BHARATHIDASAN UNIVERSITY

Tiruchirappalli- 620024, Tamil Nadu, India

Programme: M.Tech., GEOLOGICAL TECHNOLOGY AND GEOINFORMATICS

Course: Remote Sensing Application in Planetary Studies

Code : MTIGT1004

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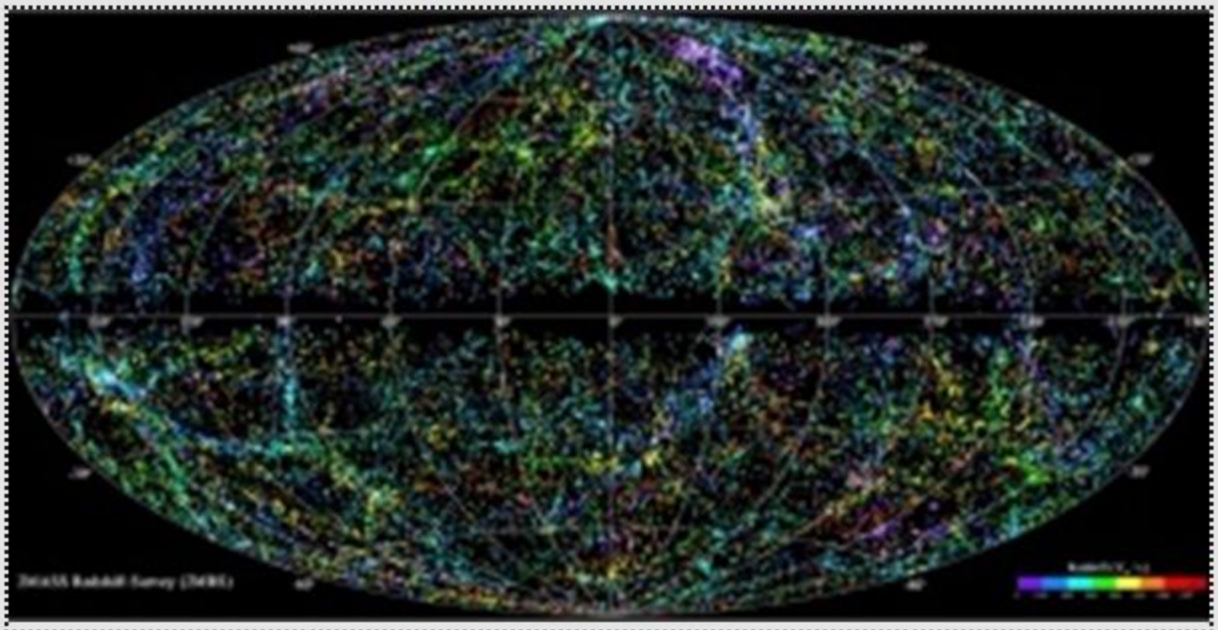
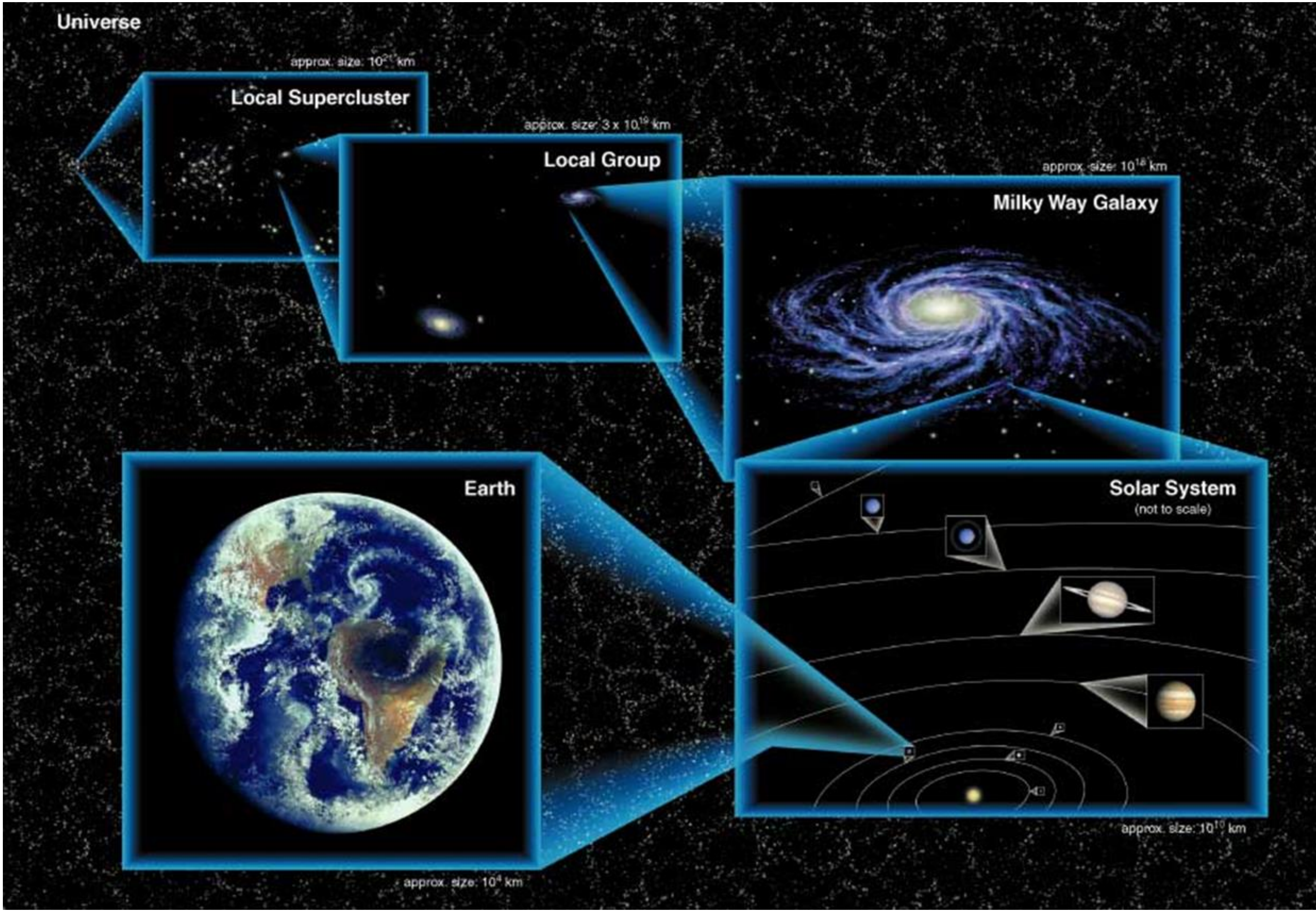
Unit-1. Universe - Origin of Universe - Big Bang theory, Evidences for Big bang, Universal expansion and Hubble’s Law, Doppler effect - General characters of Galaxy, Milky Way Galaxy - Origin of Solar System: Nebular theory – Evidences for Nebular theory - Nebular composition - Meteorites vs. Photosphere - formation and internal differentiation of the planets - General Characteristics of the Solar System

- Everything that exists in any place, all of space, matter, and energy in existence is called the universe!



Panoramic view of the entire near-infrared sky above the Earth reveals the distribution of galaxies beyond the Milky Way. Blue objects are nearest sources, green are at a moderate distance and red are the furthest. Image courtesy of Harvard-Smithsonian Center for Astrophysics.

