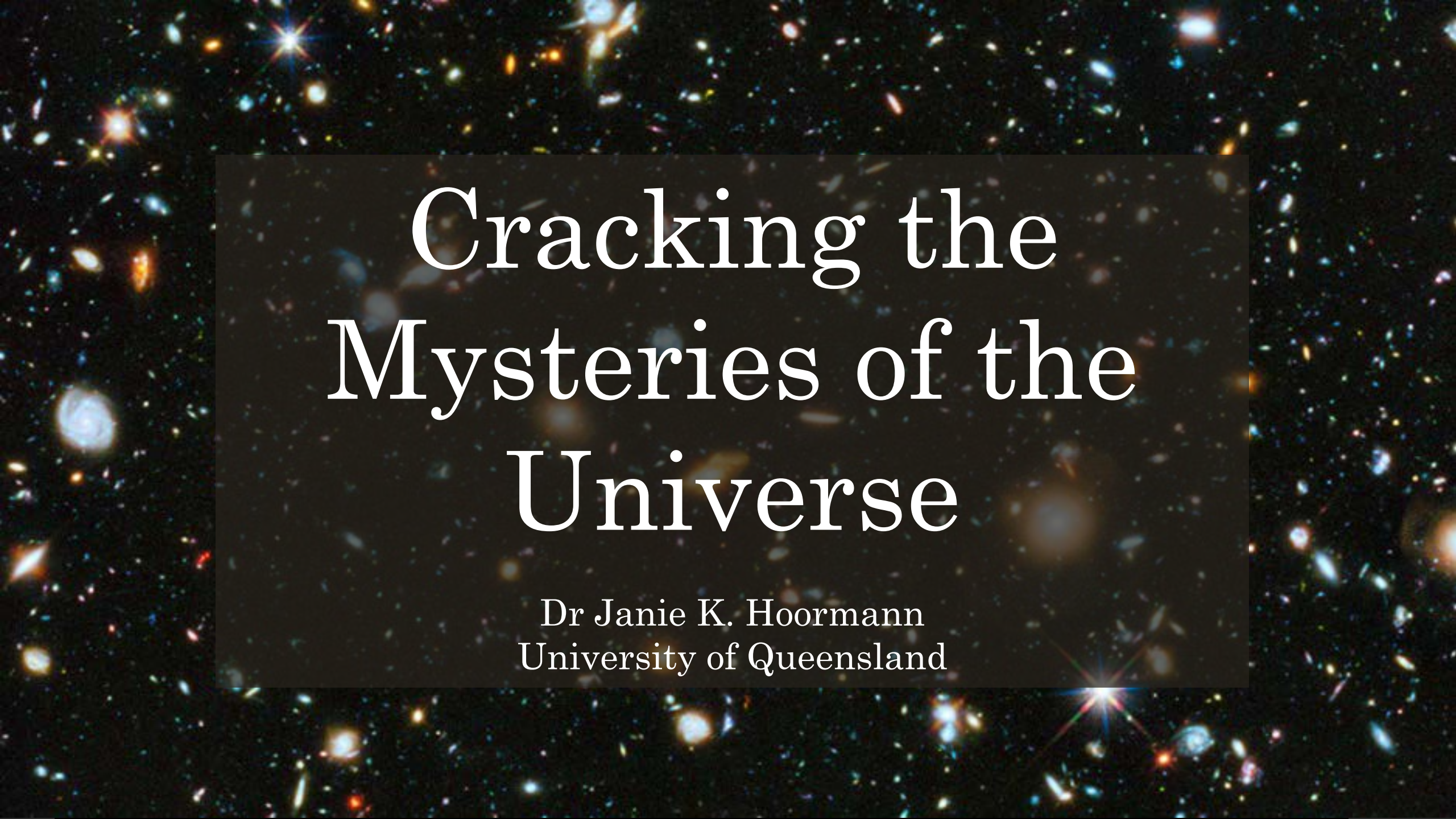
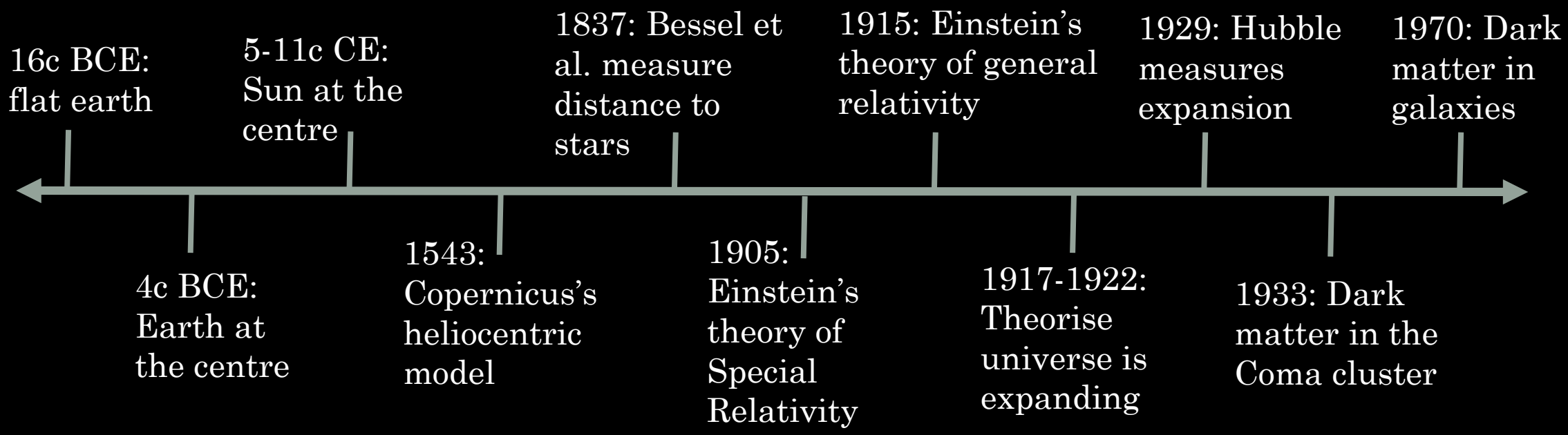
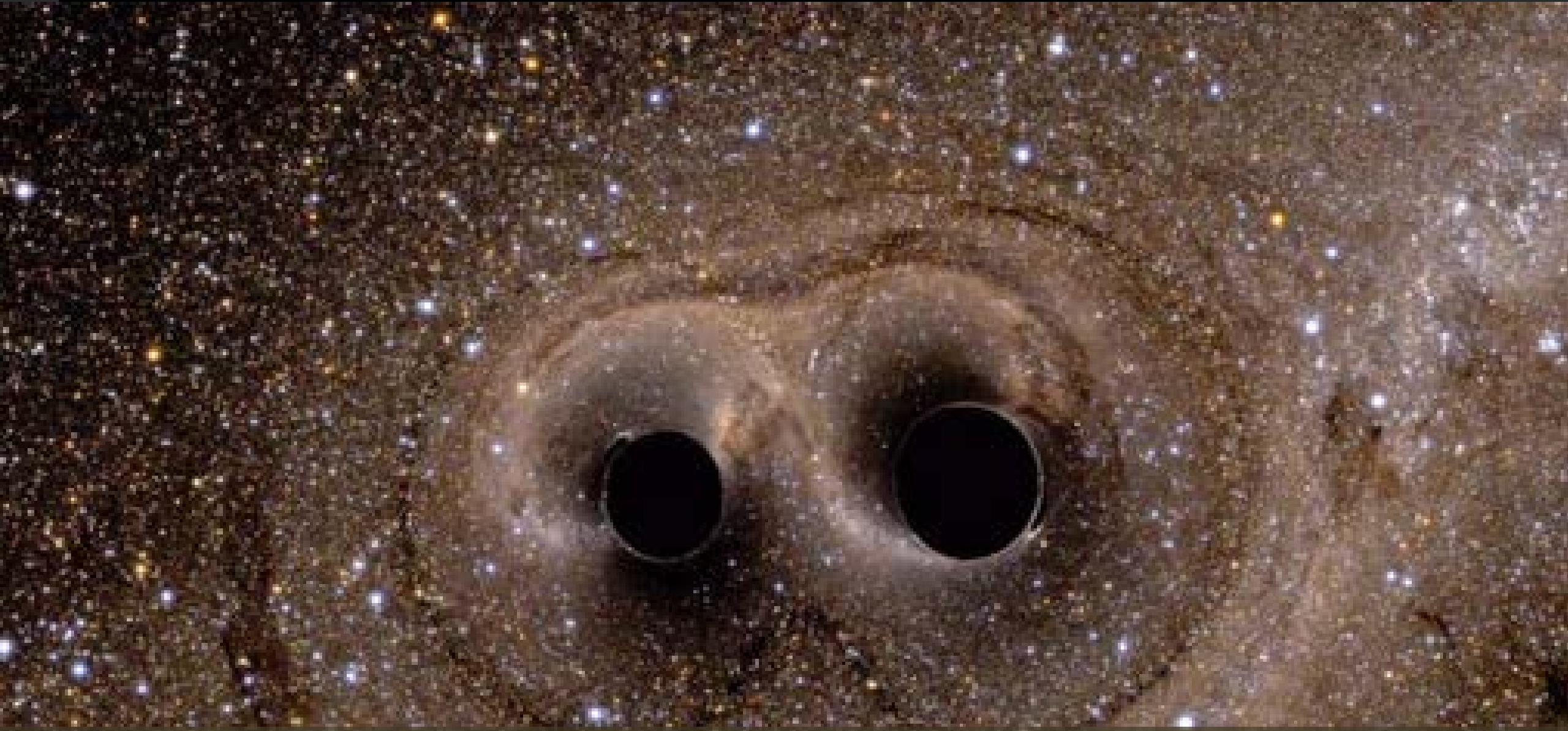


