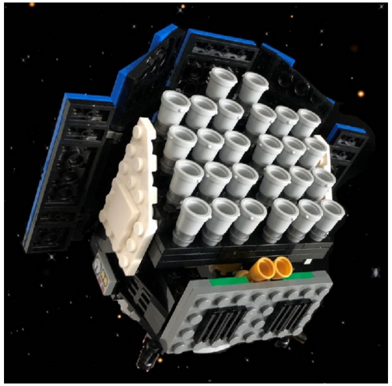


PIC inputs for photometric extraction and calibration algorithms

Réza Samadi, Victor Marchiori
and the DPA-WG

PIC meeting, Padova, 24-26 Sep. 2019

DPA inputs

- Target and contaminant stars:
  - (P) **magnitudes** and sky **positions** (ICRS)
  - **Proper motions** and **parallaxes**
  - ΔP < 10 mag ; relative accuracy: TBD (~0.05 mag)
  - Distance from the target < 4 pixels ; accuracy: < 10 mas
- Auxiliary information:
  - some color informations, e.g. T_{eff} or (Gaia) color indices: probably second-order effects (TBC)
  - Activity index, binarity flag, and variability class: for the choice of the reference stars used by the in-flight-calibration pipelines.

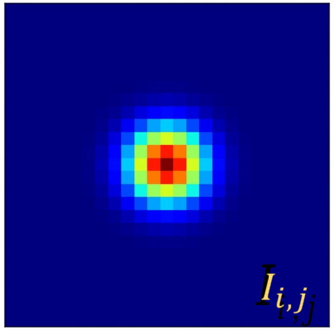
Outline

- The photometry extraction methods
- Calibration algorithms

Photometry extraction methods

PSF fitting photometry

STAR IMAGE



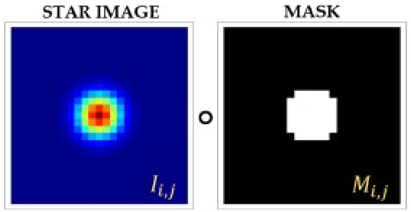
MODELLED IMAGE:

$$\hat{I}_{i,j} = a . P_{i,j}(x_c, y_c) + b$$

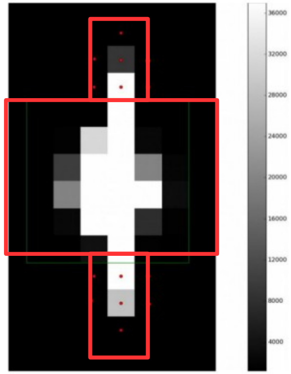
$$\chi^2 = \sum_{i,j} \frac{\left(I_{i,j} - \hat{I}_{i,j}\right)^2}{\sigma^2_{i,j}}$$

Aperture (mask) photometry (on-board)

$$f(k) = \sum_{i,j}\left(\int_{t_1}^{t_2}\left(I_{i,j} \circ M_{i,j} \right) dt\right)$$



Saturated stars photometry



“Extended” window: only useful pixels outside the standard 6x6 imagette are downloaded together with the 6x6 imagette

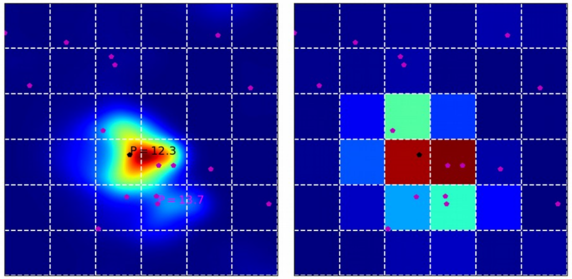
Aperture mask photometry

Instrument characteristics (physics and parameters)

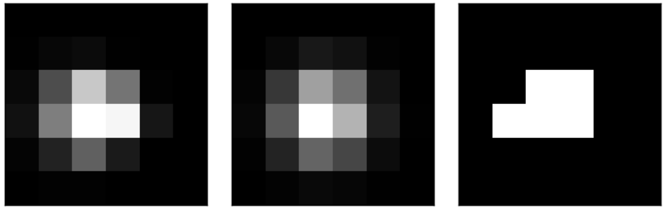
Input star catalogue (Gaia DR2)

PLATO *P*
Photometric passband
(calibrated in the VEGAMAG system)

Input images (*imagettes*)



Aperture photometry



Instrumental performance parameters

- NSR
- SPR (contamination)

Scientific performance parameters

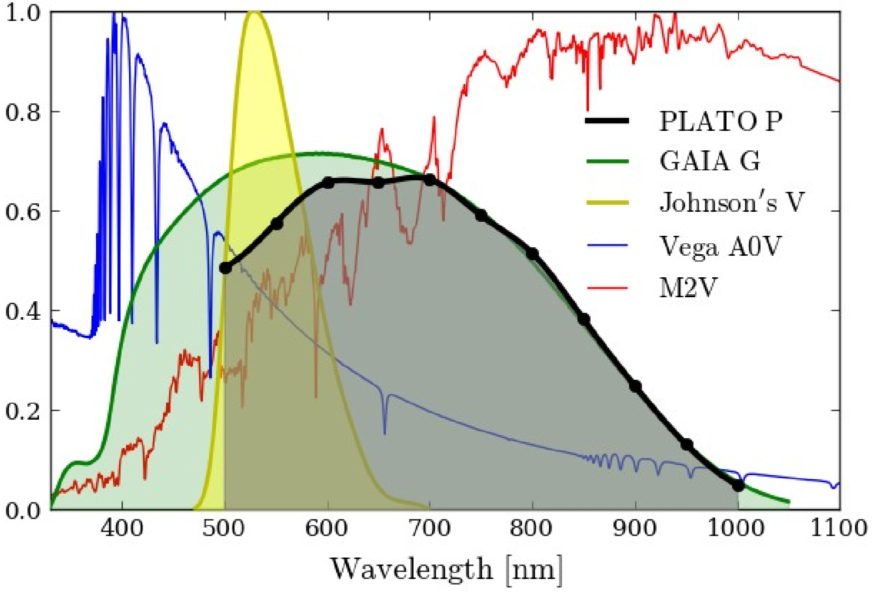
- Sensitivity to true planet transits
- Sensitivity to false planet transits

