Gravity:

My Favourite Force

In Our Universe!

Amanda Peet,
University of Toronto (Physics & Math),
Canadian Institute for Advanced Research.

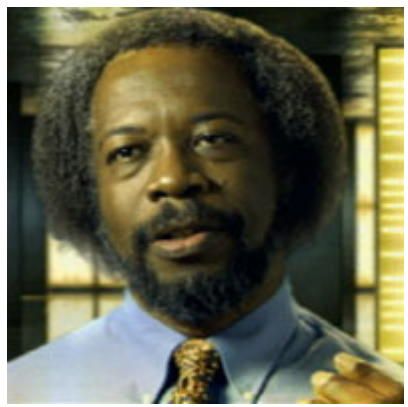
Matt's String Theory Symposium;
Terry Fox Elementary School, Barrie, Ontario;
13-15h, Tuesday, June 8th, 2004.

Who is Prof. Peet?

What Does a Physicist Look Like?

Physicist stereotype (male, white, loner, able-bodied yet un-sporty, unfashionable, with nerdy glasses, lab coat, plastic pocket protector, facial hair, and a "bad hair day") is *wrong*.

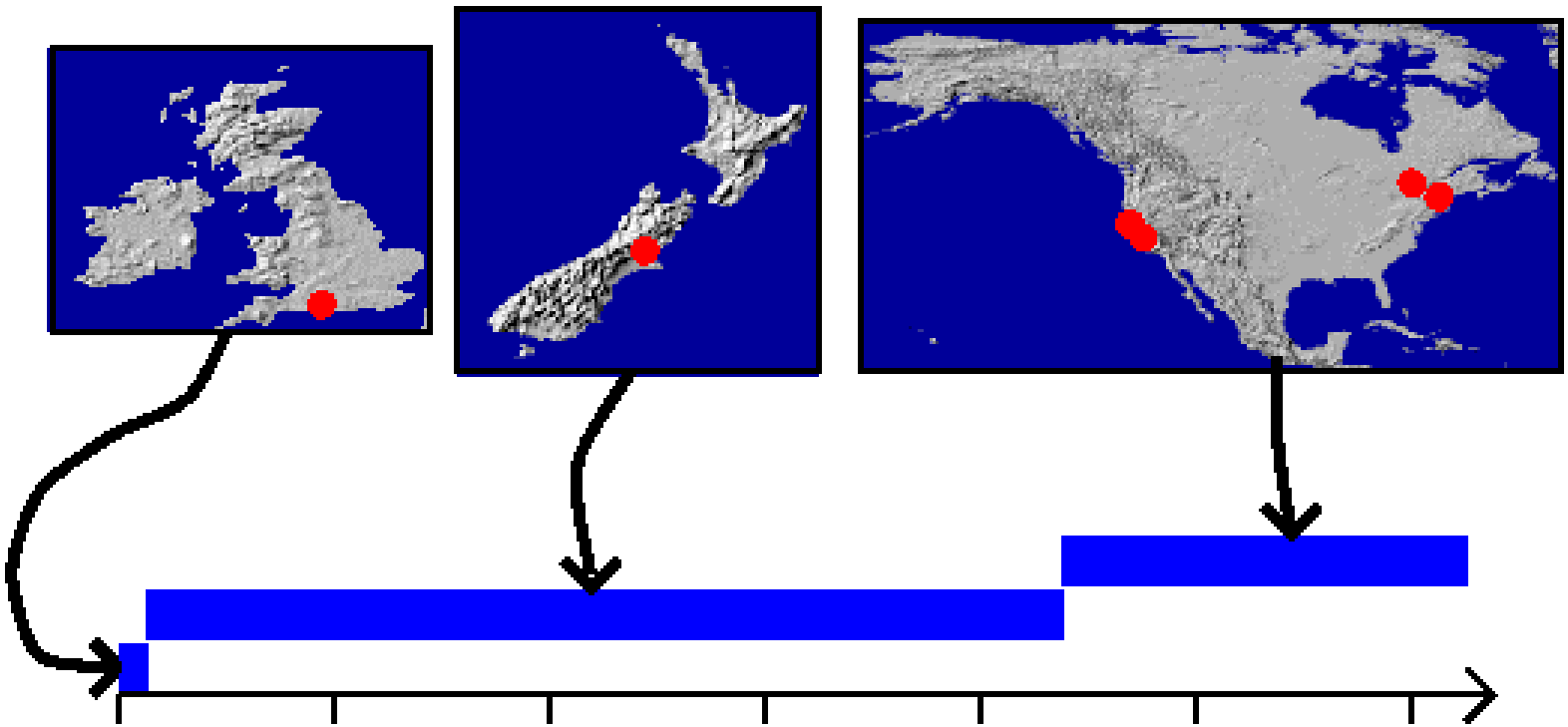
All sorts of humans like physics and do physics! ☺



e.g. I am female, with a disability, and I like hiking and skiing.

