Generalized dark matter model with the Euclid satellite

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astrophysique & planétologie

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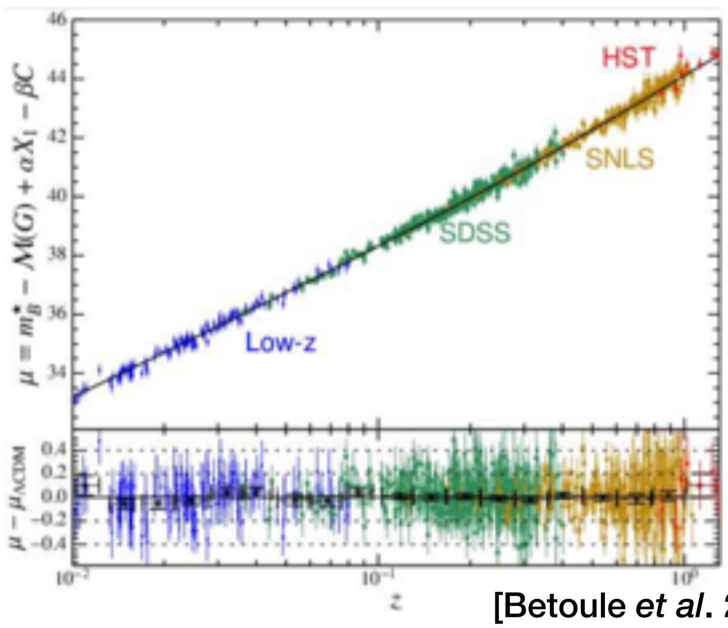
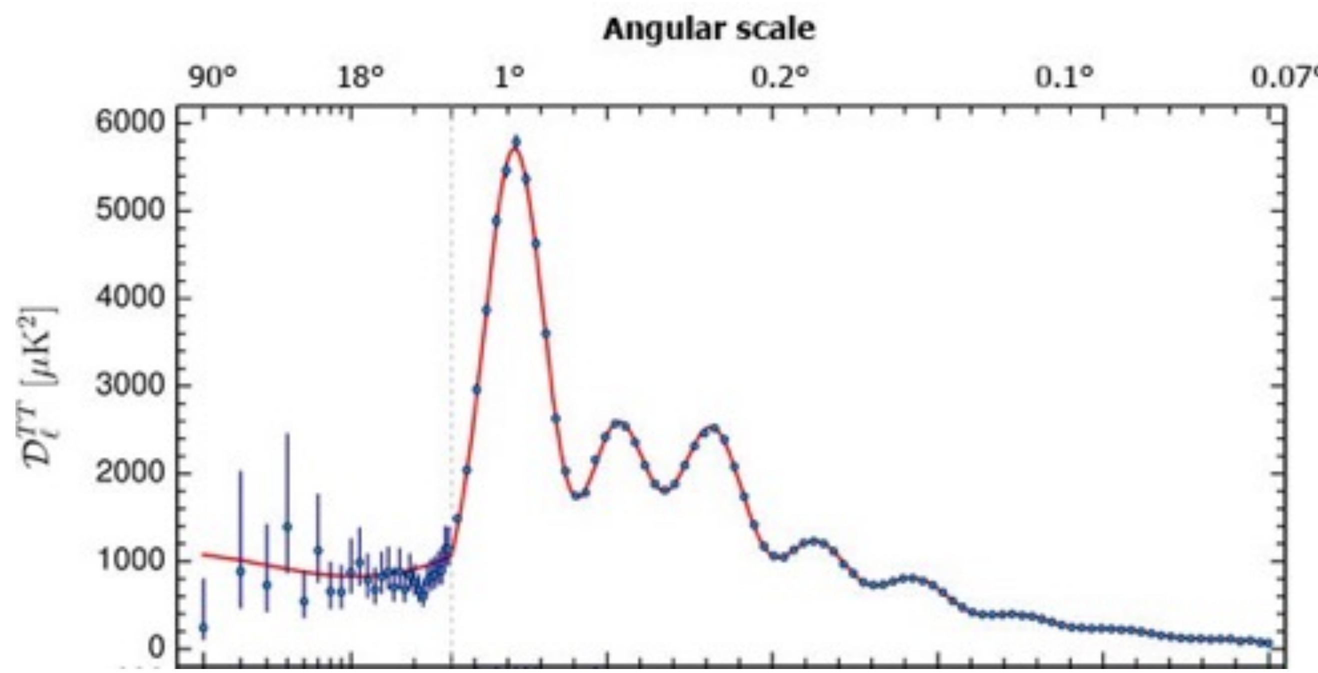
Introduction

