



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

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Motivations

- **LEMAÎTRE project** : combination of ZTF, SNLS and HSC SNe Ia surveys
- **ZTF** : thousands of low- z SNe Ia, DR2 can be used to **anchor the Hubble diagram at low redshift**
- Need for rigorous photometric calibration, especially **accurate knowledge of passbands**
- Previous ZTF passband models showed tension with observations (difference between Gaia synthetic magnitudes and observed magnitudes $\sim 10^{-1}$ in g-band)

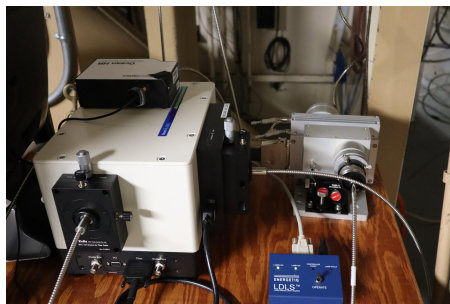
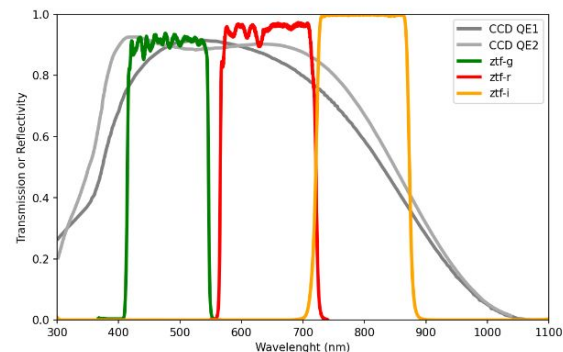
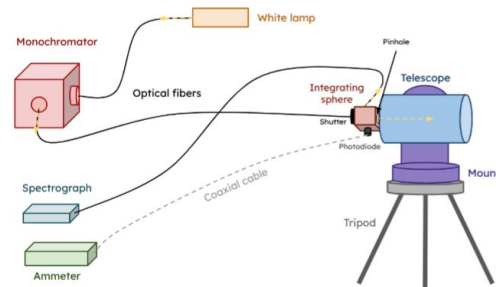
→ **Need for new ZTF passbands measurements to characterize the total telescope throughputs, with various incident angles on the primary mirror + well sampled wavelengths range**

Outline

1. Introduction
2. Experimental set-up
3. Passbands scan strategies
4. Data reduction
5. Systematics
6. Results & discussion
7. Conclusion

Experimental setup

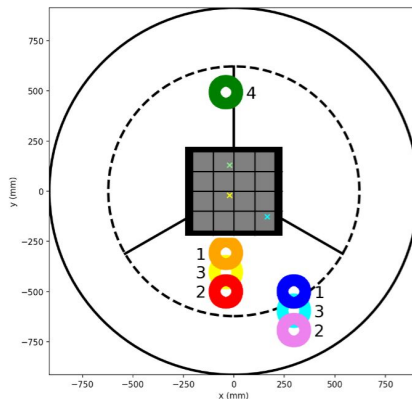
- ZTF P48 telescope and photometric instrument
 - telescope, camera, filters
- TCBP
 - instrument, assembly
- On site installation
 - pinhole choice, monochromator slits opening, TCBP telescope focus



Passbands scan strategies

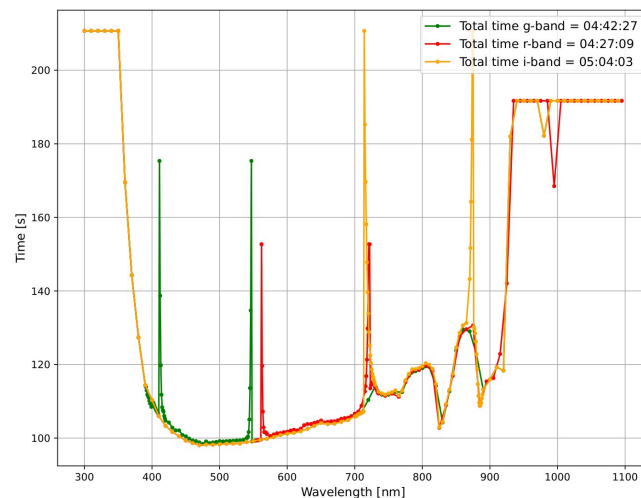
$$R_{p,f,ccd}(\lambda) = \frac{Q_{ccd}(\lambda)}{Q_{phot}(\lambda) \times R_{TCBP}(\lambda)}.$$

- Measurement principle
- Wavelength scan
- Beam positioning
- Single spot
- Multispot
- Dataset summary

