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Observational properties of very weakly coupled dark matter

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Talk based on arXiv: 1706.07442 and 1705.05567

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12/7/2017

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Evidence for Dark Matter

- Great deal of evidence for the existence of dark matter: rotational velocity curves of galaxies, Bullet Cluster, acoustic peaks in the Cosmic Microwave Background (CMB) radiation spectrum...

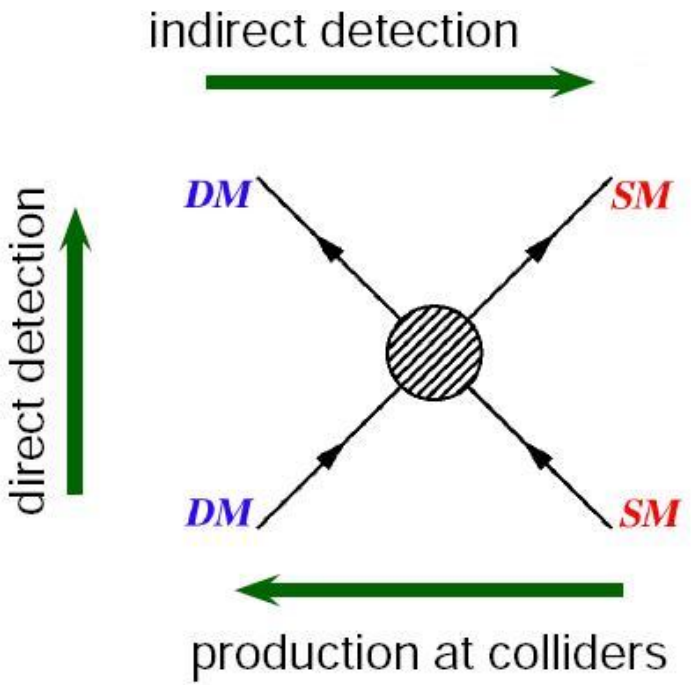
- Still the nature of dark matter is unknown

What is Dark Matter?

- What is the correct explanation for the invisible matter content observed in the universe? Does the dark matter particle exist? Or are there many dark matter particles?
- Are they WIMP's, FIMP's, SIMP's, GIMP's, PIDM's, WISP's, ALP's, Wimpzillas, sterile neutrinos, or primordial black holes? Or should gravity be modified?
- How can we tell which model is the correct one (if any)?

Search for Dark Matter

- Many on-going experiments exist



- But... what if dark matter interacts only feebly with the known particles, or not at all?

Model for a Decoupled Hidden Sector

- The scalar sector of the model is specified by the potential

$$V(\Phi, s) = \mu_{\mathrm{h}}^2 \Phi^\dagger \Phi + \lambda_{\mathrm{h}} (\Phi^\dagger \Phi)^2 + \frac{1}{2} \mu_{\mathrm{s}}^2 s^2 + \frac{\lambda_{\mathrm{s}}}{4} s^4 + \frac{\lambda_{\mathrm{sh}}}{2} \Phi^\dagger \Phi s^2$$

- Here Φ and s are, respectively, the usual Standard Model Higgs doublet and a real singlet scalar.

- The coupling between Φ and s acts as a portal between the Standard Model and an unknown Hidden Sector (the so-called Higgs portal).

Other options

- We can also introduce a sterile neutrino ψ

$$\mathcal{L}_{\text{Hidden}} = \bar{\psi}(i\partial\!\!\!/ - m_\psi)\psi + igs\bar{\psi}\gamma_5\psi$$

  or promote s to be a complex doublet of a hidden $SU(2)$ symmetry, and so on[1]

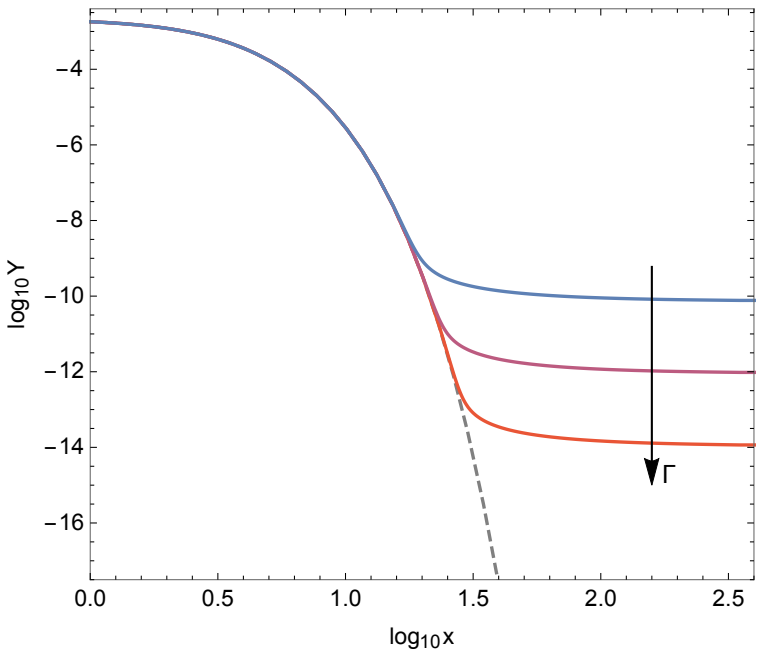
- Either the scalar s, the fermion ψ, the vector A_μ, or many of them simultaneously, can play the role of dark matter

