TESTING EXTRA DIMENSIONS

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Extra Dimensions

$(t, x, y, z) + w, v, \ldots$

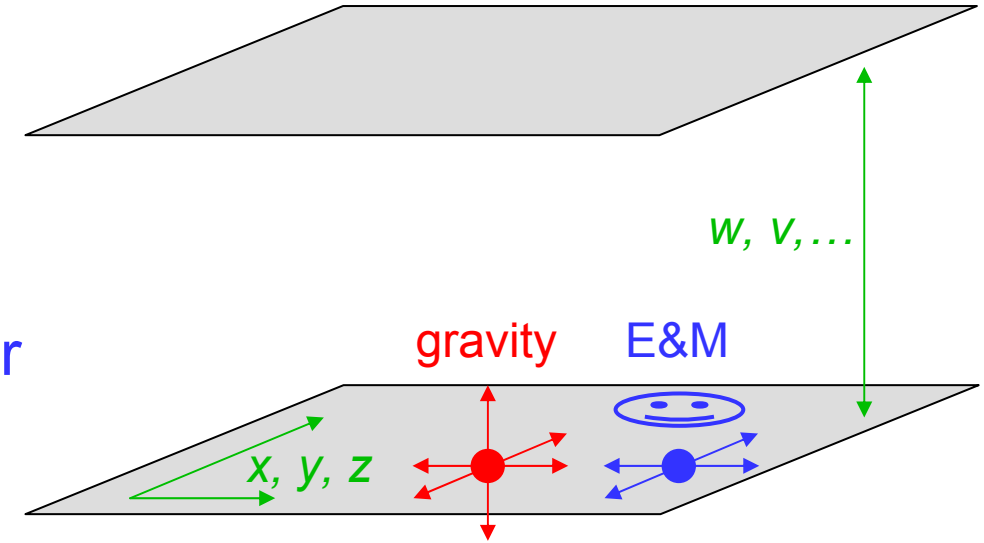
- A revolutionary idea. How can we test it?
- Searches for extra dimensions spans many subfields in physics and astrophysics and depend on the specific realization:

  How many? How big? What shape?
  What moves in the extra dimensions?

