Generalized dark matter model with the Euclid satellite

Isaac Tutusaus

Institut de Recherche en Astrophysique et Planétologie

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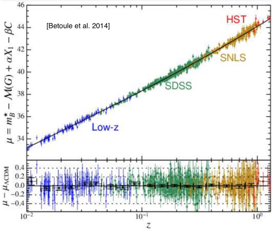
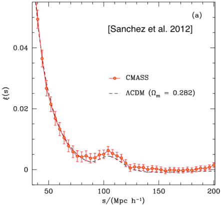
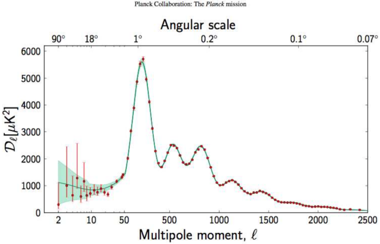
Introduction

ΛCDM Good phenomenological fit to current cosmological data:







But no direct detection of DM, neither of DE as a cosmological constant +
Some tensions between low-z and high-z data

Goal: Go beyond ΛCDM focusing on a more general phenomenology for dark matter ⇒ Generalized dark matter
[Hu 1998; Thomas *et al.* 2016; Kunz *et al.* 2016; Kopp *et al.* 2016; 2018]

Theoretical framework

- We assume that DM is only coupled to the visible sector through gravity:
  - $\Rightarrow$ DM energy-momentum tensor is conserved.
  - $\Rightarrow$ We can use the standard conservation equations for a general matter source:

$$\dot{\rho} + 3H(1+w)\rho = 0$$

- We focus on linear scalar perturbations:

$$\dot{\delta} + (1+w)\left(\theta + \frac{\dot{h}}{2}\right) + 3H\left(\frac{\delta p}{\delta \rho} - w\right) = 0$$

$$\dot{\theta} + H(1-3w)\theta + \frac{\dot{w}}{1+w}\theta - \frac{\delta p/\delta\rho}{1+w}k^2\delta + k^2\sigma = 0$$

- GDM is then specified by

$$w, \quad \delta p, \sigma \leftrightarrow \delta, \theta$$

Theoretical framework

- We consider non-relativistic DM (it can allow for the formation of galaxies) with the $c_{\rm vis}$ parameterization:

$$\delta p = c_s^2 \delta\rho - \dot{\rho}(c_s^2 - c_a^2)\theta/k^2$$

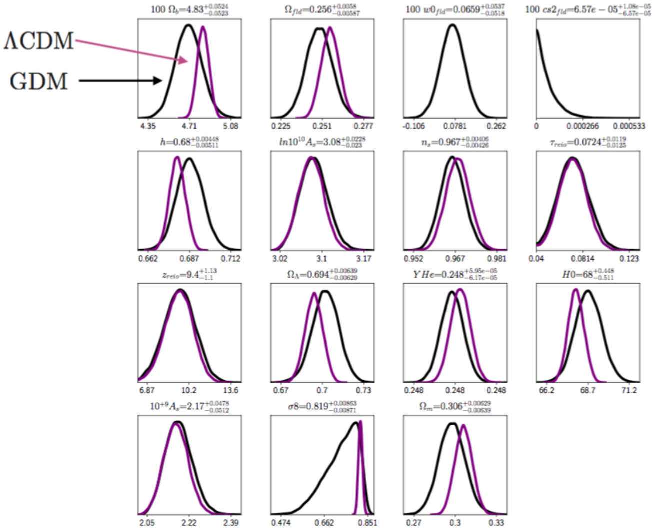
$$\dot{\sigma} + 3H\frac{c_a^2}{w}\sigma = \frac{4}{3}\frac{c_{\rm vis}^2}{1+w}(2\theta + \dot{h} + 6\dot{\eta})$$

- In conclusion, GDM is characterized by
  - Equation of state parameter $w(z) \to w_0$ (= 0 for CDM)
  - Sound speed $c_s^2(z,x) \to c_{s,0}^2$ (= 0 for CDM)
  - Viscosity $c_{\rm vis}^2(z,x) \to 0$ (= 0 for CDM)

Current data

- Markov chain Monte Carlo with Monte Python and a modified version of CLASS
  - Type Ia supernovae (JLA) [Betoule *et al.* 2014]
  - BAO [Anderson *et al.* 2014; Beutler *et al.* 2011; Ross *et al.* 2015]
  - CMB (Planck_highl_TTTEEE, Planck_lowl, Planck_lensing) [Planck Collaboration 2016]
  - CFHTLenS [Heymans *et al.* 2013]
    - ⋆ Tension with CMB data?
    - ⋆ Nonlinear scales?

