THE DARK UNIVERSE

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What is the universe made of?

- An age old question, but we live at a particularly interesting time:
  - We know how “big” the universe is.
  - We have no idea what most of it is made of.

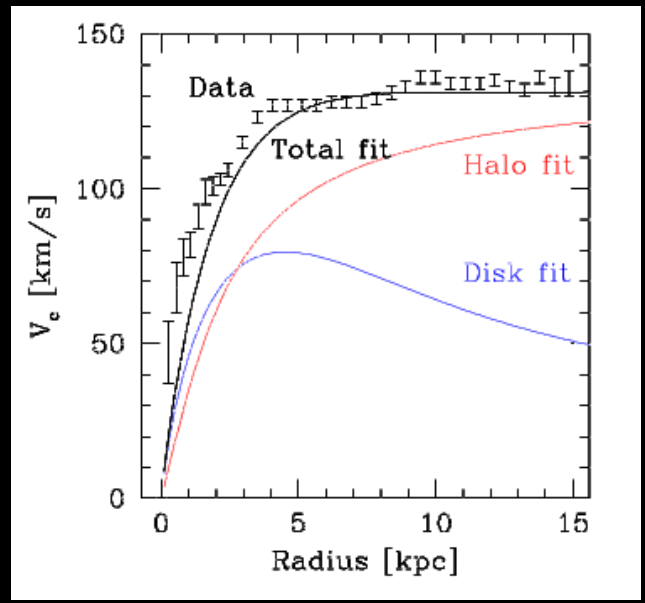
Historical Precedent

Eratosthenes measured the size of the Earth in 200 B.C.

- Much bigger than expected
- Accurate to 10%
- Led to more questions than answers

Now again, but with Earth → universe

First evidence from rotation of galaxies and galactic clusters in 1930's



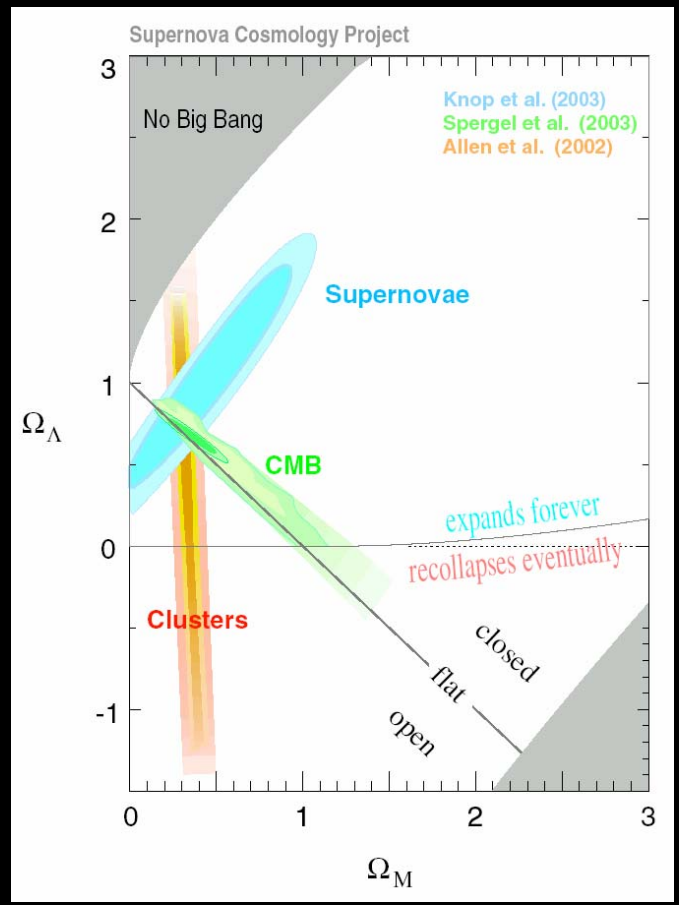
- Expect $v_c \sim R^{-1/2}$ beyond luminous region
- Instead find $v_c \sim$ constant
- Discrepancy resolved by postulating dark matter

Since 1998, these data have been supplemented by additional cosmological observations

These measurements imply:

Dark Matter: 23% ± 4%
Dark Energy Λ: 73% ± 4%

The universe is 96% dark!



