# $f\sigma_8$ with SN Ia

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CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

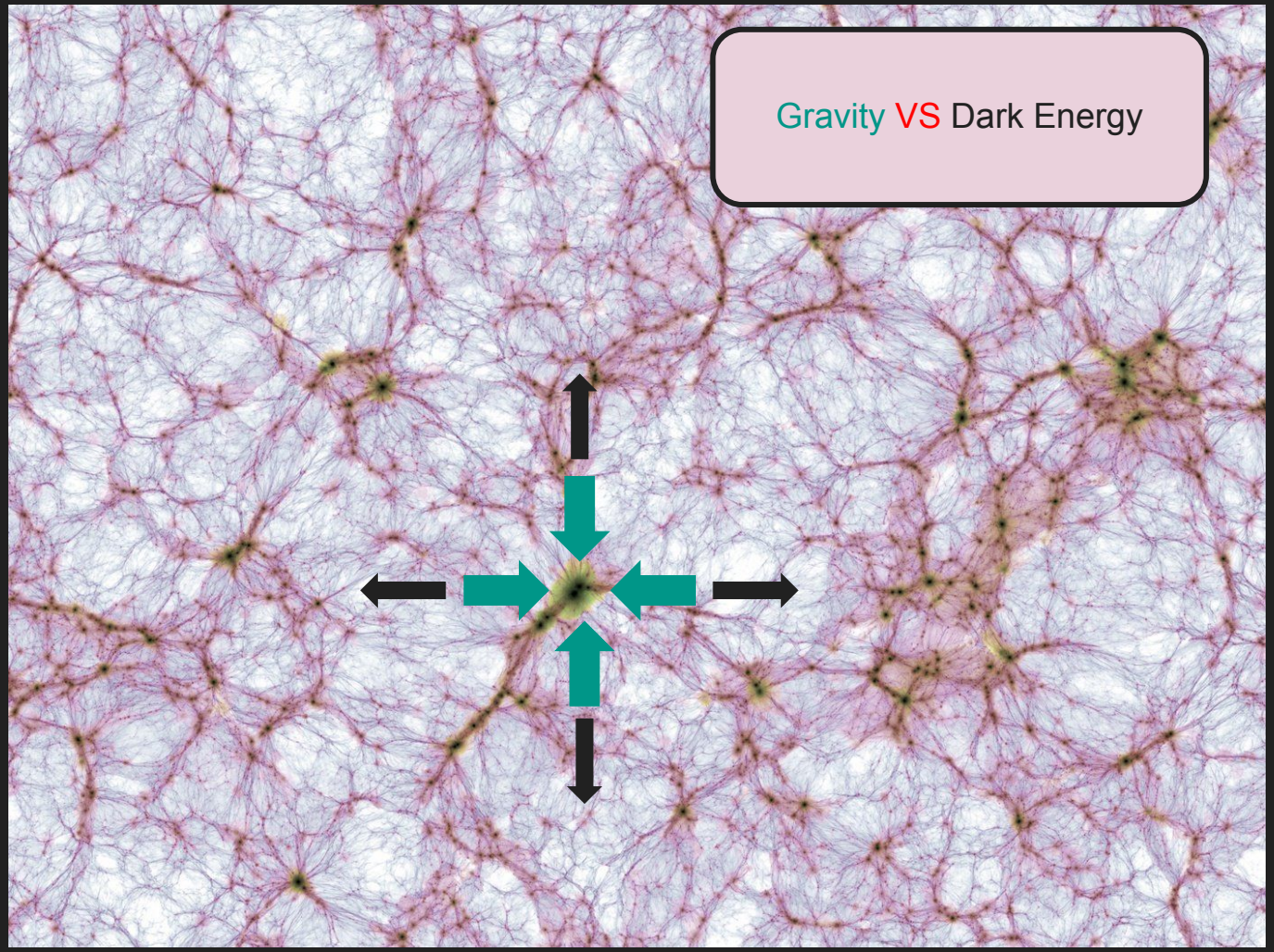
# What is $f\sigma_8$?

Growth factor

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

Growth rate

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



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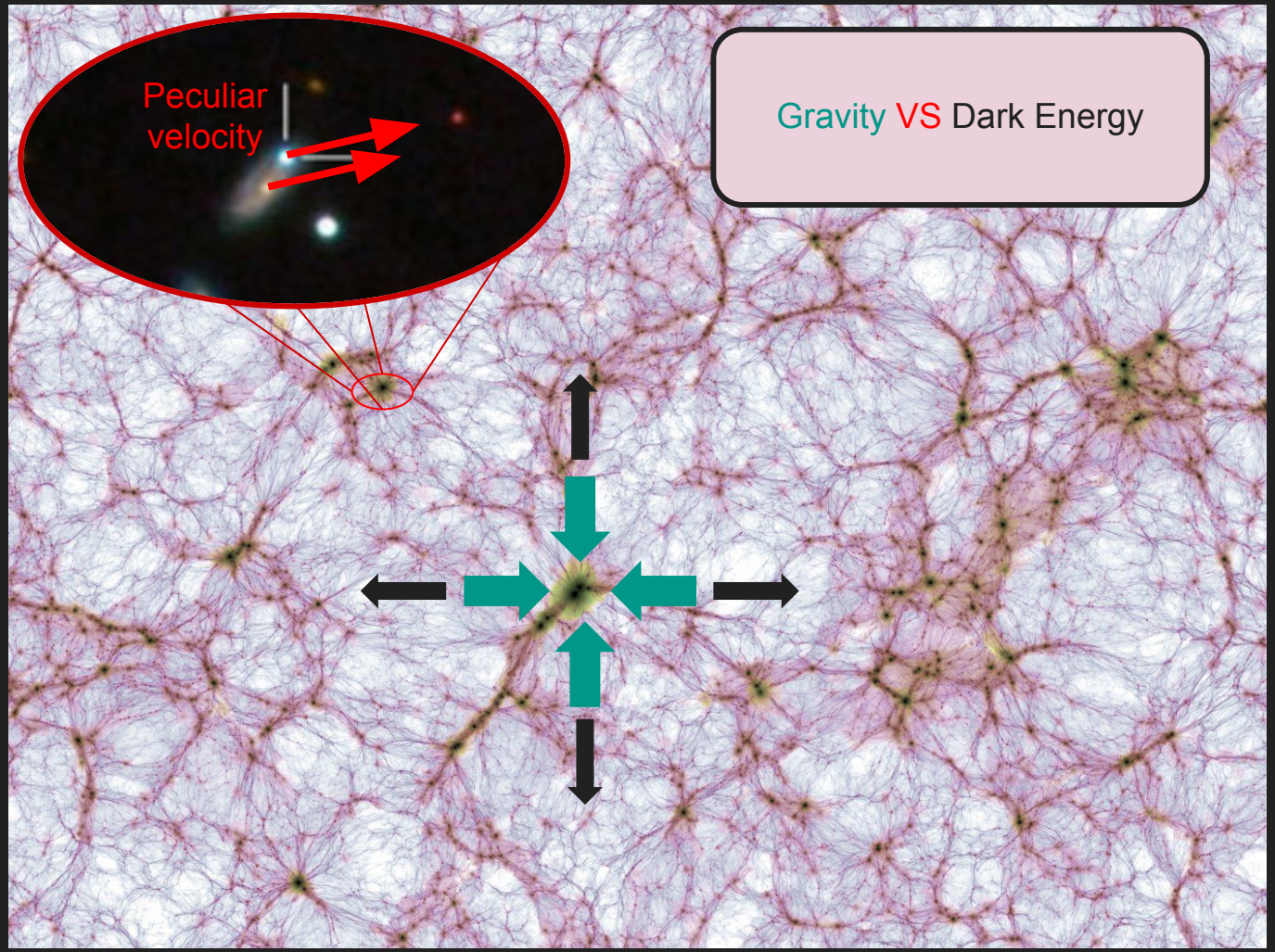
$$\nabla.\mathbf{v} \propto fD$$



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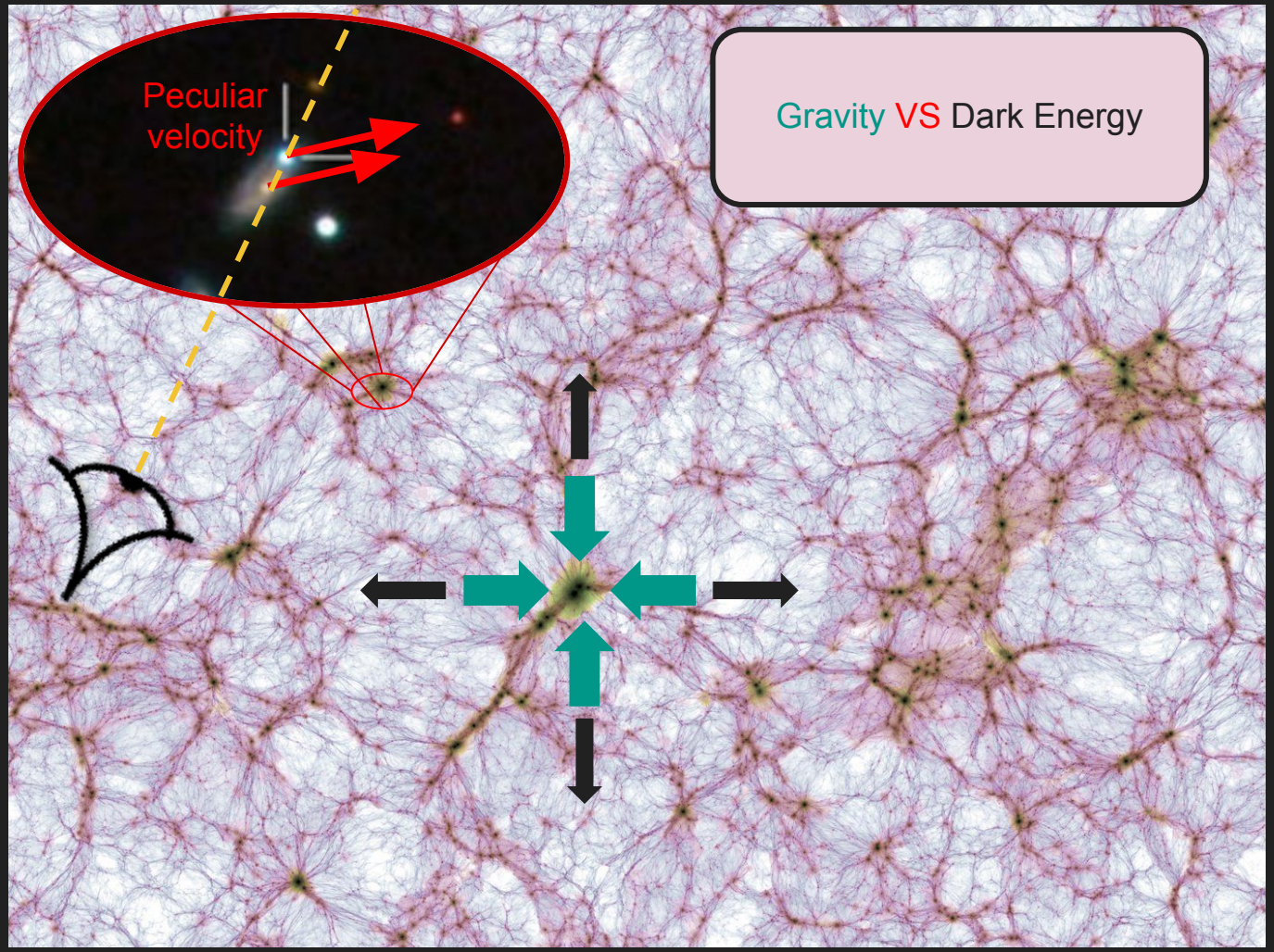
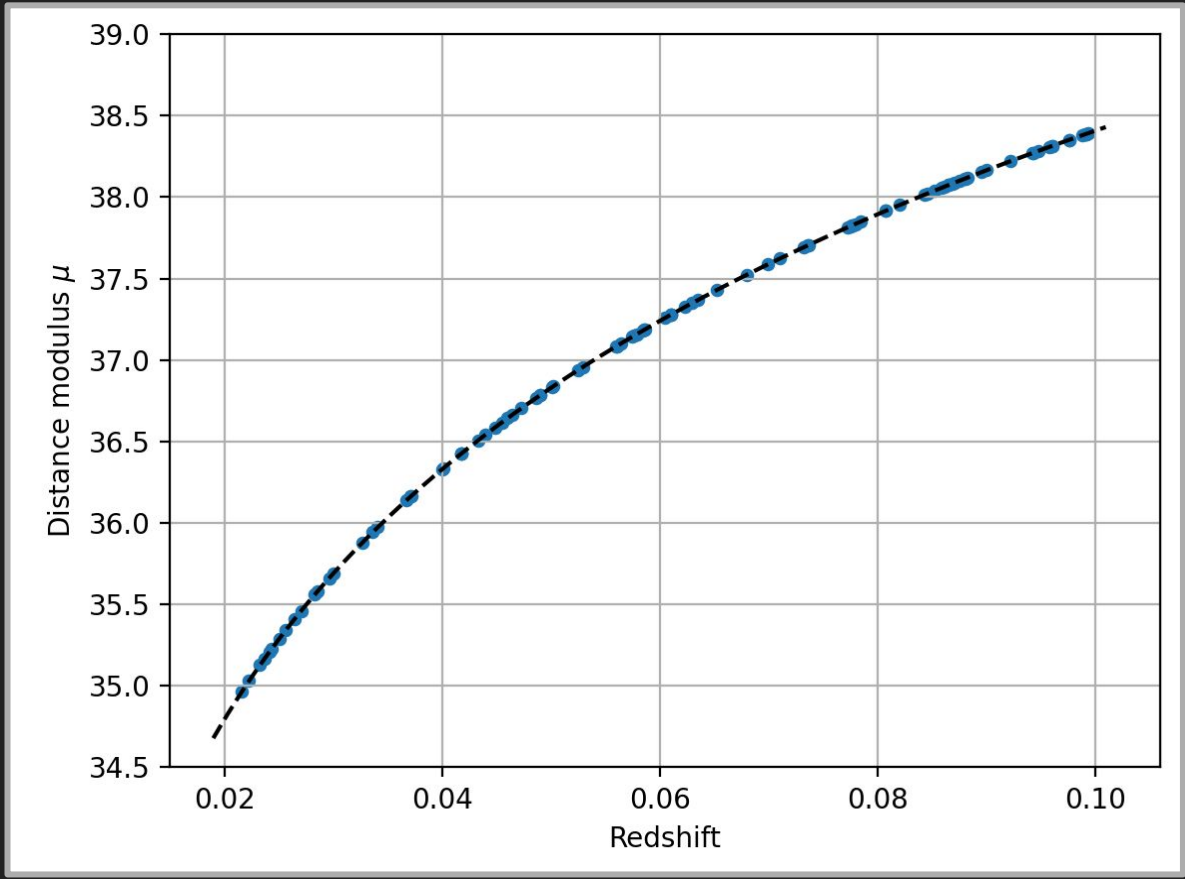