Current data: Results

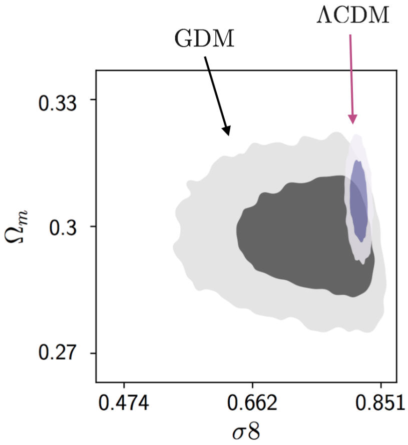


CMB + SNIa + BAO

GDM allows for:

- **Smaller** Ω_m
- **Smaller** σ_8
- **Larger** H_0

Current data: Results

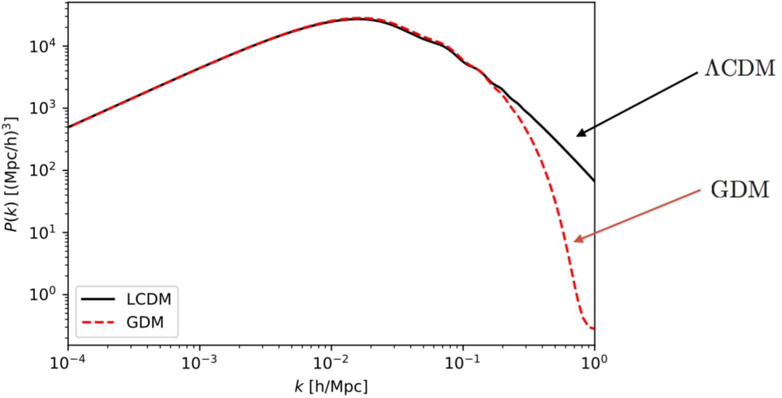


CMB + SNIa + BAO

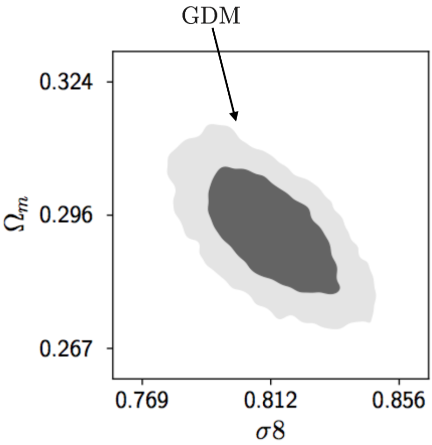
GDM could alleviate the tension between Ω_m and σ_8 (smaller value for σ_8 keeping Ω_m fixed)

Current data: Results

Probes sensitive to small scales are very important to constraint GDM



Current data: Results



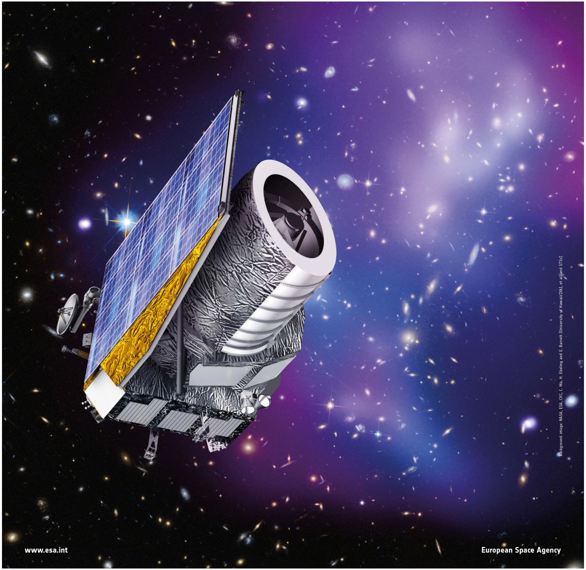
CMB + SNIa + BAO + WL

Much stronger constraints when adding WL data:

$c_s^2 < 7.65e-7 \quad \Rightarrow \quad c_s^2 < 1.14e-10$

But can GDM still alleviate the Ω_m - σ_8 tension?

The Euclid satellite



The Euclid satellite

The Euclid Mission: baseline and options

Euclid Consortium

SURVEYS In ~5.5 years		
	Area (deg2)	Description
Wide Survey	**15,000 deg^2**	Step and stare with 4 dither pointings per step.
Deep Survey	**40 deg^2**	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey

PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg^2	0.763×0.722 deg^2			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of *n* = 1.5 x10^9 galaxies			**z of *n*=5x10^7 galaxies**	
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250

Possibility other surveys: SN and/or μ-lens surveys, Milky Way ?

Ref: Euclid RB arXiv:1110.3193

Recipe for weak lensing

Observable: tomographic cosmic shear power spectrum

Cosmological parameters

- $\{\Omega_b, h, \Omega_m, n_s, w_0, w_a, \sigma_8, \mathcal{A}_{\rm IA}, \eta_{\rm IA}, \beta_{\rm IA}\}$ without any projection
- We marginalise over the intrinsic alignments (IA) nuisance parameters $\mathcal{A}_{\rm IA}, \eta_{\rm IA}, \beta_{\rm IA}$

We model five observational effects beyond calculating the linear matter power spectrum:

- Shear power spectrum
- IA power spectrum
- Small-scale modelling of the matter power spectrum
- Redshift errors
- Shot noise due to Poisson sampling
- 10 equipopulated bins from $z = 0.001$ up to $z = 2.5$

