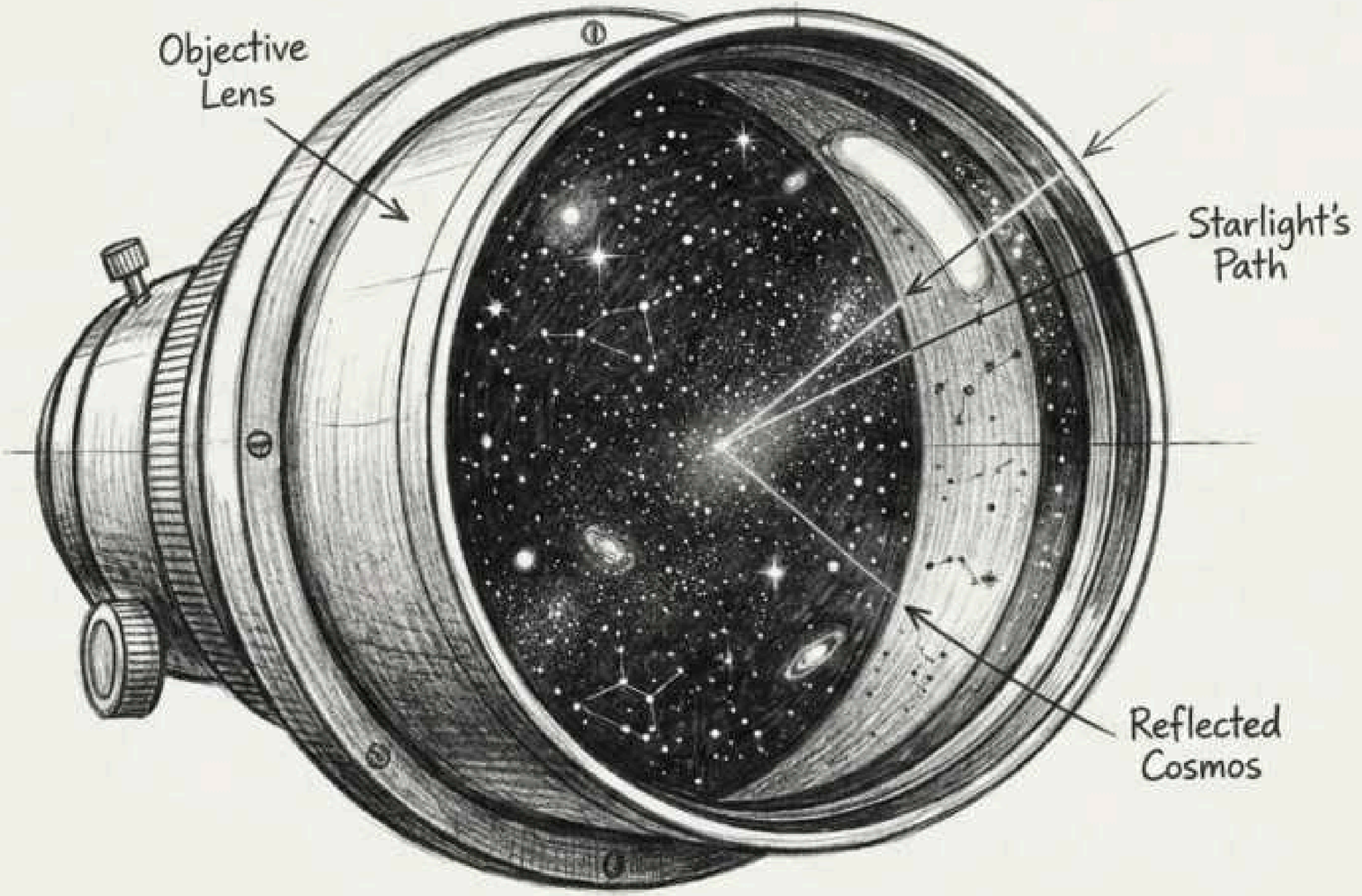
¶ 6.1

ASTR 101 B: Galaxies, Cosmology, and Life



Lecture 6
Instructor:
Gary Anderson

Gemini Notebook

The Four Cosmic Scales of Inquiry

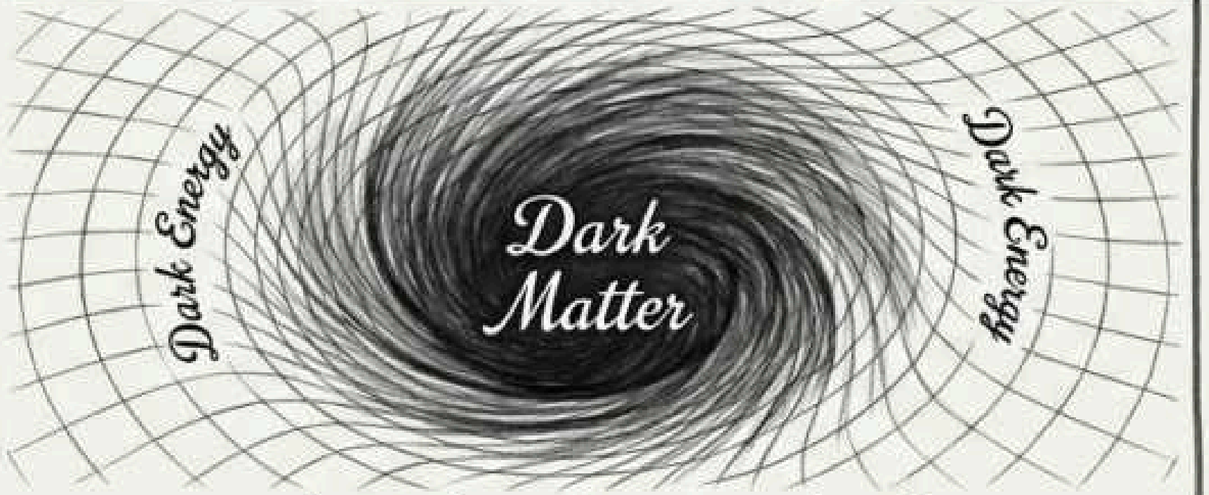
¶ 6.2



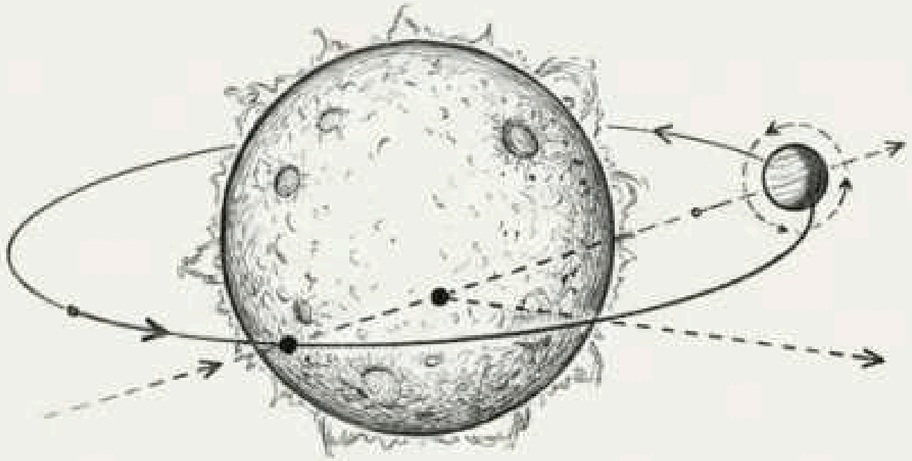
What are galaxies, and what is the Milky Way like?



How do we know the universe is expanding?



What is the universe made of?

