Cracking the Mysteries of the Universe

Dr Janie K. Hoormann
University of Queensland
Timeline of Cosmological Discoveries

- 16c BCE: flat earth
- 5-11c CE: Sun at the centre
- 4c BCE: Earth at the centre
- 1543: Copernicus’s heliocentric model
- 1837: Bessel et al. measure distance to stars
- 1905: Einstein’s theory of Special Relativity
- 1915: Einstein’s theory of general relativity
- 1917-1922: Theorise universe is expanding
- 1929: Hubble measures expansion
- 1933: Dark matter in the Coma cluster
- 1970: Dark matter in galaxies
General Relativity
Special Relativity

• Introduces spacetime

• Two postulates
  • Laws of physics same in any non-accelerating reference frame
  • Speed of light is constant

• Predicts length contraction, time dilation, …
General Relativity

- Gravity is caused by the warping of spacetime
- The more spacetime warps the stronger the gravitational field
- Many predictions to test!
Testing General Relativity

• GR made many predictions
  - Time delay
  - Light bending
  - Precession of the perihelion of Mercury
  - Gravitational Waves
  - and more!

• Many of these are testable in our solar system

"No amount of experimentation can ever prove me right; a single experiment can prove me wrong”
– Albert Einstein
Bending of Light

- Light gets bent by curved spacetime
- Stars can appear to come from a different direction
- First tested with Eddington’s solar eclipse experiment
Gravitational Time Delay

• Time moves slower in stronger gravitational fields

• Tested by bouncing radar signals off of Mercury and Venus

• Needed to make GPS satellites accurate
Precession of the Perihelion of Mercury

• Measure point of closest approach to the sun

• Observed value off from classical theoretical values by 0.012 deg/century

• GR fixed this discrepancy
Strong Gravitational Fields

- Black Holes
  - Form when massive star collapses
  - Gravity so strong light can’t escape

- Neutron Stars
  - Collapsed core of stars
  - Gravitational fields $10^{11}$ times stronger than on Earth
Approximate size of Earth if it collapsed to a black hole; it would weigh the same as Earth today.

0.7 inch

JASON TREAT AND ALEXANDER STEGMAIER, NGM STAFF
SOURCES: AVERY BRODERICK, PERIMETER INSTITUTE FOR THEORETICAL PHYSICS, UNIVERSITY OF WATERLOO, CANADA; UCLA GALACTIC CENTER GROUP
GR Outside Our Solar System

- Look at the Hulse-Taylor binary pulsar
- Orbits decay over time
- Energy carried away by gravitational waves
- 1st indirect detection of GWs!
Gravitational Waves

- Can propagate as ripples in spacetime

- Detectable in dense binary star systems
  - White dwarfs
  - Neutron stars
  - Black holes
LIGO

- Laser Interferometer Gravitational Wave Observatory
- Beam split down two arms
  - If GW present the length of the arm will shrink
- 2 locations in Washington and Louisiana USA
  - More locations being planned
GW Detections

- 3 confirmed detections so far
- All results of two black holes merging
- Turns out the black holes are bigger than we expected
Dark Matter
Dark Matter

• “Dunkle Materie” coined by Swiss astronomer Fritz Zwicky

• Coma galaxy cluster
  • Looks to have a mass 400 times greater than expected

• Proposed that the mass came from matter we couldn’t see
Galaxy Rotation Curves

- Studied by Vera Rubin and Kent Ford
- Velocity of gas is larger than expected
- Could only happen if there was more matter present than observed
- Around 21% of the total contents in the universe
New Particles?

• Weakly interacting massive particles
  • WIMPs

• Direct Detection
  • detect DM particles travelling through earth

• Indirect Detection
  • Look for particles in space

• Colliders
  • made in the lab
MACHOs

- Massive Astrophysical Compact Halo Objects

- Potentially black holes 10s times more massive than the sun
  - First observations of such black holes made with LIGO

- Observed using gravitational lensing
Dark Energy
The Expanding Universe

- Hubble saw that the universe was expanding by looking at the motion of galaxies
- Provided solution to Olbers’s paradox
- The expansion is accelerating!
Accelerating Expansion

- Use supernova as standard candles
  - Allows us to measure distance to distant galaxies

- The expansion of the universe causes this light to be redshifted

- Also use baryonic acoustic oscillations
What The Universe Is Made Of

- Dark Matter: 21%
- Normal Matter: 4%
- Dark Energy: 74%
What is Dark Energy?

• Cosmological Constant
  • Einstein’s biggest blunder

• Vacuum Energy
  • Quantum field theory predicts it $10^{100}$ too big

• Maybe we need to rethink our theory of gravity
Cosmology in Australia
Square Kilometre Array

- Located in Australia and South Africa
  - Uses thousands of antenna 1000s of km apart
  - First light in 2020

- Generate 160 TB of data a second
  - More than 35,000 DVDs/sec!

- Map billions of galaxies out the observable edge of the universe
SkyMapper

• 1.35m wide optical telescope at Siding Springs Observatory

• Images the entire southern sky multiple times

• Search for supernova to study the expansion of the universe
Australian Dark Energy Survey

- Australian arm of the Dark Energy Survey
- Uses the Anglo Australia Telescope
  - 4m optical telescope
- Measures the distances to supernova host galaxies and the mass of black holes
Thank you!
Questions?