Cosmological tests of gravity with galaxy clusters

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Galaxy Cluster France workshop 2026

1. WHY GRAVITY?

Understanding the dark Universe

- Dark energy
- Dark matter
- Cosmological tensions

2. WHY CLUSTERS?

A unique laboratory

- Complementary observables
- Different environments
- Multiple scales

3. WHY NOW?

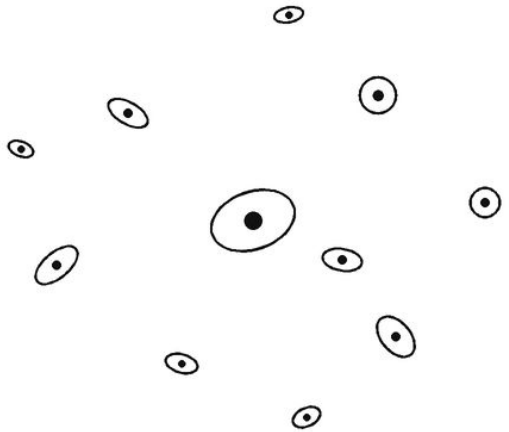
A timely opportunity

- Stage-IV surveys
- Stage-V prospects
- New potential for precision tests

Exquisite data quality • **new probes with discovery potential** • **systematic effects**

Multi-scale approach to testing gravity

Gravity at intracluster scales



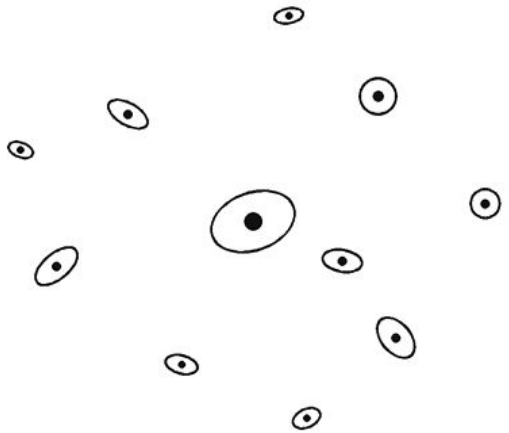
$$ds^2 = -(1+2\Psi)\,dt^2 + a^2(1-2\Phi)\,d\mathbf{x}^2$$

Gravitational redshifts

[kpc – Mpc]

$\Delta\Psi$

Gravity at cluster scales



$$ds^2 = -(1+2\Psi)\,dt^2 + a^2(1-2\Phi)\,d\mathbf{x}^2$$

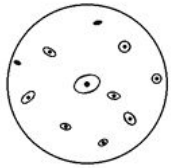
Gravitational wave strong lensing

[< 10 Mpc]

$\Phi + \Psi$

Gravity at intercluster scales

$$ds^2 = -(1+2\Psi)\,dt^2 + a^2(1-2\Phi)\,d\mathbf{x}^2$$

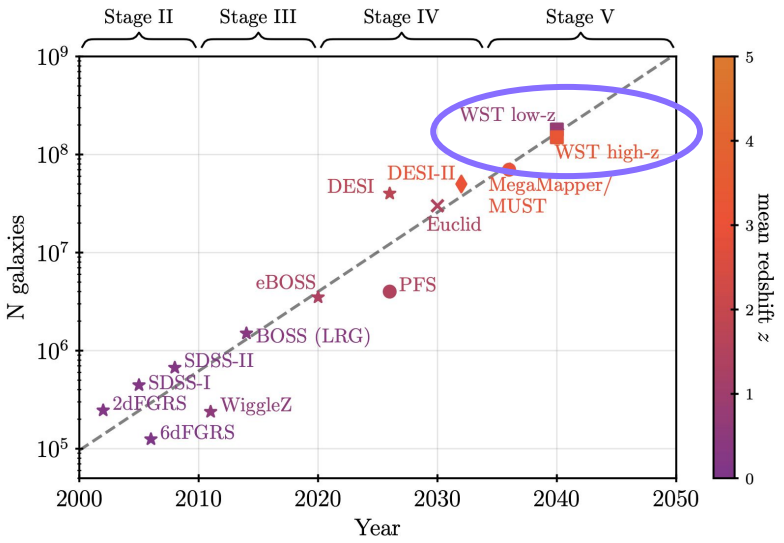


Clustering

[> 10 Mpc]

