AST121 Origin & Evolution of the Universe

Prof. Yanqin Wu

Course website:
http://www.astro.utoronto.ca/~wu/AST121
for syllabus, lecture slides, assignments, etc.

TAs: Mr. Charles Zhu,
Mr. Serguei Ossokine

This is a quantitative course!

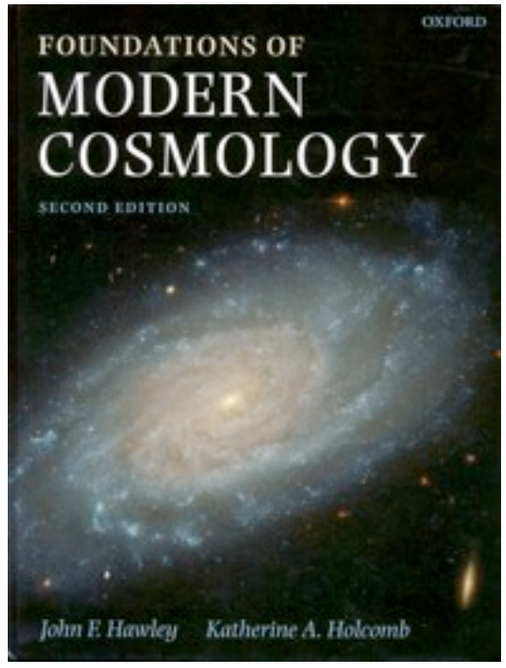
Aim of the course:

Target Audience:
This introductory course is aimed at science students, no prior knowledge of astronomy is assumed.

Course prerequisites and exclusions
Prerequisites: OAC Physics/SPH4U and OAC Calculus/MCB4U
Please note that there are several other introductory courses offered by the Department of Astronomy, e.g. AST 101, AST 201, AST 210, AST 251, which are much better suited to non-science students and to students who are not particularly happy with using mathematics as a tool to understanding. AST 121 is not any easier than the 200-level courses mentioned above. Non-science students are advised to take one of the other courses listed above.

Exclusions:
AST101, AST201, AST210. Also excluded are AST221, AST222 if taken previously or concurrently.

Required Textbook:
Foundations of Modern Cosmology
by Hawley & Holcomb, 2nd edition



optional readings:
1)**The Physical Universe, An Introduction to Astronomy**, by Frank Shu
2) **Quarks, Leptons and the Big Bang,** by Jonathan Allday
3) **Just six numbers: the deep forces that shape the universe**, by Martin Rees

Books are put on reserve in Gerstein science library. The textbook is stocked in the UofT bookstore. **Also Library has e-book version.**

Course Work

first session: Friday (1-2PM, MP102), problem set I posted online

1) weekly assignments (total of 10)
but only 3 need to be turned in, 30%
assignments can be completed in groups, and you can receive help during **help sessions.**

assignments **make up the quantitative aspect** of the course that is not well covered in lectures

2) mid-term test 20%
in-class 1 hour

3) final test 50%
3 hours

- This will be a challenging course.
- I will try my best to convey the bewilderment and excitement of modern-day cosmology, and you will be much intellectually enriched at the end!

Announcement:

Research Opportunities in Astrophysics & Cosmology

During terms & summer:
Arts & Sciences 299 and 399 programs (course credit)

Summer:
NSERC undergraduate research awards (stipend ~ $7000), backgrounds in physics, eng., math, etc. welcome

look at http://www.astro.utoronto.ca/alljobs/summerjobs
& http://www.di.utoronto.ca/
& http://www.cita.utoronto.ca/index.php/Working-CITA

Lecture 1: introduction to the universe

How big is the universe?

we don't know if it's finite or infinite. however, we know our little observable patch.

How old is the universe?

born 14 Billion yrs ago

What is in the universe?

fairly empty; if much more filled, the universe would have collapsed onto itself

are we in the centre?

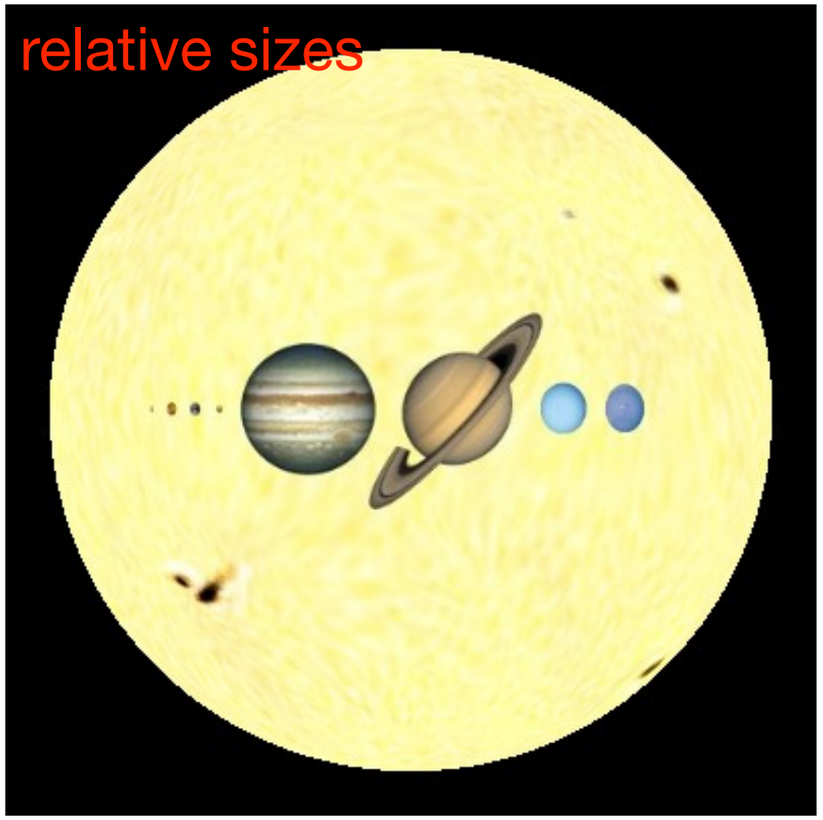
no

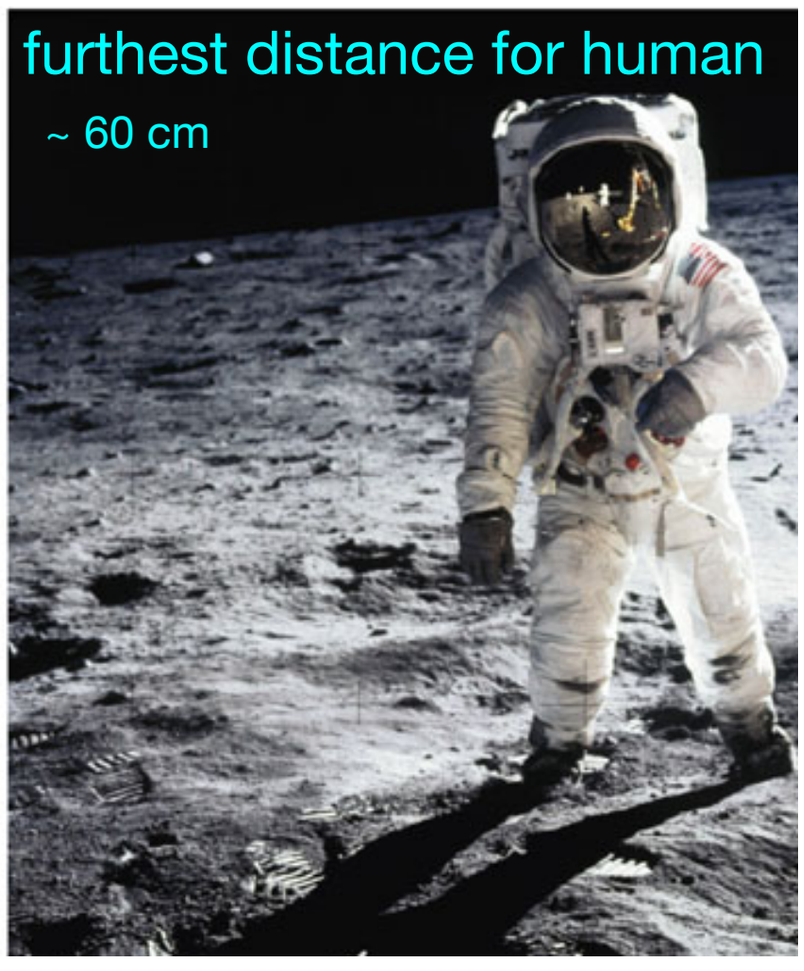
Where is the universe from? Where is it going?

Did space & time exist before the universe's birth?

If the universe is finite, what is outside?

How big is the universe?



