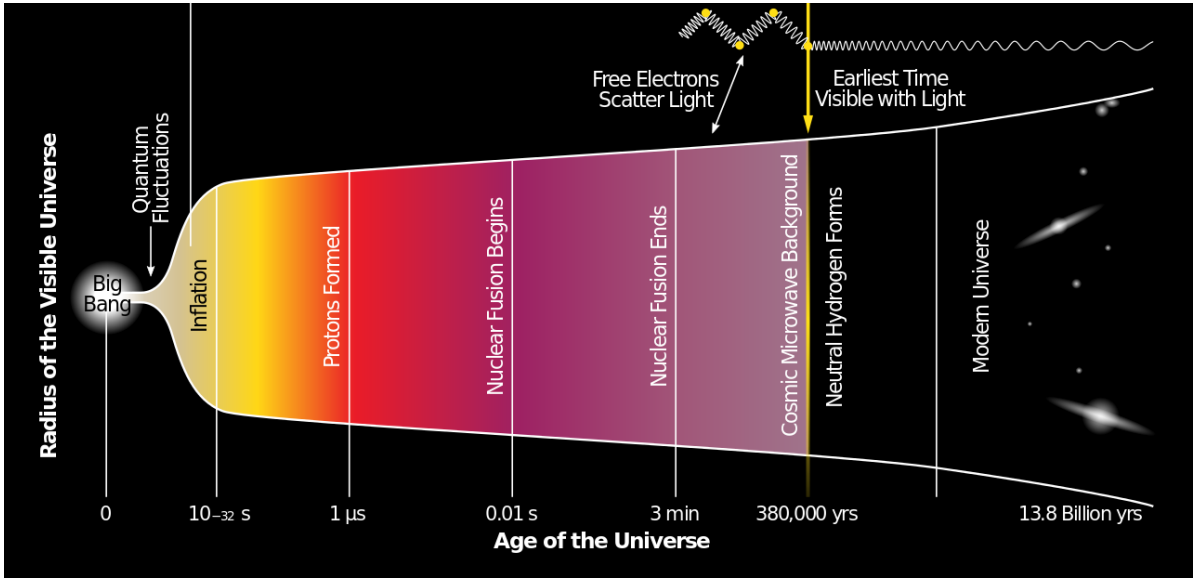
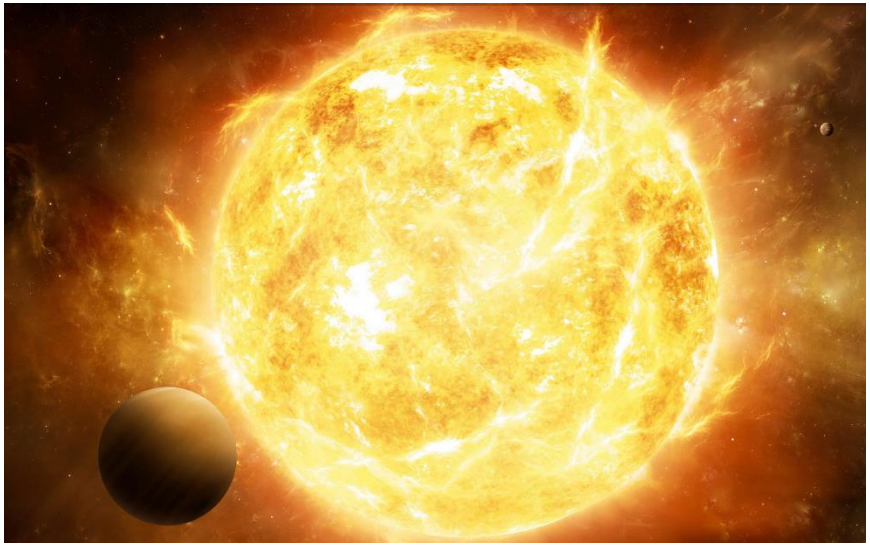
The Universe

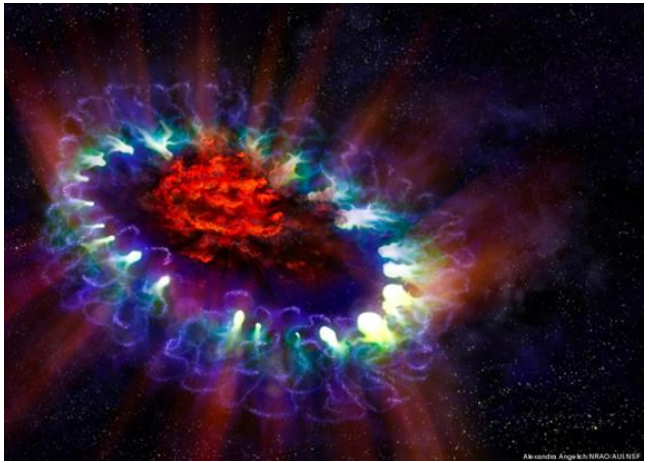
- **Life on Earth** is intimately connected with the **cosmos**:
  - **Big Bang nucleosynthesis** created the lightest atoms: mainly H (75%) & He (25%)



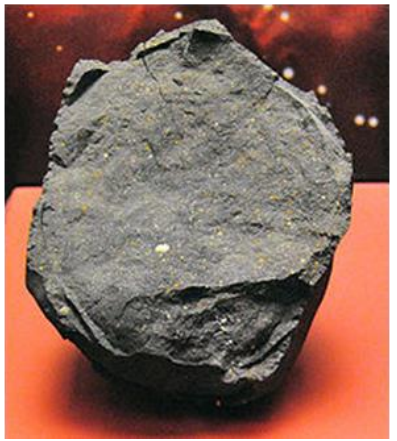
- **Life on Earth** is intimately connected with the **cosmos**:
    - **Thermonuclear fusion in stars** created the heavier elements up to iron, e.g., O, C, N, which (together with H) make up 98% of the mass of living organisms
        - Hydrogen (H) 59%
        - Oxygen (O) 24%
        - Carbon (C) 11%
        - Nitrogen (N) 4%
        - Others such as phosphorus (P) and sulphur (S) 2% combined
        - Also metals: Iron (Fe) needed for blood to carry oxygen; Magnesium (Mg) needed for plants to photosynthesize, etc.



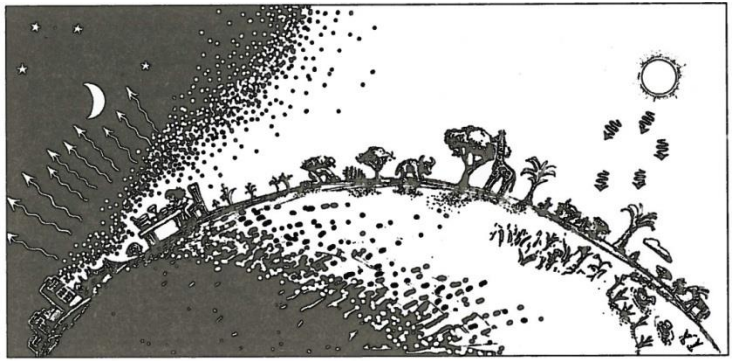
- **Life on Earth** is intimately connected with the **cosmos**:
    - **Stellar supernovae** created the elements **heavier than iron**, e.g., radioactive elements that heat the Earth's interior and help keep it geologically alive (necessary for life)



    - A significant fraction of the **organic molecules** on Earth were formed in **dusty interstellar clouds**, and eventually rained down on the Earth during the Late Heavy Bombardment

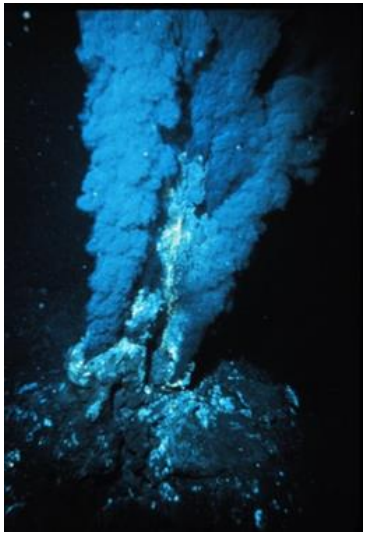


- **Life on Earth** is intimately connected with the **cosmos**:
  - But perhaps most crucially, the **universe** has provided ample sources of **free energy:**
    - ✓ The **Sun:**



  - **Low entropy** energy from the Sun is re-radiated into space as **high entropy** energy
  - The Earth is **exporting** much more entropy than it **receives**: this is the entropy **generated** by the maintenance of all the **low entropy (ordered) structures** on the Earth…like hurricanes, the water cycle, solar temperature gradients, and **life** itself

- **Life on Earth** is intimately connected with the **cosmos**:
  - But perhaps most crucially, the **universe** has provided ample sources of **free energy:**
    - ✓ The **Earth:**



  - chemical and thermal **disequilibrium**

- **Life on Earth** is intimately connected with the **cosmos**:
    - Life depends on the universe *itself* being “alive”:
      Disequilibrium, Dissipation, Gradients, Flows, etc.

- Thus, **big questions** we ask about **ourselves:**
    - Who are we? [What is the nature of life?]
    - Where do we come from? [How did life evolve?]
    - Why are we here? [Why is there life? What is its origin?]

