



Accurate measurements of the Zwicky Transient Facility camera bandpasses with a Traveling Collimated Beam Projector

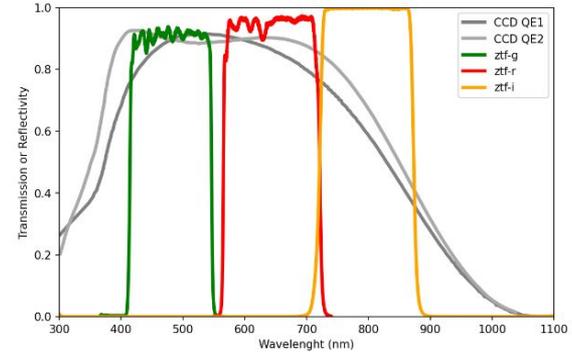
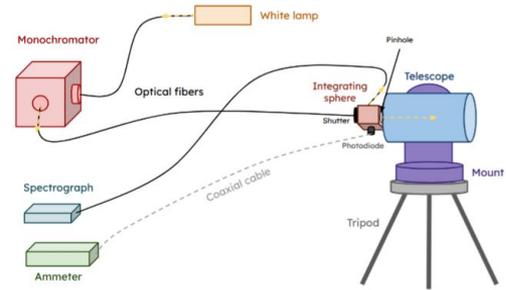
Enya Van den Abeele, Jérémy Neveu, Marie Aubert, Chloé Barjou-Delayre, Marc Betoule, Sebastien Bongard, Angelo Lamure-Fontanini, Laurent Le Guillou, Nicolas Regnault, Philippe Rosnet, Eduardo Sepulveda, and others

Plan de l'article

- | | | |
|-------------------------------|---|---------------------|
| 1. Introduction | → | à écrire |
| 2. Experimental setup | } | complètement rédigé |
| 3. Bandpasses scan strategies | | |
| 4. Data reduction | | |
| 5. Systematics | } | rédaction avancée |
| 6. Results | | |
| 7. Discussion | | |
| 8. Conclusion | → | à écrire |

Experimental setup

- Présentation TCBP
 - instruments
 - montage
- Présentation ZTF
 - télescope
 - caméra
 - filtres
- Installation sur site



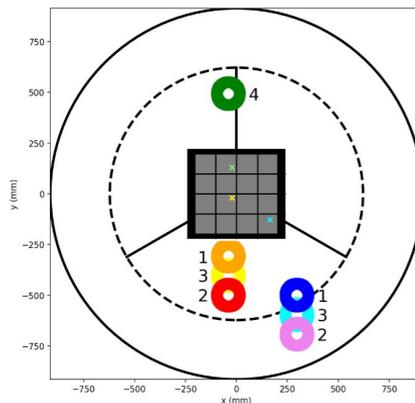
Bandpasses scan strategies

- Principe de mesure des filtres

$$R_{p,f,ccd}(\lambda) = \frac{Q_{ccd}(\lambda)}{Q_{phot}(\lambda) \times R_{TCBP}(\lambda)}$$

- Scans

- choix des temps de pose
- steps en longueur d'onde
- beam positioning



Position	1	2	3	4
P48 dec	-46°	-44°	-45°	-51.5°
TCBP Δalt	0°	-2°	-1°	5.5°

- Single spot

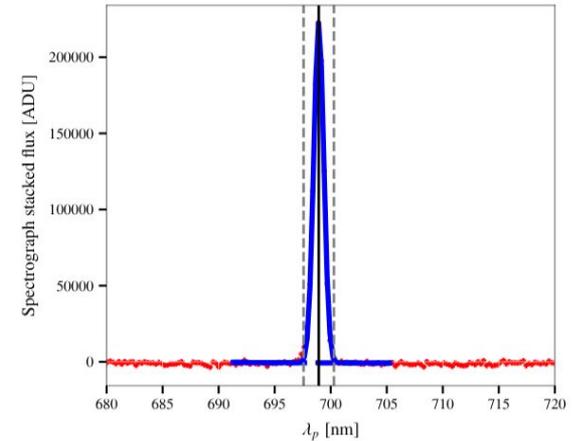
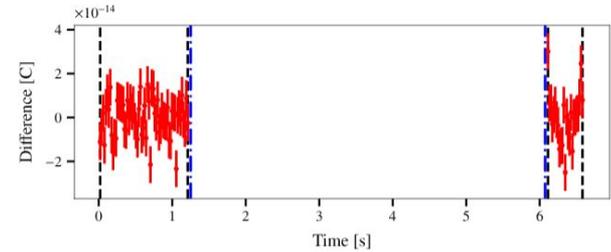
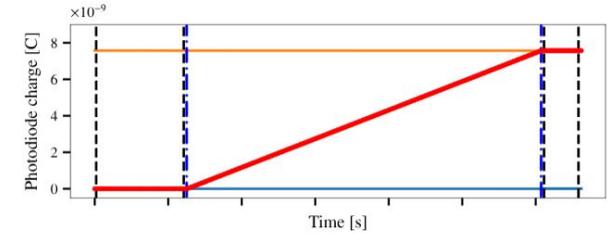
- Multispot

- Dataset summary

Filter / Scanning strategy	g	r	i	empty
Single spot (1nm step)	1	2	1	
Single spot (optimized step)	1	1	1	
Multispot position 1	1	1	1	1
Multispot position 2	1	1	2	1
Multispot position 3		1	1	
Multispot position 4	1	1	1	1

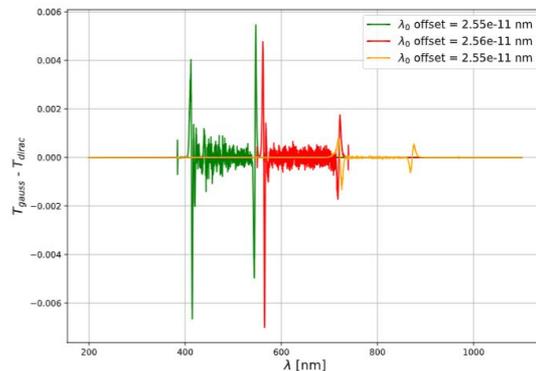
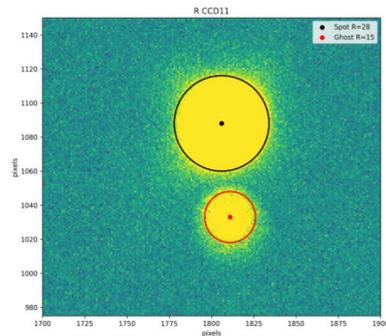
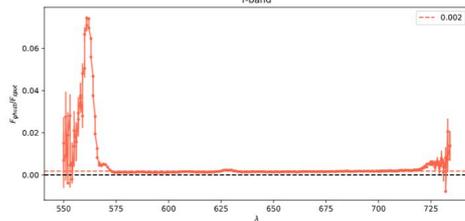
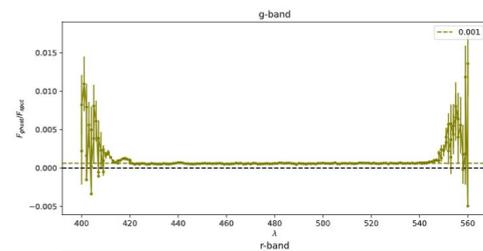
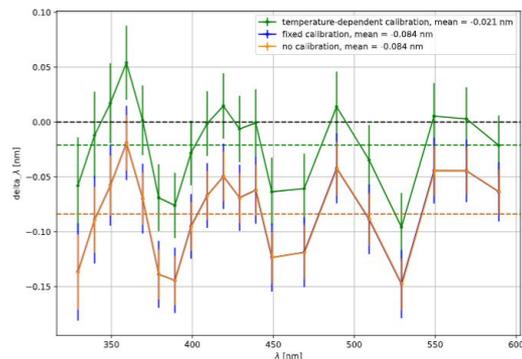
Data reduction

- Réduction données TCBP
 - Photodiode
 - Spectrographe
- Réduction données ZTF
 - image processing : correction overscan, background...
 - aperture photometry



Systematics

- Calibration longueurs d'onde du spectro
→ évolution avec la température
- Calibration télescope TCBP
→ mesure de la réponse par une cellule solaire (Souverin et al. 2025)
- Soustraction du fond
- Ghost contamination
→ impact sur la photométrie
- Spectrum deconvolution
→ impact des spectres gaussiens du TCBP sur la mesure de la transmission des filtres + λ moyen



Systematics

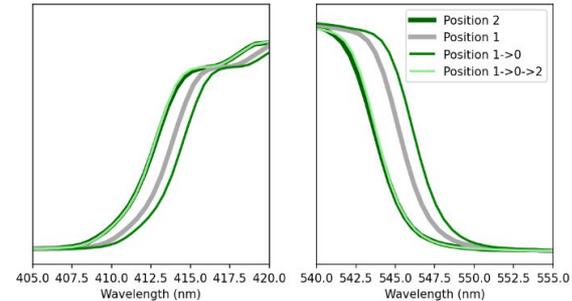
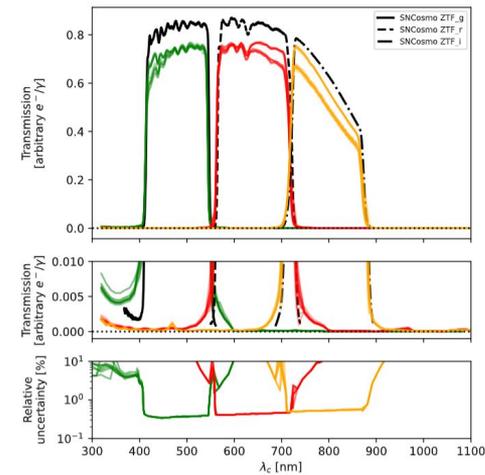
- Calibration longueurs d'onde du spectro
→ évolution avec la température
- Calibration télescope TCBP
→ mesure de la réponse par une cellule solaire (Souverin et al. 2025)
- **Soustraction du fond**
- Ghost contamination
→ impact sur la photométrie
- **Spectrum deconvolution**
→ impact des spectres gaussiens du TCBP sur la mesure de la transmission des filtres + λ moyen

À faire :

- Écrire les parties manquantes
- Discussion sur la convolution par les spectres TCBP : pousser plus loin l'étude ?
- S'assurer de l'absence (ou chiffrer la présence) de lumière parasite dans la sphère (lumière blanche en sortie du mono, fluorescence)
→ spectro Harvard

Results

- Des données réduites aux bandpasses
→ filtrage des outliers
- Scans haute résolution
- Efficacité quantique des CCDs
- Variation spatiale des filtres
→ efficacité quantique CDDs
- Blueshift
- Indice de réfraction effectifs
→ méthode de calcul (redshift et blueshift des transmissions position 1 → 2 , minimisation de chi2)



Filter name	ZTF-g	ZTF-r	ZTF-i
Bandpass (nm)	414.3 546.3	565.5 721.3	721.2 873.2
Mean transmission	0.910	0.952	0.997
Effective refractive indice	1.708 ±0.077	1.692 ±0.081	1.704 ±0.070

Results

- Des données réduites aux bandpasses
→ filtrage des outliers
- Scans haute résolution
- **Efficacité quantique des CCDs**
- Variation spatiale des filtres
→ efficacité quantique CDDs
- **Blueshift**
- Indice de réfraction effectifs
→ méthode de calcul (redshift et blueshift des transmissions position 1 → 2 , minimisation de chi2)

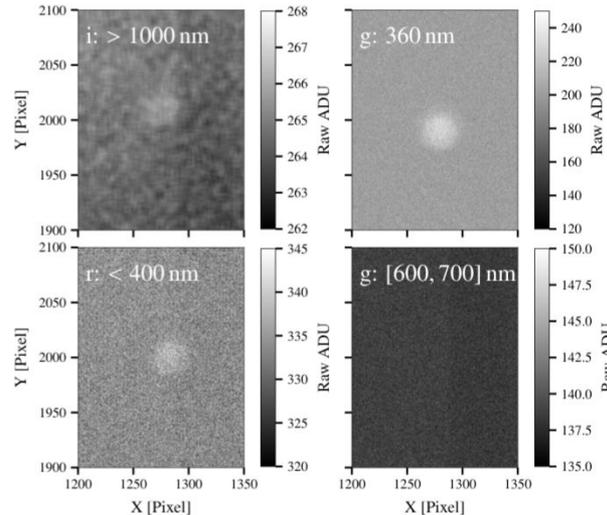
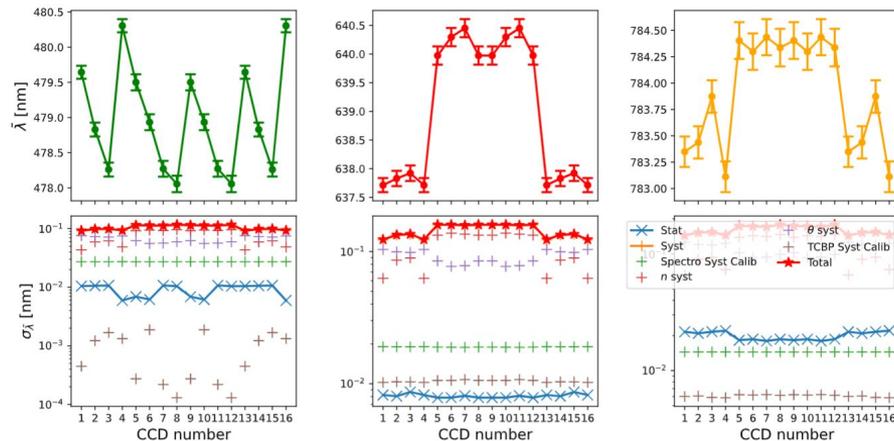
À faire :