$\nabla\ \Psi$

Gravitational redshifts: gravity at intracluster scales



- Direct test of gravity: φ(M)
- SDSS DR16 / DESI & Euclid
- **Widefield Spectroscopic Telescope**

Tsaprazi+26a
2603.25339

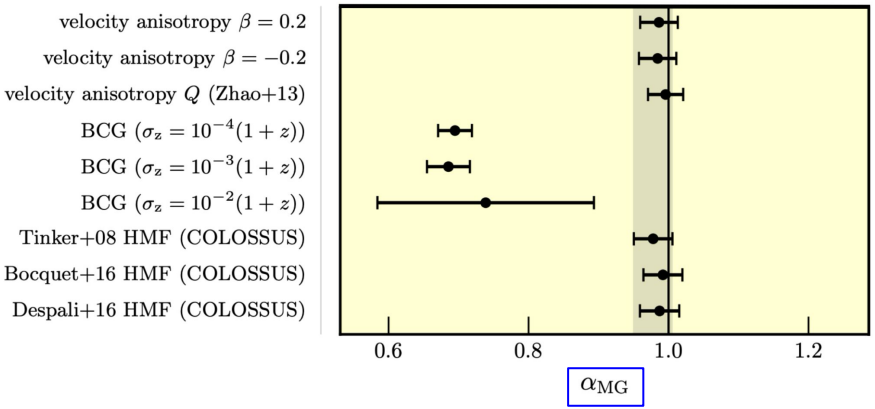
1. Signal robustness

How do uncertainties affect the gravitational redshift signal?

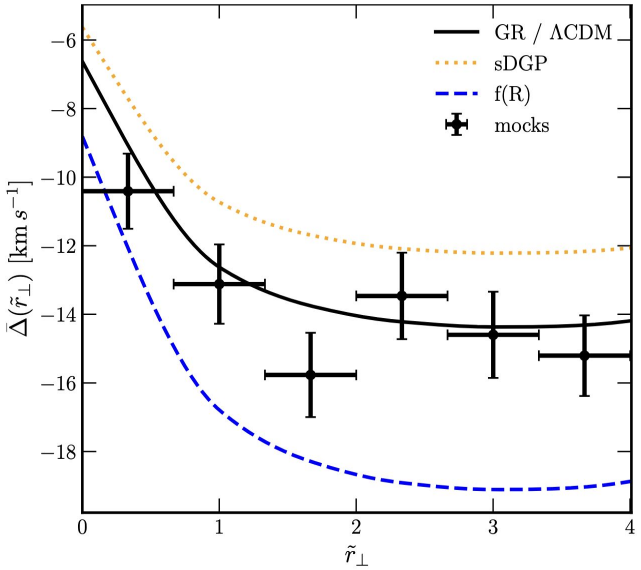
2. Survey optimisation

How can we optimise survey design to maximise its detection?

Toward %-level constraints on gravity



- Efficient design: z < 1 spec-z
- ~ % constraints on $\alpha_{\rm MG}$

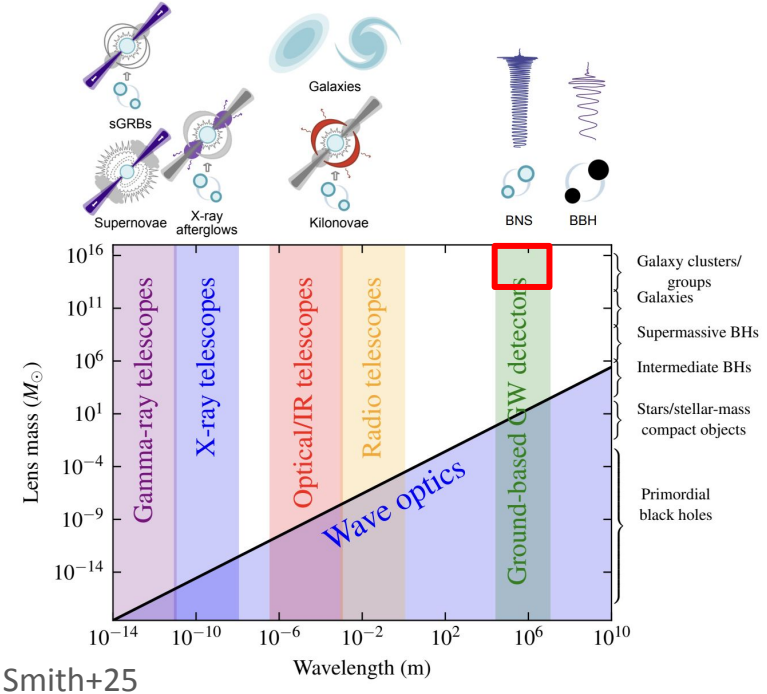


More accurate cluster centre determination?

