



Science and Astronomy

Astronomy 101: Exploring the Night Sky

January, 2018

The Very Basics

Question: A lightyear is a unit of

- A. Time
- B. Distance
- C. Mass
- D. Brightness
- E. Volume

Units

Measurements are compared to a known quantity - called a “unit”.

Common units include: metre (m), gram (g), second (s), etc.

The distance from the Earth to the Sun is about 150 000 000 000 m.

The distance from Jupiter to the Sun is about 778 000 000 000 m.

How much further is Jupiter? About 5.2x further.

Distances within the solar system typically use the unit AU (astronomical unit) to represent Earth-Sun distance. So Earth-Sun would be 1 AU.

Thus, Jupiter-Sun would be 5.2 A.U.

Common Units in this Course:

Distance: km (objects), AU (orbits), Ly (between stars)

Time: years (orbits), days (rotations / orbits), hours (rotations)

Energy: Joule

Power: Watt

Angles: degrees:arcs, hours:minutes:seconds

Temperature: Kelvin, °C

Mass: kg

Scientific Notation

Smallest Distance Ever Measured: 10^{-18}m

Size of the Universe: $8.8 \times 10^{26} \text{m}$

Practical scales aren't very useful!

Scientific notation is used to more compactly represent very large or very small numbers using impractical units.

$$10000=10^4$$

$$1000=10^3$$

$$100=10^2$$

10=10¹

1=10⁰

$$0.1=10^{-1}$$

$$0.01=10^{-2}$$

$$0.001 = 10^{-3}$$

$$0.0001 = 10^{-4}$$

Representing in Scientific Notation:

150 000 000 km

There are 7 zeroes, so this would be equal to

15 x 10⁷ km

or

1.5×10^8 km

Prefixes

It gets tiresome to write scientific notation, so for commonly used powers-of-ten, we often replace them with prefixes.

Number	Scientific Notation	Prefix	Example
0.000 000 001	10^{-9}	nano (n)	nm
0.000 001	10^{-6}	micro (μ)	μ s
0.001	10^{-3}	milli (m)	mg
1000	10^3	kilo (k)	km
1 000 000	10^6	mega (M)	MW
1 000 000 000	10^9	giga (G)	Gy

Speed

Speeds are typically measured in m/s or km/s.

Example:

Earth's orbital circumference is about 2π AU, orbital period is 365.25 d. This works out to be:

$$(2\pi \times 150\,000\,000 \text{ km}) / (365.25 \text{ d} \times 24 \text{ h/d} \times 60 \text{ min/h} \times 60 \text{ s/min}) = 30 \text{ km/s}$$

Note: Very fast speeds are measured as fractions of the speed of light, which is $\sim 300\,000\,000 \text{ m/s}$ or $3 \times 10^8 \text{ m/s}$ or $3 \times 10^5 \text{ km/s}$. This is the fastest possible speed in the universe - nothing can travel faster.

Some examples

Year: 1 y = 365.24 d = 3.154×10^7 s = 31.54 Ms

Lightyear:

$$\begin{aligned}1 \text{ ly} &= \text{speed of light} \times \text{length of time in a year} \\&= 3.0 \times 10^8 \text{ m/s} \times 3.154 \times 10^7 \text{ s} \\&= 9.46 \times 10^{12} \text{ m} = 6.34 \times 10^4 \text{ A.U.}\end{aligned}$$

Size of the galaxy $\sim 100\ 000$ ly = 10^5 ly = 9.46×10^{17} m

Common volume: 1 mL = 1 cm³ = $(1 \text{ cm} * 1 \text{ m}/100 \text{ cm})^3 = 10^{-6} \text{ m}^3$

How should I visualize the universe?

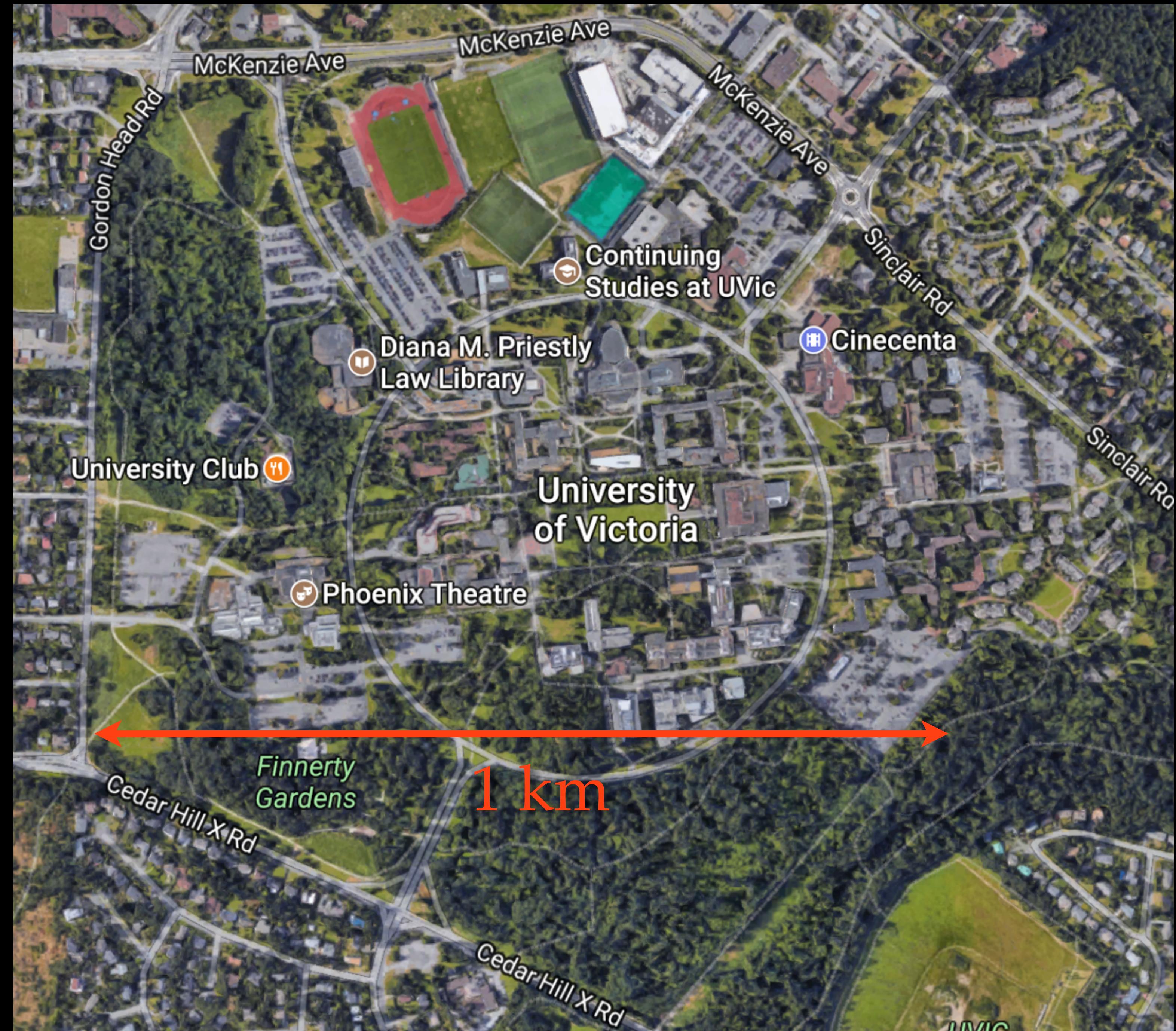
Question: Approximately how long does it take light to reach the Earth from the Sun?

- a. Almost immediately
- b. Over 1 day
- c. Over 1 hour
- d. 22 minutes
- e. 8 minutes

The Sizes of Space

UVic is approximately 1 km wide. The inner ring road has a diameter of about 620 m and a circumference of about 2 km.

UVic takes up approx. 1 km² of land area.

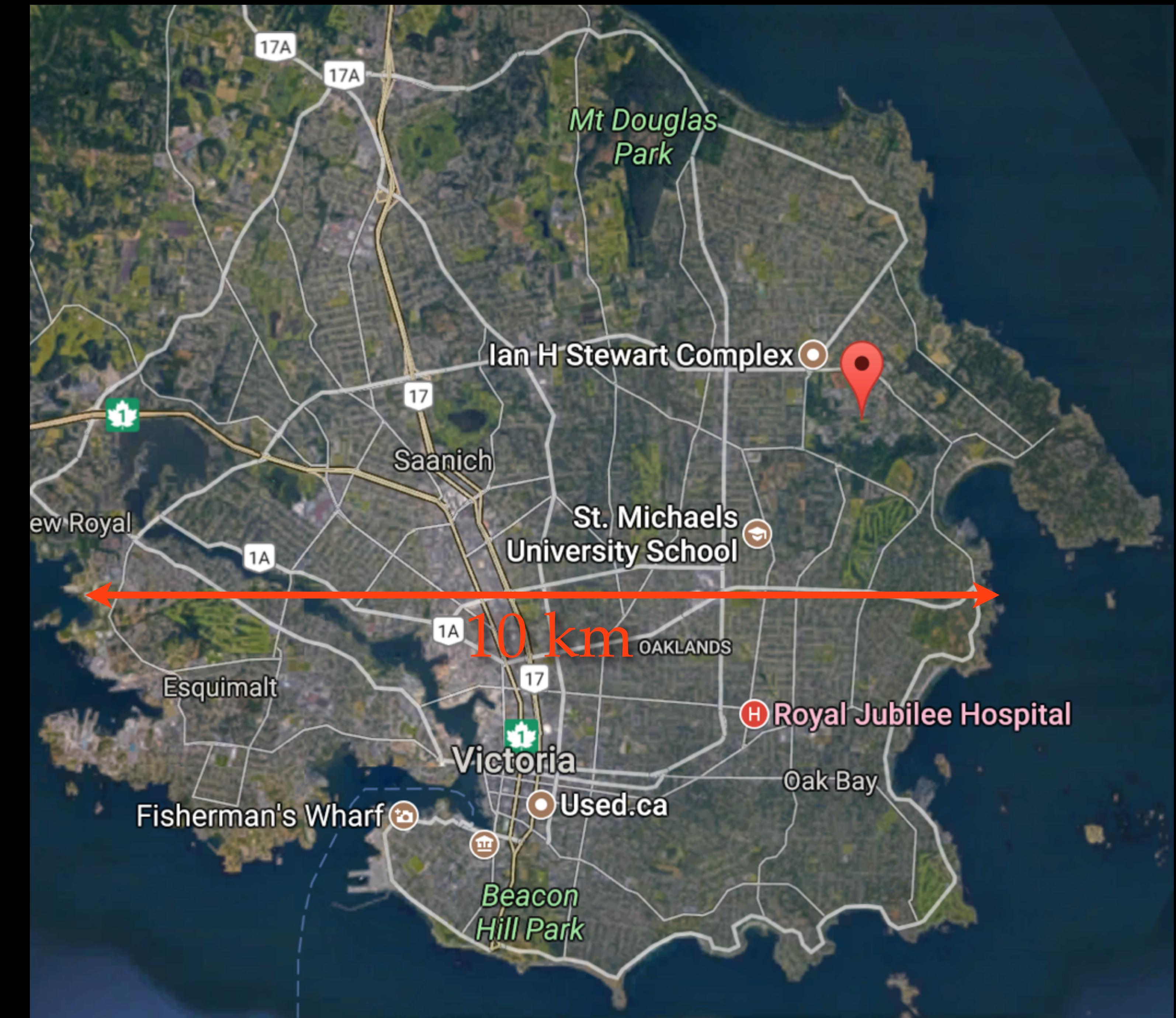


The Sizes of Space

Greater Victoria is approx.
10 km across.

Greater Victoria takes up
approximately 100 km^2 .

