Towards growth-rate measurements with DESI + ZTF

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CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

Plan

Why growth-rate measurements at low-redshift?

How to measure growth-rate with galaxies and peculiar velocities?
Methods and state-of-the-art

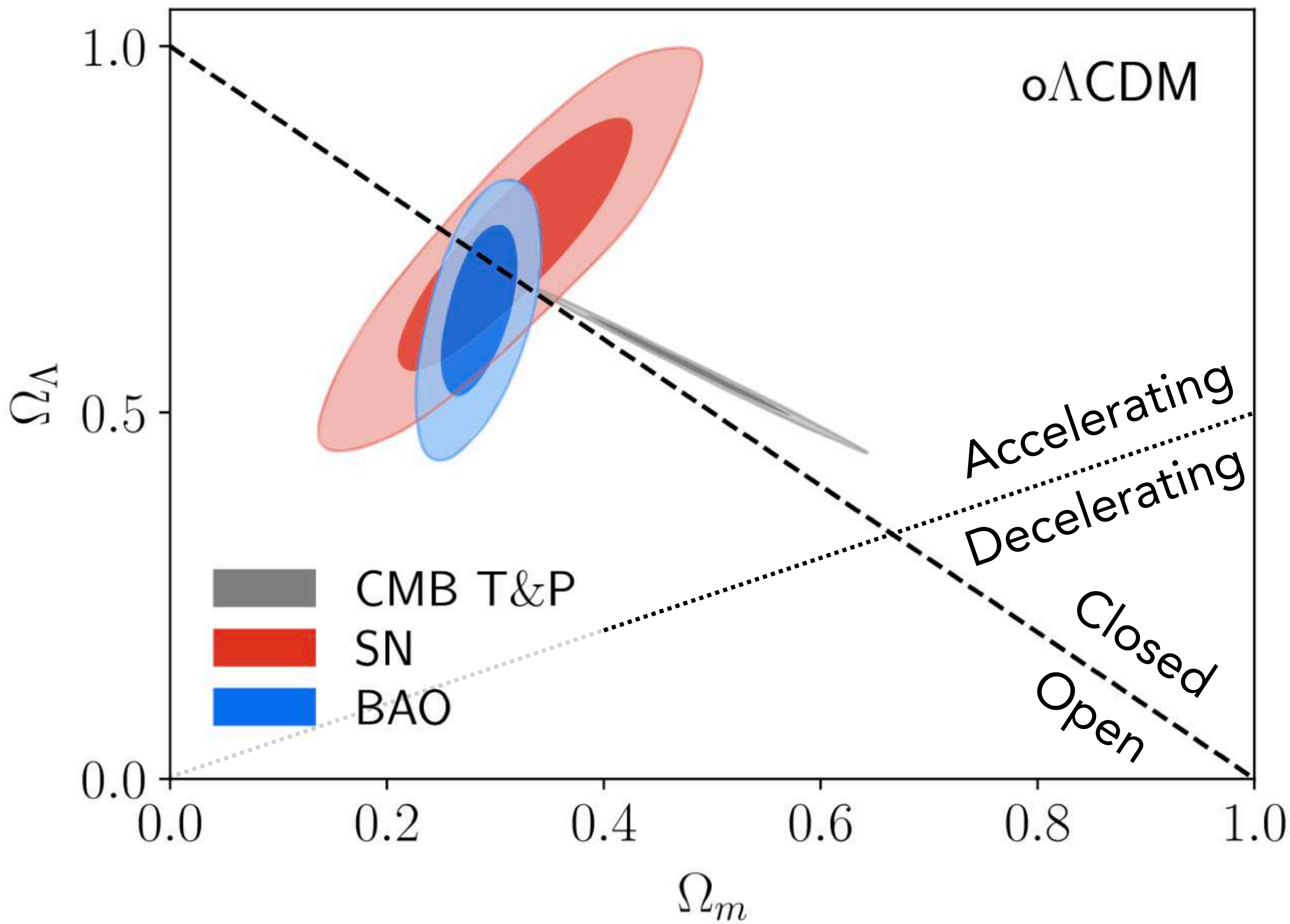
What data DESI and ZTF are providing us?
Forecasts

Challenges and work in progress

Why growth-rate measurements at low-redshift?

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

Dark energy as a cosmological constant



eBOSS Collaboration 2021

Acceleration requires dark energy

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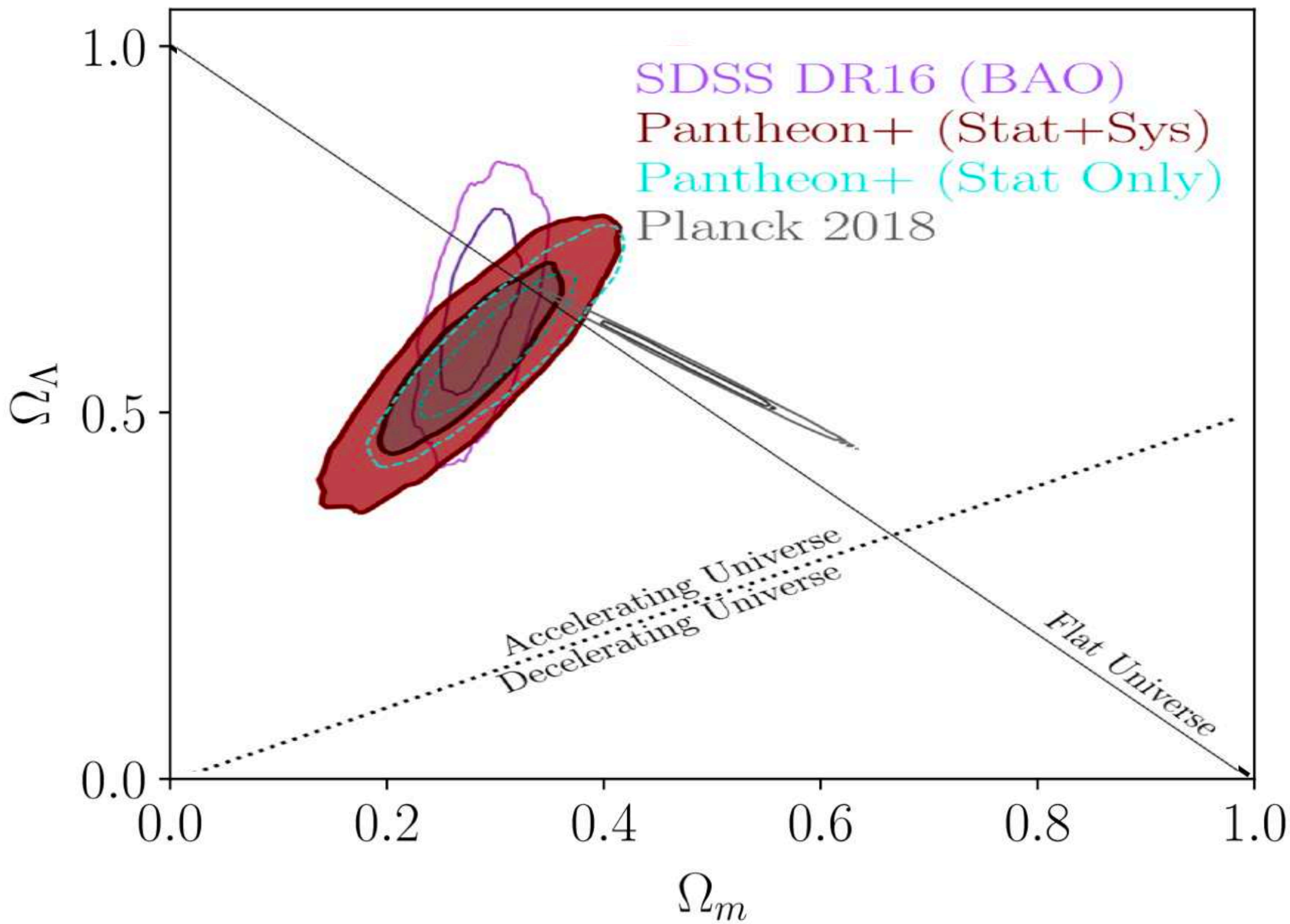
Dark energy as a cosmological constant



Pantheon+ Brout et al. 2022

Acceleration requires dark energy

Physically motivated theory ? Alternatives or extensions of General Relativity

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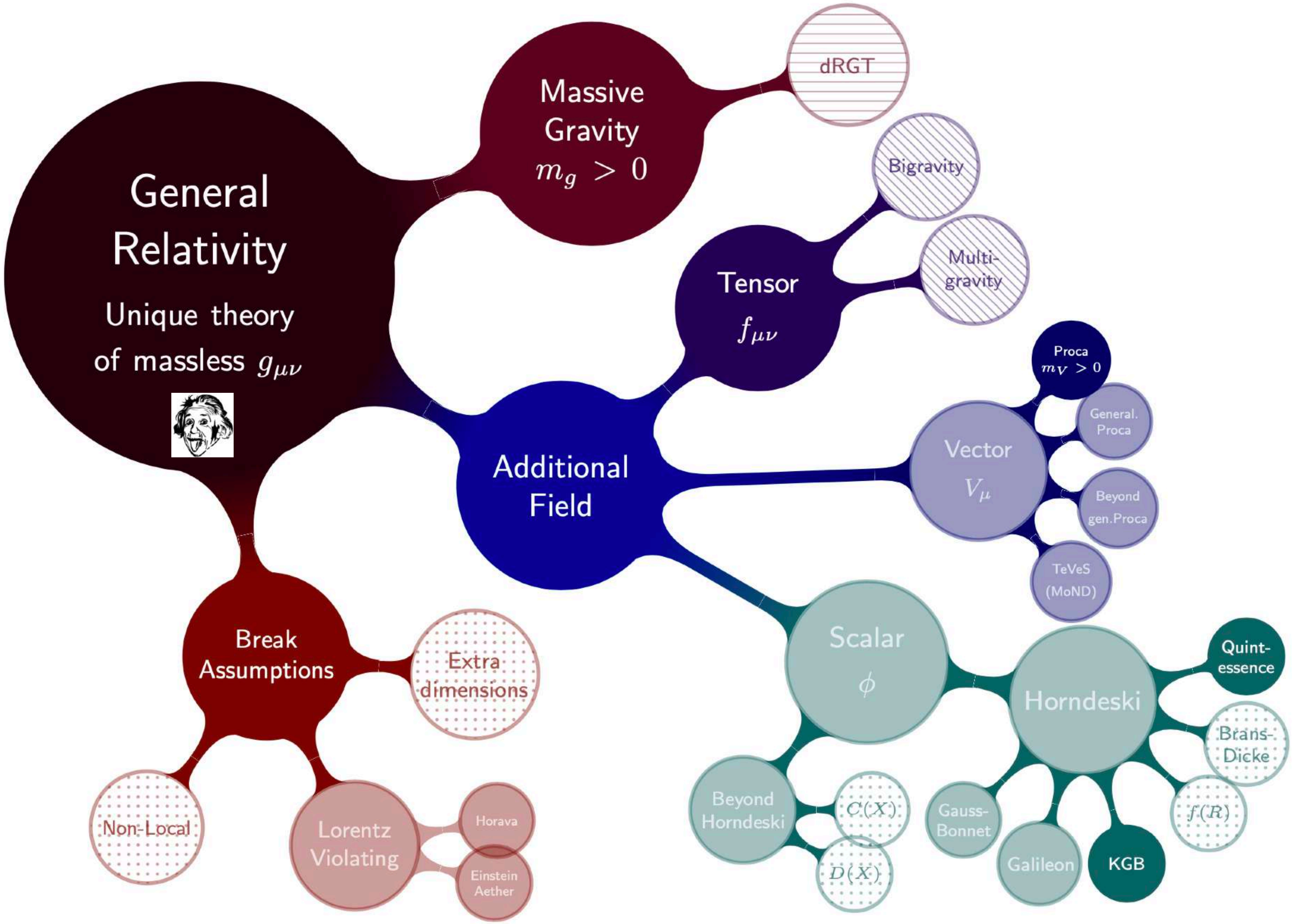
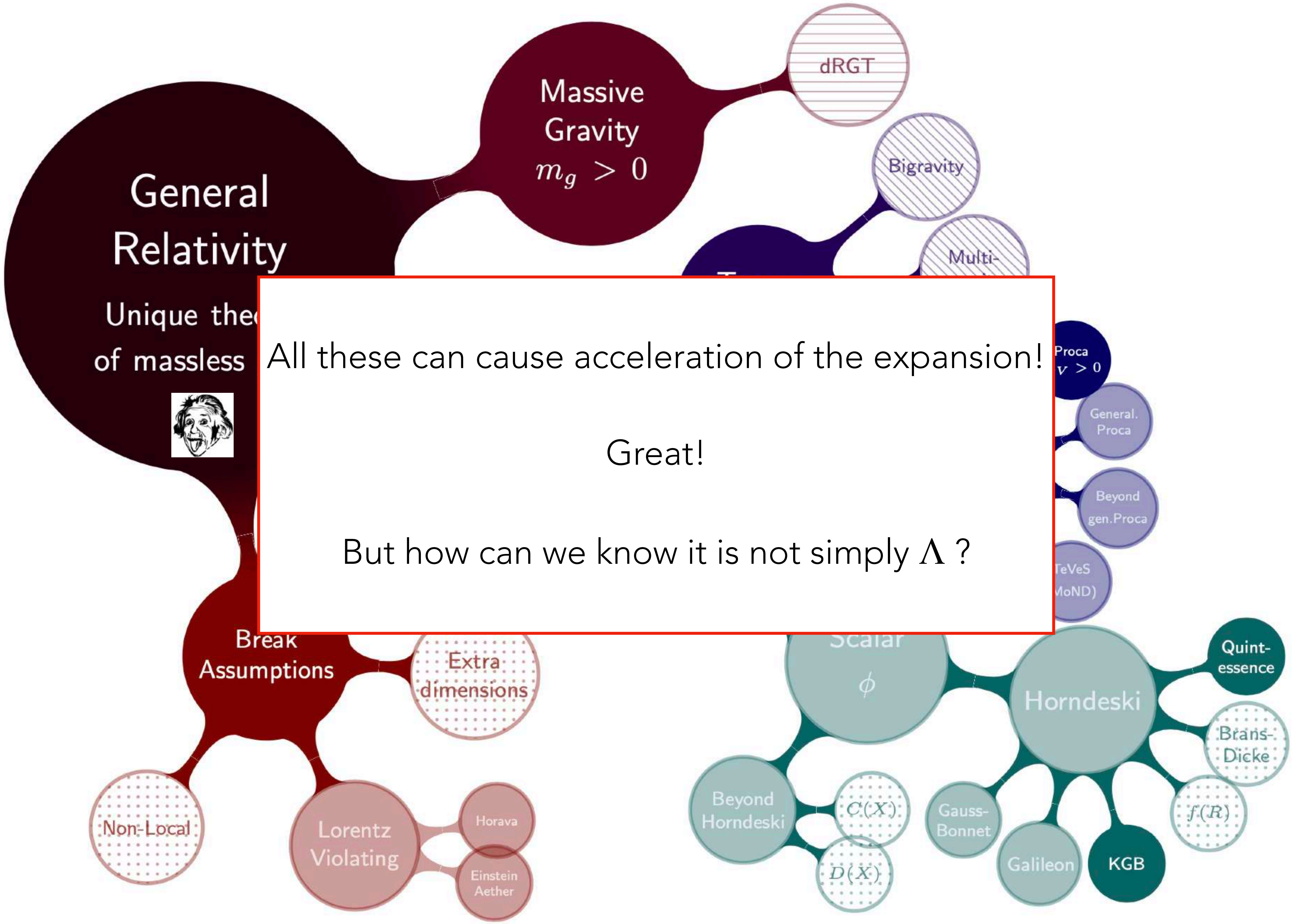


