SCI 199Y second term: Astronomy @ the Frontiers

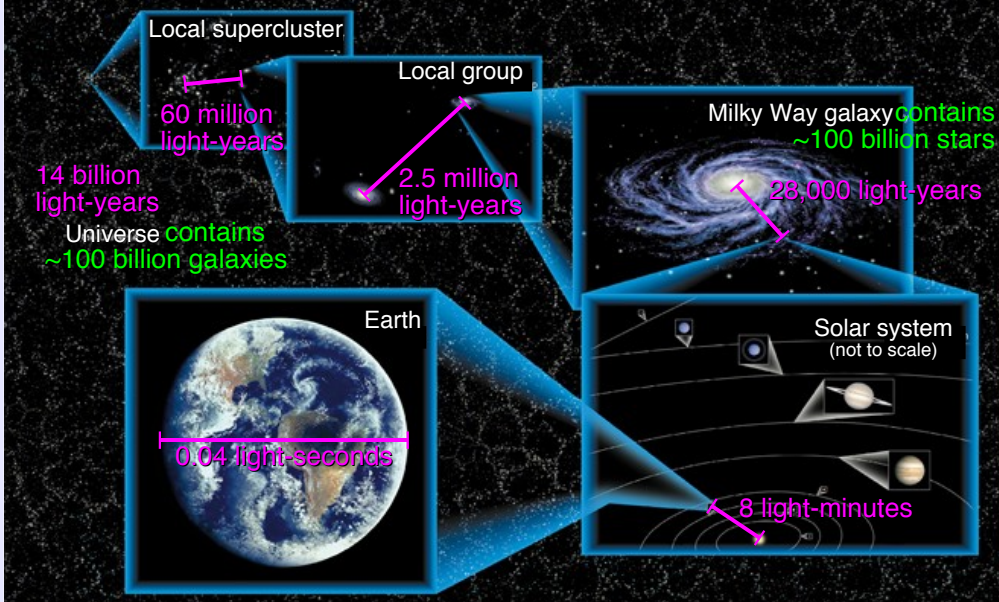
Prof. Yanqin Wu

1) Review last term and connection to this term

2) technical details

3) Measuring distances – the universe is expanding!

Lecture 1: Our Cosmic Address



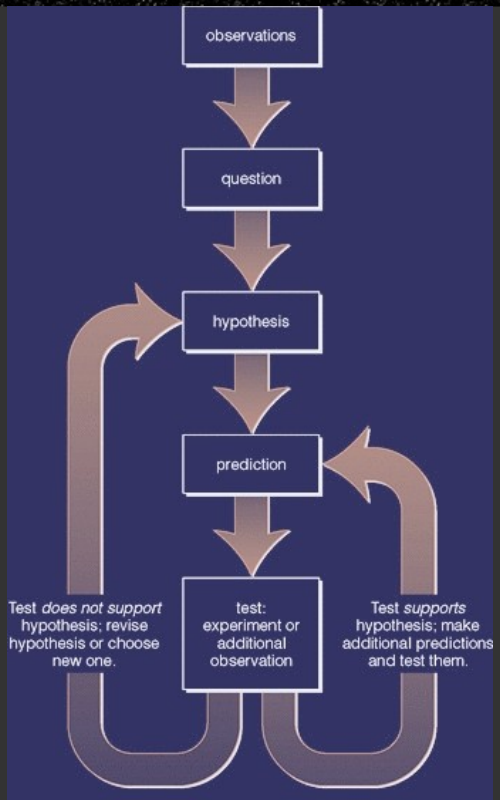
Lecture 2: Cosmic Calendar

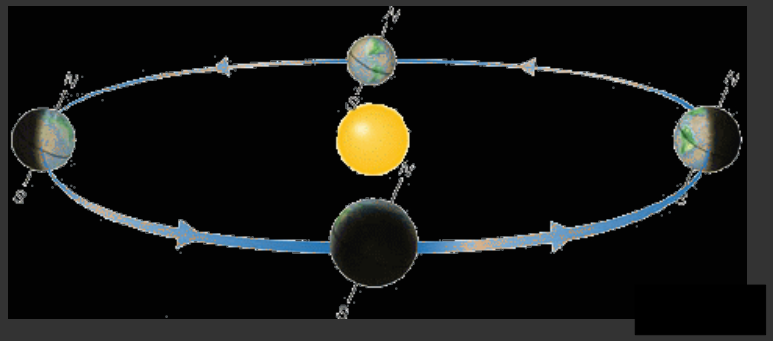
January	February	March	April
1 *Big Bang*			
May	**June**	**July**	**August**
1 *Milky Way born*			
September	**October**	**November**	**December**
9 *Solar system born* 14 *Earth forms* 25 *First life on Earth?*	2 *Oldest rocks known* 9 *Oldest fossils (bacteria/blue-green algae)*	1 *Sex invented* 12 *Oldest fossil plant* 15 *Eukaryotes flourish*	1 *Oxygen in air* 17 *Cambrian* 27 *Jurassic* 30 *Dinos extinct* 31 ... *Next slide*

Lecture 3: The Science of Astronomy

Loop: you can never prove a hypothesis, you can only disprove ("*falsify*") it

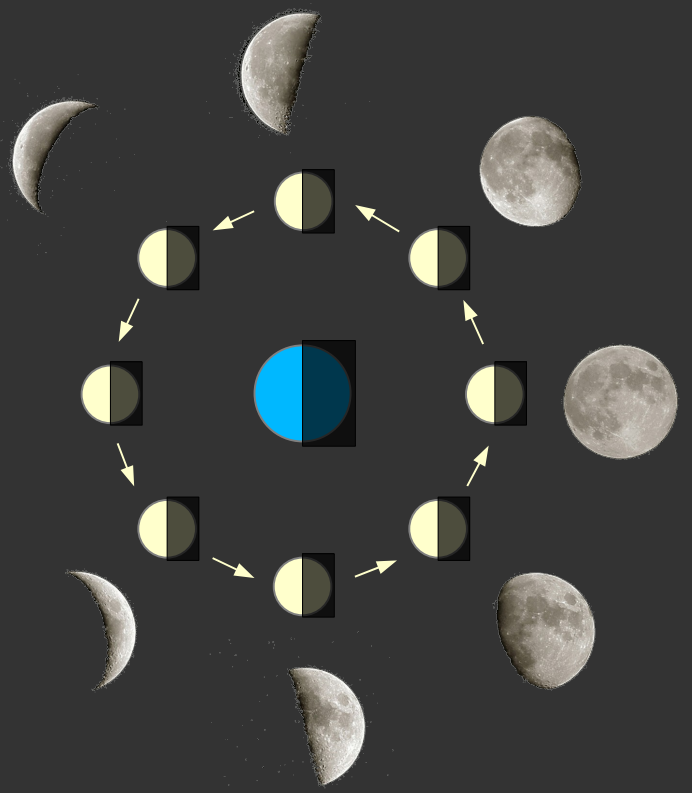
A scientific statement is falsifiable.