Tsaprazi+25b
2512.13221

Lensed gravitational waves: gravity at cluster scales

Signal: time delays between images



Smith+25

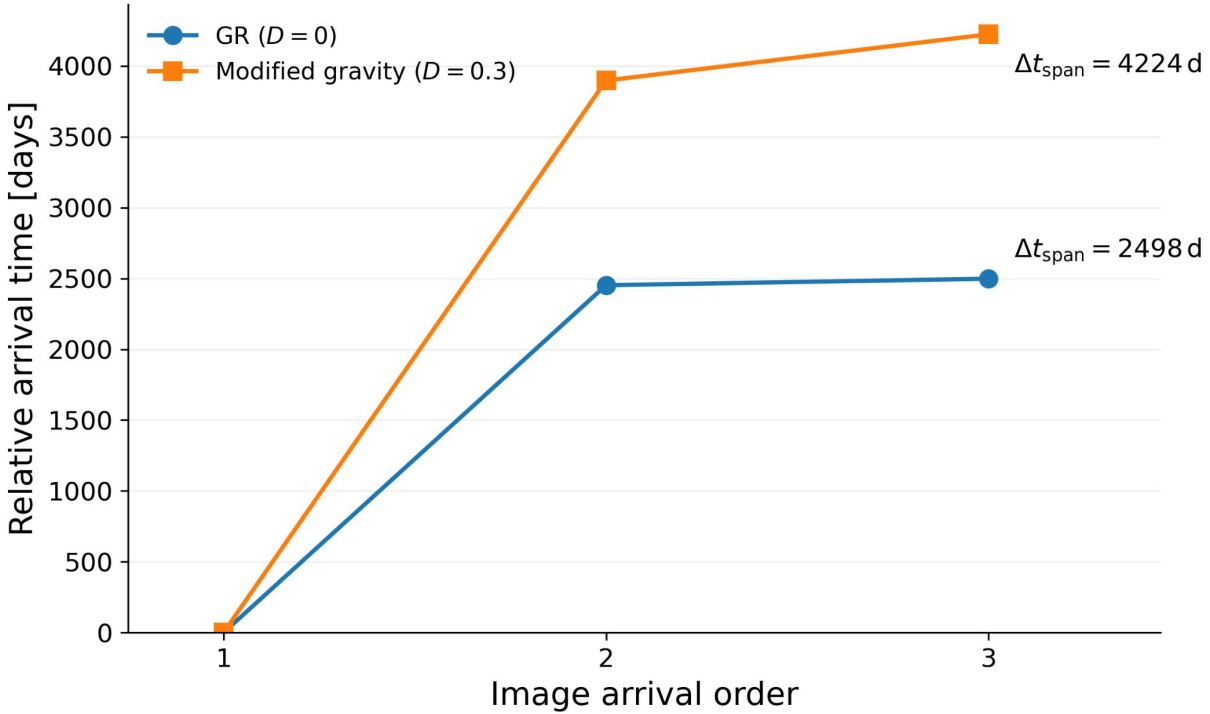
Cluster-lensed GWs:

- Exceptionally precise arrival times
- Can probe screening transitions
- Large cross sections
- Forecast currently missing

