THE SEARCH FOR PARTICLE DARK MATTER AND DARK SECTORS

Orange County Astronomers General Meeting

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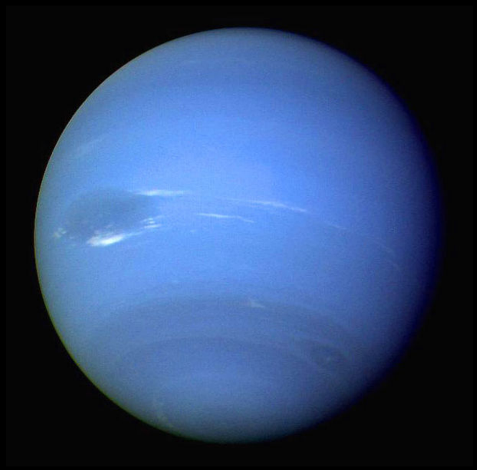
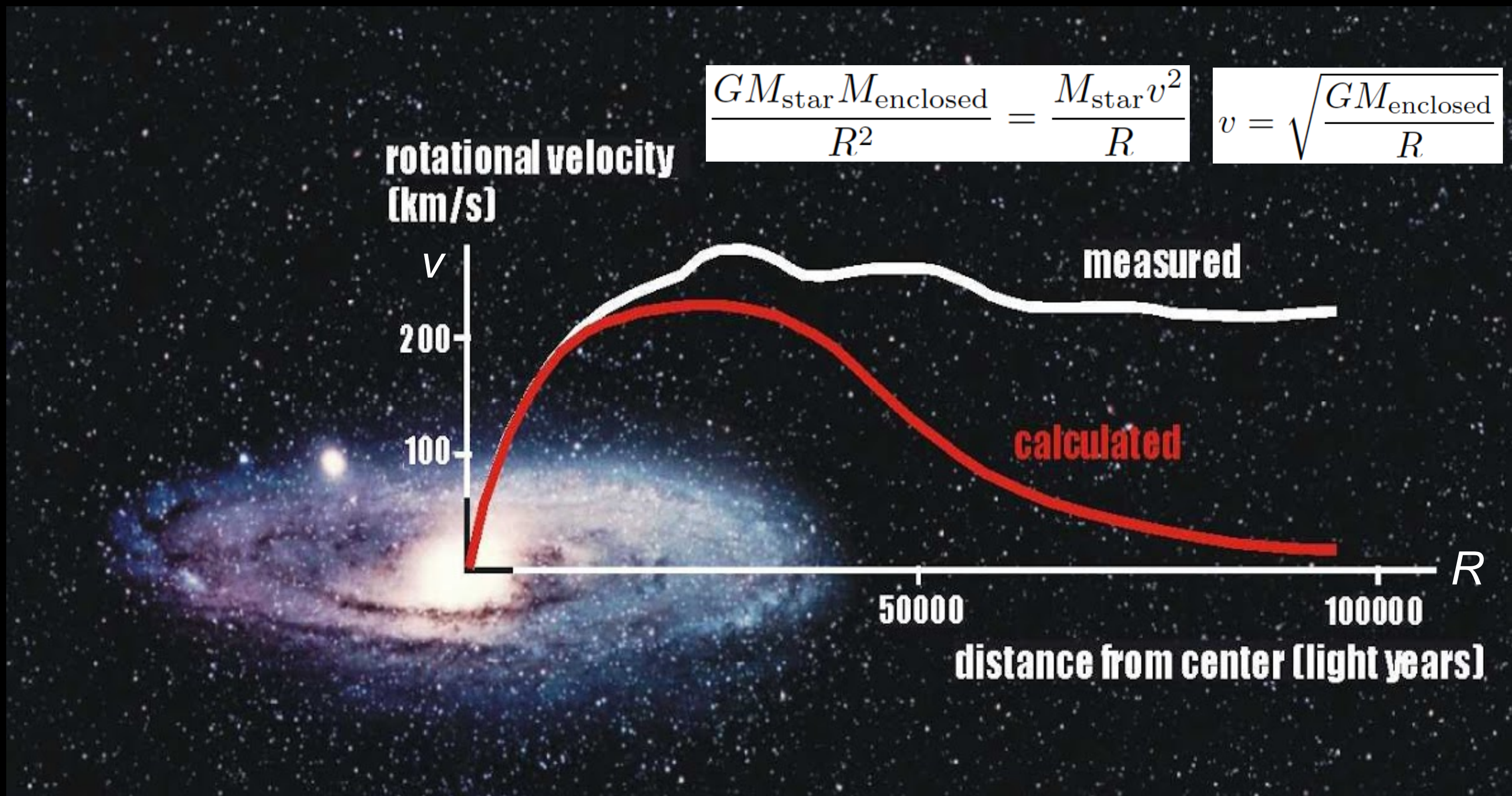
Credit: John Kormendy

DARK MATTER: HISTORICAL PRECEDENT

- In 1821 Alexis Bouvard found anomalies in the path of Uranus and suggested they could be caused by unseen matter.
- In 1845-46 Urbain Le Verrier determined where this matter should be. With this guidance, Johann Galle discovered the unseen matter at the Berlin Observatory in 1846.
- Le Verrier wanted to call it Le Verrier, but this matter is now known as Neptune, the farthest known planet (1846-1930, 1979-1999, 2006-present).

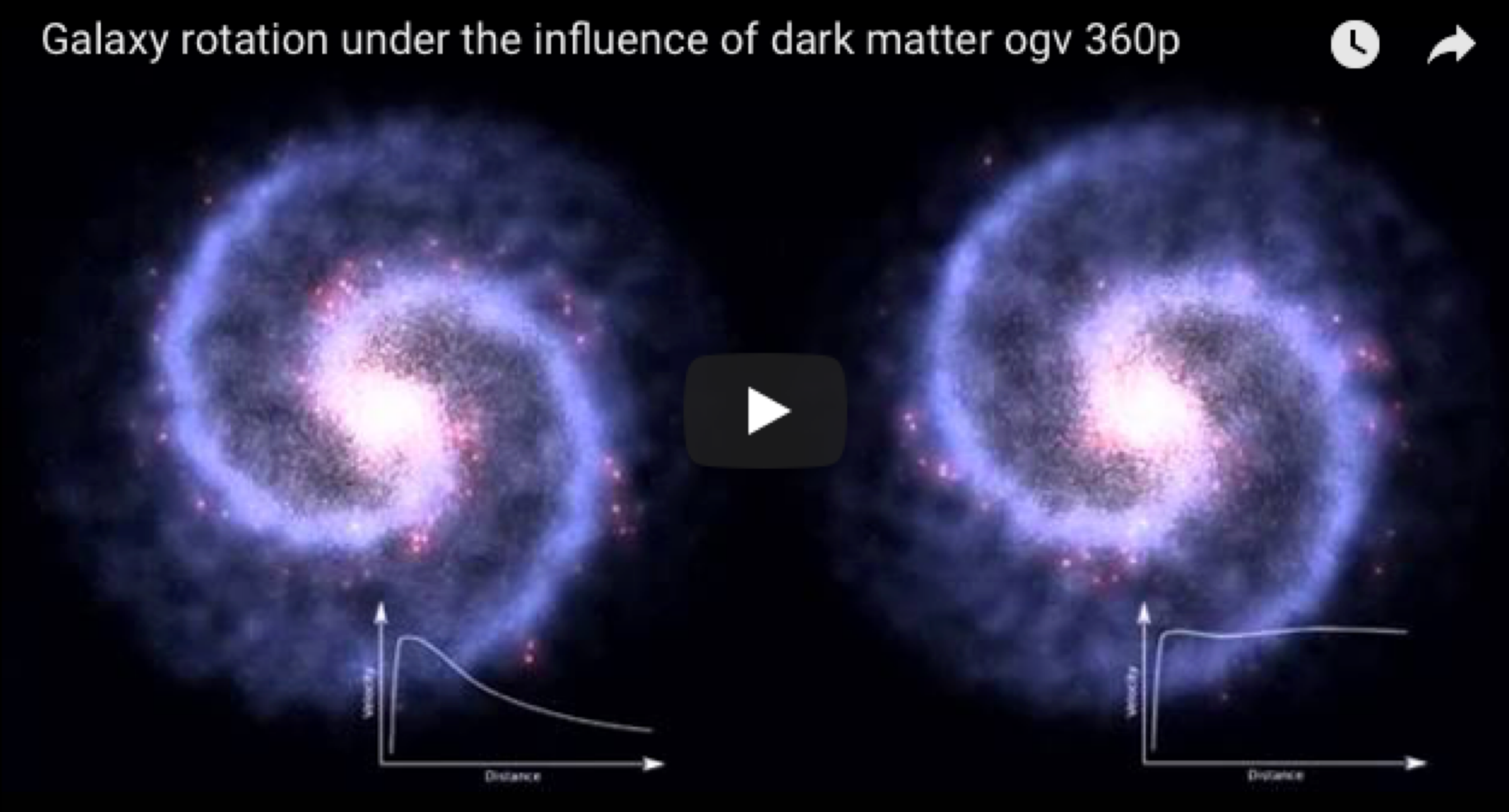


EVIDENCE FOR DARK MATTER NOW



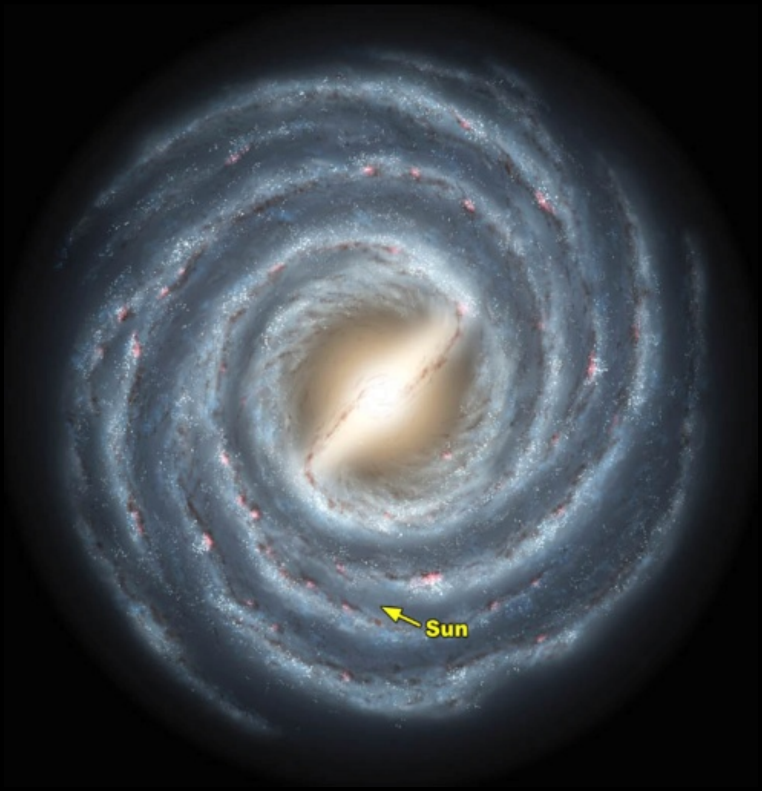
Following observations in the 1930's by Fritz Zwicky, in the 1970's Vera Rubin, Albert Bosma, and others found that stars in galaxies were rotating too fast given the visible matter

