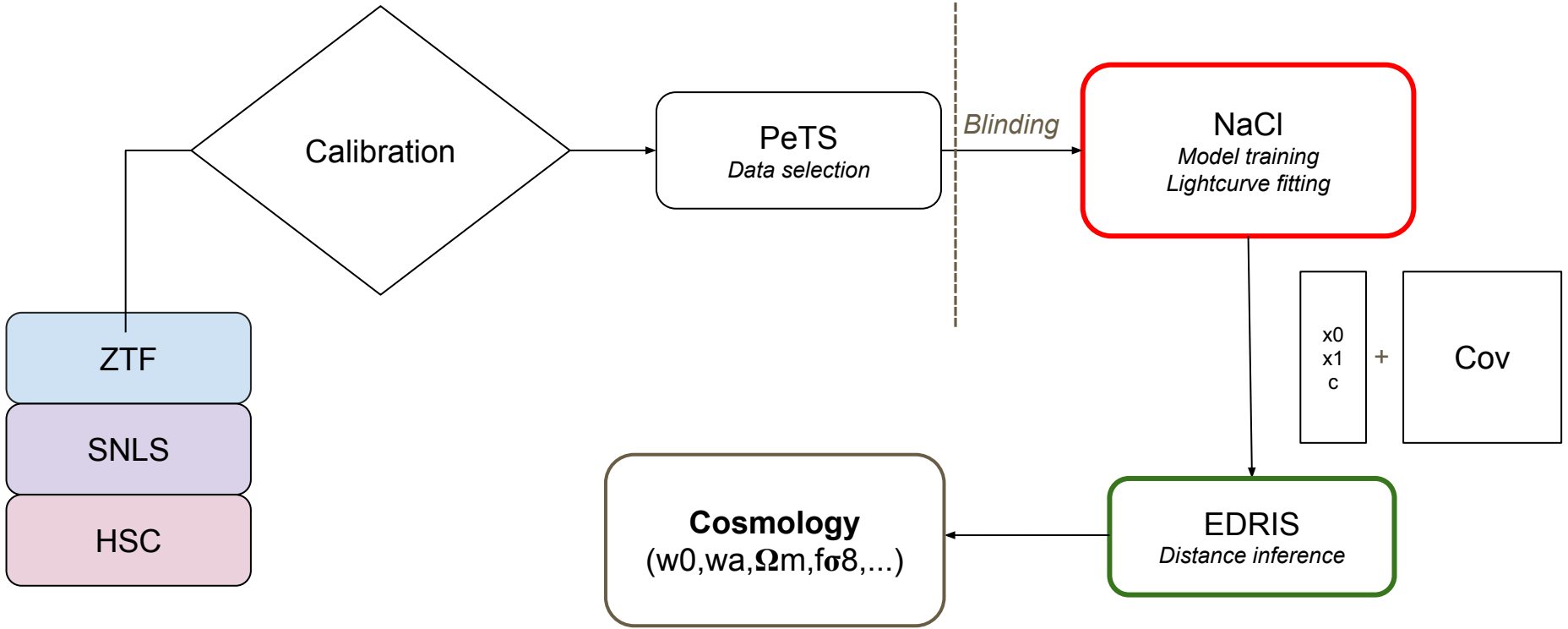
# Towards an independent measurement of Dark Energy's equation of state from a novel set of SNeIa

## *Cosmological inference in Lemaitre*

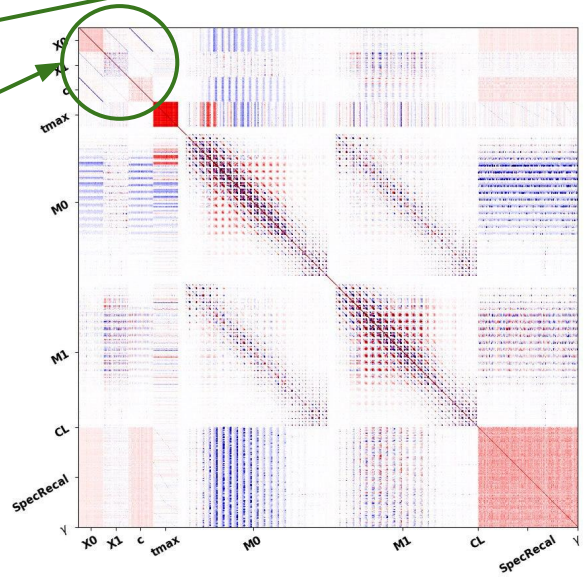
Dylan Kuhn, October 29th 2024
on behalf of the Lemaitre collaboration