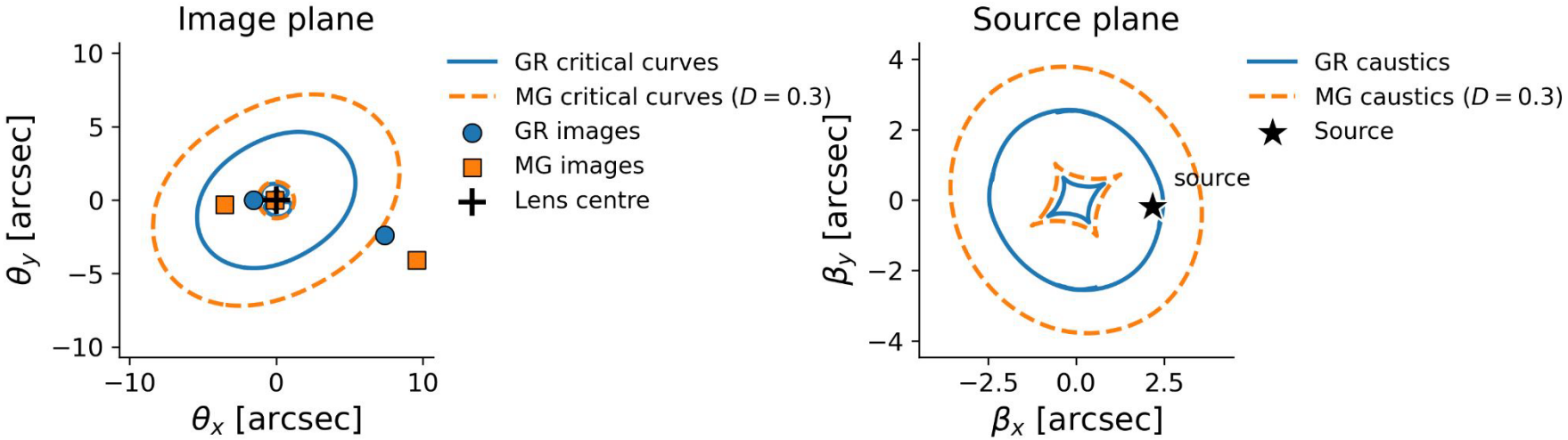
What are the requirements for cluster-lensed GWs to provide accurate forecasts and tests of gravity?

Tsaprazi+26b
2609.24351

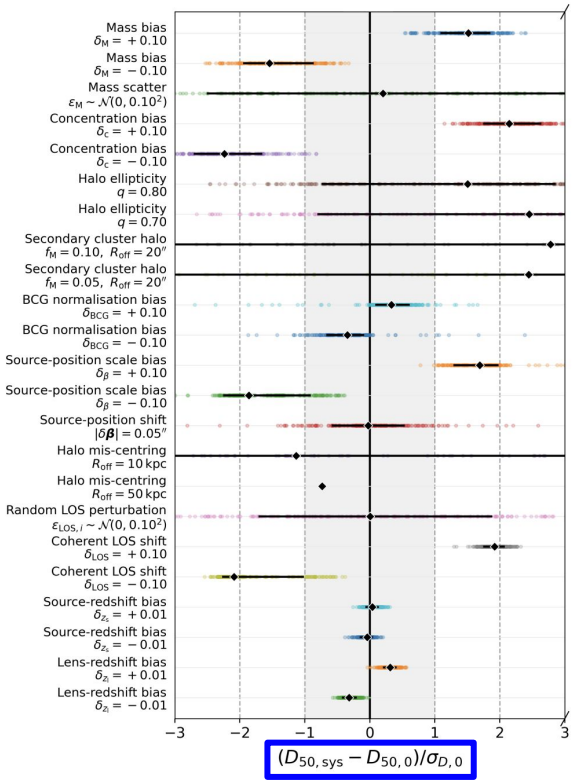
Impact of modified gravity on time delays



