Calibration accuracy of Proba-3/ASPIICS white-light coronagraph

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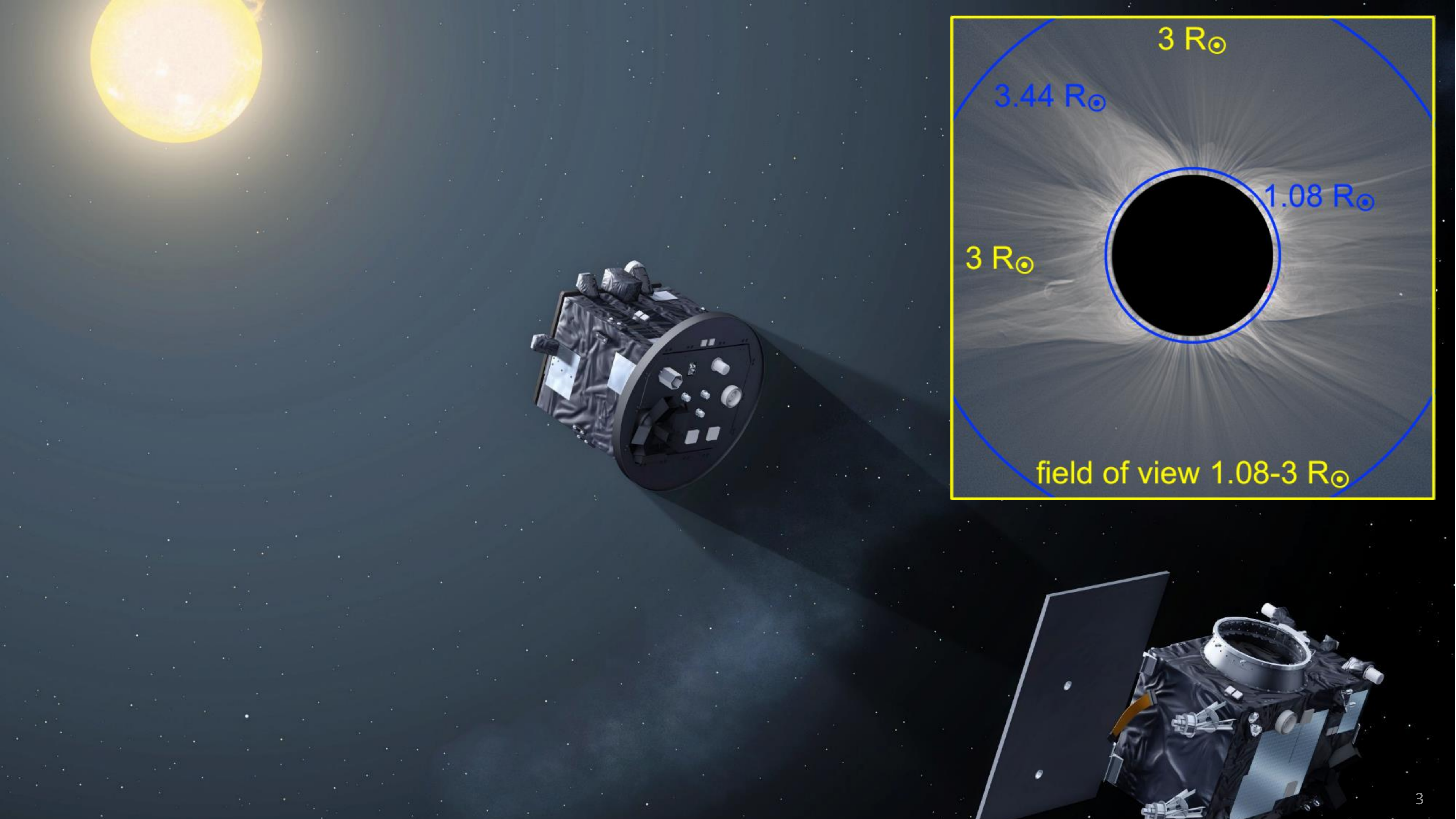
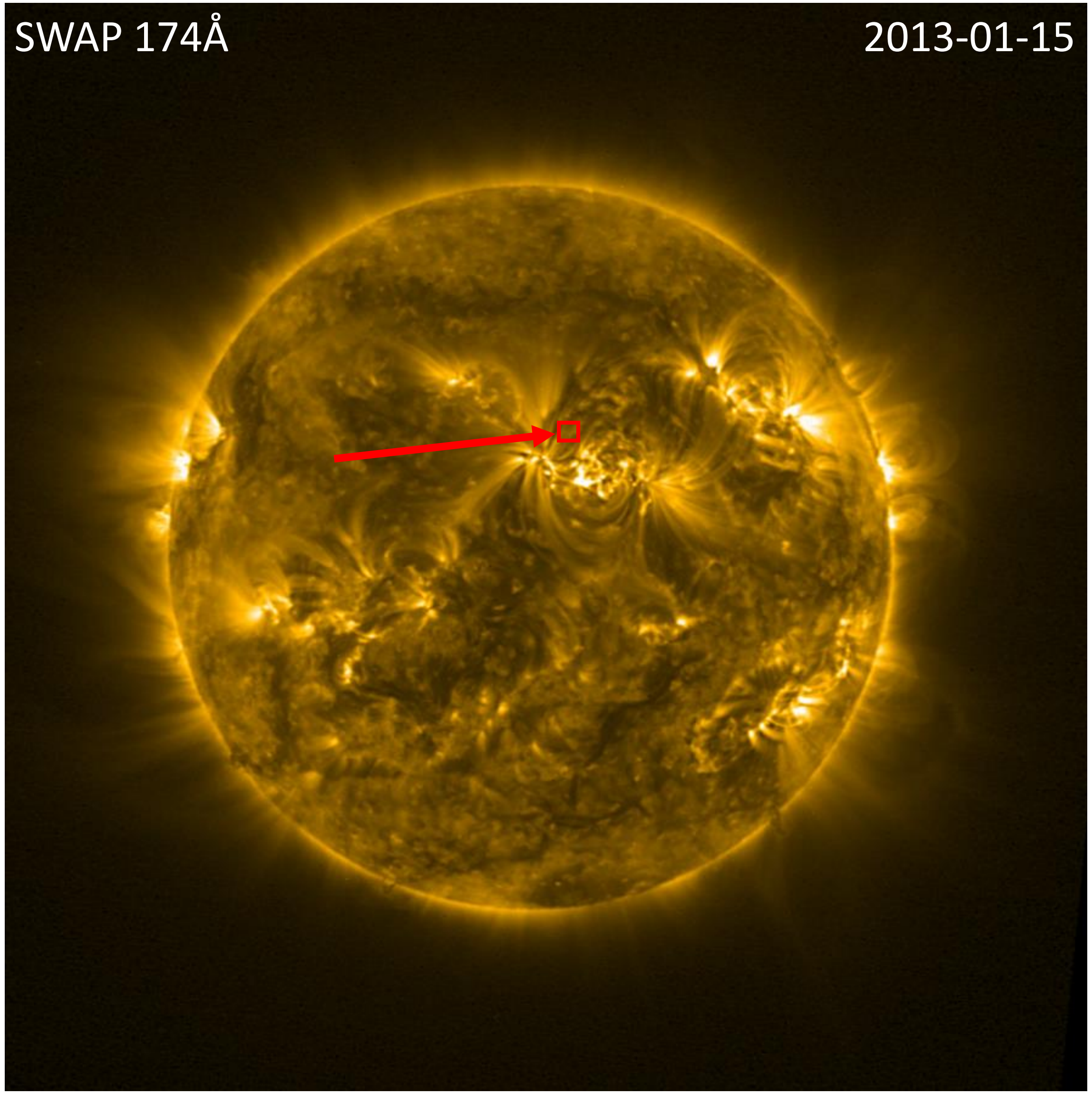
White-light – easy spectral region

