Instrumental calibration of telescopes in astronomy

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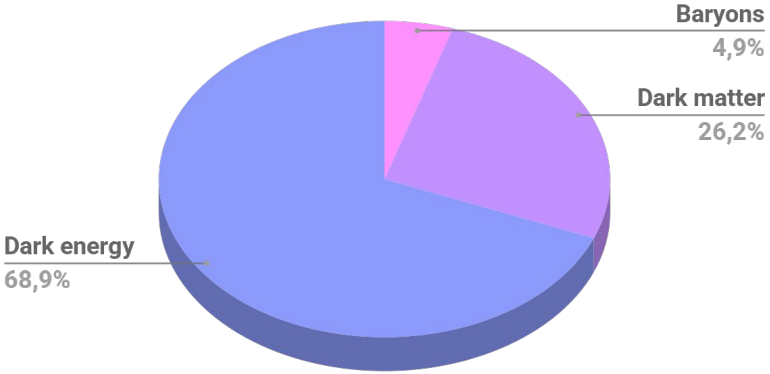
L'Univers du pôle A2C - 24/06/2025

Cosmological context

- 1998 : Discovery of the **accelerated** expansion of the Universe

  → **Dark energy**



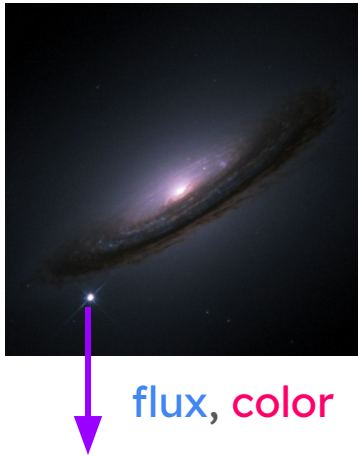
Cosmological context

- 1998 : Discovery of the **accelerated** expansion of the Universe

  → **Dark energy**

- **Type Ia supernovae** : standard candles

  → Needs accurate flux and colors measurements



Cosmological context

- 1998 : Discovery of the **accelerated** expansion of the Universe

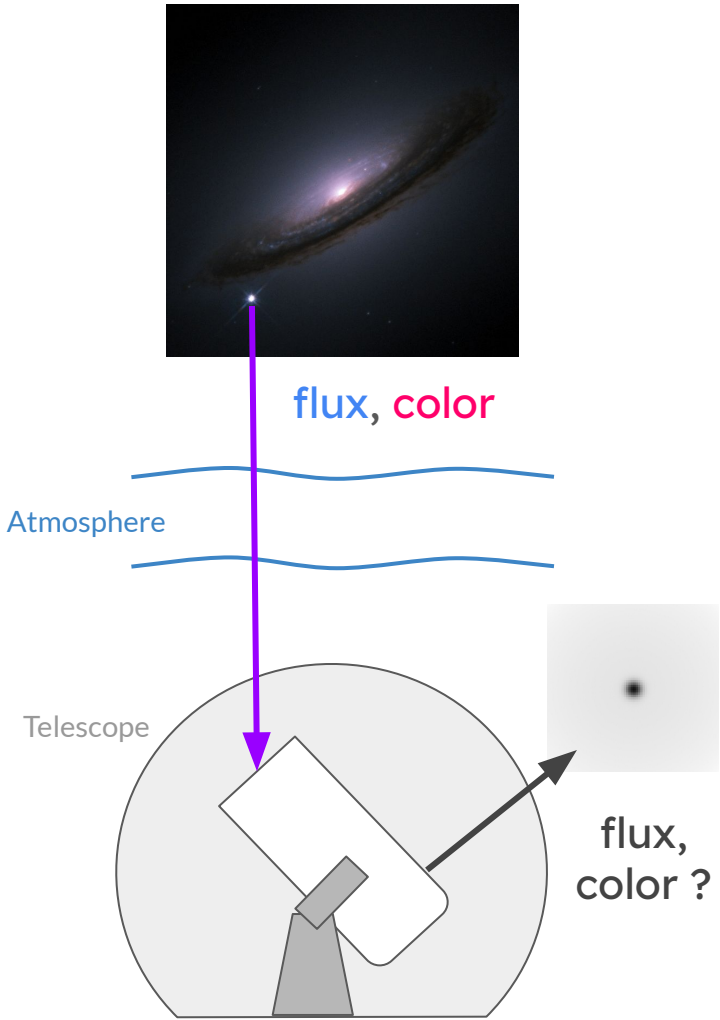
  → **Dark energy**

- **Type Ia supernovae** : standard candles

  → Needs accurate flux and colors measurements

- **Atmosphere + telescope** : poor calibration will bias flux & color measurements

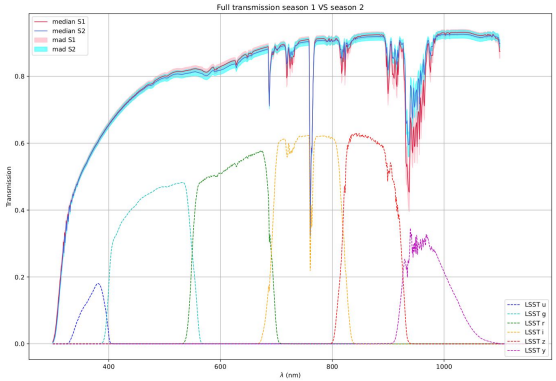
  → Today : instrumental uncertainties are dominant for dark energy parameters estimation



Calibration in astronomy

AuxTel

Atmosphere calibration



StarDICE

Standard stars calibration

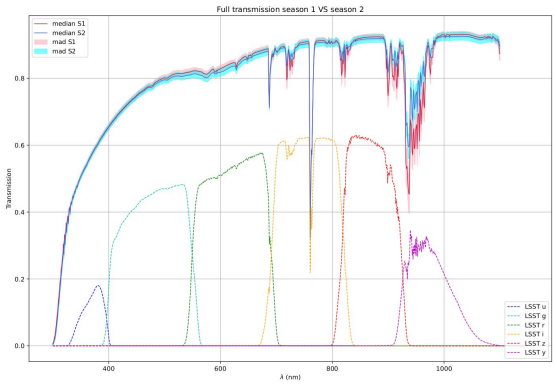
CBP

Telescope calibration

Calibration in astronomy

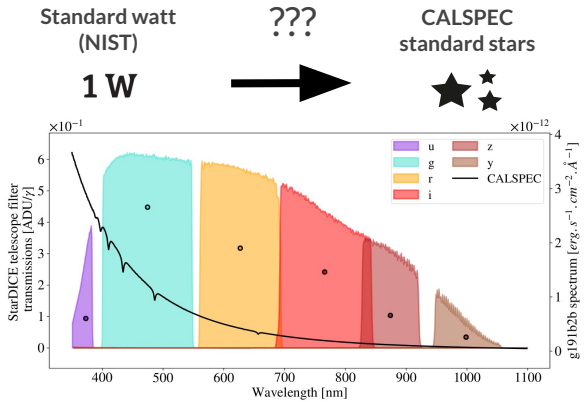
AuxTel

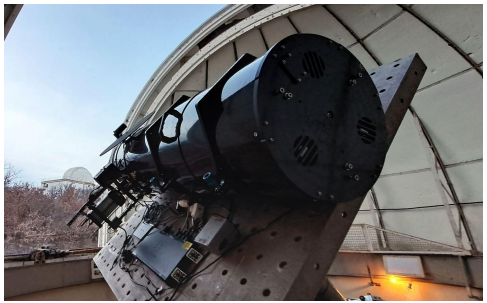
Atmosphere calibration



StarDICE

Standard stars calibration





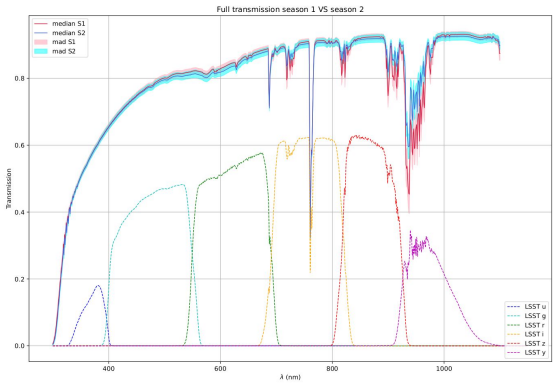
CBP

Telescope calibration

Calibration in astronomy

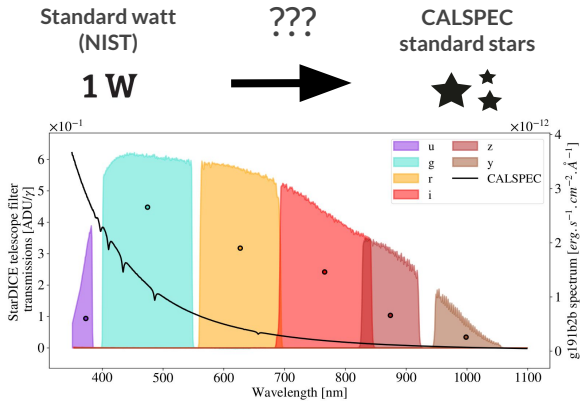
AuxTel

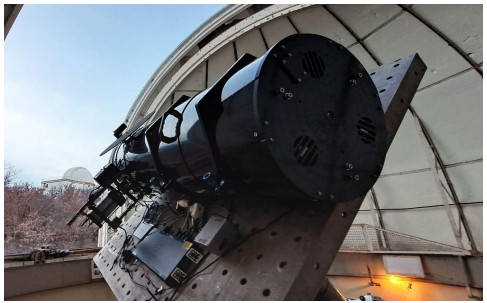
Atmosphere calibration



StarDICE

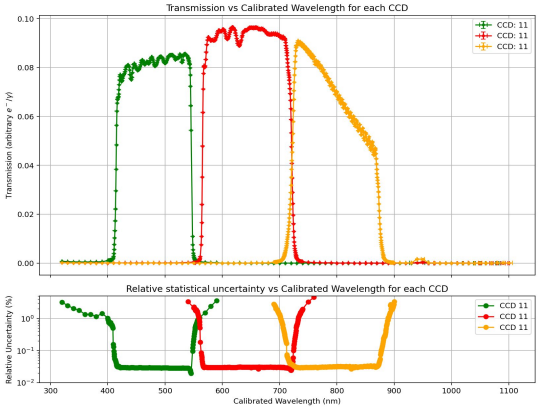
Standard stars calibration

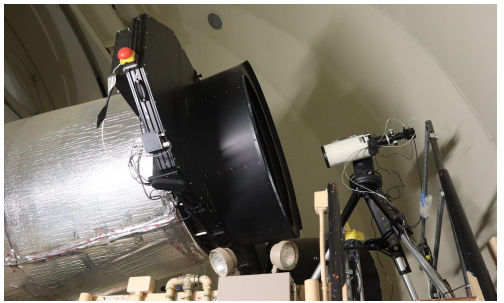




CBP

Telescope calibration





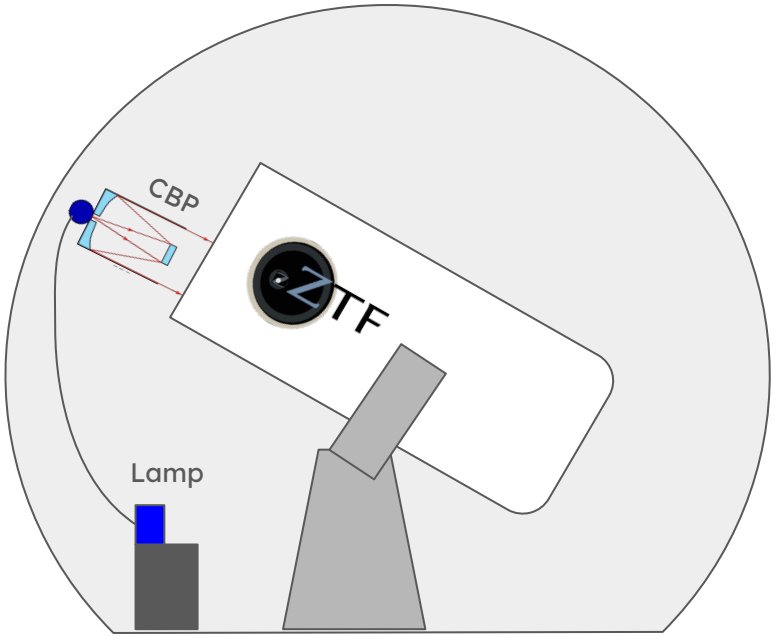
What is a CBP ? (and why)