# The Lemaitre analysis pipeline



# Cosmological inference

$$\begin{bmatrix} x_0 \\ x_1 \\ c \\ t_{max} \\ M_0 \\ M_1 \\ CL \end{bmatrix}$$




1- Standardization

$$\mu(z,\theta) = -2.5\log_{10}(x_0) - M + \alpha x_1 + \beta c$$

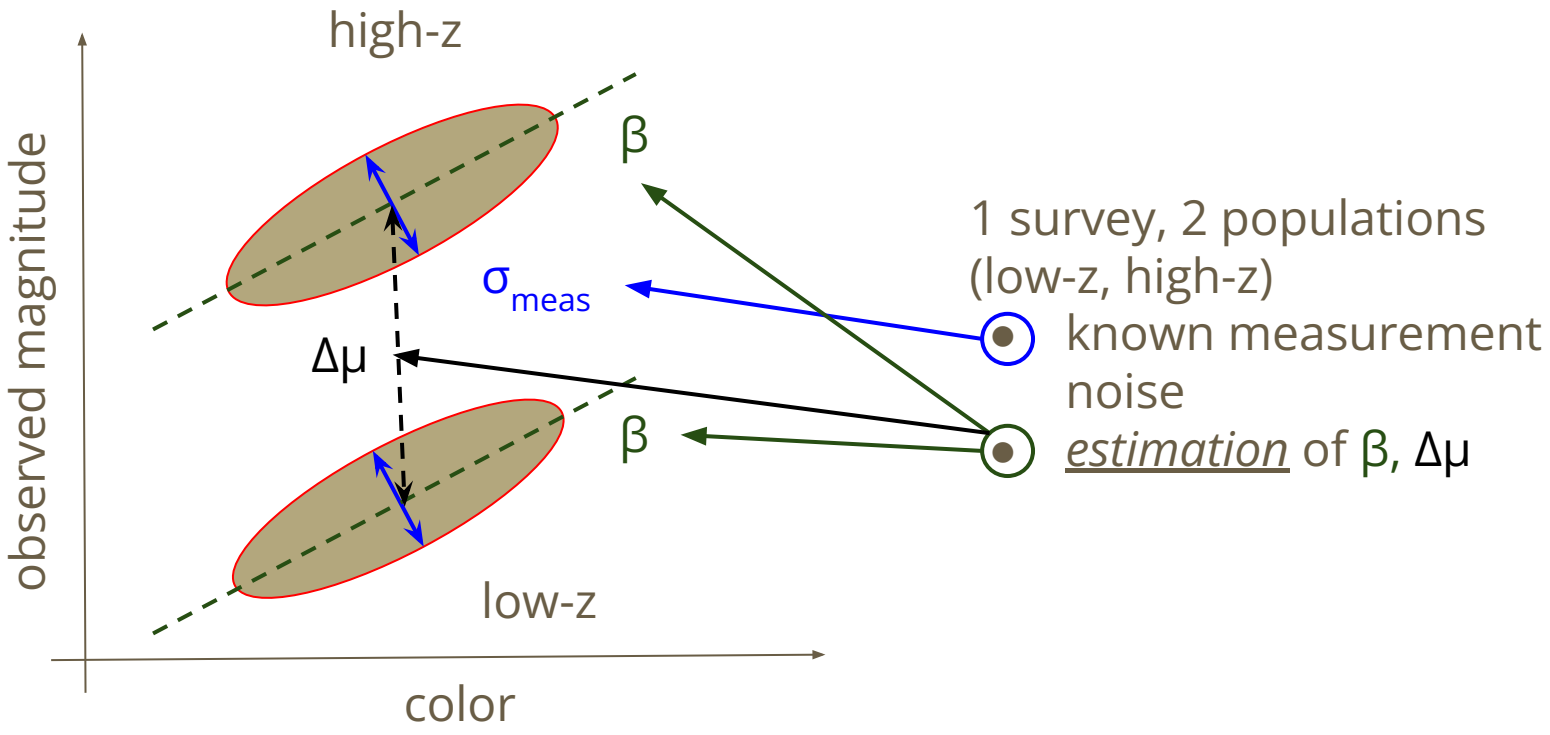
~45% dispersion at max