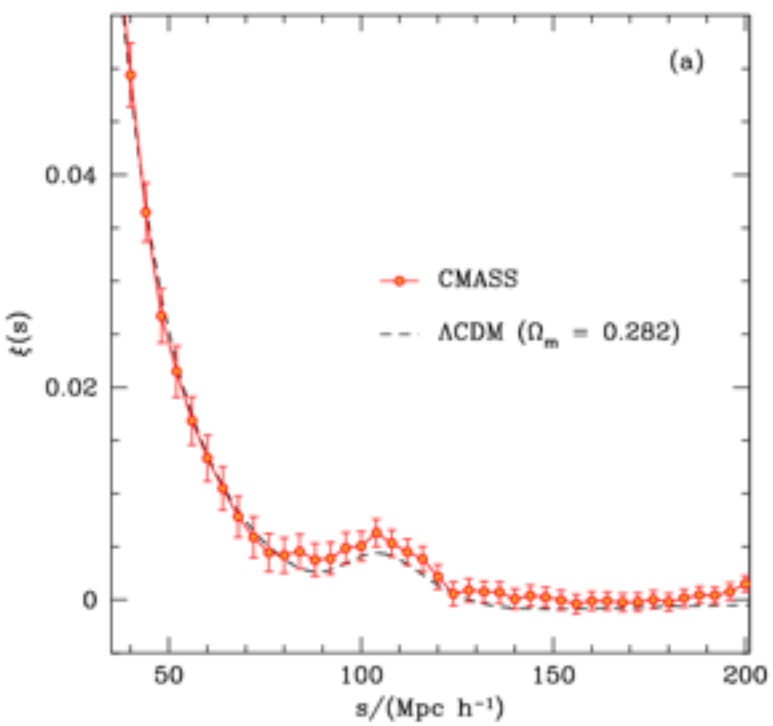
$\Lambda\mathrm{CDM}$ Good phenomenological fit to current cosmological data:



[Betoule *et al*. 2014]



[Planck Collaboration 2016]



[Sanchez *et al*. 2012]

But no direct detection of DM, neither of DE as Λ

Tension between low-z and high-z data

Theoretical framework

- We assume that DM is only coupled to the visible sector through gravity:
    - DM energy-momentum tensor is conserved.
    - 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

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

Theoretical framework

- DM particles interact very rarely compared to the time scale of cosmological evolution.
  - Thermodynamical equilibrium cannot be established.
  - We need to solve the full Boltzmann equation with the particle distribution (multipole moment decomposition).
- But each higher moment is suppressed wrt the previous one by E_c/m
  - If DM is relativistic -> we need to solve the full coupled set of eqs.
  - If DM is non-relativistic -> we can truncate the decomposition.
- We consider non-relativistic DM (it can allow for the formation of galaxies) with the $c_{\rm vis}$ parameterization:

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

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

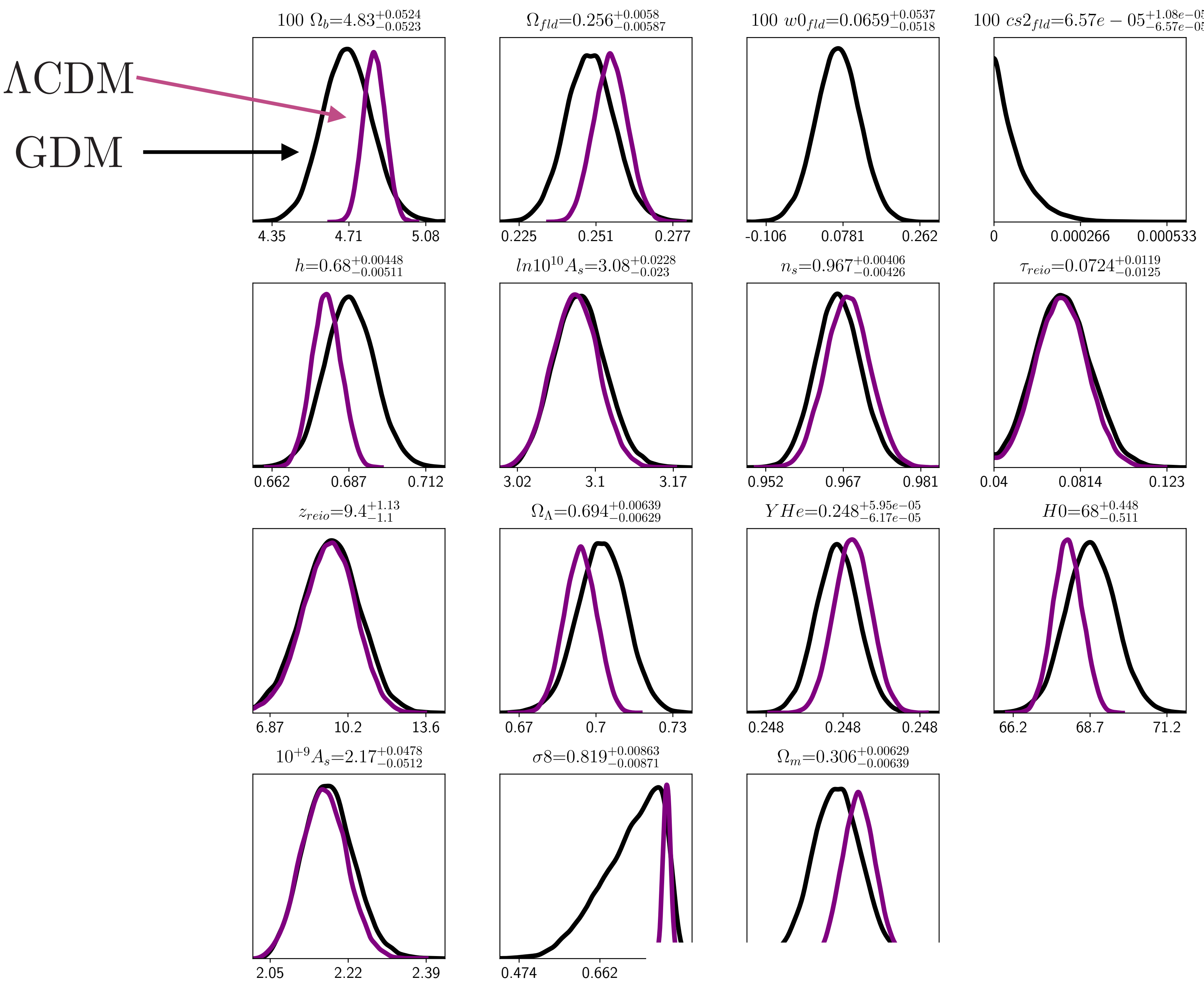
Theoretical framework

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

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

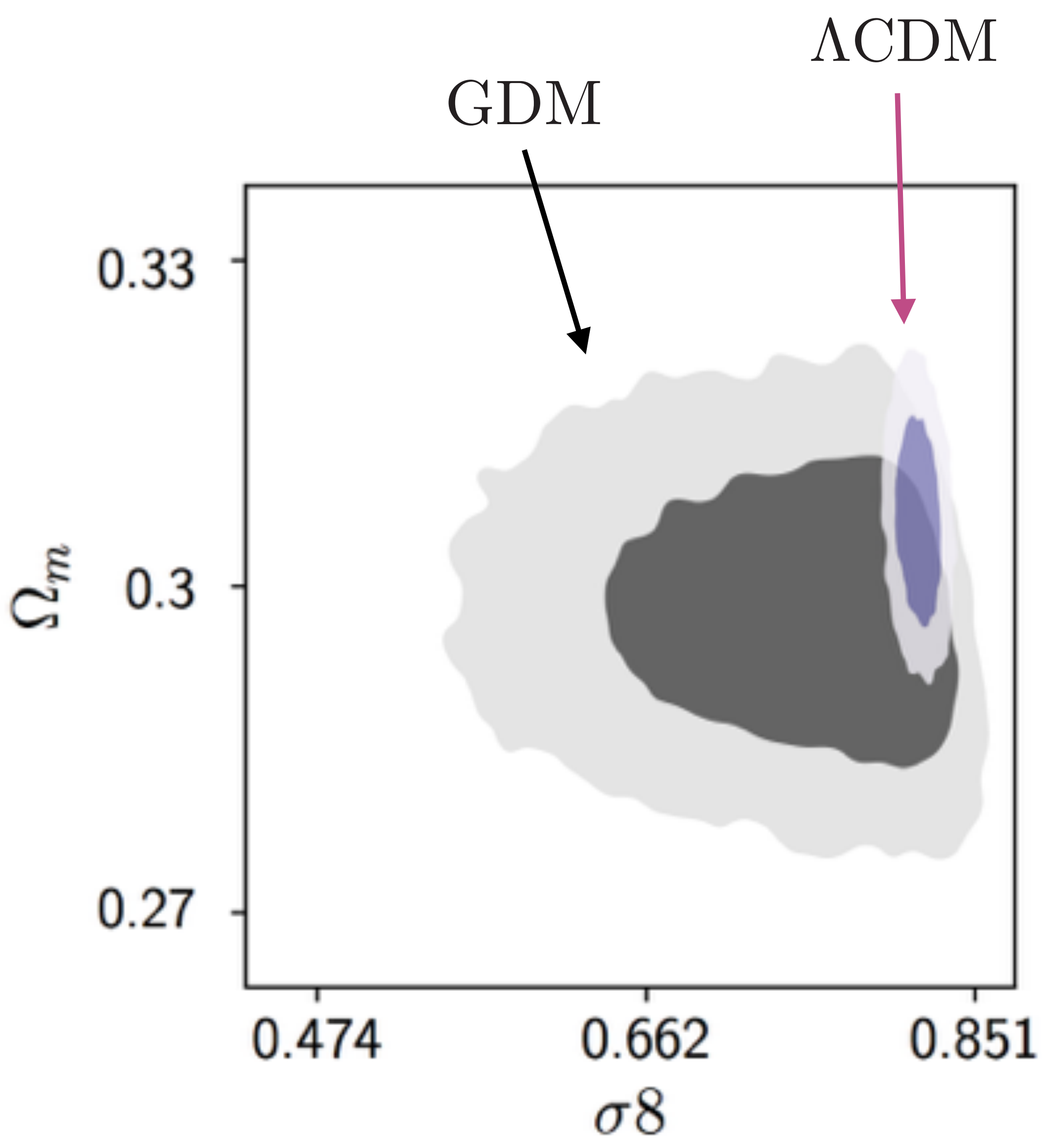


CMB + SNIa + BAO

GDM allows for:

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

Current data: Results

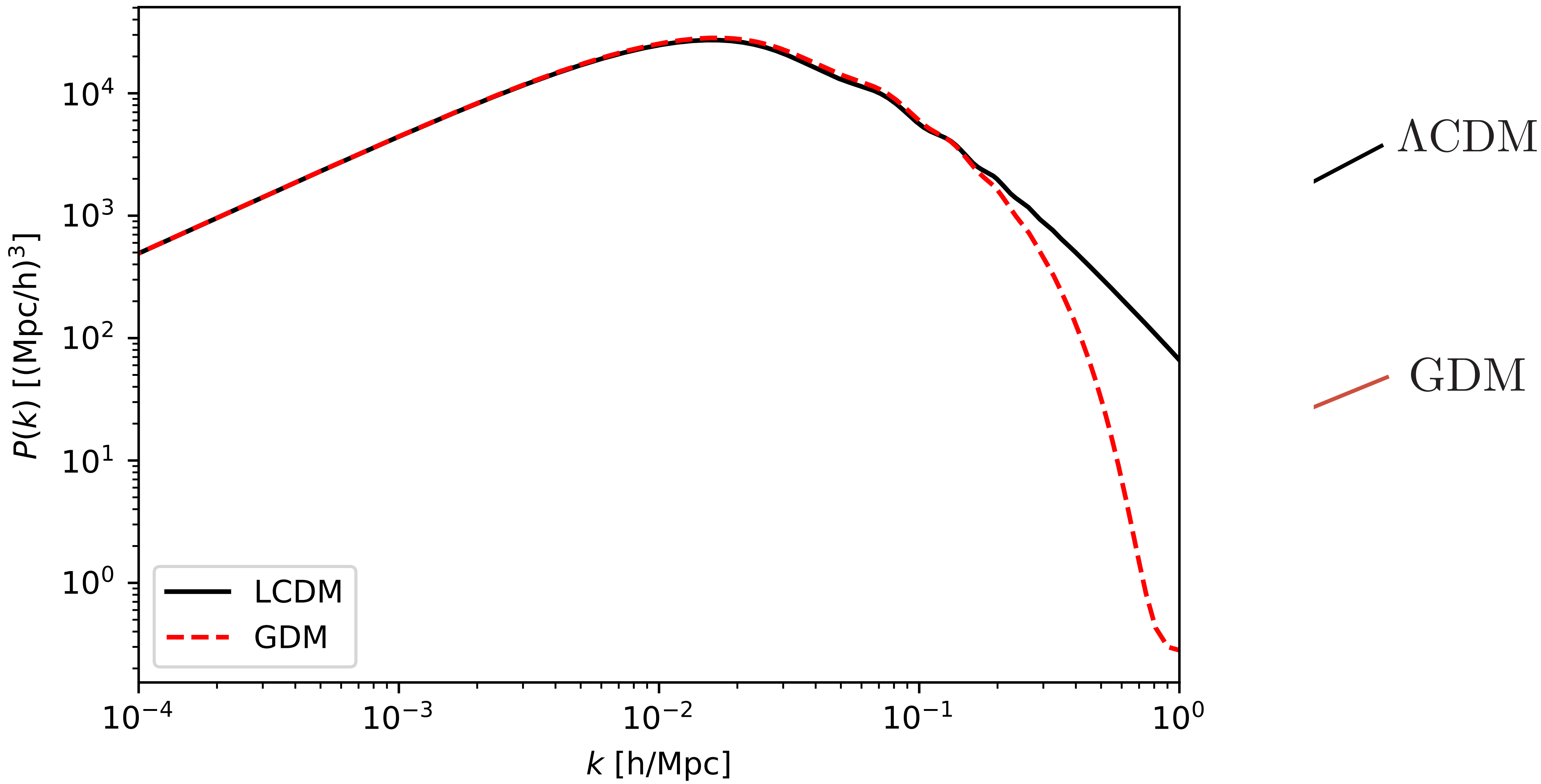


CMB + SNIa + BAO

