LSST France, 25-28 May 2021, Visio meeting

ZTF calibration: status and prospects

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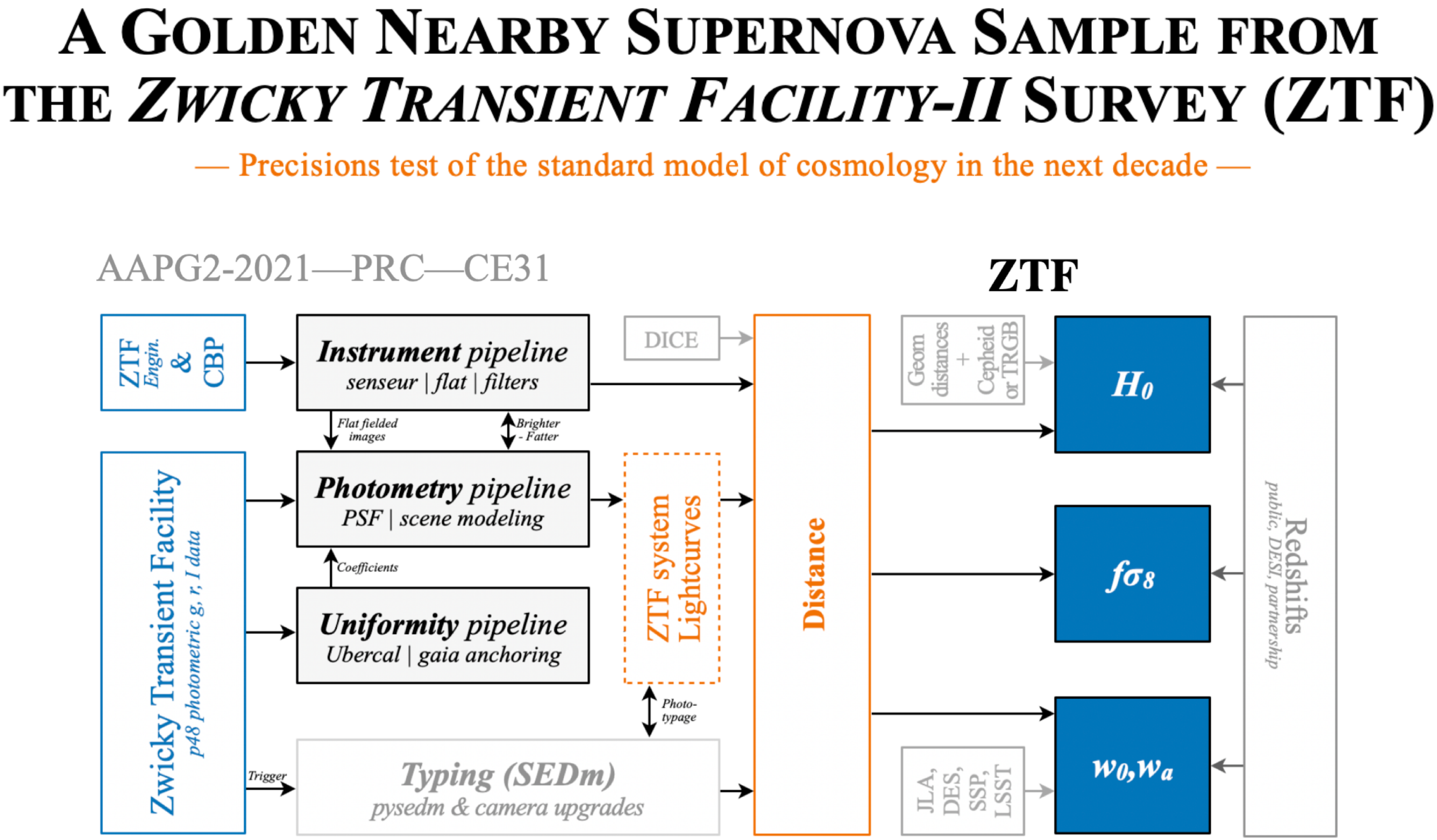
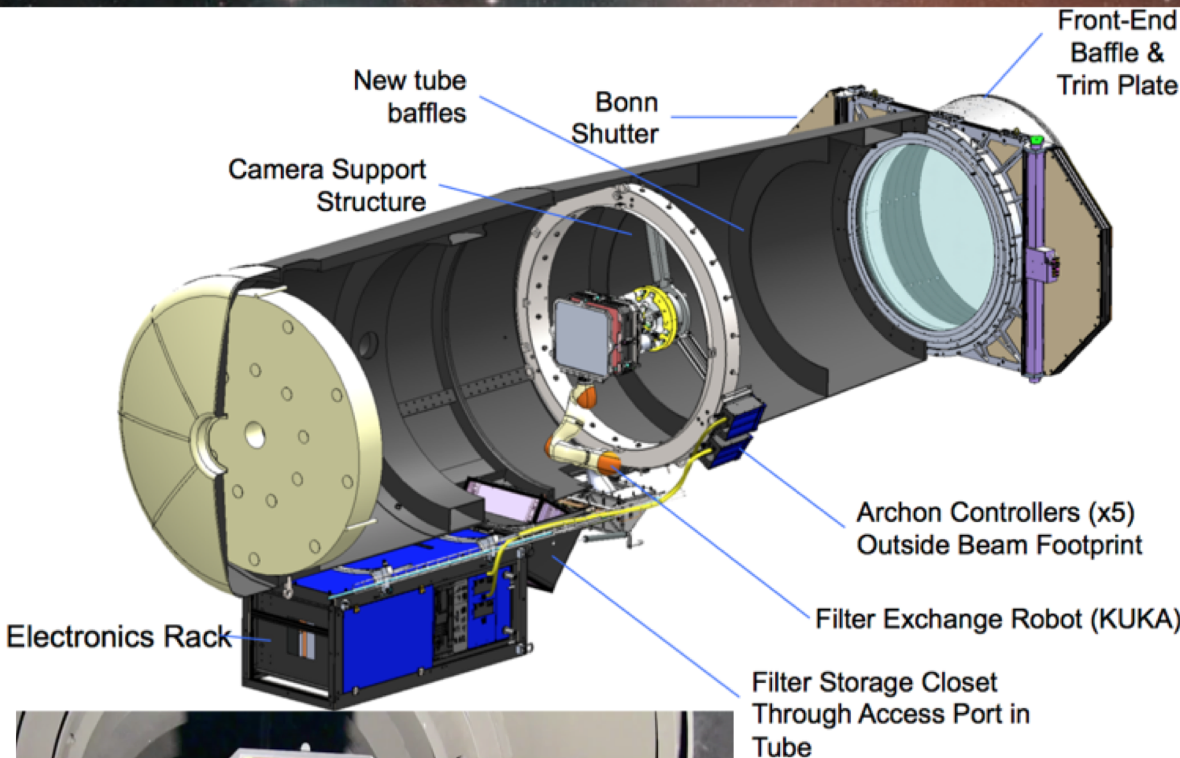
IN2P3@ZTF-II (LPNHE, LPC, IP2I, CPPM)

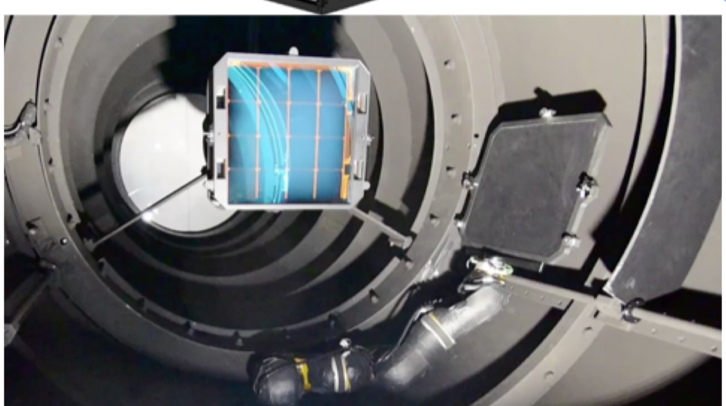


Requirement: Bring the uniformity of the survey to the 0.1%-level

ZTF Zwicky Transient Facility

Systematic Exploration of the Dynamic Sky



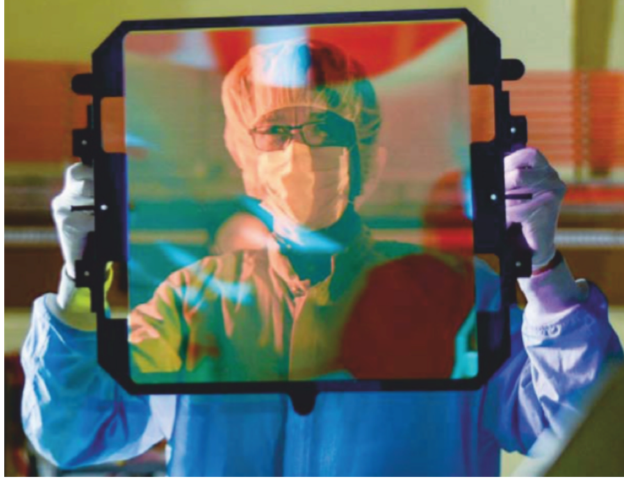


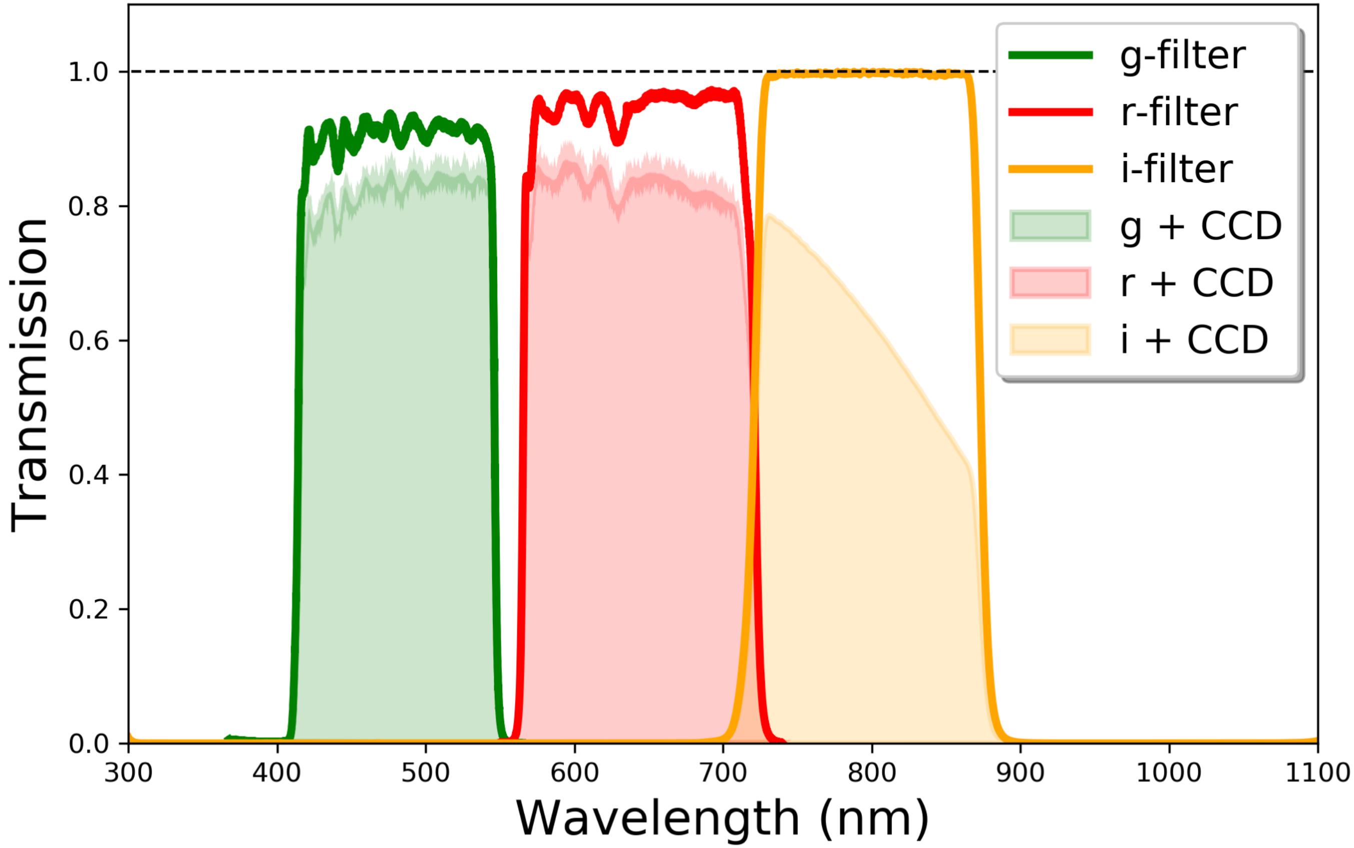
- Palomar Observatory
- Samuel Oschin 48-inch Schmidt telescope
- Camera 36 cm × 36 cm
  - 16 thin CCDs (≈ 16 µm)
  - 600 Mpixels (15 µm)
- Field-of-view = 47 deg^2
- Pixel resolution = 1 as
- Exposure time = 30 s
- Filters : g, r and i
- Limiting magnitude ≈ 21 (SN Ia with $z < 0.1$)