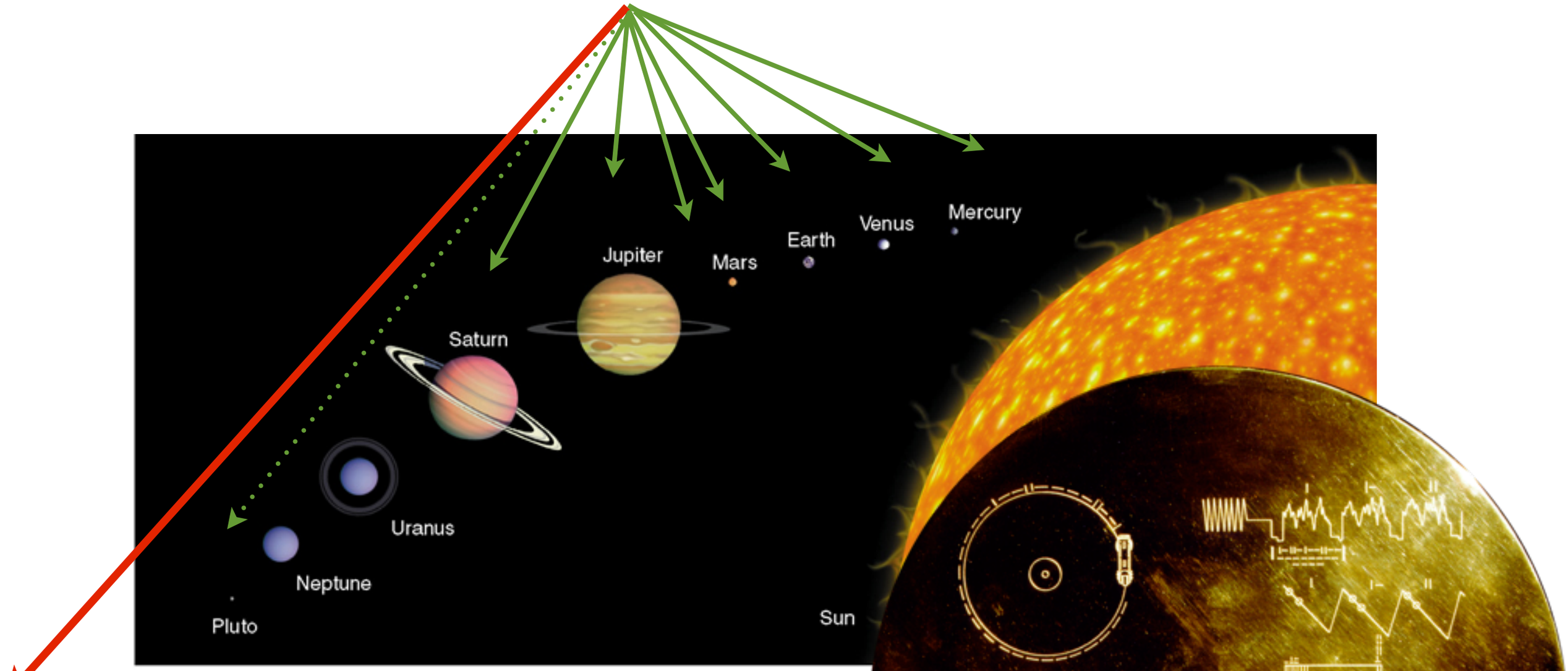


Scales in the Solar System

one astronomical unit (AU)

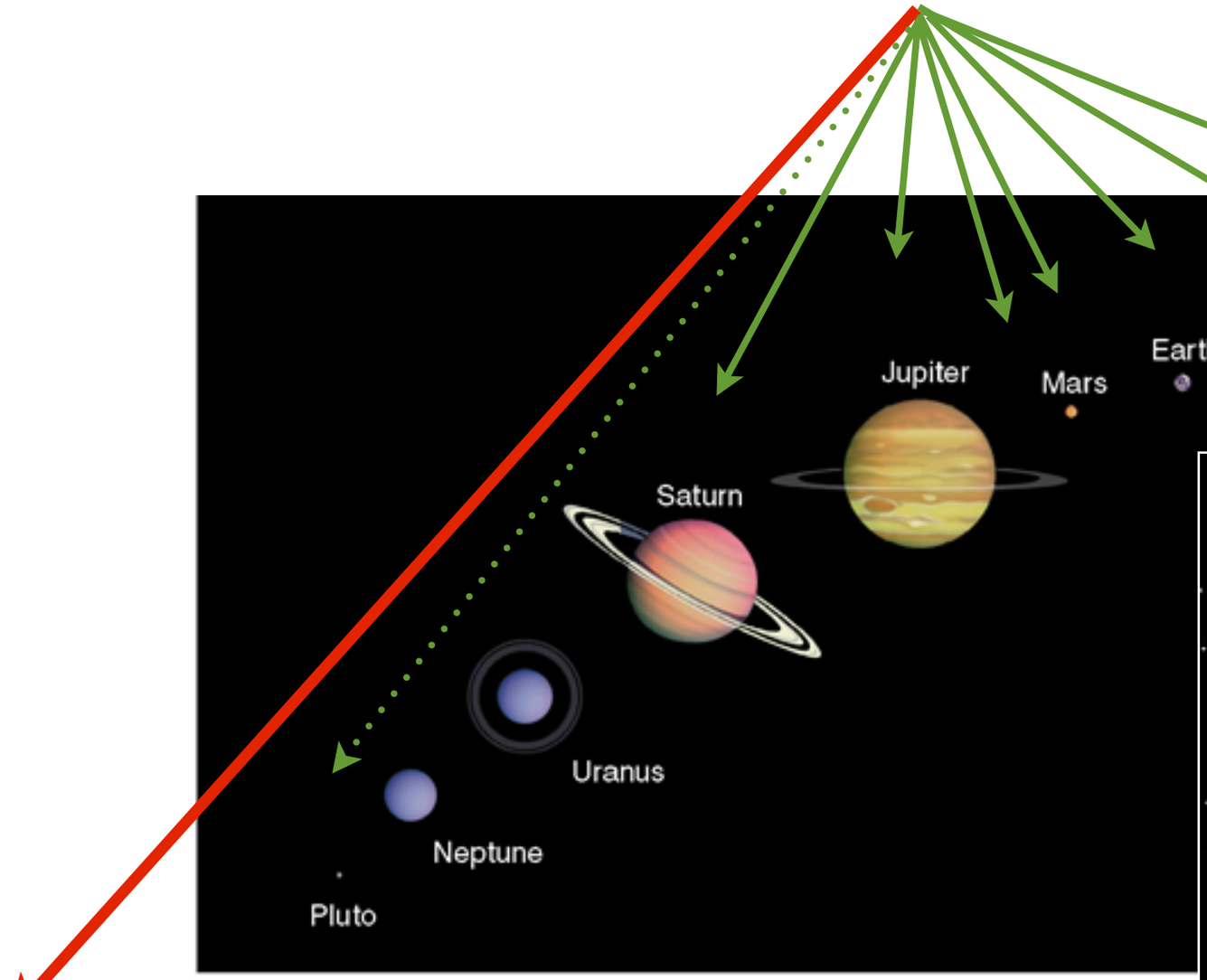
Object	*Real Distance from Sun (average)*	*Model Distance from Sun*
Sun	—	—
Mercury	57.9 million km	6 m
Venus	108.2 million km	11 m
Earth	149.6 million km	15 m
Mars	227.9 million km	23 m
Jupiter	778.3 million km	78 m
Saturn	1,427 million km	143 m
Uranus	2,870 million km	287 m
Neptune	4,497 million km	450 m
Pluto	5,900 million km	590 m

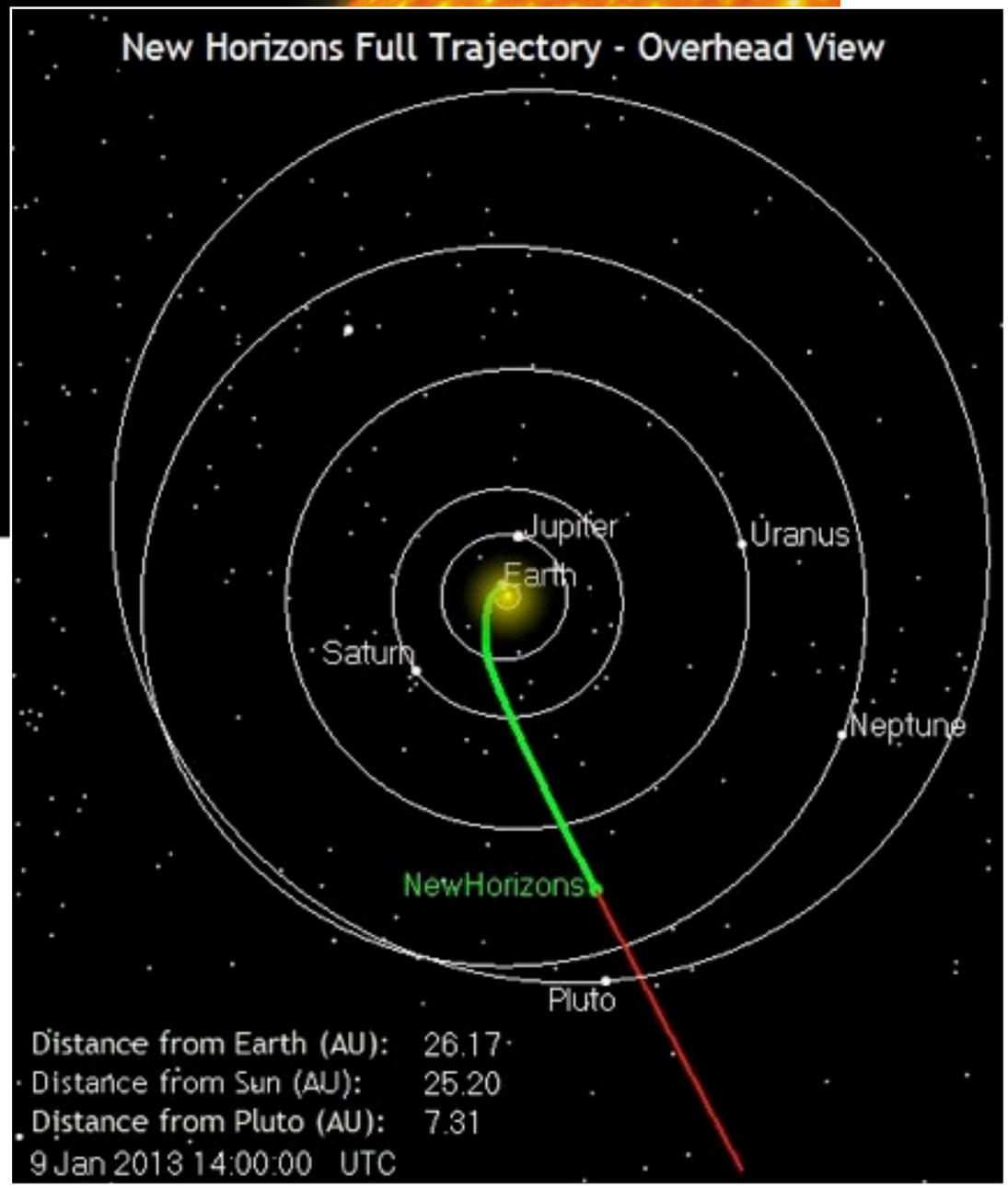
Solar system bodies visited by man-made objects



