Combining Low- and High-z SNe

Reviewing the middle rung of the cosmic distance ladder

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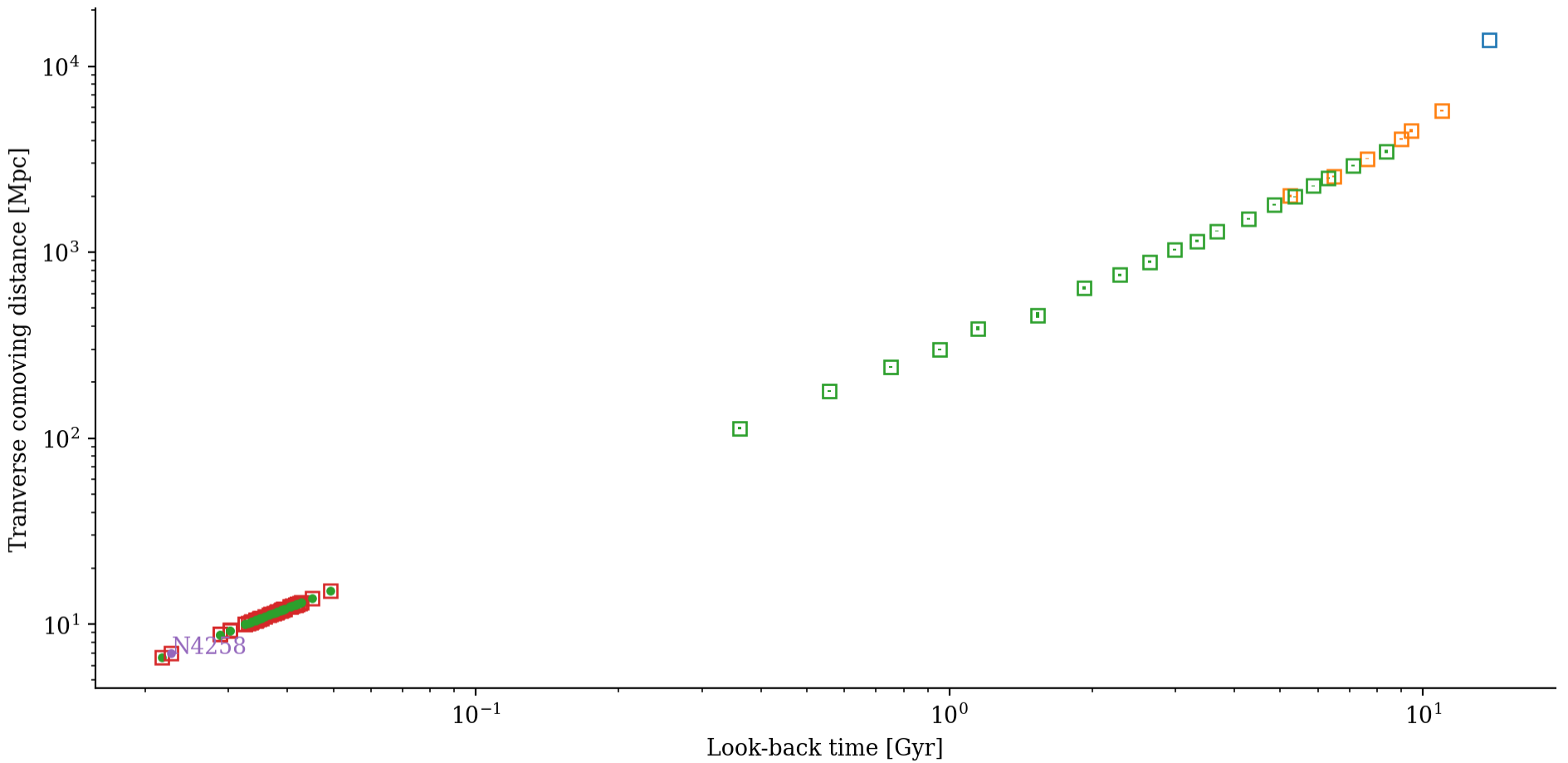
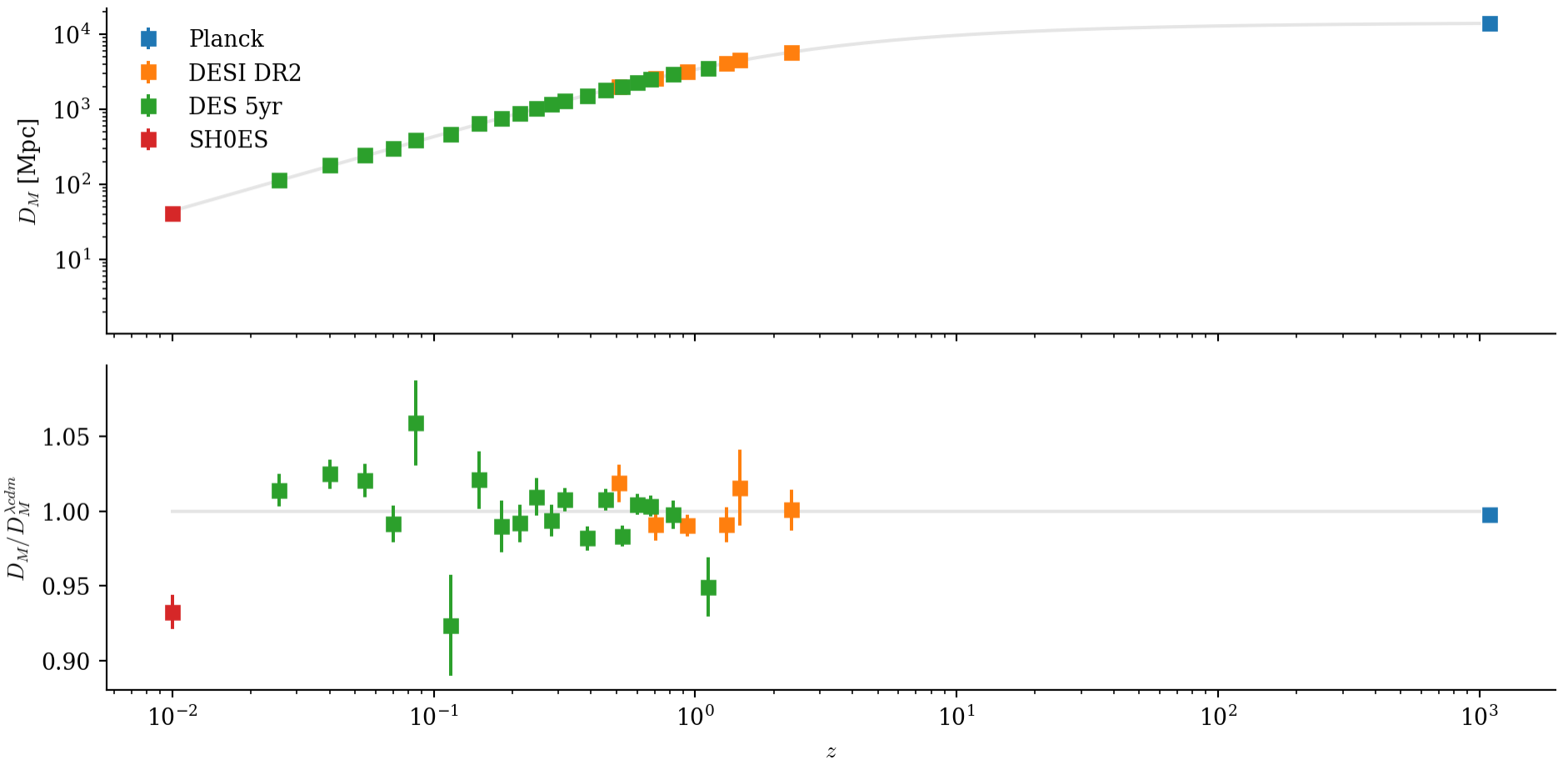
The Cosmic Distance Ladder