~15% dispersion at max

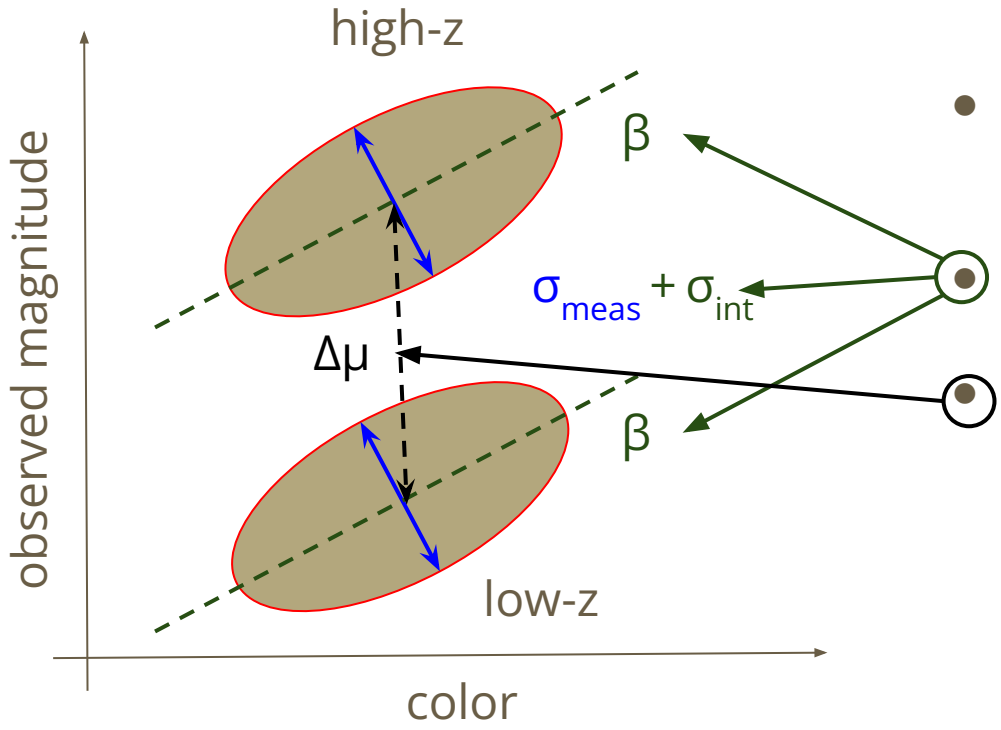
2- Estimation of residual dispersion σ

3- Estimation and correction of intrumental selection bias Δμ(σ)

# Instrumental selection bias: the “Malmquist bias”



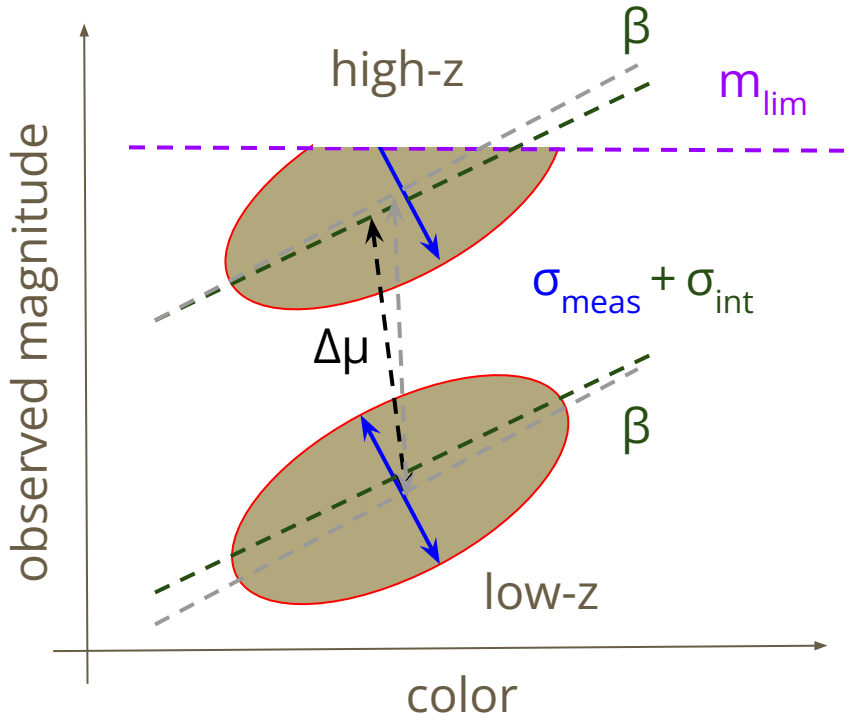
# Instrumental selection bias: the “Malmquist bias”