What I Look Like!

A Brief History of [Ti]me



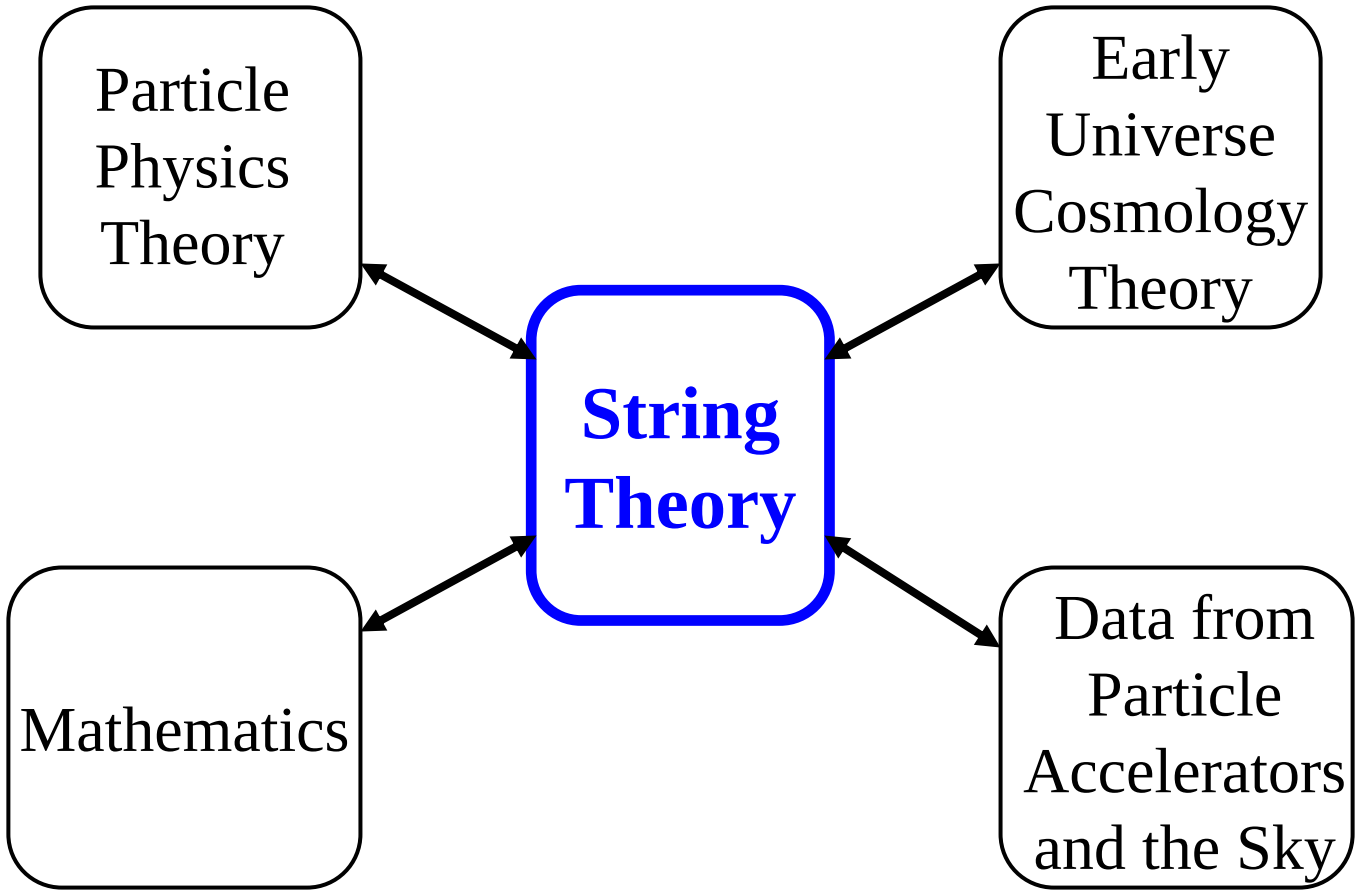
Strings ‘96 Conference in Santa Barbara

Hiking in Aspen with a New York Times Reporter

The Popular Perception ☹

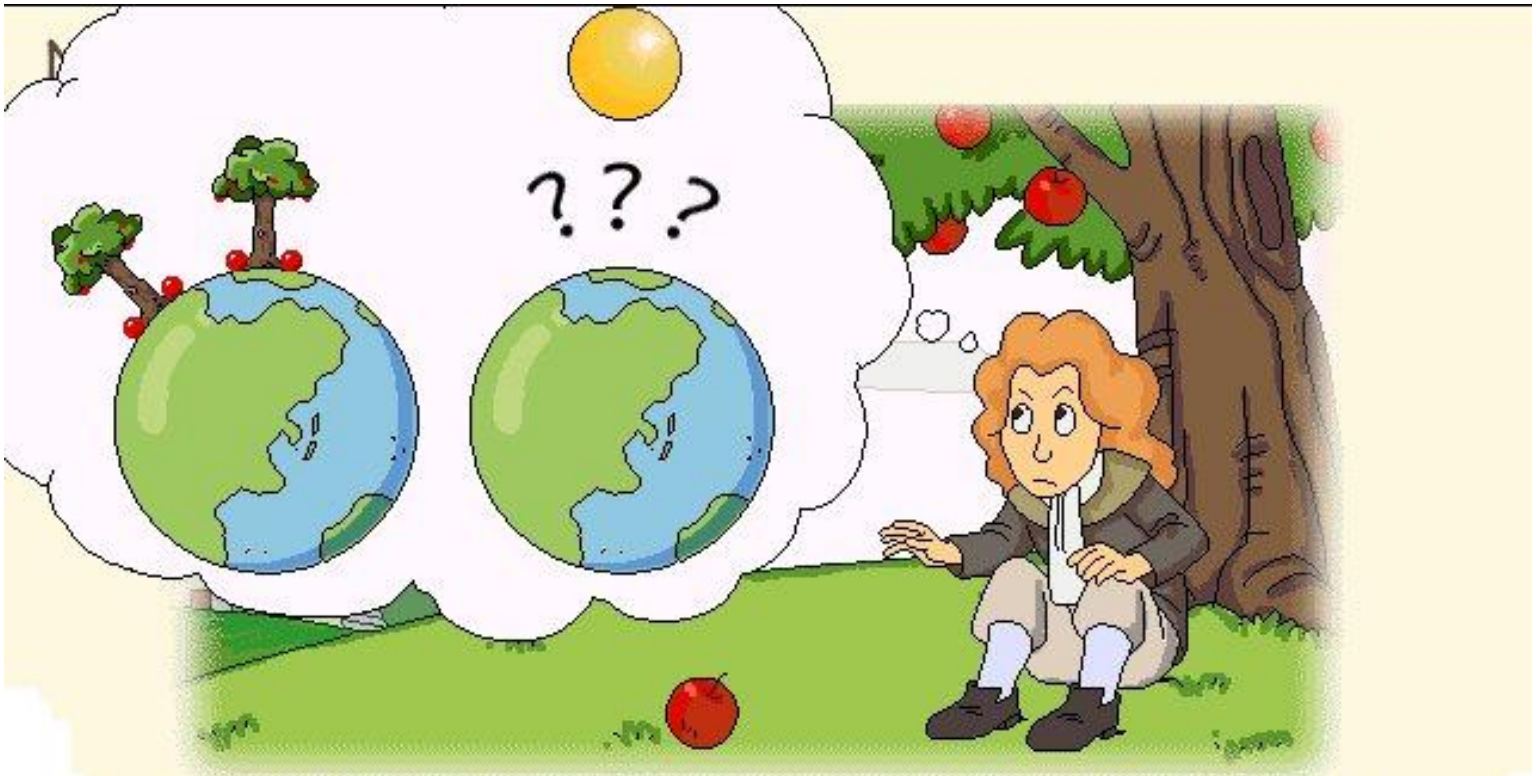
New Yorker magazine

String Theory: a Part of Physics



Gravity,
Newton & Einstein,
and Black Holes.

Newton

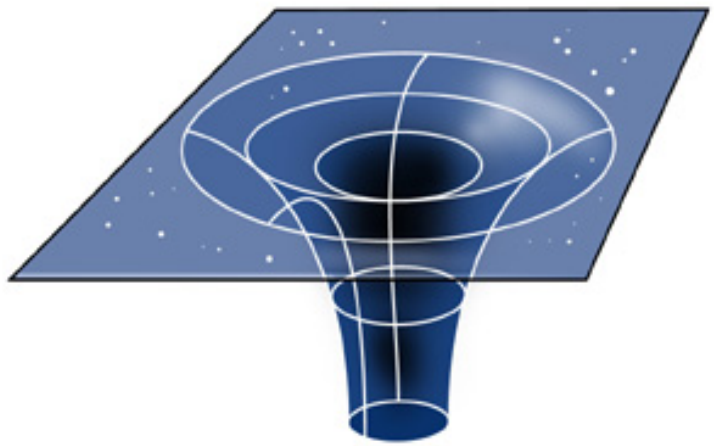


It is said that Newton discovered the law of universal gravitation as he watched an apple fall from a tree to the ground.
The falling apple started him thinking: The Earth's gravitational force attracted the apple down to the ground from the tree. But why and how does the moon orbit about the earth without being drawn by gravity to the Earth and crashing into it?