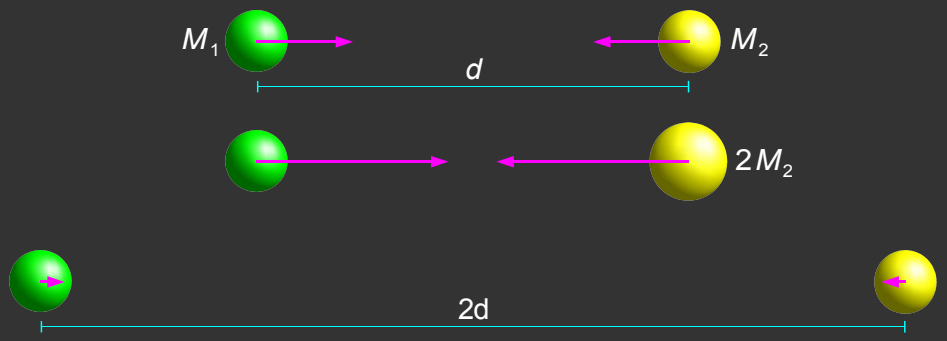
Seasons

Phases of the Moon

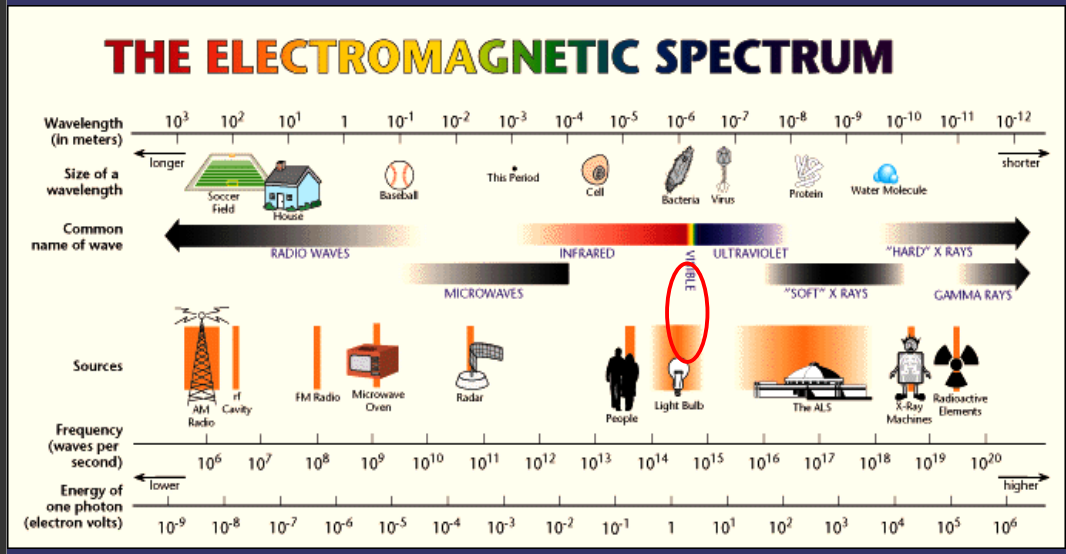


Laws of Gravity

$$F_g = G\frac{M_1 M_2}{d^2}$$



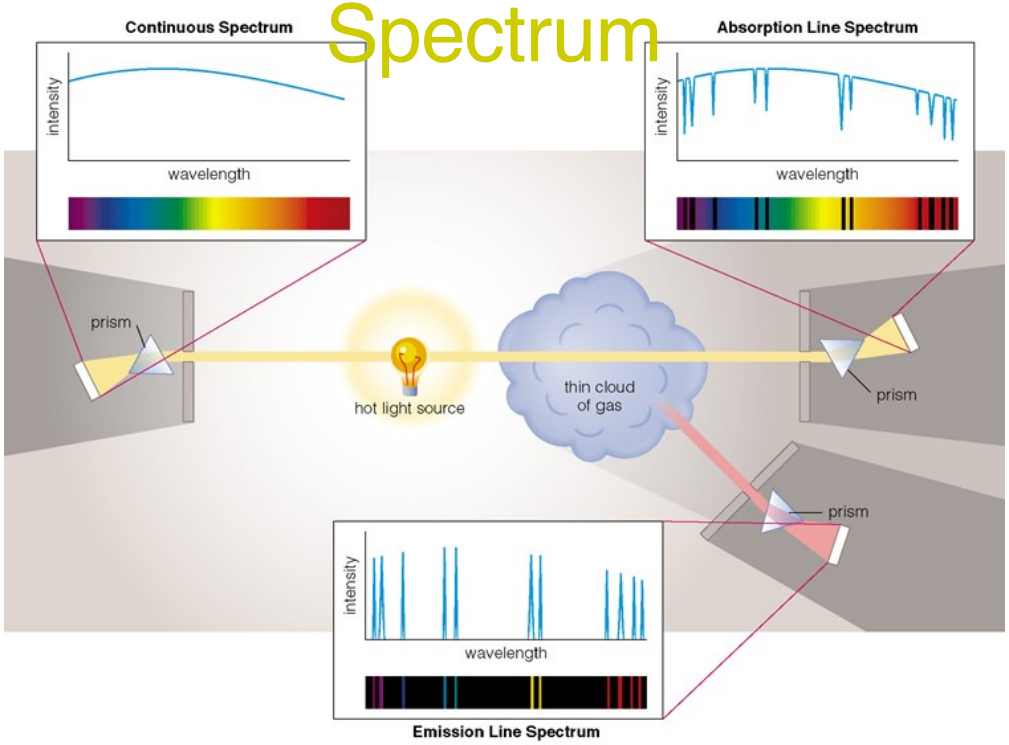
LIGHT: *wave/particle*



wavelength

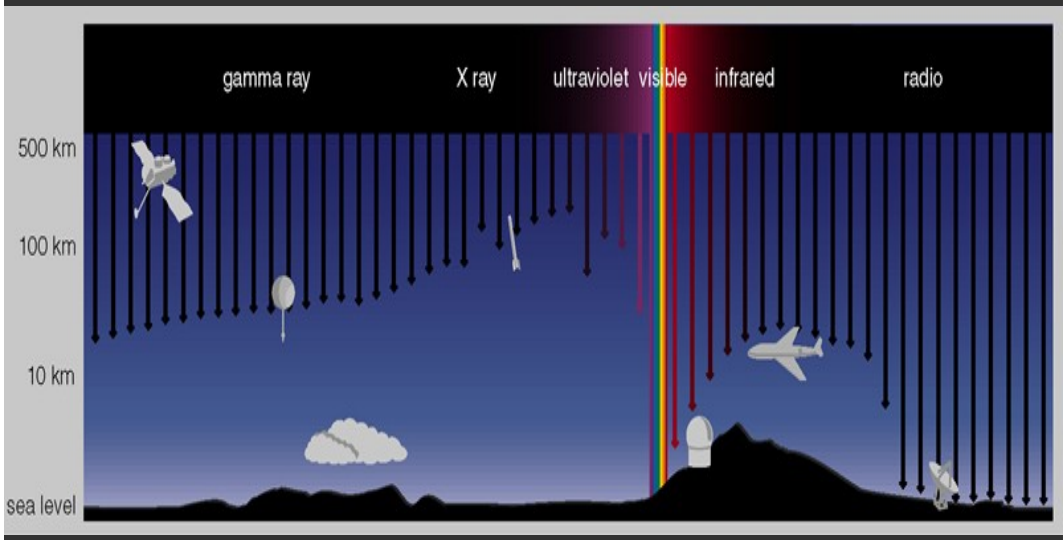
energy

Spectrum



Telescopes

Atmosphere not transparent at all wavelengths;
for all but visible and radio, need to go up!



Instant Quiz:
What keeps the Sun shining?

