AuxTel updates

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Outline

1. AuxTel in <180s
2. Fresh news from summit
3. Atmospheric studies
4. Observation strategy with Gaia
5. From AuxTel to LSST photometric corrections
6. CBP news
7. Summary

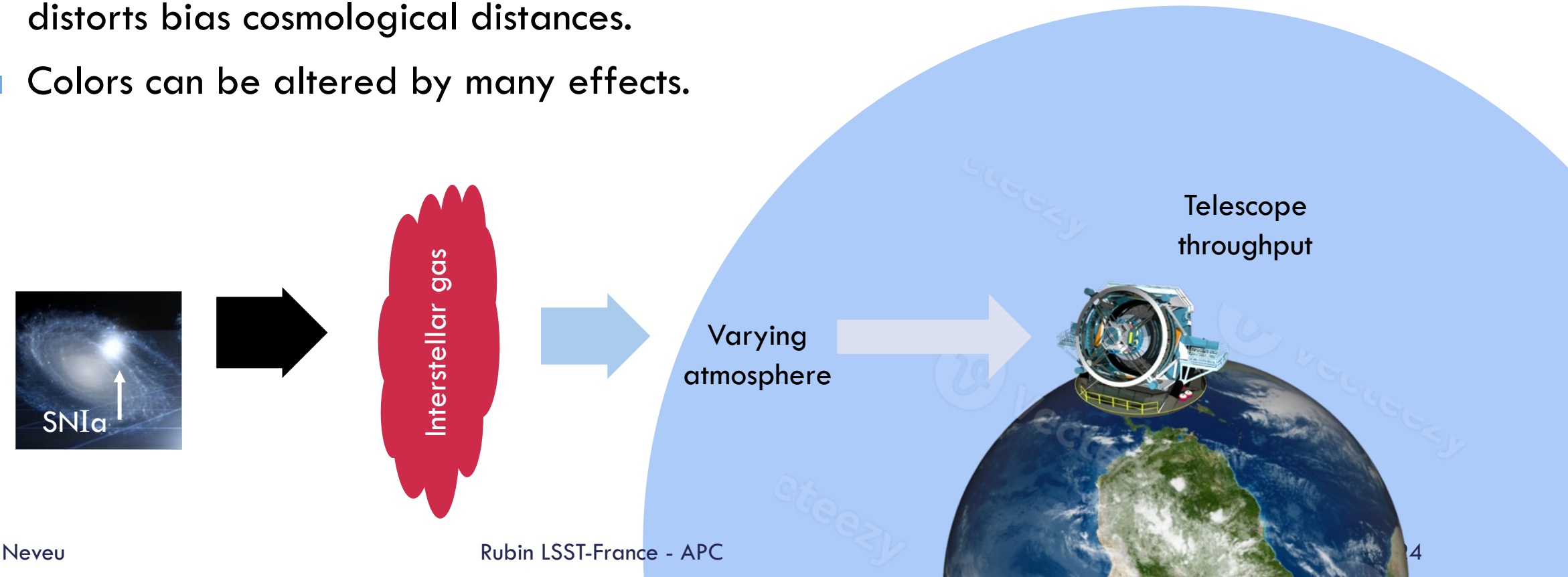
AuxTel in <180s

Photometric surveys for cosmology

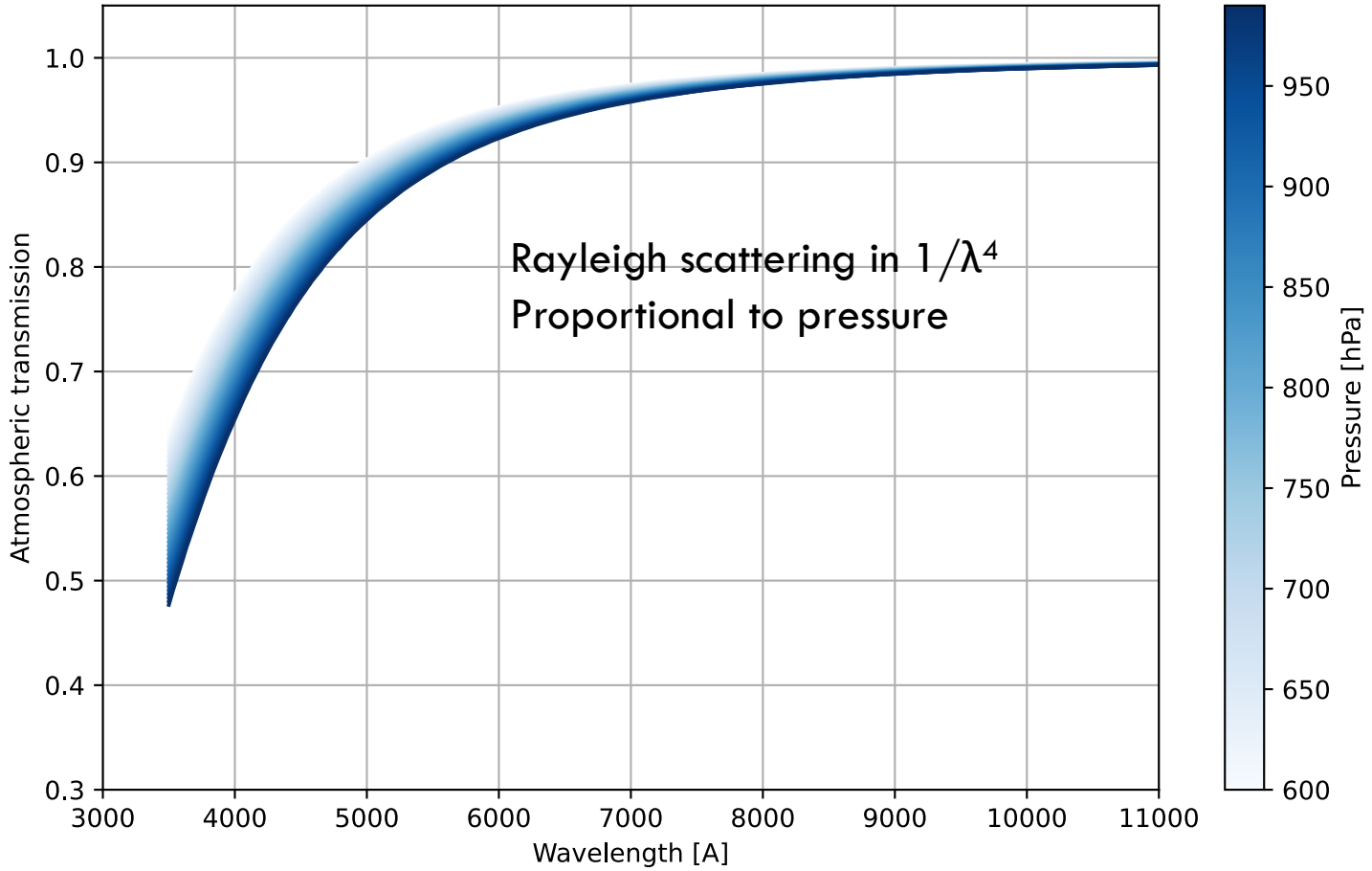
- In cosmology: the farther, the redder!

➔ colors contain information on cosmological distances.

- Any unwanted colored effect on your measurements distorts bias cosmological distances.
- Colors can be altered by many effects.



Atmosphere transmission



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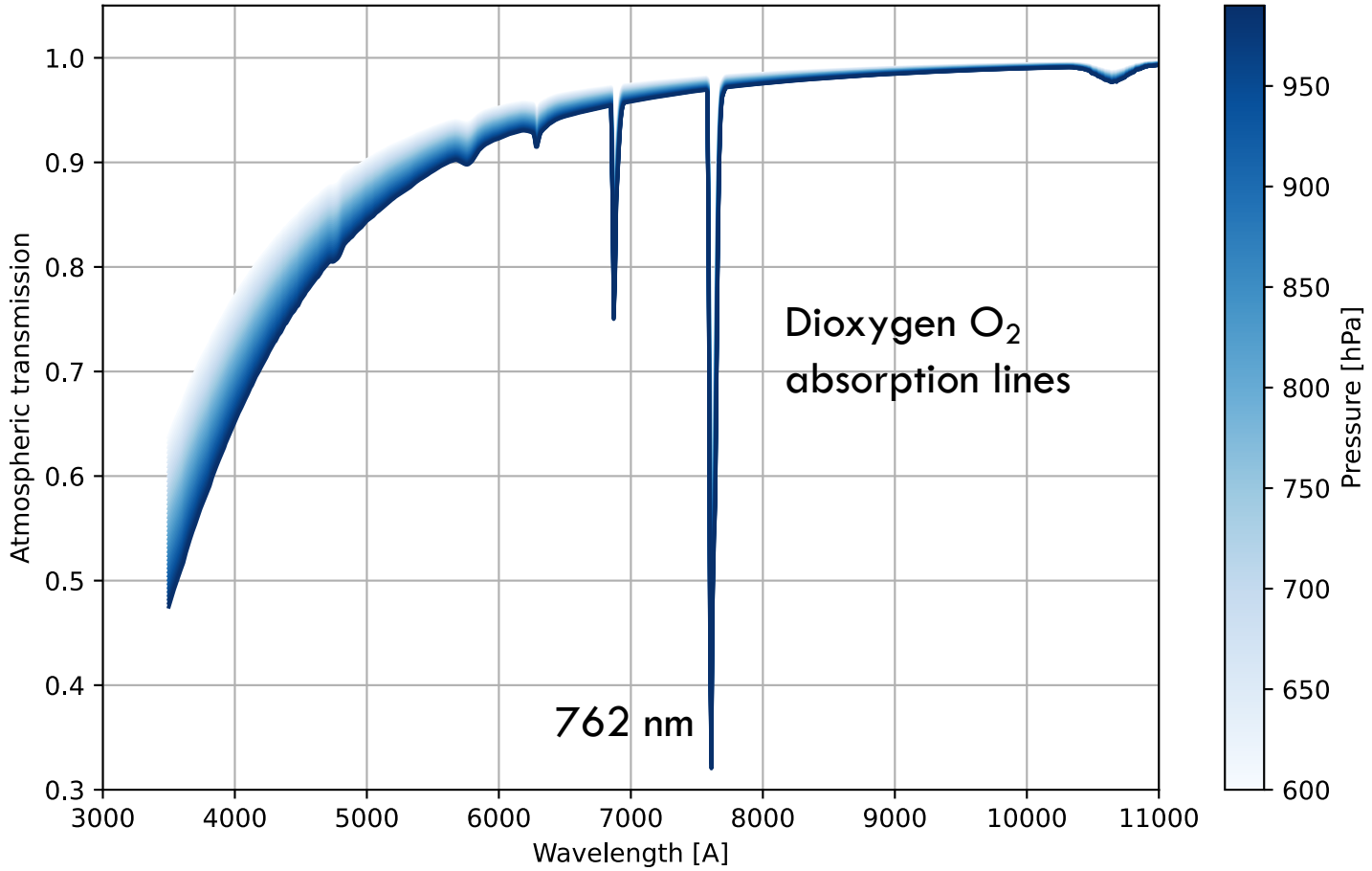

