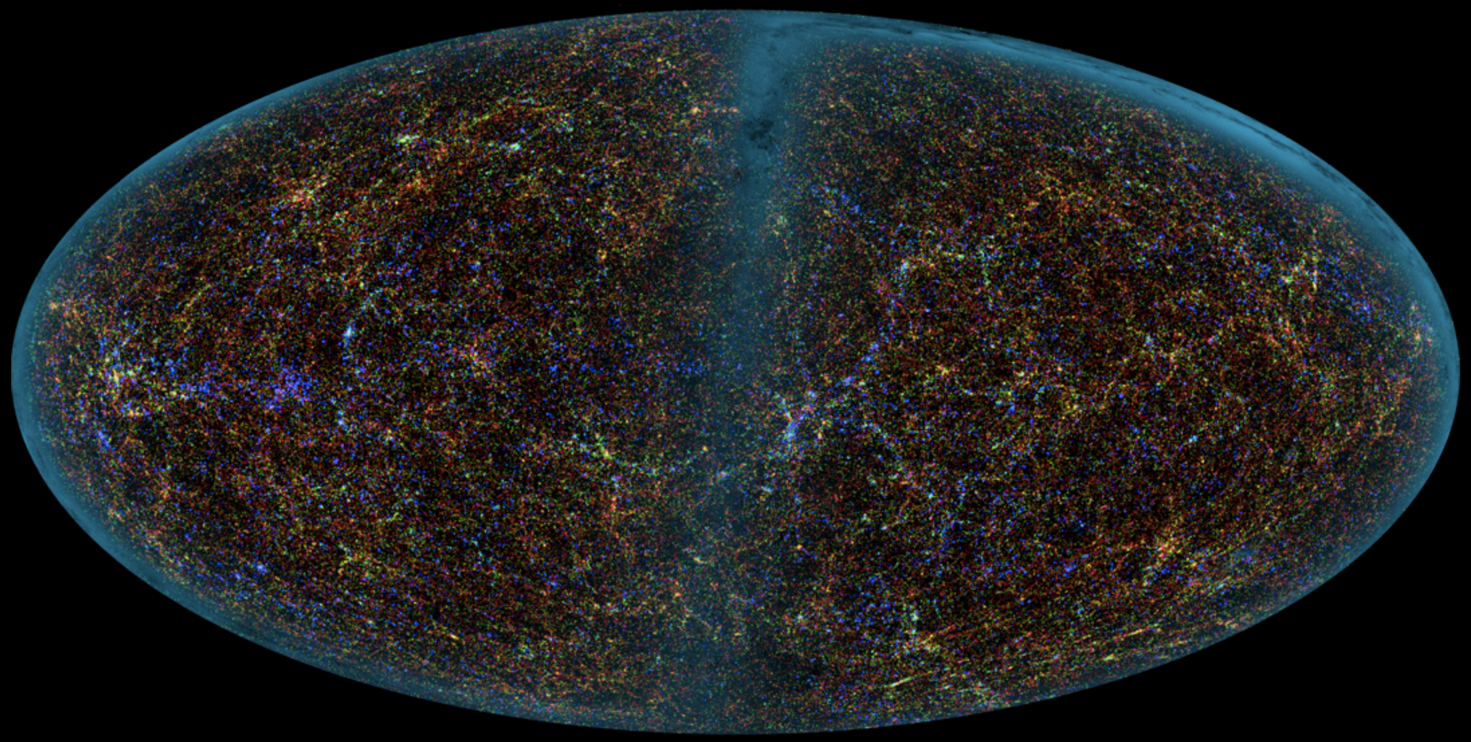
Cosmology

and Large Scale Structure



Fall 2024

ASTR 328/428
PHYS 328/428

Tuesdays / Thursdays
10:00AM - 11:15PM

Sears 552

Prof. Stacy McGaugh

27 August 2024

http://astroweb.case.edu/ssm/ASTR328/

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Cosmology and the Structure of the Universe

ASTR/PHYS 328/428

Fall 2024
TR 10:00-11:15PM
Sears 552

Prof. Stacy McGaugh
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368-1808

Office Hours
TBD

JWST early release image from CEERS

ASTR/PHYS 328/428

Fall 2024
TR 10:00-11:15PM
Sears 552

Textbook
Introduction to Cosmology
Second edition
Barbara Ryden
CWRU Bookstore | Amazon

Other texts and literature
This link lists more in-depth material including graduate level textbooks and important journal articles.

Note: the courses ASTR 328, ASTR 428, PHYS 328, and PHYS 428 meet concurrently and utilize the same textbook.

Course Links

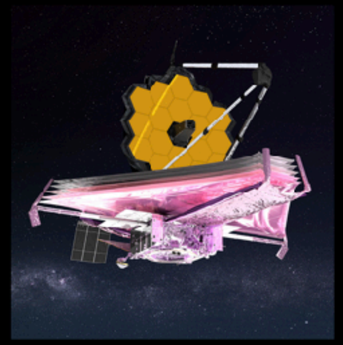
- **Calendar, including Due Dates, Lecture Notes, & Slides**
- Course Description | Outline | Learning Outcomes | Course Work and Grades | Debate Project
- Syllabus (the preceding links) in PDF format

Homework Assignments

- Problem Set 1

Course News

- News relevant to the course will appear here



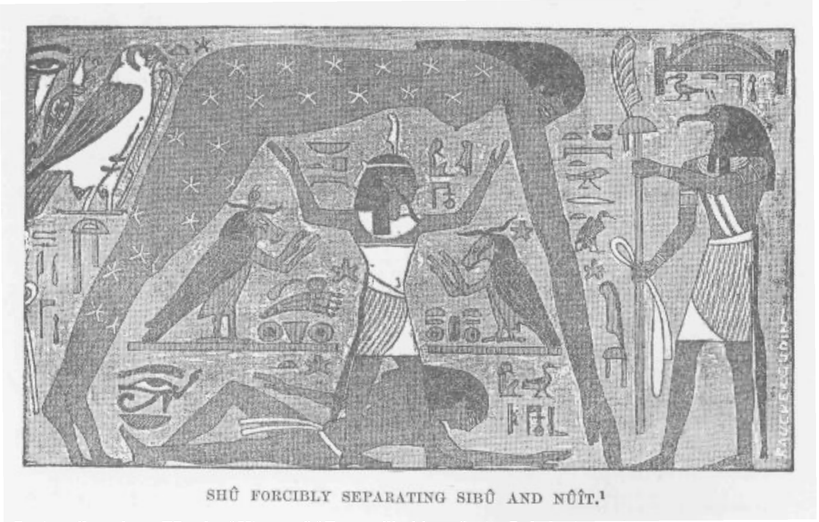
This web pages is the primary document for the course
(*not* the Canvas site)

http://astroweb.case.edu/ssm/ASTR328/

Nuit, the goddess of the night, was in a tight embrace with her husband *Sibû*, the earth god. Then one day, the god *Shû* grabed her and elevated her to [*become*] the sky despite the protests and painful squirming of Sibû. But Shû has no sympathy for him and freezes Sibû even as he is thrashing about. And so he remains to this day, his twisted pose generating the irregularities we see on the Earth's surface. Nuit is supported by her arms and legs which become the columns holding the sky.

Ancient Egyptian Creation Myth

Nuit - the sky



SHÛ FORCIBLY SEPARATING SIBÛ AND NÛÎT.[1]

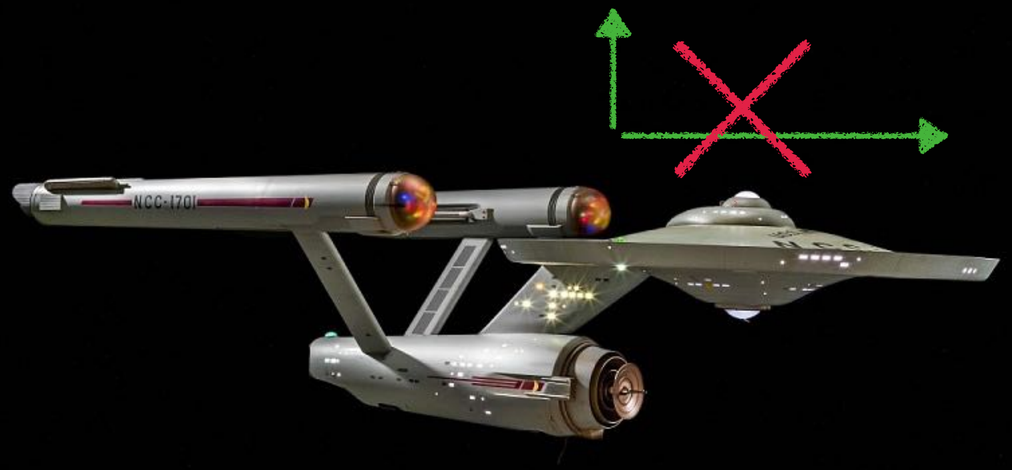
Project Gutenberg EBook of History Of Egypt, Chaldæa, Syria, Babylonia, and Assyria

Sibû - the earth

UP

DOWN

The ancient Egyptians conceived the sky as a roof placed over the world supported by columns placed at the four cardinal points. The Earth was a flat rectangle, longer from north to south, whose surface bulges slightly and having the Nile as its center. On the south there was a river in the sky supported by mountains and on this river the sun god made his daily trip (this river was wide enough to allow the sun to vary its path as it is seen to do). The stars were suspended from the heavens by strong cables, but no apparent explanation was given for their movements.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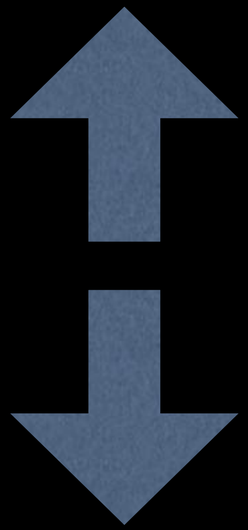
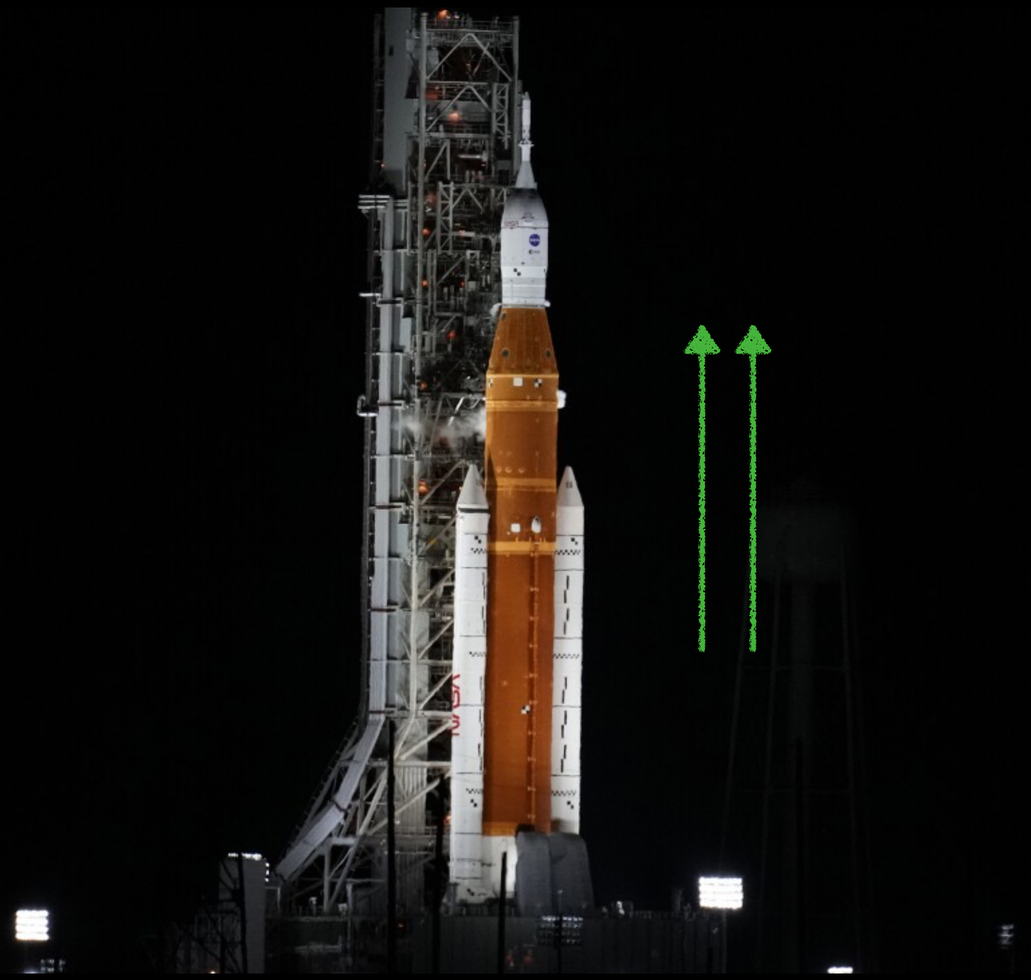
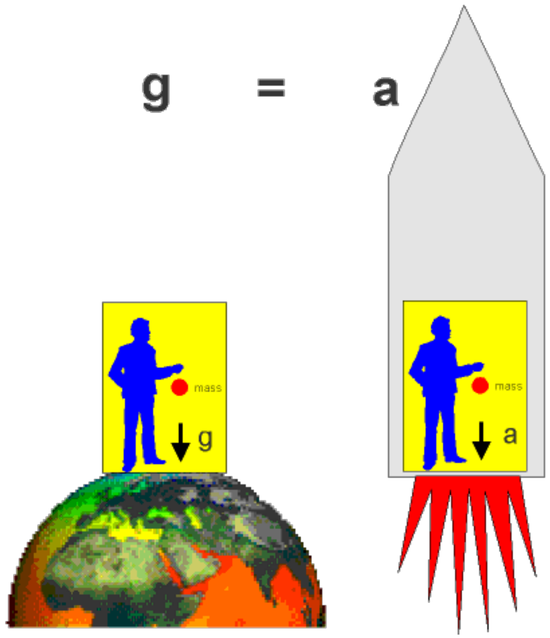




