IMPERIAL

Late-time cosmic dynamics

with Stage-IV / V surveys

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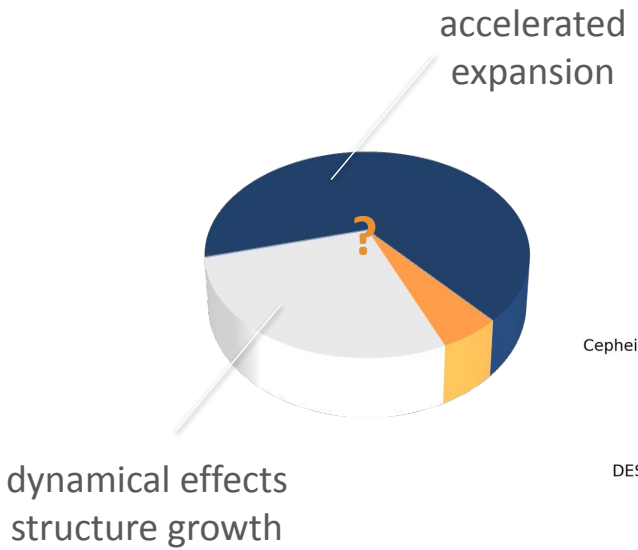
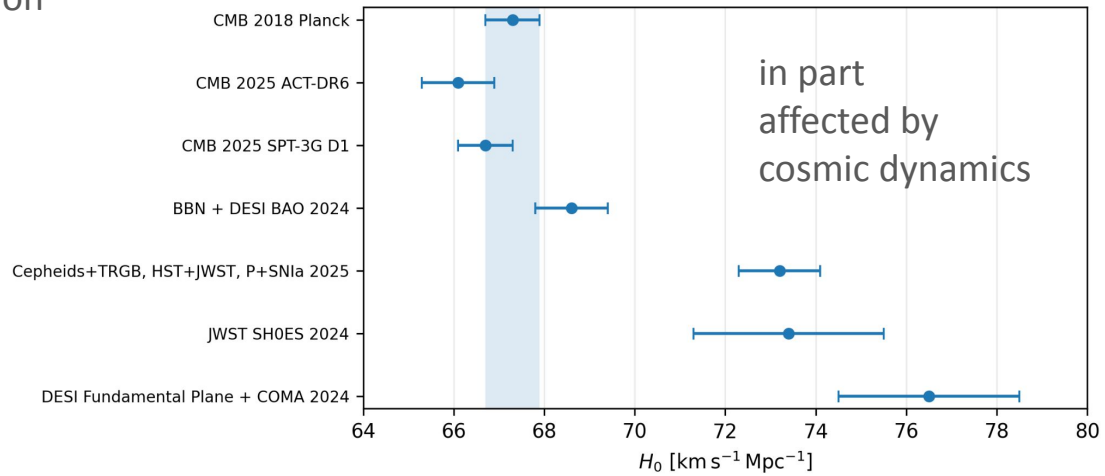
GDR CoPhy Episode 4 - 03/06/2026

1. How can we infer cosmic dynamics?
2. How to include them properly in inference?
3. How to use them as new probes with **Stage-IV** and **-V** surveys?

Late-time cosmology is a dynamics problem

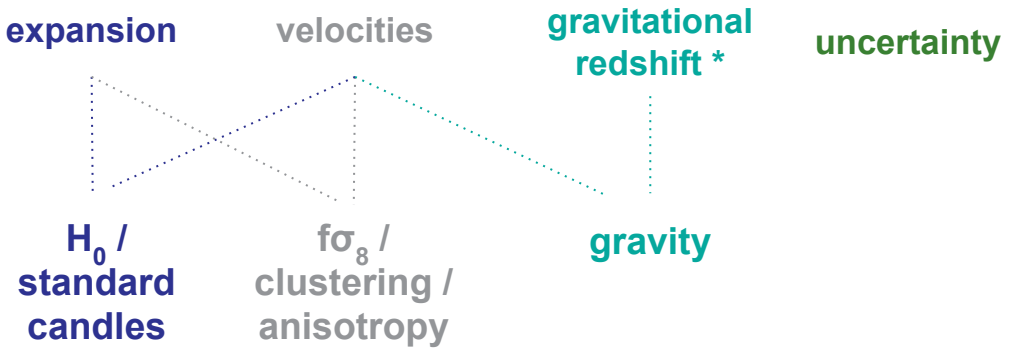




Precise and accurate tests of cosmic dynamics
to fully exploit next-generation data and avoid biases

Redshifts encode dynamics as a systematic effect and a probe

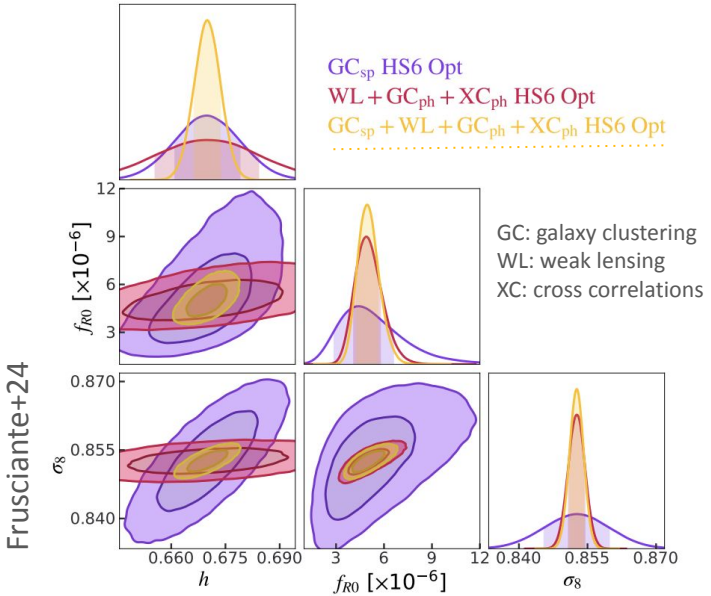
$$1 + z_{\rm obs} = (1 + z_{\rm c})\,(1 + z_{\rm pec})\,(1 + z_{\rm gz})\,(1 + \epsilon_z)$$