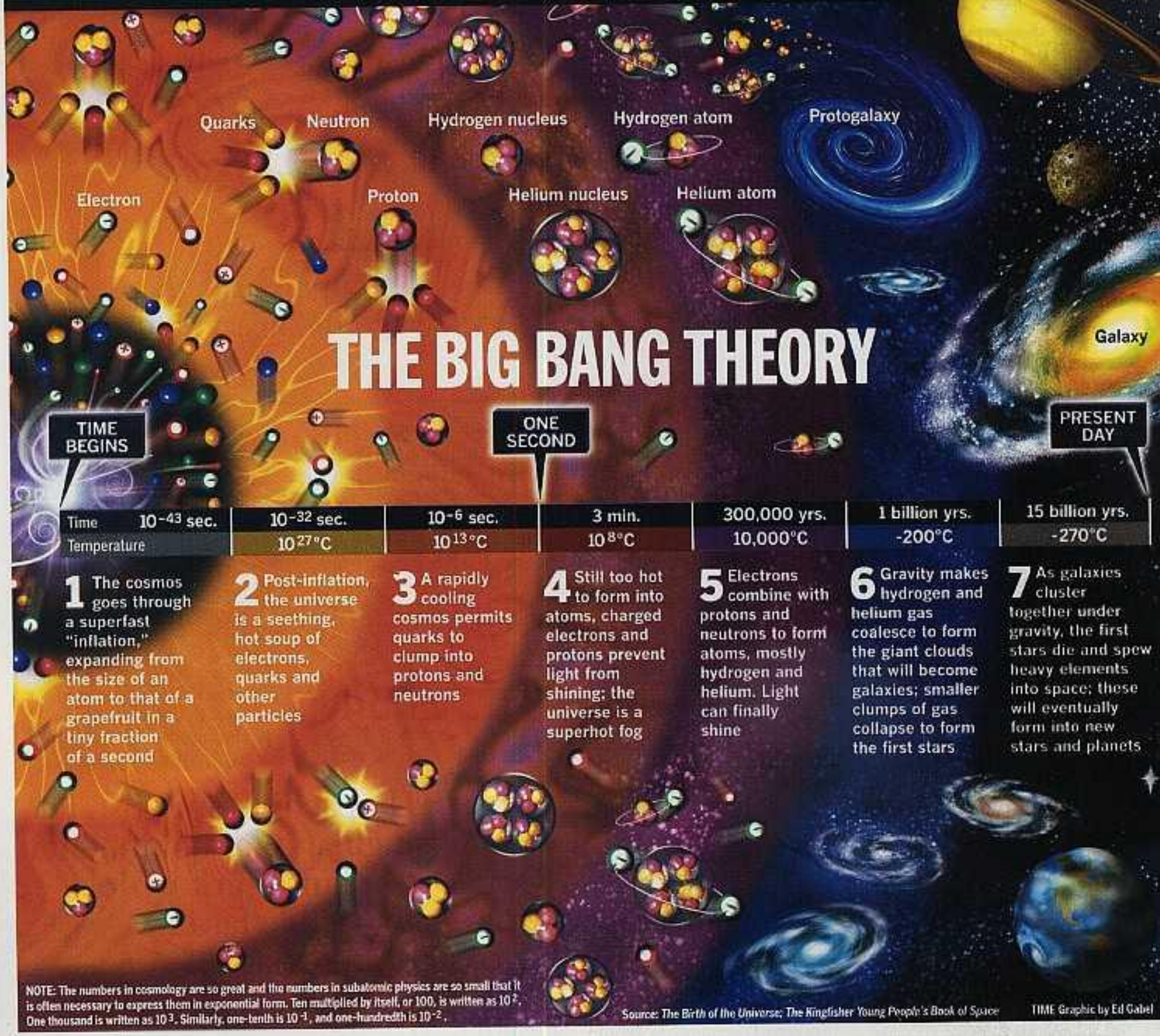

Universe
approx. size: 10²¹ km
Local Supercluster
approx. size: 3 x 10¹⁹ km
Local Group
approx. size: 10¹⁸ km
Milky Way Galaxy
Earth
Solar System
(not to scale)
approx. size: 10¹⁰ km
approx. size: 10⁴ km

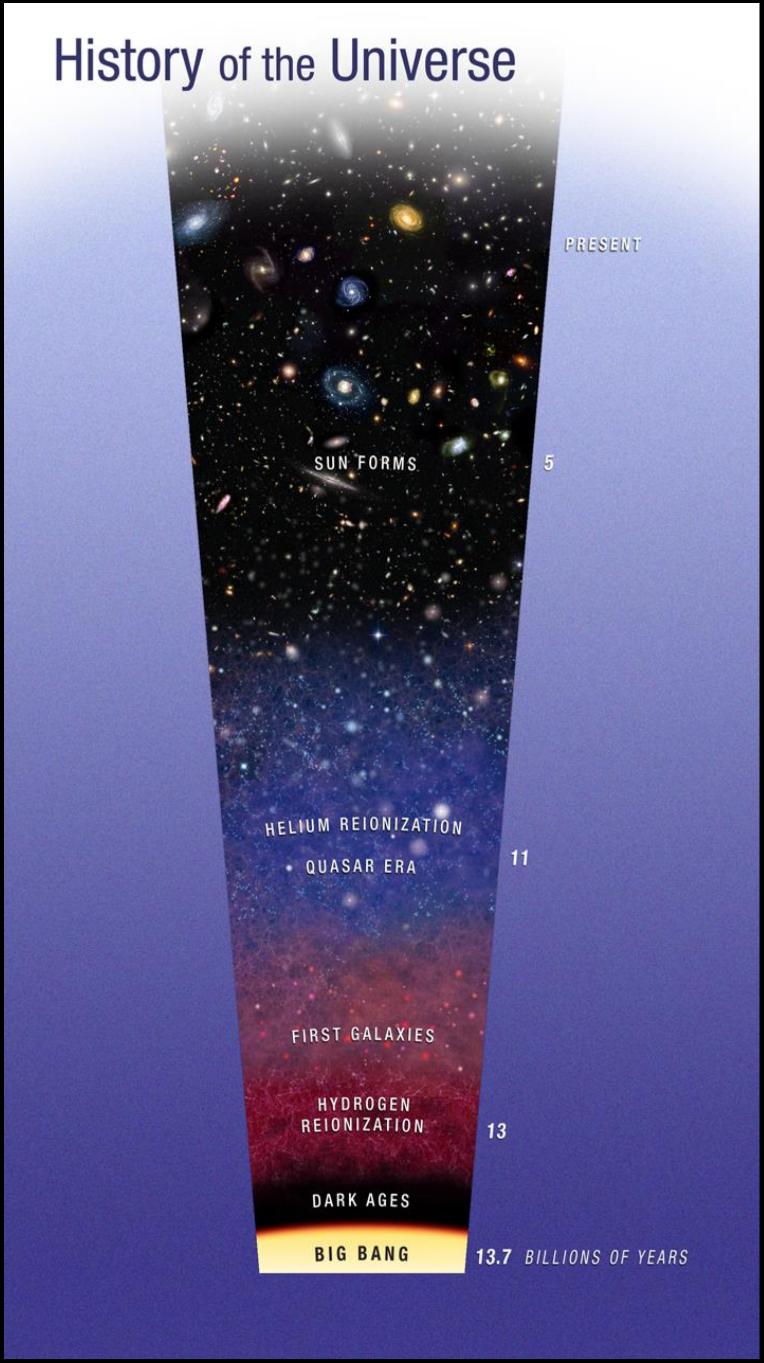
THE UNIVERSE

- **Our Earth is a cosmic body, it is an insignificant speck of dust in the universe**
- **The Universe is a vast infinite expanse of space and matter. Mostly it is space, vacuum, or state of nothingness**
- **The concentration of matter in space have been differentiated by the scientist into**
  - **Nebulae**
  - **Stars**
  - **Planets**
  - **Asteroids**
  - **Comets**
  - **Cosmic dust**
  - **Galaxies**

