

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

Simulation of the Sample Bias

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What is σ_8 ?

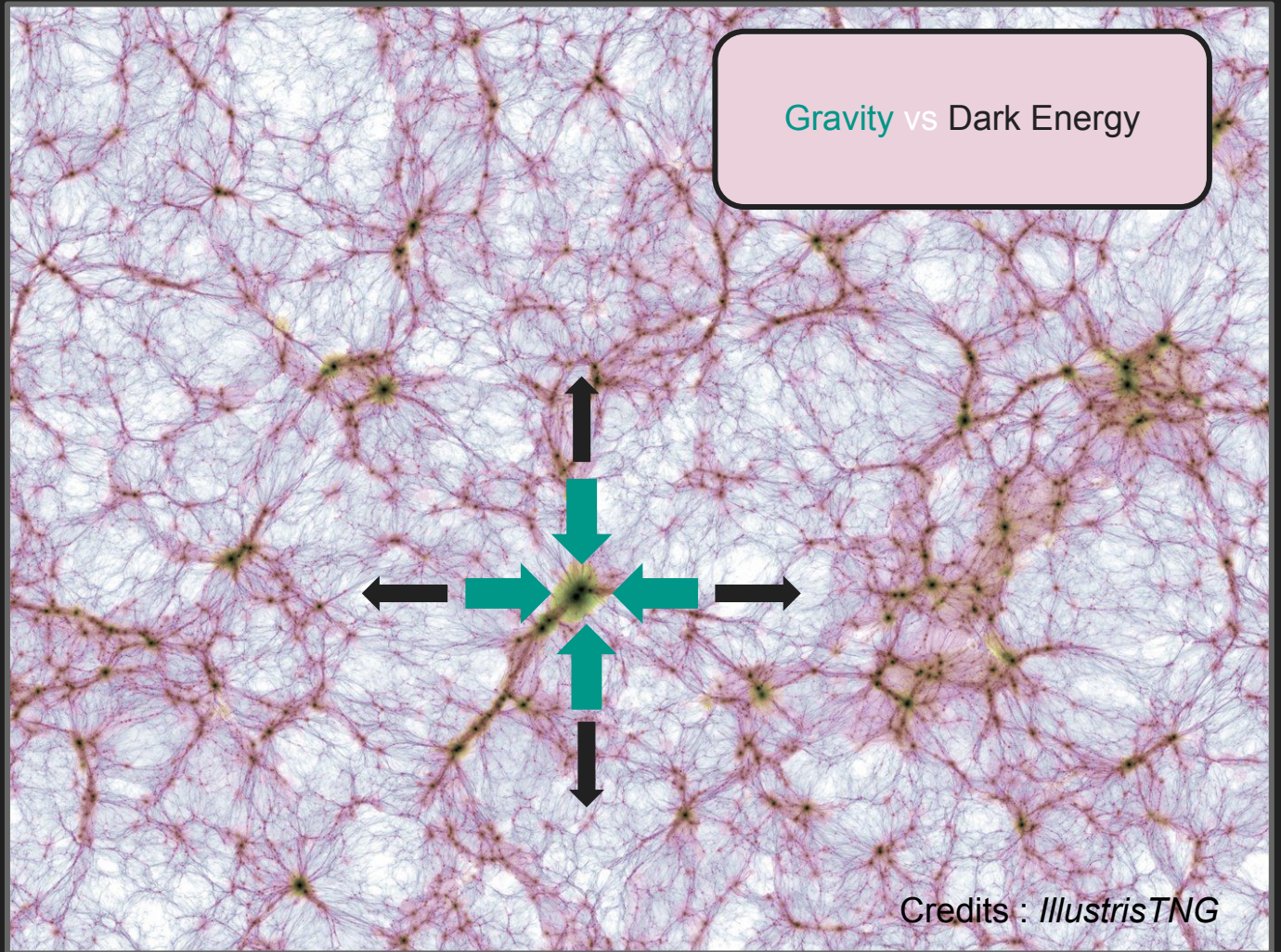
Growth factor

$$\delta_m = \hat{\delta}_m(\mathbf{x}) \boxed{D(t)}$$

Growth rate

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

Gravity vs Dark Energy



Credits : *IllustrisTNG*

What is $f\sigma_8$?

Growth factor

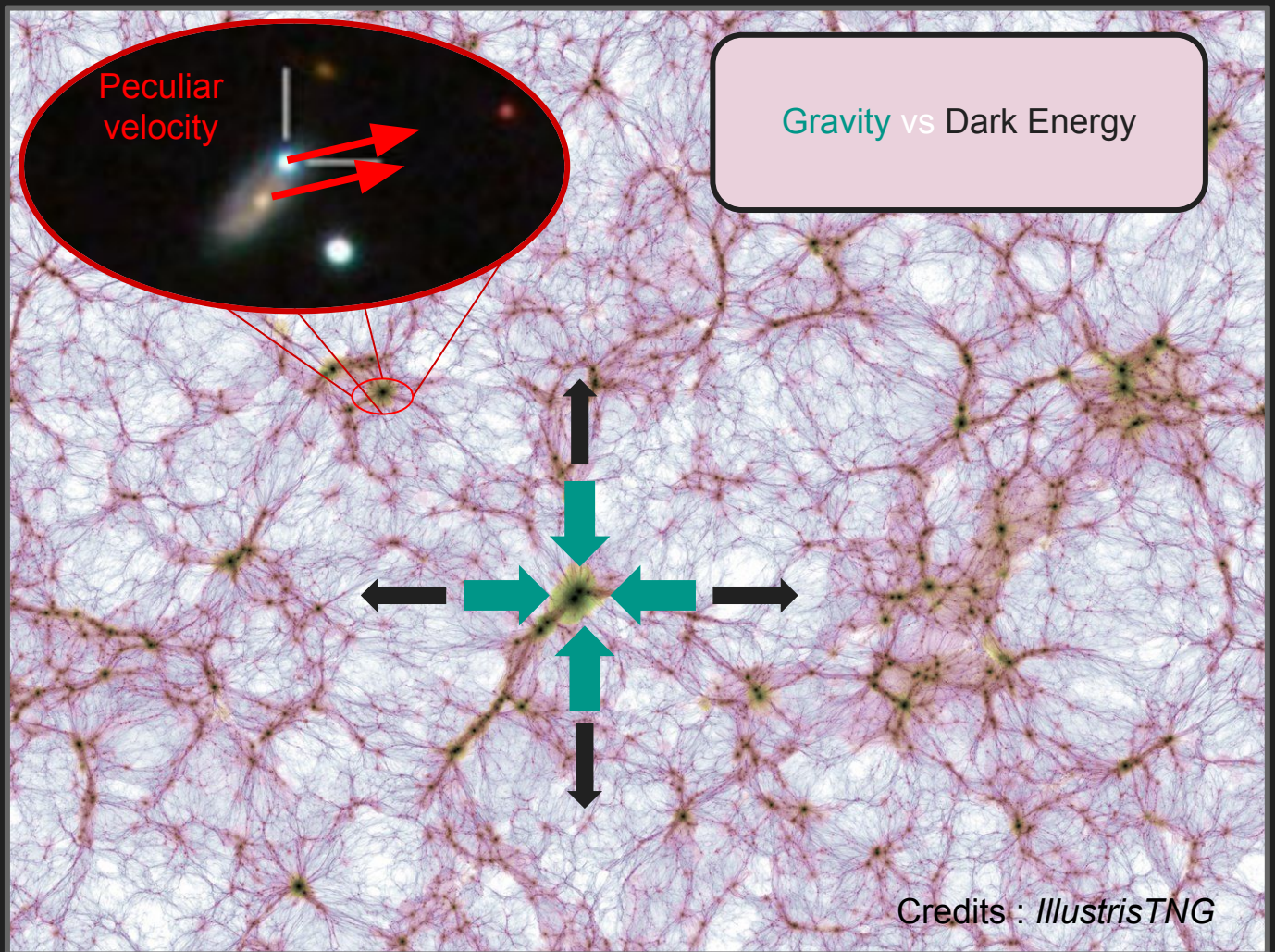
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Peculiar velocities

$$\nabla \cdot \mathbf{v} \propto f D$$



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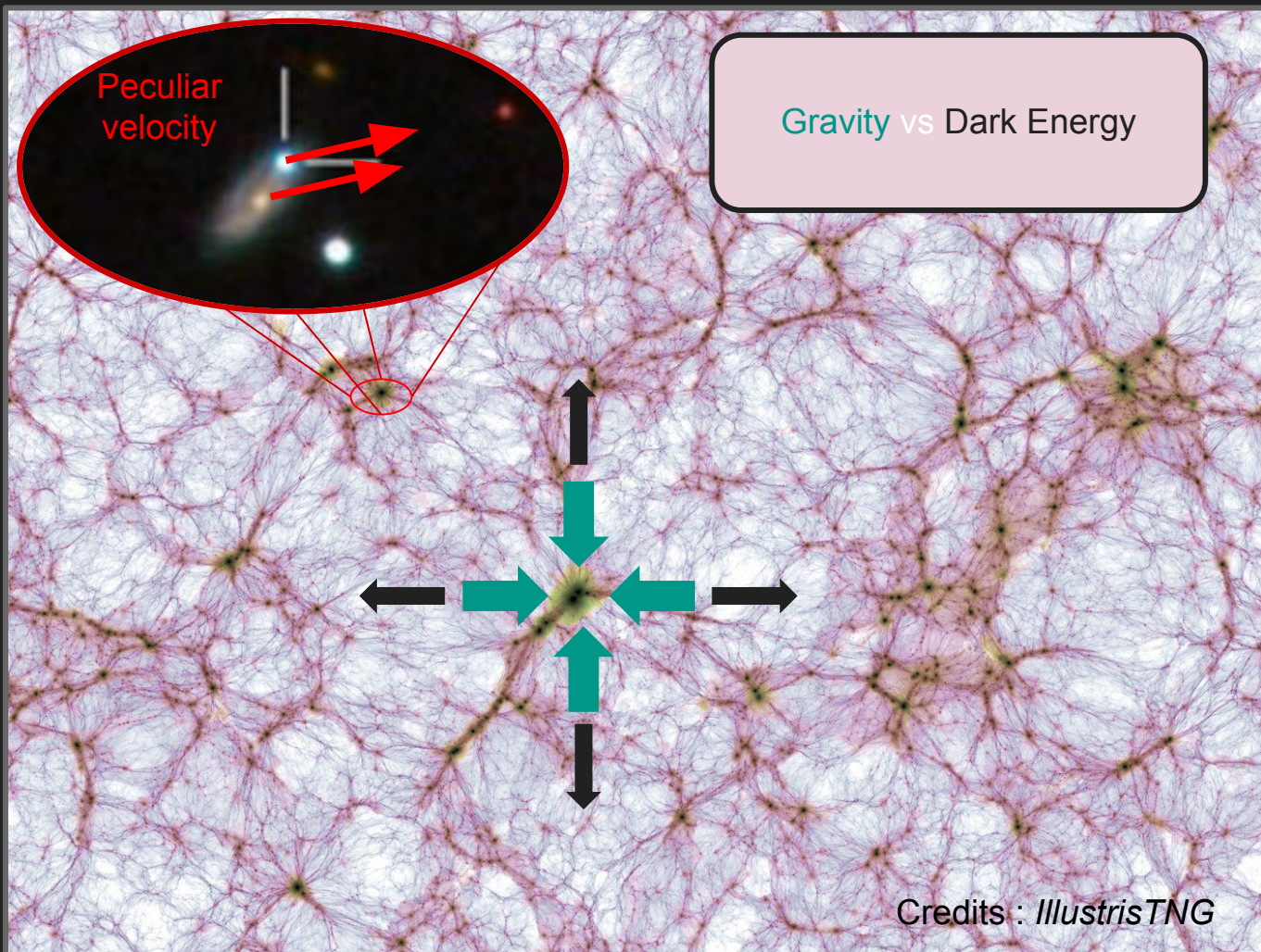
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Peculiar velocities

$$\begin{aligned} \nabla \cdot \mathbf{v} &\propto f \cancel{D} \\ &\propto f \sigma_8 \end{aligned}$$



Gravity vs Dark Energy

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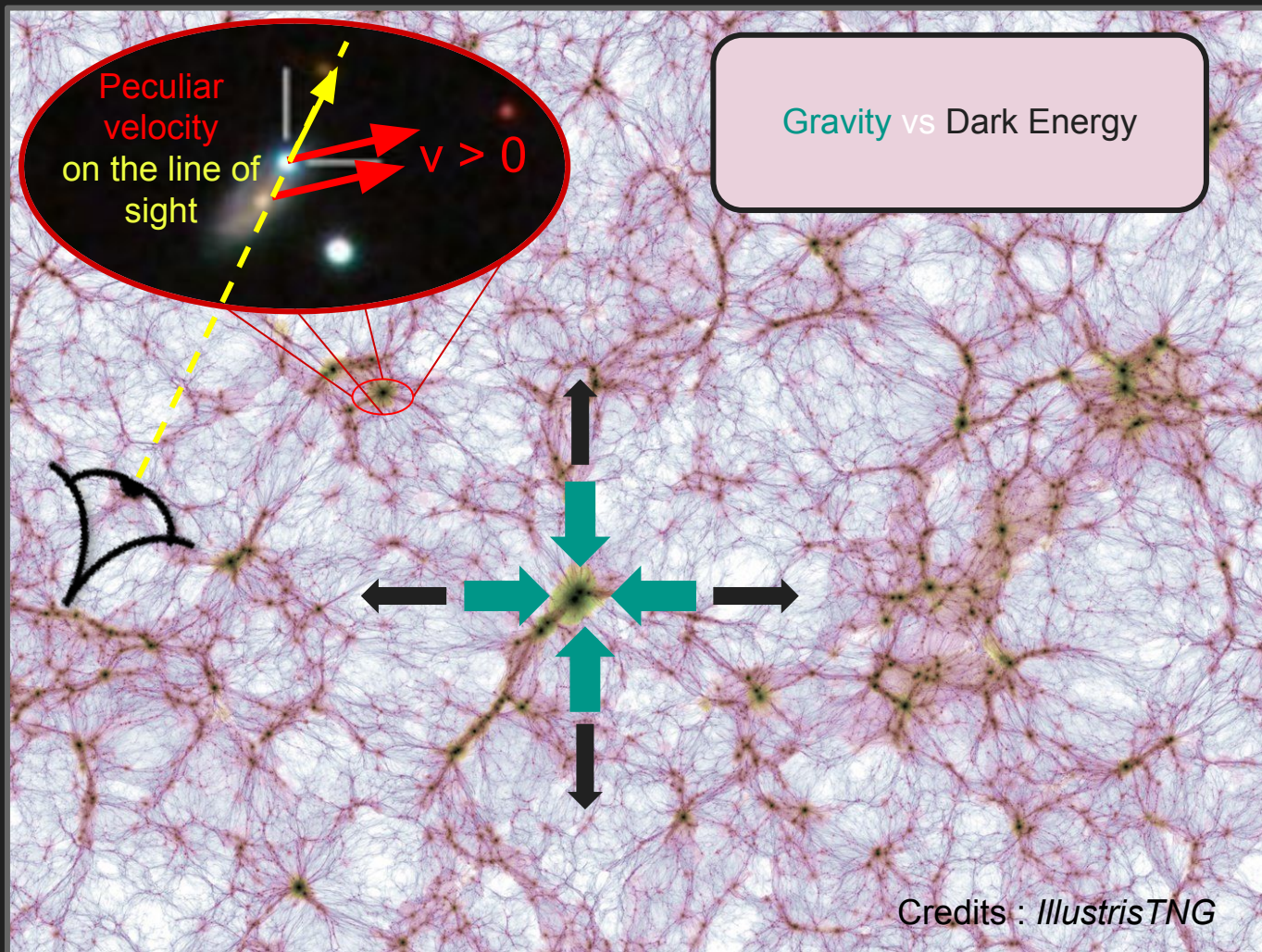
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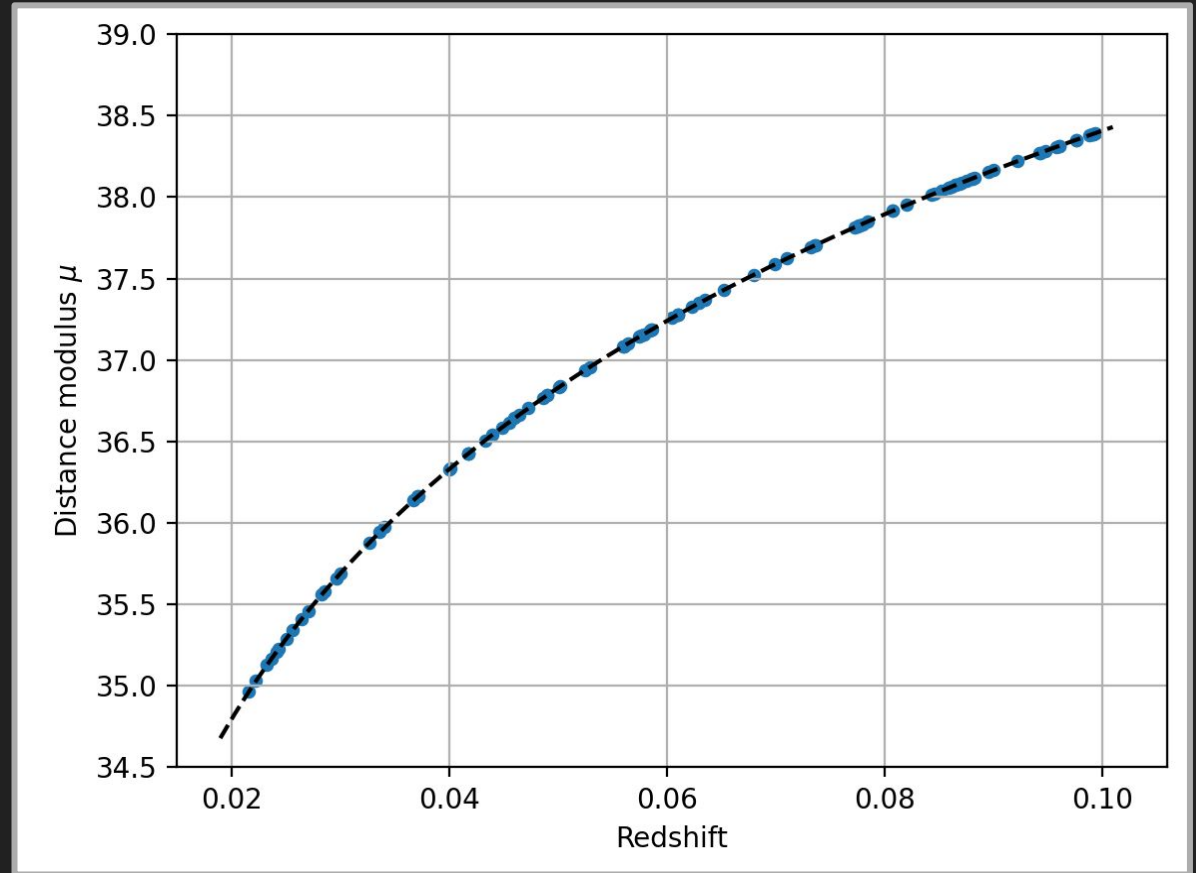
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Gravity vs Dark Energy

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The Hubble diagram : without peculiar velocities



