Peculiar velocities with Type Ia Supernovae

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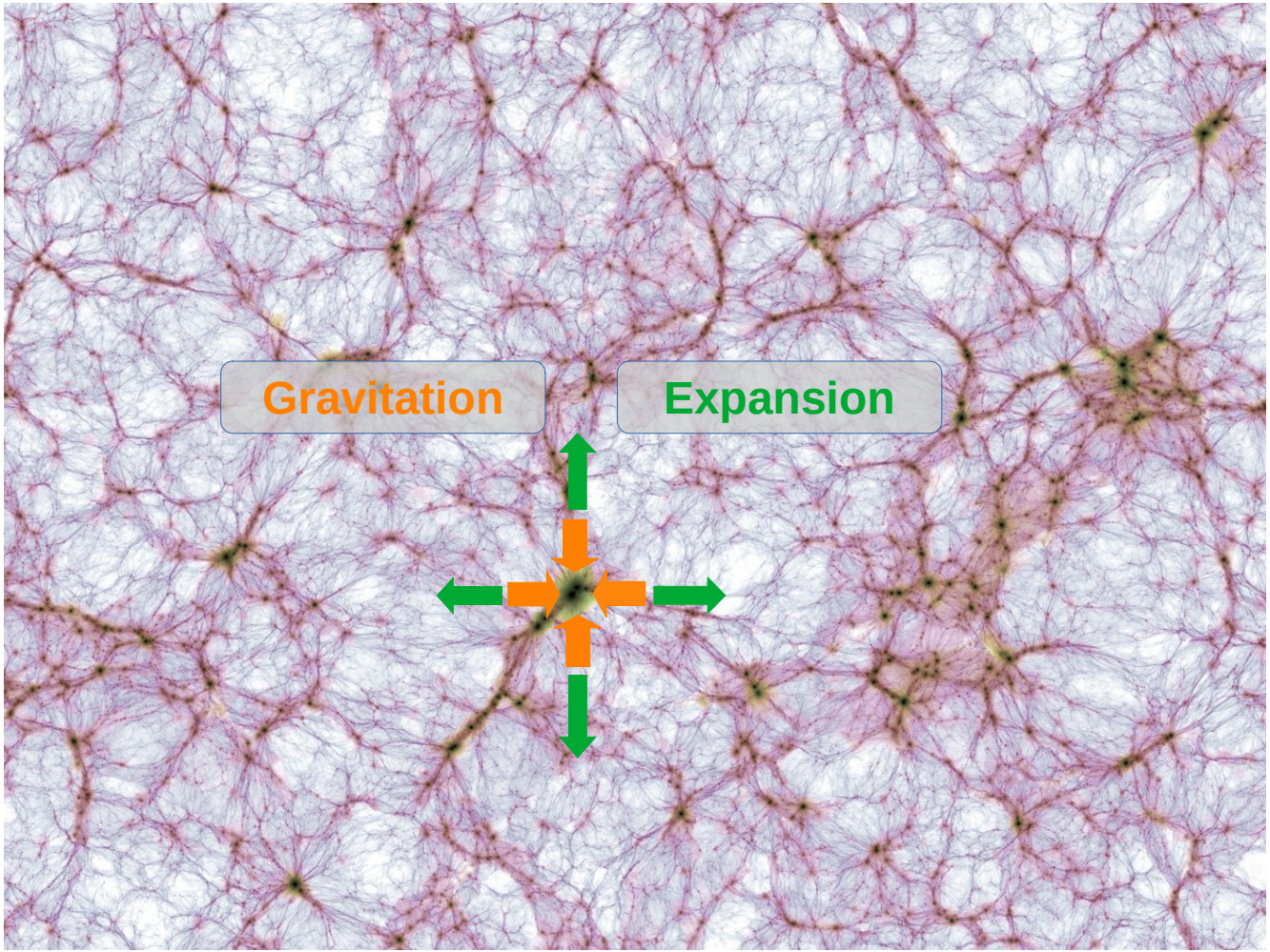
Julian Bautista, Dominique Fouchez, Fabrice Feinstein, Benjamin Racine

Outline

- Cosmology with the growth rate of structures
- Constrain the growth rate with peculiar velocities of type-Ia supernovae
- Simulation of type-Ia supernovae observations
- First results and systematic effects

Cosmology with the growth rate of structures



$$\delta(t,\mathbf{x}) = \frac{\rho(t,\mathbf{x}) - \bar{\rho}}{\rho} \simeq D(t)\hat{\delta}(\mathbf{x})$$