# The Hubble diagram with peculiar velocities



# The Hubble diagram with peculiar velocities

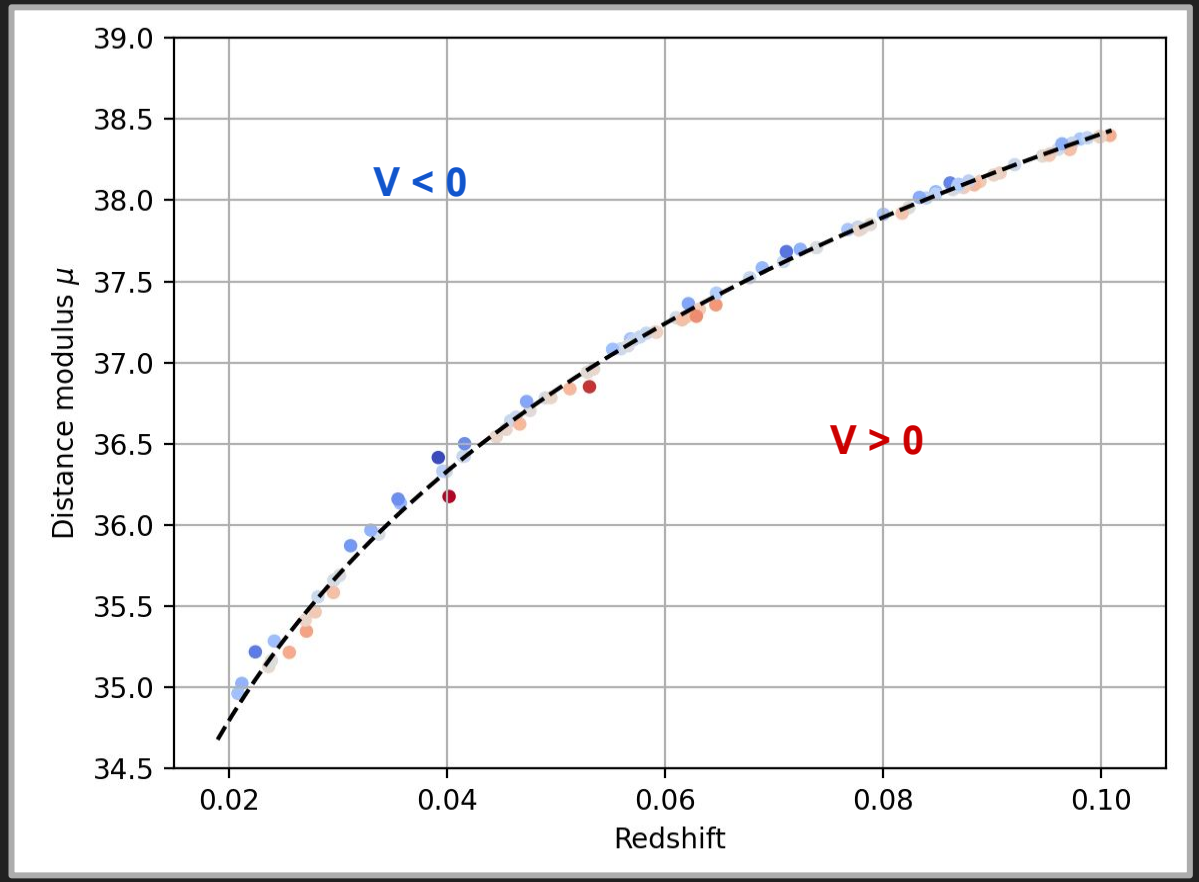
**Adding peculiar velocity :**

v ~ 300 km / s

Δz ~ 0.001

Δμ ~ 0.004 mag

Variation has the same sign as peculiar velocities



# The Hubble diagram with peculiar velocities

**Adding peculiar velocity :**

v ~ 300 km / s

Δz ~ 0.001

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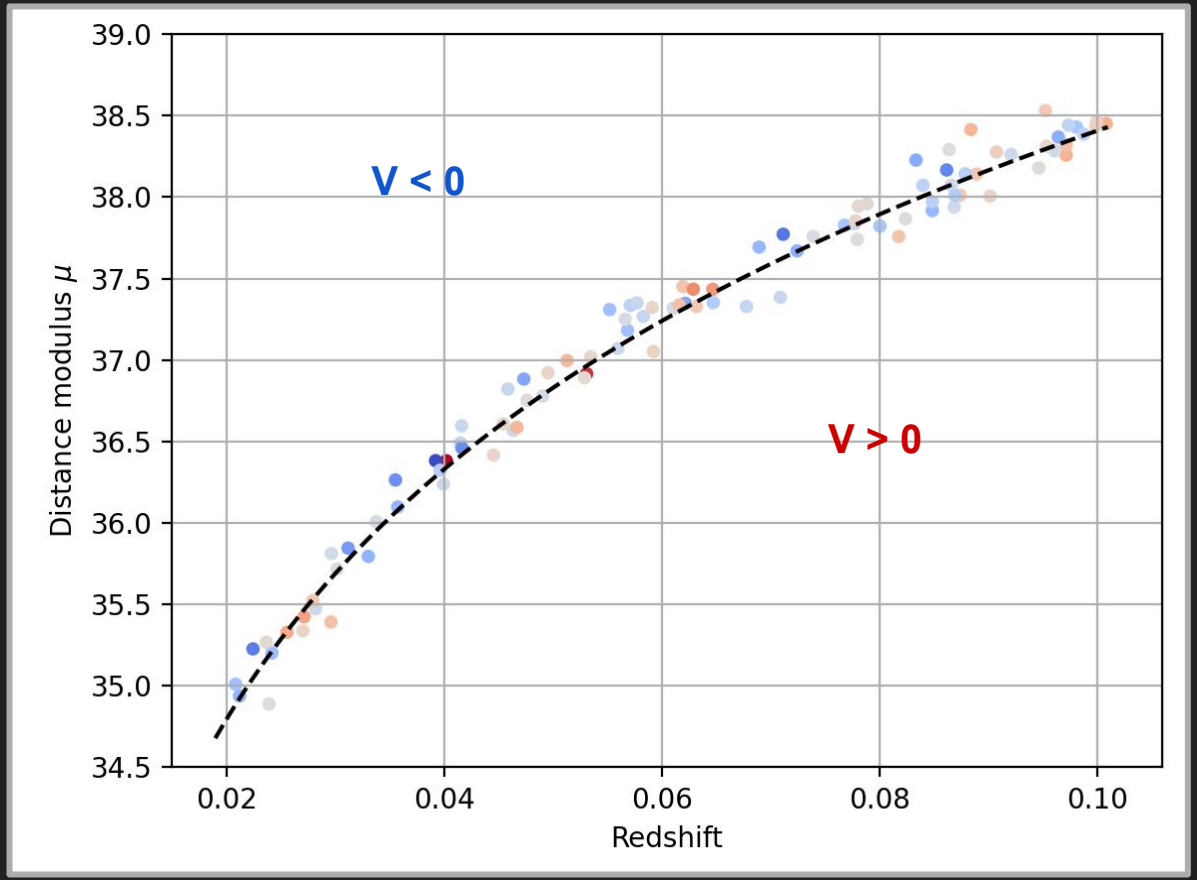
Variation has the same sign as peculiar velocities

**Adding intrinsic scatter :**

$\sigma_{int}$ ~ 0.12 mag



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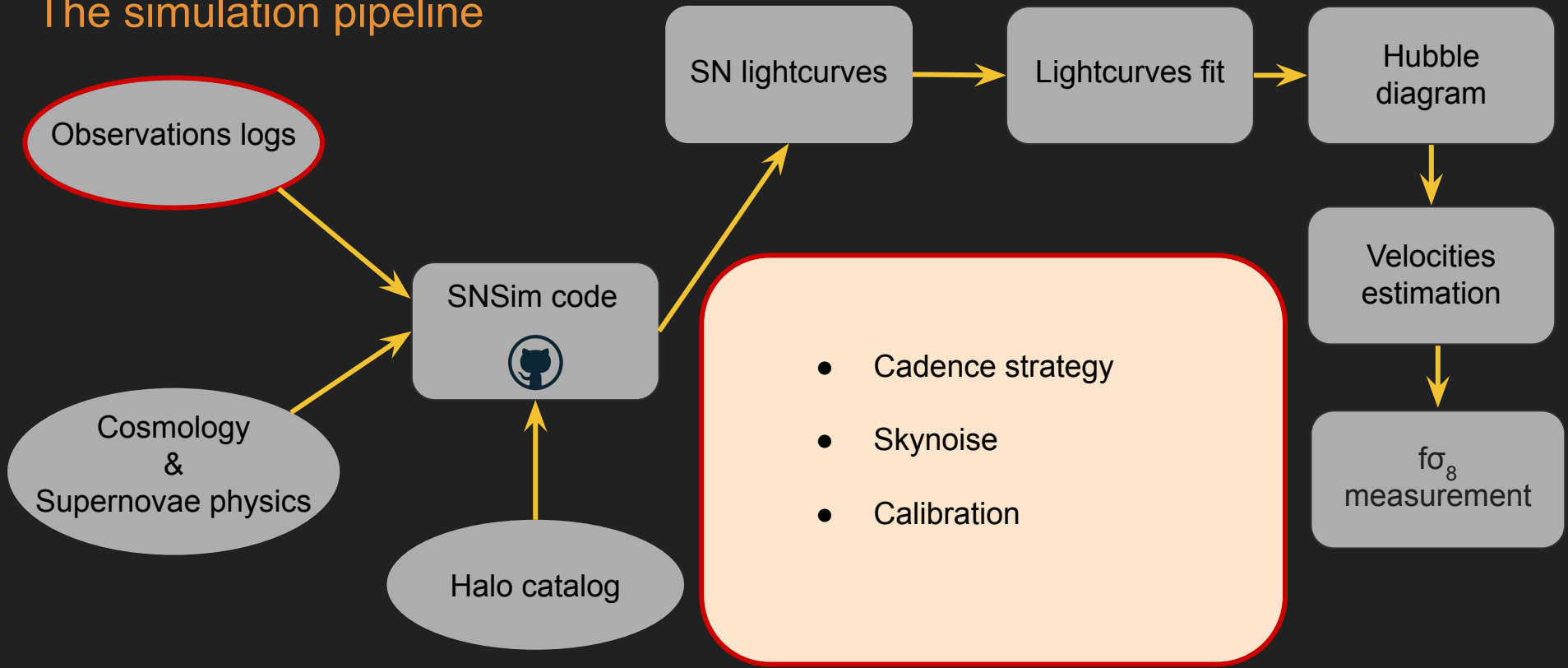

