

EXPLORING THE UNIVERSE



*For the 4th-12th graders of the
Orange County Math Circle*

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WHERE I'M FROM

- Born in Ann Arbor, Michigan
- High school in Lafayette, California, lots of math, music
- College at Harvard
- Marshall Scholarship at Cambridge
- Ph.D. at Stanford
- Research positions at Berkeley, Princeton, MIT
- Professor at UC Irvine since 2002

EARLY CAREER ADVICE



Andrew Gleason
1921-2008



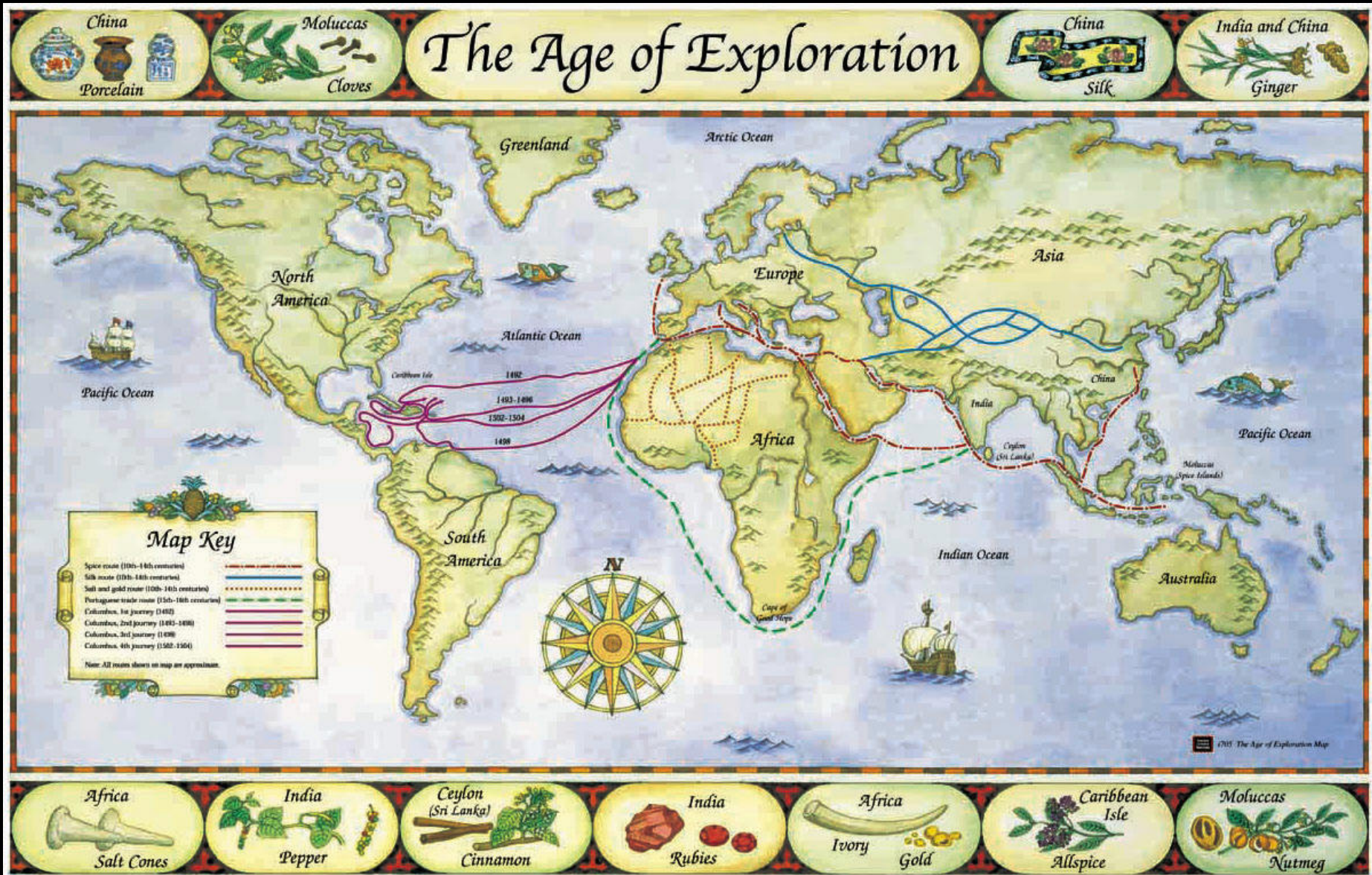
Sheldon Glashow
1932-



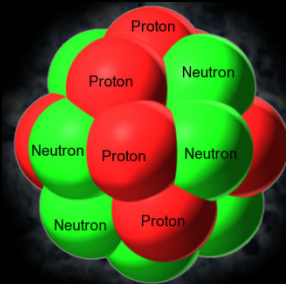
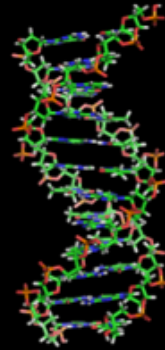
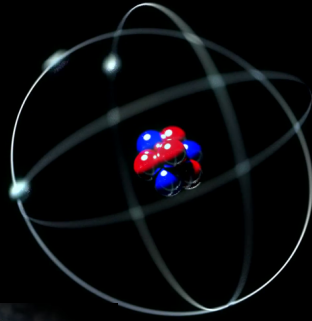
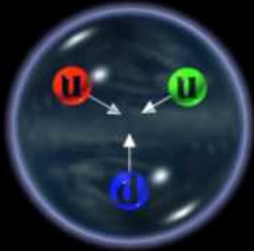
Shiing-Shen Chern
1911-2004