The Hubble diagram : with peculiar velocities

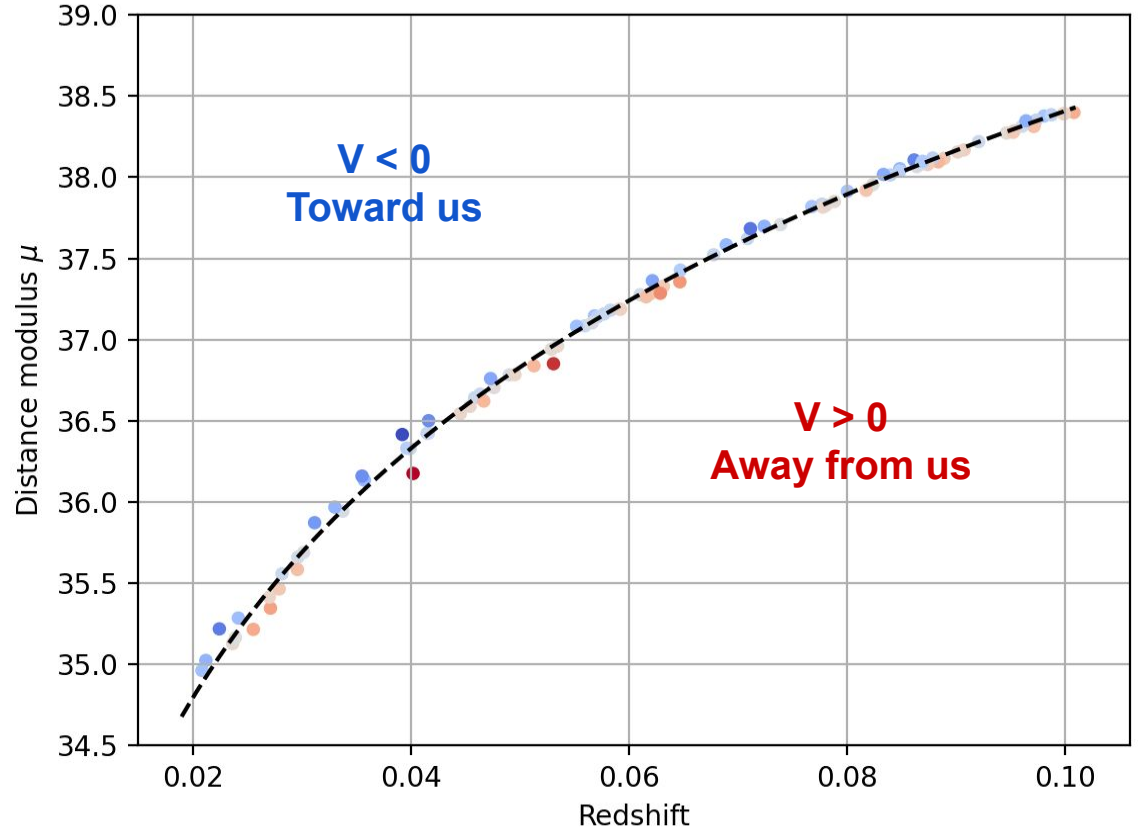
Adding peculiar velocity :

Effect of $v \sim 300$ km / s

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

$\Delta \mu \sim 0.004$ mag

Δz and $\Delta \mu$ variations have the same sign as v



The Hubble diagram : SN Ia intrinsic scattering

Adding peculiar velocity :

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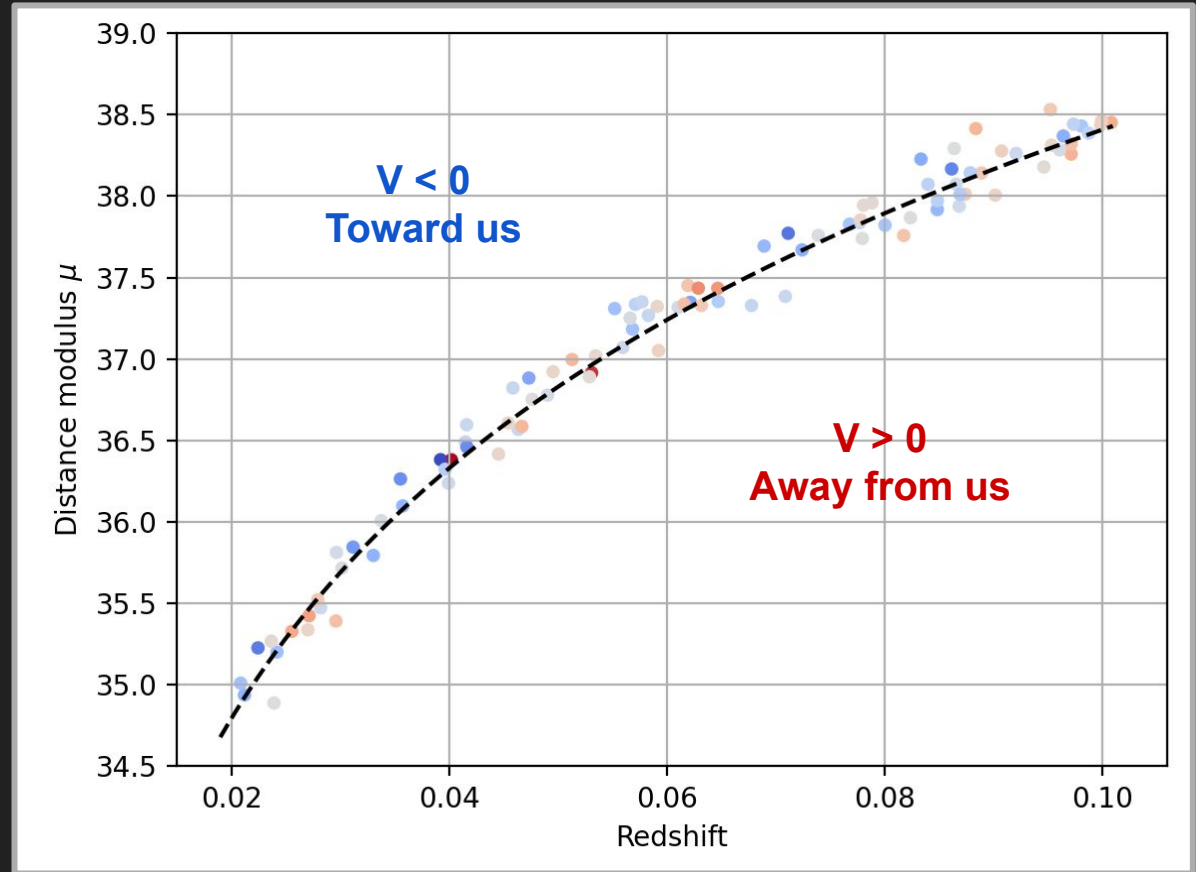
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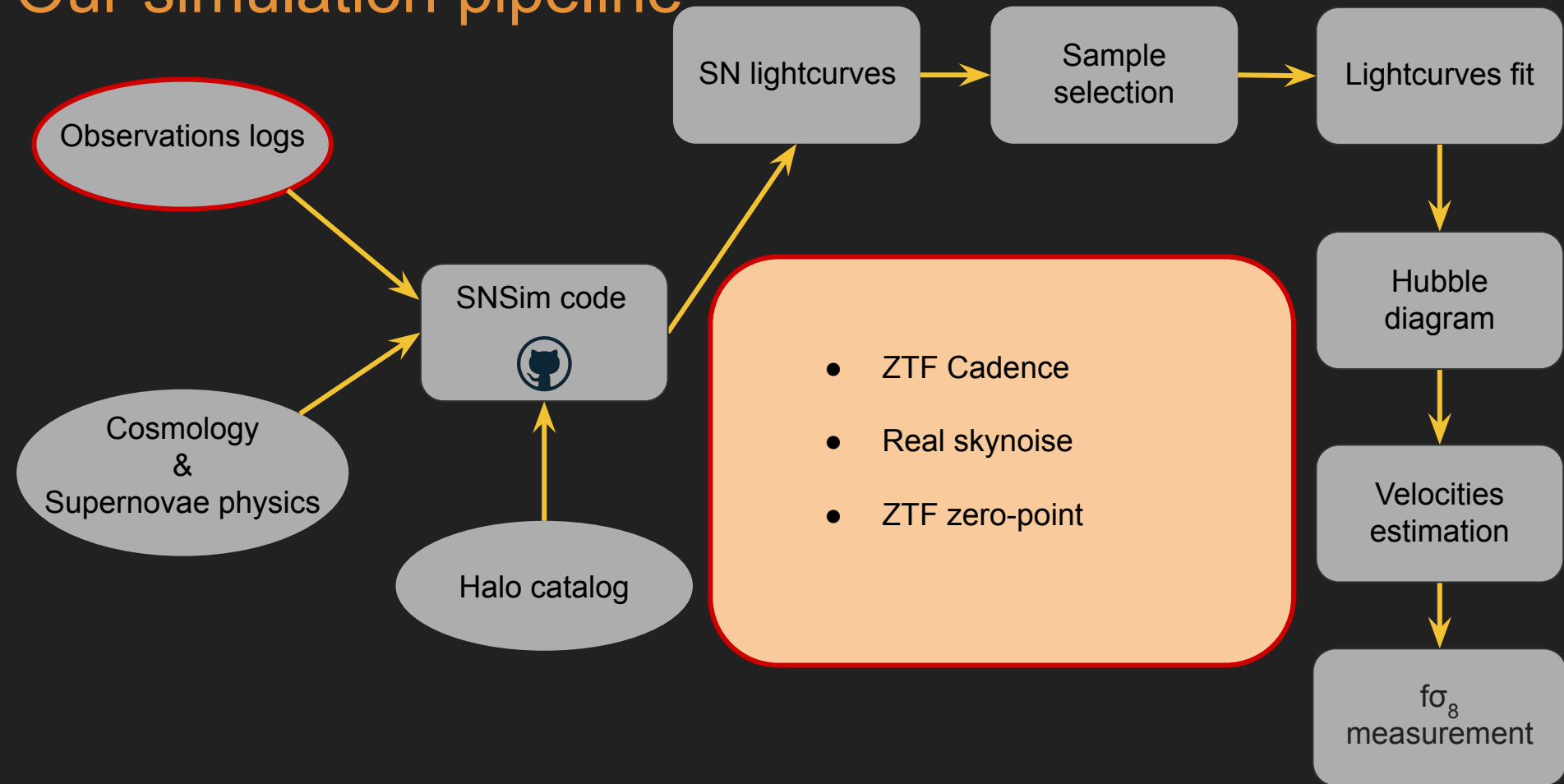
Δz and $\Delta \mu$ variations have the same sign as v

Adding SN Ia luminosity intrinsic scatter :

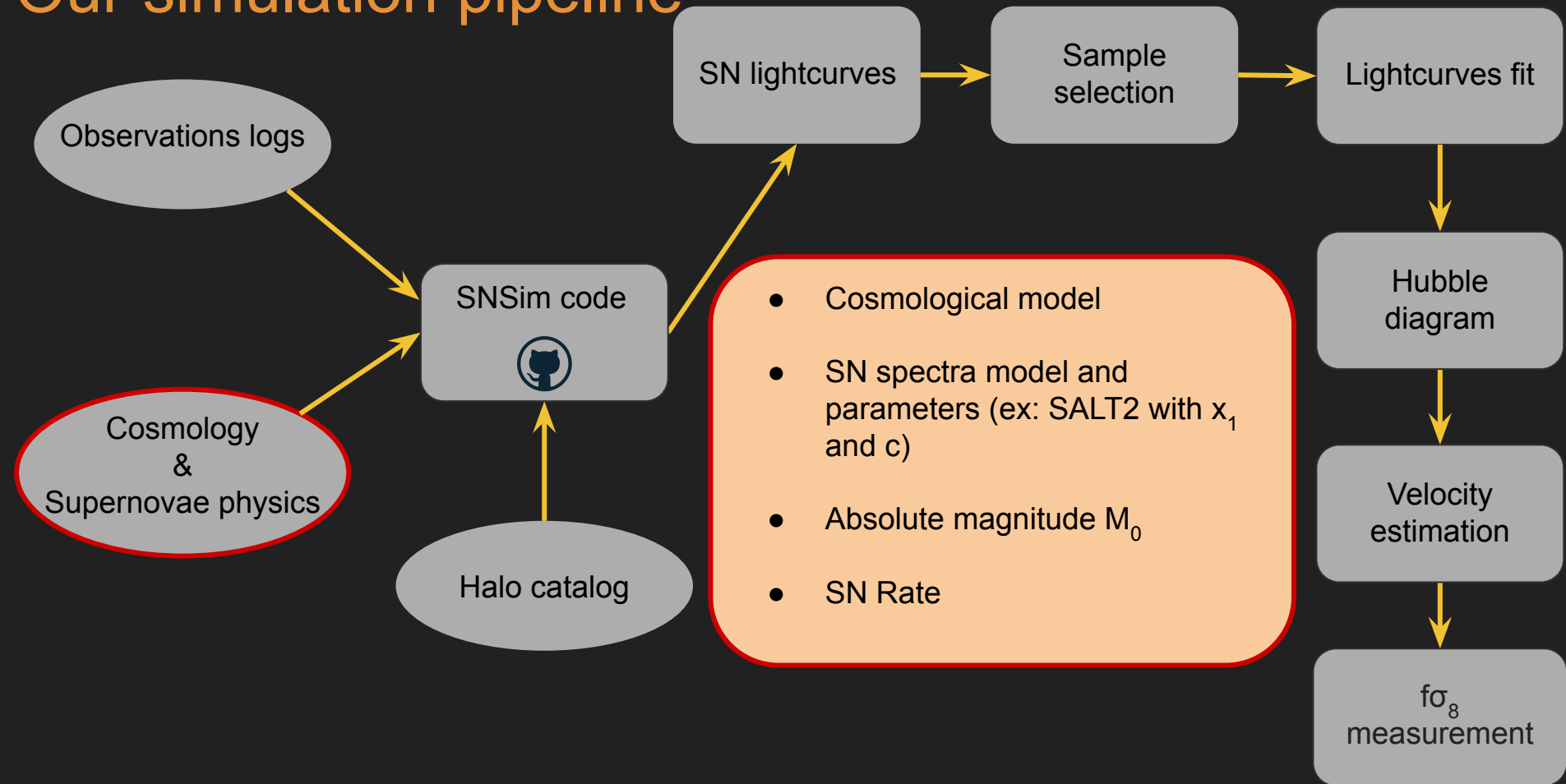
$\sigma_{\text{int}} \sim 0.12 \text{ mag}$