l'Observatoire de Paris | LESIA

PLATO passband

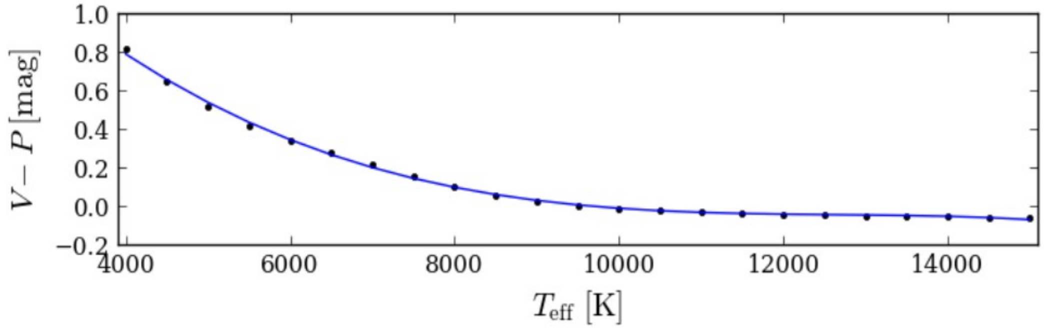
$$P = -2.5 \cdot \log_{10}\left(\frac{\int_{500\,nm}^{1000\,nm} f(\lambda) S_P(\lambda) \lambda \, d\lambda}{\int_{500\,nm}^{1000\,nm} f^{Vega}(\lambda) S_P(\lambda) \lambda \, d\lambda}\right) + 0.023$$

As for Gaia, we define the PLATO P magnitude: calibrated in the VEGAMAG system (see *Marchiori et al., 2019, A&A*)



$$G - P = -0.00628\,(G_{BP} - G_{RP})^3 - 0.05609\,(G_{BP} - G_{RP})^2 + 0.3502\,(G_{BP} - G_{RP}) + 0.00806.$$

$$V - P = -0.05856\,(G_{BP} - G_{RP})^3 + 0.2057\,(G_{BP} - G_{RP})^2 + 0.357\,(G_{BP} - G_{RP}) - 0.00243.$$



Aperture photometry methods

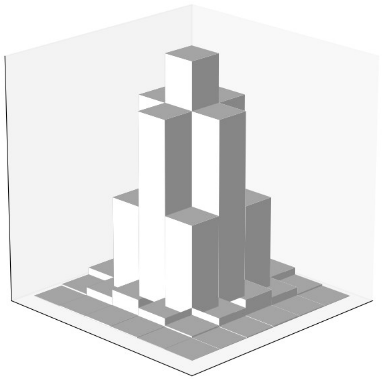
NOISE-TO-SIGNAL RATIO (NSR)

$$\mathbf{NSR}=\frac{\sqrt{\sum_{i,j}\left(\left(F_{T_{i,j}}+\left(\sum_k F_{C_{k,i,j}}\right)+B_{i,j}+R^2_{i,j}+D_{i,j}\right)\times w^2_{i,j}\right)+J^2}}{\sum_{i,j}\left(F_{T_{i,j}}\times w_{i,j}\right)}$$

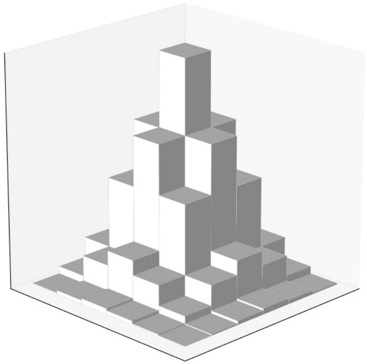
STELLAR POLLUTION RATIO (SPR)

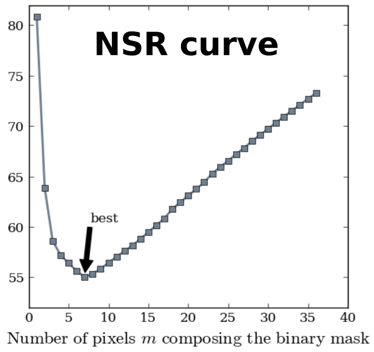
$$\mathbf{SPR}=\frac{\sum_{i,j}\left(\left(\sum_k F_{C_{k,i,j}}\right)\times w_{i,j}\right)}{\sum_{i,j}\left[\left(F_{T_{i,j}}+\left(\sum_k F_{C_{k,i,j}}\right)\right)\times w_{i,j}\right]}$$

Weighted Gradient Mask (global optimal NSR)

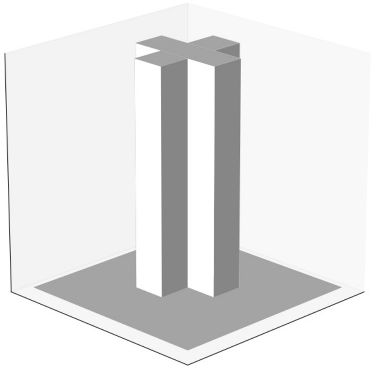


Weighted Gaussian Mask (sub-optimal NSR)

