Growth-rate measurements with DESI galaxies and ZTF supernovae

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Centre de Physique des Particules de Marseille

Plan

Why growth-rate measurements at low-redshift?

How to measure growth-rate with galaxies and peculiar velocities?

What data DESI and ZTF are providing us?

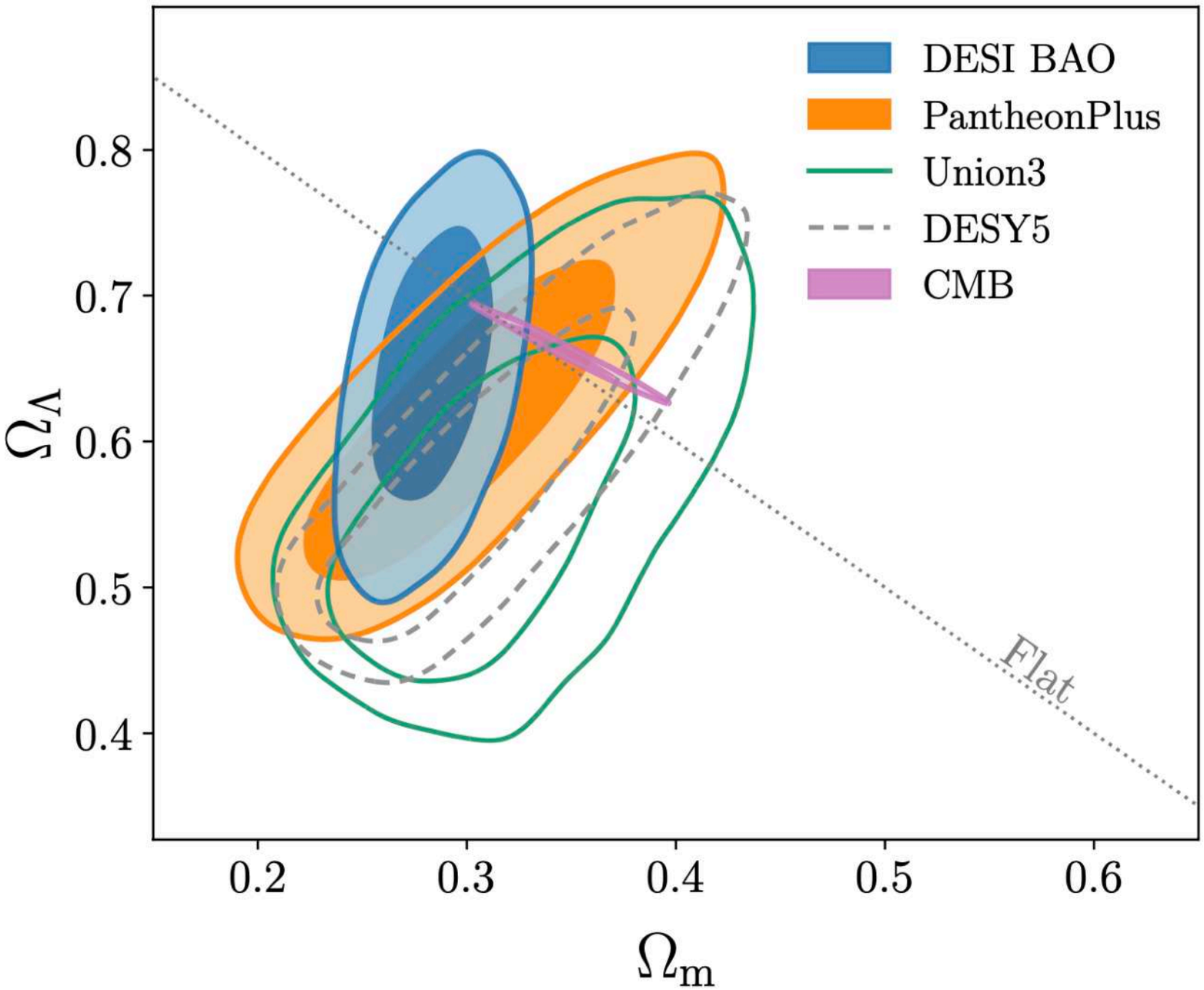
ZTF simulations

Growth-rate estimates with peculiar velocities from supernovae

Why growth-rate measurements at low-redshift?

Universe's expansion is **accelerating** as seen by SN + BAO + CMB

Dark energy as a cosmological constant Λ



DESI Collaboration 2024

Acceleration requires dark energy

Physically motivated theory ? Alternatives or extensions of General Relativity

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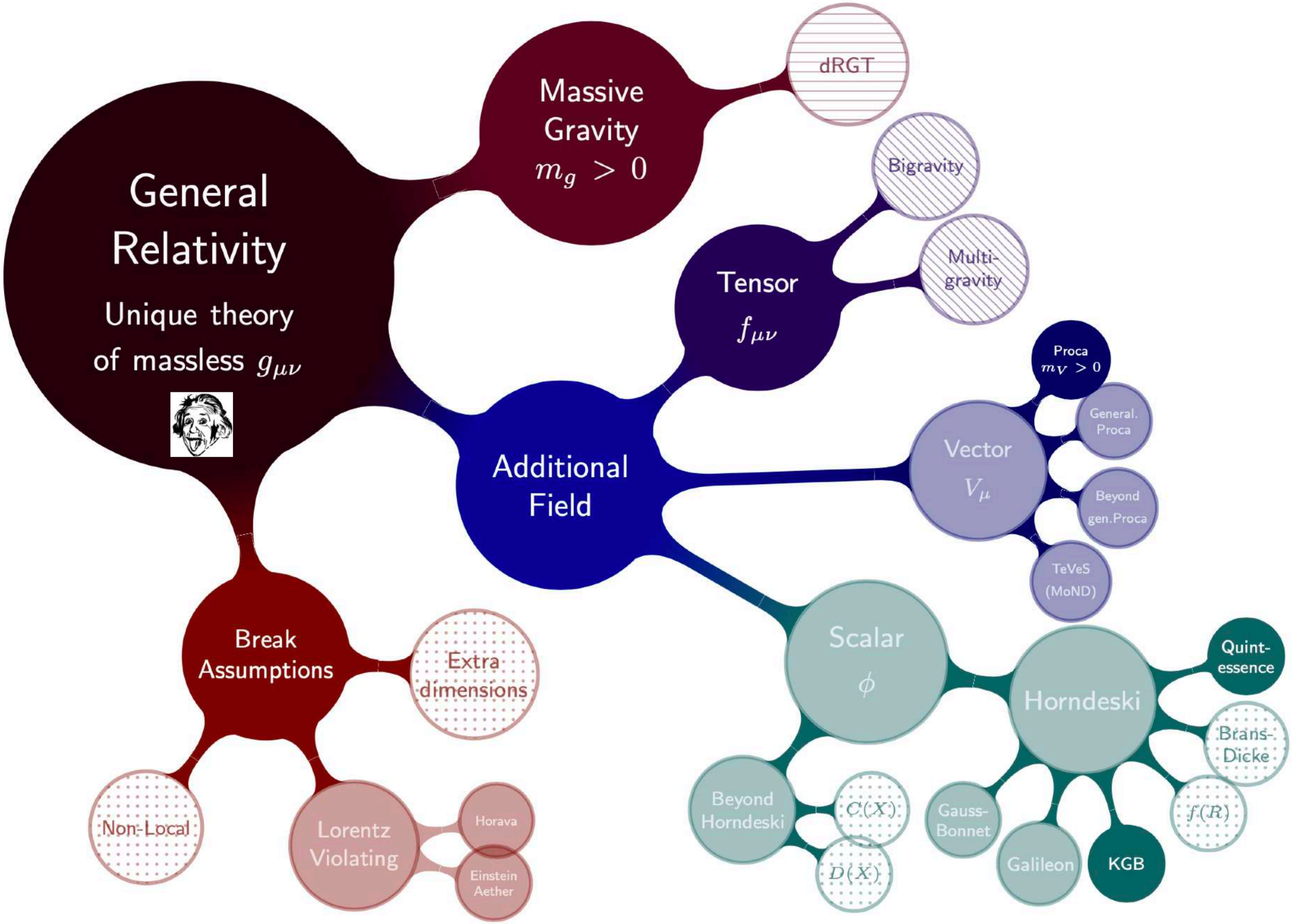
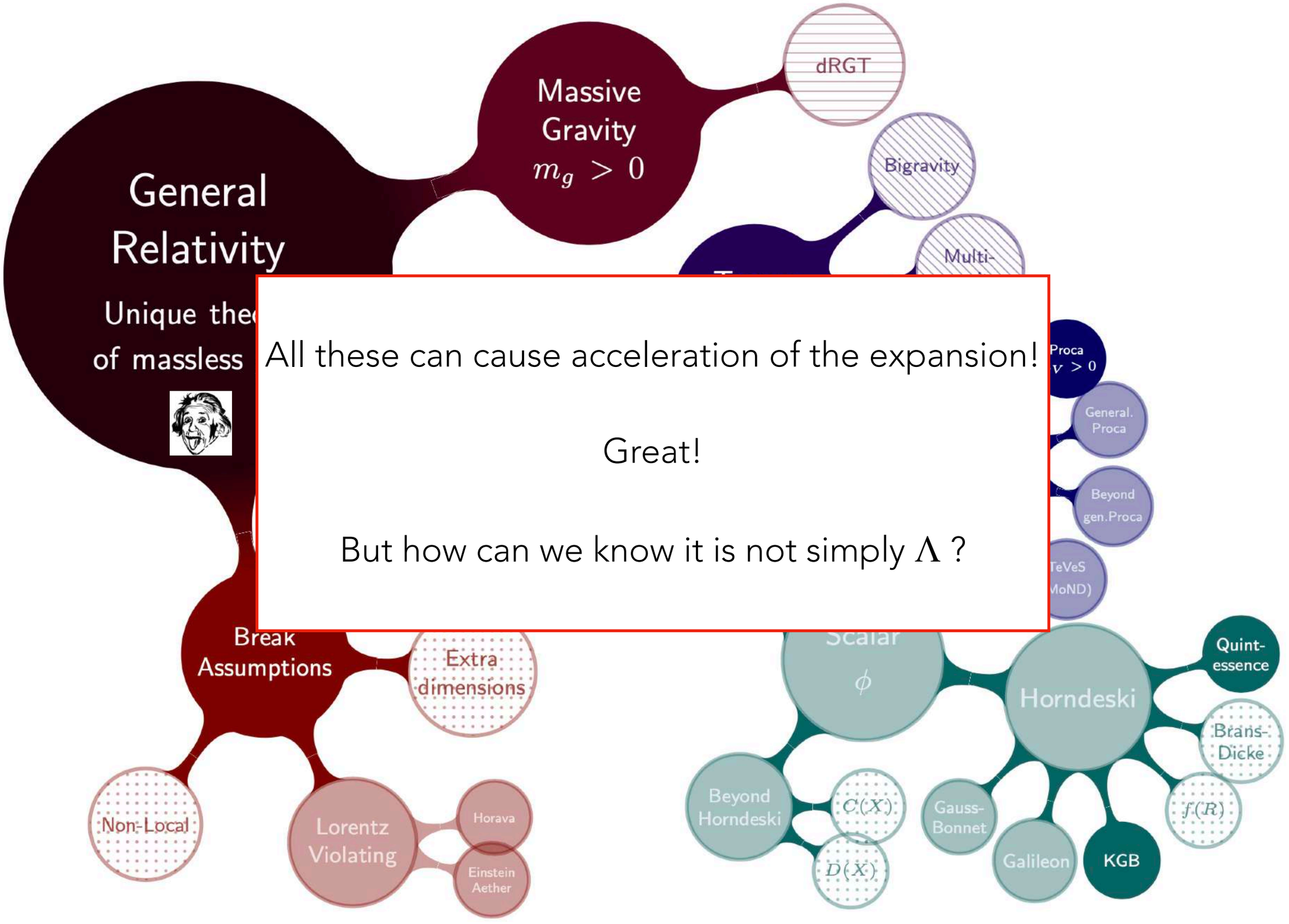


Review by Ezquiaga & Zumalacárregui 2018

Physically motivated theory ? Alternatives or extensions of General Relativity



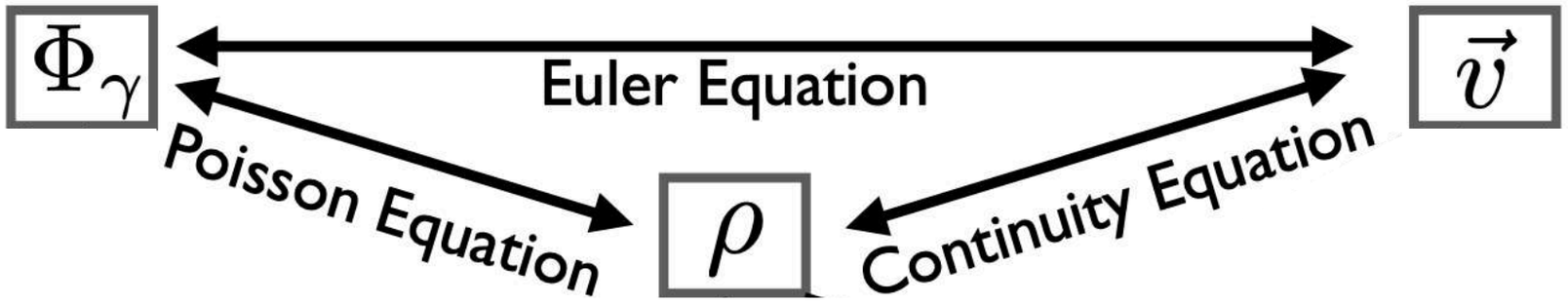
All these can cause acceleration of the expansion!

Great!

But how can we know it is not simply Λ ?

Review by Ezquiaga & Zumalacárregui 2018

Effect of modified gravity on perturbations



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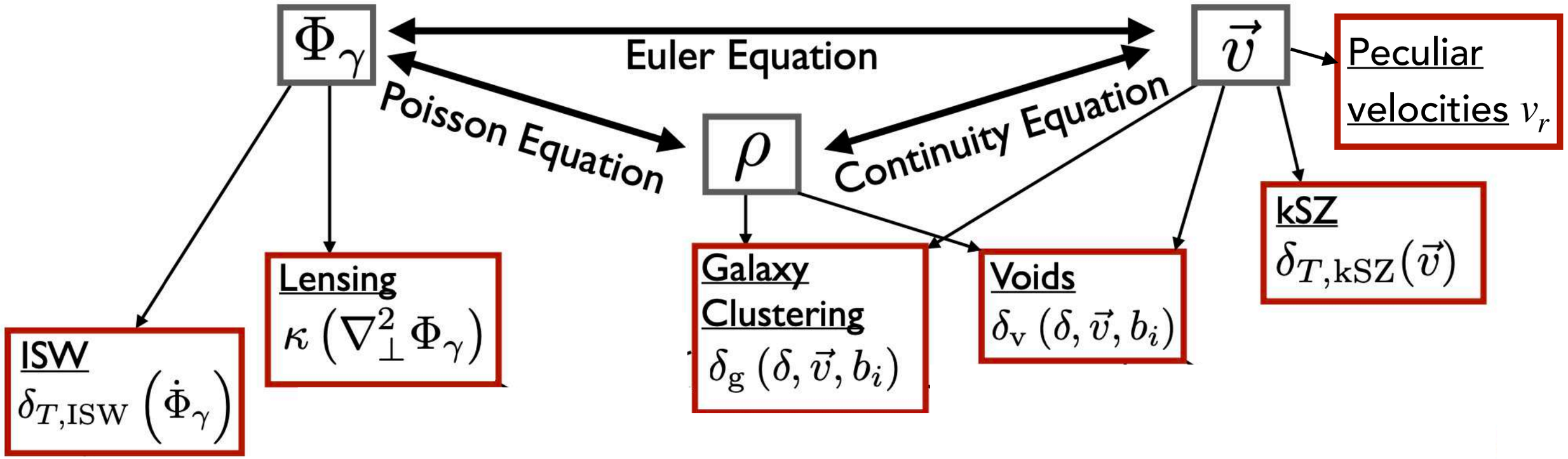

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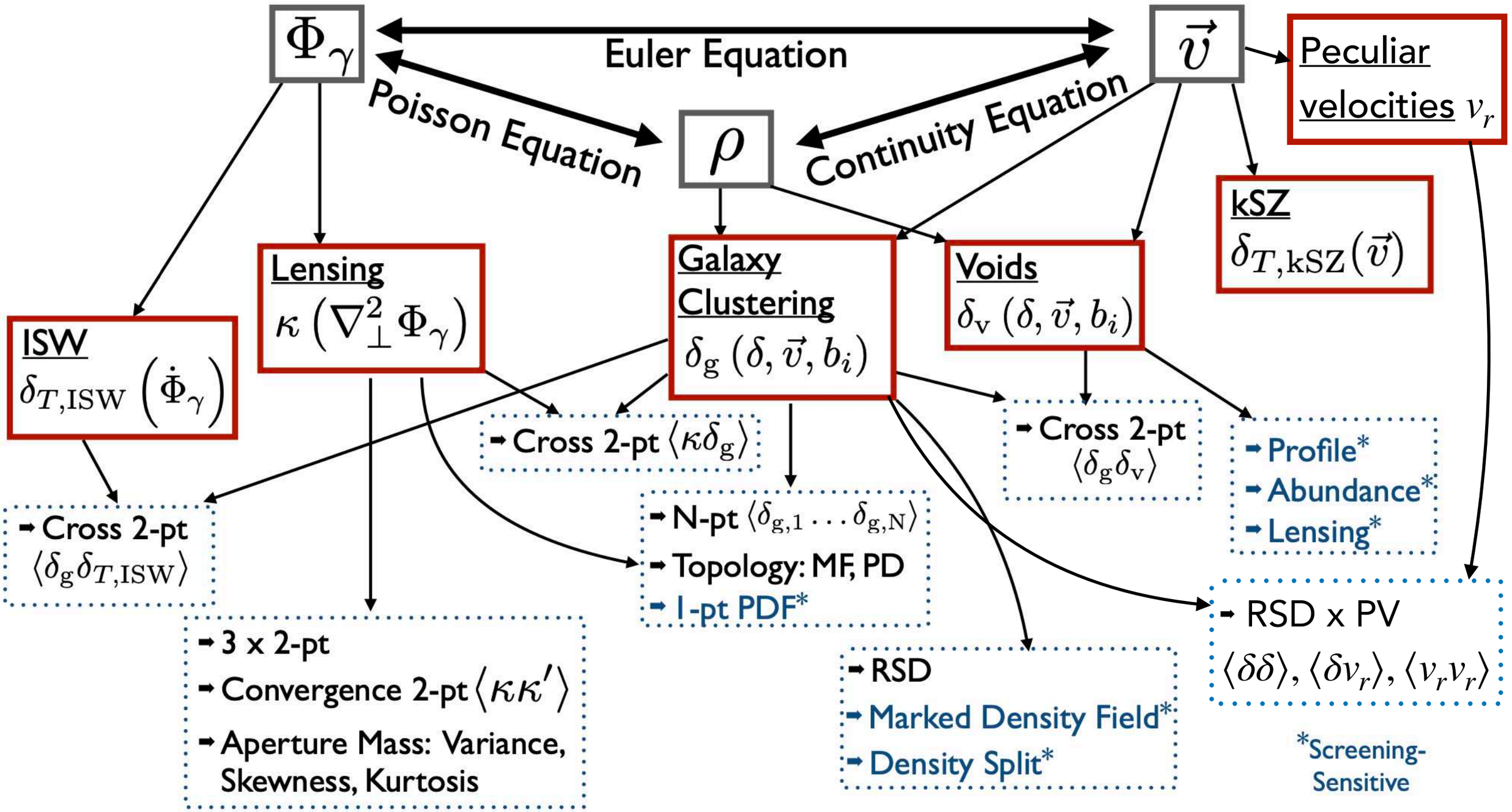

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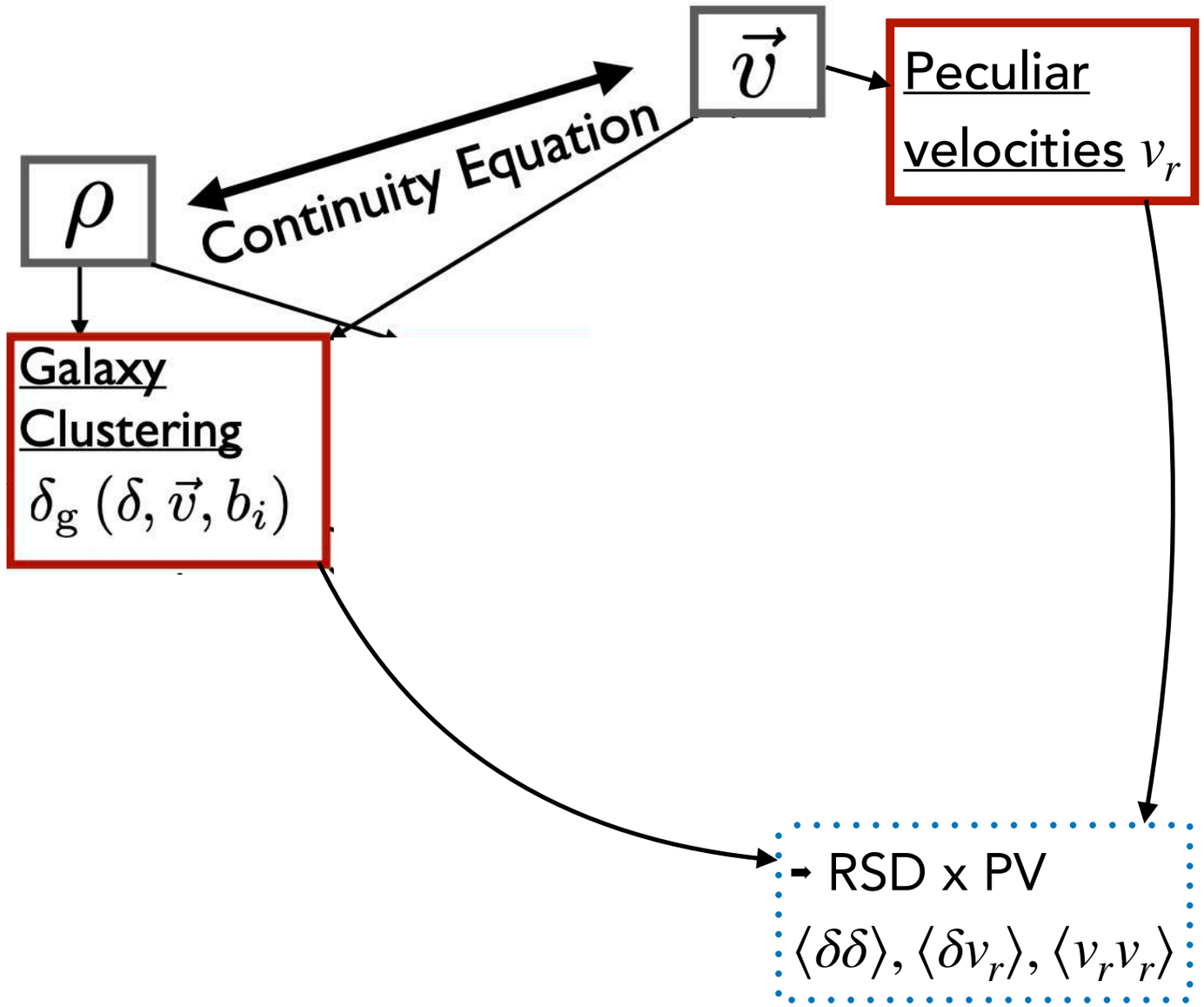

