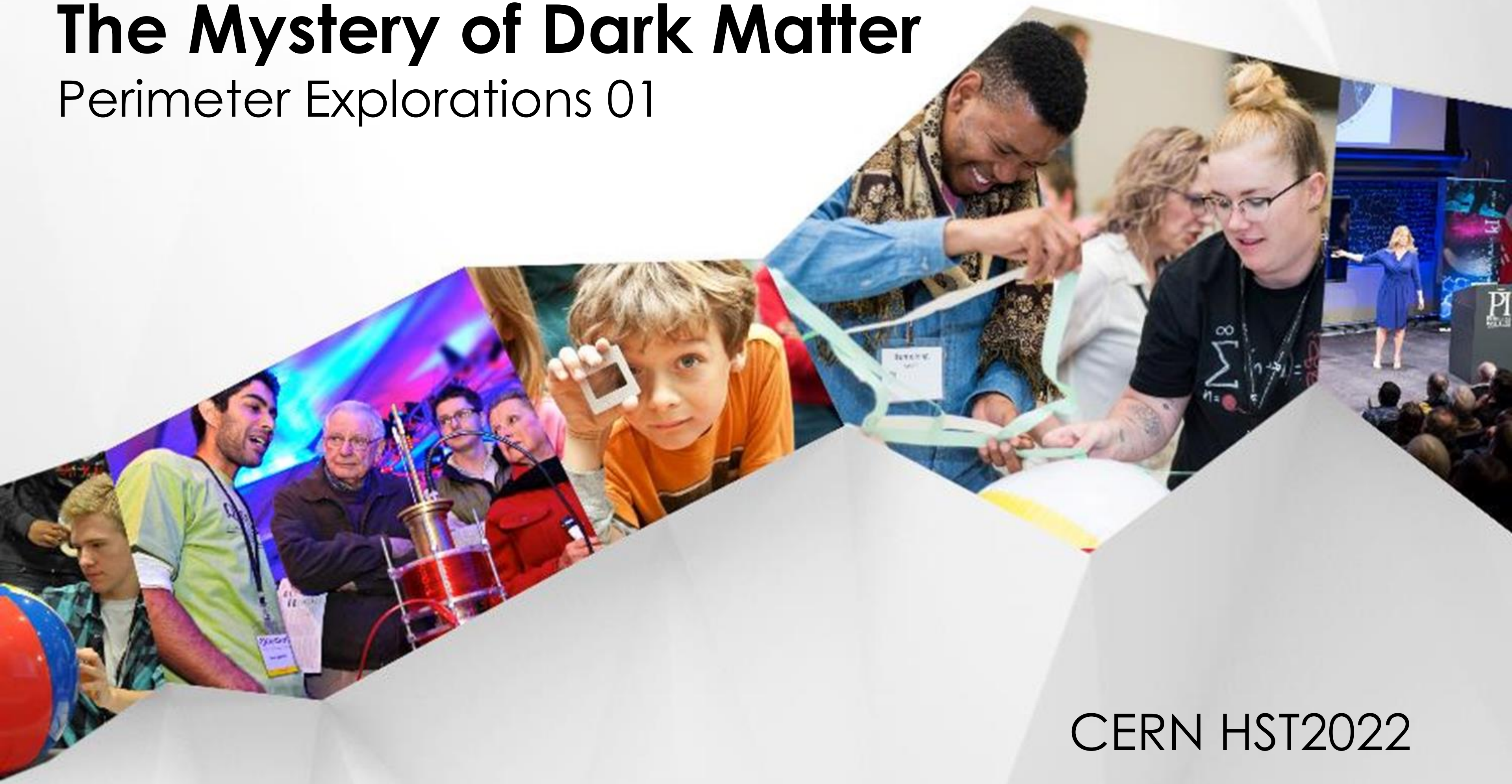
The Mystery of Dark Matter

Perimeter Explorations 01



CERN HST2022

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- **Activity 6: Dark Matter Lab**
- Curriculum Links:
  - Circular Motion
  - Netwonian Gravity

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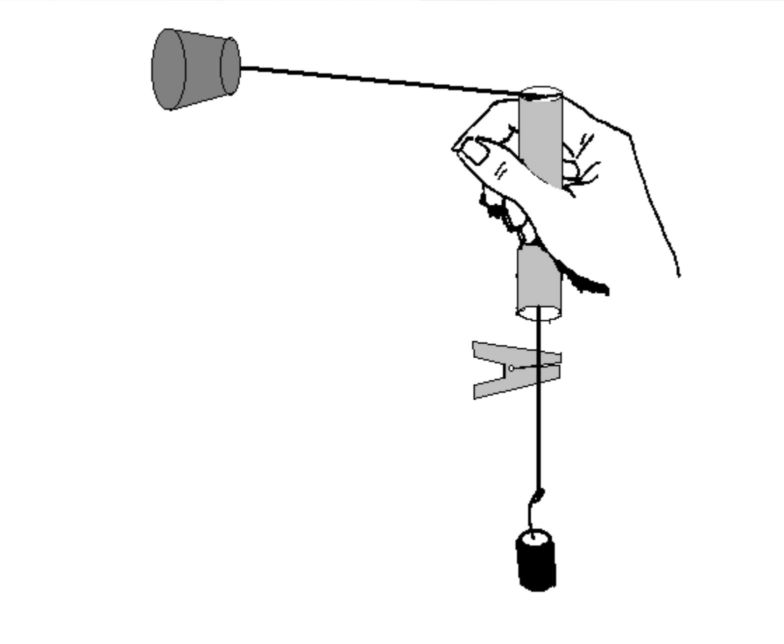
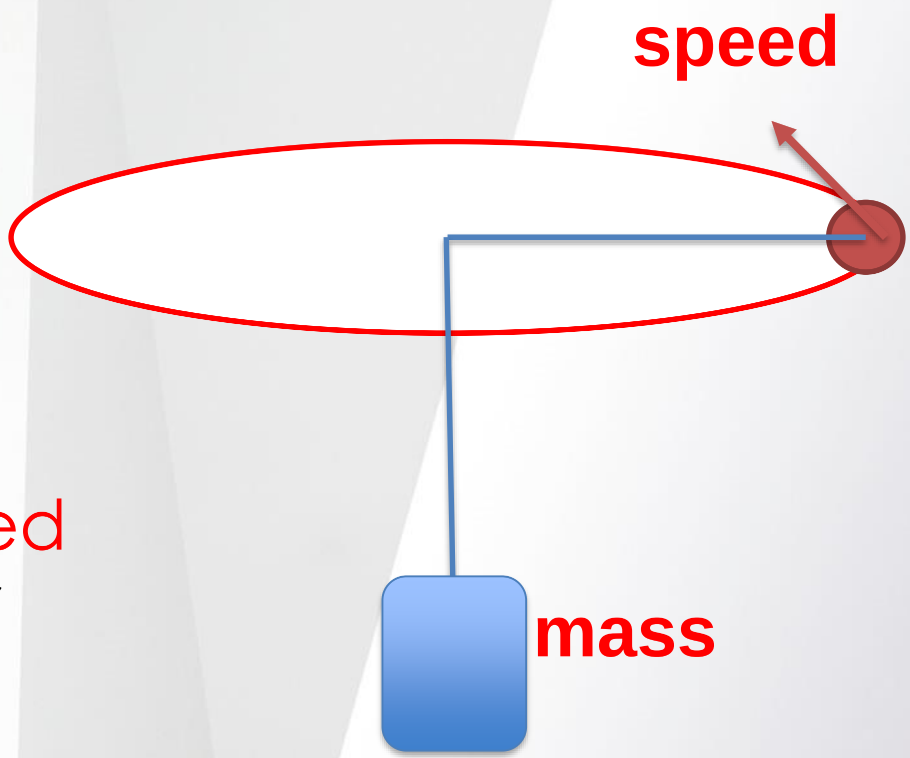
Centripetal-motion apparatus



Uniform Circular Motion

Predict
Observe
Explain

How are mass and speed connected in circular motion?



Uniform Circular Motion

Objective:

Determine the mass of an unknown item.

1. Collect data.
2. Plot a graph of speed^2 vs mass on your white boards.
3. Using your plot, determine the mass of the unknown object.

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Circular Motion Lab

Collaborative version:

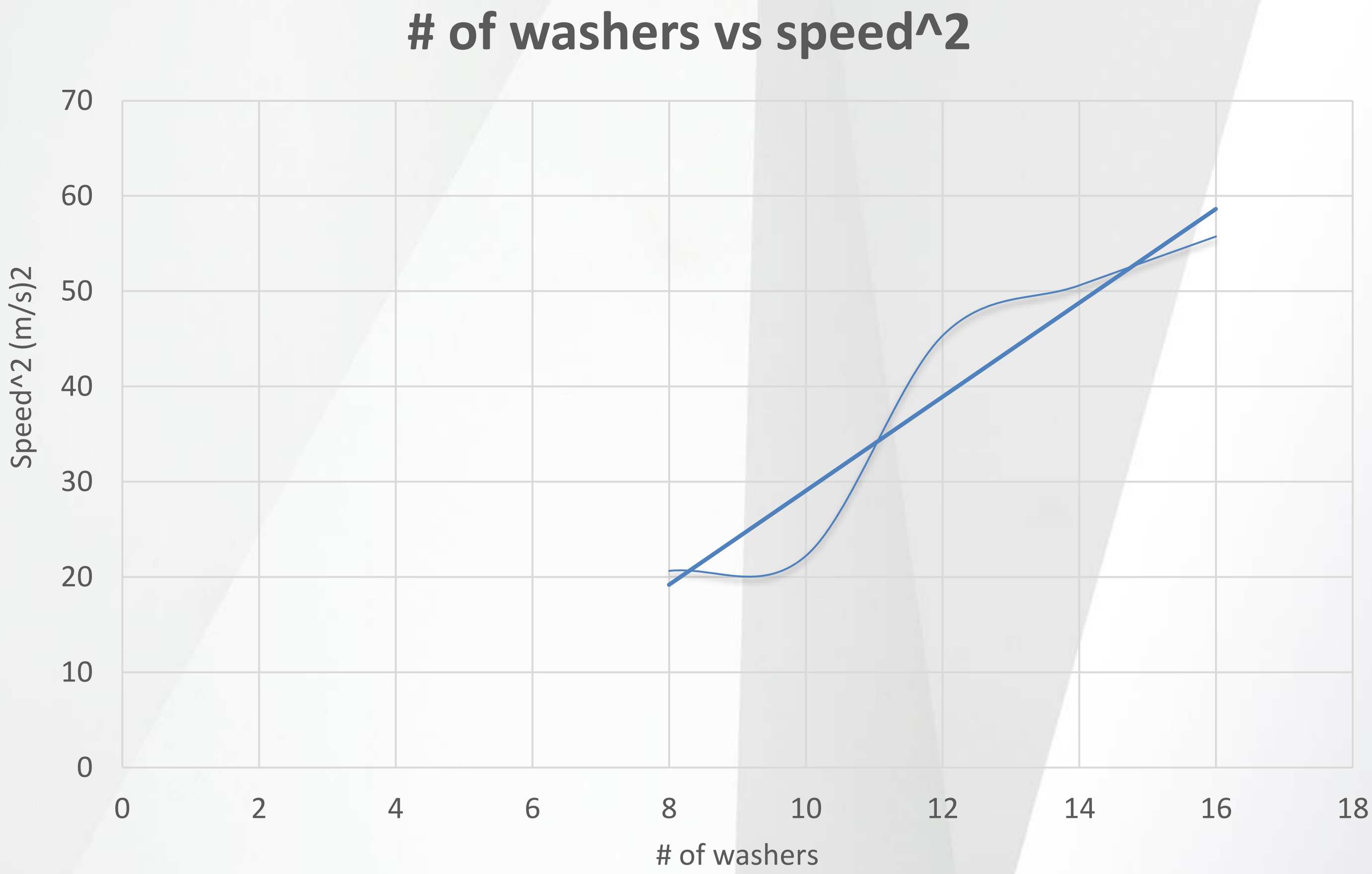
1. Set radius = 60 cm
2. Use assigned masses
3. Record period for 10 orbits
4. Compare results
5. Report results

Circular Motion Lab Results

# of washers	10 Orbits (s)
8	
10	
12	
14	
16	

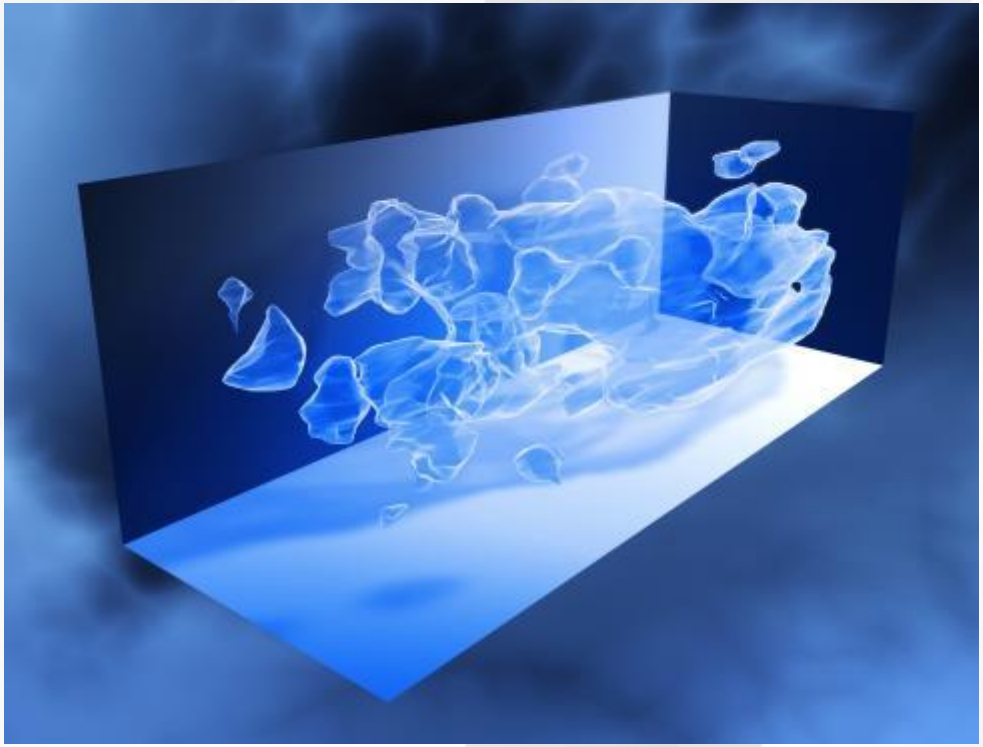
How is the orbital speed related to the mass of the washers?

Circular Motion Lab Results



Uniform Circular Motion

Theory vs. Observation → Connection to Dark Matter



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Vera Rubin's Discovery

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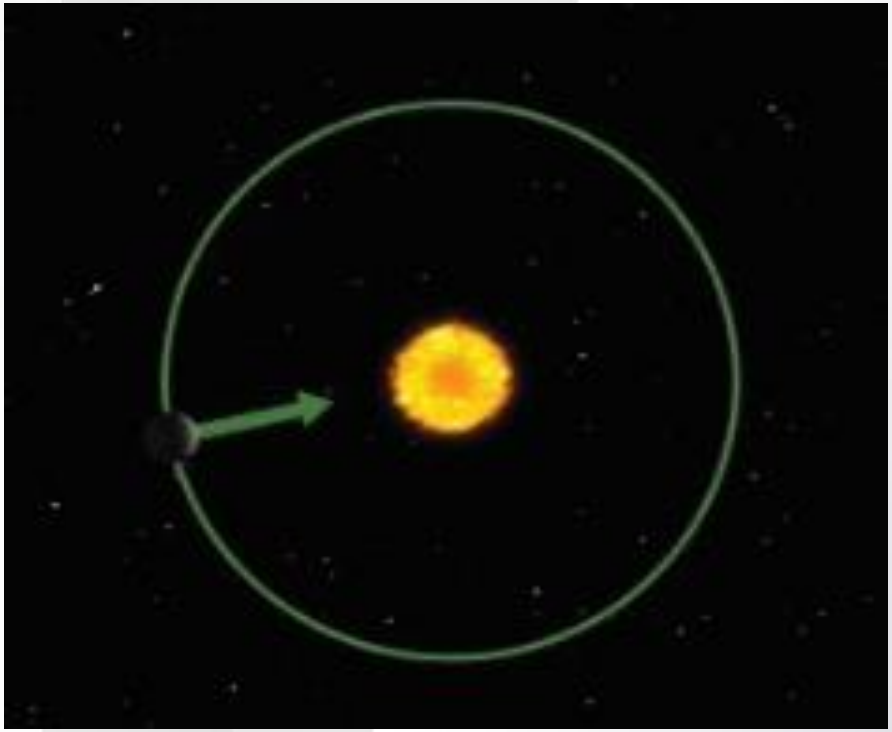
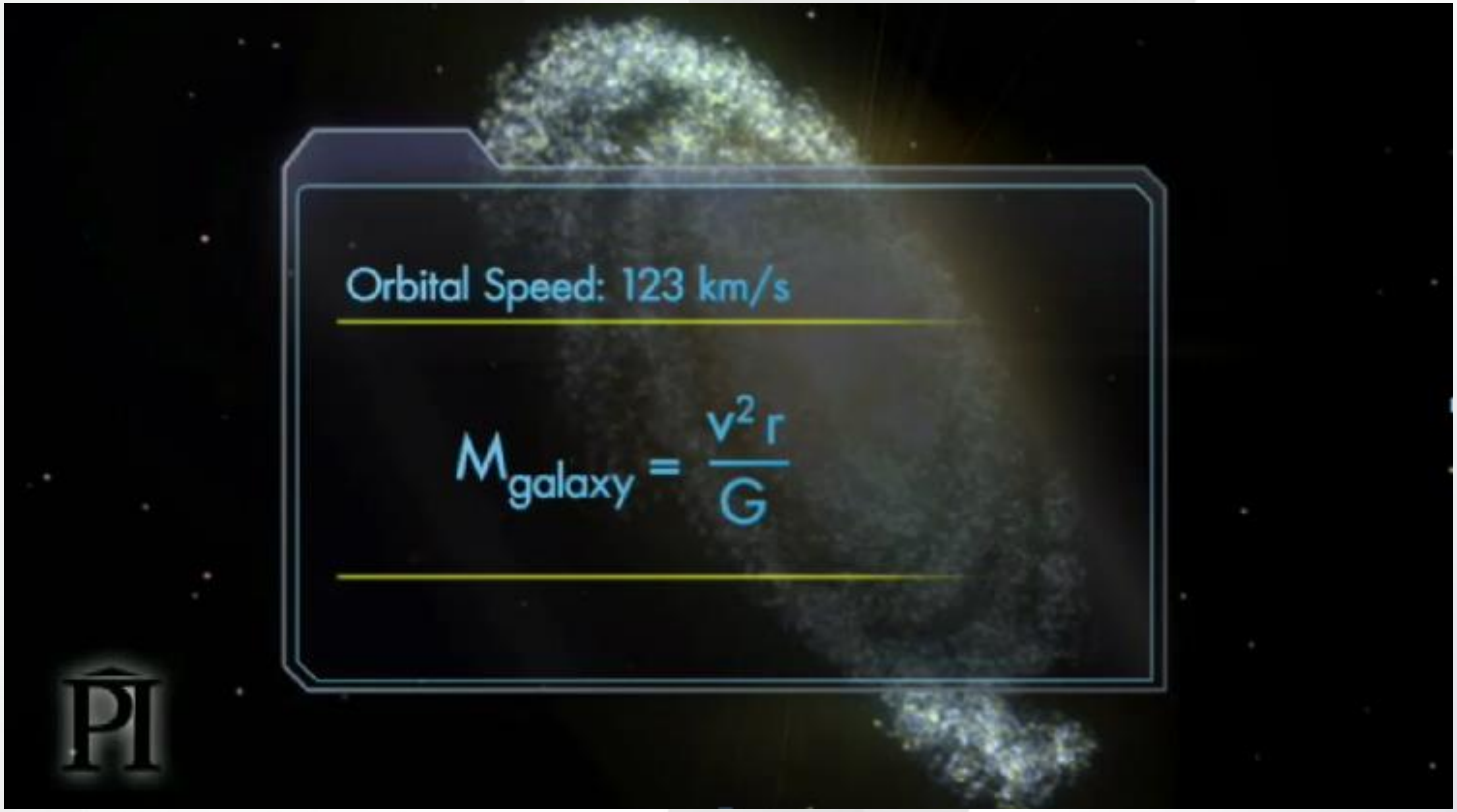
Uniform Circular Motion