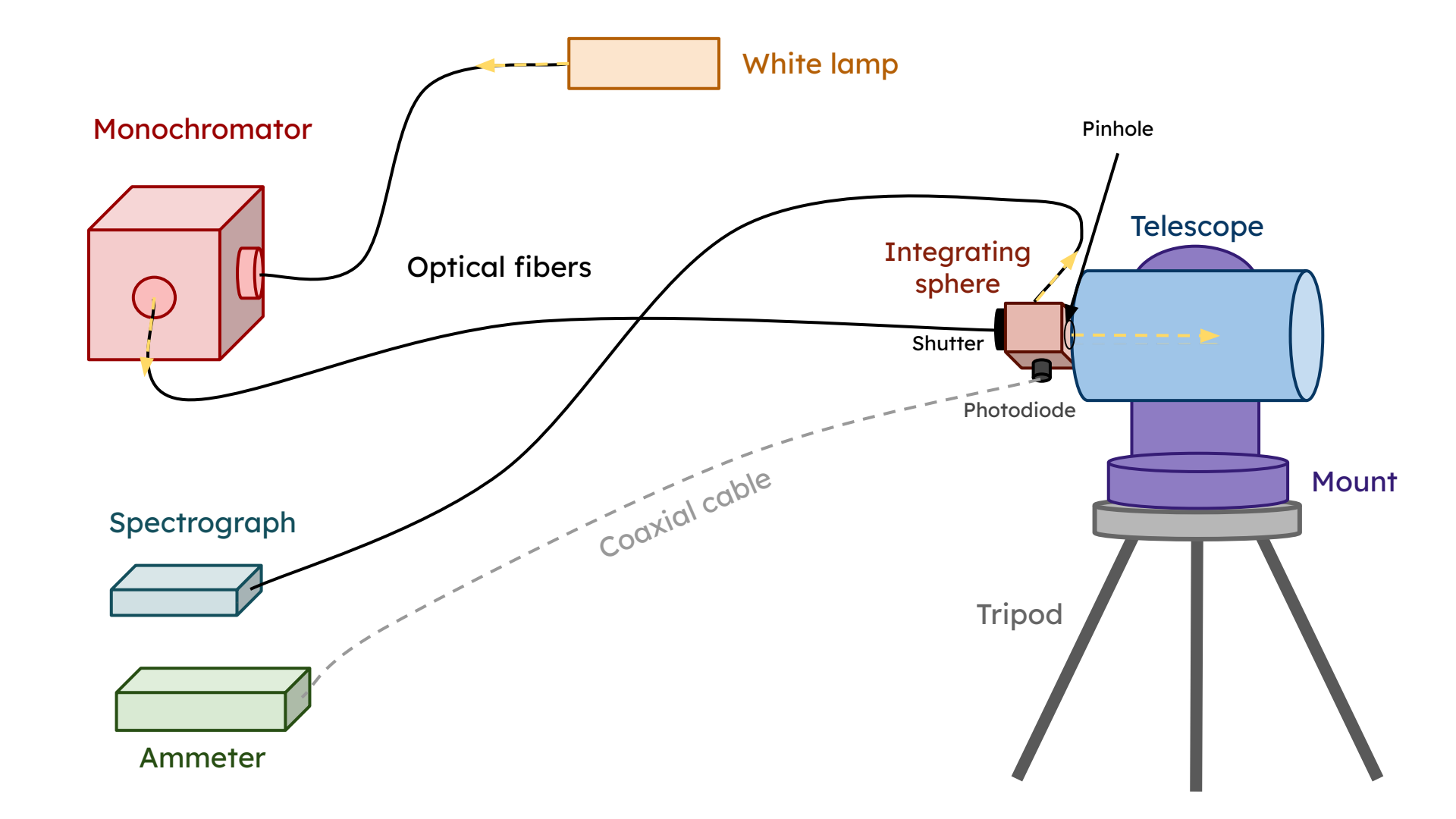
CBP (Collimated Beam Projector) → instrument shooting monochromatic parallel light beam with controlled flux and wavelength (per mil / angström level)

→ Can be used as an artificial star

→ Powerful calibration tool to measure any telescope transmission (optical and filters)

→ **Goal : Low the instrumental uncertainties from 1% to 0.1%**

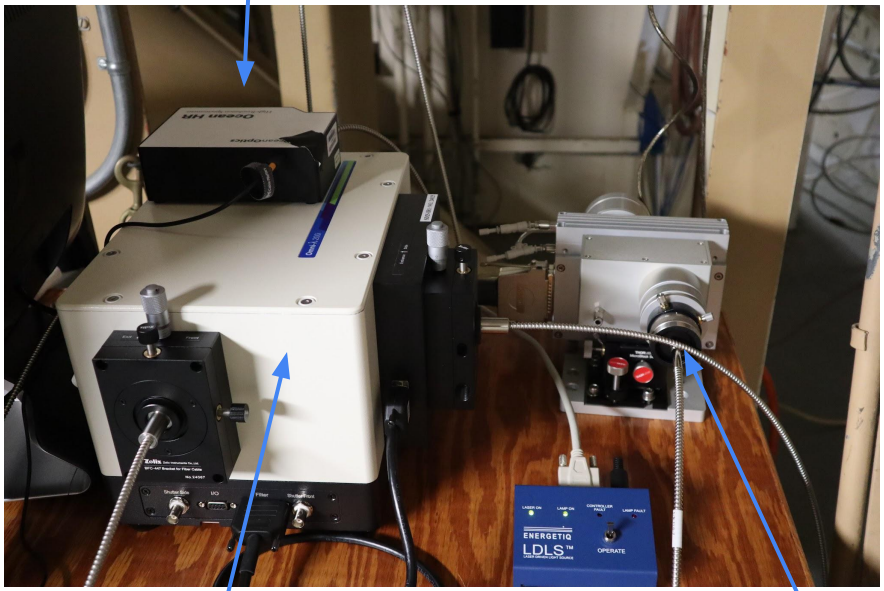



White lamp
Monochromator
Pinhole
Optical fibers
Telescope
Integrating sphere
Shutter
Photodiode
Coaxial cable
Spectrograph
Mount
Tripod
Ammeter

Traveling CBP @ ZTF
(Zwicky Transient Facility)