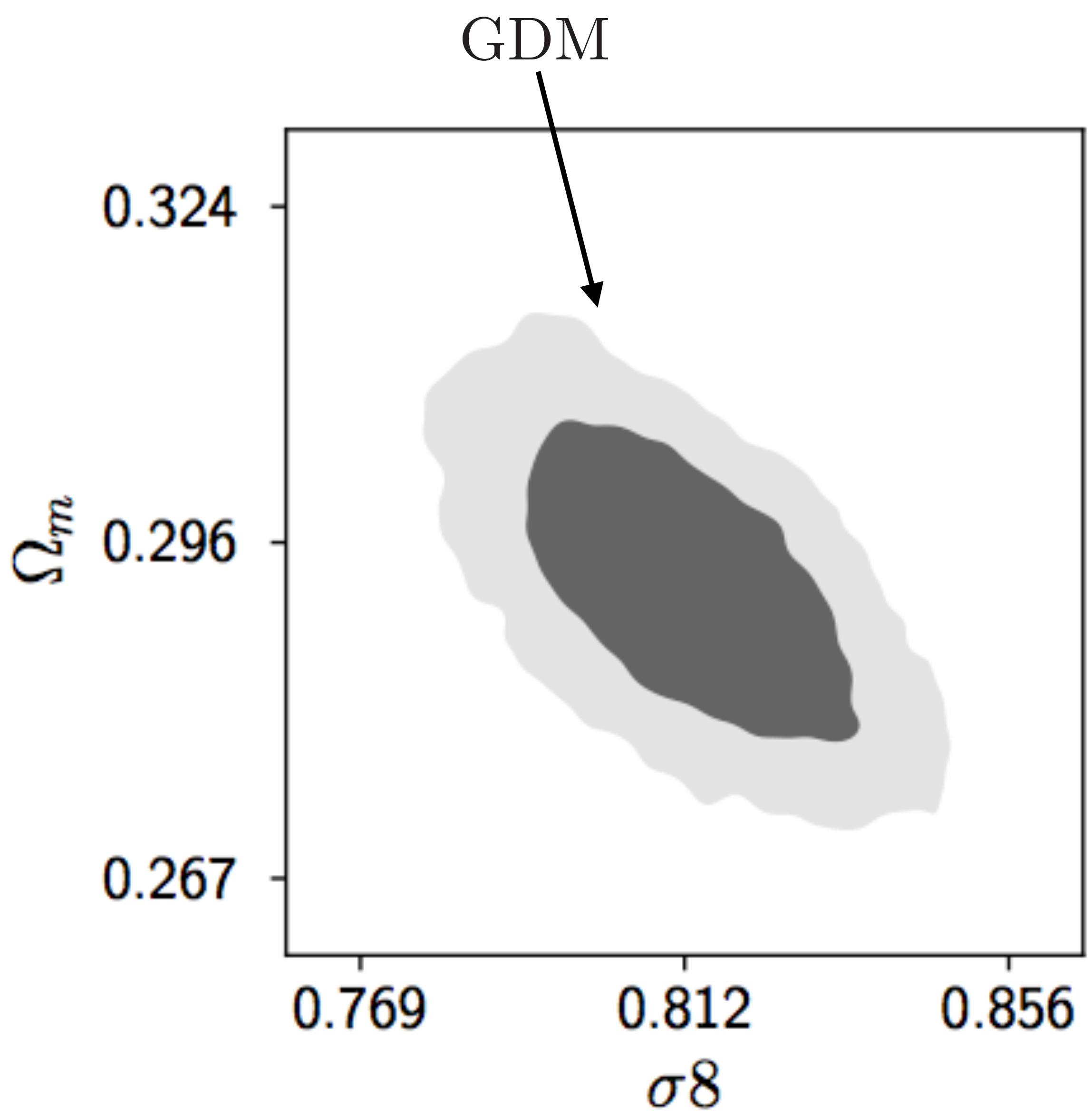
GDM could alleviate the tension between Ω_m and σ_8 (smaller value for σ_8 keeping Ω_m fixed)

