Big Bang Nucleosynthesis with Light Thermal Dark Sectors

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Based on **1910.01649** in collaboration with
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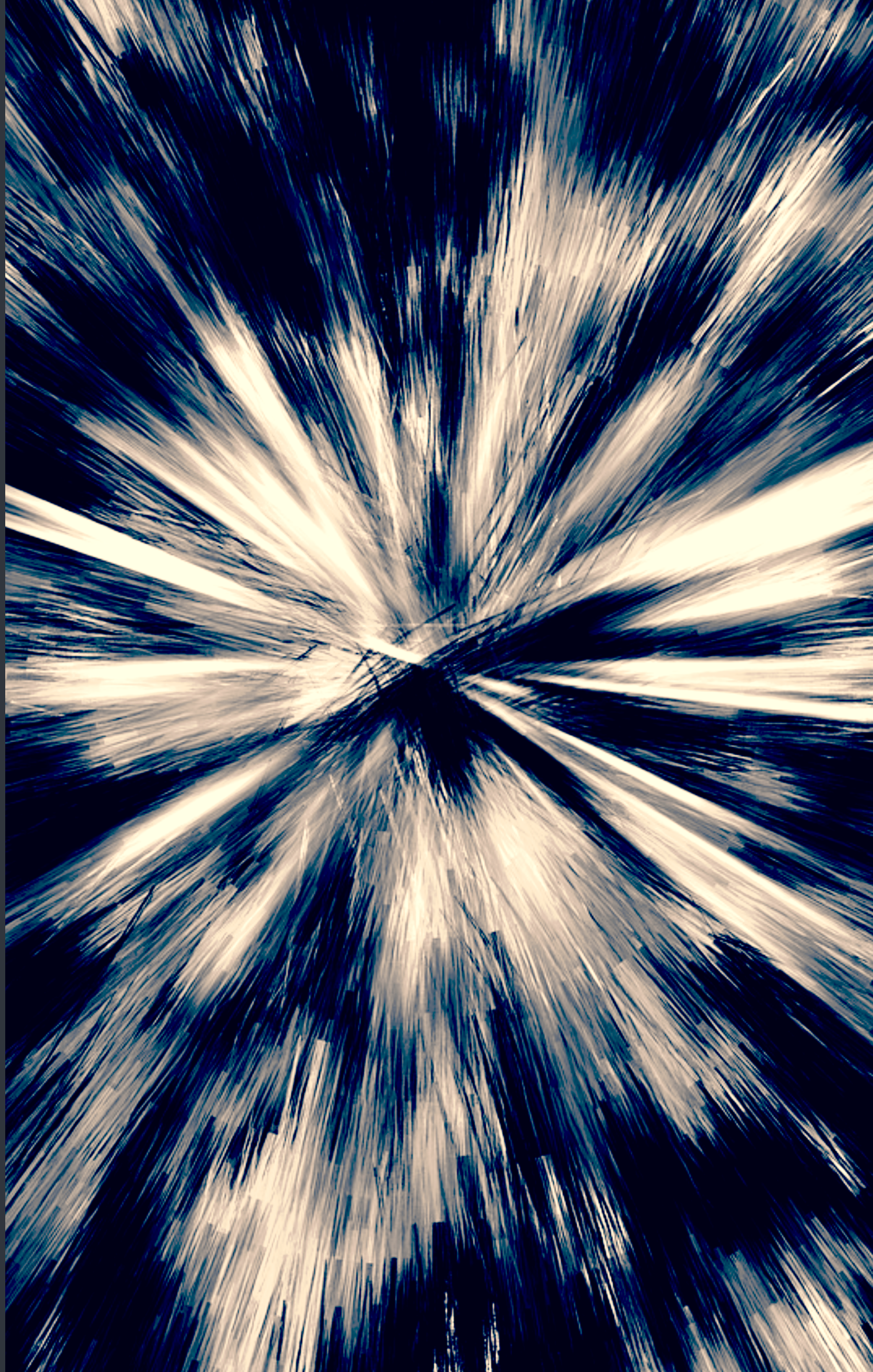

Motivation: Where to look for a WIMP?

