Astrophysical constraints on Dark Energy and Dark Matter

Jasjeet Singh Bagla

IISER Mohali

December 12, 2022

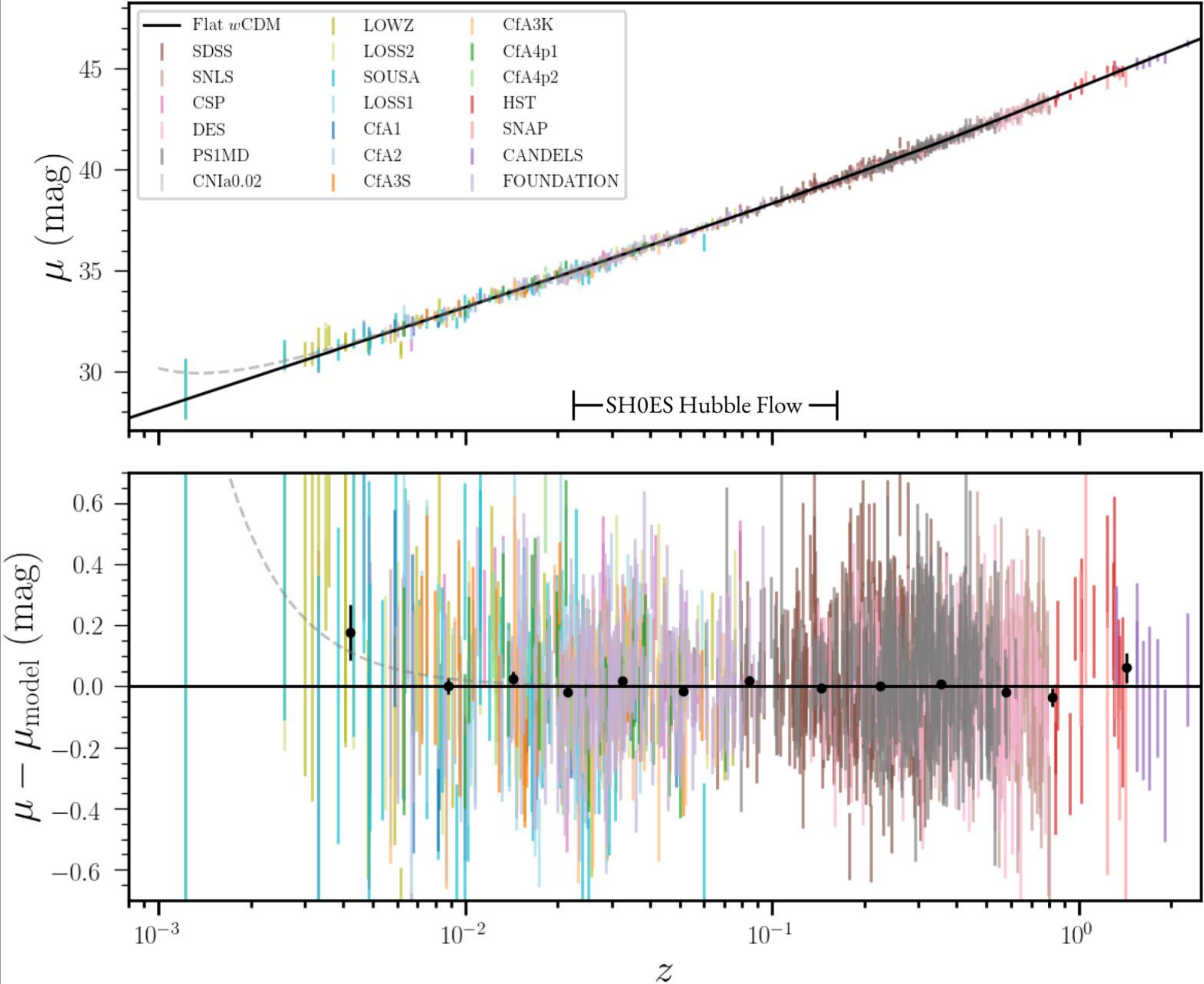
