Dark Matter

UO Quarknet
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Warning: Most figures are not my own, found on internet

Talk Goals

- Give you a brief intro to dark matter
- Pieces of Evidence
- Example dark matter candidate, weakly interacting massive particle (WIMP)
- Experimental approaches to find dark matter

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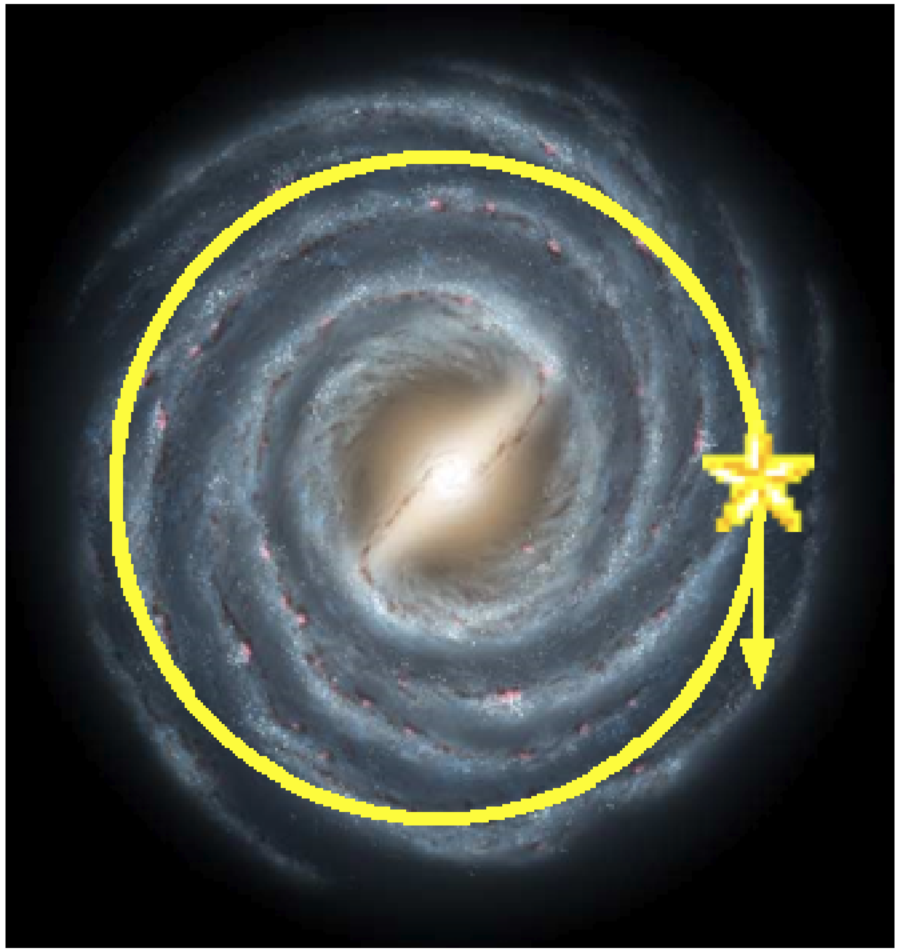
Weighing Galaxies by Rotation Curves

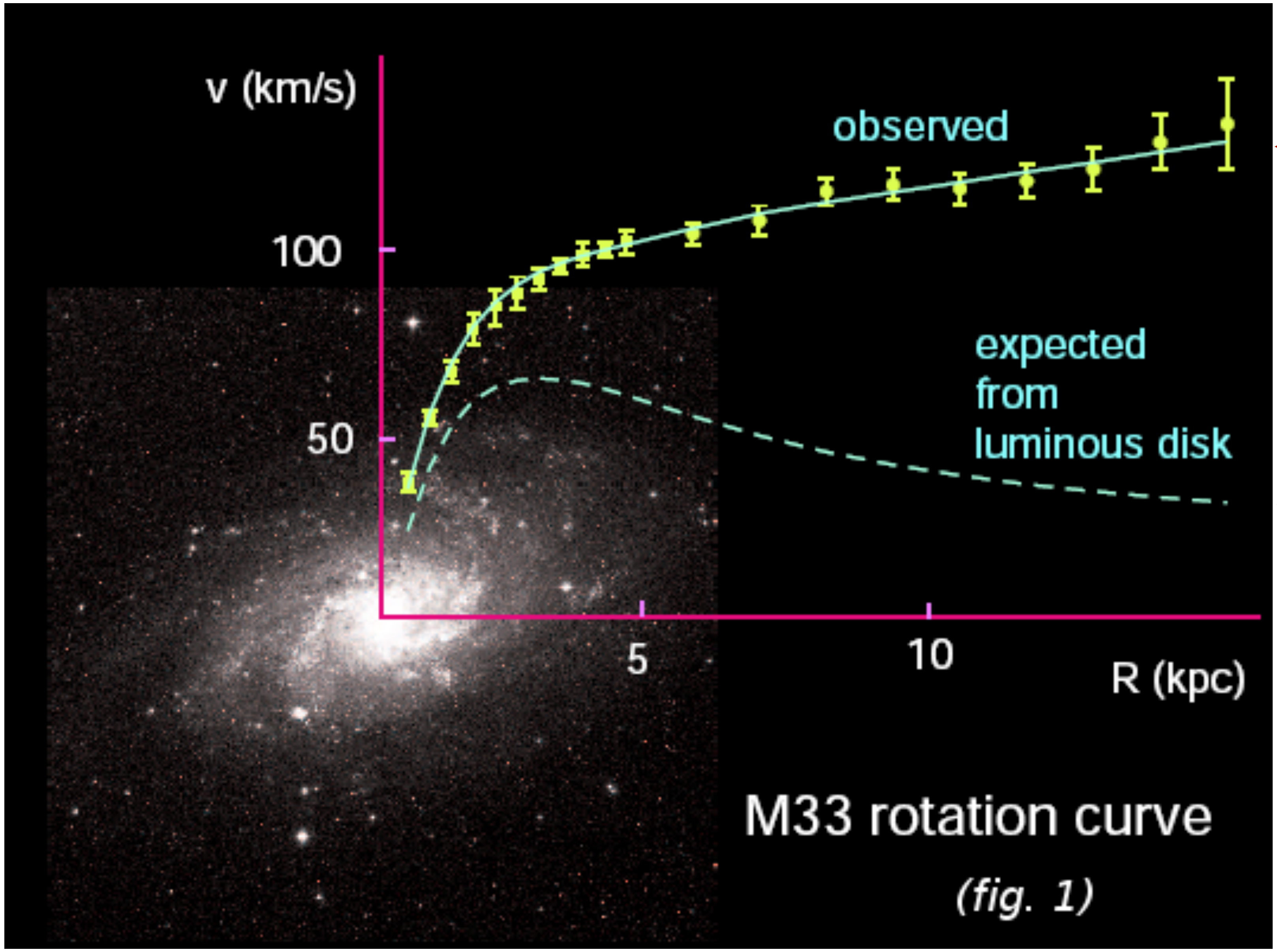


Milky Way

Centripetal Acceleration

$$G_N \frac{M(r)}{r^2} = \frac{v(r)^2}{r}$$

Observations pioneered by Vera Rubin



New dark stuff

$v(r) \sim constant$

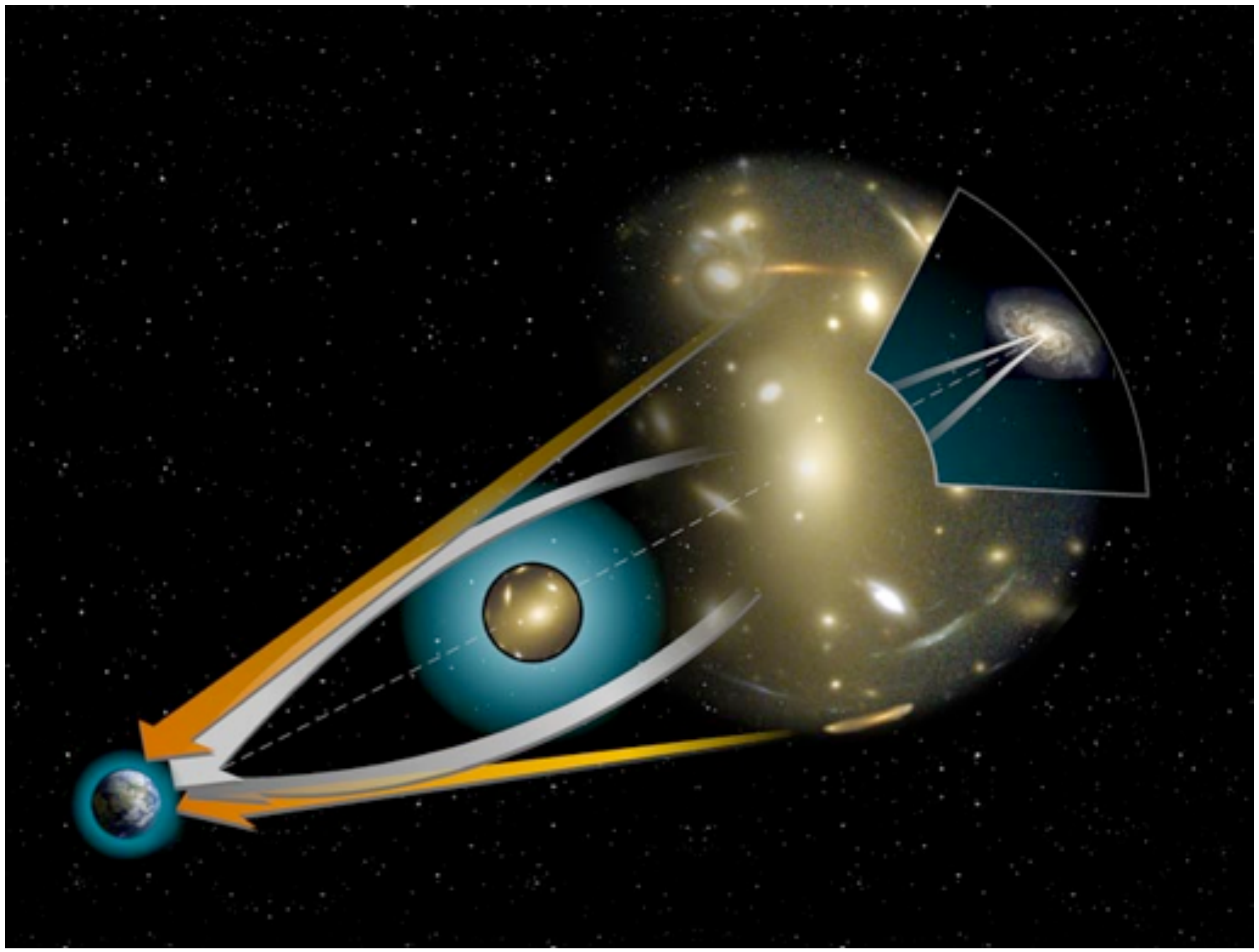
$\rho_{dark}(r) \sim 1/r^2$

Only luminous stuff

$v(r) \propto 1/\sqrt{r}$

Hint that we are surrounded in a dark matter halo

Weighing space by gravitational lensing

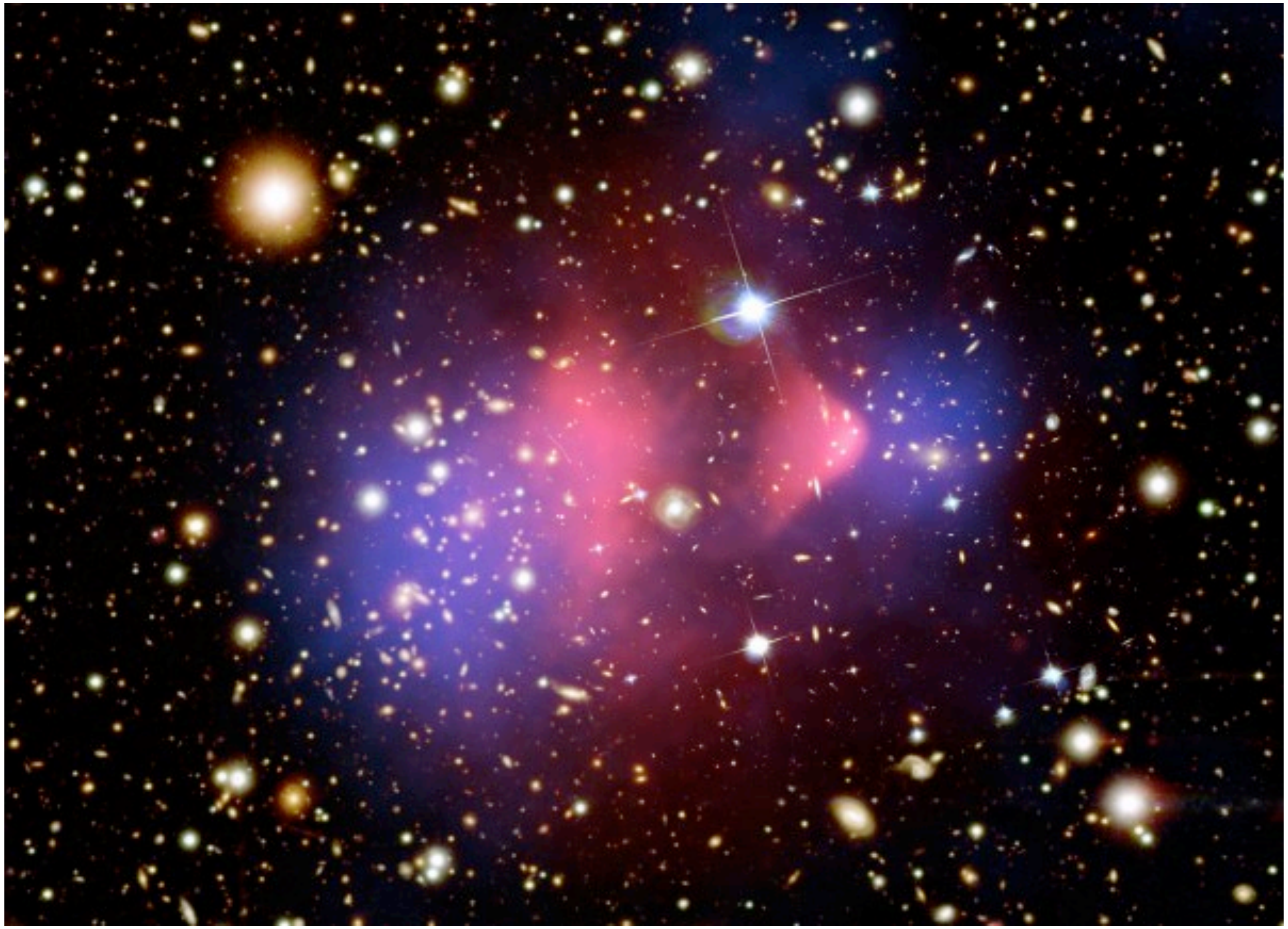


hubblesite.org

General Relativity predicts that light will be bent by gravity

Thus, galaxies can be lensed, allowing mass distribution to be inferred

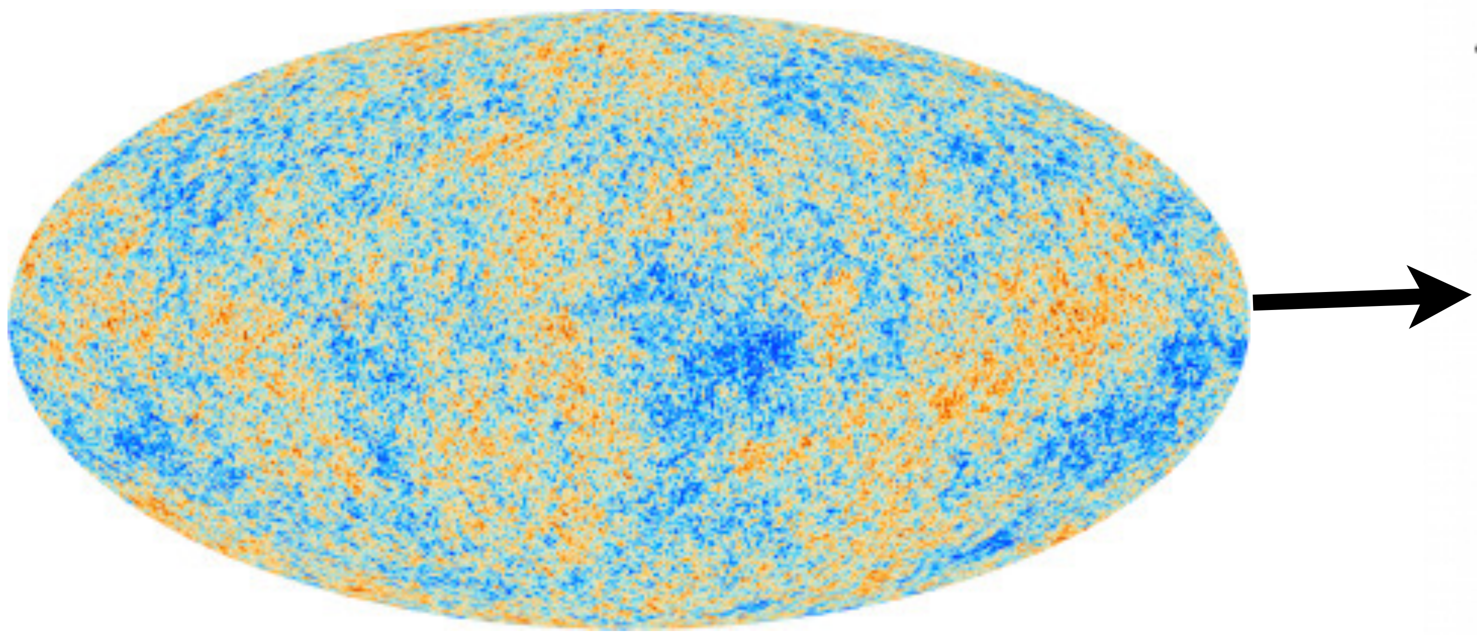
Bullet Cluster - Collision of Two Galaxy Clusters

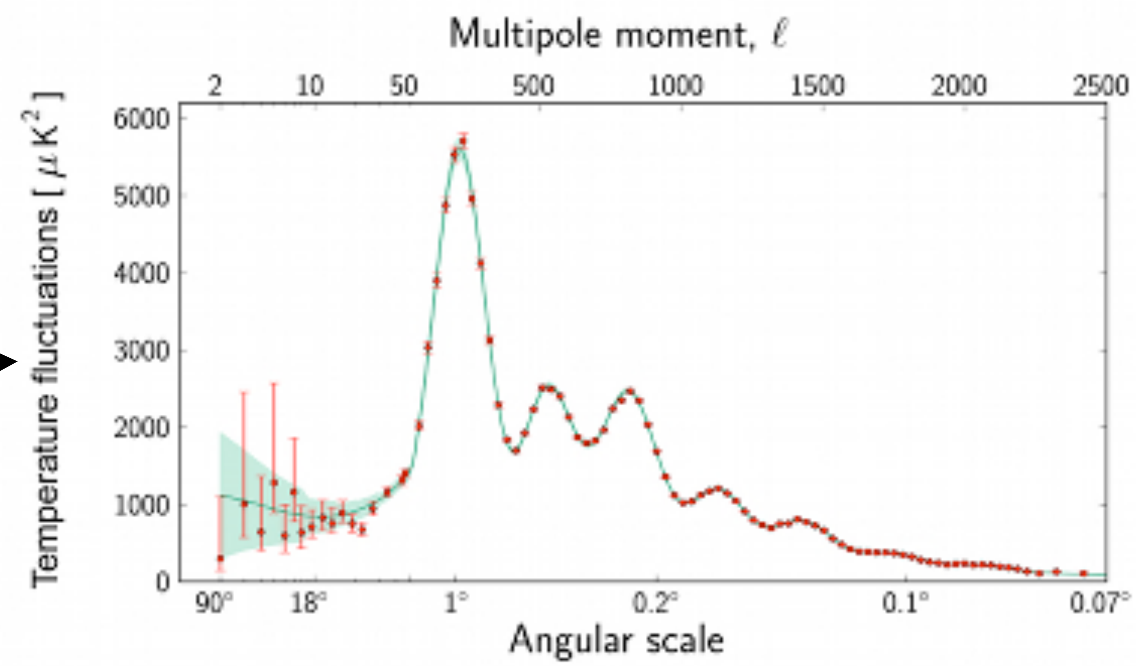


Pink - Distribution of Hot Gas in Clusters (majority of visible mass)
Blue - Mass distribution from Gravitational Lensing

Interpretation: Dark Matter has passed through without interactions

Evidence on size of Universe
Cosmic microwave background





Planck Satellite Map of Cosmic Microwave Background Temperature Anisotropy

Power Spectrum (essentially Spherical Harmonic amplitudes) has distinctive peaks

Size of peaks consistent with dark matter

Dark matter is a consistent theory
passing several different checks

However, only dark matter's gravitational
interactions have been confirmed

Next step is to understand its
fundamental particle nature (if any)

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Early Universe was a hot plasma (soup)

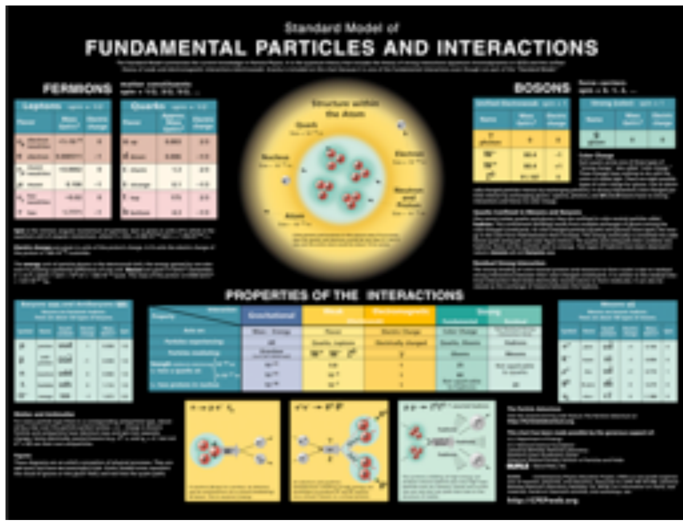
Particles that we now produce in colliders
were in great abundance

E.g. Muons

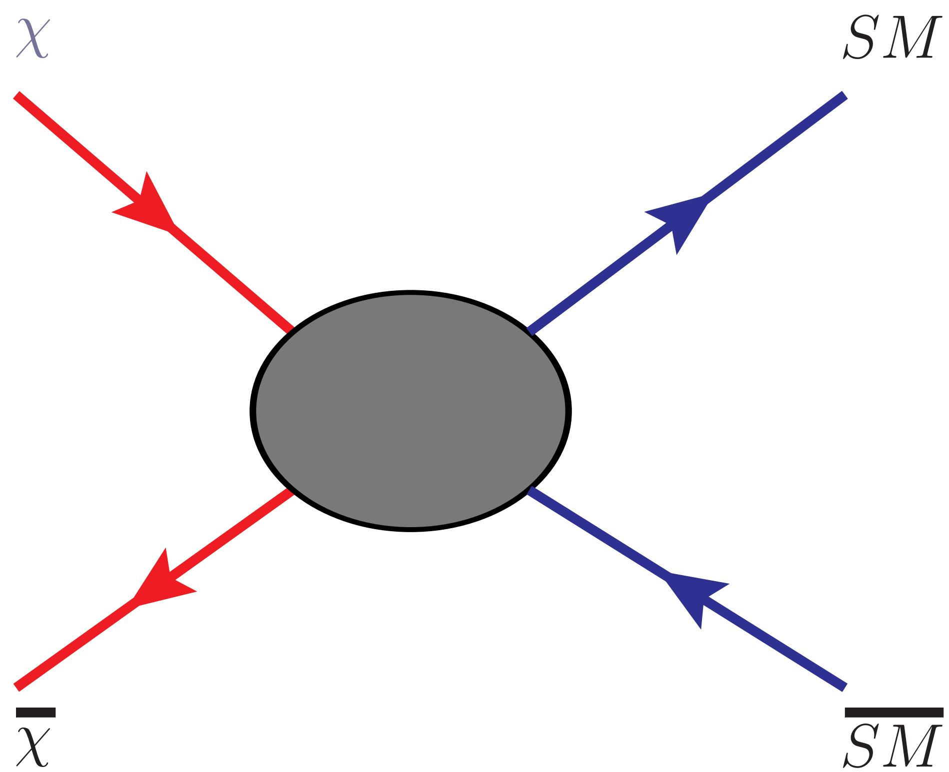
$$\mu^- + \bar{\nu}_\mu \leftrightarrow e^- + \bar{\nu}_e$$

were produced by scattering processes
when temperature was high enough so they were
energetically favorable

Dark Matter Recipe (WIMP)



Assumption: dark matter was in thermal equilibrium in the early universe



Thermal equilibrium set by Dark Matter annihilation into Standard Model particles

$$\chi + \chi \leftrightarrow SM + SM$$

As universe expands, it cools to temperature where dark matter is no longer energetically favorable

Rate of this process determines how much dark matter remains in the universe, this prediction then leads to estimate of signals to detect dark matter

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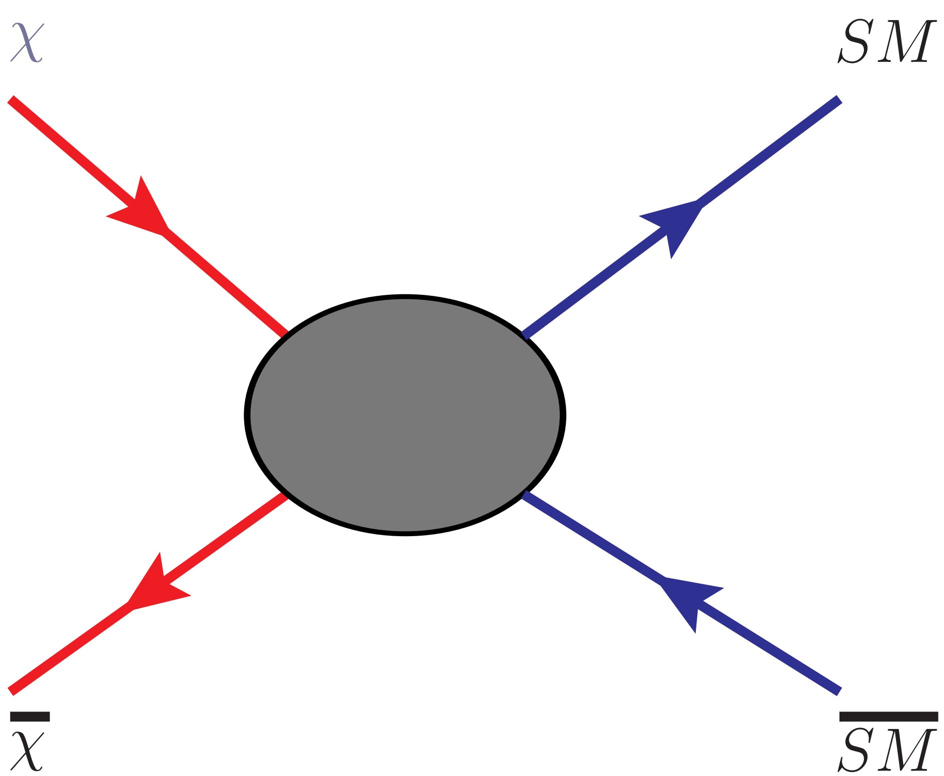
Three Approaches

- Indirect Detection - Cosmic Rays
- Direct Detection - Dark Matter scattering on Target Nuclei
- Colliders - Production of Dark Matter at Colliders

Indirect Detection

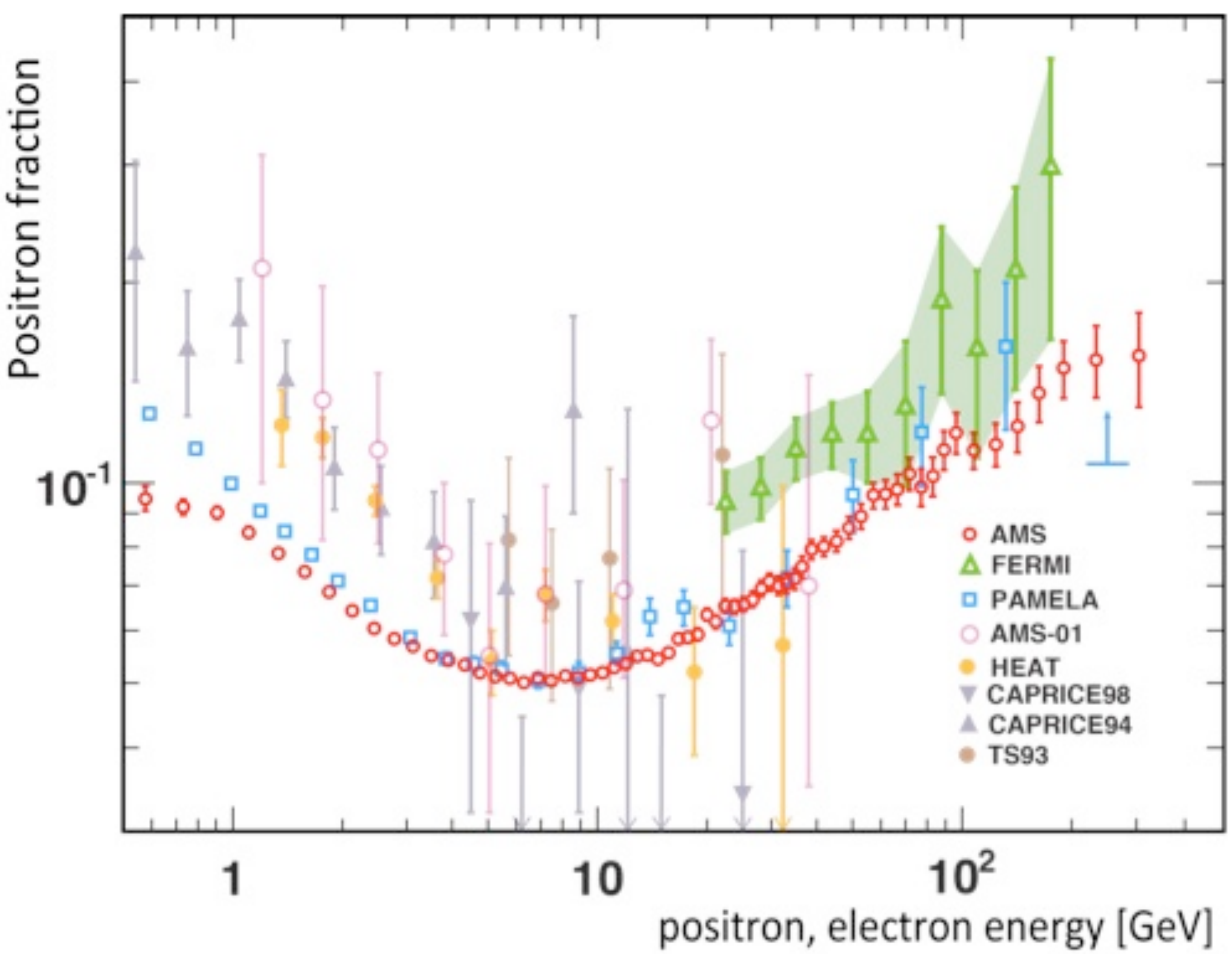


Through this process,
dark matter could be annihilating into distinctive Standard Model particles

E.g. antiparticles such as antielectrons, antiprotons

Energetic gamma rays or neutrinos

Antielectrons (aka positrons)



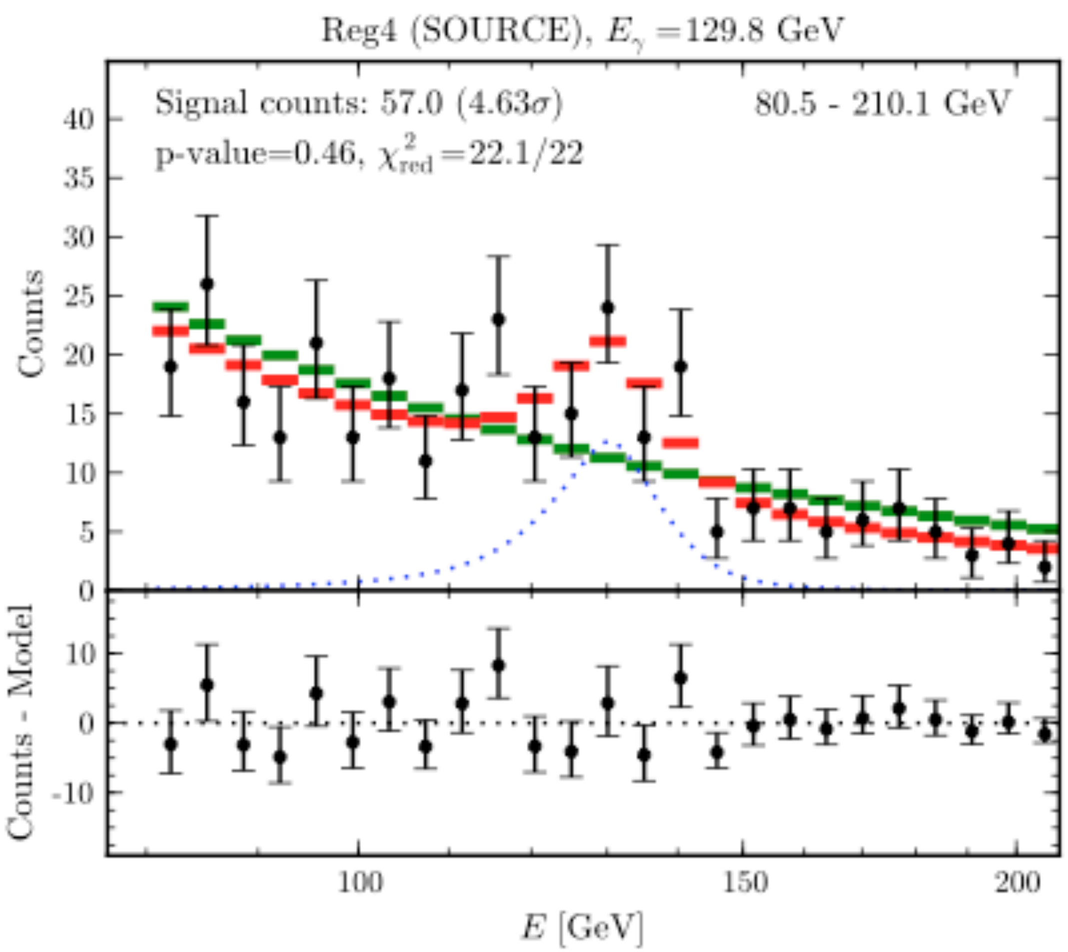
Satellite experiments looking for antielectrons

$$\text{Positron Fraction} = \frac{N_{e^+}}{N_{e^-} + N_{e^+}}$$

Rising fraction is consistent with dark matter, but also pulsars

Stay tuned...

Photons



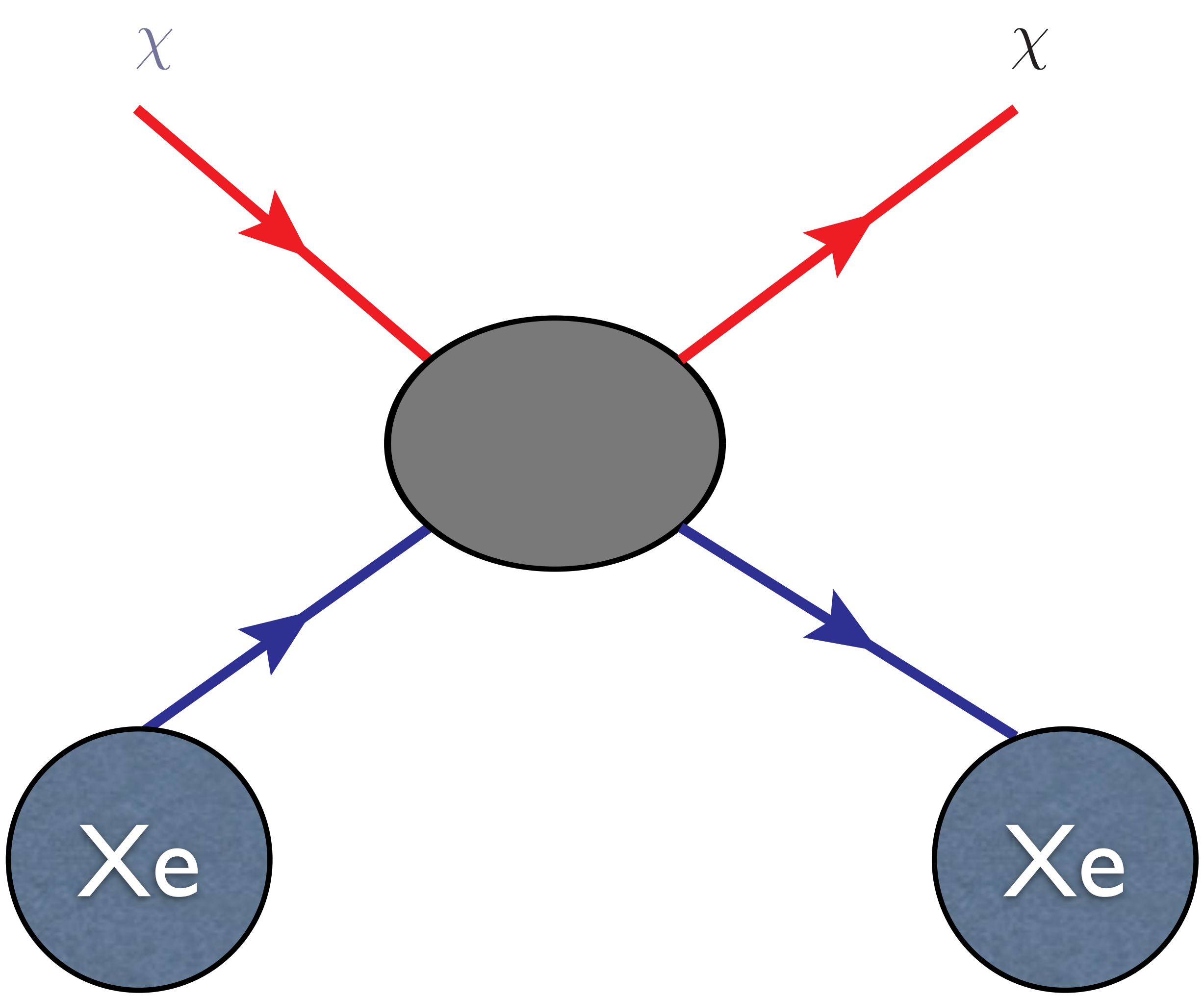
Weniger analysis of Fermi data

Evidence for a gamma ray line in Fermi satellite's data

If confirmed, would tell us mass of dark matter

Unfortunately, could be an instrumental effect

Direct Detection:
DM-nuclei scattering

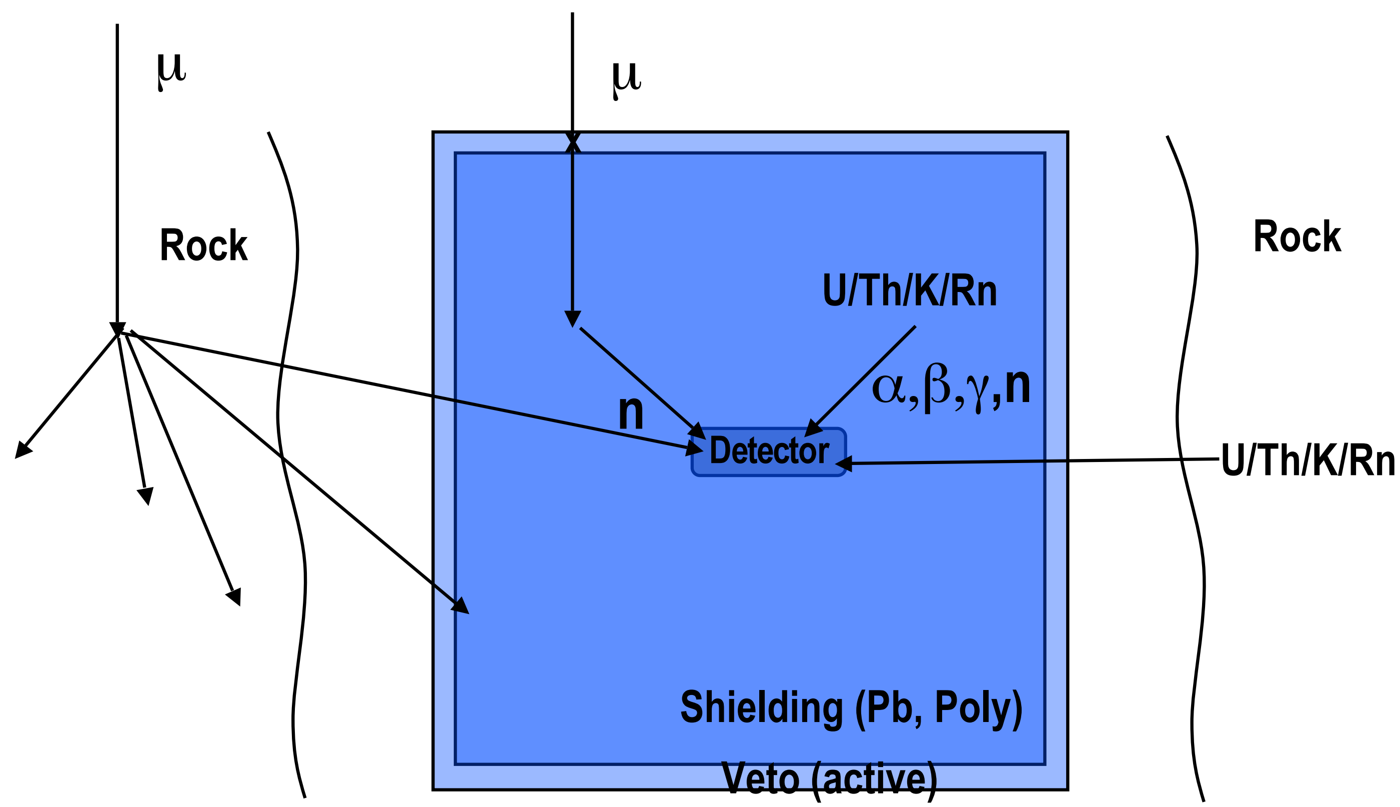


Turning the process on its side, we could have scattering off nuclei though interactions with quarks

Can probe dark matter in the Milky Way, by looking for interactions with target nuclei

Bauer

Schematic of an experiment



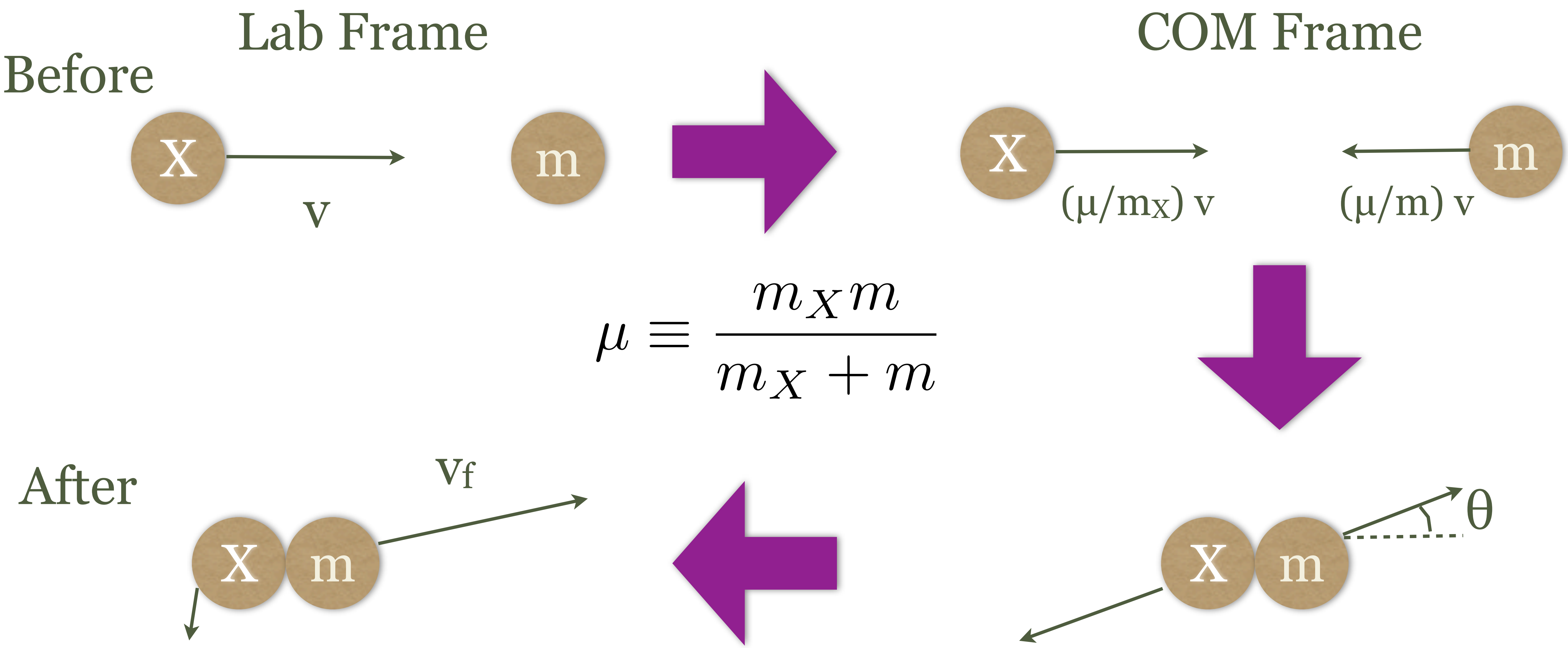
Events are rare, so need to go underground and shield against backgrounds

Direct Detection Technologies

Several sophisticated ways to measure
tiny, tiny recoil energies
and be sure that it wasn't some
background process

Example experiments: CDMS, XENON, DAMA

Dark matter in galaxy is nonrelativistic, $v \sim 10^{-3}$ c
Leads to nuclear recoils of O(10) keV



$$\mu \equiv \frac{m_X m}{m_X + m}$$

$$\begin{aligned} E_R &= \frac{1}{2} m |\vec{v}_f|^2 = \frac{1}{2} m \left(\frac{\mu}{m} v \right)^2 \left[(1 - \cos\theta)^2 + (\sin\theta)^2 \right] \\ &= \frac{\mu^2}{m} v^2 (1 - \cos\theta) \end{aligned}$$

For electrons, μ ~ m ~ .5 MeV,

so E_R ~ .5 eV

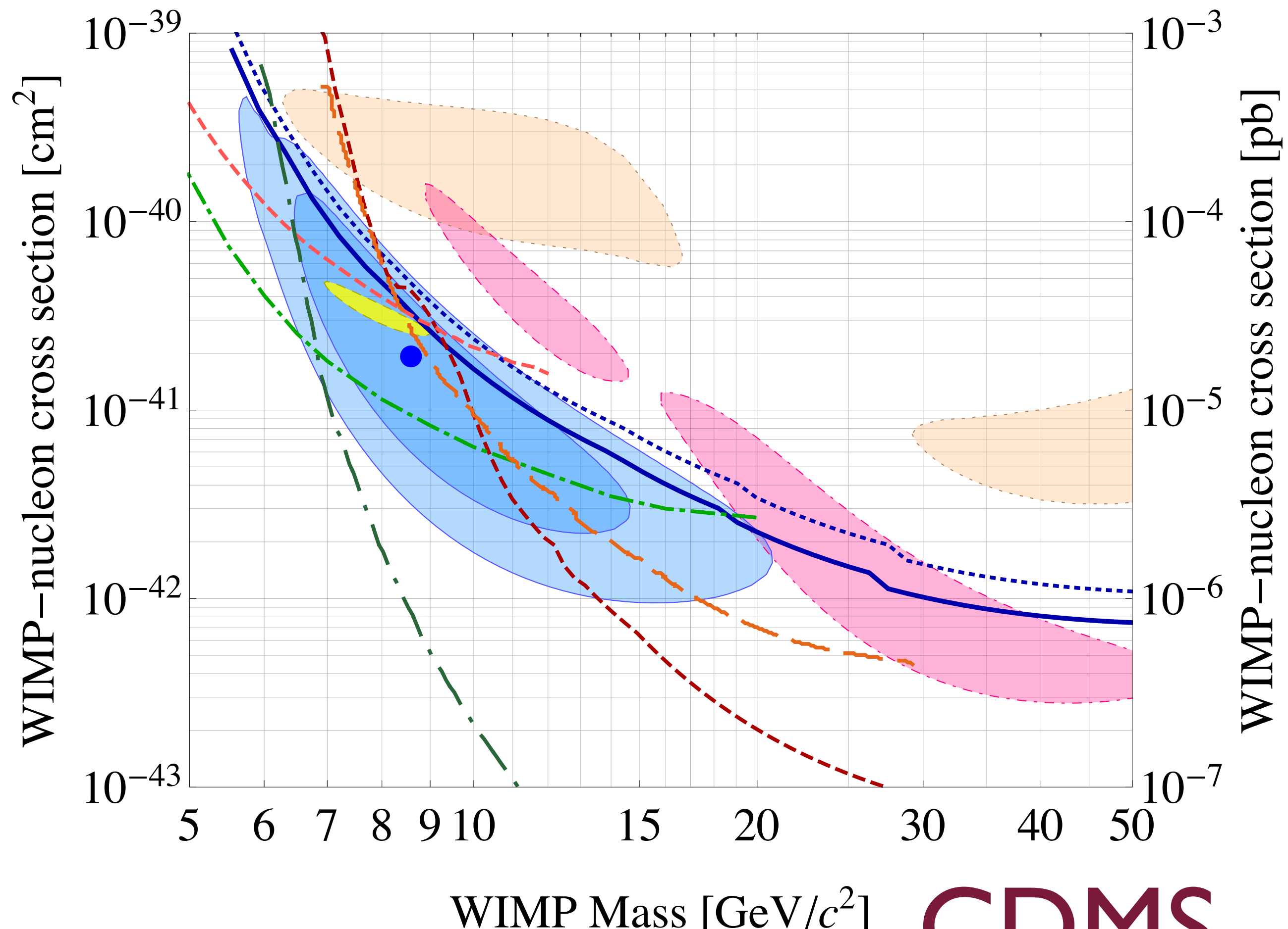
For protons E_R ~ keV

Dirty Business

Direct detection anomalies keep cropping up

Example: CDMS saw 2 events in latest release (blue contours)

Ruled out by XENON expts (green lines)



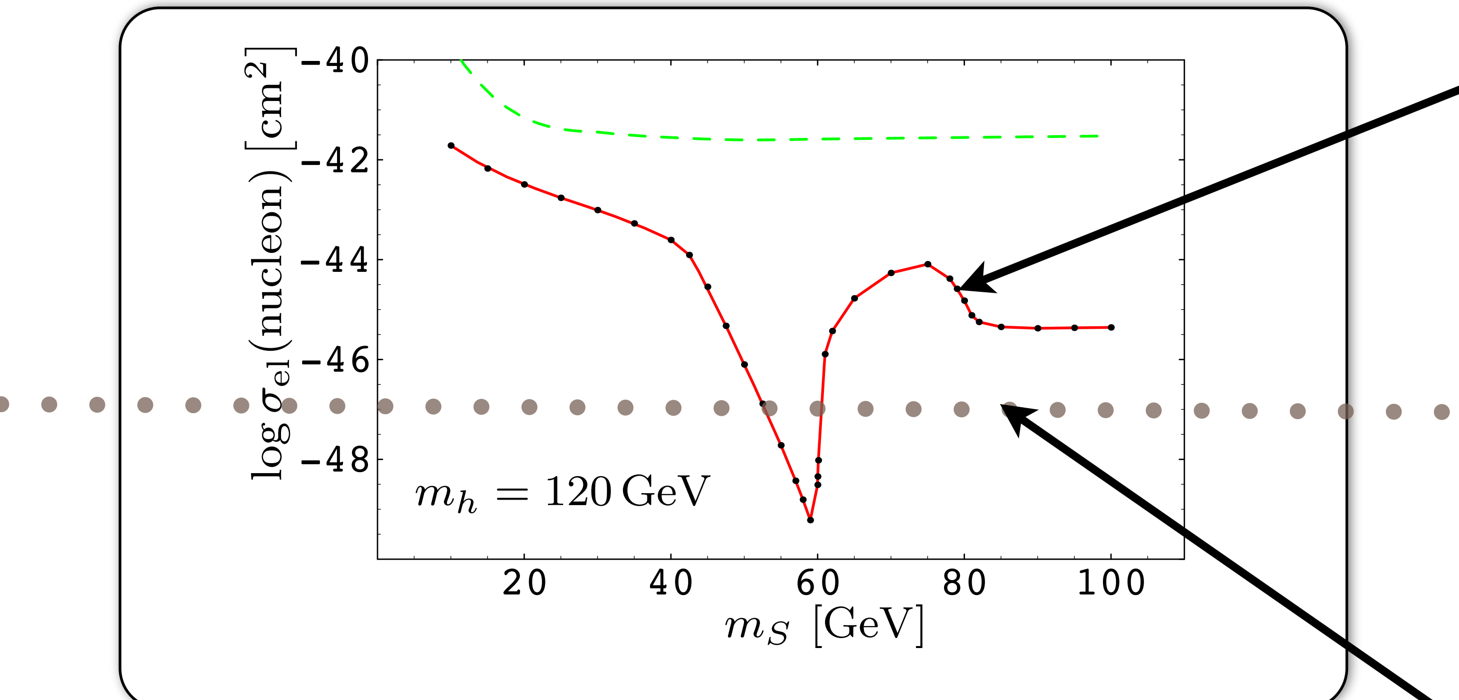
CDMS

Possibilities:

i) One or more expts are wrong

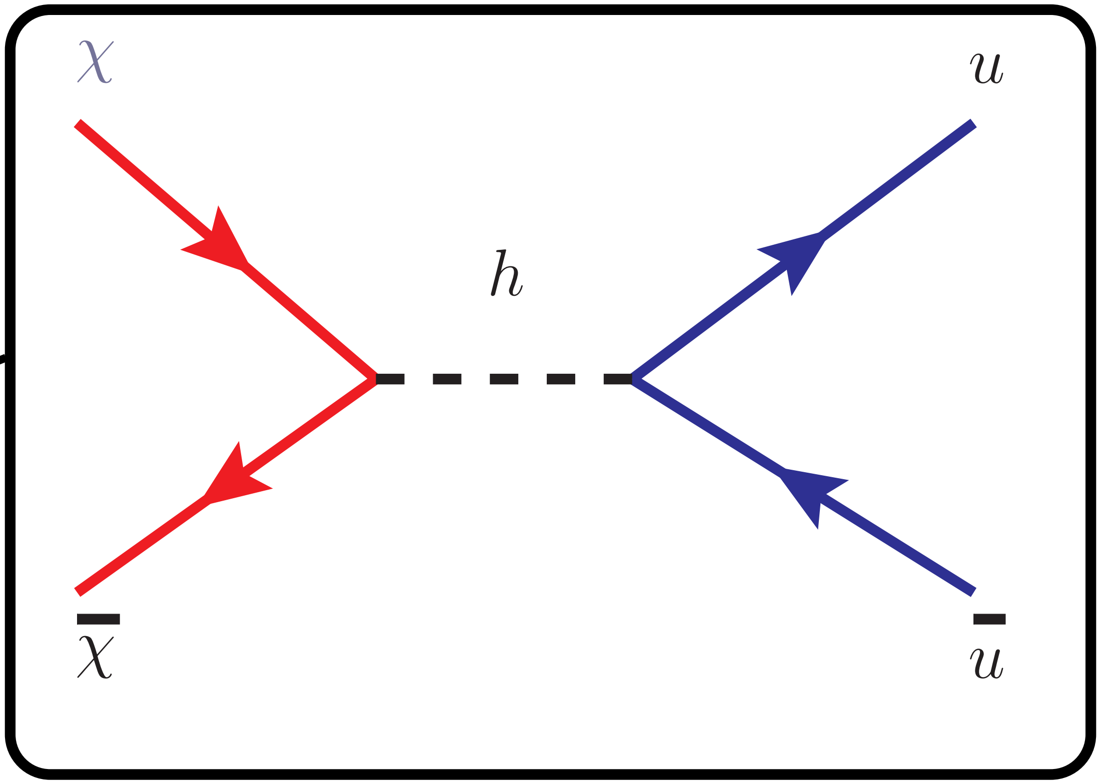
ii) Dark matter interpretation is incorrect

An upcoming frontier



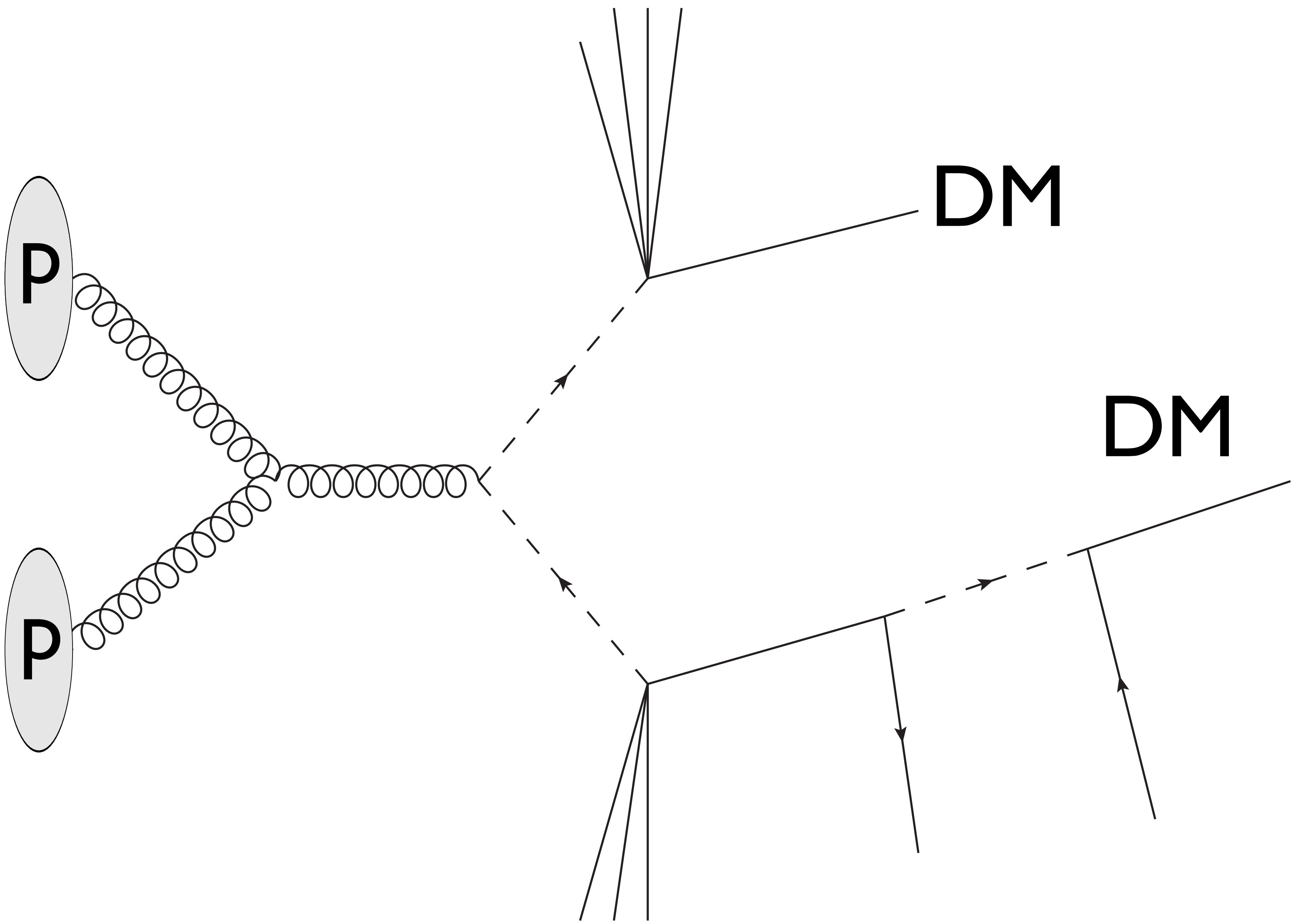
Burgess et.al.

Dark Matter Interacting with Higgs



Next Generation of Direct Detection Sensitivity

Colliders



Produce dark matter particles at Large Hadron Collider

Study and infer their properties

After two year LHC shutdown we will get more data

Missing Energy Events ala Supersymmetry

Conclusion

- Dark matter evidence is strong, but we still have to solve the puzzle of what it actually is
- Depending on the dark matter theory, there are ongoing tests to confirm or refute it
- The next decade should be extremely exciting for dark matter physics

For more, I highly recommend
"Dark Matters" on PhD Comics
http://www.phdcomics.com/comics.php?f=1430