topics in astronomy

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My favorite topics in astronomy

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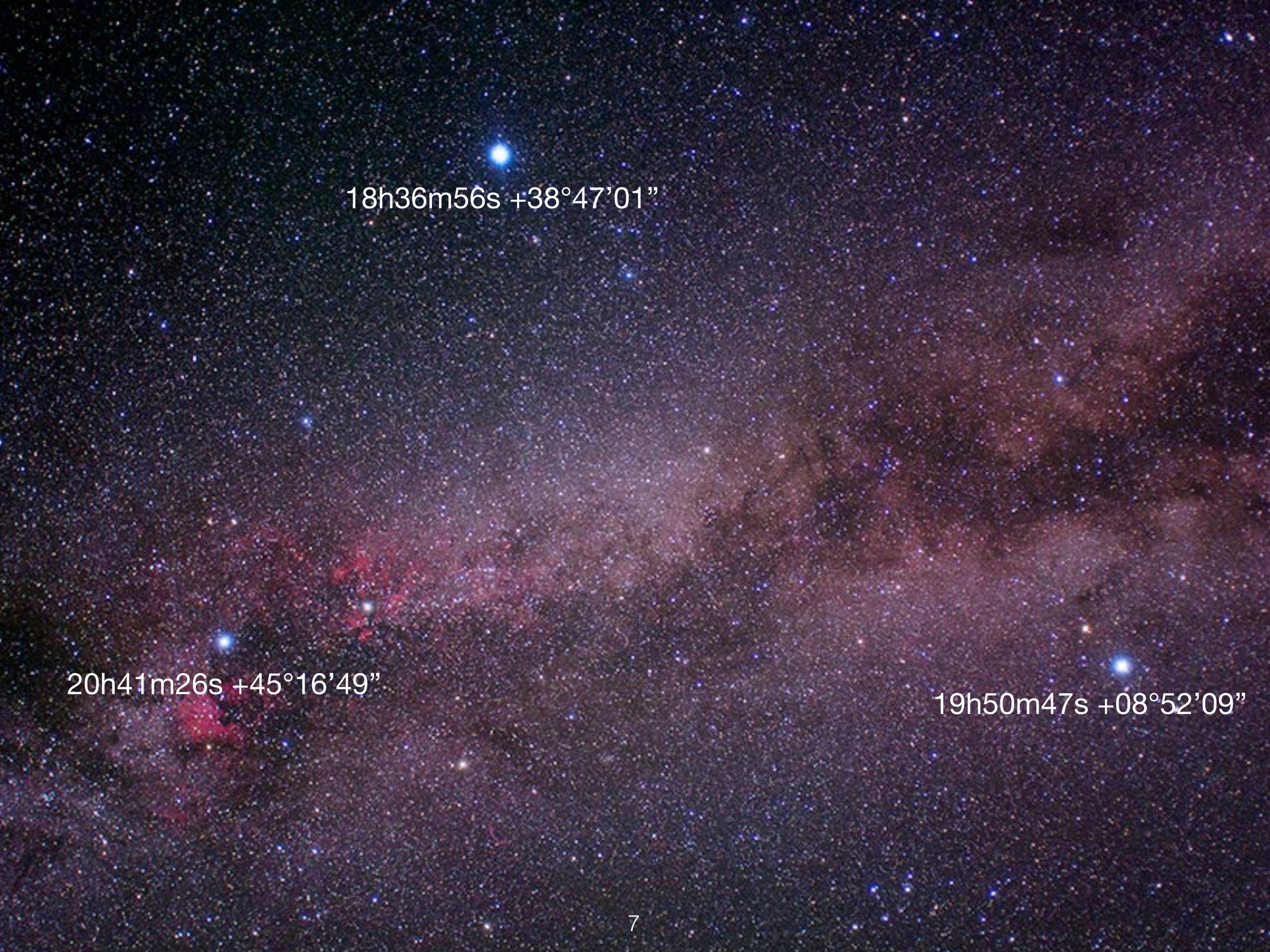
Outline

- Our eyes and astronomy
- Our place in the Universe

Astronomy is the oldest science.
Astronomers are a nostalgic bunch.


Vega
Deneb
Altair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Babylonian tablet YBC 7289
(~1600BC)

Our eyes and astronomy

Our eyes and astronomy

- Hipparchus cataloged stars based on how bright they are (150BC)

1st magnitude: brightest stars
2nd magnitude
3rd magnitude
4th magnitude
5th magnitude
6th magnitude: barely visible


Hipparchus

Vega

How much more light do we get from Vega compared to Altair?
20%, 50%, …?

Deneb

Altair

Vega

How much more light do we get from Vega compared to Altair?
20%, 50%, … the answer is 200%.

Deneb

Altair

- How much more light do we get from a 1st magnitude star compared to a 6th magnitude star? Not 5x…, but 100x!

- Our eyes are logarithmic detectors. [logarithmic: counting zeros]

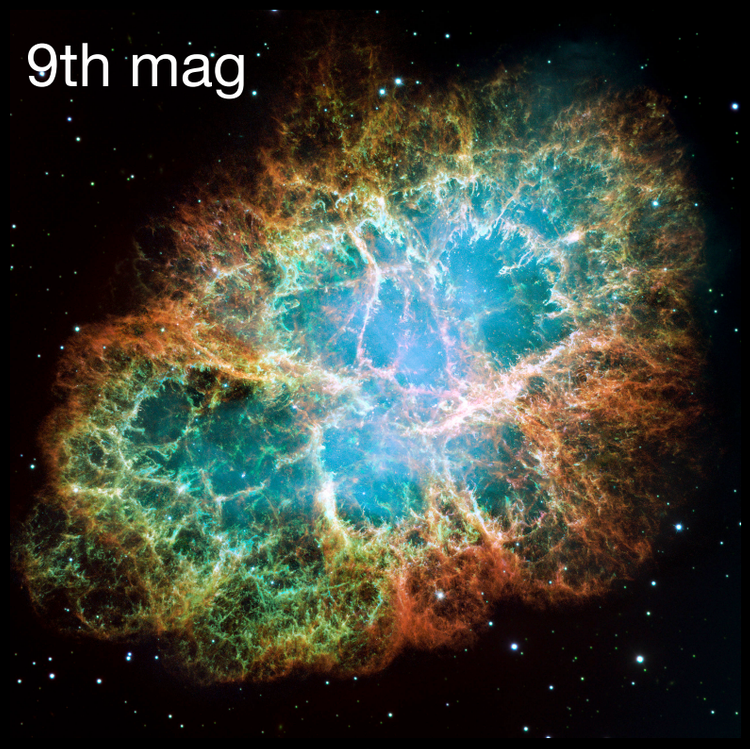
- Our eyes cannot tell small brightness differences, but can tolerate a large range of brightness.

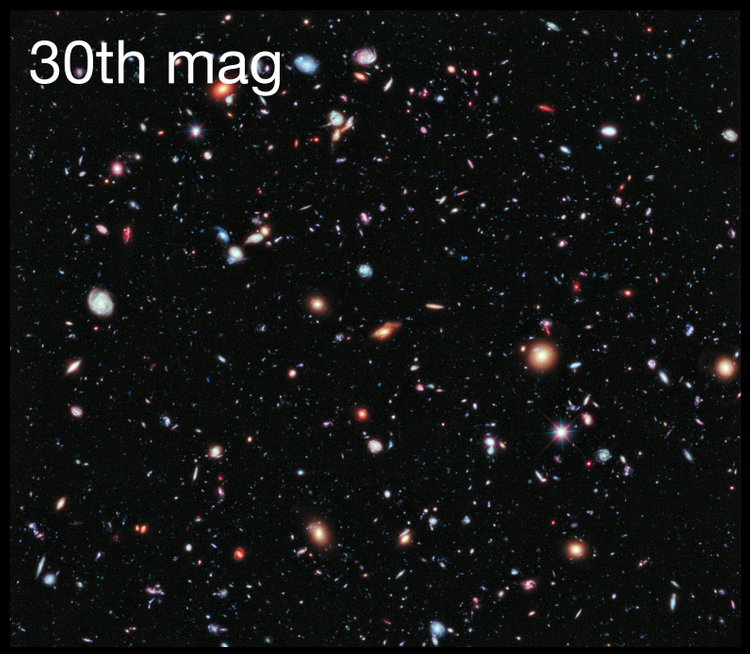
- Why have our eyes evolved to be logarithmic?

- Hipparchus' magnitude system is still used by astronomers today.

Our eyes and astronomy

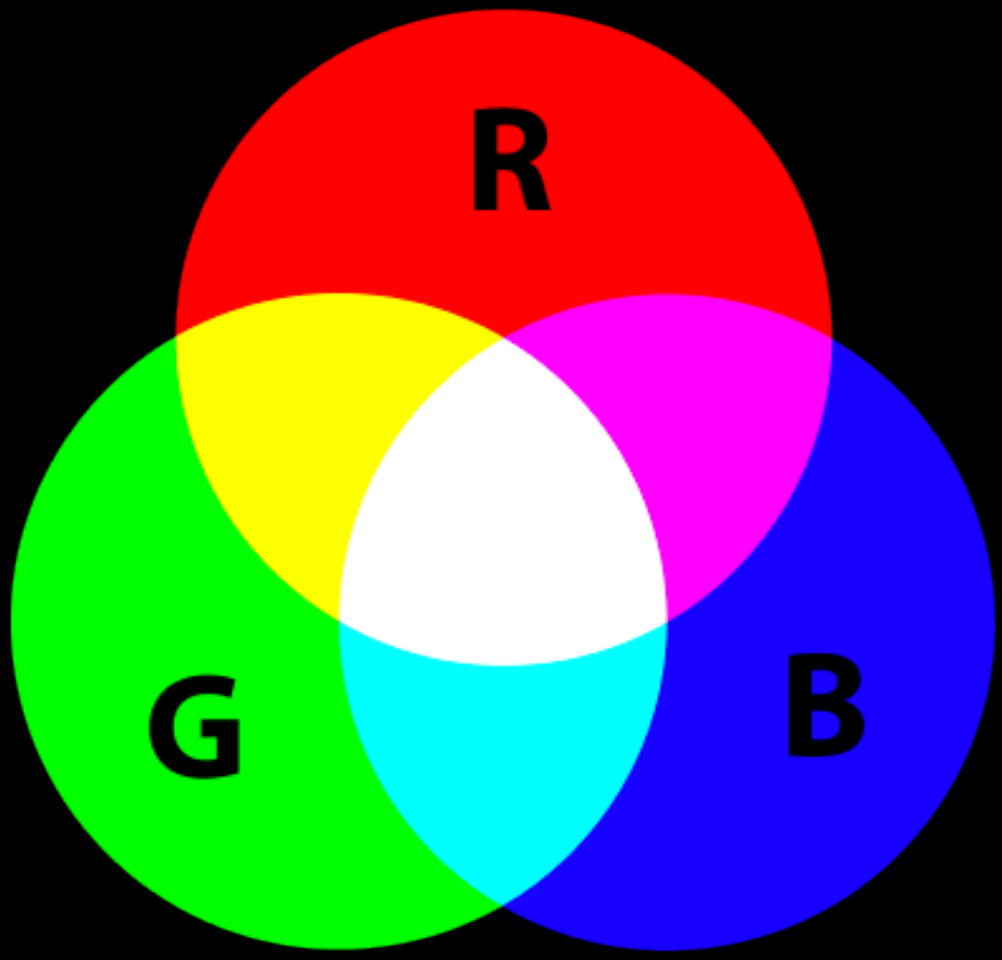
- 1st magnitude stars are the brightest.
- 6th magnitude stars are barely visible.
- 9th magnitude objects are reachable with binoculars.
- 20th mag objects are now routinely observed using modern telescopes.
- 30th mag is the record holder for the faintest objects reached.