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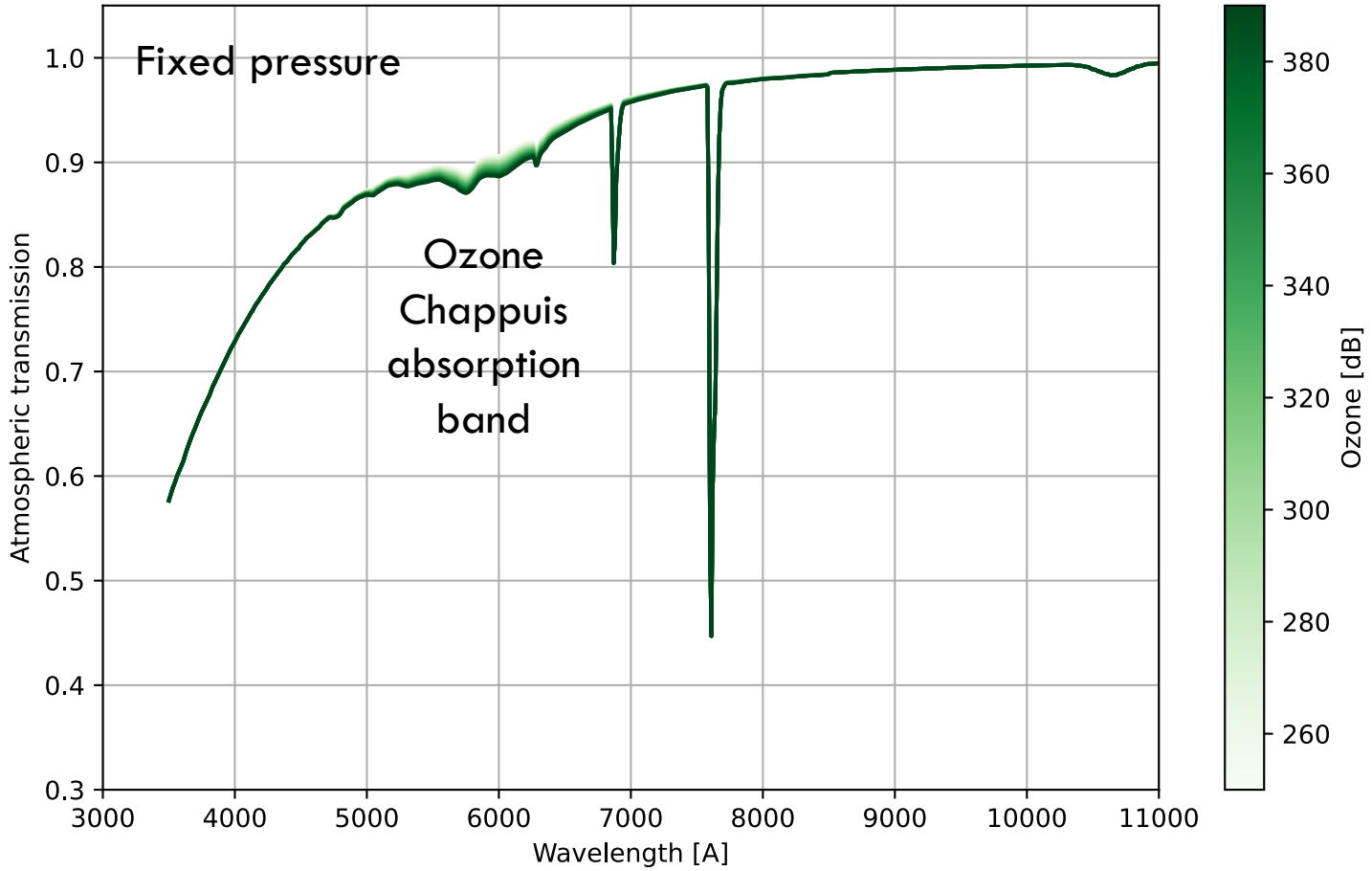
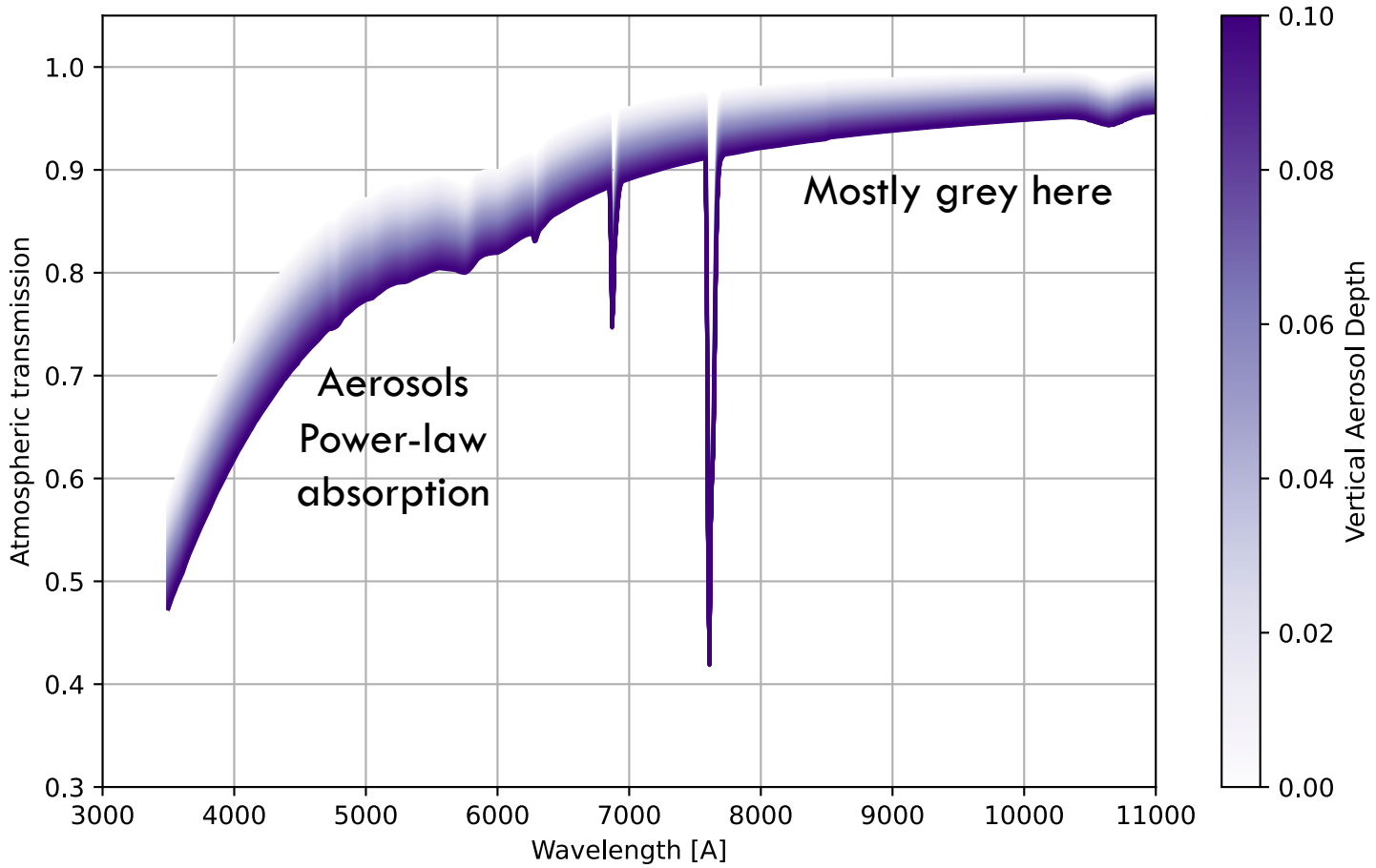
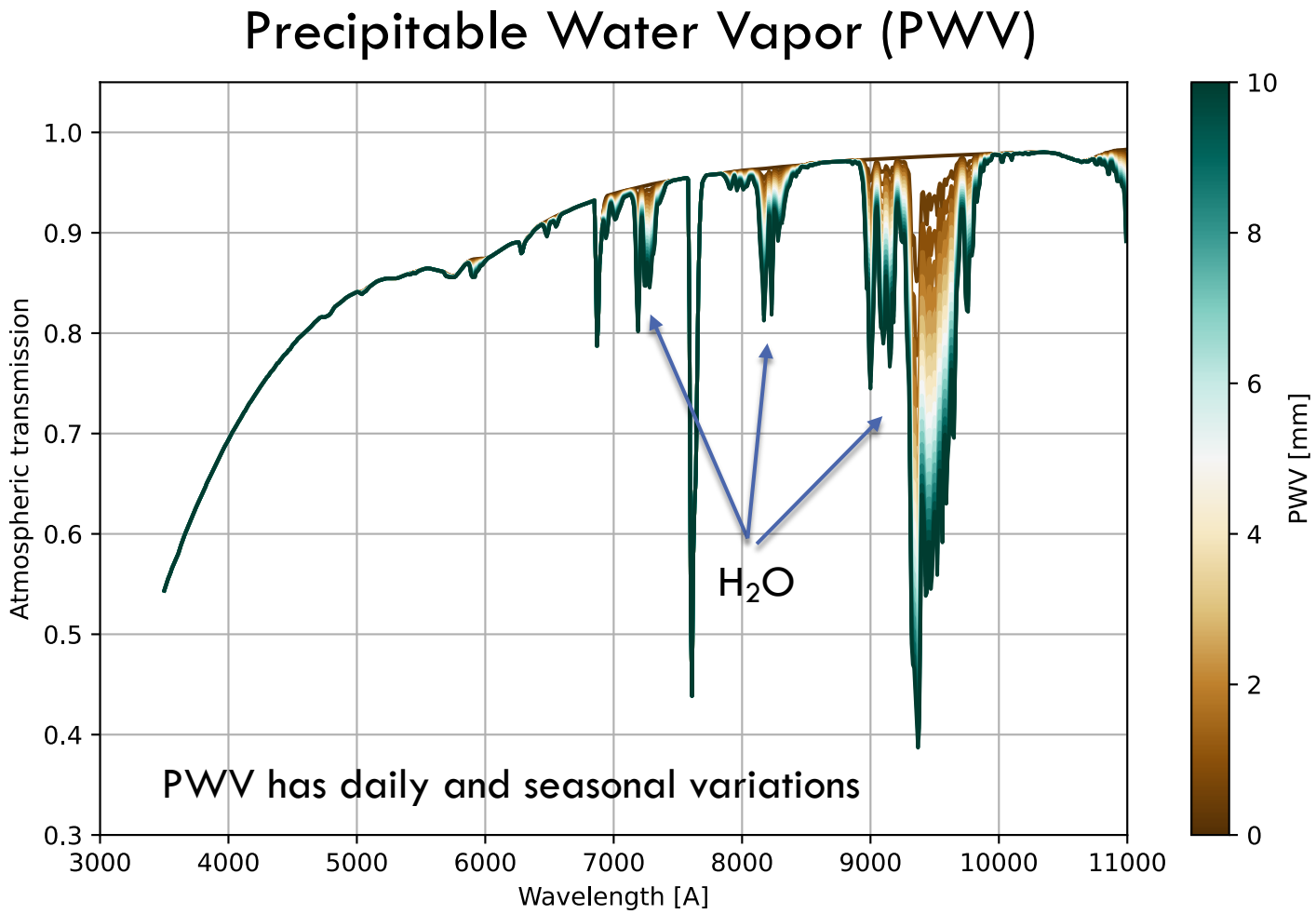


Atmosphere transmission

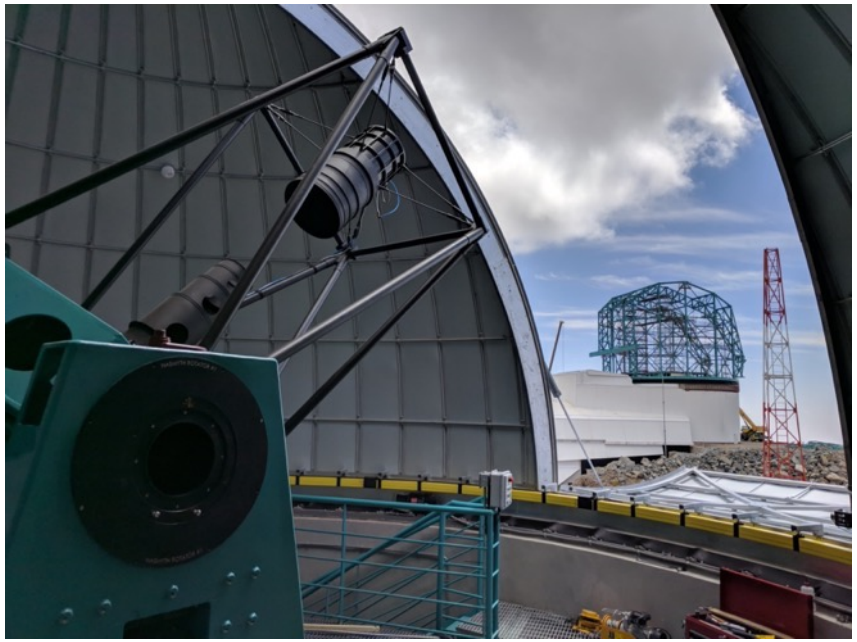


Atmosphere transmission



Rubin Auxiliary Telescope (AuxTel)

- 1.2m telescope on Rubin site equipped with a spectrograph
- Rubin Auxiliary Telescope mission is to measure on-site atmospheric transmission, parallel to main telescope



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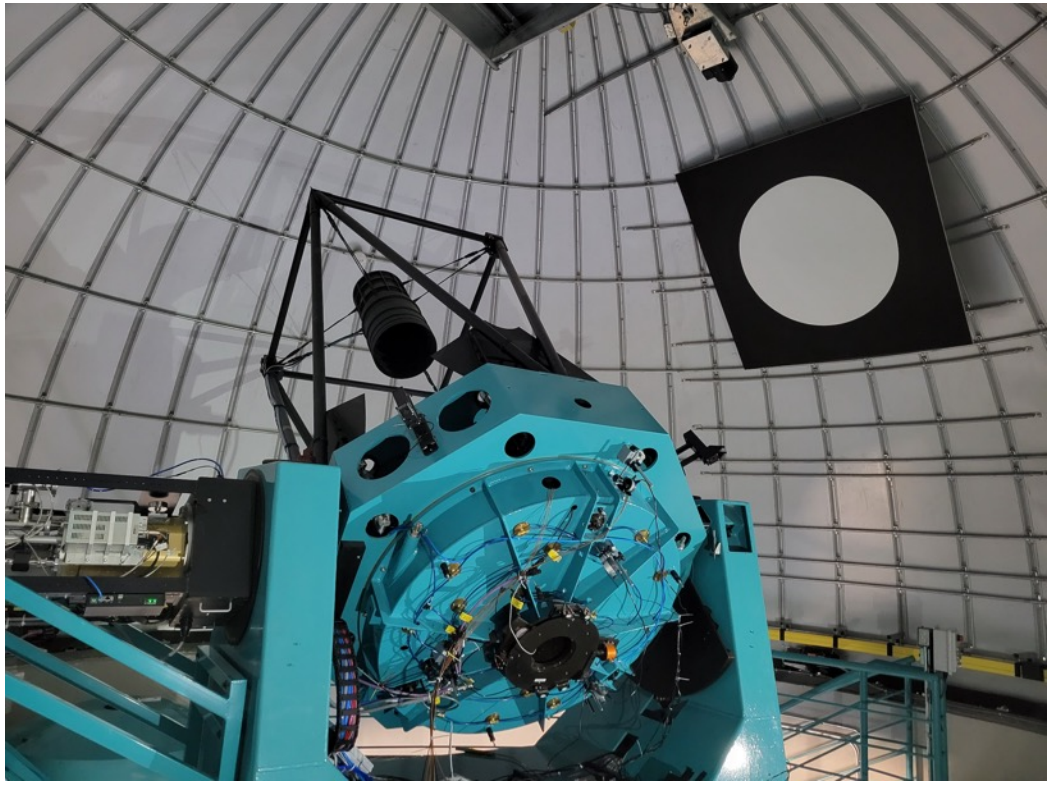
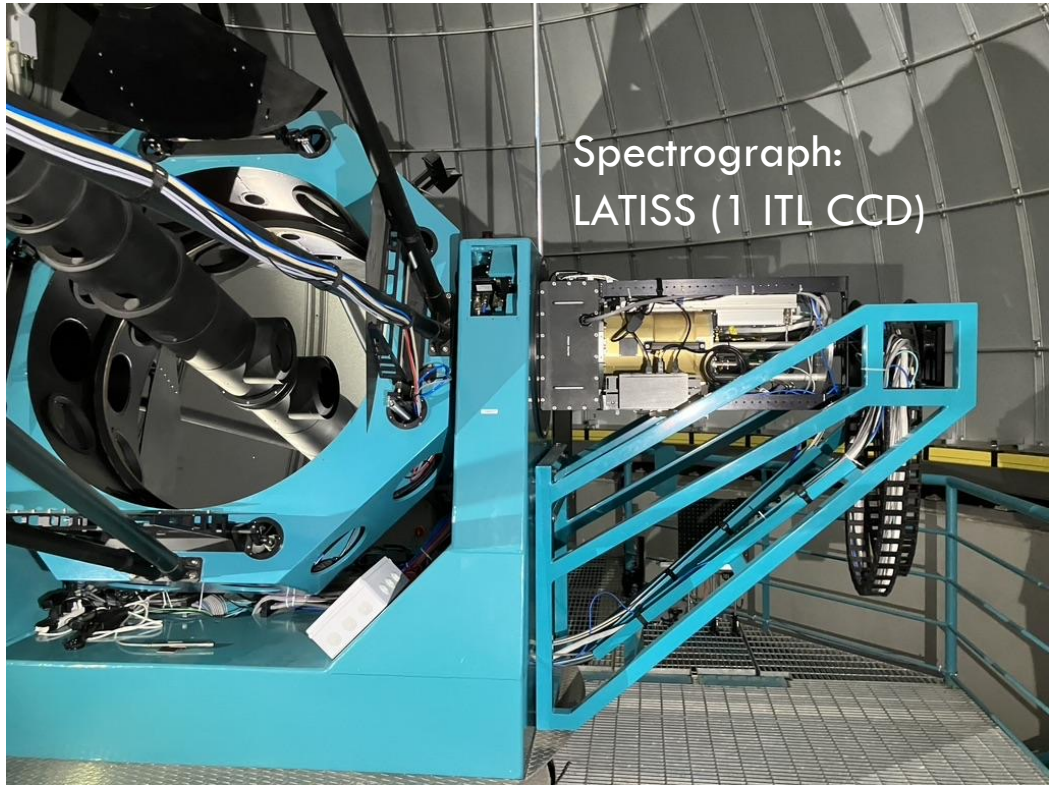
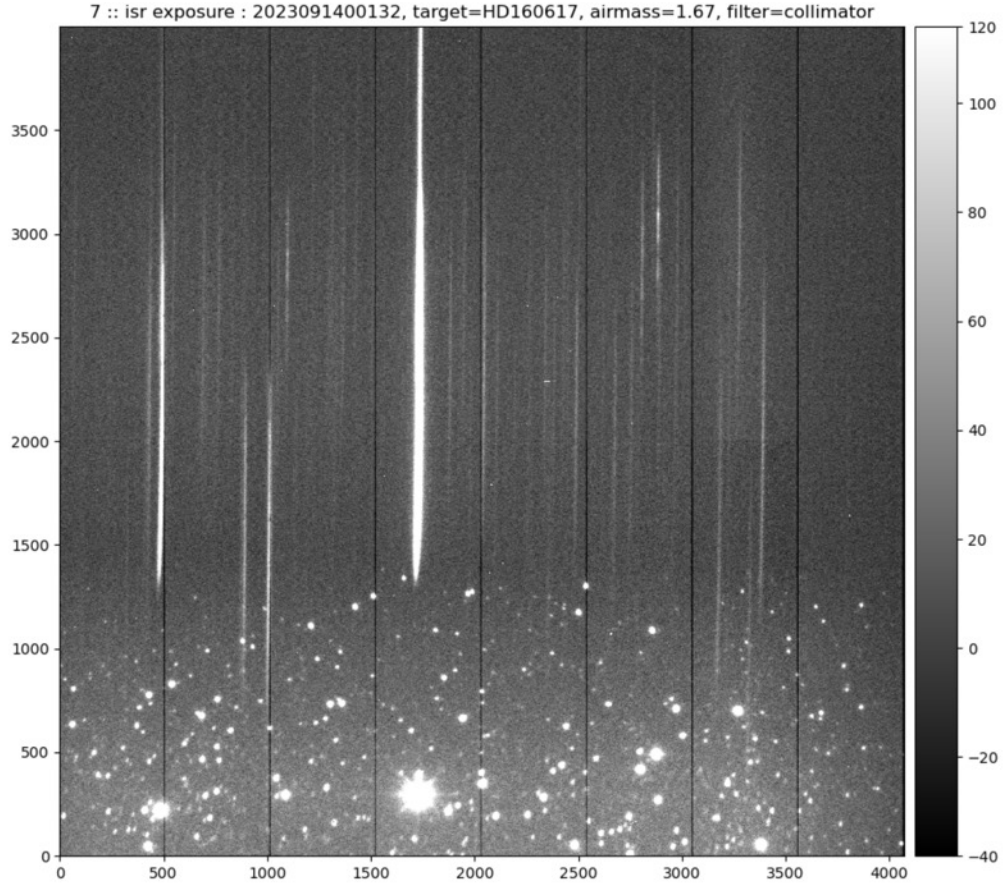