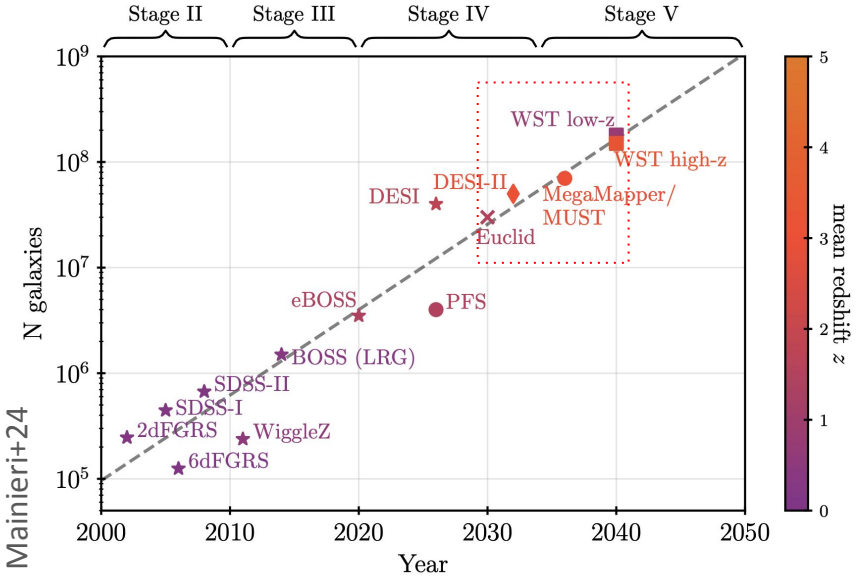
Regime: systematics to control or signals to exploit

Why now?

What data are needed to optimise constraining power?

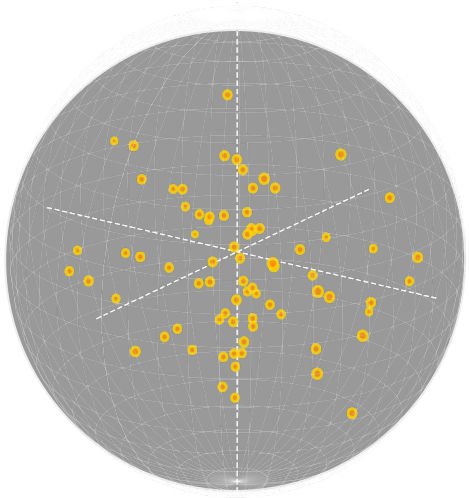


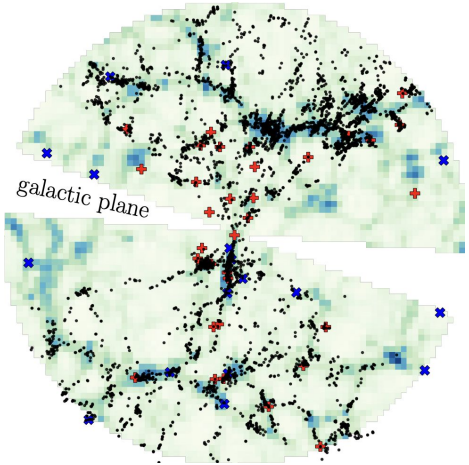
Stage-IV – data arriving
precise inference of dynamics
probe combination

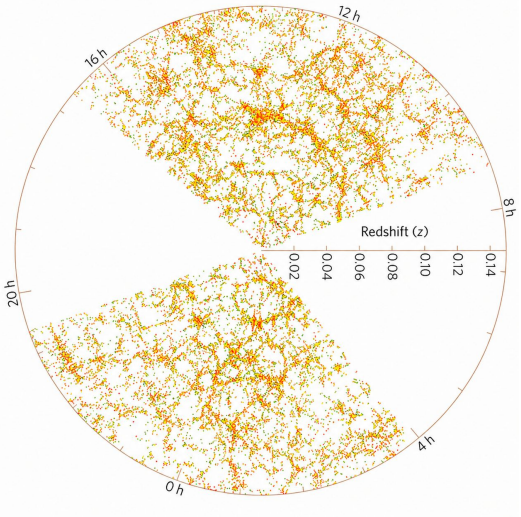


Stage-V
influence survey design
optimise for new probes

A multi-scale view of late-time cosmic dynamics







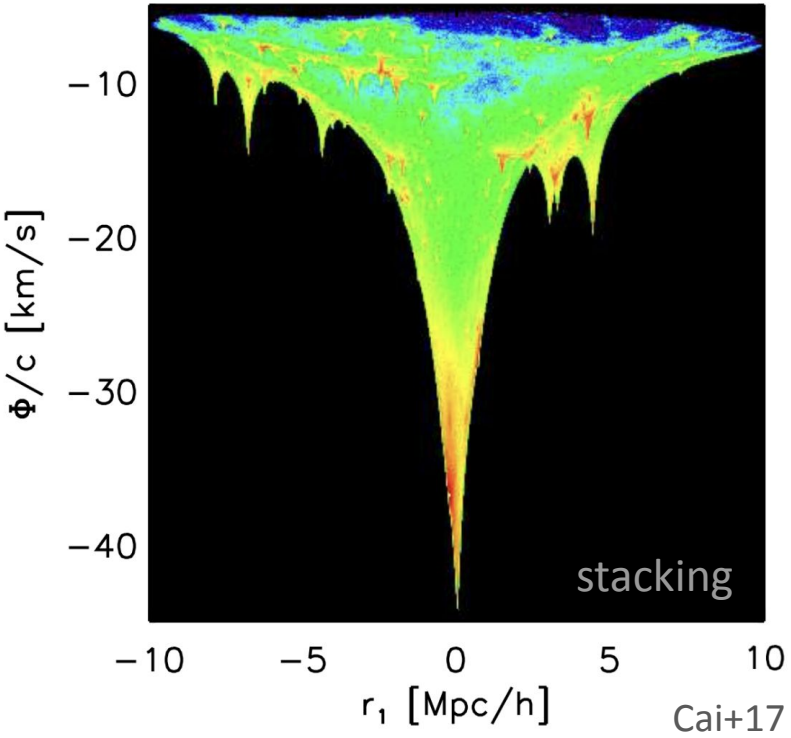
gravitational redshifts for modified gravity

peculiar velocities in H_0 inference

clustering for $f\sigma_8$ inference

Inferring gravity on cluster scales with gravitational redshifts

Gravitational redshifts: an emerging probe of gravity



Cai+17

- Direct probe of gravity: φ(M)
- SDSS DR16: 30% gravity constraints
- DESI / Euclid: underway
- WST: conceptual design

Tsaprazi+26
2603.25339

forecasting

Which uncertainties matter?