Orbital Speed Depends on the Mass of the Central Object

$$M = \frac{v^2 r}{G}$$

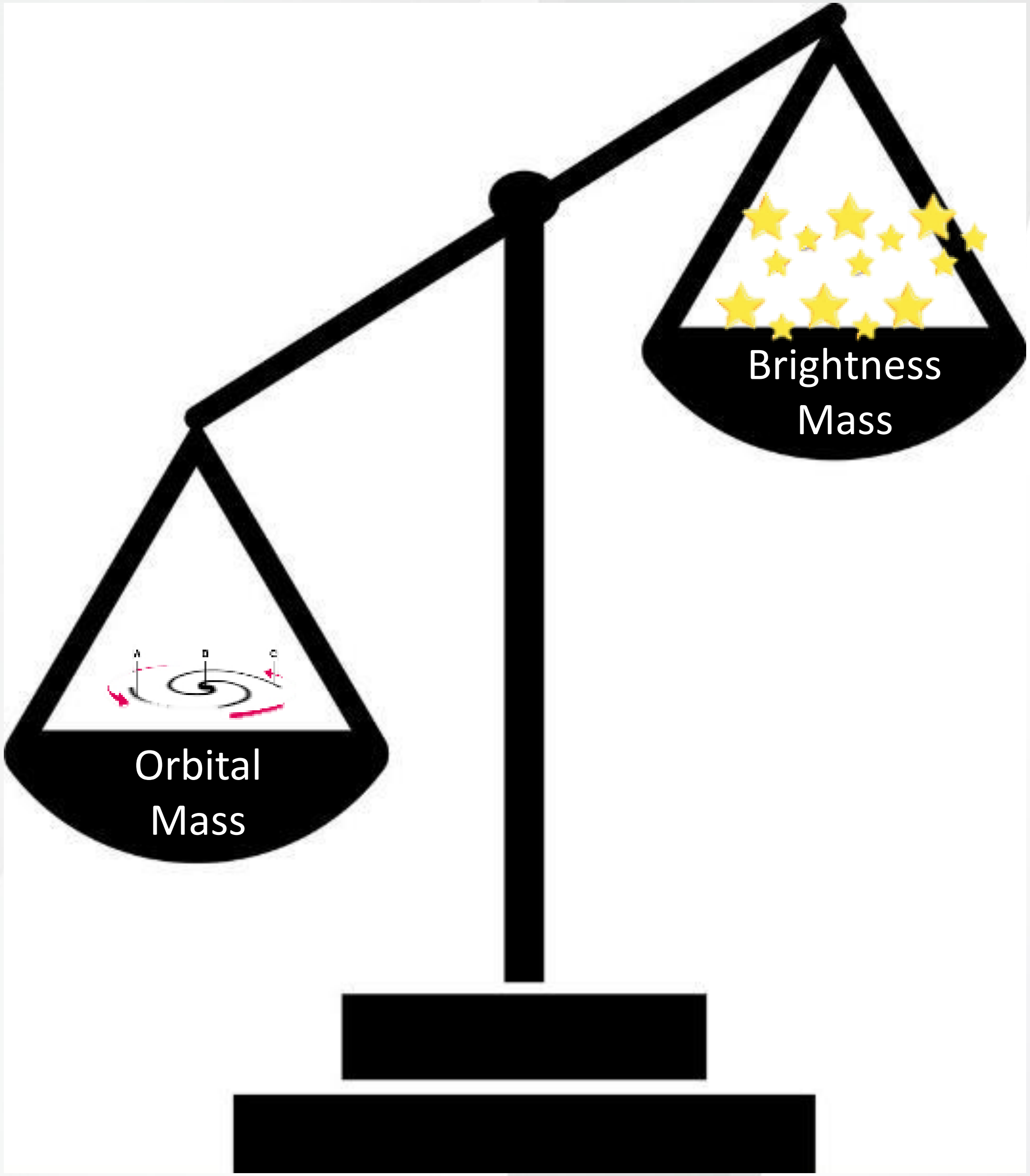


Extend this to galaxies



Stars in spiral galaxies move in uniform circular motion

mass ∝ speed



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Triangulum is More Massive Than it Looks