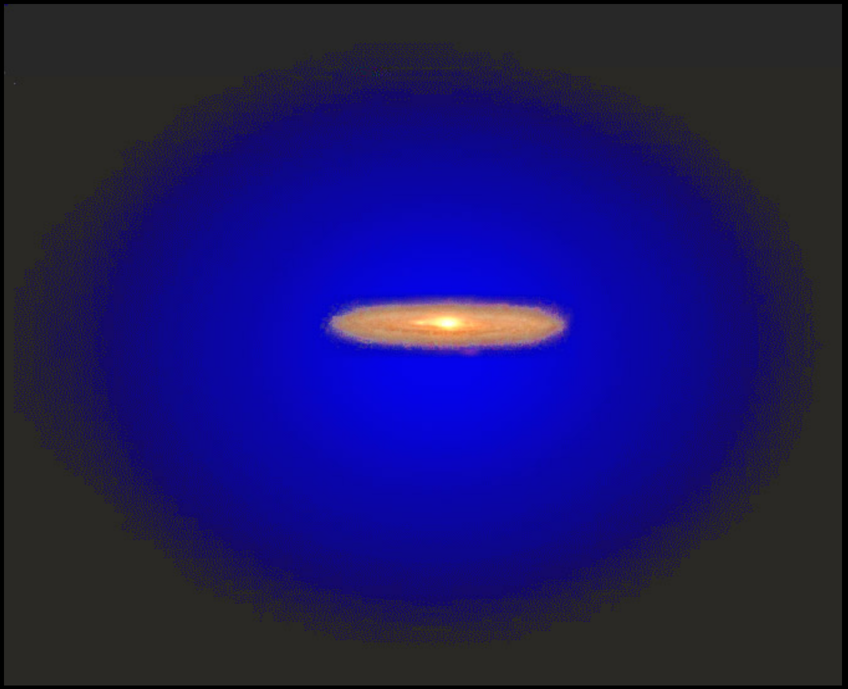
EVIDENCE FOR DARK MATTER NOW



Stars on the outskirts rotate around the galaxy faster than expected given the visible matter

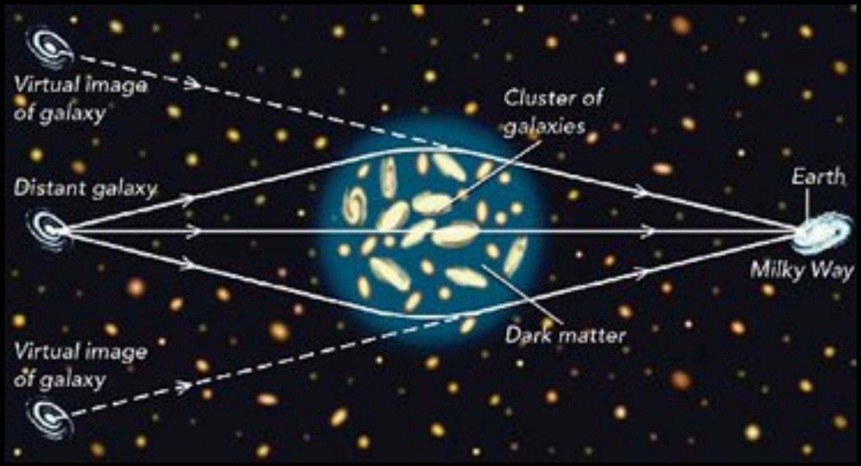
EVIDENCE FOR DARK MATTER NOW

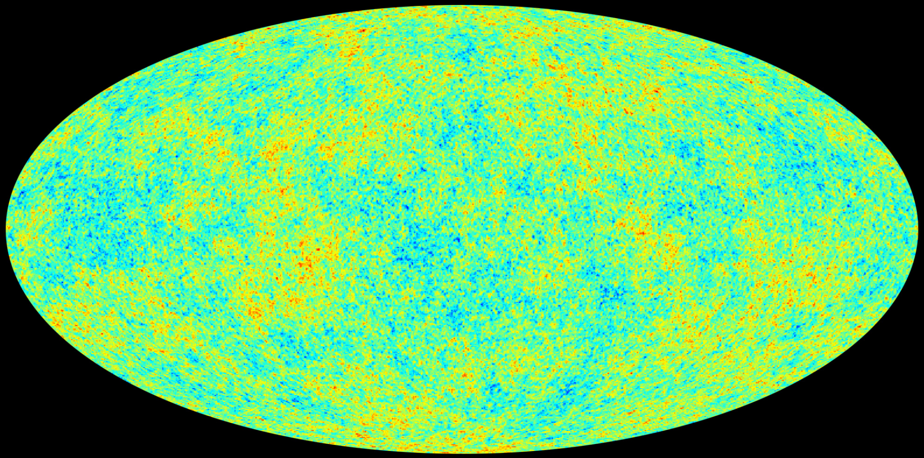




The result is that it appears that the stars we see are just islands in an ocean of invisible dark matter

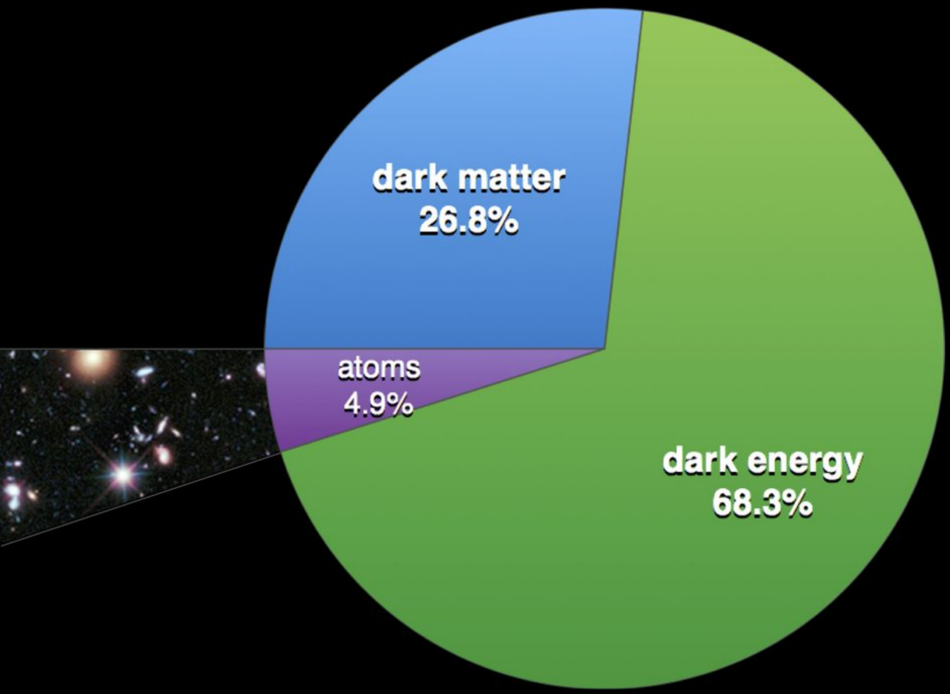
MORE EVIDENCE FOR DARK MATTER

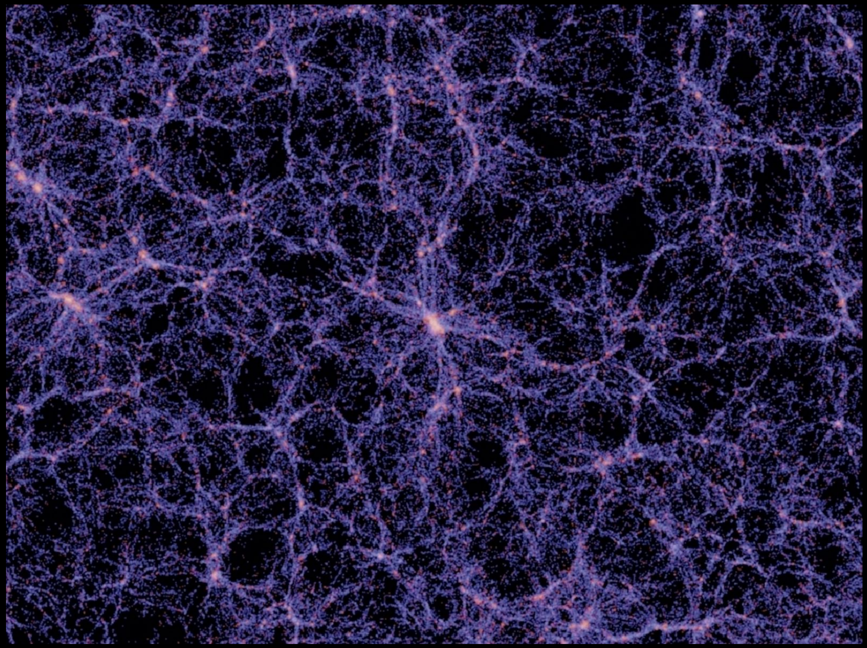




In fact, galactic rotation curves are not the only (or even the best) evidence for dark matter: strong lensing, weak lensing, cosmic microwave background, etc.