Impact of modified gravity on geometry



Mass profile modelling is crucial

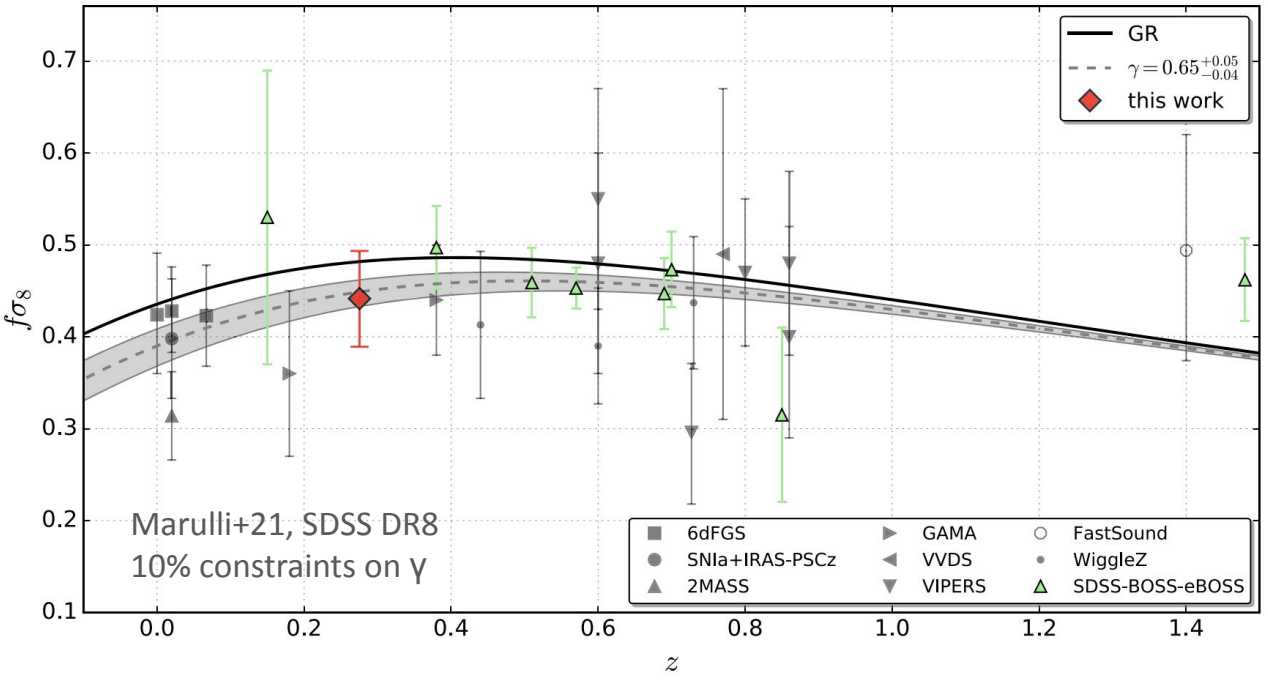


- **250 mock events sourced by binary neutron star mergers**
- **Lens-dependent** bias on D:
  - Ellipticity, secondary structure
  - LOS structure, mis-centring
  - Perturbed clusters should be avoided

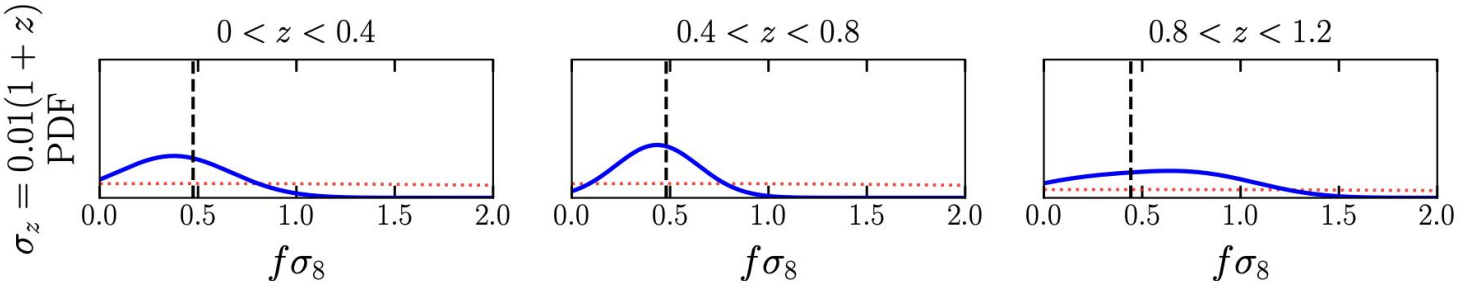
1. **Hydrodynamical simulations**
2. **Breaking degeneracies**

Cluster clustering: gravity at intercluster scales

- High-mass regime
- **Breaks degeneracies**
- **Priors on halo bias**
- **Growth index γ →**
- **2PCF**



Photometric clustering with Euclid DR1-like samples



EC: **Tsaprazi**+26
2604.25762

- **Clustering model selection: fσ_8 inference against perturbative mocks**
- Dispersion model down to > 10 h^{-1} Mpc
- Guiding the analysis choices for DR1