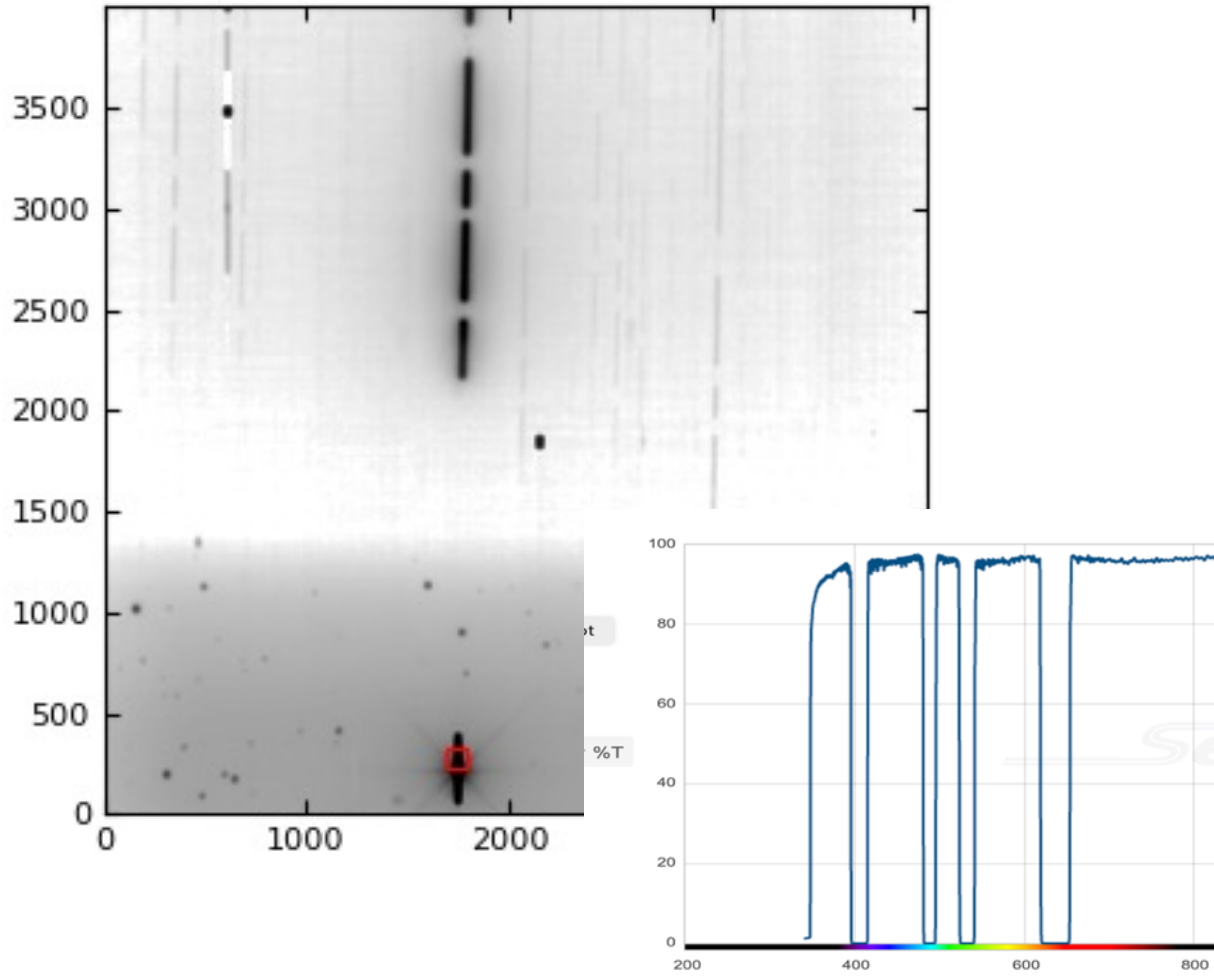


Representative AuxTel data in 2024

Hologram data



Quadnotch filter + blazed blue grating



Fresh news from Cerro Pachon

AuxTel news

- Before ComCam observations: 3 nights every week up to 2am
- Chris Stubbs on sabbatical year in Chile: got 2 full nights from sunset to sunrise with very good weather conditions!
- Stopped during ComCam campaign and maintenance:
  - dome (painting, motor checks) => should improve in-dome turbulence
  - DDS issues to run AuxTel with ComCam
- Restart after December 15th, maybe engineering runs (tests…)
- No planning for joint observations with LSSTCam

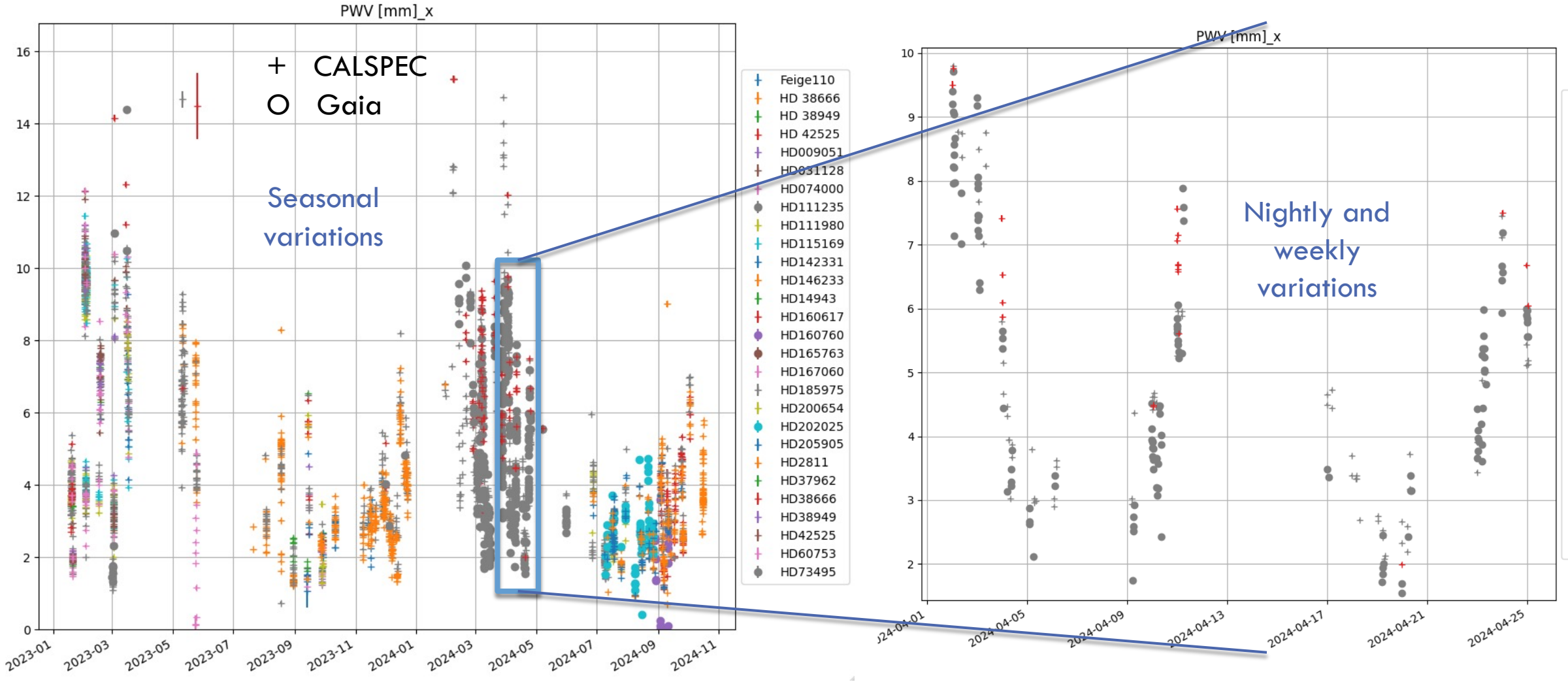
Atmospheric studies

Improvement of Spectractor pipeline

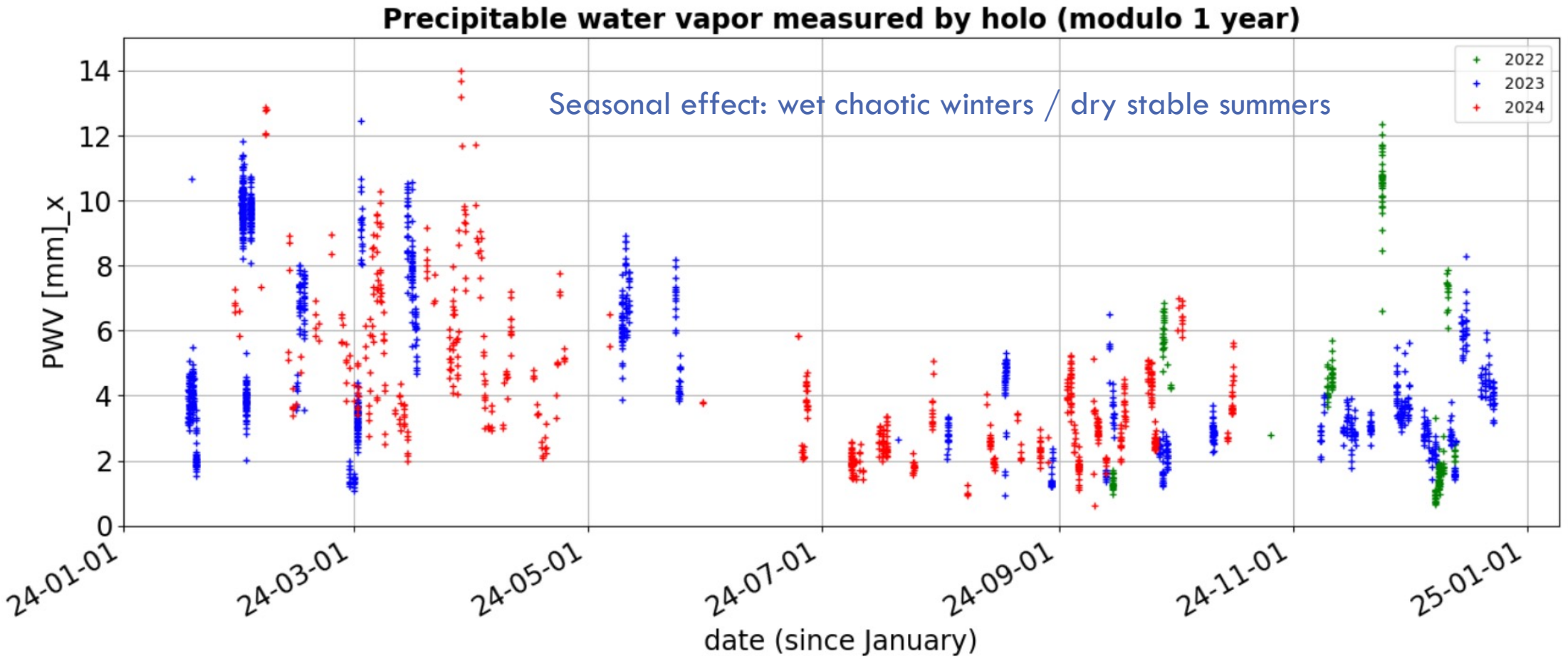
- Re-study of the diffraction 2nd order contamination
- Re-study of the atmospheric differential refraction
- Re-study of the AuxTel throughput by airmass regression
- Re-study of the forward model
- Re-study of the atmospheric model