Review by Hou, JB et al 2023

Redshift-space distortions (RSD)

... we measure **redshifts**

Distances in cosmology: $D_x(z) \approx \int_0^z \frac{1}{H(z')} dz'$

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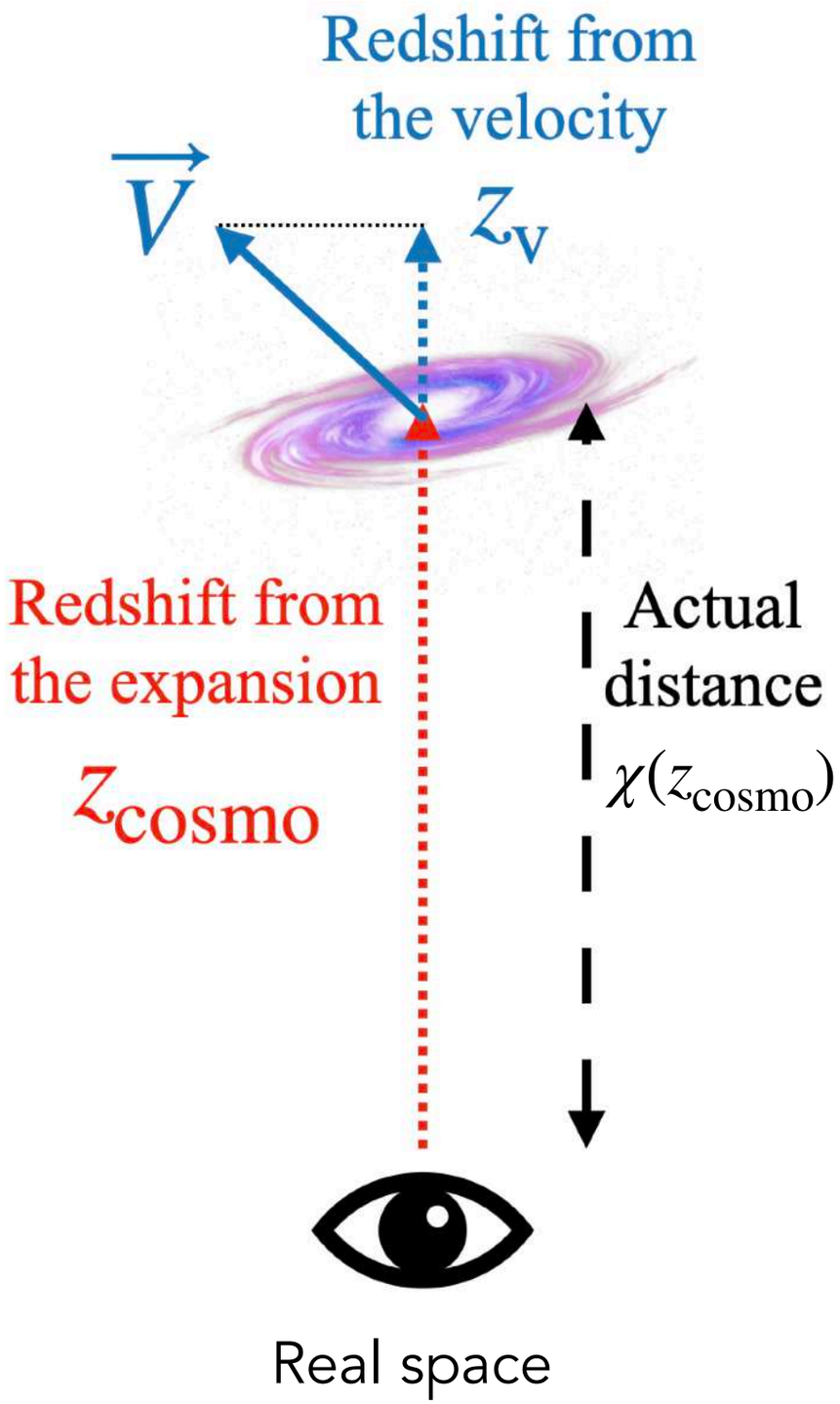

Real space

Redshift-space distortions (RSD)

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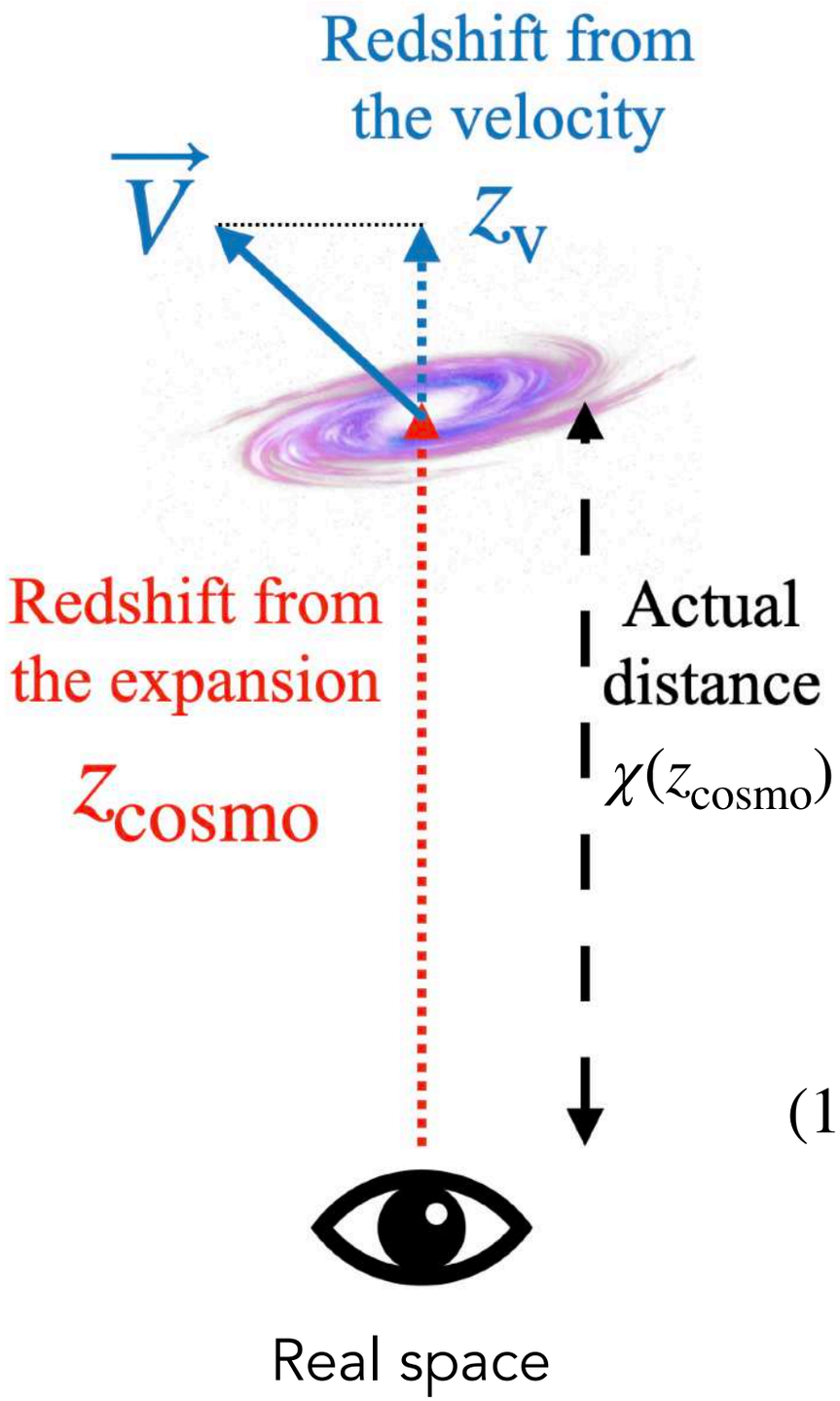

Observed redshift is :

$$(1 + z_{obs}) = (1 + z_{cosmo})(1 + z_v)$$

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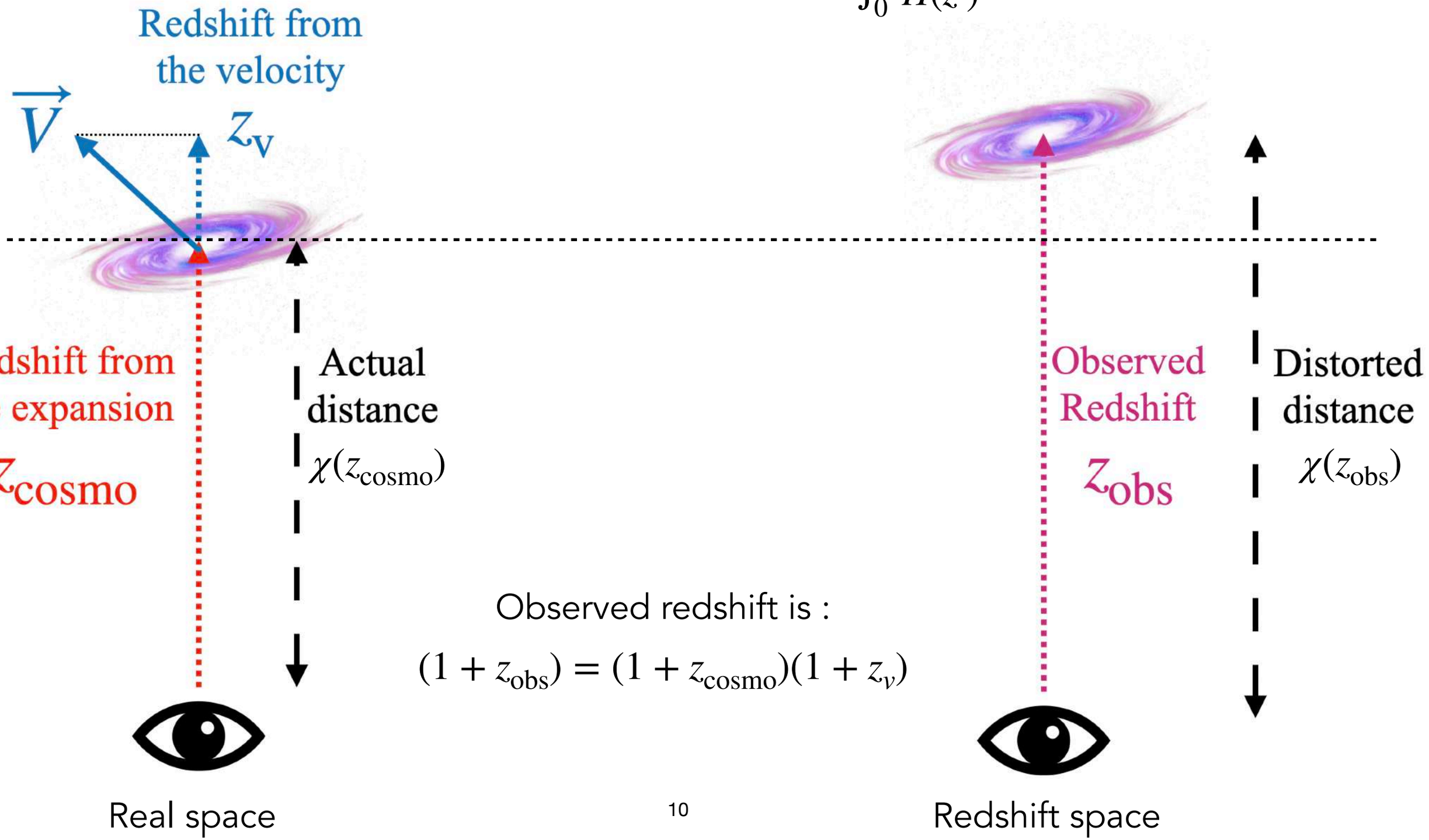

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Real space

Redshift space

Redshift-space distortions

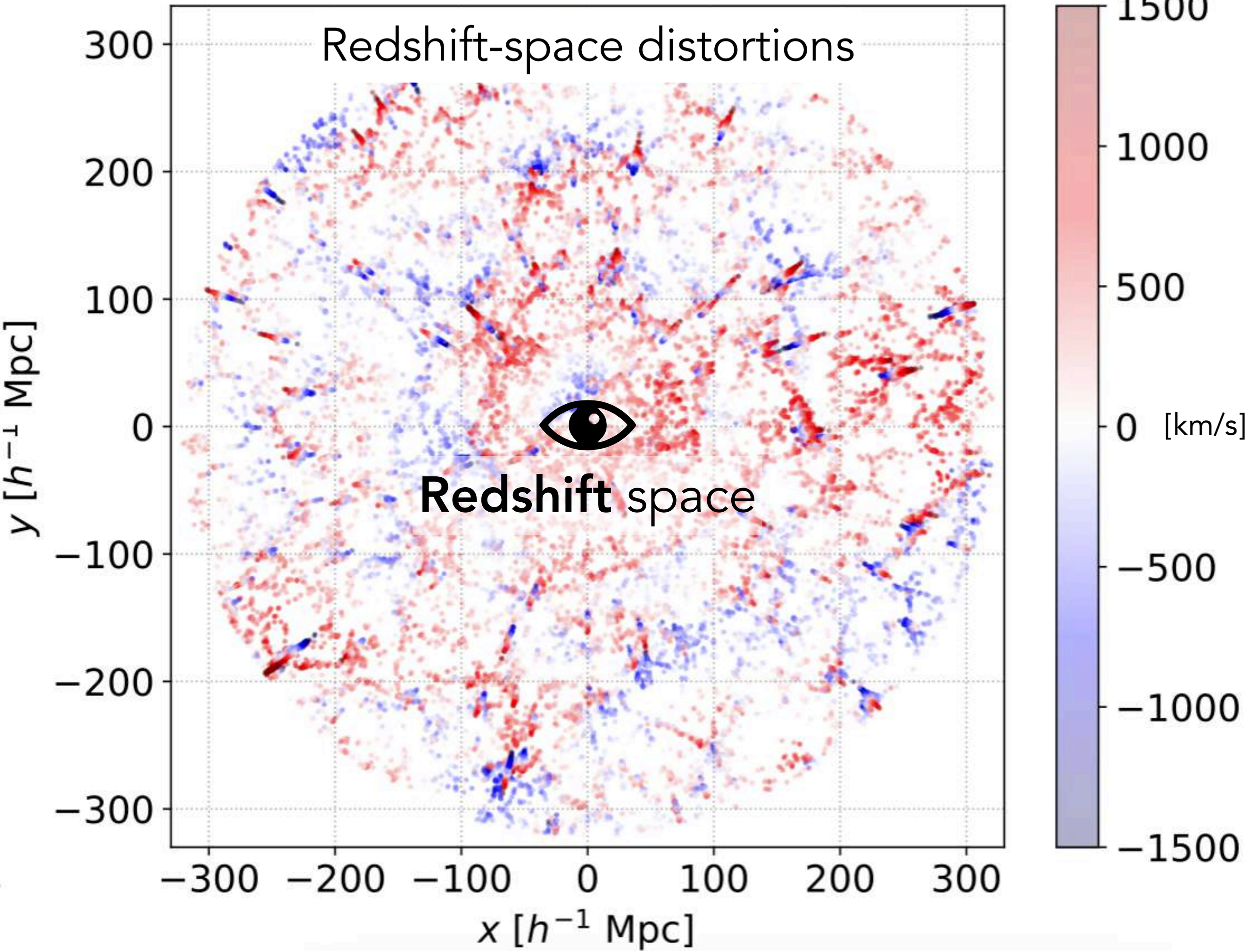
Real space

$x\ [h^{-1}\ \mathrm{Mpc}]$

$y\ [h^{-1}\ \mathrm{Mpc}]$

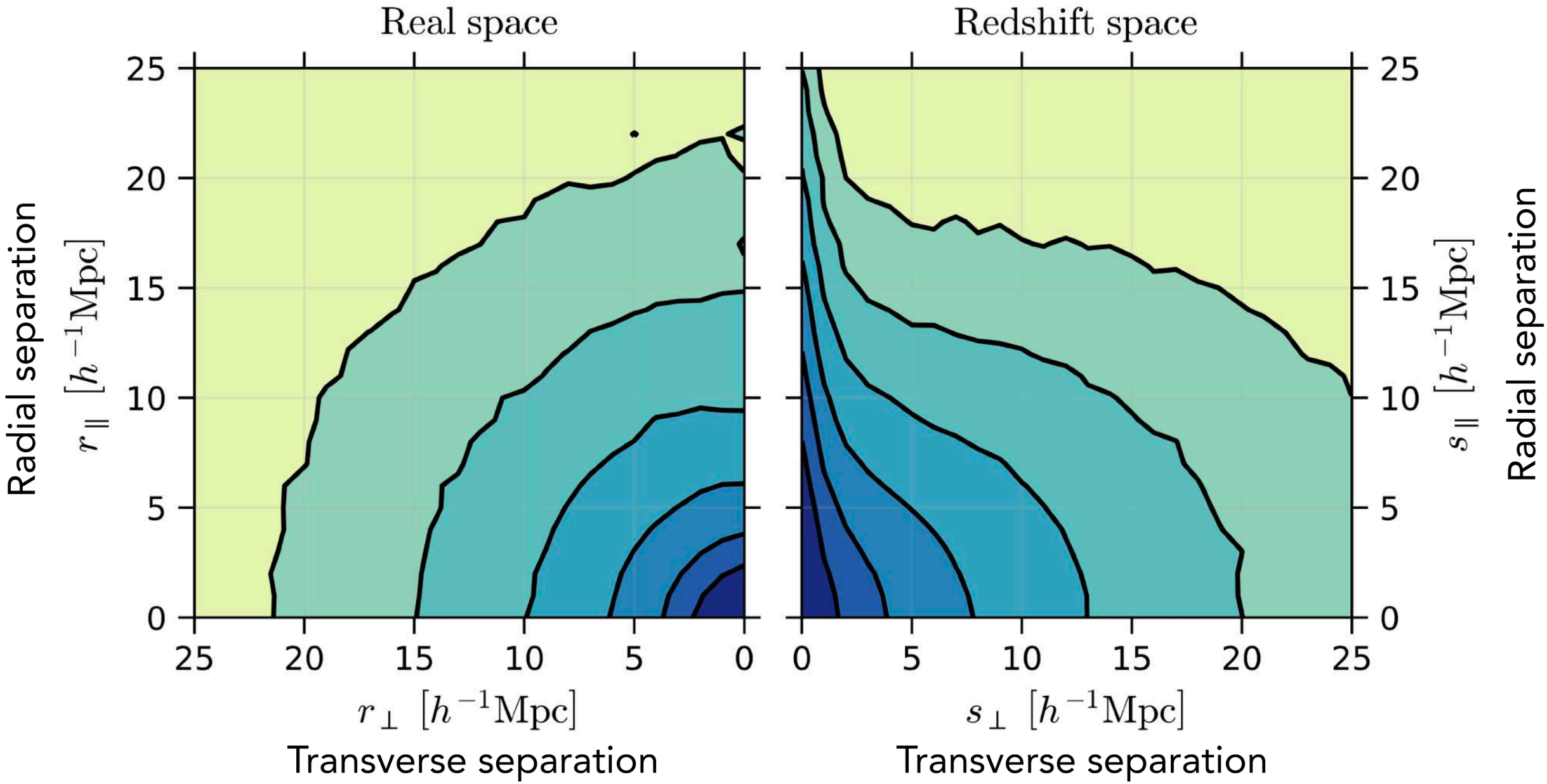
[km/s]

Redshift-space distortions



Redshift-space distortions (RSD)

Correlation function $\xi(\vec{r}) \equiv \langle \delta(\vec{x})\delta(\vec{x}+\vec{r}) \rangle = \xi(r_\parallel, r_\perp)$



Simulation by Kuruvilla & Porciani 2018

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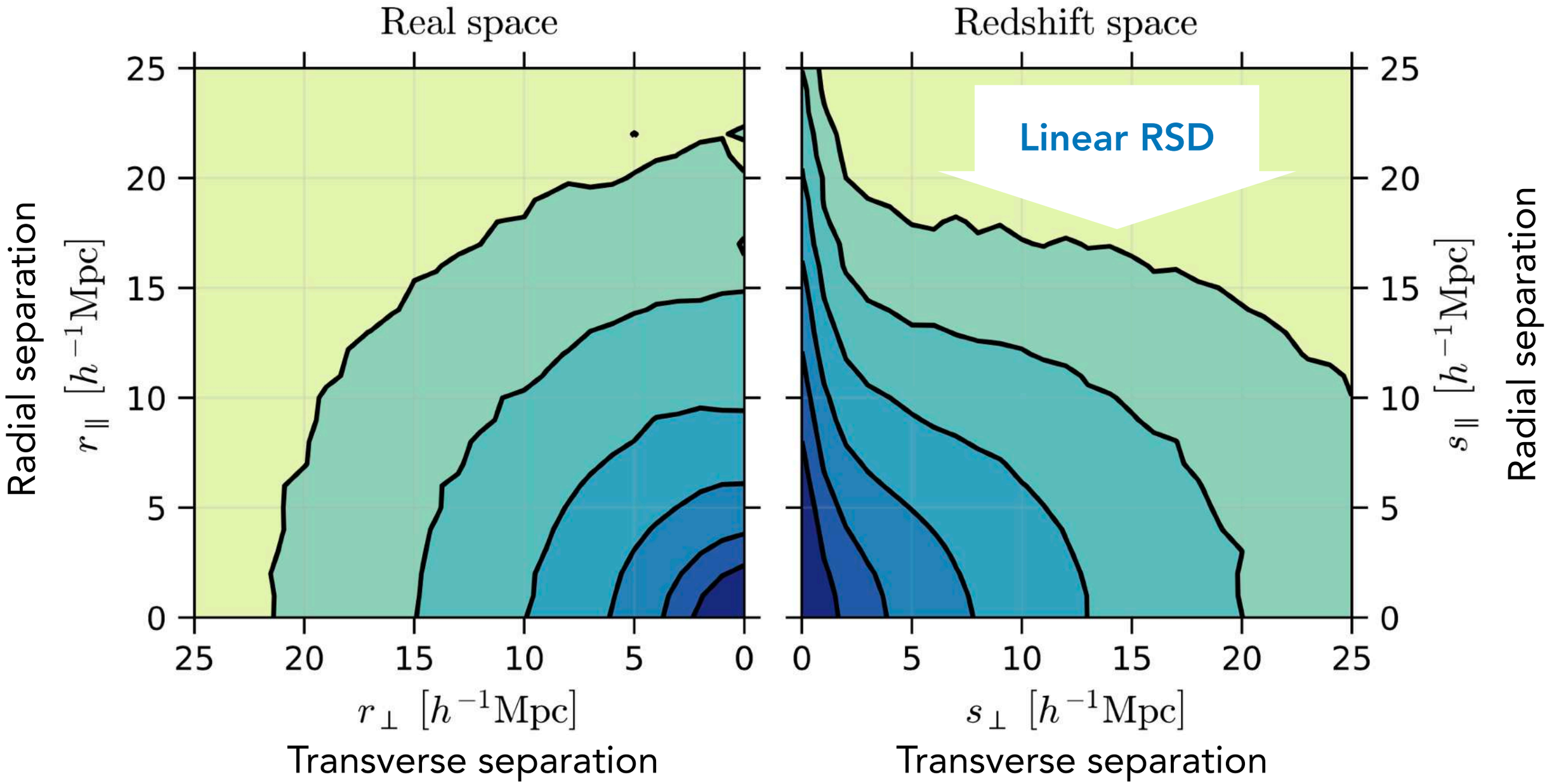