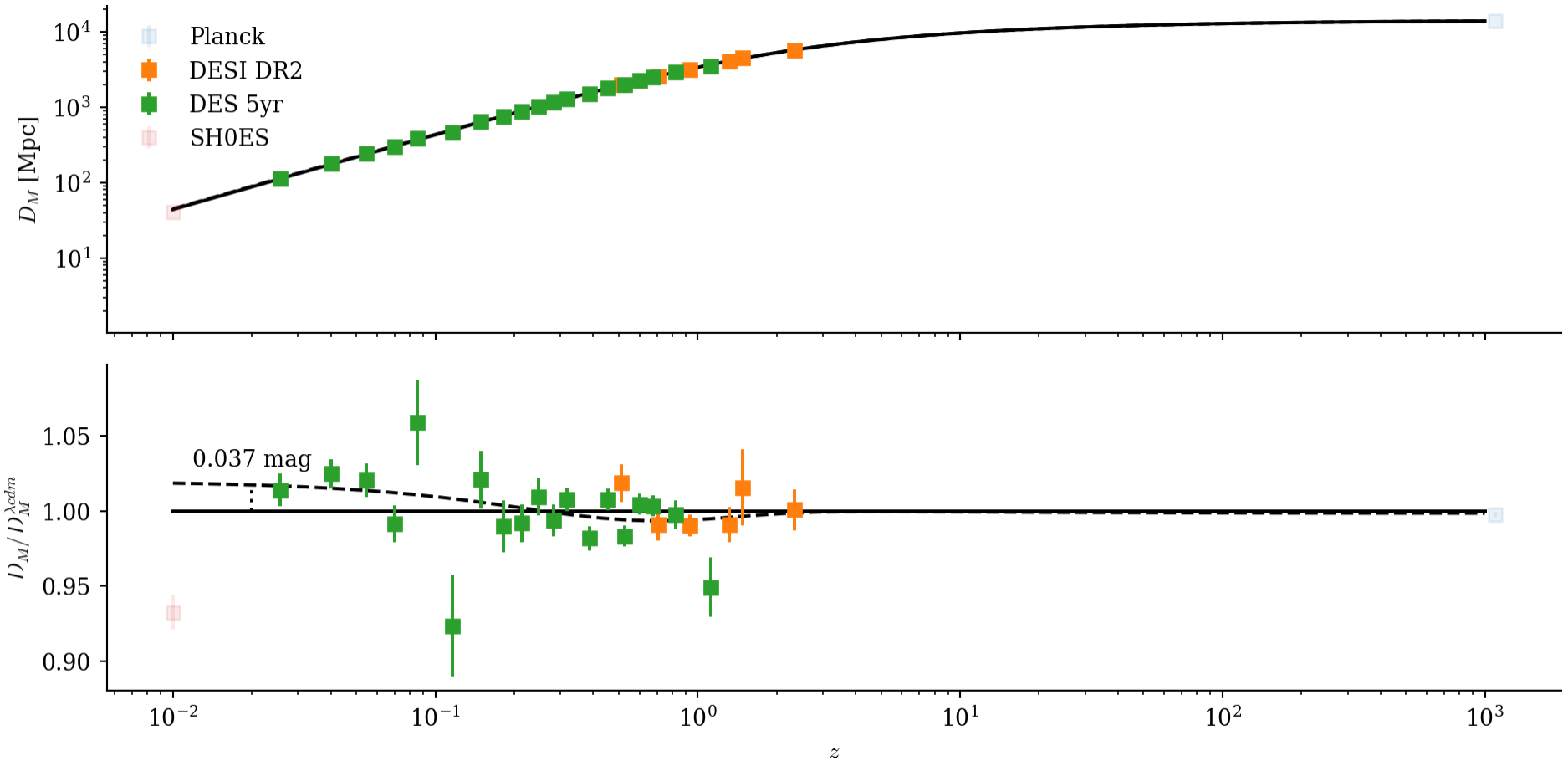


Combines overlapping Parallaxes, Standard Candles (Cepheids and SNe Ia) and Standard Ruler (BAO) to reconstruct distances in the universe.

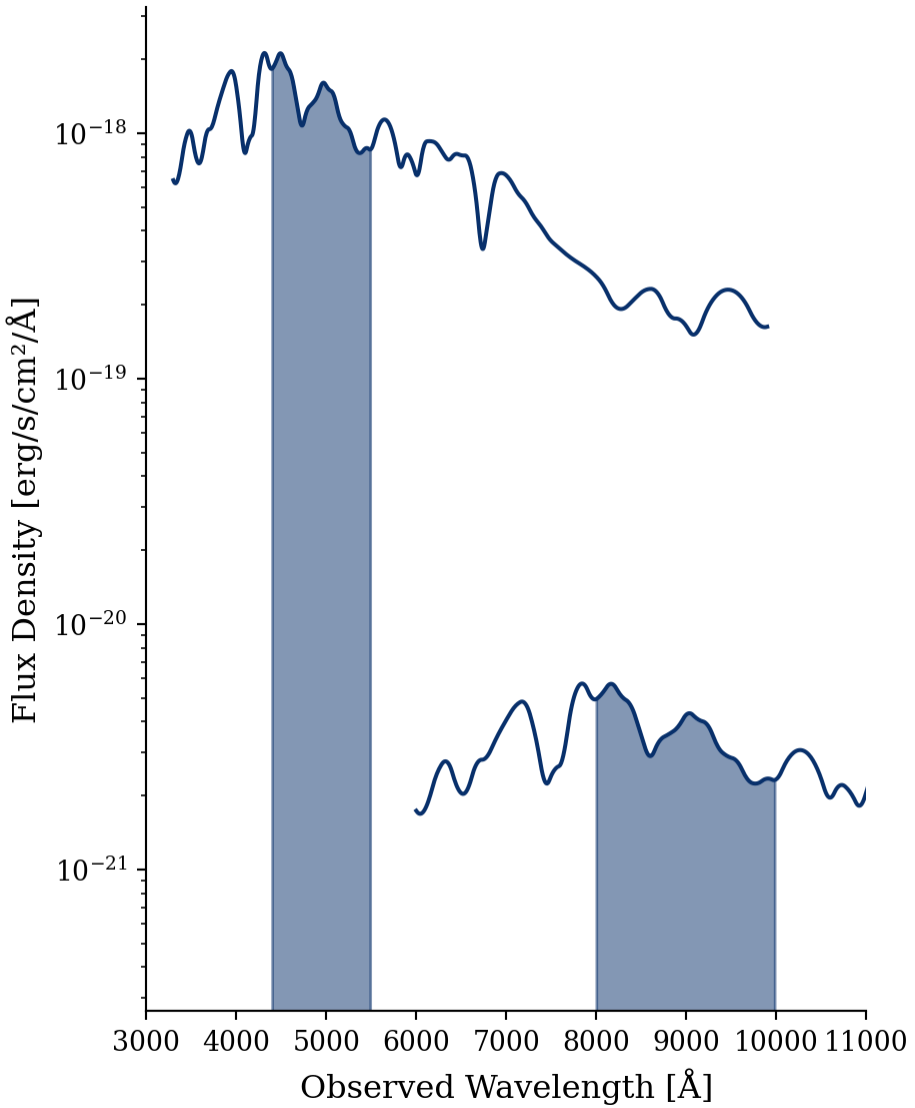
The Hubble tension: Direct comparison of two distance scales