~~On fire?~~ 1 hand up

~~Too little energy~~

~~Contracting?~~ 2 hands up

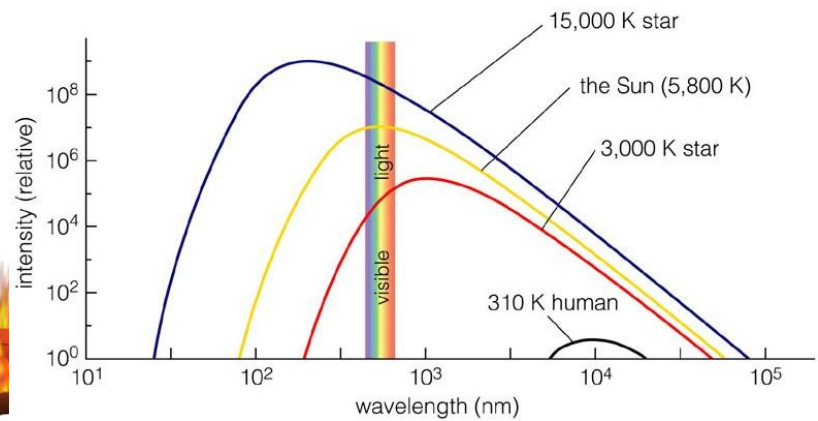
~~Sun older than 25 million years~~

Nuclear fusion? 1 hand on head

~~Nuclear fission?~~ 2 hands on head

~~Too few heavy elements~~

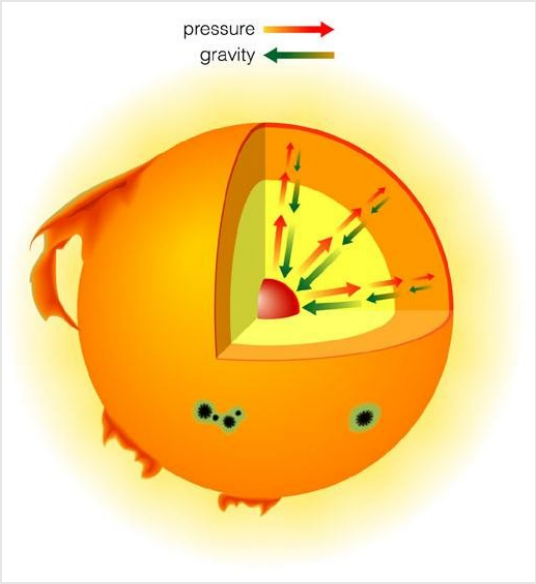
Stellar temperature



Instant Quiz: What did Carl Sagan mean when he said we are all "Star stuff"?

Life would be impossible without the Sun	1 hand up
Earth formed together with the Sun	2 hands up
Many elements essential to life were created in stars	1 hand on head
The Sun and planets formed from stuff between stars	2 hands on head

A life of a star
--- Protracted battle with gravity



To support weight:

⇒ need high pressure

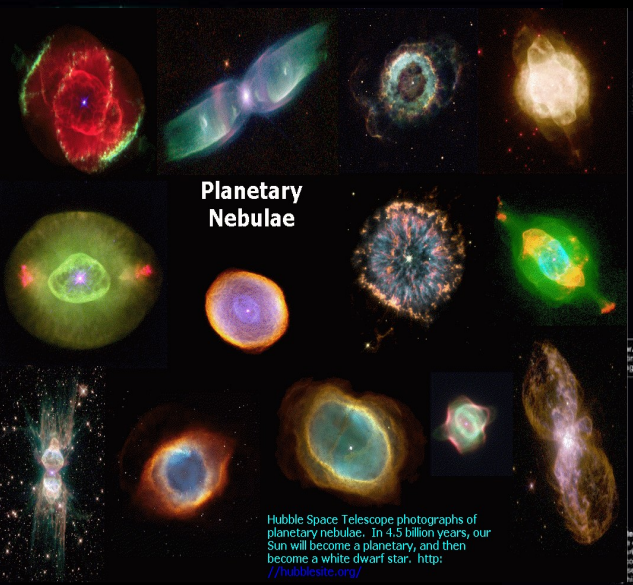
⇒ need high temperature

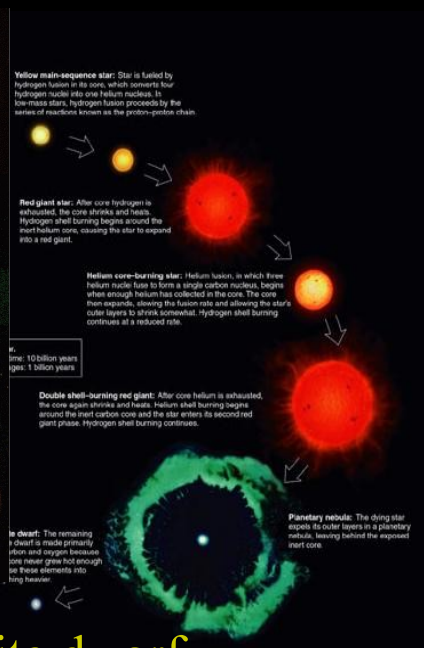
⇒ will loose energy

⇒ need energy source:
- Gravitational contraction
- Nuclear fusion

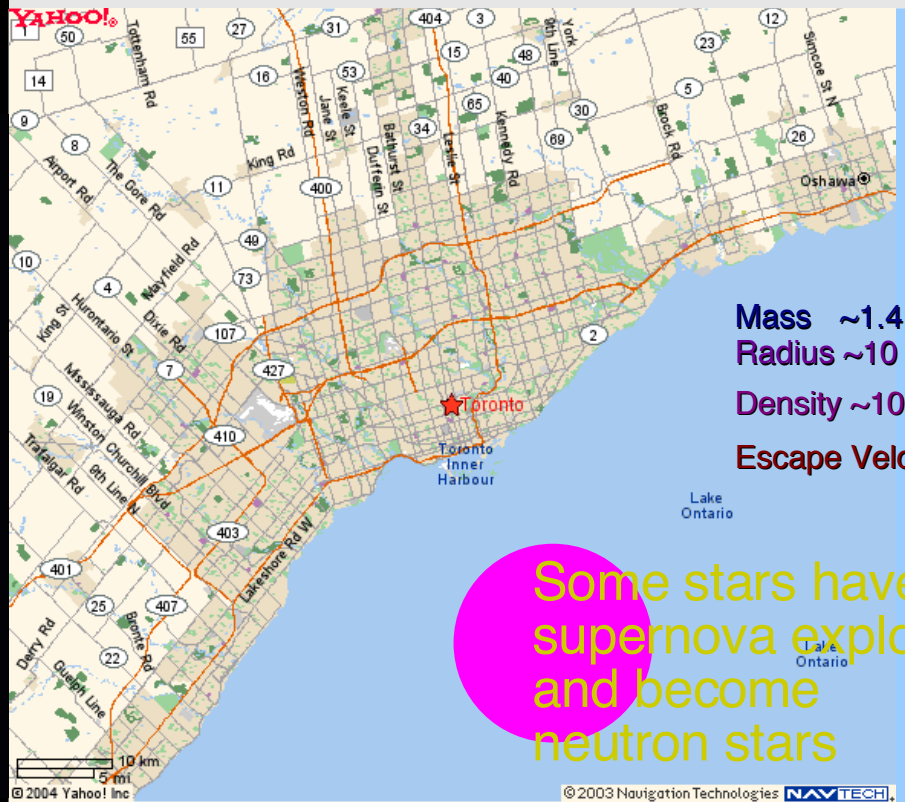
Ultimately,
Running out of nuclear fuel and thermal support...

Life of a star like the Sun





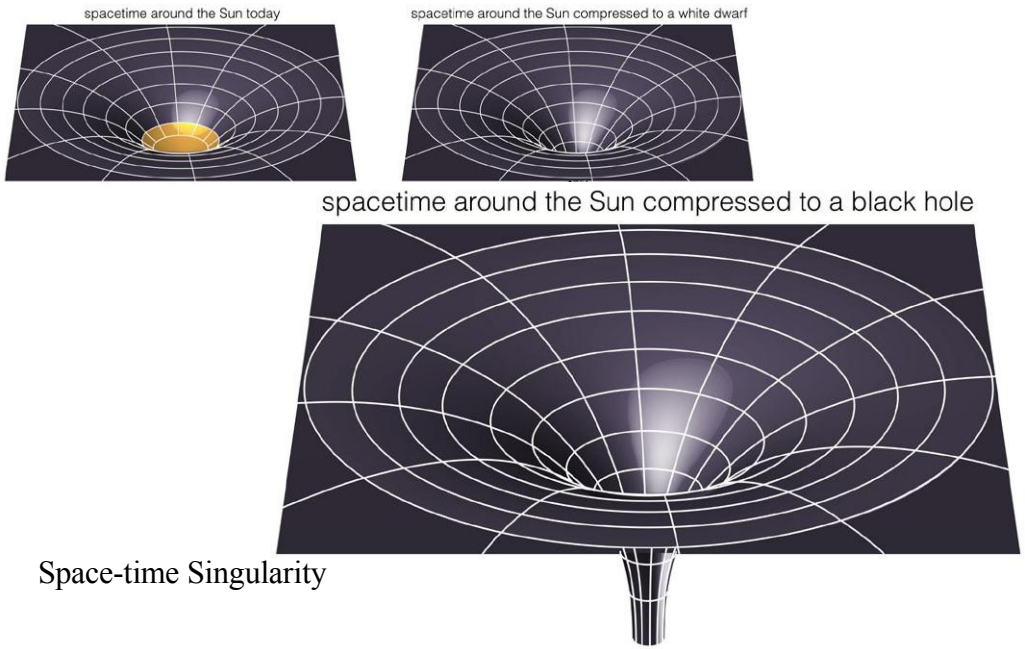
White dwarf



Mass ~1.4 $M_\odot$
Radius ~10 km
Density ~10^{15} g/cm^3
Escape Velocity ~½c

Some stars have supernova explosions and become neutron stars

Some end as Black holes



Results of short presentation & term-test posted

Advice from Prof. van Kerkwijk:

READ YOUR TEXTBOOK!

