Repulsive Gravity—22 Apr

• “Though a good deal is too strange to be believed, nothing is too strange to have happened.” Thomas Hardy
• “Nothing is too wonderful to be true.” Michael Faraday
• Data on supernovae: distant supernova are faint, even for a universe with no mass.
• Dark energy/cosmological constant

Weighing the Universe: Time the motion

• Astronomical weighing
  • Define a motion
  • Time the motion
  • If a supernova is faint, the expansion took longer, and the universe has less mass.

For SN2002ki, the motion is the expansion of the universe by a factor of 2.1
• Timing the motion
  • Supernova (specifically Type Ia) is a standard candle. All have the same luminosity.
  • If SN is faint, then it is far away
  • If distance is far, time is great. (Light travels at the speed of light.)

Observations

• Redshift z, scale R, and wavelength are related
  • R is distance between two galaxies when light was emitted compared with distance now.
  • $R = \frac{1}{1+z}$
  • $R = \frac{\lambda_{\text{emit}}}{\lambda_{\text{now}}}$. 

1. On upper plot, nearest SN is at
   a. upper right.
   b. upper left.
   c. lower right
   d. lower left.
2. For the most distant SN, the wavelength of light has ___ since the SN emitted it.
   a. doubled.
   b. halved.
   c. increased by 1%
   d. decreased by 1%
3. If the universe had more mass, the distant SN would move
   a. up in the plot
   b. down in the plot
Interpreting

- Lower plot compares data to a model with density parameter $\Omega = 0.2$.
- $\Omega = \frac{PE}{KE}$

4. The universe will expand forever if $\Omega = 0.2$. a) T; b) F.
5. The data show U has less mass than $\Omega = 0.2$. a) T; b) F.

- If a supernova is faint, the expansion took longer, and the universe has less mass.

Huh?

- Distant SN are 15% fainter than model with $\Omega = 0!$ No mass at all!
- If a supernova is faint, the expansion took longer, and the universe has less mass.
- If motion takes longer than model with no mass, need “negative gravity” or “repulsive gravity.”

Einstein’s General Relativity

- What causes gravity?
- Newton’s answer: mass.
  - Force of gravity on a little mass $m$ 
    \[ F = G \frac{M m}{R^2}. \]
- Einstein’s answer: mass and pressure
  - Force of gravity on a little mass $m$ 
    \[ F = G (M + 3P/c^2) \frac{m}{R^2}. \]

- Distant SN are 20% fainter than model with $\Omega = 0.2$.
- Distant SN are 15% fainter than model with $\Omega = 0!$ No mass at all!
Cosmological Constant

• Einstein’s answer: mass and pressure
  \[ F = G \left( M + \frac{3P}{c^2} \right) \frac{m}{R^2}. \]
• Ordinary matter is little pressure b/c speed is not near c.
• Radiation has positive pressure
  • Pressure is 1/3 mass.
    \[ F = G \frac{2M}{R^2}. \]
• Einstein in 1920s: My equations of gravity admit “cosmological constant” where pressure is negative and equal to mass
  \[ F = G \left( M - 3M \right) \frac{m}{R^2}. \]
  \[ F = - G \frac{2M}{R^2}. \]
• Repulsive gravity