The Mystery of Dark Matter

CERN HST2023

Dave

Sean

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

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Predict, Observe, Explain Demonstration: Uniform Circular Motion
This demonstration utilizes a typical uniform circular motion apparatus to introduce students to the concept of dark matter.

Hands-on Demonstrations: Gravitational Lensing
These demonstrations use simple objects to model gravitational lensing.

Activity 1: Video Summary
A set of discussion questions that review the content of the video.

Activity 2: Key Concepts
A question sheet that allows students to dig deeper into the material both numerically and conceptually.

Activity 3: Gravity and Orbital Motion
An activity where students use stretchy spacetime fabric and a variety of balls to model orbital motion.

Activity 4: Dark Matter within a Galaxy
Students use real data to explore the conflict between what is expected and what is observed.

Activity 5: Advanced Mathematical Analysis
An enrichment/extension activity for stronger students.

Activity 6: Dark Matter Lab
Students use a typical uniform circular motion apparatus to explore the connection between orbital speed and central force.

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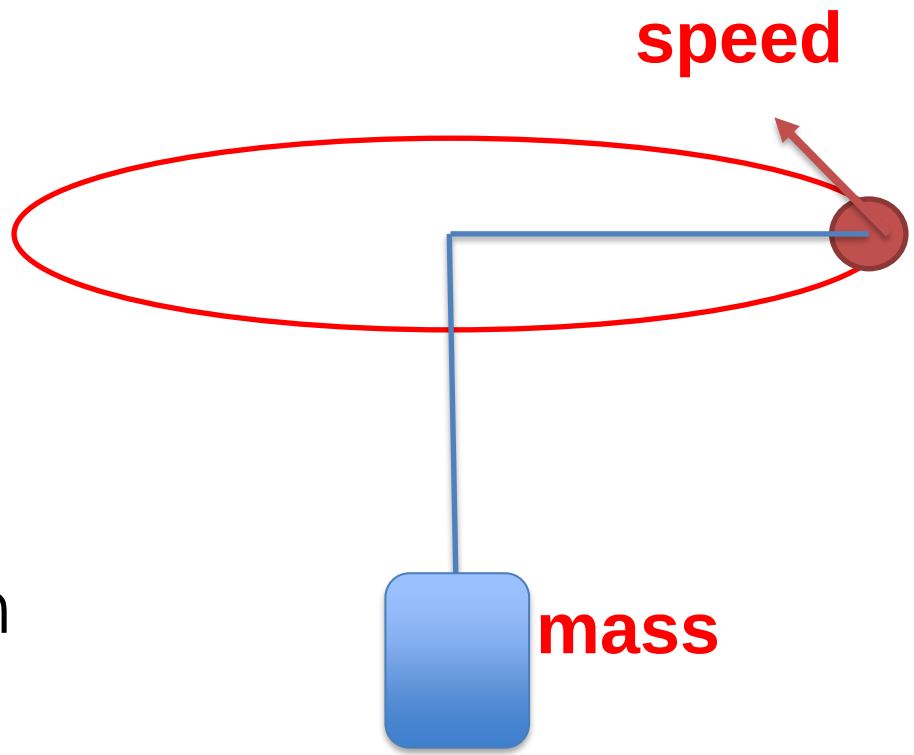
Uniform Circular Motion Activity

Predict

Observe

Explain

How are mass and speed connected in circular motion?



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Uniform Circular Motion Activity

Objective:

Determine the mass of an unknown item.

1. Collect data for one mass per group.
2. Plot a graph of speed^2 vs mass on a collaborative spreadsheet.

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Uniform Circular Motion Activity

Collaborative version:

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

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Uniform Circular Motion Results

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

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

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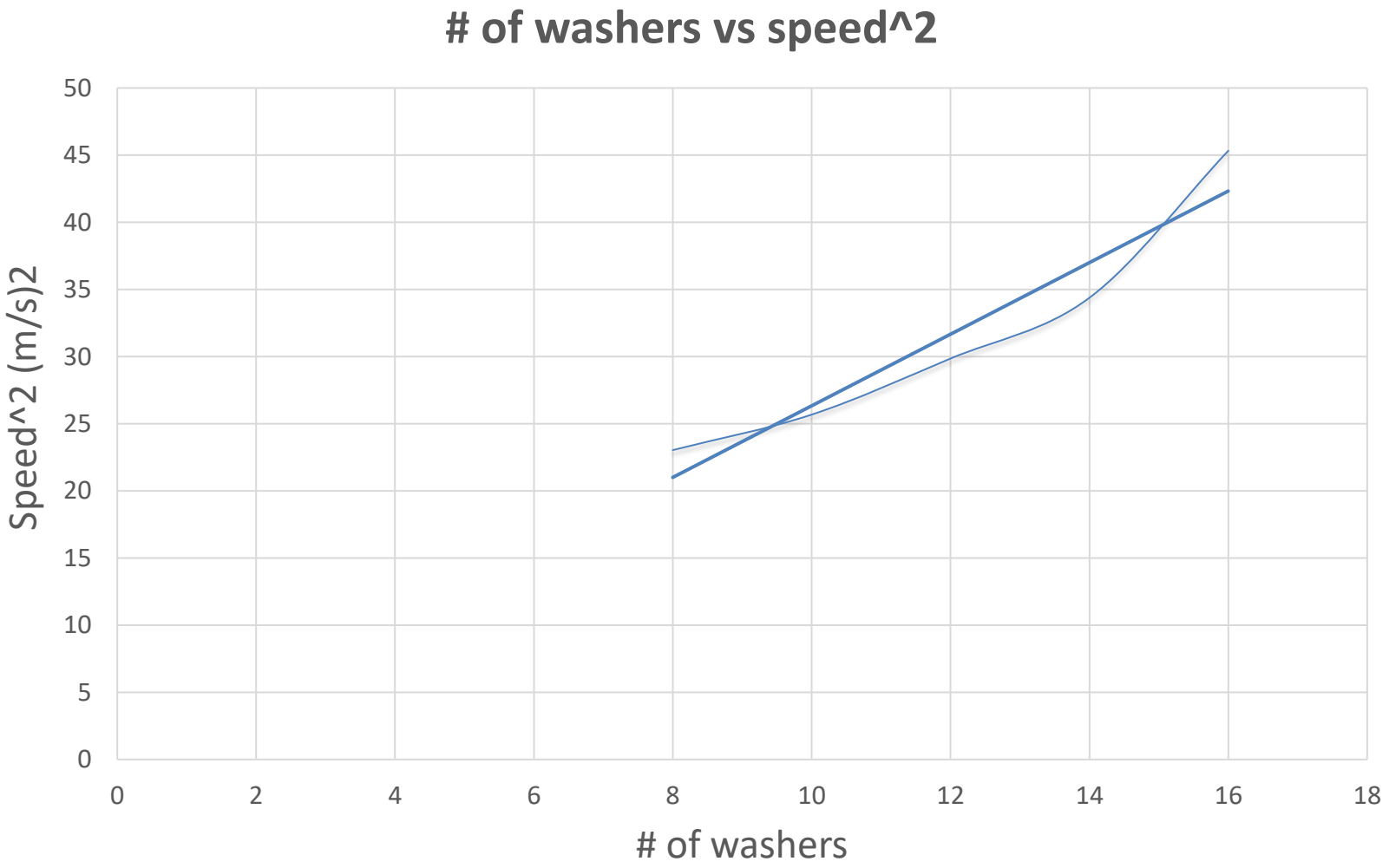
Uniform Circular Motion Results



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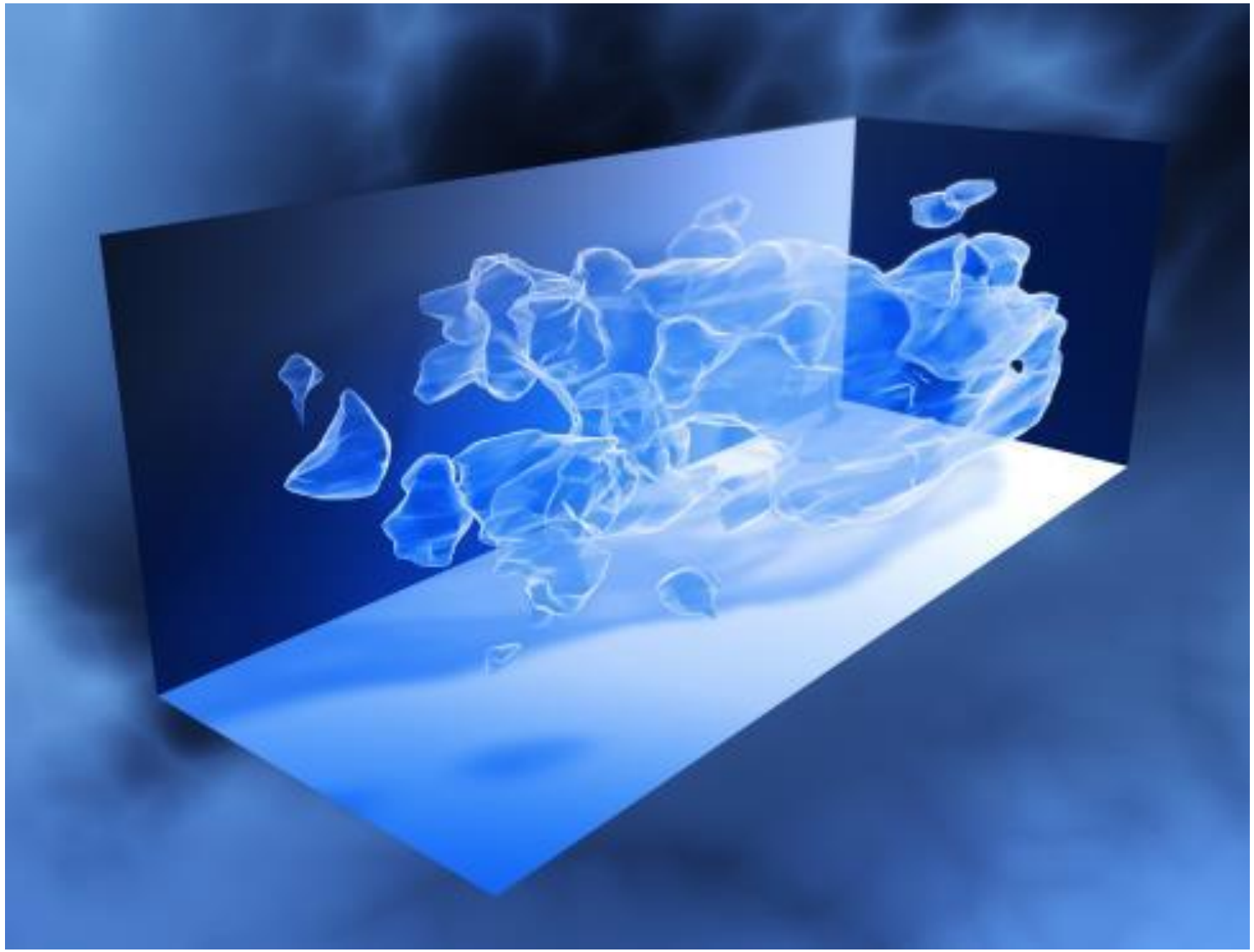
Connecting standard classroom physics to Cutting-Edge Dark Matter



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Vera Rubin's Discovery

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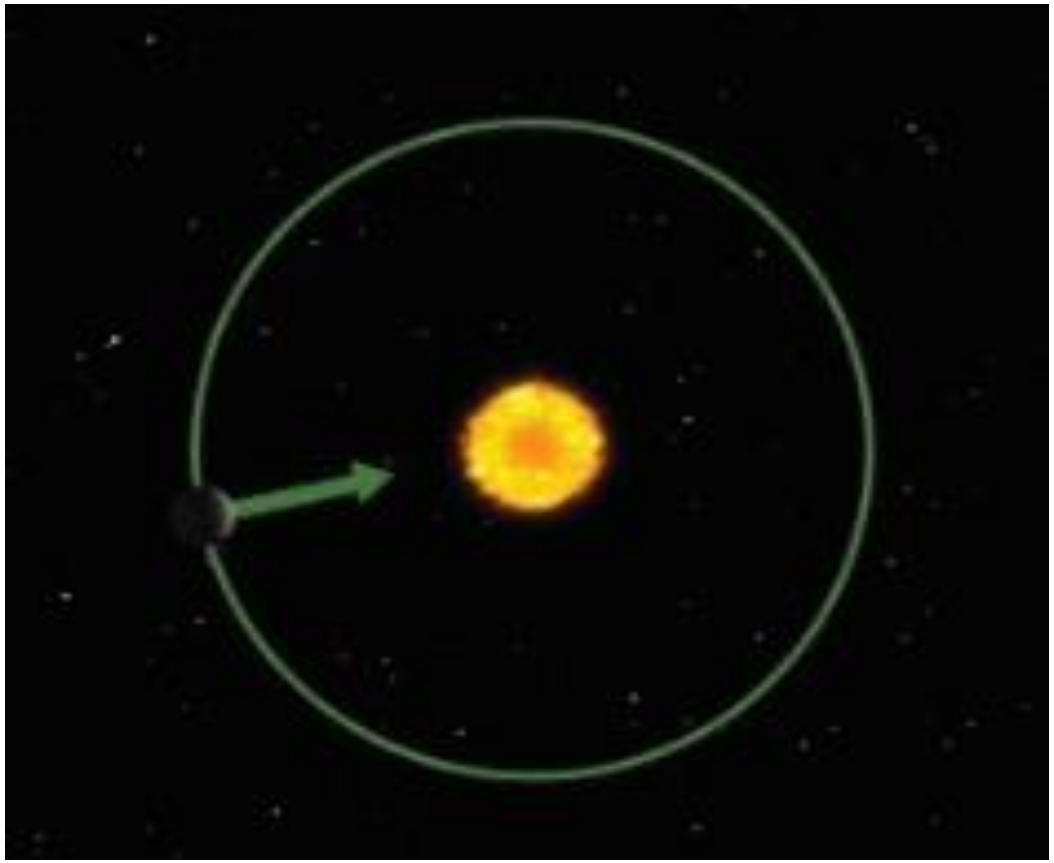
https://resources.perimeterinstitute.ca/