- …are **intimately connected** with big questions we ask about the **universe as a whole**:
    - What is the **nature** of the universe? [Size, composition, structure, role of gravity]
    - How did the universe **evolve**? [Expansion, cooling, gravitational clumping]
    - What is its **origin**? *Why something vs. nothing*? [Big Bang, inflation, other origin ideas]

Answering such questions about the universe may inform similar questions about ourselves…

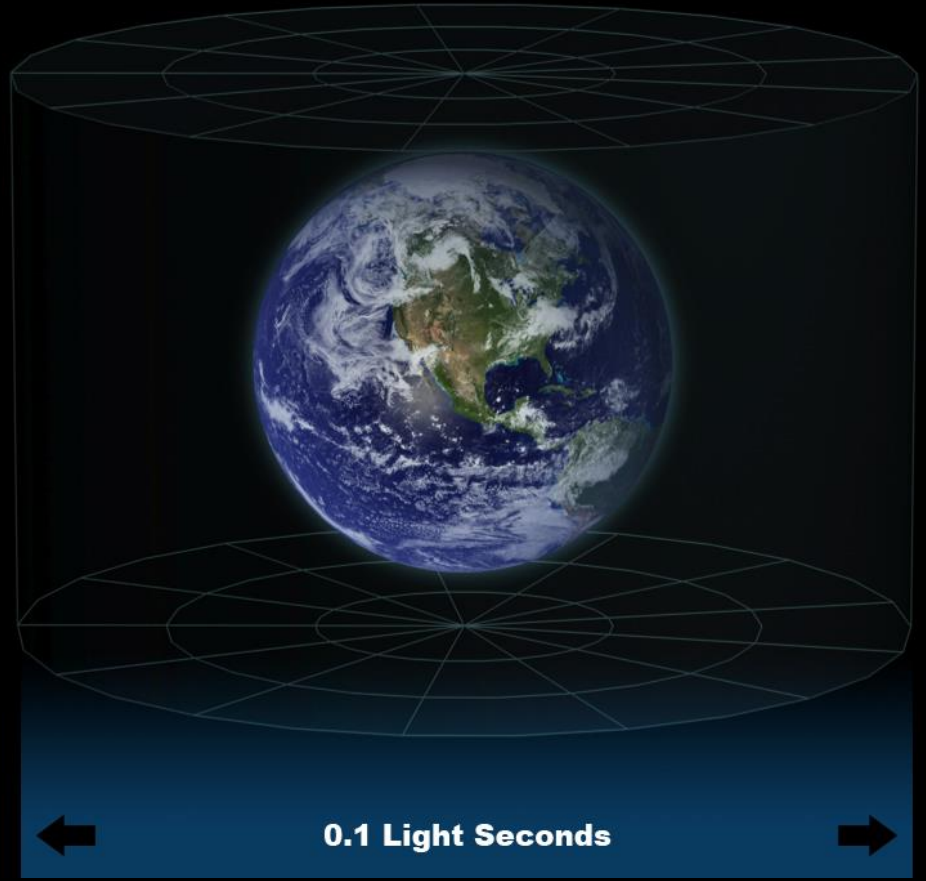
- In particular, we will address the crucial **free energy** question we asked earlier:
    - Why is the Sun a **hot spot** in an otherwise **cold sky**?
        - ✓ **Hot spot** part: What is the origin of the Sun's **free energy**? How can it be in such a relatively **low entropy** state?
        - ✓ We will trace the source of the Sun's free energy back through ever lower and lower entropy states of the universe, all the way back to the mysterious relatively very **low entropy** state of the universe at the **Big Bang**.

- In particular, we will address the crucial **free energy** question we asked earlier:
    - Why is the Sun a **hot spot** in an otherwise **cold sky**?
        - ✓ **Cold sky** part: Equivalently, why is it **dark at night**? We will see that the darkness of the night sky is intimately connected to the fact that our universe is not infinitely old, but of **finite age**—it had a **beginning**, that is *also* **deeply mysterious!**
- **Thus**: The fact that life exists at all is *intimately intertwined* with two of the greatest mysteries of the universe itself: *its* **origin**, in such a **low entropy** state.

