The Hubble Law and Quasars

Dorrit Hoffleit 1907-2007
Clicker question: you measure the wavelength of an emission line of neutral hydrogen in a galaxy to be 24 cm. The lab wavelength is 21 cm. Which of the following statements are true?

- The line is blue-shifted and the galaxy is moving toward us
- The line is blue-shifted and the galaxy is moving away from us
- The line is red-shifted and the galaxy is moving toward us
- The line is red-shifted and the galaxy is moving away from us
Hubble’s Law (1929)

- Measure radial velocity \( v \) from Doppler shift.
- Hubble’s Law:
  \[ v = H_0 \cdot d \]
- Proportionality constant \( H_0 \) is called “Hubble constant”

[See Fig 15.15]

1929

1931

today

0 1600

millions of LY
Are we particularly unpopular?

Raisin Bread Model of Expanding Universe

- Raisin-bread model shows \( V = H \) D
- Why do raisins move? Bread pushes them.

5. Why are galaxies moving?
   a. Space pushes galaxies.
   b. Big Bang set proto-galaxies in motion. Gravity slows (or accelerates) motion.

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>( d_{\text{start}} )</th>
<th>( d_{\text{end}} )</th>
<th>( d_{\text{end}} - d_{\text{start}} )</th>
<th>velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3 cm</td>
<td>6 cm</td>
<td>3 cm</td>
<td>30 cm/hr</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>14</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>32</td>
<td>16</td>
<td>46</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>40</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Looks same from any raisin
Hubble’s Law: \[ \text{velocity} = H_0 \times \text{distance} \]

Clicker question

\[ v = H \, d \]

Galaxy X is 10 million light years away. Galaxy Y is 20 million light years away. According to the Hubble Law, Galaxy Y will be

A. Moving away from us twice as fast as Galaxy X
B. Moving away from us half as fast as Galaxy X
C. Moving away from us with the same speed as Galaxy X
Distances of farthest galaxies measured from redshifts

\[ D = \frac{v}{H} \]

Discovery of quasars

Quasi-stellar object
Quasars: Quasi-Stellar Radio Sources [26]

- But most are not radio sources
- Quasi-Stellar Objects (QSOs)

Radio image

Optical image

[Fig 26.3]

The Mystery Deepens

- Quasars had weird spectra
What were they?

- One idea was that they were some kind of weird star within the Milky Way Galaxy.

Maarten Schmidt realizes quasars have big redshifts

According to the Hubble Law, the quasars would be very far away:

\[ D = \frac{v}{H} \]
Large redshifts

- Measure Doppler shift from emission or absorption lines:

\[ z = \frac{\Delta \lambda}{\lambda} = \frac{v}{c} \]

Orion nebula \( z = 0 \)

Quasar 3C 273

Largest known QSO redshift:

\[ z = 6 \]

Redshift \( z = \frac{\Delta \lambda}{\lambda} = \frac{v}{c} \) \( \Rightarrow v = 6 \, c \)

Special relativity:

\[ z = \frac{\Delta \lambda}{\lambda} = \sqrt{\frac{1 + v_{radial}/c}{1 - v_{radial}/c}} - 1 \] \( \Rightarrow v = 0.96 \, c \)

\( \Rightarrow \) Distance = 13 billion light years.
Light travel time = 13 billion years.
If quasars are far away, the must be very luminous

• What could provide so much luminosity, arising from such a small space?

Quasars & Active Galaxies

• Large redshift ➔ large distance

\[
F = \frac{L}{4\pi d^2}
\]

\[
4\pi d^2 F = L
\]

• Measured flux + distance ➔ huge luminosity
  • Up to 1000 x luminosity of an entire galaxy of stars.

• Rapid flux variability ➔ small volume.

Some luminous quasars vary in few days ➔ same size as solar system.
Quasars: events in centers of galaxies

- Hubble Space Telescope images.
  - bright star-like objects at centers of faint galaxies.

Black Holes in binary star systems

- Could black holes be the ultimate energy source in quasars? But black holes much more massive than those in binary stars?
Energy Source:
- Gas, stars fall into $10^8$ M$_\odot$ black hole.
- Gravitational potential energy $\rightarrow$ thermal energy $\rightarrow$ light

Most Quasars Lived and Died Long Ago

Rate at which stars are formed in galaxies.

Number of Quasars per unit volume

Conclusion:
Quasars are events in young galaxies.

Now = 14 billion yrs

Formation of universe

Strobel's QSO in spiral galaxy

Fig 26.17

Fig 26.18

Fig 26.19
Why don’t we see so many quasars today?

Did the black holes vanish?
   Probably not, we don’t know how we could make a supermassive black hole vanish

Did stuff stop falling into the black holes so much?
   This may be more plausible
The Leftovers: The Active Galaxy M87

Red = old stars
Blue = non-thermal

[see 26.2]

Gas Disk in Nucleus of Active Galaxy M87

The Radio Galaxy Cygnus A
These Radio Galaxies are E galaxies.

Also… Seyfert Galaxies = spirals with very low-luminosity QSO at center.