How to optimise surveys?

Mock cluster and member galaxy catalogues

Ω_m, H_0, …

HMF

(M_{500}, z, r_{500})

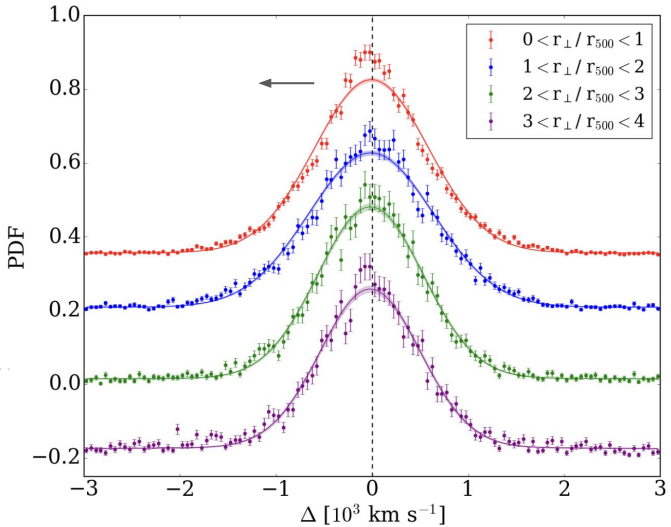
ρ(r) φ(r)

(r, v_{pec}, m, M)

selections

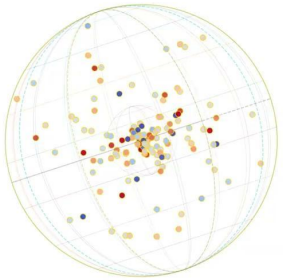
mock catalogue

Signal: φ_{grav} at galaxy - φ_{grav} at centre

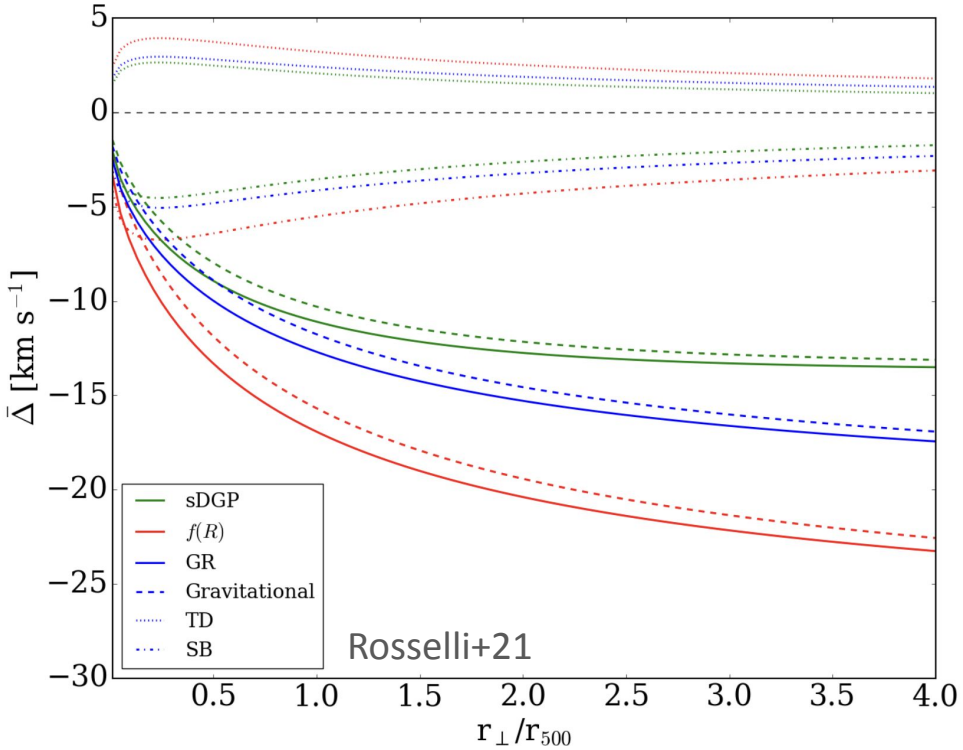


Rosselli+21

Threshold: PVs



Model contributions



transverse Doppler > 0

$$\bar{\Delta} = \bar{\Delta}_{gz} + \bar{\Delta}_{TD} + \bar{\Delta}_{SB}$$

gravitational redshift < 0

surface brightness modulation < 0

MG ~ linear re-scaling of GR

motivates parameterising deviations from GR due to systematics with a linear factor, α_{MG}

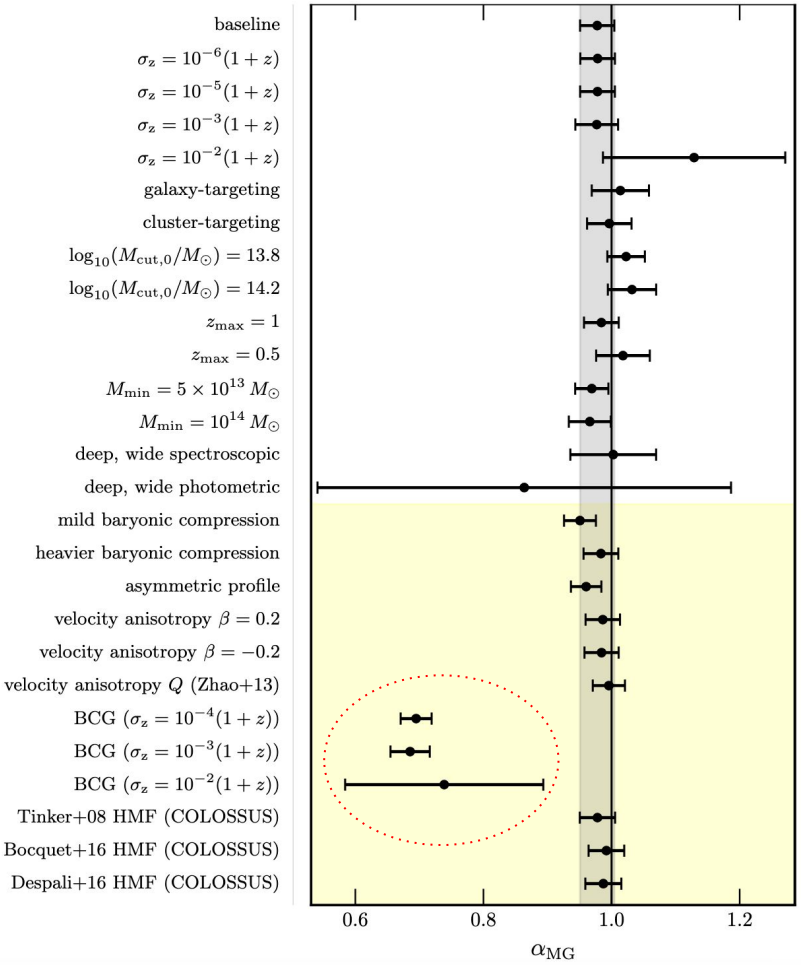
A forecasting pipeline

Observational:

- Redshift uncertainty
- Incompleteness
- Flux limits
- False cluster identification

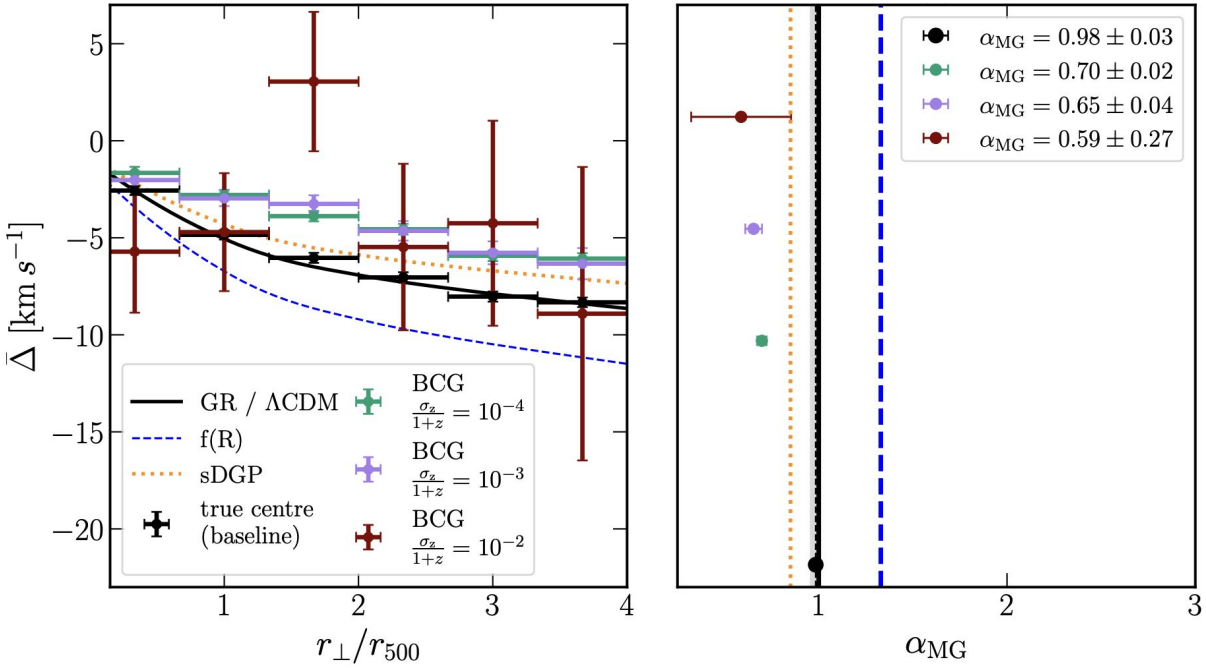
Modelling:

- asymmetry / baryons / anisotropy
- **mis-centring**



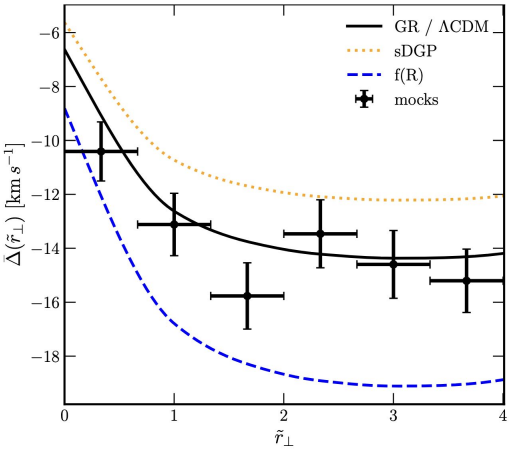
Potential mis-centring creates spurious signal

BCG: proxy for the true potential centre



Conclusions

- Resource efficient setting: z < 1 spectroscopic galaxy survey
- 4% constraints on α_{MG} for a limiting magnitude of 22–23 mag
- Mis-centring: marginalisation - averaging - multiwavelength



The Wide-Field Spectroscopic Telescope

WST

Tsaprazi+25
2512.13221

From intracluster to local Universe dynamics

Inferring cosmic expansion with local transients

Field-level inference of H_0

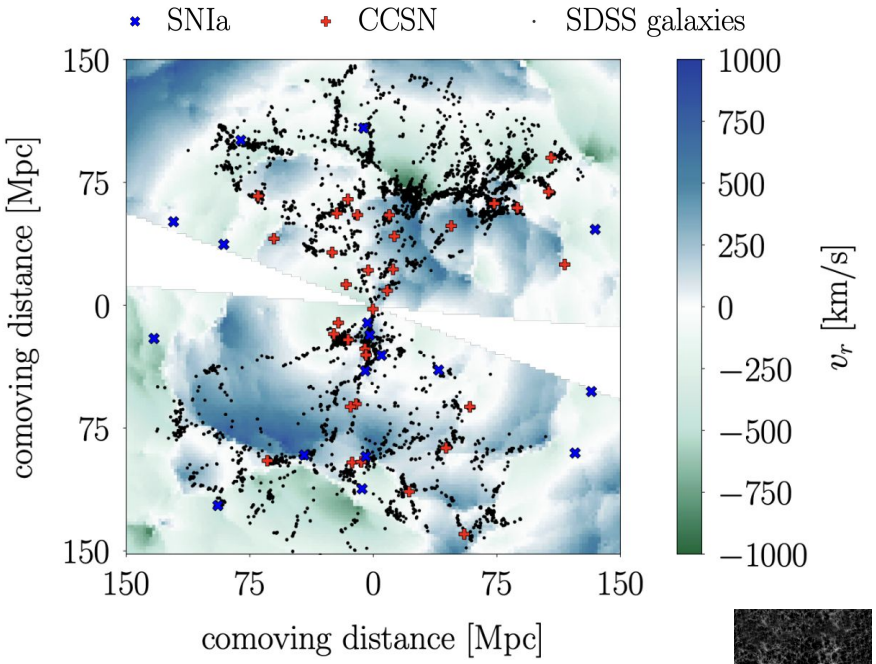
Tsaprazi & Heavens 25
2502.08385

- Inhomogeneous cosmic *expansion* due to structure
- Supernovae (d_L, $\mathbf{z_{obs}}$), biased tracers of the velocity field

Does the location of SNe in the cosmic web bias H_0 measurements?