Einstein

- 250 years after Newton, in 1916, Einstein *finally* finished a brand-new theory of gravity, "General Relativity" (GR).
- Main feature of GR: incorporates fundamental speed limit, the speed of light. *Nothing* goes faster!
- Near speed of light: pumping in more energy gives diminishing returns; objects look shrunken in direction of motion; moving clocks look to be running slow.

- Gravity became beautiful geometrical concept: spacetime.
- Matter tells spacetime how to curve; spacetime tells matter how to move.



GPS (U.S. military $10B)

- Einstein not worried with experimental testing! (Bending of starlight measured few years later, agreeing with GR.) GR mainly for black holes, gravity waves, cosmic big bang.
- Except: GPS! 24 satellites orbiting Earth, each has precise atomic clock. Need 3 or more satellite radio signals to get latitude, longitude, altitude for you, within tens of metres.
- Applied to airplane navigation, wilderness recreation, sailing, car tracking, etc.
- Satellites in high-speed orbits, and further from Earth, where space and time are a bit less curved, so they tick at different rates than ground clocks.
- Not using GR would cause navigational errors adding up quicker than ten kilometres per day!
- GPS uses GR to electronically adjust clocks, and build mathematical corrections into receiver chips solving for your location based on radio signals.

Black Holes

- When really big stars run out of gas, gravity forces them to collapse to Black Holes. Other forces powerless to resist!
- Need star with mass more than about ten times sun-mass (otherwise make neutron star or white dwarf star).
- Gravity pull of BH weak far away, stronger closer in.

- Event horizon: place of no return. If fall in, can't escape, no matter how strong your rockets. Distance from centre: few km for sun-mass BH, few mm for Earth-mass BH.
- Inside BH, everything crushed/torn to pieces. Very nasty singularity at centre.