- Focus here on two well-motivated examples

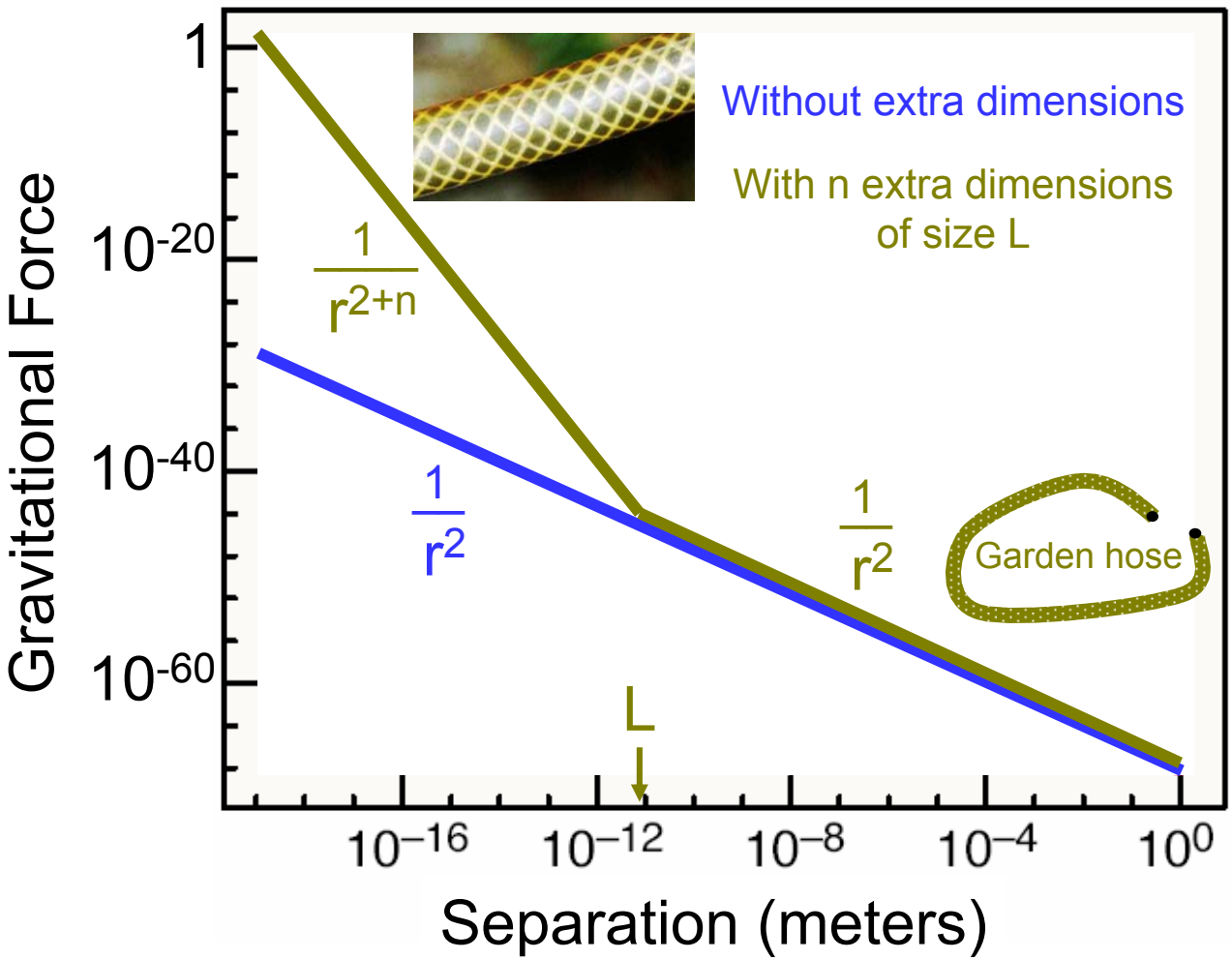
Braneworld Extra Dimensions

- One possibility is that we live in a subspace of the extra dimensions
- All particles and most forces are confined to our (brane)world: photons (electromagnetism), electrons, protons, …