This term:

by combining presentations and lectures, we will investigate:

1) the universe is currently expanding

2) what is the beginning of the universe and the beginning of time

3) what causes it to expand (and its building blocks...)

4) zoom back to our neighbourhood – the Solar System

we will end with practical issues that affect our daily lives

Long presentations:

1) hand in power-point file the Friday before

2) graded by lecturer (50%) + fellow students (50%)

3) how to make a winning presentation – see website

4) READ YOUR TEXTBOOK!

Term Test

1) April 8th, in-class

2) multiple choice + short essays

3) both lectures and long presentations

4) READ YOUR TEXTBOOK!

How far are they?

Measuring 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

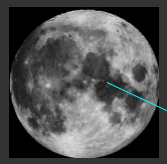
(10,000,000,000,000 km)

light-second, light-hour

Nothing in our universe travels faster than light (Einstein).

Your friends are not what they appear to be....

Distance to the Moon

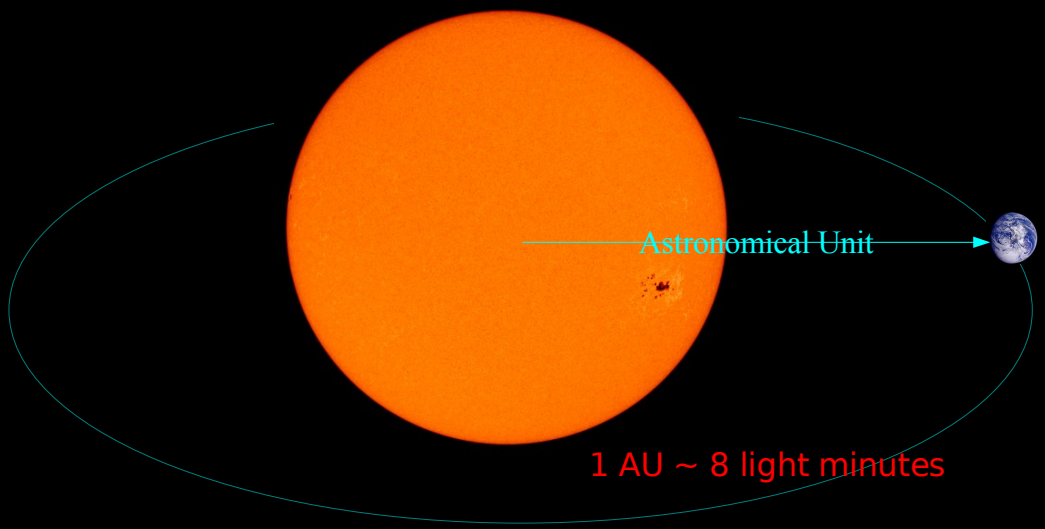


1.3 light-seconds
(~ 384,000 km)