STANDARD MODEL OF COSMOLOGY

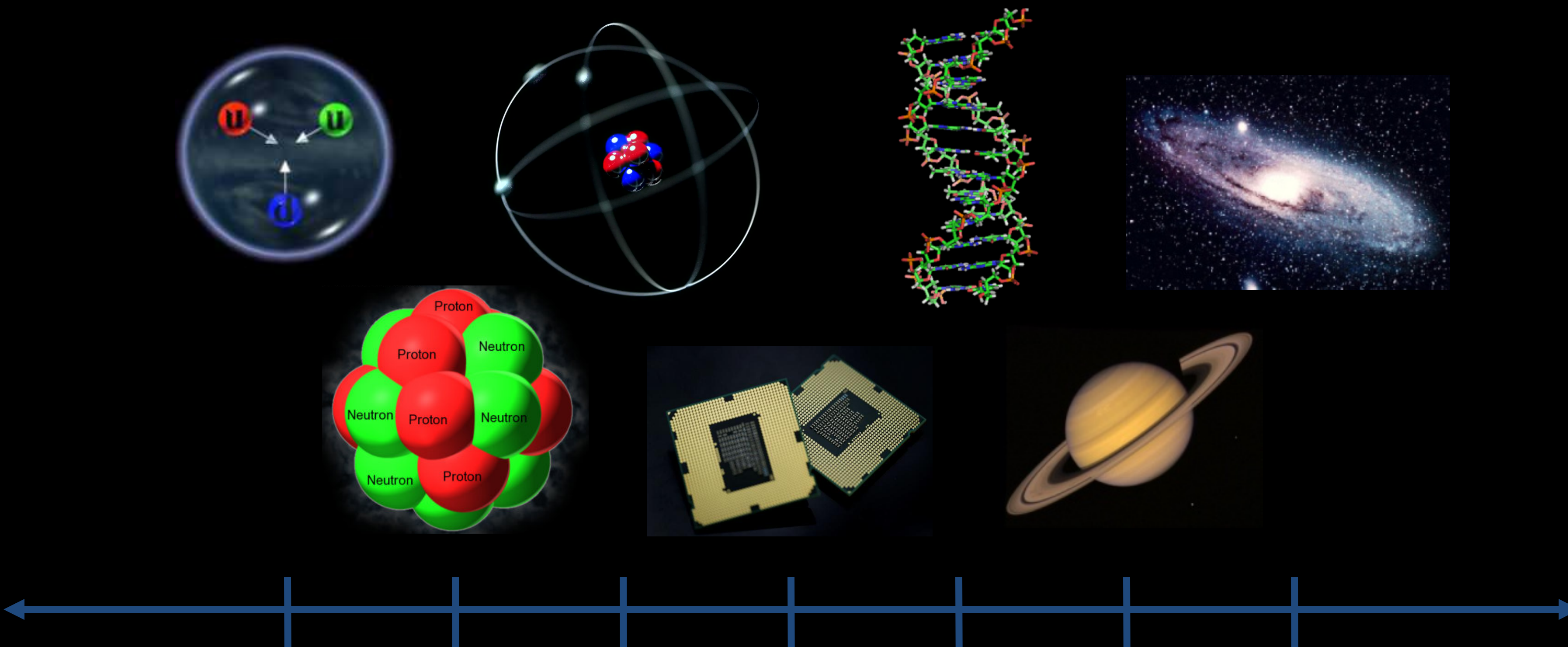




THE BOTTOM LINE: DARK MATTER IS THE DOMINANT FORM OF MATTER IN THE UNIVERSE.

BUT WHAT IS IT?