furthest man-made object: Voyager I space-craft launched 1977, currently @ 115AU (or 16 light hours)

Solar system bodies visited by man-made objects

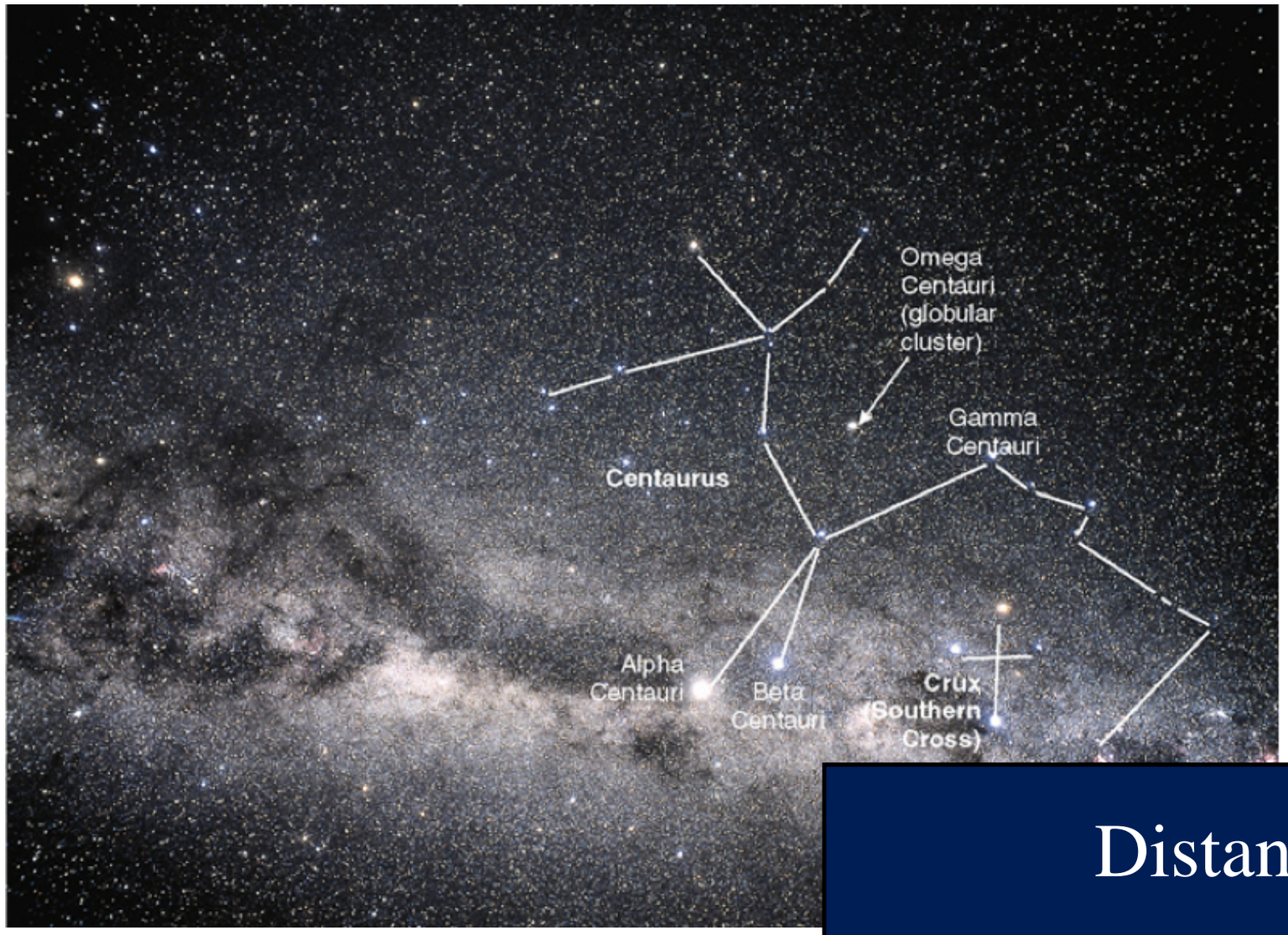




Pluto will be visited by the
New Horizon space-craft
2015

Currently,
distance ~ 26 AU
light-time ~ 3.6 hrs

Closest stars: the alpha-Centauri triple (4.4 light years)



search for life in alpha-Centauri is on-going

Breaking News: alpha-Centauri B has an Earth-like planet (Oct 2012)

Distance = speed x time

1 light year = distance light travels in a year
= speed of light (c) x 1 year
~ 10^{13} kilometers
~ 10,000 AU

How big is the universe?

photons are the fastest travellers in the universe, so we use them to measure distances.

The light-year

Distance light travels in 1 year

Speed of light: 300,000 km/s

Hence, 1 light-year is about 10 trillion km

(10,000,000,000,000 km)

Nearest star: 4.4 light-years

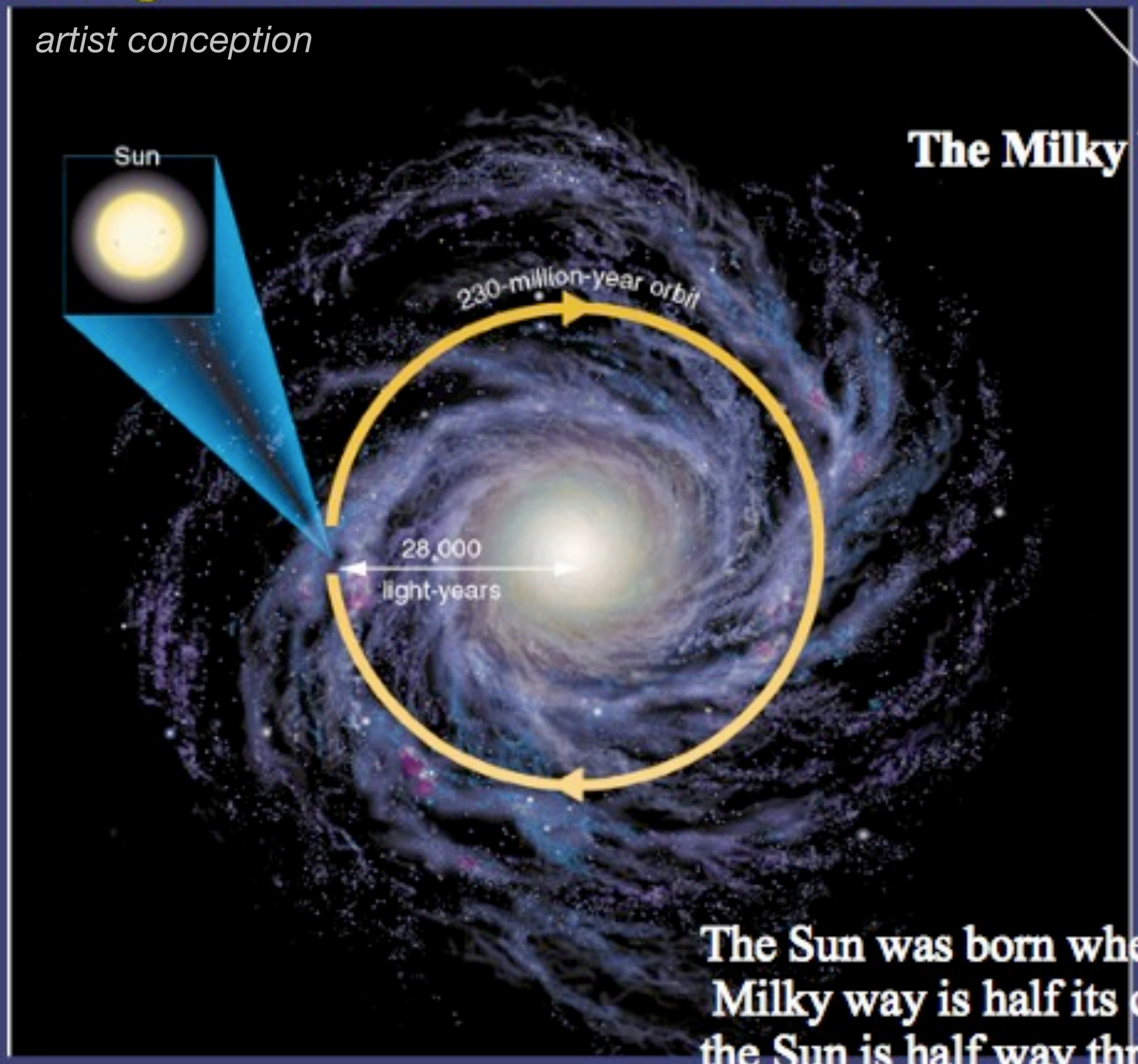
Nearest major Galaxy: 2.5 million light-years

