Cosmology with the growth rate of structures using type Ia supernovae

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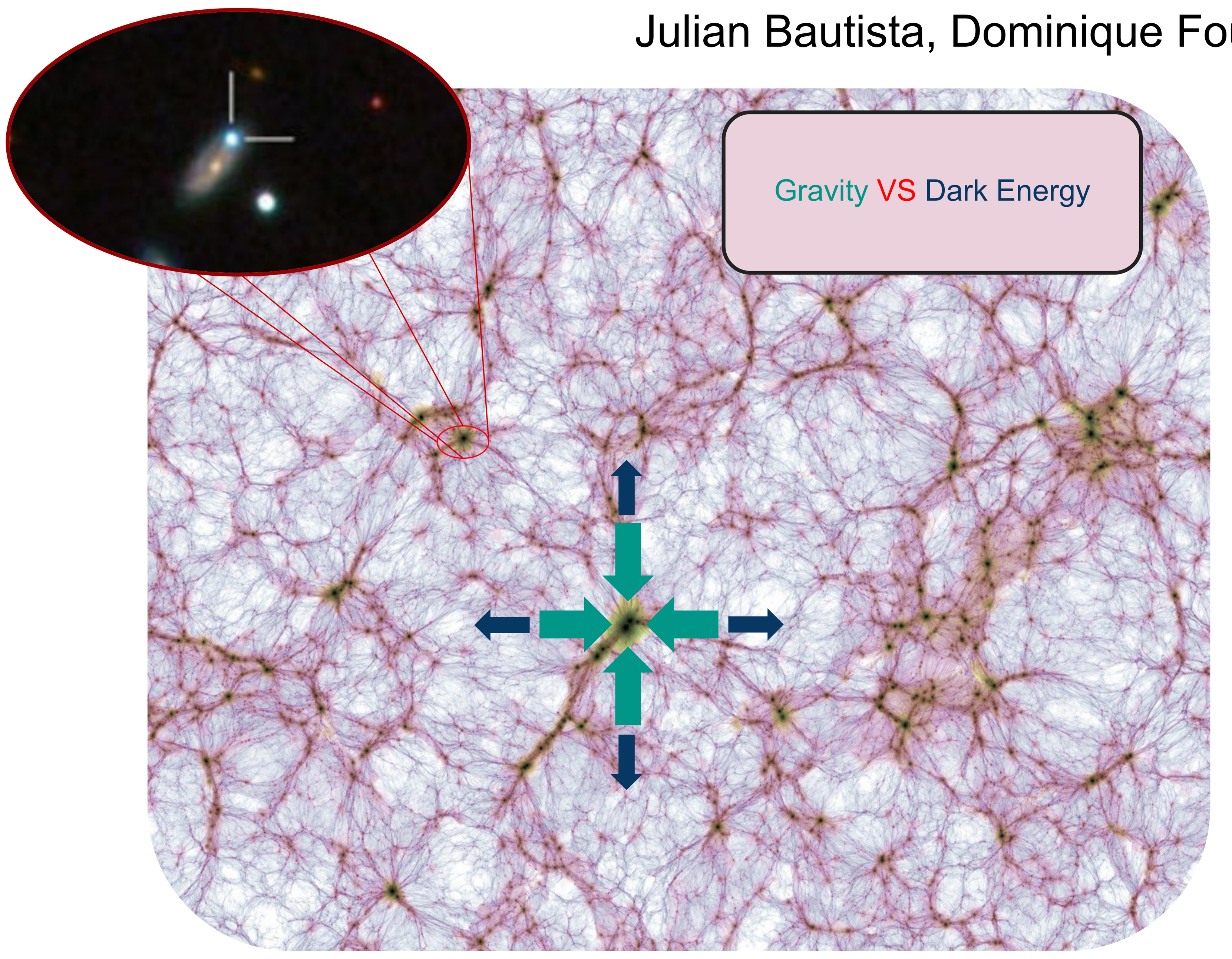


At large scale the Universe looks like a web with matter filaments, clusters and voids. Structure growth is governed by the pull of gravity and the accelerated expansion. Inside these structures there are galaxies and, inside these galaxies supernovae (sometimes) appear.

What is the growth rate?