Cracking the Mysteries of the Universe

Dr Janie K. Hoormann
University of Queensland

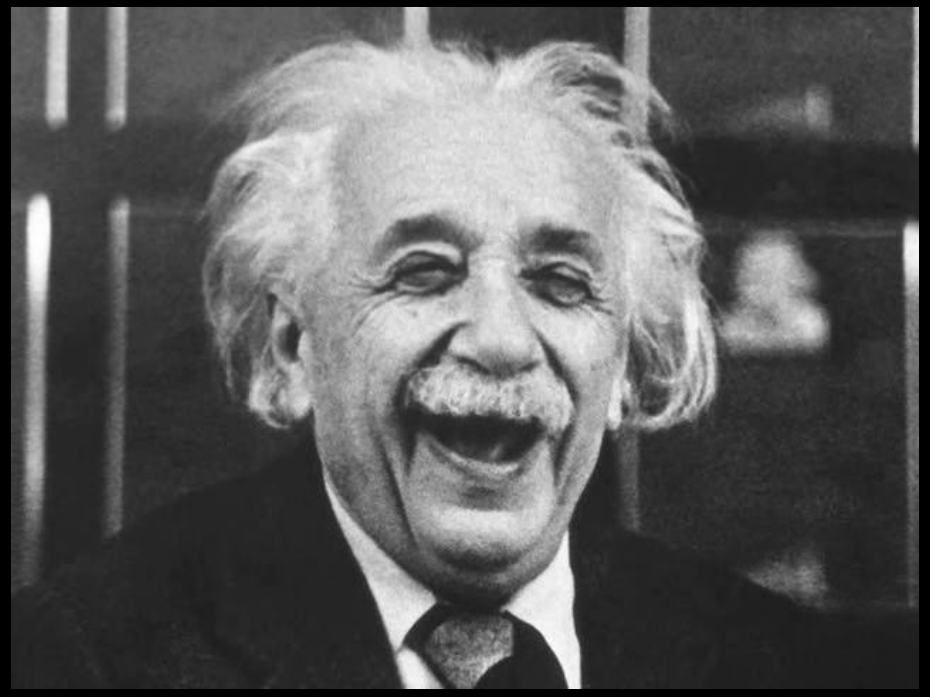
Timeline of Cosmological Discoveries





General Relativity

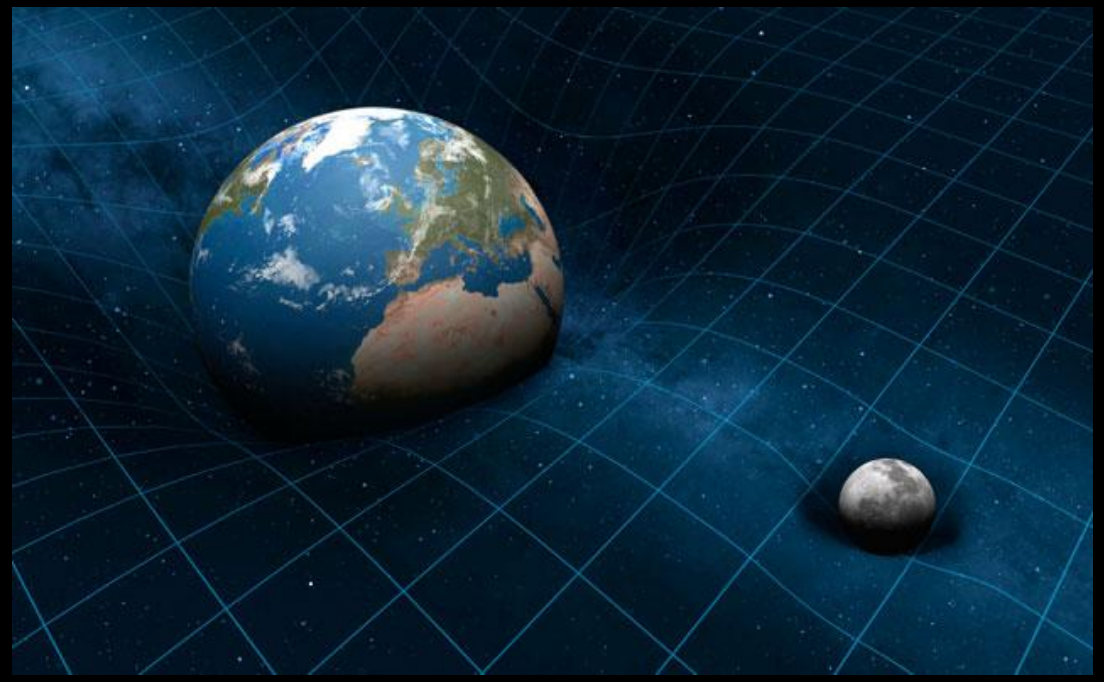
Special Relativity



- 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!