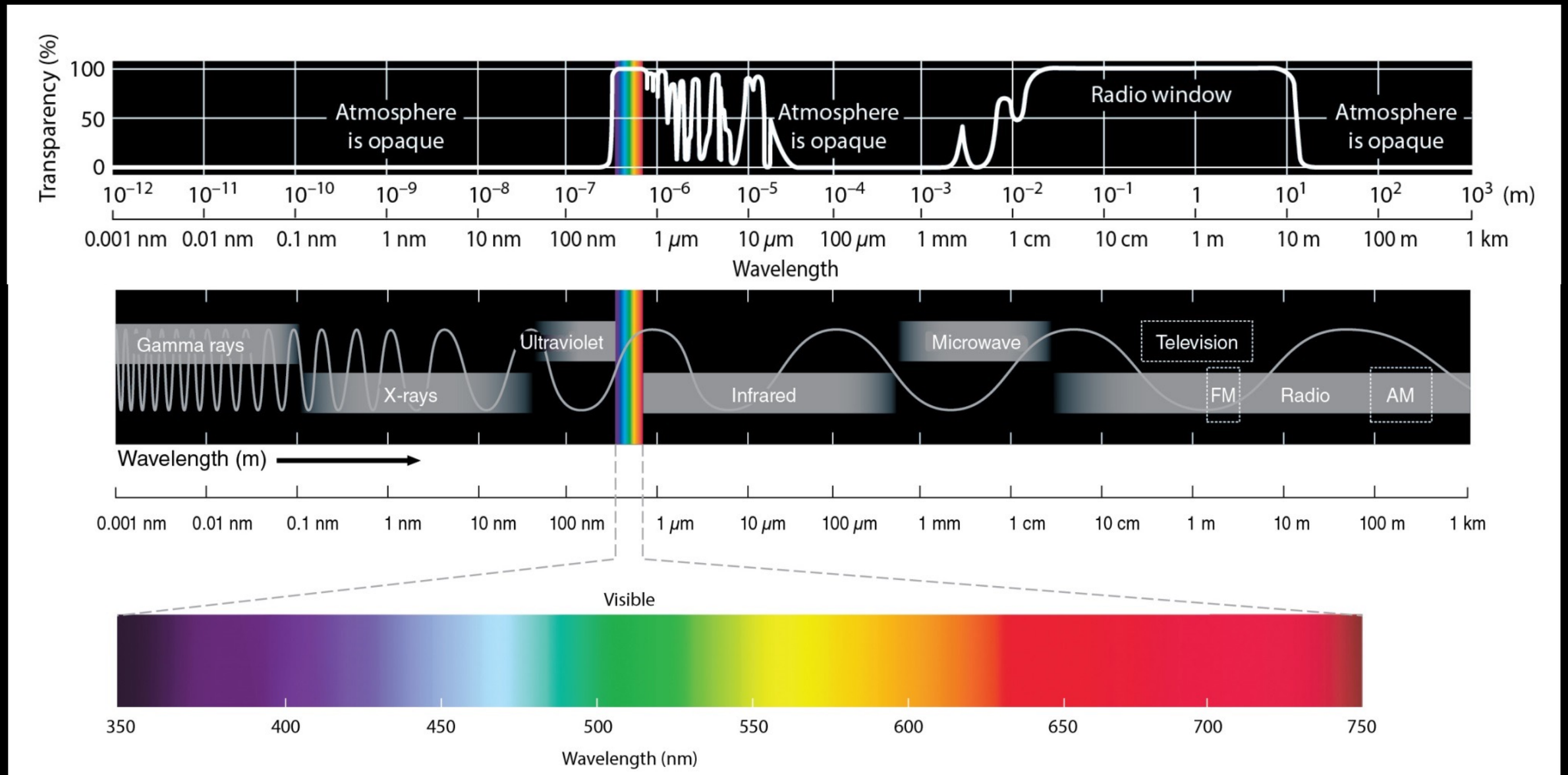


Our eyes and astronomy

- What is color?
- Our eyes perceive colors from 3 types of cone cells in the retina, each sensitive to a primary color.
- In reality, colors represent one continuous spectrum of light.



Our eyes and astronomy



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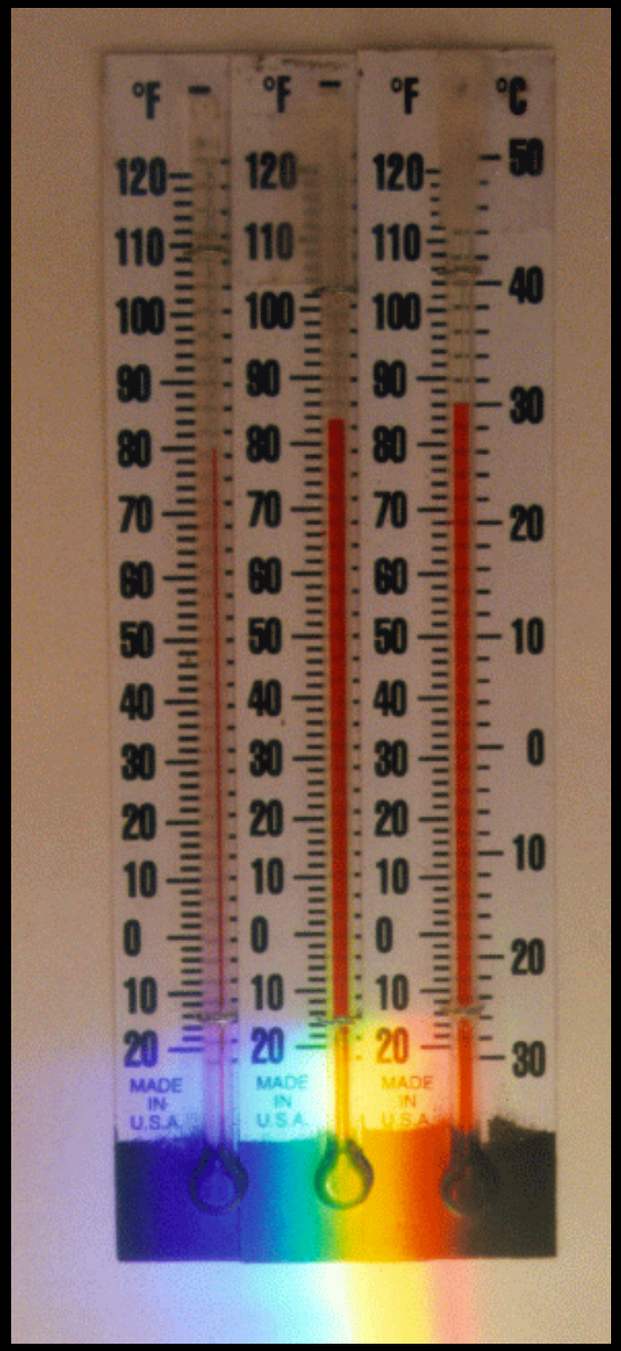
Our eyes and astronomy

- How did we learn that there is light we cannot see by eye?
- William Herschel discovered “infrared” radiation in 1800AD.

