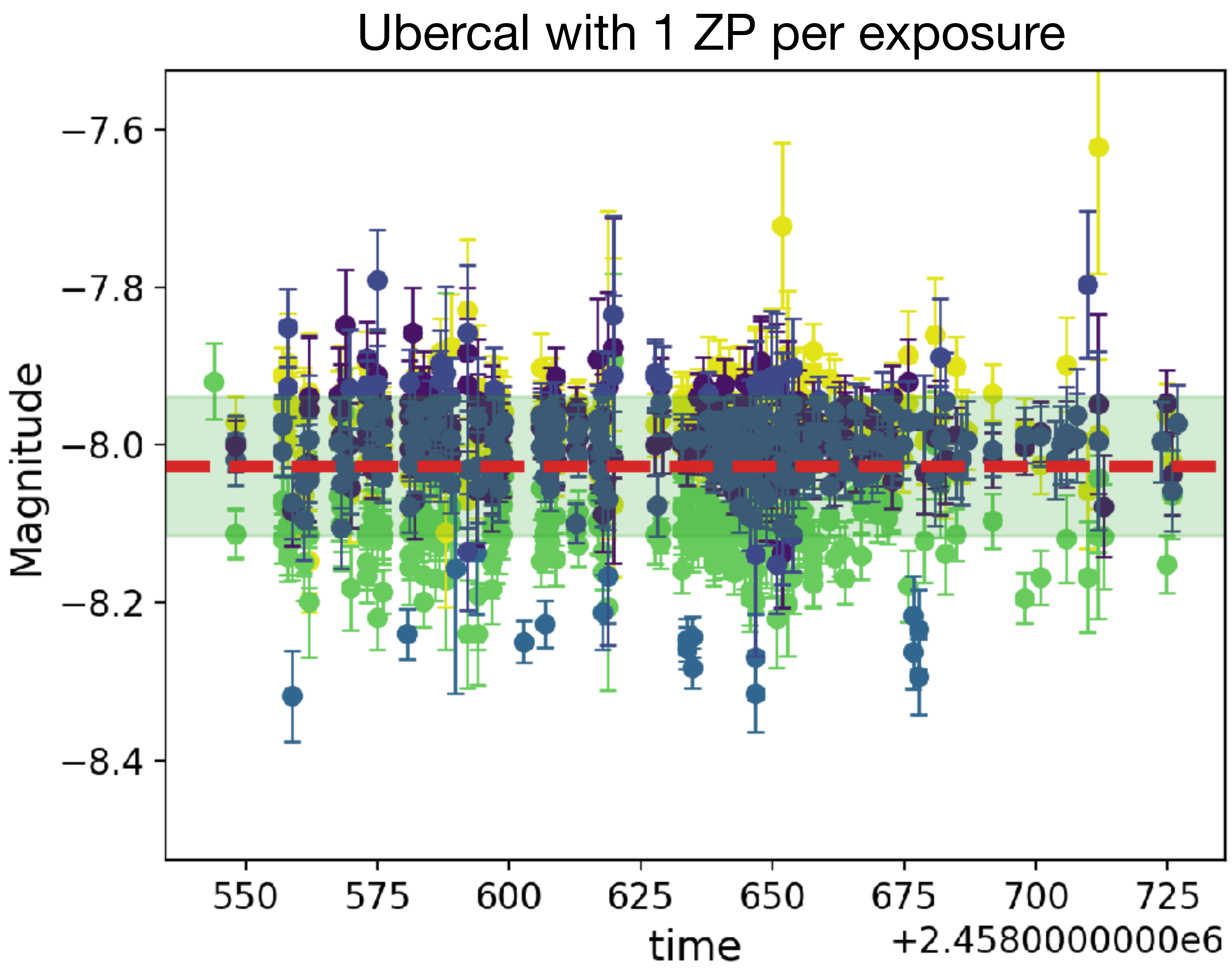


(Days)