Orbital Speed Depends on the Mass of the Central Object

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



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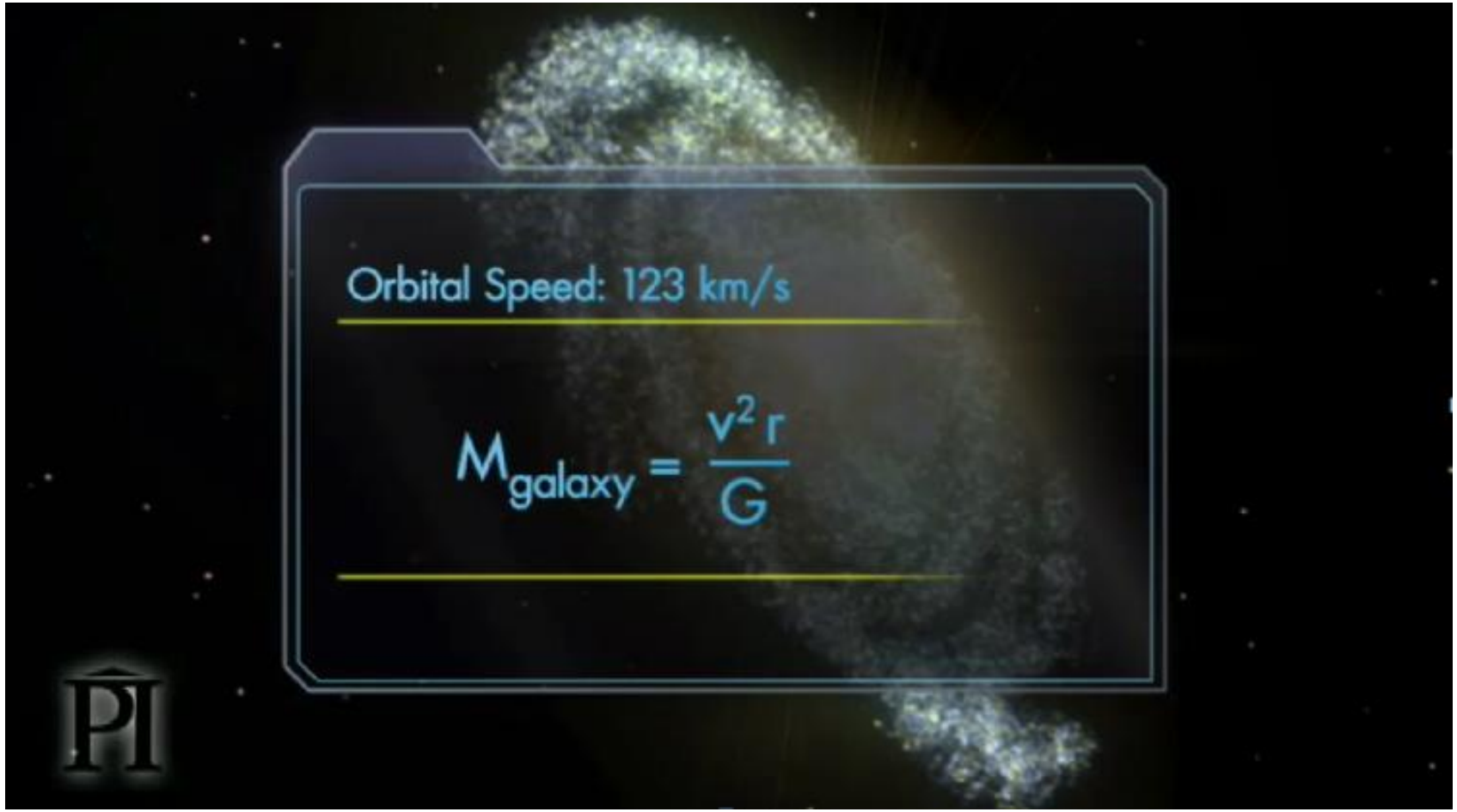
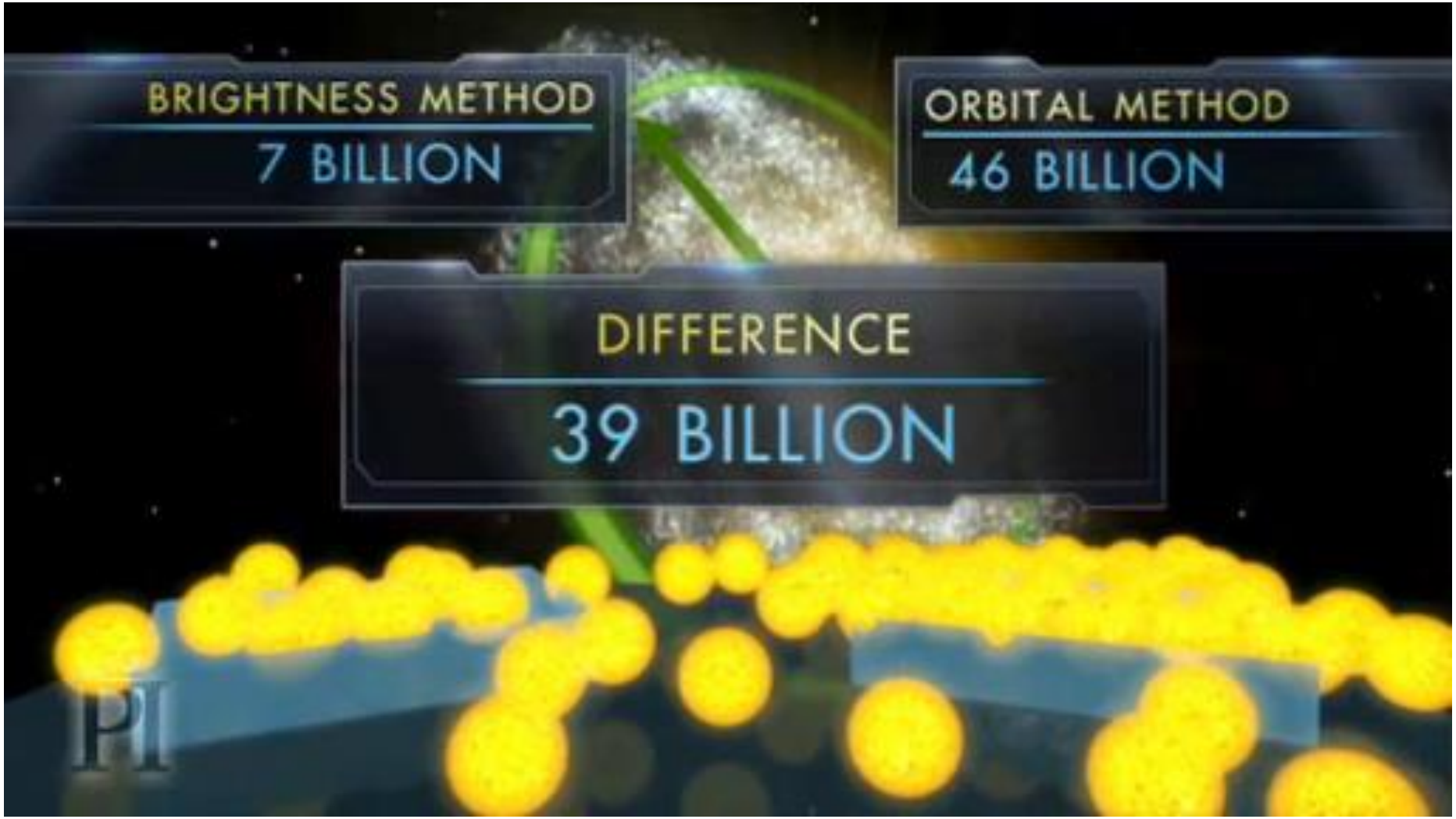
Extend this to galaxies