Herschel

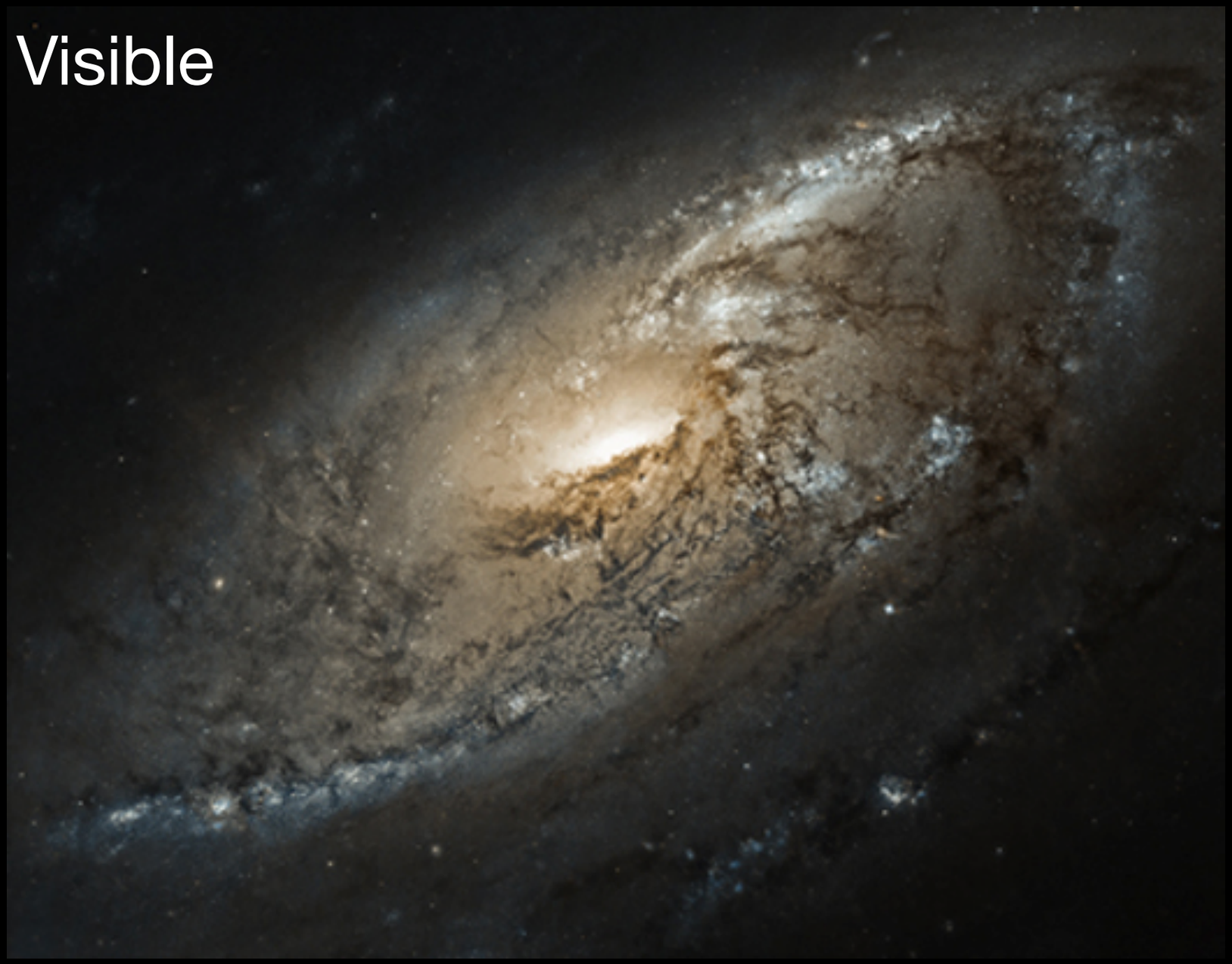
Our eyes and astronomy

- Herschel spread out sunlight with a prism, and measured the temperature of each color.
- Temperature is the highest at “infra” red.
- There is light beyond the rainbow we cannot see!



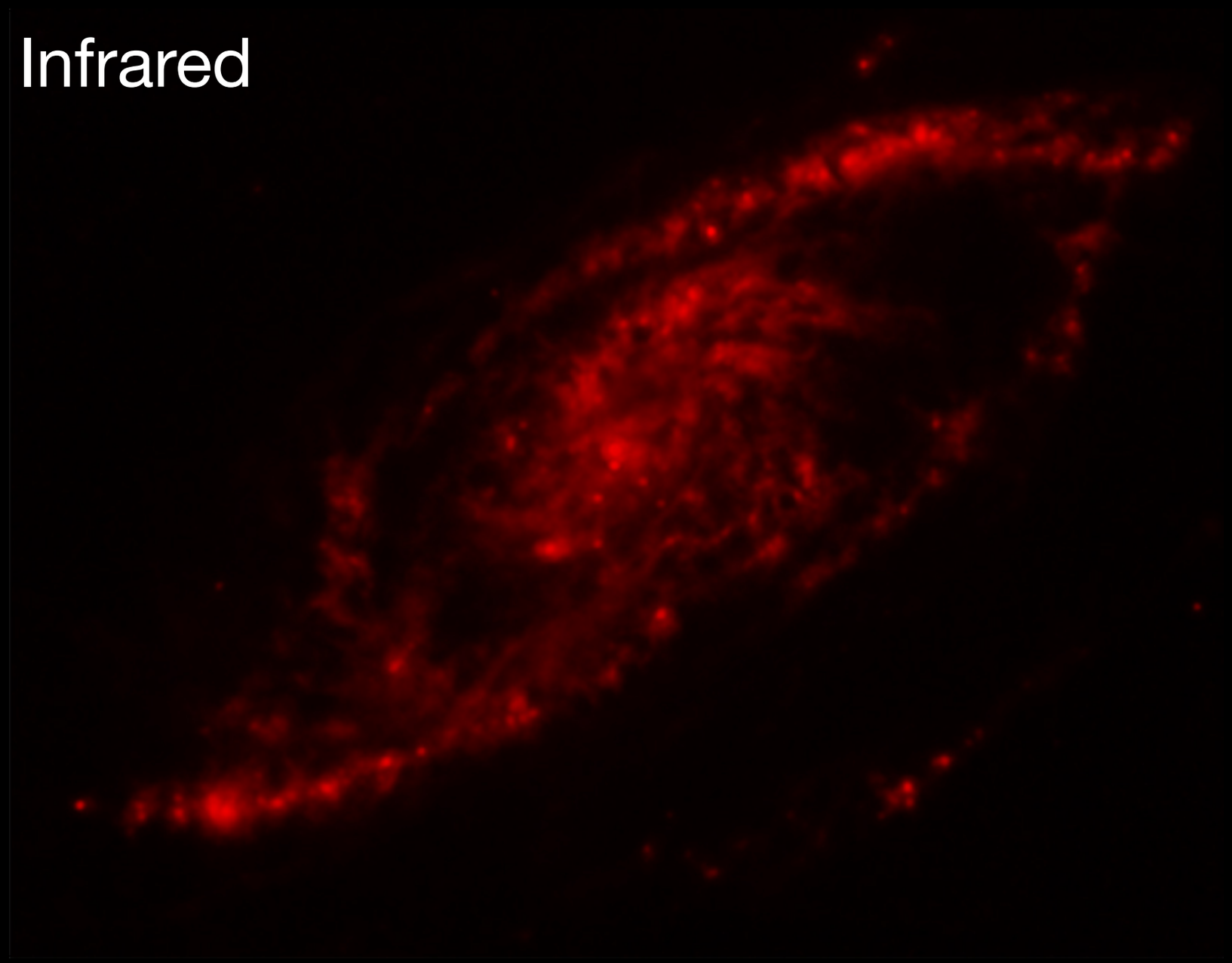
Our eyes and astronomy

Our eyes and astronomy



Our eyes and astronomy

Infrared



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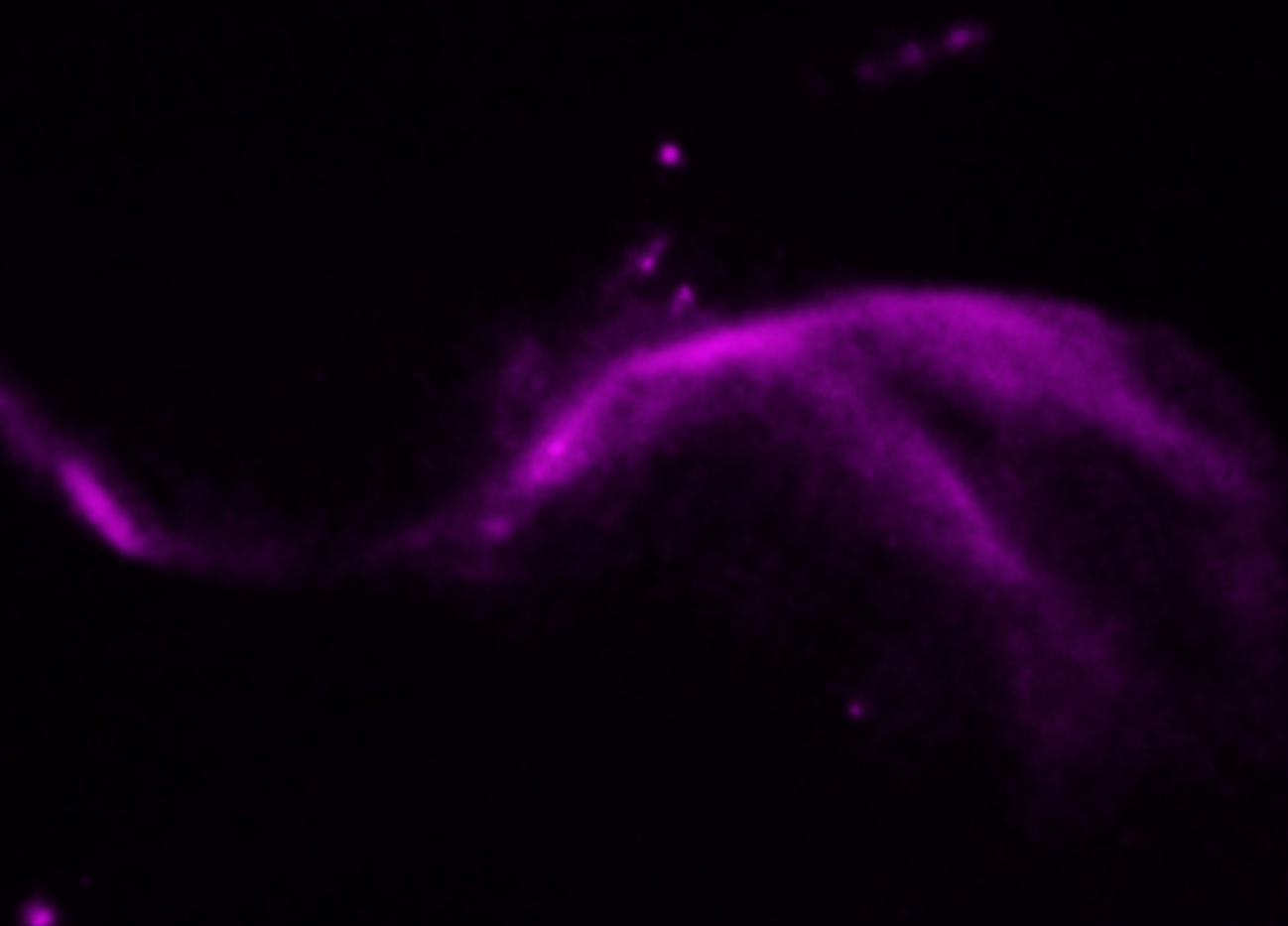
Our eyes and astronomy