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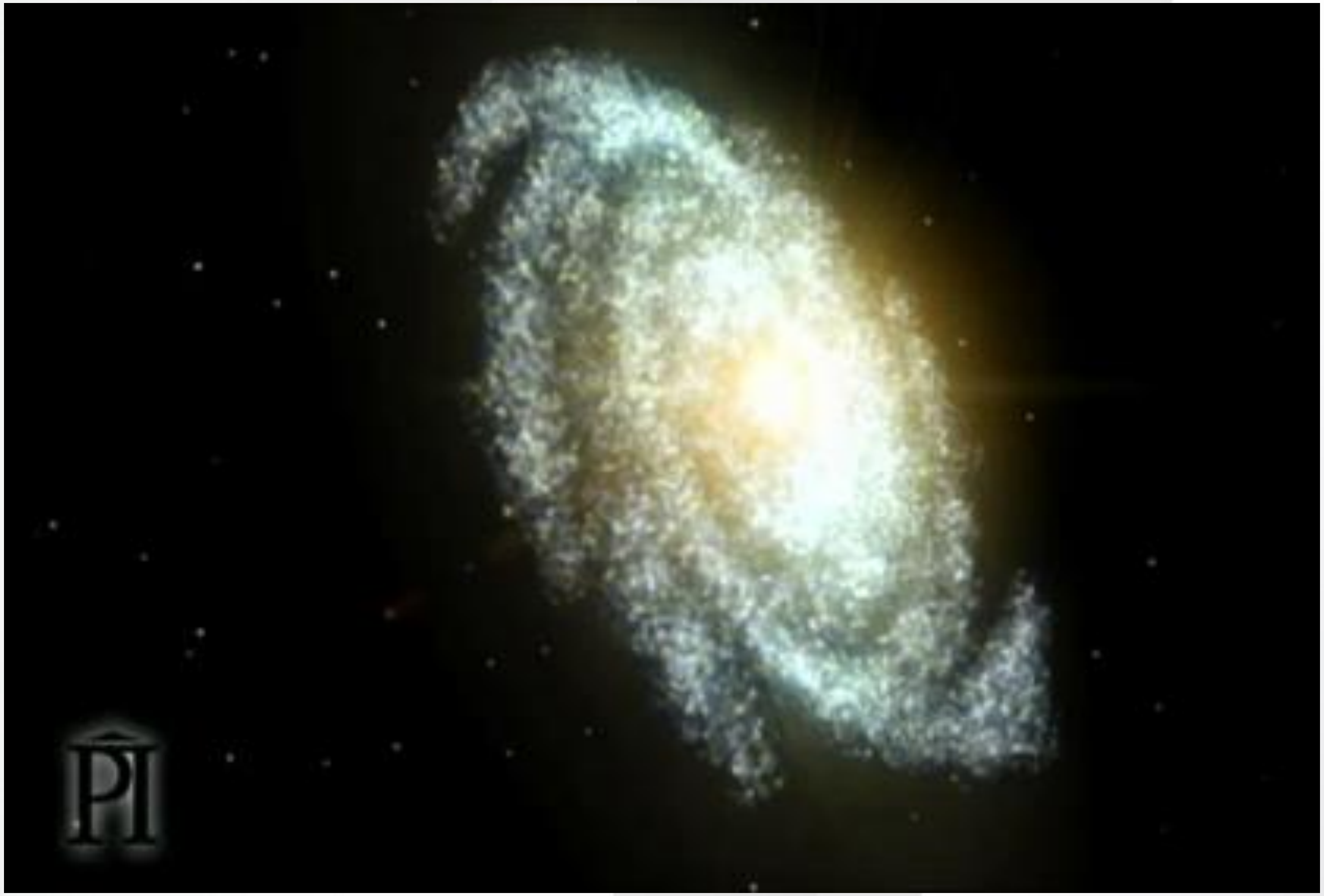
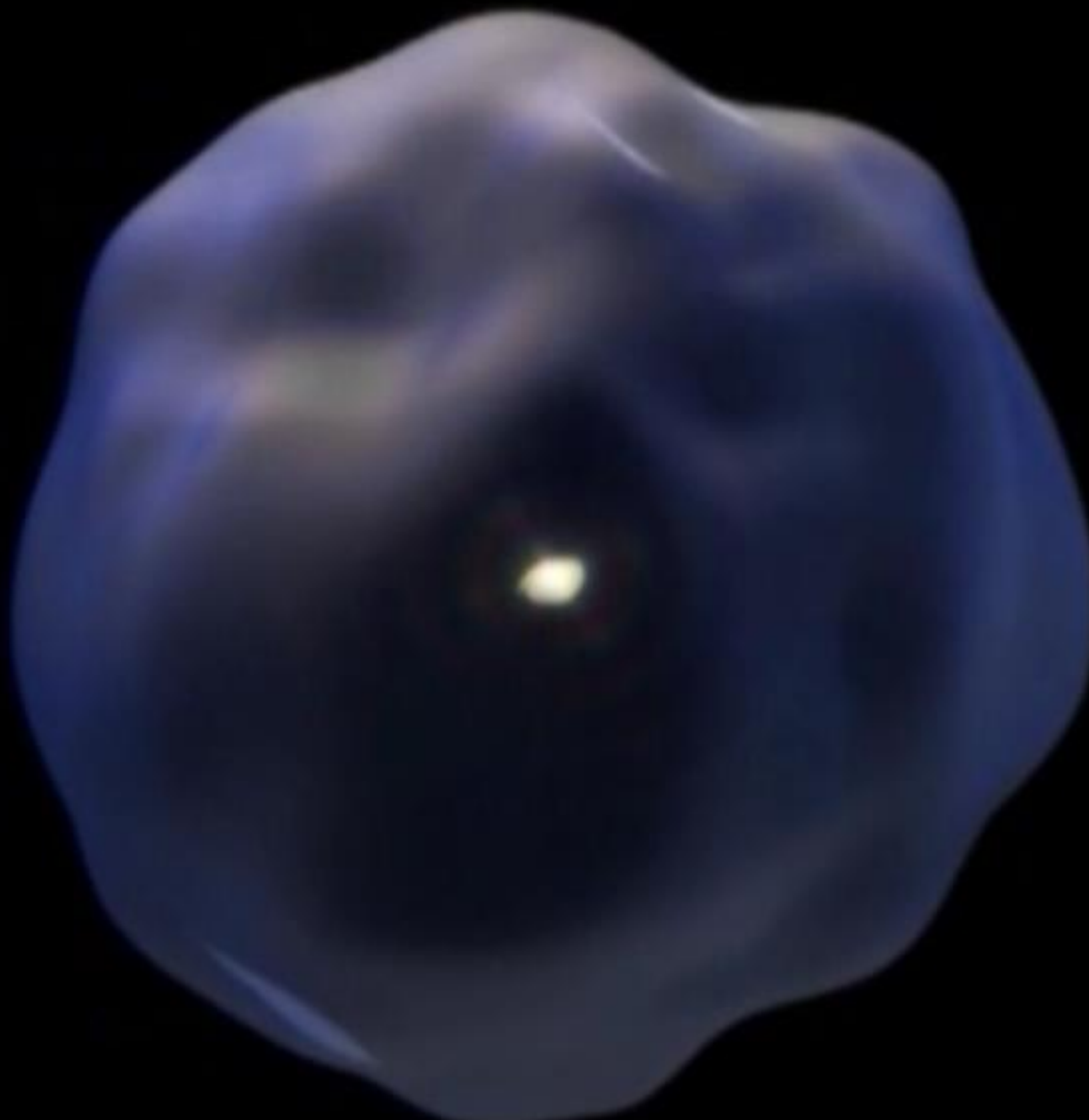
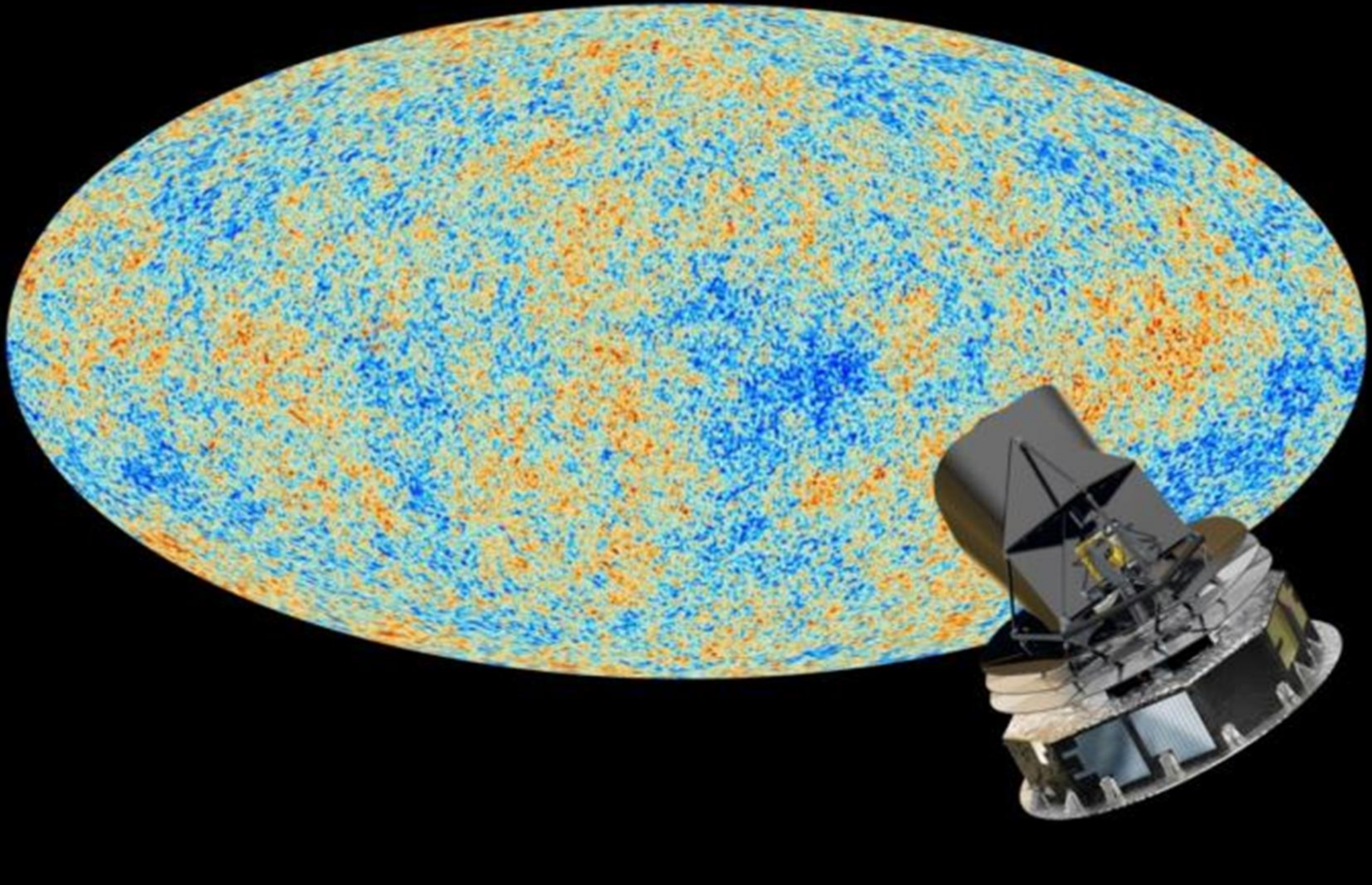
Old View