- known measurement noise
  + *intrinsic noise*
  *biased* estimation of β, $\sigma_{int}$
  estimation of Δμ

Not well defined problem but cosmology does not change

# Instrumental selection bias: the “Malmquist bias”



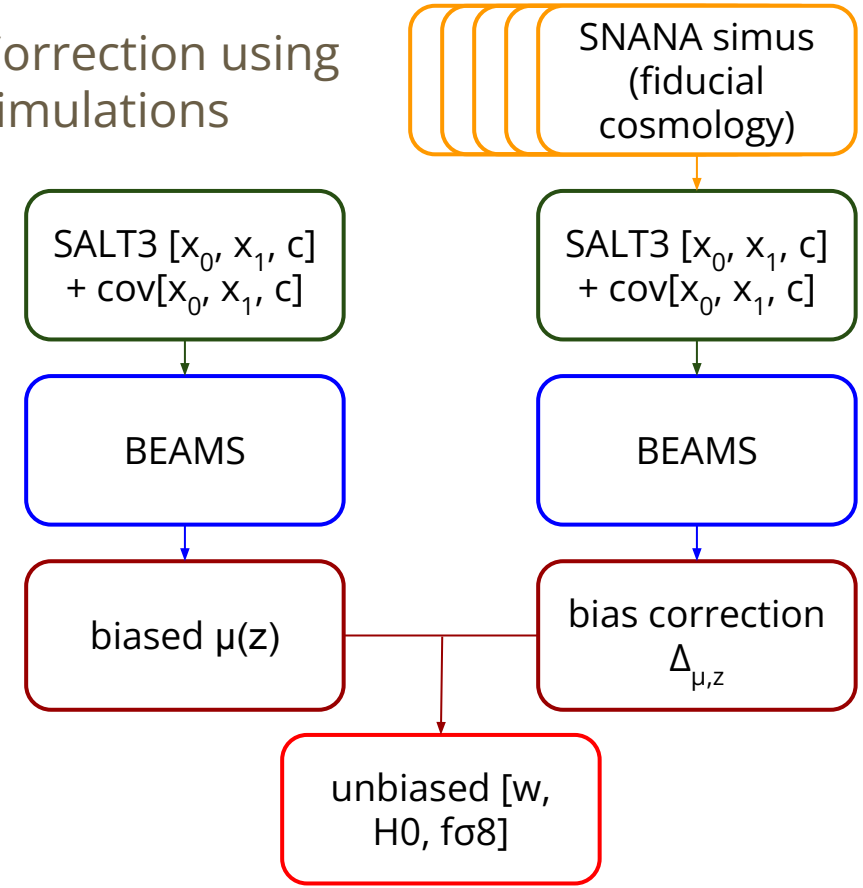

In practice, only the *intrinsically brightest supernovae* are detected:

- *truncation of data* by $m_{lim}$
- *biased* estimation of β, $\sigma_{int}$, Δμ