X-ray

Our eyes and astronomy

Radio



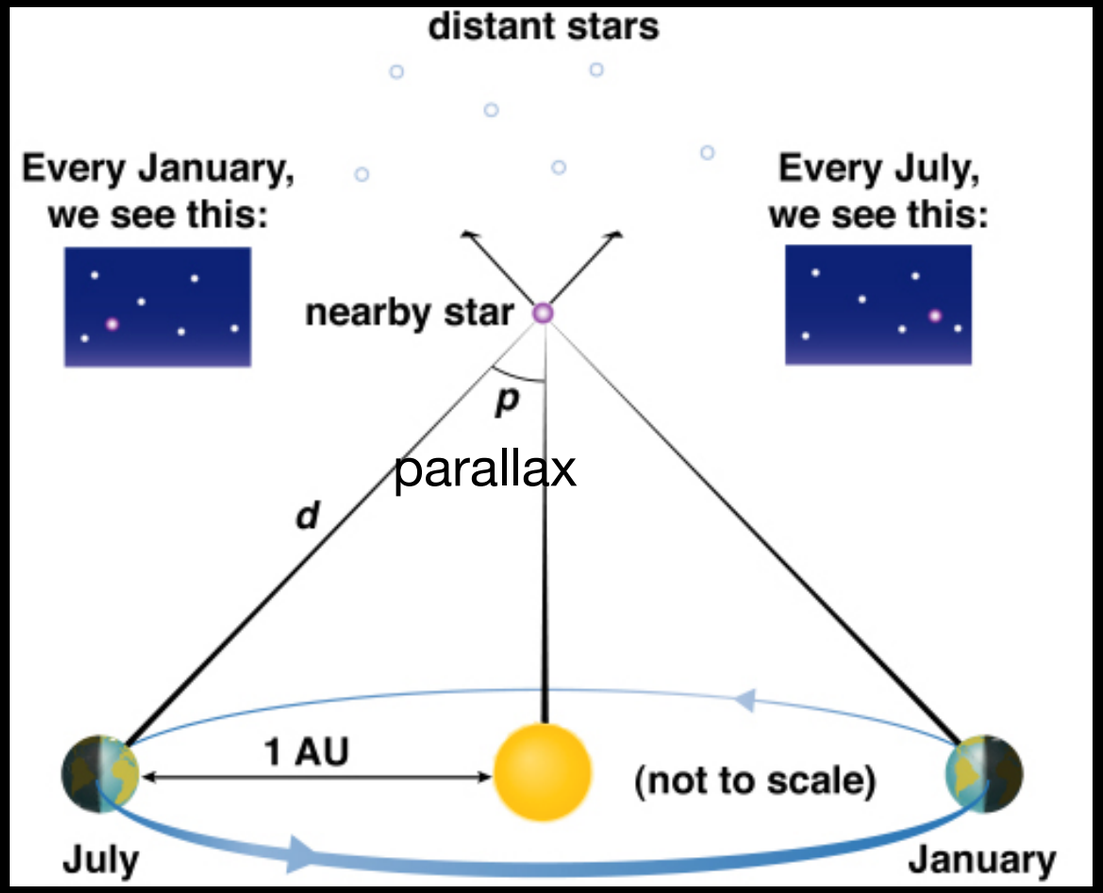
Our eyes and astronomy

Our eyes and astronomy

Our eyes and astronomy

- The separation between our eyes provides distances to objects (depth perception).

- With the same principle of parallax, we use the entire orbit of the Earth around the Sun to measure immense distances of stars.



Our eyes and astronomy

- Aristarchus proposed that stars are suns (200BC) because they show no parallax (they are far away).

- [Yes, some ancient astronomers did not believe the Earth is at the center of the Universe.]

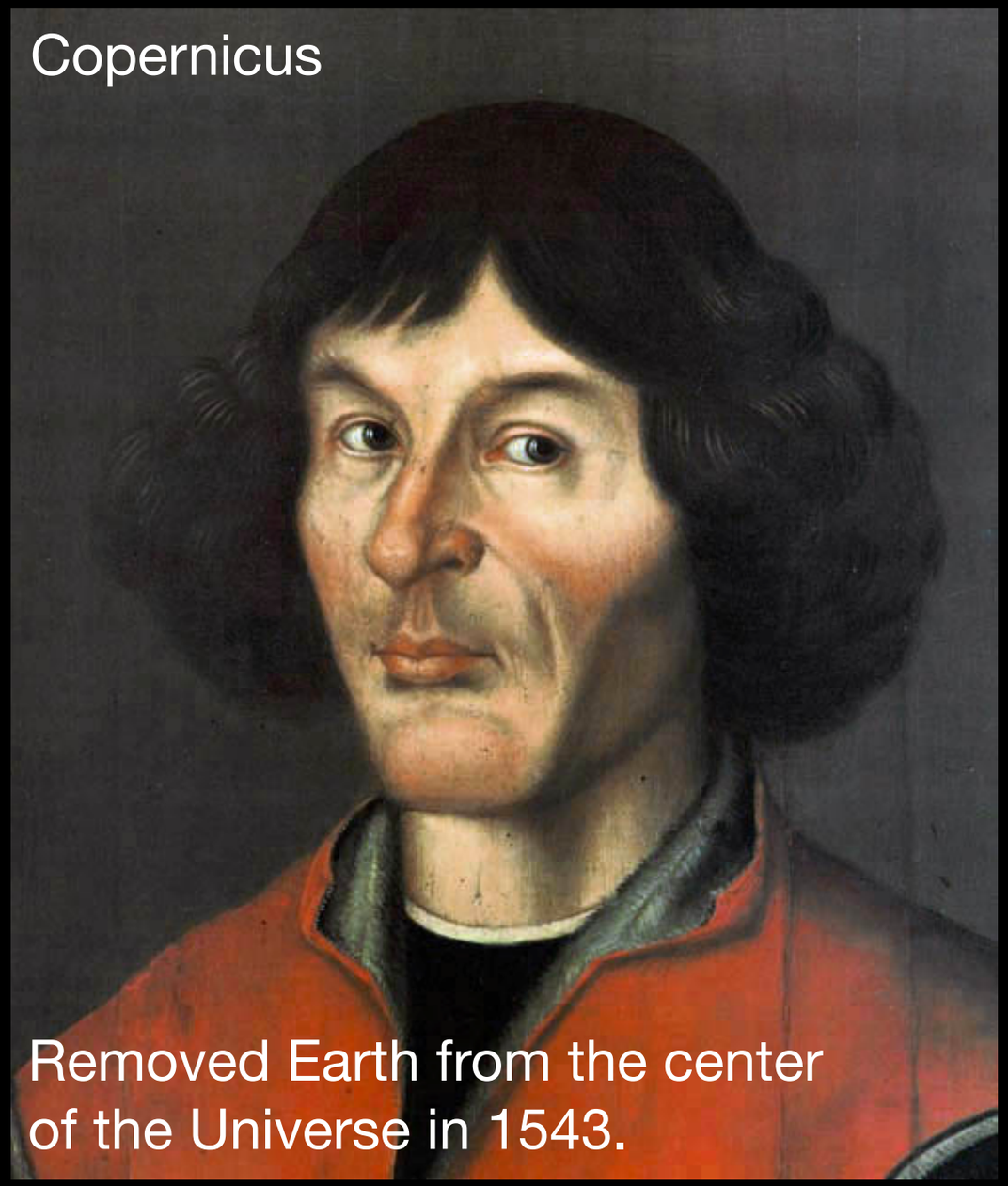
Our place in the Universe

- Ptolemy is often portrayed as the champion of the geocentric model.

- “When I follow at my pleasure the serried multitude of the stars in their circular course, my feet no longer touch the Earth.”

-Ptolemy (150AD)

Our place in the Universe



Our place in the Universe

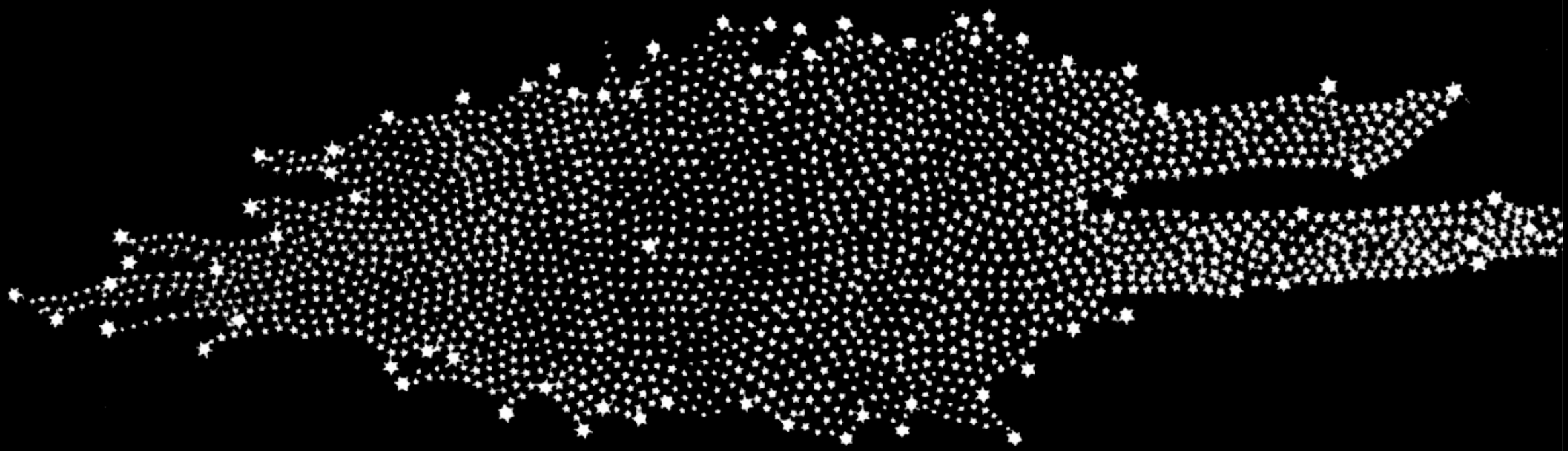
- Copernicus removed Earth from the center of the Universe, but is the Sun at the center of the Universe?

Our place in the Universe

- Herschel is an avid observer and telescope builder.
- Two key contributions:
  - Mapped the structure of the Milky Way.
  - Built a catalog of “nebulae.”