=> new atmospheric parameters

Atmospheric parameters



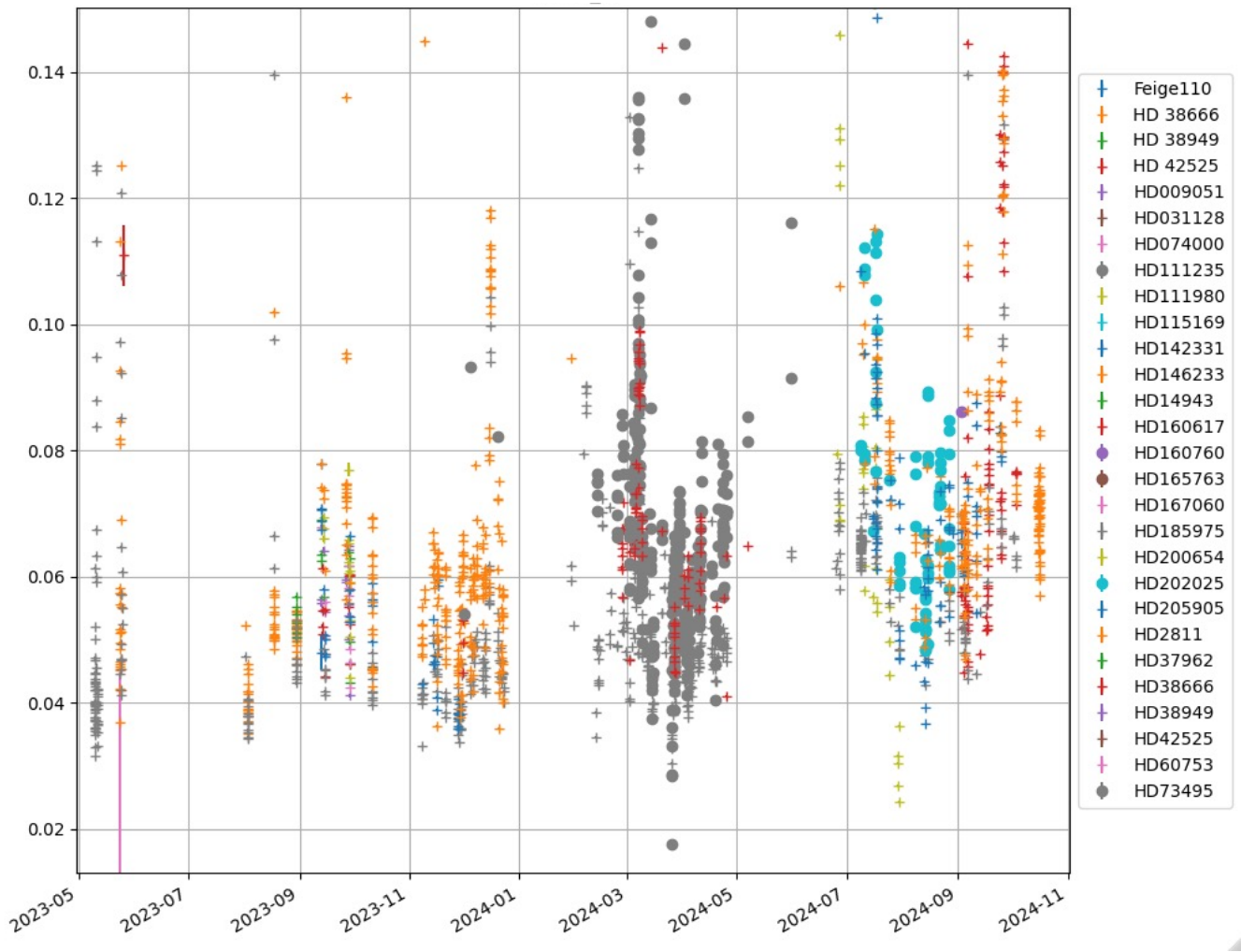
Atmospheric parameters



Atmospheric parameters

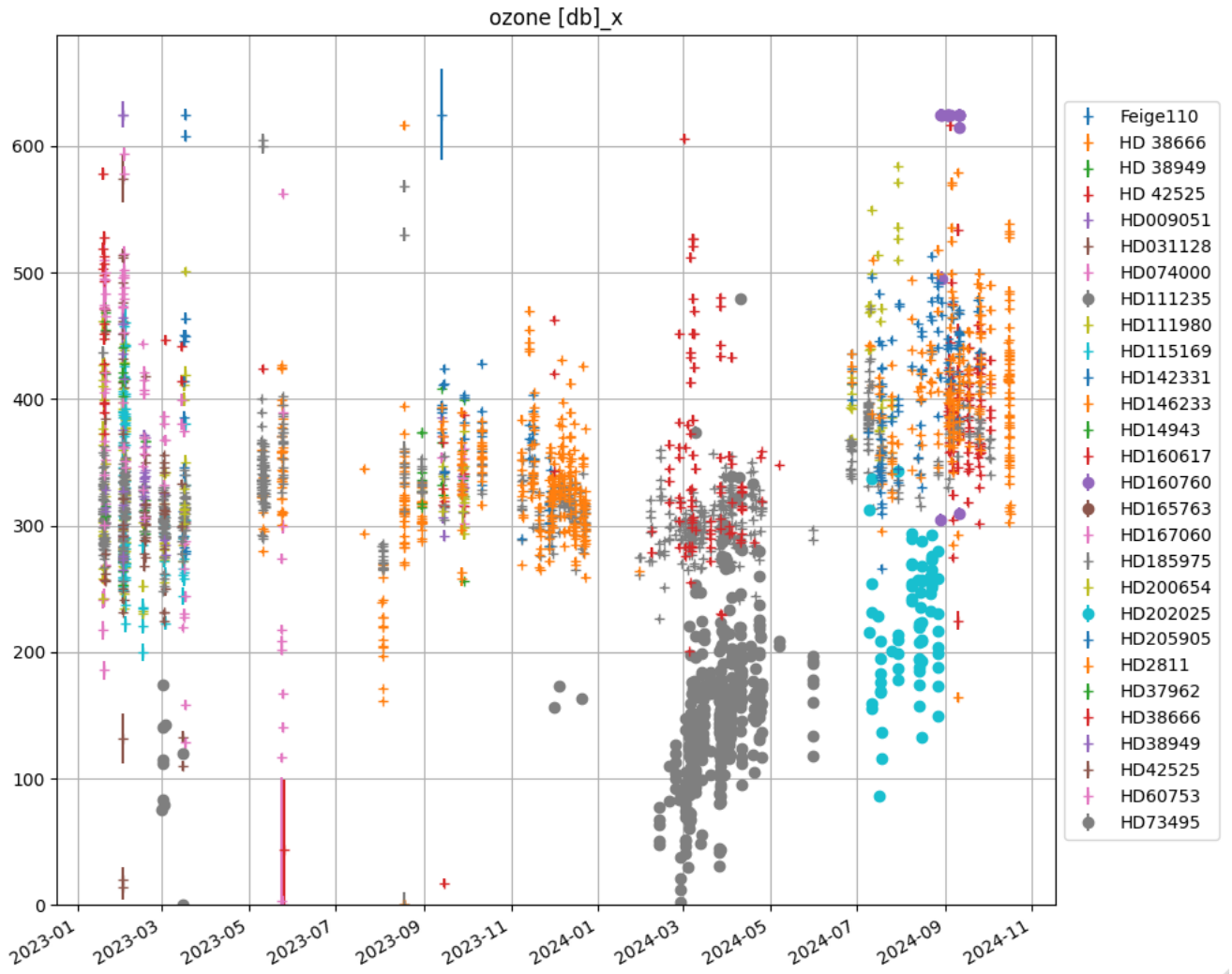
First time we get a signal => need to cross-check

Aerosols (clouds, molecules, sand, salt…)



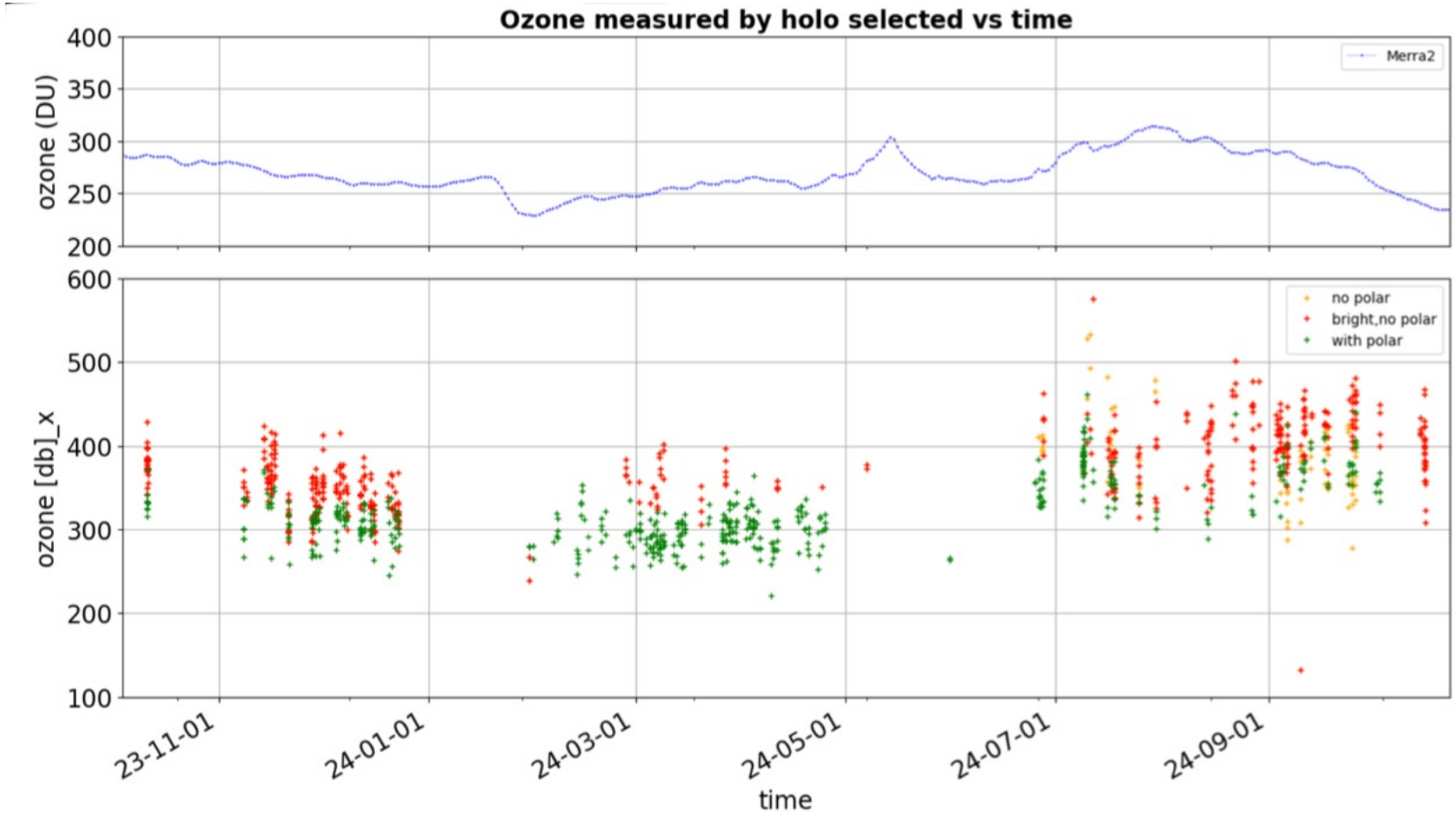
Atmospheric parameters

First time we get a signal
=> need to cross-check
=> Gaia spectra completely off



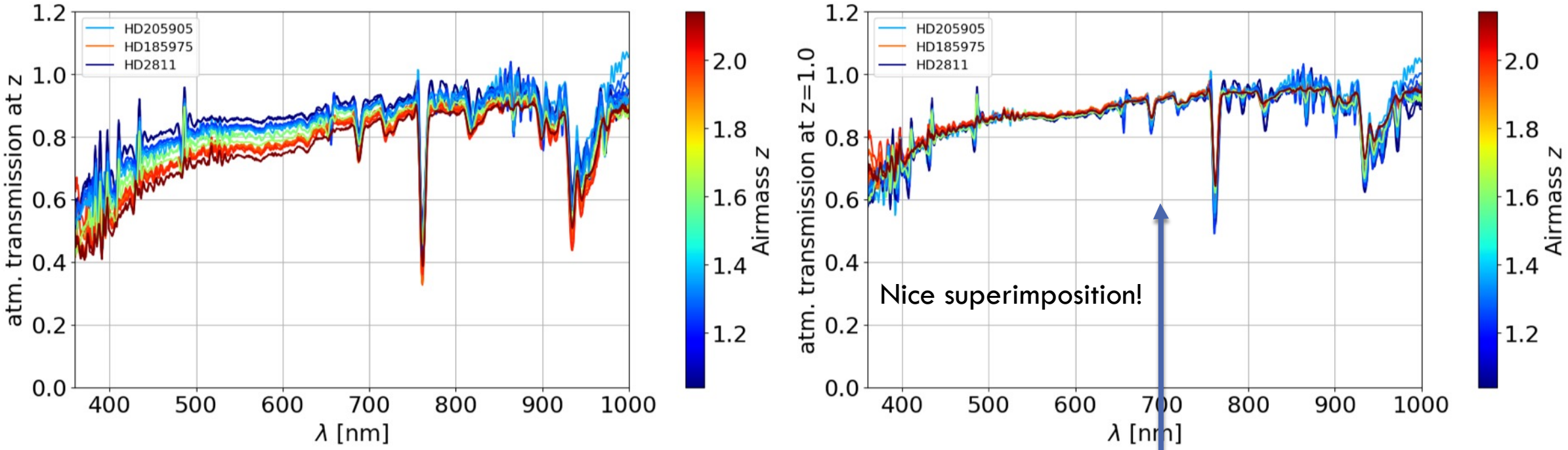
Atmospheric parameters

But good seasonal correlation with satellite's data (+ offset)



Atmospheric parameters

2023/11/27 night 🎂



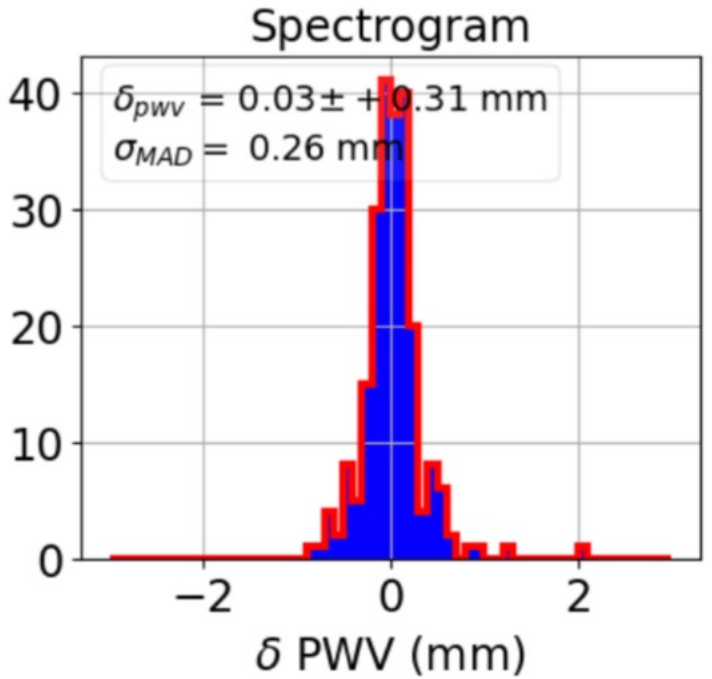
Transmissions at every airmass obtained with 3 different stars

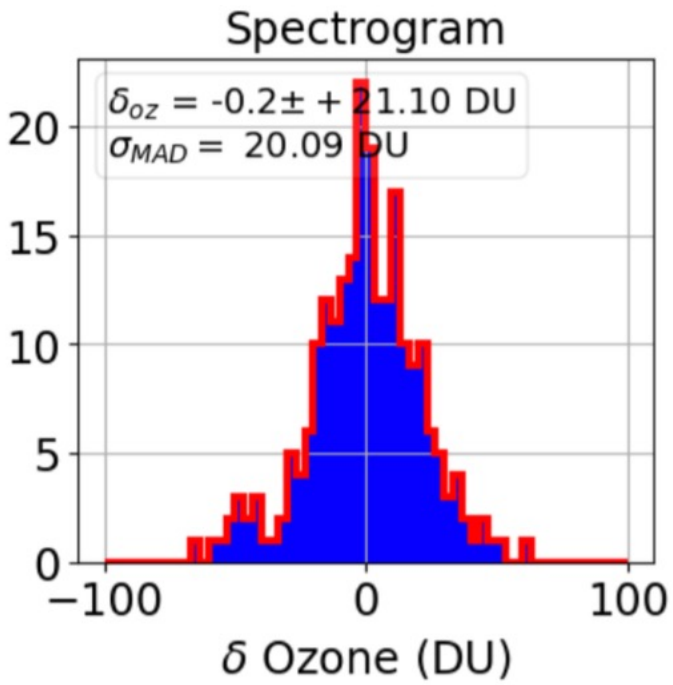
If night is photometric we can translate them at airmass=1 (zenith)

Atmospheric parameters

- Correlations with AuxTel photometry not visible
- Tests of repeatability using pairs of spectra: PWV better than 0.3mm
- Needs to assess for some systematics
- Analysis of time correlations and nightly trends

- Go for a paper about Rubin atmosphere from AuxTel first light to ComCam first light (2.5 yr)
- Next pipeline developments for AuxTel campaign after LSST first light



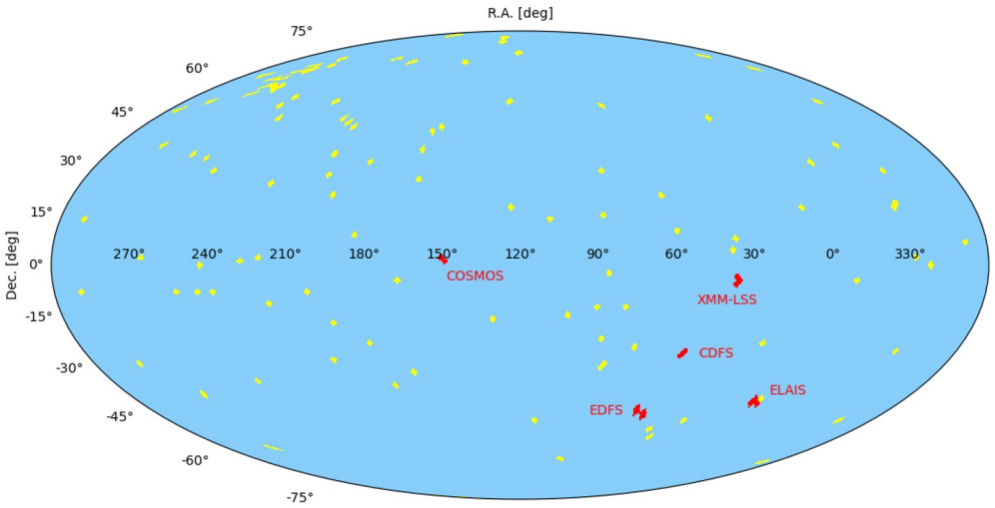


Observation strategy with Gaia

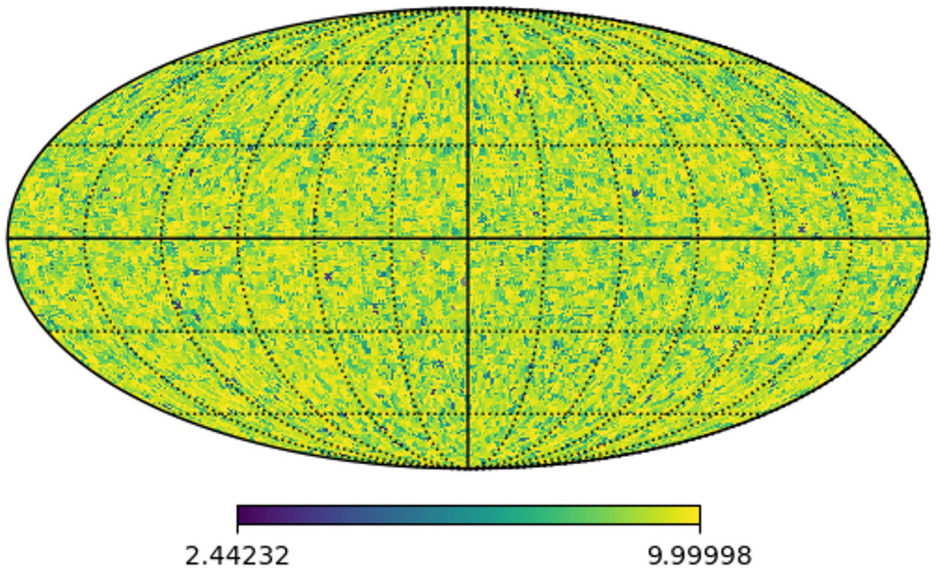
Out-of-atmosphere spectra in the sky

- **Baseline AuxTel method:** measurement of Earth's atmosphere looking at reference stars with known out-of-atmosphere spectra with a spectrograph
  - HST catalog (CALSPEC): high resolution spectra but <100 stars available
  - Gaia catalog (under study): low resolution but ~1 star/field (if not variable)