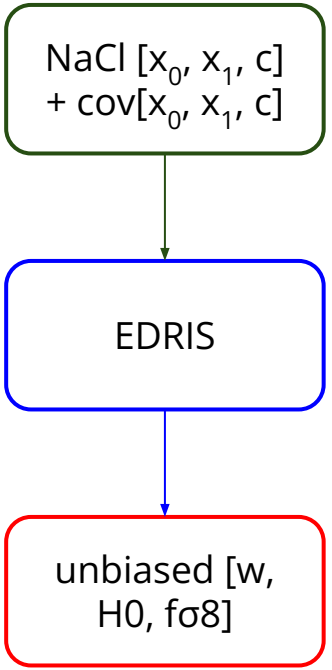
Not well defined problem and cosmology is biased by truncation

# How to tackle this issue

Correction using simulations




Account for the selection effects in the statistical model



# Our approach: NaCl + EDRIS

EDRIS:

- cosmology from NaCl [$x_0$, $x_1$, c]

- includes selection in statistical model

$$m_{obs,i} = m_{obs,i}^{*} + \eta_i \; if \; m_{obs,i}^{*} \leq m_{lim} + \kappa_i$$

$$with \; \eta_i \sim \mathcal{N}\left(0, C_i\right) \; and \; \kappa_i \sim \mathcal{N}\left(0, \sigma_{m_{lim}}^{2}\right)$$

$$m_{obs,i} \; is \; unobserved \; otherwise$$

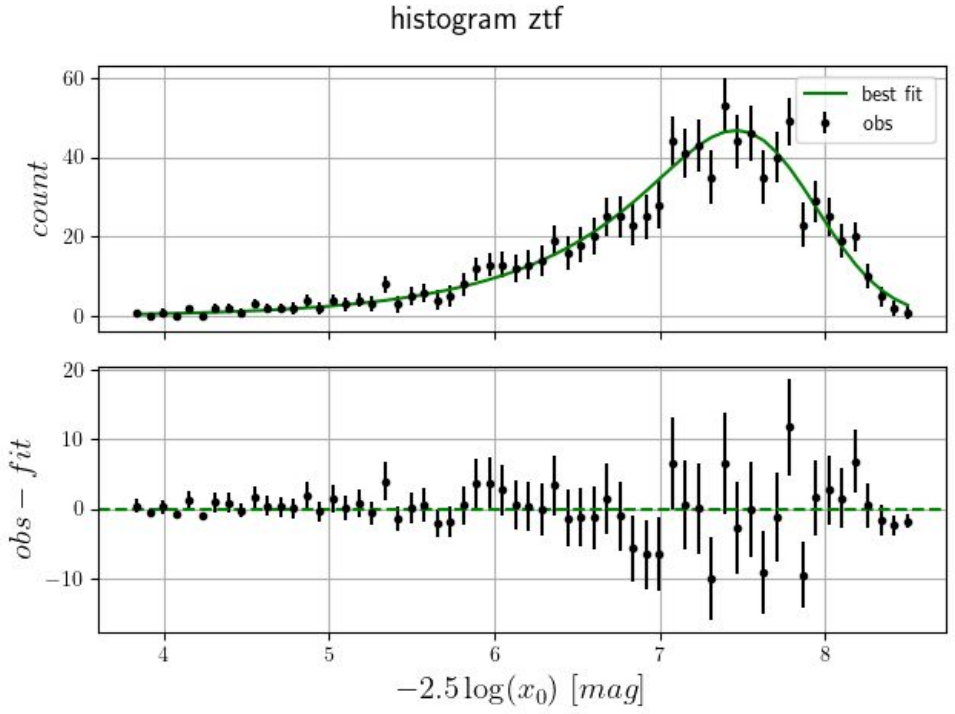
Two-step estimator:

- estimation of the selection functions [$m_{lim}$, $\sigma_{mlim}$] from $m_{obs}$ histograms

- standardization & estimation of distances

# Estimation of the selection function

Estimation of [$m_{lim}$, $\sigma_{mlim}$] for each survey from observed magnitudes histogram



# Estimation of the selection function

## *Density of SNIa*

$$\rho(z,m) = R \frac{\partial V_c}{\partial z}(z) \Phi\left(\frac{m - m_{lim}}{\sigma_{m_{lim}}}\right) \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{1}{2}\left(\frac{m - \mu(z) - M}{\sigma_m}\right)^2}$$

