StarDICE: Status on photometric calibration of standard stars at the milli-magnitude level

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Presented by Thierry Souverin

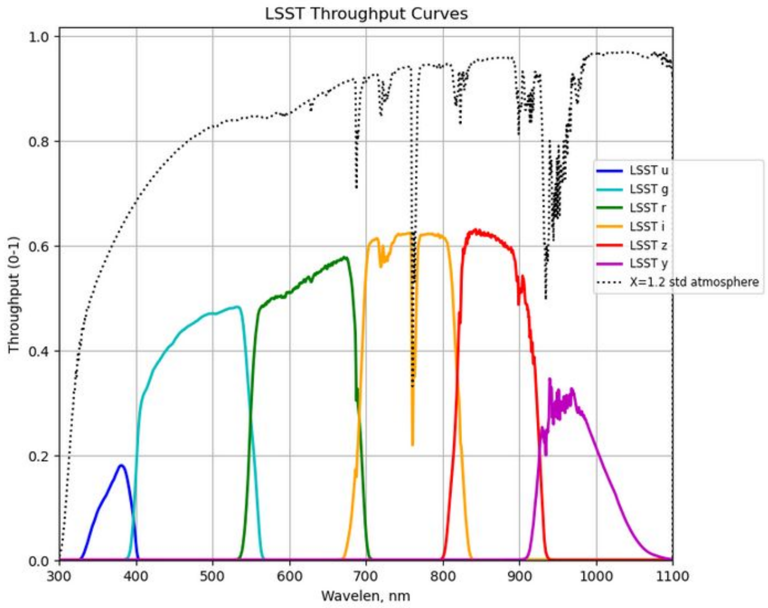
15/12/2023

I. Cosmological context

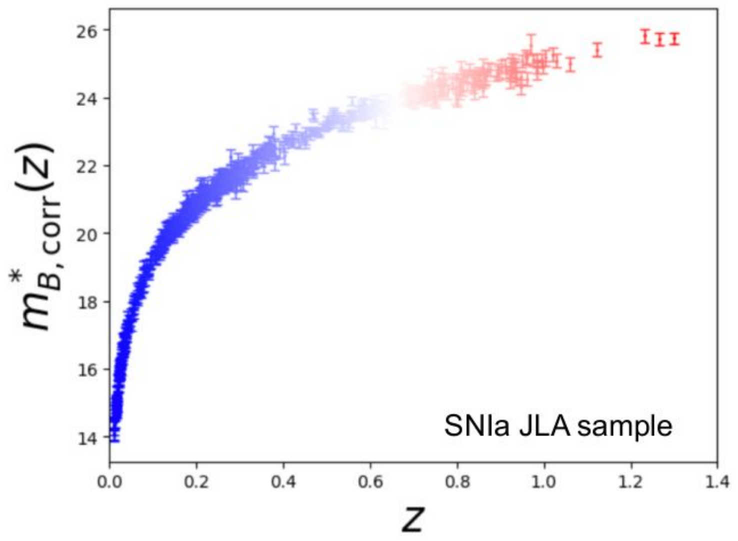
Cosmological context

For SNe Ia cosmology:

- The statistical uncertainty will decrease with the huge number of observations by LSST
- Photometric calibration will become the main uncertainty



SNe Ia Hubble diagram

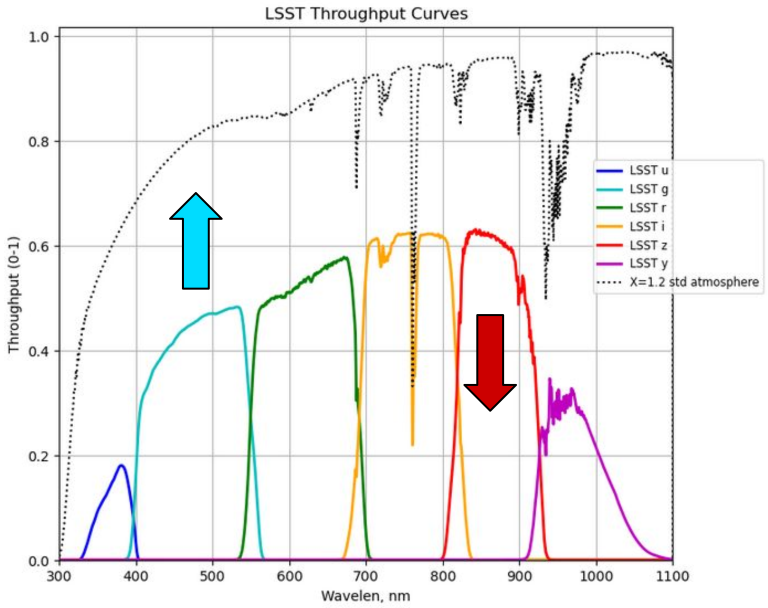


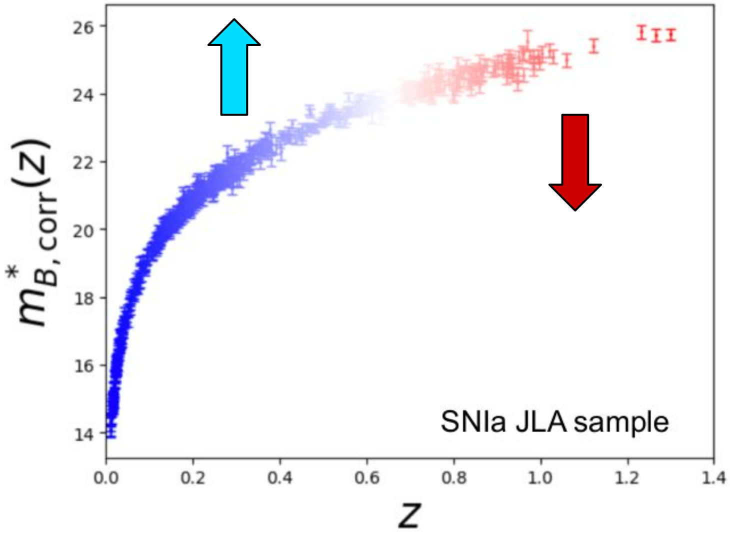
Cosmological context

For SNe Ia cosmology:

- The statistical uncertainty will decrease with the huge number of observations by LSST
- Photometric calibration will become the main uncertainty

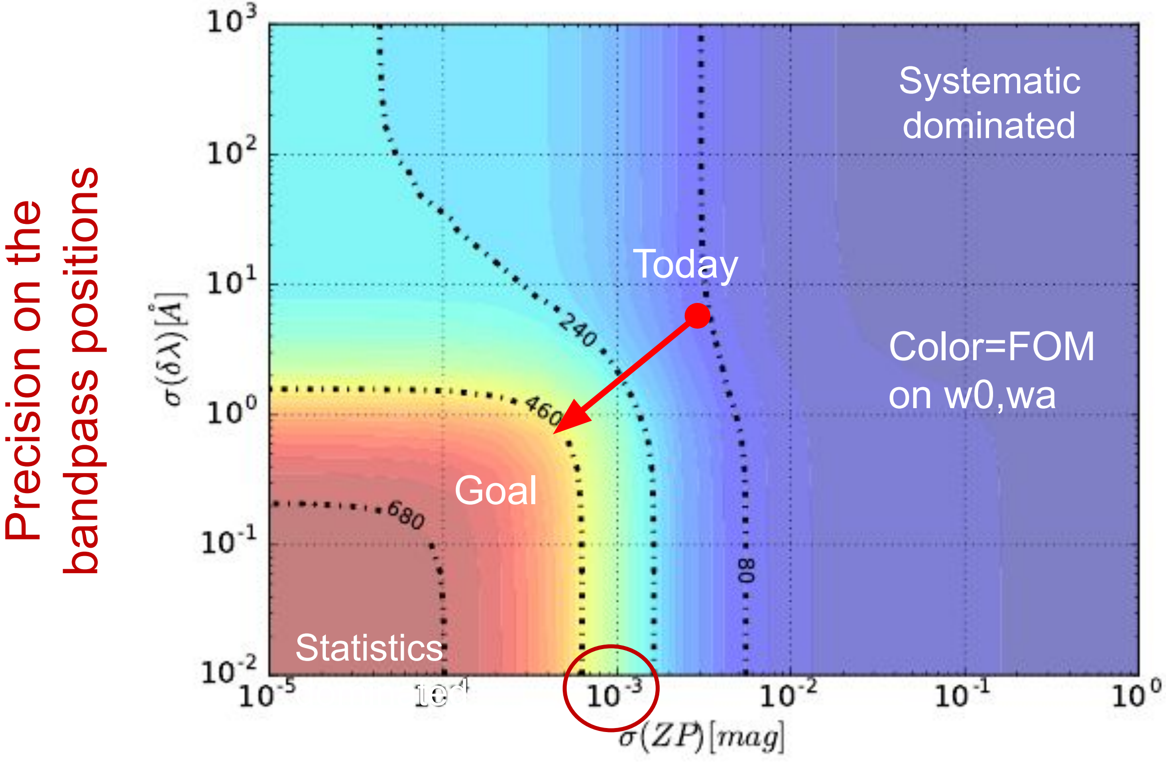
⇒ Every chromatic error in the telescope photometric calibration will distort the Hubble diagram and give different cosmologies