Cosmological information can be retrieved by studying large scale structures, in particular inhomogeneities in matter density. To quantify these inhomogeneities we measure the deviation to the mean :

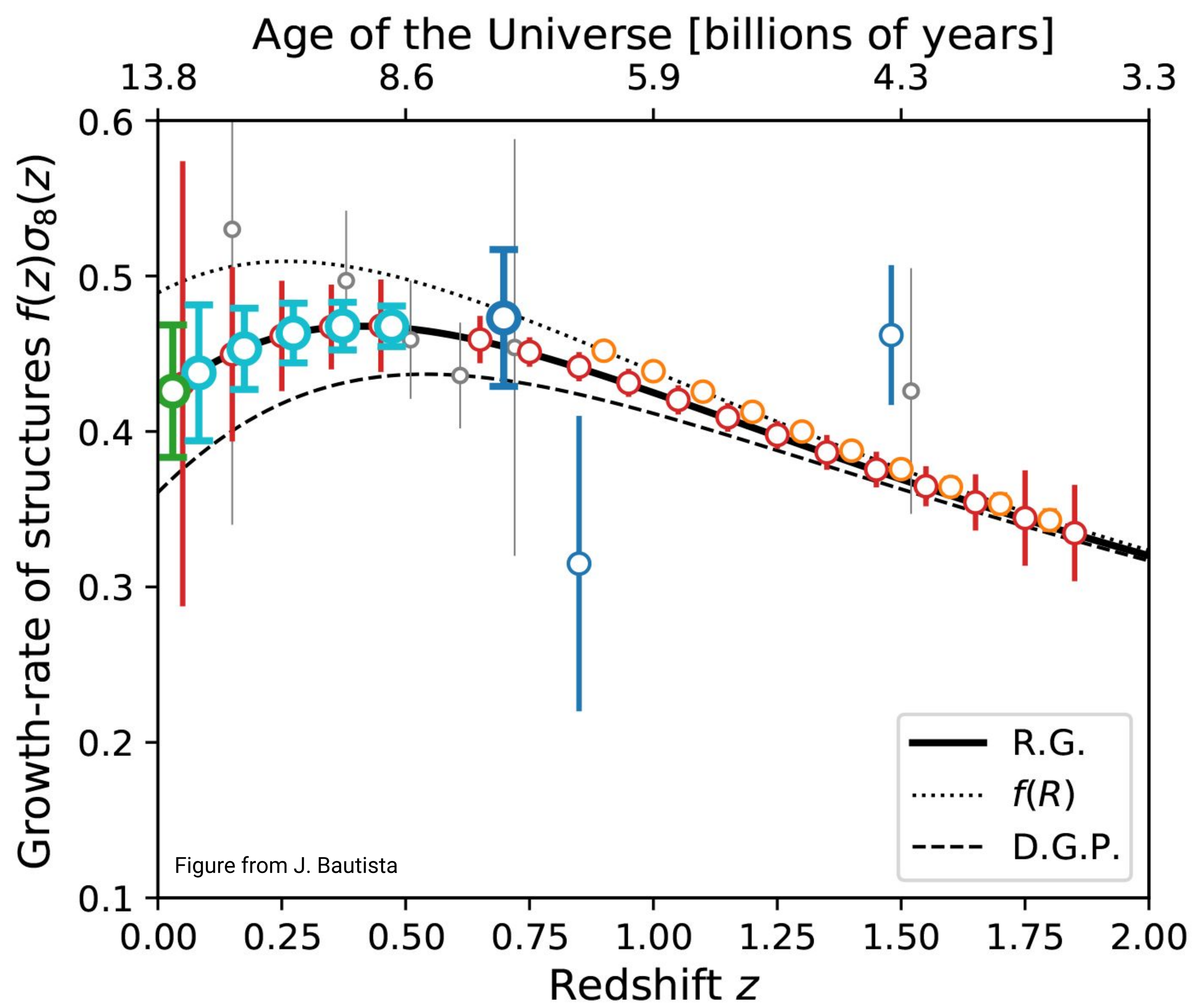
$$\delta(\mathbf{x}, t) = \frac{\Delta\rho(\mathbf{x}, t)}{\bar{\rho}(t)} = \tilde{\delta}(\mathbf{x})D(t)$$

where D(t) is the **growth factor**.

The **growth rate** of structures, f, is the logarithmic derivative of the growth factor with respect to the **scale factor *a***.

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

Velocity fields are governed by the growth rate, and are thus great probes of Gravity and Dark Energy.