Review by Ezquiaga & Zumalacárregui 2018

Physically motivated theory ? Alternatives or extensions of General Relativity

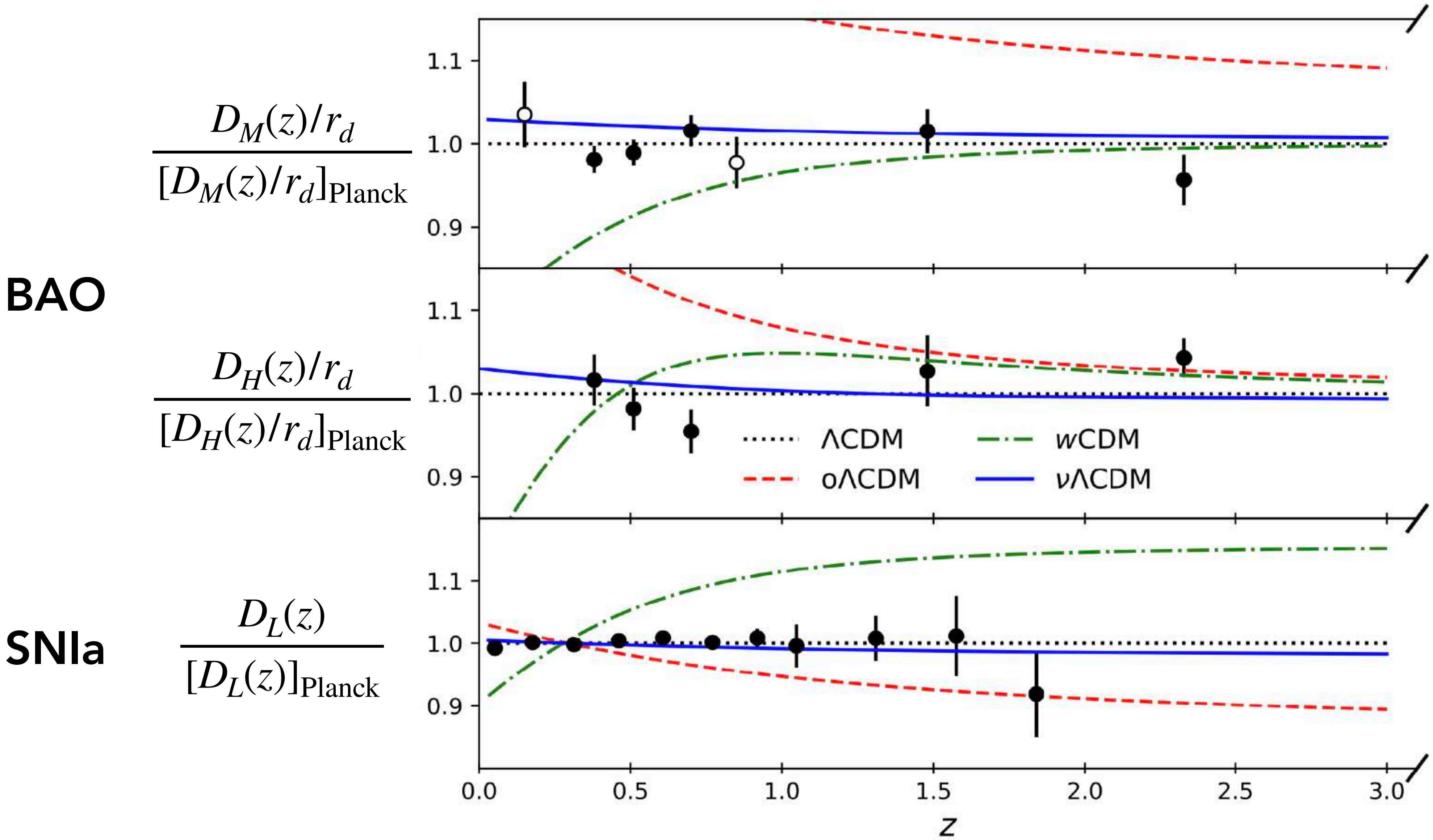


All these can cause acceleration of the expansion!

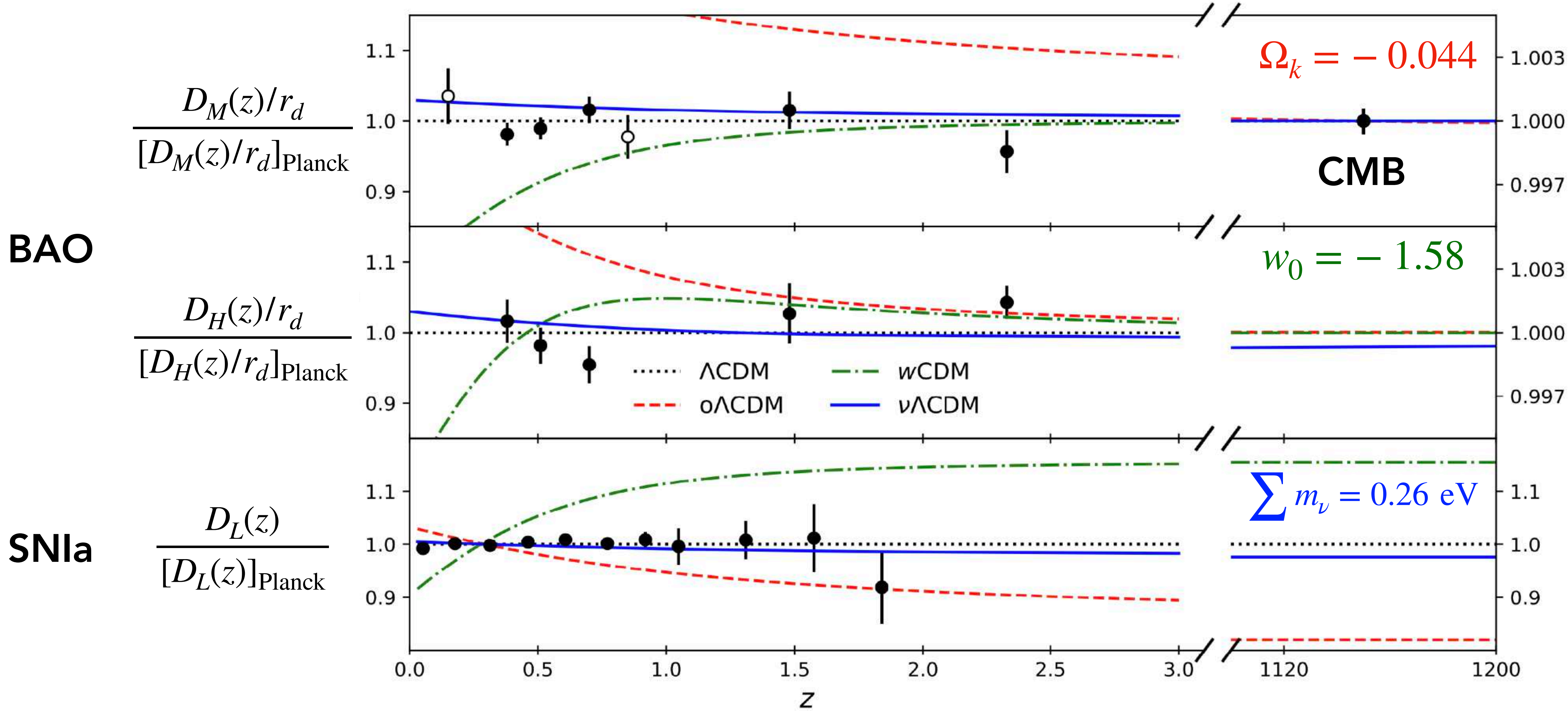
Great!

But how can we know it is not simply Λ ?

Review by Ezquiaga & Zumalacárregui 2018



RSD can break degeneracy between dark energy or modified gravity models



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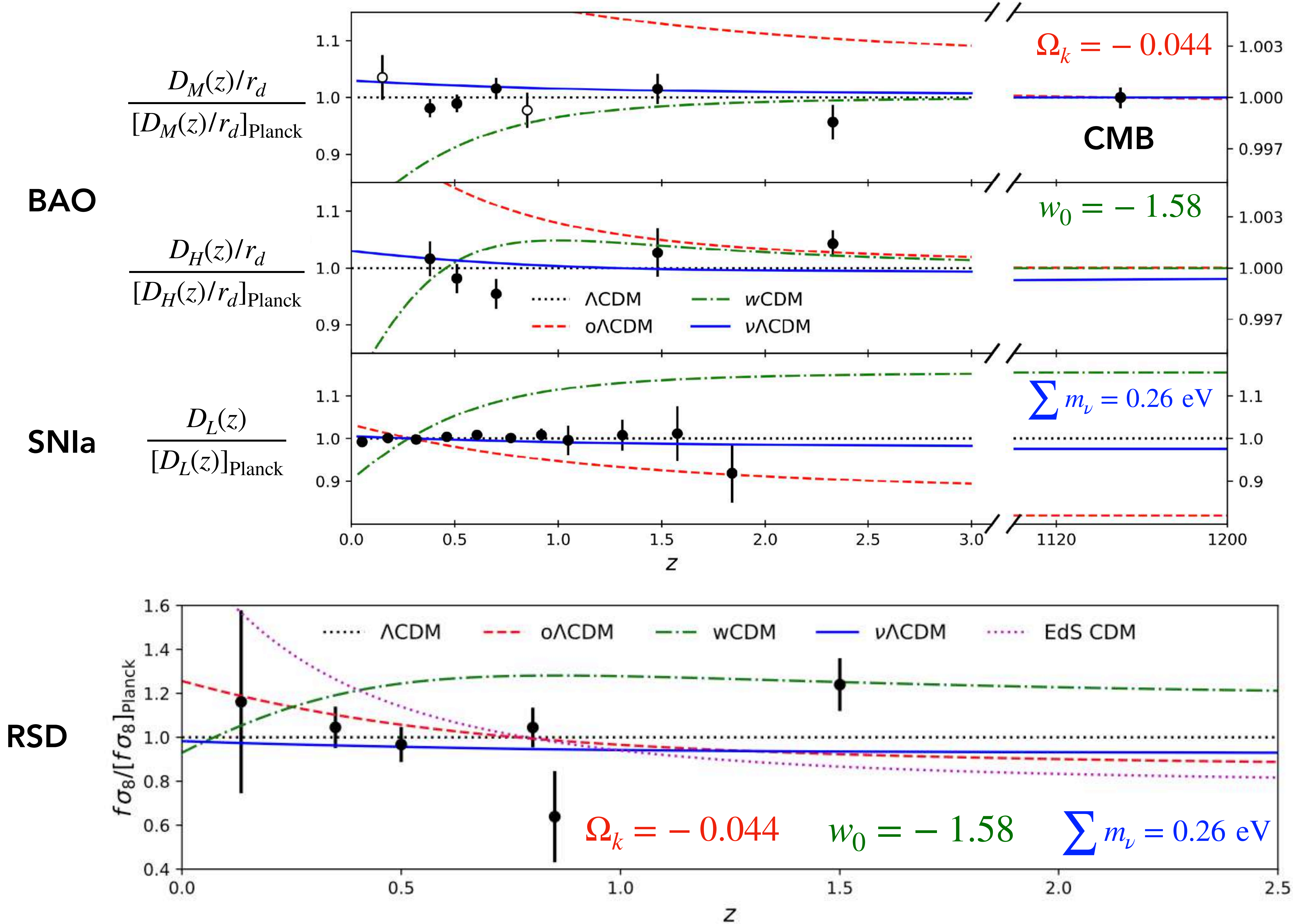
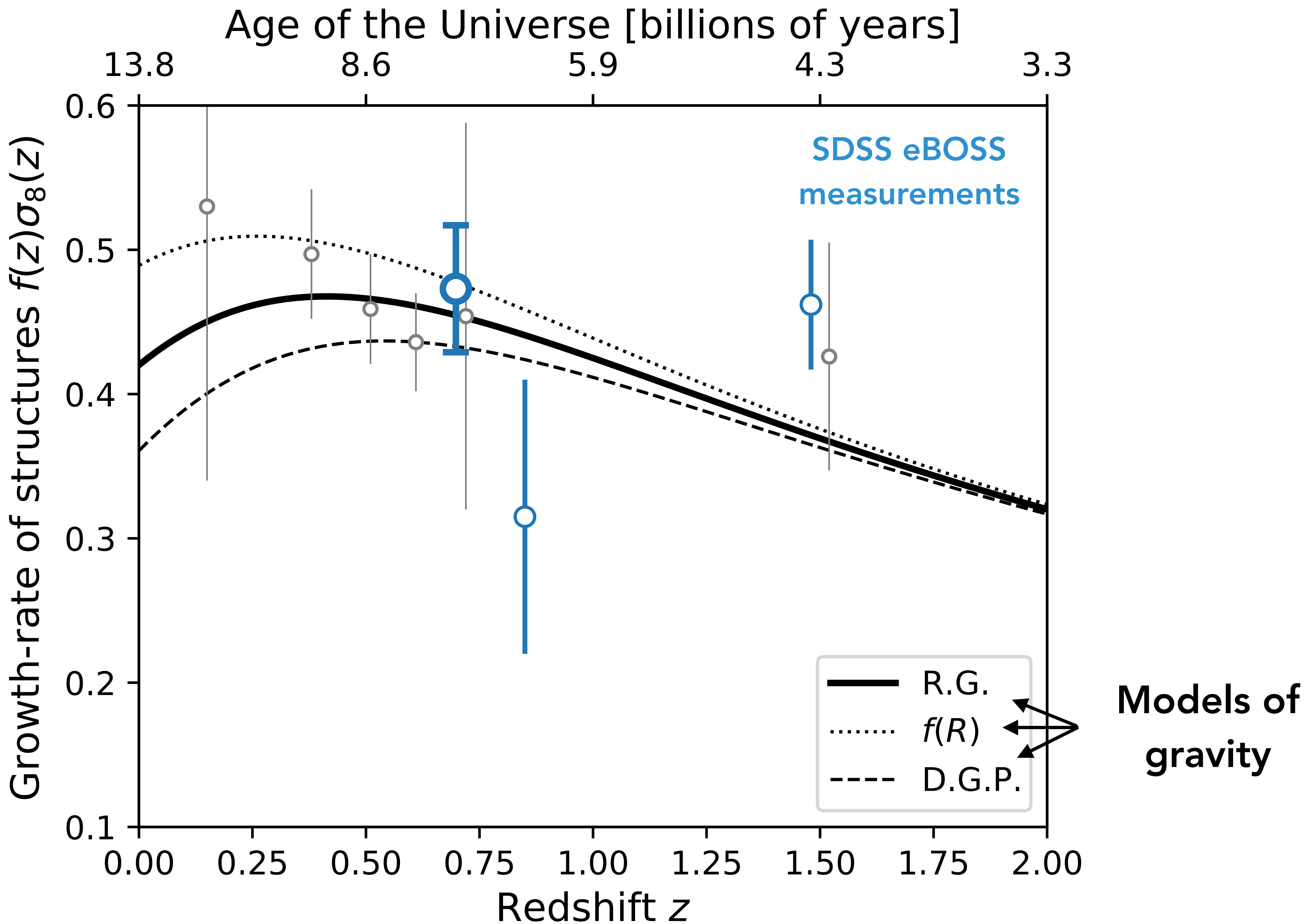
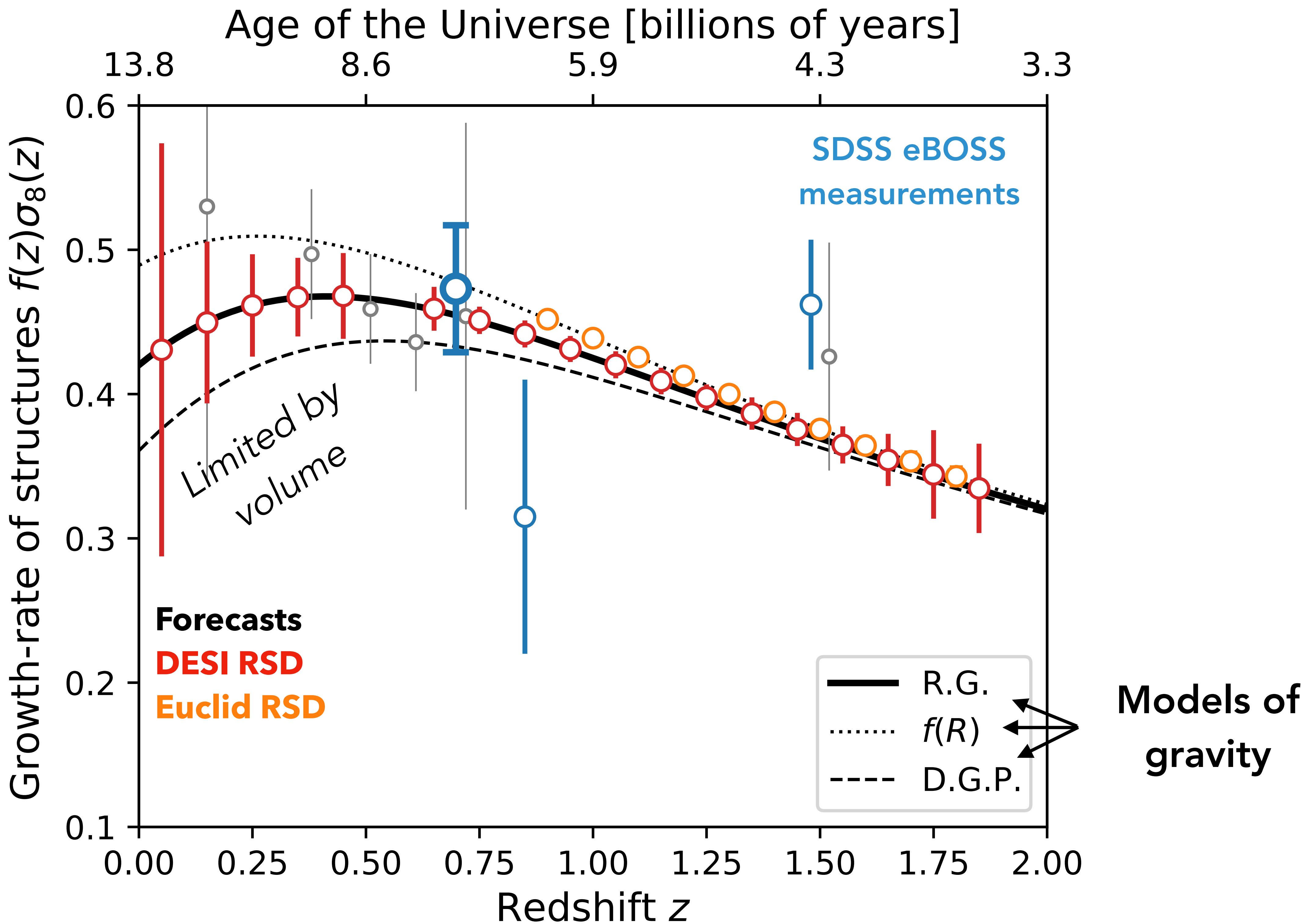


