

Welcome to AY2!

- ❖ Instructor: Prof. Connie Rockosi

Office Hours: Thursdays 1:30-3 pm or by appointment
(so I'm in my office to meet you and not in the lab)

Office: ISB 261

- ❖ TAs:

Marie Lau: wlau10@ucsc.edu

Office Hours: Friday 3:30-4:30pm, ISB 159

Plato Karpov: plkarpov@ucsc.edu

Office Hours: TBD

- ❖ Course web page, all the info you need to know now, updates during the quarter:

<http://www.ucolick.org/~crockosi/AY2Rockosi2017>

(linked from my home page, the Astro. dept. pages or use Google)

Course Stuff

- ❖ Textbook: ***Explorations***, by T. Arny & S. Schneider, 8th edition
 - The bookstore has special print version for UCSC
- ❖ Electronic material at McGraw-Hill **Connect**
- ❖ Register here: <http://connect.mheducation.com/class/w17>
 - Homework and reading assignments will be on-line assignments through Connect
 - **You MUST register for Connect for the course**
 - Two-week trial courtesy access is available, but you **must** eventually purchase this
- ❖ Connect purchase includes on-line textbook access
 - required for reading assignments
 - print version of textbook not required

Course Stuff

- ❖ i>Clickers or the REEF education polling app: for your participation credit, feedback to me
 - These must be registered on-line. You need an account with REEF and a (paid) subscription.
 - No charge for registering a new iClicker, but there is a charge for registering used ones.
 - iClickers are available from the bookstore
 - Please have either option registered by class **Thursday, 1/19**
- ❖ A small, inexpensive calculator.
 - It should be able to do powers and roots
 - It ***must not*** be able to access the internet.

Grading

- ❖ 1 midterm, in-class Tuesday, Feb. 14th: 25%
- ❖ Final exam: 25% (Wed., March 22nd, 7:30 - 10:30 pm)
 - Zero credit for either the midterm or final will result in failing the class
- ❖ Homework and Reading Assignments: 25%
 - Assigned on-line in Connect
 - No credit for late homework
- ❖ Discussion section: 10%
- ❖ In-lecture questions and quizzes: 15%

Discussion Sections

- ❖ Mon 1:20 - 2:25 pm NS Annex 101 TA: Marie Lau
- ❖ Wed 8 - 9:05 am NS Annex 101 TA: Marie Lau
- ❖ Wed 9:20 - 10:25 am NS Annex 101 TA: Plato Karpov
- ❖ Friday 2:40 - 3:45 pm NS Annex 101 TA: Plato Karpov
- ❖ Homework assignments will be due Thursday noon
 - Reading assignments before class
- ❖ Mon and Wed sections will cover homework due next week, Friday sections on homework due next week
- ❖ First section of the quarter is this Friday, 1/13

Discussion Sections

- ❖ Get help with homework
- ❖ Ask questions about reading and lecture material
- ❖ Your TA may cover a related topic or go over content from lectures or homework concepts
- ❖ **Go to section!**
 - it's required
 - get extra help for concepts you are struggling with
 - participate in group discussions and homework problem solving: find a peer group to work with
 - learn from your TA
 - get credit for your course grade

Lectures

- ❖ Posted on course web page as PDF the day of lecture

- ❖ Clarify and highlight material

Not a substitute for reading the textbook!

- ❖ in-class polling: feedback (for both of us)

points for participating/attendance = responding to questions in lecture

1 point for any answer

+1 point for a correct answer

can miss ~2 lectures without penalty

- ❖ Register your iClicker or the REEF polling app by Thursday, 1/19!

<https://reef-education.com/>

Polling Question

❖ Did you bring an iClicker to class today?

A yes

B no

Reading Assignments

- ❖ Assigned through Connect: to get credit you must answer the questions through the on-line assignment in Connect.
 - There is a button labeled “Practice” that takes you to the assignment
- ❖ Reading the paper version of the textbook will prep you for answering the questions, but the on-line questions are how you get credit
- ❖ Due 5 pm (right before lecture)
- ❖ Counts as part of your homework grade
- ❖ All you have to do for full credit is finish it!
 - Do not neglect this easy way to help your grade!
- ❖ These go over all the important material for the chapter (i.e., topics that will be on homework and exams)
- ❖ Lets us use some lecture time for other activities

Homework

- ❖ Posted: Wednesday mornings each week via Connect: connect.mheducation.com/class/w17
- ❖ Due: the following Thursday at noon
- ❖ Remember: Monday, Wednesday sections for the current week's homework, Friday section on next week's homework
- ❖ **No credit for late homework**
- ❖ Automatically submitted (assignment closed) on due date/time
- ❖ Get help with homework from your TA in section, at office hours. Learn from and with your peers.
- ❖ Get extra help from the UCSC Learning Support Center. Announcement coming Thursday

Homework

- ❖ Hints are available, use them. There is no penalty for using hints.
- ❖ You have up to three tries to answer each question. You use up one try each time you use “check my work”
- ❖ Questions for which you calculate numbers will usually let you try another version of the problem if you miss all three attempts.
 - You can try up to 10 more versions of the problem for full credit
 - ❖ that’s three tries on each of 10 version of the problem
 - If you are struggling, stop and get help before you exhaust those
- ❖ You will see your score as you go. If you finish the homework and wish you had a better score, you can try the whole assignment again, up to three times in total. You will get the best score of your three attempts, no penalty for doing the assignment multiple times.
 - Full solutions available after the due date/time

Why Astronomy?

- ❖ Universe is the ultimate physics lab:
 - Gravity: from explaining how planets orbit the sun
 - Nuclear forces: understanding what powers the sun
 - Relativity: weird and wonderful physics best tested at large distances, extreme conditions we find far from Earth
- ❖ Can't bring the universe into the lab.
- ❖ Instead, need to observe, build models to explain the data, test the models, go back and fix the models, repeat. Useful for understanding other systems we can't reproduce in the lab:
 - Geology
 - Climate
 - Evolution
 - Economics
 - Sociology

Why Astronomy?

- ❖ Making sense of the world around us
 - Seasons, eclipses, the night sky
 - Really Big Picture: How old is the universe? How did it start? How will it end? Where did the stuff we are made of (Carbon, Nitrogen, etc.) come from? Is other life out there?
- ❖ The same physics that explains your car, a basketball 3-point shot and everything around you also explains the solar system, planets, stars, galaxies and the fate of the universe
- ❖ The universe is full of amazing and beautiful things
And we can understand them!

Math and Units

- ❖ Basic high school math required

Simple equations, ratios. No calculus.

- ❖ Metric system

length: meters 1000 mm = 1 m

1000 m = 1 km

1 m ~ 3 ft, 1 mile = 1.6 km

You are 1.5 - 2 m tall

- ❖ Scientific notation:

1 mm = 0.001 m = 1×10^{-3} m

Distance to sun: 150,000,000,000 m = 1.5×10^{11} m

Wavelength of visible light: 0.0000005 m = **????**

Math and Units

- ❖ Basic high school math required

simple equations, ratios. No calculus.

- ❖ Metric system

length: meters 1000 mm = 1 m (meter)

1000 m = 1 km

1 m ~ 3 ft, 1 mile = 1.6 km

You are 1.5 - 2 m tall

- ❖ Scientific notation:

1 mm = 0.001 m = 1×10^{-3} m

Distance to sun: 150,000,000,000 m = 1.5×10^{11} m

Wavelength of visible light: 0.0000005 m = 5×10^{-7} m

We (and your calculator) need scientific notation!

Course Outline

- ❖ Part I: Motion of the earth, moon, sun and planets in space
 - Making sense of what we see in the night sky
 - Gravity, explaining and predicting motion
- ❖ Part II: Light, Energy and Stars
 - Light as energy
 - Light, matter and how we observe the universe
 - Stars, birth to death
- ❖ Part III: Galaxies and Friends, Astronomy's adventure to understand the Universe
 - Our Galaxy, the Milky Way
 - Galaxies, quasars, Black Holes, relativity
 - The Big Bang and cosmology

Chapter 1: The Big Picture

Size, Time Scales of the Universe

- ❖ Physical scale:

 - Size of our solar system vs. size of things on earth

 - How far away are the stars?

 - How big are galaxies, and how far away?

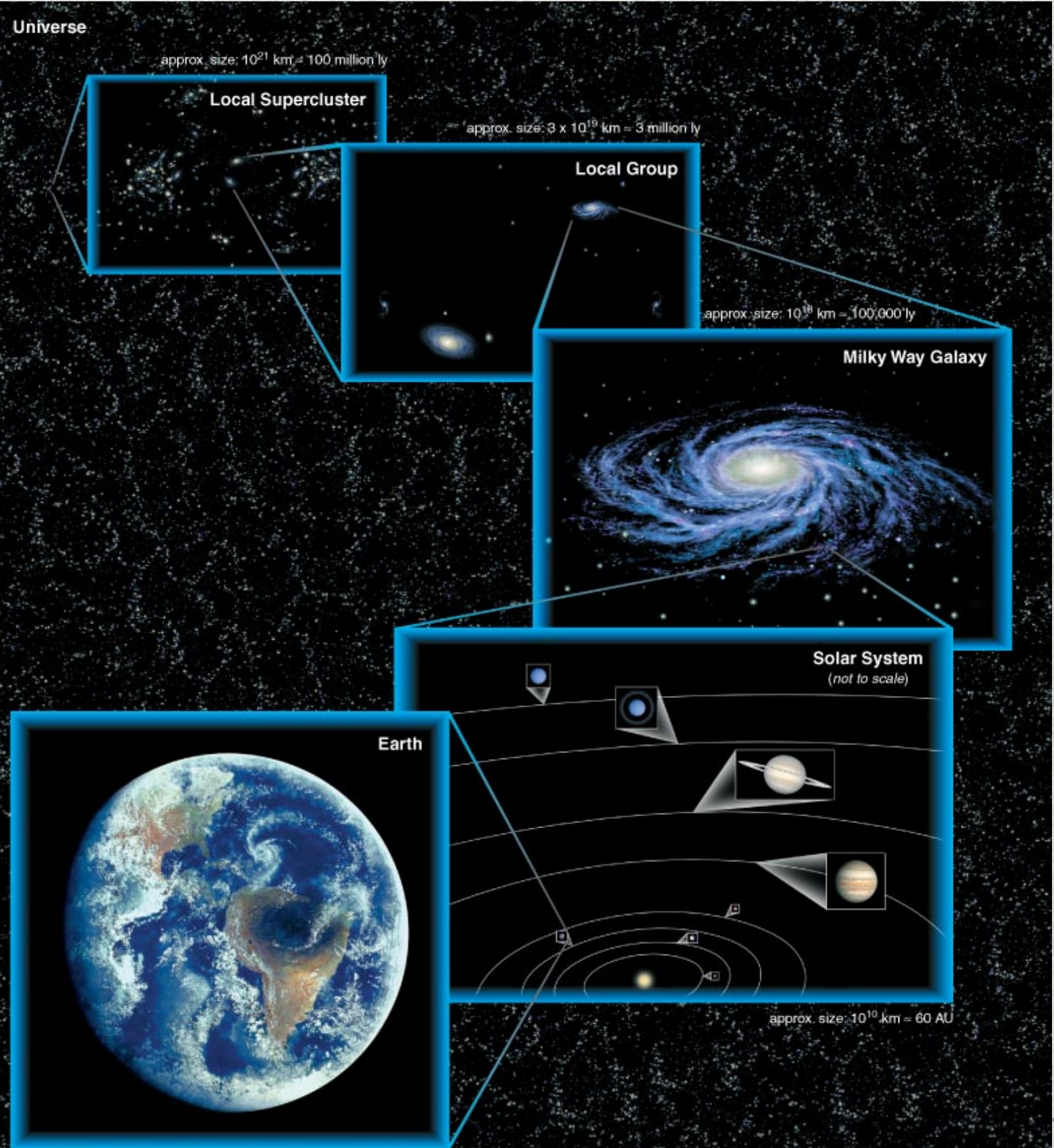
- ❖ Time:

 - Human time scale vs. the lives of stars, age of the universe

 - Looking to large distances = looking back in time

- ❖ Observing the world around us: How does the earth move?
The sun? The Galaxy? How do we know?

Orientation and Some Definitions:

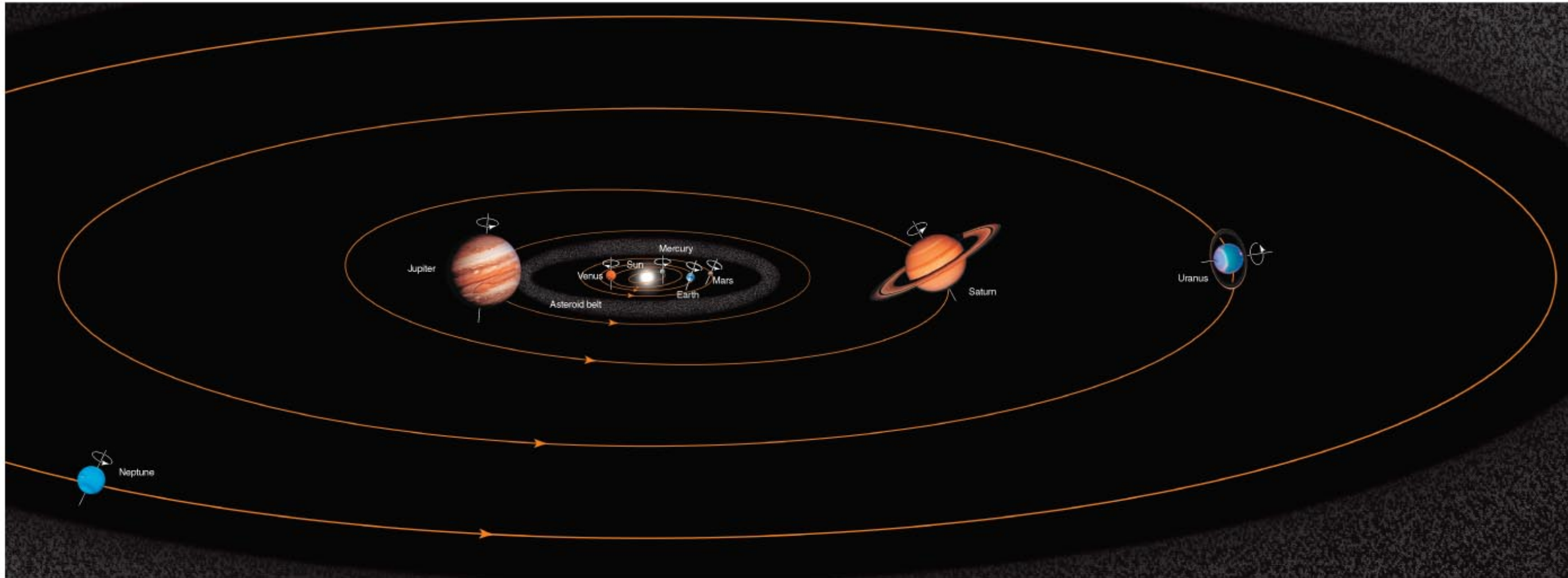


- ❖ Solar (star) system:

A star and all the stuff in orbit around it

- ❖ planets, asteroids, comets

Held together by gravity, orbiting a common center



A Star

- ❖ A massive (10^{30} kg) ball of gas, mostly hydrogen

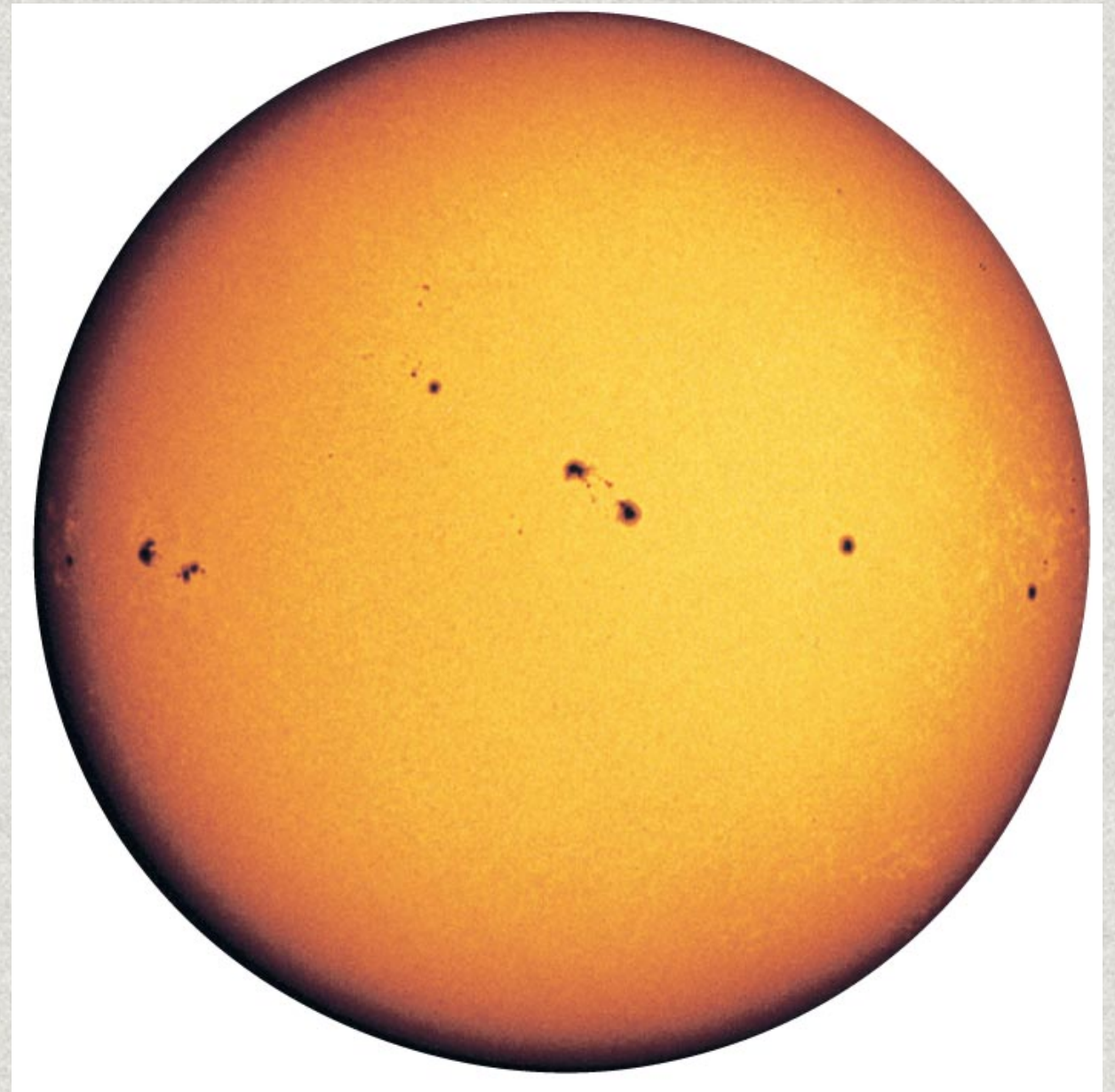
Generates its own heat and light and supports its mass via nuclear fusion

Fusion happens because stars have so much mass:

They are compressed by their own gravity.

This creates extremely high pressure in their centers.

This pressure forces gas atoms to fuse together



A Star

- ❖ A massive (10^{30} kg) ball of gas, mostly hydrogen

How big is that?

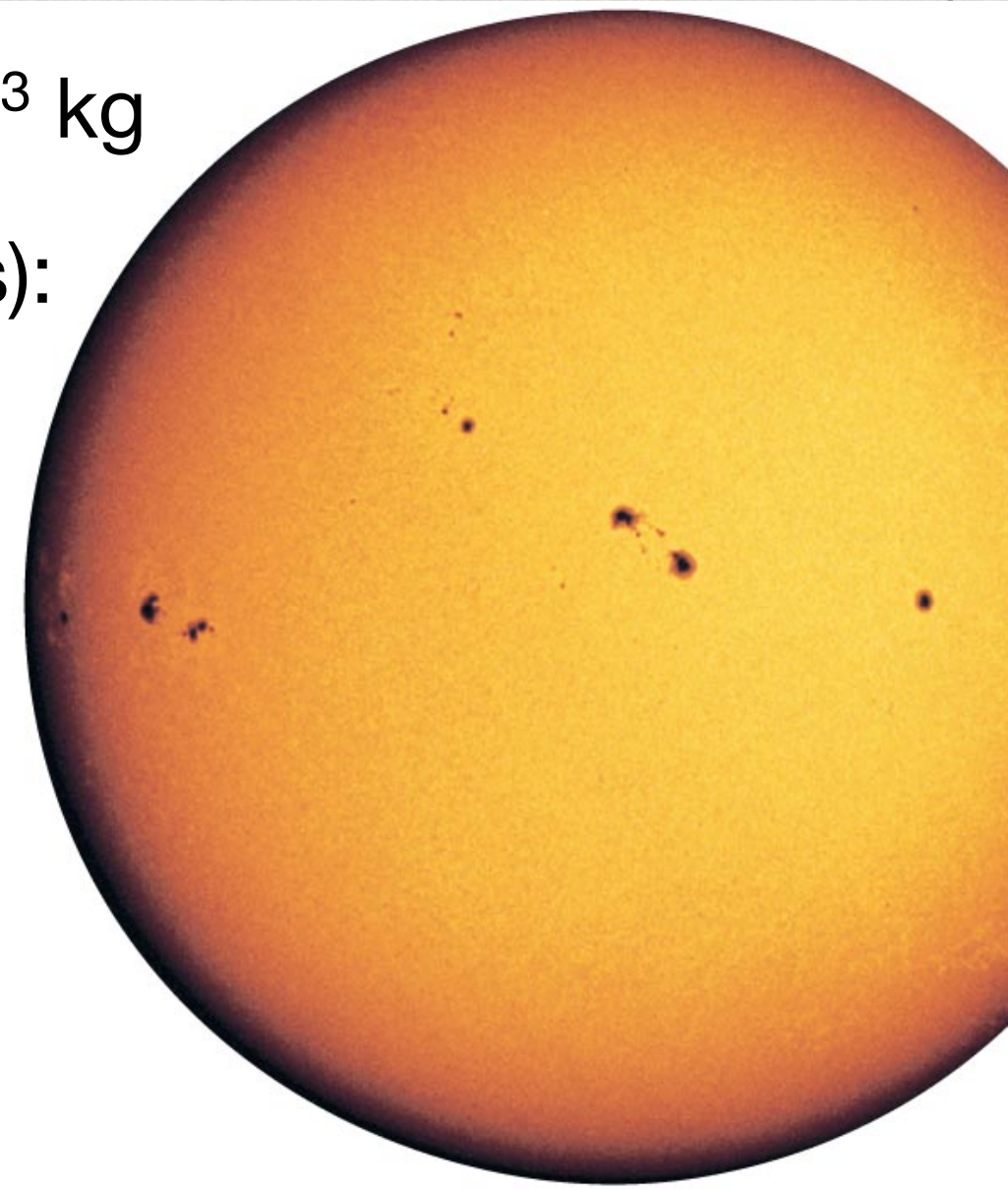
My mass is 75 kg, let's say $100 \text{ kg} = 10^2 \text{ kg}$

Toyota Prius: 1300 kg, about $1000 \text{ kg} = 10^3 \text{ kg}$

Compare 10^2 kg (me) and 10^3 kg (the Prius):

- $10^2 \times 10 = 10^3$

- the Prius is 10 times more massive than me



A Star

- ❖ A massive (10^{30} kg) ball of gas, mostly hydrogen

How big is that?

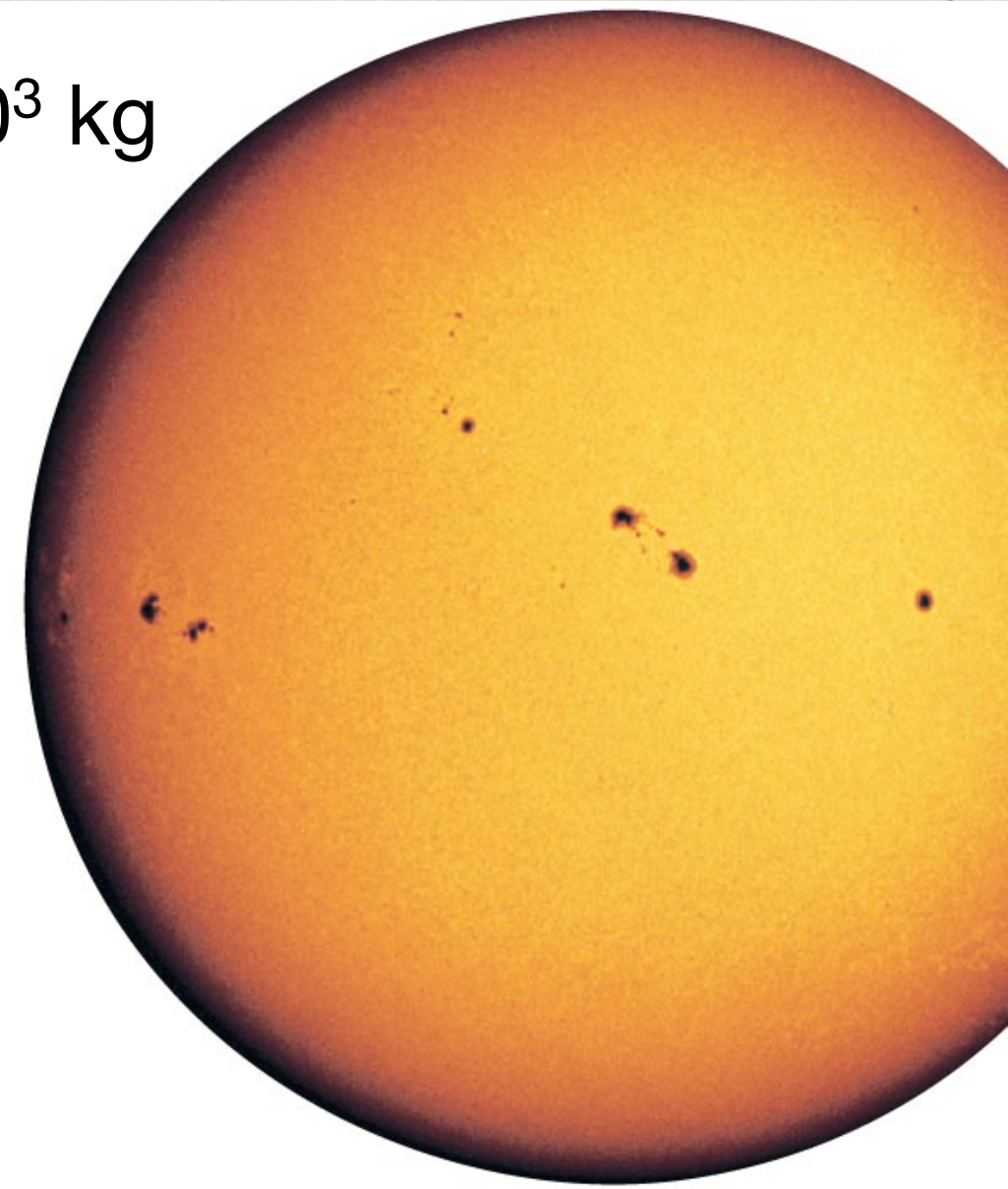
My mass is 75 kg, let's say $100 \text{ kg} = 10^2 \text{ kg}$

Toyota Prius: 1300 kg, about $1000 \text{ kg} = 10^3 \text{ kg}$

An aircraft carrier mass is about 10^8 kg

Compare 10^8 kg and 10^3 kg (the Prius):

- $10^3 \times 10^5 = 10^8$
- $10^5 = 100,000$
- Aircraft carrier is 100,000 times more massive than a Prius



A Star

- ❖ A massive (10^{30} kg) ball of gas, mostly hydrogen

How big is that?