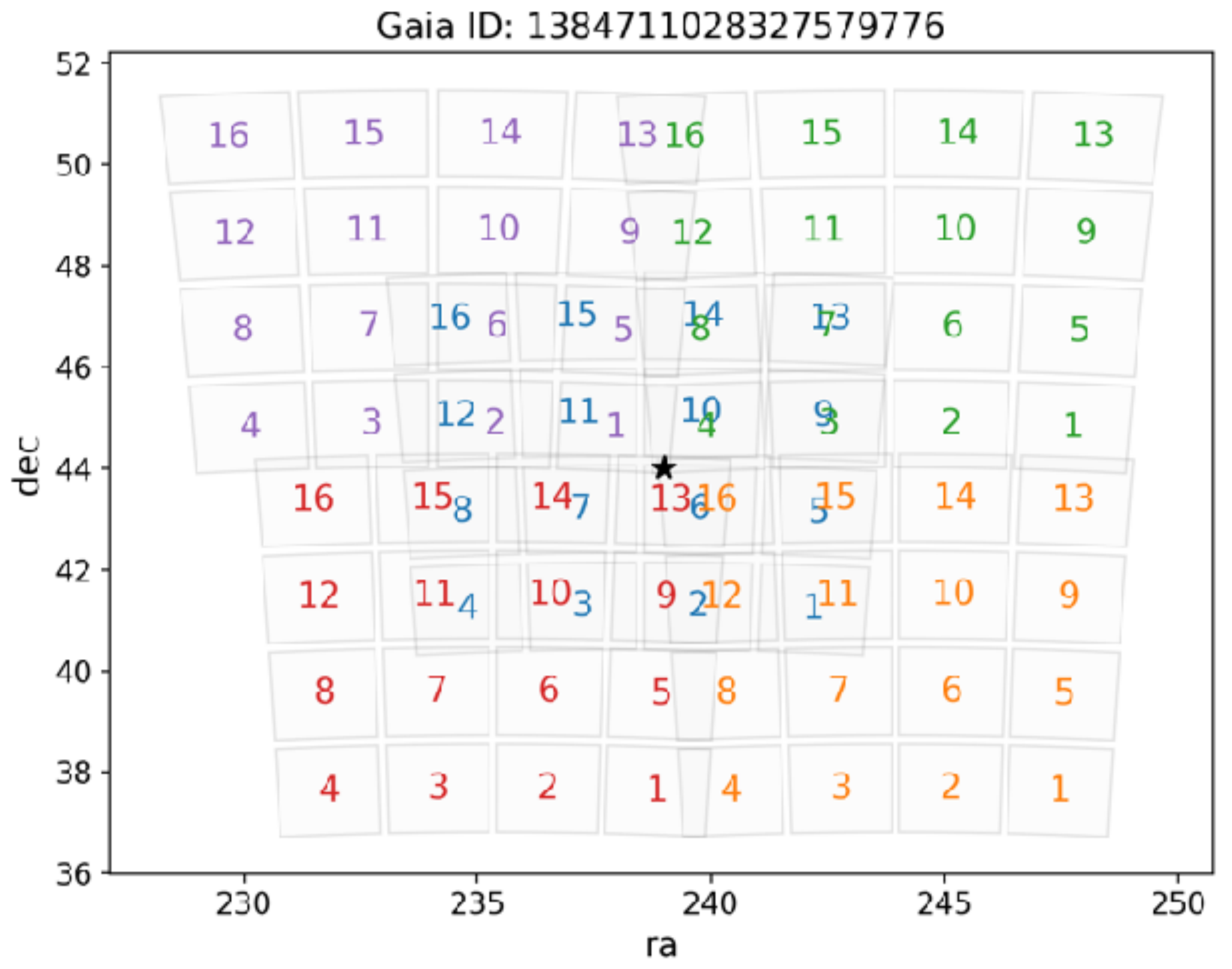
std=0.093

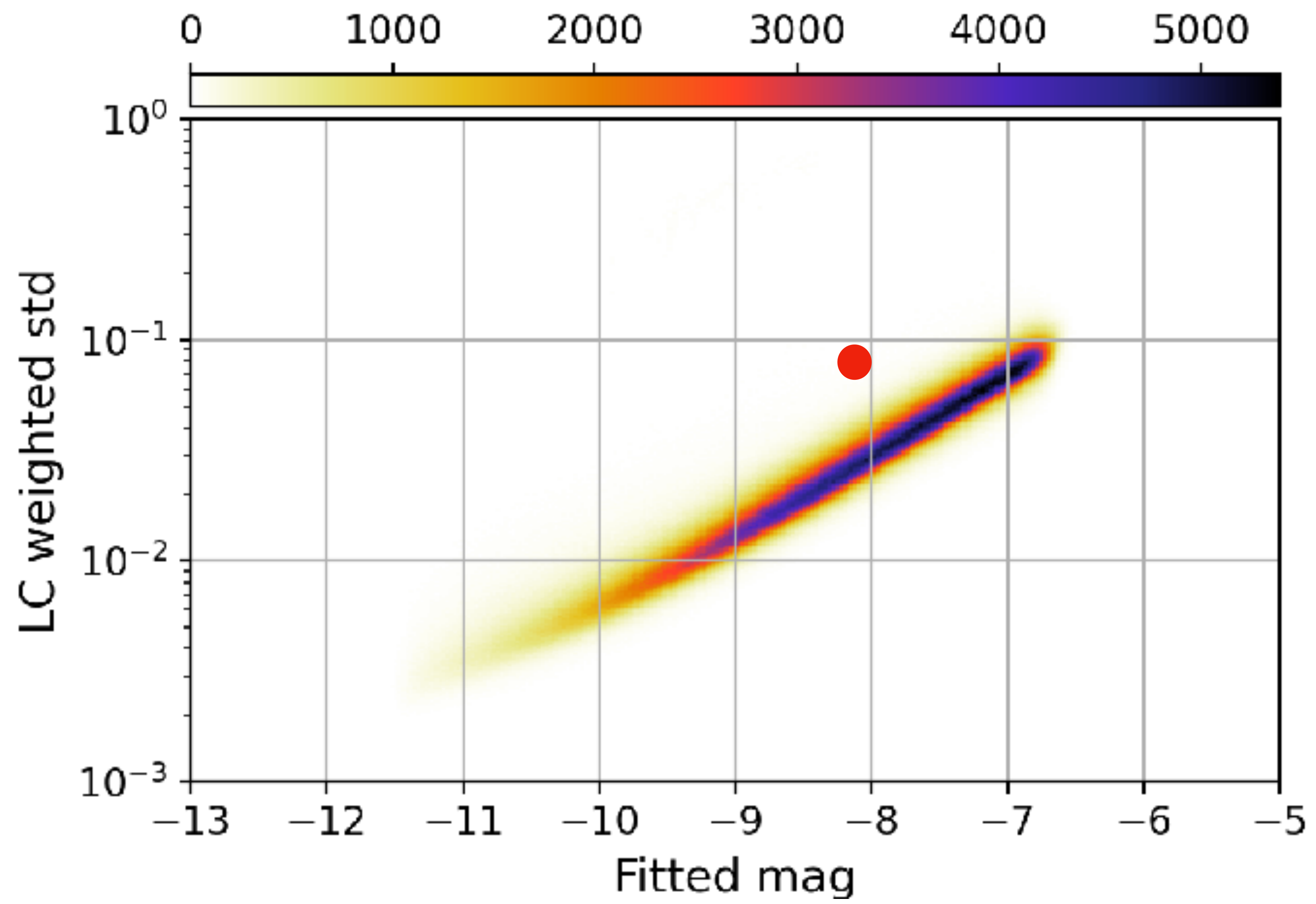




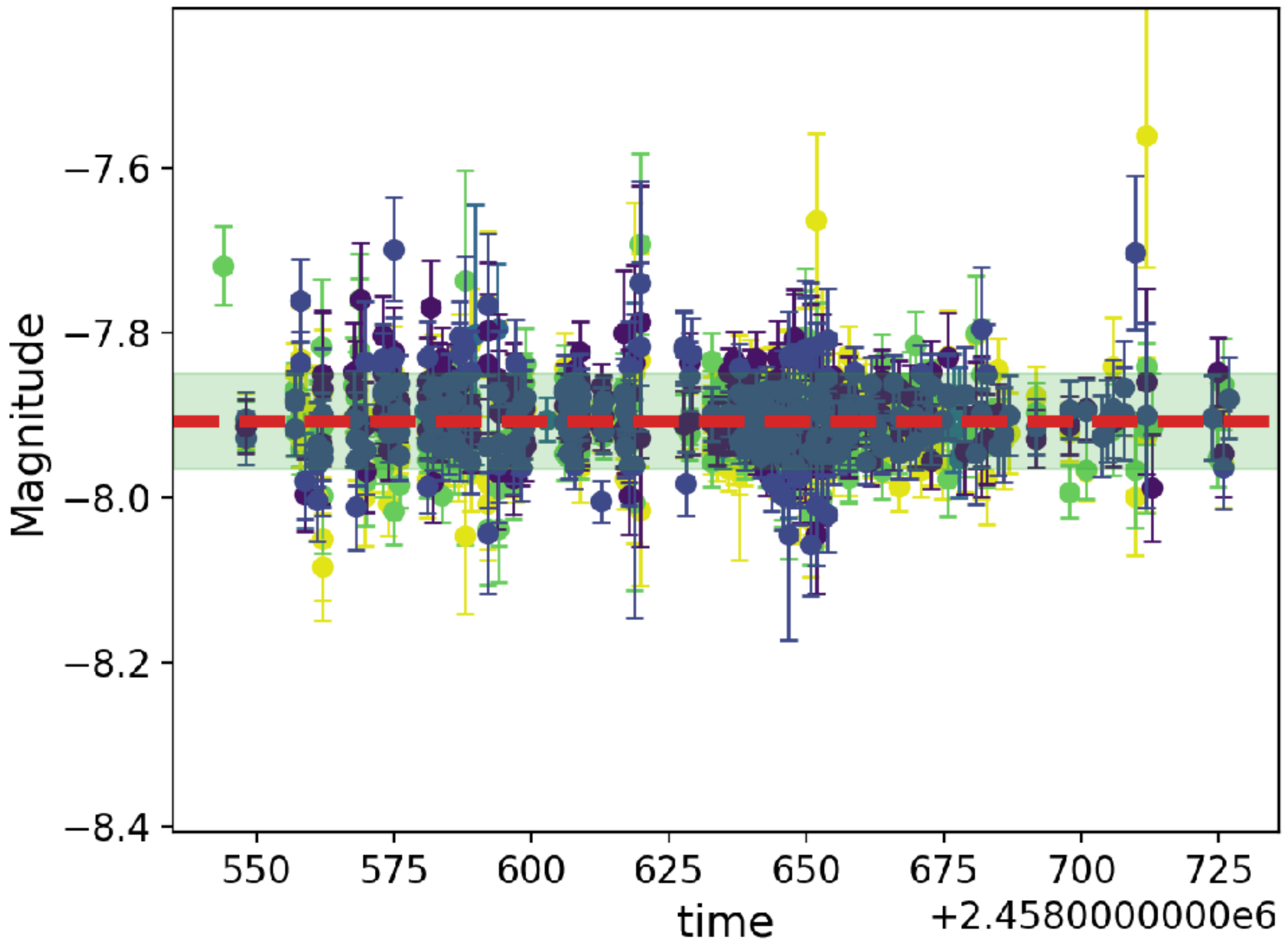

Ubercal with 1 ZP per exposure
Magnitude
time
+2.4580000000e6

std=0.088

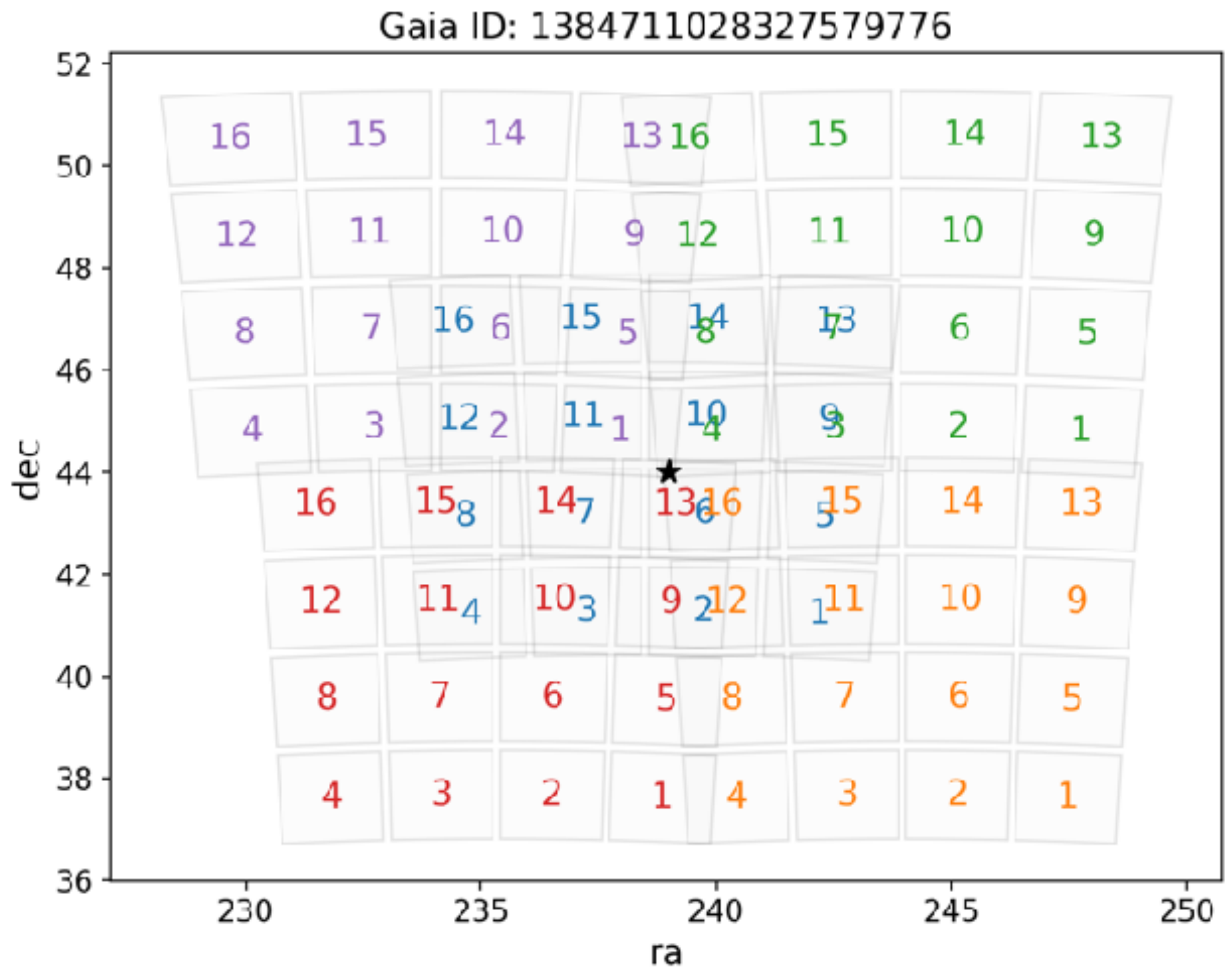

Gaia ID: 1384711028327579776
dec
ra

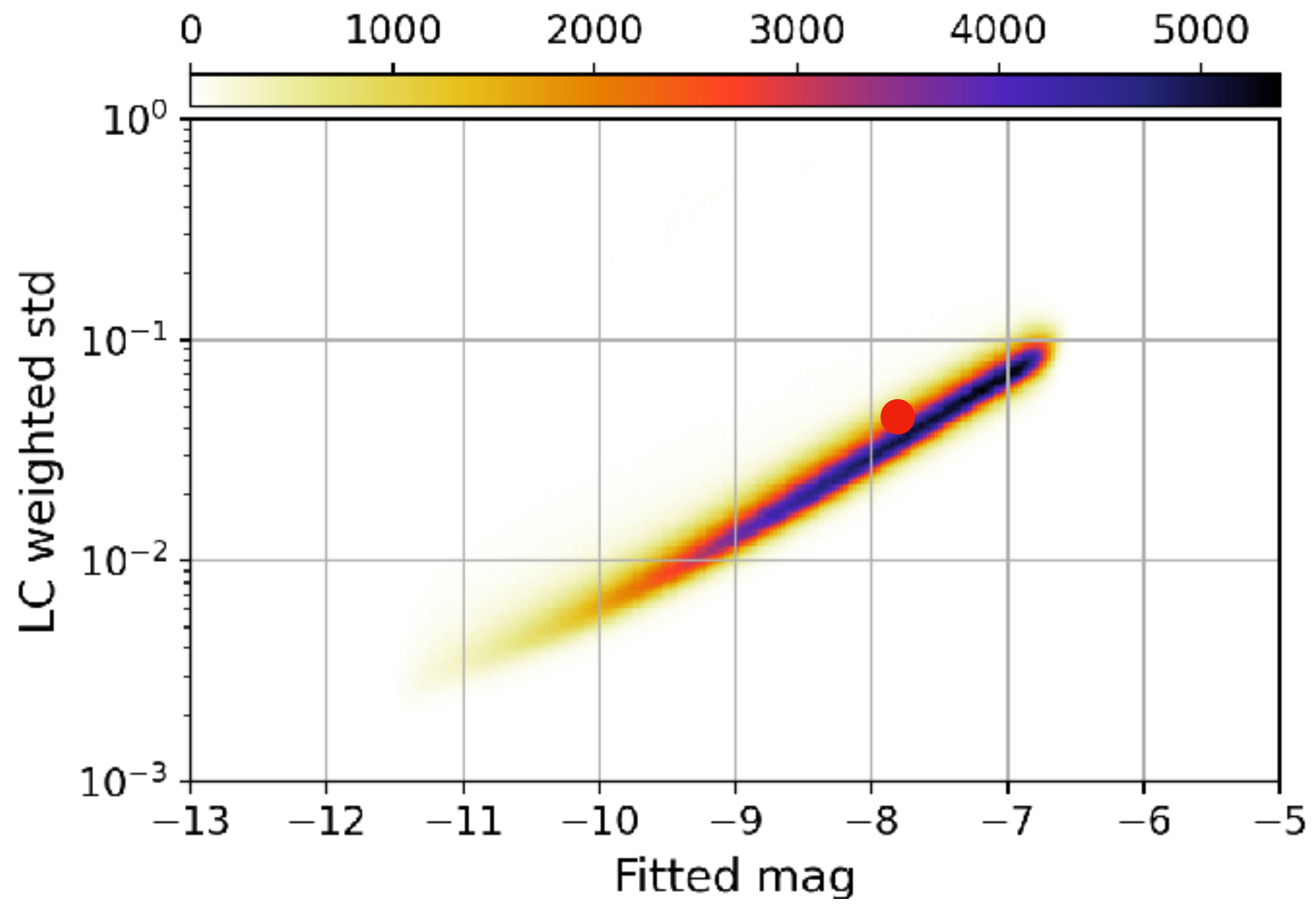

LC weighted std
Fitted mag

Ubercal with 1 ZP per exposure + starflats