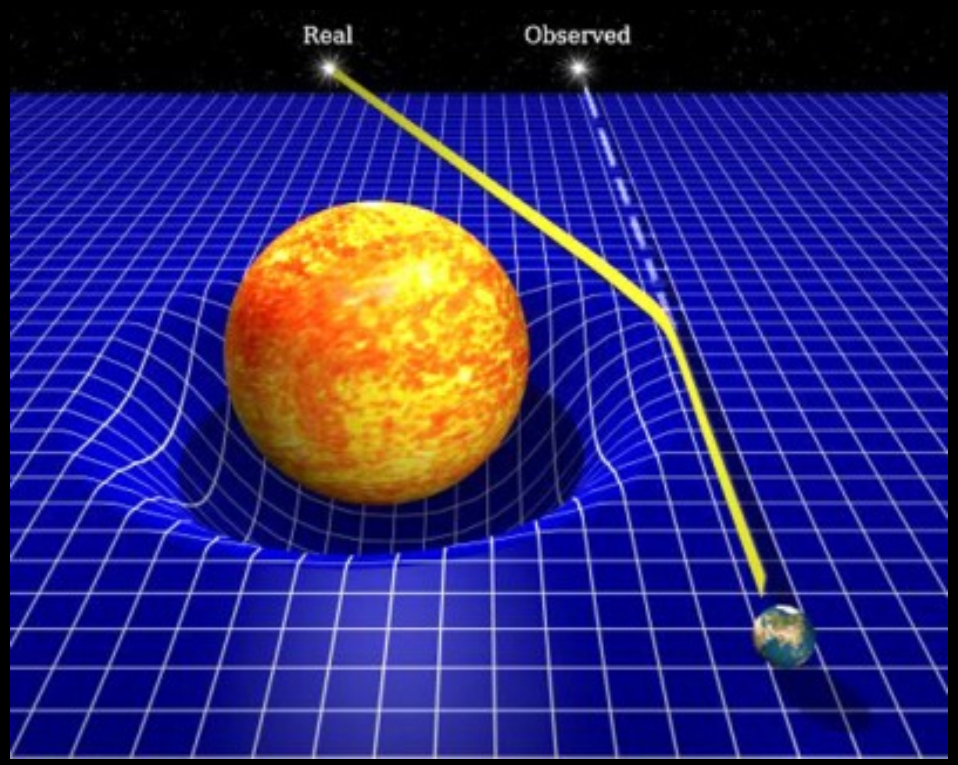


Testing General Relativity

- 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

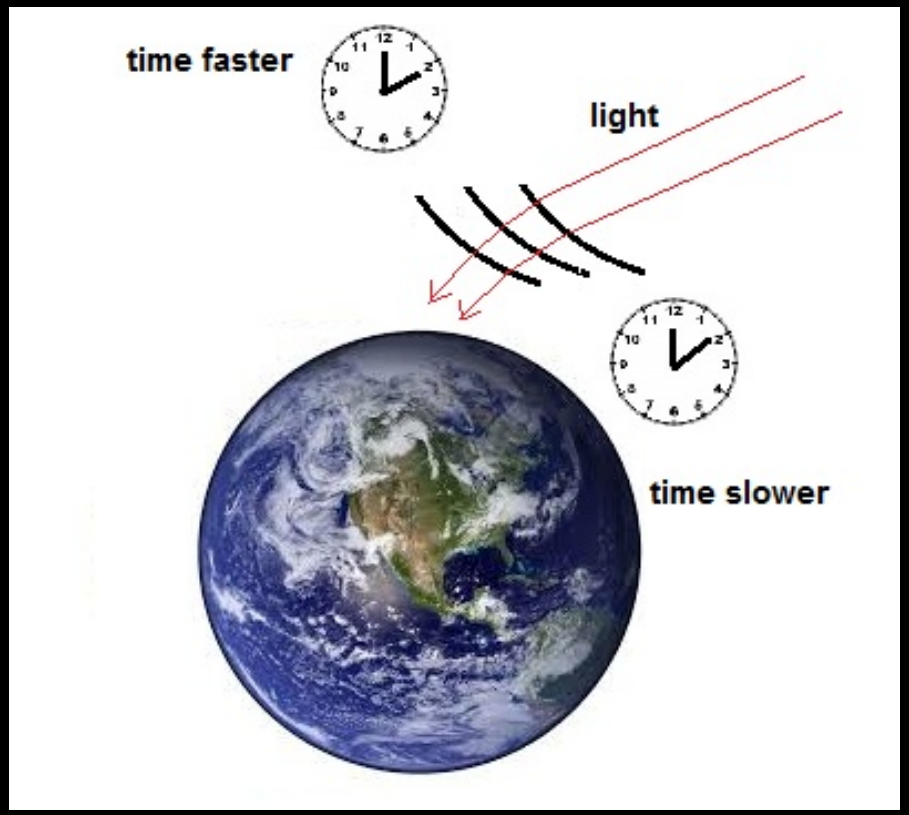
Bending of Light



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

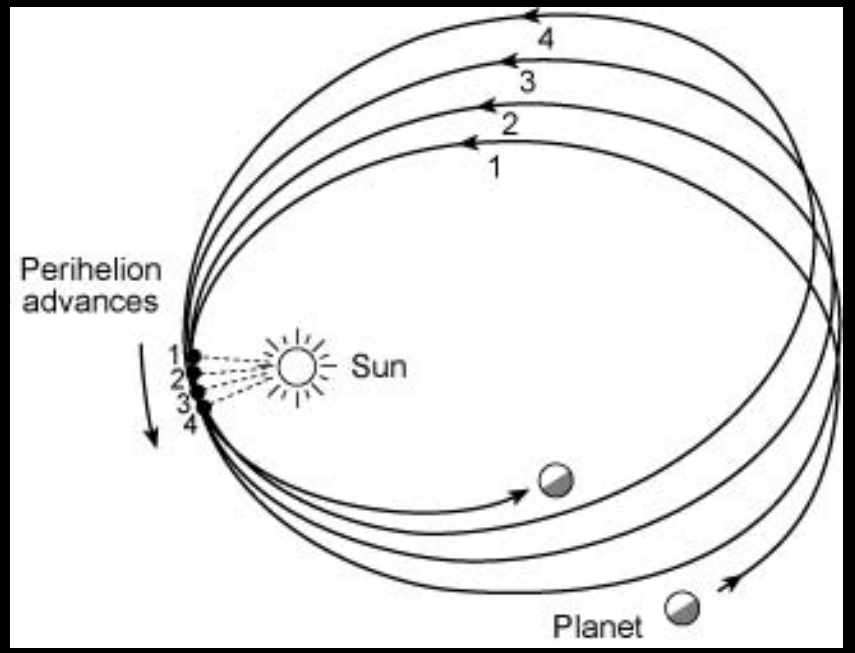
Gravitational Time Delay

- Time moves slower in stronger gravitational fields
- Tested by bouncing radar signals off of Mercury and Venus
- Needed to make GPS satellites accurate