Probing the Background dynamics



Potential issues with supernovae



Basics: B band luminosity comparison between nearby and distant events

Measurement issues

Linearity - Calibration - Interpolation - Truncation

Astrophysical issues

Dust - Galactic evolution - Structures

Probe issues

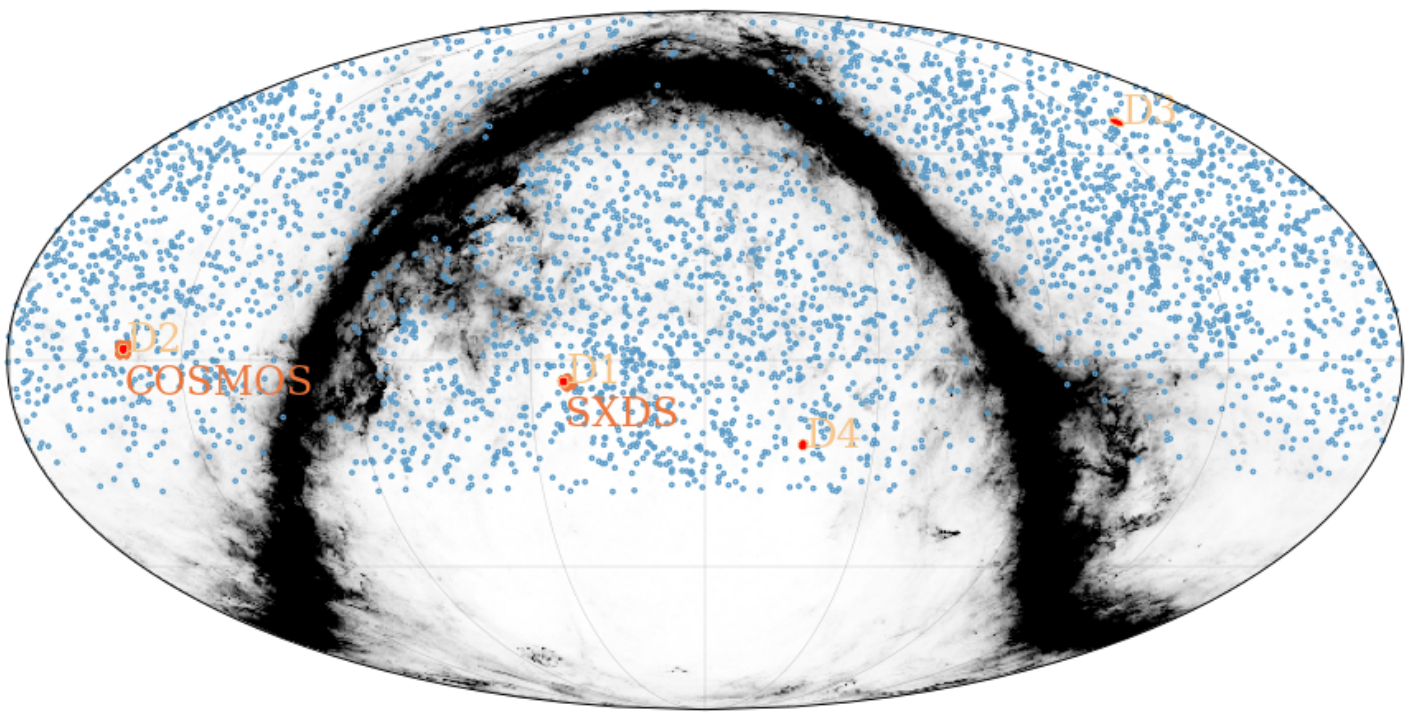
Empirical models - Population evolution

Analysis issues

Compilations - bias corrections

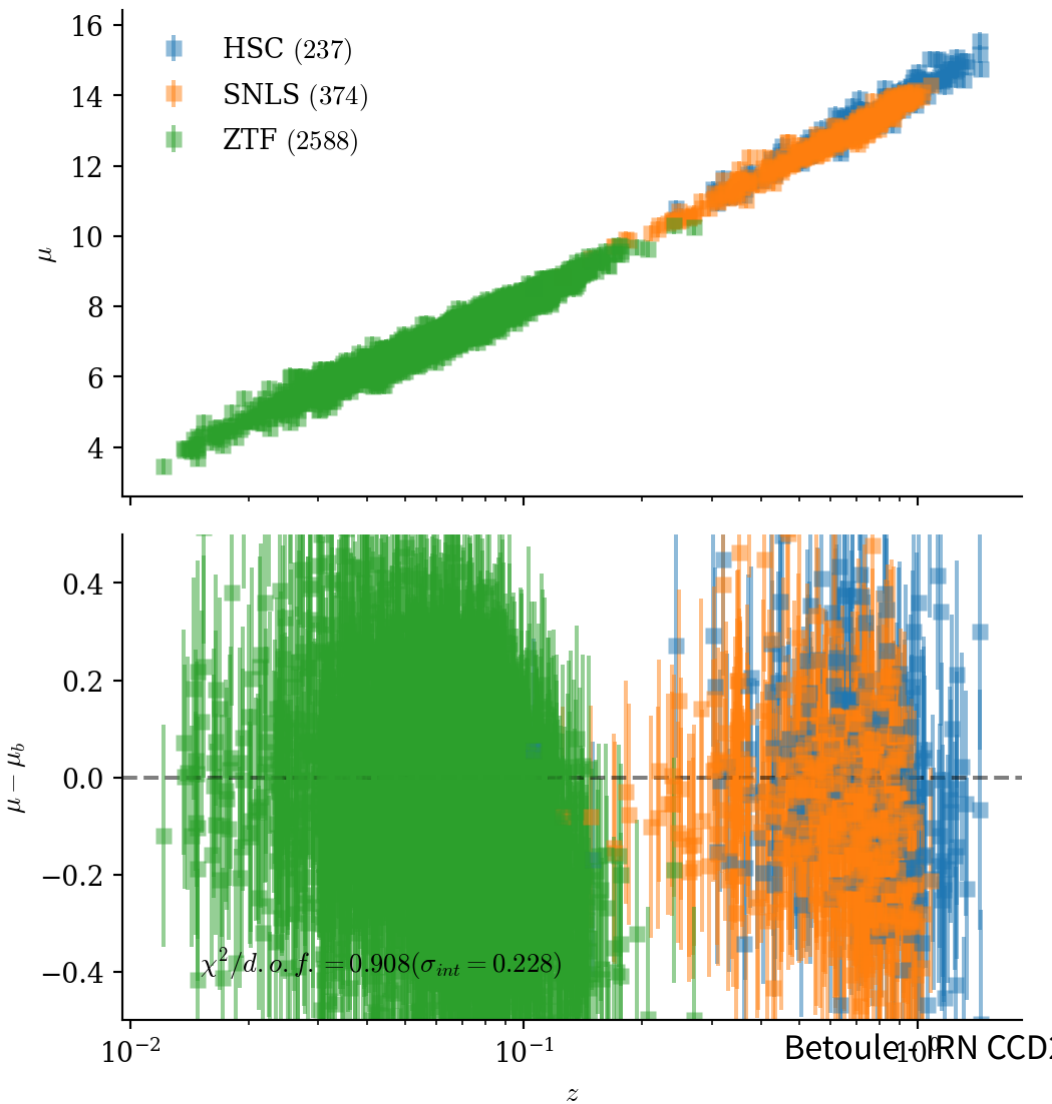
The LEMAITRE Project

A compilation from only 3 collaborations:



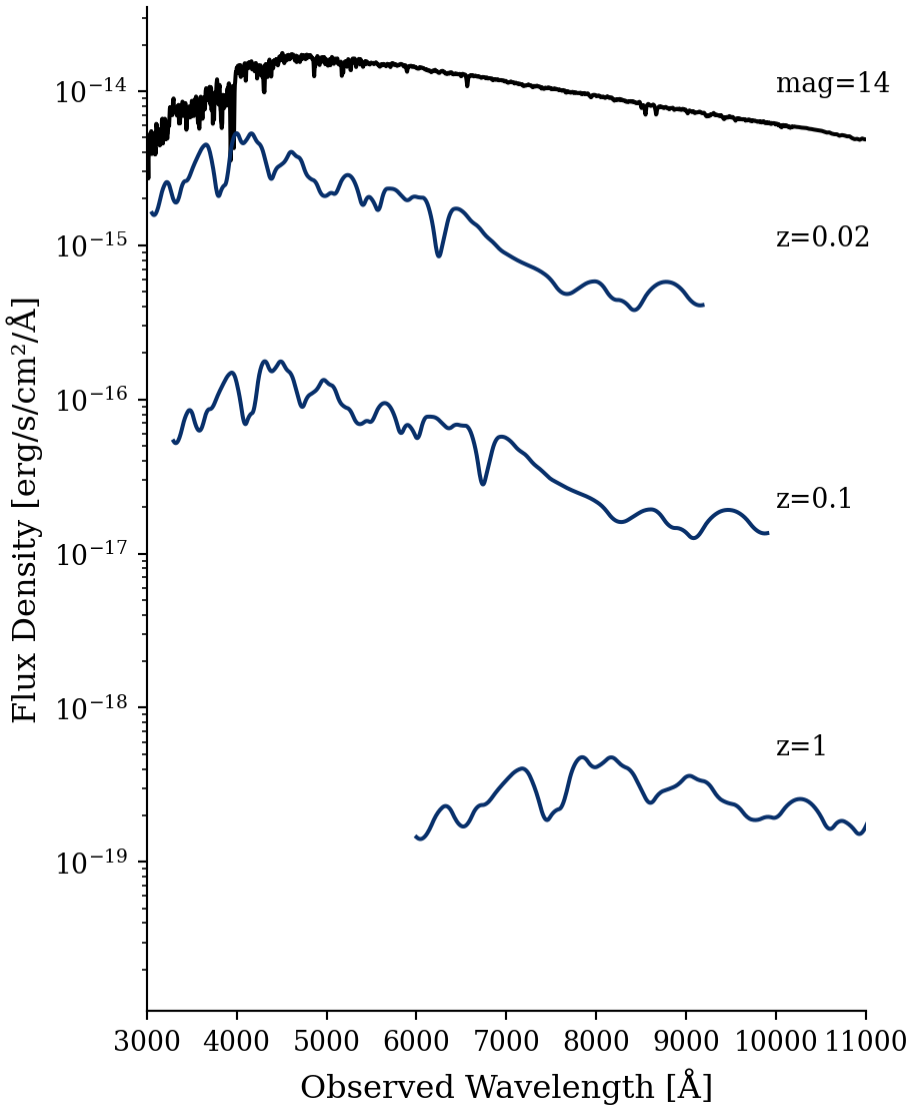
- ZTF: $2\pi, 2yr,$ $m_{lim} \sim 18.5$
- SNLS: $4deg^2,$ $2yr\ m_{lim} \sim 24$
- HSC: $3deg^2,$ $1yr,$ $m_{lim} \sim 25$

Main characteristics of the compilation



- Fully independent sample
- A very large and modern low-z sample
- All three surveys share the same photometric reduction pipeline
- All three surveys from well characterized instruments
- Fully rewriten analysis chain

Linearity of the SN photometry



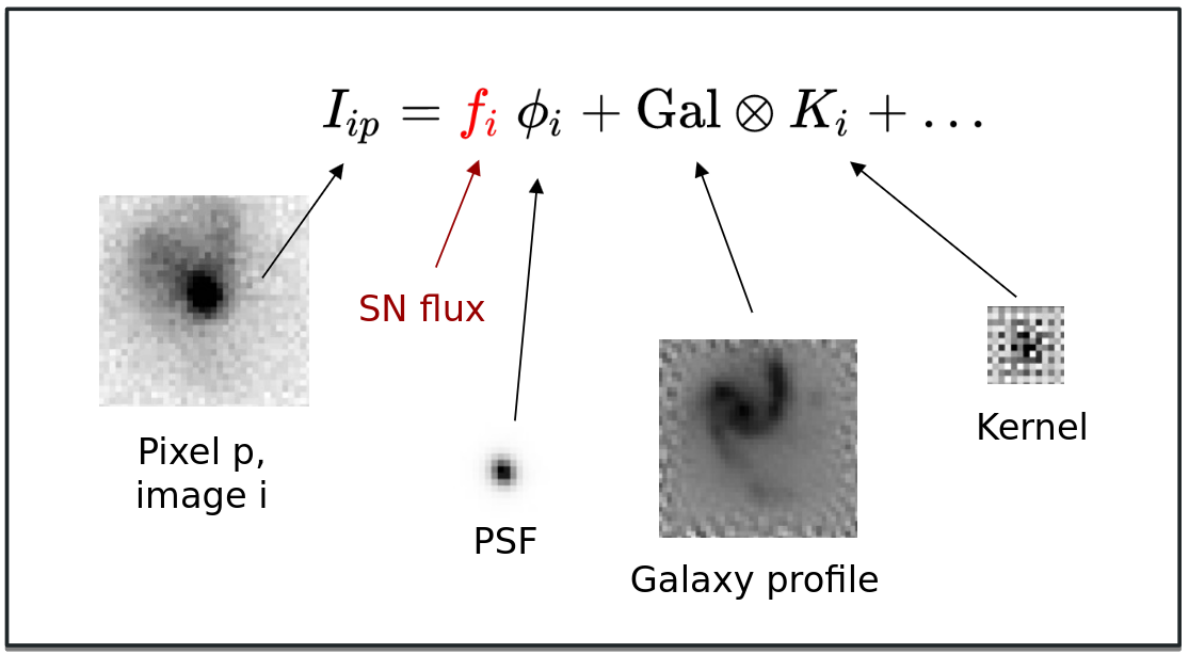
Difficulties:

- Subtraction of host galaxy flux
- Variation of observing conditions

Many low-z survey: photometry on resampled images differences

- Suboptimal
- Inability to check flux conservation

“Scene modeling” photometry



- Forward model of image sequences
- Galactic flux model
- Same estimator applied to field stars
- demonstrated to be accurate at the .1% level (*Astier et al. 2013*)

- In LEMAITRE all three survey are reduced using the same SMP pipeline
- for ZTF *Lacroix et al. 2025*: 0.02-0.05 mag shifts wrt photometry on image difference

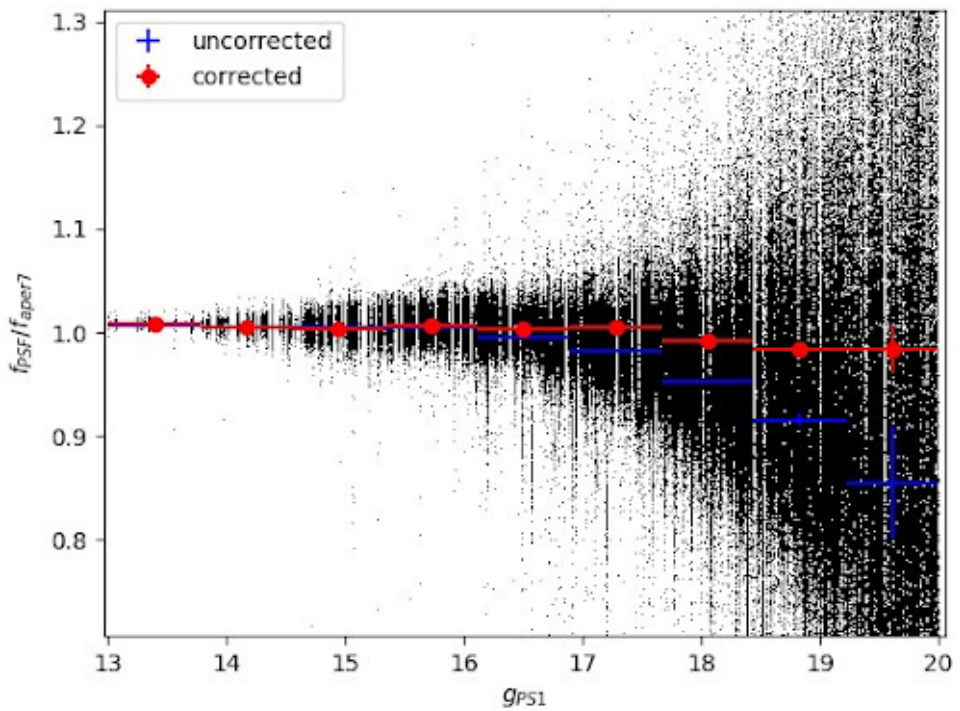
Correcting instrumental non Linearities

Sensor effects can affect the PSF shape in a flux dependent way

- Brighter fatter (2015)
- In ZTF: pocket effect (2024)

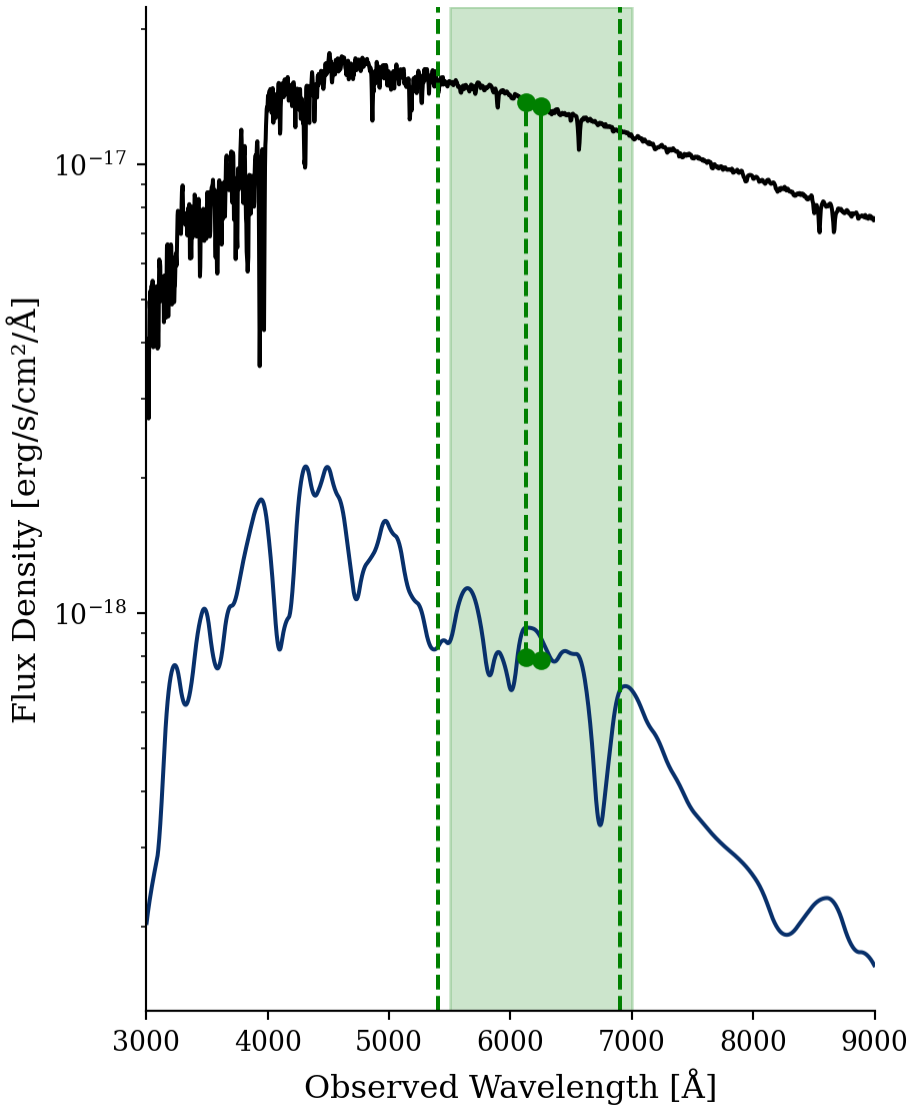
This affects the linearity of the PSF photometry

Correction of the intricate pocket effect took about a year in ZTF



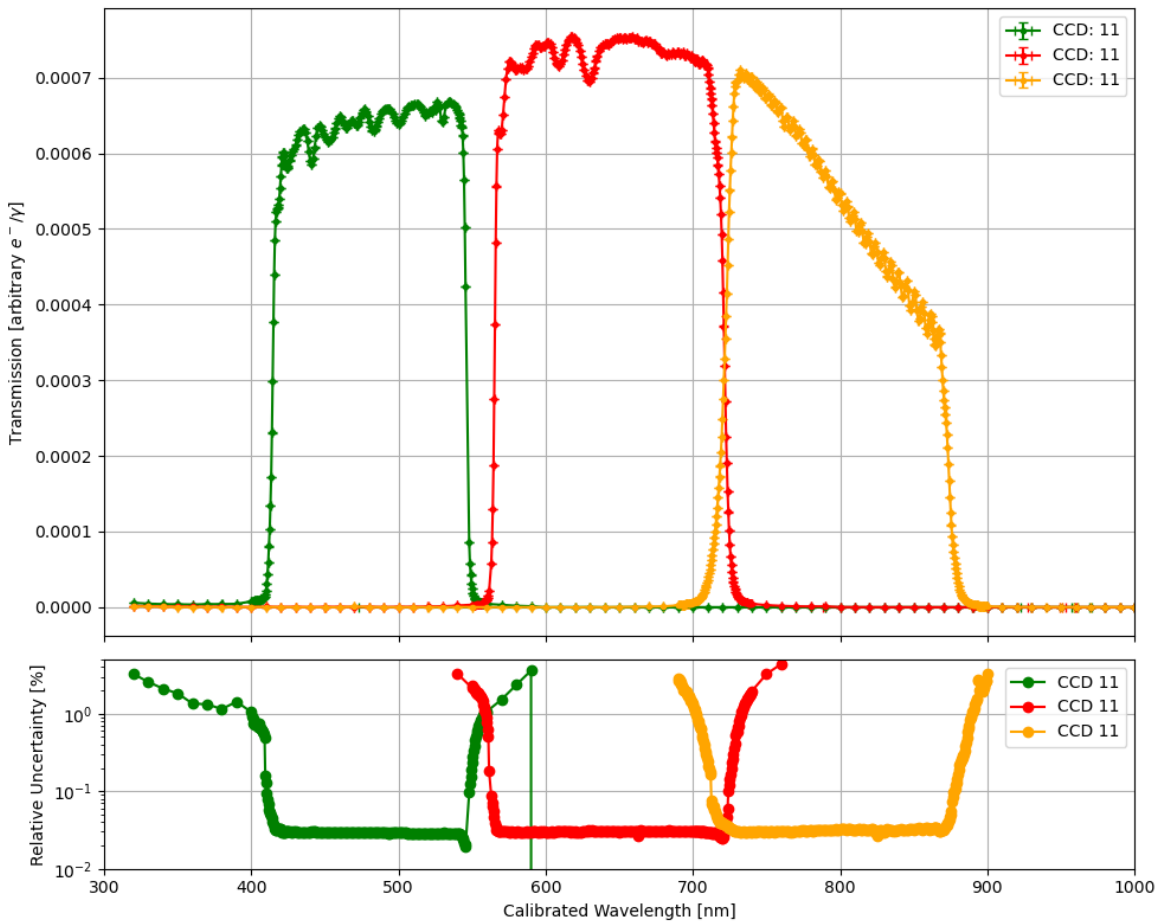
Regnault et al in prep.