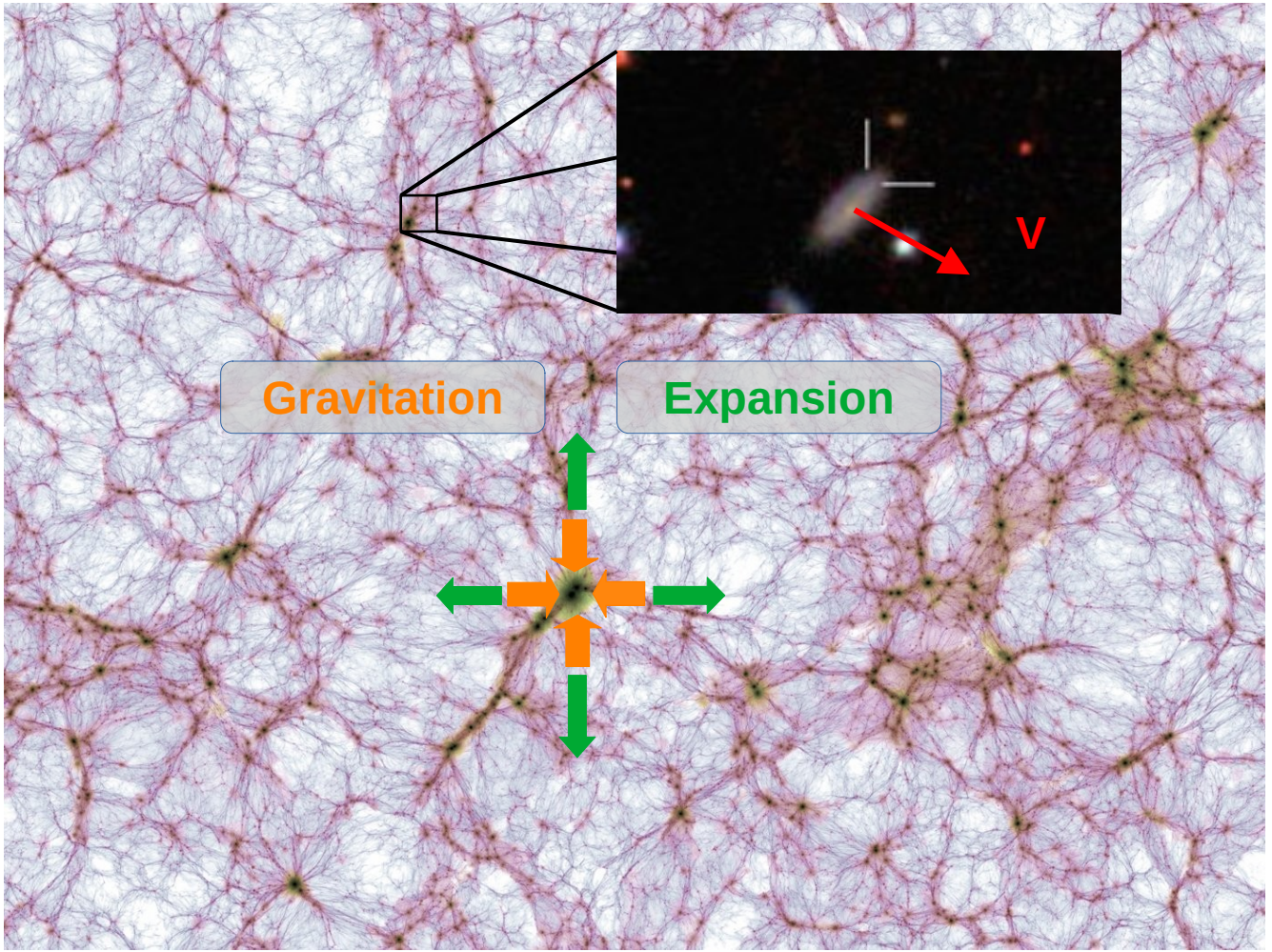
Perturbation of matter density

The **growth factor** = the change of perturbation with time

The **growth rate** f(a) is the rate of evolution of the growth of structures

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

Cosmology with the growth rate of structures



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

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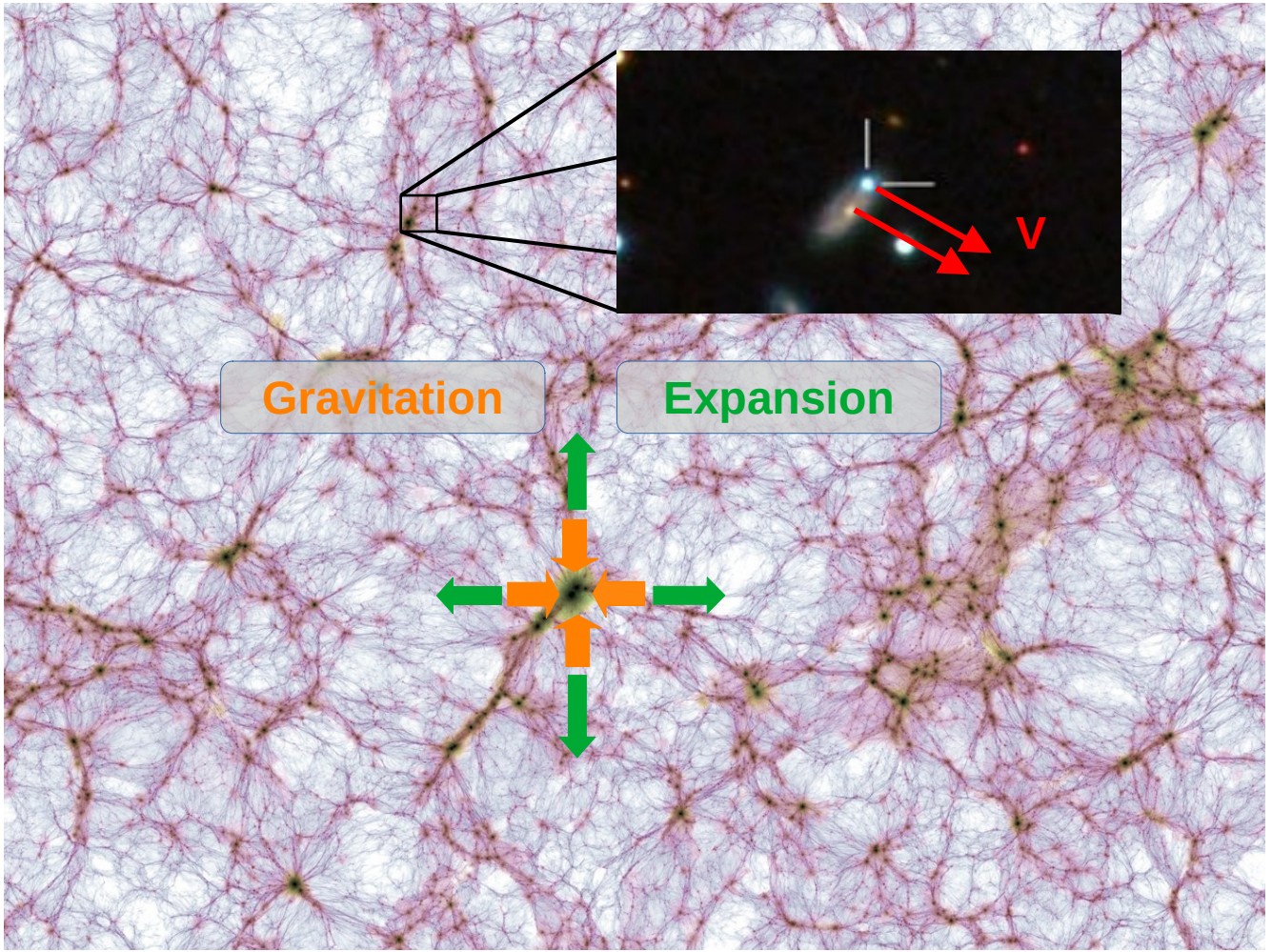

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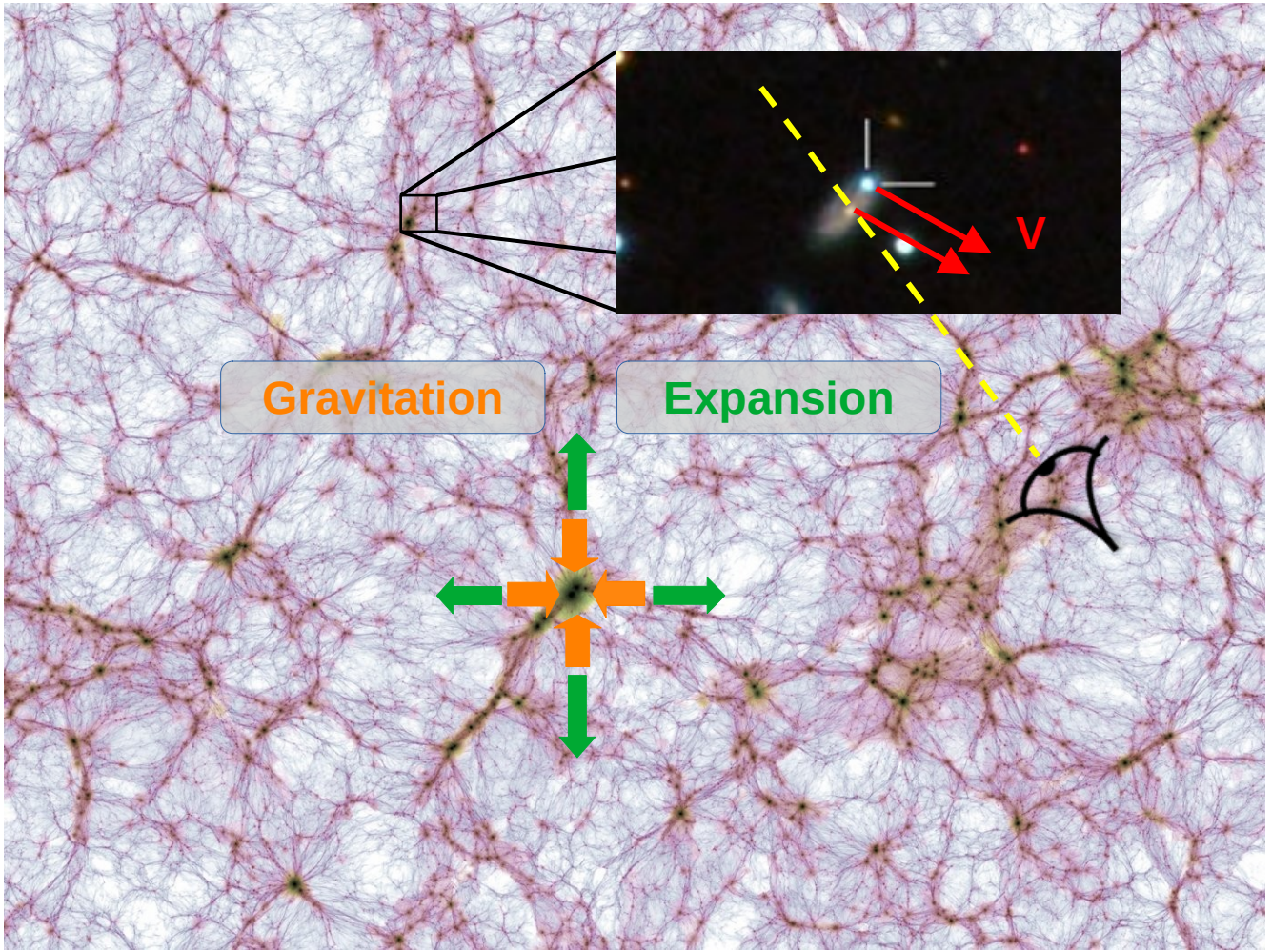