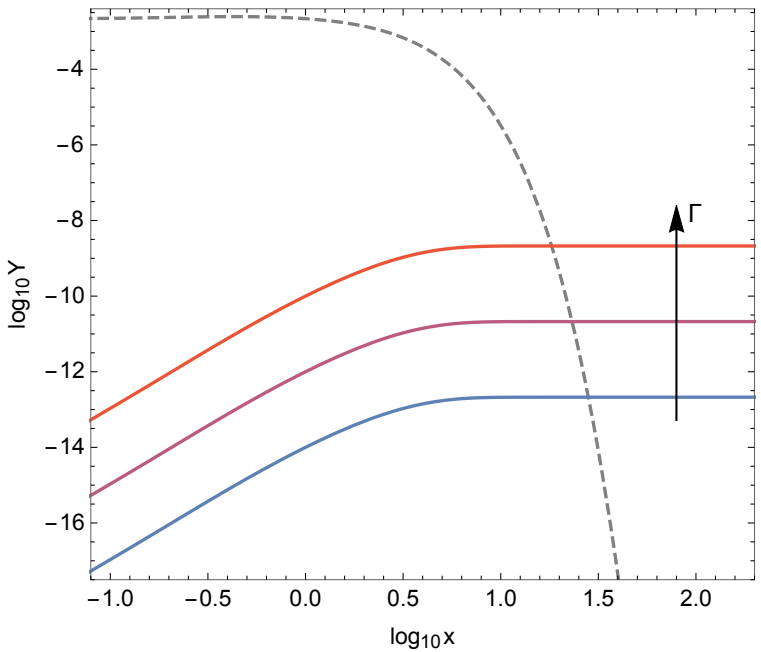
- How was the observed DM abundance produced?

[1] See e.g. Heikinheimo, TT, Tuominen (arXiv:1704.05359)

Dark Matter production mechanisms

- There are basically two mechanisms for dark matter production: freeze-out and freeze-in





The Freeze-Out

- Dark matter is initially in thermal equilibrium with the SM particles. This requires a rather strong coupling, $\lambda_{\mathrm{sh}} \simeq 0.1$.
- May lead to a WIMP miracle: thermal relic with weak cross-section and a mass $m_{\mathrm{s}} \sim$ EW scale gives the right relic abundance.
- Starts to be very constrained by experiments[2]

[2] For a recent review, see e.g. G. Arcadi et al. (arXiv: 1703.07364)

Frozen-in Dark Matter

- Requires $\lambda_{\rm sh} \lesssim 10^{-7}$, or otherwise the singlet sector thermalizes with the SM (this is sometimes called a FIMP scenario)
- Cannot (usually) be tested by collider experiments but can be tested by cosmological and astrophysical observations
- These include indirect detection signals, astrophysical imprints of self-interacting or non-thermal DM, imprints on CMB etc.

Review of freeze-in scenarios

- Out now! See arXiv: 1706.07442

The Dawn of FIMP Dark Matter: A Review of Models and Constraints

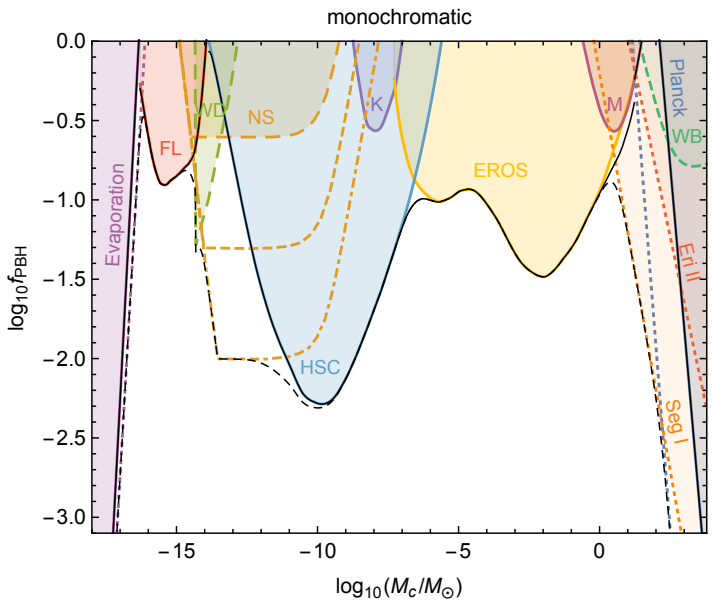
Nicolás Bernal,[a,b] Matti Heikinheimo,[c] Tommi Tenkanen,[d] Kimmo Tuominen[c] and Ville Vaskonen[e]

