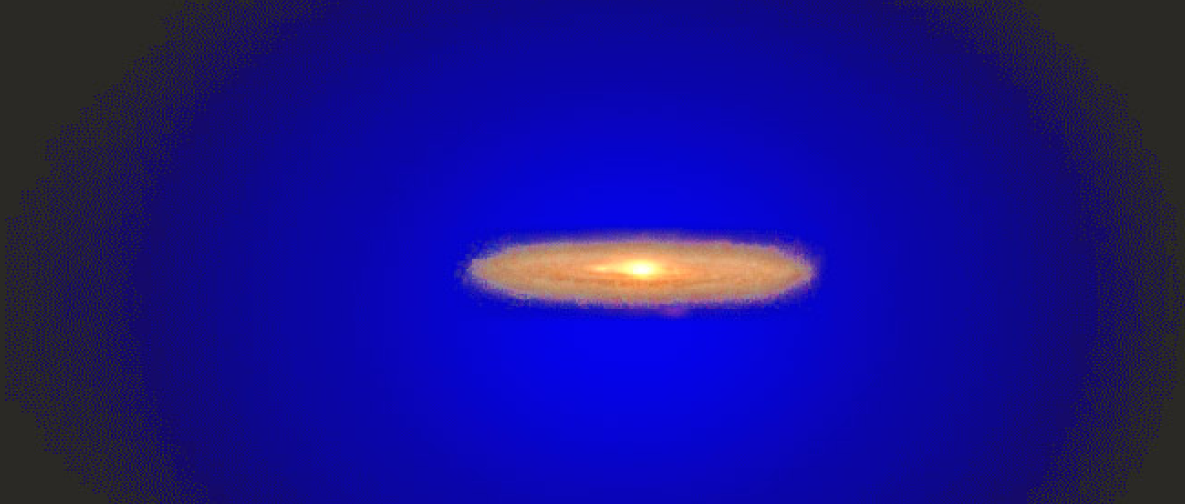
DARK MATTER

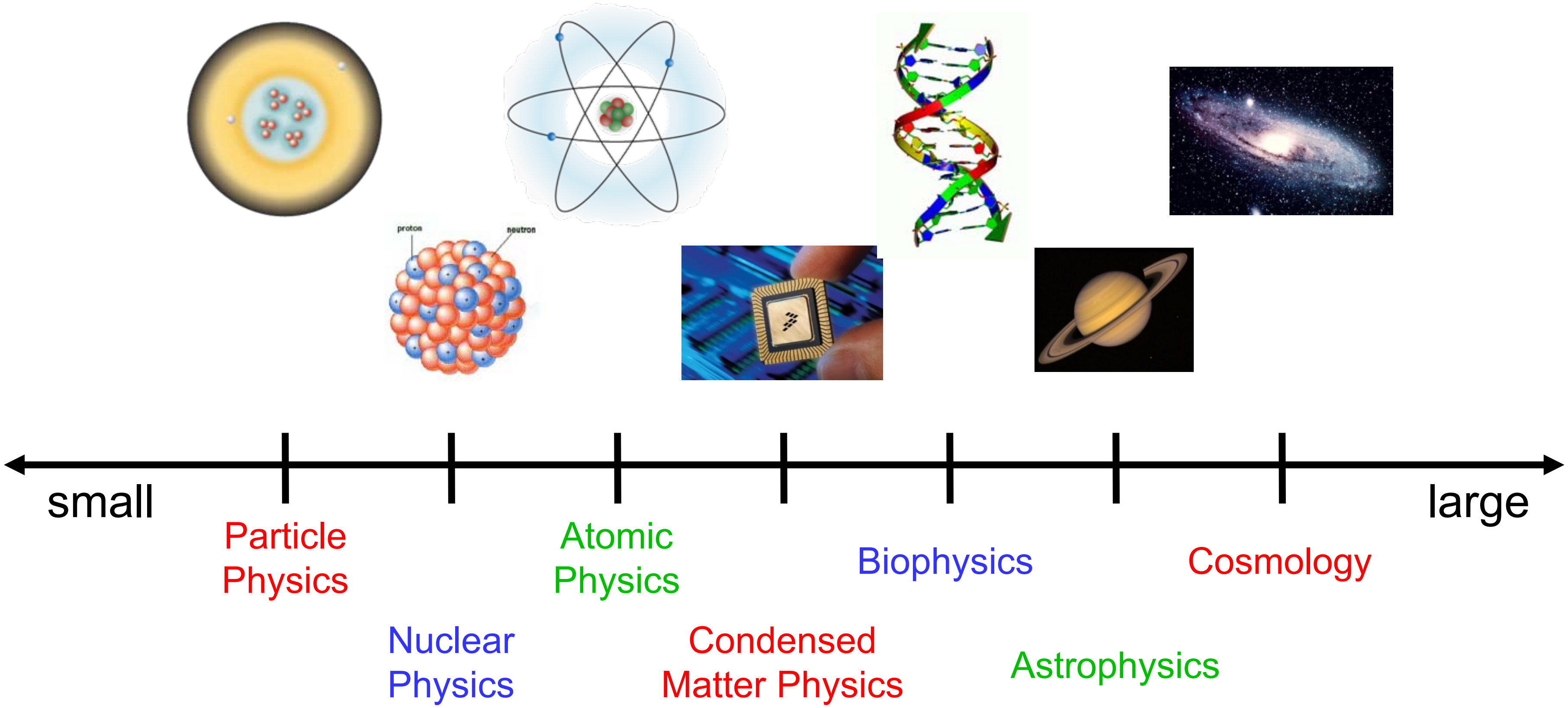


Credit: John Kormendy

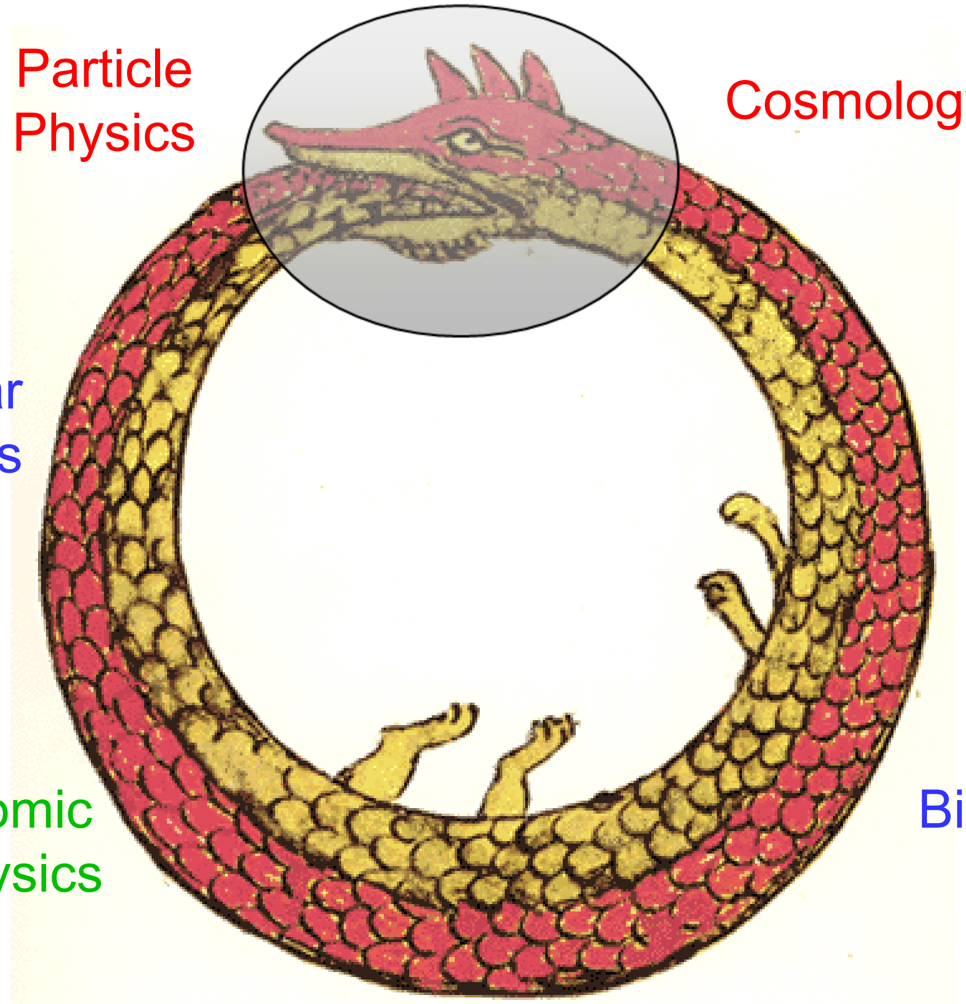
Jonathan Feng
University of California, Irvine