SNIa rate (supposed constant)

Gaussian CDF

$$\sigma_m = \sqrt{\sigma^2 + \alpha^2 \sigma_{x_1}{}^2 + \beta^2 \sigma_c{}^2}$$

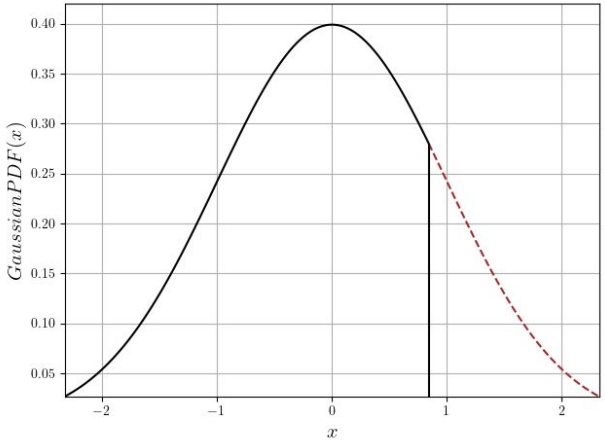
## *Number of SNIa in a bin*

$$N_b = \int_0^{\infty} \int_{m_b}^{m_{b+1}} \rho(z,m)\, \mathrm{d}z\, \mathrm{d}m$$

## *Poisson likelihood maximization*

$$\mathcal{L}_{selection} = \prod_i \frac{N_{b,i}{}^{N_{obs,i}}}{N_{obs,i}!} e^{-N_{b,i}}$$

# Standardization & estimation of distances



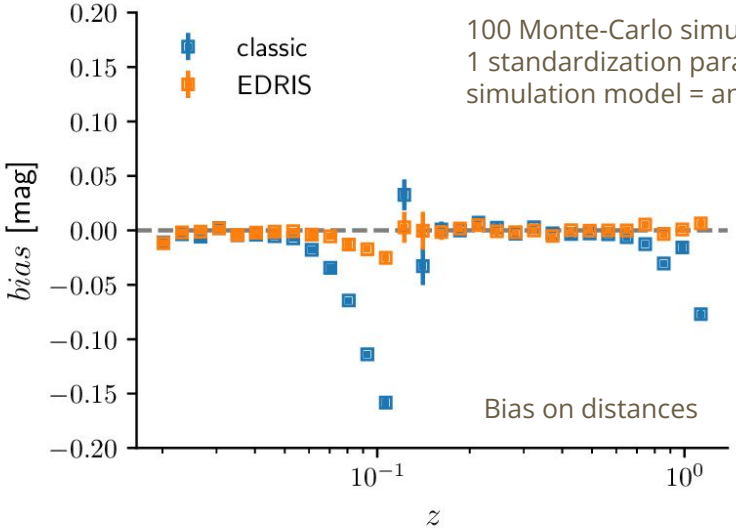

classic likelihood for multivariate normal distributions

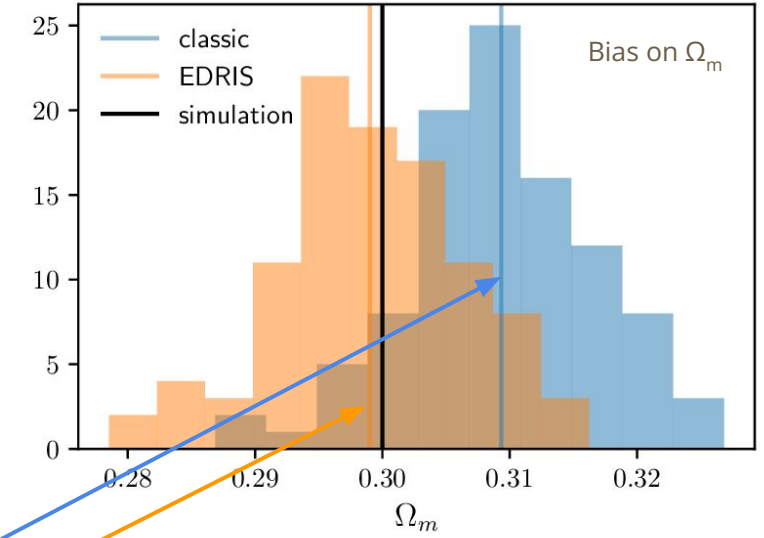
term that takes into account the truncation of data