Apollo 11 took ~
1 week to arrive

Apollo missions placed reflectors
on the lunar surface

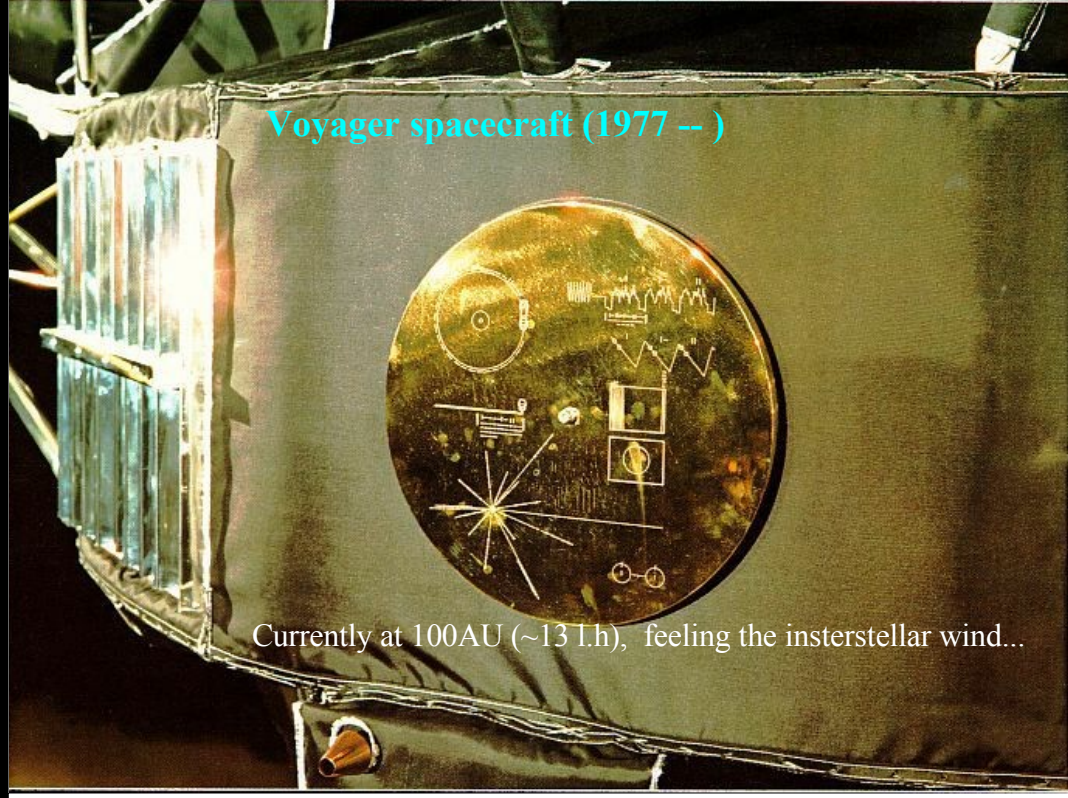
Distance to the Sun



1 AU ~ 8 light minutes

Human speed: 1m/s run
for 80 years --> 17% of a AU

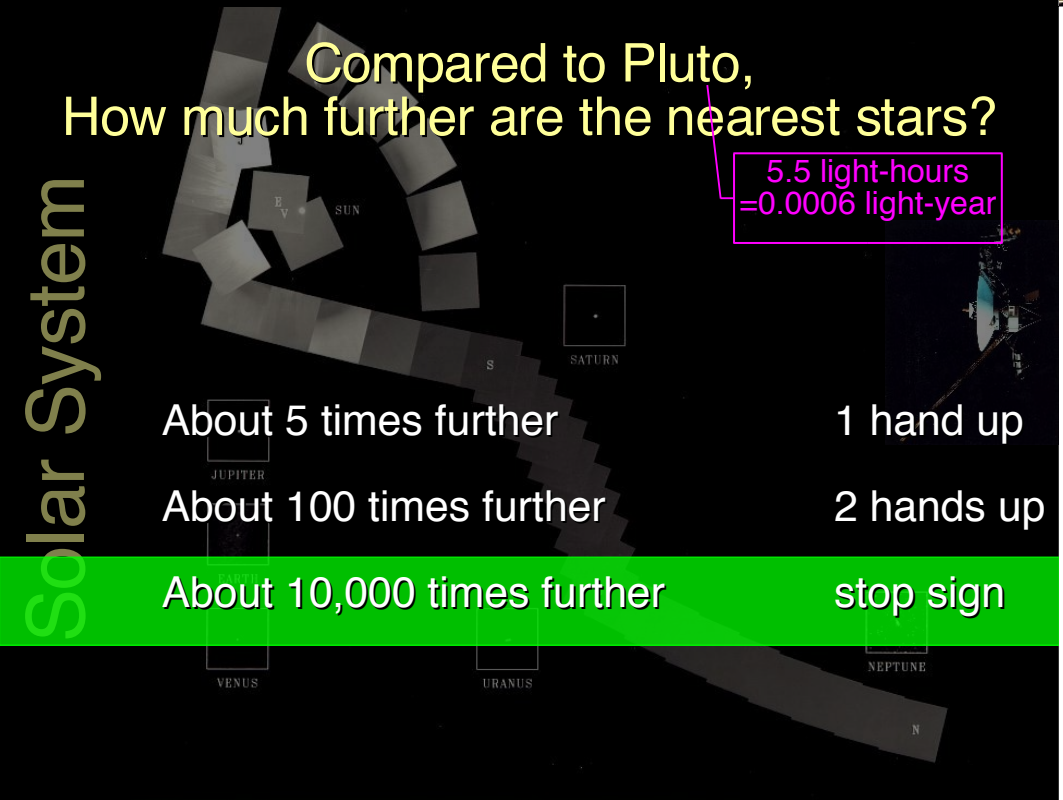
Mercury: 0.39AU
Venus: 0.7AU
Earth: lucky distance
... Pluto: 39AU (~ 5 light hours)



Compared to Pluto, How much further are the nearest stars?

5.5 light-hours
=0.0006 light-year

Solar System

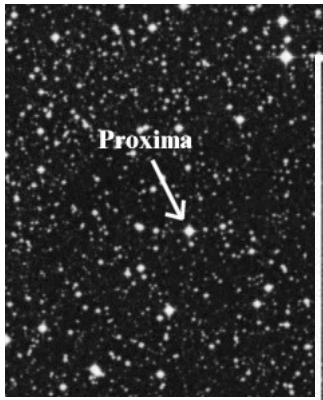


About 5 times further — 1 hand up

About 100 times further — 2 hands up

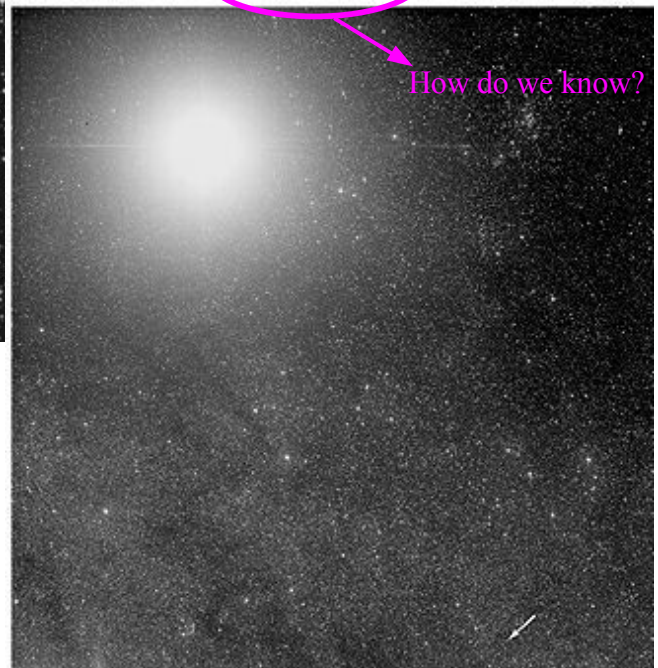
About 10,000 times further — stop sign

Our nearest stellar neighbour



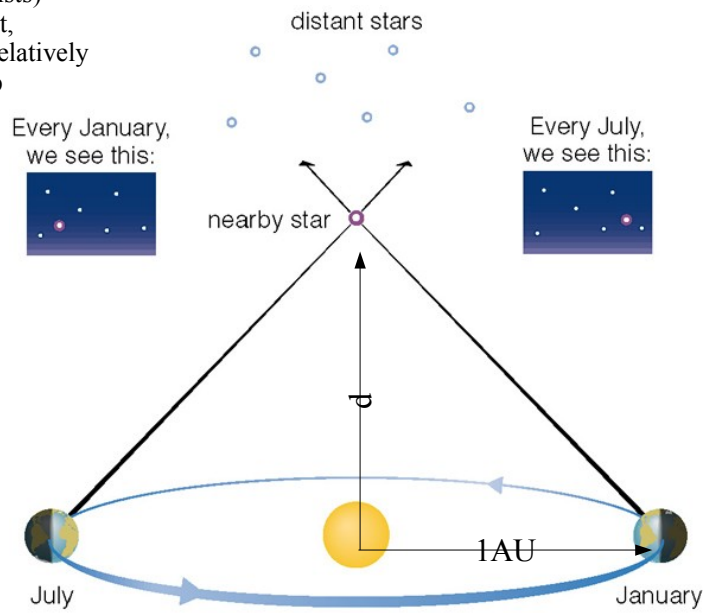
Proxima: 4.3 light years

How do we know?



How do we measure distances to stars? **Parallax**
-- the same way as you do in your everyday life...

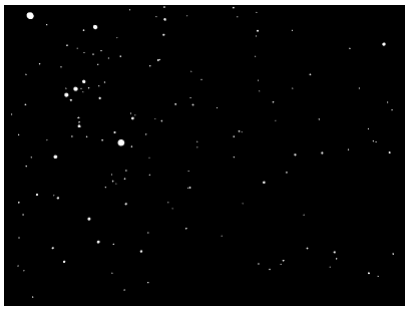
as you are sitting in a moving car, closer objects (light-poles, cyclists) move from left to right very fast, while far away objects appear relatively fixed in position. The spaceship 'Earth' does this moving for us.



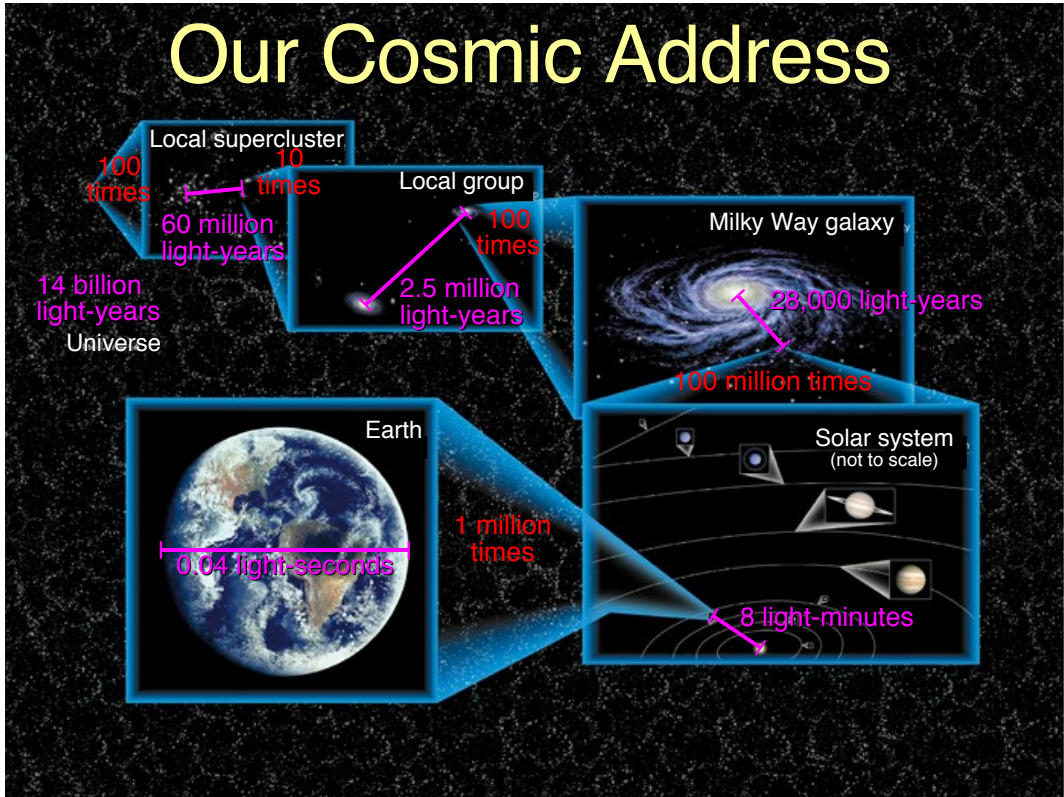
Tycho (naked-eye observation) fails to see any parallax
– he inferred that the Earth does not go around the Sun.