Cosmological context

Figure of Merit on (w0,wa) for a 10-yr LSST SNe Ia survey

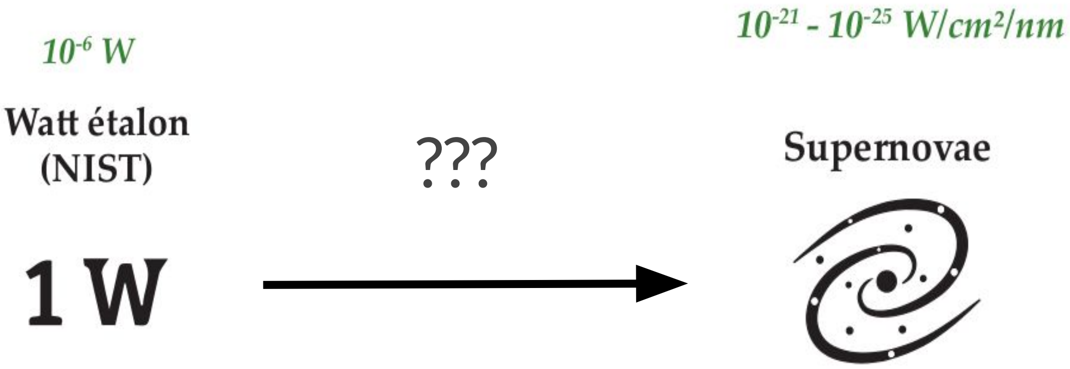


Precision on the filter flux transmission

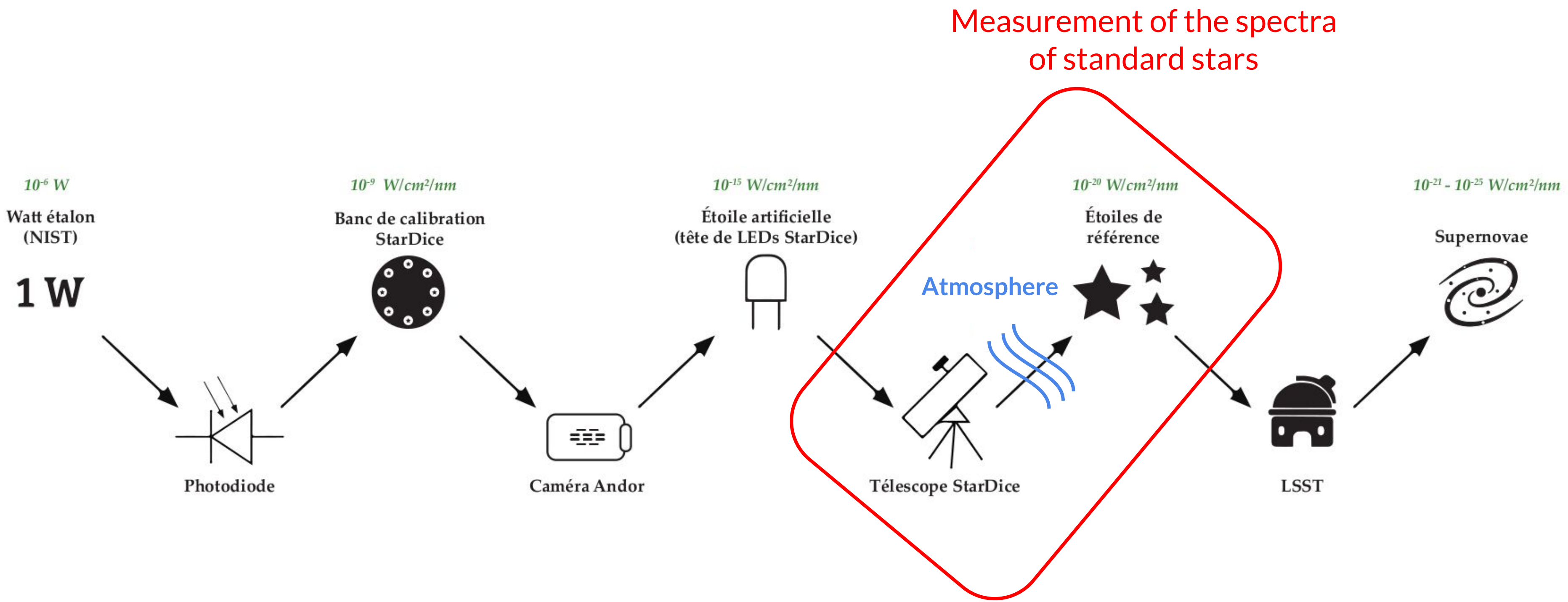
F. Hazenberg thesis

II. StarDICE experiment

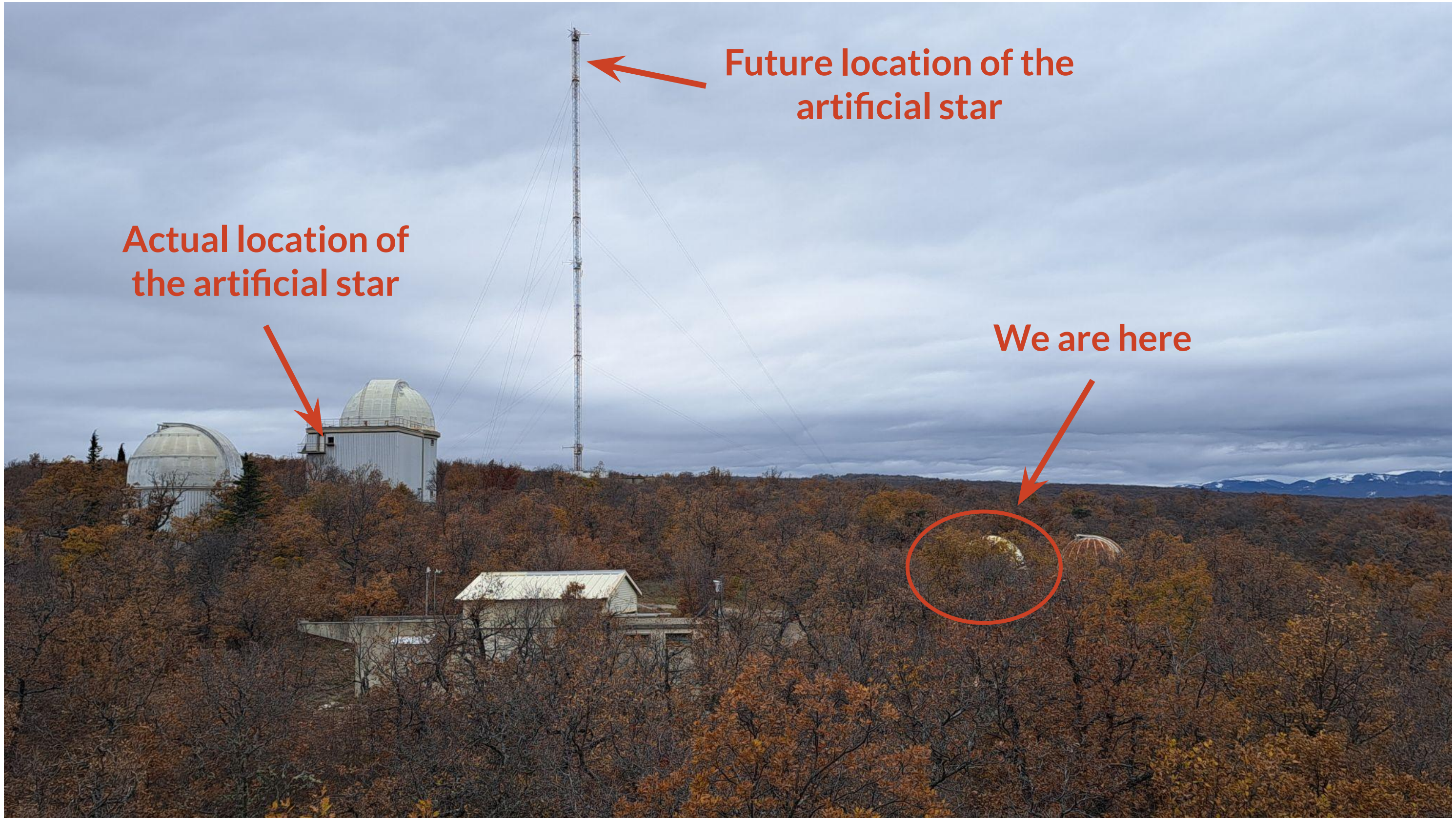
Photometric calibration transfer



Photometric calibration transfer

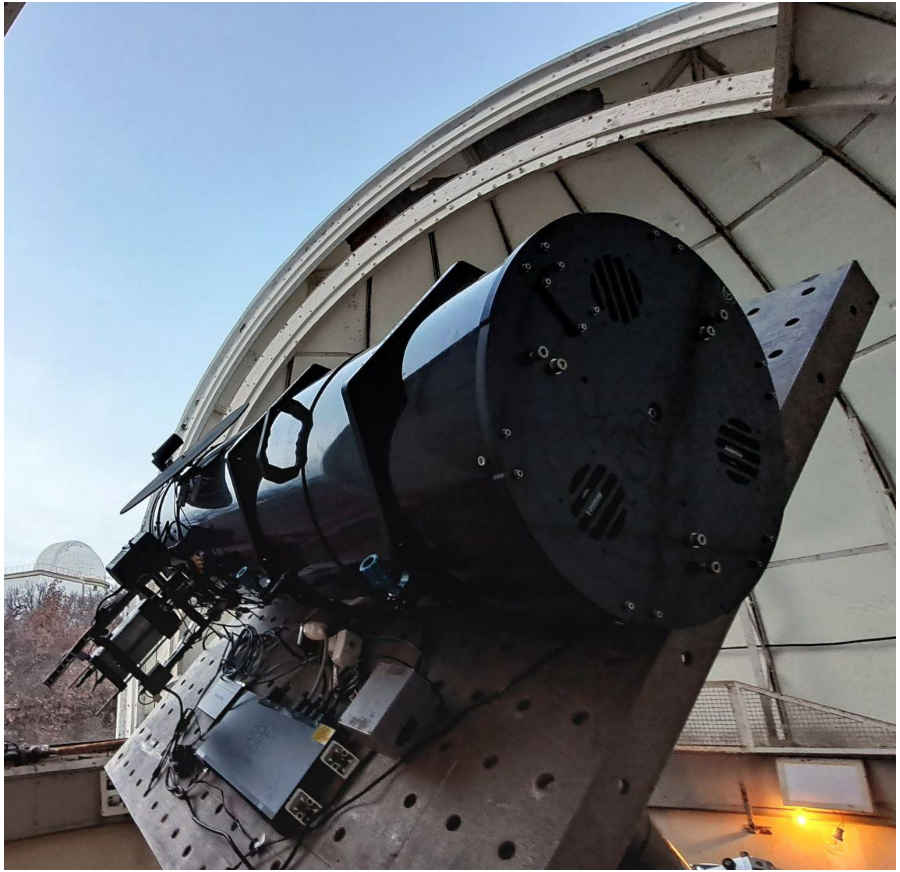


Observatory site : Observatoire de Haute-Provence



StarDICE telescope

Newton telescope ; D=40cm ; f=1.6m ; camera 1 Mpixel