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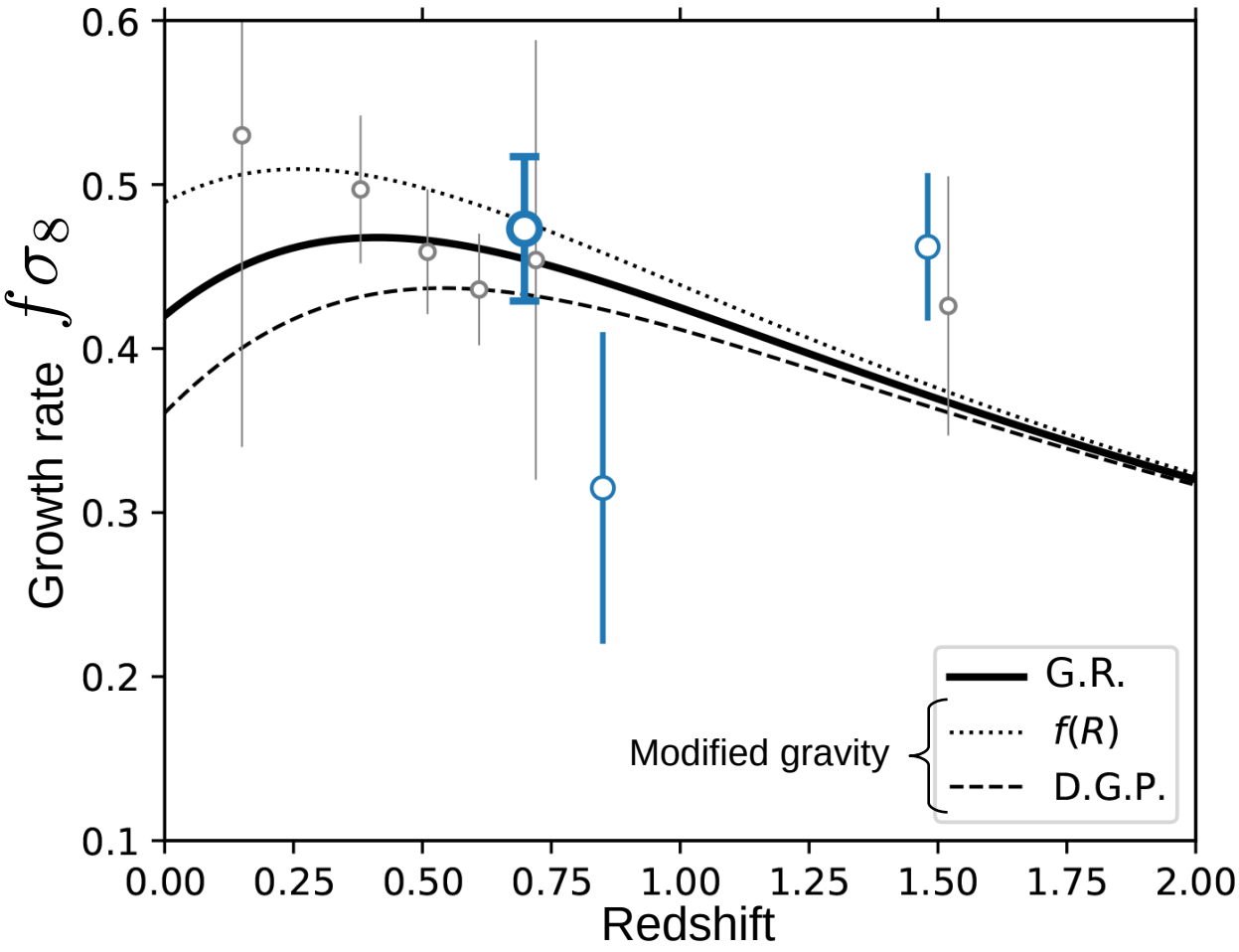
Constraining the growth rate with SN Ia

Currents methods : use RSD indirect measurement of the velocity field

eBoss



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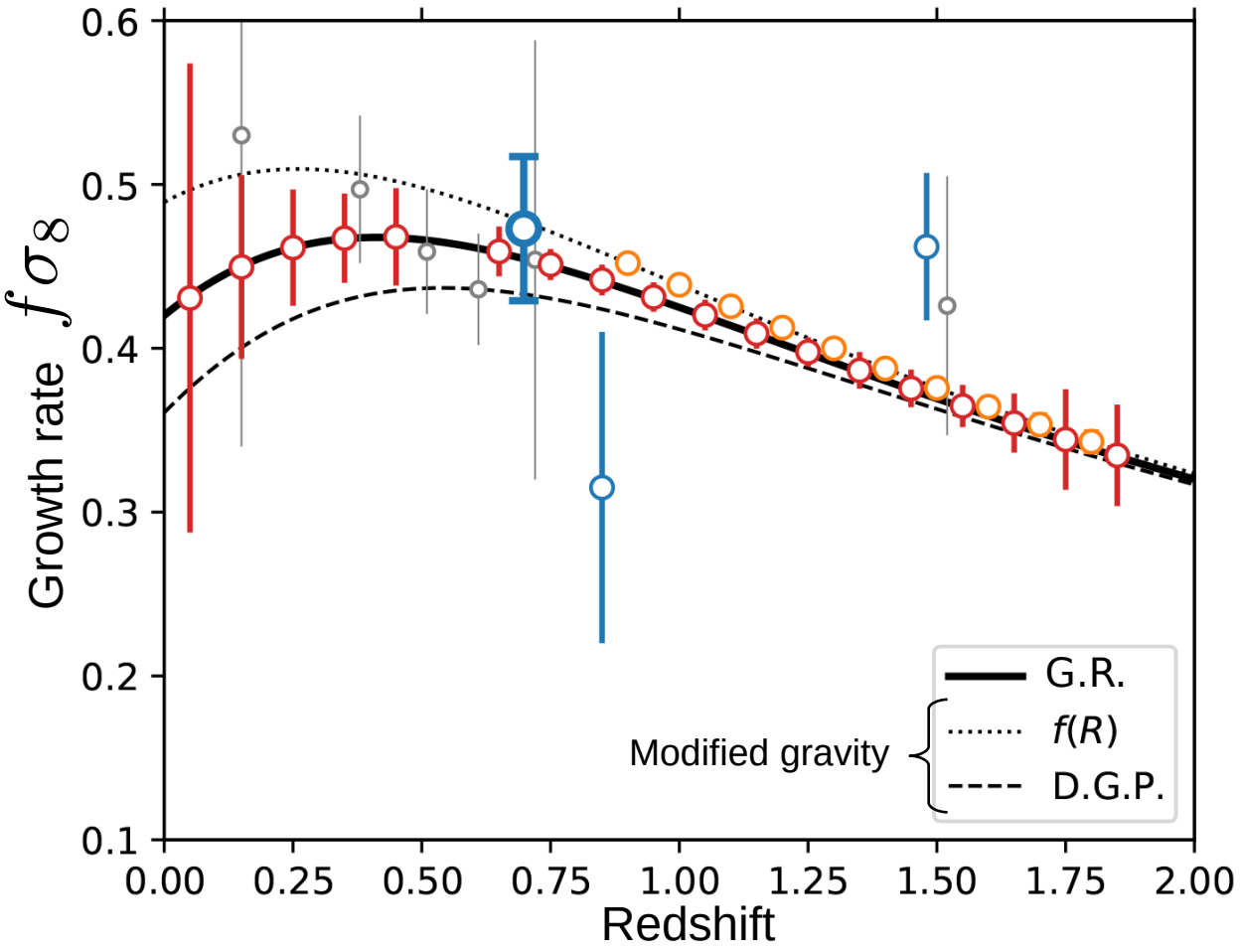