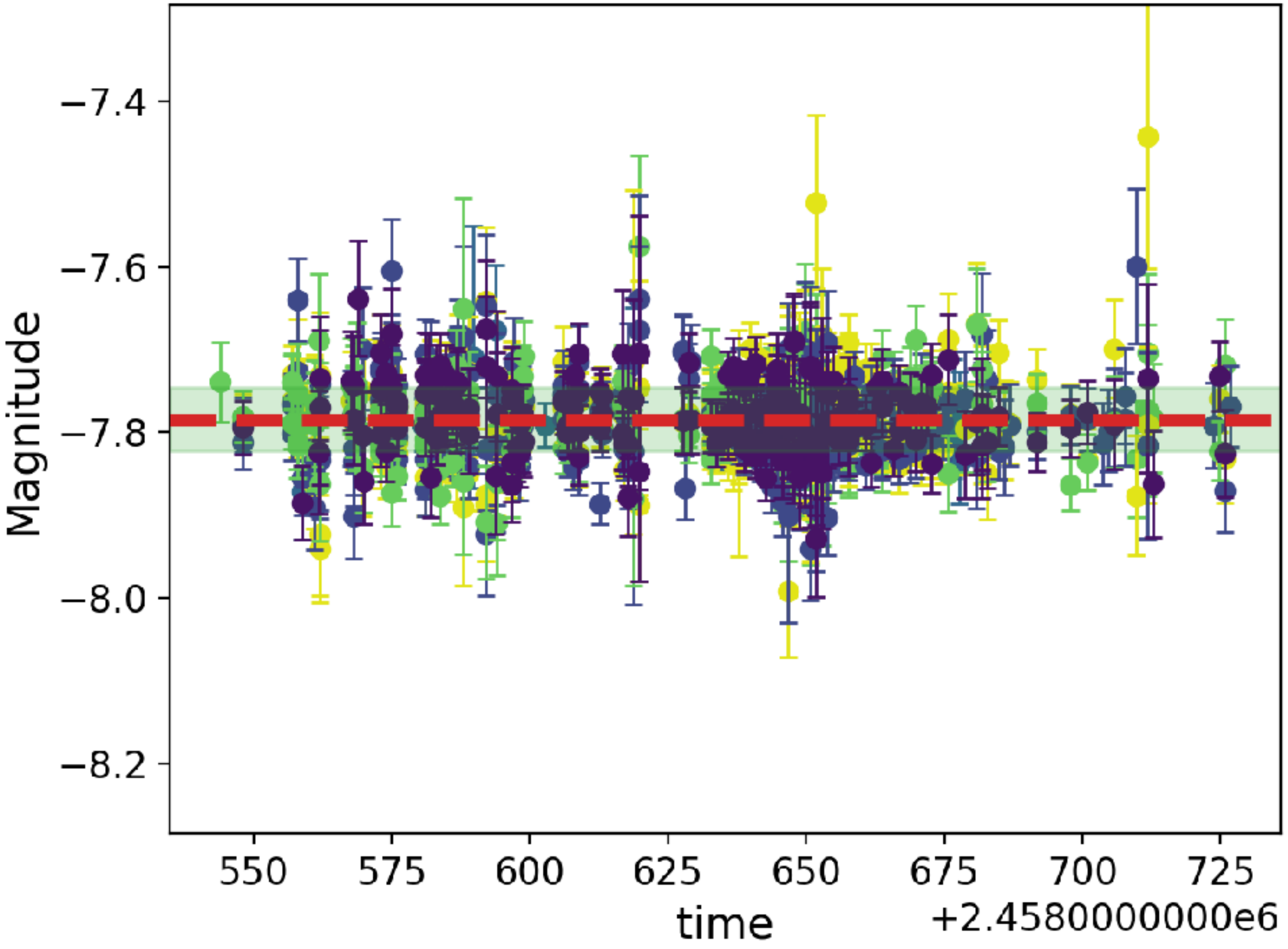


std=0.058

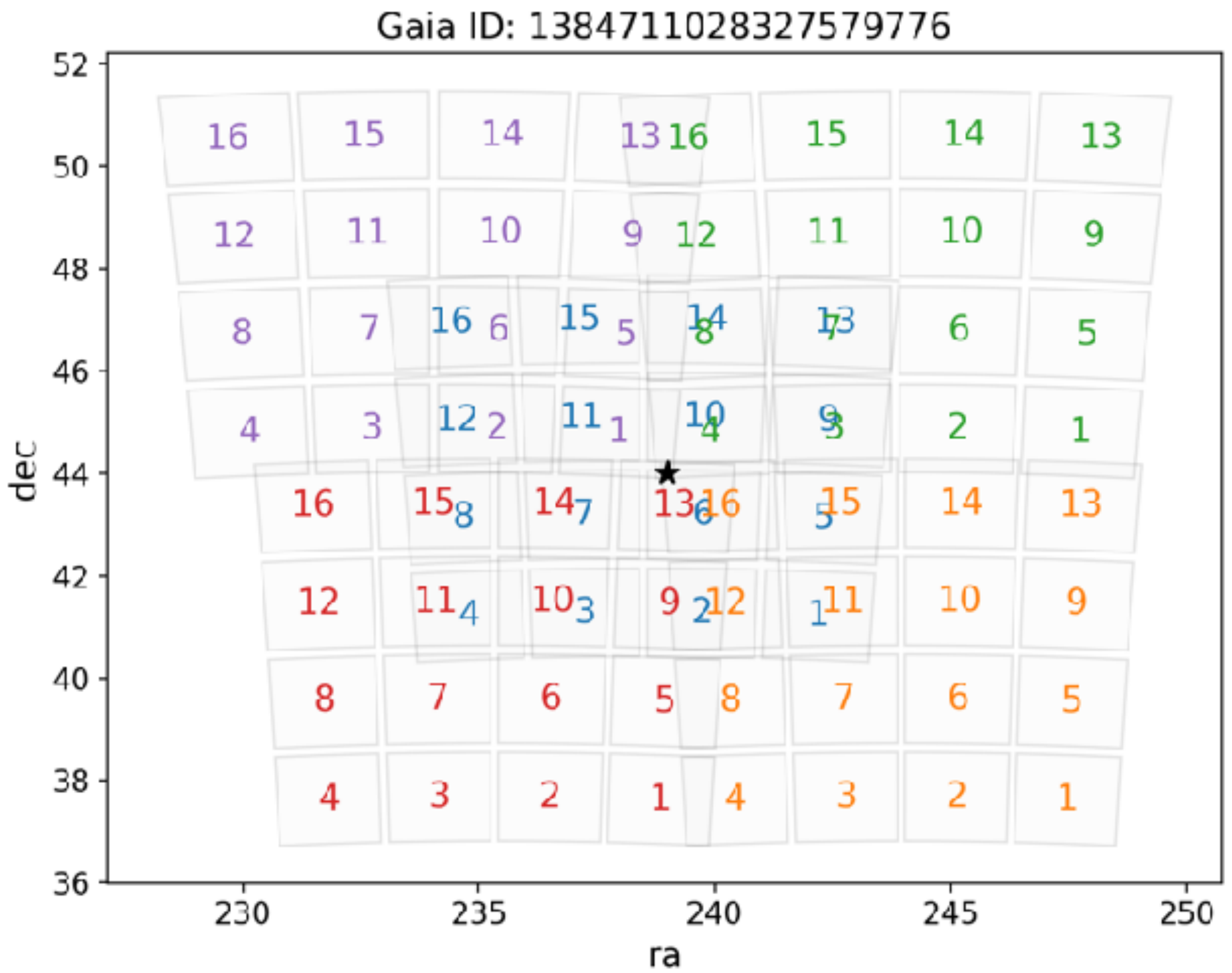


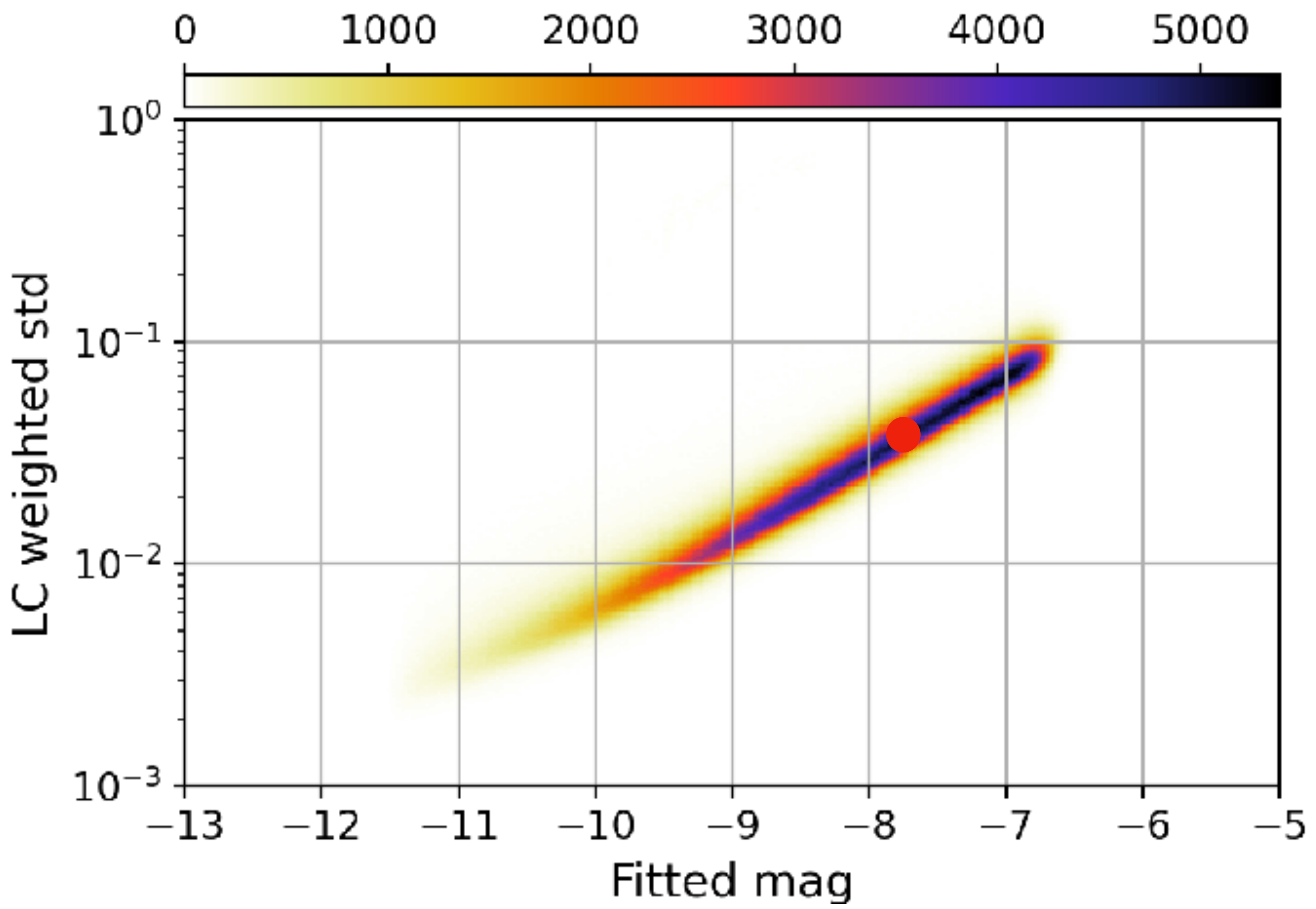


Ubercal with 1 ZP per quadrant

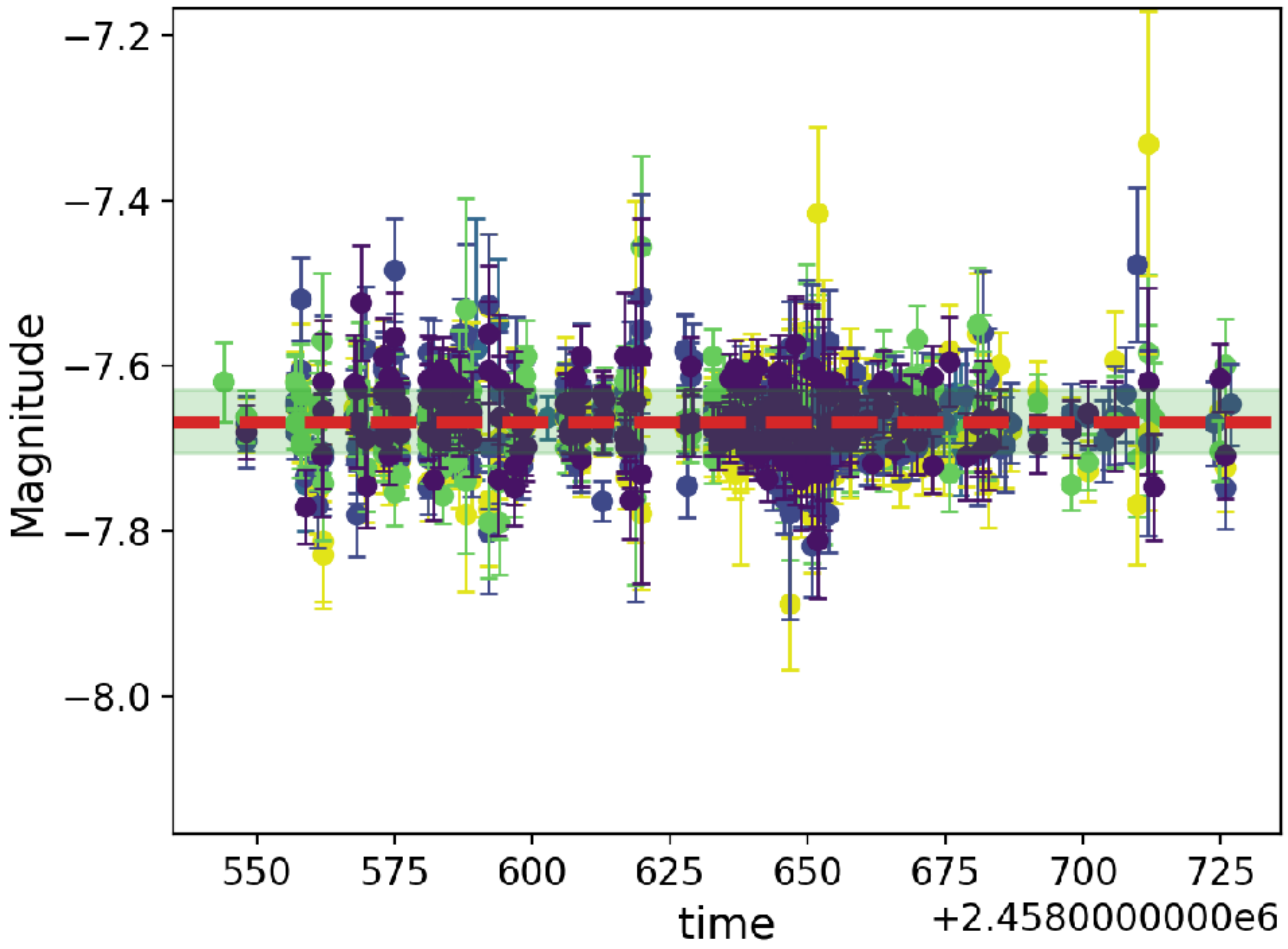


std=0.0384

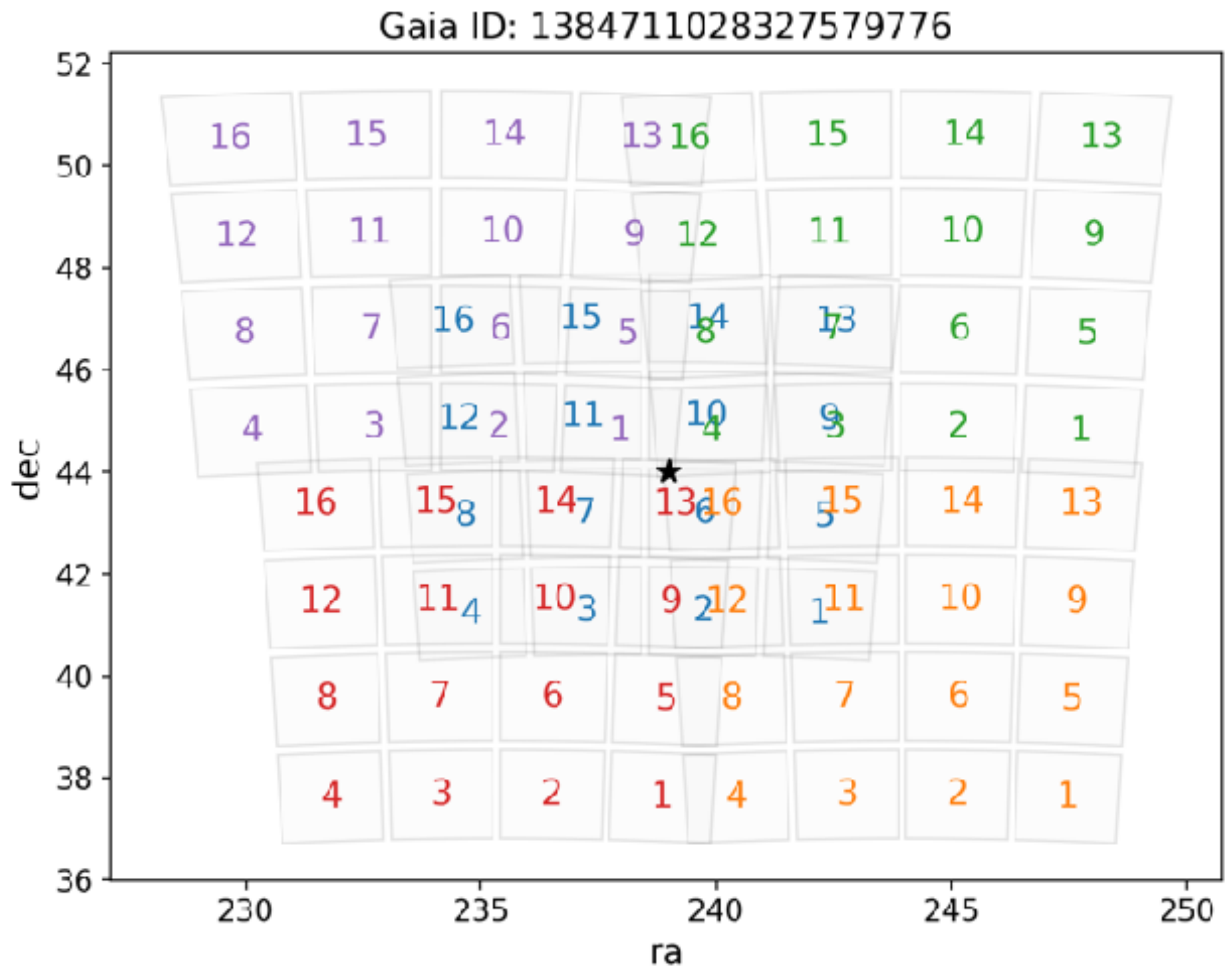


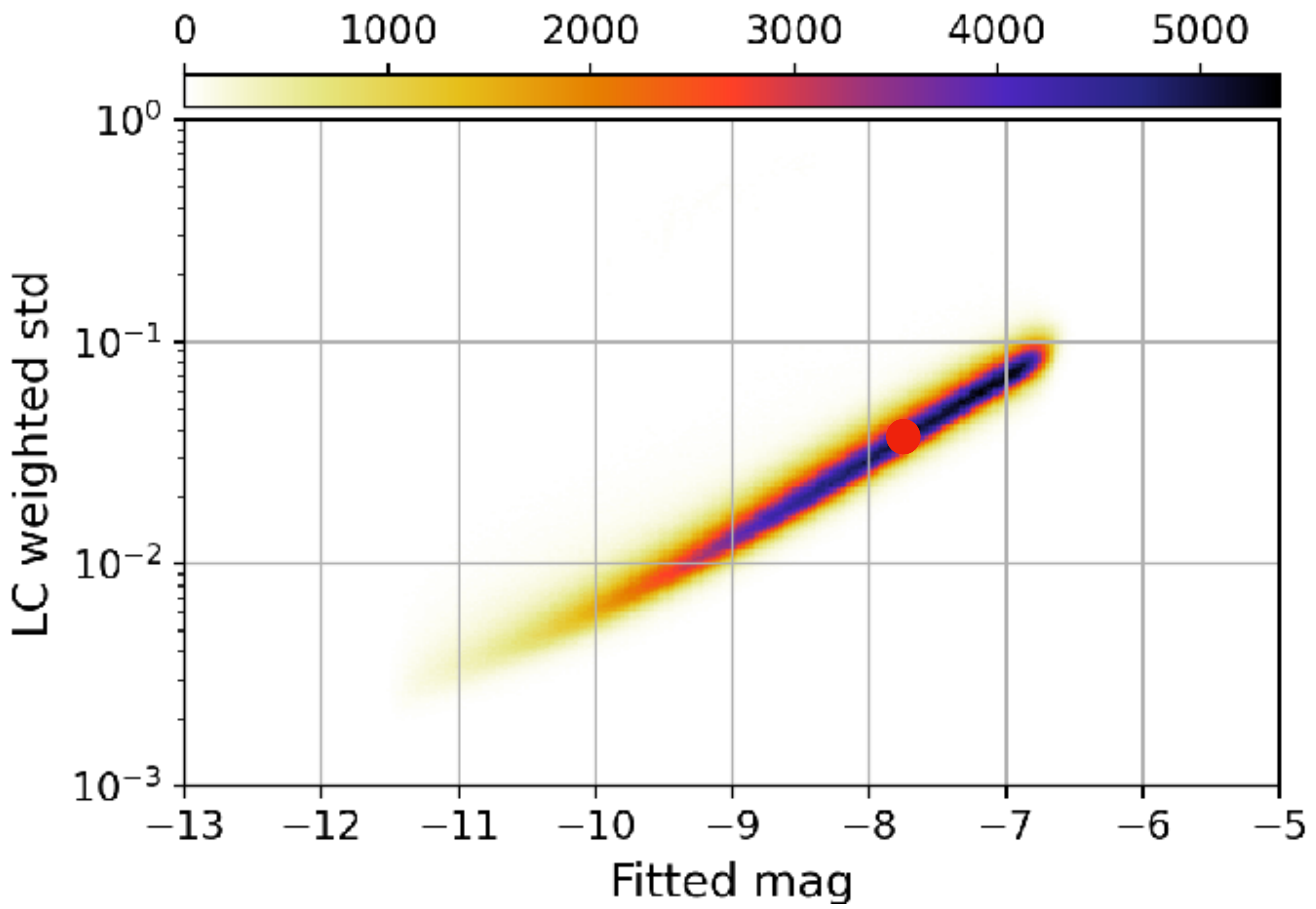


Ubercal with 1 ZP per quadrant + starflats

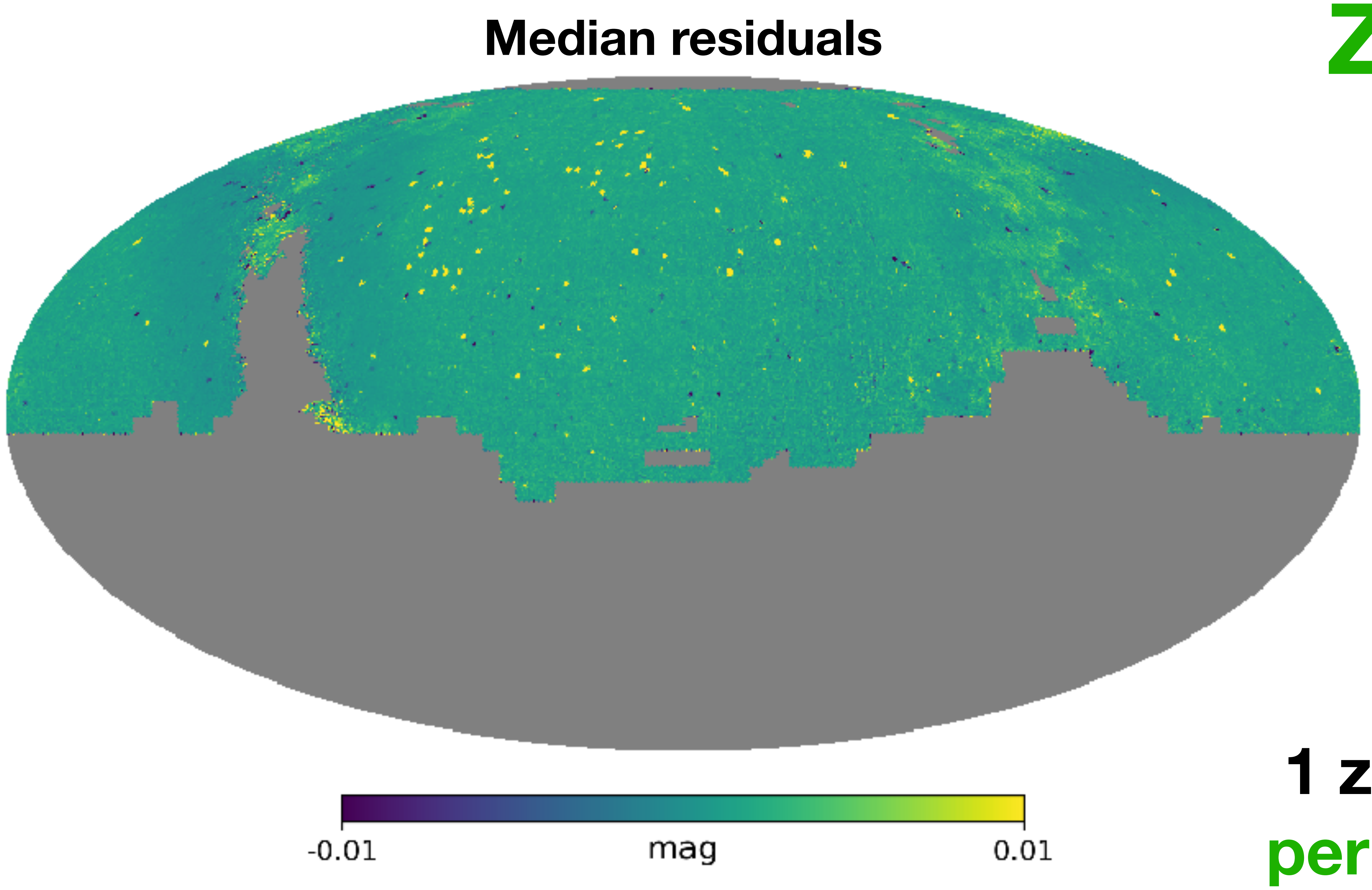


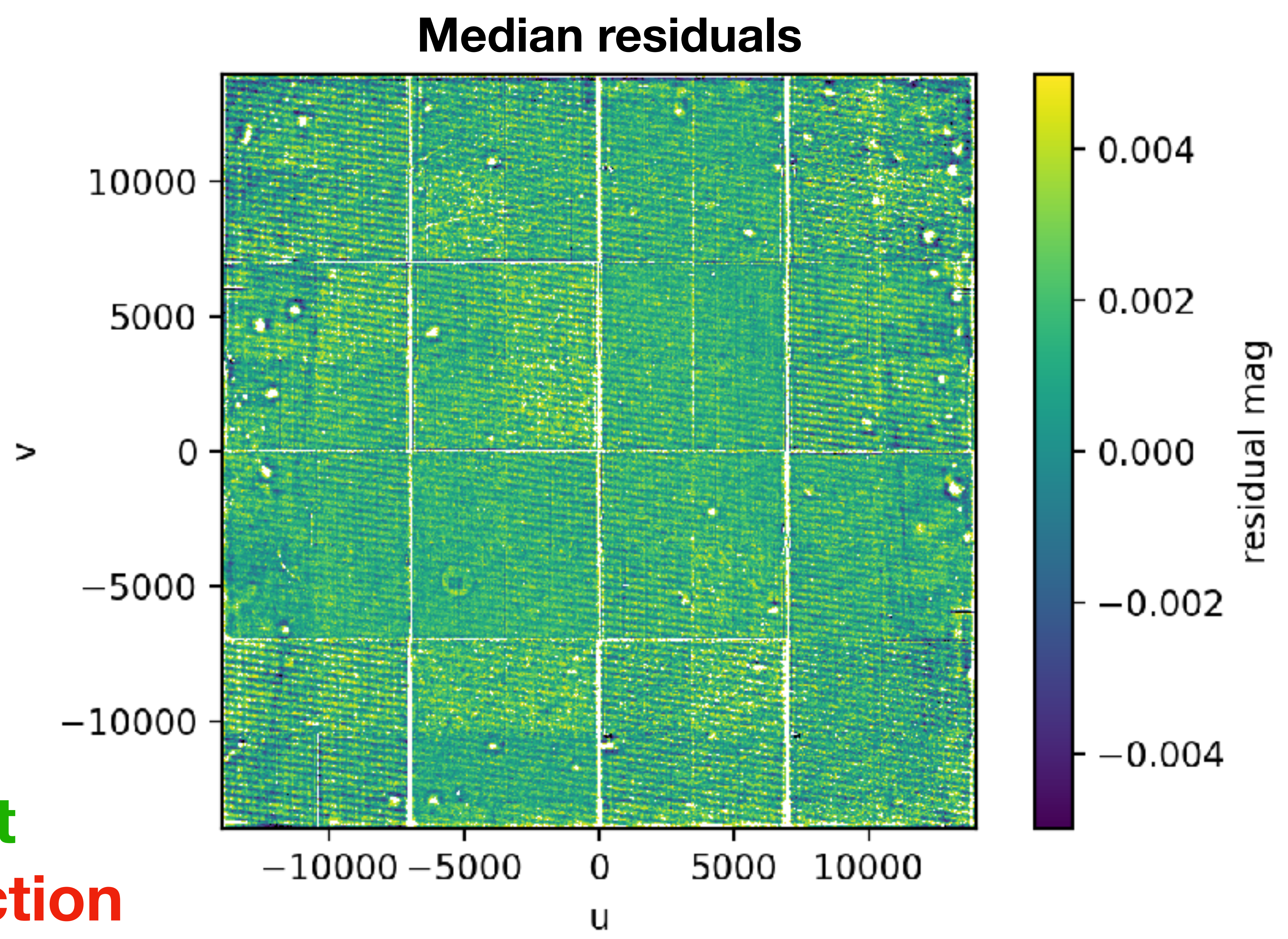
