THE LARGE HADRON COLLIDER: EARTH-EATING BLACK HOLES AND OTHER TALL TALES

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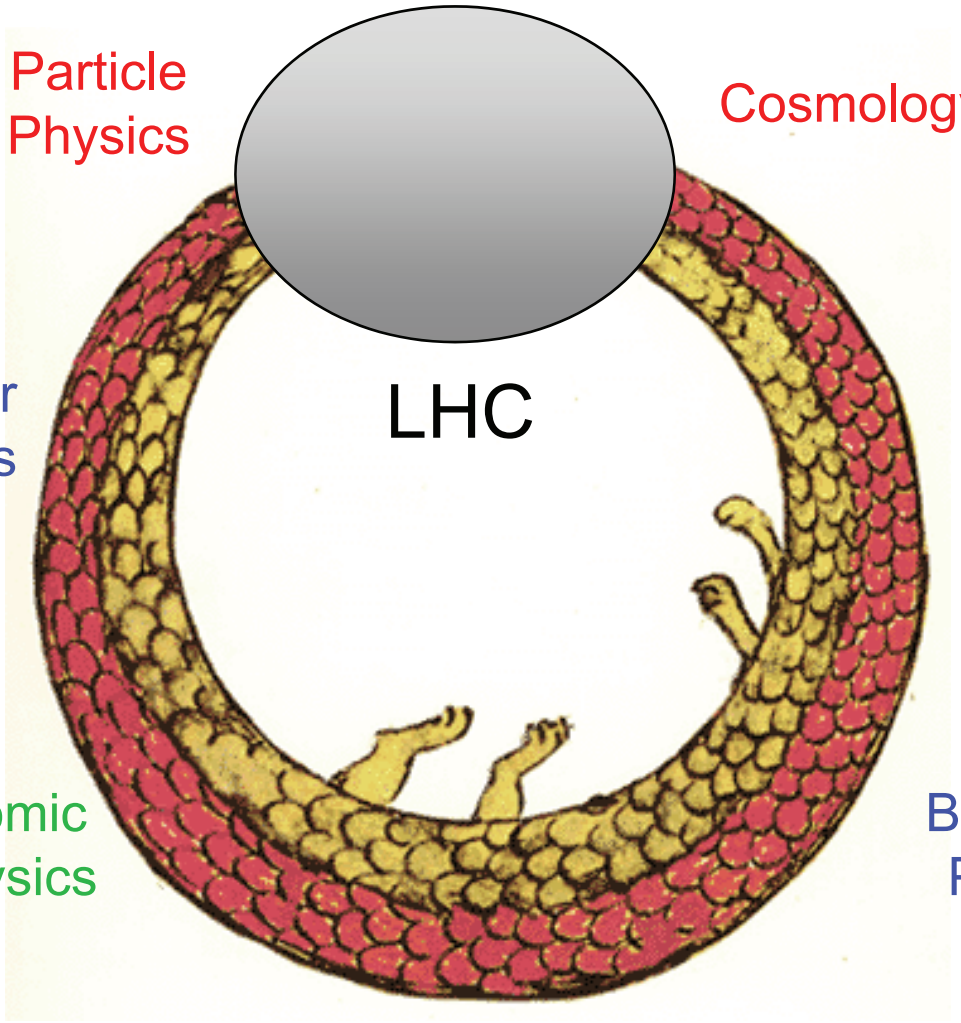
UCI University Club Forum
8 April 2009

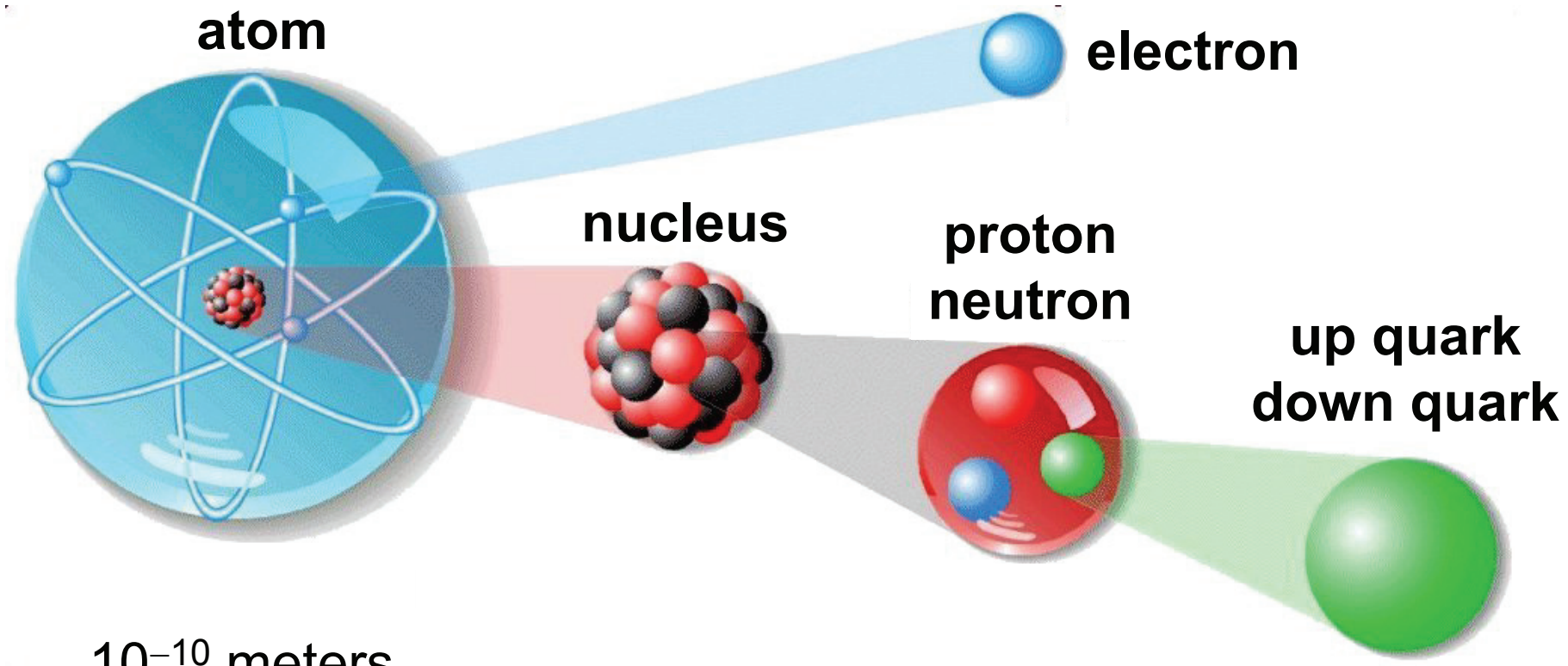
LHC BY THE NUMBERS

- Located at CERN, near Geneva
- Hadron: protons and nuclei
- Large: 17 miles of vacuum and superconducting magnets
- Accelerates protons to 99.999999% the speed of light, 10,000 round trips per second
- Proton beams squeezed down to 64 microns
- 100 million proton-proton collisions per second
- 5000 Ph.D. physicists from 90 countries
- $8 billion project
- Conceived 1984, approved 1994
- Beams in Sept 2008, collisions scheduled for Fall 2009

SCIENTIFIC GOALS



SMALL: STATE OF THE ART

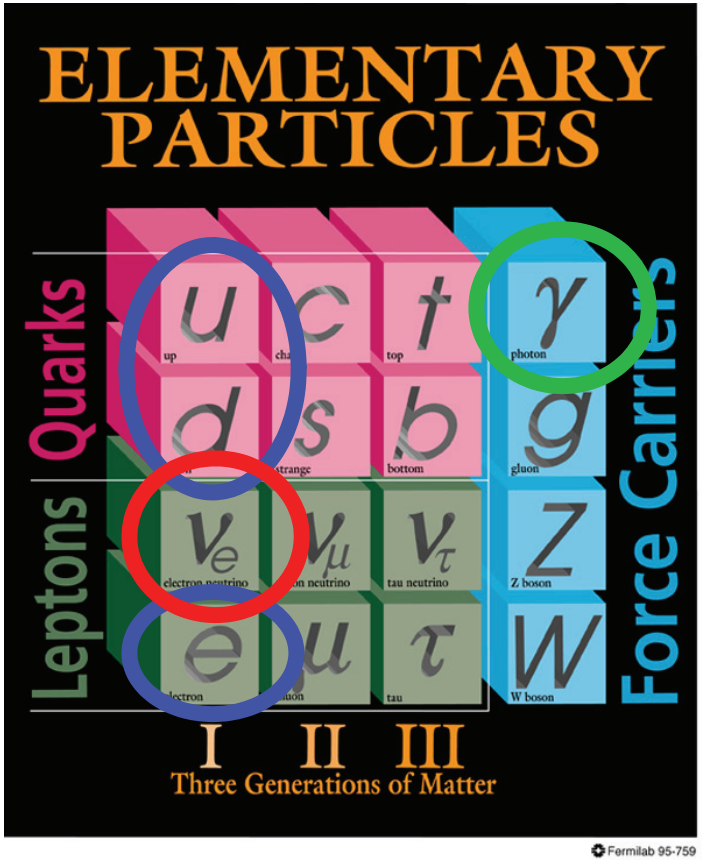


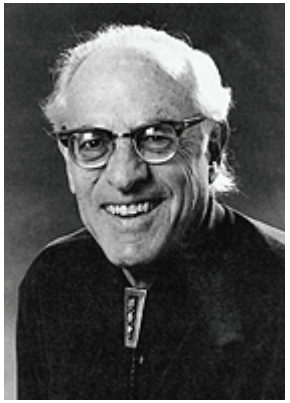
10^{-10} meters (thickness of human hair ~ 10^{-5} m)	10^{-14} meters	10^{-15} meters	$< 10^{-18}$ meters

BASIC BUILDING BLOCKS

Atoms

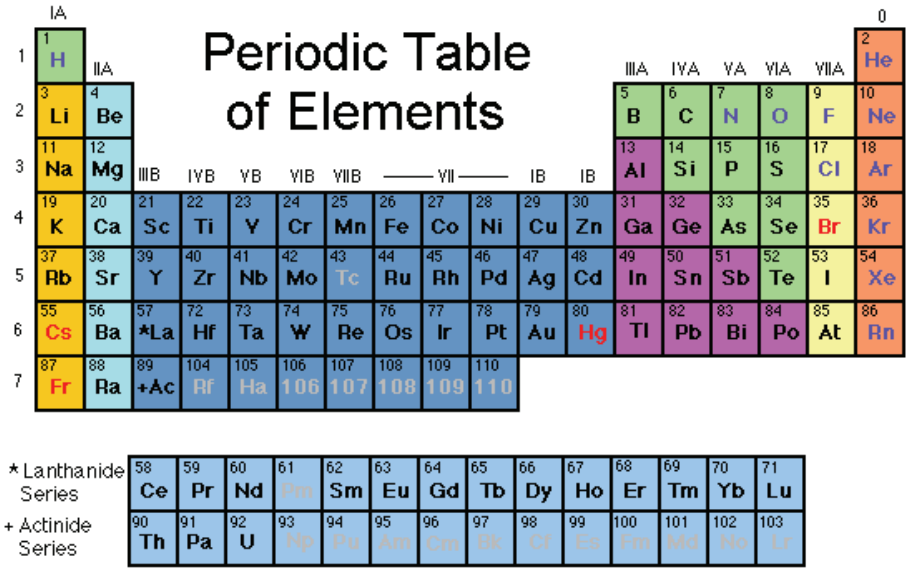
Light



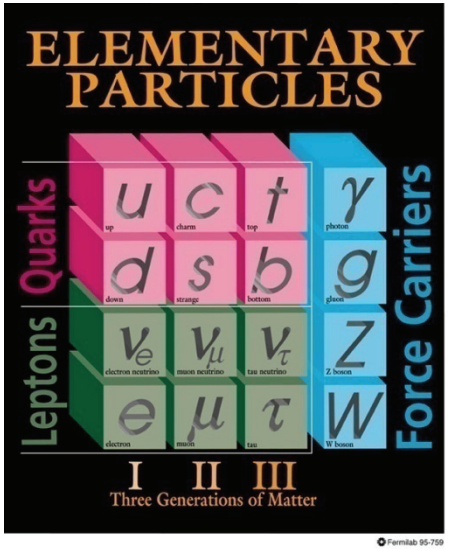


Frederick Reines
1995 Nobel Prize
for the Detection
of the Neutrino

PUZZLES



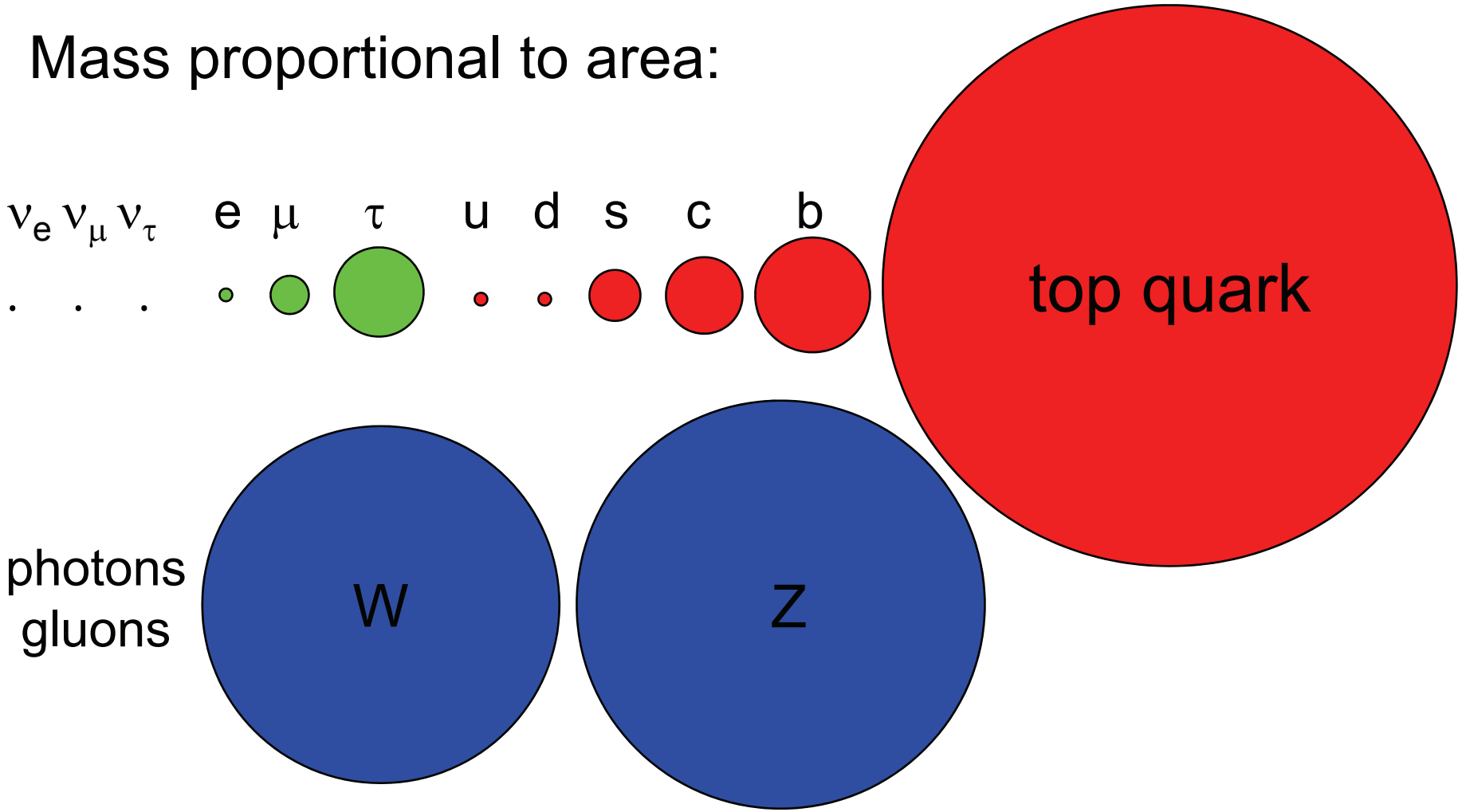
vs.



- Periodic table is…periodic. All atom masses are integral multiples of proton/neutron masses. What about elementary particles?

ELEMENTARY PARTICLE MASSES

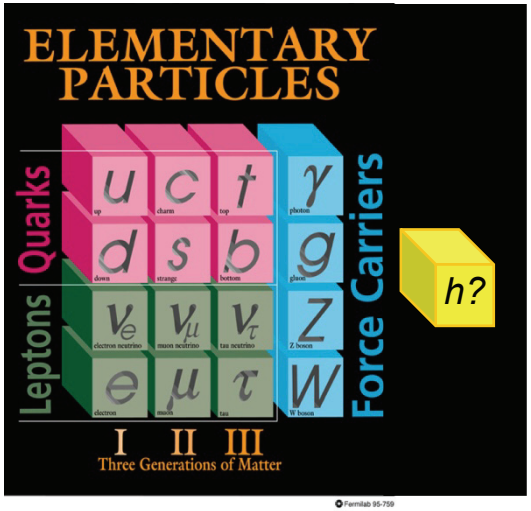
Mass proportional to area:

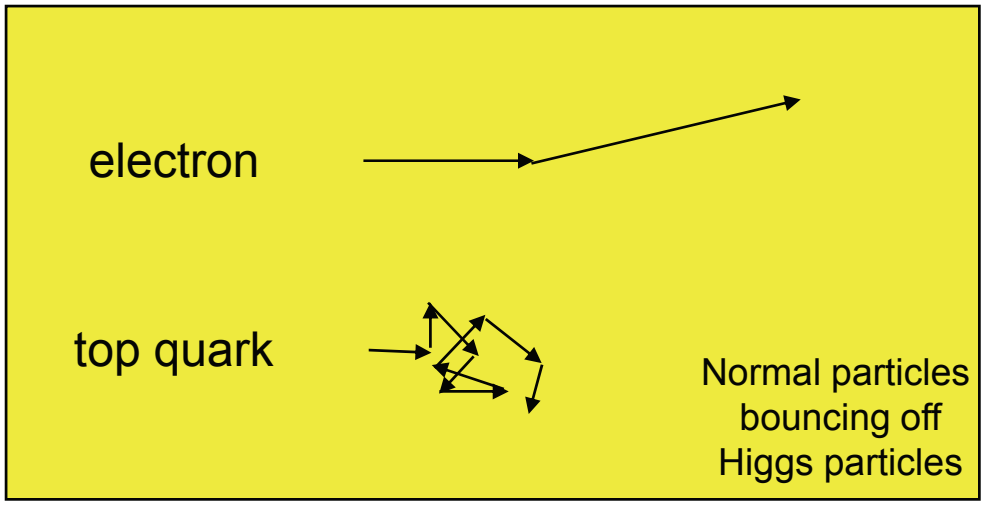


Are these made of something else? Are there more quark-, neutrino-,and electron-like particles?

THE HIGGS BOSON

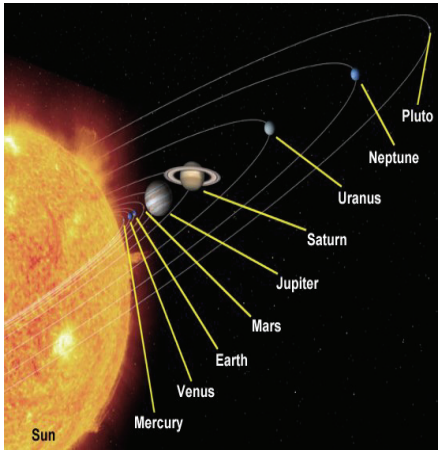
- In fact, with only the known particles, the current theory is incomplete: it predicts that all particles are massless and travel at the speed of light.
- A hypothetical particle, the Higgs boson, beautifully fixes this problem, but we've yet to find it.





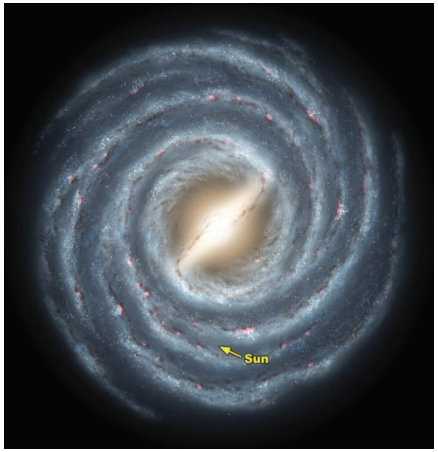
BIG: STATE OF THE ART

solar system



10^{12} meters

galaxy

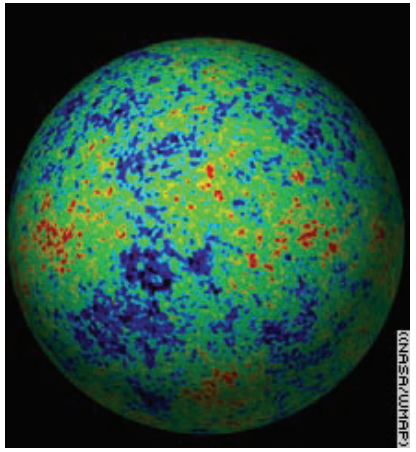


10^{17} meters

galactic cluster

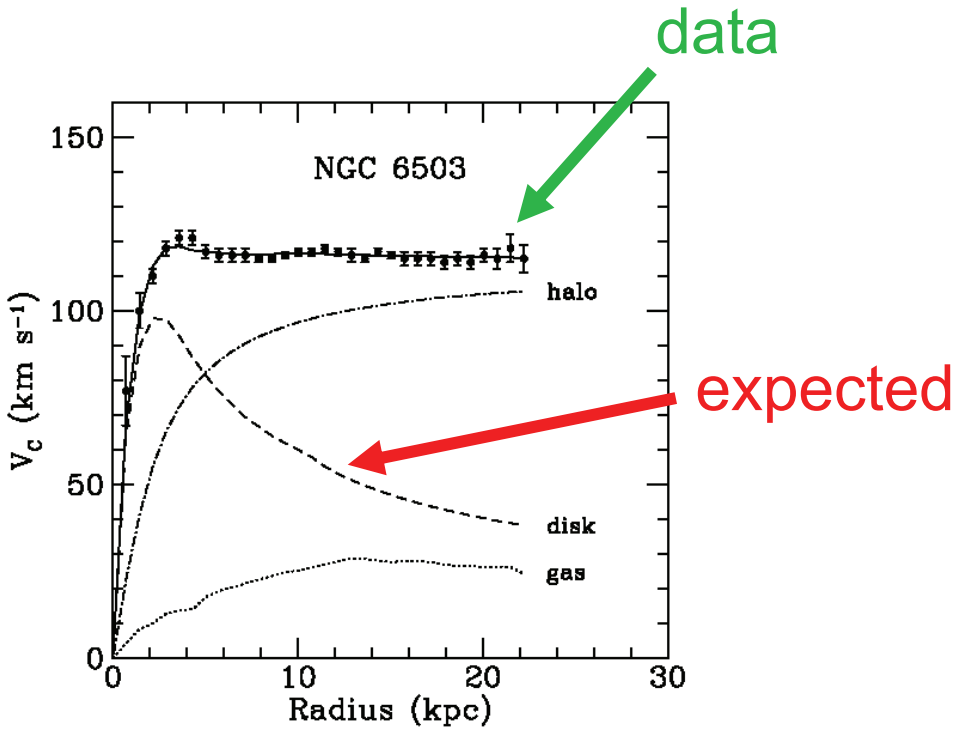
10^{23} meters

universe



$> 10^{26}$ meters

PUZZLES



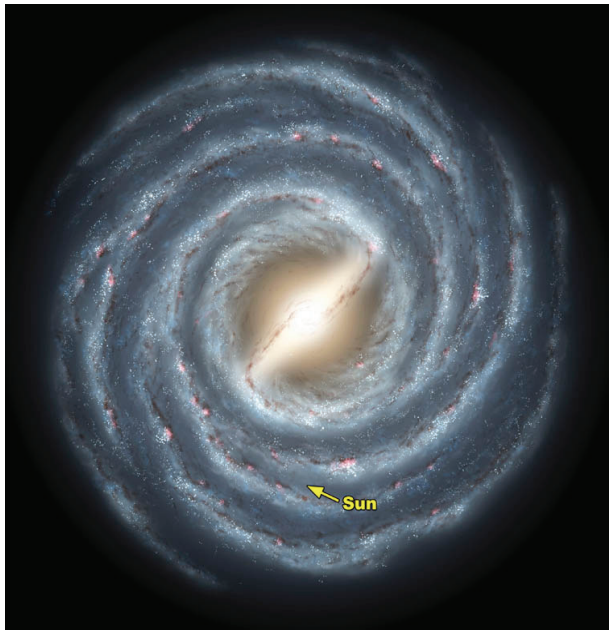
Begeman, Broeils, Sanders (1991)

Galaxies and clusters of galaxies rotate too fast
→ dark matter

$$\frac{Mv^2}{r} = \frac{GMM_{\rm tot}}{r^2} \Rightarrow v \sim r^{-1/2}$$

DARK MATTER

- What is dark matter? It is required to understand why galaxies don't fly apart, but it can't be any of the known particles.



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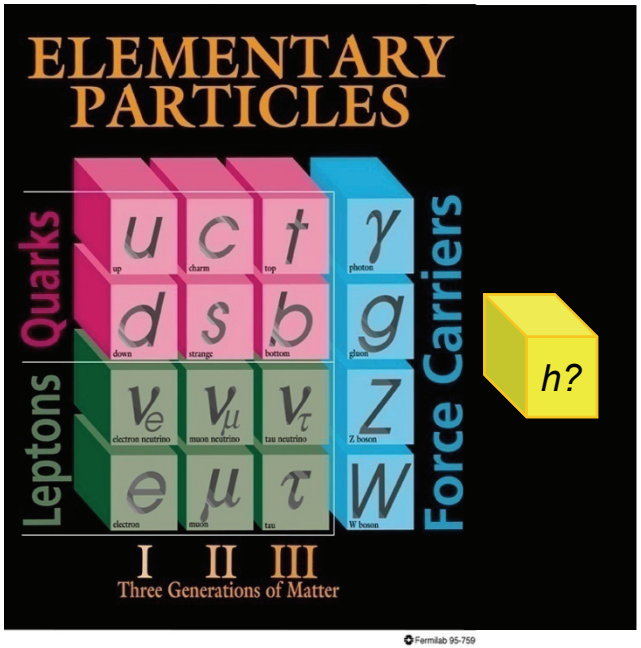
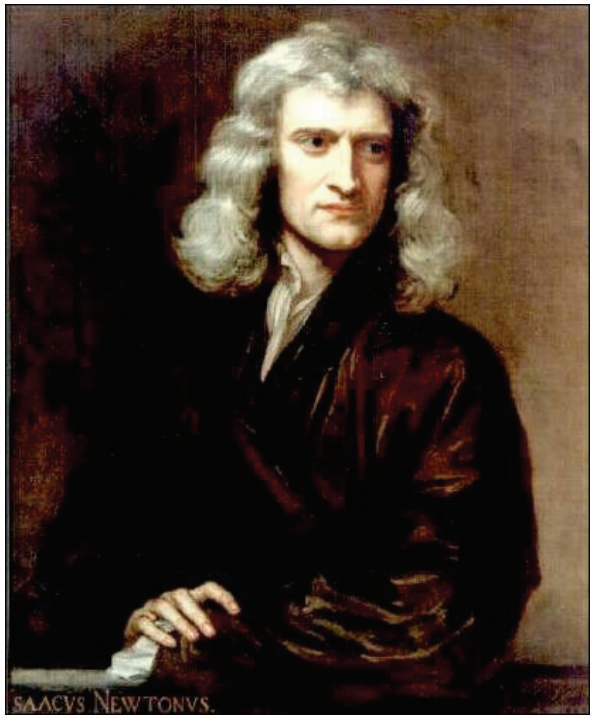
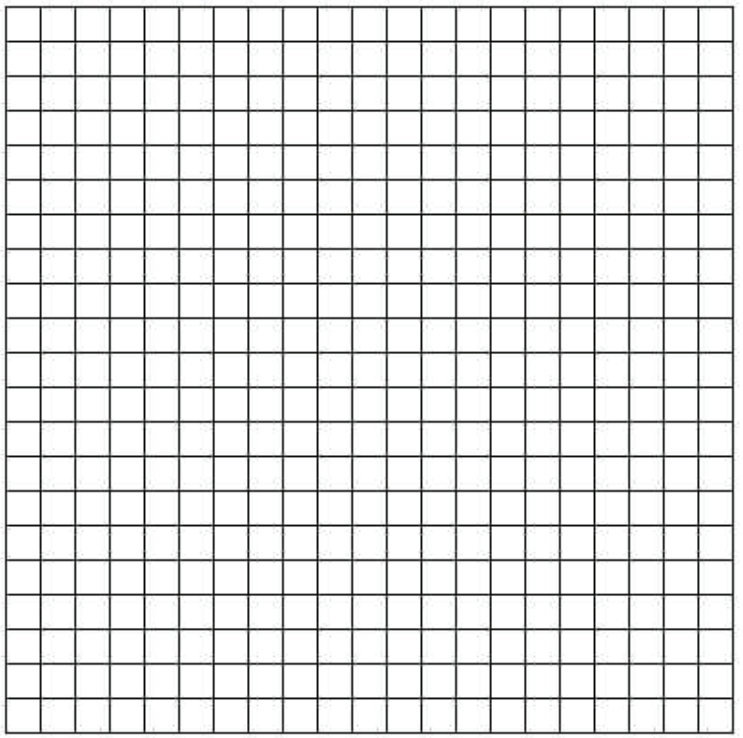


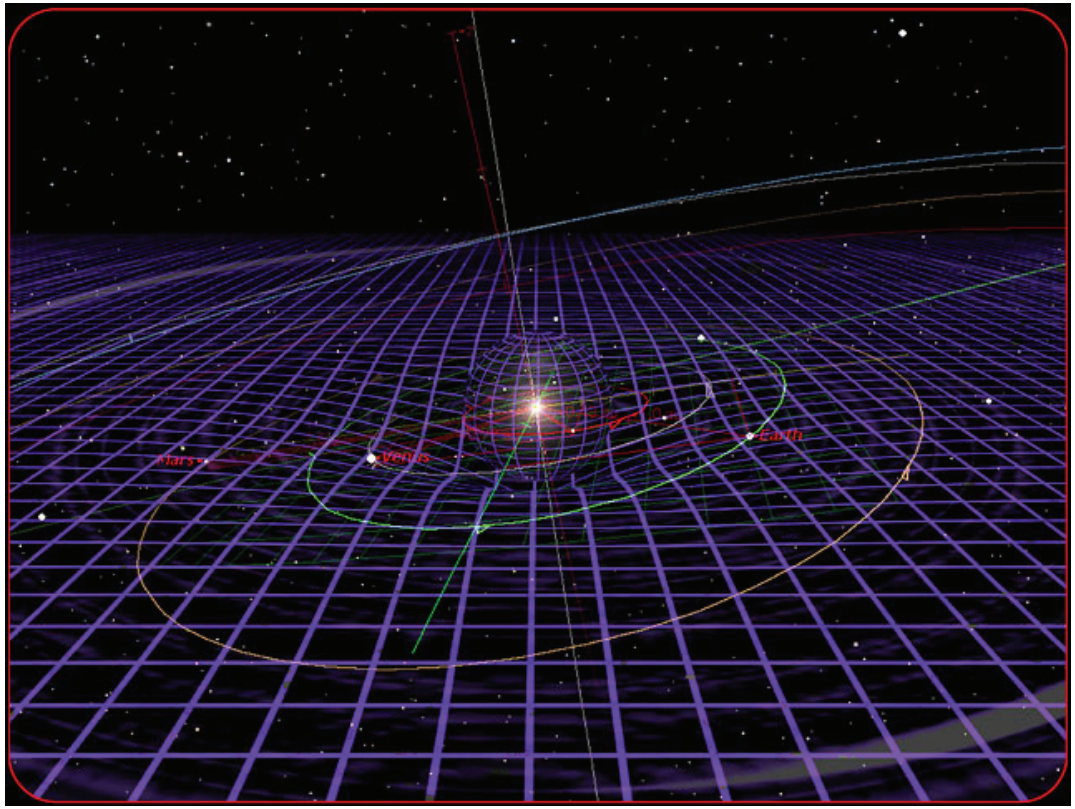
ISAAC NEWTON





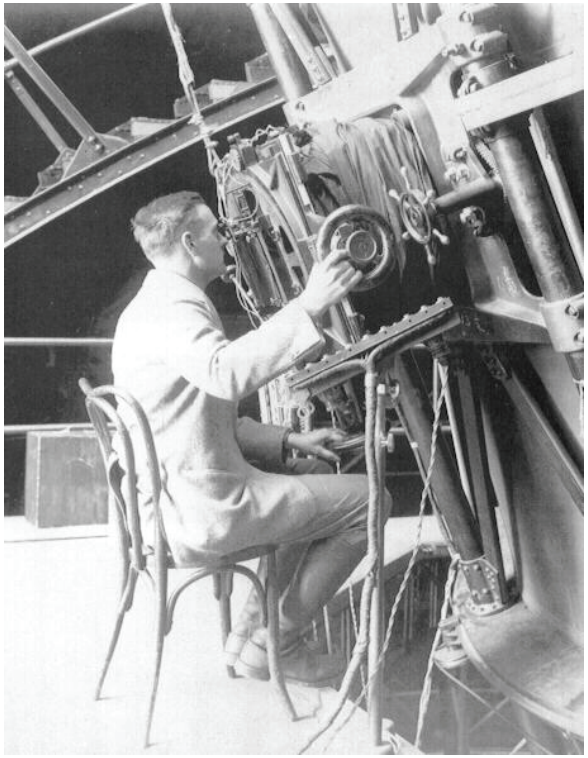
1687: Space and time are the static stage on which physical processes act

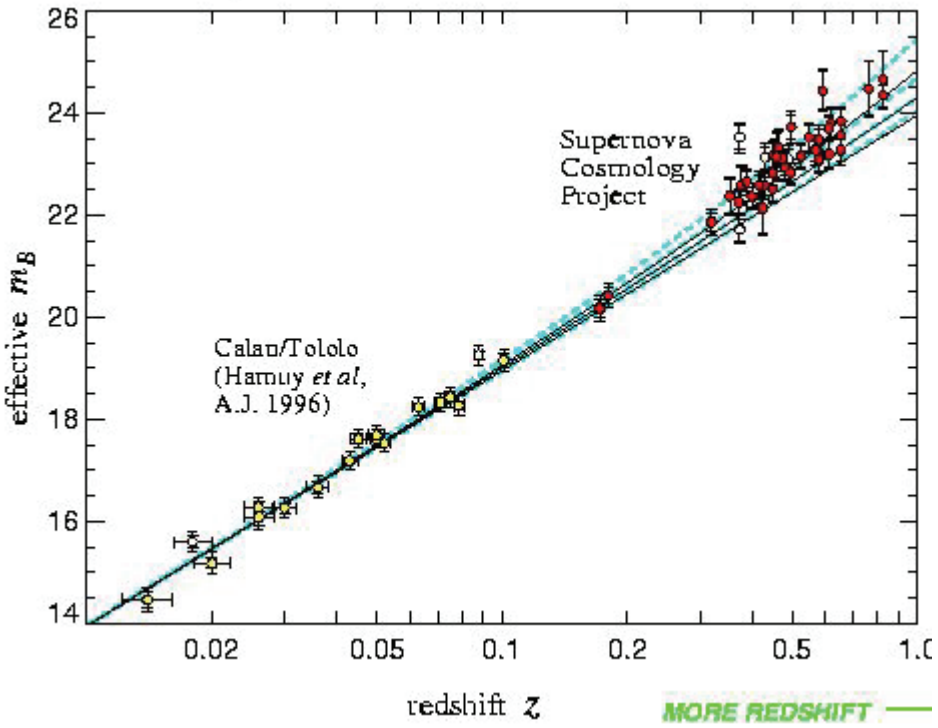
ALBERT EINSTEIN



1915: Spacetime is an active player:
curves, expands, shrinks, …

DARK ENERGY



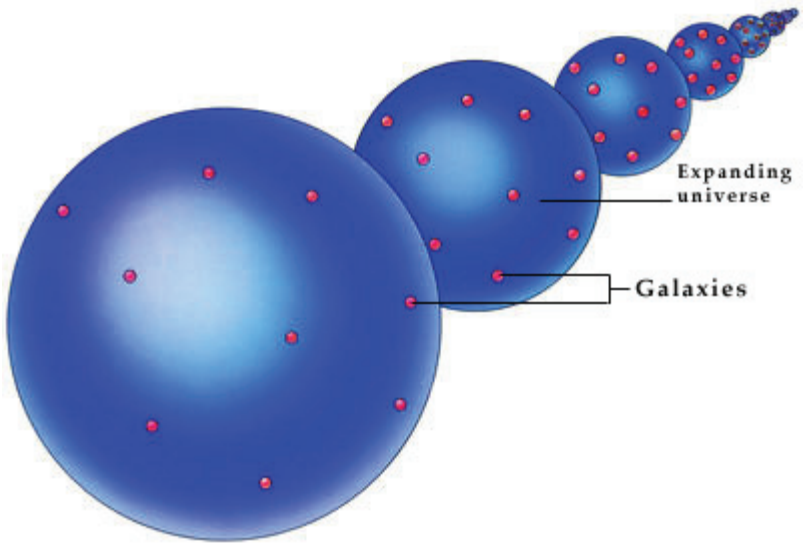


Hubble (1929): The universe is expanding

Supernovae (1998): and accelerating → dark energy

SMALL DIMENSIONS

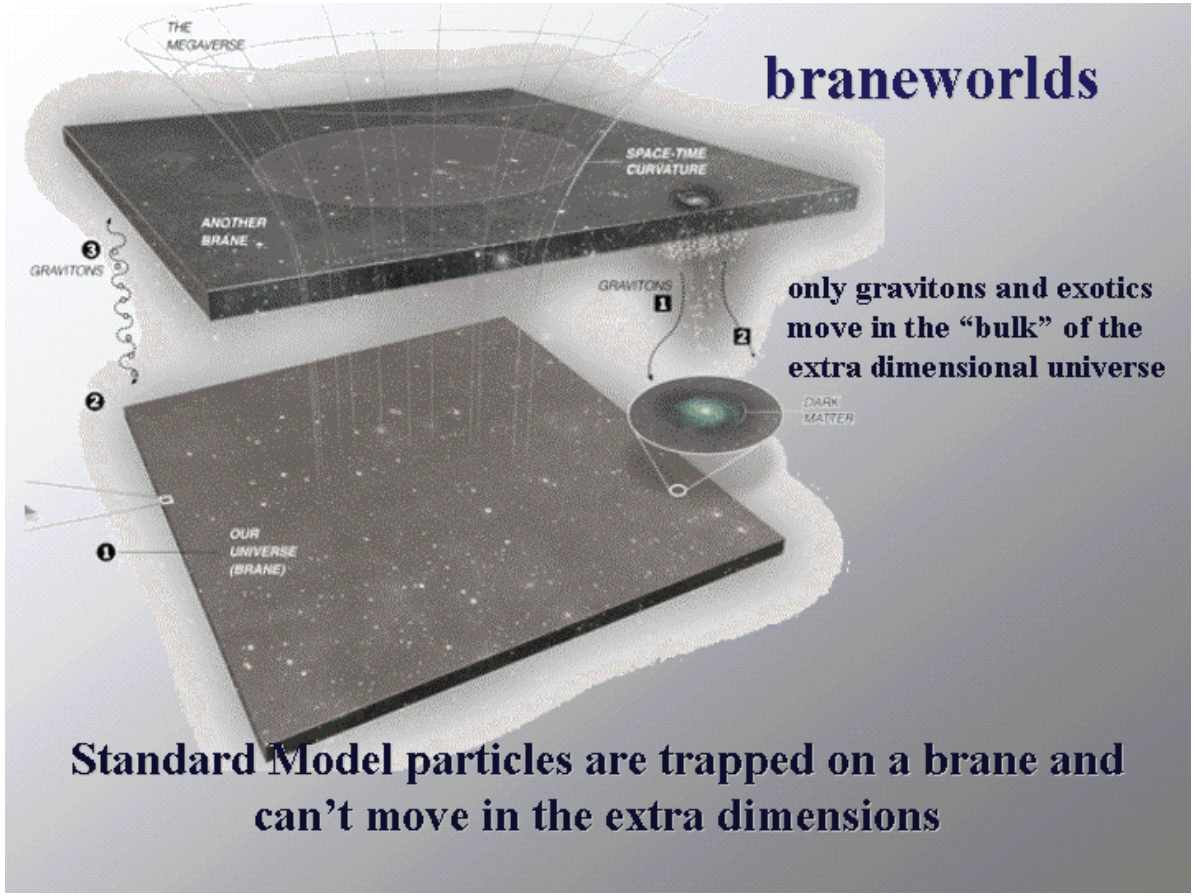
- The universe does not expand into space – space itself expands
- Extrapolating back, space was small – the Big Bang



- Other dimensions could exist but still be small. Some theories even *require* extra spatial dimensions. For example, string theory requires 6 more.

EXTRA DIMENSIONS

- Perhaps our world is only a slice of the whole universe



COMPOSITION OF THE UNIVERSE

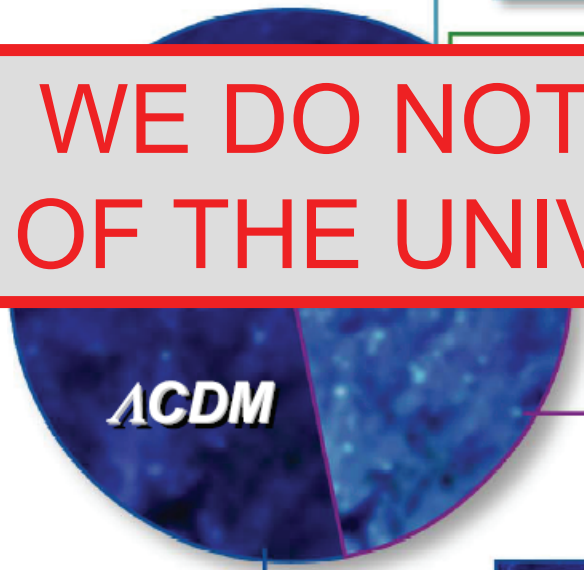
$$\Omega_i \equiv \rho_i / \rho_{\text{CRITICAL}}$$

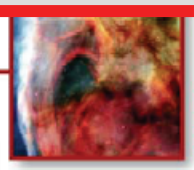
$$\Omega_{\text{TOTAL}} = 1$$

Heavy Elements:
Ω=0.0003

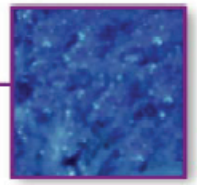
Neutrinos (ν):
Ω=0.0047

WE DO NOT KNOW WHAT
95% OF THE UNIVERSE IS MADE OF

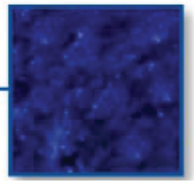




Free H & He:
Ω=0.04



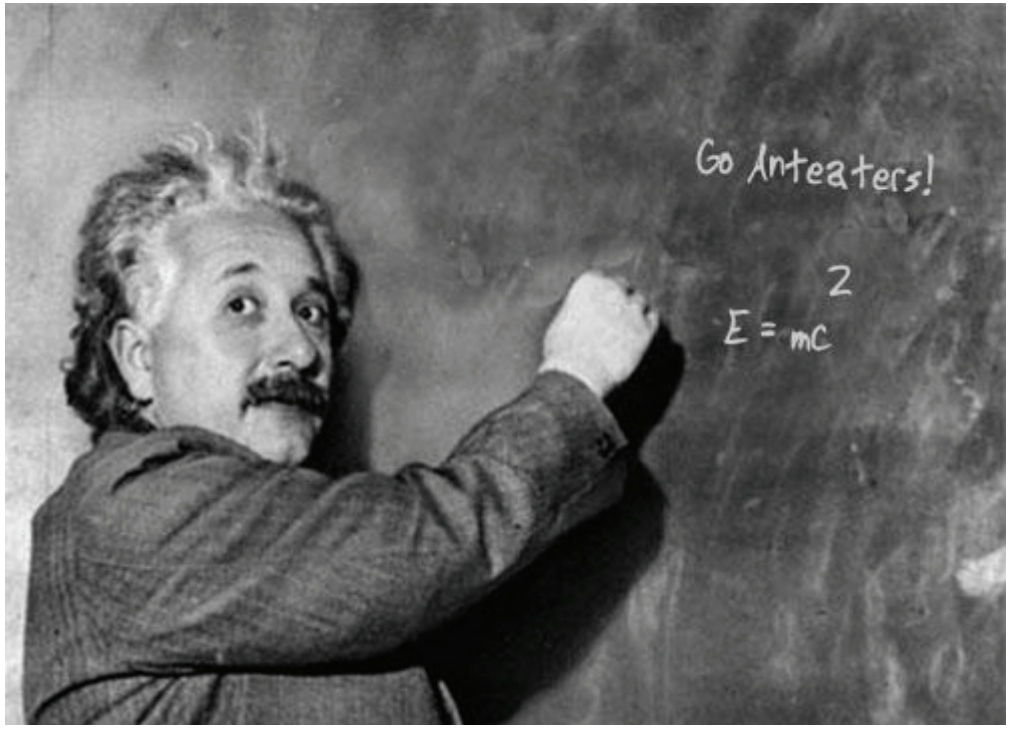
Cold Dark Matter:
Ω=0.25



Dark Energy (Λ):
Ω=0.70

$E = mc^2$

- Many of these questions involve hypothetical particles. How can we investigate them?

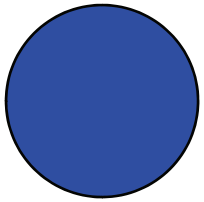


- Einstein: $E = mc^2$. Energy can be transformed into mass.

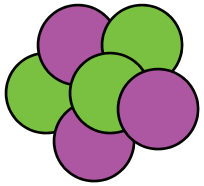
- To make new, heavy particles, smash together known particles at high energy.

MICROSCOPES

Higher energies → shorter wavelengths



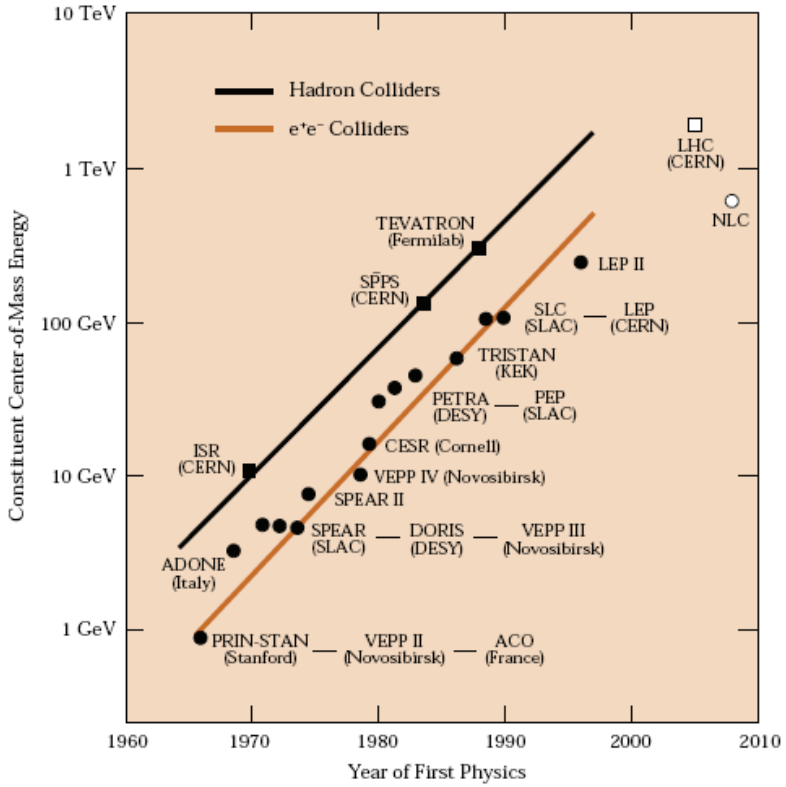
low resolution



high resolution

PARTICLE COLLIDERS

E. O. Lawrence's Cyclotron (1930s)



Livingston Plot: Moore's Law for Particle Colliders


LARGE HADRON COLLIDER
LHC: E_{COM} = 14 TeV, 10^6-10^8 top quarks/yr
[Tevatron: E_{COM} = 2 TeV, 10^2-10^4 top quarks/yr]

WHAT THE LHC IS LOOKING FOR

- The Higgs boson
- New quark-, electron-, or neutrino-like particles
- Quark and electron substructure
- New forces
- Black holes
- Extra dimensions
- Dark matter

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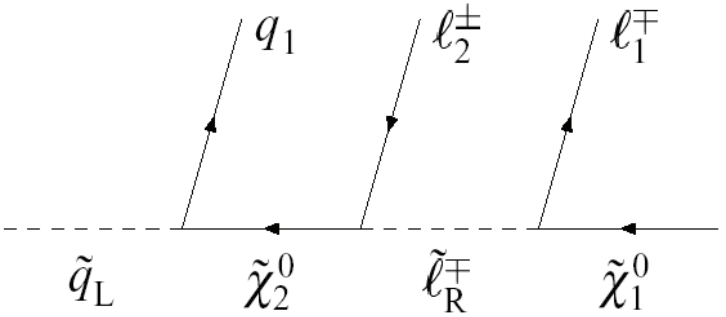
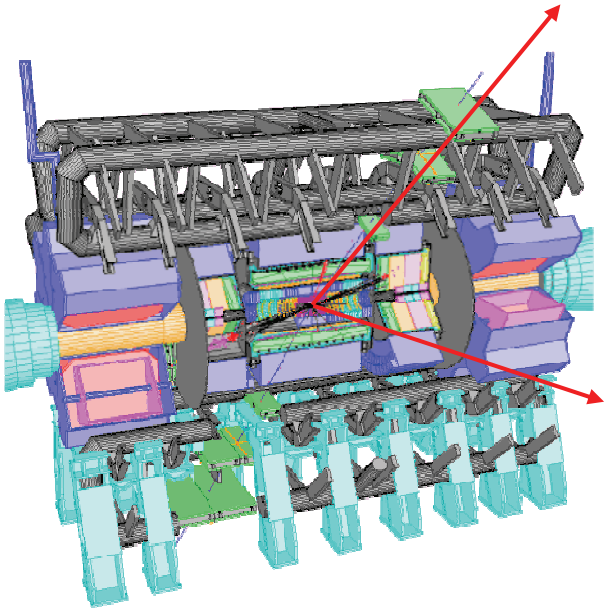
- Ideas not yet thought of

AN EXAMPLE: DARK MATTER

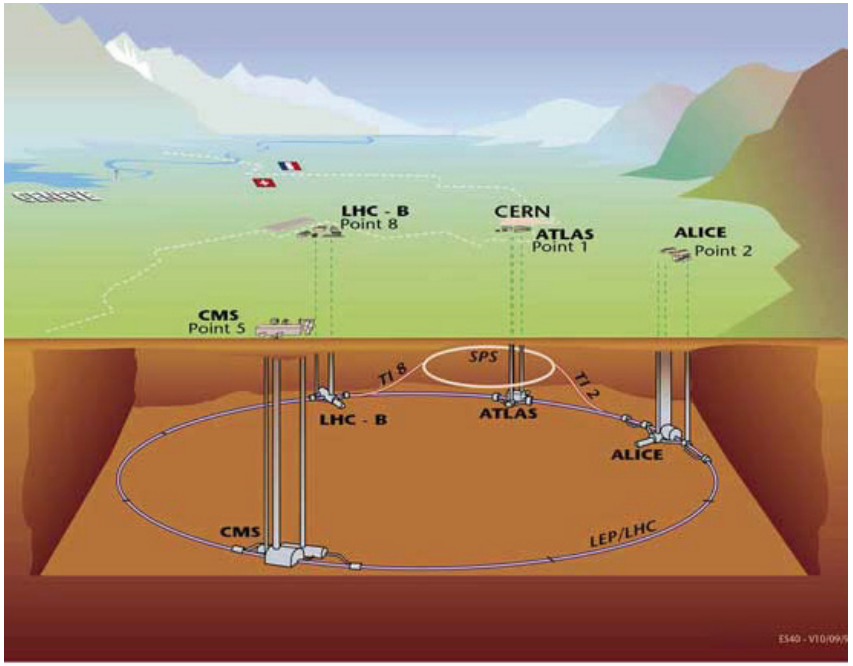
- Dark matter is very weakly-interacting – a billion dark matter particles have passed through your body since this talk started



- What the LHC could produce:
  - Pure dark matter – we'll never know!
  - Dark matter + other particles: dark matter escapes → missing energy and momentum. Can we find this?

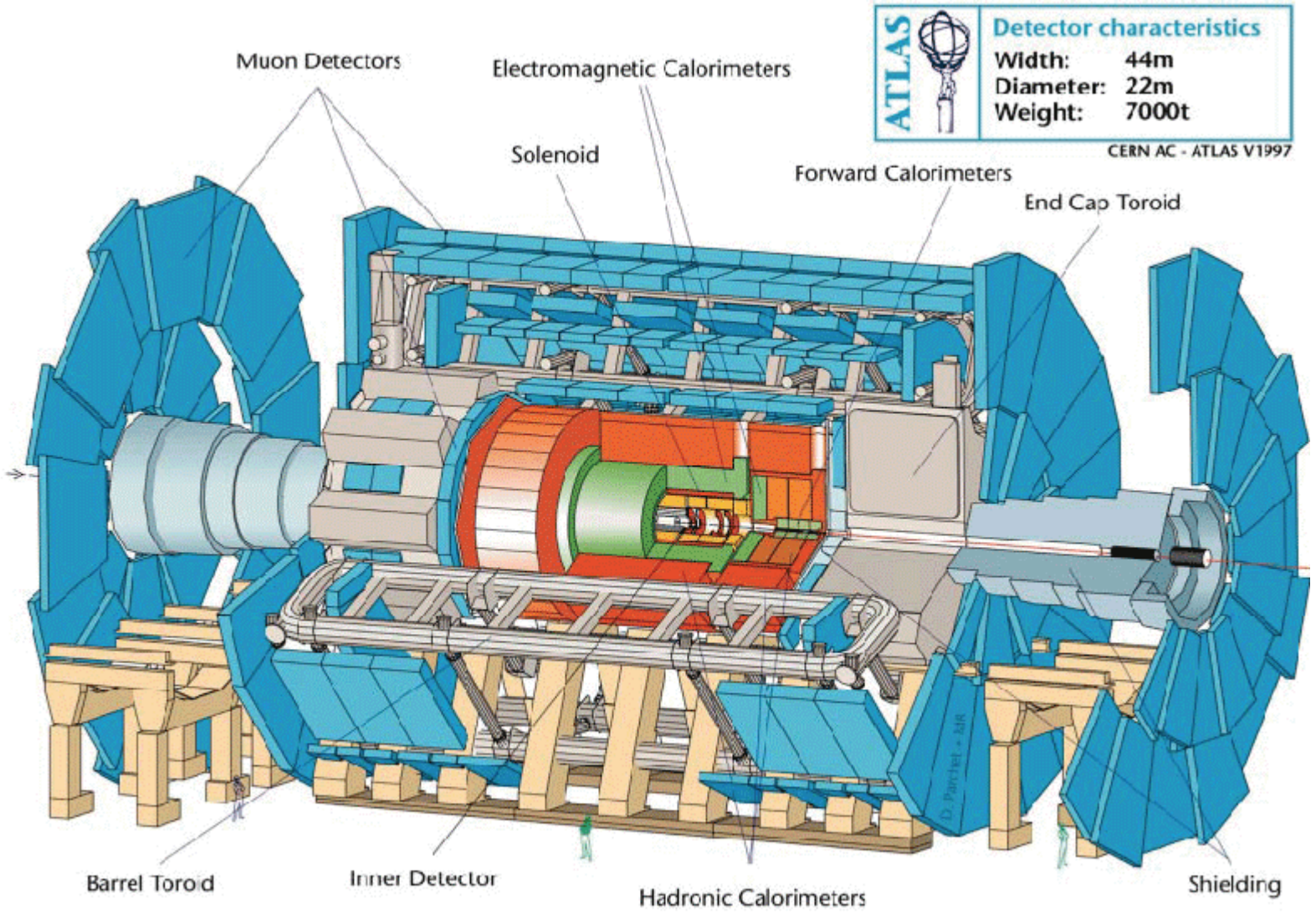


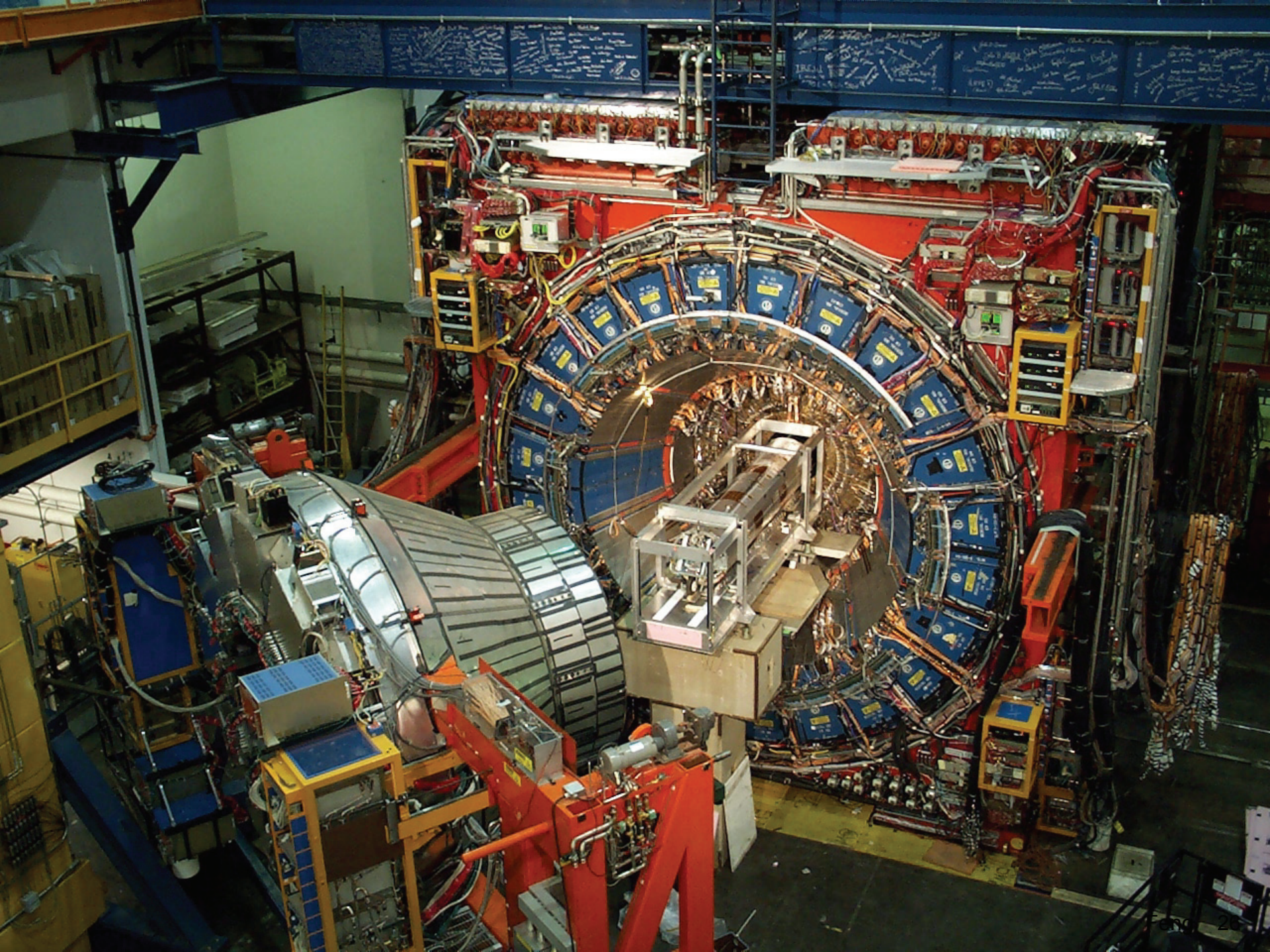
LHC DETECTORS



Two proton beams rotate in opposite directions 100 m underground. The beams collide at 4 interaction points, which are surrounded by detectors.

LHC DETECTORS



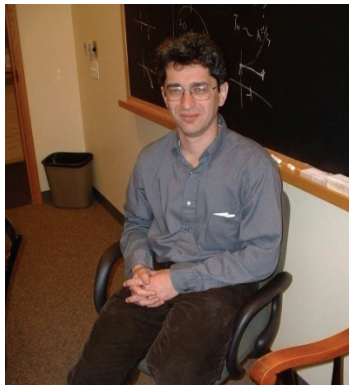


LHC FACULTY AT UCI

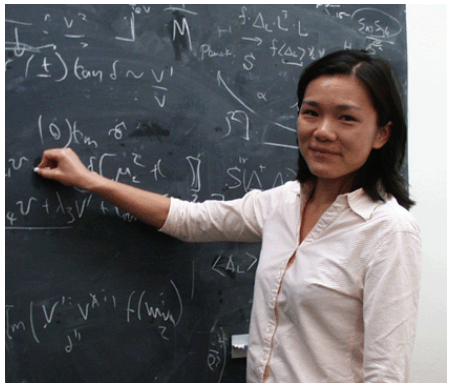
Theorists

Jonathan Feng

Arvind Rajaraman



Yuri Shirman



Mu-Chun Chen

Experimentalists

Andy Lankford

Daniel Whiteson

Anyes Taffard

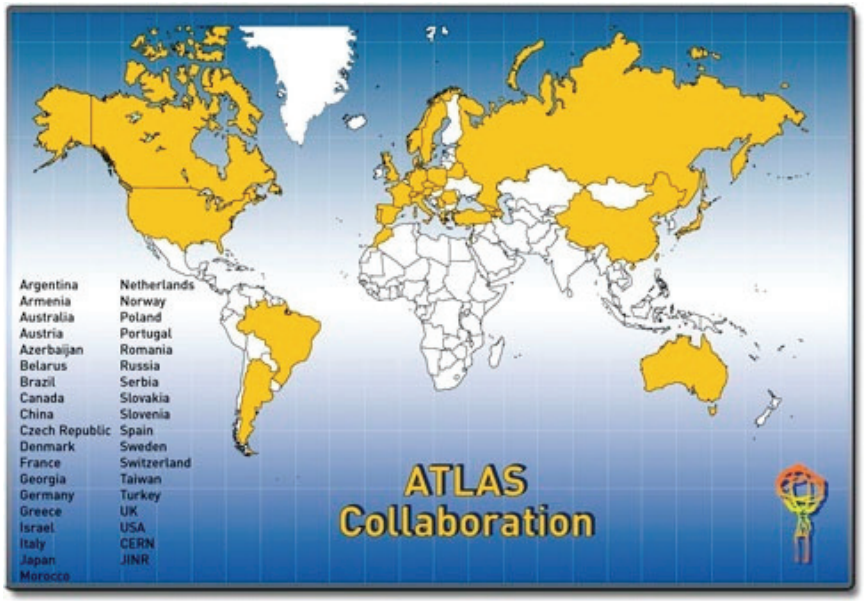
DATA COLLECTION

- The amount of data each detector receives is staggering
  - 1 Terabyte/second
  - 10,000 Encyclopedia Britannicas/second
  - 10 Libraries of Congress/minute
  - 3 300GB hard drives/second
  - 100 full length DVD movies/second
- This is 10,000 times the rate your computer can store data. The data must be reduced in some intelligent way before it is stored

LHC TRIGGERING: THE ULTIMATE SPAM FILTER

Finding needles in haystacks

LHC SOCIOLOGY



In each detector experiment, ~2000 collaborators from ~40 countries (and growing)

The procedure for sharing data and credit is not completely clear and is a topic of heated debate

LHC STARTUP

The New York Times

- September 11, 2008

  Protons and Champagne Mix as New Particle Collider Is Revved Up

- September 20, 2008

  Problems Stall Action for Collider

- September 21, 2008

  New Particle Collider to Be Shut Down for Repairs

- March 29, 2008

  Asking a Judge to Save the World, and Maybe a Whole Lot More

- June 21, 2008

  Swiss Particle Accelerator Deemed Safe

- September 30, 2008

  Suit to Halt Big Collider in Europe Is Dismissed

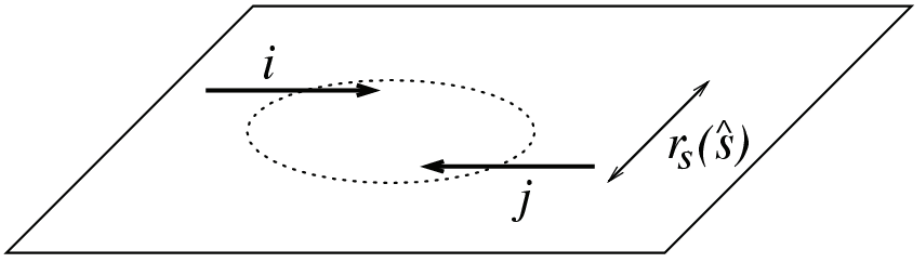
  By DENNIS OVERBYE

  A federal judge in Honolulu has dismissed a lawsuit trying to stop the running of a giant particle accelerator outside Geneva, dodging the issue of whether it could actually cause the end of the world.

LHC DOOMSDAY HYPE

BLACK HOLES AT THE LHC

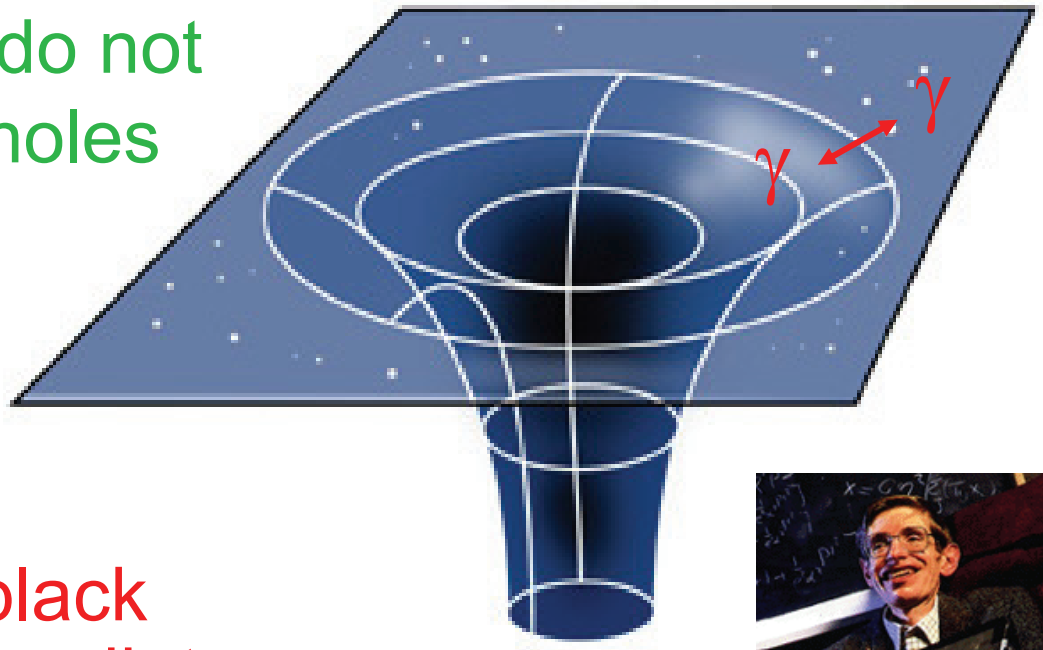
- If two particles pass close enough with enough energy, they may form a black hole



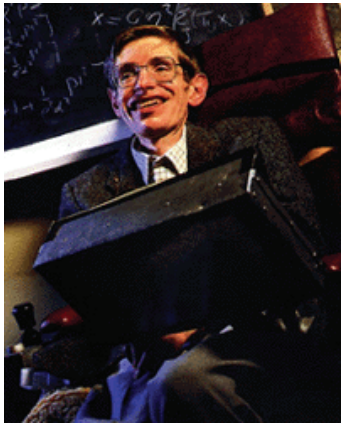
- For 3 spatial dimensions, this will never happen – gravity is too weak. But with extra dimensions, gravity may become stronger, micro black holes can be created in particle collisions

BLACK HOLES

- Classically, light and other particles do not escape; black holes are black.

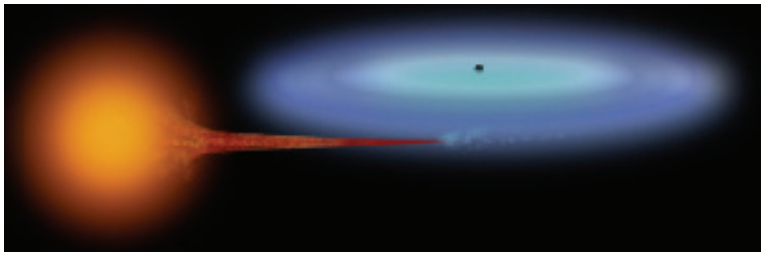


- But quantum mechanically, black holes Hawking radiate; black holes emit light!

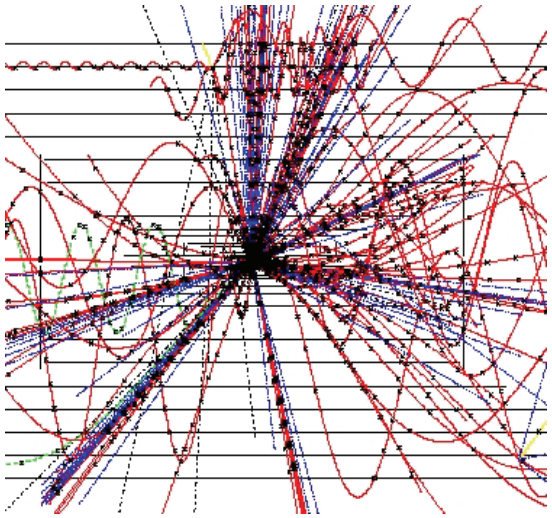


BLACK HOLE EVAPORATION

- "Normal" black holes:
  - Mass: $M_{BH} \sim M_{sun}$
  - Size: kilometer
  - Temperature: 0.01 K
  - Lifetime: ~ forever



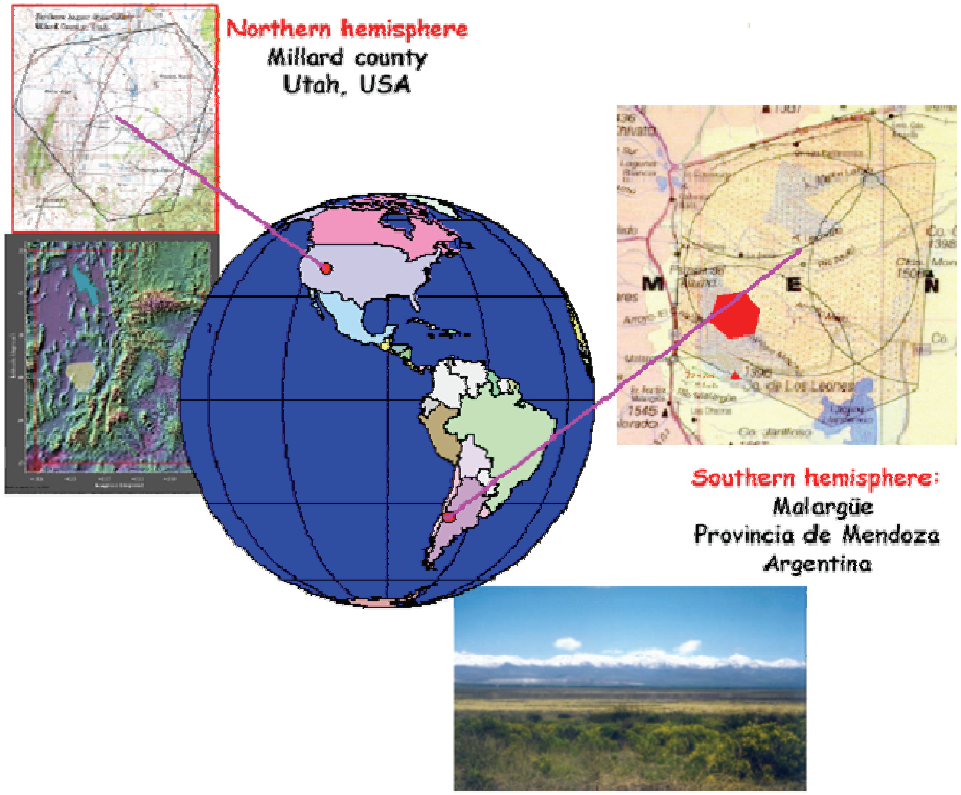
- Micro black holes:
  - Mass: $M_{BH} \sim 1000\ M_{proton}$
  - Size: 10^{-18} m
  - Temperature: 10^{16} K
  - Lifetime: 10^{-27} s

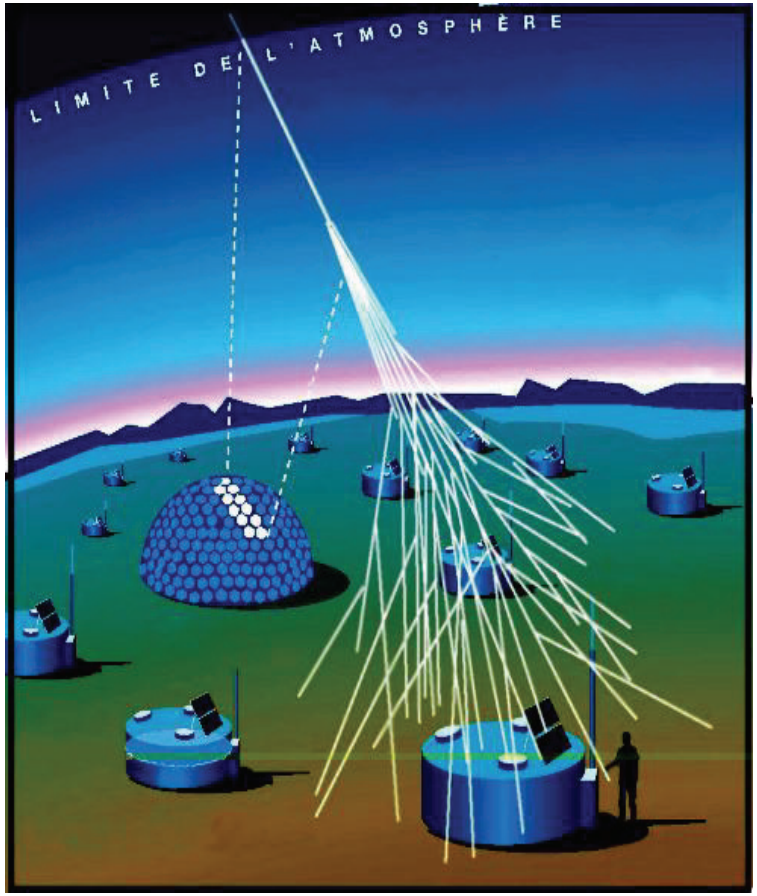


They decay instantly!

BLACK HOLES FROM COSMIC RAYS

The Auger Observatory in Argentina



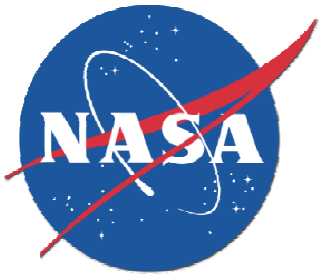


COLLISION COURSE CREATES MICROSCOPIC ‘BLACK HOLES’, 16 January 2002:

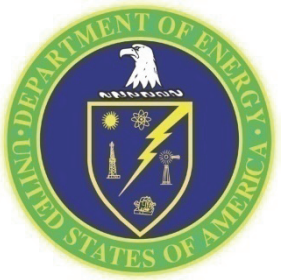
“…Dozens of tiny ‘black holes’ may be forming right over our heads… A new observatory might start spotting signs of the tiny terrors, say physicists Feng and Shapere… They’re harmless and pose no threat to humans.”

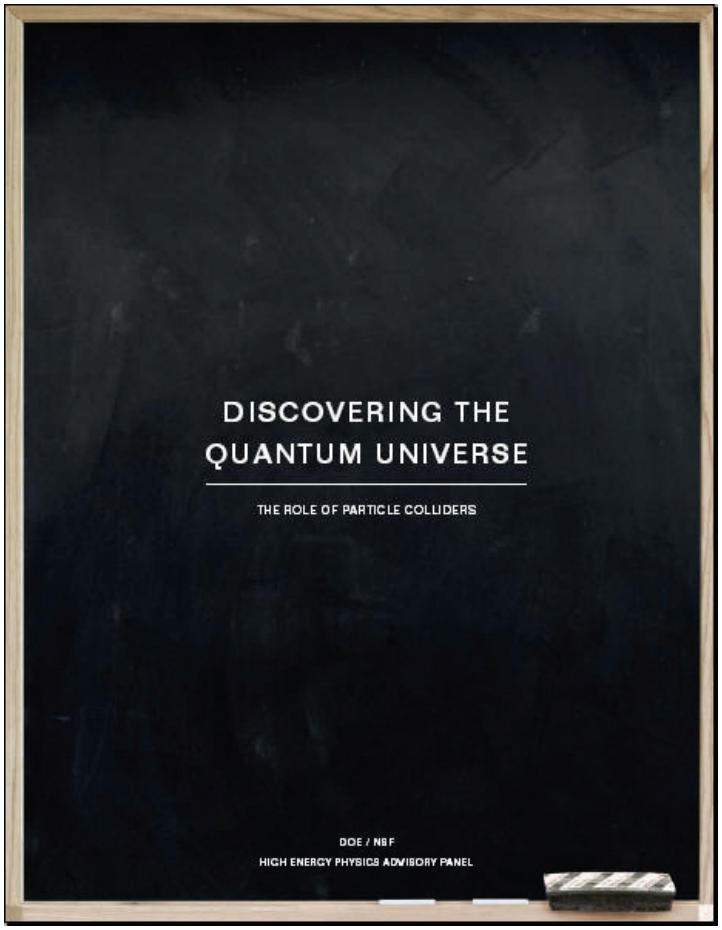
Bottom line: Nature has been performing LHC experiments for billions of years. Raises many interesting issues about scientific responsibility, but no need to worry.

ACKNOWLEDGMENTS



UCIrvine
University of California, Irvine





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