- Écrire les parties manquantes
- Nouvelle release (avec masque du ghost + calibration spectro actualisée)
- Chiffrer la variation spatiale (%)
- Checker la variation des indices optique, si elle est cohérente ou due au bruit de mesure

Filter name	ZTF-g	ZTF-r	ZTF-i
Bandpass (nm)	414.3	565.5	721.2
	546.3	721.3	873.2
Mean transmission	0.910	0.952	0.997
Effective refractive indice	1.708 ±0.077	1.692 ±0.081	1.704 ±0.070

Discussion

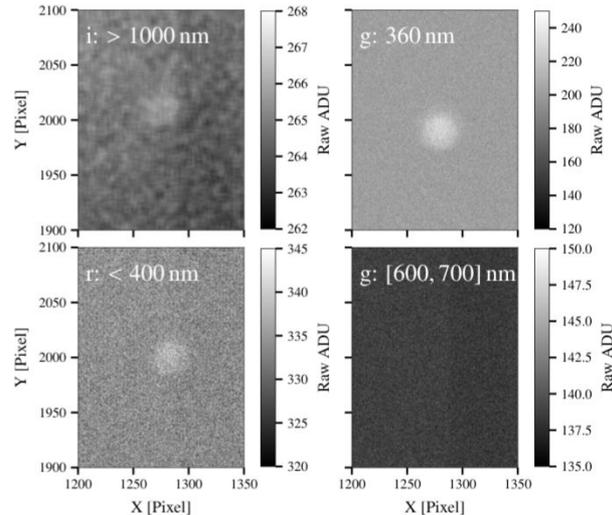
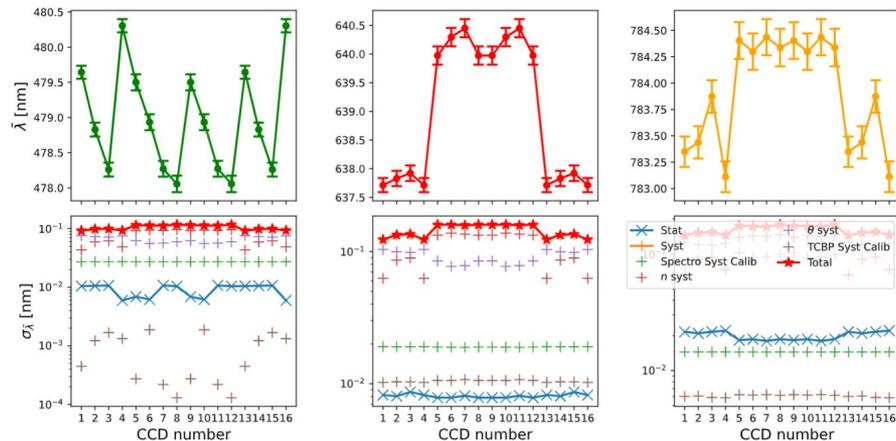
- **Lambda moyen**
→ effet du coating + efficacité quantique des CCDs
→ budget des incertitudes
- **Fuites**
→ pieds gauches des filtres g et r (0.5% en g), légère en IR pour le filtre i



Discussion

À faire :

- Discuter cette figure
→ bilan d'incertitudes
(notamment le +/- 0.2° pour les angles)
- Chiffrer les fuites :
→ % pour r et i
→ à combien de sigma ?
→ conclure capacité de détection des fuites par le TCBP (quel % avec quel sigma et pour quel temps de pose)

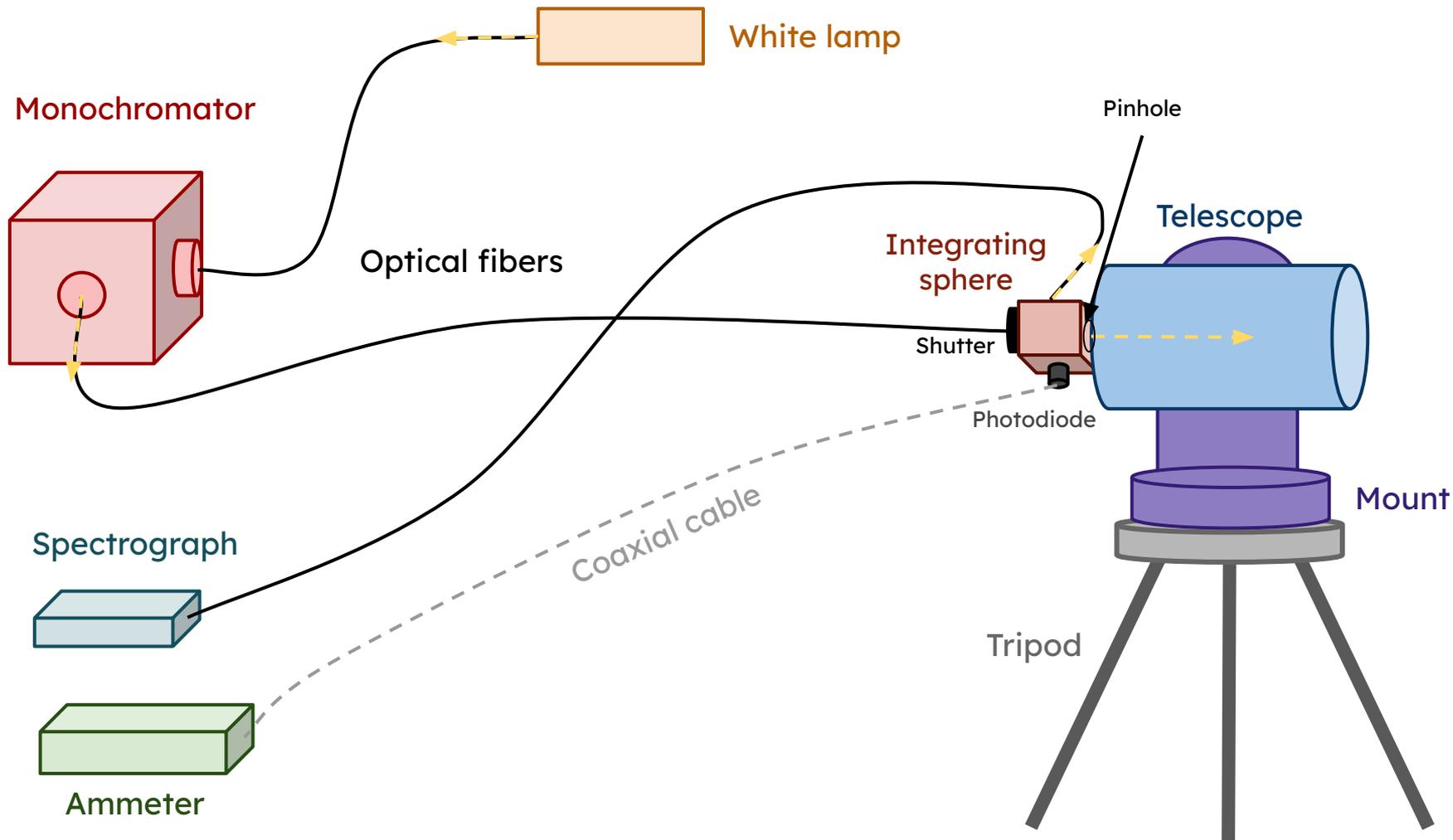


Récap

1. Introduction
2. Experimental setup
3. Bandpasses scan strategies
4. Data reduction
5. Systematics
6. Results
7. Discussion
8. Conclusion

- Nouvelle release des filtres
- Systématiques :
→ chiffrer l'éventuelle lumière parasite
- Résultats :
→ chiffrer variations spatiales
→ variations d'indices
- Lambda moyen :
→ discuter des incertitudes
- Fuites :
→ finir de chiffrer

Backups



Installation

Spectrograph



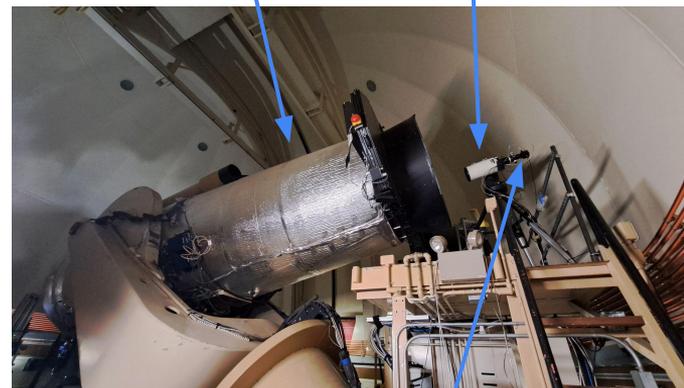
Lamp

Monochromator



ZTF telescope

TCBP telescope



Integrating sphere

Installation



pfiou pfiou

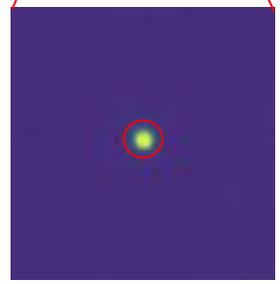
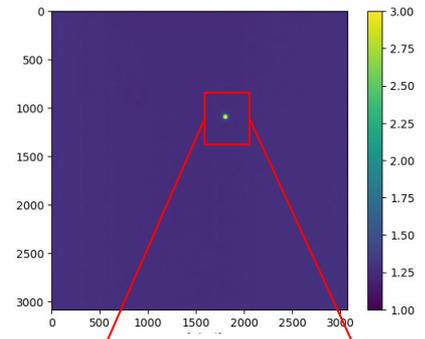
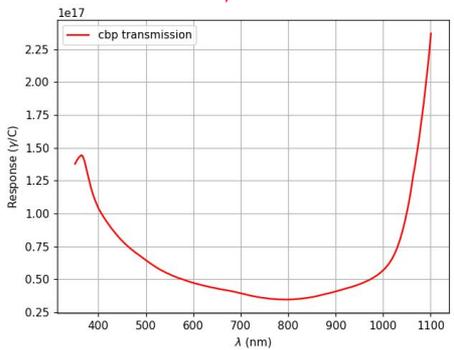
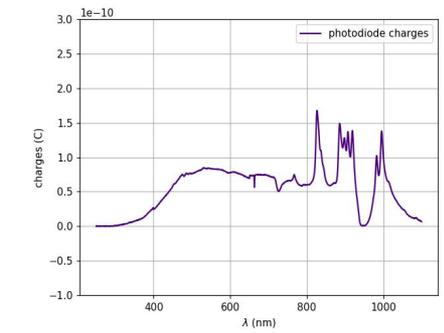
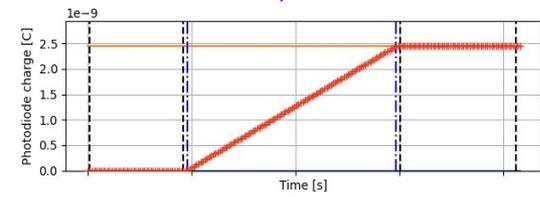