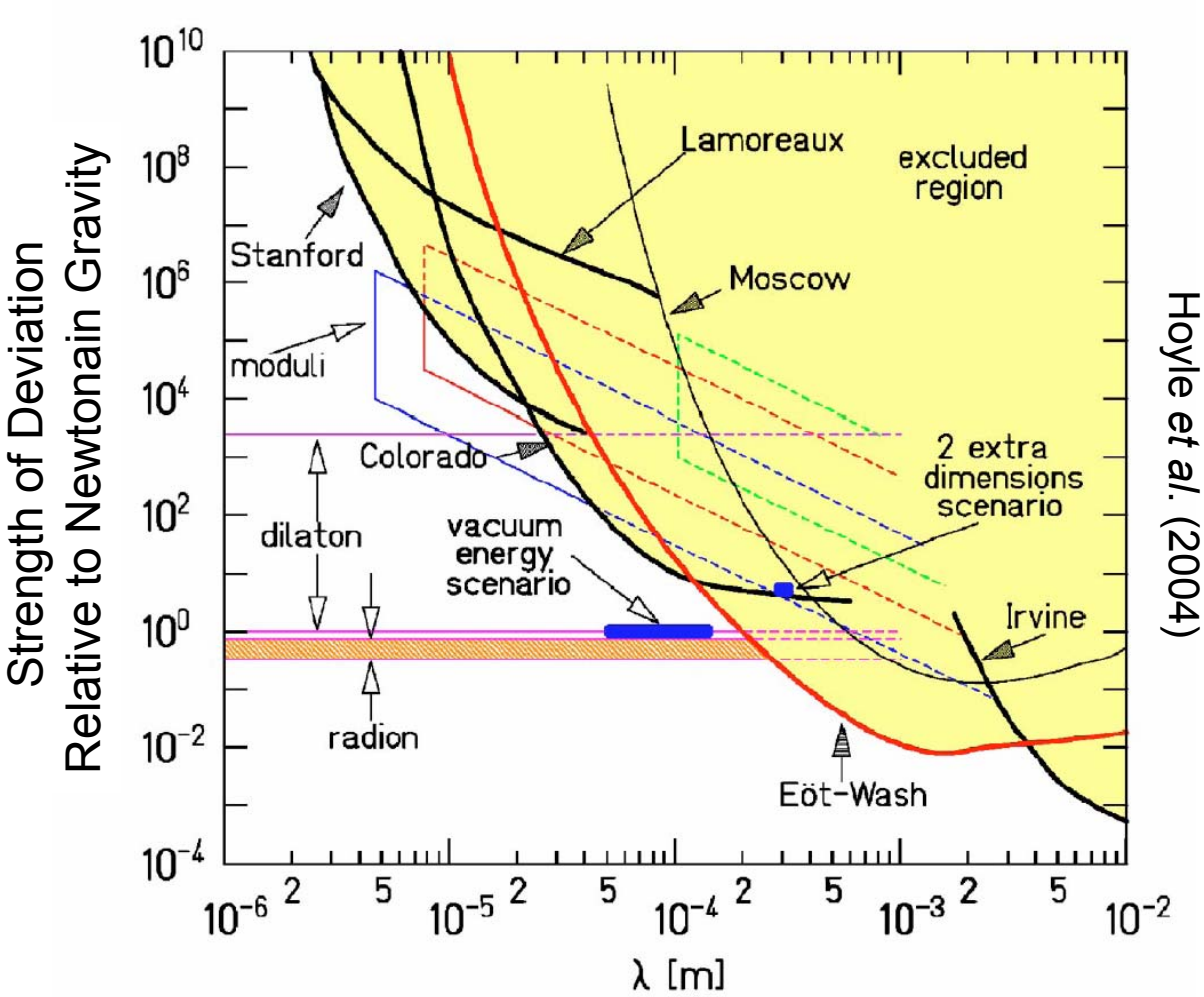
- But gravity is not confined, propagates in the full space

This changes the force of gravity



Gravity is stronger on short distances

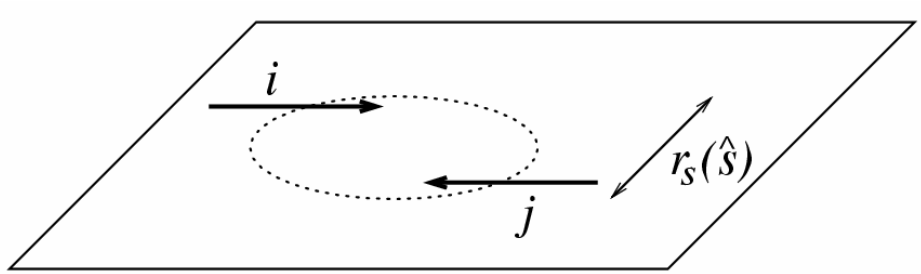
Is this possible?