Research can be lonely; be broad; don't just follow the crowd

THE AGE OF EXPLORATION



FIELDS OF PHYSICS



Particle
Physics

Atomic
Physics

Biophysics

Cosmology

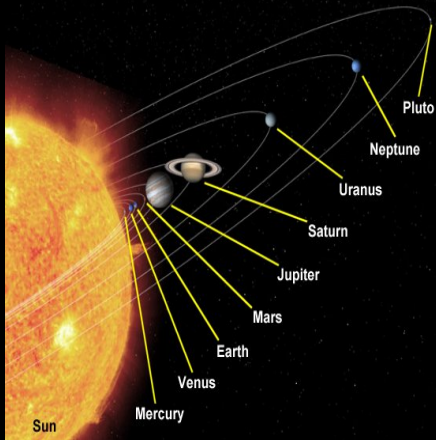
Nuclear
Physics

Condensed
Matter Physics

Astrophysics

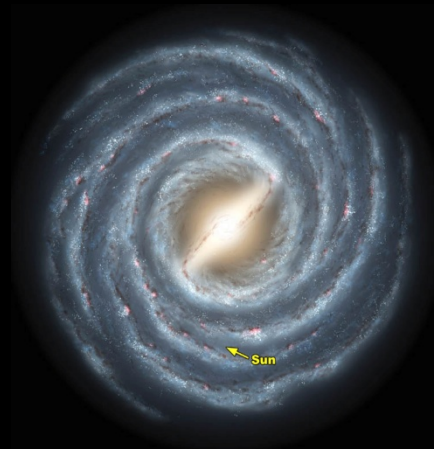
THE LARGE FRONTIER

solar system



10^{12}
meters

galaxy



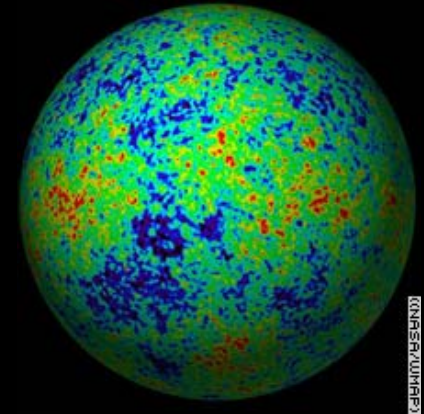
10^{17}
meters

clusters of galaxies



10^{23}
meters