Universe: 14 billion light-years

(observable)

It takes time to get there...

The Sun goes around the centre of the Galaxy



The Sun was born when the
Milky way is half its current age;
the Sun is half way through its life.

How many stars in the Galaxy?

Number of sand grains in a sandpit
~ 100 billion

The box represents stars and their motions in the local solar neighborhood.

~ 100 billion (10^{11}) stars

Friday, January 11, 2013

Galaxies form communities.

A small community is called 'group' (groups of galaxies)

galaxy = island universe

our local group =
Milky Way
+ Andromeda Galaxy
+ a few dwarf galaxies

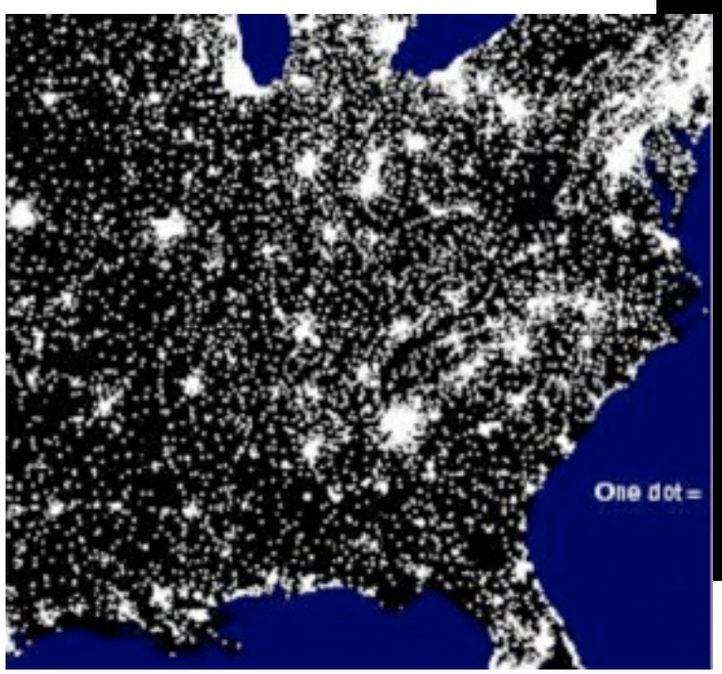
Groups of galaxies form clusters (of galaxies)

We belong to the Virgo supercluster,
~ 100 groups of galaxies
~ 10,000 galaxies

The galaxies are highly clustered.

The universe is made up of superclusters of galaxies, and voids.

US 2000 census

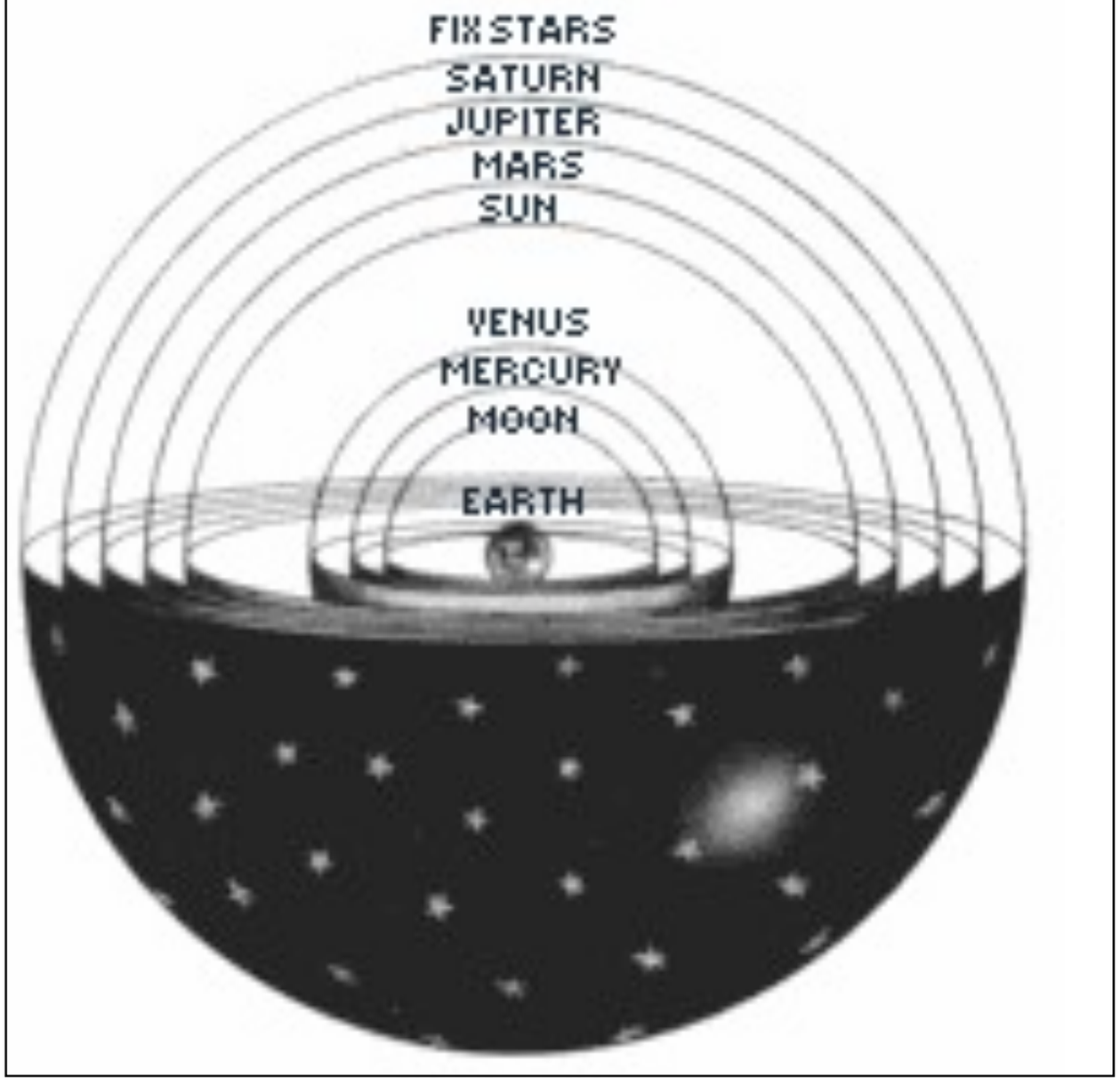


metropolitan vs. rural

Are we in the centre?

The geocentric universe

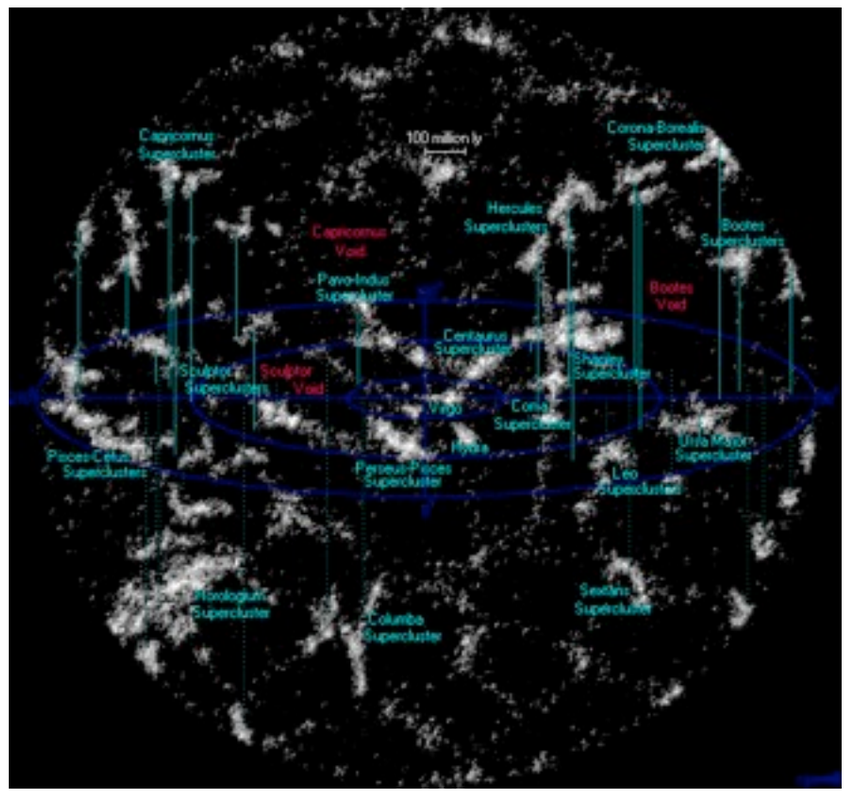
(Ptolemy)



the Copernican principle

We don't occupy a special location in the universe

nothing special about the Sun, the Milky Way, the local group, the Virgo cluster...