WG1-DAE Symposium

IISER Mohali

Dark Energy

The Pantheon+ Analysis: Cosmological Constraints

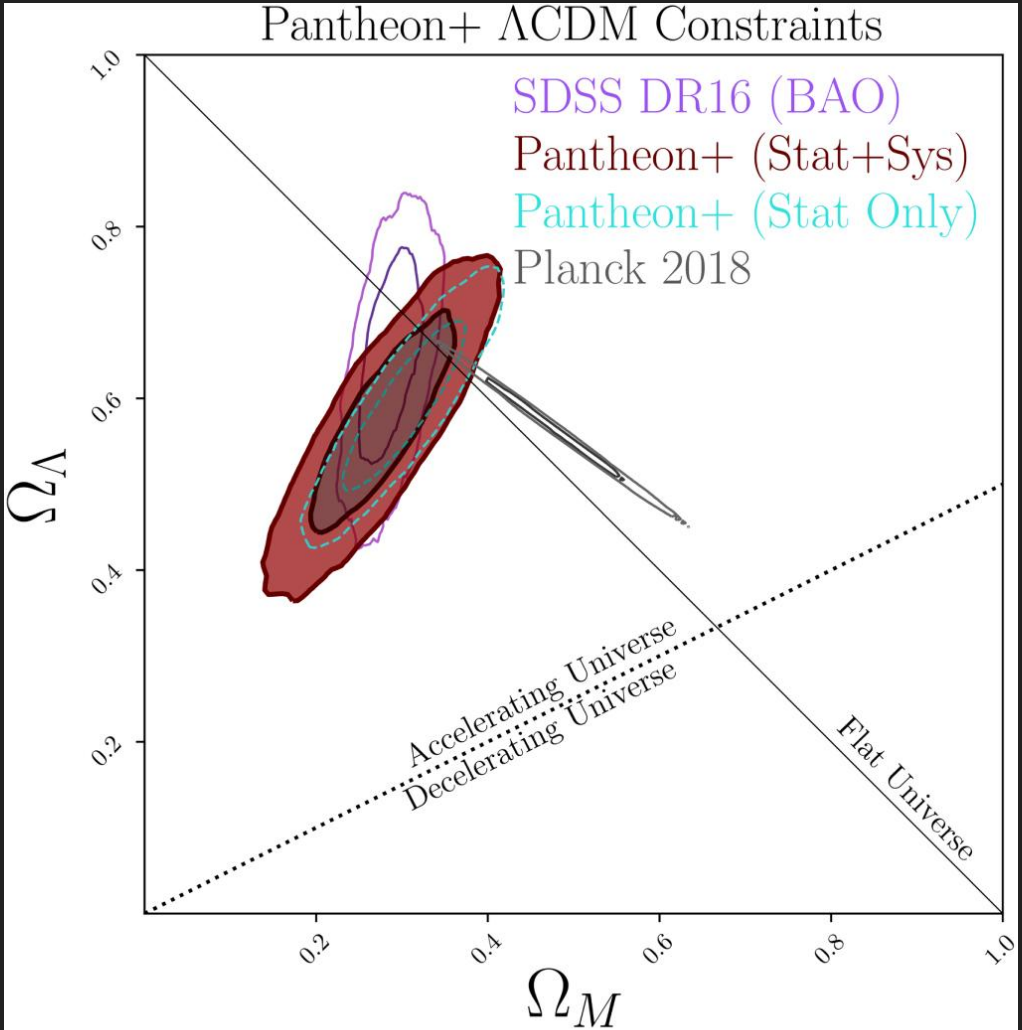
(ApJ 938:110, 2022)