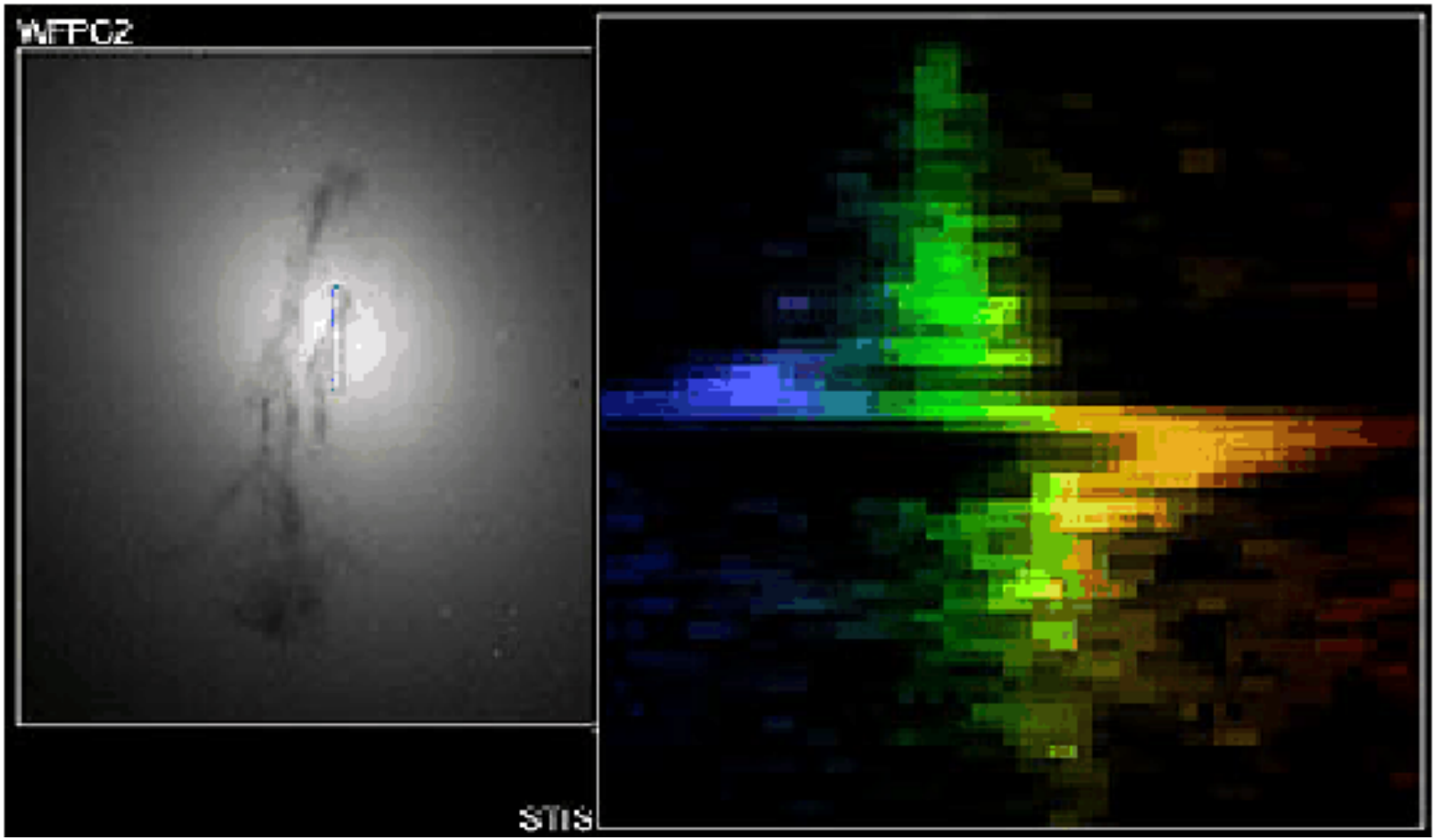
Black Hole Evidence

- BH are rather like vacuum cleaners; run on gravity power.
- Suck in stuff like gas & stars, which don't want to go in; they spit out radiation madly as spiral inward.

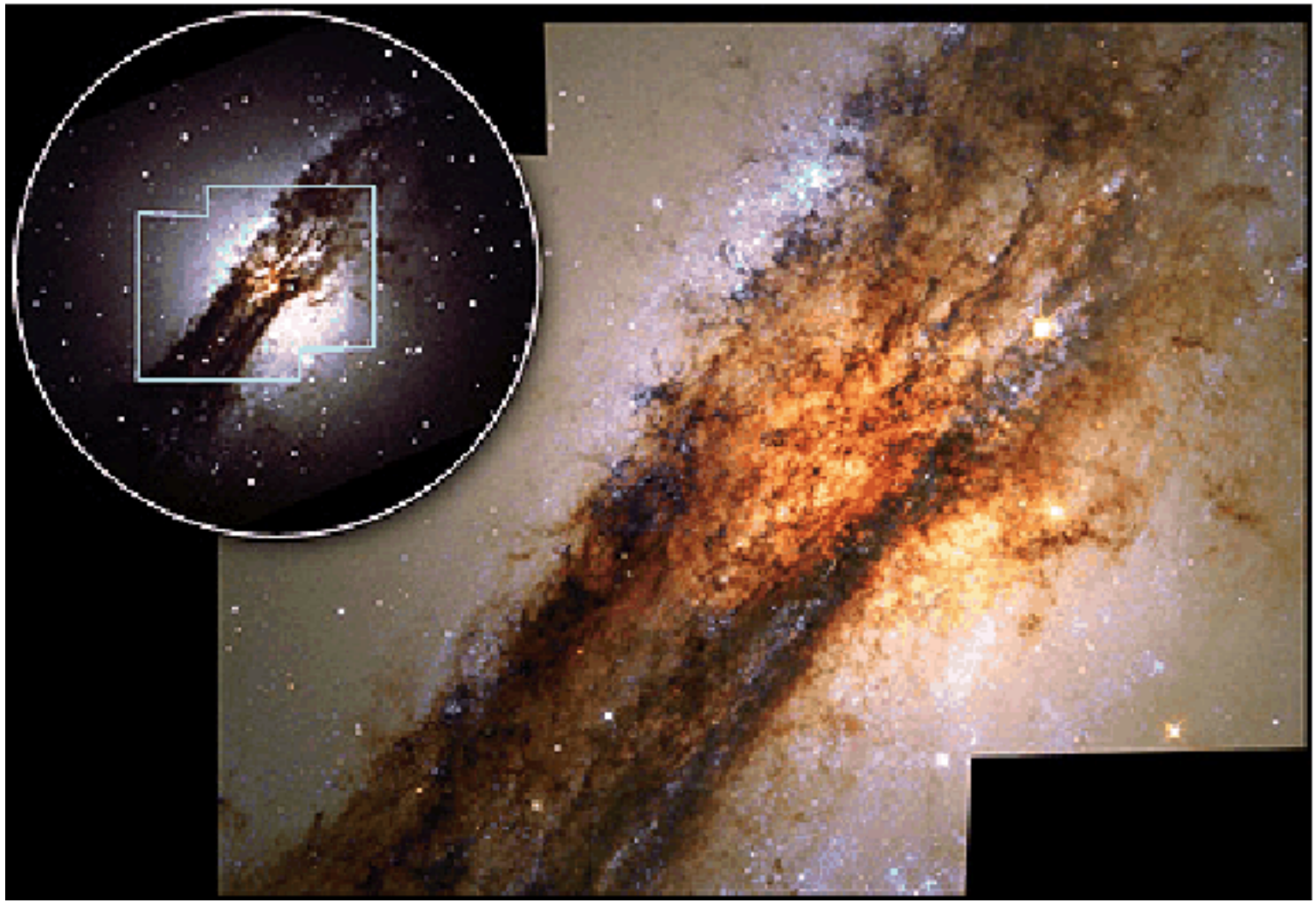
- Astronomers detect radiation in telescopes; can tell how fast stuff is going (redshift) versus distance from centre.
- Very specific relationship of speed versus distance for BH, as compared to other objects like stars.

