



2nd RED LHC workshop

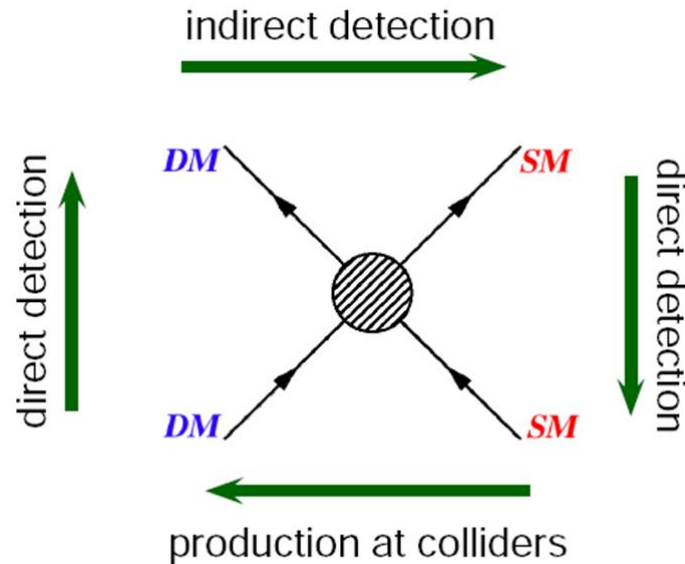
CIEMAT, Madrid, 9-11 mayo 2018

Dark matter in astrophysics and cosmology

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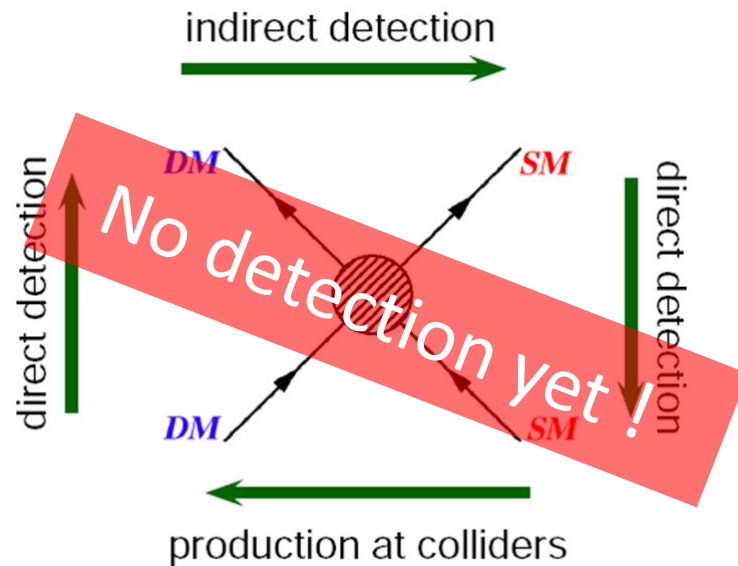
The standard cold dark matter scenario

- Observations ranging from matter distribution on cosmological (Gpc) scales down to galaxy rotation curves on (kpc) scales suggest the existence of a new form of **non-baryonic, collisionless** matter fluid with **negligible pressure (CDM)**.
- This phenomenology strongly suggests DM made of non-relativistic weakly interacting **particles** (WIMPs) beyond the SM.