From this perspective, we are unlikely to be the only intelligent life in town.

Light takes 14 Billion years to travel to the end of *our (observable) universe*

Local supercluster

60 million light-years

Local group

2.5 million light-years

14 billion light-years observable Universe contains ~100 billion galaxies

Milky Way galaxy contains ~100 billion stars

28,000 light-years

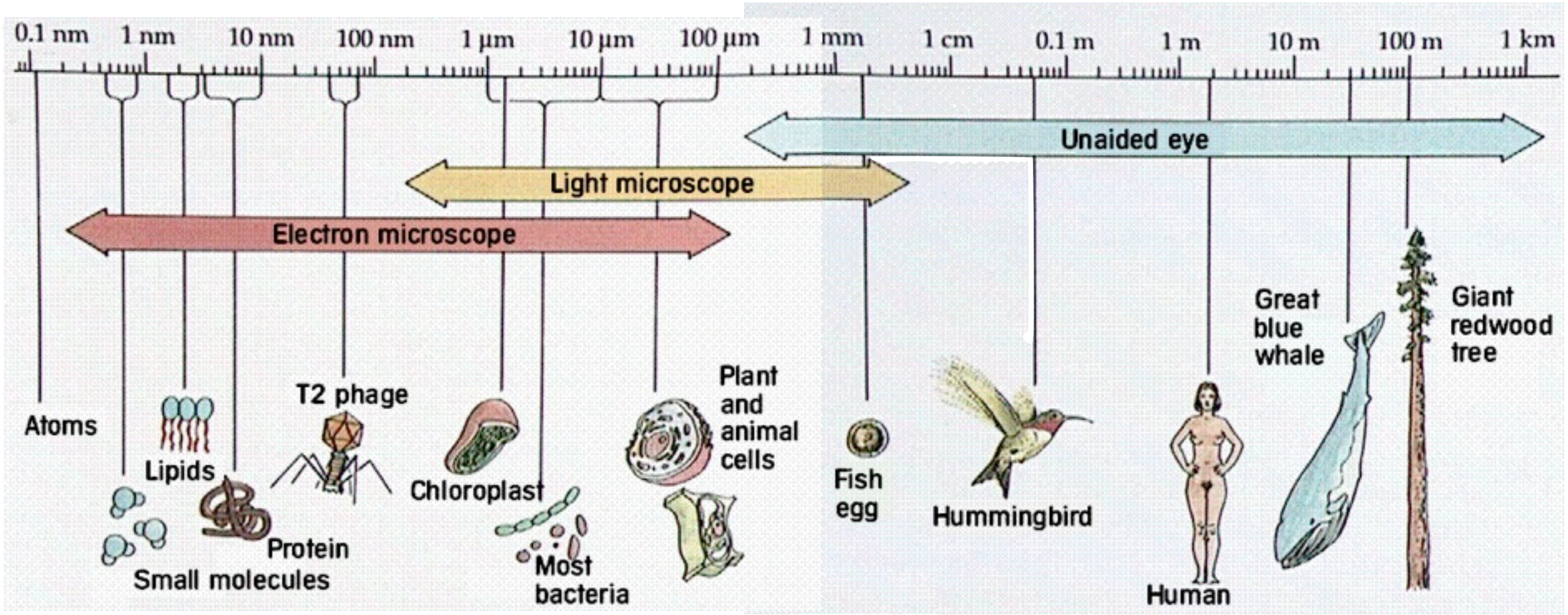
Earth

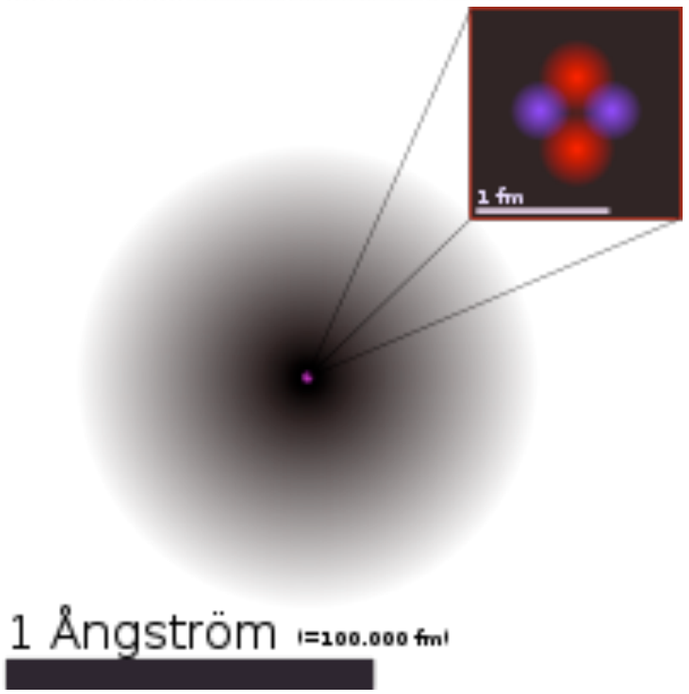
0.04 light-seconds

Solar system (not to scale)

8 light-minutes

Let's go the other way in spatial scales...





Atom size ~ Å = 10^{-10} m

proton size ~ fermi = 10^{-15} m

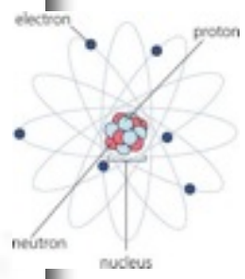
the Planck scale: ~ 10^{-35} m

Horizon:10^{26}m

Planck scale:10^{-35}m

10^{18}m

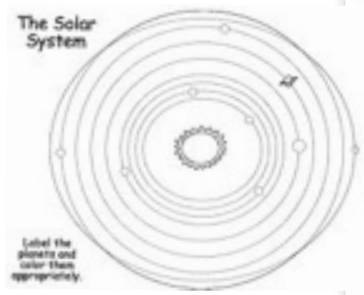
10^{-17}m



10^{-12}m

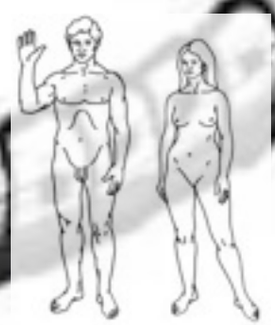
Ouraborus: emblematic serpent of ancient Egypt and Greece, represented with tail in its mouth continually devouring itself and being reborn from itself

10^{13}m

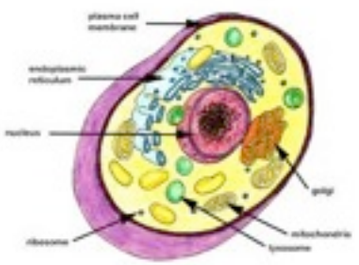


10^{-7}m

10^{8}m



1m



Ouraborus

- ~10^{11} cells in a human body
- ~10^{11} stars in our galaxy,
- ~ 10^{11} galaxies in observable universe (~ 10^{78} atoms, 'googol' = 10^{100})

- The macroscopic world runs according to rules for the microscopic particles.

Humans are made up of ~10^{29} atoms, straddling ~midway between the Sun (~10^{57} atoms) and a molecule (~ 10 atoms). Not a coincidence (Rees §1). At mercy of both the microscopic organisms as well as the macroscopic world.

- The universe started from a microscopic scale. It has expanded and has built up structures.

- The ultimate synthesis between the cosmos and the quantum still eludes us.

How Old is the Universe?

Three possibilities:
eternal
birth
cyclical

The universe is 14 Billion years old.