- Evidence for BH shows
  - e.g. Milky Way has BH around ten-sun mass;
  - million/billion-sun mass BH @ centre of most galaxies.

M84



Centaurus A



Hawking,
Quantum Black Holes
and
String Theory

Hawking Radiation

- In mid-1970s, Hawking discovered something does get out of black holes: radiation.
- Not same as radiation spit out by stuff in accretion disk. Hawking radiation happens even if BH alone in universe.

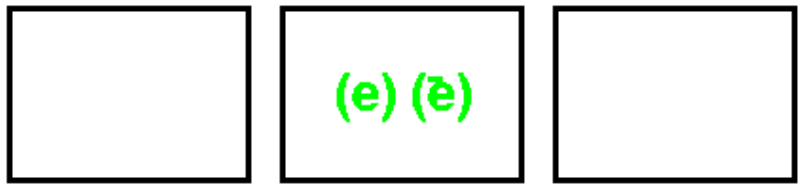
- Hawking temperature very cold for astrophysical BH. Much colder than CMB.

- Quantum weirdness allows antiparticles!
- Antiparticle has same mass & spin, but opposite charge.
- Particle and antiparticle annihilate to make pure energy

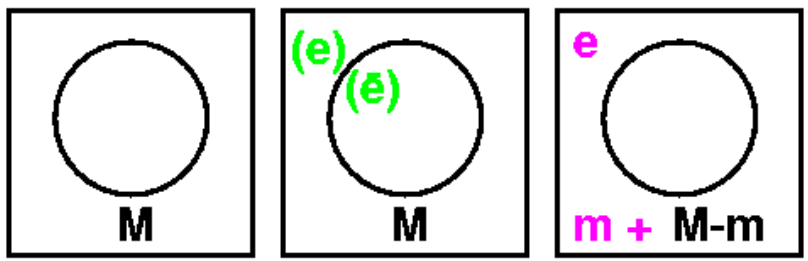
$$E = 2(mc^2)$$

Pairs Popping In and Out of Existence

- Quantum weirdness, via Heisenberg uncertainty principle, allows pair to
  - pop out of vacuum,
  - exist as virtual particles (for very short time),
  - pop back out of existence!



- Pair-popping happens everywhere all the time.
- Relatively boring, usually.
- Unless pair straddles horizon of BH... then one lost inside and other escapes as radiation.