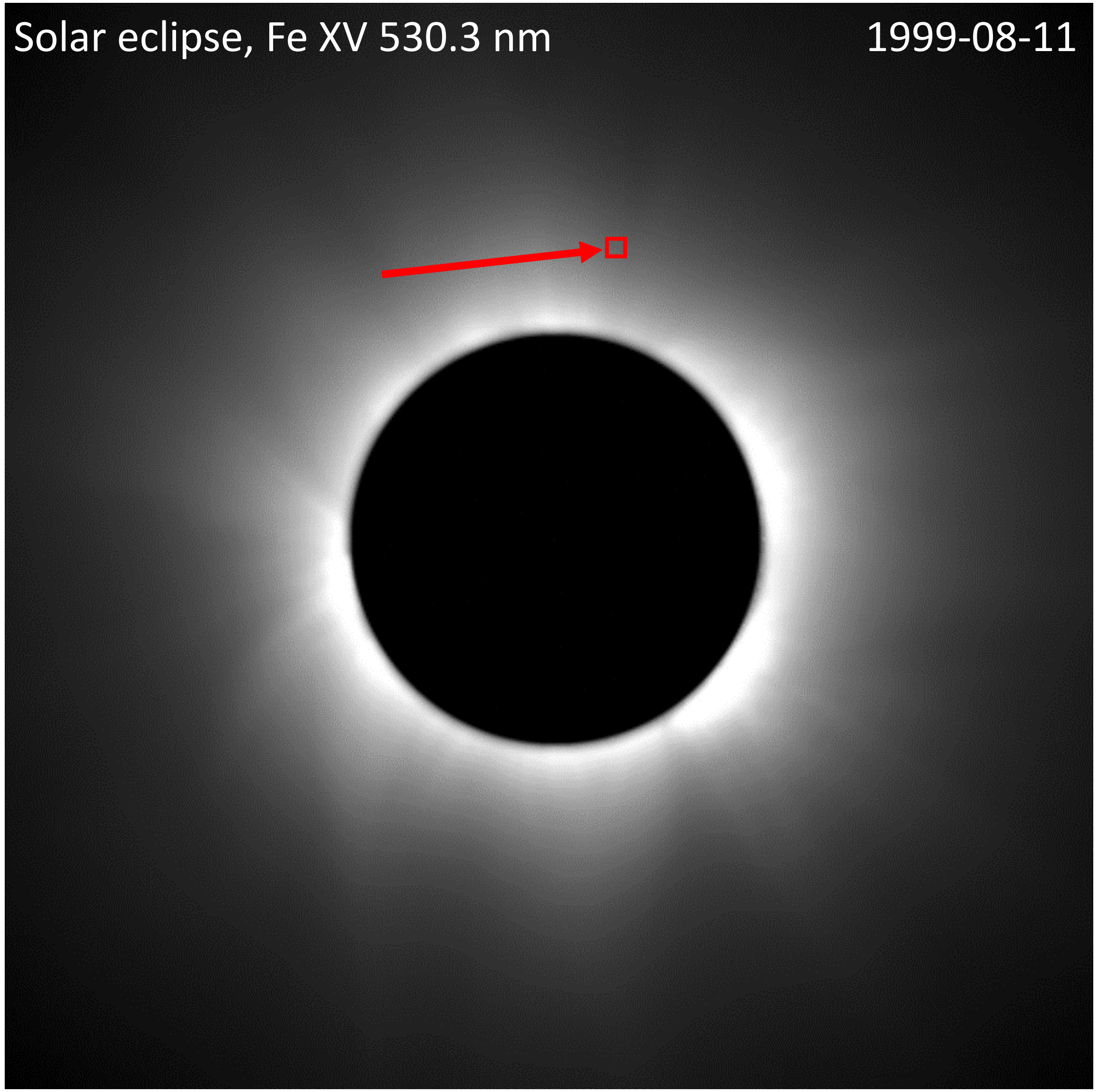
- No strong degradation of multi-layer structures & thin-film filters;
- No necessity of fancy radiation sources (synchrotron) and complicated experimental setups;
- Straightforward to create wide beam, filling the whole aperture, using of monochromatic light etc.;
- Relatively slow degradation known degradation of sensitivity (~0.5%/year);
- “Easy” model of coronal spectrum in white-light;

- Given all these simplifications, what accuracy of calibration we may expect?