Light takes 14 Billion years to travel to the end of *our (observable) universe*

Local supercluster

60 million light-years

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2.5 million light-years

14 billion light-years observable Universe contains ~100 billion galaxies

Milky Way galaxy contains ~100 billion stars

28,000 light-years

Earth

0.04 light-seconds

Solar system (not to scale)

8 light-minutes

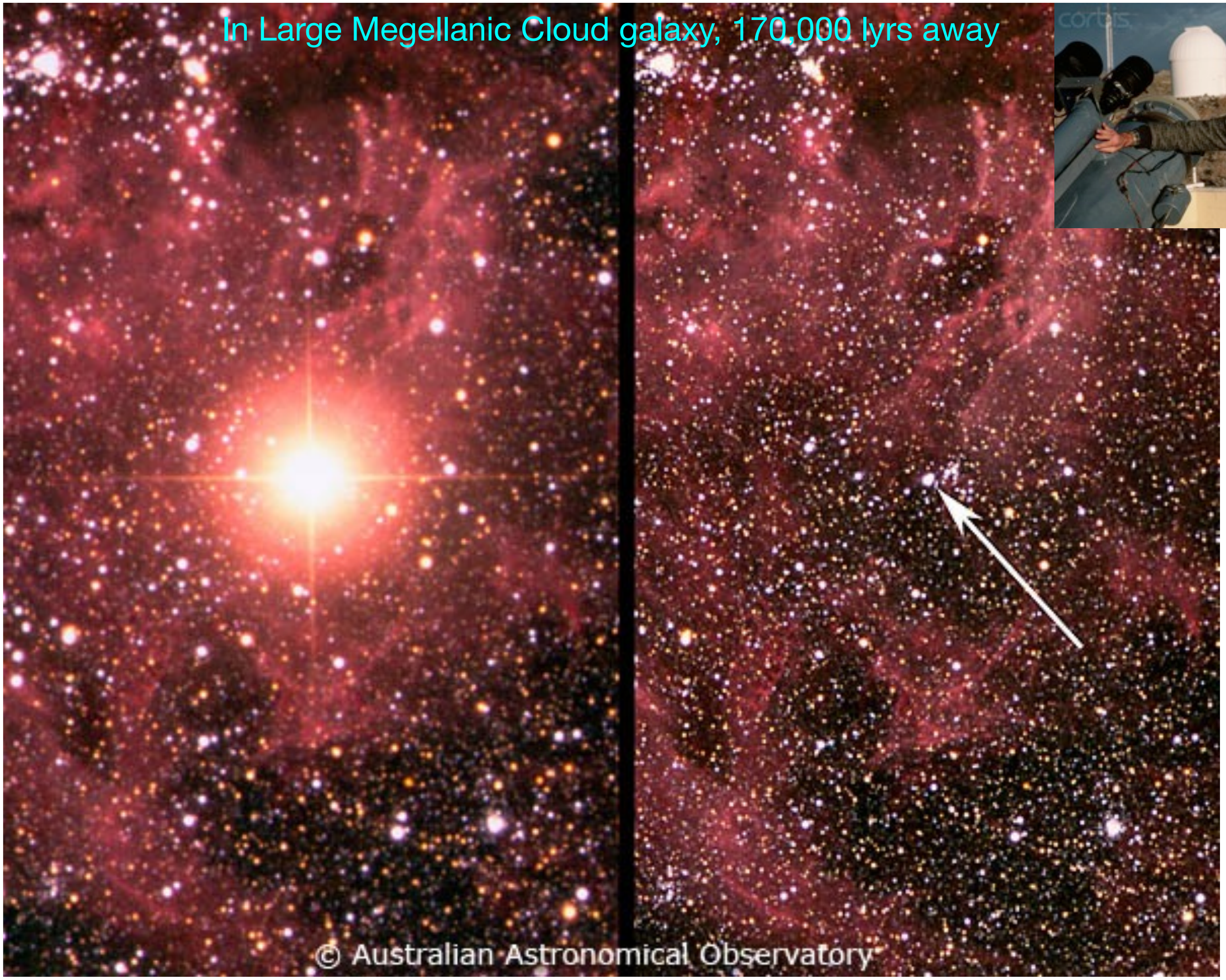
We can see the beginning of the universe!

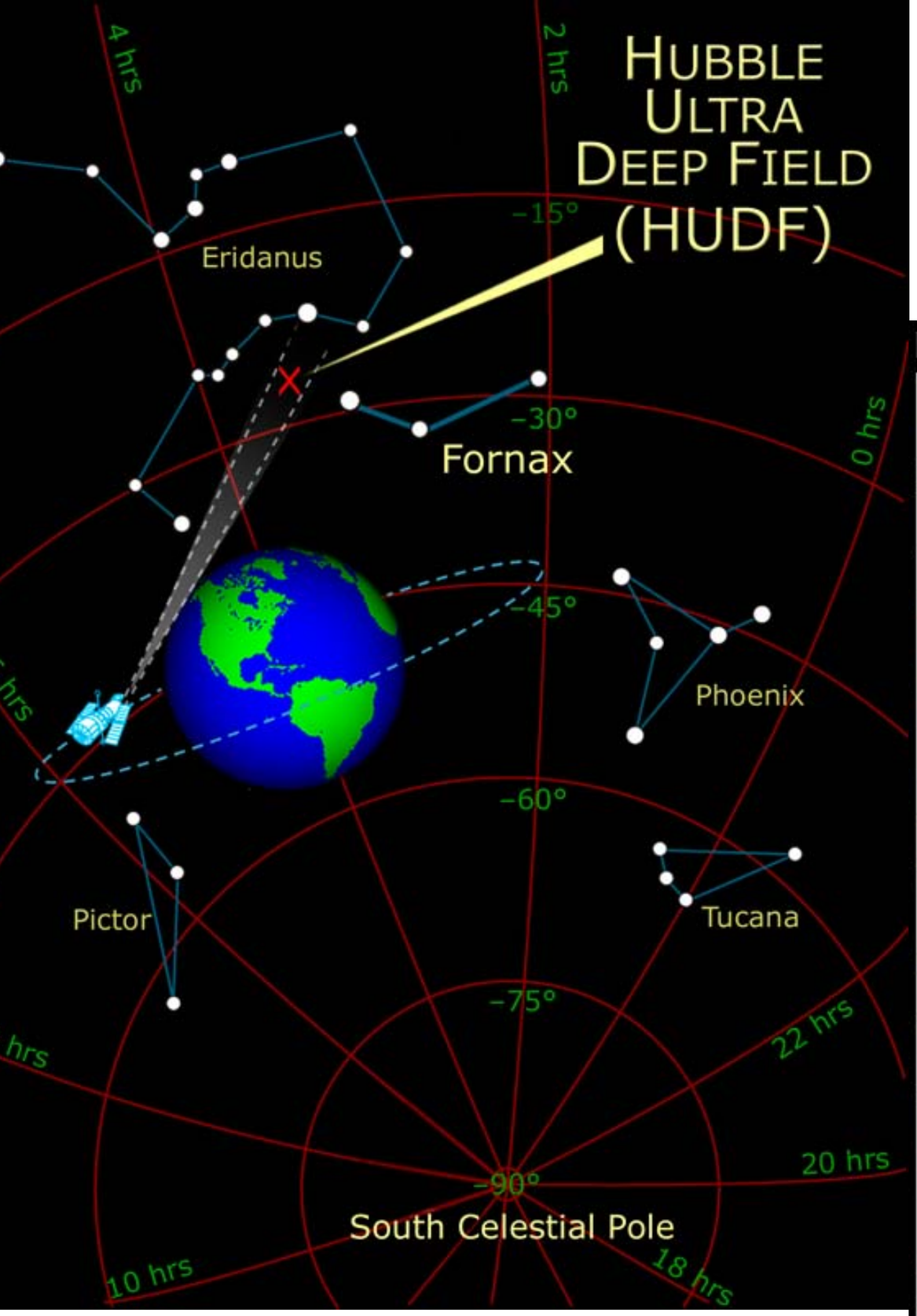
Telescopes are Time Machines

- Light, although fast, travels at a finite speed.
- The light entering your eye now is a record of the time when the light was emitted somewhere else.
- For example: the sun is 8 light minutes away, and you are seeing it as it was 8 minutes ago.
- The further out into the Universe we look, the further back in time we see!