CALSPEC (yellow) and DDF (red)

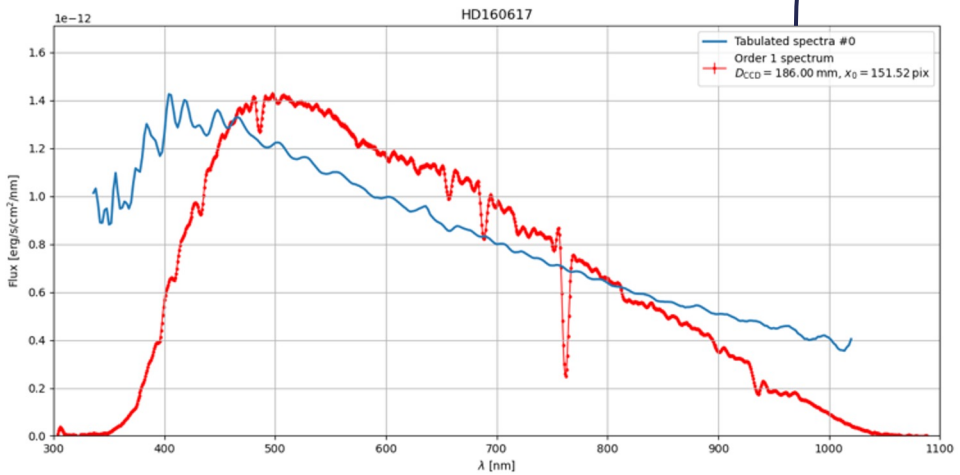


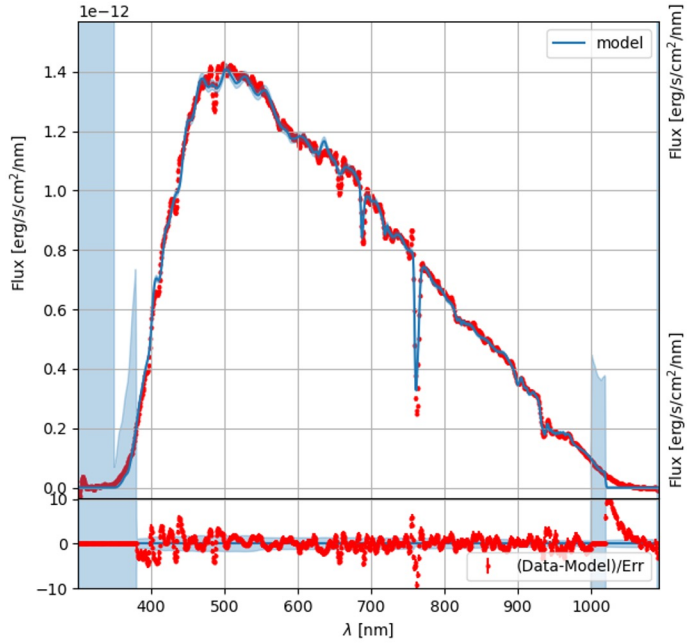
GAIA stars for PWV (g < 10)



Gaia DR3 spectra

- AuxTel is high resolution compared with Gaia: atmospheric features well defined on top of smooth Gaia spectra





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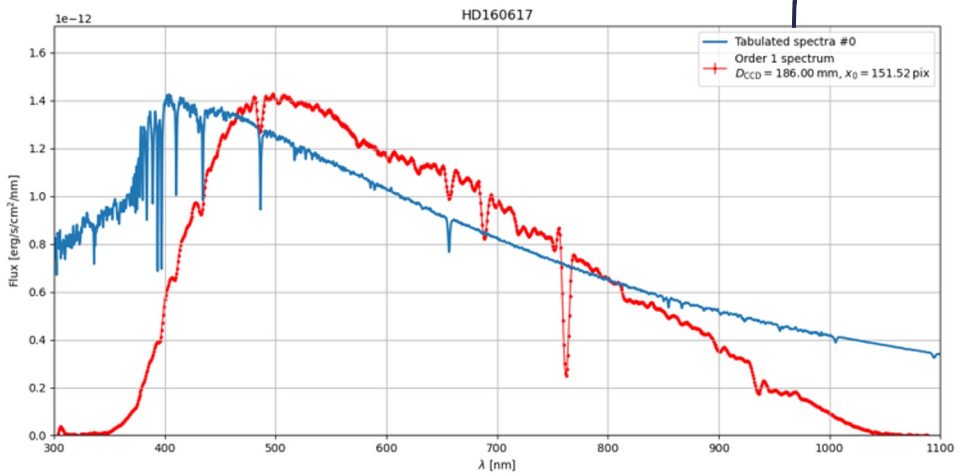
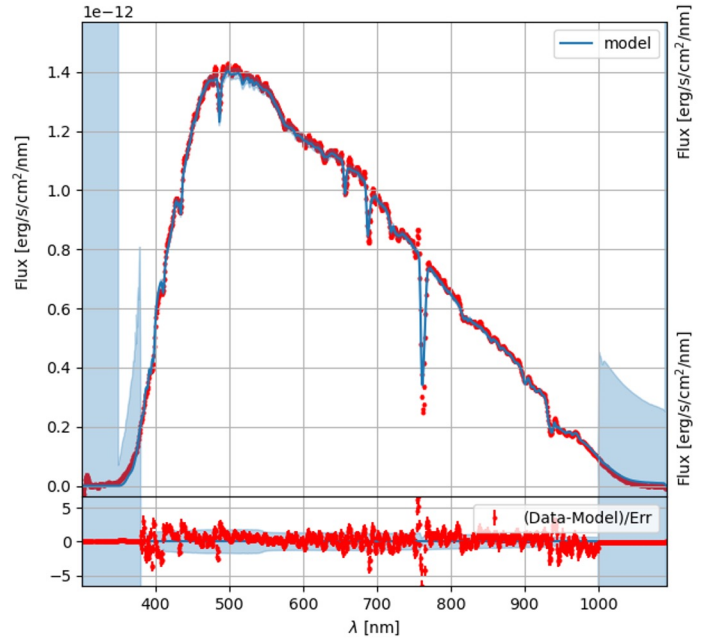
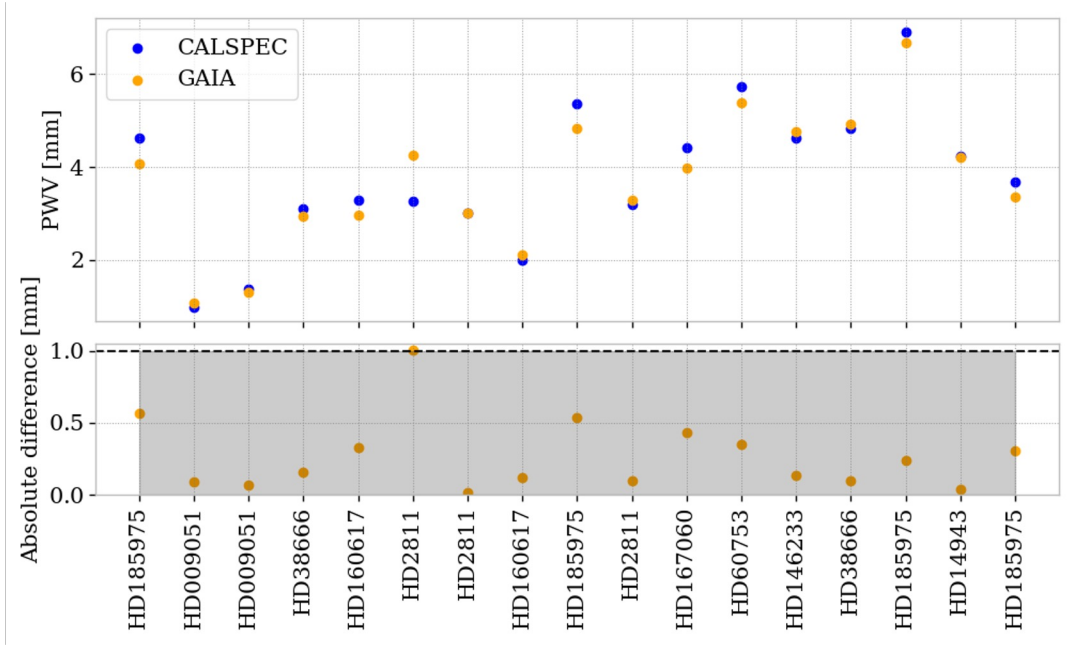




Gaia prospectives

- On a few examples, good agreement for PWV measurements but catastrophic for ozone
  - Accuracy will be checked on the full AuxTel dataset
- Water is the most important atmospheric parameter for DDF cosmology (SNIa):
  - ongoing forecasts with CALSPEC
  - search for adapted Gaia standards (in the DDF or close)



From AuxTel to LSST photometric corrections

Come to AuxTel parallel session!

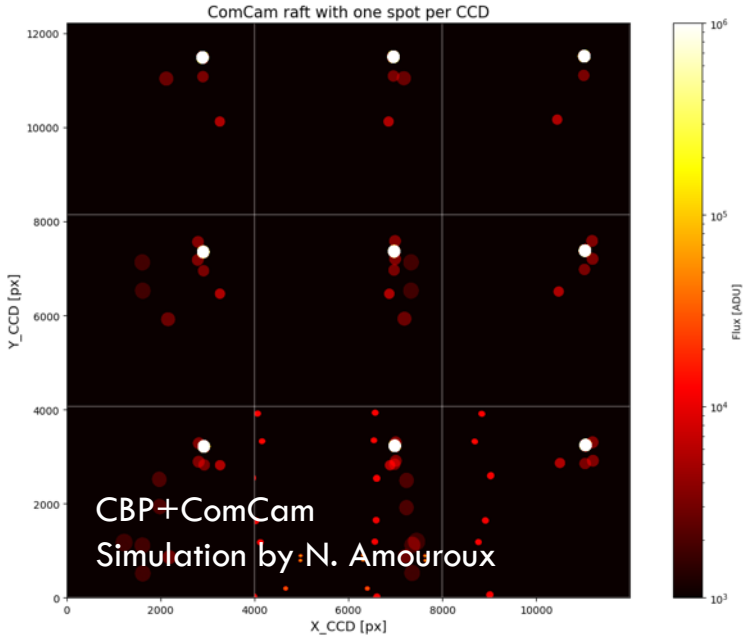
CBP news

CBP = Collimated Beam Projector

Magic tool to measure telescope's transmission with monochromatic light

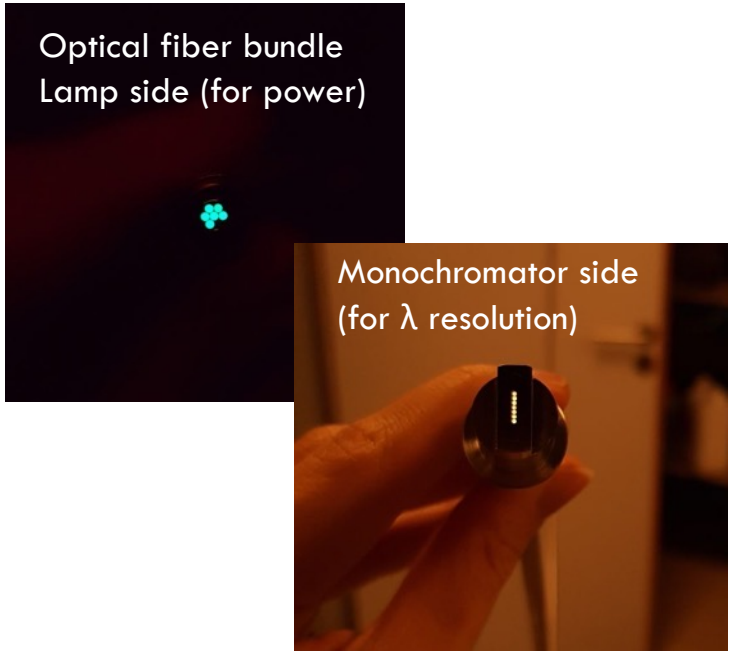
Rubin CBP

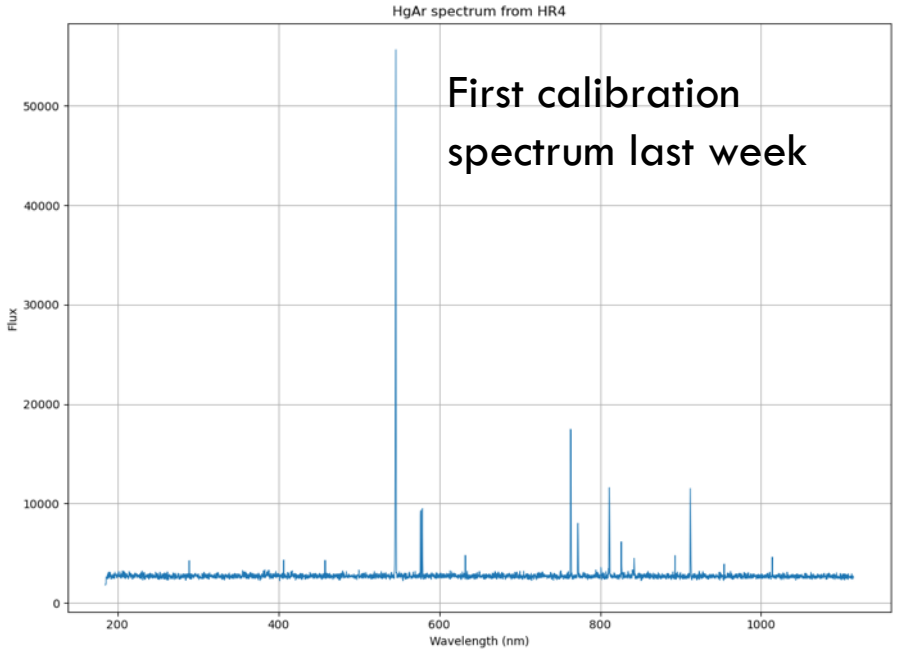
- Repaired at La Serena on October 16th
- In dome November 22th
- First photon in ComCam scheduled on December 2nd
- Ready to analyse first data

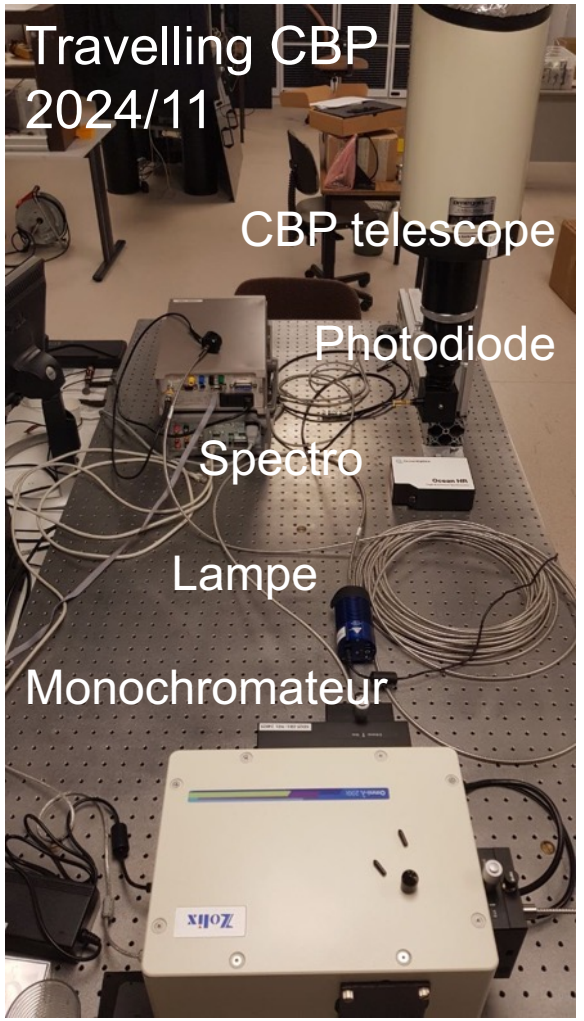


Travelling CBP

- Goal: measuring AuxTel and ZTF transmission
- All parts have been delivered at LPNHE, assembly by Laurent Le Guillou and Enya Van den Abeele







Summary

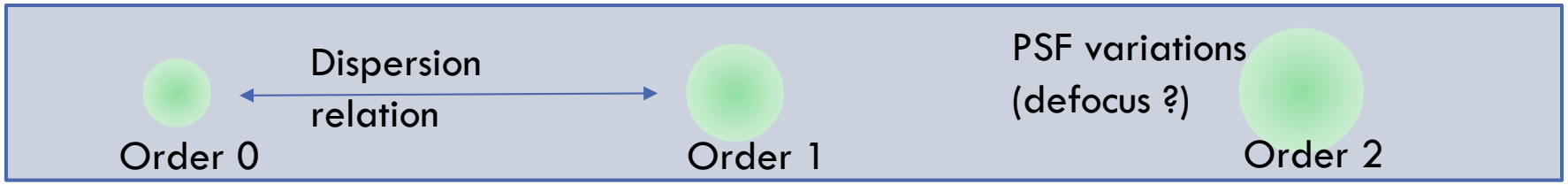
- Calibration is great.

