The different ways to look for Dark Matter

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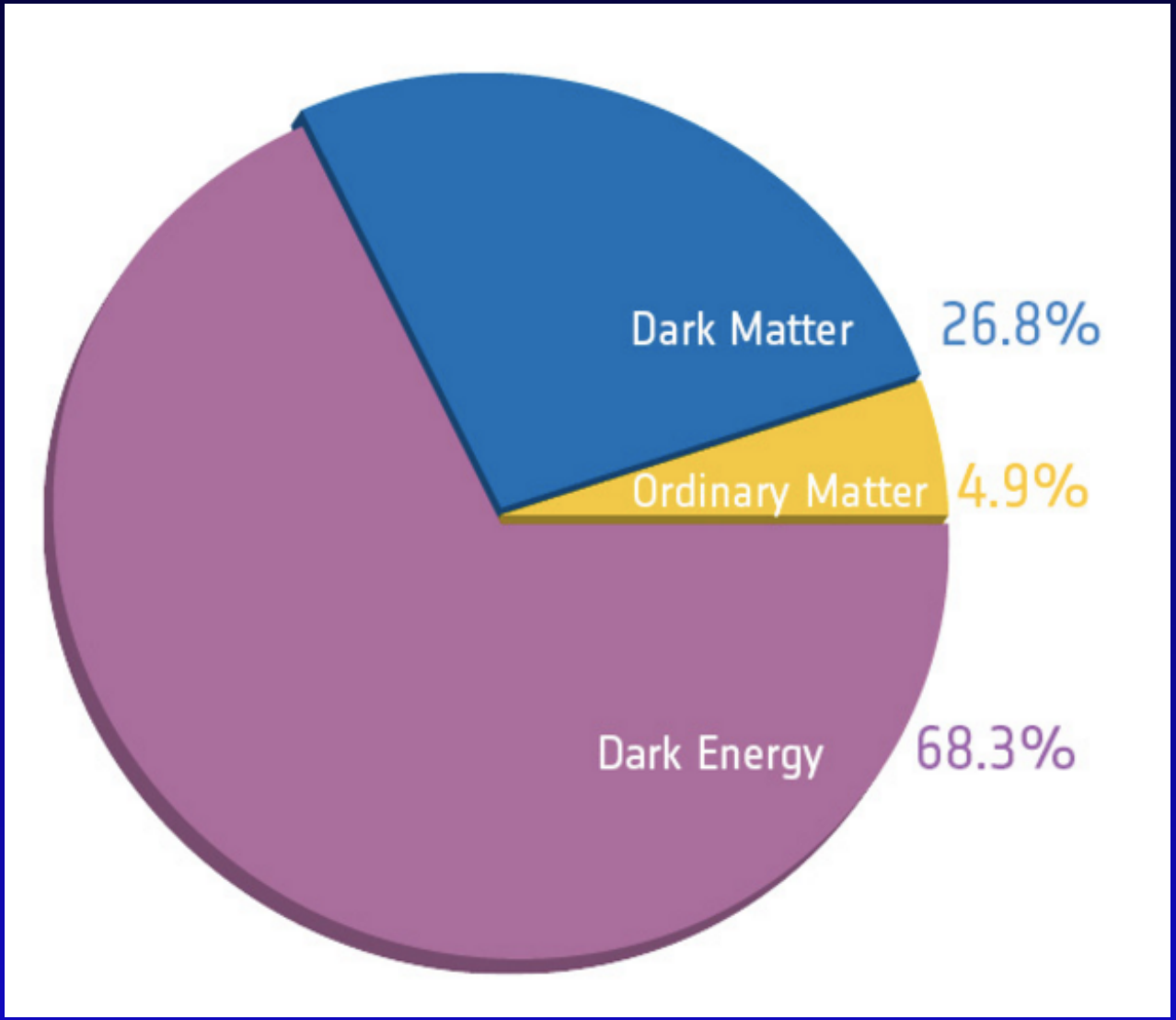
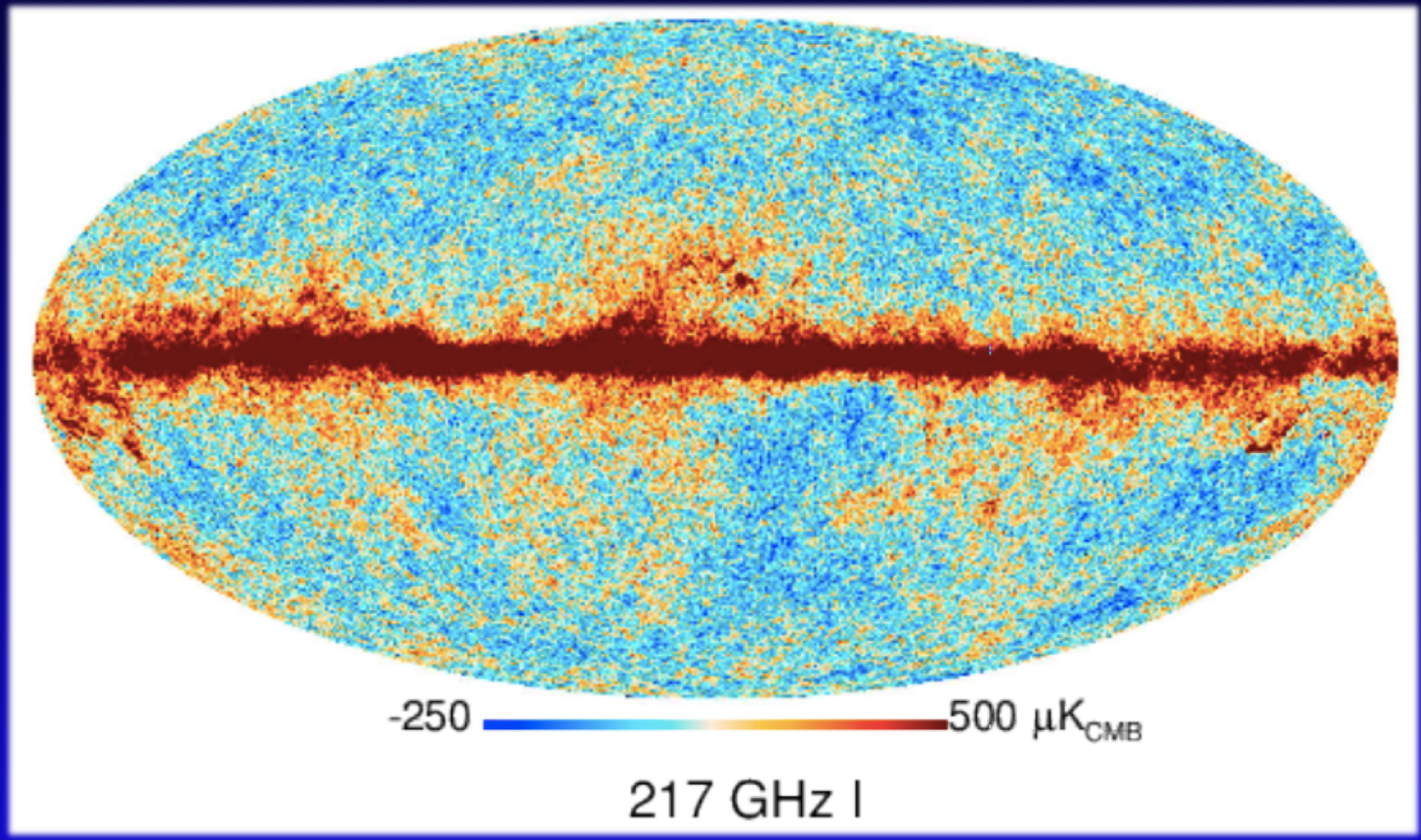
Common ground to start with

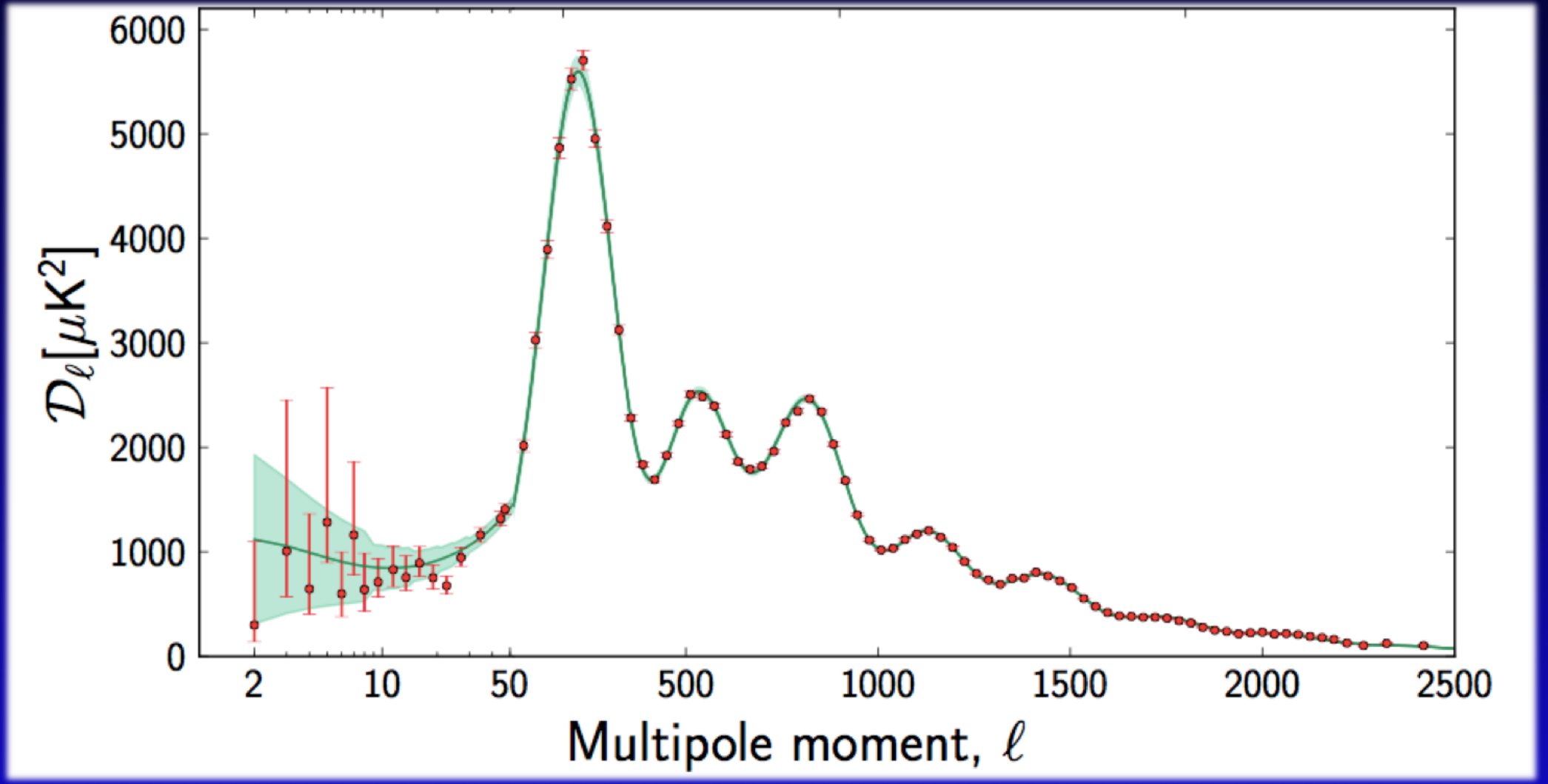


[e.g. Planck coll.]