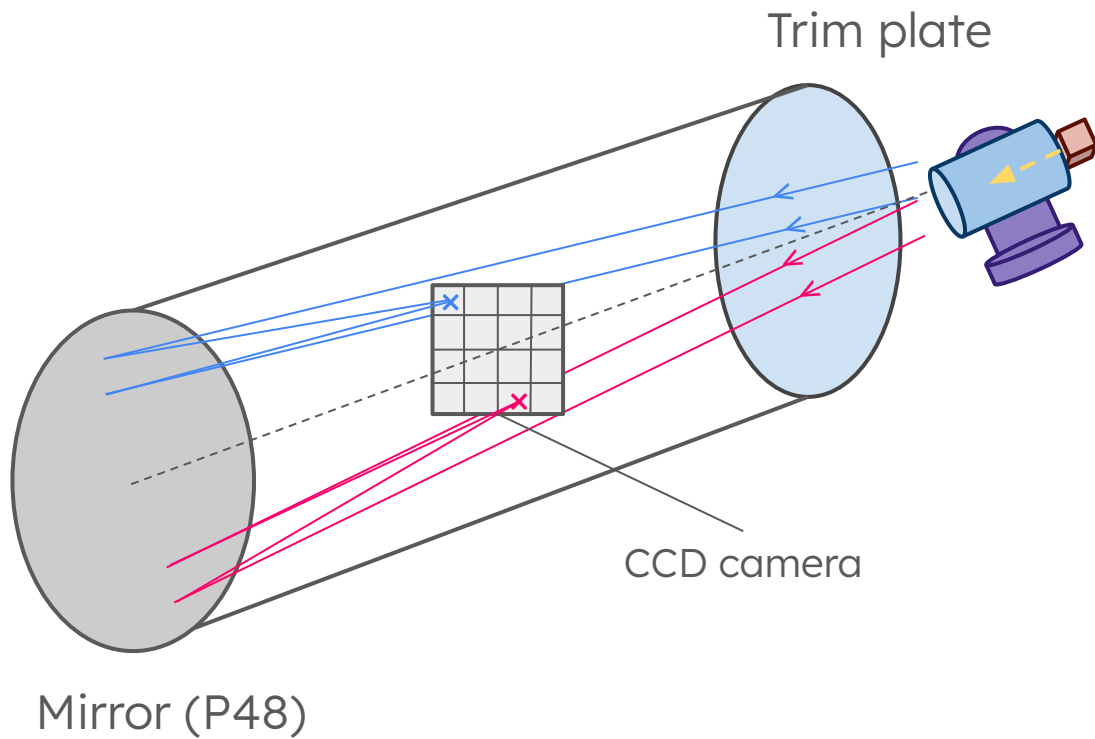
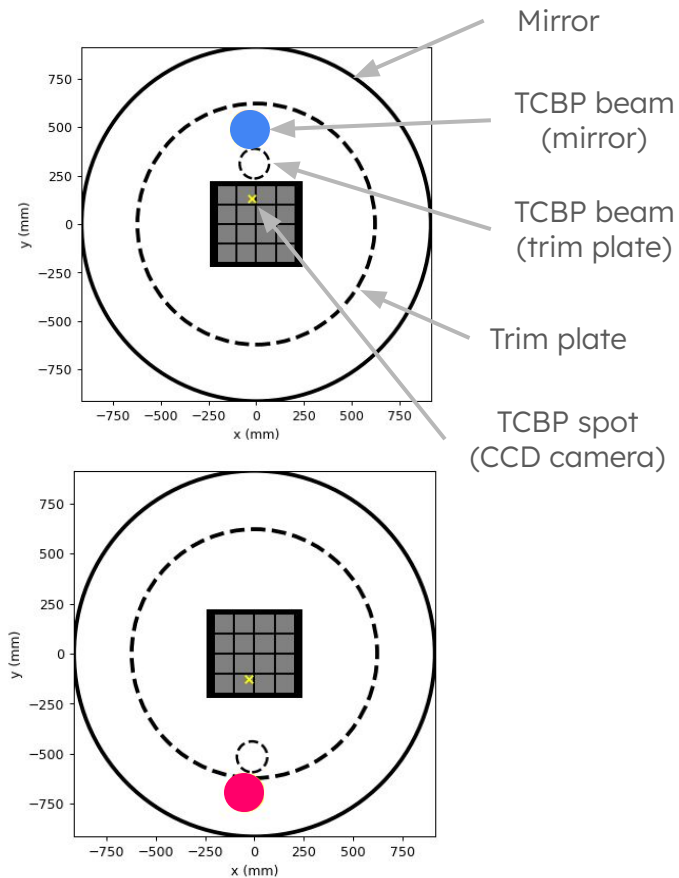


Position	1	2	3	4
P48 dec	-46°	-44°	-45°	-51.5°
TCBP Δ alt	0°	-2°	-1°	5.5°

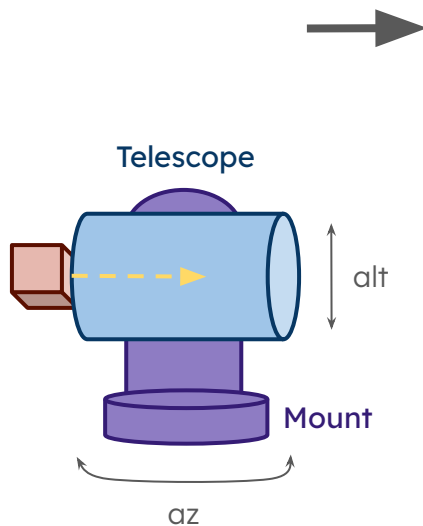
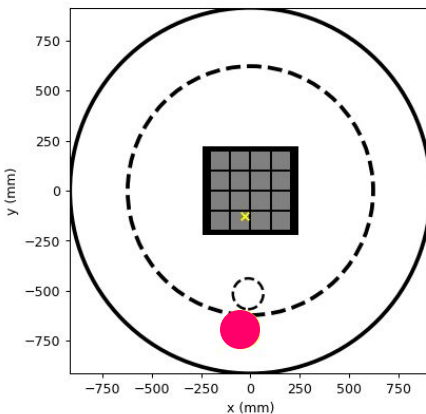
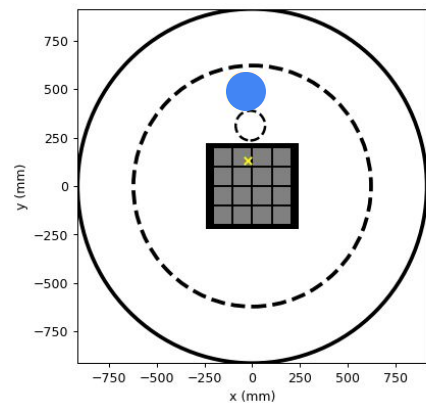
Filter / Scanning strategy	g	r	i	empty
Single spot (1nm step)	1	2	1	
Single spot (optimized step)	1	1	1	
Multispot position 1	1	1	1	1
Multispot position 2	1	1	2	1
Multispot position 3		1	1	
Multispot position 4	1	1	1	1