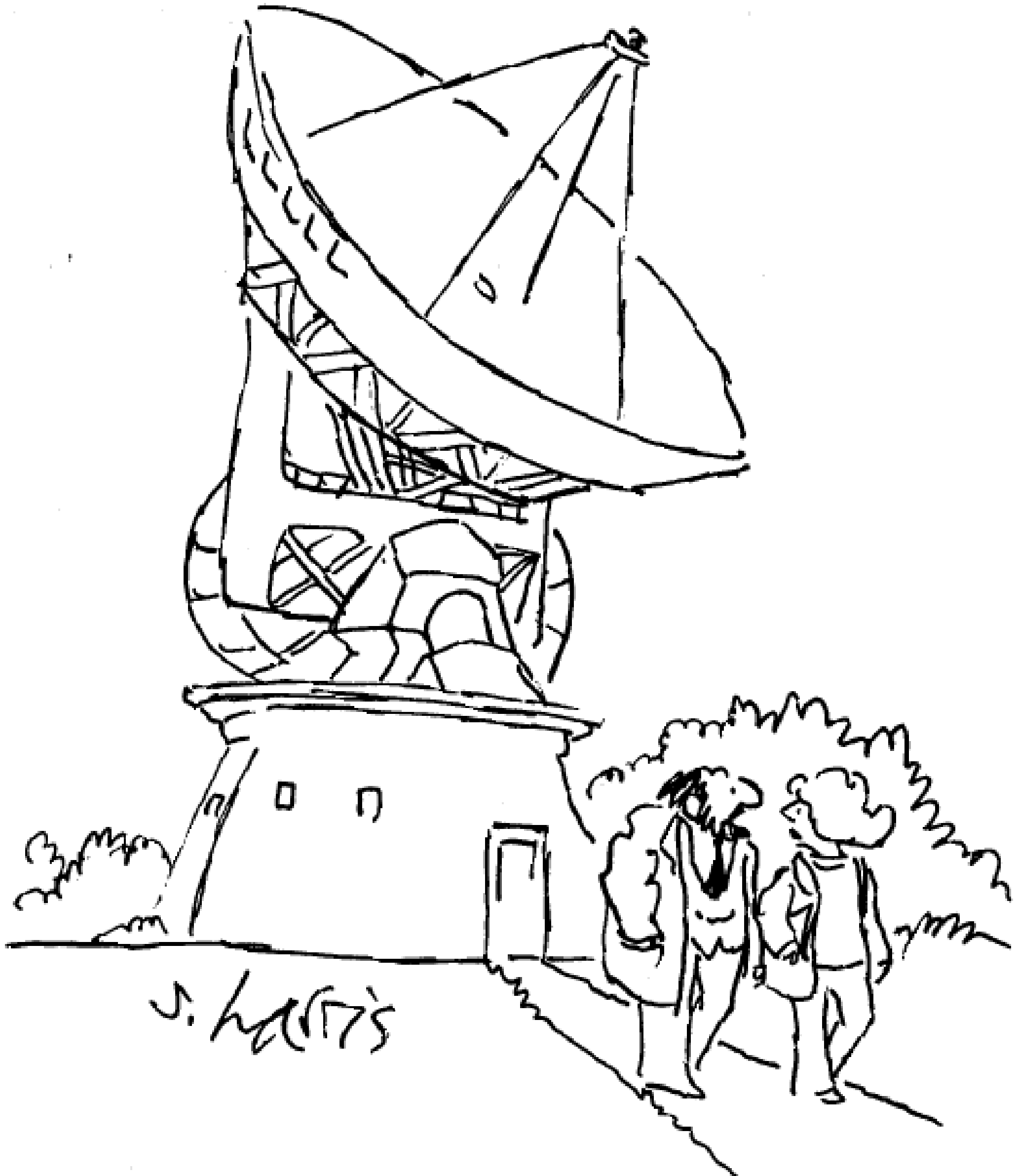
University of Colorado, Boulder
21 June 2011

PHYSICS: TRADITIONAL VIEW



PHYSICS: UPDATED VIEW

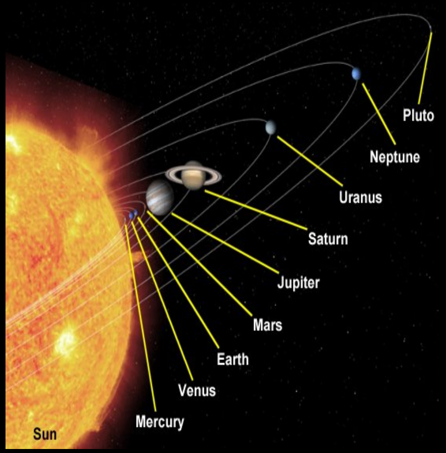




"I'LL BE WORKING ON THE LARGEST AND SMALLEST OBJECTS IN THE UNIVERSE—SUPERCLUSTERS AND NEUTRINOS. I'D LIKE YOU TO HANDLE EVERYTHING IN BETWEEN."