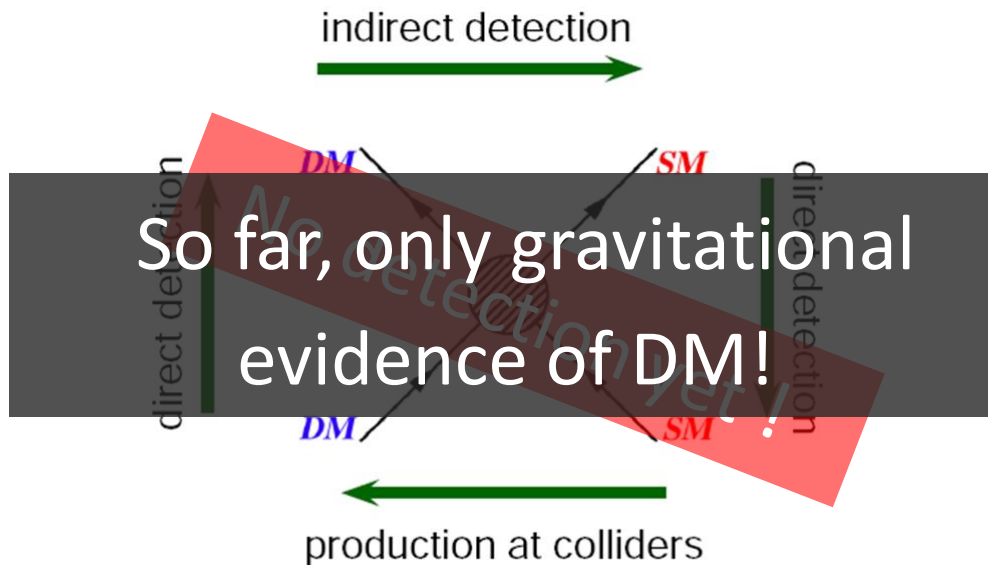
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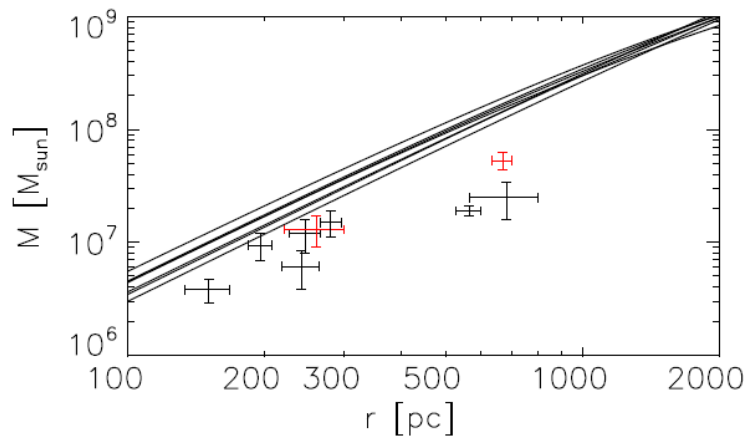
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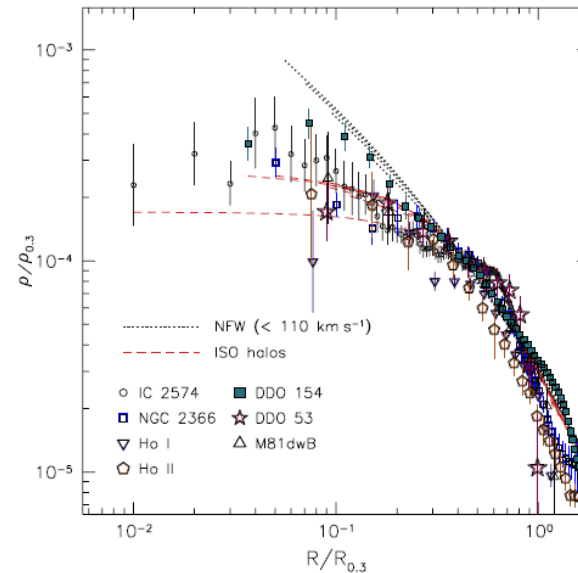
Problems of the CDM scenario