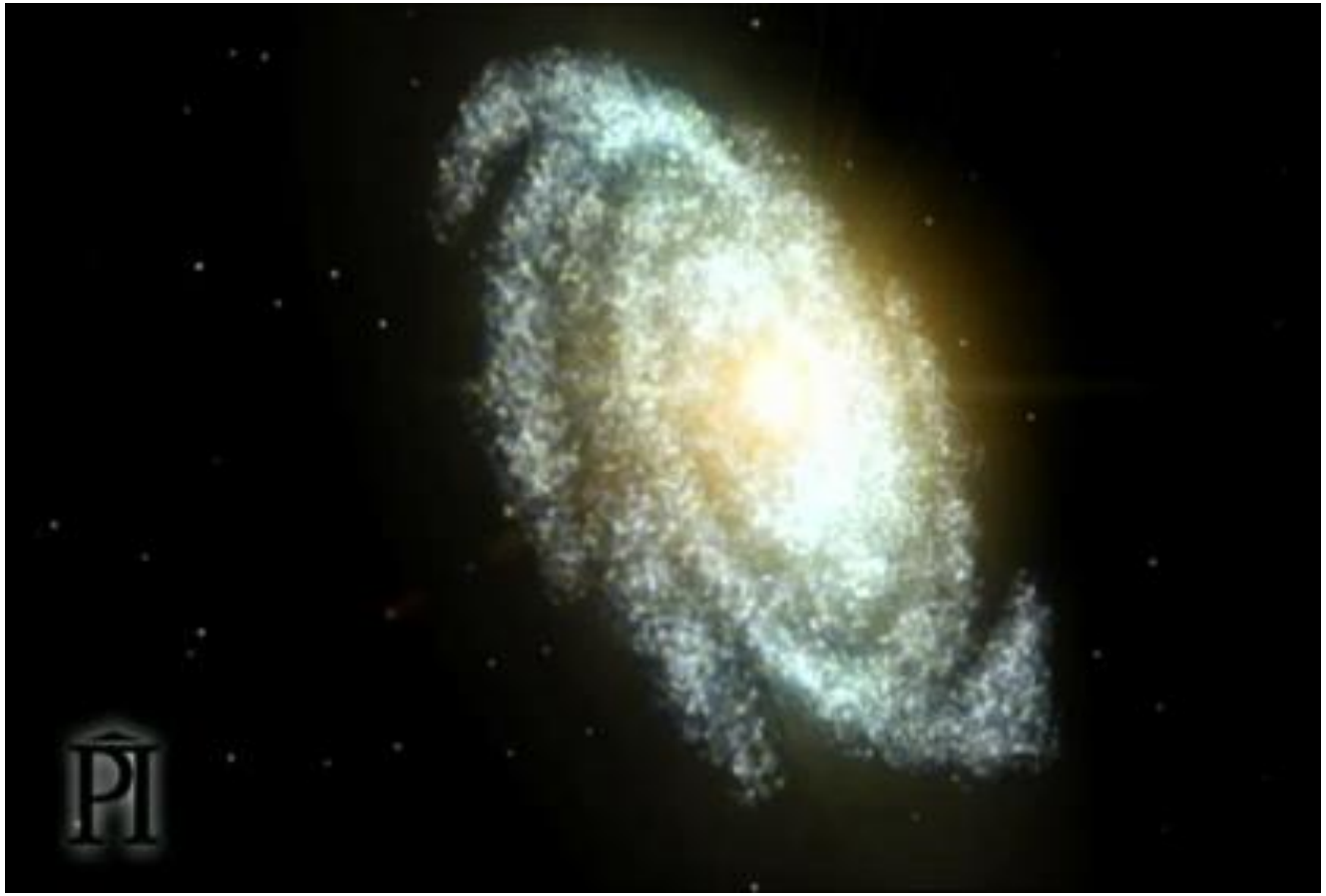


Triangulum is More Massive Than it Looks



The same discrepancy
happens in all* galaxies

Old View



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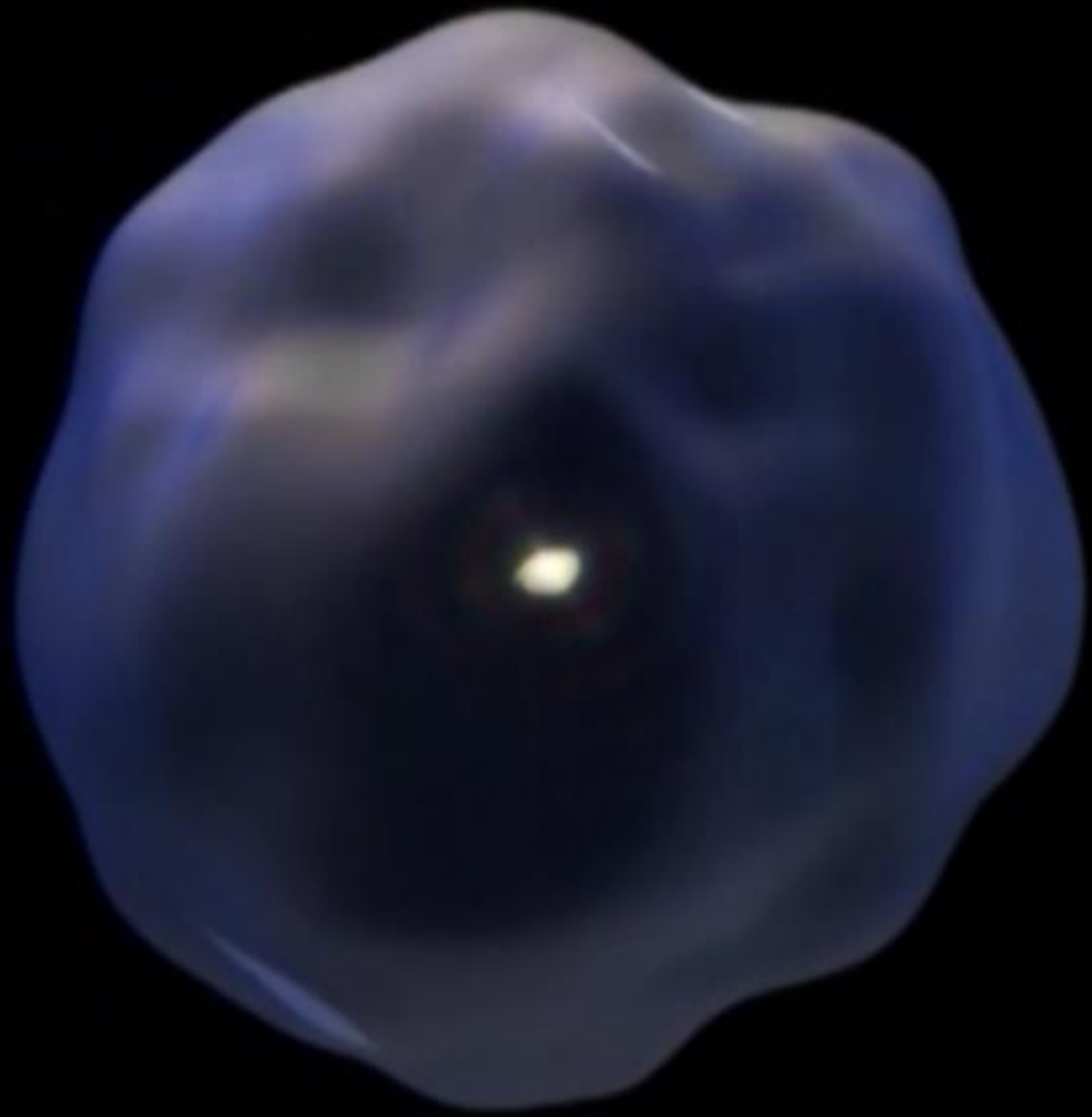
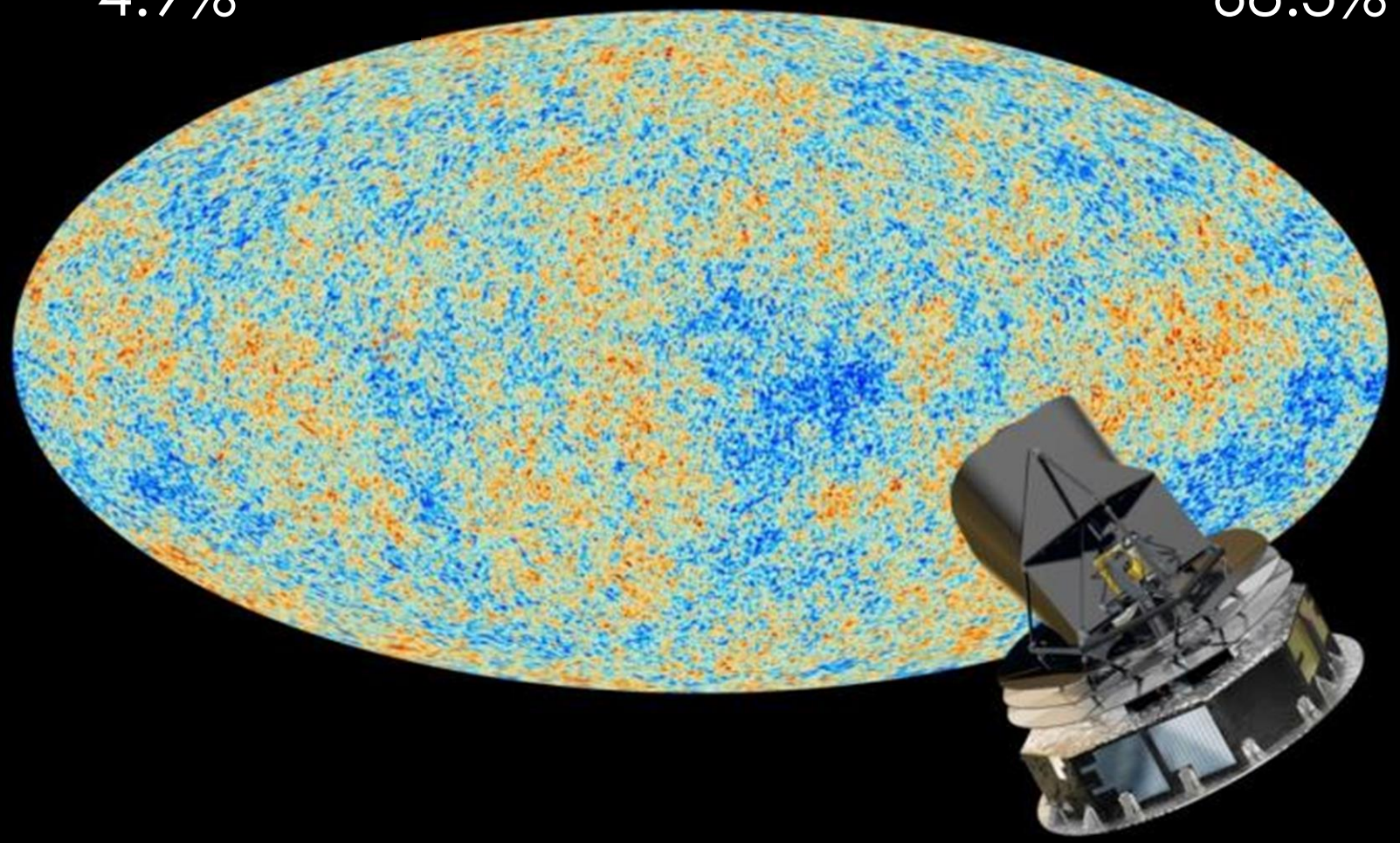
New View