Tests of gravity at short distances (~100 μm) are searches for extra dimensions

Black Holes

- Lots of mass/energy in a small volume → black hole

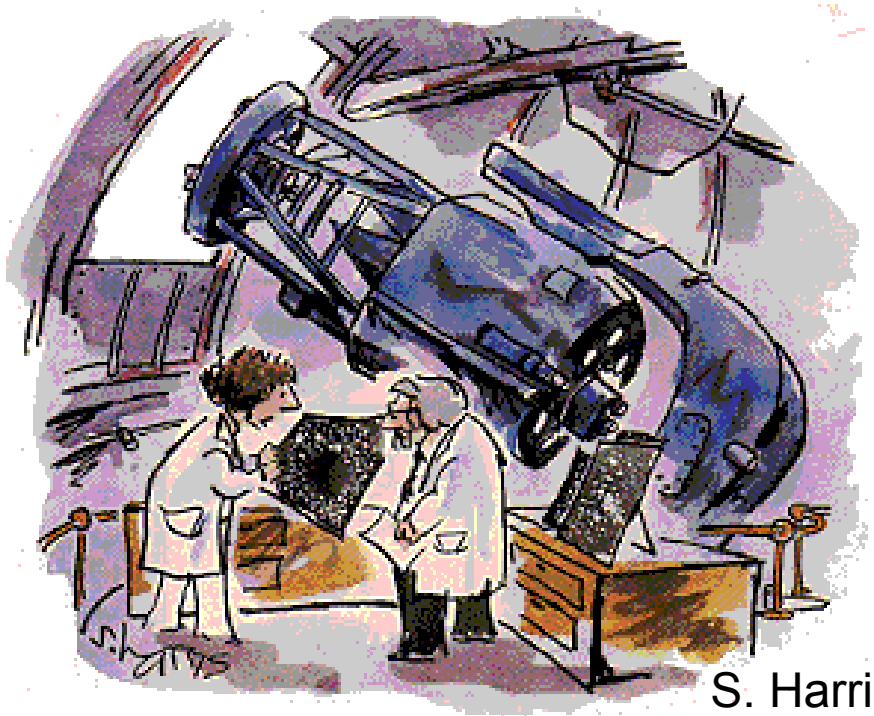


- If two particles pass close enough with enough energy, they will form a microscopic black hole

- For 3 spatial dimensions, gravity is too weak for this to happen. But with extra dimensions, gravity becomes stronger, micro black holes can be created in particle collisions!

Micro Black Holes

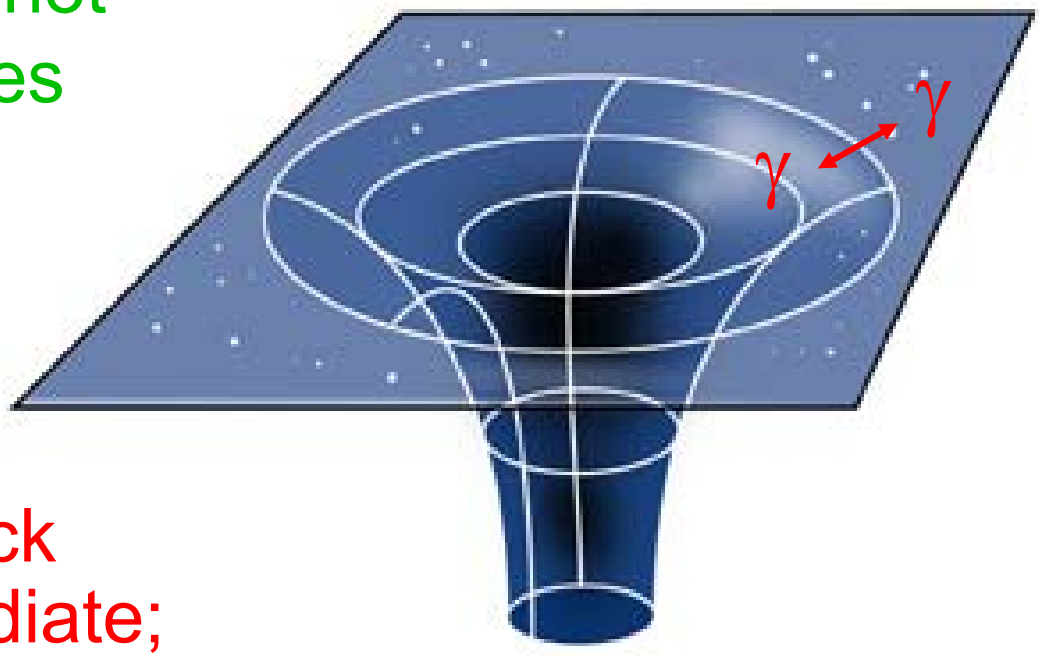
- Where could they be produced?
- How will we know if we've seen one?



"It's black, and it looks like a hole.
I'd say it's a black hole."