- **Small-scale (< kpc) problems:**
 - a) missing satellite



b) too-big-to-fail

Walker and Loeb arXiv:1401.1146

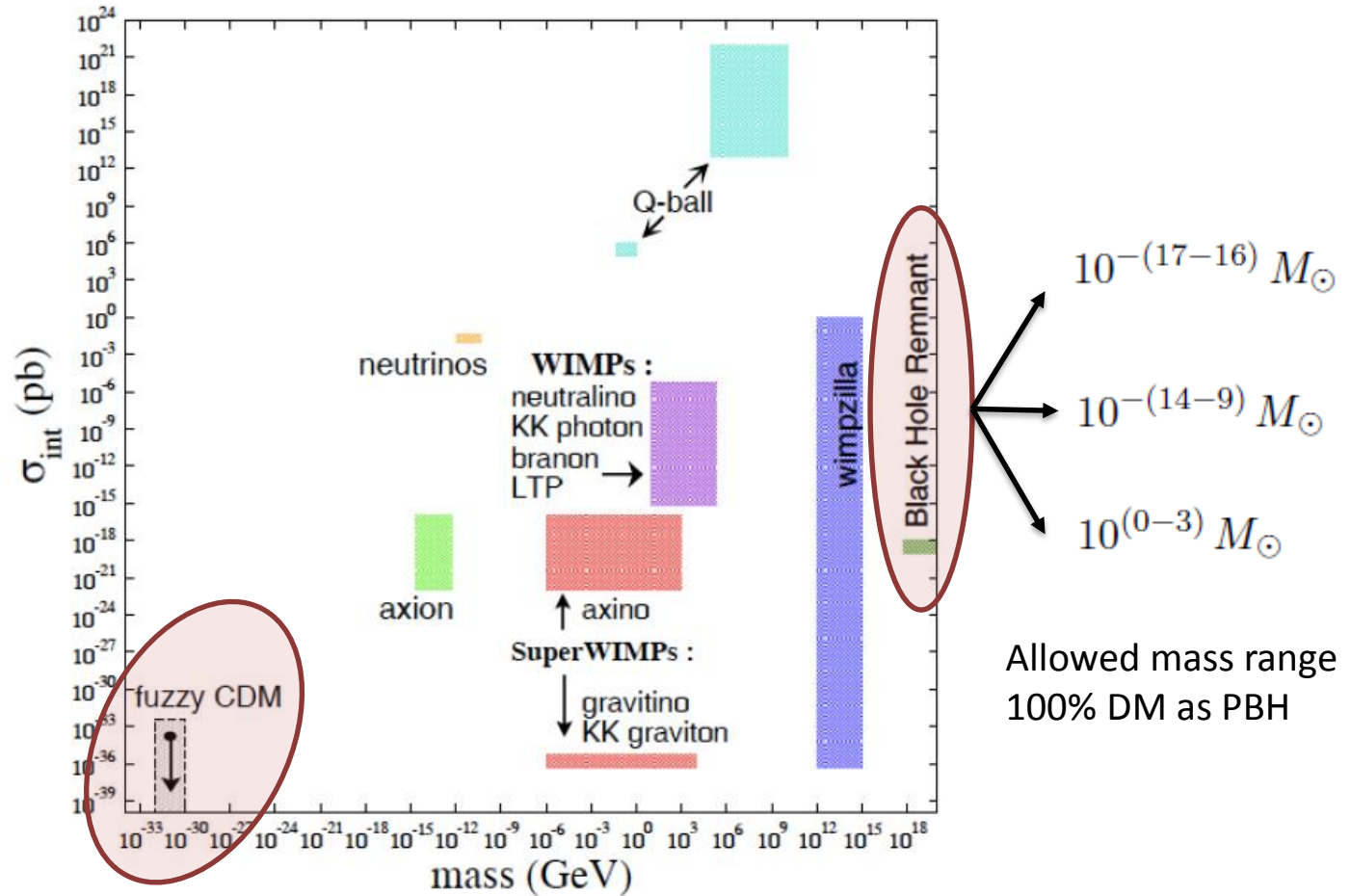


c) cusp-core

- **Solutions proposed:**
 - a) baryonic physics effects (SN feedback, stellar wind,...)
 - b) alternative DM models: warm, self-interacting, fuzzy DM ...

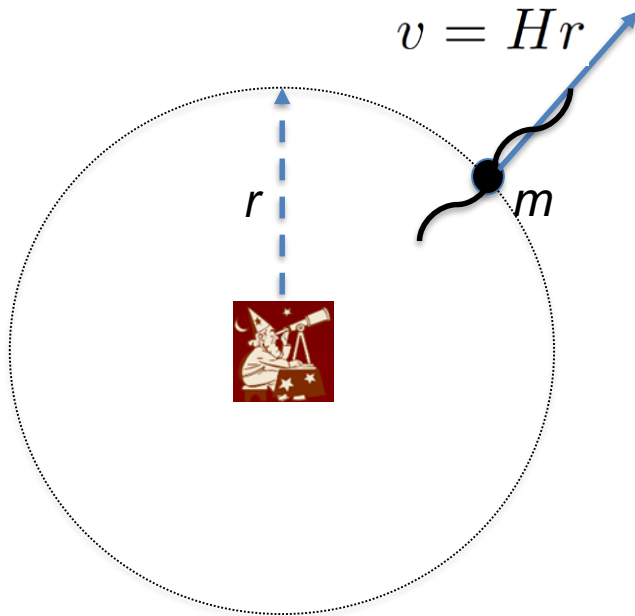
What is the nature of DM?

Gardner and Fuller, arXiv:1303.4758



Particle or non-particle?: fuzzy (wave) DM

Consider a particle of mass $m \ll 1$ eV moving with the Hubble flow H



The corresponding de Broglie wavelength:

$$\lambda_{\text{dB}} = \frac{1}{mv} = \frac{1}{mHr}$$

Thus, the particle can be localized only in a sphere with radius:

$$r \geq \lambda_{\text{dB}} \quad \Rightarrow \quad r \geq \frac{1}{\sqrt{Hm}}$$

$$k < \pi\sqrt{Hm}$$

particle-like behaviour

$$k > \pi\sqrt{Hm}$$

wave-like behaviour

Spin 0: Sin, (1994), Guzmán-Matos, (2000), Hui, Ostriker, Tremaine, Witten, arXiv:1610.08297

Spin 1: Cembranos, Maroto, Núñez-Jareño, arXiv:1611.03793

Spin 2: Aoki, Maeda, arXiv:1707.05003

The dark sector degeneracy

- Since we only have detected dark matter and dark energy gravitationally, the **DM + DE** splitting is just a useful assumption.