CMB, a dark matter probe

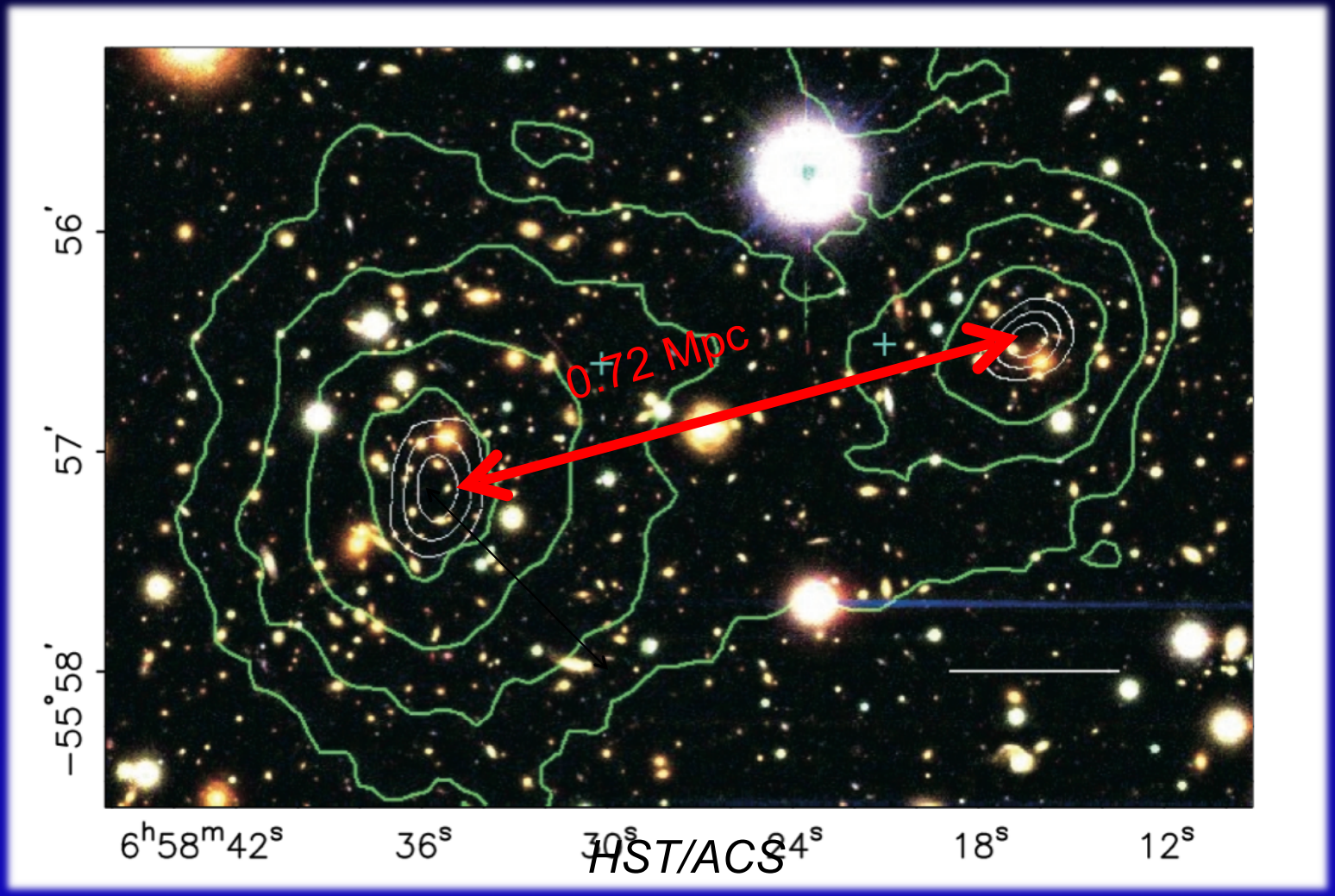


CMB, a dark matter probe



ω_m and ω_{bar} from CMB only

The "Bullet Cluster"
1E 0657-558



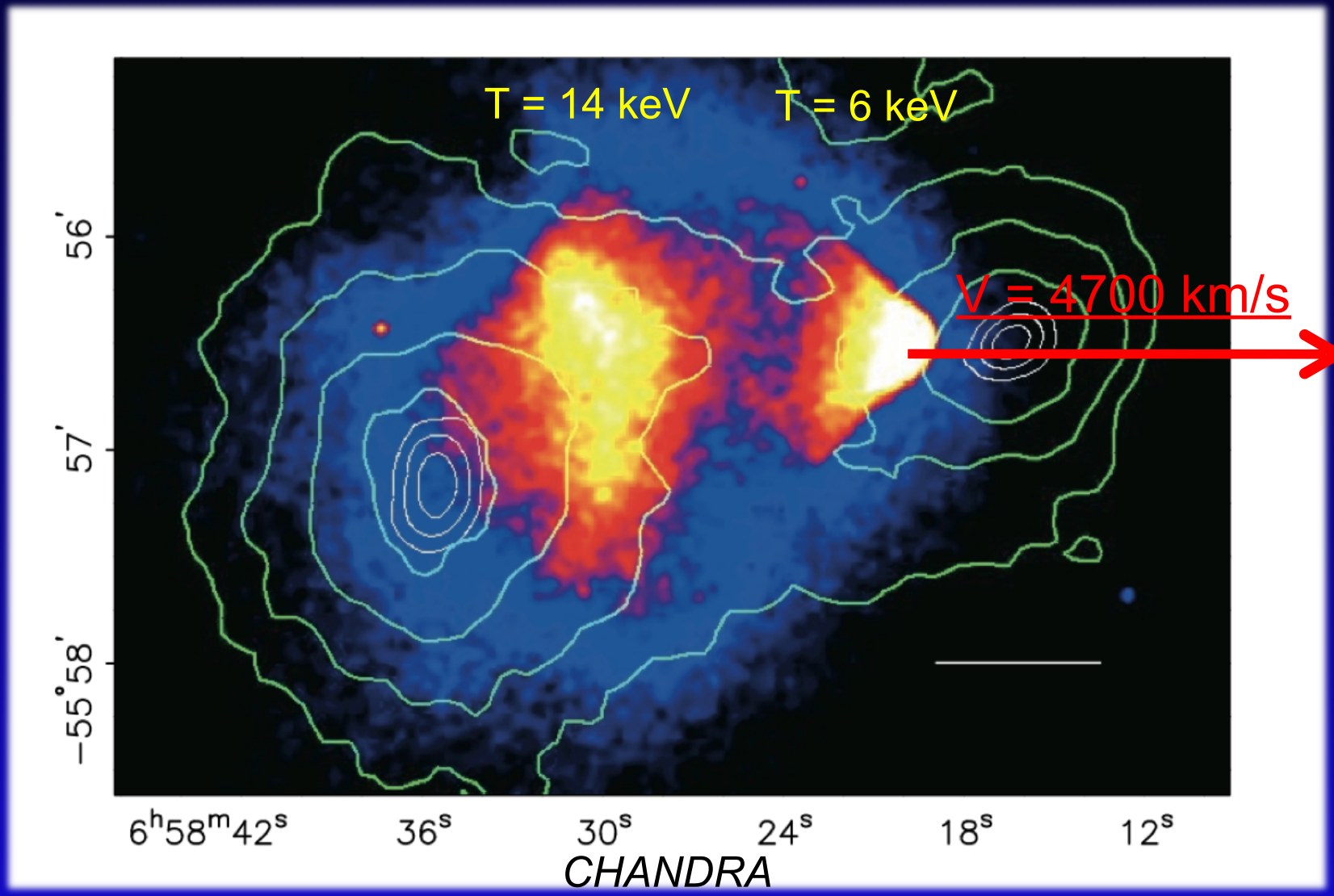
Z = 0.296

collision in the plane of the sky

[Markevitch et al. '06]

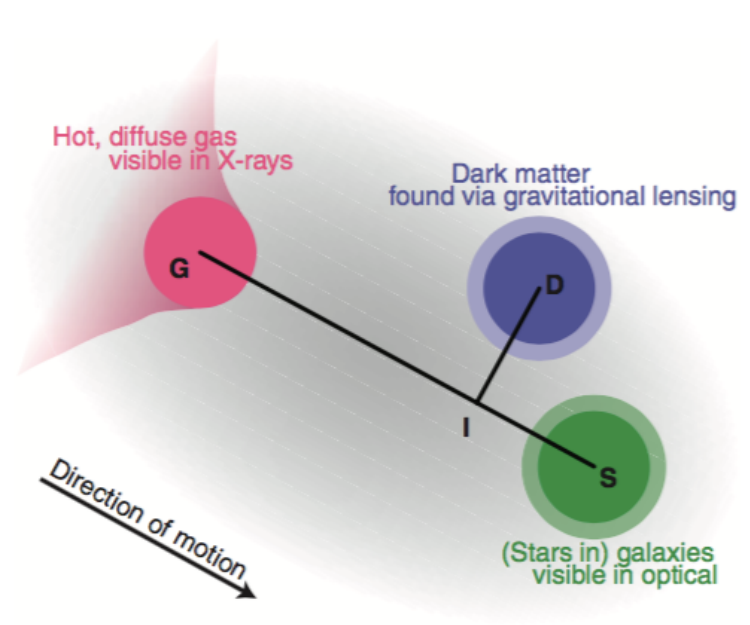
The "Bullet Cluster"