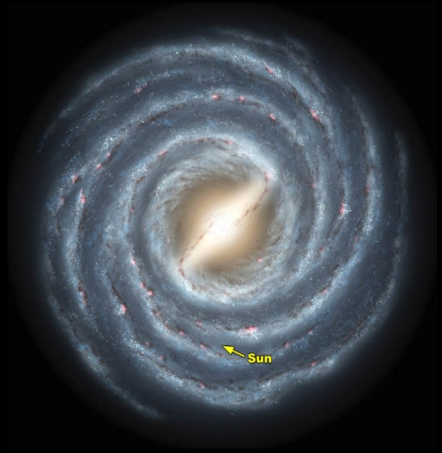
THE LARGE FRONTIER

solar system



10^{12} meters

galaxy

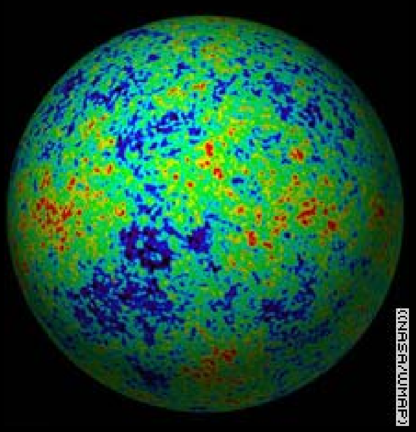


10^{17} meters

clusters of galaxies

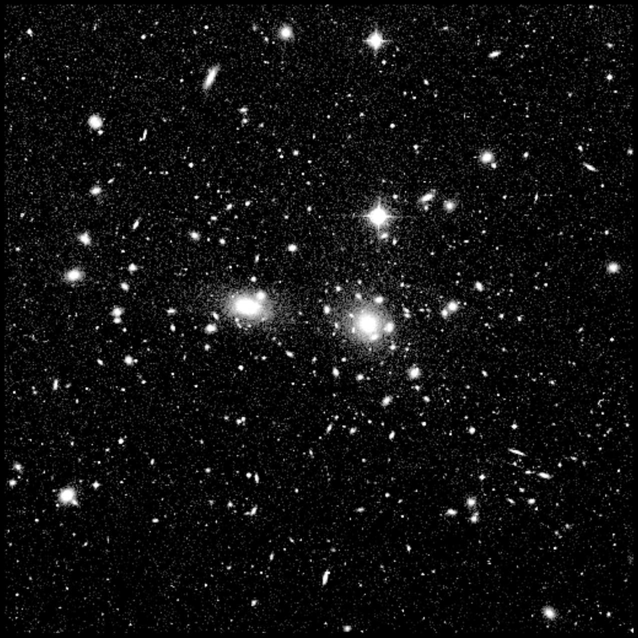
10^{23} meters

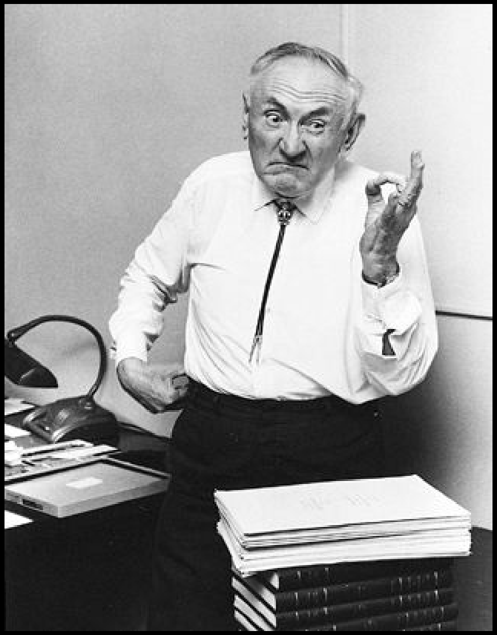
universe



$> 10^{26}$ meters

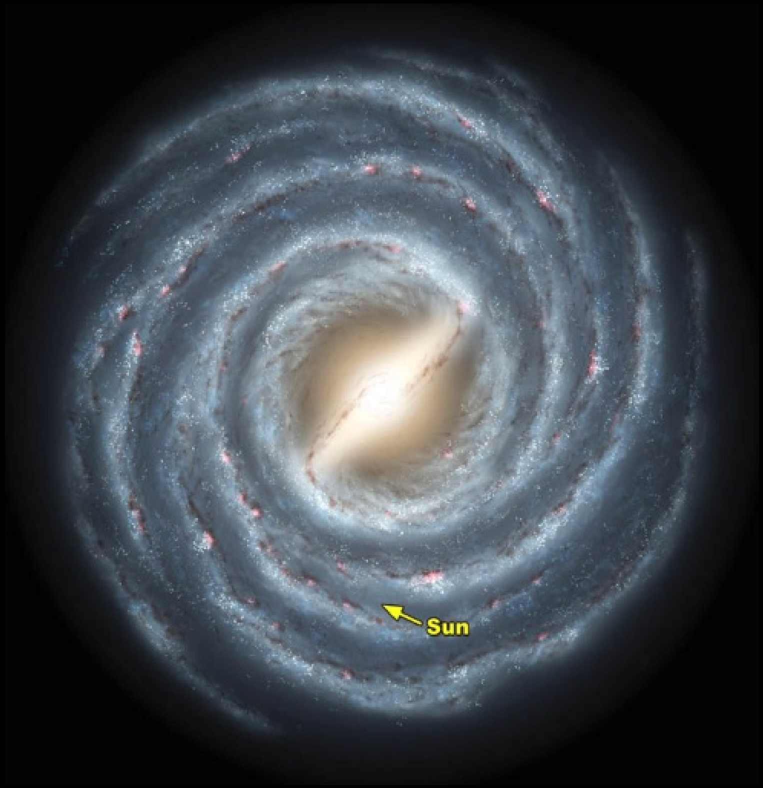
EVIDENCE FOR DARK MATTER: CLUSTERS OF GALAXIES





In the 1930's Fritz Zwicky observed the Coma cluster and found that the galaxies were moving too fast to be contained by the visible matter

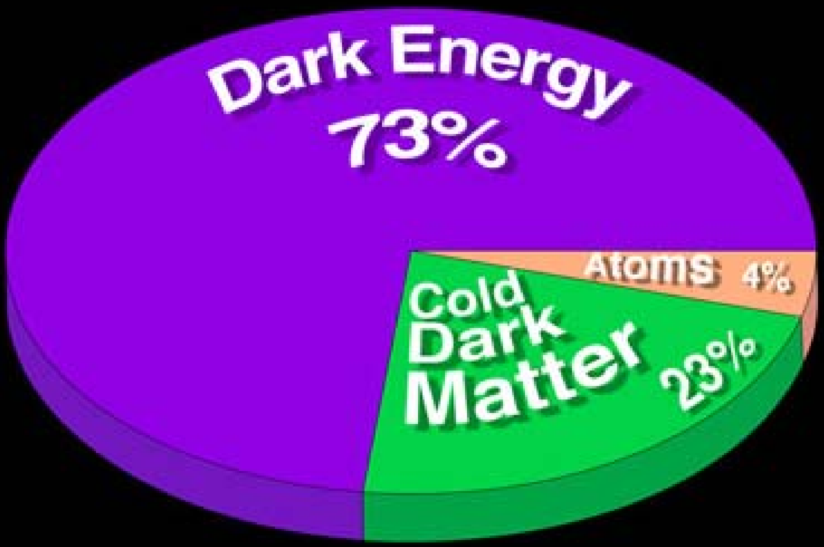
EVIDENCE FOR DARK MATTER: INDIVIDUAL GALAXIES



In the 1970's Vera Rubin and collaborators and Albert Bosma found that stars in galaxies were rotating too fast to be contained by the visible matter

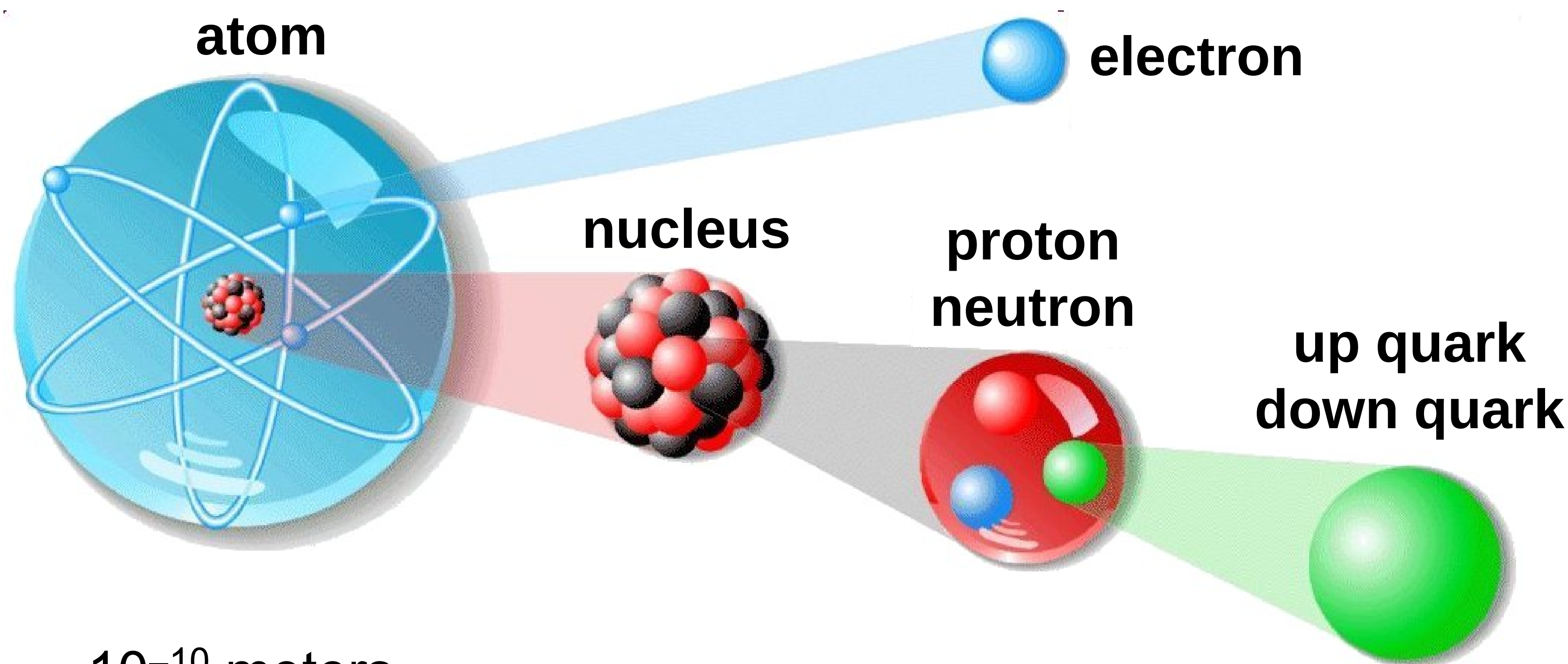
THE STANDARD MODEL OF COSMOLOGY

- Atoms make up only 4% of the Universe



- The rest of the matter is dark matter, which does not shine or reflect light
  – Not atoms
  – Cold
  – Stable
- Also, 73% of the Universe isn't even matter