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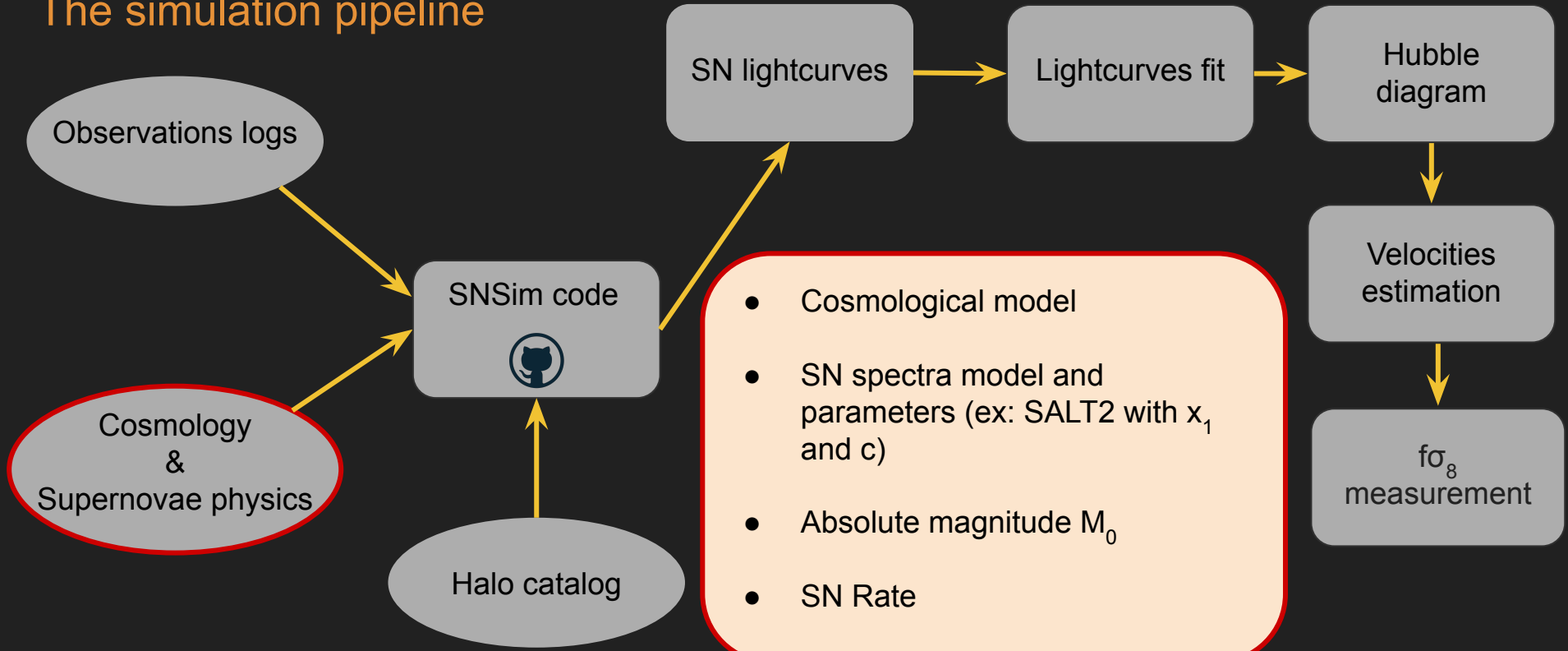

# The simulation pipeline

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Cosmology
&
Supernovae physics

SNSim code

Halo catalog

SN lightcurves

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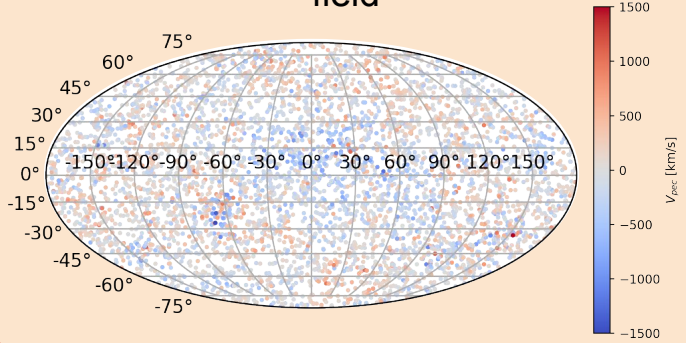
Velocities estimation

$f\sigma_8$ measurement

RA, Dec and z coordinates with velocity field



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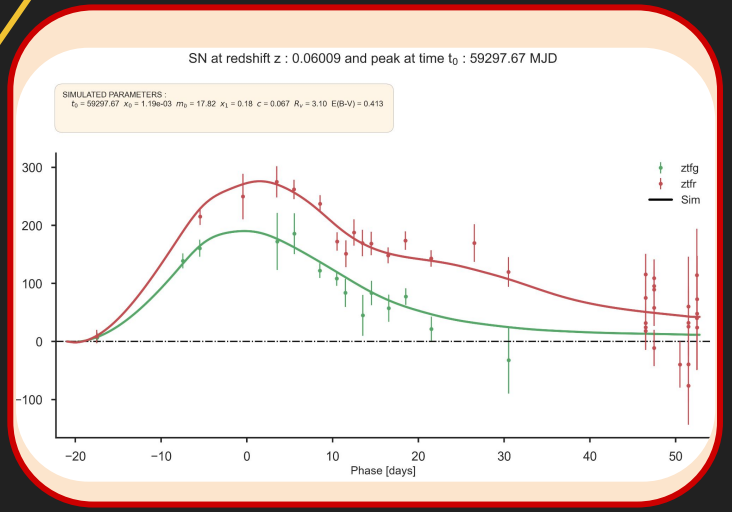

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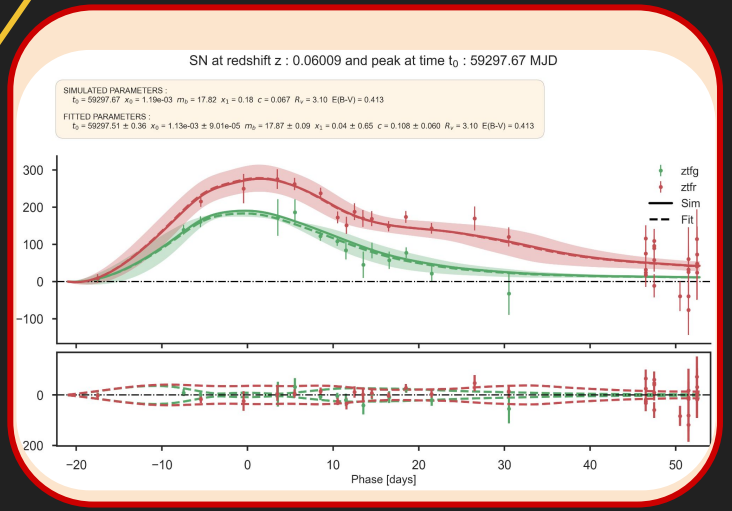

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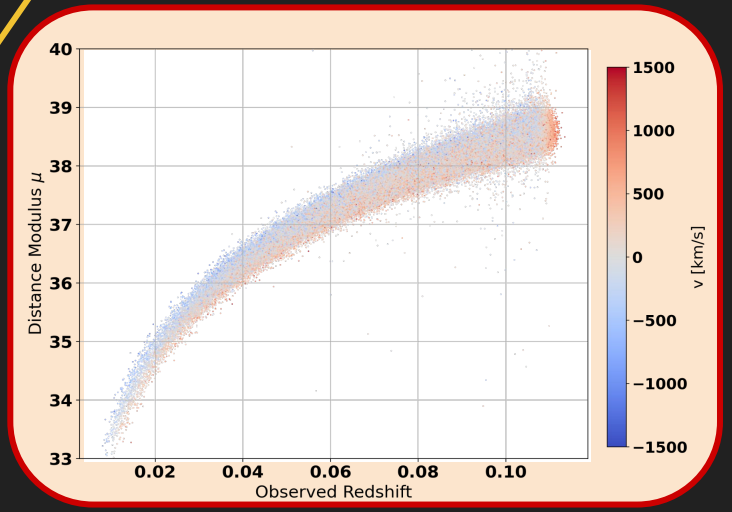

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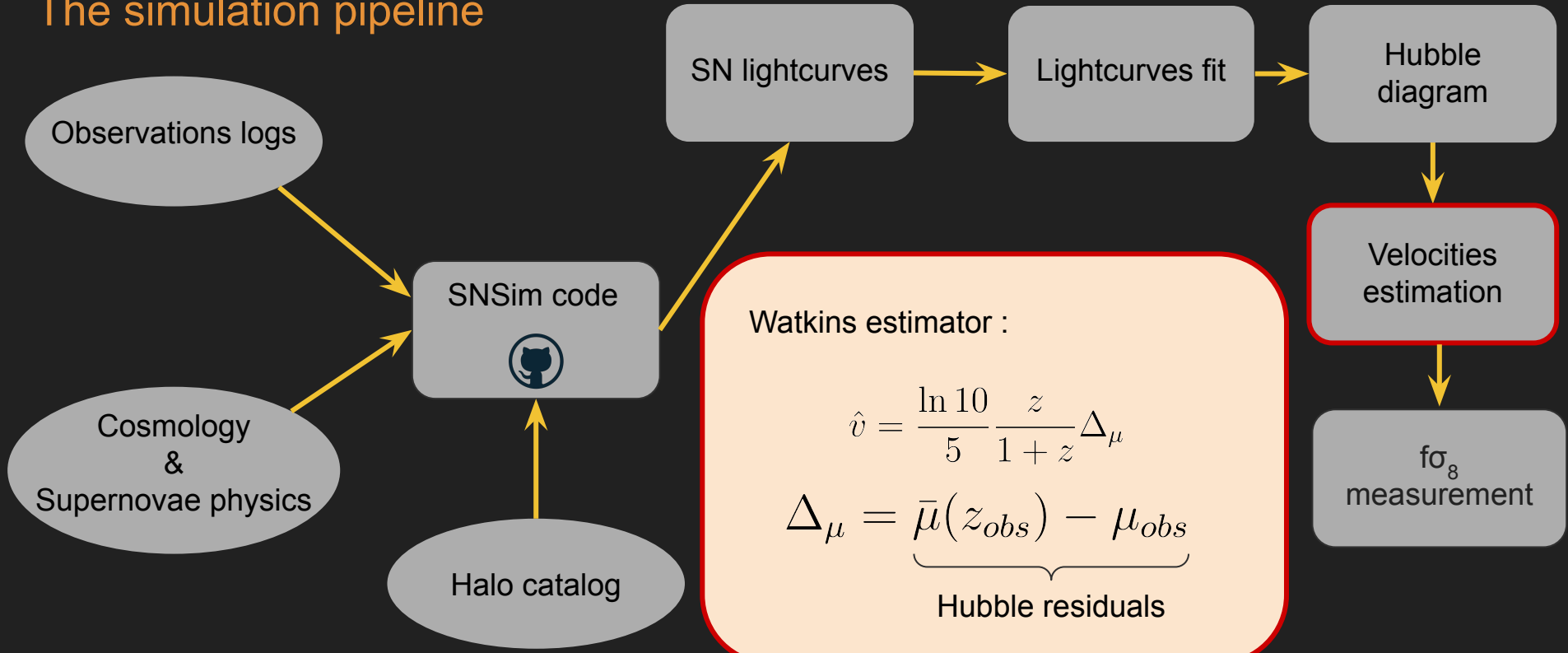

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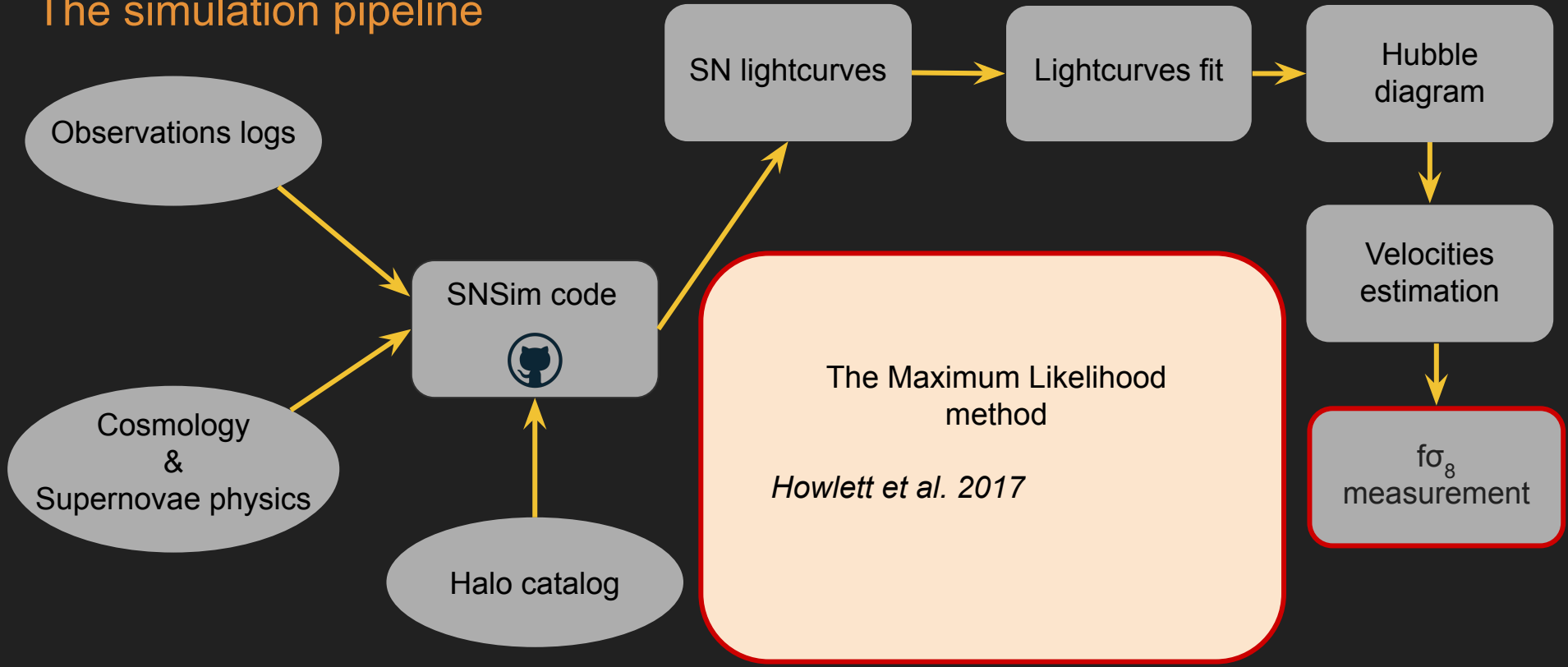