Back-up slides

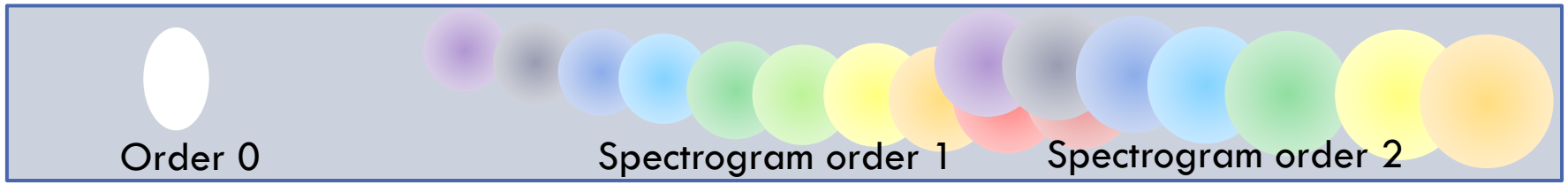
Structure of a slitless spectrum

Observation of a monochromatic (green) star without a disperser:

Observation of a monochromatic (green) star with a disperser:

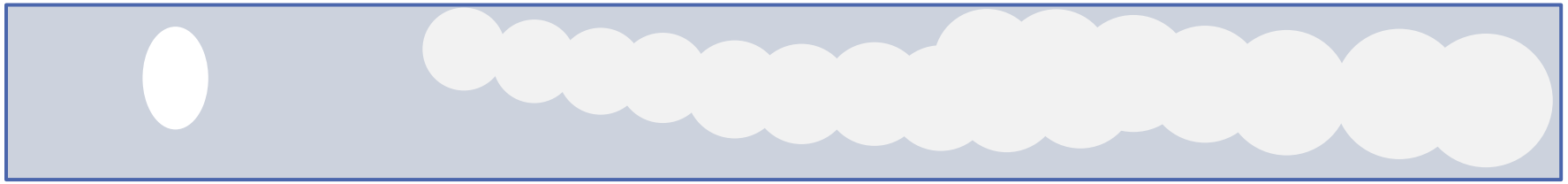


Observation of a polychromatic star with a disperser and ADR:

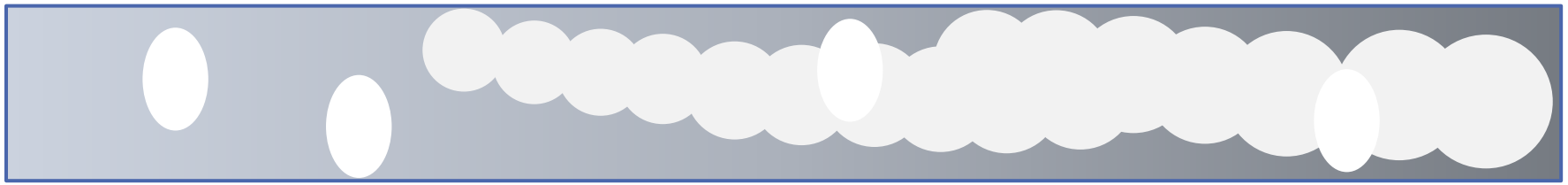


From theory to reality

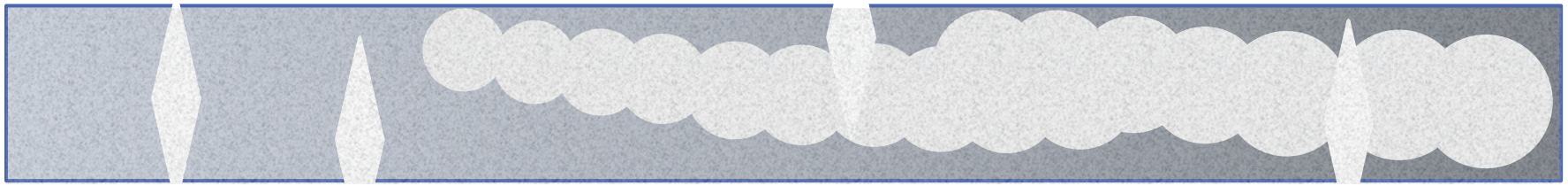
The CCD is a BW sensor:



The background can be structured, with field stars:

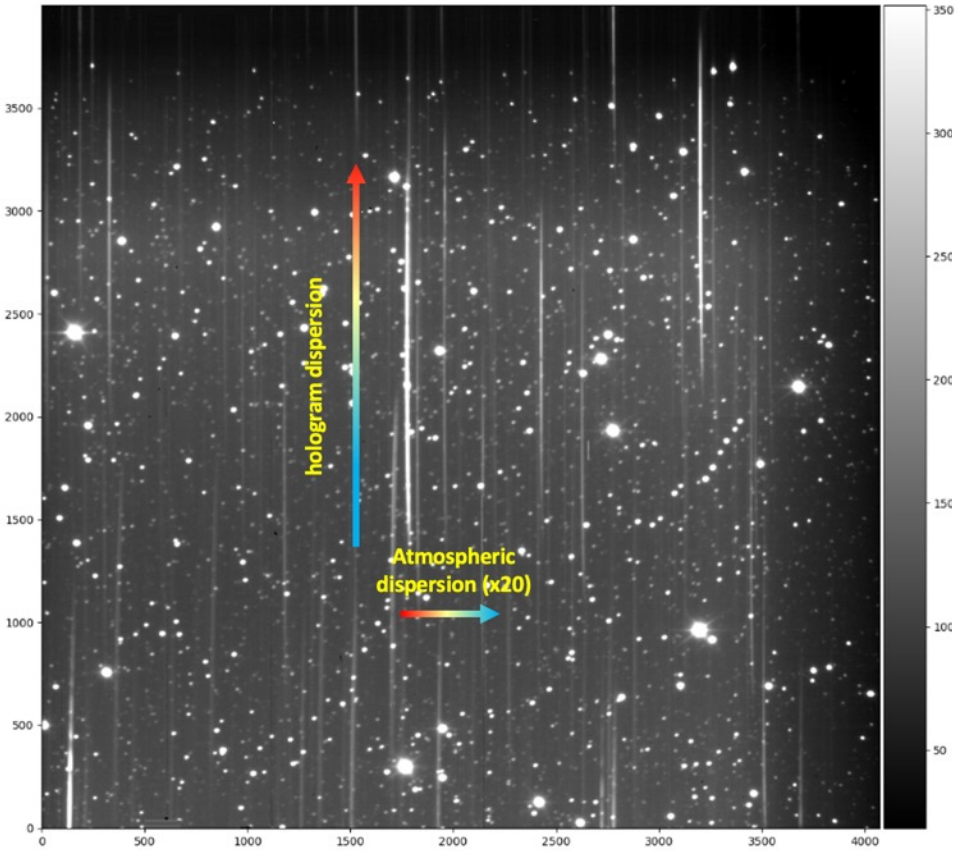


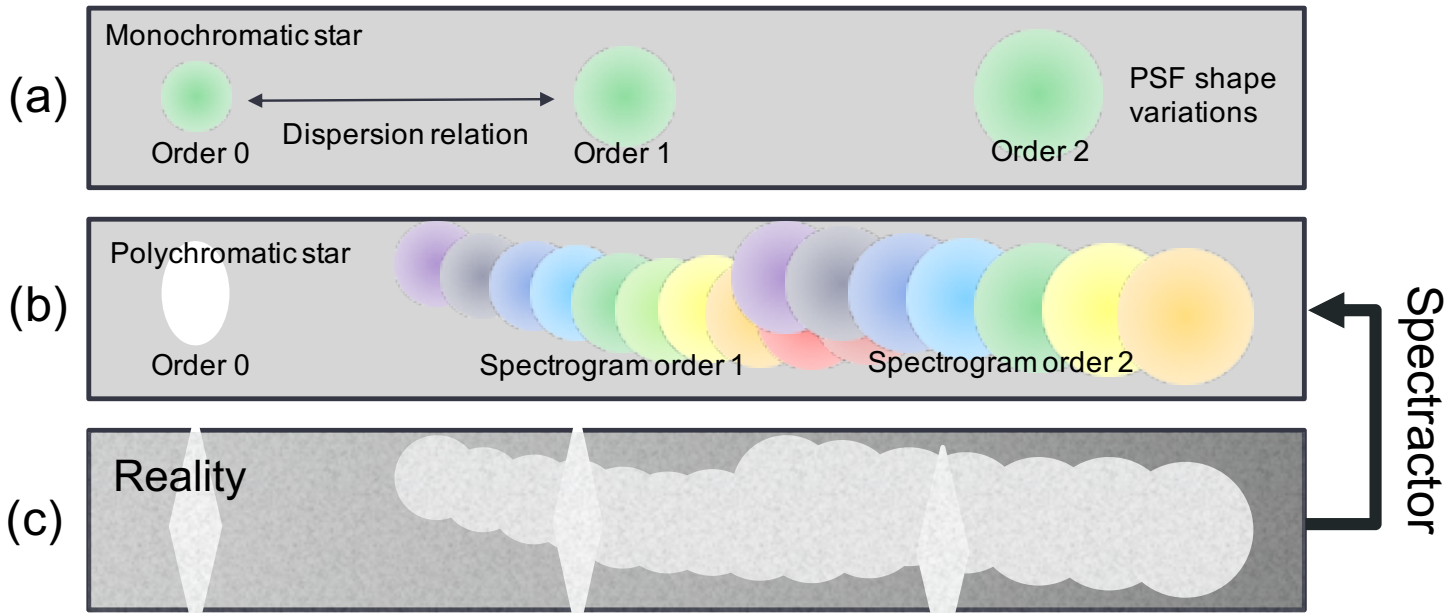
CCD effects: saturation, noise…



Spectrum extraction

- Spectrophotometric extraction by forward modelling [Neveu et al., 2023]





Mathematics of slitless forward modelling

- Observation of astrophysical source with spatio-spectral flux density

$$C_p(\vec{r},\lambda) = [T_{\mathrm{inst},p}(\lambda)\, T_{\mathrm{atm}}(\lambda|\theta_a)\, S_*(\lambda)] \times \delta\left(\vec{r} - \vec{r}_0\right)$$

with p the diffraction order, θ_a the atmospheric parameters

- Image is a stack of diffraction orders, which are a stack of monochromatic PSF kernels $\phi_p(\vec{r}|\lambda)$ dispersed by the grating:

$$I(\vec{r}) = \sum_p \int \mathrm{d}\lambda \iint \mathrm{d}^2\vec{r}'\; C_p(\vec{r}',\lambda)\, \phi_p(\vec{r} - \vec{r}'|\lambda)$$

- For a point source, the convolution product becomes:

$$\boxed{I(\vec{r}) = \sum_p \int \mathrm{d}\lambda\; S_p(\lambda) \phi_p\left(\vec{r} - \vec{\Delta}_p(\lambda)|\lambda\right)}$$

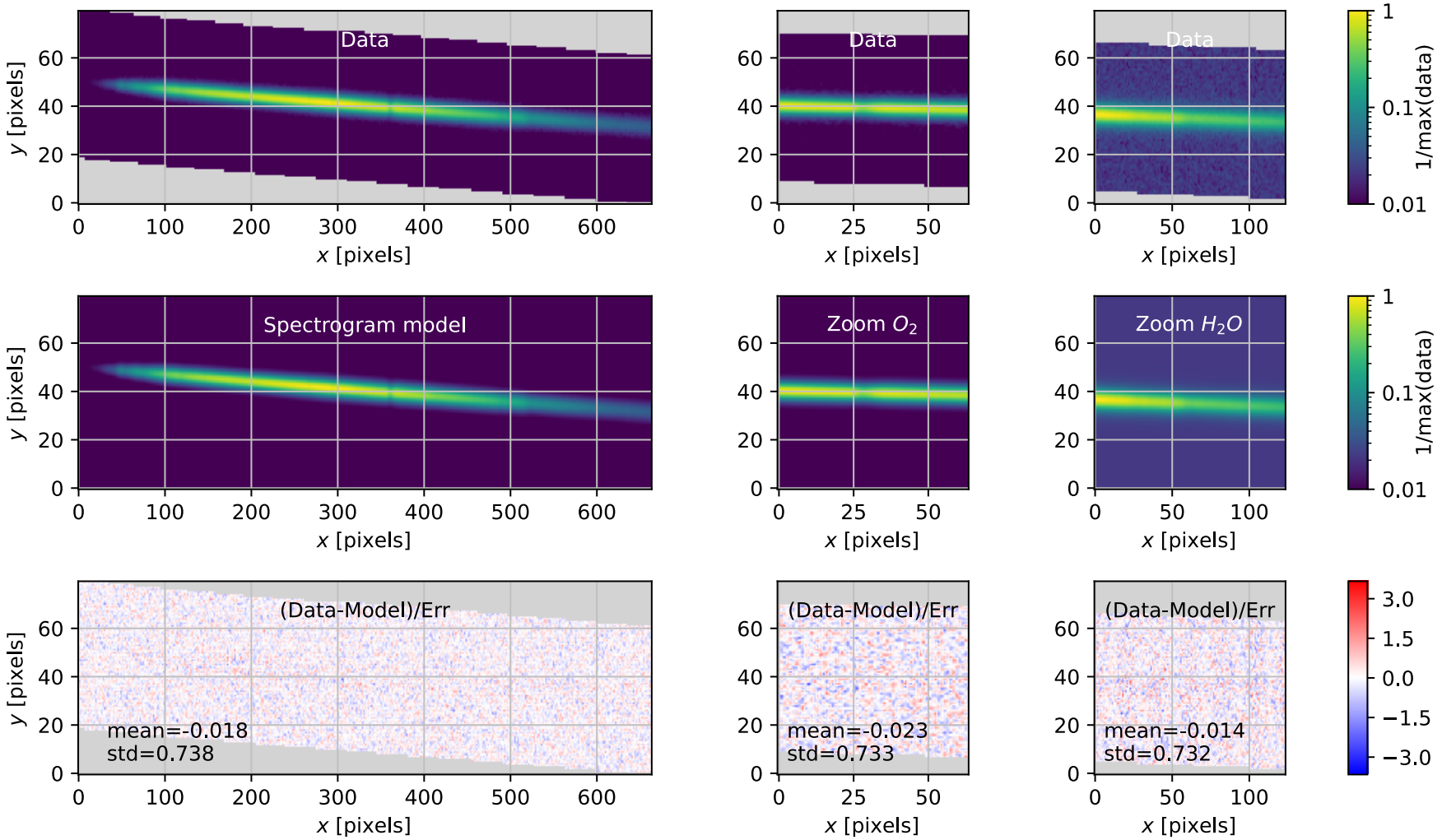
Dispersion relation

$$\vec{\Delta}_p(\lambda) = (x_{c,p}(\lambda), y_{c,p}(\lambda))$$

Spectrum

$$S_p(\lambda) = T_{\mathrm{inst},p}(\lambda)\, T_{\mathrm{atm}}(\lambda|\theta_a)\, S_*(\lambda)$$