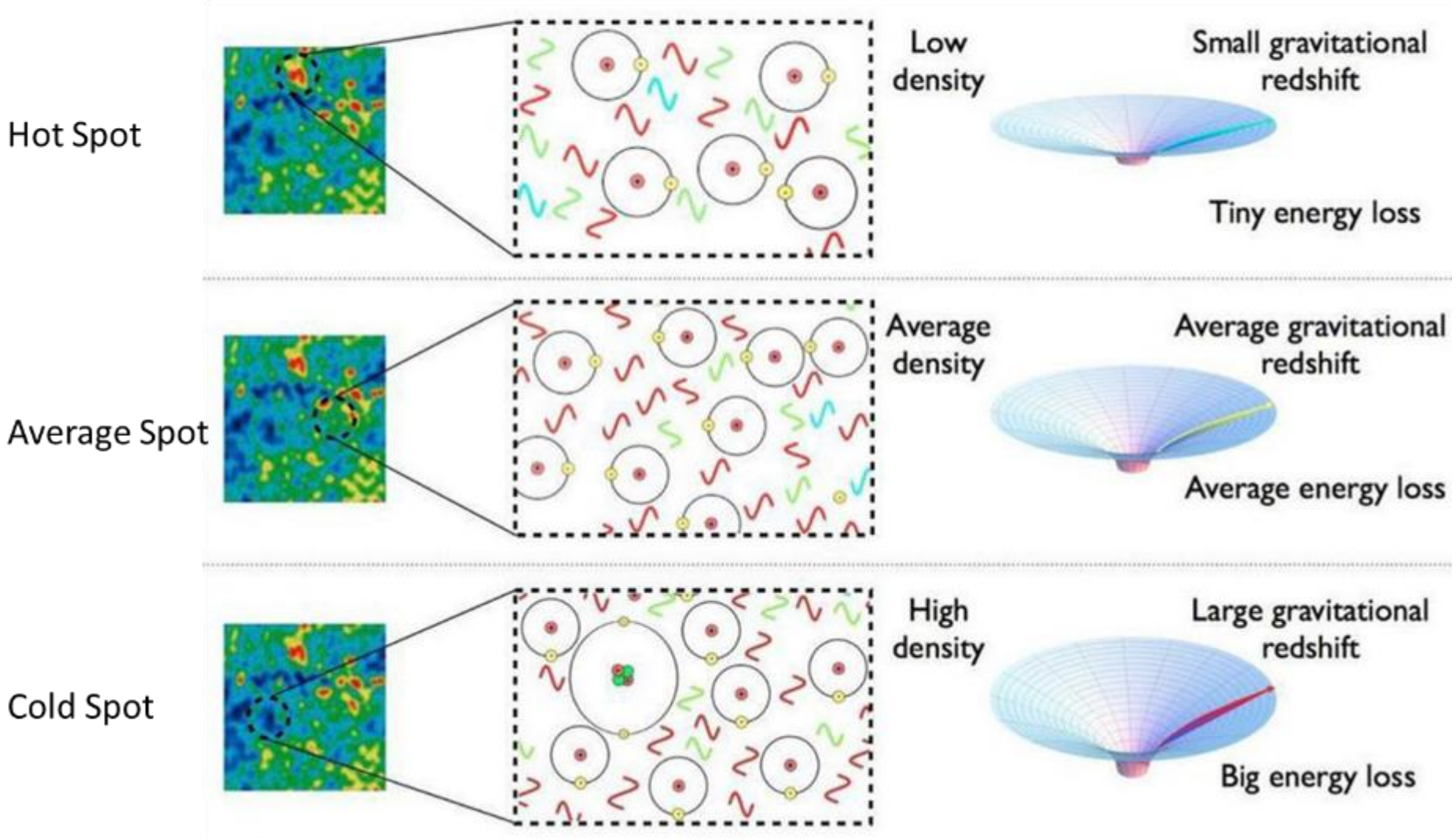
Dark Matter
26.8%

Normal Matter
4.9%

Dark Energy
68.3%



0.0001 K difference between hot and cold!



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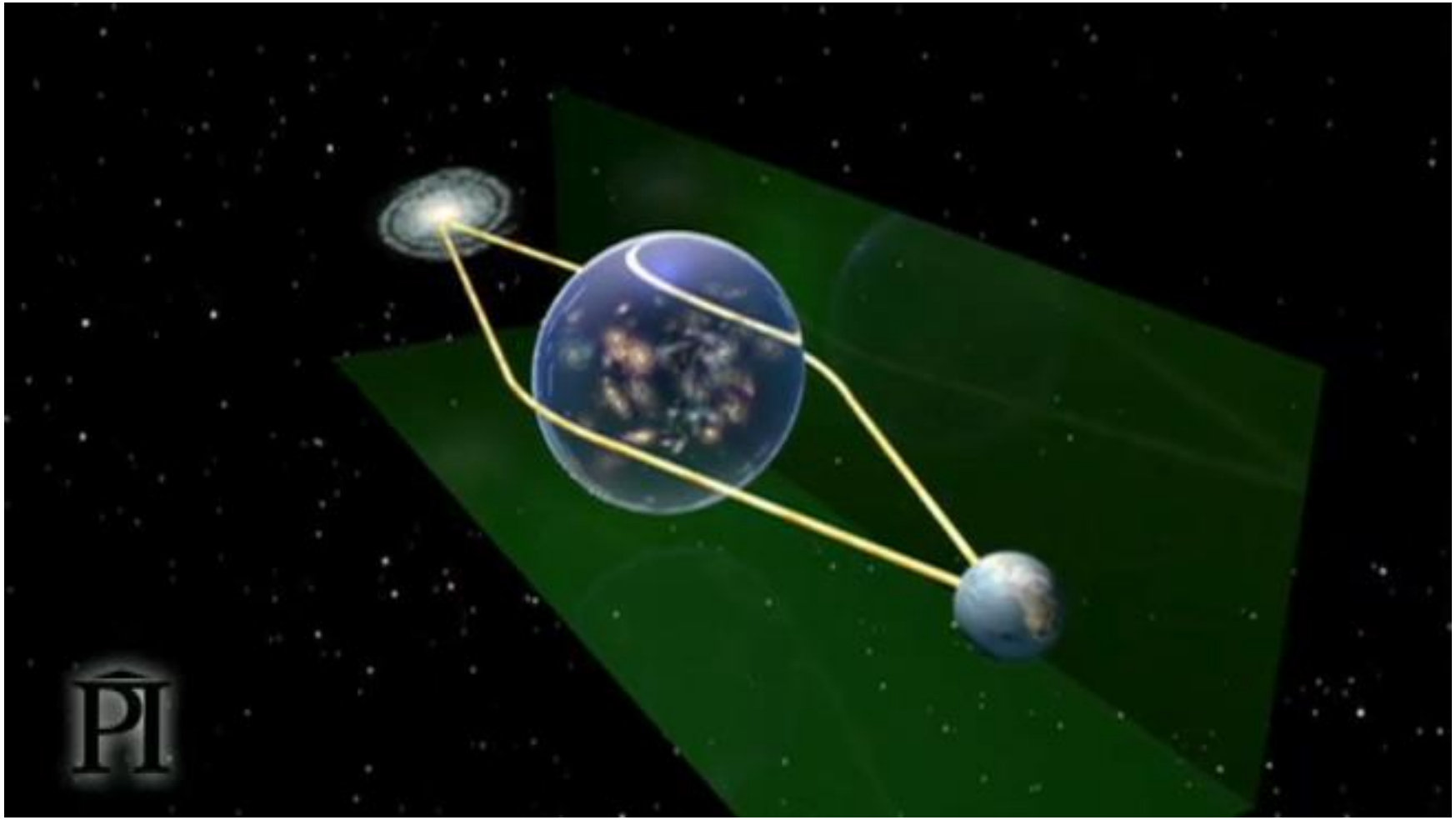
Gravitational Lensing



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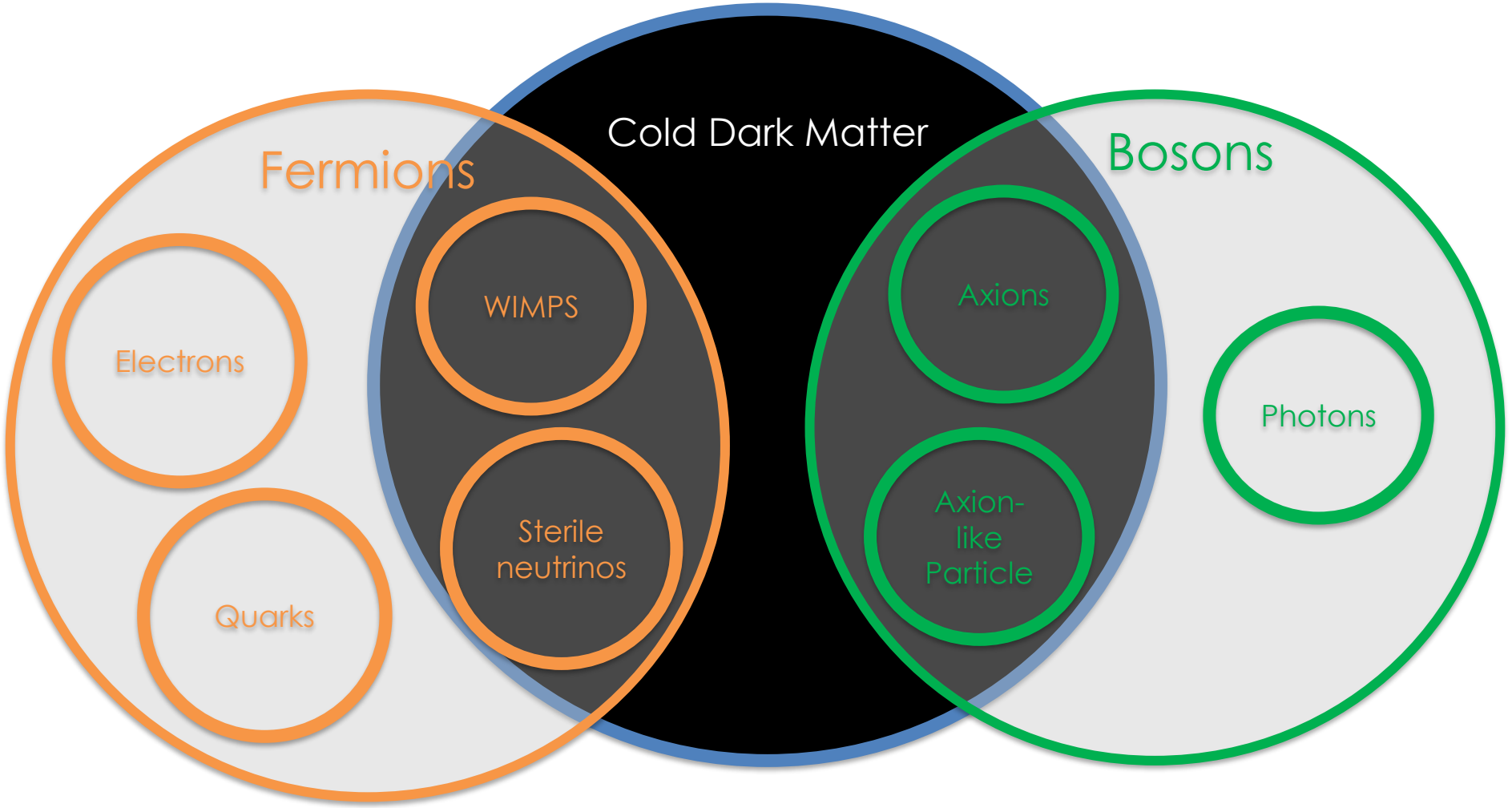
Competing Theories For Dark Matter

- 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

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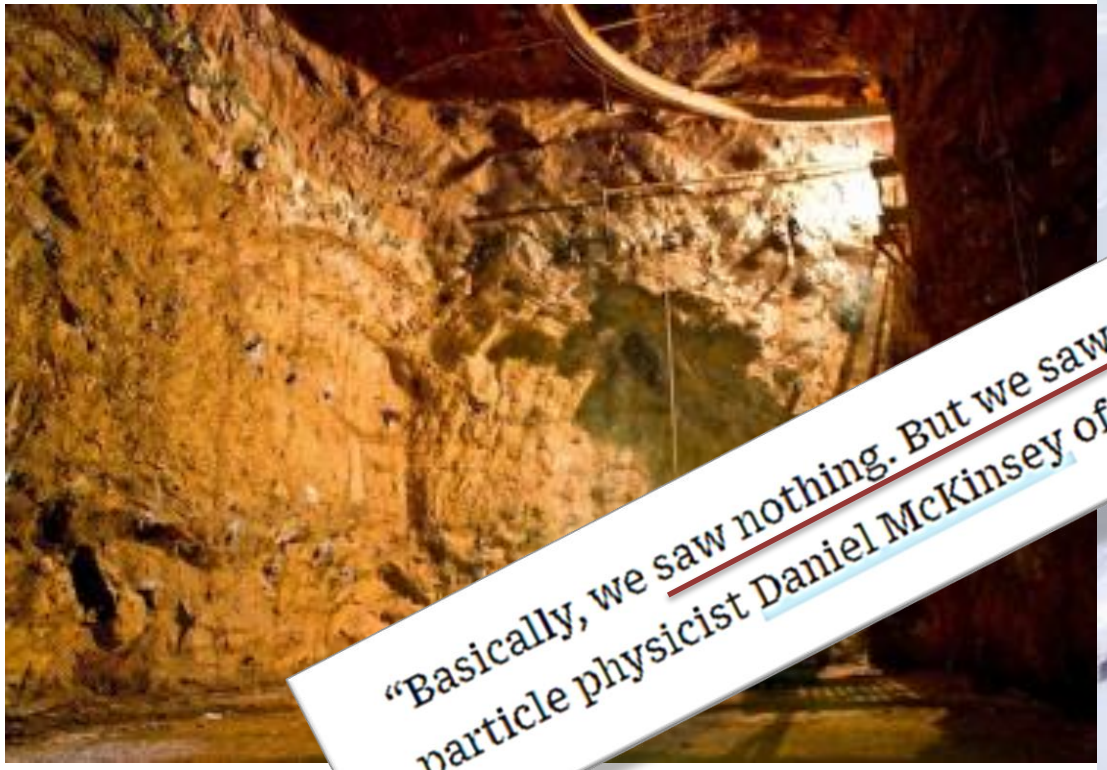
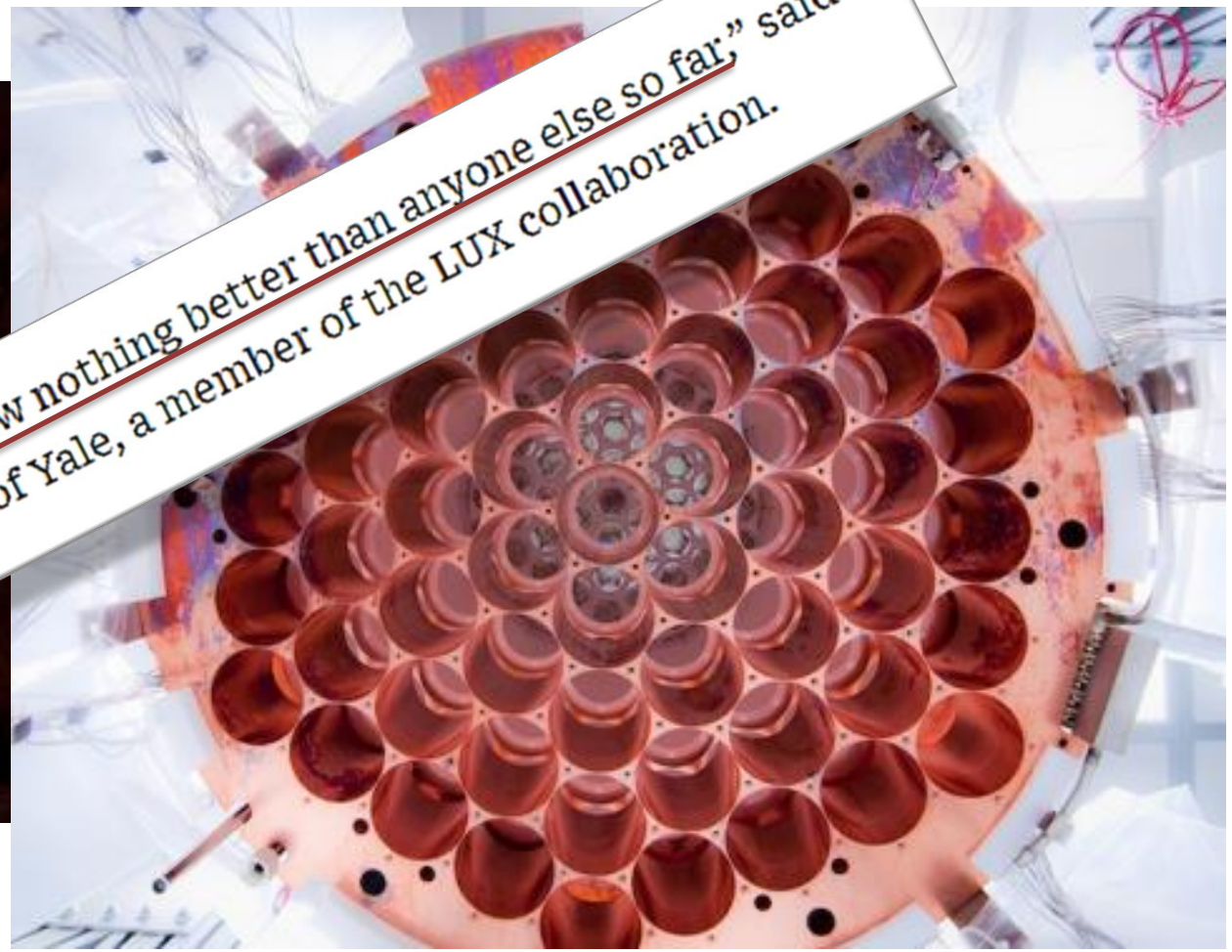
LUX- **L**arge **U**nderground **X**enon Detector



Homestake Mine, South Dakota



"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.