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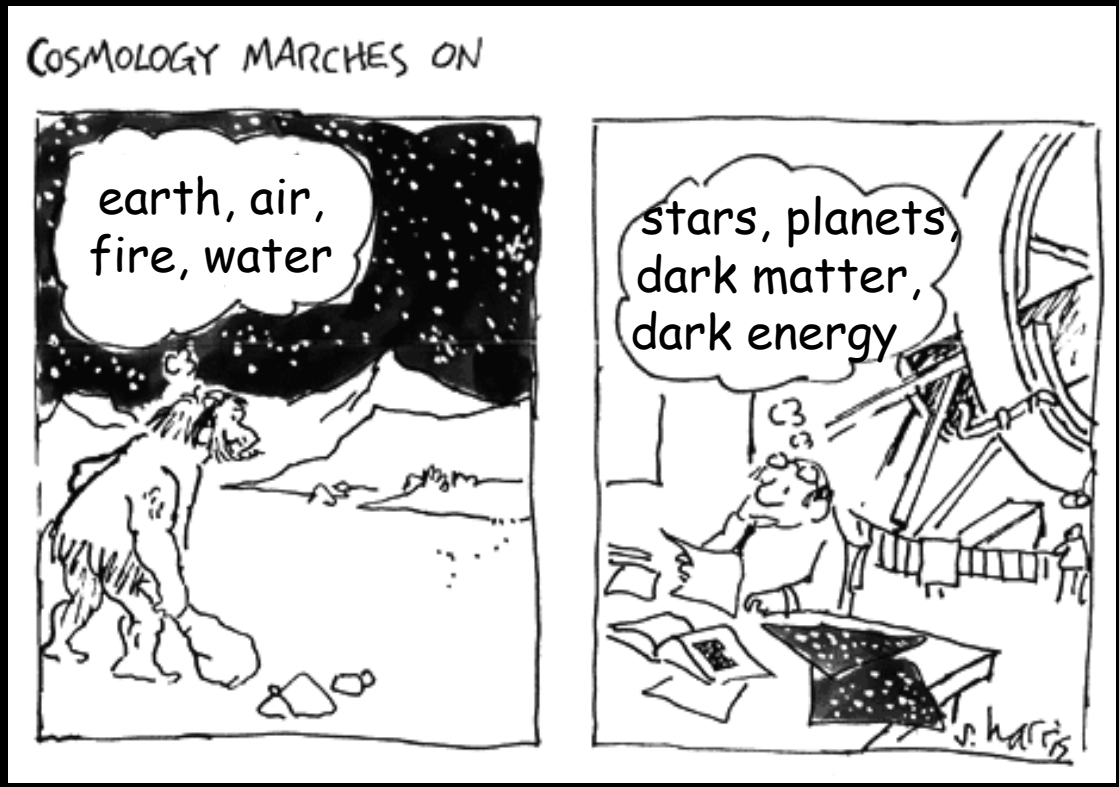
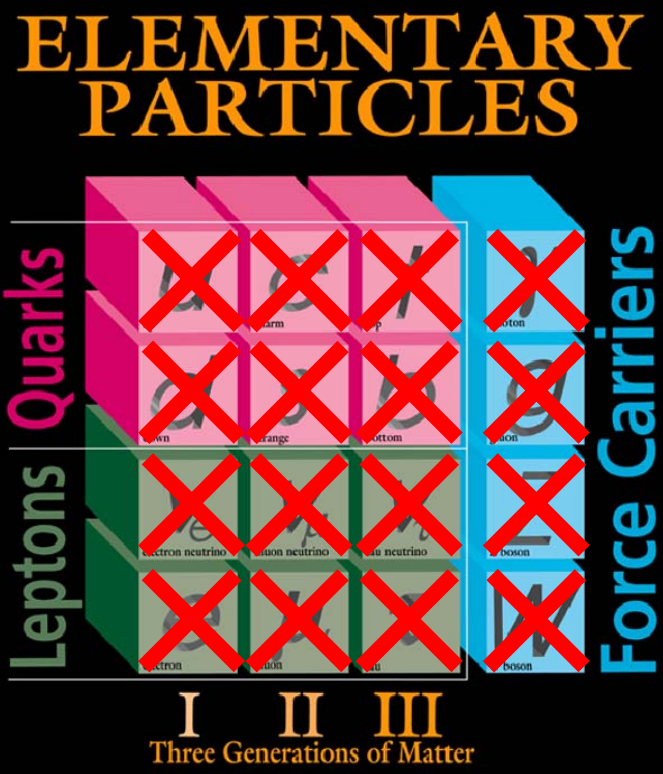

COSMOLOGY MARCHES ON
earth, air, fire, water
stars, planets, dark matter, dark energy

Dark Matter: What is it?