- **Nebulae are enormous masses of gaseous clouds without any structural differentiation**
- **Galaxies are assemblies or association of billions of stars in each case**
- **All stars in galaxy are held together by gravitation**
- **A group of stars is known as <u>constellation</u>**
- **A single galaxy with its hundreds of millions of constituents stars makes a stellar system**
- **The star may be defined as a huge, massive body of luminescent matter radiating enormous amounts of energy per second**
- **Each star is known to hold around itself under the influence of gravitation**
- **A variable number of relatively small sized non radiant bodies of matter called planets.**
- **Our sun is also a typical star. It has nine planets held around it under gravitation**

- **The universe is, at present, expanding.**
- **The Galaxies are moving away at a greater speed from one another**
- **Galaxies themselves rotate as its star components revolve around its centre**
- **For example: solar system travels at a speed of 240 kps around the centre of the galaxy and takes 200 Ma to complete one revolution**
- **Individual star rotate themselves**
- **Planets are revolving around a star and they themselves are also in rotation.**
- **Satellites are revolving around planets rotating themselves.**
- **Thus every thing in the space in the space is in certain motion**
- **The angular momentum is found to be an inherent property of these objects**
- **The angular momentum of an objects is its rotational velocity with reference to its mass**
- **Gravitational force is the binding force for all objects of the universe**

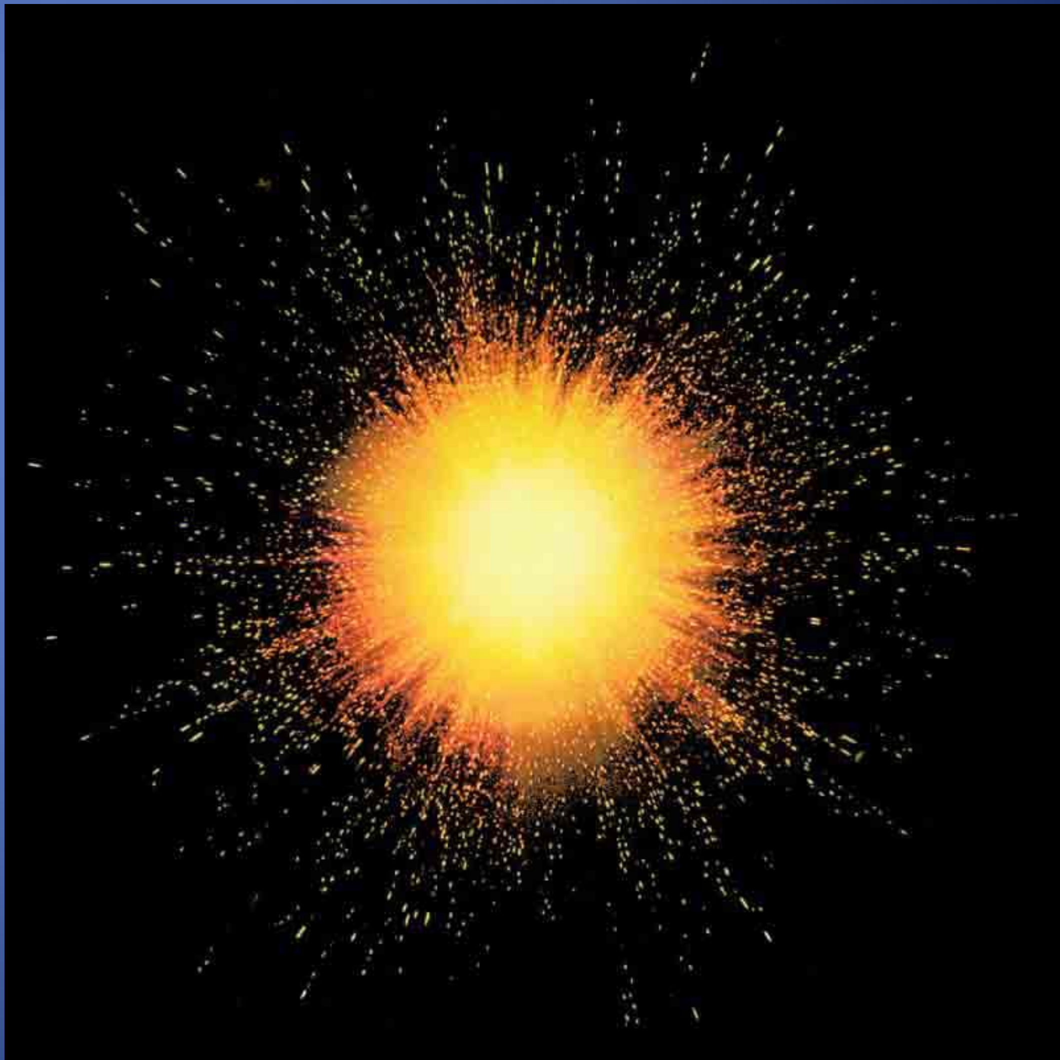

Quarks
Neutron
Hydrogen nucleus
Hydrogen atom
Protogalaxy
Electron
Proton
Helium nucleus
Helium atom
Galaxy
THE BIG BANG THEORY
TIME BEGINS
ONE SECOND
PRESENT DAY
Time | 10^{-43} sec. | 10^{-32} sec. | 10^{-6} sec. | 3 min. | 300,000 yrs. | 1 billion yrs. | 15 billion yrs.
Temperature | 10^{27}°C | 10^{13}°C | 10^{8}°C | 10,000°C | -200°C | -270°C
1 The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second
2 Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles
3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons
4 Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog
5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine
6 Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars
7 As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets
NOTE: The numbers in cosmology are so great and the numbers in subatomic physics are so small that it is often necessary to express them in exponential form. Ten multiplied by itself, or 100, is written as 10^2. One thousand is written as 10^3. Similarly, one-tenth is 10^{-1}, and one-hundredth is 10^{-2}.
Source: The Birth of the Universe; The Kingfisher Young People's Book of Space
TIME Graphic by Ed Gabel



- The universe began with a hot explosion called the Big Bang. The aftermath of the Big Bang consisted mostly of radiation, but as things cooled, the elements hydrogen and helium formed.