std=0.0383



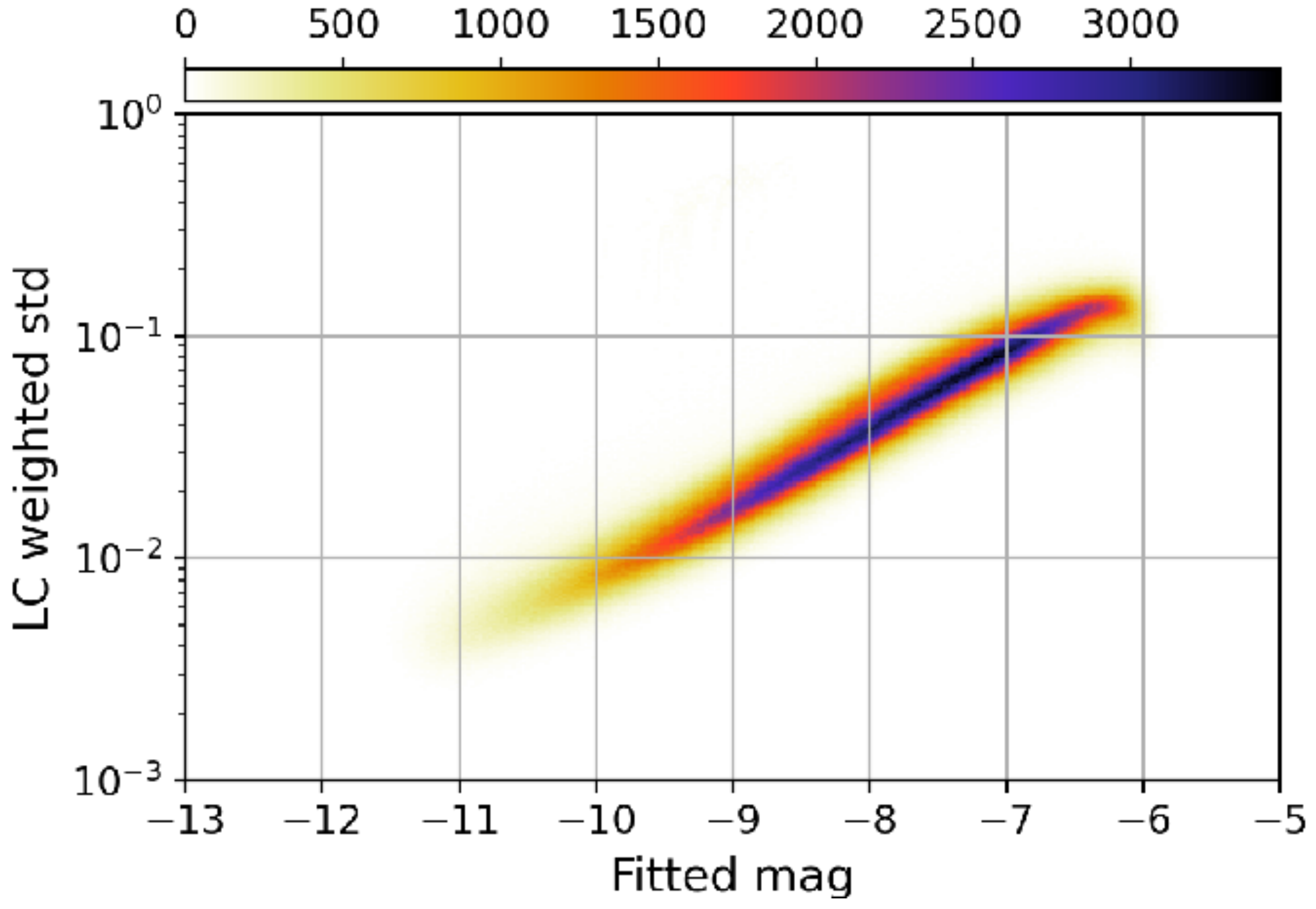


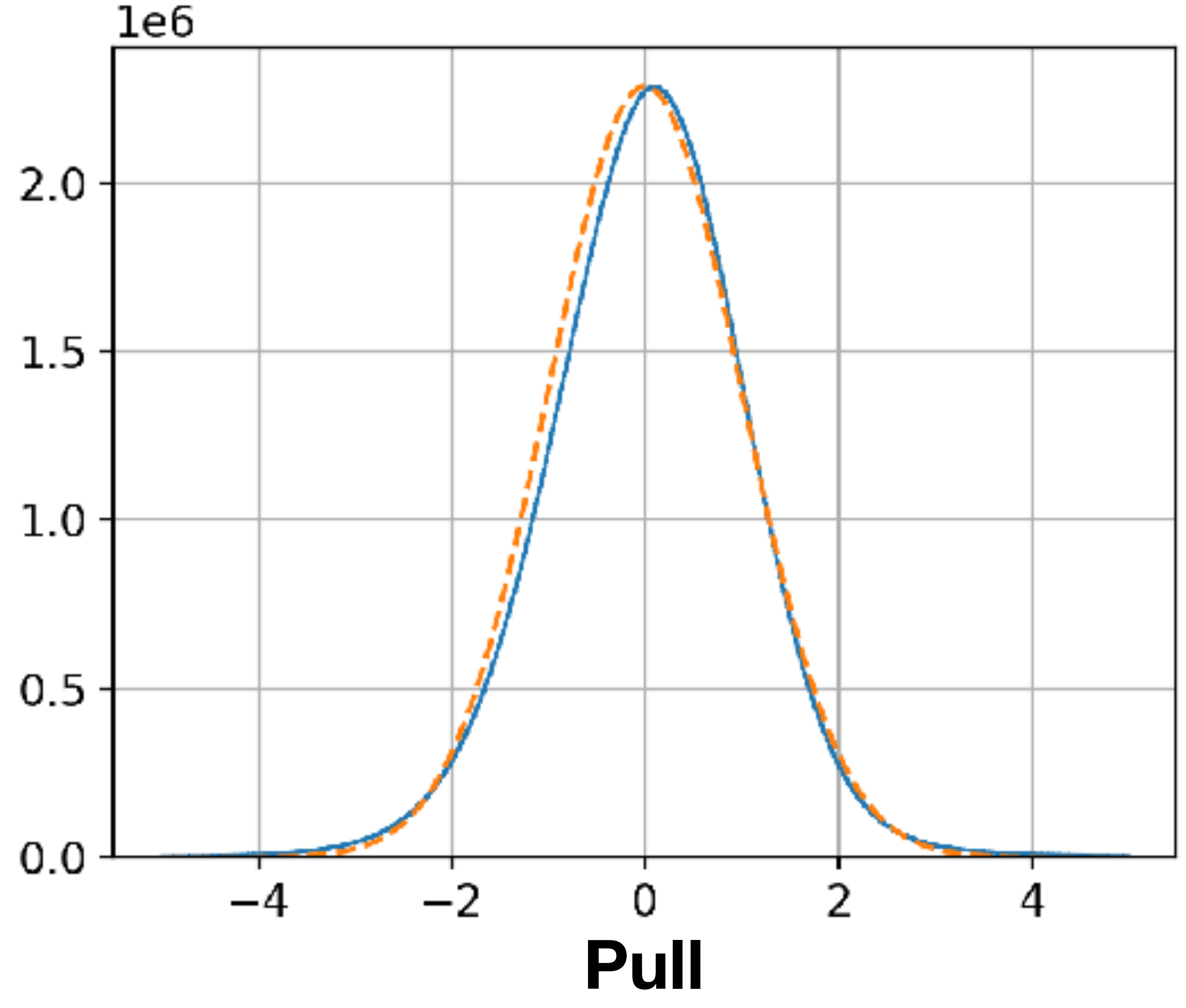
ZTF-g





Fit
1 zero point
per quadrant
& starflat correction

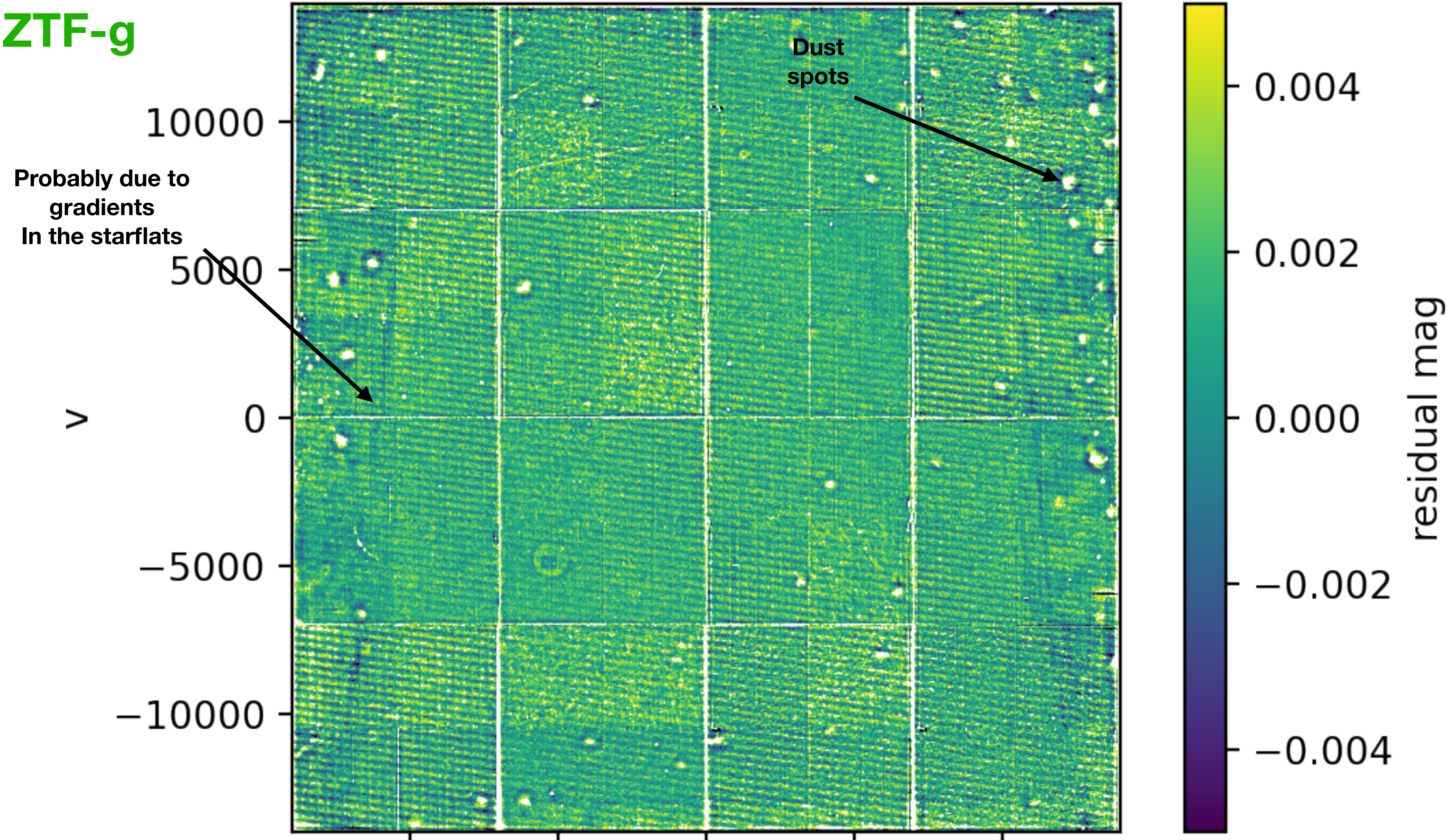





ZTF-g
10000
5000
0
−5000
−10000
v
0.004
0.002
0.000
−0.002
−0.004
residual mag

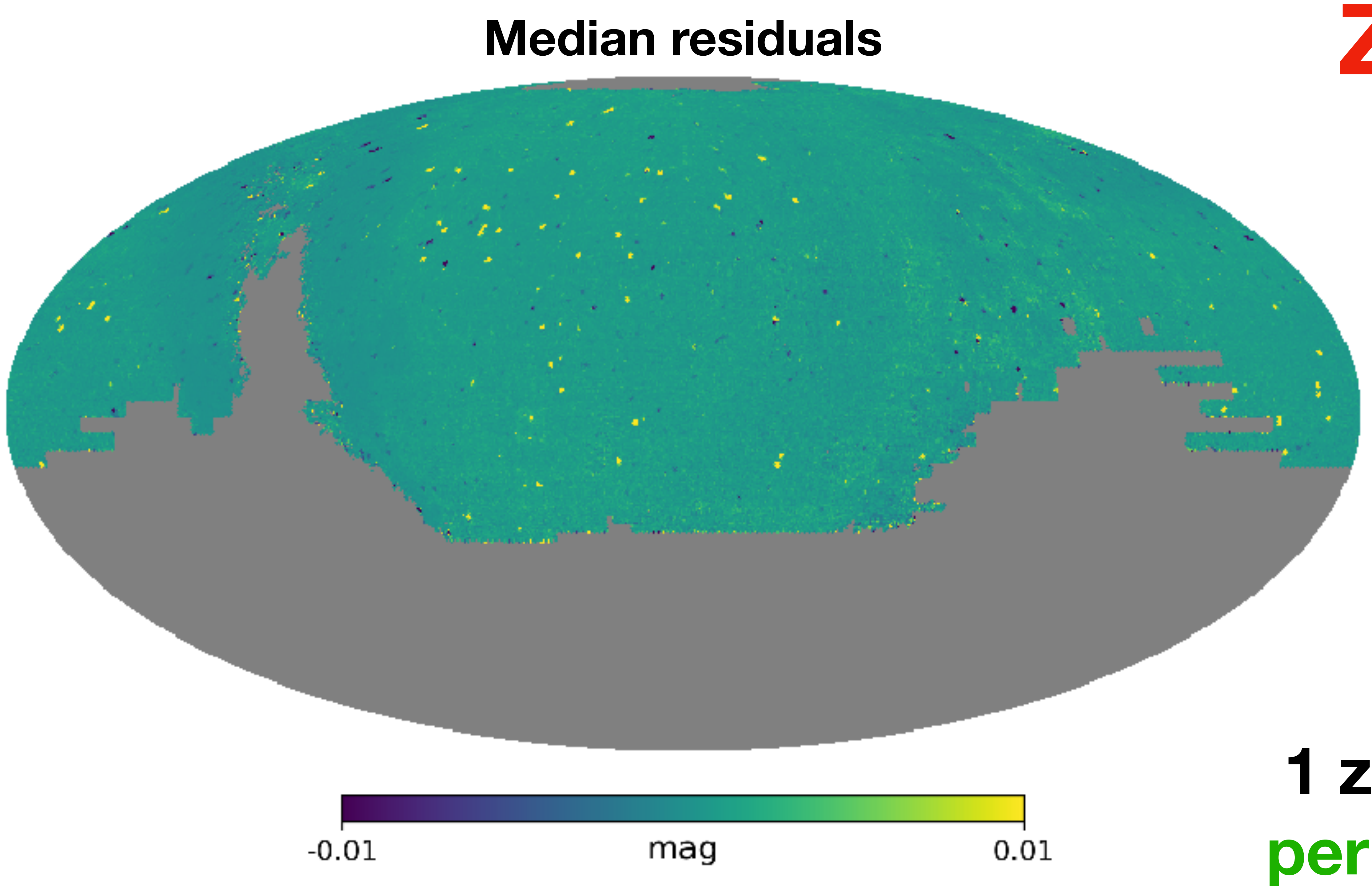

ZTF-g
Dust spots
v
10000
5000
0
−5000
−10000
0.004
0.002
0.000
−0.002
−0.004
residual mag