Let’s first think about the **size** of the universe

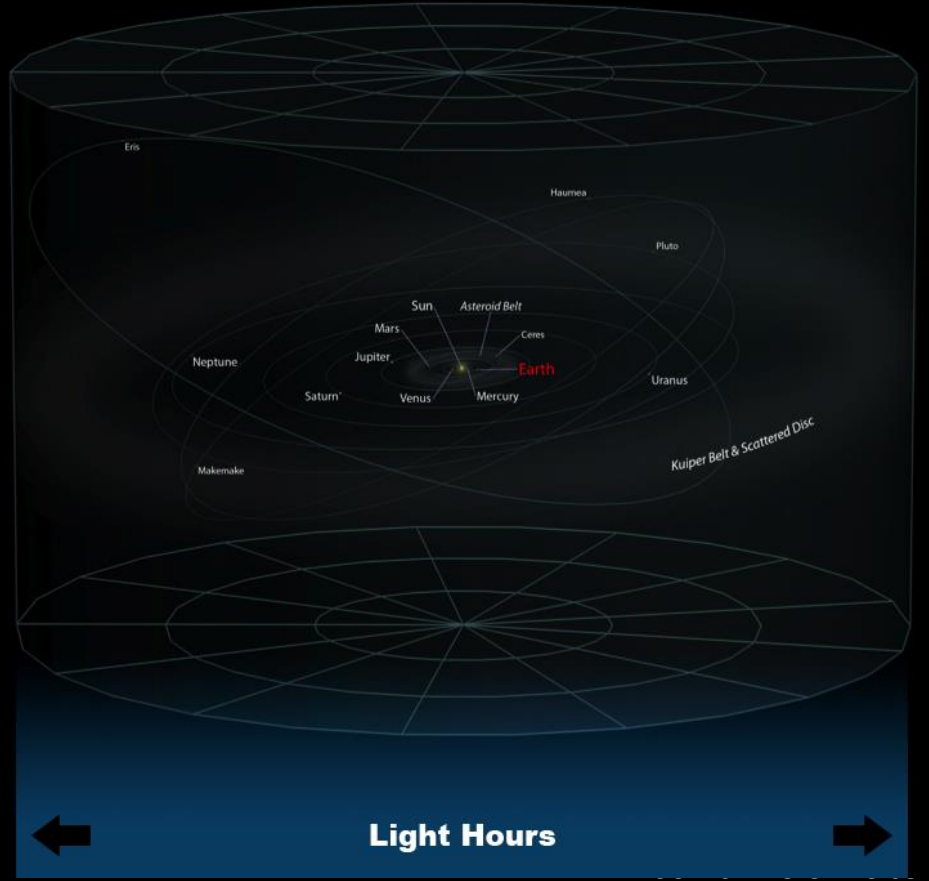
Scale of the Universe

Earth



0.1 Light Seconds

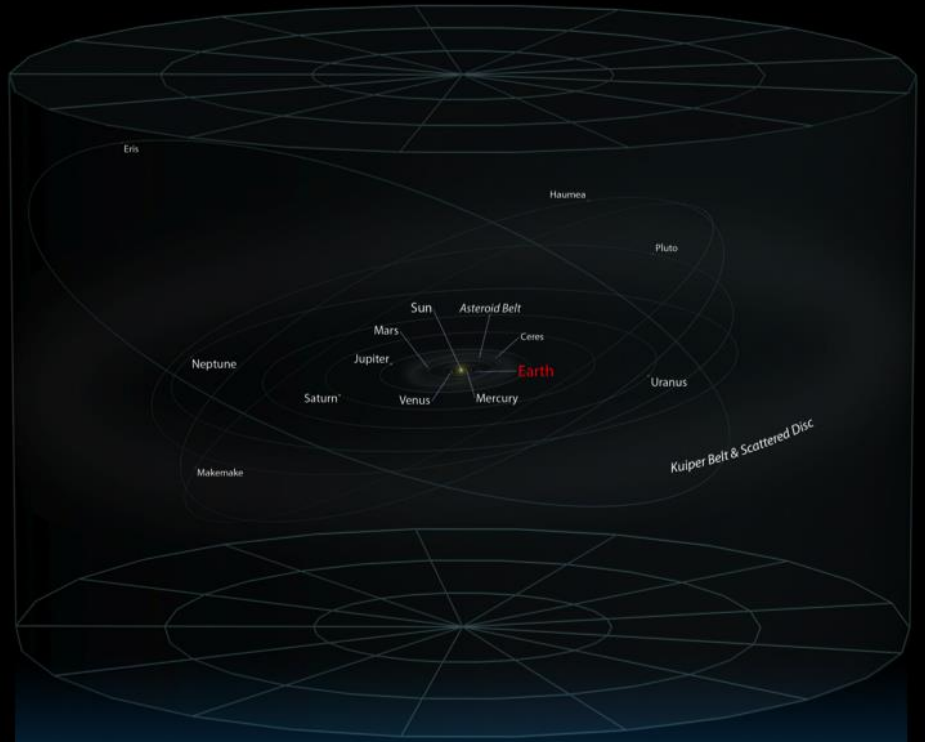
Solar System



Light Hours

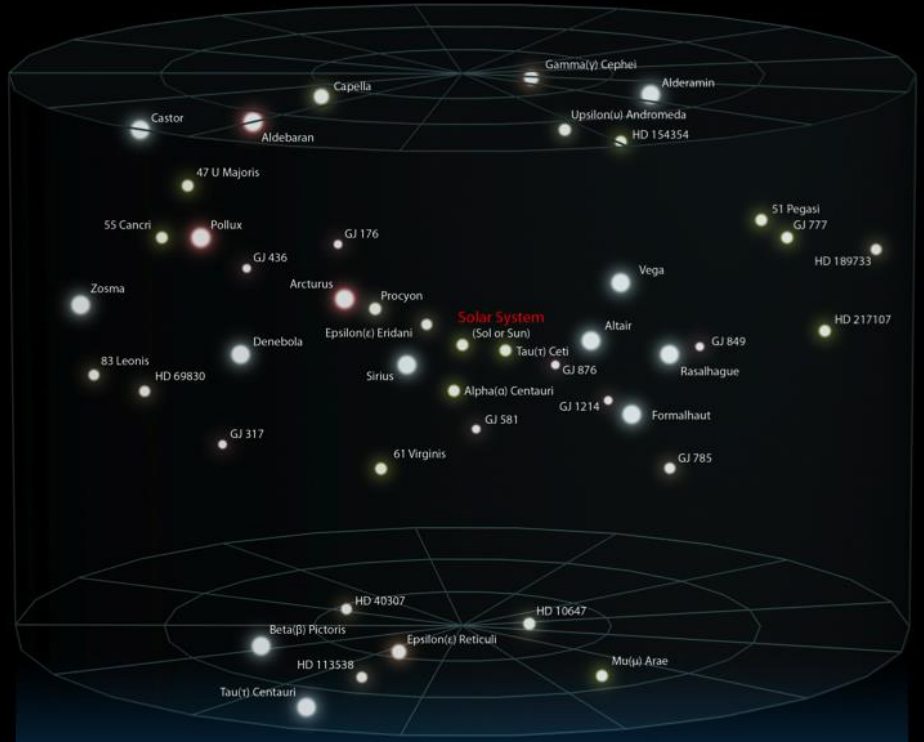
Scale of the Universe

Solar System



Light Hours

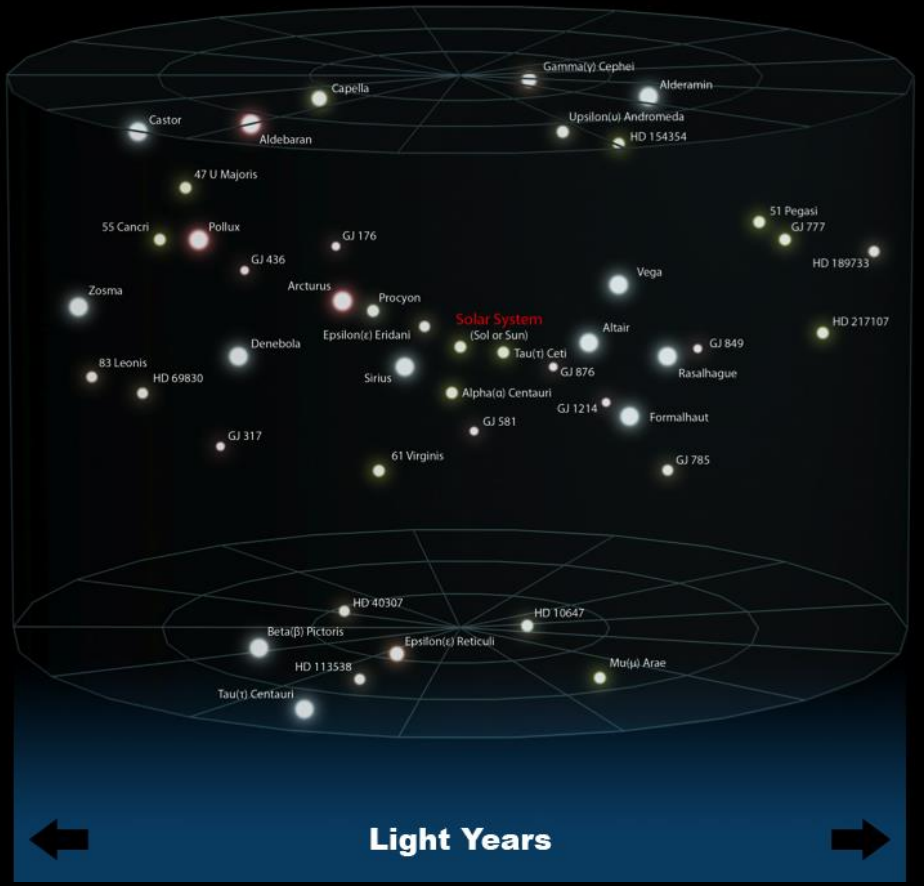
Solar Interstellar Neighborhood



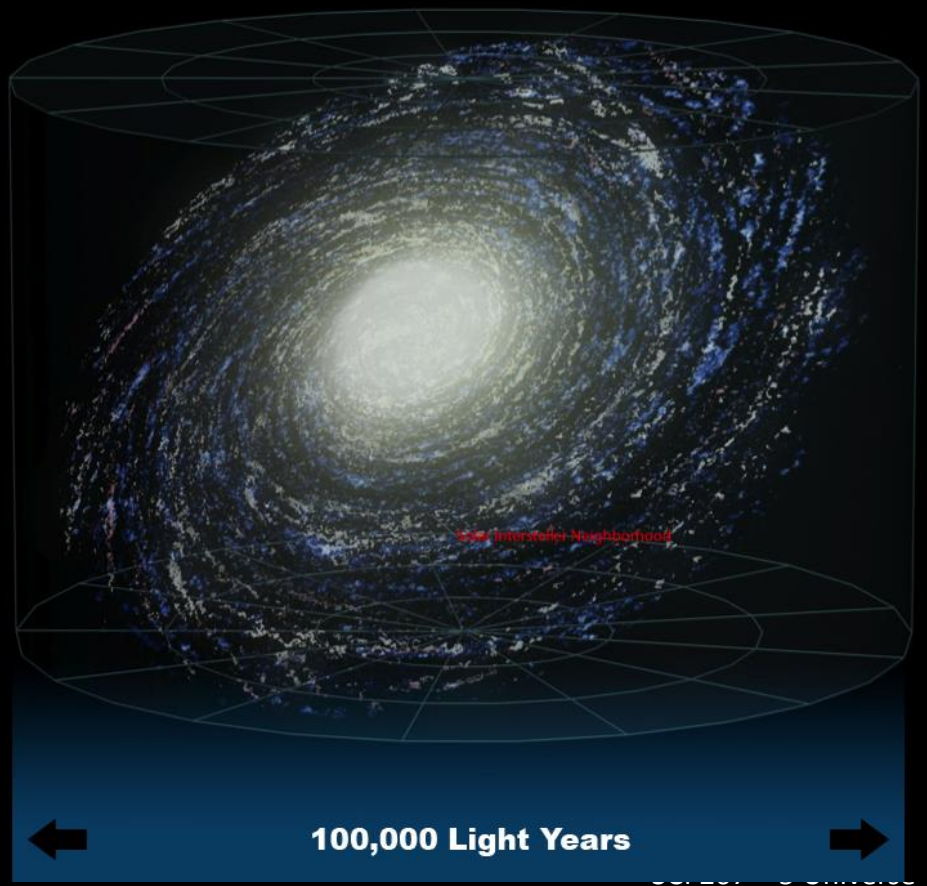
Light Years

Scale of the Universe

Solar Interstellar Neighborhood

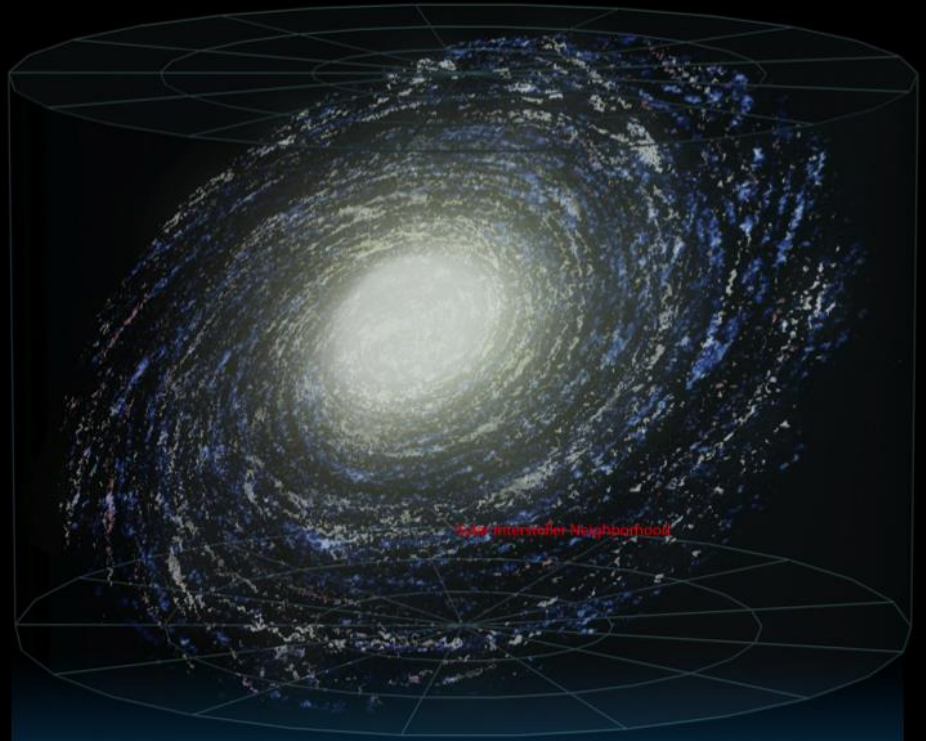


Milky Way Galaxy



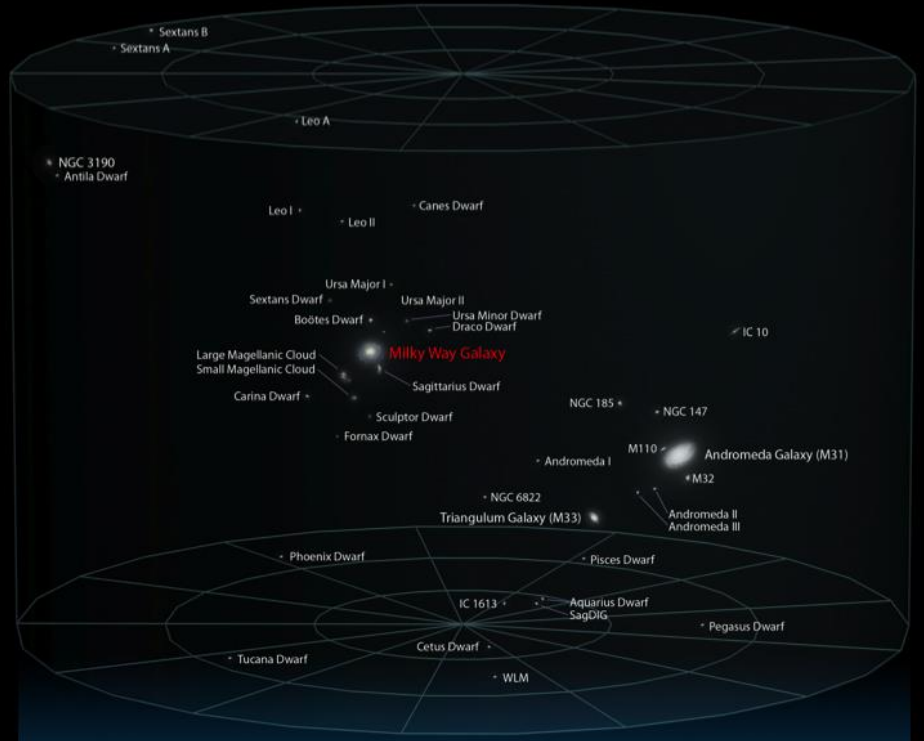
Scale of the Universe

Milky Way Galaxy



100,000 Light Years