Herschel

Our place in Universe



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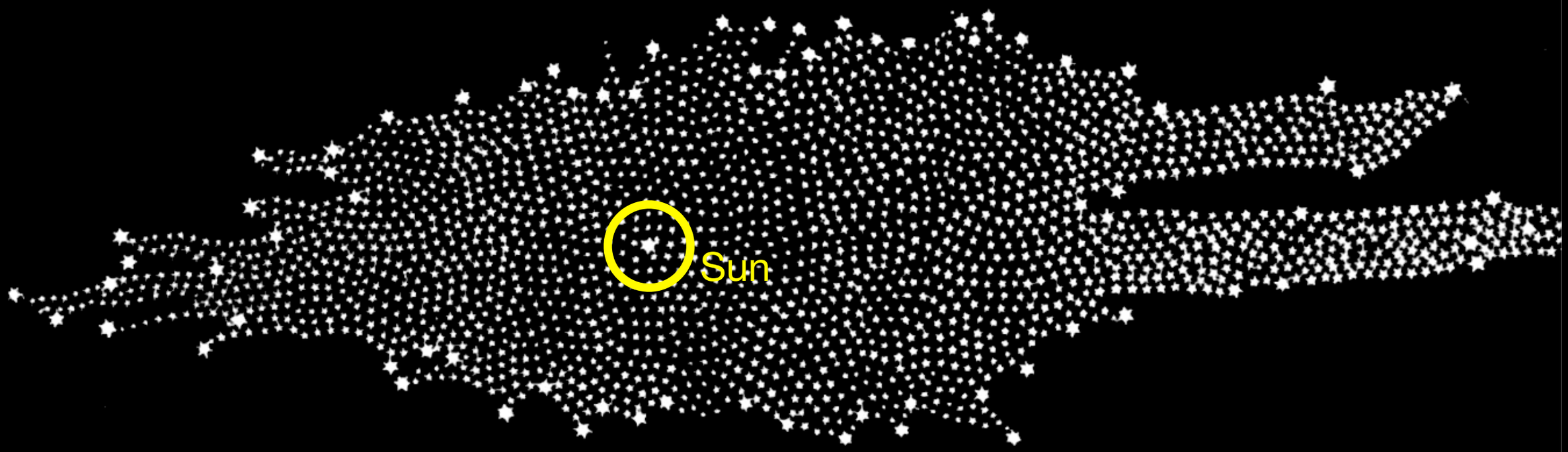
Our place in Universe



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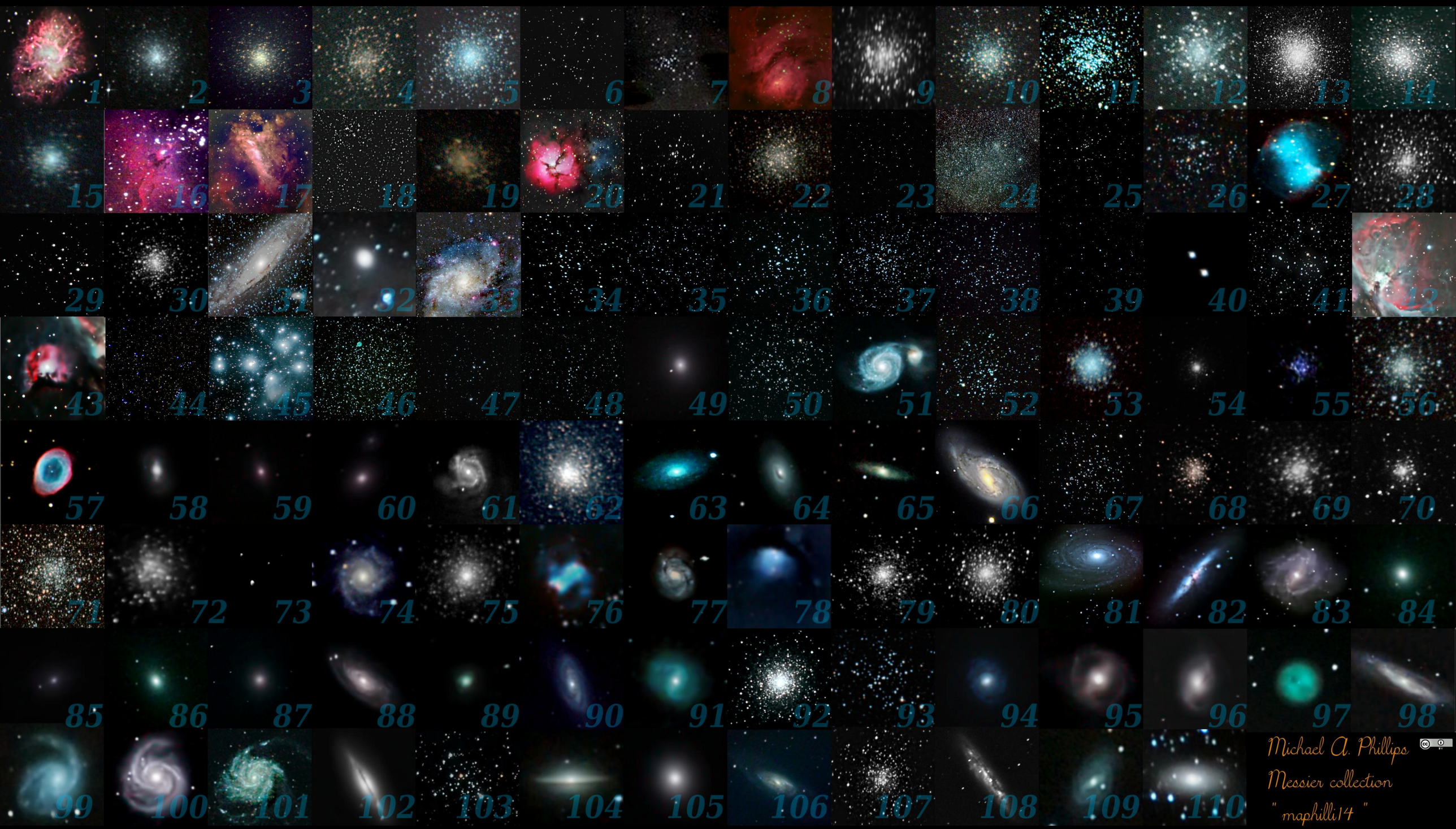
Herschel counted stars in all directions and determined:

- The Milky Way is a disk. [right]
- The Sun is approximately at the center. [wrong]

Our place in the Universe



Michael A. Phillips
Messier collection
" maphilli14 "

Our place in the Universe

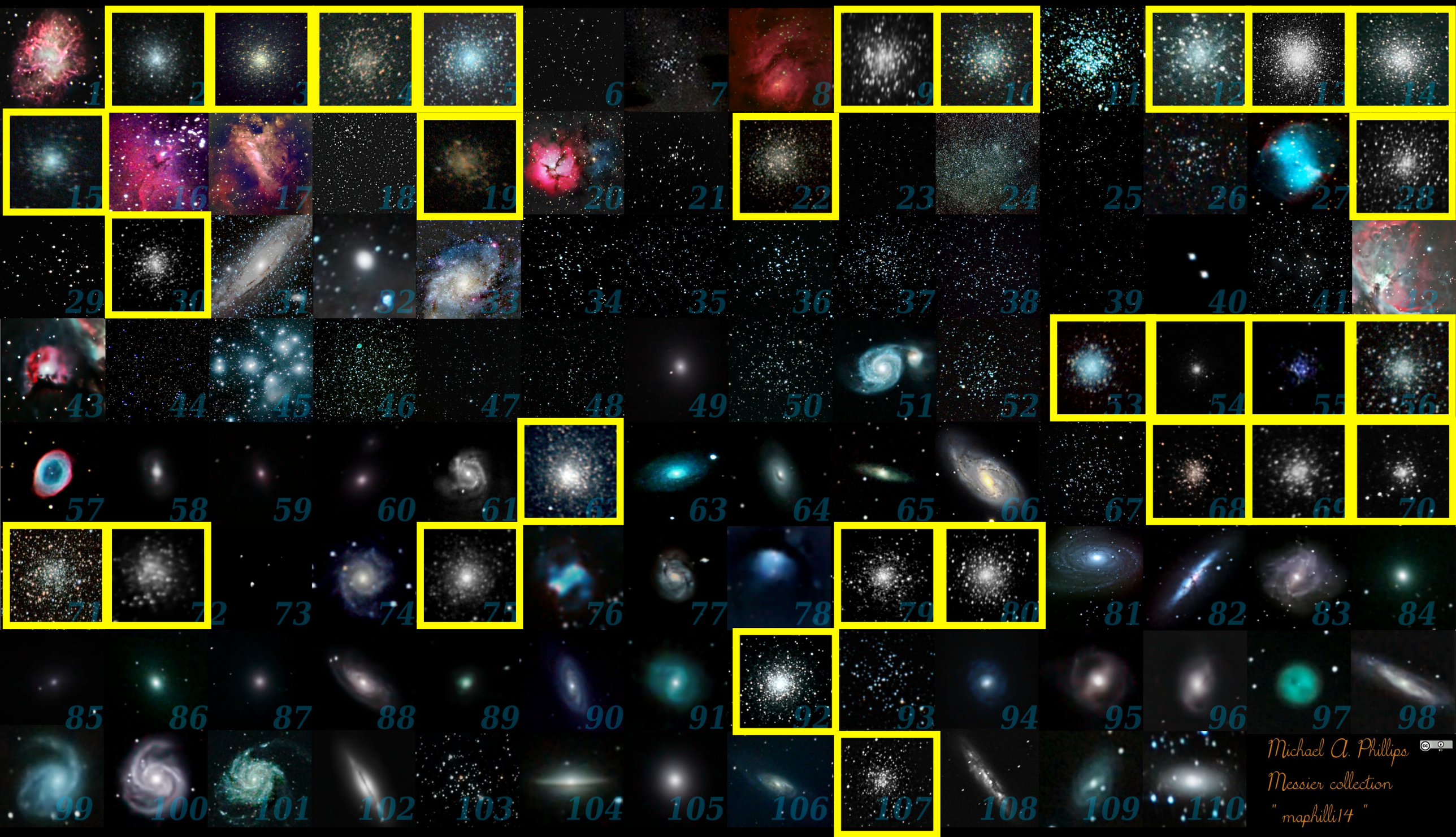
- Harlow Shapley counted globular clusters and concluded in 1920:

- The Sun is far from the center of the Milky Way. [right]

- The Milky Way is so large that it has to be the only galaxy in the Universe. [wrong]

Shapley

Our place in the Universe



Michael A. Phillips
Messier collection
" maphilli14 "

Our place in the Universe

Shapley: these “spiral nebulae,” like the globular clusters, have to be part of the Milky Way.

Pinwheel Galaxy

Triangulum Galaxy

NGC 1300

Black Eye Galaxy

Why did Herschel get the location of the Sun wrong?
The Milky Way is dusty like other galaxies.