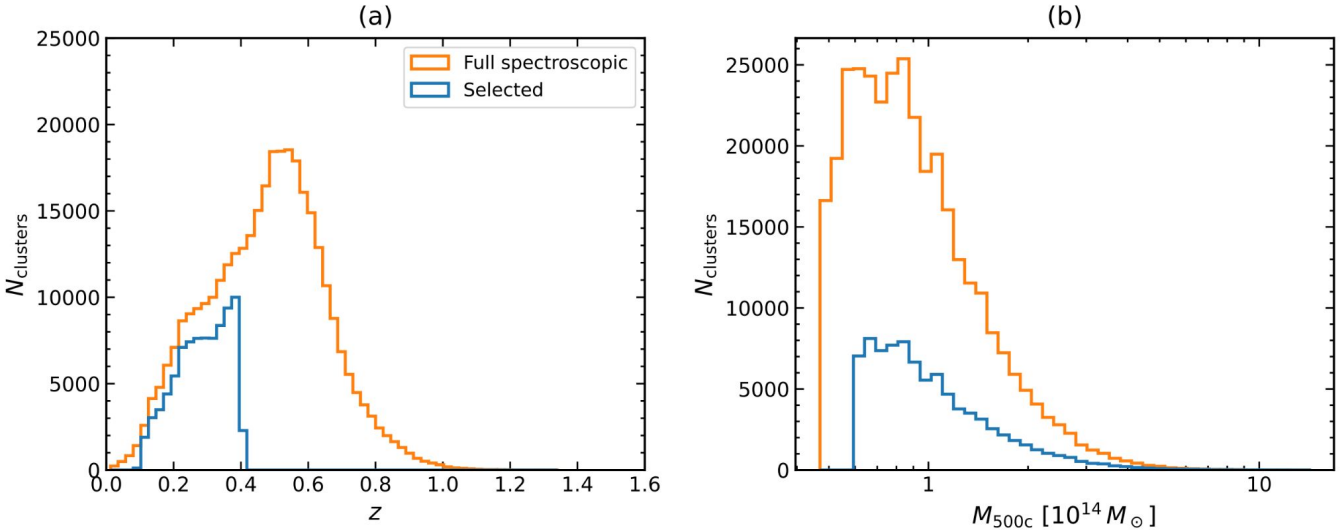
cloe-org

1. **N-body mocks**
2. **More flexible clustering models for DR2-3**

A LOOK AT REAL DATA

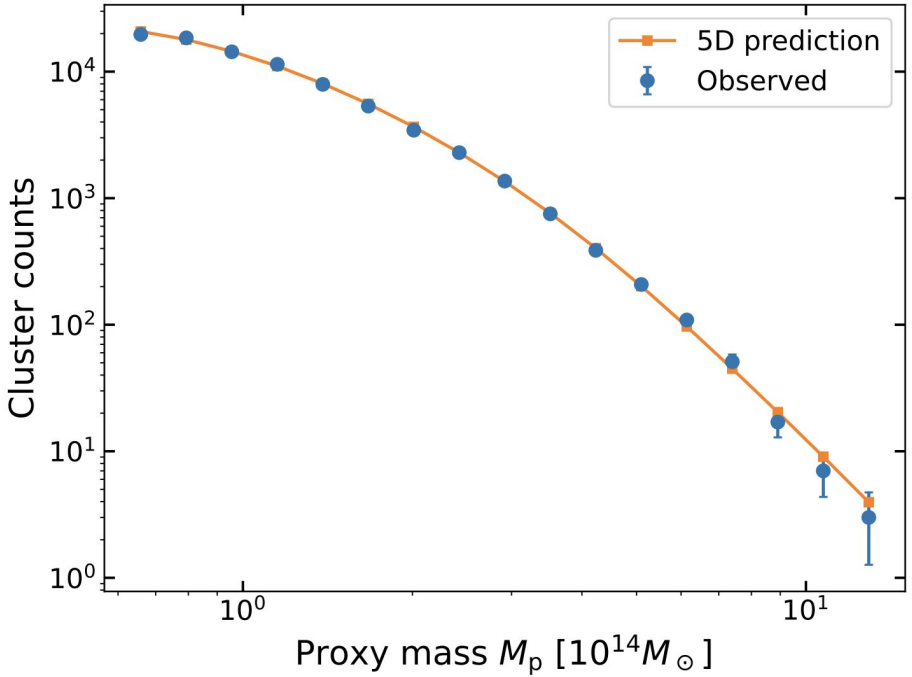
Spectroscopic clustering with the DESI Legacy Imaging Surveys: real-data constraints

