Measuring $f\sigma_8$ with the ZTF SN Ia sample

Simulation of the Sample Bias

Bastien Carreres, Julian Bautista, Benjamin Racine,
Fabrice Feinstein, Dominique Fouchez

Aix Marseille-Université, CNRS, IN2P3, CPPM, Marseille, France

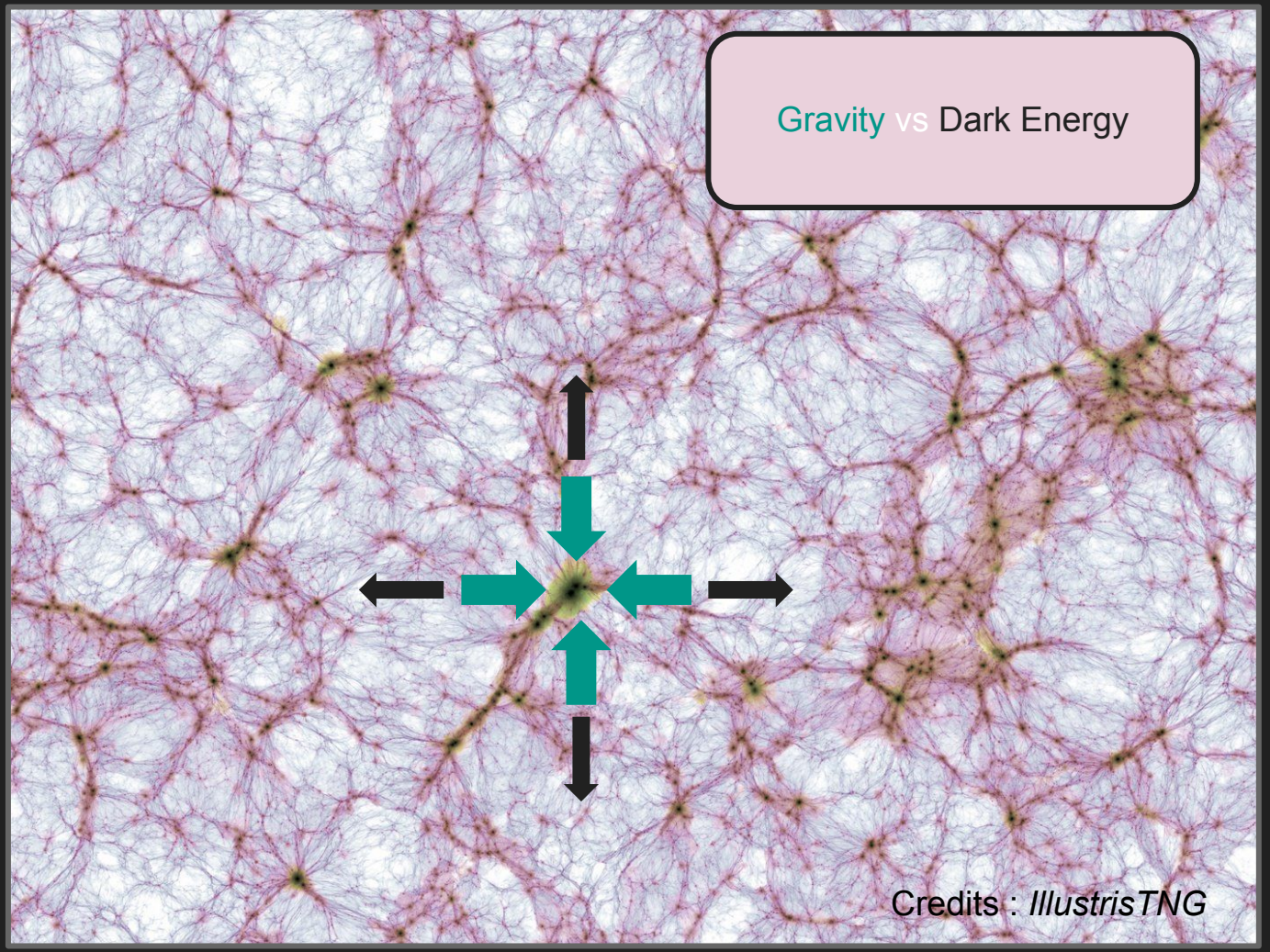
What is $f\sigma_8$?

Growth factor

$$\delta_{\rm m} = \hat{\delta}_{\rm m}(\mathbf{x})\boxed{\rm D}(t)$$

Growth rate

$$f = \frac{d\ln D}{d\ln a}$$



What is $f\sigma_8$?

Growth factor

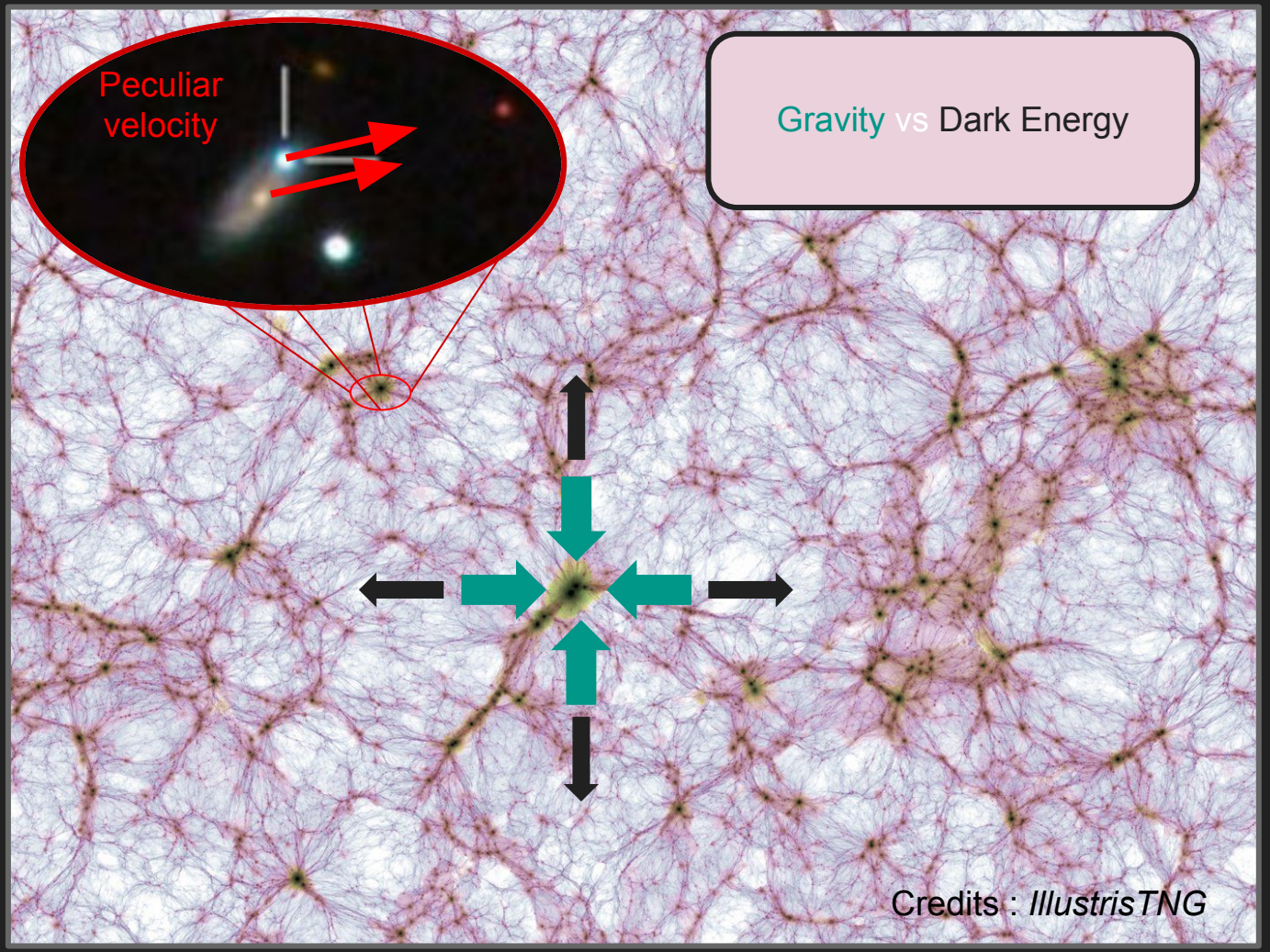
$$\delta_{\rm m} = \hat{\delta}_{\rm m}(\mathbf{x})\boxed{\rm D(\mathit{t})}$$

Growth rate

$$f = \frac{d\ln D}{d\ln a}$$

Peculiar velocities

$$\nabla.\mathbf{v} \propto fD$$



What is $f\sigma_8$?

Growth factor

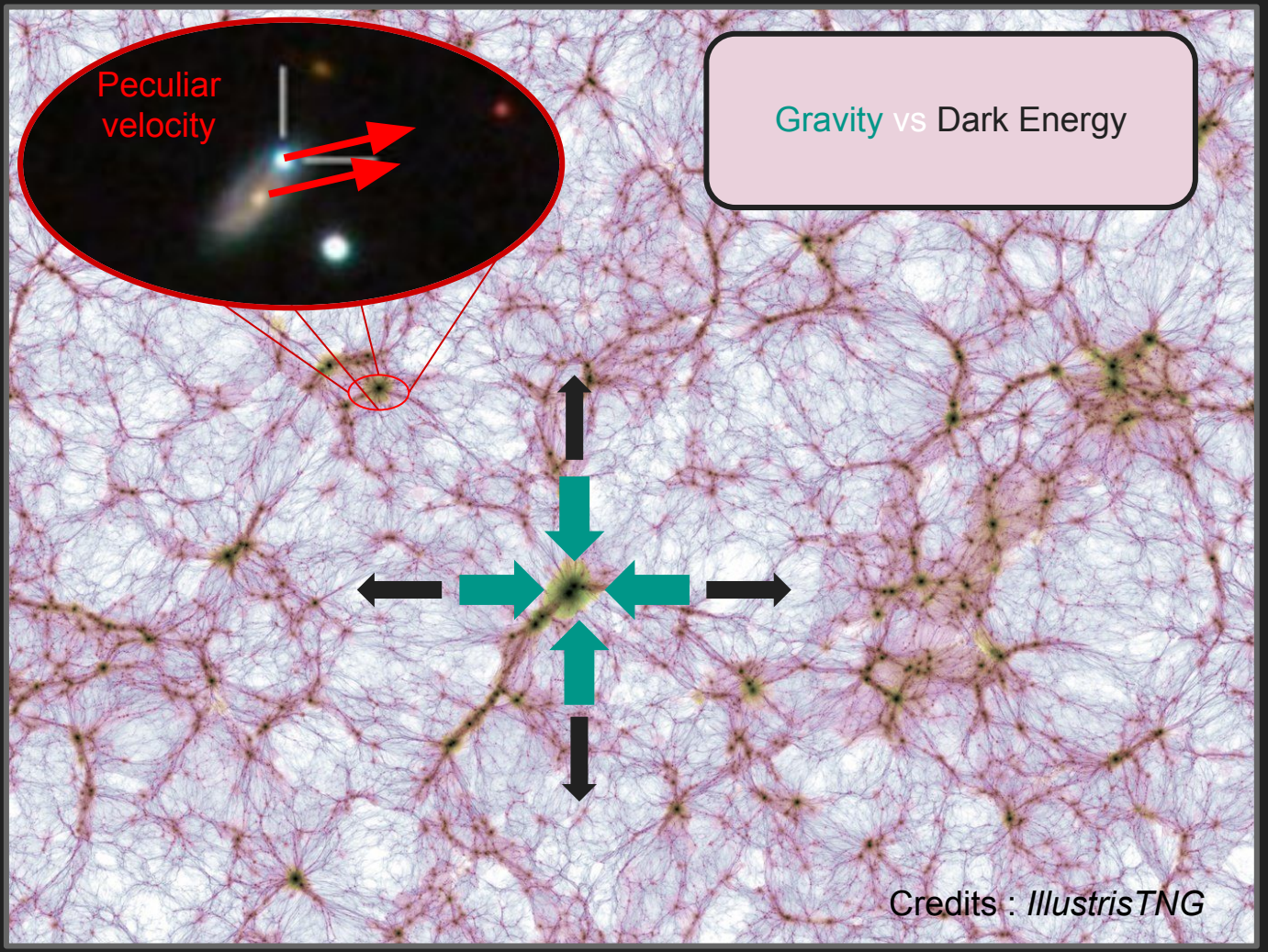
$$\delta_{\rm m} = \hat{\delta}_{\rm m}(\mathbf{x})\boxed{\rm D}(t)$$

Growth rate

$$f = \frac{d\ln D}{d\ln a}$$

Peculiar velocities

$$\nabla.\mathbf{v} \propto f\cancel{D}$$
$$\propto f\sigma_8$$



What is $f\sigma_8$?

Growth factor

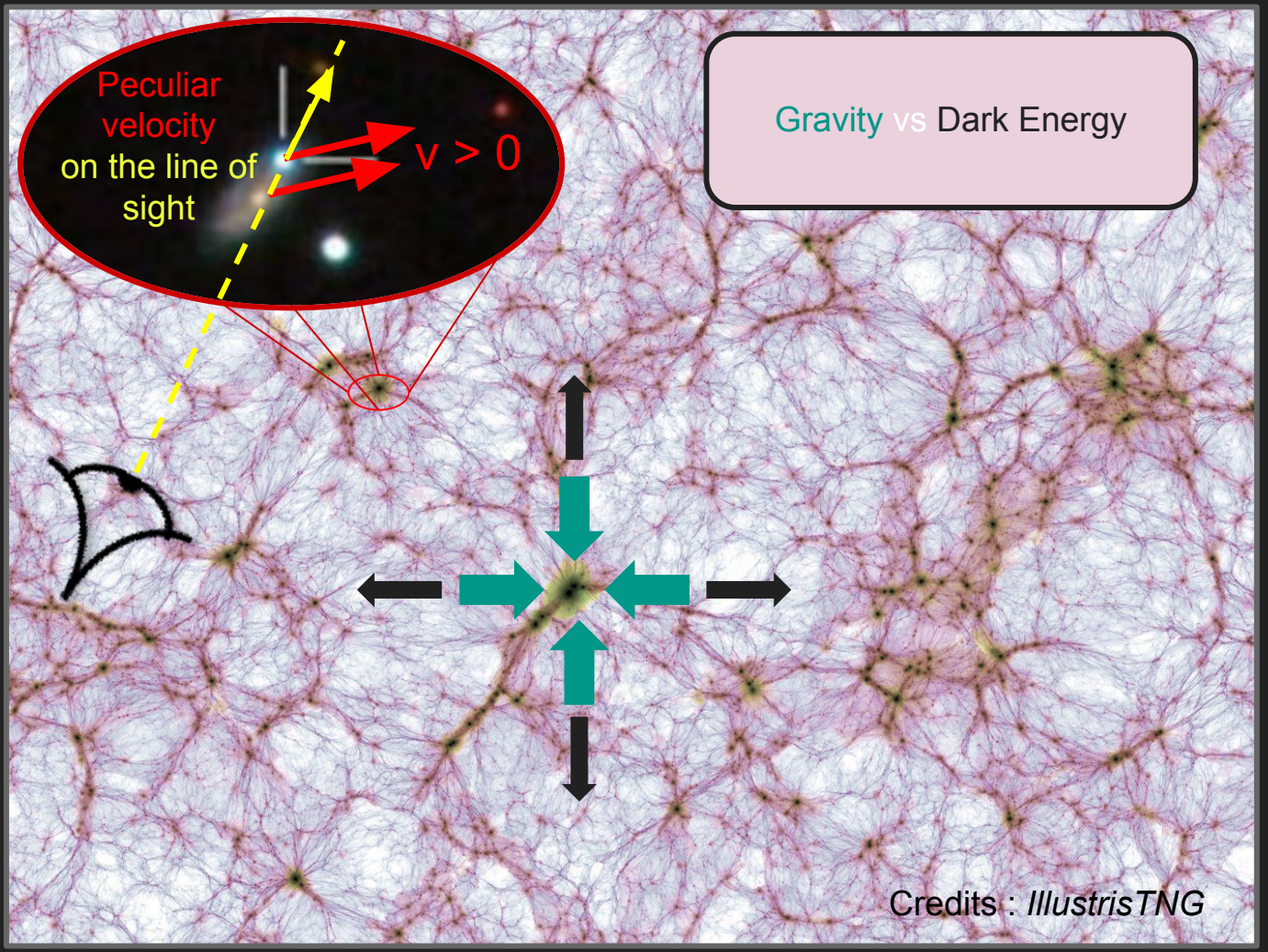
$$\delta_{\rm m} = \hat{\delta}_{\rm m}(\mathbf{x})\boxed{\rm D}(t)$$