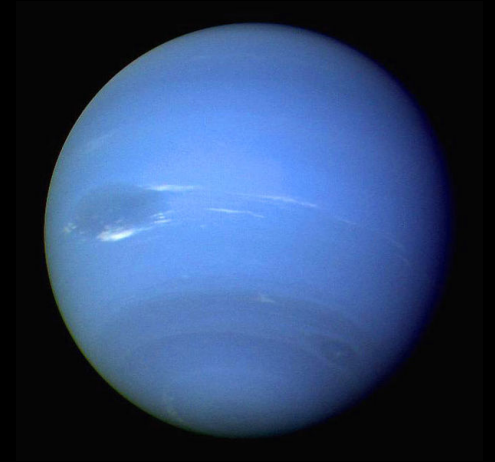
universe



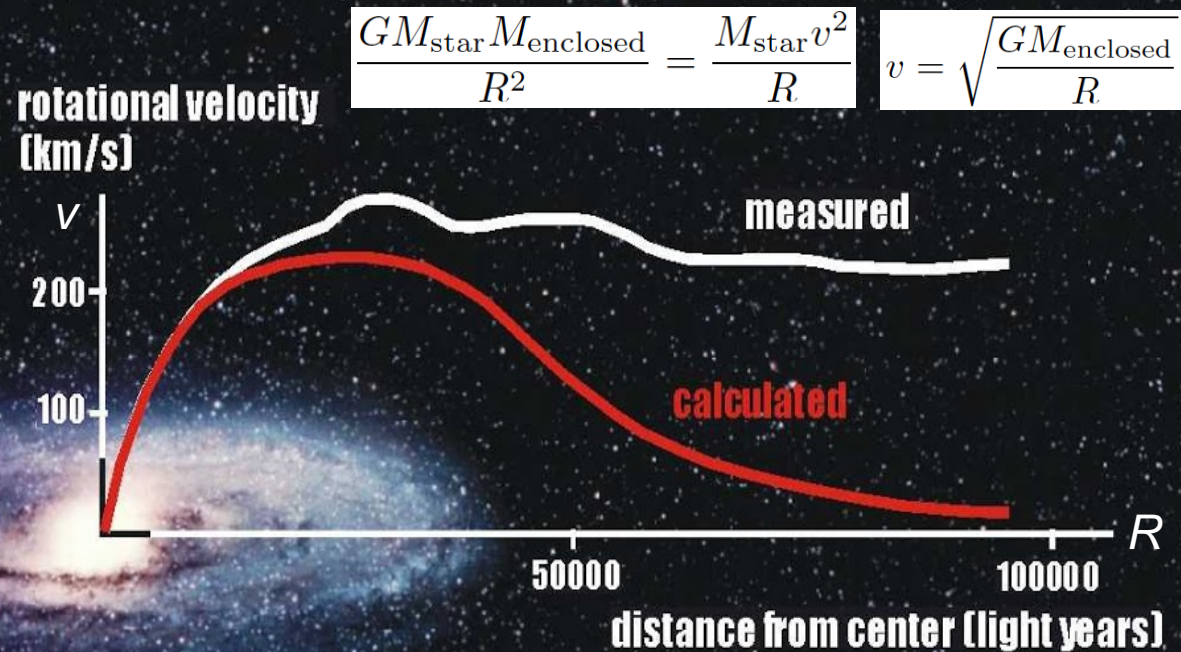
$> 10^{26}$
meters

A HISTORY LESSON

- 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 looked through a telescope and found 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



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

MODERN VIEW OF GALAXIES

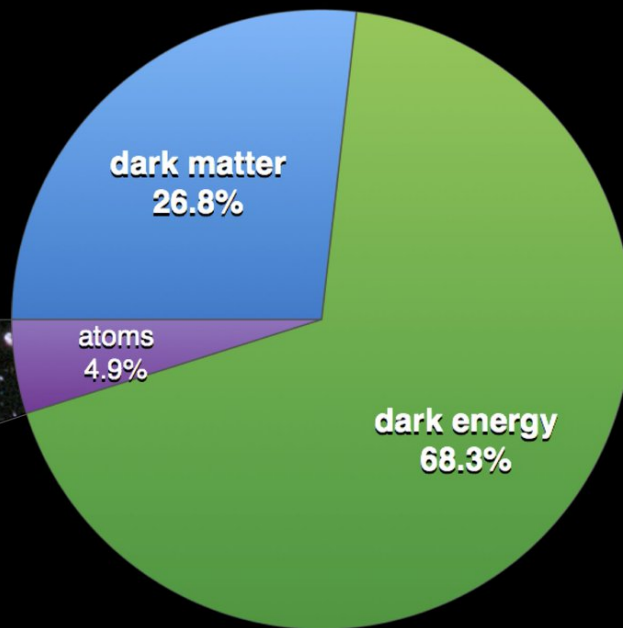


We now know that the visible galaxies are only small islands in an ocean of dark matter particles