- Non-linear, constrained PVs (**BORG**: Jasche & Lavaux 19)
- Simulated host galaxy properties

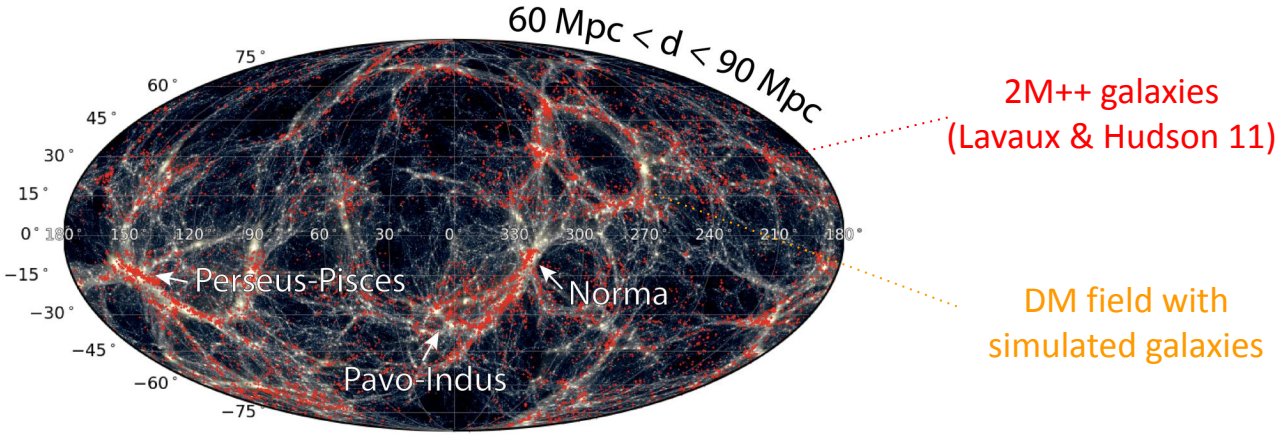
Build & validate forward model to study impact of PVs on H_0



Tsaprazi+22a

A constrained simulation of supernovae in the local Universe

- Validate pipeline against supernovae placed realistically in the LSS
- SIBELIUS-DARK: synthetic galaxies using GALFORM on constrained DM