Equivalence Principle

Free fall is universal

You cannot distinguish between
- the 1 gee you feel here on Earth from
- being accelerated at 1 gee by a rocket.



Intertial mass

$$F = m_i a$$

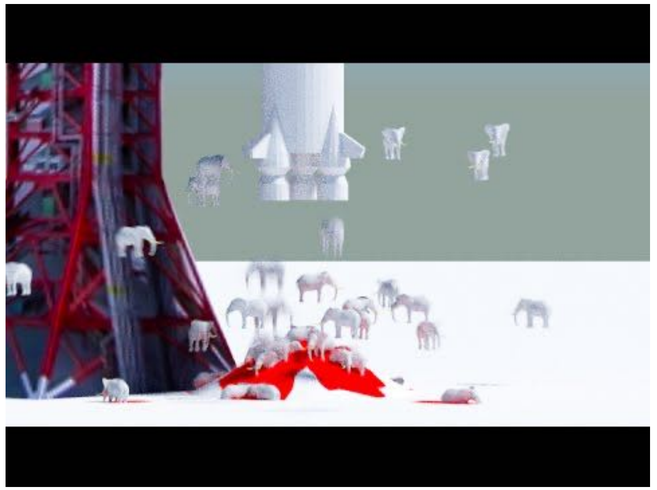
Gravitational charge

$$F = \frac{GMm_g}{d^2}$$

if

$$m_i = m_g$$

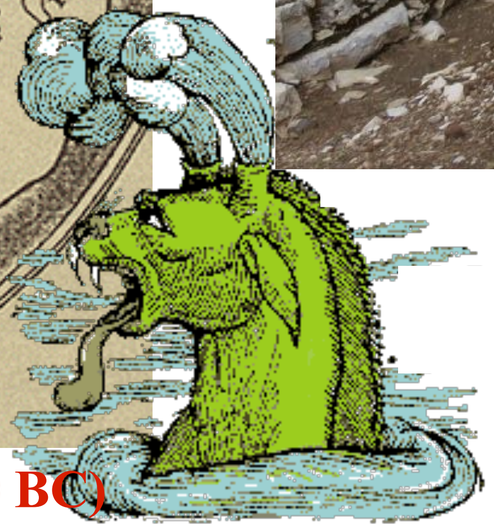
$$a = g = \frac{GM}{d^2}$$



A big rocket like the Saturn V (original Apollo program) or the new Artemis Space Launch System flings fuel out at a rate of about one elephant per second.

That's a lot of flaming hot elephants. You do not want to be anywhere nearby when a rocket this size lights up.

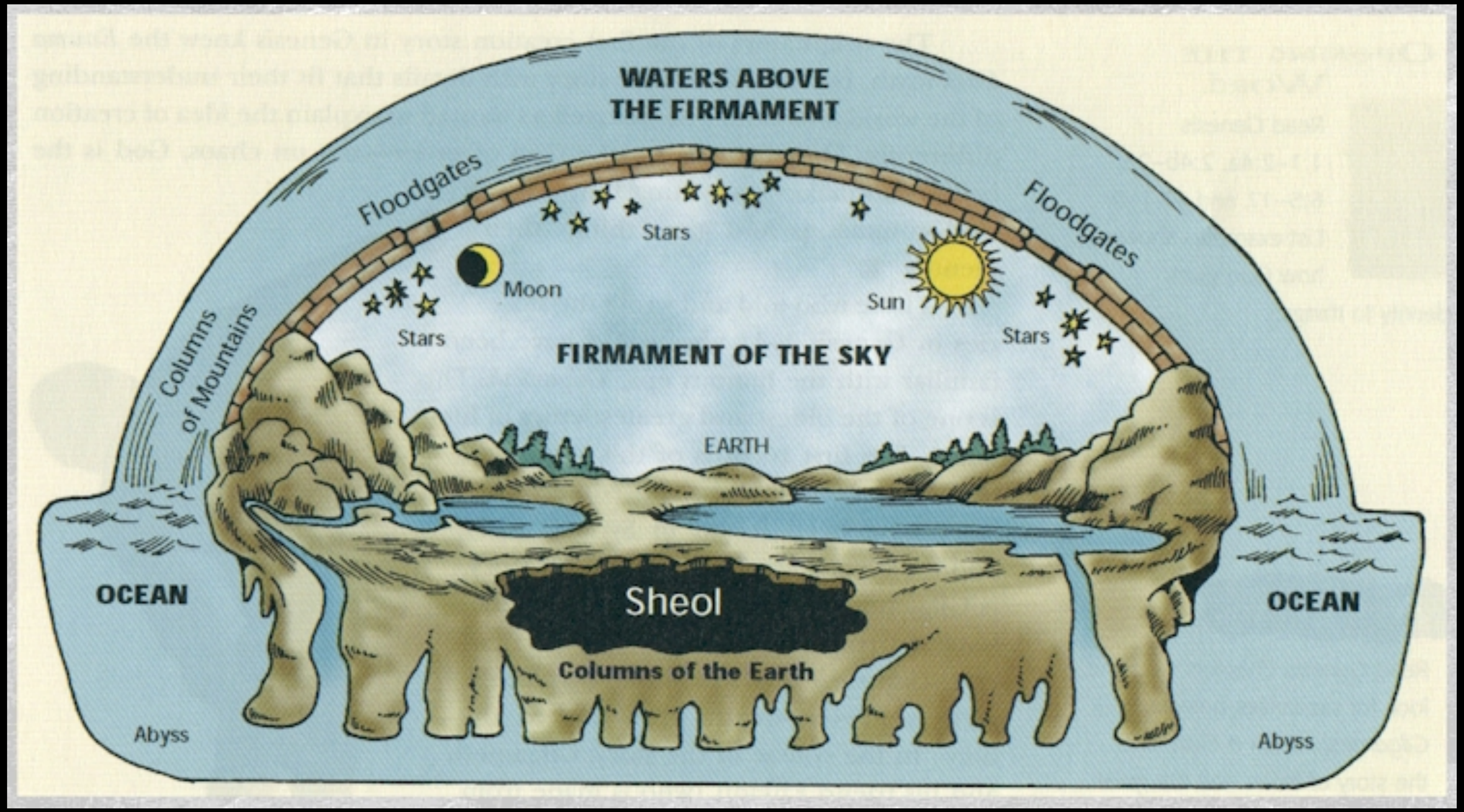
Ancient Cosmology: A Flat Earth



World Map of Hecataeus of Miletus (c. 500 BC)