Installation

Spectrograph

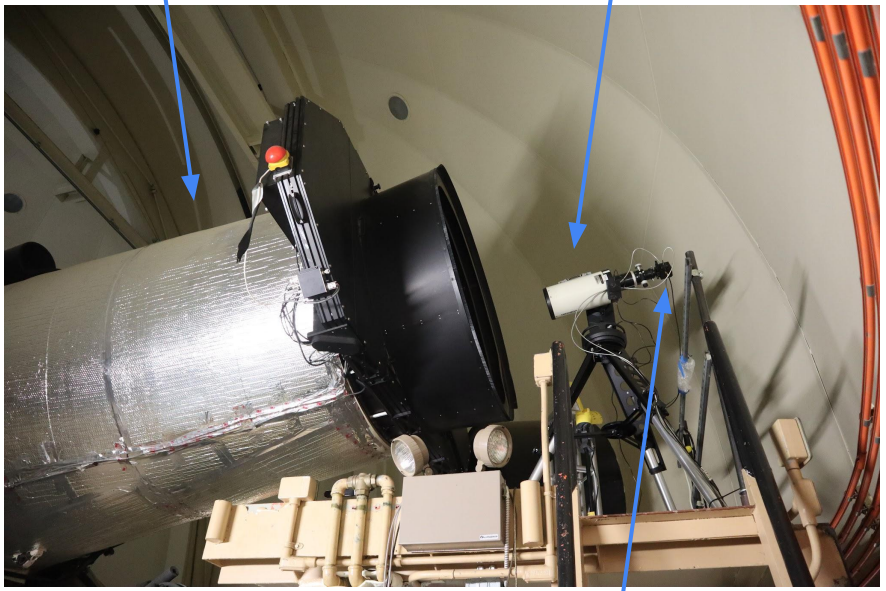


Monochromator

Lamp

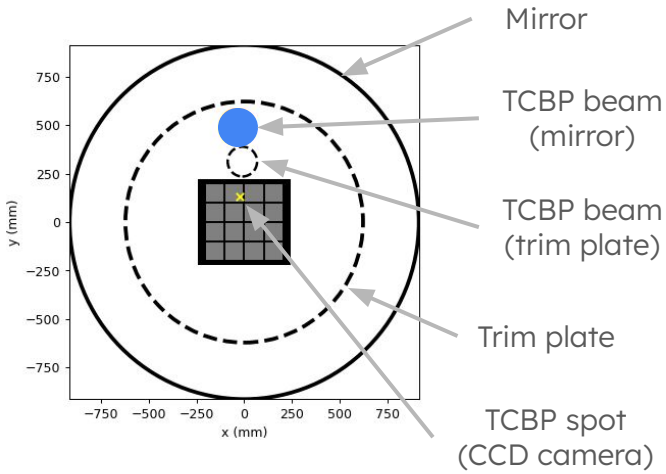
ZTF telescope

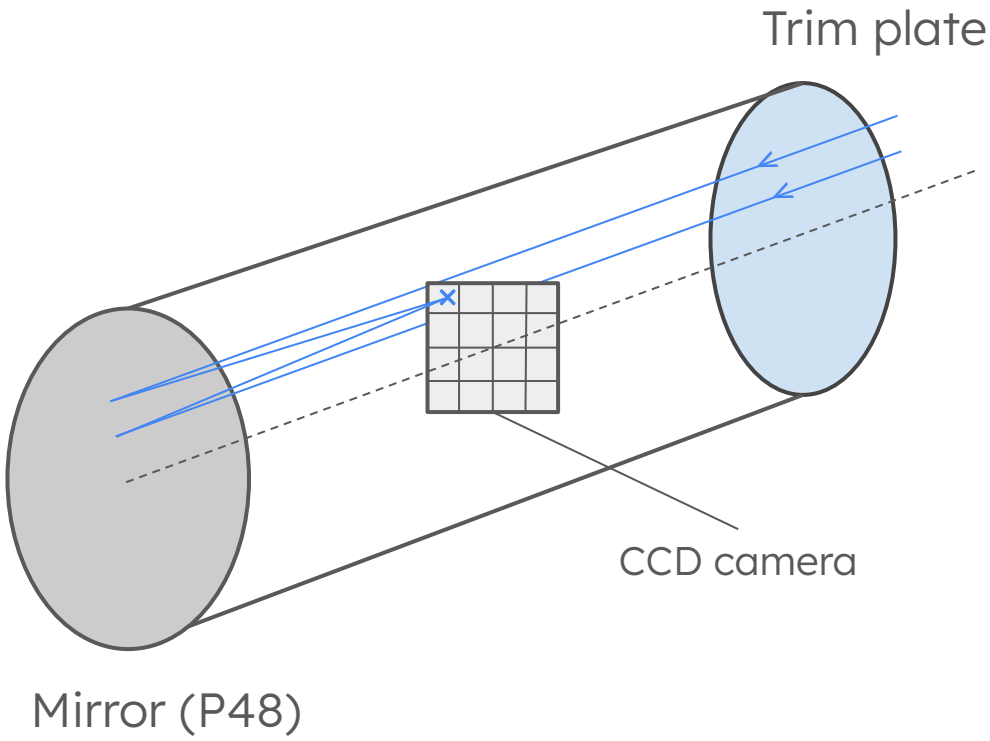
TCBP telescope



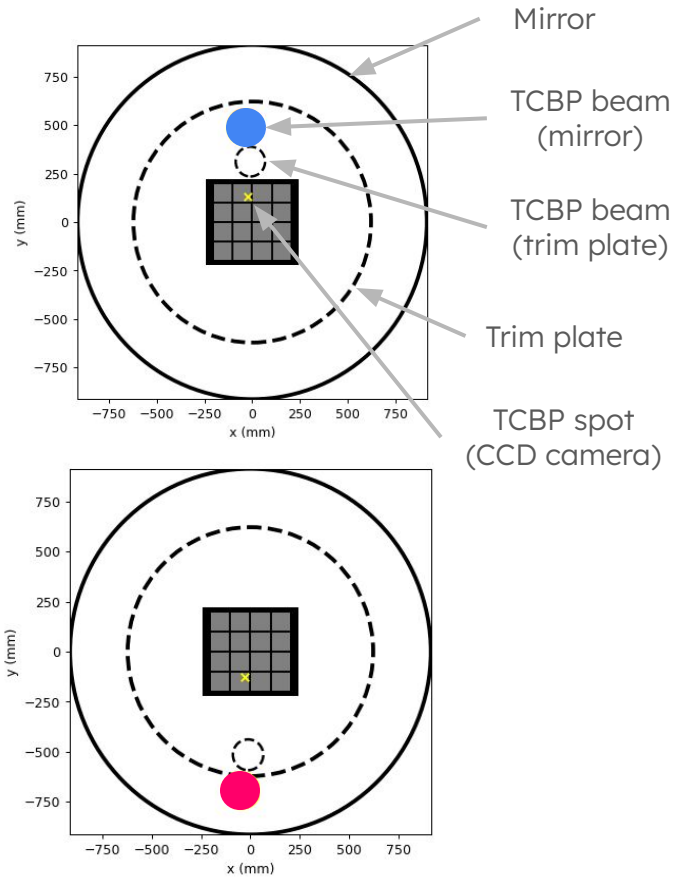
Integrating sphere

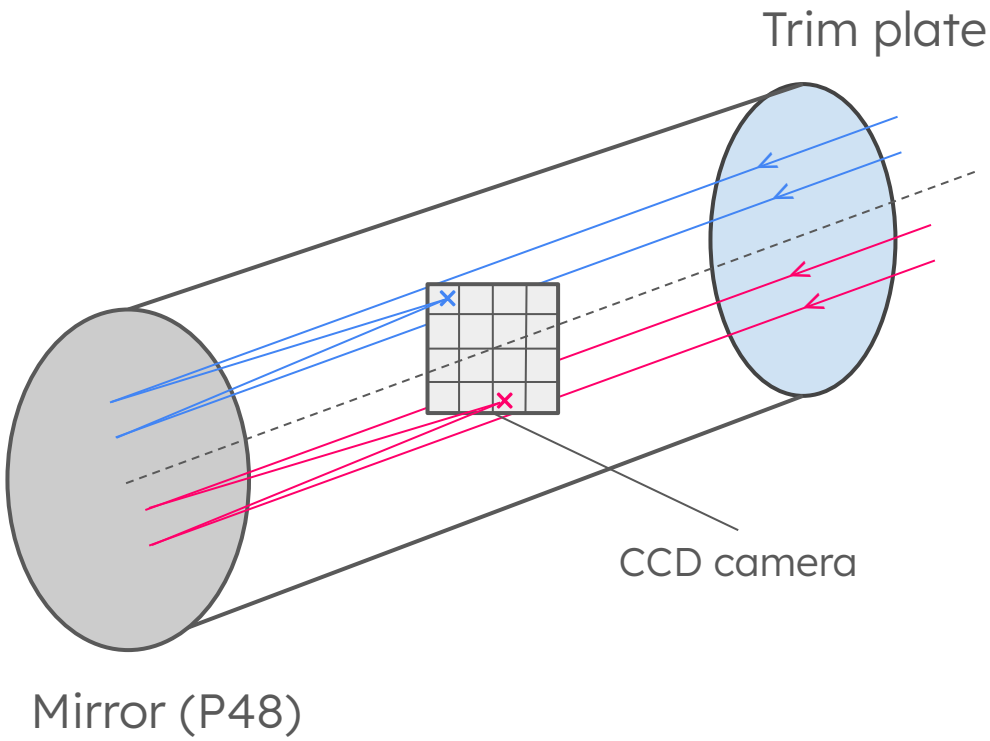
Observation strategy





Observation strategy





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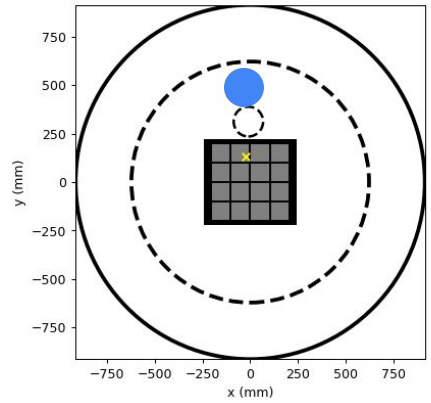
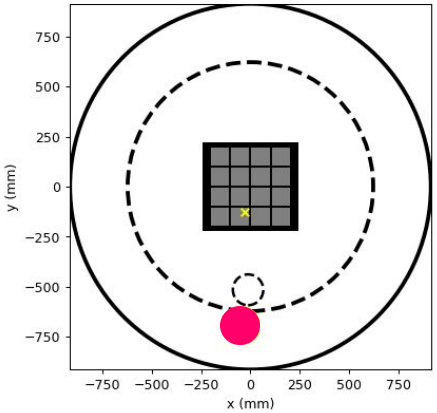
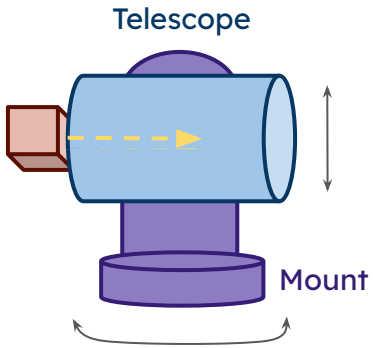
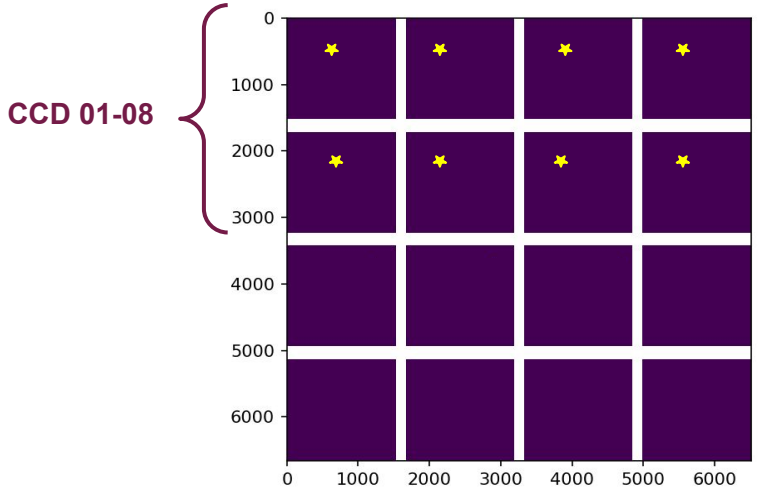
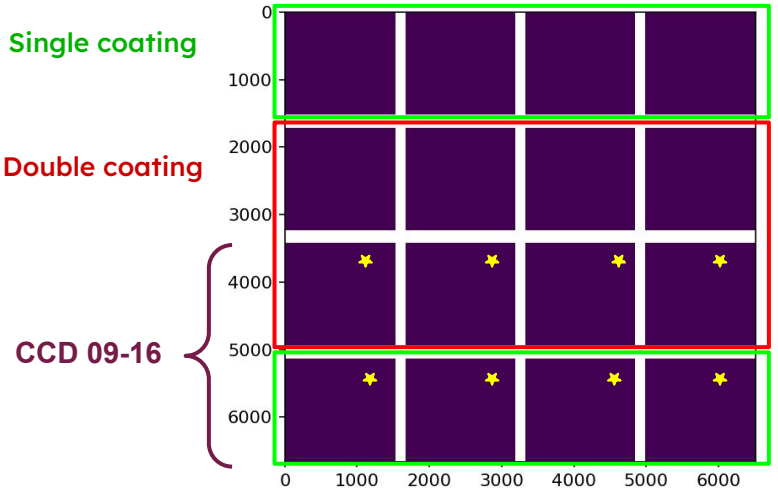


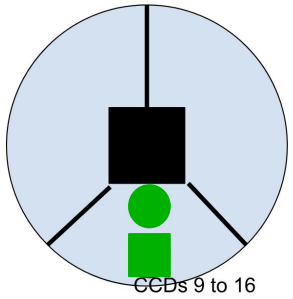


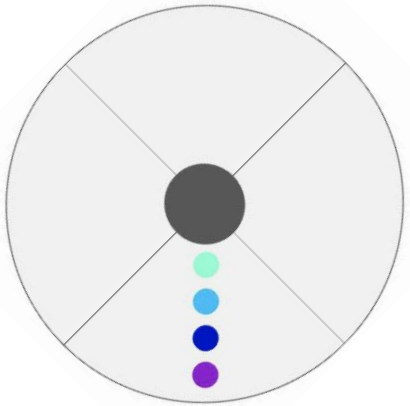


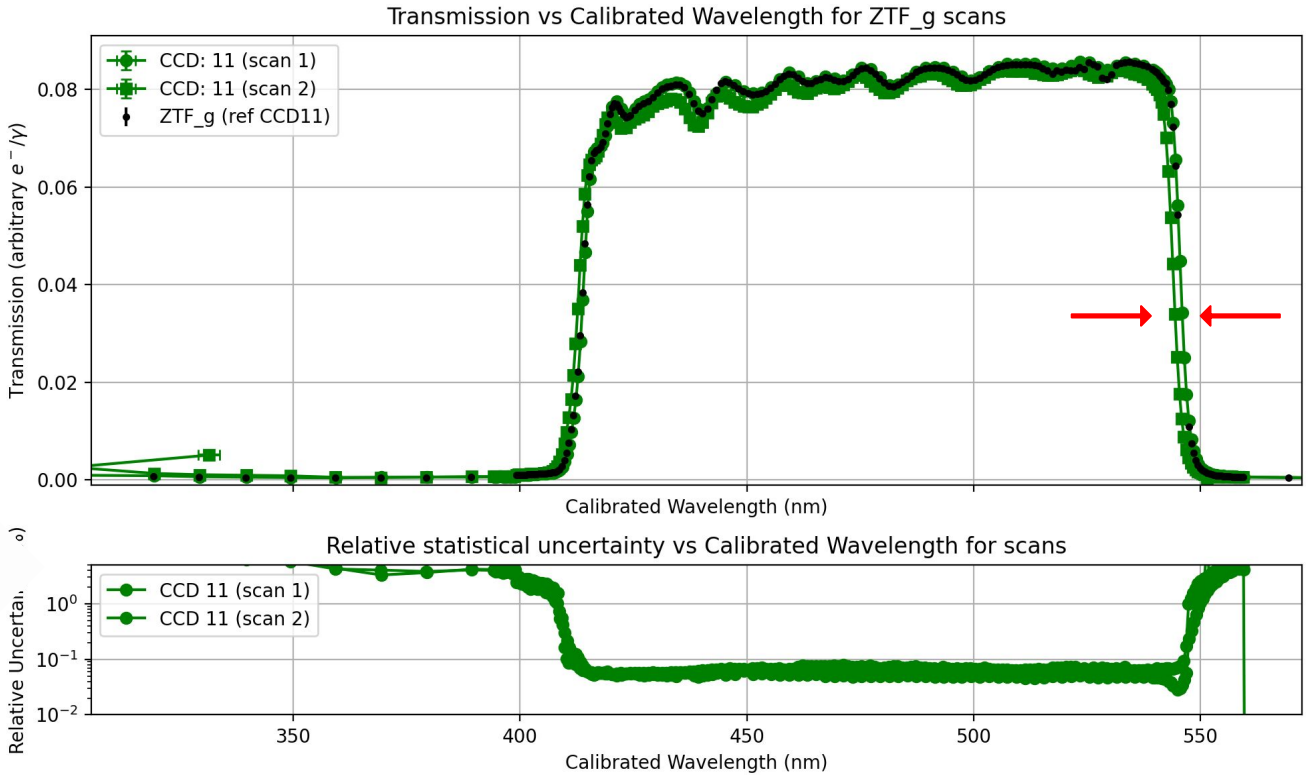




Filter shifts preliminary results

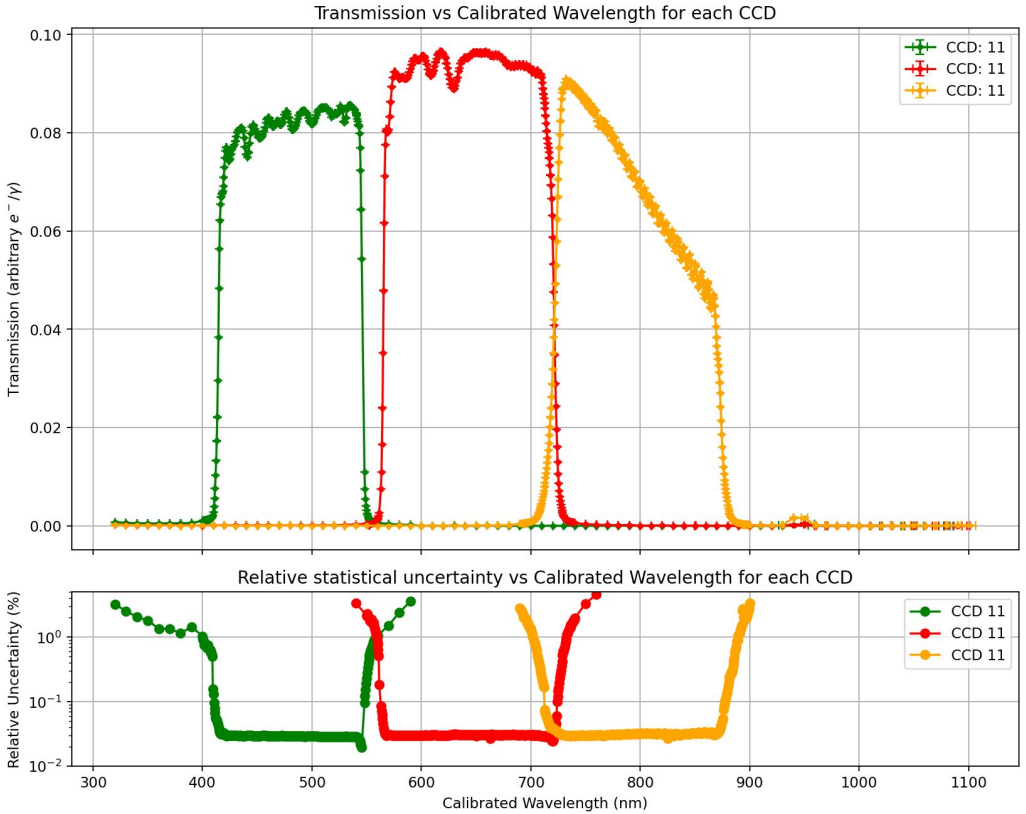






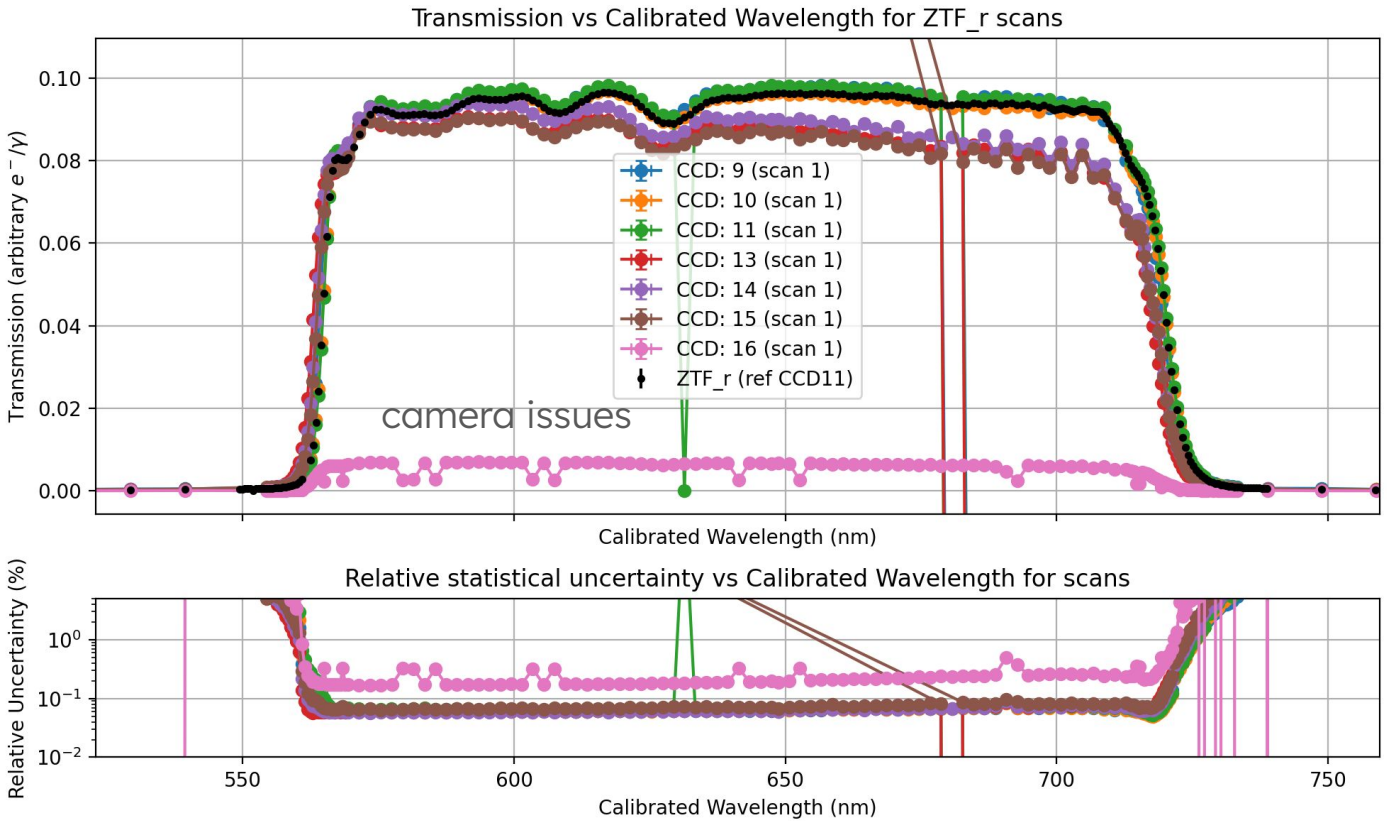
First results (one spot strategy) : fine filter scan