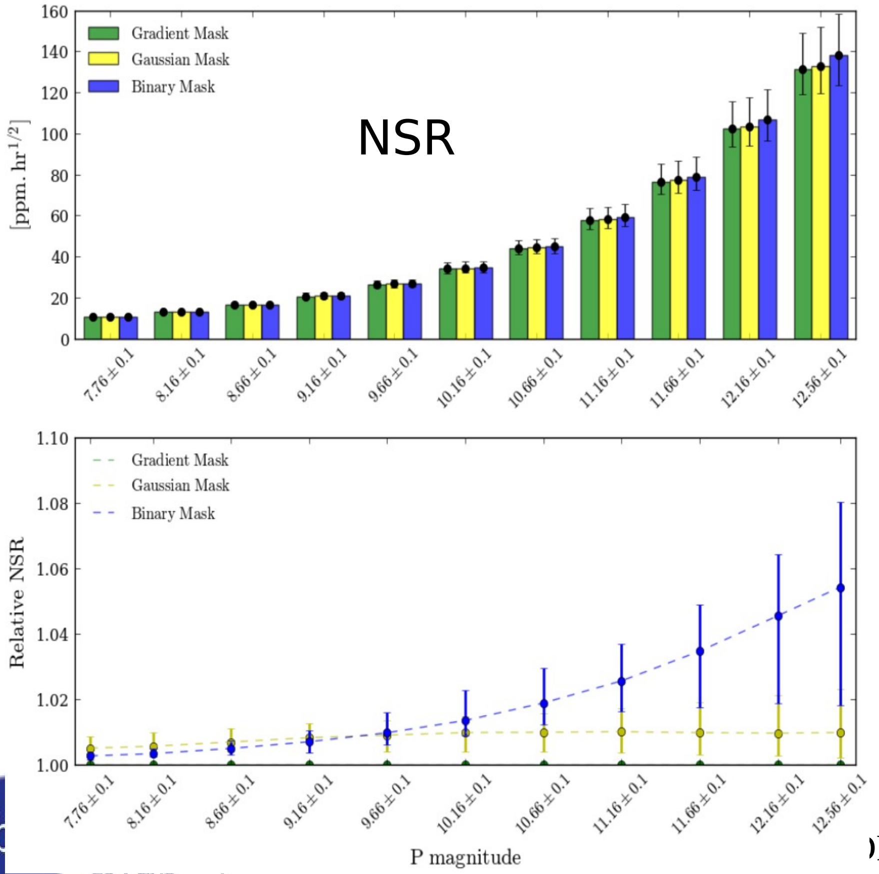


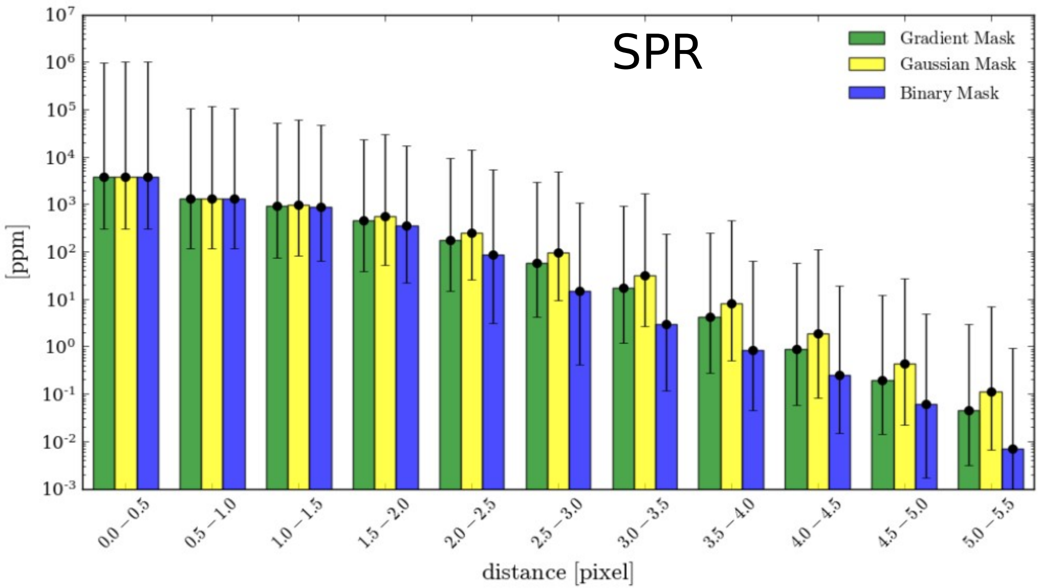


Binary Mask (narrower)



Performance: NSR & SPR





(*Marchiori et al., 2019, A&A*)

Science-driven metrics

N_{TCE}^{Good}: frequency of target sources with $\boldsymbol{\eta}>7.1$

$$\eta = \left(\frac{R_P}{R_\star}\right)^2 \sqrt{t_d\, n_{tr}}\,(1-\mathrm{SPR})/\mathrm{NSR}$$

R_P: planet radius

$R_\star$: star radius

η: classification threshold (≥ 7.1 for KOI objects)

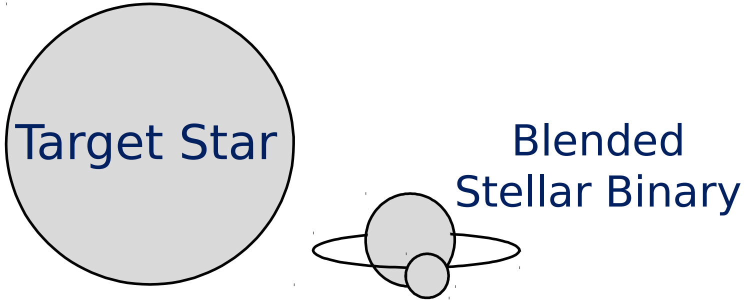
t_d: transit duration

n_{tr}: number of observed transits (≥ 3)