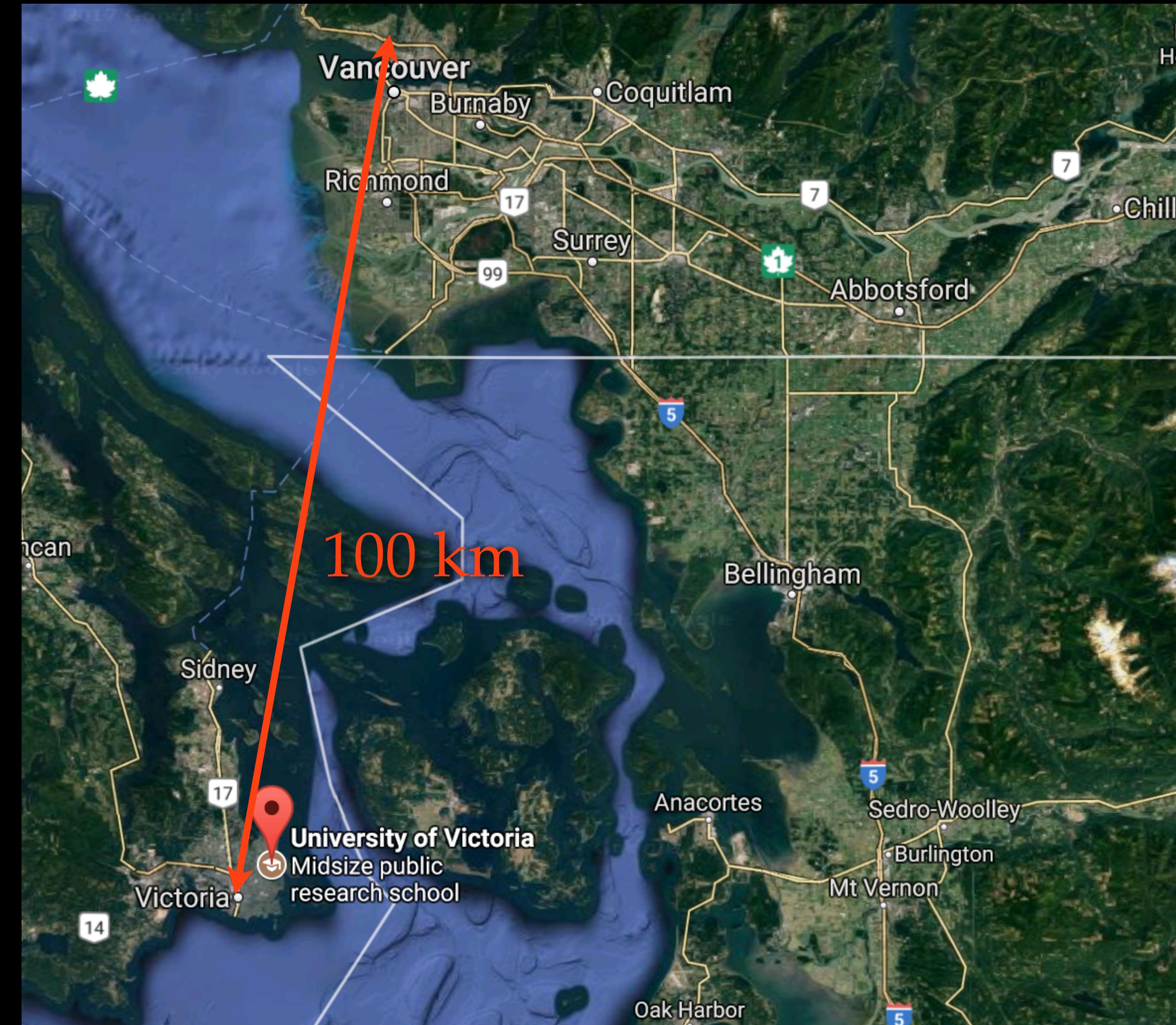
Thus, UVic takes up about
1% of the land area of
Greater Victoria.



The Sizes of Space

Grouse Mountain in North Vancouver is approx. 100 km away from downtown Victoria.

This image shows over 10 000 km² of the surface of the Earth. Greater Victoria is less than 1% of this image.

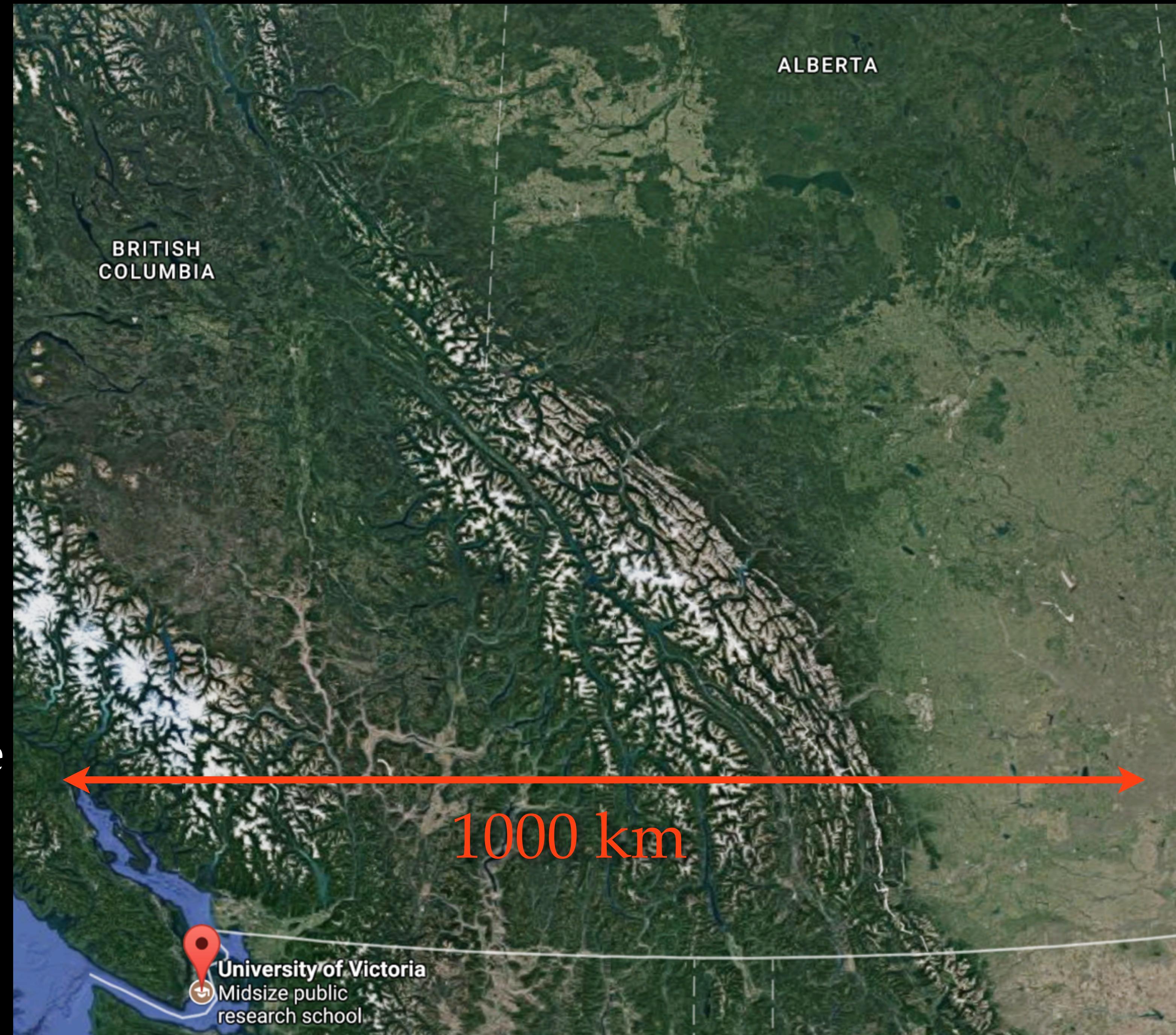


The Sizes of Space

Alberta and BC combined
are approx. 1000 km wide.

This image is therefore
approximately 10^6 km^2 .

The entire previous image
shows only about 1% of the
area of this image.



The Sizes of Space

The diameter of the Earth is about 12 742 km.

The Earth's surface is about 2×10^9 km². The previous image showed about 1/2000 of the surface of the Earth.

Earth's volume is 9×10^{12} km³.



The Sizes of Space

This is an image of the Earth and Moon, to scale.

The Moon orbits at about 30x the diameter of the Earth away.

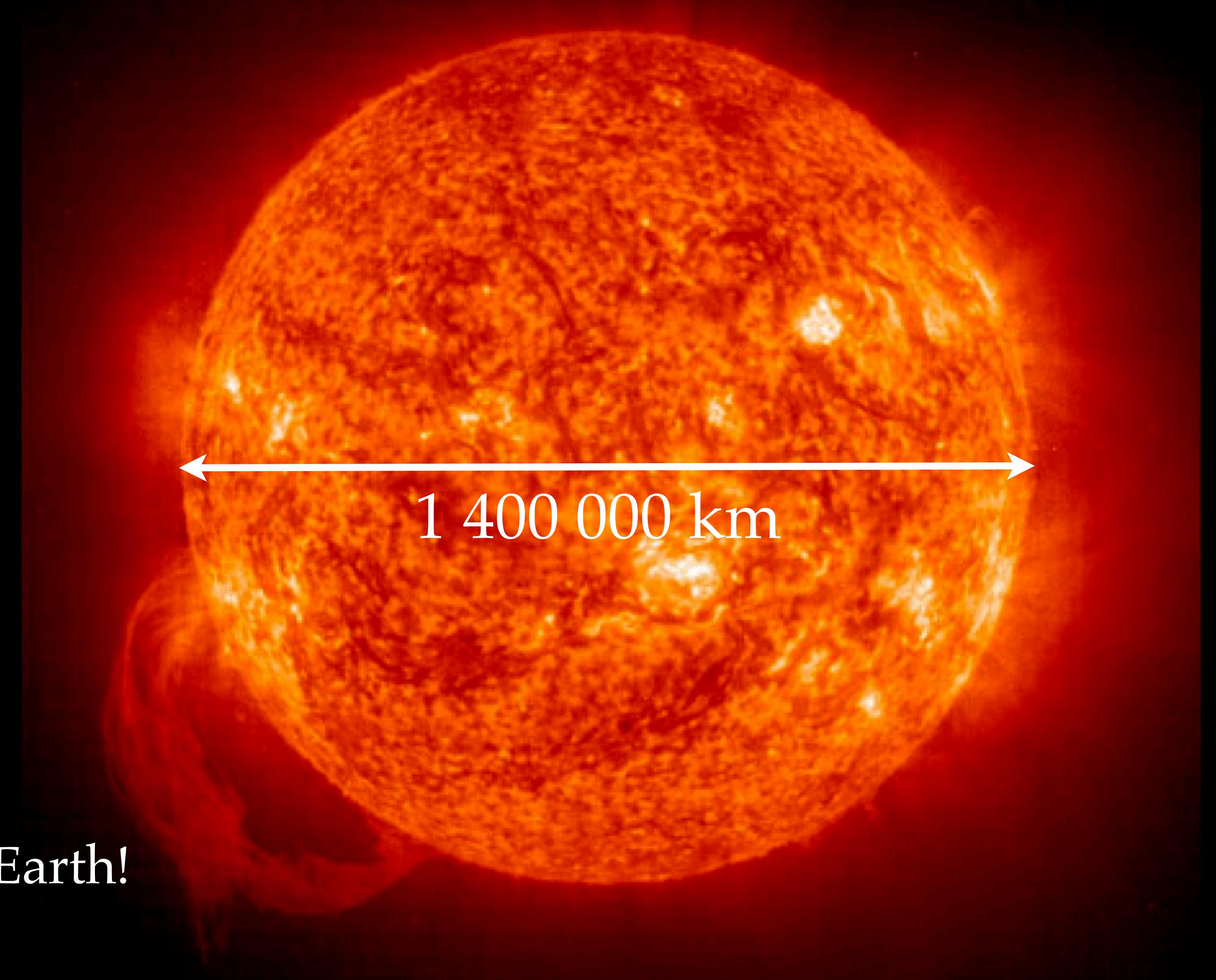


The Sizes of Space

The diameter of the Sun is about 1.4×10^6 km. This is about 113x larger than Earth's diameter.

The surface area of the Sun is about 2.5×10^{13} km².