Growth rate

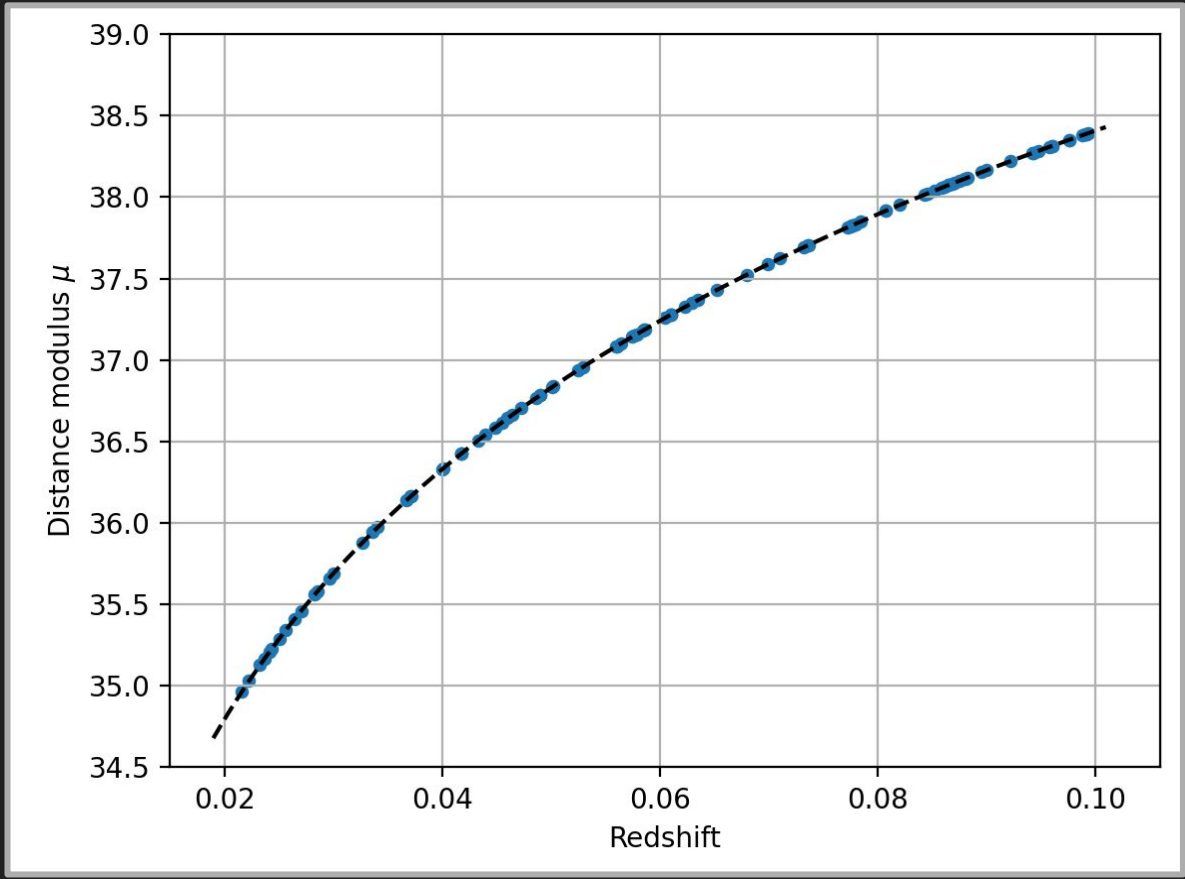
$$f = \frac{d\ln D}{d\ln a}$$

Peculiar velocities

$$\nabla.\mathbf{v} \propto f\cancel{D}$$
$$\propto f\sigma_8$$



The Hubble diagram : without peculiar velocities



The Hubble diagram : with peculiar velocities

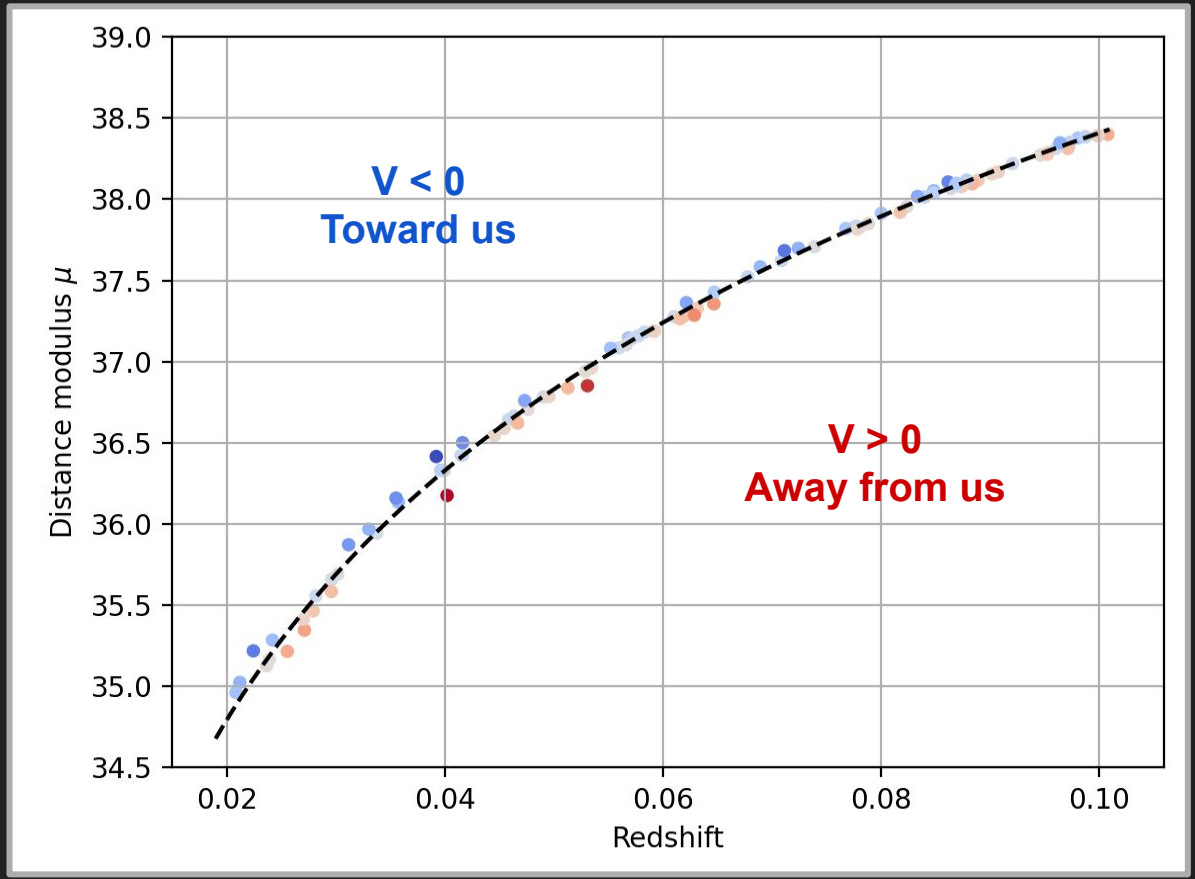
Adding peculiar velocity :

Effect of v ~ 300 km / s

$\Delta z \sim 0.001\ (v / c)$

$\Delta \mu \sim 0.004$ mag

Δz and **Δμ** variations have the same sign as **v**



The Hubble diagram : SN Ia intrinsic scattering

Adding peculiar velocity :

Effect of v ~ 300 km / s

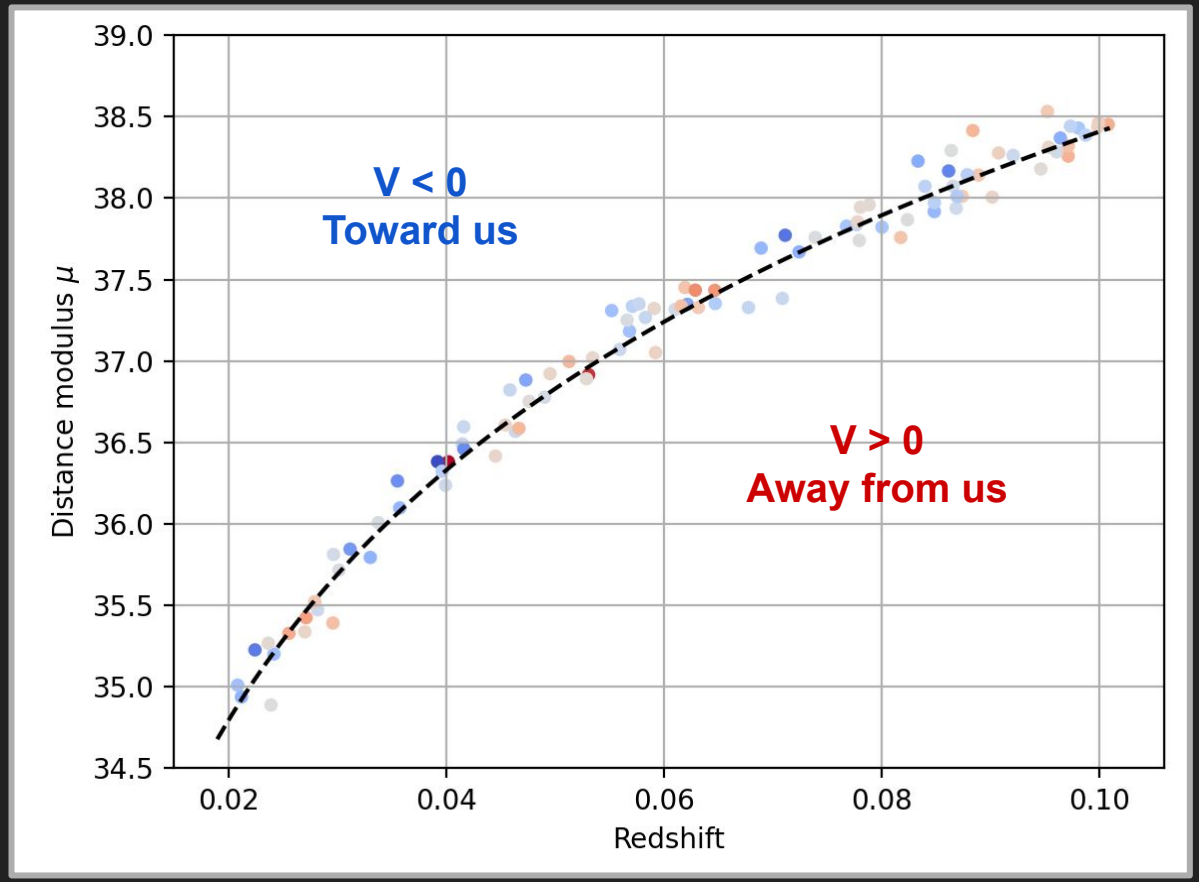
$\Delta z \sim 0.001\ (v / c)$

$\Delta \mu \sim 0.004$ mag

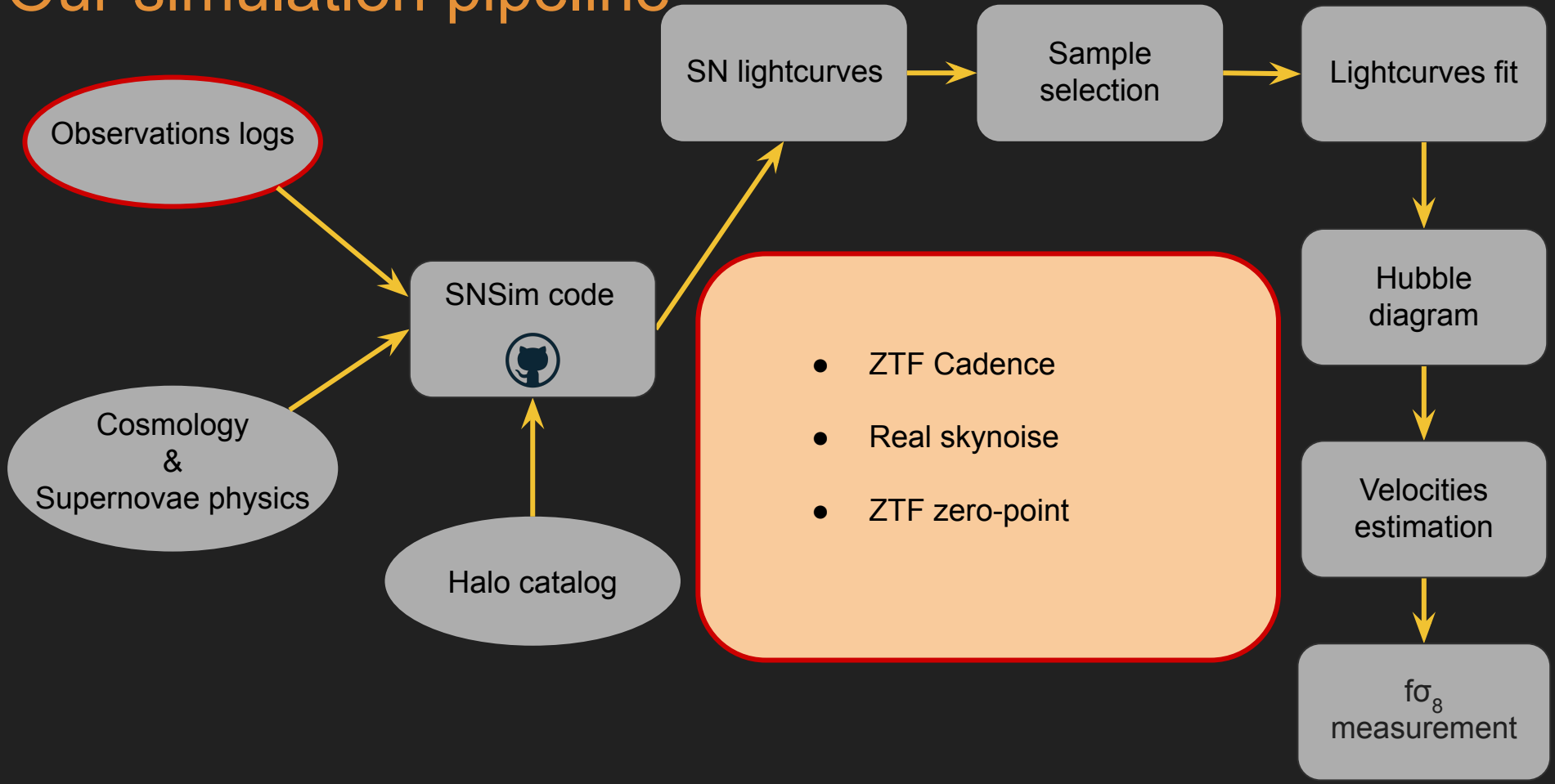
Δz and **Δμ** variations have the same sign as **v**

Adding SN Ia luminosity intrinsic scatter :

