Hubble’s Law

- Hubble’s Law: More distant galaxies are moving away faster. Speed = $H \times$ Distance
- Universe is expanding
- Universe started with a Big Bang
- How Hubble discovered Hubble’s Law

Hoag’s Galaxy
$D=900\text{ MLY}$
$v=18,000\text{ km/s}$

Coma Cluster
$D=300\text{ MLY}$
$v=6000\text{ km/s}$

Reorder topics
- Hubble’s Law, expansion of the universe
- Quasars & active galaxies

Astronomical Horizons Public Talks
- First Light for the Spartan Infrared Camera
  - Ed Loh
  - Abrams Planetarium
  - Thursday at 7:30pm
OBAFKGM winners

- **Ouch! Billy, a fat goat kicked me!** — Marissa Burns
- **Odd blue armadillos fight green killer mice.** — Brian Nekic
- **Only babies are fun giggling kissing machines.** — Garrison Warr
- **Obama blasted AIG for getting kooky with money.** — Hayley Lynch
- **Oh bummer! A fire grounded Kevin’s mission.** — Lisa Hagen
- **Our basketball and football guys kill Michigan.** — Brandon Bailey
- **Only bored astronomers find gratification knowing mnemonics.** — Sarah Harris
- **One bright astronomer finally grasped kinetic motion.** — Megan Fleming
- **Obama beat a fatigued gentleman known-as McCain.** — Andrea Goossens
- **Other Bigten athletes fear gigantic killer Michganstaters.** — Madeline Morrison
- **One black afternoon Freddie got killed mysteriously.** — Jessica Prentice
- **Only boys accepting Feminism get kissed meaningfully.** — Morgan Martens
- **Olivia Brown astonished funny Germans knowing microeconomics.** — Brent Wilson
- **Officially, Bill always felt guilty kissing Monica.** — Rachael McKenney
NGC4881, central galaxy in Coma Cluster

Milky Way Galaxy

2MASS Covers the Sky
Hubble’s Law

- Velocity $V$ is proportional to distance $D$
  - $V = H \times D$
- Demo: Let Coma & Hoag’s Galaxy move according to Hubble’s Law

1. If Coma moves one meter, how much should Hoag move?
   a. 1 m
   b. 3 m
   c. 1/3 m
   d. 9 m
   e. 1/9 m

<table>
<thead>
<tr>
<th>Dist</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milky Way</td>
<td>0 km/s</td>
</tr>
<tr>
<td>Coma</td>
<td>6,000 km/s</td>
</tr>
<tr>
<td>Hoag’s Object</td>
<td>18,000 km/s</td>
</tr>
</tbody>
</table>

2. Hoag is 3 times as far as Coma. Is this still true in the future? Was this true in the past?
   a. YY
   b. YN
   c. NY
   d. NN

<table>
<thead>
<tr>
<th>Dist</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milky Way</td>
<td>0 km/s</td>
</tr>
<tr>
<td>Coma</td>
<td>6,000 km/s</td>
</tr>
<tr>
<td>Hoag’s Object</td>
<td>18,000 km/s</td>
</tr>
</tbody>
</table>
Hubble’s Law

- V = H × D

2. The proto Milky Way and the proto Coma were very close together at one time. Was the proto Hoag’s Object close the proto Milky Way at the same time or a different time?
   A. Same
   B. Different

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milky Way</td>
<td>0 km/s</td>
<td>0 MLy</td>
</tr>
<tr>
<td>Coma</td>
<td>6,000 km/s</td>
<td>300MLy</td>
</tr>
<tr>
<td>Hoag’s Object</td>
<td>18,000 km/s</td>
<td>900MLy</td>
</tr>
</tbody>
</table>

Hubble’s Law

- V = H × D

- Hoag is 3 times as far as Coma. Is this still true in the future? Was this true in the past? YY.
- H’s Law => Universe began in a Big Bang
  - Universe was very dense
  - What became Milky Way was very close to what became Coma & Hoag’s Galaxy.
  - Current physics can explain universe 10^{-10}s after Big Bang, when proto-Coma was 1 mm from proto-us.
Hubble’s Law

• \( V = H \times D \)

3. If we are in Coma, would H’s Law still apply? (All guesses count as correct.)
   a. Y
   b. N

• Do the demo.

3. If we are in Coma, would H’s Law still apply?
   a. Y
   b. N


<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milky Way</td>
<td>0 km/s</td>
<td>0 MLY</td>
</tr>
<tr>
<td>Coma</td>
<td>6,000 km/s</td>
<td>300 MLY</td>
</tr>
<tr>
<td>Hoag's Object</td>
<td>18,000 km/s</td>
<td>900 MLY</td>
</tr>
</tbody>
</table>
The universe expands

- The universe expands.
- The distance between the Milky Way and Coma increases, because they remember the motion set in place by the Big Bang.

1. Does a piece of wood expand? Does the distance between the Earth & Sun expand?
   A. YY.
   B. YN.
   C. NY.
   D. NN.

<table>
<thead>
<tr>
<th>object</th>
<th>speed</th>
<th>distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milky Way</td>
<td>0 km/s</td>
<td>0 MLy</td>
</tr>
<tr>
<td>Coma</td>
<td>6,000 km/s</td>
<td>300MLy</td>
</tr>
<tr>
<td>Hoag’s Object</td>
<td>18,000 km/s</td>
<td>900MLy</td>
</tr>
</tbody>
</table>

Raisin Bread Model of Expanding Universe

- Raisin-bread model shows $V=H \cdot D$
- 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>$d_{start}$</th>
<th>$d_{mid}$</th>
<th>$d_{end}$</th>
<th>$d_{end} - d_{start}$</th>
<th>velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3 cm</td>
<td>6 cm</td>
<td>3 cm</td>
<td>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>
<td>46 cm/hr</td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>32</td>
<td>16</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>40</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Looks same from any raisin