Credit: John Kormendy

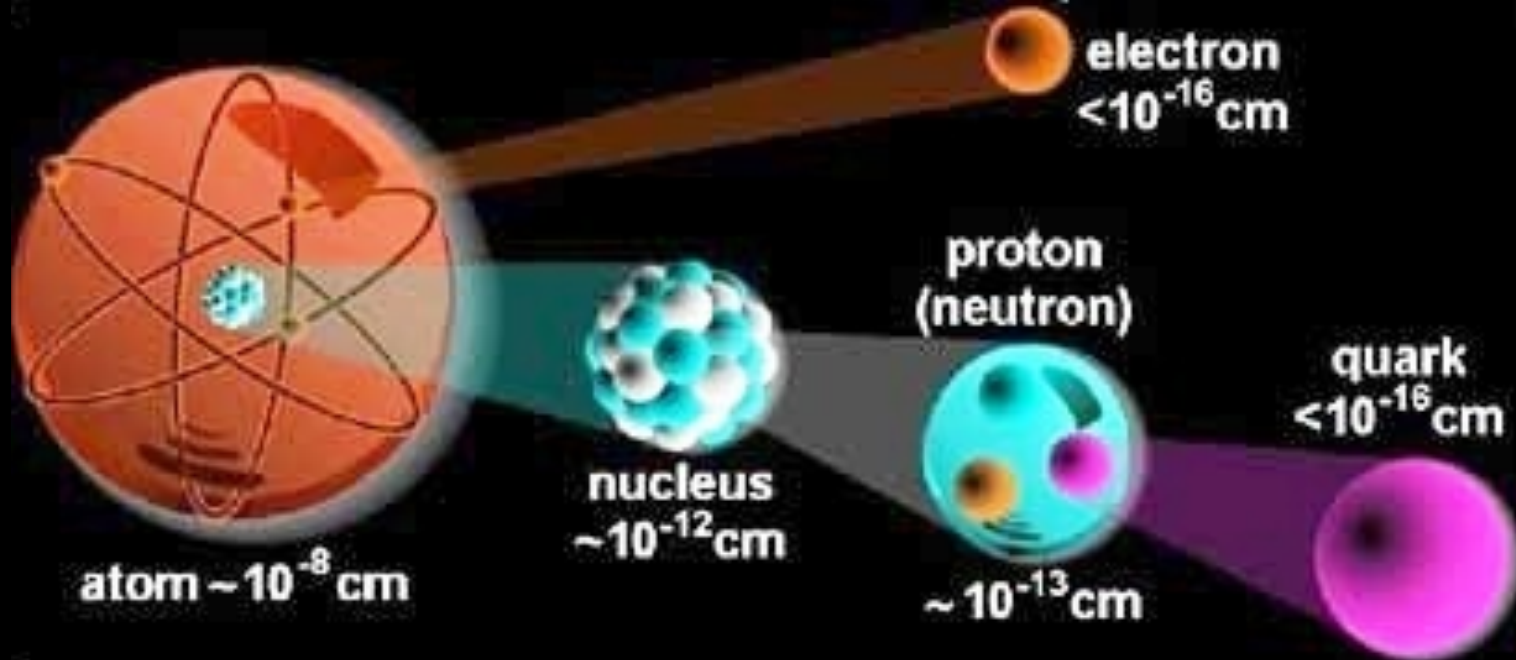
THE CONTENTS OF THE UNIVERSE

- All the atoms of the periodic table make up only 5% of the Universe



- 27% of the Universe is dark matter, which does not shine or reflect light
 - Not atoms
 - Not neutrinos
 - Not any of the known particles
- 68% of the Universe dark energy, not even matter

THE SMALL FRONTIER



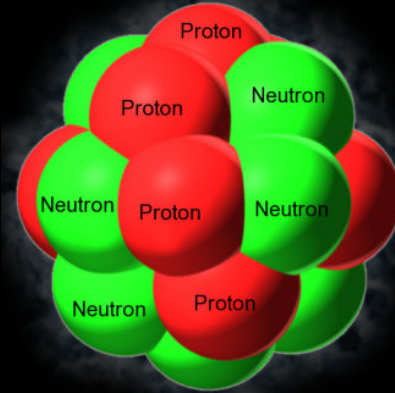
(thickness of human hair $\sim 10^{-3}$ cm)