Known DM properties

- Stable
- Cold (slow)
- Non-baryonic

Dark matter requires new kinds of particles

Particle physics ↔ Cosmology

Dark Matter Candidates

- Many different kinds of new particles are possible.
- But independent of cosmology, new particles are required to solve one of the biggest problem in particle physics: electroweak symmetry breaking.
- These particles are often WIMPs, weakly-interacting massive particles, with masses ~ 100 GeV. Could these be dark matter?

Thermal Relic DM Particles

1) Initially, DM is in thermal equilibrium:

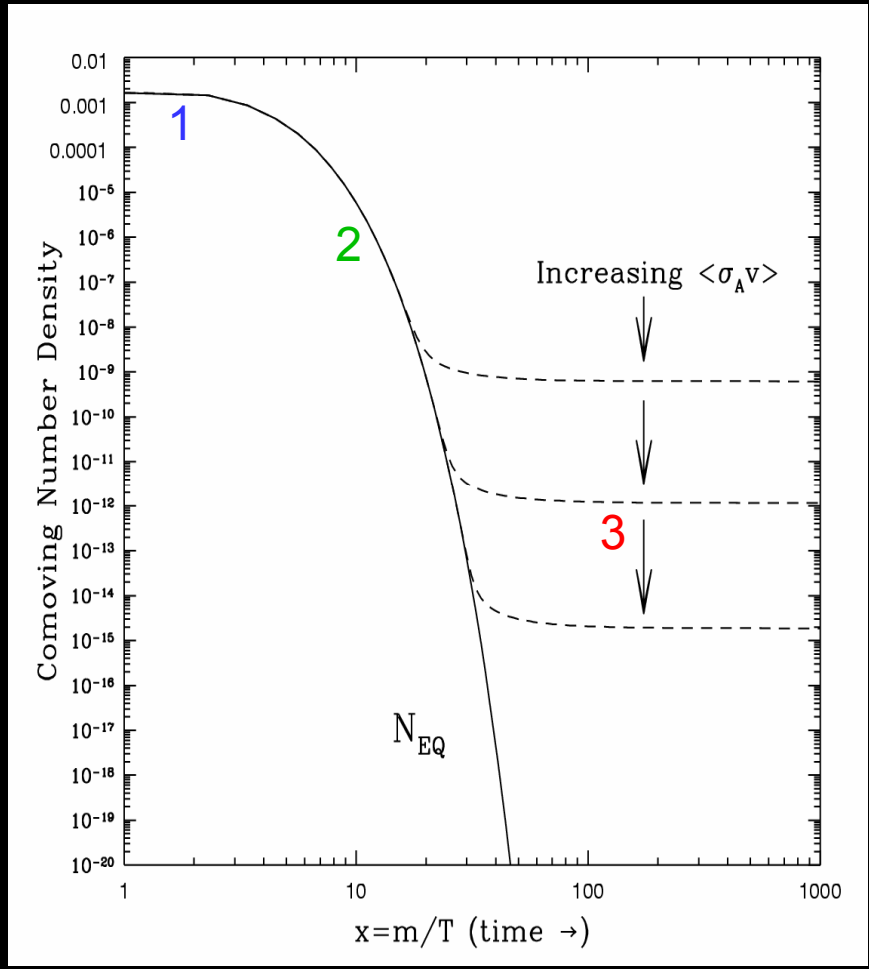
$$\chi\chi \leftrightarrow \bar{f} f$$

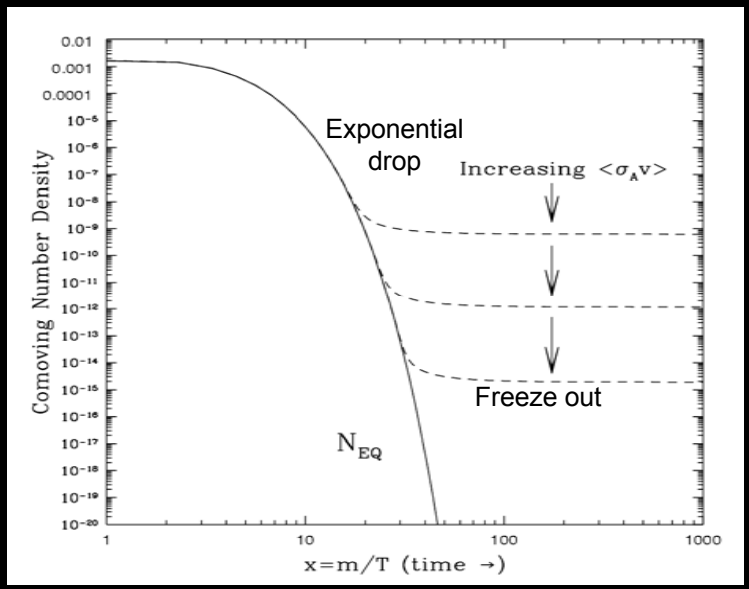
2) Universe cools:

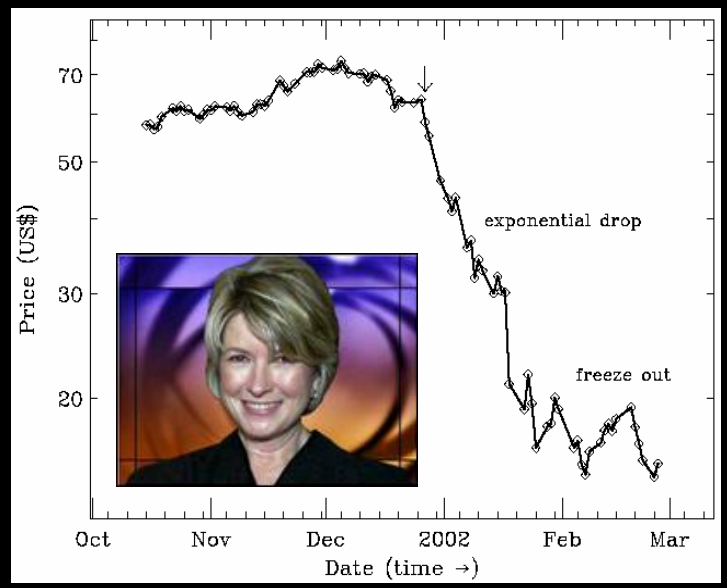
$$N = N_{EQ} \sim e^{-m/T}$$

3) χs "freeze out":

$$N \sim \text{const}$$







- Final *N* fixed by annihilation cross section:

  $\Omega_{DM} \sim 0.1\ (\sigma_{weak}/\sigma_A)$

  Remarkable!

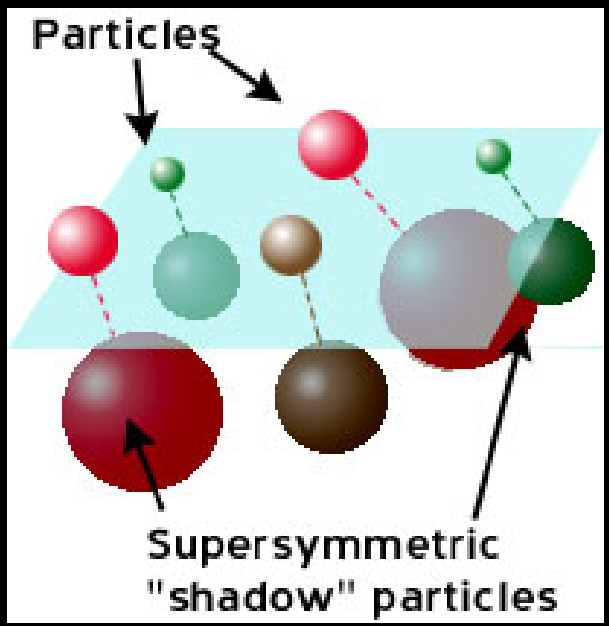
- 13 Gyr later, Martha Stewart sells ImClone stock – the next day, stock plummets