3 R⊙
3.44 R⊙
1.08 R⊙
3 R⊙
field of view 1.08-3 R⊙

EUV vs White-light imaging system

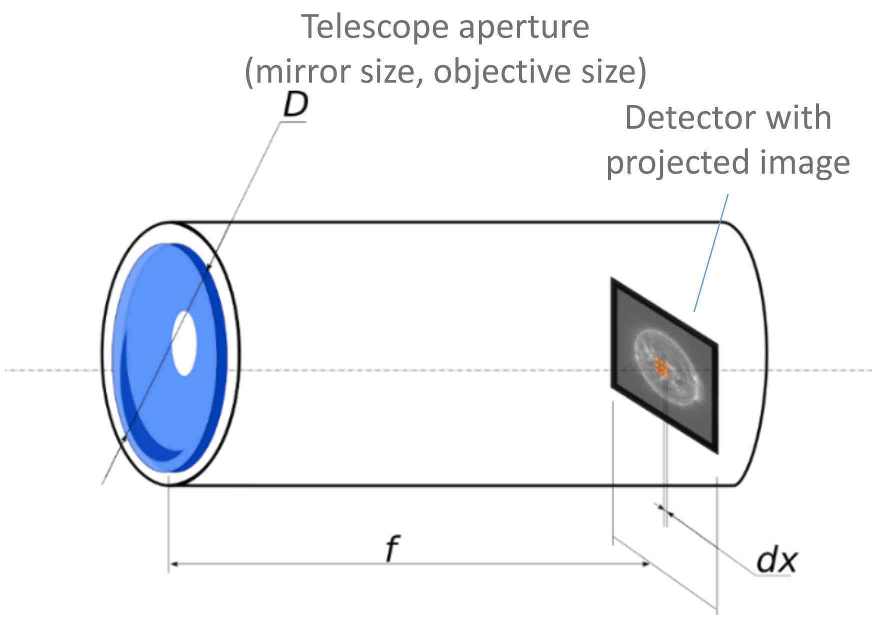




Photometric sensitivity

$$M = B \cdot \frac{\pi}{4}\left(\frac{D}{f}\right)^2 dx^2$$

$\left[\frac{\text{photons}}{\text{pixel s}}\right]$ $\left[\frac{\text{photons}}{\text{s sr cm2}}\right]$ $[\text{sr}]$ $[\text{cm2}]$



$[\text{DN}]$ $[\%]$ $\left[\frac{\text{el.}}{\text{photon}}\right]\left[\frac{\text{DN}}{\text{el.}}\right]$

$$N = B \cdot \frac{\pi}{4}\left(\frac{D}{f}\right)^2 dx^2\, T(\lambda)\, t_{exp}\, q\,(\lambda)\, \mathbf{g} + \mathbf{DC}\, t_{exp}\, \mathbf{g} + \mathbf{BIAS}$$

$\left[\frac{\text{el.}}{\text{s}}\right][s]\left[\frac{\text{DN}}{\text{el.}}\right]$ $[\text{DN}]$

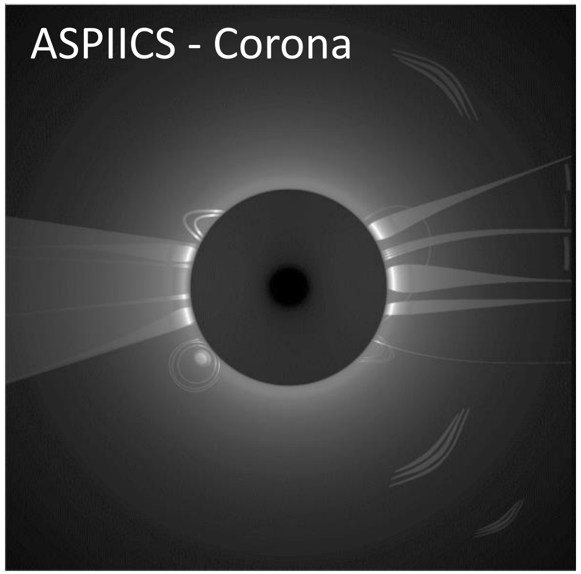
$$B = \frac{N - \mathbf{DC}' \cdot t_{exp} - \mathbf{BIAS}'}{\kappa} - B_{\text{D}} - B_{\text{G}} - B_{\text{Sc}}$$

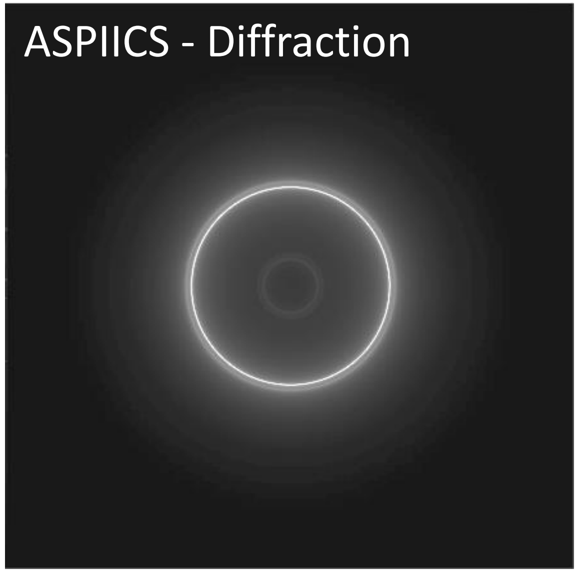
Photometric sensitivity

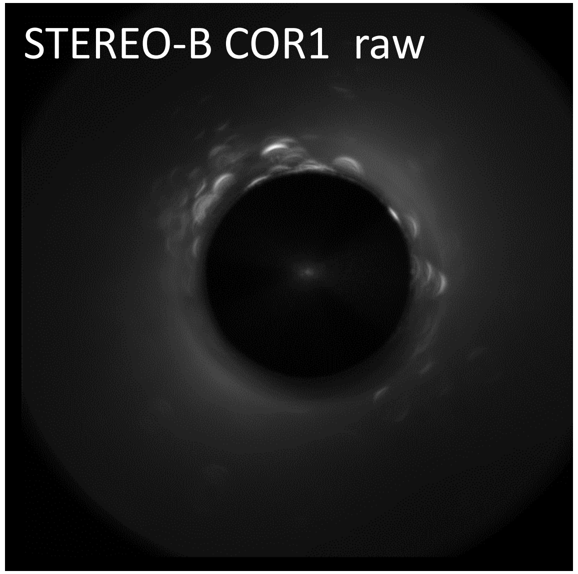
$$\boldsymbol{B} = \frac{\boldsymbol{N} - \mathbf{DC}' \cdot t_{exp} - \mathbf{BIAS}'}{\boldsymbol{\kappa}} - \boldsymbol{B}_{\mathrm{D}} - \boldsymbol{B}_{\mathrm{G}} - \boldsymbol{B}_{\mathrm{Sc}}$$

$$\boldsymbol{\kappa} = \frac{\pi}{4}\left(\frac{D}{f}\right)^2 dx^2 T(\lambda)\, t_{exp}\, \boldsymbol{q}\,(\lambda)\, \mathbf{g}$$

