

Testing cosmological models by using redshift space distortion and Type Ia supernovae data

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Introduction

- The concordance cosmological model, the Λ CDM model, have anomalies in the low-redshift universe
- To alleviate these anomalies, various alternative cosmological models have been introduced
- Examples: Modified gravity, dynamical dark energy

Testing modified gravity with RSD

- Derive $f\sigma_8$ from redshift space distortion measurement and use them for testing cosmological models
(f : cosmic growth rate, σ_8 : smoothed amplitude of density perturbation)
- Massive gravity: Give a mass to the graviton
- de Rham-Gabadadze-Tolley(dRGT) massive gravity: Nonlinear theory of massive gravity, have unstable gravitational degrees of freedom
 - > Gives unstable cosmological solutions

de Rham. Gabadadze. Tolley. 2011
De Felice. Mukohyama. 2016

Testing modified gravity with RSD

- Minimal theory of massive gravity(MTMG): Unstable degrees of freedom have removed
-> Gives stable cosmological solutions
De Felice. Mukohyama. 2016
- MTMG have the same cosmological background with the standard Λ CDM, but shows different effective gravity on linear matter perturbation

$$\delta_m'' + \left(2 - \frac{3}{2}\Omega_m\right) \delta_m' - \frac{3}{2} \frac{\bar{G}_{\text{eff}}}{G_N} \Omega_m \delta_m = 0$$

$$\bar{G}_{\text{eff}} = \frac{2}{3} G_N \left[\frac{3}{2 - \theta Y} - \frac{9\theta Y \Omega_m}{2(\theta Y - 2)^2} \right]$$