FIELDS OF PHYSICS: TRADITIONAL VIEW



Particle Physics

Nuclear Physics

Atomic Physics

Condensed Matter Physics

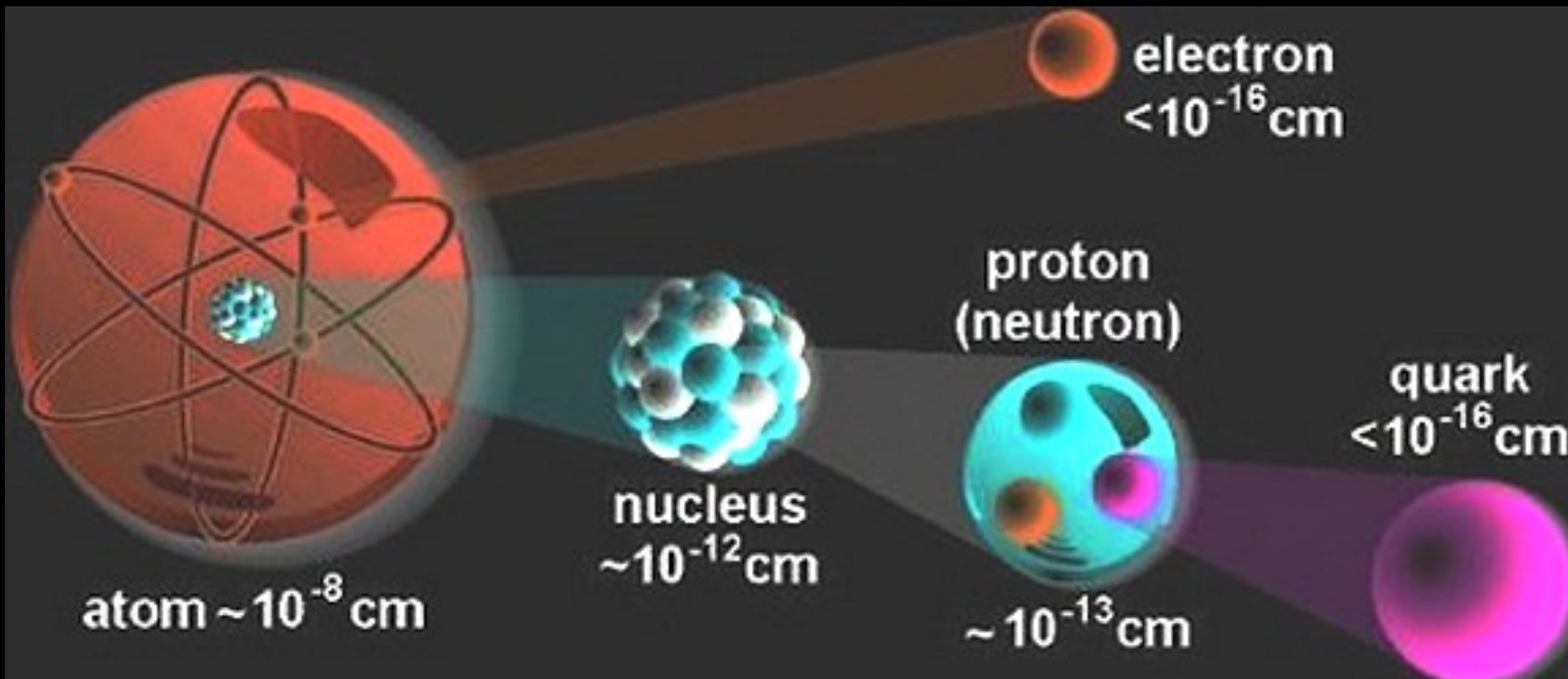
Biophysics

Astrophysics

Cosmology

FIELDS OF PHYSICS: MODERN VIEW

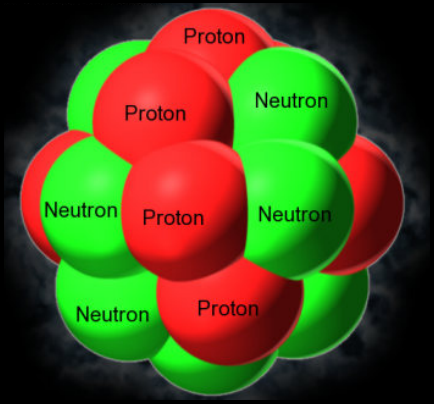
THE KNOWN MATTER



THE KNOWN FORCES

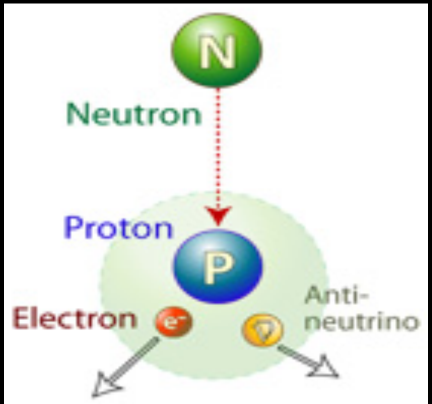
- Gravity

- Strong

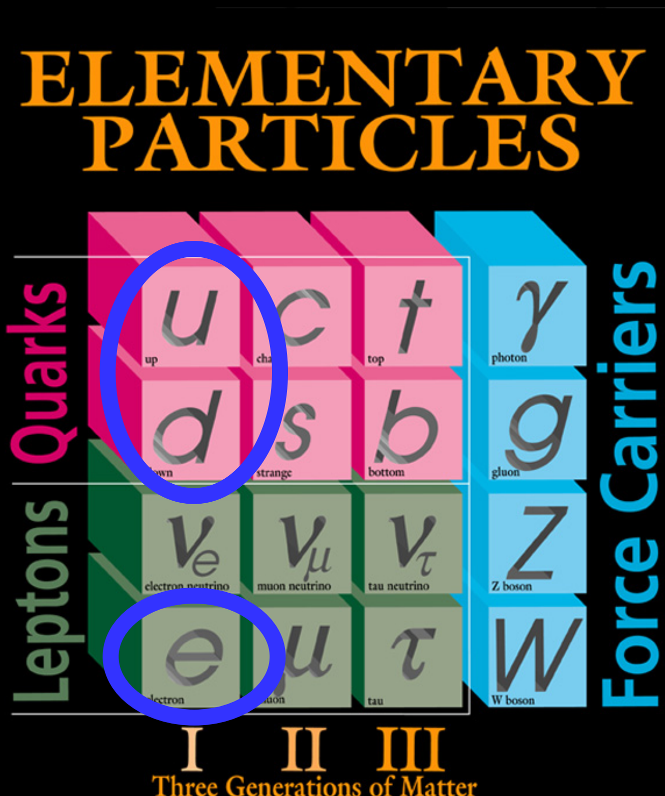


- Electromagnetism

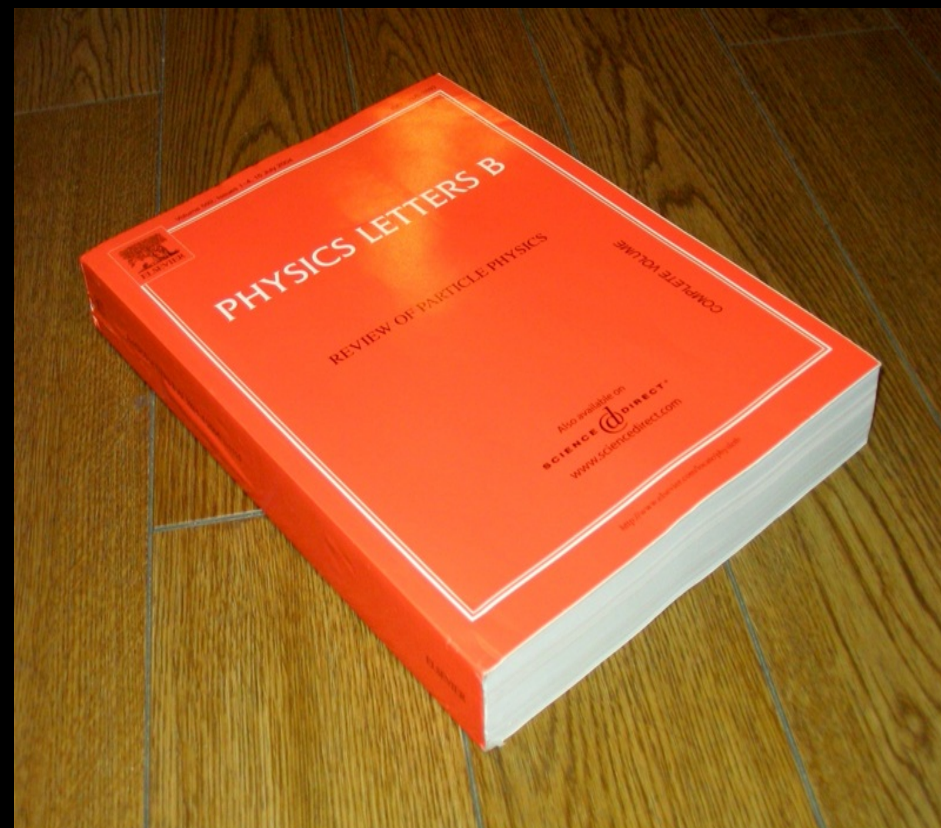
- Weak



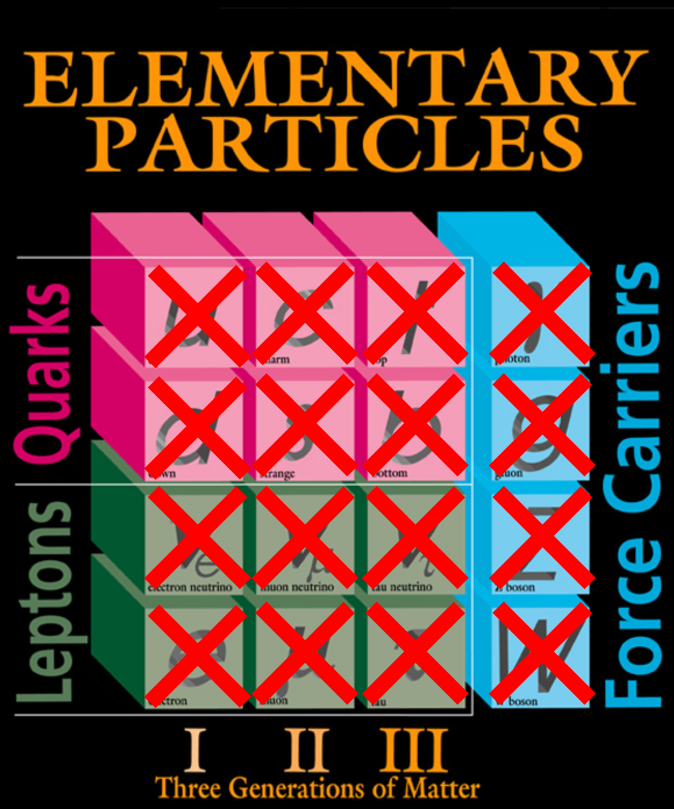
STANDARD MODEL OF PARTICLE PHYSICS



Atoms



WHICH PARTICLE IS DARK MATTER?



Known DM properties

- Not atoms
- Cold
- Stable

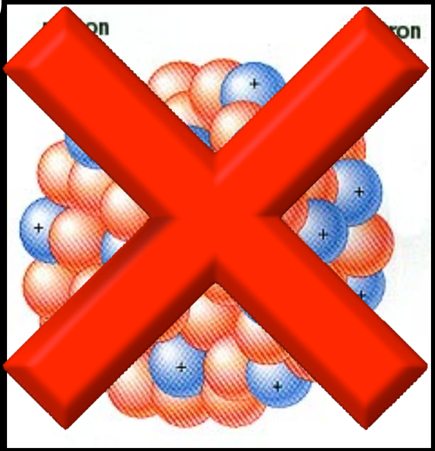
The extraordinarily successful standard models of cosmology and particle physics are inconsistent

WHICH FORCES DOES DARK MATTER FEEL?

We want to follow the historical precedent of Neptune

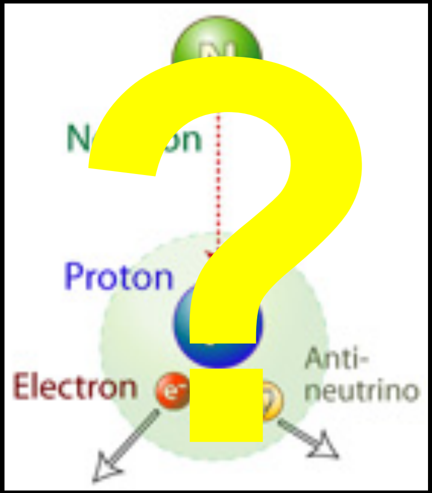
- Gravity

- Strong



- Electromagnetism

- Weak

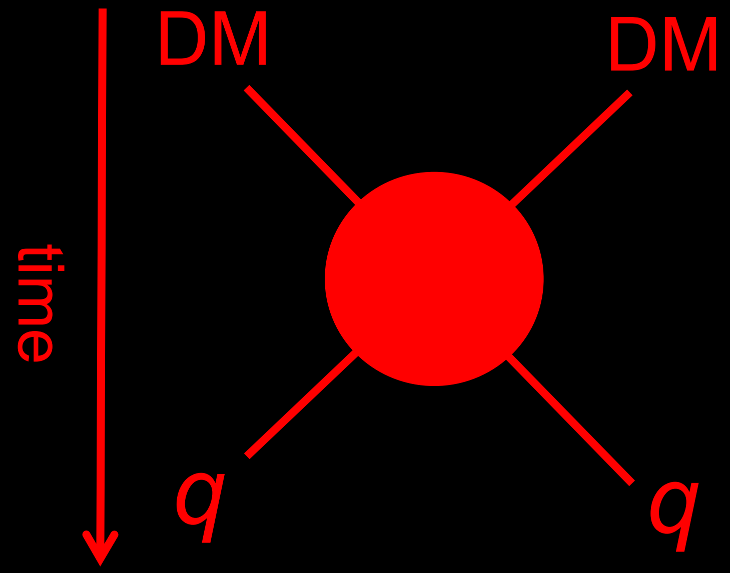


WIMPS

- Maybe dark matter feels the weak force
- DM = WIMPs: weakly-interacting massive particles
- Why WIMPs? Looking under the lamp post

THE WIMP MIRACLE

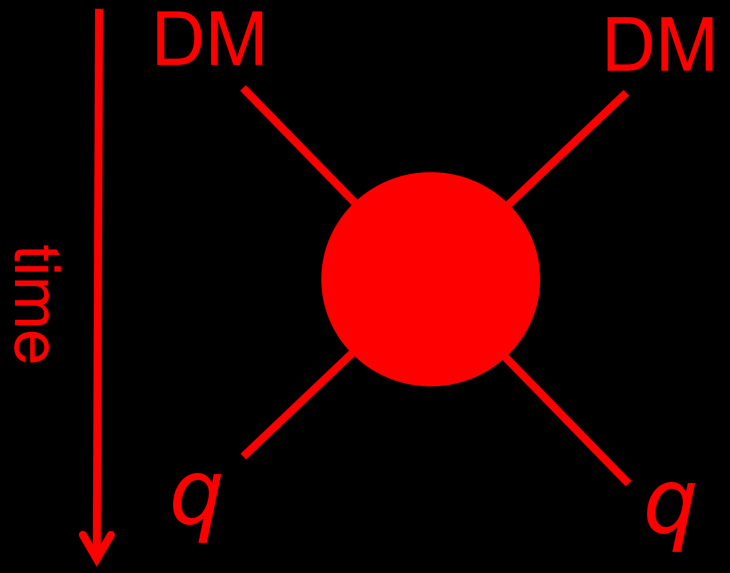
- But there's more to it than that
- Many theories predict WIMPs that are around 100 times heavier than the proton
- Such particles are present just after the Big Bang, but then annihilate in pairs. Assuming they annihilate through the weak force, calculations show that they should be ~ 10% of the Universe now. This is what is required to be dark matter!