Dark Energy

The Pantheon+ Analysis: Cosmological Constraints

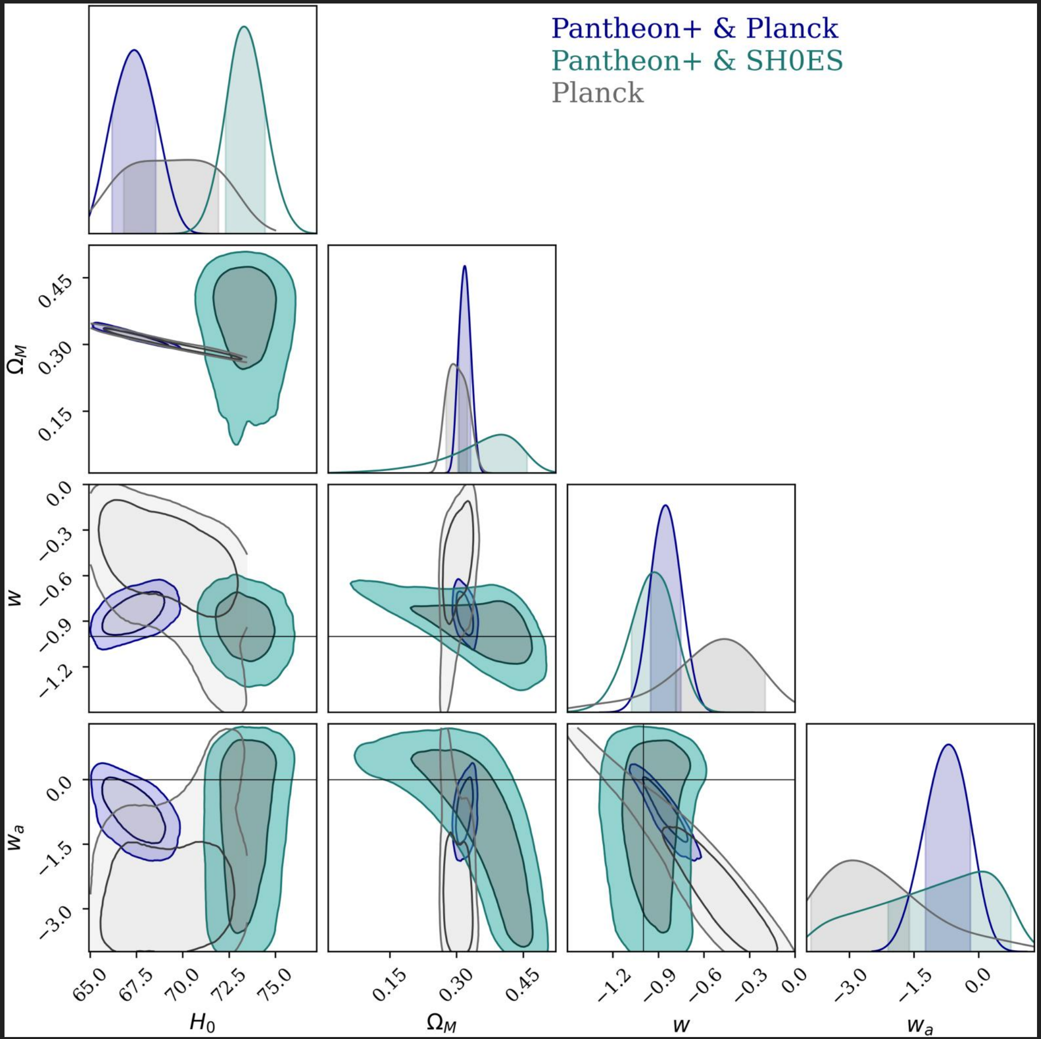
(ApJ 938:110, 2022)



Dark Energy

The Pantheon+ Analysis: Cosmological Constraints

(ApJ 938:110, 2022)



Dark Energy

Observational constraints arise from distance measurements: SNIa, CMBR anisotropies, BAO, etc.

These constrain the expansion history of the Universe a(t).

Any model of DE can be tuned to reproduce a given a(t) (Padmanabhan 2002).

Other constraints from the linear regime like the integrated Sachs-Wolfe effect (ISW), linear growth factor D+(t) for matter perturbations also depend mainly on the expansion history a(t).

Dark Energy and non-linear structure formation

Simulate non-linear structure formation using a 1+1 numerical relativity code.

Spherically symmetric perturbations with a self consistent evolution of matter and dark energy.

Large scale behaviour set to match an FRW universe by using compensated perturbations.

Rajvanshi & JSB (2018)

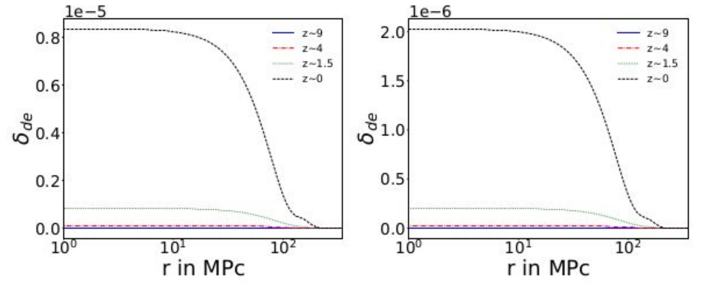


Figure 10. Density contrast for dark energy as a function of scale r for a matter under-density from simulation UD1. This is plotted at multiple epochs. We find that dark energy perturbations grow but the amplitude remains small in absolute terms. The left panel is for $V \propto \psi^2$ while the right panel is for $V \propto \exp(-\psi)$.