Cosmology, (In)direct Detection Experiments, Colliders and Theoretical Considerations can constrain the search region for WIMP candidates

M < 10 MeV	10 MeV < M < 100 TeV	M > 100 TeV
Cosmology	Direct Detection Experiments, Colliders etc.	Unitarity

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Key Events in Standard Model BBN

Neutrino Decoupling

1.9 MeV

After this the temperatures of neutrinos and photons evolve differently

The weak reactions decouple, fixing the initial neutron to proton ratio

0.7 MeV

Neutron Freeze-out

Start of BBN

70 keV

Formation of the light elements via the nuclear reaction network begins

What if we add new particles?

Freeze-out

Relevant nuclear and weak processes freeze out at different times

Expansion Rate

The cosmic time between neutron freeze-out and nucleosynthesis changes

Sector Temperatures

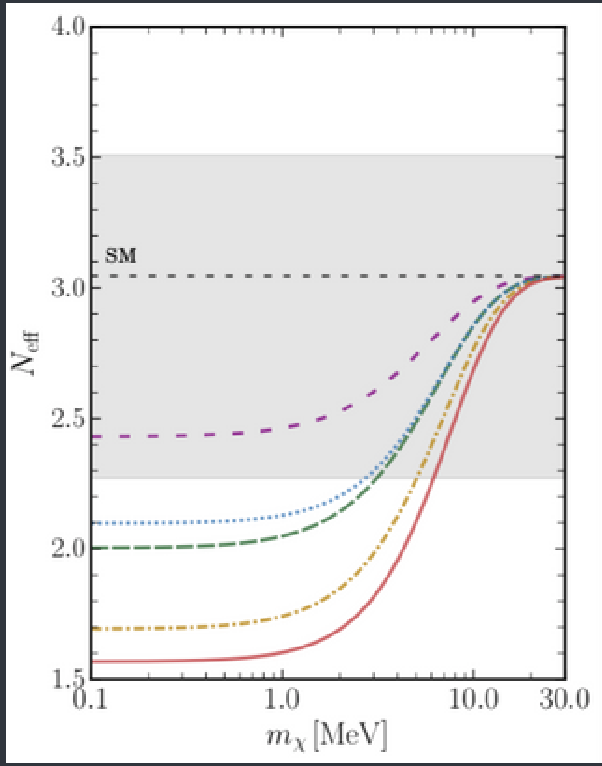
The temperature of the neutrino/photon sectors is altered by new particles

Baryon Dilution

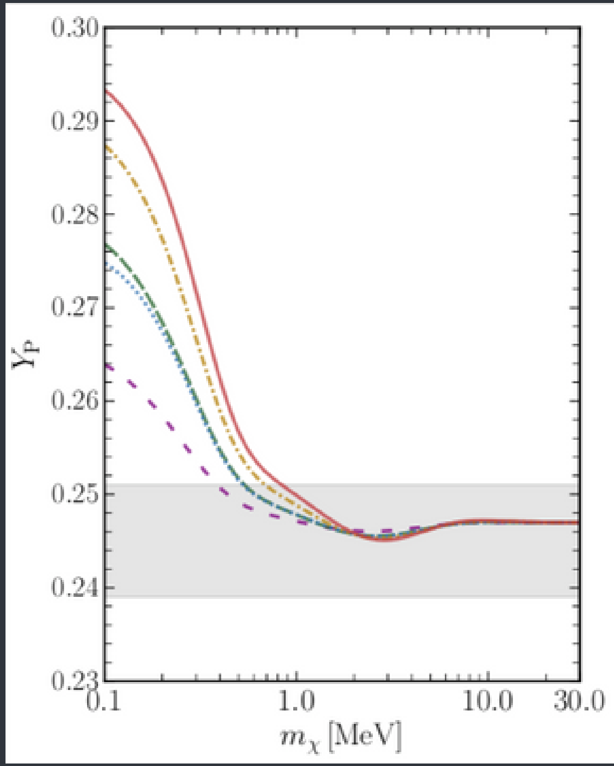
Decrease in the baryon-to-photon ratio after nucleosynthesis