Filter transmission curve recipe

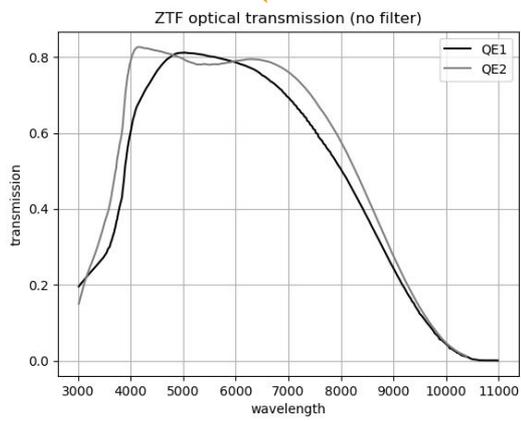
$$T_f = \frac{Q_{\text{ccd}}}{Q_{\text{phot}} \times R_{\text{CBP}}}$$

$$F_{\text{ADU}} * G \sim 6.2 \text{ e-/ADU}$$

$$QE_{\text{CCD}}$$



Aperture photometry

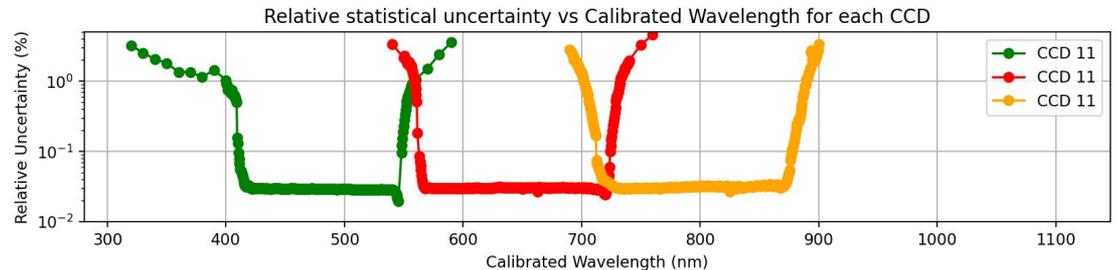
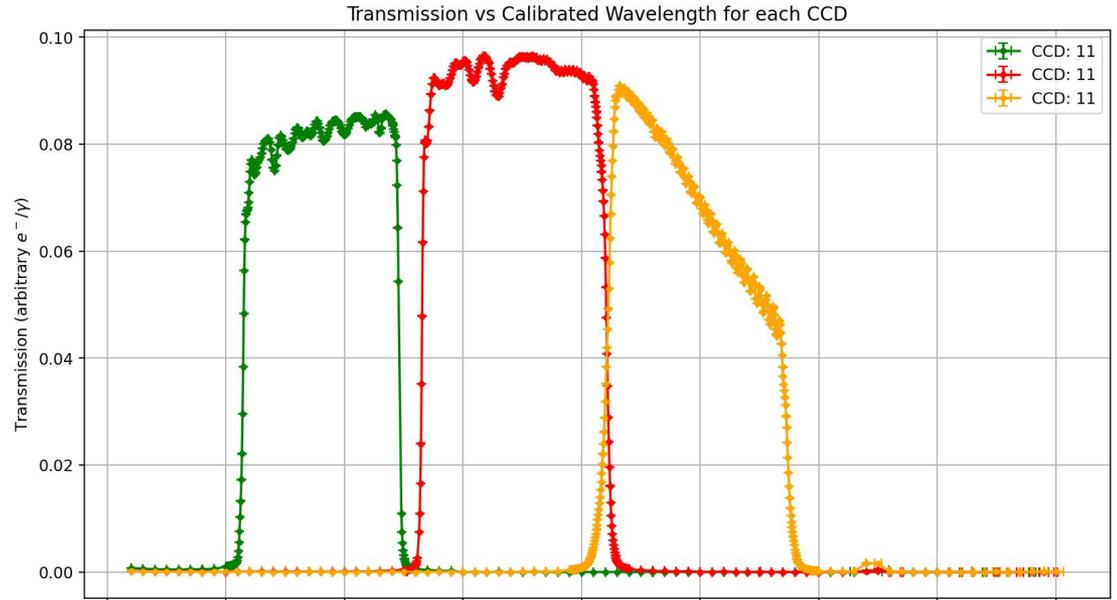


ZTF optical transmission (no filter)

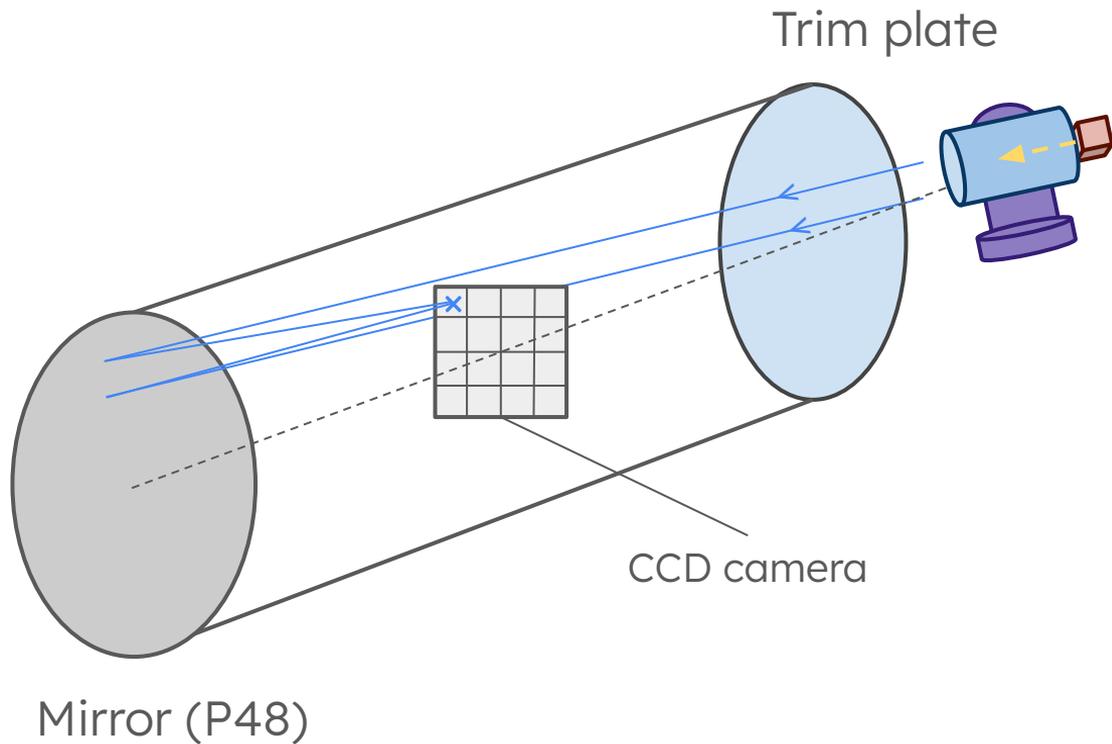
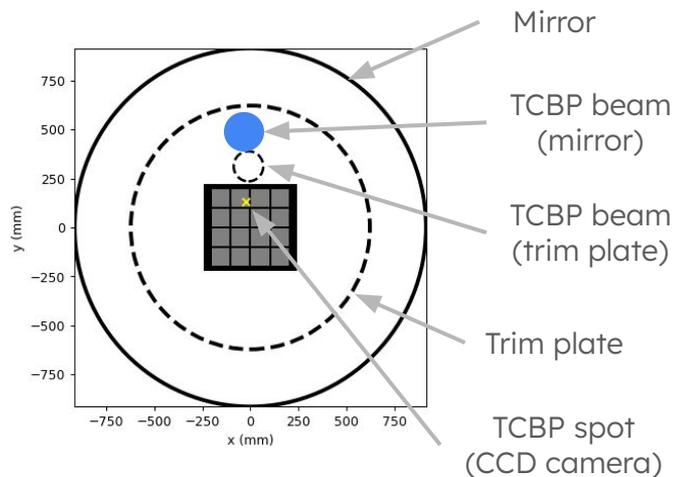
Filter transmission curve recipe

$$T_f =$$

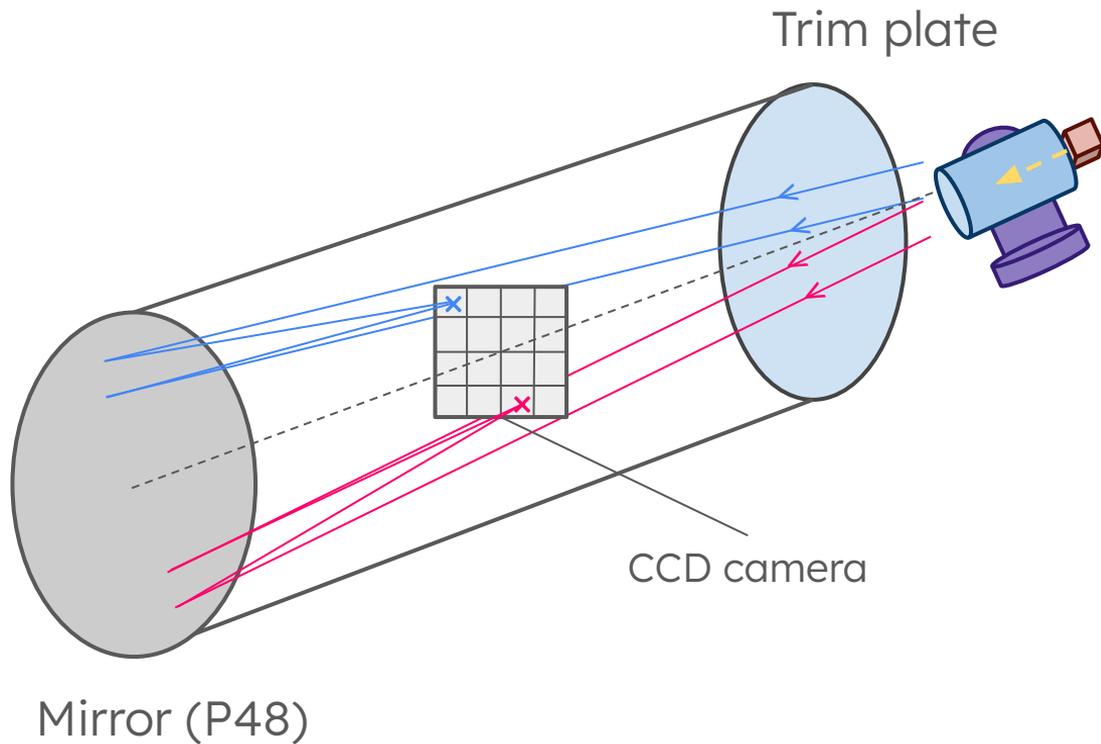
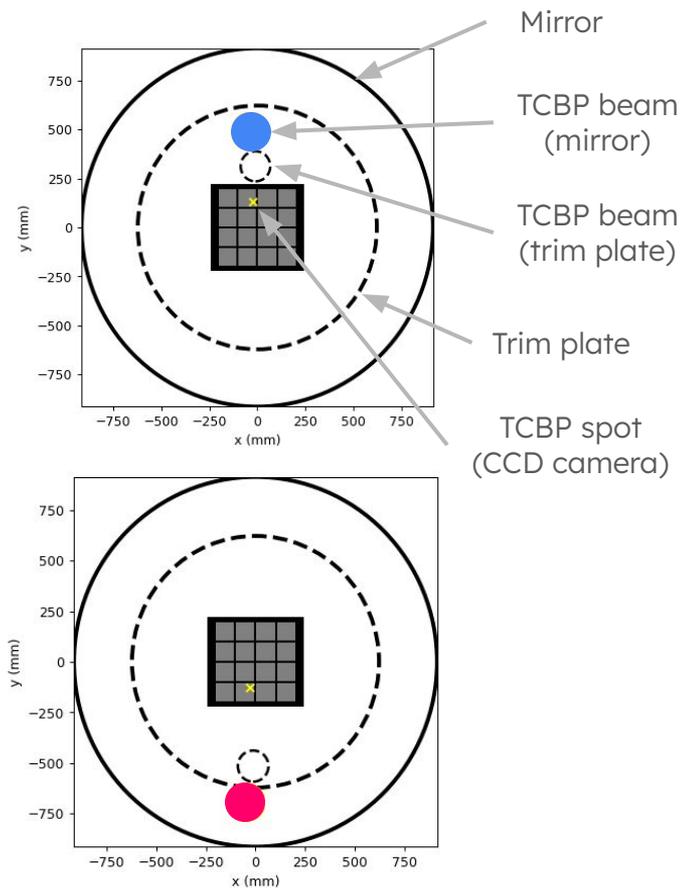
- 3 filters scanned in one day with fine steps in CCD11
- subpermil statistical uncertainties
- normalisation issue needing investigations