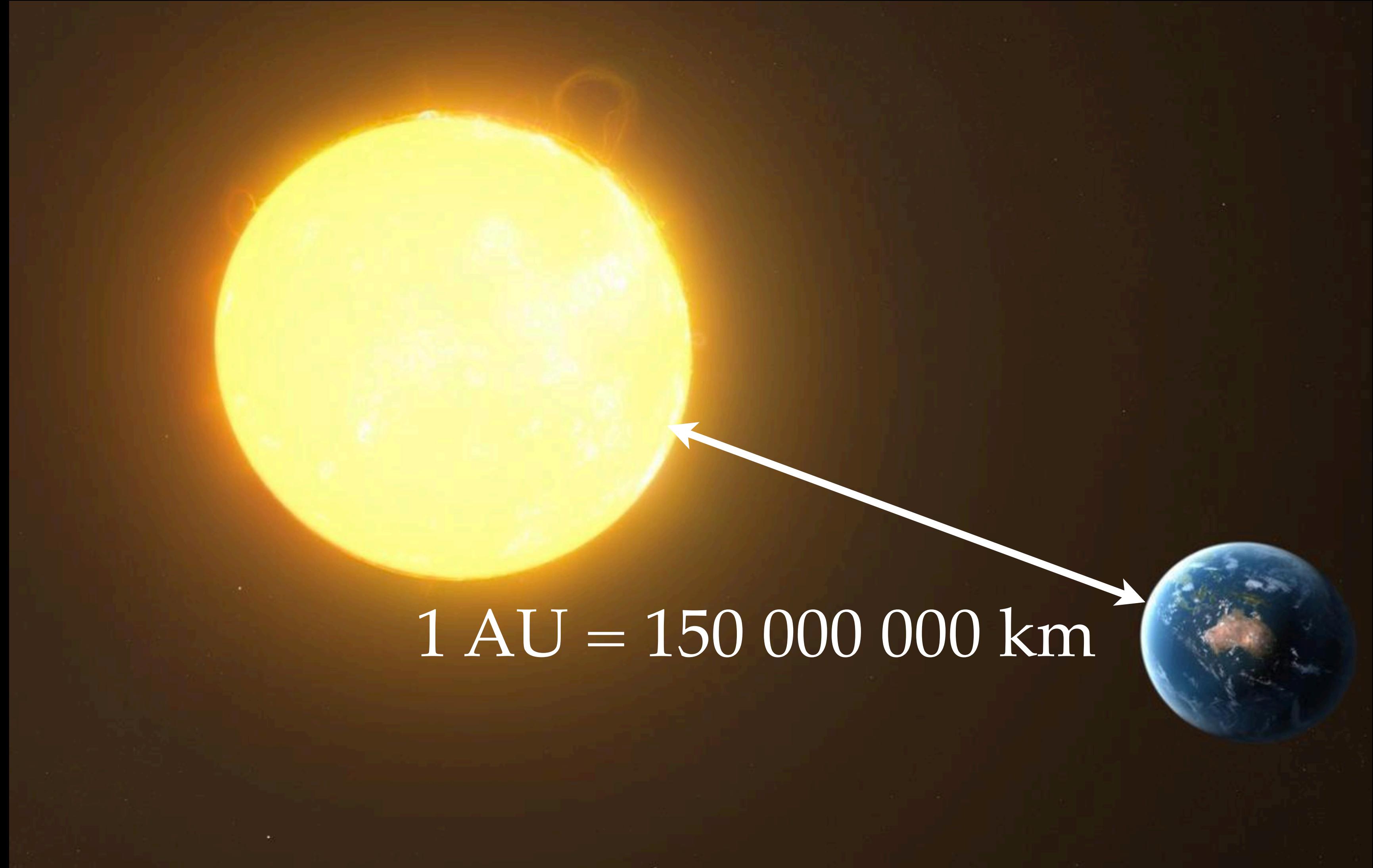
The Sun's volume is about 9×10^{18} km³. 10⁶ more than Earth!



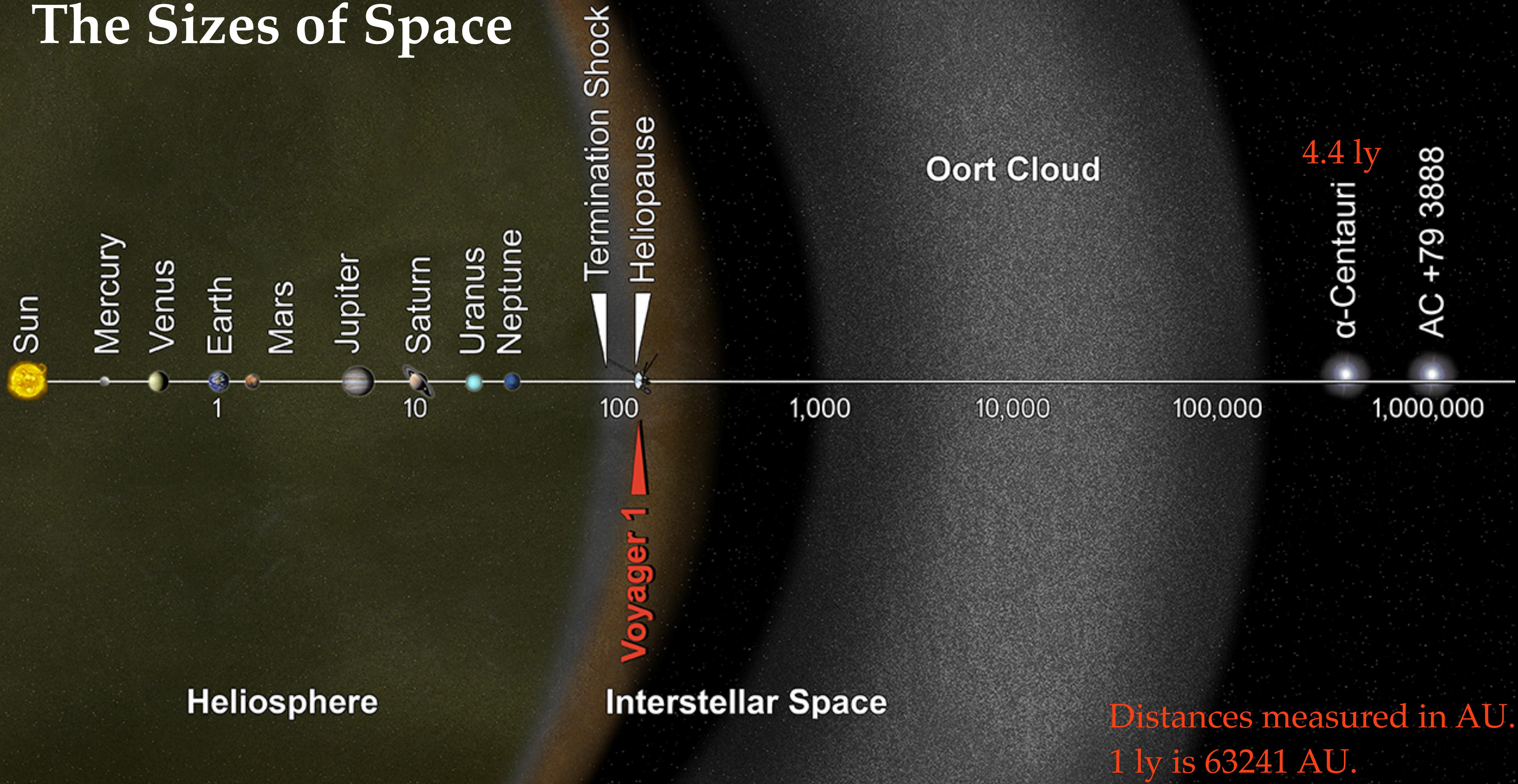
The Sizes of Space

The average orbital distance of the Earth from the Sun is 150×10^6 km.

To make it simpler, we call this 1 AU (Astronomical Unit).



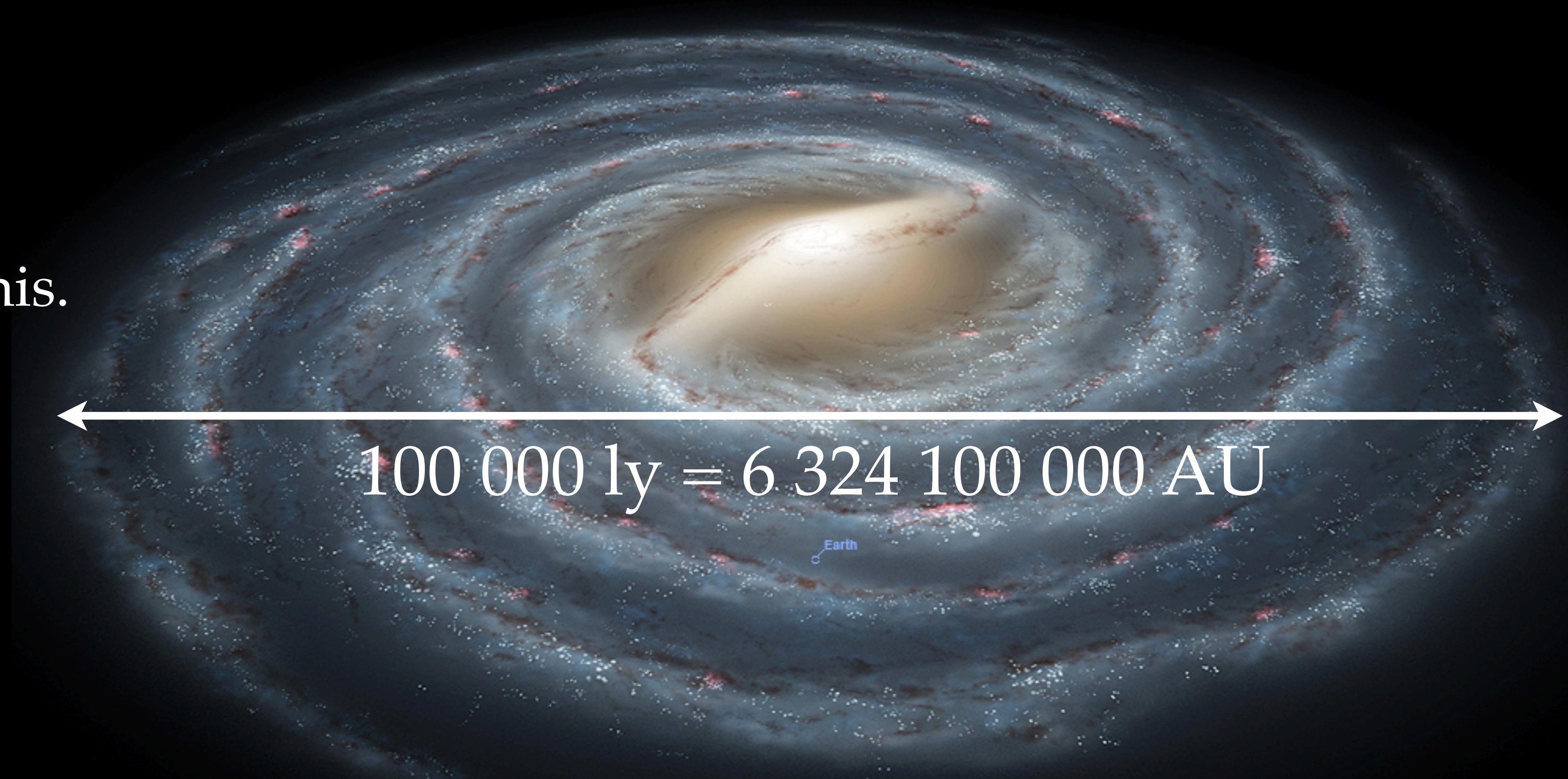
The Sizes of Space



The Sizes of Space

The Milky Way
Galaxy looks
something like this.