RSD can break degeneracy between dark energy or modified gravity models

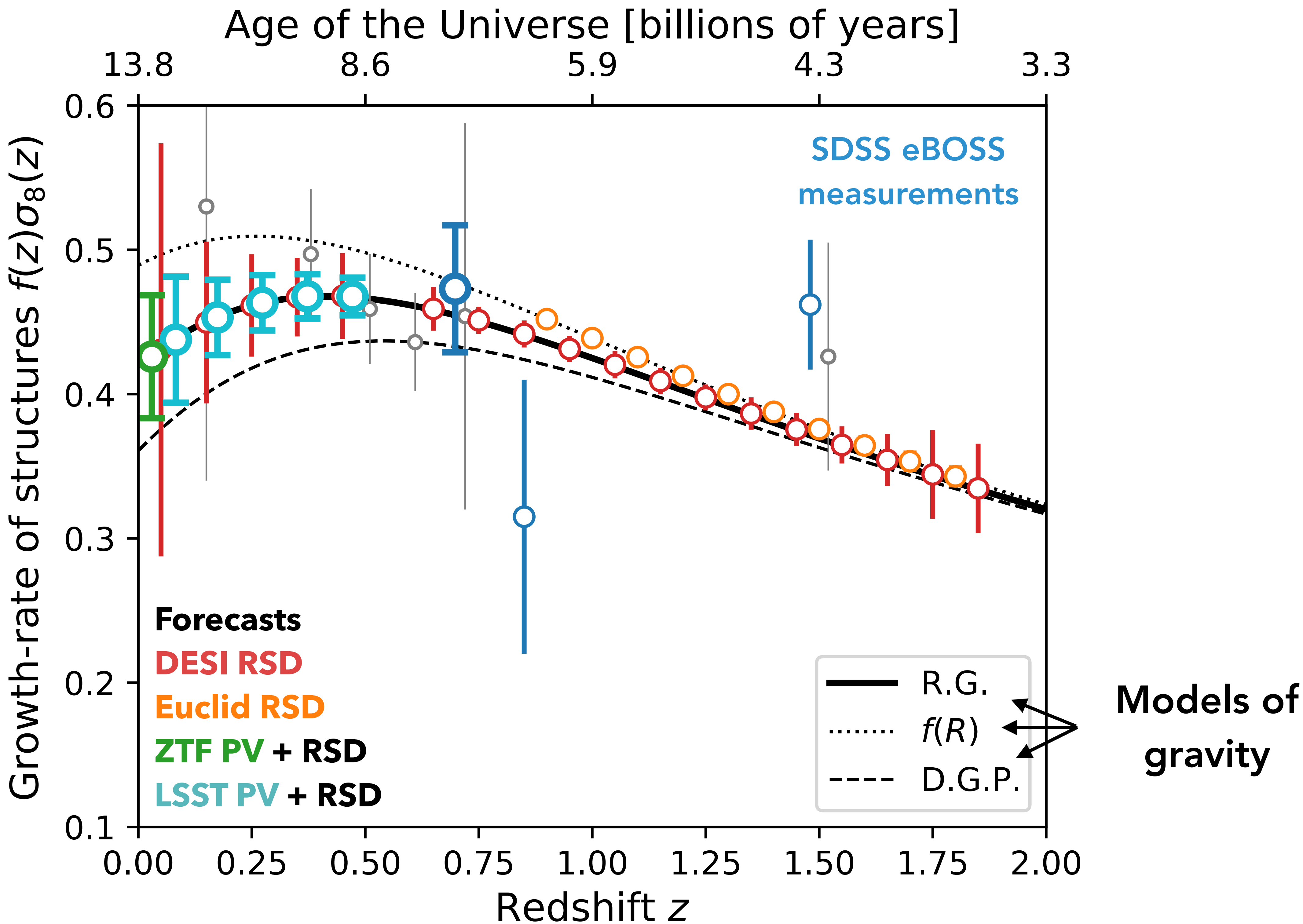
Measurements of growth-rate of structures



Measurements of growth-rate of structures



Measurements of growth-rate of structures



Significant improvement at low-z when adding **peculiar velocities** !

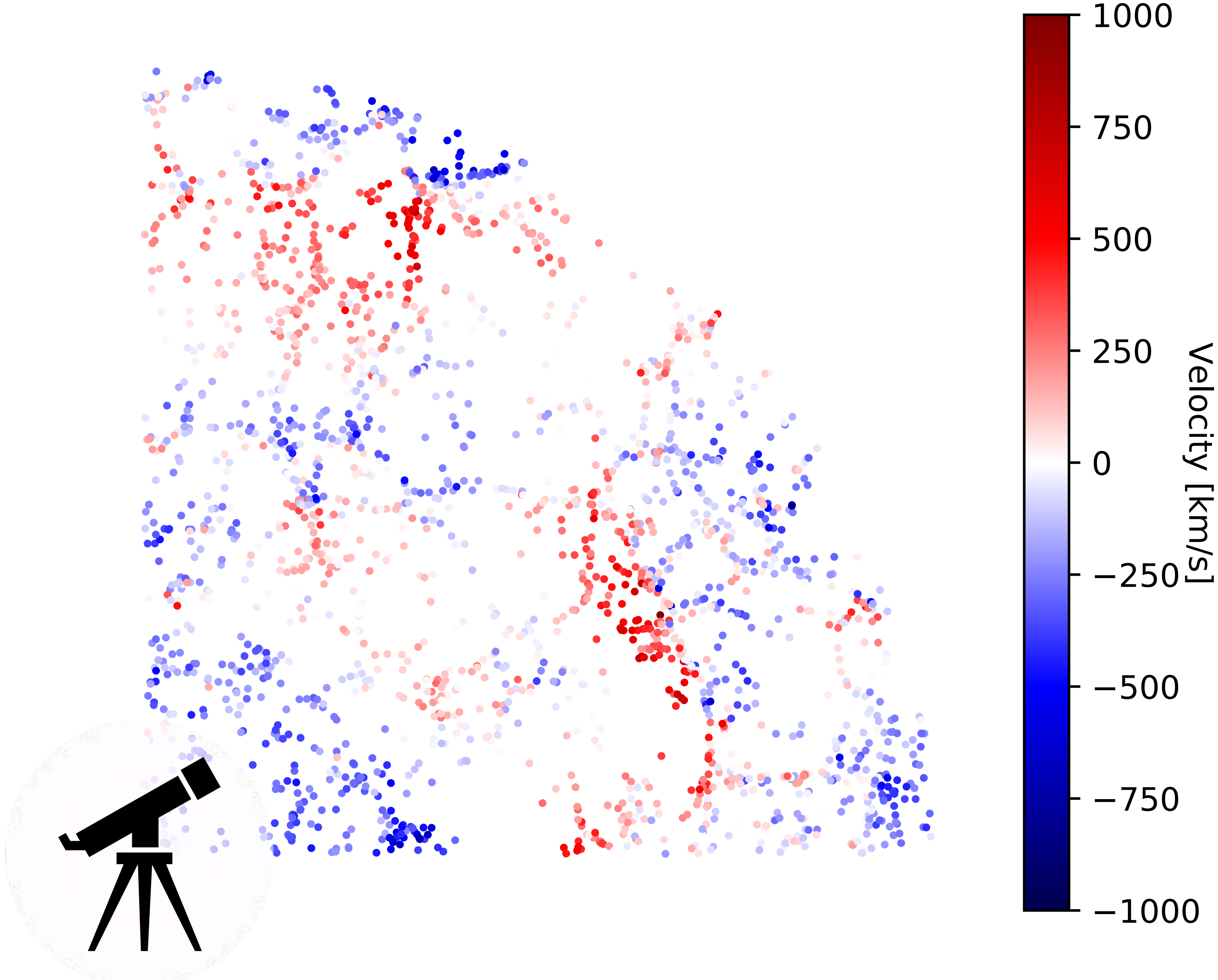
How to measure growth-rate with galaxies and peculiar velocities?