Forecast on the growth of structure parameter with new generation of surveys:
Galaxy surveys alone (RSD) : DESI and Euclid
SN Ia surveys : ZTF and LSST
Solid line is a prediction from General Relativity, dashed lines are alternative models of gravity

Type Ia Supernovae as new growth rate probes

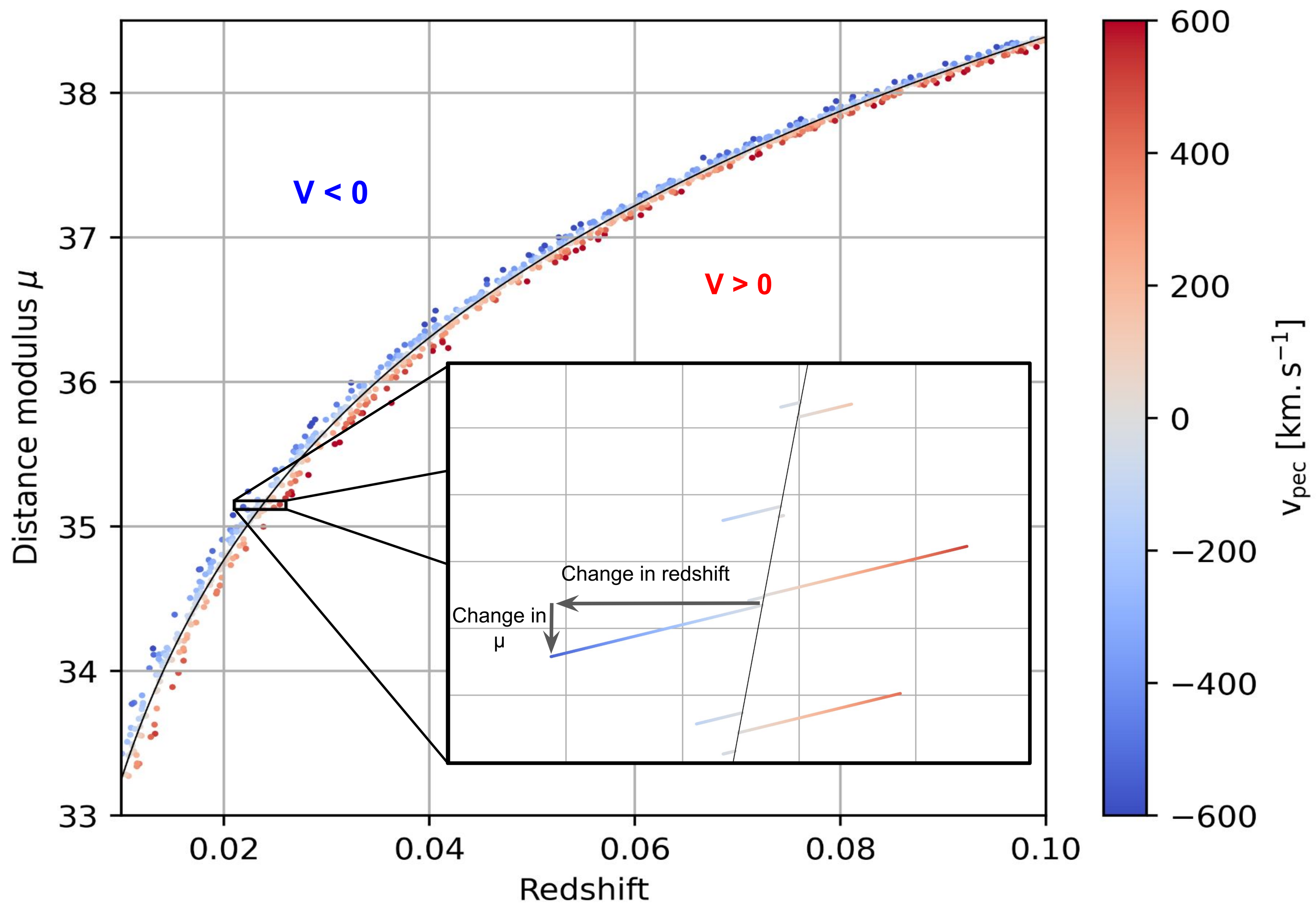
Until now, **growth of structure** has been measured using galaxy surveys:

- indirectly with the redshift space distortion (RSD) effect.
- directly using galaxy distance and redshift measurements, from which we can infer their velocity.

The first method is limited by statistics at low redshift and the second one by lack of distance precision.

With the next generation of survey as the **Zwicky Transient Facility** (ZTF) or the **Legacy Survey of Space and Time** (LSST) will provide several orders of magnitude more SN Ia than the present sample.

SNIa are standard candles. This allows the precise measurement of their distance. Combined with redshifts from spectroscopic galaxy surveys, they are competitive for a direct measurement of the **growth rate.**



Host galaxy peculiar velocities measured from SNIa

We measure the peculiar velocities by using their contribution to the **Hubble diagram residuals**.