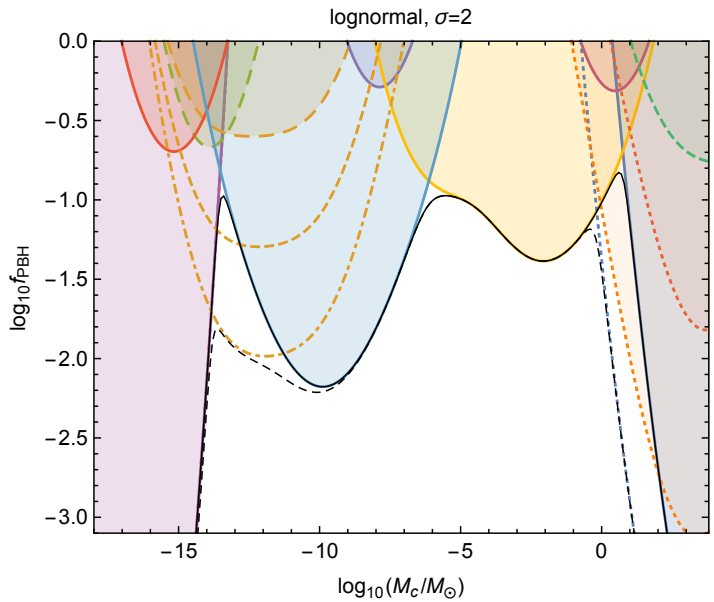
No particle DM?

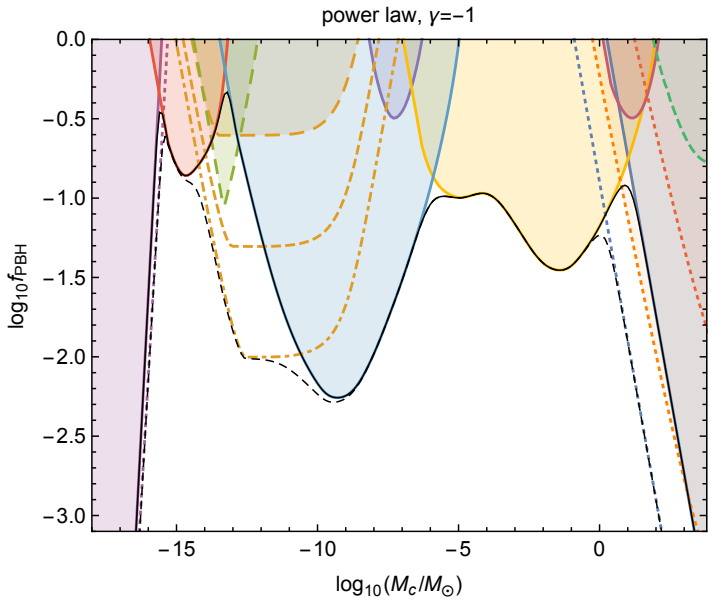
- What if DM does not consist of new particles but primordial black holes (PBHs)?
- PBHs can easily form in the early Universe from sufficiently large density perturbations[3]
- Especially the LIGO observation of $\mathcal{O}(10)M_\odot$ BH mergers is interesting for PBHs

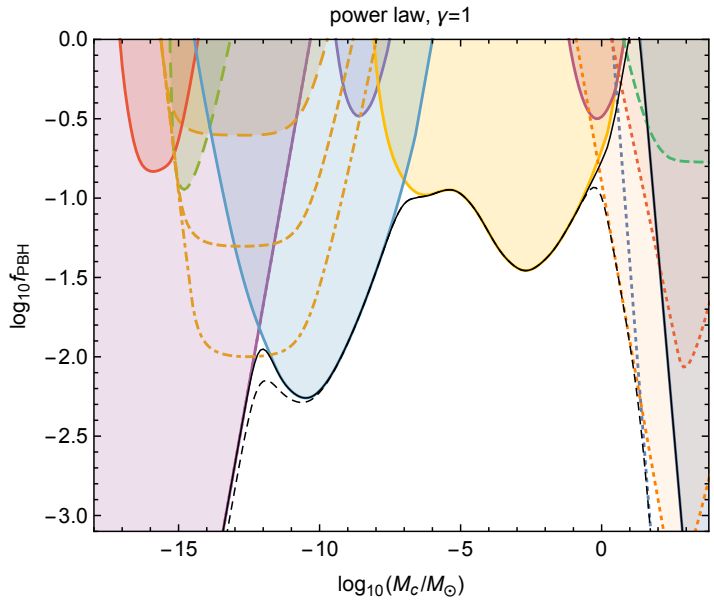
[3] See e.g. Carr et al. (arXiv: 1705.05567) and Carr, TT, Vaskonen (arXiv: 1706.03746) + refs. therein