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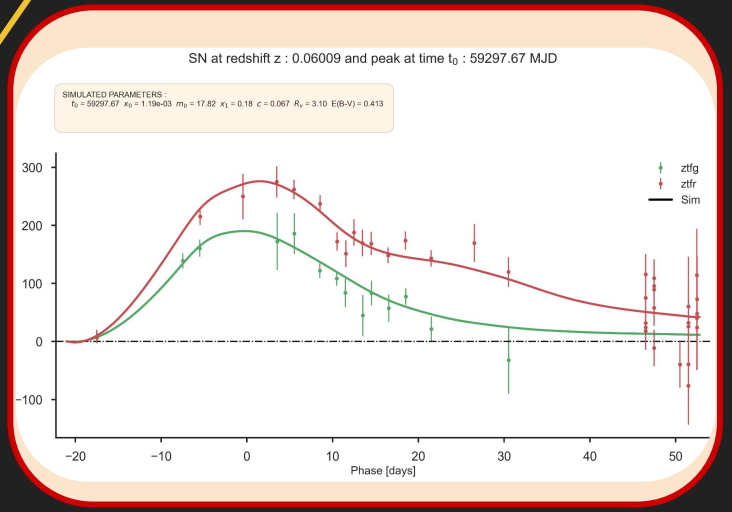
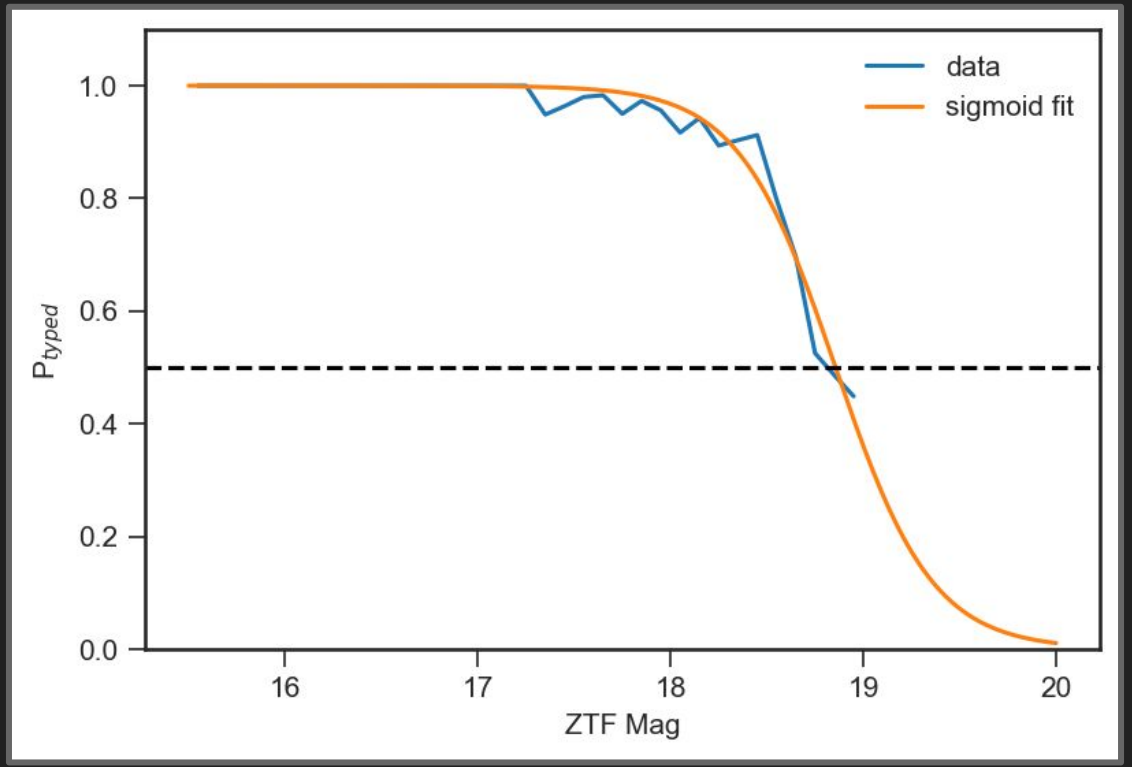


# Build a selected SN sample

Quality cut on SN can bias $f\sigma_8$ by changing peculiar velocities population.

Apply cuts :

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



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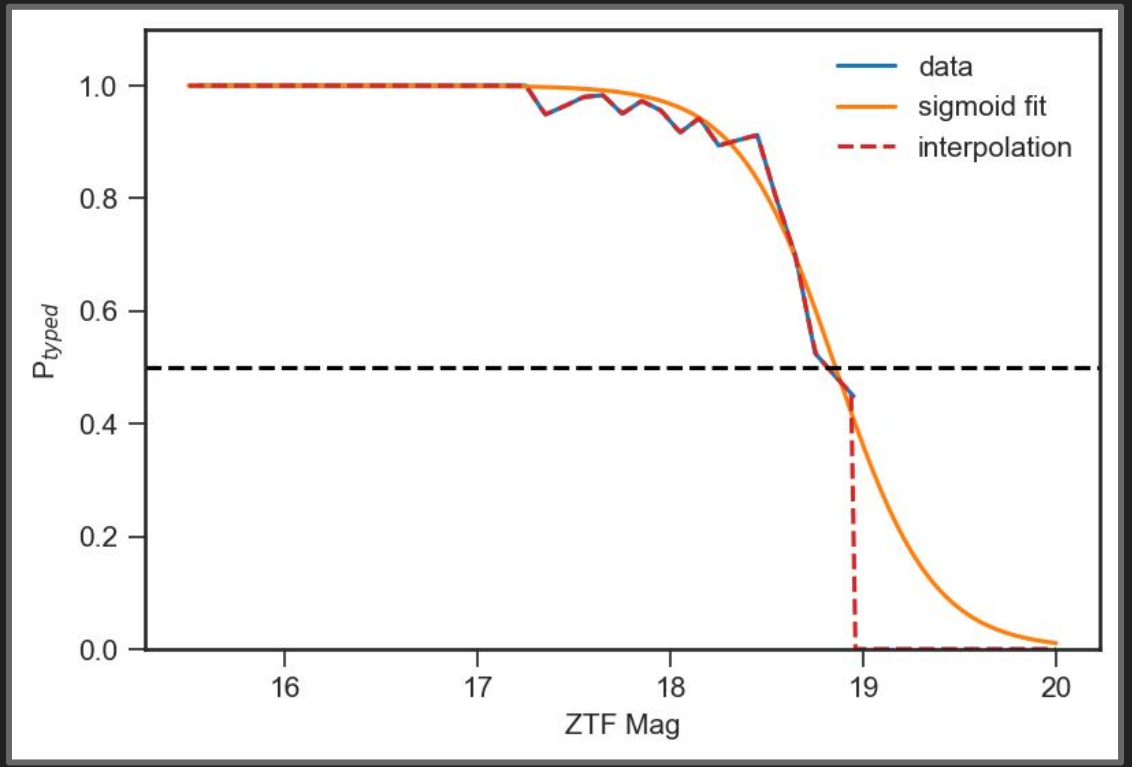

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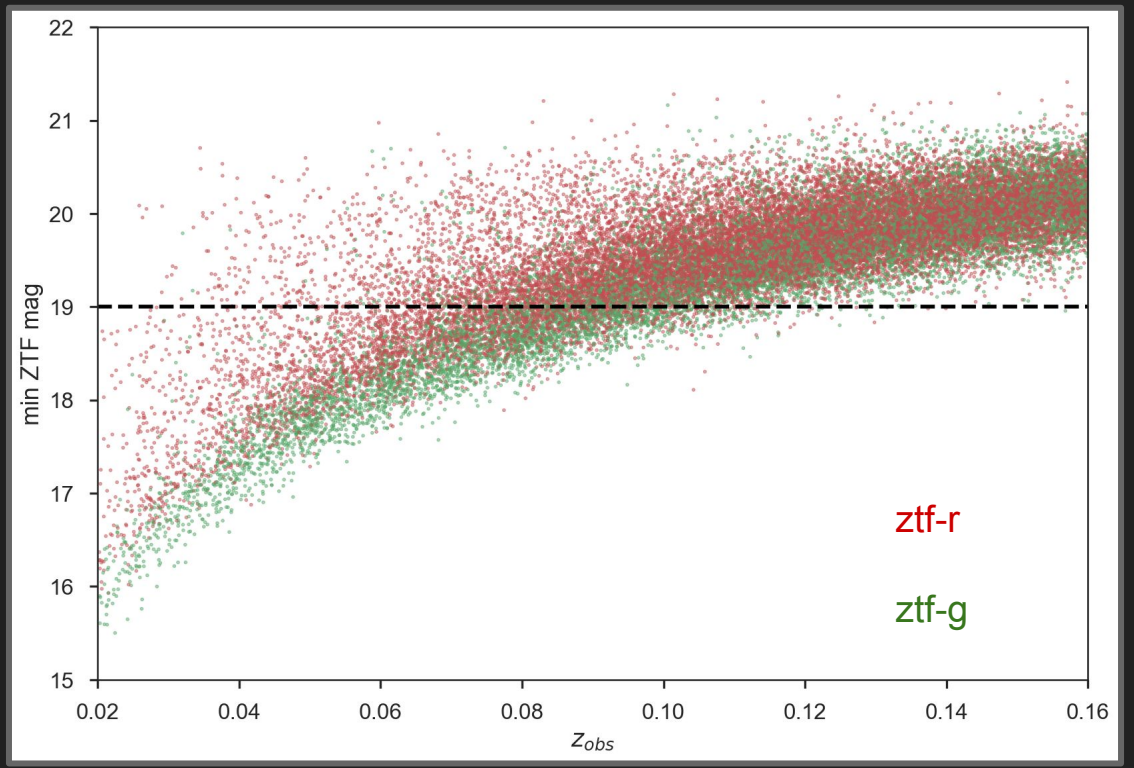