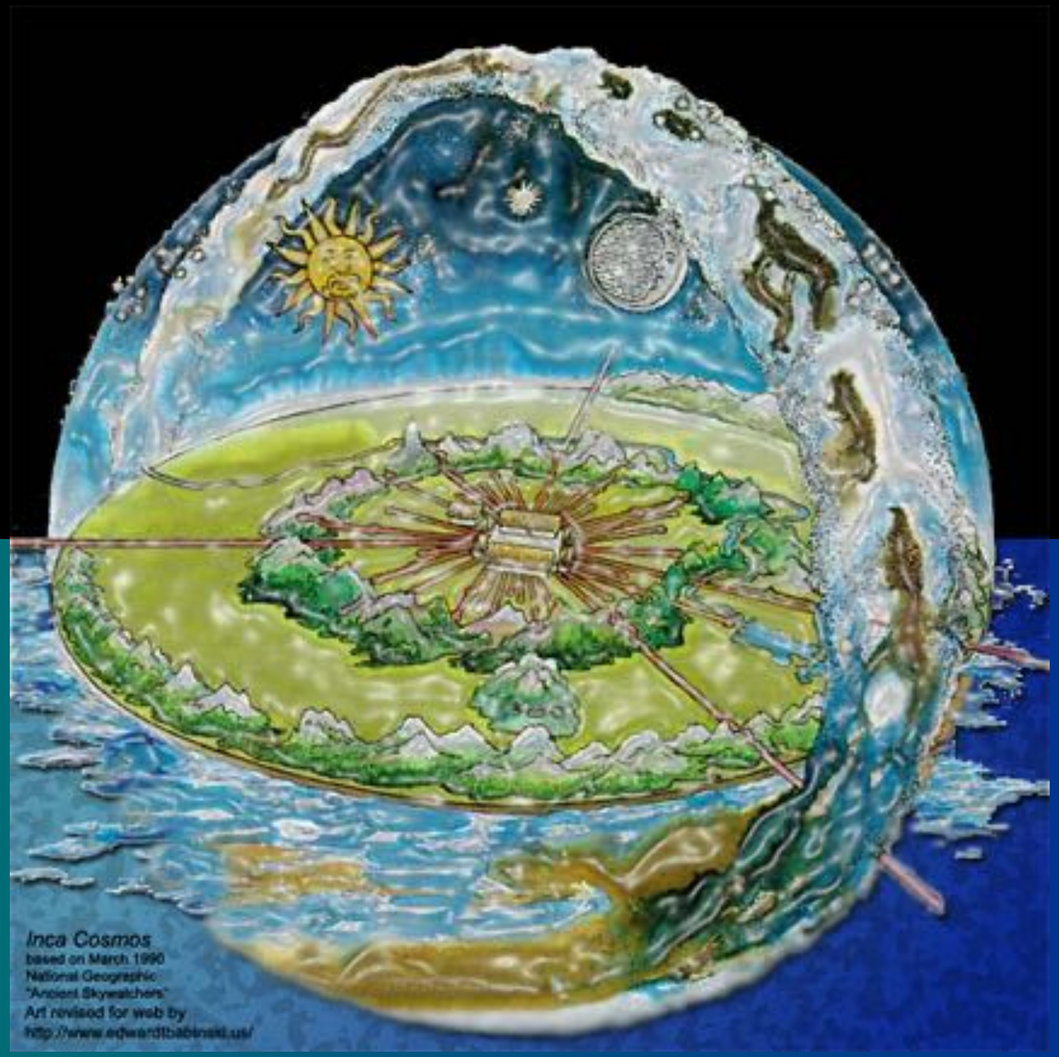
Roman Ephesus in Asia Minor

Throne of God



Ancient Hebrew Cosmology

Incan Cosmology



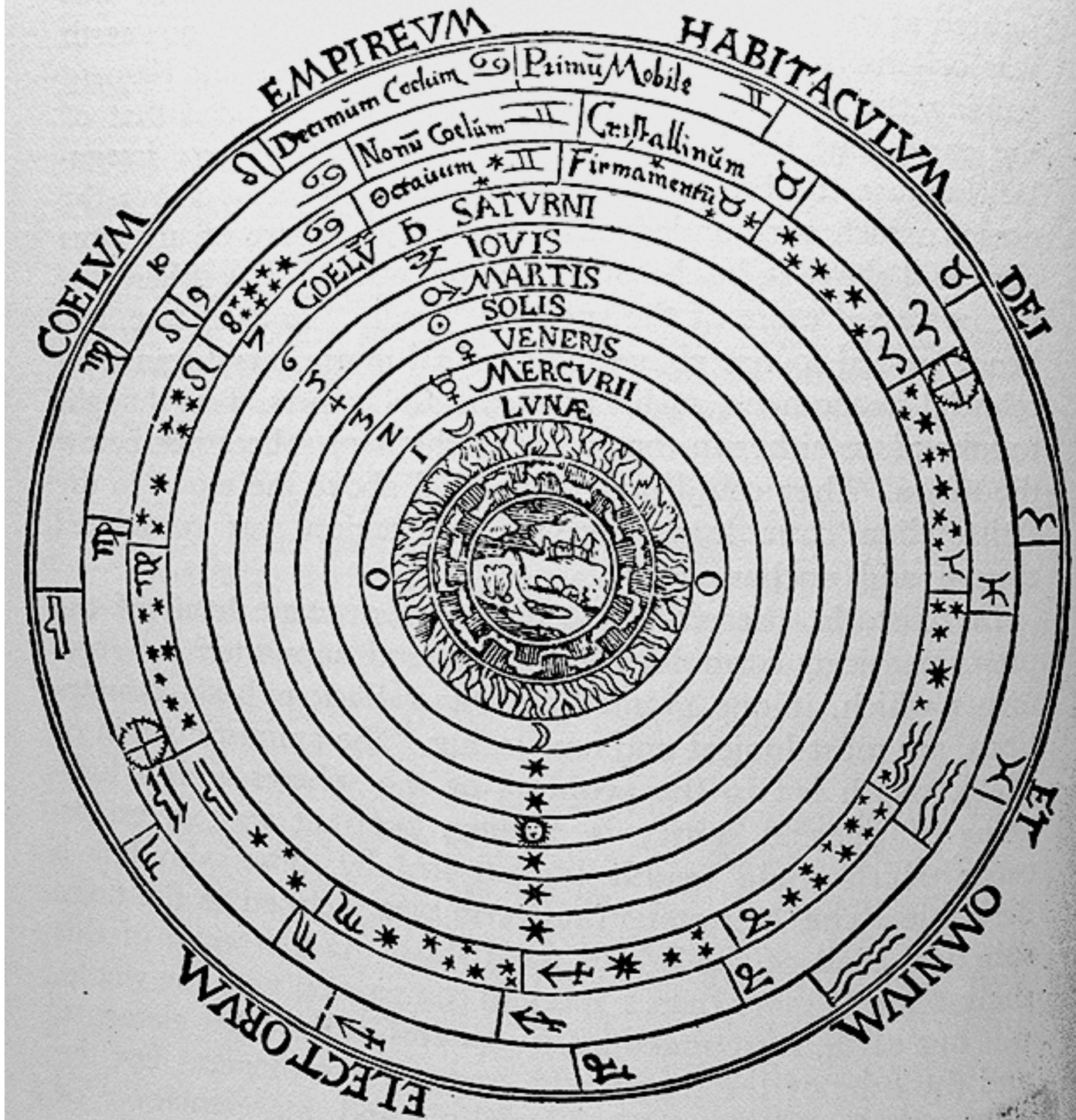
Cosmological classifications

See Harrison's *Cosmology - the Science of the Universe*

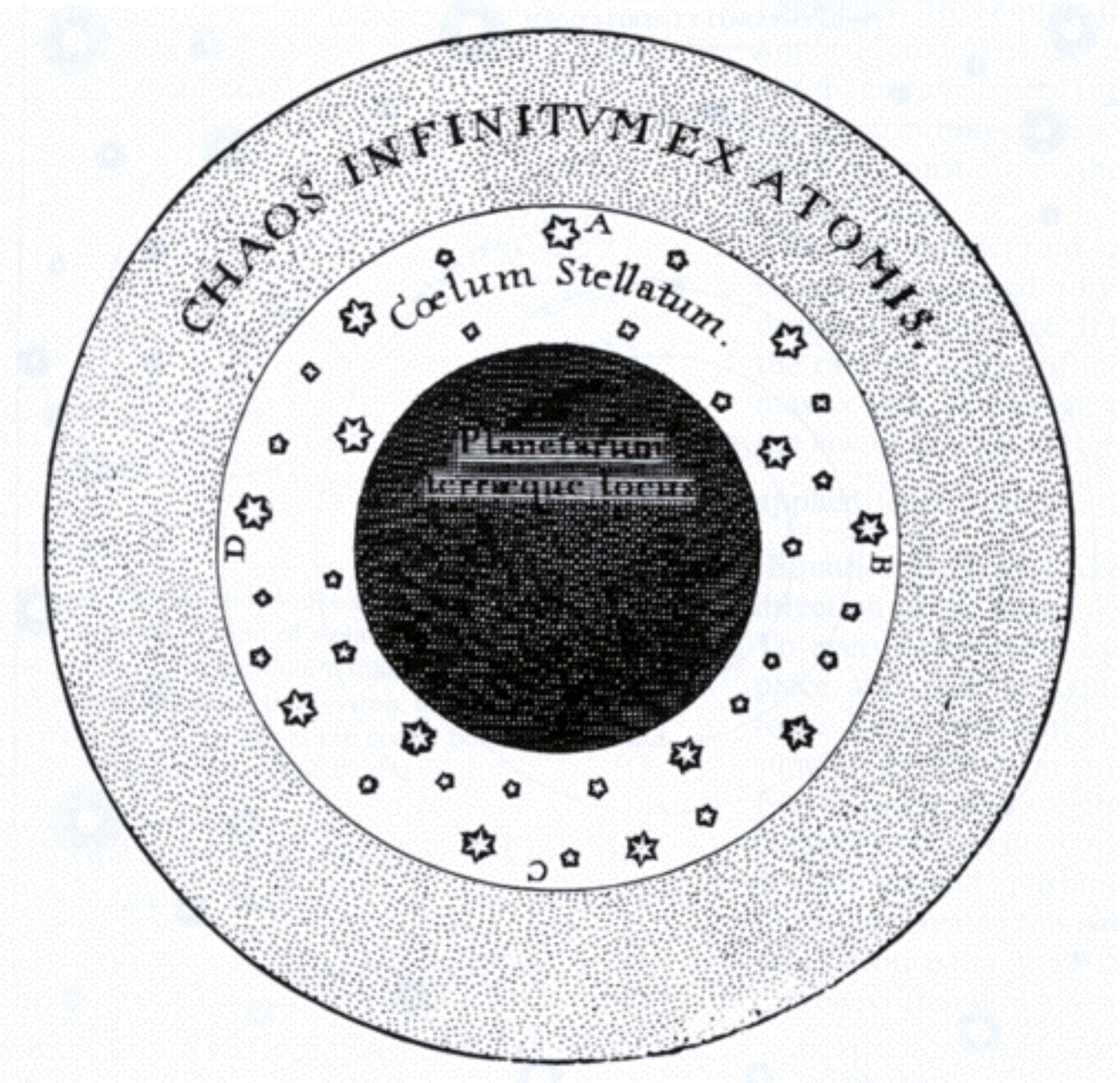
	Aristotelian	**Stoic**	**Epicurean**
Spatial Extent	Finite	Indefinite	Infinite
Center	Geocentric	Geocentric — later — Milky Way-centric	No center
Edge	Hard	Mushy	None
	Ancient/Midieval	Victorian	Modern

Aristotelean universe

Aristotle argued that the universe had to be finite so that the dome of the sky could rise and set every day - it couldn't go infinitely fast around the fixed earth.

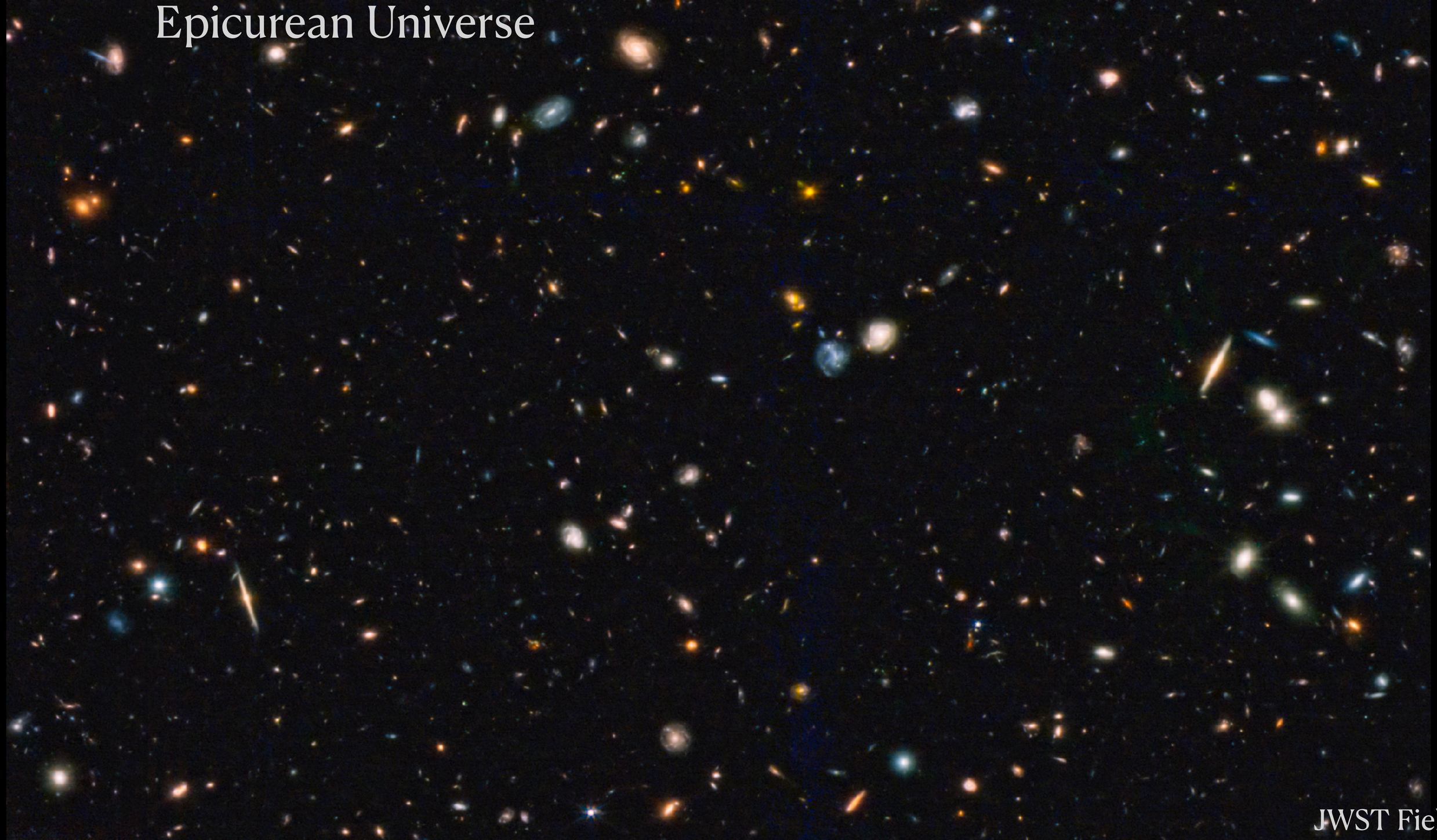


Stoic universe



Earth at the center surrounded by a finite volume of stars that trails off into an indefinite void.