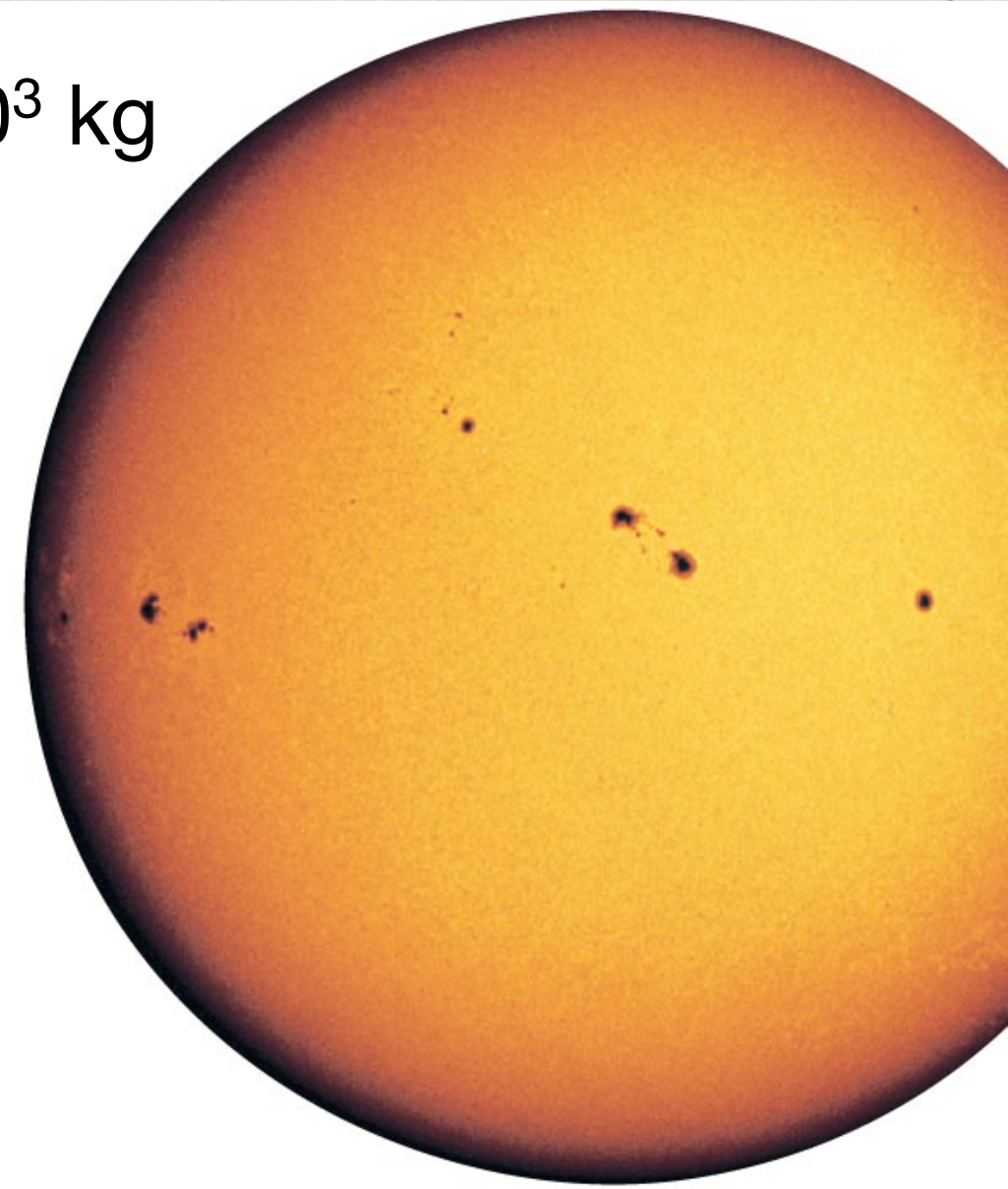
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Toyota Prius: 1300 kg, about $1000 \text{ kg} = 10^3 \text{ kg}$

An aircraft carrier mass is about 10^8 kg

Compare 10^8 kg and 10^2 kg (me):

- $10^2 \times 10^6 = 10^8$
- $10^6 = ?$



A Star

- ❖ A massive (10^{30} kg) ball of gas, mostly hydrogen

How big is that?

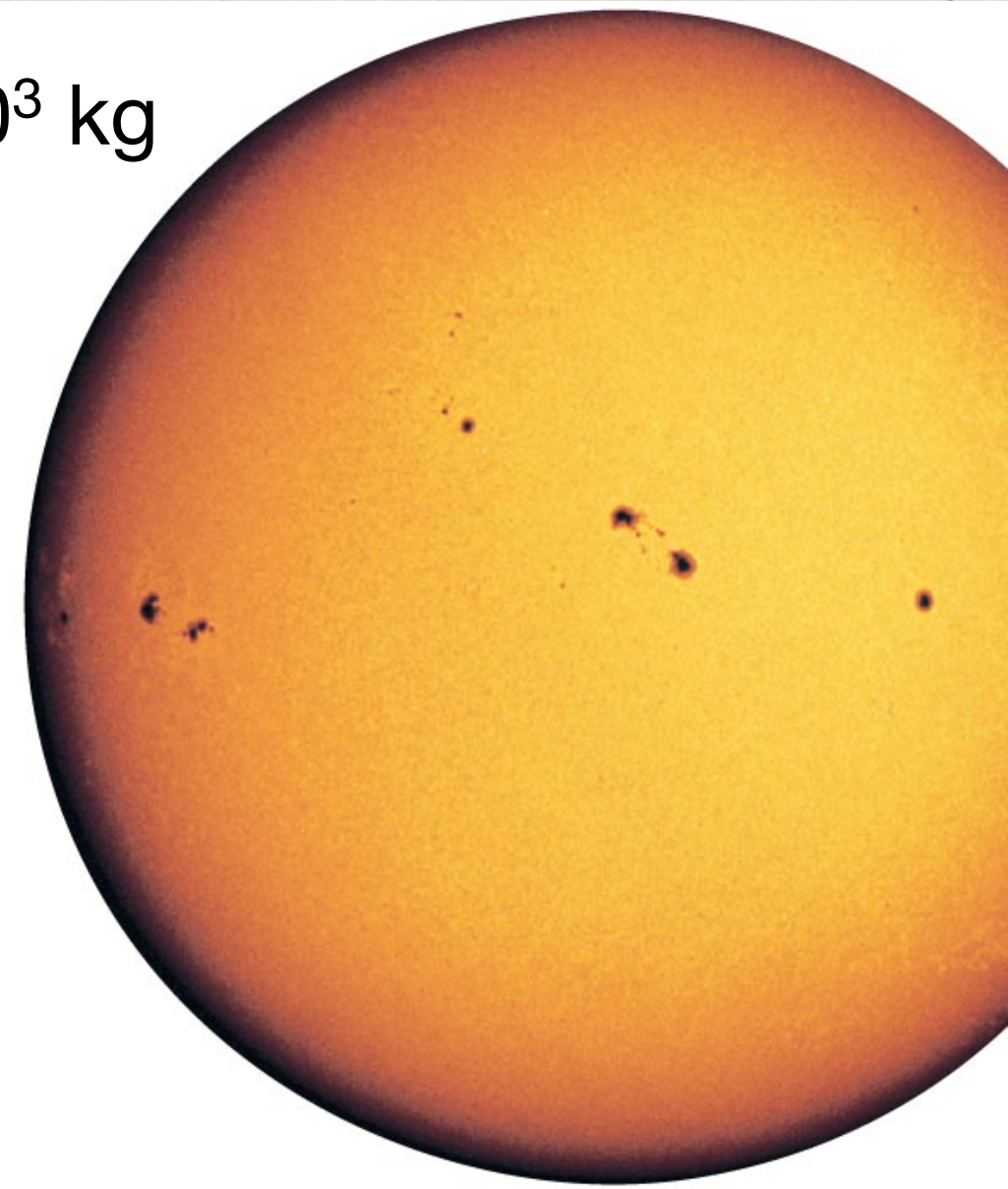
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Toyota Prius: 1300 kg, about $1000 \text{ kg} = 10^3 \text{ kg}$

An aircraft carrier mass is about 10^8 kg

Compare 10^8 kg and me, 10^2 kg :

- $10^2 \times 10^6 = 10^8$
- $10^6 = 1,000,000$
- Aircraft carrier is 1 million times more massive than me



A Star

- ❖ A massive (10^{30} kg) ball of gas, mostly hydrogen

How big is that?

Aircraft carrier: 10^8 kg, Earth mass is 10^{24} kg

Compare 10^{24} kg (Earth) to 10^8 kg

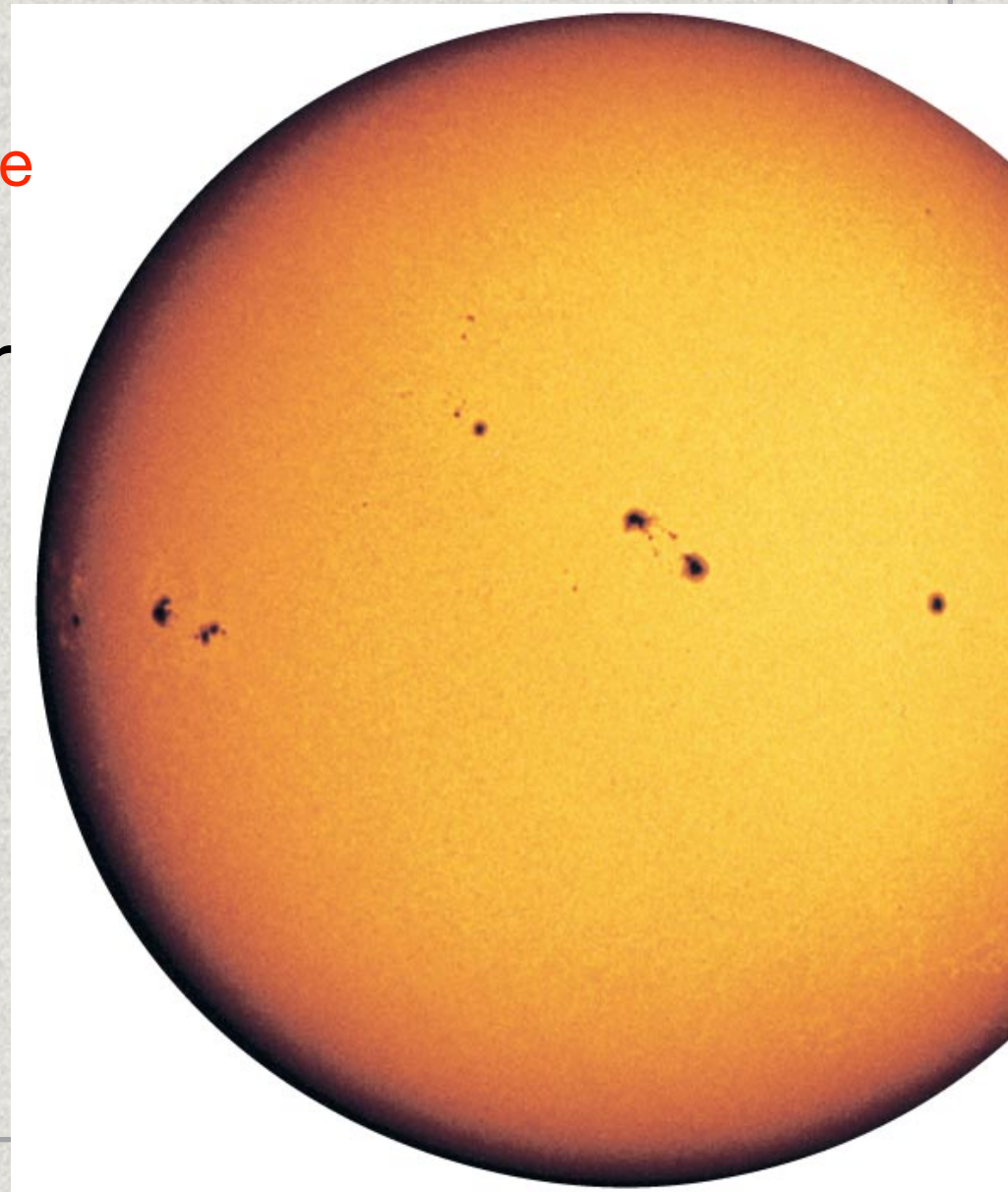
That's 10^{16} (10,000,000,000,000,000) times more massive than an aircraft carrier

1 billion would be here

Too many zeros! Try again:

7 billion people on earth, $7 \times 10^9 \sim 10^{10}$

Compare you (1 person) to the entire population of the earth (10^{10}) and multiply by another factor of 1 million.



A Star

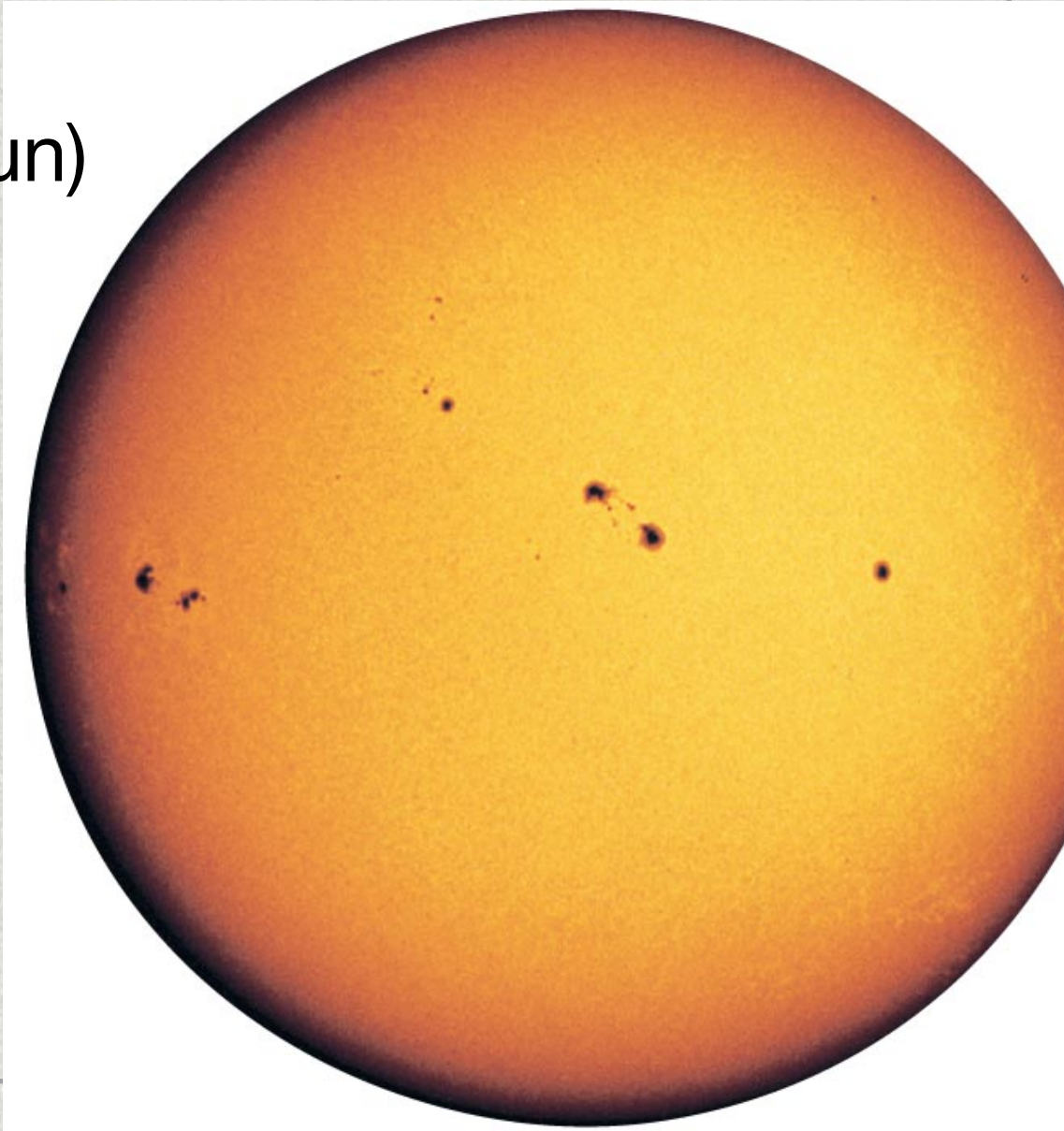
- ❖ A massive (10^{30} kg) ball of gas, mostly hydrogen

How big is that?