Black Holes

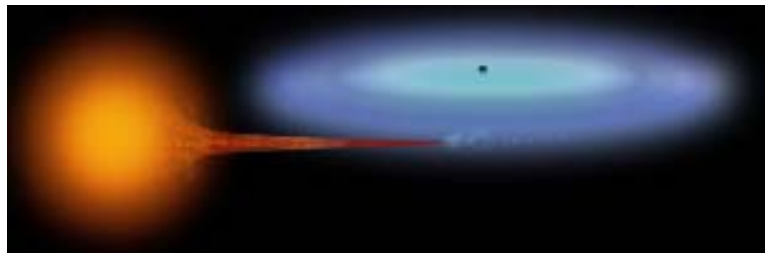
- Classically, light and other particles do not escape; black holes are black.



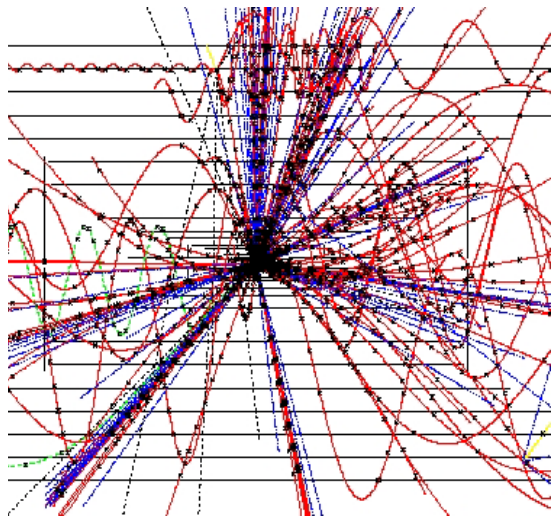
- But quantum mechanically, black holes Hawking radiate; black holes emit light

Black Hole Evaporation

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



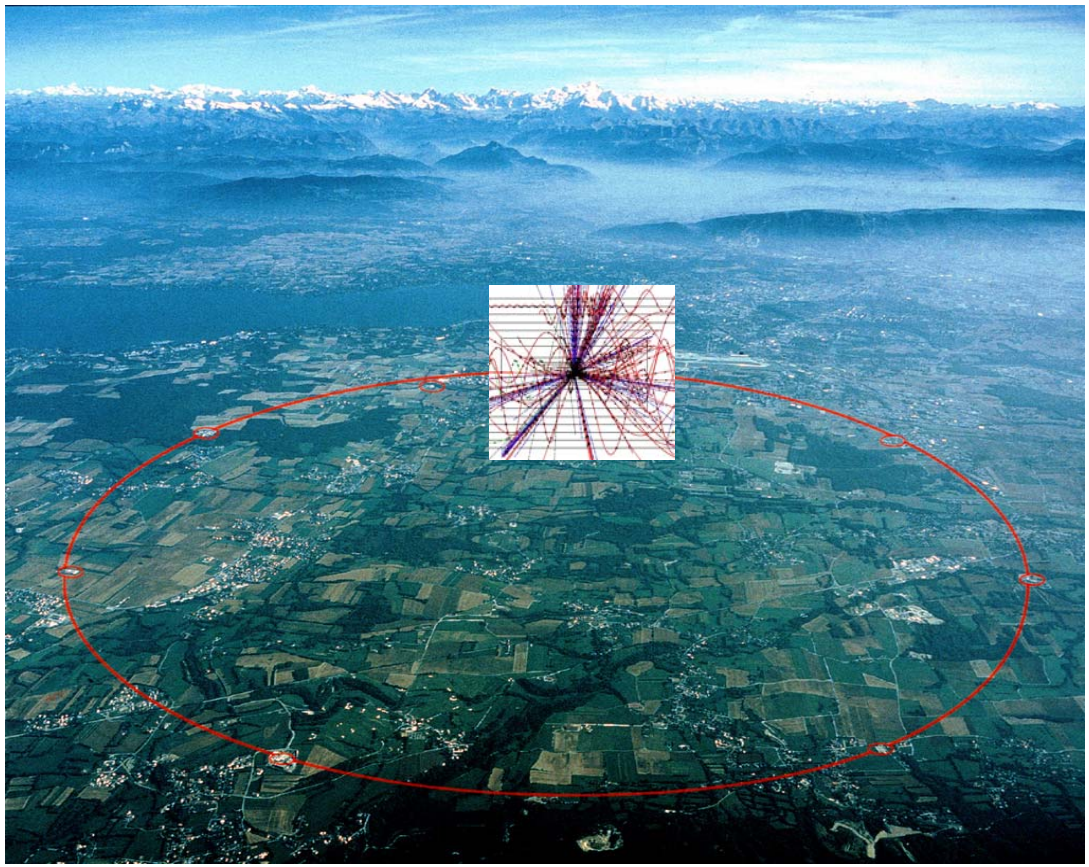
- Micro black holes:
  - Mass: $M_{BH} \sim 1000\ M_{proton}$
  - Size: 10^{-18} m
  - Temperature: 10^{16} K
  - Lifetime: 10^{-27} s