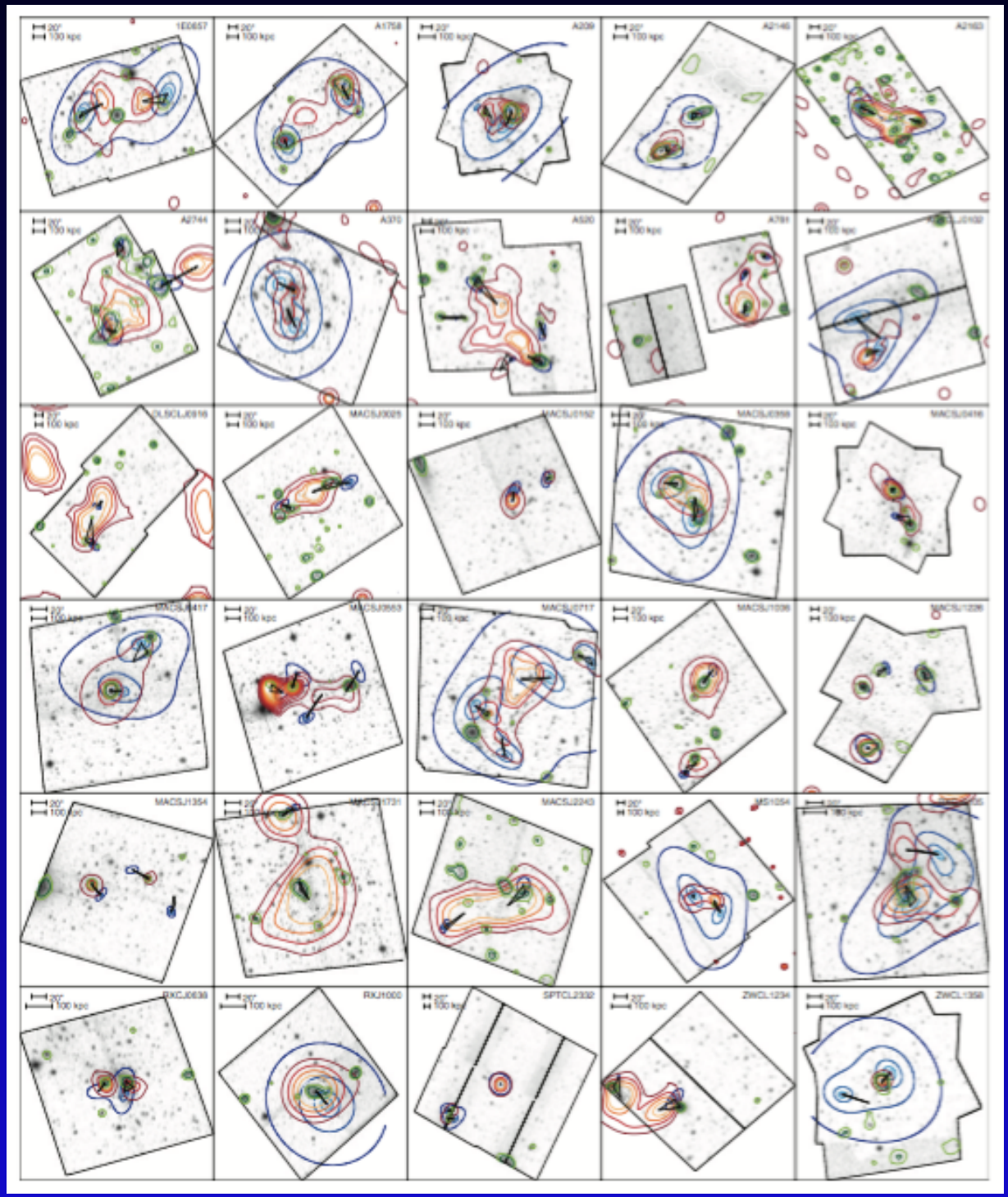
1E 0657-558



Merger 100 Myr ago

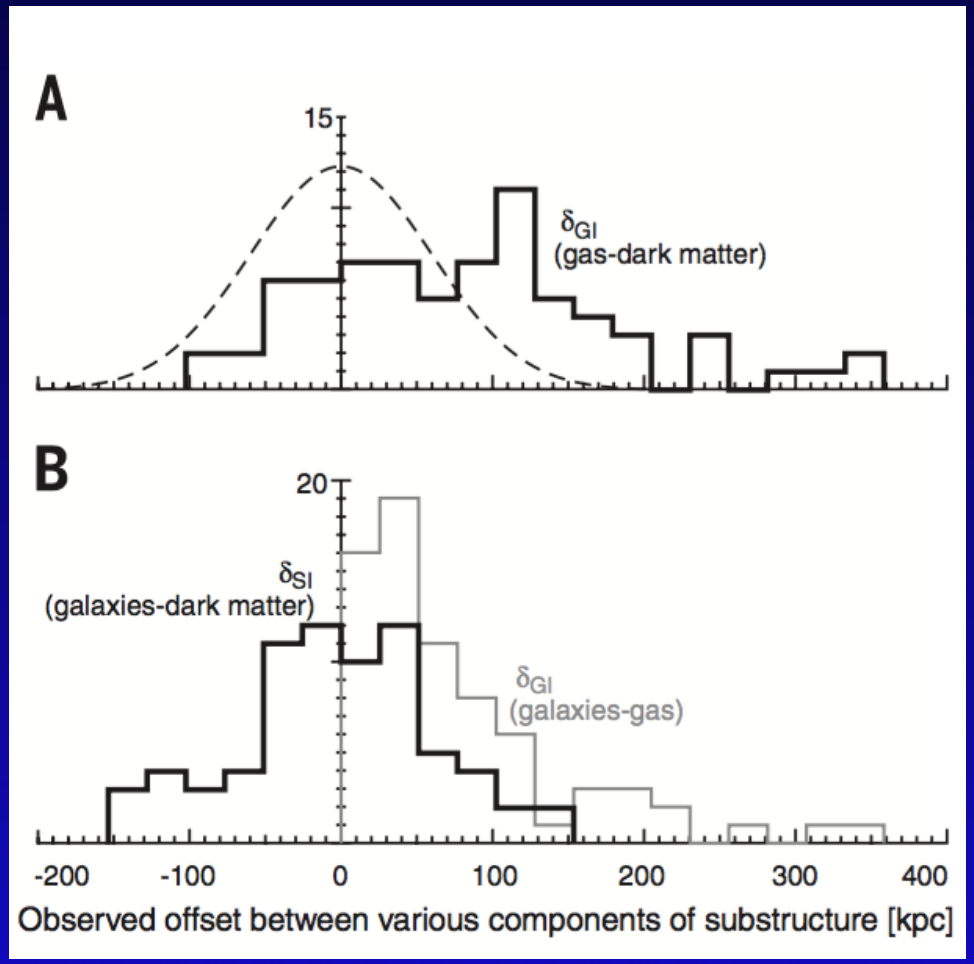
The Bullet is only the first, most famous, of a plethora of similar systems.

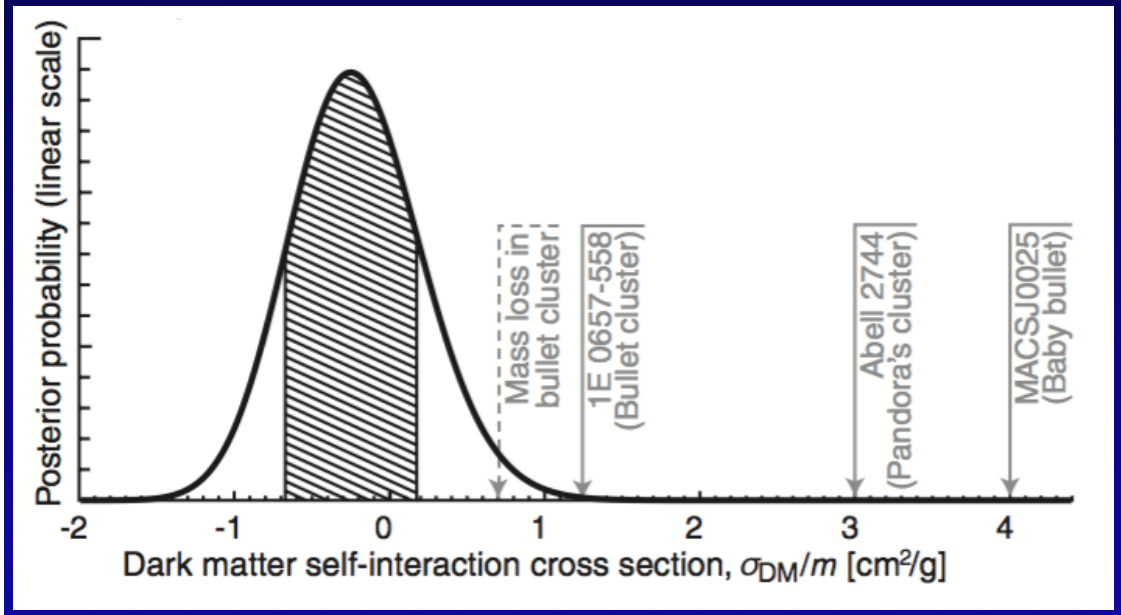




[Harvey et al. '16]

Quantitative constraints on DM-baryon separation

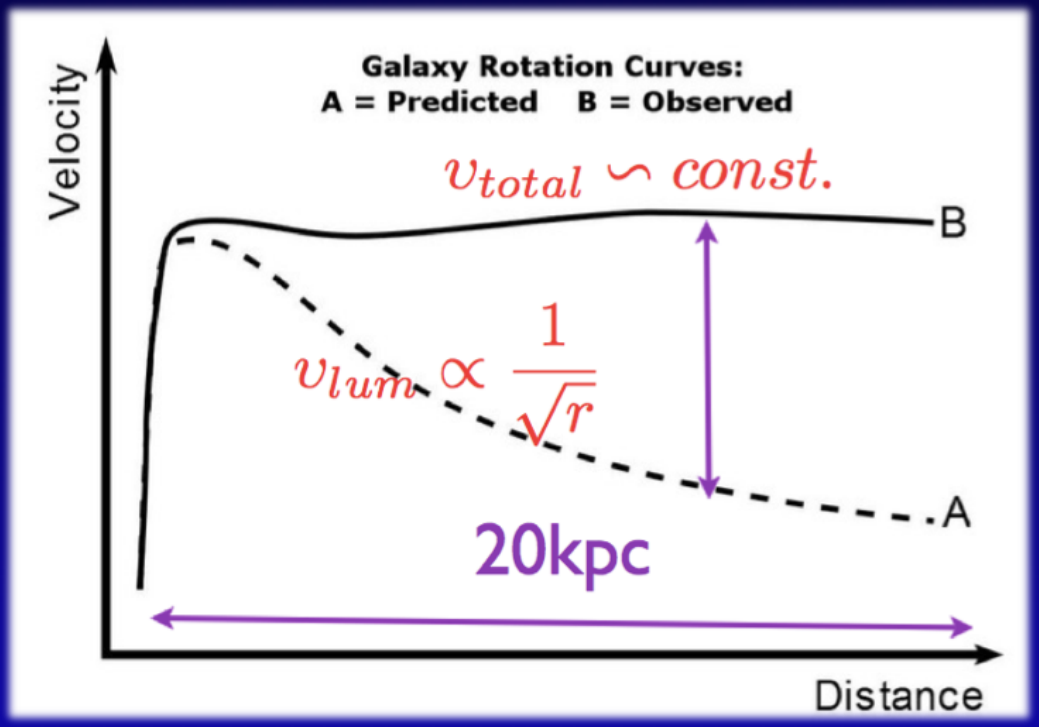


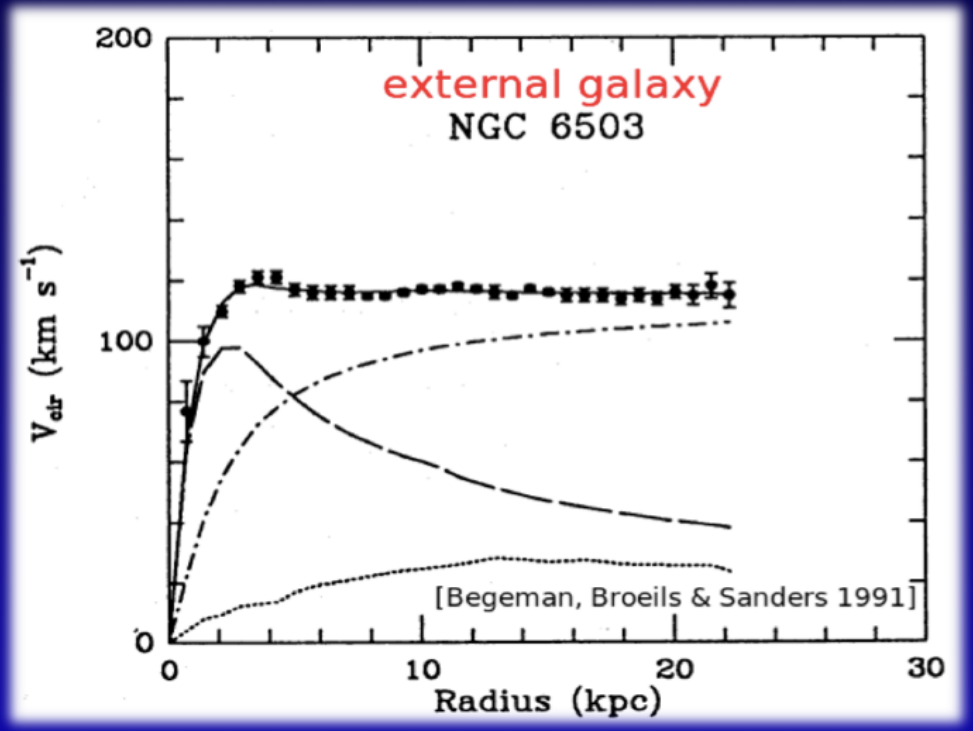


[Harvey et al. '16]

Rotation Curves in local galaxies: an evergreen classic:

(with interesting twists)