n_T: number of telescopes

SPR: Stellar Pollution Ratio

N_{TCE}^{Bad}: frequency of contaminant sources with SPR>SPR_{crit}

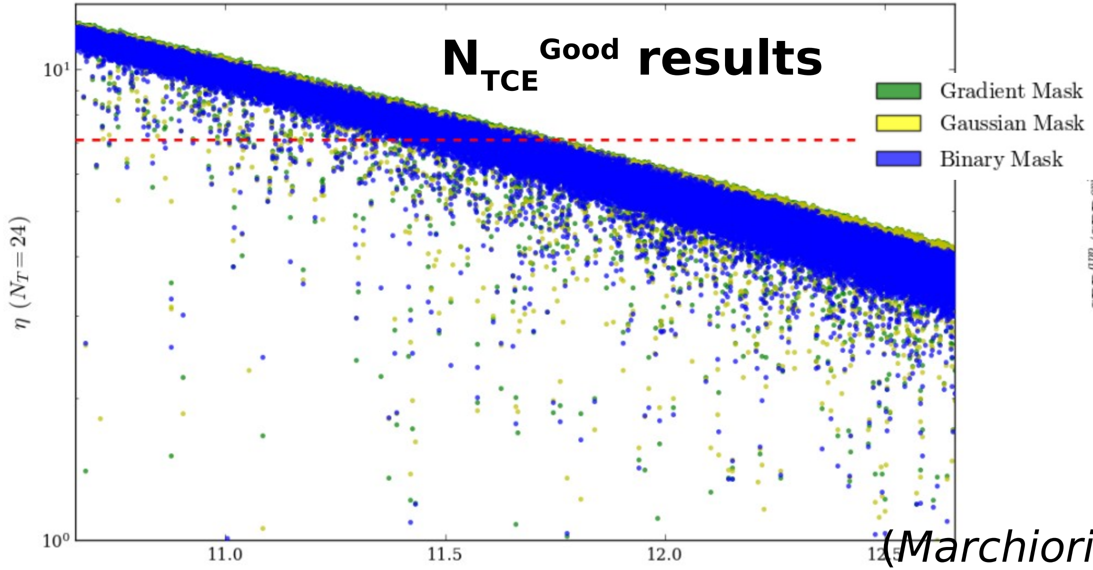


$$\delta_{obs} = \mathrm{SPR} \times \left(1 - 10^{-0.4\delta_{back}}\right)$$

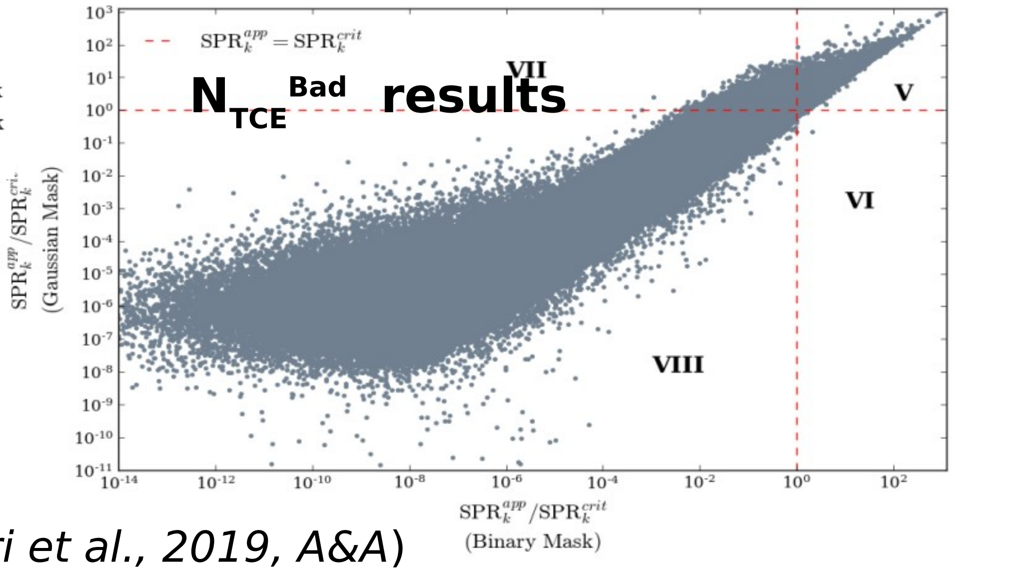
$$\mathrm{SPR}_{critical} = \frac{7.1\left(\frac{\mathrm{NSR}}{\sqrt{t_d\, n_{tr}}}\right)}{\left(1 - 10^{-0.4\delta_{back}}\right)}$$

Performance: NSR and SPR

N_{TCE}^{Good} **results**



N_{TCE}^{Bad} **results**

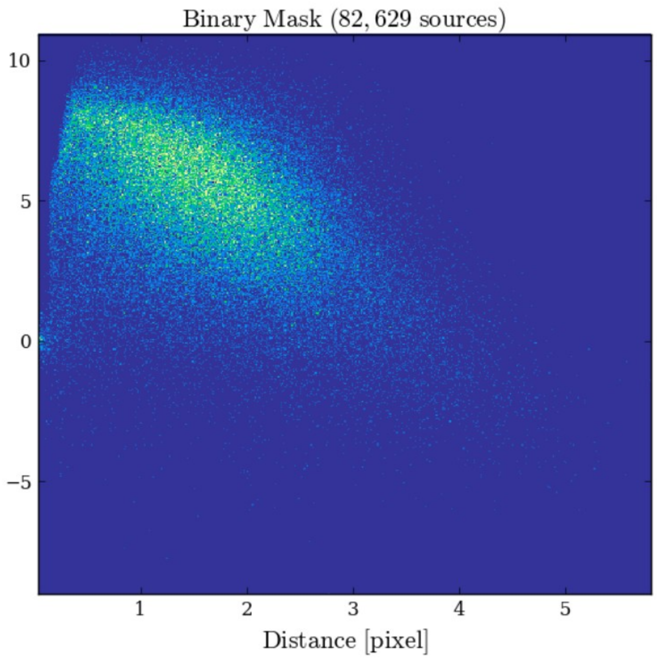


(Marchiori et al., 2019, A&A)

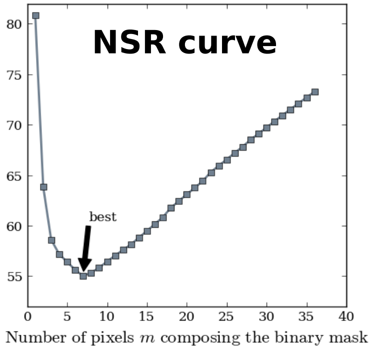
N_T	Gradient Mask	Gaussian Mask	Binary Mask
24	19,608 (39.2%)	19,319 (38.6%)	18,637 (37.3%)
18	15,510 (31.0%)	15,264 (30.5%)	14,806 (29.6%)
12	10,909 (21.8%)	10,701 (21.4%)	10,441 (20.9%)
6	5625 (11.2%)	5527 (11.1%)	5456 (10.9%)
Weighted total	10,318 (20.6%)	10,141 (20.3)%	9,884 (19.8)%