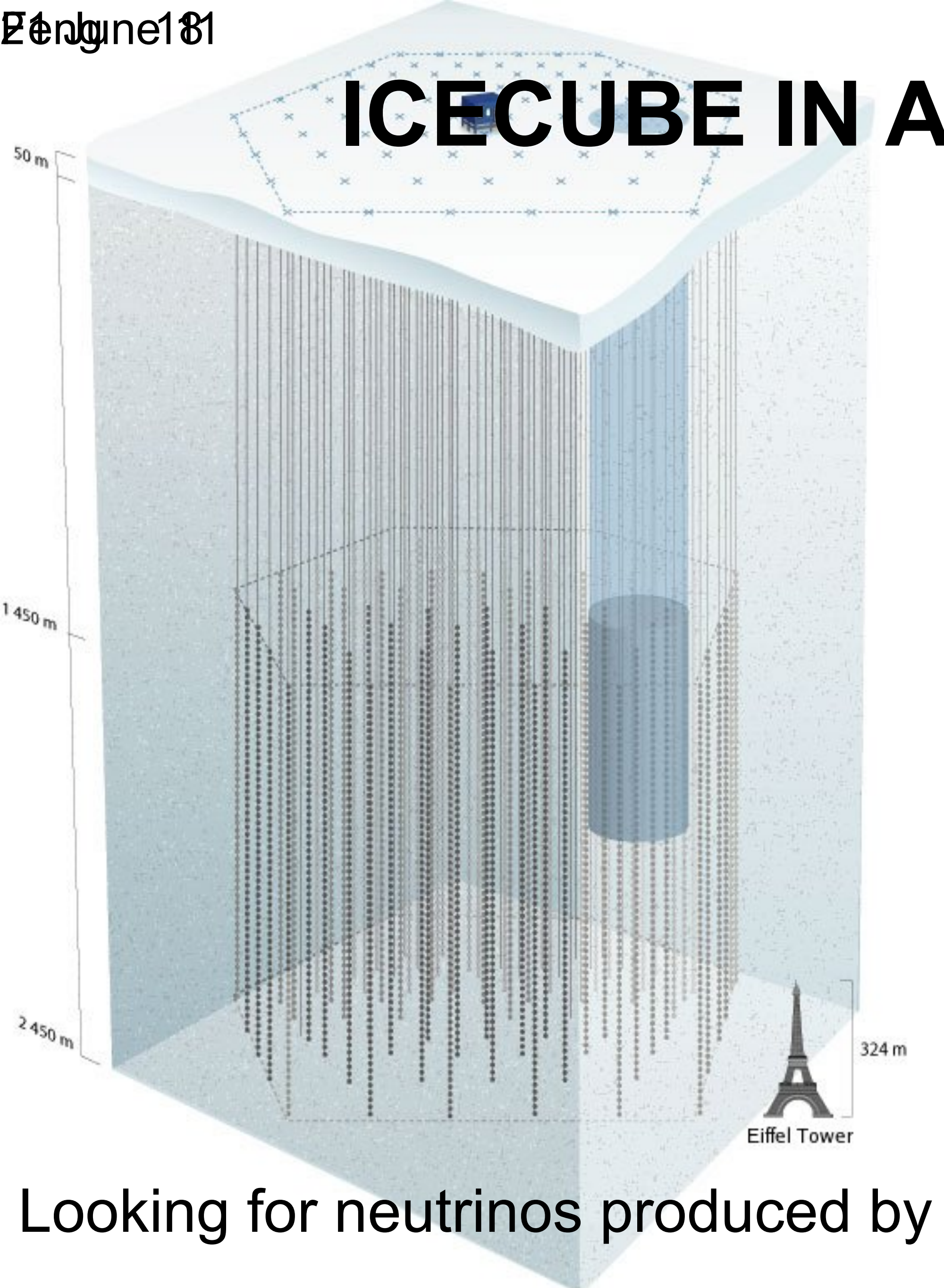
WIMP ANNIHILATION

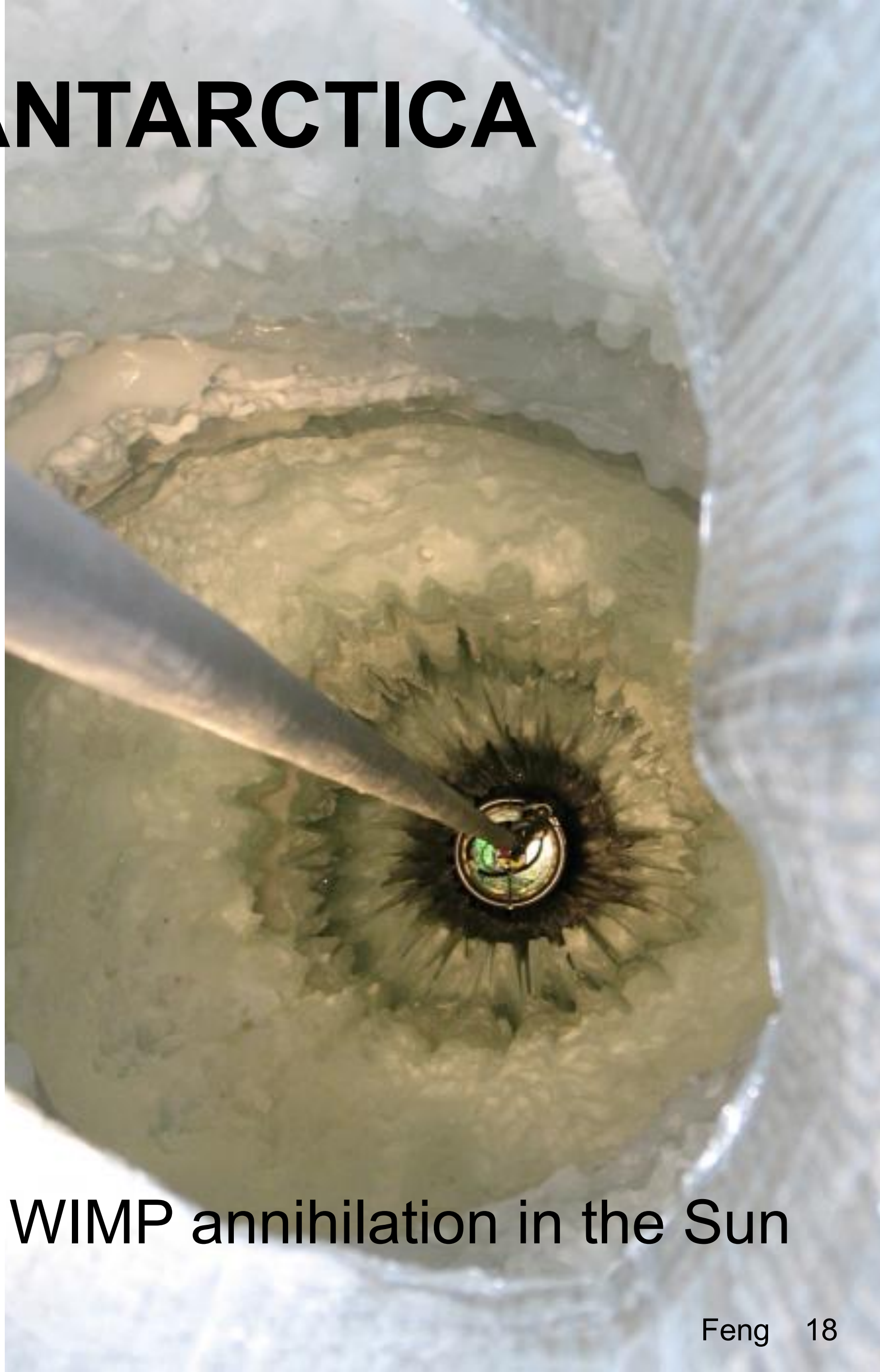
- If WIMPs annihilated in the early Universe, they should also be doing that now

- We can look for rare forms of matter and anti-matter created in these collisions