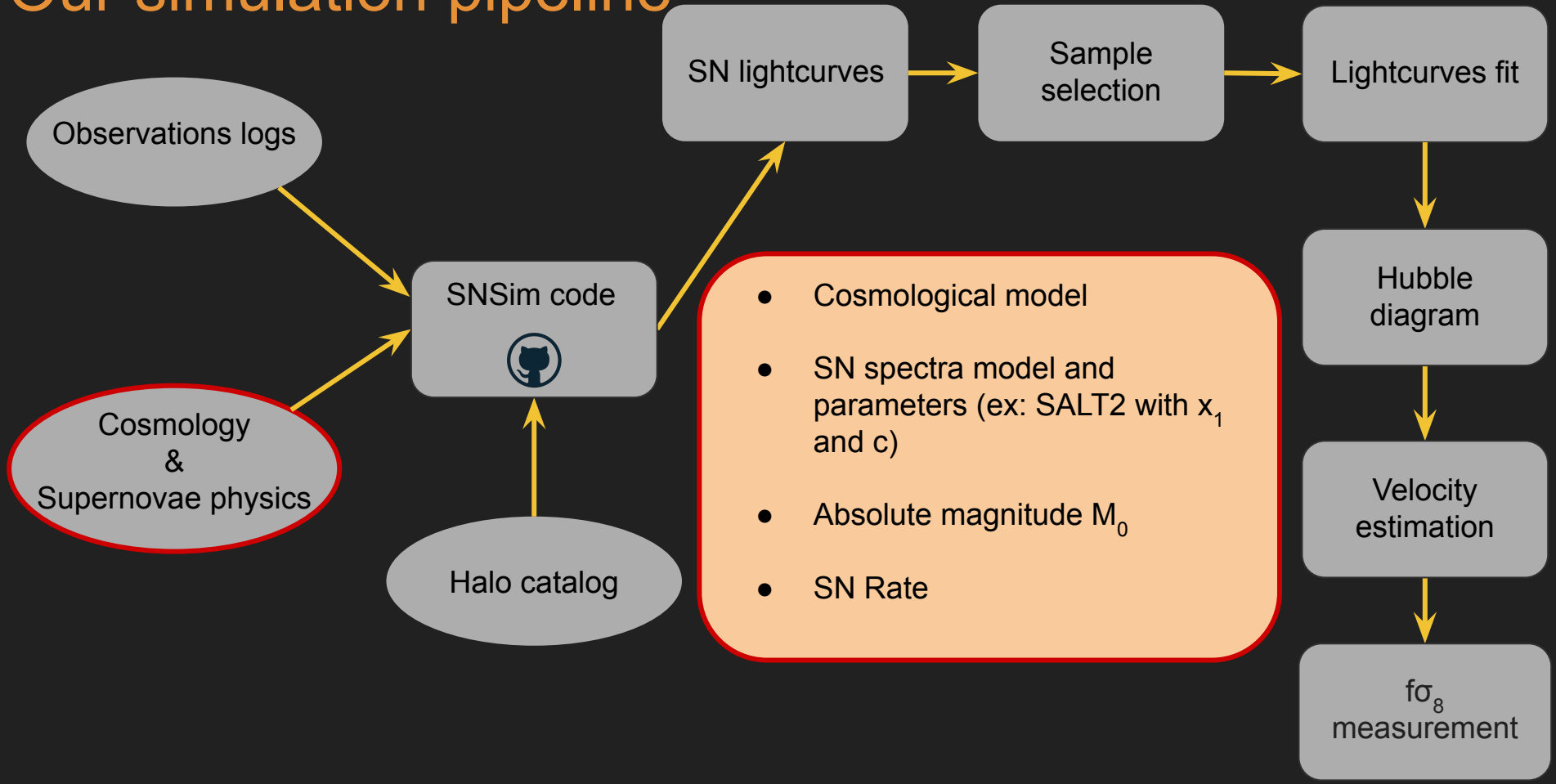
$\sigma_{int} \sim 0.12$ mag



Our simulation pipeline



Our simulation pipeline



Our simulation pipeline

Observations logs

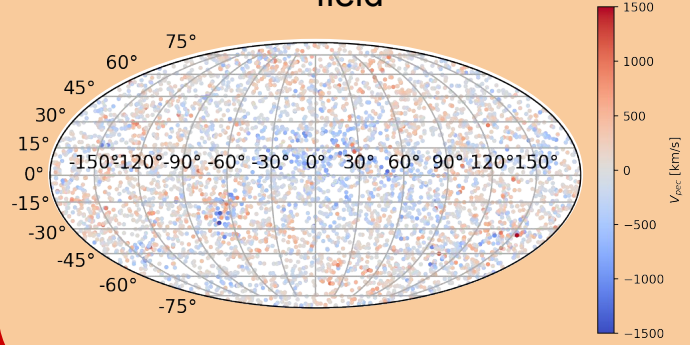
Cosmology
&
Supernovae physics

SNSim code

Halo catalog

SN lightcurves

RA, Dec and z coordinates with velocity field



Sample selection

Lightcurves fit

Hubble diagram

Velocity estimation

$f\sigma_8$ measurement

Our simulation pipeline

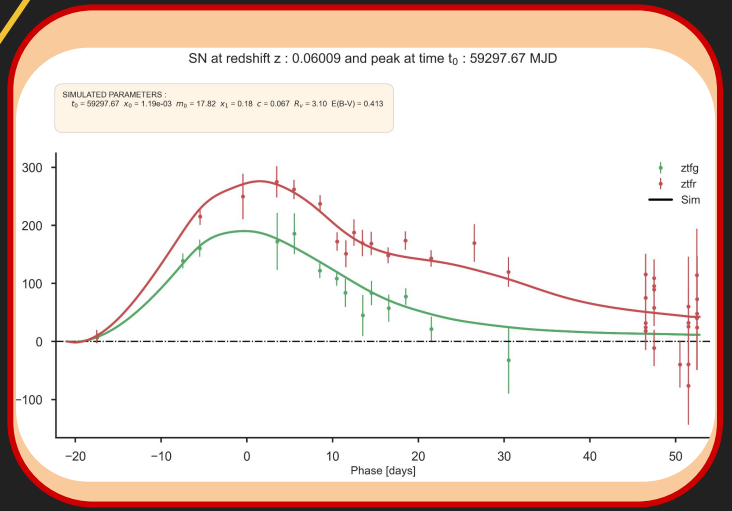
Observations logs

Cosmology & Supernovae physics

Halo catalog

SNSim code

SN lightcurves



Sample selection

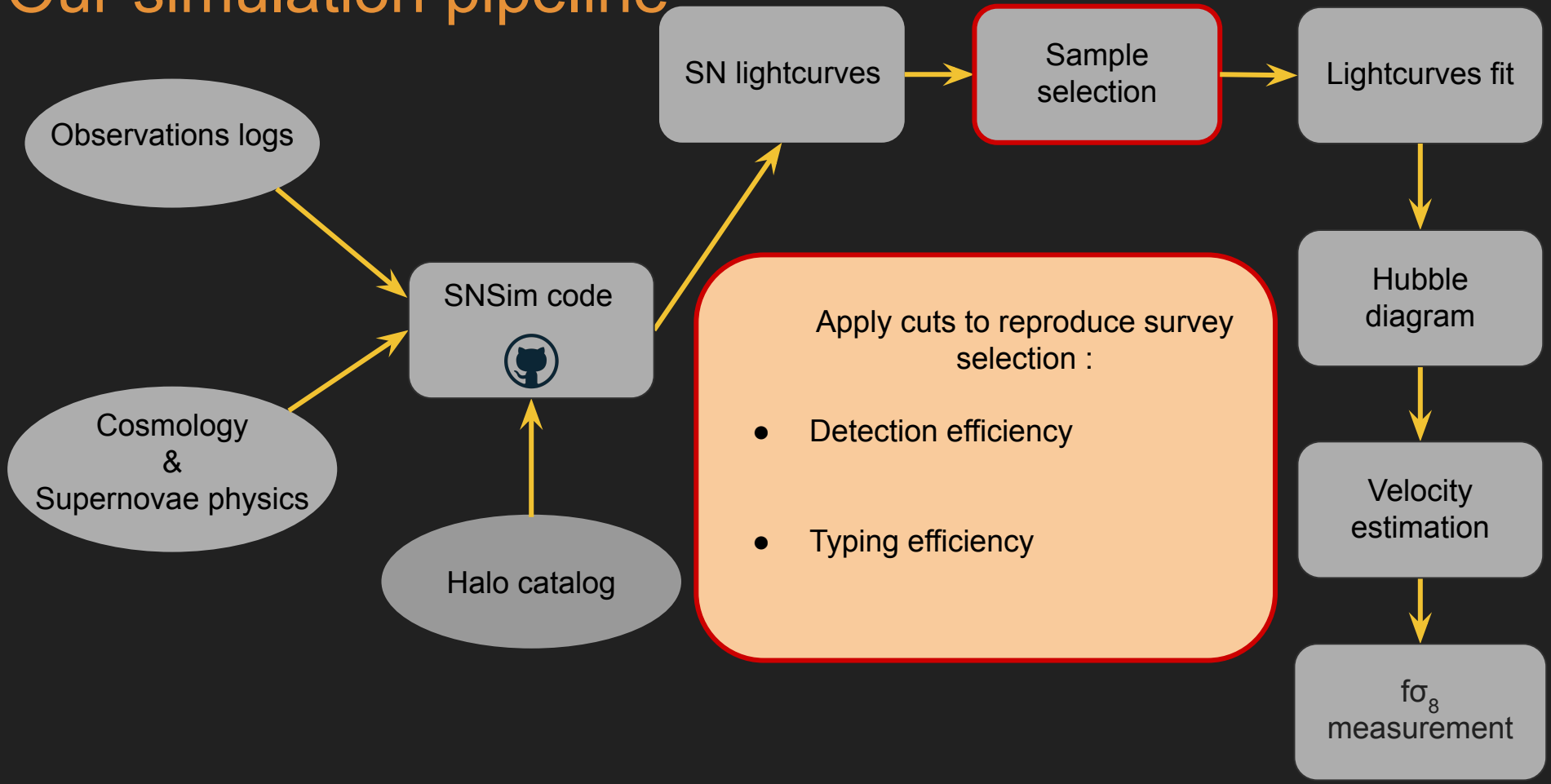
Lightcurves fit

Hubble diagram

Velocity estimation

$f\sigma_8$ measurement

Our simulation pipeline



Our simulation pipeline

Observations logs

Cosmology & Supernovae physics

Halo catalog

SNSim code

SN lightcurves

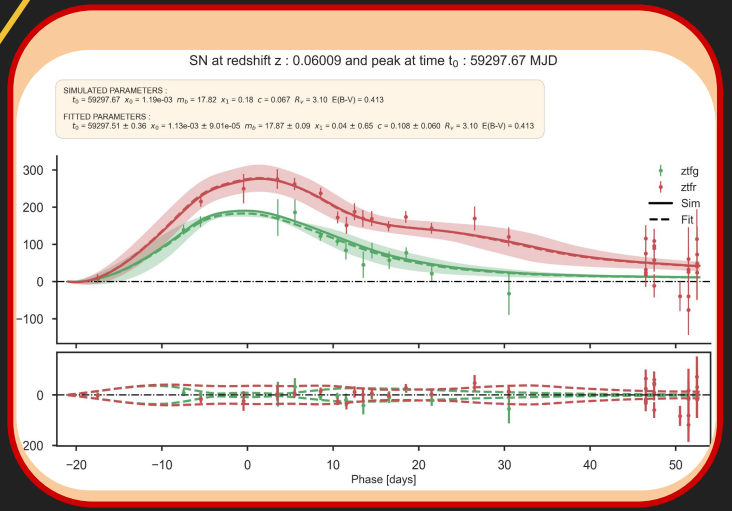
Sample selection

Lightcurves fit

Hubble diagram

Velocity estimation

$f\sigma_8$ measurement



Our simulation pipeline

Observations logs

Cosmology
&
Supernovae physics

Halo catalog

SNSim code

SN lightcurves

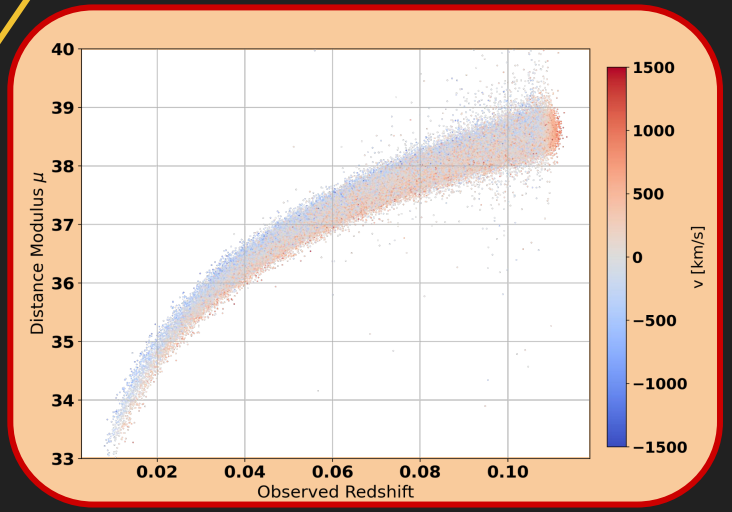
Sample selection

Lightcurves fit

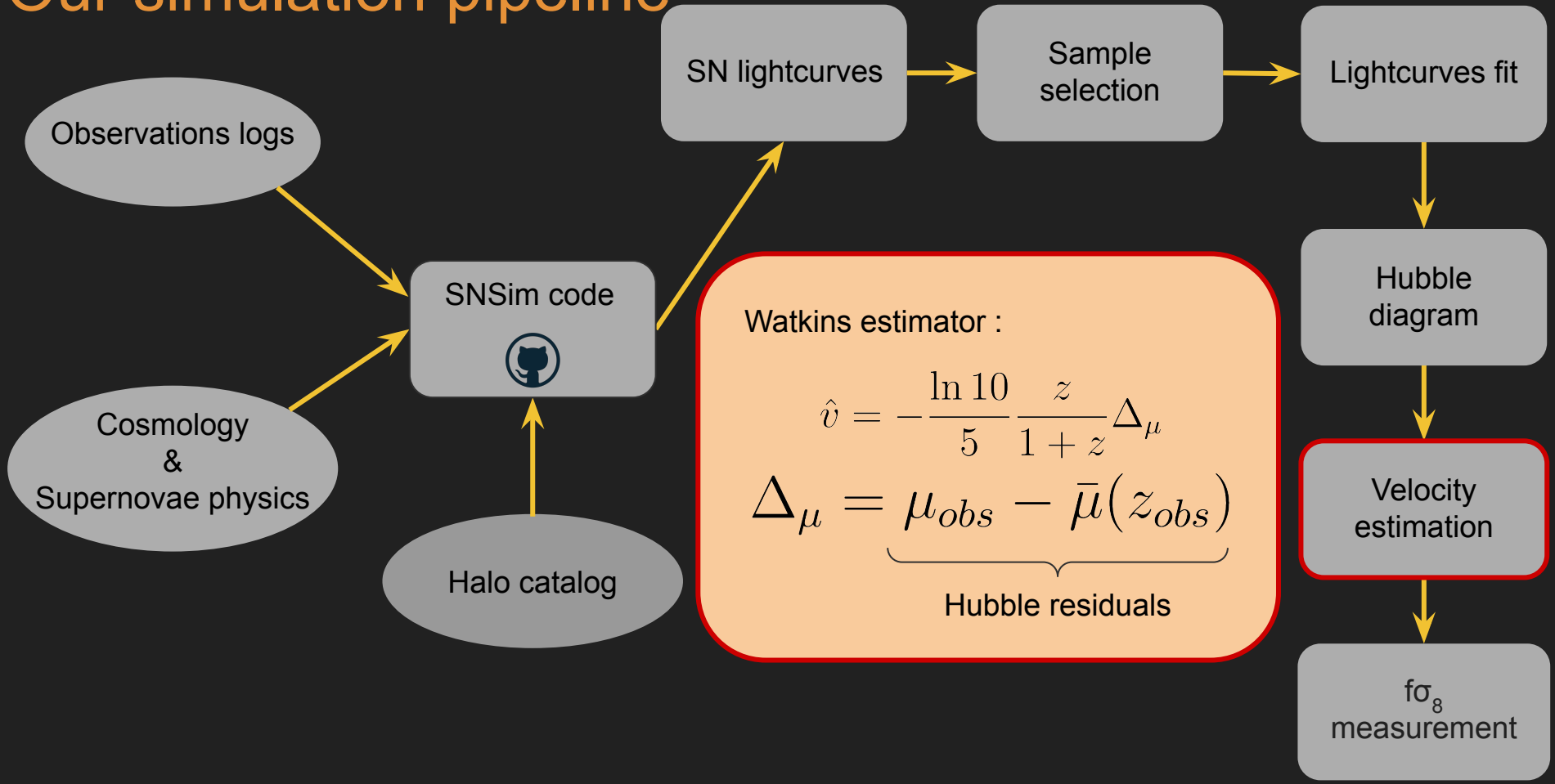
Hubble diagram

Velocity estimation

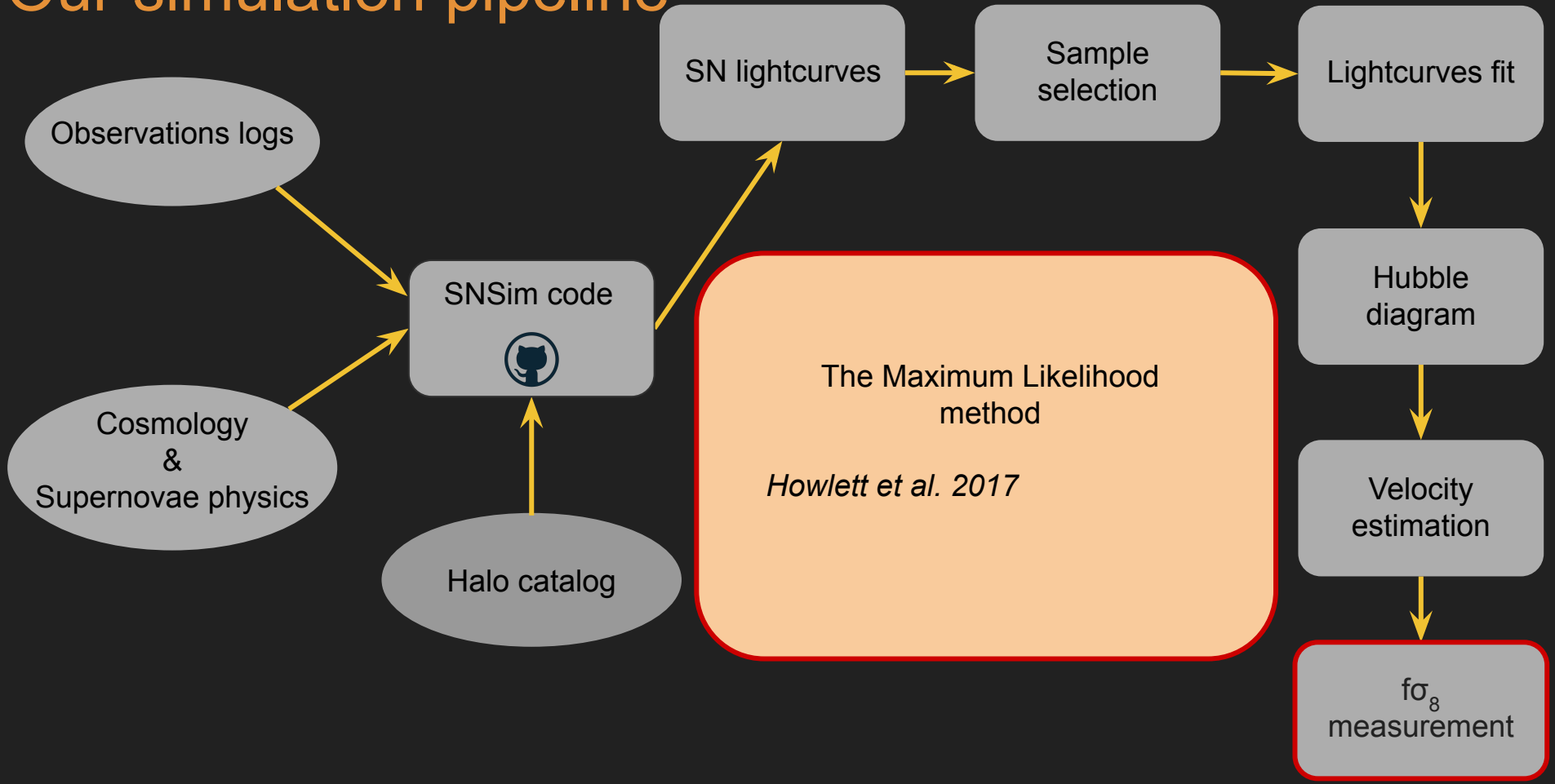
$f\sigma_8$ measurement