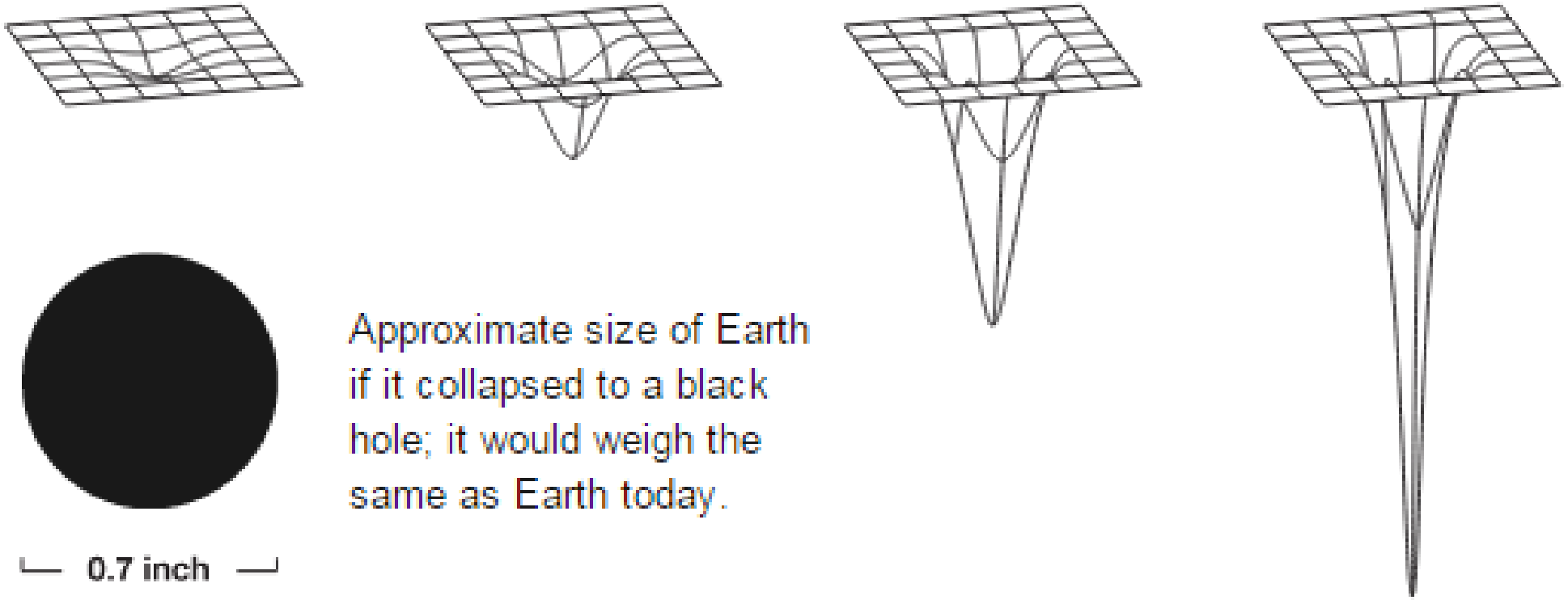
Precession of the Perihelion of Mercury

- 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

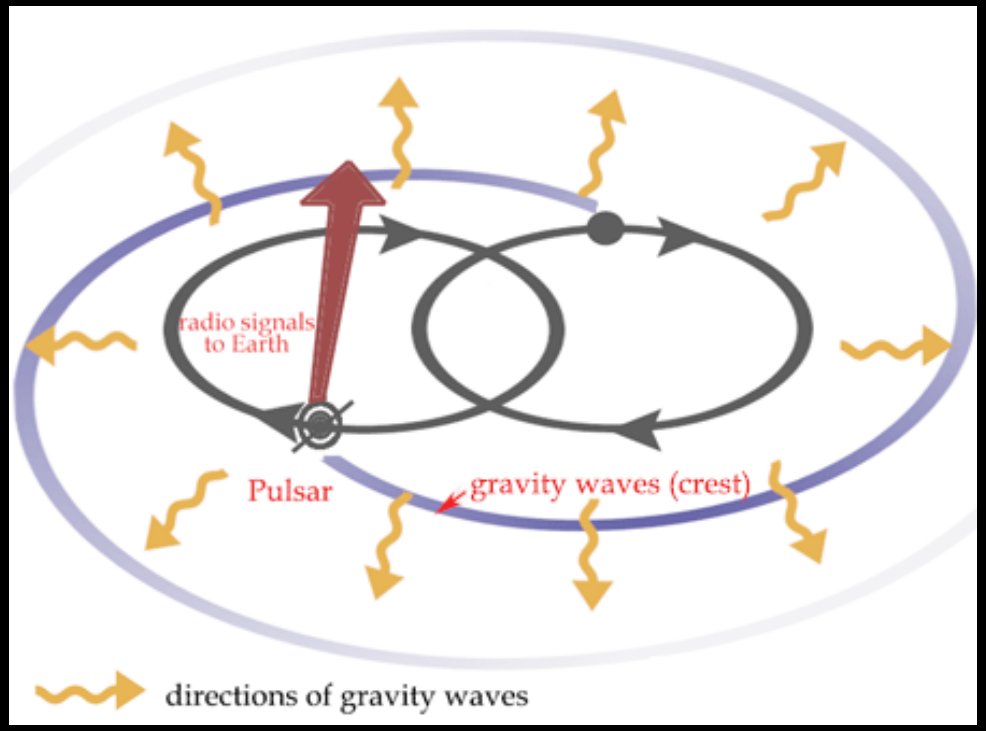
- Black Holes
  - Form when massive star collapses
  - Gravity so strong light can't escape
- Neutron Stars
  - Collapsed core of stars
  - Gravitational fields 10^{11} times stronger than on Earth



JASON TREAT AND ALEXANDER STEGMAIER, NGM STAFF

SOURCES: AVERY BRODERICK, PERIMETER INSTITUTE FOR THEORETICAL PHYSICS, UNIVERSITY OF WATERLOO, CANADA; UCLA GALACTIC CENTER GROUP

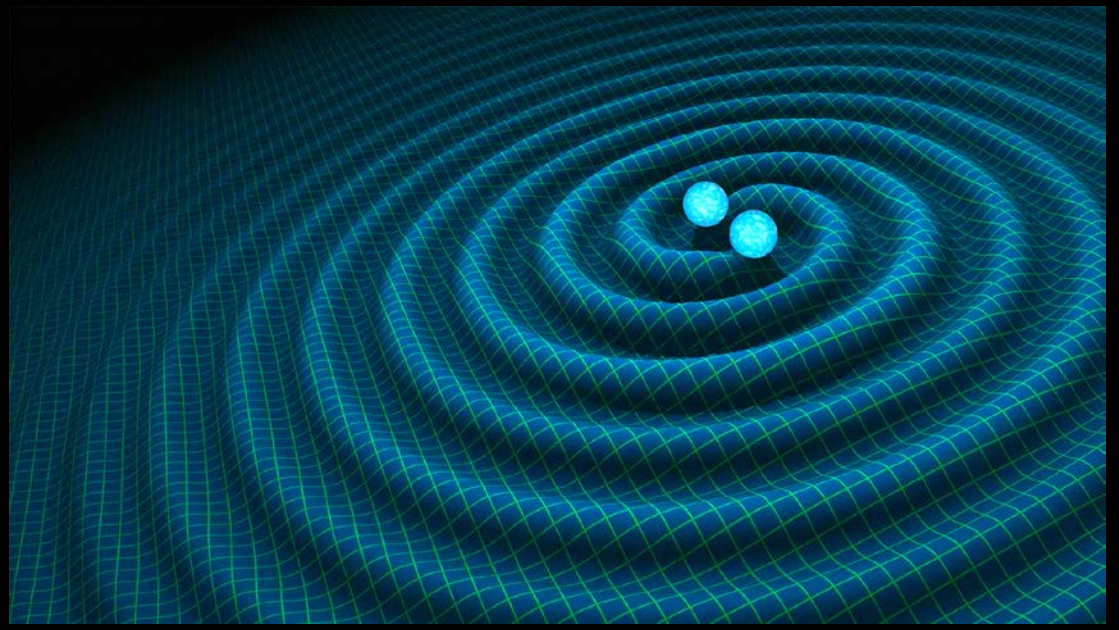
GR Outside Our Solar System



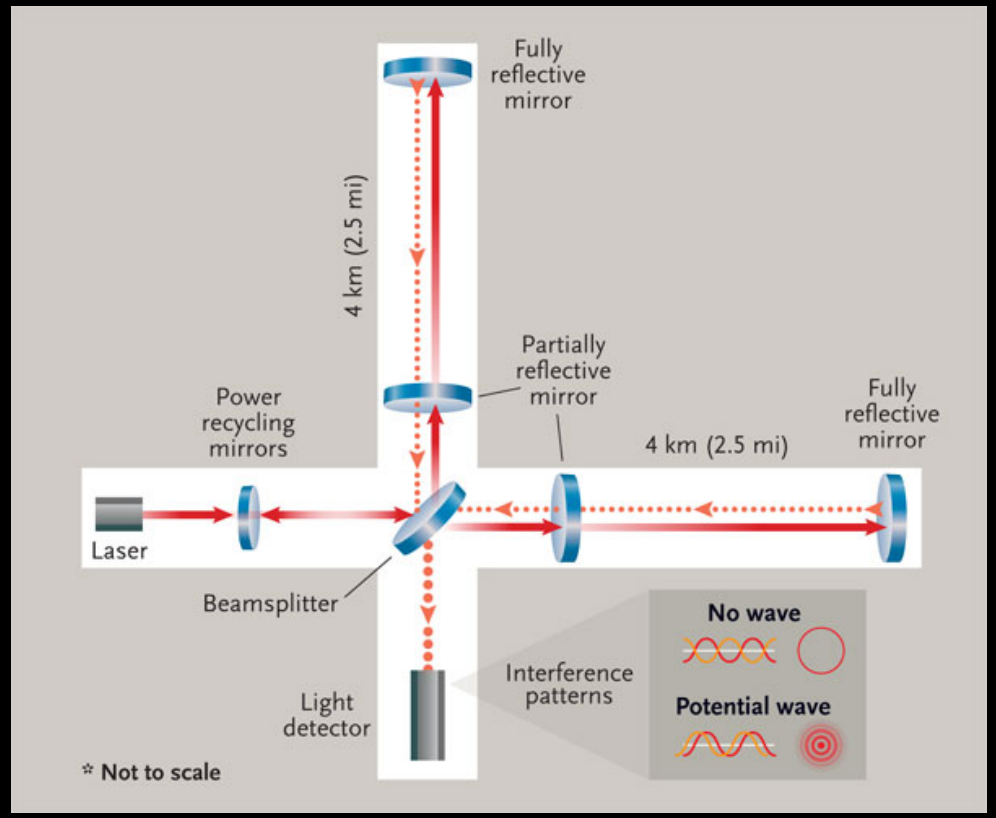
- Look at the Hulse-Taylor binary pulsar
- Orbits decay over time
- Energy carried away by gravitational waves
- 1st indirect detection of GWs!