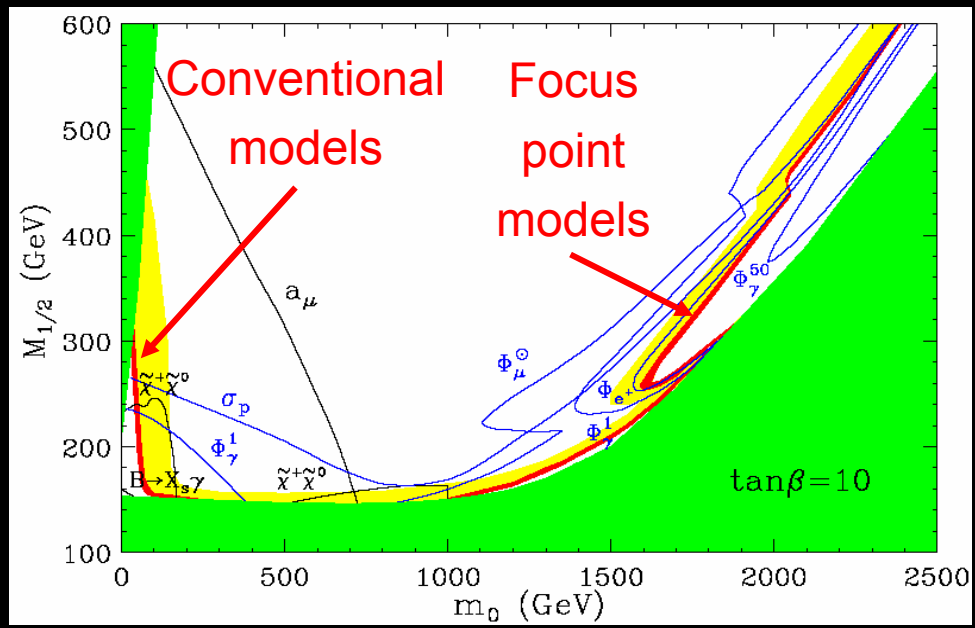
Coincidences? Maybe, but worth serious investigation!

New Possibilities for Dark Matter

Supersymmetry predicts a partner particle for every known particle. The partner of the photon is generally an excellent DM candidate, but different models have different implications for detection.

Feng, Matchev, Wilczek (2000)