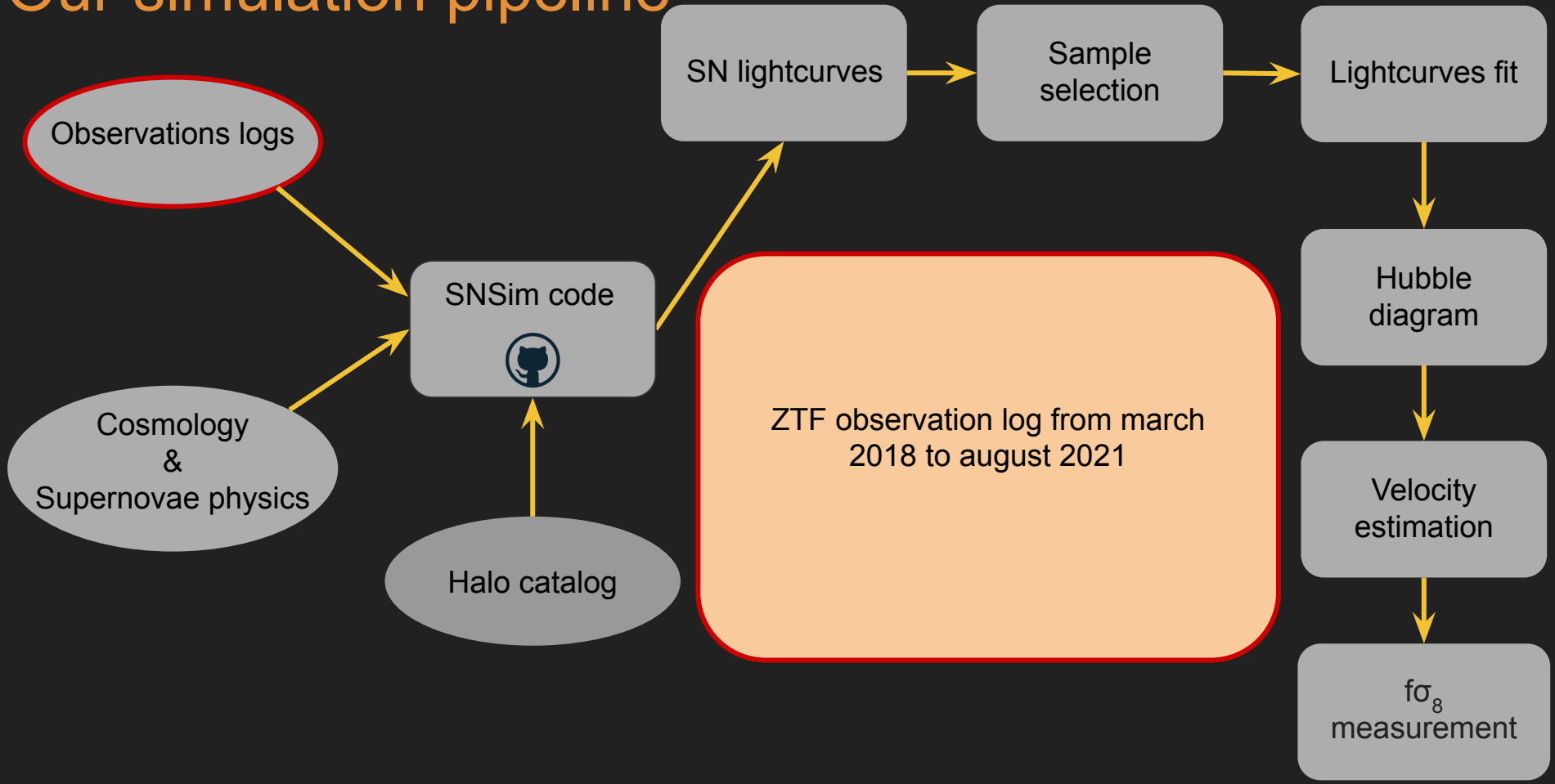
Our simulation pipeline



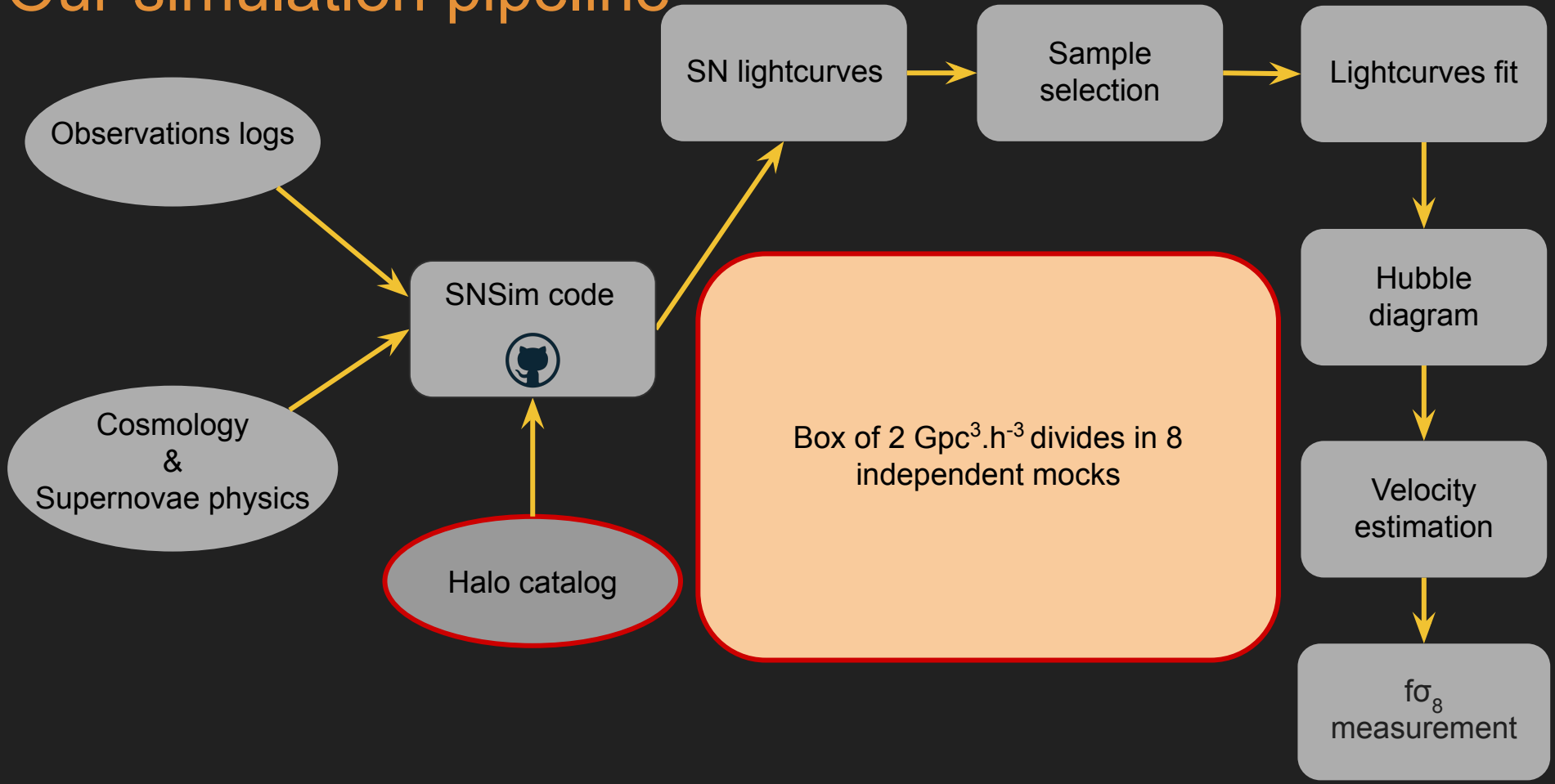
Our simulation pipeline



Our simulation pipeline



Our simulation pipeline



Our simulation pipeline

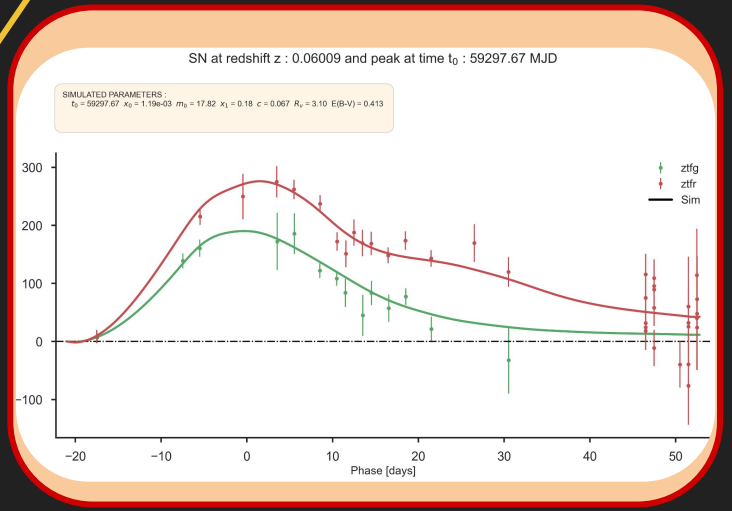
Observations logs

Cosmology & Supernovae physics

Halo catalog

SNSim code

SN lightcurves



Sample selection

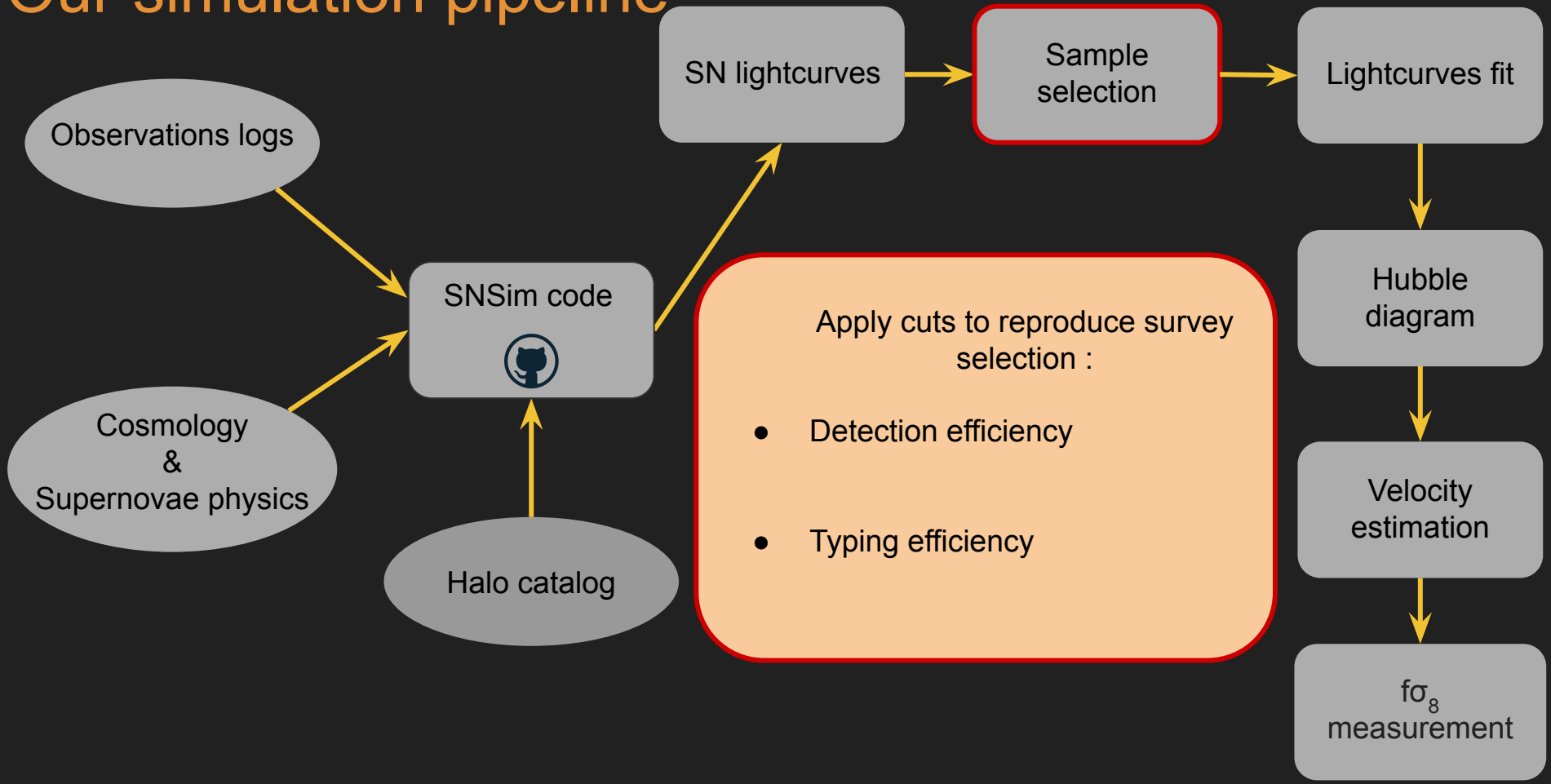
Lightcurves fit

Hubble diagram

Velocity estimation

$f\sigma_8$ measurement

Our simulation pipeline



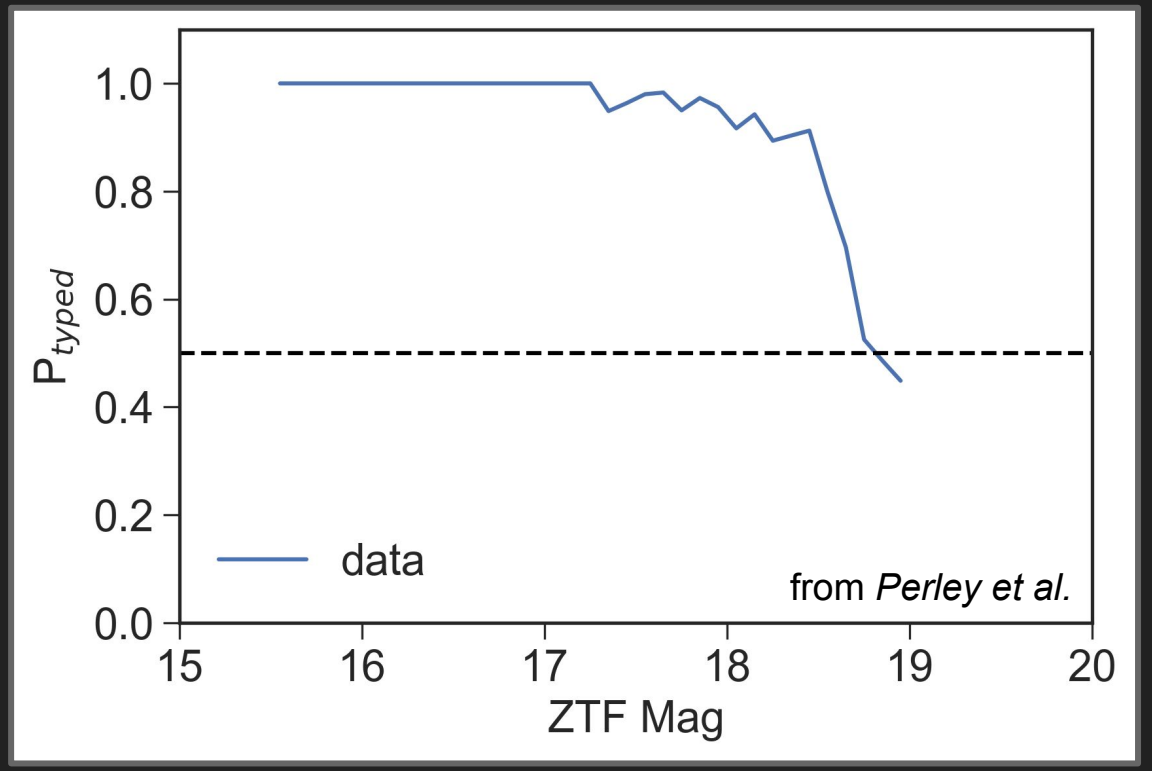
Reproduce the sample selection :

Detection & typing criteria

Apply cuts :

- Detection : at least 4 epochs with SNR > 5
- Typing : use typing efficiency dependent on magnitude

Typing efficiency wrt minimum magnitude

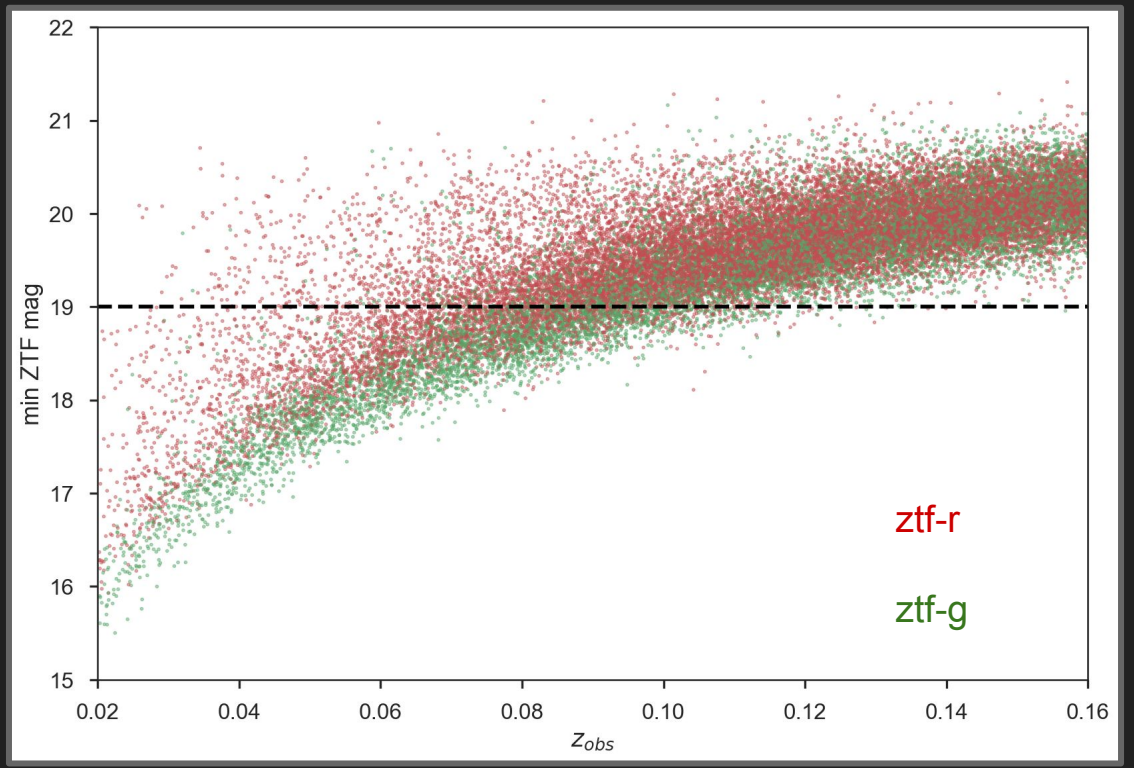


Reproduce the sample selection :
ZTF magnitudes

Minimum magnitude of full sample

Apply cuts :

- Detection : at least 4 epochs with SNR > 5
- Typing : use typing efficiency dependent on magnitude

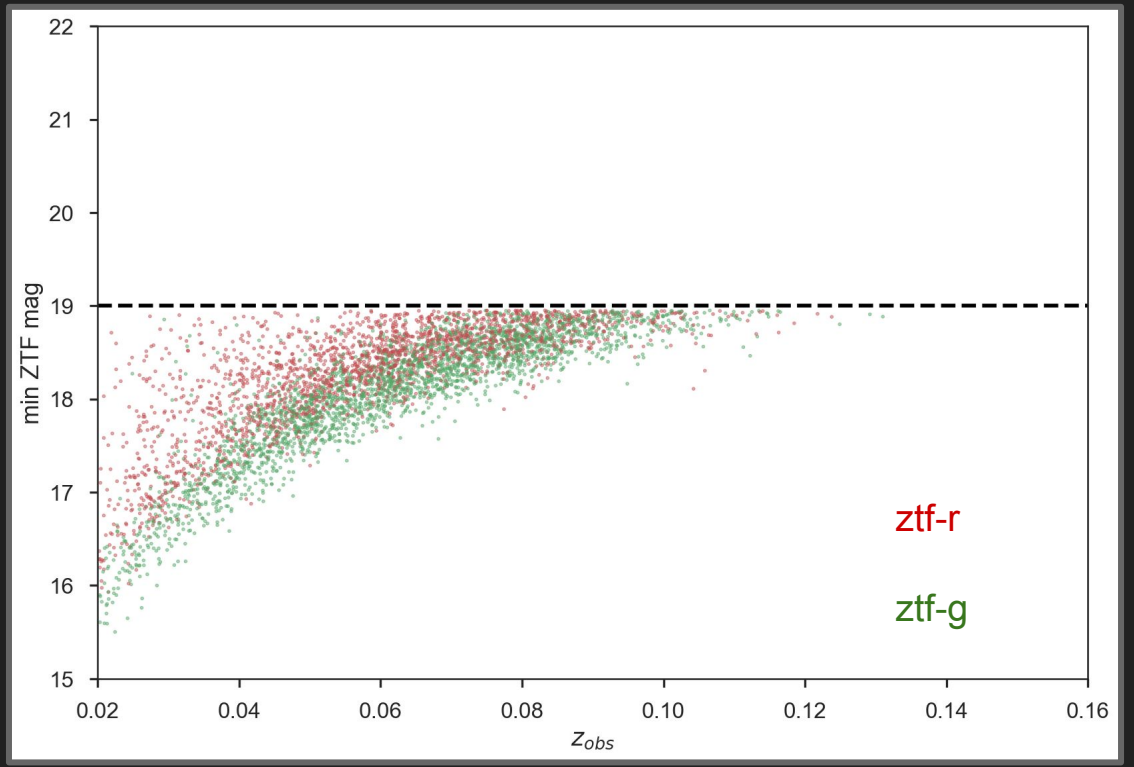


Reproduce the sample selection :
ZTF magnitudes

Minimum magnitude of selected sample

Apply cuts :

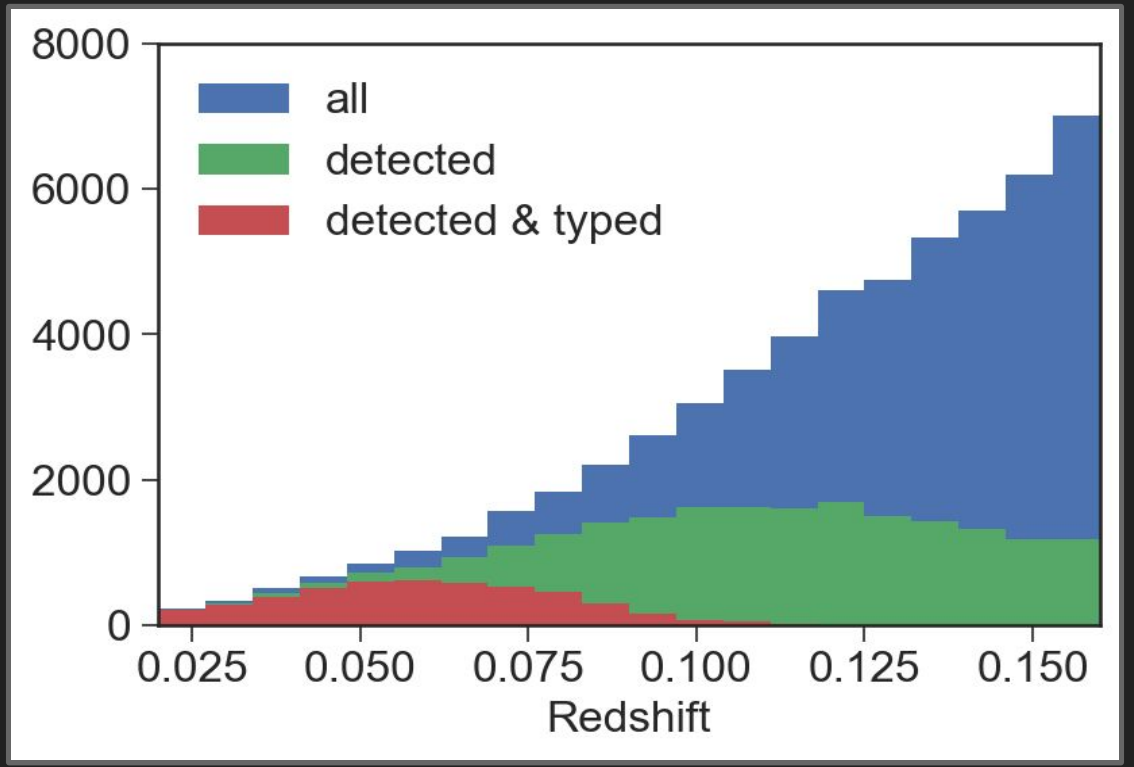
- Detection : at least 4 epochs with SNR > 5
- Typing : use typing efficiency dependent on magnitude



Reproduce the sample selection :