Response of the telescope calibrated :

- $R_{tel,CBP}$ high resolution with the CBP (talk J. Neveu)
- $R_{tel,DICE}$ low resolution monitoring with the StarDice artificial star

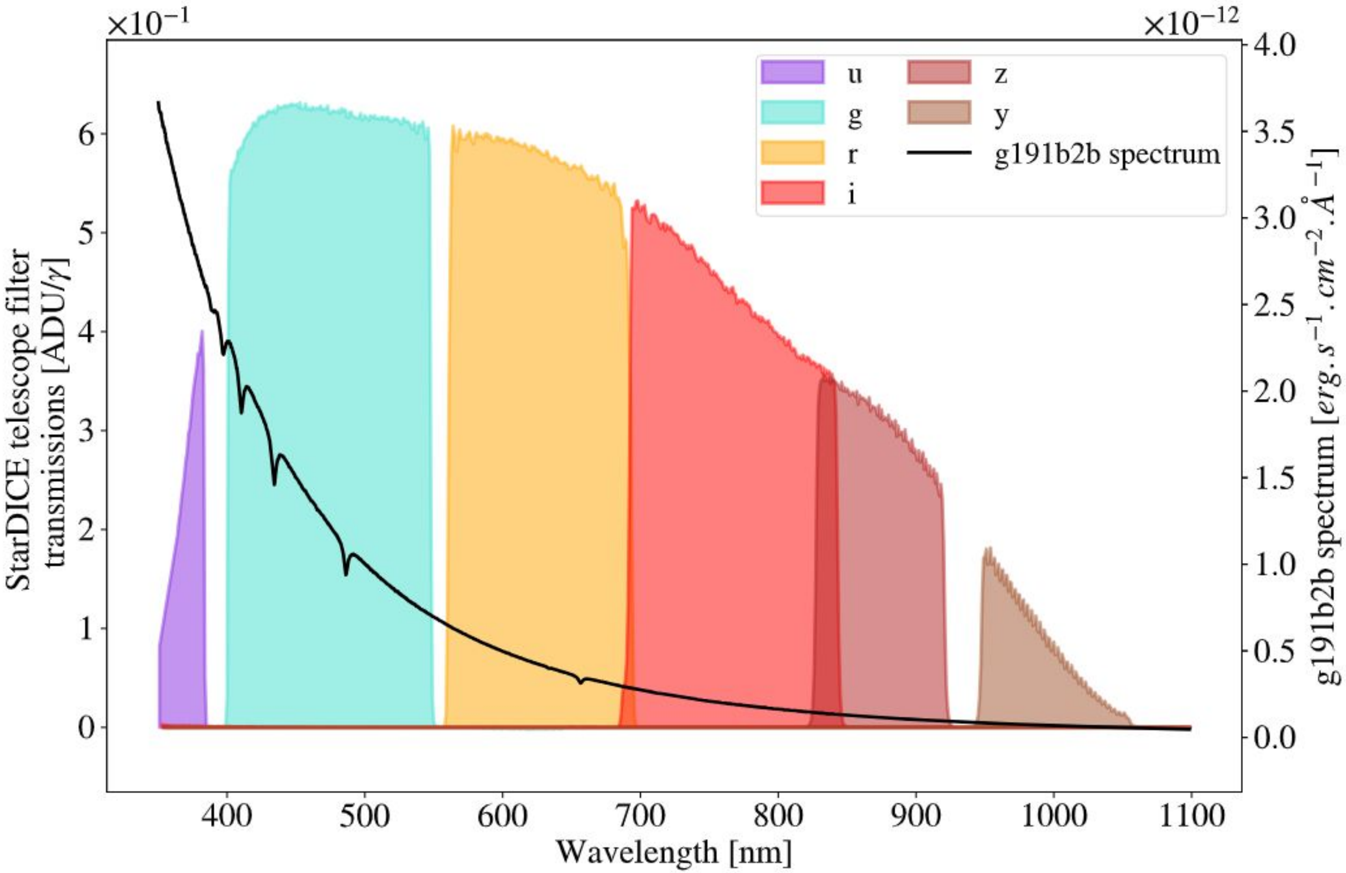
Filterwheel :

- **Grating** → low resolution (R~150) spectrophotometry to fit $T_{atm}(\lambda)$
- **ugrizy filters** → broadband photometry calibration

Adjusting spectrum from CALSPEC

StarDICE is observing photometric standards

- Prior spectra given by CALSPEC
- Prior knowledge of filter transmissions (CBP + DICE)
- Prior atmosphere simulation