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



Multispot results : r band

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



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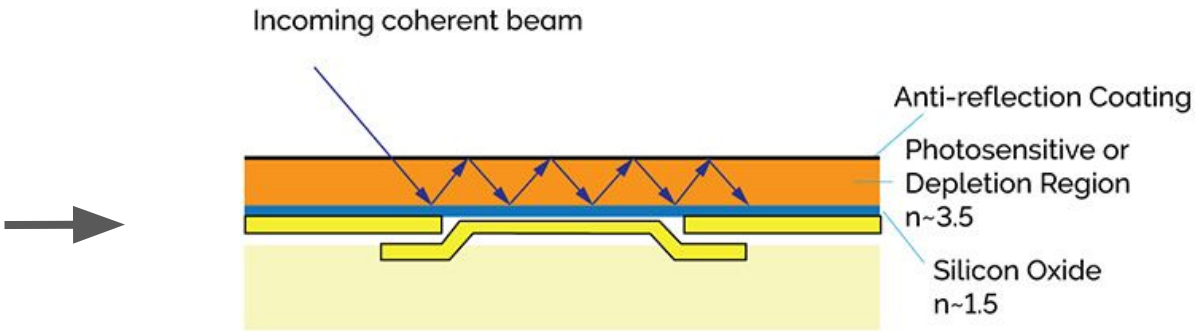

Multispot results : i band

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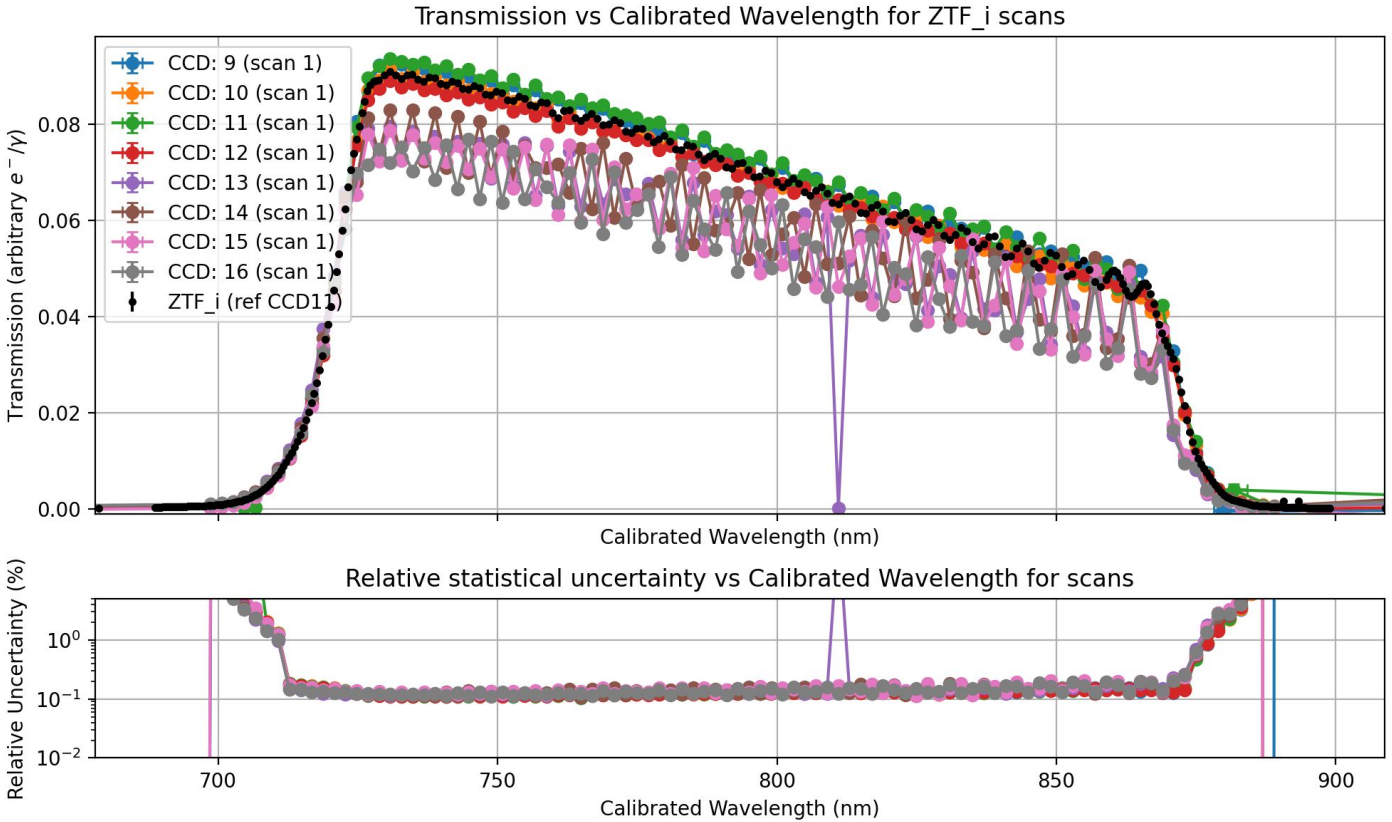


What’s next ?

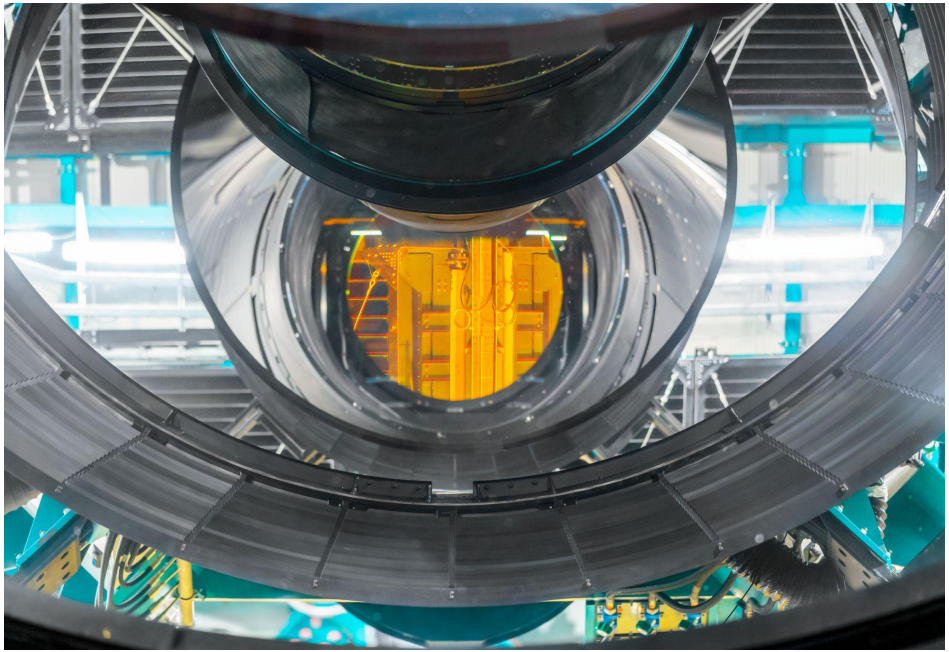
Future of TCBP

- **Next TCBP trip : Chile ! (beginning of 2026)**

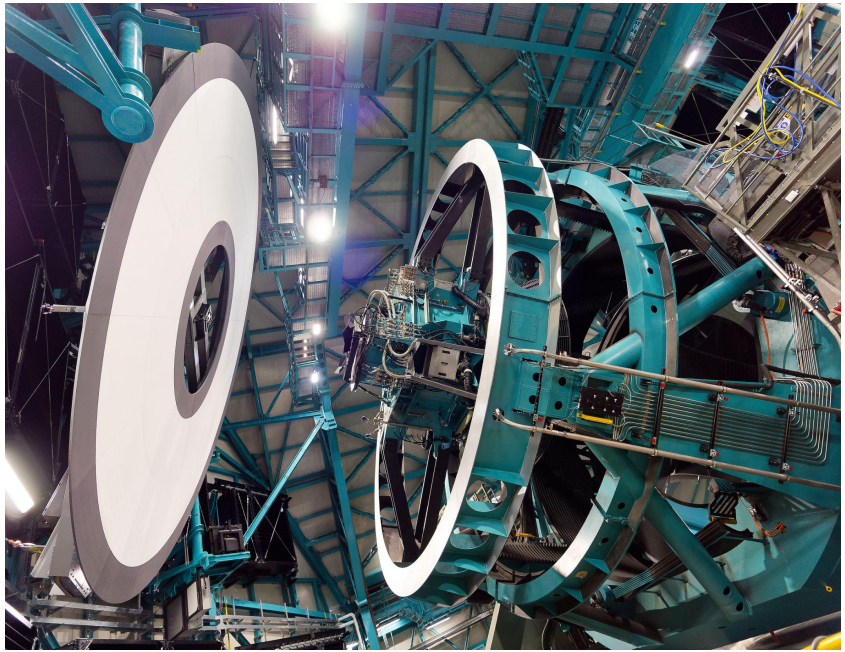
  → to calibrate Rubin's auxiliary telescope (AuxTel)