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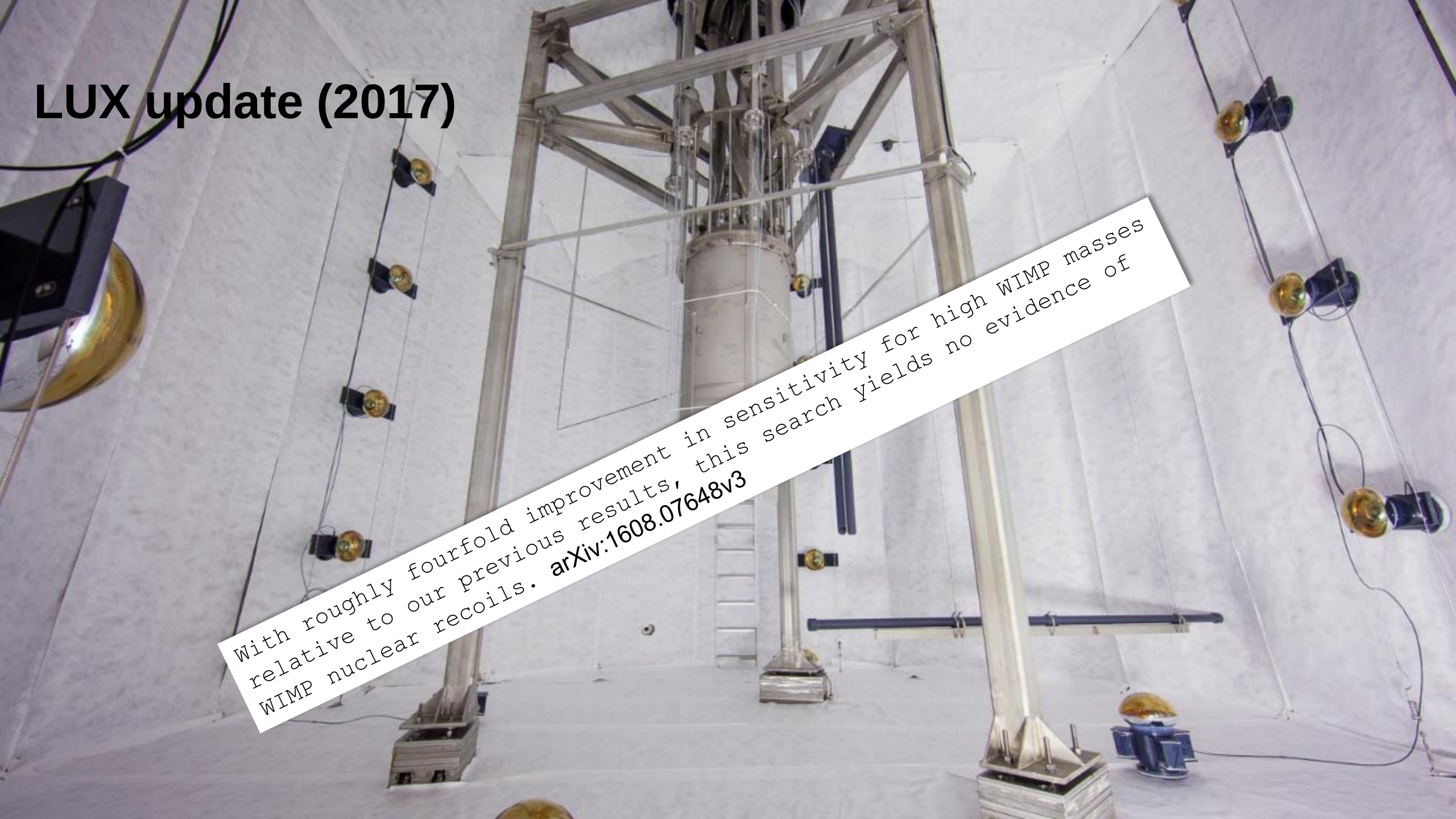
LUX update (2017)



LUX-ZEPLIN (LZ) update (2022)

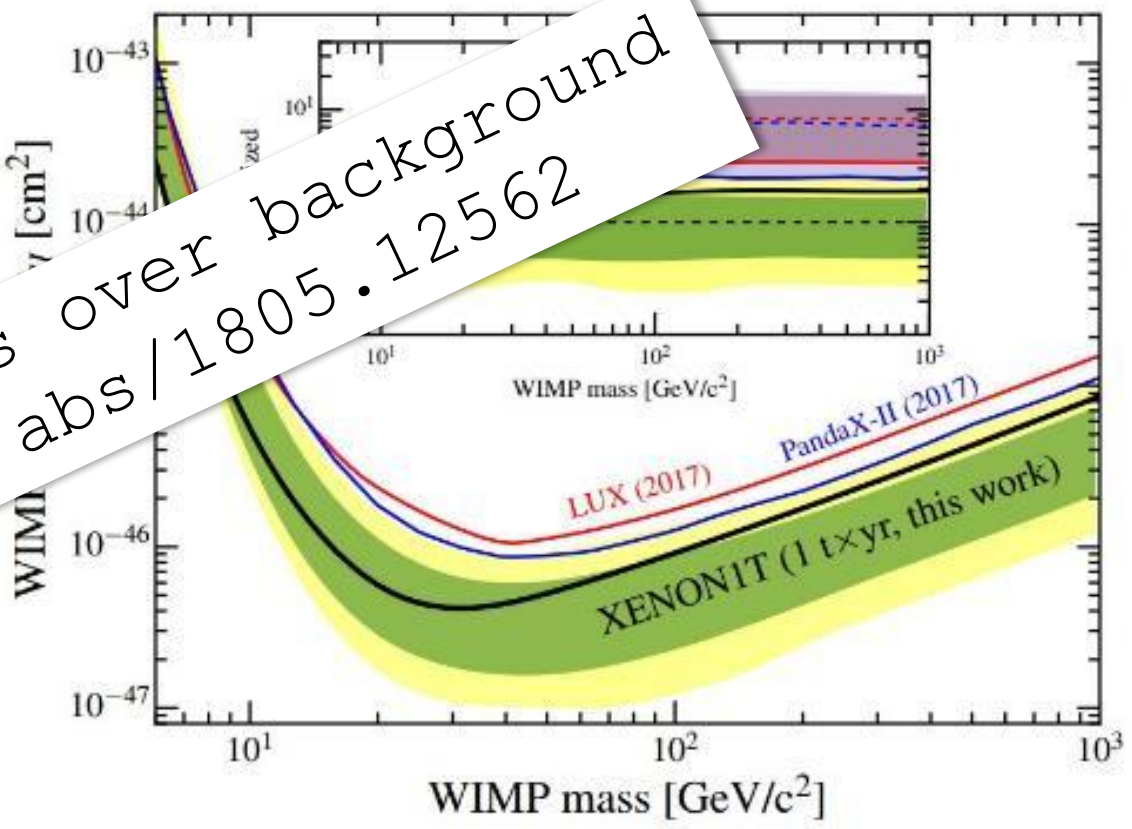
A profile-likelihood ratio analysis shows the data to be consistent with a background-only

https://arxiv.org/abs/2207.03764

XENON1T (2018)

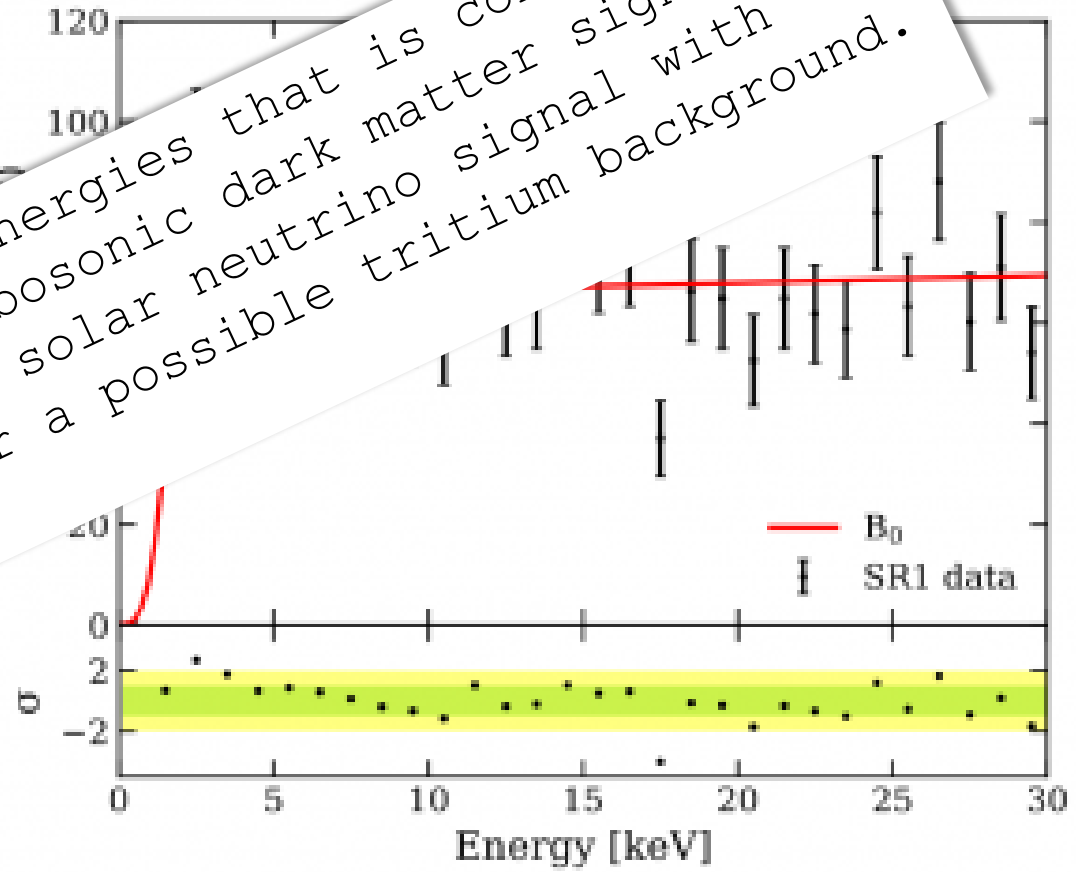
Image credit: Robe[illegible] Corrieri and Patrick De Perio