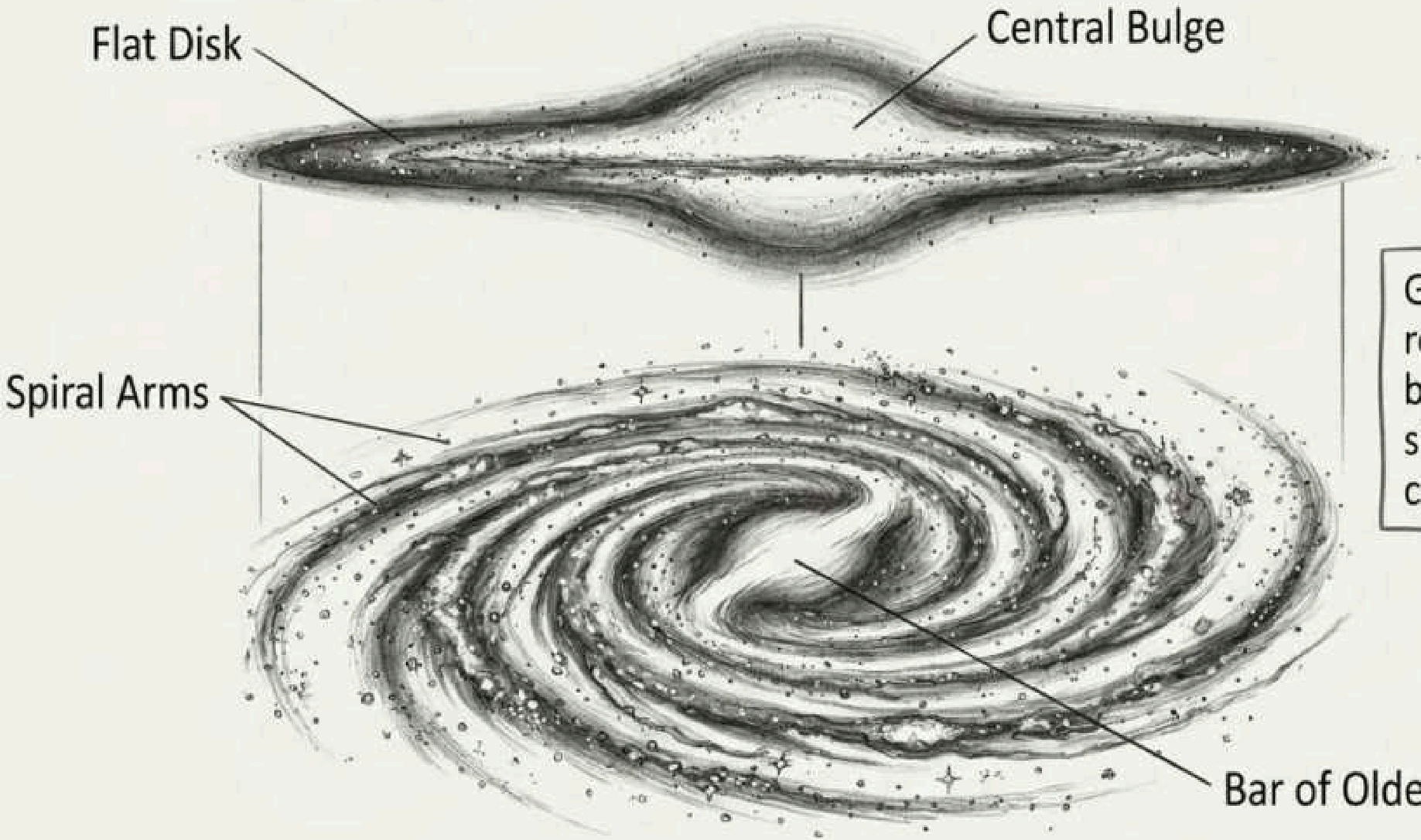


The search for other worlds and life.

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¶6.3

Architecture of the Milky Way

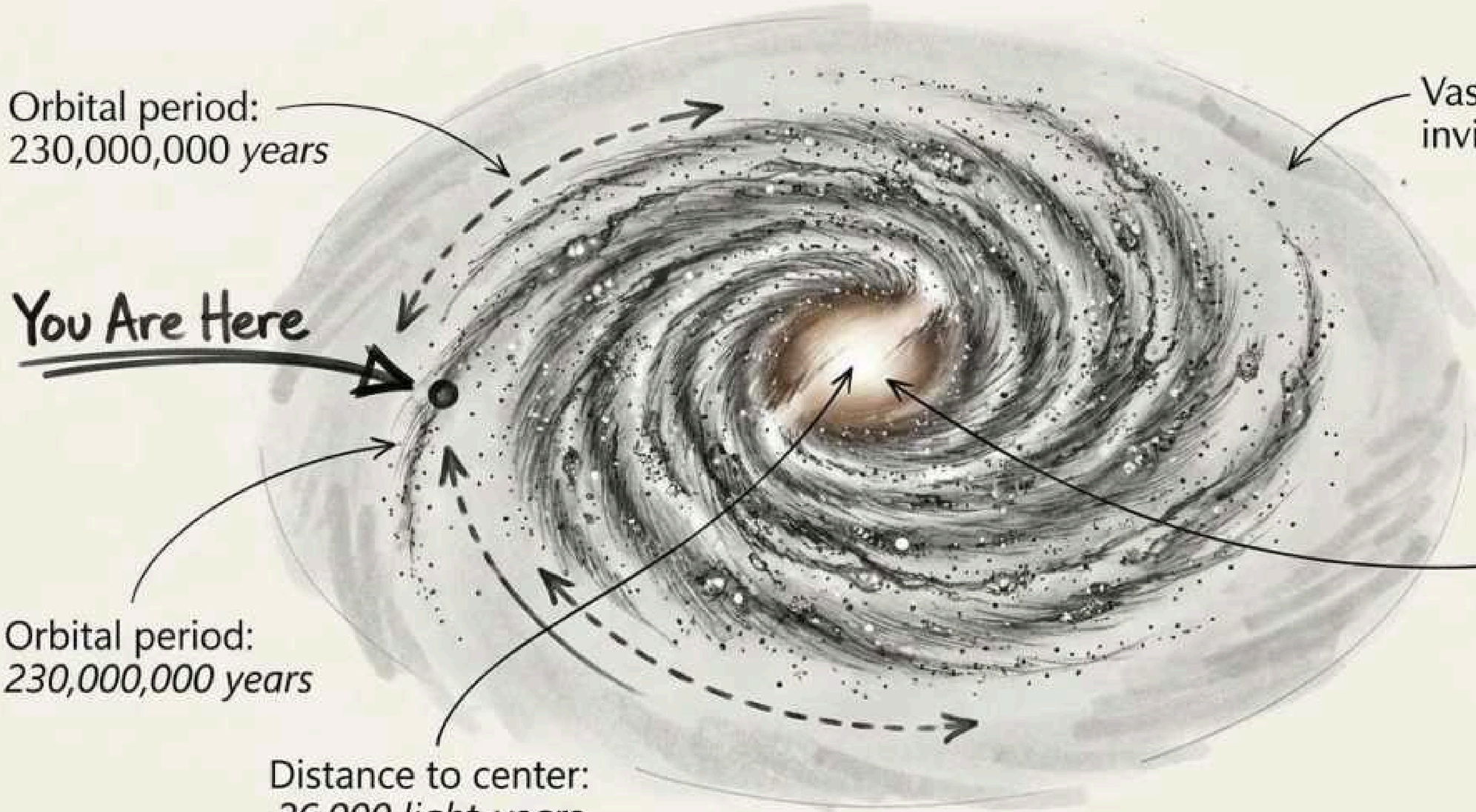


Galileo's telescope revealed the pale band in the night sky is made of countless stars.

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Our Galactic Address and Orbit

¶6.4



Contents:

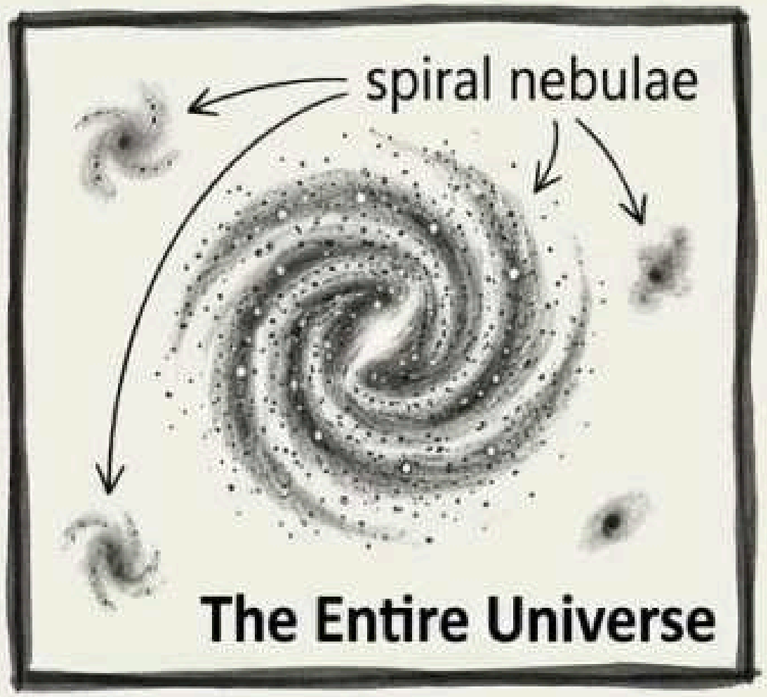
Hundreds of billions of stars.