Epicurean Universe



JWST Field

- **Aristotelean Cosmology**
  - Geocentrism required by Plato's school; later perfected by Ptolemy
  - Most successful, long-running cosmology in history - default picture of all early cultures
  - Required the Scientific Revolution (circa 1600) to disavow

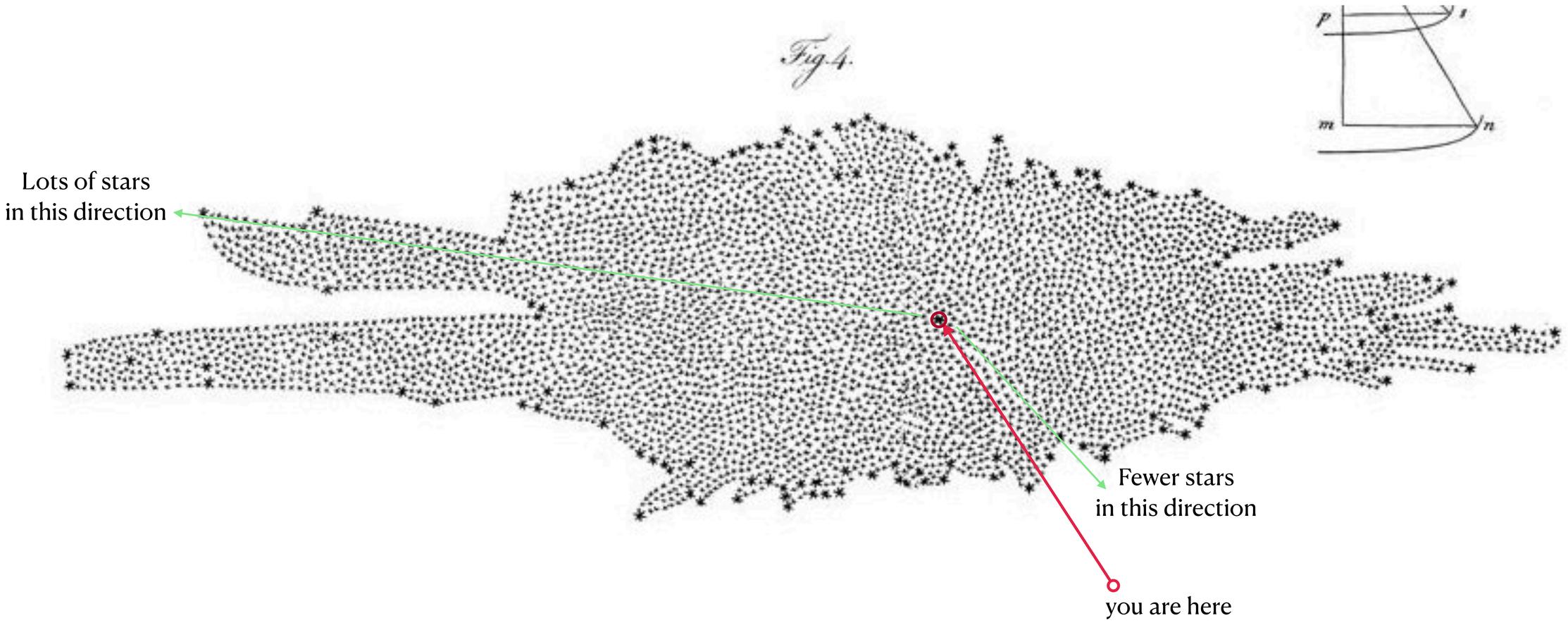
- **Stoic Cosmology**
  - Standard from 1785 through the 1920s
  - Scientifically well-grounded

- **Epicurean Cosmology**
  - An practically infinite, expanding universe the standard cosmology since Hubble (1929)
  - Hot Big Bang standard since the discovery of the Cosmic Microwave Background (Penzias & Wilson 1964; Peebles & Dicke 1964).

The Milky Way Map of William Herschel (1785)

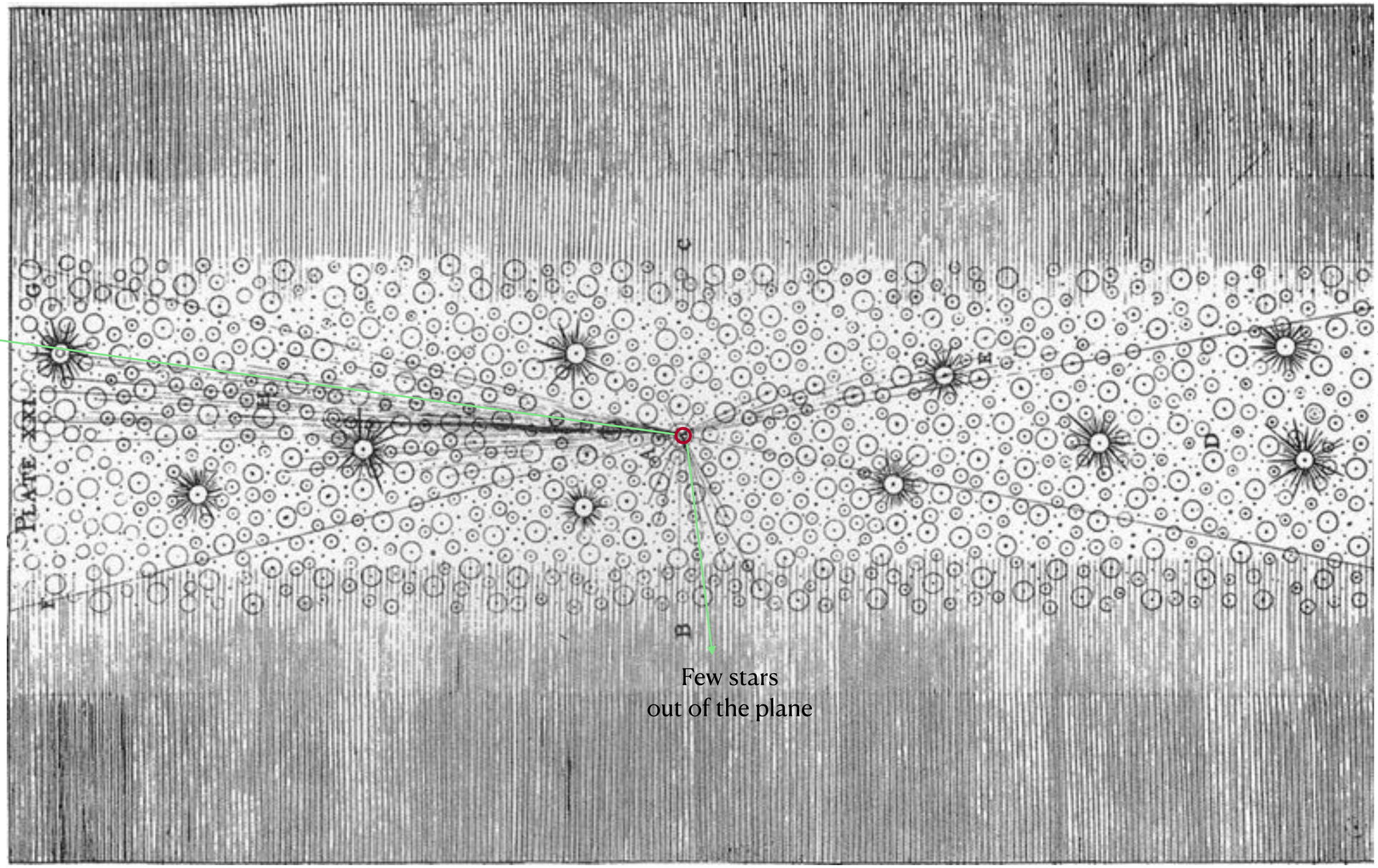
The sun is near the center of a thin, oblong collection of stars.

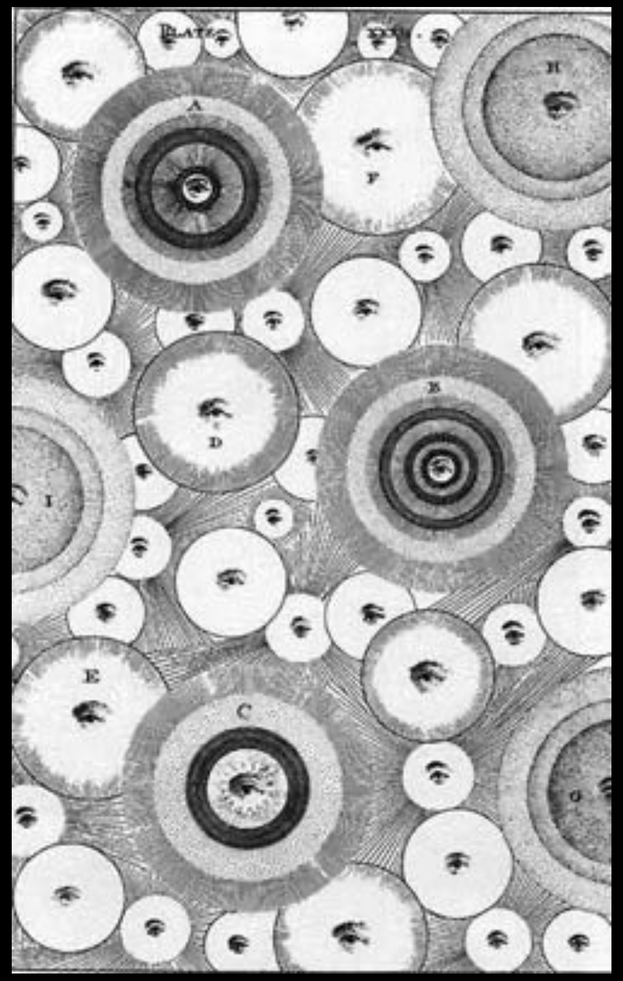
Follow-up work produced largely consistent results into the early 20th century



Philosophical Transactions of the Royal Society of London (1785), **75**, 213

Victorian Universe
Stoic-like with a vast Milky Way embedded in an indefinite void