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



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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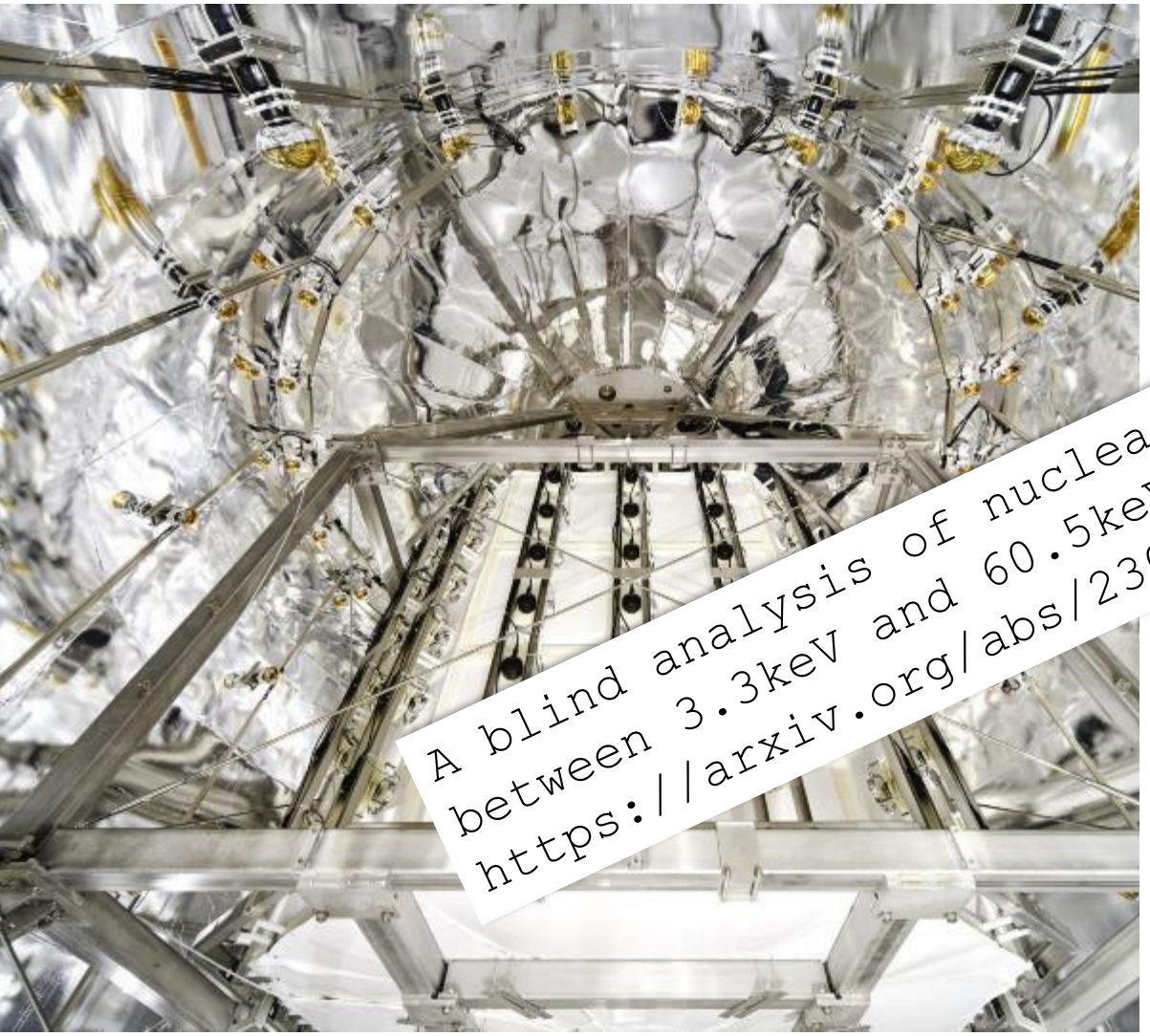
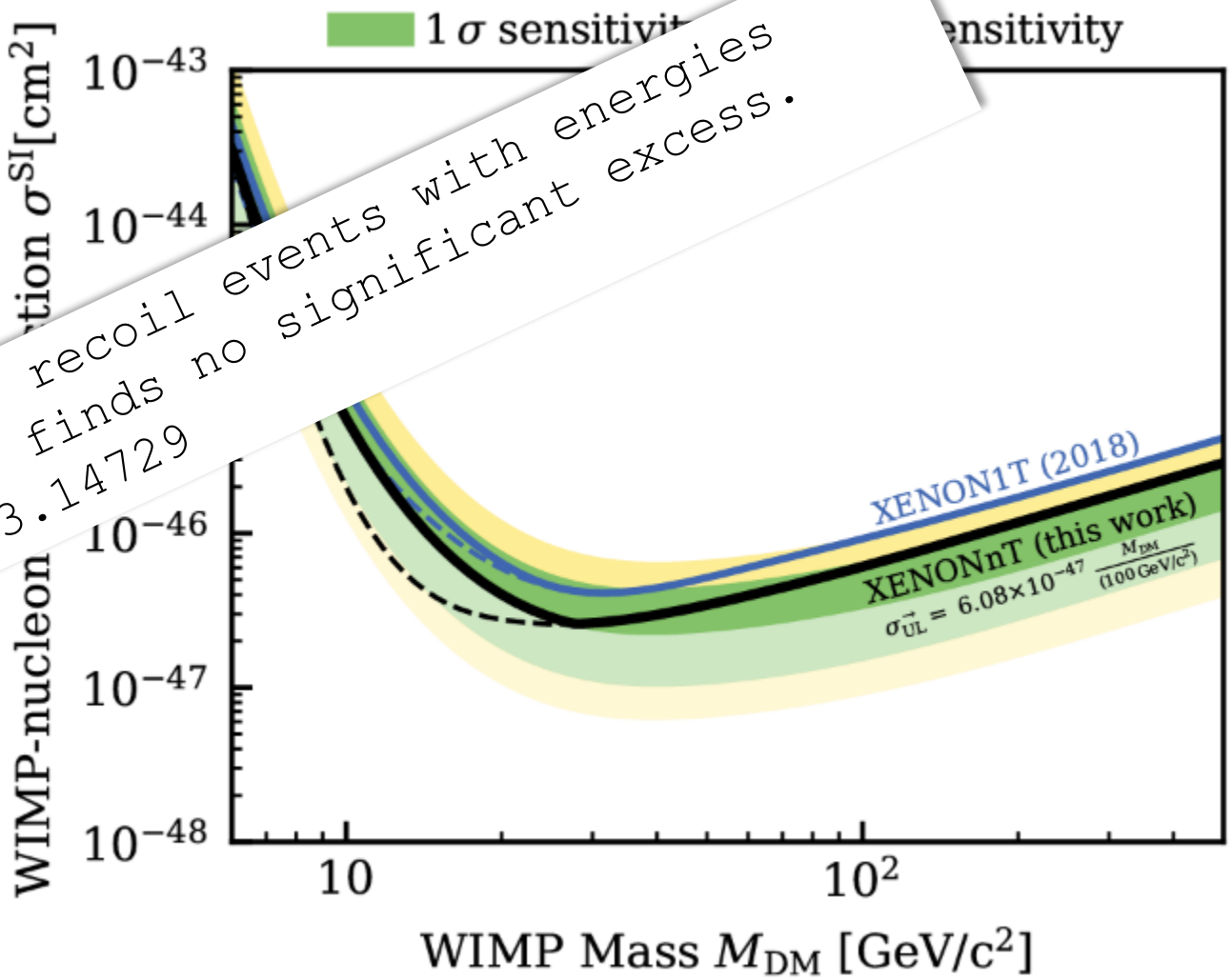
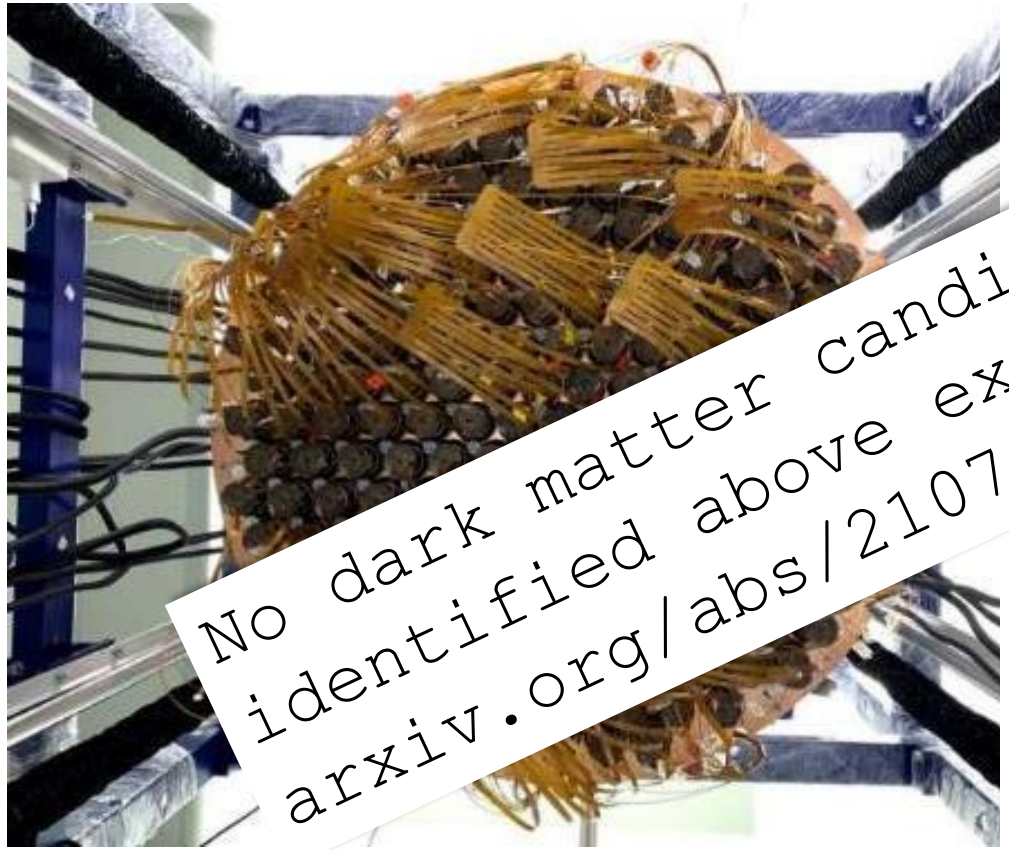
XENONnT – (2023)



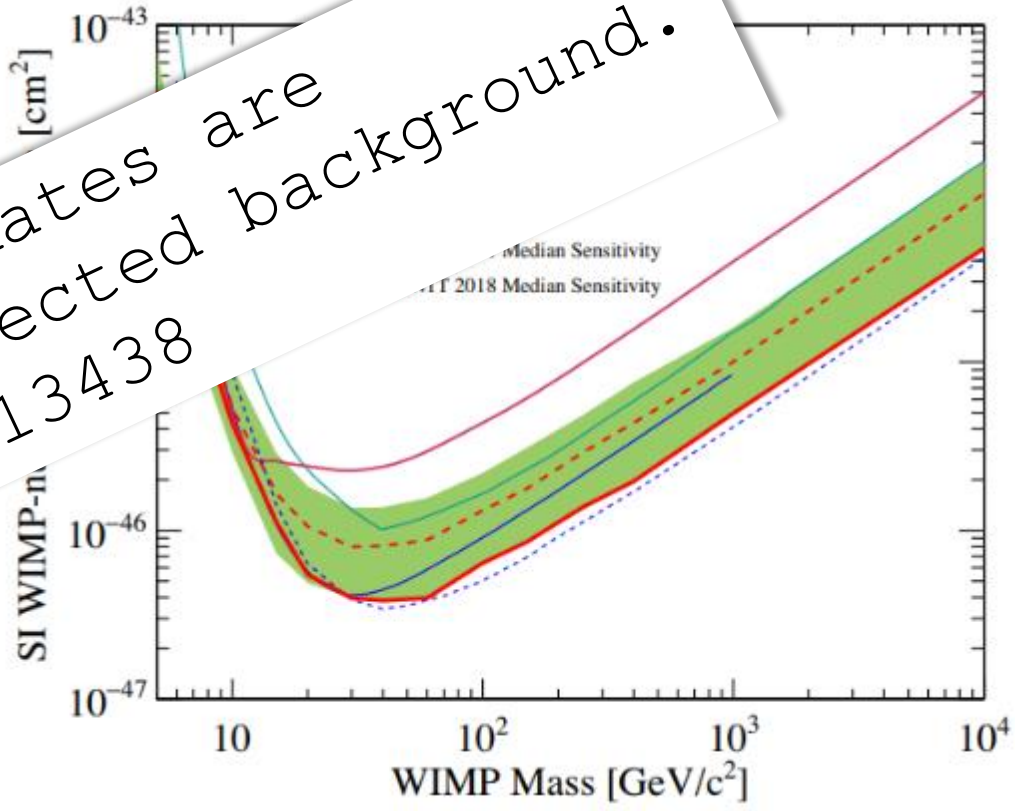
A blind analysis of nuclear recoil events with energies between 3.3keV and 60.5keV finds no significant excess.
https://arxiv.org/abs/2303.14729



PANDAX- 4T (2021)