THE KNOWN FORCES

- Gravity



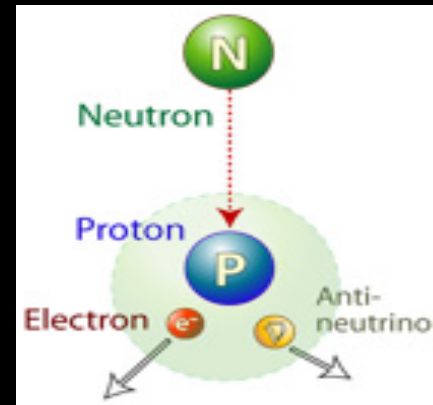
- Strong



- Electromagnetism



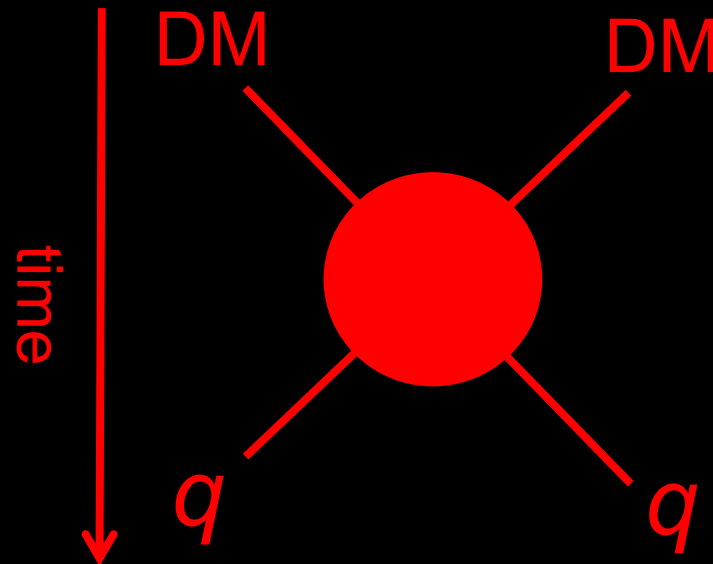
- Weak



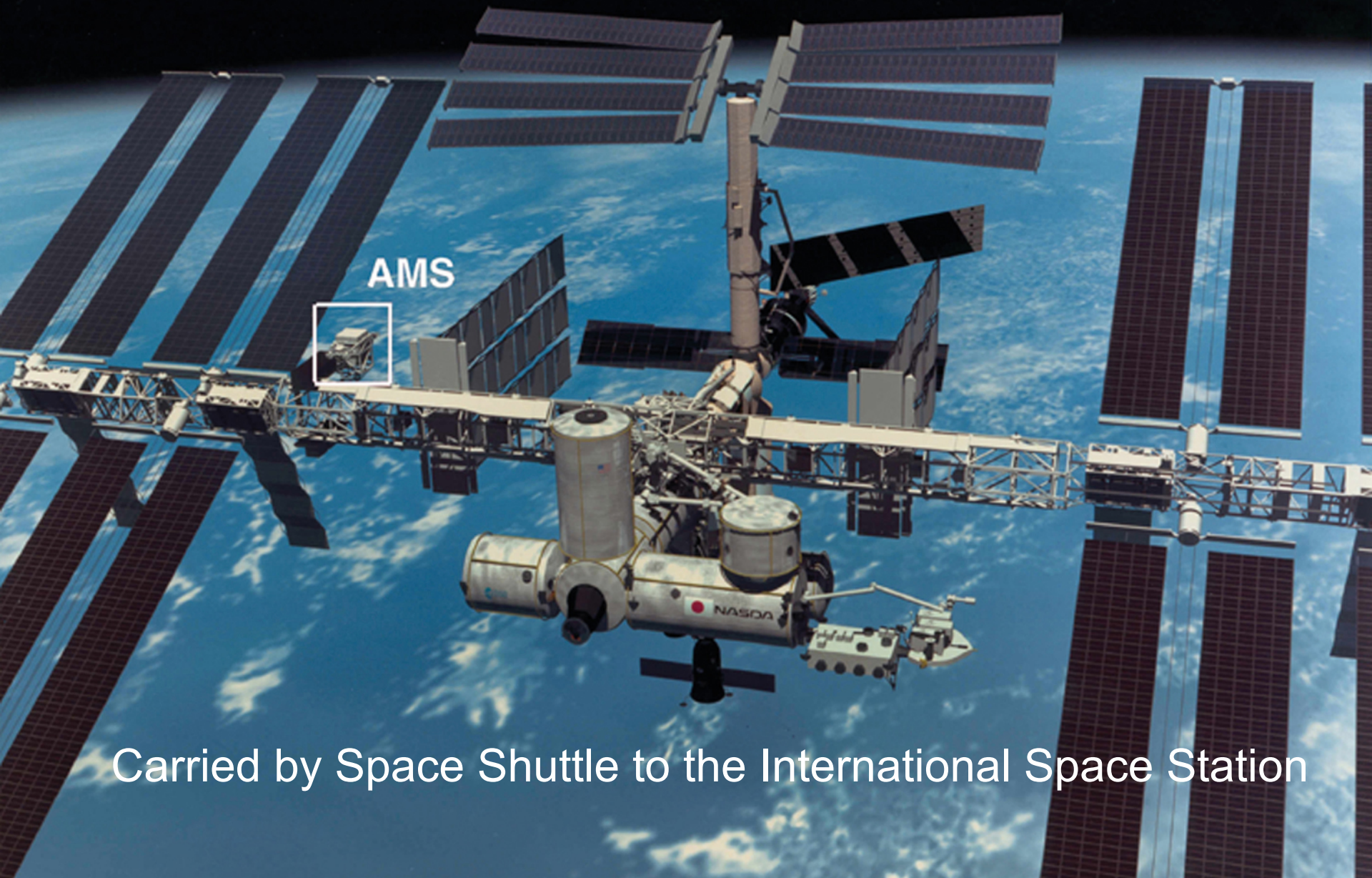
- Is there a 5th force?