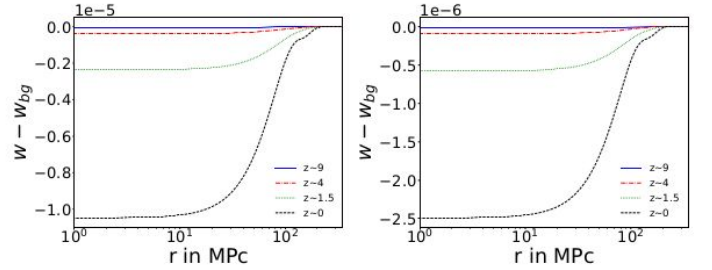


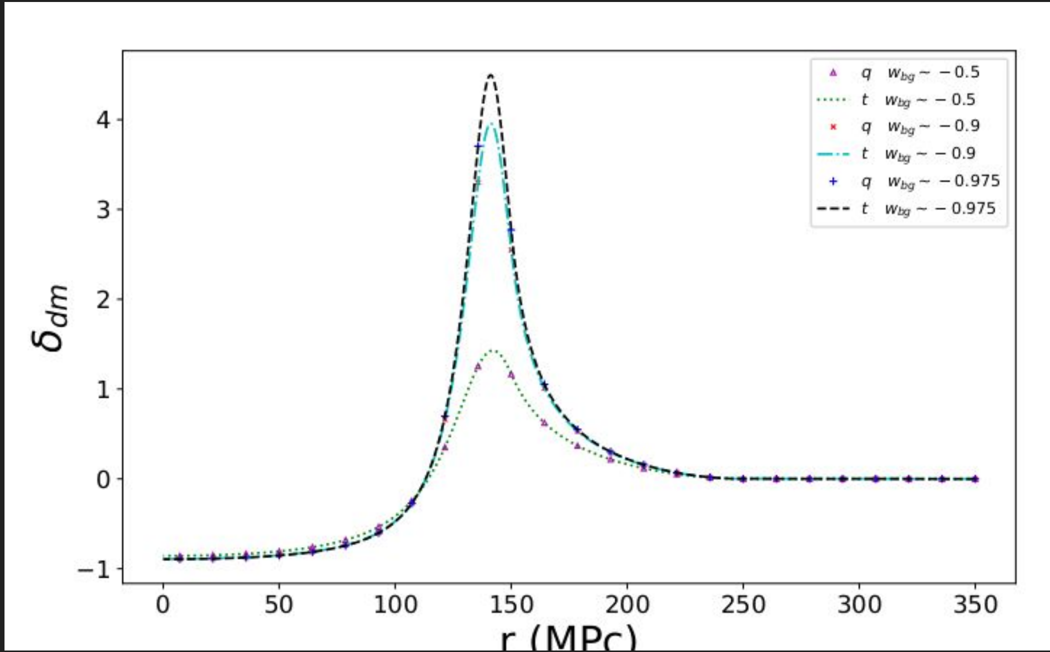
Figure 11. Equation of state parameter w as a function of scale r for a void, i.e., a matter under-density for simulation UD1. This is plotted at multiple epochs. We find that w inside the void is smaller than at large scales. The left panel is for $V \propto \psi^2$ while the right panel is for $V \propto \exp(-\psi)$.

Dark Energy: Non-linear Regime

There is no imprint of dark energy perturbations on dark matter perturbations IF the expansion history is the same.

Plot here is for Quintessense & Tachyon models of DE.

Rajvanshi & JSB (2020)