Black Eye Galaxy

Andromeda Galaxy

Our place in the Universe

- In 1924, Edwin Hubble determined the distance to Andromeda Galaxy to be 100x the size of the Milky Way!

- These “spiral nebulae” are galaxies like the Milky Way or “island universes”.


Hubble

Our place in the Universe

- In 1908, Henrietta Leavitt discovered that for a certain type of variable star, brighter ones have longer periods.

- The “period-luminosity P-L” relation for cepheids is then used to determine distances that are out of reach of the parallax method.

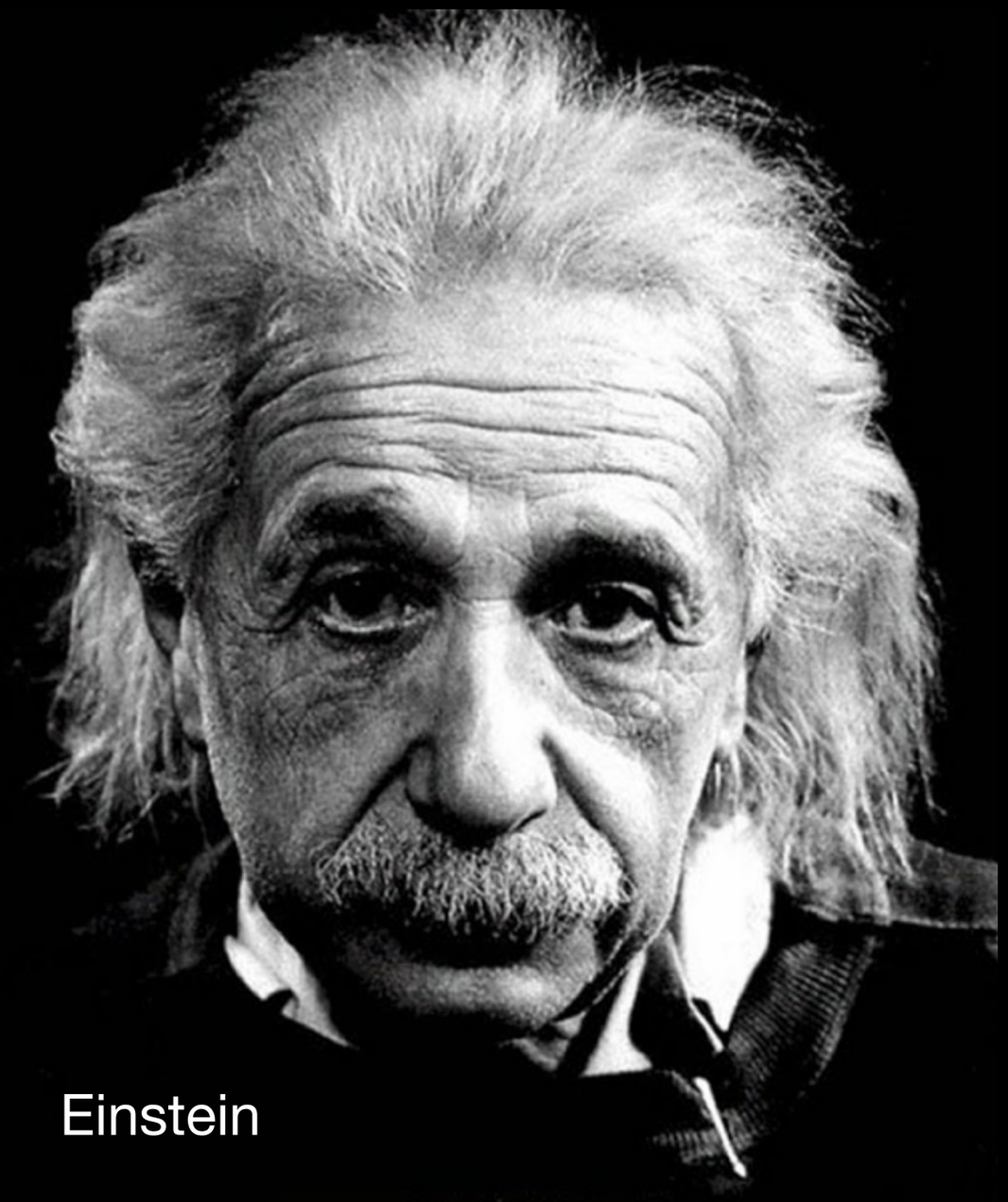
Our place in the Universe

- In 1915, Einstein developed General Relativity.

$$\boxed{G_{ik}} + \Lambda g_{ik} = \boxed{8\pi G T_{ik}}$$

Geometry of the Universe

Stuff in the Universe



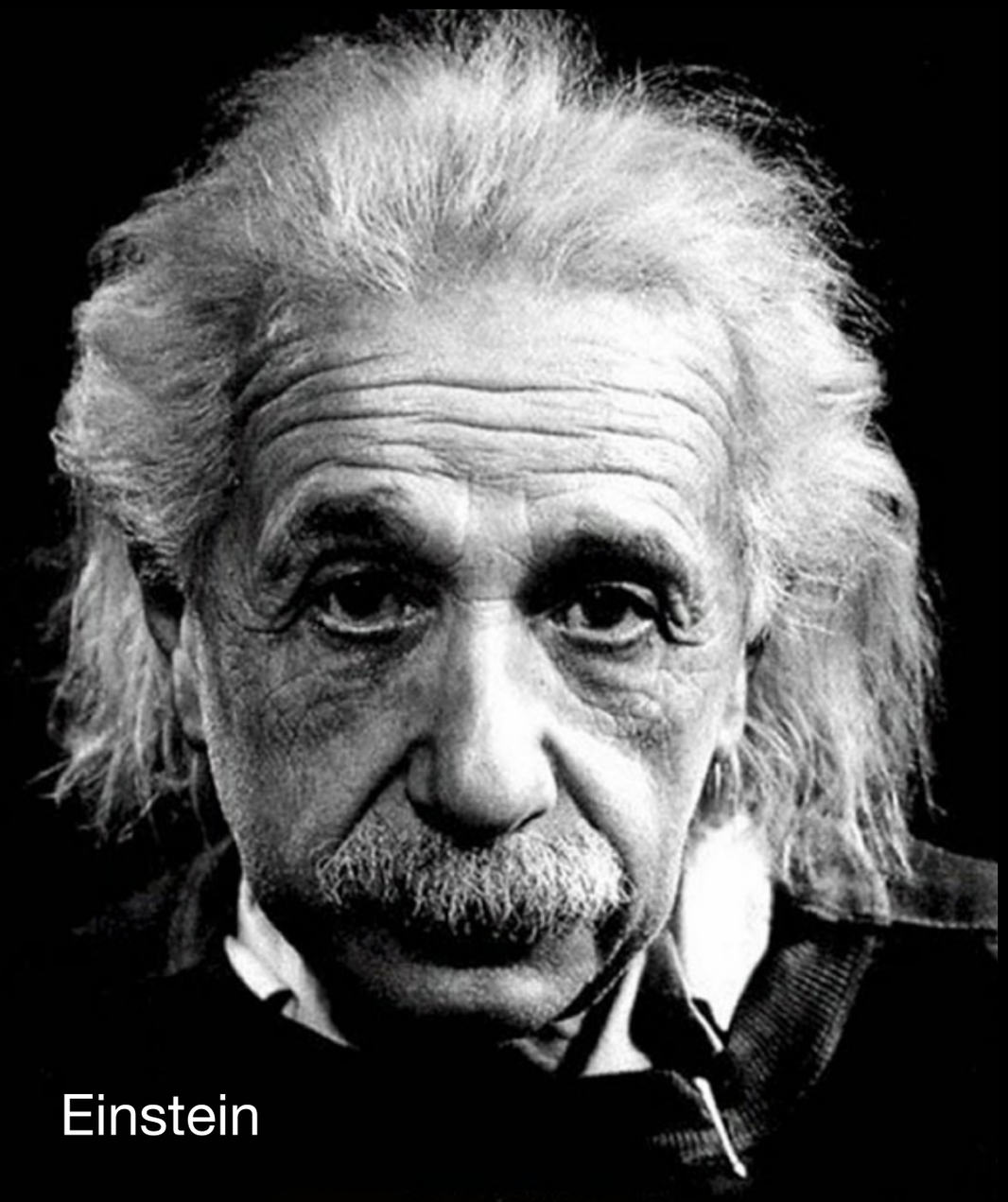
Einstein

Our place in the Universe

- In 1915, Einstein developed General Relativity.

$$G_{ik} + \boxed{\Lambda g_{ik}} = 8\pi G T_{ik}$$

Einstein added a “cosmological constant” to keep the Universe static.