Electrophilic Particles

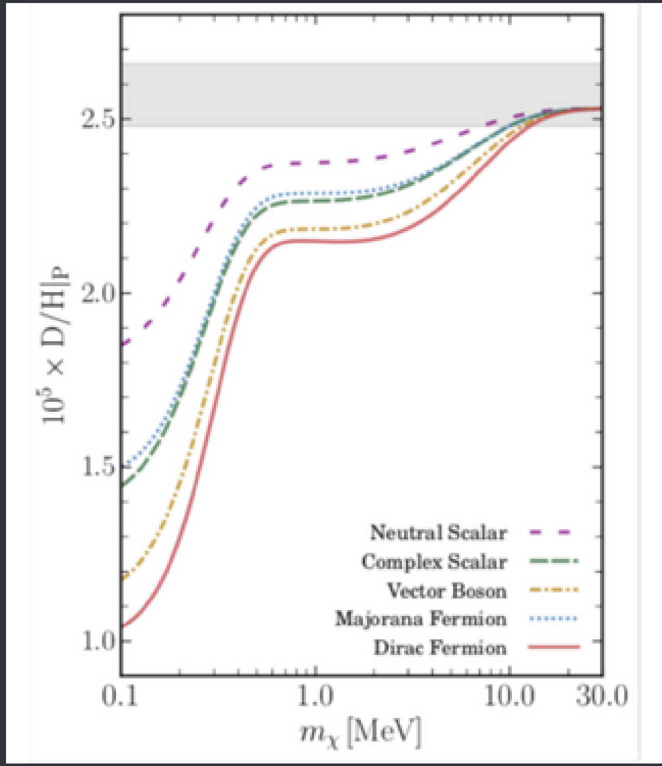
Electrophilic particles dump entropy into the electromagnetic plasma (photons and electrons)