Current data: Results

Probes sensitive to small scales are very important to constraint



Current data: Results



CMB + SNIa + BAO + WL

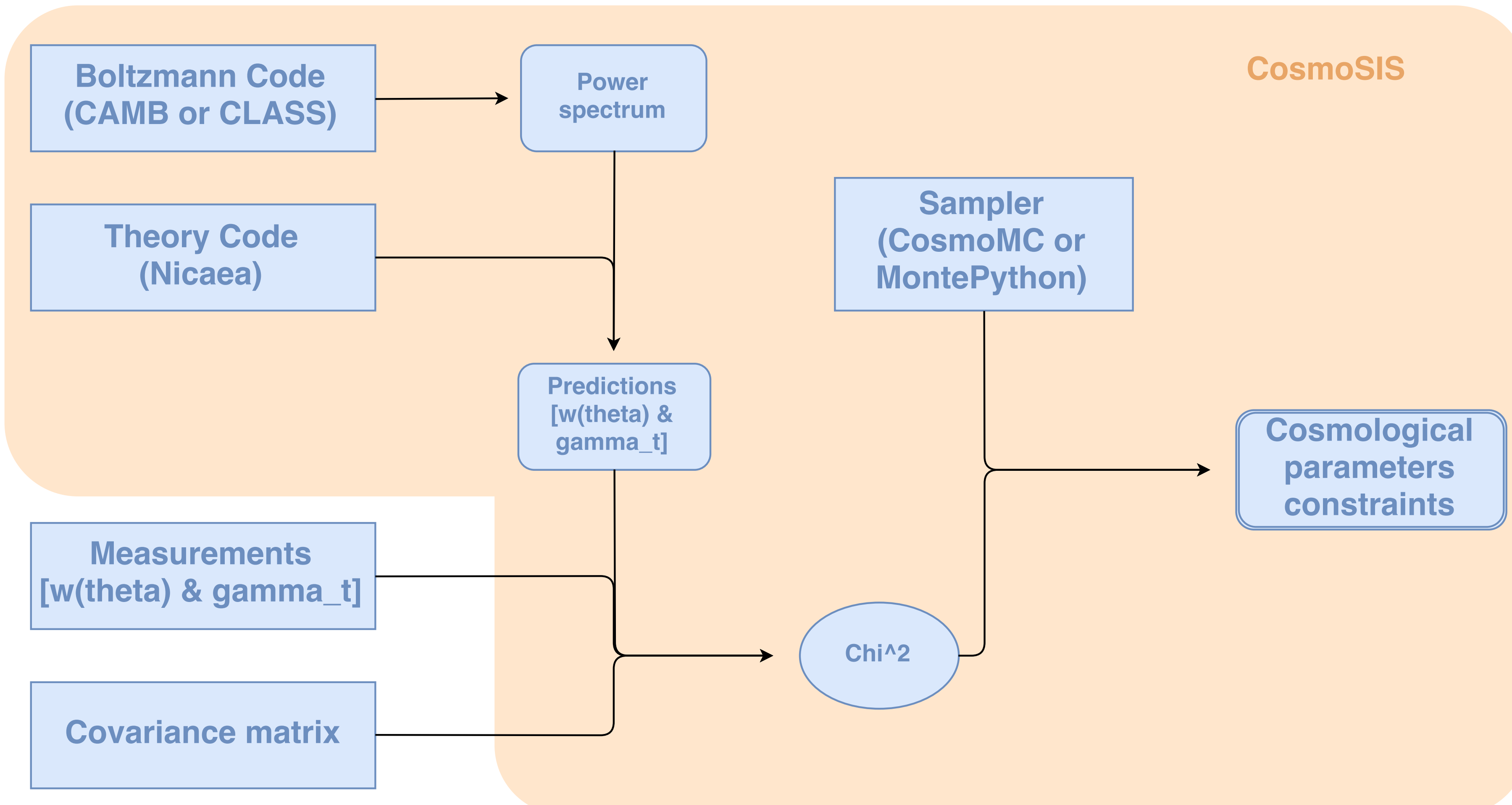
Much stronger constraints when adding WL data:

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

But can GDM still alleviate the Ω_m - σ_8 tension?