THE SMALL FRONTIER



10^{-10} meters (thickness of human hair ~ 10^{-5} m)

10^{-14} meters

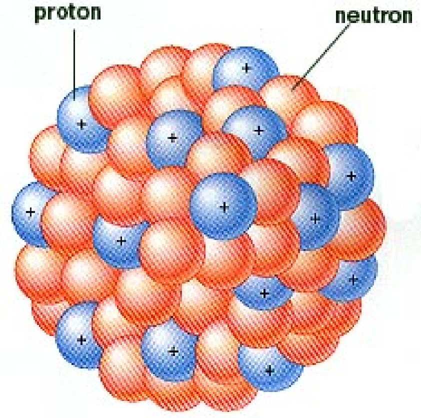
10^{-15} meters

$< 10^{-18}$ meters

4 FORCES OF NATURE

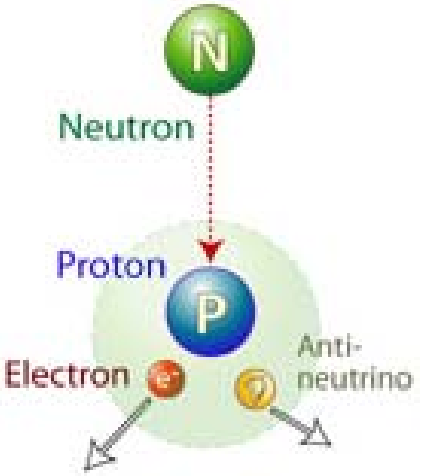
- Gravity

- Strong

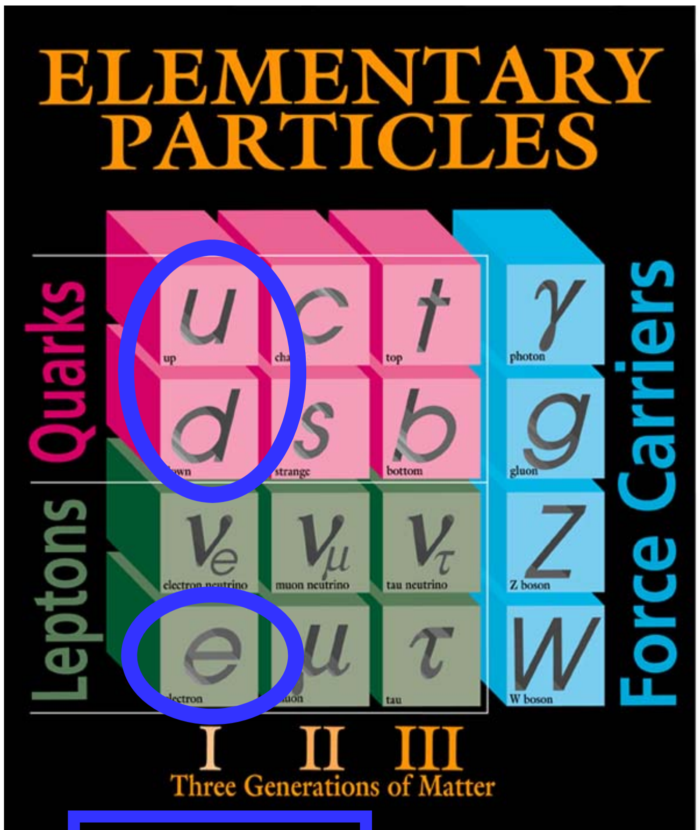


- Electromagnetism

- Weak

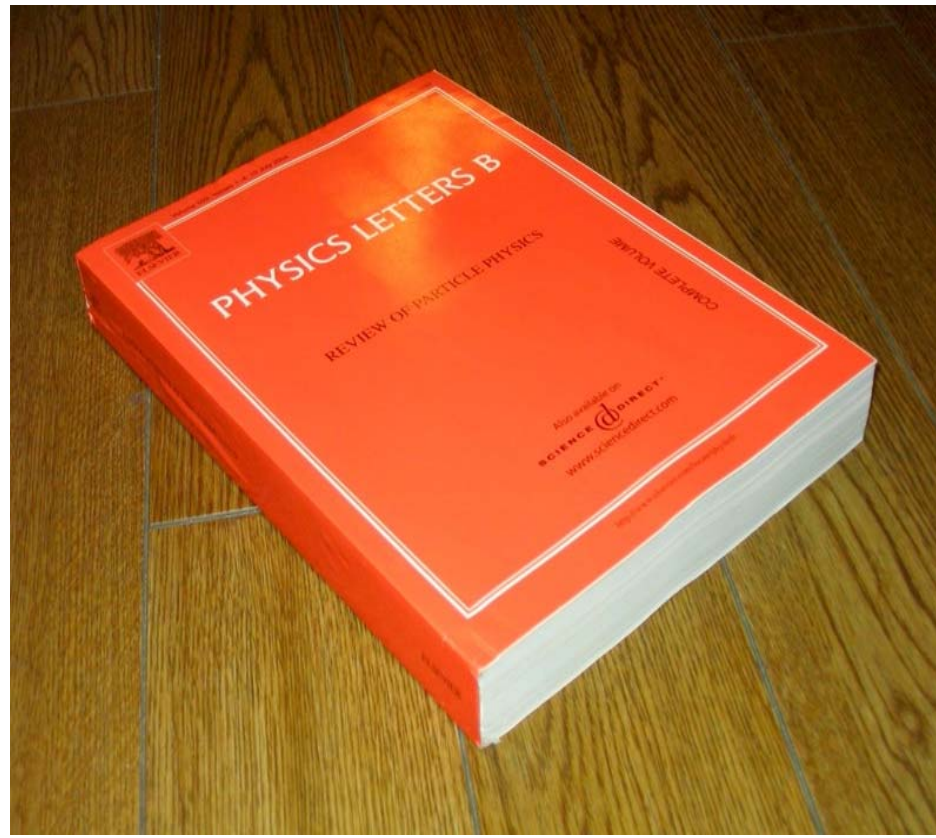


STANDARD MODEL OF PARTICLE PHYSICS

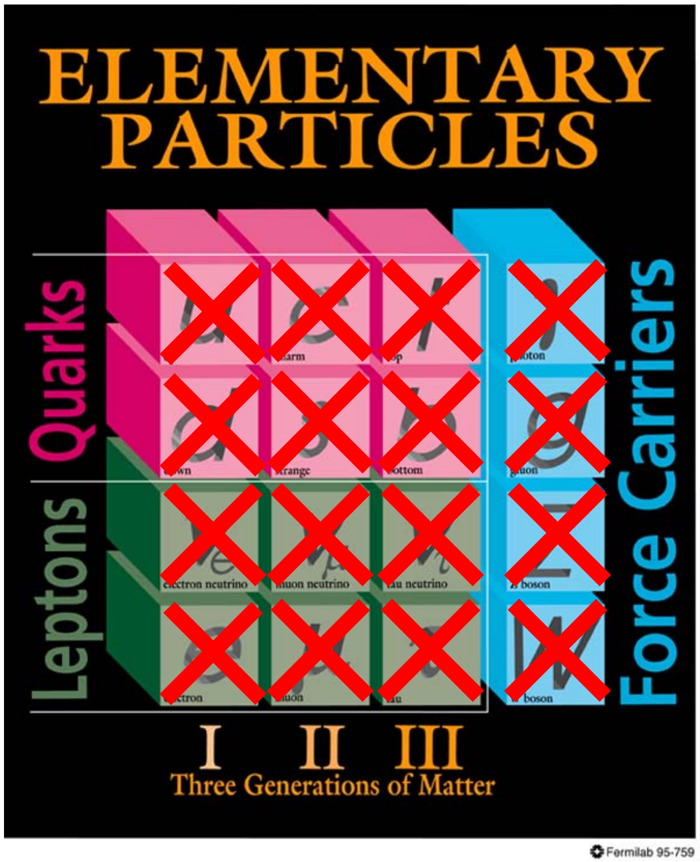


Atoms

Fermilab 95-759



WHICH PARTICLE IS DARK MATTER?