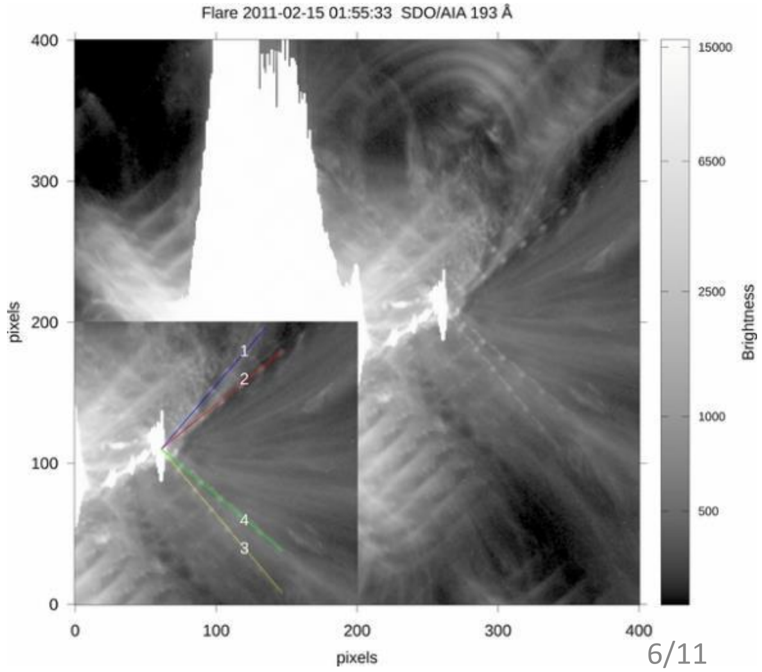
- Vignetting (i.e. filter mesh, variation of T with FOV)
- Optical throughput
- Detector flat field and sensitivity
- *f*, *D*, *dx*







AIA diffraction pattern

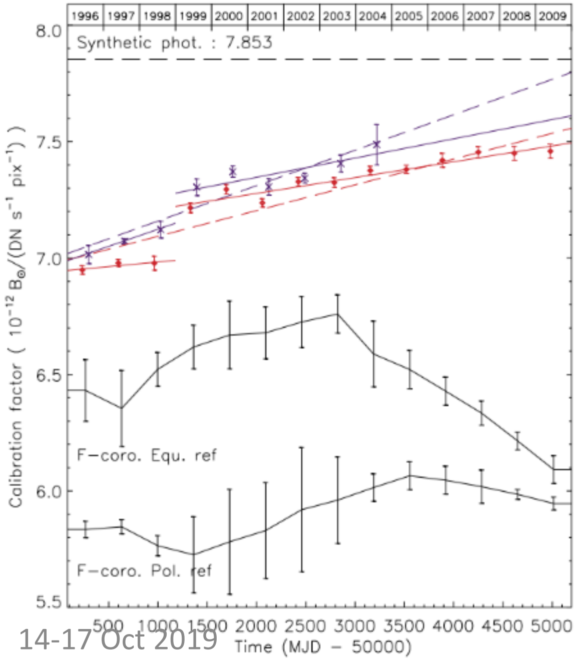


Photometric sensitivity

$$\boldsymbol{B} = \frac{\boldsymbol{N} - \mathbf{DC}' \cdot t_{exp} - \mathbf{BIAS}'}{\boldsymbol{\kappa}} - \boldsymbol{B}_{\mathrm{D}} - \boldsymbol{B}_{\mathrm{G}} - \boldsymbol{B}_{\mathrm{Sc}}$$

$$\boldsymbol{\kappa} = \frac{\pi}{4}\left(\frac{D}{f}\right)^2 dx^2 T(\lambda)\, t_{exp}\, \boldsymbol{q}\,(\lambda)\, \mathbf{g}$$

- Vignetting (i.e. filter mesh, variation of T with FOV)
- Optical throughput
- Detector flat field and sensitivity
- *f*, *D*, *dx*



LASCO C2: Gardès et al. 2013

(also Llebaria et al. 2006;
Colaninno & Howard 2015 – different result)

LASCO C3: Thernisien et al. 2006 – ±6.7%

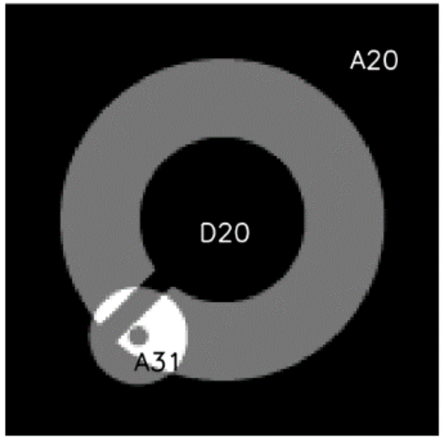
COR1 STEREO: Thompson and Reginald 2008

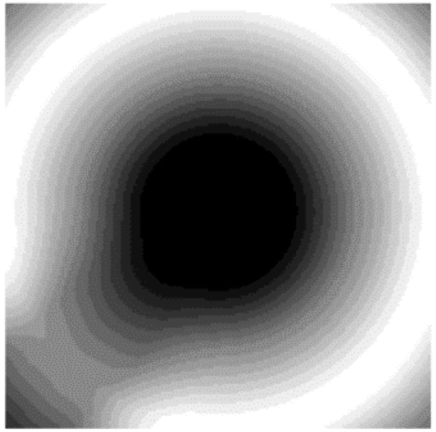
Table 3 Comparison of the preflight calibration factors (MSB s DN^{-1}) with those determined from the Jupiter observations.

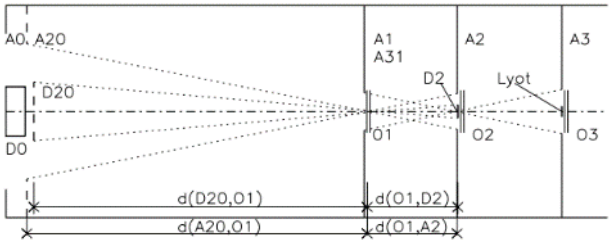
Telescope	Preflight	Jupiter
COR1-A	7.10×10^{-11}	6.578×10^{-11}
COR1-B	5.95×10^{-11}	7.080×10^{-11}