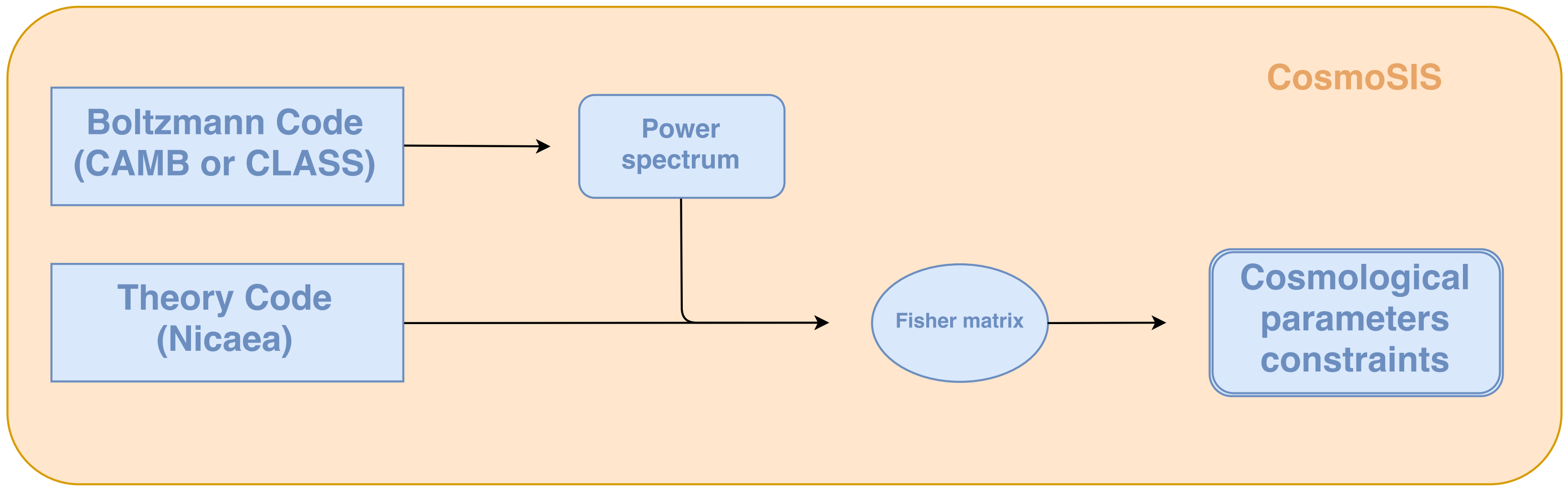
Euclid satellite

Standard data analysis:



Euclid satellite

Fisher matrix forecast:



$$F_{ij} \equiv -\left\langle \left(\frac{\partial^2 \ln \mathcal{L}}{\partial \theta_i \partial \theta_j} \right) \right\rangle_D = -\int \left(\frac{\partial^2 \ln \mathcal{L}}{\partial \theta_i \partial \theta_j} \right) \mathcal{L} \, \mathrm{d}D$$

Cramér-Rao lower bound: $C(\hat{\theta}) - F^{-1} \geq 0$

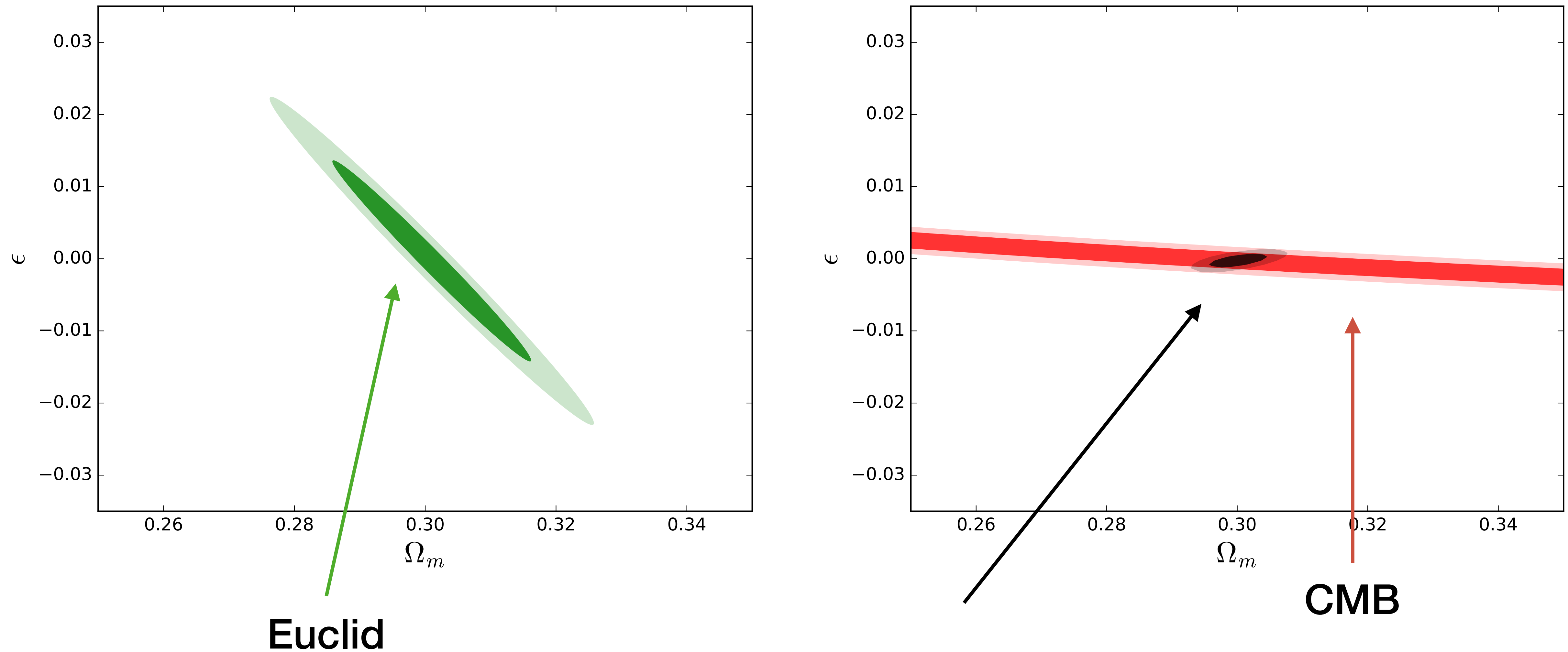
Goal: Euclid forecast for GDM parameters with:

$$\mathrm{GC}_{\mathrm{phot}} * \mathrm{WL}_{\mathrm{phot}} + \mathrm{GC}_{\mathrm{spec}}$$