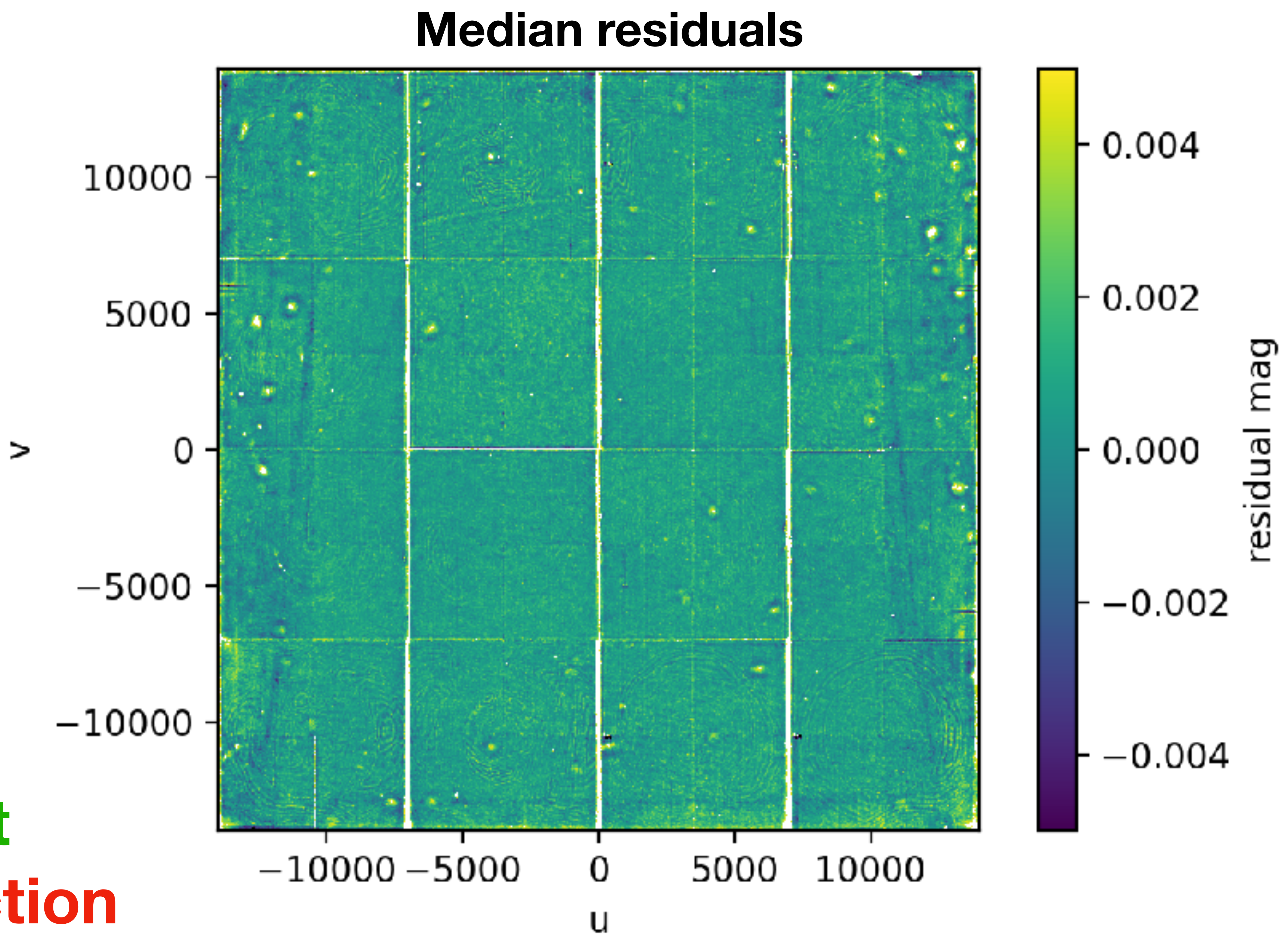
ZTF-g


Dust spots
Probably due to gradients In the starflats
10000
5000
0
−5000
−10000
v
0.004
0.002
0.000
−0.002
−0.004
residual mag

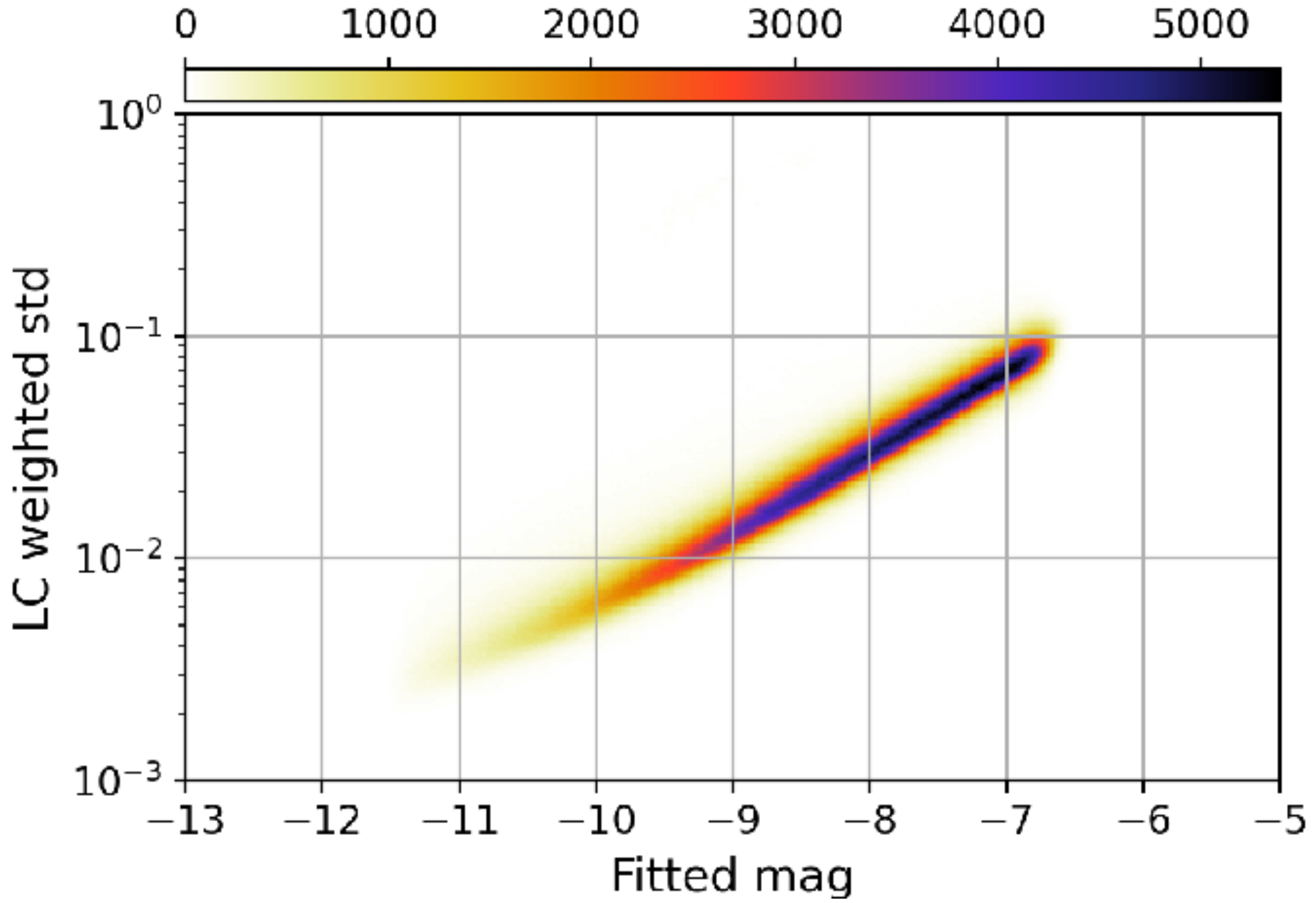

ZTF-g
Dust spots
Probably due to gradients In the starflats
Laser annealing effects could be corrected better with new flats
10000
5000
0
−5000
−10000
v
0.004
0.002
0.000
−0.002
−0.004
residual mag