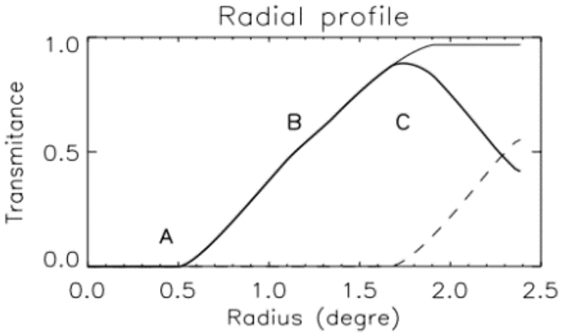
Vingetting in external coronagraphs

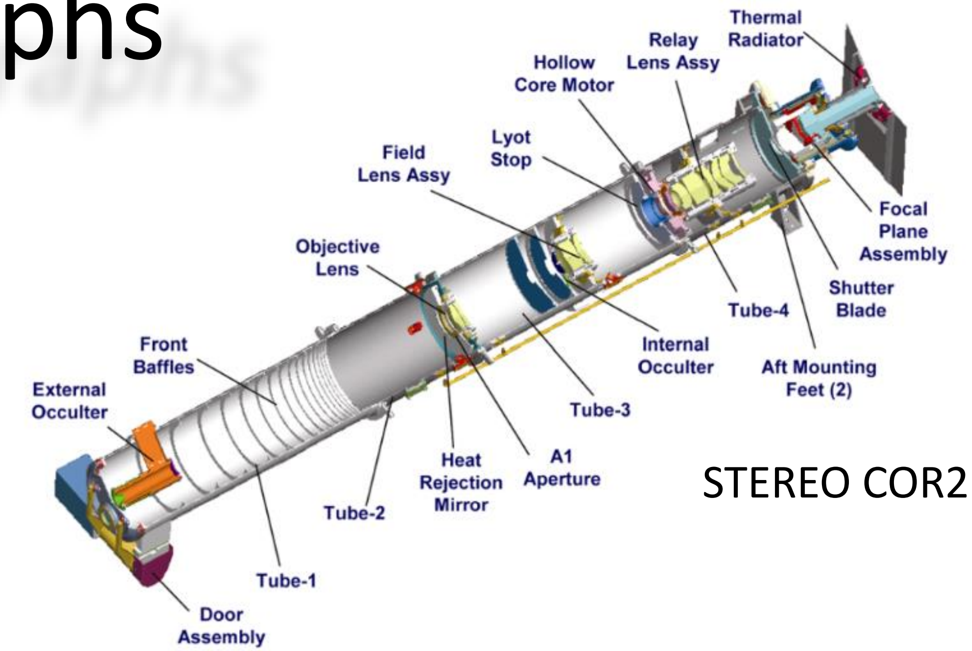
LASCO C2 vignetting









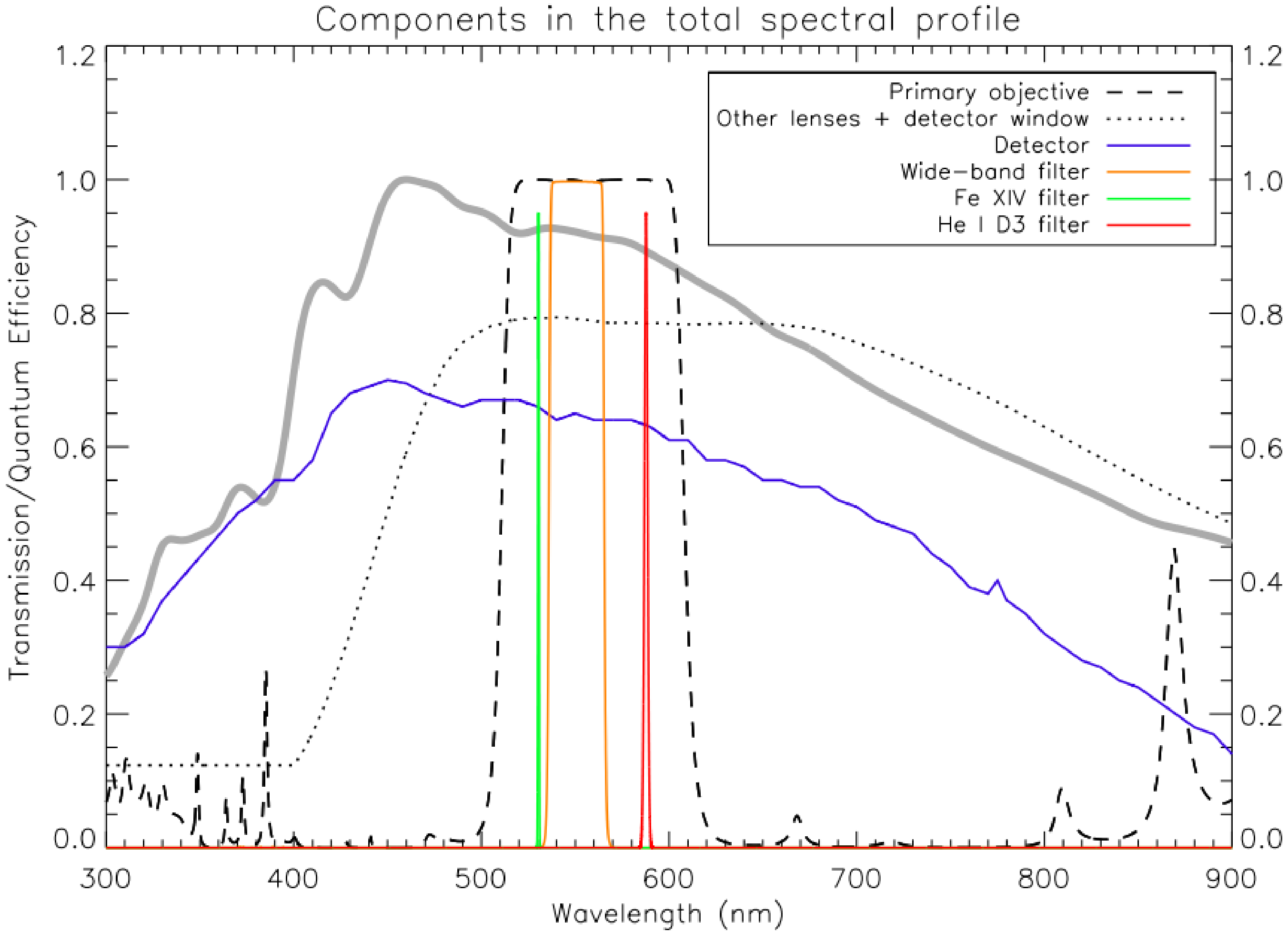


STEREO COR2

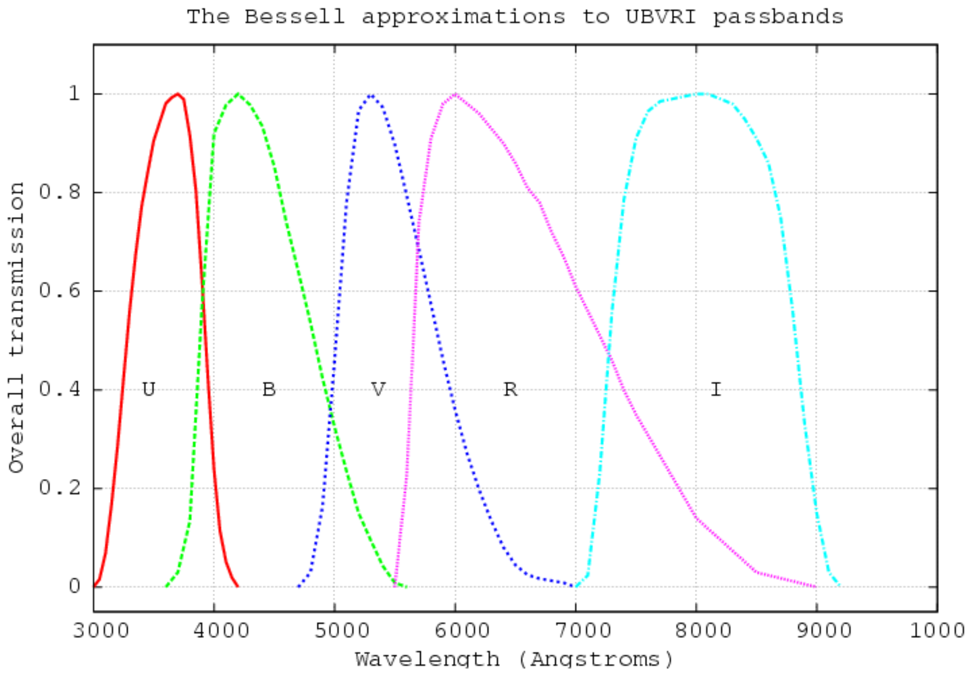
ASPIICS

Spectral response

ASPIICS spectral response