Filter transmission

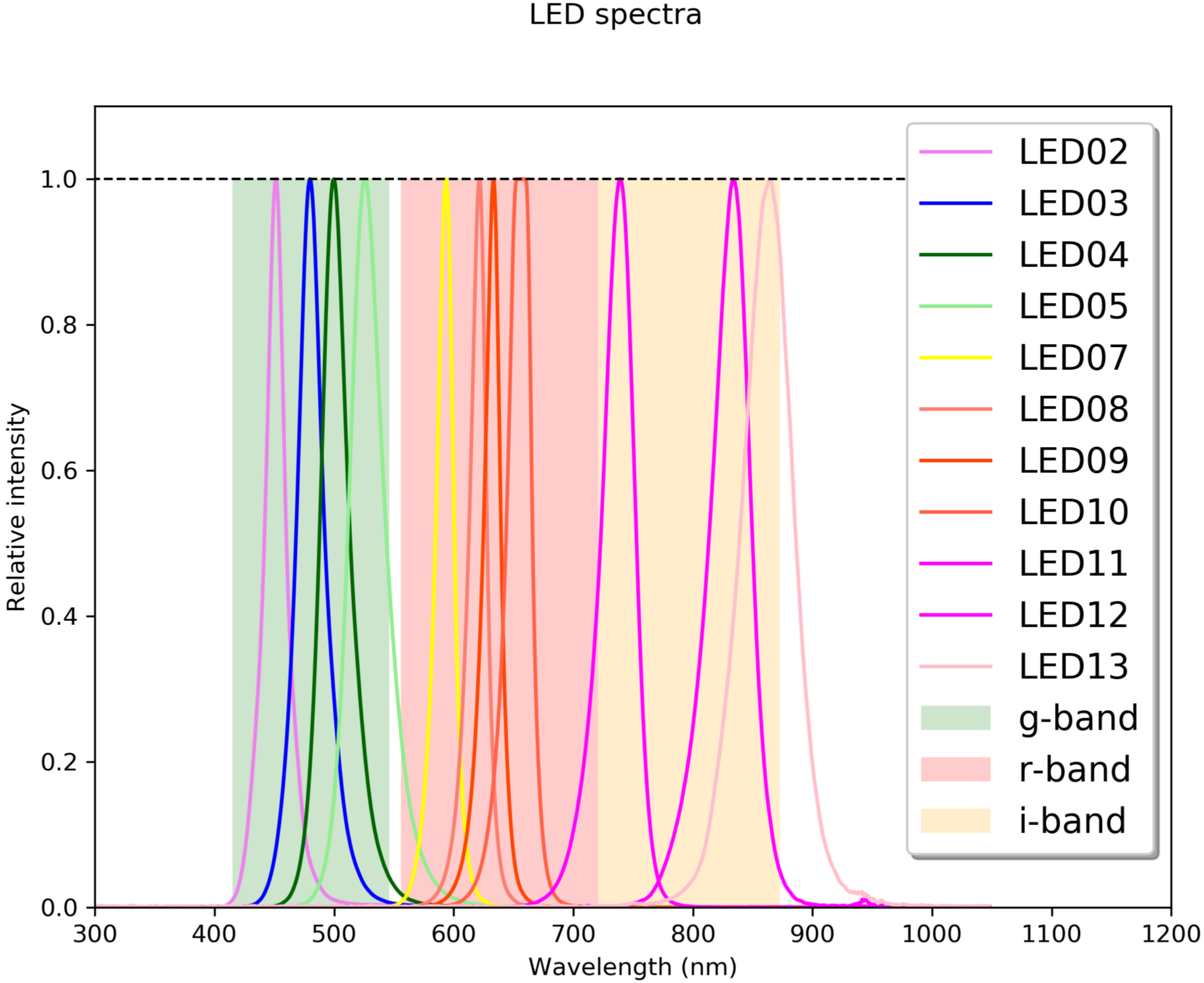
Measured filter transmission without and with CCD quantum efficiency

Sky & Telescope, June 2019

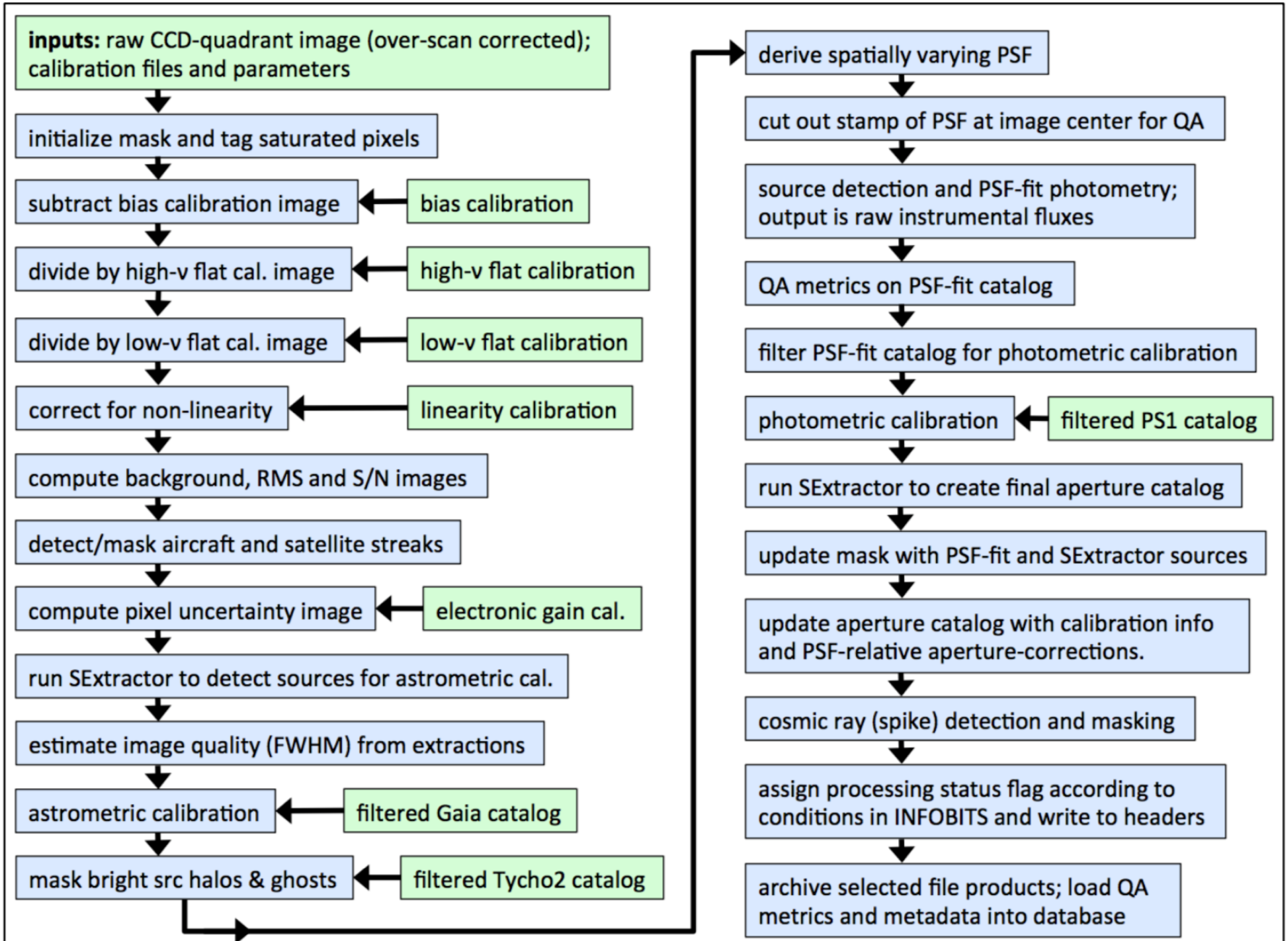




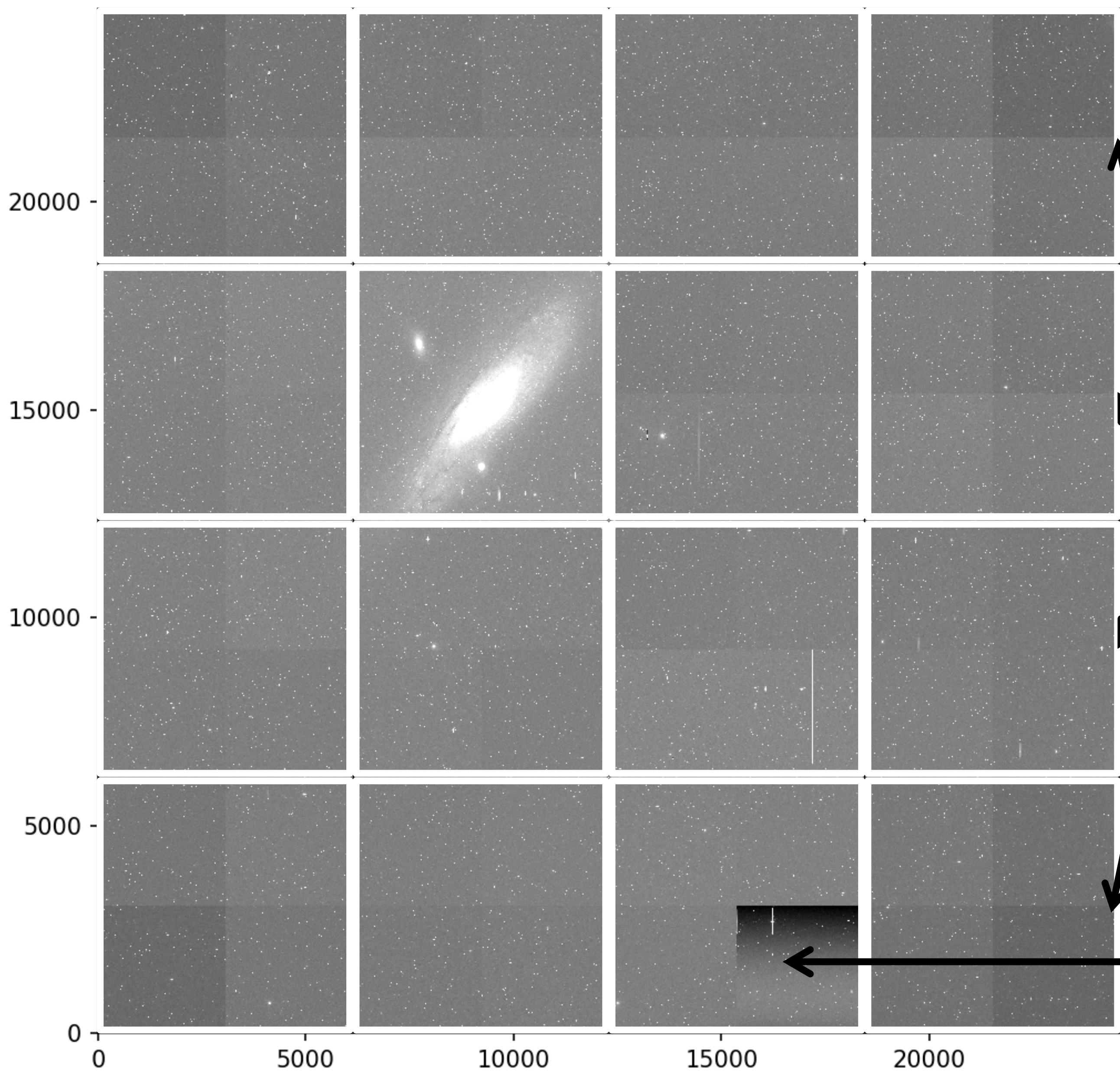
LED spectra for dome-flat



ZTF instrumental & astro/photometric calibration pipeline



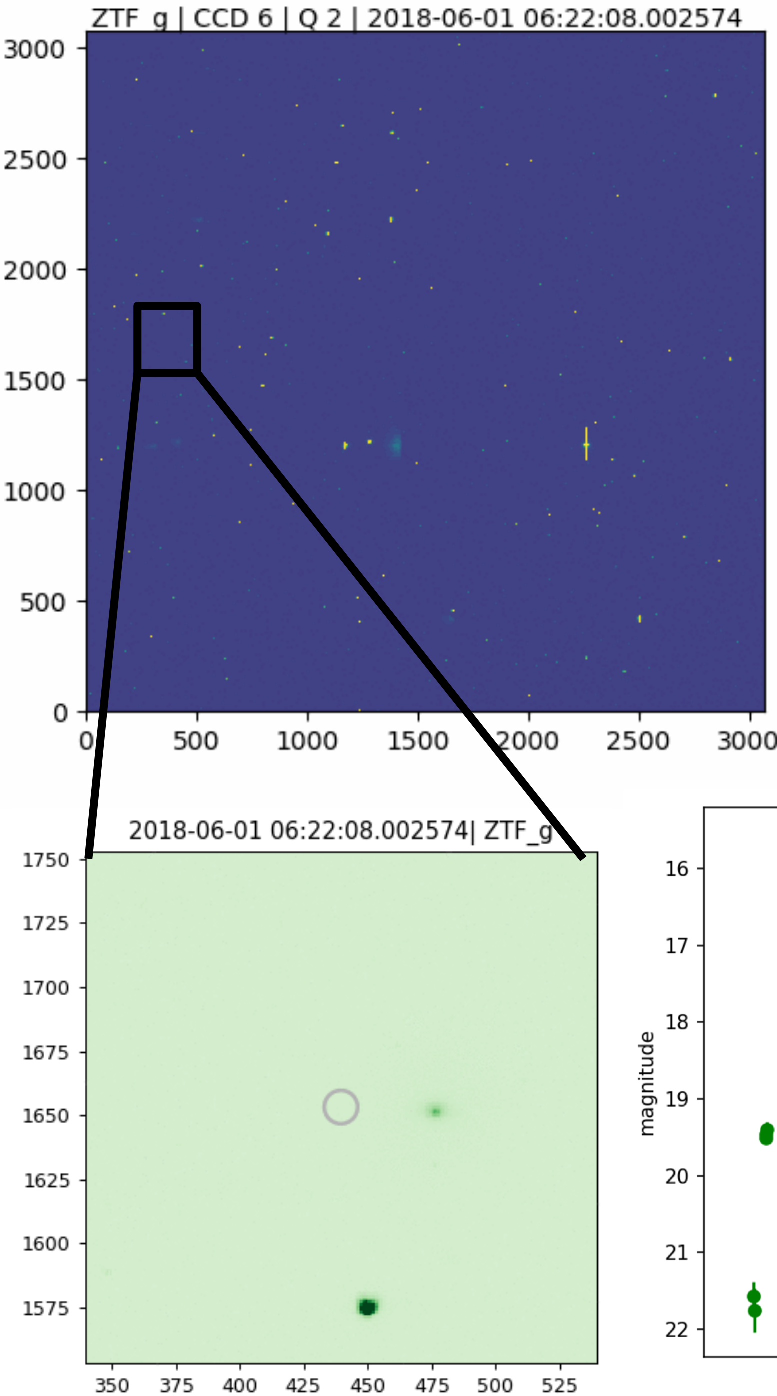
ZTF science image (M31 field): r-Band



- 16 CCD (6k × 6k pixels)
- 4 readout channels or quadrants per CCD
- **ZTF pipeline per quadrant**