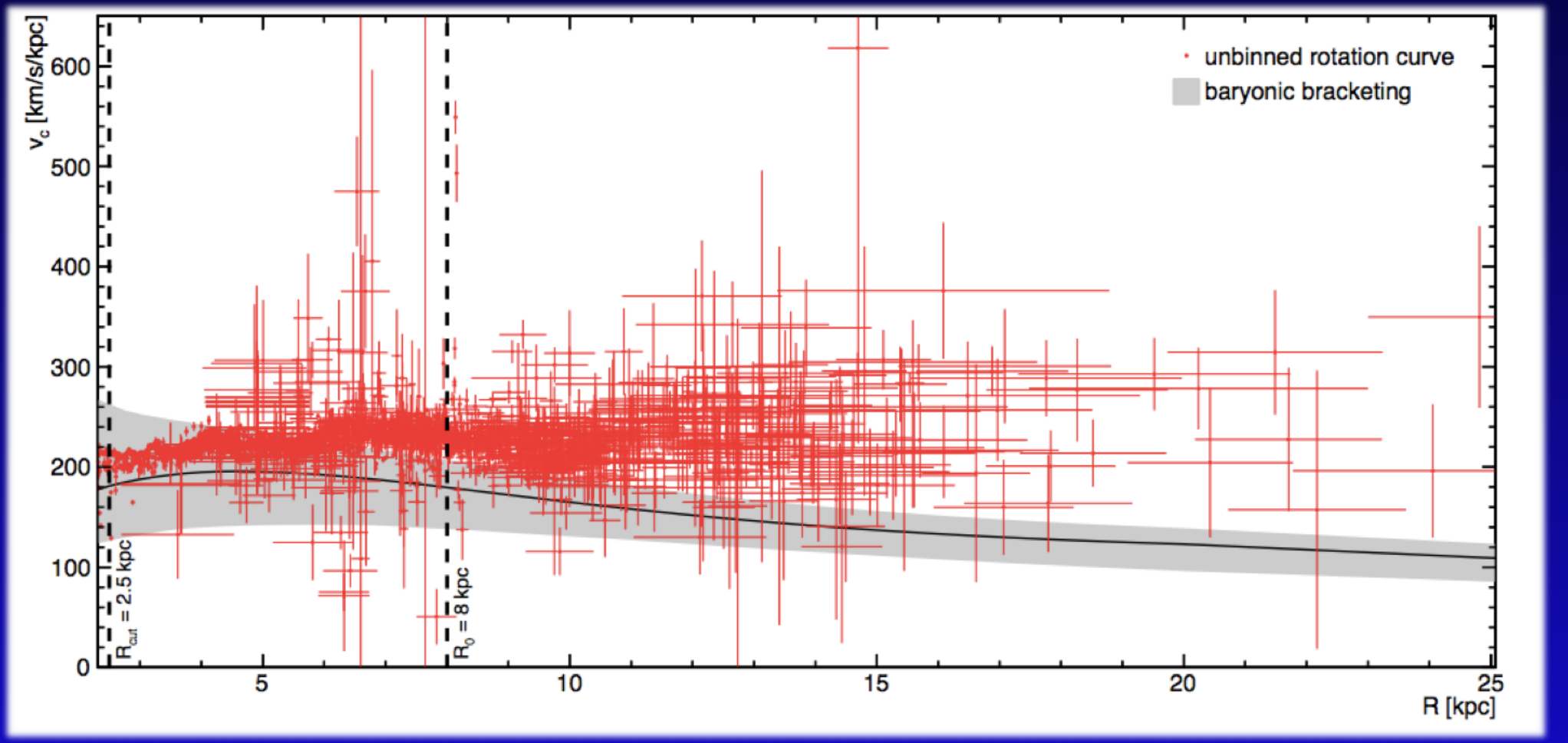


discrepancy between observed and predicted (from visible matter only)

The Milky Way:

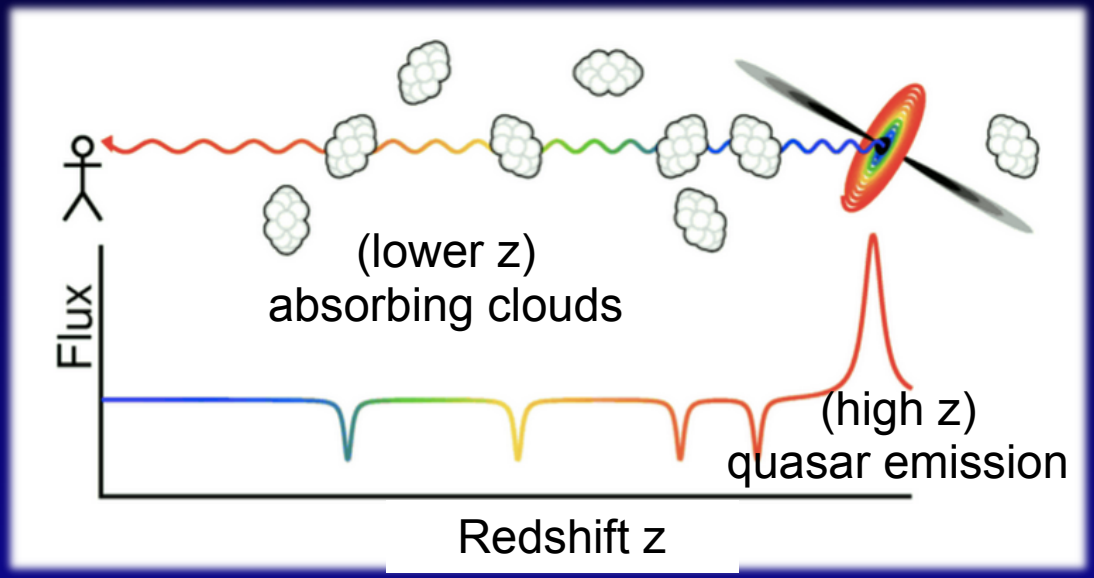
one more spiral Galaxy

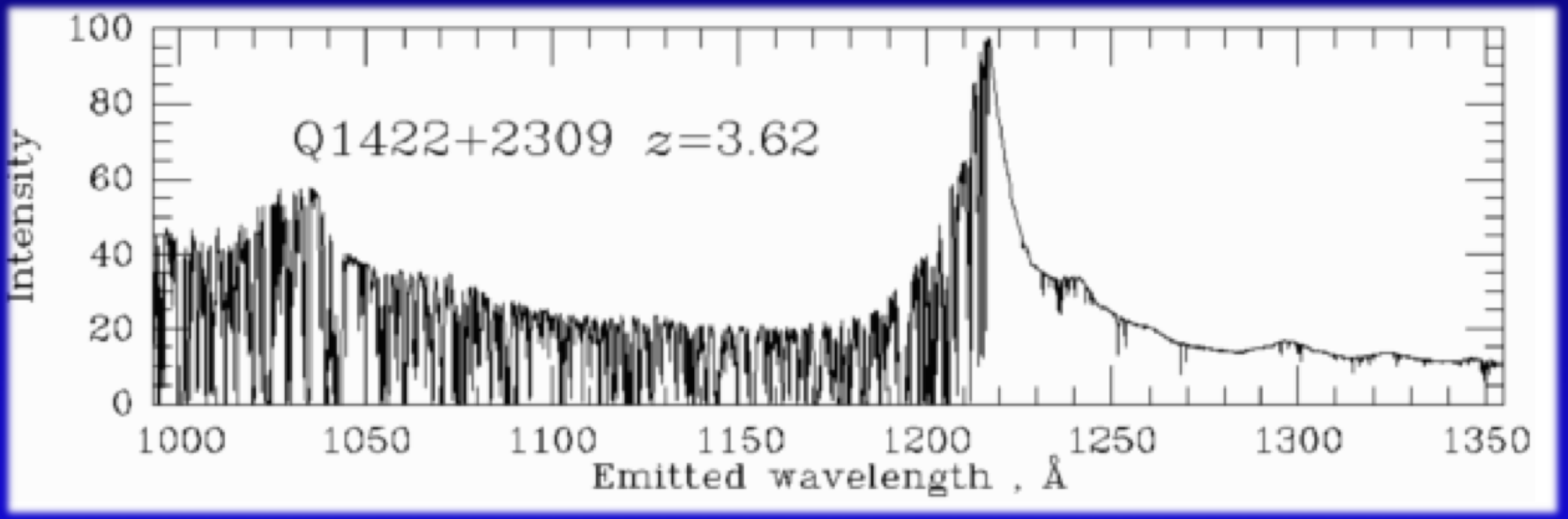
(and its Rotation Curve)



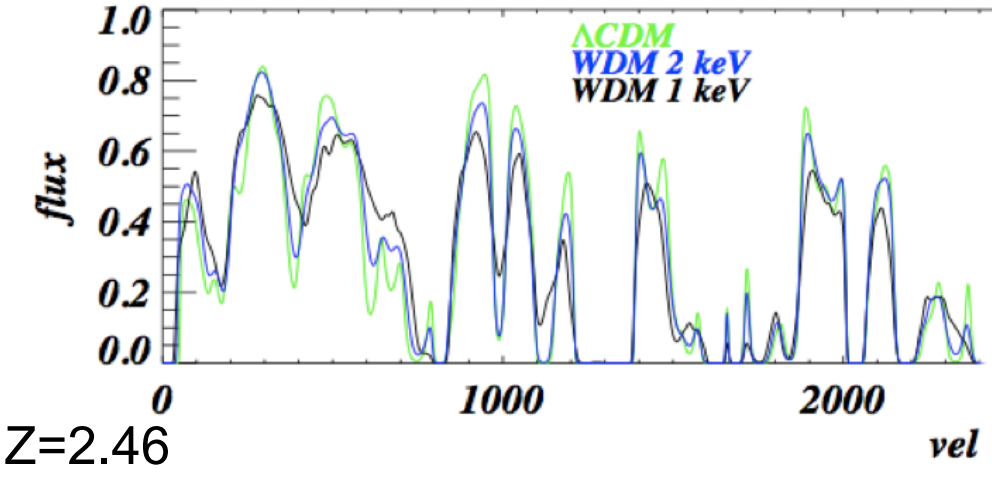
[Iocco, Pato, Bertone, Nature Physics 2015]

Ly-α forest: probing structures during Universe evolution

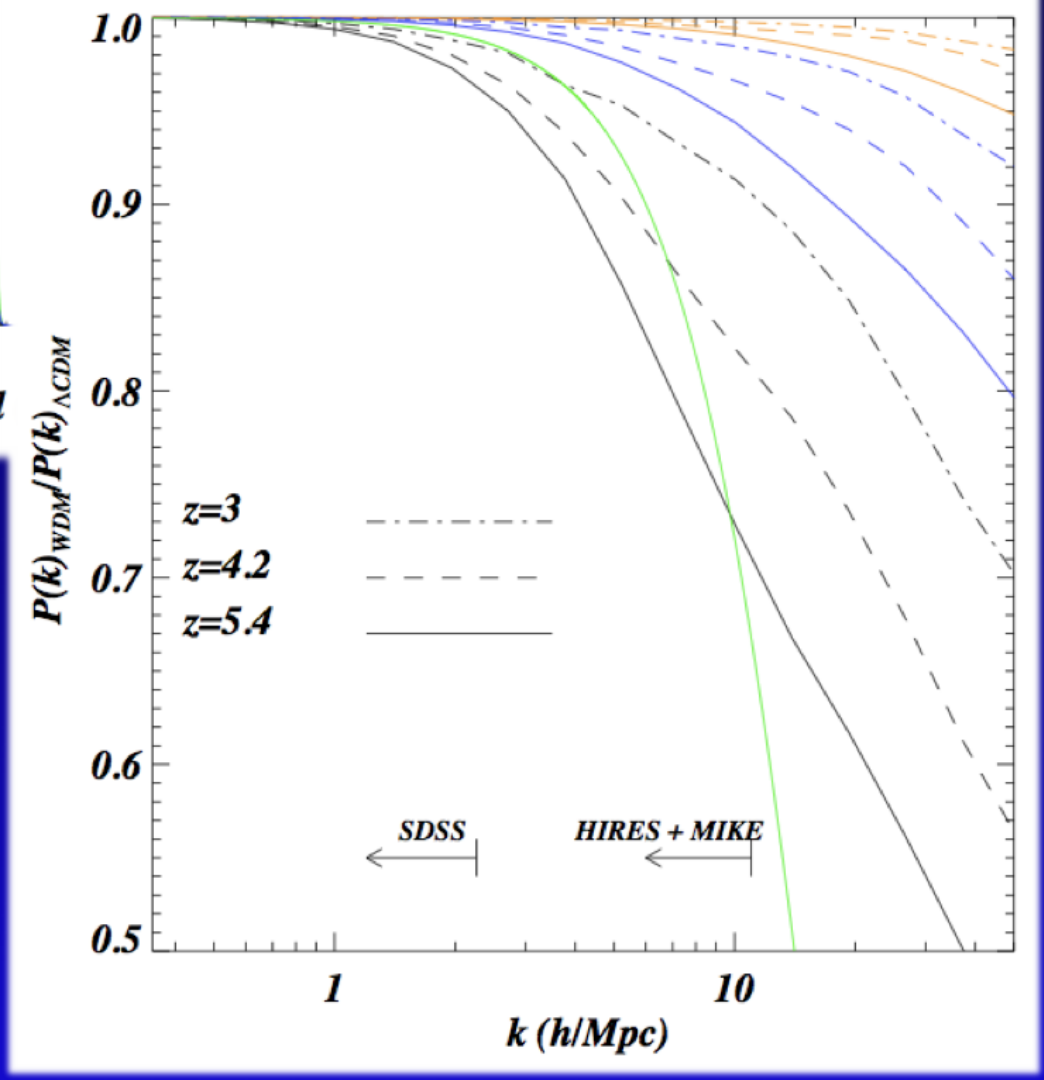




Ly-a forest to constrain the perturbation power spectrum



Z=2.46



[Viel et al., 2013]

What can we learn from astrophysics (about DM?)