Forward model tested on simulations



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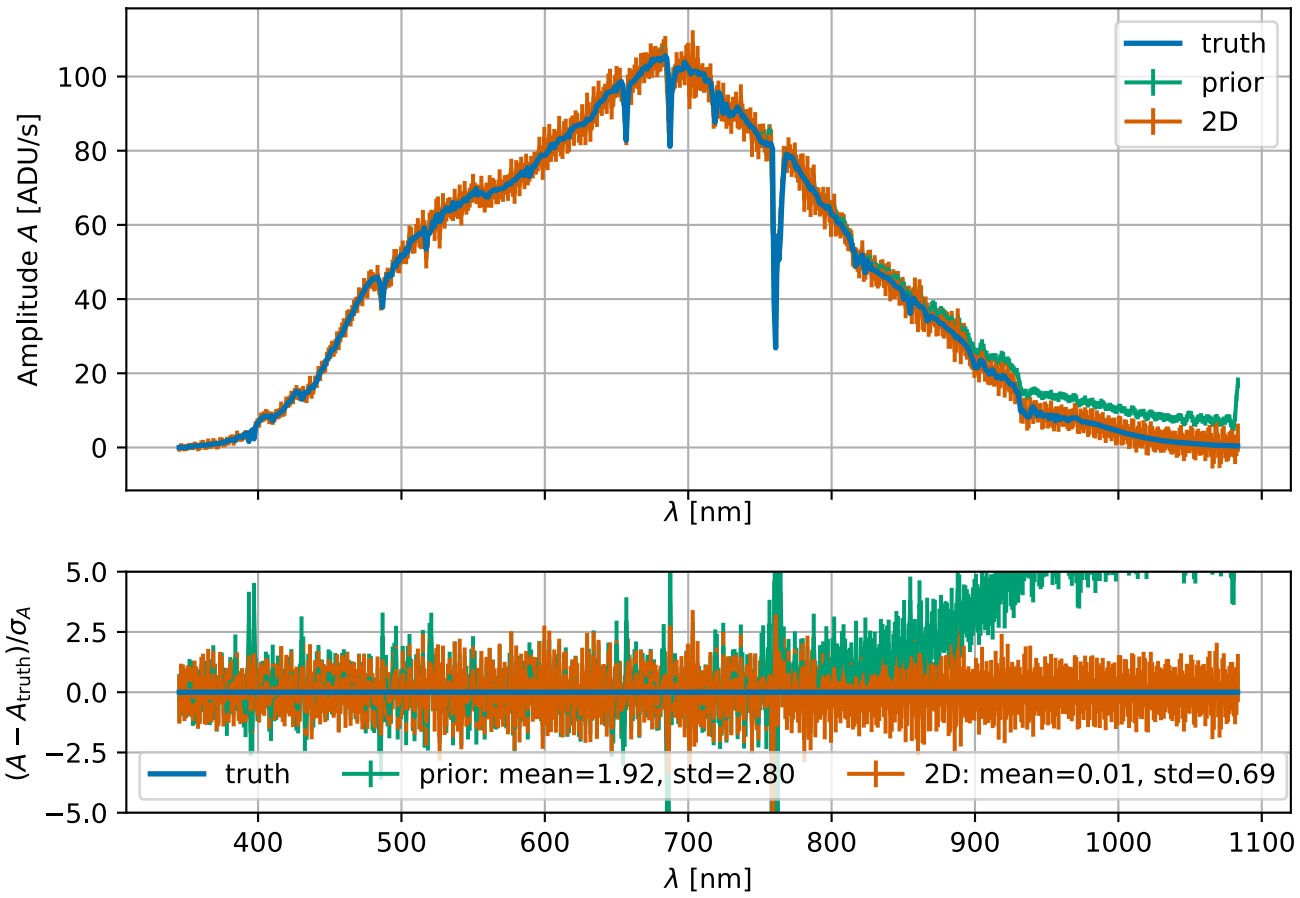
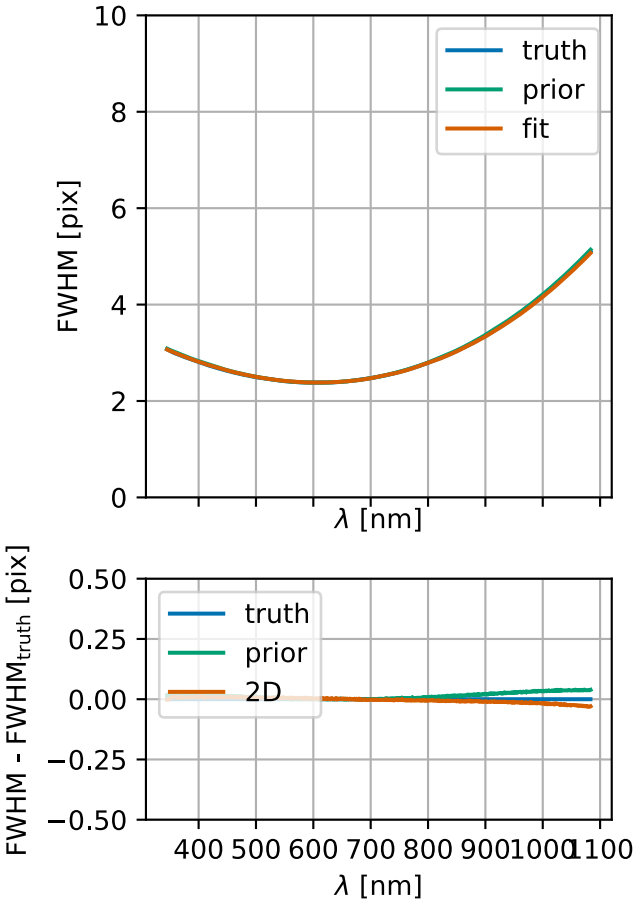
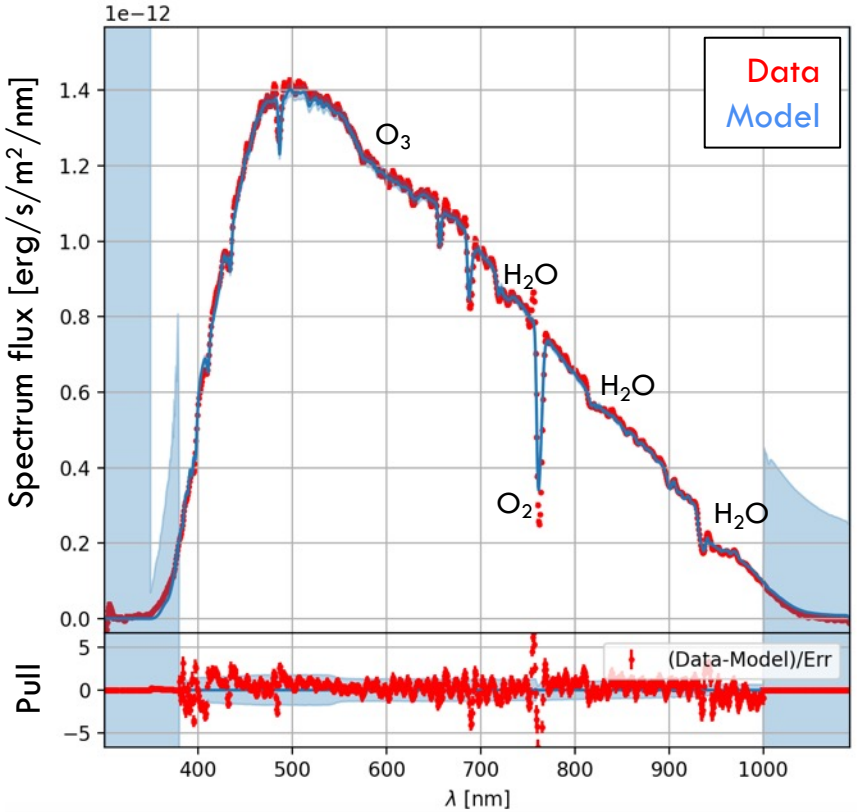




Rubin Auxiliary Telescope (Auxtel)

- Fit of atmospheric parameters on ~4000 spectra since 2023/01 via Libradtran library [Emde et al., 2016]



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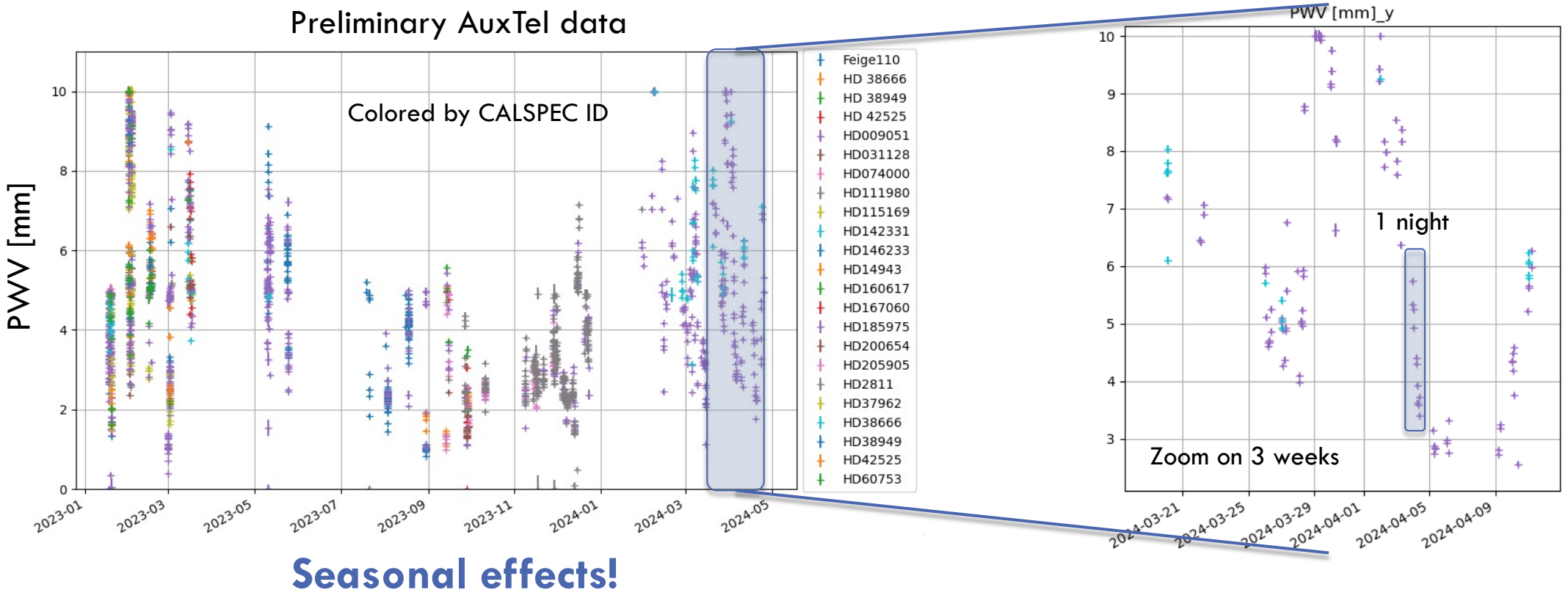


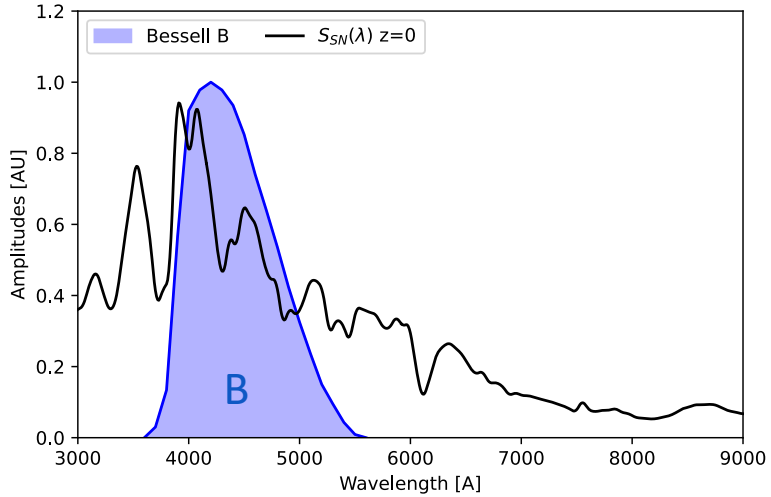
Seasonal effects!

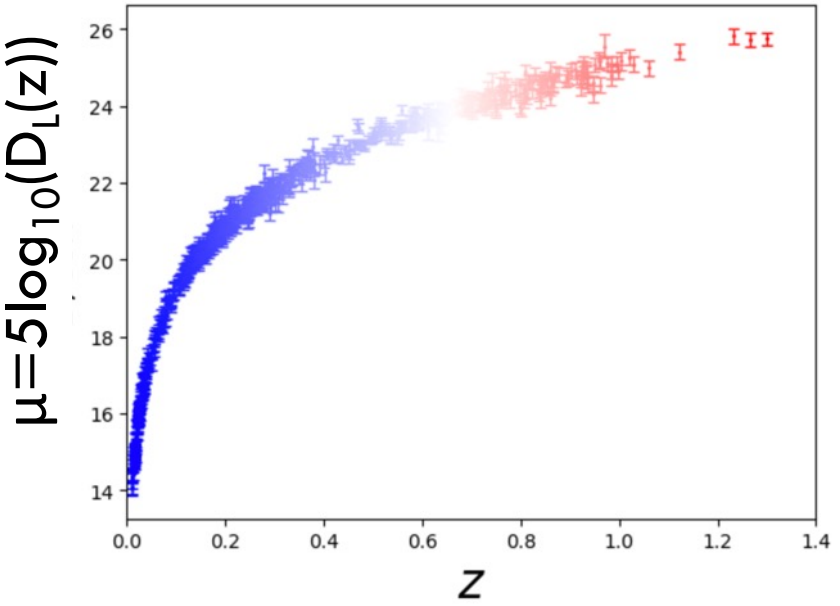
Type Ia supernova cosmology with LSST

- SNIa Hubble diagram is built using standardized B band rest-frame magnitudes of supernovae with:

$$\mu = 5\log_{10}(D_L(z)) \sim B - 3(B\text{-}V)$$

- It depends strongly on our capacity to convert observer frame magnitudes (ugrizy) to rest-frame B magnitudes ➔ photometric calibration
- Back-of-the-envelope computations:
  - SNIa intrinsic dispersion: σ_{int}=0.15mag
  - with 35000 SNIa: $\sigma_\mu = \sigma_{int}/\mathrm{sqrt}(35000) \sim 1$mmag
- **Photometric calibration systematics must be at most of 1mmag also to benefit from the full statistical power of the LSST survey**