Instrument passband knowledge

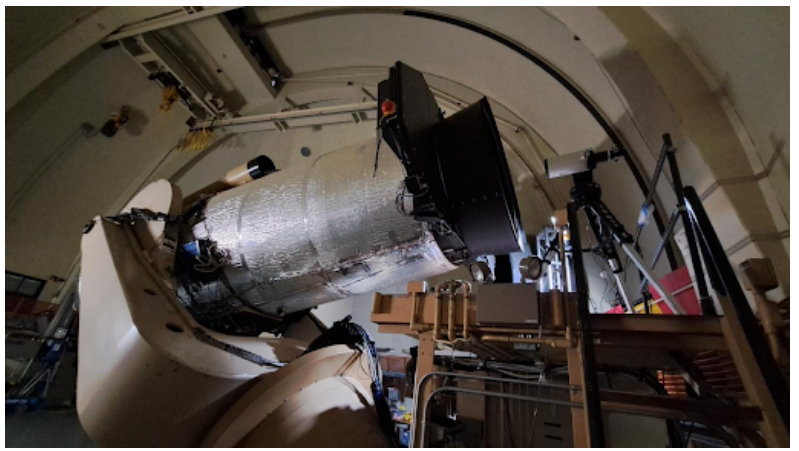


- Reference stars and SNe have very different spectra.
- Errors in instrument passbands translate into z-dependant errors in photometry.
- Rule of thumb: 1nm shift translates to 5mmag per mag in color
- Most historical low-z passbands are reverse engeneered to PS1 in current analyses

CBP measurement of ZTF

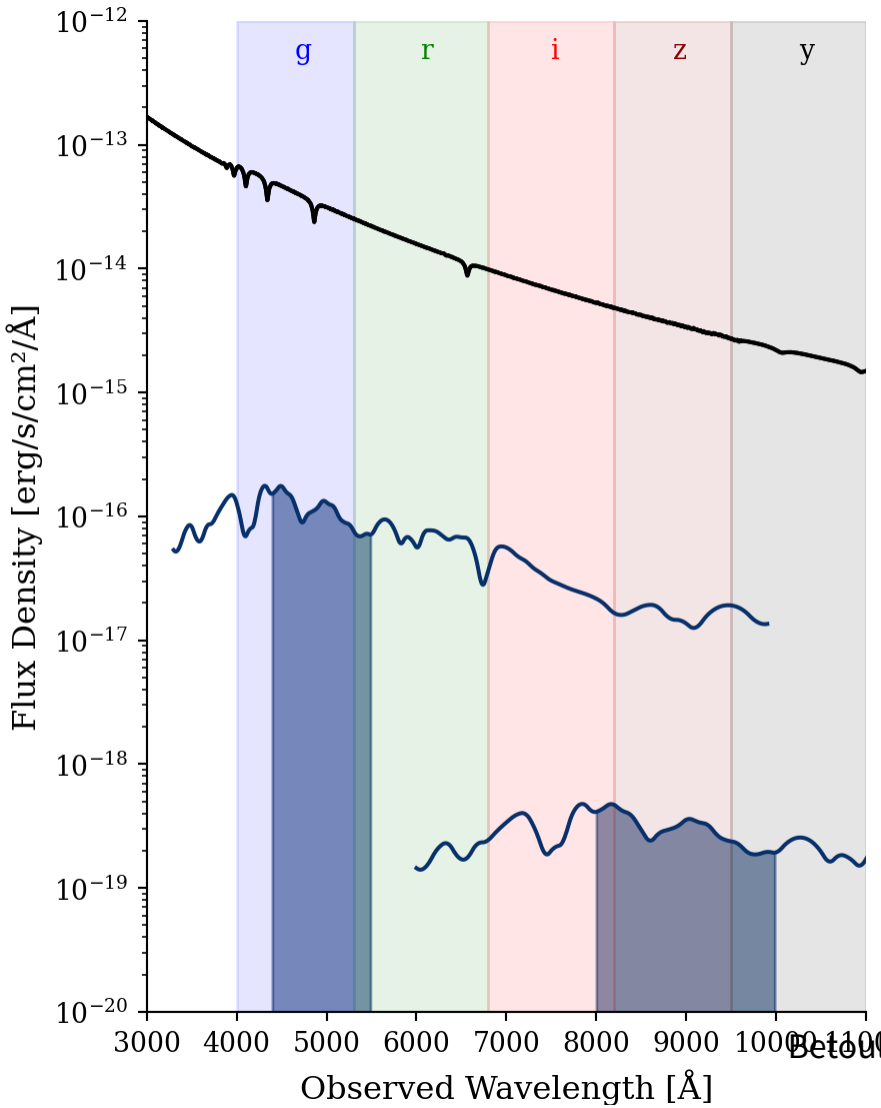


Neveu et al. in prep.



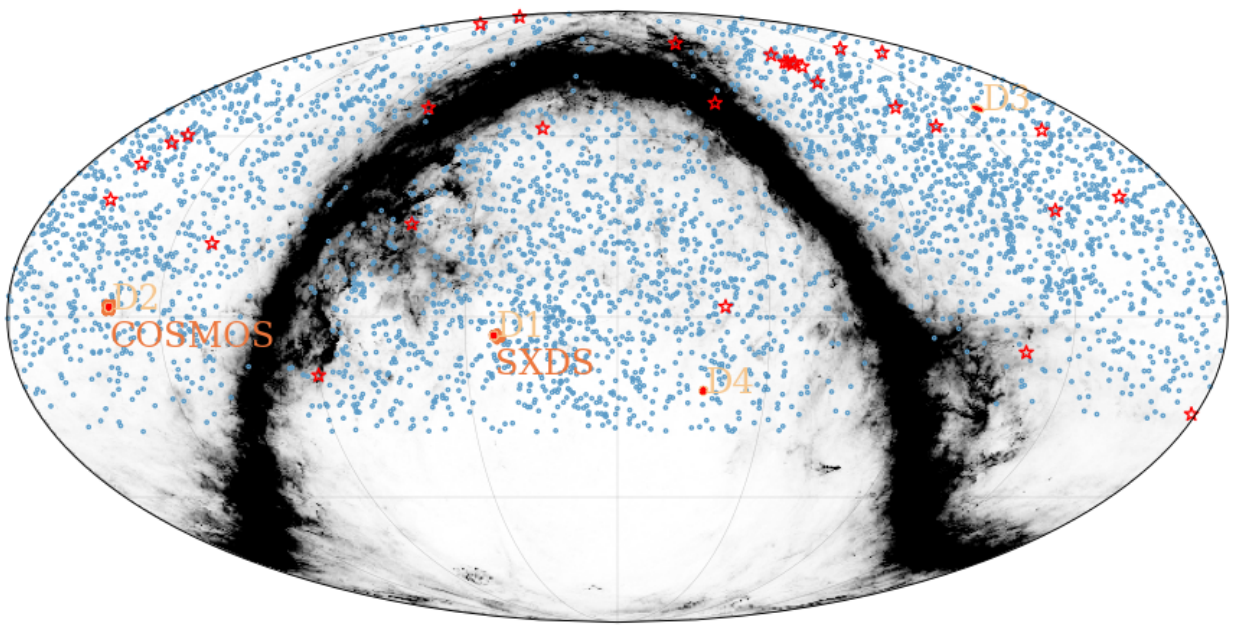
- Measurement of the integrated instrument response curve (not just the transmission of the filters)
- 10^{-3} uncertainties on shape
- 0.2 nm uncertainty on wavelength calibration