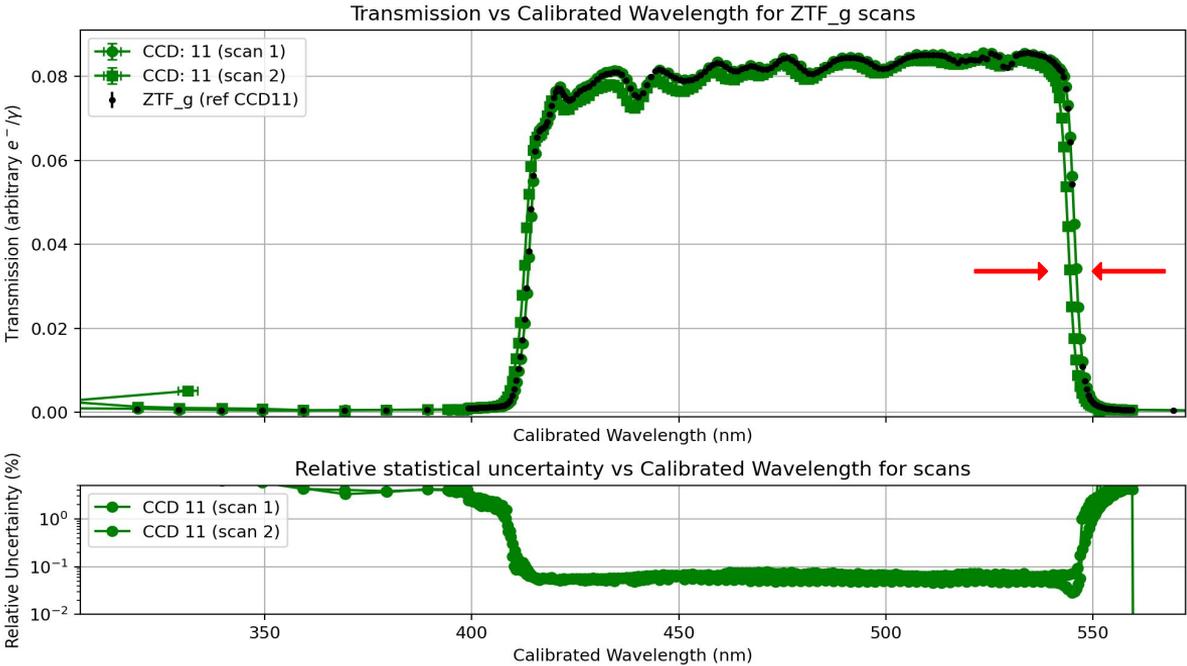
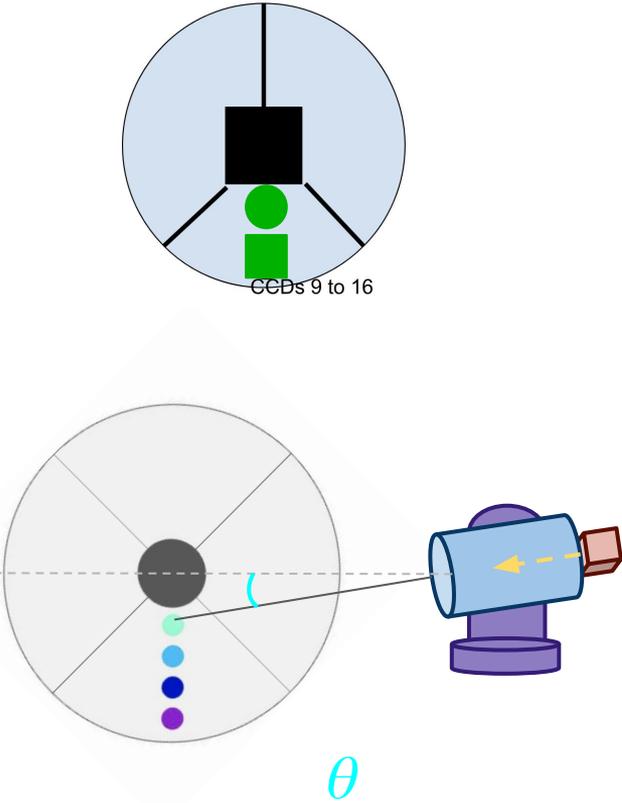
Observation strategy : different incident angles



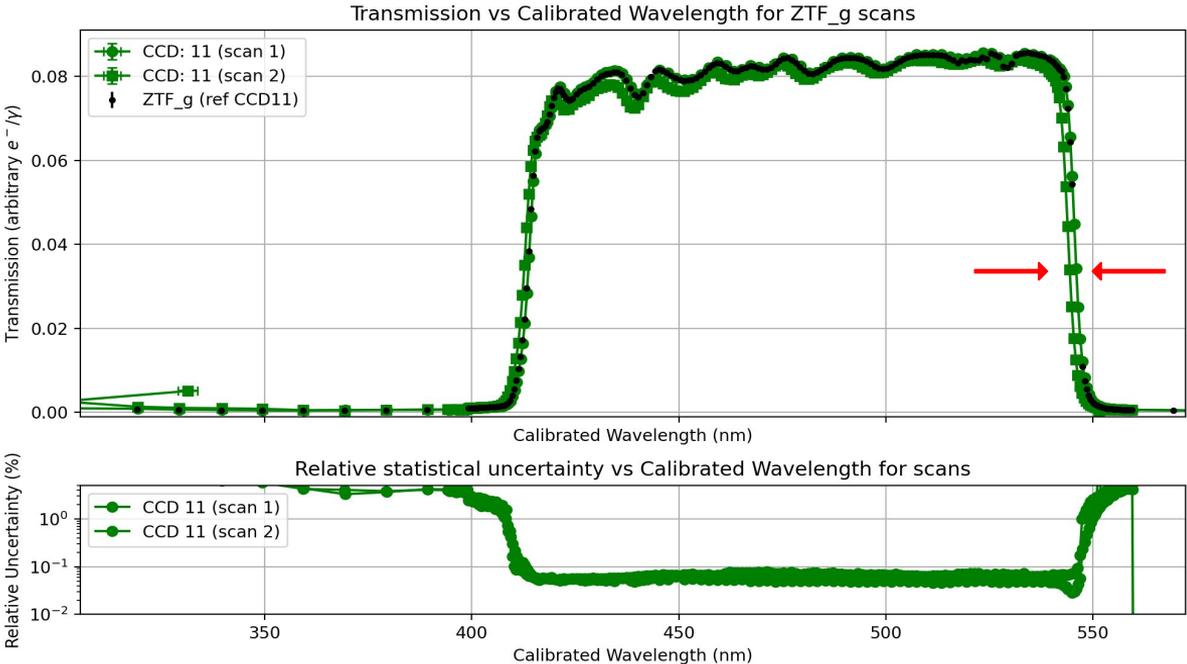
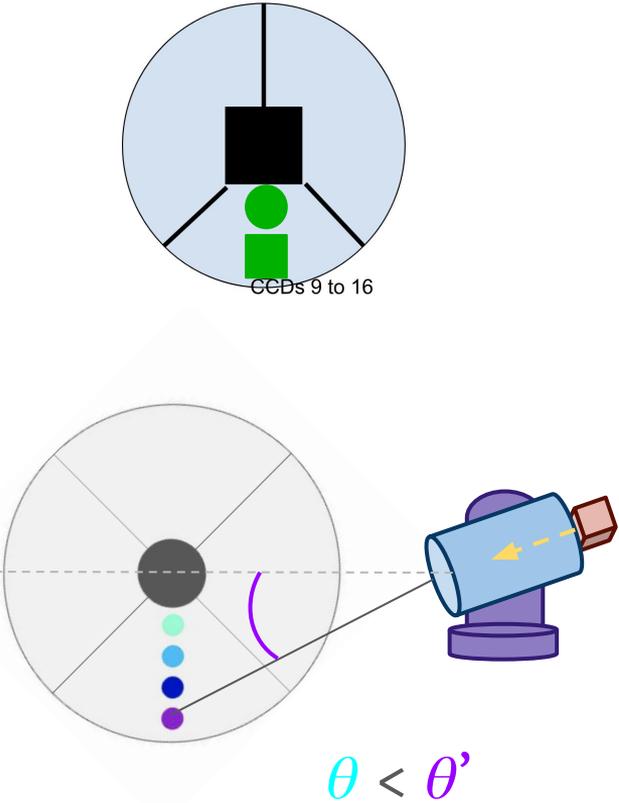
Observation strategy : different incident angles



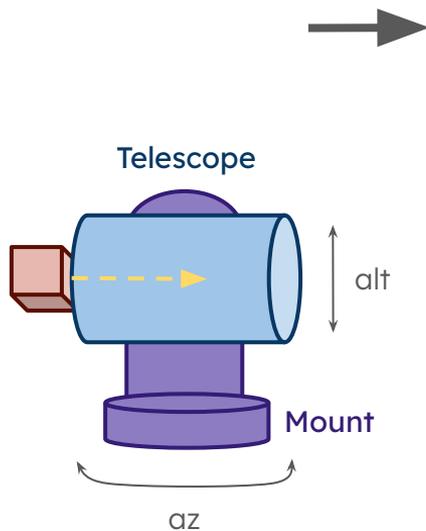
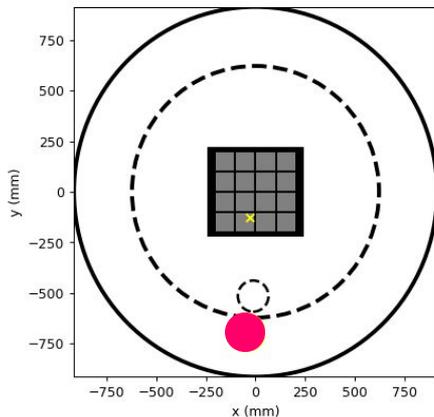
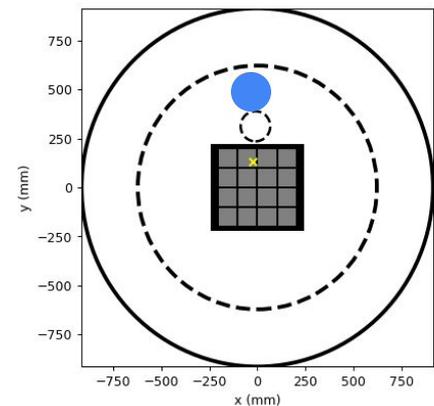
Filter shifts preliminary results



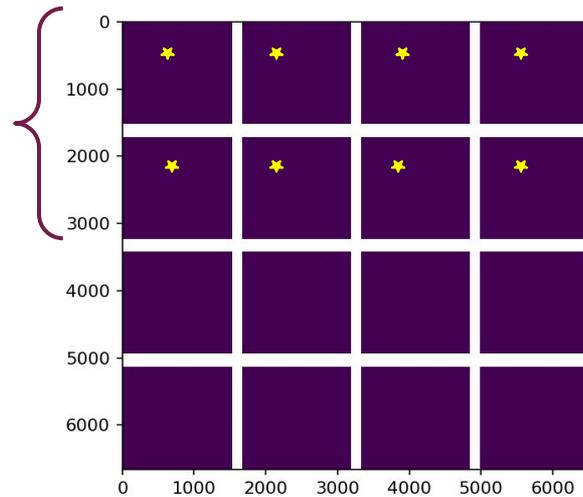
Filter shifts preliminary results



Observation strategy : multispot



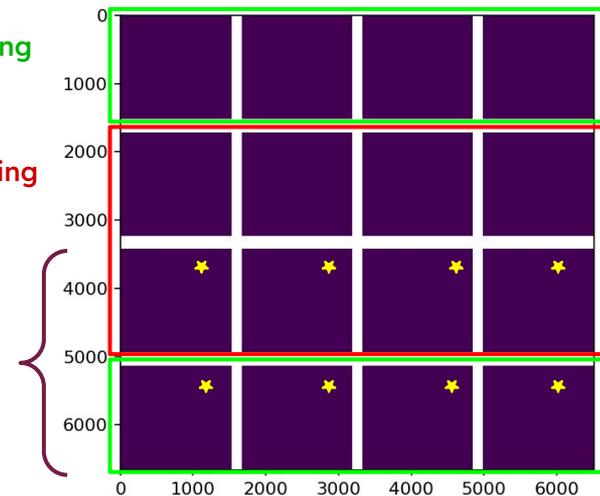
CCD 01-08



Single coating

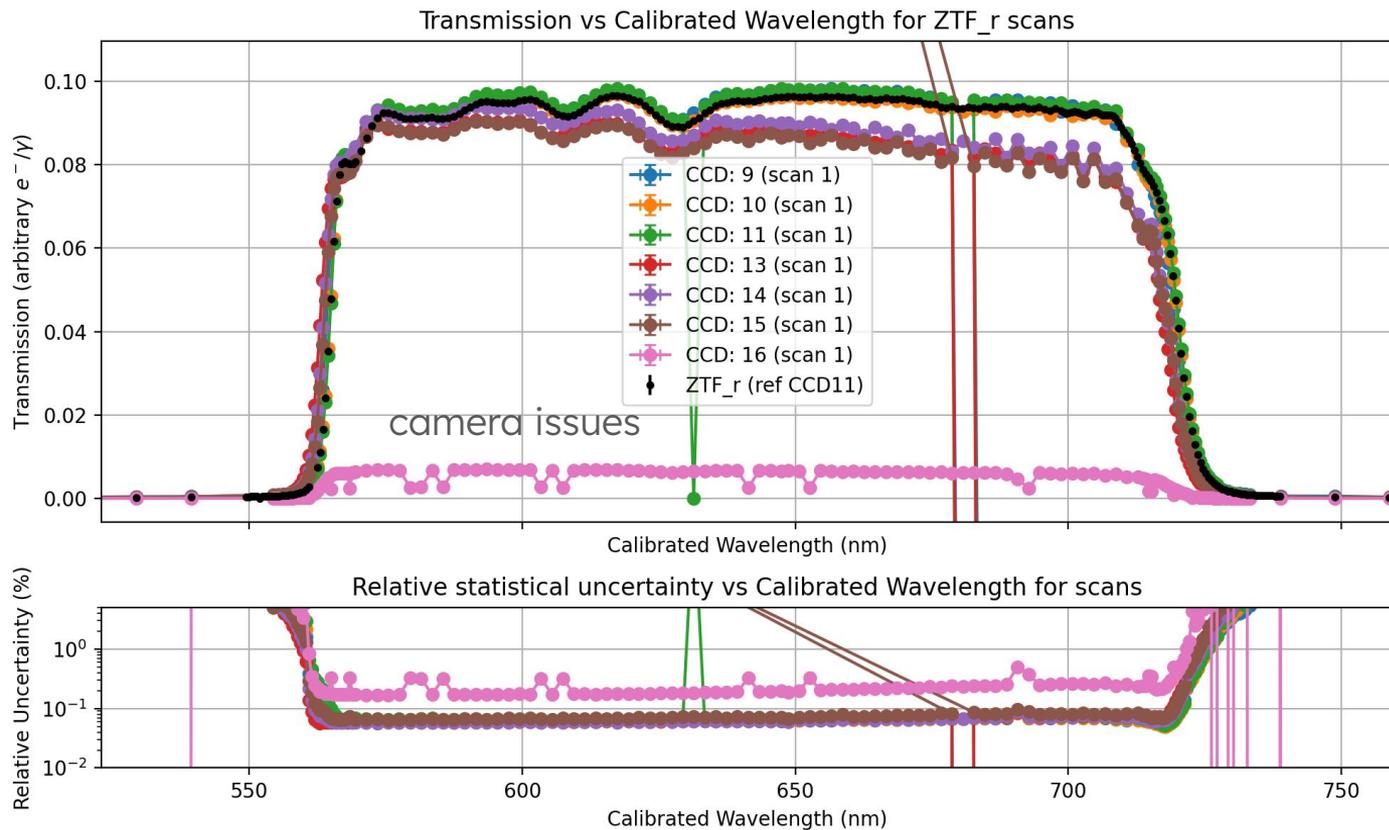
Double coating

CCD 09-16



Multispot results : r band

- 2 CCD families
- But still internal dispersion between them
- Fringing more pronounced for CCDs 13-16 (single coating)