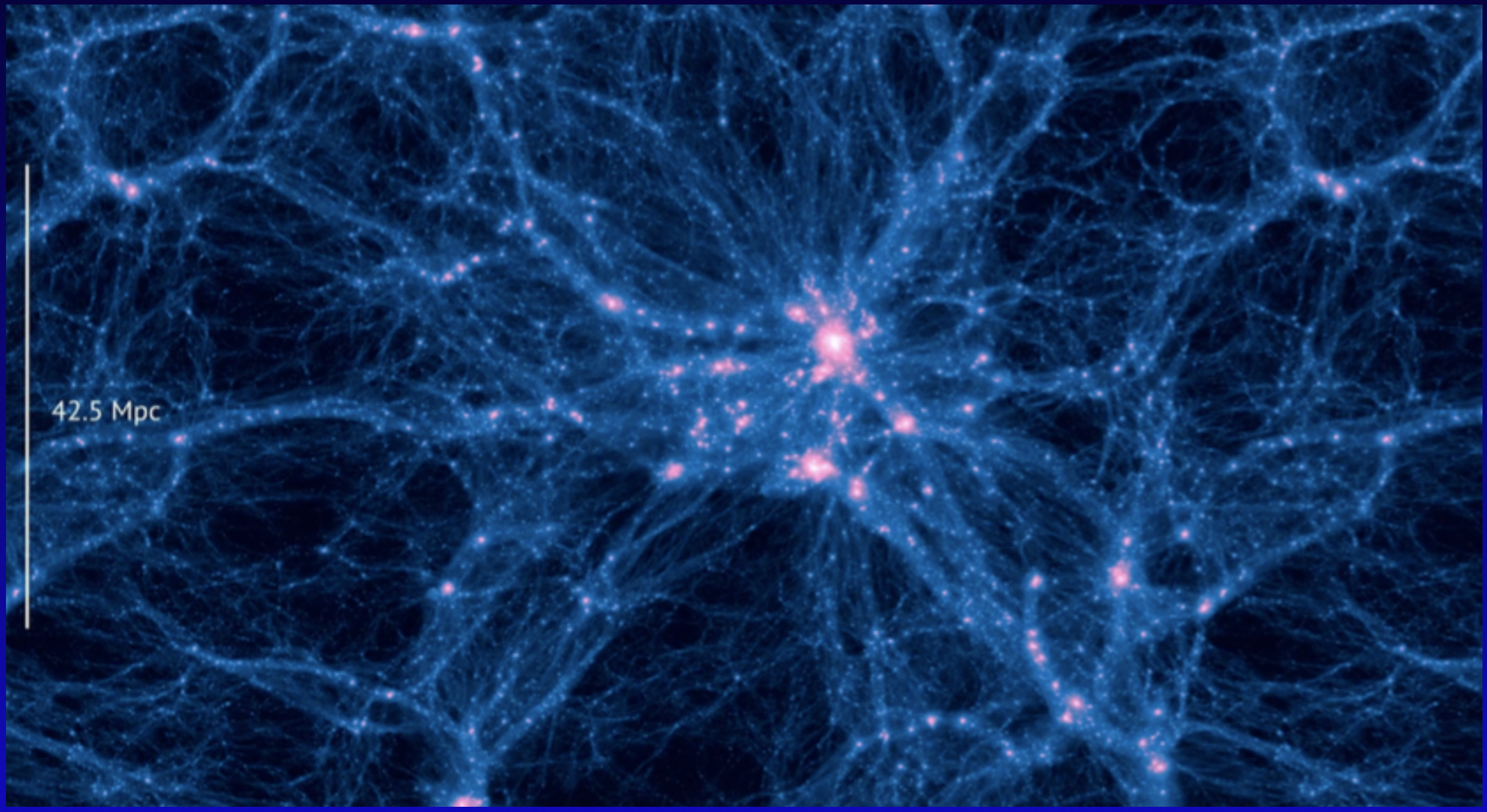
DM is there, at different scales
(≈100 Mpc, ≈1Mpc, ≈10kpc)

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



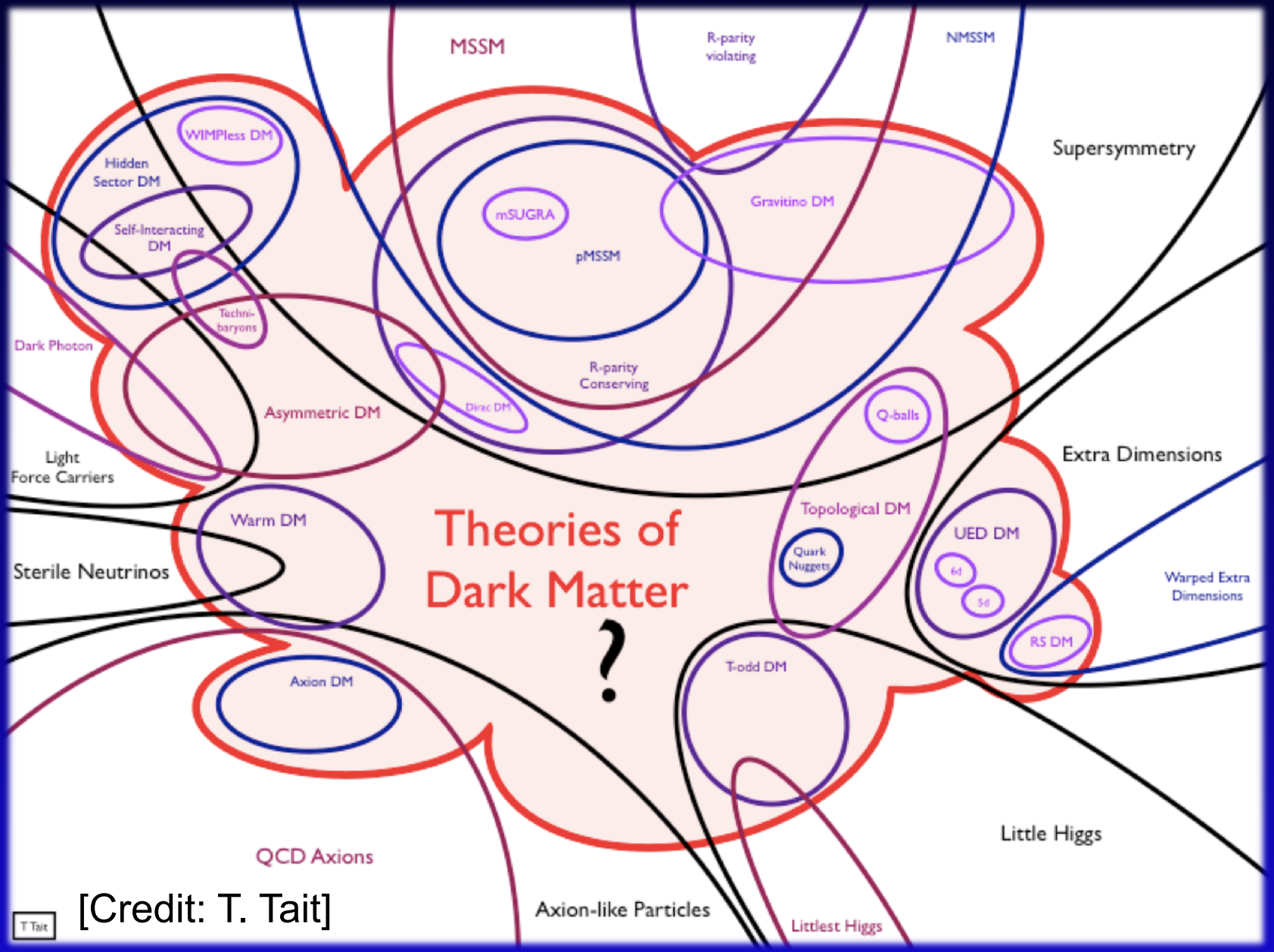
[Illustris, Vogelsberger 2014]

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?*

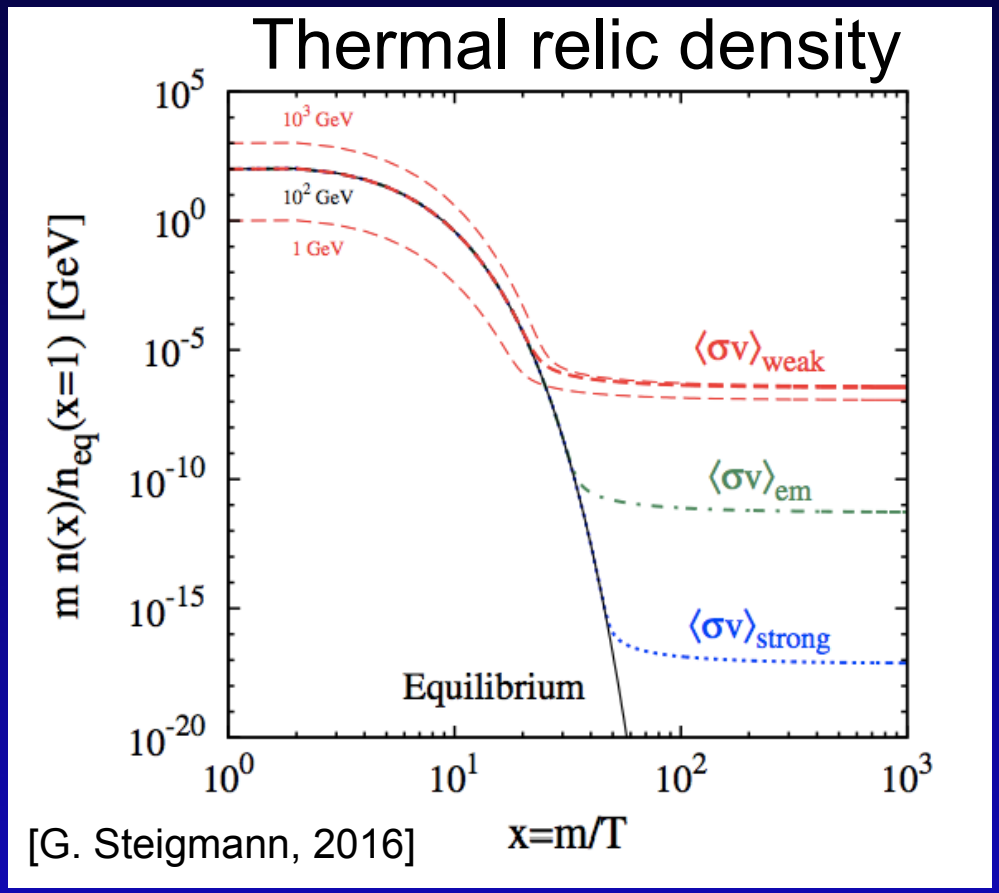
[Taoso et al., 2007]