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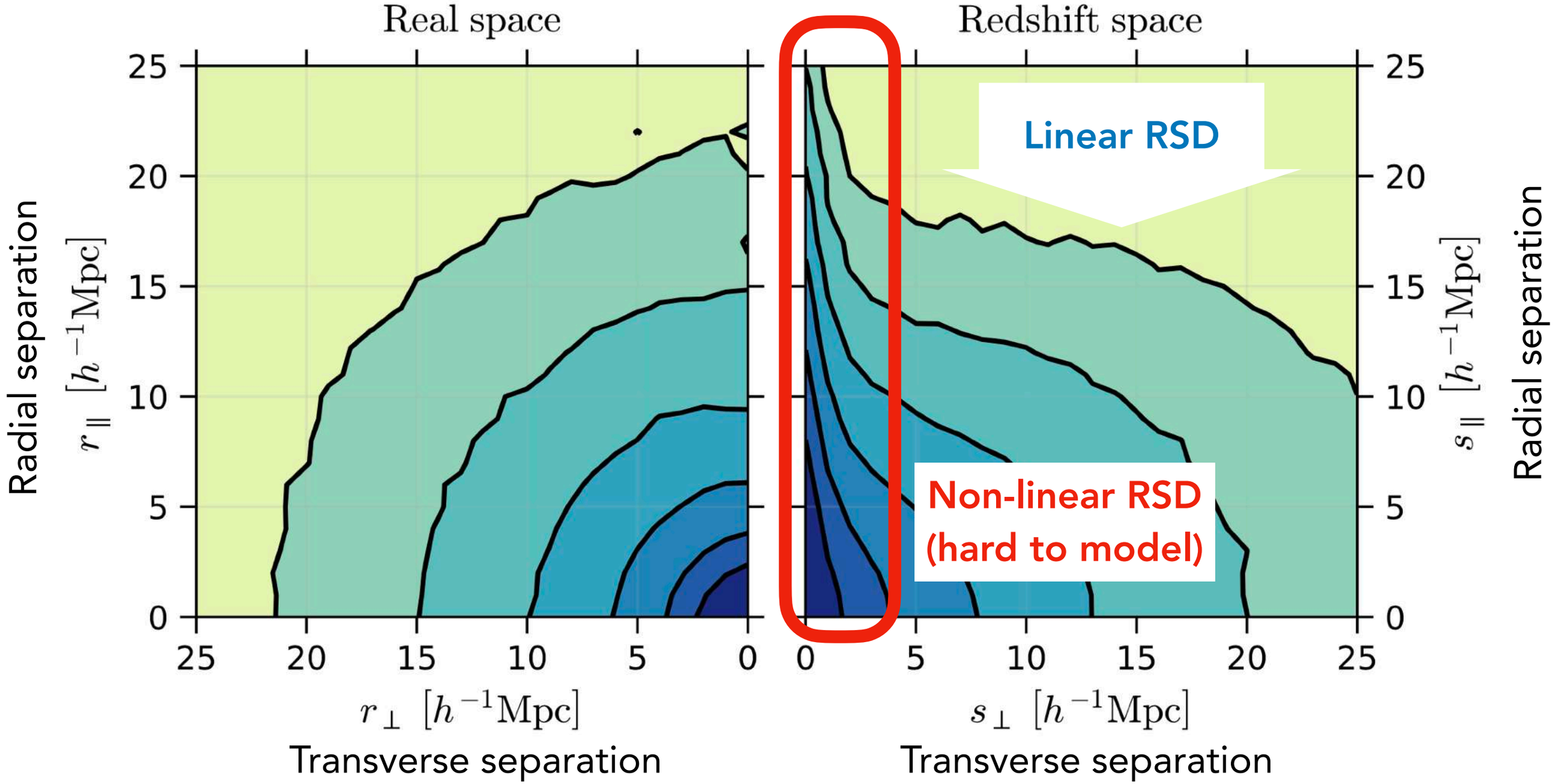

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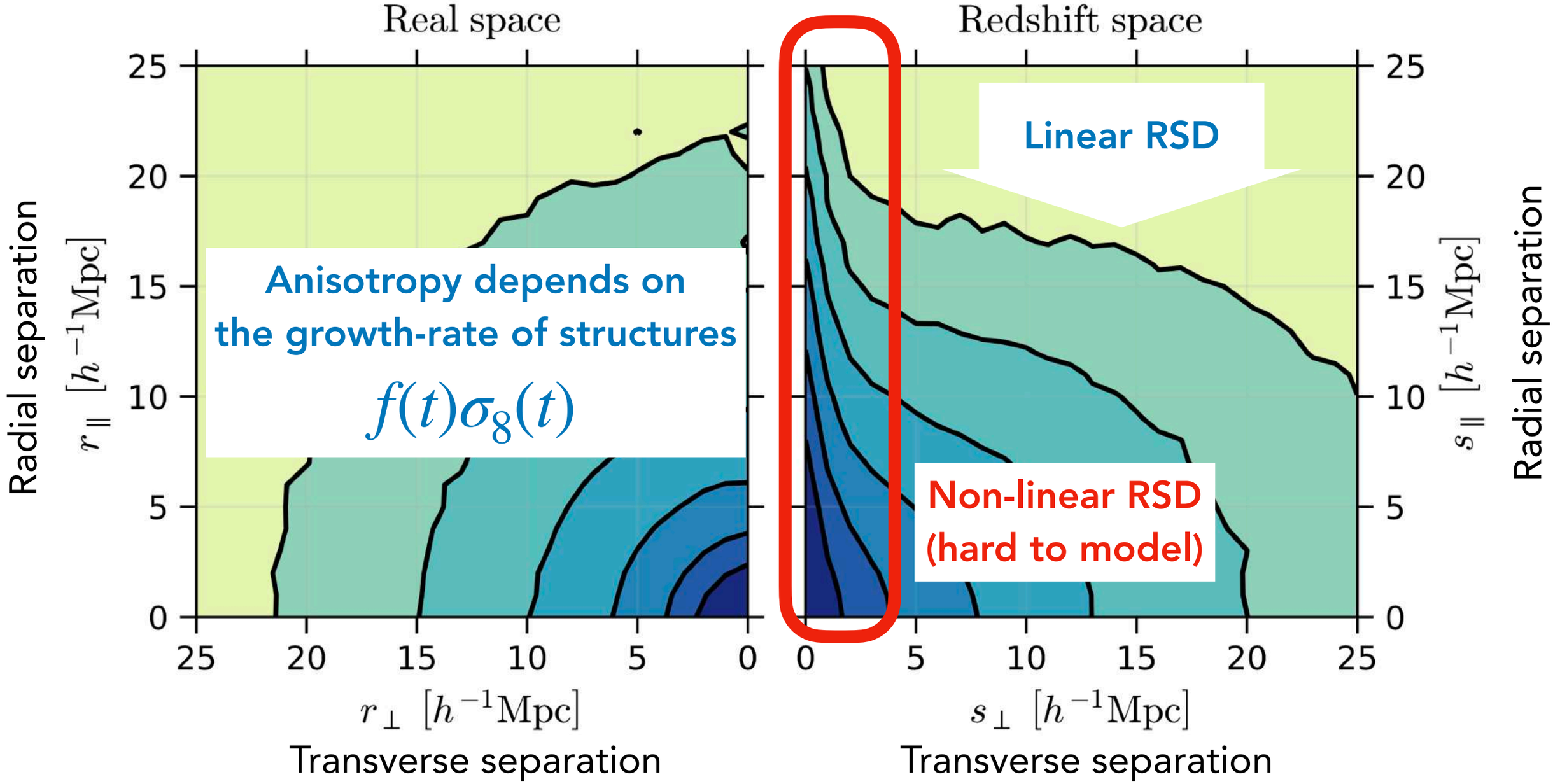

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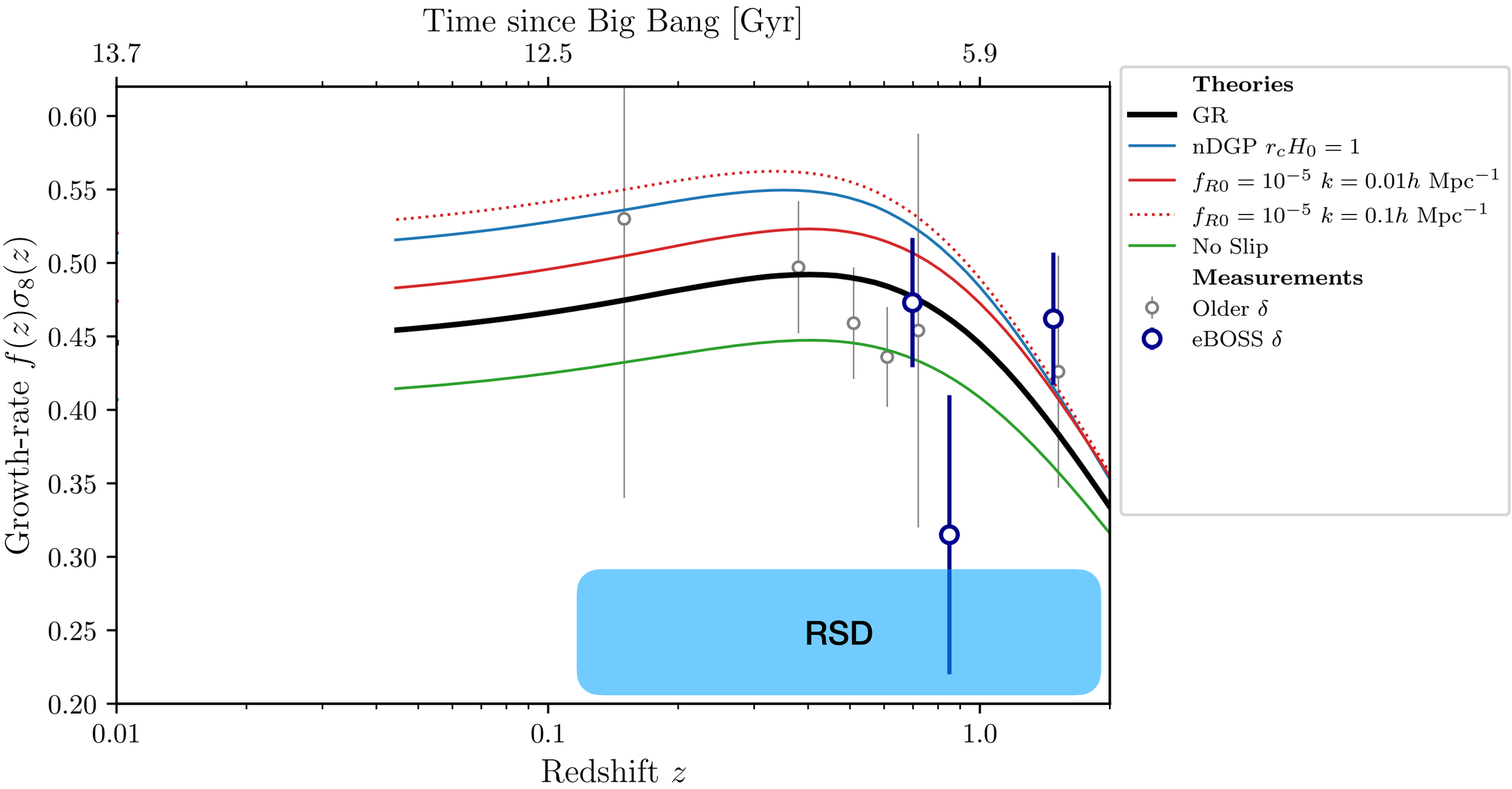
Measurements of growth-rate of structures



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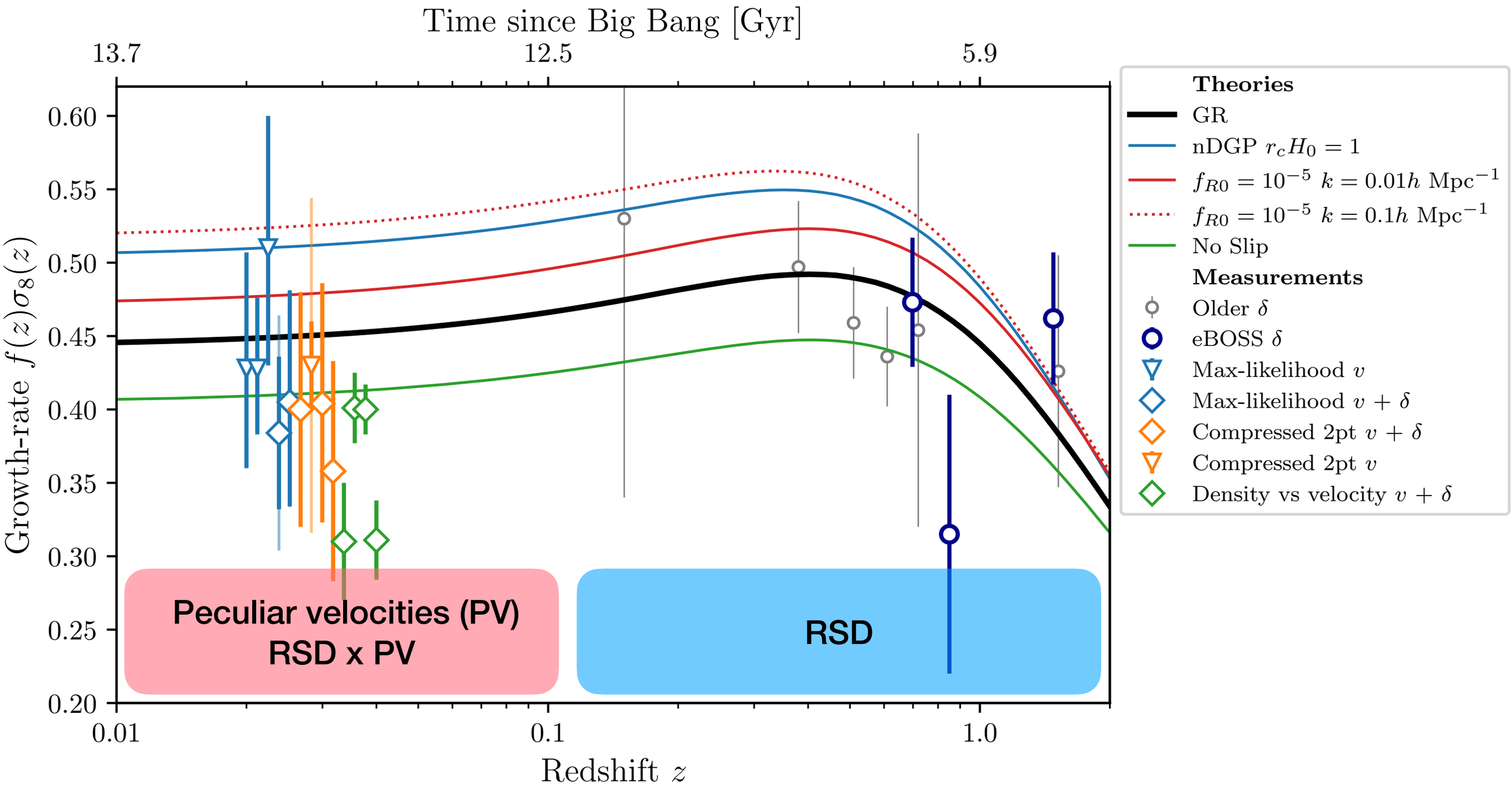

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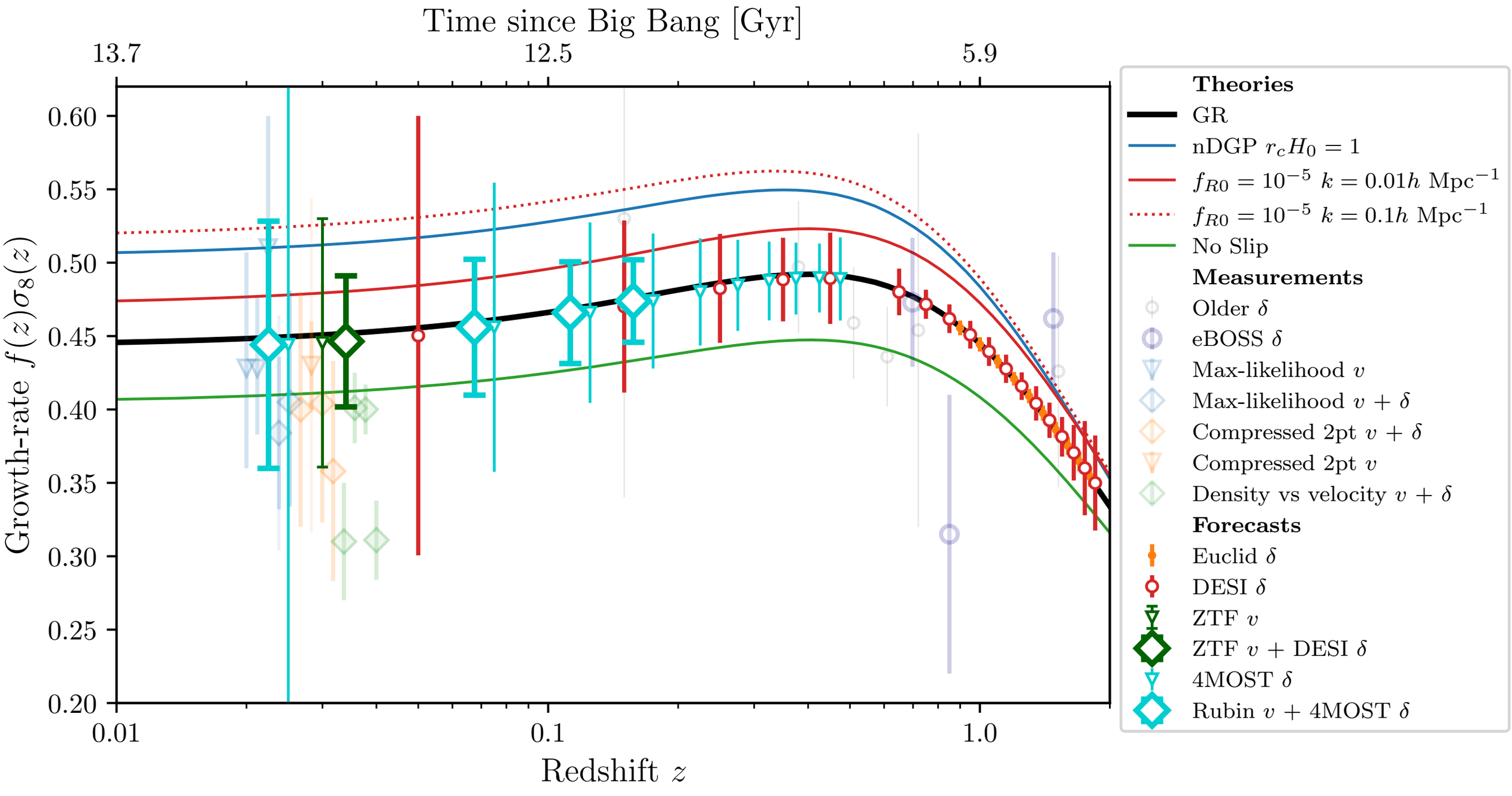

RSD x PV : potential to observe deviations from GR !

How to measure growth-rate with peculiar velocities?

Peculiar velocity measurements

Observed redshift is :

$$(1 + z_{\rm obs}) = (1 + z_{\rm cosmo})(1 + z_v)$$

Spectroscopic survey

Distance indicator

Radial peculiar velocity

Tully-Fisher **Fundamental plane** **Type-Ia supernova**

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	Tully-Fisher	**Fundamental plane**	**Type-Ia supernova**
Intrinsic scatter (in distance)	$\frac{\sigma_D}{D} \sim 20\,\%$	$\frac{\sigma_D}{D} \sim 20\,\%$	$\frac{\sigma_D}{D} \sim 7\,\%$

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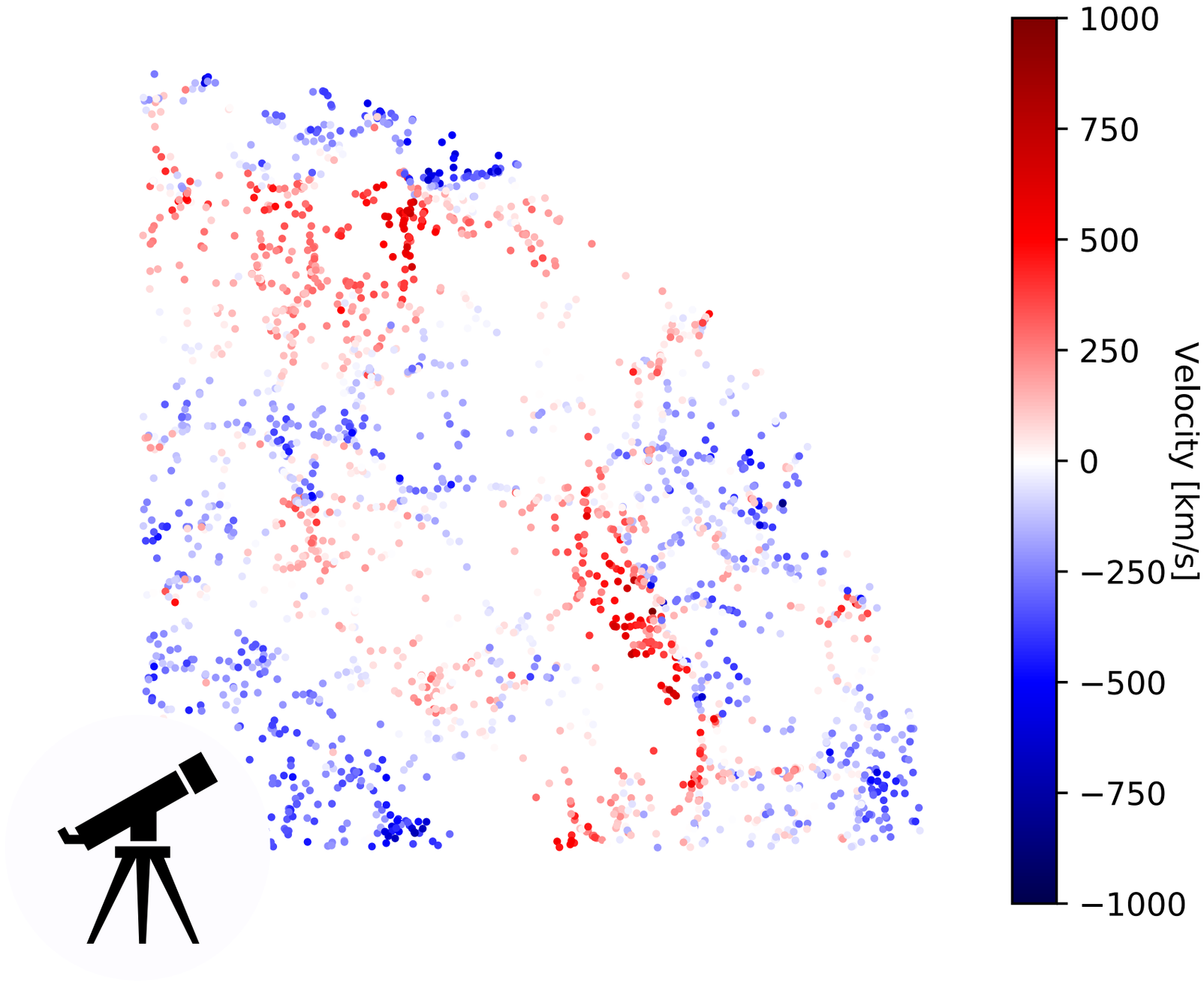
Future datasets	WALLABY ~ 30k **DESI ~ 53k**	Taipan ~ 50k **DESI ~ 133k**	**ZTF ~ 5k** LSST ~ 30 to 100 k (?)