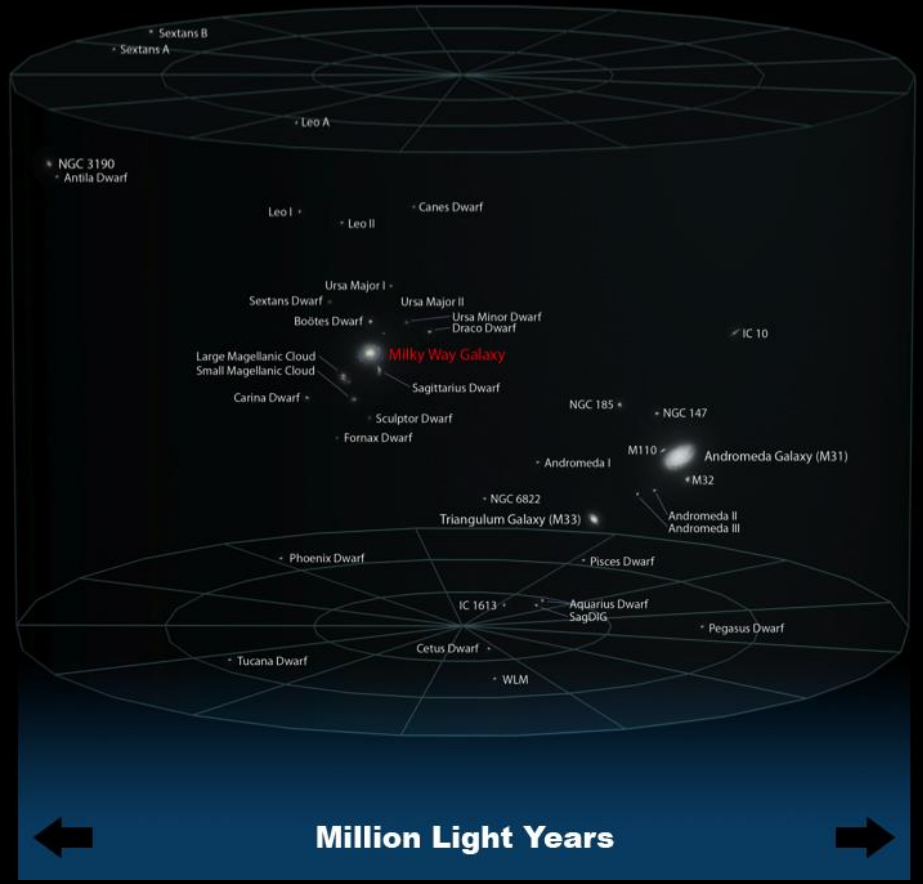
Local Galactic Group



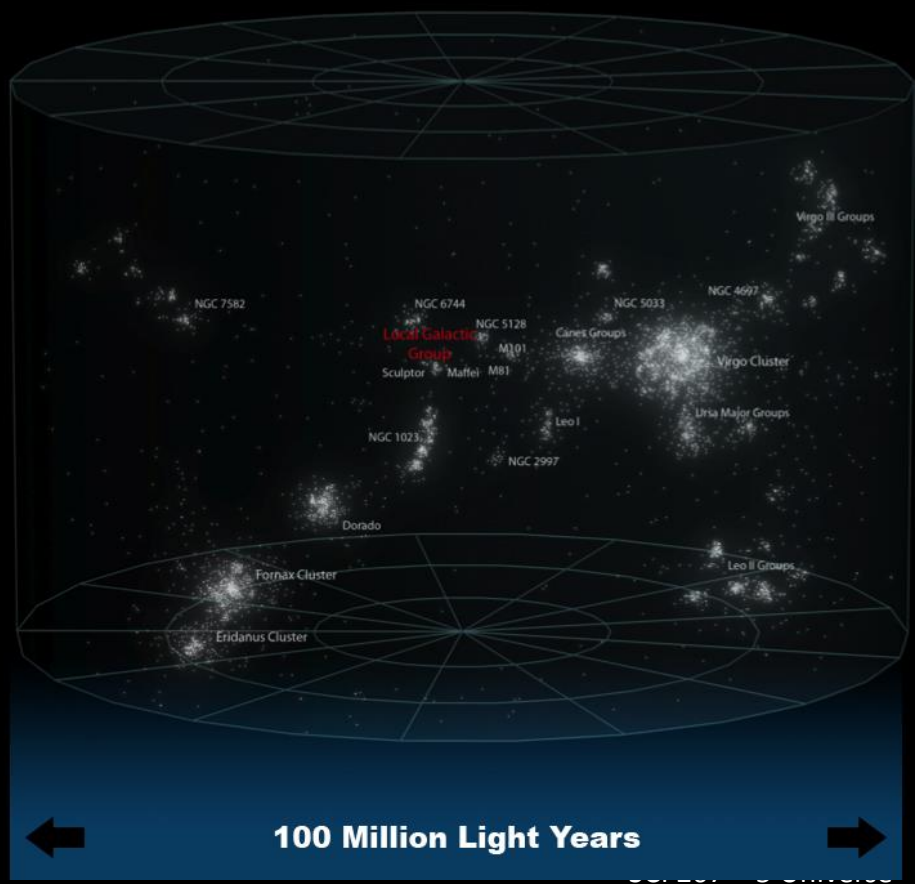
Million Light Years

Scale of the Universe

Local Galactic Group

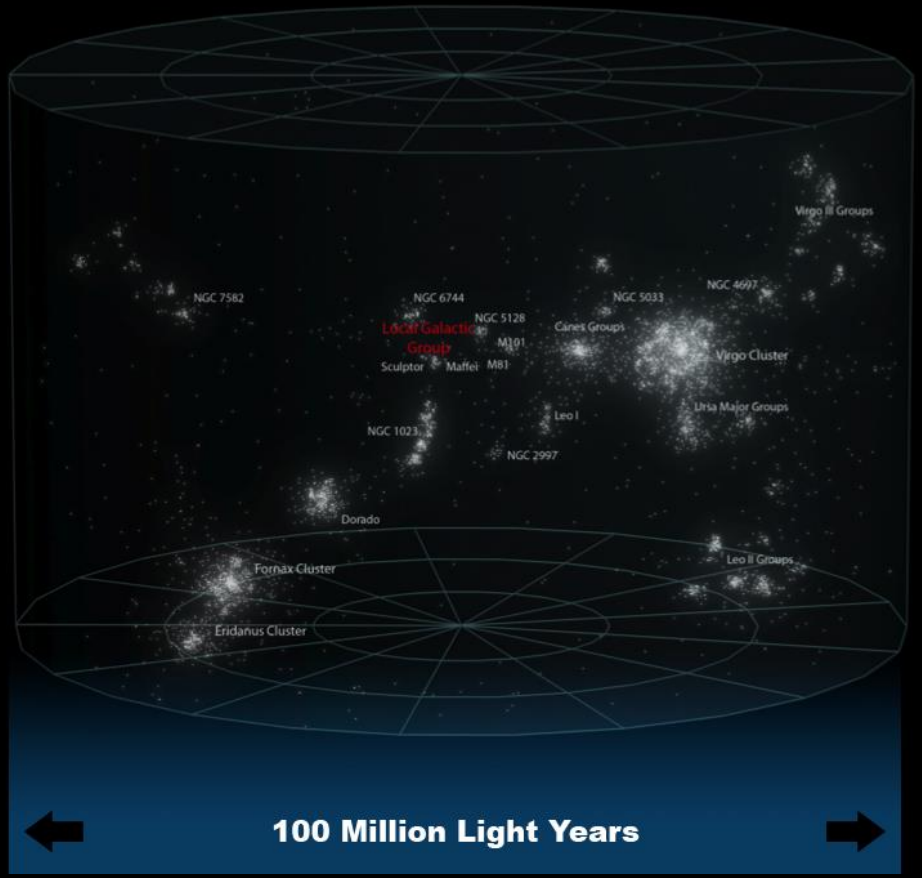


Virgo Supercluster

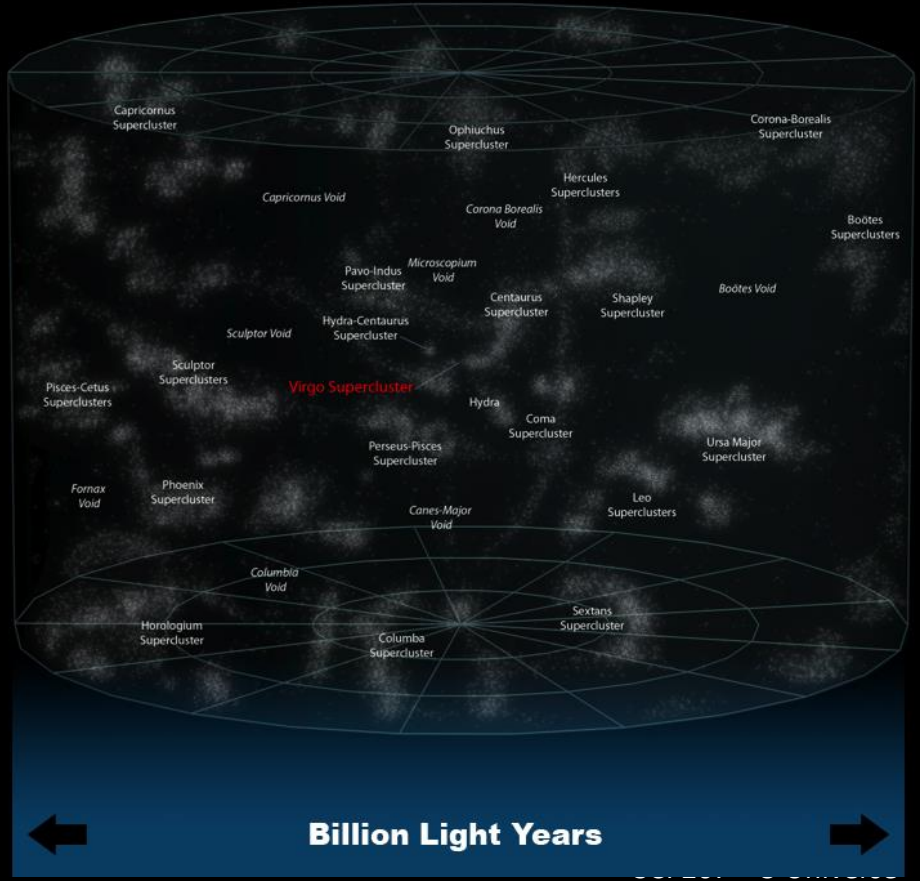


Scale of the Universe

Virgo Supercluster

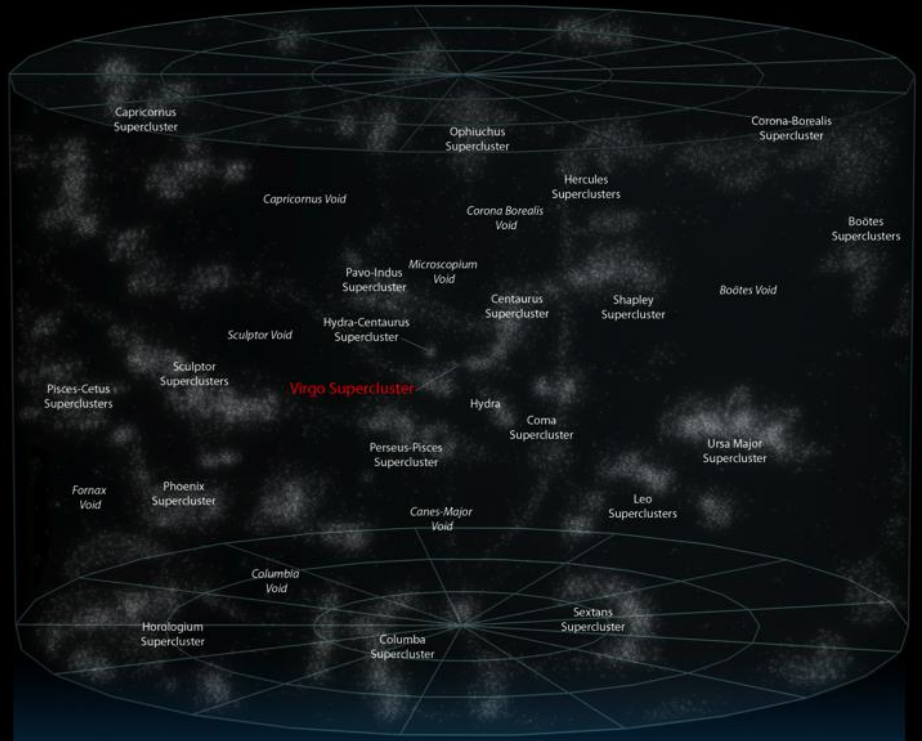


Local Superclusters



Scale of the Universe

Local Superclusters

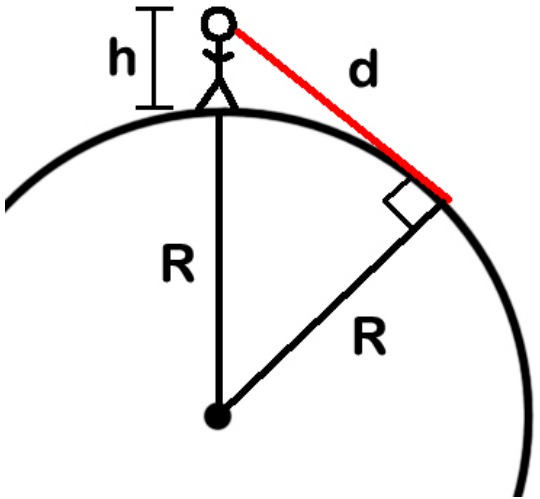


Billion Light Years

Observable Universe

100 Billion Light Years

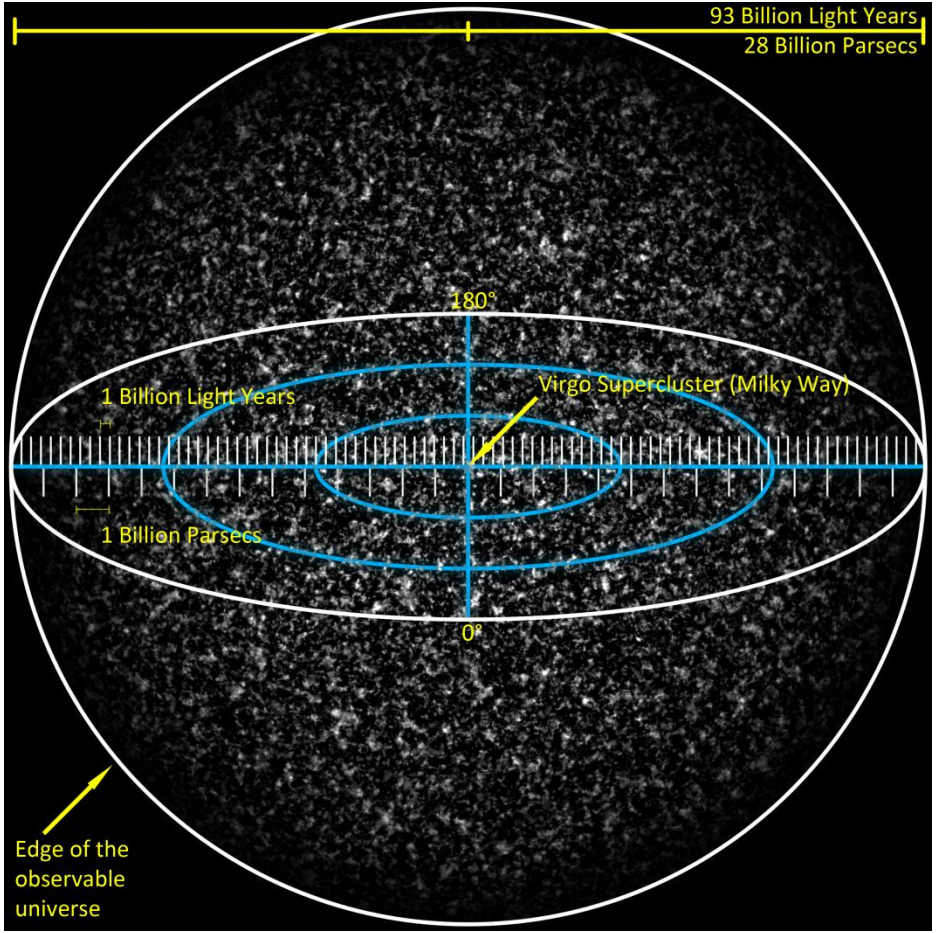
- **Observable Universe?**
  - We'll talk about this later. **Quick explanation** for now:
    - Because light moves at **finite speed**, *the farther out in space we look, the further back in time we see.*
    - Since the universe **had a beginning** (Big Bang), *we can't look further back in time than this, and thus farther out in space than this.*
    - The edge of the "observable universe" is called our **cosmological horizon**, much like a horizon on Earth: *there is certainly "stuff" beyond it, we just can't see it*!



- **Observable Universe?**

Question:

How big is the Solar System in this picture?

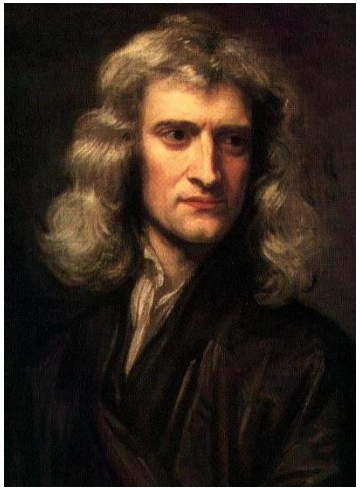


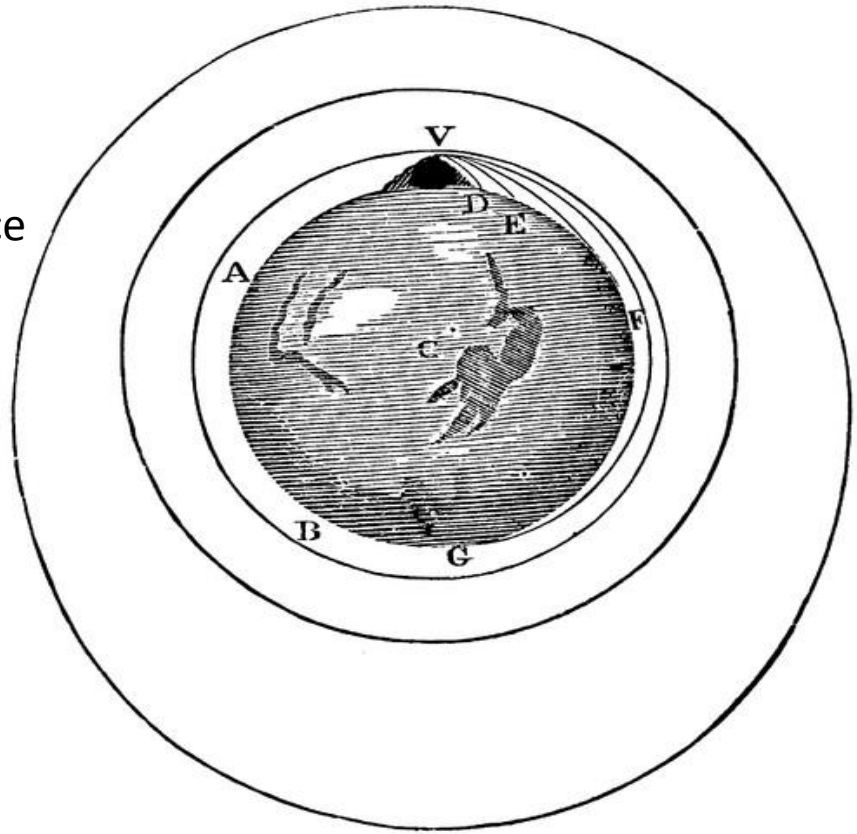
Mind Warp:

Universe is BIG

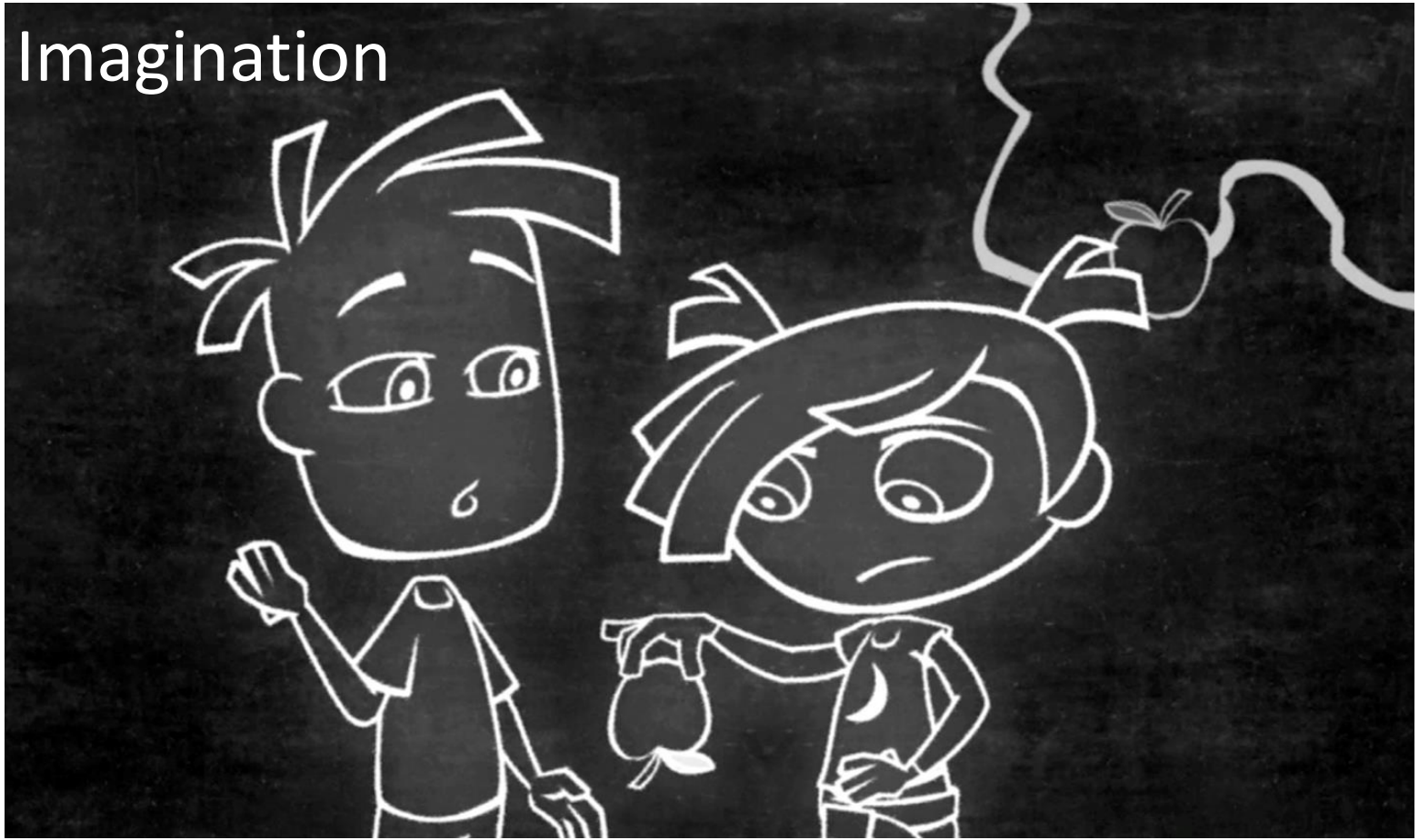
How big is the observable universe?

- **Isaac Newton:**
  - Imagined Earth's gravity **reaches to the Moon**, and figured out how the strength of gravity would need to diminish with distance to explain the Moon's orbit: **as inverse distance squared**

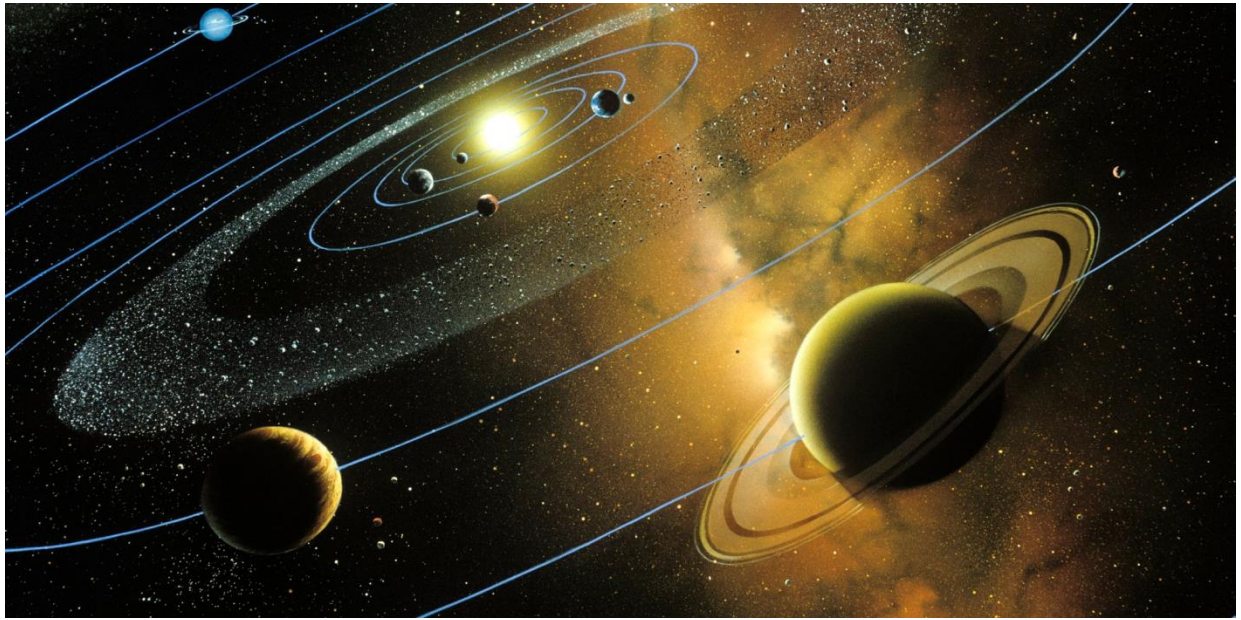




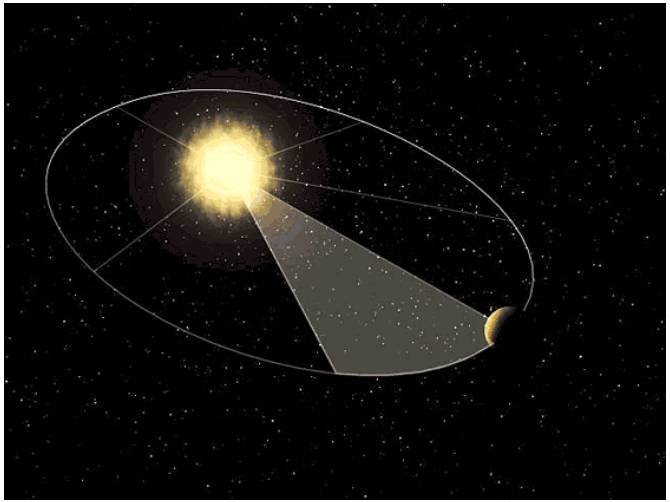
Newton's Imagination

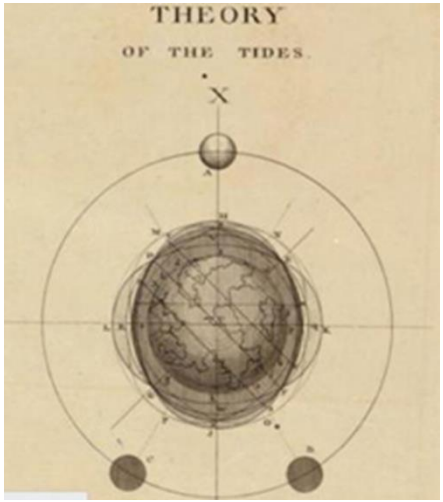


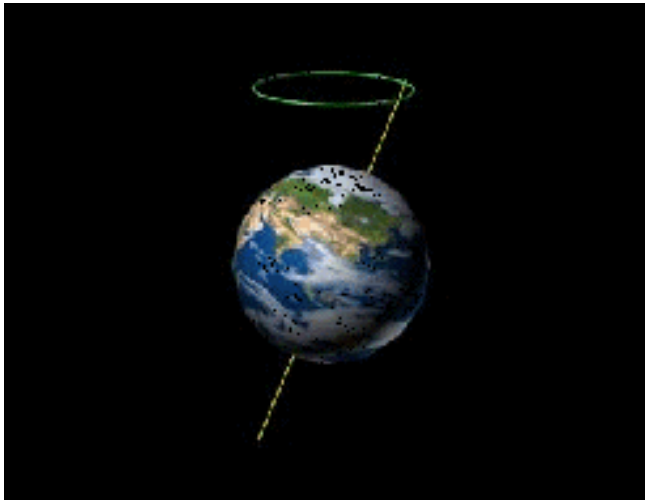
- **Isaac Newton:**
    - He then **extended** the idea to imagine the **Sun has gravity (*with inverse square force law*)**, which reaches **throughout the solar system** and controls the motions of the **planets**.