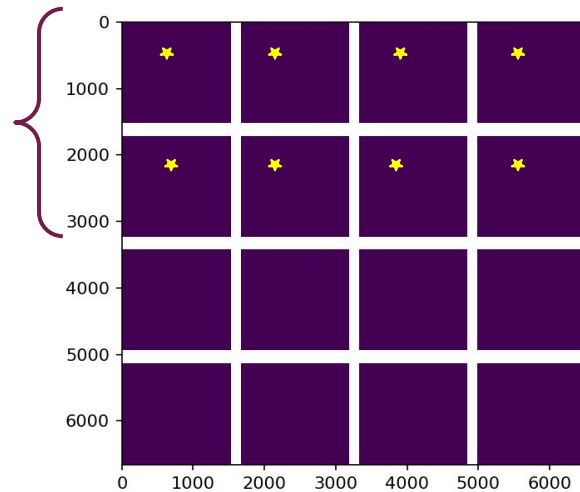
Scanning strategy



Scanning strategy



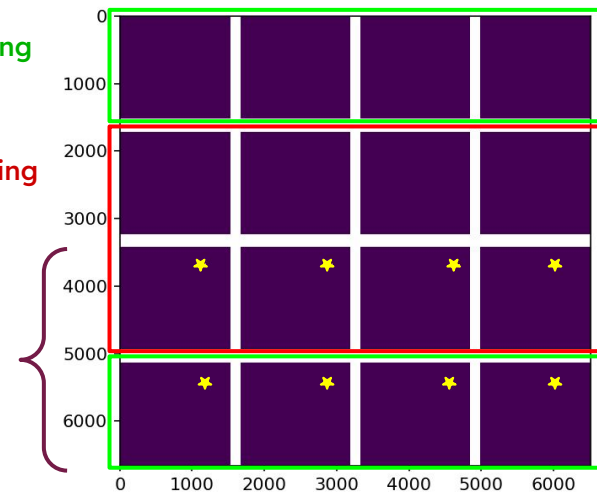
CCD 01-08



Single coating

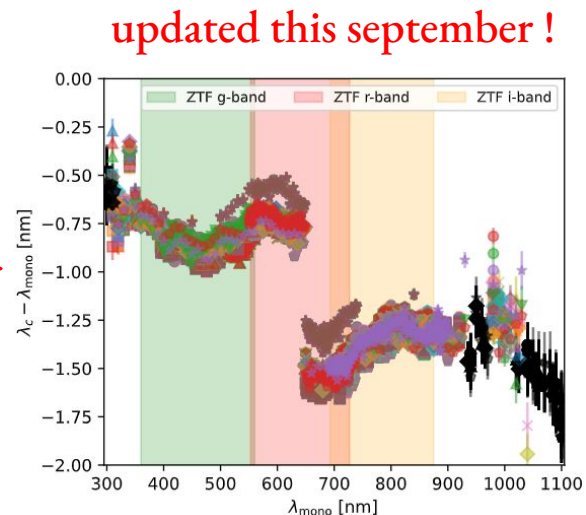
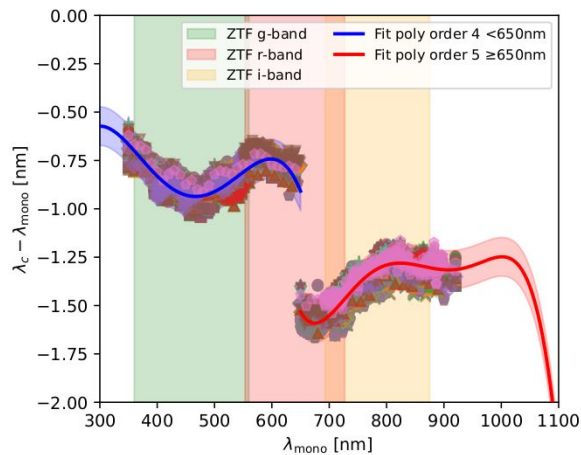
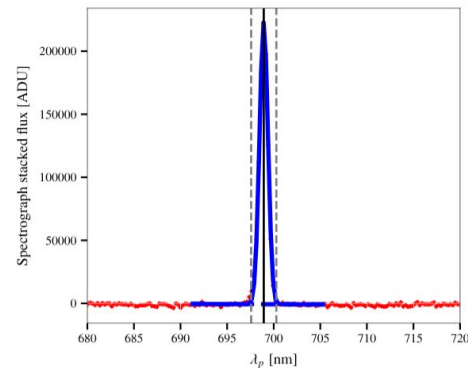
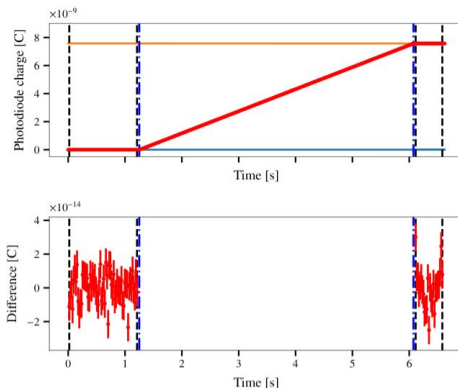
Double coating