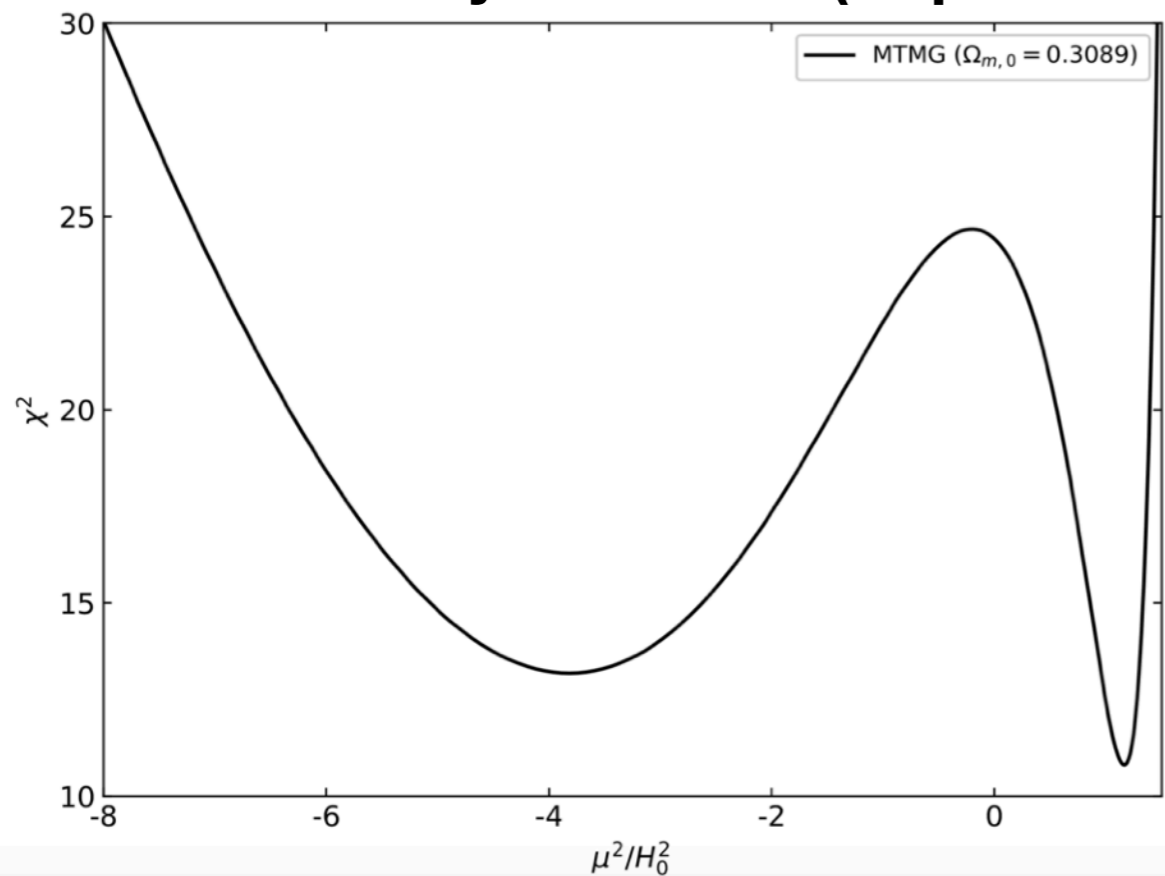
De Felice. Mukohyama. 2017

μ : mass of the gravitational wave, $\theta = \mu^2/H_0^2$

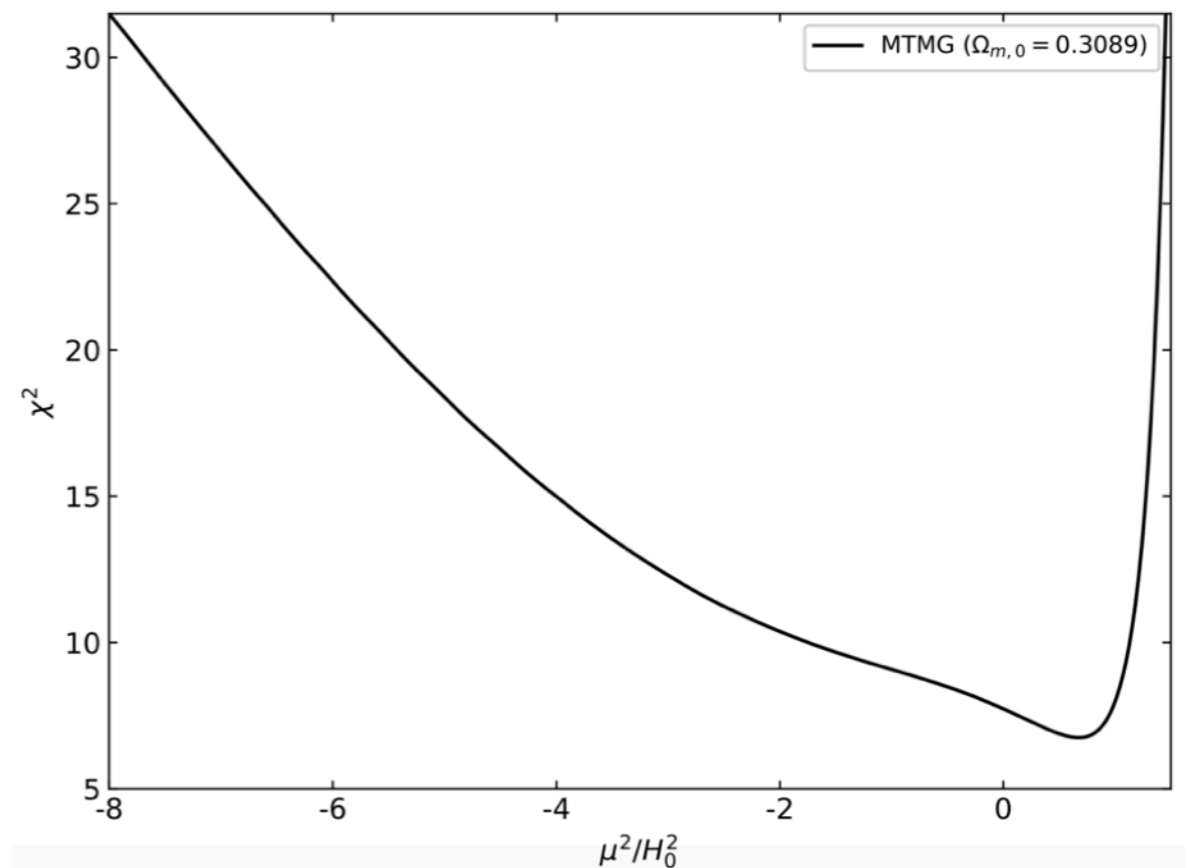
Testing modified gravity with RSD

- $f\sigma_8$ values from the old RSD measurements disfavor the standard Λ CDM model ($\mu^2/H_0^2=0$), while those from the more recent one do not (μ : mass of the gravitational wave)

De Felice. Mukohyama. 2017 (Reproduced)