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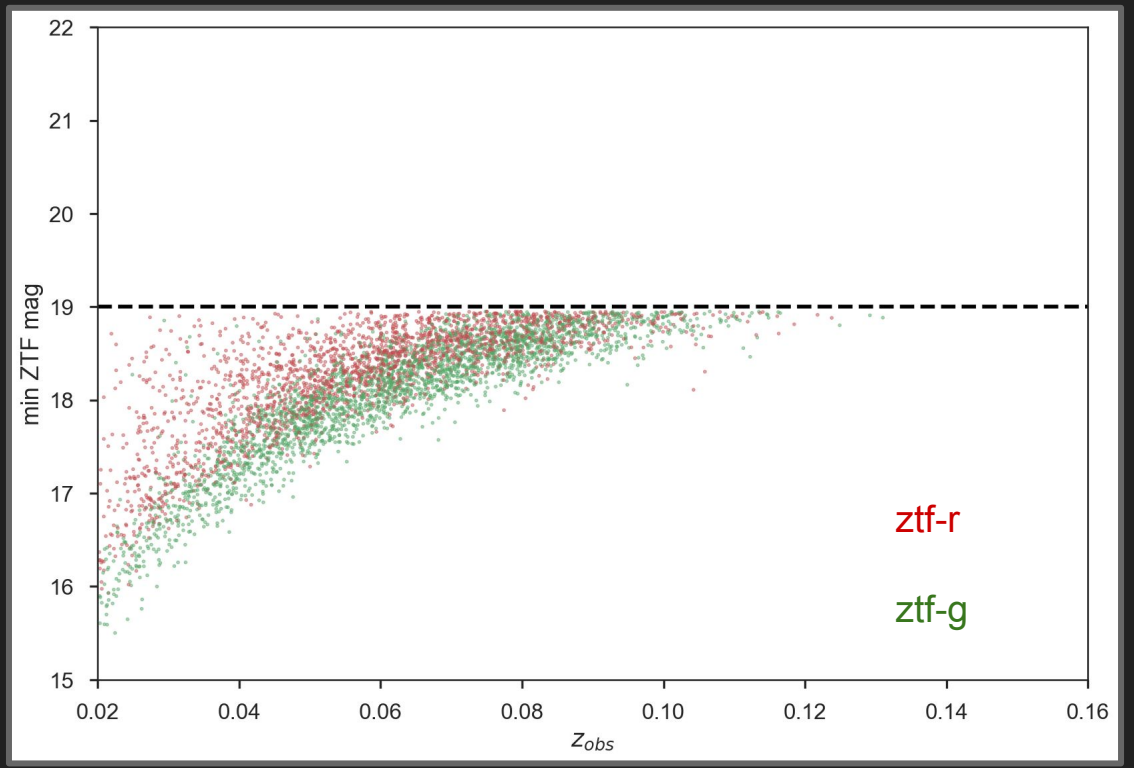
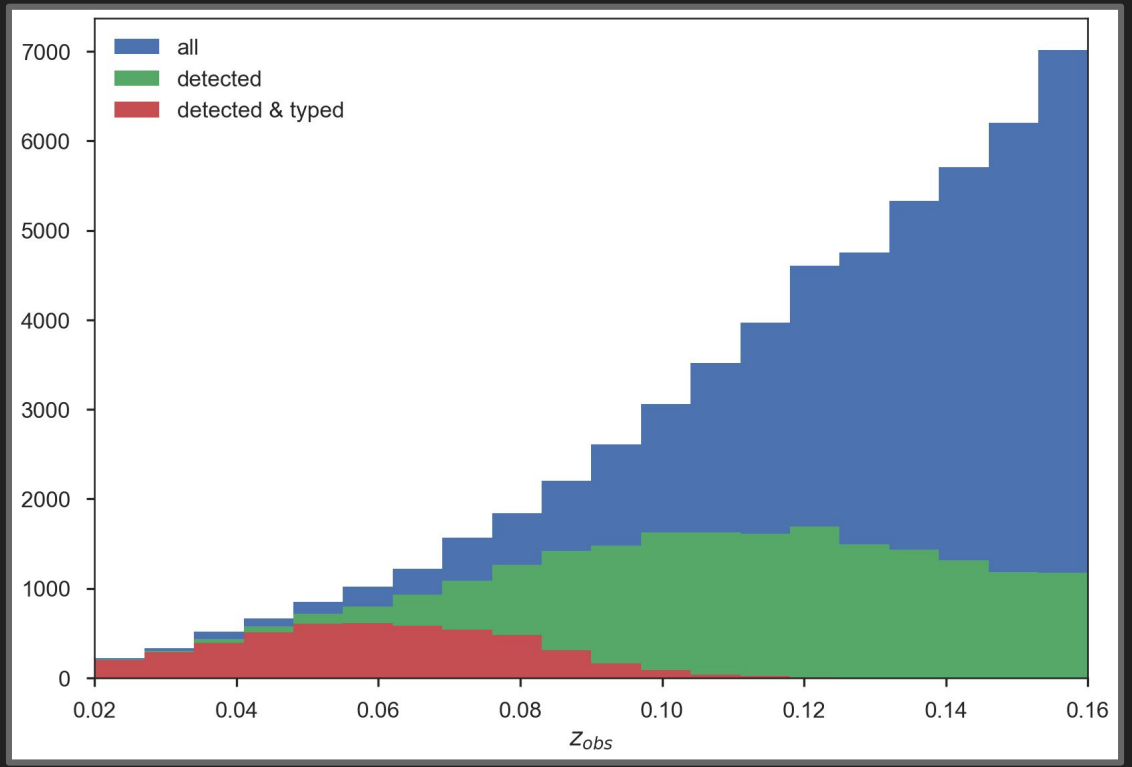


# Build a selected SN sample

Quality cut on SN can bias $f\sigma_8$ by changing peculiar velocities population.

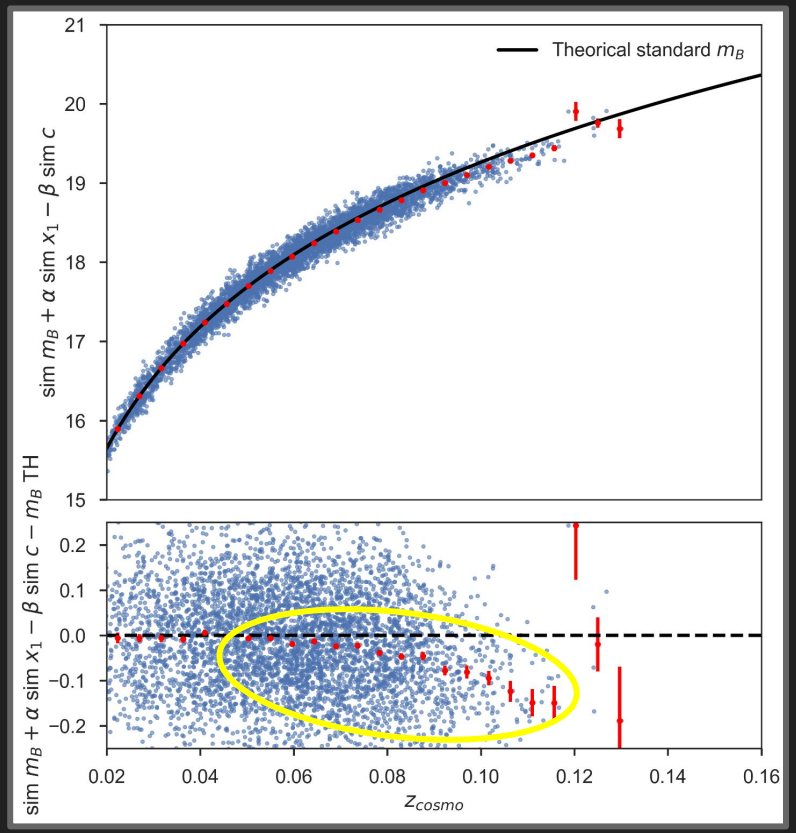
Selected SN :

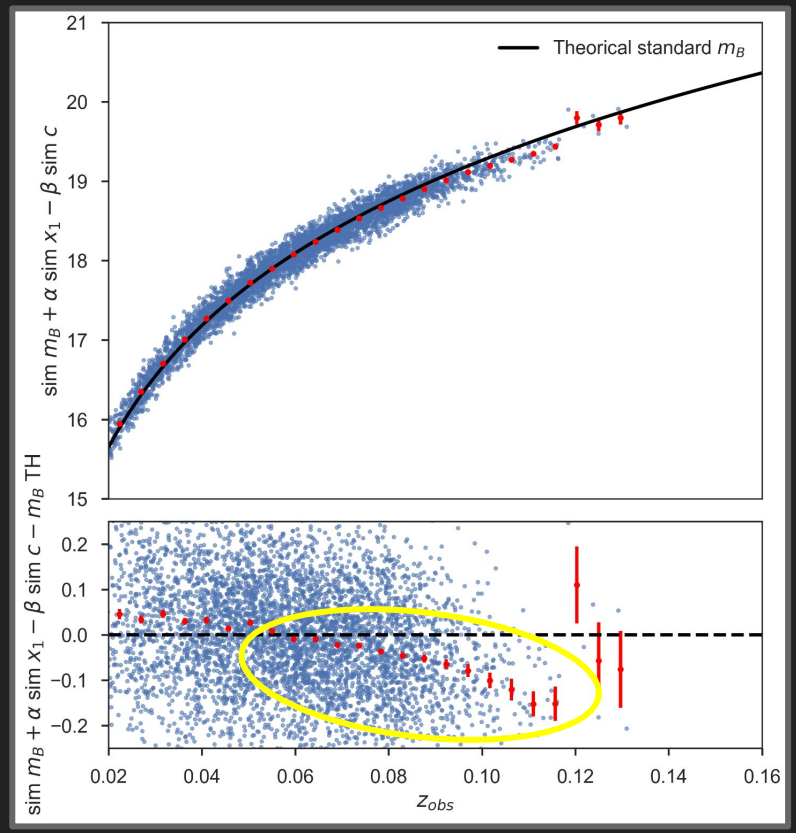
- Median redshift = 0.06
- Max redshift = 0.13



# A first look to the simulated HD after selection

Selection bias appear at z ~ 0.06



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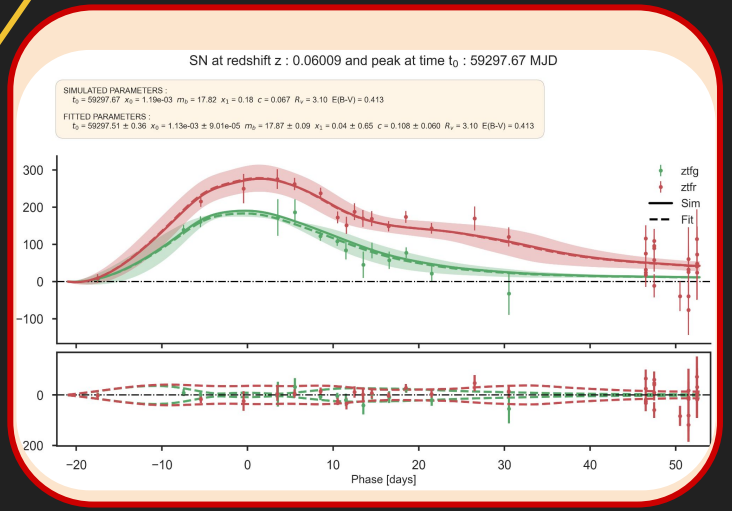

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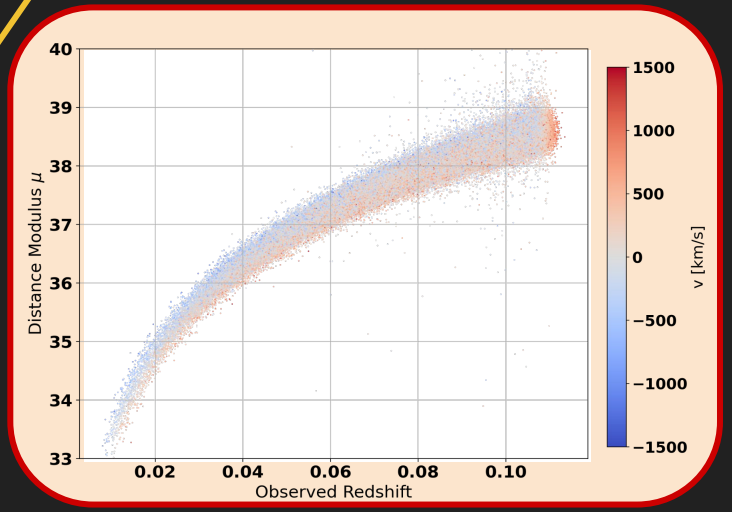


# Fit for α, β, $M_0$ and $\sigma_M$

$$\chi^2 = (\mu_i(\alpha, \beta, M_0) - \mu_{\Lambda\mathrm{CDM}})^T \, \mathrm{C}^{-1} \, (\mu_i(\alpha, \beta, M_0) - \mu_{\Lambda\mathrm{CDM}})$$

$$-2 \ln \mathfrak{L}_{\mathrm{REML}} = \sum_i w_i (\mu_i - \mu_{\lambda CDM})^2 - \sum_i \ln(w_i) + \ln\left(\sum_i w_i\right)$$ from Betoule *et al.* 2014