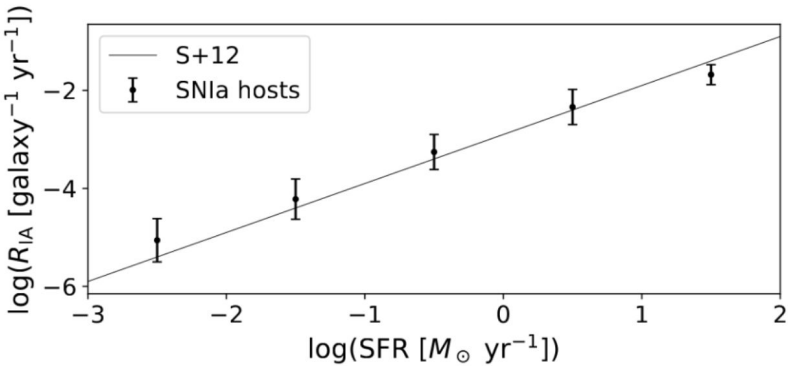


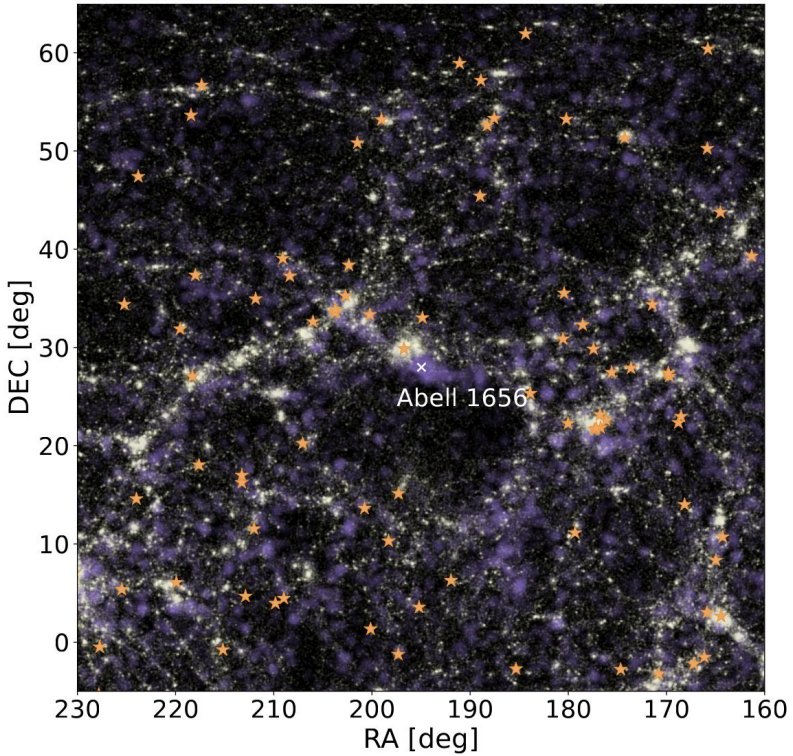
McAlpine+22, Sawala+21a

Building a SN simulation in the large-scale structure

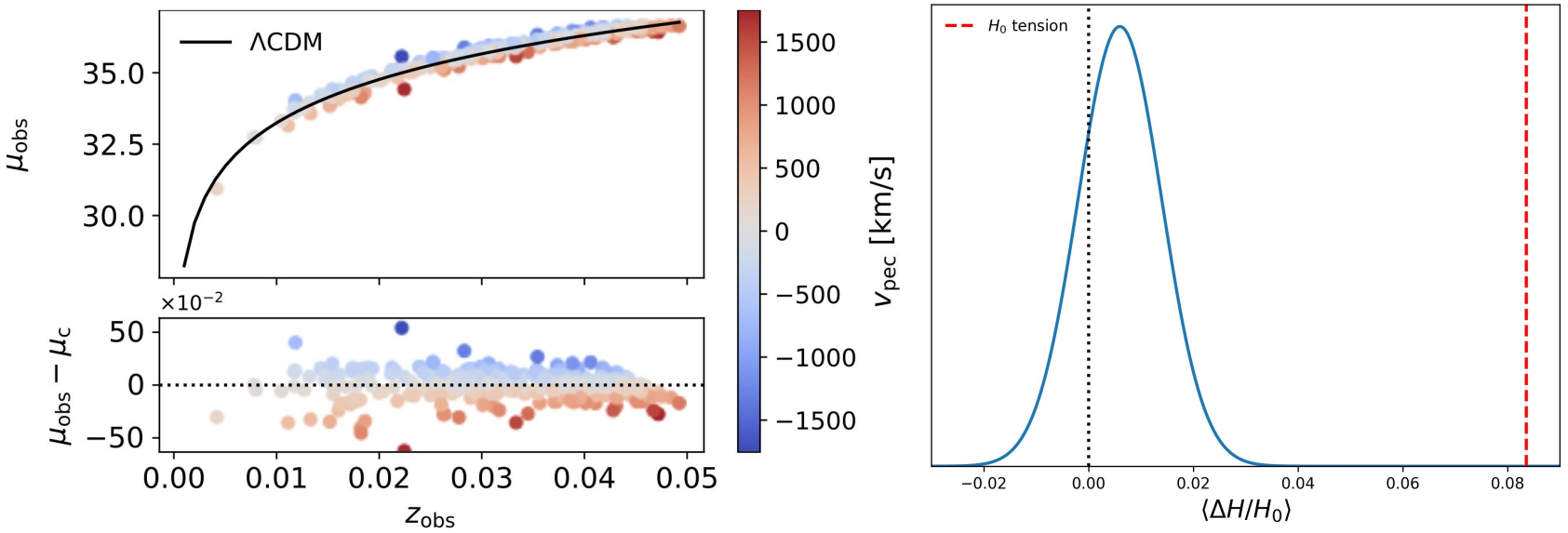
- Simulated SFHs

$$R_{\rm IA} = \int_{t_0}^{t_{\rm f}} \Psi(t_0 - \tau)\Phi(\tau)d\tau$$



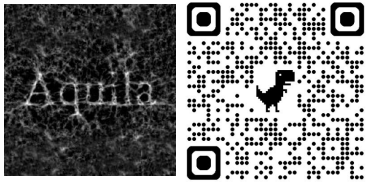


For supernovae local dynamics doesn't reconcile the H_0 tension



- We can recover H_0 accurately from SNe at $z > 0.023$
- Exploit SNe at $z < 0.023$ which would otherwise be discarded
- In the very local Universe we do have to worry about dynamics

For Cepheids, local dynamics can matter



Stiskalek+26
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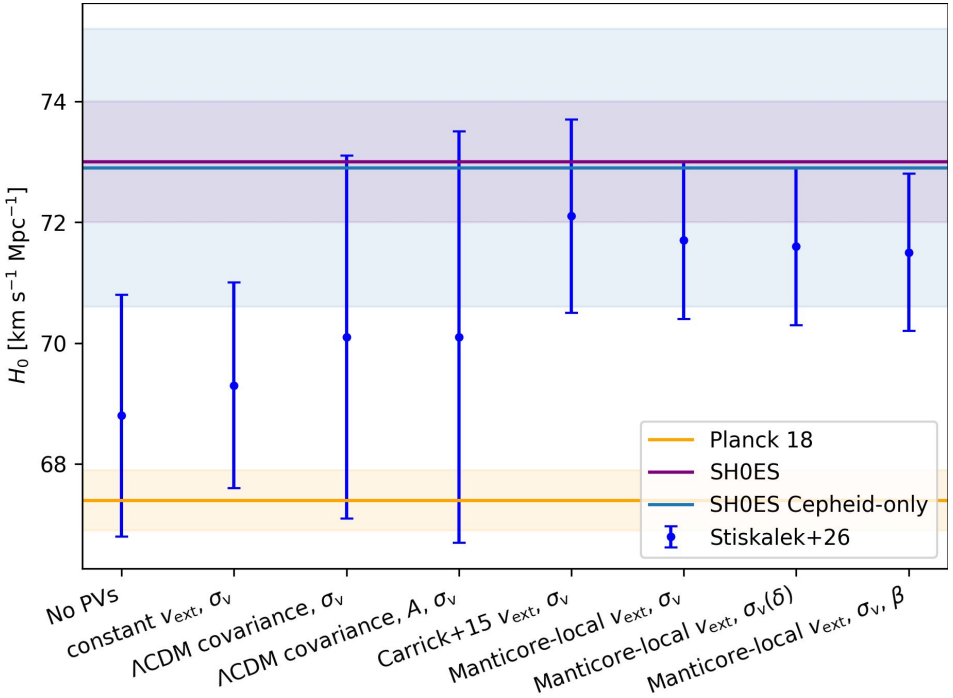
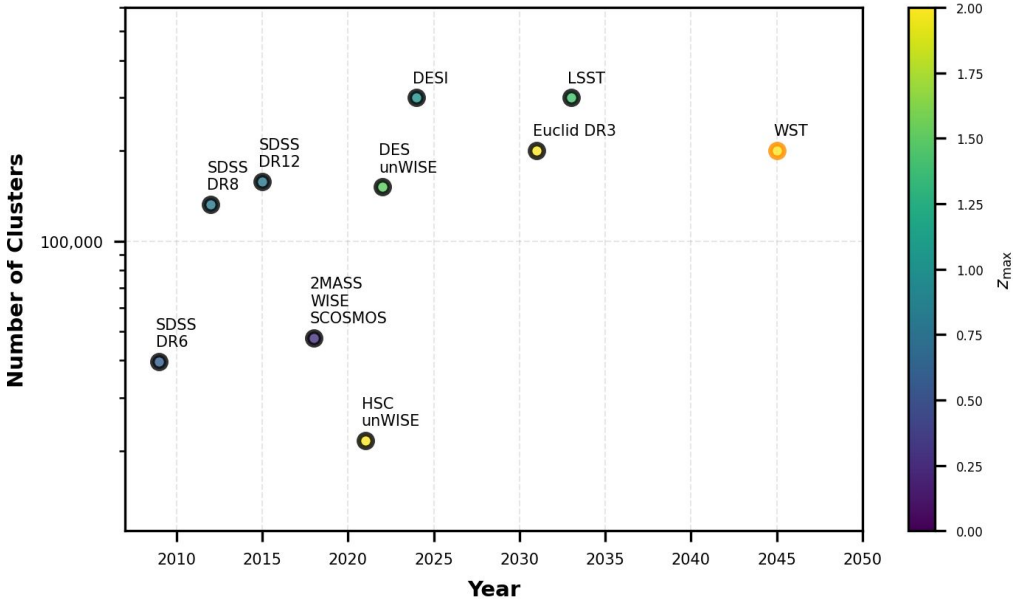