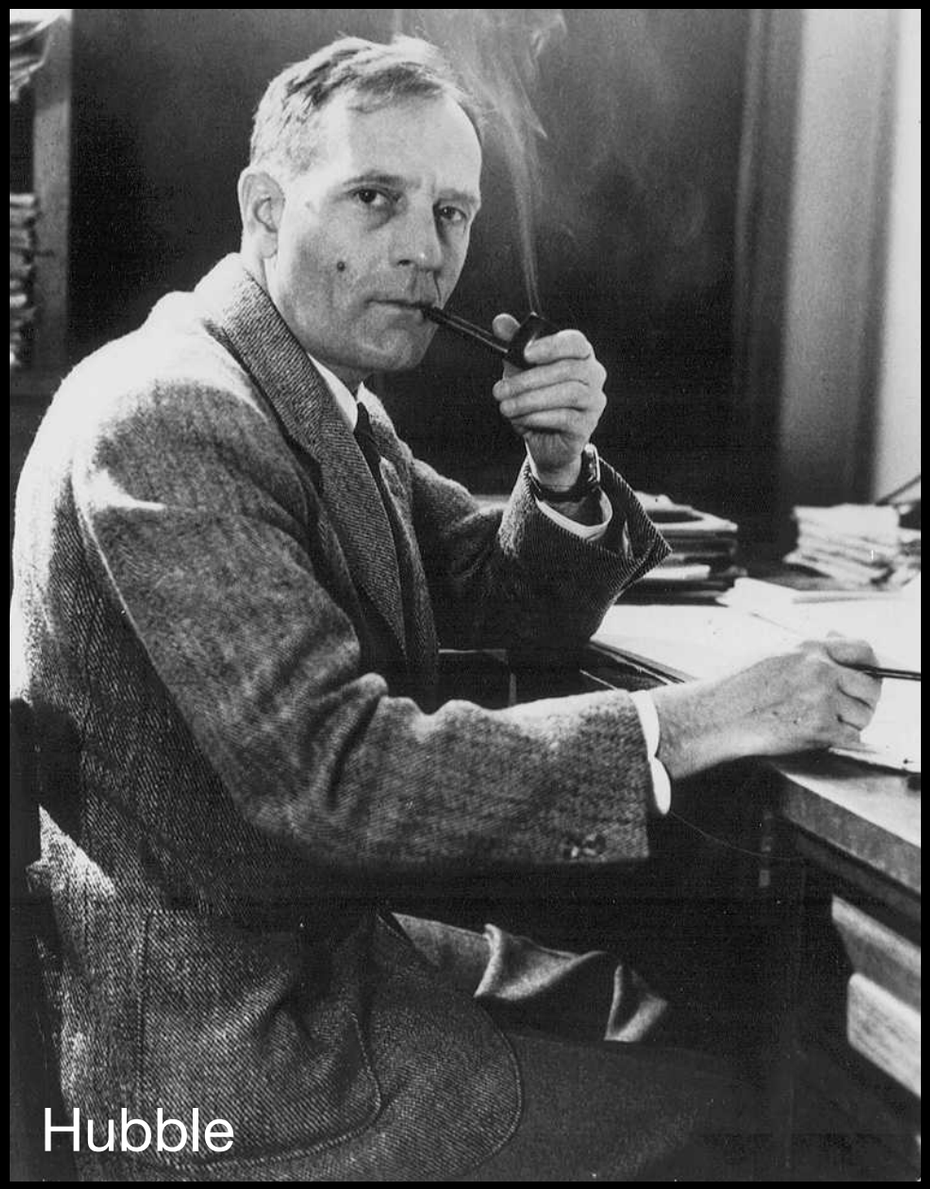


Einstein

Our place in the Universe

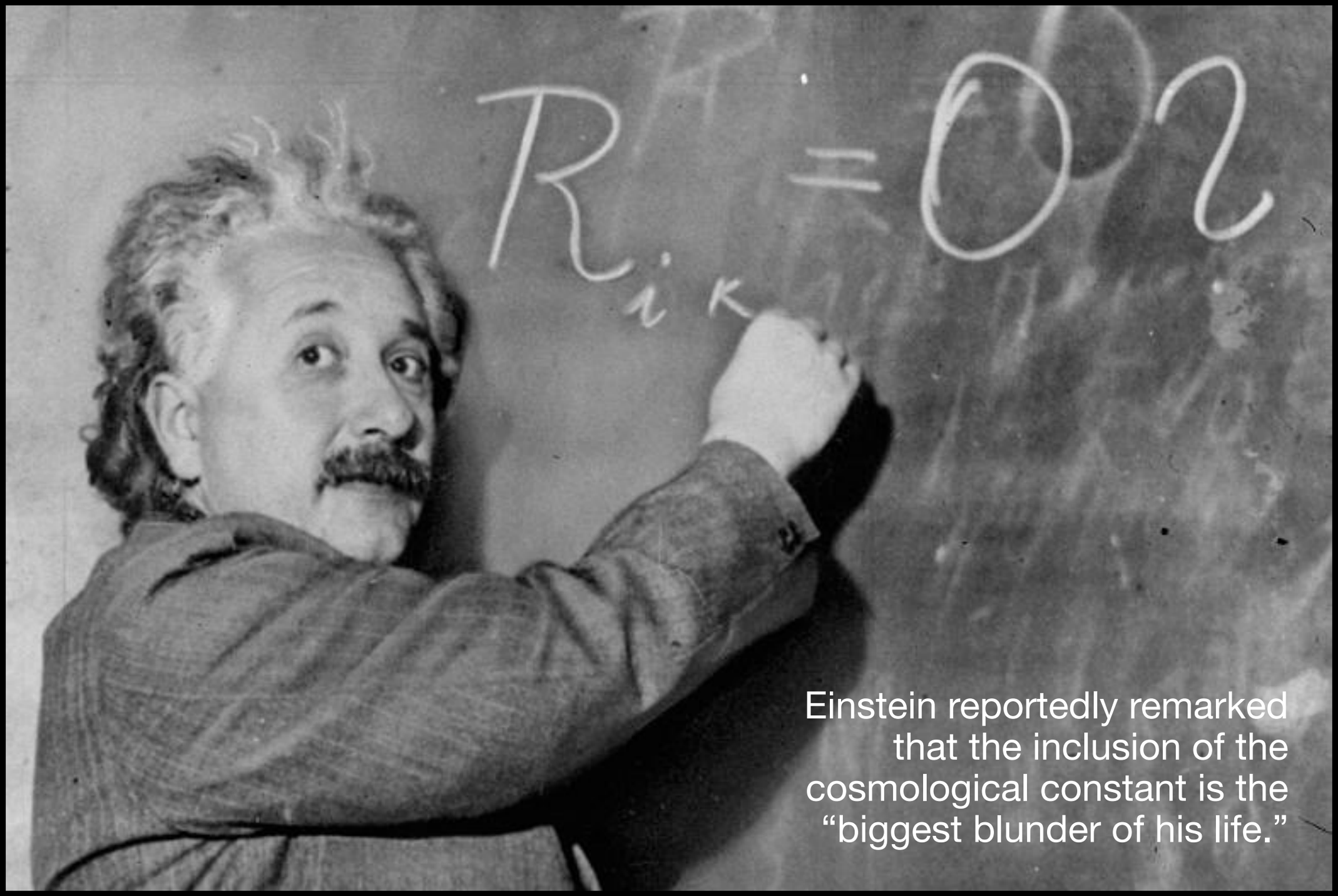
- By 1929, Hubble had measured distances to several galaxies using Leavitt's P-L relation.

- Comparing to their velocities, Hubble provided evidence for an expanding Universe.



Hubble

Our place in the Universe



Einstein reportedly remarked that the inclusion of the cosmological constant is the "biggest blunder of his life."

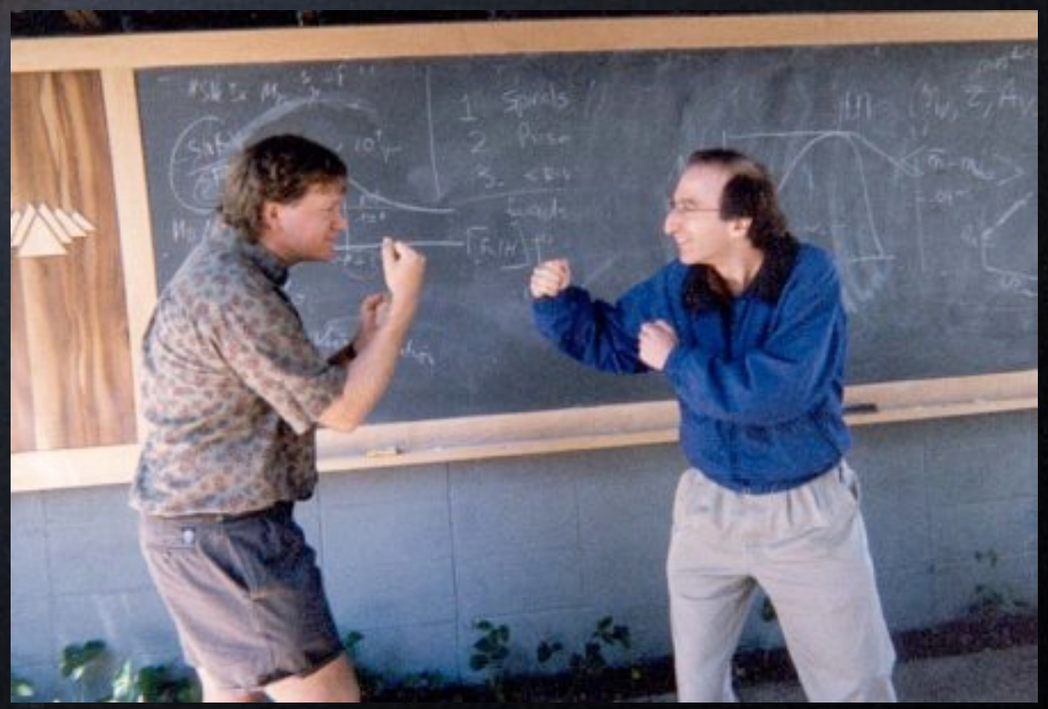
Astronomers found that a certain type of stellar explosion (Type Ia supernova) are bright and have uniform intrinsic brightness.

These supernovae provide measures of even greater distances than even Leavitt's P-L relation can reach.

In the 1990s, astronomers began to use them as "standard candles" and map the expansion history of the Universe.