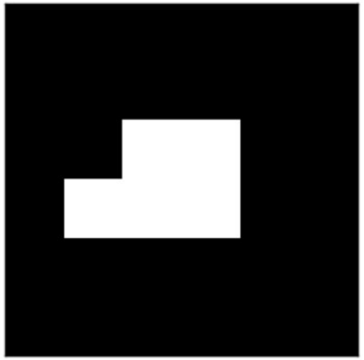
$\delta_{back,k}$ [mag]	depth [%]	Binary Mask (I + II) = (V + VI)	Gradient Mask (I + III)	Gaussian Mask (V + VII)
10^{-3}	9.2×10^{-2}	**1,632**	1,839 (**+12.7%**)	2,465 (**+51.0%**)
10^{-2}	9.2×10^{-1}	**9,208**	10,753 (**+16.8%**)	13,075 (**+42.0%**)
10^{-1}	8.8	**36,390**	44,476 (**+22.2%**)	51,644 (**+41.9%**)
0.8	52.1	**82,629**	105,029 (**+27.1%**)	120,949 (**+46.4%**)

Contaminant stars



$$\mathbf{NSR} = \frac{\sqrt{\sum_{i,j}\left(\left(F_{T_{i,j}} + \left(\sum_{k} F_{C_{k,i,j}}\right) + B_{i,j} + R^2_{i,j} + D_{i,j}\right) \times w^2_{i,j}\right) + J^2}}{\sum_{i,j}\left(F_{T_{i,j}} \times w_{i,j}\right)}$$





Byproduct: contamination ratio (for each mask)

Targets – contaminants:

- Magnitude difference: **ΔP < 10 mag**
- Distance from the target: **d < 4 pixels**

(*Marchiori et al., 2019, A&A*)

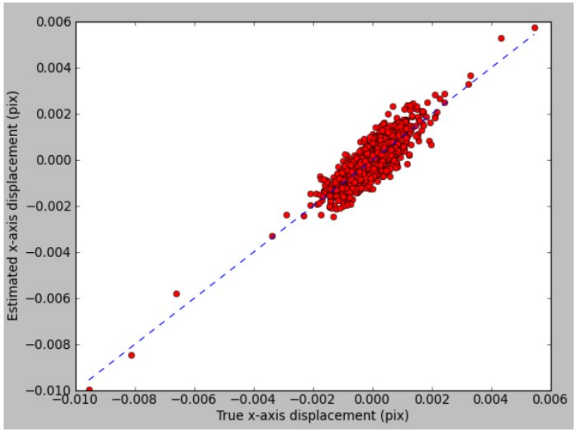
PSF fitting photometry

- WP 323 300 – Photometry of imagettes: S. Deheuvels & J. Ballot (IRAP)
- To be applied on all imagettes time-series (P1, P2, P4 samples and a sub-sample of the P5 sample and a sub-sample of the guest observer program sample)
- Almost insensitive to perturbations due to the jitter and the long-term drift (some residual expected, but lower than for the aperture-mask photometry) → next slide
- To some extend, the impacts of the contaminant stars can be suppressed → next slide

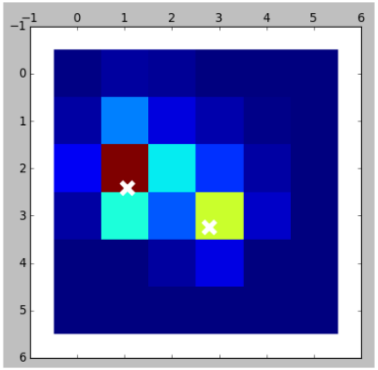
PSF fitting photometry

- Almost insensitive to jitter noise and long-term drift (some residual expected, but lower than for the aperture-mask photometry)
- To some extend, the impacts of the contaminant stars can be suppressed

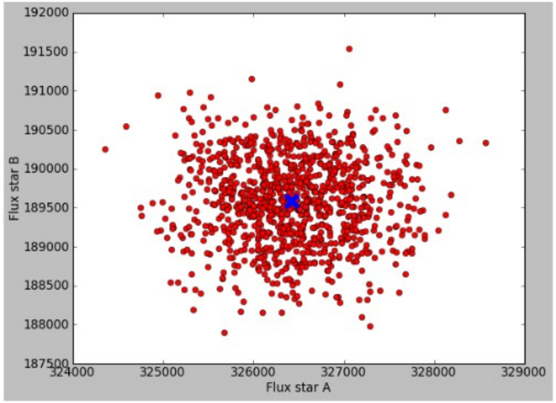
Reconstructed displacements versus true ones



Contaminant at 1.9 pixel from the target



Free centroids for both stars

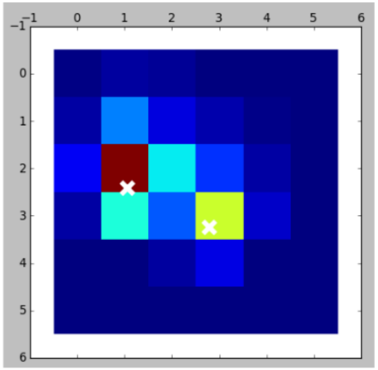


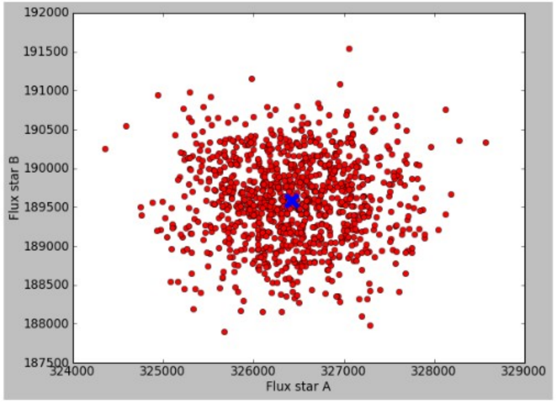
PSF fitting photometry

- Almost insensitive to jitter noise and long-term drift (some residual expected, but lower than for the aperture-mask photometry)
- To some extend, the impacts of the contaminant stars can be suppressed