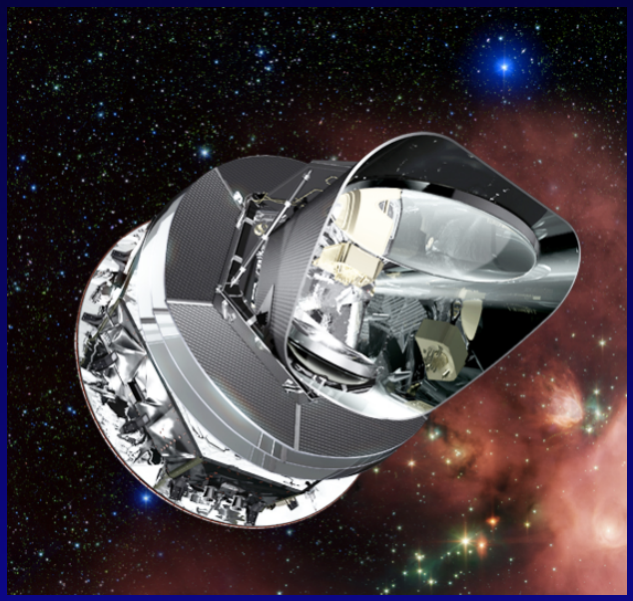
In fact, there's plenty of options

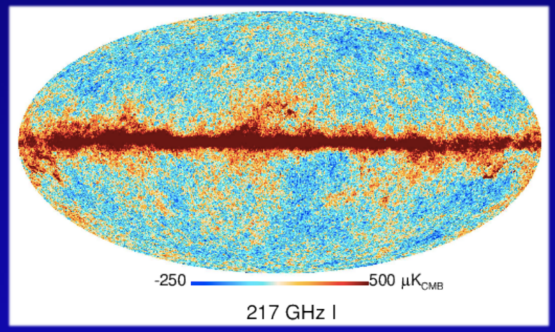


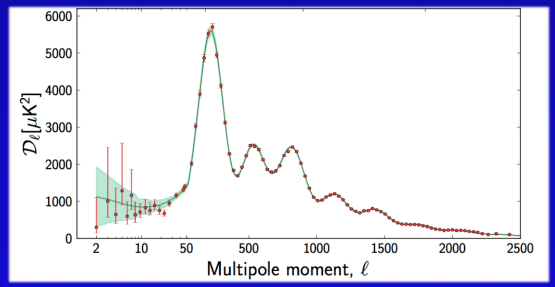
[Credit: T. Tait]

The way we look for it, depends on what we expect









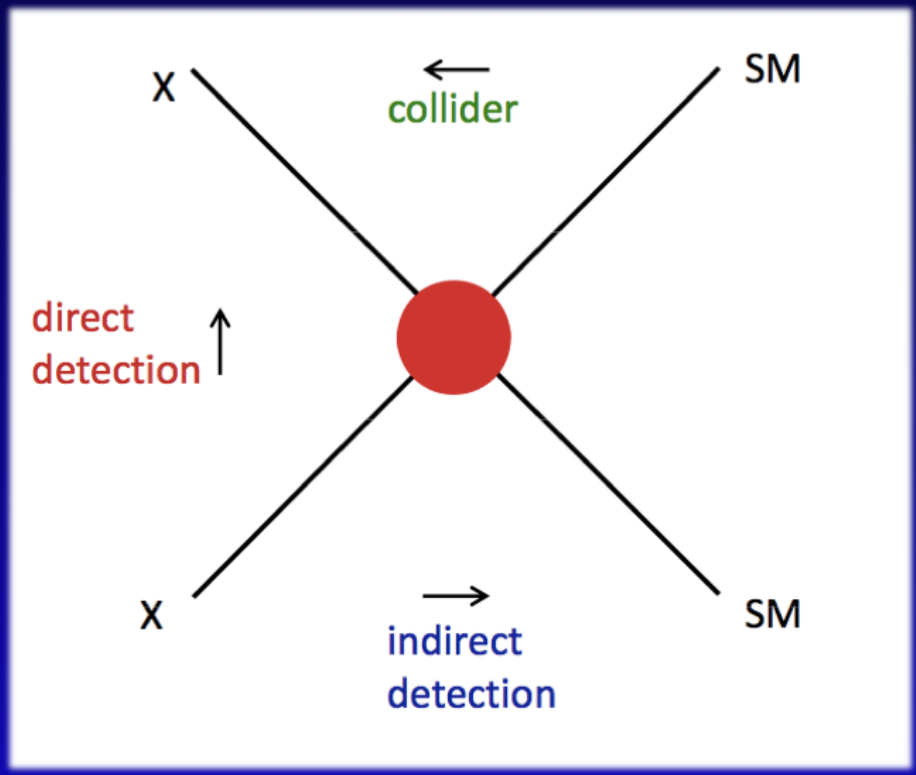
Weakly Interacting Massive Particles:

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.

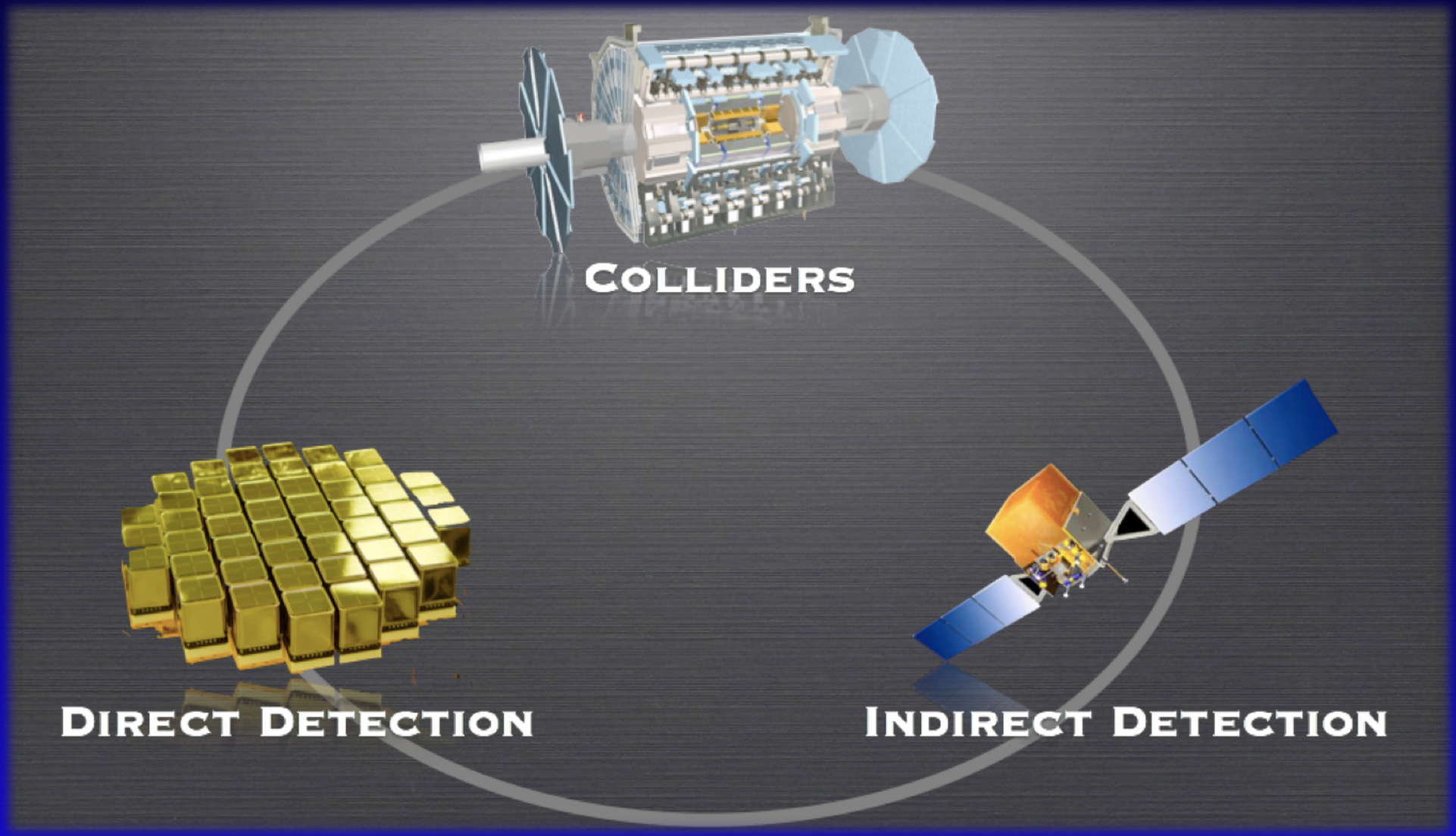
Production at LHC



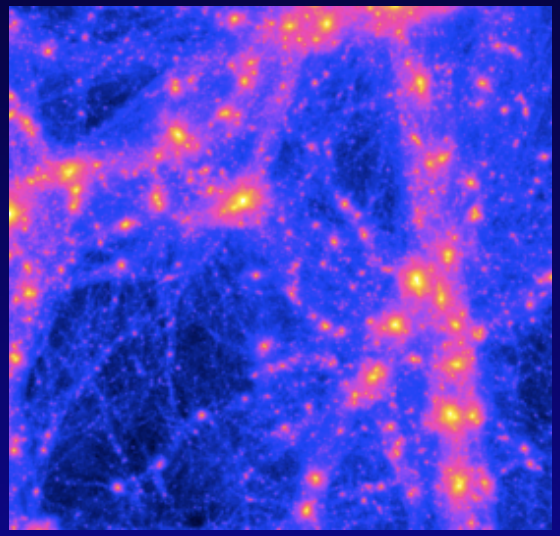
Direct, indirect and collider searches

A brief state-of-the-art on WIMPs

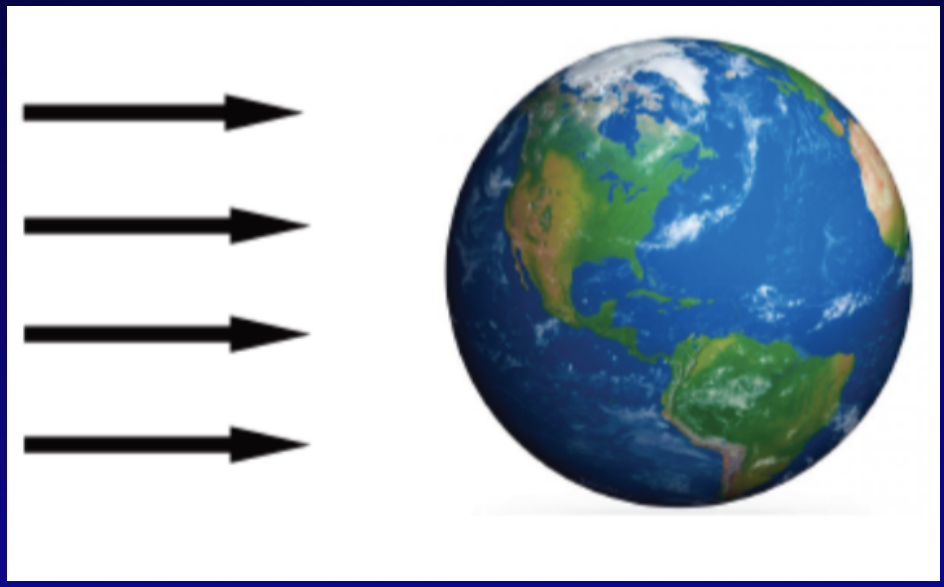
(ideal testbed of complementary techniques)