Observables

Redshift survey → Distorted density field

$\mathrm{RA}_i, \mathrm{Dec}_i, z_i$ $\quad\quad$ $\delta_g(\vec{s})$



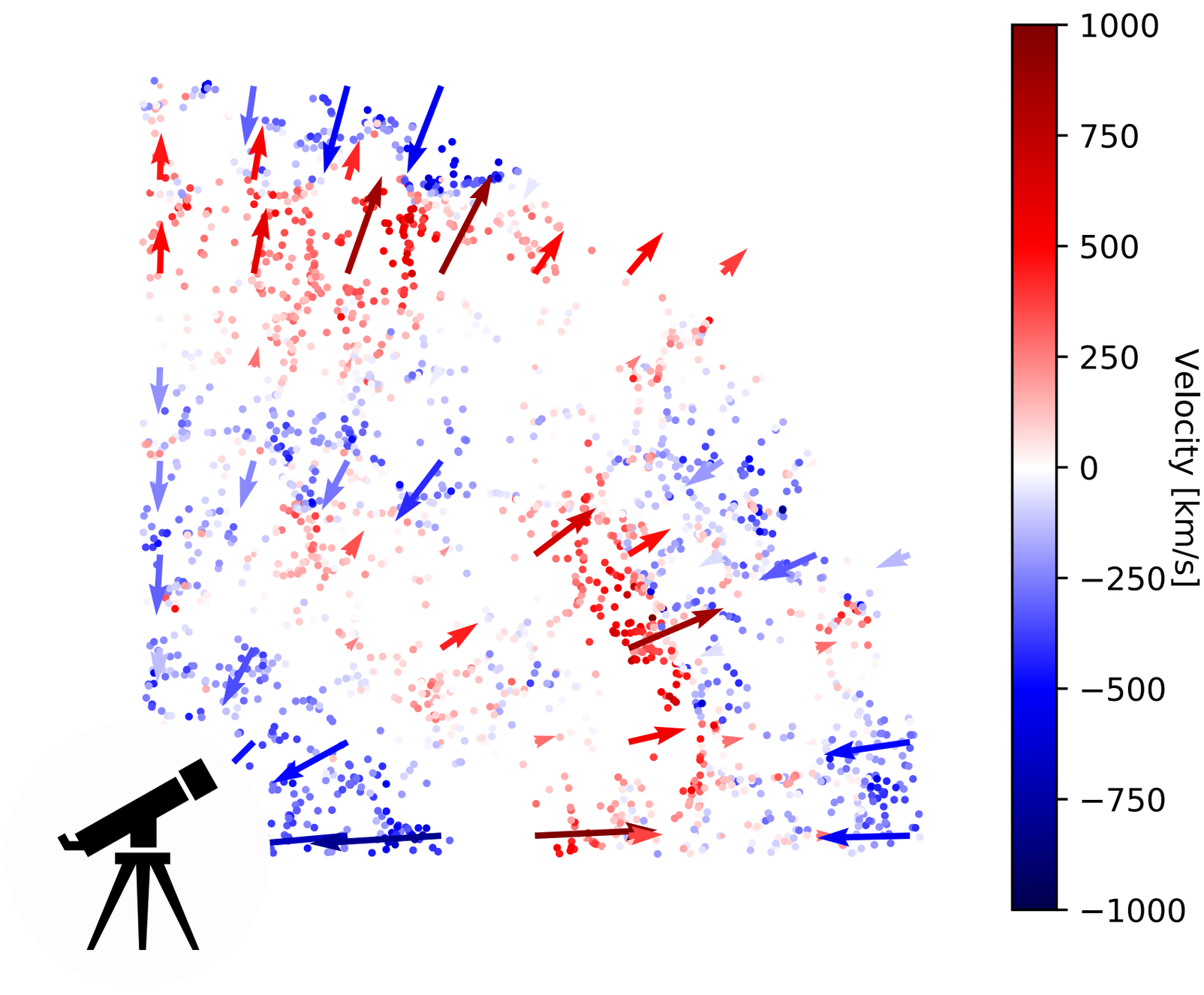
Observables

Redshift survey → Distorted density field

$\mathrm{RA}_i, \mathrm{Dec}_i, z_i$ → $\delta_g(\vec{s})$

Distance survey → Radial velocity field

$\mathrm{RA}_j, \mathrm{Dec}_j, z_j, D_j$ → $v_r(\vec{s})$



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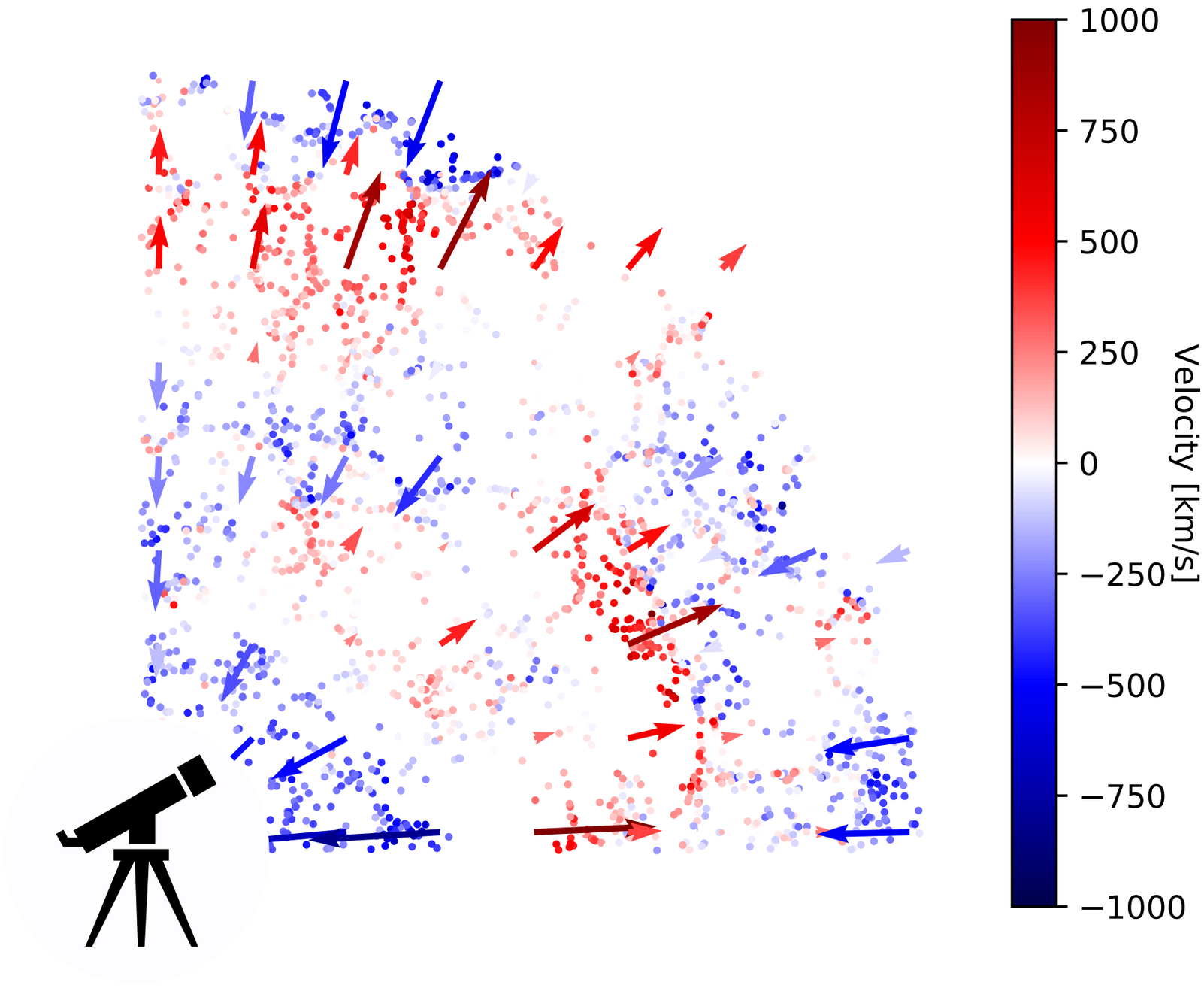


How to measure peculiar velocities?

Methods to exploit densities and velocities

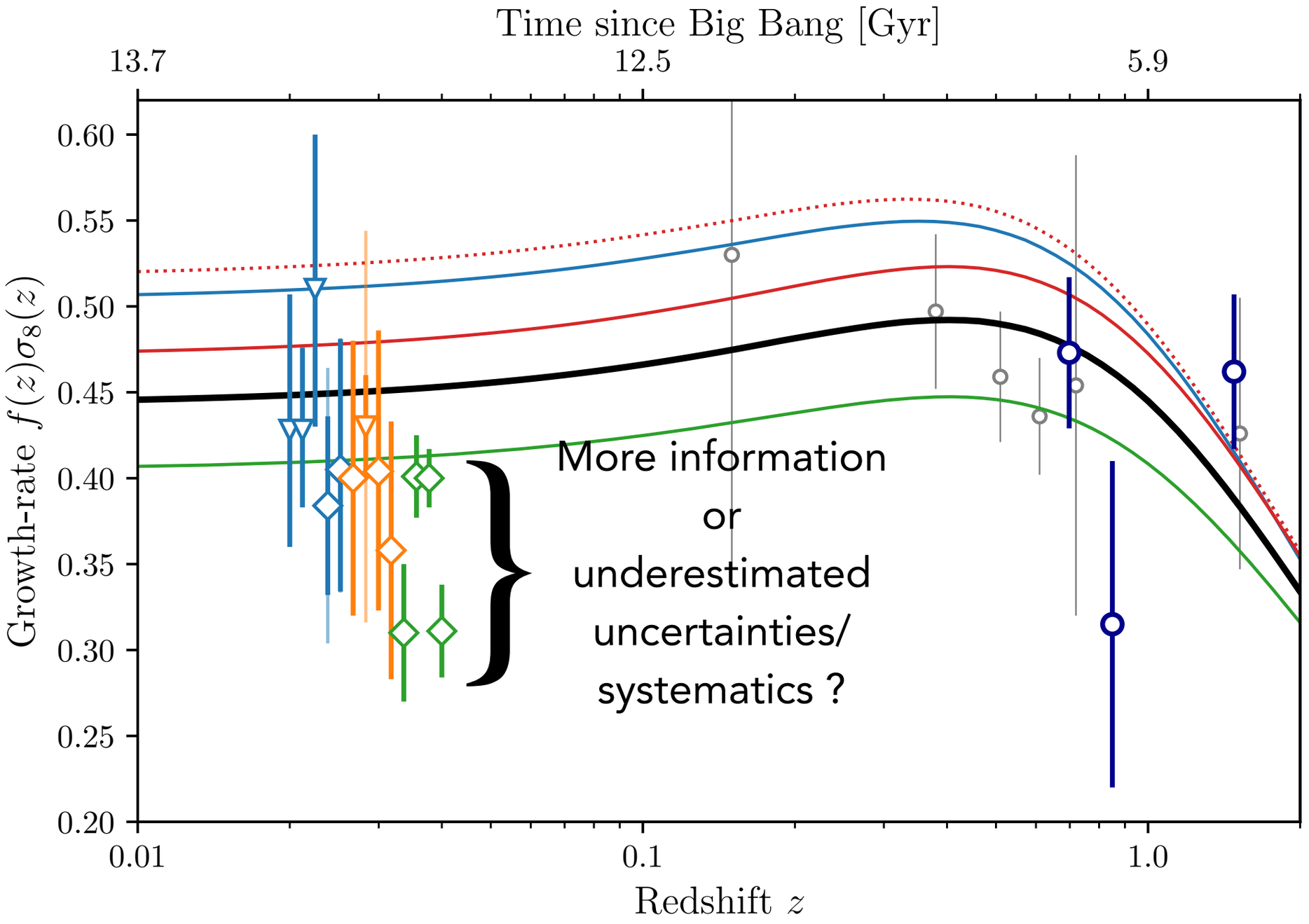
	Data vector	Model	References
Maximum likelihood	Uncompressed 2-pt statistics	2-pt statistics	Johnson++ 2014 Howlett++2017 Adams & Blake 2017/2020 Lai, Howlett, Davis 2022 **Carreres, JB++2023**
2pt functions $\langle\delta_g\delta_g\rangle, \langle\delta_g p_r\rangle, \langle p_r p_r\rangle$	Compressed 2-pt statistics	2-pt statistics	Ferreira++1999 Dupuy++2019 Turner, Blake, Ruggeri 2021 Howlett++2019 Qin++2020
Density-velocity comparison	Velocity field $v_r(\vec{s})$	Reconstruct $v_r(\vec{s})$ from $\delta_g(\vec{s})$	Davis++2011 Springbob++2014 Carrick++2015 Boruah++2020 Said++2020
Forward-modelling	Both fields $\delta_g(\vec{s}), v_r(\vec{s})$	Evolution from initial conditions	Graziani++2019 Boruah, Hudson, Lavaux 2020

Methods to exploit densities and velocities

Maximum likelihood

2pt functions

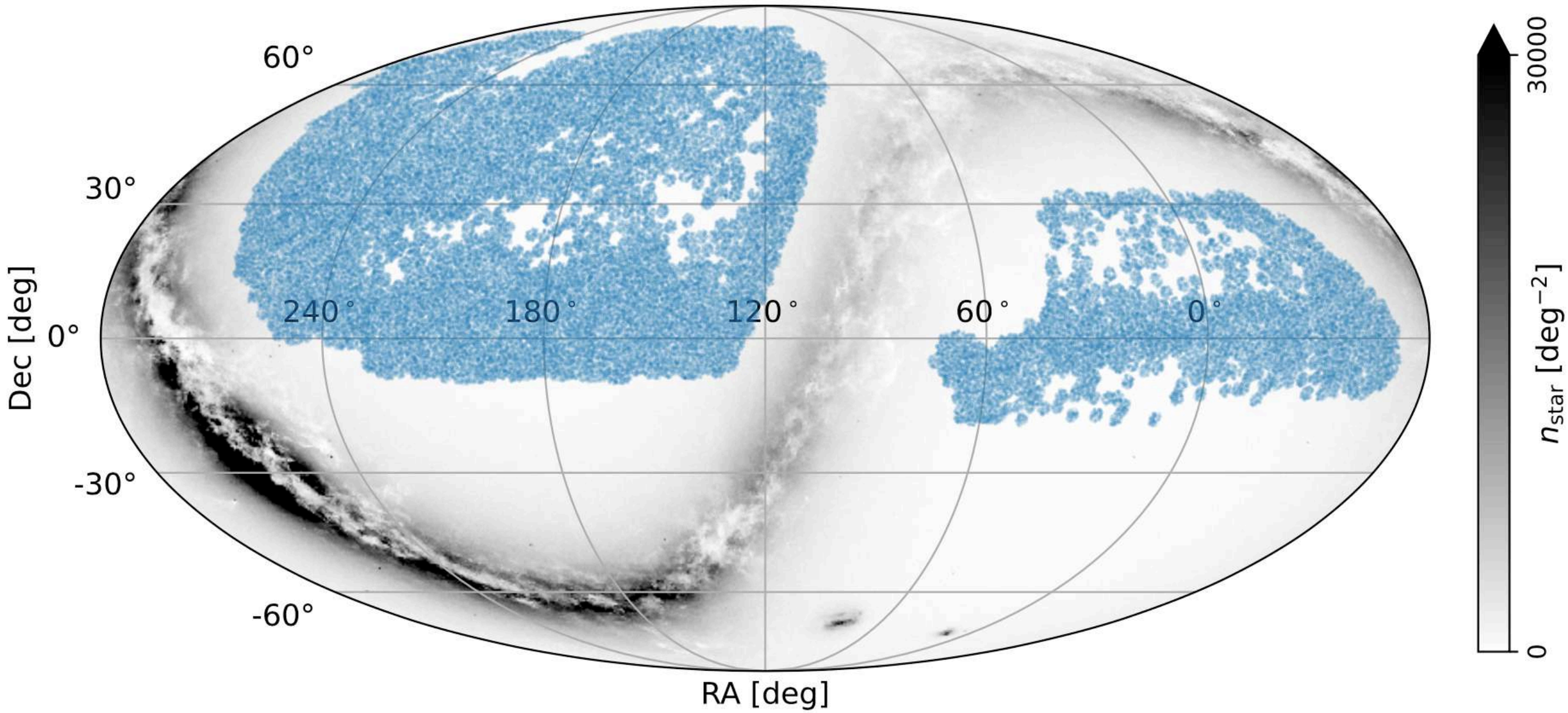
Density-velocity comparison



What data DESI and ZTF are providing us?