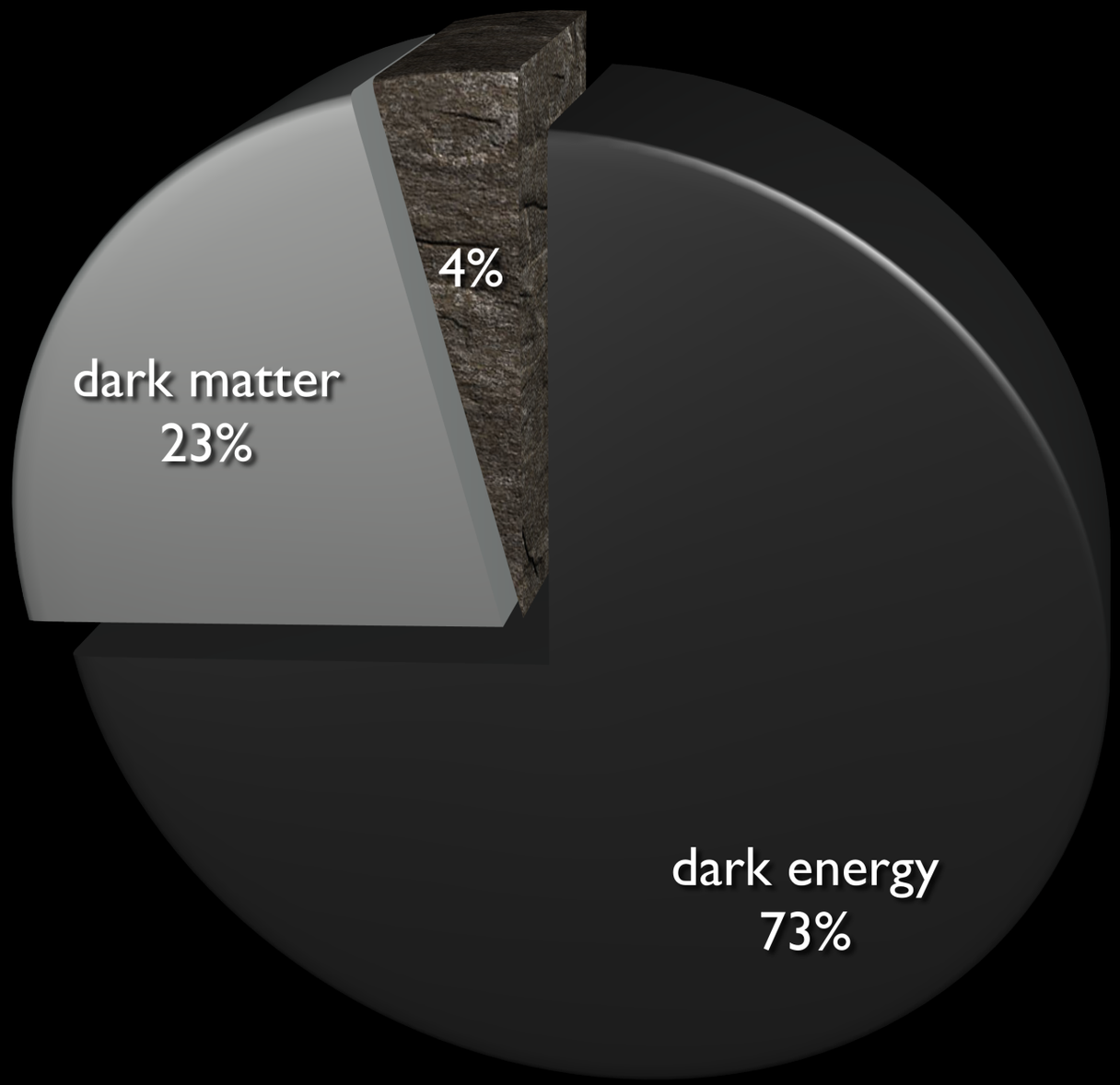
To their surprise, the expansion rate of the Universe
is not slowing down, but speeding up!

The unknown driver of the acceleration is often dubbed “dark energy.”



Our place in the Universe

- Counting up the stuff in the Universe, the “known unknowns” constitutes 96%!



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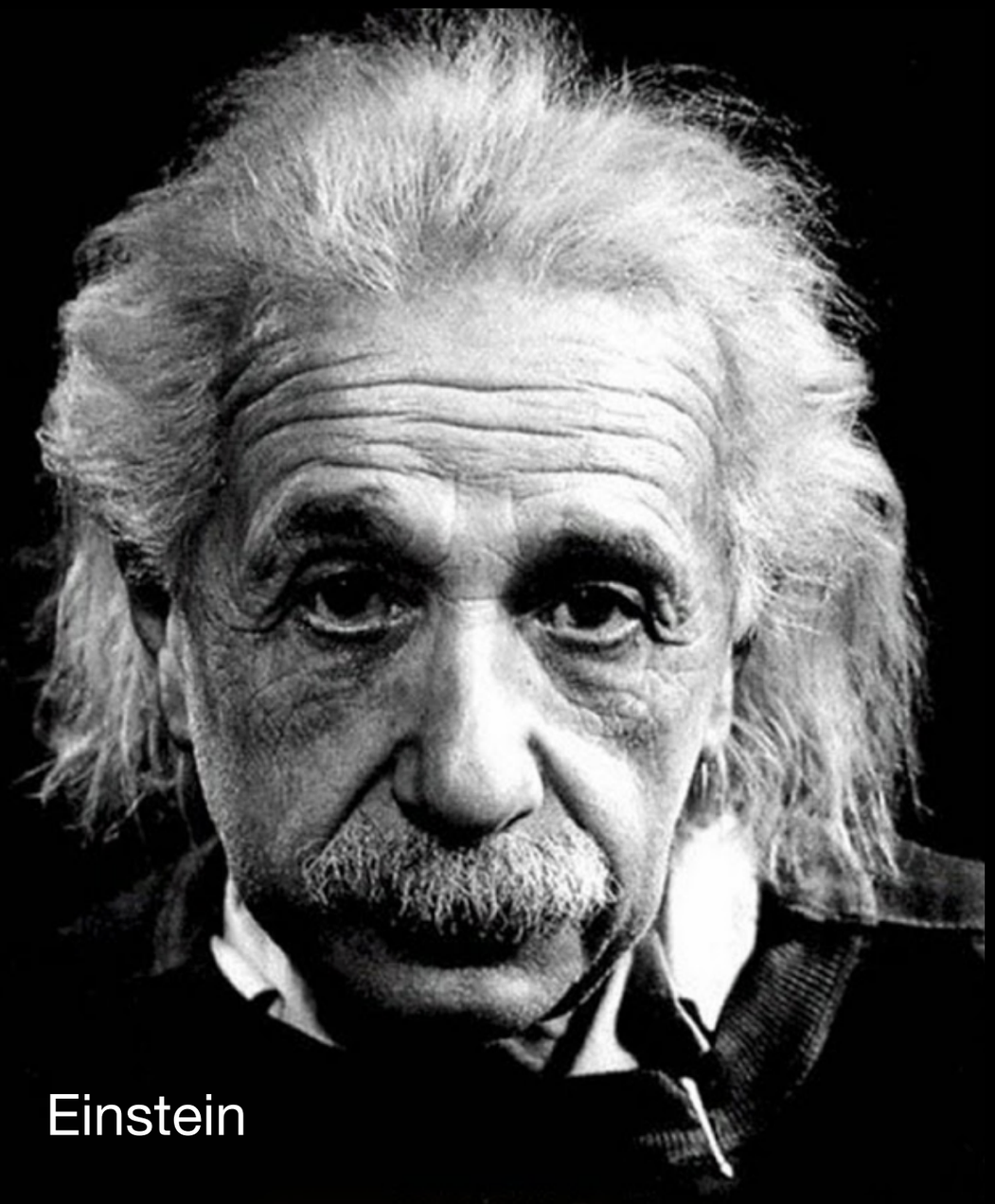
Our place in the Universe

- Biggest blunder?

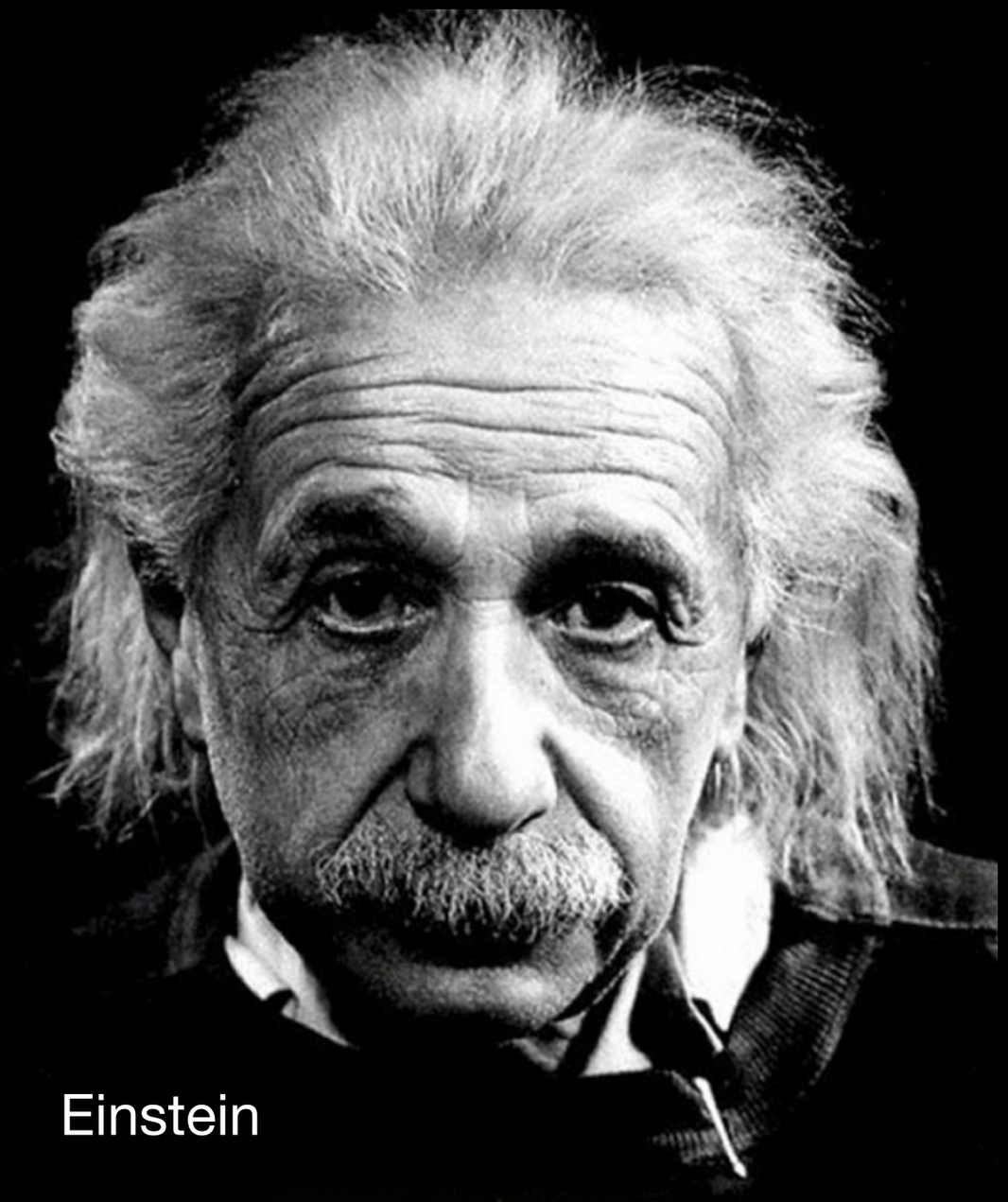
- The cosmological constant currently provides the best description to the latest supernova data.



Einstein

Our place in the Universe

- Does God play dice?
- There are fundamental incompatibilities between General Relativity and Quantum Mechanics.
- If we naively take dark energy as quantum vacuum energy, the discrepancy is up to 10^{100}x!
- Understanding observed dark energy may be the key.



Einstein