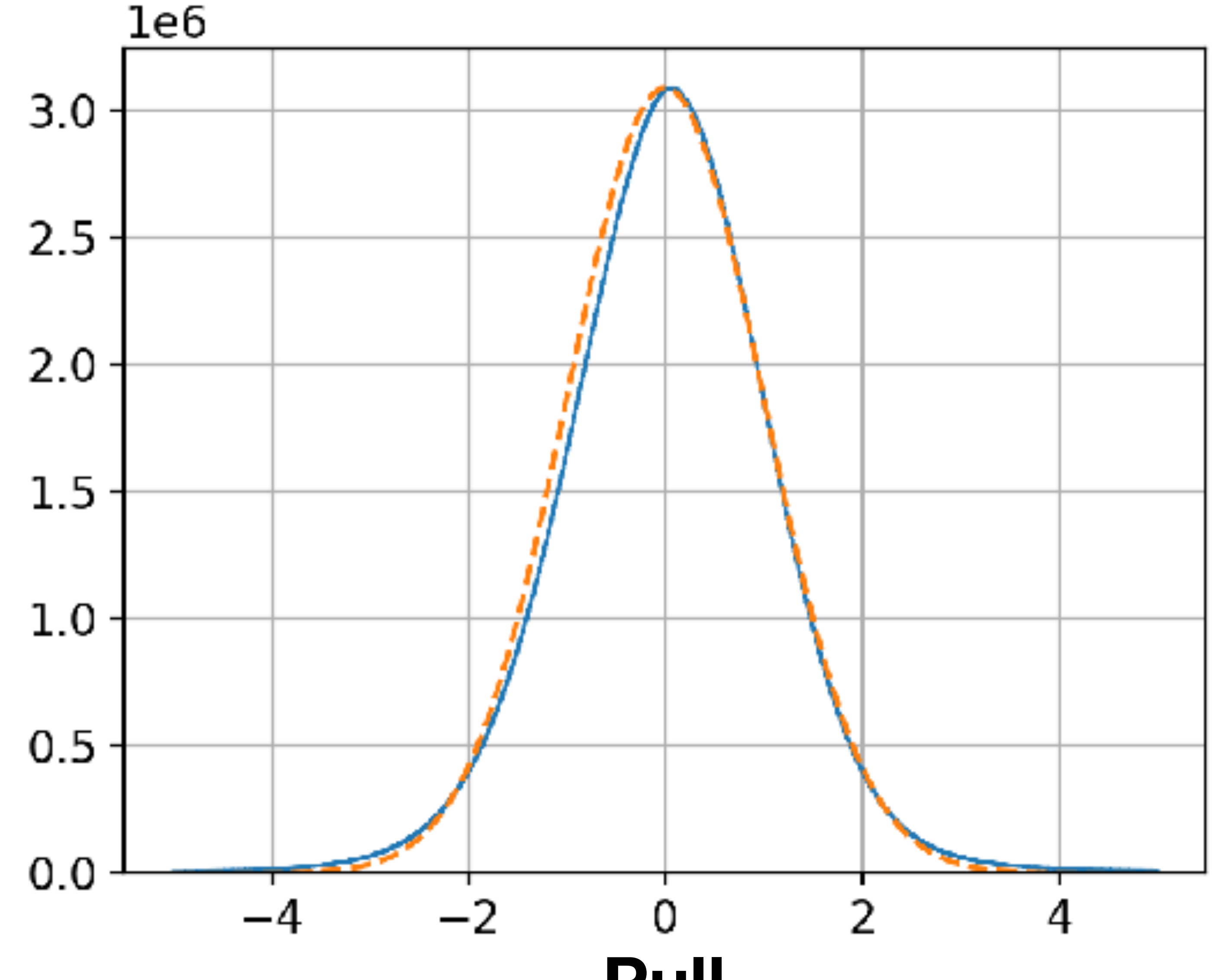
ZTF-r



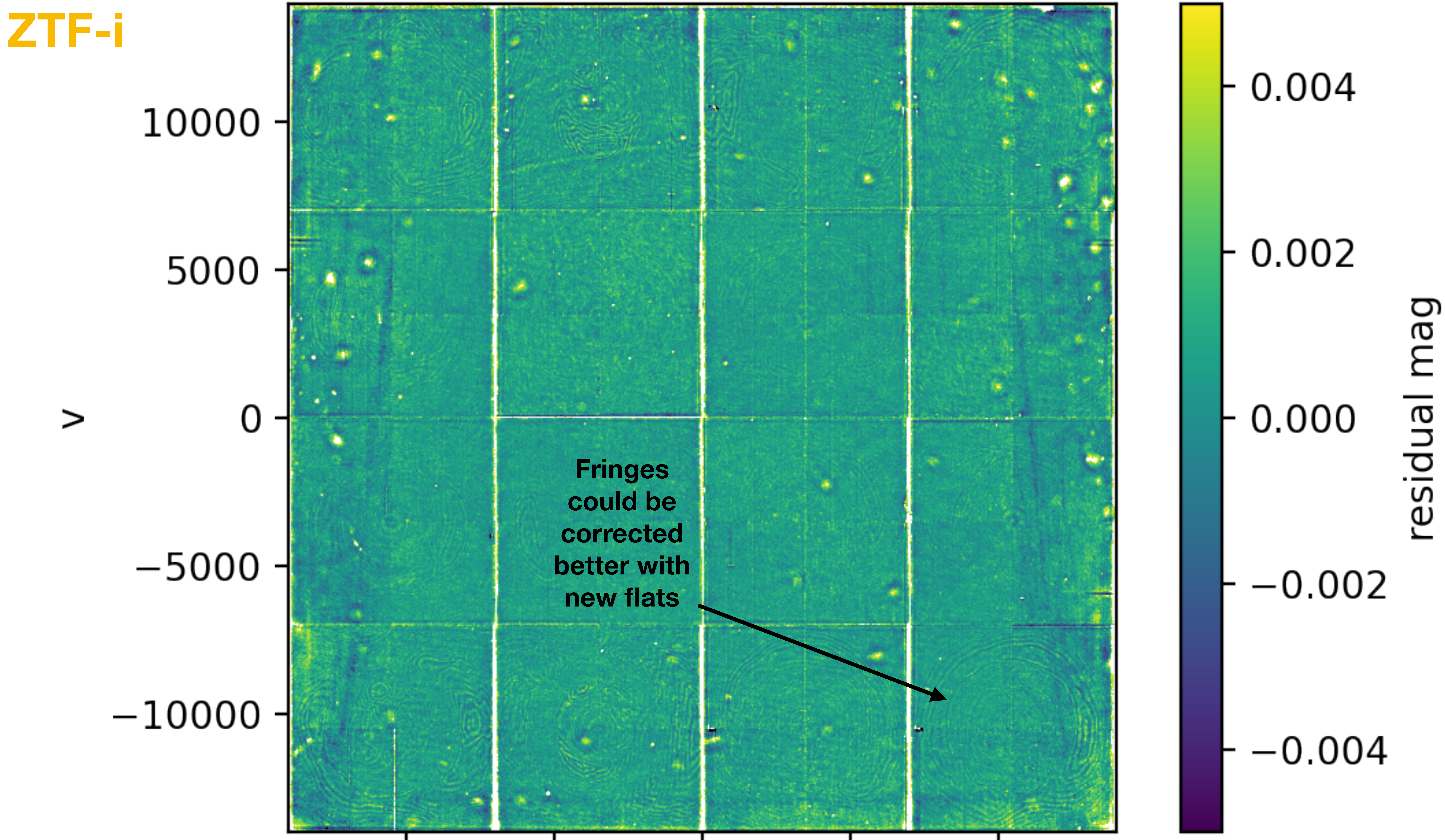


Fit
1 zero point
per quadrant
& starflat correction



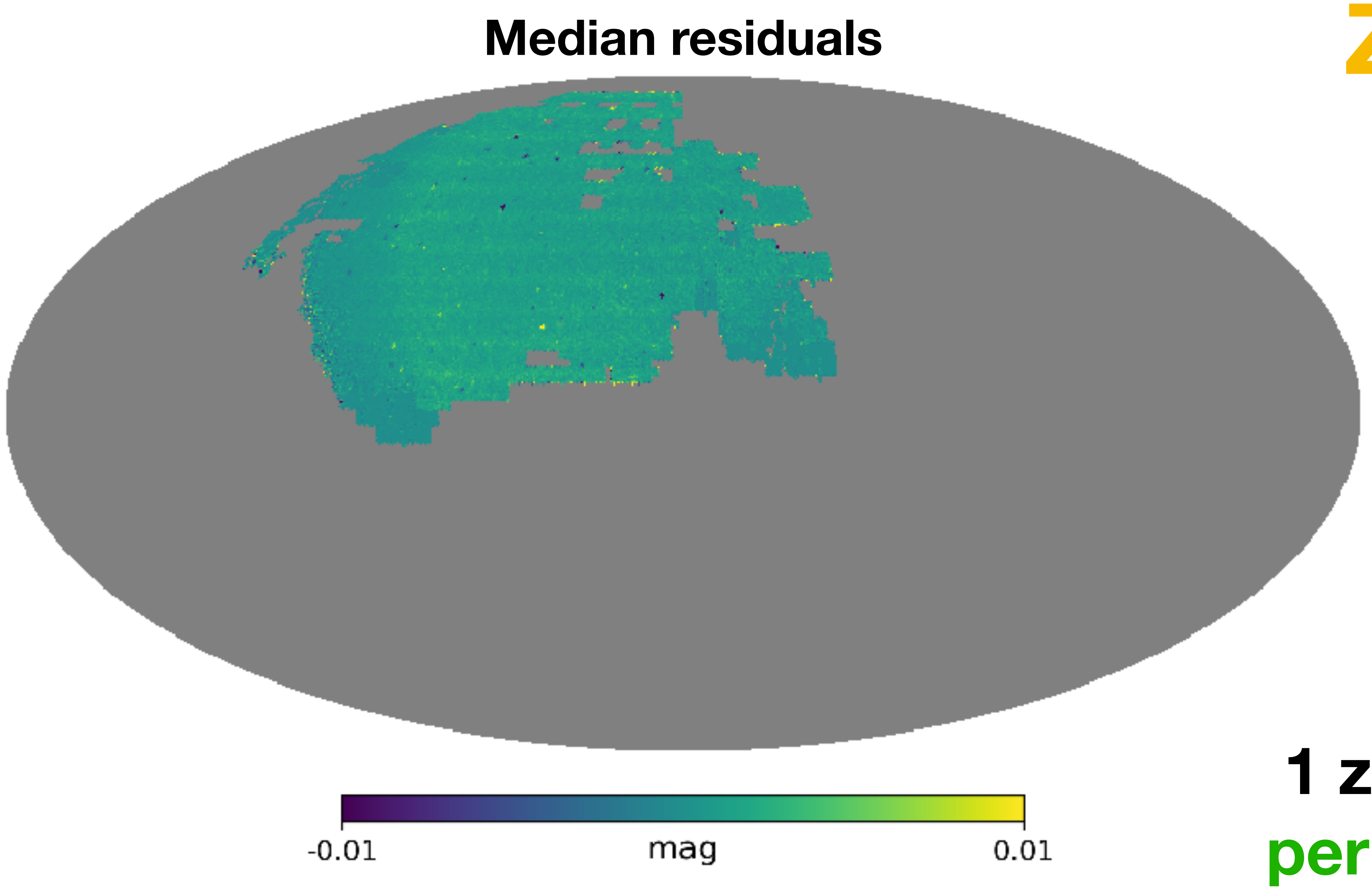



ZTF-i
v
10000
5000
0
−5000
−10000
0.004
0.002
0.000
−0.002
−0.004
residual mag

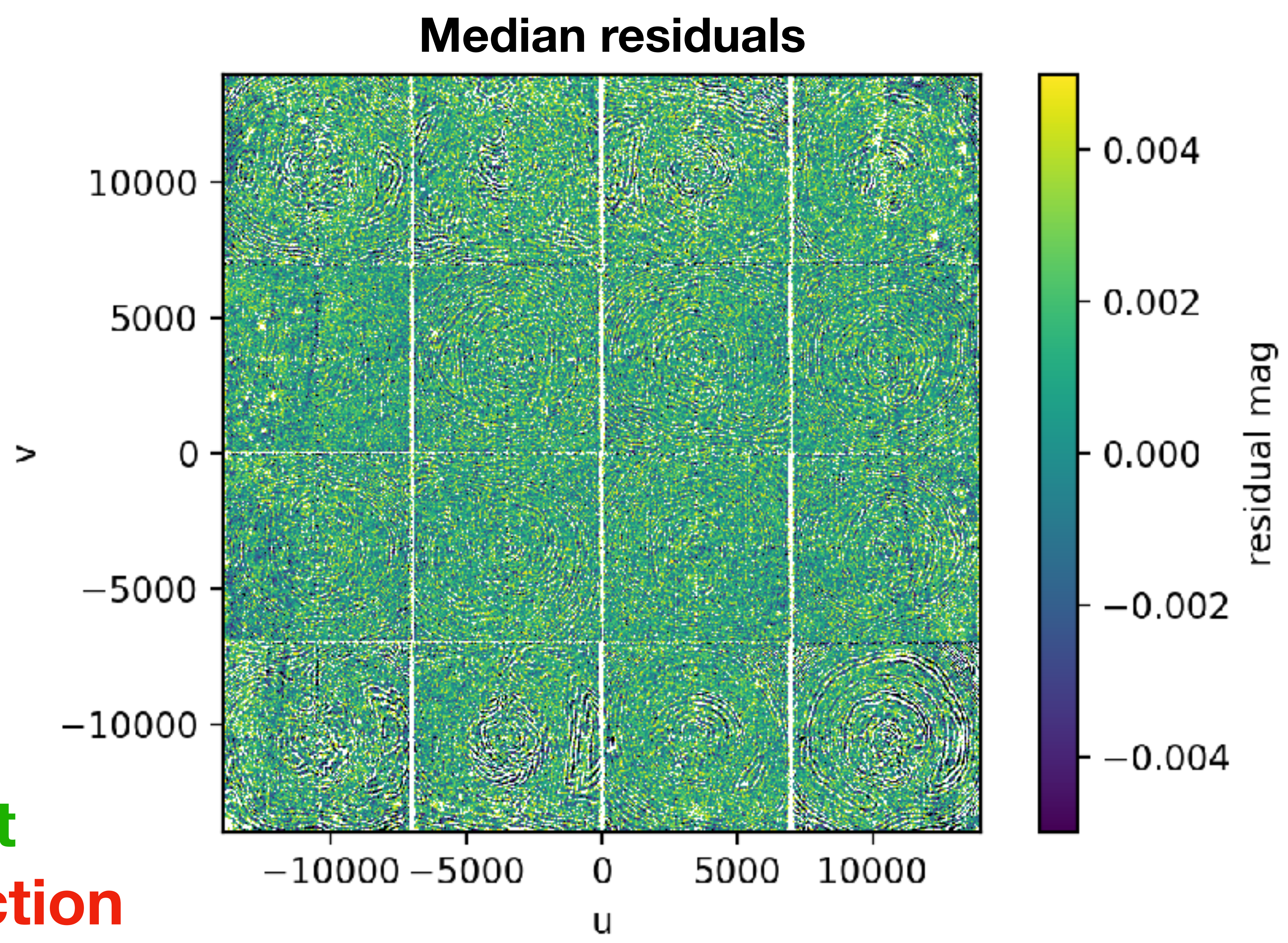

ZTF-i
10000
5000
0
−5000
−10000
v
Fringes could be corrected better with new flats
0.004
0.002
0.000
−0.002
−0.004
residual mag

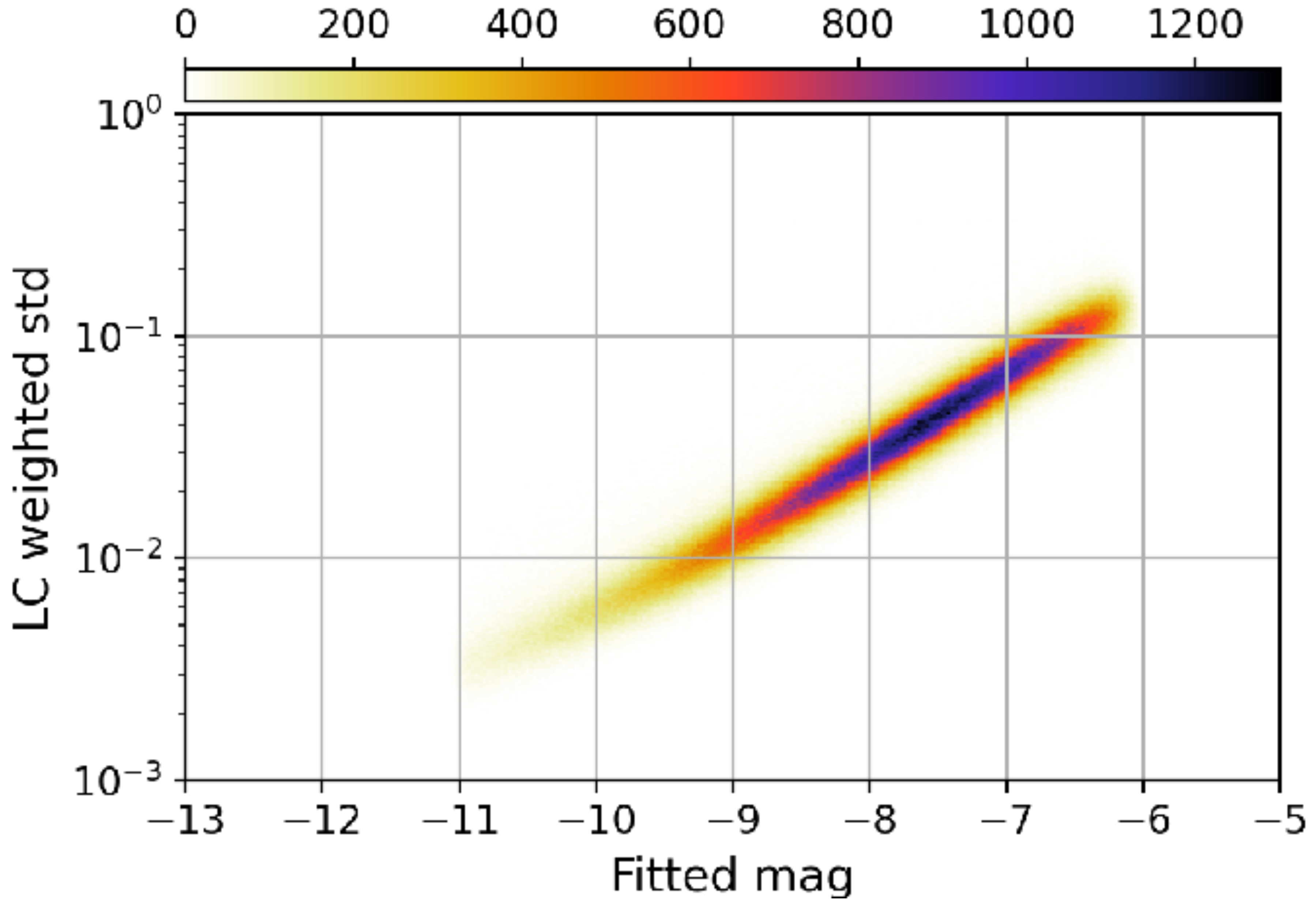
ZTF-i
Dust spots
Fringes could be corrected better with new flats
10000
5000
0
−5000
−10000
v
0.004
0.002
0.000
−0.002
−0.004
residual mag

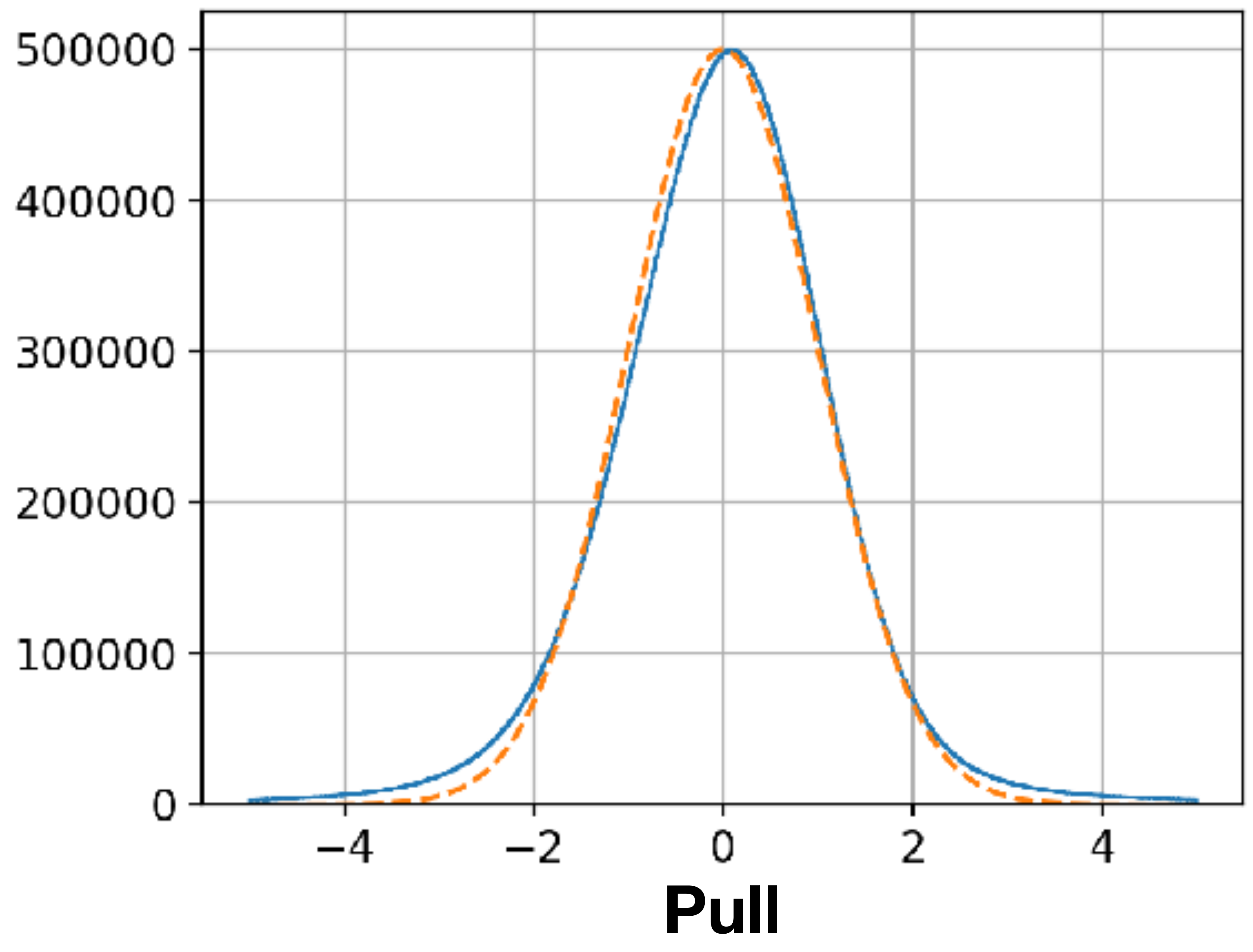
ZTF-i



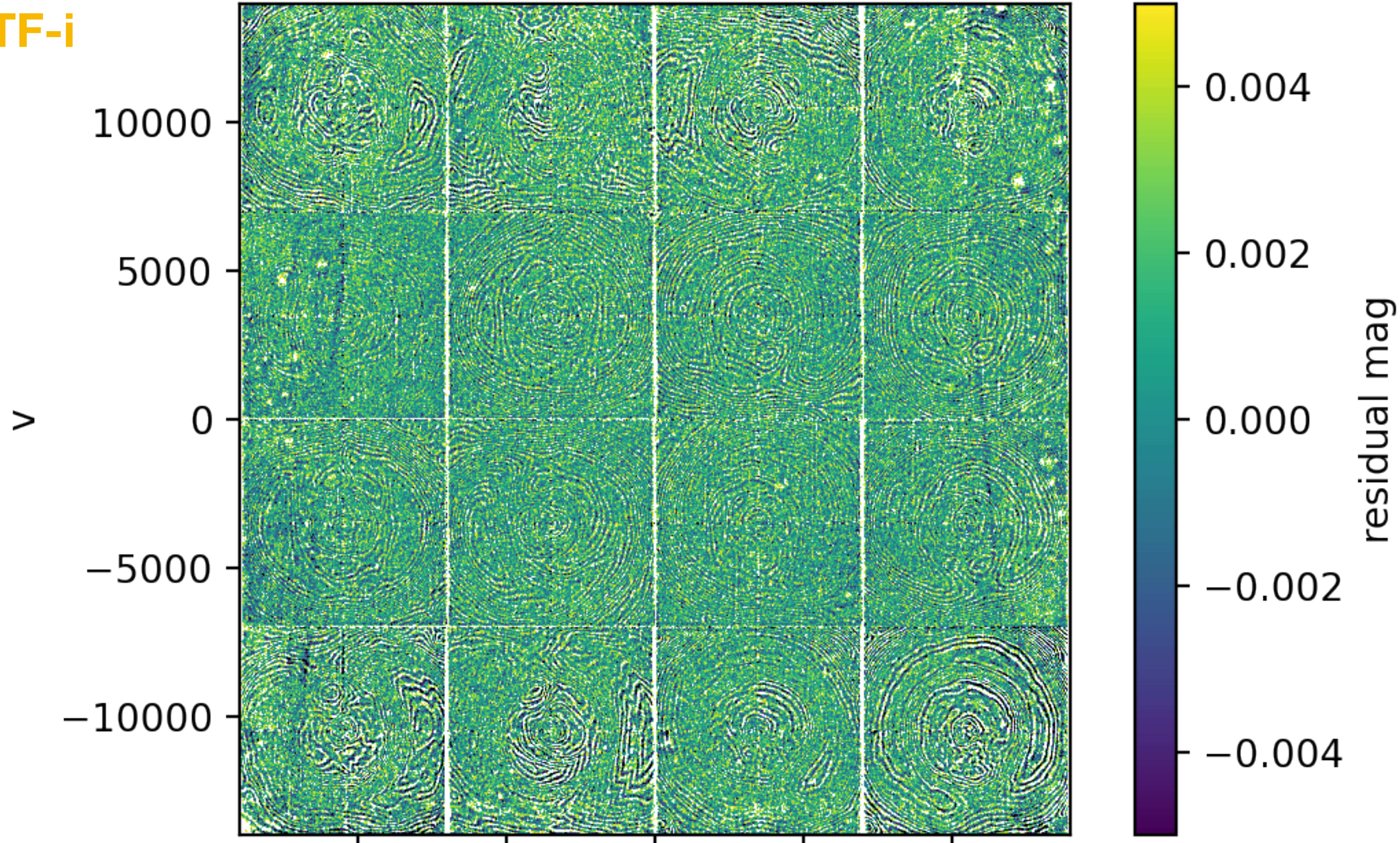
Fit
1 zero point
per quadrant
& starflat correction







ZTF-i



10000
5000
0
−5000
−10000
v
0.004
0.002
0.000
−0.002
−0.004
residual mag


ZTF-i
10000
5000
0
−5000
−10000
v
0.004
0.002
0.000
−0.002
−0.004
residual mag
Fringes could be corrected better with new flats