Credit: Olivier Bonin/SLAC National Accelerator Laboratory

Bonus : Rubin first look

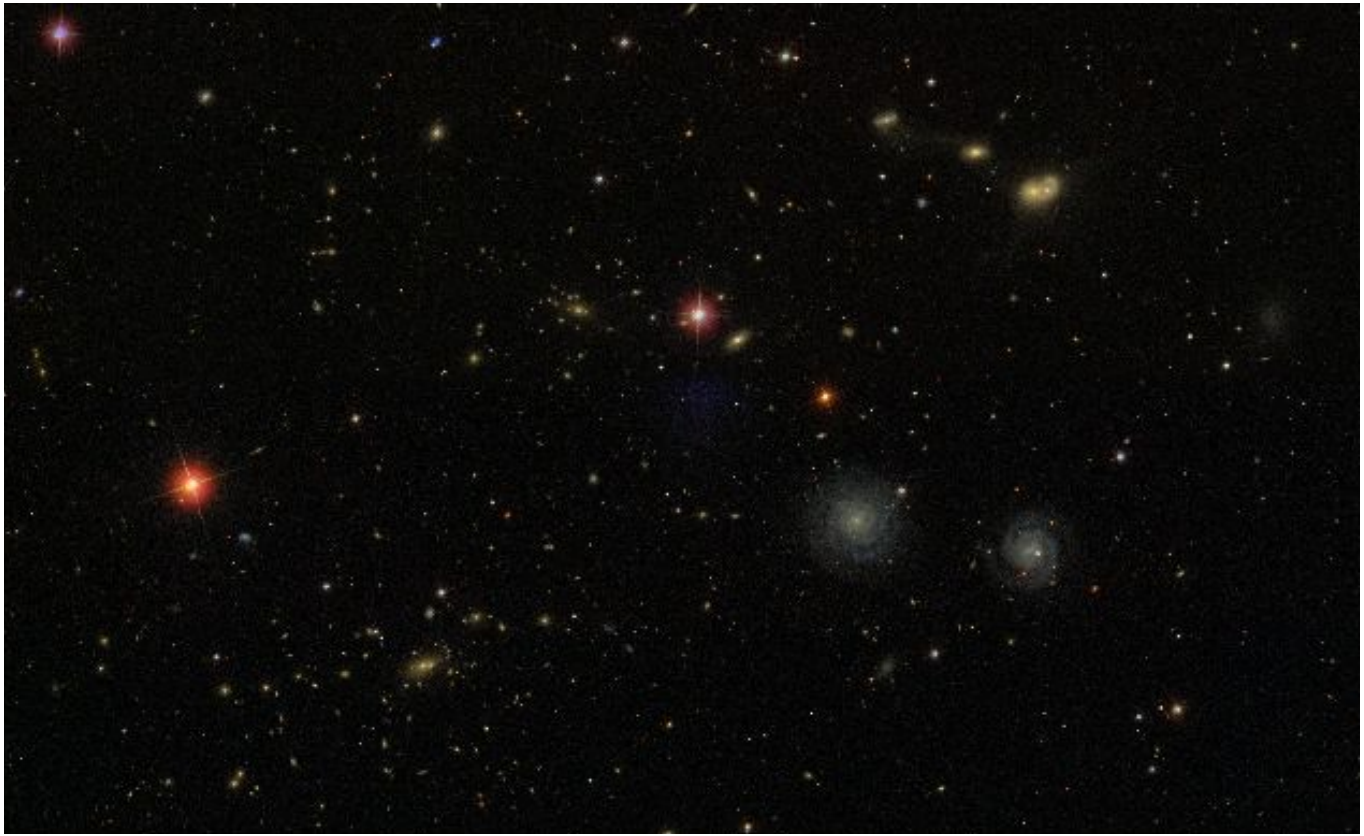


Credit: RubinObs/NSF/DOE/NOIRLab/SLAC/AURA



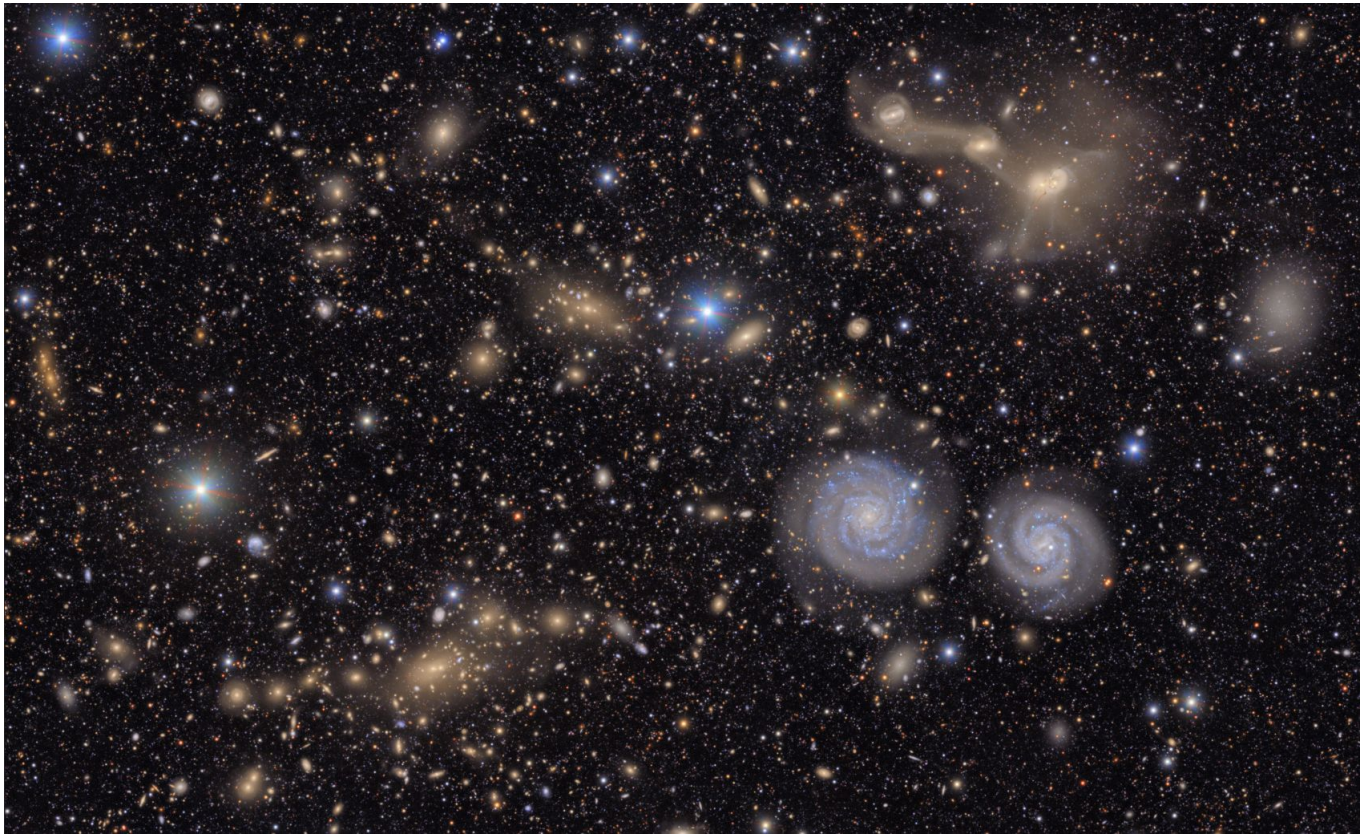
Credit: RubinObs/NOIRLab/SLAC/DOE/NSF/AURA/W. O'Mullane

Bonus : Rubin first look



Sloan Digital Sky Survey

Bonus : Rubin first look



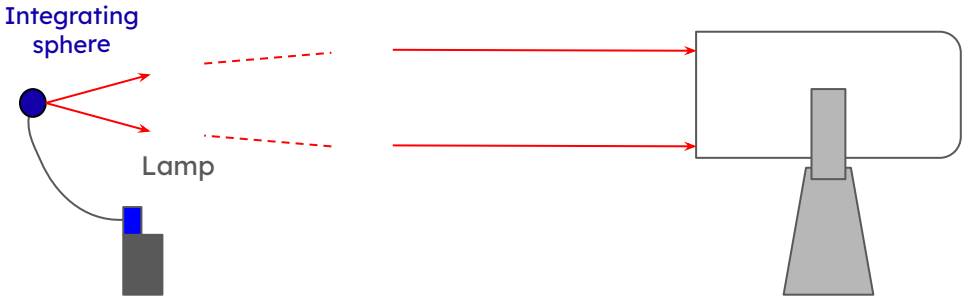
Vera Rubin Observatory

Thank you !

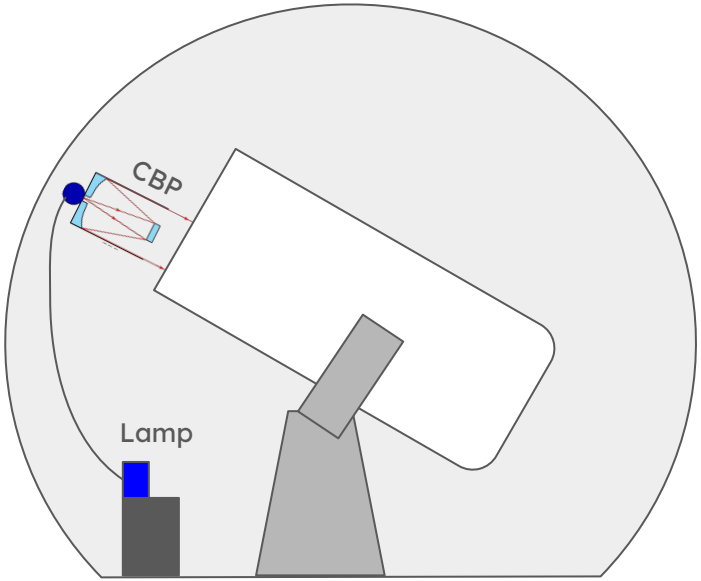
Backups

Different setups

1) Shoot light inside the instrument with a long distance monochromatic source (artificial star)

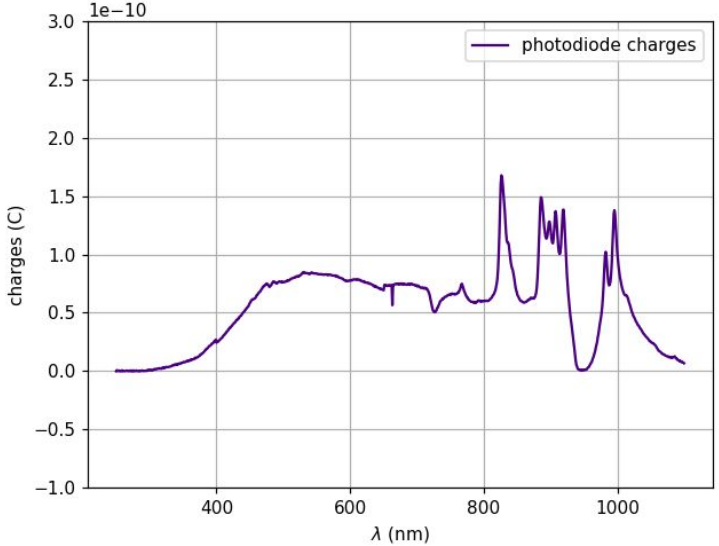


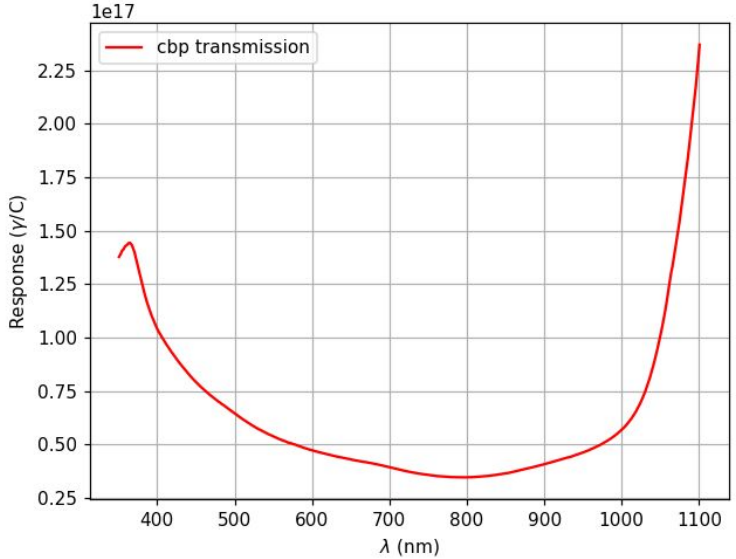
2) Shoot a monochromatic parallel light beam inside the instrument to calibrate



