### The Great Debate: *The Size of the Universe* (1920)

<table>
<thead>
<tr>
<th>Heber Curtis</th>
<th>Harlow Shapley</th>
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</table>
| • Our Galaxy is rather small, with Sun near the center.  
  • 30,000 LY diameter.  
  • Kapteyn’s result.  
  • Universe composed of many separate galaxies  
    • Spiral nebulae = “island universes” | • Our Galaxy is very large, with Sun far from center.  
  • 300,000 LY diameter.  
  • Sun 60,000 LY from center.  
  • Based on distribution of globular clusters,  
    • Pulsating variables.  
  • Spiral Nebulae are inside our galaxy.  
    • “nova” magnitudes  
    • “Proper motion” ➔ rapid rotation. |

The Judges?
Astronomy in 1926

- ~1770: Messier catalogue
- 1888: NGC, IC catalogues
- Van Maanen’s “contribution”
- 1920: Curtis-Shapley debate
- 1923: Hubble measured distance to M31

- 1929 Expanding Universe
- 1936: *Realm of the Nebulae* described Hubble classification system.

100 inch telescope
Completed 1918

Edwin Hubble

The Types of Galaxies

- Ellipticals
- Barred Spirals
- Spirals
- Also… Irregulars
Usual classes used at current time:

- E0-E7
- S0, Sa, Sab, Sb, Sbc, Sc, Scd, Sd, Sdm, Sm, Im, Ir (or amorphous)
- SB0, SBa, SBab, SBb, SBbc, SBc, SBcd, SBd, SBdm, SBm

General Properties of Galaxy Types

- **E**
  - $M_B = -8$ to less than $-23$
  - Mass = $10^7 - 10^{13}$ $M_\odot$
  - Diameters <1 kpc – hundreds of kpc

- **S**
  - $M_B = -16$ to $-23$
  - Mass = $10^9 - 10^{12}$ $M_\odot$
  - Luminous diameters 5-100 kpc

- **Irr**
  - $M_B = -13$ to $-20$
  - Mass = $10^8 - 10^{10}$ $M_\odot$
  - Luminous diameters 1–10 kpc

- **Sa → Sc**
  - Bulge:disk ratio
  - Tightness of winding
  - Resolution of arms into star clusters & H II regions.

LMC (Irr I, SBm)  SMC (Irr I, Im)  M82 (Irr II, Ir)
Morphological Types of Local Galaxies

(images taken from Frei, Guhathakurta, Gunn & Tyson 1996)

Sun near center of small universe.
(Herschel, 1784 ➔ Kapteyn, early 1900’s)

Mapping our Galaxy up until ~1920

Counting Stars:

Lick 36" Refractor
1888
Pulsating Variable Stars
• These stars regularly expand & contract.
• Like a big spring.
• Change in size ➔
  • change in temperature
  • change in luminosity

The Instability Strip
• In populations of old stars.
• For example, Globular Clusters
• Occurs during He burning
Mapping Our Galaxy

Herschel (1784)

Kapteyn (1922). Surfaces of constant star density.

Shapley (1920)

RR-Lyraes in Globular Clusters

From star counts

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Dust [12.1]

- Tiny grains
  - ≤ 1µm
- Cores consisting of
  - Graphite
  - Silicates (Mg_{x}Fe_{1-x}SiO_{3}; Mg_{2x}Fe_{2-2x}SiO_{4}; etc)
- Ices can condense on surface: molecules of most common elements after hydrogen and helium
  - C, O combined with H
  - Depletion of C, O, Fe, Si
- Absorb and scatter light
  - Effect strongest in blue, less in red.
  - We cannot see very far through disk of galaxy except at infrared, and (better yet) radio wavelengths.
$R = 2.75$

$R = 3.52$

$R = 5.30$

~1/λ dependence in IR-optical.

Particle size ~ 0.01 – 0.1 μm

2175Å feature ⇒ graphite

$A_λ / A_V \propto e^{-\tau_λ}$

in magnitudes

$A_λ = -2.5 \log \left( \frac{I_λ}{I_{λo}} \right)$

$= -2.5 \log e^{-\tau_λ}$

$= 1.08 \tau_λ$

Determine $\tau_λ$ from change in color

$A_v = R_v \cdot E(\lambda - \nu)$

$E(\lambda - \nu) = (\lambda - \nu) - (\lambda - \nu)_o$

$R_v \sim 3$ but different in different places.