Gravitational Waves

- Can propagate as ripples in spacetime
- Detectable in dense binary star systems
  - White dwarfs
  - Neutron stars
  - Black holes



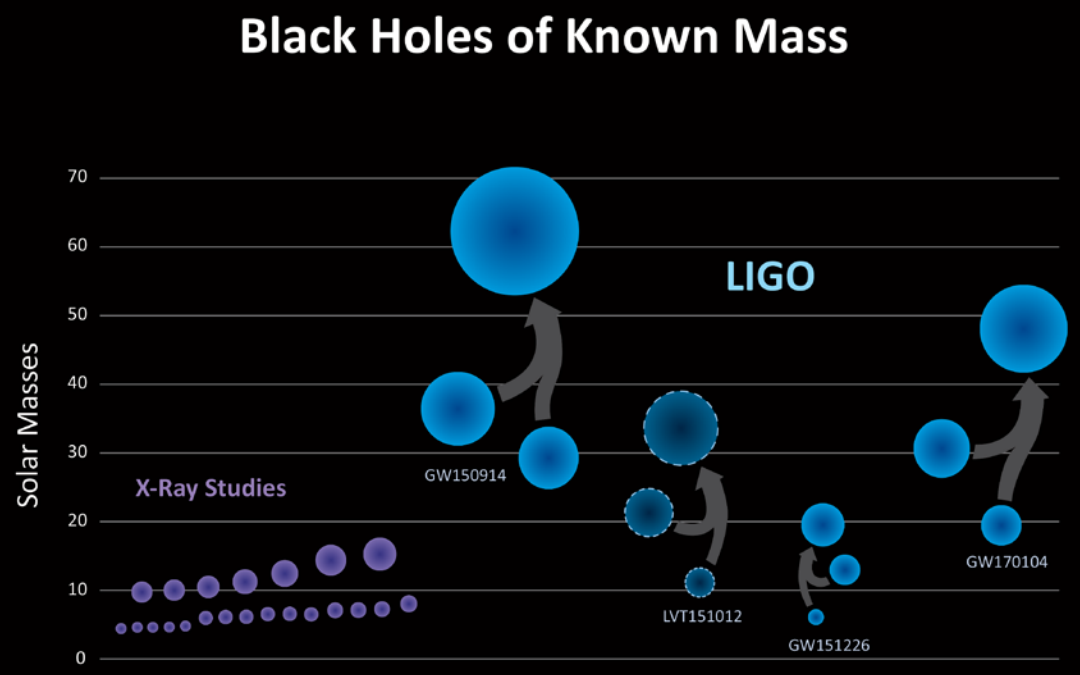
LIGO

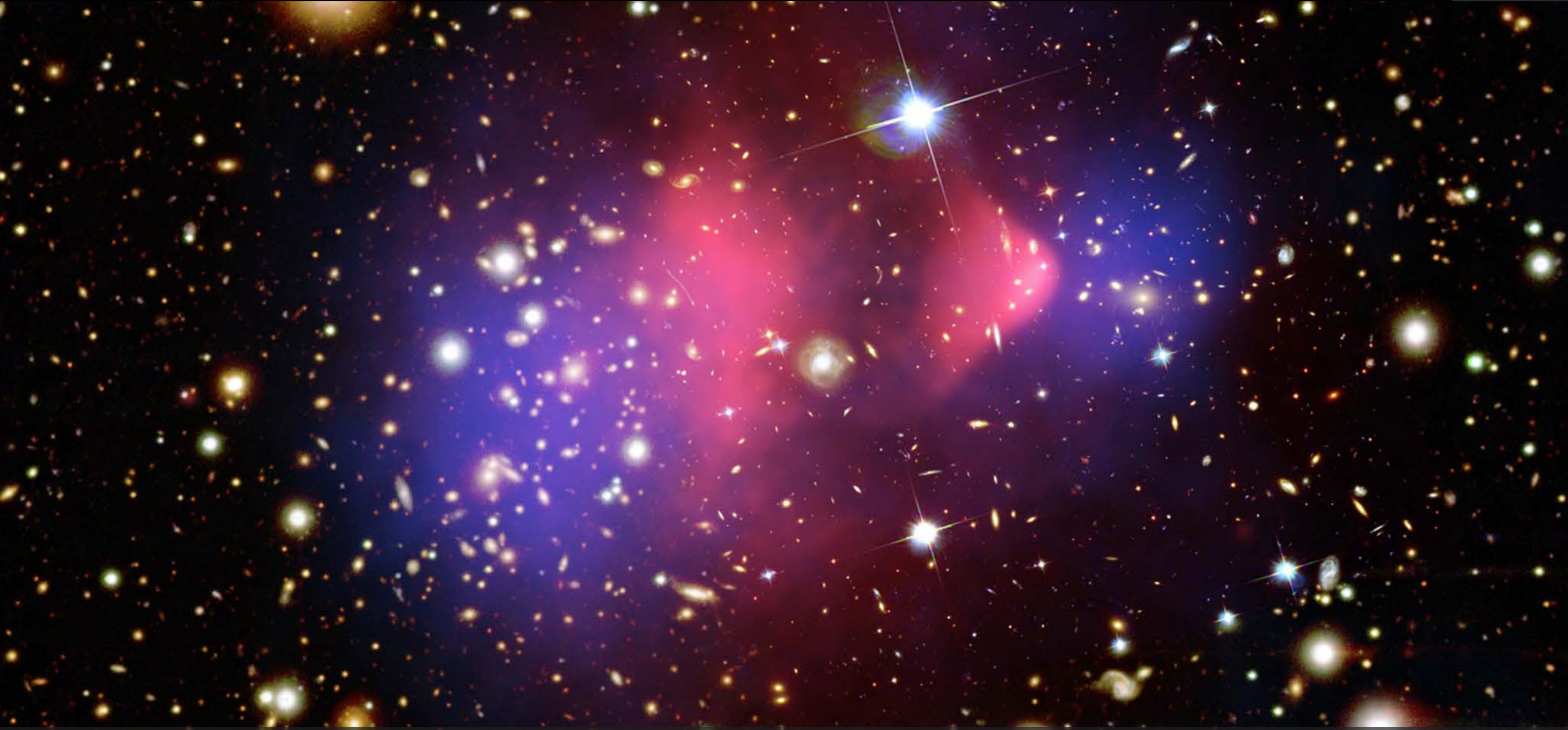


- Laser Interferometer Gravitational Wave Observatory
- Beam split down two arms
  - If GW present the length of the arm will shrink
- 2 locations in Washington and Louisiana USA
  - More locations being planned