Recipe for photometric galaxy clustering

Observable: tomographic angular galaxy clustering

Cosmological parameters

- $\{\Omega_b, h, \Omega_m, n_s, w_0, w_a, \sigma_8, b_i\}$ without any projection
- We marginalise over the galaxy bias nuisance parameters b_i

We model five observational effects beyond calculating the linear matter power spectrum:

- Angular clustering spectrum
- Galaxy bias
- Small-scale modelling of the matter power spectrum
- Redshift errors
- Shot noise due to Poisson sampling
- 10 equipopulated bins from $z = 0.001$ up to $z = 2.5$

Euclid Forecast: Probe combination

Observables:

$$C_{ij}^{\gamma\gamma}(\ell) = \int \mathrm{d}\chi \frac{W_i^{\gamma}(\chi)\, W_j^{\gamma}(\chi)}{\chi^2} P_{\delta\delta}\left(\frac{\ell+1/2}{\chi}, z(\chi)\right)$$

$$C_{ij}^{\delta_g\gamma}(\ell) = \int \mathrm{d}\chi \frac{W_i^{\delta_g}\left(\frac{\ell+1/2}{\chi}, \chi\right) W_j^{\gamma}(\chi)}{\chi^2} P_{\delta\delta}\left(\frac{\ell+1/2}{\chi}, z(\chi)\right)$$

$$C_{ij}^{\delta_g\delta_g}(\ell) = \int \mathrm{d}\chi \frac{W_i^{\delta_g}\left(\frac{\ell+1/2}{\chi}, \chi\right) W_j^{\delta_g}\left(\frac{\ell+1/2}{\chi}, \chi\right)}{\chi^2} P_{\delta\delta}\left(\frac{\ell+1/2}{\chi}, z(\chi)\right)$$

Euclid Forecast: Probe combination

Fisher matrix for probe combination:

For the photometric galaxy clustering and weak lensing:

$$F_{\alpha\beta}^{XC} = \sum_{\ell} \sum_{AB} \sum_{pq} \frac{\partial C_p^{AB}(\ell)}{\partial \theta_\alpha} (\mathbf{Cov}^{-1})_{pq}^{AB}(\ell) \frac{\partial C_q^{AB}(\ell)}{\partial \theta_\beta}$$

with the joint covariance matrix:

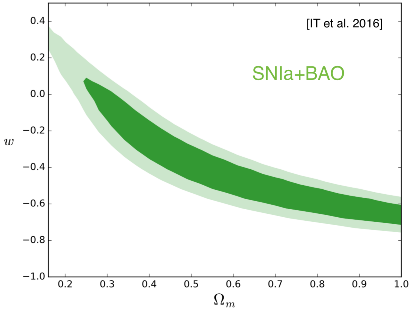
$$\mathbf{Cov}_{ij}(\ell) = \frac{C_{ij}^{AB}(\ell) + N_\ell^{AB}}{(2\ell + 1) f_{\rm sky} \Delta\ell}$$

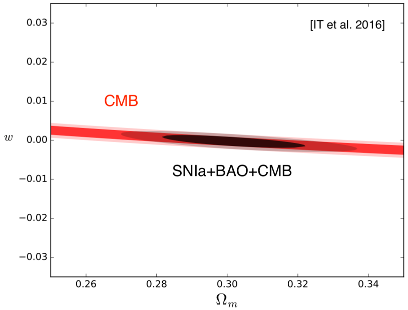
In practice: CosmoSIS [arXiv:1409.3409]

Framework for structuring cosmological parameter estimation in the form of calculation modules

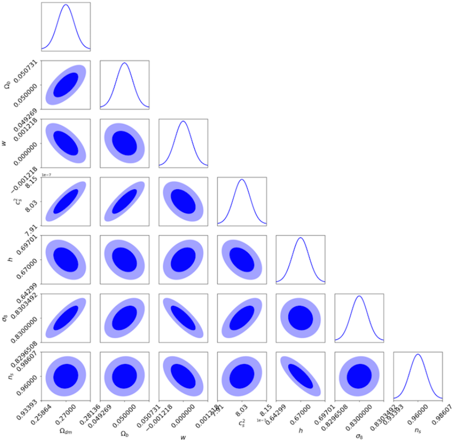
Euclid Forecast: Probe combination

$c_s^2 = 0$





Euclid Forecast: Probe combination



	CMB+SNIa+BAO	Euclid GCp+WL+XC
Ω_b	1.23e-3	2.44e-4
Ω_{dm}	8.51e-3	3.79e-3
w	5.37e-4	4.06e-4
c_s^2	1.08e-7	4.04e-9
h	8.18e-3	9.00e-3
σ_8	9.41e-2	1.16e-4
n_s	4.36e-3	8.69e-3

Conclusions

- The nature of DM is not yet well understood, so it is important to study models proposing a more general approach.
- A more generalized treatment of DM seems to alleviate the tension between low-z and high-z data.
- Adding WL data can be tricky (non-linearities) but it is a key probe to constrain GDM.
- Euclid may provide exquisite constraints on DM properties, showing whether GDM is preferred over standard CDM, and if the tension between low-z and high-z data is alleviated.