Ubercal summary

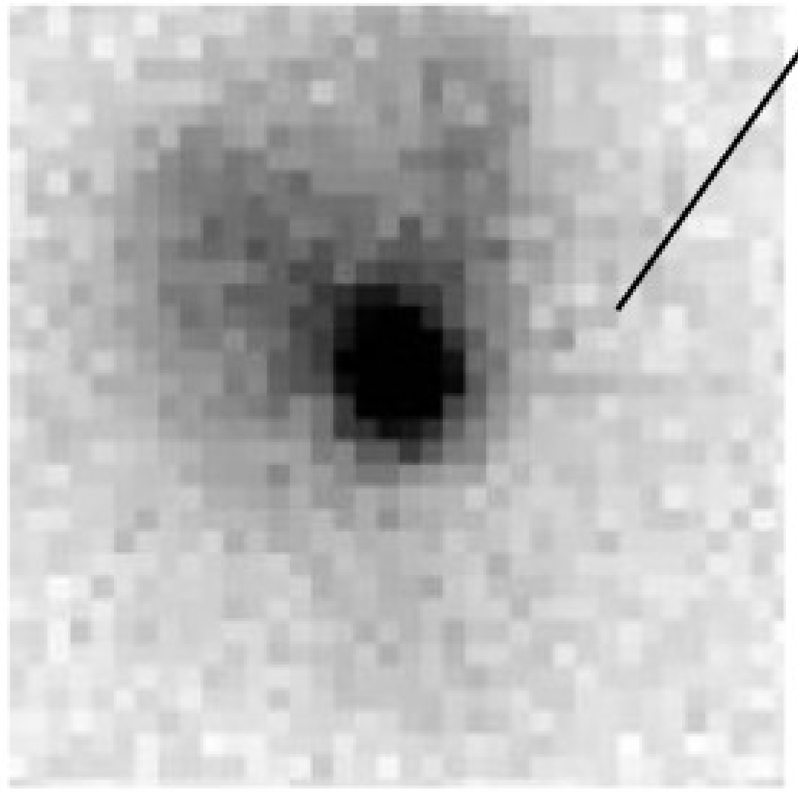
- Method works
- 1st ubercal : few percents
- Now we are well under 1%
(a few dust spots, fringes, and some bad regions in the sky)
- Goal is to have a first ubercal catalog at the end of the year to calibrate the transients (scene modeling photometry)

Scene modeling

Leander Lacroix, Nicolas Regnault

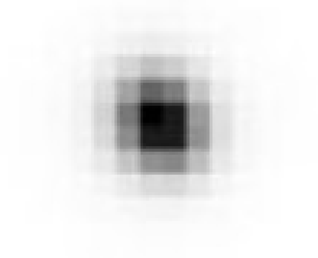
Scene modeling

$$I_i = f_i P_i + \mathrm{Gal} \otimes K_i$$

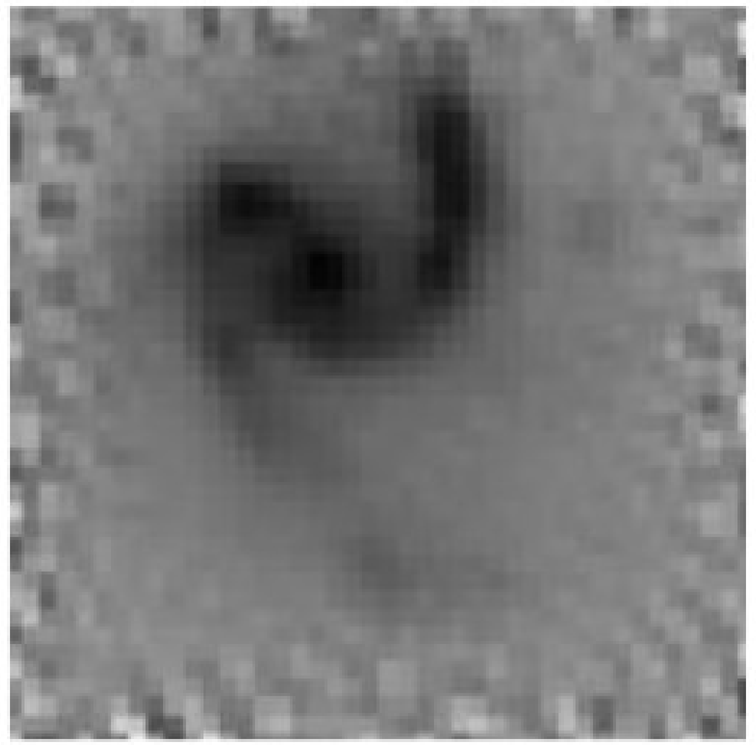


pixel p,
image i

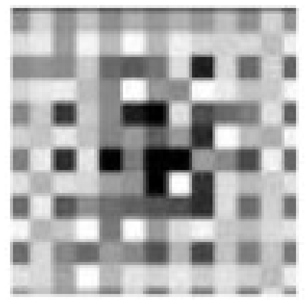
SN
flux



PSF



Galaxy
profile



kernel

Scene modeling

$$I_{i,p} = \alpha_i P_i(x_p - \varphi_i(x_{\mathrm{SN}}))f_i + \alpha_i G_p(\varphi_i^{-1}(x_p)) \otimes K_i$$

- Fit by Least Square

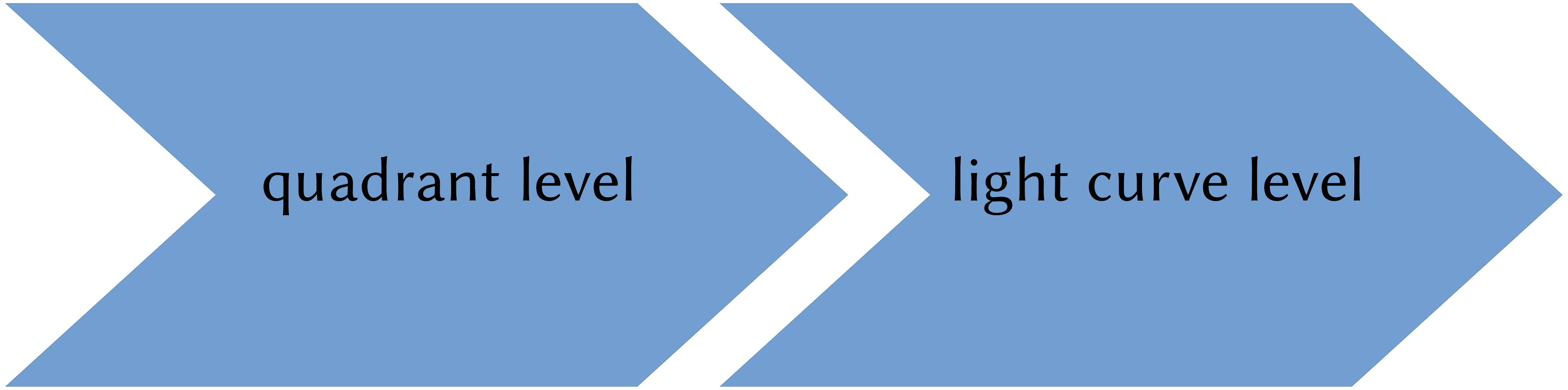
$$V = \begin{pmatrix} f_1 & \dots & f_n & x_{\mathrm{SN},1} & x_{\mathrm{SN},2} & G_1 & \dots & G_N \end{pmatrix}$$

Ingredients and pipeline for scene modeling

- Stamps of the stars and the SN
- Reference quadrant
- PSF model ϕ_i
- Kernel K_i from reference PSF to current image PSF
- Relative astrometry φ_i
- Relative photometry α_i

Raw pixels

- biases
- dead pixels
- flats

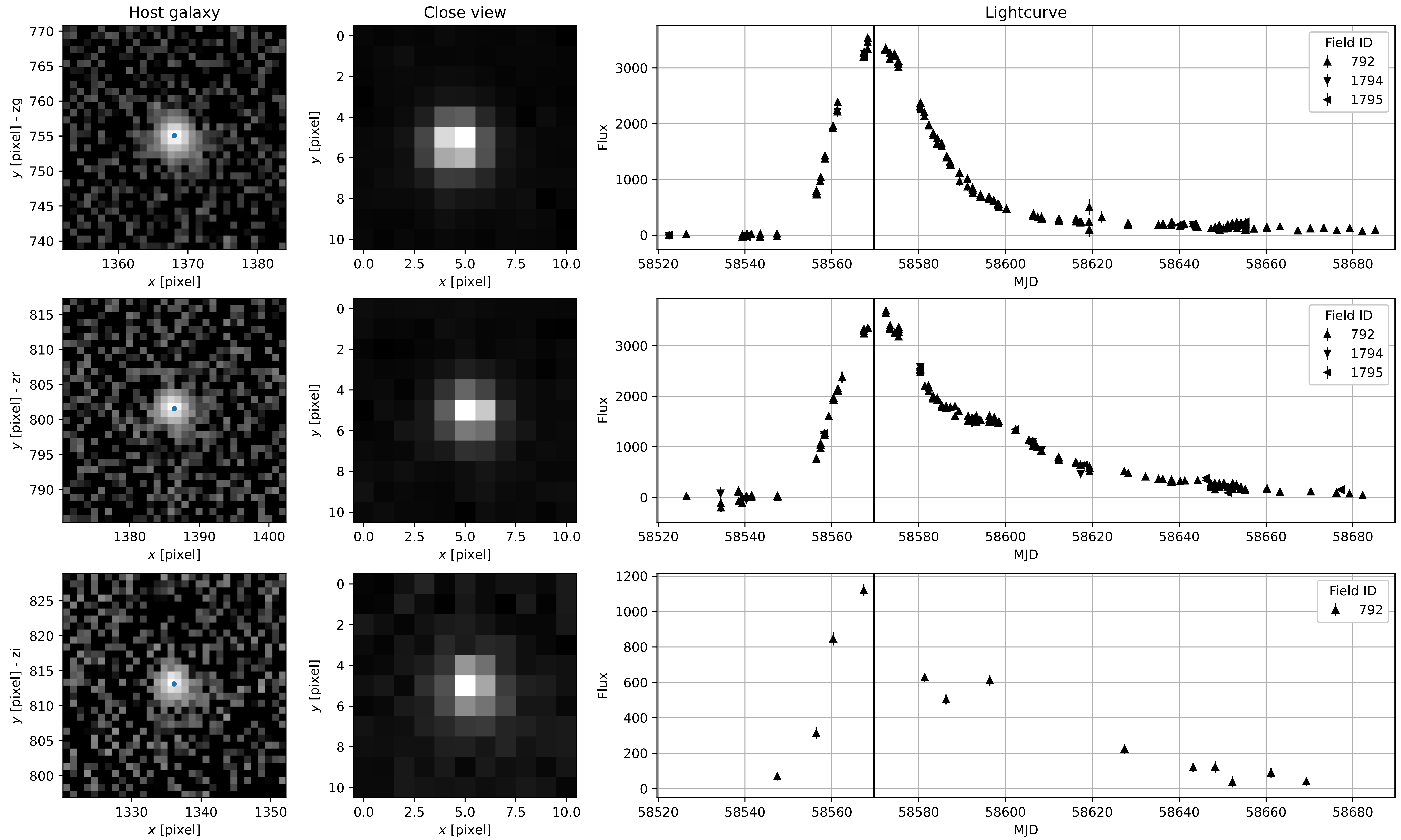


Calibrated lightcurves

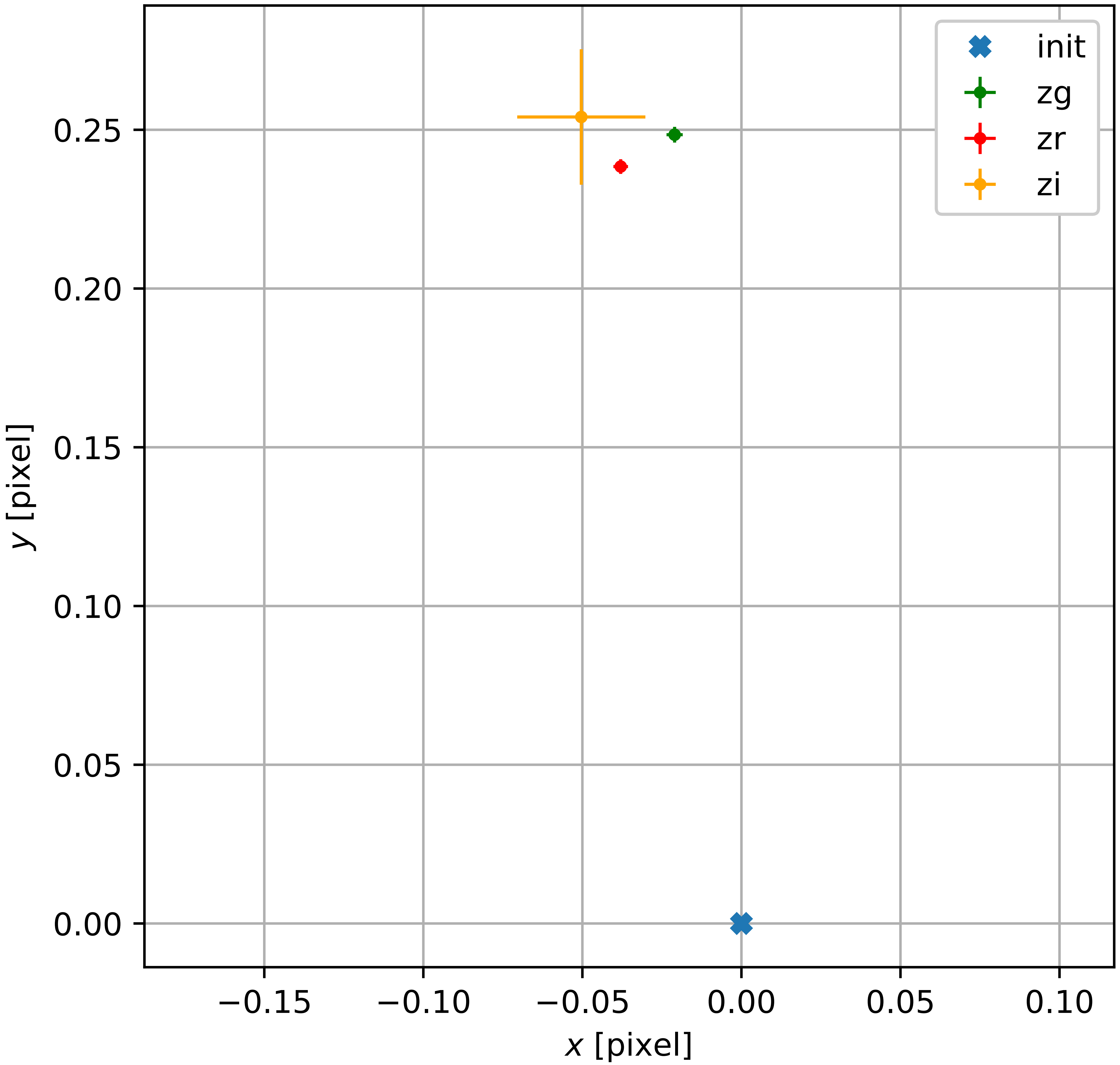
Some statistics on the reduced dataset

- 2 to 5 ZTF fields per SN
  - ~ 1500 stars per SN
- All detected stars are in the GAIA catalog
- Without modifying the Poloka code: 95% success rate
- Computing time:
  - Personal laptop, 200 quadrants, 4 cores: 17 min (~ 0.2 quadrant/s)
  - At CC, 33k quadrants, 600 workers: ~ 3h (~ 3 quadrant/s)

