PSF Normalization in High contrast Imaging

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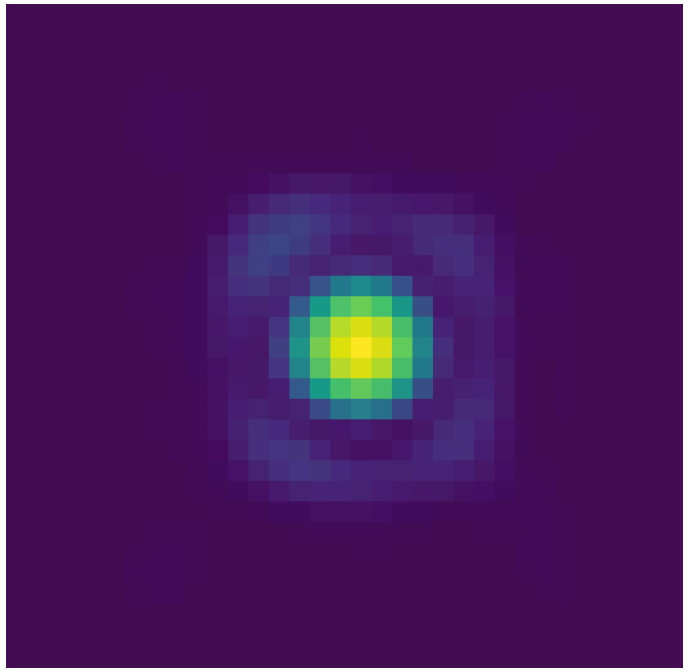
Why Normalisation is Needed

Normalization procedures are required for:

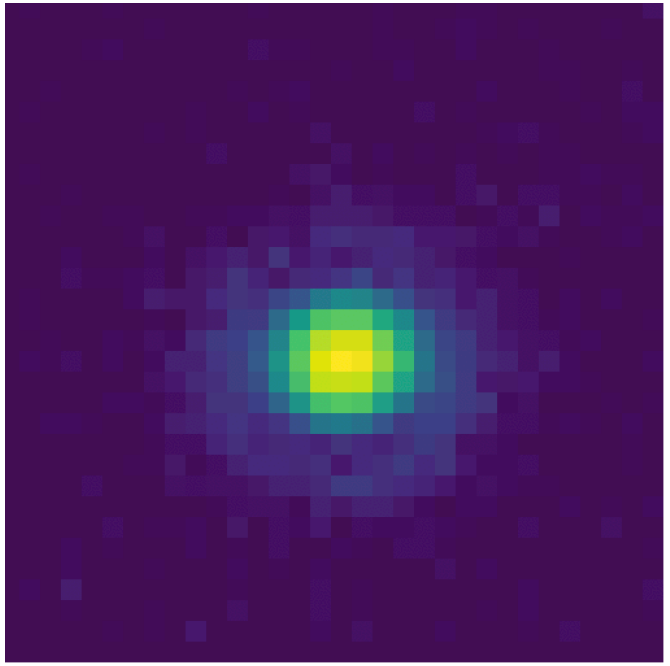
1. Taking account of the Strehl variations during the observing sequences for accurate photometry (Strehl, or DTTS)
2. Estimating absolute photometry in contrast from different epochs (Strehl, or DTTS)
3. Multi-epochs combination (PACOME)
4. Estimating the photon noise limits (ultimate detection limit) (DTTS is required to estimate the integrated number of photons received when both the PSF and coronographic images are recorded)