Earth mass: 10^{24} kg

Compare: 10^{24} kg (Earth) to 10^{30} kg (Sun)

Sun: 1 million times more massive than Earth



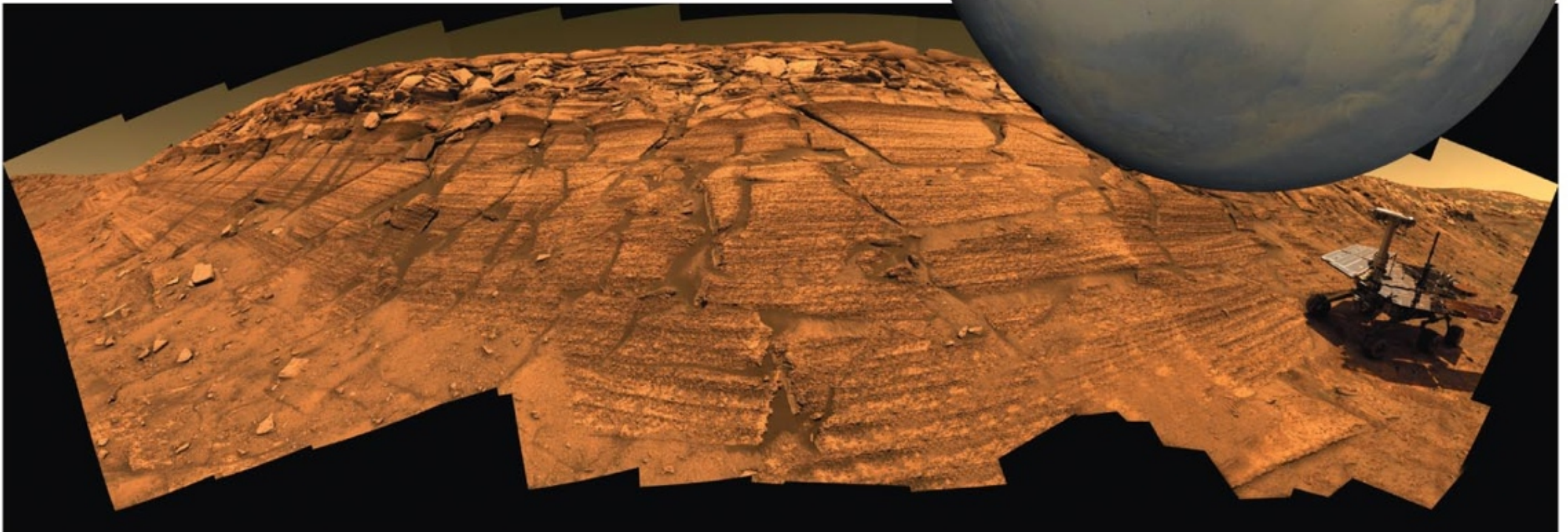
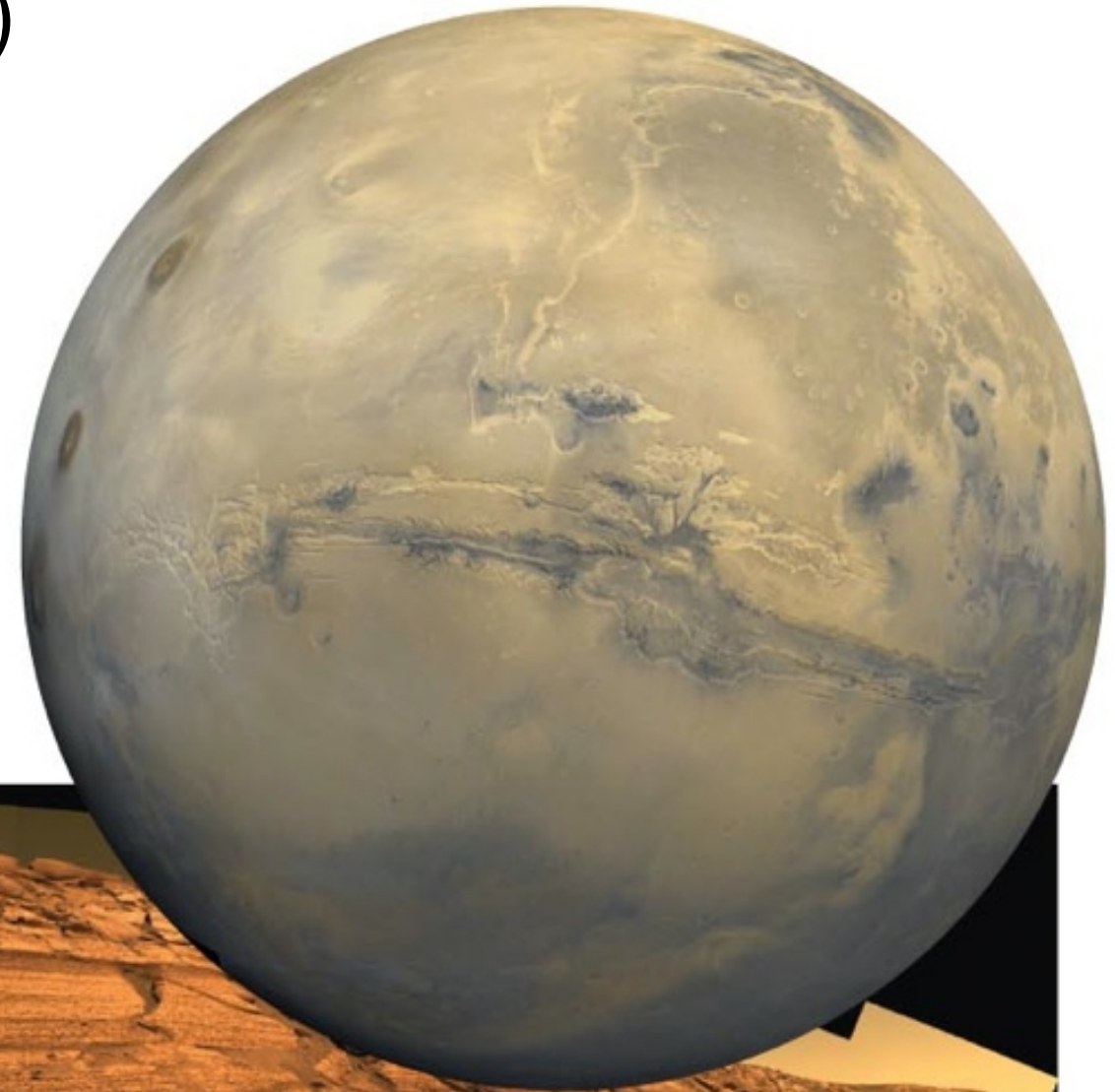
Planet

- ❖ A moderately massive (10^{22} - 10^{27} kg) object which orbits a star

Earth: 6×10^{24} kg

stars: 10^{30} kg

- ❖ Shines by reflected light
- ❖ May be rocky, icy or gaseous



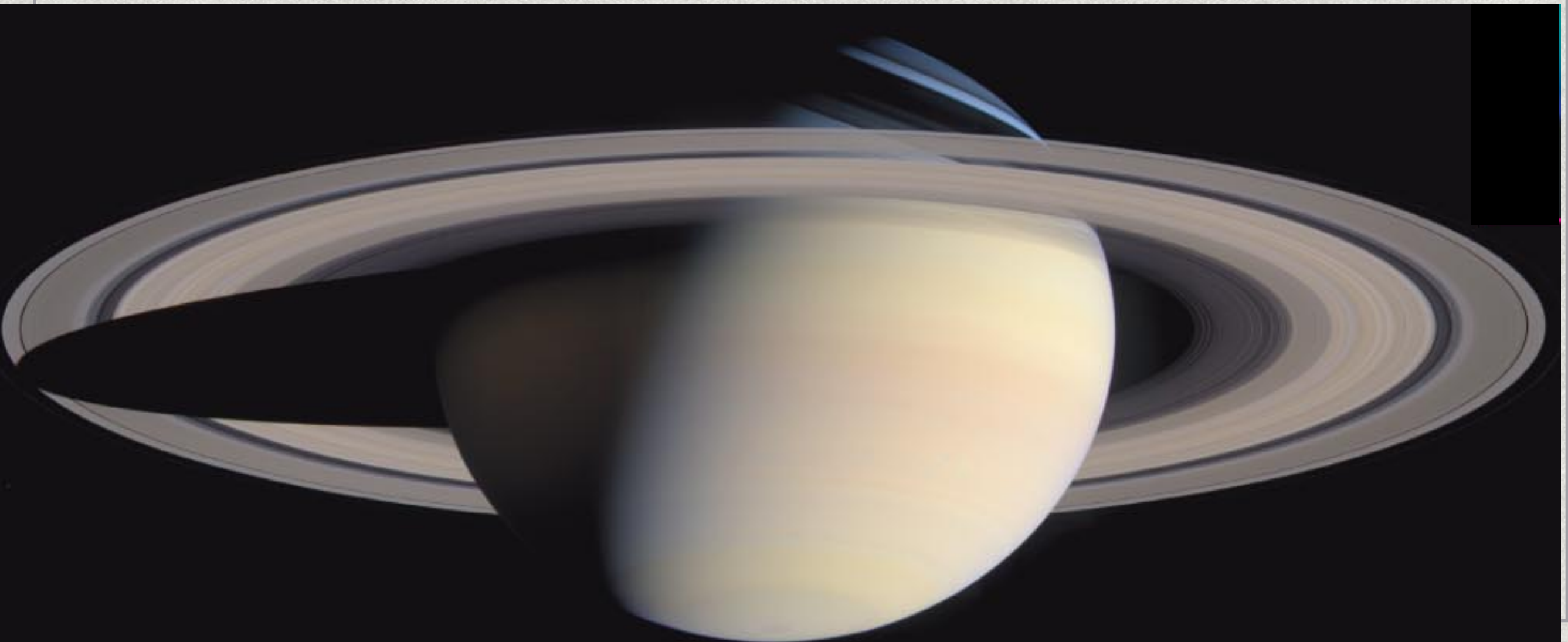
Planet

- ❖ A moderately massive (10^{22} - 10^{27} kg) object which orbits a star

earth: 6×10^{24} kg

stars: 10^{30} kg

- ❖ Shines by reflected light, may be rocky, icy or gaseous



Moon

- ❖ Small body, usually rocky, that orbits a planet
- ❖ Our moon: 7×10^{22} kg



Sizes

Moon: 7×10^{22} kg

Earth: 6×10^{24} kg

Jupiter (large planet): 2×10^{27} kg

stars: 10^{30} kg

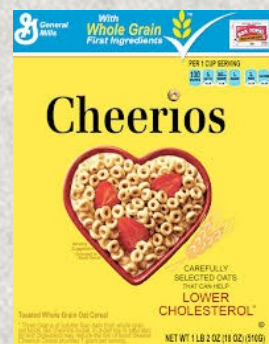
Compare:

Jupiter (10^{27} kg) vs. star (10^{30} kg):

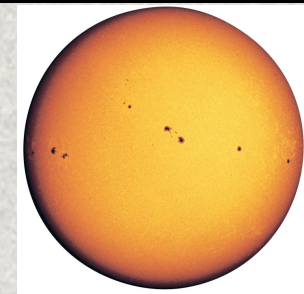
$$10^{27} \times 10^3 = 10^{30}$$

- Stars are a factor 1000 (10^3) heavier

cereal box: 1lb



car: ~1000 lbs



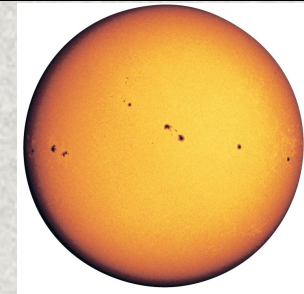
Sizes

Moon: 7×10^{22} kg

Earth: 6×10^{24} kg

Jupiter (large planet): 2×10^{27} kg

stars: 10^{30} kg



Compare:

Moon vs stars: factor $\sim 10^8$

rent: $\sim \$1200$ ($\$1.2 \times 10^3$)

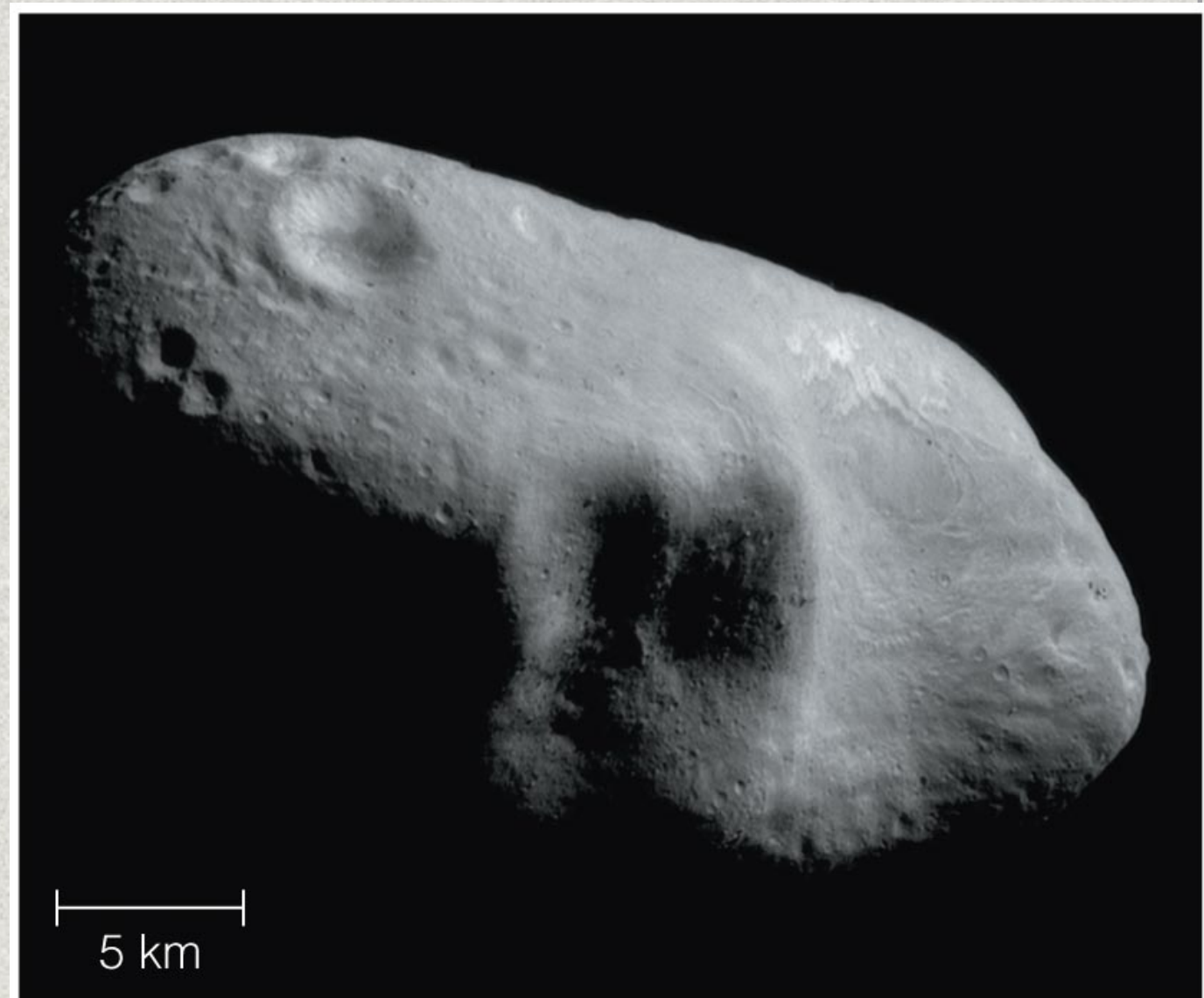
CA state budget: $\$122$ billion ($\$1.22 \times 10^{11}$)