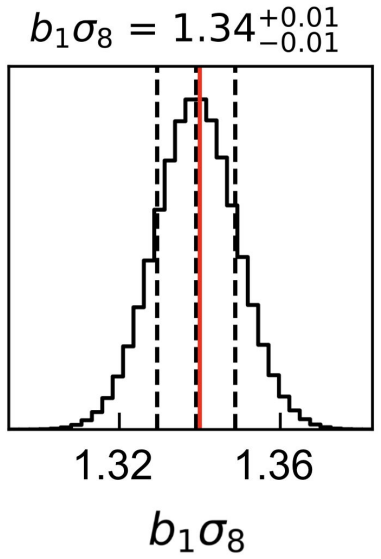
Tsaprazi+26c
2611.23104



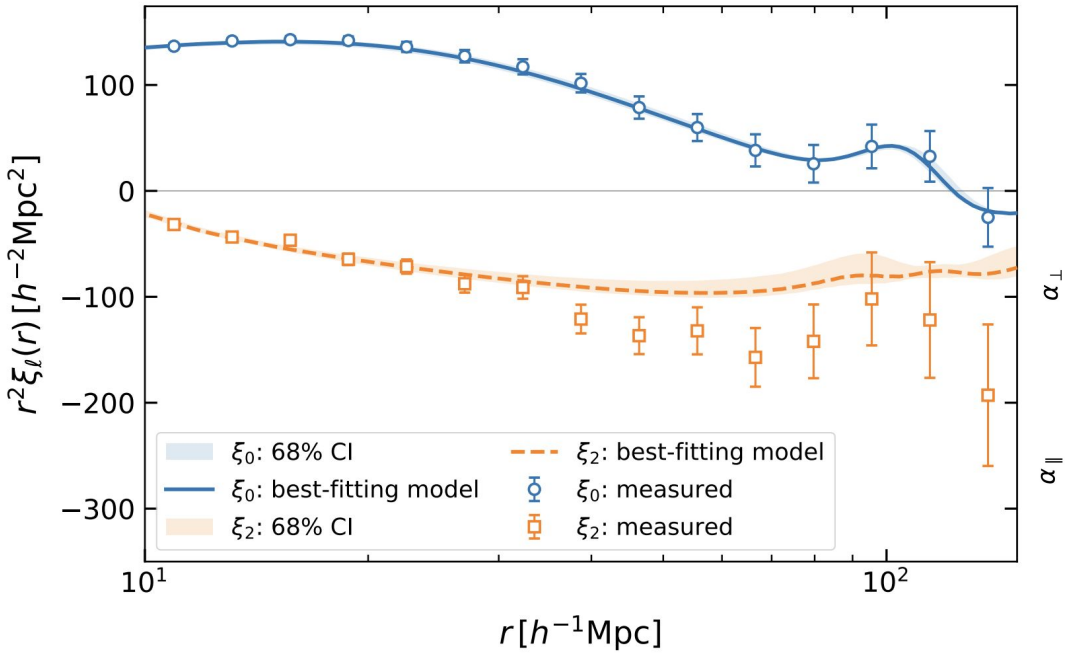
Fixed template analysis with halo bias prior derived in the absence of selection information

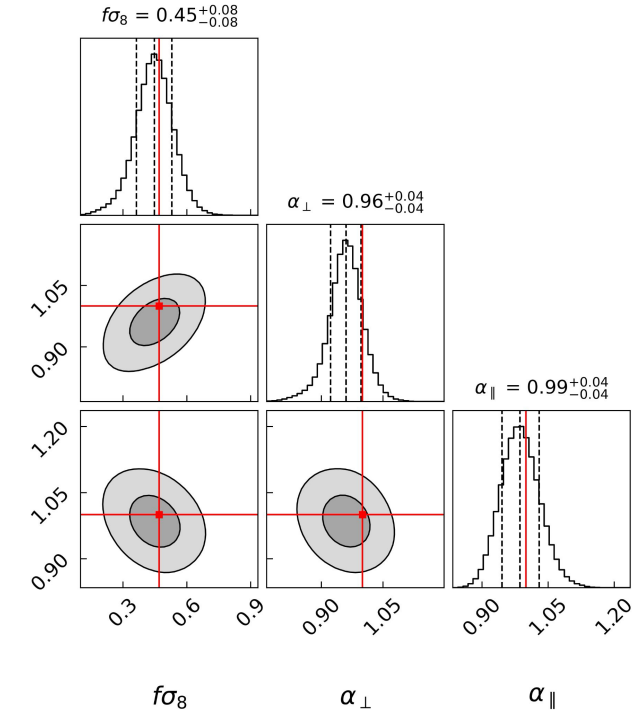
Cluster counts analysis to derive the halo bias prior