- **Isaac Newton:**
    - He showed how this **correctly explained** virtually all aspects of the hitherto mysterious **Solar System** (Kepler's laws of planetary motion, Earths tides, precession of the equinoxes, etc.)—a real *tour de force*. The *Principia* is "justly regarded as one of the **most important works in the history of science**".





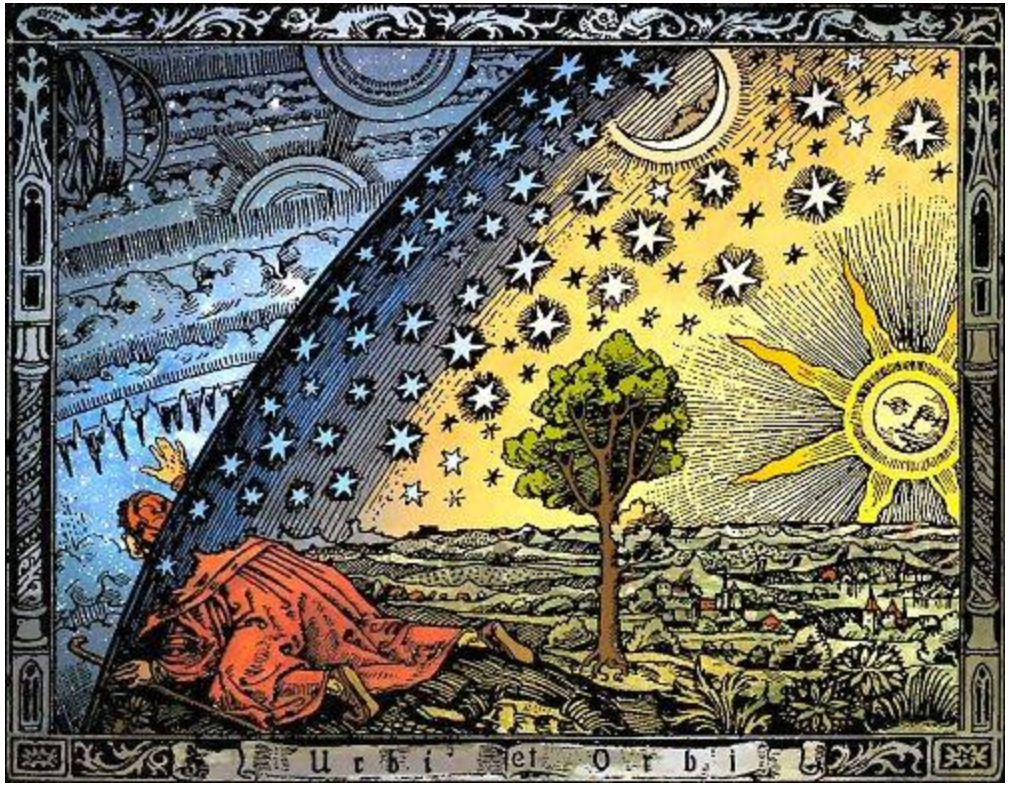


Role of Gravity

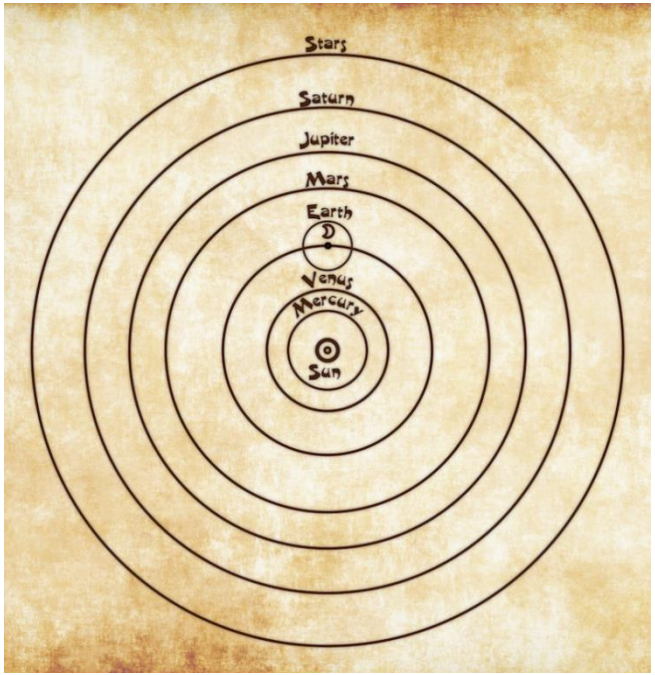
How did Newton explain the tides?

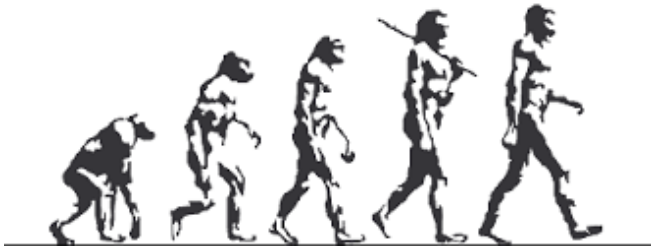
Role of Gravity

- **Isaac Newton:**
  - By showing that the planets orbit for the same reason an apple falls, Newton quite literally **unified the heavens and the Earth**.
  - He demolished the age-old separation between us and the cosmos, opening up a **whole universe of mysteries** for science to explore.

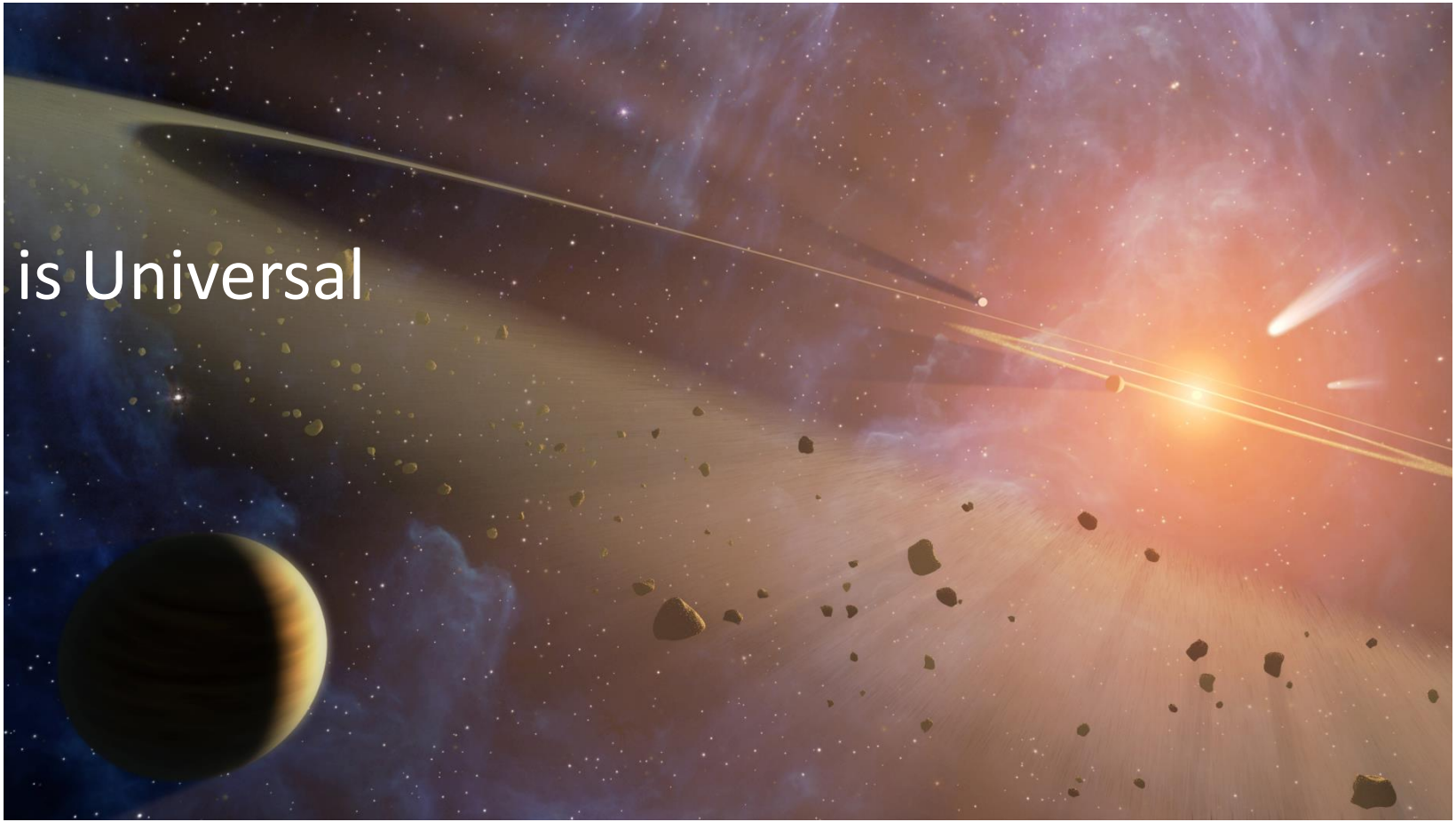


- **Isaac Newton:**
  - Together with Galileo's **observations**, Newton provided the crucial **theoretical** support that eventually convinced everyone that **Copernicus was right**: The Earth (and so also "Man") are **not** at the center of the universe.
  - This had a profound impact on how we understand our **place in the universe**, rivalled only by Darwin's **theory of evolution**: two of the greatest "mind warps" of all time.