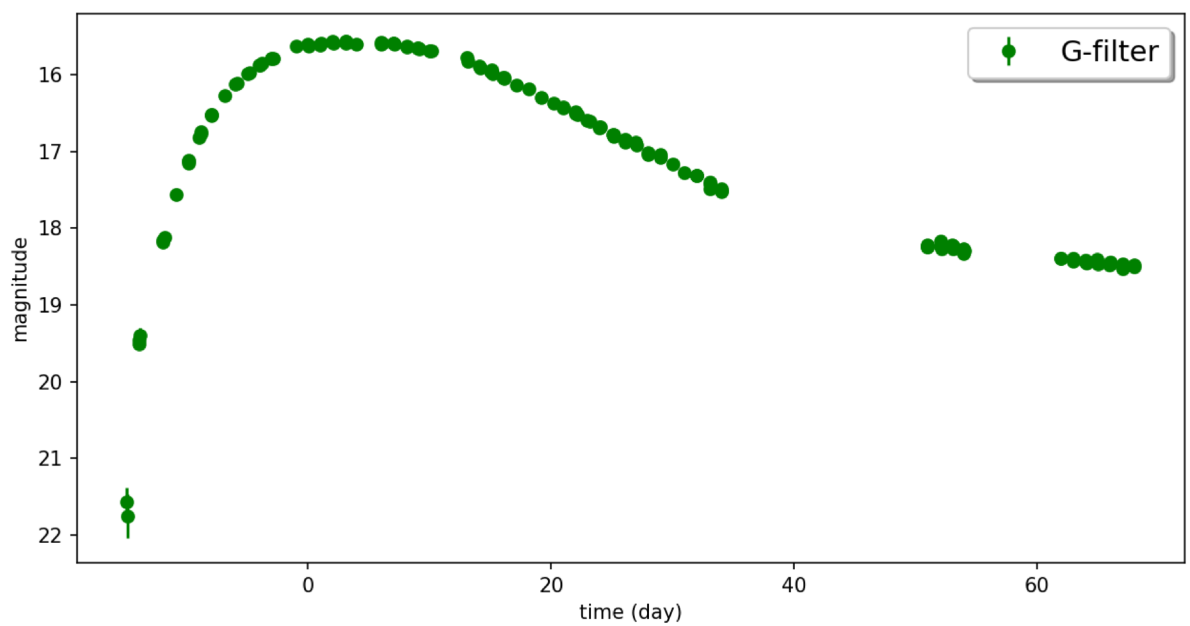
Bad overscan subtraction

Typical SN Ia light-curve (g-band)



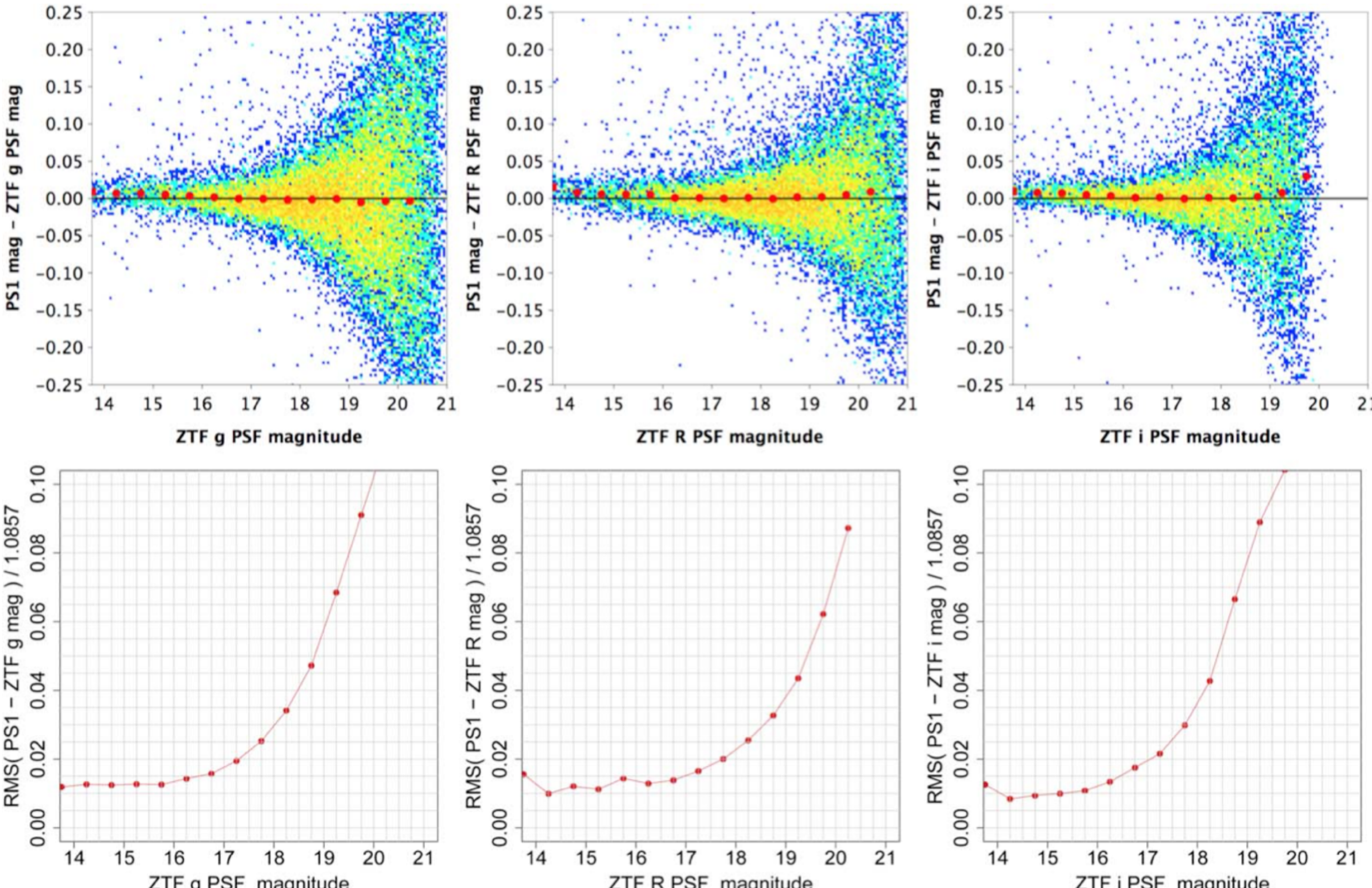
<u>ZTF18abauprj</u>

- NGC 6279
- z = 0.024



Current photometric performance

Masci et al., PASP131, 2019



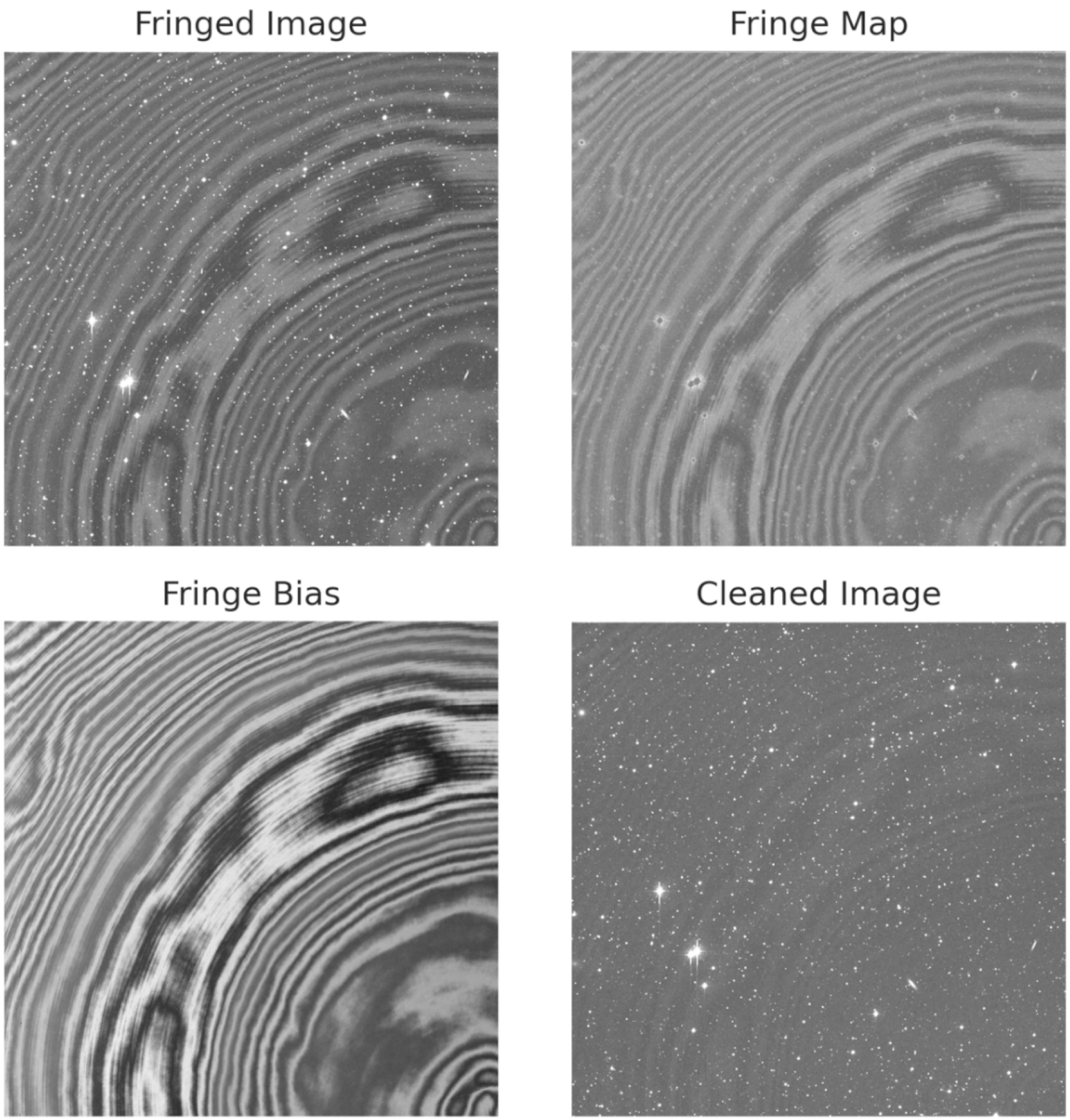
$$g^{PS1} - g = ZP_g + c_g(g^{PS1} - r^{PS1})$$
$$r^{PS1} - r = ZP_r + c_r(g^{PS1} - r^{PS1})$$
$$i^{PS1} - i = ZP_i + c_i(r^{PS1} - i^{PS1})$$

ZTF PSF-fit w.r.t. PS1-catalog calibrators

- Bias up to 20 mmag
- RMS scatter ~1.5% for magnitude < 18

i-band fringing

- Sky spectrum = atmospheric emission lines from non-thermal atomic and molecular transitions
- CCD self-interference caused by multiple internal light reflexion before absorption
- Fringe patterns mainly in i-band ZTF images due to wavelength dependency of absorption length in silicon
- Subtraction of fringe pattern implemented in ZTF pipeline since January 2020



Removing Atmospheric Fringes from Zwicky Transient Facility i-Band Images using Principal Component Analysis

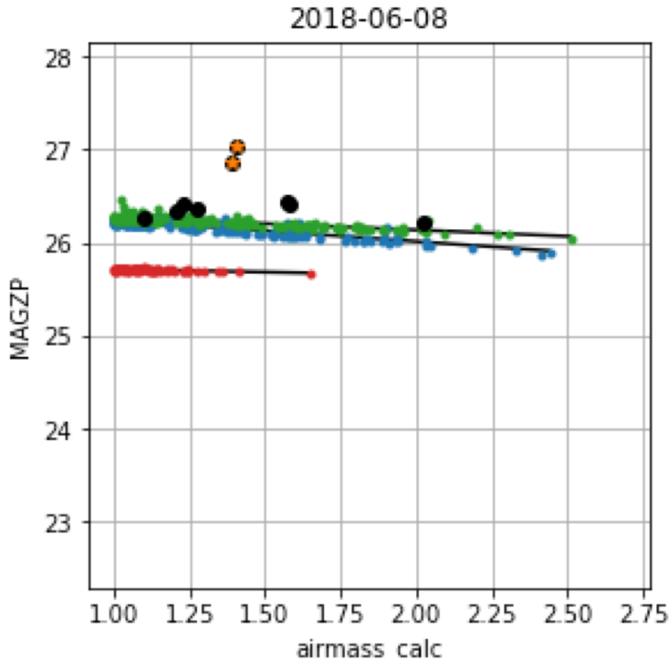
Michael S. Medford,[1,2] Peter Nugent,[2] Danny Goldstein,[2] Frank J. Masci,[3] Ron Beck,[3] and Michael W. Coughlin[4]

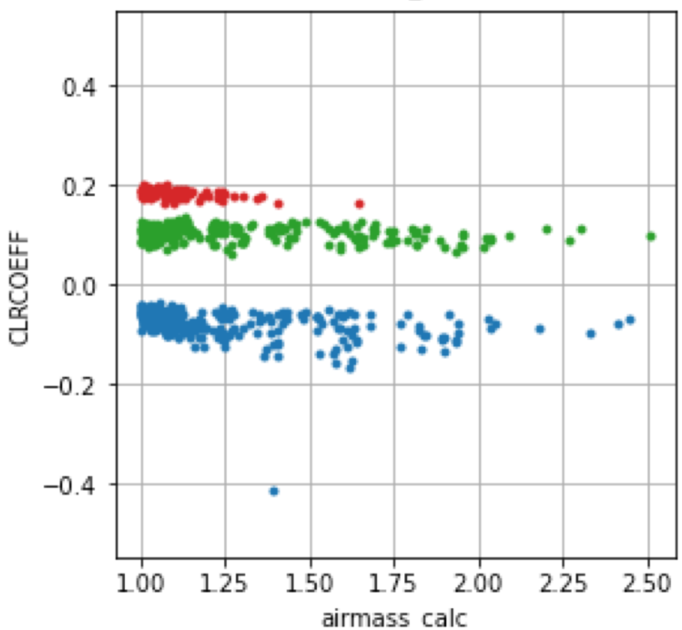
Limits of current photometry

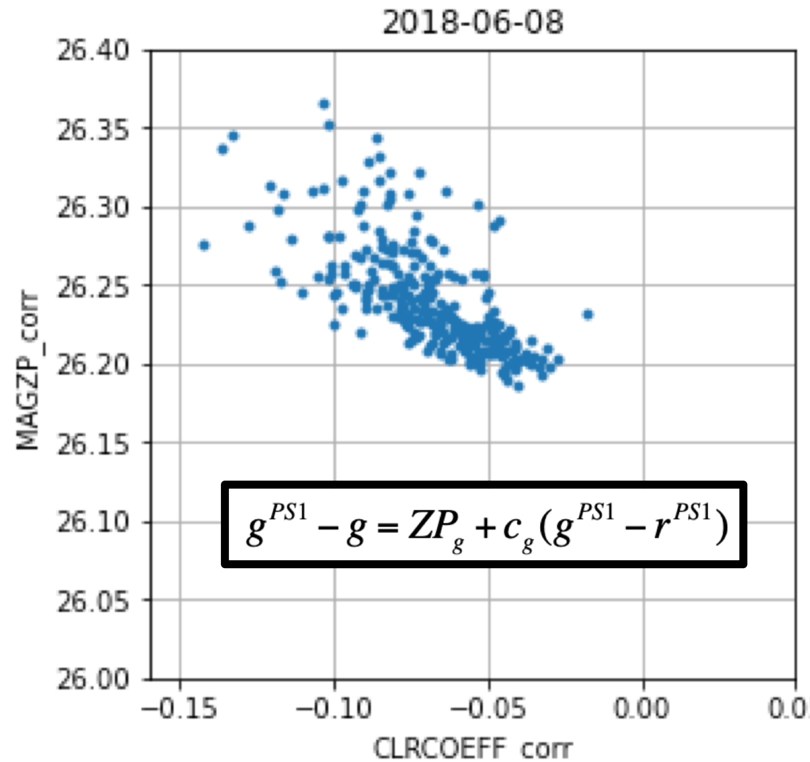
- **Filter transmission mapping**
  - To be done with a monochromatic collimated beam projector ☞ LPNHE
- **Fine sensor characterization**
  - Brighter-fatter effect ☞ P. Antilogus with the help of R. Zouhhad (M1)
  - CCD thickness investigation ☞ PR
- **Focal plane non uniformity**
  - Spatial residual map ☞ A. Drake (Caltech)
  - Star-flat analysis ☞ E. Robert (M2) with M. Rigault
- **PSF modelling**
  - Adaptation of PIFF code to ZTF -> ZIFF to investigate PSF modelling ☞ M. Rigault (R. Graziani)
- **Photometric calibration**
  - Airmass dependency ☞ M. Amenouche (PhD, LPC), B. Racine & F. Feinstein
  - Calibrator choice: Gaia versus PS1 ☞ M. Cherrey (M2) with PR
  - Multi-epoch fit ☞ M. Amenouche