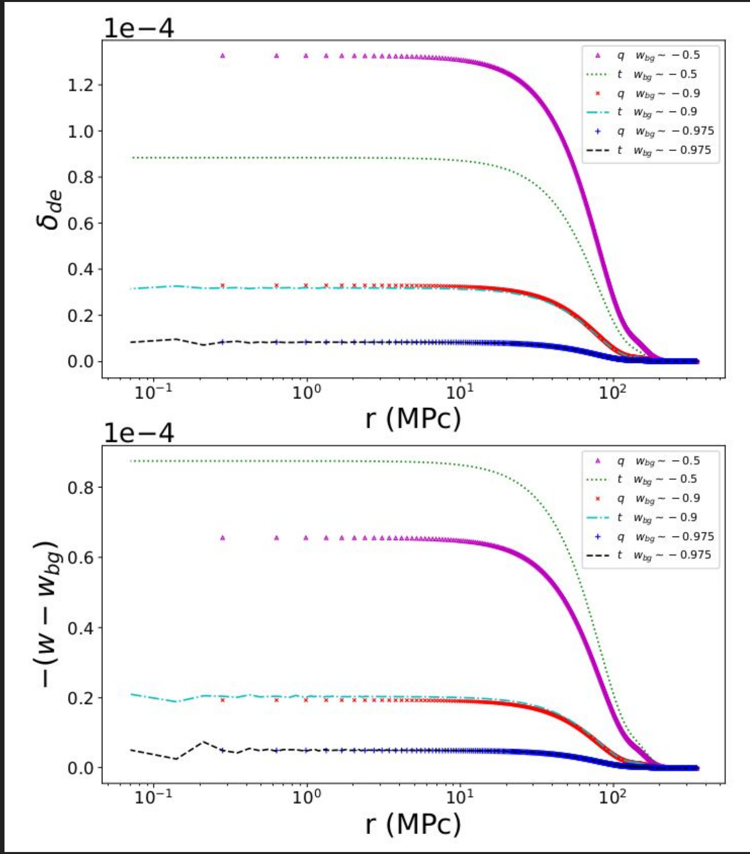
Dark Energy: Non-linear Regime

There are significant differences in DE perturbations if (1+w) is large.

Rajvanshi & JSB (2020)

If sound speed for DE perturbations is large, and (1+w) is small, the effect of DE perturbations is relegated to higher orders.

(Rajvanshi et al 2021)



Dark Energy Models

Given that FR models can be mapped to Quintessence, and observations suggest that (1+w) is very small (zero?), this is depressing news.

We may not be able to use cosmological observations anytime soon to differentiate between models of dark energy.

We can only figure out the expansion history of the Universe.

The positive spin to this is that we can choose whichever model is convenient for doing calculations.

Dark Matter and Neutrinos

Constraints on dark matter arise from a variety of observations:

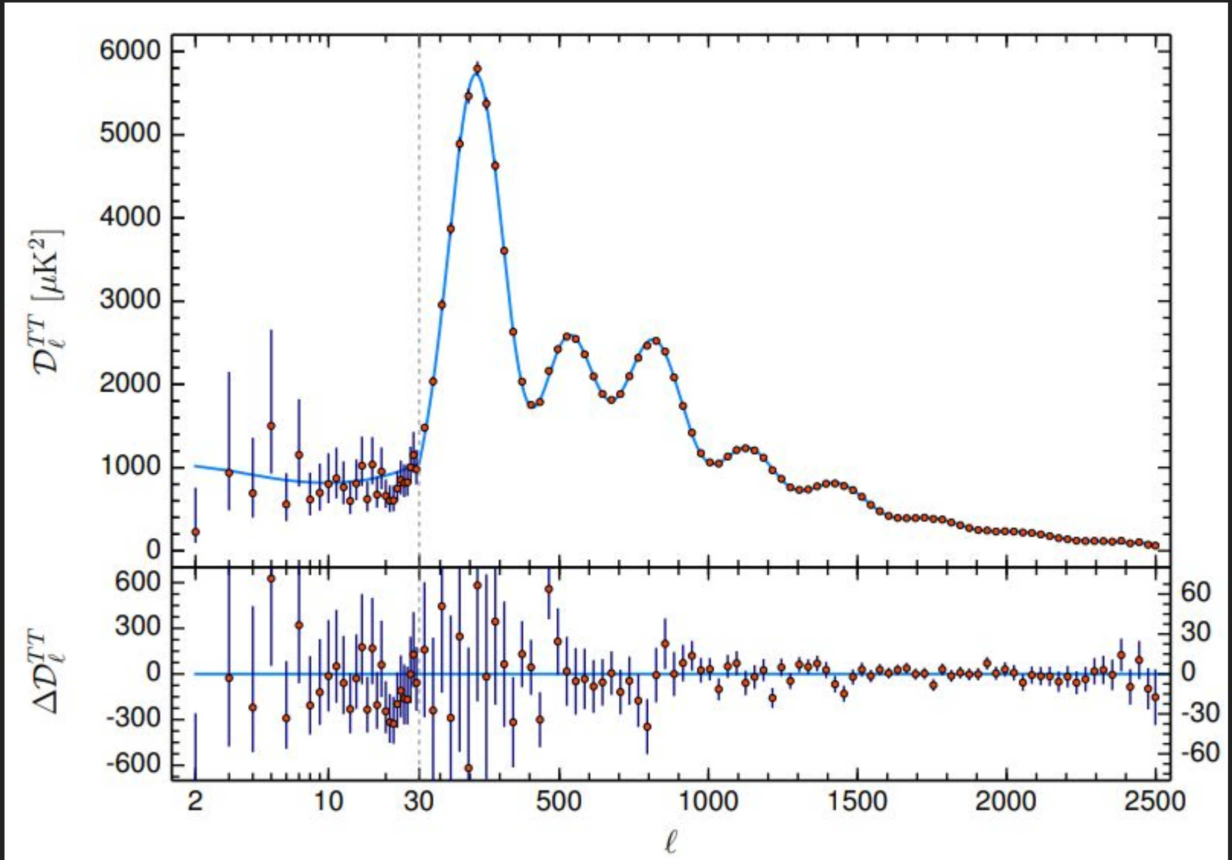
- Microlensing (Primordial Black Holes, MACHOs)
- Shapes of central parts of dark matter halos (self interaction of DM particles)
- Density profiles of dark matter halos (self interaction of DM particles, cold vs warm DM)
- Abundance of dark matter halos as a function of mass (cold vs warm DM)
- Growth factor D+(z) (warm/decaying DM)
- Gravitational lensing (substructures: warm vs cold DM)