Redshift distribution

Redshift distribution of full and selected samples

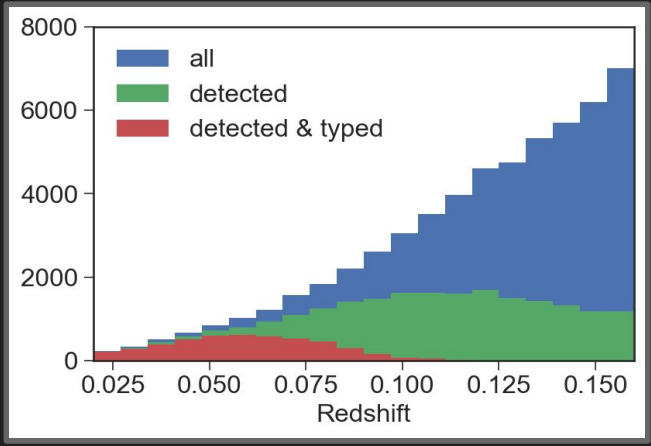


Selected SN :

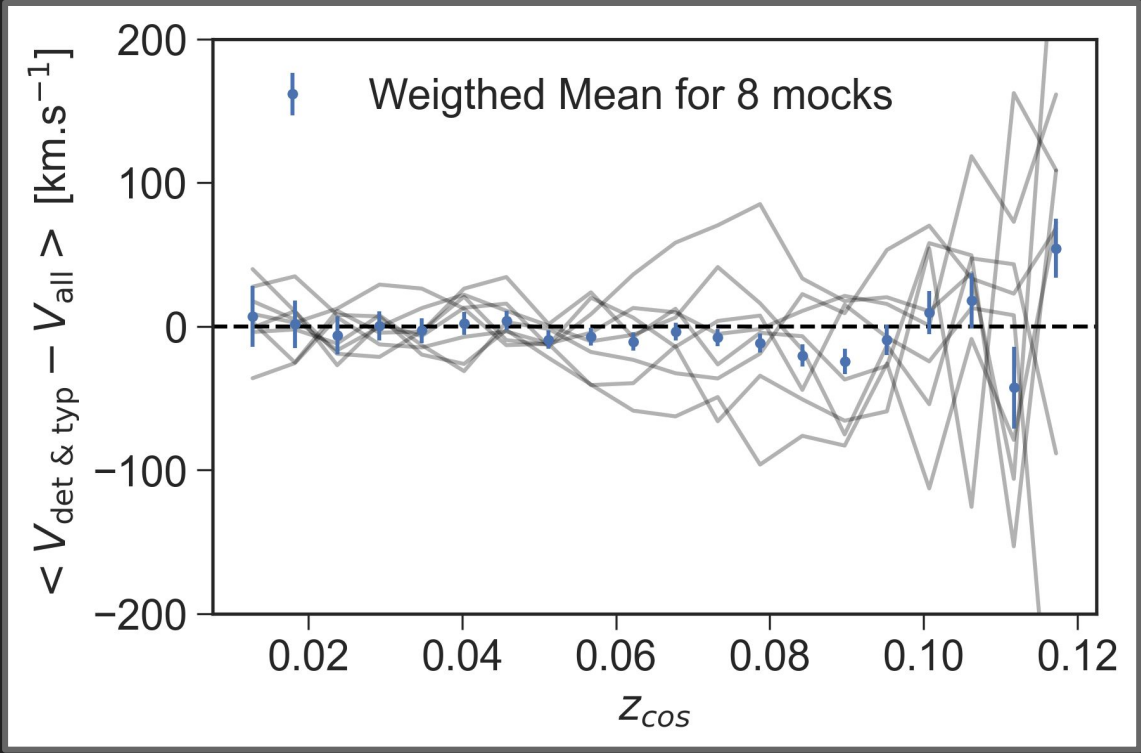
- Median redshift = 0.06
- Max redshift = 0.13

Reproduce the sample selection :

Is there already a bias ?

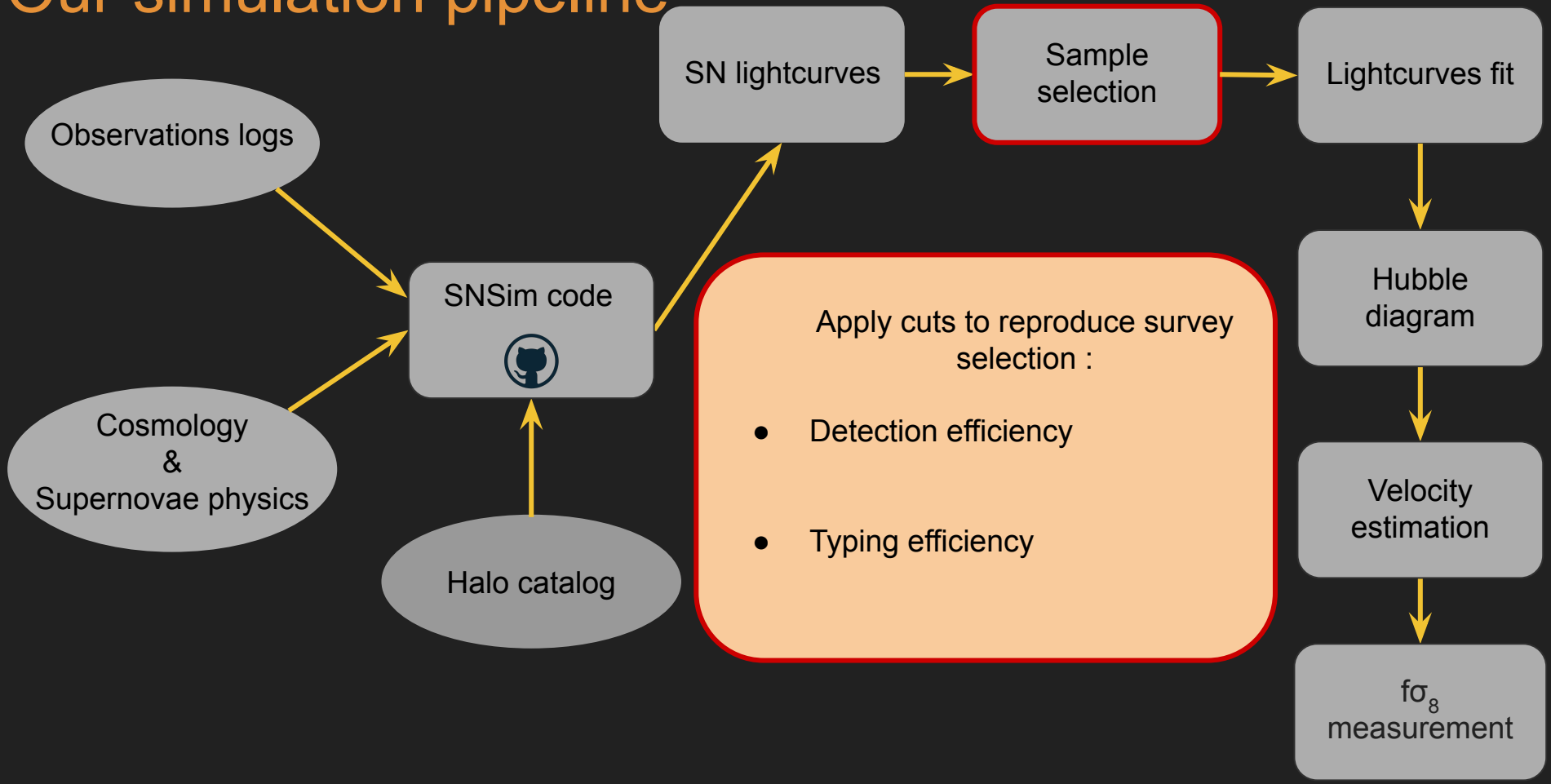


Difference between full sample and selected sample velocities



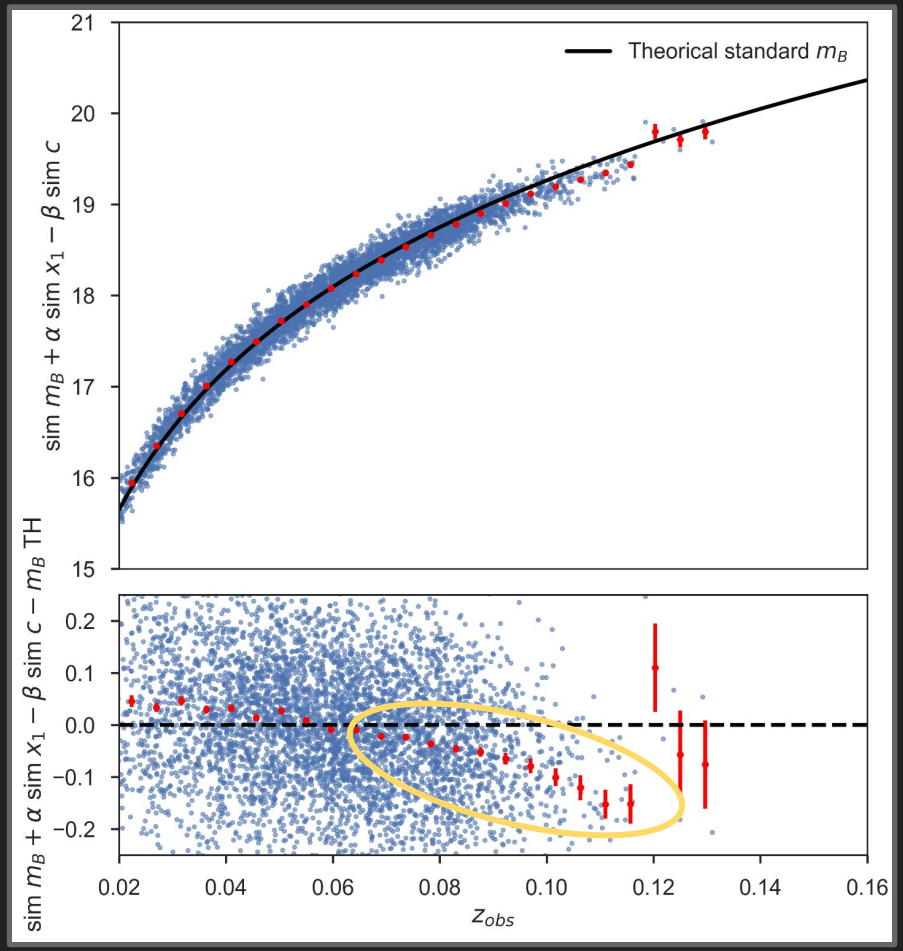
The selection doesn't introduce **any bias** on velocities

Our simulation pipeline



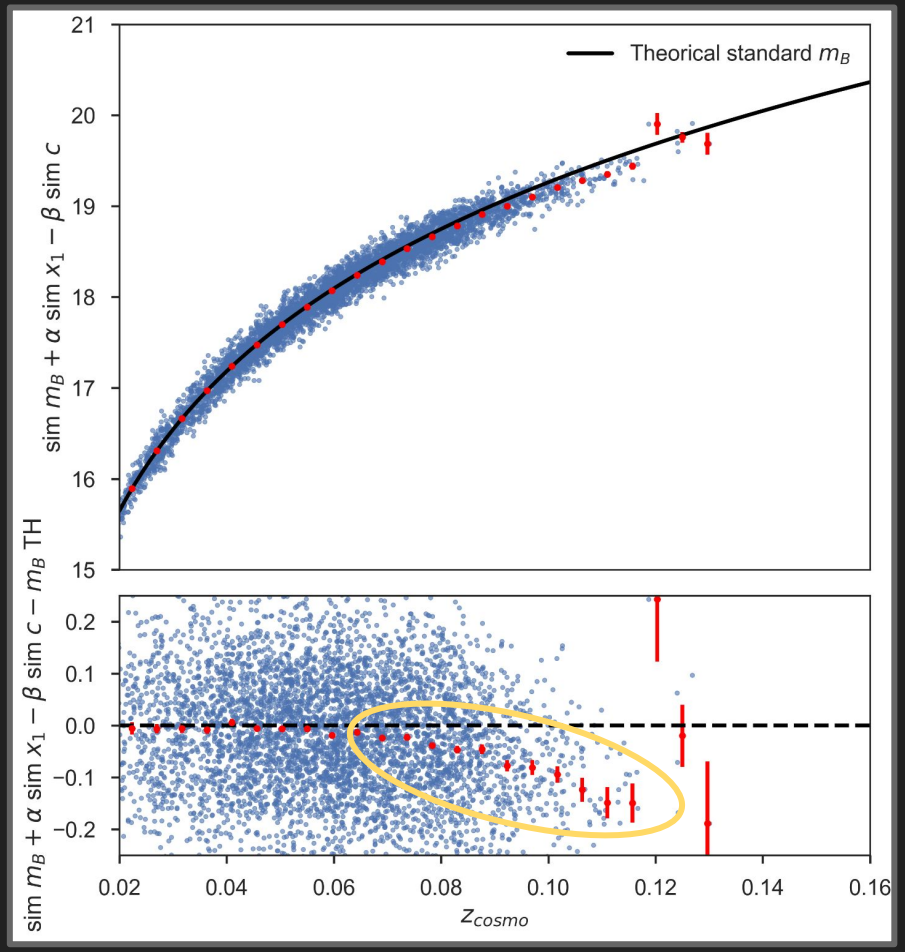
A first look at the simulated HD after selection