Time begins

- The universe begins ~13.7 Billion years ago
- The universe begins as the size of a single atom
- The universe began as a violent expansion
  - All matter and space were created from a single point of pure energy in an instant

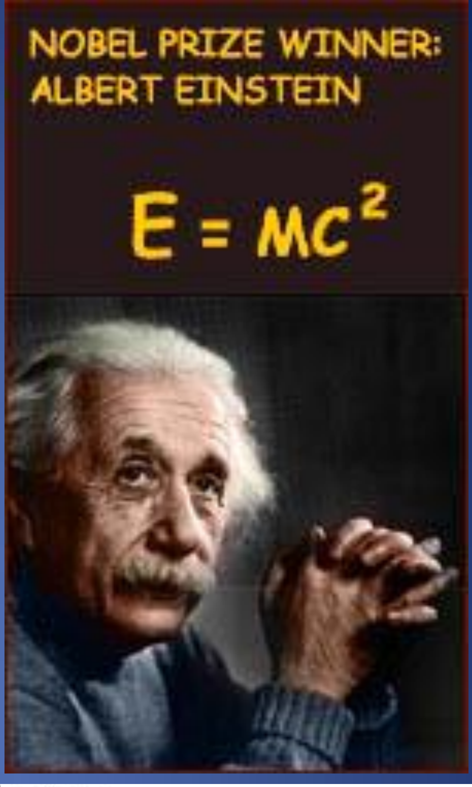


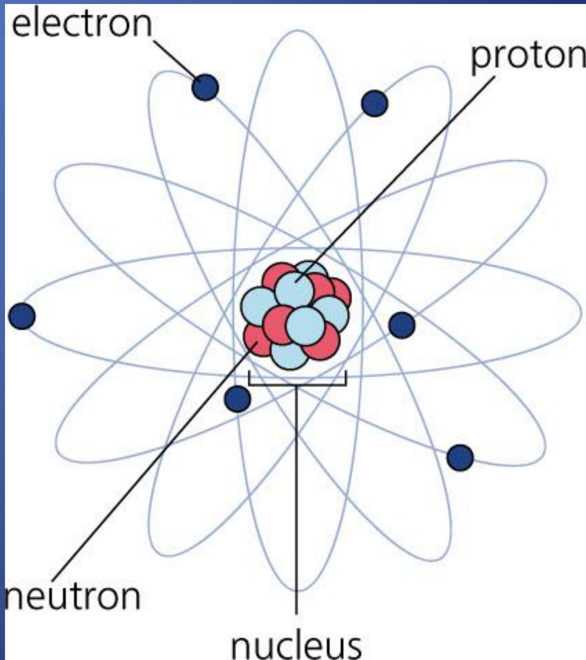
Big Bang.....

- there was no explosion; there was (and continues to be) an expansion
  - Rather than imagining a balloon popping and releasing its contents, imagine a balloon expanding: an infinitesimally small balloon expanding to the size of our current universe
- we tend to image the singularity as a little fireball appearing somewhere in space
  - space began inside of the singularity. Prior to the singularity, *nothing* existed, not space, time, matter, or energy - nothing.

~ 3 minutes after big bang

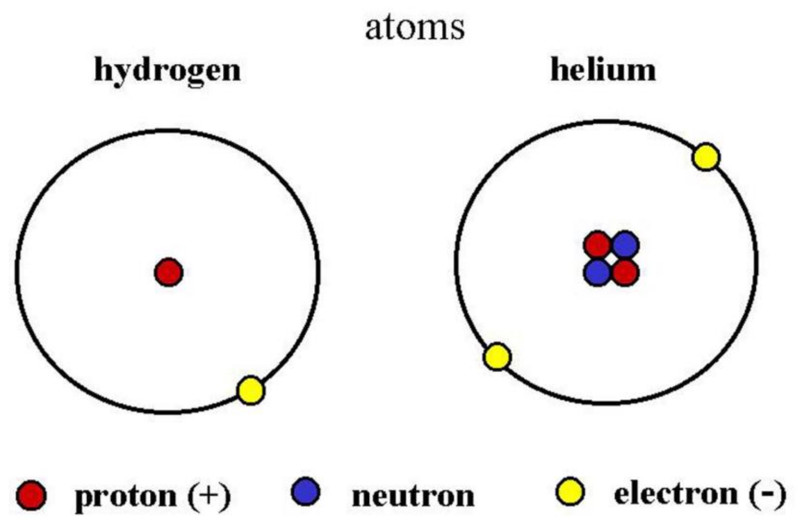
- The universe has grown from the size of an atom to larger than the size a grapefruit
- $E=mc^2$
- energy froze into matter according to Albert Einstein's equation.
- This basically says that like snowflakes freezing, energy forms matter into clumps that today we call protons, neutrons and electrons.
- These parts later form into atoms





~ Several hundred thousand years

after Big Bang



Neutrons and protons are held together in the nucleus by the "strong" force, which has to overcome the electrical repulsion of the two positively charged protons in helium (and in more complex atoms too). Electrons are held around the atom by the electrical attraction between their negative charge and the positive charge of the protons in the nucleus.

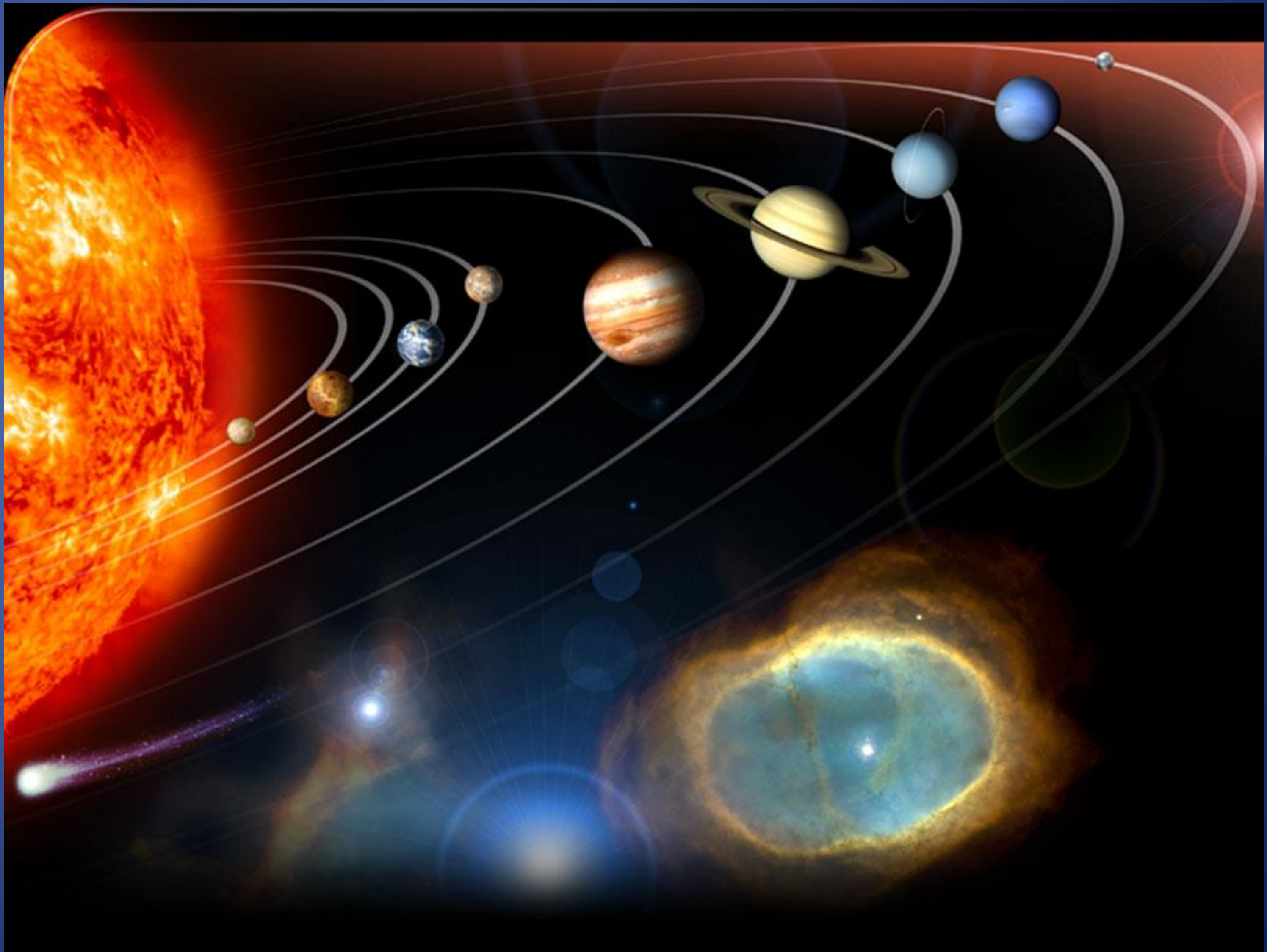
- ATOMS form (specifically Hydrogen and its isotopes with a small amount of Helium.)
- The early Universe was about 75% Hydrogen and 25% Helium. It is still almost the same today.