Adjusting spectrum from CALSPEC

StarDICE is observing photometric standards

- Prior spectra given by CALSPEC
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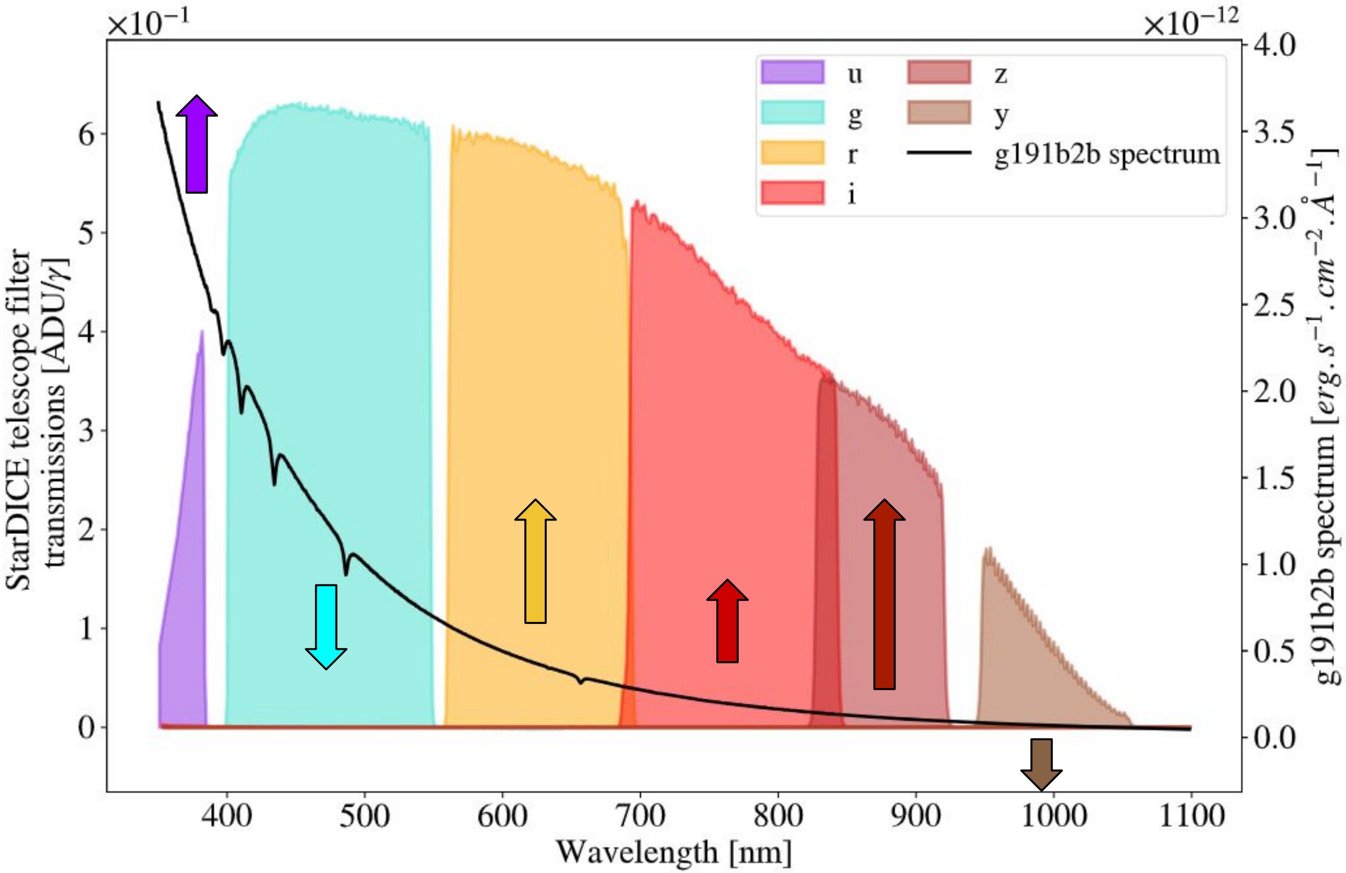
⇒ Theory/Measurements to adjust the spectrum for each filter

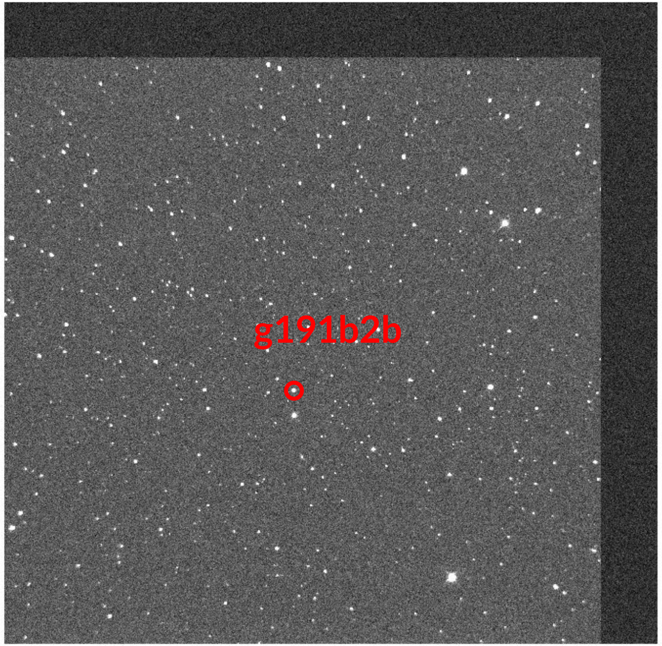


III. Preliminary photometry analysis on *g191b2b*

Status on *g191b2b* analysis

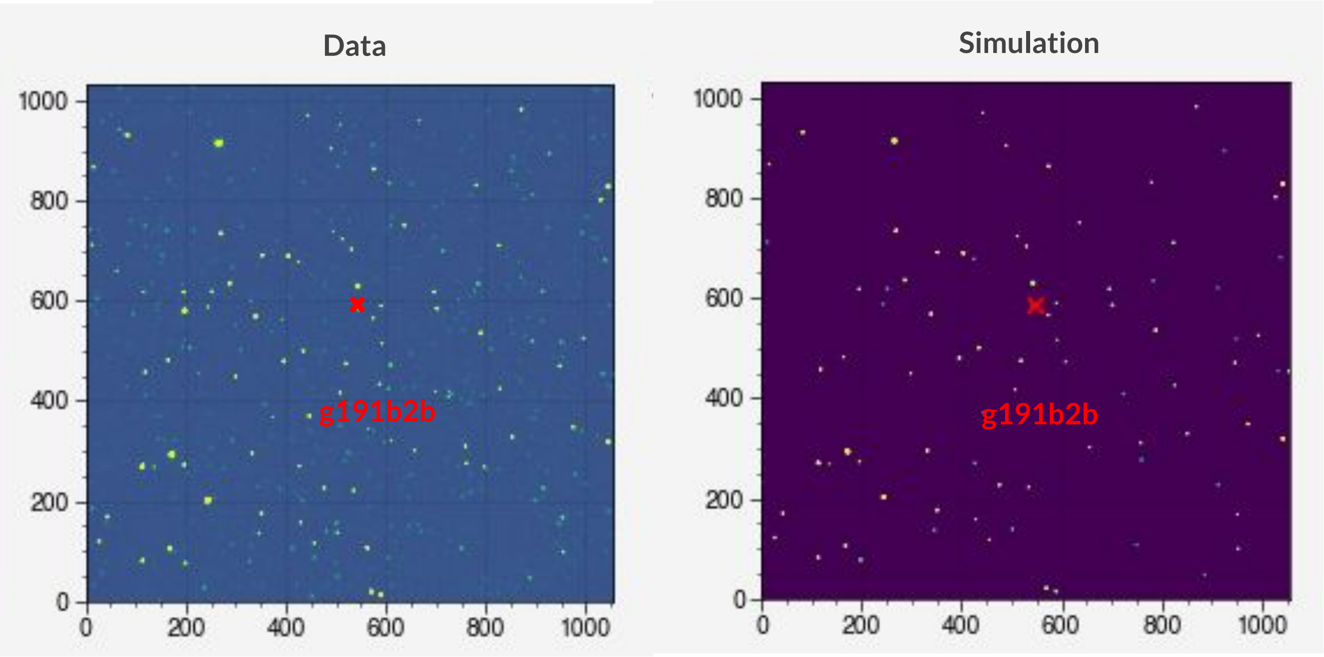
- ~2000 images by night
- 10 nights
- Total of ~20 000 images
- Observations in “ugrizy” filters + “grating”
- 726 stars studied in the field

g filter



Field simulation for *g191b2b*

Simulate the flux of stars in the StarDICE field with GAIA catalog



$$\Delta m = m_{\text{photometry}} - m_{\text{simulation}} = -2.5 \times \log_{10}\left(\frac{F_{\text{photometry}}}{F_{\text{simulation}}}\right)$$

Theoretical flux formula

$$F_{\mathrm{SD}} = \int_\lambda S_\star(\lambda) \times R_{\mathrm{SD}}(\lambda) \times T_{\mathrm{atm}}(\lambda) \times t_{\mathrm{exp,SD}} \times A_{\mathrm{mirror,SD}} \times \frac{\lambda d\lambda}{hc}$$