Constraining the growth rate with SN Ia

Currents methods : use RSD indirect measurement of the velocity field

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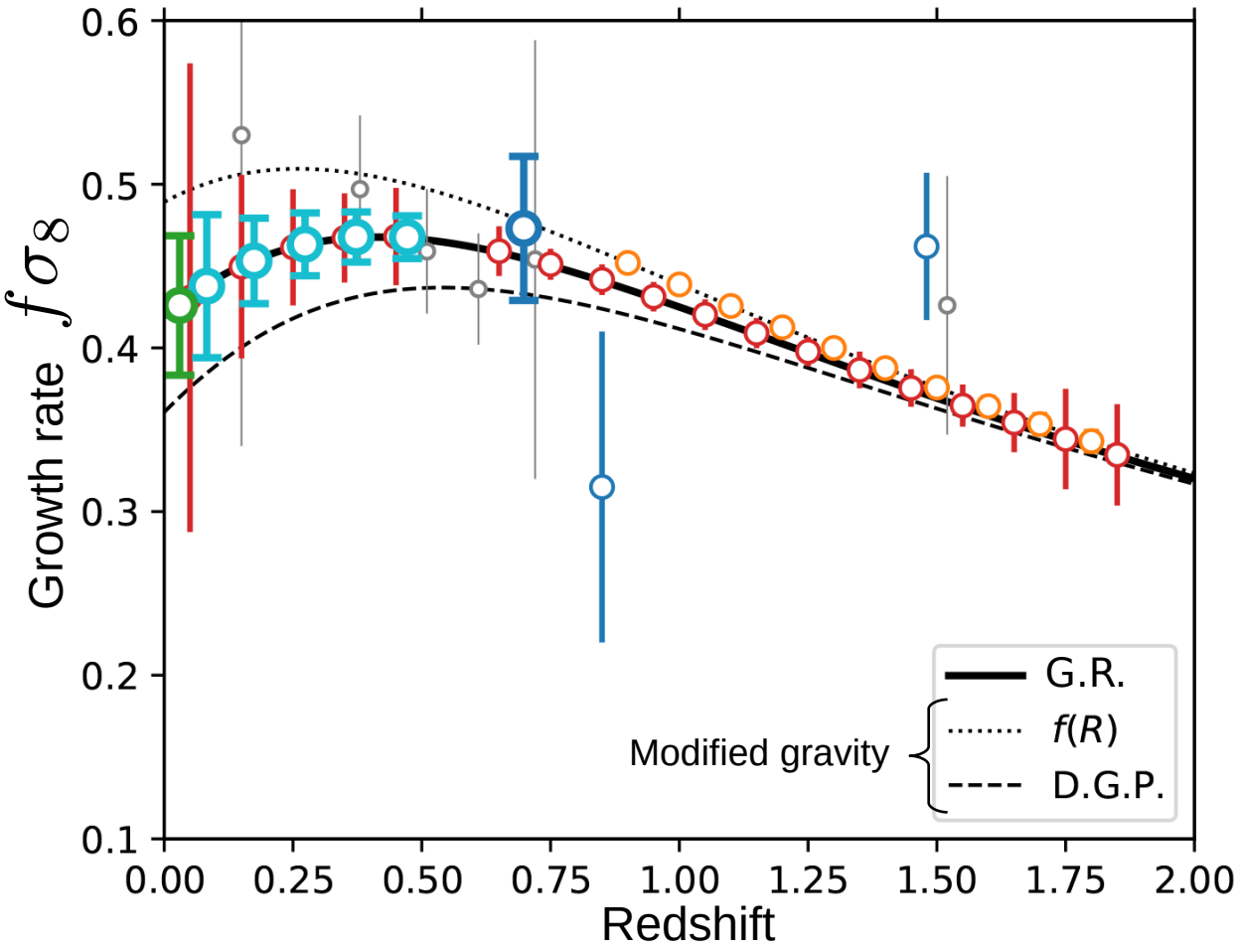
Next survey : SN Ia direct measurement of the velocity field

- ZTF
- Rubin observatory



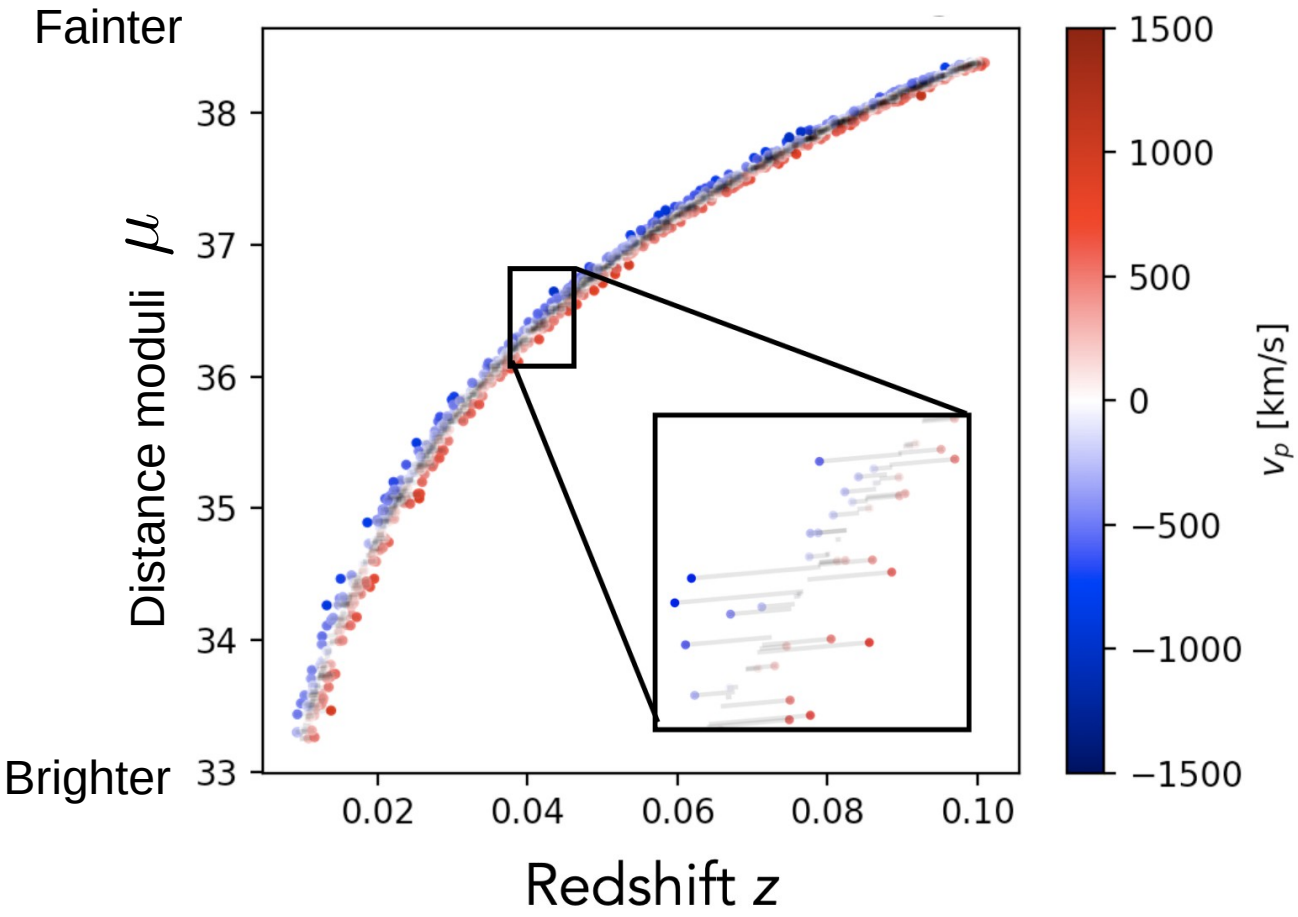
Peculiar velocities measurement with SN Ia