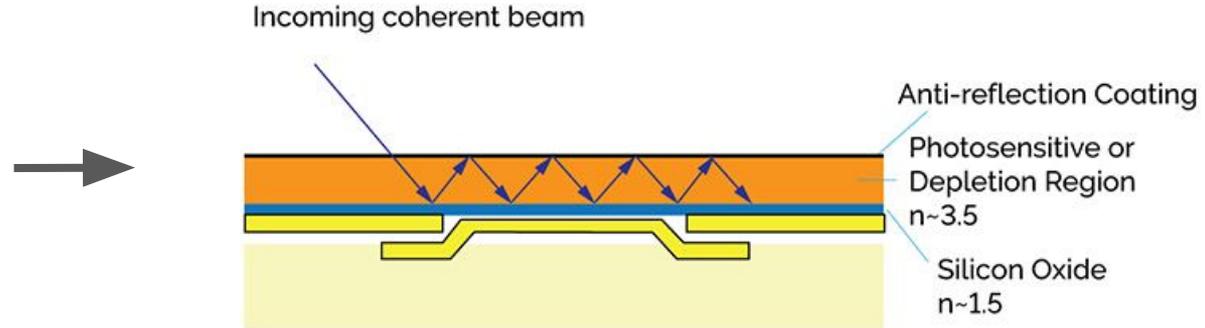
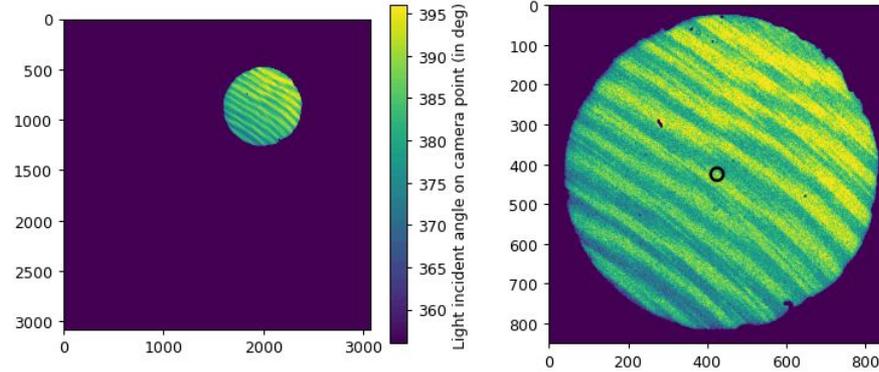


Multispot results : r band

Credit: Philippe Rosnet

- 2 CCD families
- But still internal dispersion between them
- Fringing more pronounced for CCDs 13-16 (single coating)

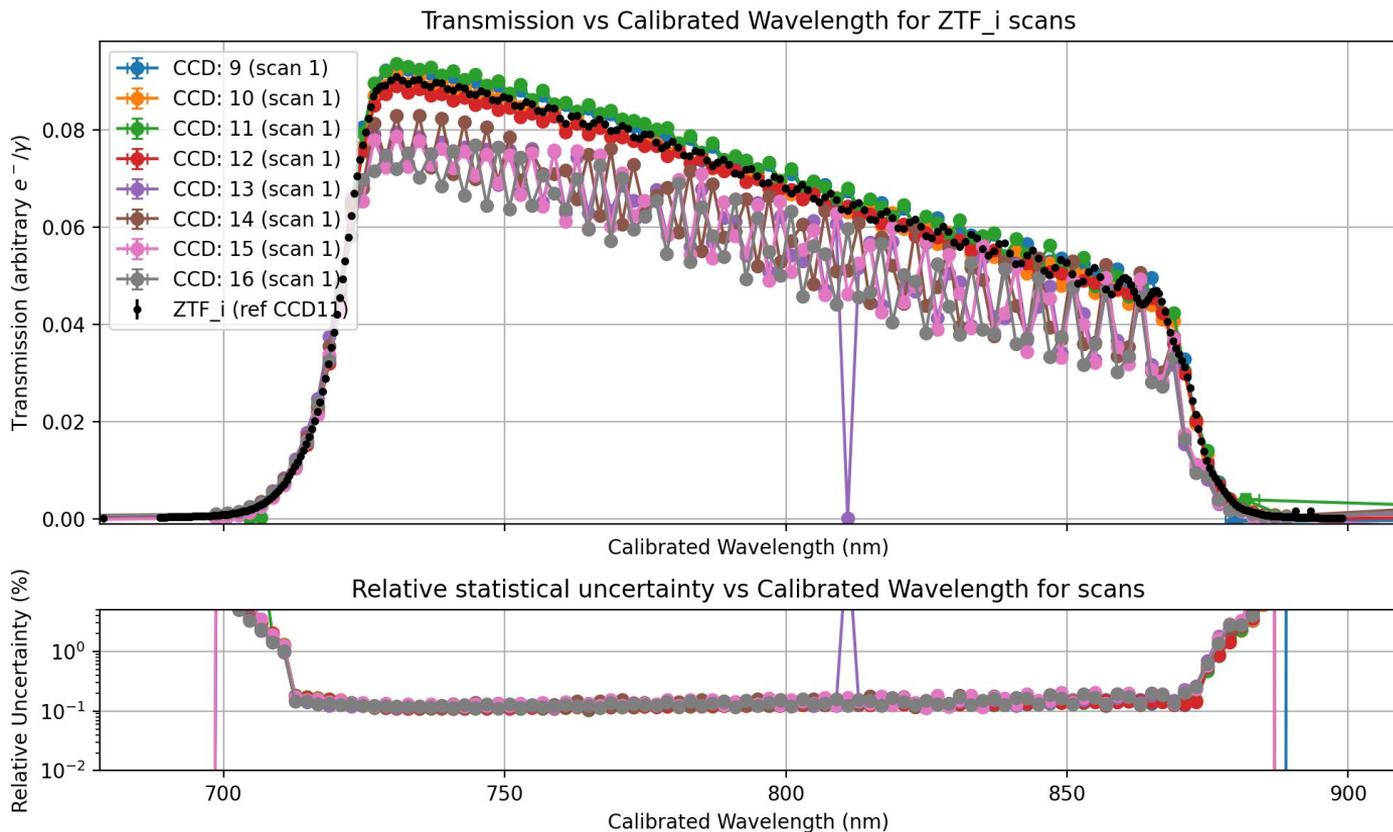
scan CCD11 empty: 7500 Å



Credit: andor.oxinst.com

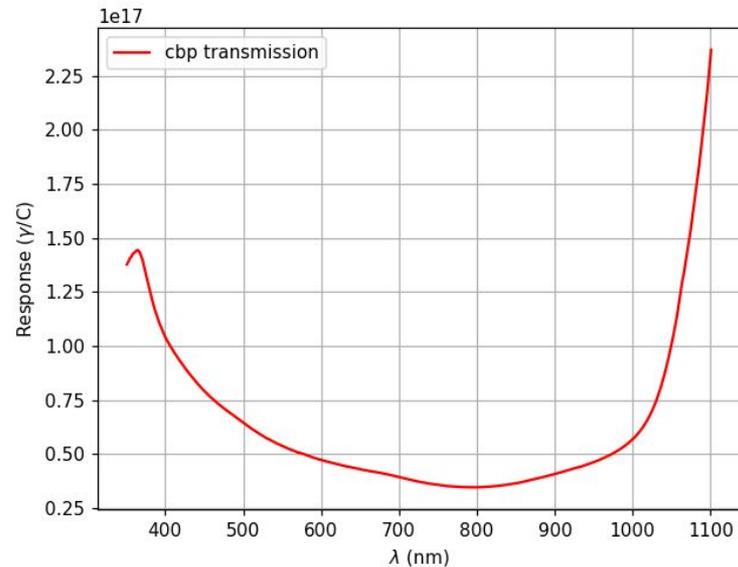
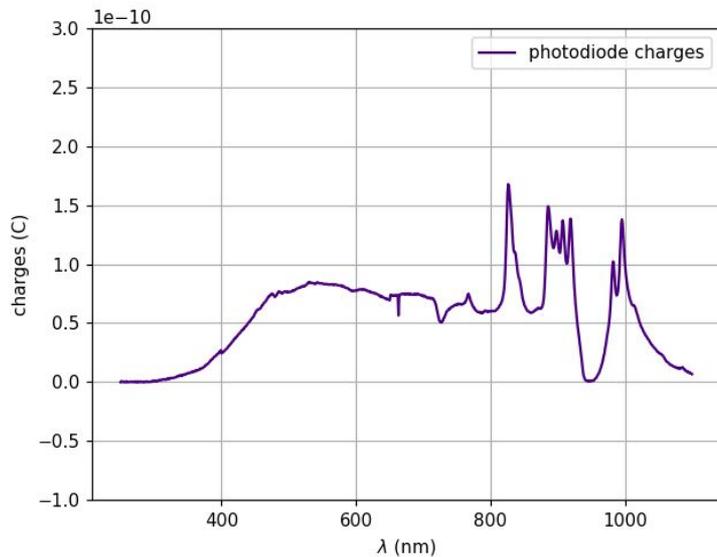
Multispot results : i band

- 2 CCD families
- But still internal dispersion between them
- Fringing more pronounced for CCDs 13-16 (single coating)

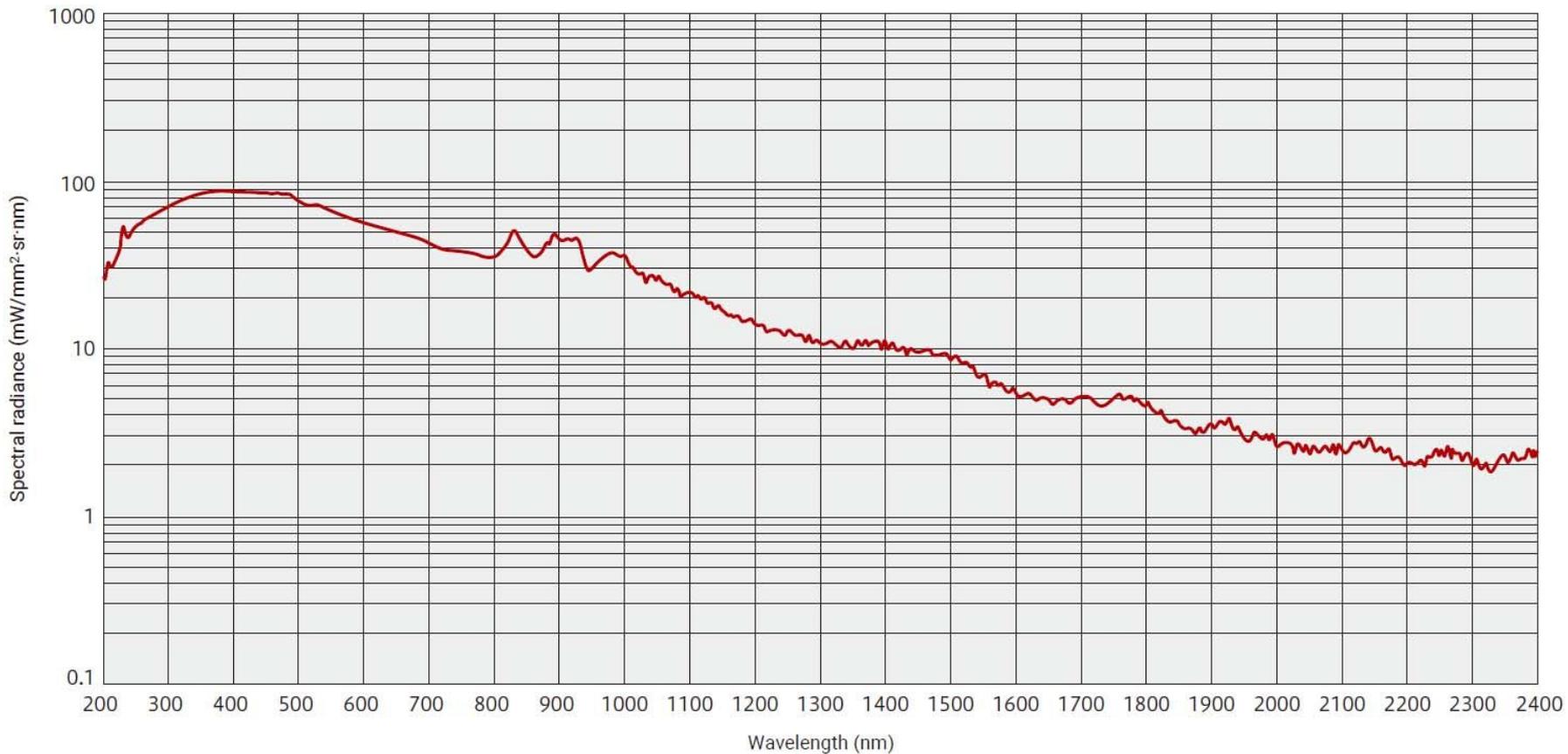


CBP transmission

$$R_{\text{tel}} = \frac{Q_{\text{ccd}}}{Q_{\text{phot}} \times R_{\text{CBP}}}$$

