The different ways to look for Dark Matter

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Common ground to start with

- Dark Matter: 26.8%
- Ordinary Matter: 4.9%
- Dark Energy: 68.3%

[e.g. Planck coll.]
CMB, a dark matter probe
CMB, a dark matter probe

$\omega_m$ and $\omega_{\text{bar}}$ from CMB only
The “Bullet Cluster”
1E 0657-558

collision in the plane of the sky

Z = 0.296

[Markevitch et al. `06]
The “Bullet Cluster”
1E 0657-558

Merger 100 Myr ago
The Bullet is only the first, most famous, of a plethora of similar systems.

[Harvey et al. `16]
Quantitative constraints on DM-baryon separation

[Harvey et al. '16]
Rotation Curves in local galaxies: an evergreen classic:
(with interesting twists)

discrepancy between observed and predicted (from visible matter only)
The Milky Way: one more spiral Galaxy (and its Rotation Curve)

[Iocco, Pato, Bertone, Nature Physics 2015]
Ly-α forest: probing structures during Universe evolution
Ly-a forest to constrain the perturbation power spectrum

[Viel et al., 2013]
What can we learn from astrophysics (about DM?)

DM is there, at different scales
(≈100 Mpc, ≈1 Mpc, ≈10 kpc)

Upper limits on DM coupling to the baryons

Upper limits on the DM coupling to itself

Upper limits on the “warmth” of DM
The Universe in a box

[ Illustris, Vogelsberger 2014 ]
While staying agnostic on its very nature, a checklist for its properties (see later)

1. Does it match the appropriate relic density?
2. Is it cold?
3. Is it neutral?
4. Is it consistent with BBN?
5. Does it leave stellar evolution unchanged?
6. Is it compatible with constraints on self-interactions?
7. Is it consistent with direct DM searches?
8. Is it compatible with gamma-ray constraints?
9. Is it compatible with other astrophysical bounds?
10. Can it be probed experimentally?
In fact, there's plenty of options.
The way we look for it, depends on what we expect

Thermal relic density

[G. Steigmann, 2016]
Weakly Interacting Massive Particles: a very good candidate (but not the only one, nonetheless)

Direct detection: DM scattering against nuclei, recoil

Indirect detection: Annihilation in astrophysical envir. Observation of SM products of annih.

Production at LHC

Direct, indirect and collider searches
A brief state-of-the-art on WIMPs
(ideal testbed of complementary techniques)
Direct DM searches

(Elastic) scatter of a DM particle over a nucleus induces recoil Measure recoil in controlled environment: Lab on Earth (but also…)

The DM cloud
Direct Detection: principles and dependencies

A big mountain (or a deep mine)

a relatively cheap detector

Your observed data

Your ticket to Stockholm
Direct Detection: principles and dependencies (to go…)

\[ \frac{dR}{dE} \propto \frac{1}{\mu^2} \frac{\sigma_\chi}{m_\chi} \rho_0 \eta(v, t) \]
No observations: constraints
Indirect DM searches

Looking for byproducts of DM annihilation/decay into SM. You need a lot of DM ➔ astrophysical (big) objects
Indirect Detection: principles and dependencies

\[ \chi + \chi \rightarrow q\bar{q}, W^+W^-, \ldots \rightarrow \gamma, \bar{p}, D, e^+ \& \nu's \]

\[ F_i \propto \frac{1}{4\pi d^2} B_i \frac{\langle \sigma v \rangle}{m_\chi} \int \rho^2(r) dV \]
Indirect Detection: principles and dependencies

Galactic center, Dwarf Galaxies, Galactic Halo…
dependence on density structure

discovery (or constraints) subject to same uncertainty

\[
F_i \propto \frac{1}{4\pi d^2} B_i \frac{\langle \sigma v \rangle}{m_\chi} \int \rho^2(r) dV
\]

\[
J_{\text{annih}} \propto \int_{\text{los}} \rho^2(r) dV
\]

\[
\Phi_{DM}(E) = \Phi_{PP}(E') J
\]
Indirect Detection: constraints
(what to do when there is no signal)

[FERMI COLL, 2015]