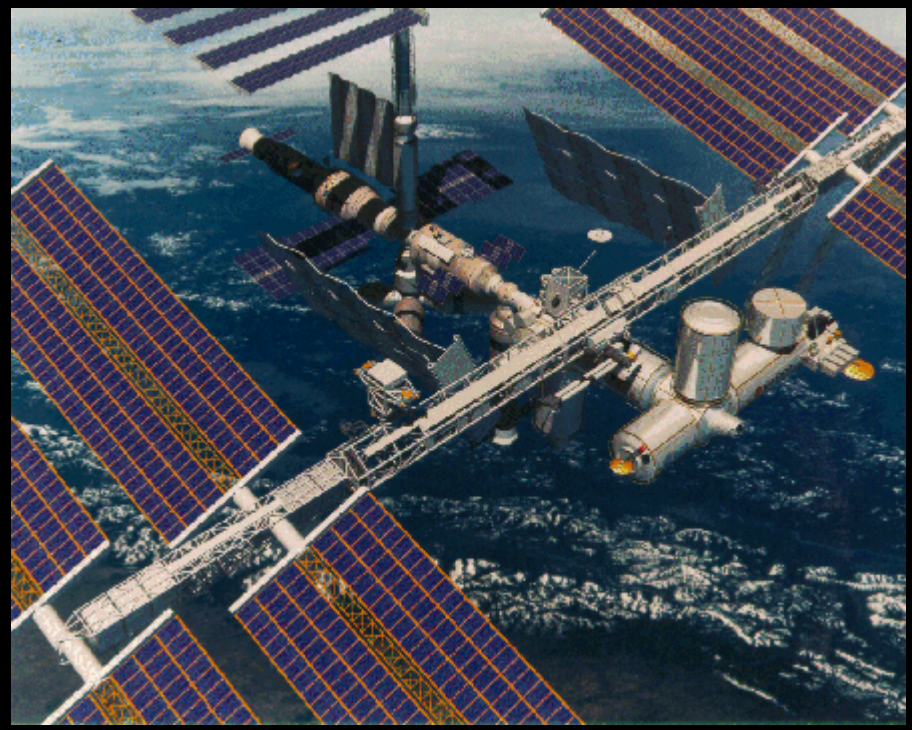


Focus point dark matter predicts enhanced detection rates

$\chi\chi \rightarrow$ neutrinos in the Sun

AMANDA in the Antarctic Ice

$\chi\chi \rightarrow$ positrons in the halo

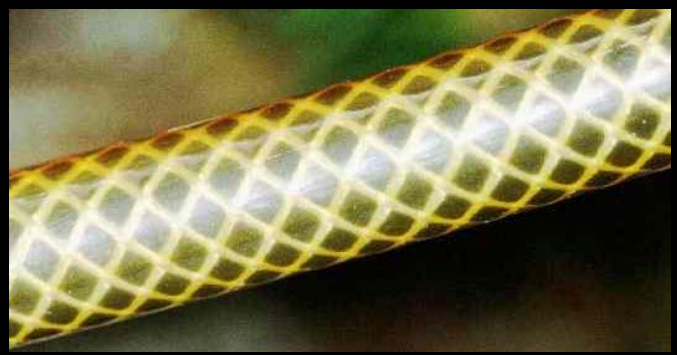


AMS on the International Space Station

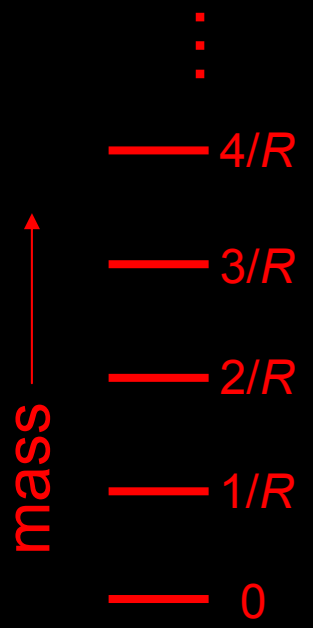
Extra Dimensional Dark Matter

Cheng, Feng, Matchev (2002)

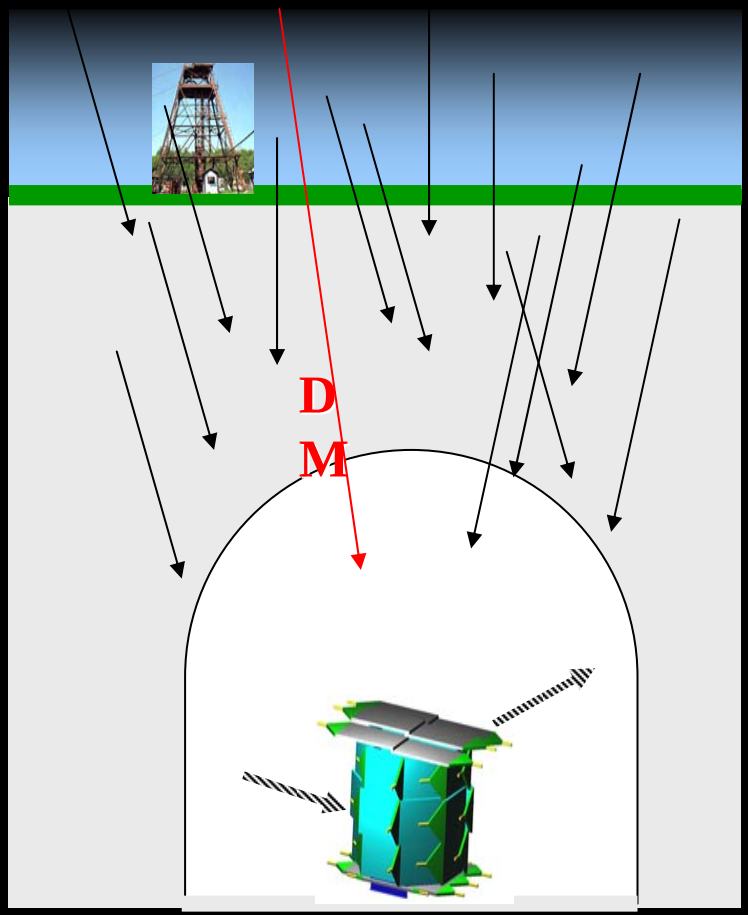
- Extra spatial dimensions could be curled up into small circles.



- Particles moving in extra dimensions appear as a set of copies of normal particles.