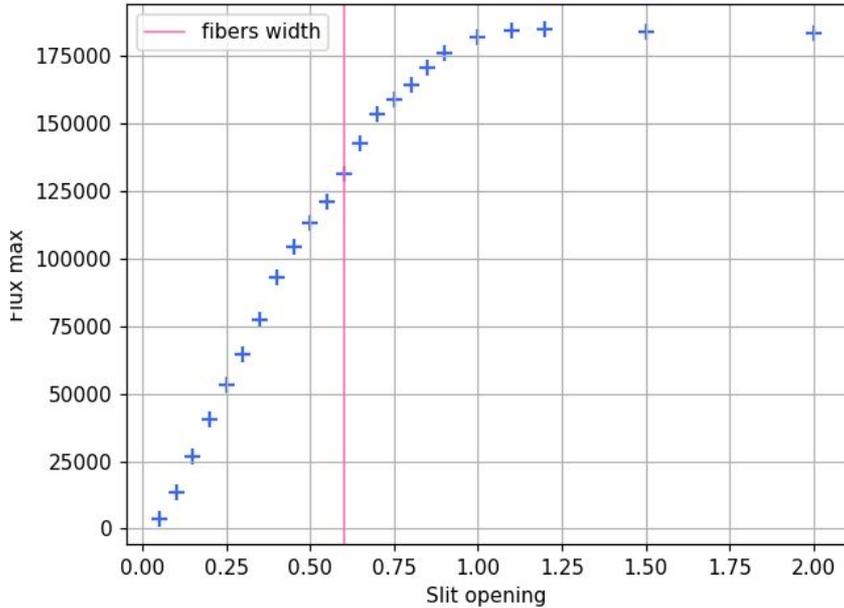


LDLS spectral radiance

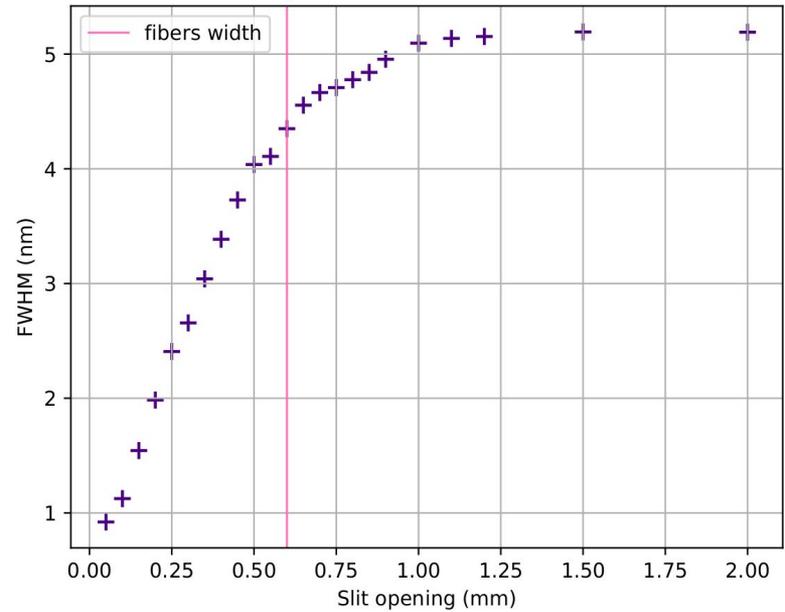


Monochromator resolution (500nm)

Peak's maximal flux **VS** slit opening



Peak's FWHM **VS** slit opening



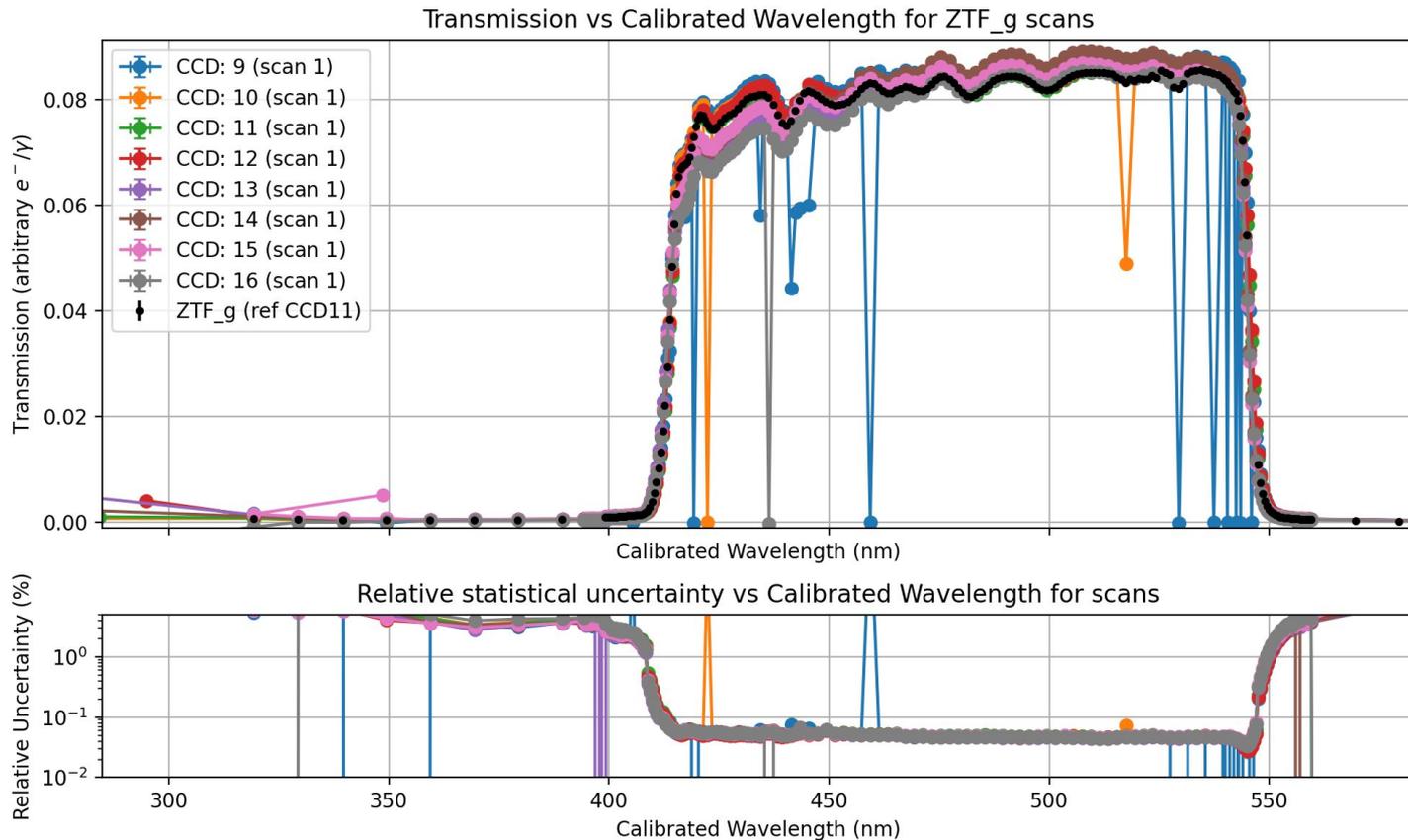
Data set summary

	Filter	g	r	i	empty
CCD 11	1 nm steps	One scan	Two scans	One scan	
	Optimized steps	One scan	One scan	One scan	
CCD 09-16	Multispot pos1	One scan	One scan	One scan	One scan
	Multispot pos2	One scan	One scan	Two scans	One scan
	Multispot pos3		One scan (well sampled to see fringing)	One scan	
CCD 01-08	Multispot pos4	One scan	One scan	One scan	One scan

Multispot preliminary results

2 CCD families

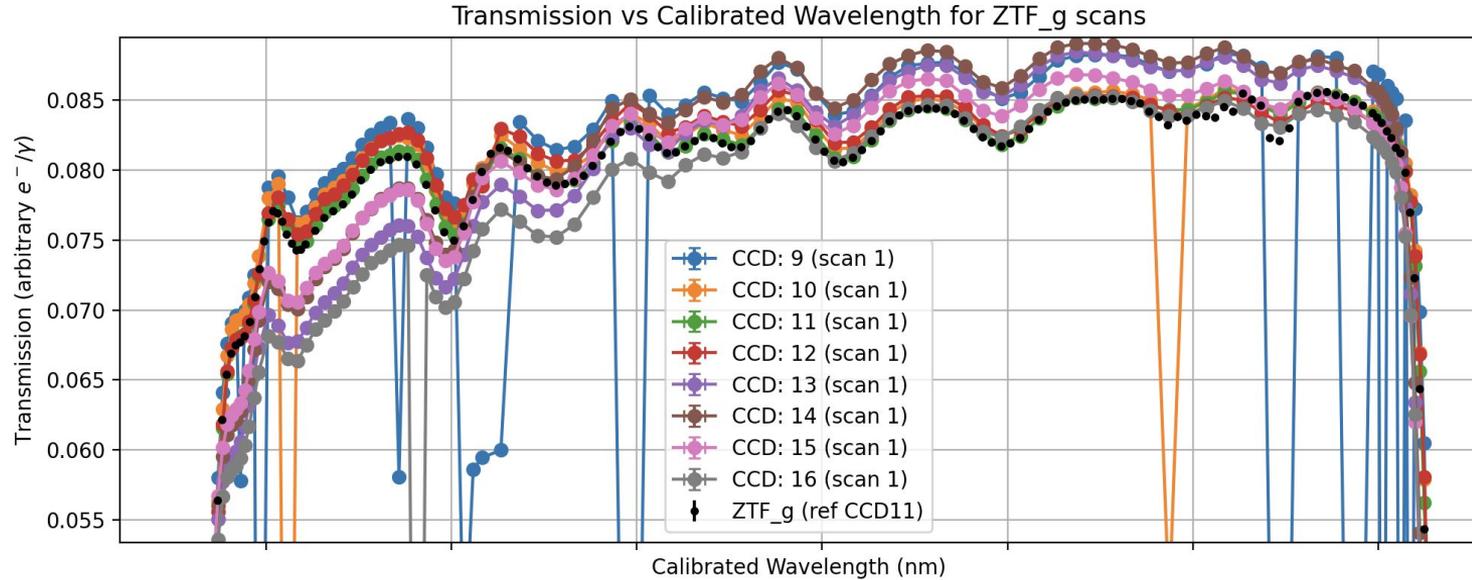
but still internal
dispersion
between them