Effective No. of Relativistic Neutrino Species



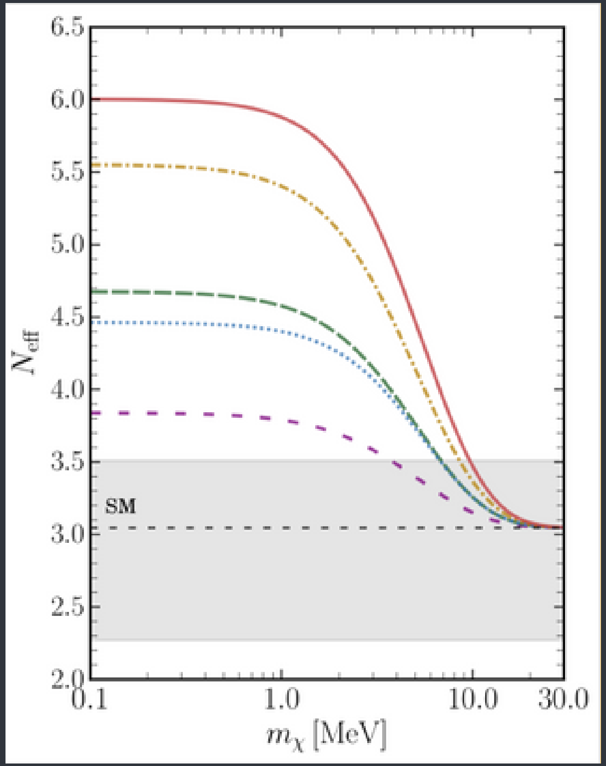
Primordial Helium Abundance



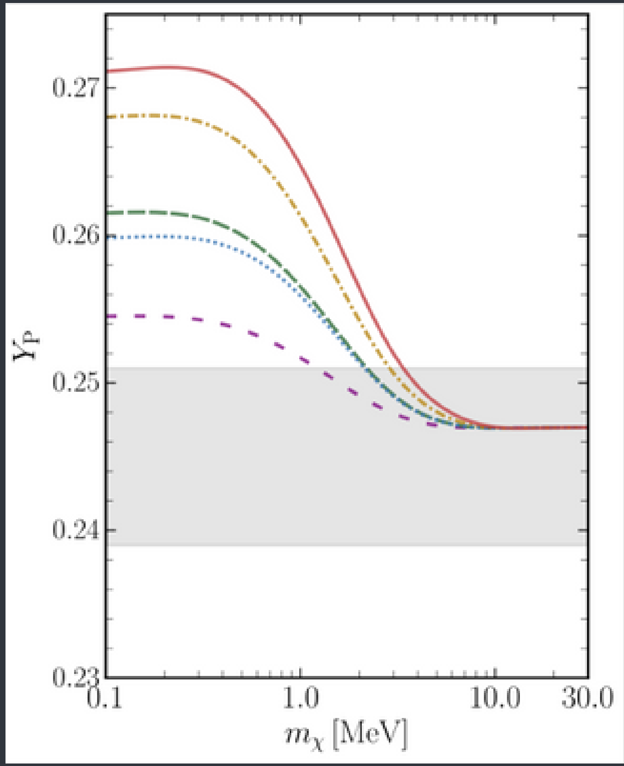
Primordial Deuterium Abundance

Neutrinophilic Particles

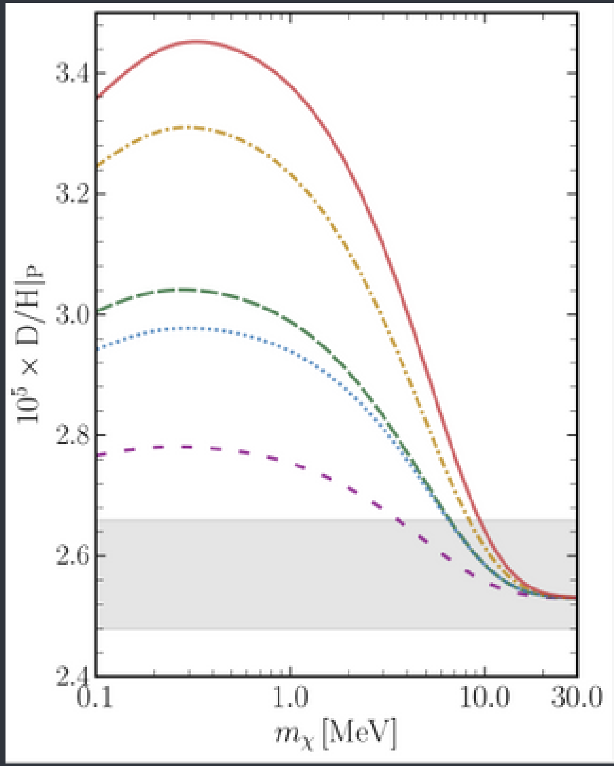
Neutrinophilic particles dump entropy into the neutrino plasma via interactions



Effective No. of Relativistic Neutrino Species



Primordial Helium Abundance



Primordial Deuterium Abundance

How do we constrain new physics?

- **PRIMAT**

  Modified state-of-the-art BBN code with updated nuclear reaction rates

- **Incomplete Neutrino Decoupling**

  Accurately modeled the energy transfer in the incomplete decoupling of neutrinos before nucleosynthesis