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Breaking the Boundary of the Universe

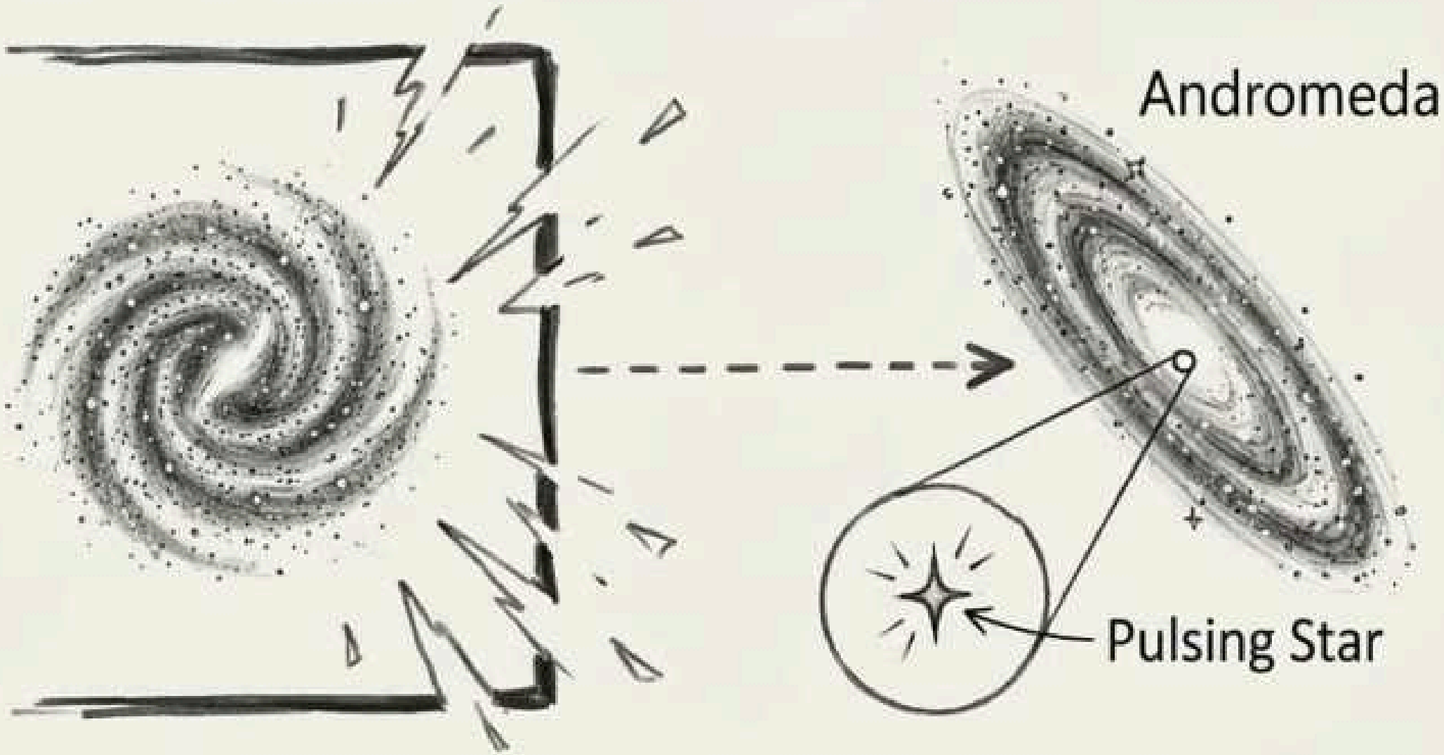
¶6.5

Pre-1920s consensus:



Milky Way = The Universe

1924 Observation:



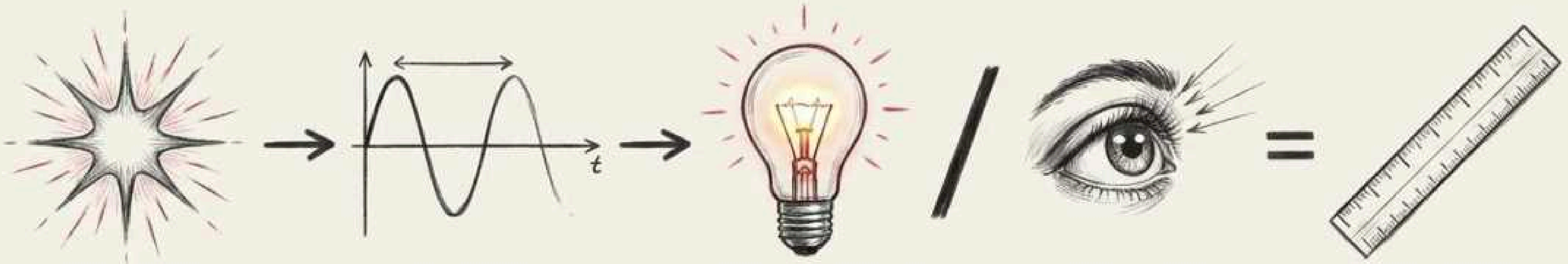
Edwin Hubble identifies a pulsing star in Andromeda, proving it lies far outside our galaxy.

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The Standard Candle Mechanism

¶ 6.6

Discovery by Henrietta Leavitt



Cepheid variable → Period (time to pulse) → True Luminosity (longer pulse = brighter) / Apparent Brightness = Distance

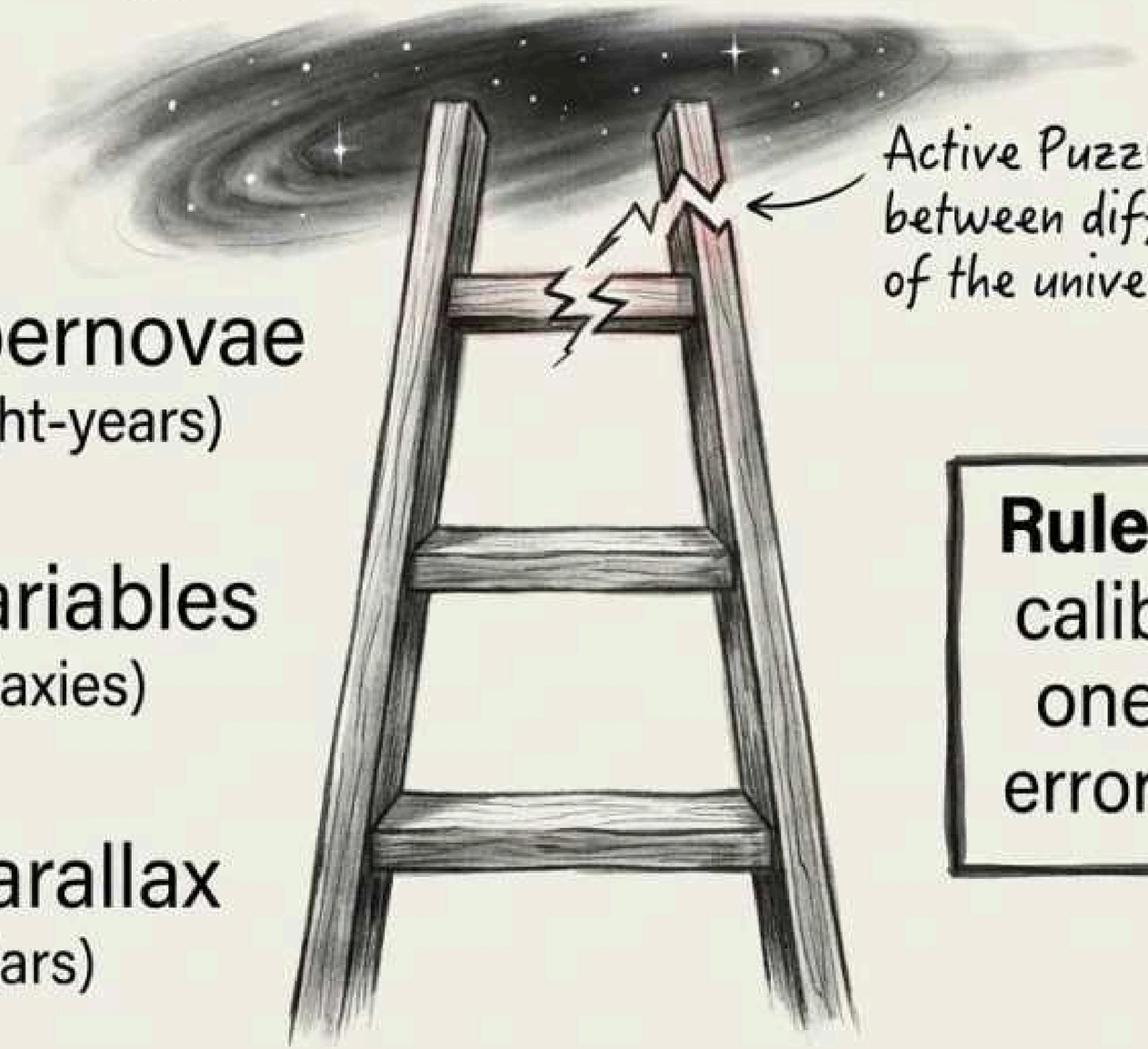
$$m - M = 5 \log_{10}(d) - 5$$

Logic: Measure Period -> Know Luminosity -> Compare to Apparent Brightness -> Calculate Distance.

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Calibrating the Cosmic Distance Ladder

¶6.7



Active Puzzle: The slight mismatch between different measurements of the universe's expansion rate.

Type Ia Supernovae
(Billions of light-years)

Cepheid Variables
(Nearby galaxies)

Radar & Parallax
(Nearby stars)

Rule: Each rung is calibrated by the one beneath it; errors compound.