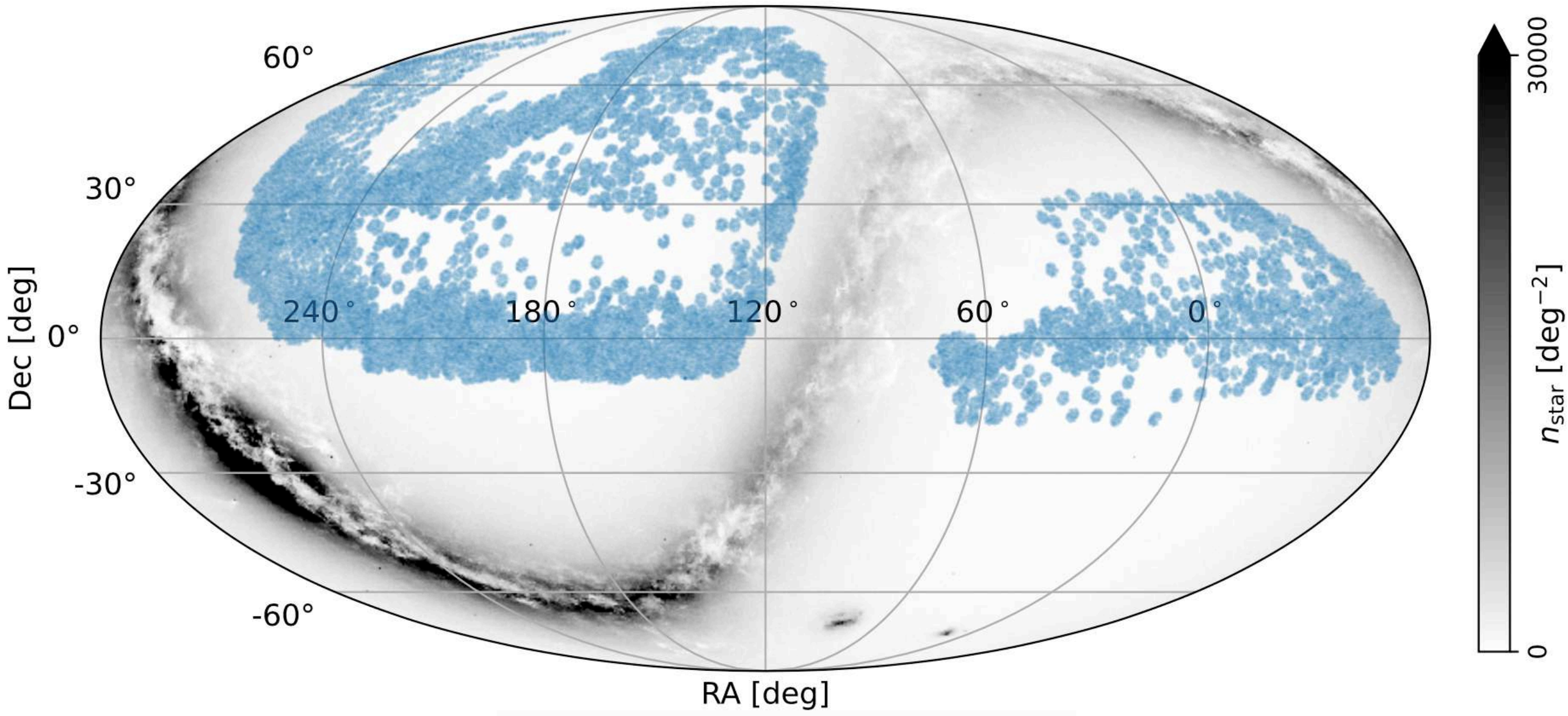
DARK ENERGY SPECTROSCOPIC INSTRUMENT

DESI Bright-time Survey - Today
59% complete



DARK ENERGY SPECTROSCOPIC INSTRUMENT

DESI Year 1 Sample



BAO results published

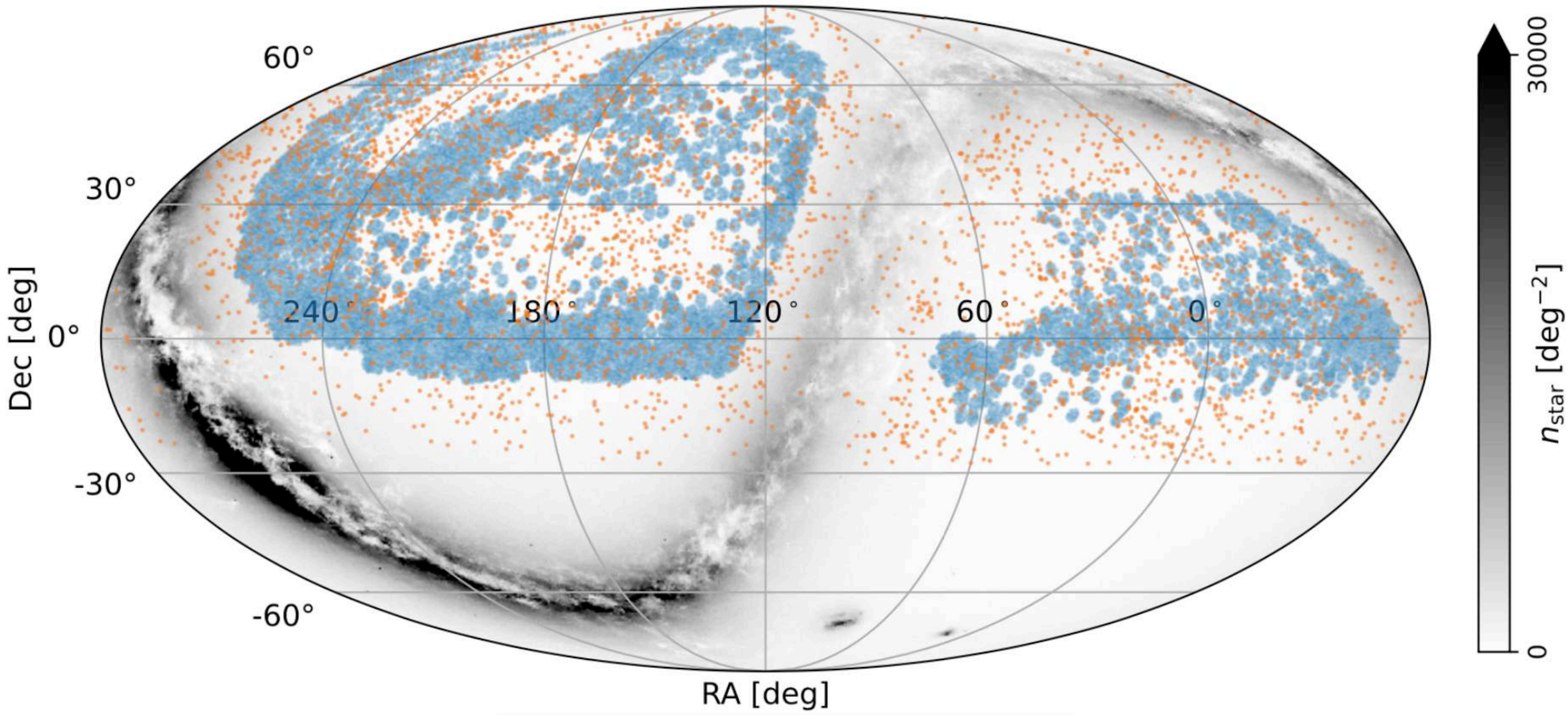
Public data release end of 2024

DARK ENERGY SPECTROSCOPIC INSTRUMENT

ZWICKY TRANSIENT FACILITY

DESI Year 1 Sample

ZTF DR2



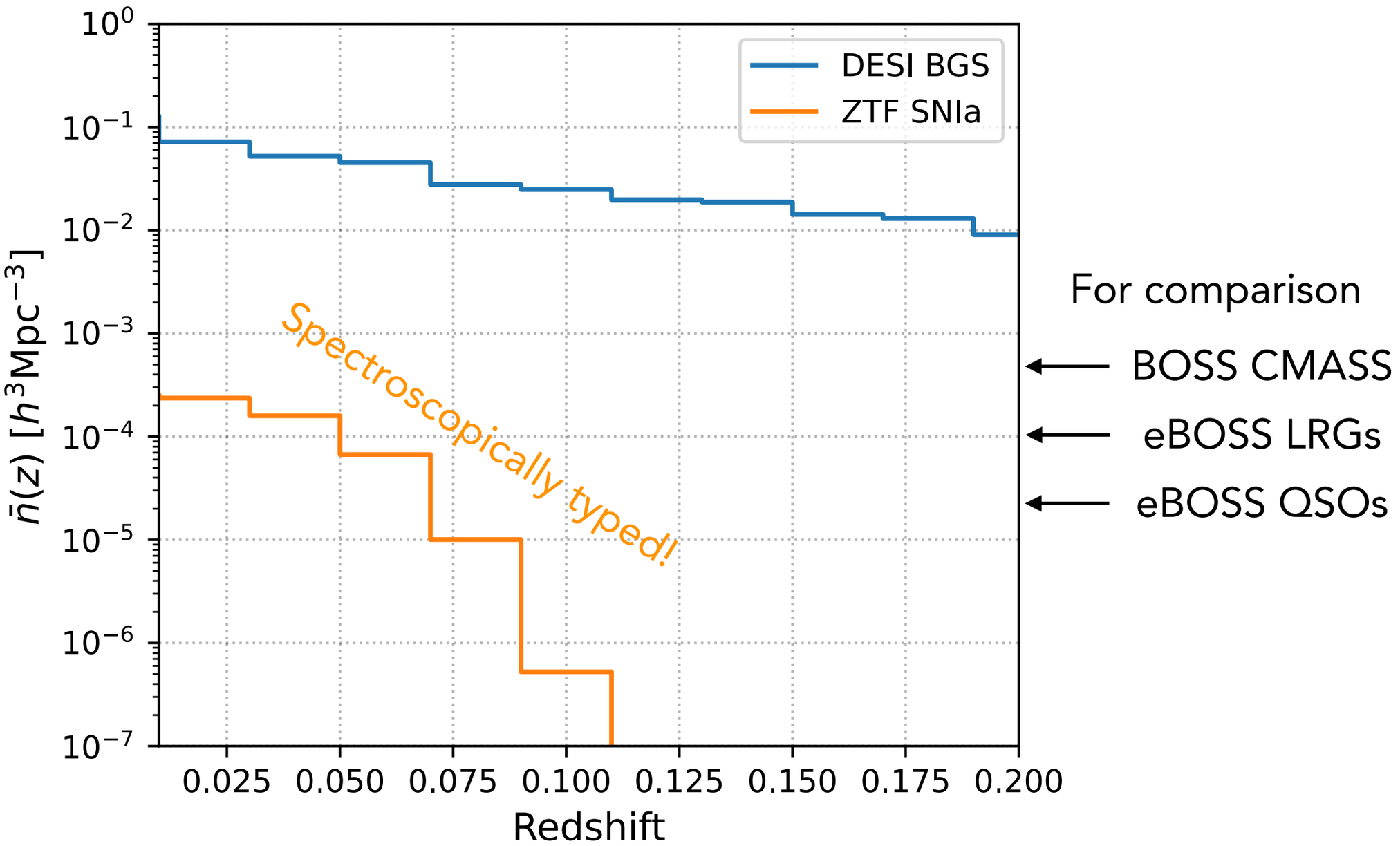
BAO results published

Public data release end of 2024

Several publications under peer-review

Redshift distribution

expected at the end of both programs



Fewer SNIa but very valuable !

Growth-rate measurement with type-Ia supernovae using ZTF survey simulations

Bastien Carreres[1,⋆], Julian E. Bautista[1], Fabrice Feinstein[1], Dominique Fouchez[1], Benjamin Racine[1], Mathew Smith[2], Mellissa Amenouche[3], Marie Aubert[3], Suhail Dhawan[4], Madeleine Ginolin[2], Ariel Goobar[5], Philippe Gris[3], Leander Lacroix[6], Eric Nuss[7], Nicolas Regnault[6], Mickael Rigault[2], Estelle Robert[2], Philippe Rosnet[3], Kelian Sommer[7], Richard Dekany[8], Steven L. Groom[9], Niharika Sravan[8], Frank J. Masci[9], and Josiah Purdum[9]

https://arxiv.org/abs/2303.01198

Aix*Marseille université Socialement engagée

A*Midex Initiative d'excellence Aix-Marseille

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

ZTF simulations of supernovae

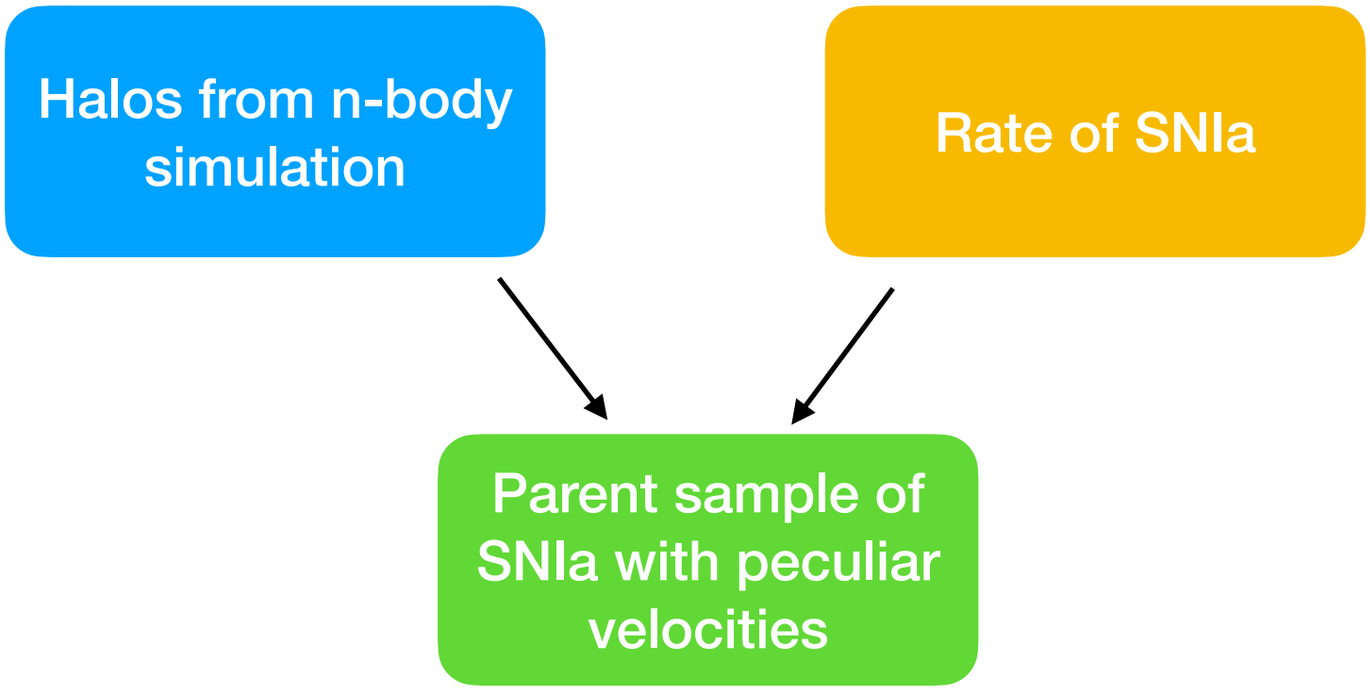
Creating ZTF simulations of type-Ia SN with peculiar velocities

Halos from n-body simulation

Rate of SNIa

Public python package SNSIM
https://snsim.readthedocs.io

Creating ZTF simulations of type-Ia SN with peculiar velocities



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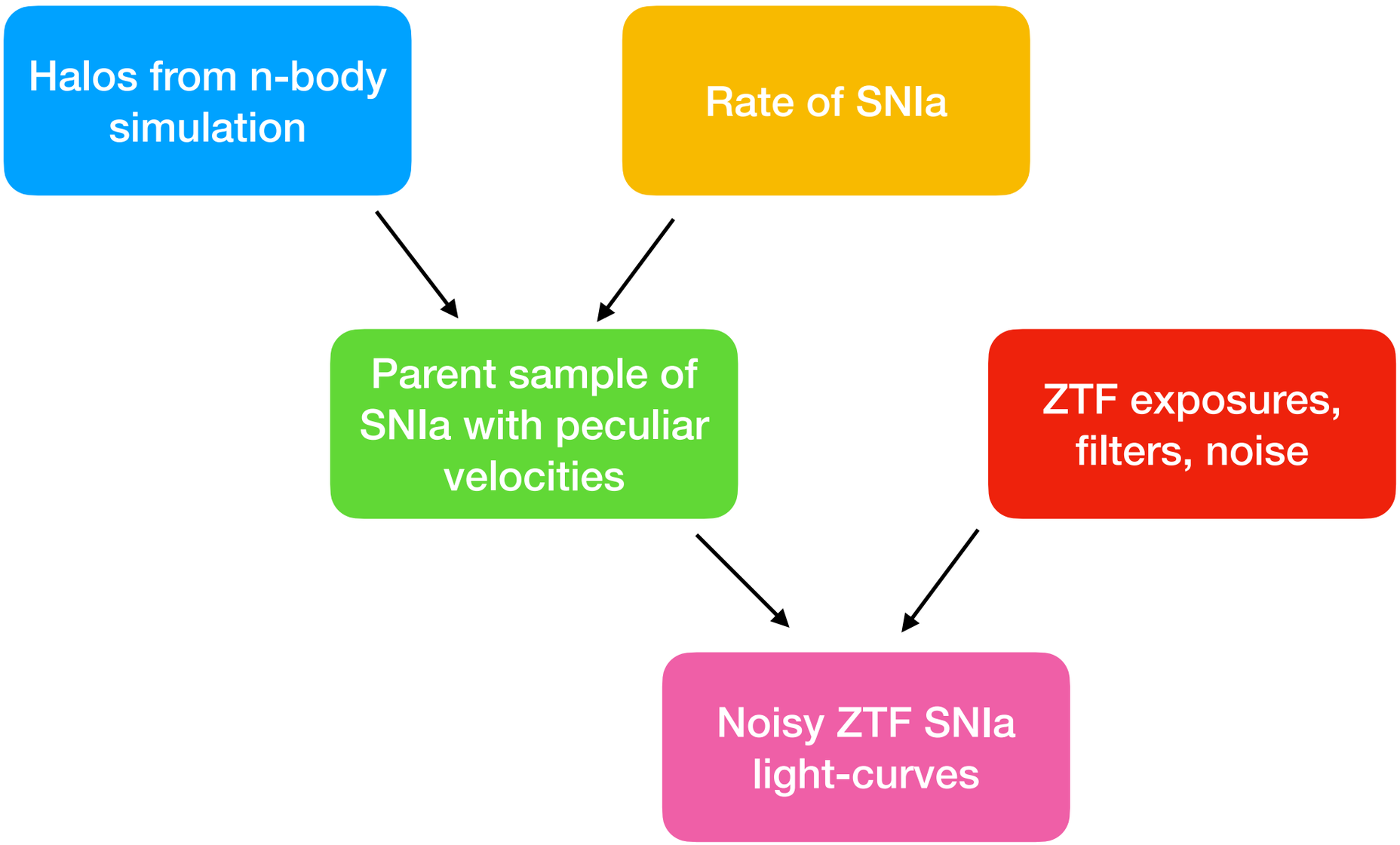

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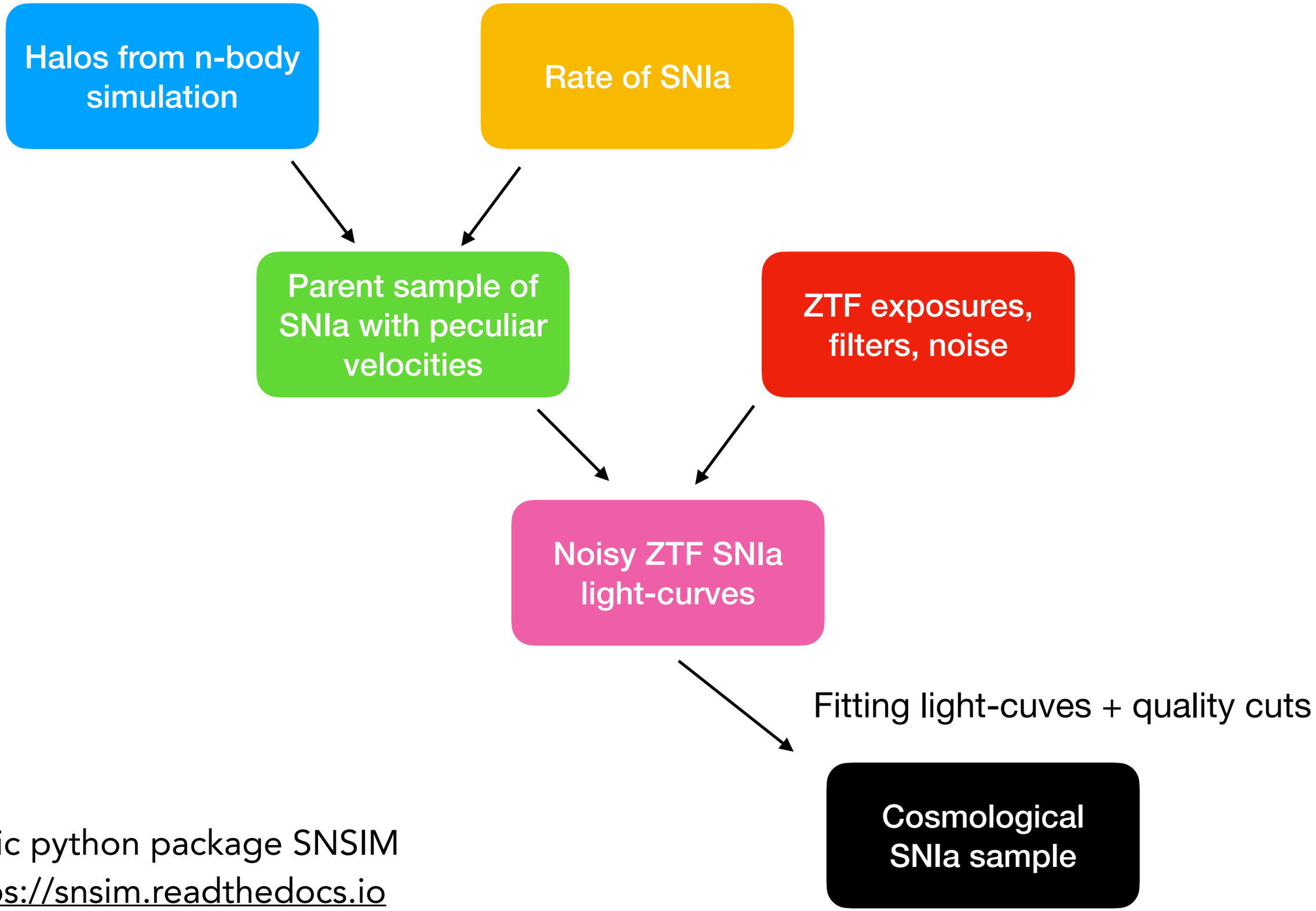

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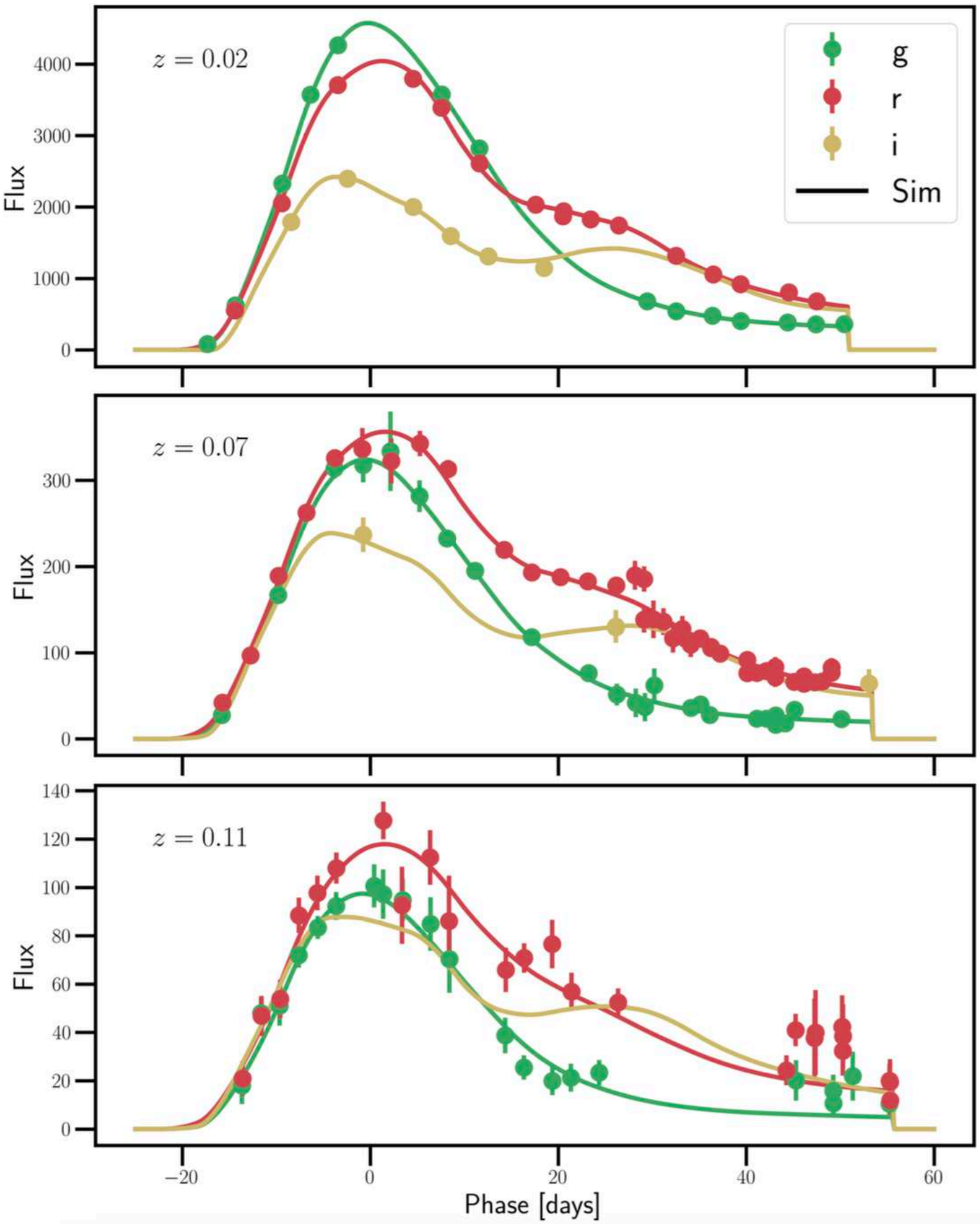

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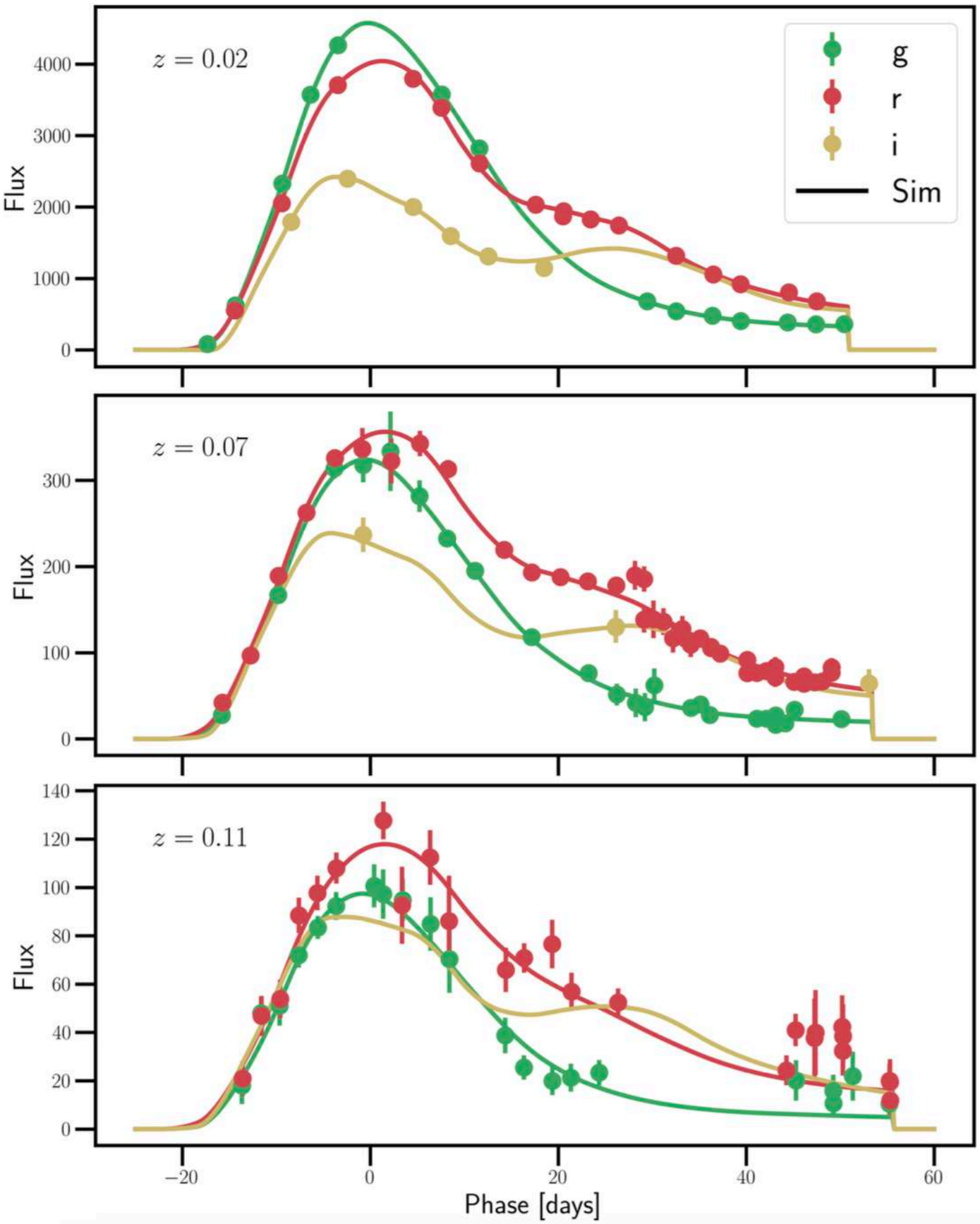
- Stretch distribution: Nicolas et al. 2021
- SALT 2 or 3
- Input light-curves by SNCOSMO