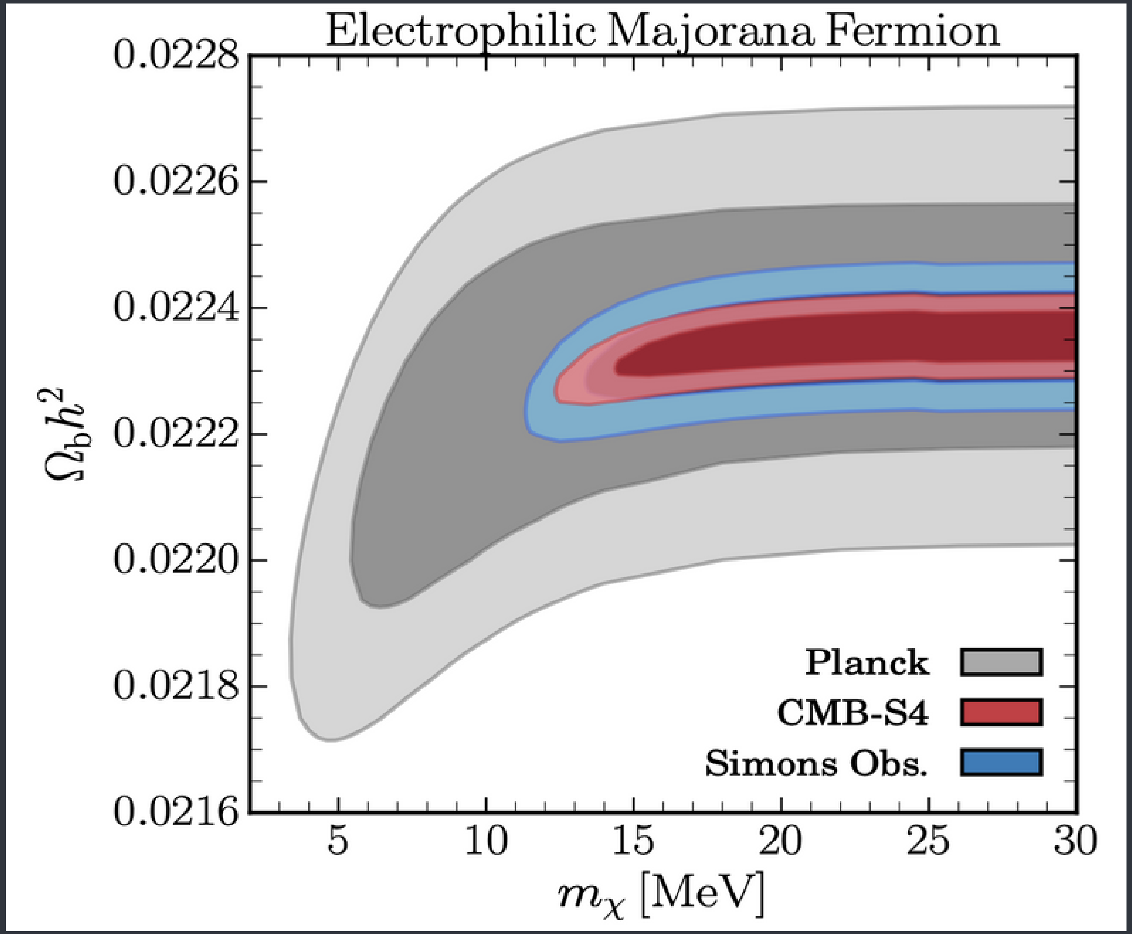
- **Baryon Density**

  Derived a cosmologically independent BBN bound by marginalising over the baryon density, the only free parameter in SM BBN