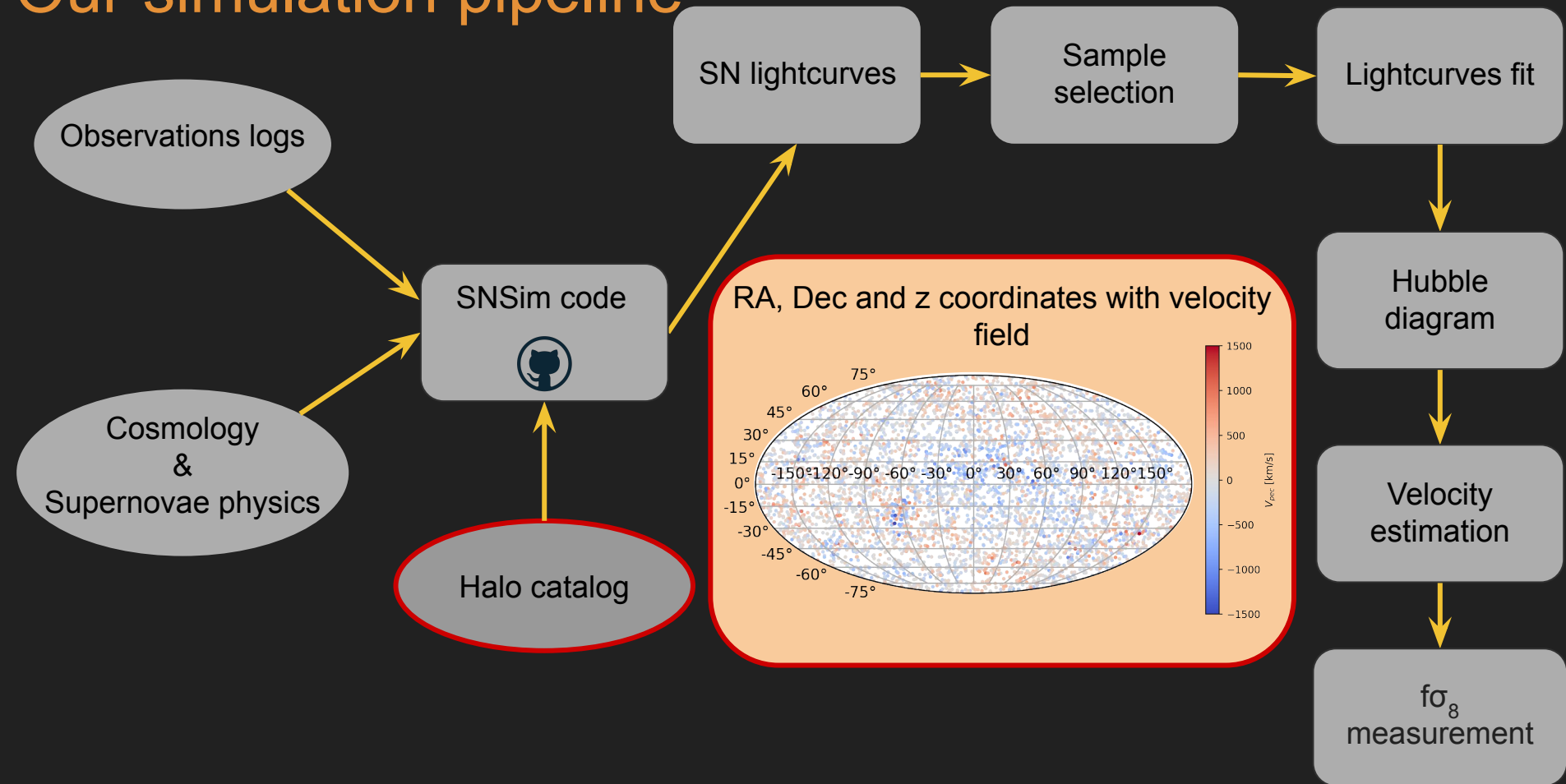
Our simulation pipeline



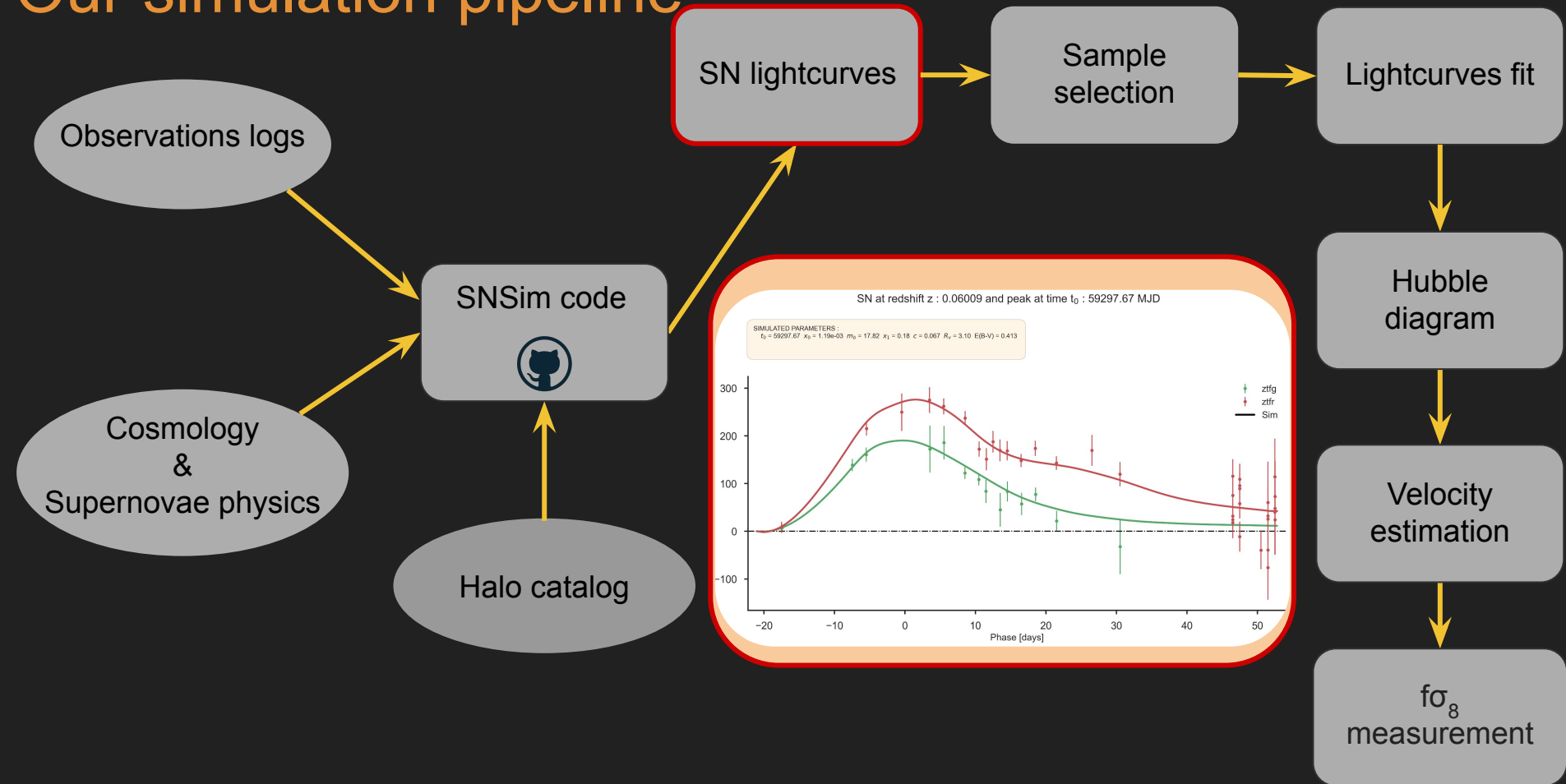
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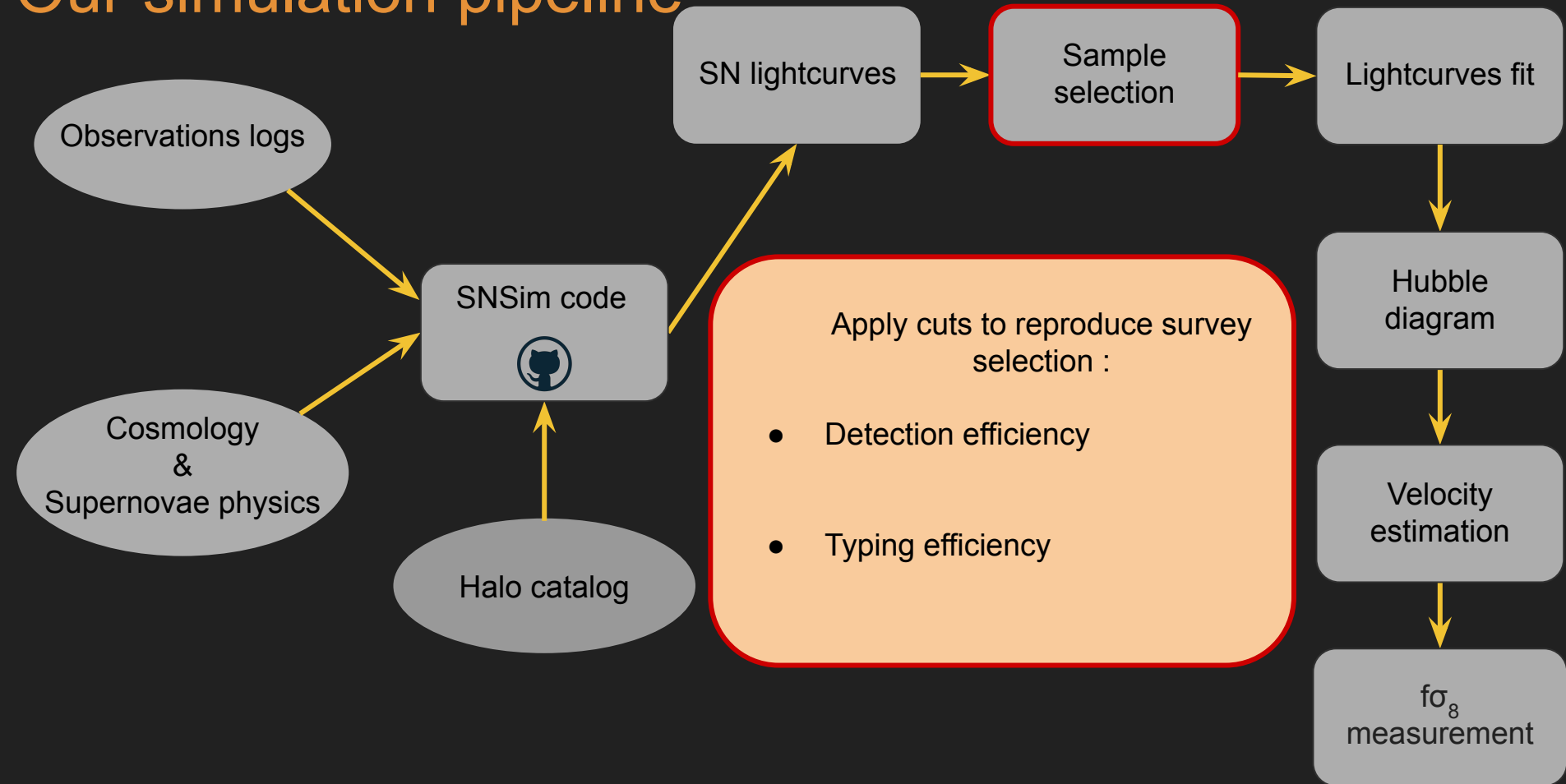
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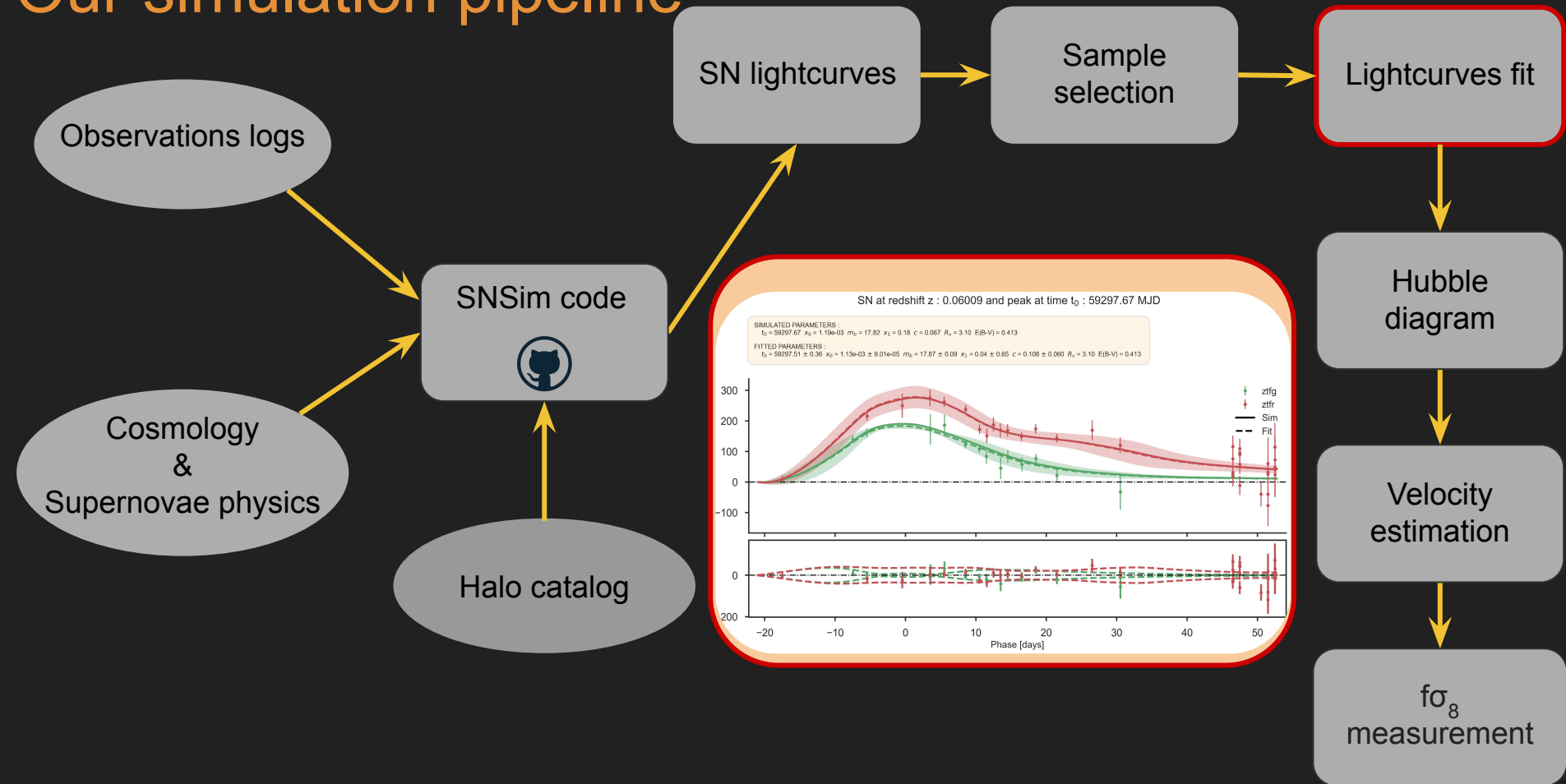
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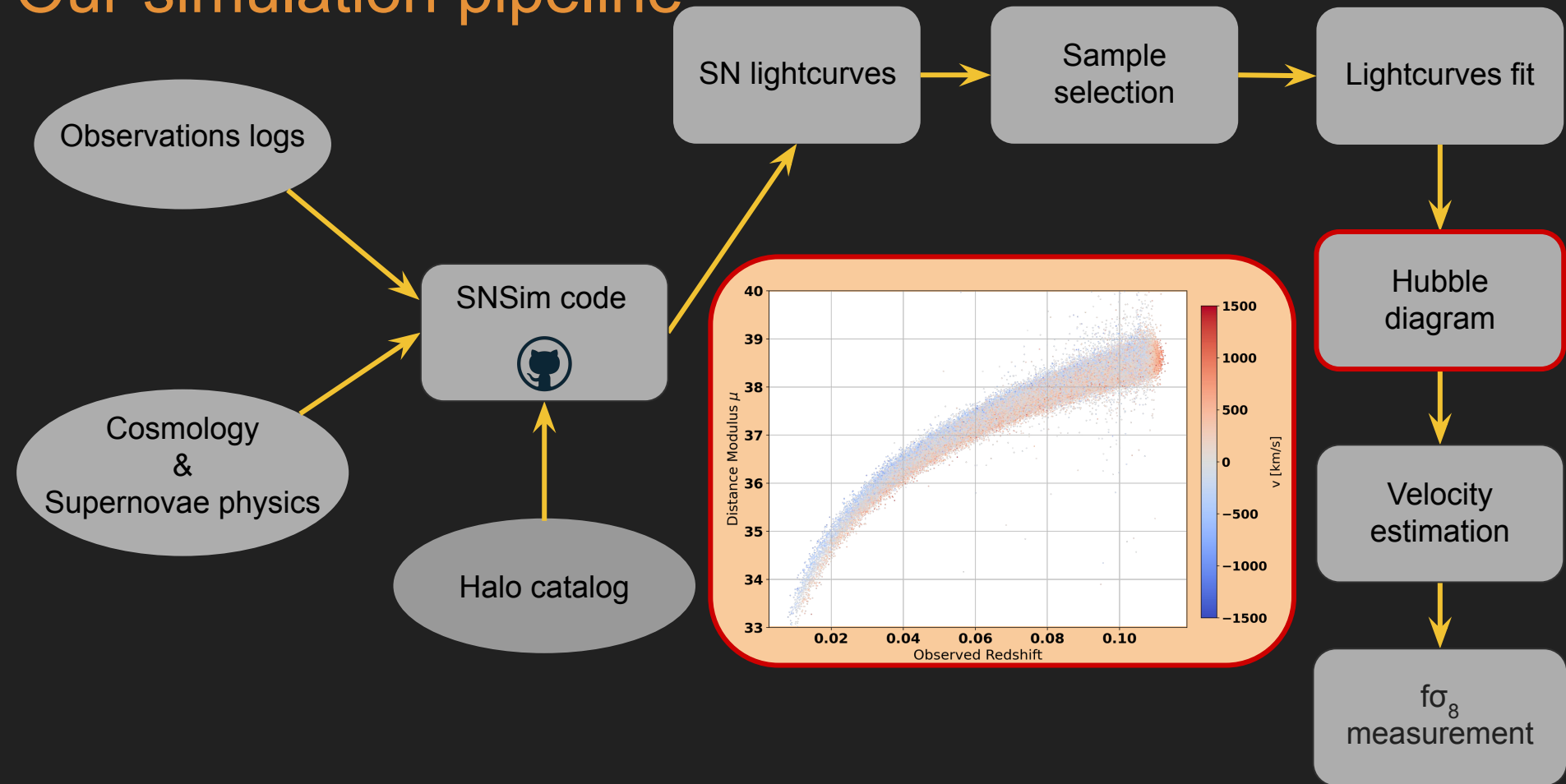
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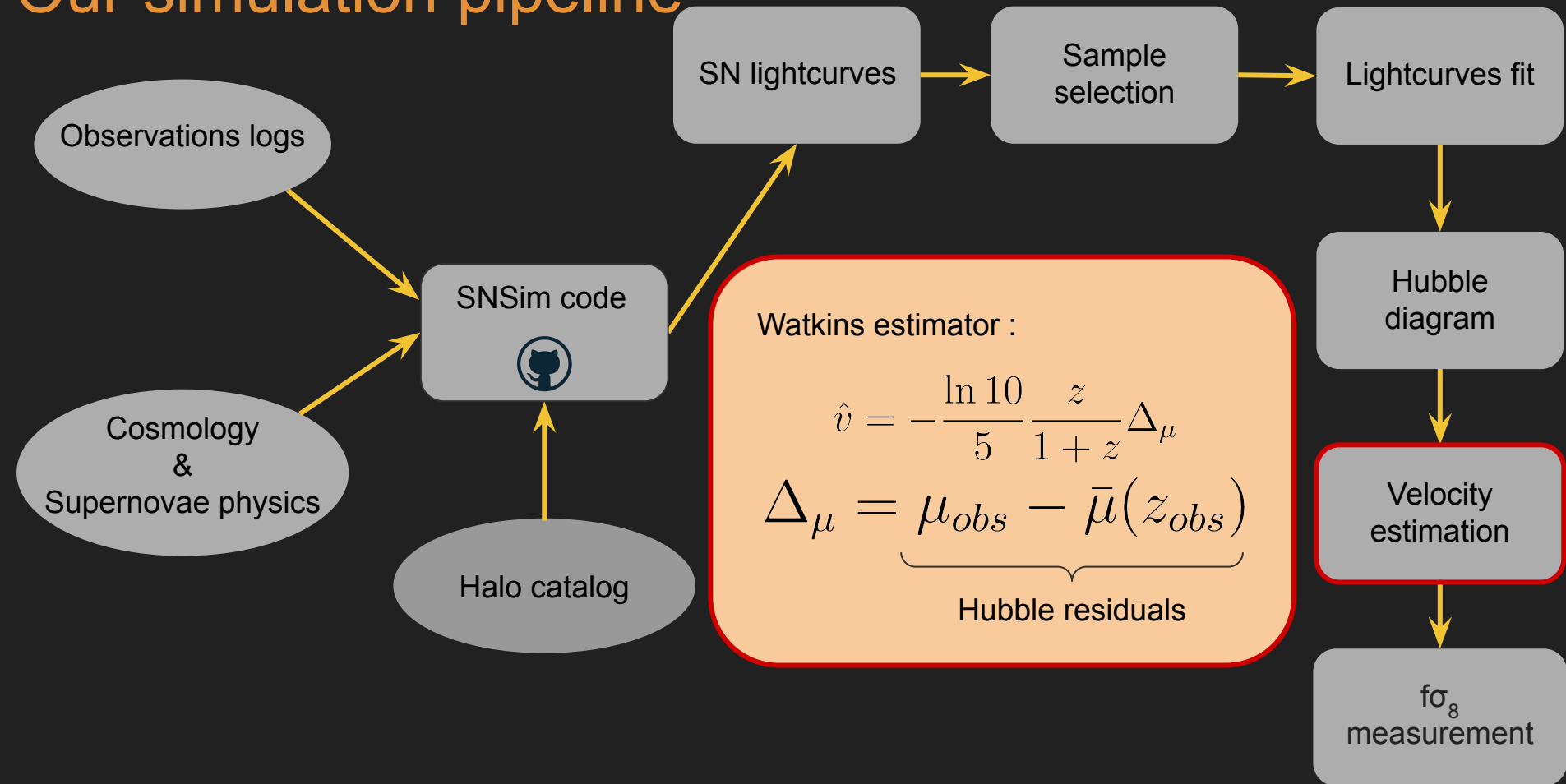
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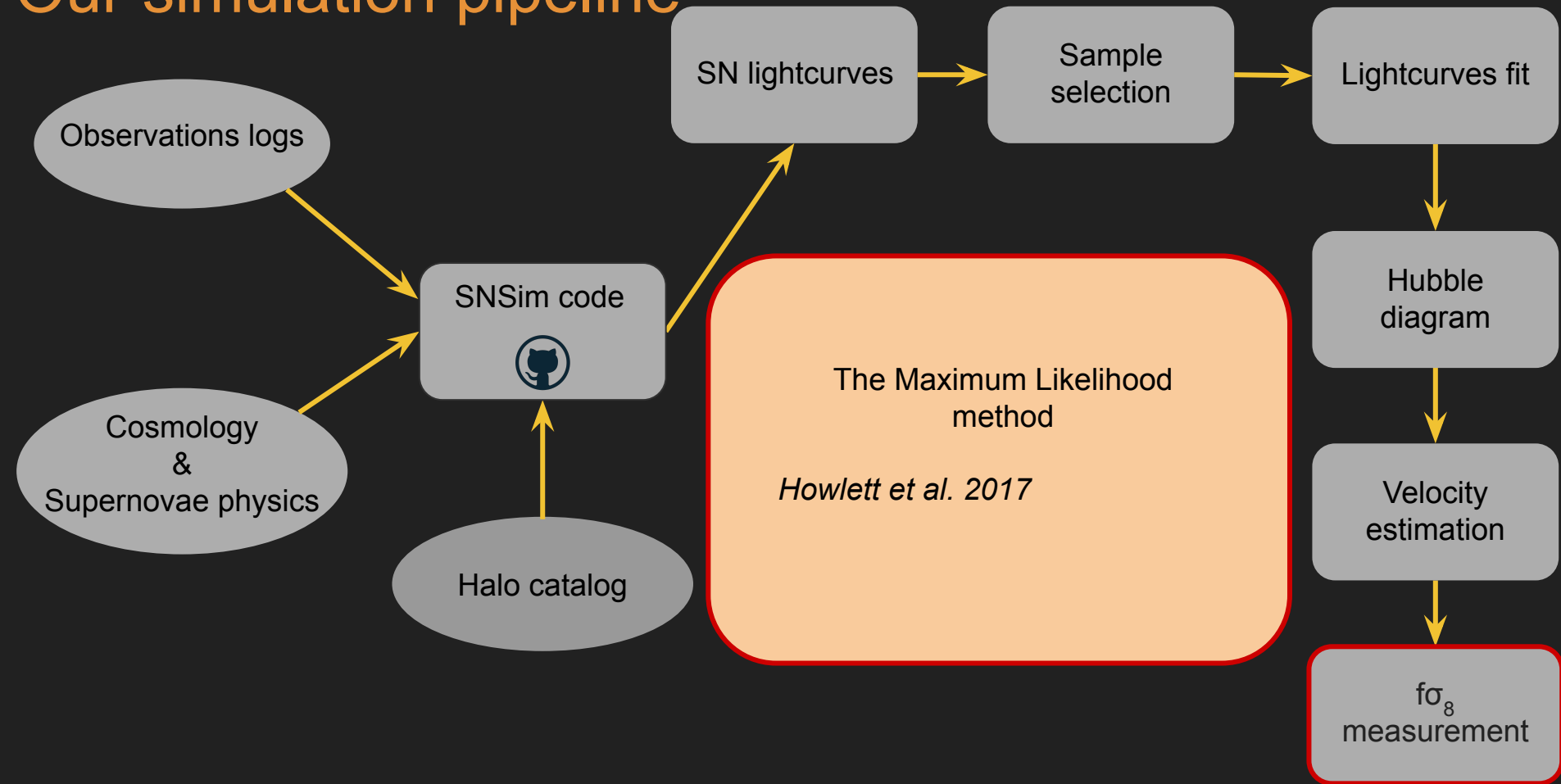
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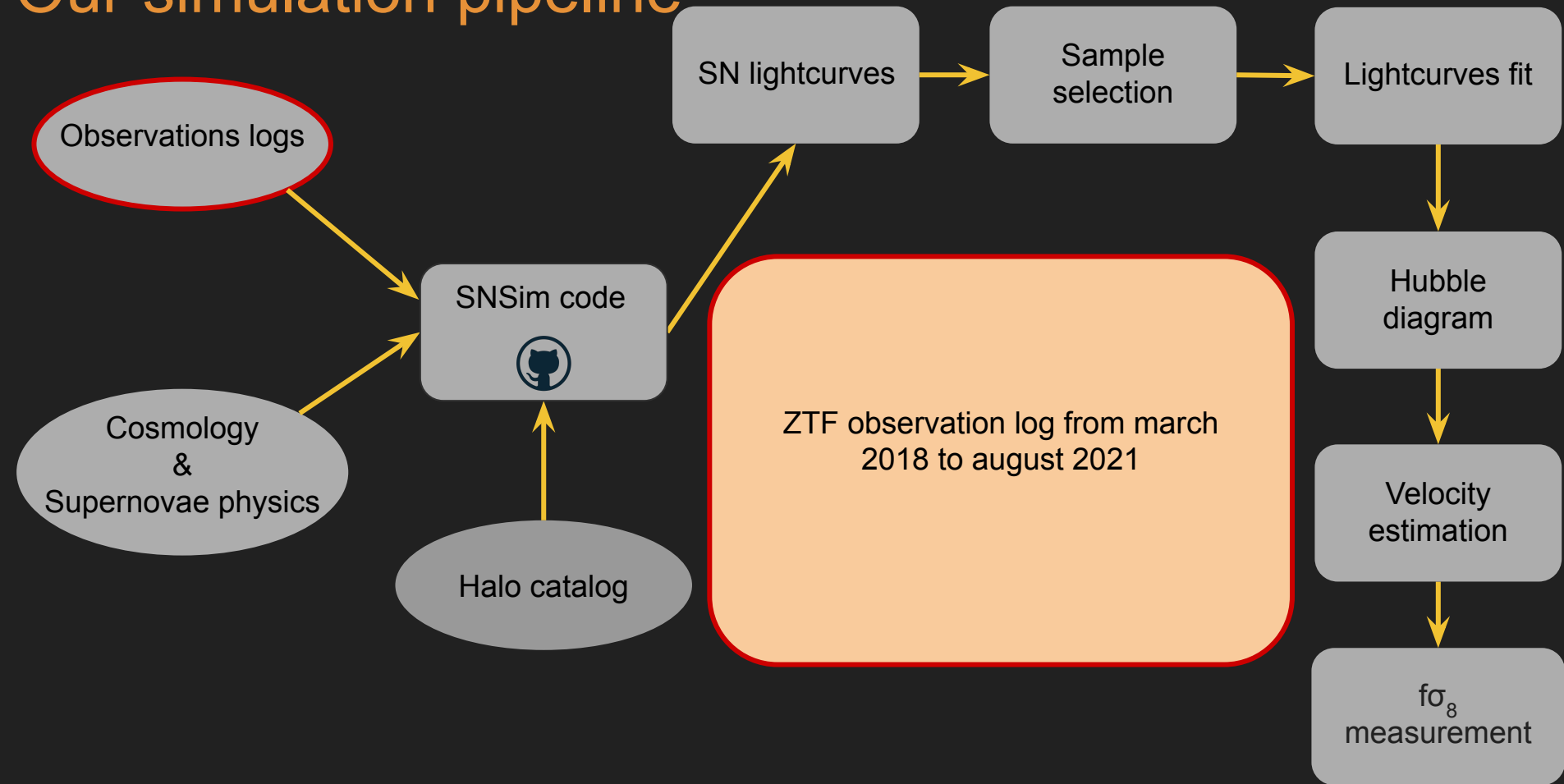
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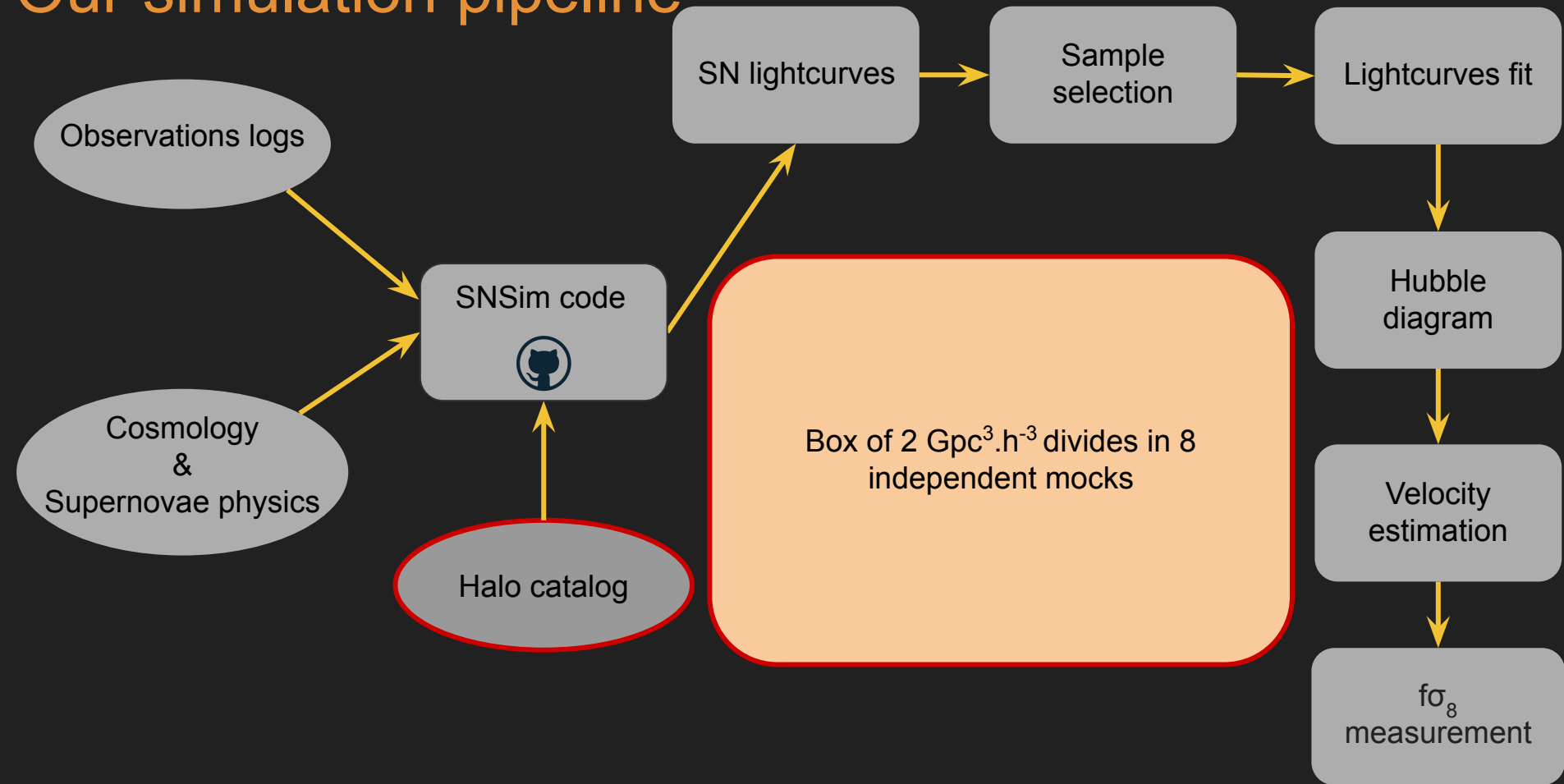
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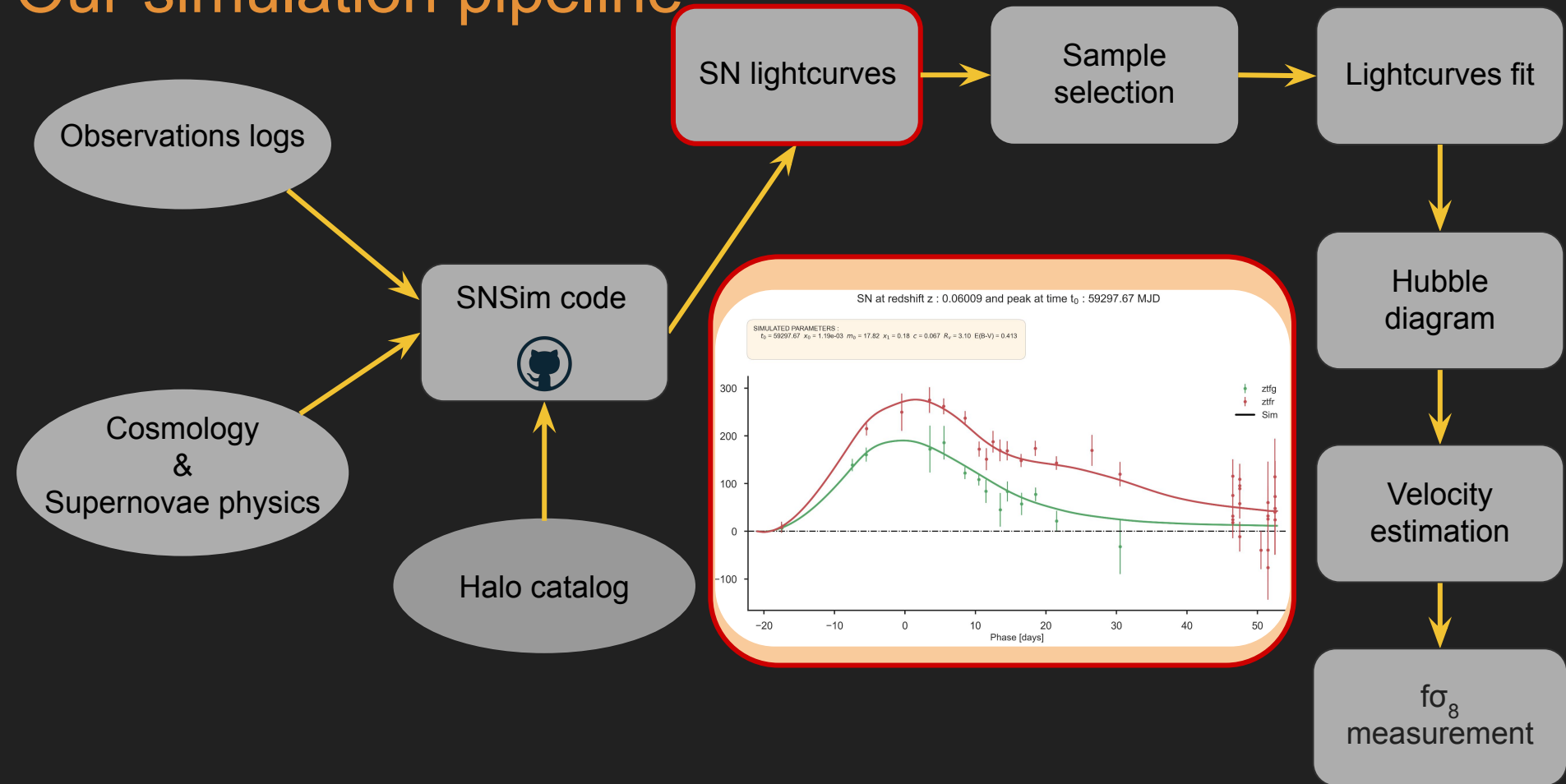
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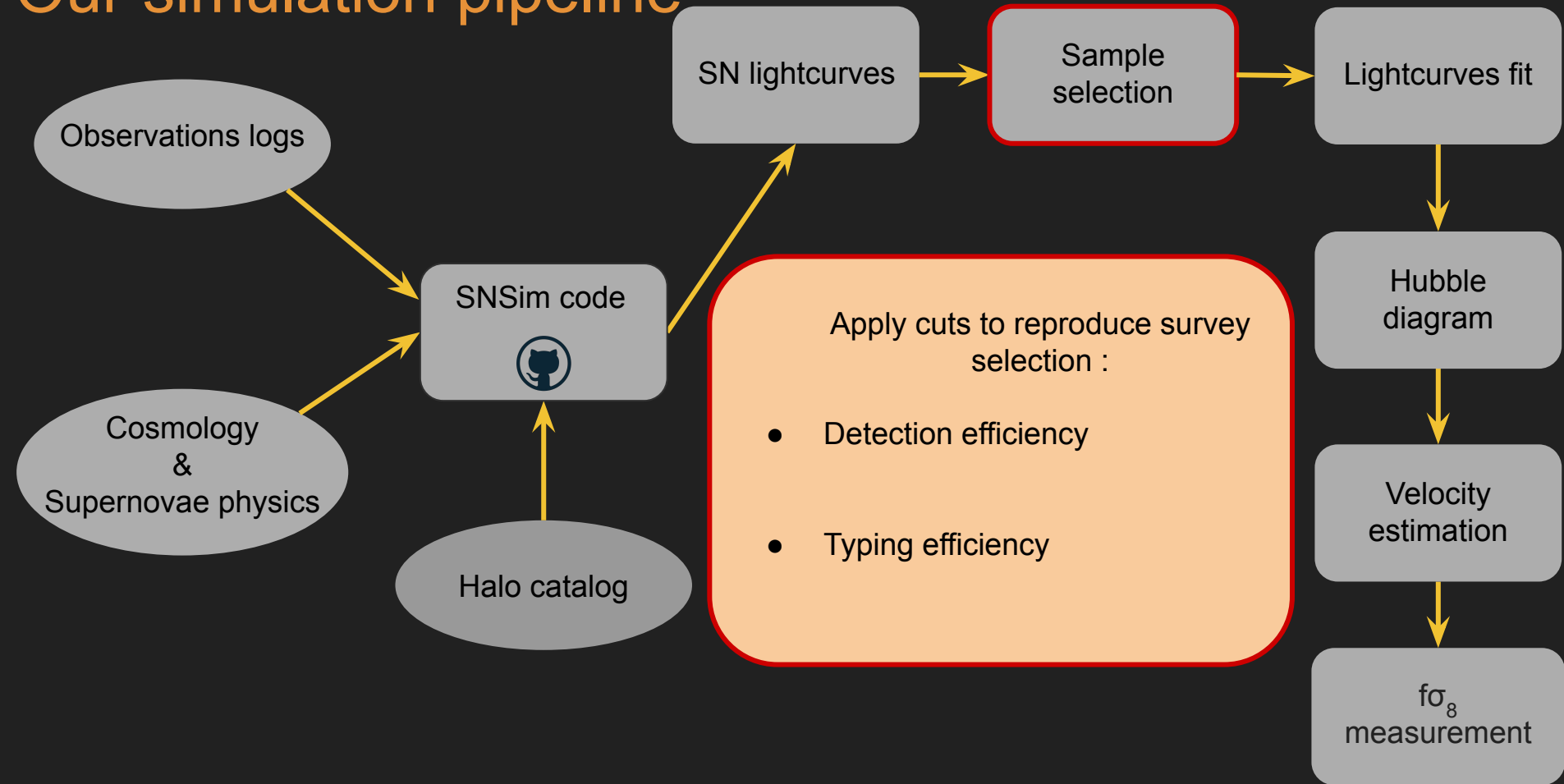
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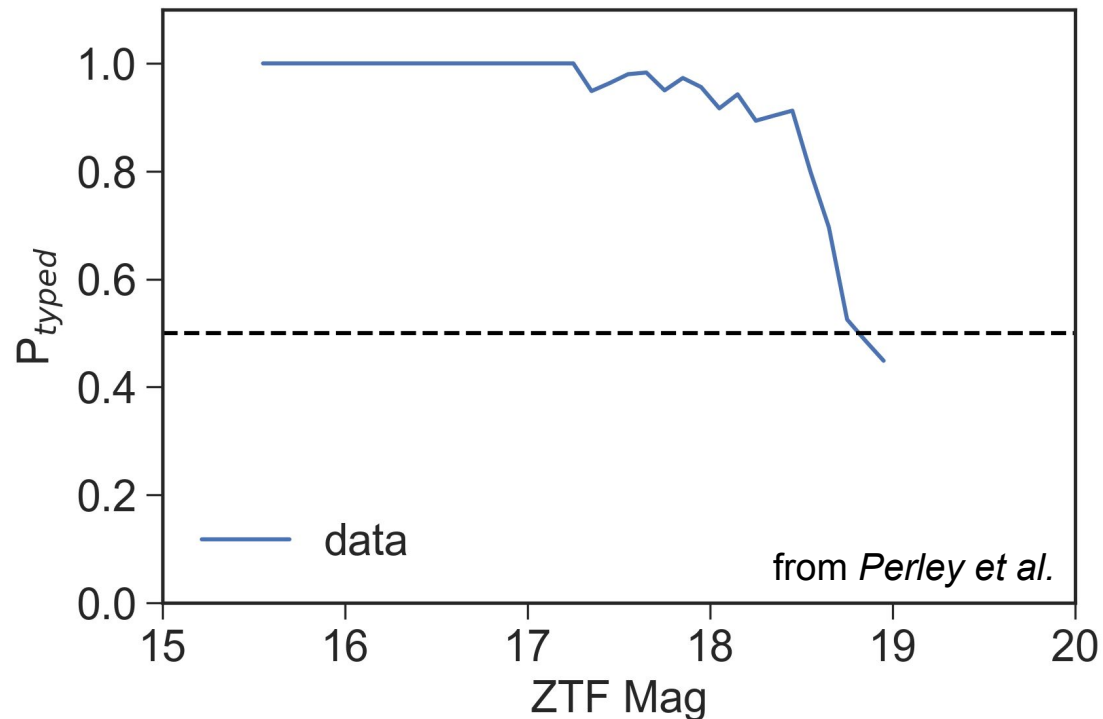
Reproduce the sample selection :