StarDICE flux

Star SED

StarDICE telescope response

Atmosphere transmission

Exposition time

StarDICE collection surface

Simulation formula

$S_\star(\lambda)$ → GAIA catalog low resolution spectra

$R_{\mathrm{SD}}(\lambda)$ → Preliminary CBP measurements

$T_{\mathrm{atm}}(\lambda)$ → Libradtran simulations with airmass, pressure and humidity (ozone, aerosols and PWV are fixed)

Model

Difference between model and observation

$\mathcal{N}(0,\ \sigma_{is})$

$$\Delta m_{is} = \Delta ZP_i + \Delta m_s + \epsilon_{is}$$

Difference of zero point for each image

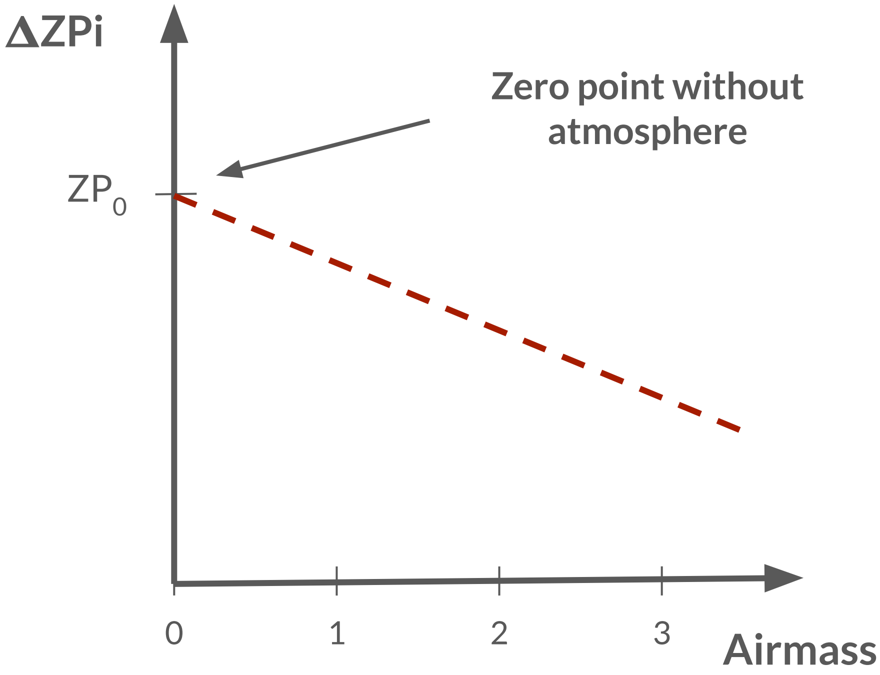
$$\Delta ZP_i = \frac{\sum_s \frac{(\Delta m_{is} - \Delta m_s)}{\sigma^2_{is}}}{\sum_s \frac{1}{\sigma^2_{is}}}$$

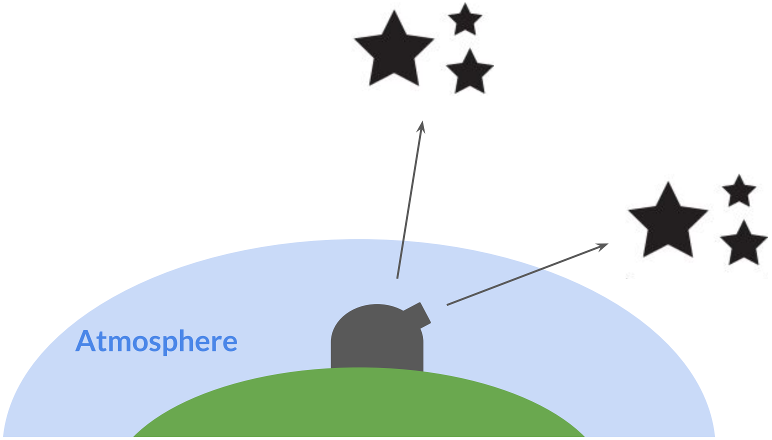
Difference of mean magnitude for each star

$$\Delta m_s = \frac{\sum_i \frac{(\Delta m_{is} - \Delta ZP_i)}{\sigma^2_{is}}}{\sum_s \frac{1}{\sigma^2_{is}}}$$

Goal : zero point outside of the atmosphere

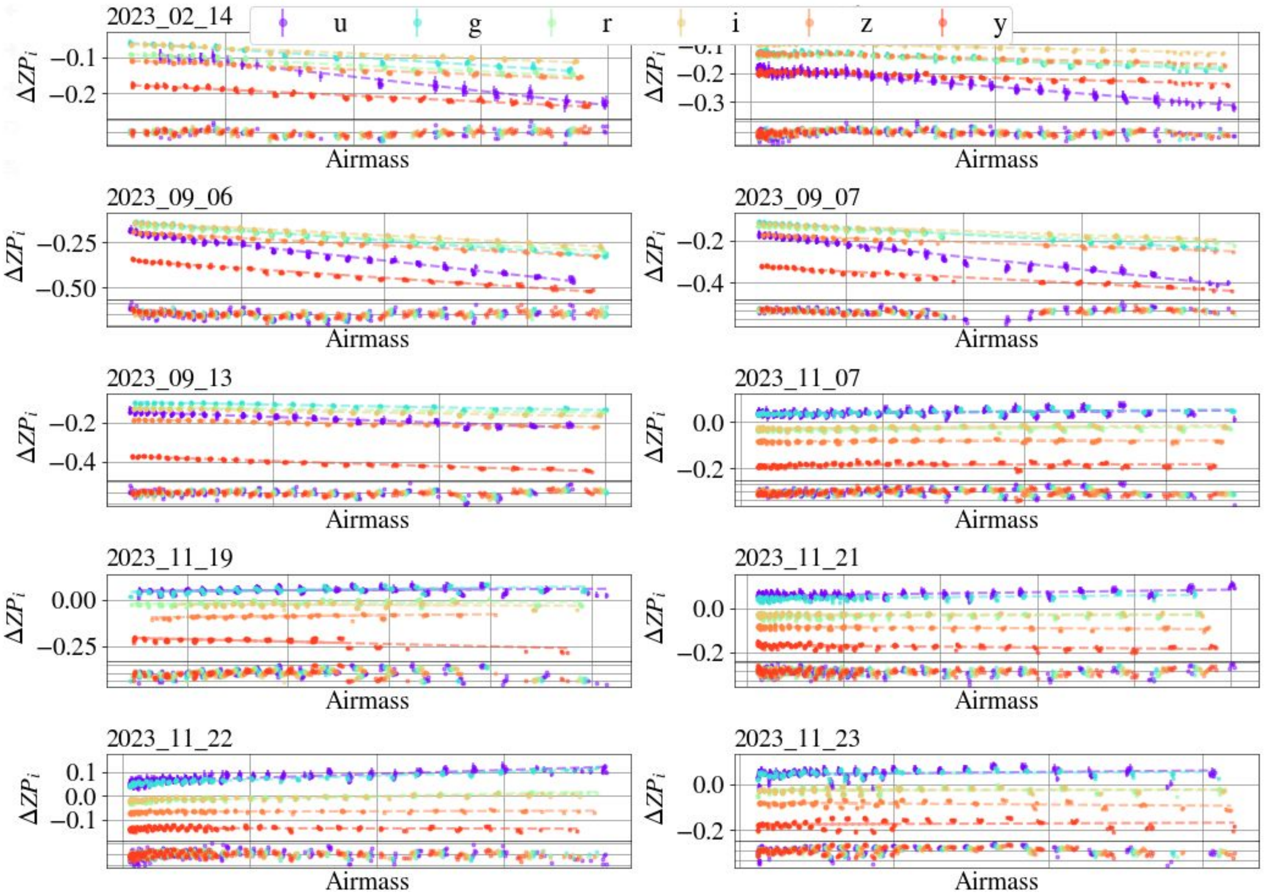
$$\Delta ZP_i = \frac{\sum_s \frac{(\Delta m_{is} - \Delta m_s)}{\sigma^2_{is}}}{\sum_s \frac{1}{\sigma^2_{is}}}$$