Benjamin & Fabrice

Airmass dependency



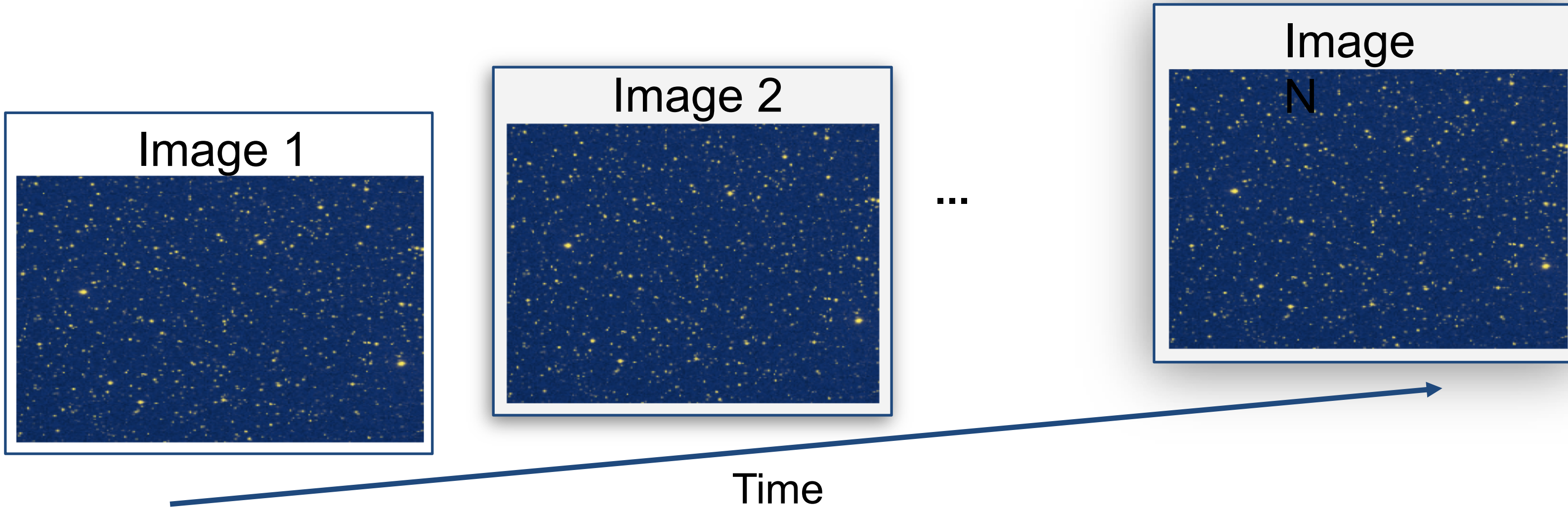




- ZP biased by colour term compensation in linear photometric fit
- Global airmass correction can not remove this dependency

Melissa

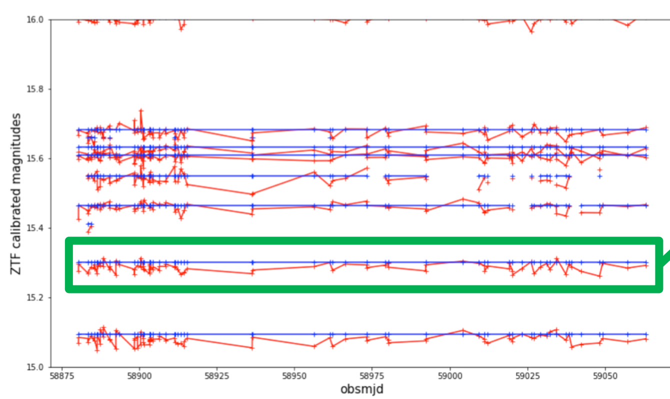
Multi-epoch fit: principle



- Fitting a series of images of the same field-of-view = same calibrators = unique colour coefficient

$$r^{PS1} - r = ZP_r + c_r(g^{PS1} - r^{PS1}) + \alpha_r(x-1) + \beta_r(x-1)(g^{PS1} - r^{PS1})$$

- Addition of the airmass x dependency for each calibrator



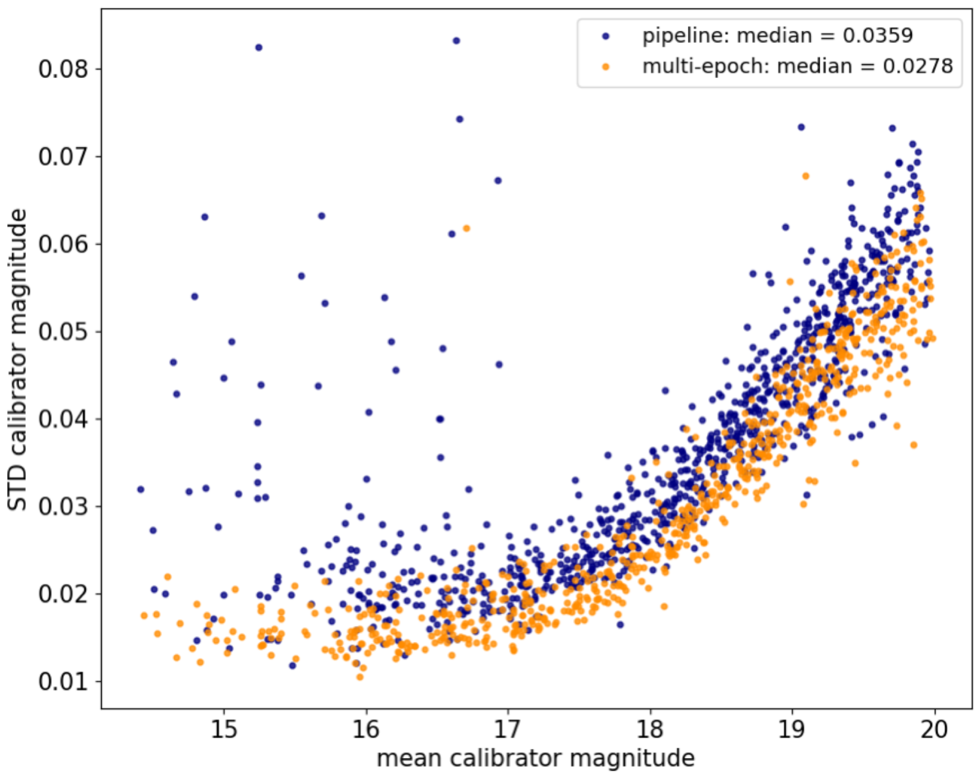
Maxime

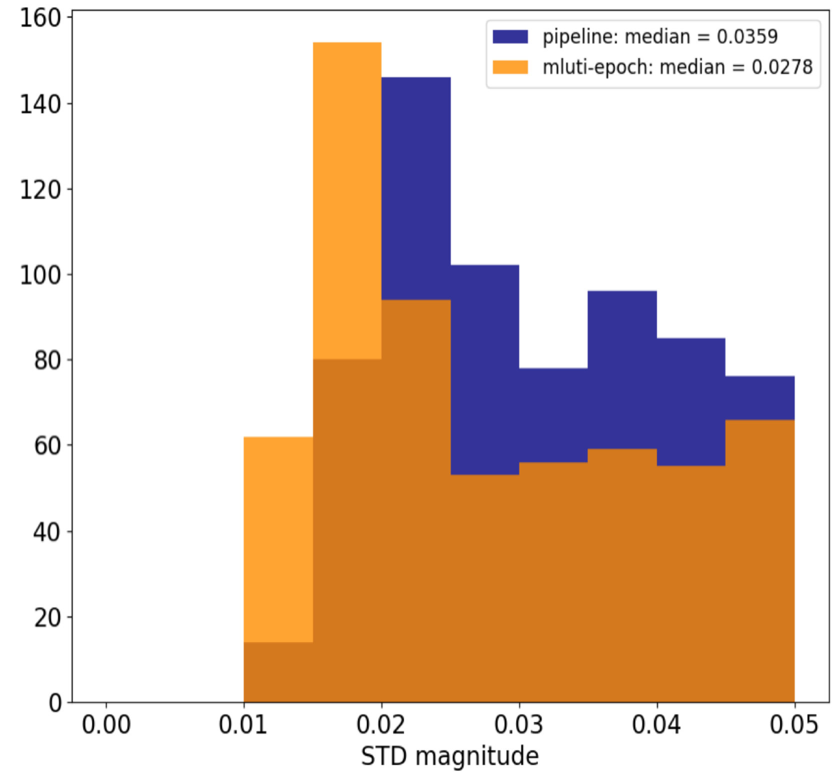
Photometry performances estimated via calibrator light-curve

- $\langle m \rangle - m^{PS1}$ ➔ calibration bias
- σ_m ➔ calibration precision

Melissa

Multi-epoch fit: results

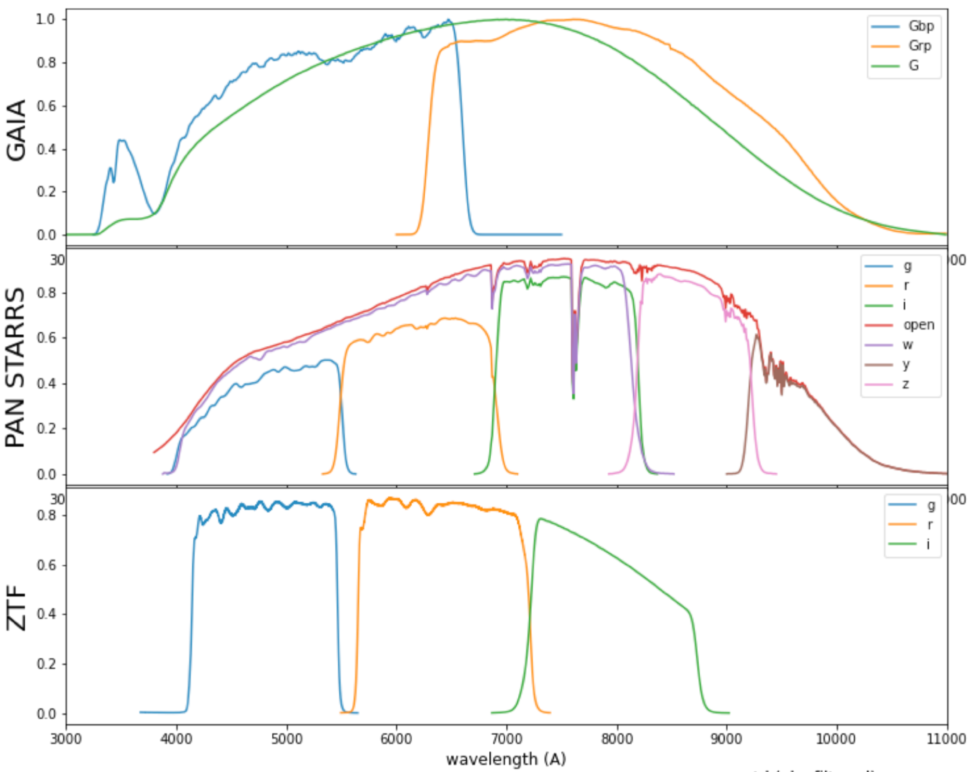


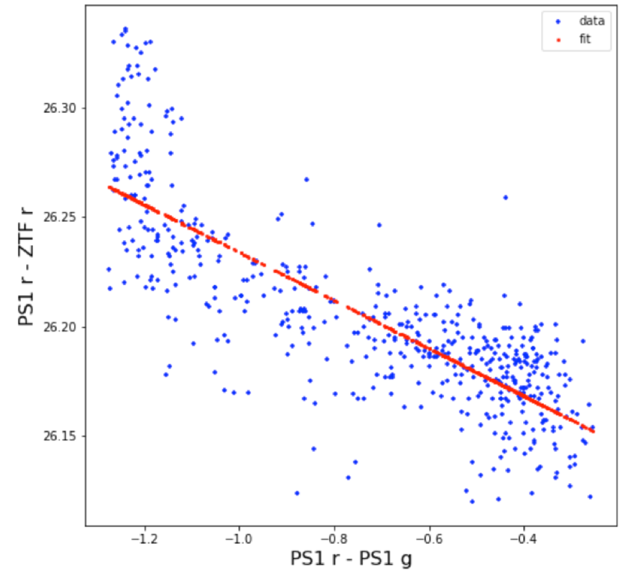


- Study limited to 1 field, 1 quadrant and 1 filter (r-band)
- Improvement of photometric performances
- Study to be generalized over the mosaic, filters and fields

Maxime

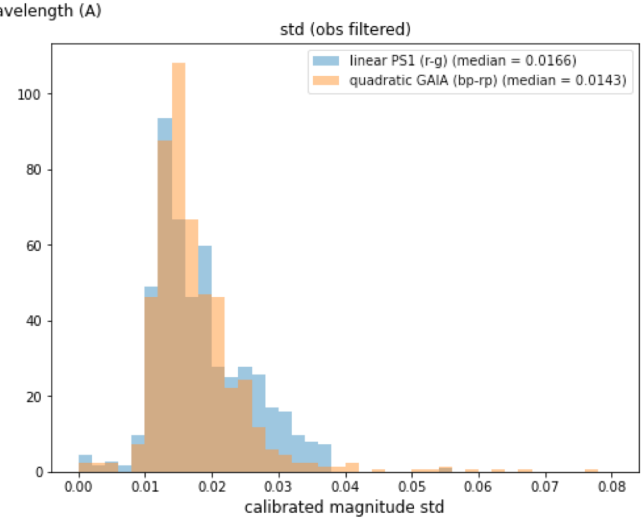
Calibrator choice: ~~PS1~~ -> Gaia ?