Asteroid

- ❖ Small, rocky object that orbits a star

too small (not massive enough) to become spherical under its own gravity

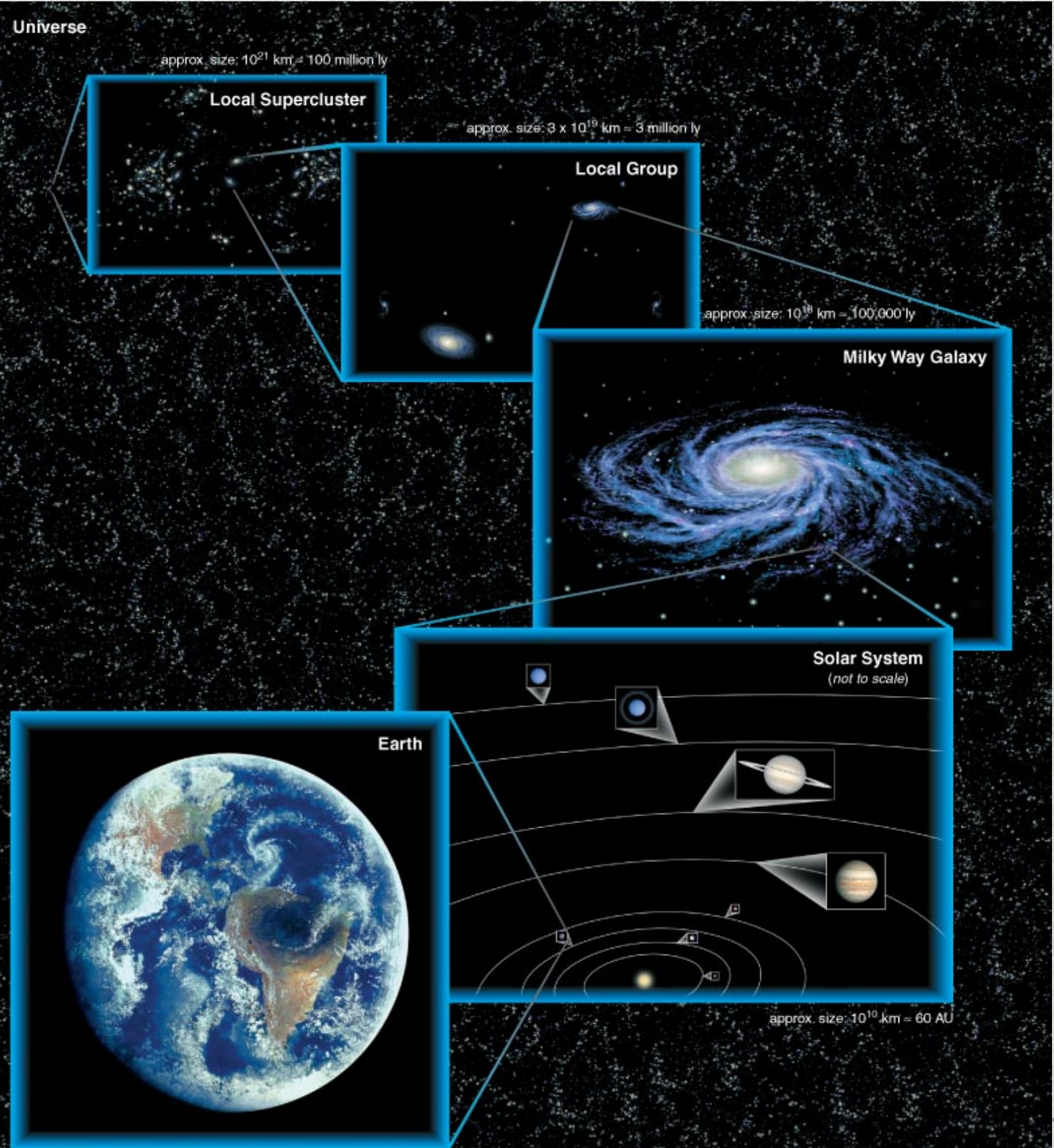


Comet

- ❖ A relatively small and icy object that orbits a star



Orientation and Some Definitions:



A Star

- ❖ A massive (10^{30} kg) ball of gas, mostly hydrogen

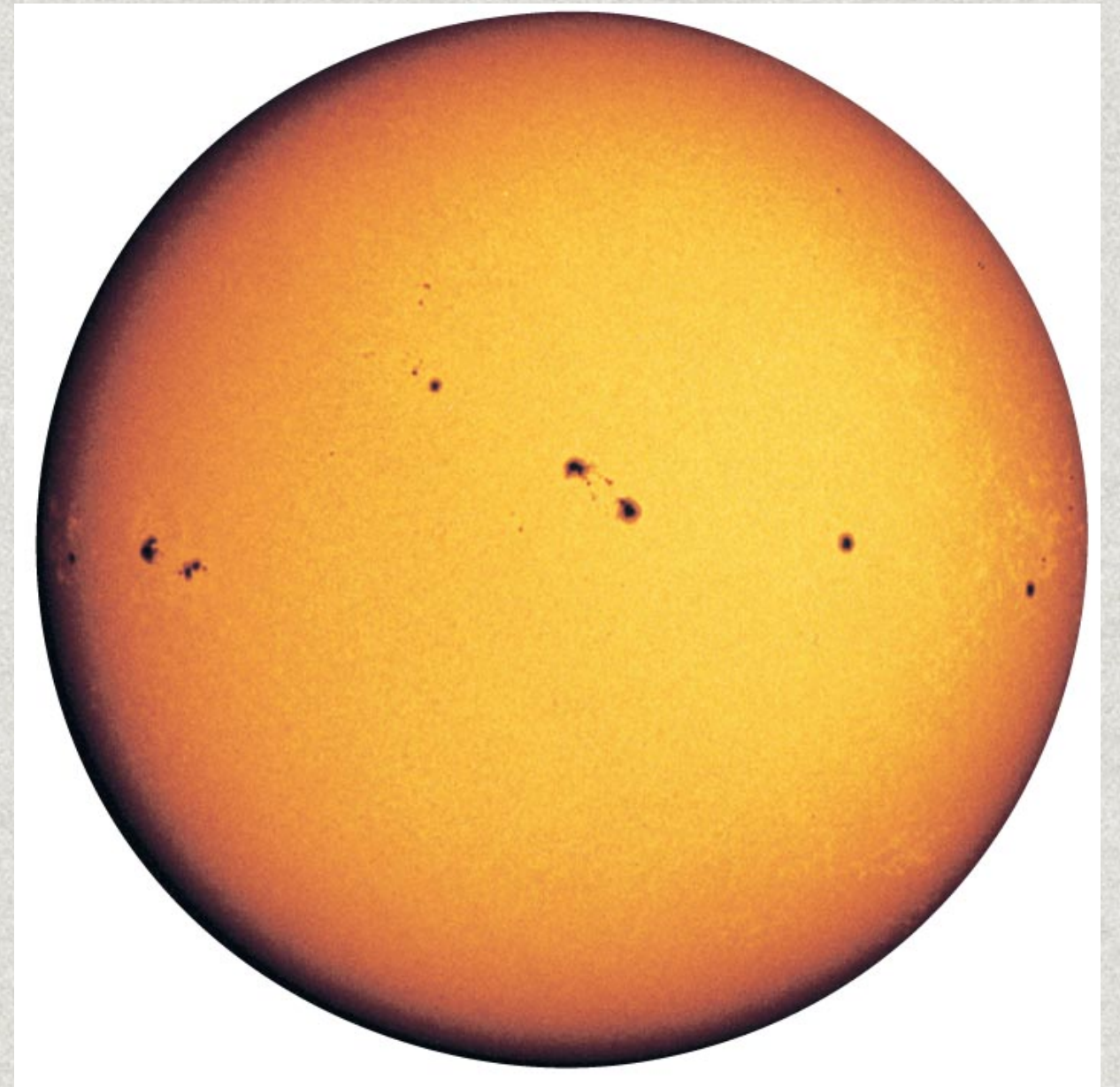
Generates heat and light via nuclear fusion

Fusion happens because stars have so much mass:

They are compressed by their own gravity.

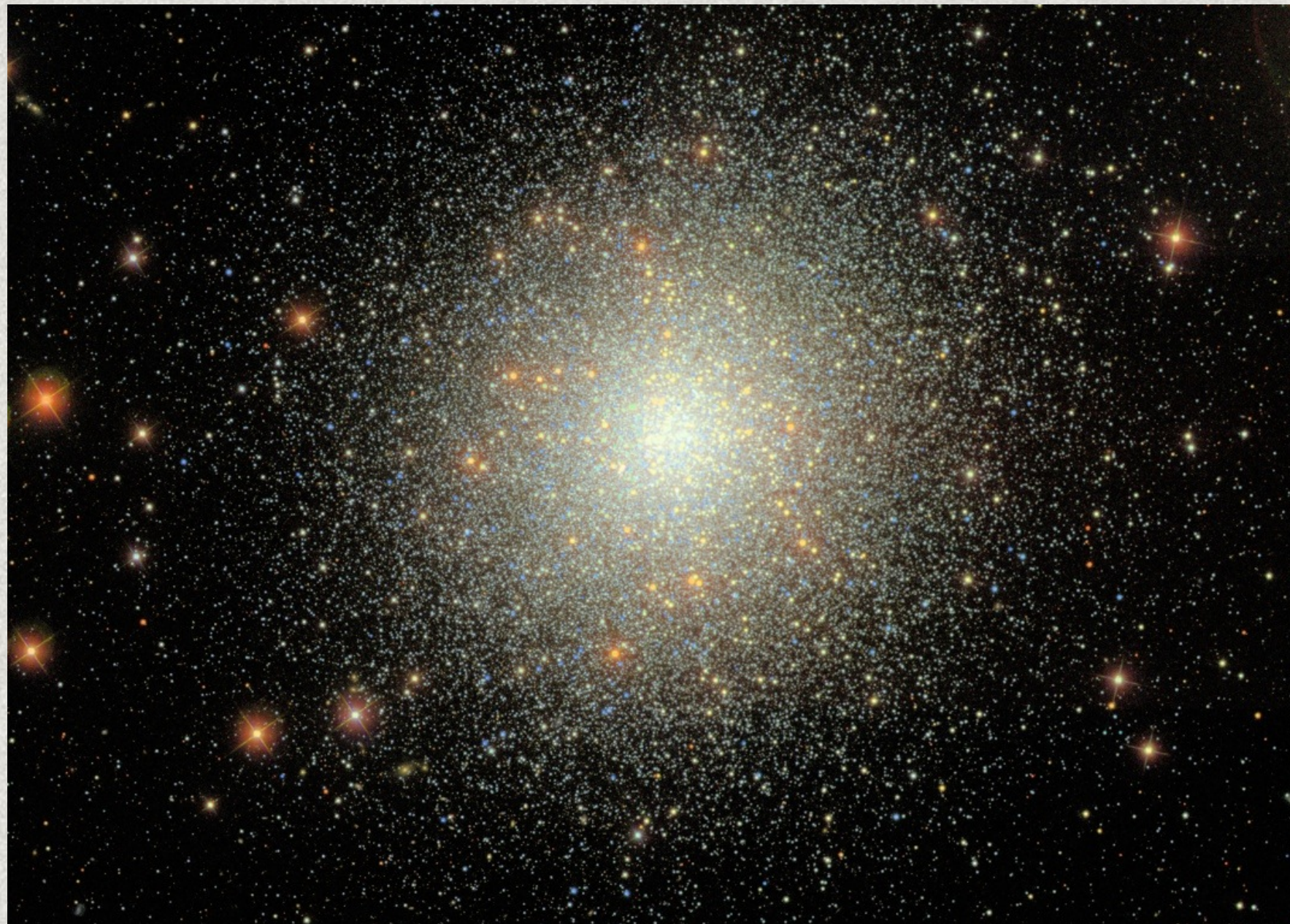
This creates extremely high pressure in their centers.

This pressure forces gas atoms to fuse together



Star Cluster

- ❖ Tens of thousands of stars, all gravitationally bound to one another



A Galaxy

- ❖ Many billions (10^9) of stars all held together by gravity and orbiting a common center
- ❖ Stars live in galaxies, not scattered throughout space



Galaxies come in many shapes and sizes

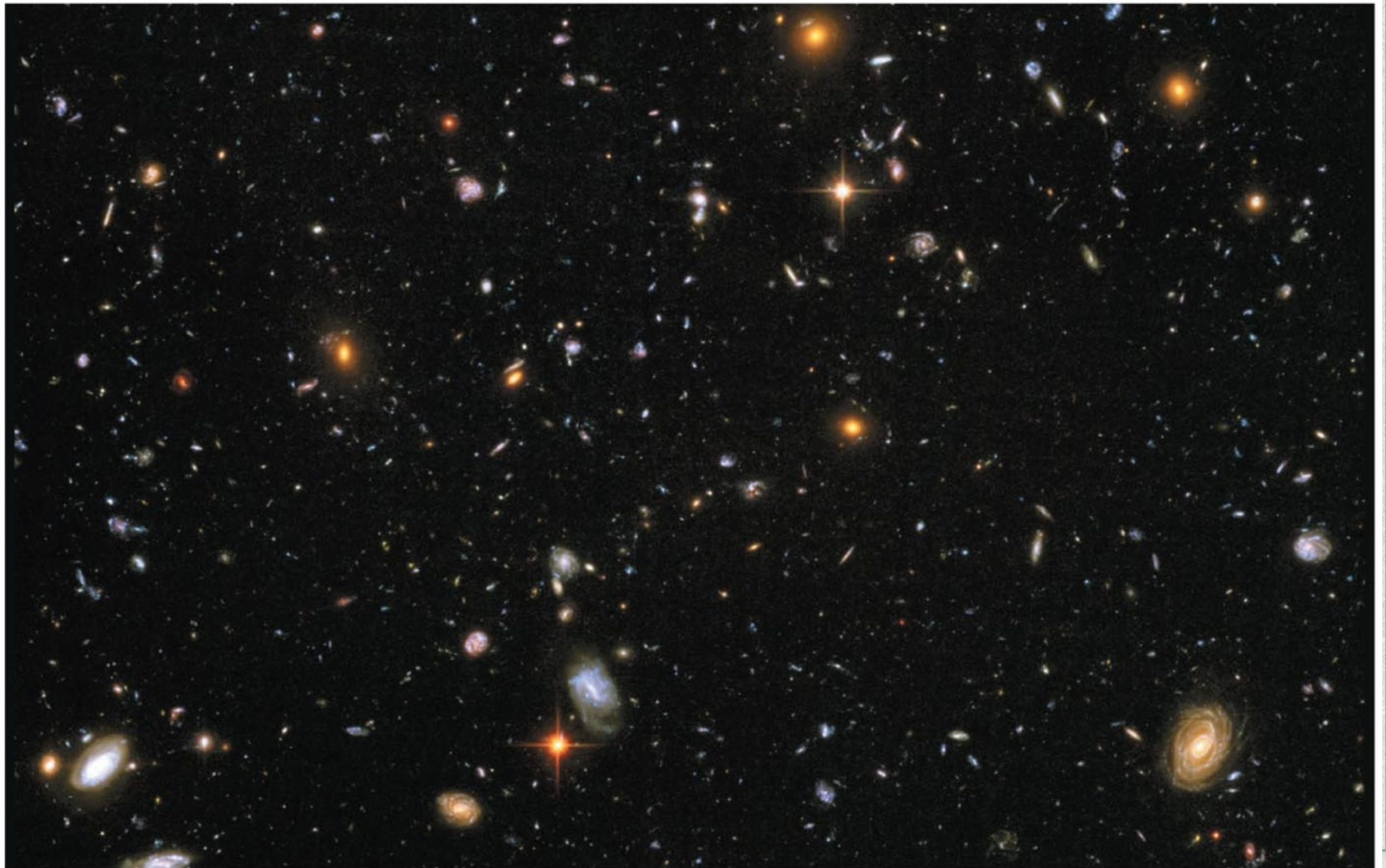


A cluster of galaxies

- ❖ Thousands of galaxies all held together by gravity and orbiting a common center