SN Ia = Standard candles

Measurement of distances

Peculiar velocities affect both redshifts and distances

Peculiar velocities can be extracted from Hubble diagram residuals



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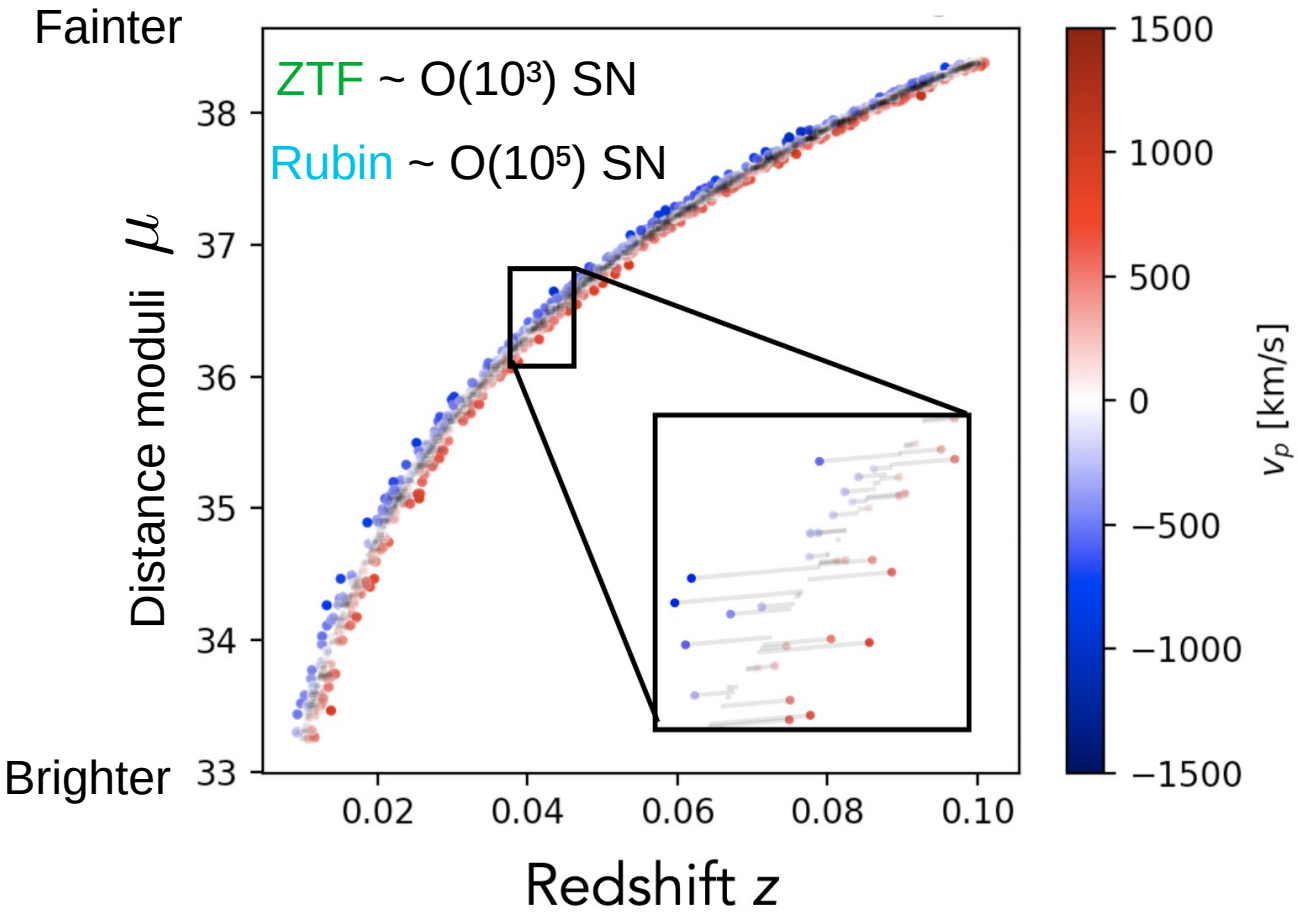


How can we estimate the systematics errors ?

Simulation = essential tool to study systematics errors levels and make forecast for future analysis !

Examples of systematics:

- Observational selection effect
- Angular instrumentation correlation
- Velocity bias of host galaxies
- Non Ia contamination
- ...

Forecast:

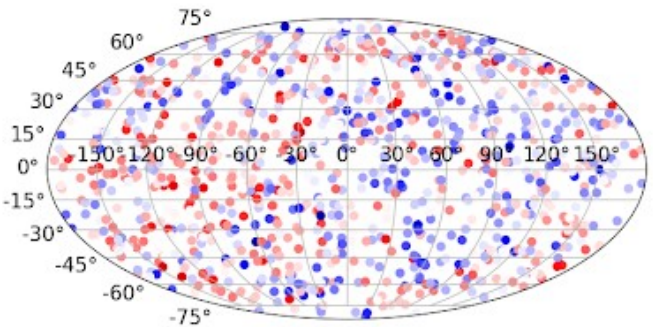
- Impact of cadence
- Impact of calibration