Using the DTTS



IRDIS PSF

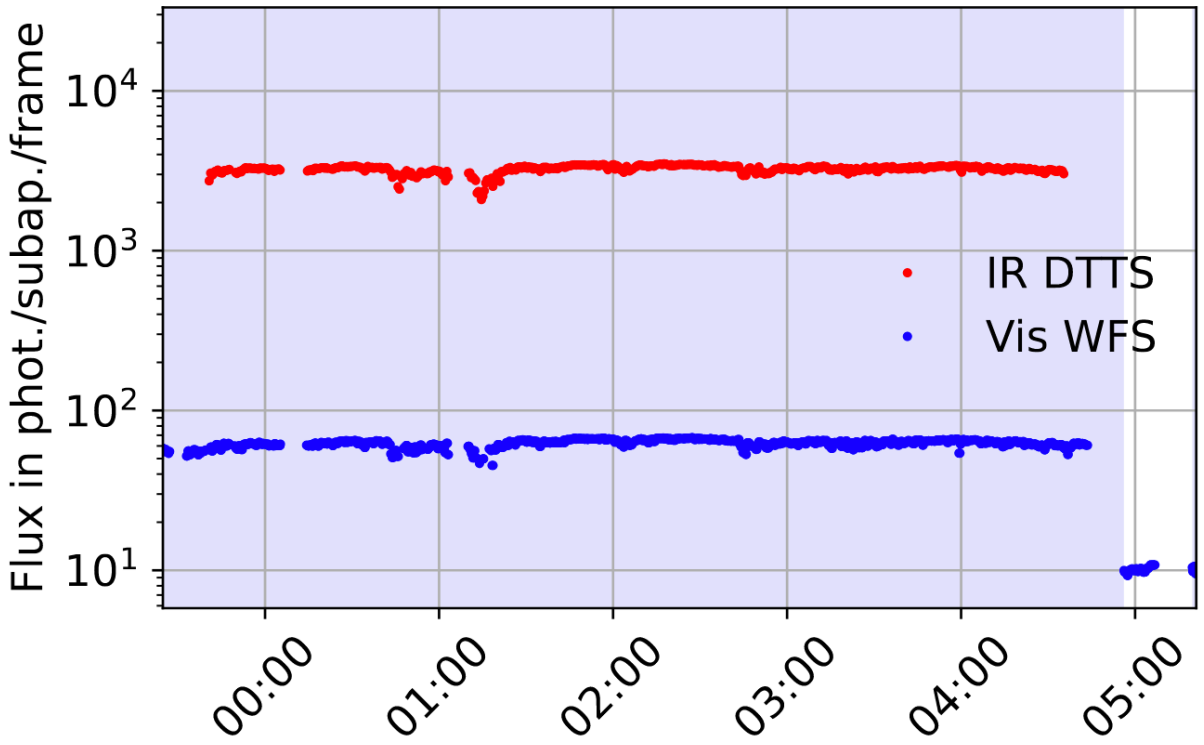
+

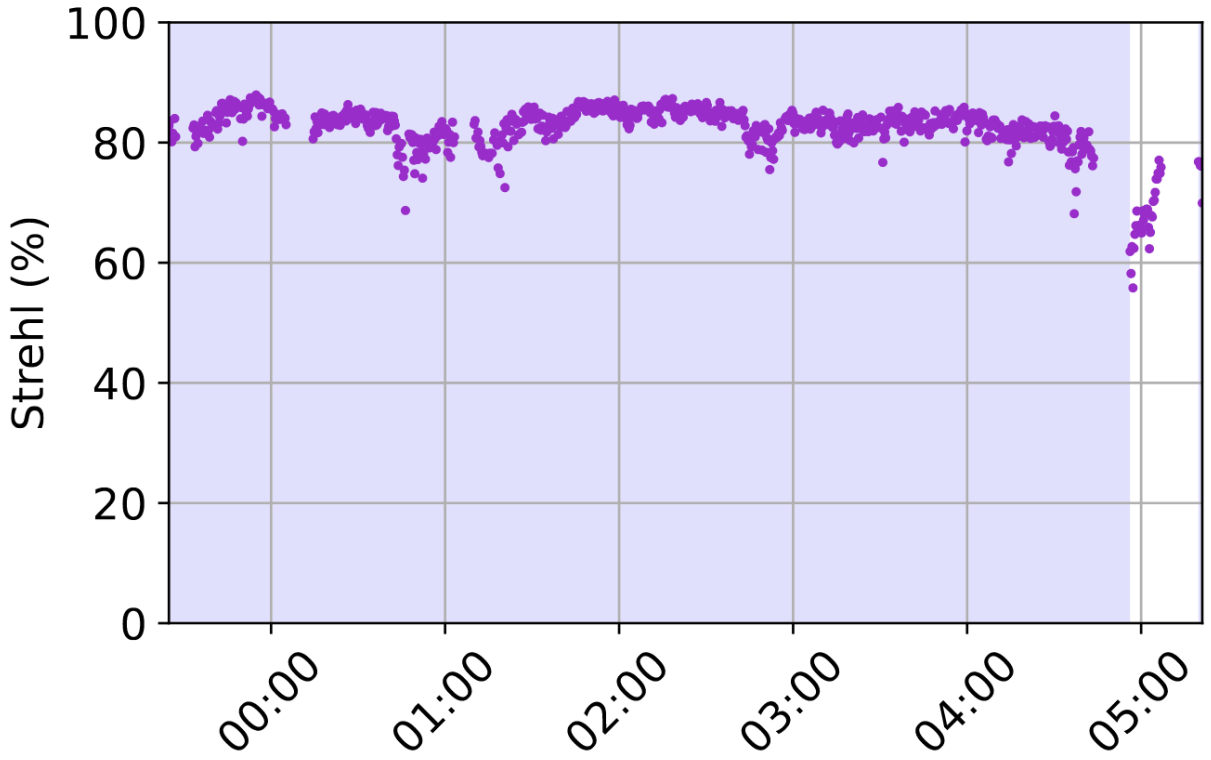


DTTS median PSF (15 frames)

Frames look alike but are noisier on the DTTS (shorter exposure & noisy camera)