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



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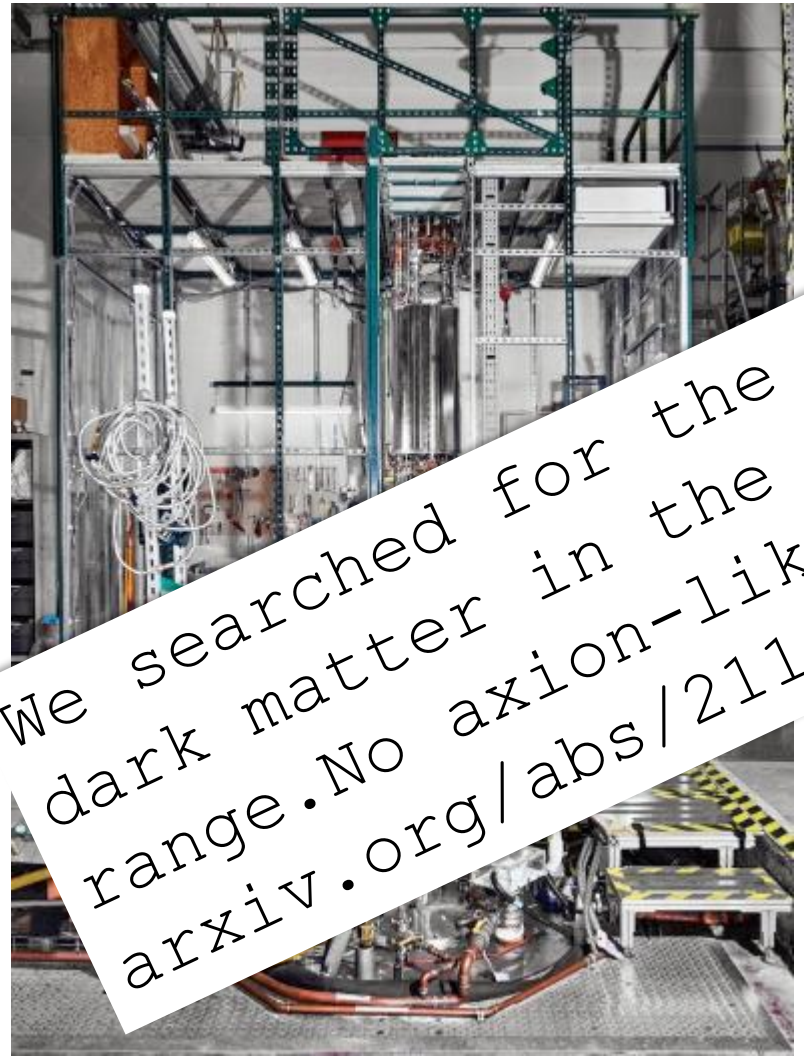
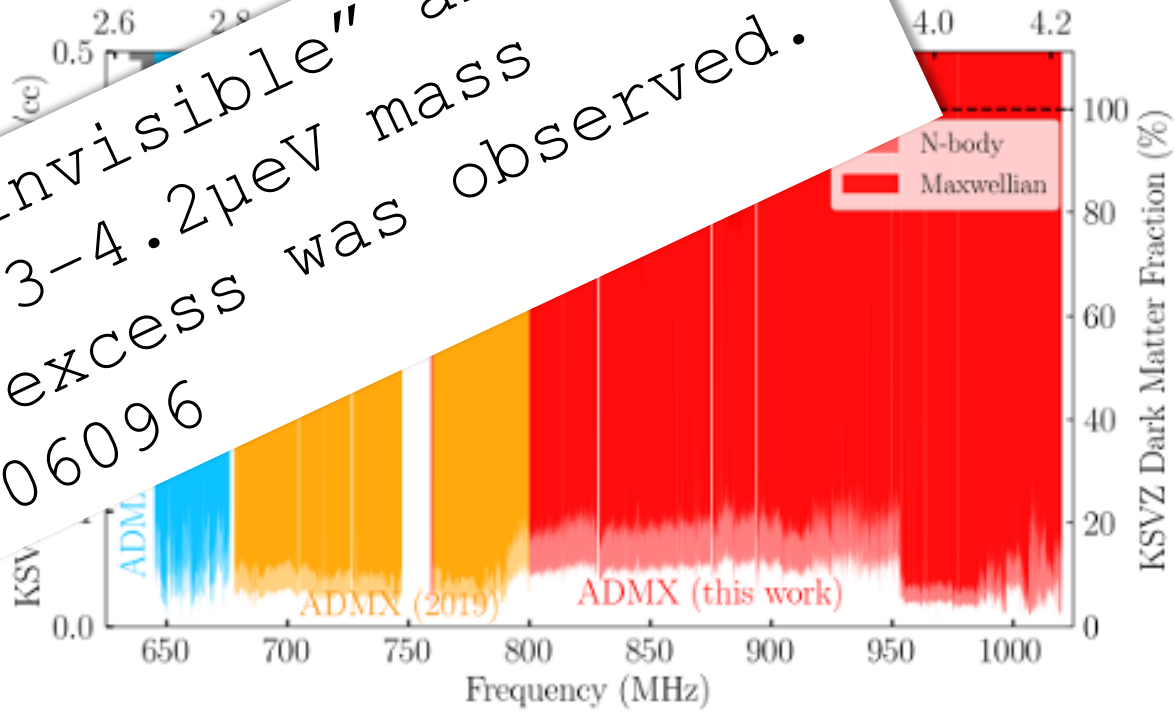
ADMX (2021)



We searched for the "invisible" axion dark matter in the 3.3–4.2μeV mass range. No axion-like excess was observed. arxiv.org/abs/2110.06096



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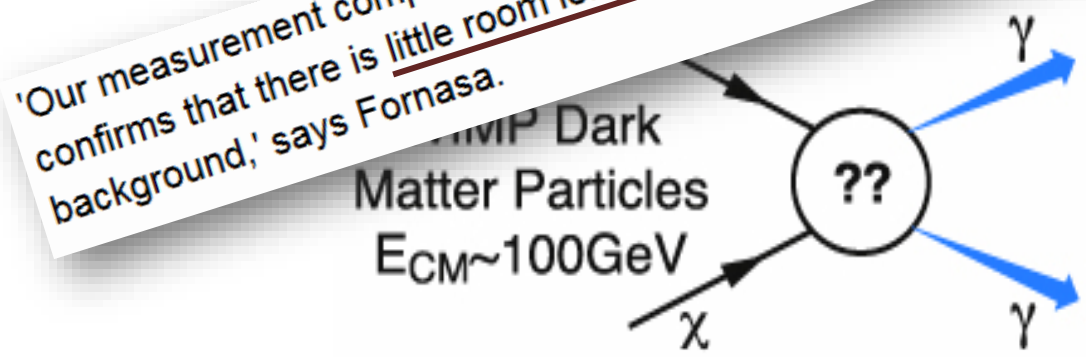
FERMI

- Detects ɣ-rays
- DM particle annihilation

'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.



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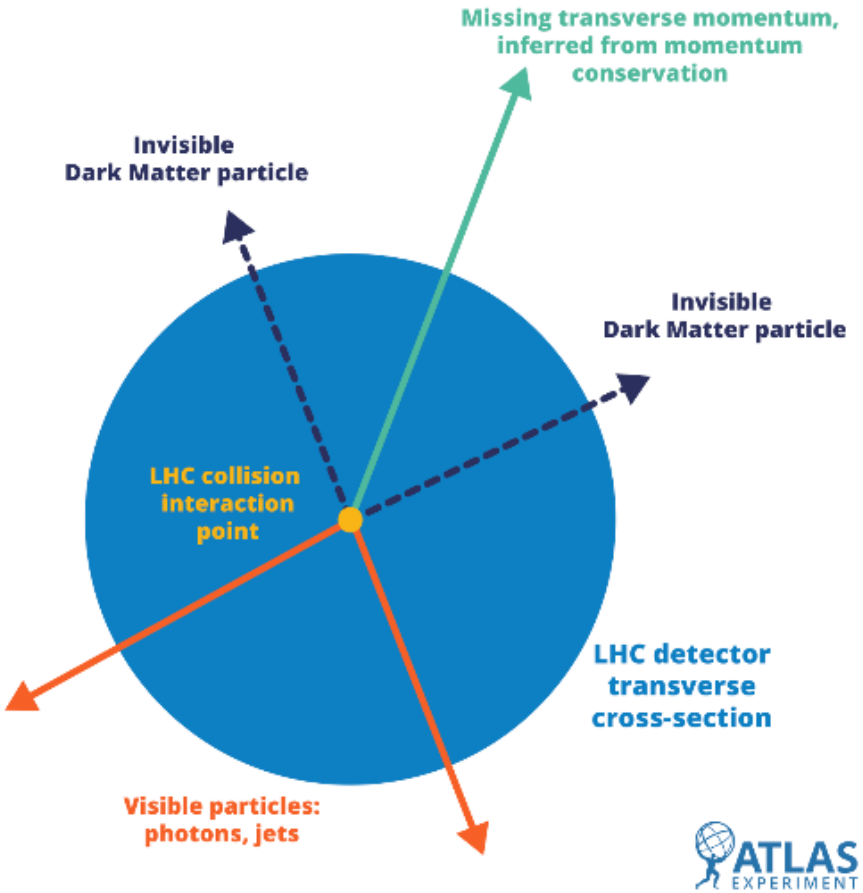
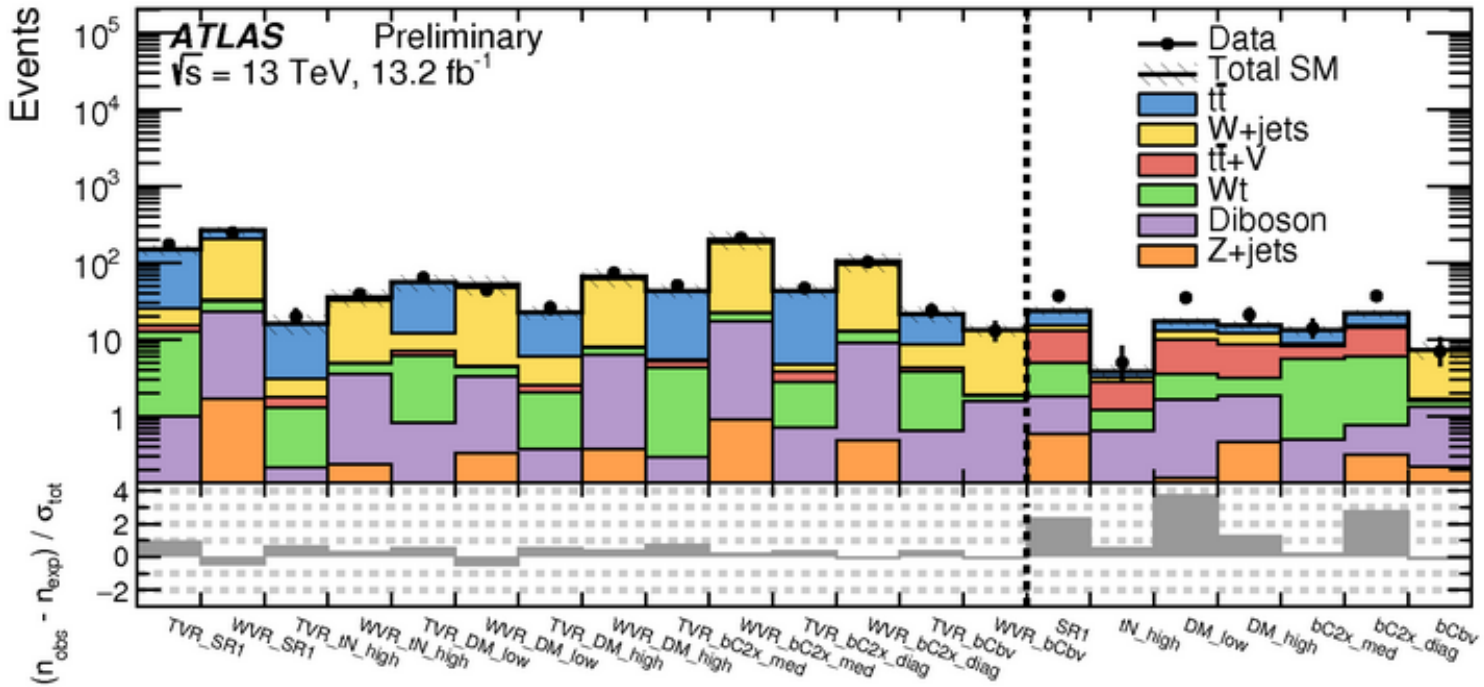
LHC





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Empty-Handed?