~200 to 400 million years after Big Bang

- 1st stars and galaxies form

~ 4.6 billion years ago

- Our Solar system forms



Big Bang Timeline –

- Big Bang – energy
- Matter
  - E=mc2
    - protons
    - Neutrons
    - electrons
- Atoms
  - Hydrogen
  - helium
- Stars and galaxies
- Our solar system
  - Sun and all planets
- Earth (present day)

Big Bang evidence

- Universal expansion and Hubble's Law
- background radiation
- Radioactive decay
- Stellar formation and evolution
- Speed of light and stellar distances

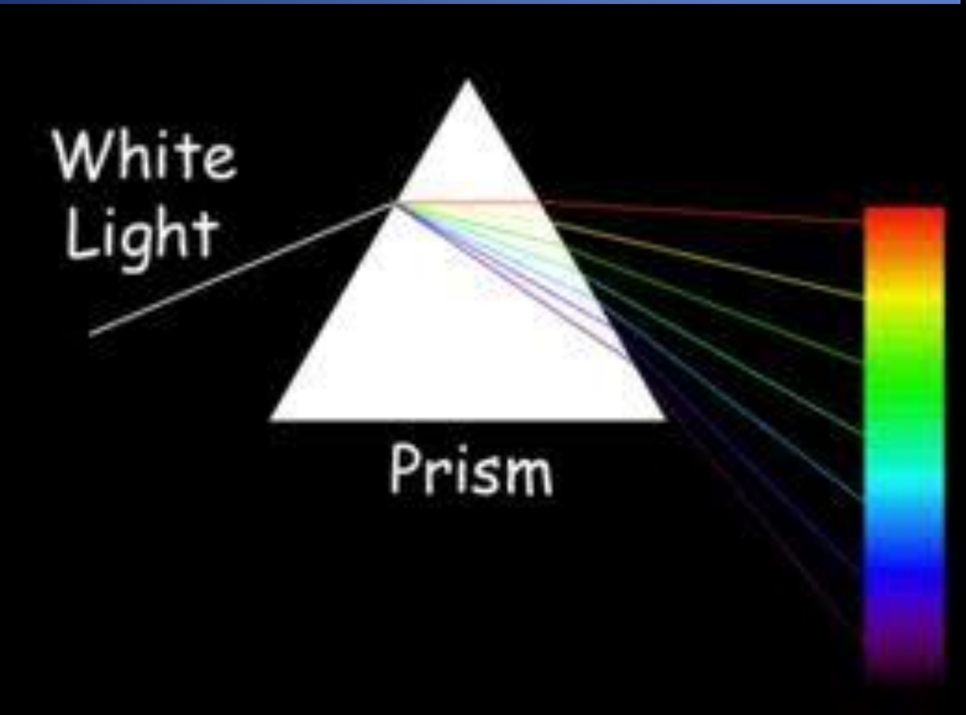
- Big Bang Theory - Evidence for the Theory
- First of all, we are reasonably certain that the universe had a beginning.
- Second, galaxies appear to be moving away from us at speeds proportional to their distance. This is called "Hubble's Law.” This observation supports the expansion of the universe and suggests that the universe was once compacted.
- Third, if the universe was initially very, very hot as the Big Bang suggests, we should be able to find some remnant of this heat. In 1965, this was discovered a 2.725 degree Kelvin (-454.765 degree Fahrenheit, -270.425 degree Celsius) Cosmic Microwave Background radiation (CMB) which pervades the observable universe.
- Finally, the abundance of the "light elements" Hydrogen and Helium found in the observable universe are thought to support the Big Bang model of origins.

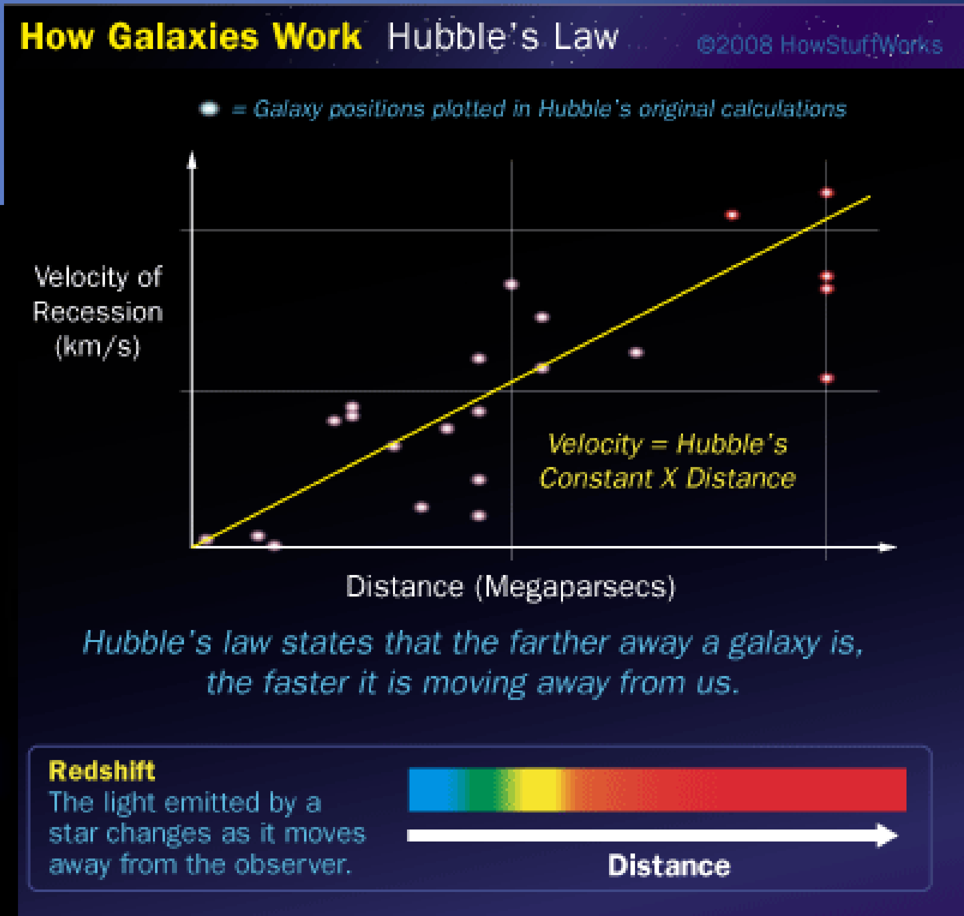
Universal expansion and Hubble's Law

a) Hubble observed the majority of galaxies are moving away from us and each other

