Does the Dark Matter Problem have a WIMPy Solution?

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Dark Matter

- “Normal” matter only makes up about 5% of the universe.
- Another 25% is composed of dark matter, but we don't know what it is.
- One of the biggest gaps in human knowledge.
Outline

Astronomy
- “Houston, we have a problem”

Particle Physics
- A WIMPy solution?

Experimental Searches
- Looking for Weakly Interacting Massive Particles
Different Approaches

This is what's so cool about it... it's a clash of world views:

For a long time, particle physicists have been drilling down into smaller and smaller length scales.

Then, completely separate, you had astronomers looking further and further out...

Just recently, these two successful ways of doing science sort of... clashed.

What are you looking at?
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Galactic Rotations
Anatomy of a Galaxy

• Hypothesis: galaxy's mass is mostly stars
• Stars are bright, so mass is visible
• Brightest near center, most mass is there
• Galaxy rotates around this center

Messier 33 (M33)
The Triangulum Galaxy
Galaxy vs. Solar System

- Reminiscent of our solar system
- Small objects orbiting a bigger one
- We should expect them to behave similarly
Planetary Orbits

- Predict the relationship between velocity and distance via Kepler's laws
- Classical theory matches experiment
Galactic Rotations

- Vera Rubin discovered a large discrepancy between theory and observation.
- Stars far from center move about as fast as stars near center.
- Typical of spiral galaxies.
Invisible Mass

Dark Matter Simulation

- Run simulations of galactic rotations
- More accurate if we add invisible mass
- Good marketing – call it dark matter
Astronomy

Gravitational Lensing
Mass and Luminosity

- Galaxy's mass is mostly due to stars
- Direct proportion between mass of galaxy and light it emits
- Method to “weigh” a galaxy

Andromeda
Our Closest Neighbor
Einstein and General Relativity

- Space-time is curved by mass
- Imagine the surface of a trampoline
Mass and Curvature

- Standing on the trampoline curves its surface
- Curvature is proportional to mass
• Tennis ball's path across trampoline would bend
• Space-time's curvature bends the path of light
• More mass, more bending
Gravitational Lensing
Gravitational Lensing
Dark Matter

• Two ways to measure a galaxy's mass
  – Use light – measure its luminous output
  – Use gravity – lensing of distant objects
• Gravitational lensing measures six times more mass!
• Corresponds with galactic rotation results
• Mass that isn't visible, hence dark matter
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The Standard Model

- Summarizes our knowledge of particle physics
- Universe's basic building blocks
- Three forces
  - Weak nuclear
  - Strong nuclear
  - Electromagnetism
- No gravity!
The Force(s)

- Strong and weak forces appear in radioactive decay.
- All macroscopic forces except gravity are electromagnetism.
- Electromagnetic force is exchange of light particles.
Supersymmetry

- One possible extension of the Standard Model
- Predicts big particles that don't interact very often
- Otherwise we would have found them already
Hypothesis: WIMPs

- Weakly Interacting Massive Particles
- Supersymmetric particles and dark matter candidate
- Don't interact with light – wouldn't notice them
- Have mass, so interact with gravity
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WIMP Hunting

- Three methods
  - Collider Production
  - Indirect Detection
  - Direct Detection

- Extremely varied
Collider Production

- Smash protons together and look through the aftermath of collisions for WIMPs
- ATLAS and CMS detectors at the Large Hadron Collider in Geneva, Switzerland
- Humanity's biggest experiment to date
Indirect Detection

- Look for products of WIMP decay or annihilation
- Use telescopes to search for distant signals from the early universe
- AMS (ISS), IceCube (Antarctica)
Direct Detection

- WIMPs should be all around, but we wouldn't notice
- Look for collisions with atomic nuclei
- Deep underground
- Low temperature
- LUX (Homestake, SD)
  CDMS (Soudan, MN),
Still Searching

- Haven't found conclusive evidence for WIMPs
- Learning where not to look
The Next Generation

Direct Detection
- NSF and DOE
- July 15, 2014
- SuperCDMS
- LUX-ZEPLIN
- Bigger detectors
- Increased sensitivity
- Deeper underground

Collider Production
- LHC Run 2 starting soon!
Conclusion

• Dark matter is one of the biggest (25%!) unsolved mysteries in the universe
• Lots of mass that we cannot see
• WIMPs would bridge the gap between Astronomy and Particle Physics
• Many different ways to search for WIMPs
• No results yet, but bigger and badder experiments are on the way
Thank you!

Questions?