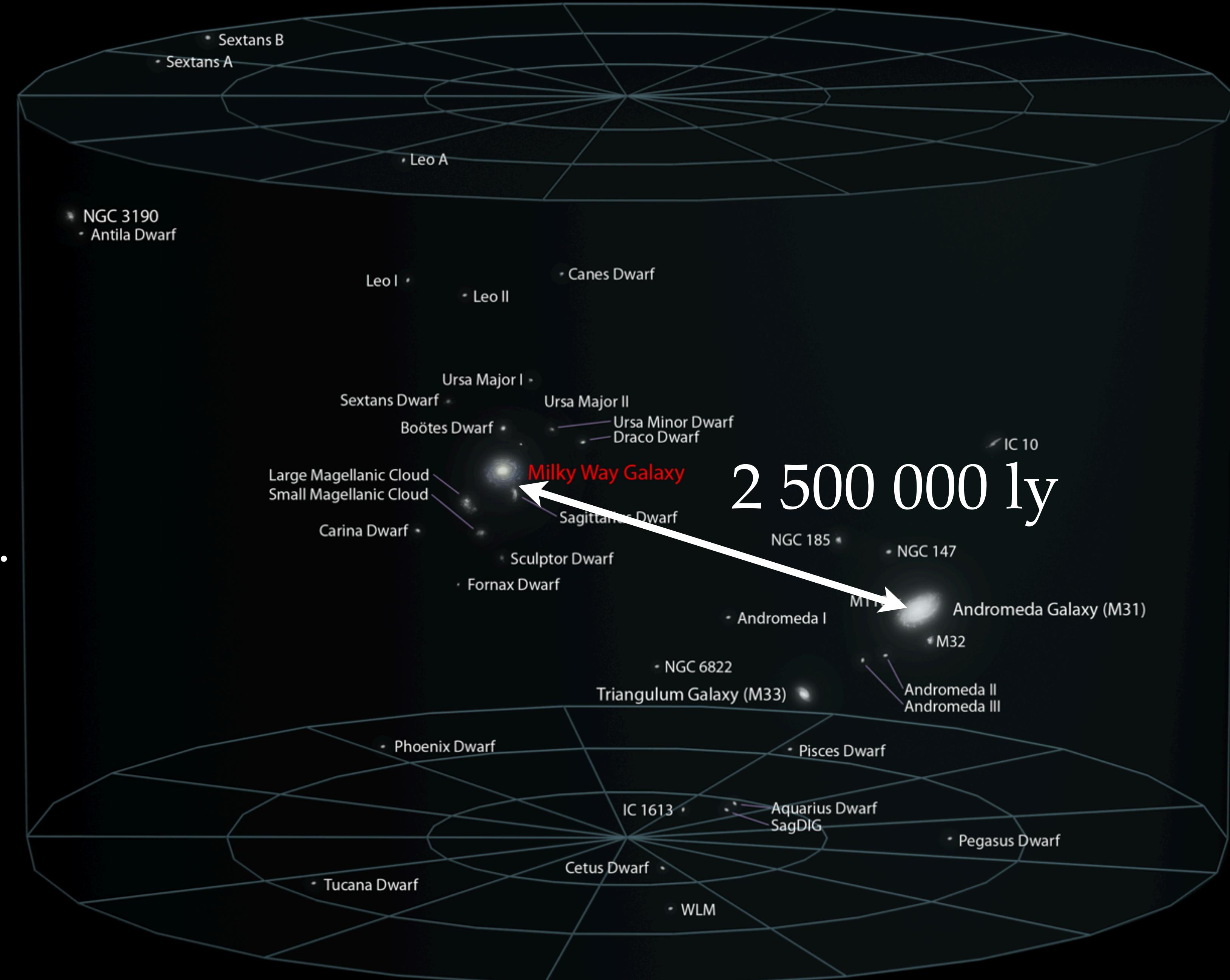
The Sun orbits
the Milky Way
about 26 000 ly
from the centre.



The Sizes of Space

The Milky Way and Andromeda Galaxies are part of a Local Group of galaxies that are gravitationally connected.

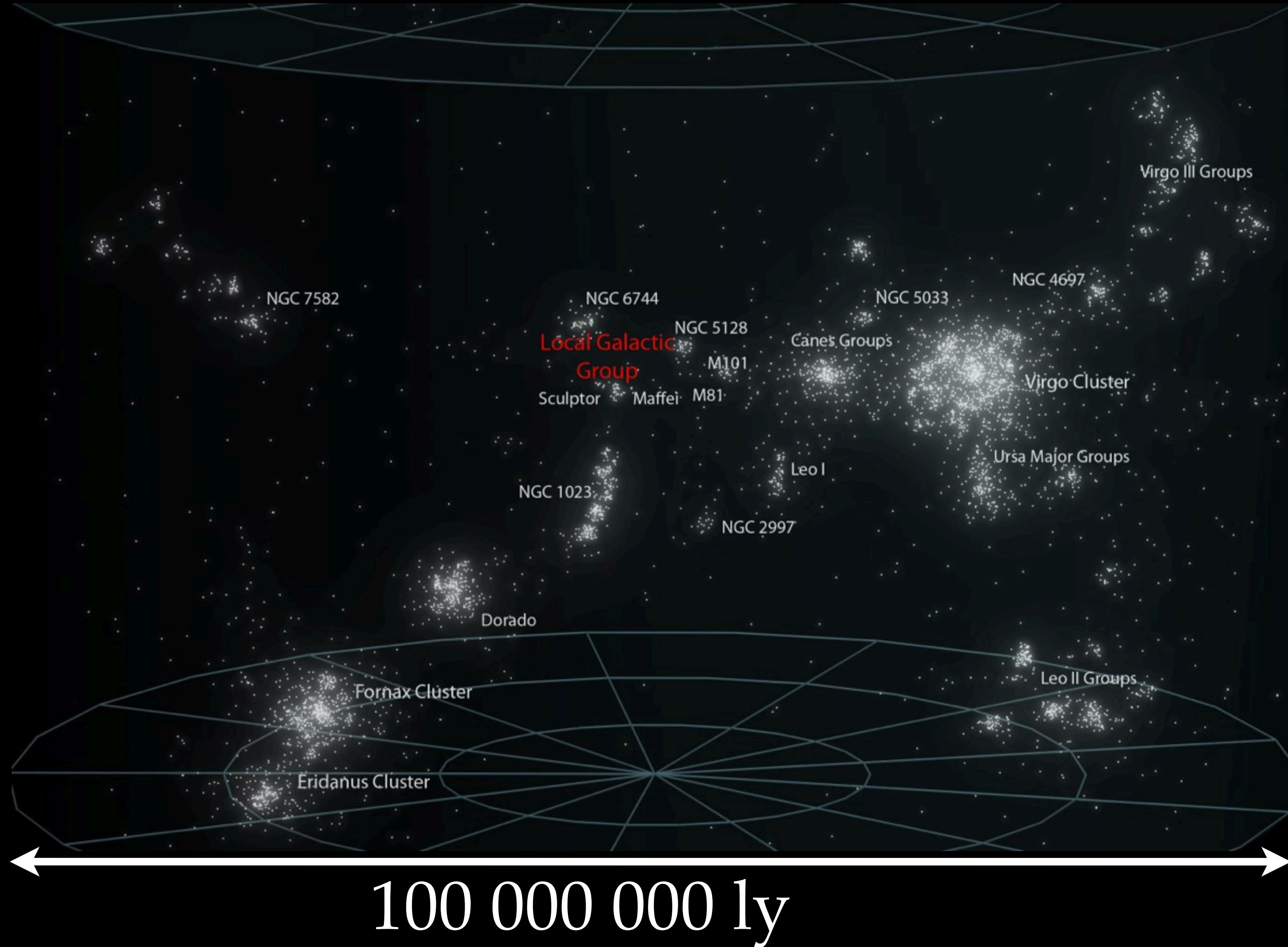
The Local Group is approx. 10^7 ly across.



The Sizes of Space

The Local Group is part of a larger gravitational system called the Virgo Supercluster.

This structure is 10^8 ly across.



The Sizes of Space

The Virgo Supercluster
is part of a network of
other superclusters that
are all gravitationally
connected.

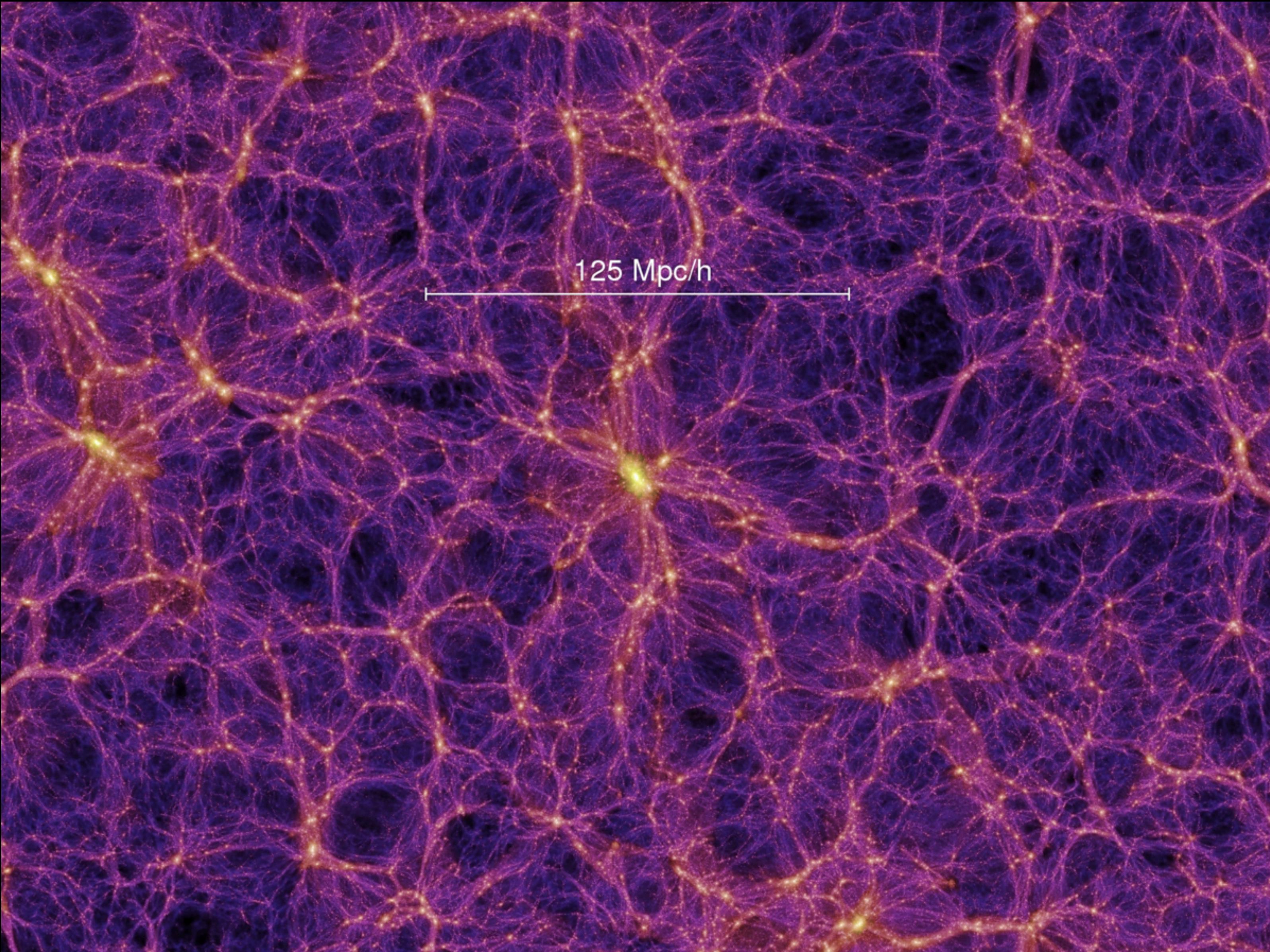
Every dot on this image
is another galaxy,
like our own, with 100s
of billions of stars.



The Sizes of Space

And as we continue to zoom out, the structure of the universe looks like a web of matter, connected together, despite the vast distance, by gravity.

(Current best hypothesis.)



The Night Sky

We see all of this
from this
perspective.

For this course,
we will focus
just on our solar
system.

But now you know
everything is connected!



Knowledge and the Scientific Method

Knowledge

Knowledge is derived from interactions with our environment - senses provide a feedback system through which we can act on the environment and then sense the response.