THE SEARCH FOR DARK MATTER AND FORCES

- Dark matter is hard to detect. A billion dark matter particles have flowed through your body since we started talking!
- But since it is floating around all around us, perhaps it annihilates with itself and creates matter that is easier to detect



ALPHA MAGNETIC SPECTROMETER

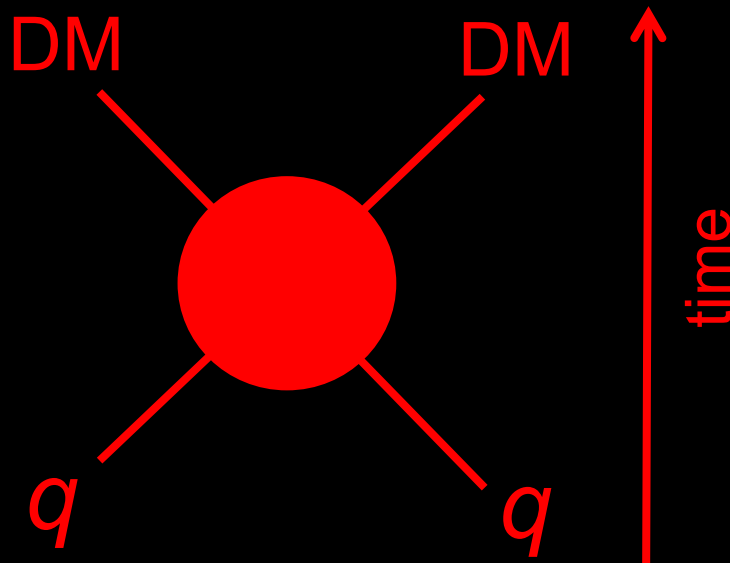


AMS

Carried by Space Shuttle to the International Space Station

THE SEARCH FOR DARK MATTER AND FORCES

- Alternatively, perhaps we can make dark matter in the laboratory?
- We can collide two normal particles at high velocities to create dark matter, which we detect as missing energy



LARGE HADRON COLLIDER

An aerial photograph of the LHC tunnel region in Switzerland, showing the circular path of the collider overlaid in red. The landscape is a mix of green fields and urban areas, with snow-capped mountains in the background. The LHC tunnel is represented by a red circle with several yellow dots marking the locations of the detectors: CMS, LHCb, ATLAS, and ALICE. There are also two small red circles on the tunnel path, likely representing the ATLAS and CMS interaction points.