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

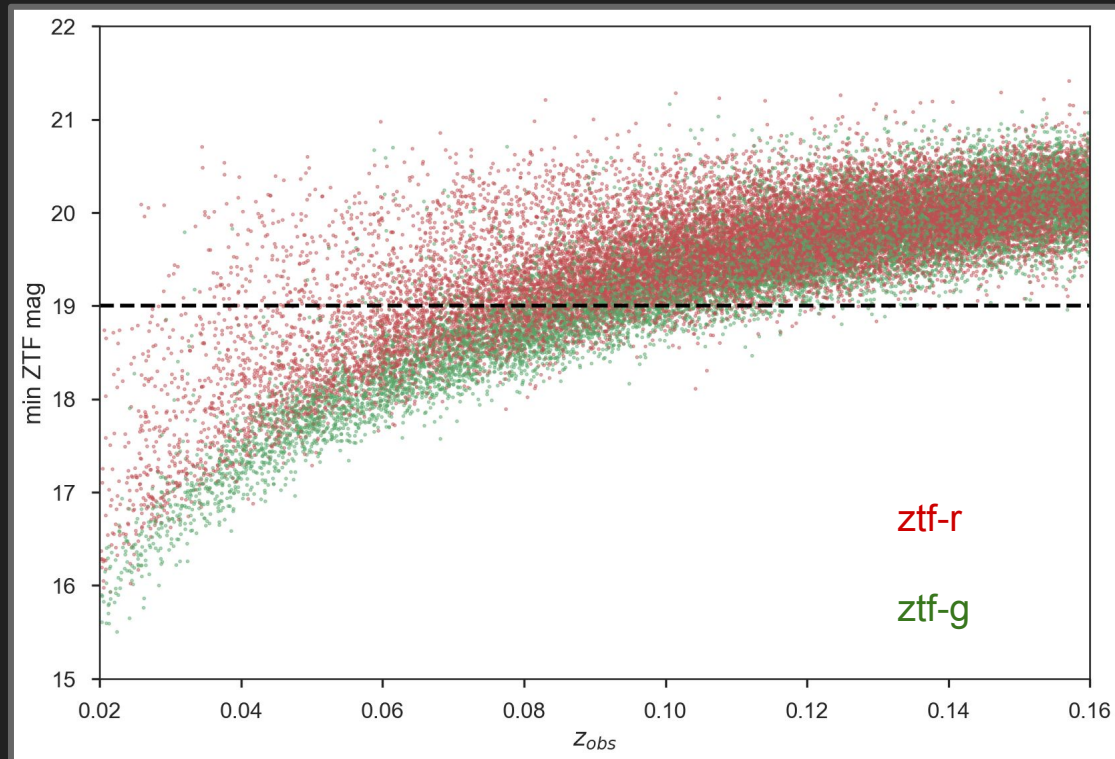


Reproduce the sample selection : ZTF magnitudes

Apply cuts :