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The Three Morphologies of Galaxies

¶6.8

Spiral



- Flat disk
- Spiral arms
- Active star birth

Elliptical



- Smooth ball of older stars
- Little gas

Irregular



- No regular form
- Chaotic



Milky Way + Andromeda



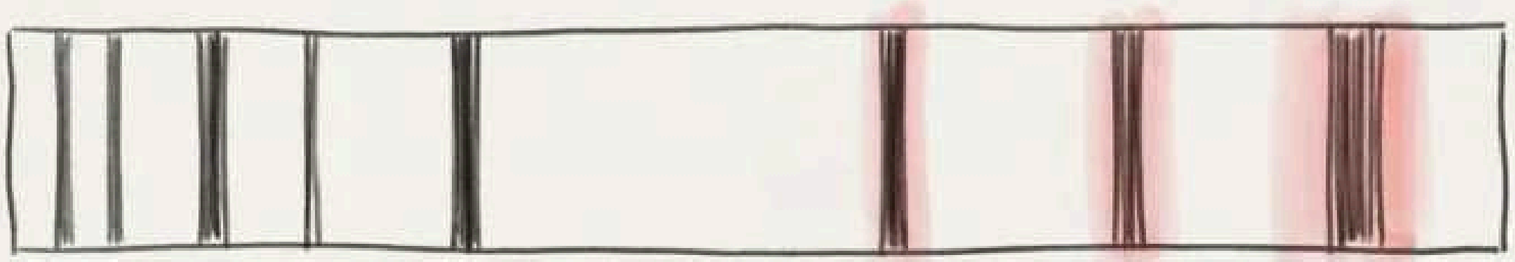
Future forecast:
In 4-5 billion years, merge into one great elliptical galaxy.

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The Doppler Shift in Galactic Spectra

¶ 6.9





$$z = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}}$$

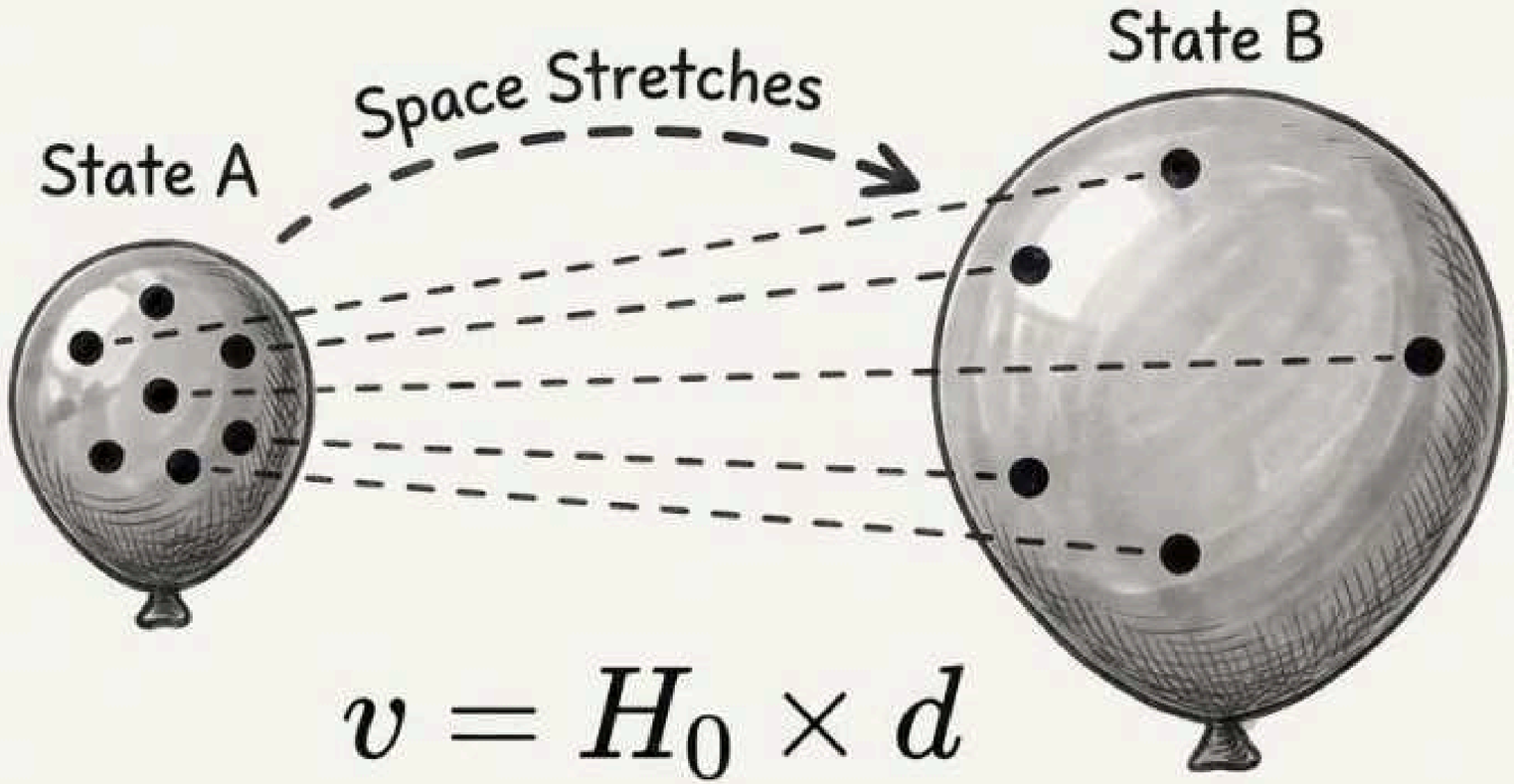
1920s Observation: Almost all galaxies exhibit lines shifted to the red.

1929 Pattern (Hubble): The farther away a galaxy is, the faster it appears to move away from us.

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Hubble's Law and Stretching Space

¶ 6.10



$$v = H_0 \times d$$

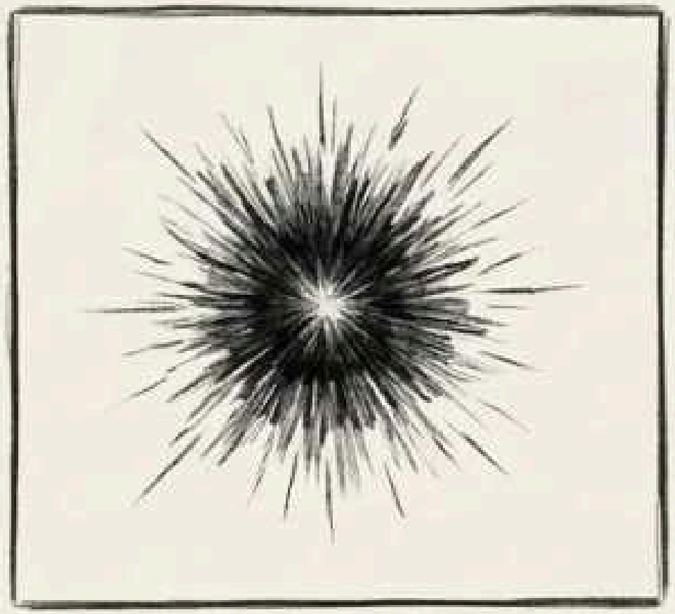
Key Concept: Galaxies are not rushing through space. Space itself is stretching and carrying the galaxies with it.

We are not at the center; every dot moves away from every other dot.

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Rewinding the Clock to the Big Bang

¶ 6.11



The Big Bang



Dense Past



Present Universe

Timeline: 13.8 billion years ago

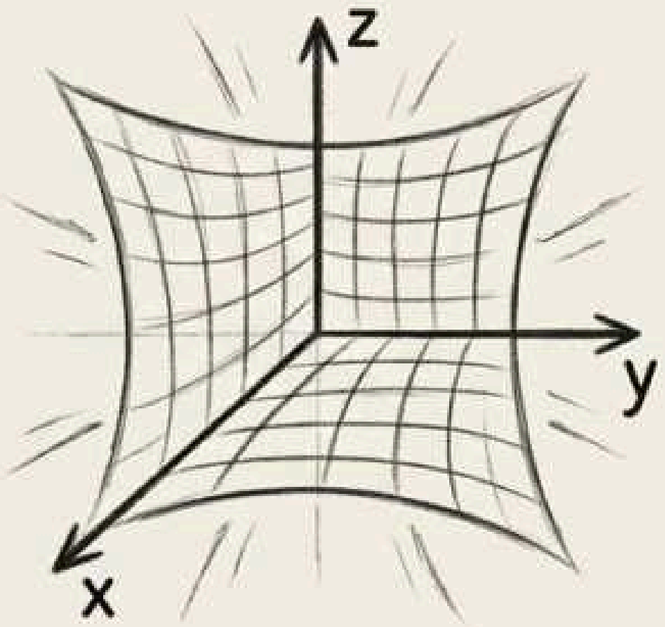
Clarification: The Big Bang was not an explosion IN space; it was the expansion OF space itself. The beginning of cosmic history.