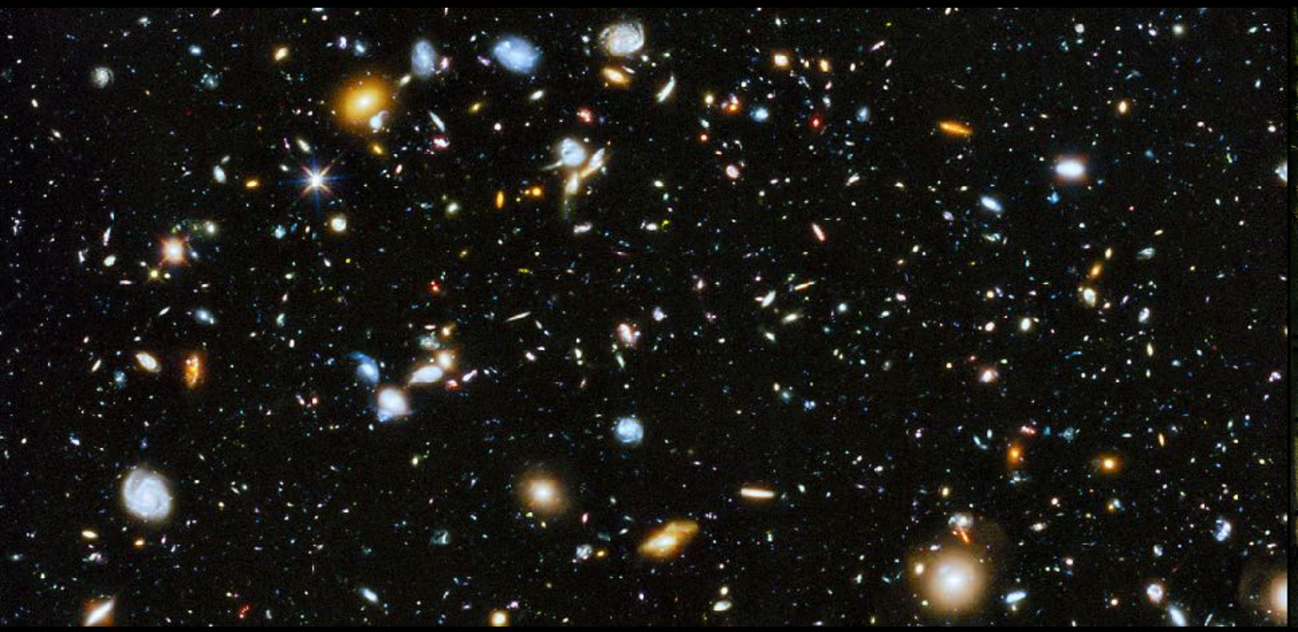


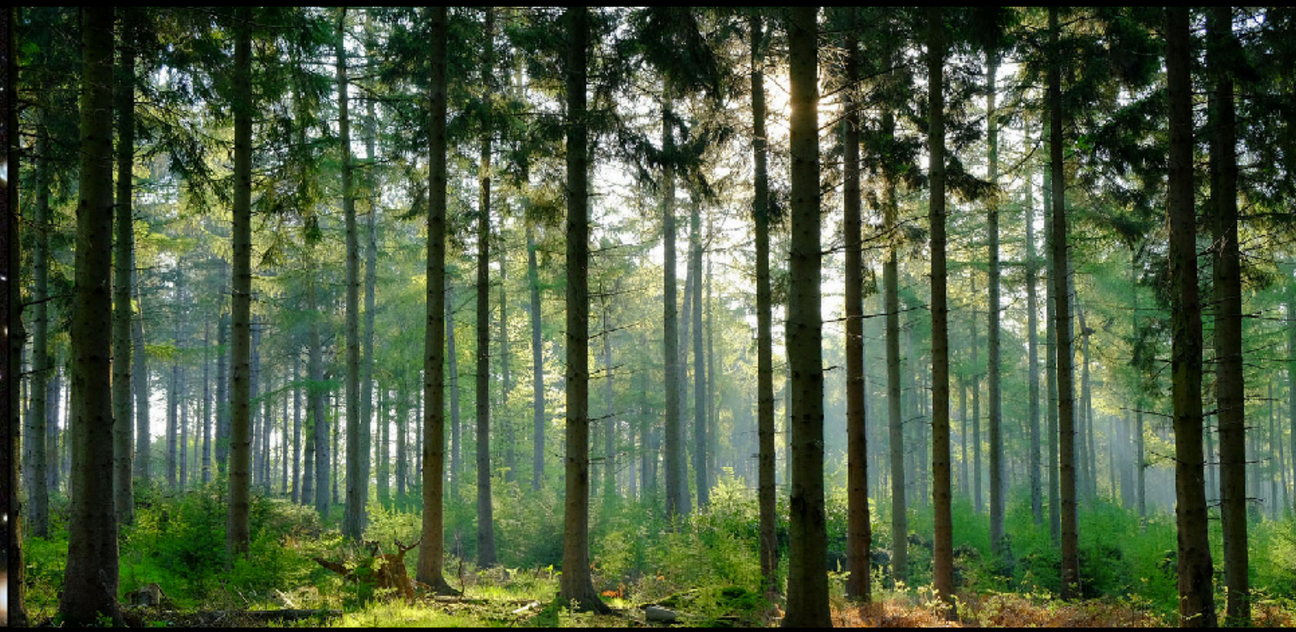
“No competent thinker, with the whole of the available evidence before him, can now, it is safe to say, maintain any single nebula to be a star system of coordinate rank with the Milky Way. A practical certainty has been attained that the entire contents, stellar and nebular, of the sphere belong to one mighty aggregation” [i.e., the Milky Way]

- Agnes Mary Clerke (1890)

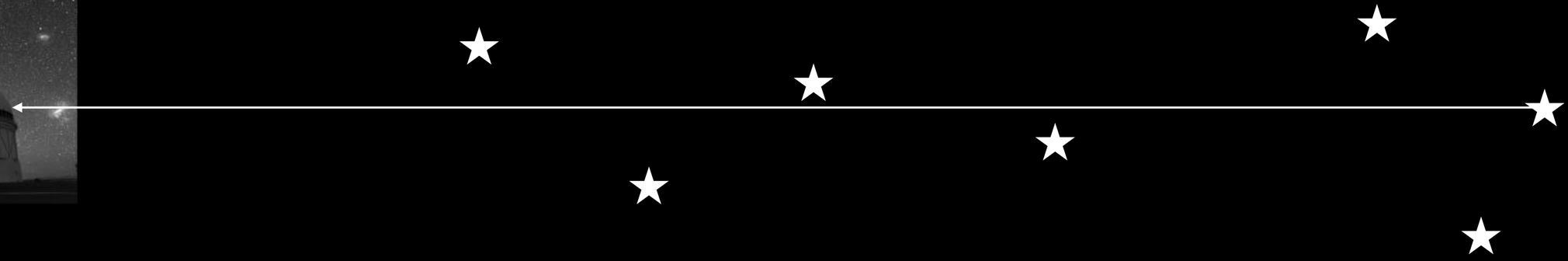
Popular History of Astronomy during the Nineteenth Century

Olber's paradox: why is the sky dark at night?

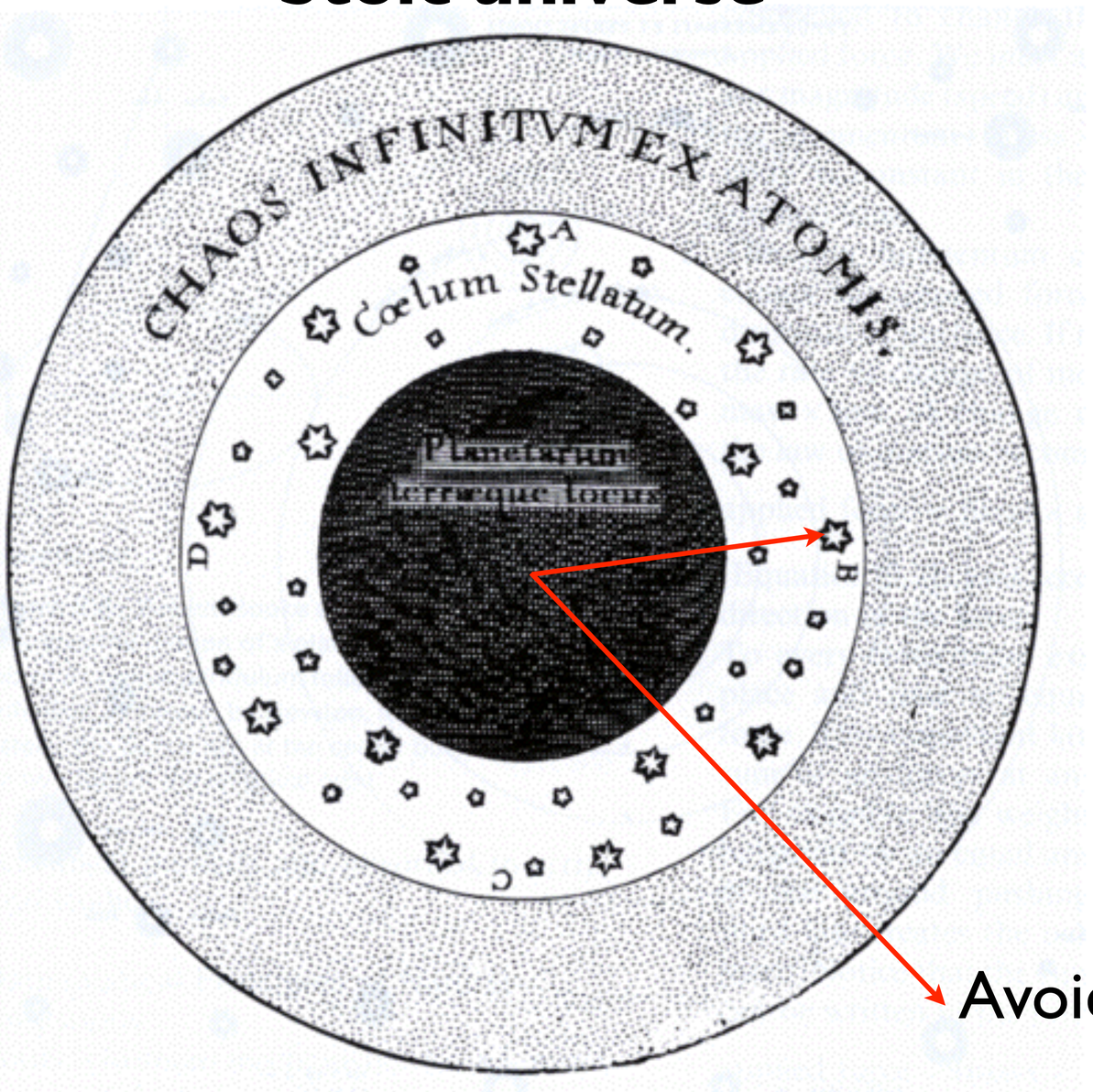




If the universe is infinite in extent, eventually every line of sight should intersect the surface of a star. Surface brightness is distance independent in a Euclidean geometry, so the whole sky should be as bright as the surface of a star!



Stoic universe



Avoids Olber's Paradox.

Milky Way at the center surrounded by a finite volume of stars that trails off into an indefinite void.

- **Aristotelean Cosmology**
  - Universe finite
  - Satisfies Olber's Paradox

- **Stoic Cosmology**
  - Universe indefinite, but contents finite
  - Satisfies Olber's Paradox

- **Epicurean Cosmology**
  - Universe infinite
  - **Flunks** Olber's Paradox

Curtis-Shapley Debate
(the "Great Debate" - 1920)

Shapley

The Milky Way is big; we are not near the center

Other nebulae are clouds of gas within the Milky Way

Curtis

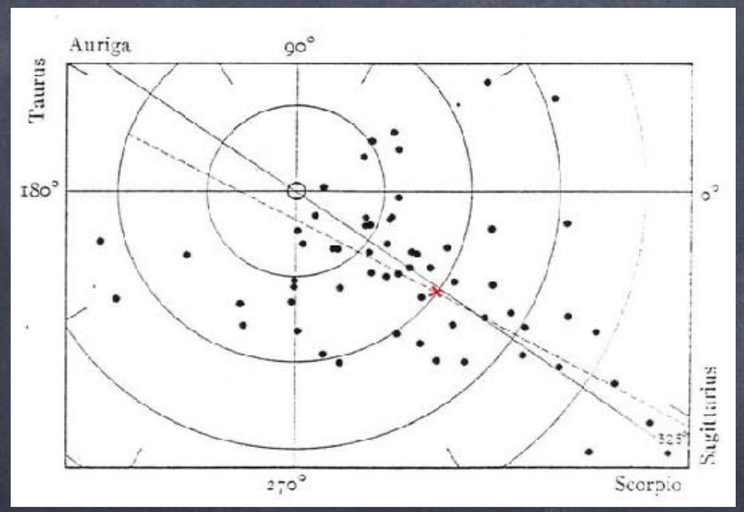
The Milky Way is small; we happen to be near the center