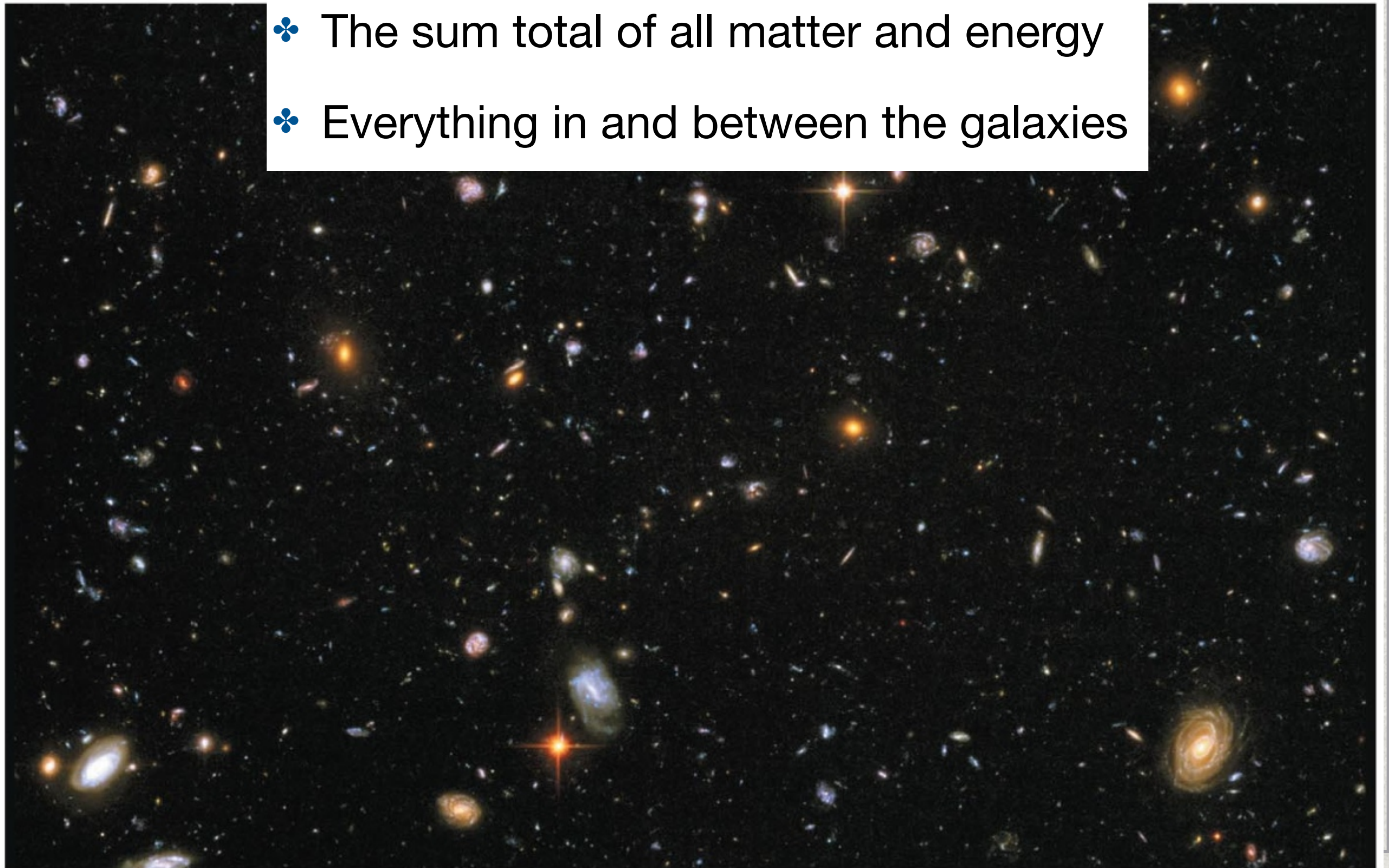


Galaxies in the Universe



The Universe

- ❖ The sum total of all matter and energy
- ❖ Everything in and between the galaxies



Physical Scale: Distance to the Sun

Earth-Sun distance = 1 Astronomical Unit (AU) = 1.5×10^{11} m = 93 million miles

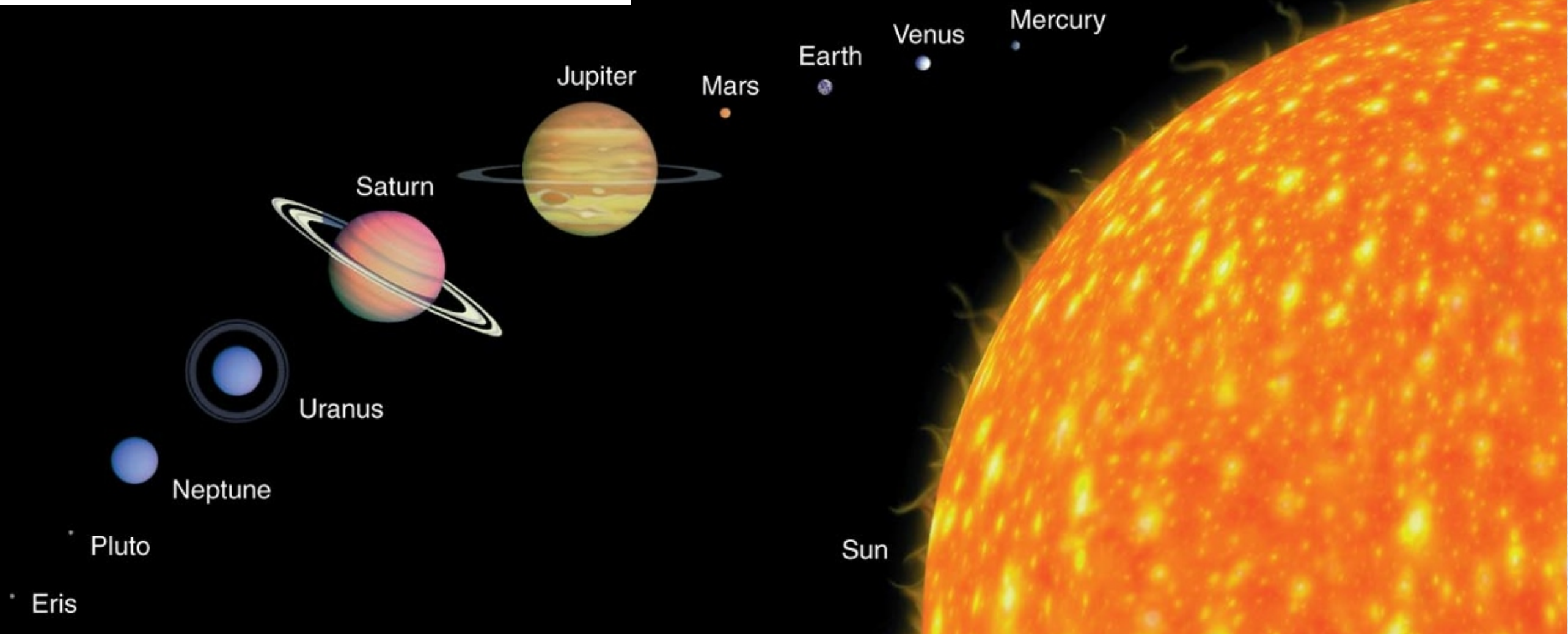
AU: a useful unit for measuring distance in astronomy, like a “foot”

Distances of the planets to the sun in AU

Neptune Uranus Saturn Jupiter Mars Earth Venus Mercury

30.1 19.2 9.6 5.2 1.5 1 0.7 0.4

Size scale for planets and sun is correct, distance scale is *NOT*



Physical Scales: Distances

An useful unit of distance comes from measuring how far light can travel in some fixed amount of time: a minute, an hour, a day, a year, ...

Light travels at a fixed speed, 3×10^8 m/s

- that's 300 million meters each second

Because the speed of light is fixed, it takes time for light to travel between any two places.

Think about driving. You and your friend both drive at 60 mph.

Just like light, you travel at a fixed speed.

You drive for 30 minutes. Your friend drives for 4 hours.

Who drives a larger distance?

Physical Scales: Distances

An useful unit of distance comes from measuring how far light can travel in some fixed amount of time: a minute, an hour, a day, a year, ...

Light travels at a fixed speed, 3×10^8 m/s

- that's 300 million meters each second

Because the speed of light is fixed, it takes time for light to travel between any two places.

Like between the earth and the sun:

Earth-Sun distance = 1 Astronomical Unit (AU) = 1.5×10^{11} m

Physical Scales: Distances

An useful unit of distance comes from measuring how far light can travel in some fixed amount of time: a minute, an hour, a day, a year, ...

Light travels at a fixed speed, 3×10^8 m/s

1 Astronomical Unit (AU) = distance from sun to earth = 1.5×10^{11} m

How long does it take light to travel that distance?

Physical Scales: Distances

An useful unit of distance comes from measuring how far light can travel in some fixed amount of time: a minute, an hour, a day, a year, ...

Light travels at a fixed speed, 3×10^8 m/s

1 Astronomical Unit (AU) = distance from sun to earth = 1.5×10^{11} m

How long does it take light to travel that distance?

➔ It takes $\frac{1.5 \times 10^{11} \text{ m}}{3 \times 10^8 \text{ m/s}} = 500 \text{ seconds} = 8.3 \text{ minutes}$ for light to travel the distance from the sun to the earth

Physical Scales: Distances

An useful unit of distance comes from measuring how far light can travel in some fixed amount of time: a minute, an hour, a day, a year, ...

Light travels at a fixed speed, 3×10^8 m/s

1 Astronomical Unit (AU) = distance from sun to earth = 1.5×10^{11} m

➔ It takes $\frac{1.5 \times 10^{11} \text{ m}}{3 \times 10^8 \text{ m/s}} = 500 \text{ seconds} = 8.3 \text{ minutes}$ for light to travel the distance from the sun to the earth

- We can use this as a way to measure distance:
 - The distance that light can travel in 1 minute is called a “light-minute”
 - The distance from the earth to the sun is about 8 light-minutes
 - The distance light can travel in 1 year is called a “light-year”

Physical Scales: Distances

1 Astronomical Unit (AU) = distance from sun to earth
= 8 light-minutes = 1.5×10^{11} m

The nearest star is 4.4 light-years away.

Light from the nearest star takes 4.4 years to get to earth

Light always travels at the same speed.

So if it takes light longer to get to earth from the nearest star than it takes light to get from the sun to the earth, the nearest star must be farther away from the earth than the sun.

How much farther?

Physical Scales: Distances

1 Astronomical Unit (AU) = distance from sun to earth = 8 light-minutes

The nearest star is 4.4 light-years away.

Light always travels at the same speed, so if it takes longer to get to earth from the nearest star, the nearest star must be farther away than the sun. **How much farther?**

First step: 1 year = ? minutes

365 days/year x 24 hours/day x 60 minutes/hour:

$$\text{units: } \frac{\text{days}}{\text{year}} \times \frac{\text{hours}}{\text{day}} \times \frac{\text{minutes}}{\text{hour}} = \frac{\text{minutes}}{\text{year}}$$

= 525,600 minutes in one year.

4.4 years = ? minutes

$$4.4 \times 525,600 = 2.3 \times 10^6 \text{ (2.3 million) minutes in 4.4 years}$$

Physical Scales: Distances

1 Astronomical Unit (AU) = distance from sun to earth = 8 light-minutes

Nearest star is 4.4 light-years away. How much farther is that?

Light travels at the same speed from the sun to the earth and from the sun to the nearest star.

It takes 8 minutes for light to travel from the sun to the earth.

From the previous slide: It takes light 2.3 million minutes (= 4.4 years) to travel from the sun to the nearest star.

How much longer does it take light to travel to the nearest star?