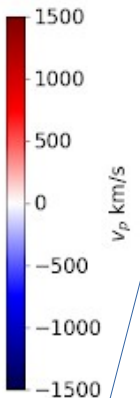
SN Ia simulations with halo catalogue

Halo catalogue :
- Coordinates
- Peculiar velocities

Our code

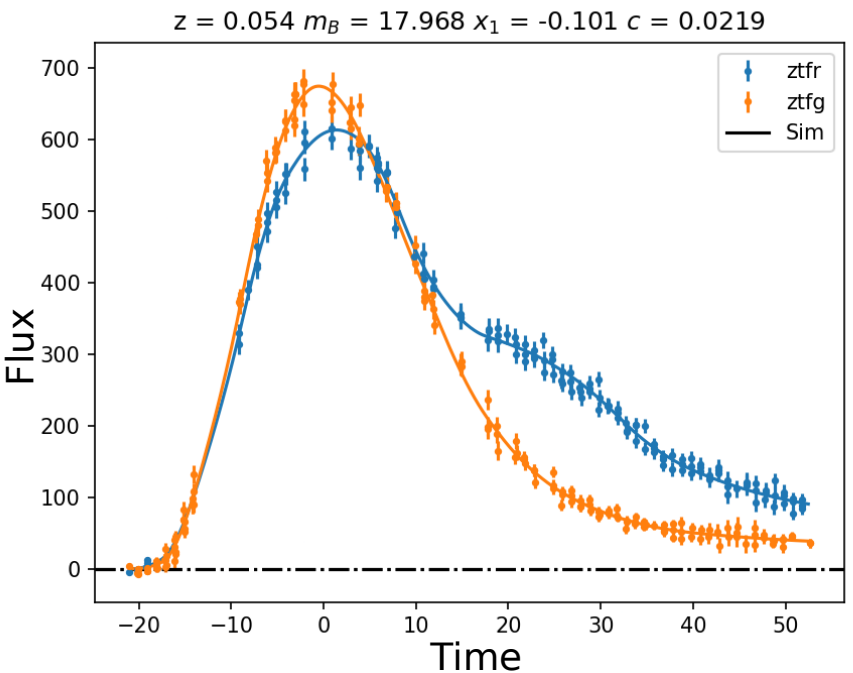
Lightcurves simulation with sncosmo





SN Ia physics

Observations database :
- Time
- Coordinates
- Filter
- Skynoise



From simulation to the growth rate (fσ8)