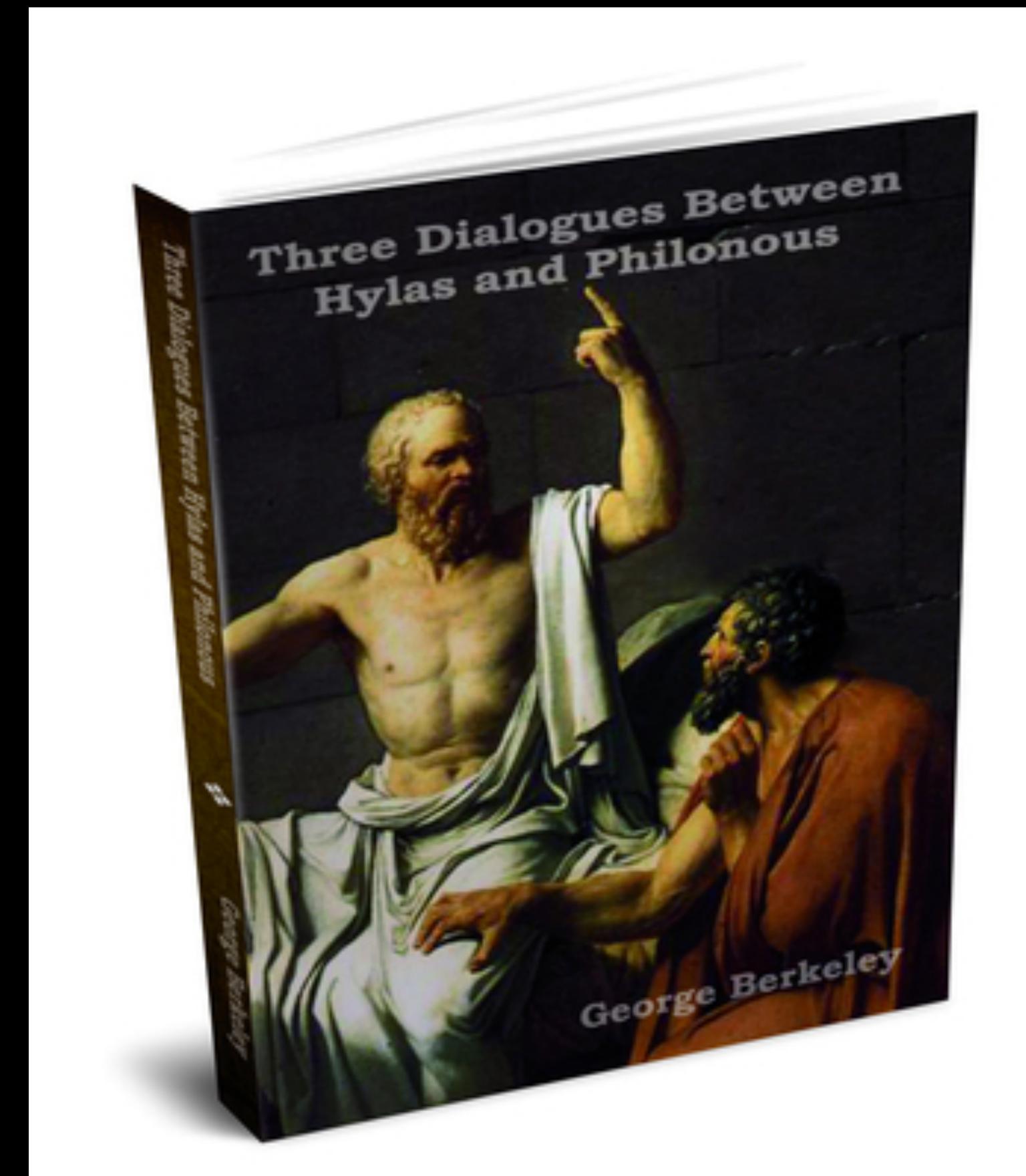
Colour we know through sight

Temperature we know through touch

Size we know through sight and touch

Mass we know by touch

Time we know by thought (cogito ergo sum)



Beyond the Senses

We quantify new experiences by comparing them to standardized experiences.

How large is an object? Compare its dimensions to a known distance (metre)

What colour is that? Compare it to a colour wheel.

What temperature is that? Use a thermometer.

What mass is that? Compare the masses on a scale to known masses.



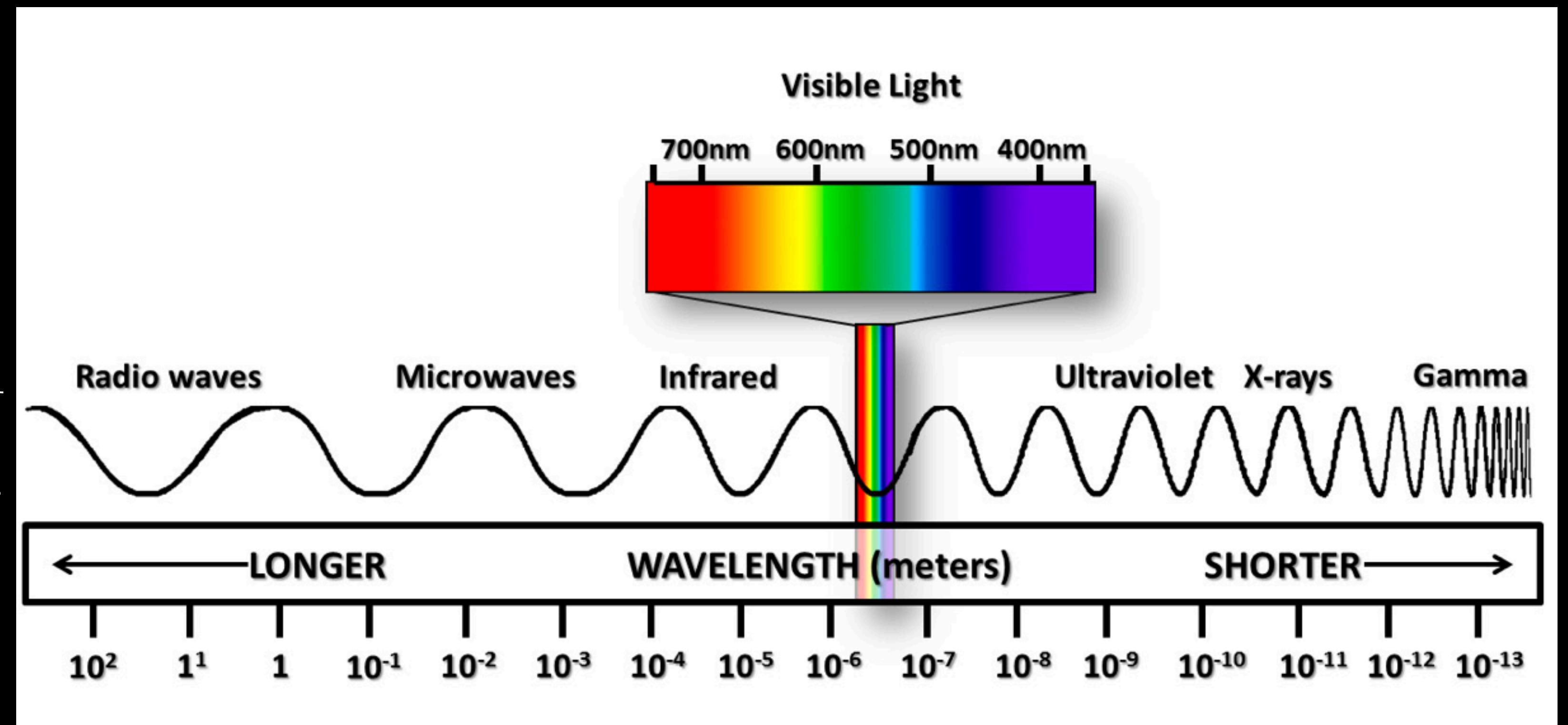
Direct Knowledge -> Indirect Knowledge

Devices do the comparison for us.

There are many other things that exist beyond what we can directly experience! But devices can experience them.

Example: Colour

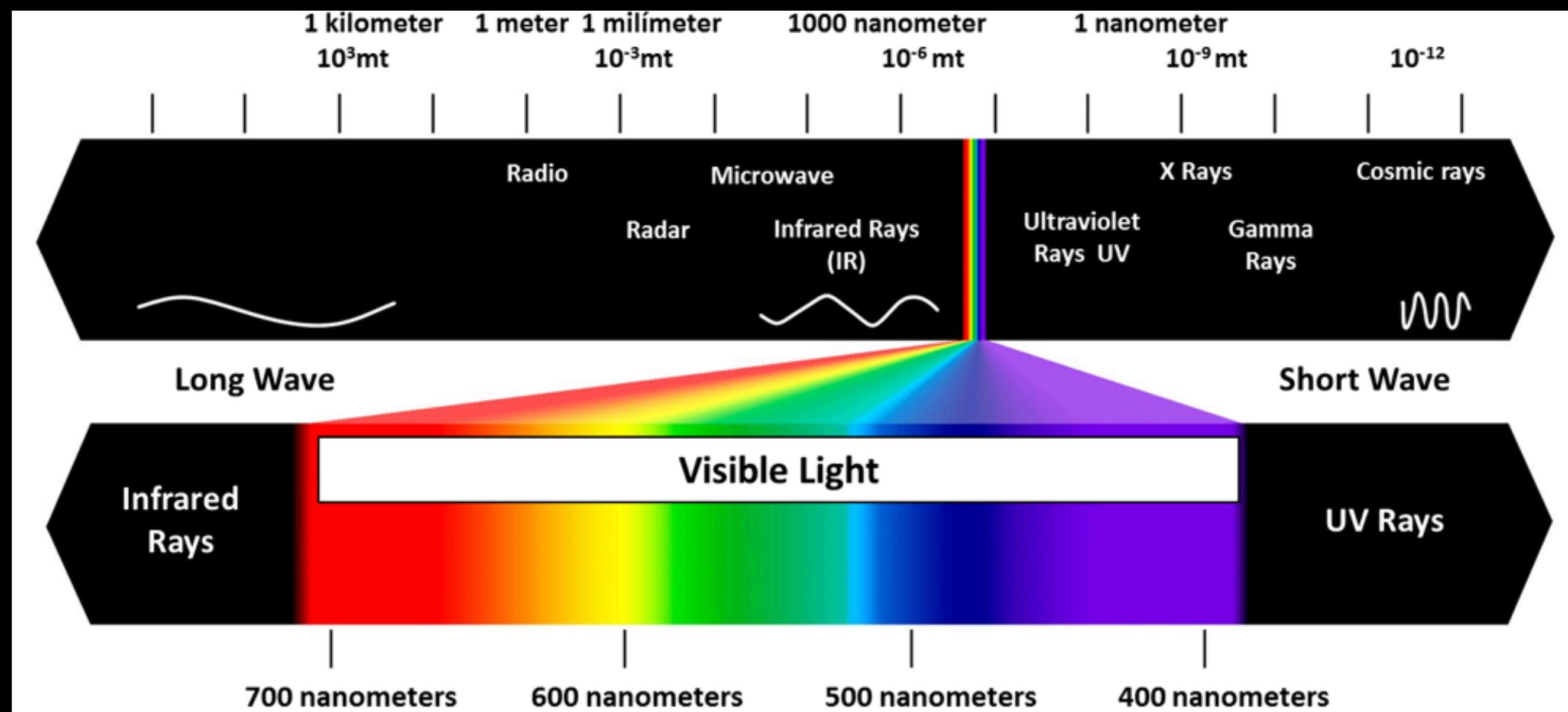
Visible light is just EM waves with wavelength (λ) between 400-700nm.



How to get Indirect Knowledge

First knowledge from experiences:

Size/shape, mass/inertia,
colour, temperature, time

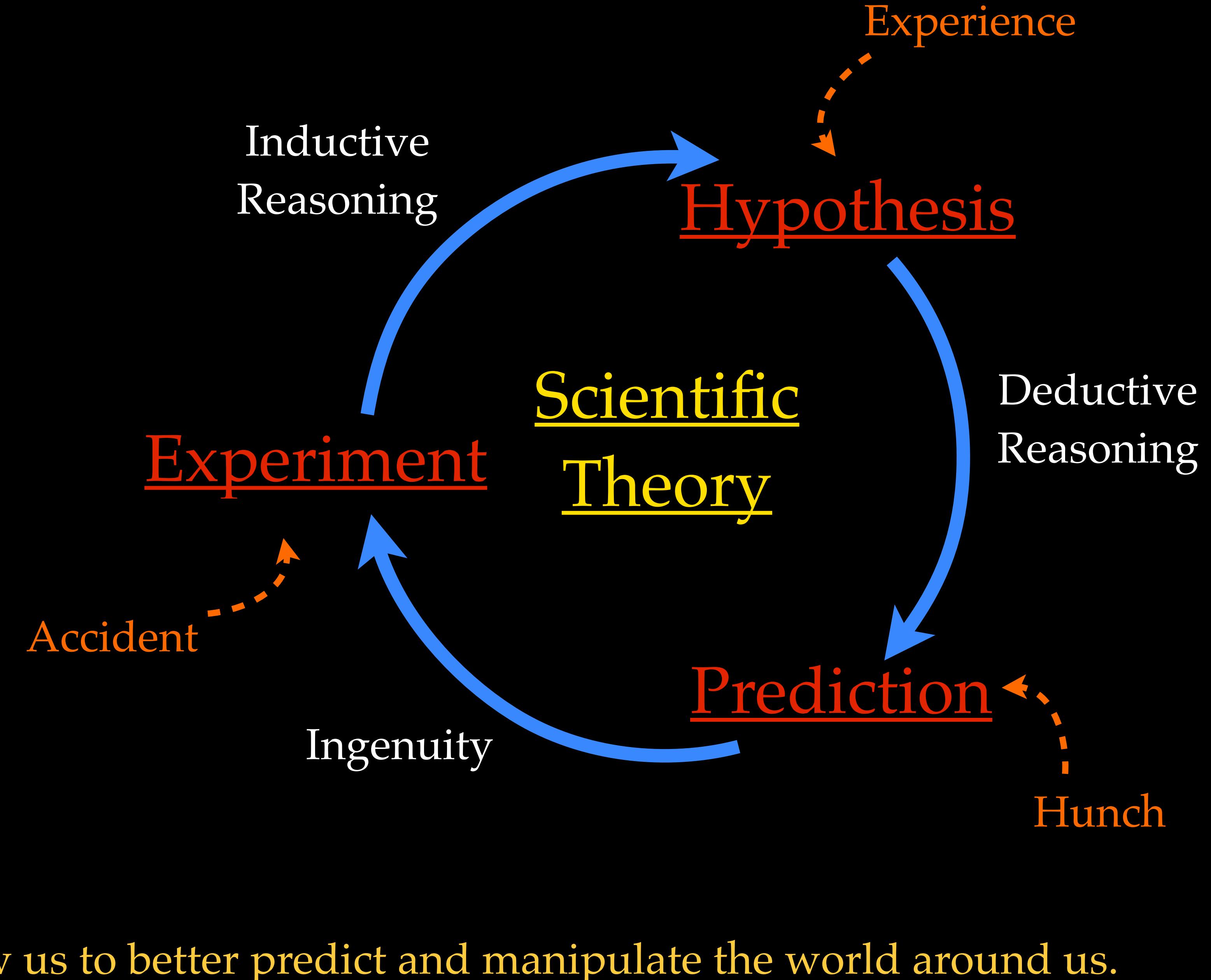


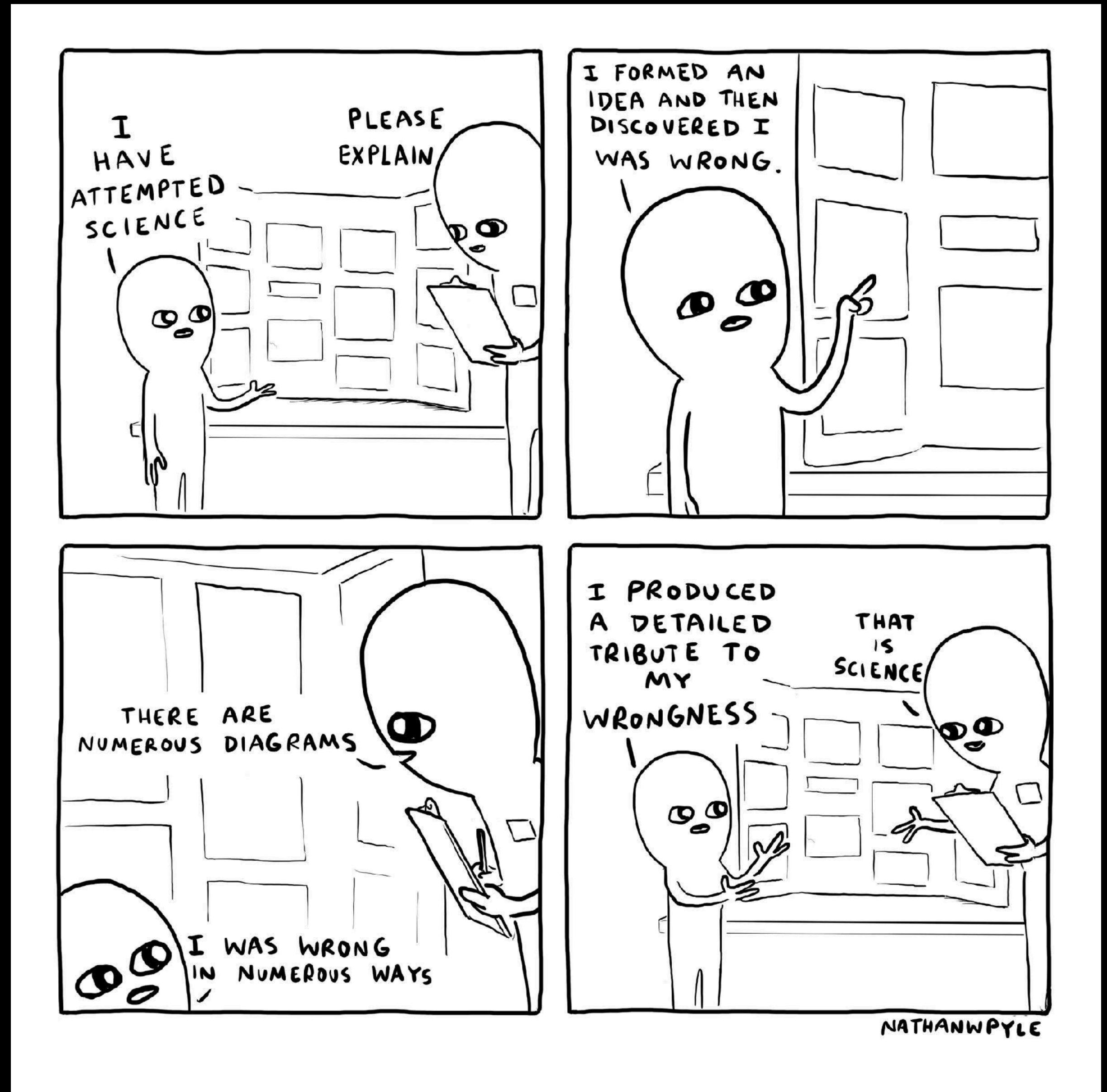
Use the scientific method to critically judge experiences and relate them to knowledge/theory about why experience happened.

Scientific Method

Scientific method follows a pattern of deductive and inductive reasoning to produce USEFUL knowledge about the world around us.

Goal is not to prove but to DISPROVE bad ideas.





The scientific method explained by Nathan W. Pyle

Inductive Reasoning

Generalizing knowledge from specific observations. (Evidence)

Example:

Observations: I throw a ball up 10 times, and each time it comes down.

Conclusion: Every time I throw a ball up, it will come back down.

All phenomena can occur infinitely many times - problem of induction!

Deductive Reasoning

Starting with a premise, deduce the logical outcomes. (Predict)

Example:

If: All things with mass attract each other gravitationally.

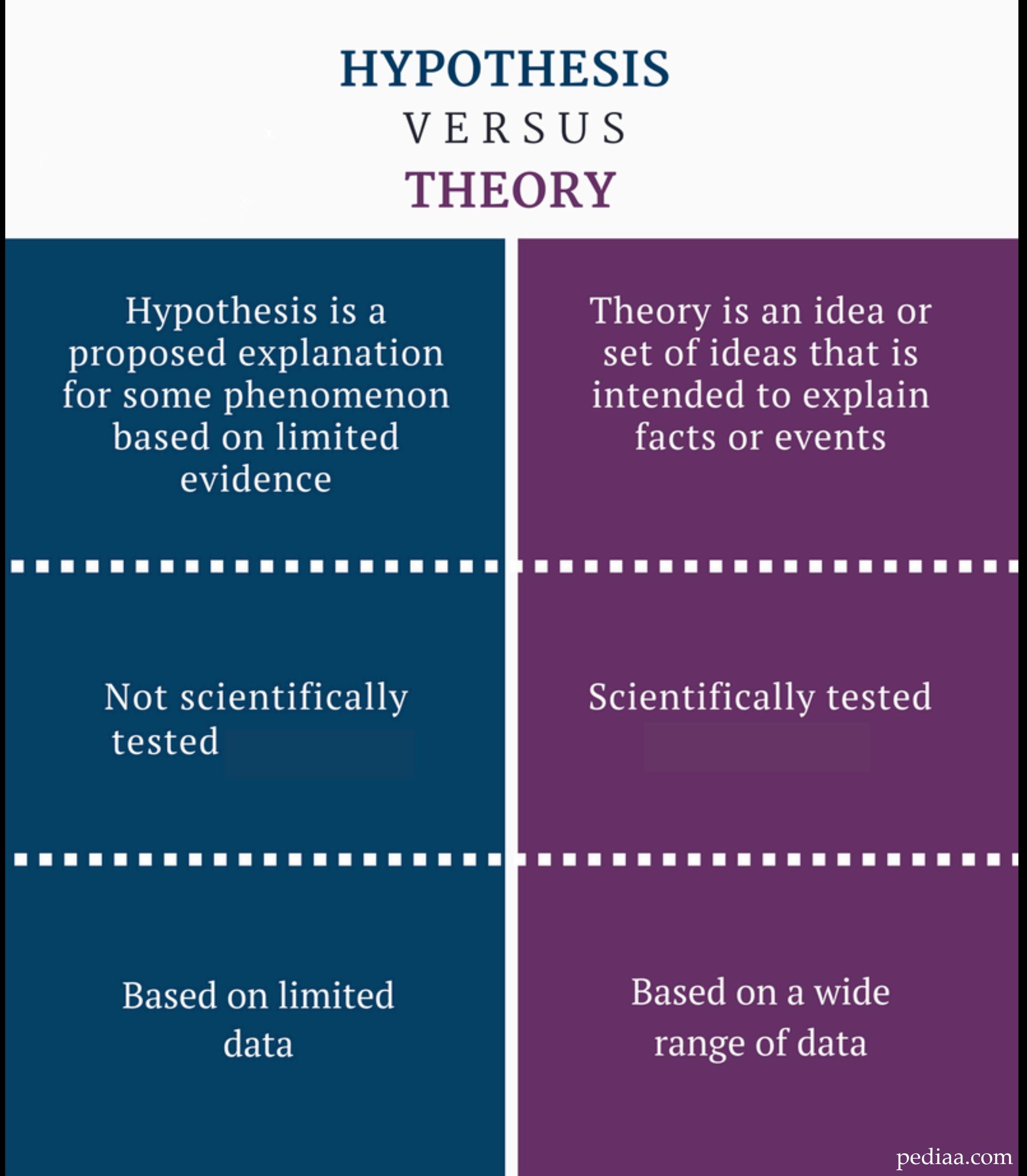
Then: The gravity between the Earth and the ball causes it to come back down.

Theory vs Hypothesis

Technical use of the scientific terms:

Hypothesis is simply an idea or proposed explanation.

A theory has made specific predictions that have been shown to be correct.



The Demon Haunted World

Science is more than a body of knowledge; it is a way of thinking. I have a foreboding of an America in my children's or grandchildren's time — when the United States is a service and information economy; when nearly all the key manufacturing industries have slipped away to other countries; when awesome technological powers are in the hands of a very few, and no one representing the public interest can even grasp the issues; when the people have lost the ability to set their own agendas or knowledgeably question those in authority; when, clutching our crystals and nervously consulting our horoscopes, our critical faculties in decline, unable to distinguish between what feels good and what's true, we slide, almost without noticing, back into superstition and darkness.

~Carl Sagan

Scientific Theories

Falsifiability of Scientific Theories

For a theory to be scientific, it must make a prediction that can be tested.

If an idea / theory is rationalized to be true despite contradictory evidence, then it is not falsifiable, and it is not science / bad science.

Example: Theory of the Supernatural (ghosts, etc)

What are some other untestable theories?

(Practically unfalsifiable also counts!)



Repeatability of Experiments

The experiment must be repeatable so that anyone else can verify it - doubt any claim made by someone that you cannot also investigate!

More than this: experiments must be repeated! Doubt any claim until an independent group has duplicated the results via a DIFFERENT method!

Example: Astrology

What are some other non-repeatable experiments?

Homeopathy



Select a substance that causes similar side effects to observed symptoms (arsenic, mercury, venom, etc).

Place in water, and let the water absorb its essence.

Dilute water until <1 atom of substance remains, but essence permeates the water.

Question: Which of these best explains why Homeopathy not a scientific theory?

- a. Scientists are opposed to alternative medicines.
- b. It does not make predictions.
- c. Homeopathic experiments are not repeatable.
- d. Homeopathic experiments are not falsifiable.