b) The farther, the faster they move

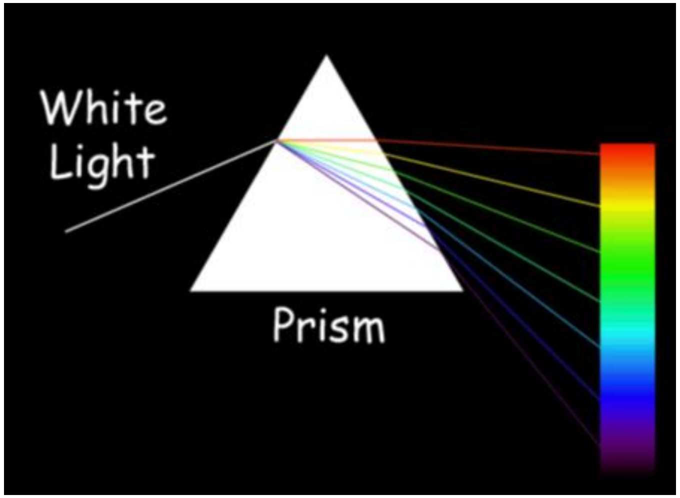
c) Red Shift

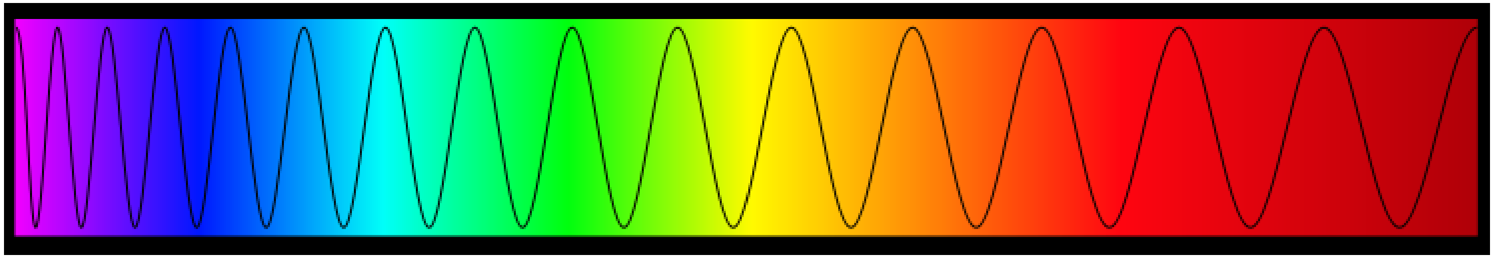




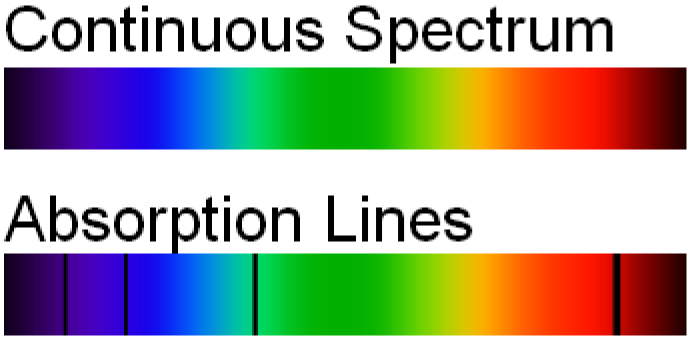
Doppler Effect /Red Shift-

- Each element (Hydrogen, H and Helium, He) gives off electromagnetic radiation.
- This radiation can be observed by the spectrum of a star (ROYGBIV)