- **Latest Cosmological Data**

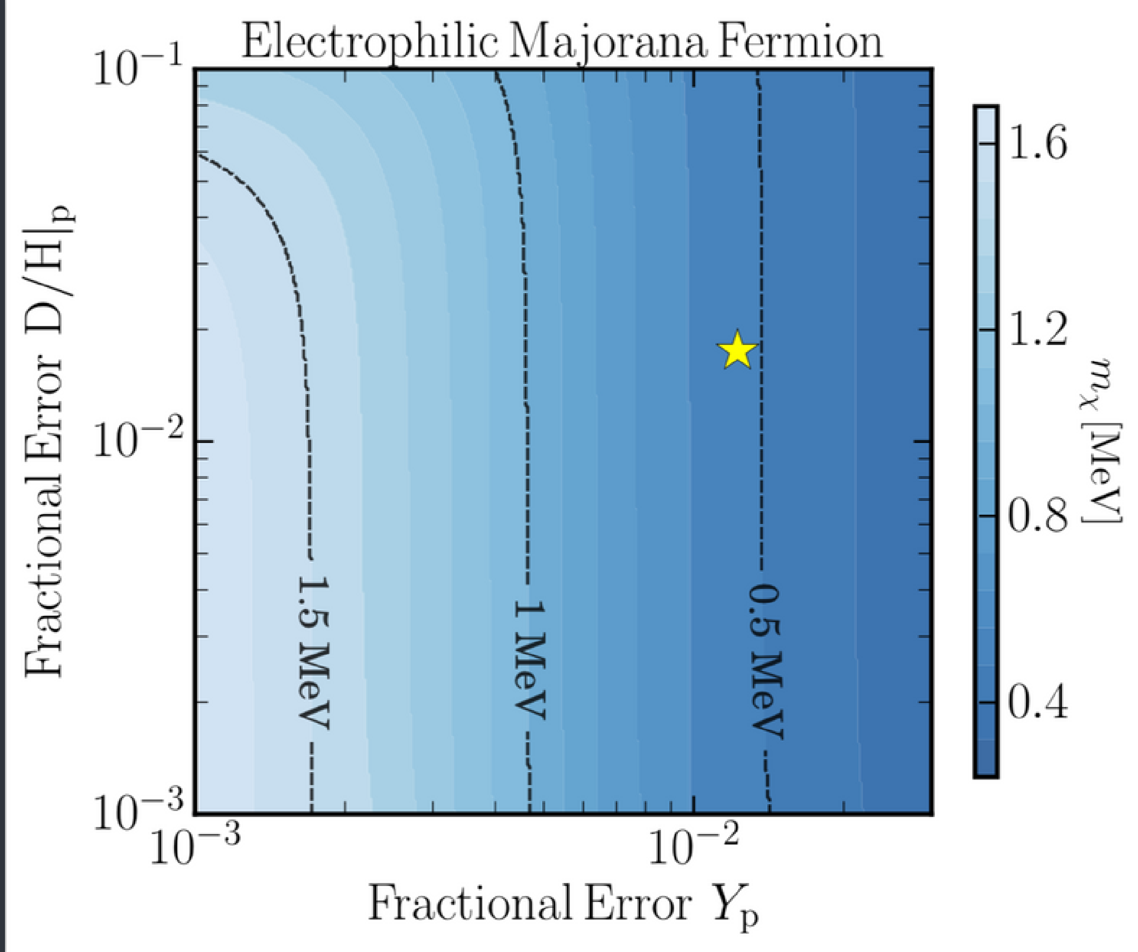
  Used up-to-date abundance and CMB measurements

Reach of Future CMB Experiments



- **CMB-S4** and **Simons Observatory** will be able to significantly strengthen the bounds
- They will also provide a far more precise determination of the **baryon density**

Effect of Future Abundance Measurements



- Better measurements of the **deuterium abundance** do not improve the mass bounds, only the determination of the baryon density
- However, improved measurements of the **helium abundance** can have a large effect (even larger for neutrinophilic particles)

Conclusions

BBN Constraints

Nucleosynthesis measurements strongly constrain additional light thermal particles

We rule out light thermal WIMPs for masses below **0.4 MeV** (BBN only) and **3.7 MeV** (BBN + Planck)

Validity

These bounds apply to **any** particle that has been in thermal equilibrium with the plasma e.g. dark photons

Future Experiments

Future experiments such as CMB-S4 and the Simons Observatory can greatly improve these bounds

Thank you, questions?