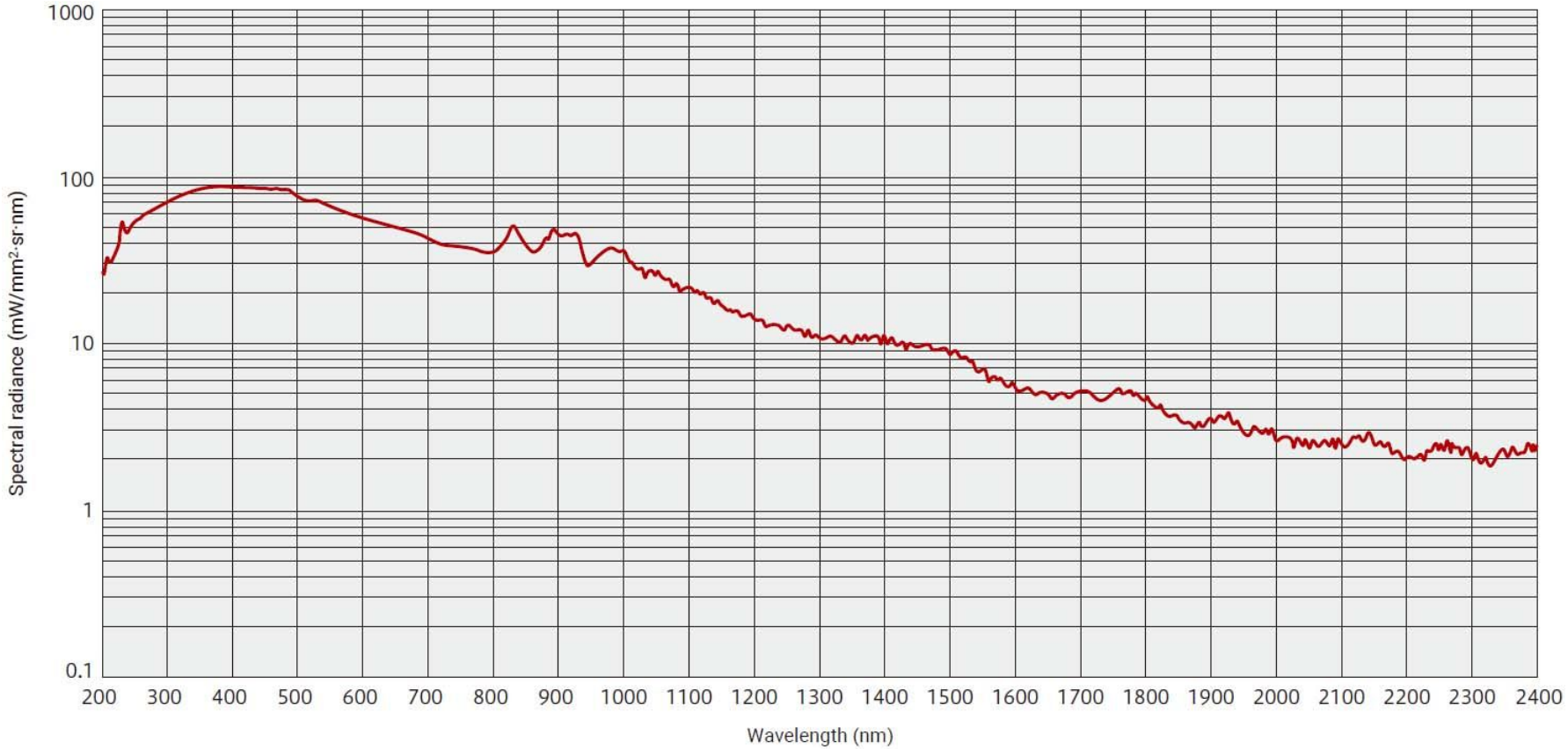
CBP transmission

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



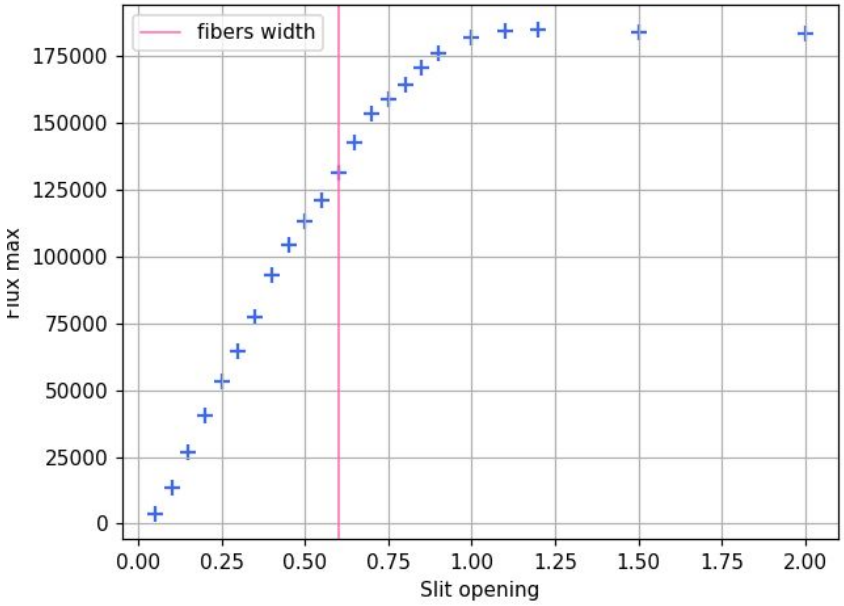


LDLS spectral radiance

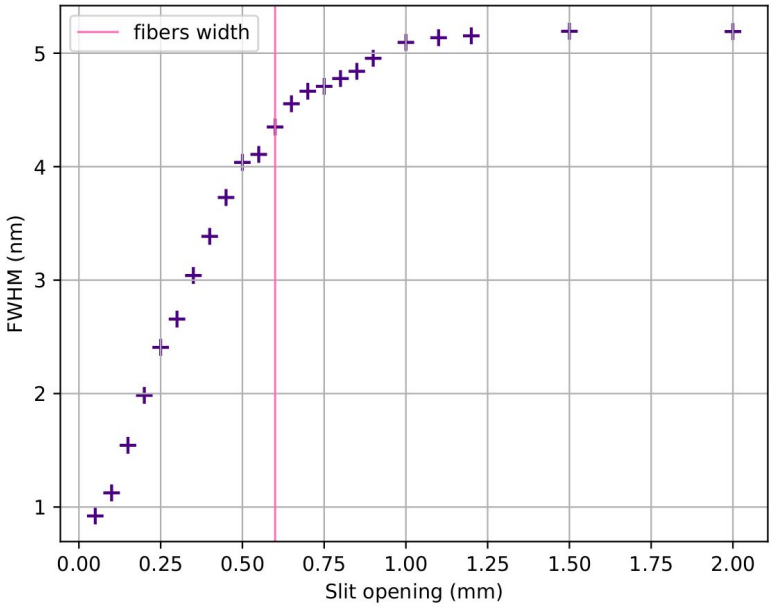


Monochromator resolution (500nm)

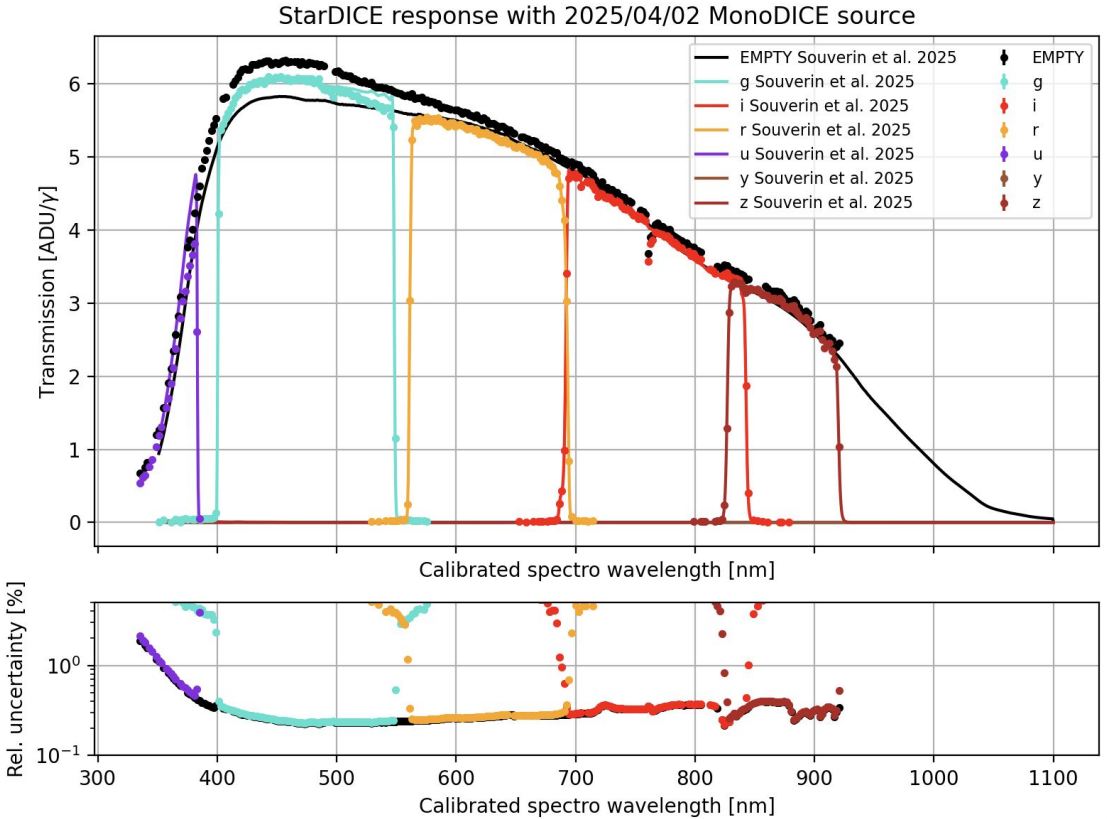
Peak's maximal flux **VS** slit opening



Peak's FWHM **VS** slit opening



MonoDICE @ OHP : Comparison to CBP-laser measurements



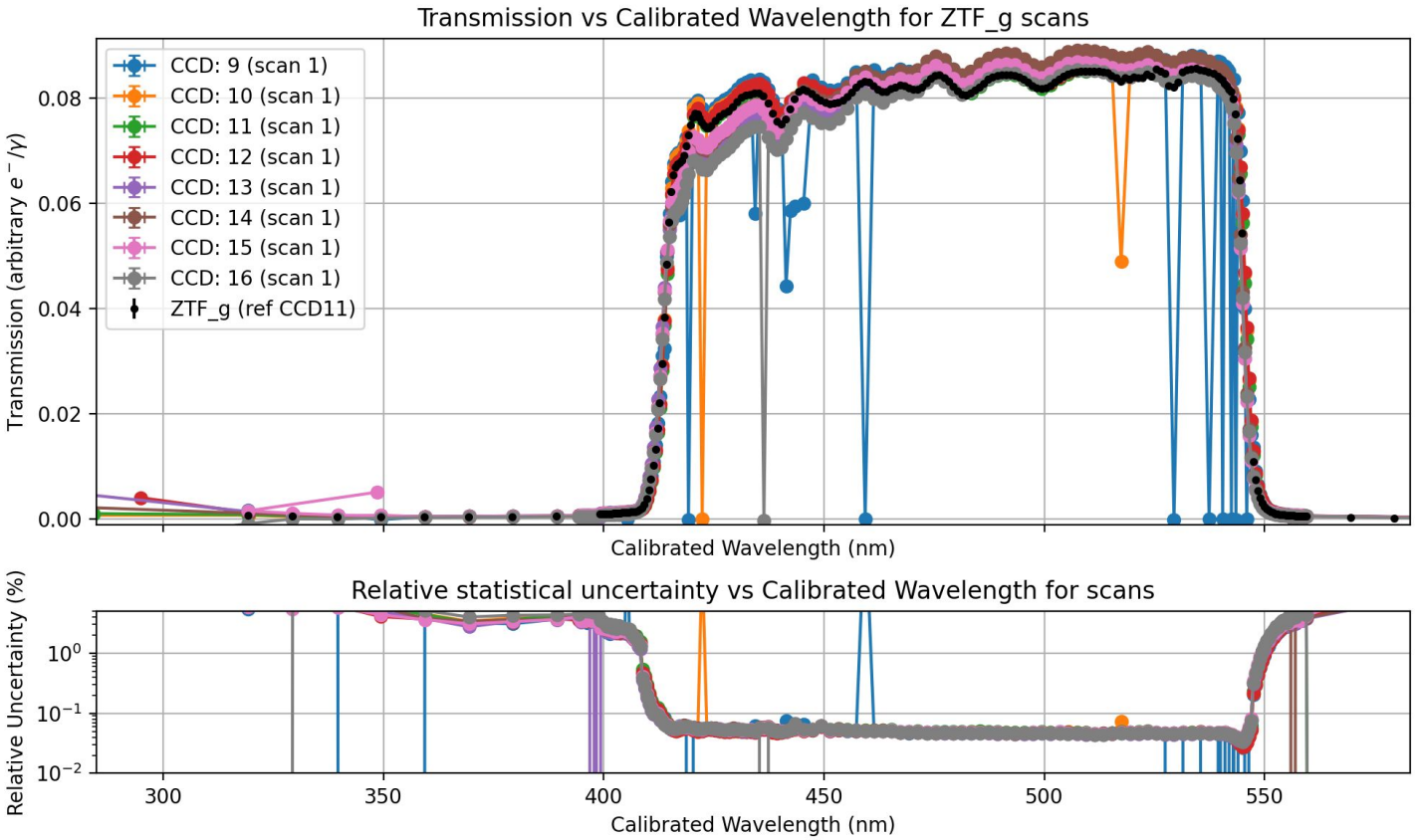
Data set summary

	Filter	g	r	i	empty
CCD 11	1 nm steps	One scan	Two scans	One scan	
CCD 11	Optimized steps	One scan	One scan	One scan	
CCD 09-16	Multispot pos1	One scan	One scan	One scan	One scan
CCD 09-16	Multispot pos2	One scan	One scan	Two scans	One scan
CCD 09-16	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