From the more recent data



Combining MTMG and dynamical DE

- Adding dynamical DE on MTMG would bring different result
e.g. w CDM, CPL(Chevallier-Polarski-Linder) parametrization
- Dynamical DE requires additional free parameters
e.g. CPL parametrization($w = w_0 + w_a(1-a)$) requires w_0, w_a
- Adding dynamical DE on MTMG also requires additional free parameters to describe modified effective gravity

Testing cosmological models with SNe Ia

- Reconstructed expansion history from the SNe Ia data also need to be used for testing cosmological models
- Reliable calibration of μ measurement is required
(μ : distance modulus)
- Iterative smoothing method is useful to smooth μ and reconstruct expansion history from the SNe Ia data
Shafieloo et al. 2006; Shafieloo 2007; L'Huillier & Shafieloo et al. 2017&2018

Testing cosmological models with SNe Ia

SNe Ia observational data:

- JLA: SDSS-II+SNLS
Betoule et al. 2014
- Pantheon: Pan-STARRS1
+SDSS+SNLS+lowz+HST
Scolnic et al. 2018

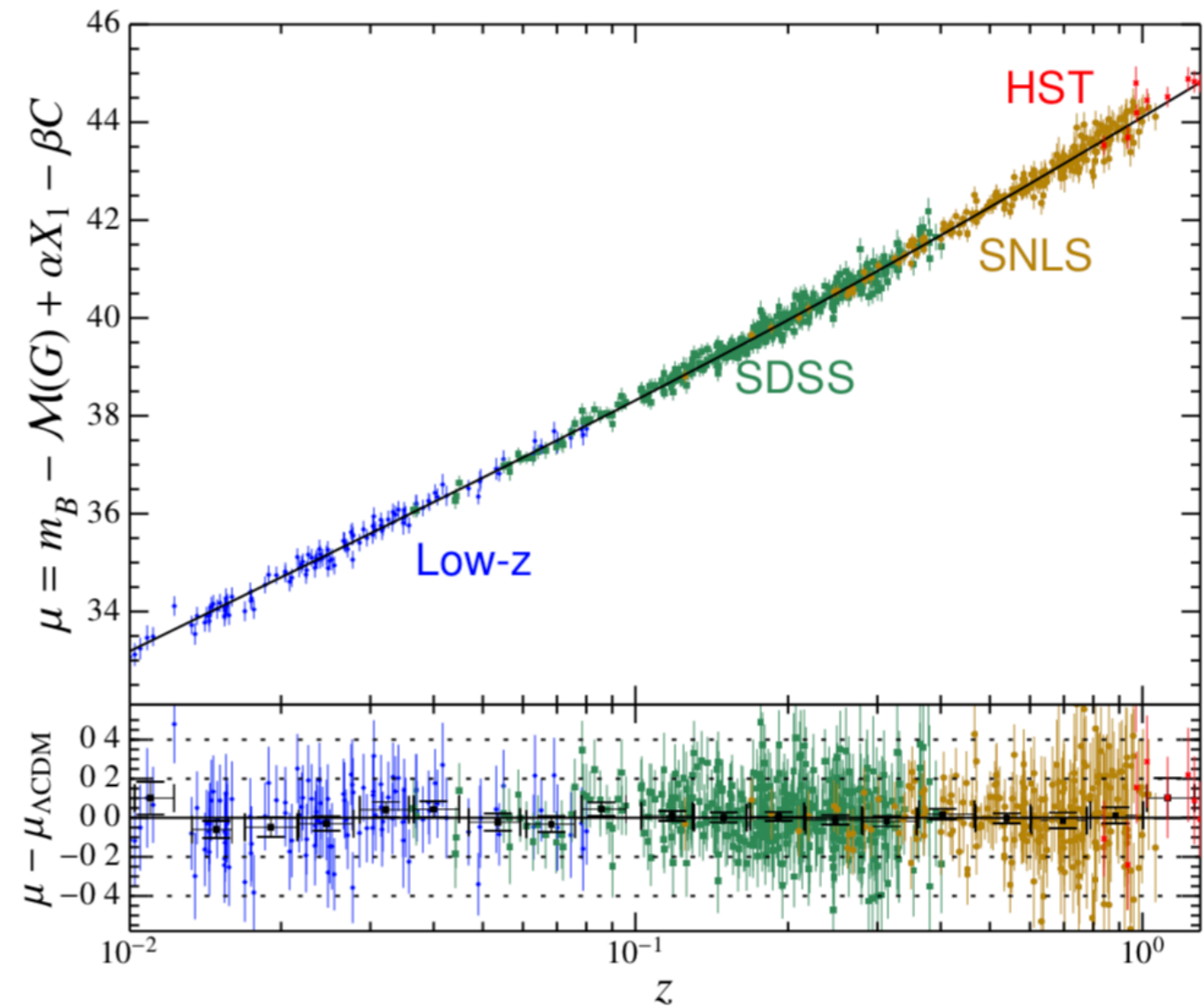


Figure 8, Betoule et al. 2014

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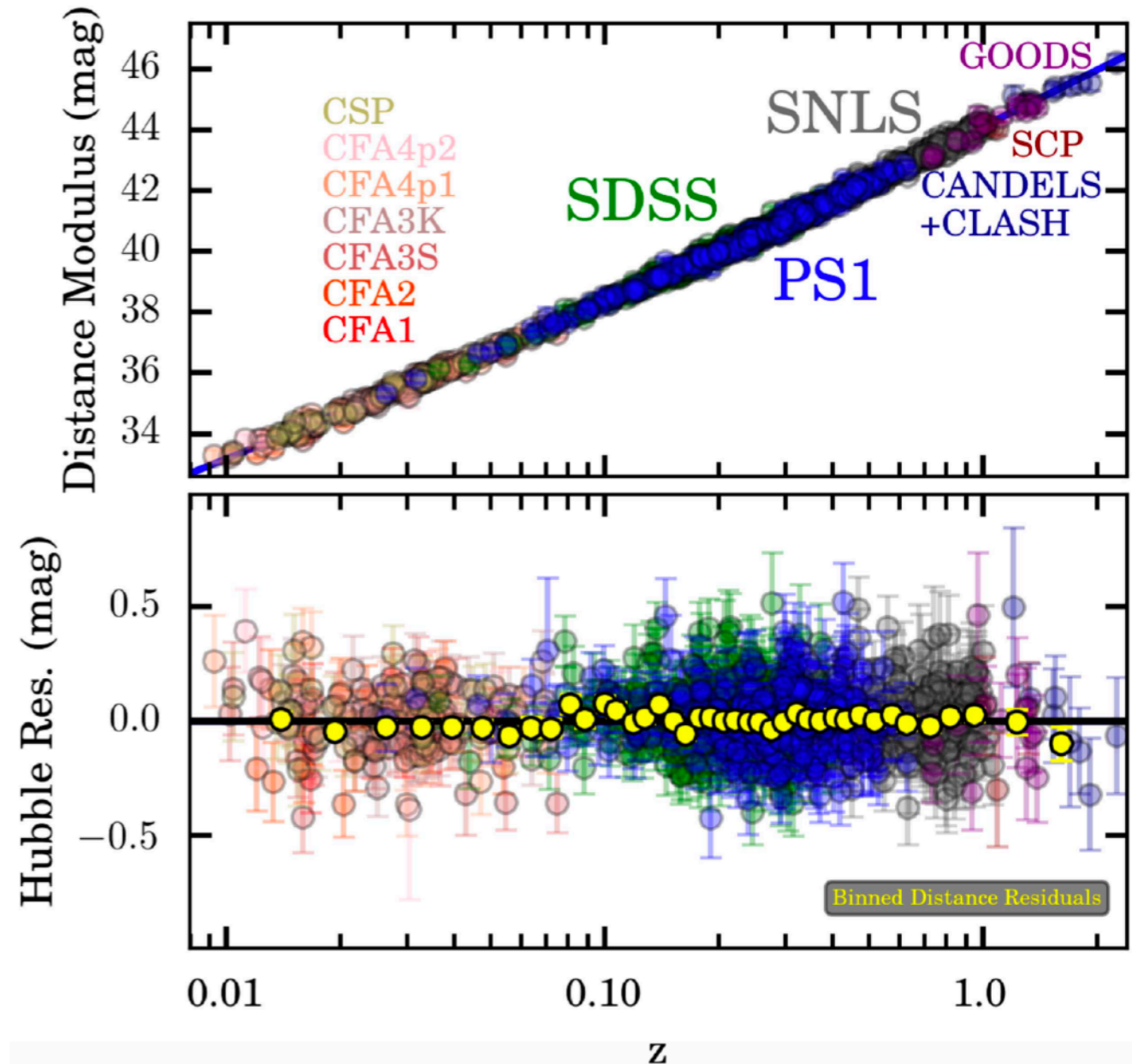


Figure 11, Scolnic et al. 2018