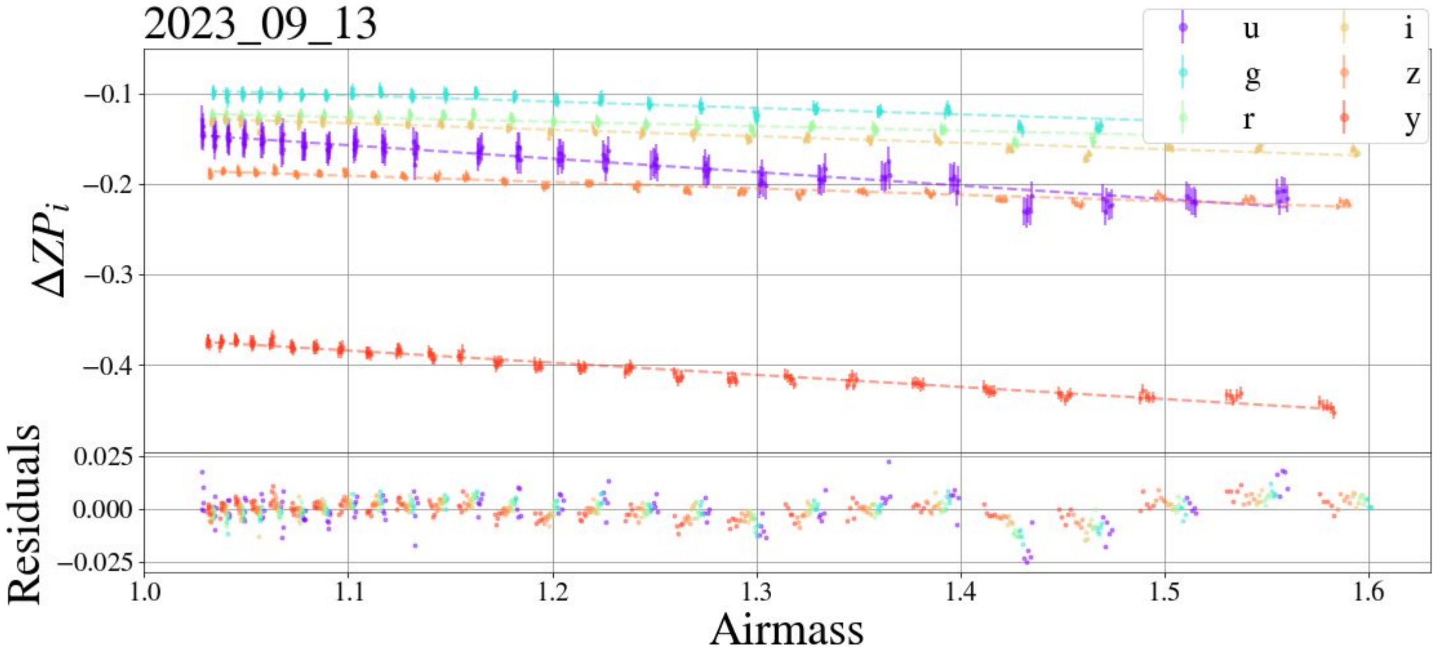


Airmass schematic

ΔZP_i vs airmass



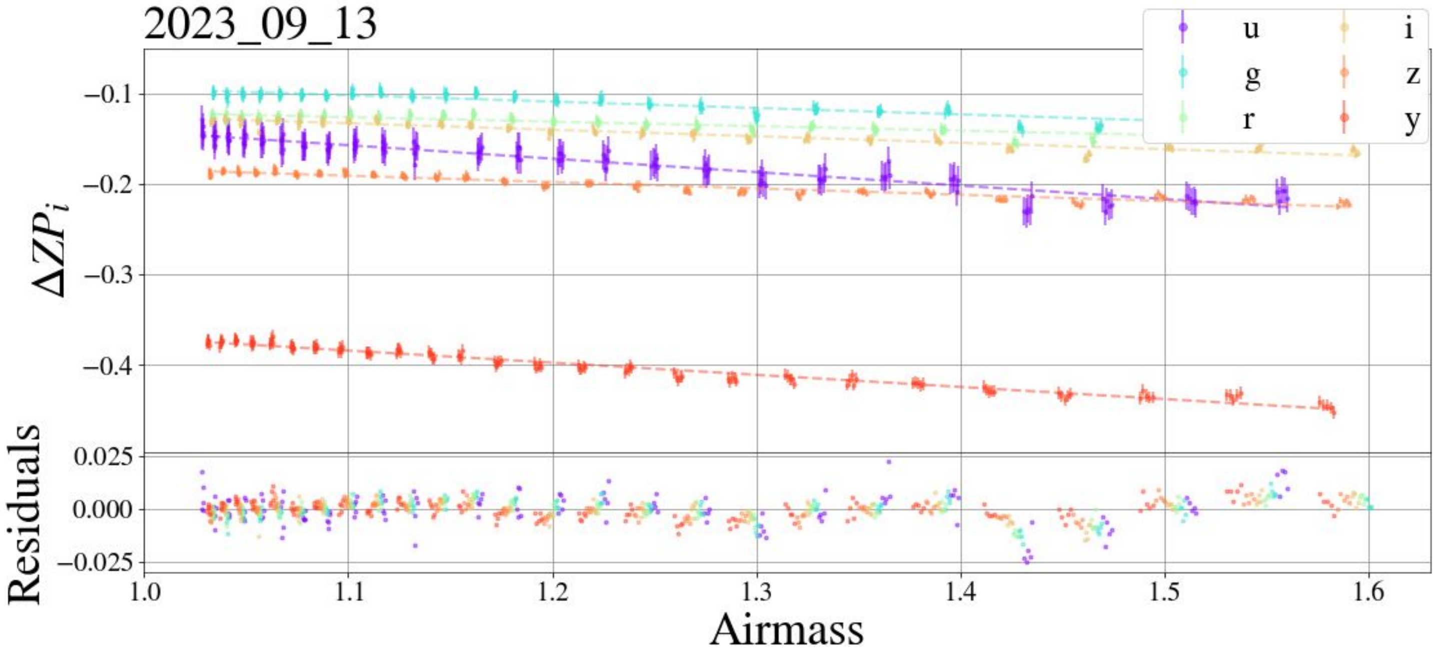
ΔZP_i vs airmass



$$\Delta ZP_i = k \times \text{airmass} + ZP_0$$

ZP_0 : estimation of the zero point outside the atmosphere

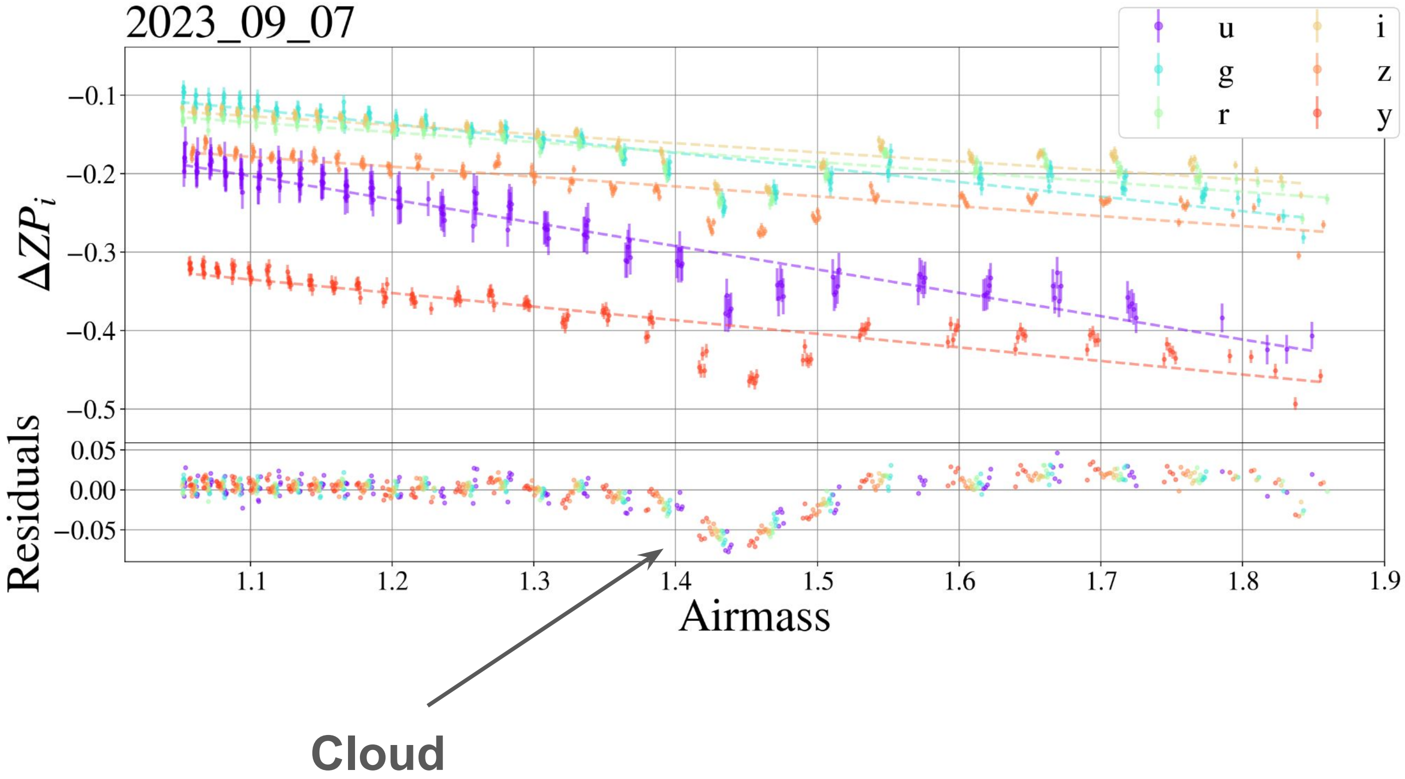
ΔZP_i vs airmass : clean night



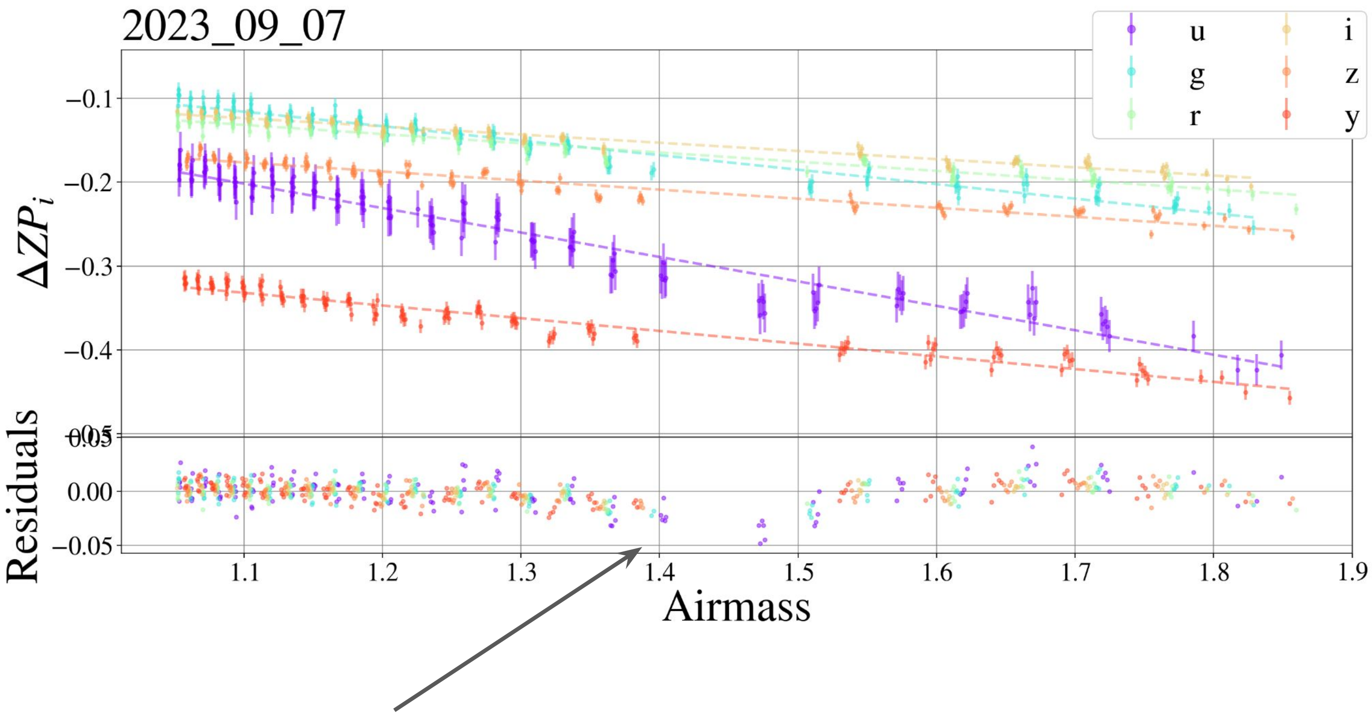
$$\Delta ZP_i = k \times \text{airmass} + ZP_0$$

ZP_0 : estimation of the zero point outside the atmosphere