But stars are much, much further than Tycho can imagine.

F. Bessel (1784-1845) first discovered parallax
0.314 arcsecond (size of a bacteria at arm's length)
for star 61 Cygni, translates to ~ 10 l.y.



Parallax method fails for objects very far
(current limit: ~ 1000 l.y.)
Have to resort to other means for larger distances...



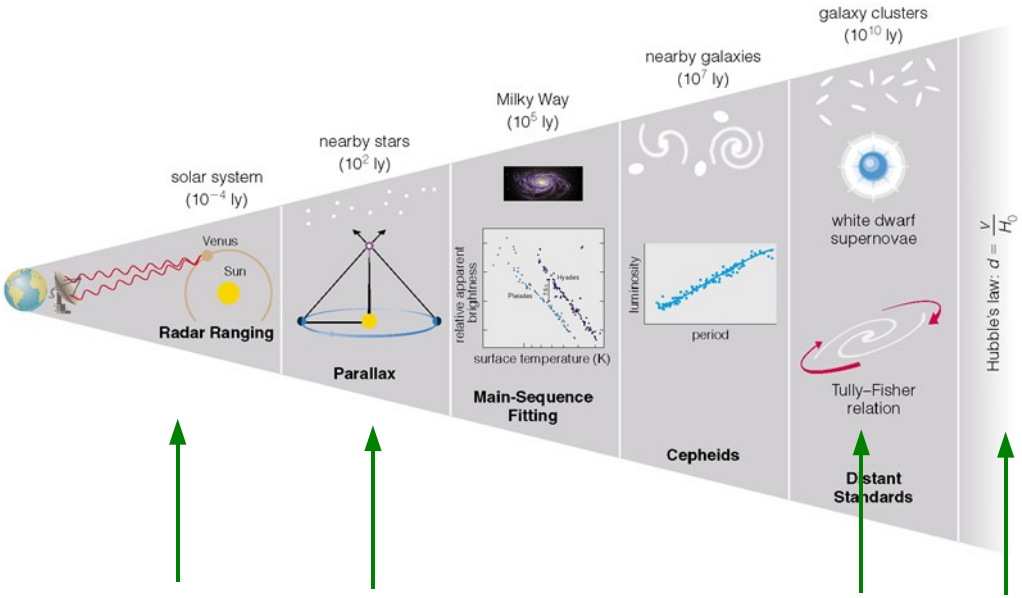
Measuring local distances:

- radar ranging
- parallax

Measuring cosmic distances:

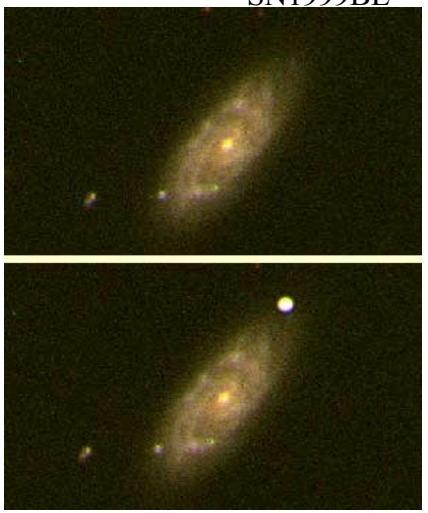
- standard candles (Cepheids, supernova...)
- Hubble's expansion law

The ladder for distance measurements



Supernova: a star explodes at the end of its life

SN1999BE



when this occurs, an individual star can outshine an entire galaxy (100 billion stars)

... no warning...

Supernova 1054AD:

the last time we had a nearby (6300 l.y.) supernova

M1 by Ricky Murphy

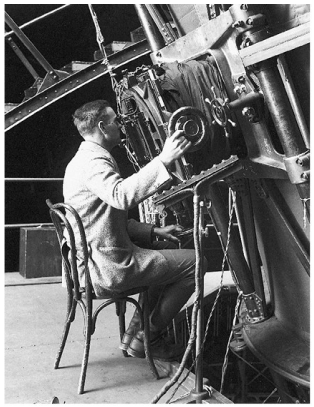
Supernova 1054AD: the "Guest Star"

From the Sung-hui-yao [Essentials of the Sung dynasty history] (Chapter 52)

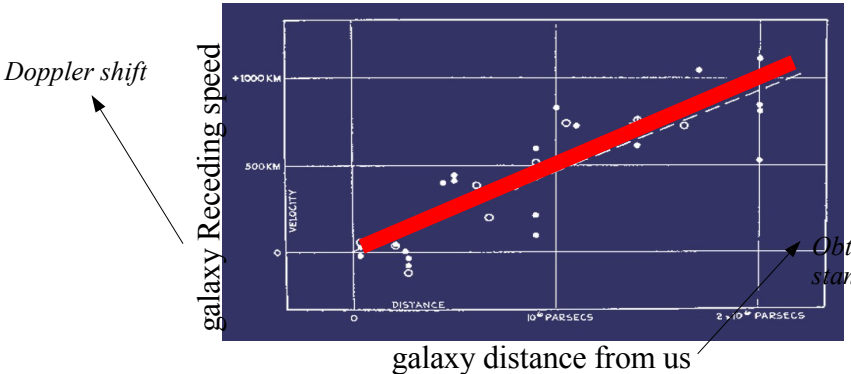
"On the 1st year of the Chih-ho reign period, 7th month, 22nd day [August 27, 1054] ... Yang Wei-te said '**I humbly observe that a guest star has appeared**. Above the star in question there is a faint glow, yellow in colour. If one carefully examines the prognostications concerning the emperor, the interpretation is as follows: The fact that the guest star does not trespass against Pi and its brightness is full means that there is a person of great worth. I beg that this be handed over to the Bureau of Historiography'. All the Officials presented their congratulations and the Emperor ordered that it be sent to the Bureau of Historiography.

"It was visible in daytime, like Venus...
Altogether it was visible in daytime for 23 days.

And Arizona Indians?



Edwin Hubble discovered
Expansion of the Universe (1920s)

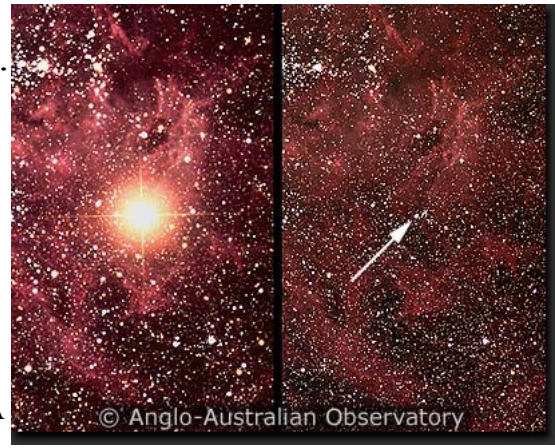


Standard Candles:

If all supernovae are intrinsically equally bright, the further-away ones will appear dimmer.

From this, we obtain distances to far-away galaxies

--- if we stare, stare, stare..