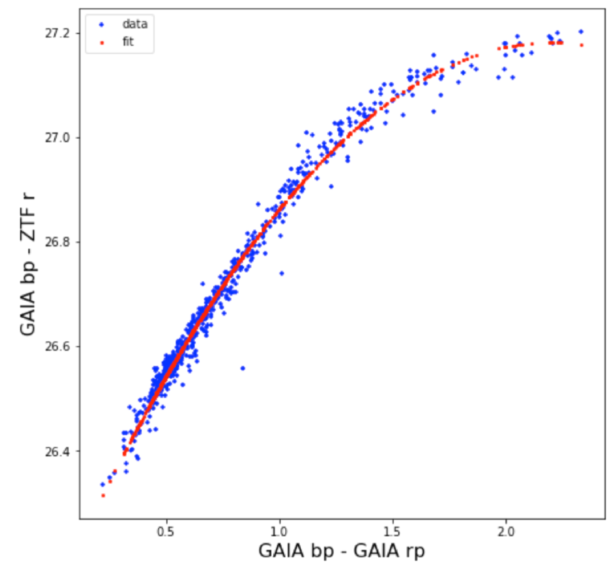




- Results for r-band with m < 18 similar to PS1 calibrators

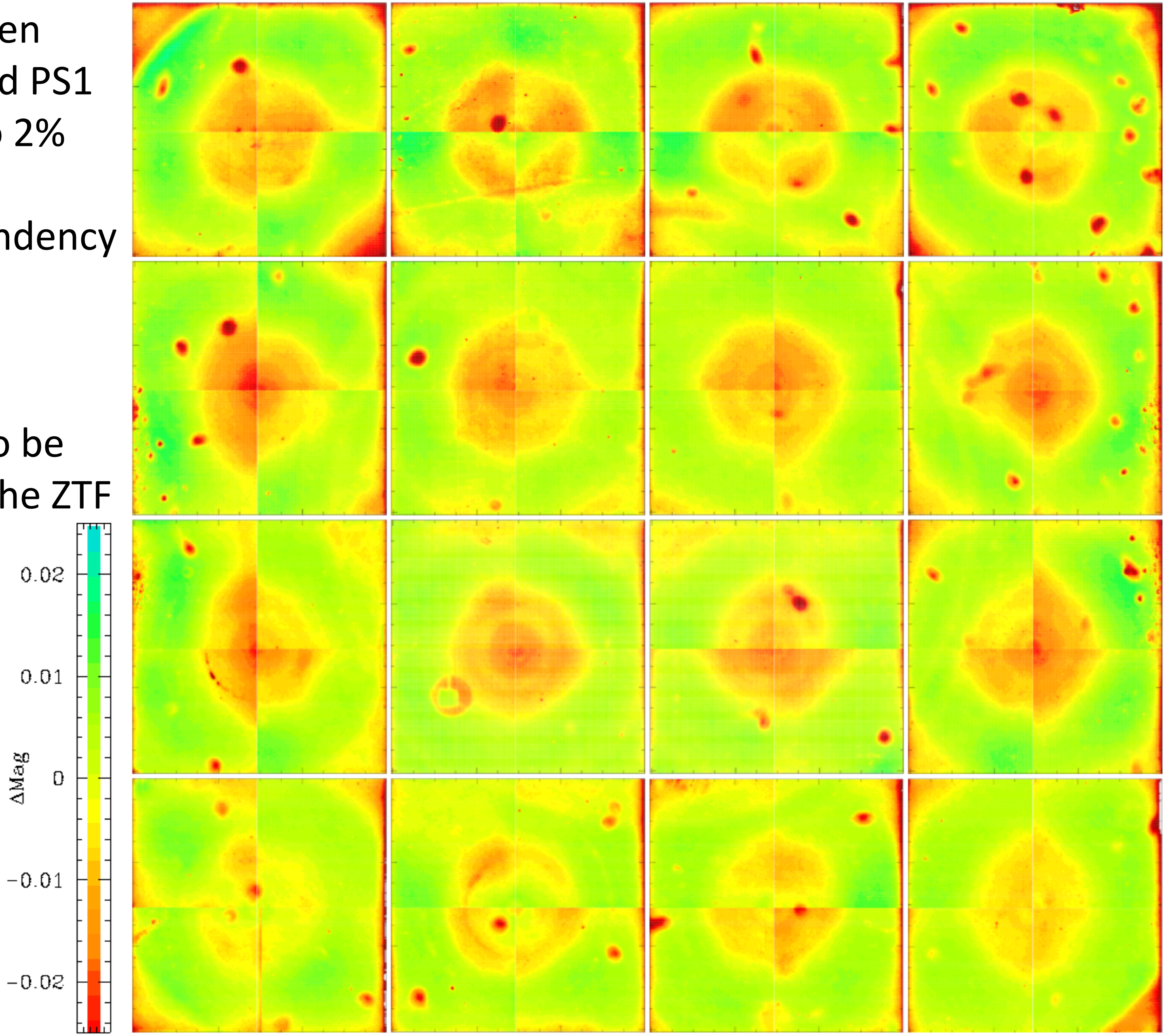
- But Gaia survey uniformization?





Spatial residual map: g-band

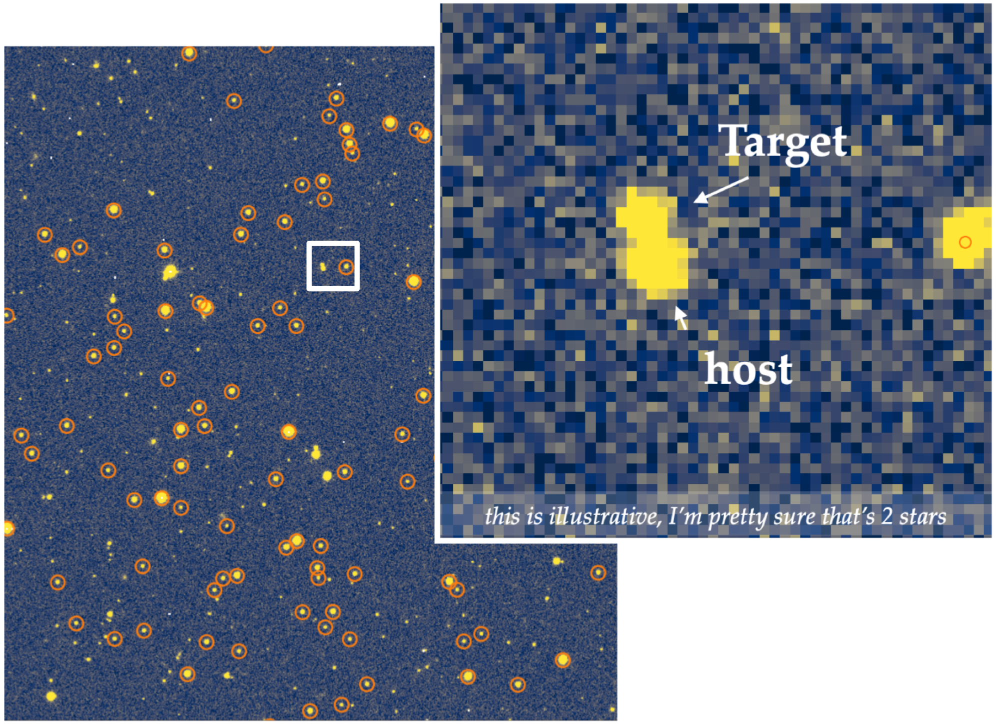
- Difference between ZTF-calibrated and PS1 magnitudes up to 2%
- Strong CCD dependency
- Dust spots
- Map scheduled to be implemented in the ZTF pipeline



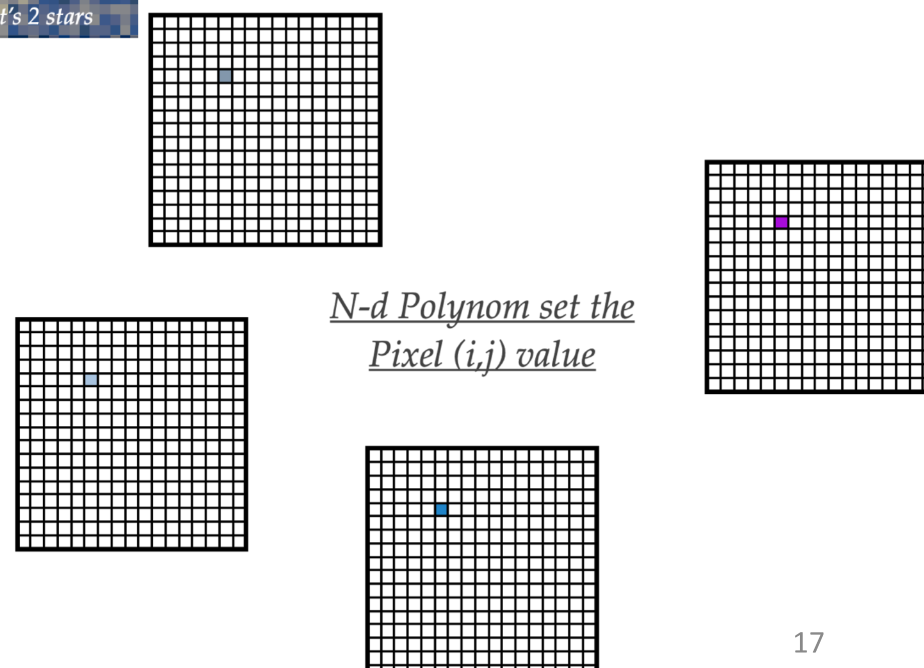
Mickael

PSF modelling

PIFF [Jarvis et al. 2021] adapted and applied to ZTF



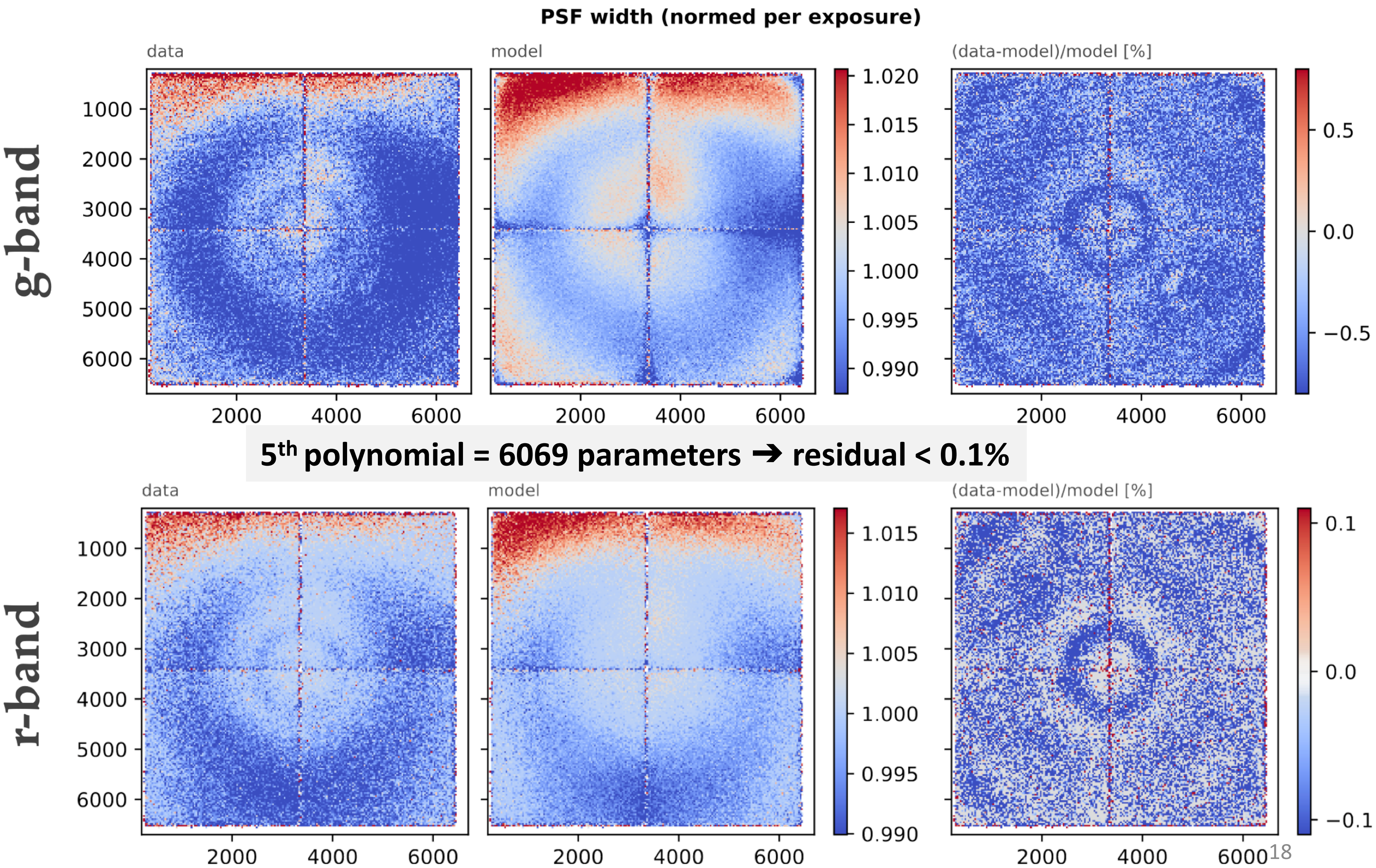
X% error on PSF 'width' corresponds to about X% error on flux