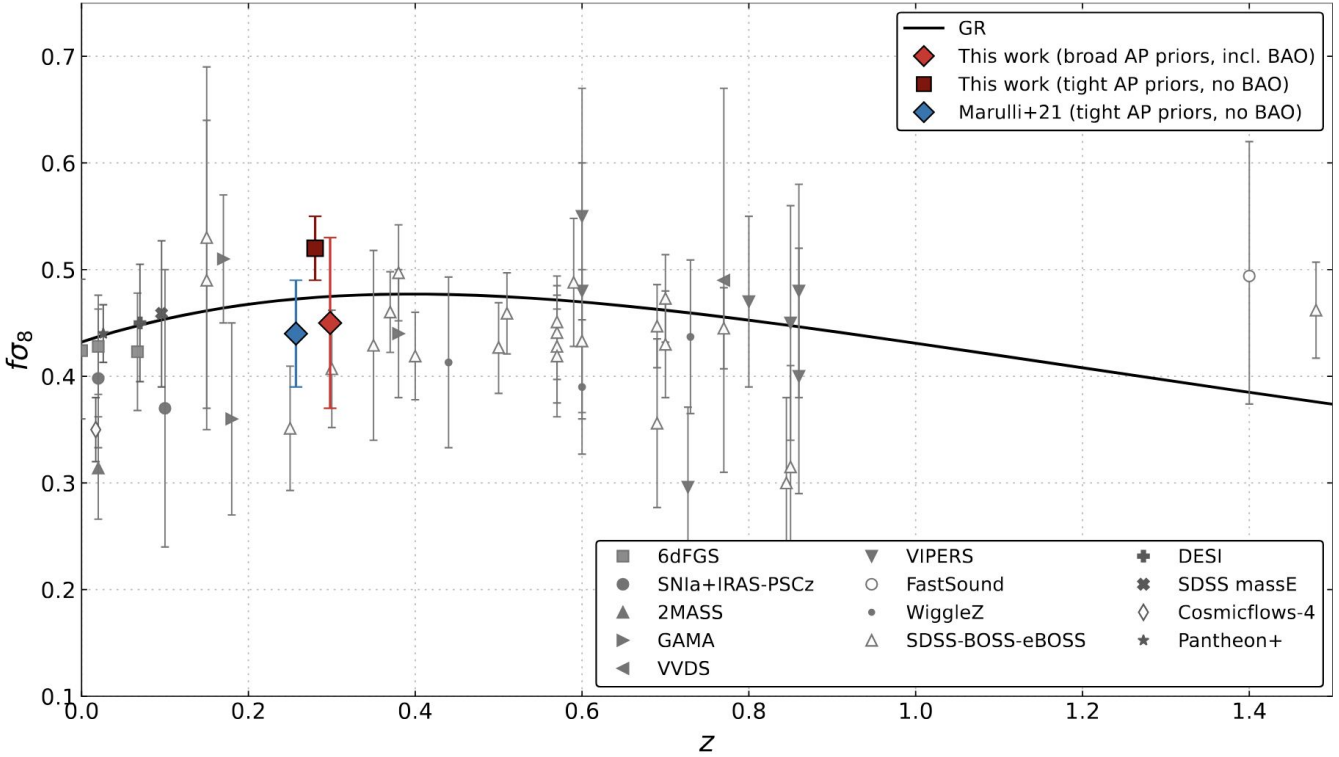


Best constraints from cluster clustering to date





Best constraints from cluster clustering to date



A **multi-scale** approach to testing general relativity with clusters

We need:

- Techniques to mitigate mis-centring for gravitational redshifts
- Additional data to constrain mass profiles for gravitational wave lensing
- Tight priors on the BAO scales to achieve % precision on $f\sigma_8$

Gravitational redshifts: forecast & real data



Matteo Macchione

GW lensing: forecasting



Ettore Delpogetto

Clustering: DR1 data

Incoming in 2027