ZTF SN simulations



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Two selection effects

Photometric detection (r < 20.5)

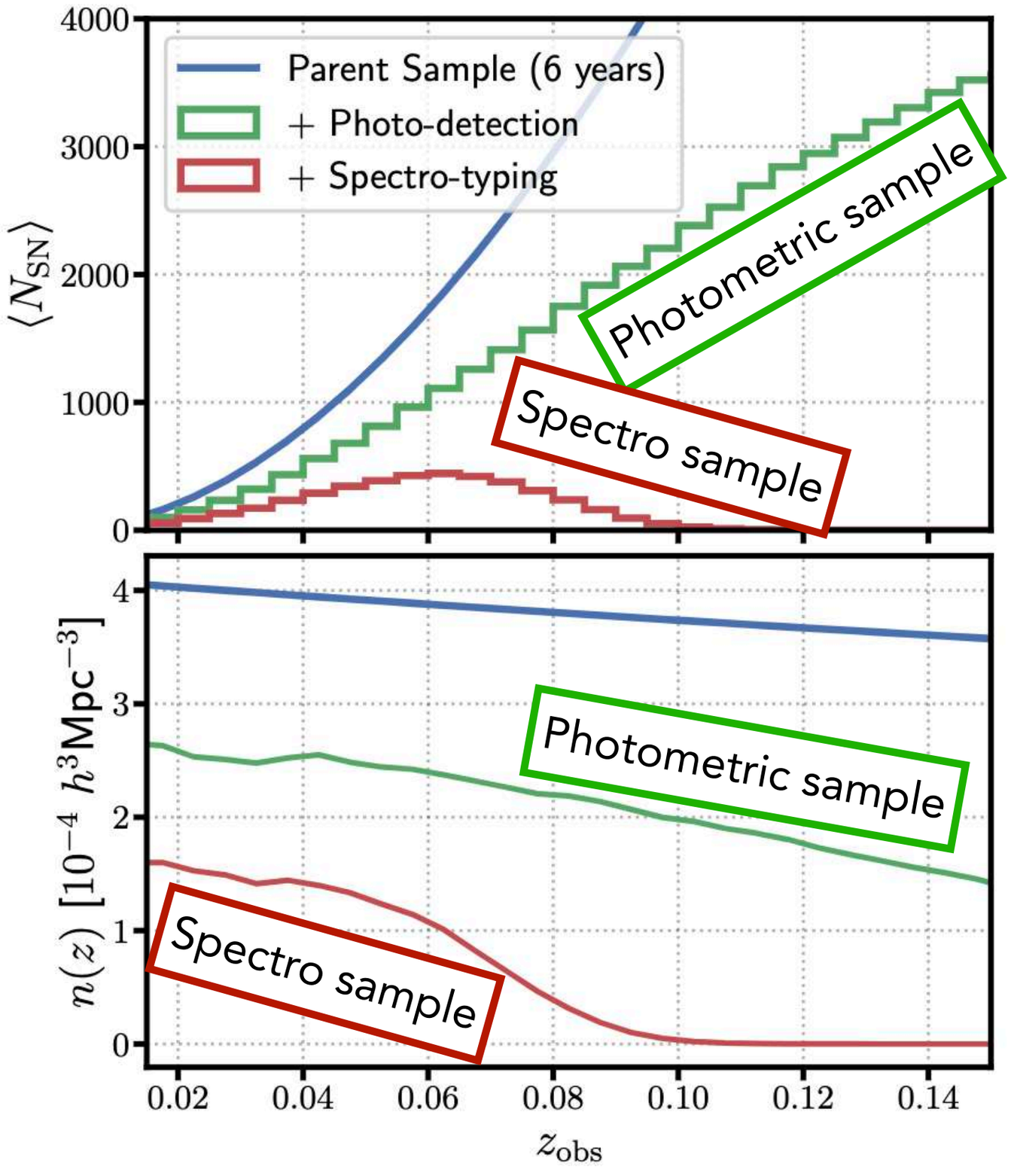
Spectroscopic follow-up for typing (r < 18.5)

Selection effects

Redshift distribution (mean of 27 mocks)

Number counts

Comoving number density



Measuring peculiar velocities

Impact of velocities on Hubble diagram

$$\begin{cases} (1+z_{\text{obs}}) = (1+z_{\text{cosmo}})(1+z_{\text{pec}}) \longrightarrow \text{Dominant effect} \\ \mu_{\text{obs}} = \mu_{\text{cosmo}} + 10\log_{10}(1+z_{\text{pec}}) \end{cases}$$

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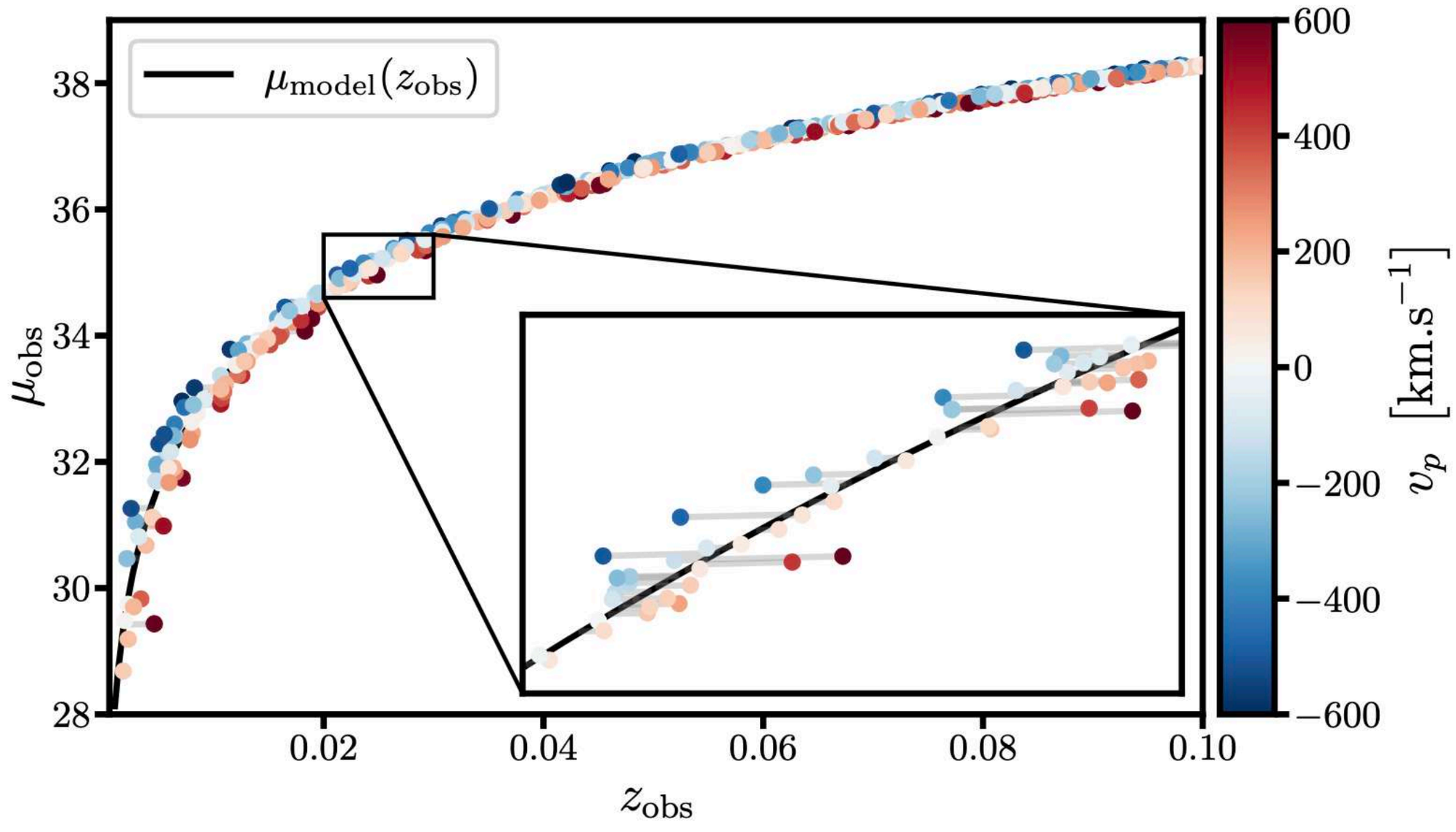
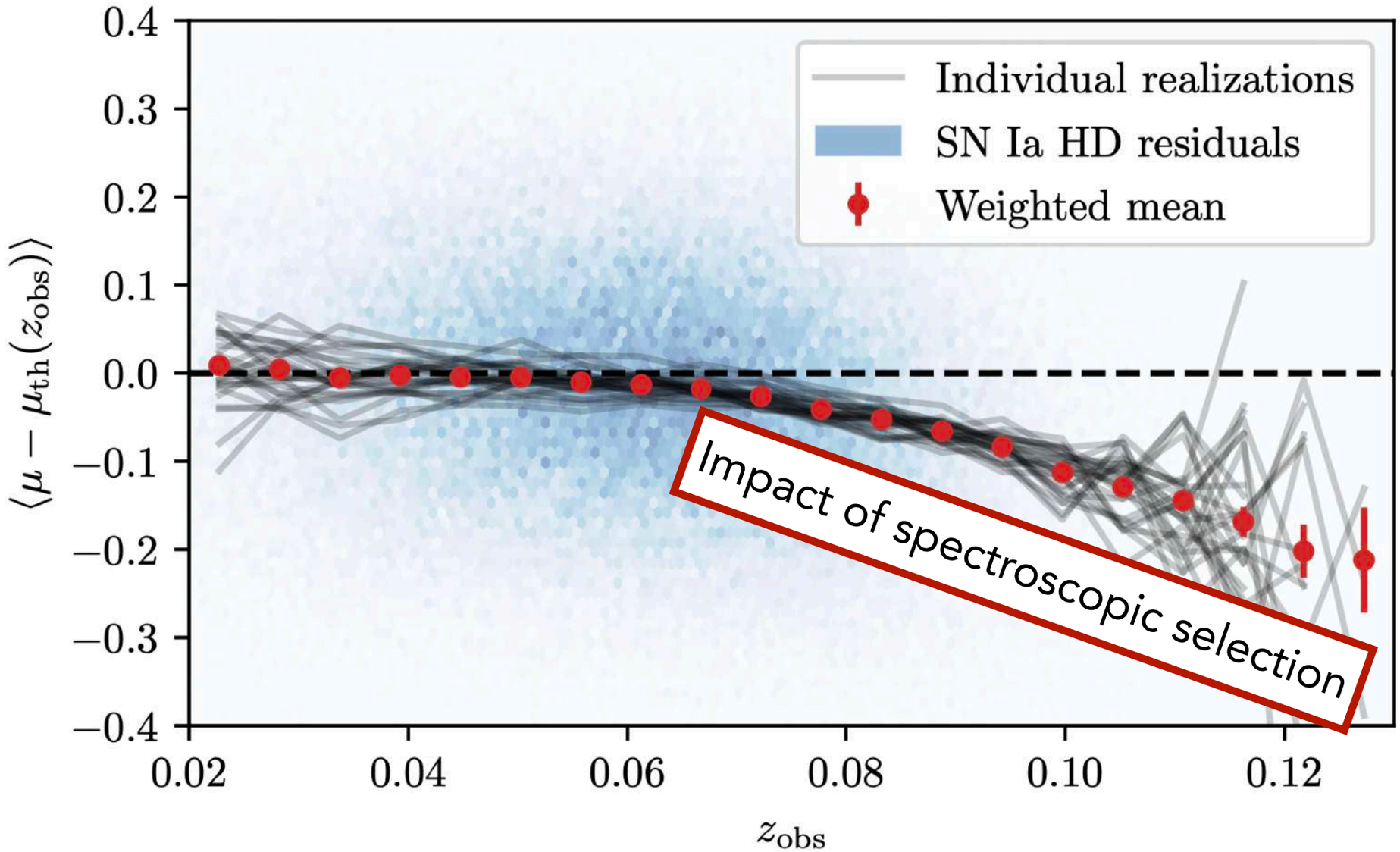
Ideal case without scatter in flux



Measuring peculiar velocities

Fit light-curves -> Fit Hubble Diagram

Distance moduli

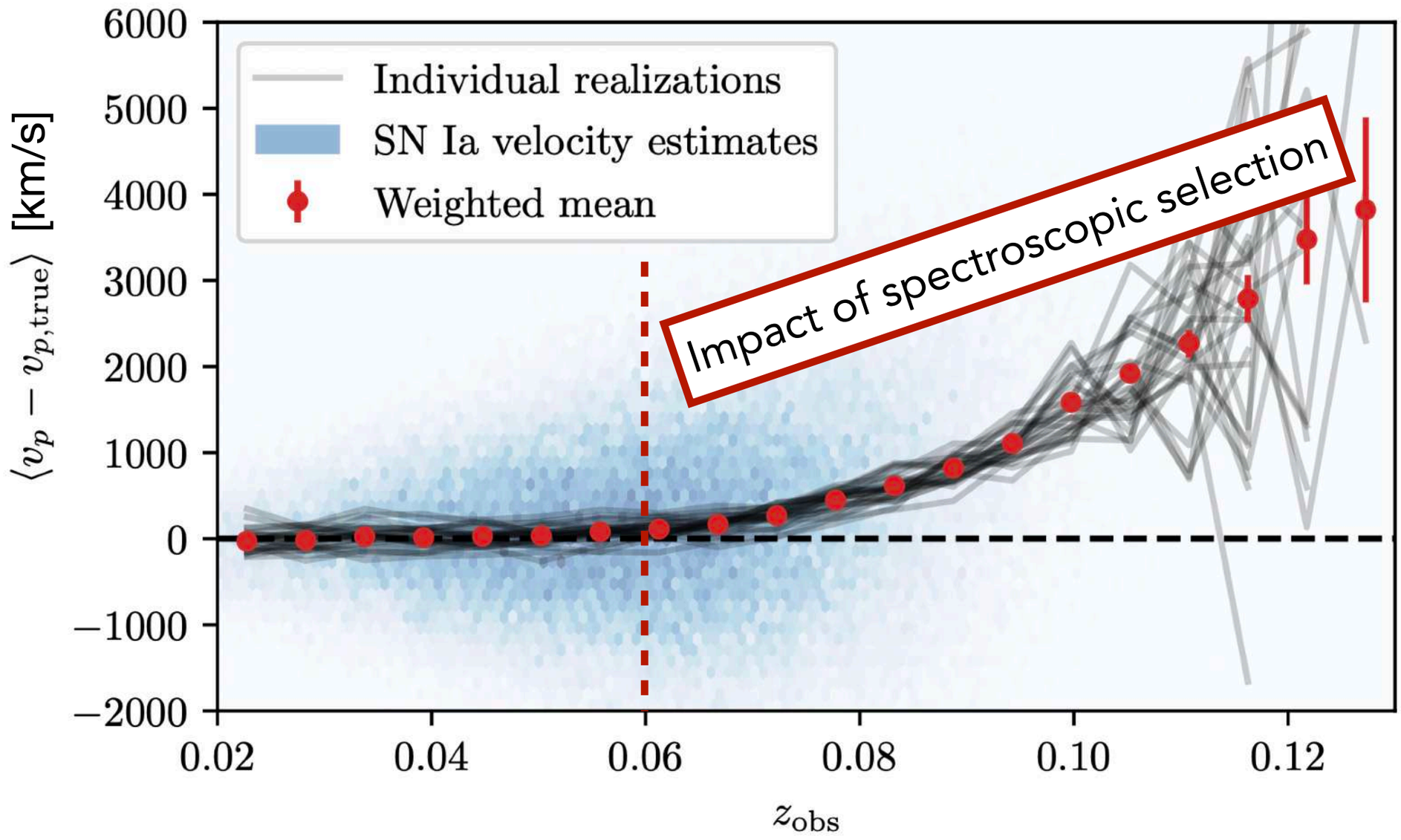


What is the bias on velocities and on $f\sigma_8$ due to selection (Malmquist) bias ?

Measuring peculiar velocities

Fit light-curves -> Fit Hubble Diagram -> Extract velocities from residuals

Peculiar velocities



Velocities are biased above z ~ 0.06

Measuring $f\sigma_8$

Maximise multi-variate Gaussian likelihood

(Johnson et al. 2014, Huterer et al. 2017, Howlett et al. 2017, Adams & Blake 2020, Lai et al. 2023)

$$\mathscr{L}(\vec{p}) = \frac{1}{(2\pi)^{n/2}[\det C(\vec{p})]^{1/2}} \exp\left[-\frac{1}{2} v_i C_{ij}^{-1}(\vec{p}) v_j\right]$$

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v_i : data-vector of **measured** radial peculiar velocities

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v_i : data-vector of **measured** radial peculiar velocities

$C(\vec{p})$: covariance matrix containing **model** of 2-pt statistics of velocities

$$C_{ij} = \langle v_i(\vec{x}_i) v_j(\vec{x}_j) \rangle$$

Measuring $f\sigma_8$

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$$\mathscr{L}(\vec{p}) = \frac{1}{(2\pi)^{n/2}[\det C(\vec{p})]^{1/2}} \exp\left[-\frac{1}{2} v_i C_{ij}^{-1}(\vec{p}) v_j\right]$$

v_i : data-vector of **measured** radial peculiar velocities

$C(\vec{p})$: covariance matrix containing **model** of 2-pt statistics of velocities

$$C_{ij} = \langle v_i(\vec{x}_i) v_j(\vec{x}_j) \rangle$$

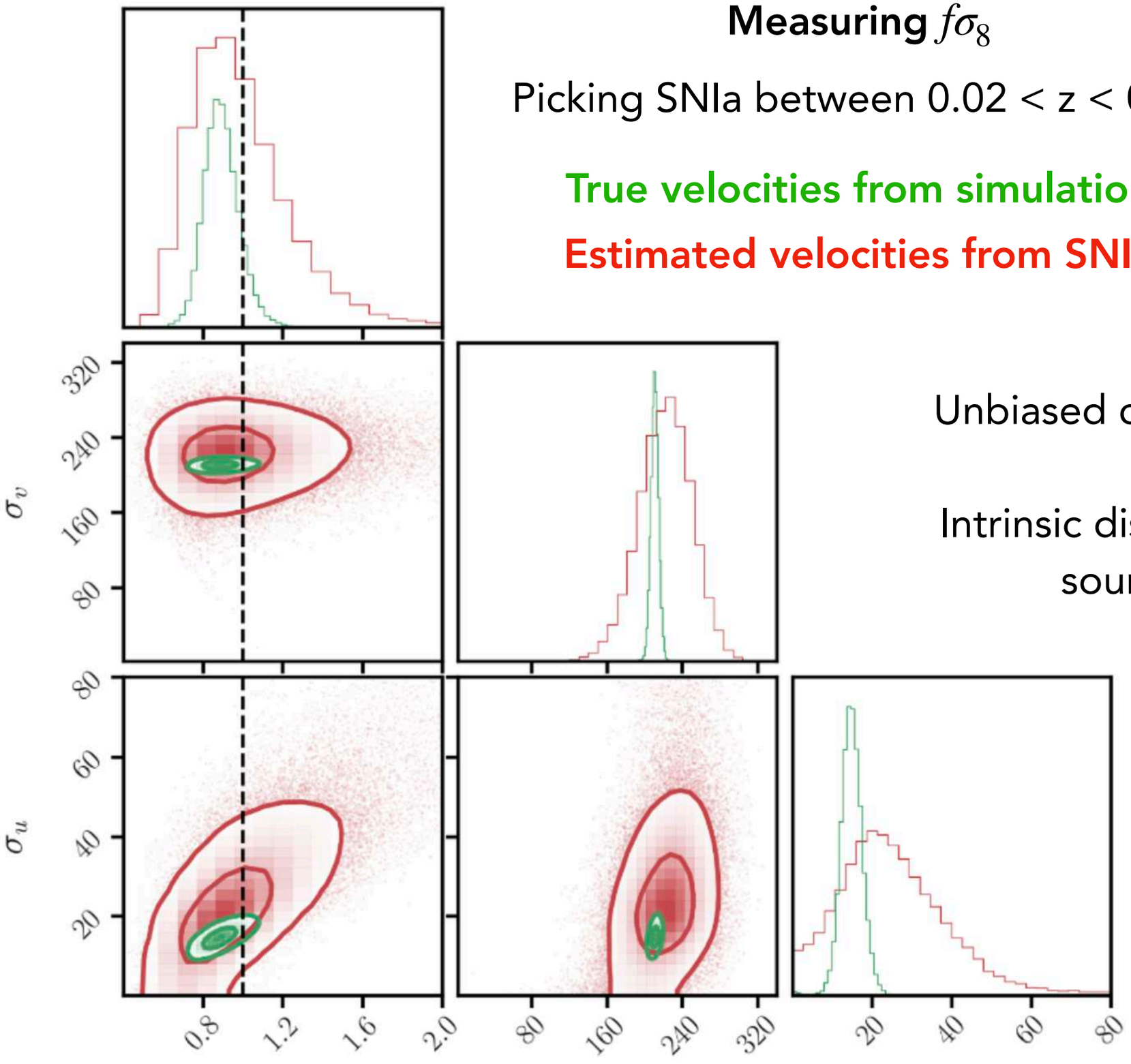
$\vec{p}$: parameters of the model, including $f\sigma_8$ and nuisance terms