Supernova 1987A

Discovered by Ian Shelton in 1987



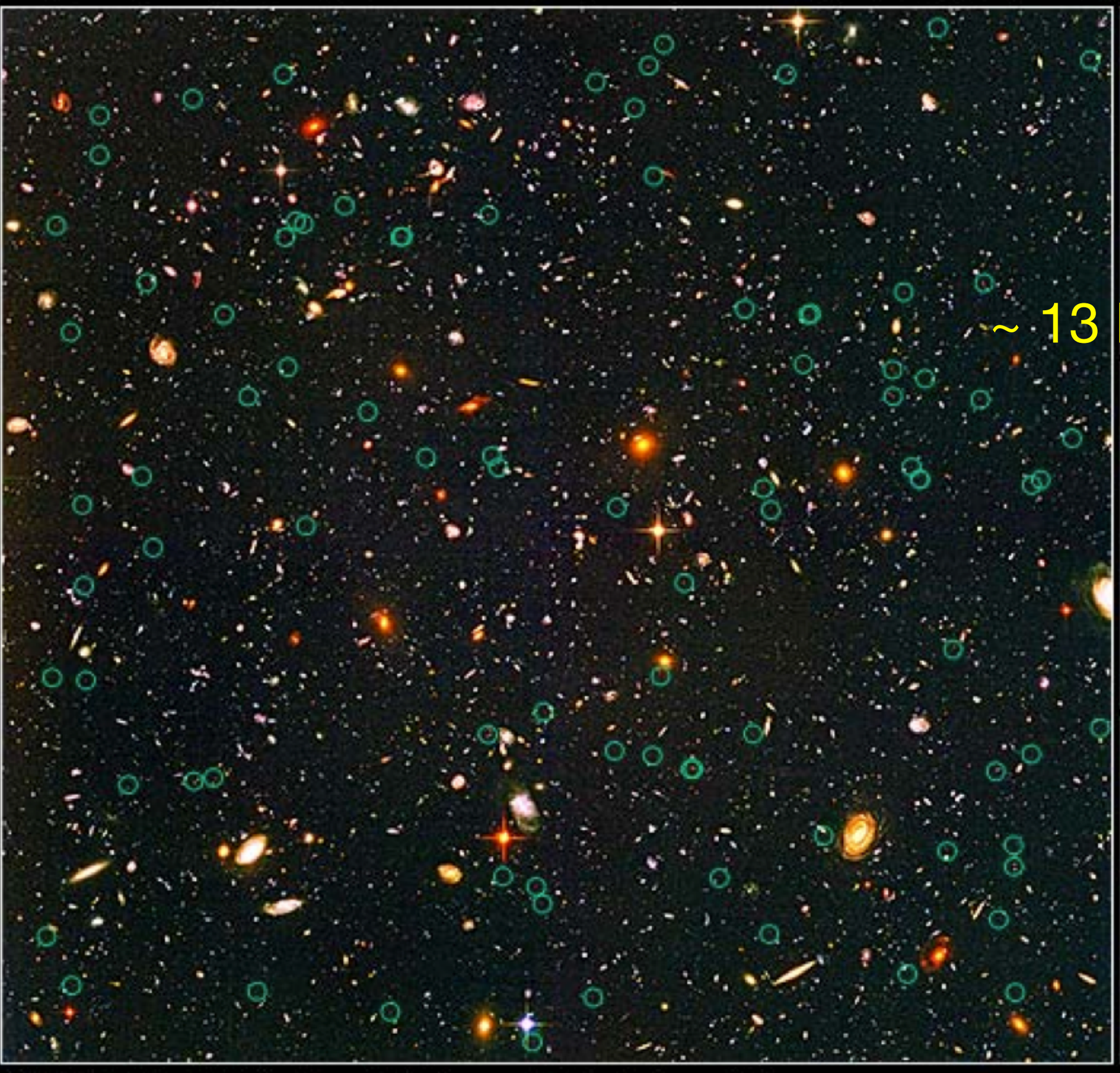

HUBBLE ULTRA DEEP FIELD (HUDF)
4 hrs
2 hrs
0 hrs
22 hrs
20 hrs
18 hrs
10 hrs
hrs
−15°
−30°
−45°
−60°
−75°
−90°
Eridanus
Fornax
Phoenix
Pictor
Tucana
South Celestial Pole


Hubble Ultra Deep Field
HST ▪ ACS
NASA, ESA, S. Beckwith (STScI) and The HUDF Team
STScI-PRC04-07a

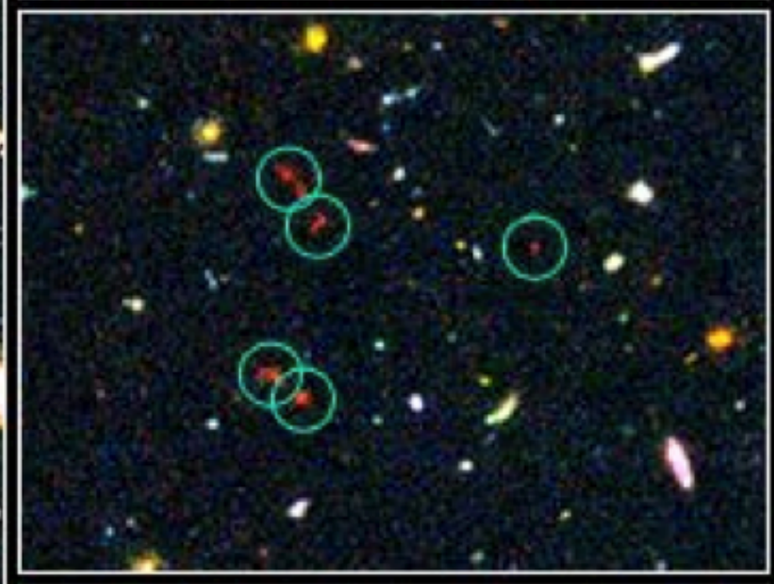
Friday, January 11, 2013

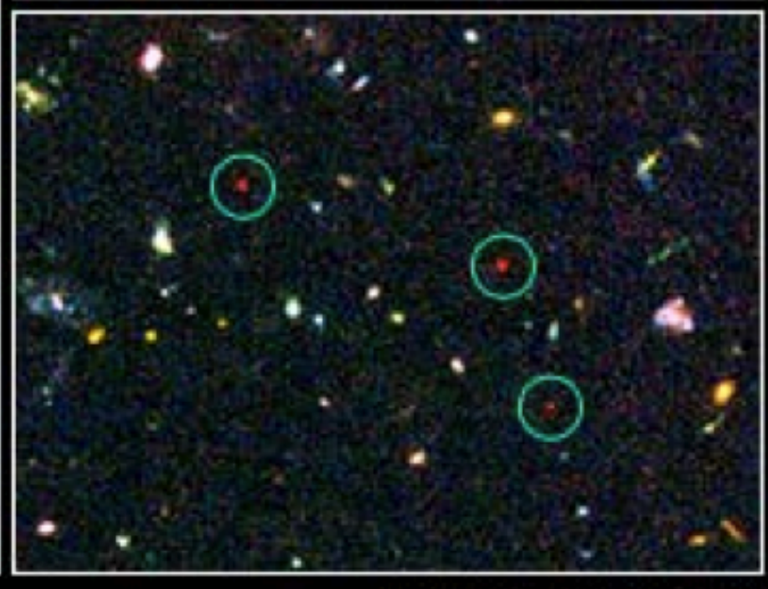
Distant Objects in the Hubble Ultra Deep Field

HST • ACS



~ 13 billion light years

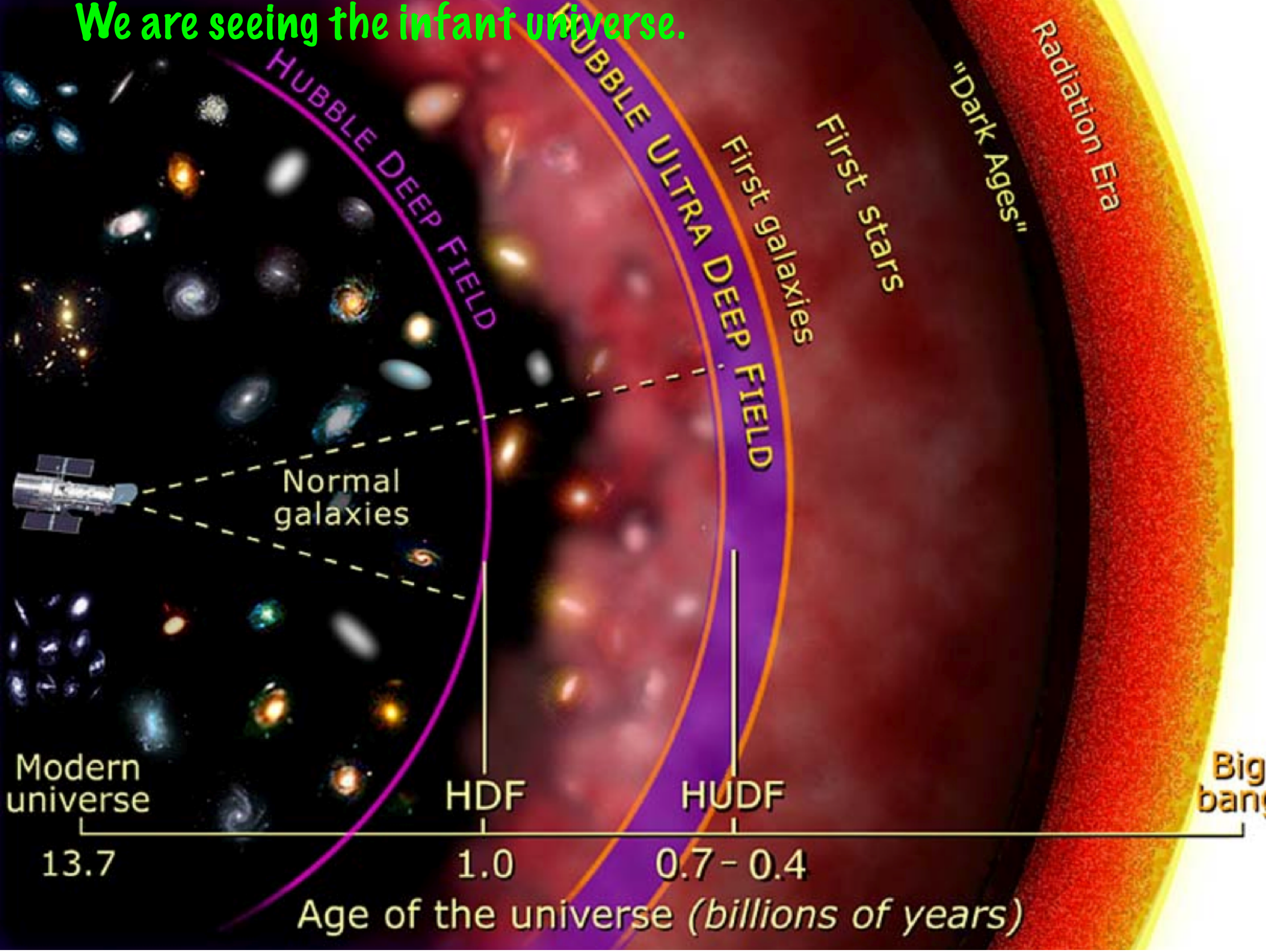




NASA, ESA, R. Windhorst (Arizona State University)
and H. Yan (Spitzer Science Center, Caltech)