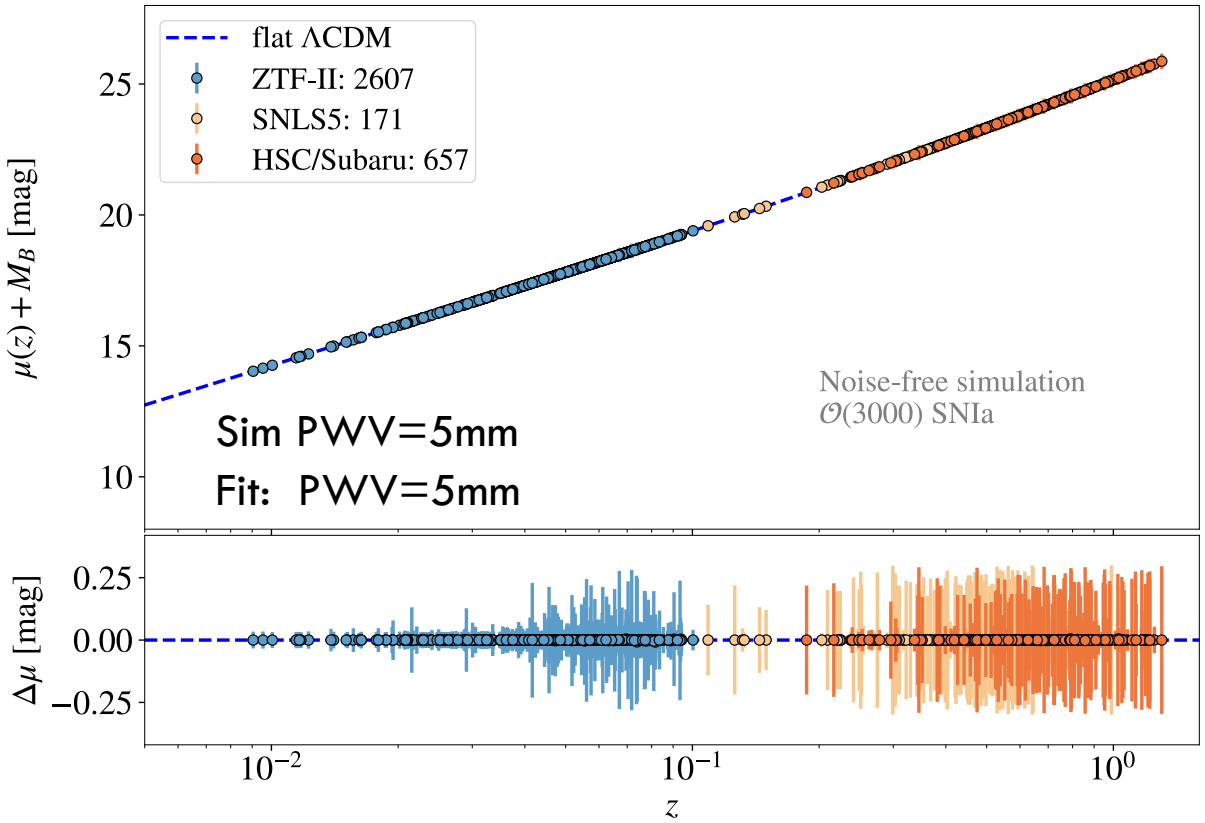




Impact on cosmology

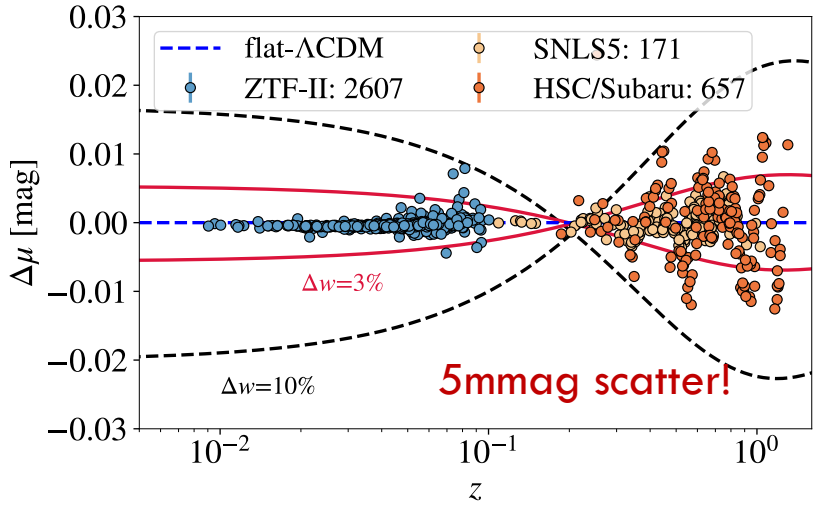
Is it important to know Earth's atmosphere transmission for cosmology?

- Exercise:
  - Simulation of a ZTF-II (wide) + SNLS5 + HSC (deep) = LEMAITRE survey
  - Noise-free, no intrinsic scatter, with PWV=5mm constant
  - Fit of SN lightcurves with PWV=3mm, 5mm or 7mm

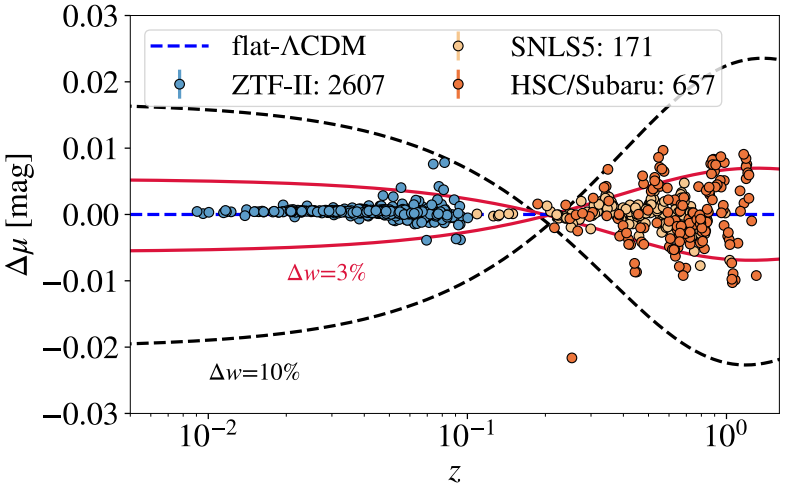


Impact on cosmology

Sim PWV=5mm
Fit: PWV=3mm

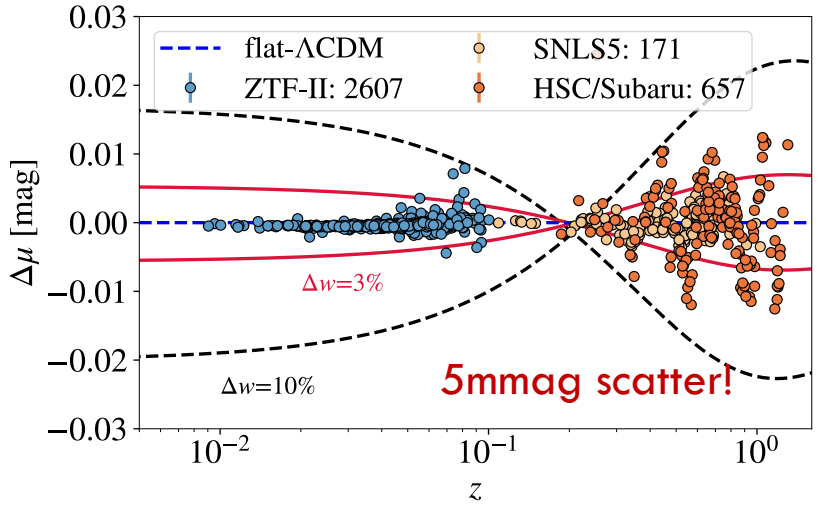


Sim PWV=5mm
Fit: PWV=7mm

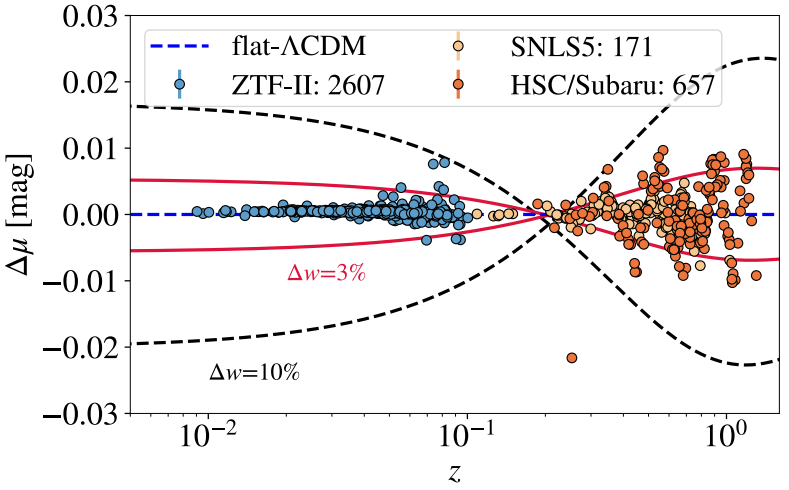


Impact on cosmology

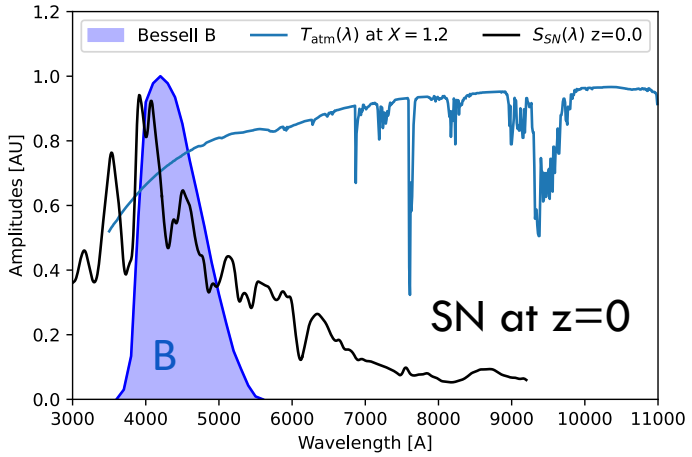
Sim PWV=5mm
Fit: PWV=3mm

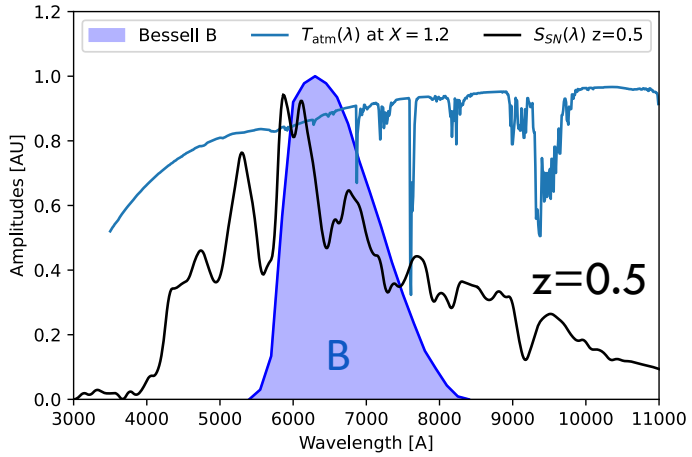


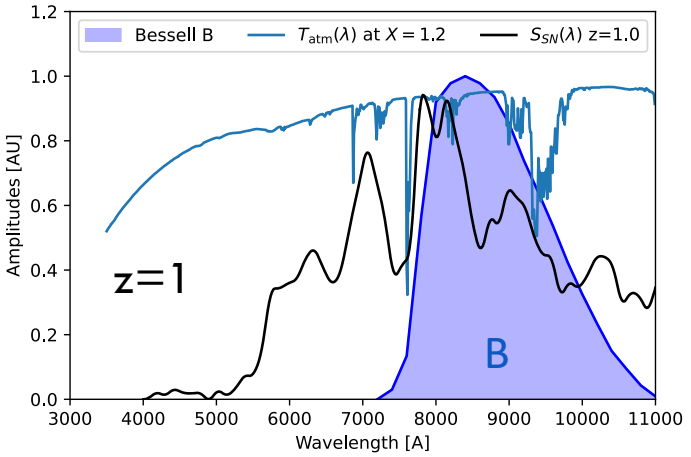
Sim PWV=5mm
Fit: PWV=7mm



Distance moduli μ are estimated using the B-band rest-frame magnitude of the SNIa… which shifts with redshift in Earth frame

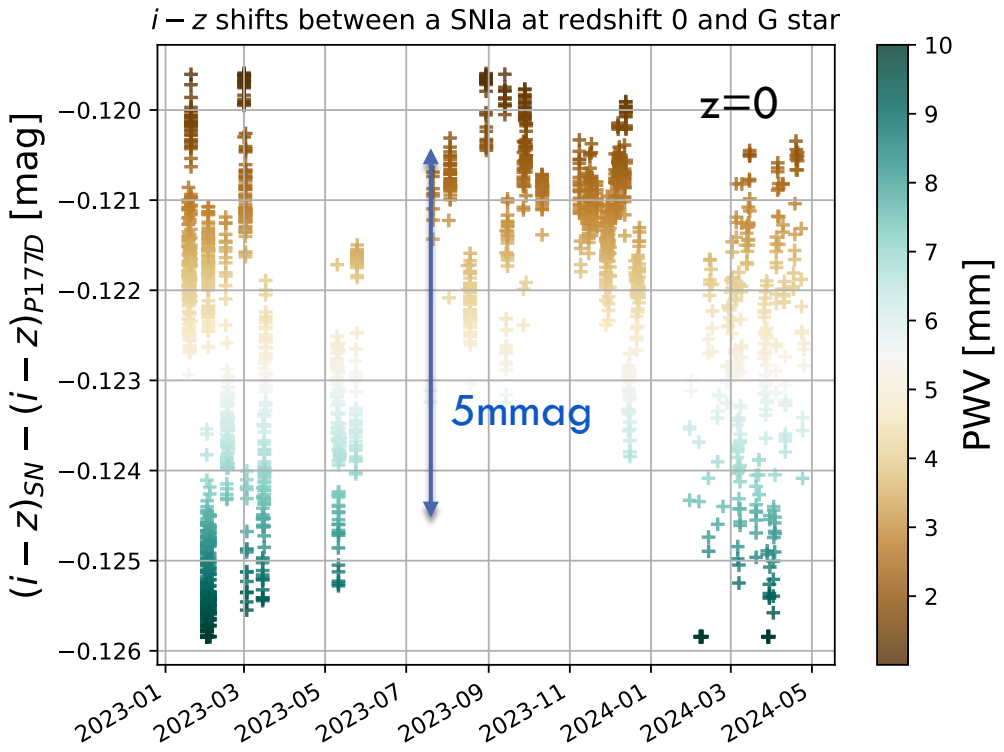


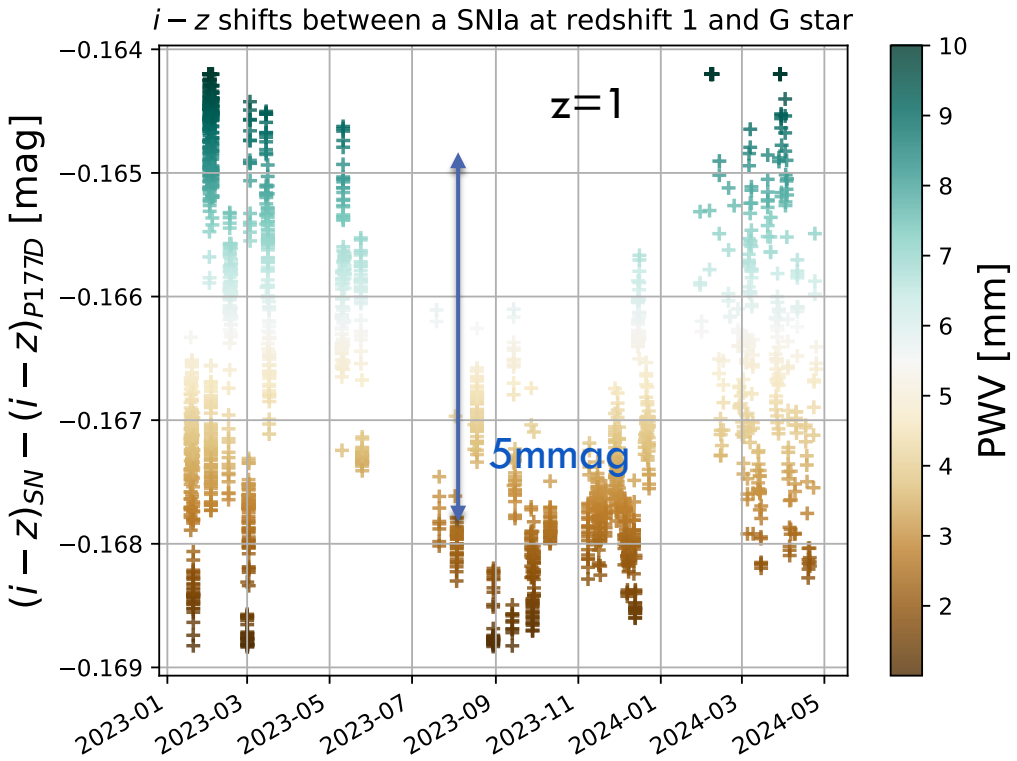




Water seasonal effects on SNIa colors

- Let's compare (i-z) SN color residuals due to PWV if average atmosphere is determined using field stars





Grating for convergent beam: holograms