Measuring $f\sigma_8$

Picking SNIa between 0.02 < z < 0.06

True velocities from simulation

Estimated velocities from SNIa



Growth-rate

$$\frac{[f\sigma_8]_{\text{est}}}{[f\sigma_8]_{\text{true}}}$$

Velocity dispersion σ_v [km/s]

RSD dispersion σ_u [Mpc/h]

Unbiased constrains for both cases

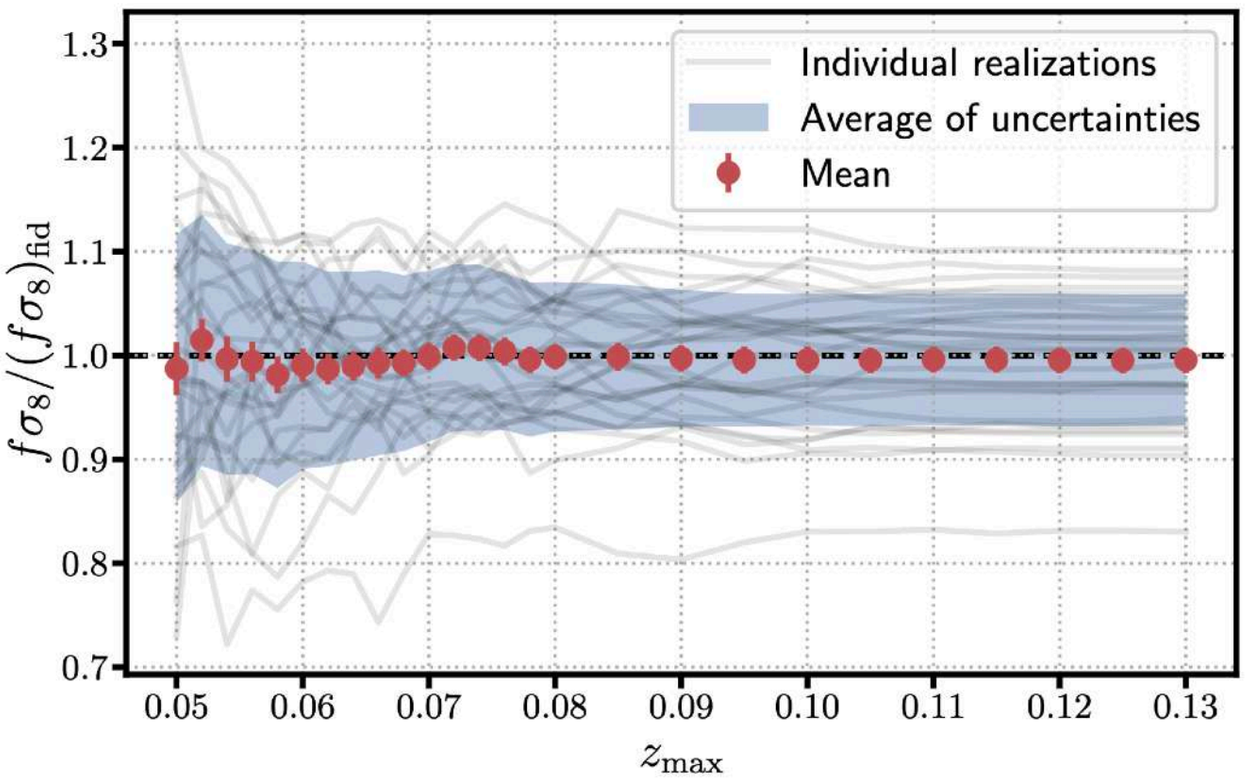
Intrinsic dispersion of SNIa is main source of uncertainty

Measuring $f\sigma_8$

Picking SNIa between $0.02 < z < z_{max}$

27 realisations

Using true velocities from simulation



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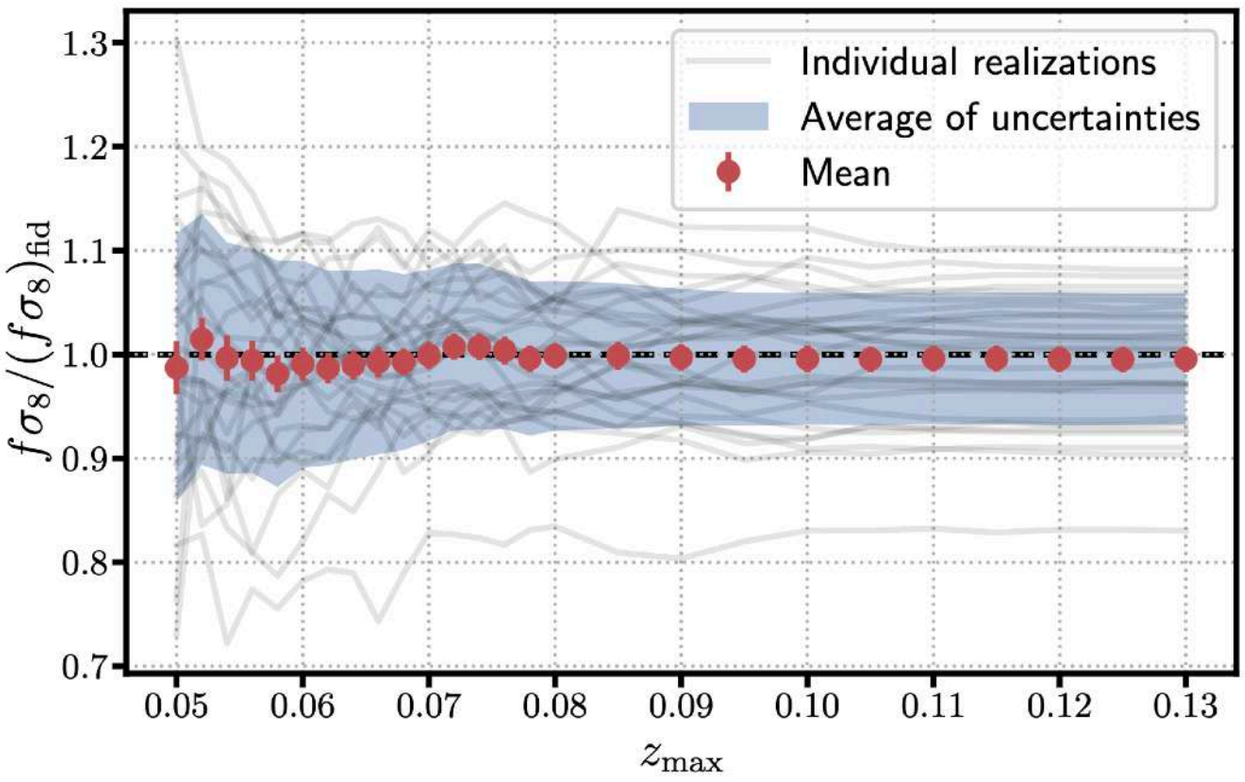
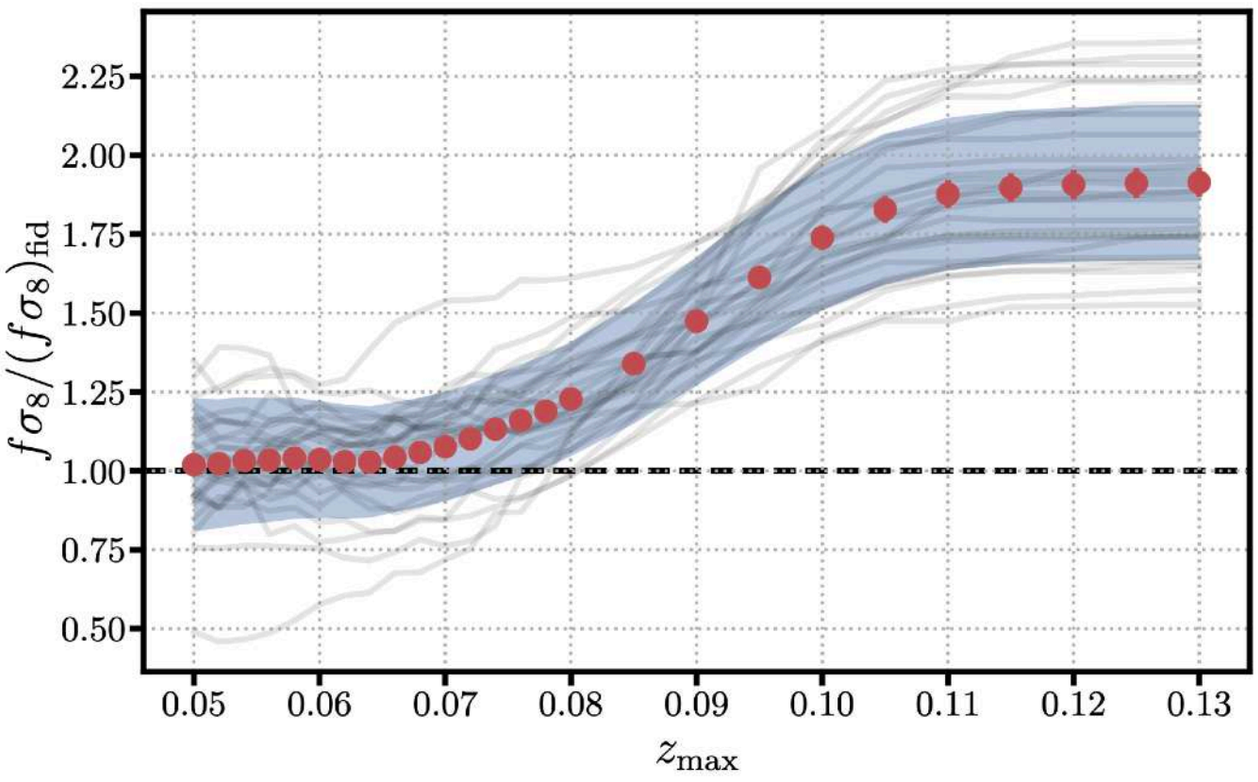


Estimated velocities from simulated SNIa



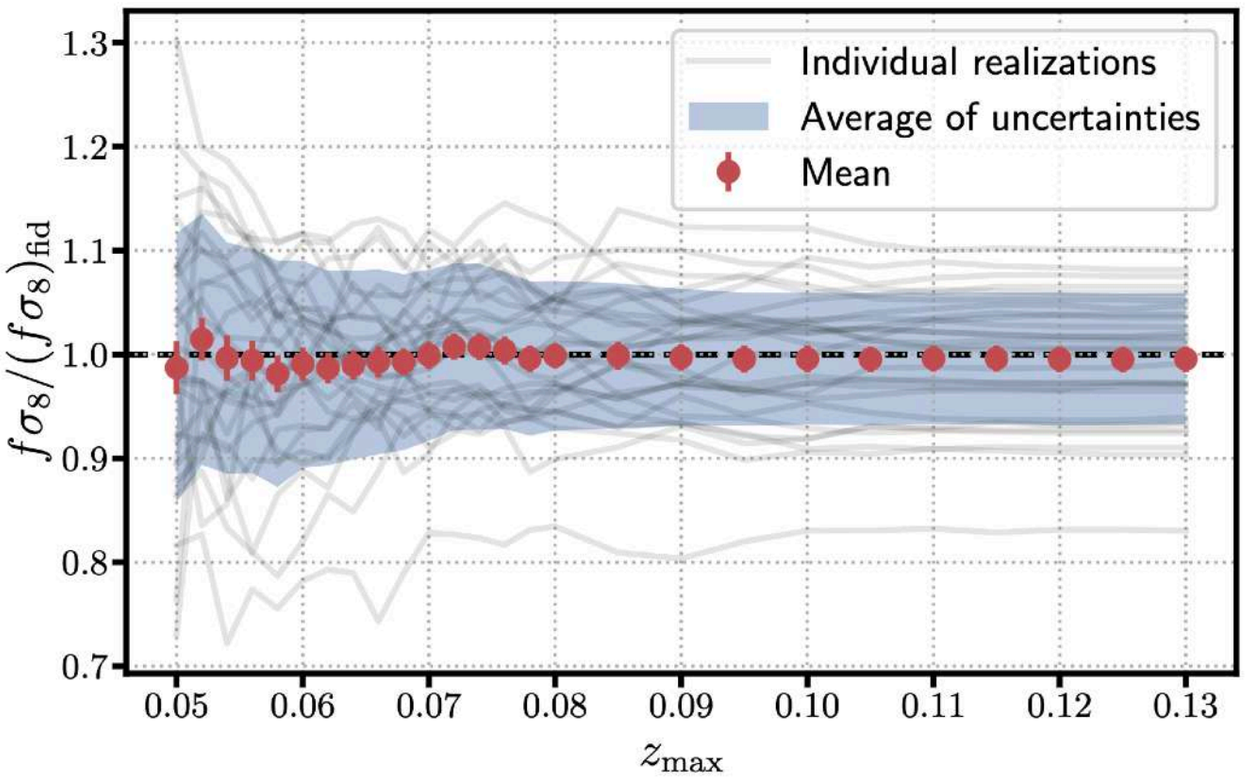
Selection effects quick in at z_{max} ~ 0.06

Measuring $f\sigma_8$

Picking SNIa between $0.02 < z < z_{max}$

27 realisations

Using true velocities from simulation



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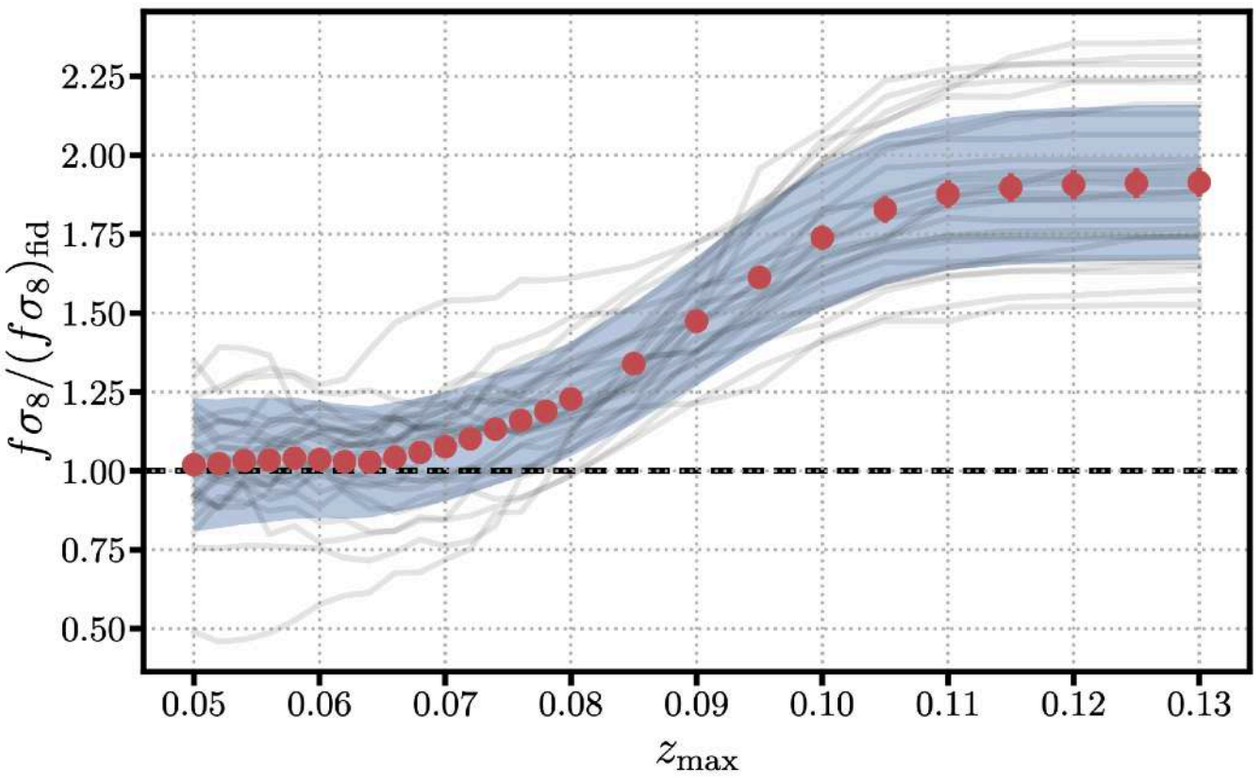
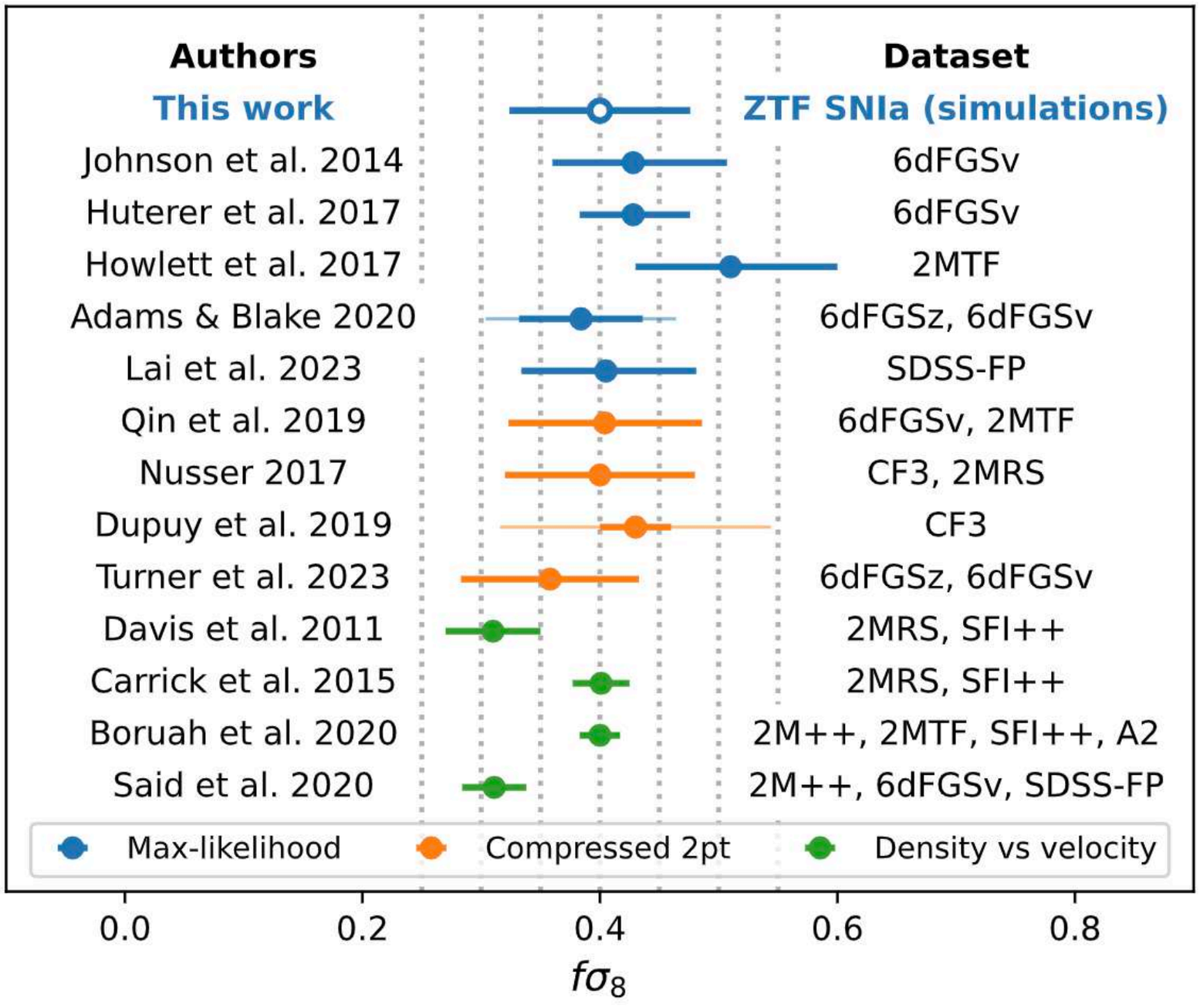


Selection effects quick in at $z_{max} \sim 0.06$

Forecast of **19%** uncertainty of growth-rate from **SNIa velocities only**
(Carreres, JB, et al. 2023)

Forecast on $f\sigma_8$ based on simulations

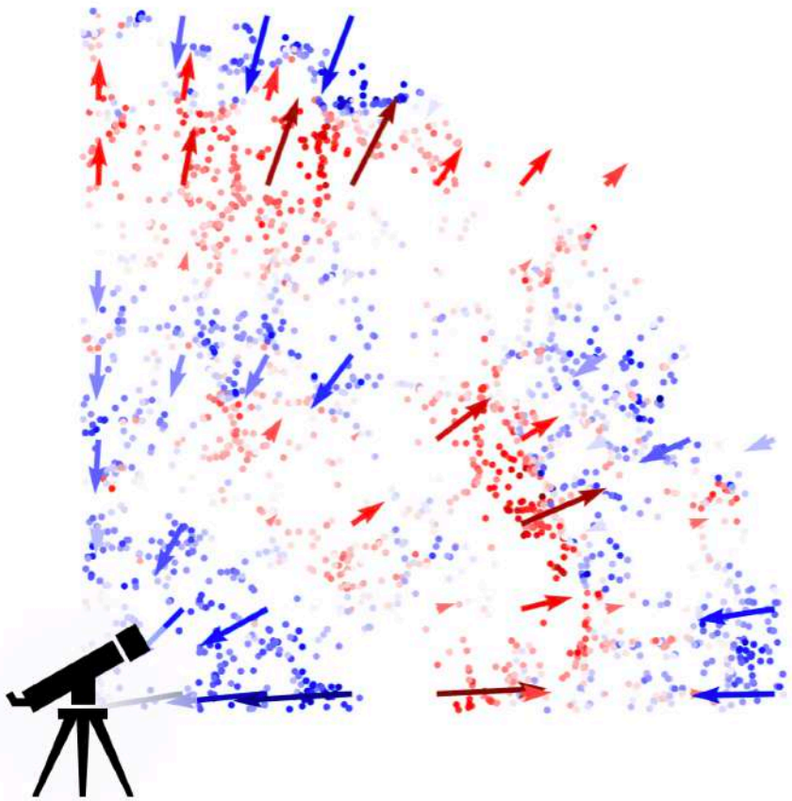
~ 2000 ZTF spectroscopically typed SNIa sample
$0 < z < 0.06$



19% uncertainty from velocity-velocity only

Steps forward

Steps forward



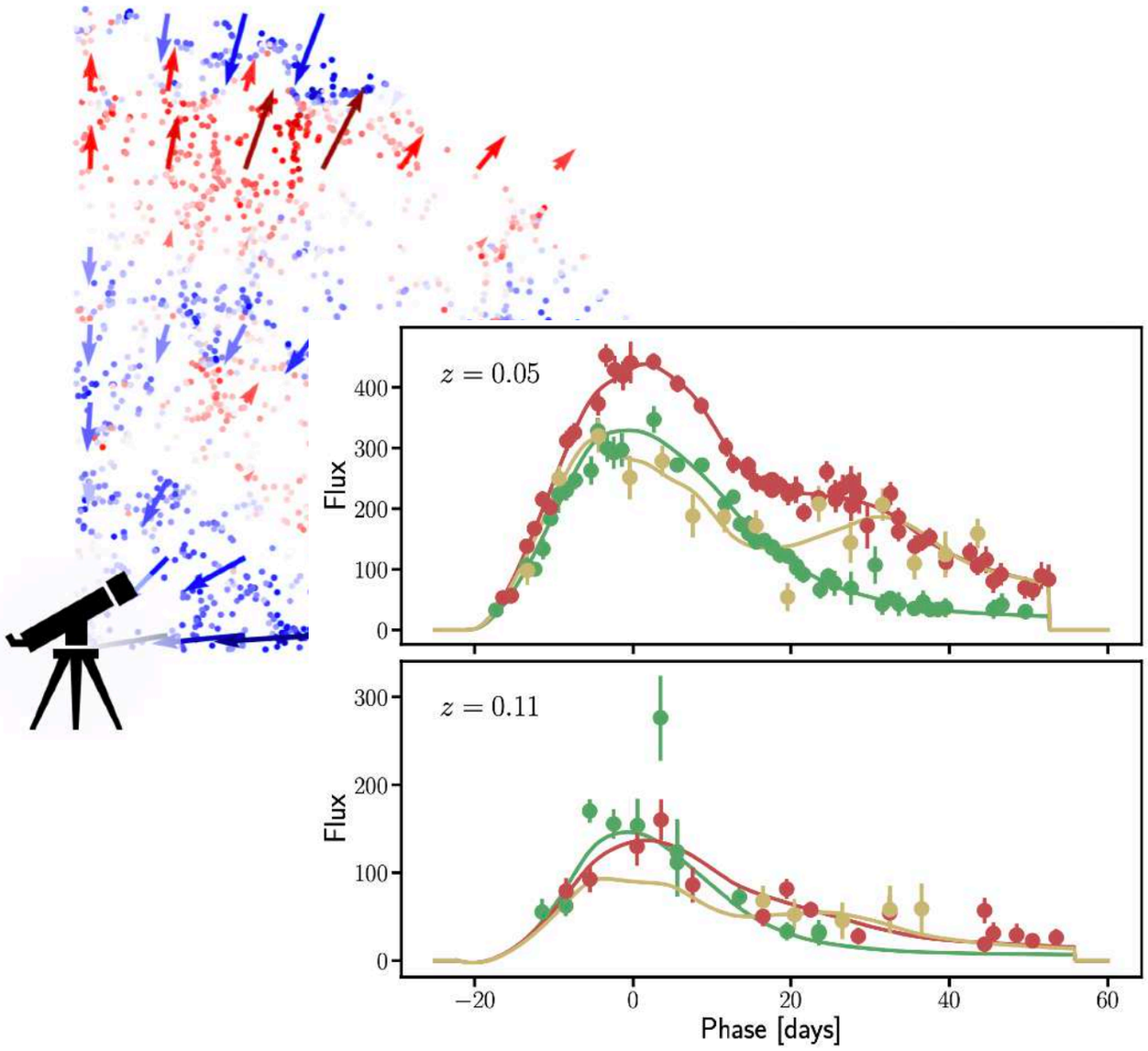
- combine ZTF SNIa with DESI galaxies: expected factor 2 improvement on uncertainties!