GW Detections

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

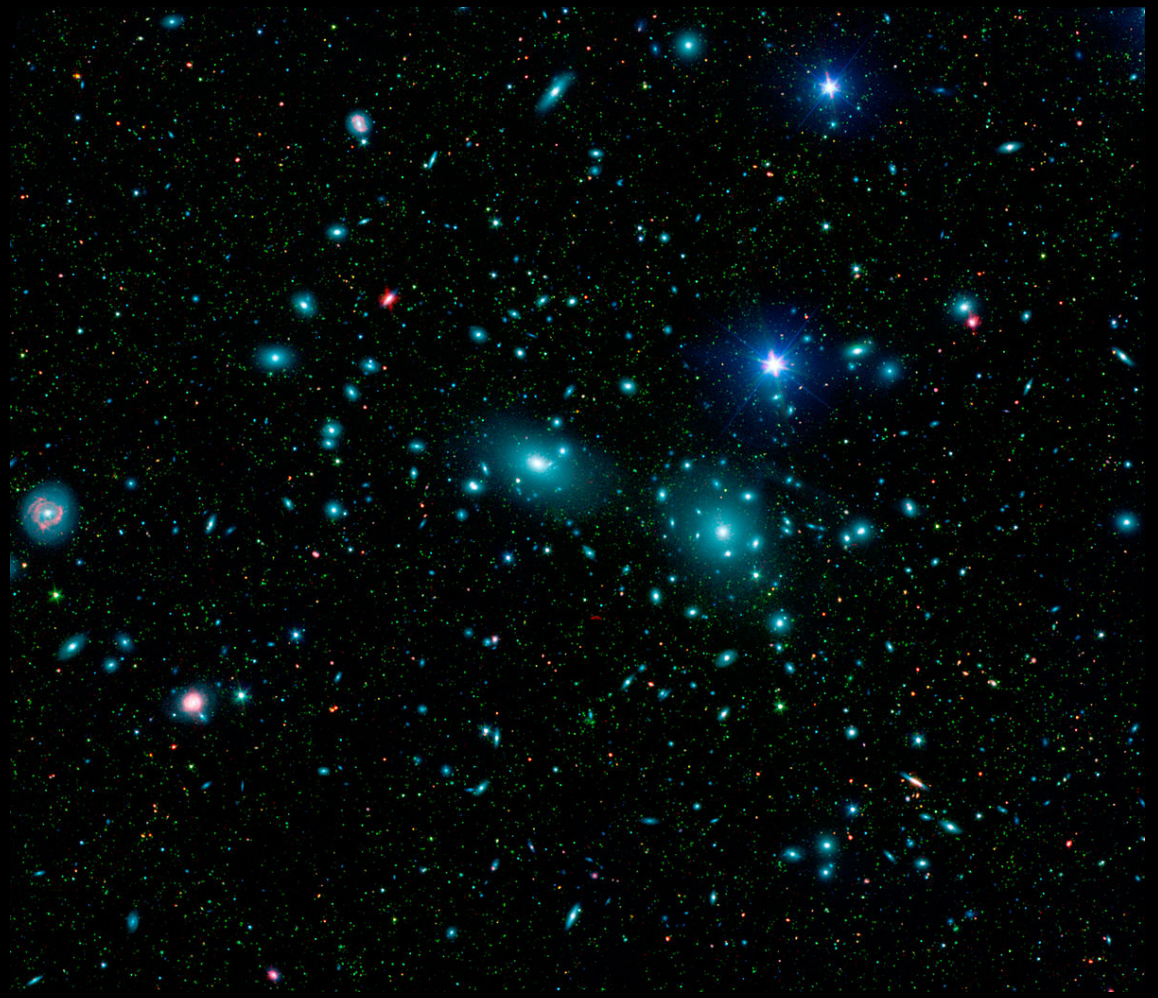




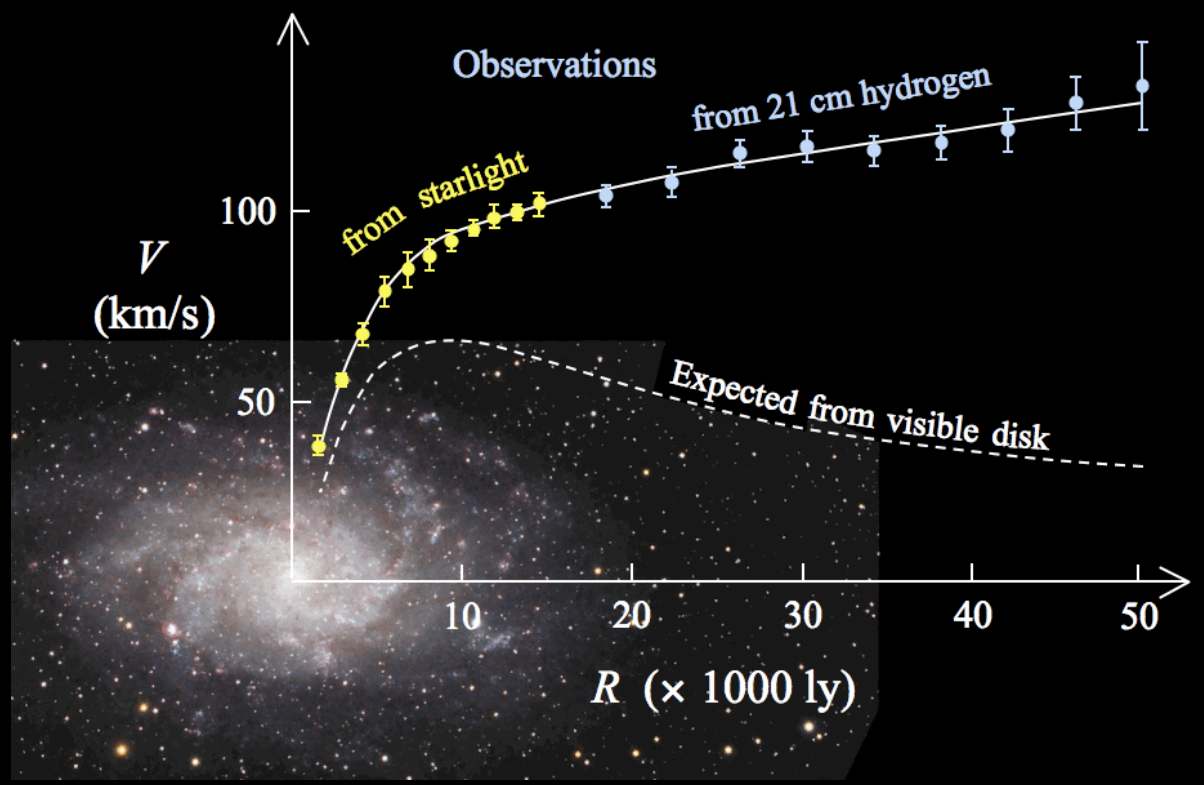
Dark Matter

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



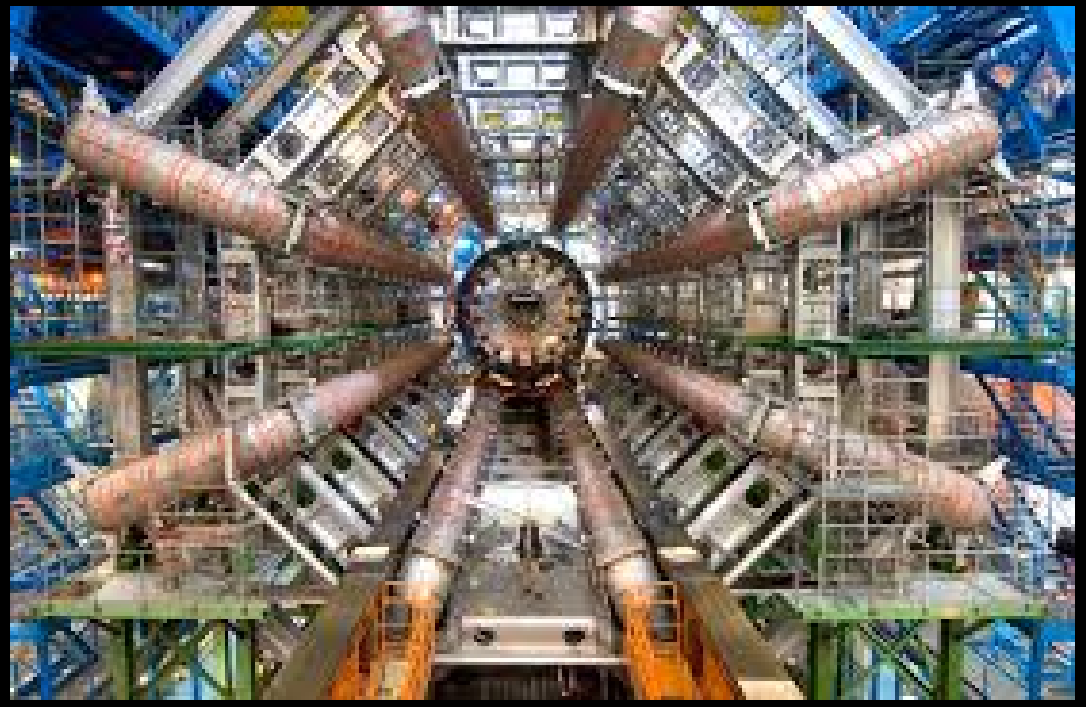
Galaxy Rotation Curves



- 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

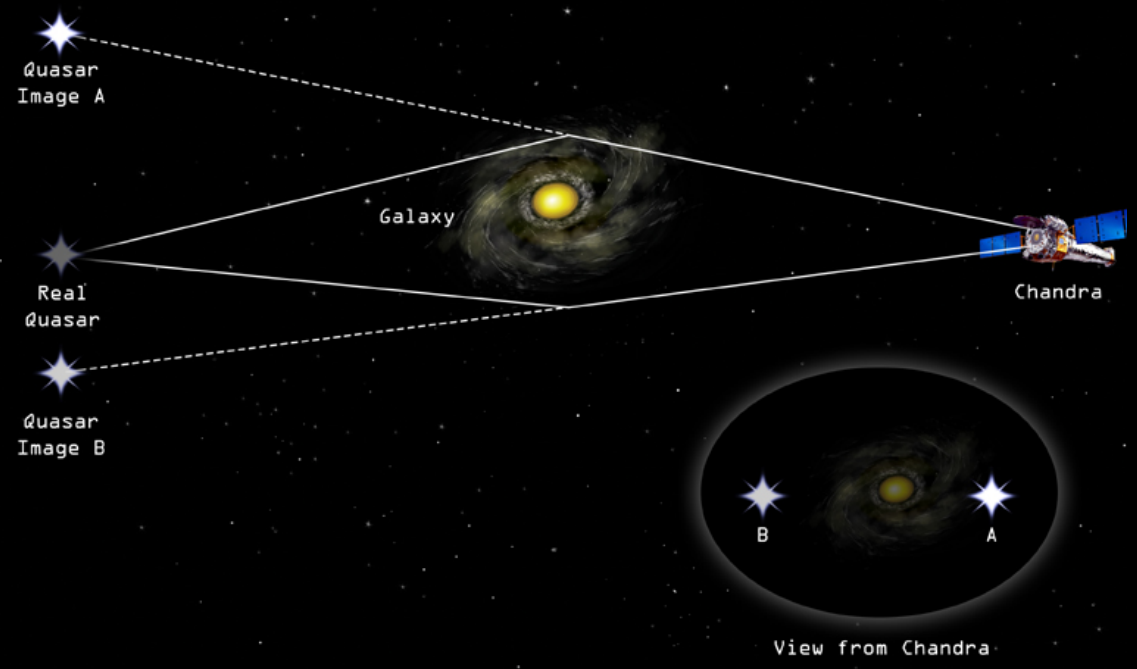
New Particles?