Primordial black holes (arXiv: 1705.05567)

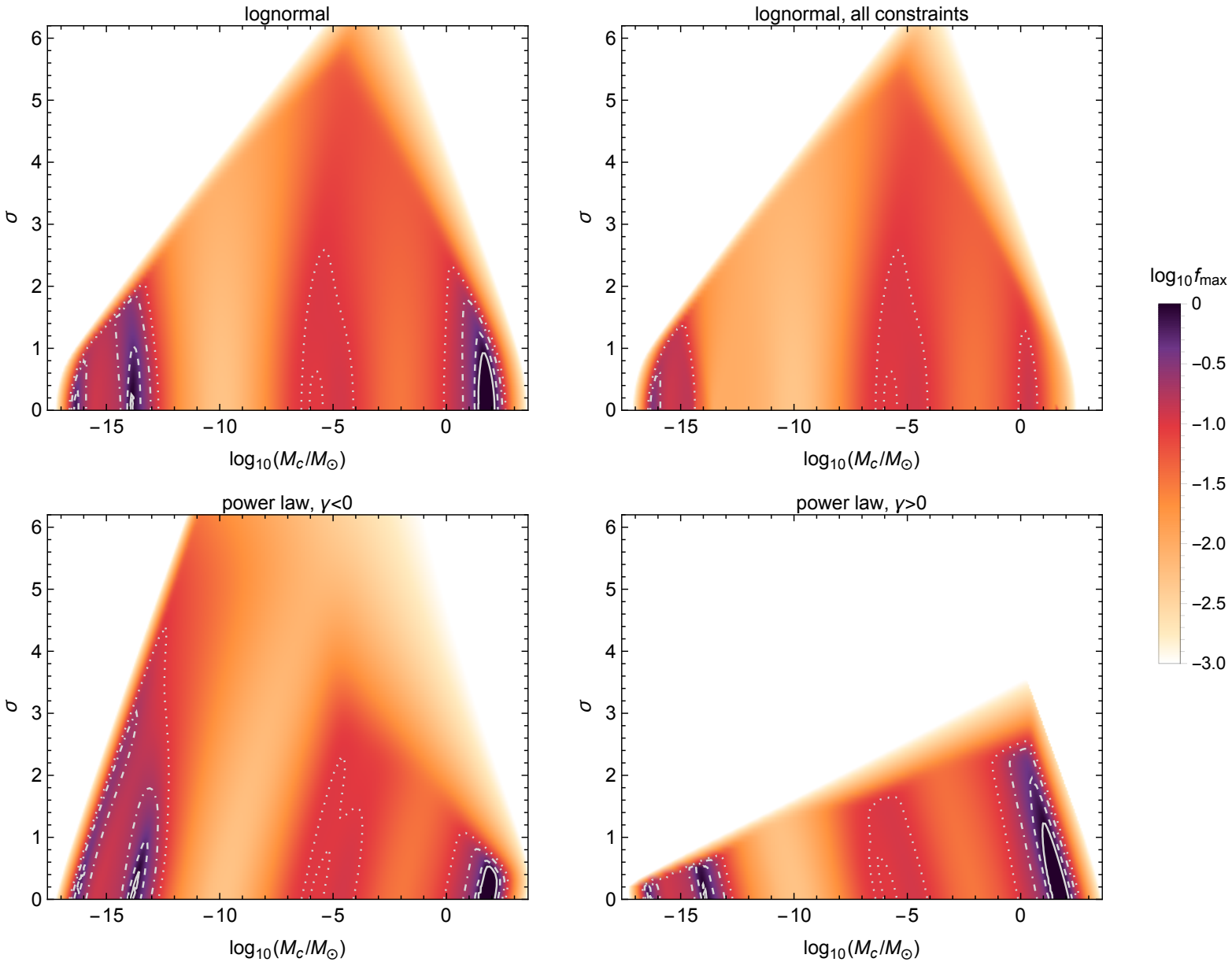








Primordial black holes (arXiv: 1705.05567)



Conclusions

- The nature of dark matter is still unknown
- Weakly coupled hidden sectors contain many interesting features, which have NOT been studied extensively
- Primordial black holes are a compelling alternative to particle DM and may constitute all DM
- Cosmological and astrophysical observations provide a valuable resource on testing different dark matter models