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Three Pillars of Evidence for the Big Bang

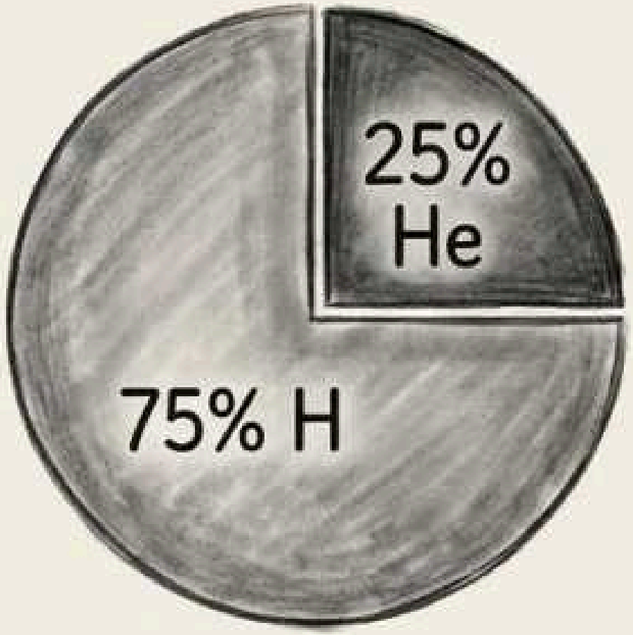
¶ 6.12

1. The Expansion



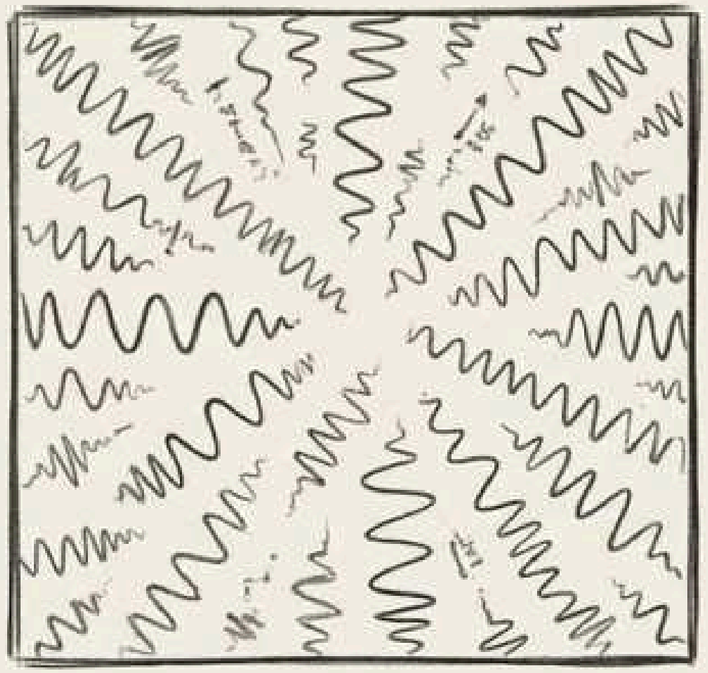
The observed ongoing expansion of space.

2. Light Elements



Oldest gas matches predicted mass ratio: ~75% H, ~25% He.

3. The Cosmic Glow

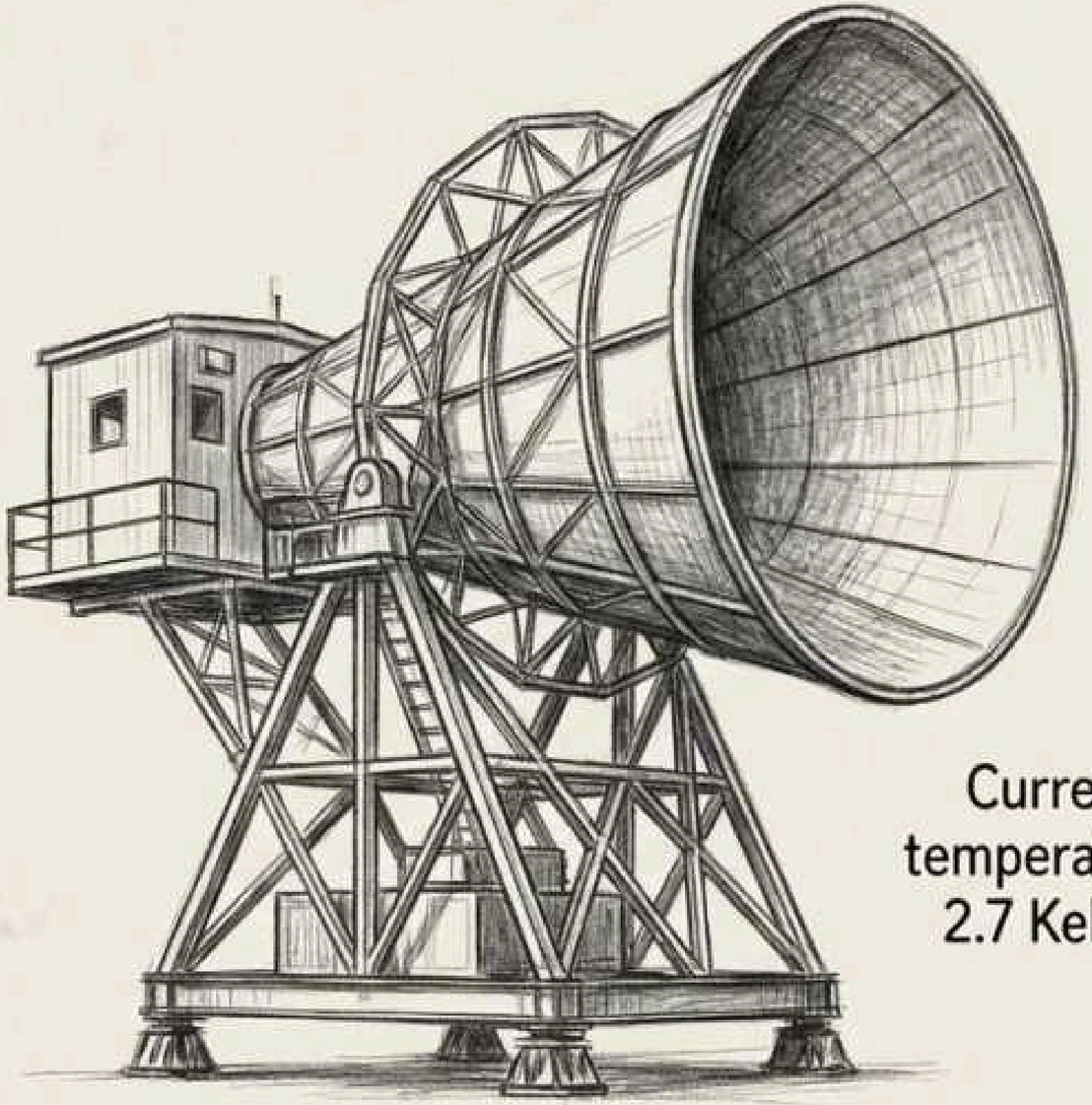


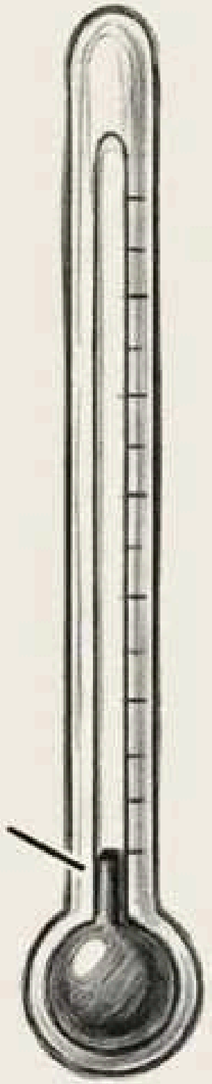
The faint glow filling the whole sky (Cosmic Microwave Background).

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Discovering the Cosmic Microwave Background

¶ 6.13





Current temperature: 2.7 Kelvin

Origin: Universe cooled enough for atoms to form; light traveled freely, stretching into microwaves over time.

Timeline: 380,000 years post-Big Bang.