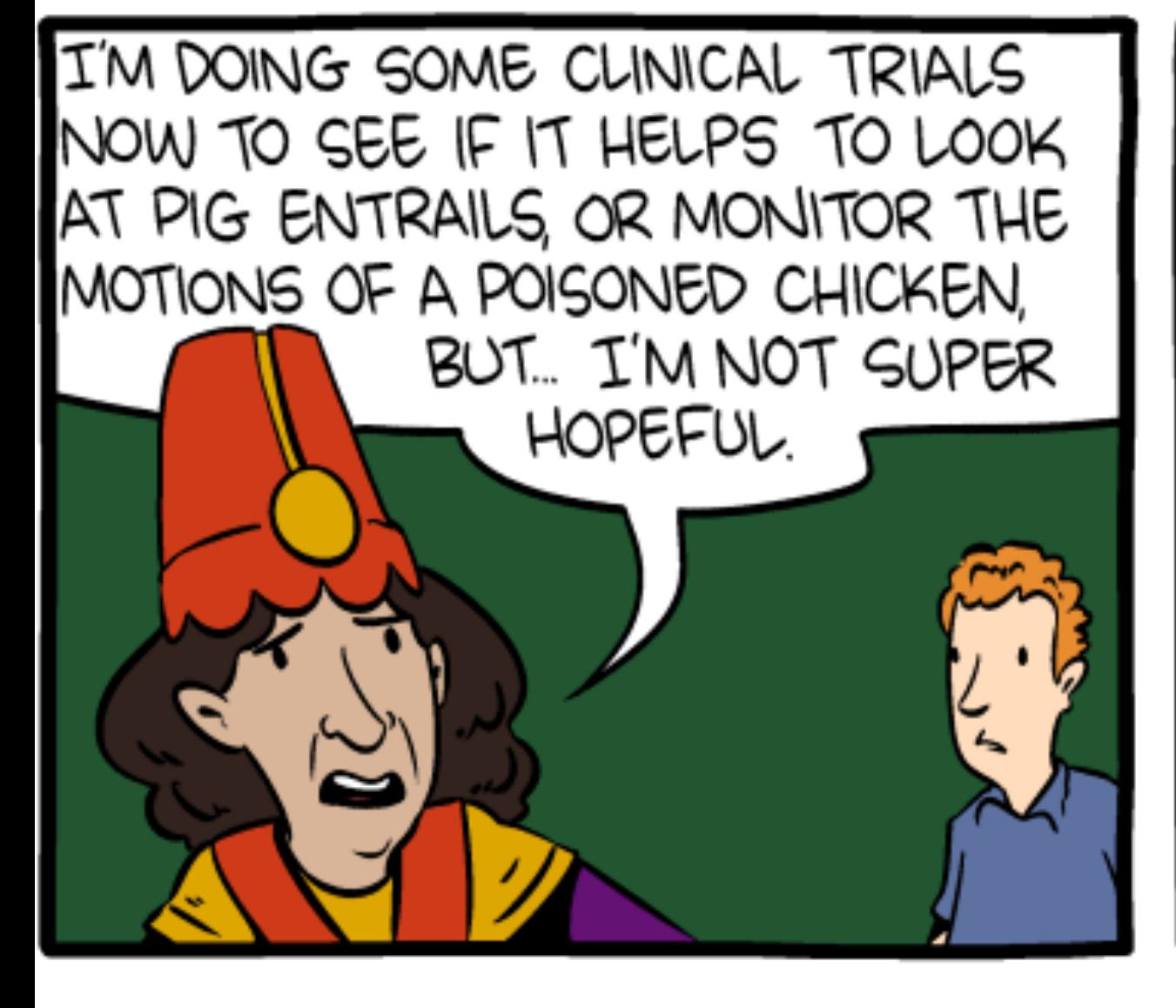
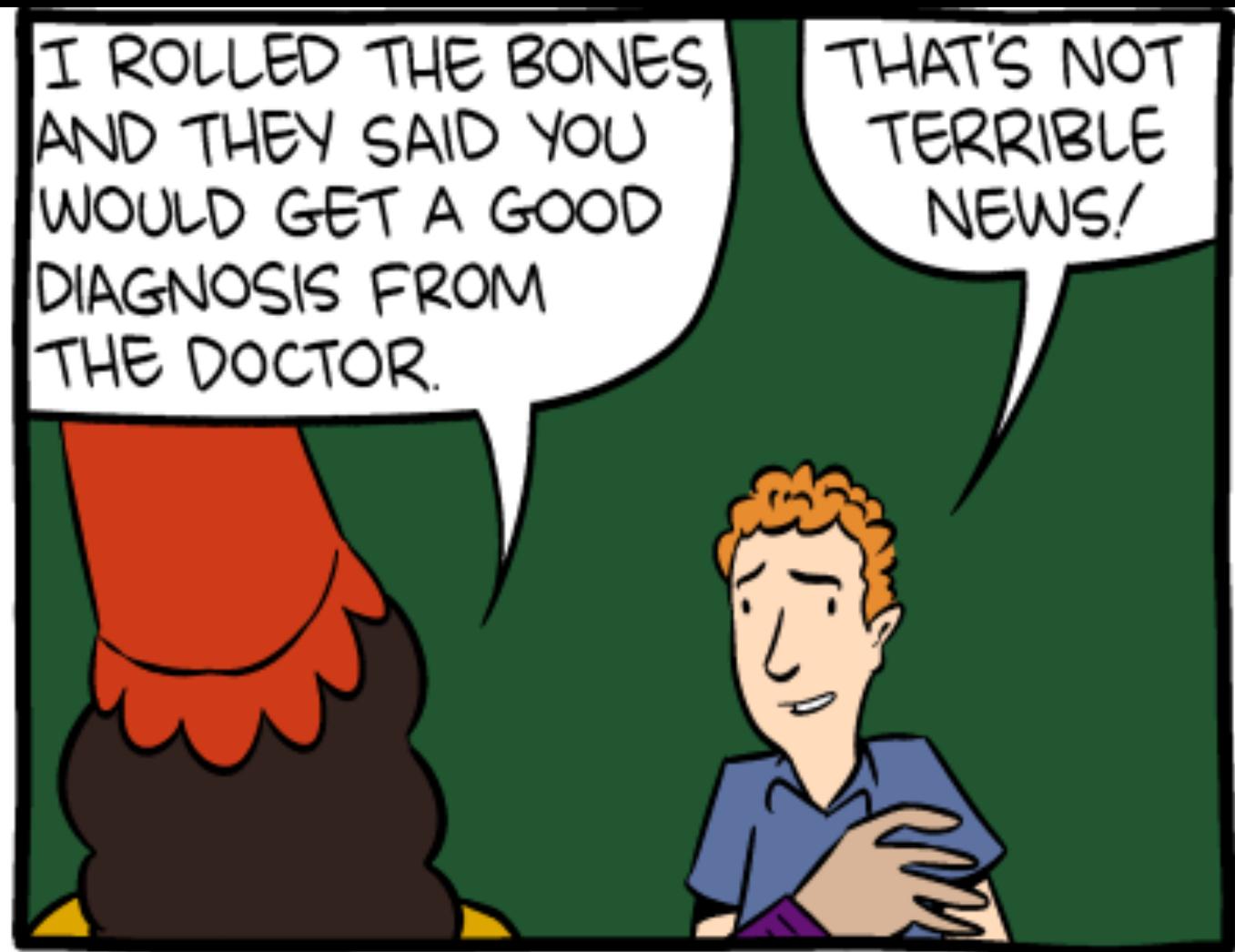
Placebo Effect

The senses can be fooled - see Rene Descartes's "Cogito ergo sum" argument.

People can be convinced they have a malady that they don't (hypochondria).

The body can also release chemicals that can help it heal, if it is convinced it is receiving help to heal.





smbc-comics.com



Saturday Morning
Breakfast Cereal

by Zach Weinersmith

www.smbc-comics.com

Example: “All swans are white.”

Is this a theory?

Is this a falsifiable statement?

Does it promote a
repeatable experiment?

How can/should we fix
this statement?



Simplicity and Elegance

Scientific theories should not make any unnecessary claims (simplicity).

Scientific theories should tie together multiple phenomena such that the resulting understanding is greater than the individual parts (elegance).

Example: Theory A - The planets and Sun orbit the Earth.

Theory B - the planets all orbit the Sun. (Hint: Neither are correct!)

What are some other examples of non-simple or non-elegant theories?

Example: Astrology

Astrology is the study of the movements and relative positions of celestial bodies interpreted as having an influence on human affairs and the natural world.

In form of a theory: “The movement and relative positions of celestial bodies impact the personalities of humans, as well as the interpersonal events within human society.”



The Theory of Astrology

Is it falsifiable?

Is it repeatable?

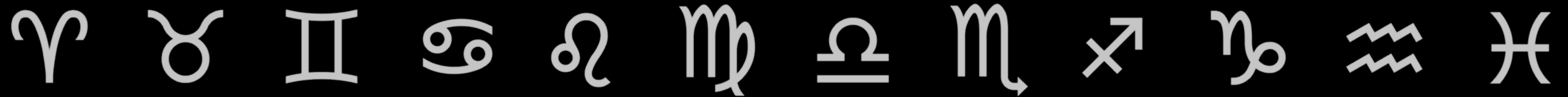
Is it simple?

Is it elegant?



Does this apply to you?

You are steady and function best under harmonious atmosphere. The two most important life aspects for you are a stable and prosperous financial condition and an emotionally stimulating life partner. You are capable of great devotion to your mate, but can become absolutely desolate and withdrawn if otherwise. You need wealth and comfort to be really happy in life. You are steady about your love life and emotions.



Astrology Experiment

Description
Accurate

Description Not
Accurate

Correct Sign

Evidence in favour of
the theory of Astrology

Evidence against
the theory of Astrology

Incorrect Sign

Evidence against
the theory of Astrology

Does not contribute
to experiment

Astrology Experiment

Description
Accurate

Sign = Taurus

Sign != Taurus

2

(True Positive)

14

(False Positive)

Description Not
Accurate

2

(False Negative)

33

(True Negative)

Astrology Experiment

Description
Accurate

Sign = Taurus

3

(True Positive)

Sign != Taurus

54

(False Positive)

Description Not
Accurate

11

(False Negative)

84

(True Negative)

Astrology Experiment

Description
Accurate

Sign = Taurus

4

(True Positive)

Sign != Taurus

63

(False Positive)

Description Not
Accurate

7

(False Negative)

111

(True Negative)

Astrology Experiment

Description
Accurate

Sign = Taurus

Sign \neq Taurus

0

(True Positive)

17

(False Positive)

Description Not
Accurate

1

(False Negative)

32

(True Negative)

Astrology Experiment

Description
Accurate

Sign = Taurus

5

(True Positive)

Sign != Taurus

52

(False Positive)

Description Not
Accurate

8

(False Negative)

96

(True Negative)

Bad Science

>60% of foods have been found to either cause or cure cancer in separate studies - some do both!

Just because the scientific method is principled, doesn't mean people follow the principles - bad science can and does occur

But this doesn't negate good science! DISPROVE, NOT PROVE!

Science-Based Medicine

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Articles

<https://www.sciencebasedmedicine.org/everything-causes-cancer/>

Everything Causes Cancer

 Posted by Steven Novella on September 11, 2013 132 Comments

It's likely you know someone who has bought into the notion that nutrition is everything, the source of all health and the cause of all illness. Nutrition is very important, to be sure, but it is only one of many possible causes of disease, and if you live in a Western industrialized nation you probably have adequate nutrition. The notion, however, that food can heal is powerfully alluring, and it makes great headlines. The result is that people who read the headlines for the latest food to avoid, or the latest ingredient that will make them live longer or stave off disease, seem to have an association for everything. Eating around them is to be constantly told that food X is good for you and will prevent Y, or that some other food should be avoided because it causes Z.

Studies show only 10% of published science articles are reproducible. What is happening?

Posted on [May 3, 2012](#) by [Moshe Pritsker](#)

Studies show a very low reproducibility for articles published in scientific journals, often as low as 10-30%. Here is a partial list:

- The biotech company Amgen had a team of about 100 scientists trying to reproduce the findings of 53 “landmark” articles in cancer research published by reputable labs in top journals.
[Only 6 of the 53 studies were reproduced](#) (about 10%).
- Scientists at the pharmaceutical company, Bayer, examined 67 target-validation projects in oncology, women's health, and cardiovascular medicine. Published results were reproduced in only [14 out of 67 projects](#) (about 21%).
- The project, PsychFileDrawer, dedicated to replication of published articles in experimental psychology, shows a [replication rate 3 out of 9](#) (33%) so far.



The Social Factor

You cannot separate the science from the scientists!

Science may be principled, but it is only as principled as the scientists who use/abuse it: Money corrupts! Power corrupts! Science can be corrupted.

Scientific method is still the best means for understanding the natural world.

Be careful about what you believe.



Skepticism

Misconception 1: “Scientists don’t believe in anything.”

“Belief” is not a word that describes scientific knowledge. But scientists are people and do fill in the gaps with beliefs.

Scientific skepticism is not a rejection of beliefs. It is simply a quality that describes the requirement of reproducible evidence for trust in ideas.

