# Introductory Astronomy

## Week 7: Galaxies

## Clip 12: Hubble Red Shift



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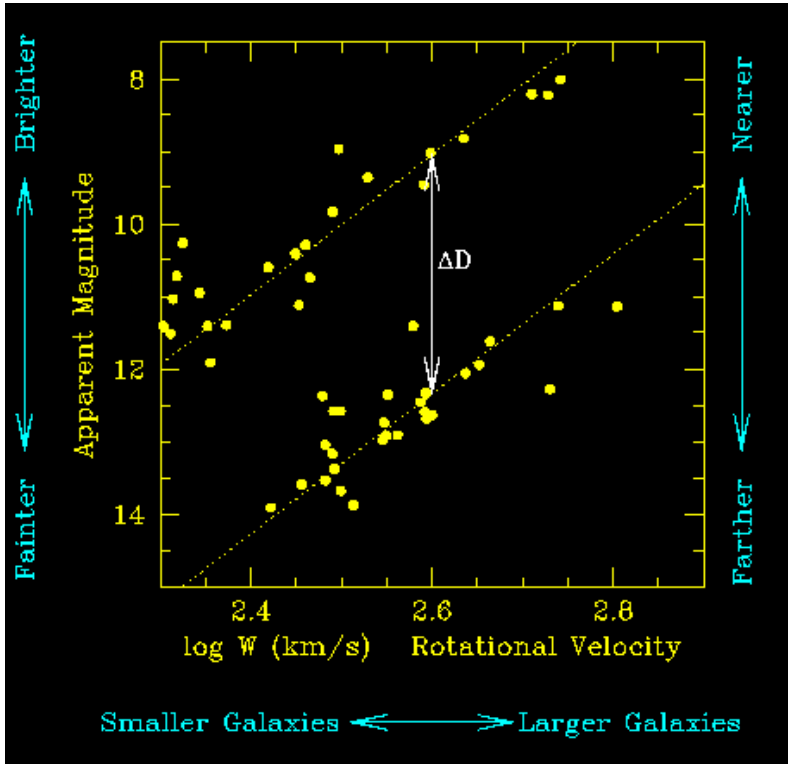
# Distance Measures

- Distances to nearby galaxies measured with Cepheids to $10^7$ pc
- Tully-Fisher relation for spirals relates rotation to luminosity and type
- Fundamental Plane for ellipticals relates luminosity to size and velocity dispersion
- Allows galaxies to be used as standard candles for distance measurement



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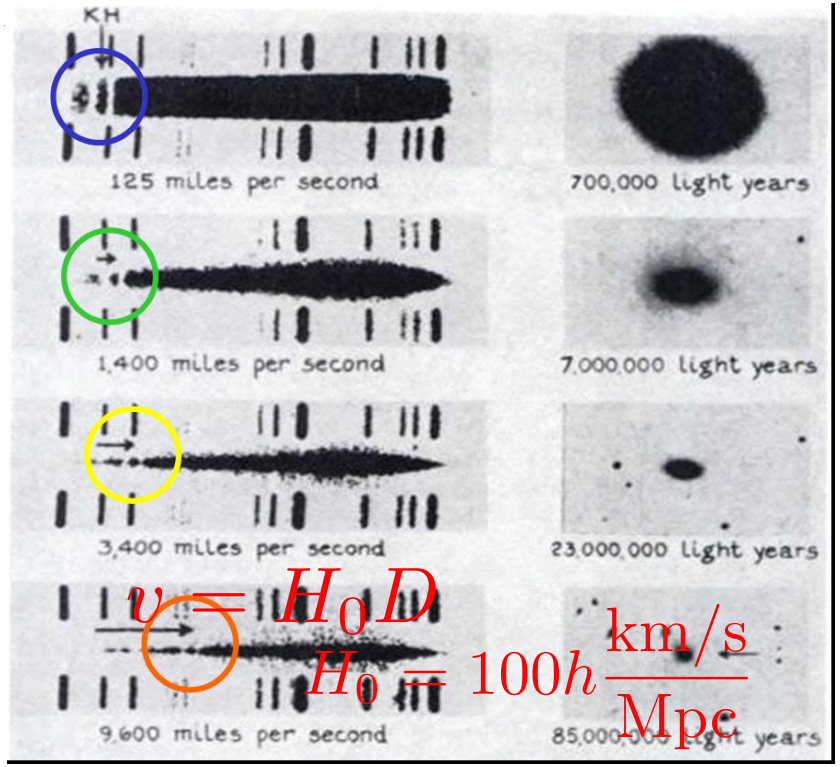
# What Hubble Found