[Bessell, PASP 102, 1181 (1990)](#)

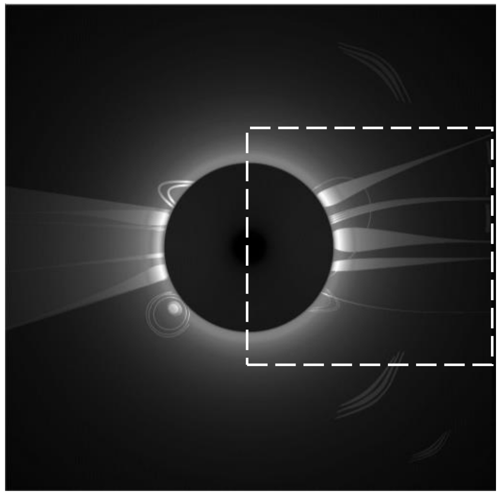


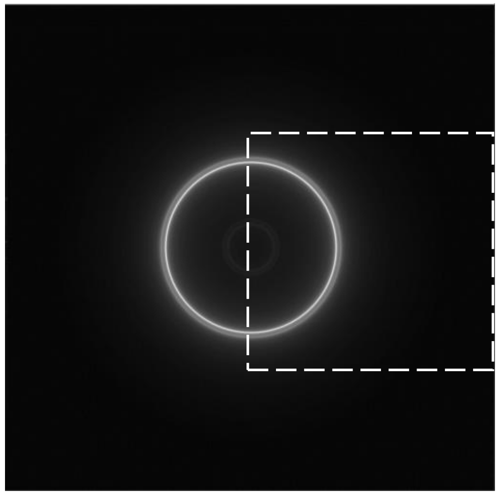
Also: measuring star intensity can be tricky – either aperture method, or PSF fitting

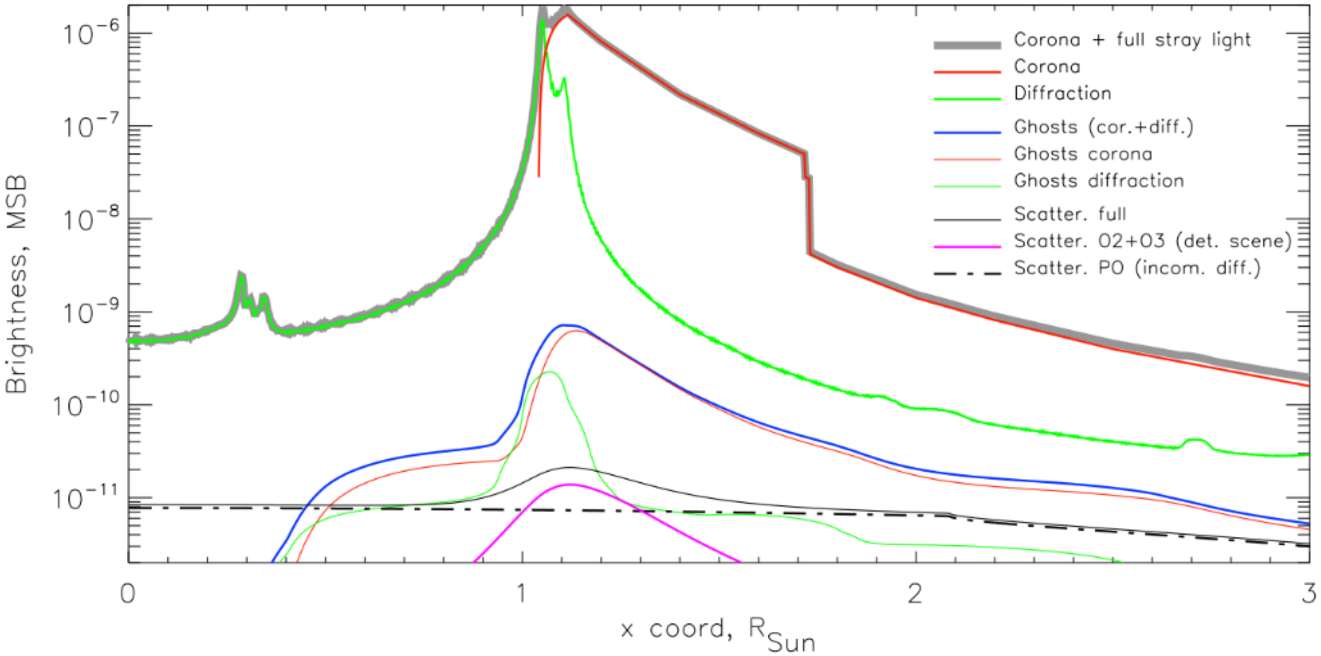
Uncertainties in photometric sensitivity