Model = PixelGrid (17px × 17px) & N-d polynomial interpolation

Mickael

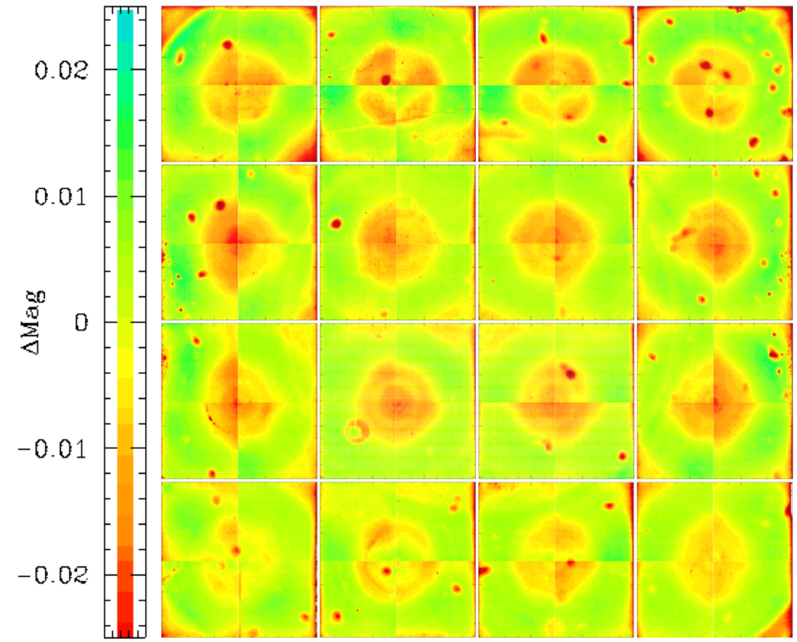
PSF modelling: results (CCD07)

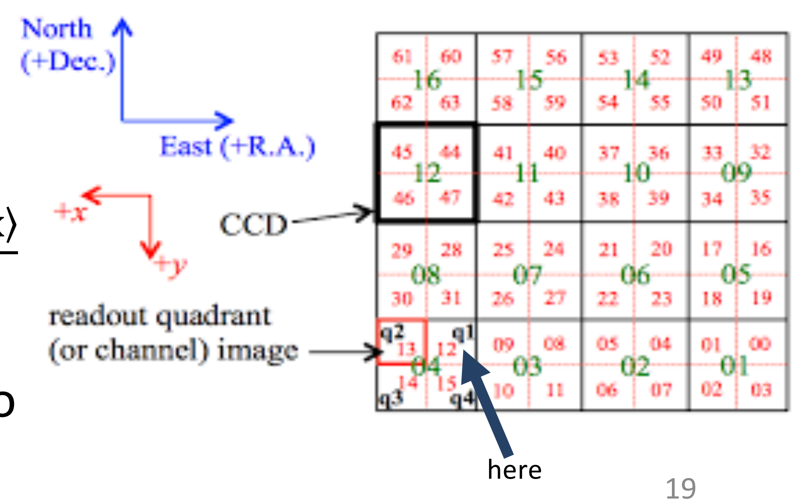


5th polynomial = 6069 parameters ➔ residual < 0.1%

Star-flat: introduction

- **Goal**: comparison between PSF models and aperture photometry
- **ZTF images**
  - Observation day: 2018-02-21
  - CCD 4, q1
- **Aperture photometry algorithm**
  - Isolated (no objects in 20" Gaia catalog) and no saturated stars
  - Radius between 1 and 15 pixels
  - Background subtraction
  - Flux computation (*SEP module Python*)
- **Star-flat: residual map per stars** $= \frac{\text{flux} - \langle\text{flux}\rangle}{\langle\text{flux}\rangle}$
  - Binnig of u,v (focal plan coordinates)
  - In each bin, perform median of this ratio

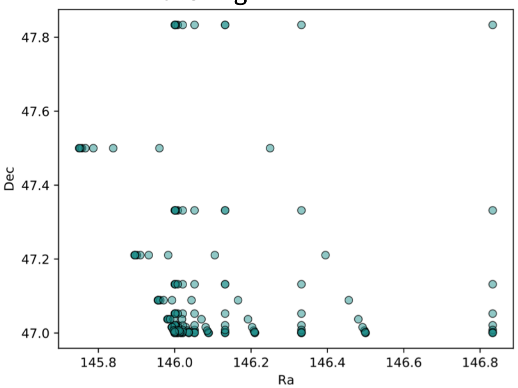




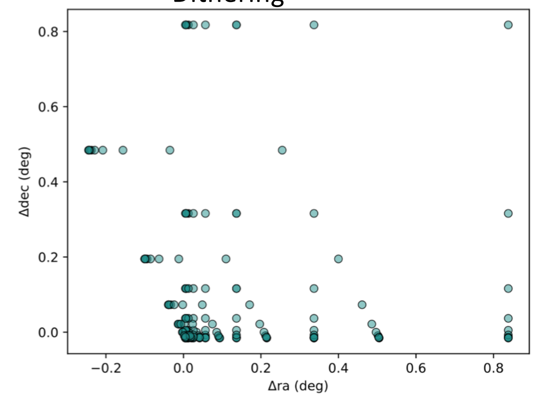
Star-flat: statistics

Estelle

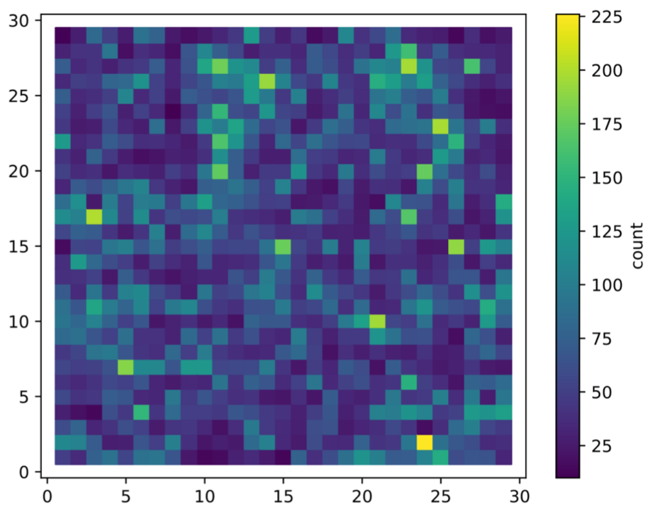
Dithering



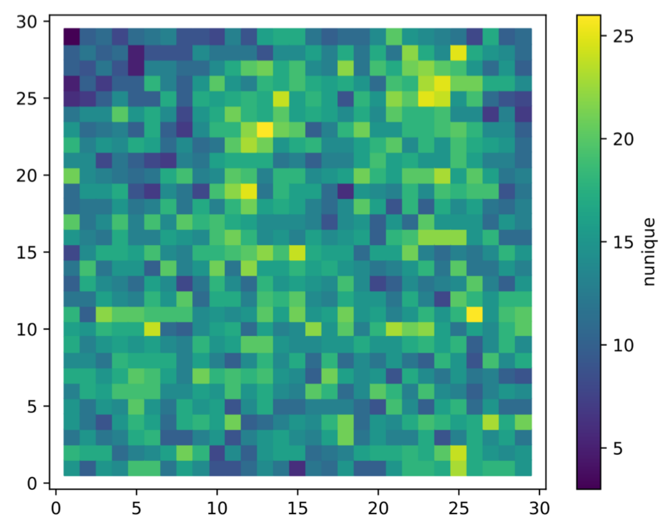
Dithering



[{'CCDID': 4, 'QID': 1, 'RCID': 12}]



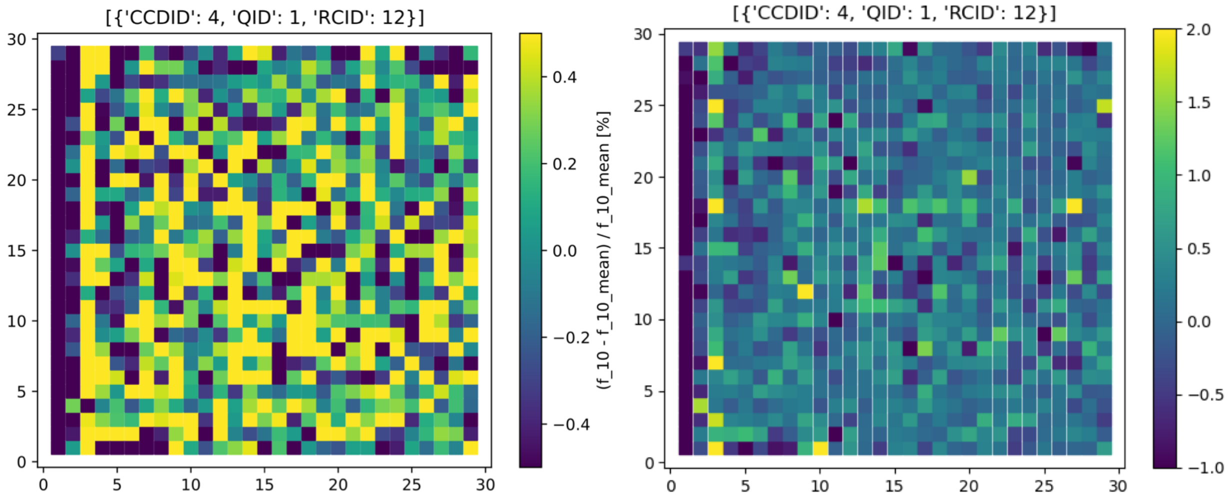
All stars



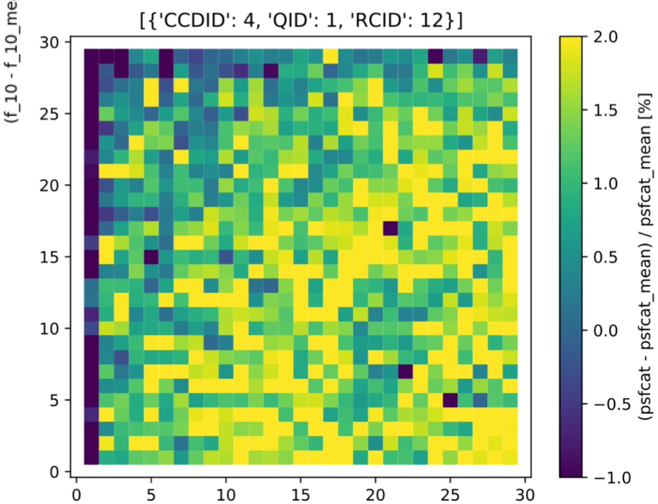
Unique stars

Star-flat: preliminary results

gmag range: [12,18]



Aperture photometry



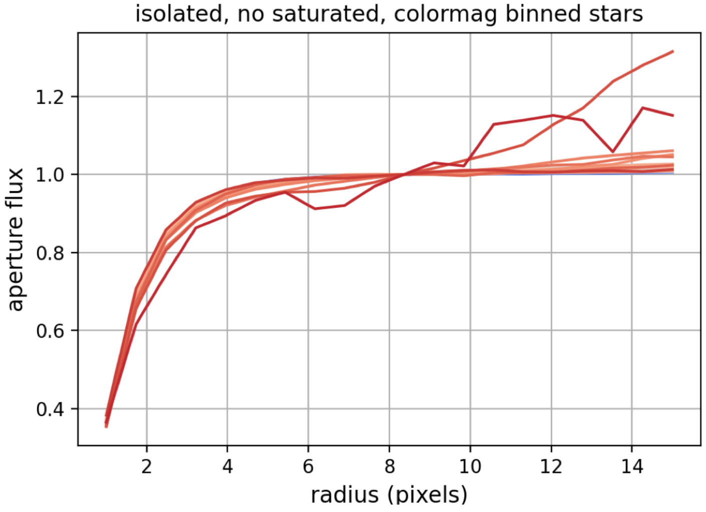
ZTF PSF

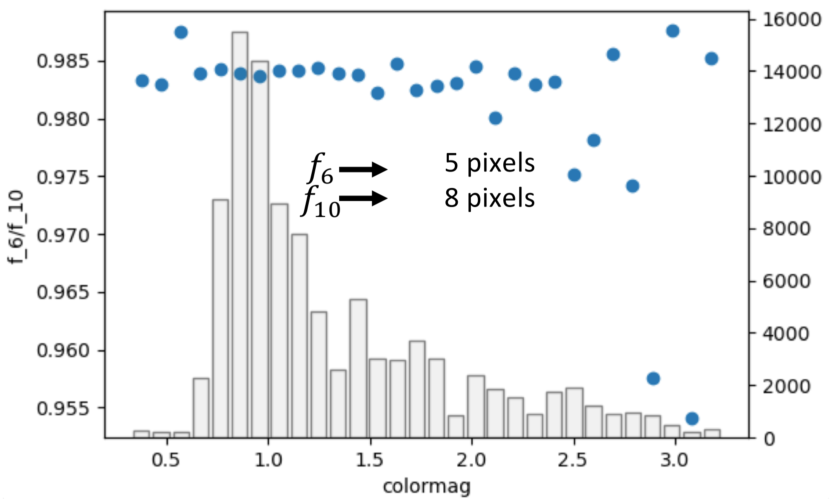
- Result with 203 images
- Spatial residual with aperture photometry much smaller compared to ZTF PSF

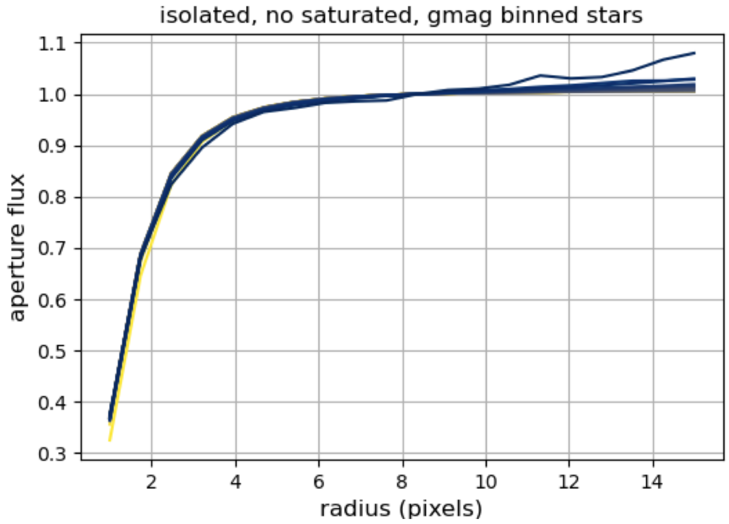
Estelle

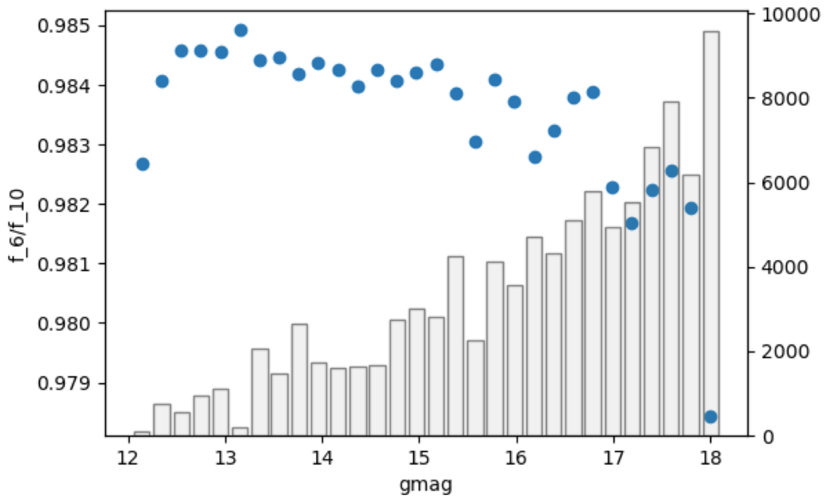
Star-flat: more on the aperture photometry