Multispot preliminary results

2 CCD families

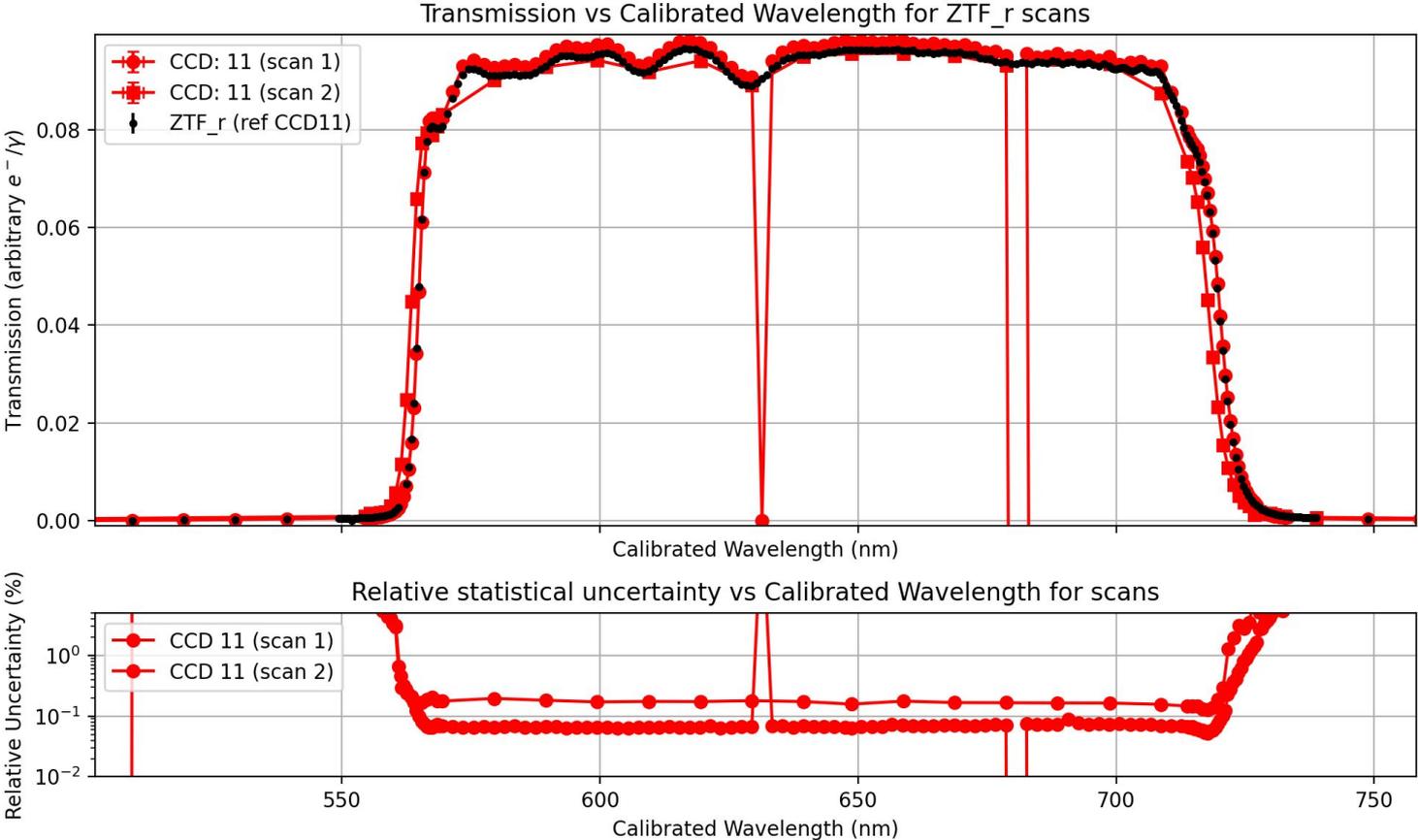
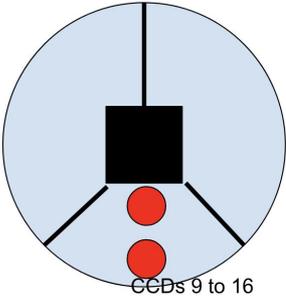
but still internal
dispersion
between them



look at (pink,violet) curves or
(blue,orange)

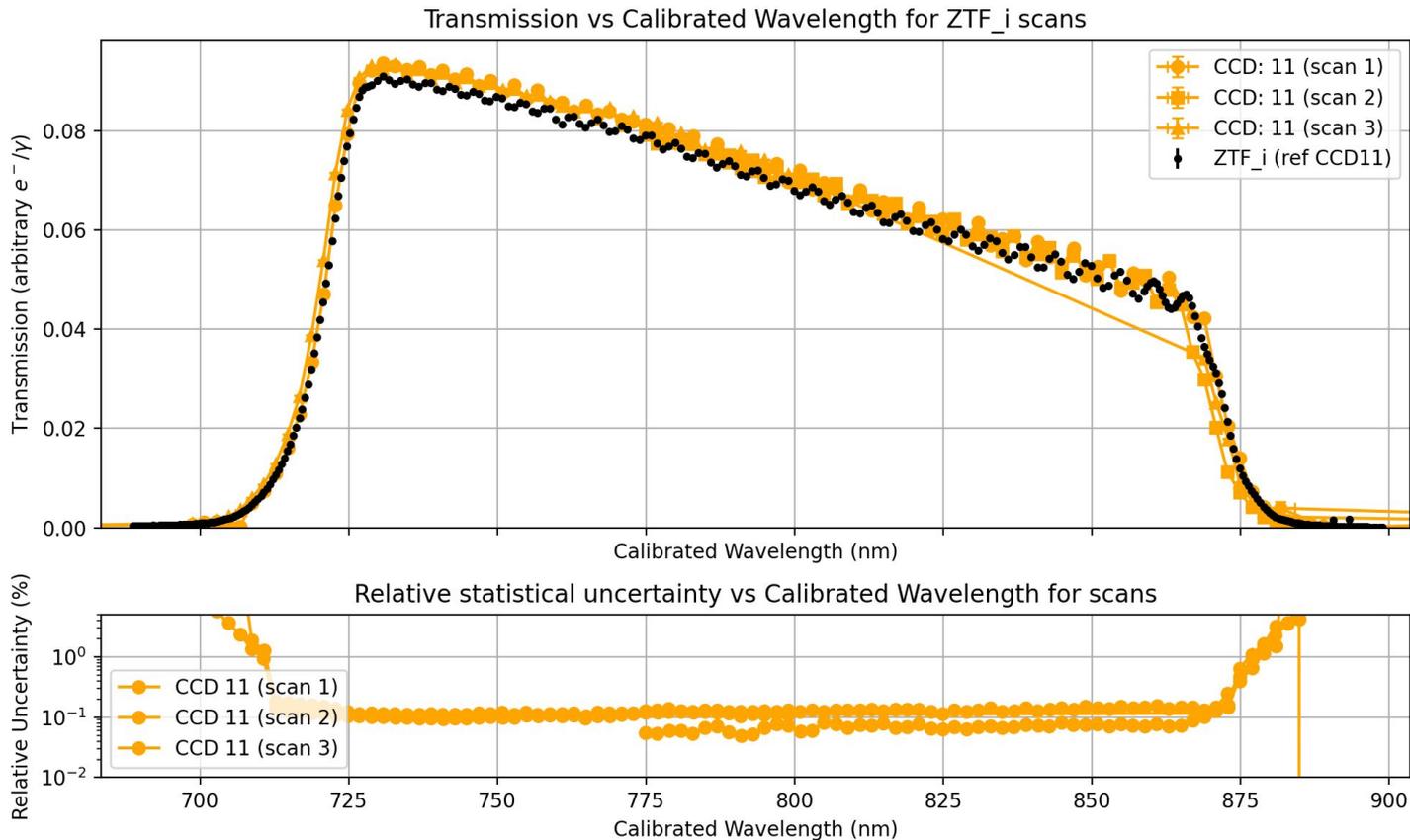
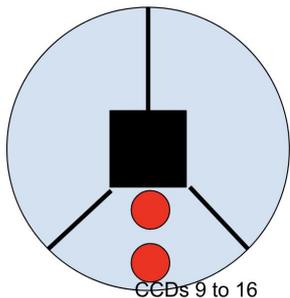
Filter shifts preliminary results

CCD11

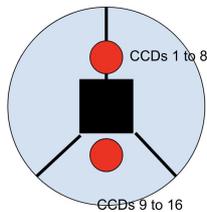


Filter shifts preliminary results

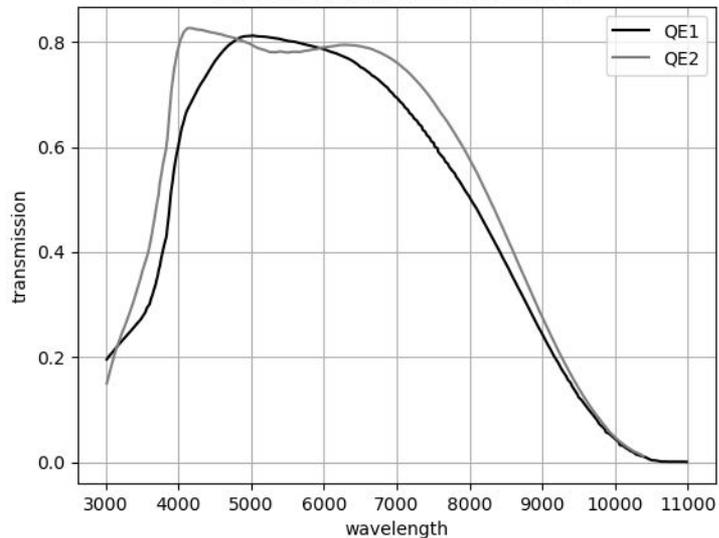
CCD11



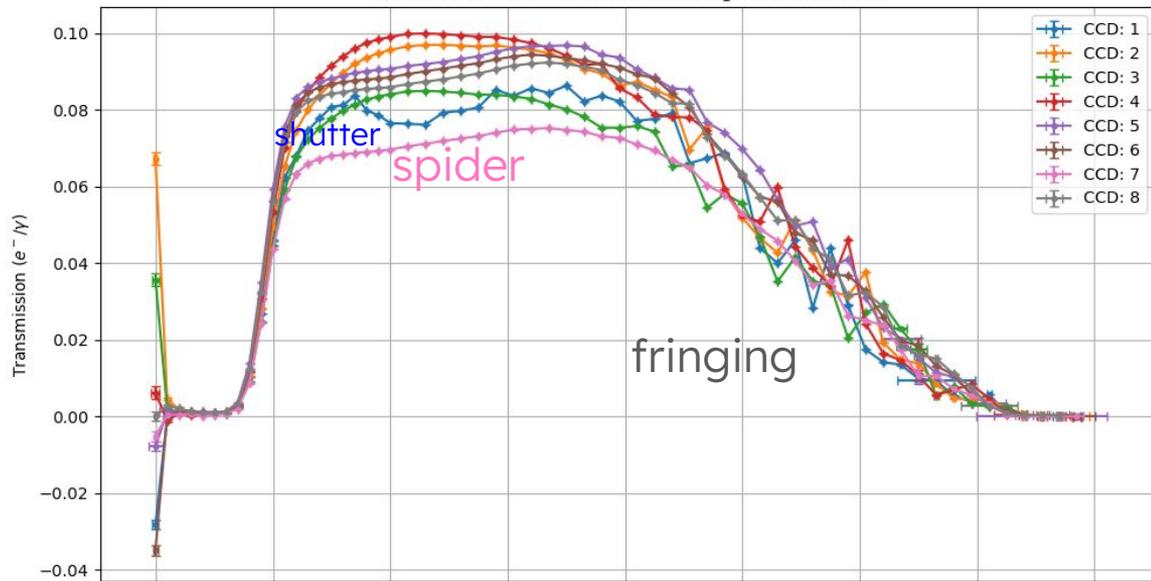
CCD QEs



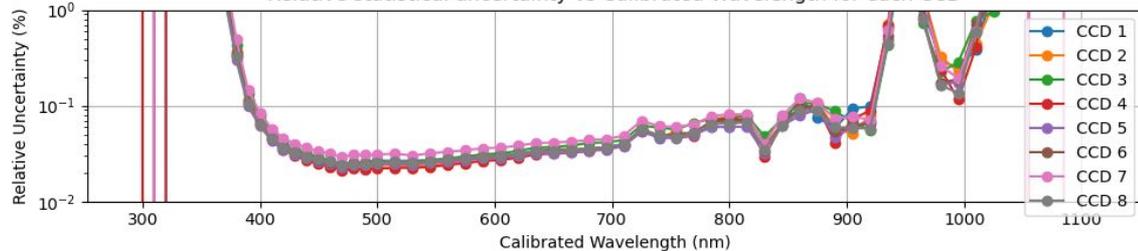
ZTF optical transmission (no filter)



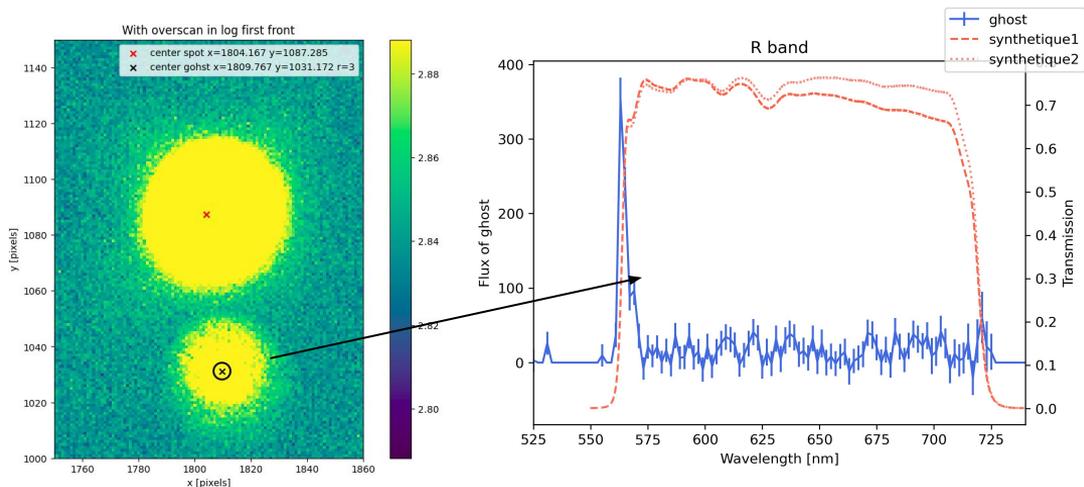
Transmission vs Calibrated Wavelength for each CCD