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

Minimum magnitude of full sample

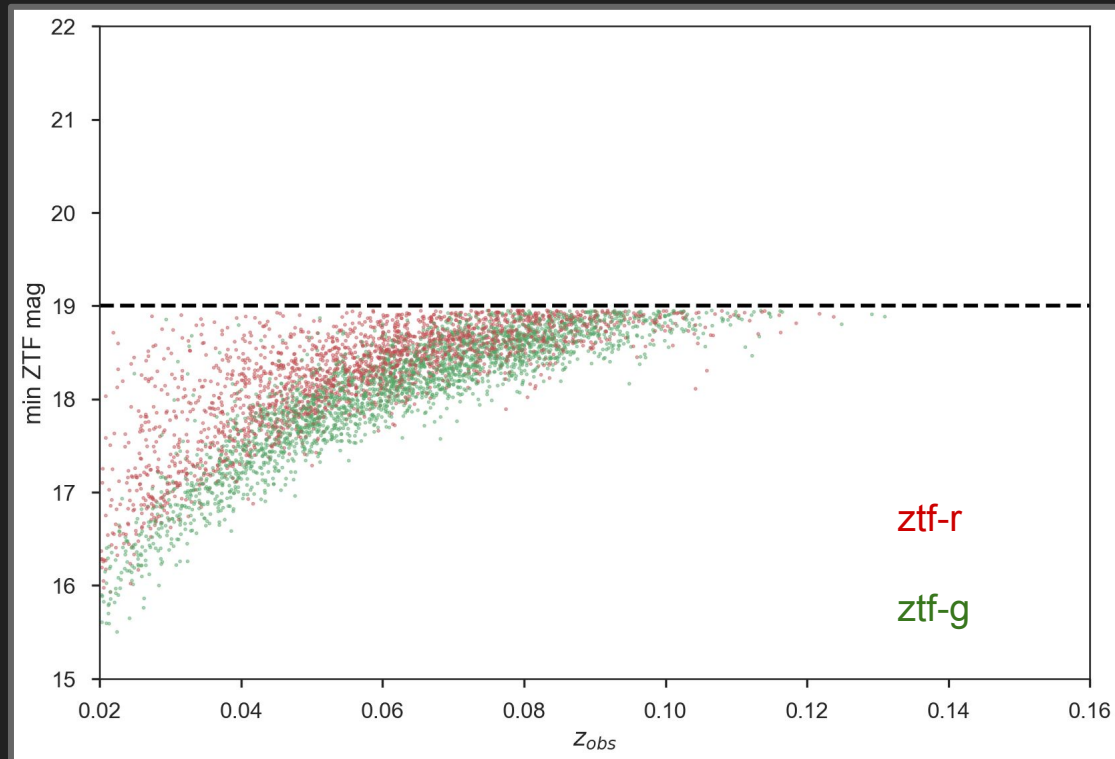


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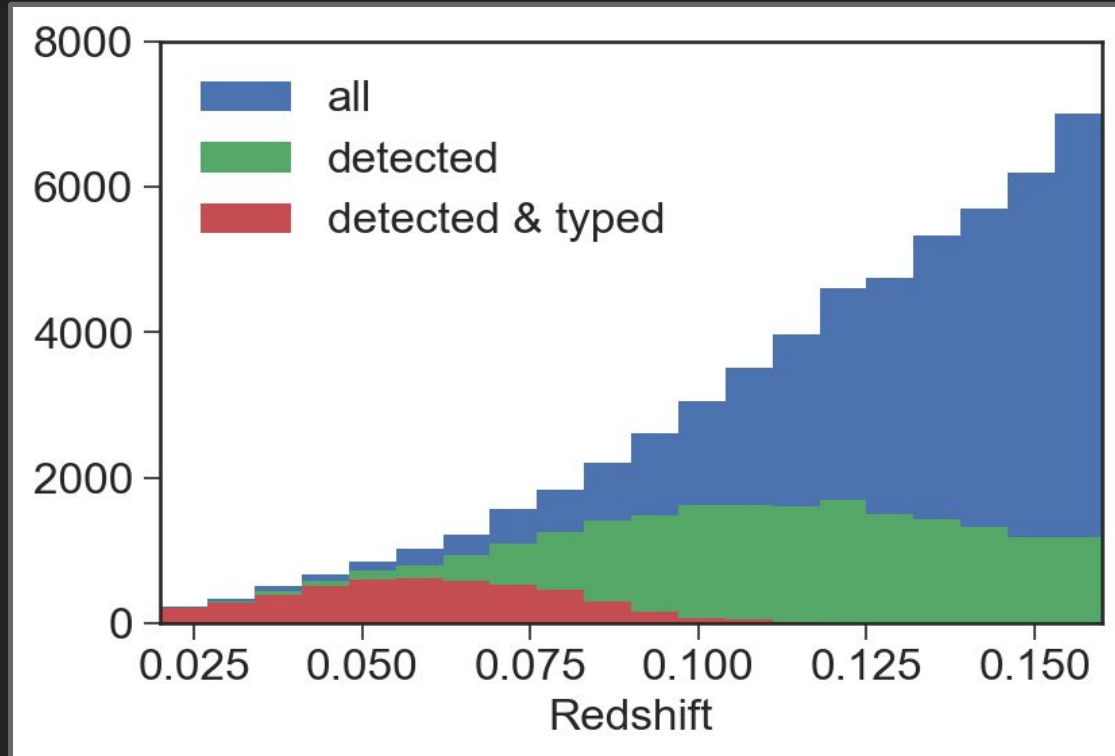


Reproduce the sample selection : Redshift distribution

Redshift distribution of full and selected samples

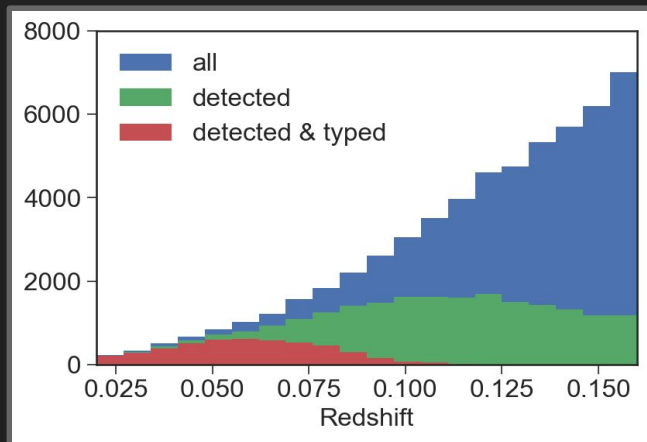
Selected SN :

- Median redshift = 0.06
- Max redshift = 0.13



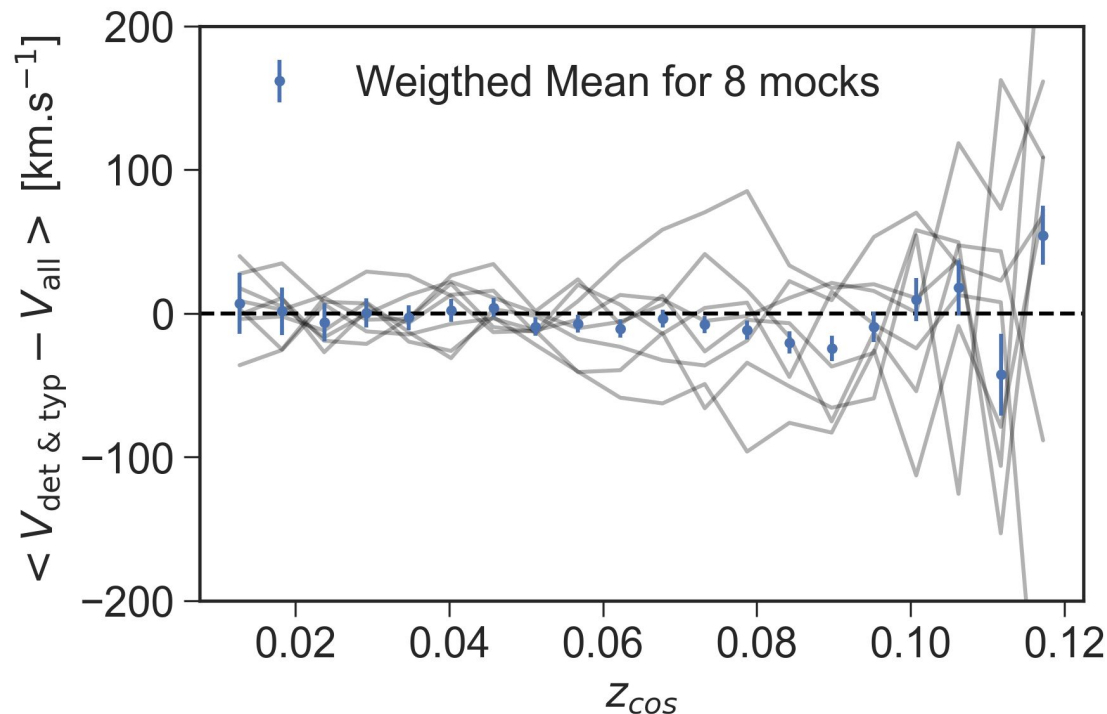
Reproduce the sample selection :

Is there already a bias ?

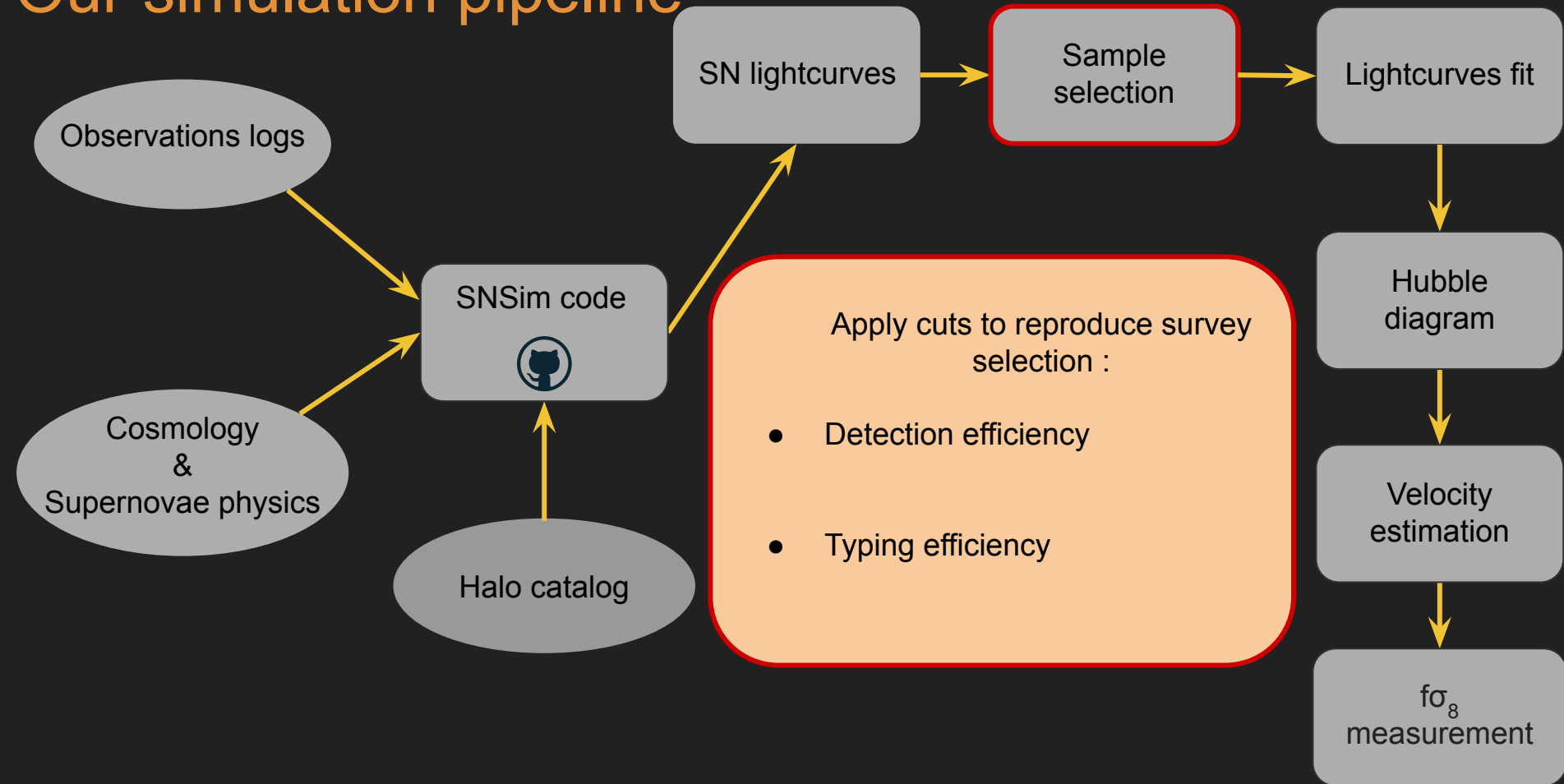


The selection doesn't introduce **any bias** on velocities

Difference between full sample and selected sample velocities

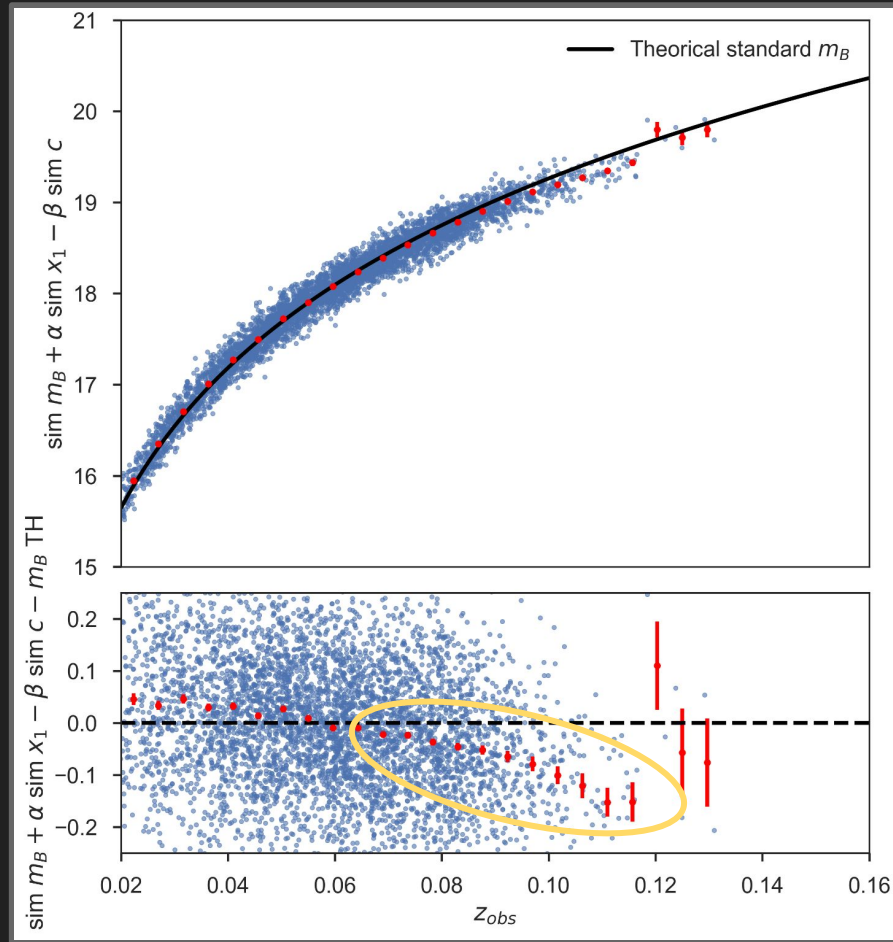


Our simulation pipeline



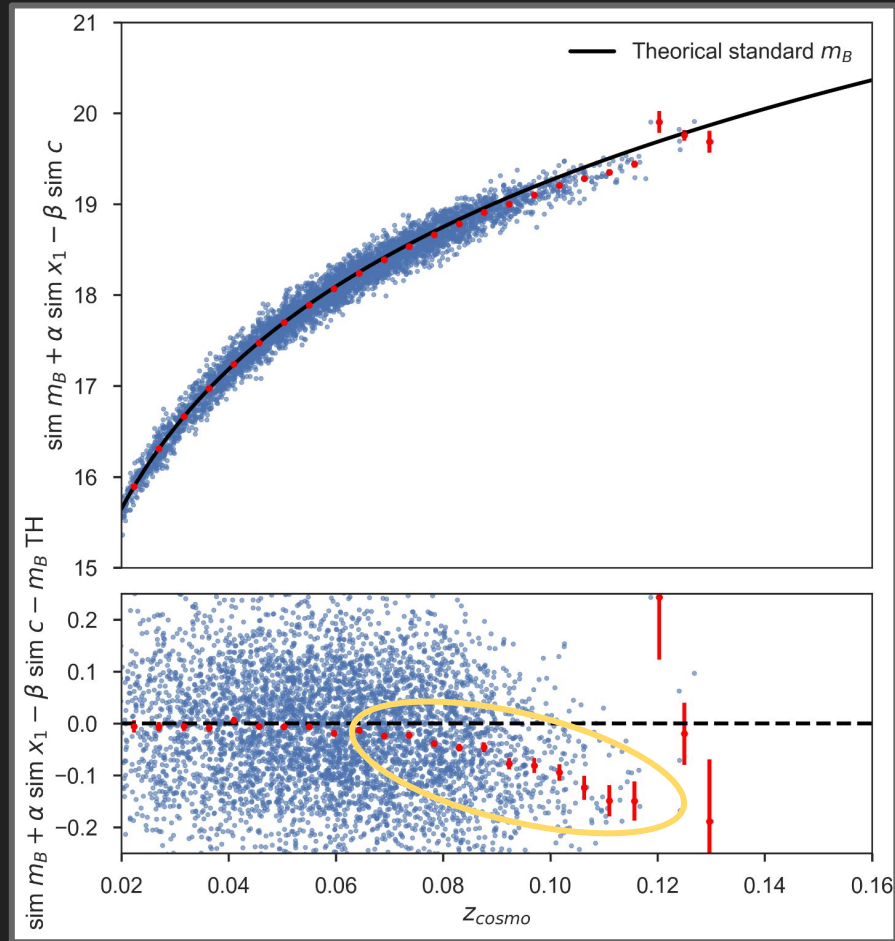
A first look at the simulated HD after selection