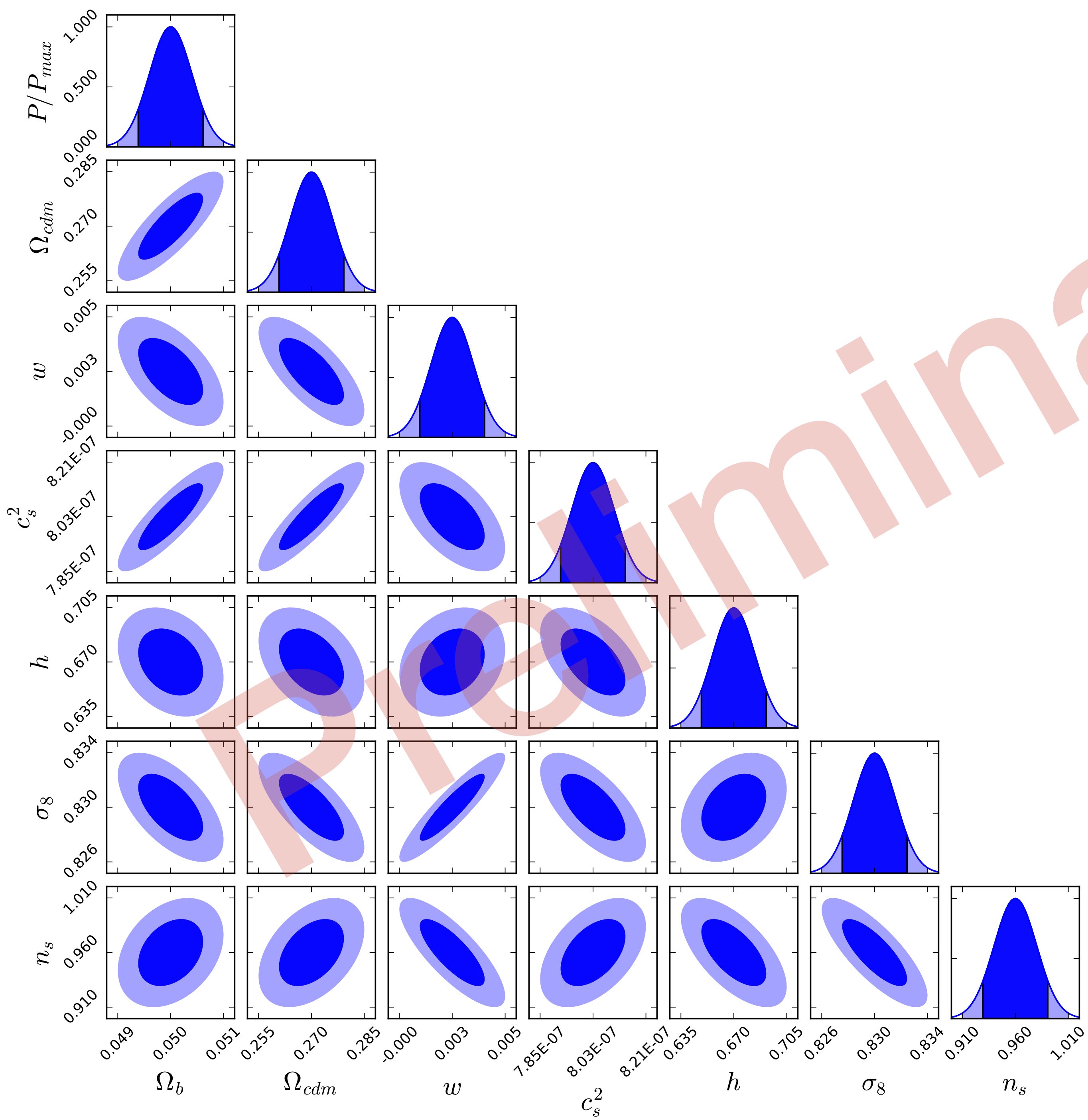
Euclid satellite: Results

Spectroscopic GC only [IT *et al.* 2016]

We assume here $c_s^2 = 0$



Euclid satellite: Results



CMB+SNIa+BAO	Euclid GC*WL
1.19e-3	4.98e-4
8.46e-3	5.97e-3
5.32e-4	1.06e-3
2.33e-9	7.07e-9
8.07e-3	1.41e-2
1.58e-2	1.77e-3
4.31e-3	2.00e-2

Preliminary

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's a key probe to constraint 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.