CMBR constraints on DM

Planck data (2018) requires a significant amount of dark matter.

It is not possible to fit observations without this.

However it does not constrain the properties of DM beyond ruling out hot DM.

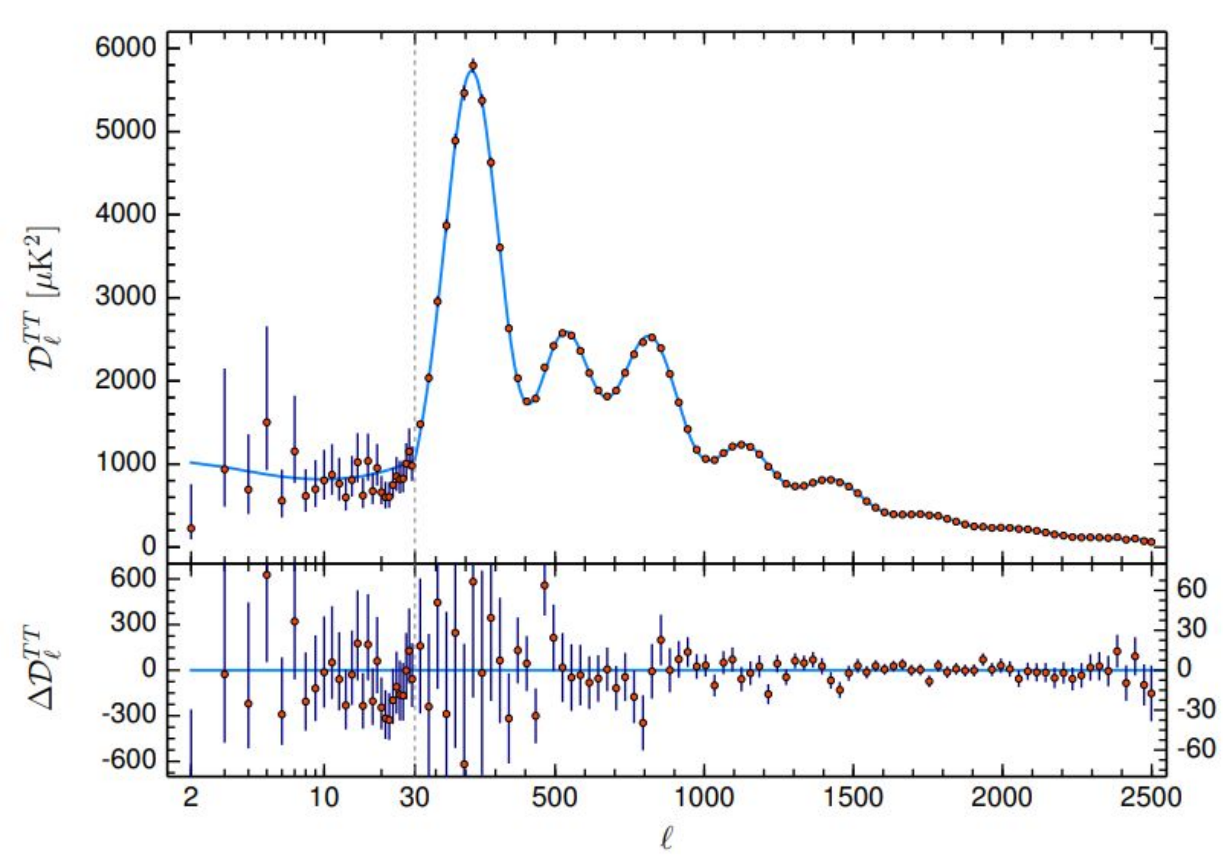


CMBR constraints on Neutrinos

Planck data (2018) constrains the relativistic component of DM.