The spiral nebulae are "island universes" comparable to the Milky Way

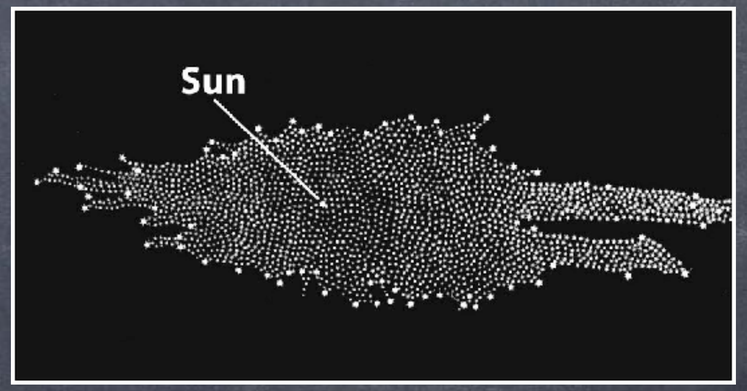
Size of Milky Way

Shapley

Curtis

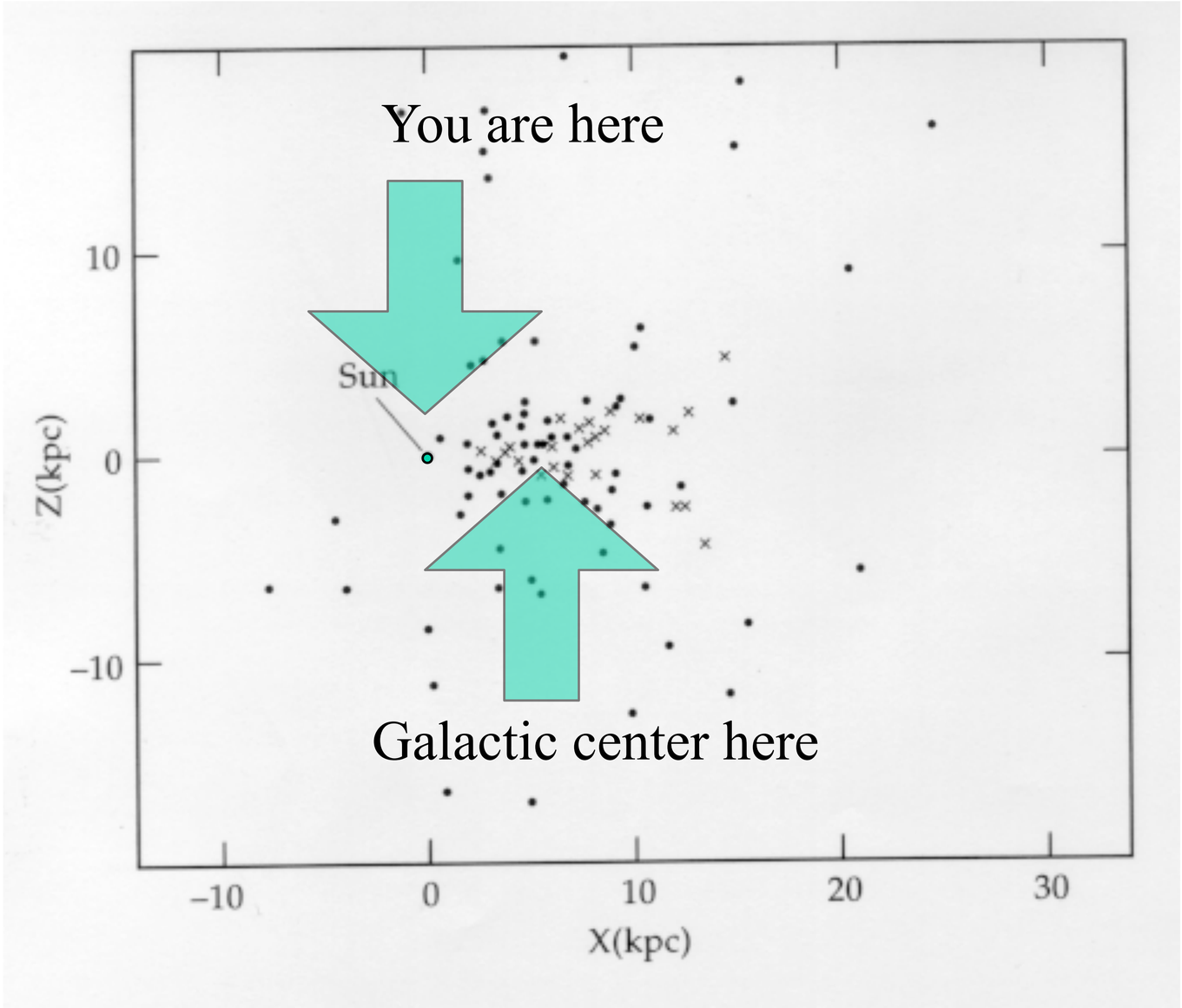


Globular clusters not centered on sun's location

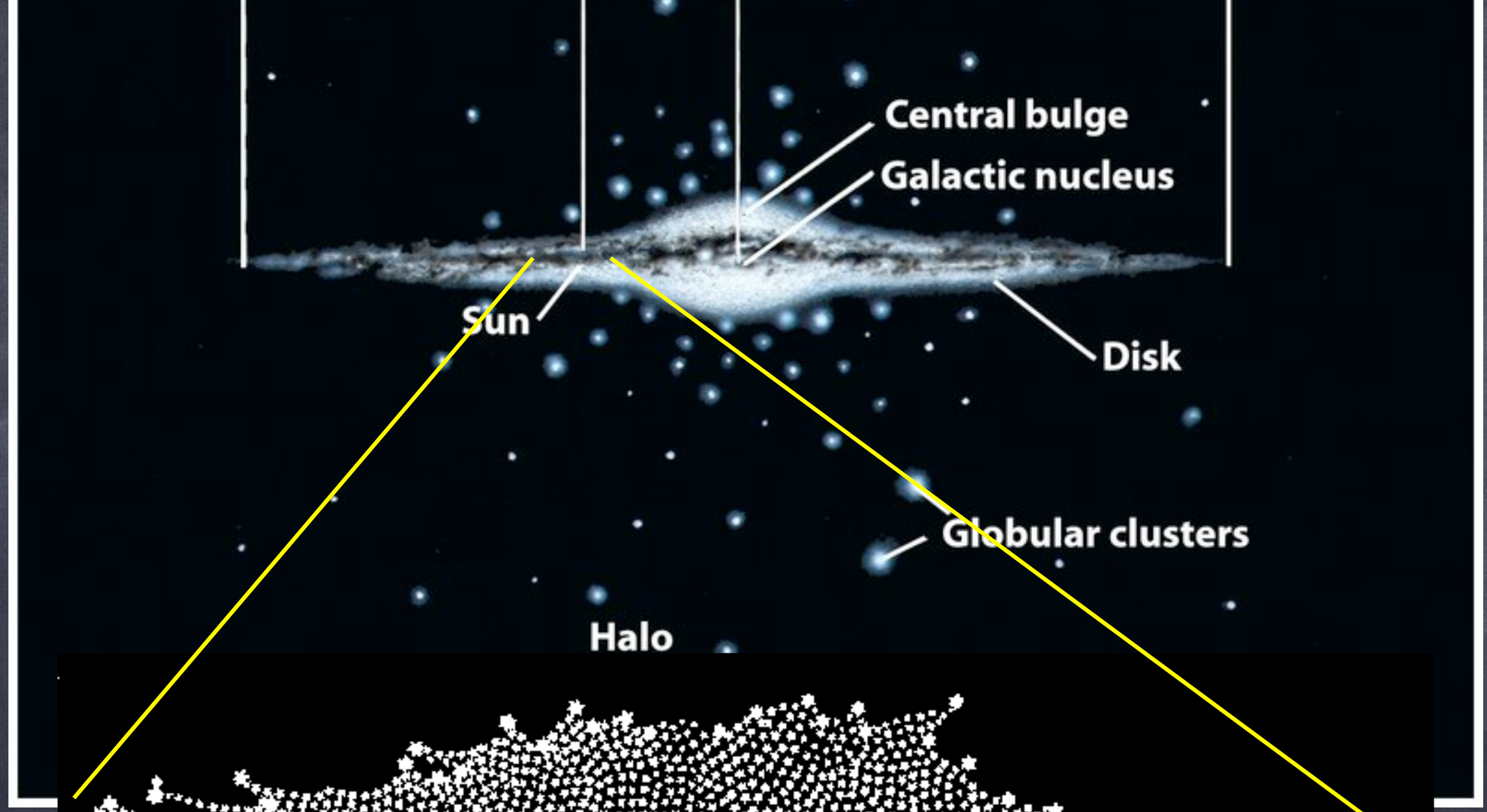


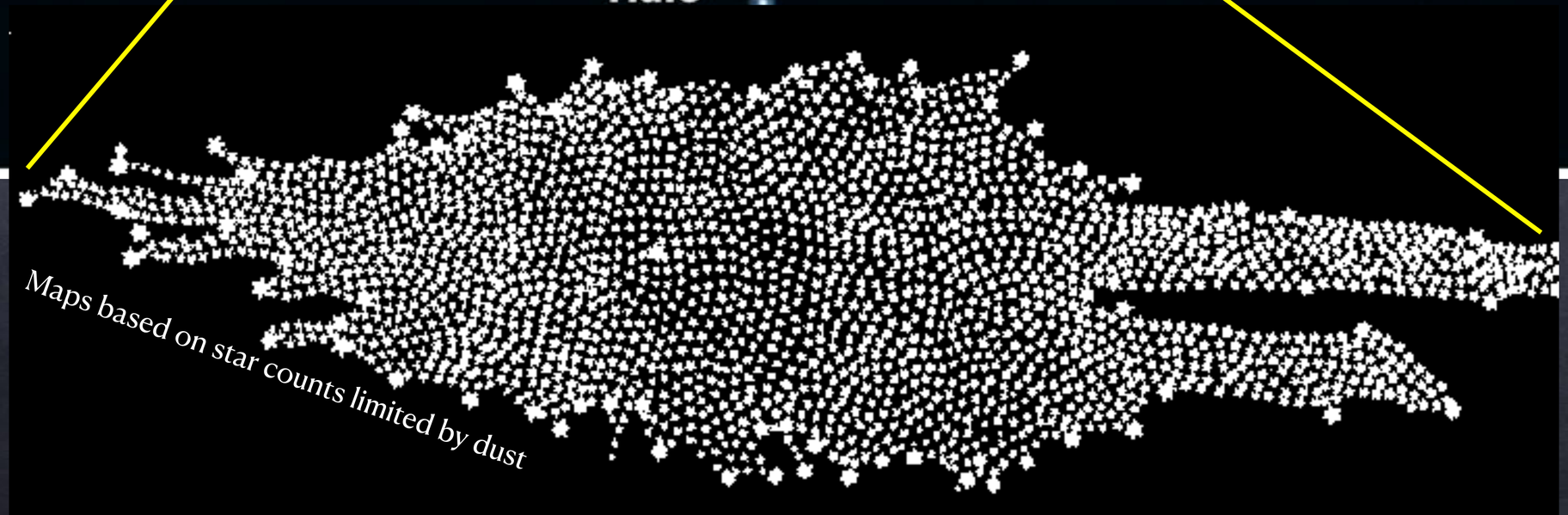
We've counted the stars; this is what it looks like

Shapley argued that we were unlikely to be near the center - the Copernican Principle. The center of the galaxy was likely in the direction where all the globular clusters were.

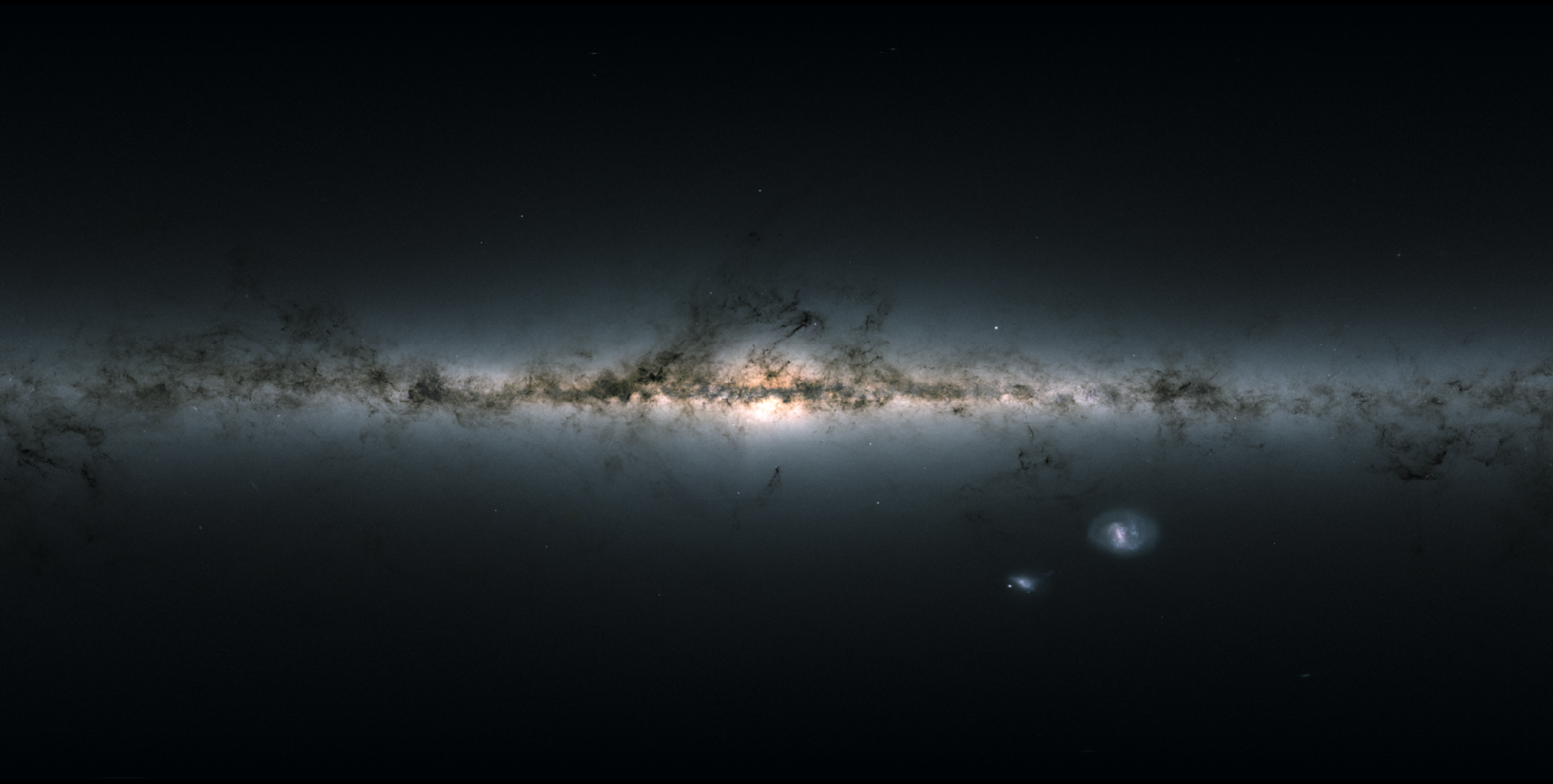


Curtis's map was incomplete because of dust


Central bulge
Galactic nucleus
Sun
Disk
Globular clusters
Halo


Maps based on star counts limited by dust

Milky Way as seen by Gaia



Shapley

Curtis

Nature of Spiral Nebulae

Some nebulae appear to rotate (van Maanen)

Nova-based distance placed M31 in Milky Way

"Island universes" have dust lanes

M31 had lots of novae; strange for one little patch of the Milky Way

Shapley argued that the spiral nebulae were just pinwheels of gas within the Milky Way.