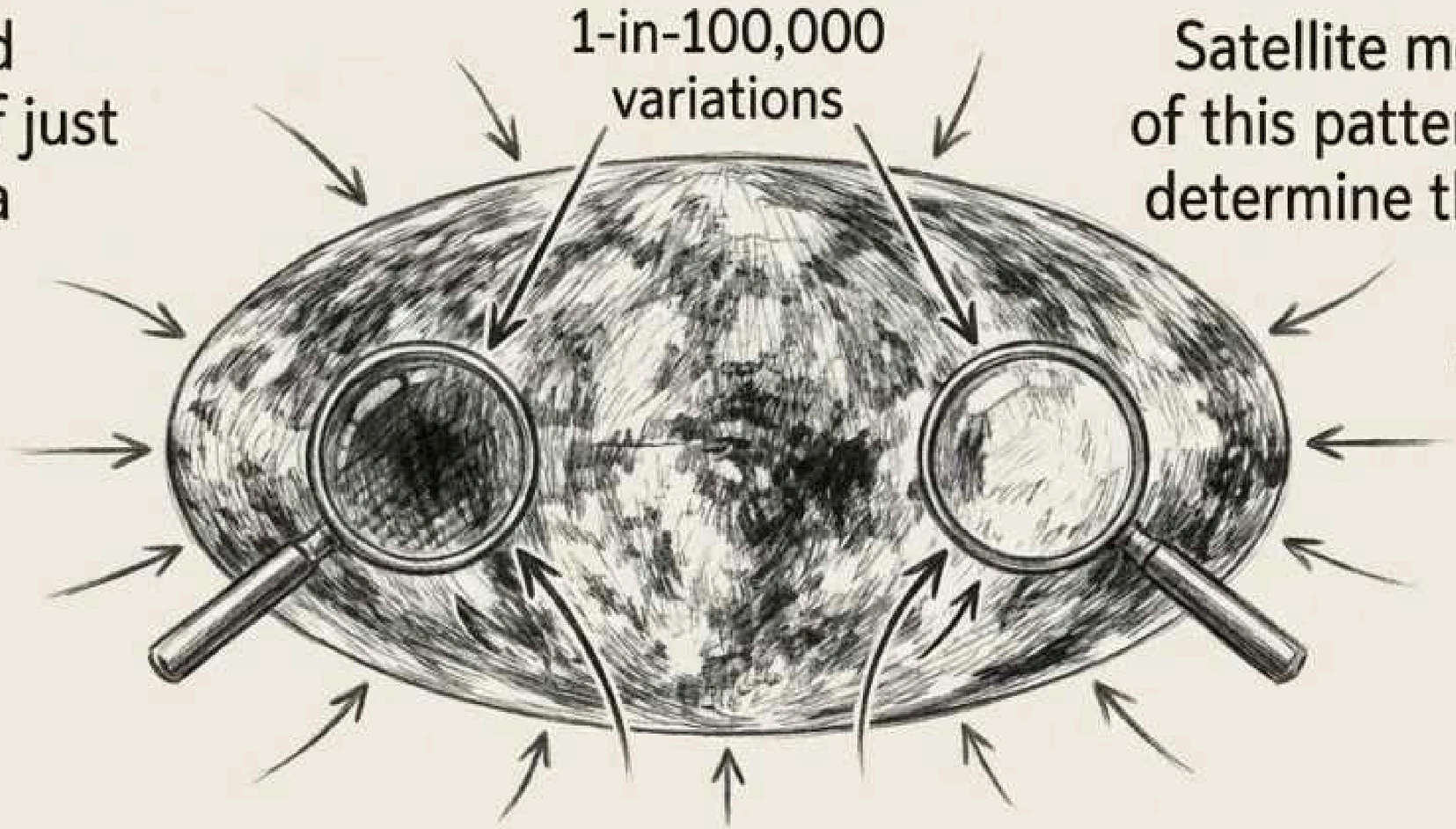
1965 Discovery: Arno Penzias and Robert Wilson accidentally detected this light as unexplained noise in their radio antenna.

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Seeds of Cosmic Structure

¶ 6.14

Hot and cold variations of just one part in a hundred thousand.

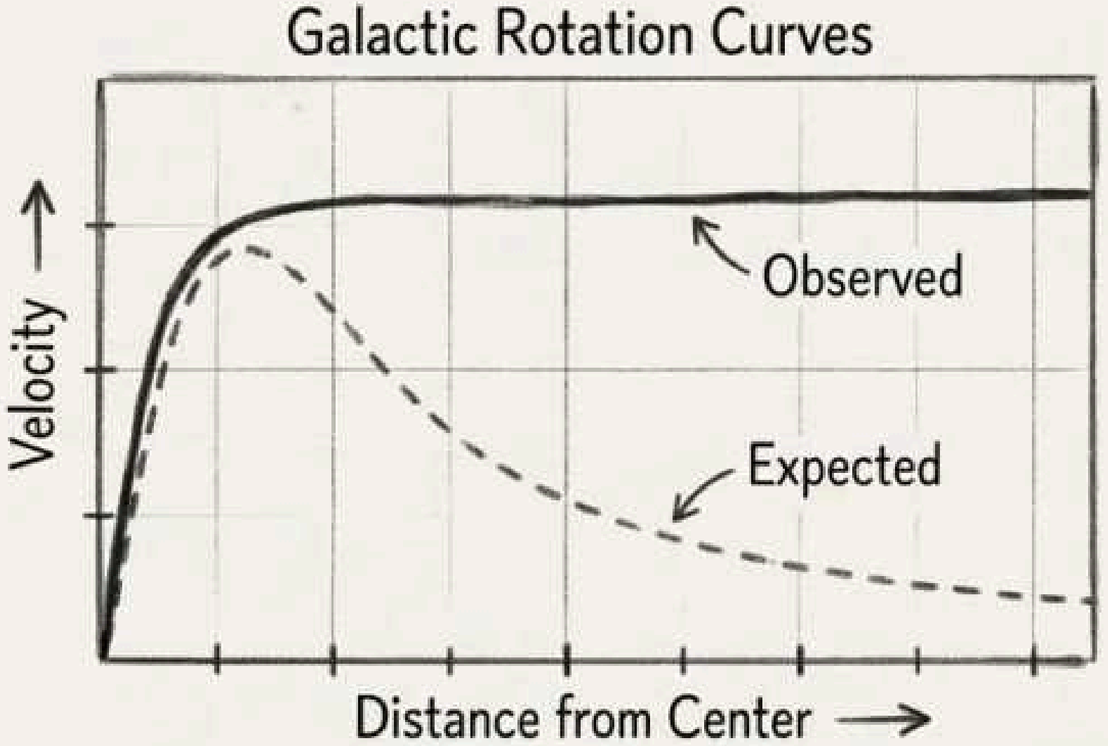


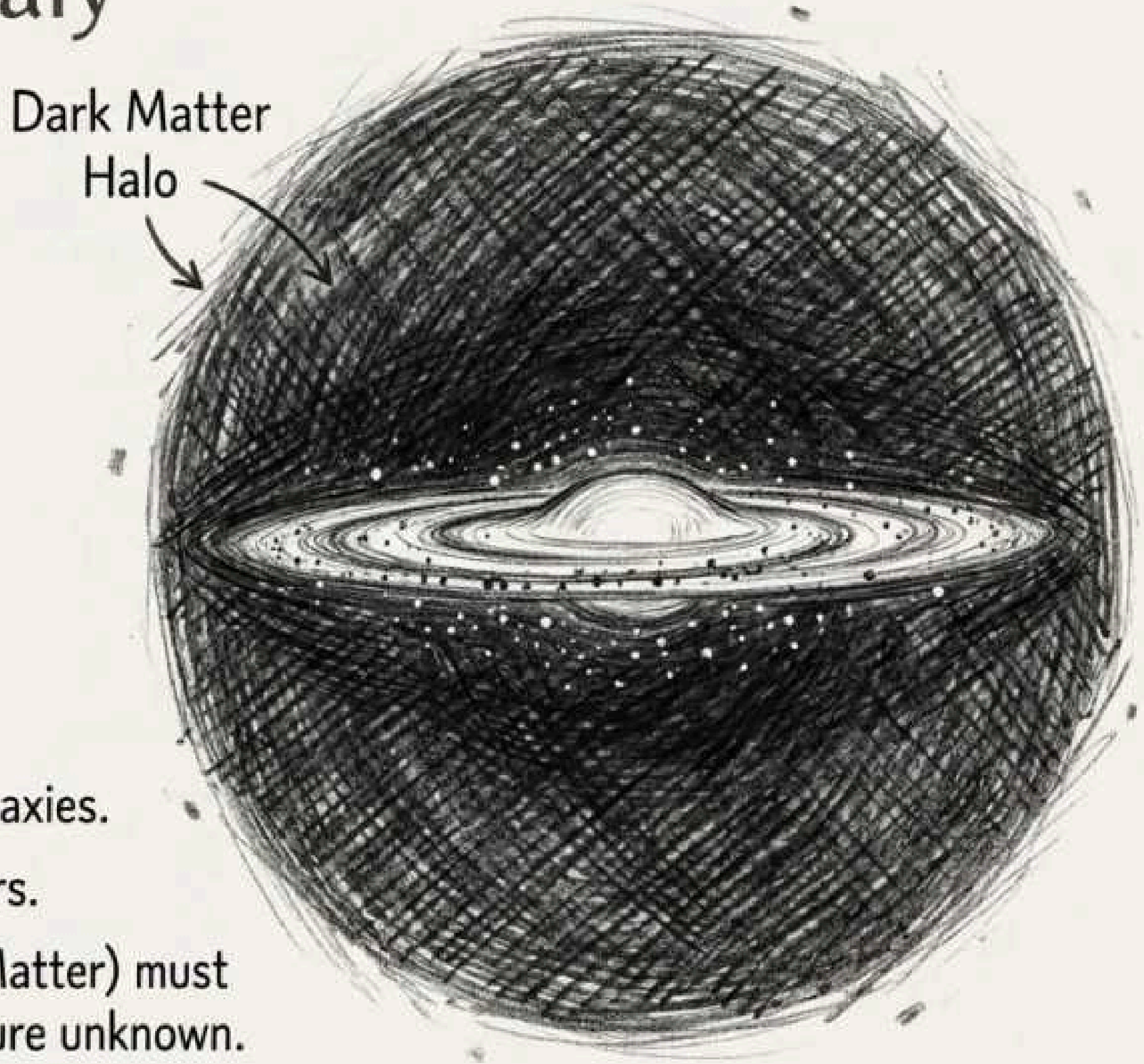
Satellite measurements of this pattern accurately determine the universe's s age and makeup.