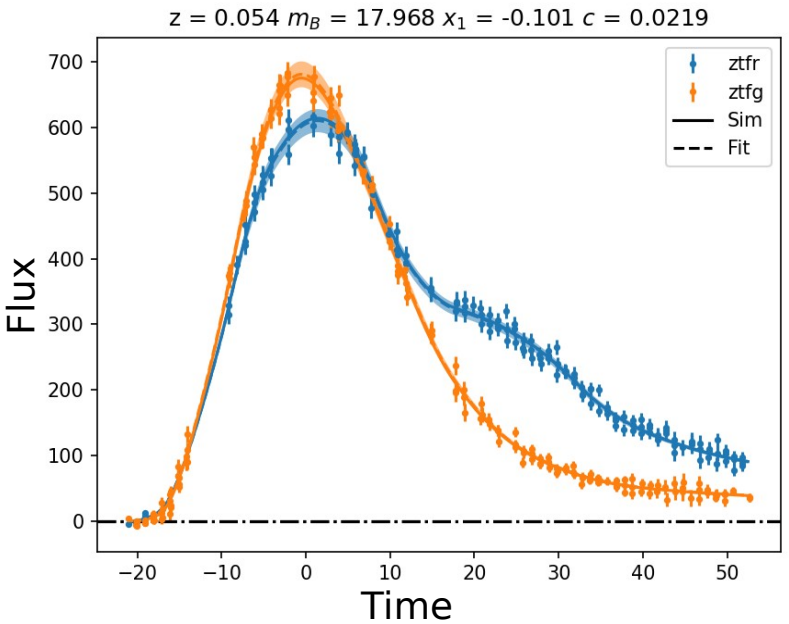
Lightcurves simulation

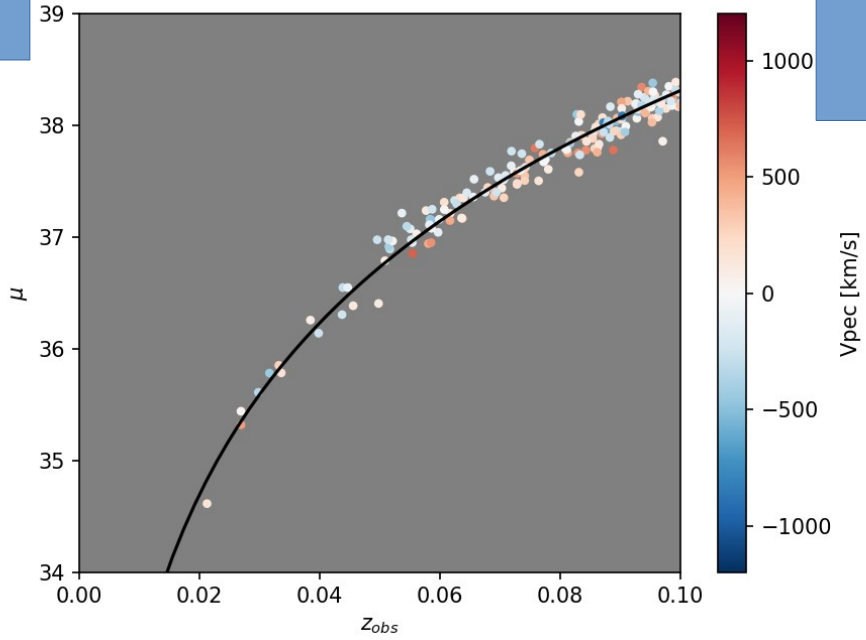
Lightcurves fit

Peculiar velocities measurement with Hubble diagram

Summary statistics of velocities

Growth rate measure

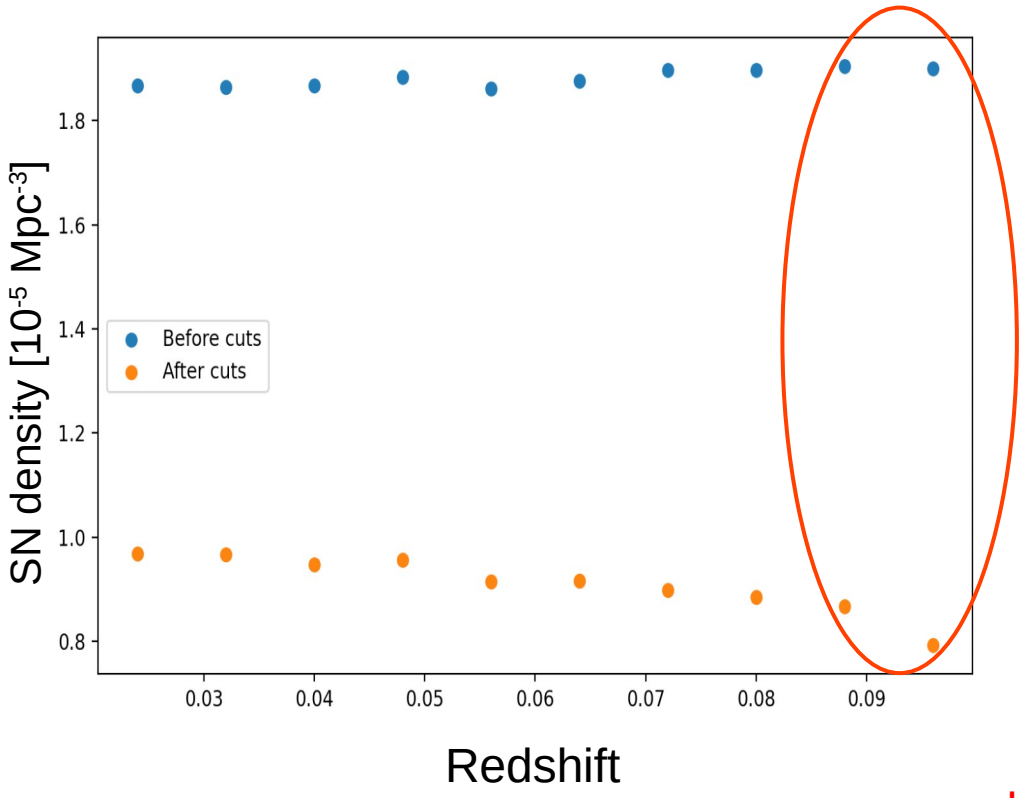


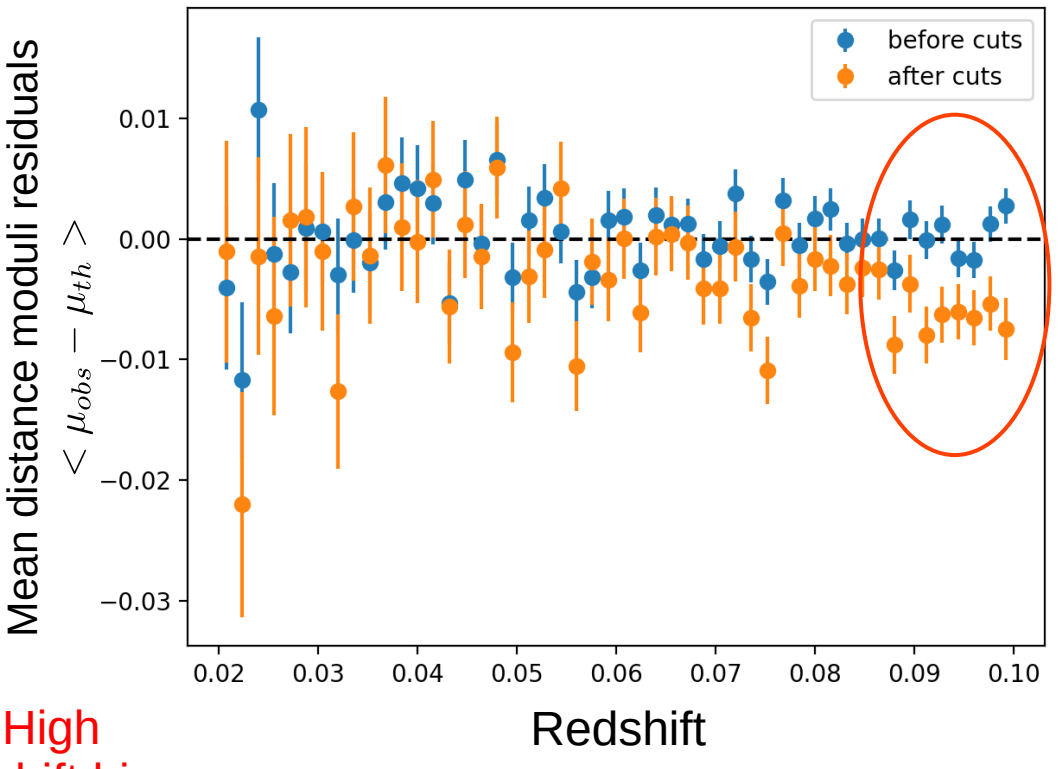


Selection bias (preliminary)

Noise + instrument depth + cadence

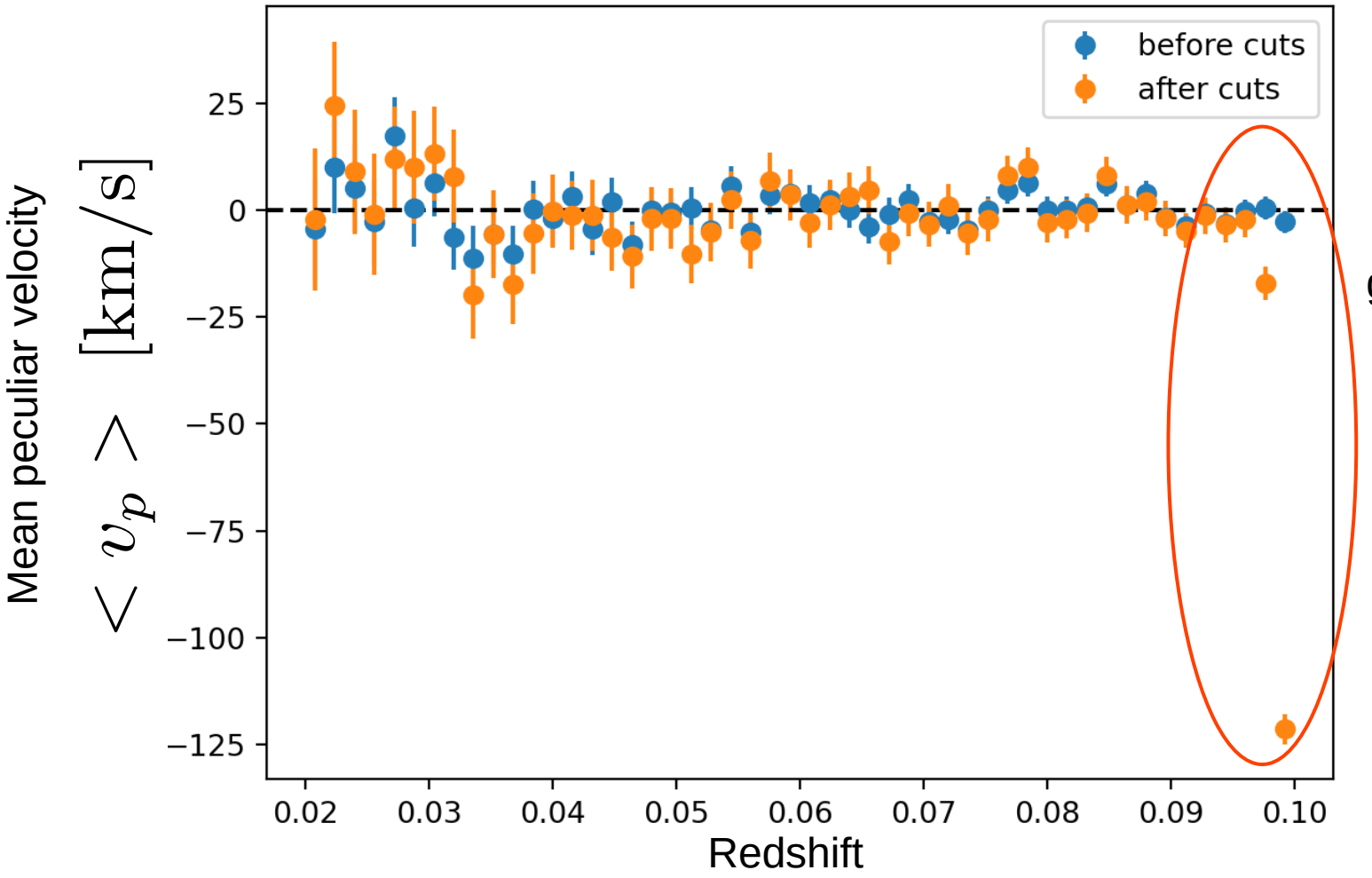
Not all SN can be used for cosmology
→ Apply selection criteria





High redshift bias

Selection bias (preliminary)



Bias for the growth rate ?