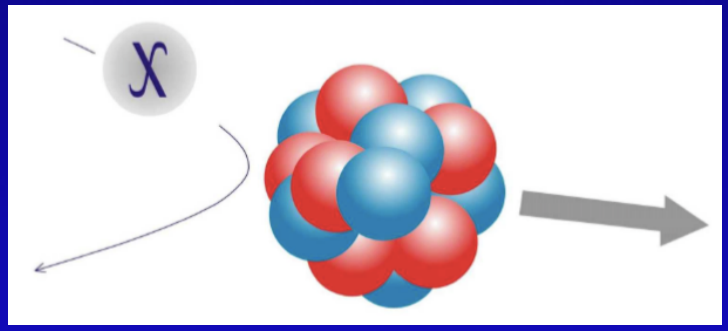


Direct DM searches



The DM cloud



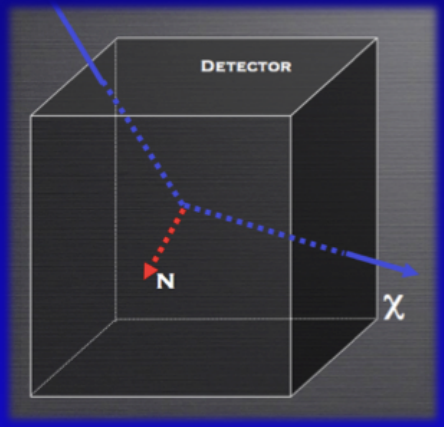


(Elastic) scatter of a DM particle over a nucleus induces recoil
Measure recoil in controlled environment: Lab on Earth (but also…)

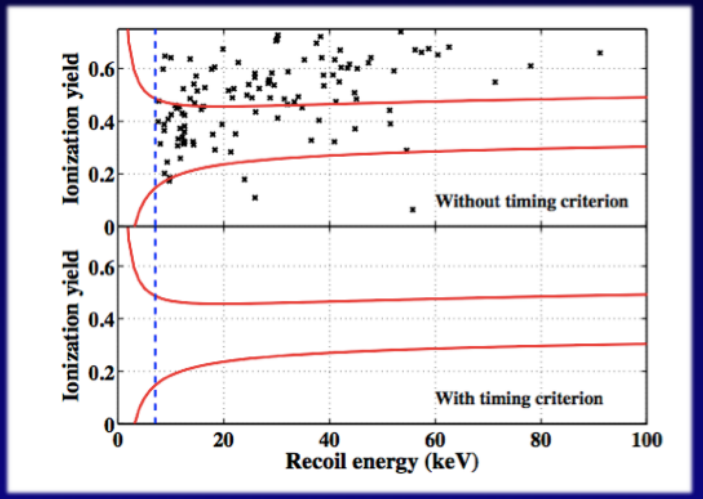
Direct Detection: principles and dependencies

A big mountain
(or a deep mine)

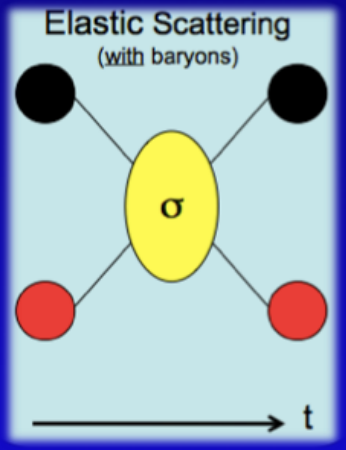
a relatively cheap detector



Your observed data

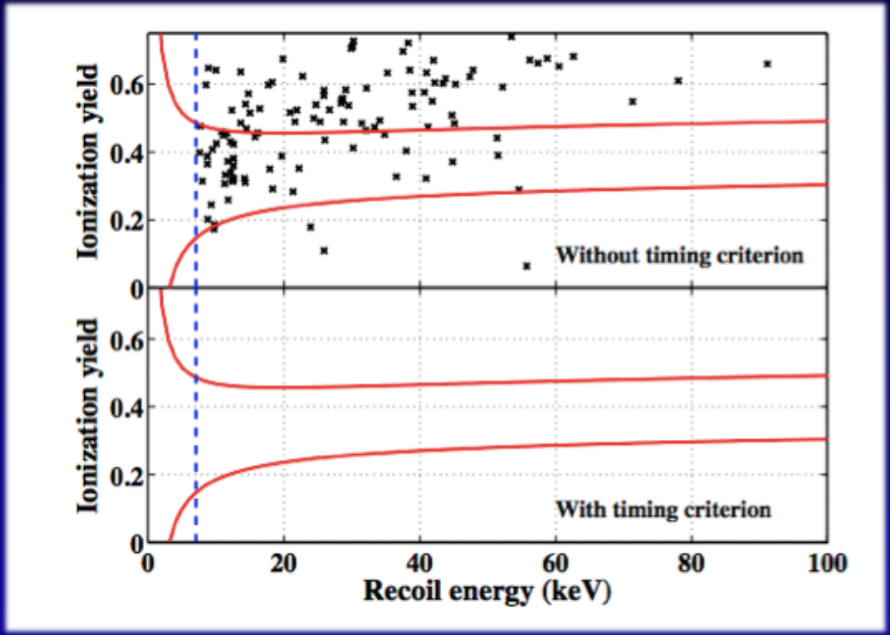


Your ticket to Stockholm

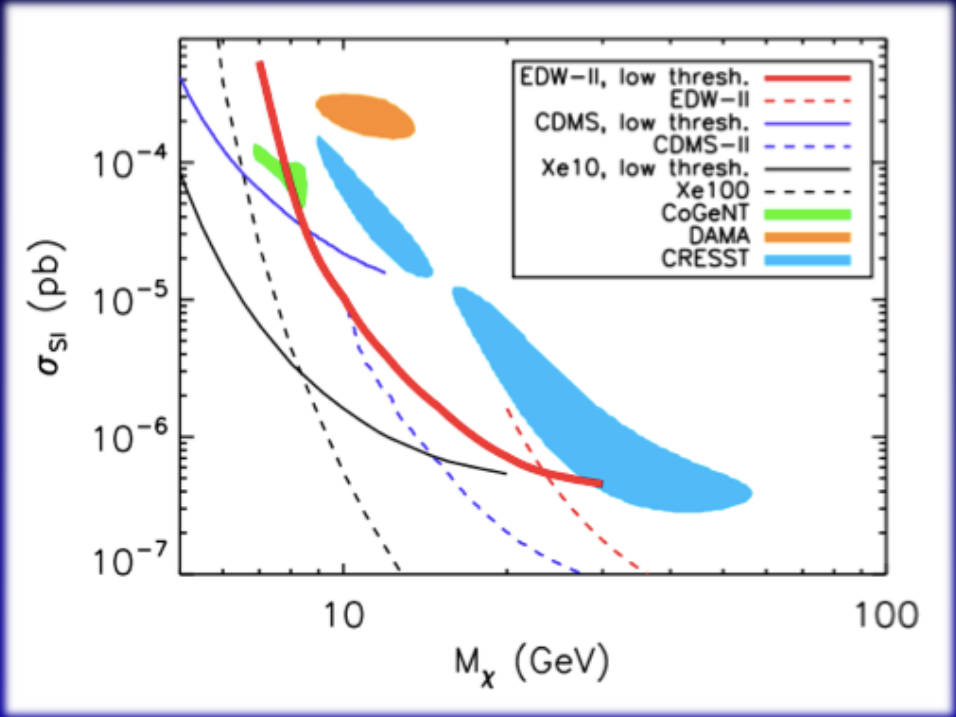


Direct Detection: principles and dependencies (to go…)

from this



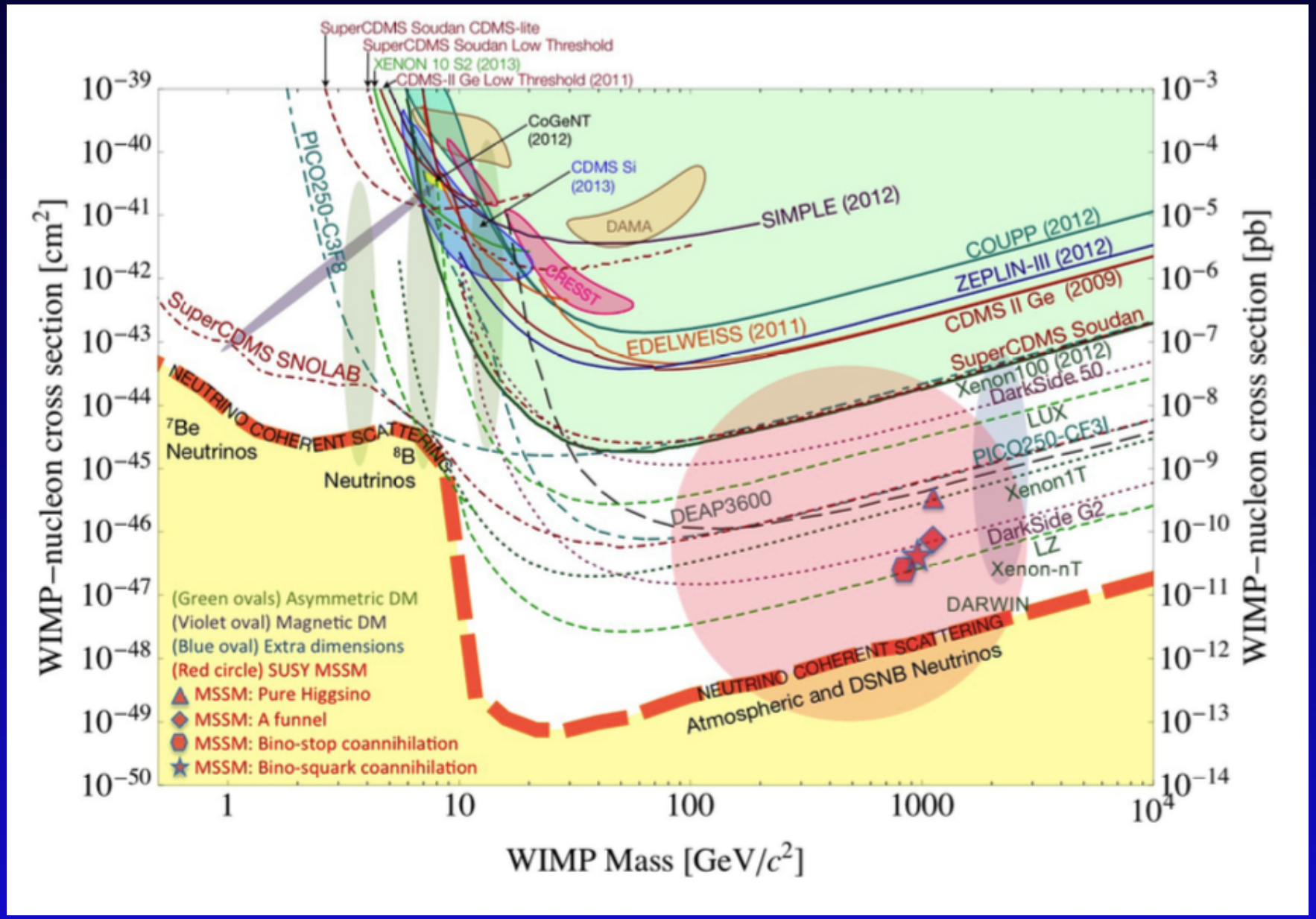
to this



you need this

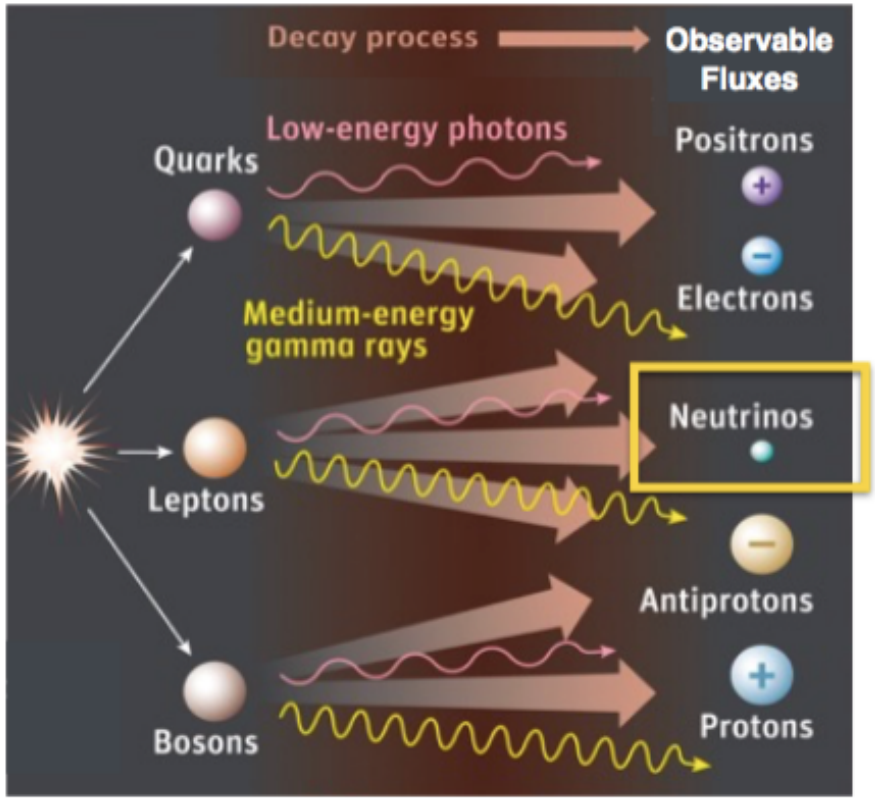
$$\frac{dR}{dE} \propto \frac{1}{\mu^2} \frac{\sigma_\chi}{m_\chi} \rho_0 \eta(v,t)$$