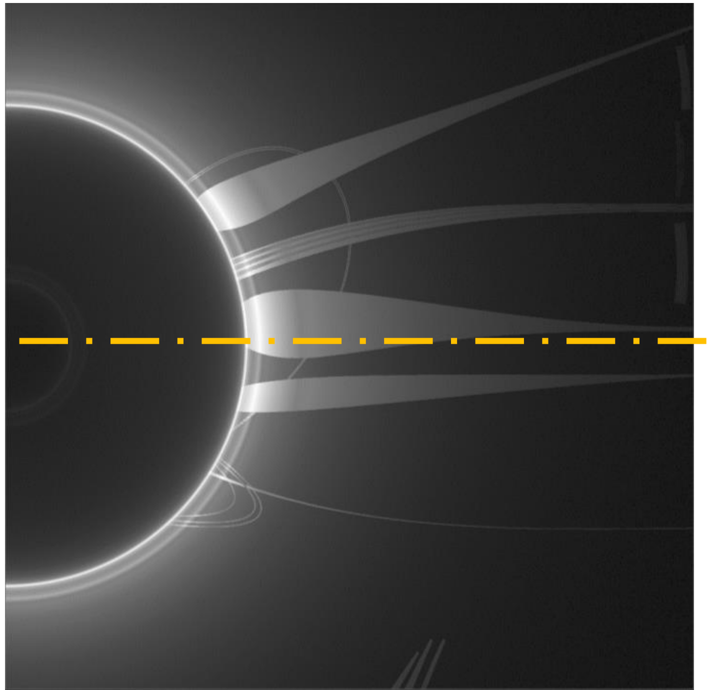
$$B = \frac{N - \mathrm{DC}' \cdot t_{exp} - \mathrm{BIAS}'}{\kappa} - B_{\mathrm{D}} - B_{\mathrm{G}} - B_{\mathrm{Sc}}$$

$$\Delta_{\Sigma} \qquad \Delta_{P} \qquad \Delta_{D} \quad \Delta_{G} \quad \Delta_{Sc}$$