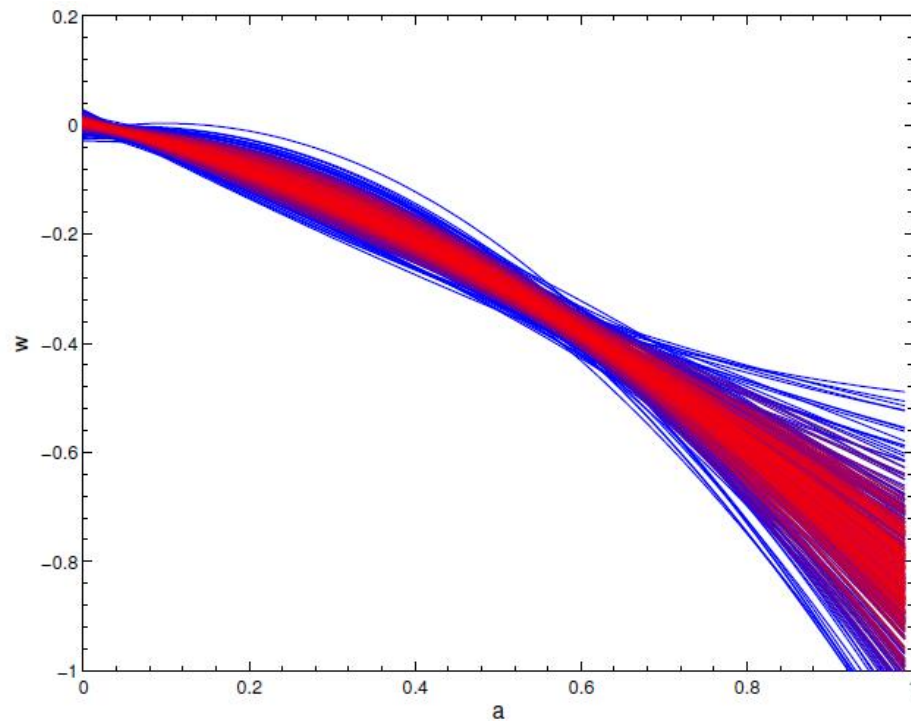
$$G_{\mu\nu} = 8\pi G \left(\underbrace{T_{\mu\nu}^{(baryons)} + T_{\mu\nu}^{(rad)}}_{\text{non-gravitational detection}} + \underbrace{T_{\mu\nu}^{(DM)} + T_{\mu\nu}^{(DE)}}_{T_{\mu\nu}^{(dark)}} \right)$$

Dark sector **degeneracy**

The dark sector

Effective equation of state of the dark sector:

$$T_{\nu}^{\mu}(\text{dark}) = \text{diag}(\rho, -p, -p, -p), \quad w(t) = \frac{p(t)}{\rho(t)}$$



Exploring the dark sector: astrophysics and cosmology

- In the “nightmare scenario” (only gravitational interactions) or if DM is not particle-like we still have observational probes.
- Galaxy (optical, IR and radio) and lensing surveys, 21 cm, Ly- α , astrometry, CMB and GW will test dark matter distribution (scale and redshift dependence), DM-DE, DM-baryon and DM-neutrino interactions.

Astrometry (space based)	GAIA ^a [440] JWST ^b [441] WFIRST [442]	Galaxy surveys (optical/IR)	DES ^f (photometry) [449] DESI (spectroscopy) [450] EUCLID ^g (photometry, slitless spectroscopy) [451, 452] HSC ^h (photometry) [453] LSST ⁱ (photometry) [454] PFS (spectroscopy) [455] WFIRST (photometry, spectroscopy) [442]
CMB	ACT ^c CMB-S4 [443, 444] CORE [445] Keck Array ^d [446] PIXIE [447] Simons Observatory ^e [448]		
Intensity mapping [456] & radio galaxy surveys [457]	CHIME [458] SPHEREx ^j [459] SKA and its pathfinders ^k FIGGS [460] GALFA-HI [461] SHIELD [462]		

Exploring the dark sector: astrophysics and cosmology

Buckley and Peter, arXiv:1712.06615