New View



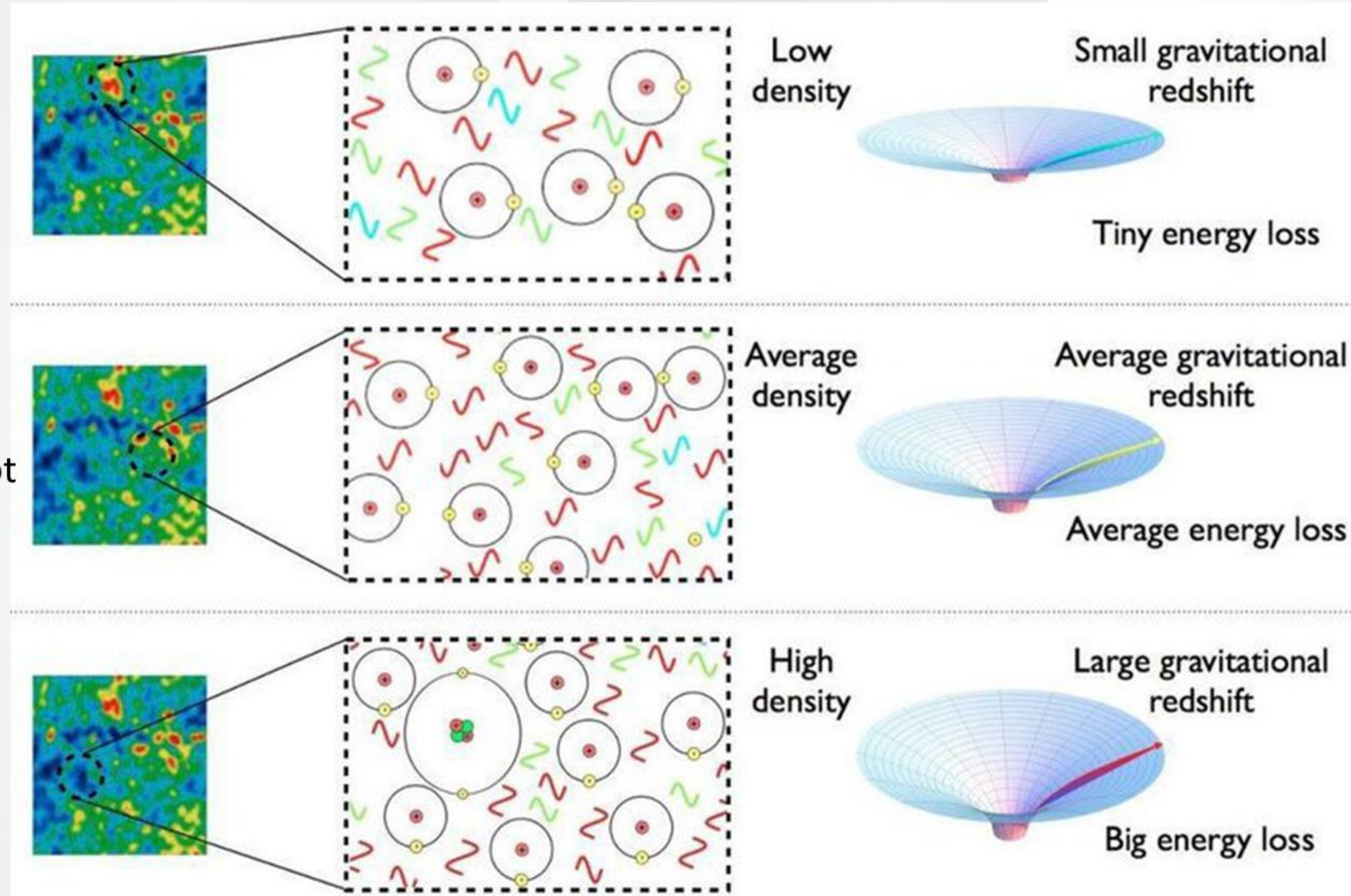


0.0001 K difference between hot and cold!

Hot Spot

Average Spot

Cold Spot



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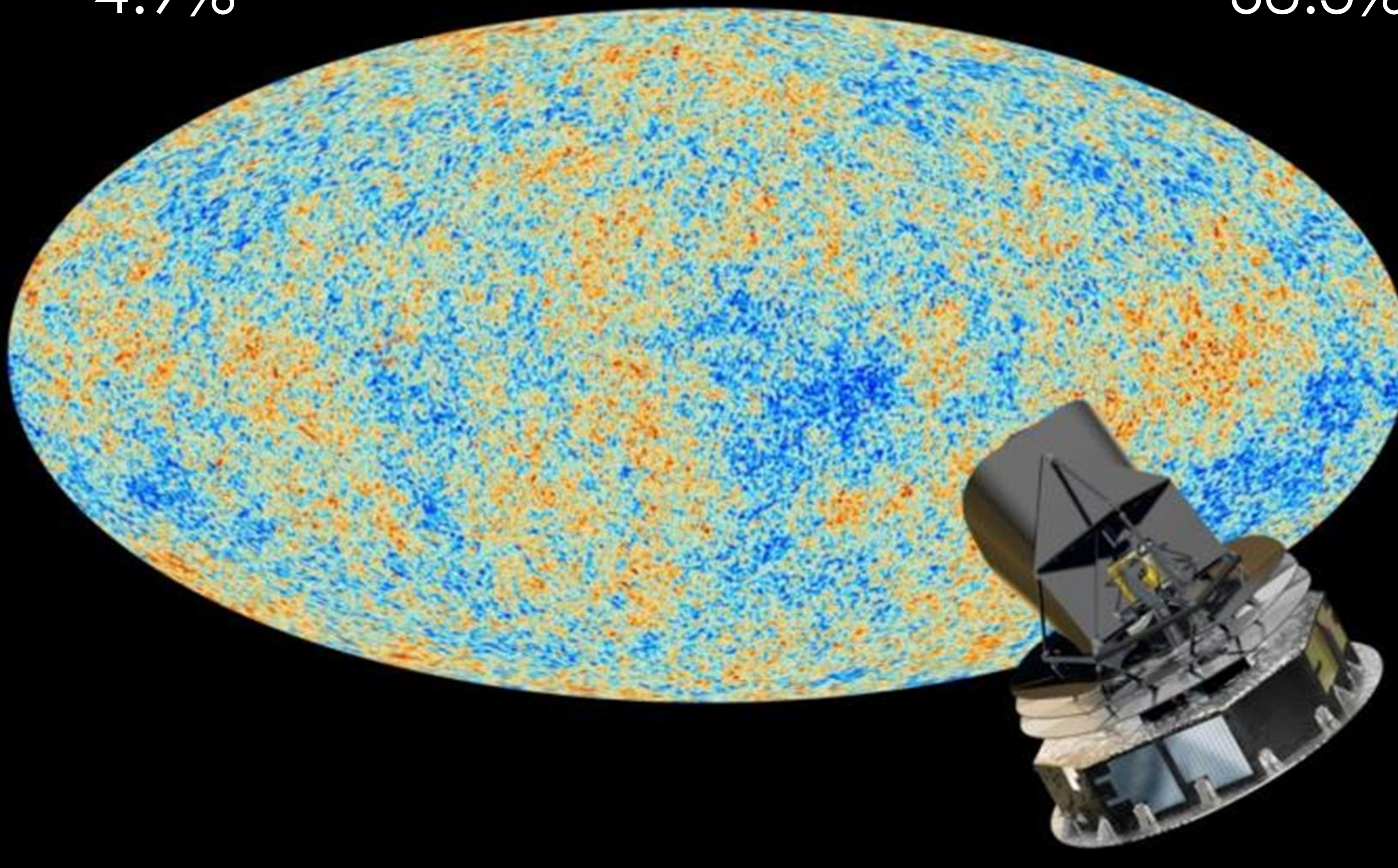
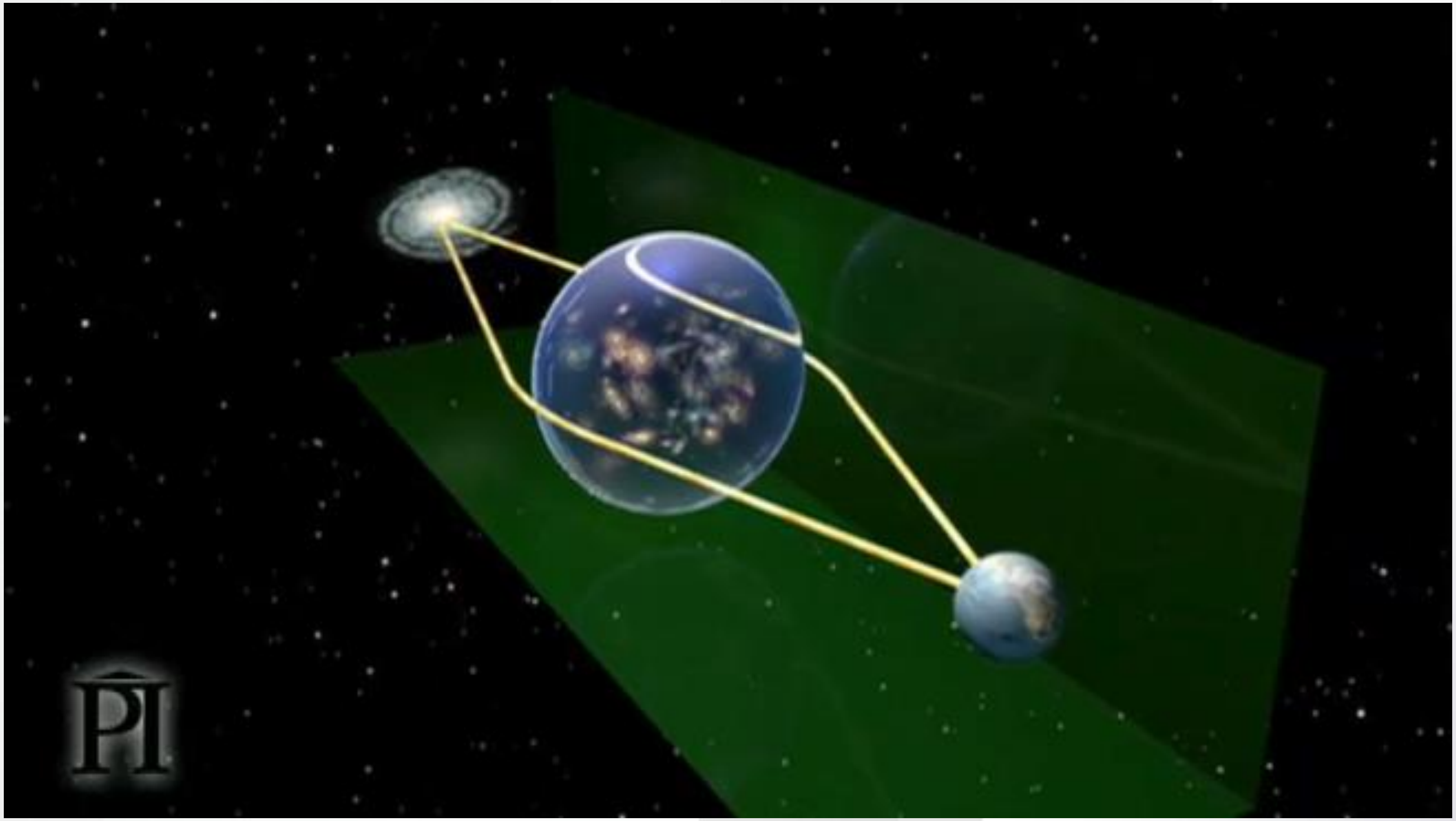
Dark Matter
26.8%