ΔZP_i vs airmass : cloudy night

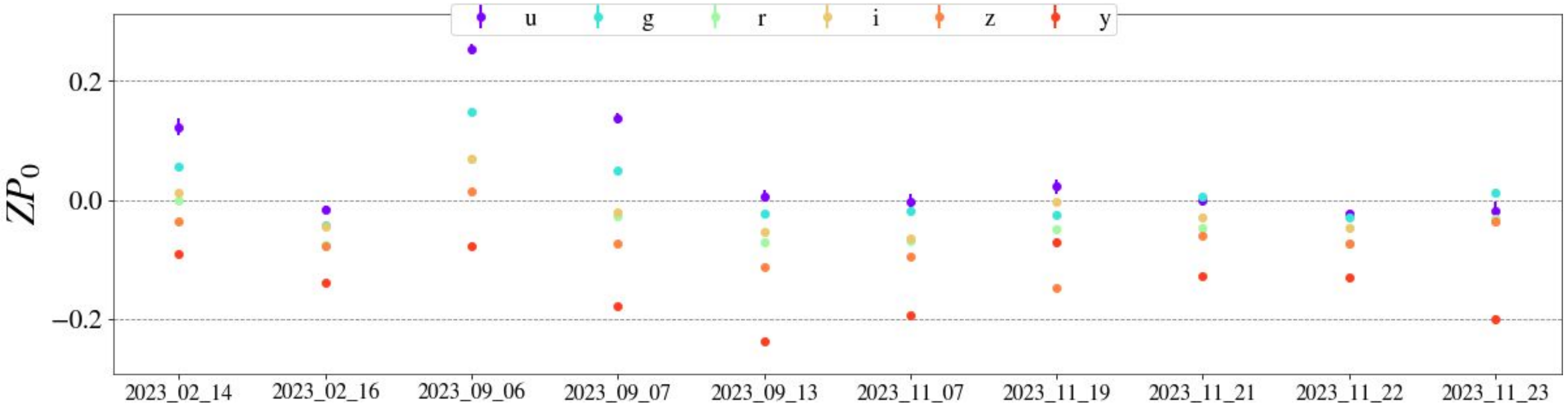


ΔZP_i vs airmass : cloudy night



No more cloud
→ sigma clipping

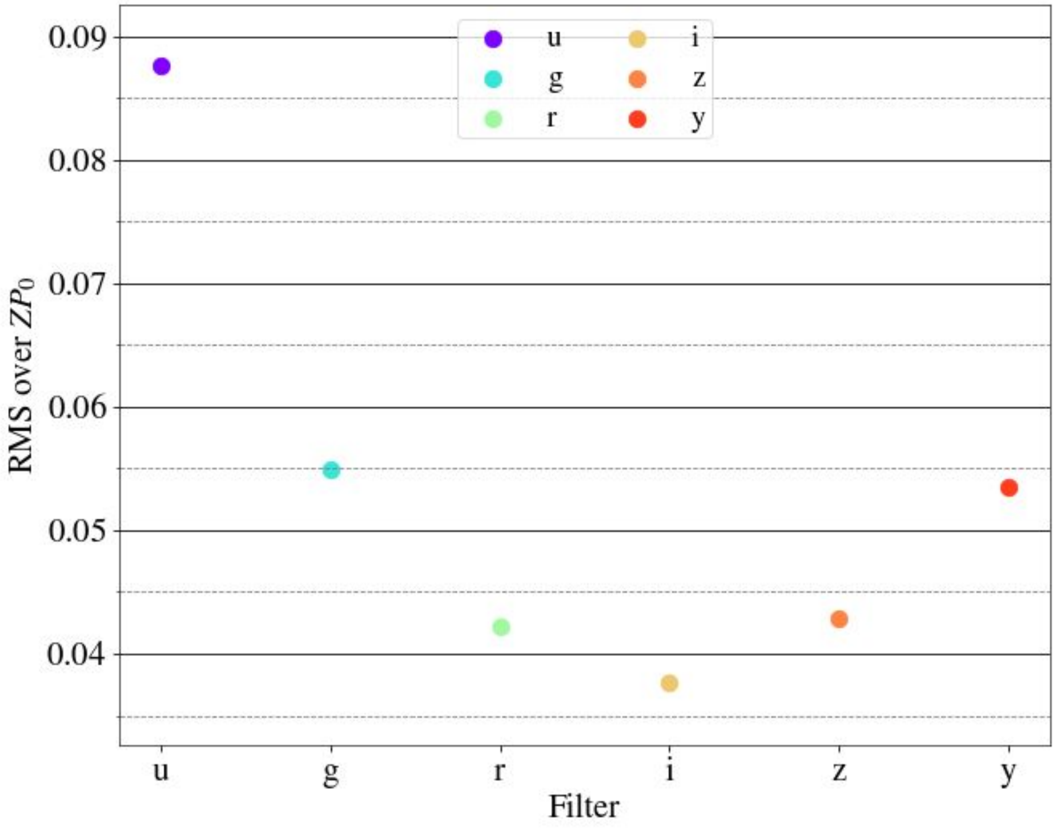
ZP_0 estimations



$$\Delta ZP_i = k \times \text{airmass} + ZP_0$$

ZP_0 : estimation of the zero point outside the atmosphere

ZP_0 estimation : RMS and MAD



ZP_0 : estimation of the zero point outside the atmosphere

We aim for a 0.1% dispersion, corresponding to millimagnitude photometric calibration