From simulation to the growth rate (fσ8)

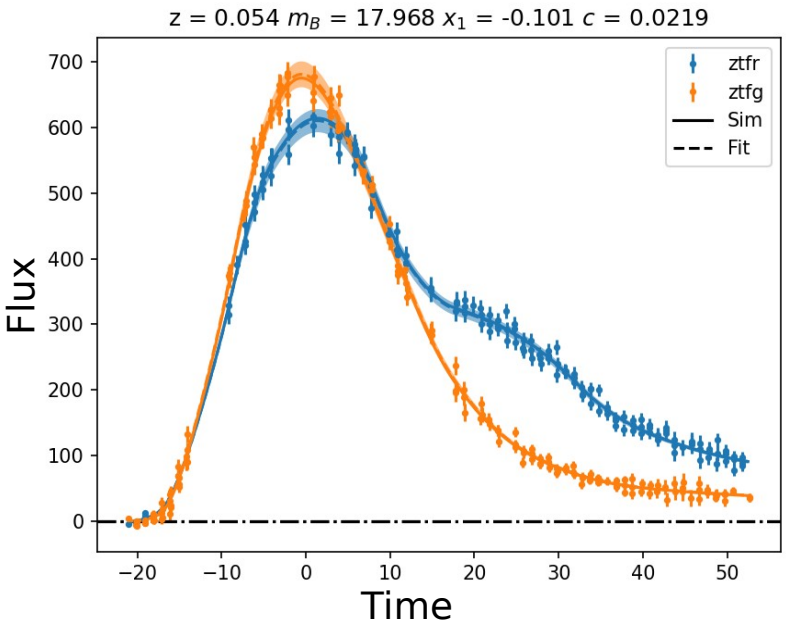
Lightcurves simulation

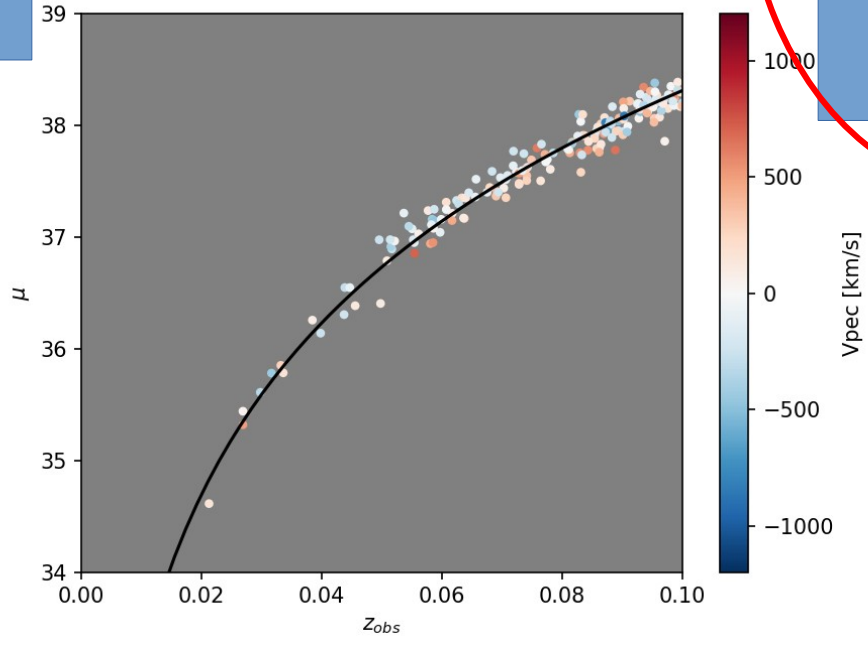
Lightcurves fit

Peculiar velocities estimation with Hubble diagram

Summary statistics of velocities

Growth rate estimation





Growth rate estimation from peculiar velocities

Maximum-likelihood method
(Johnson et al 2014, Howlett et al. 2017c, Adams & Blake 2017, 2020)

One mock realisation
of ~ 6000 halos

$z < 0.1$

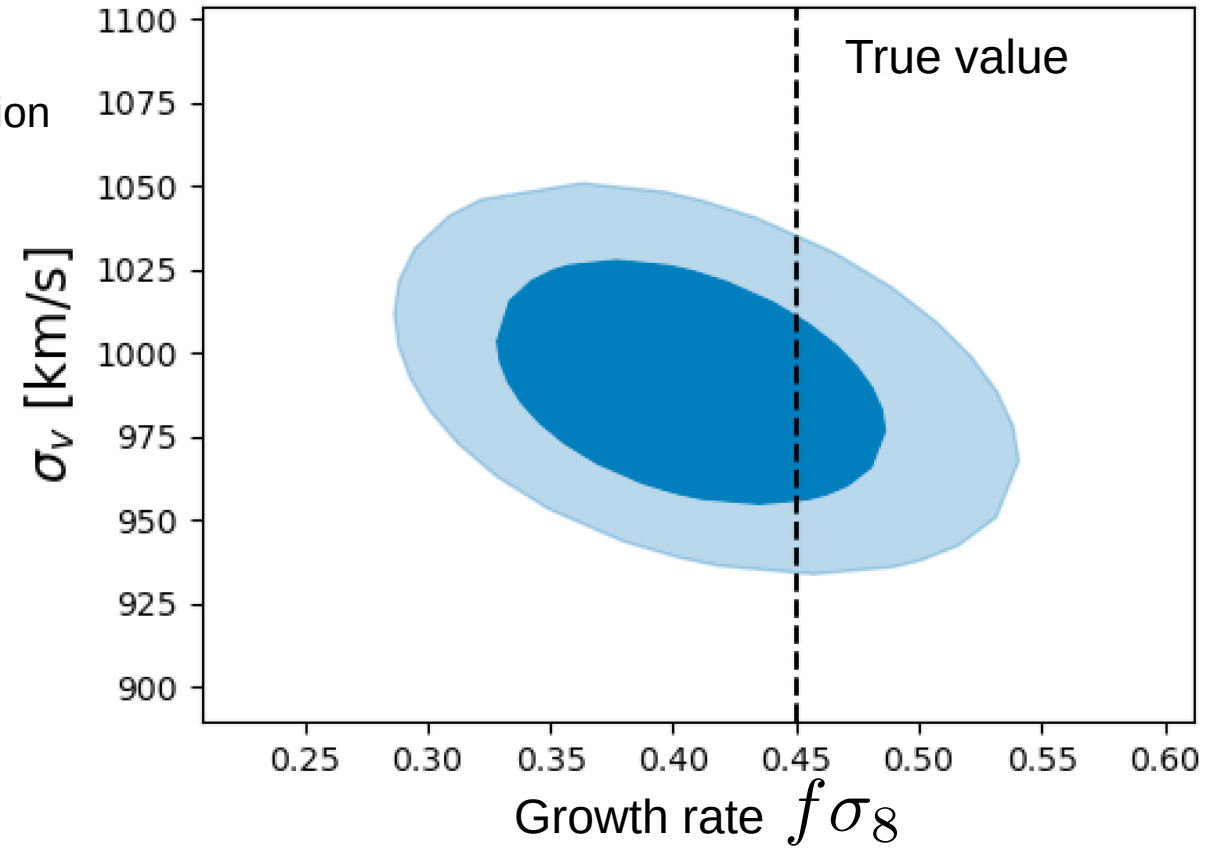


Figure from J. Bautista

Conclusion

- ZTF and Vera Rubin will have large homogeneous sets of type-Ia supernovae for growth-rate measurements
- Simulations are needed to evaluate and correct systematics errors :
  - Observational selection effect
  - Angular instrumentation correlation
  - Velocity bias of host galaxies
  - Non Ia contamination
- Happy to collaborate with you!

Thank you for your attention !