Methods and state-of-the-art

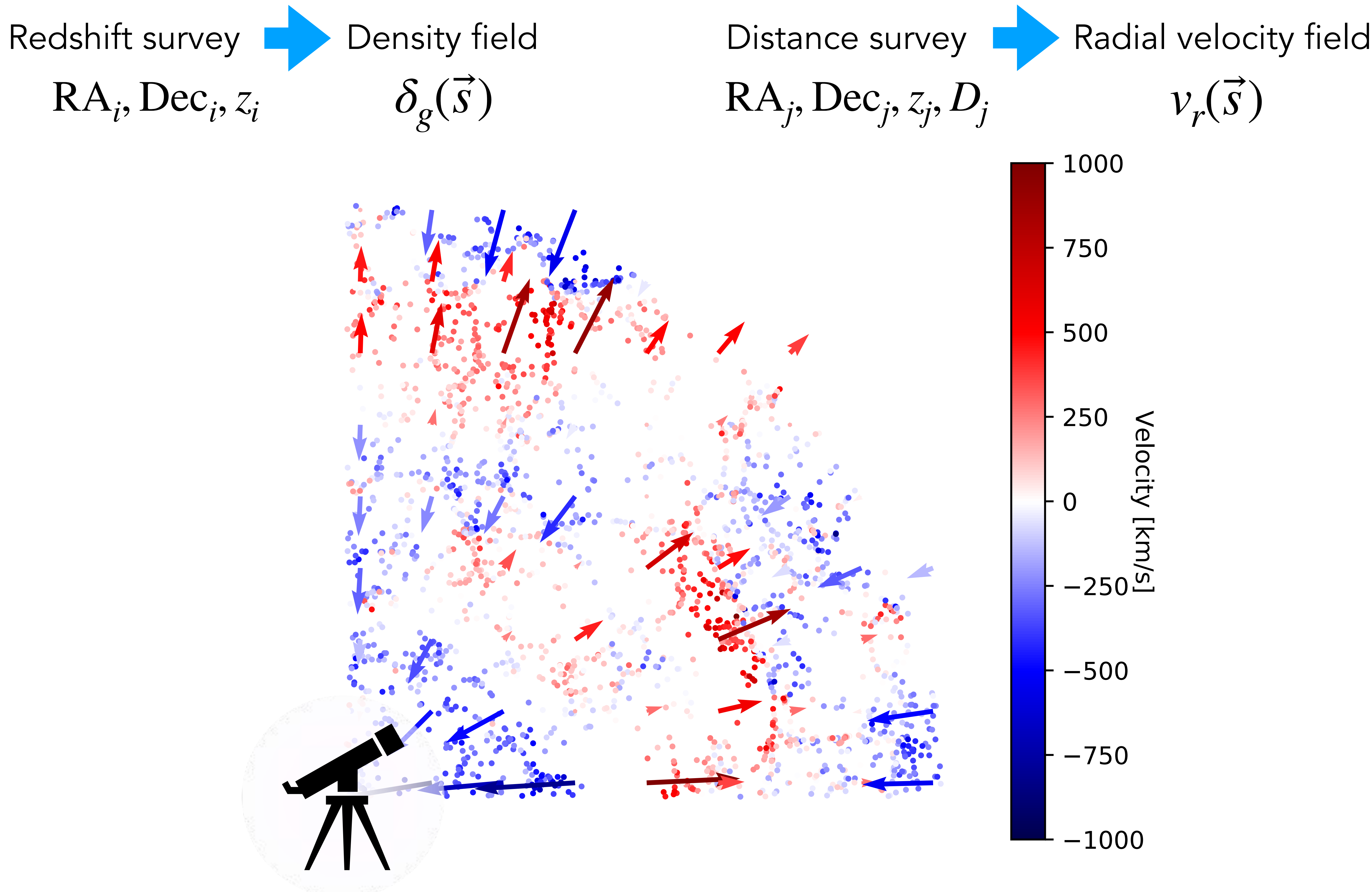
Observables

Redshift survey → Density field

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



Observables



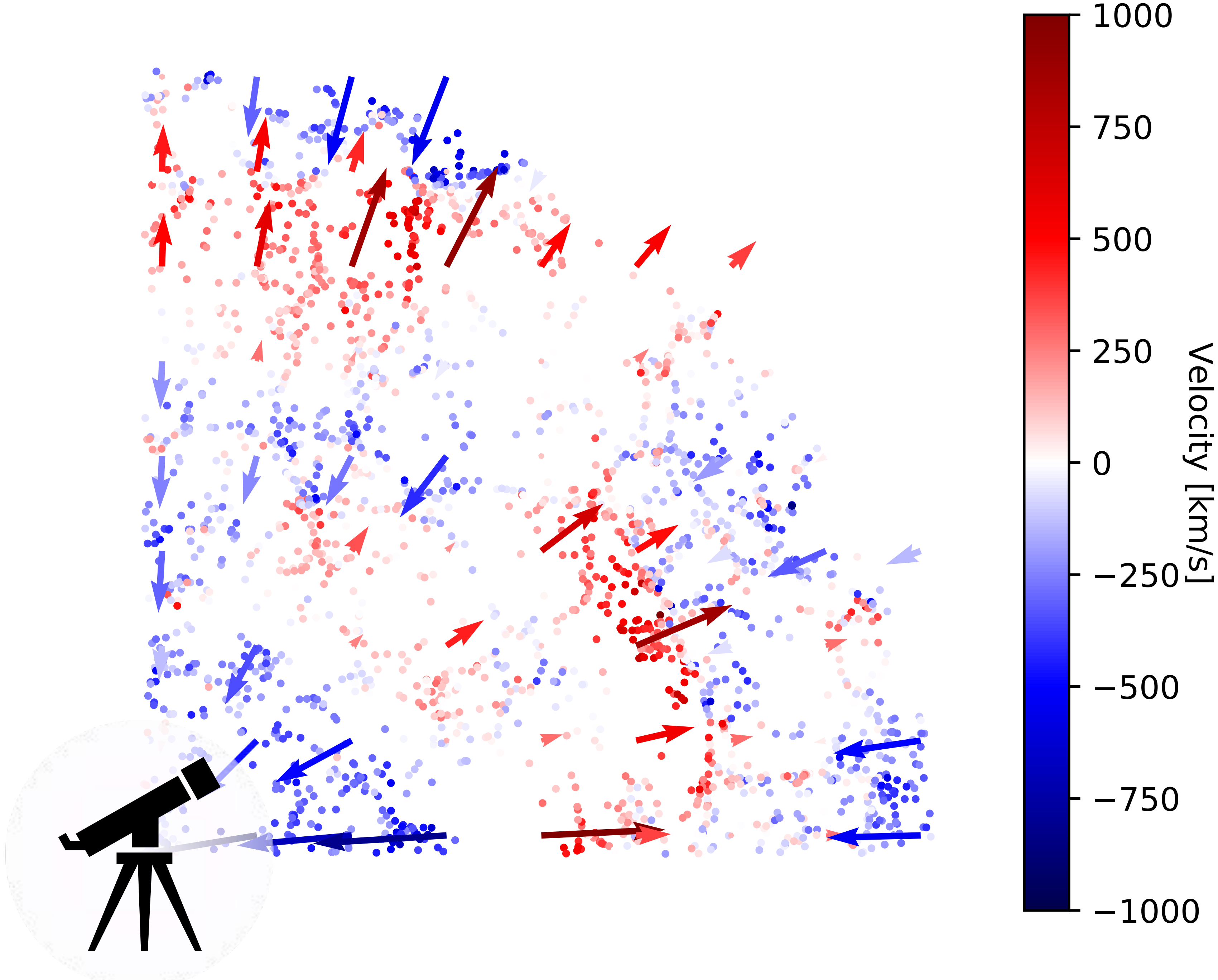
Observables

Redshift survey → Density field

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

Distance survey → Radial velocity field

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



How to measure peculiar velocities?

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Tully-Fisher

Fundamental plane

Type-Ia supernova

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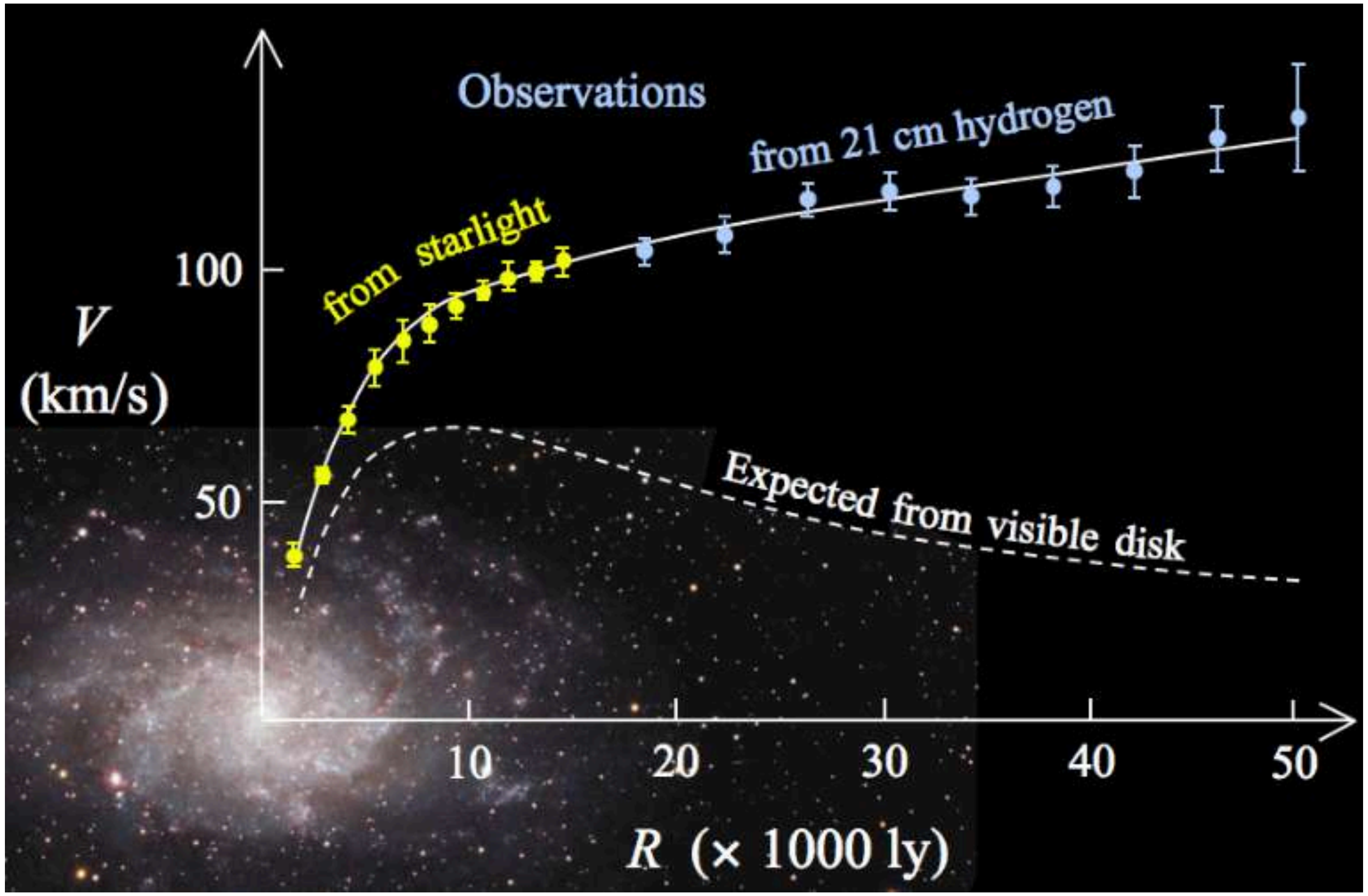
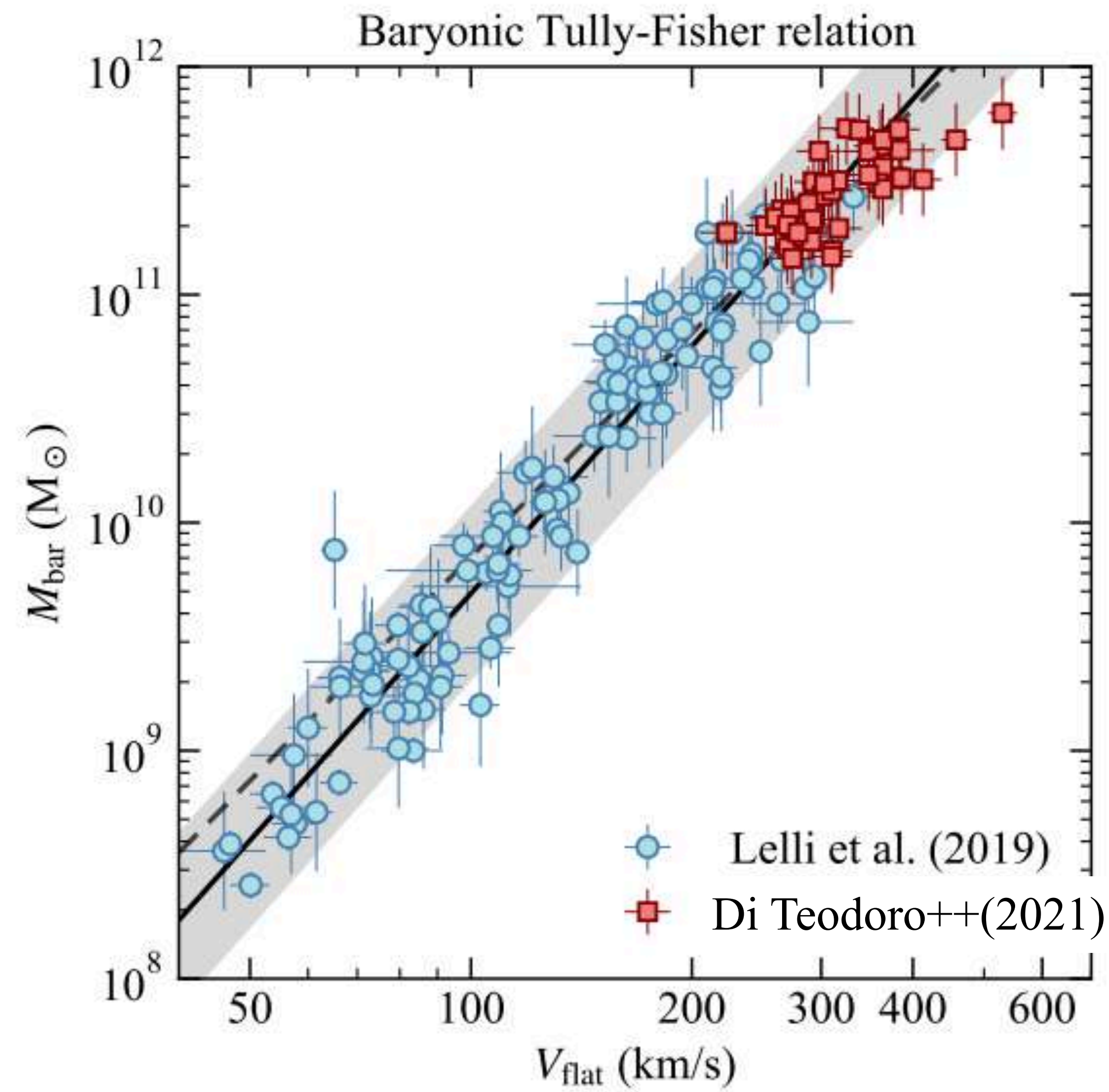




Relation between asymptotic **rotational velocity** *Distance independent* and **luminosity** *Distance dependent*

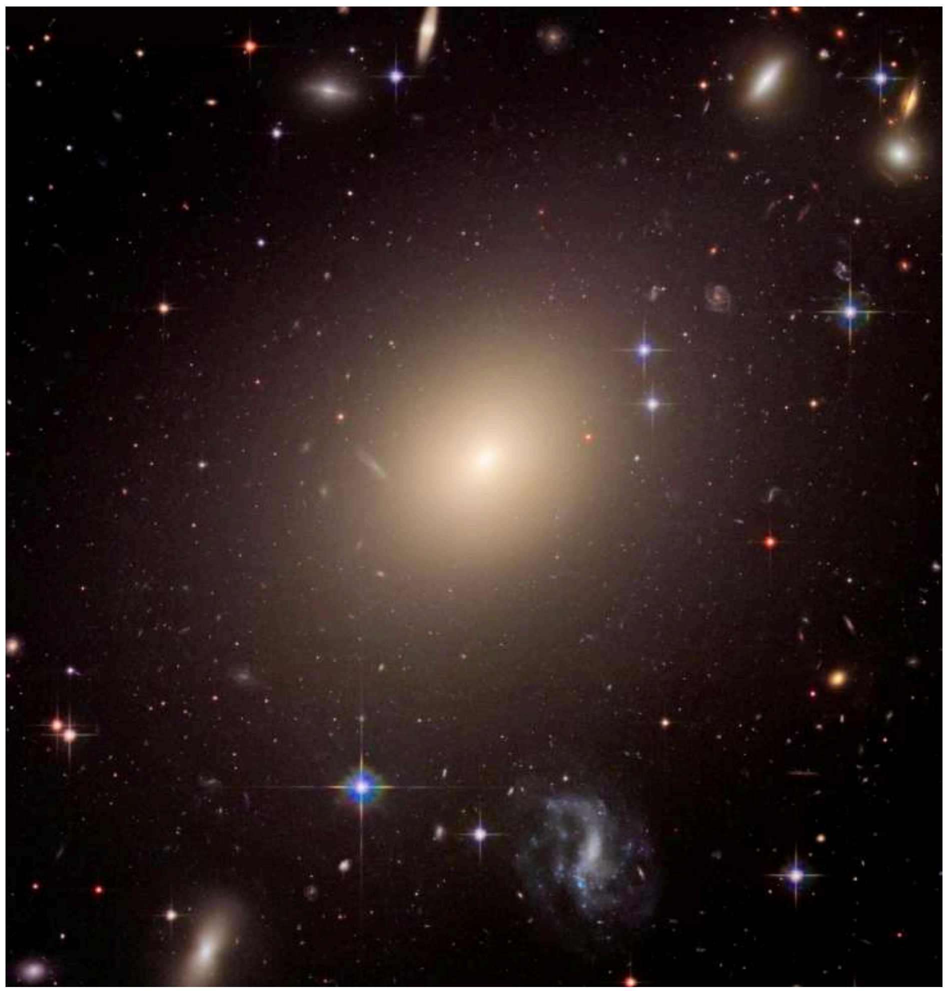
Largest catalogue to date: ~10k distances CosmicFlows4
(Kourkchi et al. 2022, Tully et al. 2022)