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Modified Gravity Theories

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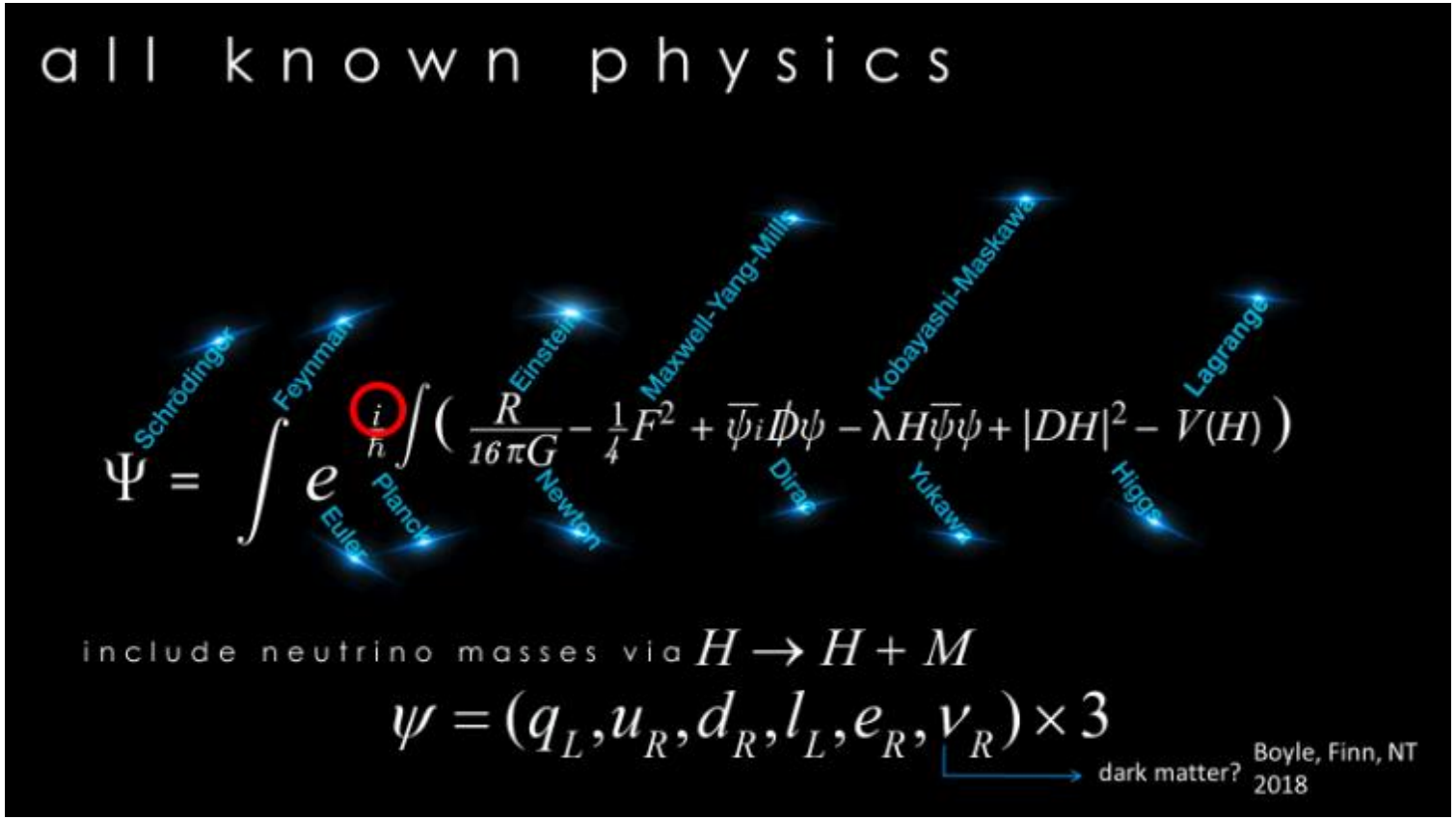
Sterile Neutrinos



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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

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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

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Current Status of Dark Matter

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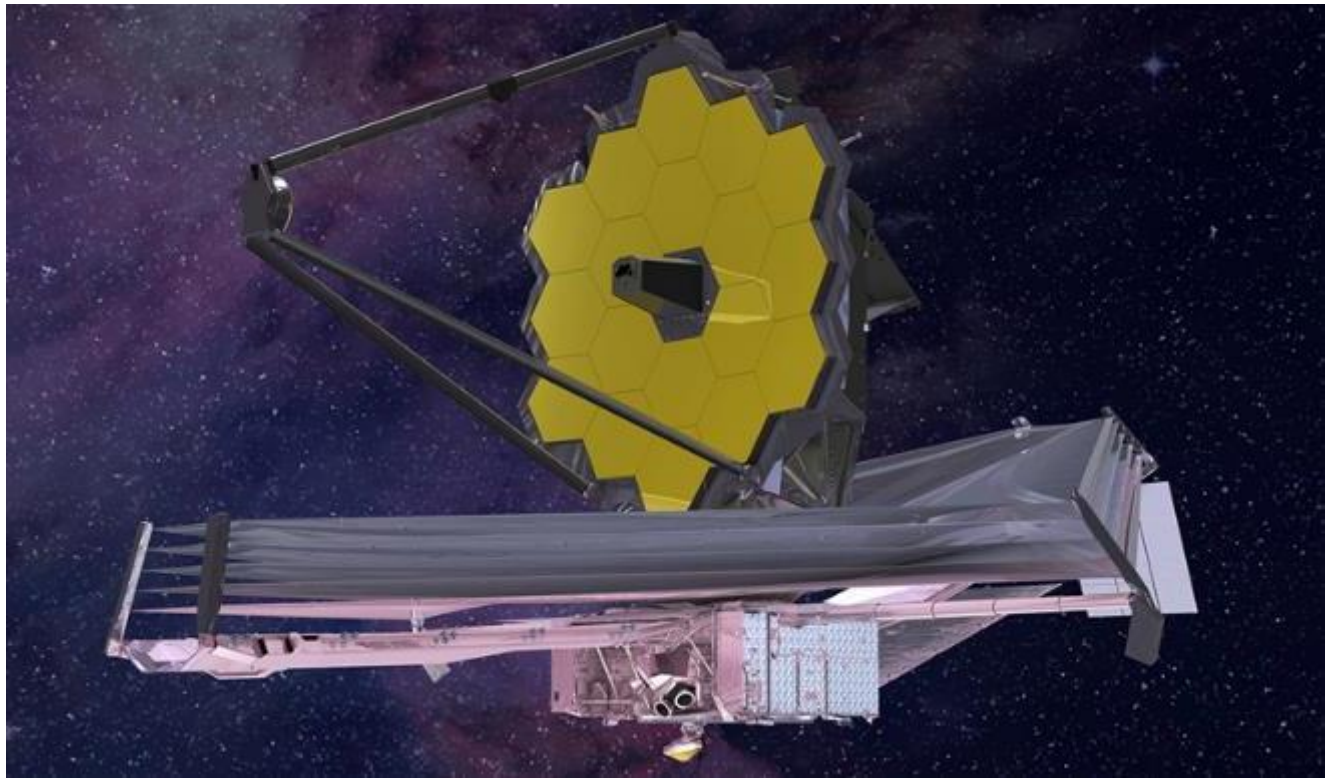
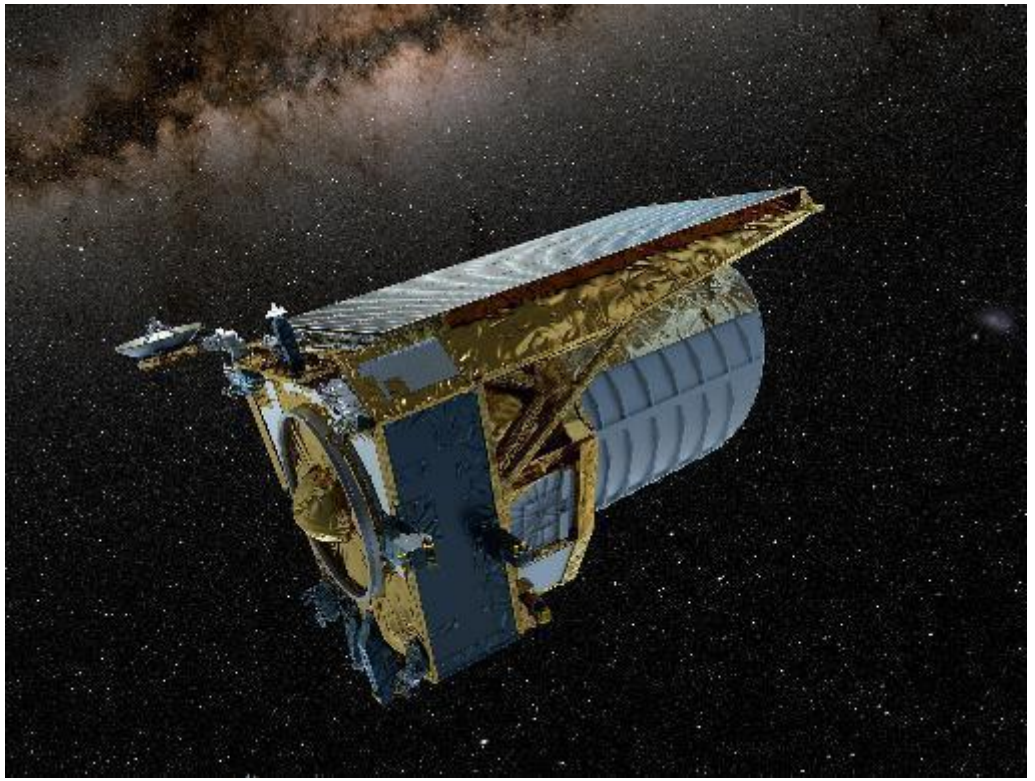
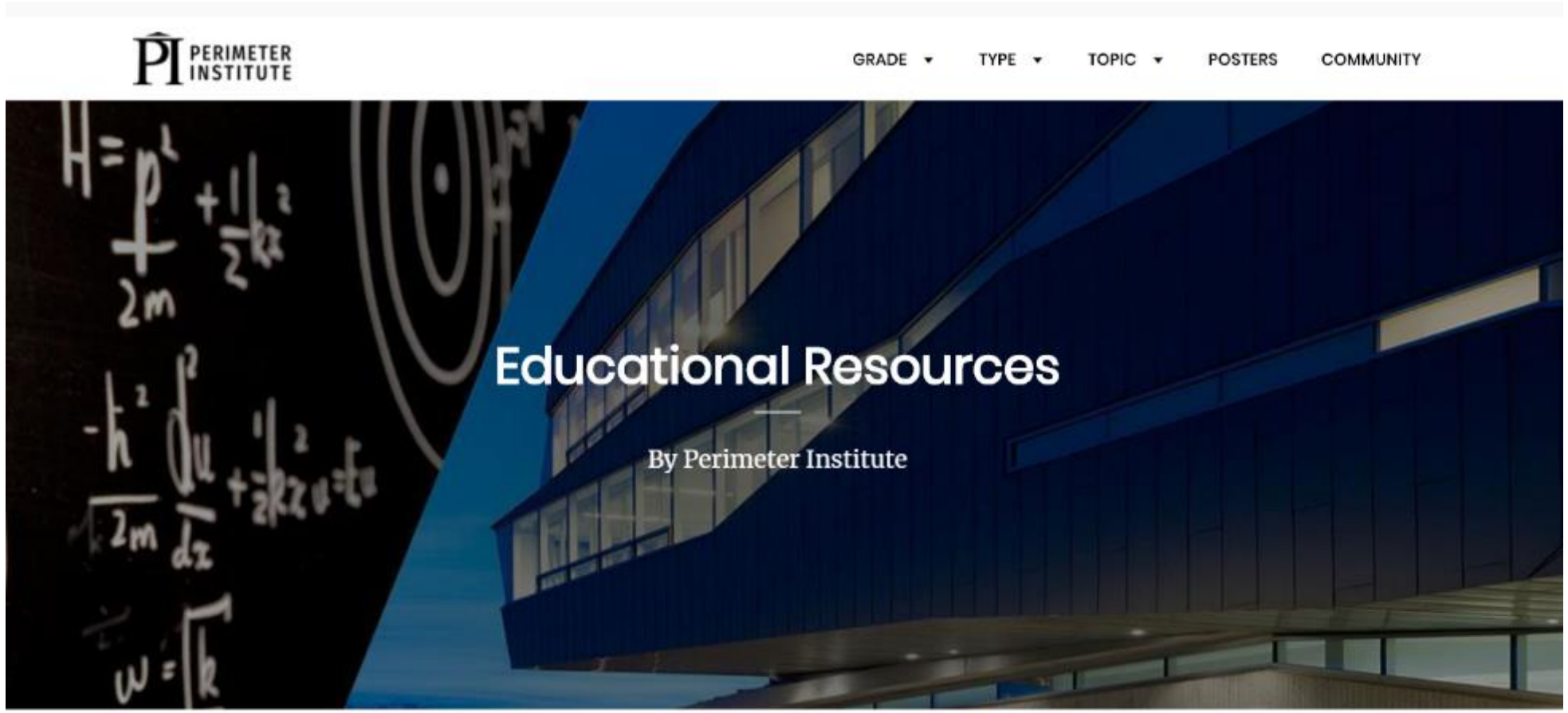
JWST and Euclid Space Telescopes







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Thank You!!

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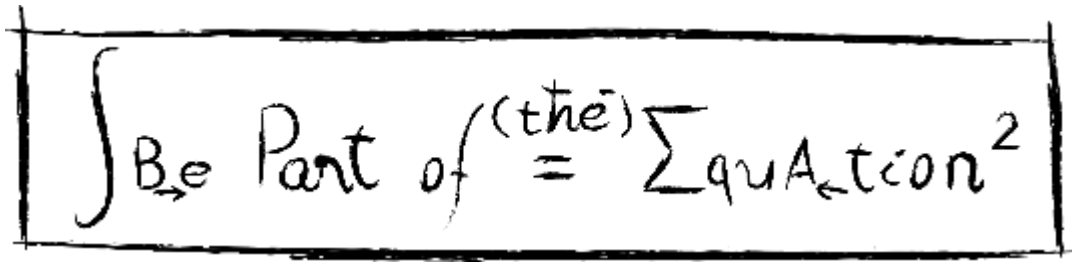

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