Gravity pulled gas into denser regions, forming the first stars and galaxies.

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The Dark Matter Anomaly





1970s: Vera Rubin measures star orbits in spiral galaxies.

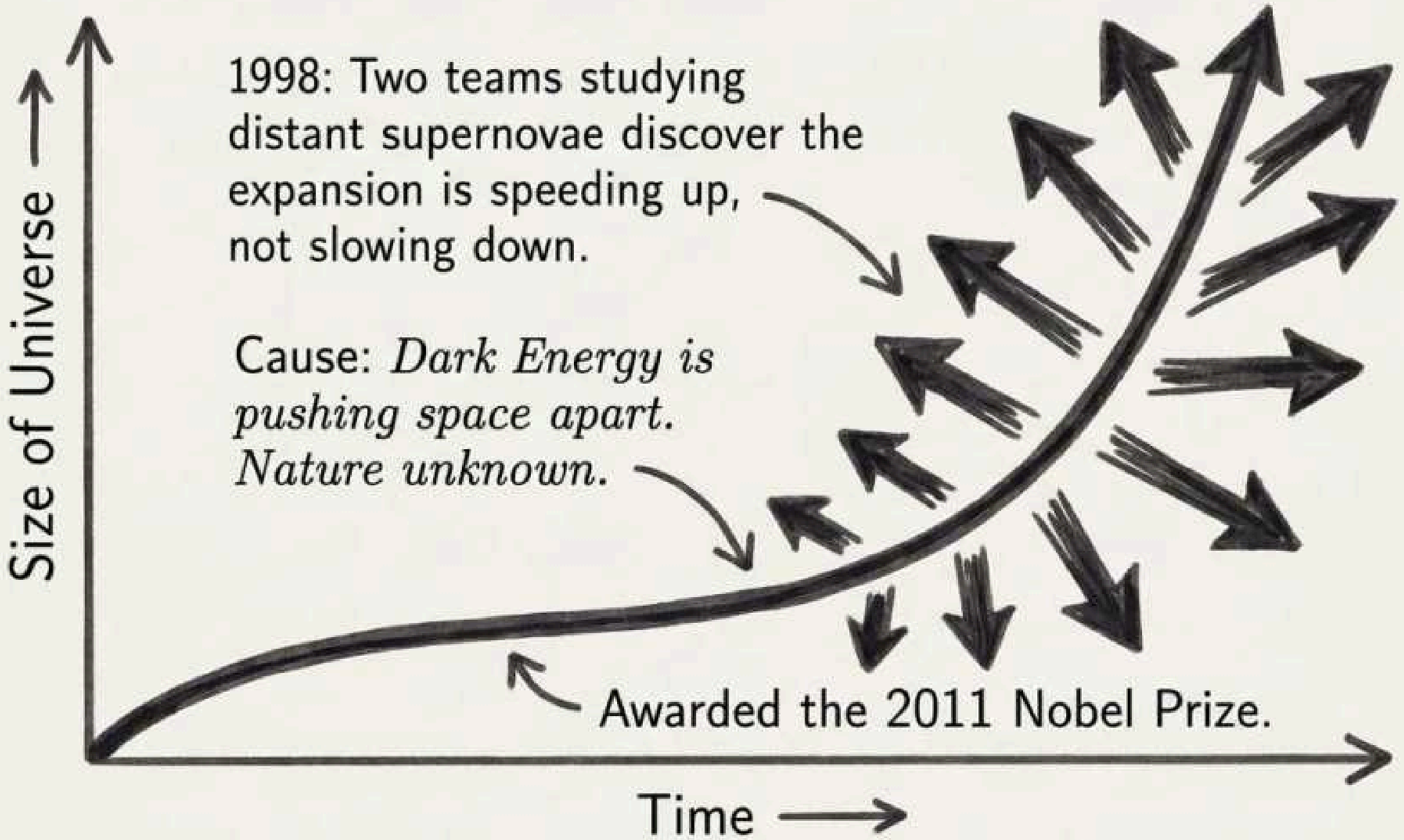
Observation: Edge stars move as fast as center stars.

Conclusion: Vast amounts of invisible mass (Dark Matter) must be present, detectable only by its gravity. Nature unknown.

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¶ 6.16

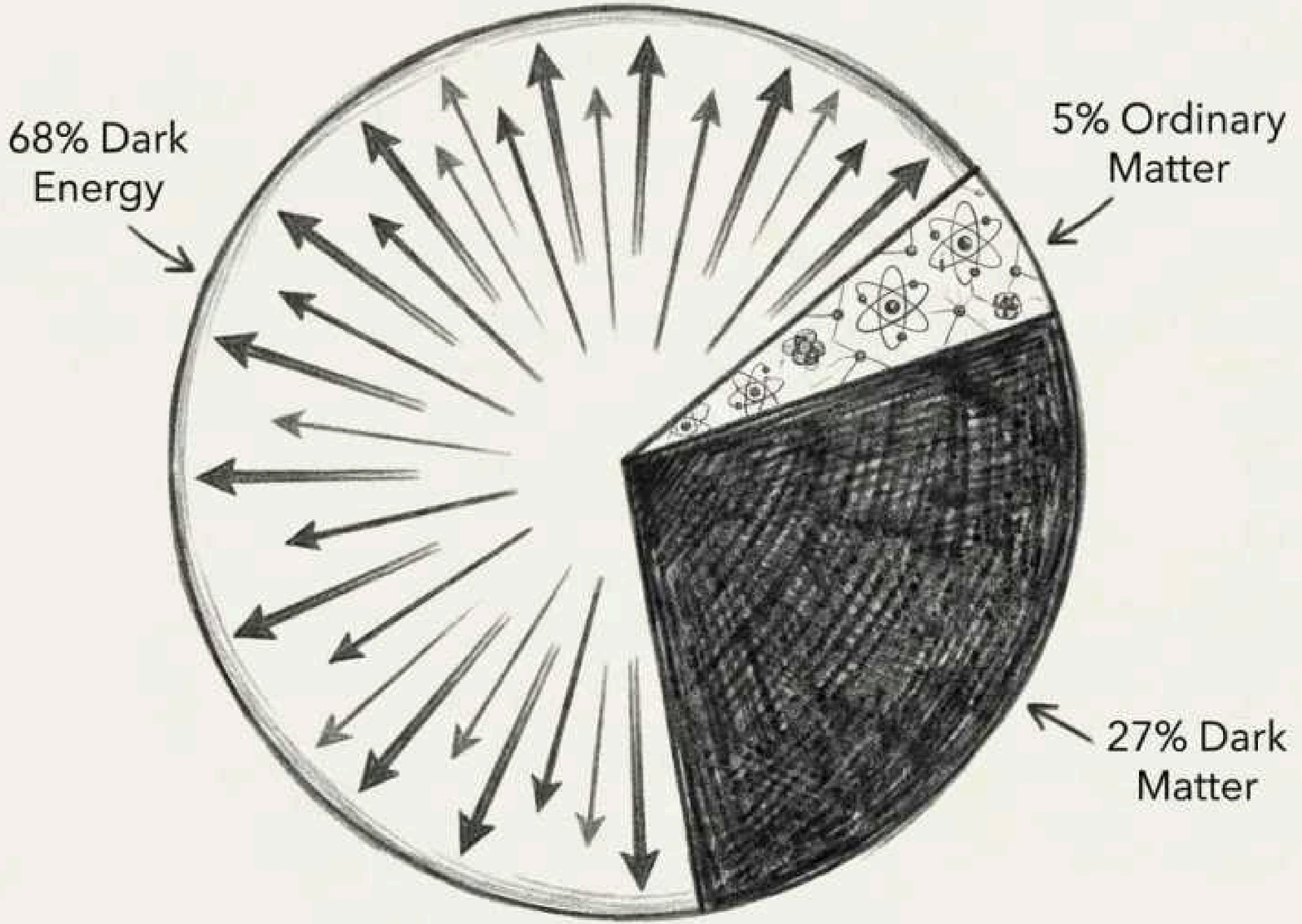
Accelerated Expansion and Dark Energy



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¶ 6.17

The Cosmic Recipe



5% Ordinary Matter (everything made of atoms: stars, galaxies, us).