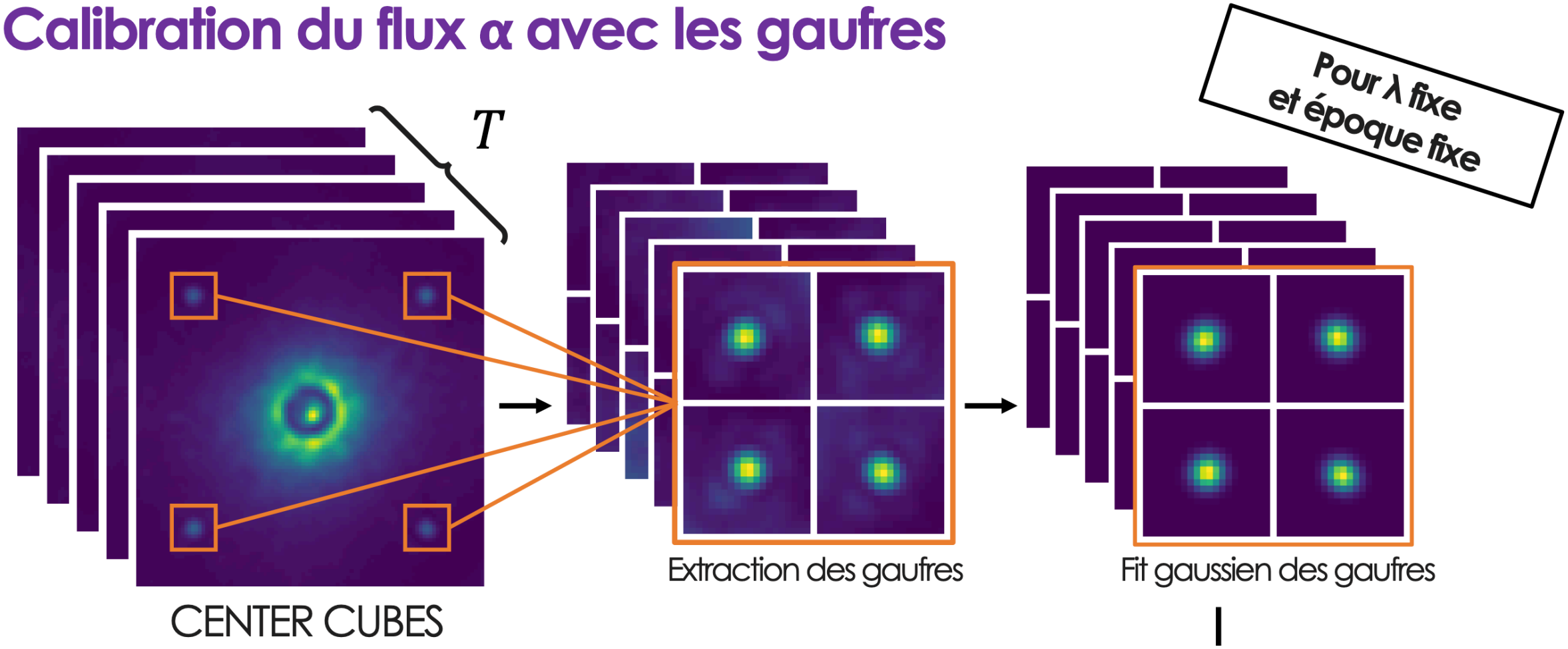
Using DTTS and Strehl from SPARTA

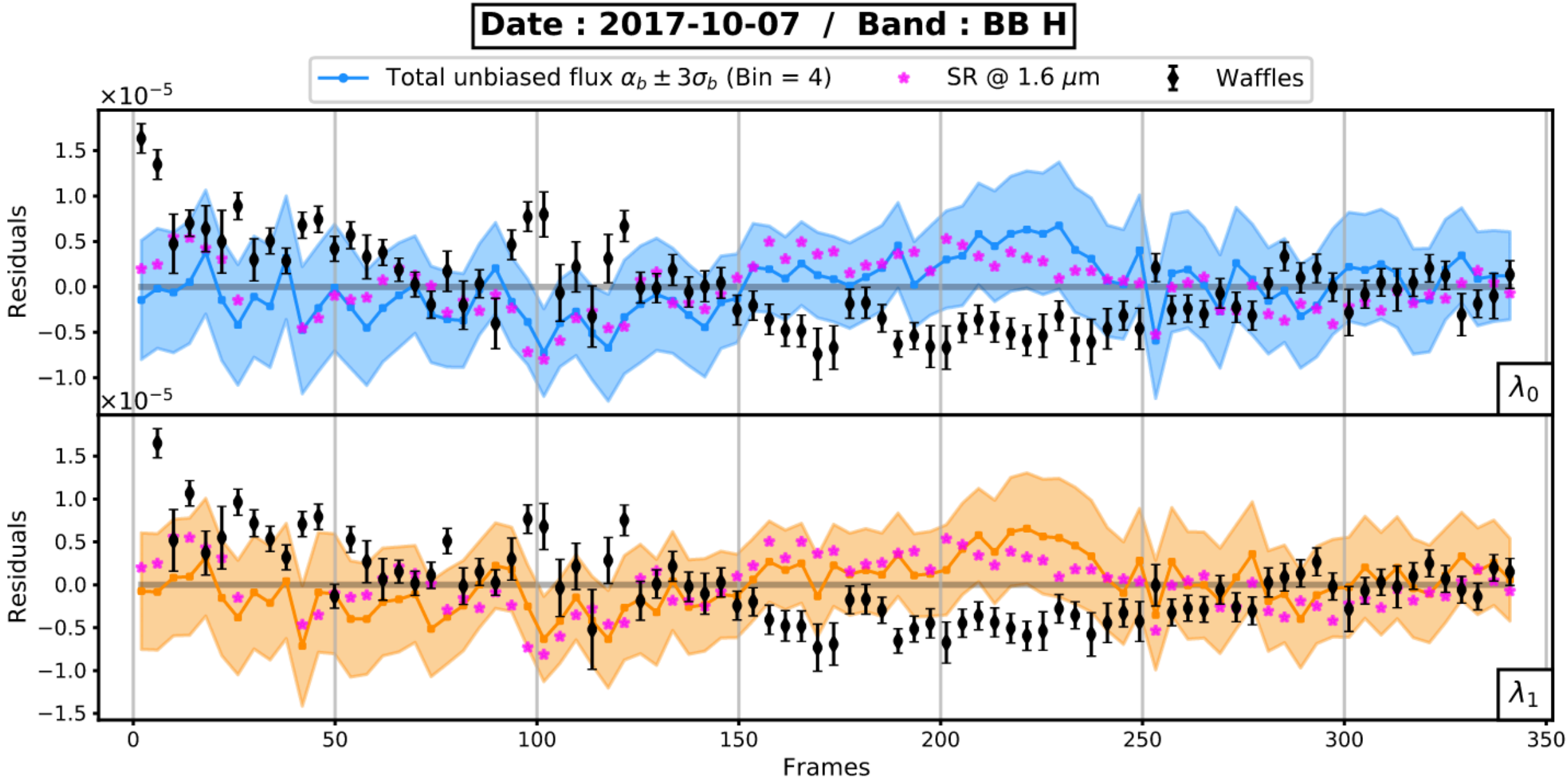




Calibration during the observing sequence

Calibration du flux α avec les gaufres




Date : 2017-10-07 / Band : BB H
Total unbiased flux $\alpha_b \pm 3\sigma_b$ (Bin = 4)
SR @ 1.6 μm
Waffles
$\times 10^{-5}$
Residuals
λ_0
λ_1
Frames