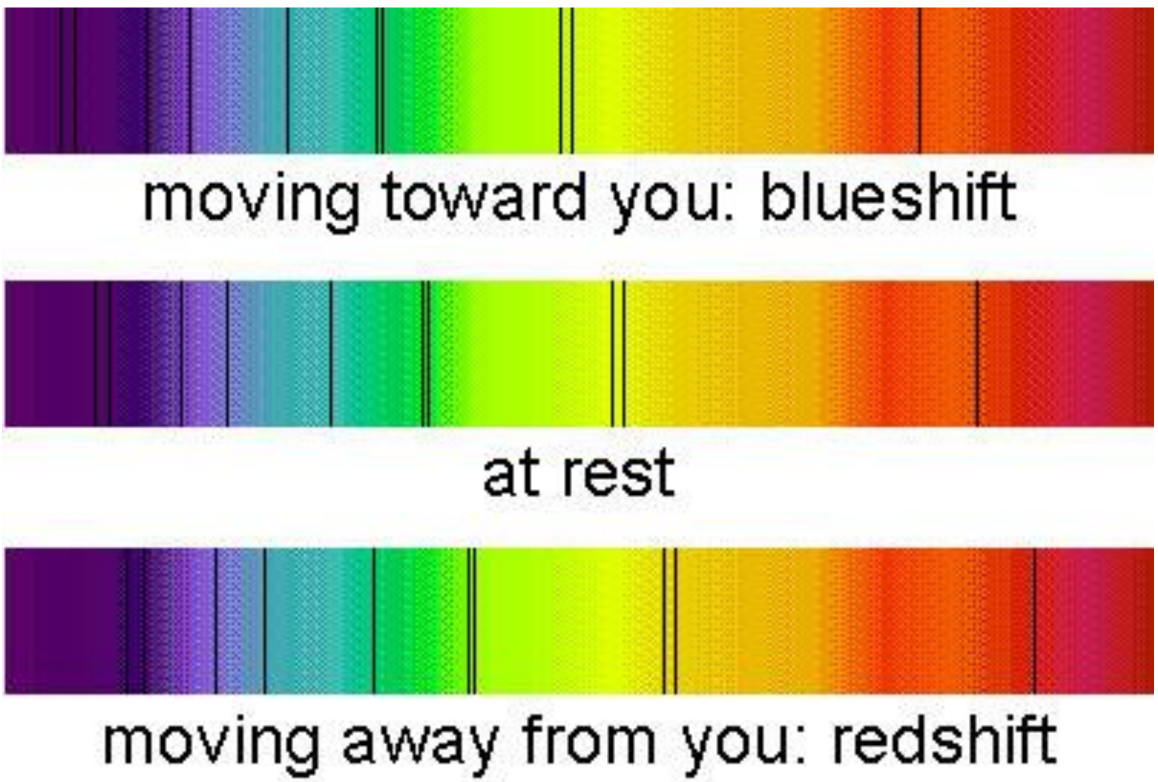




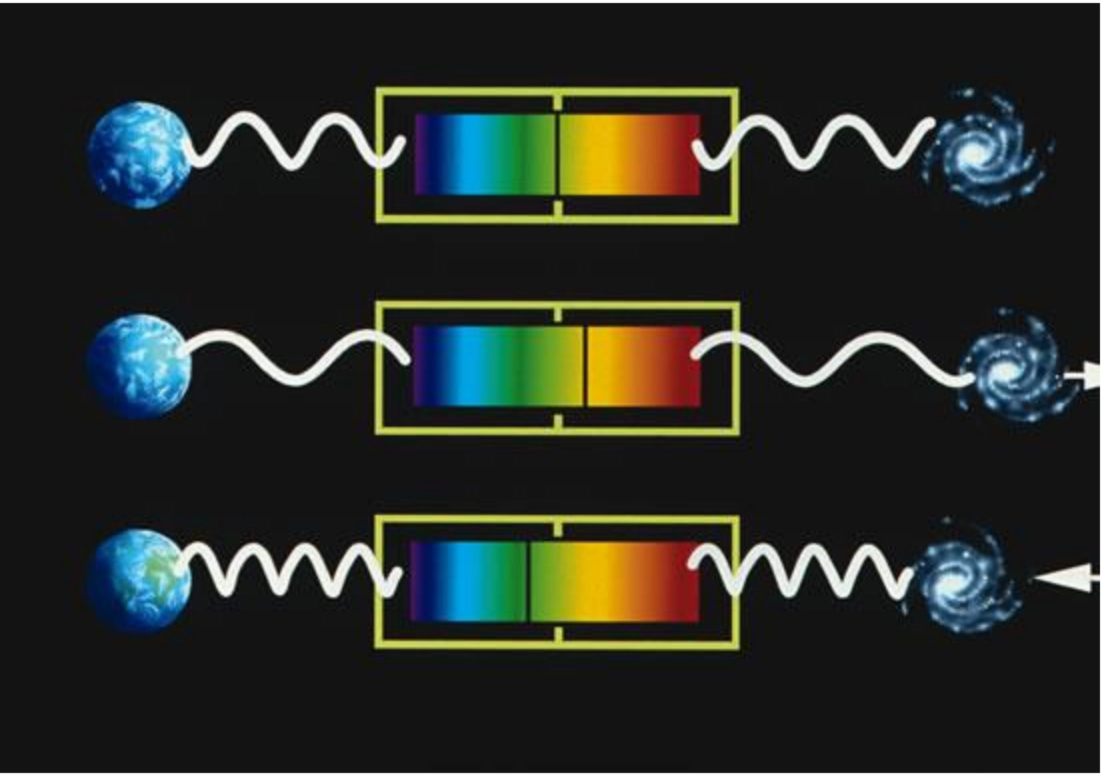
- Since each element has a specific spectrum (fingerprint), scientists can tell what types of elements are in stars based on their spectrum.

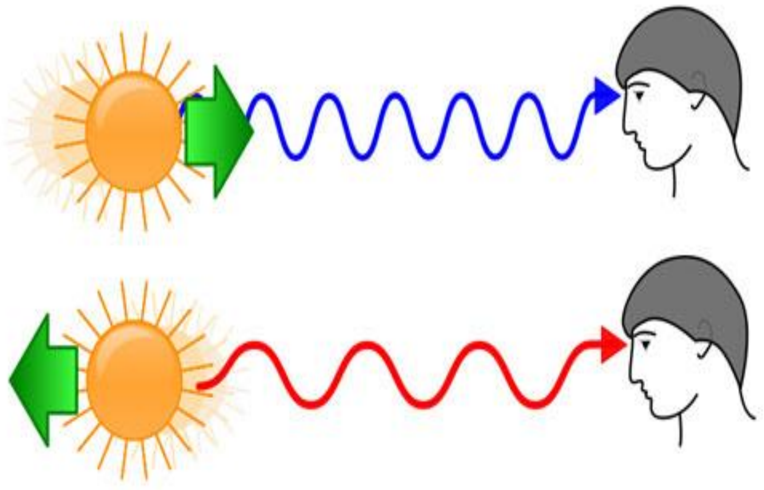


- Some of the observed spectra of stars are shifted toward the red or blue end of the spectrum. This apparent shift in wavelength is called the Doppler Effect.



- This Doppler shift is caused by the motion of the object emitting the radiation. An object moving toward the Earth would have a blue Doppler shift and an object moving away from the Earth would have a red Doppler shift.



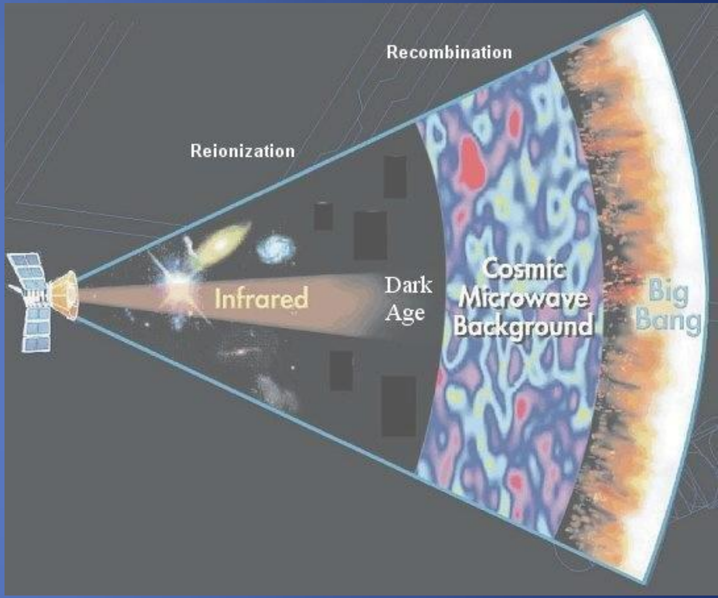


- Collective light from the stars in all galaxies is shifted to the red end of the spectrum indicating the universe is expanding.

- The farther away a galaxy is from Earth, the greater the red shift, indicating the rate of expansion of the universe is increasing.

Back ground radiation

a) Scientist have found evidence of longwave background radiation coming from all directions in the universe. This radiation is from the Big Bang, and is evidence supporting the theory. It comes from all directions with no exact source (no star or galaxy origin).



b) C.O.B.E satellite confirmed for the entire universe that noise radiation (static) is evenly spread

Stellar formation and evolution

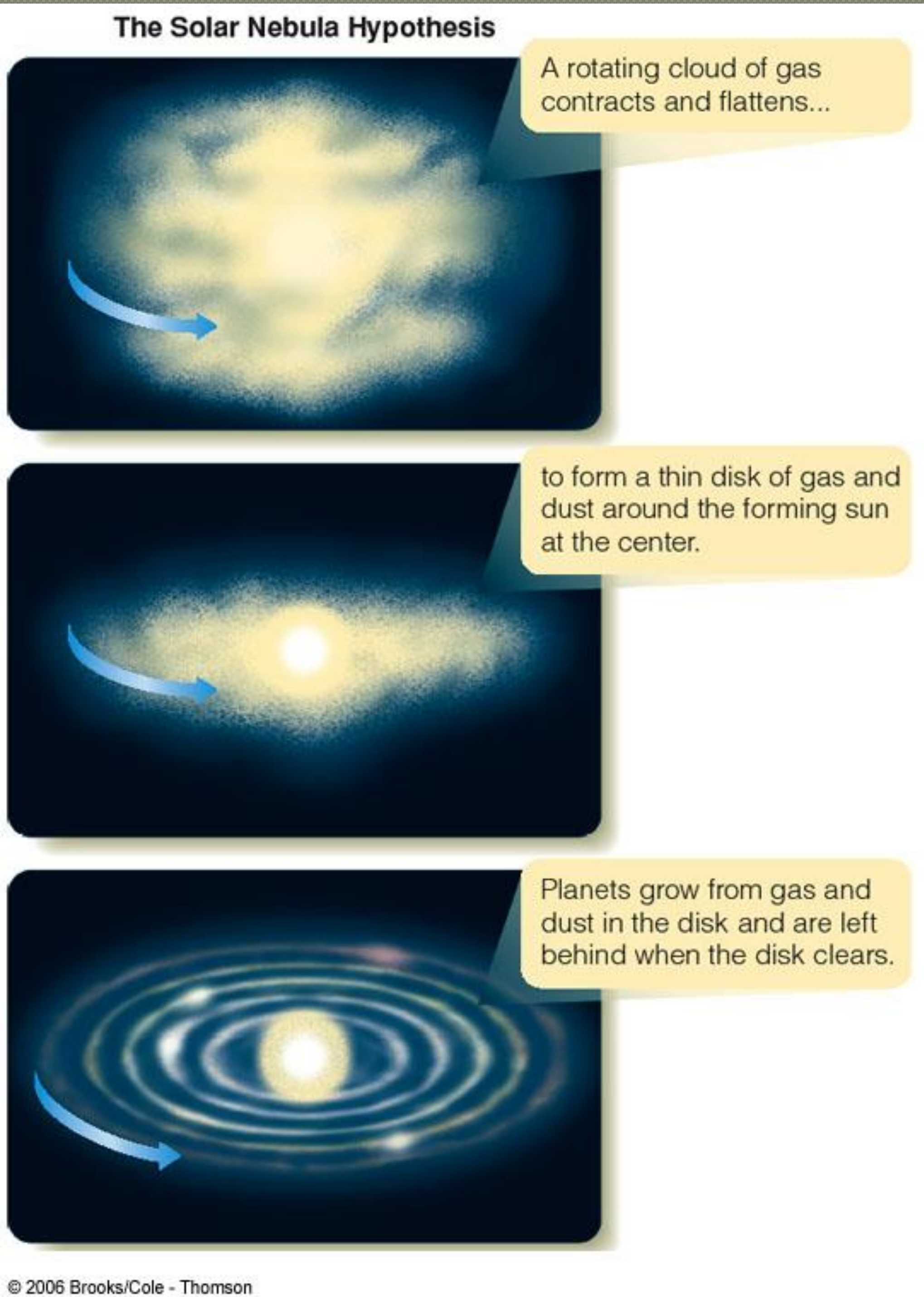
- We observe the life cycles of stars across the universe using tools such as satellites and telescopes
- we view stars form, burn and explode