- Binning fluxes w.r.t. colormag or gmag in gmag range [12;18]
- Computing ratio between 2 fluxes for 2 different radius









Star-flat: preliminary conclusions

Estelle

- Comments
  - Opposite behaviour: for red stars PSF less spread
  - Issue with background subtraction
  - Aperture curves for faints stars: impossible

- Next?
  - Make the code run in parallel
  - Star-flat on other quadrants and CCDs to have a global view of the focal plan
  - Compare with Mickael's PSF model

Brighter-fatter: presentation

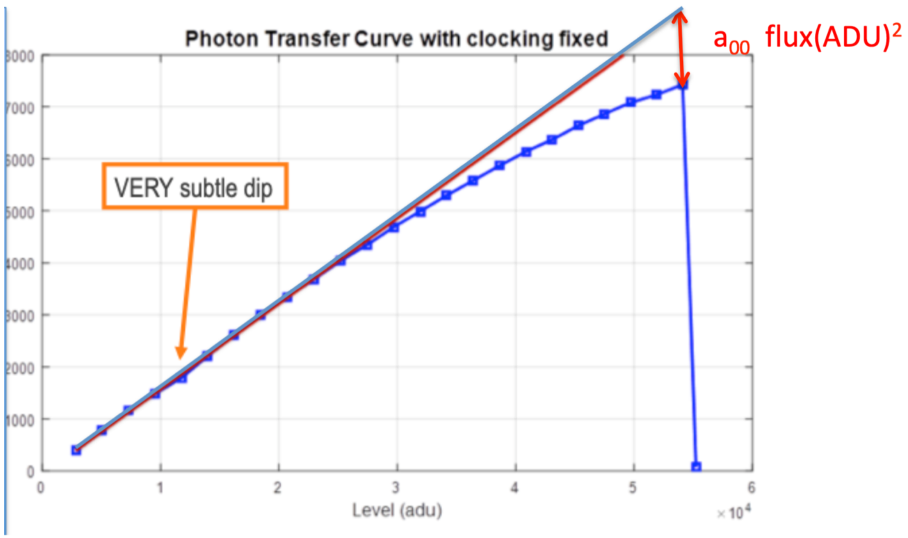
- Brighter-fatter effect: PSF spreading as a function of the flux due to electrostatic field distortions [P. Astier et al. 2019]

- Methodology: Quantification via the study of the pixels covariances

$$C_{ij}(\mu) = \frac{\mu}{g}\left[\delta_{i0}\delta_{j0} + a_{ij}\mu g + \frac{2}{3}[\boldsymbol{a}\otimes\boldsymbol{a} + \boldsymbol{ab}]_{ij}(\mu g)^2 + \frac{1}{6}(2\boldsymbol{a}\otimes\boldsymbol{a}\otimes\boldsymbol{a} + 5\boldsymbol{a}\otimes\boldsymbol{ab})_{ij}(\mu g)^3 + \cdots\right] + \frac{n_{ij}}{g^2}$$

At first order:

- $a_{ij} > 0$: change of pixel area per unit stored charge caused at a pixel located at i columns and j rows from the source pixel $(0{,}0)$
- $a_{00} < 0$: deficit in variance PTC (photon transfer curve)



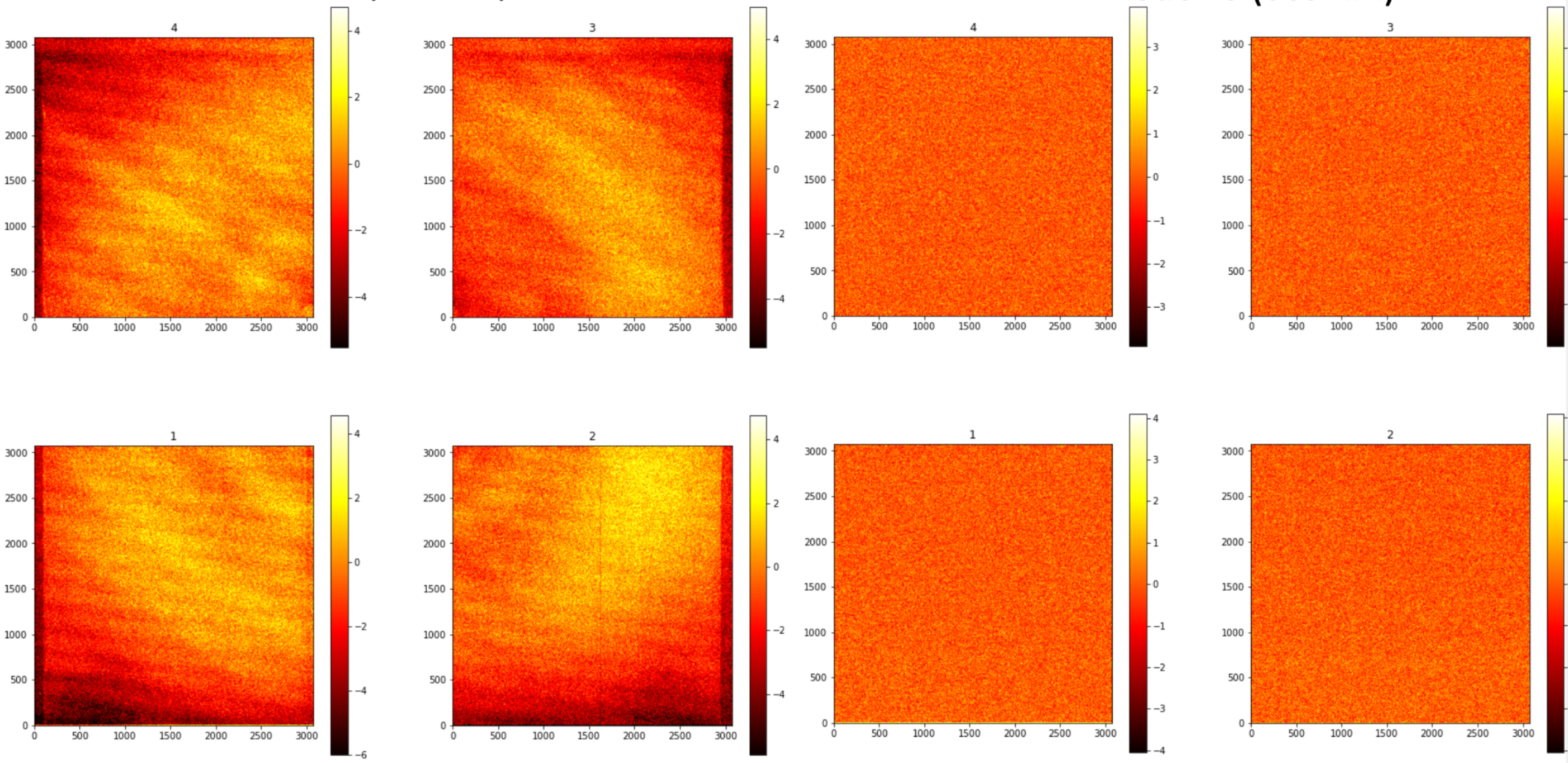
- Experimental requirement: Mean covariance obtained from dome-flat differences

Pierre & Rahima

Brighter-fatter: stacking flat # by pair

CCD07

Diode 2 (452 nm) | Diode 13 (865 nm)

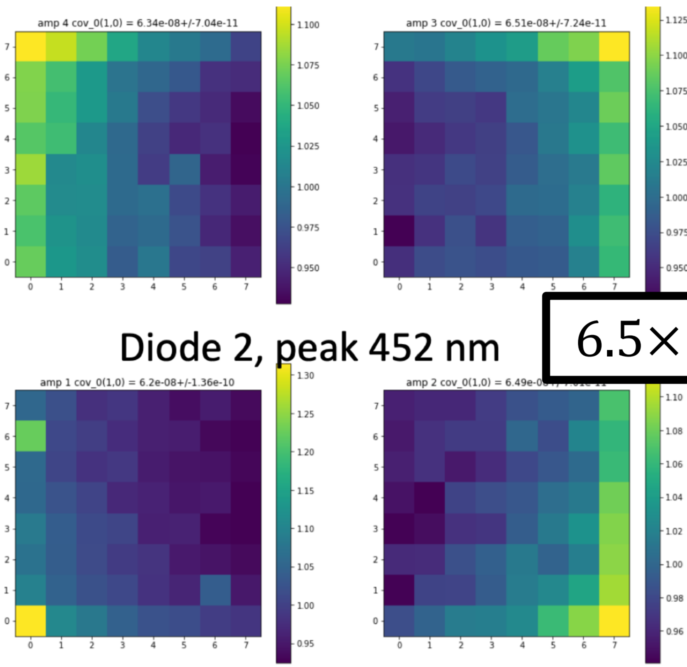


- Issue with LED (diode) 2: variation of wavelength with temperature ?
- Not 100% efficient for brighter-fatter estimation

Pierre & Rahima

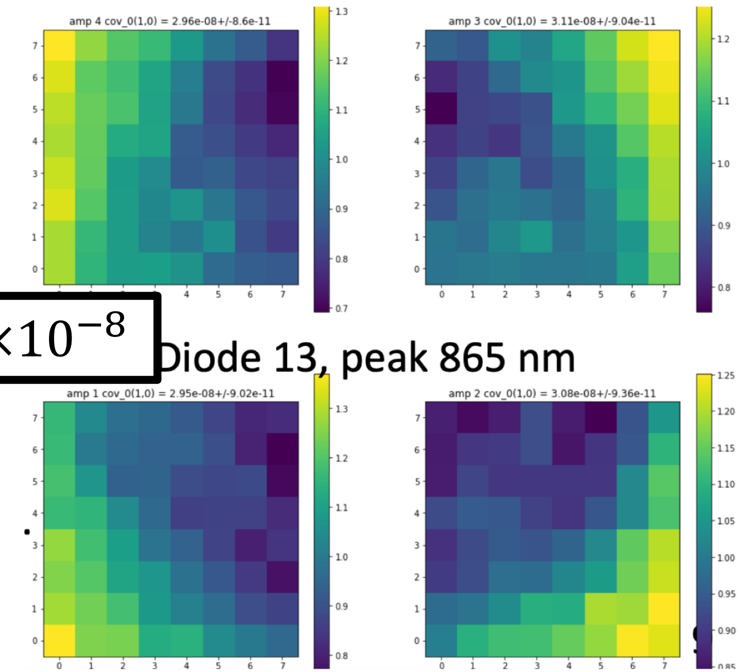
Brighter-fatter: first results (CCD07)

Example: C_{10} = covariance between serial pixels k and $k+1 \sim a_{10}\langle \text{flux} \rangle^2$



Diode 2, peak 452 nm

$6.5\times10^{-8} \leftarrow a_{10} \rightarrow 3.8\times10^{-8}$



Diode 13, peak 865 nm

First conclusions

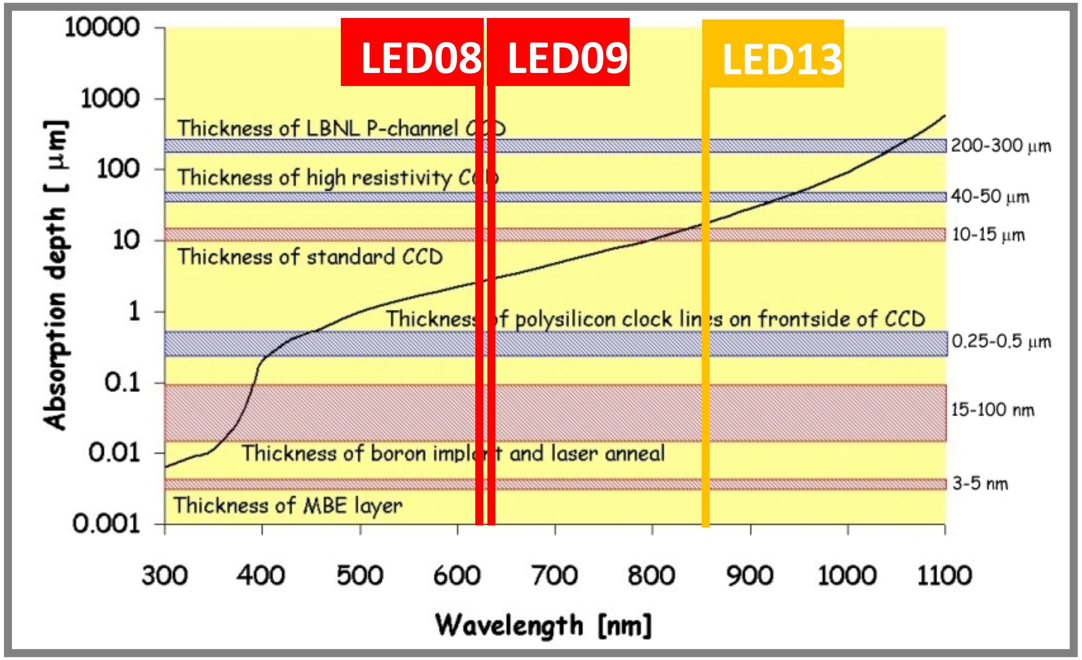
- ZTF brighter-fatter ~ 1/3 LSST brighter-fatter
- ZTF full well ~ 3 LSST full well

} Same effect

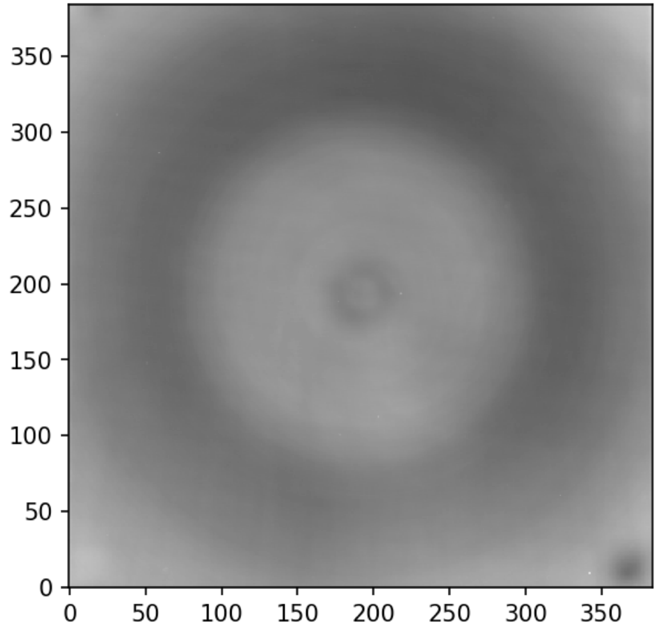
- But ZTF brighter-fatter wavelength dependent (specific to thin CCD) ⇒ difficult to manage