1 - Use $\chi^2$ to fit α, β, $M_0$ a first time using a fixed $\sigma_M = 0.1$

2 - Use value of α, β, $M_0$ to compute $\sigma_M$ with REML

3 - Re-do the $\chi^2$ fit using the $\sigma_M$ value obtained before

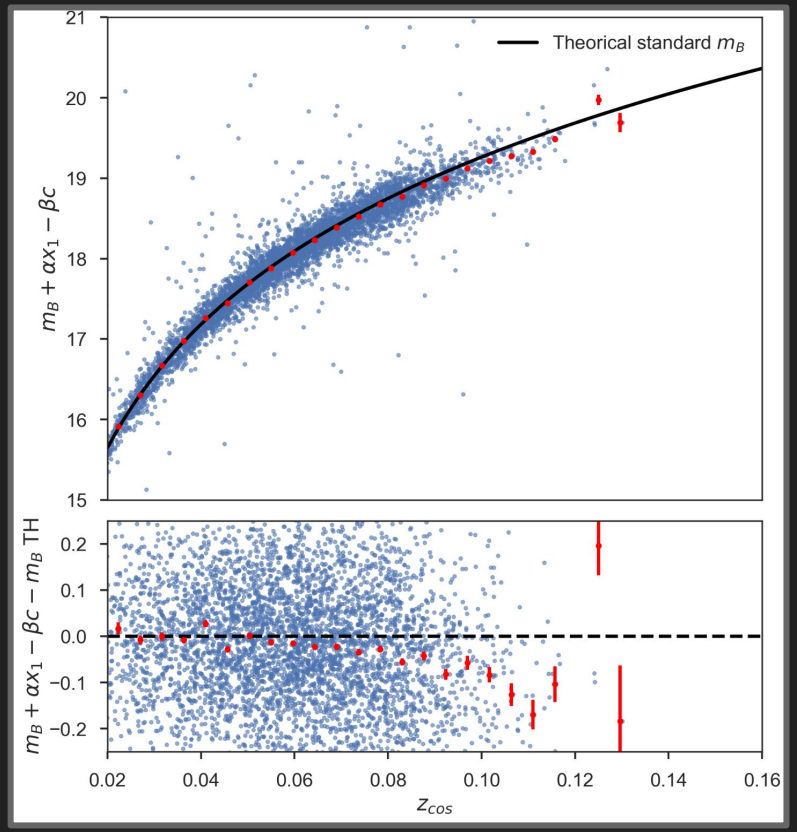
True values : $\alpha = 0.14 \quad \beta = 2.9 \quad M_0 = -19.1451 \quad \sigma_M = 0.12$

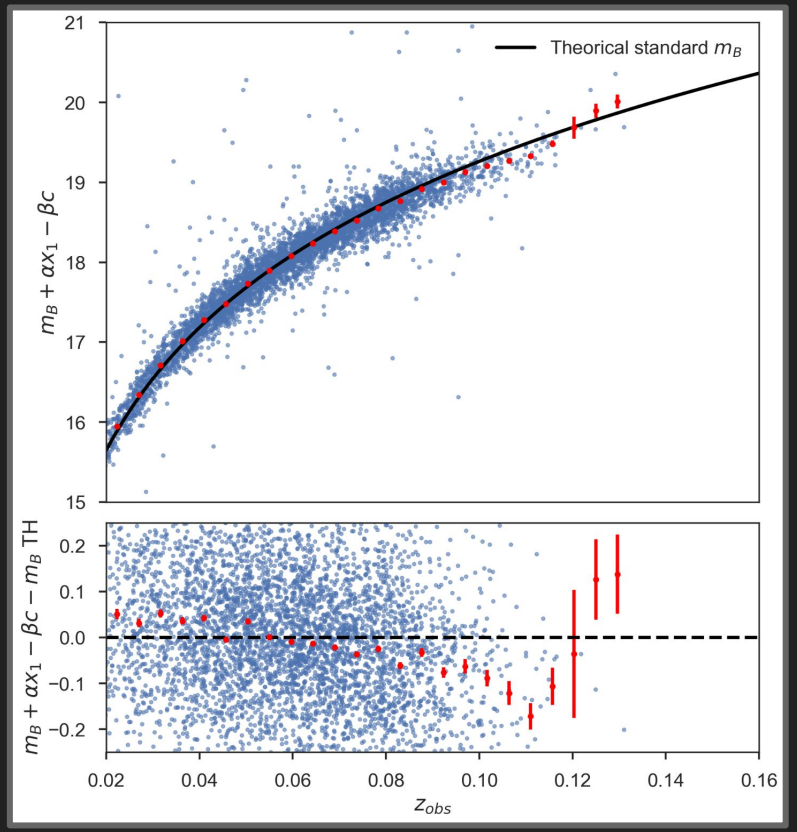
Results on simulation : $\hat{\alpha} = 0.1453 \pm 0.0023 \qquad \hat{\beta} = 2.890 \pm 0.025$

$\hat{M_0} = -19.1654 \pm 0.022 \quad \hat{\sigma_M} = 0.1211 \pm 0.0016$

# The Hubble diagram after SALT fit

Selection bias appear at z ~ 0.06



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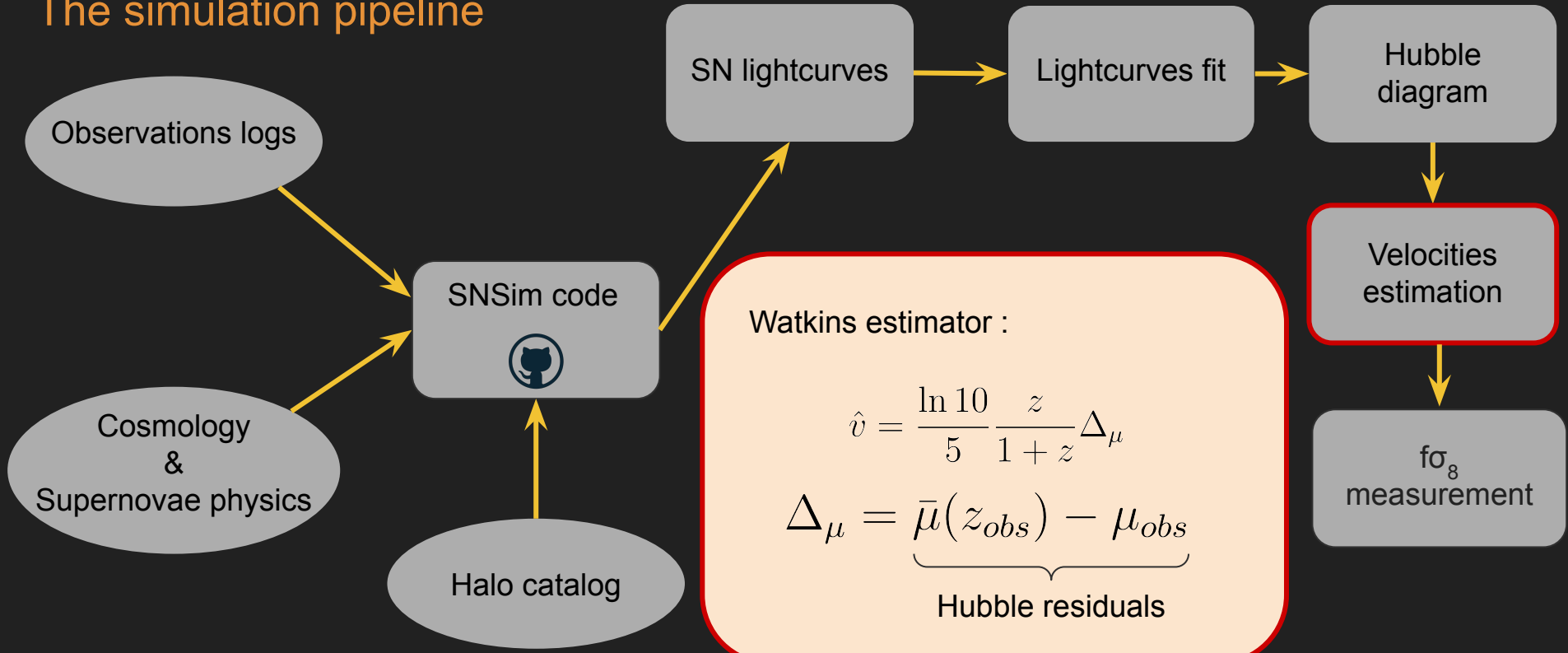
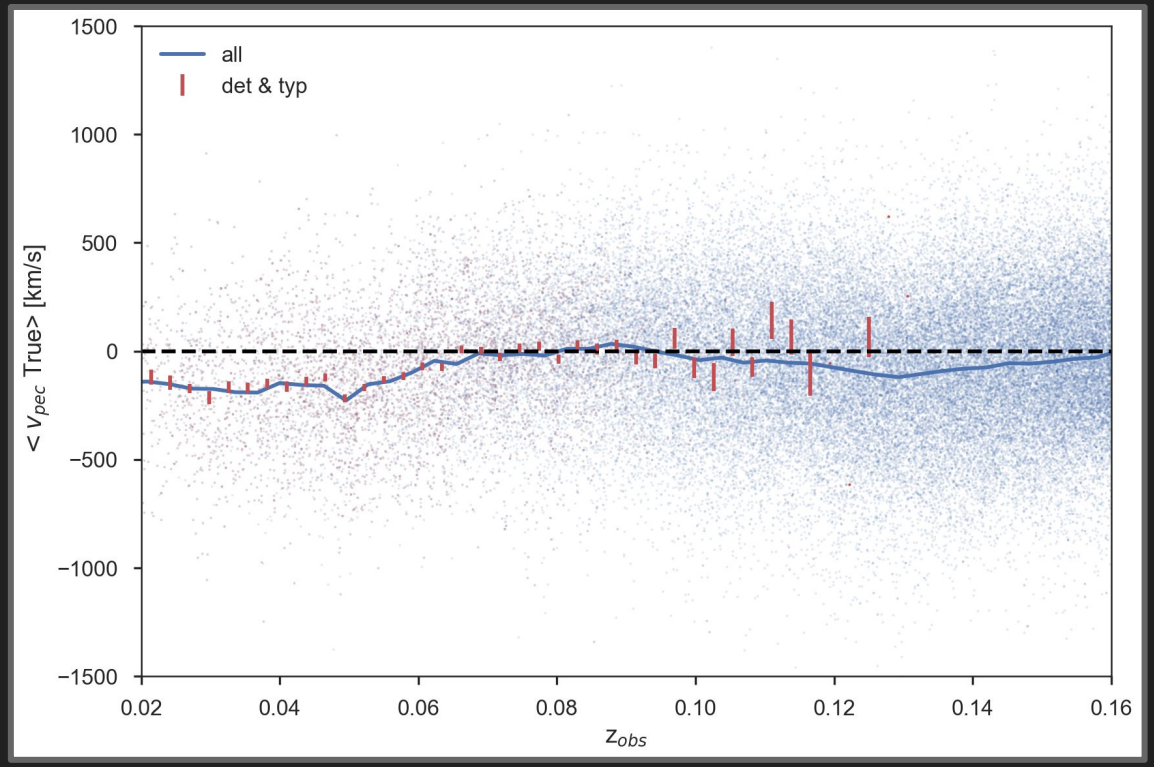


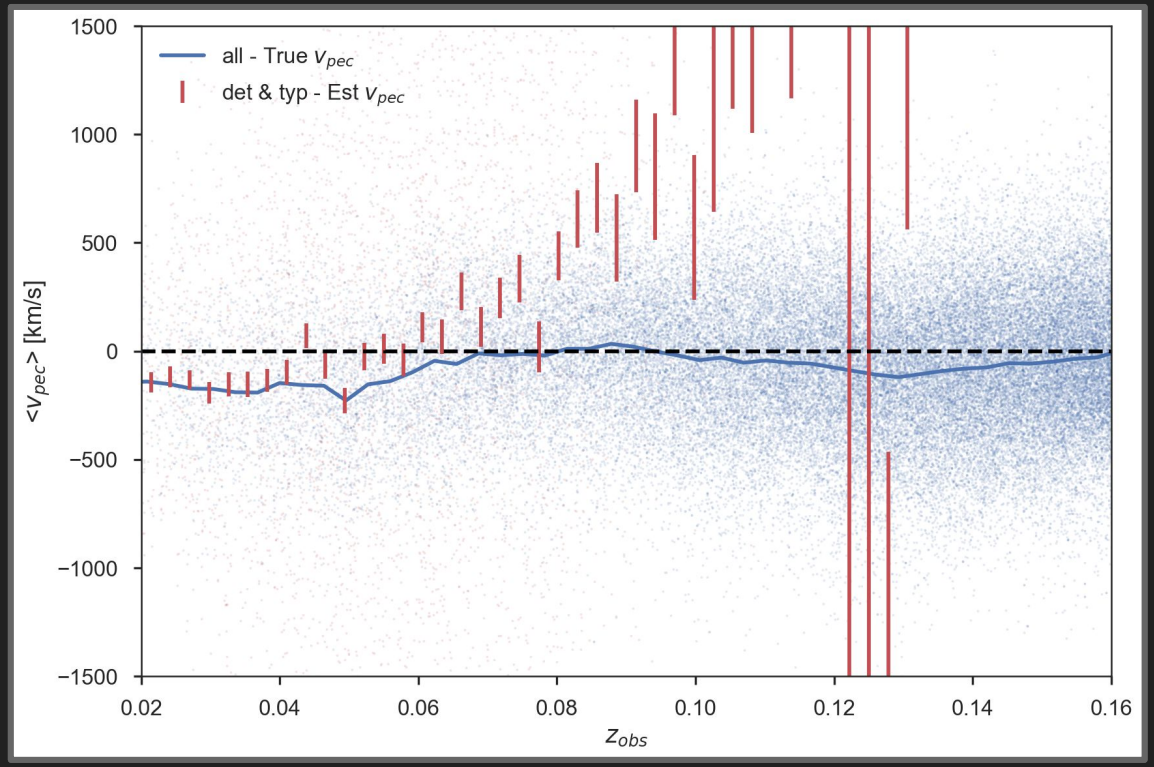
# Velocities estimation from residuals

"No difference" between the true peculiar velocities of the full sample and of the selected sample…