Skepticism

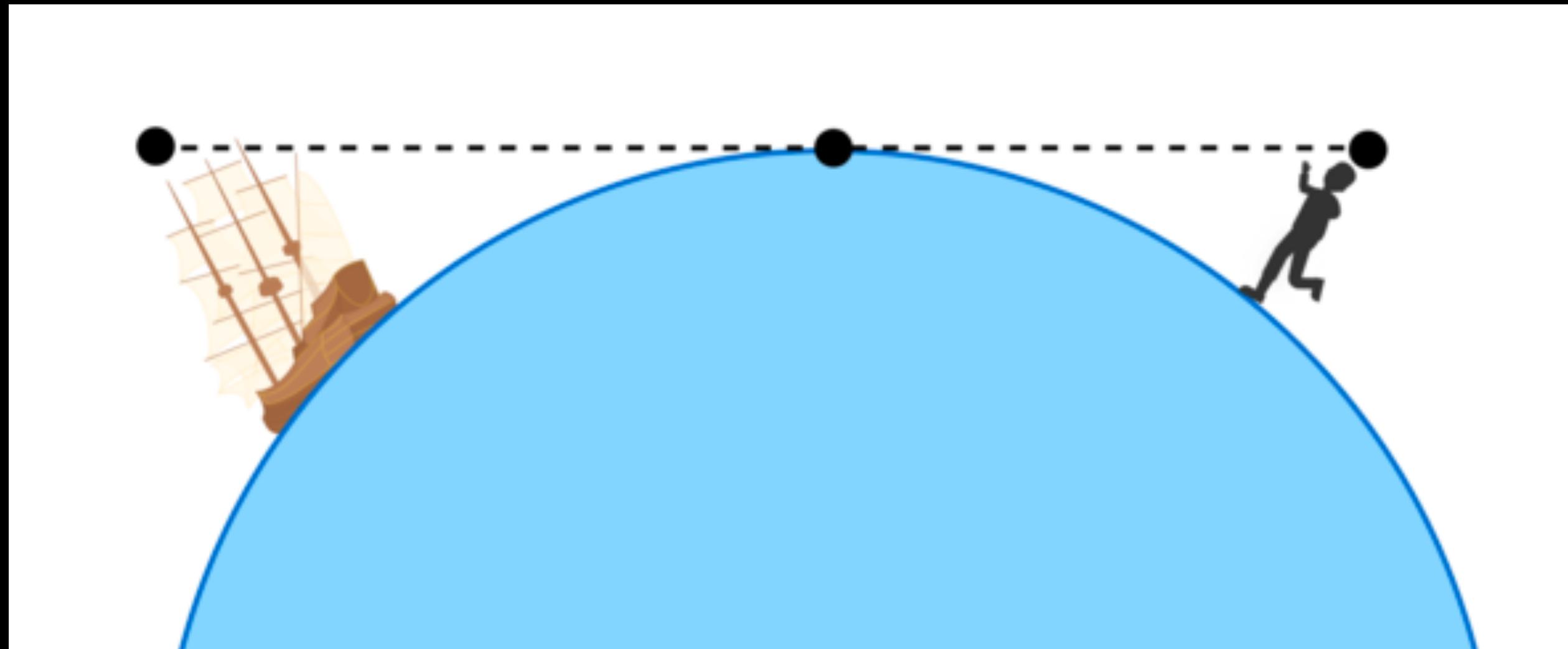
Misconception 2: “Scientists only believe what other scientists say and reject knowledge of <insert group/ideology>.”

Scientists are skeptical of each other’s work, and are constantly looking for a new understanding.

Scientists reject e.g. alternative healing because they have been scientifically tested and shown to have no effect.

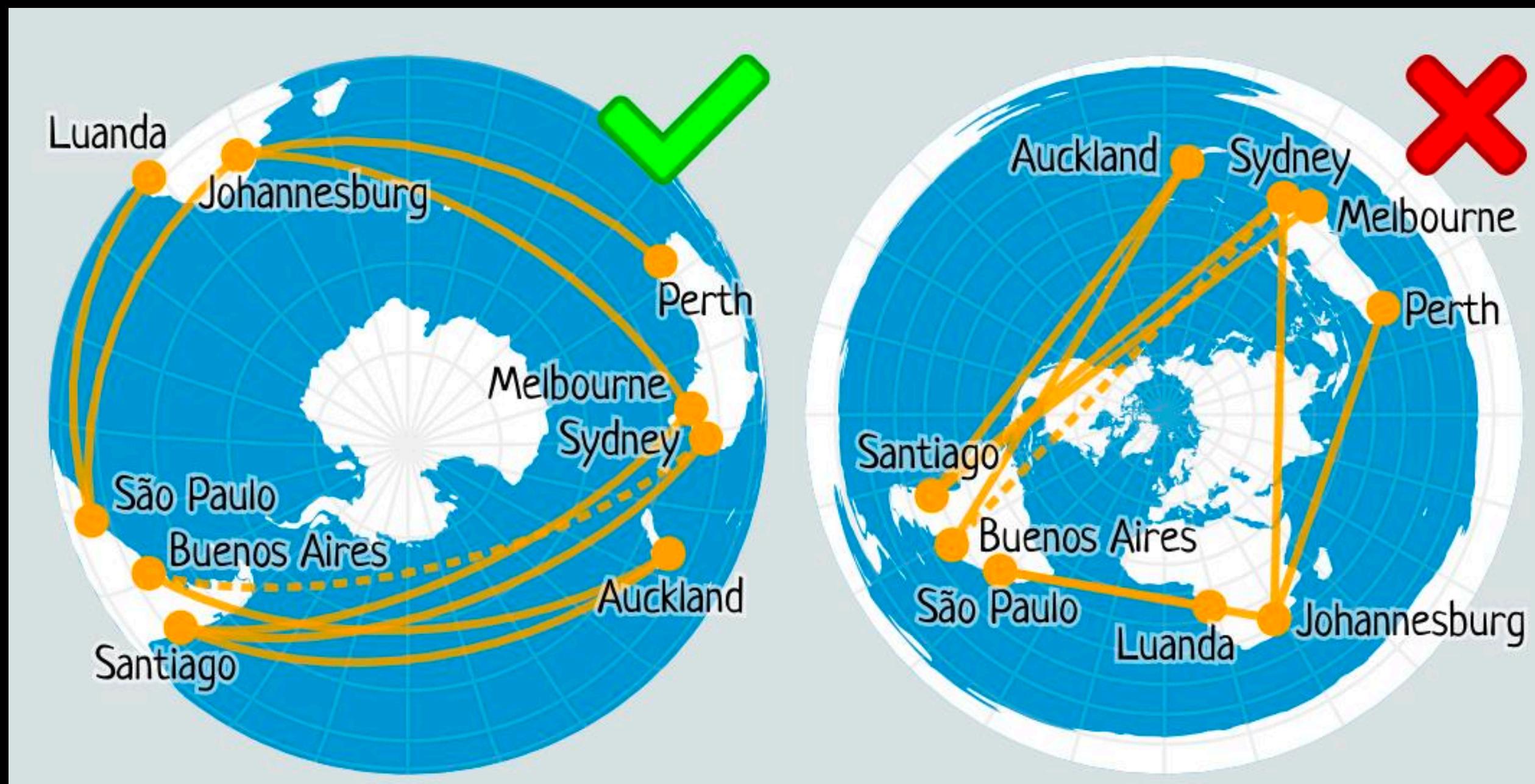
Astronomy

Hypothesis: The Earth is flat.



Prediction: Ships should just get smaller as they get further away.

Observation: Ships disappear from the bottom up as they get further away.



Prediction: The distance from South America to Australia is ~20000km by plane.

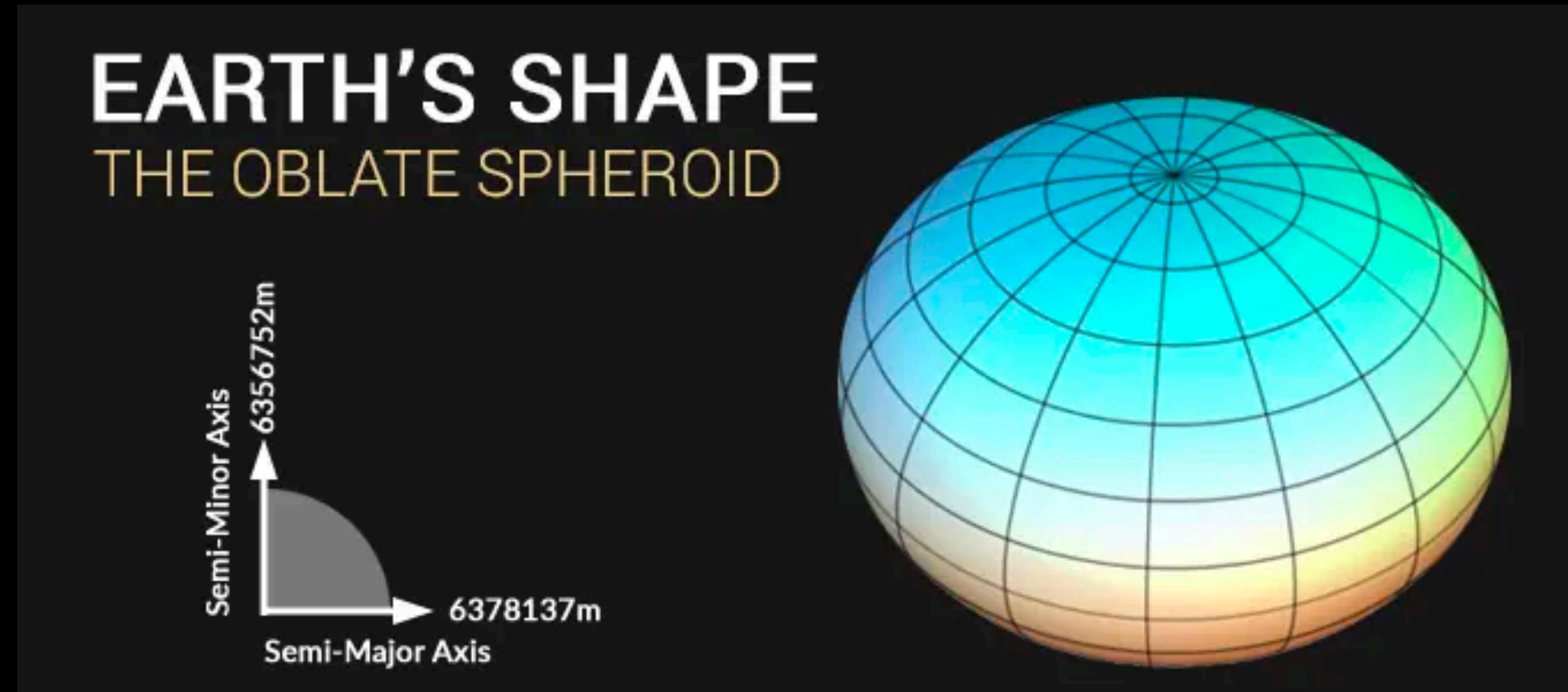
Observation: Planes only fly ~11000km to get from South America to Australia.

~~Hypothesis:~~ The Earth is flat.

Astronomers can conclusively disprove that the Earth is flat.

Astronomers can similarly disprove that the Earth is a sphere.

Astronomers cannot disprove that the Earth is oblate spheroid in shape.



There are also irregularities on the surface that make it an imperfect spheroid. These include mountains, buildings, trees and other things.

Astronomy as a Science

Common misconception: We can't experiment on stars / planets, so astronomy is not a science.

Reality: Nature plays the role of experimenter.

Make observations of similar objects.

Look for patterns.

Theorize about cause of patterns.

Make predictions from theories.

Make new observations that might disprove those theories.

Example: Aristotle's Theory on Lunar Eclipse

Many ancient cultures distinguished the Lunar Eclipse from the phases of the moon.



Phases of the Moon



Lunar Eclipse

Example: Aristotle's Theory on Lunar Eclipse

Incan peoples believed a Jaguar attacked the Moon.

Darkness of Jaguar explained darkening.

Reddish Moon explained as blood.



Mesopotamian peoples believed a demon attacked the Moon. The redness was blood. Other cultures included variations on the theme.

Example: Aristotle's Theory on Lunar Eclipse



Aristotle observed that the curvature of the shadow was circular and always the same for lunar eclipses.

Theorized that it was a shadow of a round object - the Sun was not in the sky, so thus it was the shadow of Earth.

Example: Aristotle's Theory on Lunar Eclipse



Theory: Earth is round. When the Sun is on the opposite side of the Earth to the Moon, it casts a shadow on the Moon.

Falsifiable - testing if the Earth really is round.

Repeatable - eclipses happen repeatedly, check curvature each time.

Simple - shadows are a simple concept.

Elegant - ties together multiple concepts (shape of Earth, cause of eclipse)