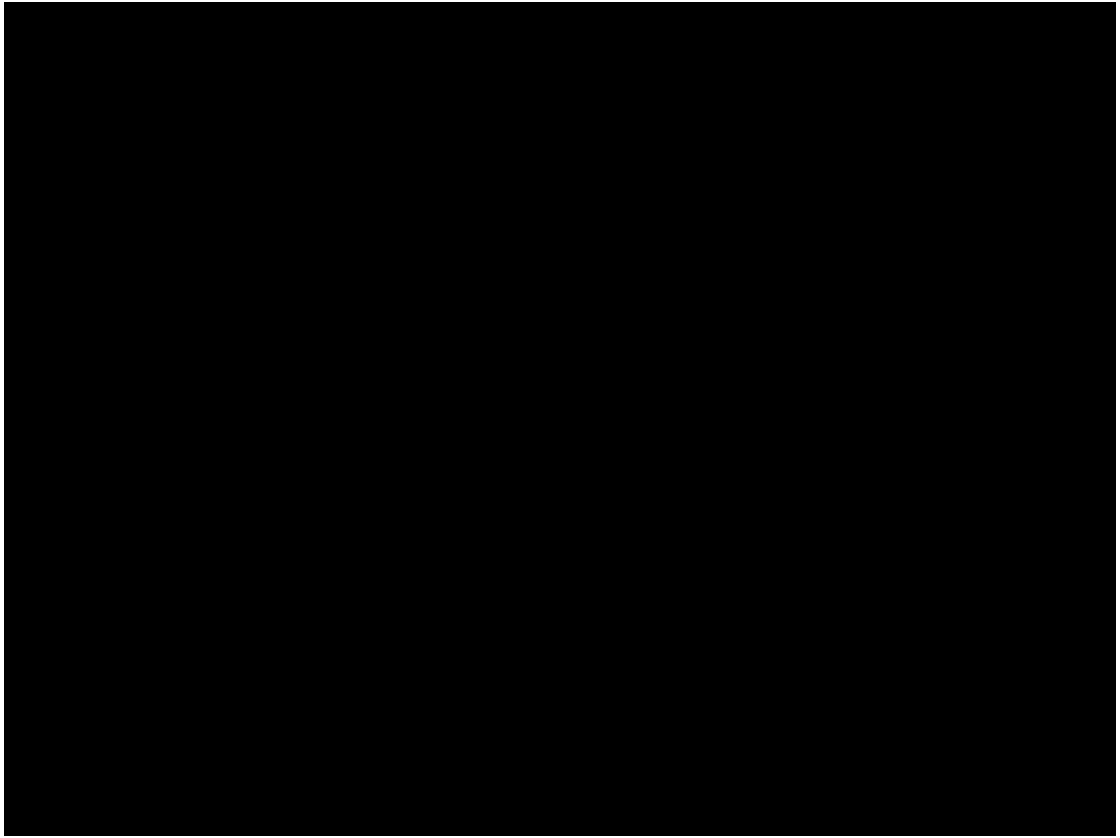
Conclusion and improvements

- We are able to measure a **zero point outside of the atmosphere** for StarDICE filters
- The priors measurement can be improved (monitoring of StarDICE telescope with the artificial star, **fit** of the **atmosphere transmission** with the grating data and **Spectractor**
- The analysis can be improved with **forced photometry** (remove the bias of selection for faint stars)
- **Infrared data** to measure smaller gray extinction from clouds (see Kélian's talk)

⇒ **More nights to come**

https://docs.google.com/file/d/1aA6a6GPbzXxqQoM8xRcYqnLURGNLSLzT/preview

Thank you for your attention



Backup

Variance modelization

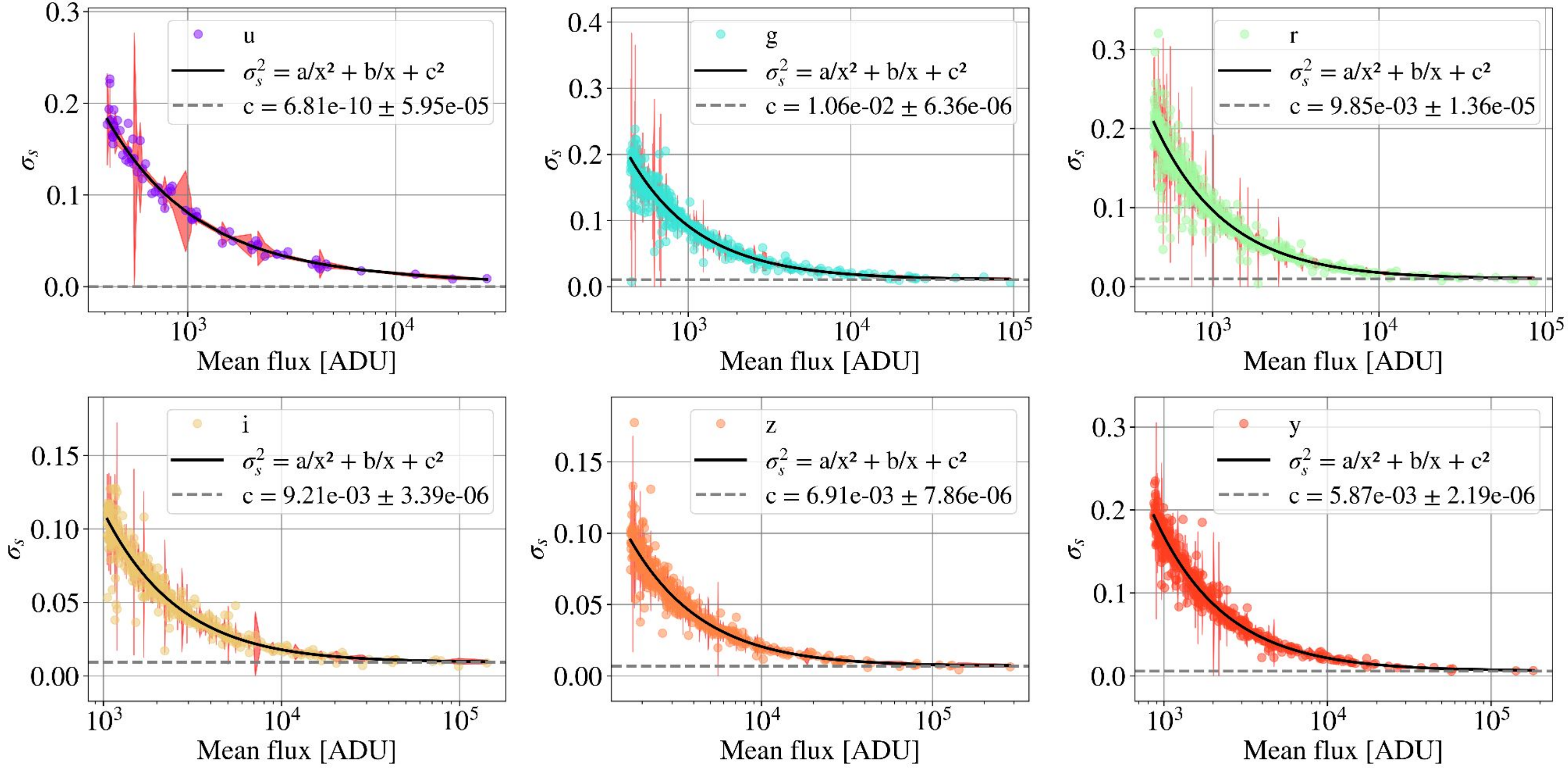
Gain

$$\frac{var(\phi)}{F^2} = \frac{1}{F^2}\left[\frac{B}{G^2} + var(b_{RO})\right] + \frac{1}{FG^2} + var(\alpha)$$

Readout noise and background

Inhomogeneities of the focal plane

Star dispersion σ_{is}



When flux increase, the variance converge at <1% for every filters

⇒ inject σ_{is} in the model of ΔZP_i

ΔZPi dispersion per night