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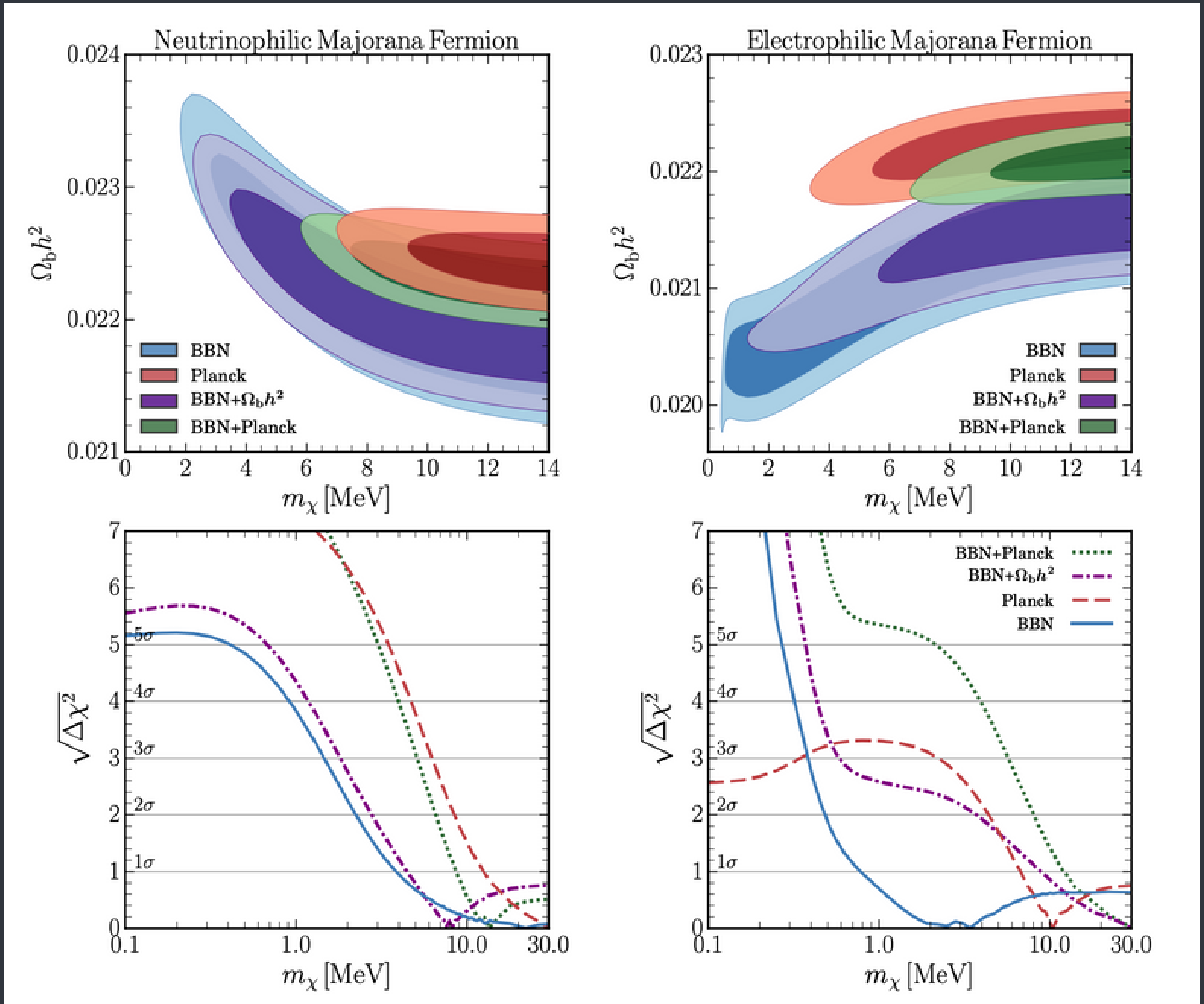
Backup Slides

Confidence Intervals and Exclusions

(Top): The 68% and 95.4% confidence intervals for the baryon density and particle mass

(Bottom): The marginalised exclusion plots as a function of the particle mass



Neutrinophilic Case: Future Experiments

(Left): Confidence Intervals for the different future CMB experiments
(Right): Dependence of the bounds on the determination of the helium and deuterium abundances