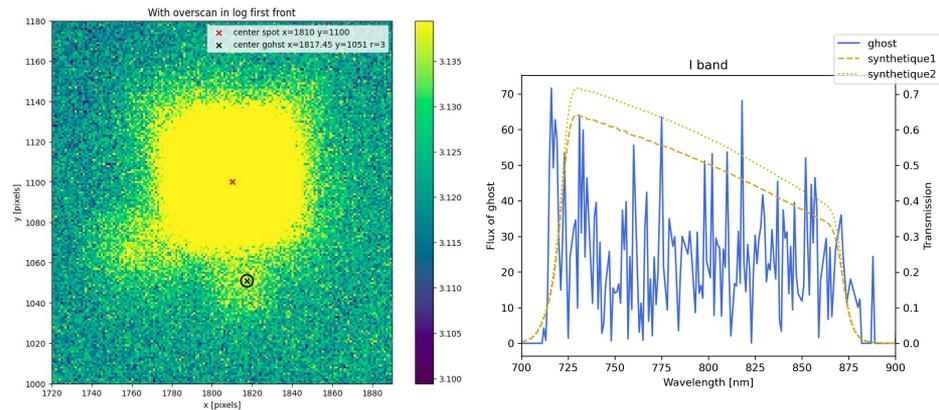
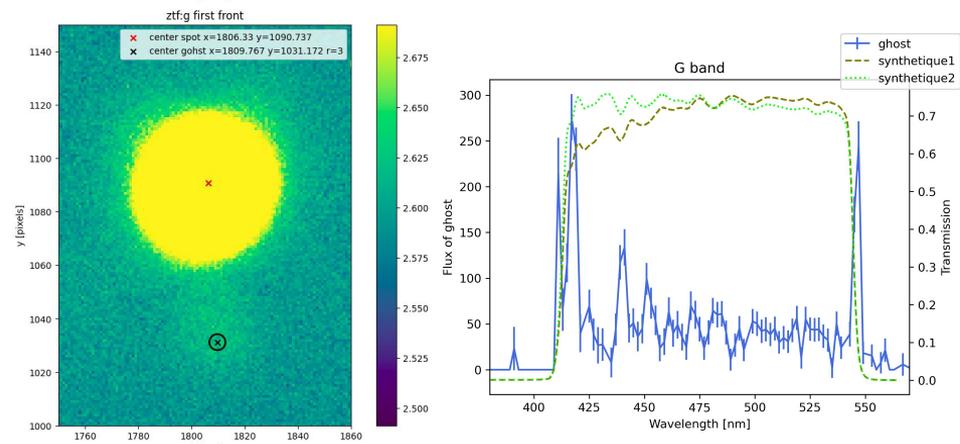
Relative statistical uncertainty vs Calibrated Wavelength for each CCD



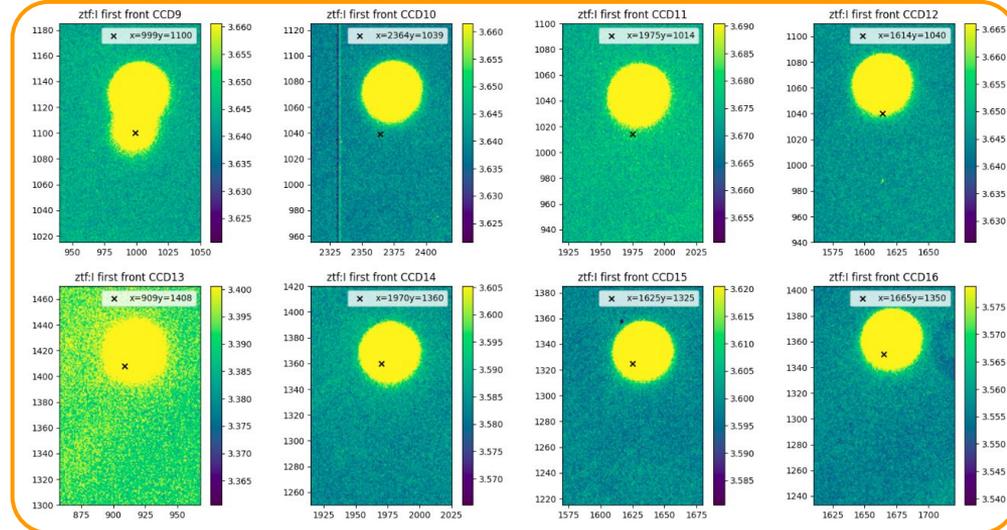
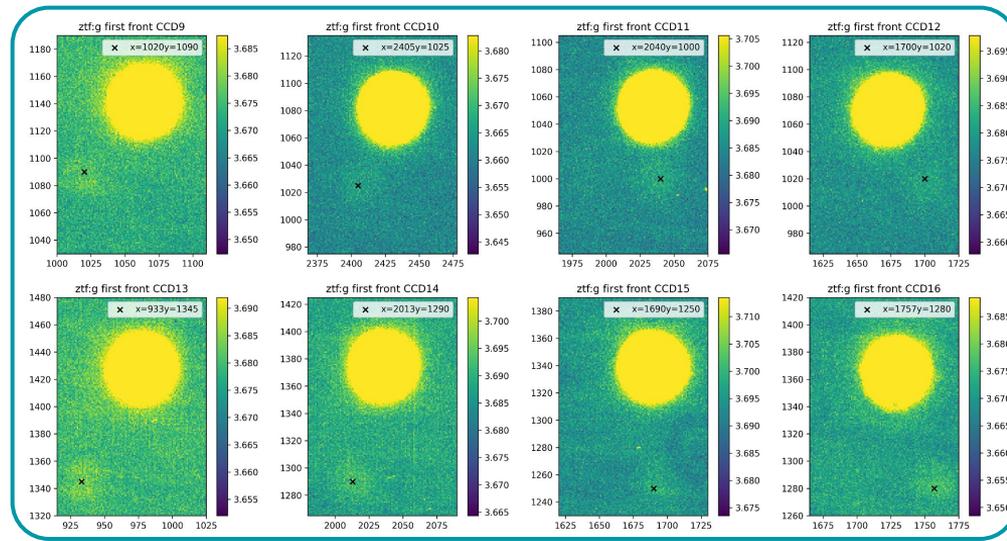
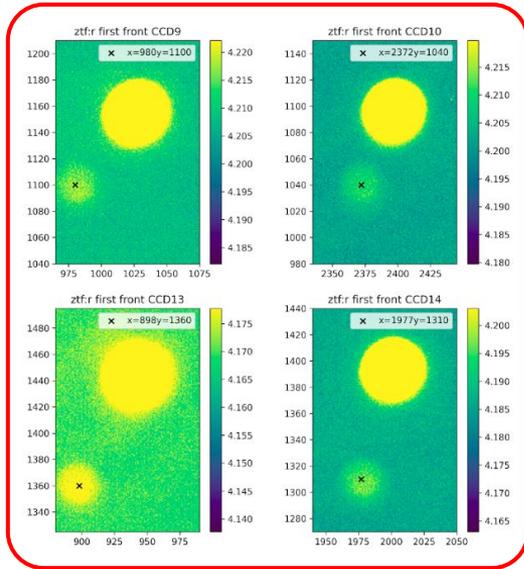
TCBP @ ZTF : Ghosts



- One ghost in the first edge in the r-band
- One ghost in each edge of the g band
- In all the i band

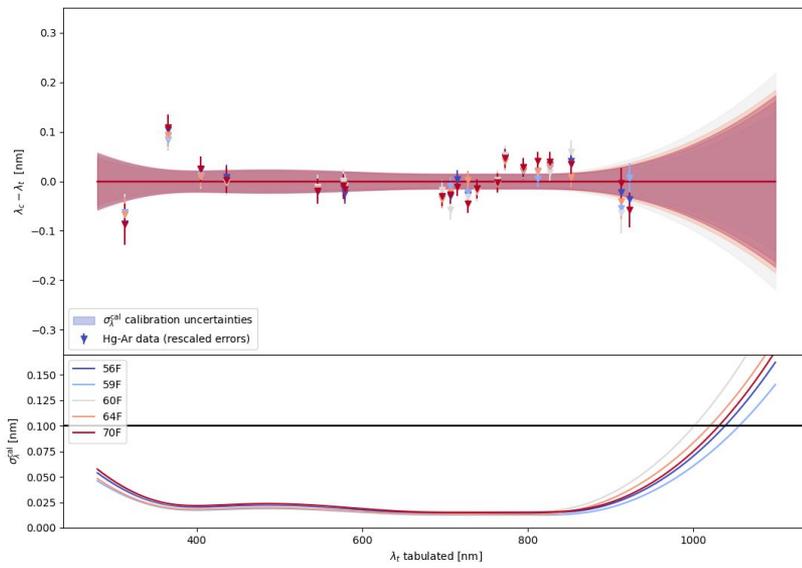
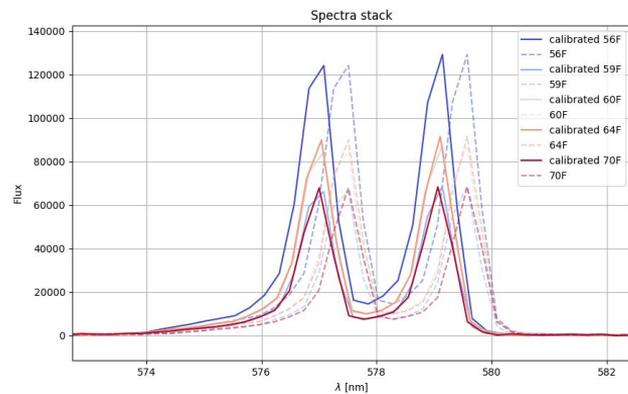
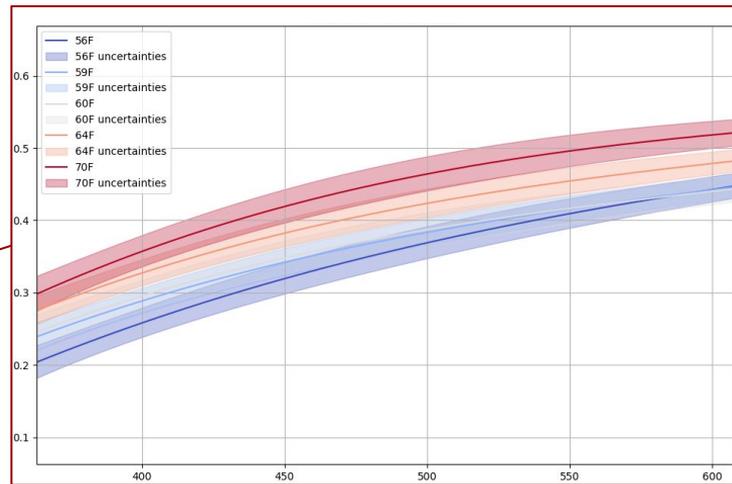
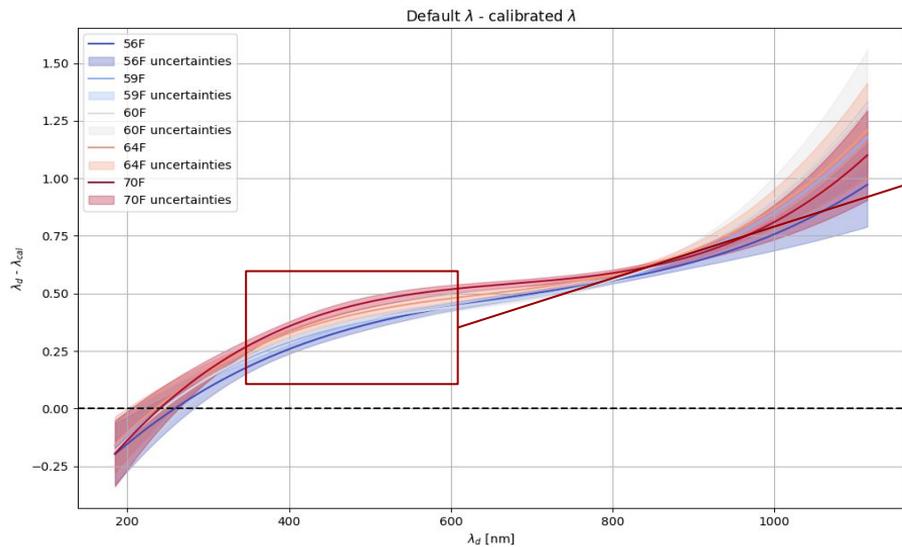


TCBP @ ZTF : Ghosts



- **r band** : only CCD9,10,13,14. Ghost farther away from the spot for single coating.
- **g band** : lower intensity but at different locations as a function of the CCD.
- **i band** : ghost merging with the spot ?

TCBP @ ZTF : Spectro calibration



calib
uncertainty < 1Å !