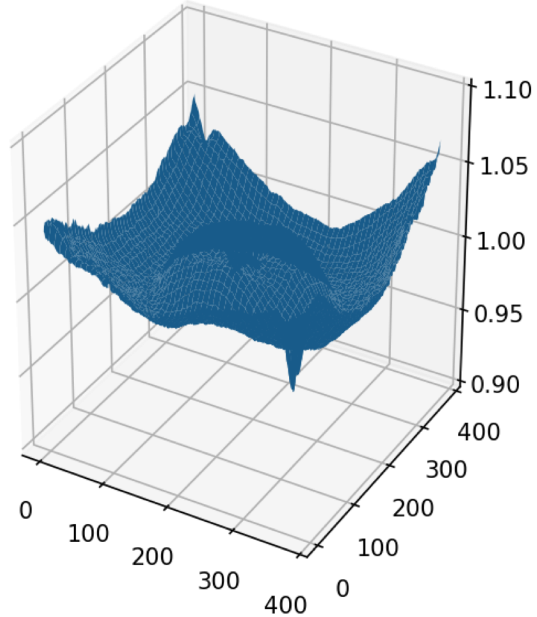
CCD thickness: introduction

Goal: try to estimate the CCD thickness variation to infer its influence on PSF via a charge transport model



CCD thickness profile proxy (CCD01):
LED13 (865 nm) / LED09 (633 nm)



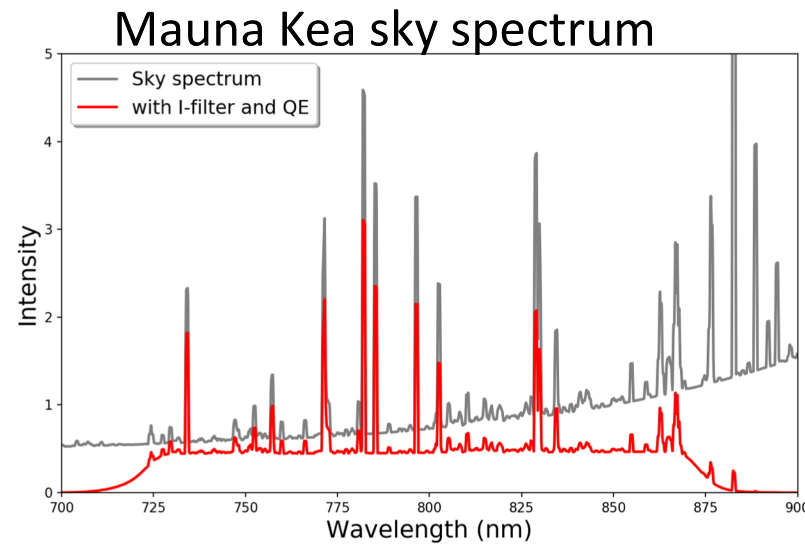


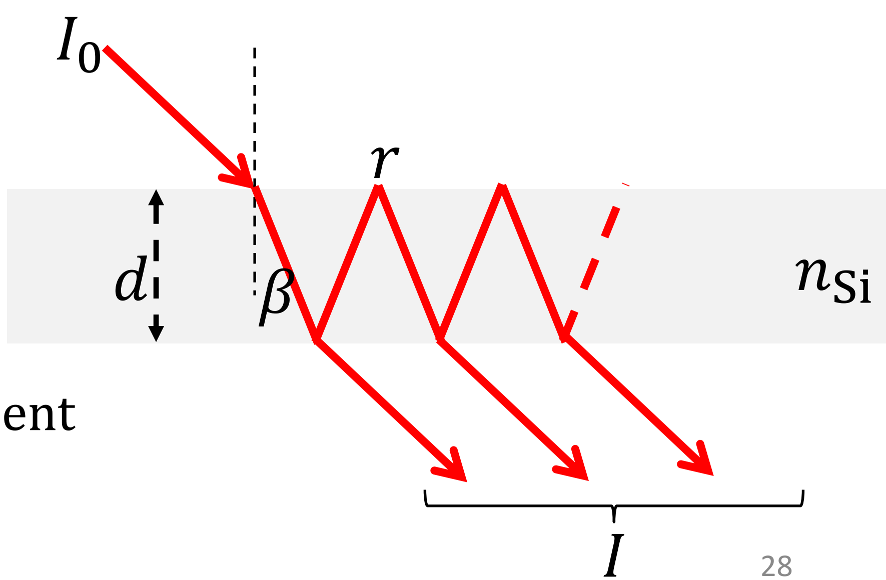
CCD thickness: forward modelling

Transmitted intensity through a thin film

$$I = I_0 \frac{a(1-r)^2}{1 + a^2 r^2 - 2\, a\, r \cos \Delta\phi}$$

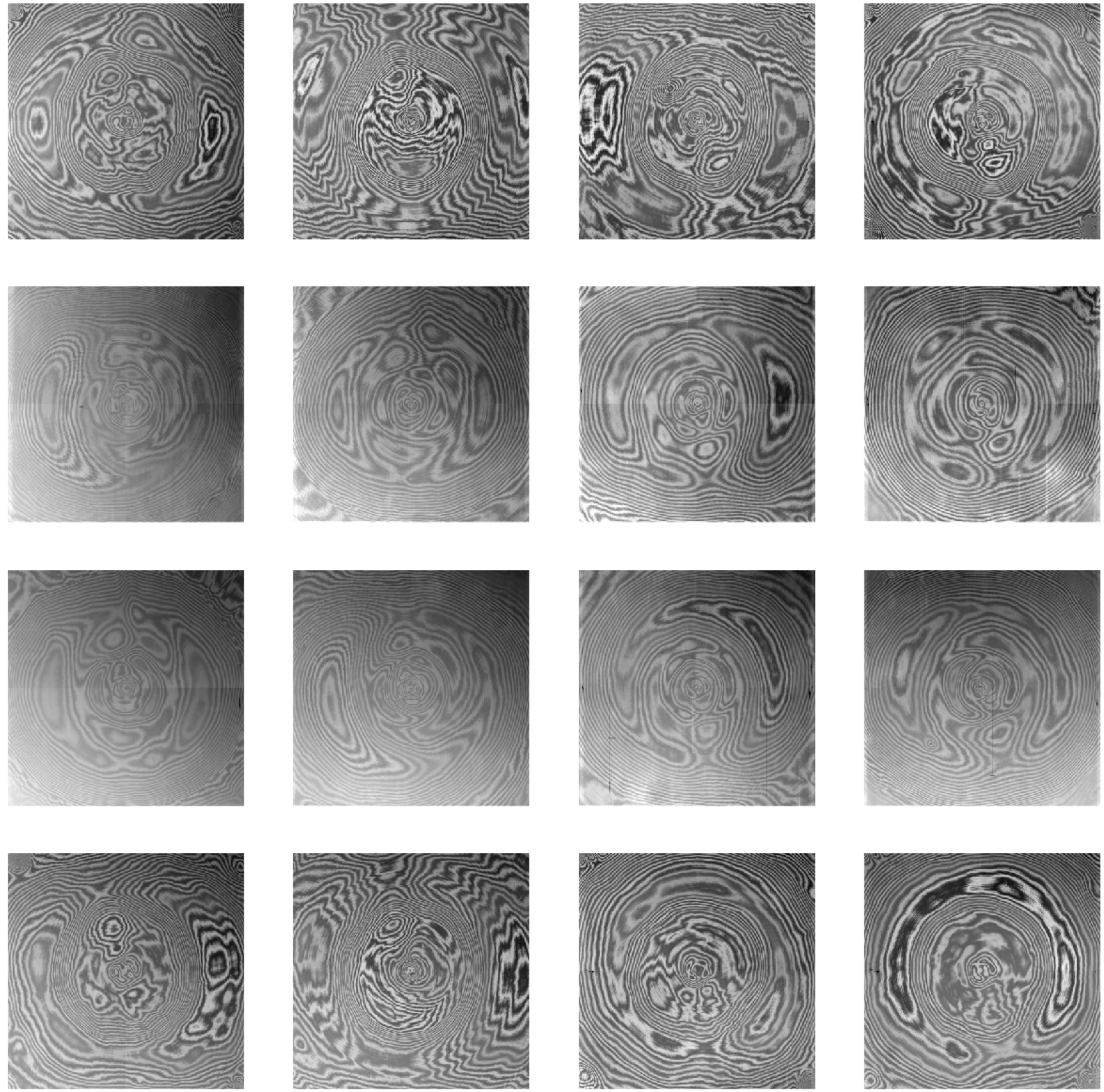
I_0 = incident light intensity
$r = 0.5$ = interface reflexion coefficient
$\Delta\phi = \frac{4\pi}{\lambda} n_{\mathrm{Si}} d \cos\beta$ = dephasing
$\mathrm{a} = \exp\left(-\frac{4\pi}{\lambda}\frac{k_{\mathrm{Si}} d}{\cos\beta}\right)$
$d = 25\ \mu\mathrm{m}$ = thickness
$n_{\mathrm{Si}} = n(\lambda)$ = Silcon refractive index
$k_{\mathrm{Si}} = k(\lambda)$ = Silcon extinction coefficient
$\beta = 0$ = angle of refraction





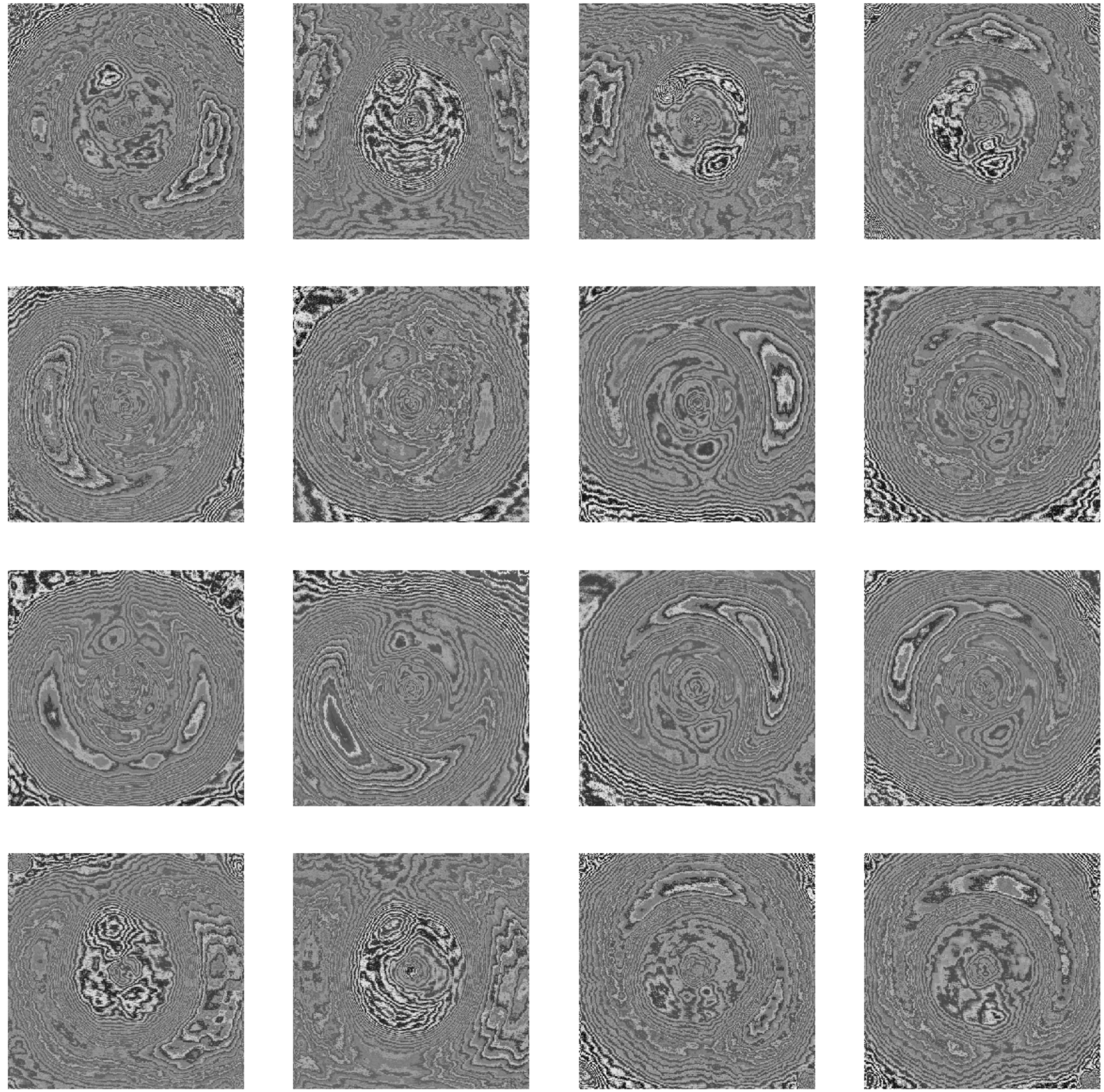
CCD thickness: observed fringe pattern

- Specific fringe pattern for each CCD
- Bigger effect on bottom and top CCD rows: single-layer anti-reflective coating, while double-layer coating for middle rows



CCD thickness: fringe pattern modelling

- Reproduction of fringe pattern for each CCD
- Potential bias to deduce CCD thickness:
  - Dependency to sky spectrum emission lines
  - the glue to fix the substrate on the package
- Further study of similar CCD with laser beam intended…



Conclusions

- **Current ZTF pipeline photometry** limited to about 15-20 mmag

- **Spatial variations** up to 20 mmag
  - seems to be related to CCD thickness variation implying spatial evolution of charge diffusion and then PSF bias, as shown by preliminary study of star-flats
  - but brighter-fatter effect also at work, to be taken into account

- **PSF modelling** with spatial variation interpolation underway: must be tested

- Room for **photometry improvements**
  - by taking into account airmass
  - With a multi-epoch fit

- Final goal of IN2P3 team: provide a **scene modelling** to ZTF Collaboration

Perspectives