Selection bias appears at z ~ 0.06



A first look at the simulated HD after selection

Selection bias appears at z ~ 0.06



Our simulation pipeline

Observations logs

Cosmology & Supernovae physics

Halo catalog

SNSim code

SN lightcurves

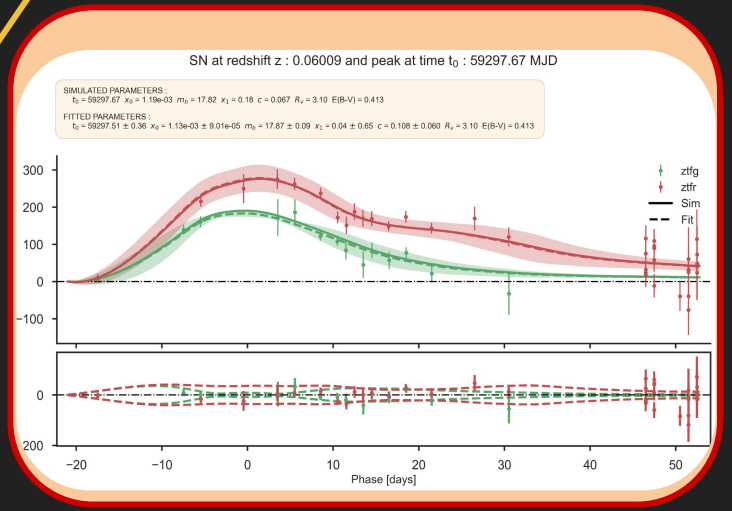
Sample selection

Lightcurves fit

Hubble diagram

Velocity estimation

$f\sigma_8$ measurement



Our simulation pipeline

Observations logs

Cosmology
&
Supernovae physics

Halo catalog

SNSim code

SN lightcurves

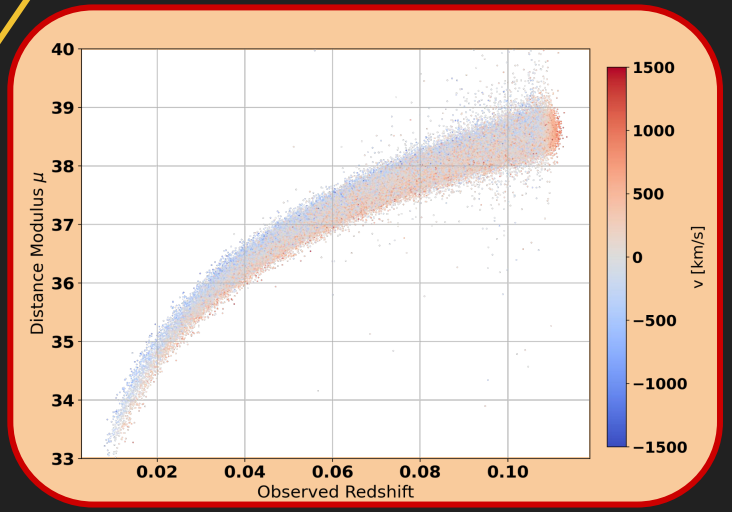
Sample selection

Lightcurves fit

Hubble diagram

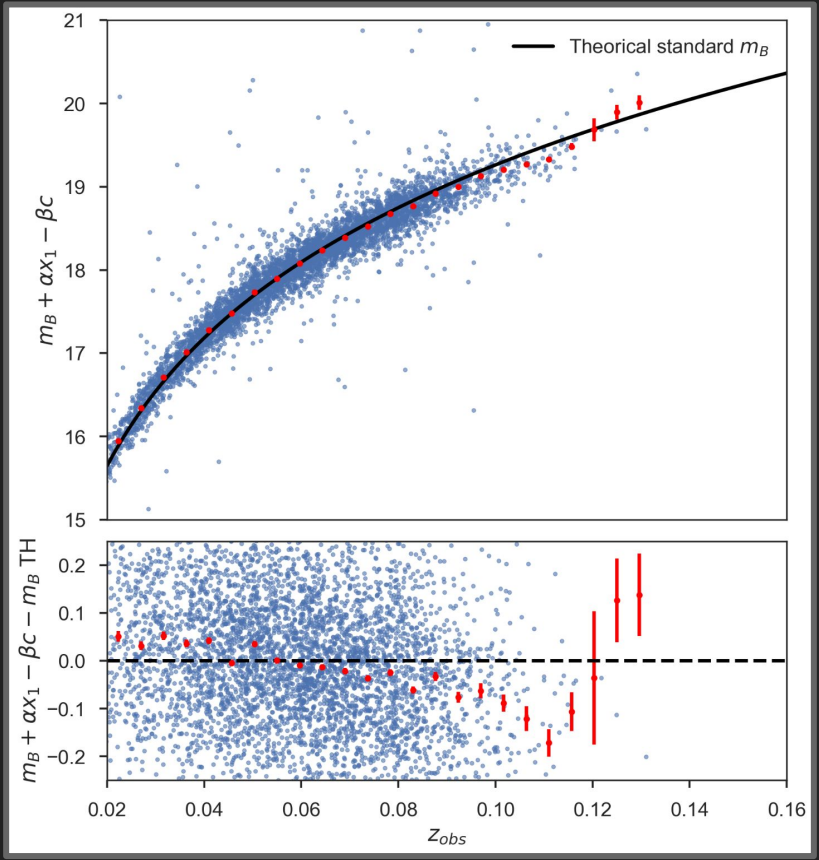
Velocity estimation

$f\sigma_8$ measurement

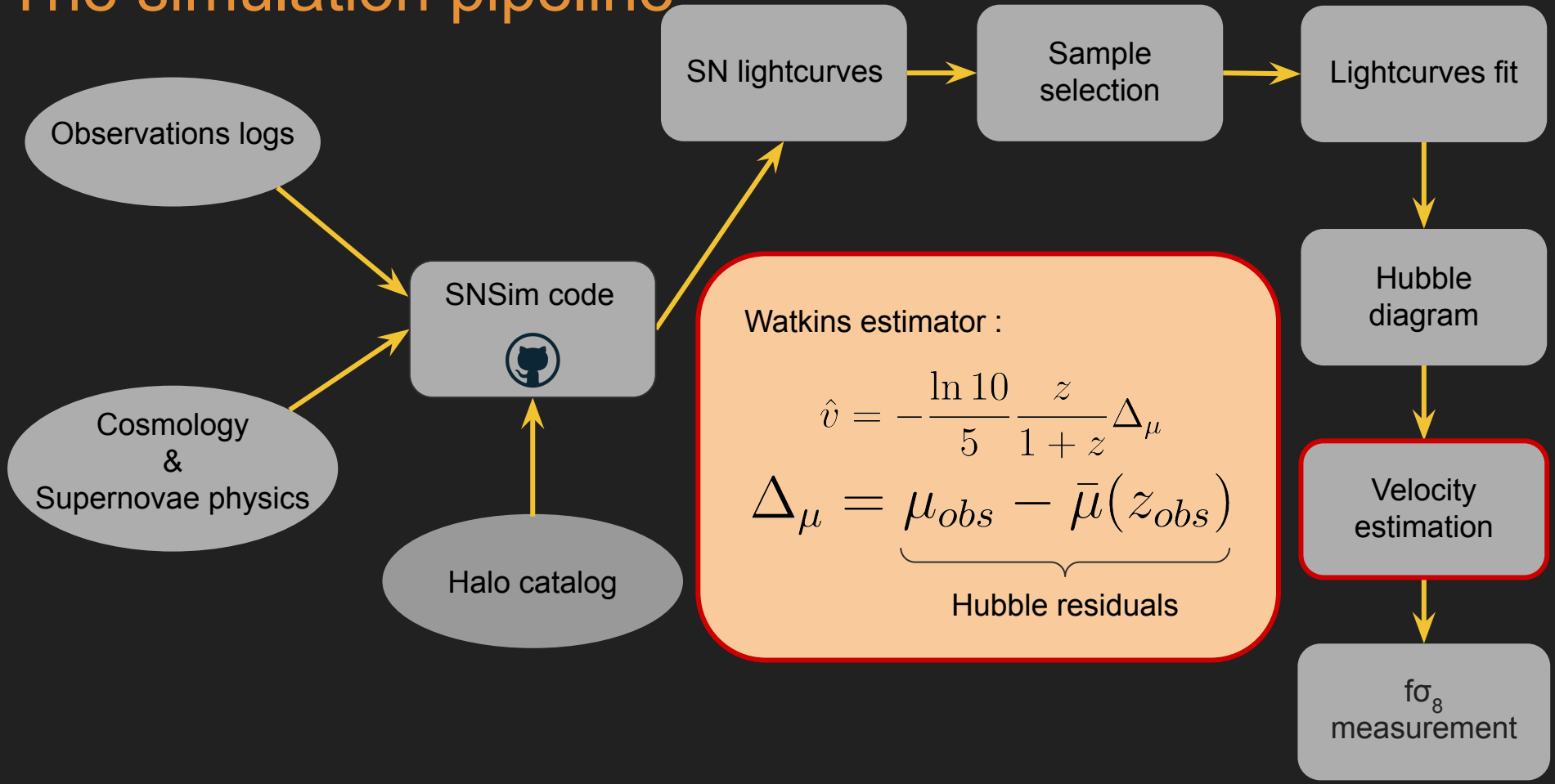


The Hubble diagram after SALT fit

Selection bias appear at z ~ 0.06



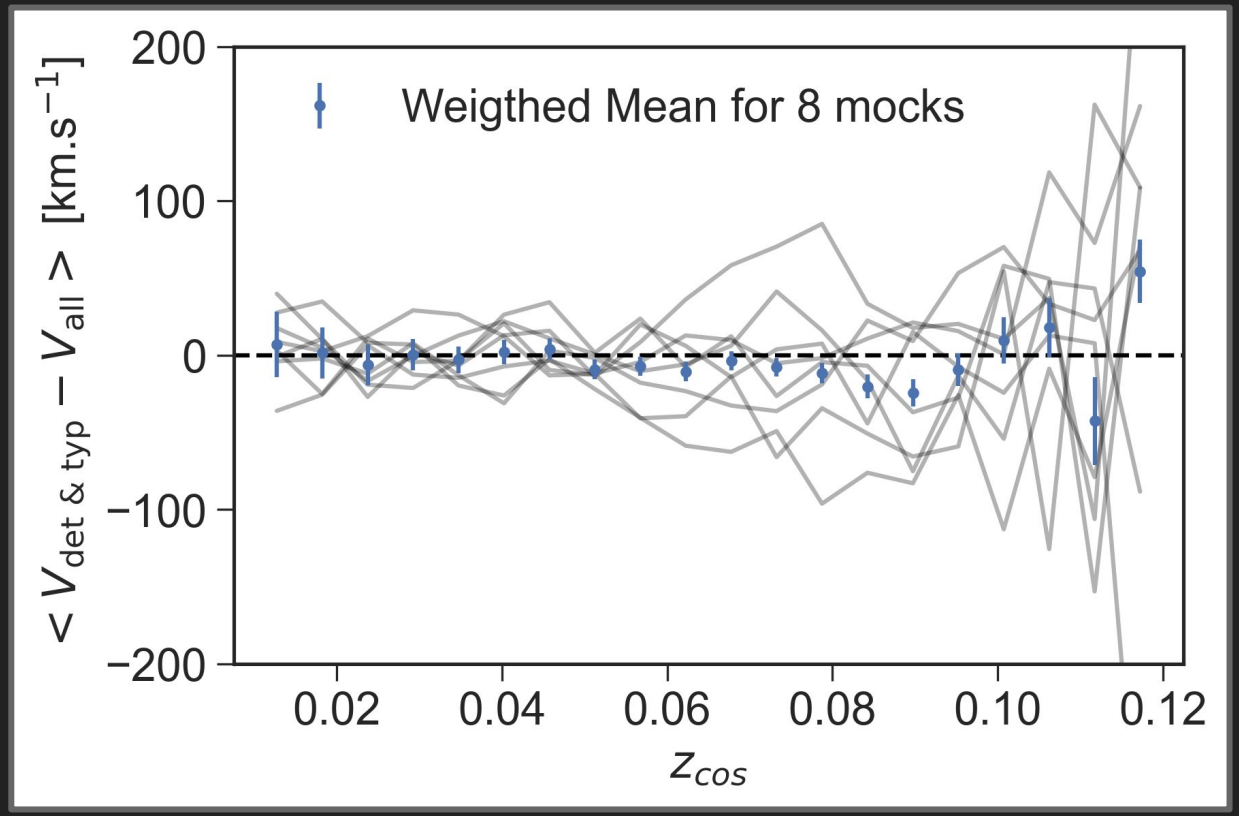
The simulation pipeline



Velocities estimation from residuals : expose the bias

Difference between full sample and selected sample velocities

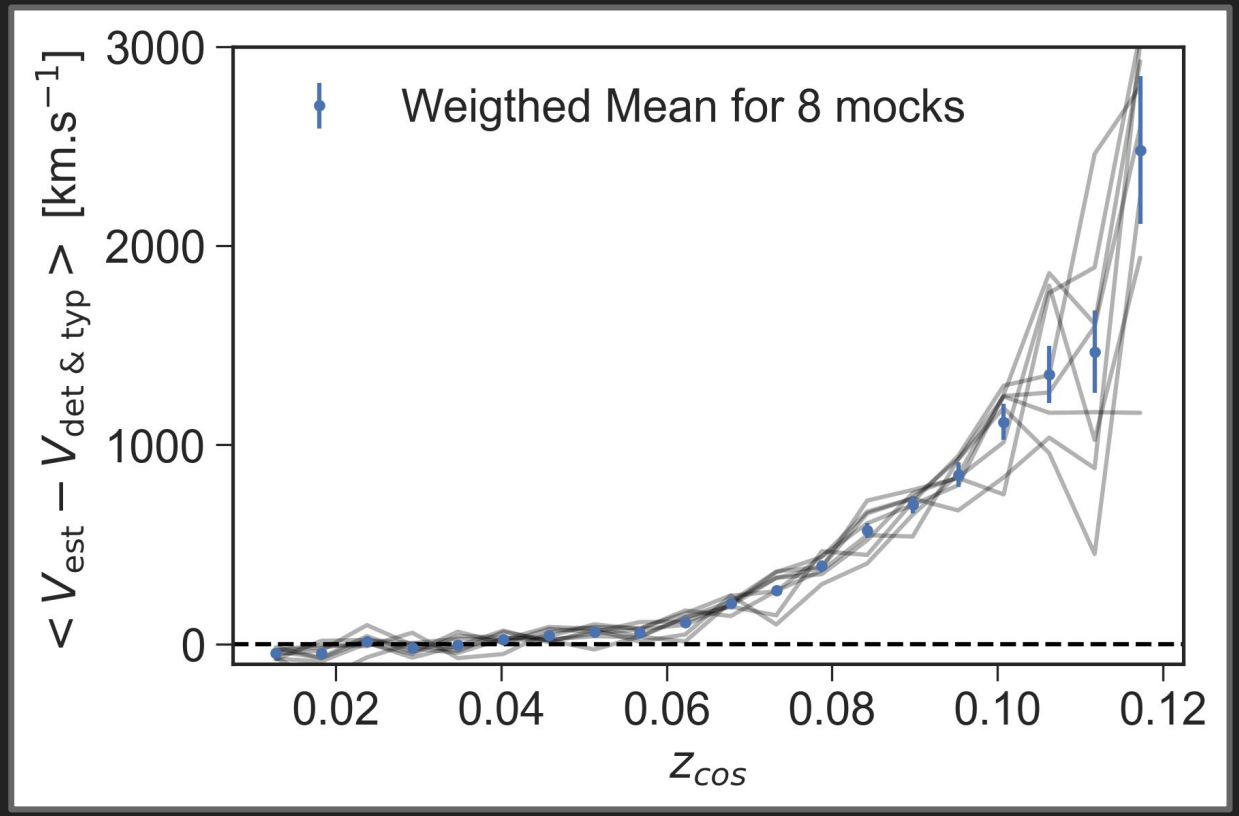
The selection doesn't introduce **any bias** on velocities (checked on true values) ...



Velocities estimation from residuals : expose the bias

Difference between full sample true velocities and selected sample estimated velocities

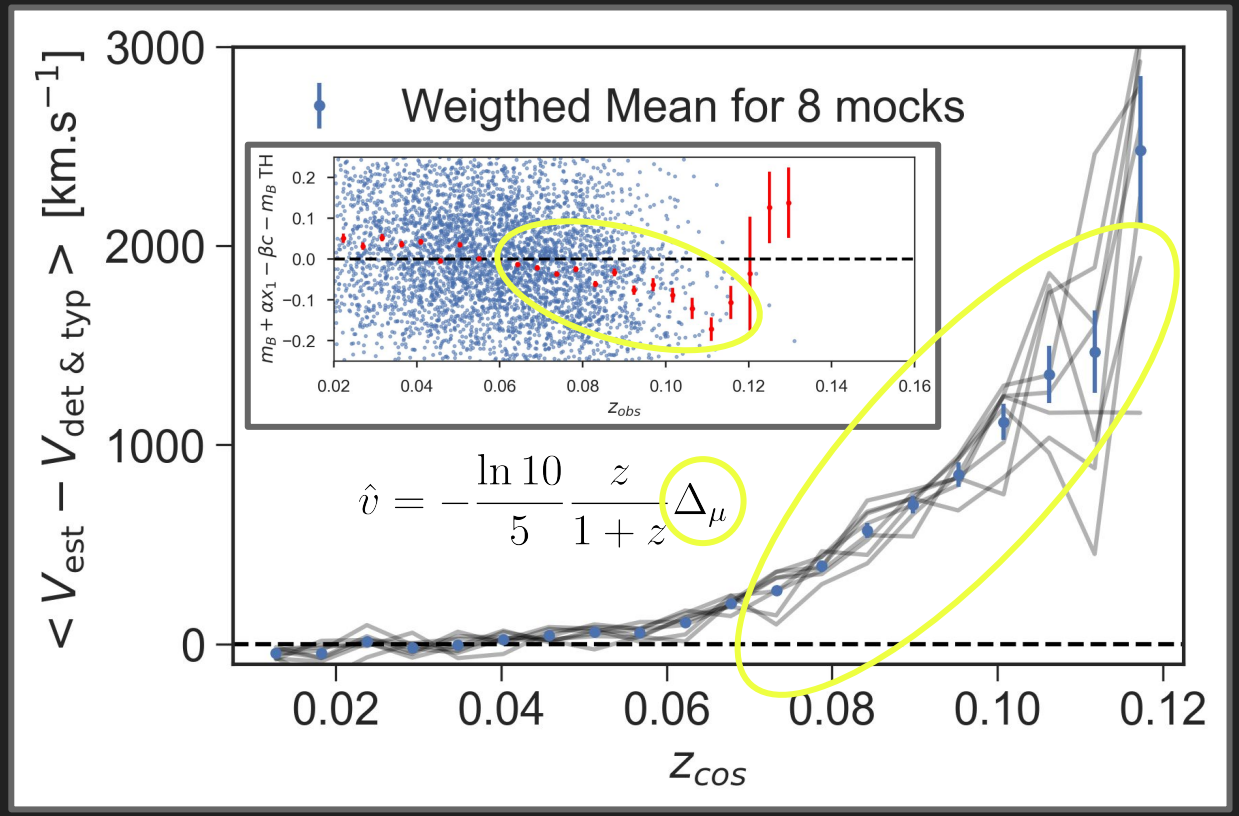
… But the **estimate velocities** are **biased** for z > 0.06



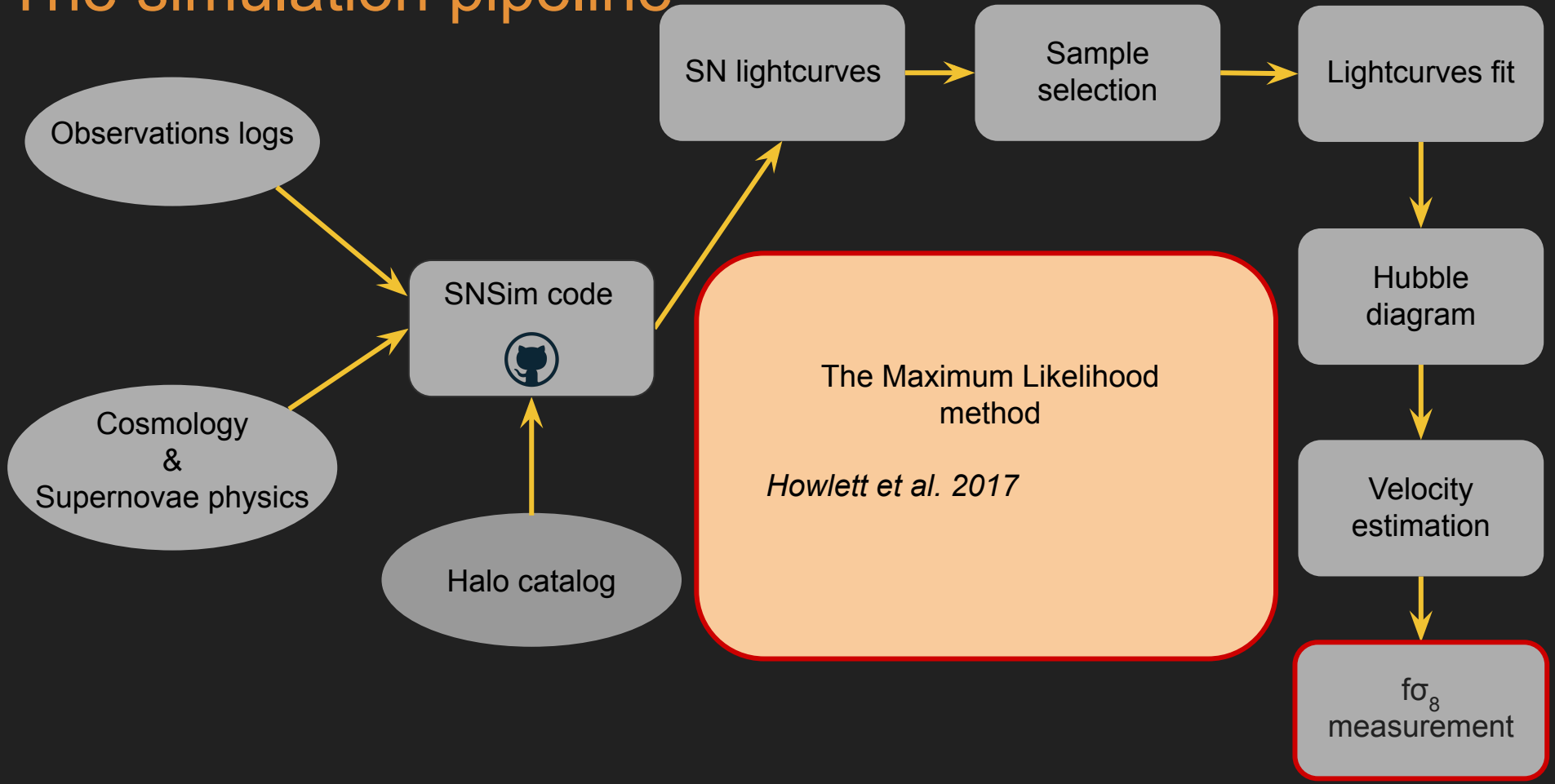
Velocities estimation from residuals : expose the bias

Difference between full sample true velocities and selected sample estimated velocities

… But the **estimate velocities** are **biased** for z > 0.06



The simulation pipeline



The maximum likelihood method

From Howlett *et al.* 2017

$$\mathcal{L} = \frac{1}{(2\pi)^{\frac{n}{2}}\sqrt{|\mathrm{C_{tot}}|}} e^{-\frac{1}{2}\mathbf{v}^T \mathrm{C}_{\mathrm{tot}}^{-1}\mathbf{v}}$$

Peculiar velocities

$$\mathrm{C_{tot}} = (f\sigma_8)^2 \mathrm{C_{cos}} + \mathrm{C_{obs}}$$

$f\sigma_8$ measurement : bias effect

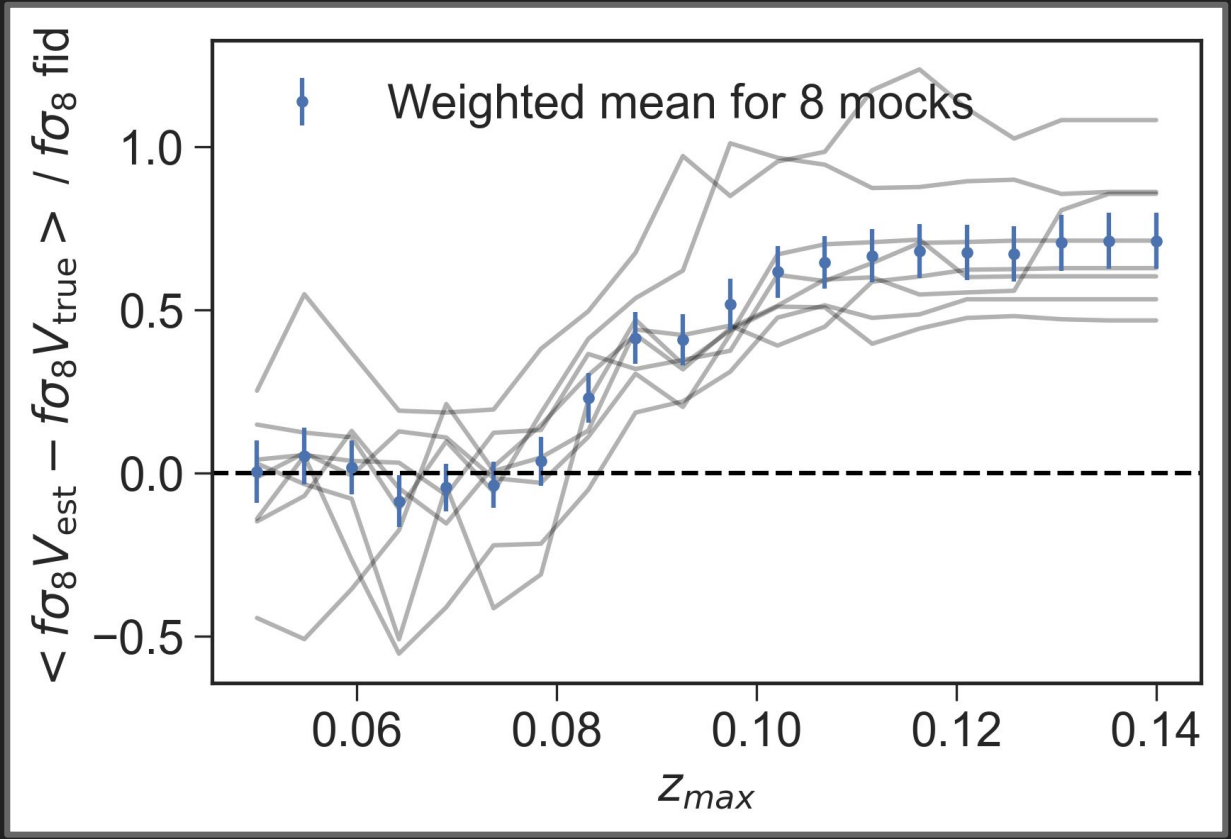
Difference between $f\sigma_8$ from true velocities and $f\sigma_8$ from estimated velocities