Color calibration and cross-calibration between surveys



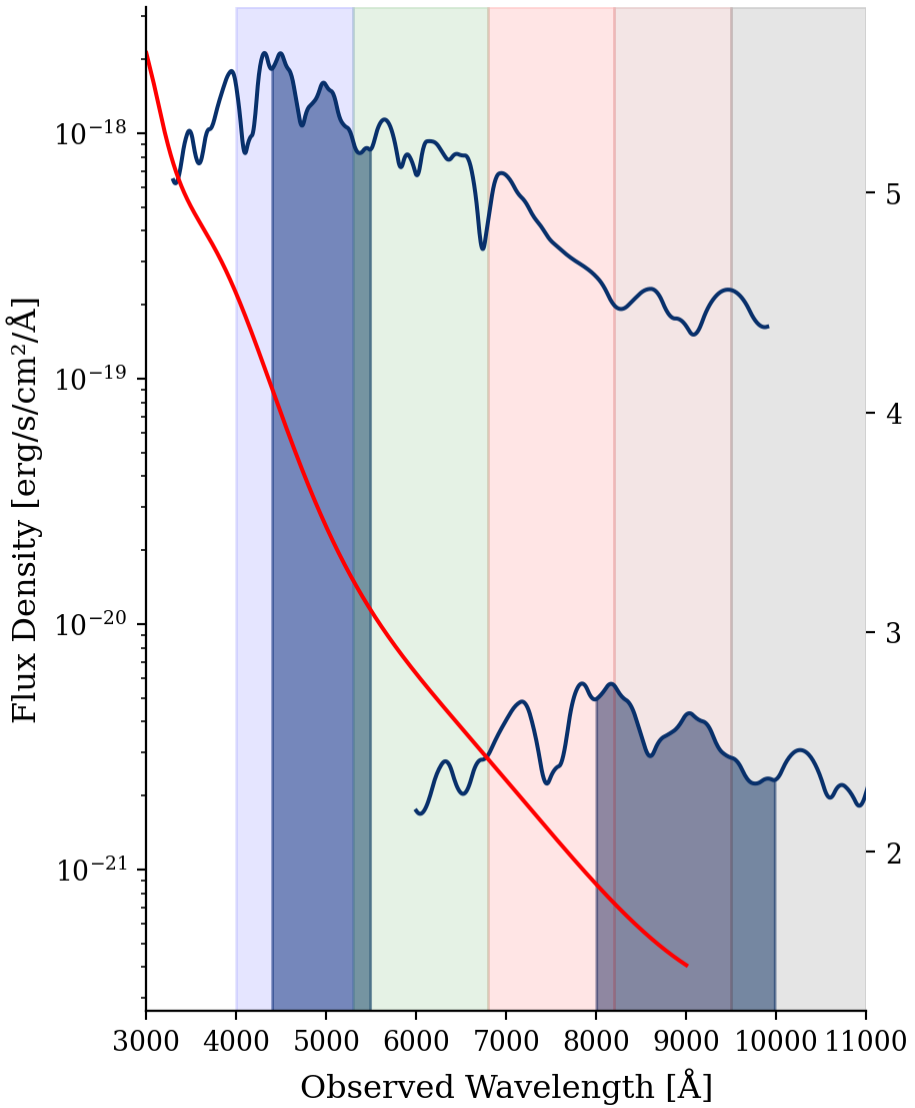
- Linking measurement between different surveys require overlapping field stars (typically PS1)
- Linking different wavelength involves observing spectrophotometric standard stars
  - very bright
  - typically specific or indirect observations

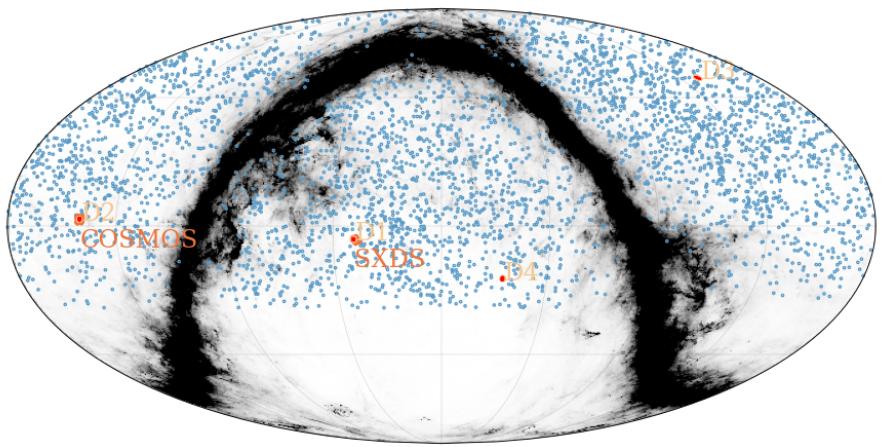
ZTF ubercal and CALSPEC calibration



- ZTF-SNLS-HSC fields are overlapping
- ZTF saturation limit is high enough that many spectroscopic standard stars are part of the regular observations
- SNLS has a long dedicated program for standard stars observations

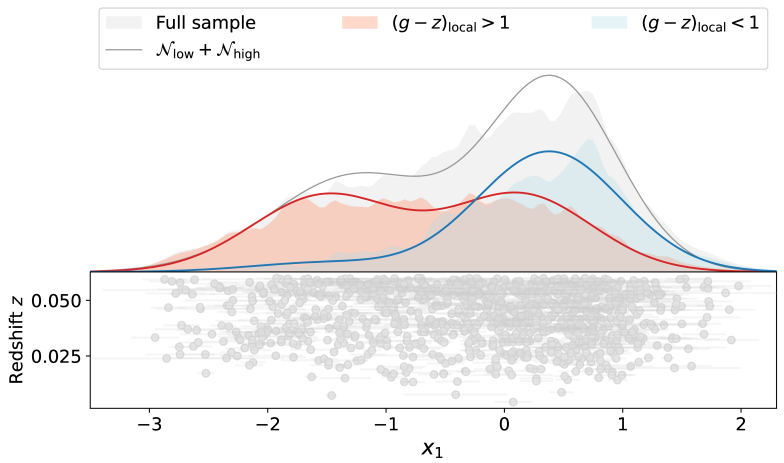
Milky way dust

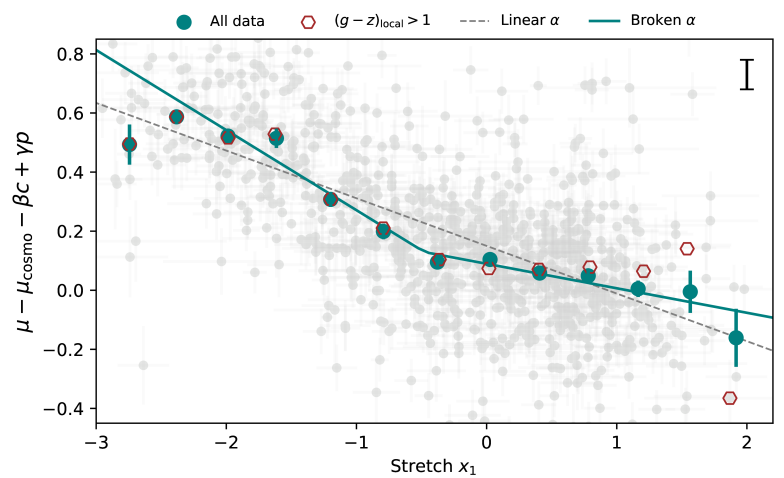




- High-z SN: low-extinction, infrared filters
- Low-z SN: everywhere, visible filters
- Errors in the extinction correction translate into distance ratio errors
- In ZTF cutting at $E(B-V) < 0.1$ retains 80% of the statistics

Galactic evolution





Ginolin et al. 2025

The issue is two-fold

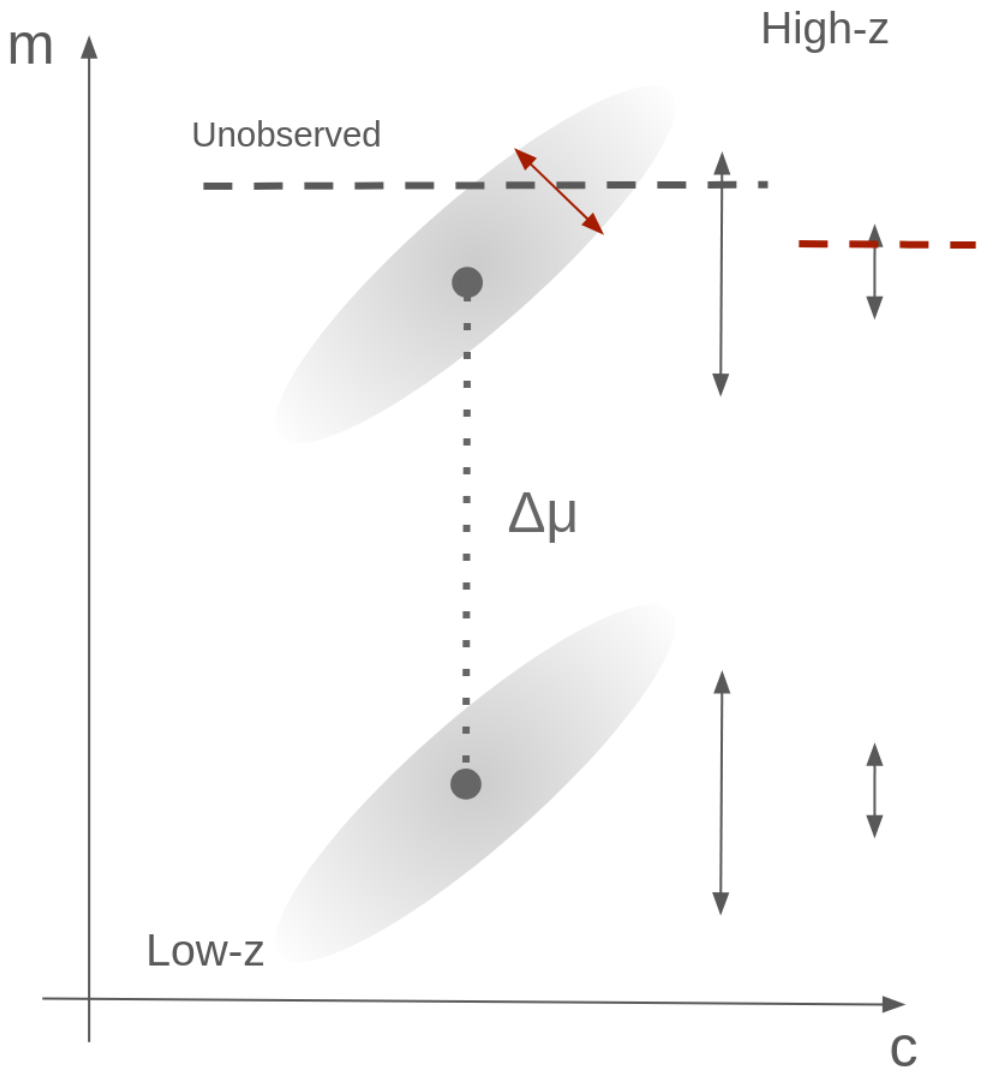
- Change in the environment (e.g. Dust, metallicity…)
- Population drift