Selection bias appears at $z \sim 0.06$

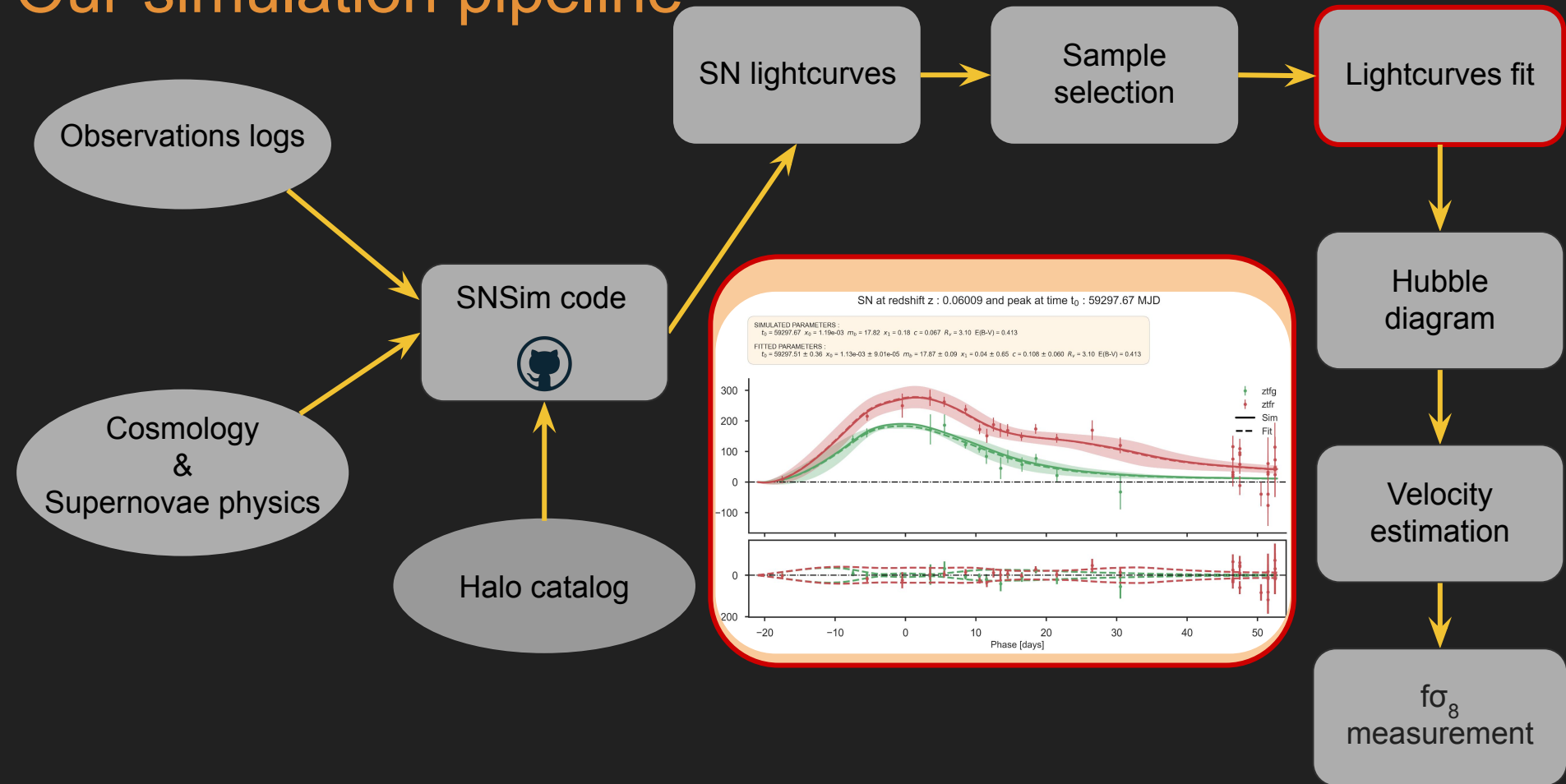


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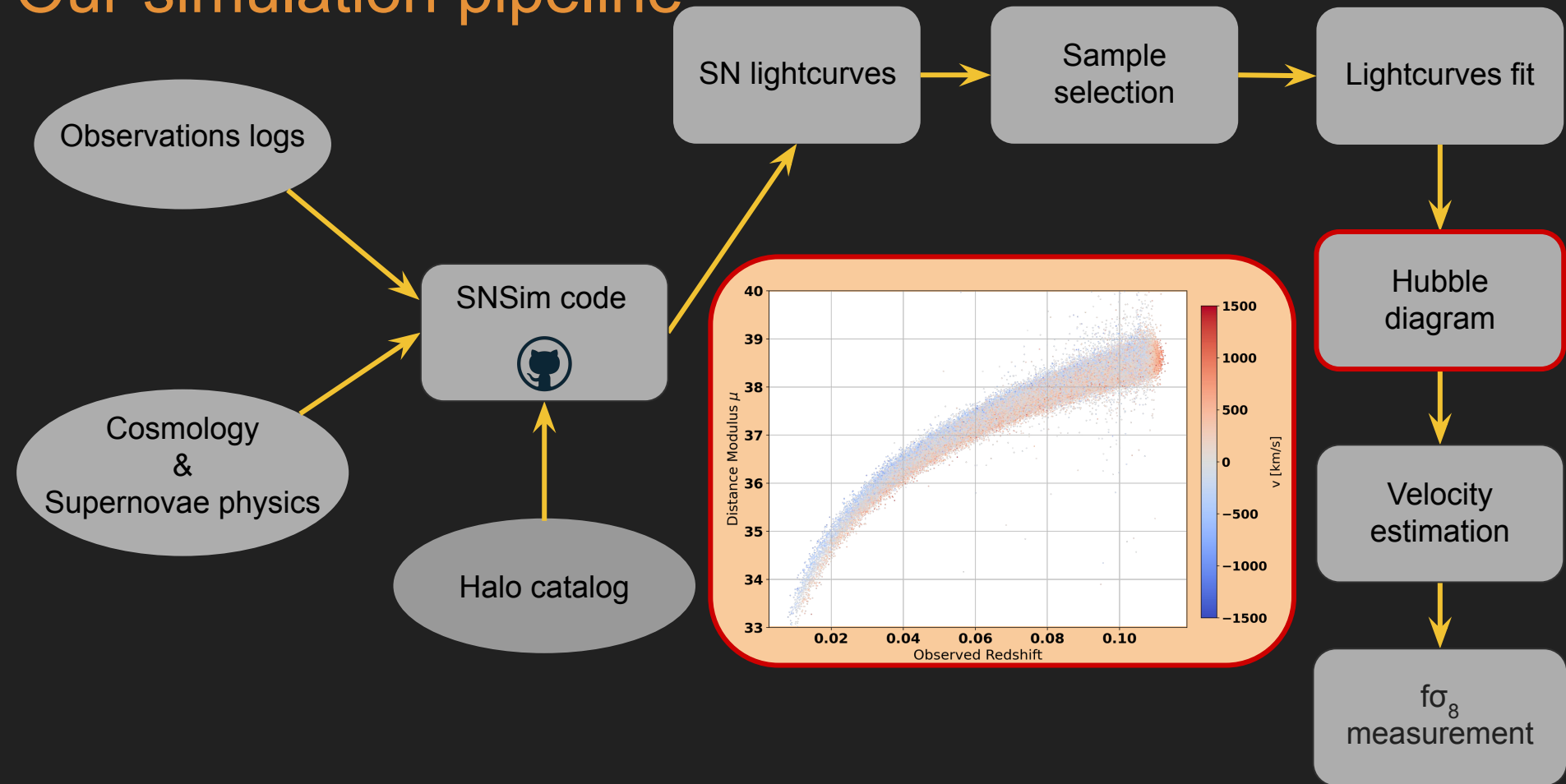
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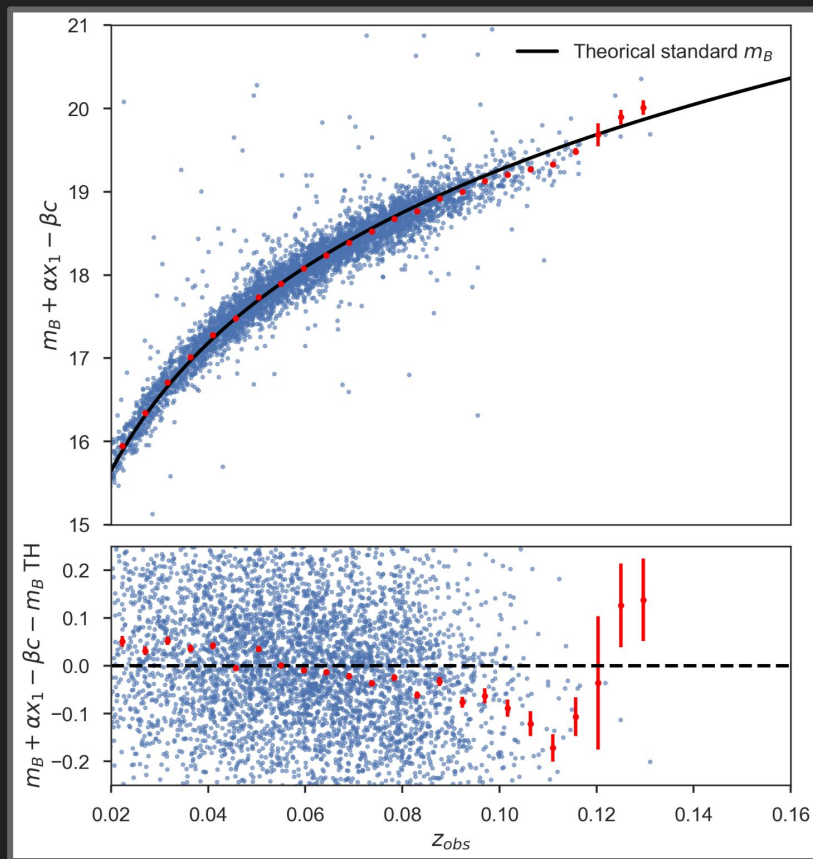


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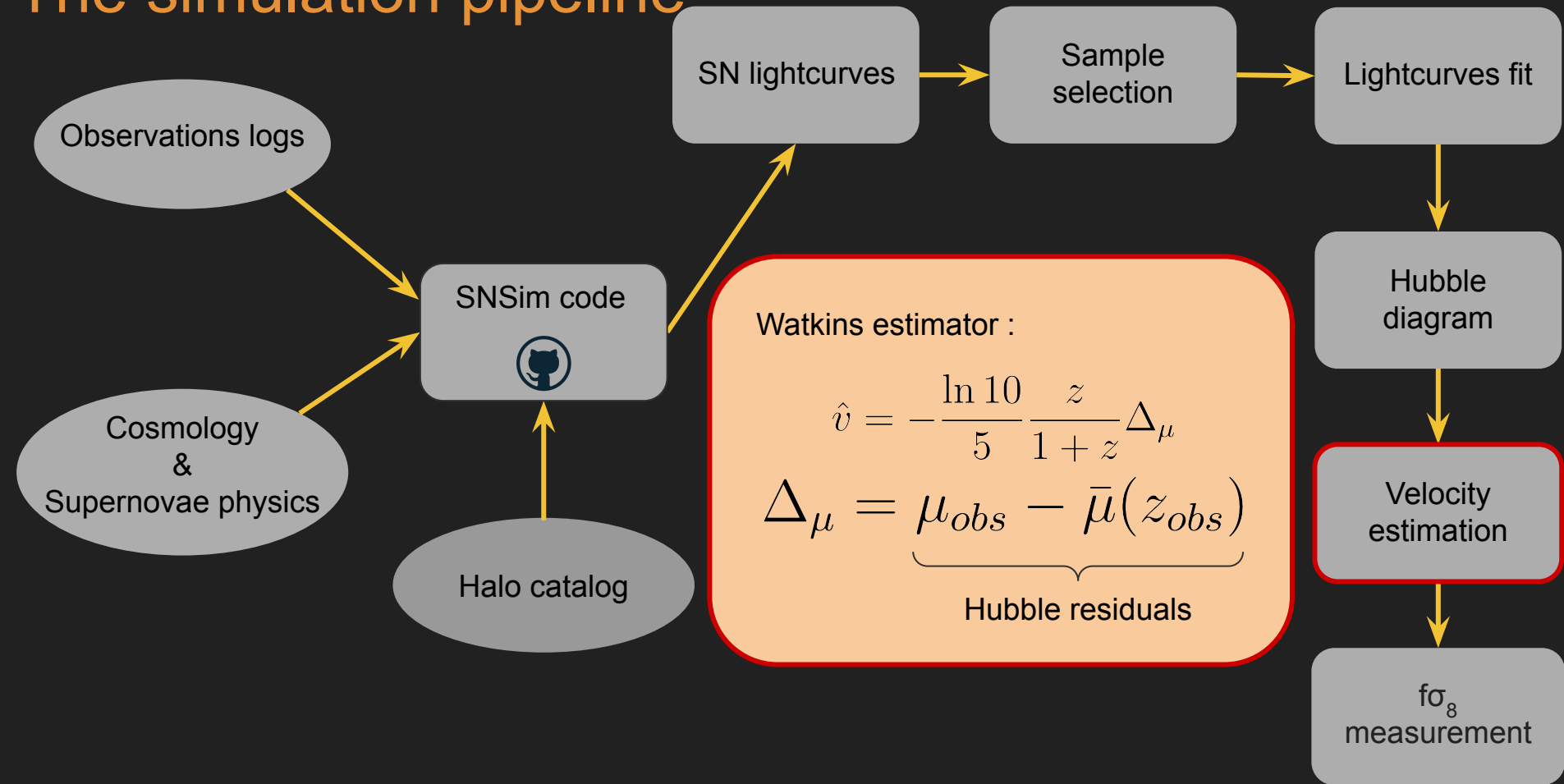


The Hubble diagram after SALT fit

Selection bias appear at $z \sim 0.06$



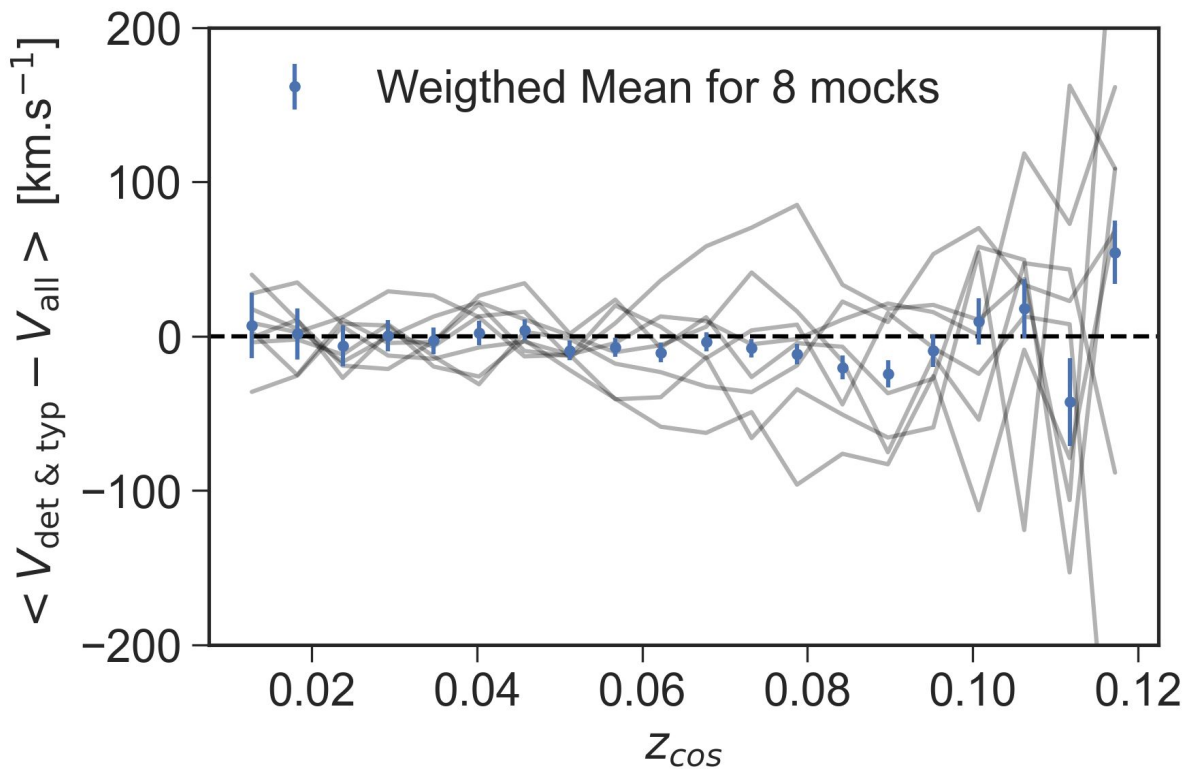
The simulation pipeline



Velocities estimation from residuals : expose the bias

Difference between full sample and selected sample velocities

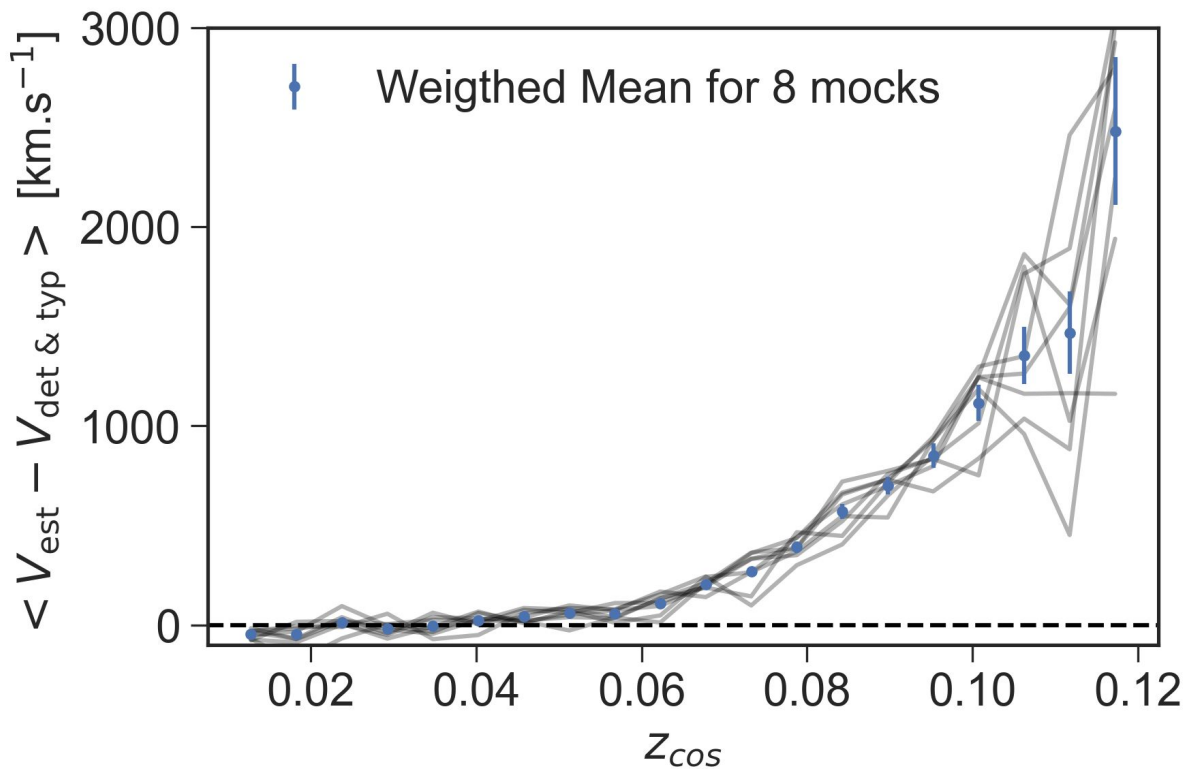
The selection doesn't introduce **any bias** on velocities (checked on true values) ...



Velocities estimation from residuals : expose the bias

Difference between full sample true velocities and selected sample estimated velocities

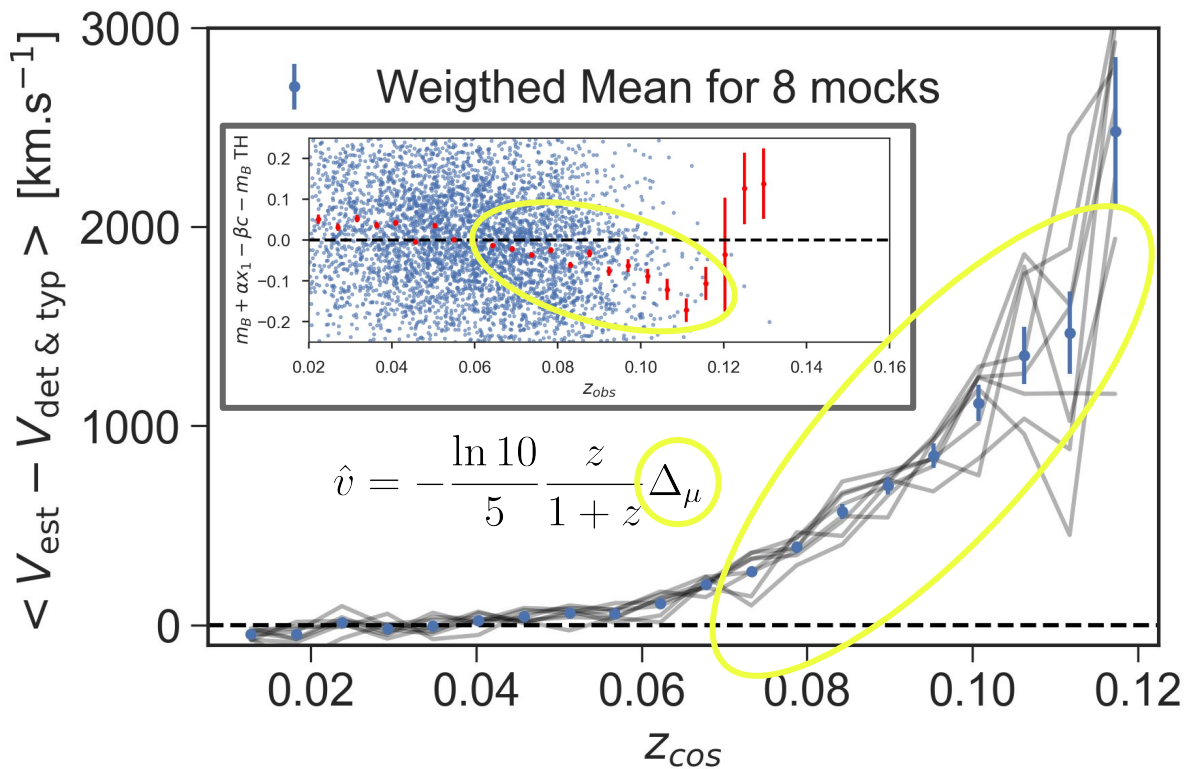
... But the **estimate velocities** are **biased** for $z > 0.06$