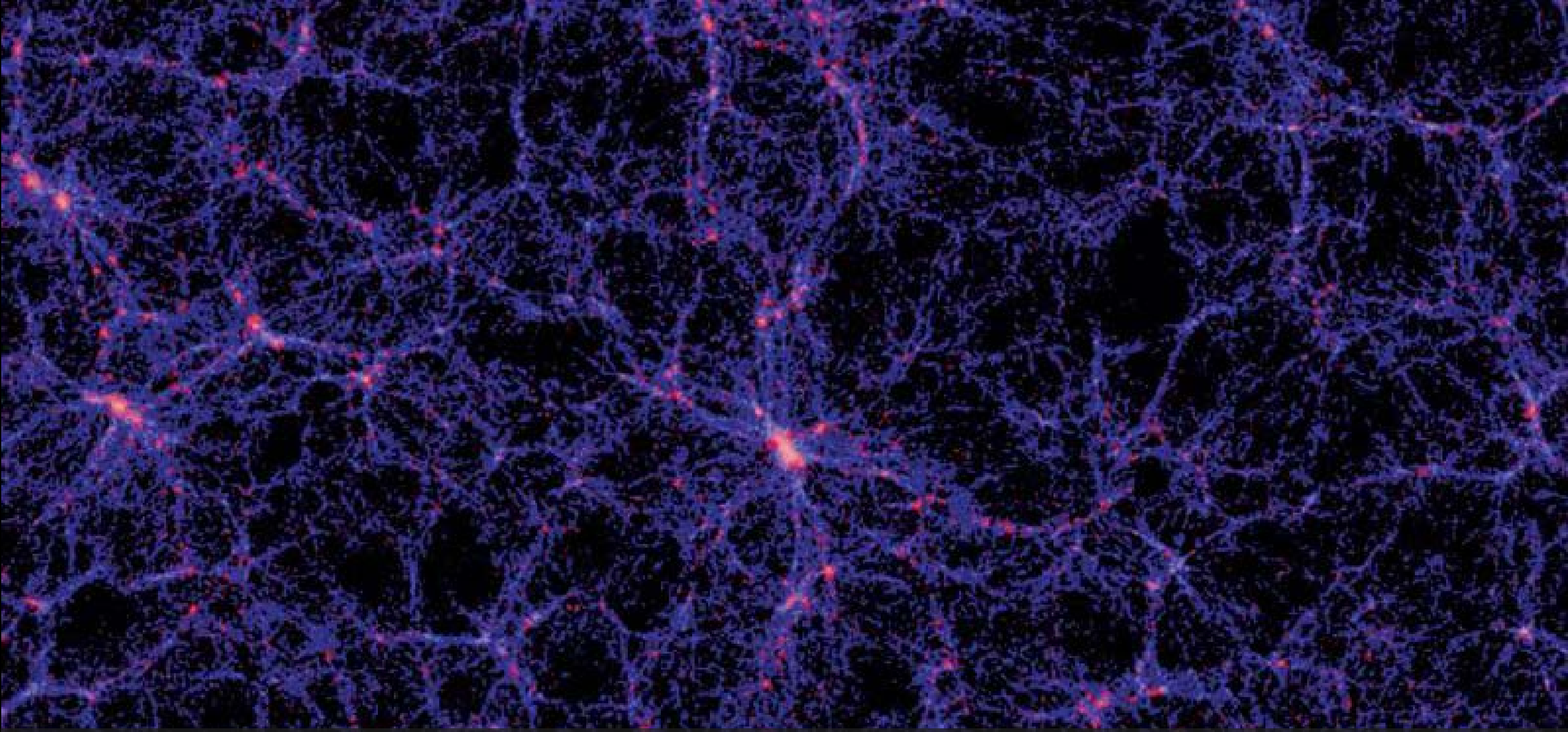
- Weakly interacting massive particles
  - WIMPs
- Direct Detection
  - detect DM particles travelling through earth
- Indirect Detection
  - Look for particles in space
- Colliders
  - made in the lab



MACHOs

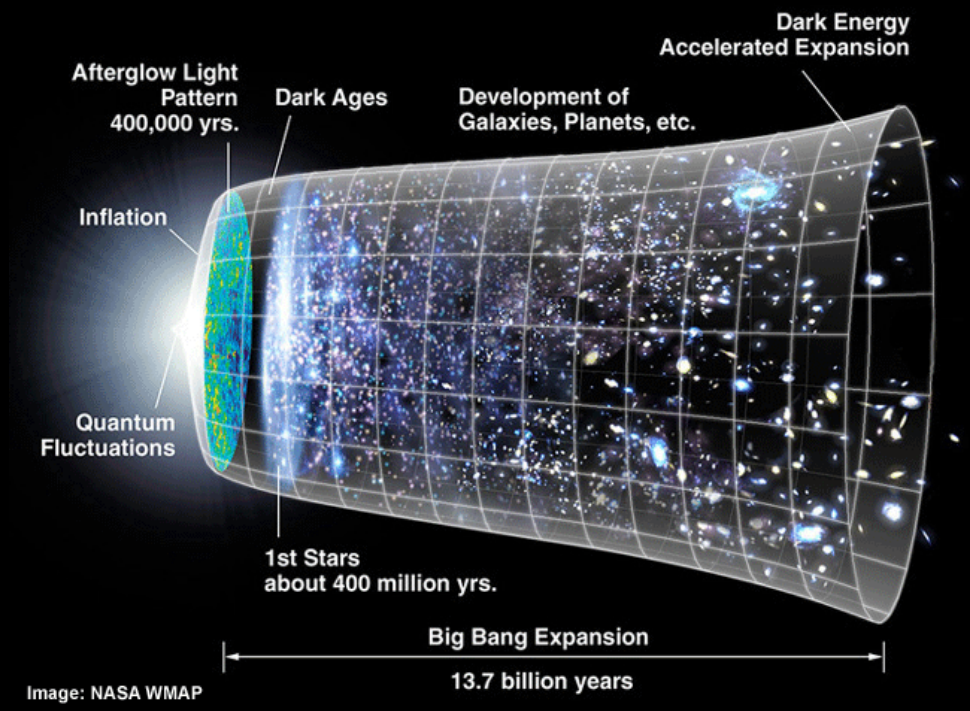
- Massive Astrophysical Compact Halo Objects
- Potentially black holes 10s times more massive than the sun
  - First observations of such black holes made with LIGO
- Observed using gravitational lensing