The use of targeted survey of big galaxy at low-redshift worsen the issue

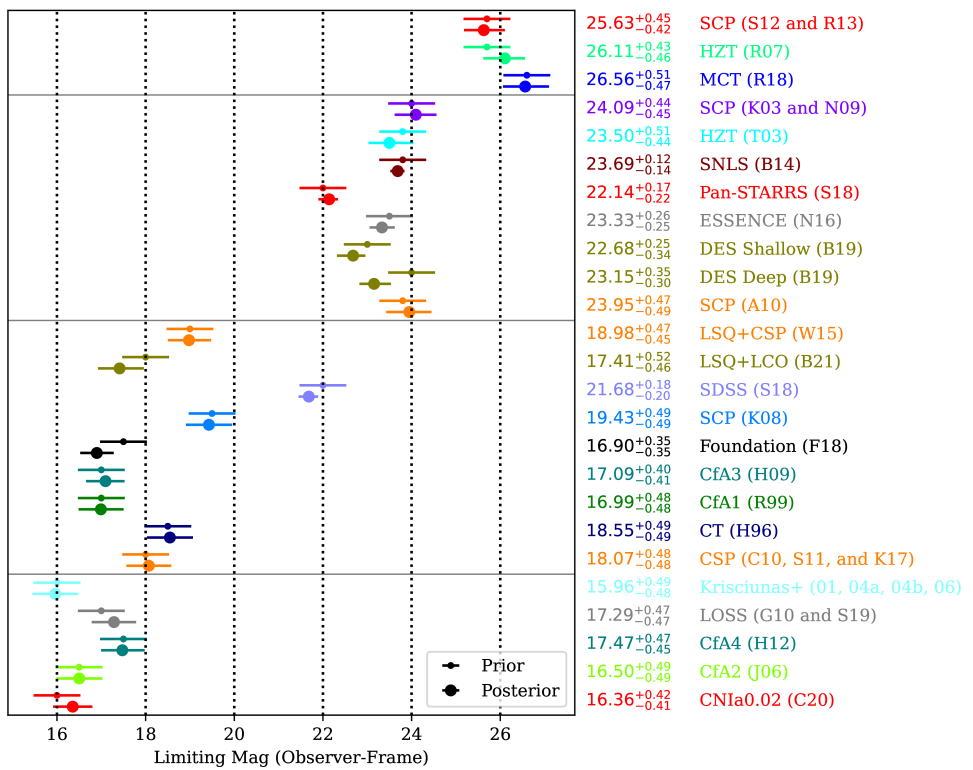
ZTF ease the problem

- Rolling search unbiased survey
- Due to its large size we could reselect environments to match the high redshift demography
- The large statistics uncover effects as demonstrated in DR2: https://ztfcosmo.in2p3.fr/papers