$$\Gamma = -\ln\left(\left|C(\sigma)^{-1}\right|\right) + r^t C(\sigma)^{-1} r + \sum_i 2\ln\left(\Phi\left(\frac{m_{lim} - M^* - \mu_i - \alpha x_{1,i}^* - \beta c_i^*}{\sqrt{\sigma^2 + \sigma_{m_{lim}}^2}}\right)\right) - 2\ln\left(\Phi\left(\frac{m_{lim} - m_{obs,i}}{\sqrt{\sigma_{m_{lim}}^2 + f(C_i)}}\right)\right)$$

$$with\ \Phi(z) = \frac{1}{2}\left(1 + \mathrm{erf}\left(\frac{z}{\sqrt{2}}\right)\right)\ and\ r = m_{obs} - M^* - \mu - \alpha x_1 - \beta c$$

# Bias on distances and cosmological parameters

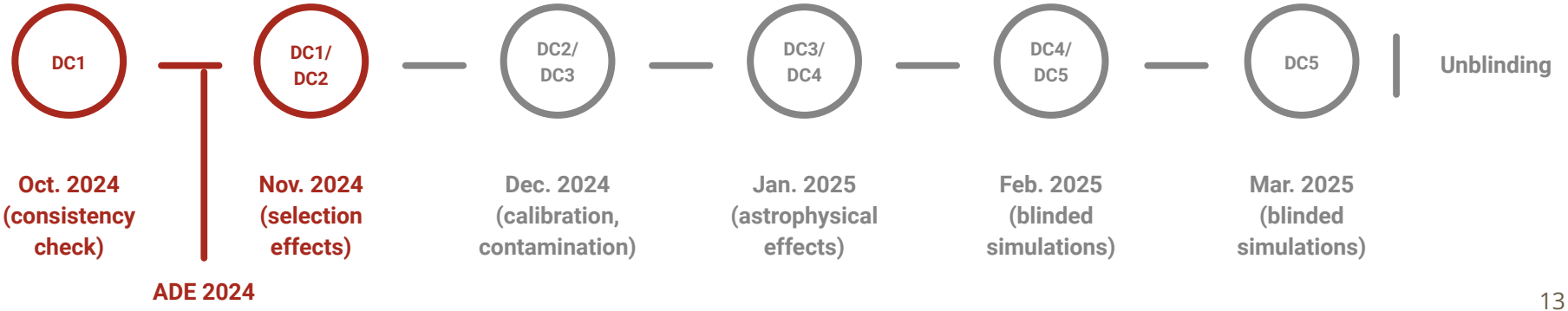



| Estimator | Bias on $\Omega_m$ | Mean of reconstructed $\Omega_m$ | $\sigma(\Omega_m)$ |
|---|---|---|---|
| classic | 0.0093 ± 0.0007 | 0.309 | 0.007 |
| EDRIS | -0.0010 ± 0.0007 | 0.299 | 0.007 |

# End-to-end validation on simulations: data challenges

- 5 data challenges towards data unblinding
- Increasing complexity and realism
- Pipeline extensively tested through continuous integration
- After pipeline validation, no need for simulations anymore



# Goals achieved by data challenges

- Ensuring that the inference pipeline can reconstruct unbiased cosmology taking into account several effects:

  - correlated uncertainties

  - realistic selection functions

  - foregrounds (dust, lensing, etc)

  - increasingly complex evolution effects

- Ensuring that the error on cosmological parameters incorporates all sources of uncertainties: calibration, measurement, model, color scatter, etc

# What's next for EDRIS ?

- Work for next month : merging cosmo likelihood and selection likelihood

  → fit all parameters at the same time

- DC2 : key date → validation of the method on realistic simulations (several open questions)

  → what happens when NaCl is trained on truncated dataset ?

  → is EDRIS able to reconstruct unbiased cosmology ?

- DR2.5 paper : methodology paper

  → method (started drafting)

  → behaviour of the estimator on a realistic case (todo)