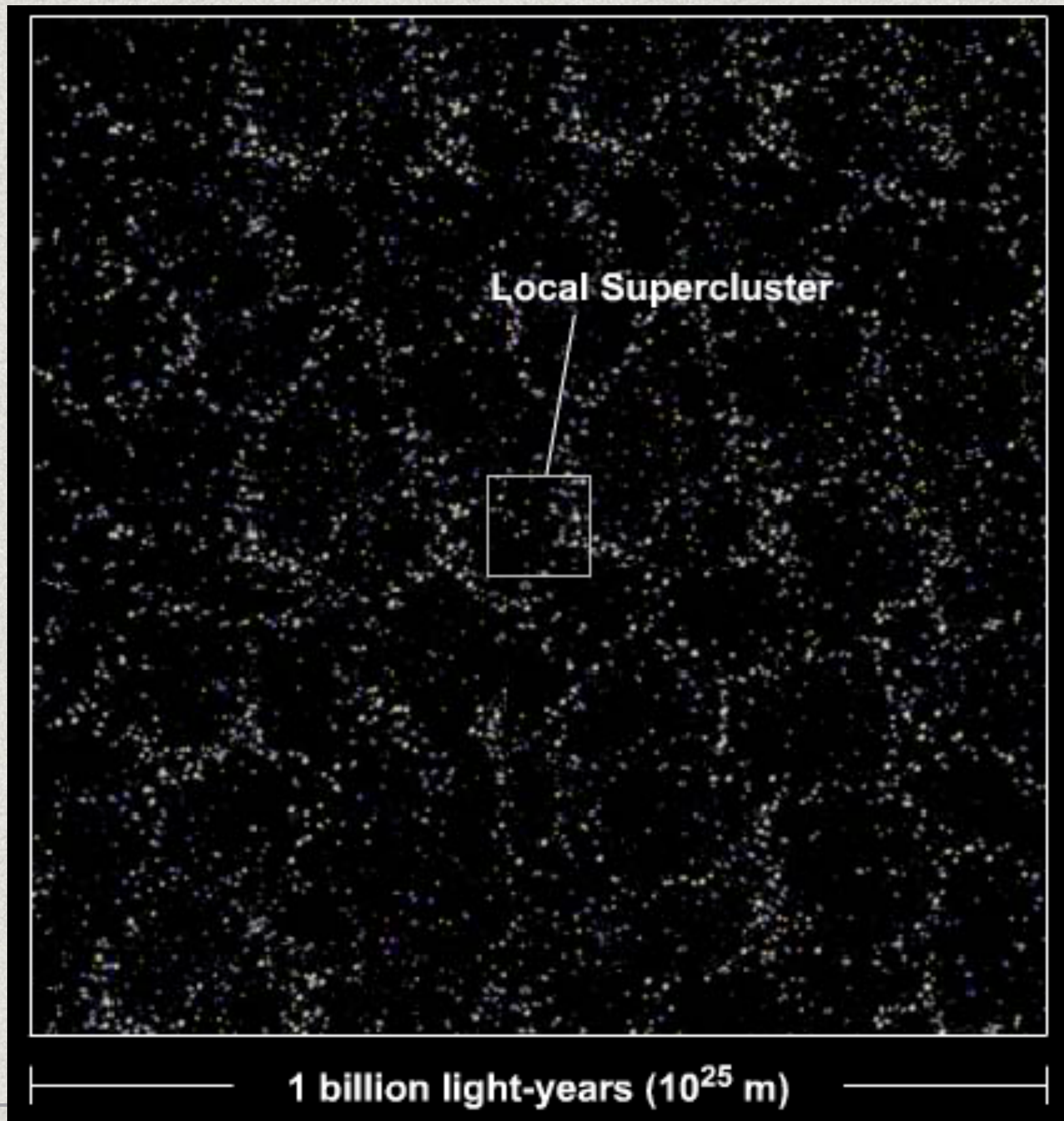
$$\frac{2.3 \times 10^6 \text{ minutes}}{8 \text{ minutes}} \sim 300,000 \text{ times as long.}$$

So the star must be $\frac{2.3 \times 10^6 \text{ light-minutes}}{8 \text{ light-minutes}} \sim 300,000$ times as far away

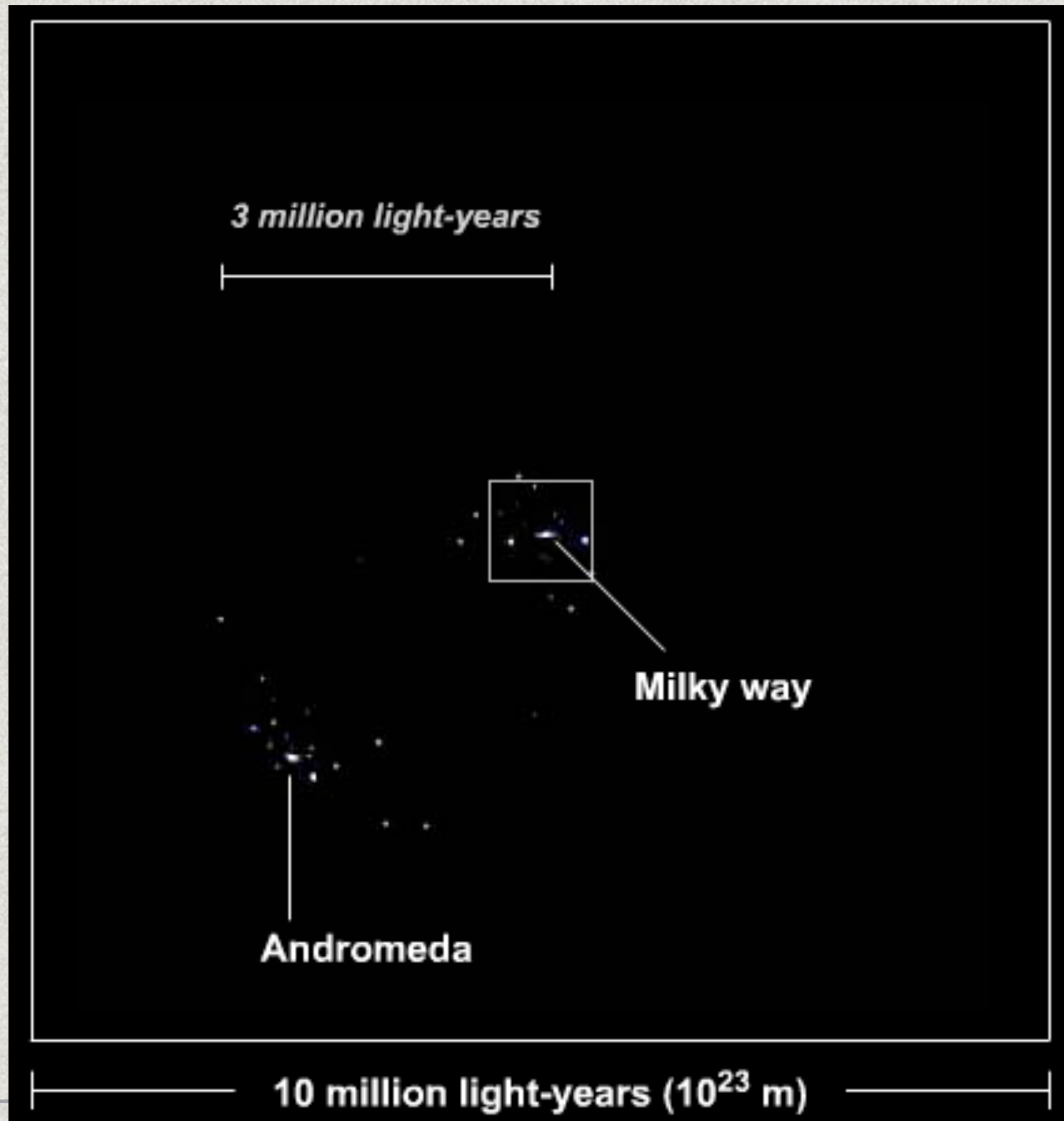
Fun animation and movie about distance scales

- ❖ Cary and Michael Huang: Scale of the Universe
- ❖ also: Classic Eames "Powers of Ten" movie