CCD 09-16



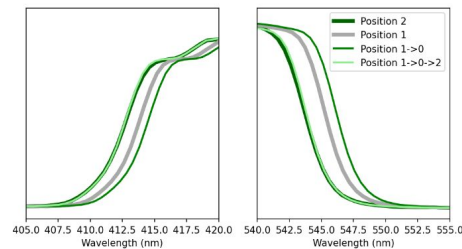
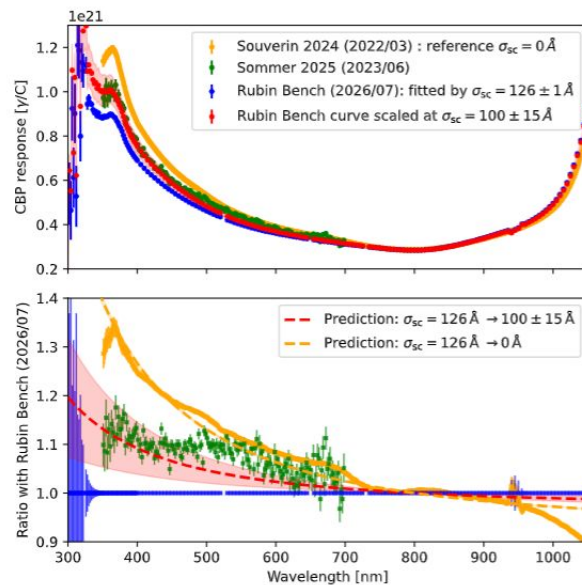
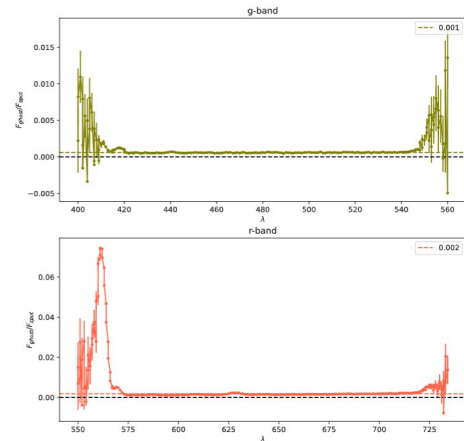
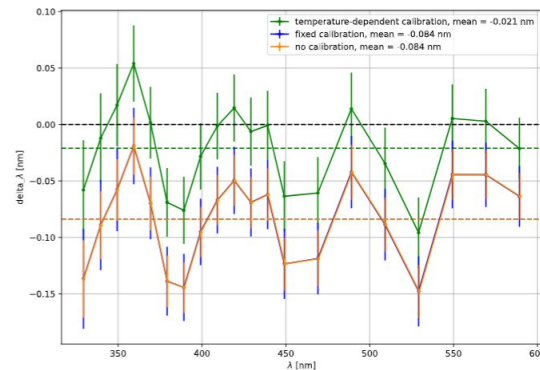
Data reduction

- TCBP
 - photodiode
 - spectrograph
- ZTF
 - image processing
 - aperture photometry
- From reduced data to filter passband



Systematics

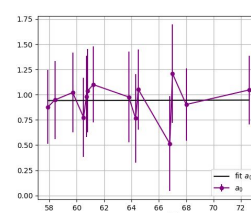
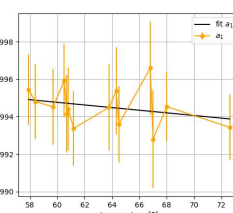
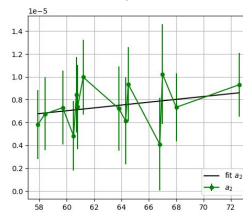
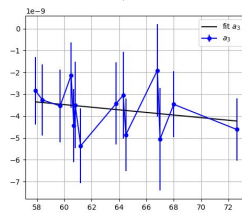
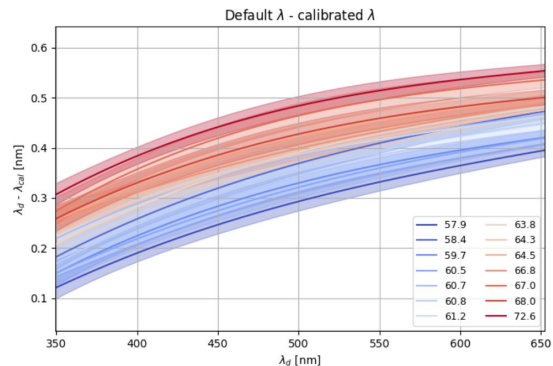
- Spectro wavelengths calibration
- TCBP telescope calibration (see next presentation by Jérémy)
- Background
- Ghost contamination
- Spectrum deconvolution
- Filter effective refractive index
- No-filter transmission variation
- Missing measurements