ZTF19aamhhae



ZTF19aamhhae



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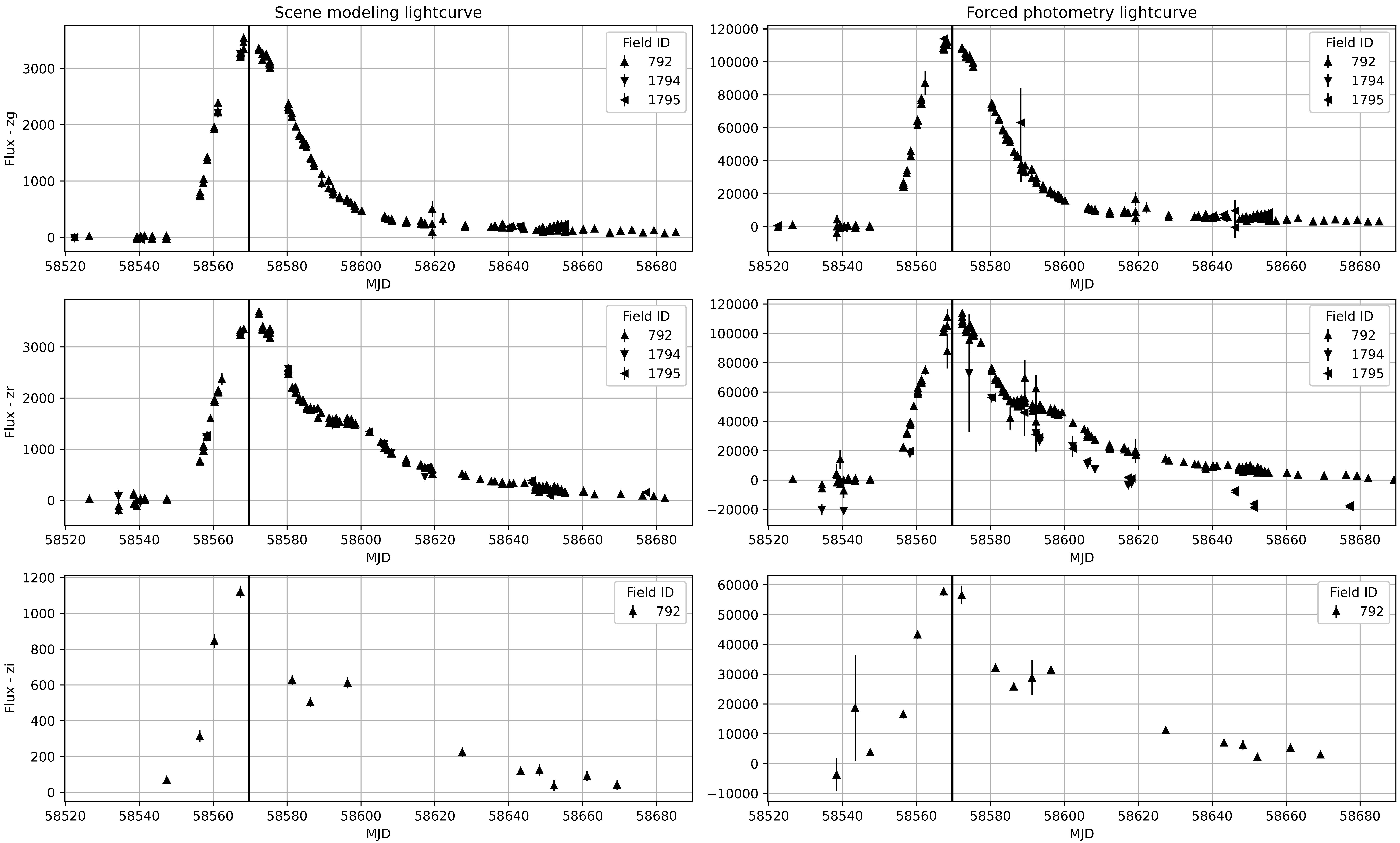
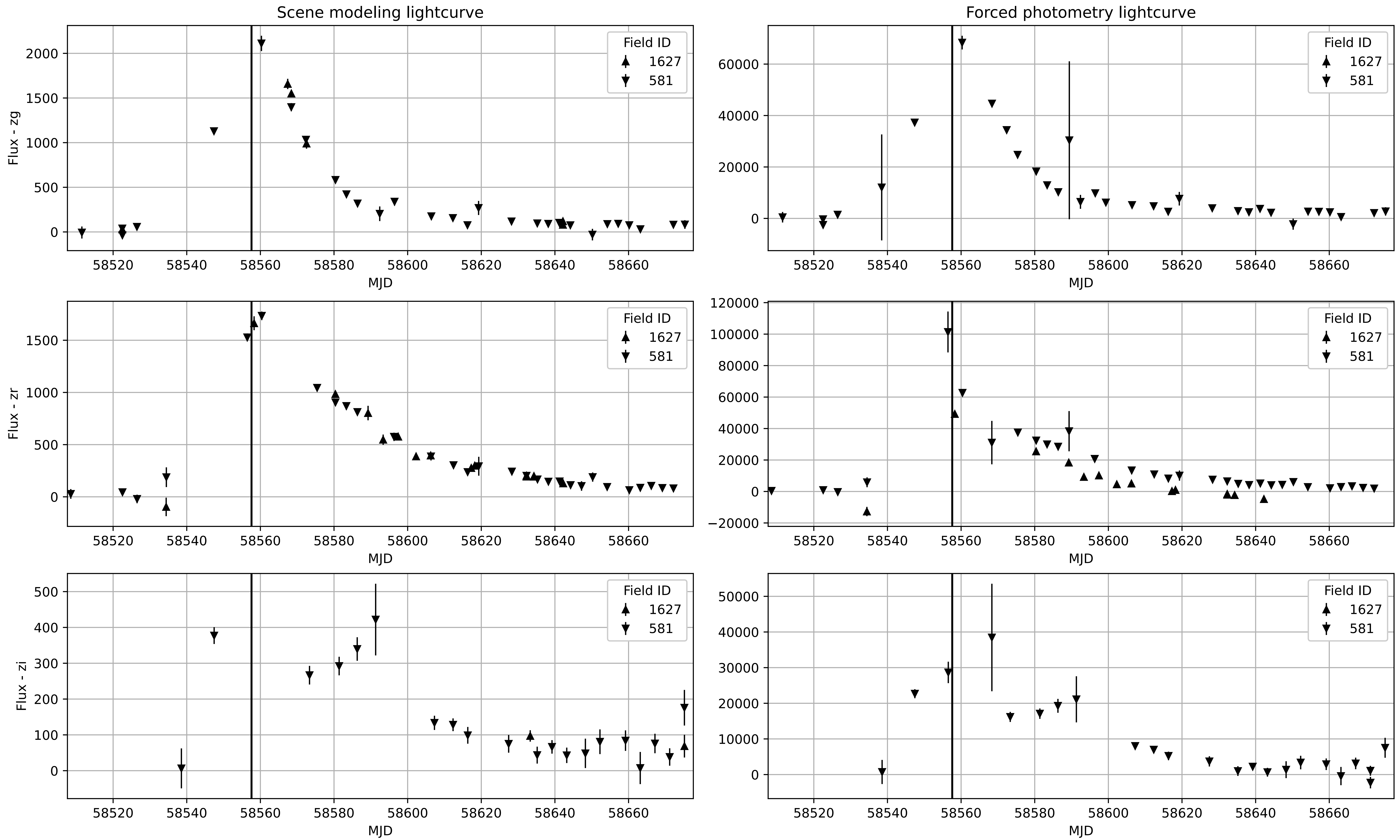
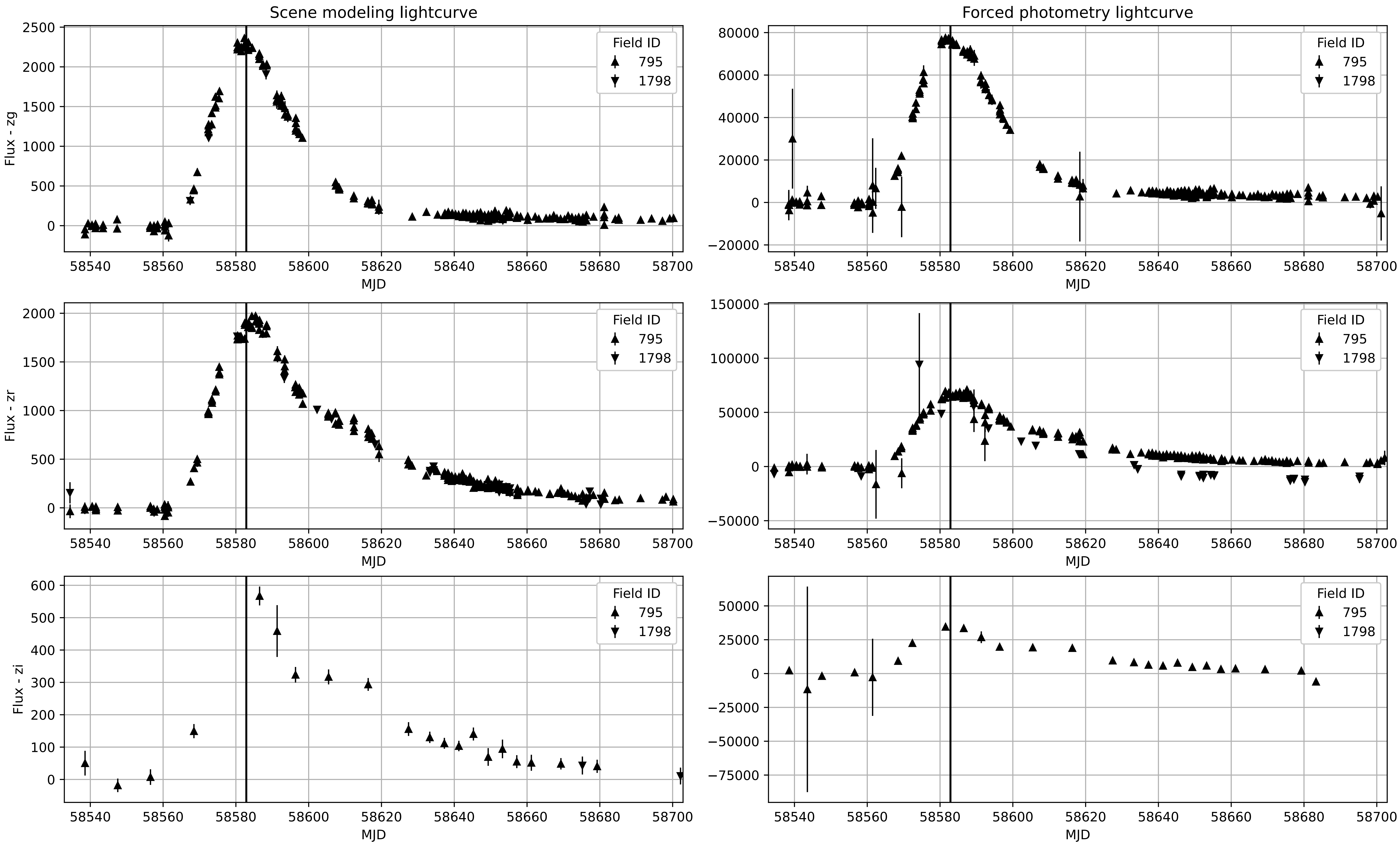


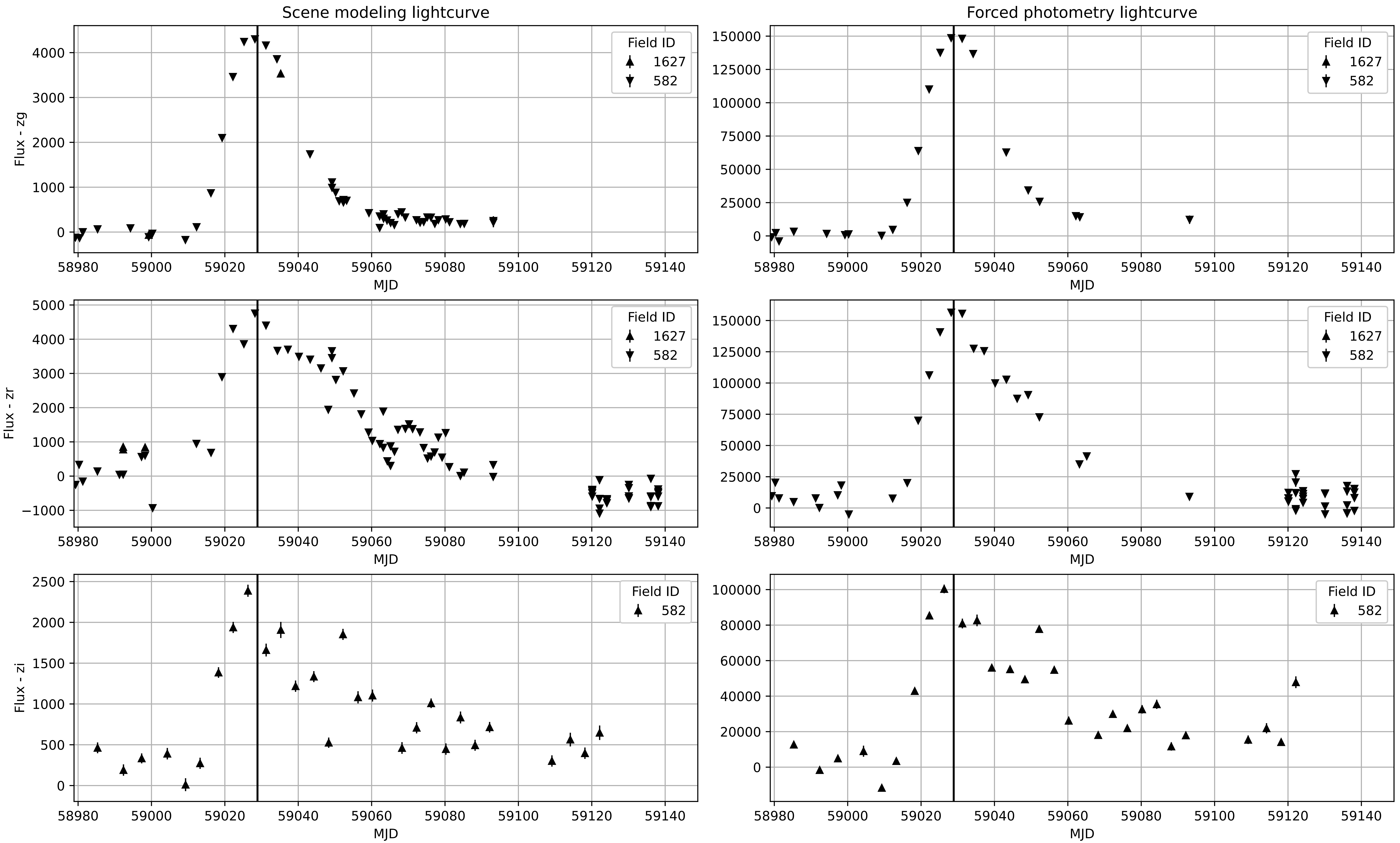
ZTF19aalzmmt



ZTF19aanircs



ZTF19aamdmcs



Future goals

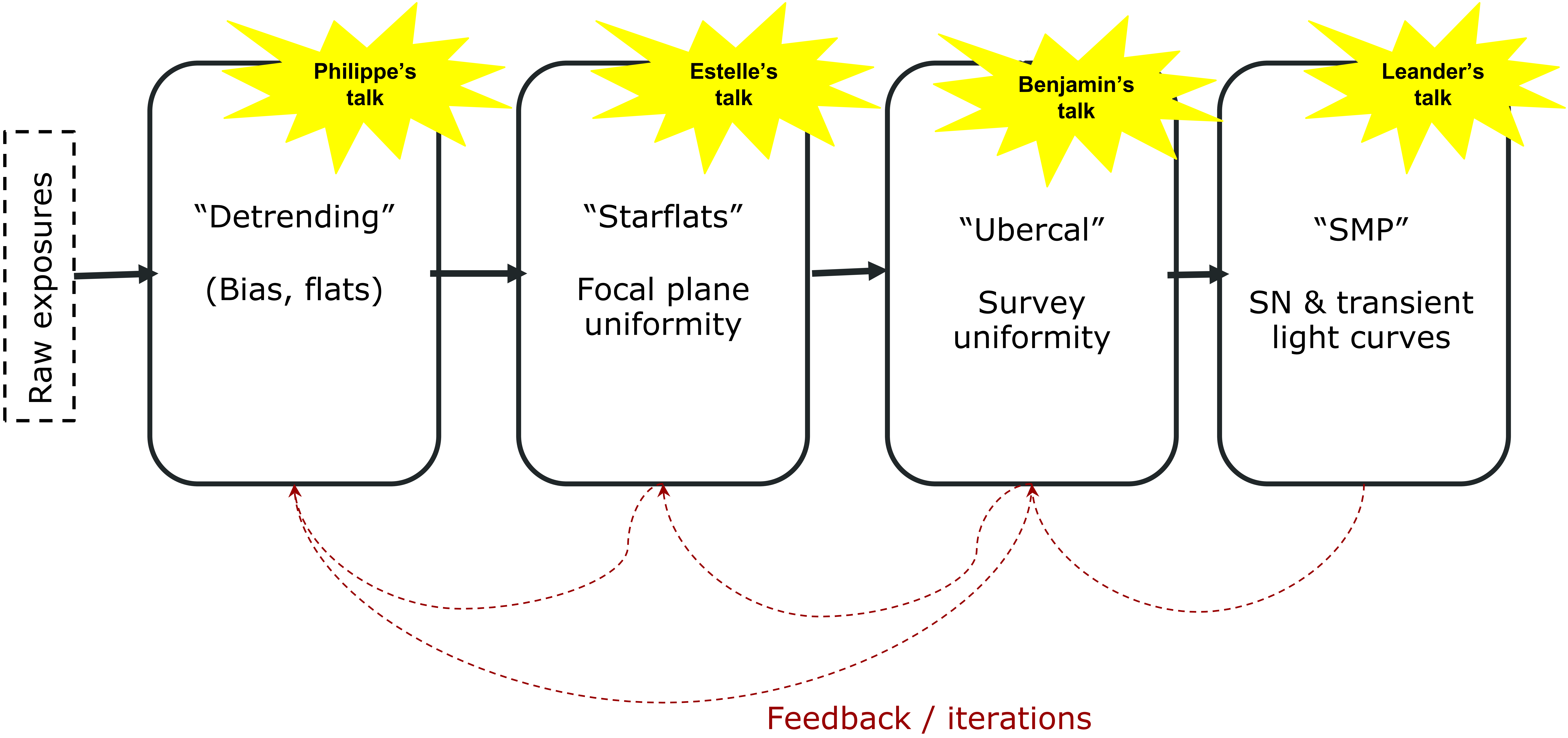
- Better photometry
  - GAIA stars
  - Ubercal
- Modernize code

- **Data release!!**

Computing forecast

- 3678 SNa 1a (ZTFCosmo IDR 2)
- ~4M quadrants on ~10K bands (with 5x off stats): ~400 quadrant/band
- ~217 TB: 36 days to download quadrants... (assuming 70 MB/s and 55 MB/quadrant)
- Processing times
  - Quadrants (preprocessing), 17 days*
  - Bands (scene modeling), 104 days (assuming ~10 min/band, single core)

*on 600 cores at IN2P3 computing center


Raw exposures
Philippe's talk
"Detrending"
(Bias, flats)
Estelle's talk
"Starflats"
Focal plane uniformity
Benjamin's talk
"Ubercal"
Survey uniformity
Leander's talk
"SMP"
SN & transient light curves
Feedback / iterations

Thanks

Summary

- We correct for small scales instrumental effects with new flats/starflats
- We then find a uniform solution on the full survey with ubercal to compute a calibrated catalog
- SMP uses this catalog to calibrate the scene and provide calibrated LC

Ubercal To-do

- compare with Pan-STARRS and Gaia, study error modes
- full year study (enlarge secondary grid coverage)
- iterate:
  - outliers rejection
  - select data using current iteration etc.
- complexify model : airmass, color, try higher resolution
- anchor ubercal to calspecs? Gaia?
- longer term: rerun everything after new flat-fielding/debiasing procedure