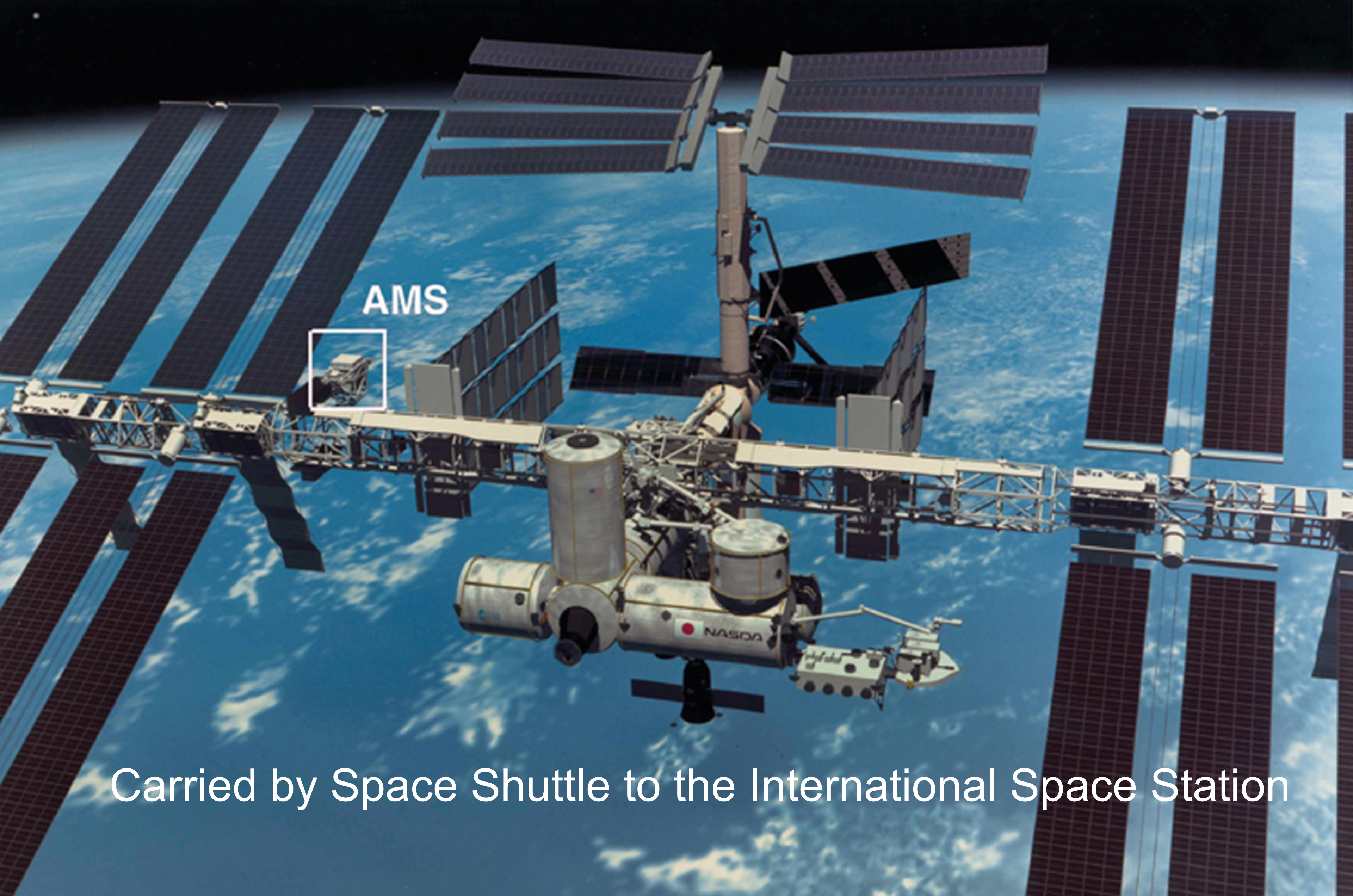
ICECUBE IN ANTARCTICA





Looking for neutrinos produced by WIMP annihilation in the Sun

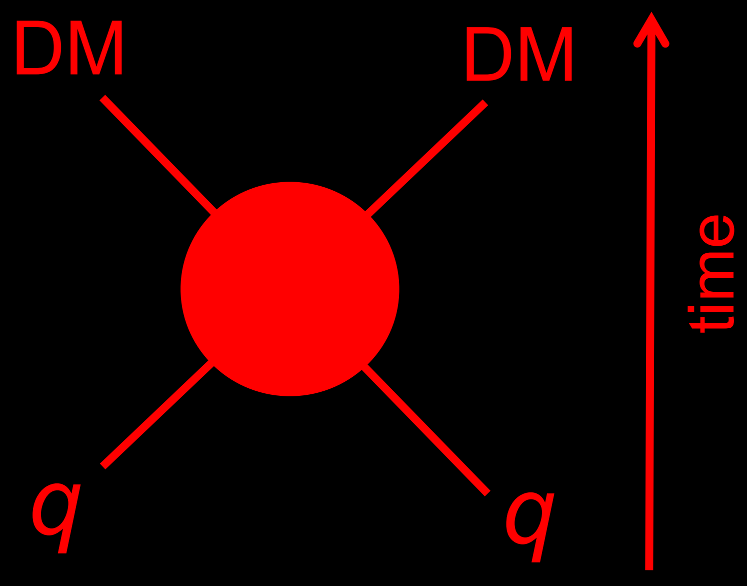
ALPHA MAGNETIC SPECTROMETER



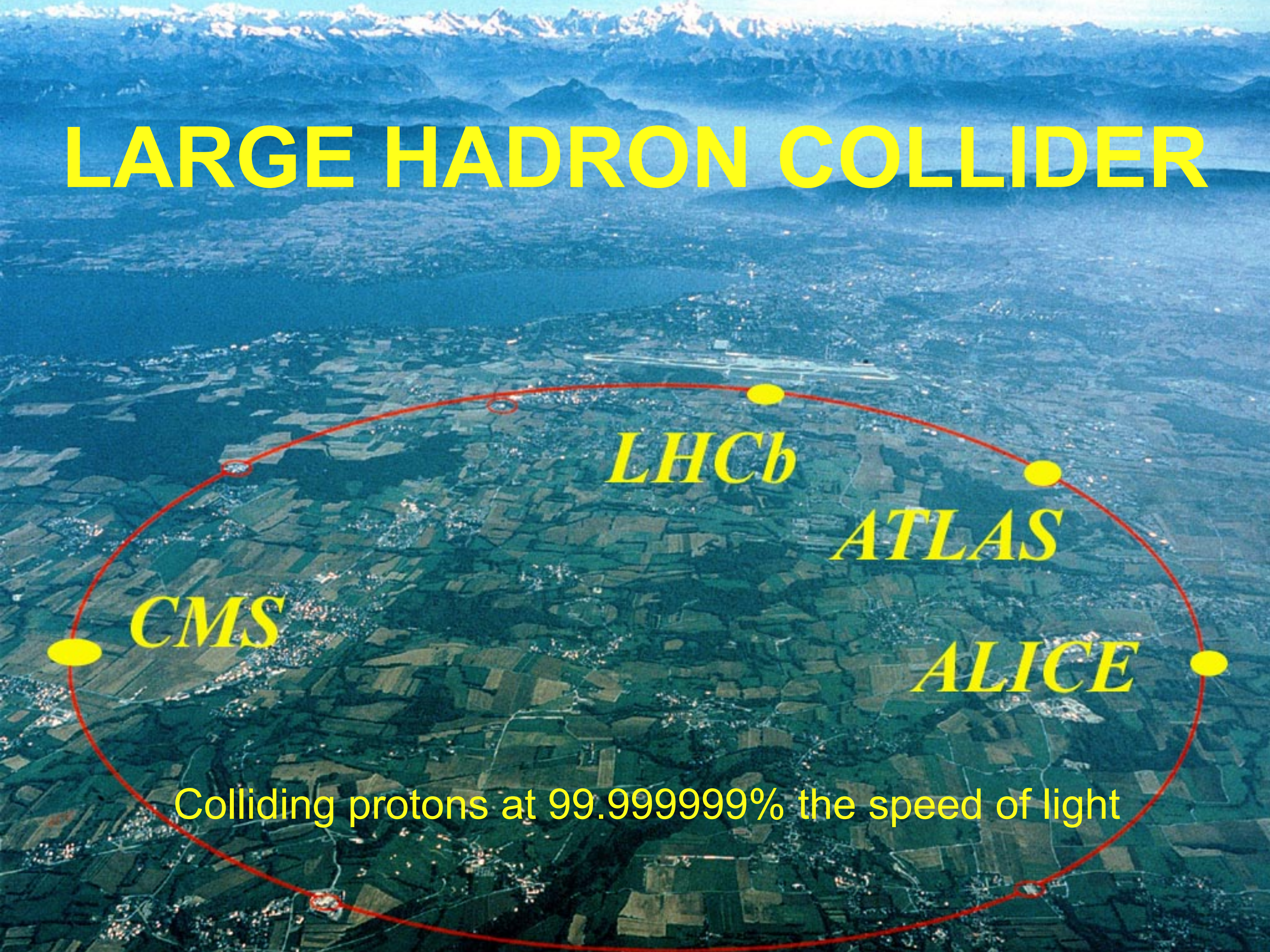
Carried by Space Shuttle to the International Space Station

WIMP PRODUCTION

- Alternatively, if dark matter annihilated to normal matter, it should also be possible to run time *backwards*
- We can collide two normal particles at high velocities to create dark matter, which we detect as missing energy

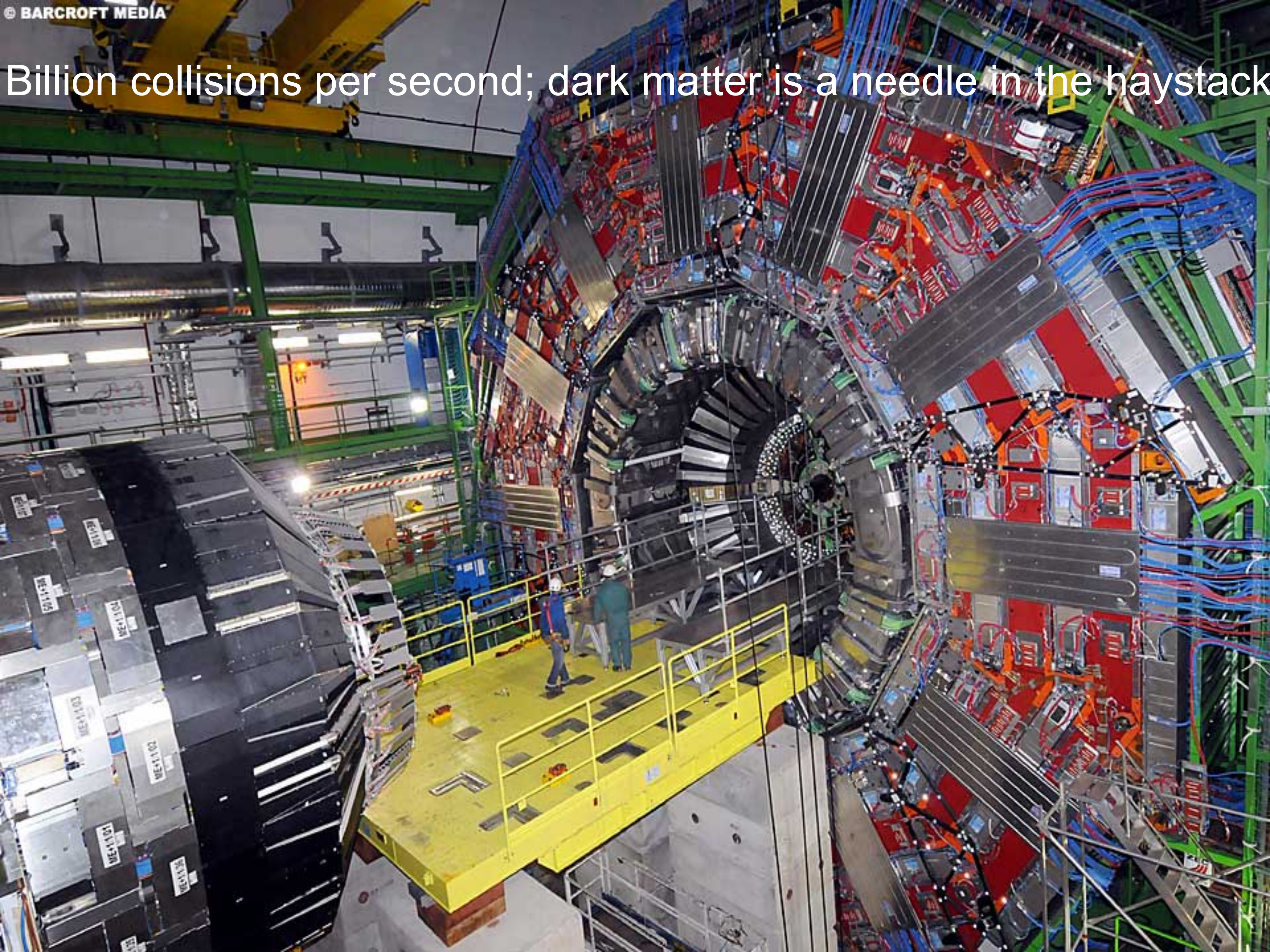


LARGE HADRON COLLIDER



Colliding protons at 99.999999% the speed of light

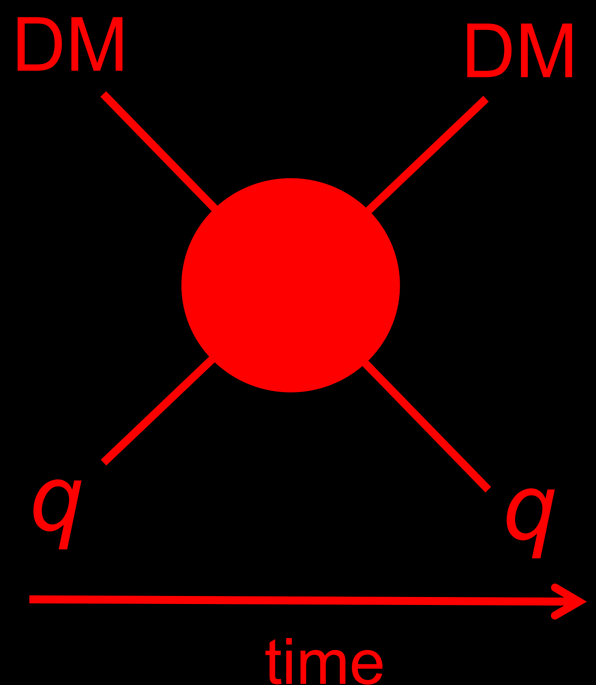
Billion collisions per second; dark matter is a needle in the haystack



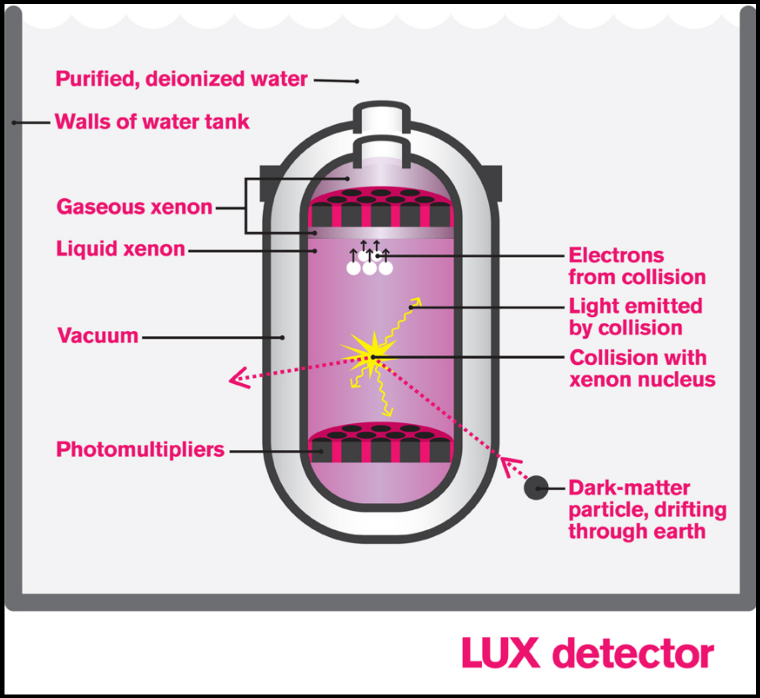
WIMP RECOILS

- If WIMPs annihilated in the early Universe, we should also be able to run time *sideways*

- We can watch for normal matter recoiling from a WIMP collision. At any given time, there is roughly 1 WIMP per coffee cup, but their interactions are weak and recoils are rare