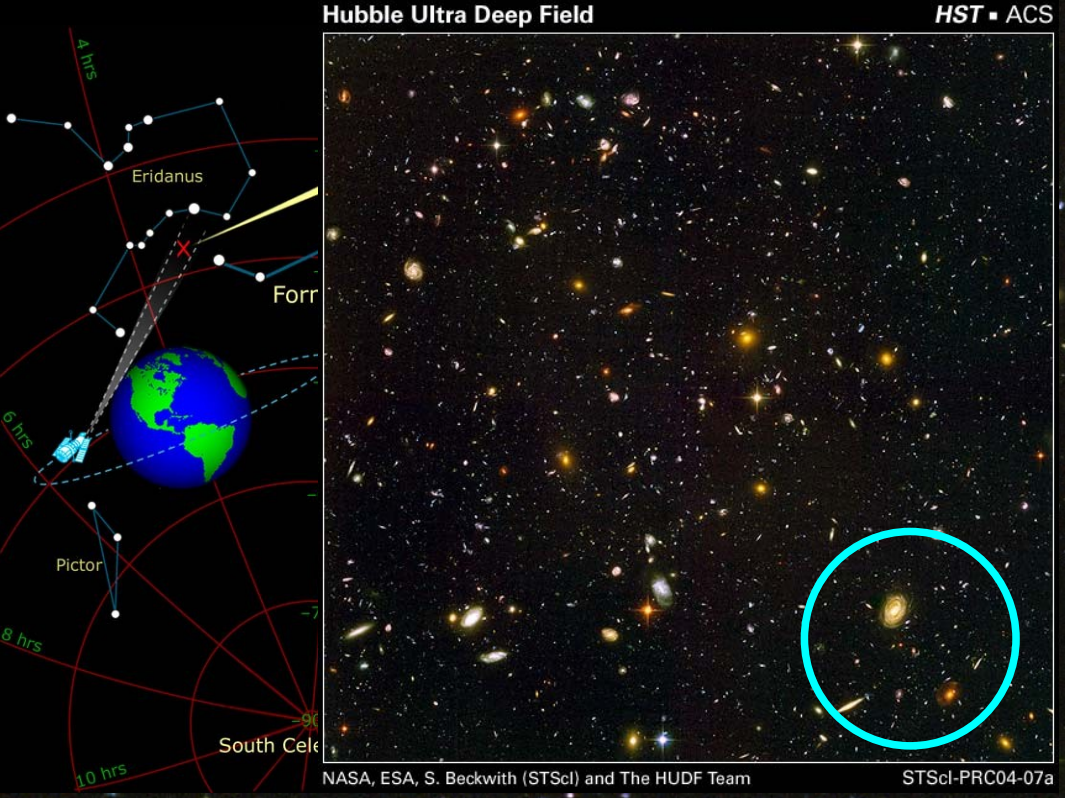
SN1987A

The Hubble constant:
H ~ 20 kms/M.y.

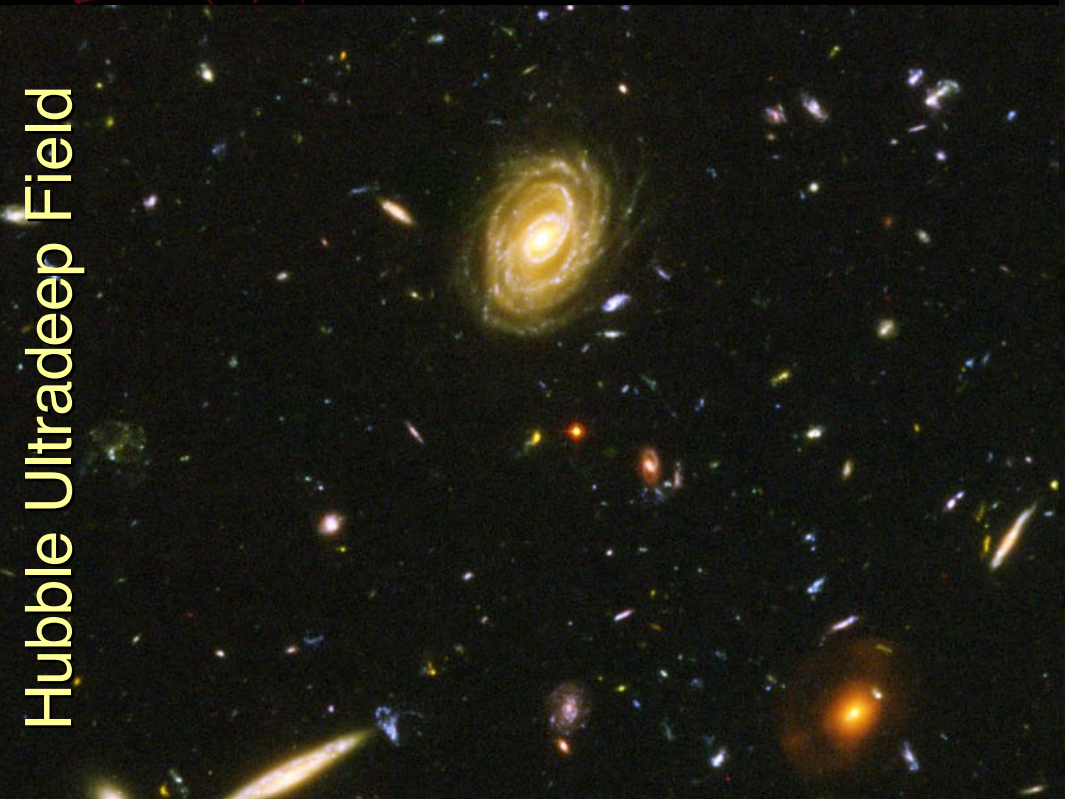
a galaxy at 1My is receding at 20kms
.....2My 40kms
.....10My 200kms