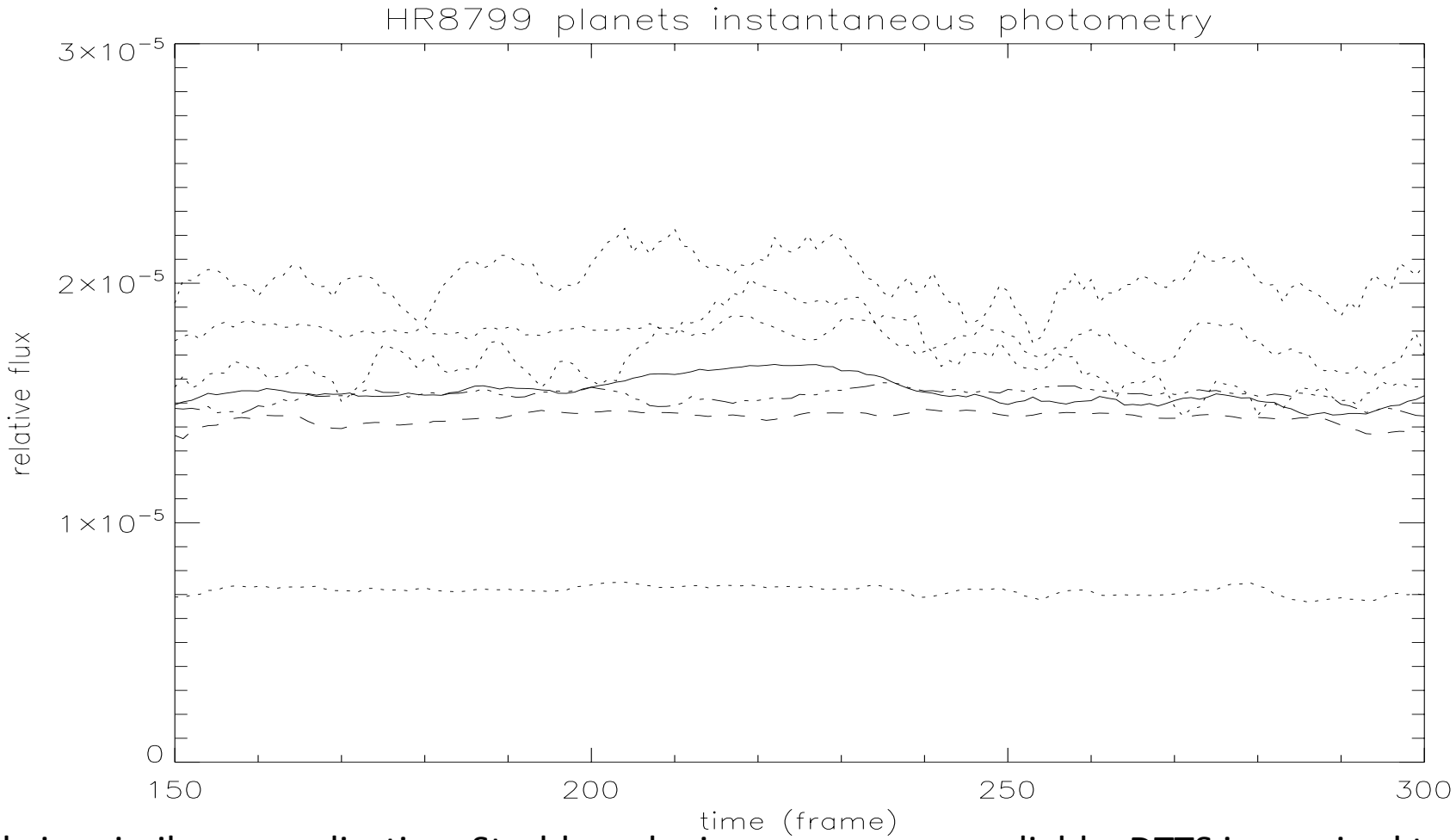
`Method

- Baseline normalization using non simultaneous PSF taken at t0
- Any change or flux variation (strehl or/and transmission) is not taking into account (between t0 and t1 and during the sequence)
- This leads to issues when comparing different epochs
- Strehl and DTTS are available at t0 an at the start of the observation (t1)

We can use them efficiently:

- Coro/PSF1= coro/PSF0*Strehl1/Strehl0
- Coro/PSF1= coro/PSF0*DTTS1/DTTS0 (DDTS=Peak/Total flux)

Comparing DTTS and Strehl



DTTS & Strehl give similar normalisation, Strehl can be in some cases unreliable, DTTS is required to take into account the evolution of the transmission

Contrast lower bound (LB)

Direct model of the observations: $d = \alpha h + f \in \mathbb{R}^N$

Statistics-based criterion: $\mathrm{SNR} = b/\sqrt{a} \quad \alpha = b/a \Rightarrow \alpha = \mathrm{SNR}/\sqrt{a}$

If covariances of nuisance component are perfectly captured by C, it holds:

$$a = h^{\mathrm{t}}\mathrm{C}^{-1}h = \sum_{n=1}^{N} \frac{h_n^2}{\mathrm{C}_{n,n}} \quad \text{and} \quad b = h^{\mathrm{t}}\mathrm{C}^{-1}h = \alpha\, a$$