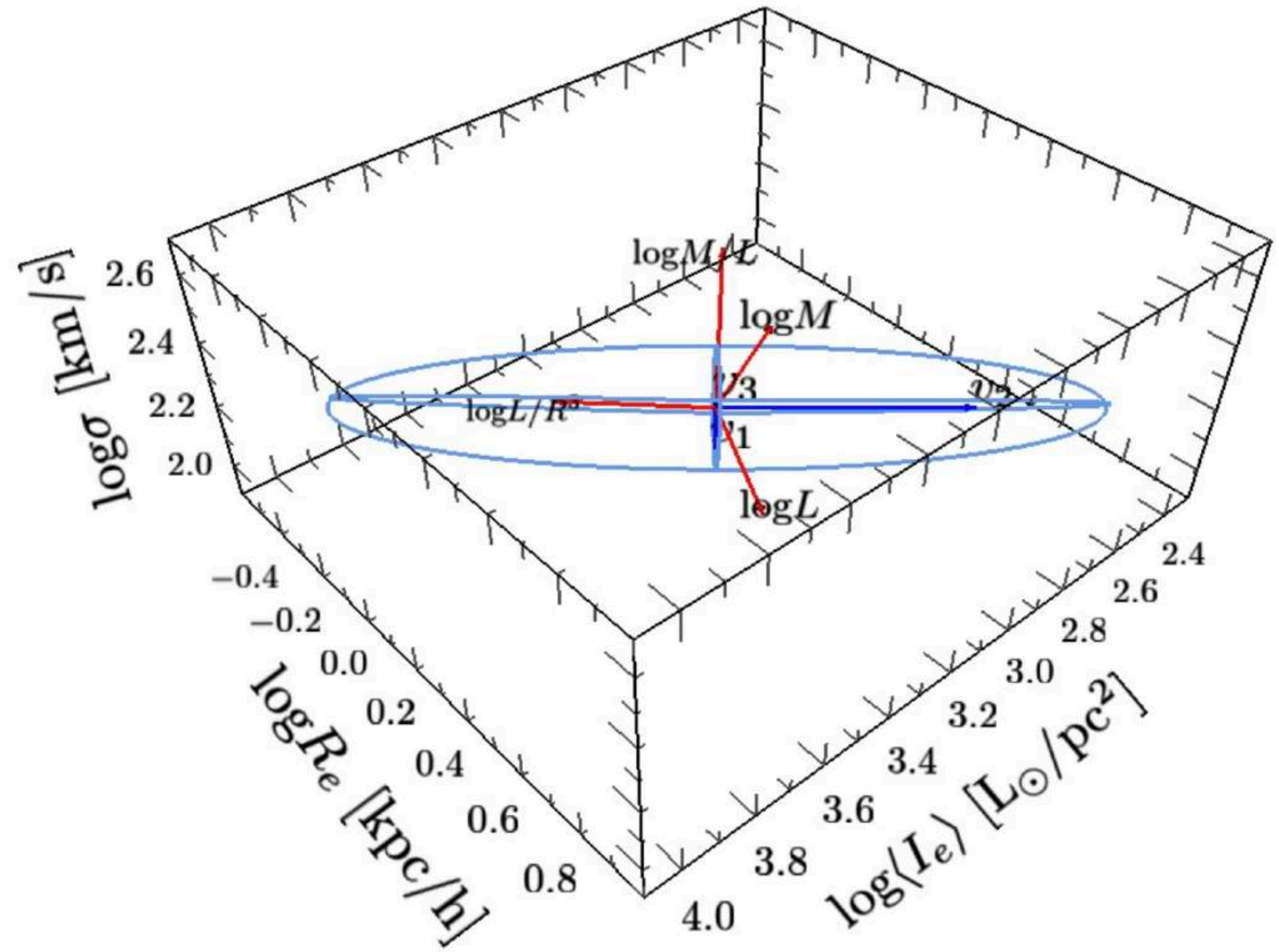
How to measure peculiar velocities?

Tully-Fisher

Fundamental plane

Type-Ia supernova





Relation between **velocity dispersion, surface brightness** *Distance independent* and **effective radius** *Distance dependent*

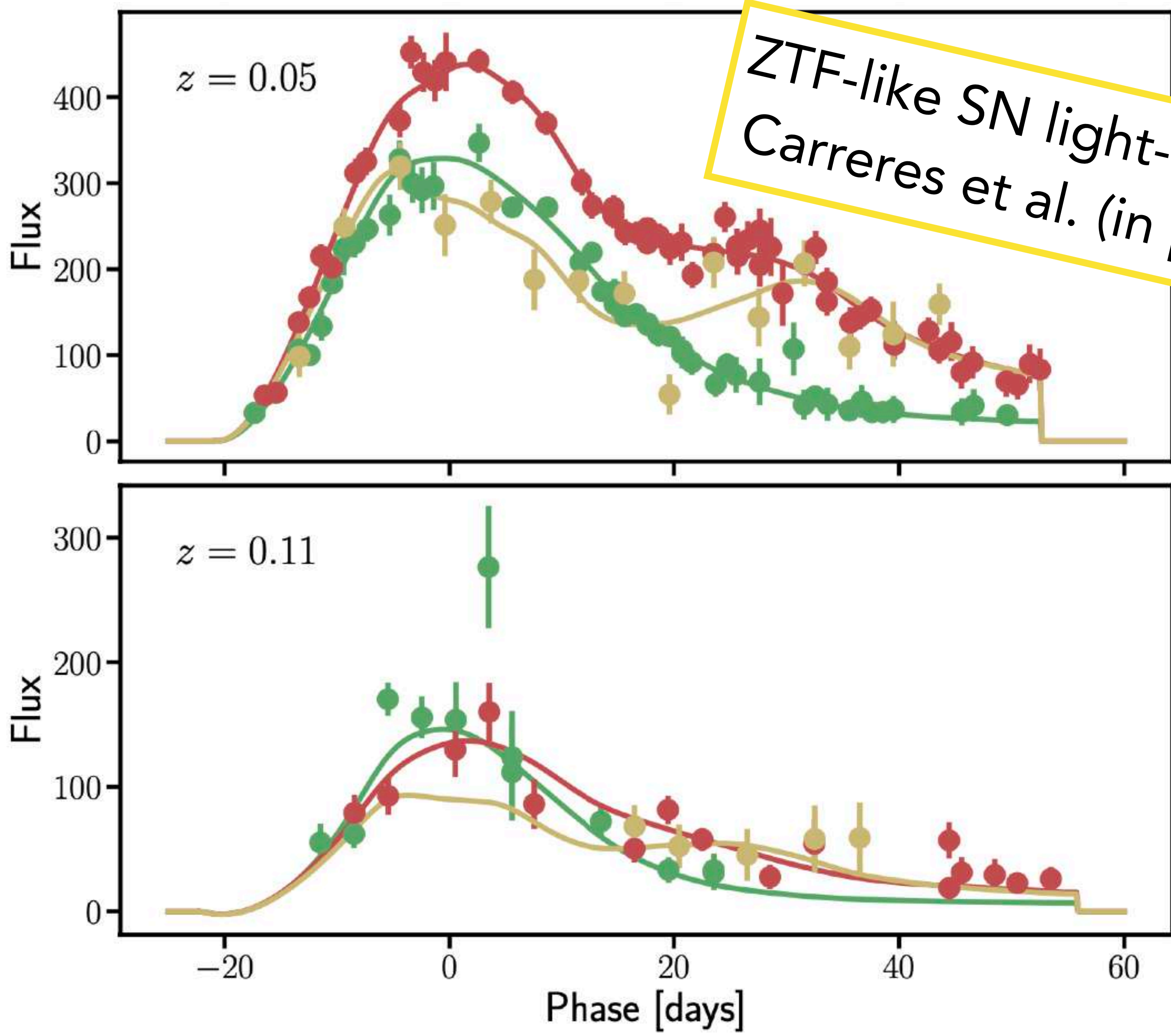
Largest catalogue to date: ~40k distances SDSS (Howlett et al. 2022)

How to measure peculiar velocities?

Tully-Fisher

Fundamental plane

Type-Ia supernova



ZTF-like SN light-curves
Carreres et al. (in prep)

stretch + colour + redshift

magnitude at peak

Relation between **light-curve shape** *Distance independent* and **magnitude at peak brightness** *Distance dependent*

Largest catalogue to date: 1550 distances (Pantheon+)

How to measure peculiar velocities?

Tully-Fisher	Fundamental plane	Type-Ia supernova
Loads of galaxies	Loads of galaxies	"Fewer" SNIa
Needs several spectra / galaxy	One optical spectrum is enough	Good photo-cadence + spectro follow-up
Needs asymptotic rotation (easy radio, harder in optical)	Precise photometry	Precise photometry

Intrinsic scatter (in distances):

Tully-Fisher	Fundamental plane	Type-Ia supernova
$\frac{\sigma_D}{D} \sim 20\,\%$	$\frac{\sigma_D}{D} \sim 20\,\%$	$\frac{\sigma_D}{D} \sim 7\,\%$

Future datasets

Tully-Fisher	Fundamental plane	Type-Ia supernova
WALLABY ~ 30k DESI ~ 53k	Taipan ~ 50k DESI ~ 133k	ZTF ~ 5k LSST ~ ? k

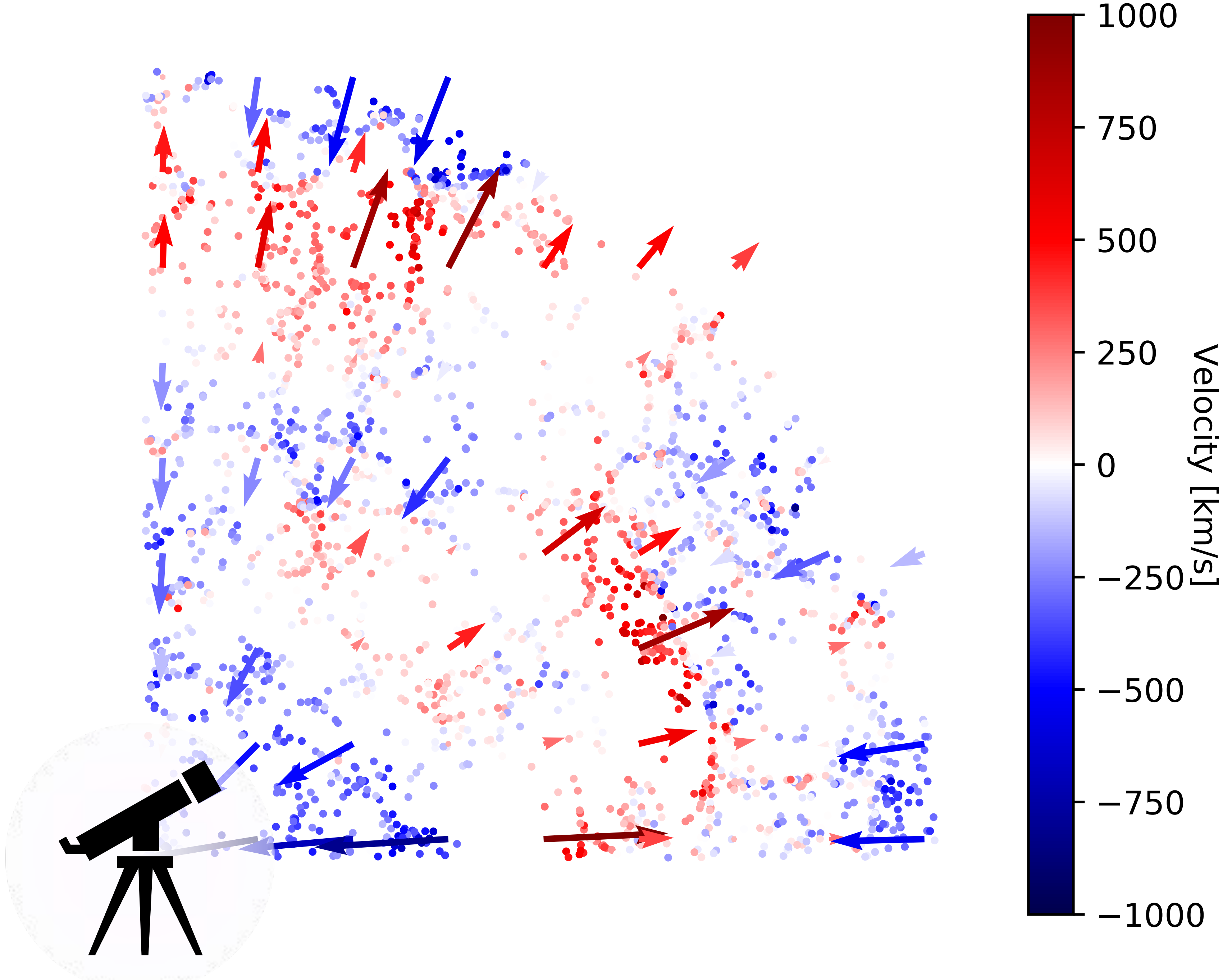
Observables

Redshift survey ➔ Density field

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

Distance survey ➔ Radial velocity field

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



How to measure growth-rate / cosmology with these observables?

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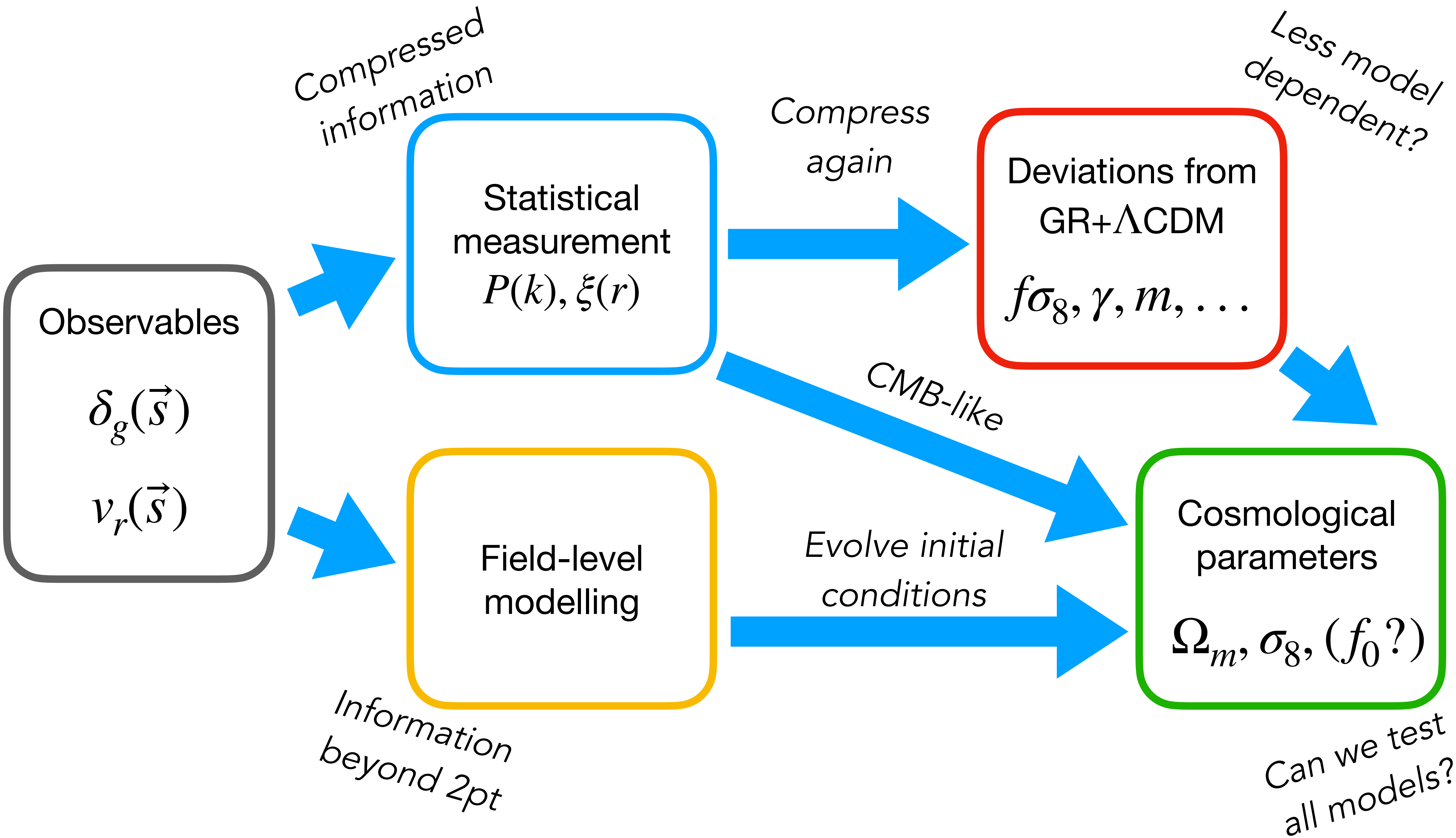
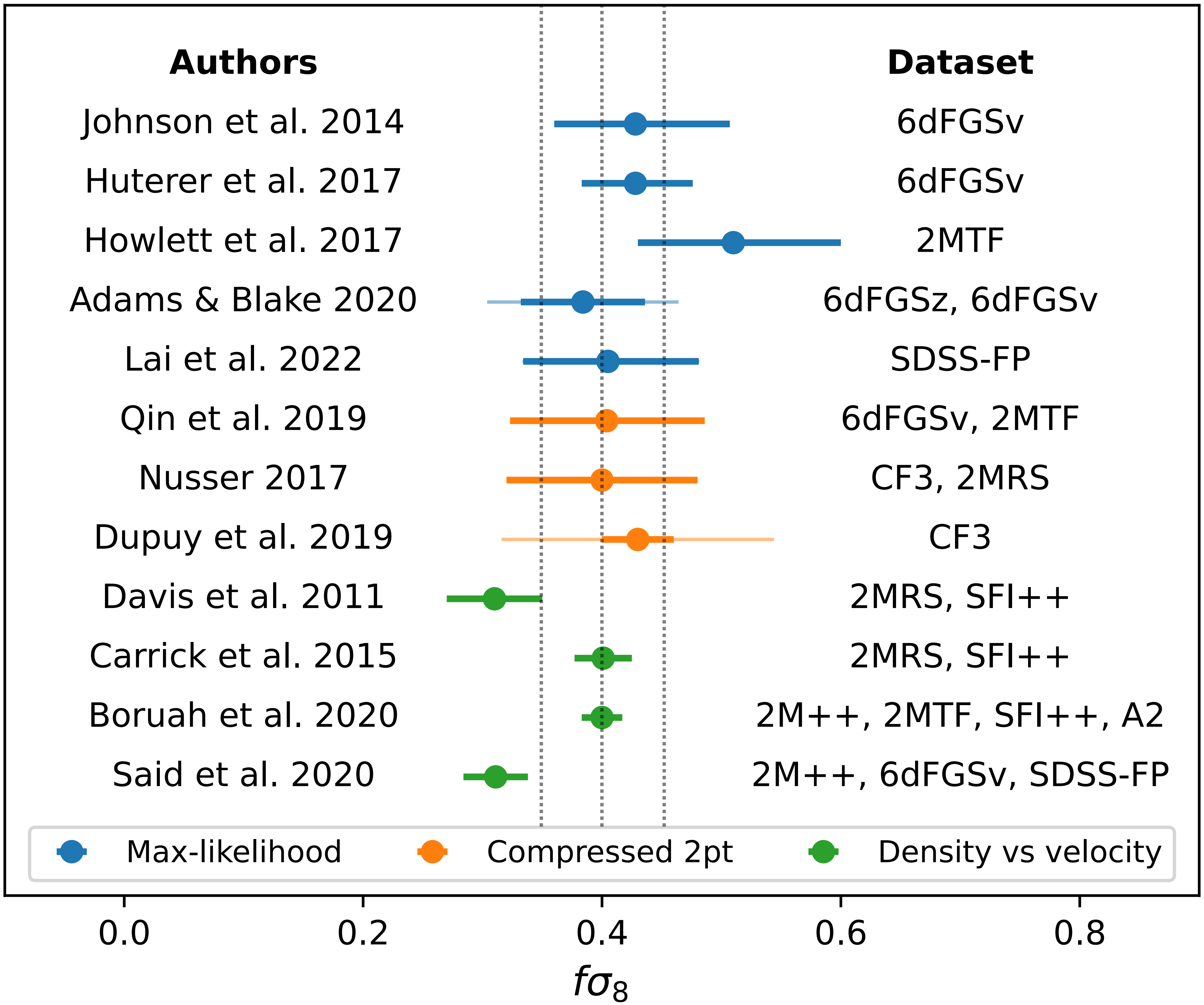