Contaminant at **1.9 pixel** from the target

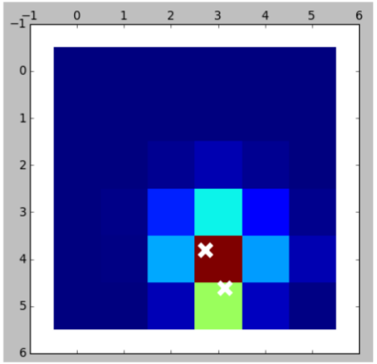
Free centroids for both stars

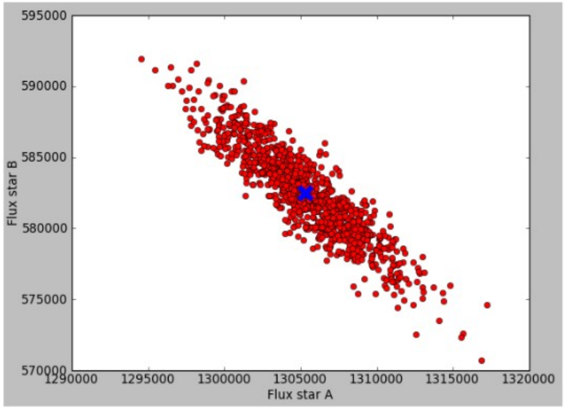




Contaminant at **0.9 pixel** from the target

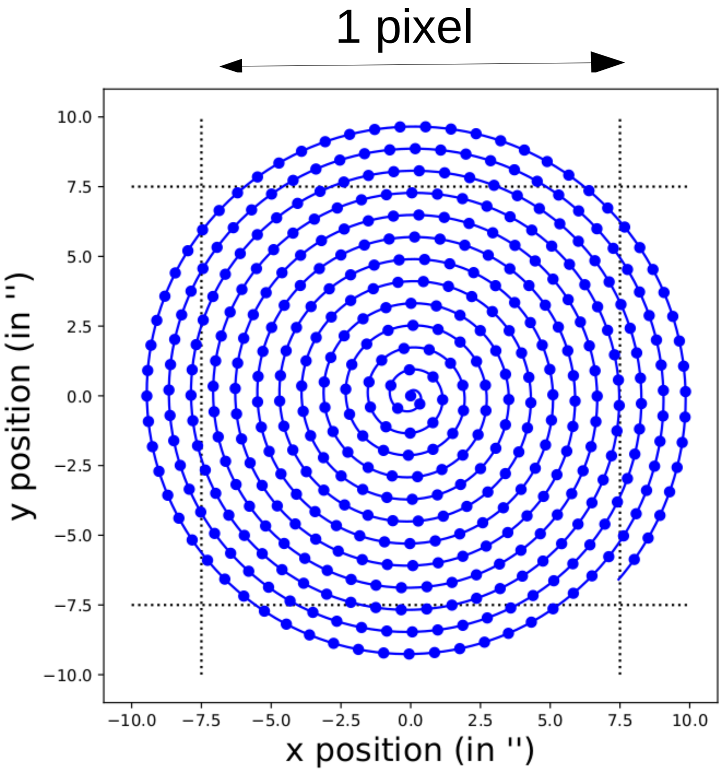
Free centroids for both stars





Microscanning and PSF

WP 321: Daniel Reese (LESIA)



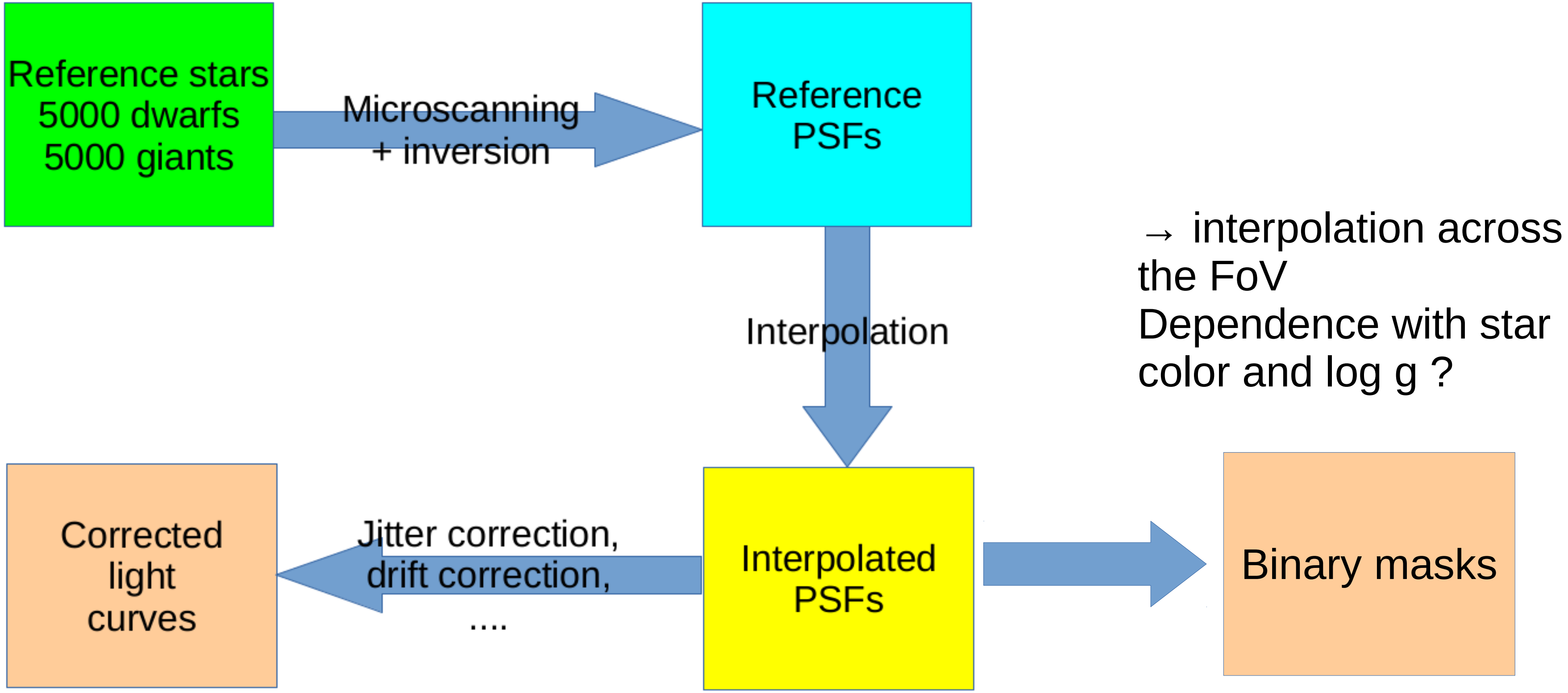
(credit: D. Reese)