.....10Gly .....200,000 kms

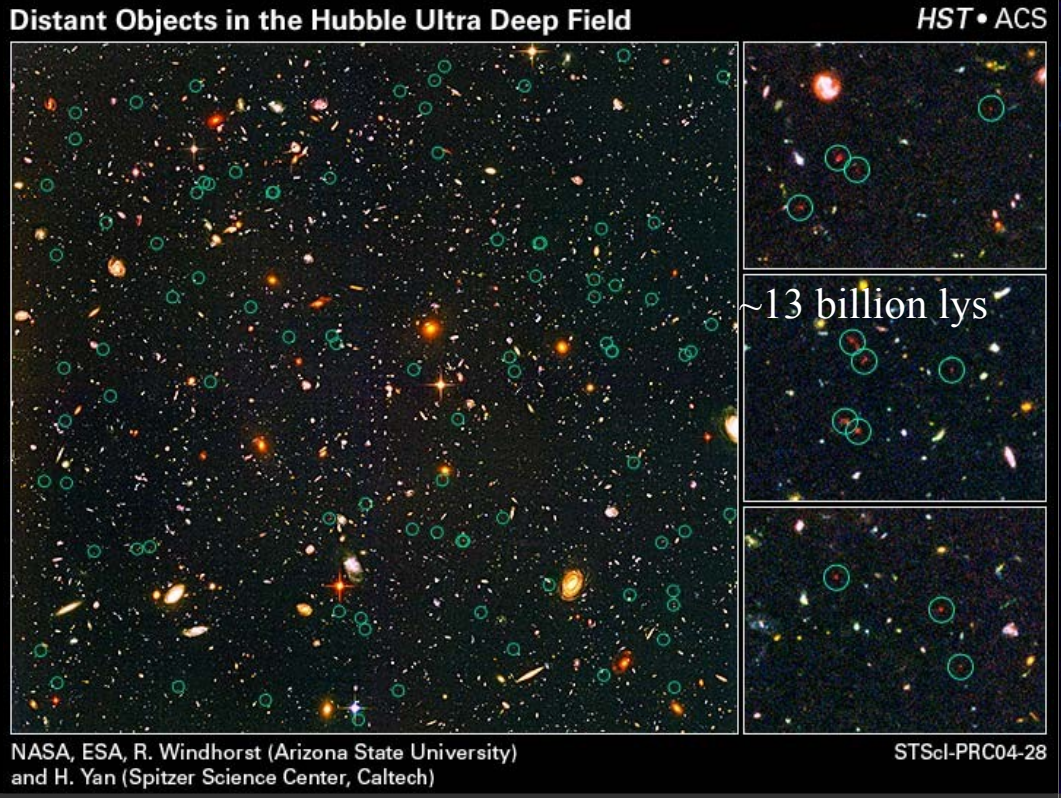
speed of light = 300,000 kms

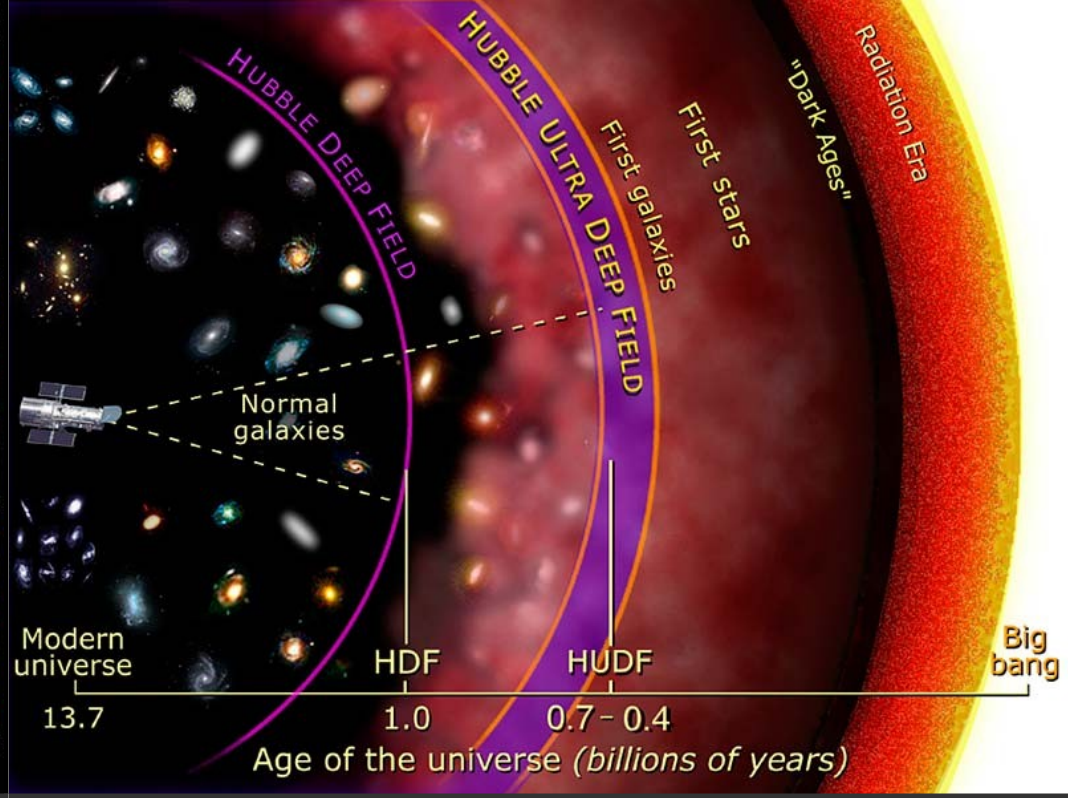

Hubble Ultra Deep Field
HST ▪ ACS
4 hrs
Eridanus
Forr
6 hrs
Pictor
8 hrs
South Cele
10 hrs
NASA, ESA, S. Beckwith (STScI) and The HUDF Team
STScI-PRC04-07a


Hubble Ultradeep Field


Hubble Ultradeep Field


Hubble Ultradeep Field





The Hubble constant:
H ~ 20 km/s/My

a galaxy at 1 My, receding at a rate of 20km/s, is right up to us at a distant past (t)

t ~ distance/speed
~ 1 My/(20km/s)
~ 13.7 Gyrs

expansion rate of the universe,
==> age of the universe

The universe was smaller yesterday than it is today.

At some point in the past, the universe is just a point.

Importance of Hubble's Law

Measuring distance using Hubble's law:

by measuring how fast a galaxy is receding away from us (redshift), we can obtain its distance from us.

Tells the age of the universe (~ 14 billion yrs):

Dividing distance by speed, we find that all galaxies were at the same point 14 billion years ago. Something set off the cosmic expansion.

Tells the size of our cosmic horizon (~ 14 b.l.y):

Furthest galaxies one can see are receding away from us with speed of light. Light we see now left these galaxies 14 billion years ago (baby galaxies)

(looking further out to space == looking further back in time)

How old is the Universe?

1929: Hubble discovers that the further away a galaxy is, the faster it receded from us. This implies the Universe is expanding.

1997/8: teams led by Perlmutter and Schmidt find that the expansion is accelerating.

2000: a team led by De Bernardis & Lange finds the Universe is not curved using Balloon measurements of the microwave background.

2001: a team led by Friedman makes the most precise measurement yet of the local expansion rate of the Universe.

2003: a team led by Bennett uses the satellite WMAP to measure the microwave background, and finds the Universe is 13.7±0.2 billion years old.




Why are galaxies appearing to be moving away from us?

possibility #1:

Milky way is at the center of the universe, except for us, everyone else is going somewhere.

possibility #2:

The space itself is expanding. So it appears they are leaving us. It looks the same to an Andromedean.

Instant Quiz
More distant galaxies...

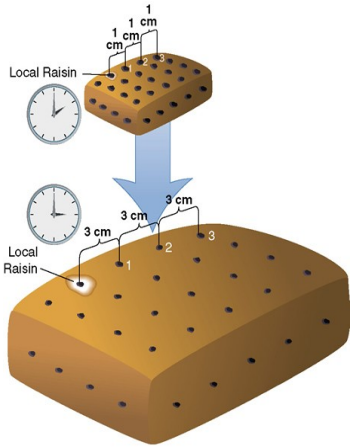
Look younger because they were made later — 1 hand up

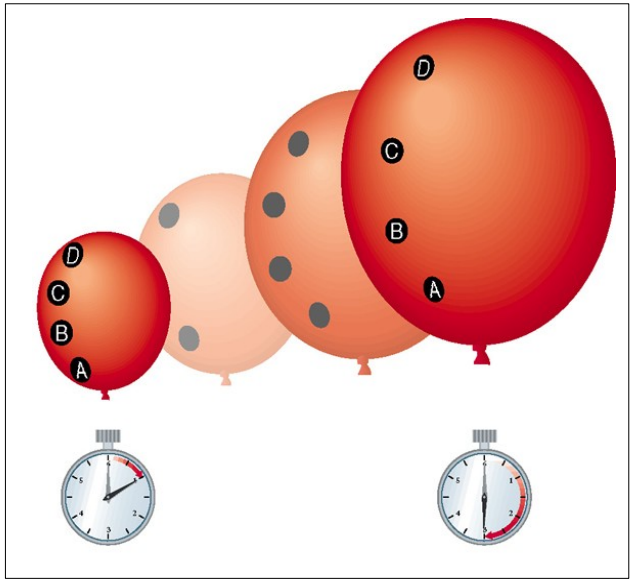
Look redder because the stars in them are older — 2 hands up

Can have formed at the same time as our galaxy — Pray sign

Look younger because we cannot see them very well — Stop sign

Expansion speed increases with distance from us (or anybody) ----- the space itself is expanding.





Are the human bodies expanding with time?

1) No. Because my length measurement stays the same.

2) Yes, but very imperceptibly.

3) Yes. This explains why as our human ancestors are shorter.

4) No. We are holding ourselves together despite the cosmic expansion.

Size of the Universe

1) The universe is infinite in every sense.

1 hand up

2) We only know about our observable universe.
It is 14 Billion light years in radius.

2 hands up

3) The universe has an edge and it is vacuum outside.

pray sign

4) There are multiple universes and they neighbour each other.

stop sign

Instant Quiz: Galaxies at the edge of our observable Universe...

Can see other galaxies that we cannot see	1 hand up
Cannot see us	2 hands up
Can see the same Universe that we see	1 hand on head
Look very old	2 hands on head