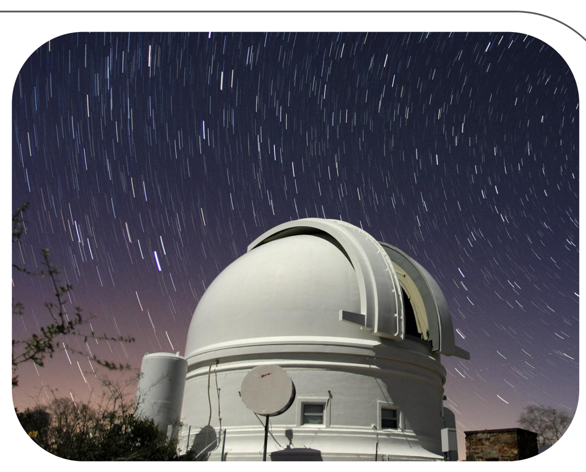
Peculiar velocities (~300 km/s) have two effects on the SN Ia Hubble diagram :

- **Change in redshift** (Δz~0.001) due to Doppler effect.
- **Modification of the apparent distance modulus** (Δμ ~ 0.004 mag) due to relativistic beaming.

The analysis pipeline

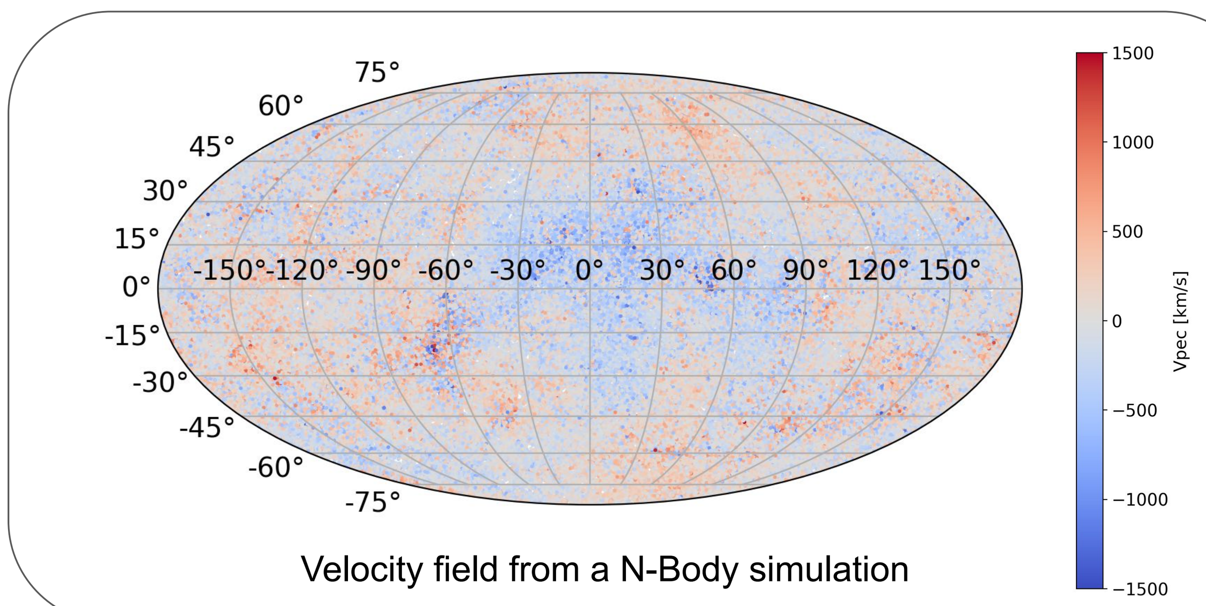
We develop the **SNsim** code to simulate supernovae with peculiar velocities. The diagram represents the pipeline from simulations to growth rate measurement. We currently work with ZTF data to prepare for the analysis.

The Vera Rubin Observatory (Chile) will start LSST in 2023. Picture from *lsst.org*