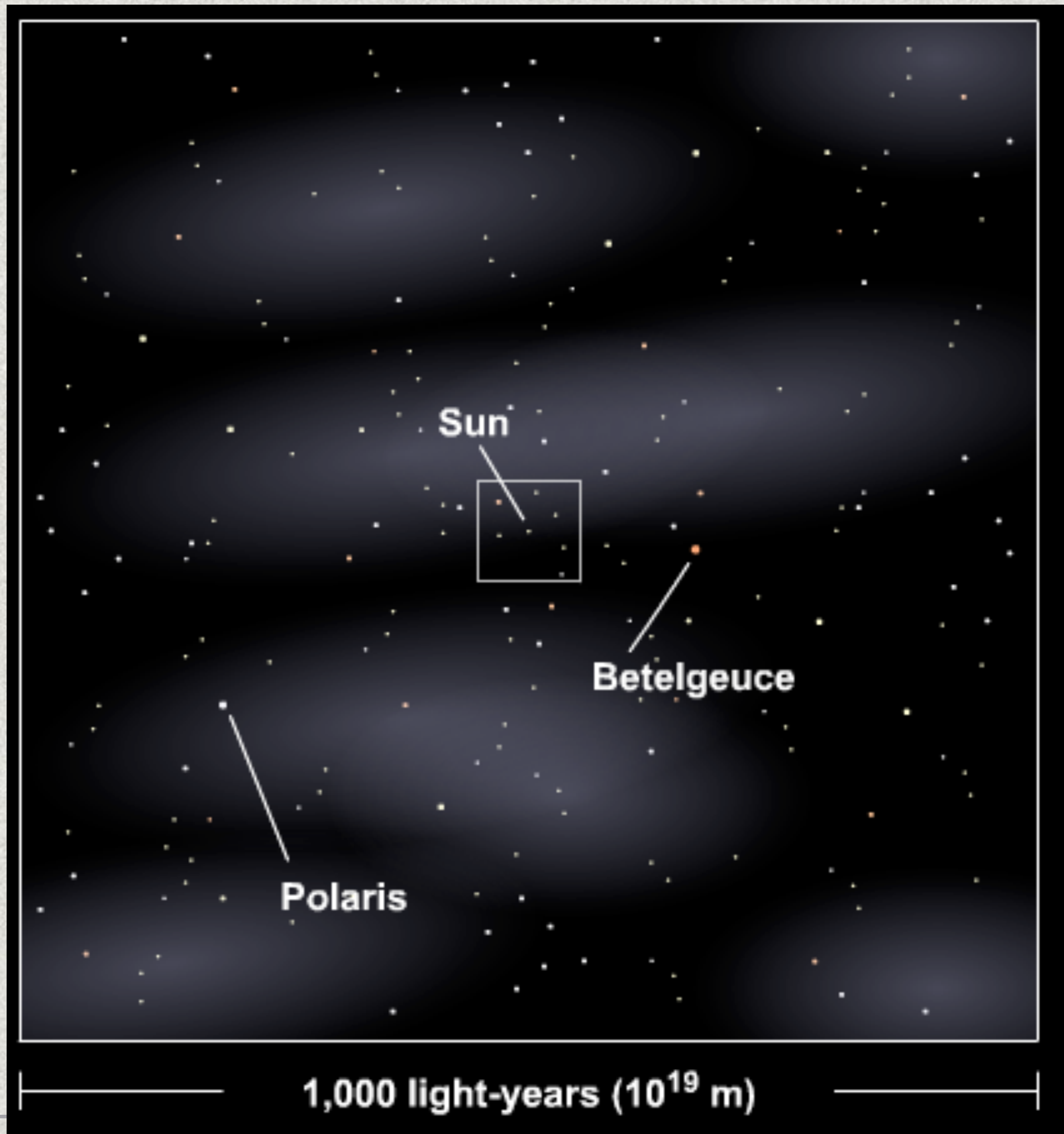
Scales in the Universe



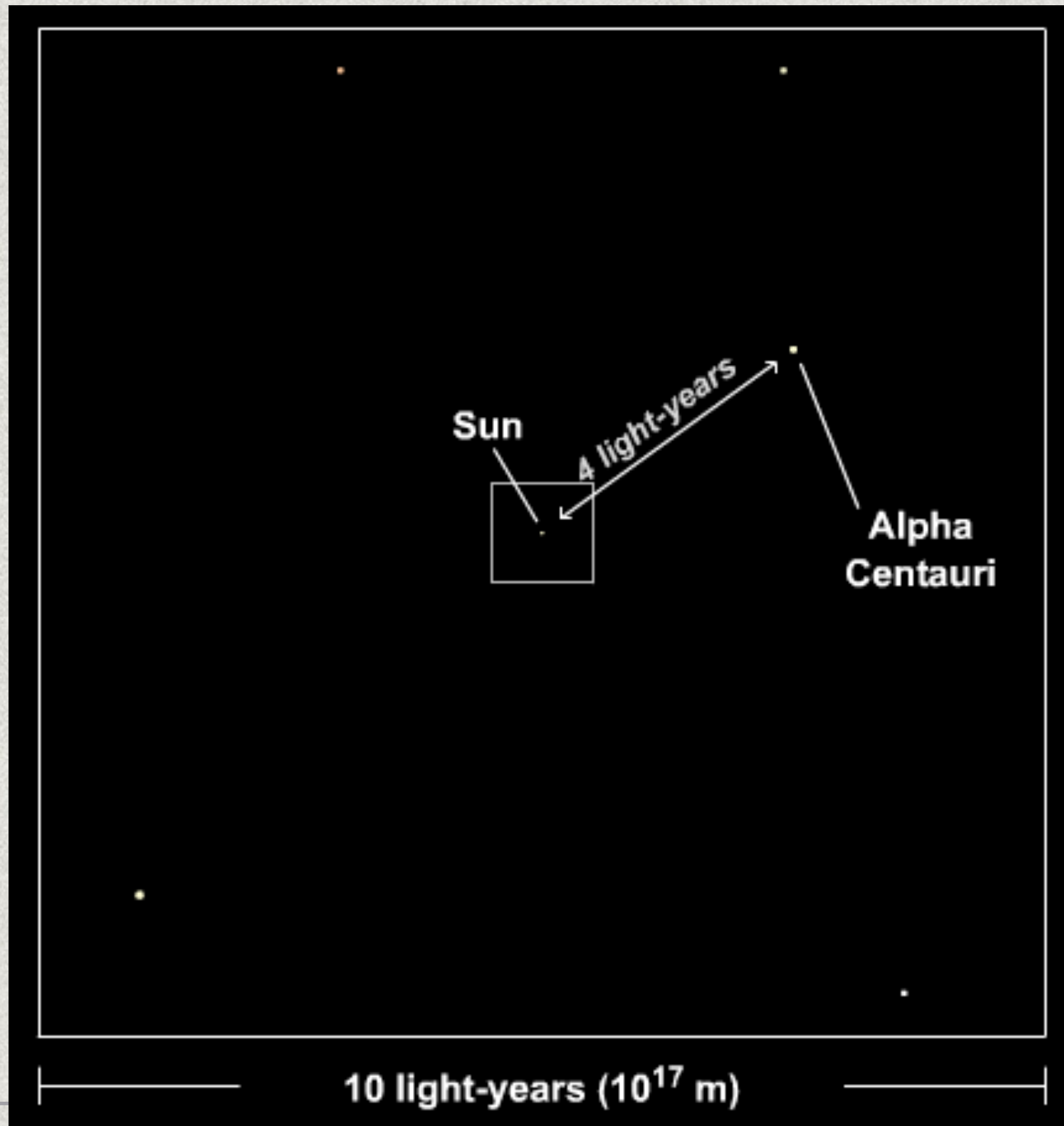
Scales in the Universe



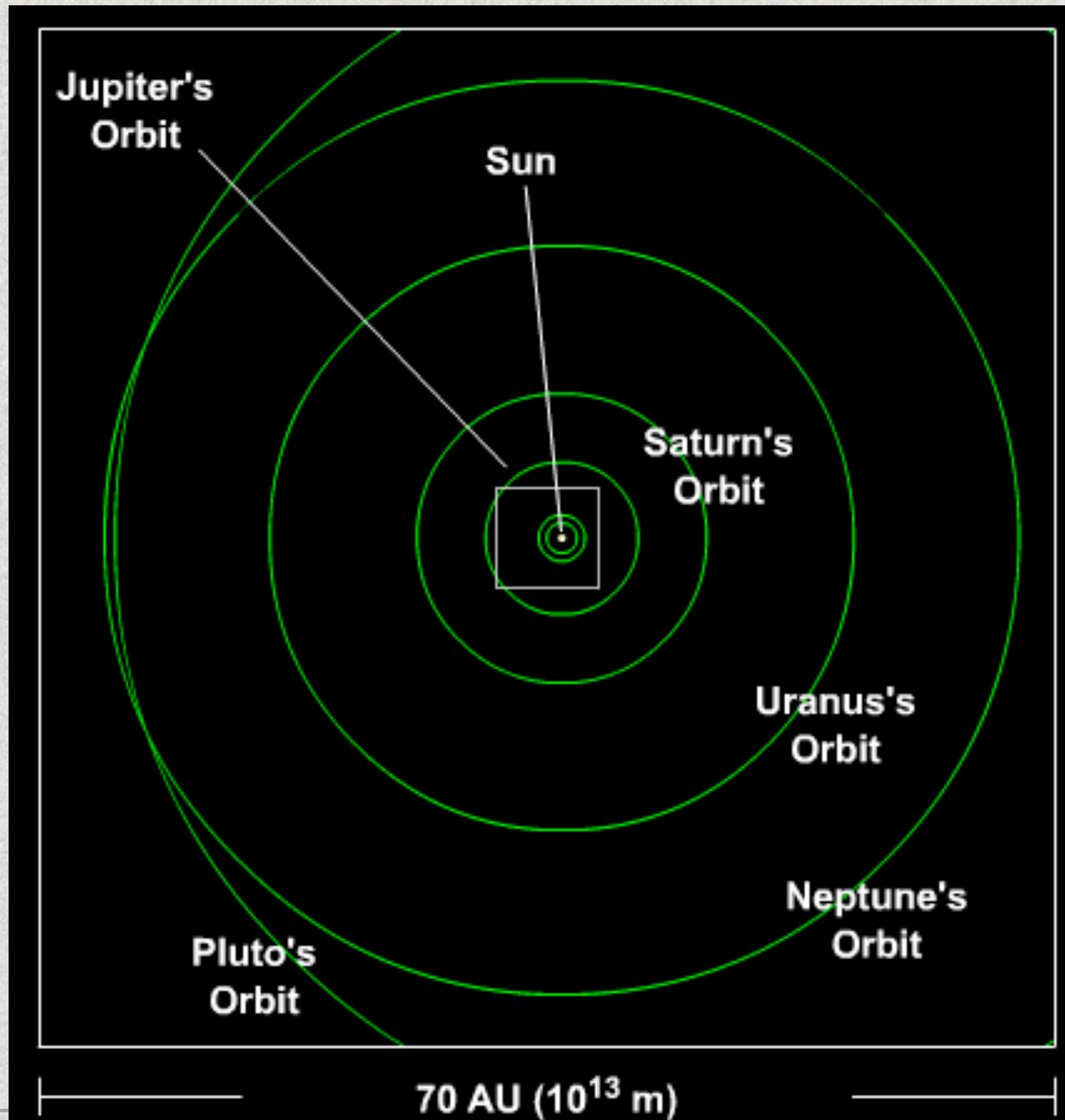
Scales in the Universe



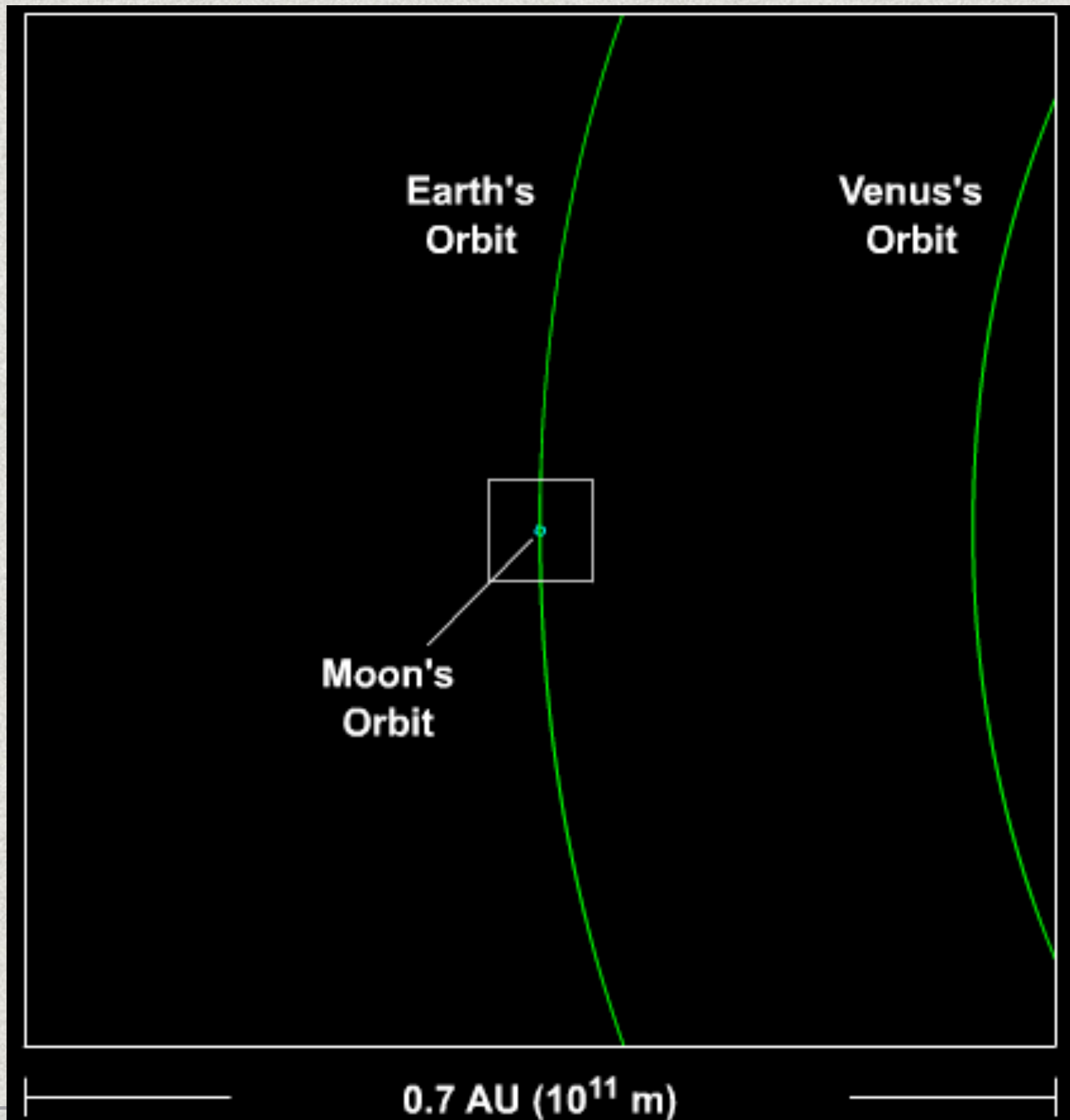
Scales in the Universe



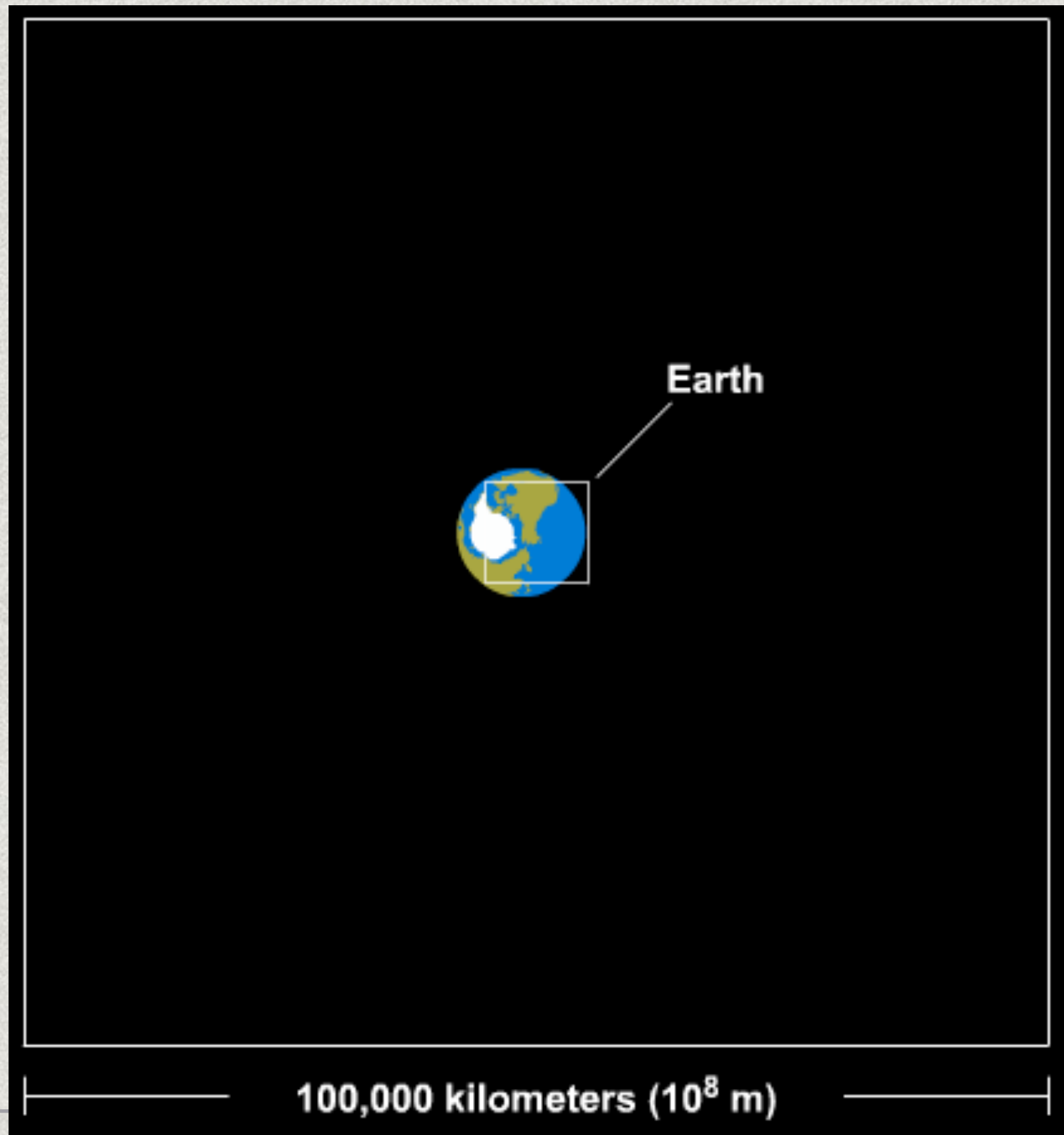
Scales in the Universe



Scales in the Universe



Scales in the Universe



Scales in the Universe



How Old is the Universe?

- ❖ Cosmic Calendar:

The universe is 13.6 billion years old

(How do we know that? We'll get there when we talk about cosmology)

If the entire age of the universe were one calendar year, one month would be about 1 billion (10^9) real years

- ❖ The earth is 4 billion years old

- ❖ Astronomy is how we learn about the universe before there was an earth

How Do We Study the Universe Over Such Huge Scales?

- ❖ We can't bring the universe to us, we can only observe what's out there
- ❖ Light is our messenger

Light travels at a fixed speed: $c = 3 \times 10^8$ m/s (300,000,000)

How FAR does light travel in a year?

distance = velocity x time

$$3 \times 10^8 \text{ m/s} \times 3.15 \times 10^7 \text{ seconds} = 9.46 \times 10^{15} \text{ m/year}$$

$$1 \text{ light-year} = 9.46 \times 10^{15} \text{ m}$$

$$1 \text{ light-minute} = 3 \times 10^8 \text{ m/s} \times 60 \text{ s} = 1.8 \times 10^{10} \text{ m/minute}$$

$$\text{compare: earth circumference} = 4 \times 10^7 \text{ m}$$

How Do We Study the Universe Over Such Huge Scales?

1 light-year = 9.46×10^{15} m

1 light-minute = 3×10^8 m/s \times 60 s = 1.8×10^{10} m

Some distances:

- ❖ Sun to earth: 8 light-minutes (10^{-5} light-years)
- ❖ Nearest star: 4.4 light-years
- ❖ Nearest group of young stars: 1500 light-years
- ❖ Nearest galaxy (Andromeda): 2.5 million light-years

Looking Back In Time

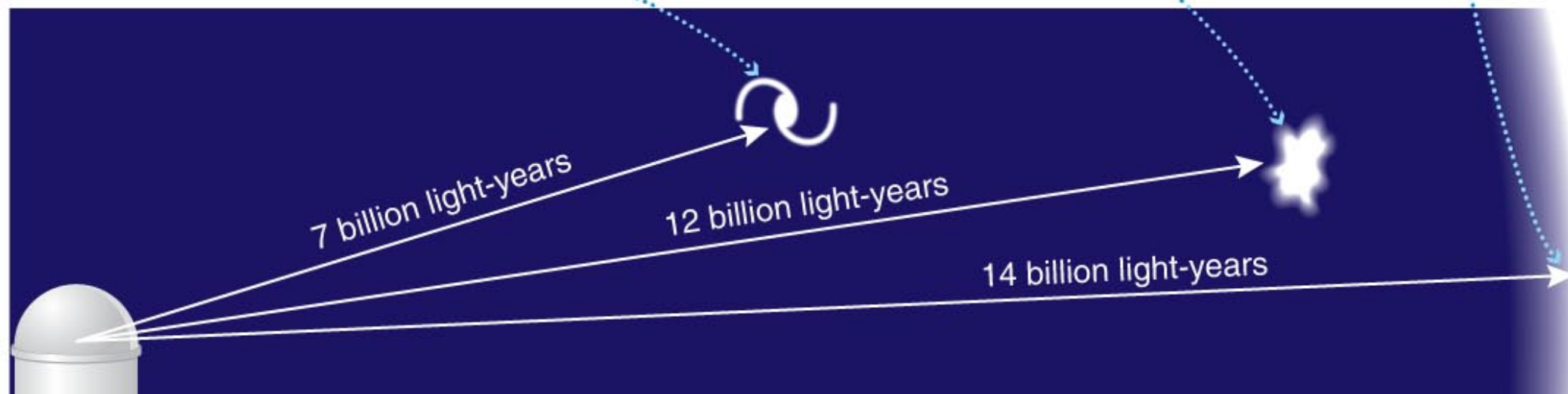
- ❖ Because light takes time to travel to us, the farther away we look in the universe, the further back in time we see!

The Andromeda galaxy is 2.5 million light-years away, so the light we see today left Andromeda 2.5 million years ago

Far: We see a galaxy 7 billion light-years away as it was 7 billion years ago—when the universe was about half its current age of 14 billion years.

Farther: We see a galaxy 12 billion light-years away as it was 12 billion years ago—when the universe was only about 2 billion years old.

The limit of our observable universe: Light from nearly 14 billion light-years away shows the universe as it looked shortly after the Big Bang, before galaxies existed.



Beyond the observable universe: We cannot see anything farther than 14 billion light-years away, because its light has not had enough time to reach us.

For Next Time:

- ❖ Check the class web site:

<http://www.ucolick.org/~crockosi/Ay2Rockosi2017/>

- ❖ Register at: <http://connect.mheducation.com/class/w17>

You will need to purchase access if you didn't buy the textbook package at the bookstore

- ❖ register your iClicker or the REEF polling app:

<https://reef-education.com/> (either the app or iClickers)

for iClickers: <https://www1.iclicker.com/>