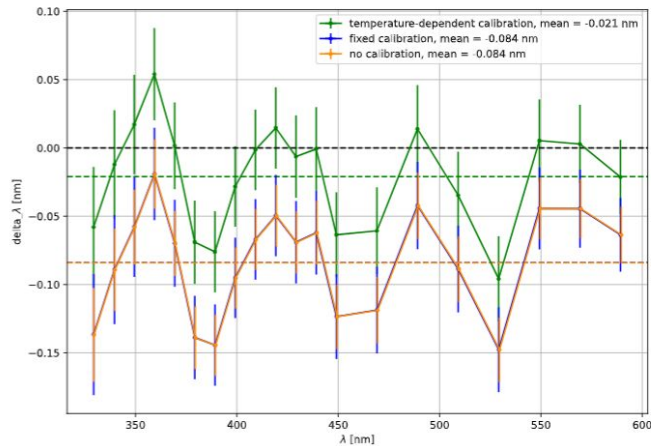
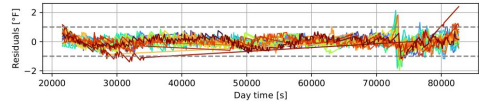
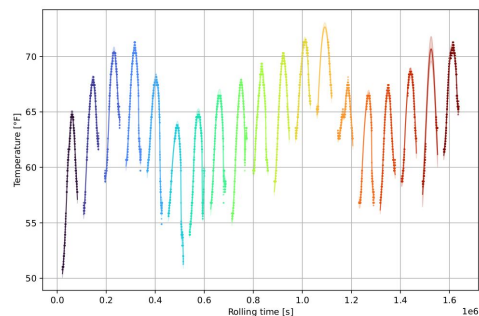
Filter name	ZTF-g	ZTF-r	ZTF-i
Bandpass (nm)	414.3	565.5	721.2
	546.3	721.3	873.2
Mean transmission	0.910	0.952	0.997
Effective refractive indice	± 0.077	± 0.081	± 0.070

Spectrograph wavelengths calibration

$$\lambda_c \equiv c(\lambda_g) \equiv \hat{a}_3 \lambda_g^3 + \hat{a}_2 \lambda_g^2 + \hat{a}_1 \lambda_g + \hat{a}_0$$



temperature dependency



from almost
1Å to 0.2Å!

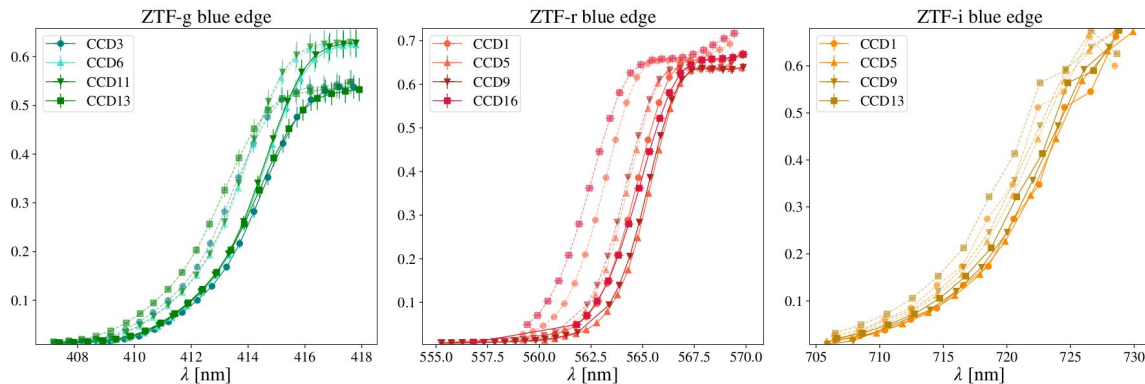
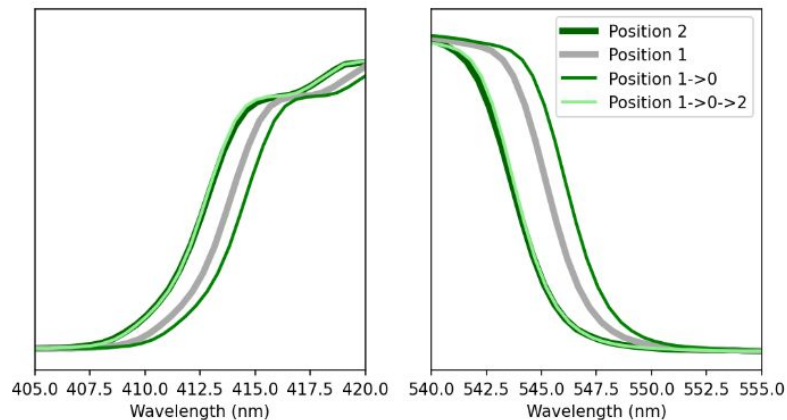
Effective refractive indices

$$T(\lambda, \theta) = T \left(\lambda \left[1 - \frac{\sin^2 \theta}{n^2} \right]^{-1/2}, \theta = 0 \right).$$