Selection effects

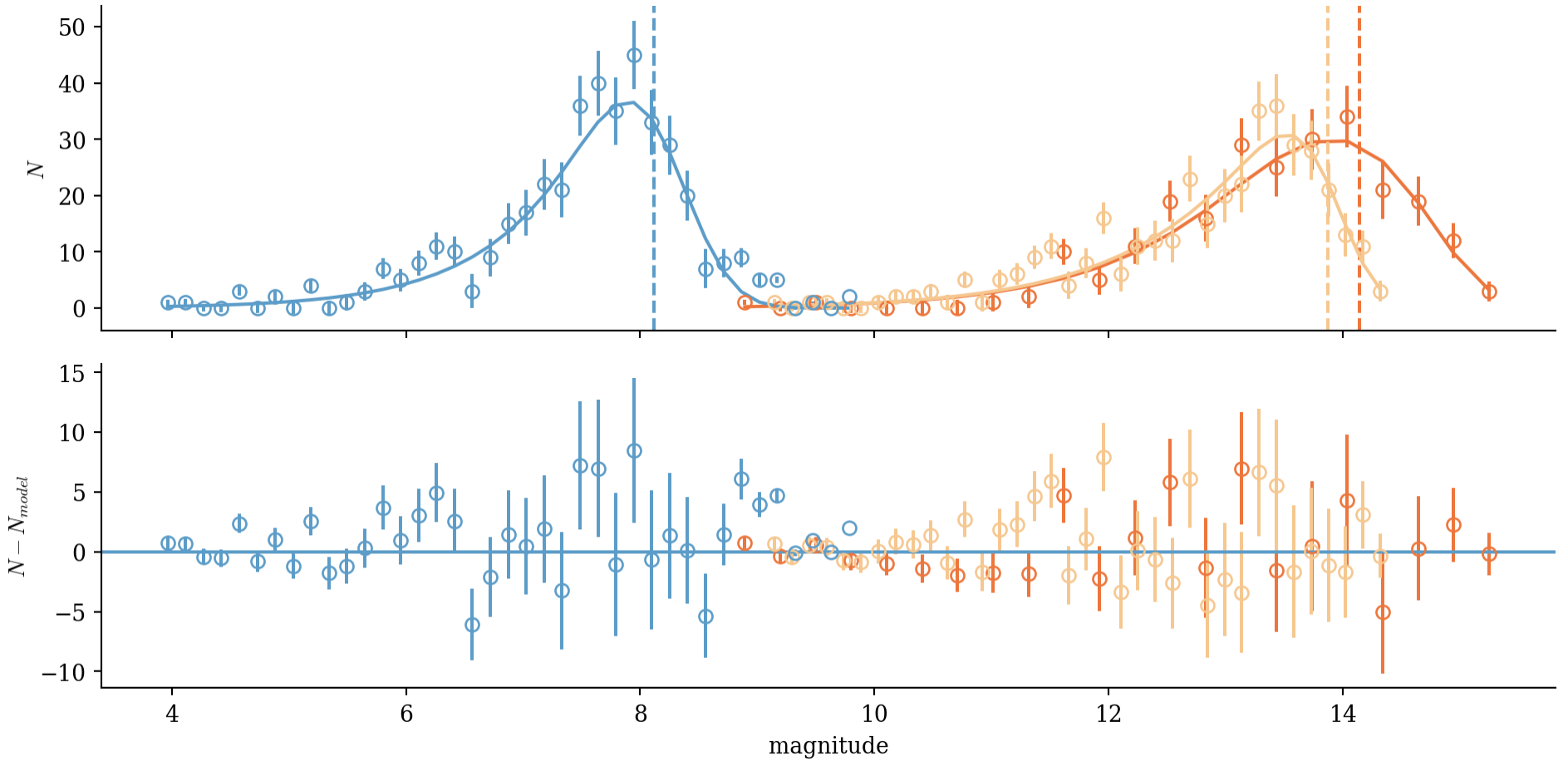


- bias due to “incomplete” standardization
- Selection functions must be known



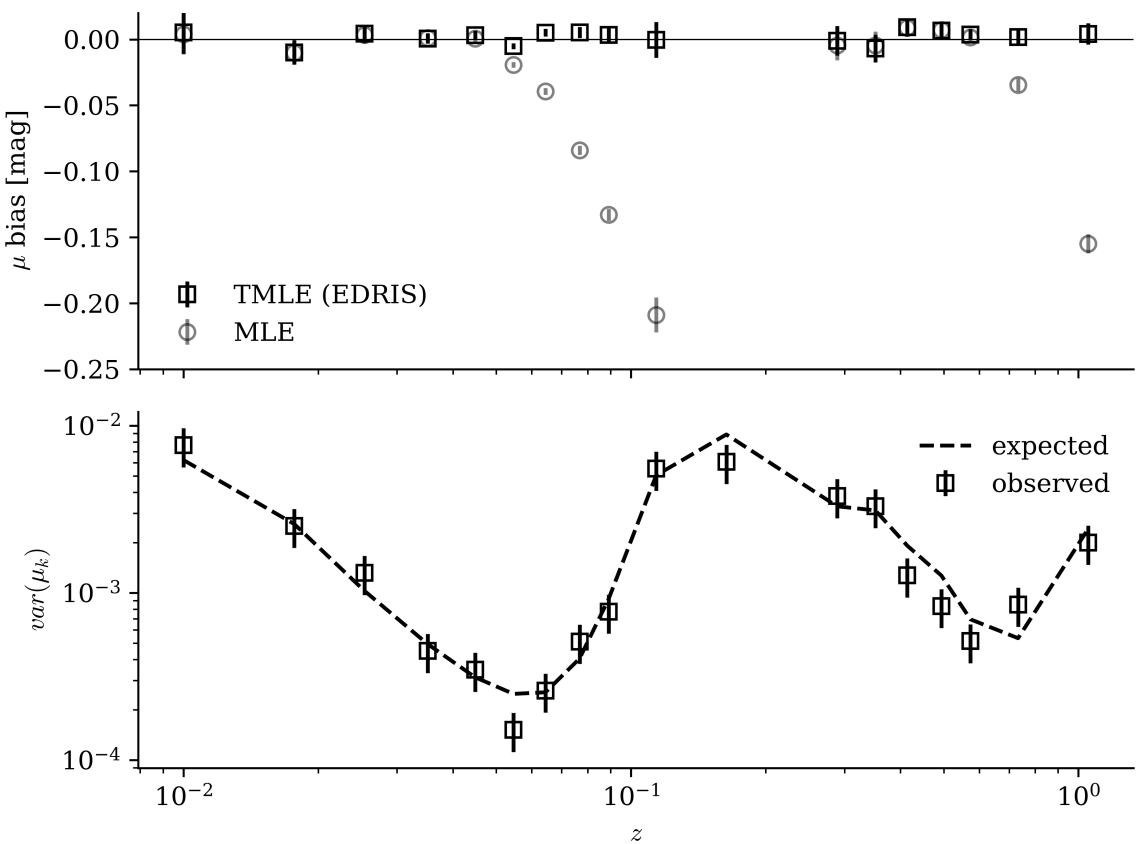
Union3: Rubin et al. (2025)

LEMAITRE selection functions



- 3 large rolling search surveys -> well determined
- Uncertainties on the selection function can be neglected

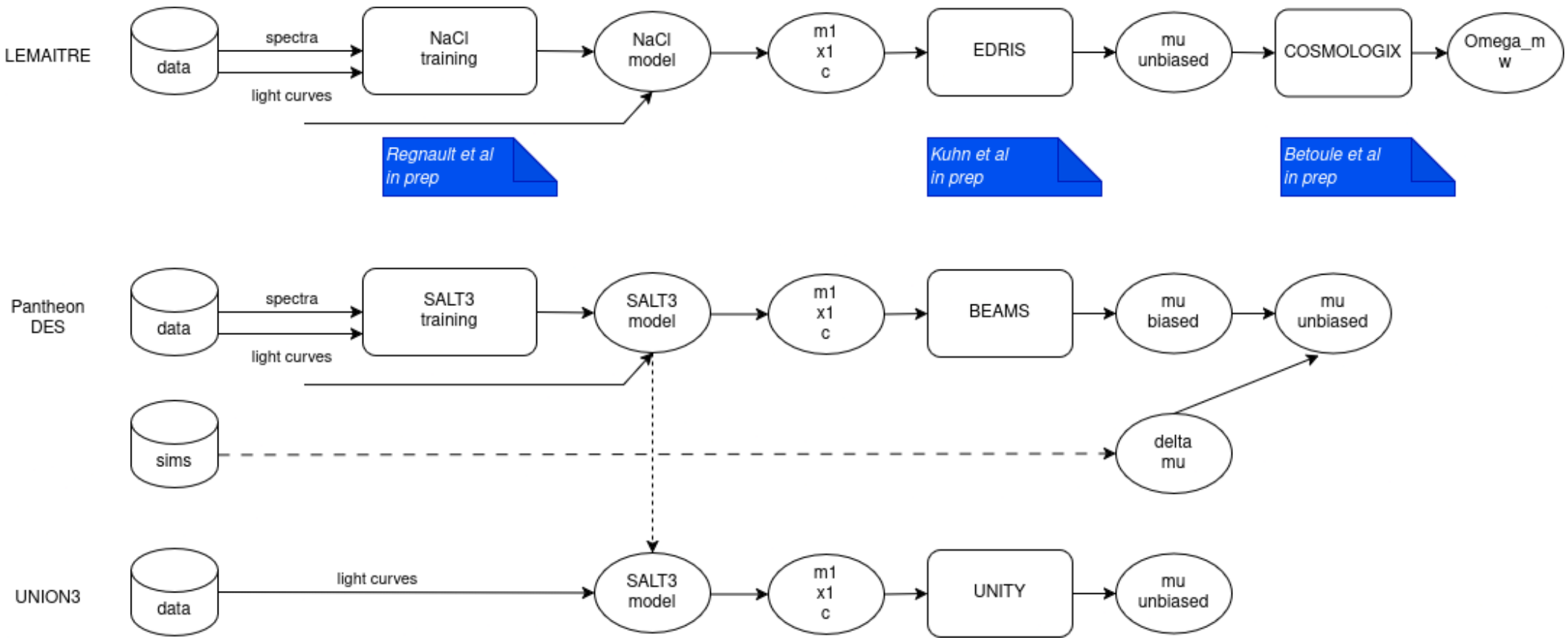
A direct unbiased MLE of distance exists in this case



- Include the truncation in the statistical model
- Straightforward and fast distance inference from minimizing the modified likelihood
- Opens the way to a largely simplified analysis
  - No need for expansive simulations

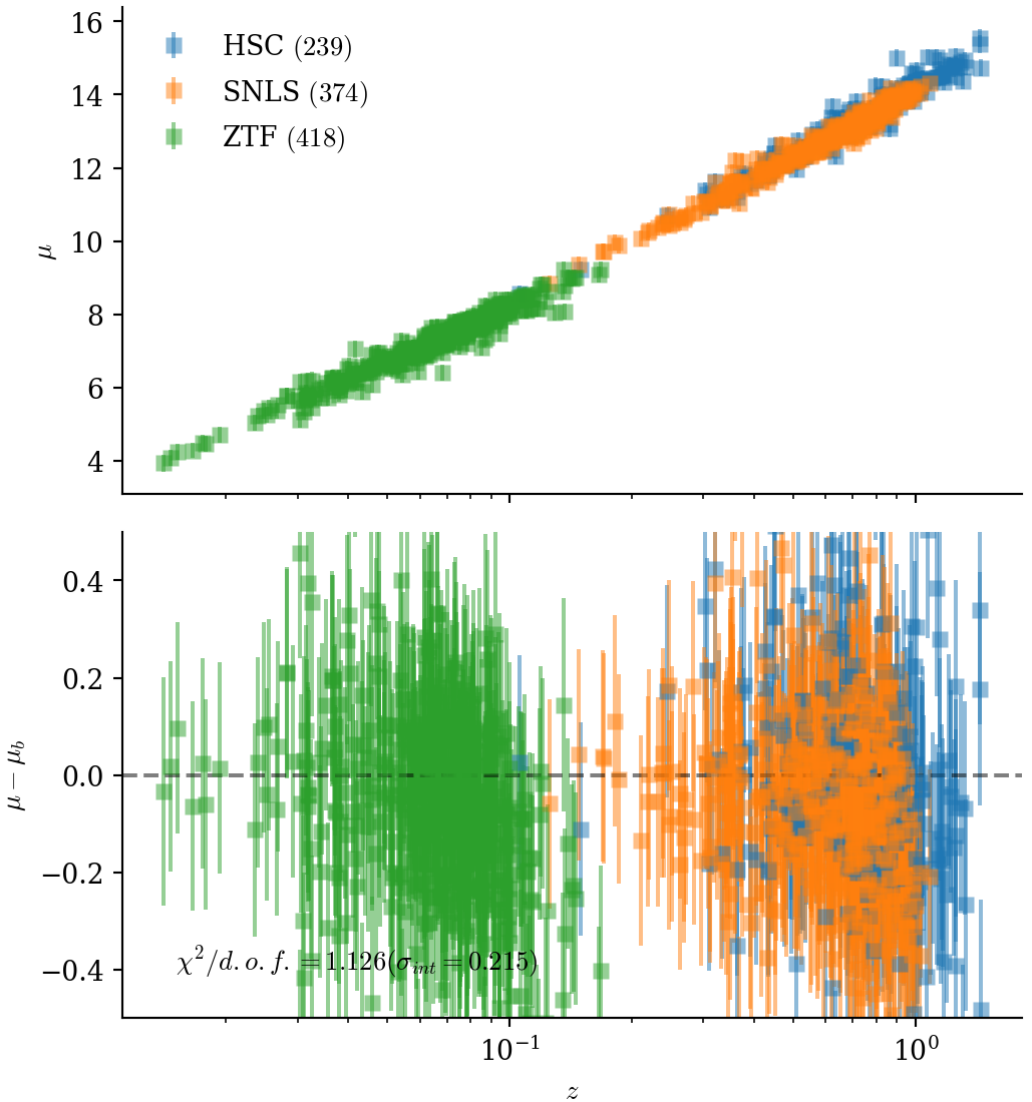
Kuhn et al. in prep.

A fully rewritten analysis chain



- The goal is to build a simulation free consistent distance estimate
- Tested on end to end simulations (including the light-curve model training)
- So far we have a one sigma effect

Conclusion



The LEMAITRE project

- Solves most potential measurement issues in the low-z sample by processing the ZTF sample with the same accuracy as large high-z survey
- Is statistically independent from available compilations
- Naturally eases some probe issues (lower extinction, non-targeted, known selection)
- Unblinding in wait for validation of the chain in data challenges