Known DM properties

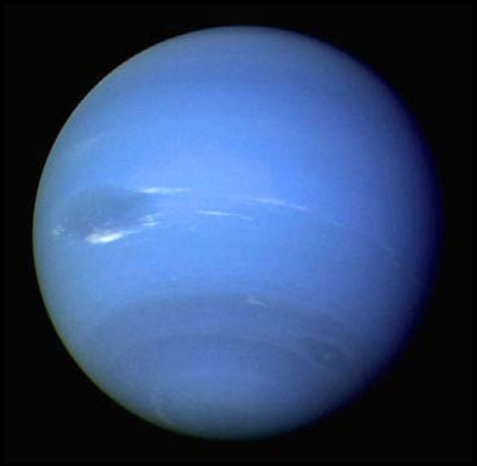
- Not atoms
- Cold
- Stable

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

WHAT SHOULD WE DO?

- 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

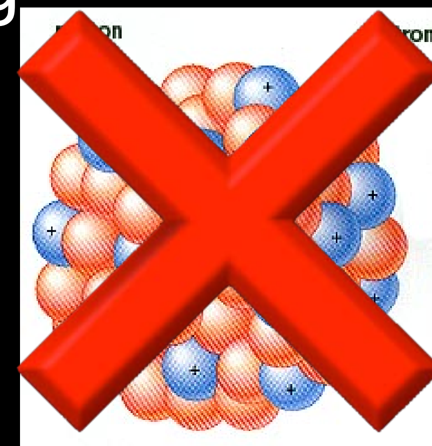


- Le Verrier wanted to call it Le Verrier, but this matter is now known as Neptune, the farthest known planet (1846-1930, 1979-1999, 2006-present)

WHICH FORCES DOES DARK MATTER FEEL?

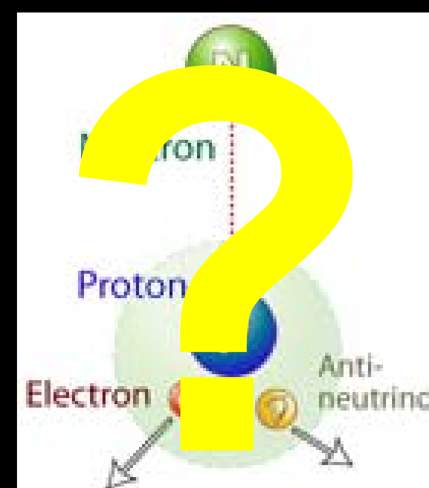
- Gravity

- Strong



- Electromagnetism

- Weak



OPTION 1: WIMPS

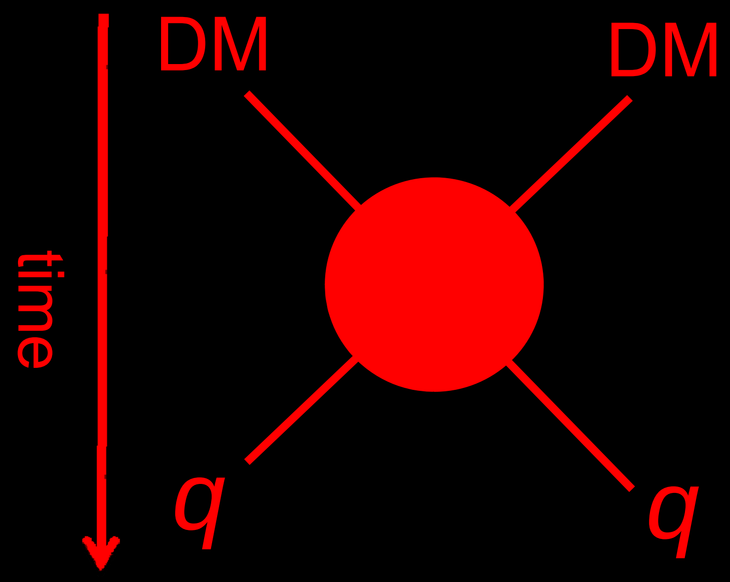
- Dark matter feels the weak force
- DM = WIMPs: weakly-interacting massive particles
- Why WIMPs? Looking under the lamp post

THE WIMP MIRACLE

- But there's more to it than that

- Many theories predict WIMPs that are around 100 times heavier than the proton

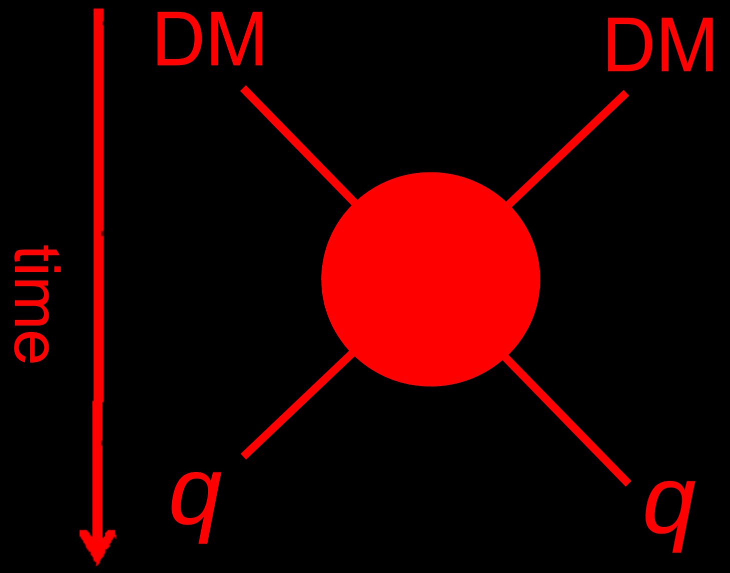
- Such particles are present just after the Big Bang, but then annihilate in pairs. Assuming they annihilate through the weak force, calculations show that they should be ~ 10% of the Universe now. This is what is required to be dark matter!