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

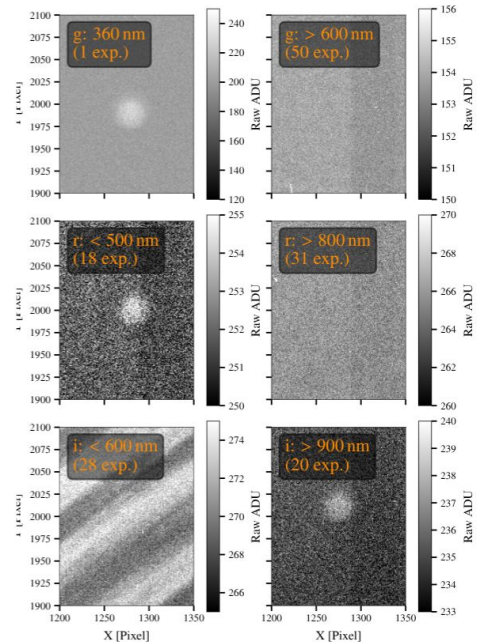
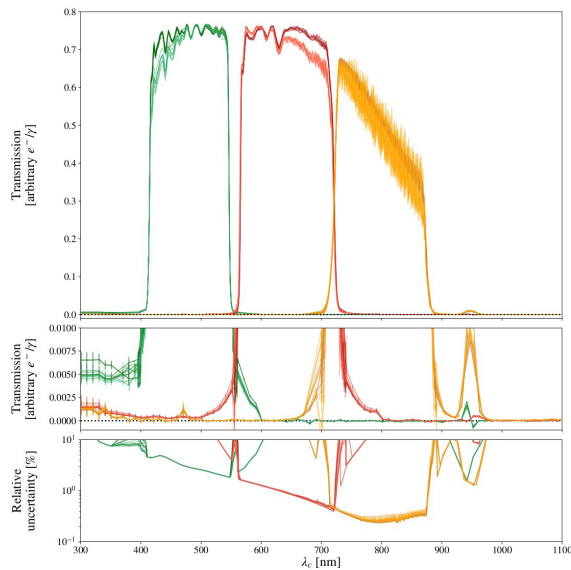
This work :

g-band : 414.0 ; 546.04
r-band : 565.15 ; 720.12
i-band : 722.46 ; 873.0

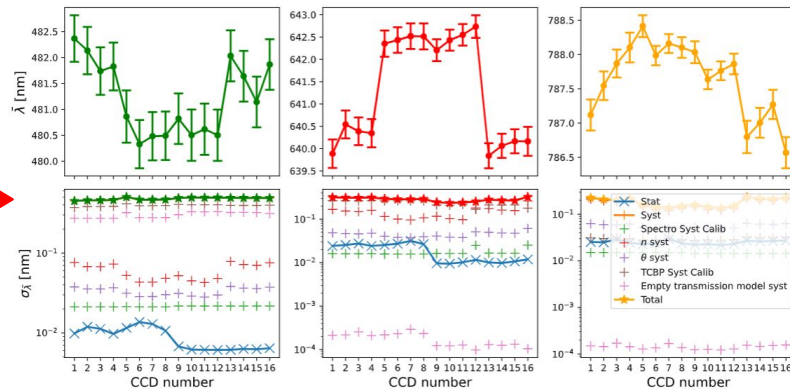


Results

- ZTF passbands transmission at normal incidence
- Out-of-band leakages
- Final uncertainties on mean wavelengths
- Source of spatial variation in transmission
- Comparison with previous measurements