Fit with a binning grid of 80 $Mpc.h^{-1}$

No bias for $z < 0.08$

Effect of selection bias is clear after $z \sim 0.08$

Bias at $z = 0.14 \sim 60$ %



$f\sigma_8$ measurement : bias effect

Fit with a binning grid of 80 $Mpc.h^{-1}$

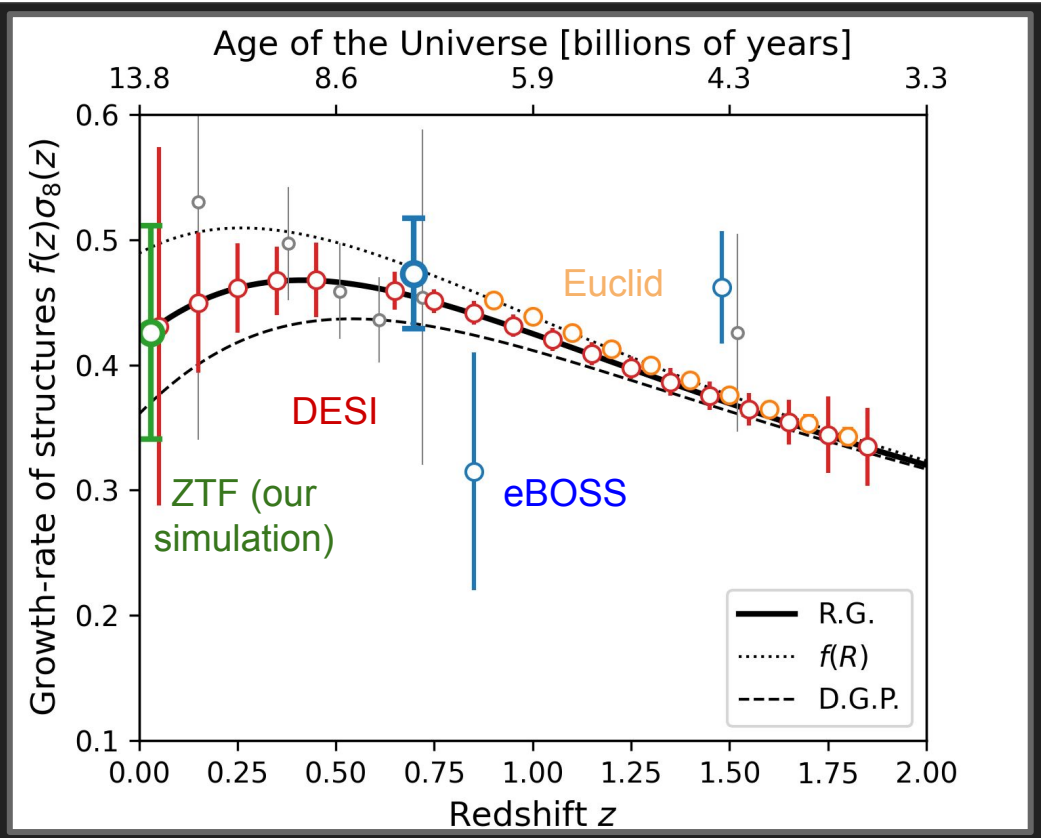
No bias for $z < 0.08$

Effect of selection bias is clear after $z \sim 0.08$

Bias at $z = 0.14 \sim 60$ %

With sample at $z < 0.06$ no bias and relative error of ~ 20 %

$f\sigma_8$ measurement comparison with actual data and future survey

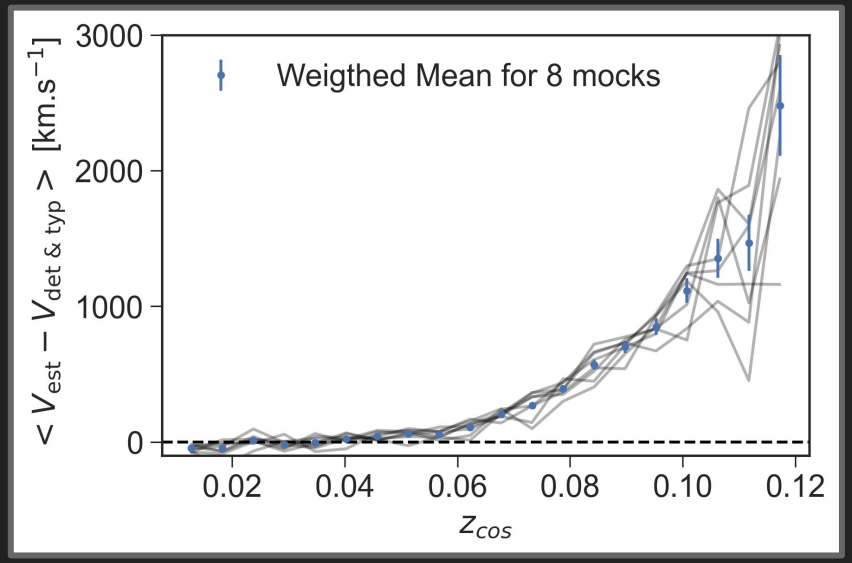


How much can we improve the $f\sigma_8$ precision using sample z > 0.06 ?

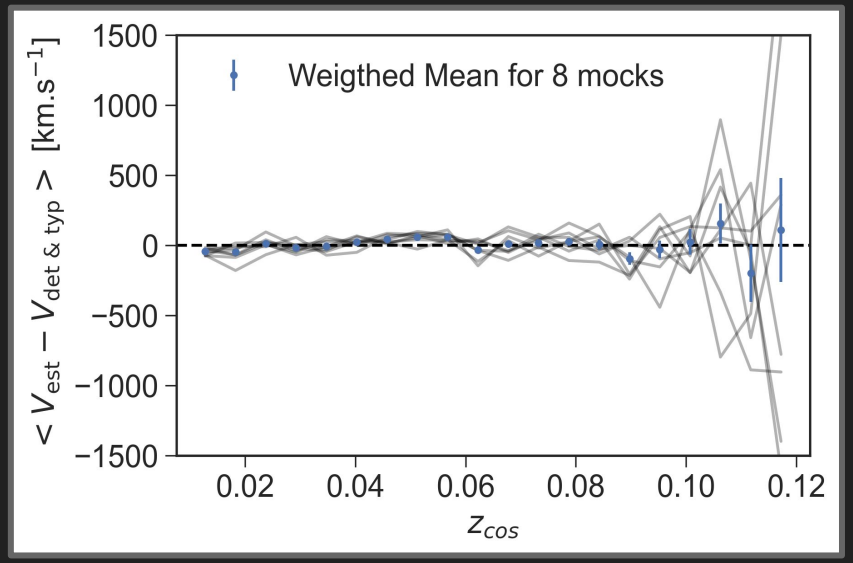
Fake debias of the estimator

Draw velocities for SN with z > 0.06 $v_{\rm fake} \sim N(v_{true}, \sigma_{est})$

Before fake debias



After fake debias

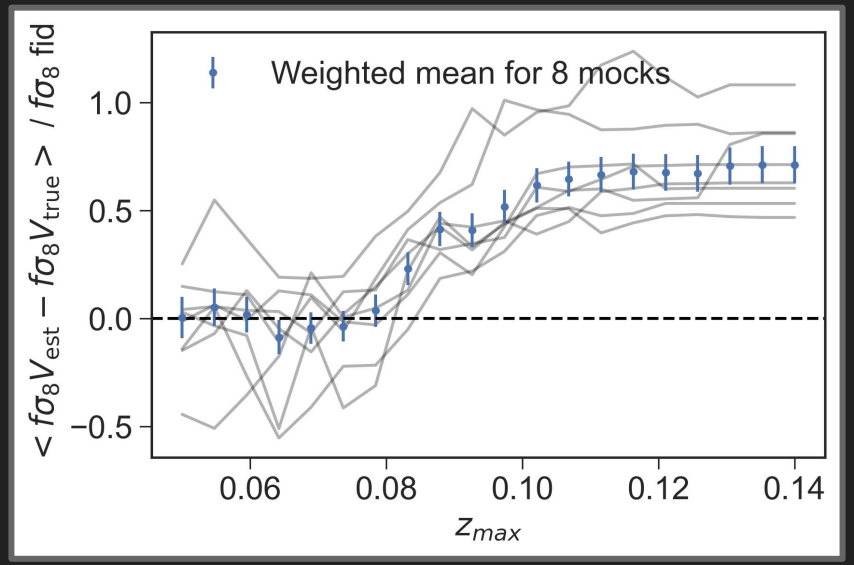


How much can we improve the $f\sigma_8$ precision using sample z > 0.06 ?

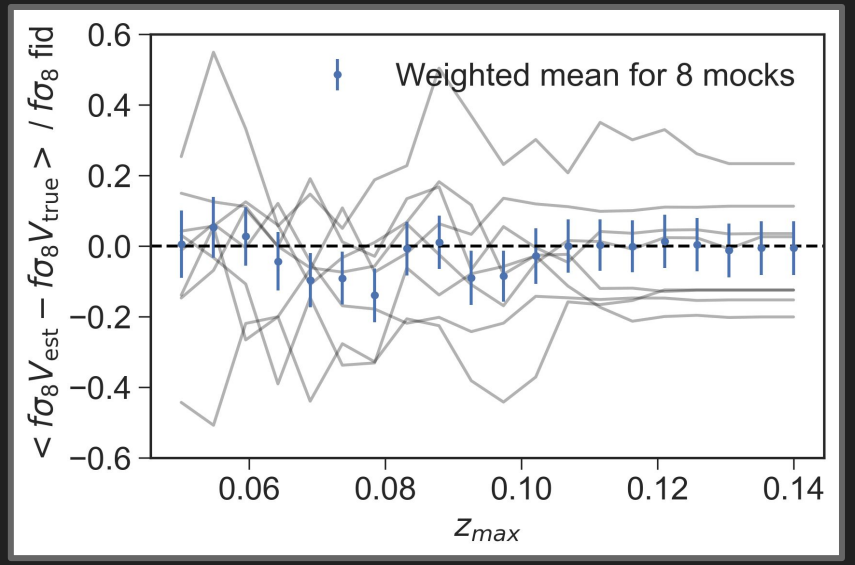
Fake debias of the estimator

Draw velocities for SN with z > 0.06 $v_{\rm fake} \sim N(v_{true}, \sigma_{est})$

Before fake debias



After fake debias

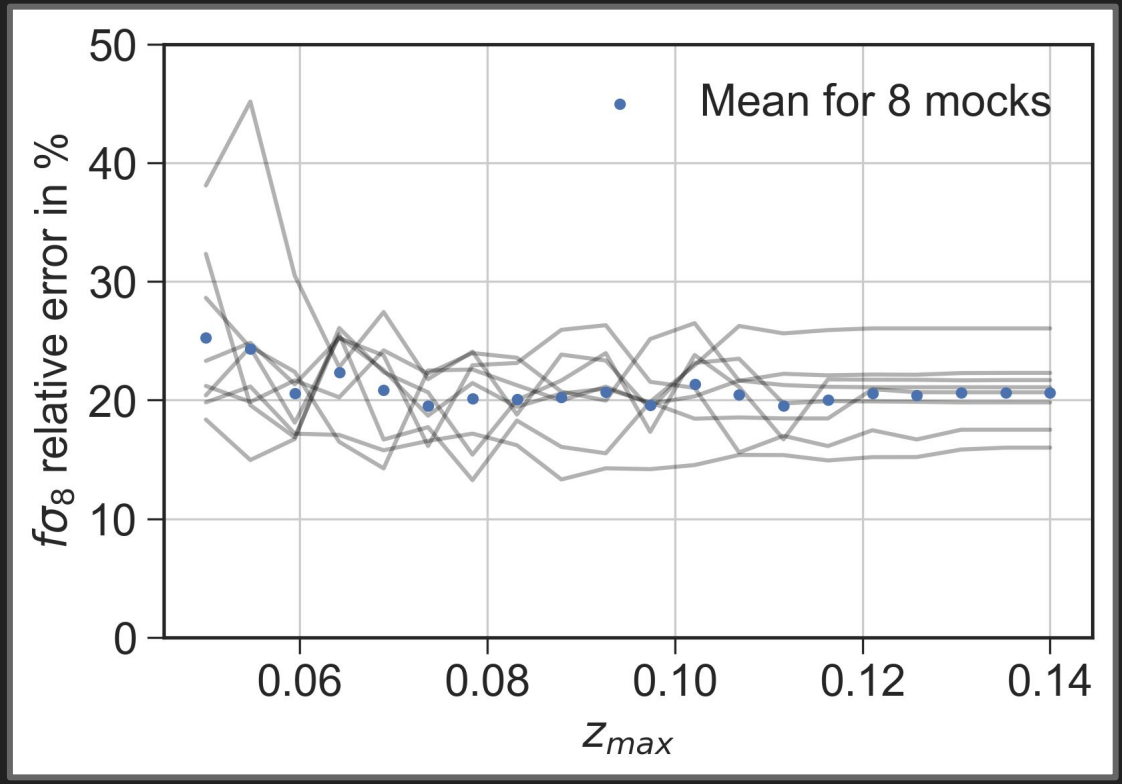


How much can we improve the $f\sigma_8$ precision using sample $z > 0.06$?

At $z = 0.06$ the relative error on $f\sigma_8$ is ~ 20 %

The error on $f\sigma_8$ doesn't change by including the statistic after $z > 0.06$ for the selected sample

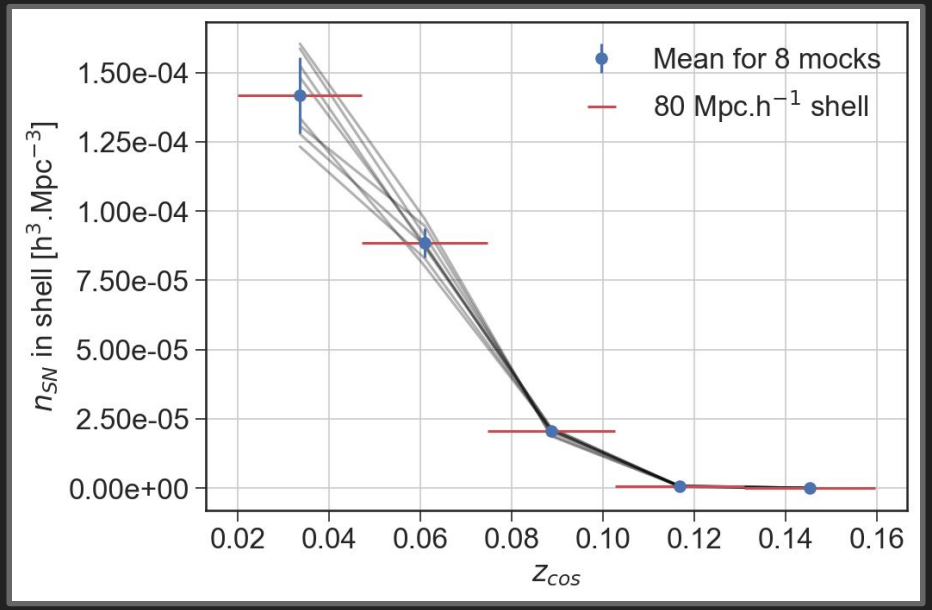
Relative error on $f\sigma_8$ from fake debias sample for $0 < z < z_{max}$

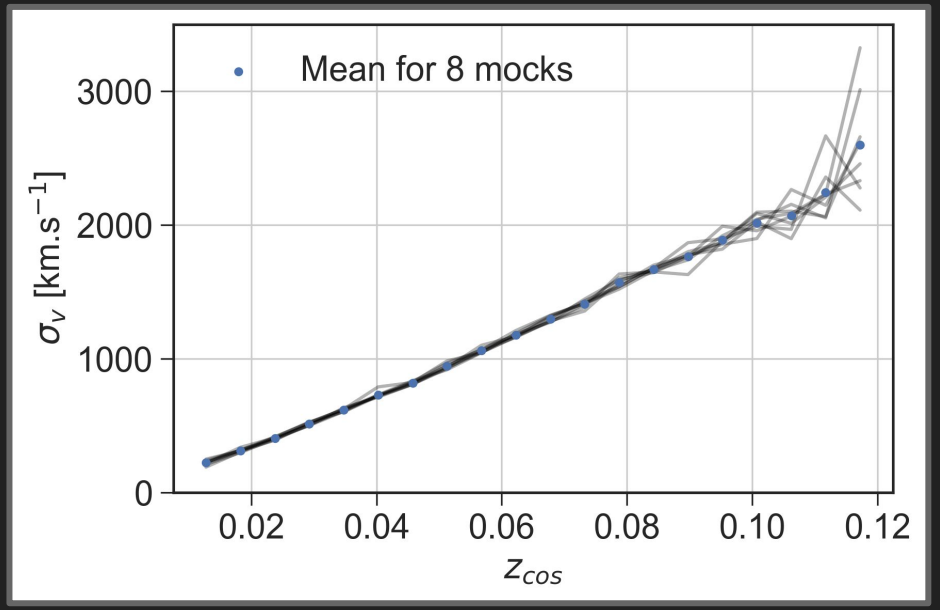


How much can we improve the $f\sigma_8$ precision using sample z > 0.06 ?