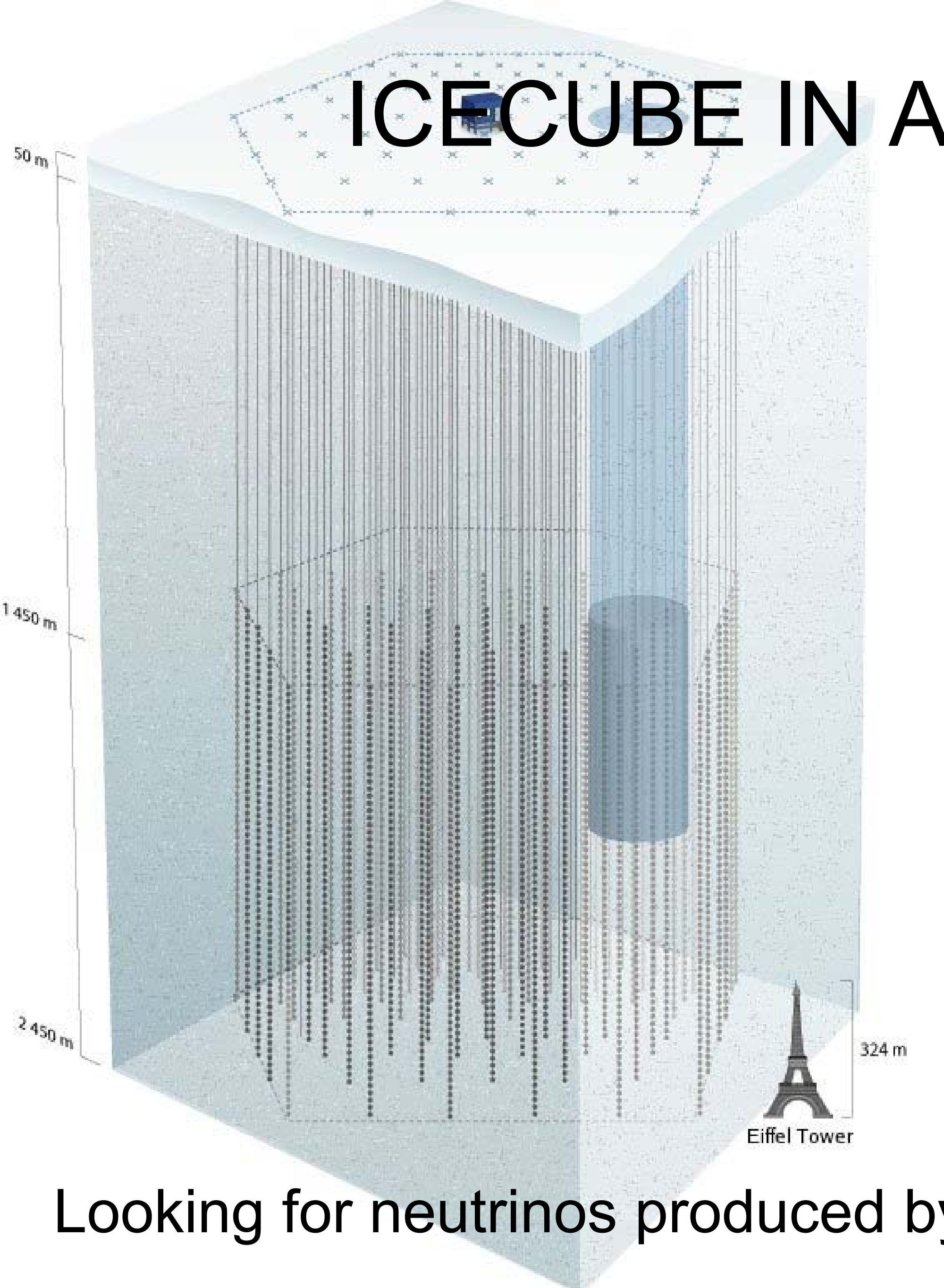
WIMP DETECTION

- 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

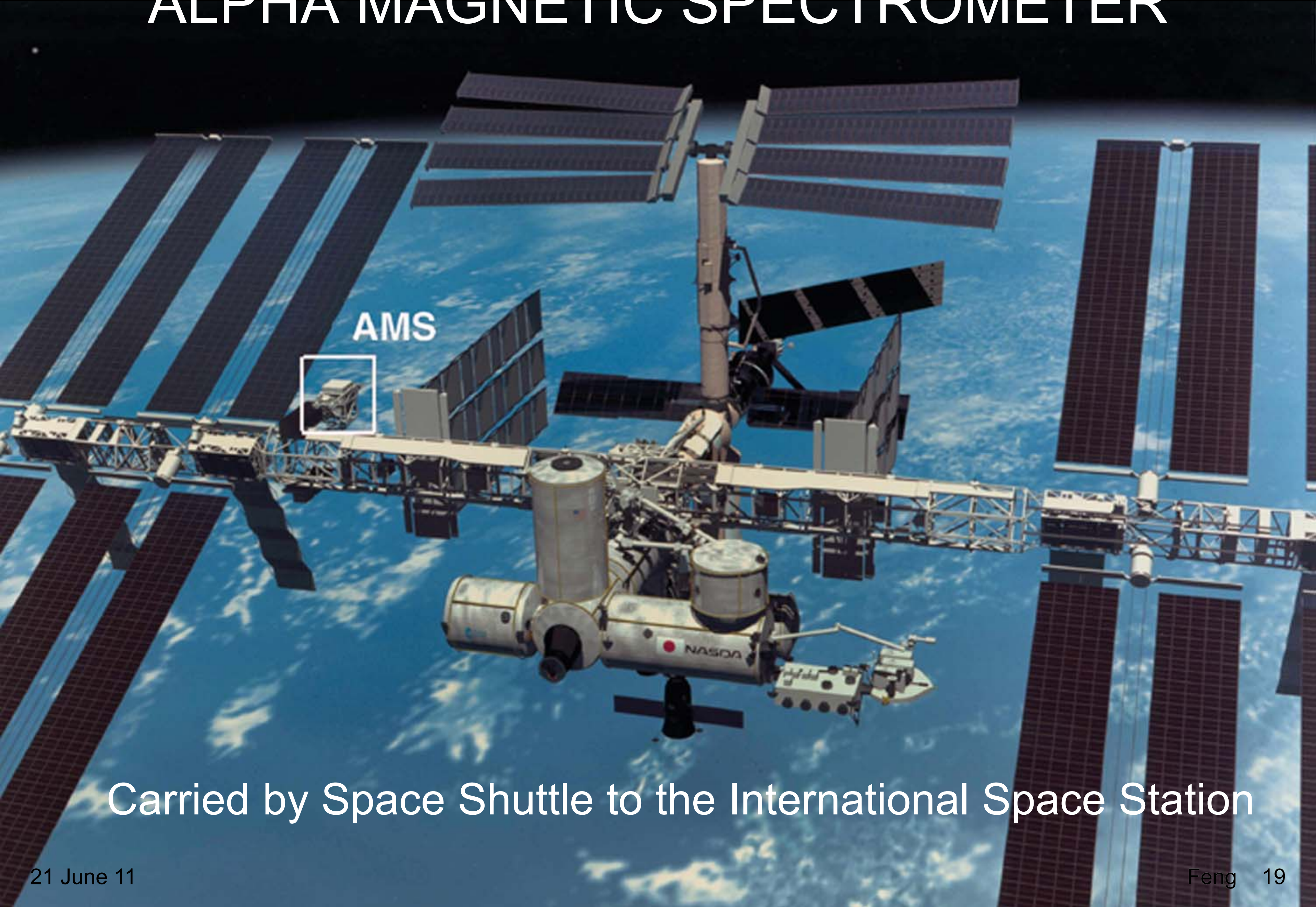


ICECUBE IN ANTARCTICA



Looking for neutrinos produced by WIMP annihilation in the Sun

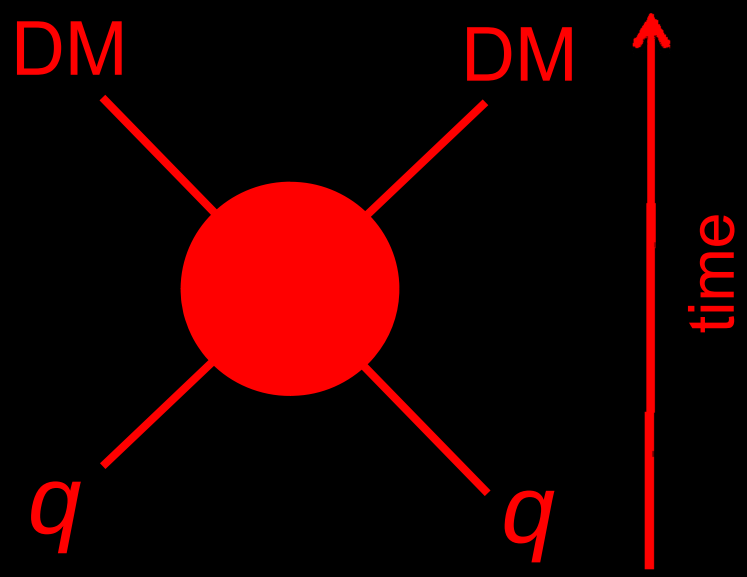
ALPHA MAGNETIC SPECTROMETER