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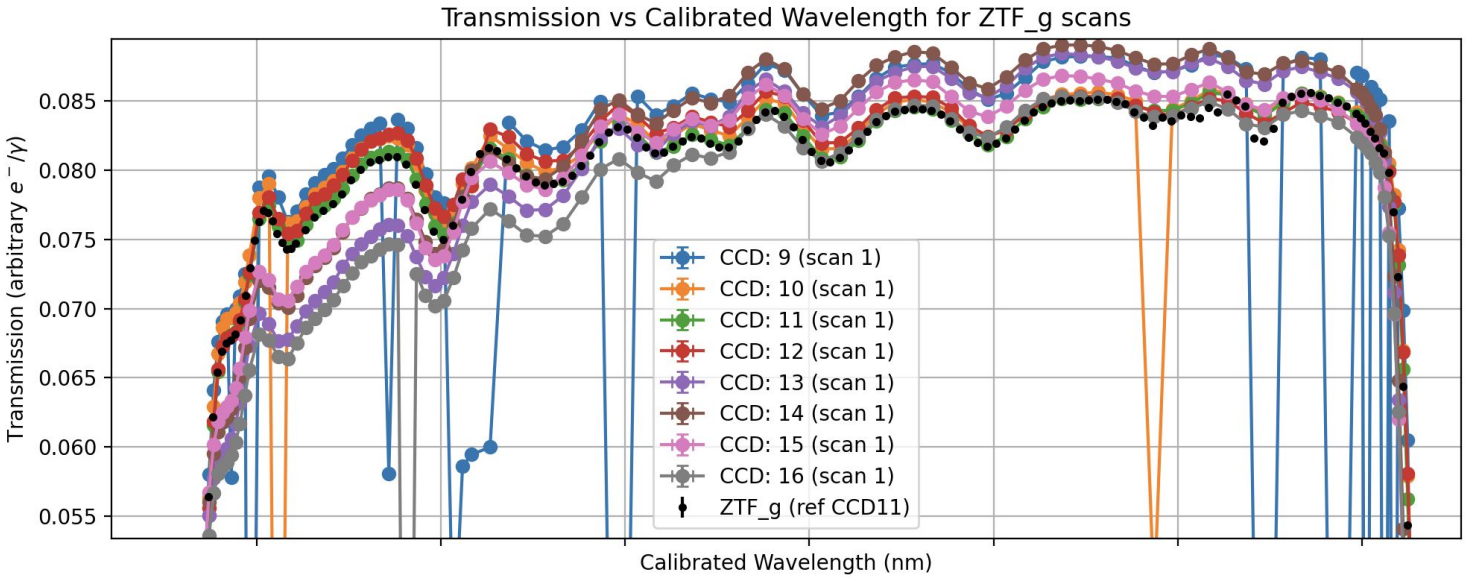
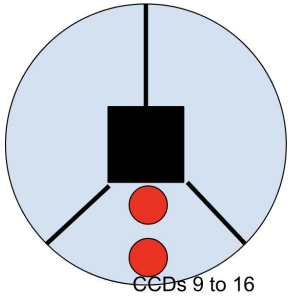
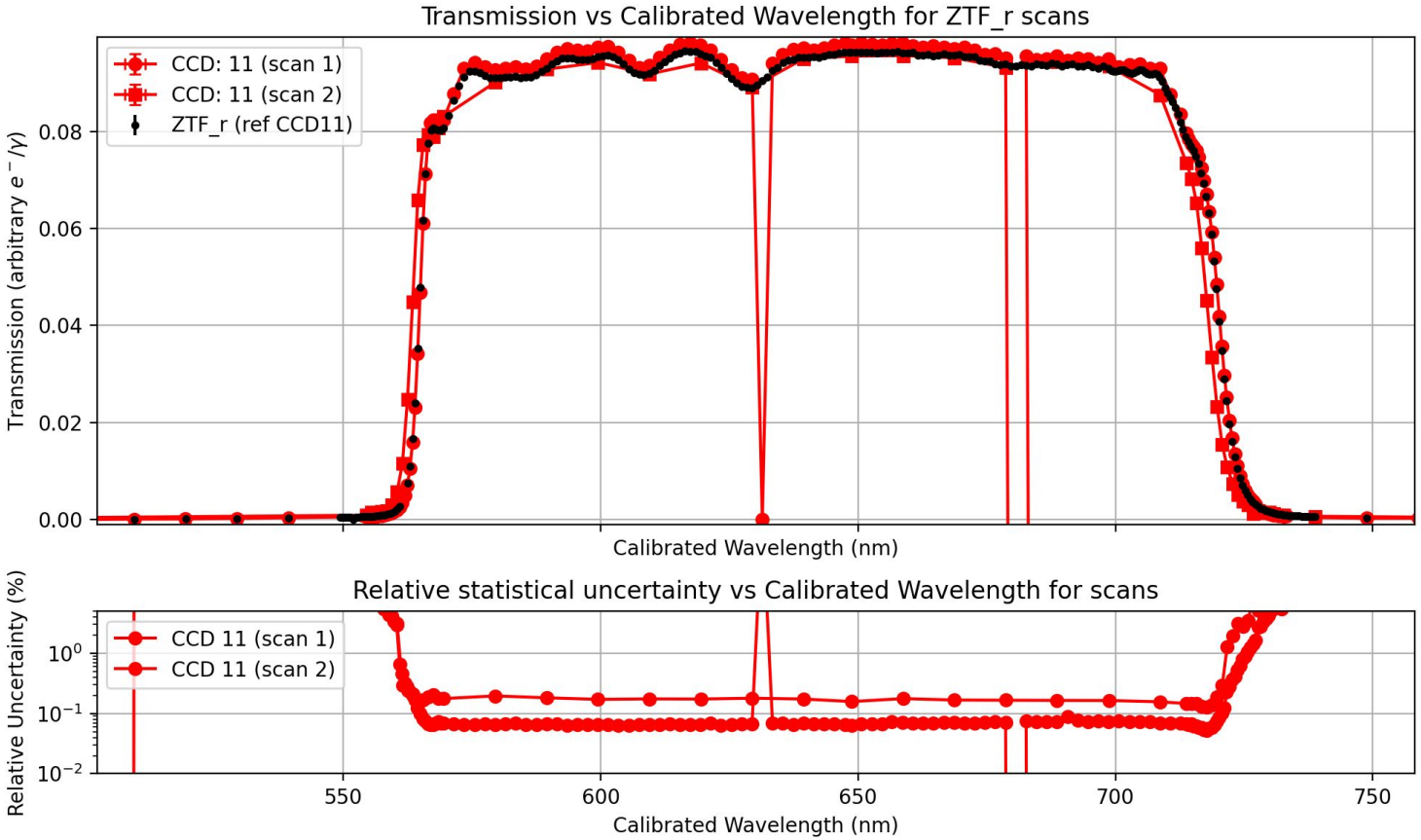


look at (pink,violet) curves or (blue,orange)

Filter shifts preliminary results

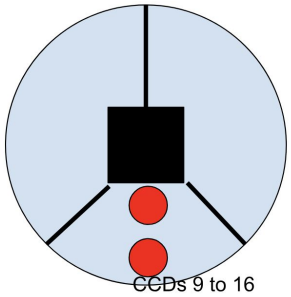
CCD11

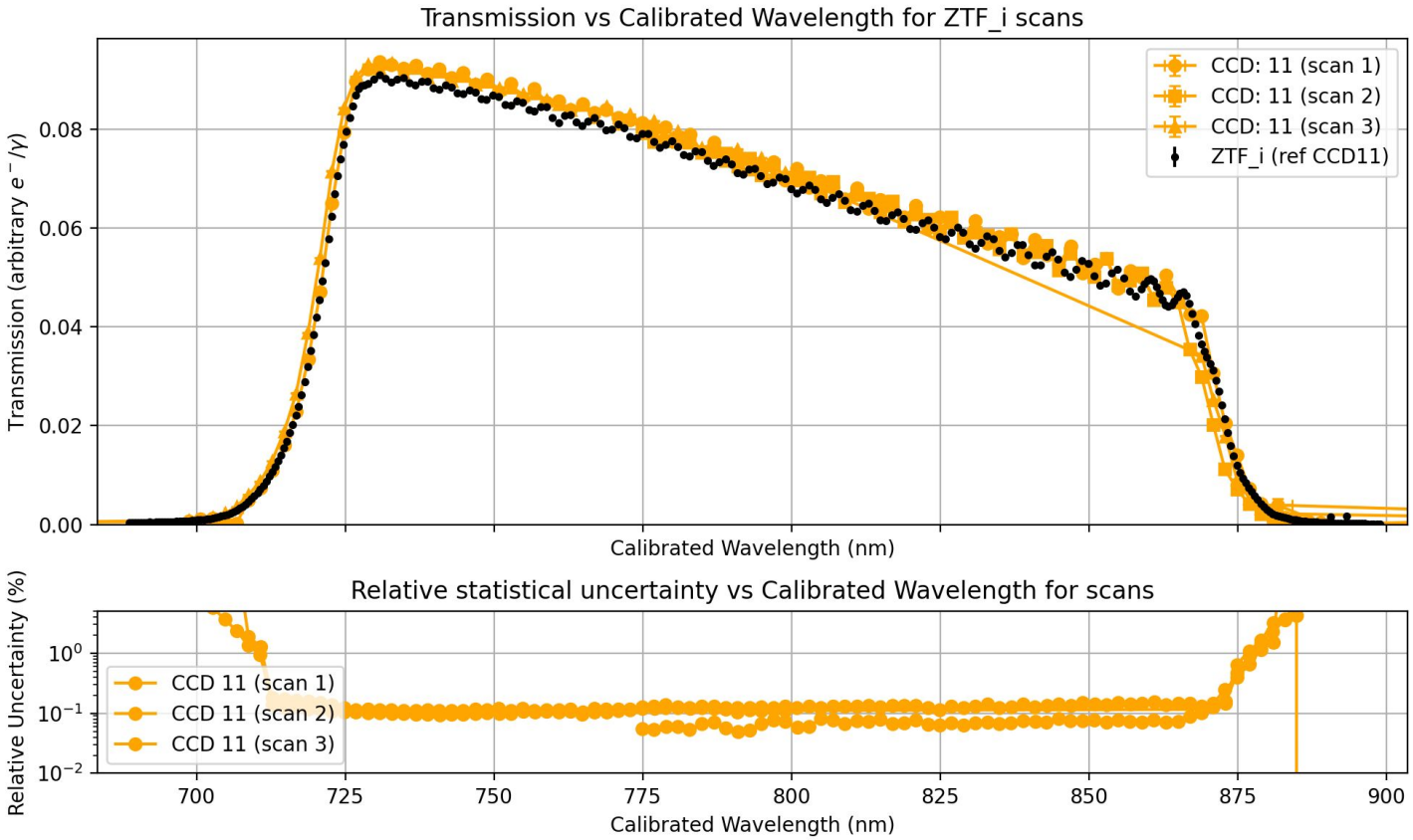




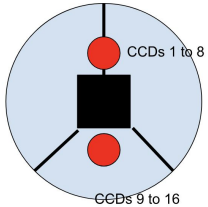
Filter shifts preliminary results

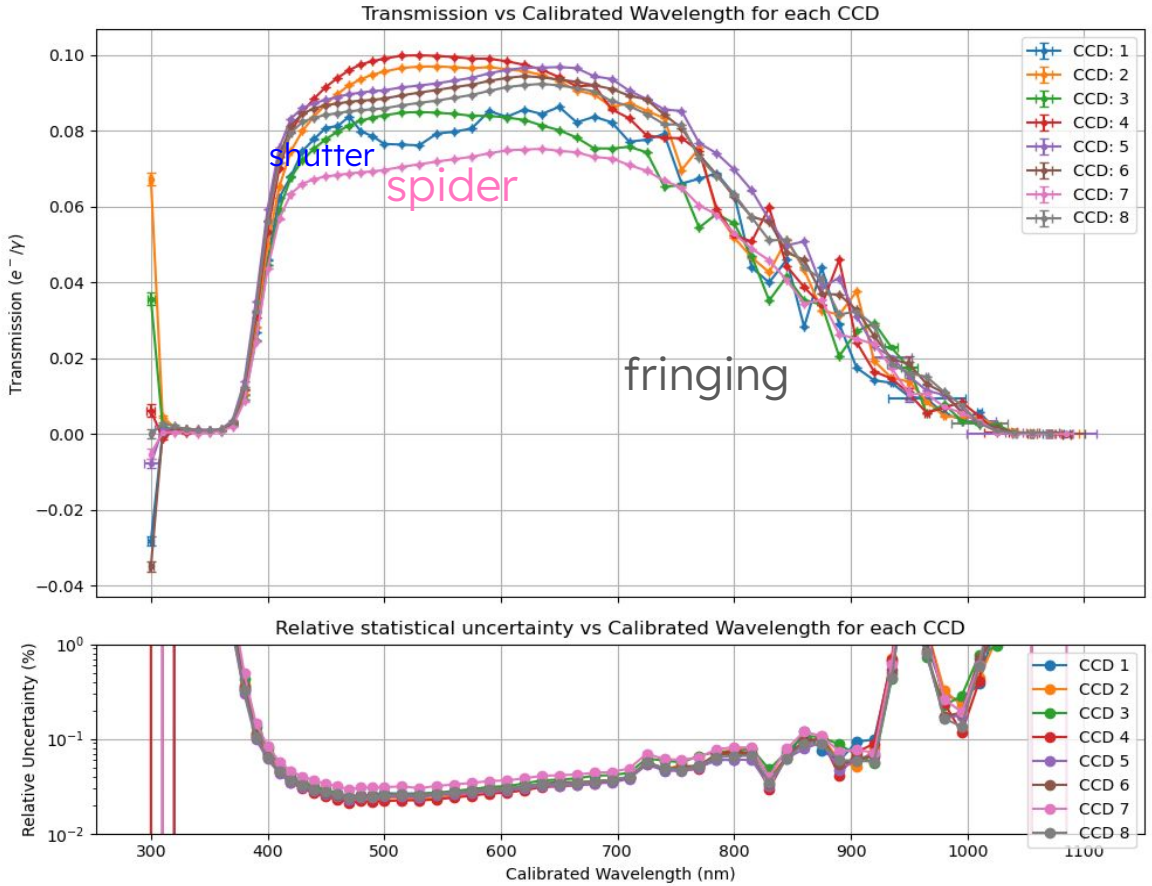
CCD11

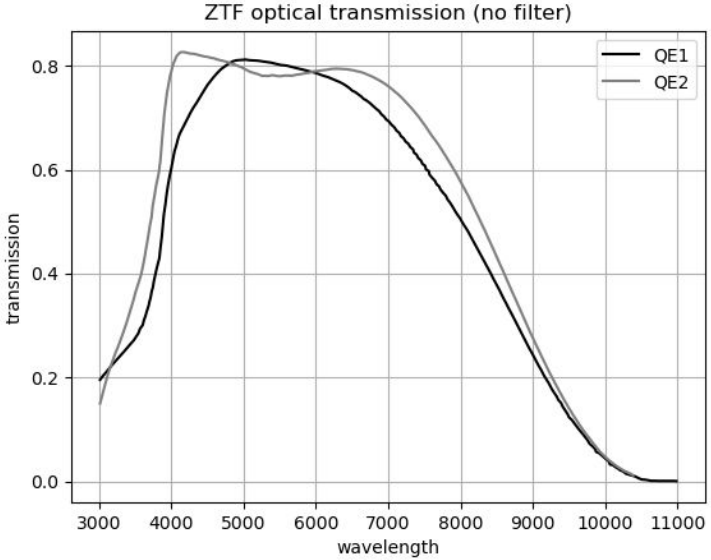




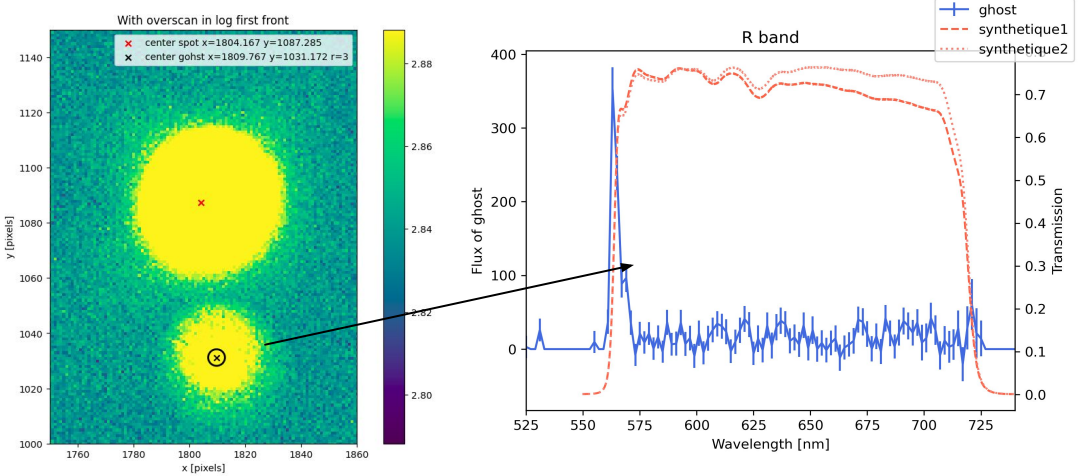
CCD QEs


CCDs 1 to 8
CCDs 9 to 16

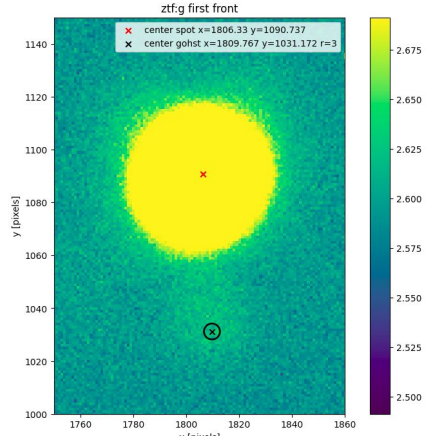

Transmission vs Calibrated Wavelength for each CCD
Transmission (e^-/y)
shutter
spider
fringing
CCD: 1
CCD: 2
CCD: 3
CCD: 4
CCD: 5
CCD: 6
CCD: 7
CCD: 8
Relative statistical uncertainty vs Calibrated Wavelength for each CCD
Relative Uncertainty (%)
Calibrated Wavelength (nm)
CCD 1
CCD 2
CCD 3
CCD 4
CCD 5
CCD 6
CCD 7
CCD 8