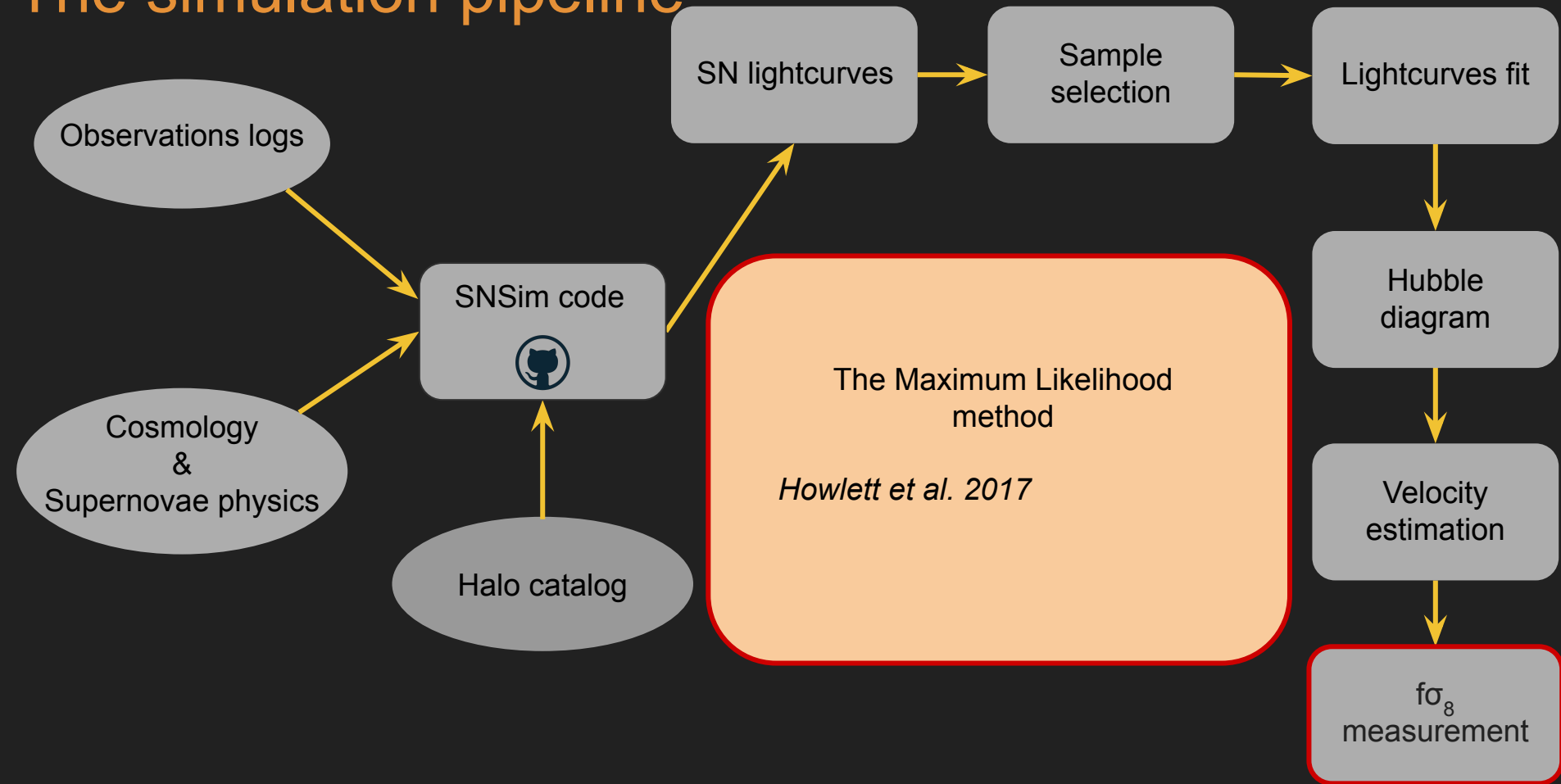
Velocities estimation from residuals : expose the bias

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

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

Peculiar velocities

$$\mathbf{C}_{\text{tot}} = (f\sigma_8)^2 \mathbf{C}_{\text{cos}} + \mathbf{C}_{\text{obs}}$$

$f\sigma_8$ measurement : bias effect

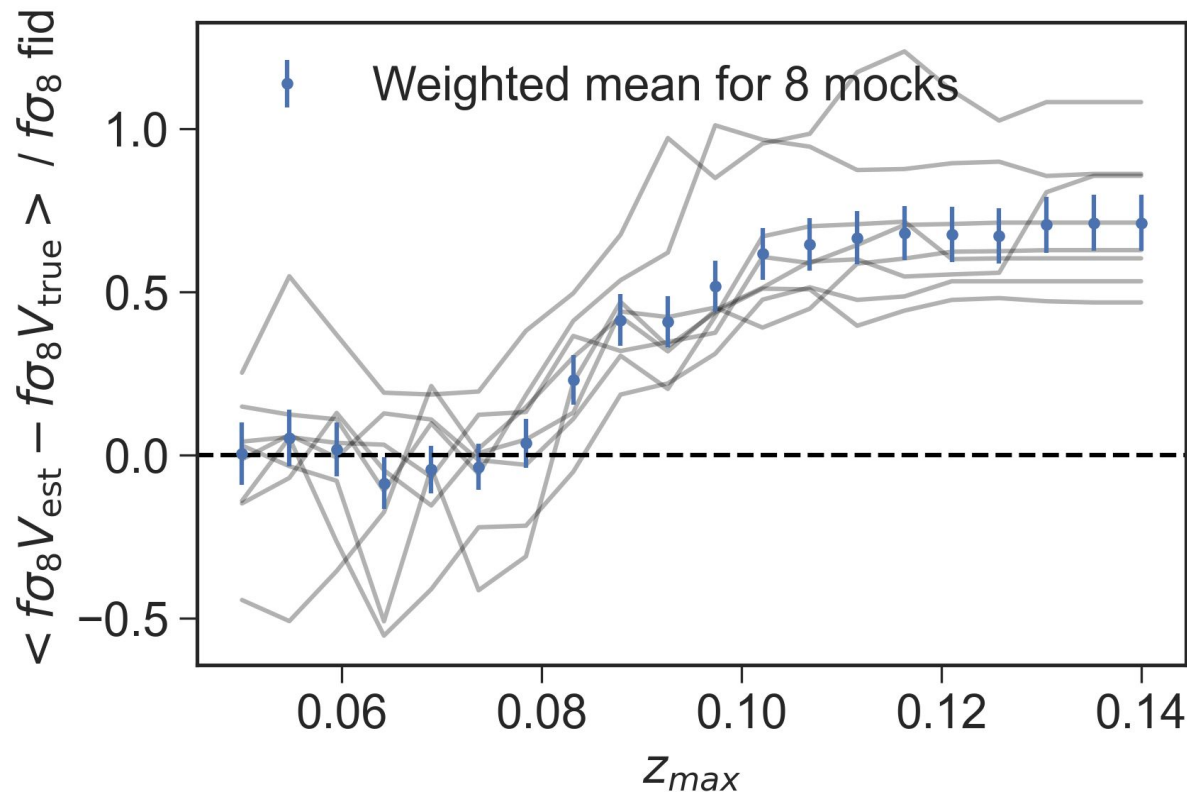
Difference between $f\sigma_8$ from true velocities and $f\sigma_8$ from estimated velocities

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

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

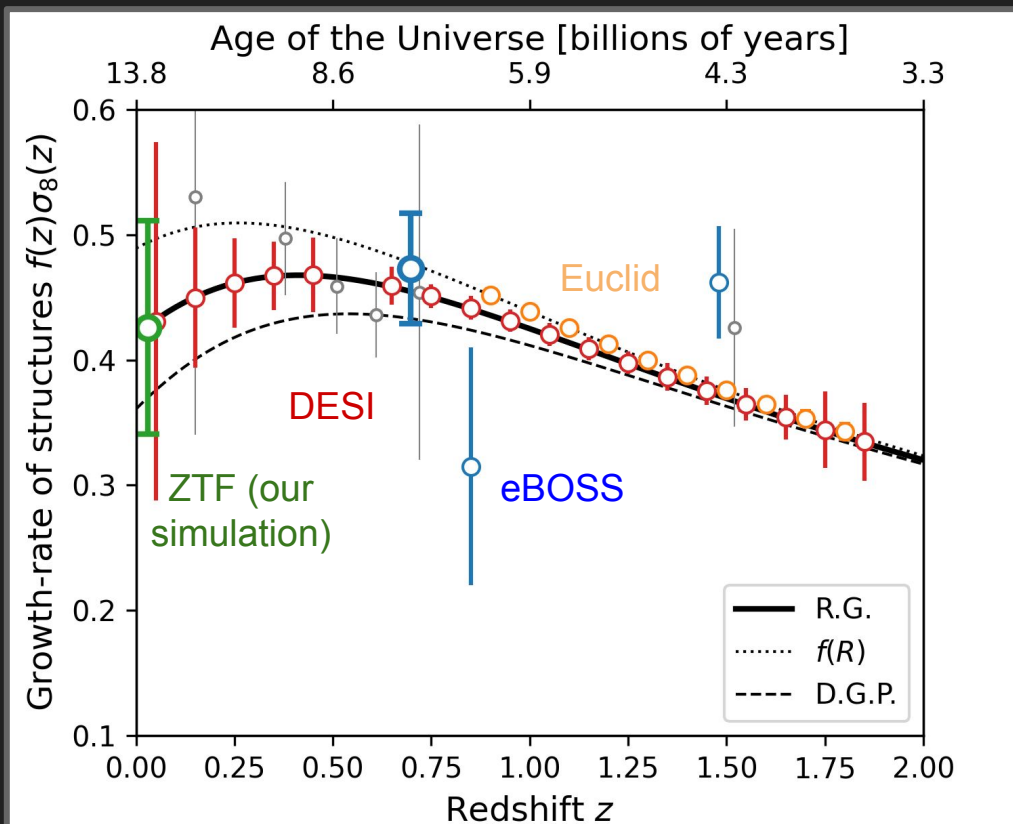
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Bias at $z = 0.14 \sim 60 \%$

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

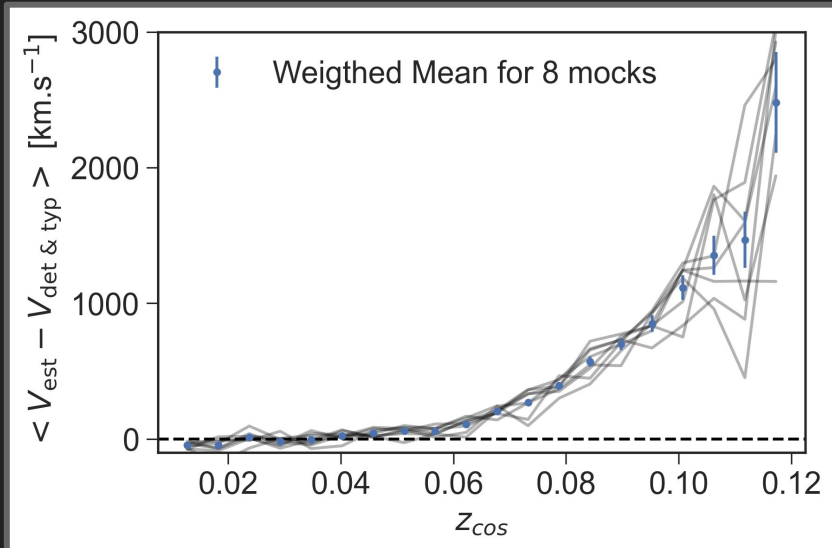


How much can we improve the $f\sigma_8$ precision using sample $z > 0.06$?

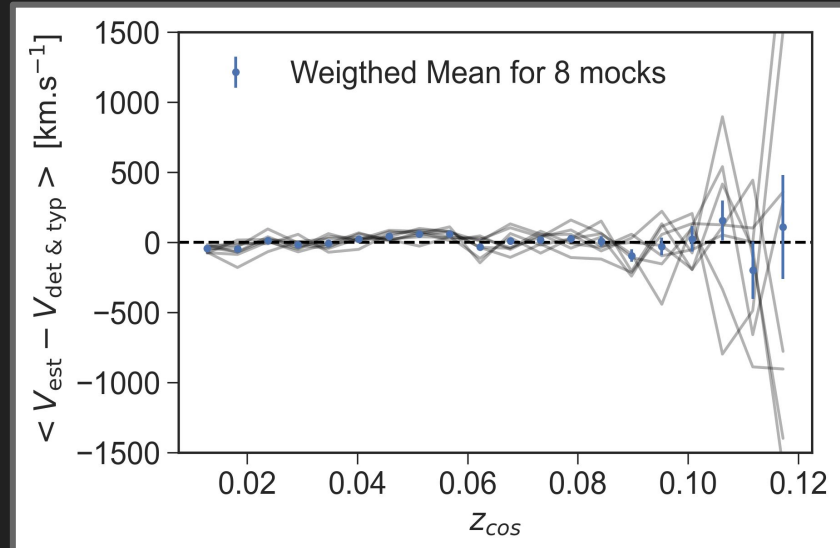
Fake debias of the estimator

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

Before fake debias



After fake debias

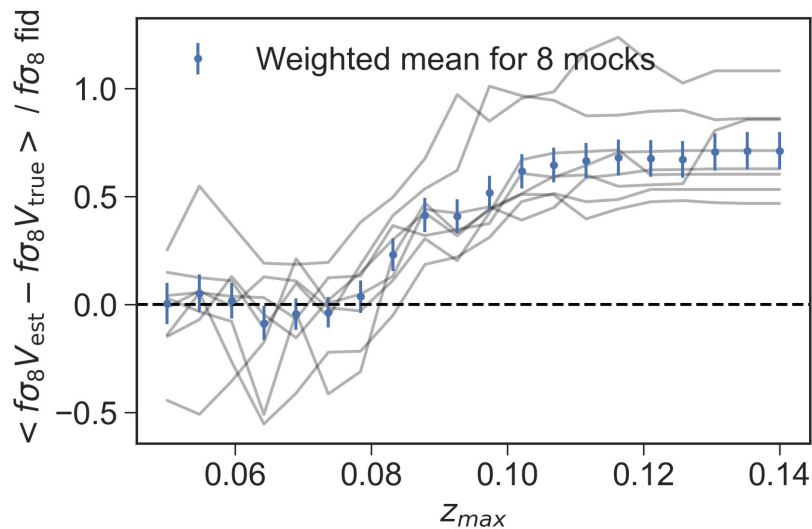


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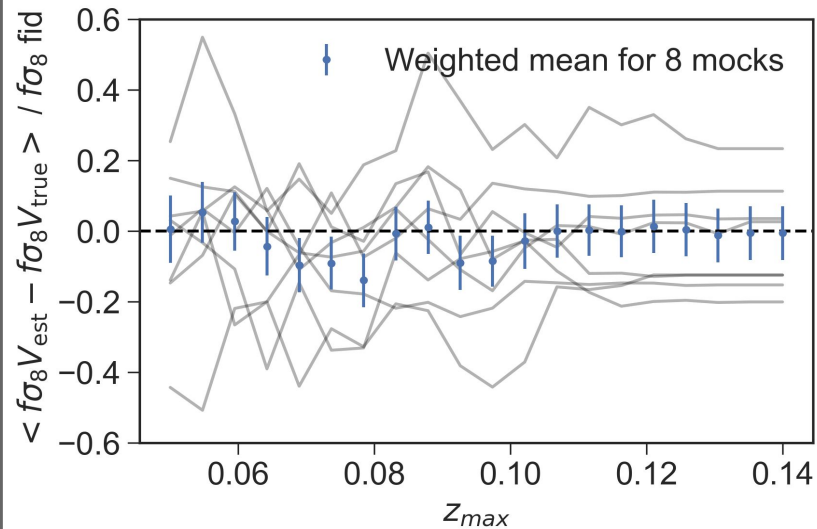
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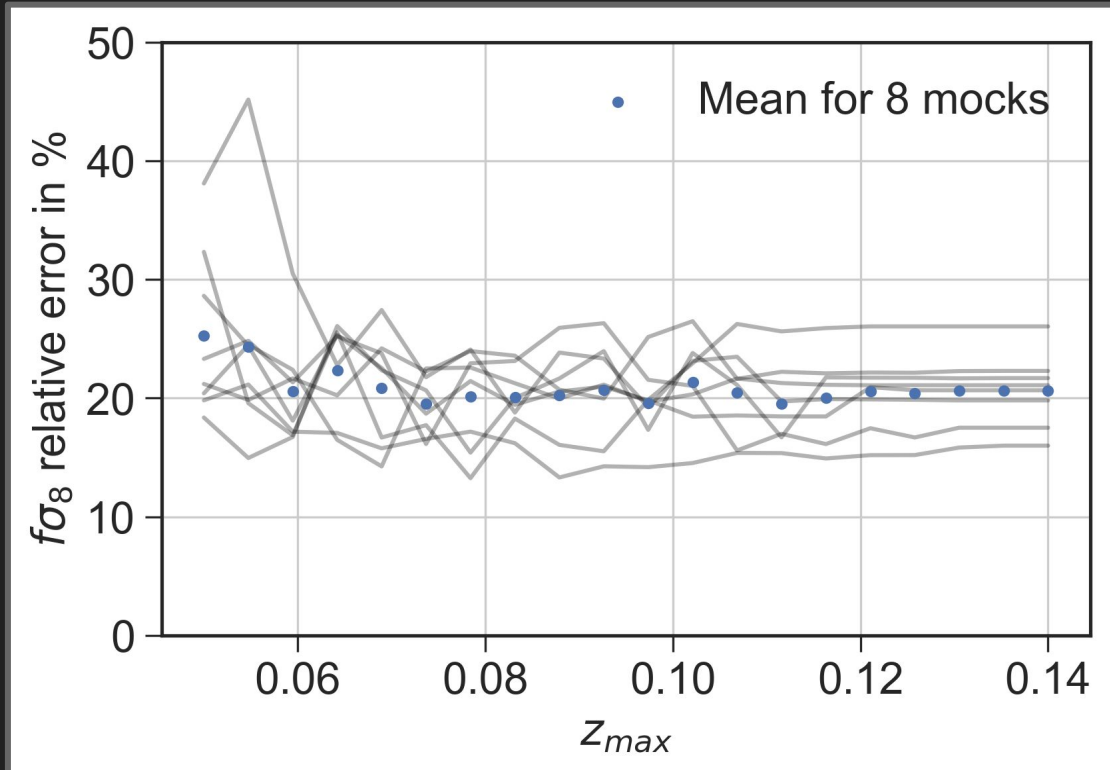


How much can we improve the $f\sigma_8$ precision using sample $z > 0.06$?