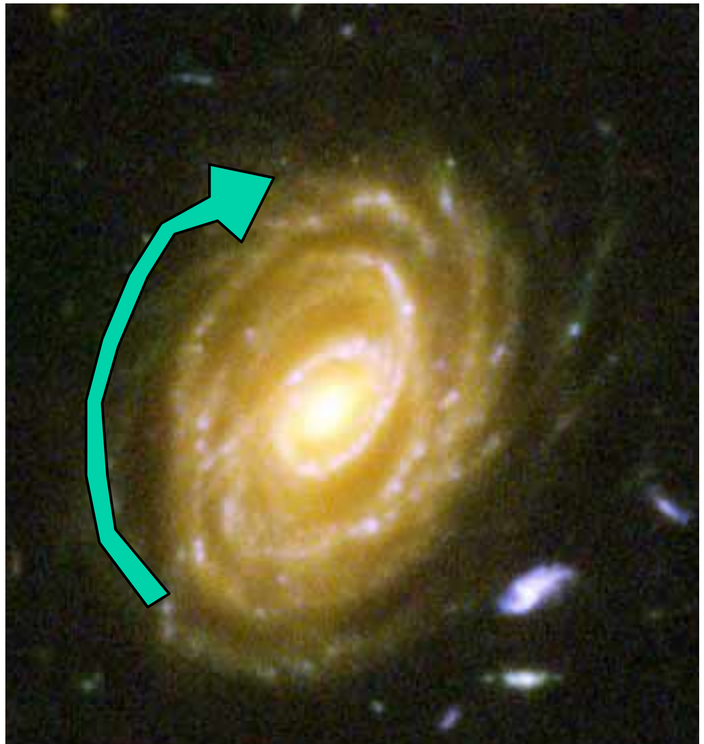
Two critical observations:

(1) spiral galaxies seen to rotate

Just plain wrong.

(2) a nova in Andromeda suggested a distance closer than globular clusters.

Really was a supernova (unknown at the time).



Shapley

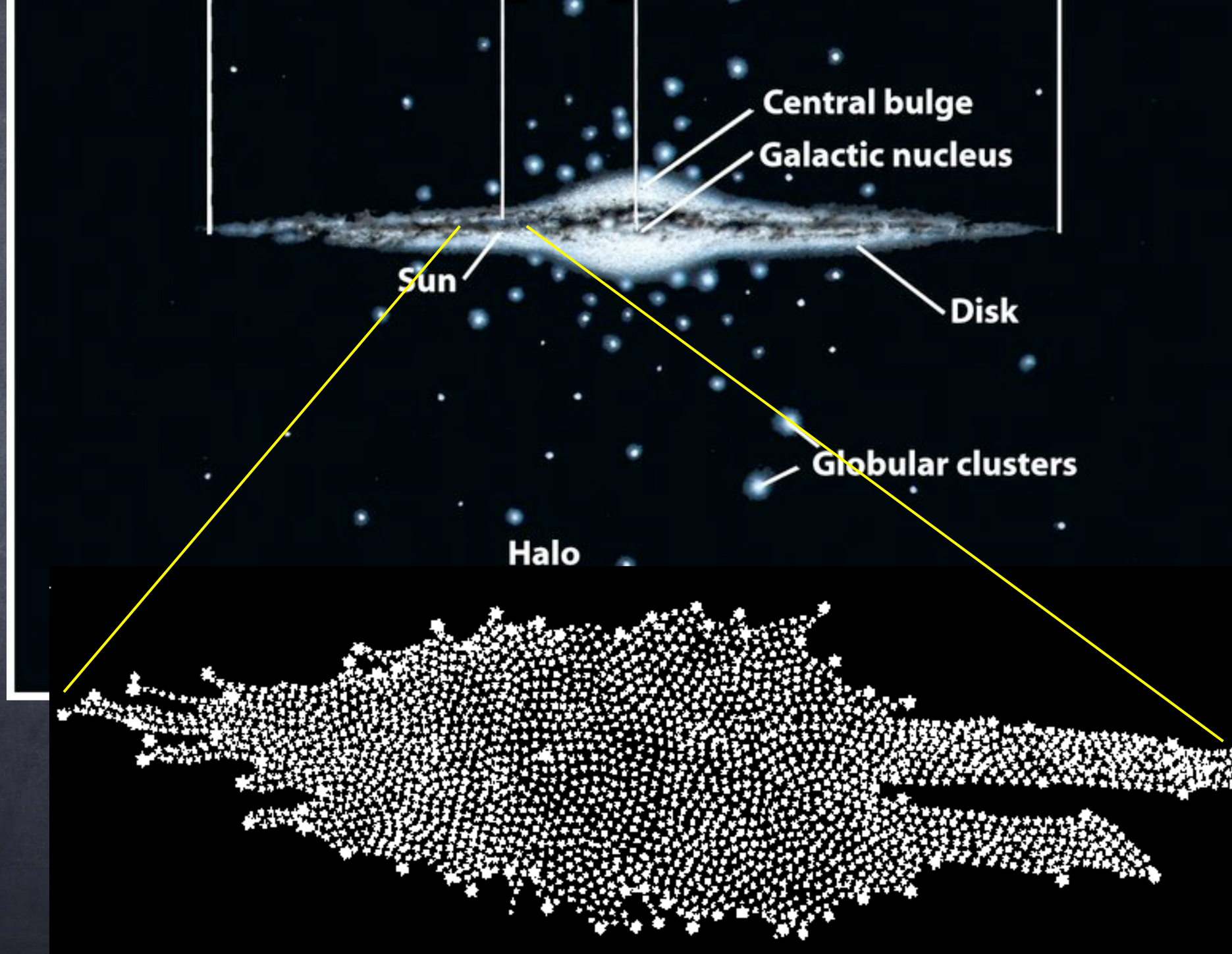
- <u>SHAPLEY</u>
- ✗ Spiral nebulae are small gas clouds contained within the Milky Way
- ✓ Milky Way big; we're not at its center

Curtis

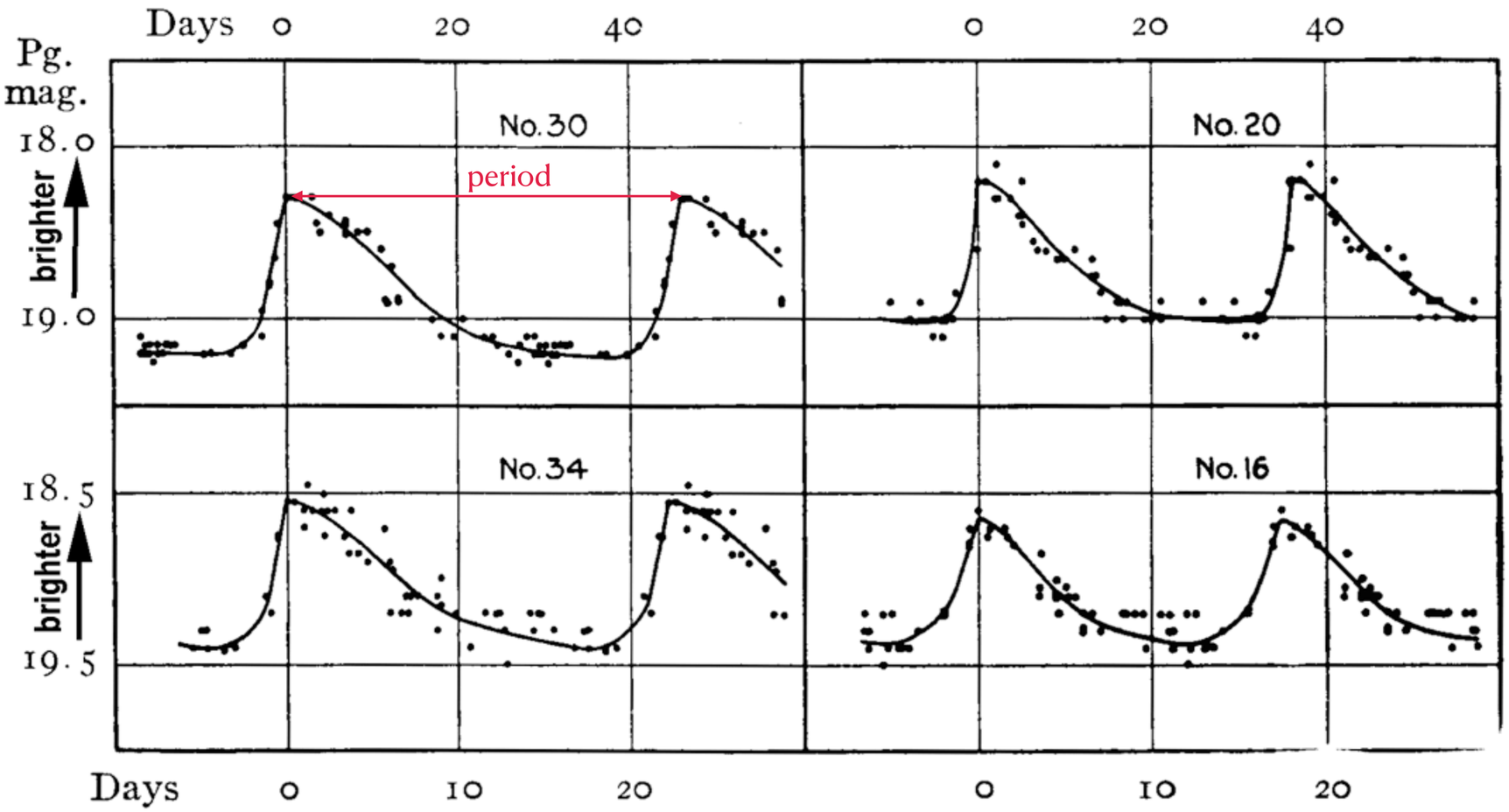
- <u>CURTIS</u>
- ✓ Spiral nebulae are external galaxies of coordinate rank to our own Milky Way
- ✗ Milky Way small; we're near its center

The Milky Way mapped by Herschel was limited by obscuration from interstellar dust. It is just our local patch of the Milky Way, so Shapley had that part right.

By the end of the decade, Hubble had demonstrated that spiral nebulae were external galaxies far outside the Milky Way, so Curtis had that part right.