"Microscanning" technique:

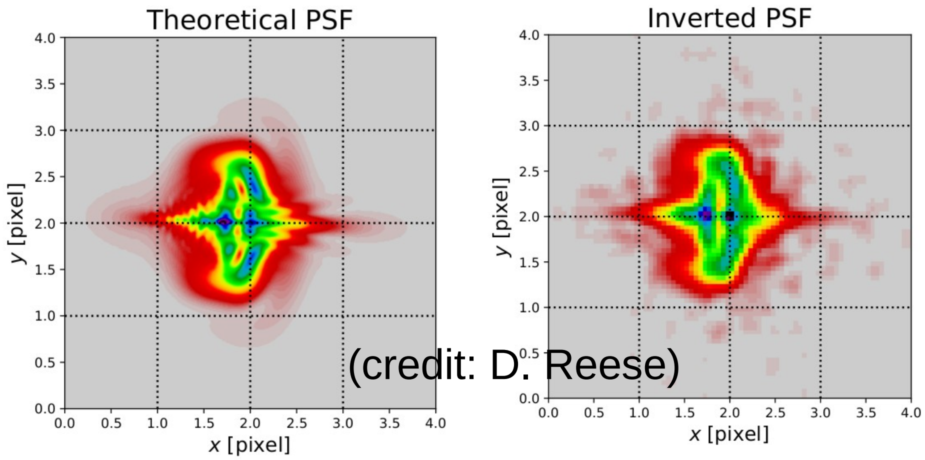
- Series of imagettes acquired during a imposed slow motion of the satellite (pure translation → variations of the transverse angles only)

- Coupled with an **inverse technique**: reconstruction of the PSF at different positions across the field of view

Microscanning and PSF

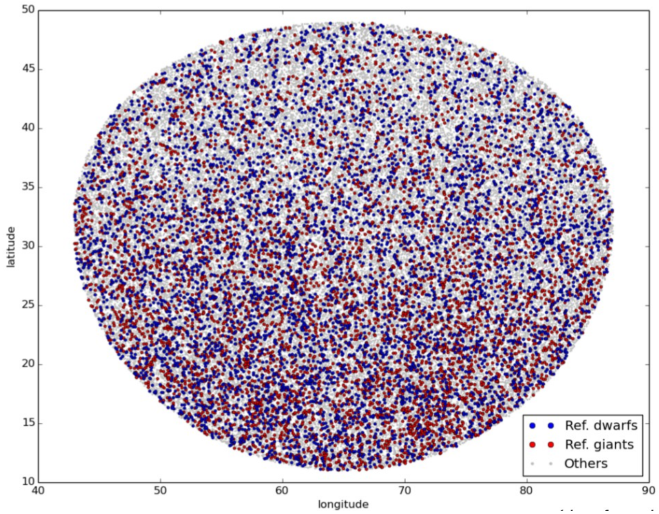


Microscanning and PSF



(credit: D. Reese)

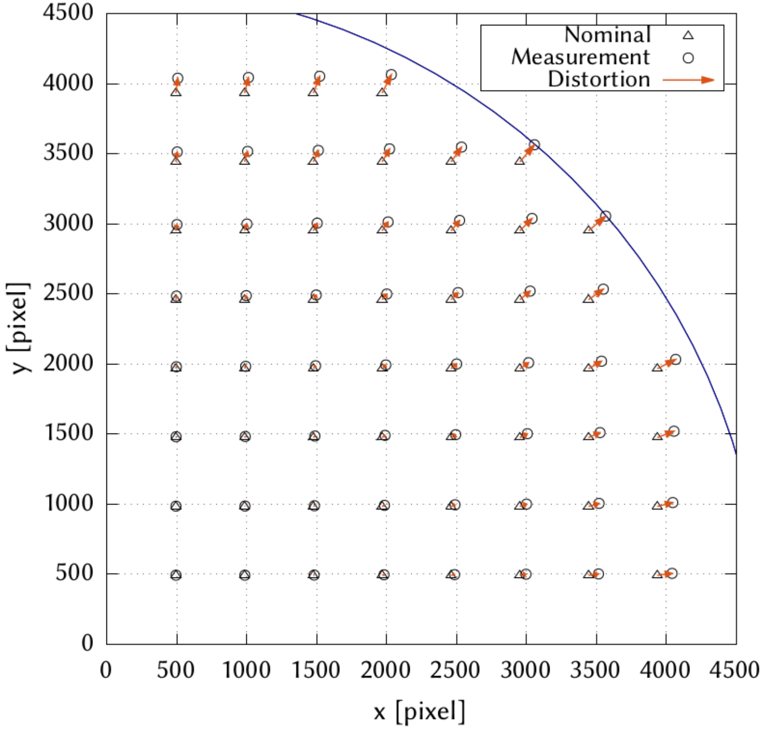
- Stellar variability with time-scale longer than 25s should have no impact (TBC) on inversion results
- Telemetry budget allows ~15 000 targets per camera (compression factor 2)
- Contamination is not an issue: taken into account in the inversion



- Targets (“reference stars R2”) will all be taken from the P1 sample: about 6, 000 targets per camera
- Star selection can probably be pushed up to magnitude ~ 12 – 13 (→ sample P5)
- Main criteria: brightness !
- Sample P4: stars in general too faint (P>12) !