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

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

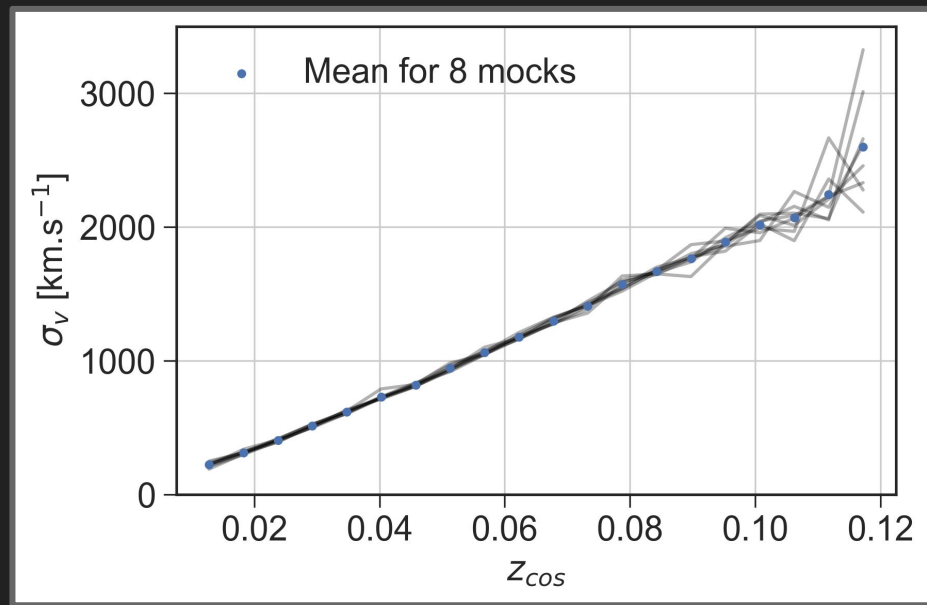
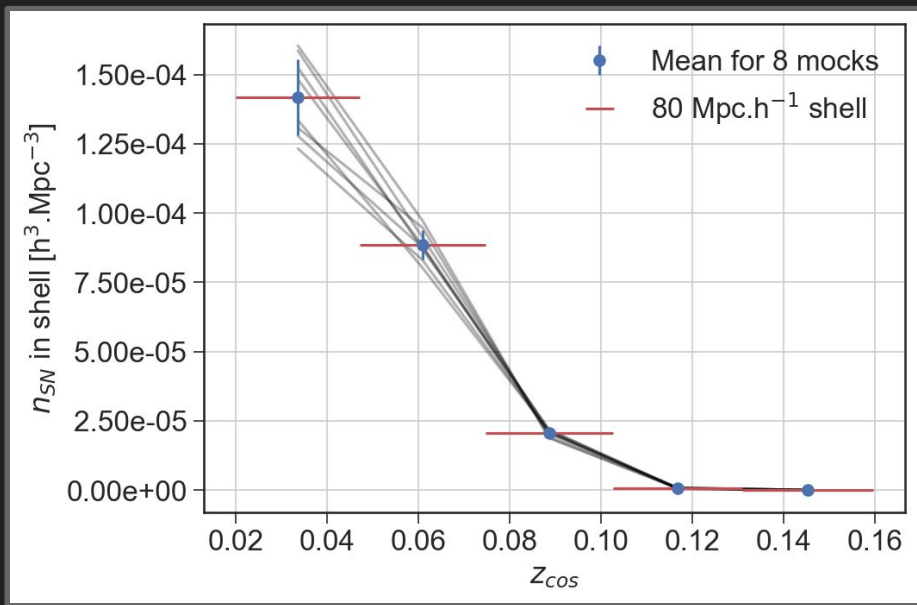
The error on $f\sigma_8$ doesn't change by including the statistic after $z > 0.06$ for the selected sample



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 $z \sim 0.08$, the selection bias has a relative impact of up to $\sim 60\%$ 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 $z \sim 0.06$**

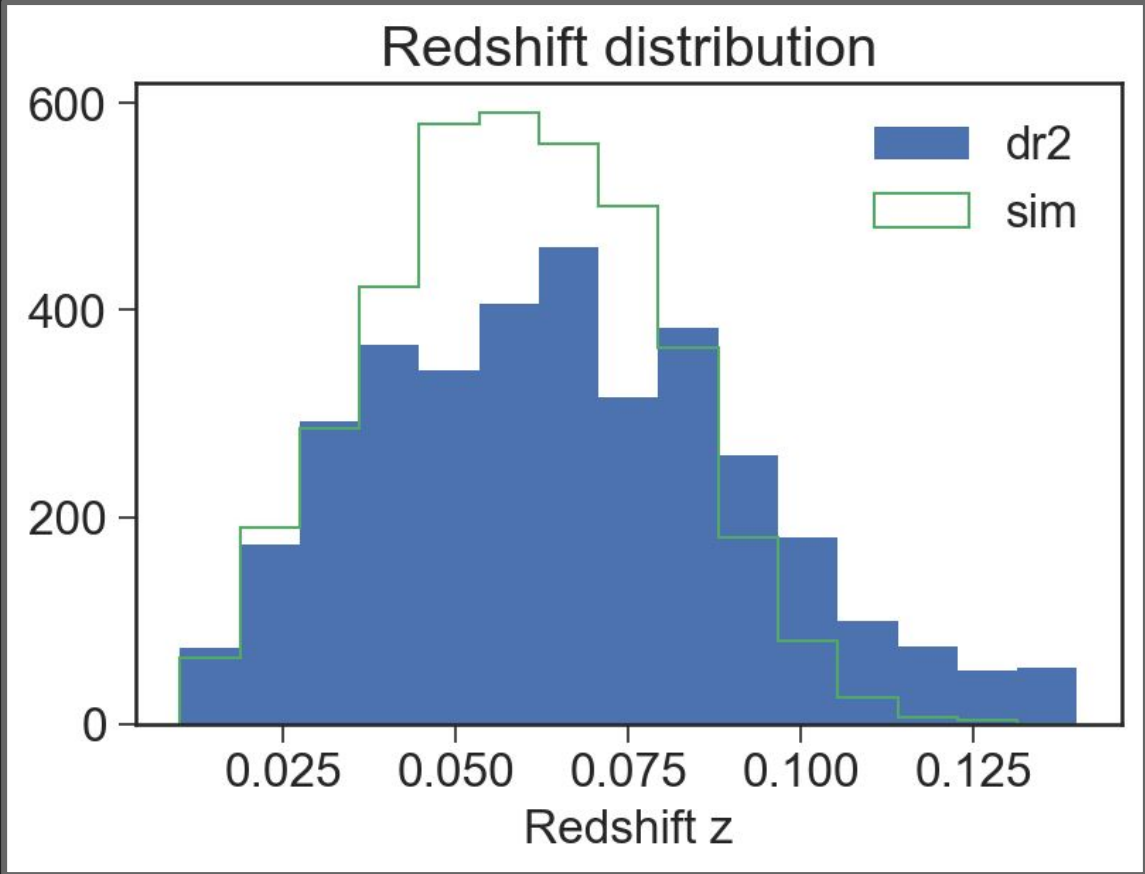
Work plan

- 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 ?

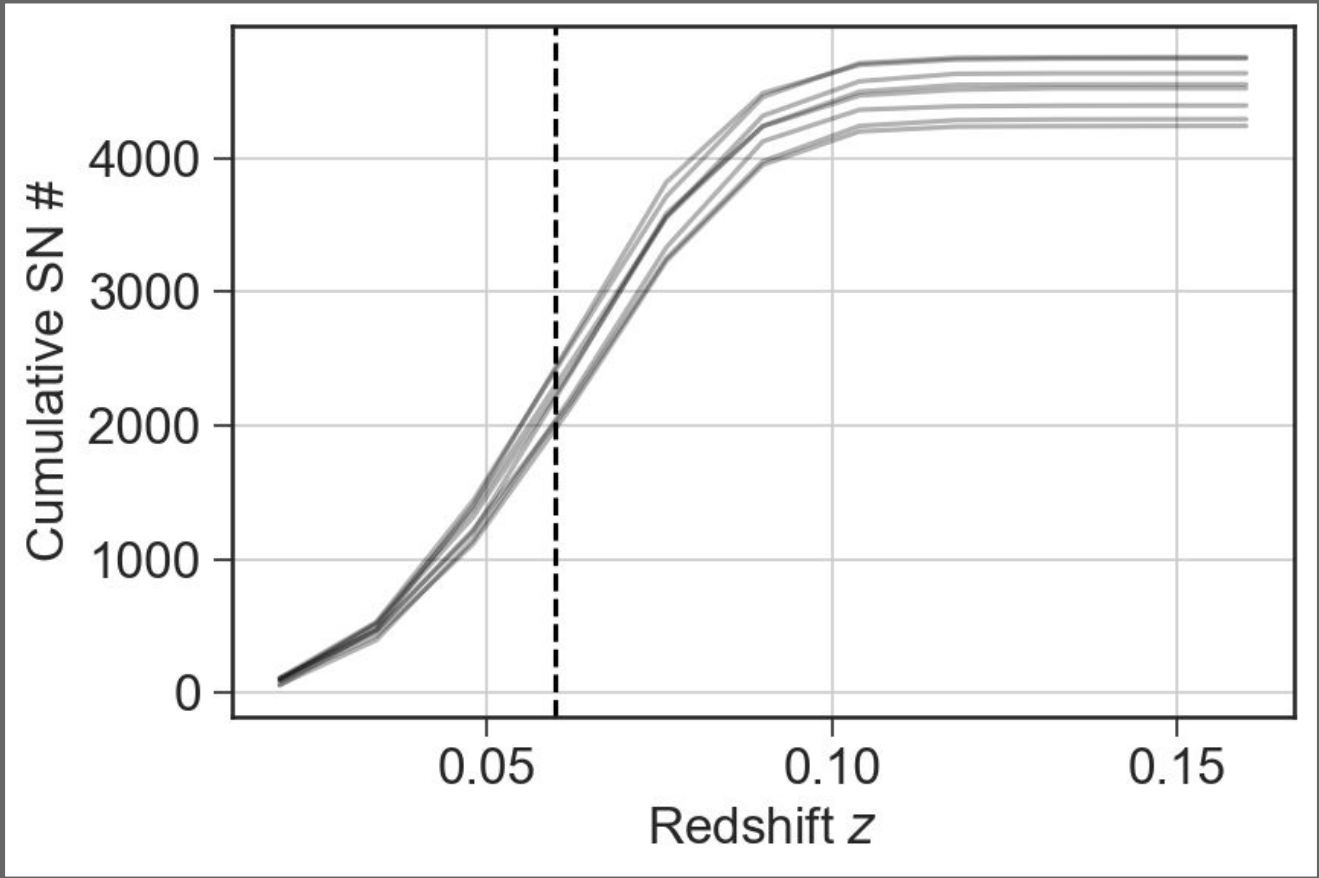
Happy to collaborate !!!

Thanks for your attention

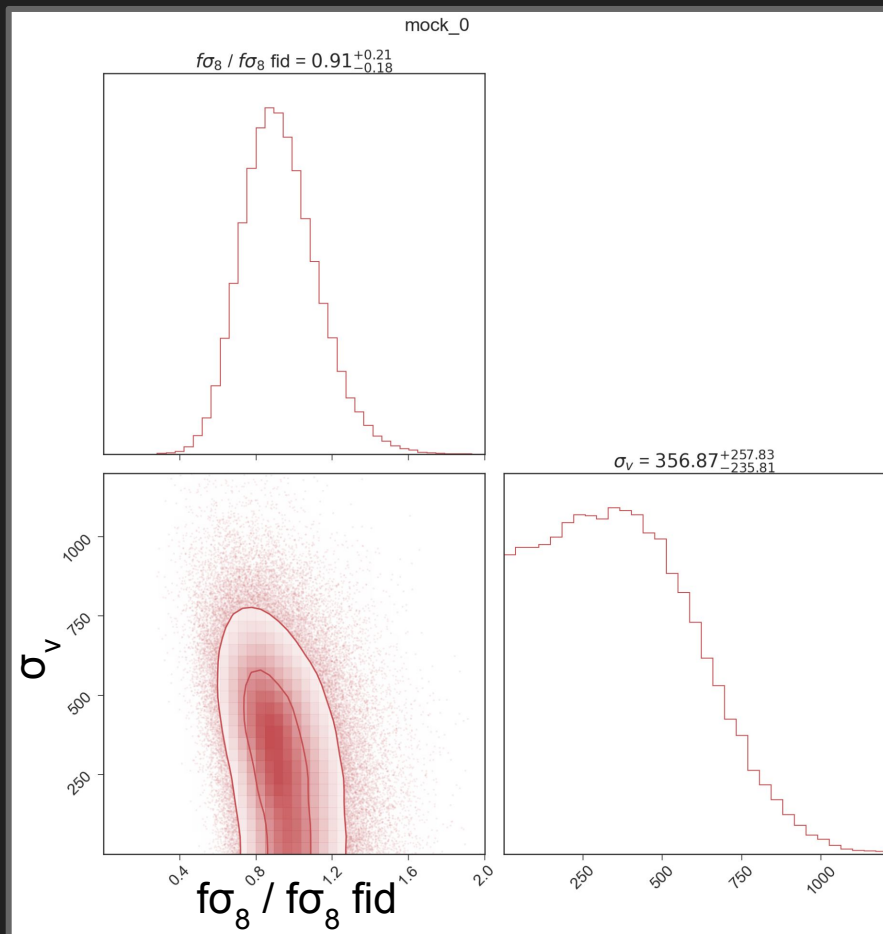
Backup : Still a simulation



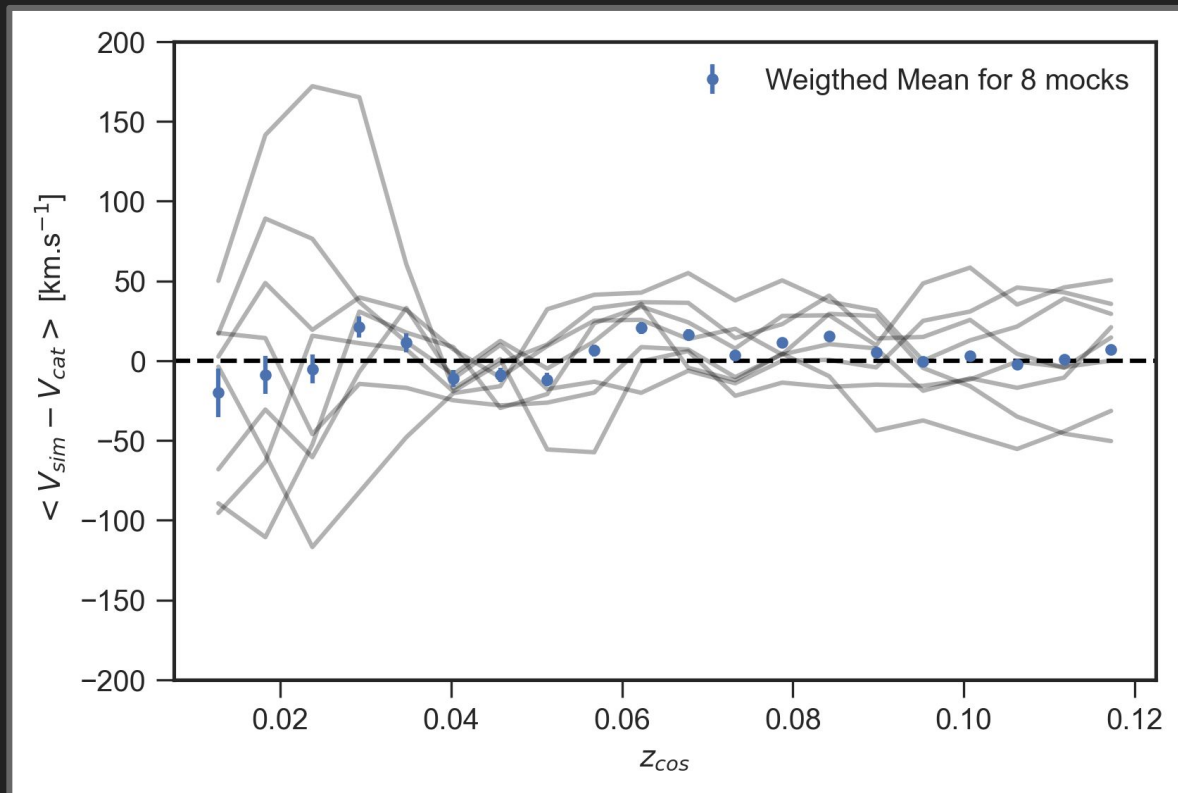
Backup : Cumulative number of SN



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



Backup : Catalog vs simulated SN



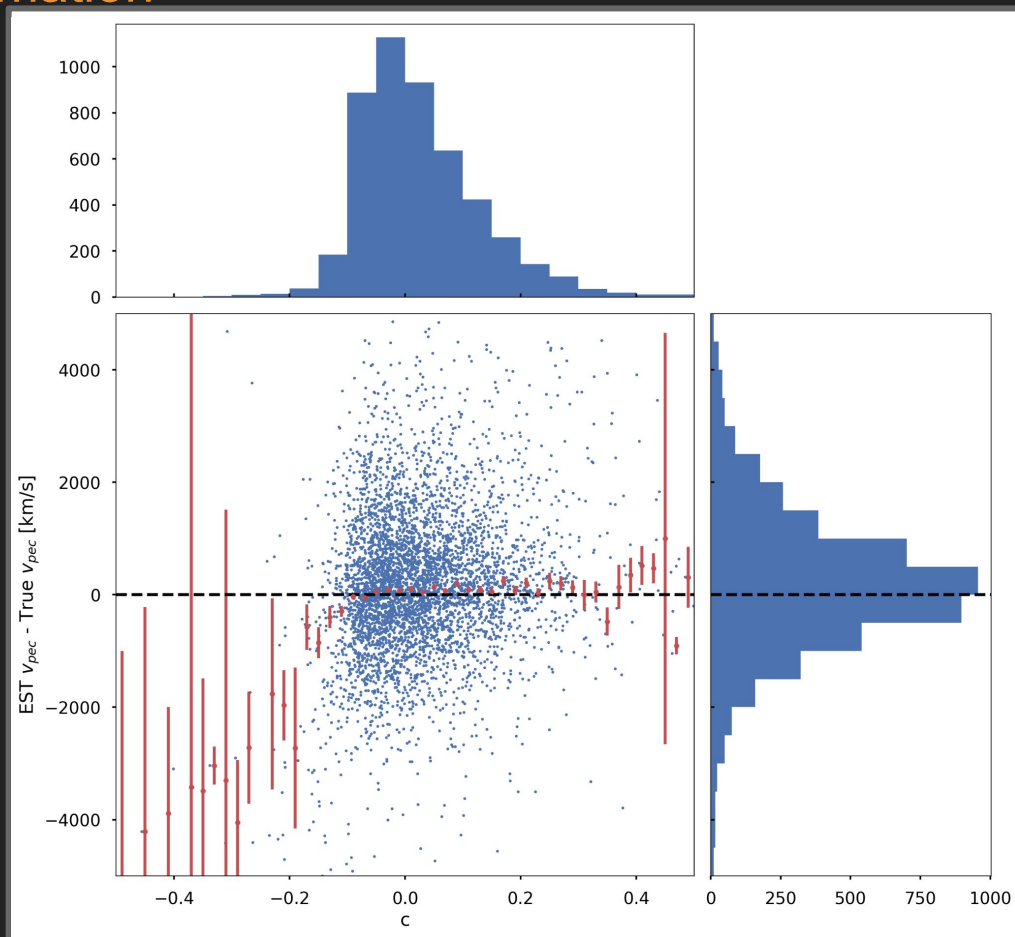
Backup : SALT c effect on v_{pec} estimation

$$-\beta c \rightarrow \mu \searrow$$



Over-estimate c \rightarrow Positive velocity

Under-estimate c \rightarrow Negative velocity



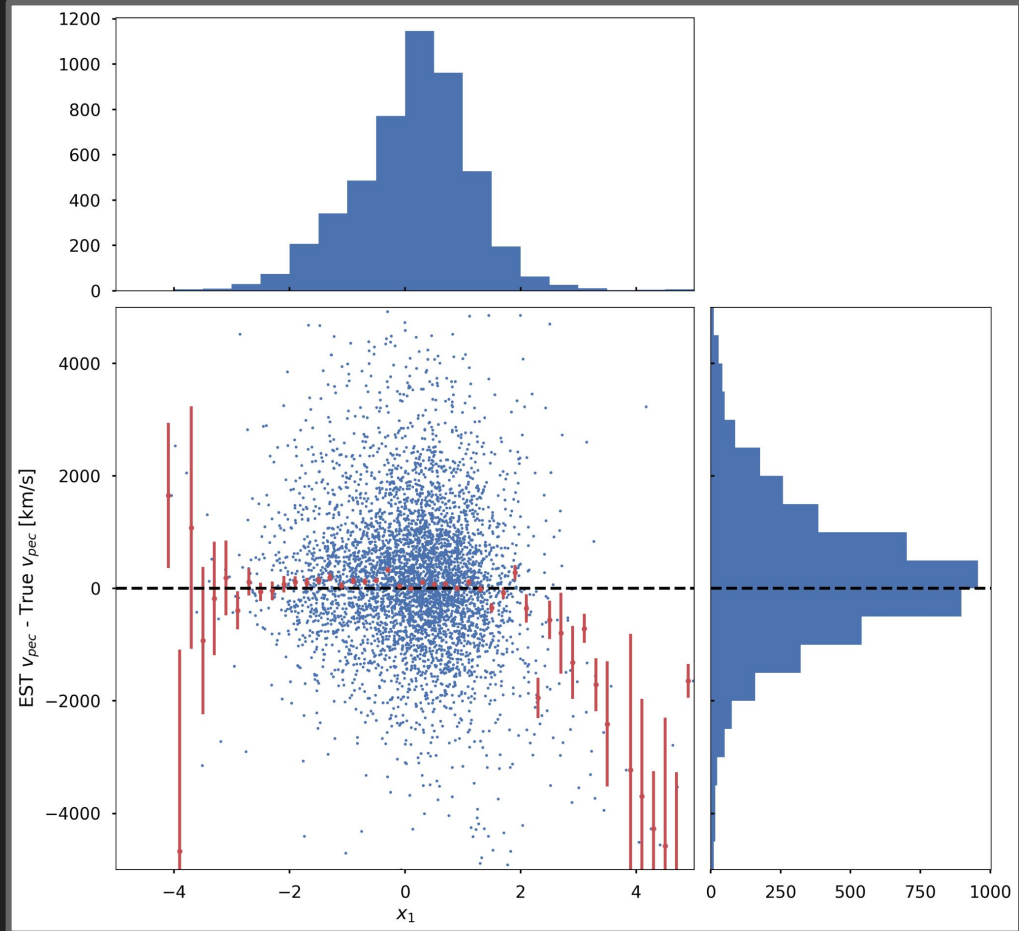
Backup : SALT x_1 effect on v_{pec} estimation

$$+\alpha x_1 \longrightarrow \mu \nearrow$$



Over-estimate x_1 \longrightarrow Negative velocity

Under-estimate x_1 \longrightarrow Positive velocity



Backup : Velocities estimation from residuals

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