No observations: constraints



Indirect DM searches

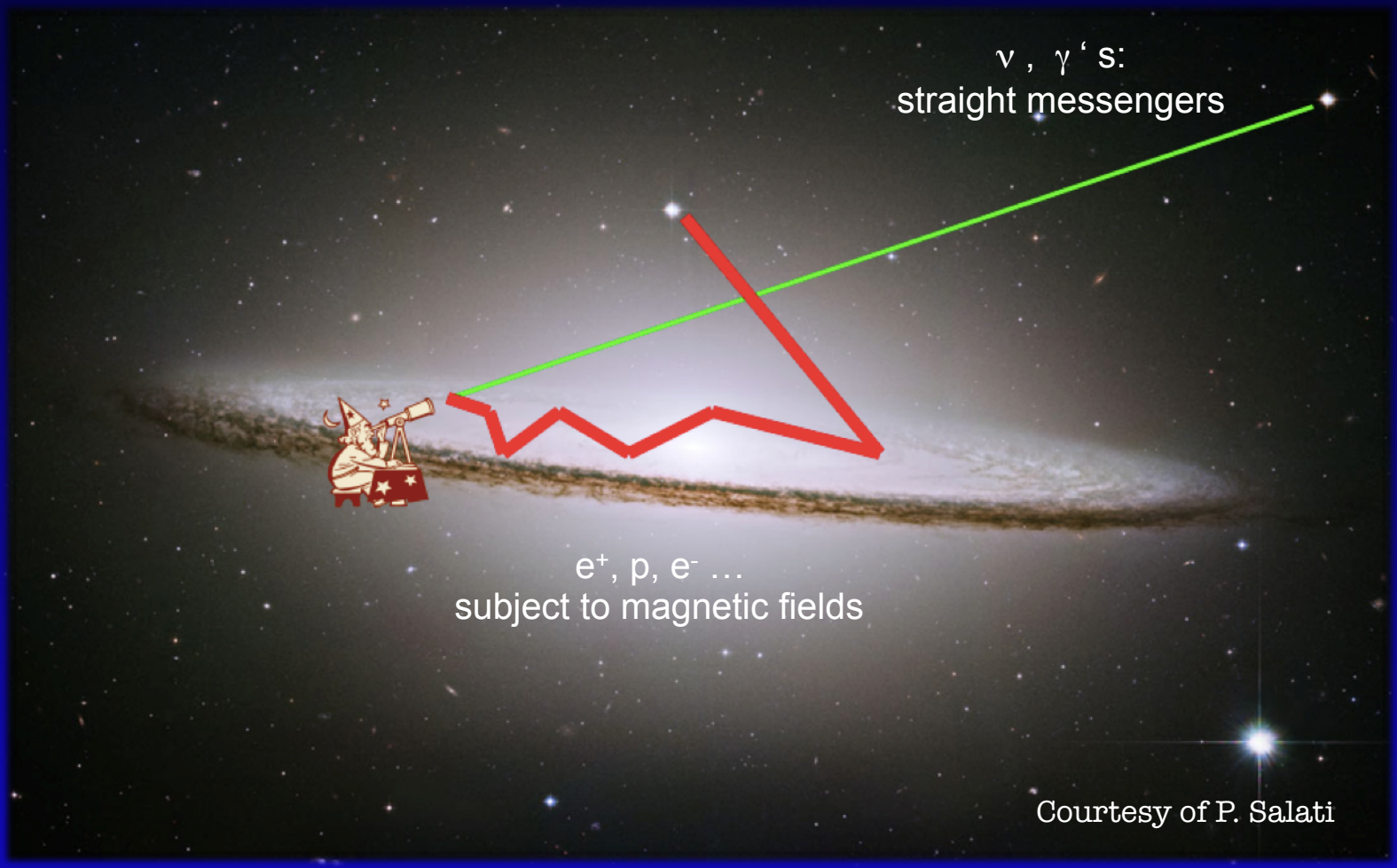
DM annihilation/decay



Looking for byproducts of DM annihilation/decay into SM.
You need a lot of DM ➔ astrophysical (big) objects

Indirect Detection: principles and dependencies

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



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

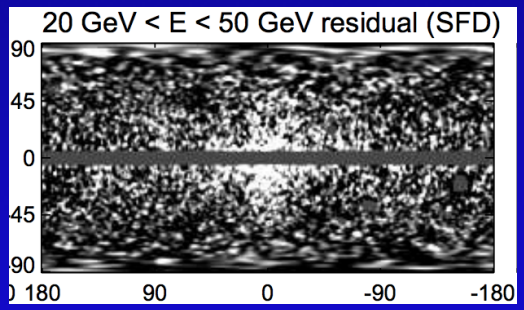
Indirect Detection: principles and dependencies

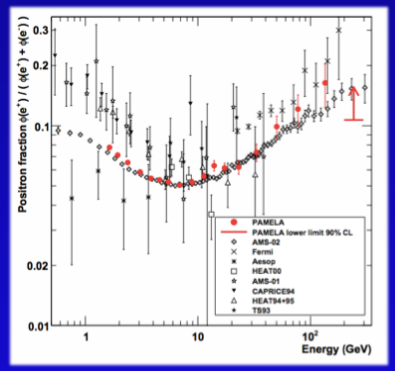
Galactic center, Dwarf Galaxies, Galactic Halo…
dependence on density structure
discovery (or constraints) subject to same uncertainty

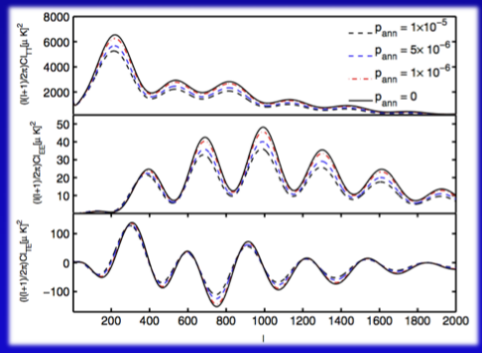
$$F_i \propto \frac{1}{4\pi d^2} B_i \frac{\langle \sigma v \rangle}{m_\chi} \int \rho^2(r) dV$$

$$J_{annih} \propto \int_{los} \rho^2(r) dV$$

$$\Phi_{DM}(E) = \Phi_{PP}(E) \mathcal{J}$$

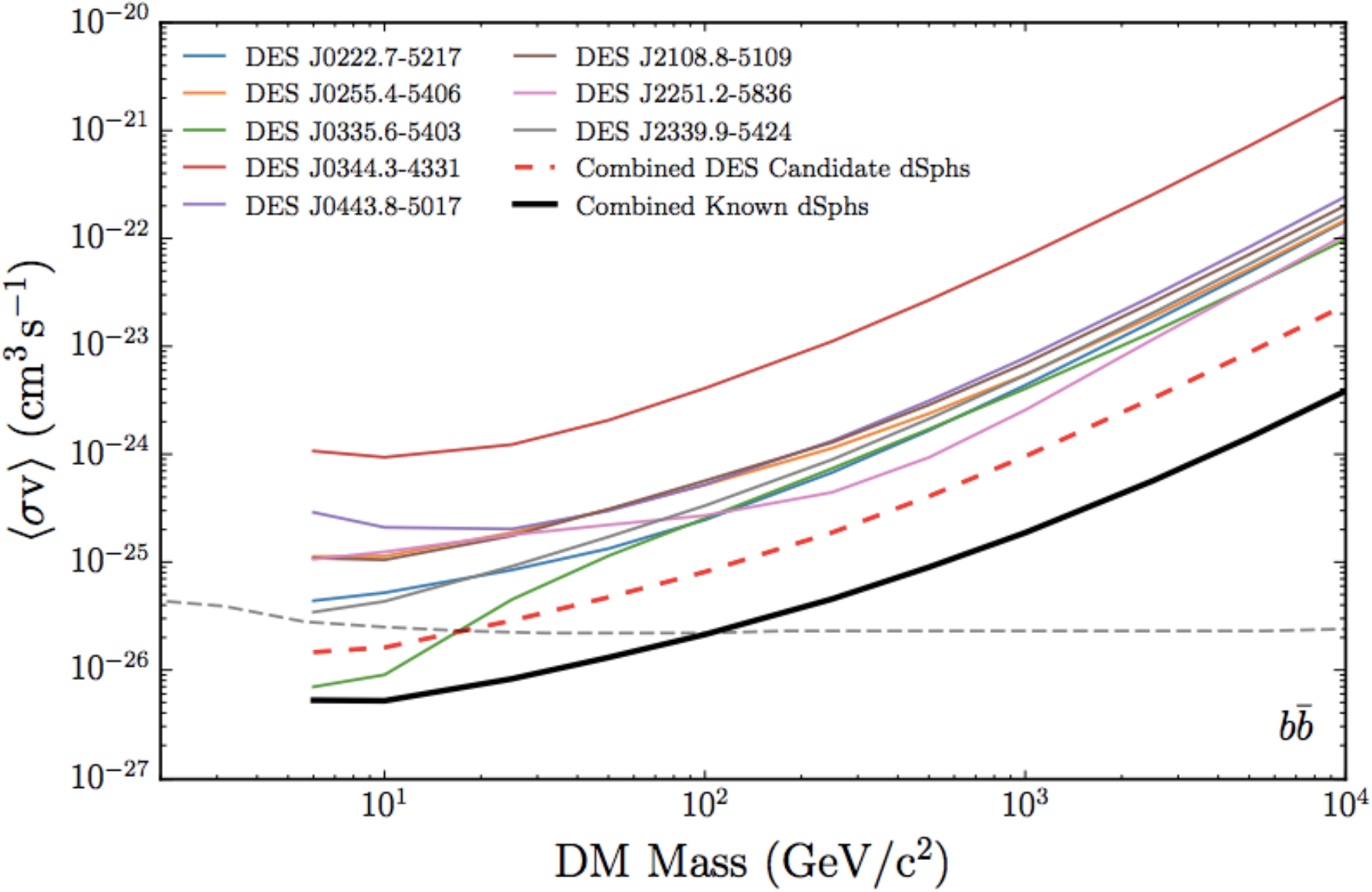






Indirect Detection: constraints

(what to do when there is no signal)



[Fermi coll, 2015]