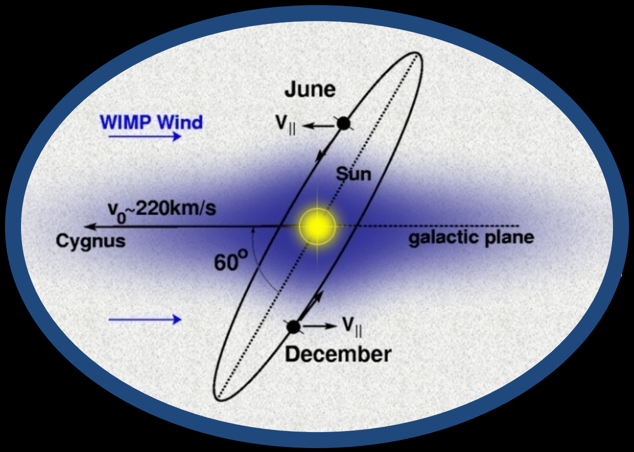
DIRECT DETECTION SEARCHES



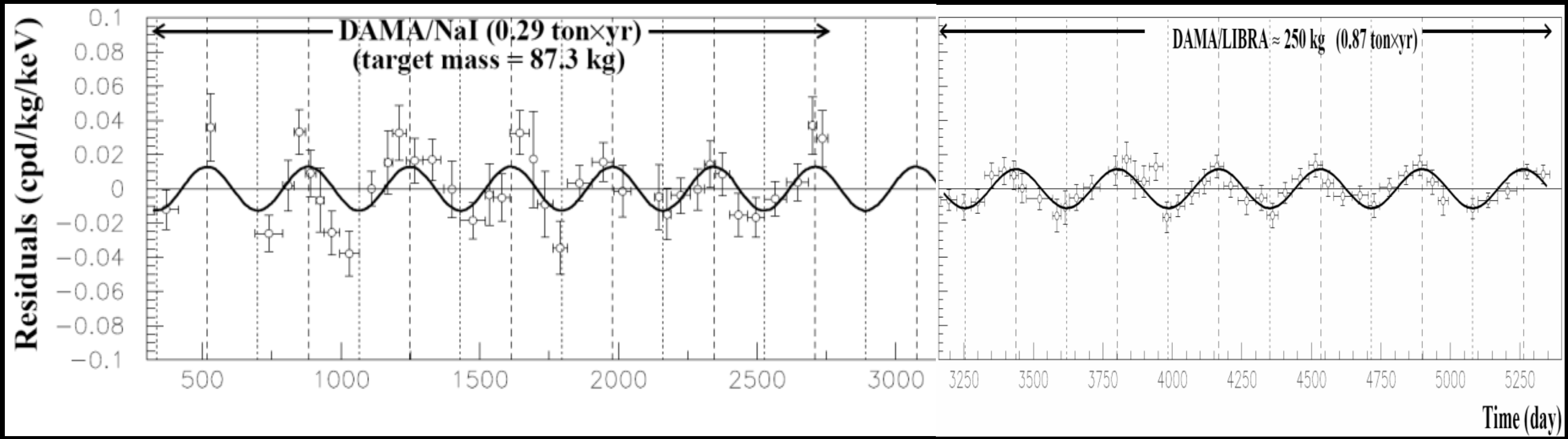
These and other similar experiments are operating deep underground and sensitive to 1 interaction per ton per year

DAMA/LIBRA IN ITALY

Collision rate should change as the Earth goes around the Sun: annual modulation

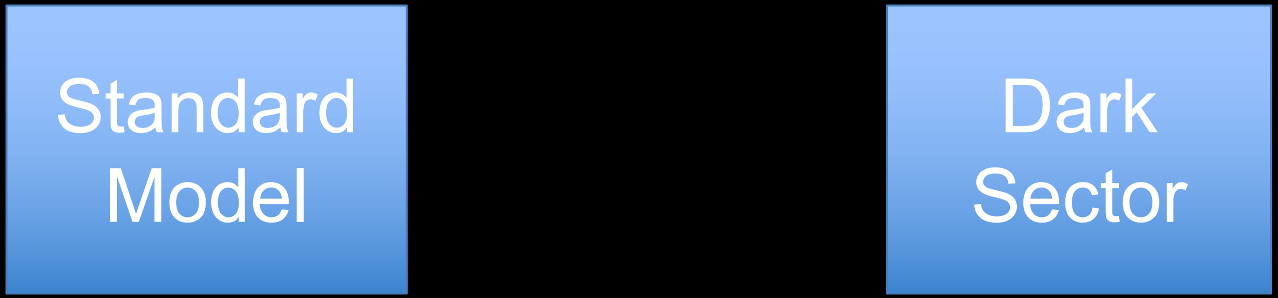


DAMA/LIBRA signal with period ≈ 1 year, maximum ≈ June 2



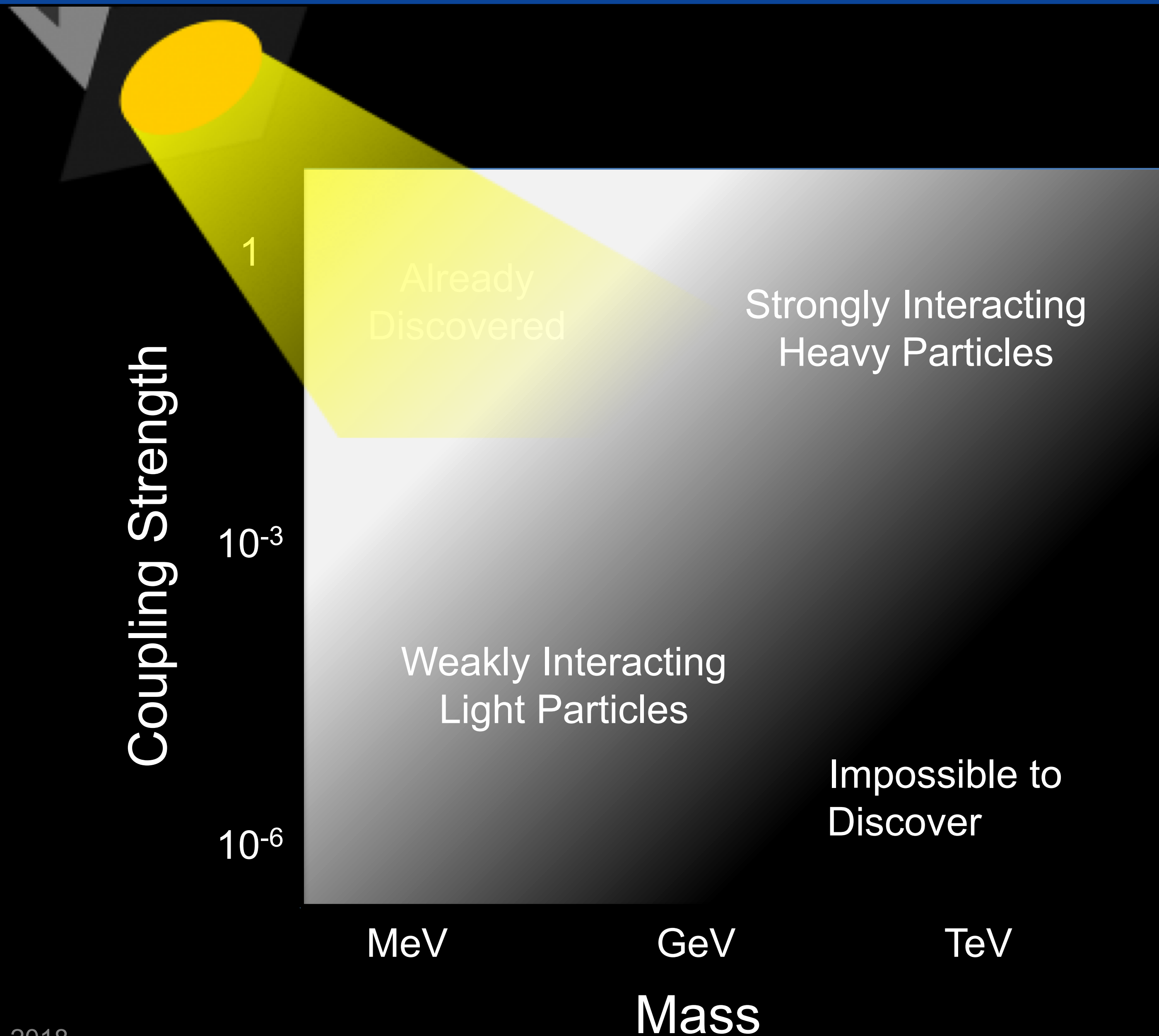
DARK SECTORS

- Despite tantalizing hints, so far no compelling signals of particle dark matter have appeared.
- What are other possibilities? Dark sectors!



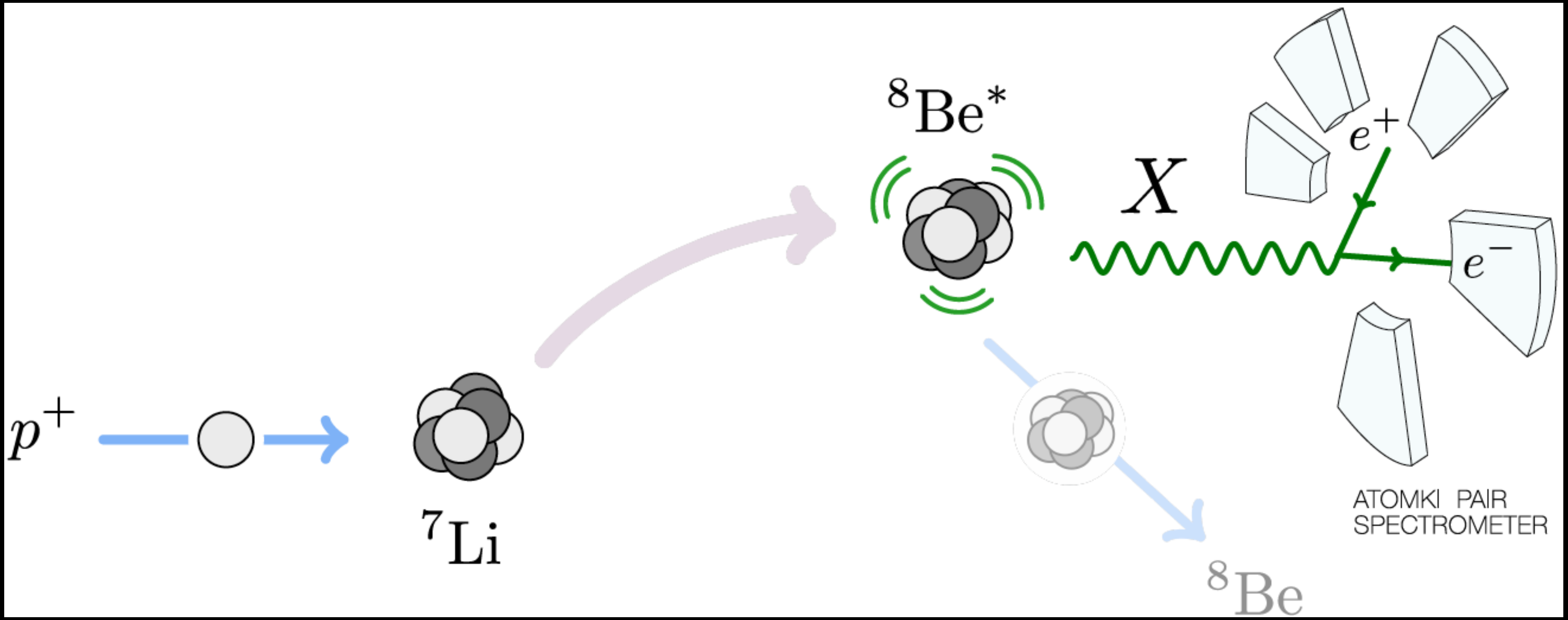
- The dark sector includes dark matter, but also possibly other forces – a 5th force. We can look for this by looking for a new force-carrying particle. These could be far lighter than WIMPs, opening up new avenues for detection.