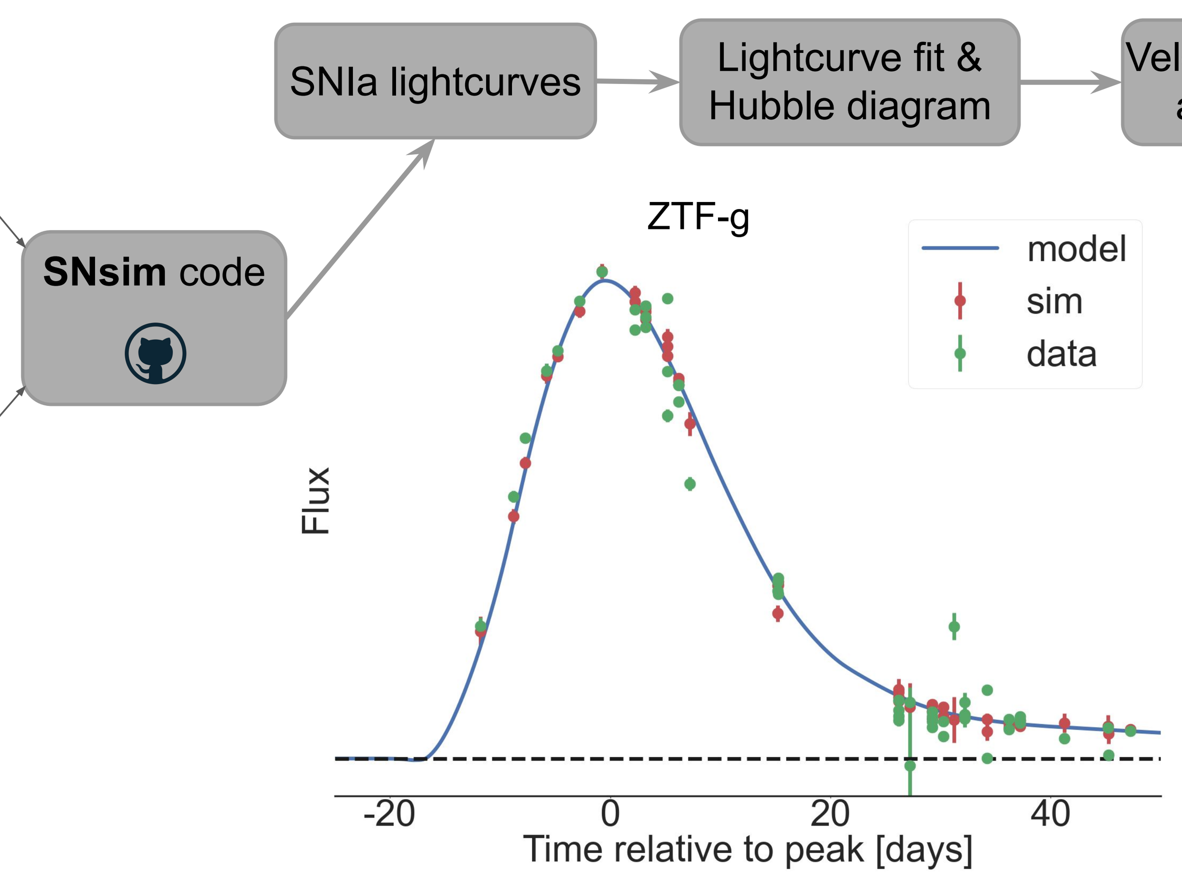


ZTF (California) running since 2018. Picture from *caltech.edu*

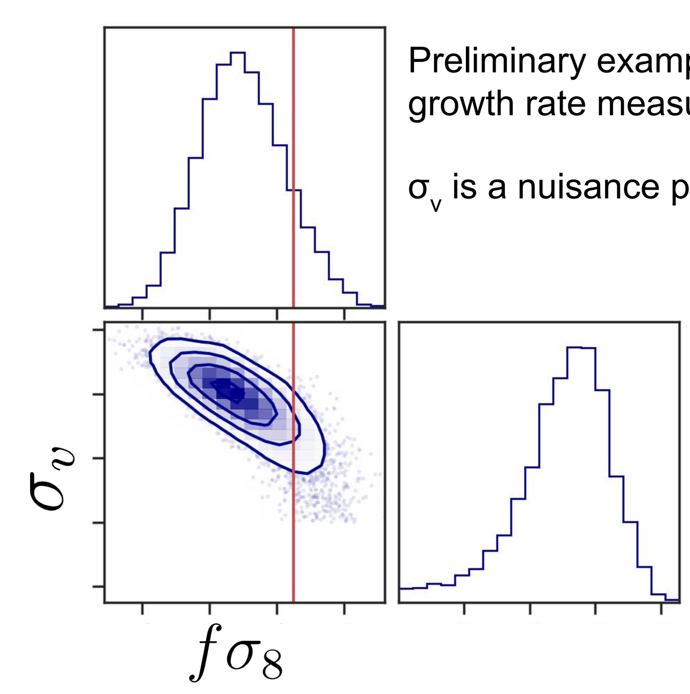
Observations and instrumental characteristics



Velocity field from a N-Body simulation



Example of a ZTF-g band SNIa lightcurve comparison data - simulation



Preliminary example of growth rate measurement :
σ_v is a nuisance parameter

https://github.com/bcarreres/snsim