Calibration of the Image Geometry Model (IGM)

WP 324: E. Duarte (UOL)



Credit: D. Griessbach

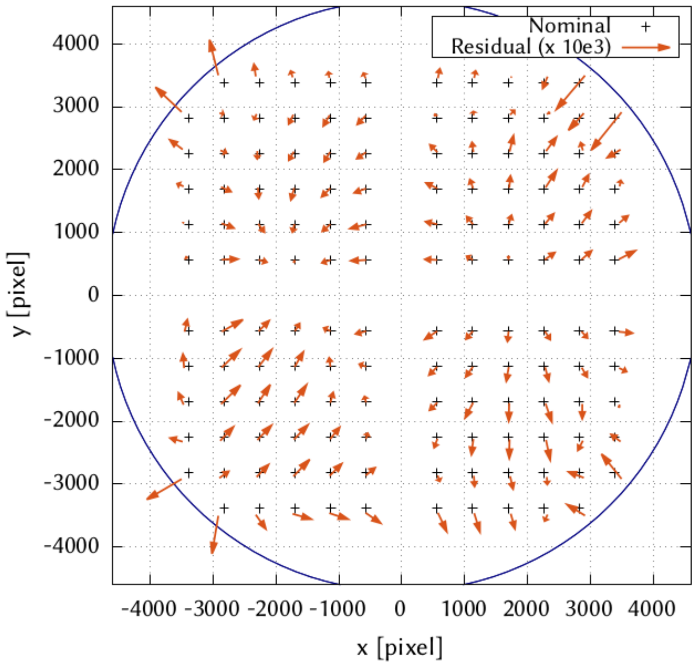
Distortion model (Brown 1971):

$$\begin{pmatrix} x_d \\ y_d \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix} + \boldsymbol{\delta}_r(x, y, \mathbf{k}) + \boldsymbol{\delta}_t(x, y, \mathbf{p})$$

$$\boldsymbol{\delta}_r(x, y, \mathbf{k}) = \begin{pmatrix} x \\ y \end{pmatrix} (k_1 r^2 + k_2 r^4 + k_3 r^6 + \cdots).$$

$$\boldsymbol{\delta}_t(x, y, \mathbf{p}) = \begin{pmatrix} p_1(3x^2 + y^2) + 2p_2 xy \\ p_2(x^2 + 3y^2) + 2p_1 xy \end{pmatrix} (1 + p_3 r^2 + p_4 r^4 \cdots).$$

Calibration of the Image Geometry Model (IGM)



Distortion model (Brown 1971):

$$\begin{pmatrix} x_d \\ y_d \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix} + \boldsymbol{\delta}_r(x, y, \mathbf{k}) + \boldsymbol{\delta}_t(x, y, \mathbf{p})$$

$$\boldsymbol{\delta}_r(x, y, \mathbf{k}) = \begin{pmatrix} x \\ y \end{pmatrix} (k_1 r^2 + k_2 r^4 + k_3 r^6 + \cdots).$$

$$\boldsymbol{\delta}_t(x, y, \mathbf{p}) = \begin{pmatrix} p_1(3x^2 + y^2) + 2p_2xy \\ p_2(x^2 + 3y^2) + 2p_1xy \end{pmatrix} (1 + p_3 r^2 + p_4 r^4 \cdots).$$

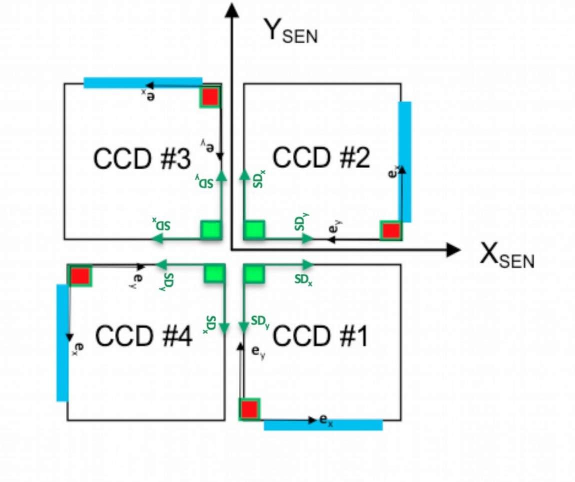
Residual: < 0.02 pixel (95th percentile)

Credit: D. Griessbach

See PLATO-DLR-PL-TN-0016, i2.1

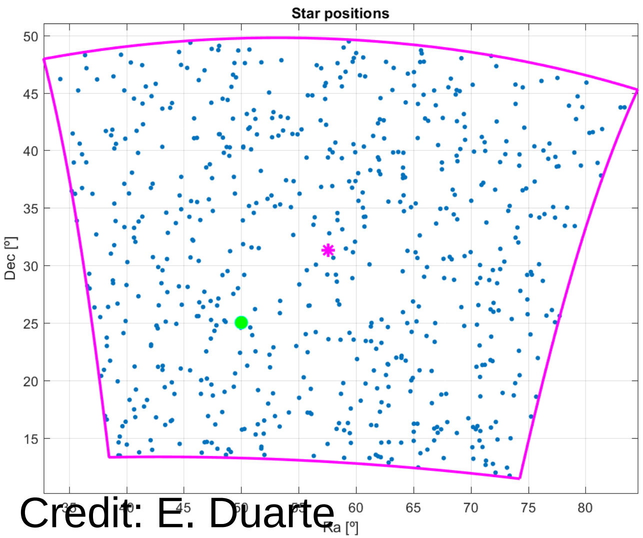
Calibration of the Image Geometry Model (IGM)

- Requires Center Of Brightness (COB) measurements for a large number of targets: extracted from full CCD images
- Attitude independent method



Free parameters:

- Focal length
- Distortion coefficients
- CCD positions
- CCD orientations



Credit: E. Duarte

- Up to ~ 2, 000 reference stars ("R1")
- All taken from sample P1
- Criteria:
  - Brightness
  - Contamination
  - Homogeneous distribution across FoV

DPA inputs

Task	Inputs
Mask calculation	**Magnitude** and **position** (star and contaminant)
ICRS → BCRS → GCRS	**Proper motion**, **parallax**, position
Microscanning	Magnitude and position (star and contaminant)
PSF interpolation	Magnitude, position, **color information** (star and contaminant)
IGM calibration	Magnitude, position, color information (star and contaminant), **binarity flag**
Throughput, efficiency map, instrument passband	Magnitude, position, color information (star and contaminant), **activity index**, **variability class**

DPA inputs

Quantity	**Accuracy** (95th percentile)
Magnitude	TBD (~ 0.05 mag)
Positions	< 10 mas
Color / T_{eff}	TBD (~ 500 K)
Proper motion and parallax	TBD – not critical Gaia accuracy largely enough
Activity index, binarity flag, variability class	TBD

END