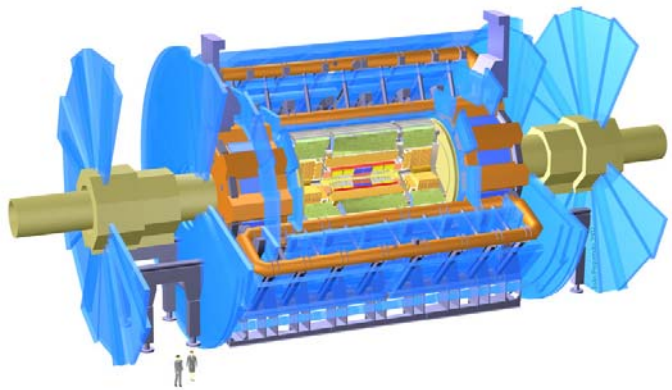


They explode!

Micro Black Holes at Colliders

Large Hadron Collider in Geneva (2007-)

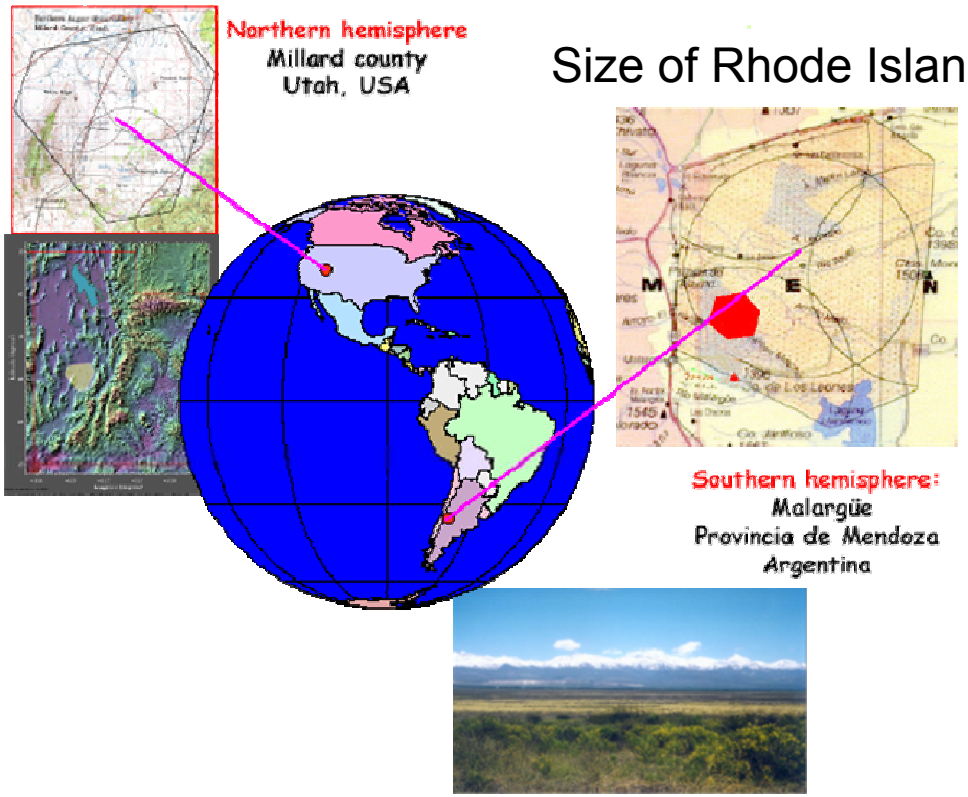




Micro Black Holes from Cosmic Rays

Energy of MLB fastball

Auger Observatory in Argentina (now-)