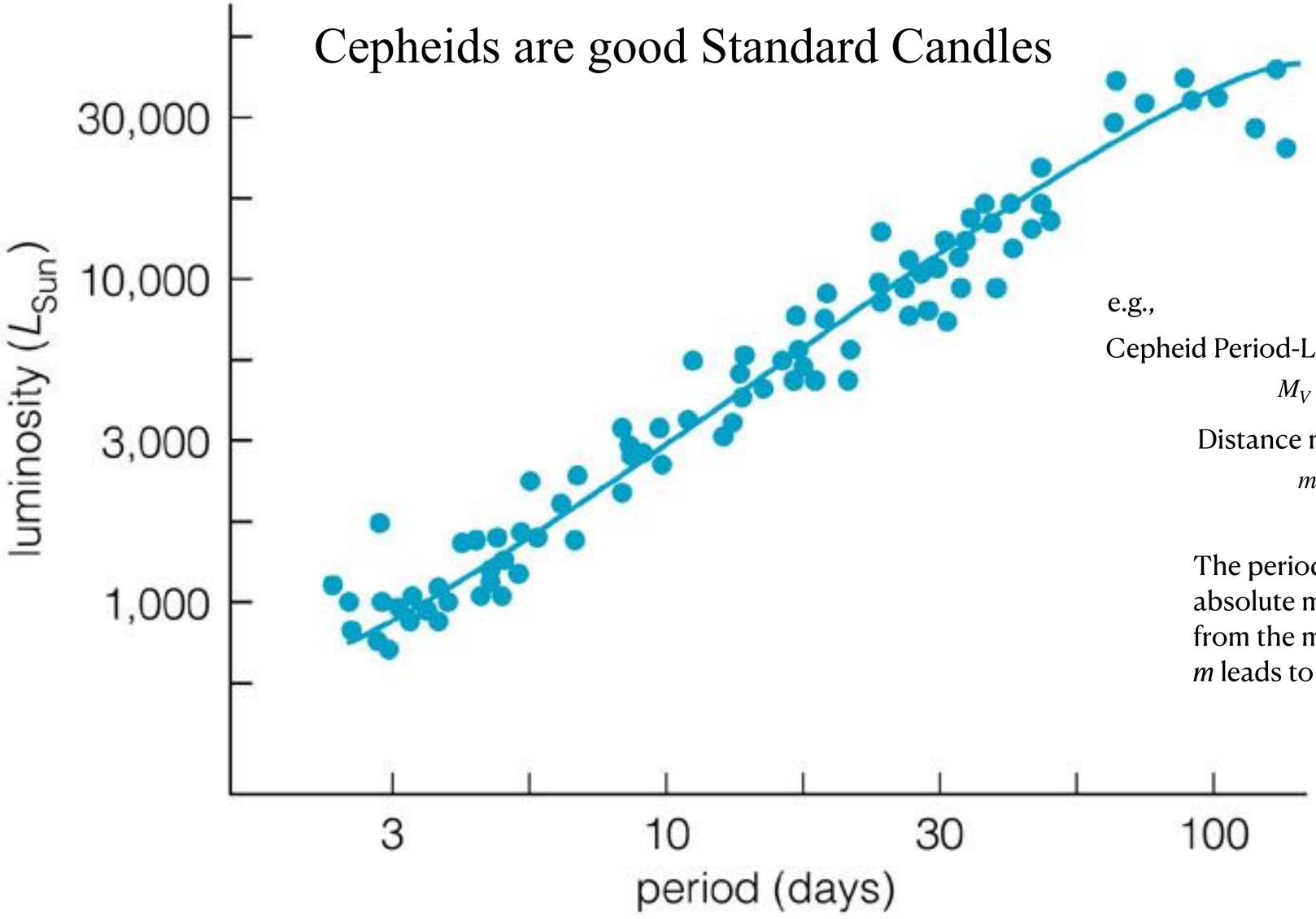


Cepheid Variable Stars



The light curves of several *Cepheid variable stars*.

Cepheids are good Standard Candles



e.g.,

Cepheid Period-Luminosity Relation

$$M_V = 2.76[\log(P) - 1] - 4.16$$

Distance modulus (D in Mpc)

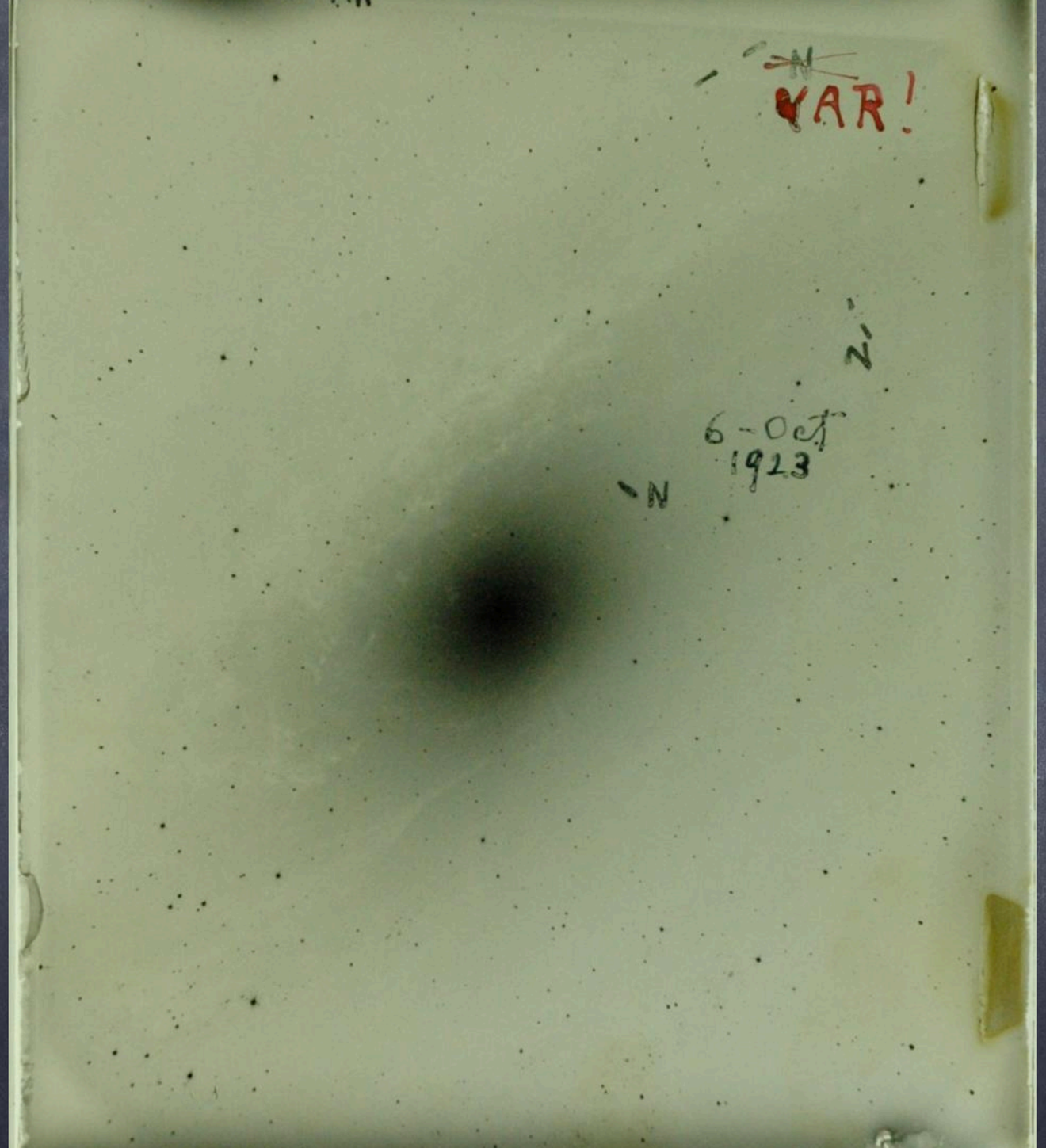
$$m - M = 5\log(D) + 25$$

The period P is used to estimate the absolute magnitude M whose difference from the measured apparent magnitude m leads to the distance D.

Cepheid variable stars with longer periods have greater luminosities: measuring the period tells us the luminosity, which can be combined with the inverse square law to infer a distance.

M31 Andromeda

Hubble discovered Cepheids in Andromeda, demonstrating that it had to be far outside the Milky Way and comparable to it in size.

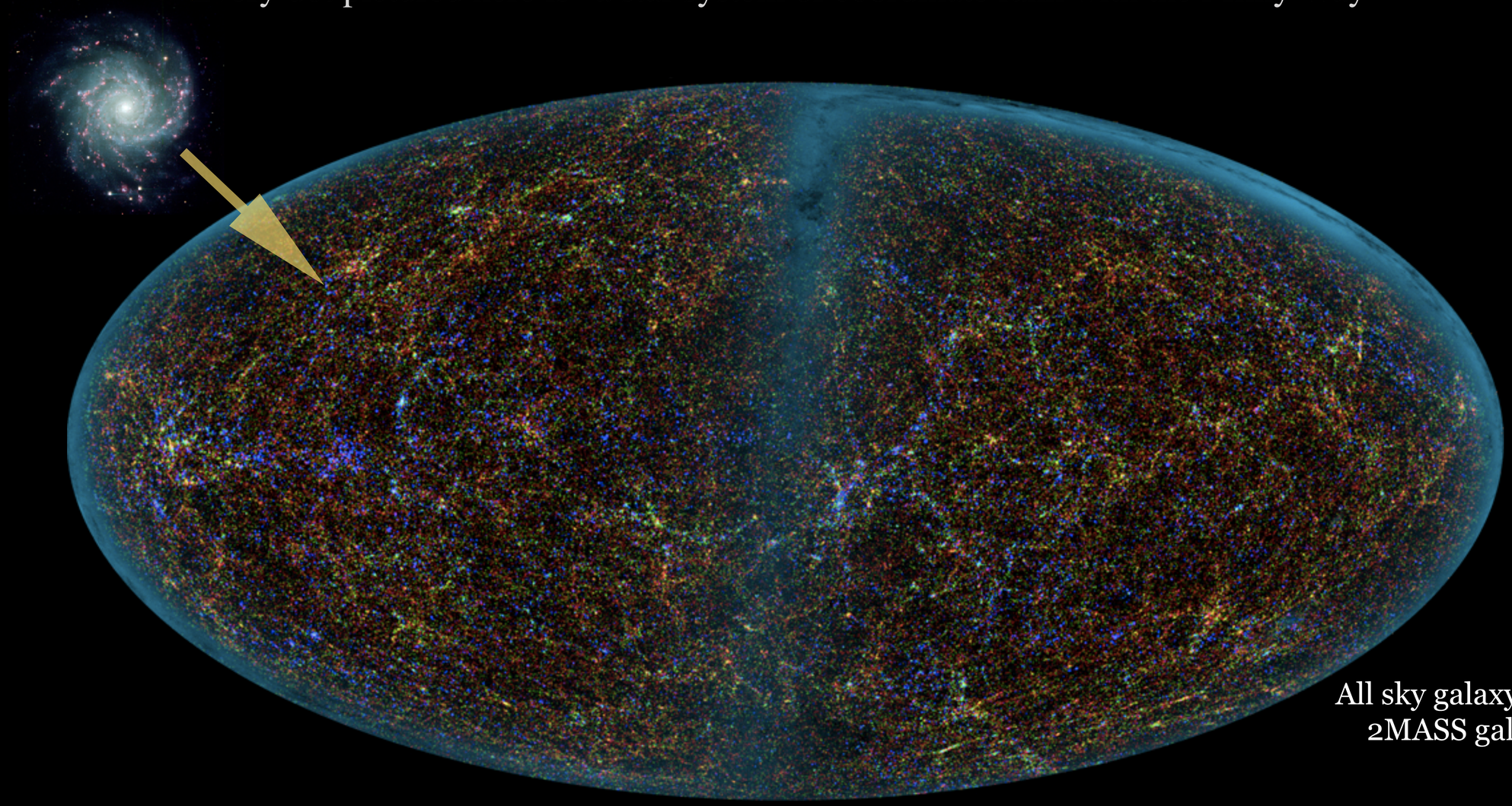


Hubble

Mount Wilson Observatory 100” (2.5m) Hooker telescope (1917)

Galaxies are the building blocks of the universe

Every dot pictured here is “a star system of coordinate rank with the Milky Way”



All sky galaxy distribution
2MASS galaxy survey

The color-coding corresponds to redshift: redder galaxies are more distant.
The distribution of galaxies is structured into enormous filaments and walls surrounding giant voids.

Hubble

- Showed that galaxies were distant systems, comparable in size to the Milky Way
  – settled Great Debate.

- Classified galaxy morphology (Hubble types)

- Discovered expansion of the Universe.