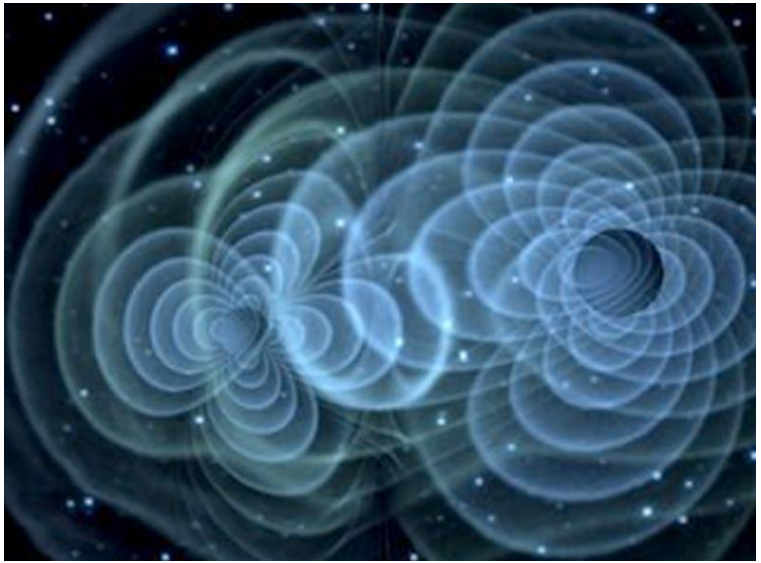




Gravity is Universal

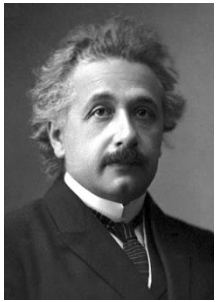


Role of Gravity

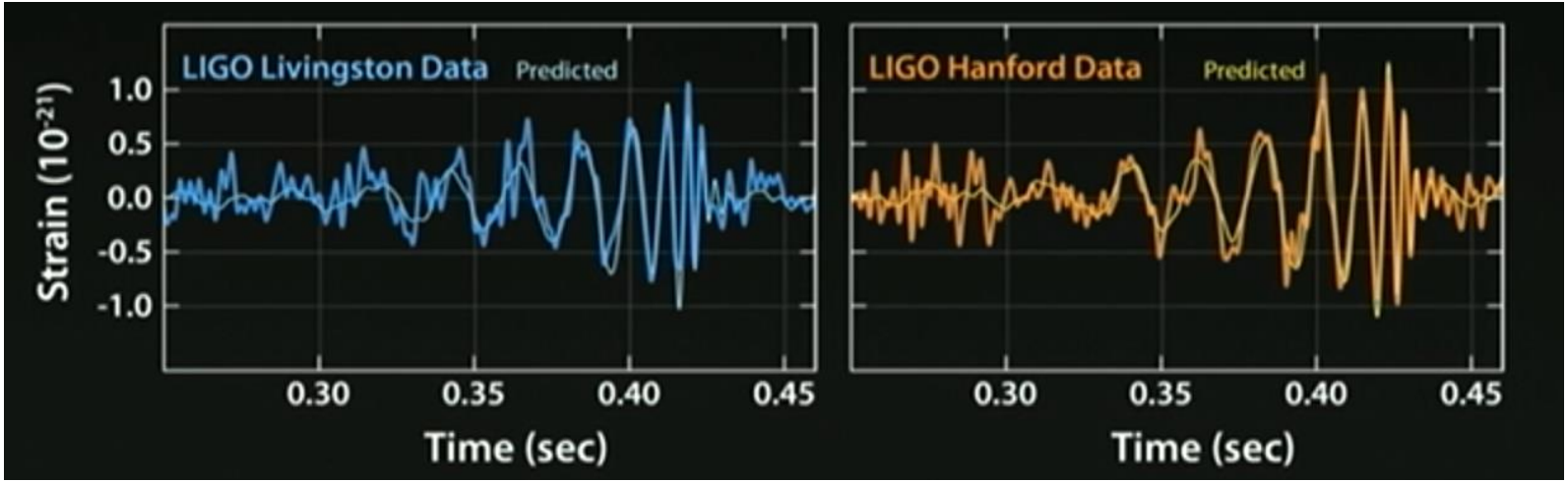


LIGO (Laser Interferometer Gravitational-Wave Observatory)

4 km length



Role of Gravity

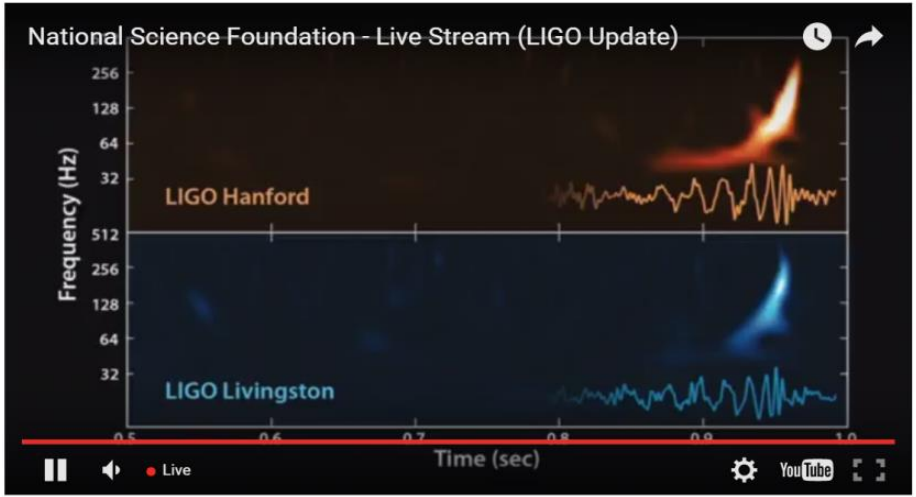


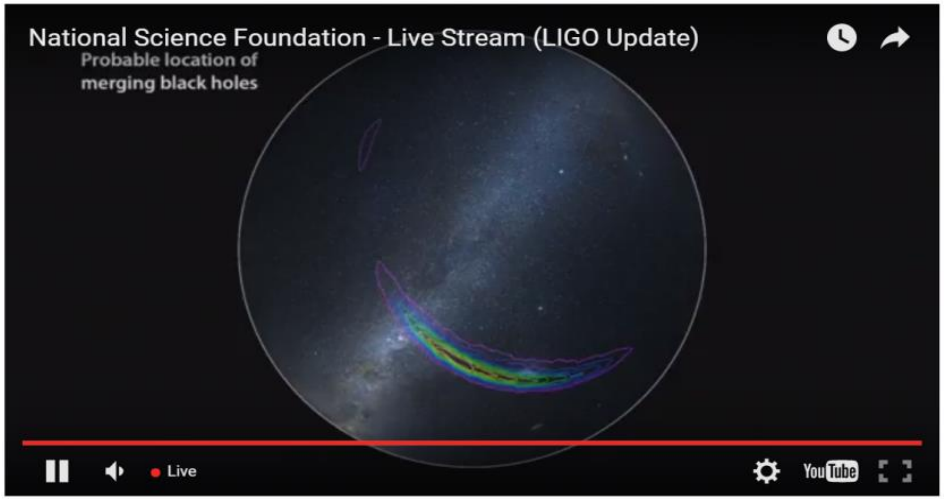
Strain = 10^{-21} → 1/1000 times size of proton (!)

Inspiral signal (“chirp”) lasted about 7 ms

Repeated in two independent detectors

Role of Gravity





Merger of two black holes about 1 billion light years away

3 solar masses worth of energy converted to gravitational wave energy

Opens entirely new window on the universe: “hear” instead of just “see”!

Role of Gravity

- **Gravity** is also the **dominant force** on large scales (planets, galaxies, cosmos):
    - The **strong** and **weak** nuclear interactions are **short-range** forces. They act only between particles separated by nuclear distances, e.g., inside the nucleus of atoms.
    - **Electromagnetism** is a relatively **strong**, **long-range** force, but it tends to **cancel out** over large distance because there is an **equal amount** of **positively** and **negatively** charged particles in the universe: strong electrostatic attraction tends to bring these together and **neutralize** them (e.g., atoms are normally electrically neutral).
    - Gravity is a relatively **weak**, **long-range** force, but it tends to **add up** on large scales because **all particles have positive mass** (no negative mass particles to cancel the effects of the positive mass particles). E.g.: The Earth has a gravitational field, but virtually no net electrostatic field.

Gravity Dominates

Role of Gravity

- Even though gravity is the most **familiar** force we experience, it is the most **mysterious**:
    - It is **not a "force"** like the others (strong, weak, and electromagnetic). As Einstein discovered, it is ***geometry***: the "curvature of spacetime".
    - It is the only "force" **not yet understood** in the context of the **quantum** nature of the universe. Finding a unified theory of **quantum gravity** is the "holy grail" of theoretical physics.
    - Both the **energy** and **entropy** of the gravitational field are poorly understood, despite the importance of these concepts to fully understanding the **evolution** of the universe (in particular, how this evolution resulted in the "**right conditions**" for life) and constructing a theory of **quantum gravity.**

Role of Gravity

What is Gravity?