From the local Universe to large-scale dynamics

Inferring gravity with cluster clustering

Cluster clustering with Stage-IV and beyond



Power spectrum

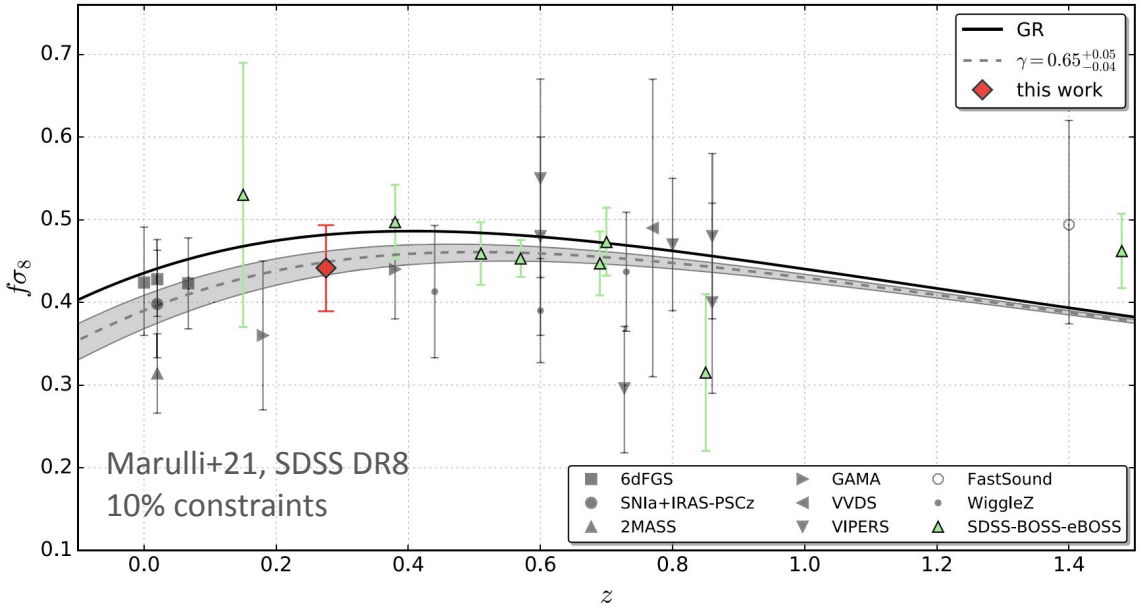
- anisotropic due to PVs
- contains information on gravity through growth of structure and PVs

$$P^{s}(k,\mu,z) = D[k\mu\sigma_{v}(z)] \left[1 + \frac{f(z)}{b(z)}\mu^2\right]^2 b^2(z) P_{\delta\delta}(k,z)$$

Photo-z / FoG — RSDs — halo bias

- Lower SNR than galaxies
- High-mass regime & break degeneracies

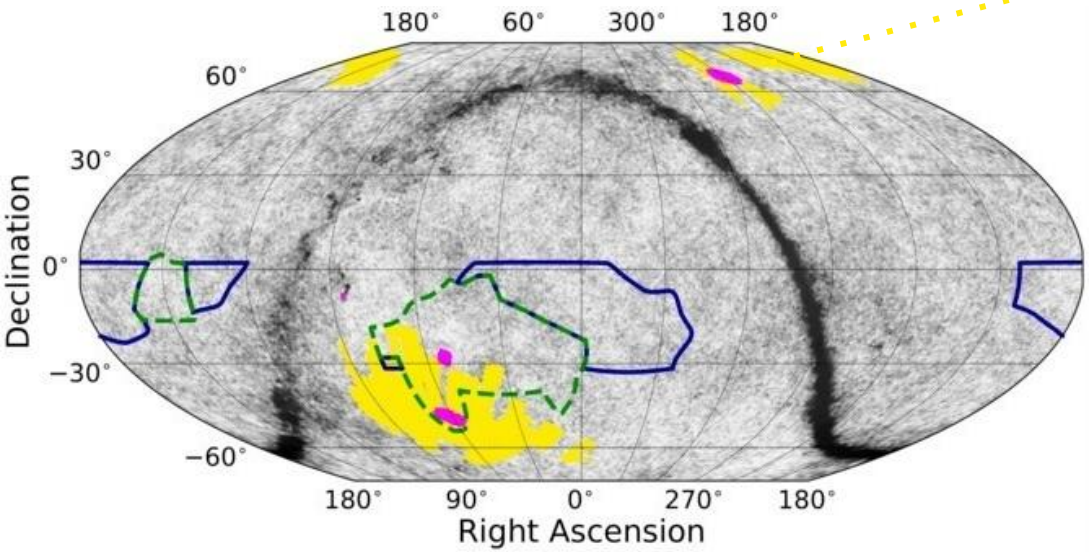
Modelling the redshift-space signal is complex



EC: **Tsaprazi**+26
2604.25762

- Spectroscopic surveys: higher-order non-local bias + loop corrections
- Photometric surveys: Is the same complexity required?

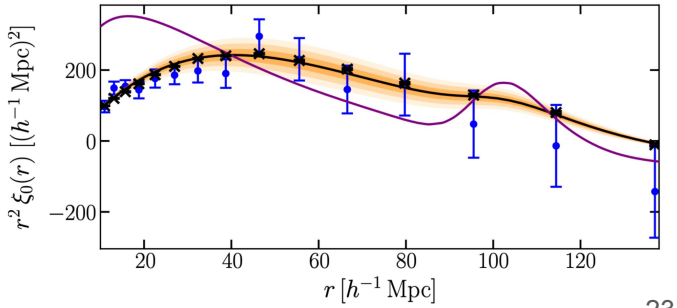
What do we expect from Euclid DR1?