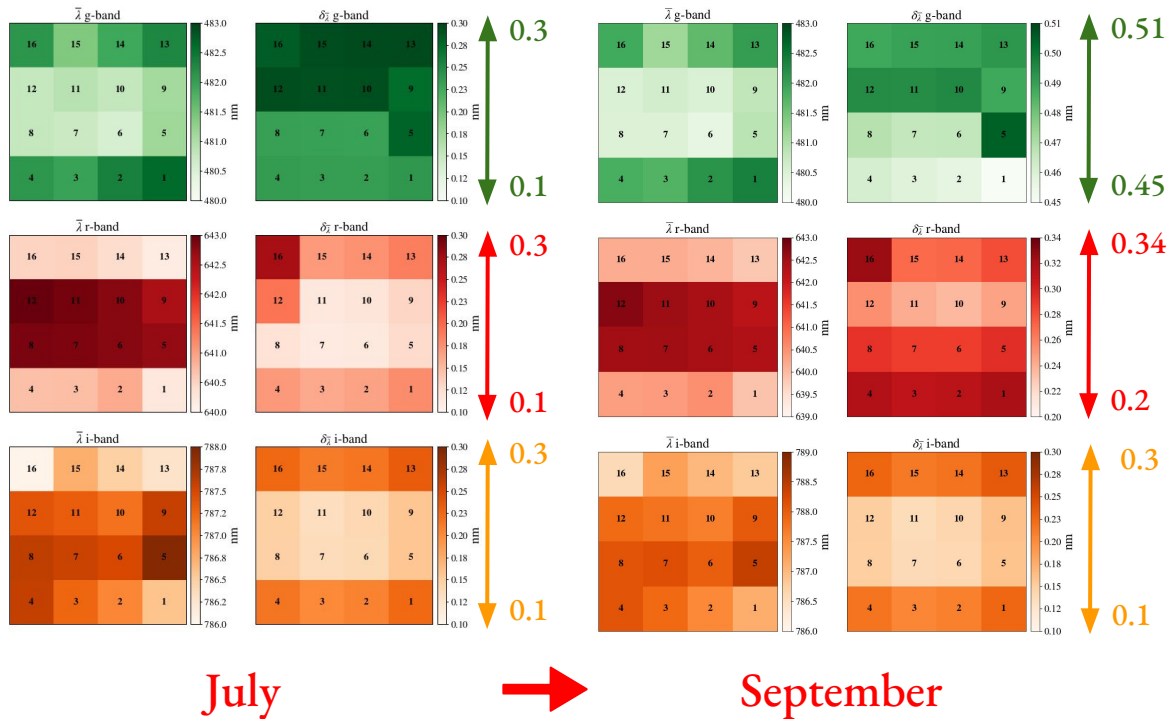


updated with
new TCBP
calibration



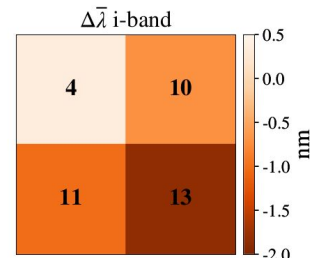
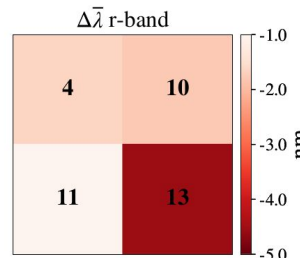
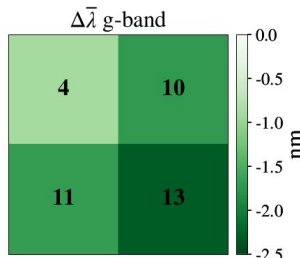
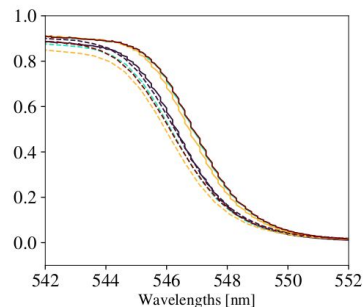
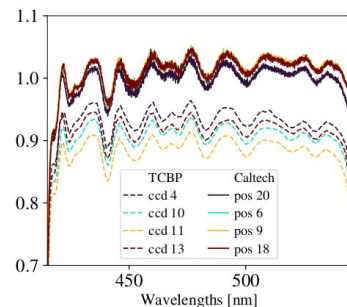
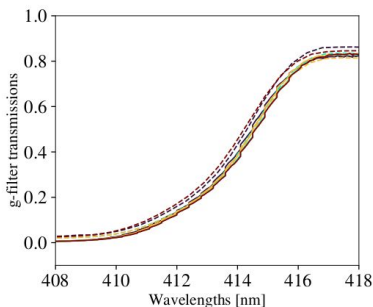
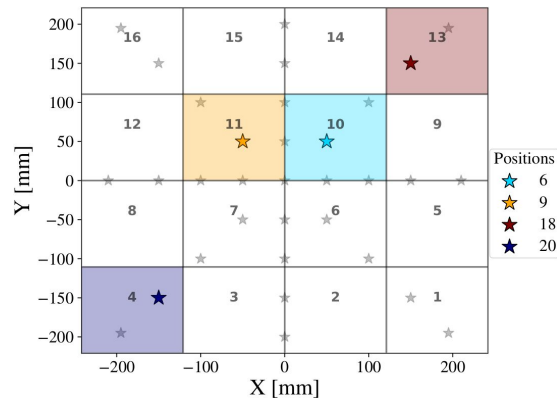
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Results

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Conclusion

- 3 weeks on-site campaign at Palomar Observatory to measure ZTF passbands
- We scanned the three bands (+ no-filter) with **several incident angles** on the primary mirror in the **300-1100 nm range**
- We delivered **one transmission curve per CCD for the three bands**
- **Out-of-band leakages** were detected :
 - in the g-band with **20σ significance**
 - in the r-band with **5σ significance**
- Significant mean lambda discrepancy across the focal plane (3-4 nm peak-to-peak), uncertainties of **0.5 nm for the g-band** and from **0.1 to 0.35 nm for r and i-band**
- Overall shapes of the filters similar to Caltech, **mean lambda offset around 1-2 nm** (in average)

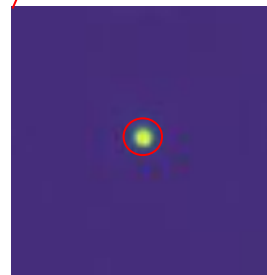
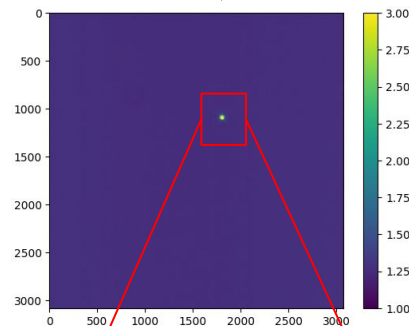
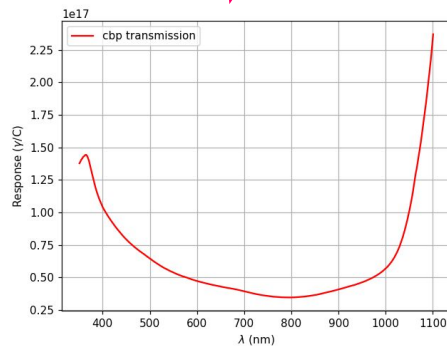
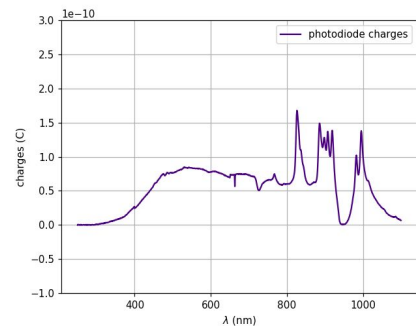
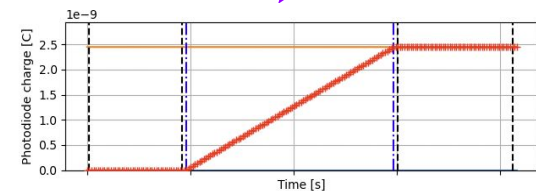
Backup