We should try everything !

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++(in prep)
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 et al. 1999 Dupuy et al. 2019 Turner, Blake, Ruggeri 2021 Howlett et al. 2019 Qin et al. 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 Robert++(in prep)

Current growth-rate measurements at z < 0.05



More information or underestimated?

Not necessarily **smaller** uncertainties, but **better** uncertainties !

What data DESI and ZTF are providing us?

Forecasts

DARK ENERGY SPECTROSCOPIC INSTRUMENT

ZWICKY TRANSIENT FACILITY

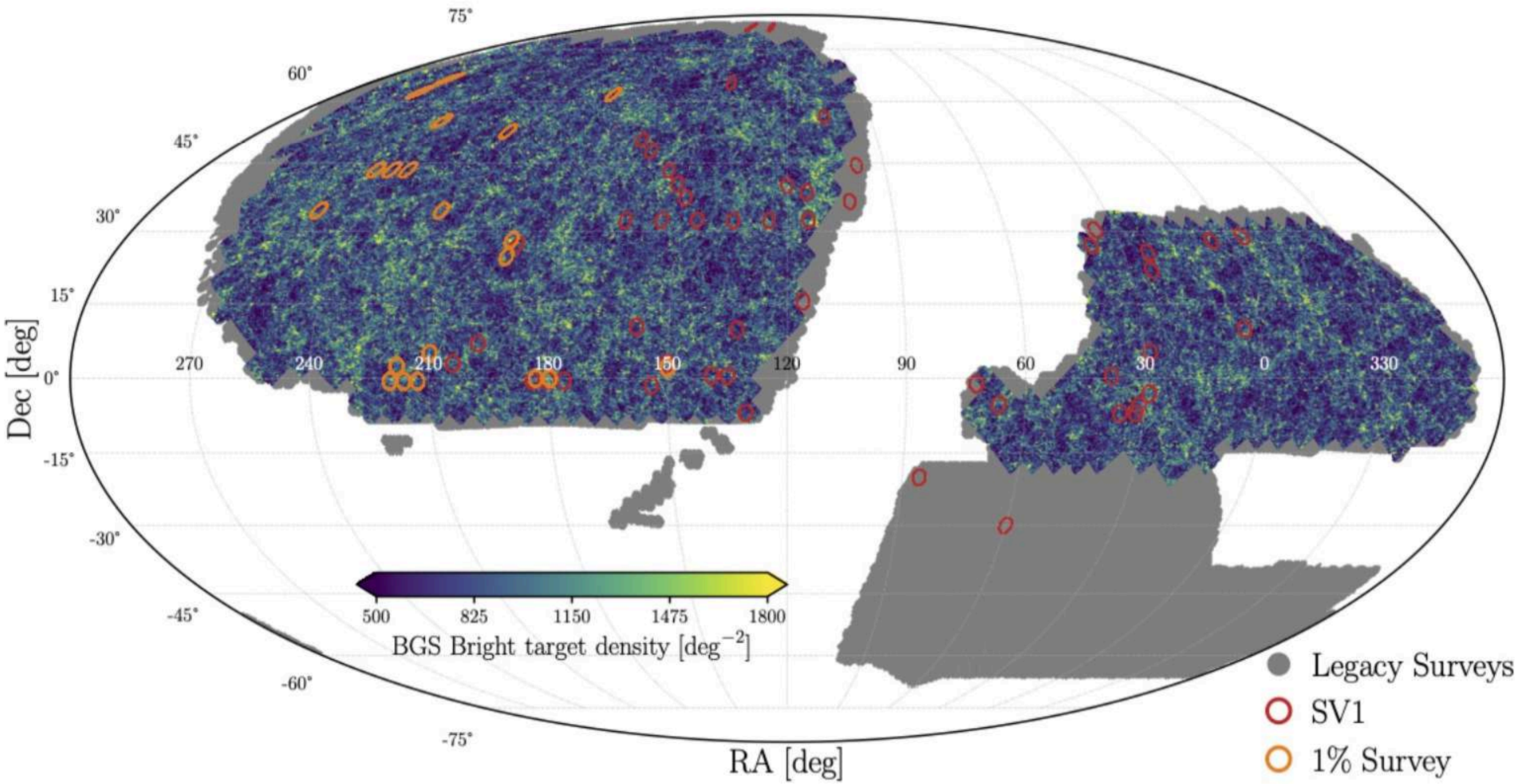
Talk by Pauline Zarrouk

Talk by Mat Smith

DARK ENERGY SPECTROSCOPIC INSTRUMENT

DESI Sky Coverage

Expected coverage of the Bright Galaxy Survey : 14k deg²

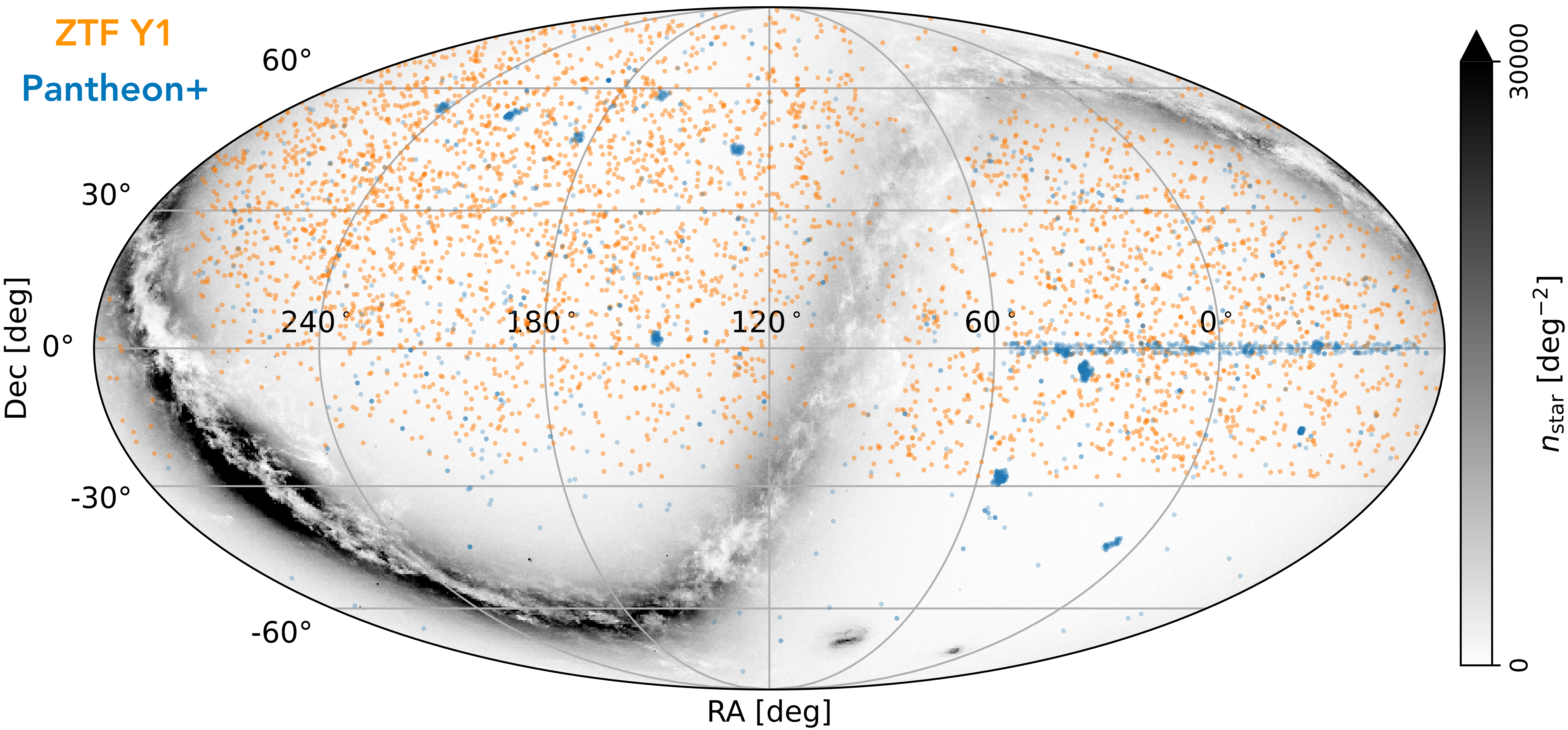


Hahn et al. 2022

The best low-redshift (z<0.4) flux-limited galaxy sample

ZTF Sky coverage

Expected extra-Galactic coverage : 17k deg^2



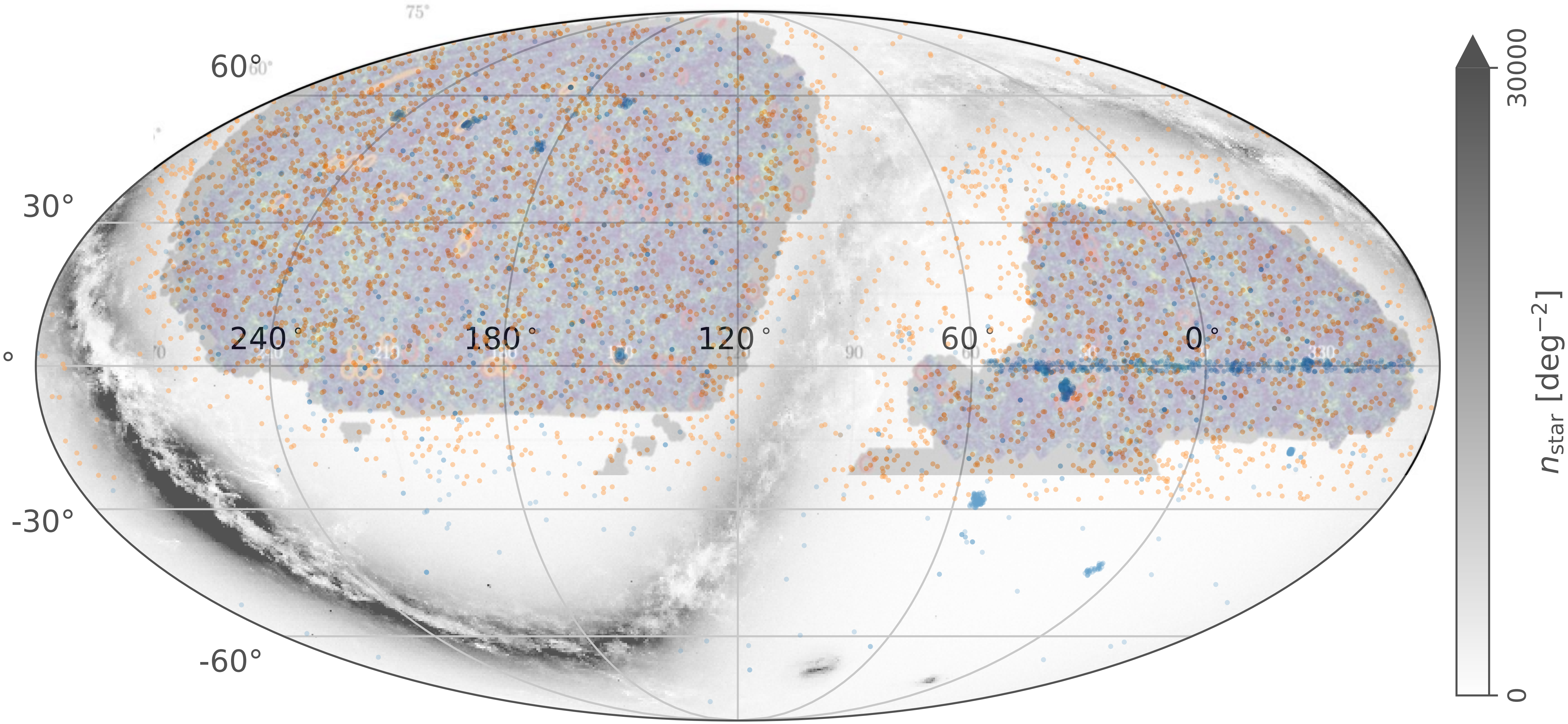
Year 1 sample: Dhawan et al. 2022

The largest and most uniform low-z SNIa survey

DARK ENERGY SPECTROSCOPIC INSTRUMENT

DESI+ZTF Sky Coverage

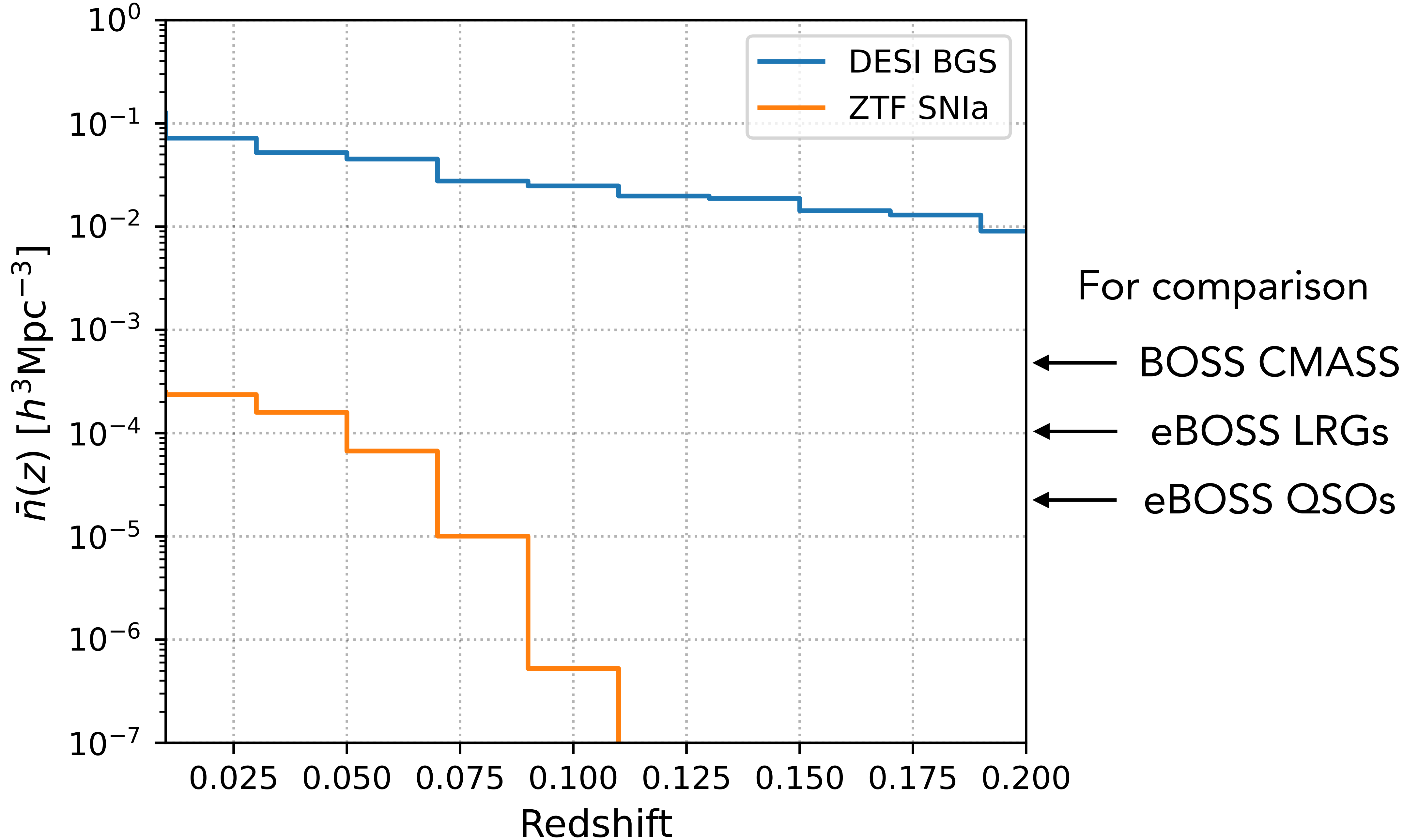
ZWICKY TRANSIENT FACILITY



Excellent overlap between DESI and ZTF

Redshift distribution

expected at the end of both programs



Fewer SNIa but very valuable !

Fisher forecast on growth-rate $f\sigma_8$

Measurement : 3x2pt functions

$$\mathbf{C}(r, k, \mu_\phi) = \begin{bmatrix} P_{\delta\delta}(r, k, \mu_\phi) + \dfrac{1}{\bar{n}_\delta(r)} & P_{\delta v}(r, k, \mu_\phi) \\ P_{\delta v}(r, k, \mu_\phi) & P_{vv}(r, k, \mu_\phi) + \dfrac{\sigma^2_{\mathrm{obs}}(r)}{\bar{n}_v(r)} \end{bmatrix}.$$

Howlett et al. 2017

https://github.com/CullanHowlett/PV_fisher

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Density of galaxies

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Density of galaxies

Uncertainty in velocities

Density of velocities

Fisher matrix

$$F_{ij} = \frac{\Omega_{\text{sky}}}{4\pi^2} \int_{r_{\text{min}}}^{r_{\text{max}}} r^2 dr \int_{k_{\text{min}}}^{k_{\text{max}}} k^2 dk \int_0^1 d\mu_\phi$$
$$\text{Tr}\left[\mathbf{C}^{-1}(r, k, \mu_\phi) \frac{\partial \mathbf{C}(r, k, \mu_\phi)}{\partial \lambda_i} \mathbf{C}^{-1}(r, k, \mu_\phi) \frac{\partial \mathbf{C}(r, k, \mu_\phi)}{\partial \lambda_j} \right]$$

Howlett et al. 2017

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Fisher forecast on growth-rate $f\sigma_8$

Measurement : 3x2pt functions

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Howlett et al. 2017

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Fisher forecast on growth-rate $f\sigma_8$

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Density of galaxies

Uncertainty in velocities

Density of velocities

Fisher matrix

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Smallest scale we can model

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Parameter of interest: $f\sigma_8$

Marginalising over: $b, \sigma_{FoG,\delta}, \sigma_{FoG,v}$

Howlett et al. 2017

https://github.com/CullanHowlett/PV_fisher

Fisher forecast on growth-rate $f\sigma_8$

Depends on accurate clustering modelling

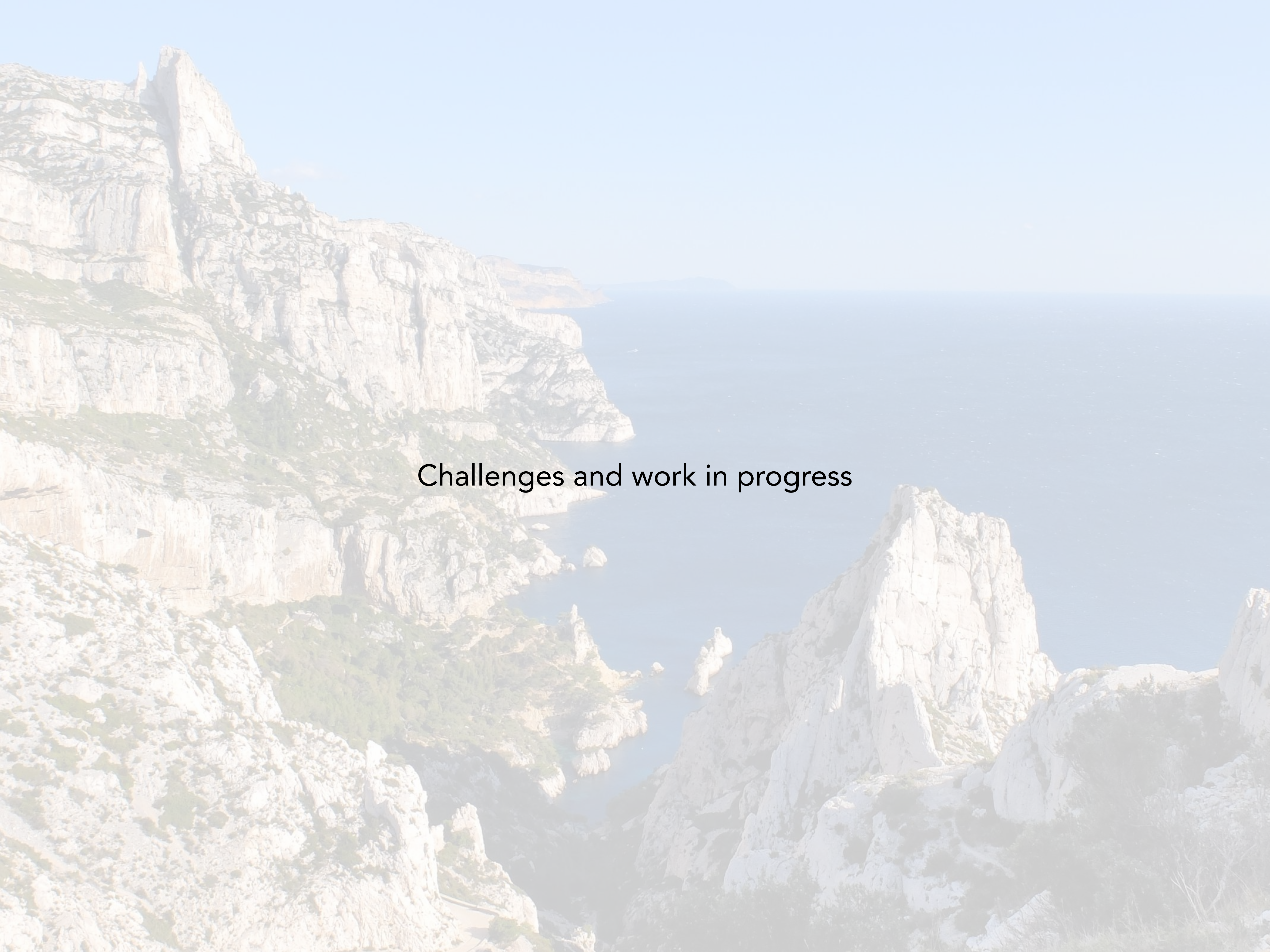
Depends on accurate SNIa modelling and flux calibration

Dataset	$k_{\max}$	$\sigma(D_L)/D_L$	$\sigma\left(f\sigma_8(z_{\rm eff})\right)/f\sigma_8(z_{\rm eff})$
DESI BGS	0.1	-	0.58
DESI BGS	0.2	-	0.21
ZTF SNIa	0.1	0.05	0.22
ZTF SNIa	0.1	0.10	0.35
ZTF SNIa	0.2	0.05	0.19
ZTF SNIa	0.2	0.10	0.32
DESI BGS + ZTF SNIa	0.1	0.05	0.12
DESI BGS + ZTF SNIa	0.1	0.10	0.20
DESI BGS + ZTF SNIa	0.2	0.05	0.09
DESI BGS + ZTF SNIa	0.2	0.10	0.13

Pessimistic

Optimistic

Combining DESI and ZTF leads to a **factor 2 improvement** in uncertainties



Challenges and work in progress

Challenges

DARK ENERGY SPECTROSCOPIC INSTRUMENT

Understand non-cosmological density fluctuations

Accurate models of non-linear galaxy clustering

Accurate covariance matrices

ZWICKY TRANSIENT FACILITY

Selection effects

- versus redshift
- versus angle in sky

Redshifts for hosts

Improve photometry

Test methodologies of growth-rate measurements

Mock catalogues of both datasets

Obtain precise statistical and systematic uncertainties

Work in progress @ CPPM

Work in progress @ CPPM

	DARK ENERGY SPECTROSCOPIC INSTRUMENT	ZWICKY TRANSIENT FACILITY
	Vincenzo Aronica	*Bastien Carreres*
Data	RSD analysis of BGS	
Simulations	Photometric systematics	Growth-rate with simulated SNIa

Work in progress @ CPPM

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Data **Simulations**	*Vincenzo Aronica* RSD analysis of BGS Photometric systematics	*Bastien Carreres* Growth-rate with simulated SNIa
Modelling	*Tyann Dumerchat* Emulators for RSD+PV	*Elena Sarpa* Understanding density-velocity comparison

Work in progress @ CPPM

Data Simulations

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RSD analysis of BGS
Photometric systematics

Modelling

Tyann Dumerchat
Emulators for RSD+PV

Anchor (high-z) measurements

Tyann Dumerchat
Joint Fourier+Config BAO analysis

Vincenzo Aronica
Joint Fourier+Config RSD analysis

Corentin Ravoux
RSD in Void-Lyα (z ~ 2.3)

Bastien Carreres
Growth-rate with simulated SNIa

Elena Sarpa
Understanding density-velocity comparison

Elena Sarpa
BAO with Euclid
Impact of neutrinos

Work in progress @ CPPM

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Anchor (high-z) measurements	*Tyann Dumerchat* Joint Fourier+Config BAO analysis *Vincenzo Aronica* Joint Fourier+Config RSD analysis *Corentin Ravoux* RSD in Void-Lyα (z ~ 2.3)	euclid *Elena Sarpa* BAO with Euclid Impact of neutrinos
Combining everything	*Everyone + collaboration in France and rest of the world*	

Conclusion

We need to test if GR is valid on cosmological scales

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

DESI and ZTF are providing great datasets

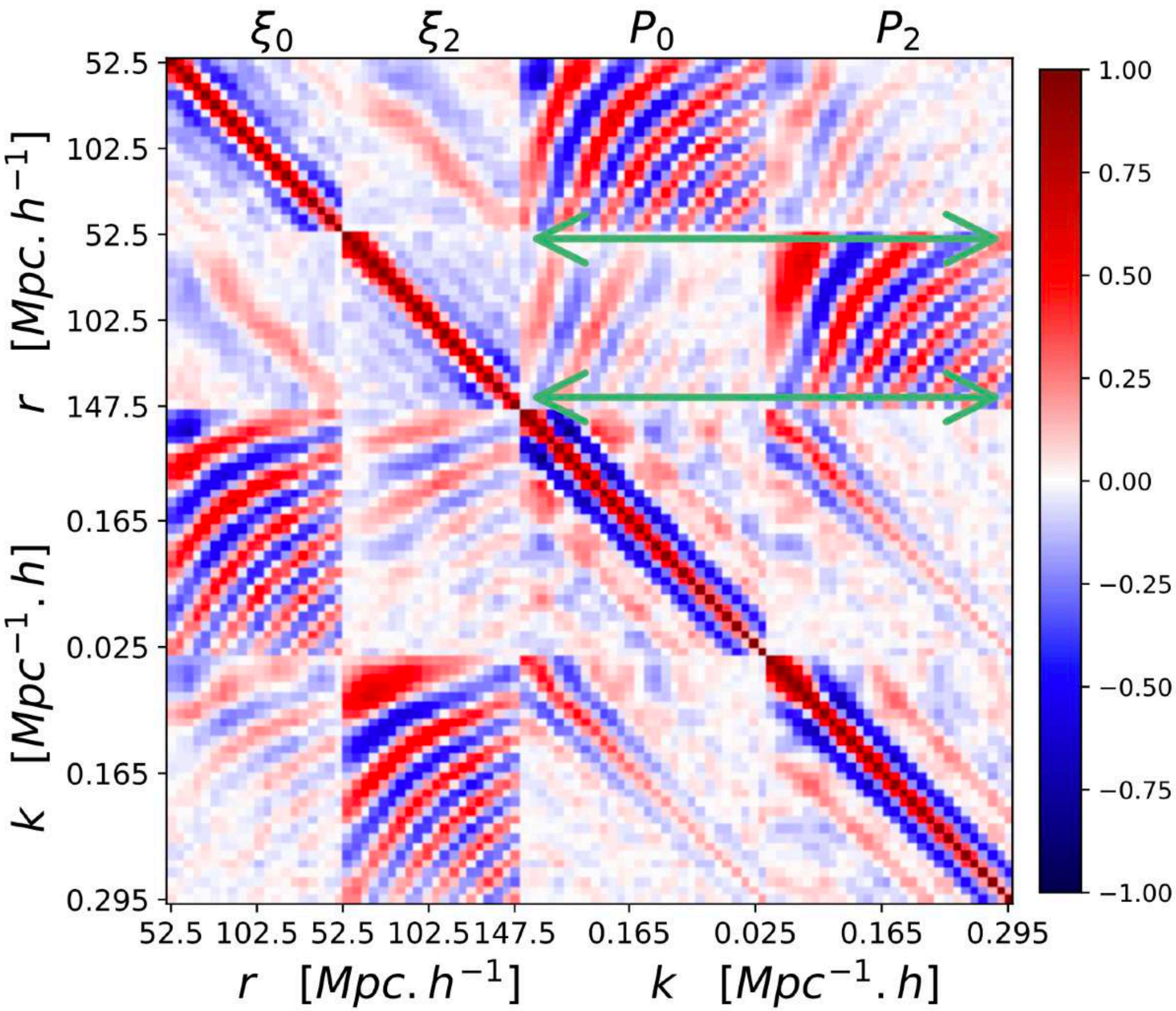
Lots of work to be done to understand biases and uncertainties