+

- realistic mocks of DESI + ZTF

Corentin Ravoux

Steps forward



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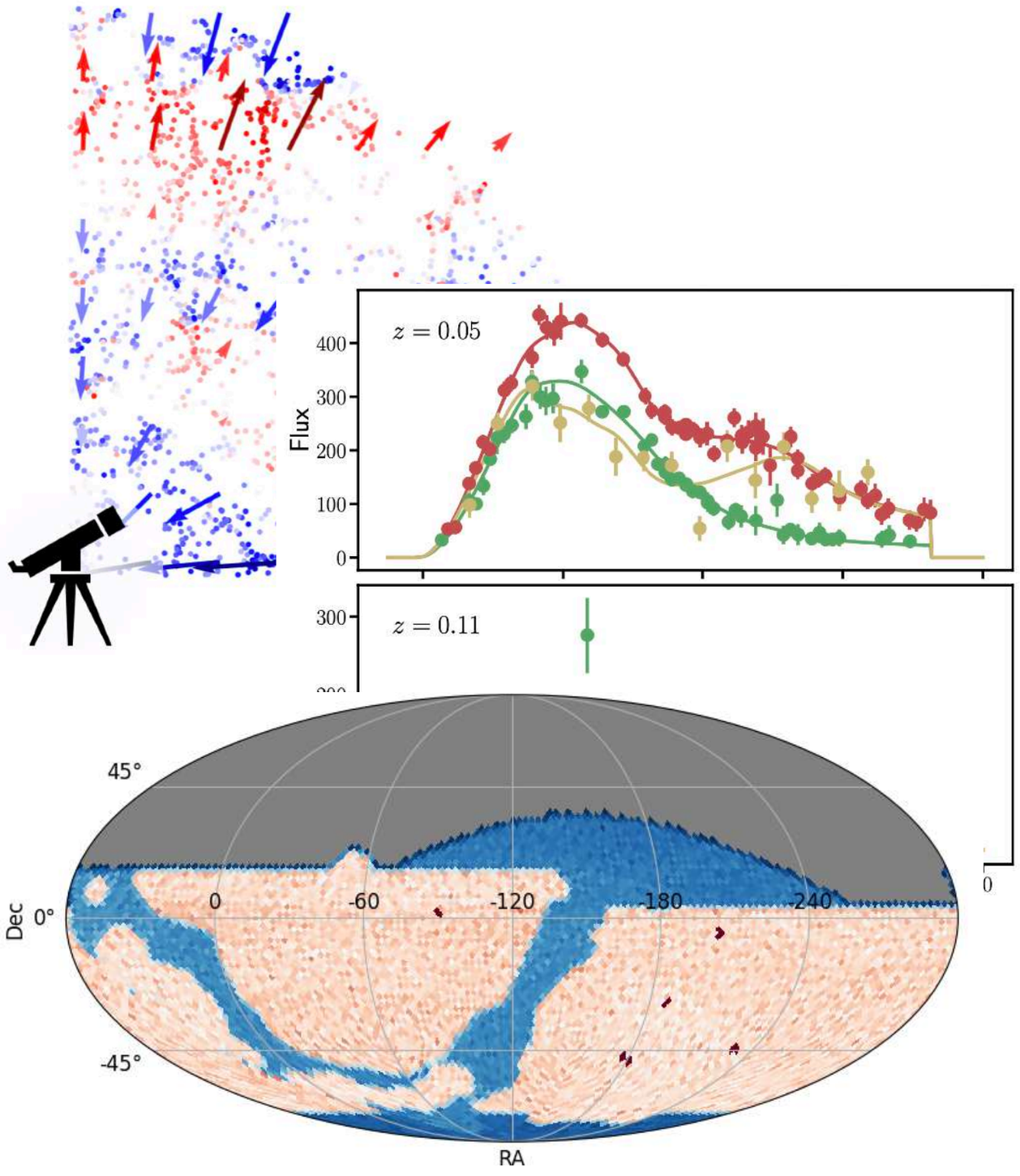
  Corentin Ravoux

- consider photometric typing: more SNIa, higher redshift, contamination by non-Ia

Steps forward



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  Corentin Ravoux

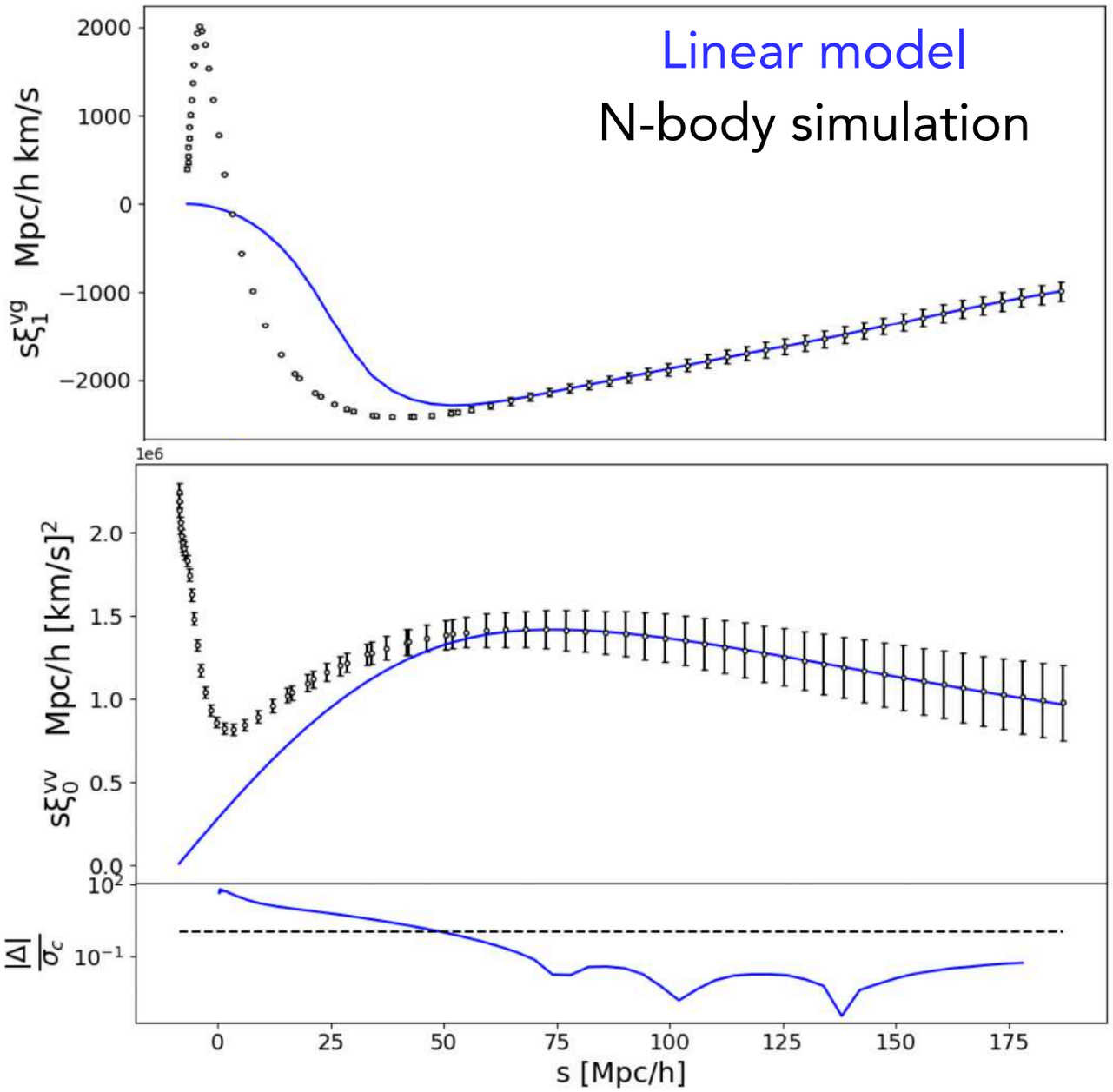
- consider photometric typing: more SNIa, higher redshift, contamination by non-Ia

+

- simulate Rubin-LSST SNIa samples

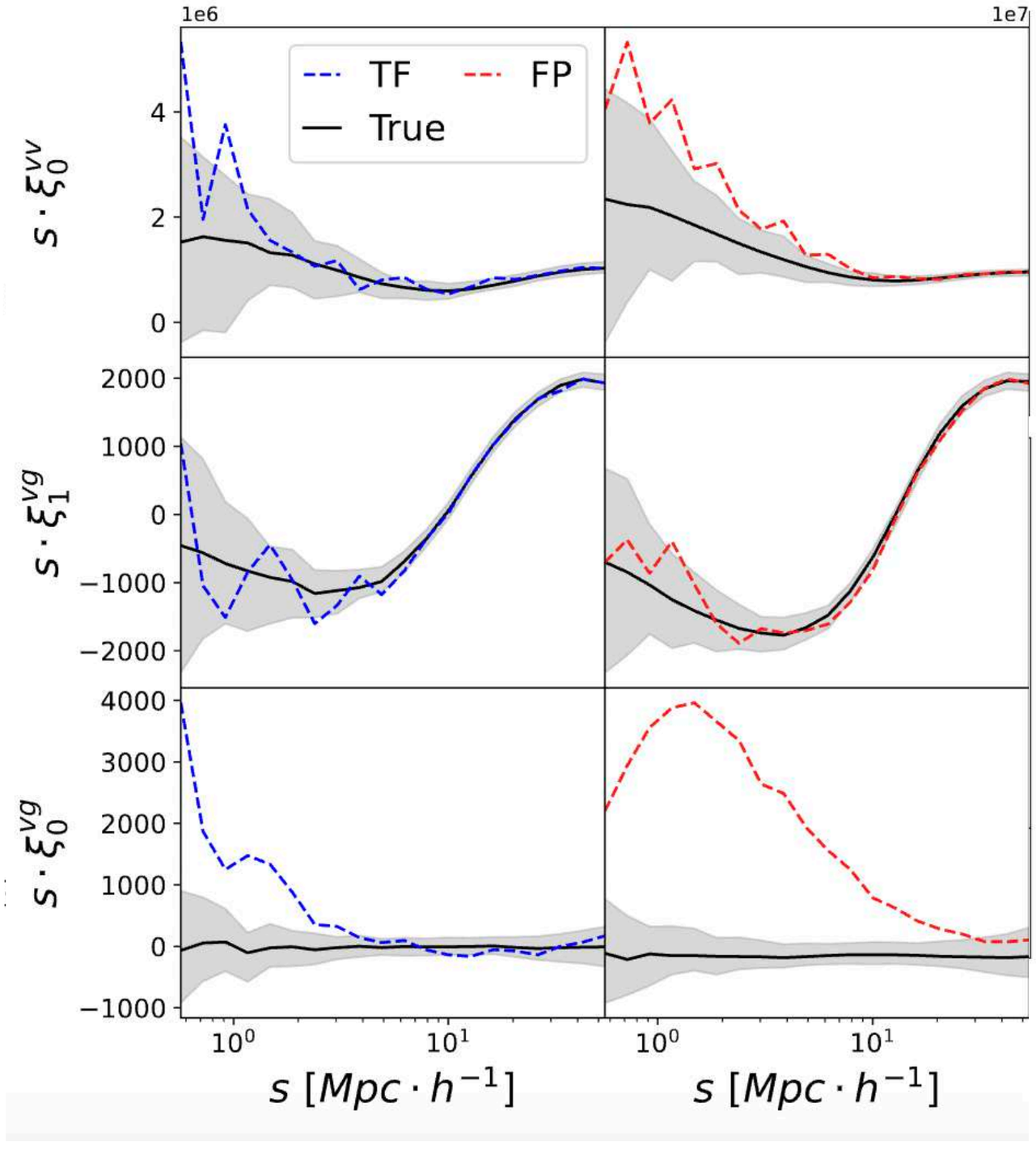
  Damiano Rosselli

Steps forward



- simulation-based non-linear models

Steps forward



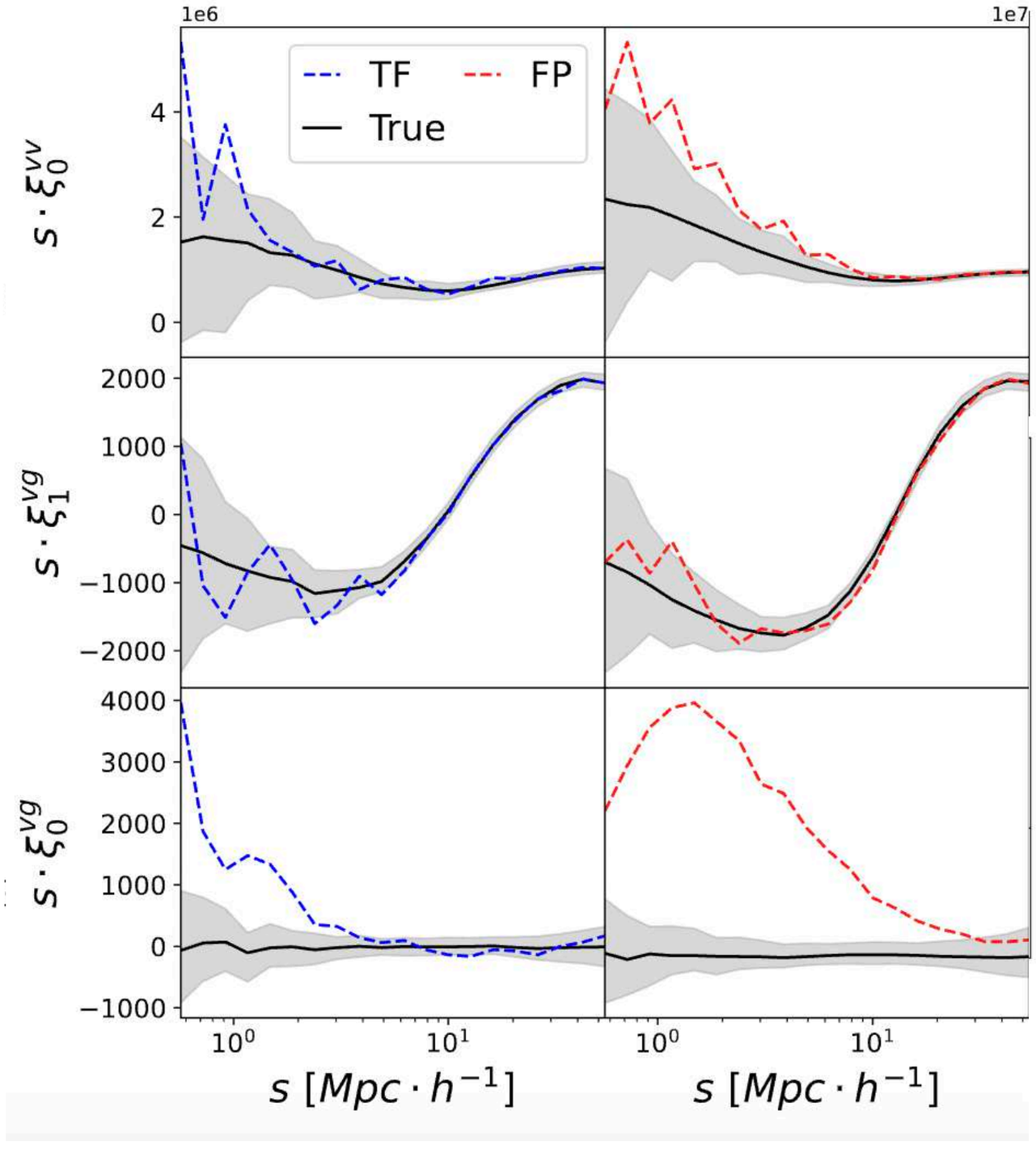
- simulation-based non-linear models

+

- astrophysical systematics on velocities from hydro-simulations

Tyann Dumerchat

Steps forward



- simulation-based non-linear models

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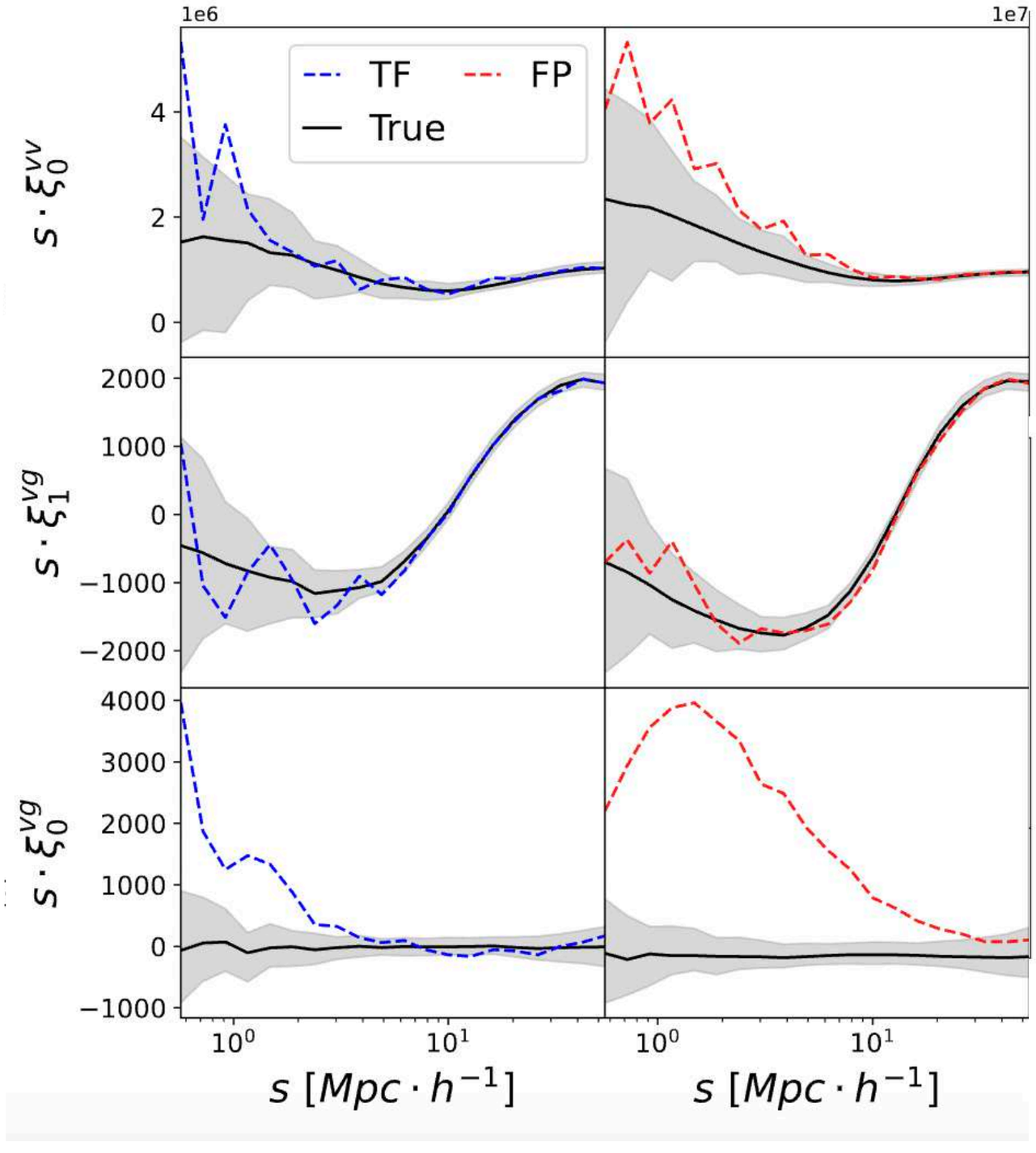
- astrophysical systematics on velocities from hydro-simulations

  Tyann Dumerchat

- Environmental dependencies of SNIa velocities

  Vincenzo Aronica

Steps forward



- simulation-based non-linear models

+

- astrophysical systematics on velocities from hydro-simulations

  Tyann Dumerchat

- Environmental dependencies of SNIa velocities

  Vincenzo Aronica

- And much more !

Conclusion

We need to measure the growth rate, as a test of dark energy and gravity models

Peculiar velocities are essential for low-z growth-rate measurements:
up to factor 2 improvement over RSD only

DESI and ZTF are currently providing one of the datasets for such analysis
4MOST and LSST in the near future

Simulation based forecast on ZTF SNIa sample yields 19% uncertainty on growth rate

Lots of work ahead

Aix*Marseille université
Socialement engagée

A*Midex
Initiative d'excellence Aix-Marseille

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM