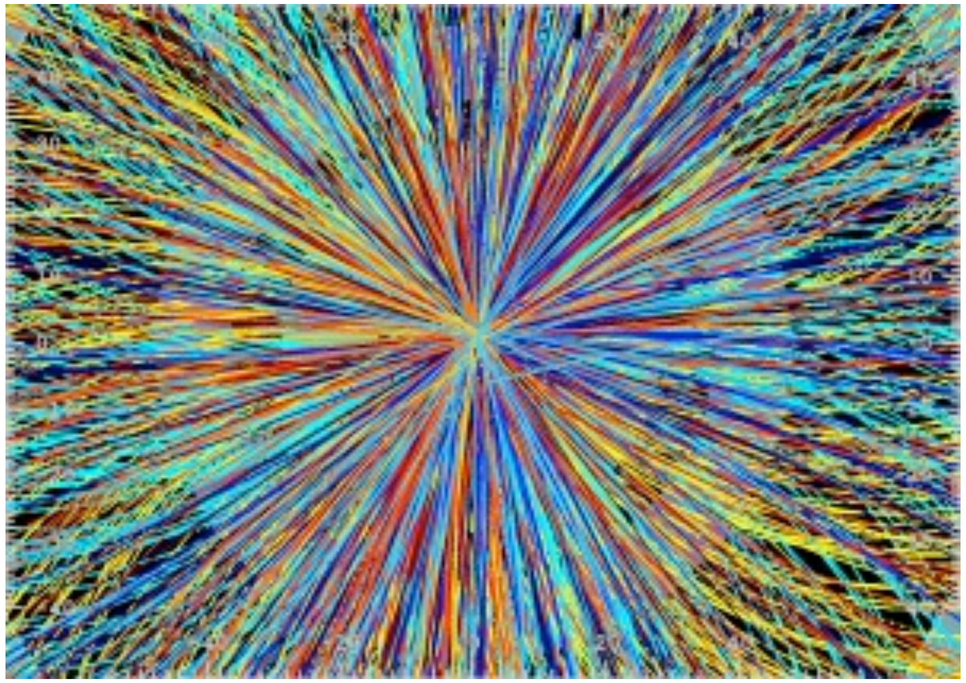
Astronomy 150: Killer Skies
Lecture 24, March 16

Assignments:

- HW7 due at the start of class
- Night Observing due
- HW8 due Friday after break

Last time: When Stars Attack!

Today: Death by Subatomic Particles!?



iClicker Poll:
ASTR 150 on Break

During Spring break, how far away will you be from where are are right now?

A. less than 10 miles

B. 10 to 100 miles

C. 100 to 1000 miles

D. 1000 to 3000 miles

E. > 3000 miles

Last Time: Nearby Supernovae

Nearby Supernova Threat

- biggest problem: destruction of ozone in stratosphere
- then Sun's UV unshielded
- large UV dose damages bottom of food chain
- damage propagates upward
- minimum safe distance: 8 pc

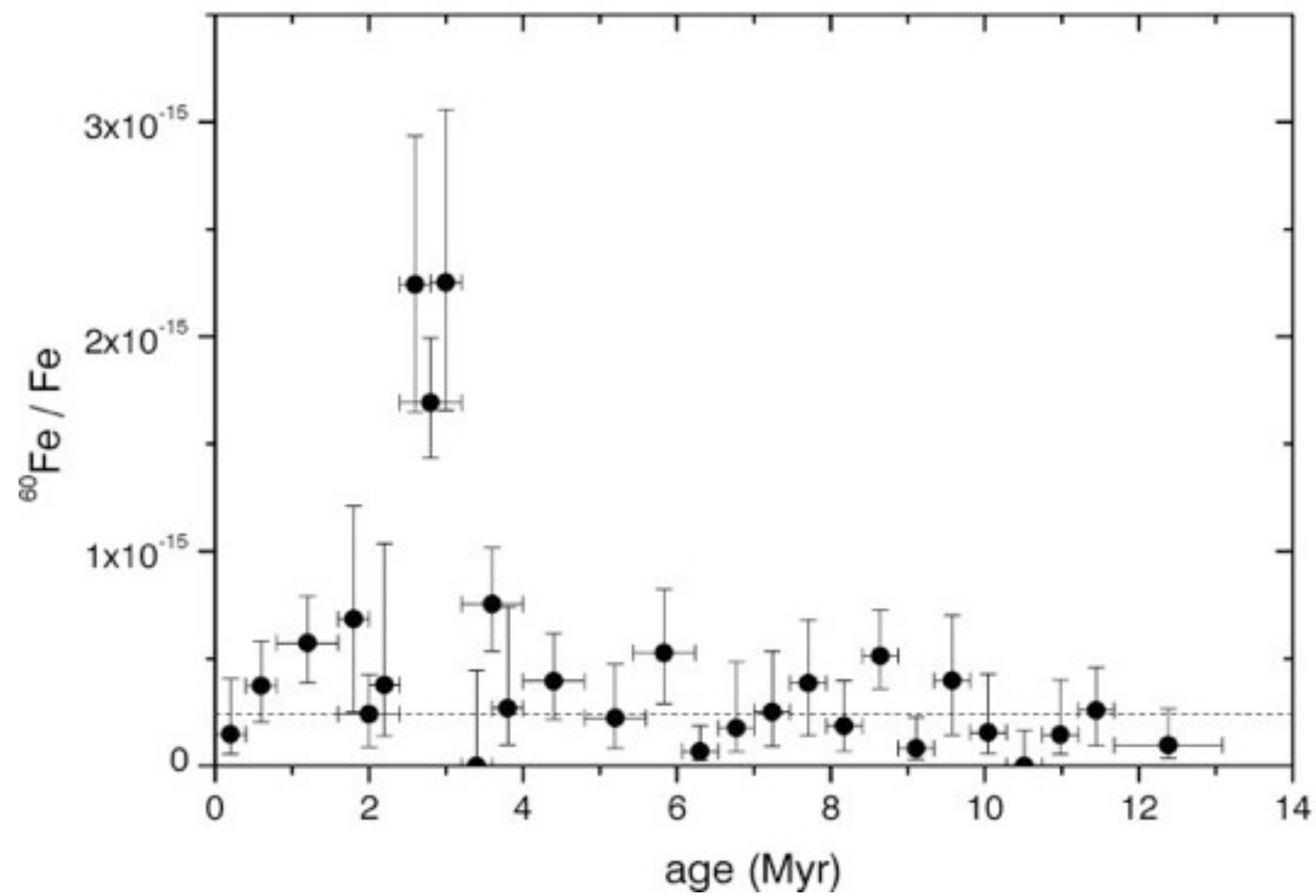
How Would We Know?

- if supernova close enough to hurt, close enough to leave "smoking gun" -- Earth inside supernova remains, receives debris
- live (not decayed) radioactivity is signature of supernova

Undersea Evidence for a Nearby Supernova?

- live radioactive iron (^{60}Fe) found in deep ocean sample
- points to recent nearby supernova!
- when? 2-3 million years ago
- how far? 20-100 pc away

Q: compare distances--what does this mean?



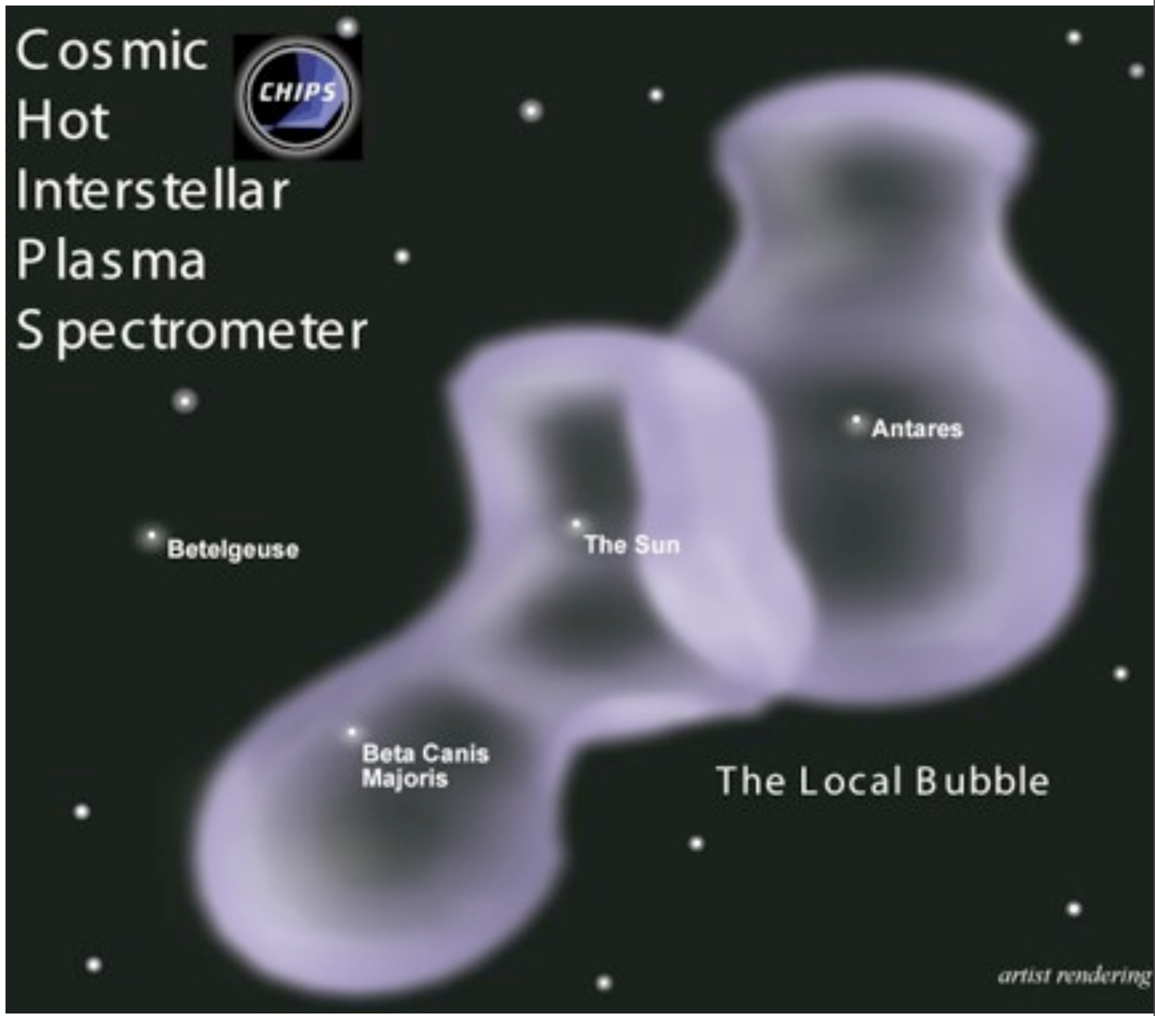
Aftermath: The Local Bubble?

The Sun lives in region of hot, rarefied gas P Frisch

- The Local Bubble
- hot cavity ~50 pc ⇒ huge
- seen via foreground absorption in nearby starlight

Nearby SN needed

- we live inside SN remains
- bubble models require >> 1 SN in past 10 Myr Smith & Cox 01
- ^{60}Fe event from nearest massive star cluster? Benitez et al 00



Other Signals?

Lunar Soil

consistency check for deep-ocean signal

if supernova can put debris on Earth, should also put debris on Moon (and elsewhere in solar system)

but: have to worry about radioactivity created by cosmic ray bombardment of lunar surface

Cook et al 2010

^{60}Fe excess in top layer of lunar drill core!

Alan Bean, Apollo 12 (1969)

A Near Miss?

$d > d_{\text{kill}} \sim 10\ \text{pc}$...but barely: "near miss"

¿ cosmic ray winter?

¿ bump in extinctions?

If true:

possible effects on prehistoric environment and maybe human evolution?

Image: Mark Garlick
www.markgarlick.com

Deep-Ocean Radioactivity
Lessons

Near-Earth supernova explosions can and do happen

- Even near-misses may influence the development of life

We have the technology in hand to detect their evidence

- but the measurements are very challenging!

Also: supernova debris on Earth is huge opportunity

- chance to look at supernova matter in the laboratory
- "sea sludge as a telescope" !

Supernova Attack: Mitigation

Q: what do you think?

Not much can be done!

- Try not to live too close to a massive star near the end of its life.
- With time, our species should one day travel to the stars.
- We could monitor nearby candidates.

  recall: surface luminosity, temperature do not change much near death--no hints of when the end is near

  but if nearby supernova, neutrino signal very large, and changes violently during late stages: early warning!

  could measure with large detector

Imagine

- Astronomers are the first to know.
- Neutrino detectors around the world are overwhelmed by the blizzard of signals
- Gamma and x-ray telescopes are quickly blinded by the bright light from the object
- Then in the night sky a star gets brighter and brighter, easily seen with the naked eye and still getting brighter.
- Can easily be seen during the daytime!
- The first supernova in 400 years!

Imagine

The power grid collapses

The sky around the star is blue!

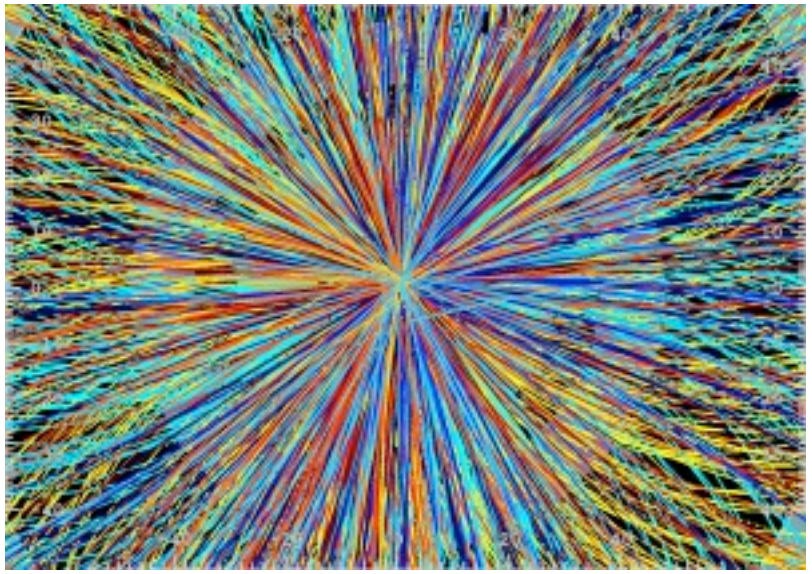
Gamma Rays have already destroyed the ozone layer, we just don’t know it yet.

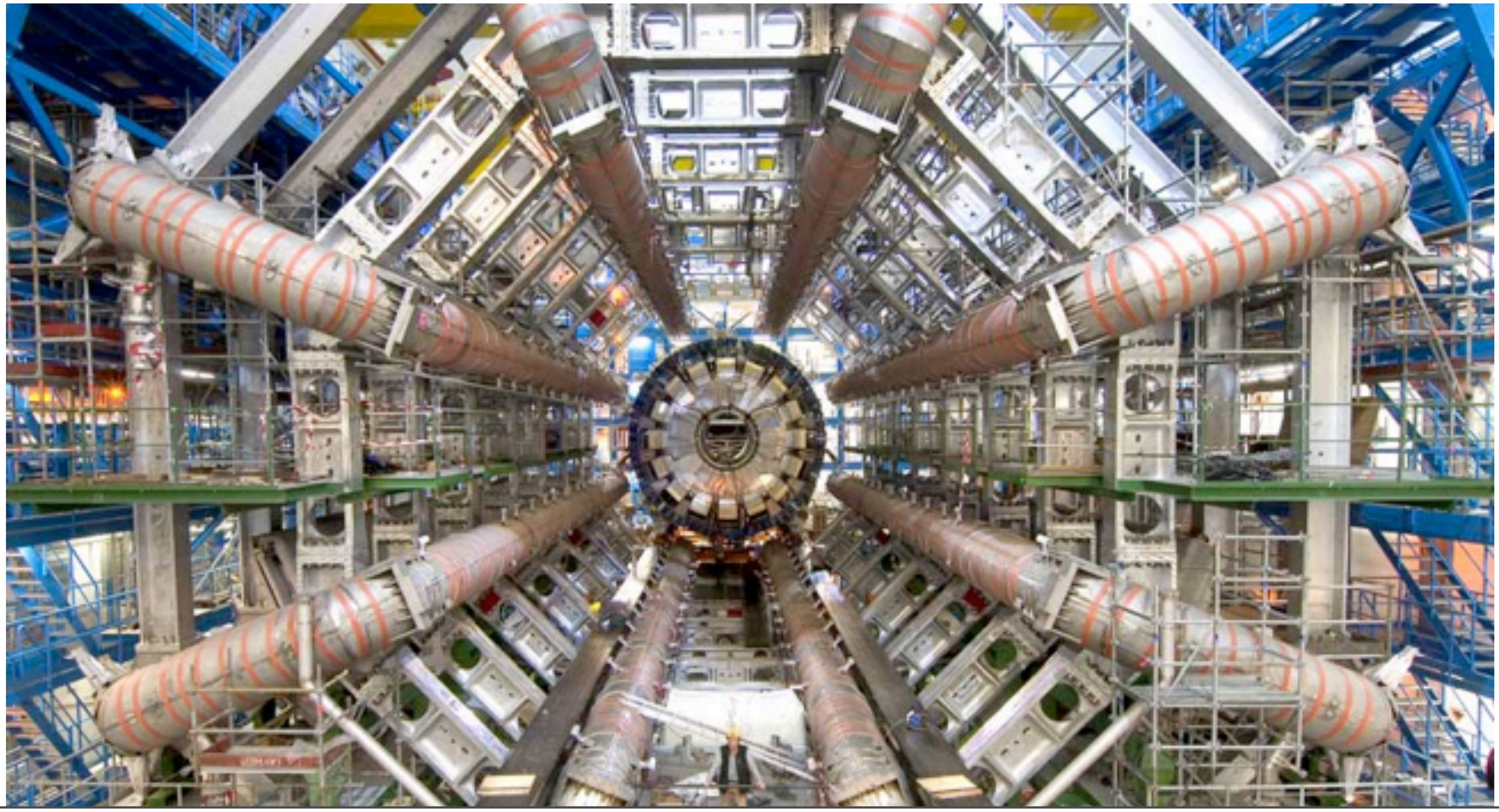
Severe sunburn, but UV radiation will kill off phytoplankton, the base of the food chain

A new mass extinction is happening!

As you die blissfully, you wonder what Brian was going to talk about this week.

Spring Break Warmup
Death by Subatomic Particle?





The Inner Space/Outer Space Connection

By now a theme has emerged in this course

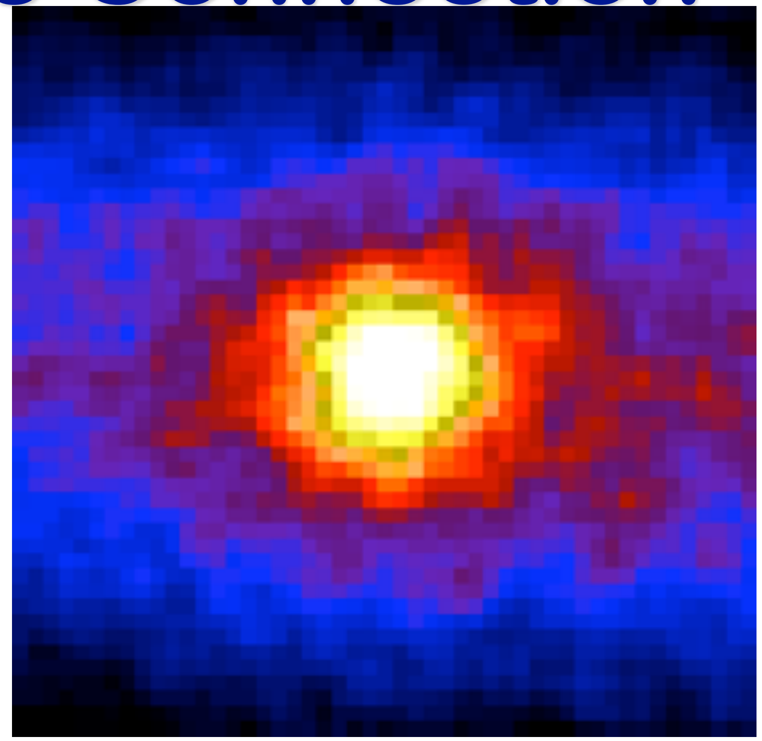
- the nature of the cosmos on the largest scales
  - planets, stars, even the universe as a whole
- is intimately connected with
- the nature of the cosmos on the smallest scales
  - the properties of atoms and of subatomic particles
  - e.g., nuclear and neutrino properties crucial for the workings of the Sun and stars

But also works the other direction:

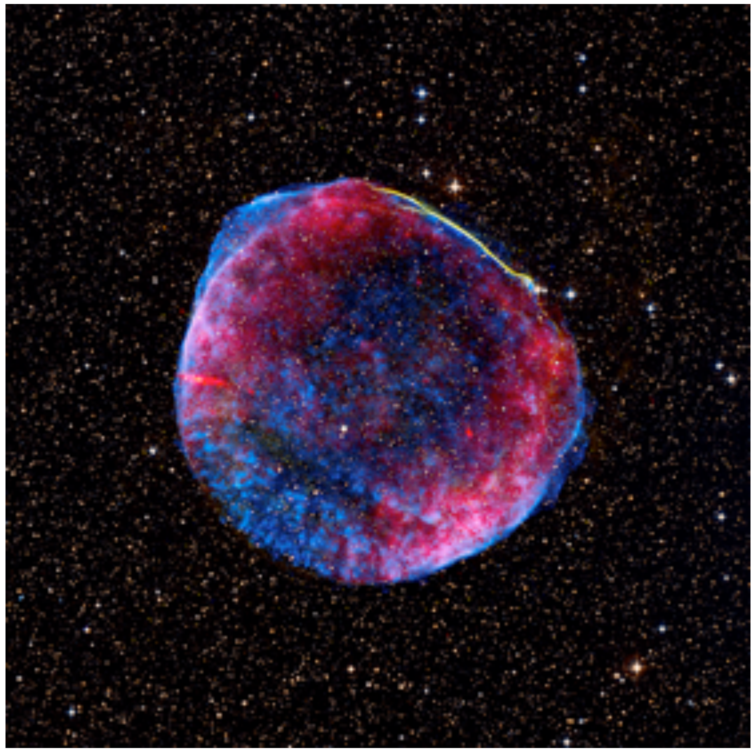
- by studying extreme environments in the cosmos (outer space)
- we can learn about yet-unknown properties of the subatomic world (inner space)

"The Universe is the poor person's accelerator"

-- cosmologist Yakov Zel'dovich



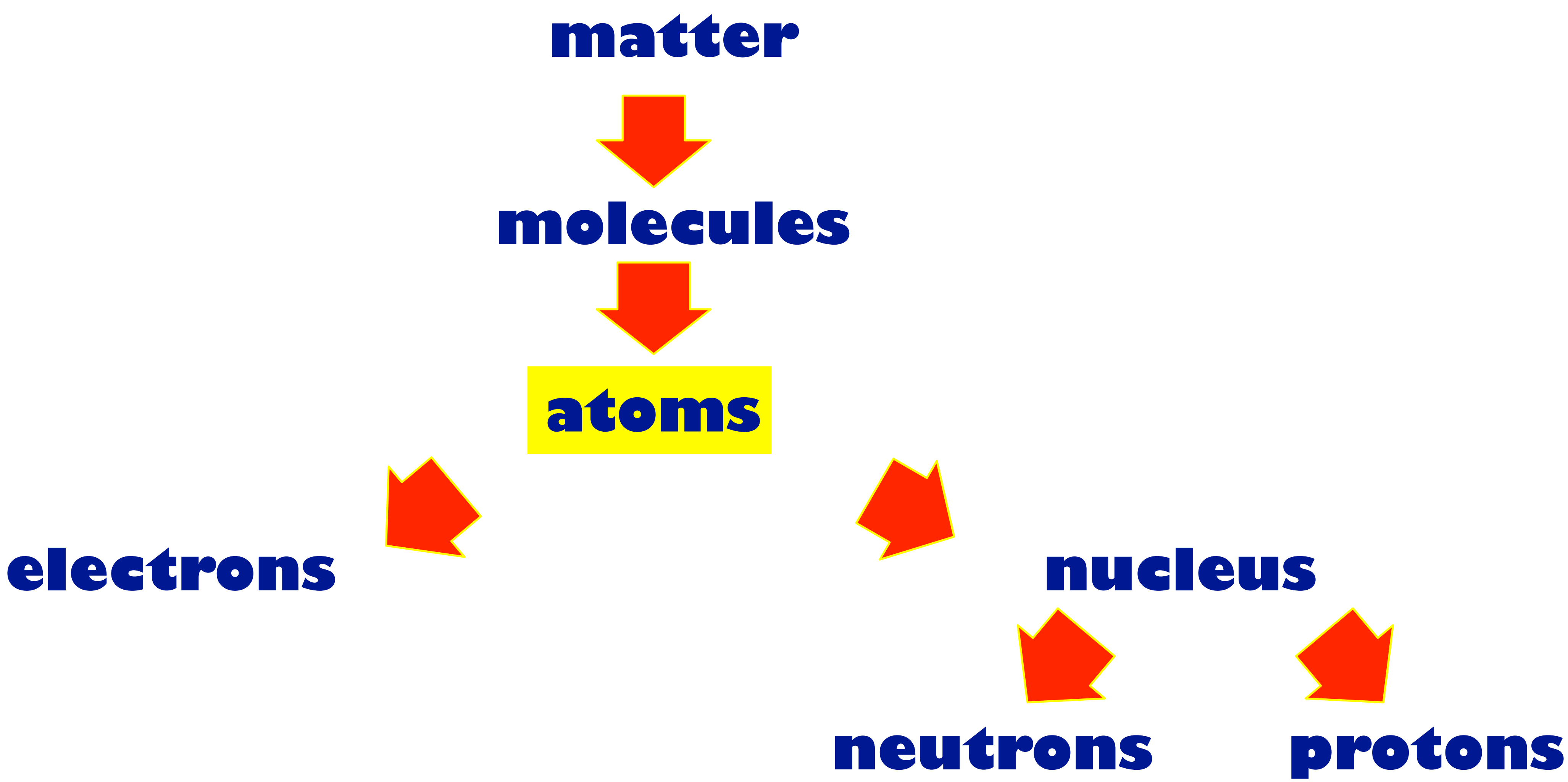
Neutrino Image of the Sun



Supernova:
Element, Neutrino, and Cosmic-Ray Factory

Matter*

All known substances ever studied in any lab have this structure



*Wierdo dark matter not included in this discussion

What's in a Proton?

matter is made of atoms

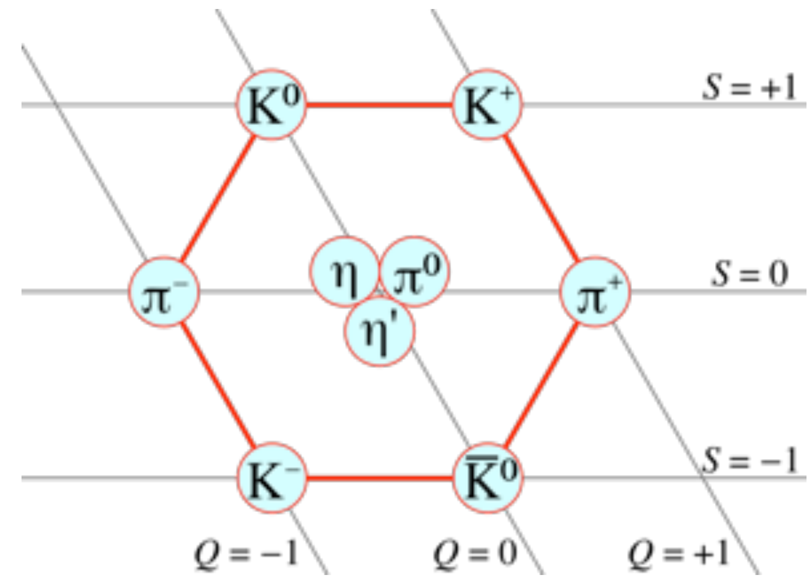
themselves made of

- electrons
- nuclei, which are themselves made of
  - protons and neutrons

but what about protons and neutrons?

to learn what's inside, have to break apart!

- collide electrons with nuclei
- or other nuclei with nuclei
- see what you get



these experiments done in 1950's and 1960's

- answer: a zoo of particles, most of which are unstable!
- the unstable particles decay
  - either back to protons and neutrons
  - or some decay in other ways, e.g., electrons and neutrinos
  - but always obey this rule: #p+#n before = #p + #n after

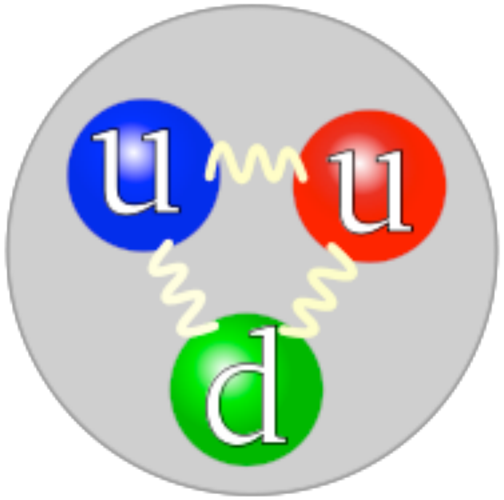
today: > 1000 such unstable particles known!

and many more...

Making Sense of the Particle Zoo

How are these new particles made?

- accelerators create particle beams (electrons or nuclei) with high speed, high kinetic energy
- in collisions, kinetic energy converted to mass
- Einstein says: $E = mc^2$
- mass is energy, but also energy can become mass!



inside a proton: quarks

Why do we get so many new particles?

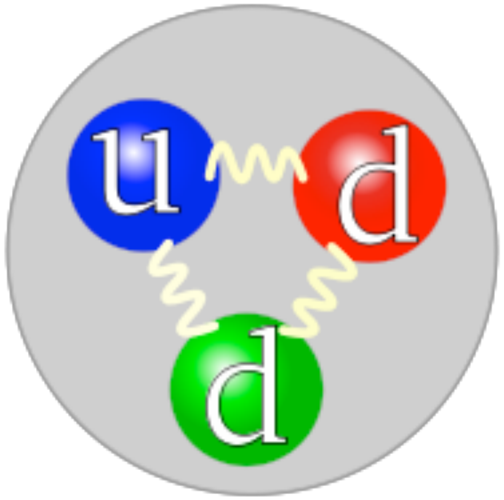
- can we make sense of all this confusion?
- 1970's and 1980's: yes!
- what if: protons, neutrons, and all the rest of this zoo are not elementary particles
- that is, they all are made of smaller pieces
- proposed new pieces: quarks
- e.g., proton and neutrons:

  each made of three quarks

  with different combinations of two kinds ("flavors") of quark

  u = "up" and d = "down"

  proton = uud, neutron = udd

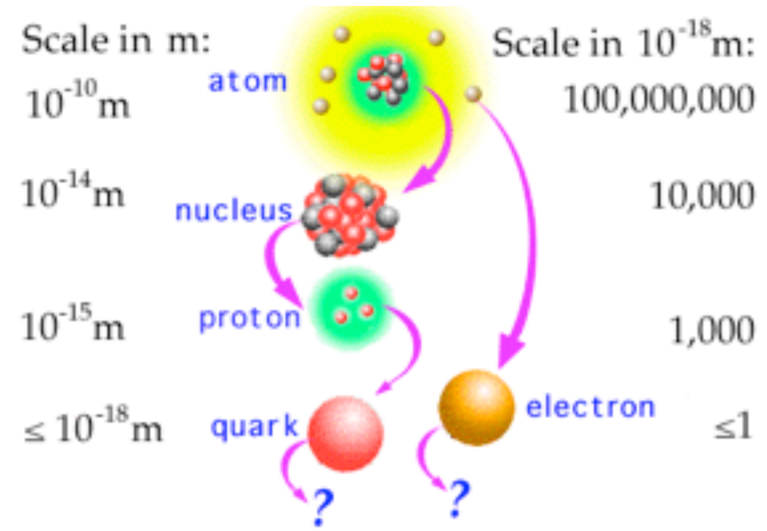


inside a neutron: quarks

All other crazy particles: different combinations of 2 or 3 quarks

- some made by other, new "flavors" that always decay to u and d

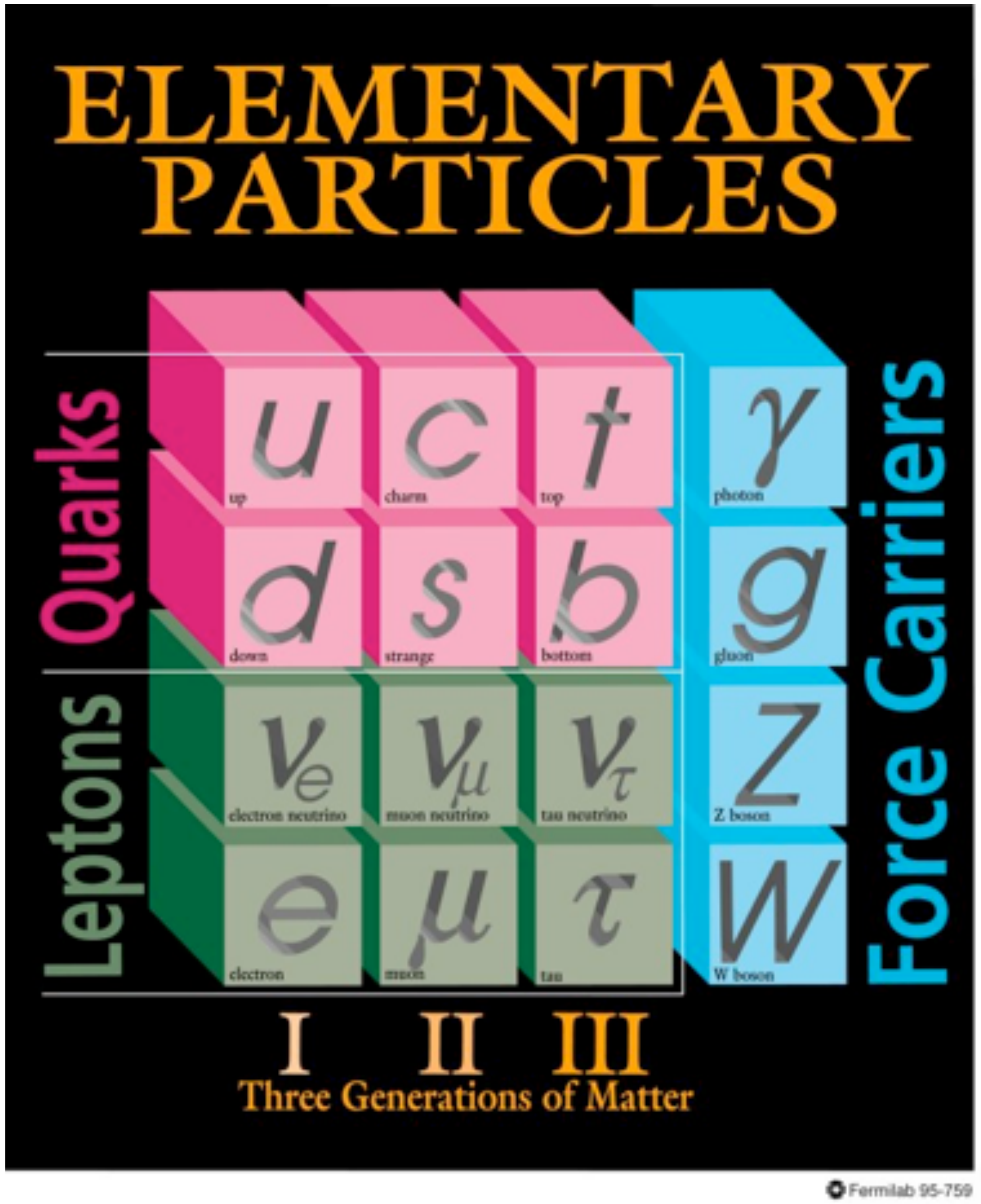
Simplicity Regained



Where do we stand today?

current picture: the "Standard Model," which says:

- matter made of quarks and electrons
  - e.g., protons and neutrons are bound states ("atoms") of 3 quarks
- neutrinos also can interact with quarks and electrons
- u & d quarks, electron, and a neutrino make a "family"
- two more massive "copies" of this family exist
  - e.g., in 1990's last and heaviest quark, t = "top" discovered at Fermilab
- forces between quarks, electrons, neutrinos are carried by other particles
  - e.g., electric forces carried by photons: particles of light!



how well does the "Standard Model" work?

- no disagreement with any experiments!
- hugely successful!
- many Nobel prizes handed out for building the theory and testing it
- all aspects thoroughly tested, except one...

The Origin of Mass: The Higgs Particle

The entire Standard Model = our entire understanding of elementary particles

- assumes the existence of one particle not yet discovered
- the Higgs (sometimes called Higgs boson)

Higgs is key to everything

Why? If Higgs doesn't exist: Standard Model says

- all particles should be massless!
- all forces should have same strength!
- in other words: Higgs responsible for giving all particles mass
- also crucial to make forces act in the way we observe

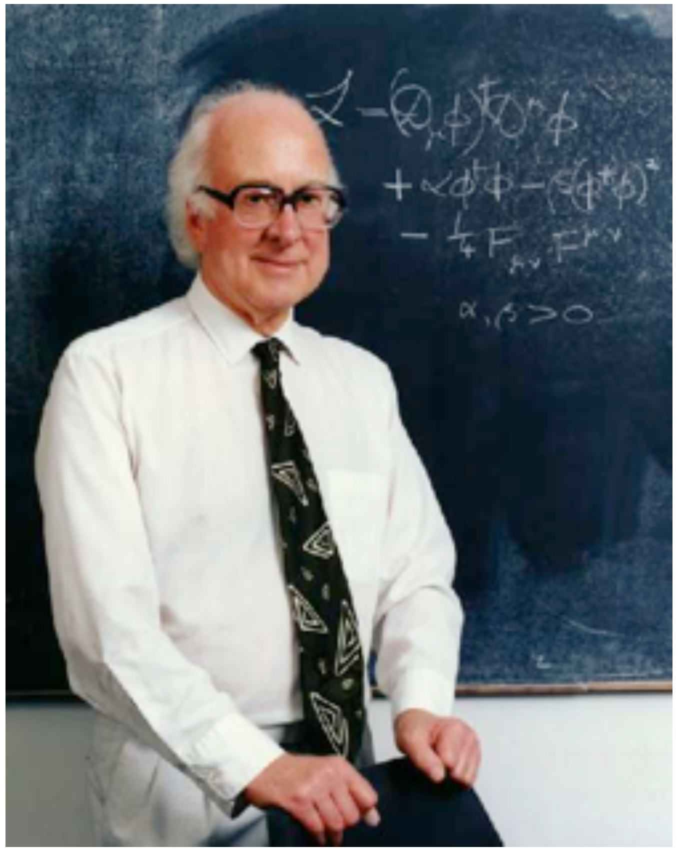
In other words:

- Newton taught us that mass is source of gravity
- Einstein taught us that mass is a form of energy
- but neither told us what mass is!
- Higgs is a possible answer to this

But Higgs particle not seen in lab....yet

- why? Higgs expected to have high mass

  $M_{\text{Higgs}} > 100\ M_{\text{proton}}$
- so $E_{\text{Higgs}} = M_{\text{Higgs}}\ c^2$ very high: need very powerful accelerator



Peter Higgs

Hunting for the Higgs

Race between world's most powerful accelerators

Fermilab: Batavia Illinois

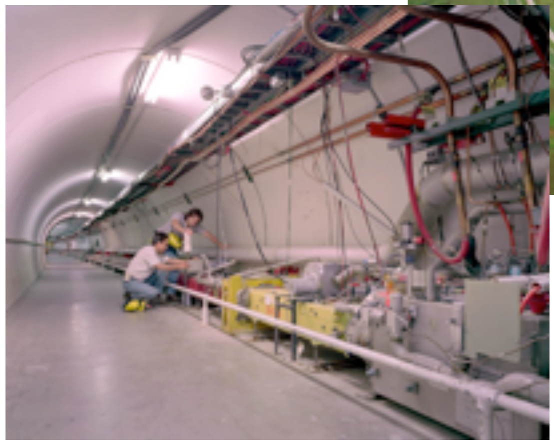
- collides protons and antiprotons
- until last year was highest energy accelerator in world
- just finished years of running
- a few weeks ago: announced hints of Higgs particle

Large Hadronic Collider: CERN Laboratory

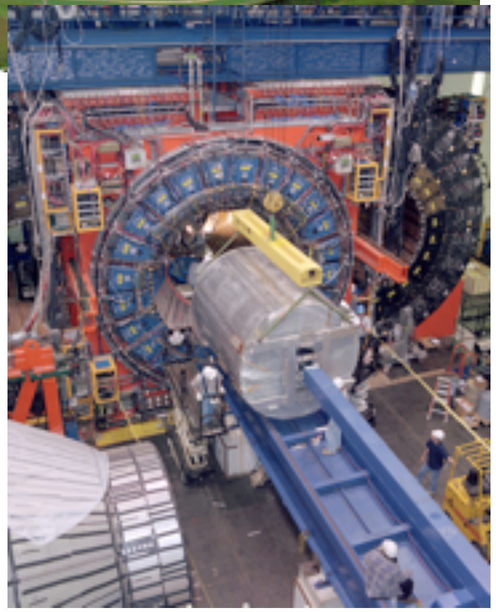
- large: big
- hadronic: hitting protons with protons
- located mostly in Geneva Switzerland
  but particles go in and out of France once per cycle
- turned on in 2009, began cranking up proton energies
- now the highest energy accelerator in the world
- two months ago: announced first hints of Higgs

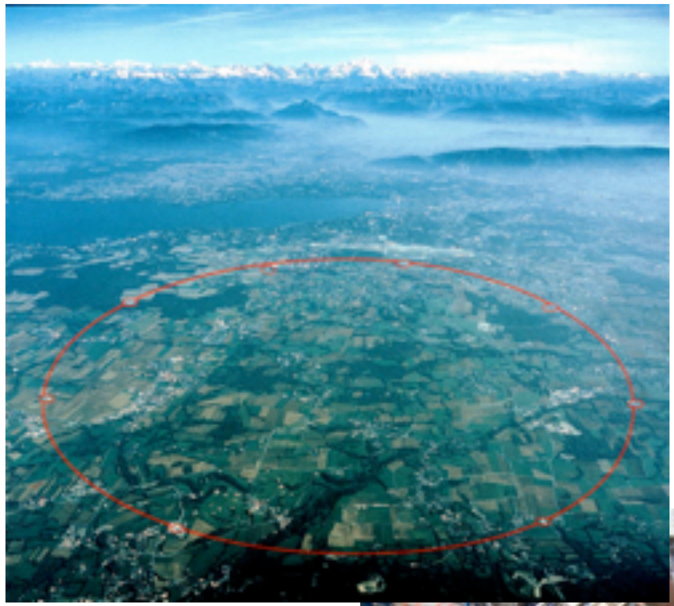
Within one year from now, something big will happen

- Higgs discovery confirmed!
  Standard Model complete
  big step in understanding origin of mass
- or: Higgs particle not found!
  Standard Model incomplete--yet otherwise works well?!
  our entire theoretical understanding will have to be revised
- Illinois a player in both experiments!

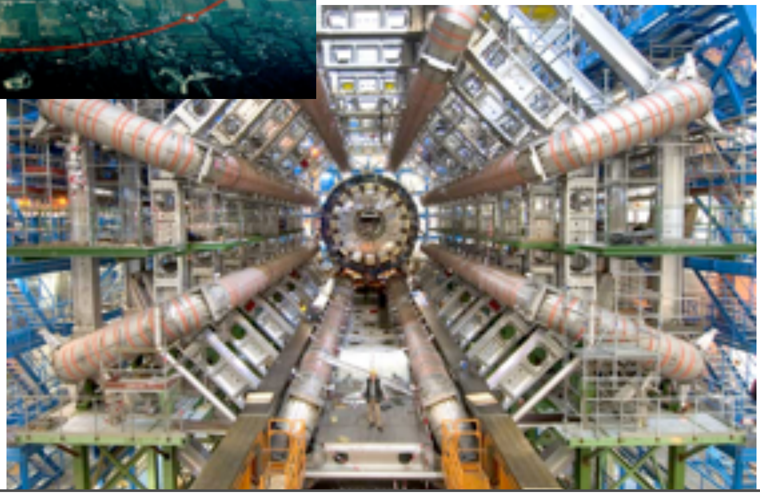


Fermilab





CERN



Big Bang in the Lab

Recall inner space/outer space connection:

- Fermilab and CERN accelerators are not just microscopes
- but also telescopes!

These experiments recreate extreme microscopic conditions

- much more violent than in supernova
- equivalent to microscopic conditions in earliest moments of big bang: $t<10^{-14}$ seconds

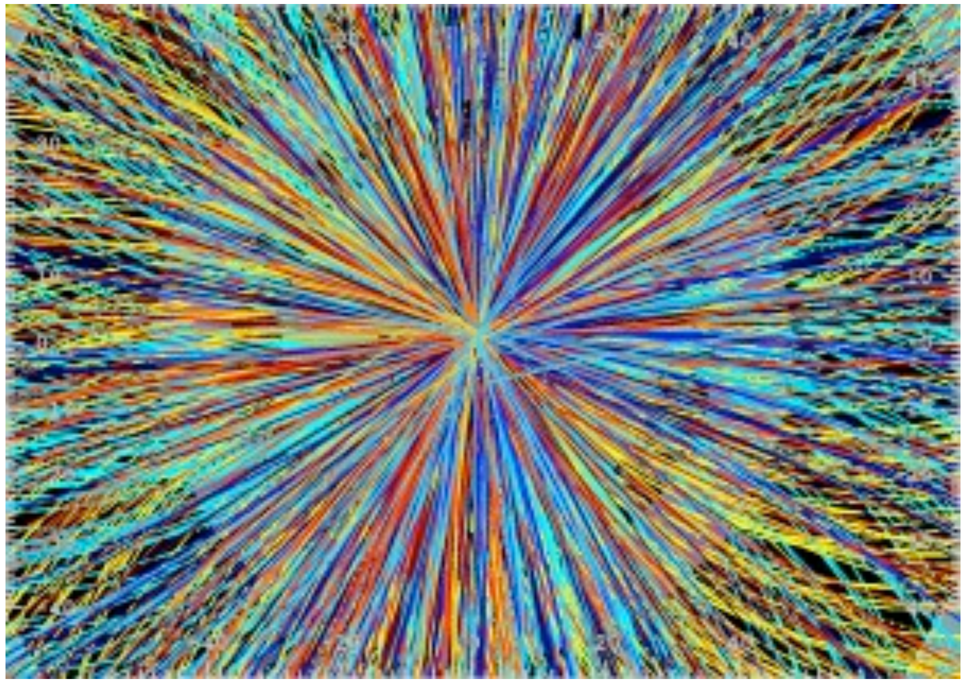
Hope to recreate exotic particles thought to make up dark matter in the universe

(much more on this later)

The most exciting possibility:

- create particles nobody has even imagined

...but could this be a bad thing?



Particle Blizzard in LHC

In 2009, it was claimed that particle physics experiments at the Large Hadron Collider could create *micro black holes*

Could these swallow the Earth?

i>clicker poll

Are you worried about micro black holes produced by the Large Hadron Collider?

A. Yes - I'm flying to Switzerland tonight to stop those mad scientists!
B. No - I'm sure scientists have evaluated the risks and concluded there's no danger
C. Unsure - I'm going to Google this right after class and see what the internets have to say
D. As long as it happens after Spring Break, don't care, just get me outta here!

Could the LHC produce a micro black hole?

Probably not

Expected energy needed for micro black hole ~10^{19} GeV (10^9 J)

Far beyond the limits of current technology

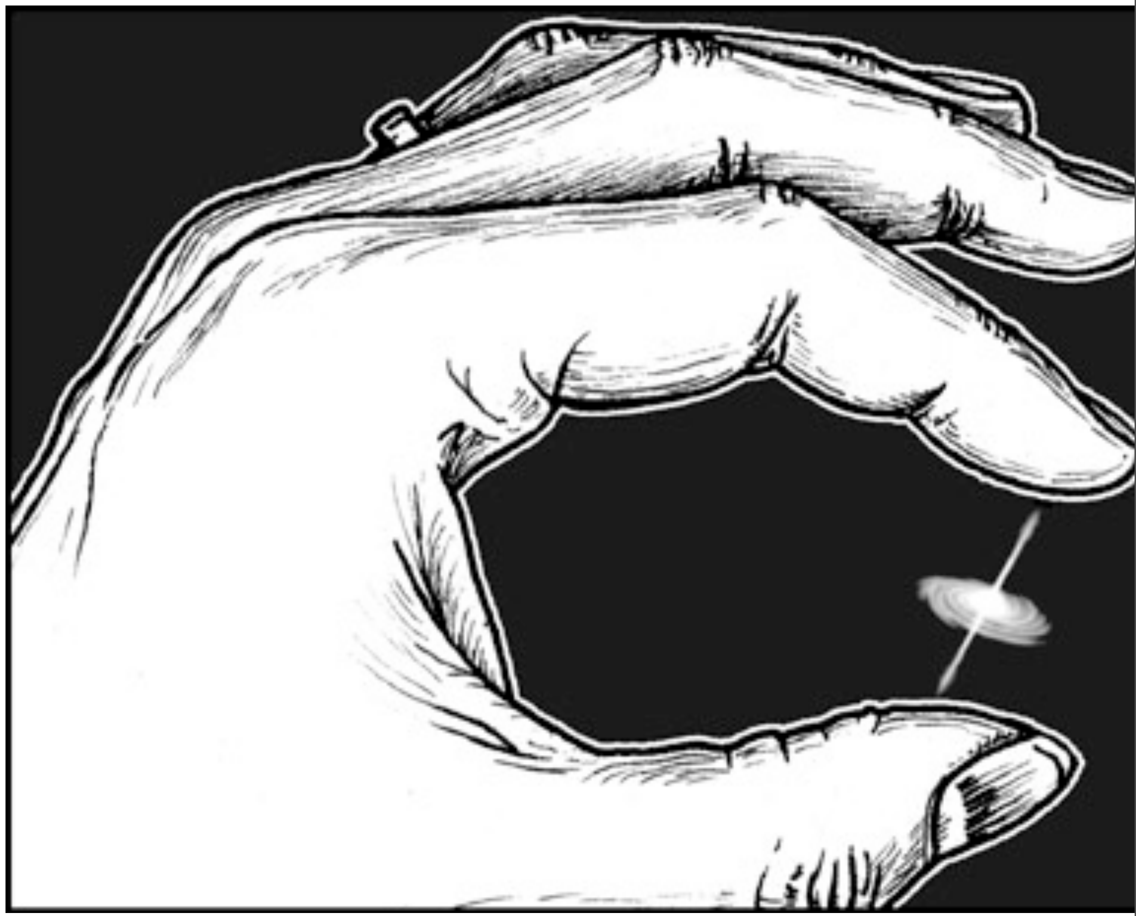
- LHC would need to be 1000 light years across to produce that much energy

also: small black holes should be unstable

- decay by (Stephen) Hawking radiation

...but these reassurances are based on known particle theory

- what if this is a big nasty surprise waiting?



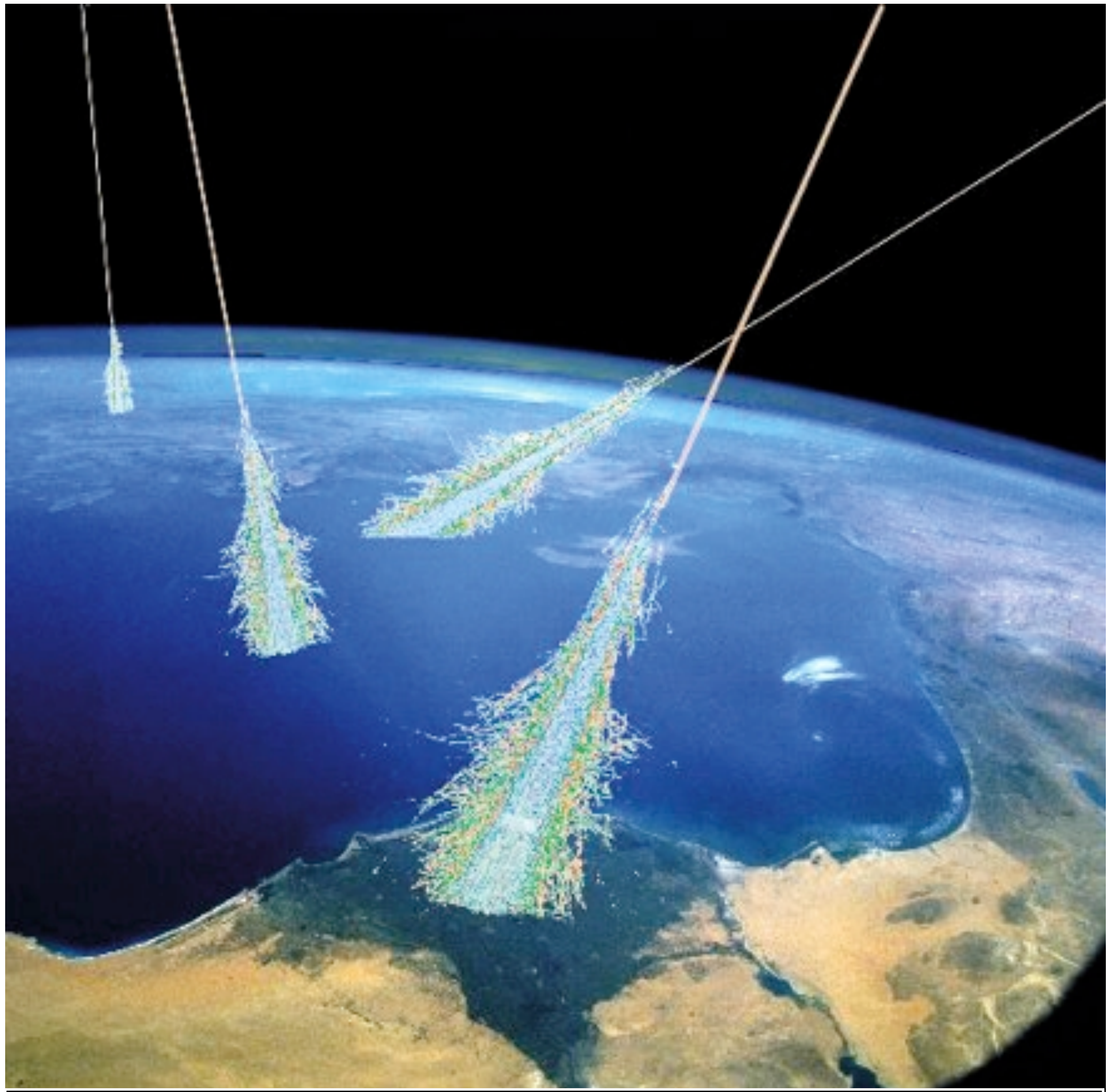
Cosmic rays produce more energetic collisions than the LHC

Cosmic ray collisions have more energy than the LHC and happen every day!

If LHC can produce black holes, so can cosmic rays!

- Over the lifetime of the Earth, cosmic-ray bombardment amounts to huge number of LCH experiments
- But Earth is still here!

Thus, even if stable micro black holes exist, not dangerous



Cosmic rays hitting Earth's atmosphere

http://www.youtube.com/watch?v=Q7g-VMKJdfQ&feature=results_main&playnext=1&list=PLA560F046AB8836D1

http://www.thedailyshow.com/watch/thu-april-30-2009/large-hadron-collider

Antimatter

Recall: every particle has an antiparticle

- e.g., anti-electron e^- = e^+ positron
- e.g., anti-p= antiproton
- Fermilab: proton/antiproton collisions

antiparticles: same masses, opposite charges

- Antimatter predicted in 1920's before observed
- unavoidable outcome of combining relativity and quantum physics

Anitmatter is not a second class citizen!

- by itself, antimatter is as stable as ordinary matter
- can combine antiprotons and positrons to make anti-hydrogen atoms
- this has been done at CERN!

The Problem: Antimatter and Matter do not play well togther

- combine particle and antiparticle→ energy → other particles such as photons (gamma rays)
- annihilation
- energy release is huge
  - donut + antidonut: 6 Megaton = same as huge nuclear explosion

Antimatter Threat?

Antimatter is as stable as matter

- anti-atoms already made in lab
- what if there are anti-planets, anti-stars, anti-galaxies

If some of this stuff came to Earth--watch out

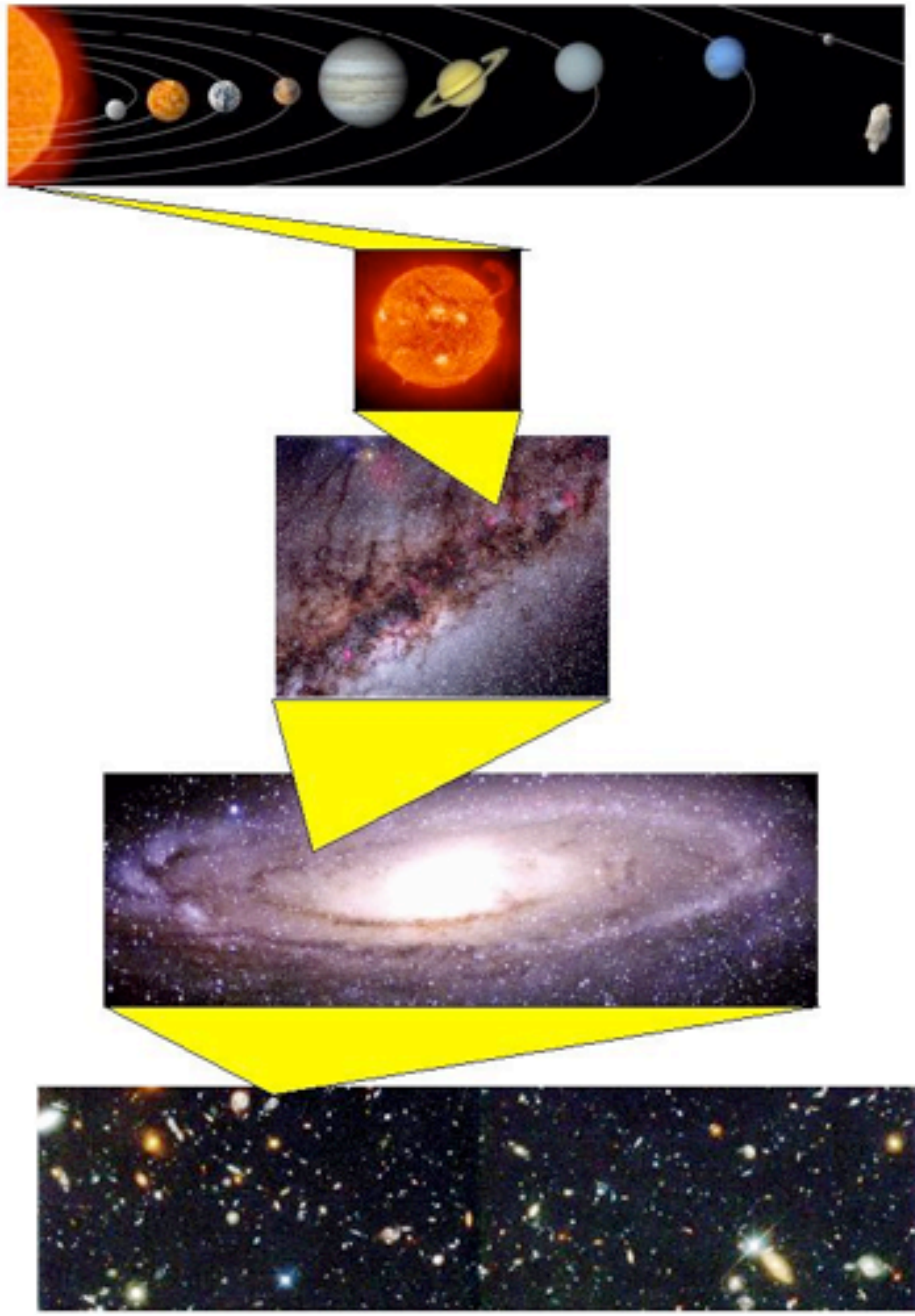
- annihilations with Kuiper Belt alone would have effects similar to nearby Supernova

So how much antimatter does the Universe have

- is the Universe only matter,
- or equal amounts of matter and antimatter?

versus

Antimatter in Our Universe



A democratic universe?

Imagine U made of regions of matter (protons & electrons) and regions of antimatter (antiprotons and positrons)

- Q: what would life be like in the anti-regions?
- How would it differ from life here?

Searching for antimatter:

what observable evidence tells us:

- Are there antimatter domains in this room?
- ...on the Earth?
- Is the Moon matter or antimatter?
- ...the Sun?
- ...other solar system bodies?
- Is the local solar neighborhood matter or antimatter?
- Are there domains in our Galaxy?
- Are galaxy clusters matter/antimatter combinations?

Matter Only!

At matter-antimatter boundaries must have annihilations

- would have huge energy release
- and huge signals in gamma rays

But we see no such evidence anywhere

Conclude: Universe is made entirely aof matter

- Interesting cosmological question: how id it get this way?

Immediate practical implication:

- no need to worry about being annihilated!

Outlook

Don't worry about death by LHC

Don't worry about antimatter

Do look out for news of Higgs

Have a fun and safe break!