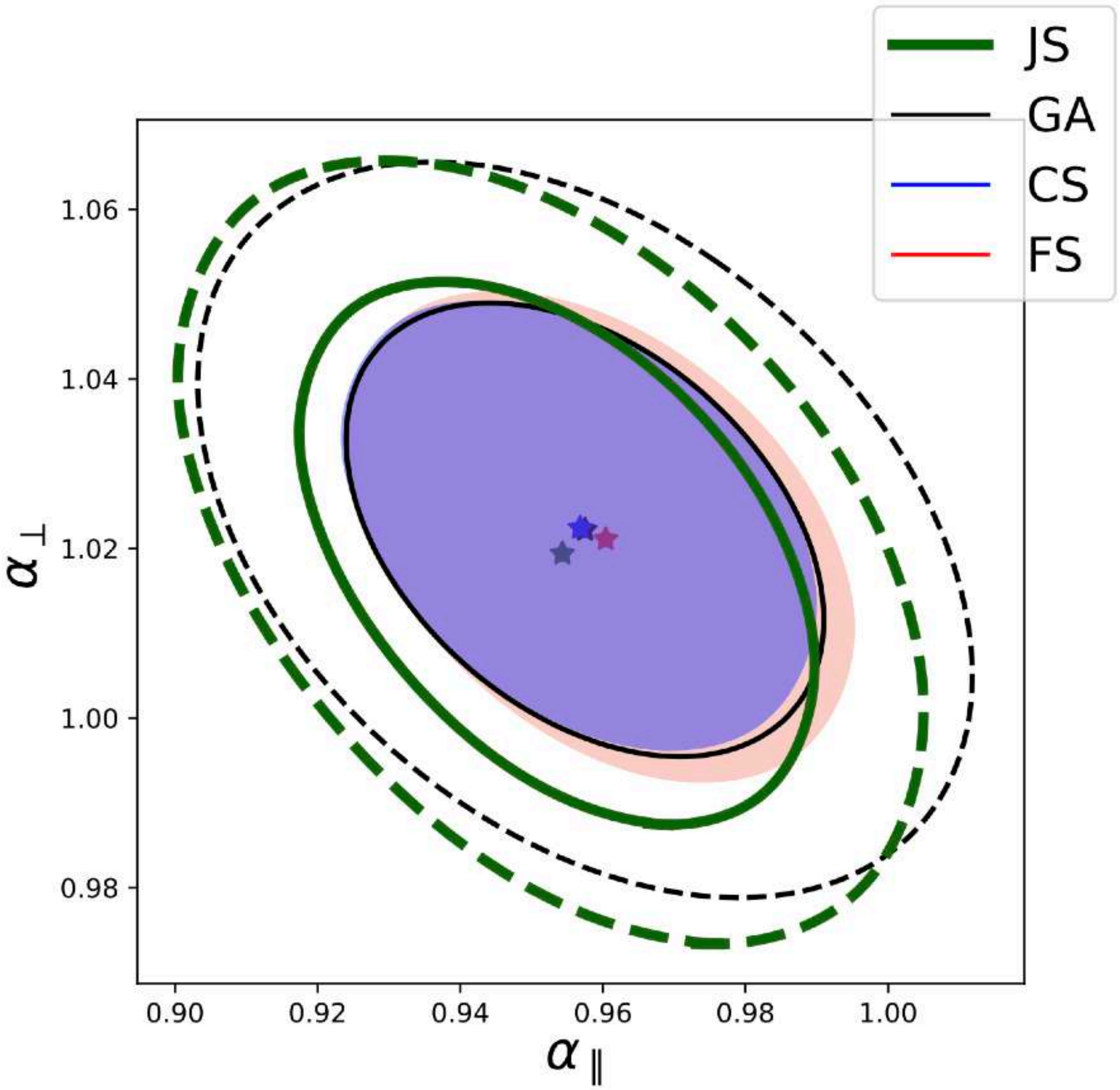
Thank you

Joint Fourier+Configuration space BAO analysis

Dumerchat & Bautista 2022 baopy

Correlation matrix from 1000 mocks

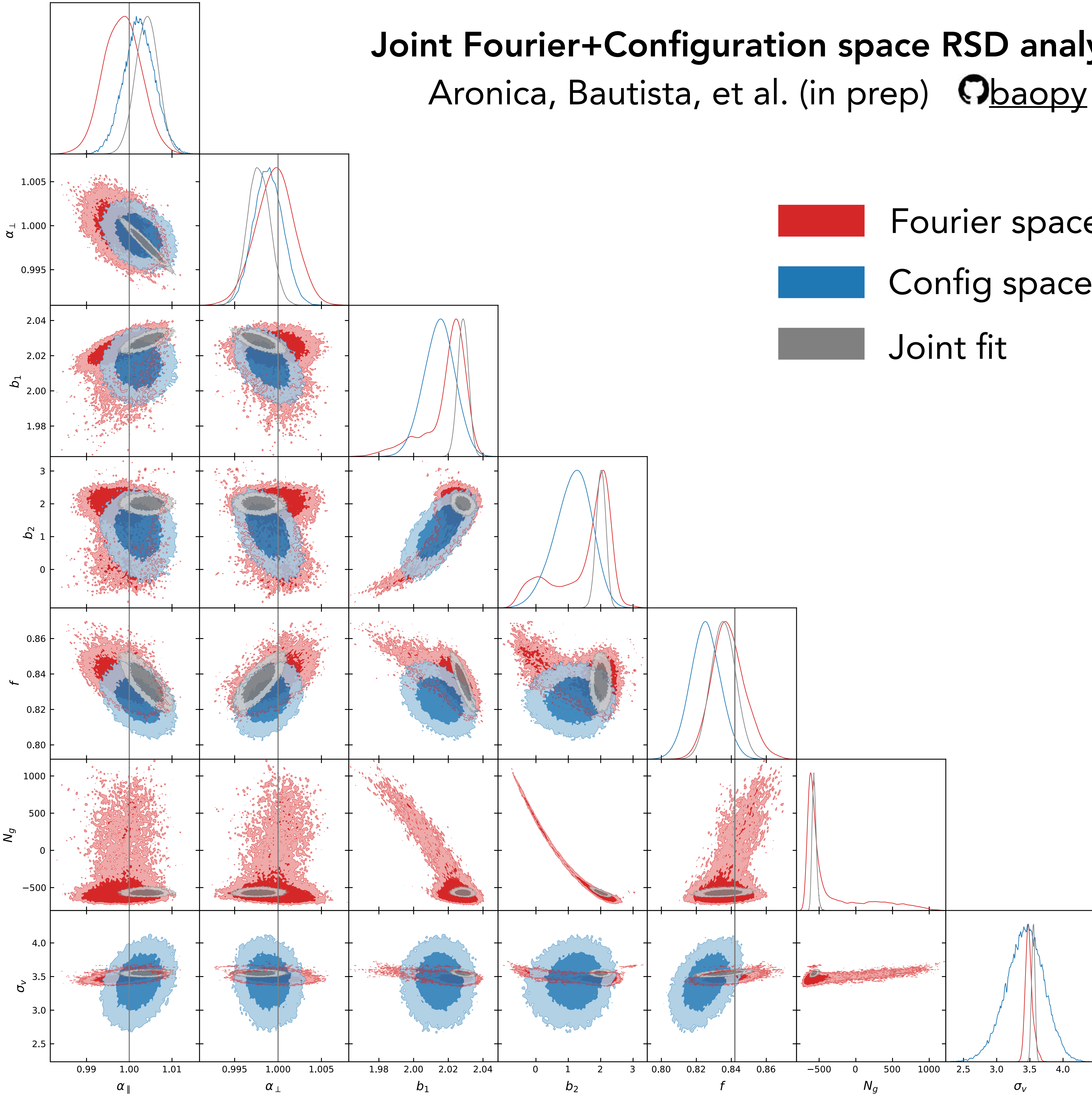




Currently being used within DESI

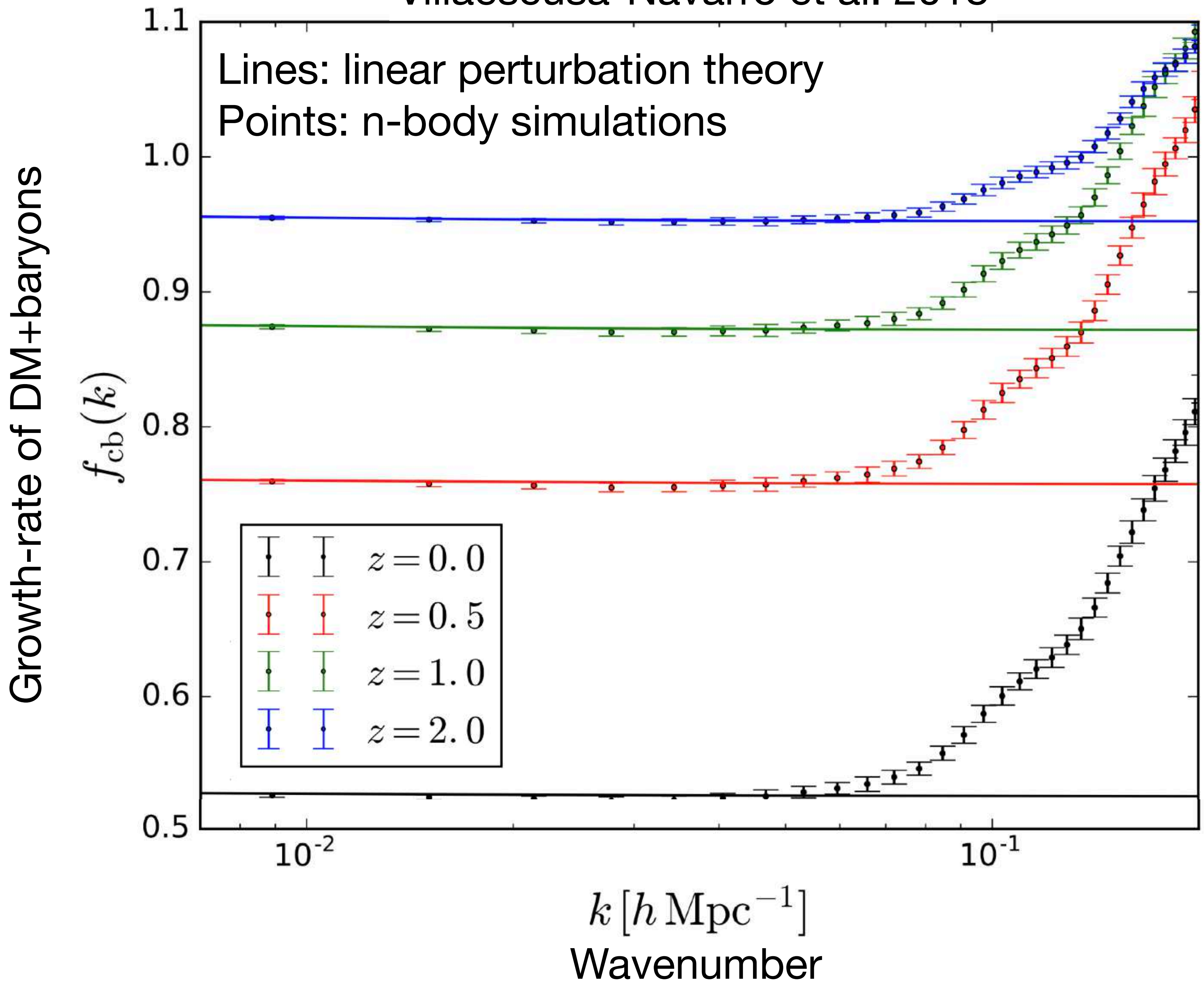
Joint Fourier+Configuration space RSD analysis

Aronica, Bautista, et al. (in prep) baopy



Non-linear clustering of density field

Villaescusa-Navarro et al. 2018



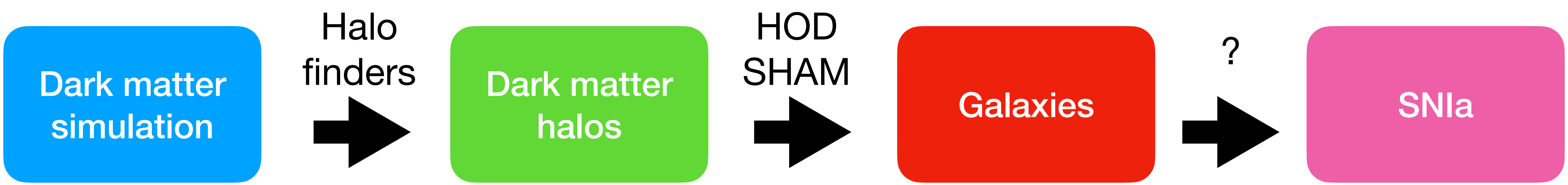
Clustering of matter is very non-linear at z ~ 0

Need to add halo bias, galaxy bias, SNIa bias on top of that

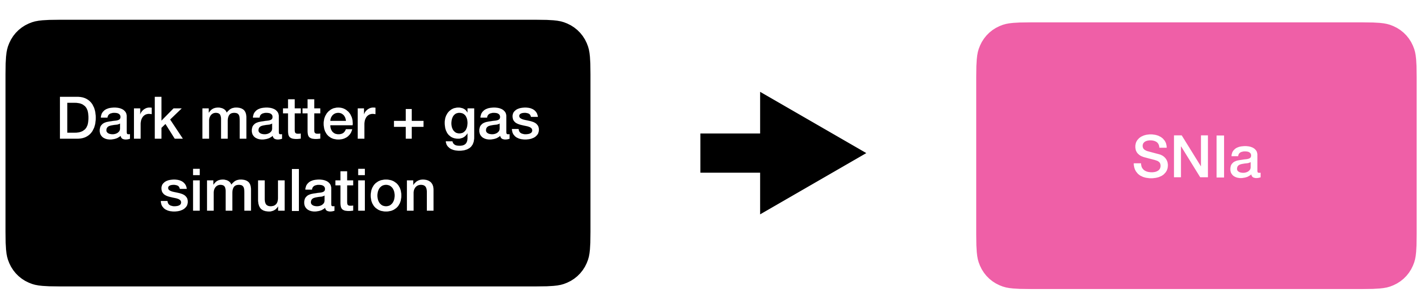
Mock catalogues

Essential to test methodologies
Robust uncertainties: statistical and systematic

How good mocks need to be?



How good hydro-sims model SNIa?
Are they useful/enough to calibrate mock catalogues?



ZTF is great for this kind of study