Normal Matter
4.9%

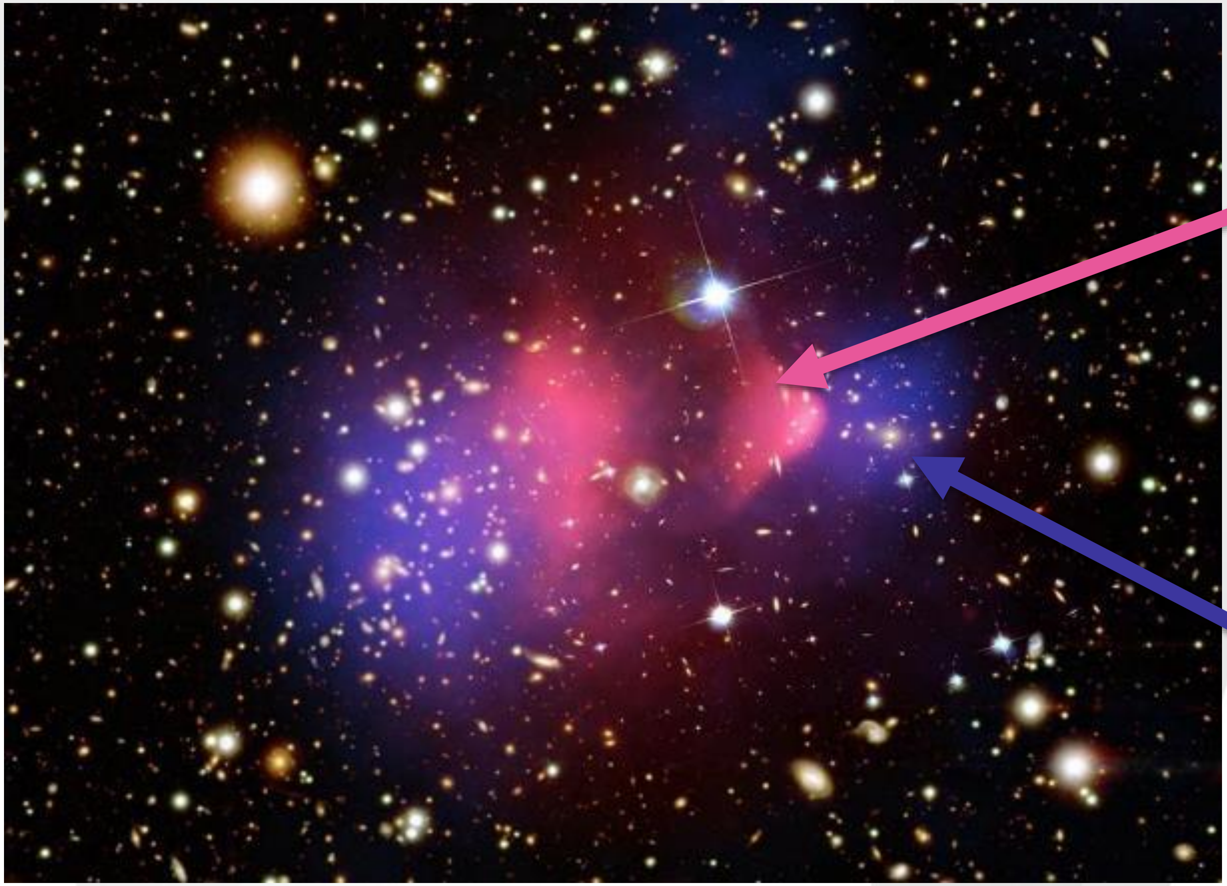
Dark Energy
68.3%



Gravitational Lensing



Bullet Cluster



Most of the baryonic matter

Mass map from lensing

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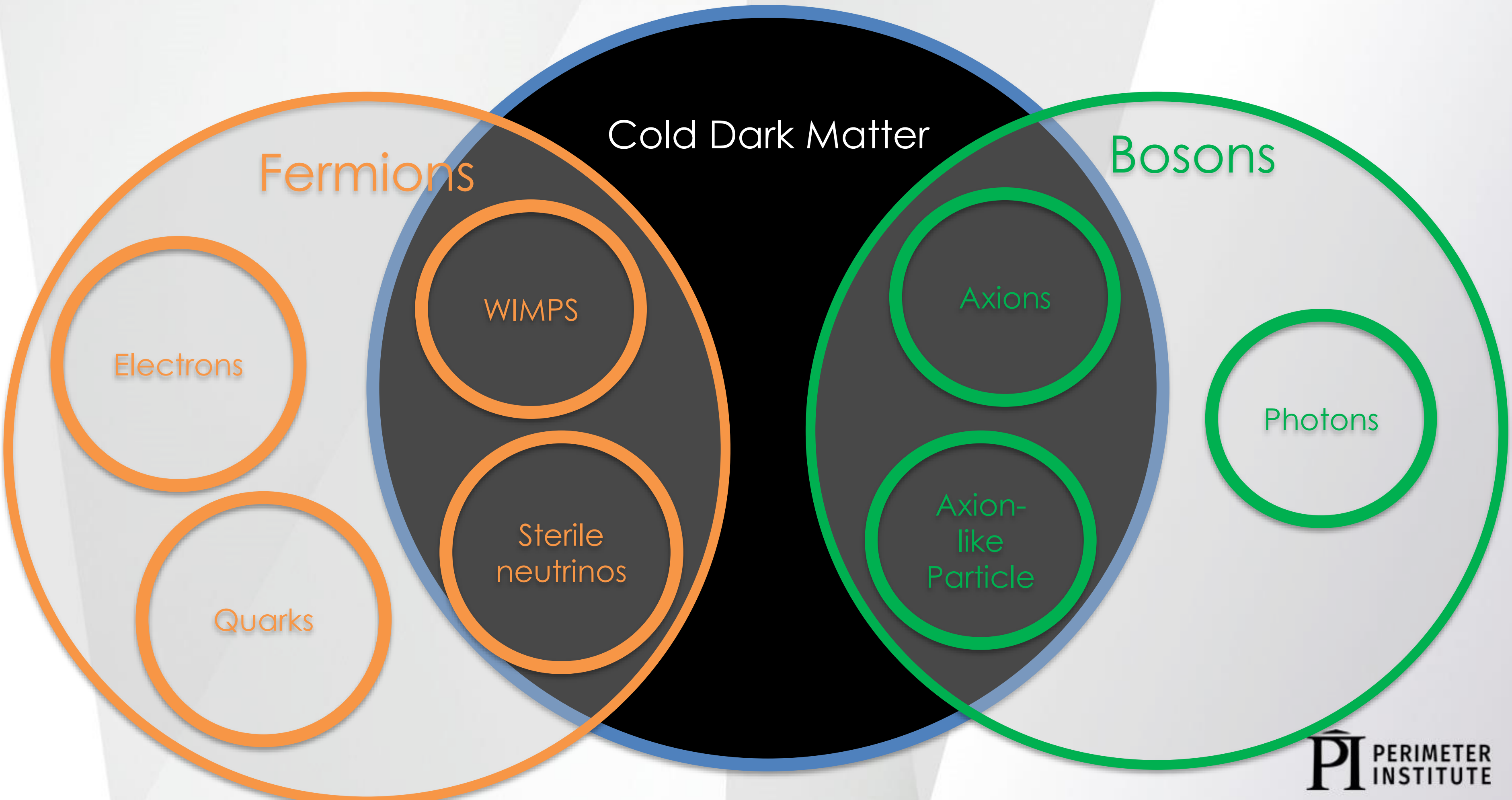
Competing Theories For Dark Matter

- Particle that hasn't been discovered yet



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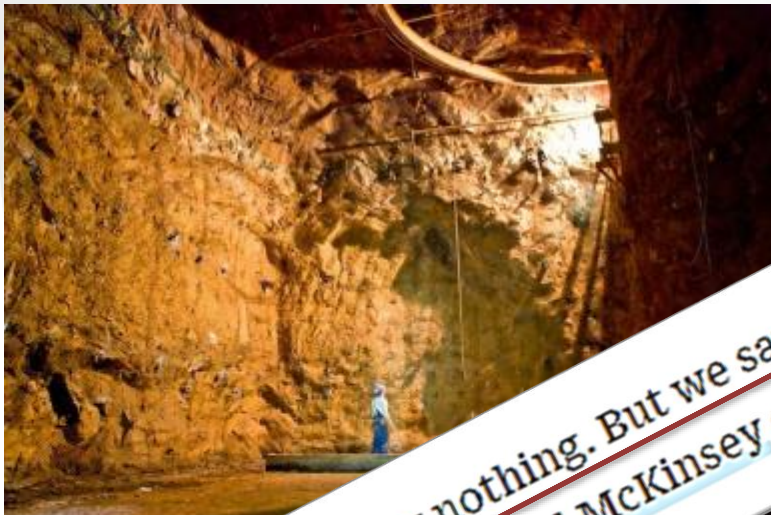
How to Look for Dark Matter Particles

- Direct detection: wait for it to hit a detector
- Indirect detection: look for other signatures
- Particle colliders: make it