- Spectra of galaxies show Doppler shift reflecting radial motion relative to Sun
- Distant galaxies show redshift increasing with distance

$$\frac{\lambda}{\lambda_0} = \sqrt{\frac{1+v/c}{1-v/c}} \sim 1 + v/c$$




$$v = H_0 D$$
$$H_0 = 100h \frac{\mathrm{km/s}}{\mathrm{Mpc}}$$



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# Hubble Constant

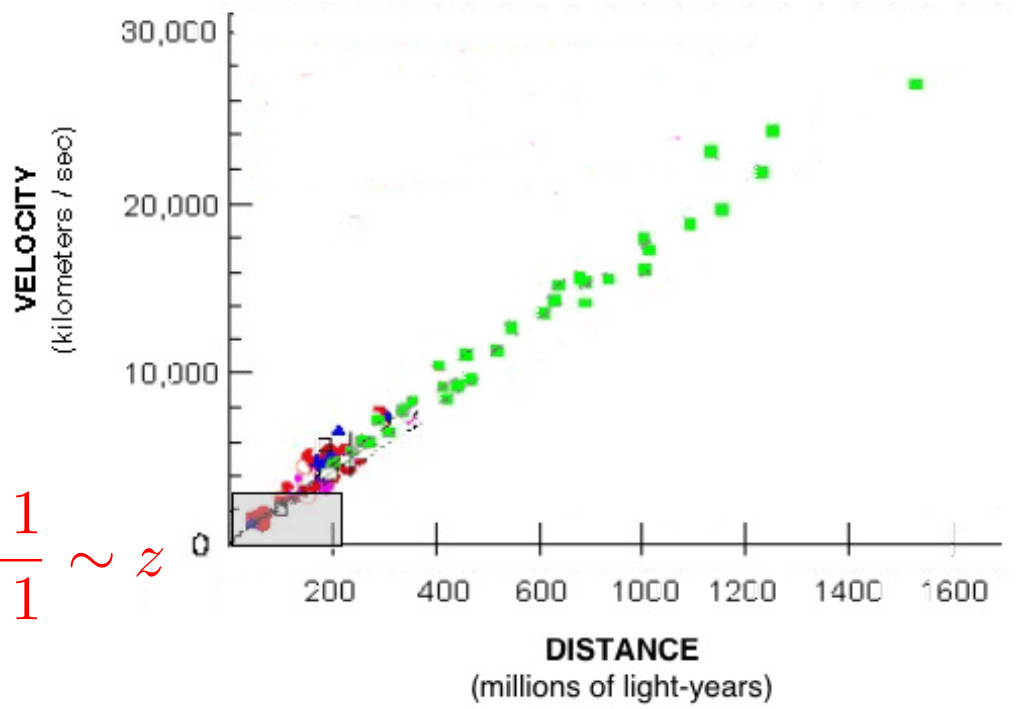
- Best measurements

$$h = 0.71 \pm 0.03$$

- Use redshift $z$ as surrogate for distance

$$\lambda = (1+z)\lambda_0$$

$$v/c = H_0 D/c = \frac{(1+z)^2 - 1}{(1+z)^2 + 1} \sim z$$



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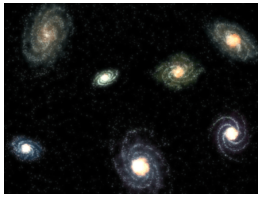
# Cosmic Expansion

- Isotropic recession means we are in center?
- Expanding Universe: All distances grow
- Every observer finds all others recede

$$D(t) = D(t_0)\,(1 + H_0(t - t_0))$$

- Hubble Flow superposed on peculiar motion
- Valid for unbound objects





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# Big Bang

- $D(t) = D(t_0)\,(1 + H_0(t - t_0))$ means $D(t) = 0$ for

$t = t_0 - H_0^{-1}$

$$
\begin{aligned}
H_0^{-1} &= 0.01h^{-1}\,\frac{1\,\mathrm{Mpc}}{\mathrm{km/s}} \\
&= 0.01h^{-1} \cdot 206265 \cdot 1.49598 \times 10^{17}\,\mathrm{s} \\
&= 3.1h^{-1} \times 10^{17}\,\mathrm{s} = 9.8h^{-1}\,\mathrm{Gy} = 13.8\,\mathrm{Gy}
\end{aligned}
$$



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# Space and Time

- Redshift $z$ determines distance $D = zc/H_0$
- Also determines lookback time

$$t_{em} = t_0 - D/c = t_0 - zH_0^{-1}$$

- Note $\frac{\lambda_{em}}{\lambda_{abs}} = (1+z)^{-1} \sim 1 - z = 1 + H_0(t_{em} - t_0) = \frac{D(t_{em})}{D(t_0)}$
- Redshift can be thought of as cosmological

# Credits

- Hubble Expansion Data: E. Hubble, PNAS March 15, 1929 vol. 15 no. 3 168-173 http://www.pnas.org/content/15/3/168.full.pdf+html NASA/GSFC http://cosmictimes.gsfc.nasa.gov/teachers/guide/1929/guide/universe_expanding.html
- Expansion Animation: NASA/SNAP http://snap.lbl.gov/multimedia/animations/