Possible explanations :

Two effects that contribute to the lack of statistical power for z > 0.06





Summary

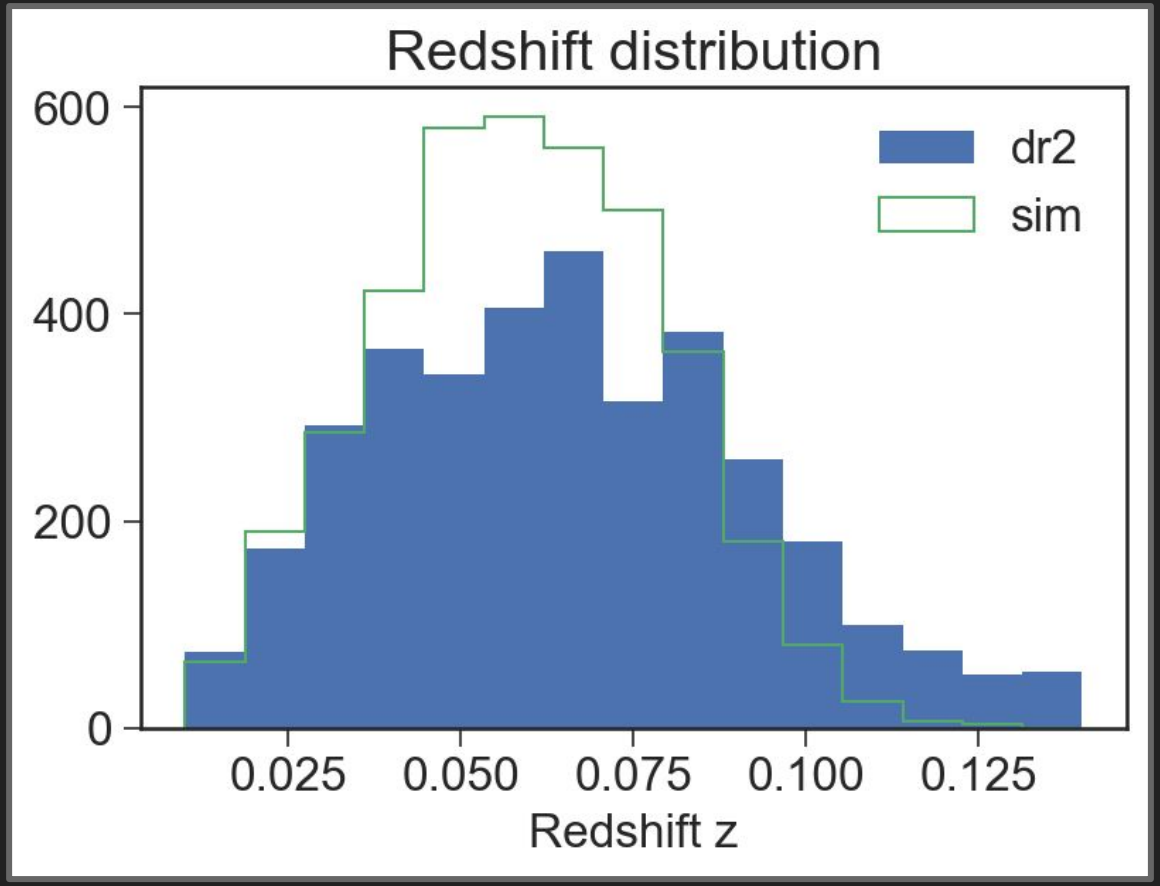
- We have a **full simulation pipeline** to study the growth rate analysis
- Using the ztf observations log from March 2018 to August 2021 **(DR2-like)** and 8 mocks we find that, using the **sample at z < 0.06**, we can reach a **precision of 20% on $f\sigma_8$**
- Using the selected sample, we found that, **above z ~ 0.08, the selection bias has a relative impact of up to ∼ 60 % on the measurement of $f\sigma_8$**
- Using our $f\sigma_8$ measurement method and a perfect unbiased velocity estimation (from simulation truth) **the precision doesn't improve when including data above z ~ 0.06**

Work plan

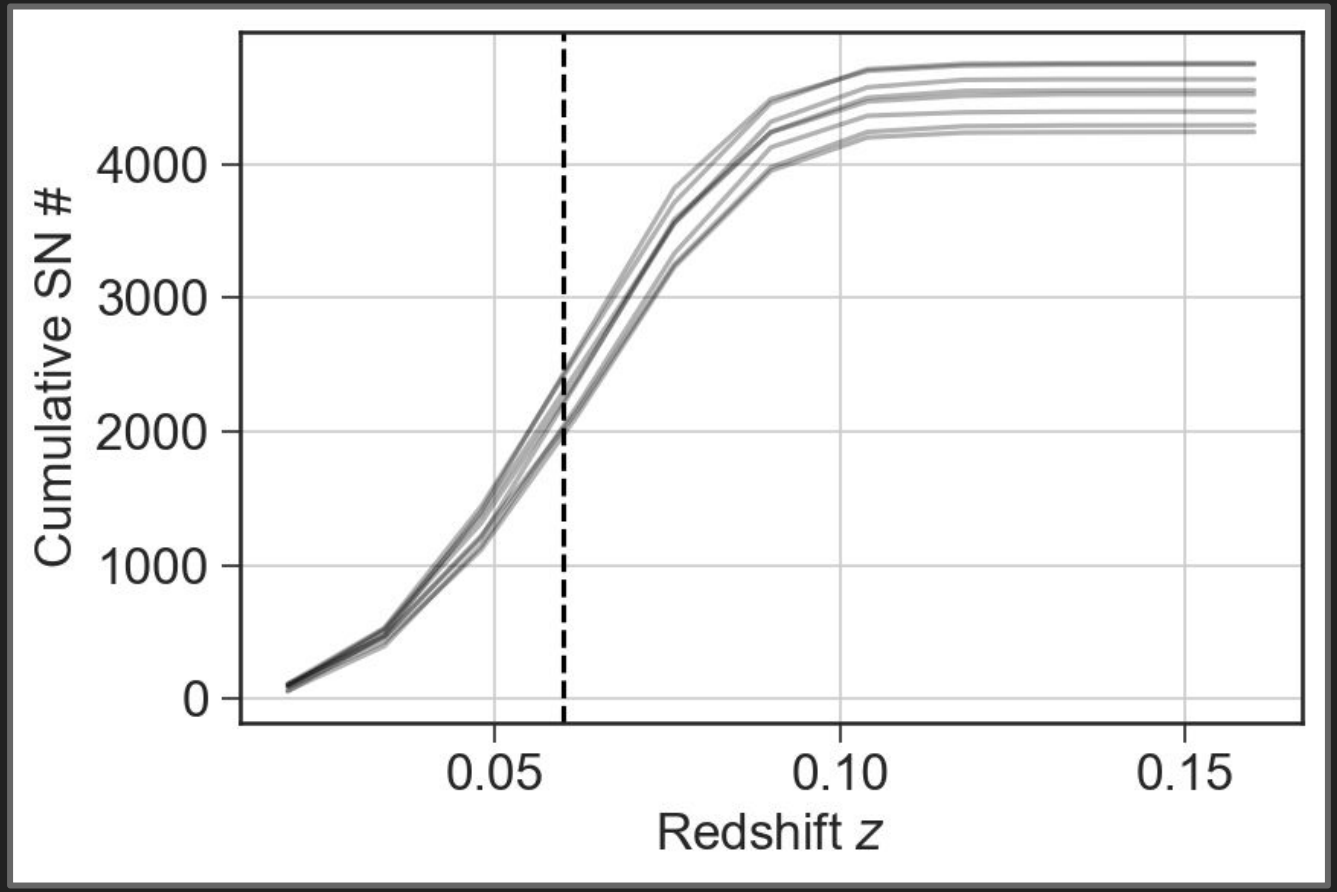
- Refine the selection function to better match with DR2
- Use new logs with more realistic sky noise
- Publish this work
- Apply this work to measure $f\sigma_8$ with ZTF data

Thanks for your attention

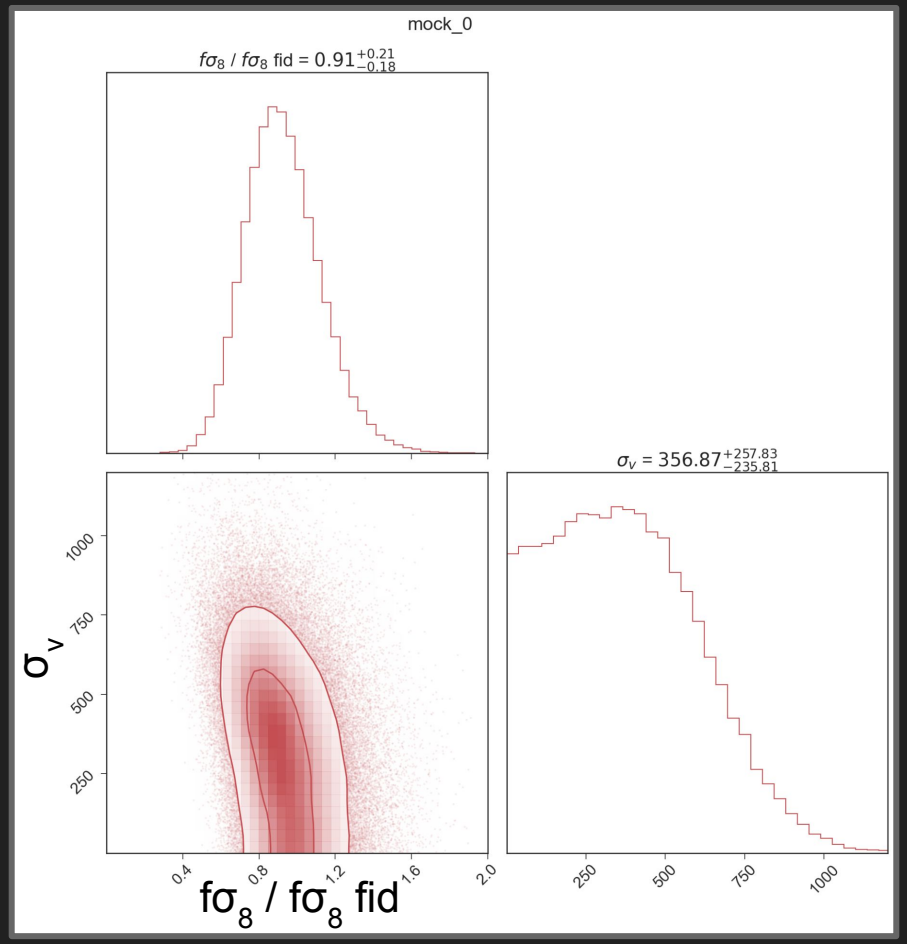
Backup : Still a simulation



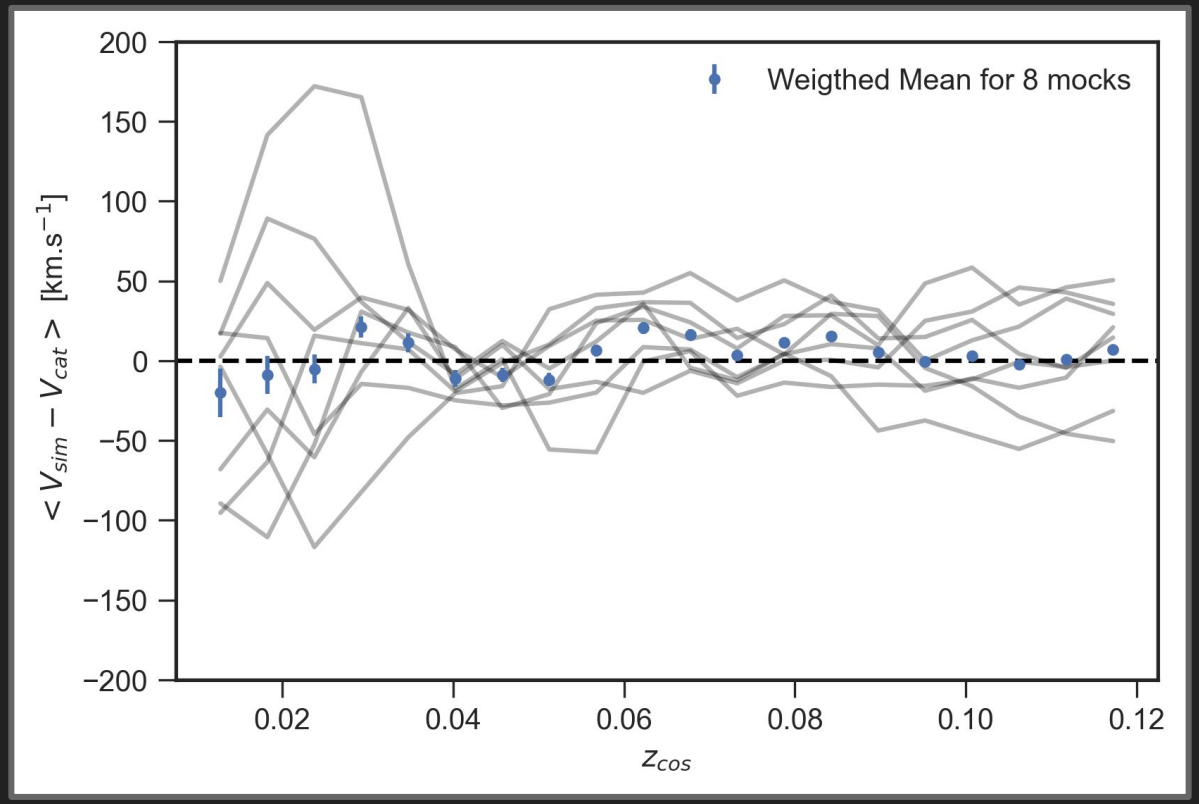
Backup : Cumulative number of SN



Backup : $f\sigma_8$ with $z < 0.06$



Backup : Catalog vs simulated SN



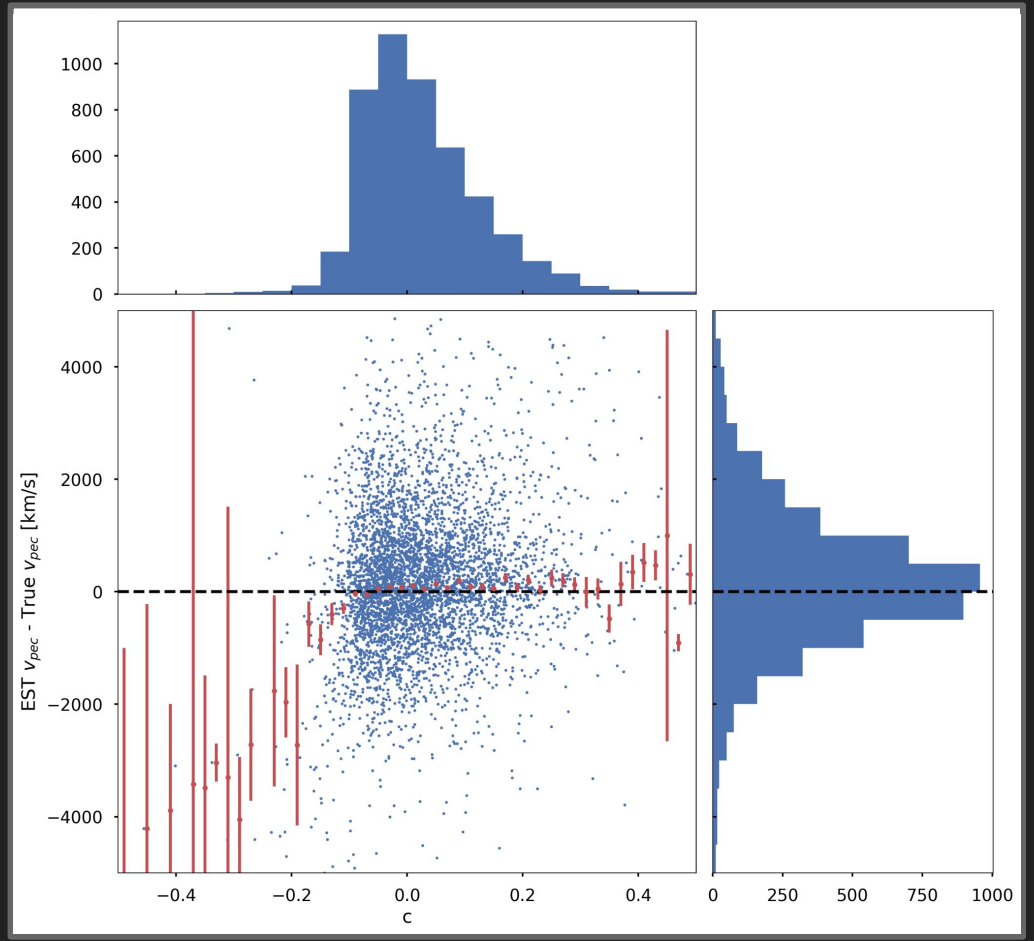
Backup : SALT c effect on v_{pec} estimation

$$-\beta c \Rightarrow \mu \searrow$$

$\Downarrow$

Over-estimate c $\Rightarrow$ Positive velocity

Under-estimate c $\Rightarrow$ Negative velocity



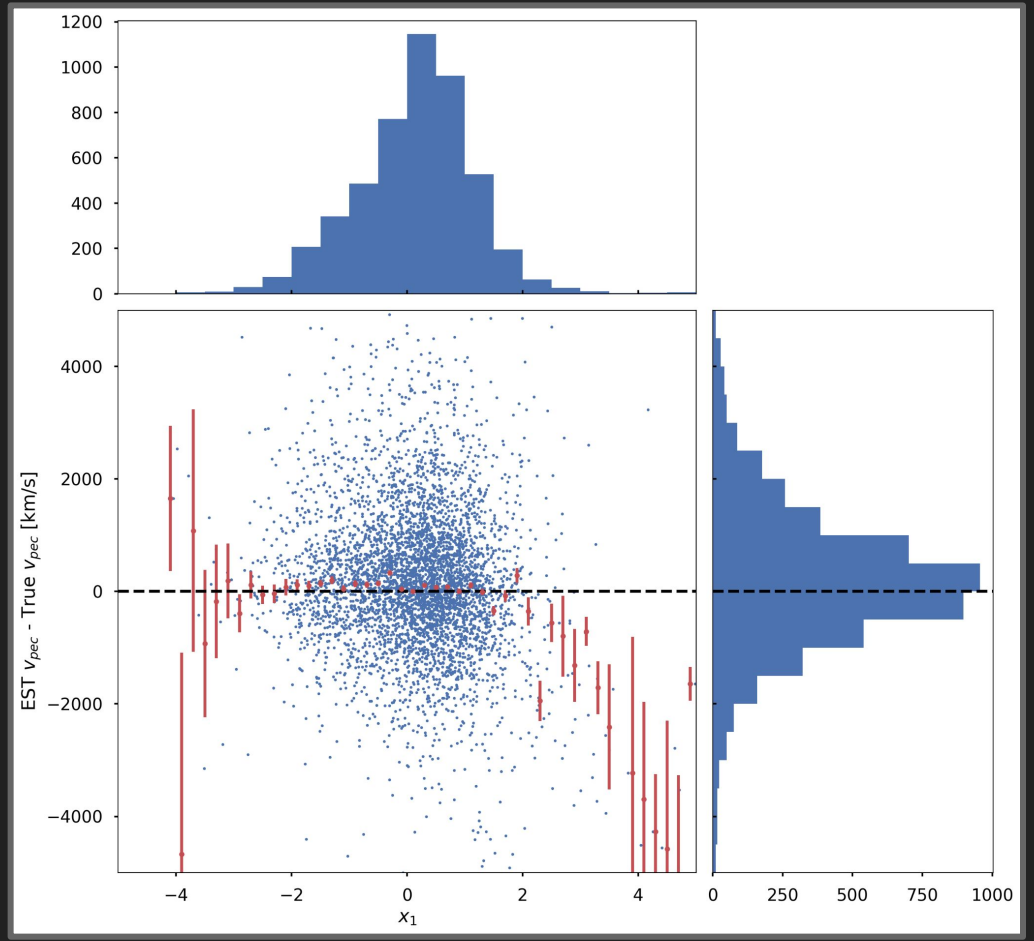
Backup : SALT x_1 effect on v_{pec} estimation

$+\alpha x_1 \Rightarrow \mu\nearrow$

$\Downarrow$

Over-estimate x_1 ⇒ Negative velocity

Under-estimate x_1 ⇒ Positive velocity



Backup : Velocities estimation from residuals

Apply ZTF - DR1 cuts $|x_1| < 3$ and $|c| < 0.3$