

Astronomy 350L (Spring 2005)



# The History and Philosophy of Astronomy

(Lecture 24: Hubble II)

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#### Edwin P. Hubble: Mariner of the Nebulae



- 1889 (Missouri) 1953 (Pasadena)
- leading observational astronomer of 20<sup>th</sup> century:
   discovers galaxies (1924):
  - à Milky Way but one of innumerable "island universe"
  - expansion of the universe (1929):
    à Hubble's Law:
    v = H<sub>0</sub> x d

# Mount Wilson Observatory



• 1919 onwards: world's largest telescope

## Mount Wilson Observatory



#### George Hale (1868-1938)



**100-inch Hooker Telescope** 

# Classification of Nebulae (=galaxies)



#### • 1923: Tuning-fork diagram

#### **Big Q: How do the Spiral Nebulae Move?**



 figure out radial velocities by taking spectra, and measure the shift of spectral lines à Doppler effect!

#### The Doppler Effect (1842)

blueshift



#### **Christian Doppler (1803-53)**

#### **The Doppler Effect for Spectral Lines**



 By measuring the shift in wavelength of spectral lines, one can figure out radial velocity of source with high precision!

#### The Flight of the Spiral Nebulae (1912)



Vesto M. Slipher (1875-1969)



- Important discovery: most spiral nebulae display redshifts in their spectra!
- From Doppler effect: Do spiral nebulae move away from us???

• 1917: Einstein constructs model of the universe that is eternal and static



 balance between attractive gravity and repulsive cosmological constant ("anti-gravity")

#### • finite but without boundary (spatially closed)

 1917: de Sitter constructs a model of the universe that contains no matter, but predicts motion!



Willem de Sitter (1872-1934) • an empty universe!

 1917: de Sitter constructs a model of the universe that contains no matter, but predicts motion!



particles are "scattered away" from origin ("de Sitter effect")
 -- the larger the distance, the larger the apparent speed!

#### Hubble and the Distance to Andromeda (M31)

#### • October 1923: He obtains photograph of M31



#### **Brightness vs time**



• Hubble discovers a Cepheid variable in Andromeda!

#### What are the Cepheids?

#### A: Pulsating stars (periods of ~ few days)



*Cepheid* variables: outward pressure (P) and inward gravity compression are out of sync, so star changes size and temperature: it **pulsates**. *RR-Lyrae* variables are smaller and have pulsation periods of less than 24 hours. Also, their light curve looks different from the Cepheid light curve.

#### **Cepheids as Standard Candles**

#### Standard Candle

As a car approaches on a highway, its lights appear to get brighter. However, the amount of light or energy produced by the lights is constant. The apparent brightness of the headlights is a function of how far away the car is. The closer the car, the brighter the headlights. Astronomical objects that produce specific amounts of energy can be used to determine the distance to that object if the apparent brightness is measured. These objects are known as Standard Candles.

#### **Cepheids as Standard Candles**





#### 2) Calculate luminosity



#### 3) Calculate distance

The inverse square law



inverse-square law:
 flux=luminosity/distance<sup>2</sup>

measure

#### Hubble teams up with Humason

#### • Hubble and Humason become partners in nebular reserach





Milton L. Humason (1891-1972)

#### **Discovery of the Hubble Law (1929)**



 Great Discovery: Redshift is proportional to distance ("Hubble Law")

#### **Discovery of the Hubble Law**



• greatly improve accuracy by reaching larger distances!

#### Meaning of the Hubble Law

- recession speed = (Hubble) constant x distance
- $v = H_0 \times d$
- (H<sub>0</sub>=500 km s<sup>-1</sup> Mpc<sup>-1</sup>)



 Hubble initially did not interpret his law as implying an expanding universe! (He only referred to "de Sitter effect")

# • 1922: an expanding universe (GR without cosmological constant)



Alexander Friedmann (1888-1925)



• 1927: Lemaitre independently (re-) discovers the expanding-universe solutions of GR





Georges Lemaitre (1894-1966)

### The Expanding Universe (early 1930s)

• Lemaitre interprets Hubble's Law as indicating that space itself expands!



• redshifts due to stretching of expanding space!

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#### The Age of the Expanding Universe

• Estimate expansion age of the universe:



# History of H<sub>0</sub>



# Hubble Wars



in last decade – see later

# Big Q: What happened in the past, when all the galaxies where close together???



#### • an initial "Big Bang"???

#### Hubble (part 2)

## • Discovery of Recession of Spiral Nebulae (1929-31)

- already known: most spirals show redshifts in their spectra
- Hubble and Humason use Cepheids and other standar candles to determine distances to spiral nebulae
- "Hubble's Law": v = H<sub>o</sub> x d
- Initial estimate of "Hubble's constant": H<sub>0</sub> = 500 km s<sup>-1</sup> Mpc<sup>-1</sup>

#### Interpretation of Hubble's Law (1930s)

- Lemaitre (rediscovering Friedmann's work) proposes solutions to Einstein's General Relativity for an expanding universe!
- Naturally explains "Hubble's Law" ( $v = H_0 x d$ ) with expansion of space itself!