# Velocities estimation from residuals

…But the mean of the estimate peculiar velocities are biased



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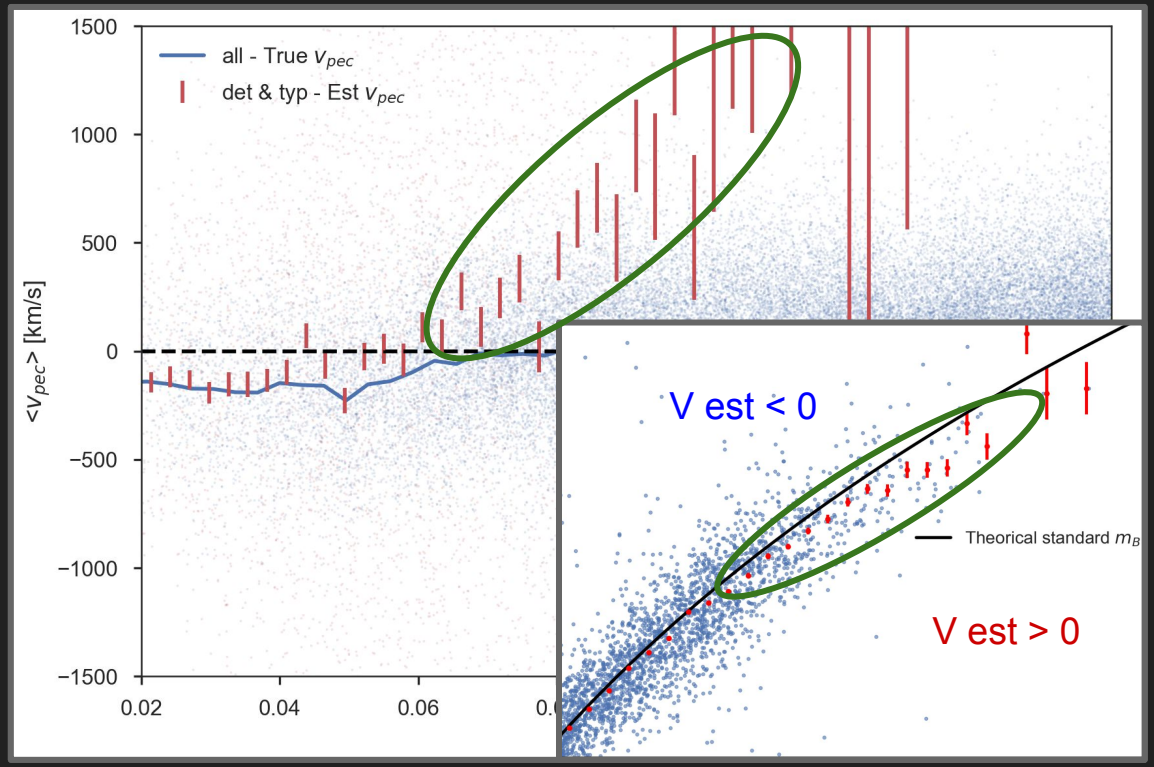


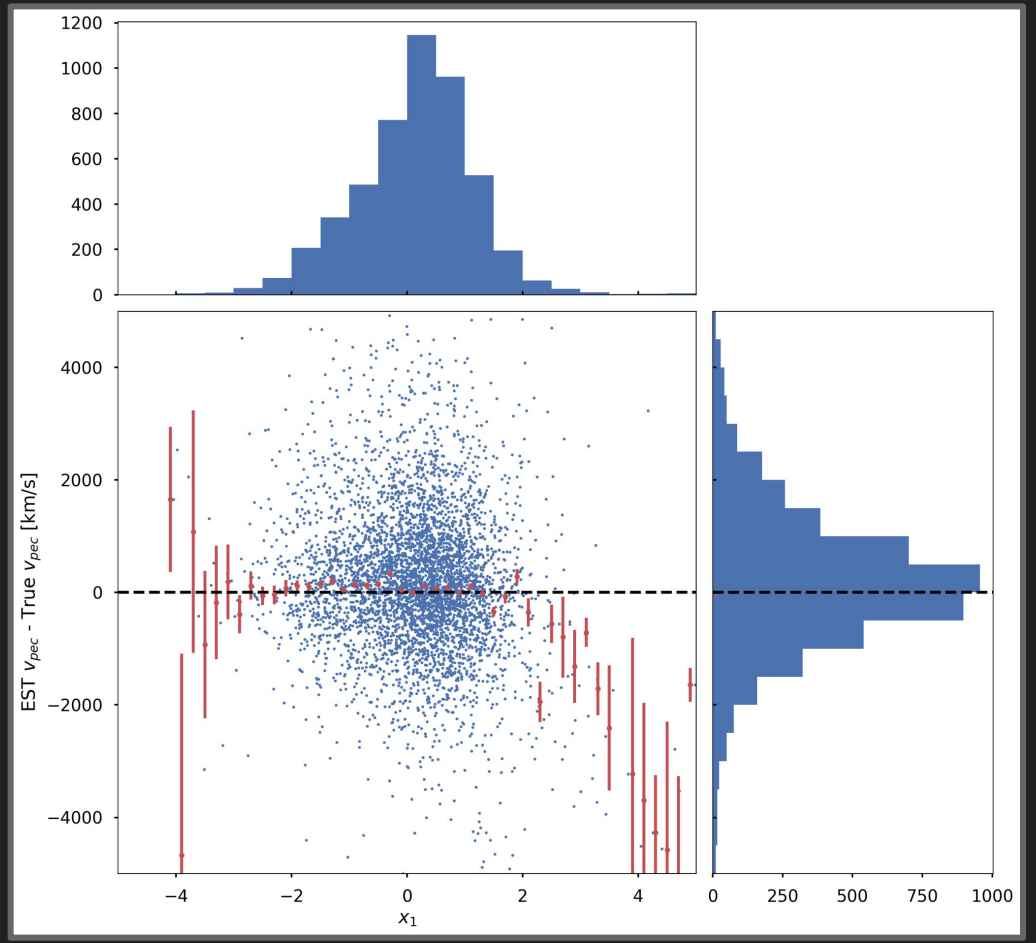
# SALT $x_1$ effect on $v_{pec}$ estimation

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

$\Downarrow$

Over-estimate $x_1$ ⇒ Negative velocity

Under-estimate $x_1$ ⇒ Positive velocity



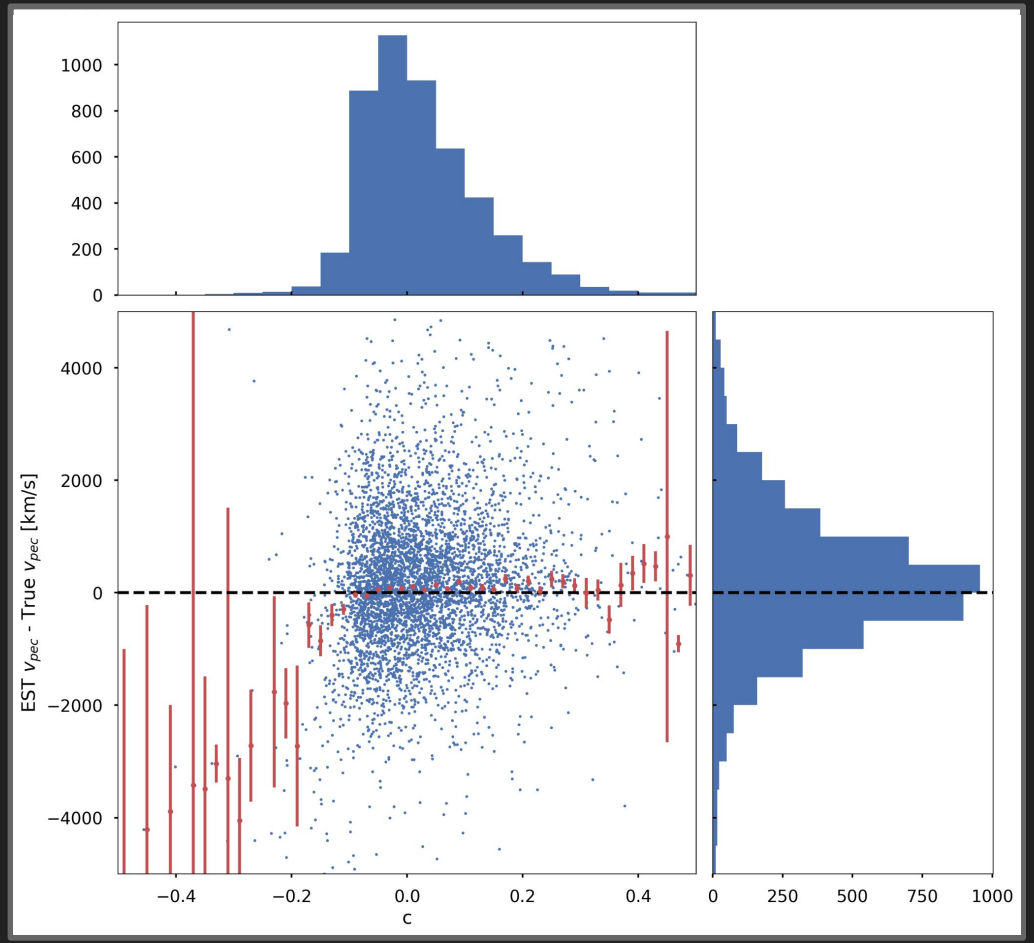
# SALT c effect on $v_{pec}$ estimation

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

$\Downarrow$

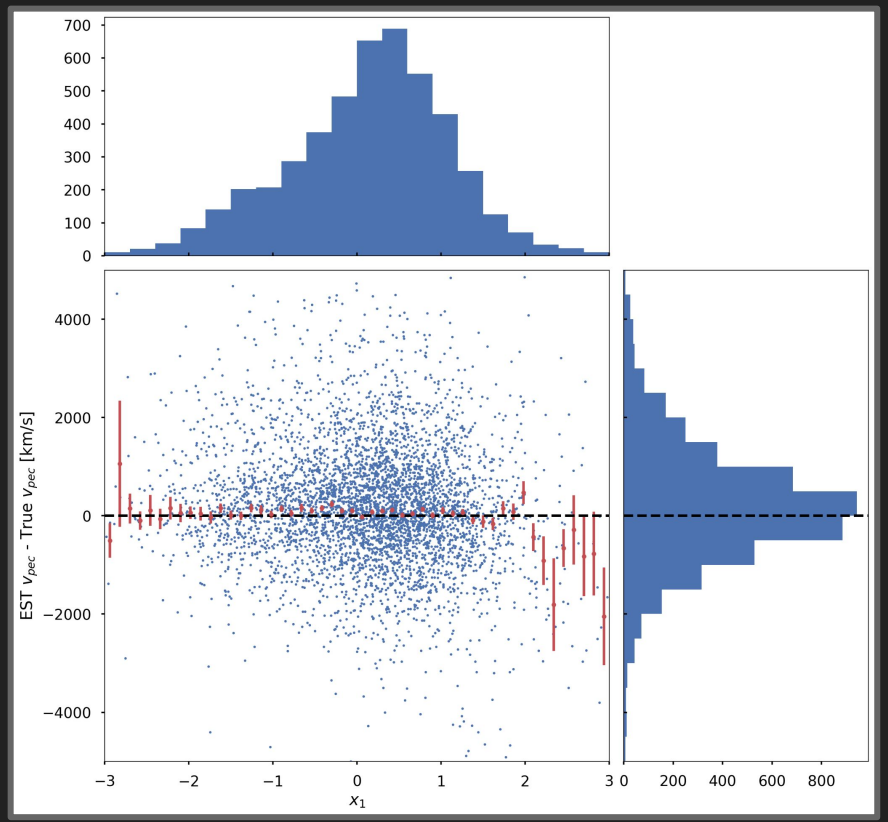
Over-estimate c $\Rightarrow$ Positive velocity