Lux- Large Underground Xenon Dete r



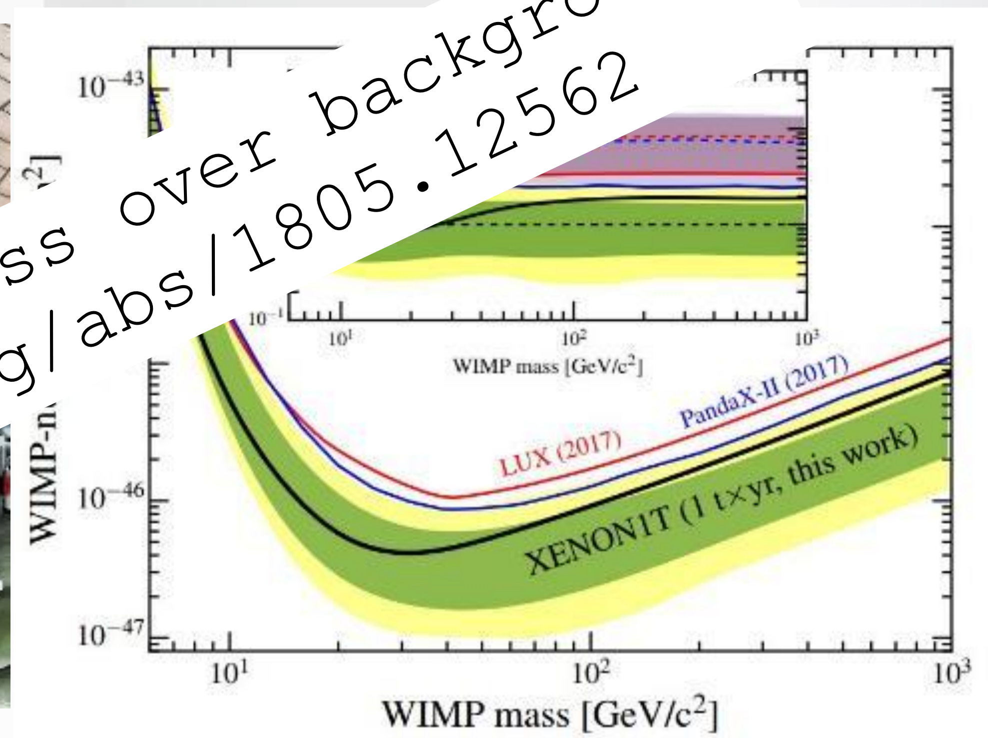
Homestake

"Basically, we saw nothing. But we saw nothing better than anyone else so far," said particle physicist Daniel McKinsey of Yale, a member of the LUX collaboration.

LUX update (2017)

With roughly fourfold improvement in sensitivity for high WIMP masses relative to our previous results, this search yields no evidence of WIMP nuclear recoils. arXiv:1608.07648v3

XENON1T most sensitive measurement yet (2018)



No significant excess over background is found. arxiv.org/abs/1805.12562

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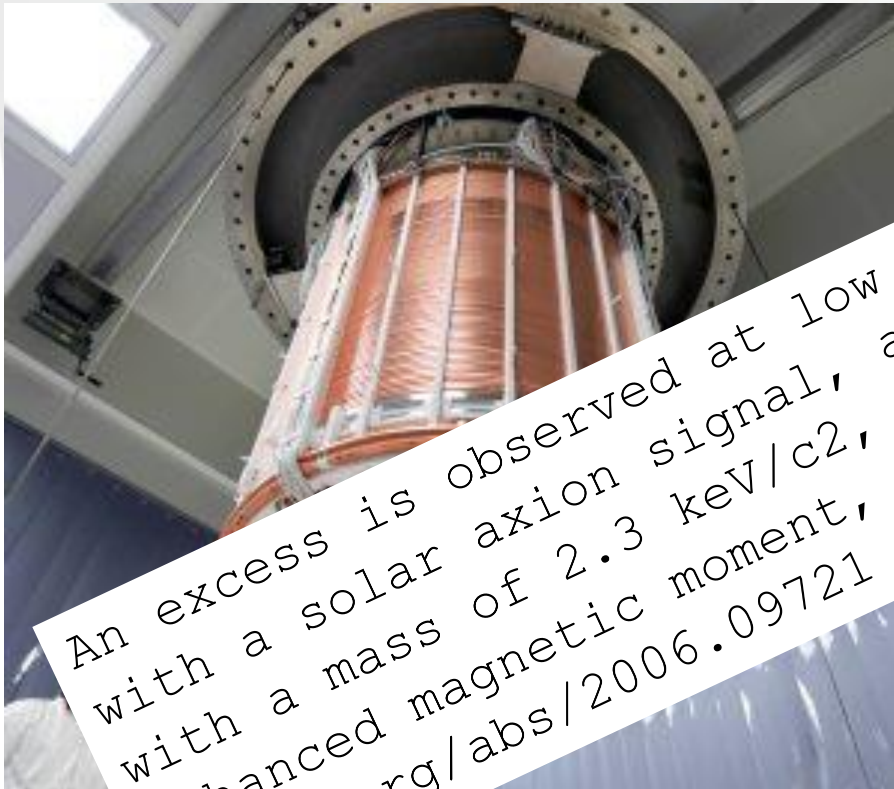
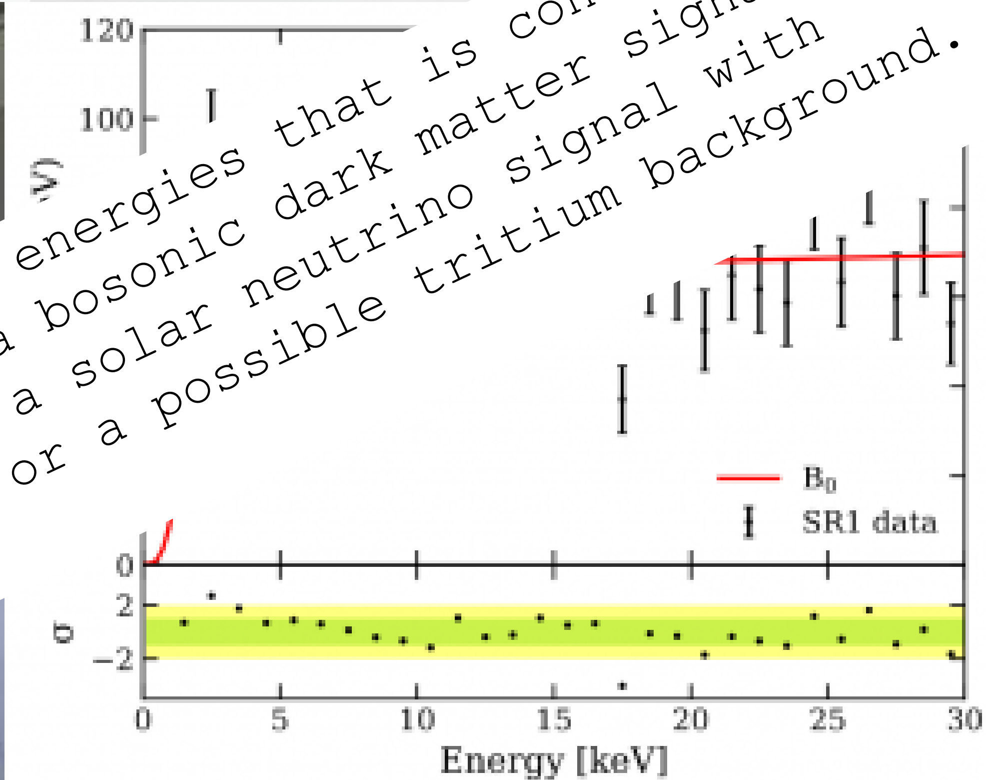
XENON1T – electronic recoil excess (2020)





An excess is observed at low energies that is consistent with a solar axion signal, a bosonic dark matter signal with a mass of 2.3 keV/c2, a solar neutrino signal with enhanced magnetic moment, or a possible tritium background.
arxiv.org/abs/2006.09721

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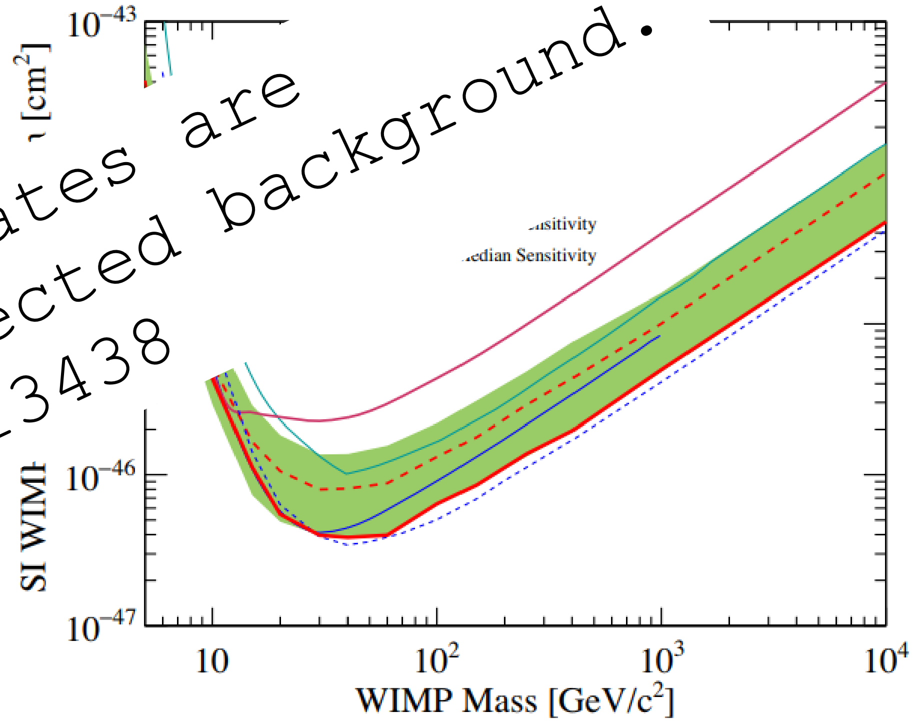
PANDAX-4T (2021)



No dark matter candidates are identified above expected background.
arxiv.org/abs/2107.13438