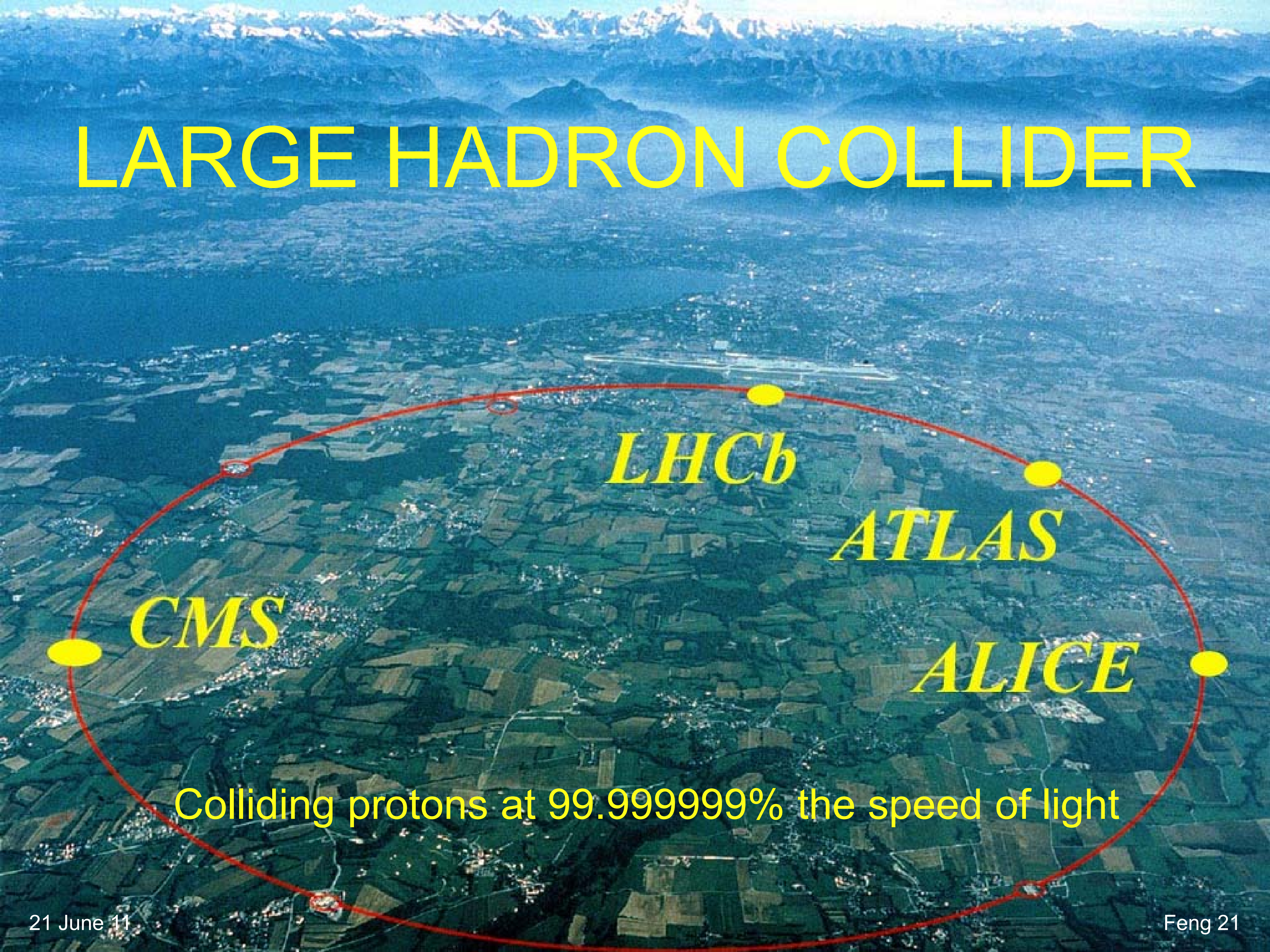
Carried by Space Shuttle to the International Space Station

WIMP PRODUCTION

- If WIMPs annihilated in the early Universe, we should also be able to run time backwards
- We can collide two normal particles at high velocities to create dark matter, which we detect as missing energy