Dark Matter Detection



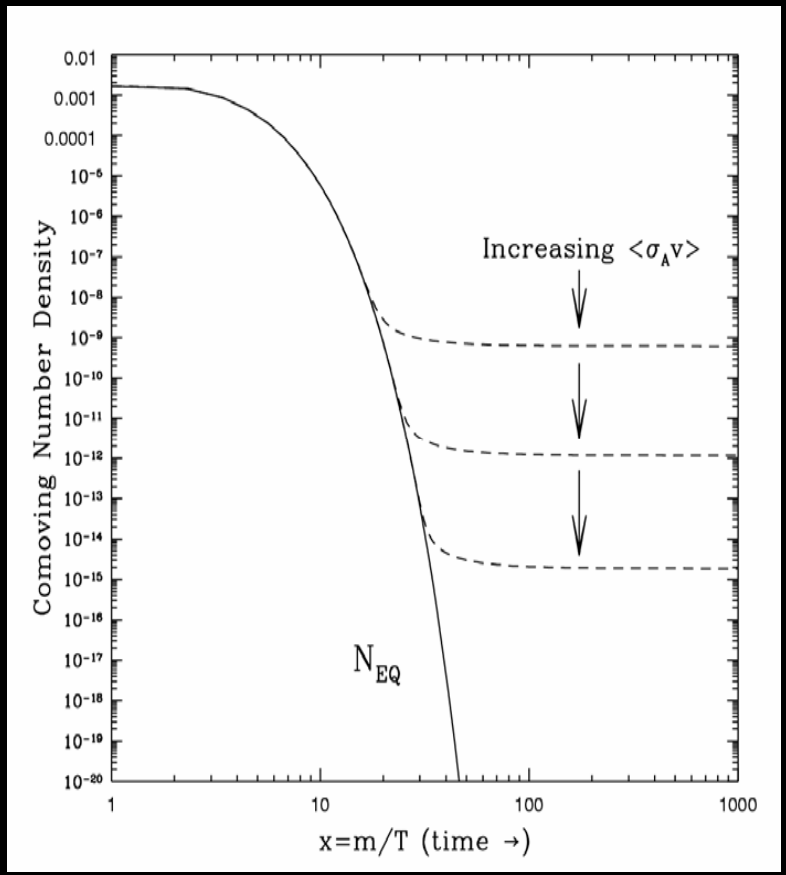
CDMS in the Soudan mine
½ mile underground in Minnesota

SuperWIMP Dark Matter

Feng, Rajaraman, Takayama (2003)

- Both supersymmetry and extra dimensions predict partner particles for all known particles. What about the partners of the graviton?
- Such partners interact only through gravity, that is, extremely weakly.
- Can they have the right relic density?

SuperWIMP Dark Matter



- Early universe behaves as usual, WIMPs freeze out with desired thermal relic density

„ WIMP → $\tilde{G}$ $M_{Pl}^2/M_W^3 \sim$ year

- A year passes…then WIMPs decay to graviton partners

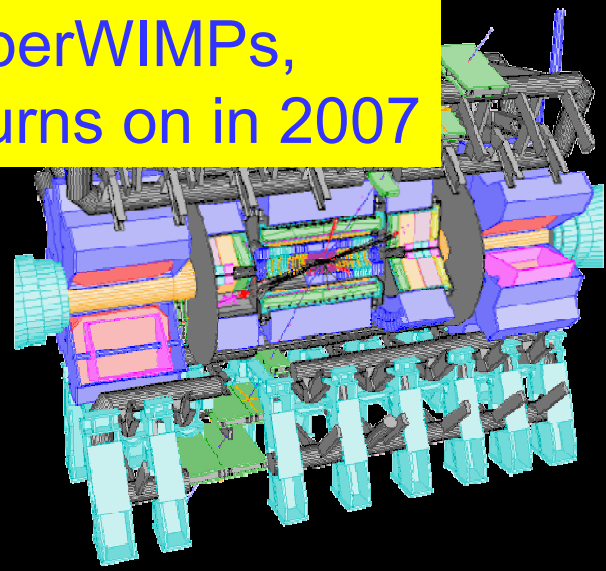
Graviton partners inherit the right density, but escape most searches – they are superweakly-interacting “superWIMPs”

Dark Matter at Colliders

Large Hadron Collider at CERN, Geneva

If dark matter is WIMPs or superWIMPs,
we will know soon after the LHC turns on in 2007

Andy Lankford



Acknowledgments

Physics and Astronomy Department staff

Szu Wang