LHCb

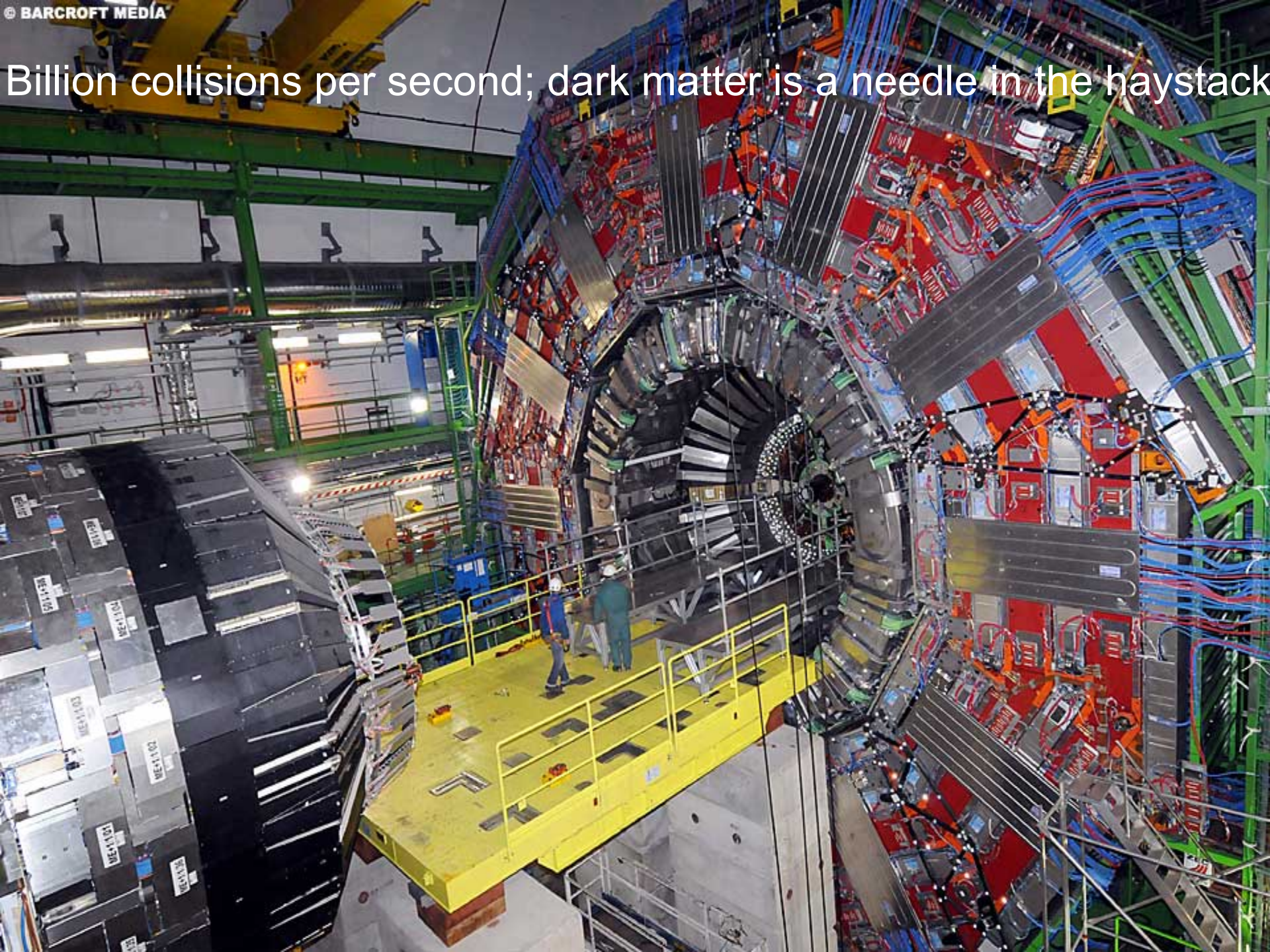
ATLAS

CMS

ALICE

Colliding protons at 99.999999% the speed of light

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



SUMMARY

- In the last few decades, we have made tremendous progress in understanding the Universe.
- But there are many pieces which we don't understand, and many interesting frontiers to explore!
- For further information, see