Filter transmission recipe

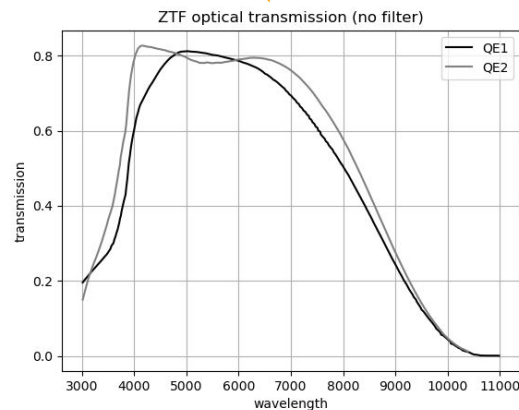
$$T_f = \frac{Q_{\text{ccd}}}{Q_{\text{phot}} \times R_{\text{CBP}}}$$

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

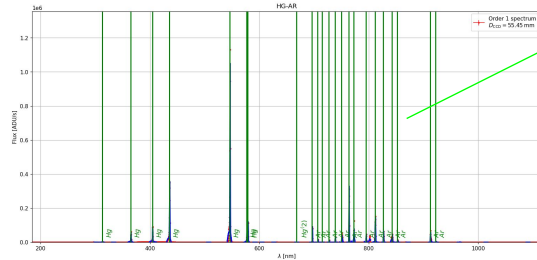
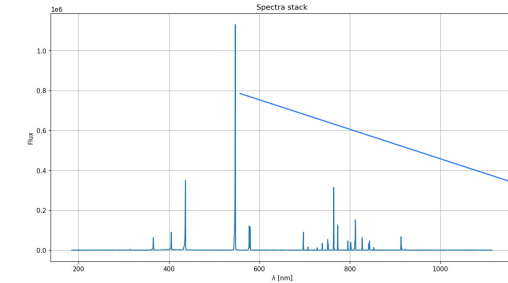
$$QE_{\text{CCD}}$$



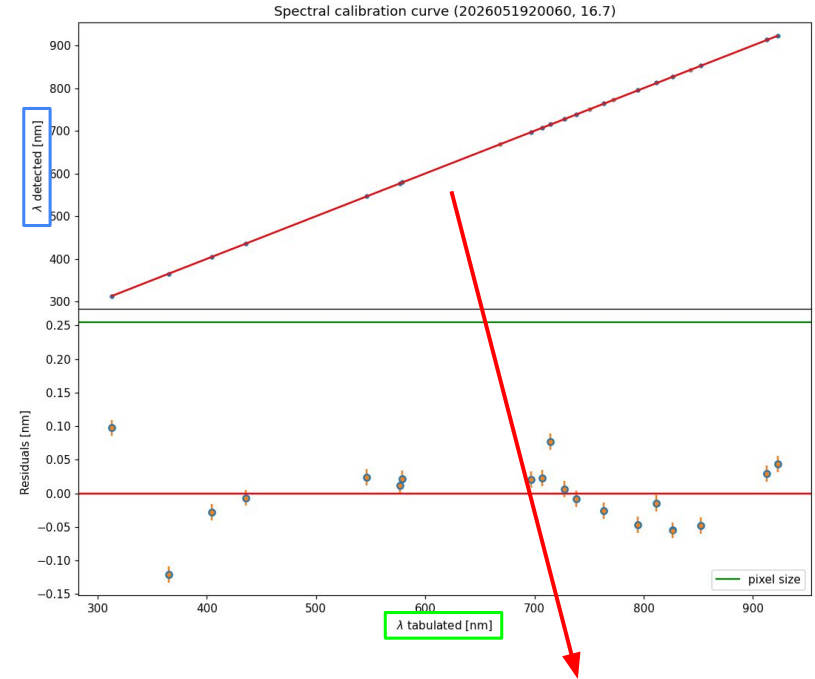
Aperture photometry



Spectrograph wavelengths calibration



Line	Tabulated	Detected	Shift	Err
	nm	nm	nm	nm
str12	float32	float32	float32	float32
Hg	313.155	313.32056	0.1655503	9.3959345e-05
Hg	365.015	365.50043	0.48541212	5.8364317e-06
Hg	404.656	405.1125	0.4564751	3.6965382e-06
Hg	435.833	436.31158	0.47858962	9.641272e-07
Hg	546.074	546.637	0.56303173	2.8259927e-07
Hg	576.96	577.5587	0.5986885	2.446726e-06
Hg	579.066	579.6561	0.5901177	2.348588e-06
Hg 3)	668.295	668.6302	0.3342093	0.0004592619
Ar	696.543	697.2103	0.6673198	2.9227829e-06
Ar	763.511	764.26666	0.755658	9.118964e-07
Ar	772.376	773.1823	0.8063298	5.0168355e-06
Ar	794.818	795.6172	0.7991675	6.088496e-06
Ar	811.531	812.311	0.7799881	2.916703e-06
Ar	826.452	827.284	0.831976	5.08318e-06
Ar	842.465	843.303	0.8380993	8.271336e-06
Ar	852.144	852.9909	0.84690344	2.6659181e-05
Ar	912.297	913.1299	0.83290523	5.587649e-06
Ar	922.45	923.2803	0.8302653	8.7313805e-05



Order 3 polynomial fit, returns the 4 coeffs a_0 , a_1 , a_2 , a_3

Caltech filter measurements