Dark Energy

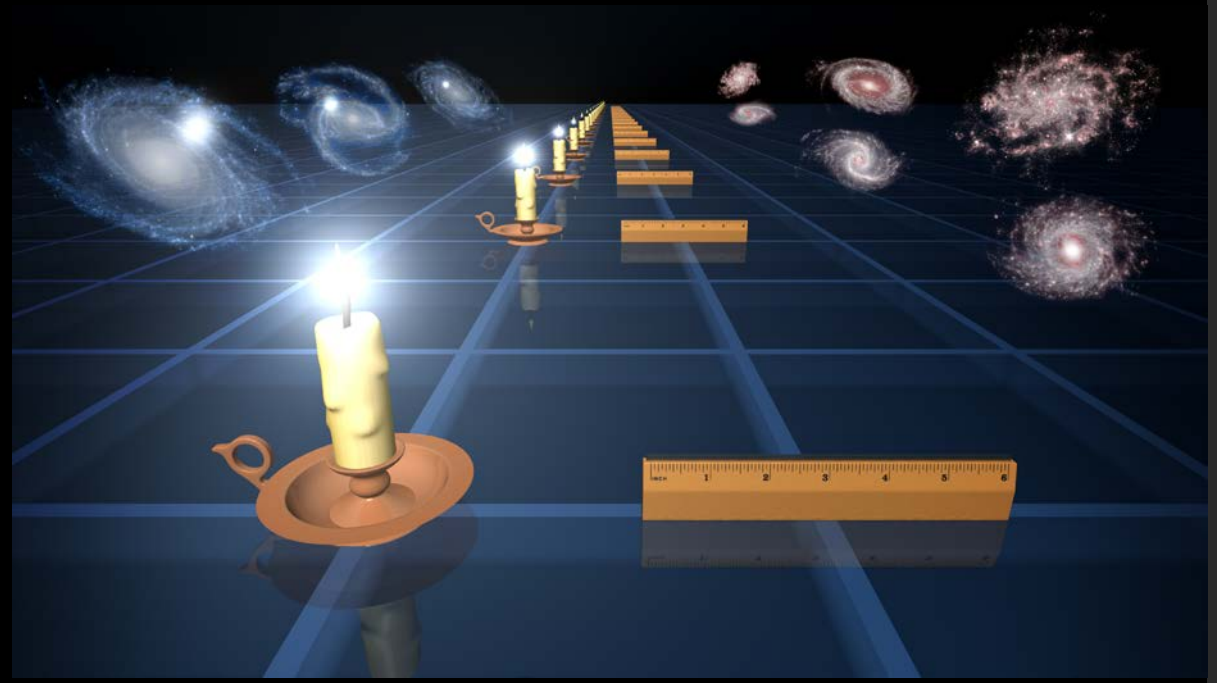
The Expanding Universe

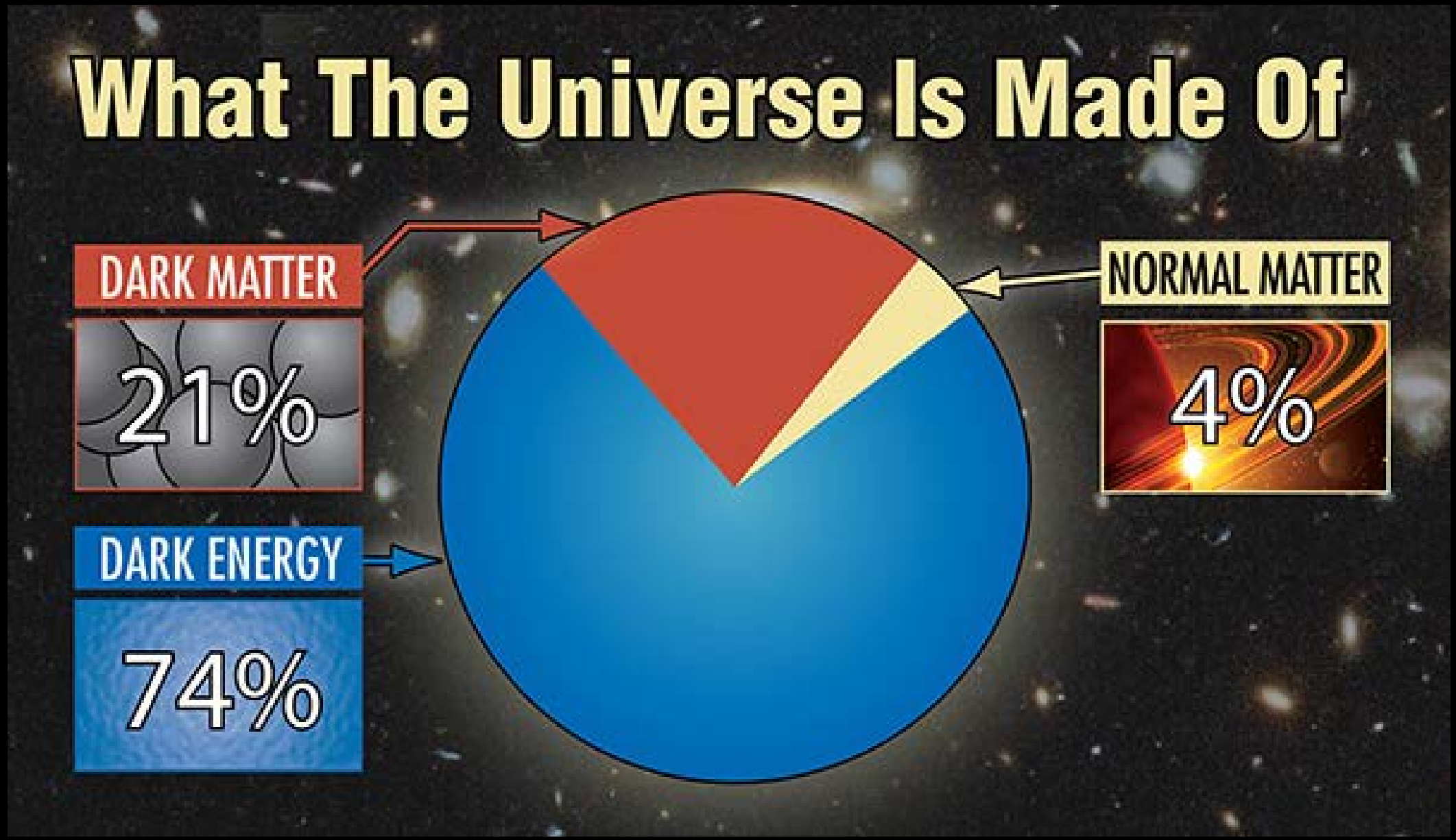


- Hubble saw that the universe was expanding by looking at the motion of galaxies
- Provided solution to Olbers's paradox
- The expansion is accelerating!

Accelerating Expansion

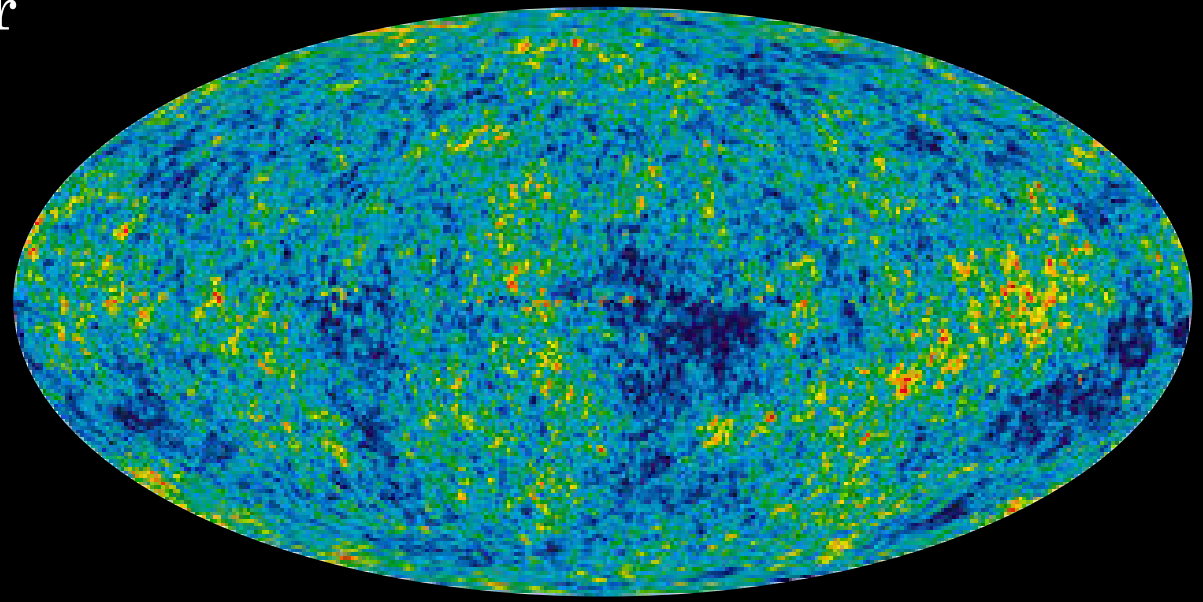
- Use supernova as standard candles
  - Allows us to measure distance to distant galaxies
- The expansion of the universe causes this light to be redshifted
- Also use baryonic acoustic oscillations




What The Universe Is Made Of
DARK MATTER
21%
DARK ENERGY
74%
NORMAL MATTER
4%

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?