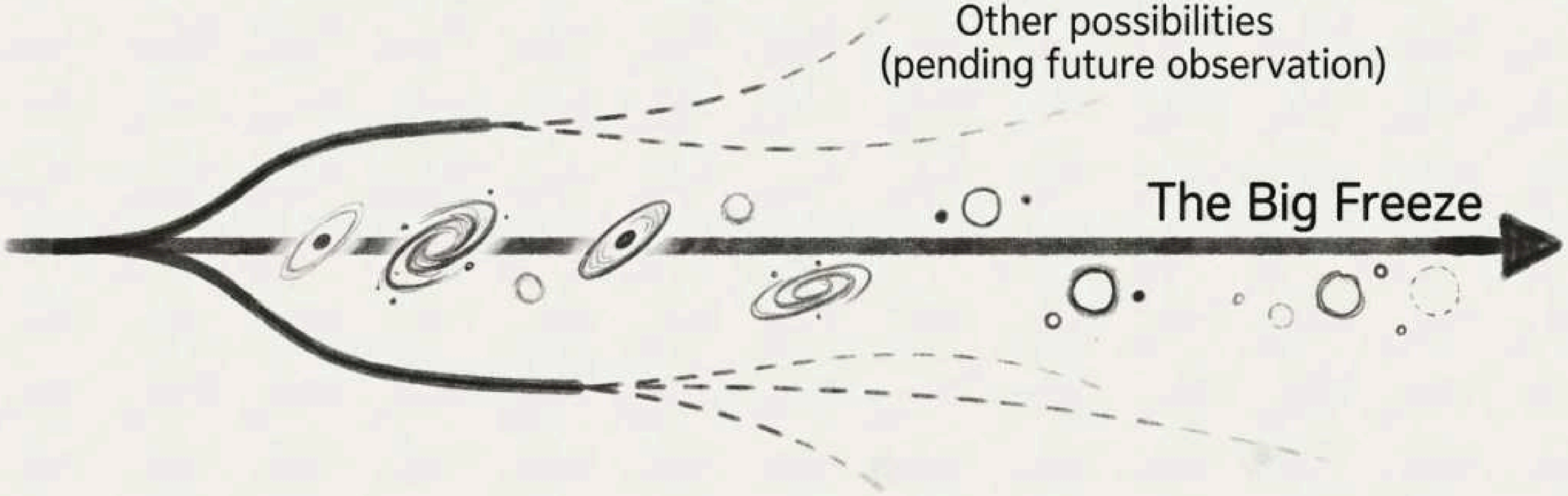
27% Dark Matter.

68% Dark Energy.

The stars and galaxies that fill our telescopes are a small part of the whole. A great deal remains to be discovered.

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The Ultimate Fate of the Universe

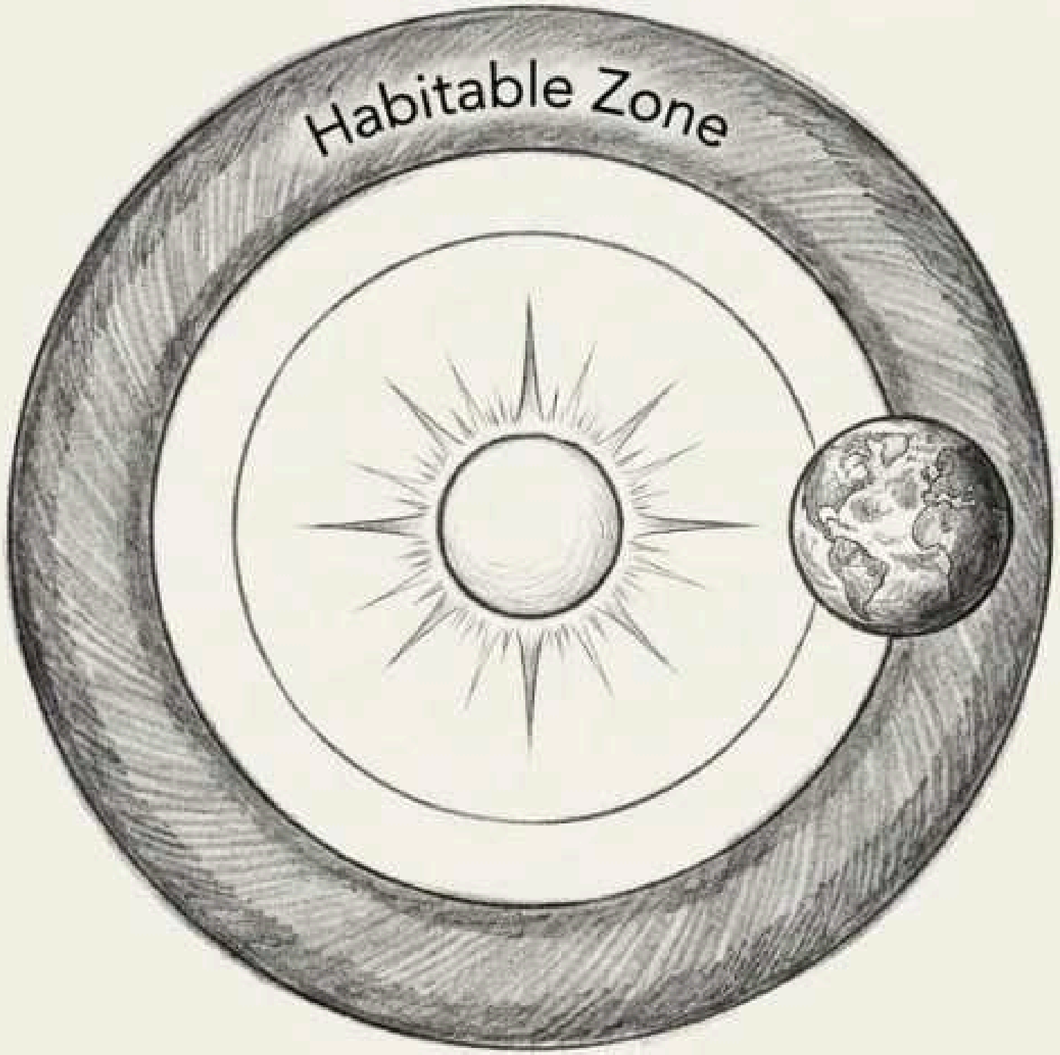


Prediction (if Dark Energy remains constant): Expansion goes on forever.
Galaxies drift out of reach, stars burn out over trillions of years.
The universe grows cold and dark.

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¶ 6.19

The Search for Exoplanets and Life



1995: Michel Mayor and Didier Queloz find the first planet around a Sun-like star.

Present: 5,000+ confirmed exoplanets.

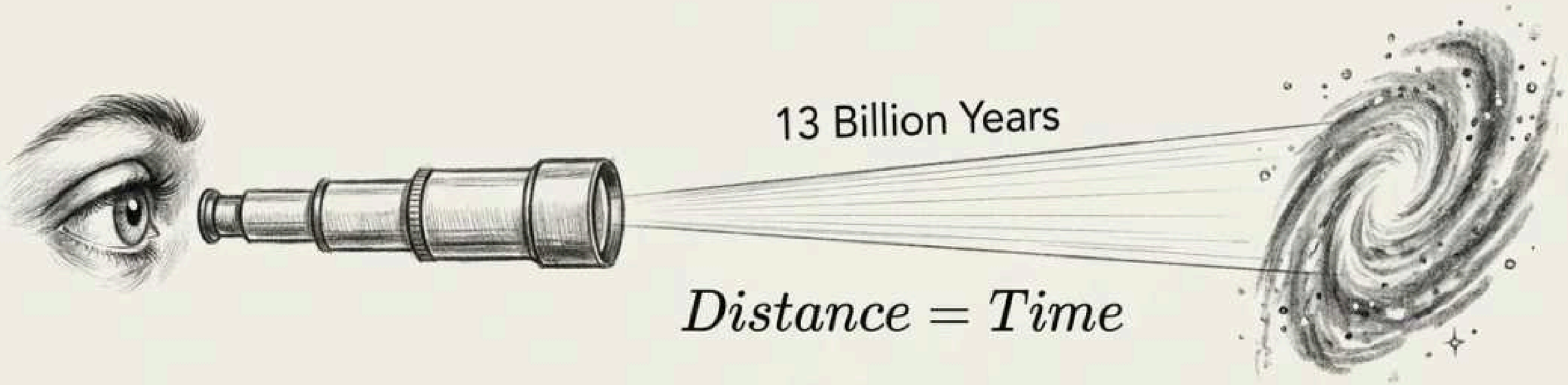
Habitable Zone: The region where liquid water could exist on a rocky surface.

Conclusion: Planets are common, and the ingredients for life are everywhere.

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¶6.20

Looking Back to Look Past



Light from the most distant galaxies has traveled for over 13 billion years.

To look far away is to look into the past.

What question about the universe would you most like answered?

Contact: garyanderson@mail.grokbot.com | X: @garyanderson

Thank you for taking Astronomy 101 B.

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