Euclid Caltech

Euclid DR1-like halo catalogues:

- 1900 deg^2
- 20 000 clusters
- $0 < z < 2$
- $\sigma_z = 0.01(1+z)$



A hierarchy of redshift-space clustering models

$$P^{\rm s}(k,\mu,z) = D[k\mu\sigma_{\rm v}(z)]\left[1+\frac{f(z)}{b(z)}\mu^2\right]^2 b^2(z)P_{\delta\delta}(k,z)$$

loop corrections

divergence

density

monopole

quadrupole

hexadecapole

spectro-z

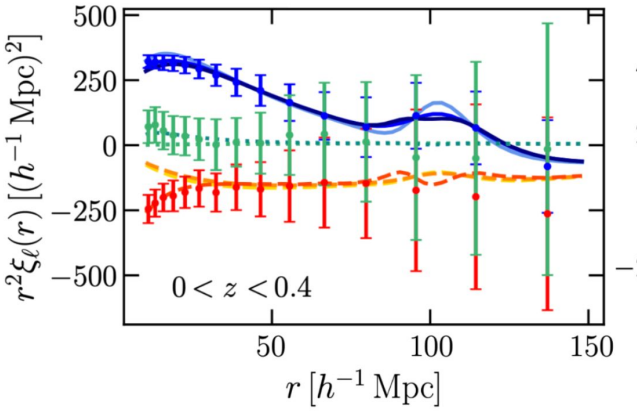
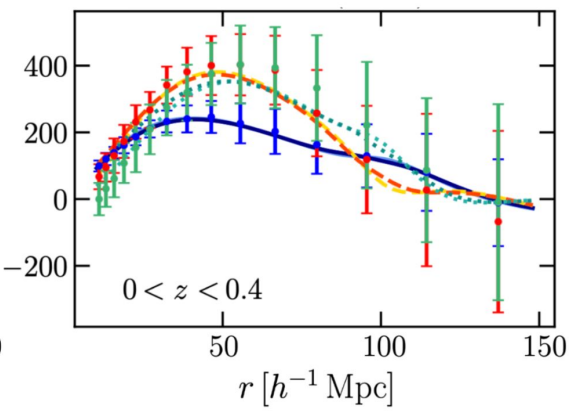


photo-z



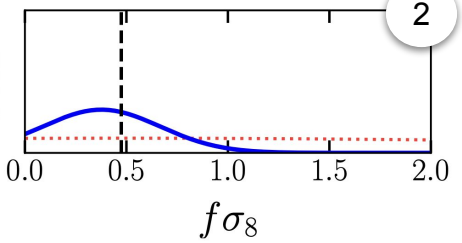
- Different predictions on small scales, for spectro-z: model comparison
- Photo-z: small difference, down to what scales can we trust the simplest model?

Which scales can be trusted for cosmological inference?

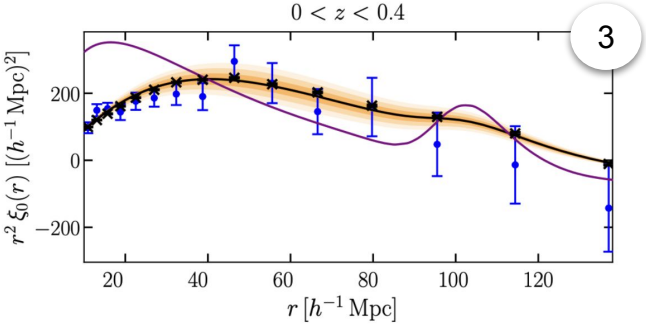
1

$r_{min,\ell}$

2



3



4

- χ^2
- FoB
- coverage
- calibration

5

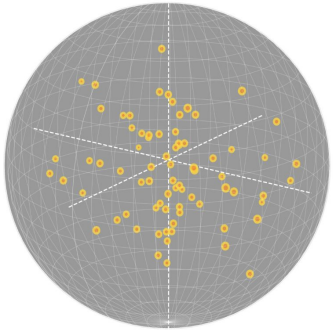
pass / fail

- Permissive: dispersion model down to 10 h^{-1} Mpc
- Restrictive:
  - redshift- and ℓ-dependent cut off scale
  - z > 1 inference may require non-linear halo bias

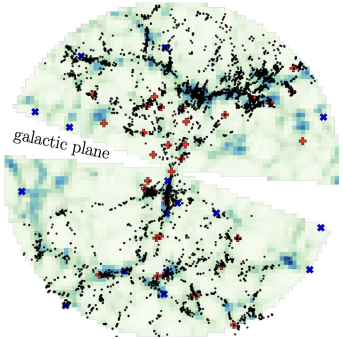
Outlook

- **Dispersion model – inference robust to clustering model > 10 h^{-1} Mpc**
  - Models are very similar above that scale ⟶ CLOE
- DR1 data: Criteria will guide choice of $r_{min,\ell}$
- DR2/3: x 4–7 # of clusters in DR1
  - Non-linear halo bias at high-z
  - Move from 3LPT ⟶ Euclid Flagship N-body

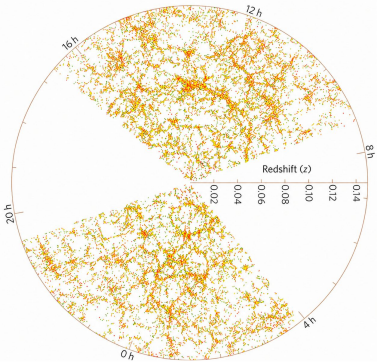
Dynamics: From systematic effects to cosmological probes



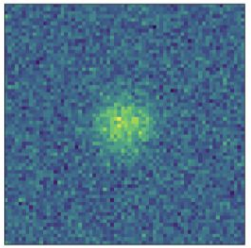
%-level constraints on modified gravity with Stage-V
mis-centring



Toward sub %-level constraints on H_0
with increased statistics from JWST, LSST, Roman



Optimistic 30% constraints on $f\sigma_8$ for DR1
will require nonlinear halo bias - N-body



Shear forward modelling Mendoza+26
2604.22048