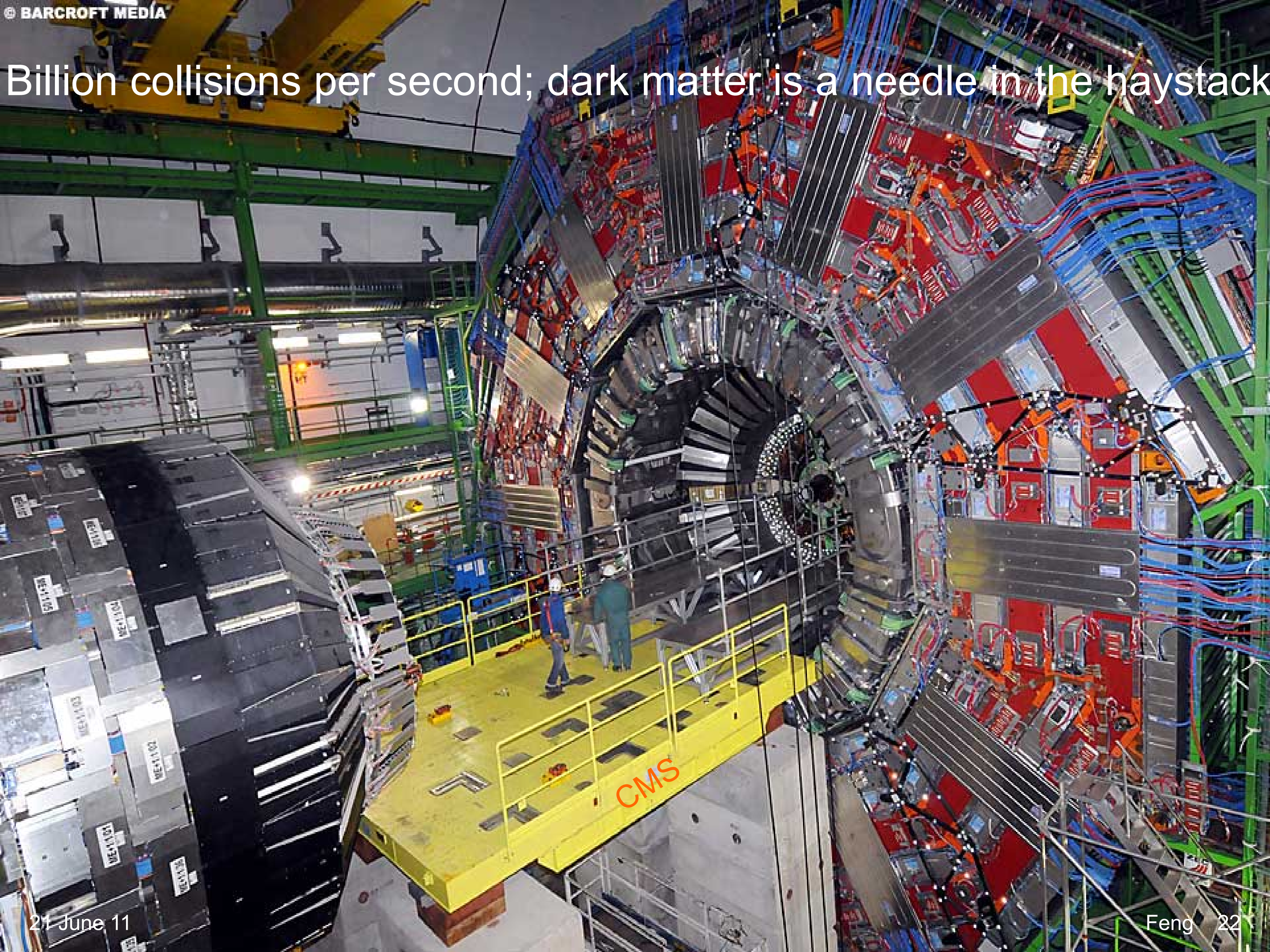


LARGE HADRON COLLIDER



Colliding protons at 99.999999% the speed of light

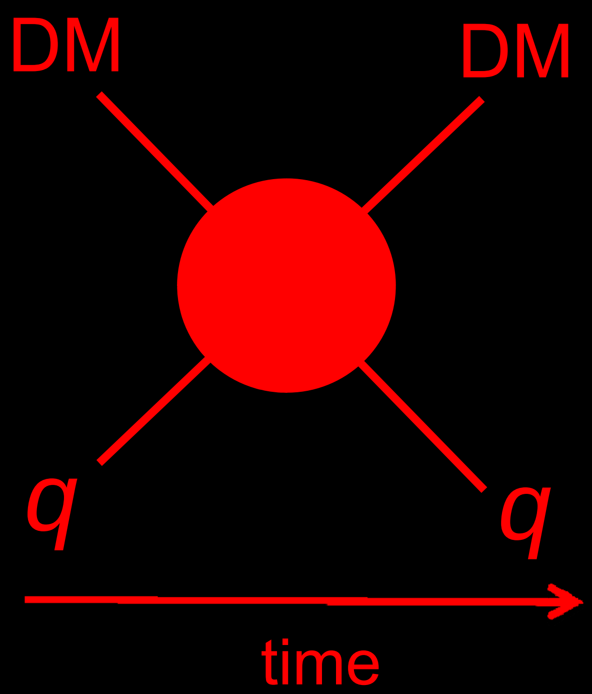
Billion collisions per second; dark matter is a needle in the haystack



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

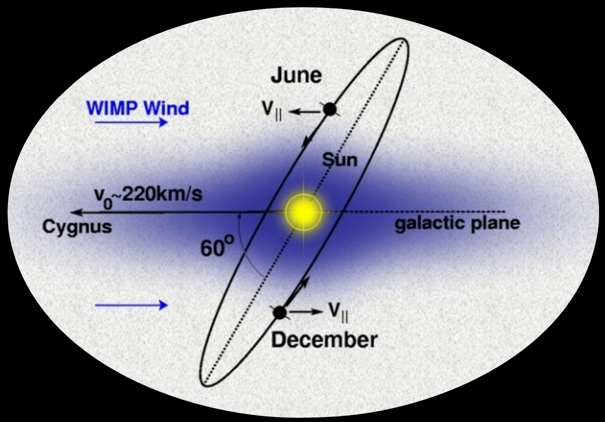


CRYOGENIC DARK MATTER SEARCH

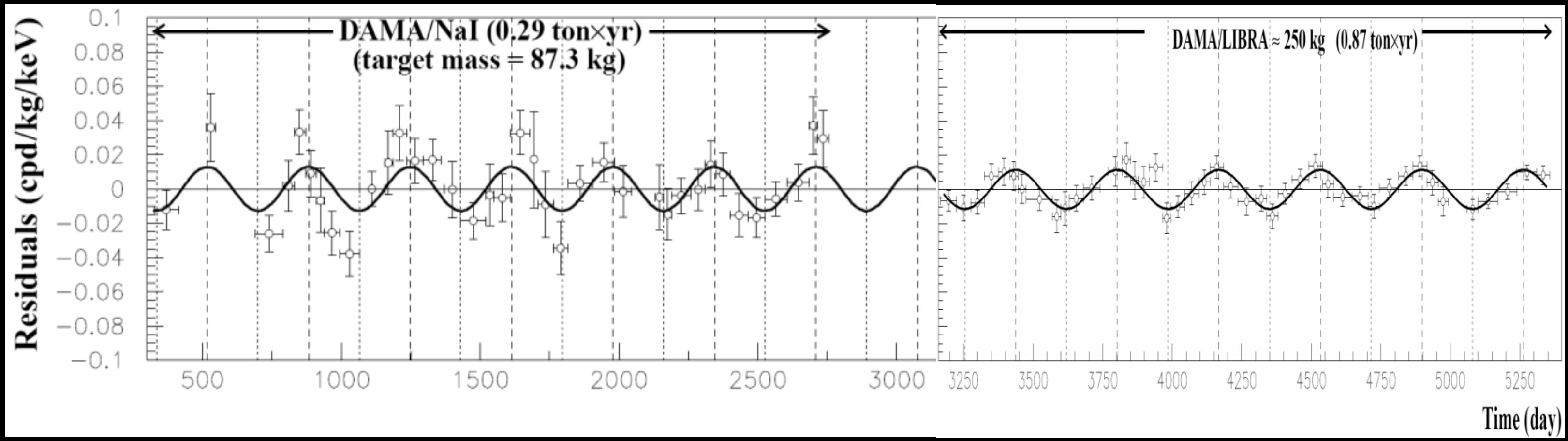
Operating at milli-Kelvin temperatures in a mine in Minnesota

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

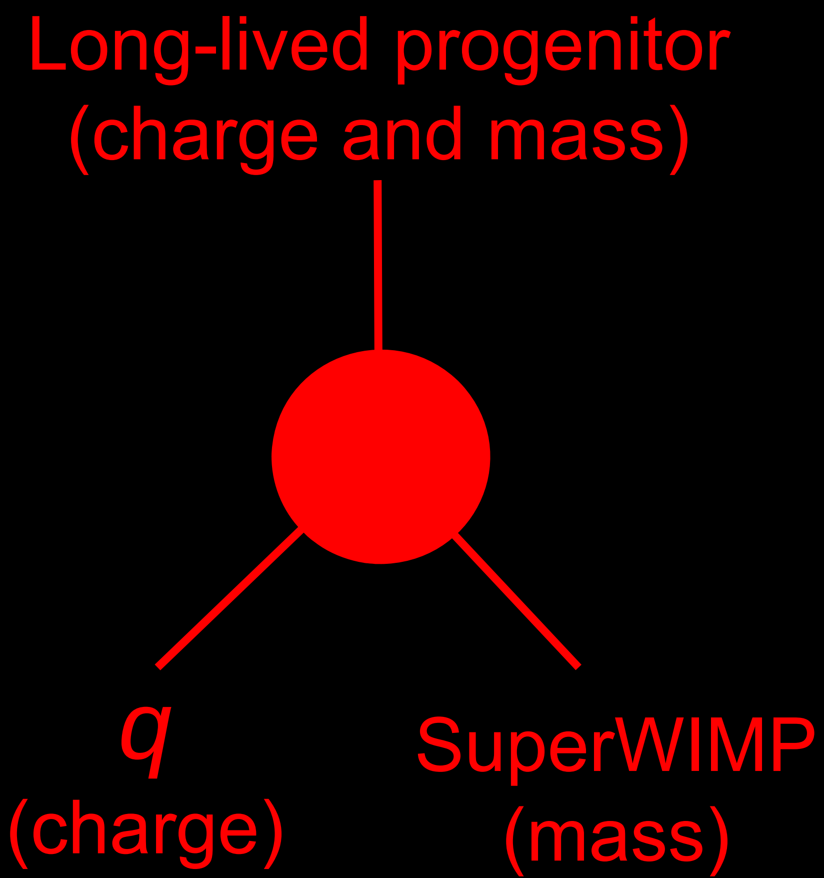


OPTION 2: SUPERWIMPS

- Dark matter does not feel the weak force
- DM = SuperWIMPs: superweakly-interacting massive particles
- Seemingly a lost cause

GRAVITINOS

- An example: gravitinos proposed by Pagels and Primack in 1982
- Gravitinos feel only gravity
- But they may be created by decaying particles that have dramatic implications for the LHC



GRAVITINOS AT THE LHC

SUMMARY

- We now have two extraordinarily successful theories of the large and small, but they don’t match
- A quarter of the Universe is dark matter, but we don’t know what it is
- We have some ideas, though, and many interesting search experiments underway