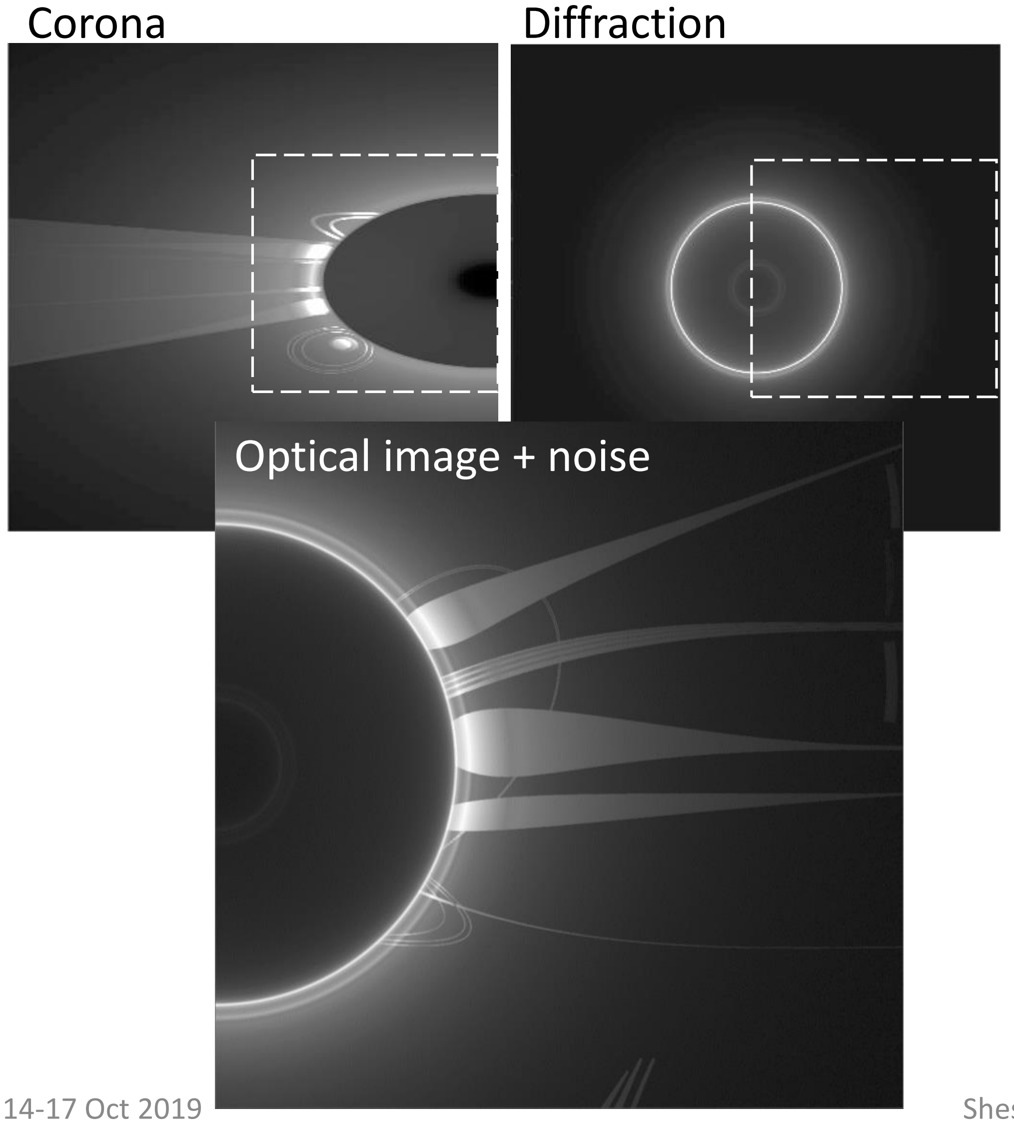


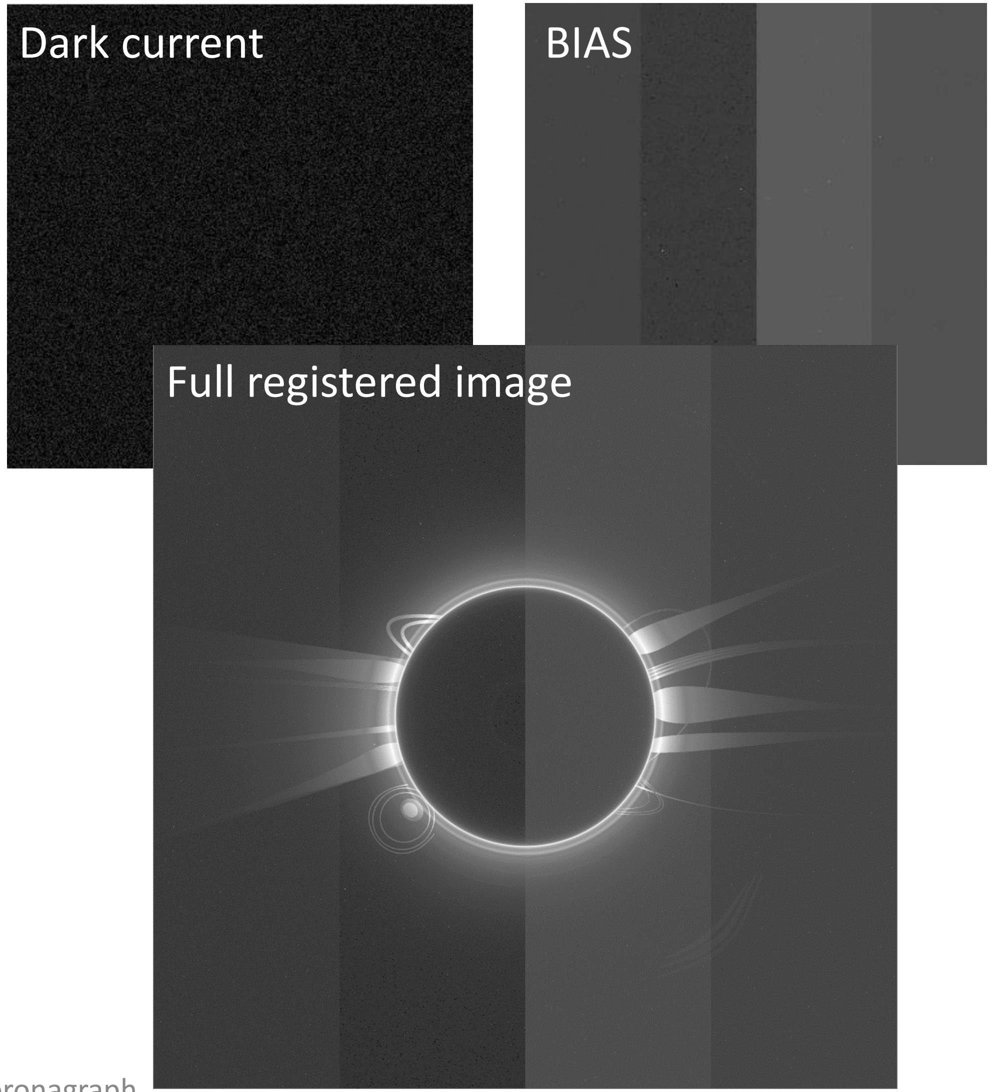
Discussion

- Calibration accuracy can be inferred by applying different methods;
- Known coronagraphs – discrepancy up to 10%;
- Calibration using stars is the most reliable; however requires a lot of observational time;
- Influence of stray light for coronal photometry;

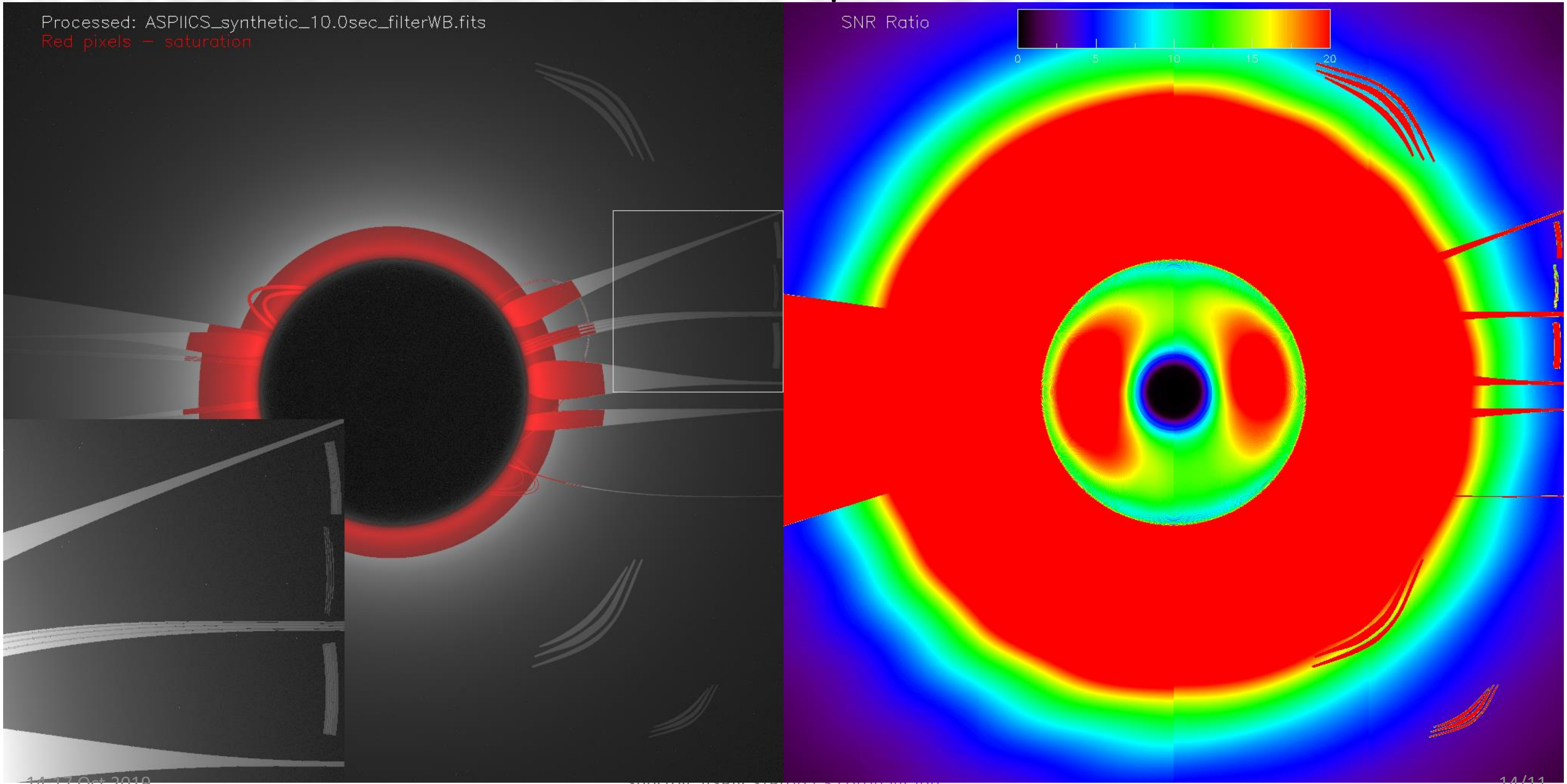
Thank you!

Example for ASPIICS





APSIICS, wide-band filter, t_{exp}=10 s



APSIICS, wide-band filter, t_{exp}=0.1 s

$$\boldsymbol{B}_{\mathrm{Cor}} = \frac{\boldsymbol{N}_i - \mathbf{DC}'\, t_{exp} - \mathbf{BIAS}'}{\boldsymbol{\kappa}} - \boldsymbol{B}_{\mathrm{SL}}$$

$$\delta \sim 10\%$$

$$\Delta_{\Sigma} \qquad \Delta = \delta \cdot A \qquad \Delta_{\mathrm{SL}}$$