THE LAMPPOST LANDSCAPE



NEW FORCES IN NUCLEAR EXPERIMENTS

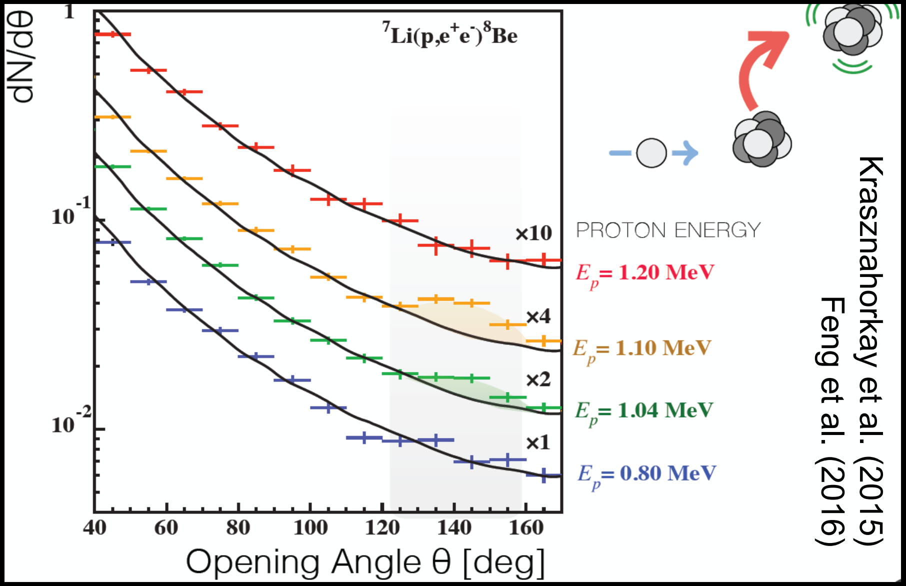
- We can look for new force carrying particles by creating excited nuclear states and watching them decay.
- For example, the decays of excited Beryllium-8 nuclei:



THE ATOMKI ^{8}BE EXPERIMENT

THE ATOMKI ANOMALY

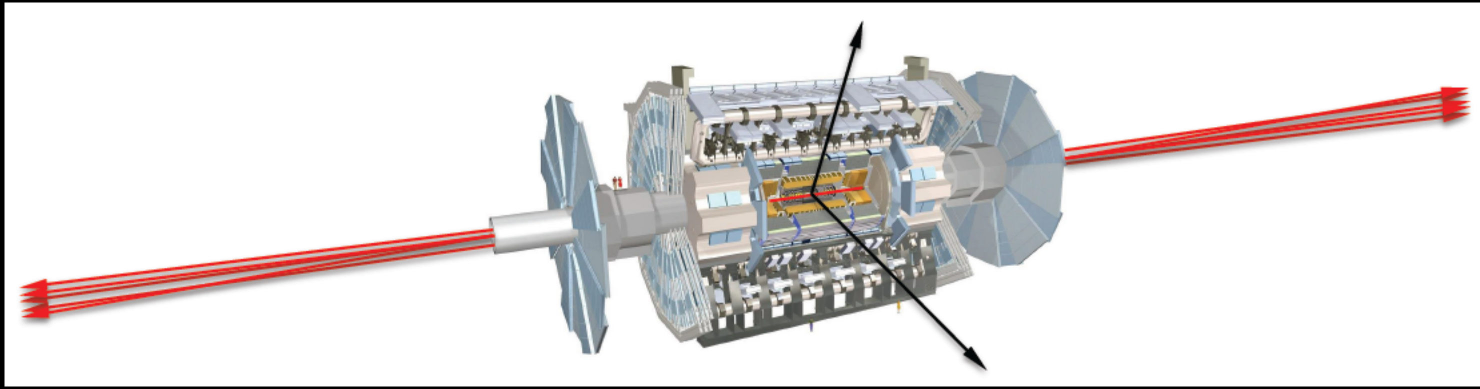
- A bump at ~140 degrees is observed as one passes through the ^{8}Be* resonance – it looks like the e^+e^- pairs are coming from the decays of a new kind of particle.
- Background fluctuation probability: 5.6 x 10^{-12} (6.8σ)



- This may be the first sign of a new force or an experimental error; follow-up experiments are underway.

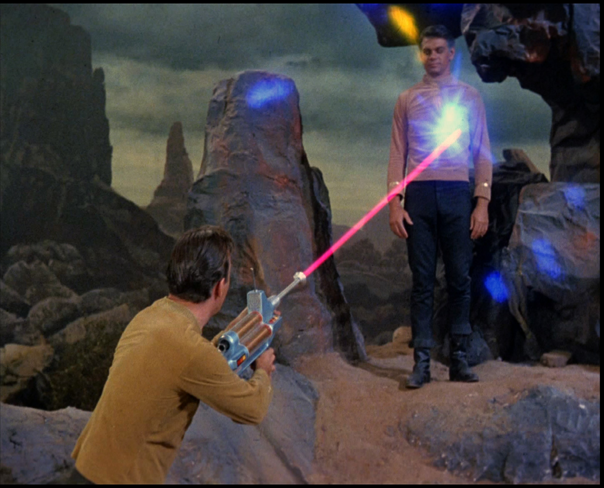
NEW SEARCHES FOR DARK SECTORS

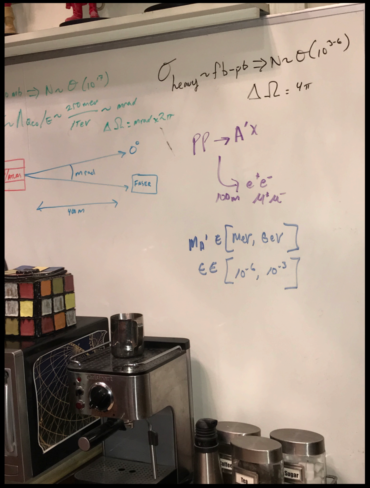
- We can also try to make new force-carrying particles at colliders.
- If they are very light, we can search for these with fast, small, and cheap experiments, opening the floodgates for new proposals.
- An example: at the LHC, such particles are dominantly produced parallel to the beam, not perpendicular to it.



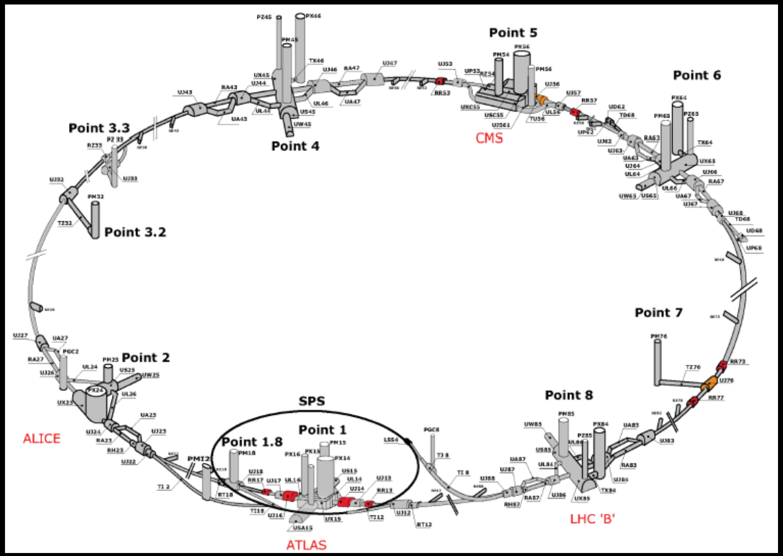
FASER

- To take advantage of this, a group of researchers at UCI, CERN, and other institutions have proposed a new experiment at the LHC called FASER.
- FASER: ForwArd Search ExpeRiment. “The acronym recalls another marvelous instrument that harnessed highly collimated particles and was used to explore strange new worlds.”





FASER


Point 5
Point 6
Point 3.3
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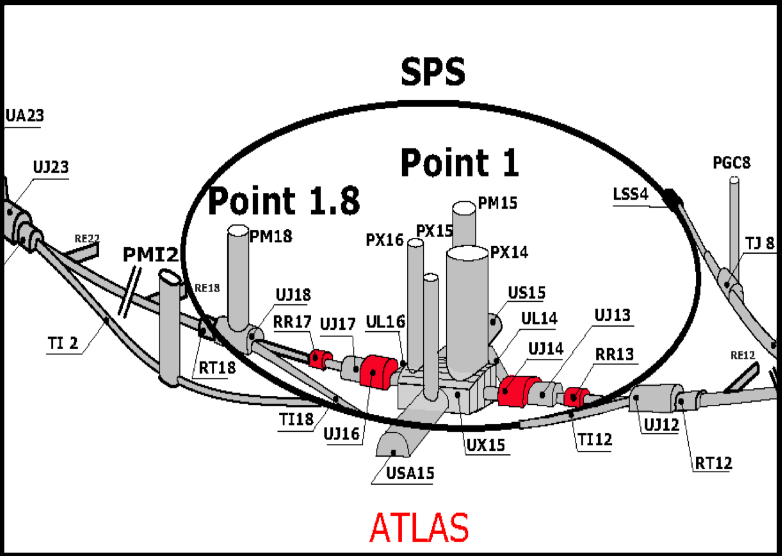
ALICE
SPS
Point 1
Point 1.8
Point 8
LHC 'B'
ATLAS


SPS
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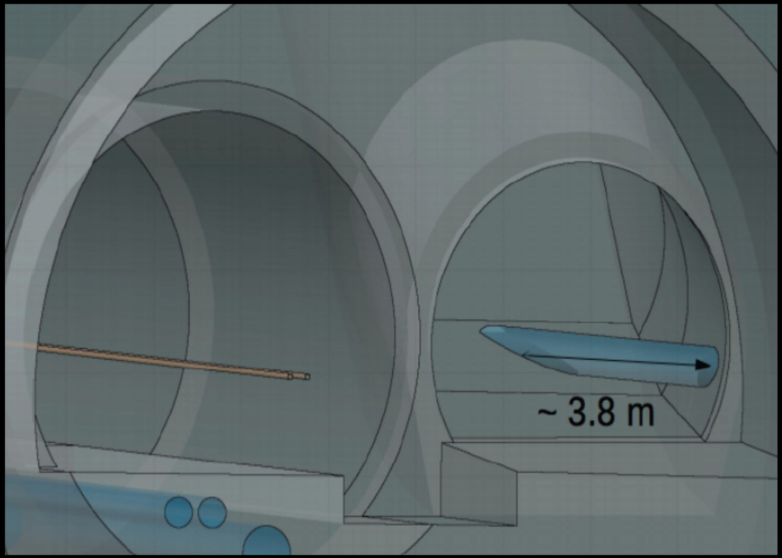
~ 3.8 m

SUMMARY

- We’ve learned an awful lot about the universe in the last few decades, but 95% of it is still a mystery.
- Most of the matter in the universe is dark matter, and identifying it requires the synergy of particle physics and astrophysics.
- There are many, diverse search experiments ongoing and proposed. A lot to look forward to!