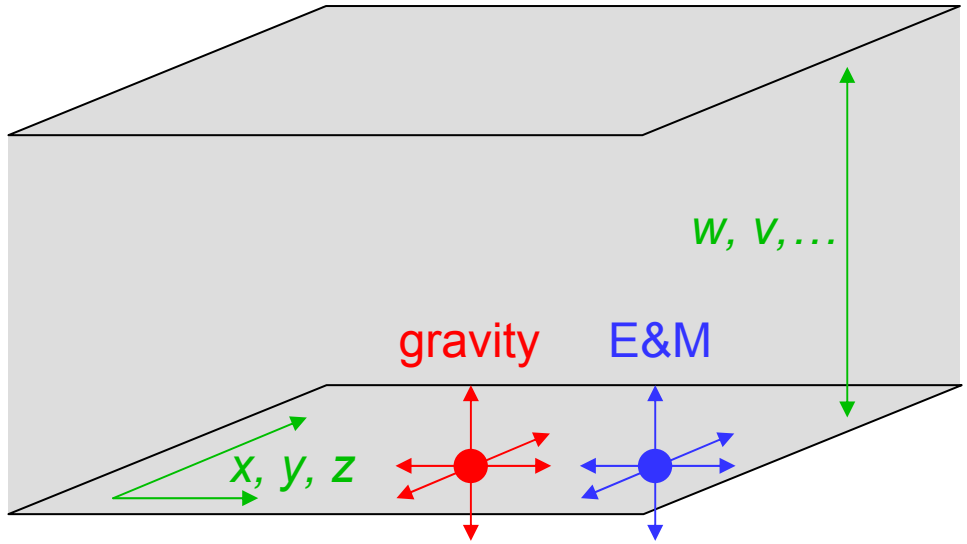


COLLISION COURSE CREATES MICROSCOPIC 'BLACK HOLES':

"…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… They're harmless and pose no threat to humans."

Universal Extra Dimensions

- A 2nd possibility is that *all* particles propagate in the extra dimensions
- This is a much more radical modification, because all forces are changed. The maximal size of a *universal* extra dimension is ~ 10^{-17} m



- But now matter particles move in the extra dimensions, many new implications

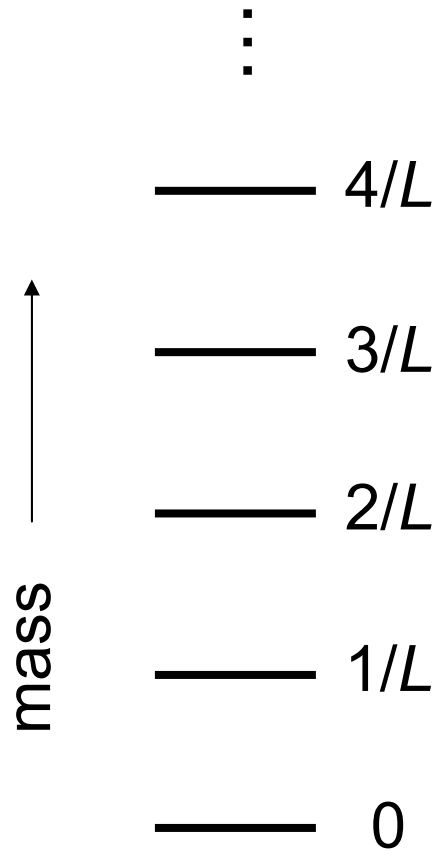
Extra Dimensional Matter

- A particle moving in an extra dimension of size *L* appears to us as a set of particles with masses