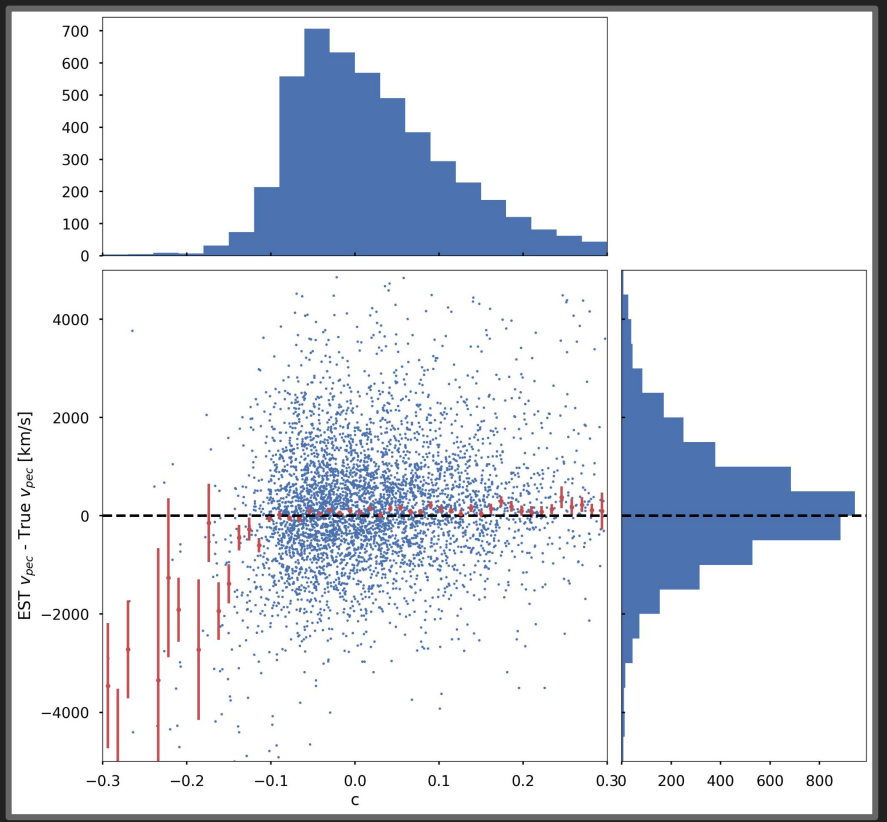
Under-estimate c $\Rightarrow$ Negative velocity



# Velocities estimation from residuals

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



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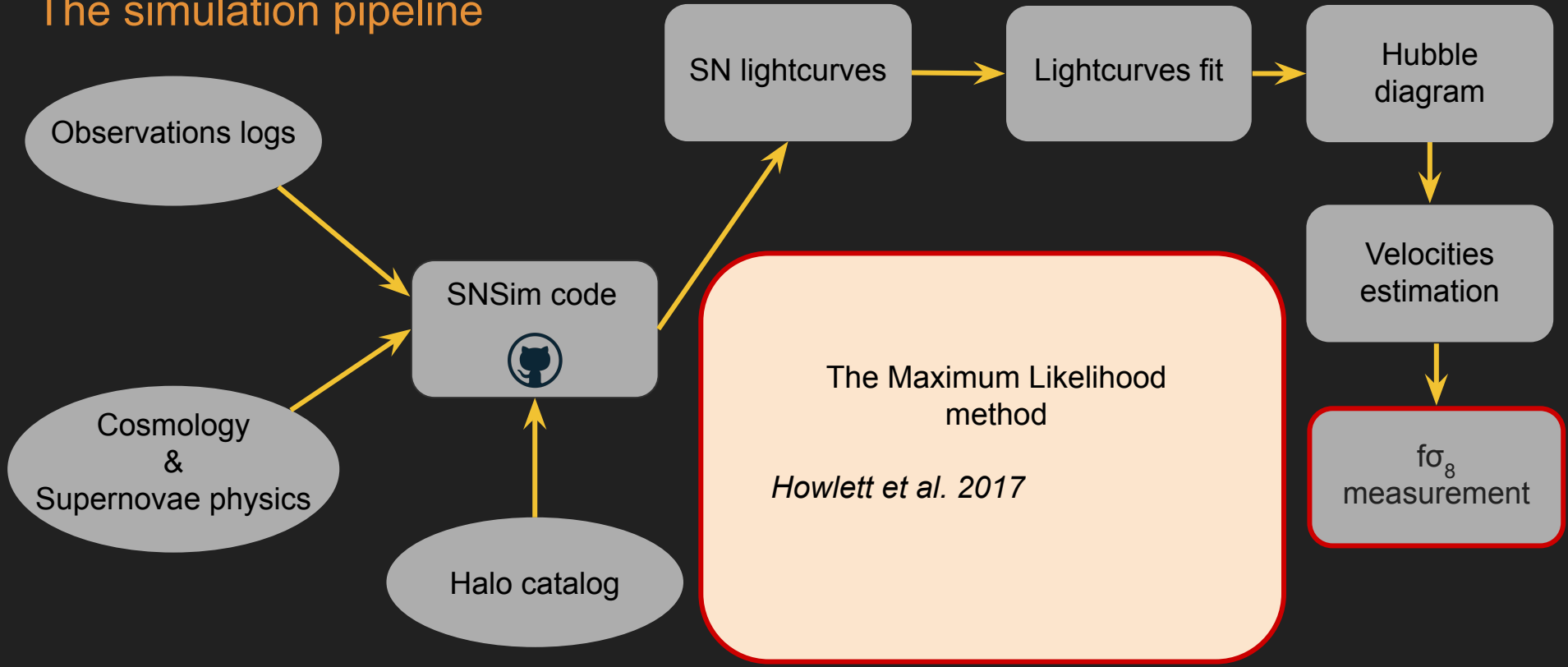


# Method we want to test : the maximum likelihood

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

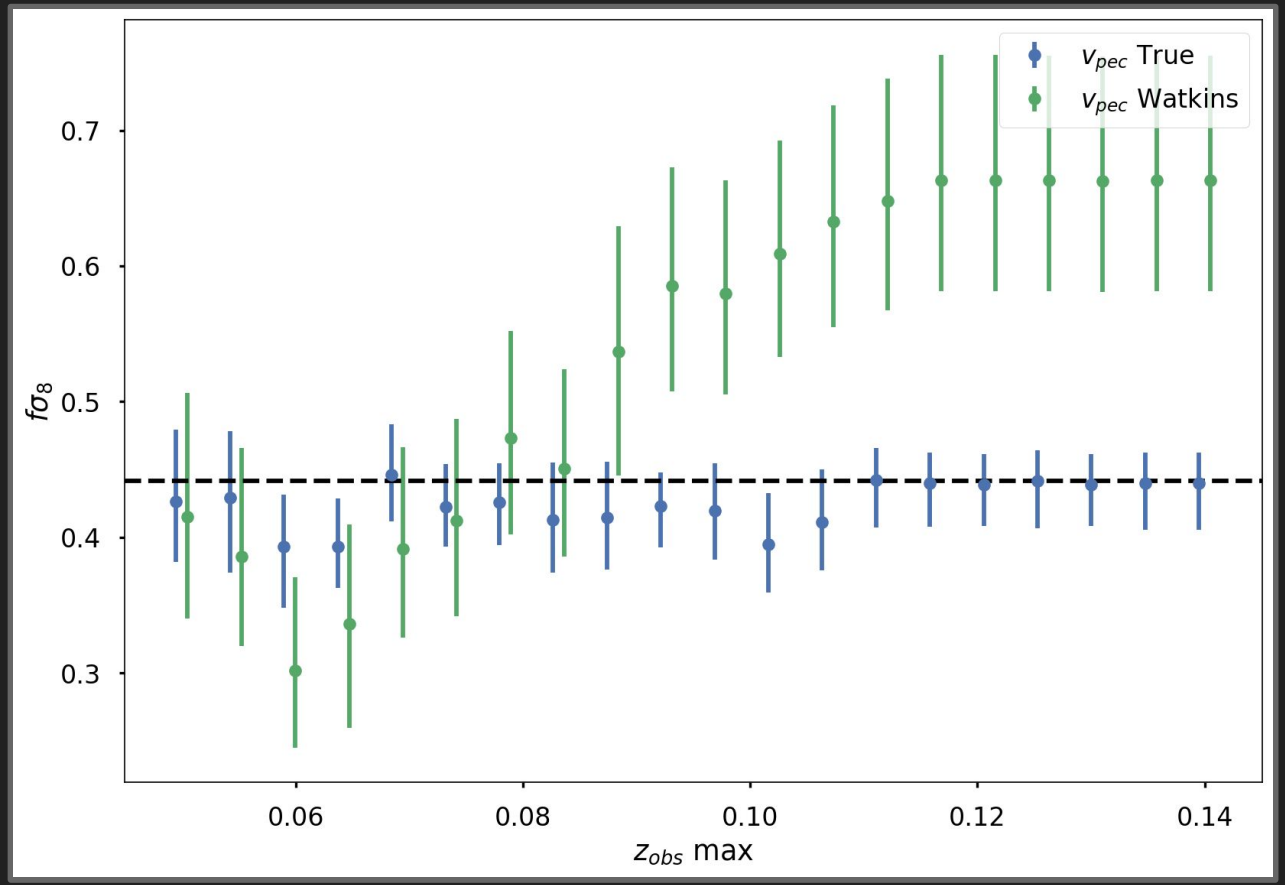
$$\mathrm{C_{tot}} = (f\sigma_8)^2 \mathrm{C_{cos}} + \mathrm{C_{obs}}$$

# $f\sigma_8$ measurement

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

Effect of selection bias appear after z∼0.08

Expected $f\sigma_8$ = 0.441



# $f\sigma_8$ measurement

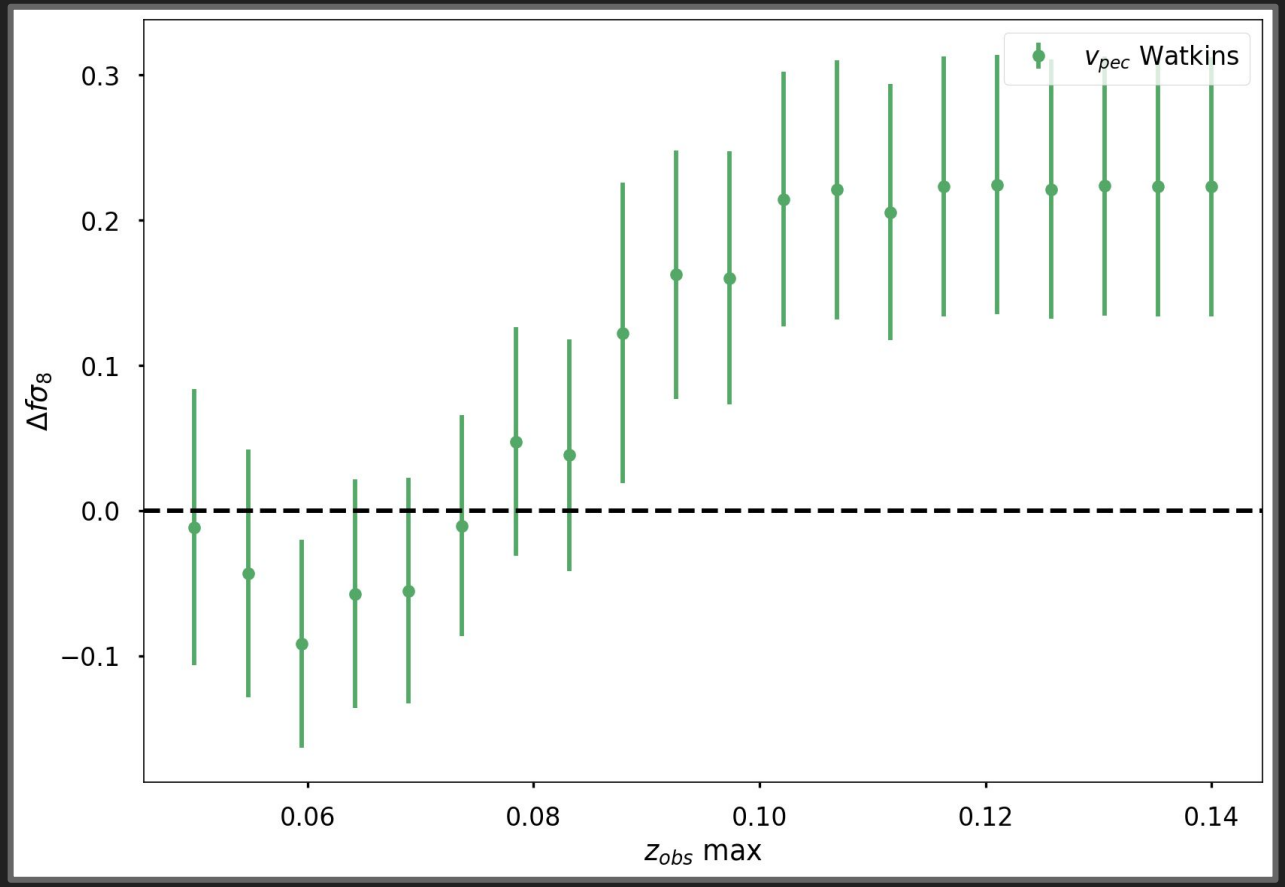
Fit with a binning grid of 80 $Mpc.h^{-1}$

Effect of selection bias appear after $z \sim 0.08$

Expected $f\sigma_8 = 0.441$

Bias on $f\sigma_8 \sim 0.2$

$\Delta f\sigma_8 / f\sigma_8 \sim 45\ \%$



# Conclusion and future plan

- Using one mock we found that selection bias have a relative impact of ∼45 % on the measurmeent of $f\sigma_8$
- Preliminary result of $f\sigma_8$ = 0.492 ± 0.075 using only SN with $z_{obs} < 0.08$ ~ 4000 SN
- We plan to make the same analysis for more mocks
- Validate the selection function
- Try to correct the bias

# Thanks for your attention