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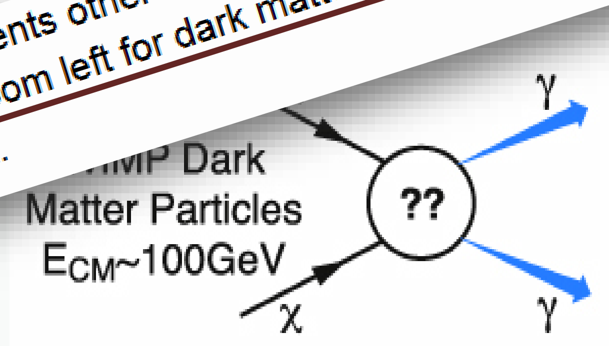
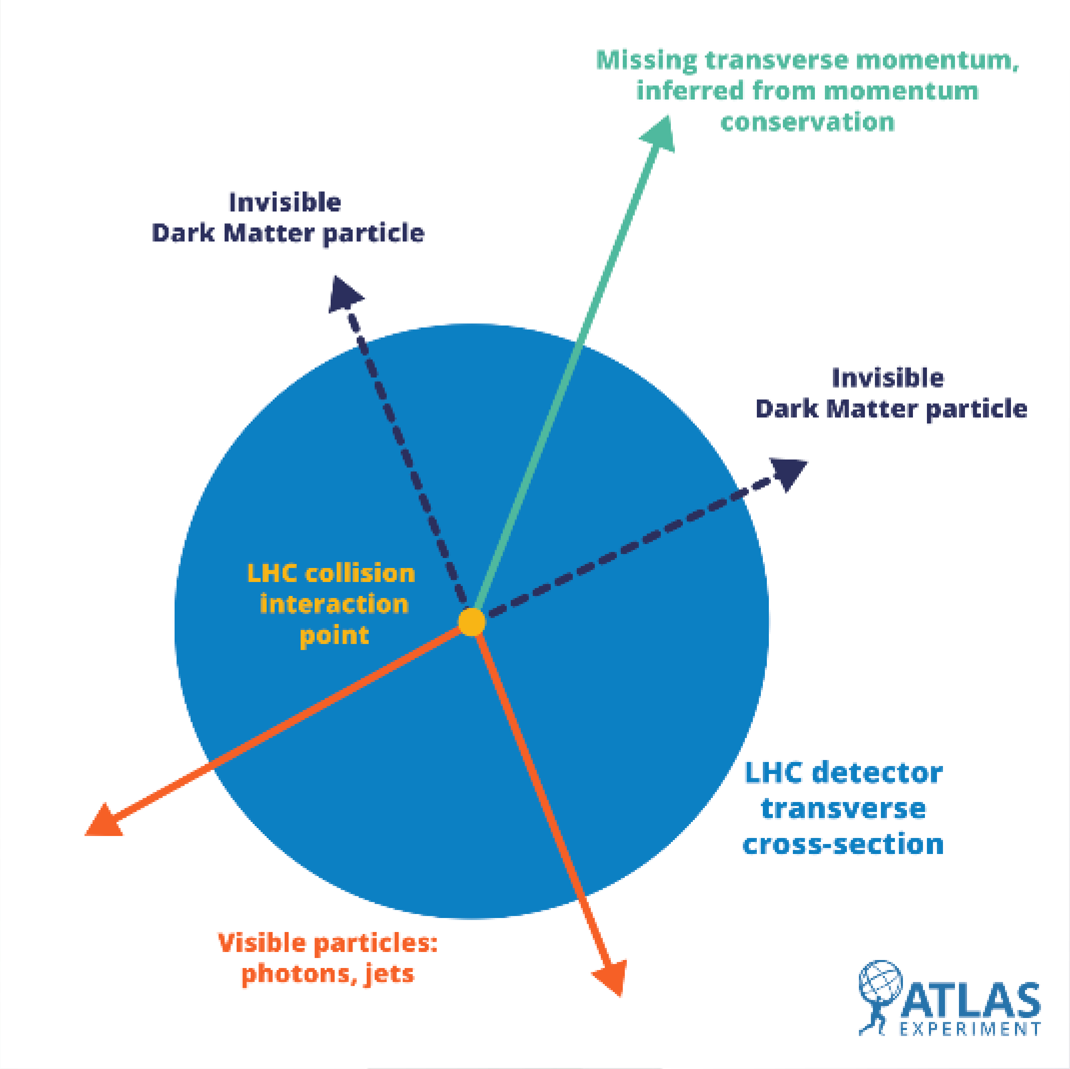
FERMI

- Detects γ-rays
- DM particle ann

'Our measurement complements other search campaigns that used gamma rays to look for dark matter and it confirms that there is little room left for dark matter induced gamma-ray emission in the isotropic gamma-ray background,' says Fornasa.



LHC



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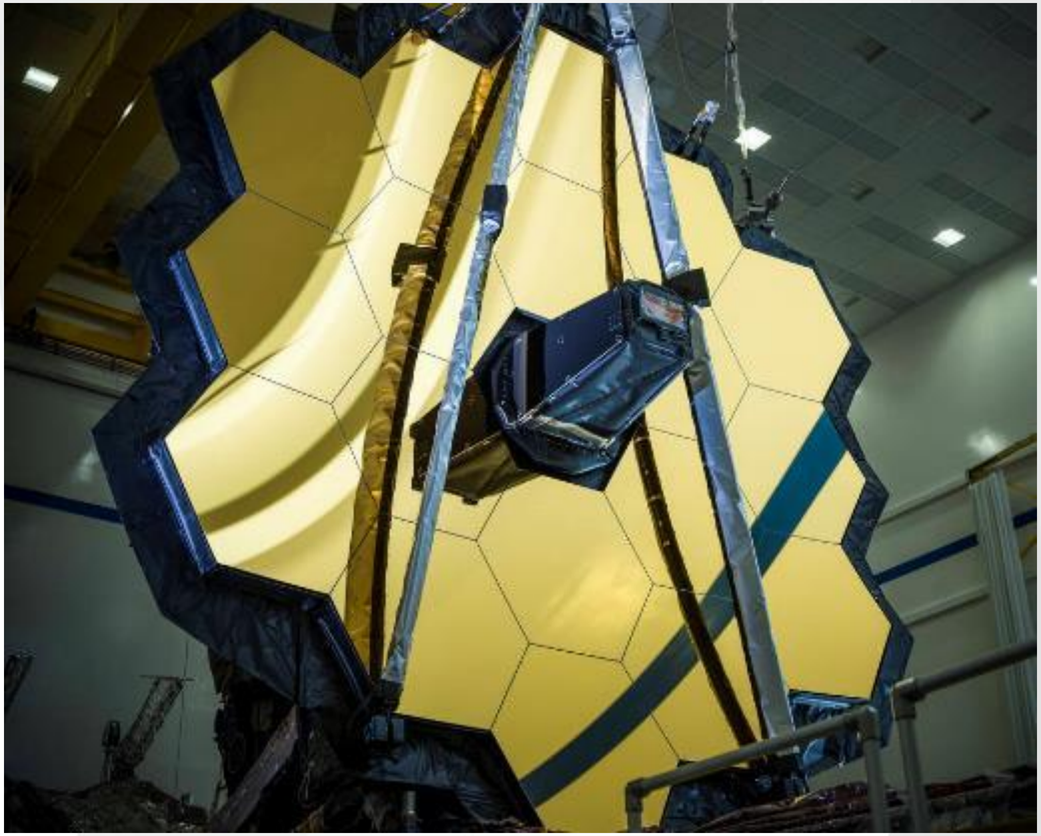
Looking for CDM



Dark Matter Dominated
Dwarf Galaxies

Moving beyond the Dark Matter vs Modified Gravity debate

DM

1. Most of the matter in the universe is luminous matter, namely the particles (excluding neutrinos) described by the standard model of particle physics (SM);

2. Their gravitational interaction is correctly described (before reaching the regime of quantum gravity) by General Relativity (GR)—and Newtonian Gravity as its non-relativistic limit.

MG

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Dark Matter

- Works well on cosmological scales
- Does not work well in detail for galaxy rotation curves (small scale problems)
- We haven't found it

Modified Gravity

- Predicts galaxy rotation curves very well
- Does not predict well or ignores the data from CMB or gravitational wave data

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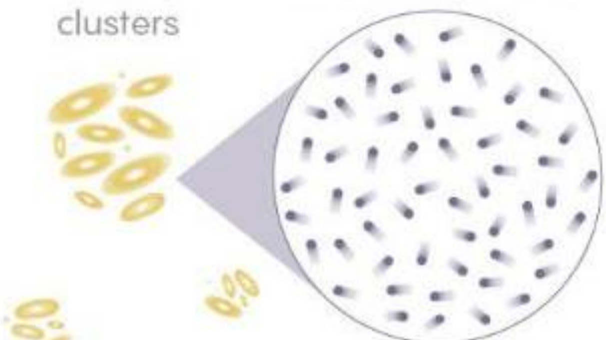
Stalemate

Superfluid Dark Matter

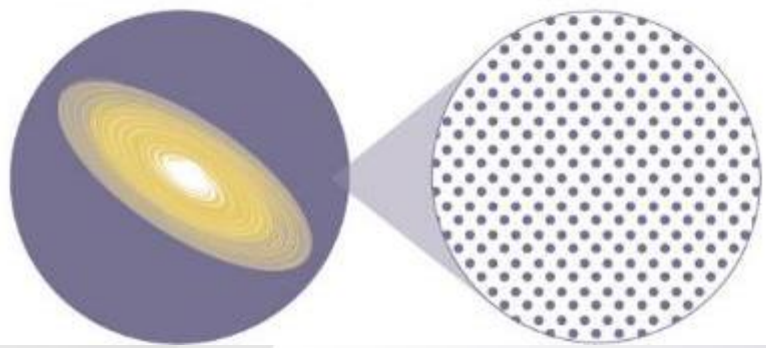
Galaxy Clusters

Large clusters of galaxies behave as though they're held together by an extra gravitational force. Dark matter particles can account for this force.



Galaxies

Individual galaxies also need an additional force to hold together. But ordinary dark matter models have trouble describing this force.



Credit: Quanta Magazine