  0, 1/L, 2/L, 3/L, 4/L, …

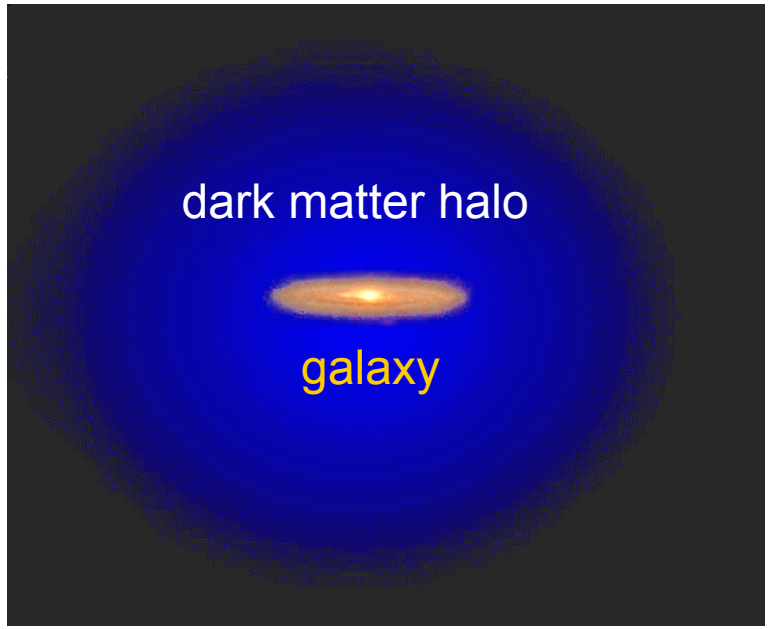
- Each known particle has a heavy partner at each mass level.

- We can try to find these particles. Or maybe we already have. . .



Dark Matter

- Dark matter is required to hold galaxies together
- It cannot be any of the known particles
- 25% of the energy density of the universe is in dark matter (cf. 4% for normal matter)



Perhaps it's a particle predicted by extra dimensions; for example, a heavy photon

Dark Matter Detection

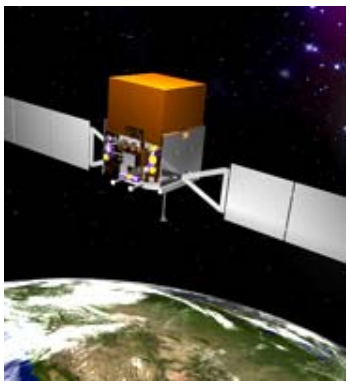
VITAL STATISTICS

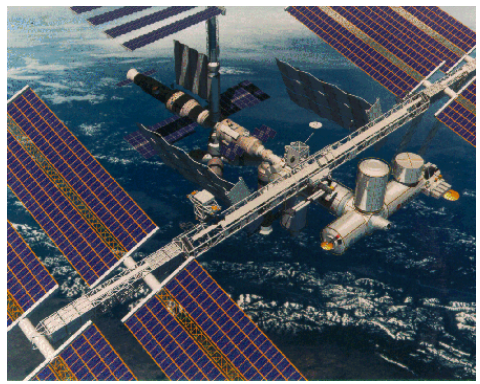
- Mass: 100 m_{proton}
- Density: 1 per liter
- Velocity: 10^{-3} c
- Interactions with normal matter: < 10 / kg / yr

CDMS experiment searching for dark matter recoils in the Soudan mine in Minnesota, ½ mile underground

Dark Matter Detection

Alternatively, can look for the products of dark matter particles pair annihilating somewhere in the galaxy





[NB: Work required for dark matter → extra dimensions]

Summary

- Extra dimensions are well-motivated theoretically, but there are many qualitatively different realizations
- In some cases, extra dimensions may shed light on longstanding puzzles (weakness of gravity, dark matter, …)
- Diverse searches (anomalous gravity, micro black holes, dark matter,…) are ongoing worldwide