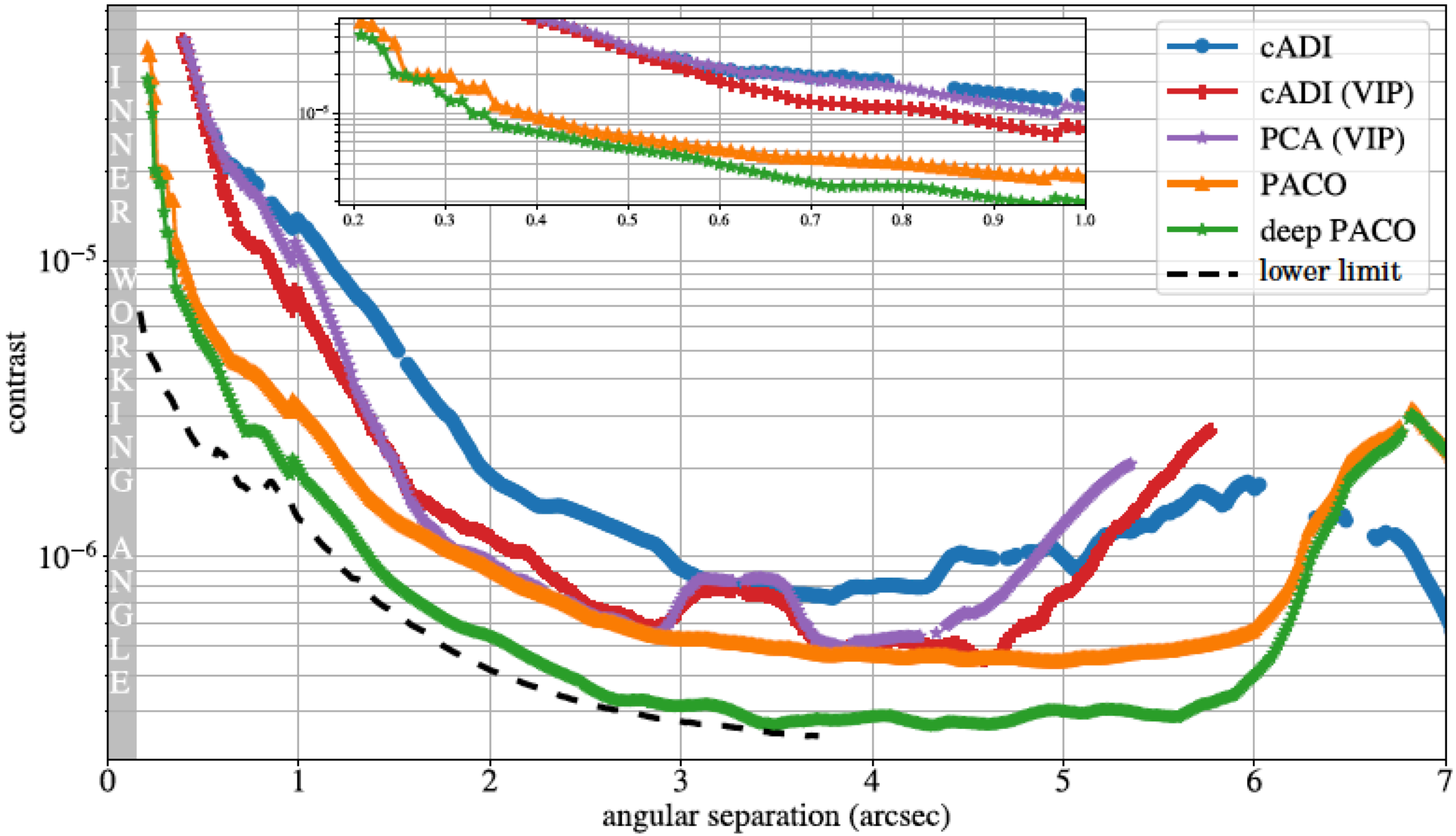
Expanding $\mathrm{C}_{n,n} = \mathrm{Var}(d_n)$ yields: $\mathrm{Var}(d_n) = \sigma_n^2 + \mathbb{E}(f_n)/g_n + \underbrace{\alpha\, h_n/g_n}_{\text{neg. } \alpha \to 0}$

- σ: detector readout standard deviation, *(estimated value: ?)*
- $g_n \simeq g \,\forall n$: gain electron/ADU, *(estimated value: 50)*
- $\mathbb{E}(f_n)$ estimated empirically by accounting for total received flux.

Contrast lower bound: $\boxed{\alpha_{\mathrm{LB}} = \mathrm{SNR}\sqrt{\frac{\sigma_n^2 + \mathbb{E}(f_n)/g_n}{h_n^2}}}$ with target $\mathrm{SNR} = 5$

Empirical contrast – *PACO, deep PACO, PCA, cADI vs LB*

dataset 6: HIP 88399, 2018-04-11, IRDIS, H2, good obs. cond.



Conclusion

- Next steps:
  - Automatic identification of Sparta data (Strehl & DTTS) synchronous with PSF normalization
  - Strehl is easier but can be unreliable (estimated from wavefront error, not sensitive to low wind,,..)
  - DTTS images have NCPA but the PSF core and integrated number of photon does not seem to be too much affected
  - DTTS also capture the intensity distribution of the PSF but this will require some NCPA removal post-processes – could be use to monitor the PSF evolution