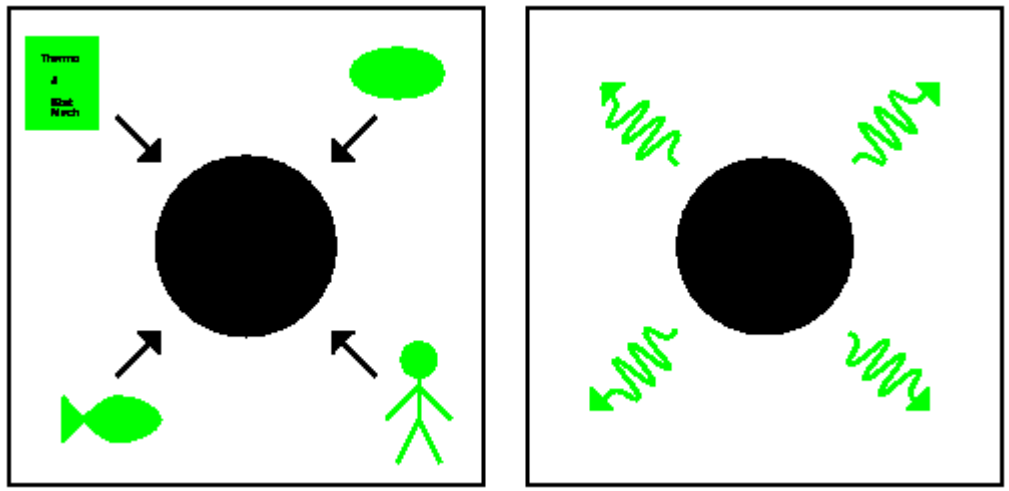
Black Hole Entropy

- If have gas, don't have to describe motion of each little molecule. Knowing temperature or pressure pretty useful.
- Entropy tells us how disorganized something is. e.g.
  - if room neat and tidy, low entropy;
  - if room messy as hell, high entropy!
- Physics principle: if we know fundamental quantum theory of lots of individual items, can compute entropy of whole lot of stuff, using mathematical techniques.

- Gravity theorists in mid-1970s figured out entropy of black holes, by fumbling around with how BH behave.
- BH have most enormous entropy of anything known. Didn't know how to compute it from first principles. Much confusion for 25 years, till string theory came along.

Black Hole Information Puzzle

- Puzzle of entropy related to another puzzle!
- Hawking's mathematical calculations said: all that ever comes out of BH is radiation, depending only (@#^*!) on mass and angular momentum of infalling stuff.



- So you lose information about what went in? Gone??
- Perhaps if we know more about quantum theory of gravity we can explain where information went. Hope not lost!

String Theory to the Rescue!

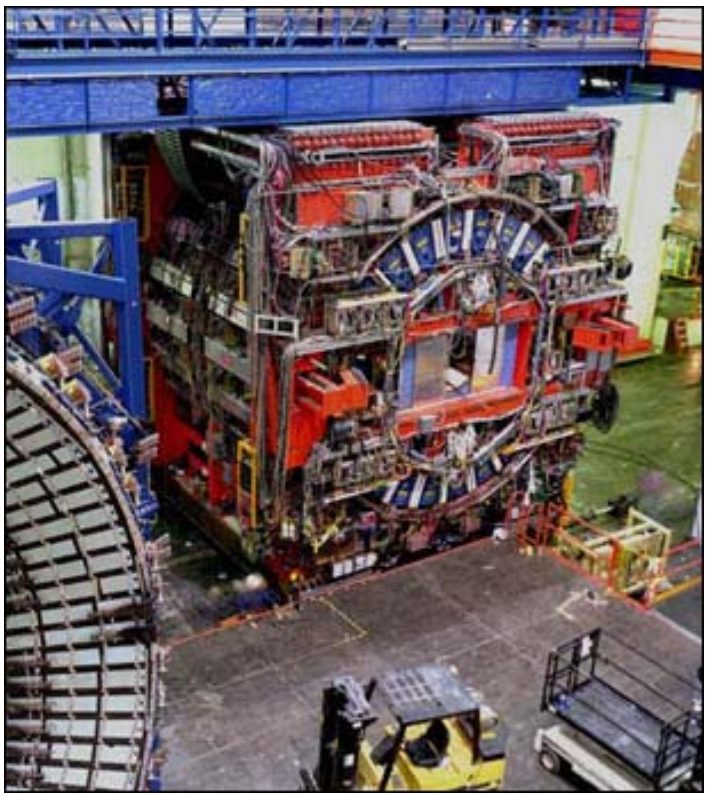
- Superstrings (strings for short) are basic constituents of everything in universe.
- Our most powerful microscopes can't see them yet.
- Different vibrations of string are different particles. Includes matter and force-carriers. Nature's Symphony!
- Includes gravity neatly and beautifully.

- Recent excitement: use quantum physics of strings and D-branes to compute black hole entropy with mathematics. Get same answer as relativity guys 25 years ago. Success! Also string theory gives ideas about information problem.

Discovery Frontiers

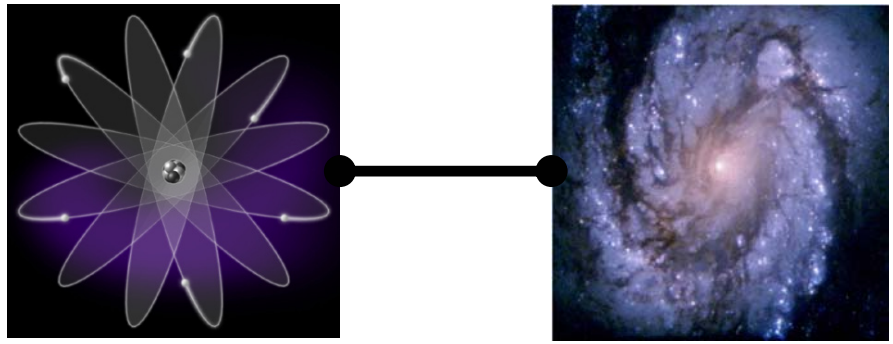
Particle physics: probe shorter distance with higher energy. Biggest "FermiLab" in IL, US; bigger "LHC" Geneva 2007.