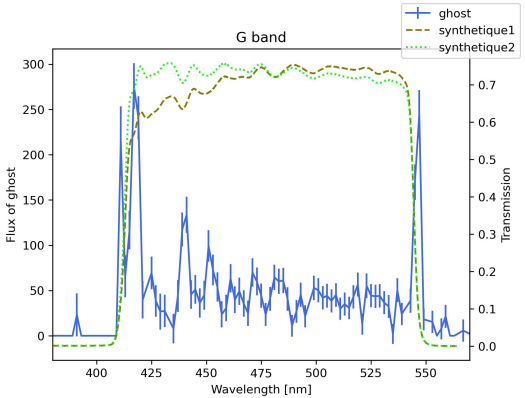

ZTF optical transmission (no filter)
QE1
QE2
transmission
wavelength

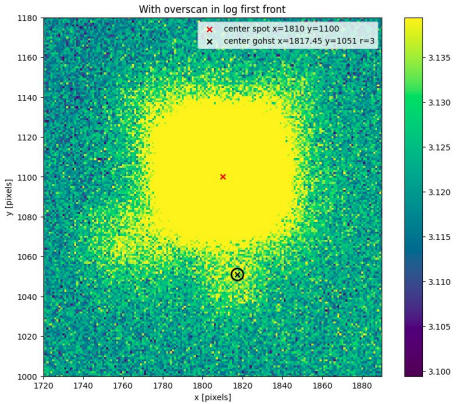
TCBP @ ZTF : Ghosts

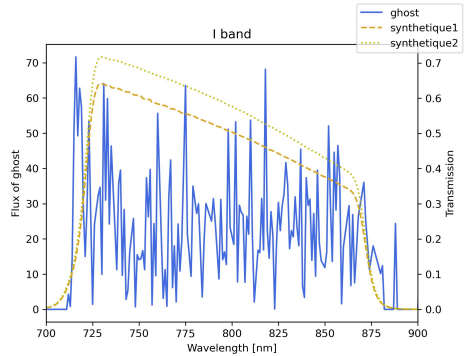


- One ghost in the first edge in the r-band
- One ghost in each edge of the g band
- In all the i band

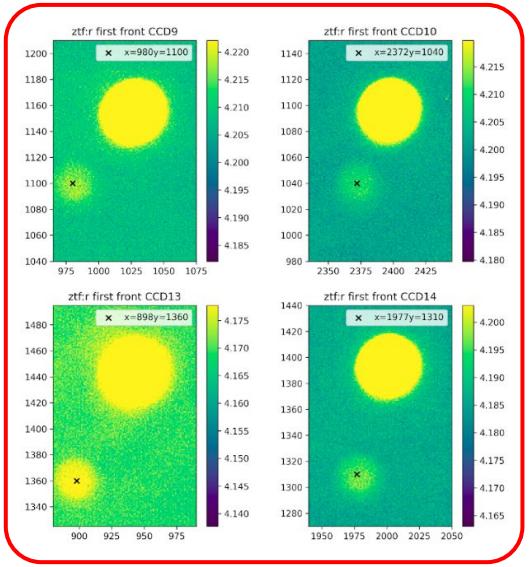




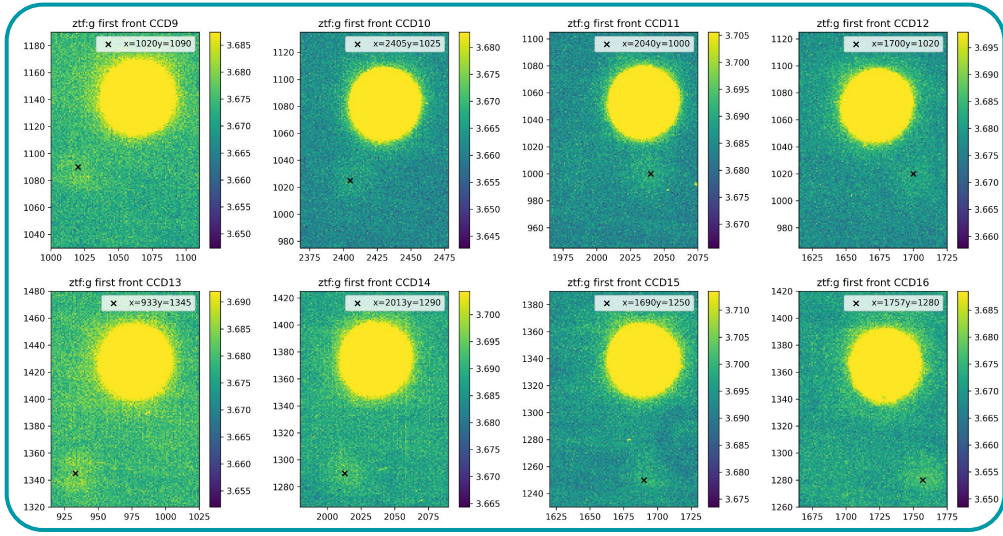


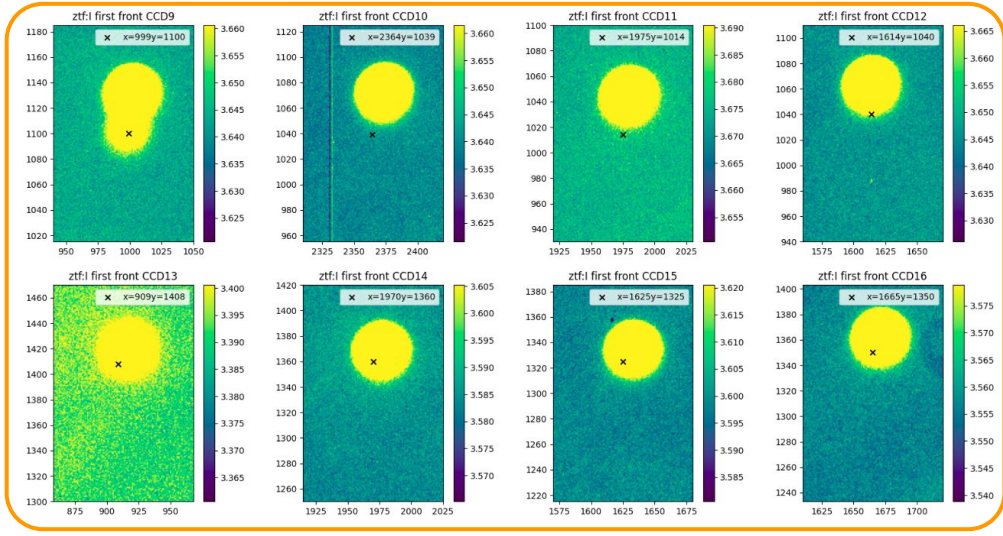


TCBP @ ZTF : Ghosts

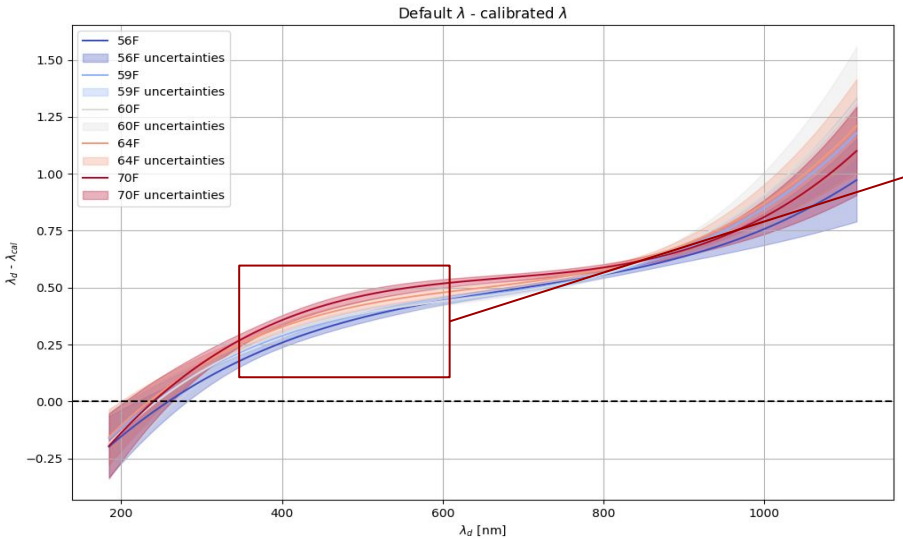


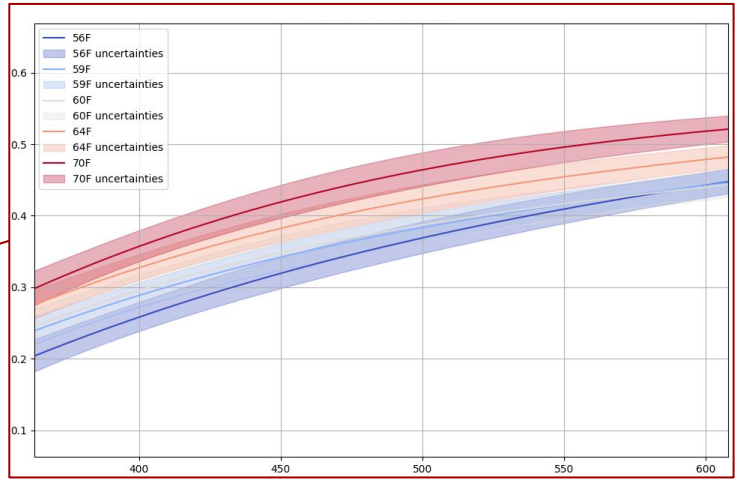
- r band : only CCD9,10,13,14. Ghost farther away from the spot for single coating.
- g band : lower intensity but at different locations as a function of the CCD.
- i band : ghost merging with the spot ?



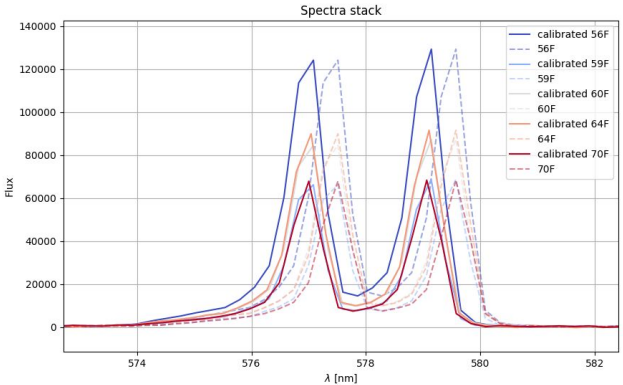


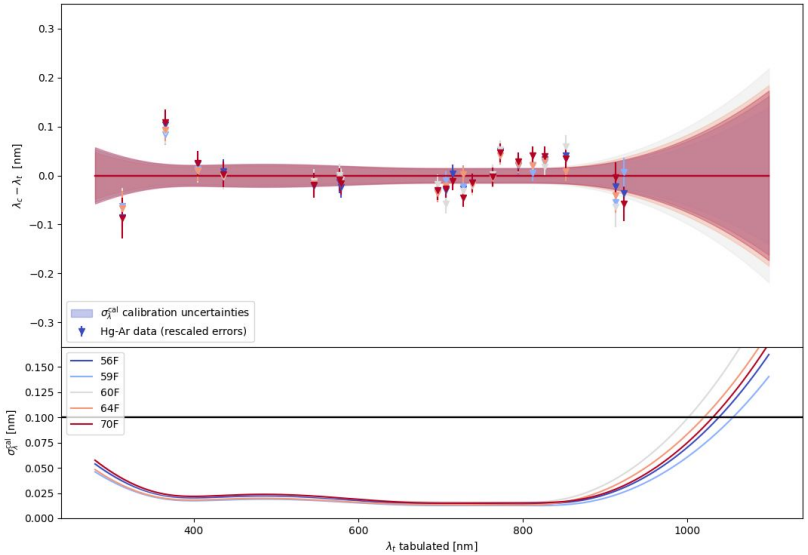
TCBP @ ZTF : Spectro calibration





Temperature dependency





calib uncertainty < 1Å !

Filter shift