STScI-PRC04-28

We are seeing the infant universe.



to appreciate such a vast timescale:

Carl Sagan (1934-1996)

Cosmic Calendar

-- Big bang: midnight Jan 1st; now: mid night Dec. 31st

-- one month will be just over a billion real years

-- one day would be about 37 million real years

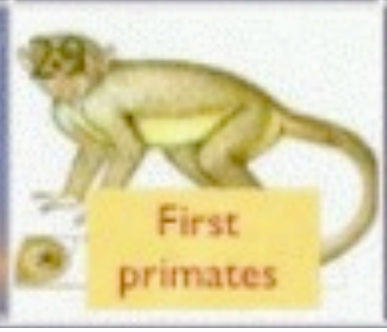
-- one second is ~ 500 years

-- *everything for which 'we' are relevant occurs in the last* ***minute***

Cosmic Calendar (Carl Sagan)

January	February	March	April
1 Big Bang			
May	**June**	**July**	**August**
1 Milky Way born			
September	**October**	**November**	**December**
9 Solar system born *14 Earth forms* *25 First life on Earth?*	*2 Oldest rocks known* *9 Oldest fossils (bacteria/blue-green algae)*	*1 Sex invented* *12 Oldest fossil plant* *15 Eukaryotes flourish*	*(zoomed in next slide)*

December (Note: dates depend on source!)

Sun	Mon	Tue	Wed	Thur	Fri	Sat
	1 Oxygen in atmosphere	2	3	4	5  Mars active	6
7	8	9	10	11	12	13
14	15	16  First worms	17  Cambrian explosion	18	19	20
21	22	23	24  Dinosaurs appear	25	26  First mammals	27
28  Dinosaurs become extinct	29  First primates		31 (Next slide)			

December 31

~13:30 Origin of Proconsul and Ramapithecus, probable ancestors of apes and men

~22:30 First humans

first hominid ~ 2 million years ago

23:00 Widespread use of stone tools

23:46 Domestication of fire by Peking man

23:56 Beginning of most recent glacial period

23:58 Seafarers settle Australia

23:59 Extensive cave painting in Europe

23:59:20 Invention of agriculture (~10,000 years ago)

10,000 years ago

23:59:35 Neolithic civilization; first cities

23:59:50 First dynasties in Sumer, Ebla and Egypt; development of astronomy

5000 yrs ago

23:59:51 Invention of the alphabet; Akkadian Empire

4000 yrs ago

23:59:52 Hammurabic legal codes in Babylon; Middle Kingdom in Egypt

23:59:53 Bronze metallurgy; Mycenaean culture; Trojan War; Olmec culture; invention of the compass

23:59:54 Iron metallurgy; First Assyrian Empire; Kingdom of Israel; founding of Carthage by Phoenicia

23:59:55 Asokan India; Ch'in Dynasty China; Periclean Athens; birth of Buddha

23:59:56 Euclidean geometry; Archimedean physics; Ptolemaic astronomy; Roman Empire; birth of Christ

23:59:57 Zero and decimals invented in Indian arithmetic; Rome falls; Muslim conquests

23:59:58 Mayan civilization; Sung Dynasty China; Byzantine empire; Mongol invasion; Crusades

23:59:59 Renaissance in Europe; voyages of discovery from Europe and from Ming Dynasty China; emergence of the experimental method in science (~1400AD)

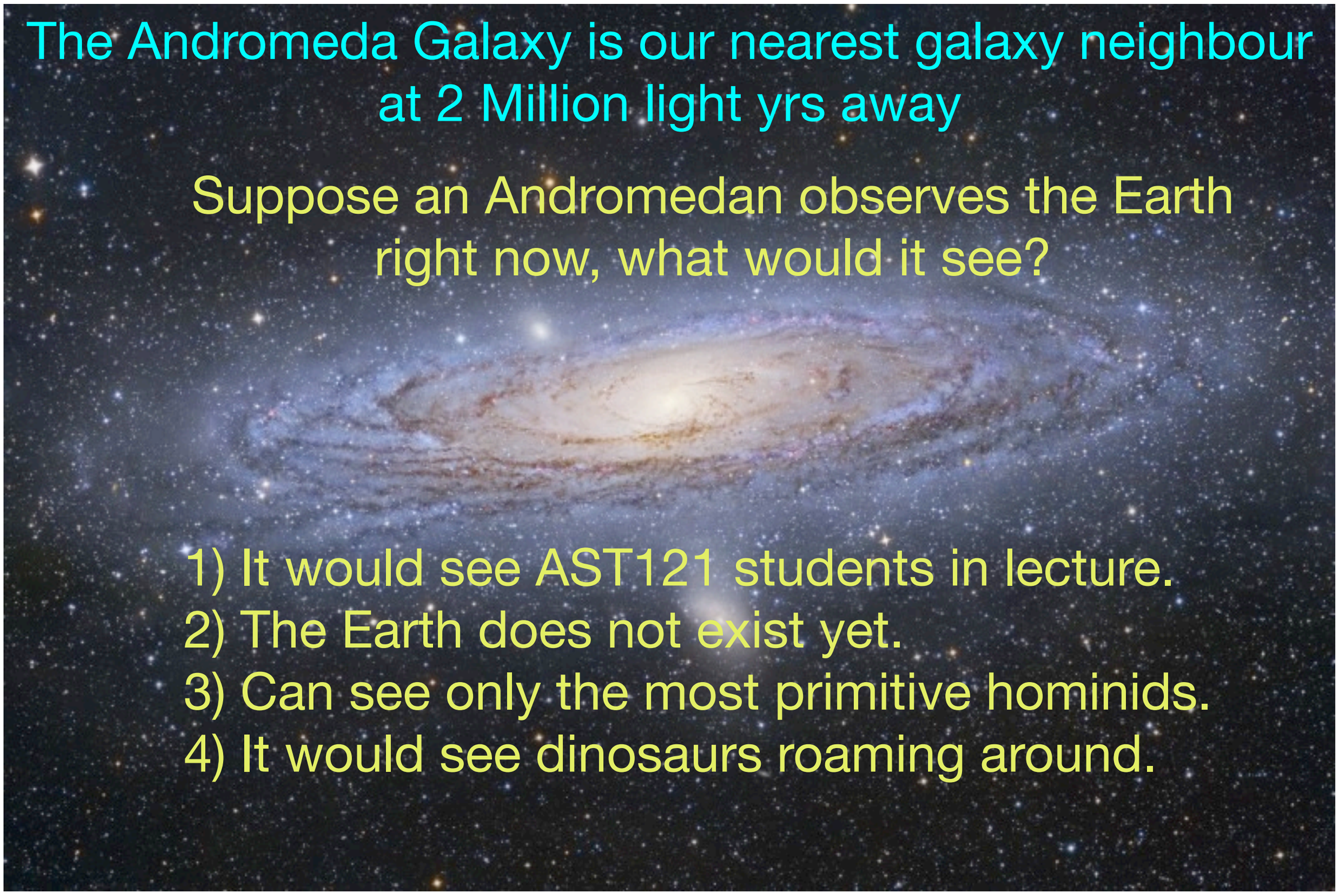
500 yrs ago

All recorded history can fit in 10 seconds.

Evidence of intelligence < 1 min

Look-back time:

looking away in distance = looking back in time



Summary of Key Concepts:

The size of our observable universe 14 billion light years.

The universe is 14 billion years old.

looking away in space = looking back in time

we can therefore witness events going back almost all the way to the big bang

the universe is an Ouraboros; fate of the universe is determined at the smallest scale

After thousands of years' enquiry, we now stand at a special point in history:

1. we now know what stars are and how far they are (~ 100 yrs)

2. we now know what the 'Milky Way' is (~ 100 yrs)

3. we now know why stars shine and why they die (~ 70 yrs)

4. we now know quite a bit about planets (here and elsewhere) (~ 20 years)

5. we now know the age of the universe, 14 Gyrs (~ 20 years)

6. we are getting to understand how everything arises in this universe (~ 10 years)

What will we know in 20 years?

our native curiosity has driven us where we are.

but as a species that have attained civilization for a mere 2000 yrs (vs. 14 Billions), we can only be starting to probe the depth.

In this class, we will be discussing what we have learned and what we have yet to find out.