Interpreted in terms of neutrinos, the constraint is on the sum of neutrino masses with the upper limit of **0.54 eV** (95%CL).

Combined with other data this can be lowered further to **0.12 eV**.



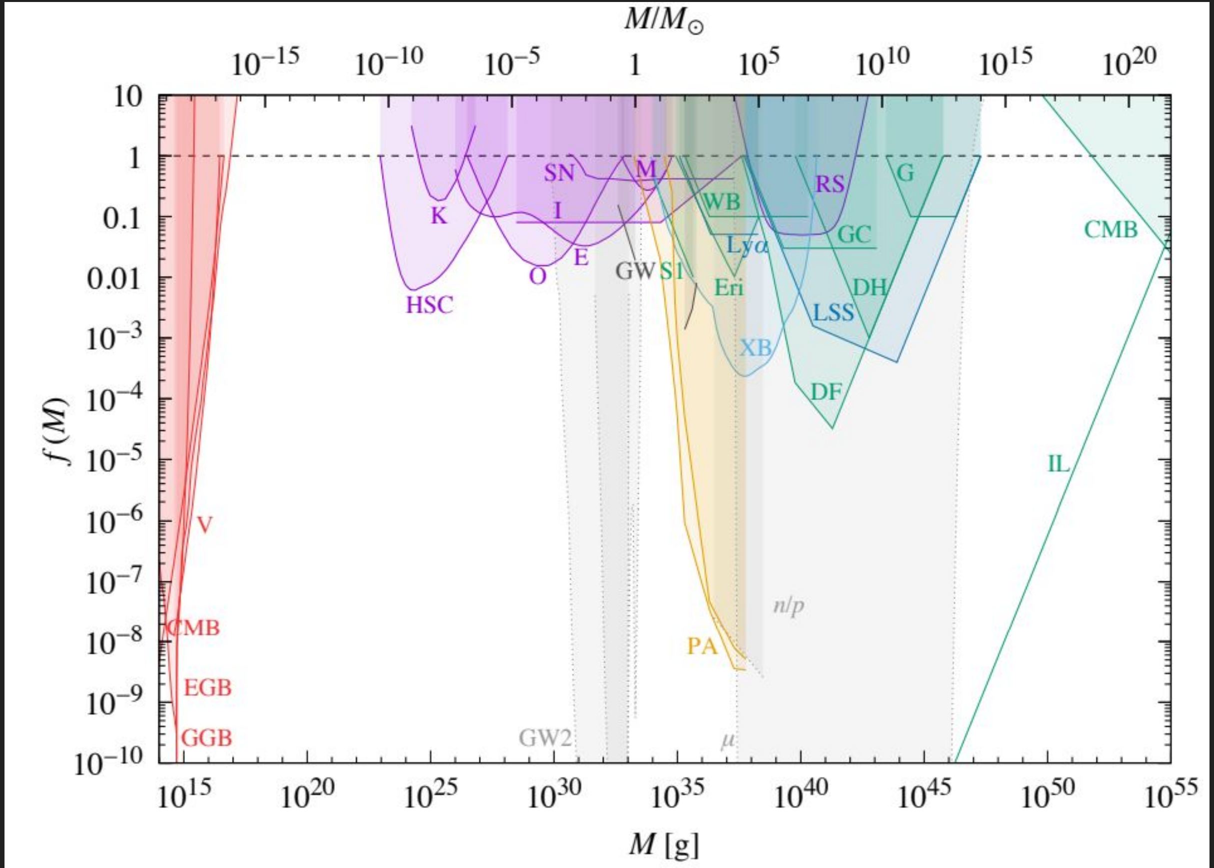
Primordial Black Holes

Bernard Carr et al 2021, Reports on Progress in Physics 84:116902

Low mass: evaporation of PBH

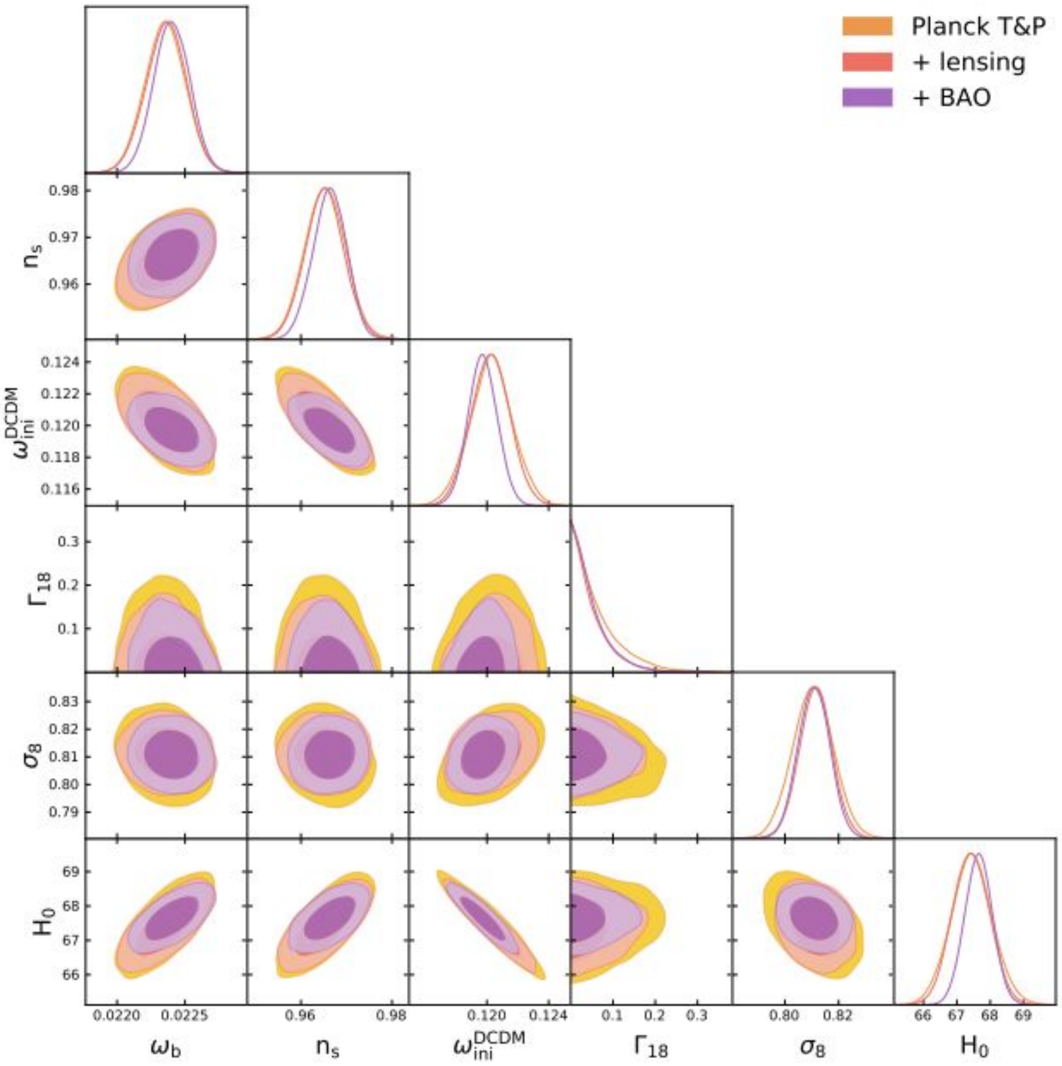
Intermediate: Microlensing

High mass: clustering, etc.



Decaying DM

Alvi et al. Journal of Cosmology and Astroparticle Physics, 2022:015



Self Interacting DM

Self interaction leads to gravo-thermal catastrophe

This leads to formation of a core (no cuspy halos)

This can be prevented or its onset delayed by keeping interaction cross-section weak.

This limit is of the order of 1-10 cm^2/g depending on the specific observation used.

Fuzzy DM

Ultralight scalar DM particle, with a de Broglie wavelength of astronomical scales (kpc)

This requires a mass of around 10^{-22} eV (Wayne Hu et al, 2020; Lam Hui et al, 2017) ($m > 10^{-23}$ eV from DES 1 yr Weak lensing data, Dentler et al 2022)

This prevents formation of a strong cusp, and also of excessive substructure that is expected in CDM models.

Implications and scenarios being studied.

Will there be problems with early galaxy formation?

Warm DM

A keV class particle as DM.

If mass is too low then it becomes warm, if too high then it becomes cold.

Suppresses formation of substructure in halos.

Suppresses formation of halos at high redshift.

This can be used to put constraints.

$m_X > 1.6$ keV (de Souza et al, 2013)