Astrophysics: probe early universe by looking back in time (universe expanding fast; speed of light finite)

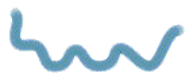


Two Big Ideas to Take Away

- Idea #1: **unity of particle physics and astrophysics**. Interconnectedness of physics at small and large distance scales.



- Idea #2: **string as Lego**. Incredibly tiny wee vibrating strands of energy comprise everything!



The End ...

Where to Learn More

BLACK HOLES and the INFORMATION PARADOX

What happens to the information in matter destroyed by a black hole? Searching for that answer, physicists are groping toward a quantum theory of gravity

By Leonard Susskind

SOMEWHERE in outer space, Professor Windbag's time capsule has been sabotaged by his rival, Professor Goulash. The capsule contains a mathematical formula vital to future generations. But Goulash's diabolical scheme to plant a bomb on board has succeeded. Bang! The formula is vaporized into a cloud of electrons, nucleons, photons and an occasional neutrino. Windbag is distraught. He has no record of the formula and cannot remember its derivation.

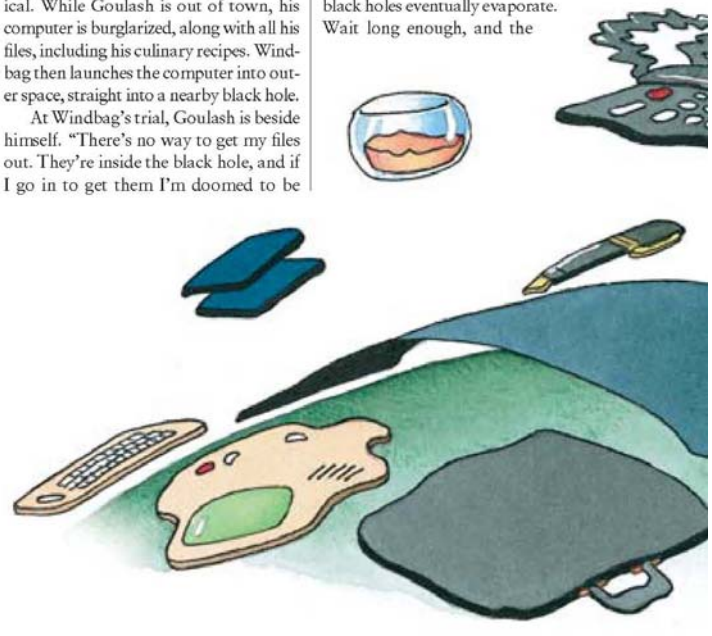
Later, in court, Windbag charges that Goulash has sinned irrevocably: "What that fool has done is irreversible. Off with his tenure!"

"Nonsense," says an unflustered Goulash. "Information can never be destroyed. It's just your laziness, Windbag. All you have to do is go and find each particle in the debris and reverse its motion. The laws of nature are time symmetric, so on reversing everything, your stupid formula will be reassembled. That proves, beyond a shadow of a doubt, that I could never have destroyed your precious information." Goulash wins the case.

Windbag's revenge is equally diabolical. While Goulash is out of town, his computer is burglarized, along with all his files, including his culinary recipes. Windbag then launches the computer into outer space, straight into a nearby black hole.

At Windbag's trial, Goulash is beside himself. "There's no way to get my files out. They're inside the black hole, and if I go in to get them I'm doomed to be crushed. You've truly destroyed information, and you'll pay."

"Objection, Your Honor!" Windbag jumps up. "Everyone knows that black holes eventually evaporate. Wait long enough, and the



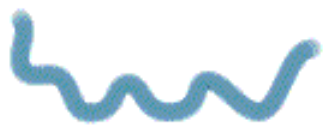
BLACK HOLE'S SURFACE looks to Windbag [in the spaceship] like a spherical membrane, called the horizon. Windbag sees Goulash, who is falling into the black hole, being slowed down and flattened at the horizon; according to string theory, Goulash also seems to be spread all over it. Thus, Windbag, who represents the outside observer, sees the information contained in everything that falls into the black hole as stopping at the surface. But Goulash finds himself falling right through the horizon to the center of the black hole, where he becomes crushed.

Updated from the April 1997 issue

Where to Learn More

The Official STRING THEORY Web Site

www.superstringtheory.com



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