What is a “nebula”?

- A cloud in space
- Made of gas and dust
- Most of the ones we see are inside our Milky Way Galaxy

Orion image at

- **Some event (e.g. supernova) triggers gravitational collapse of a cloud (nebula) of dust and gas**
- **As the nebula collapses, it forms a spinning disk (due to conservation of angular momentum)**
- **The collapse releases gravitational energy, which heats the centre**
- **The central hot portion forms a star**
- **The outer, cooler particles suffer repeated collisions, building planet-sized bodies from dust grains (accretion)**
- **Young stellar activity blows off any remaining gas and leaves an embryonic solar system**
- **These argument suggest that the planets and the Sun should all have (more or less) the same composition**



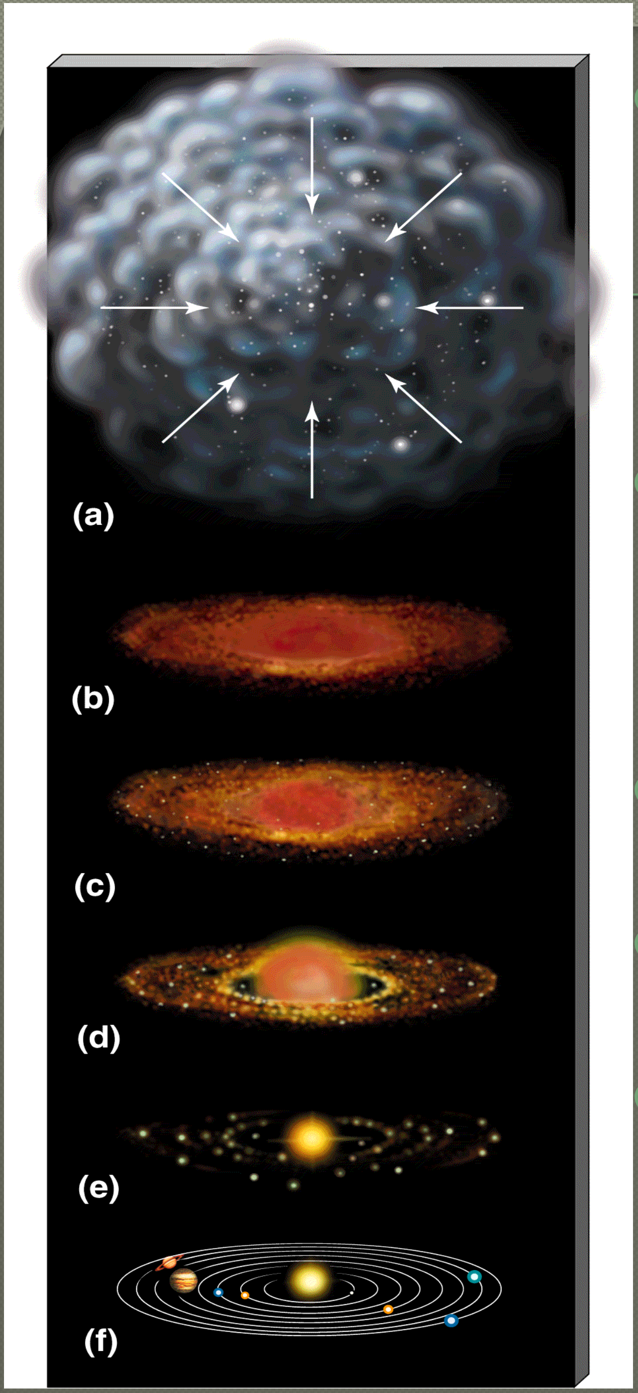
The Solar Nebula Theory

Basis of modern theory of planet formation.

Planets form at the same time from the same cloud as the star.

Planet formation sites observed today as dust disks of T Tauri stars.

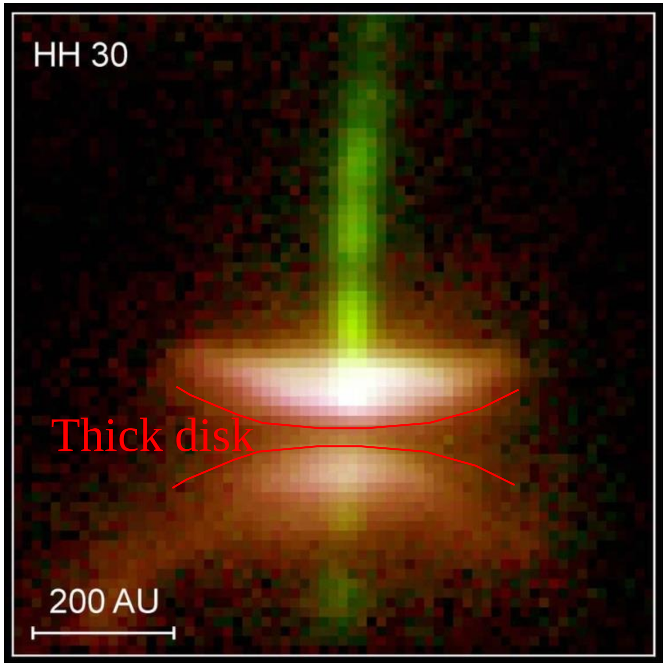
Sun and our solar system formed ~ 5 billion years ago.



- *a), (b) The solar nebula contracts and flattens into a spinning disk. The large blob in the center will become the Sun. Smaller blobs in the outer regions may become jovian planets.*
- *(c) Dust grains act as condensation nuclei, forming clumps of matter that collide, stick together, and grow into moon-sized planetesimals.*
- *(d) Strong winds from the still-forming Sun expel the nebular gas.*
- *(e) Planetesimals continue to collide and grow.*
- *(f) Over the course of a hundred million years or so, planetesimals form a few large planets that travel in roughly circular orbits.*

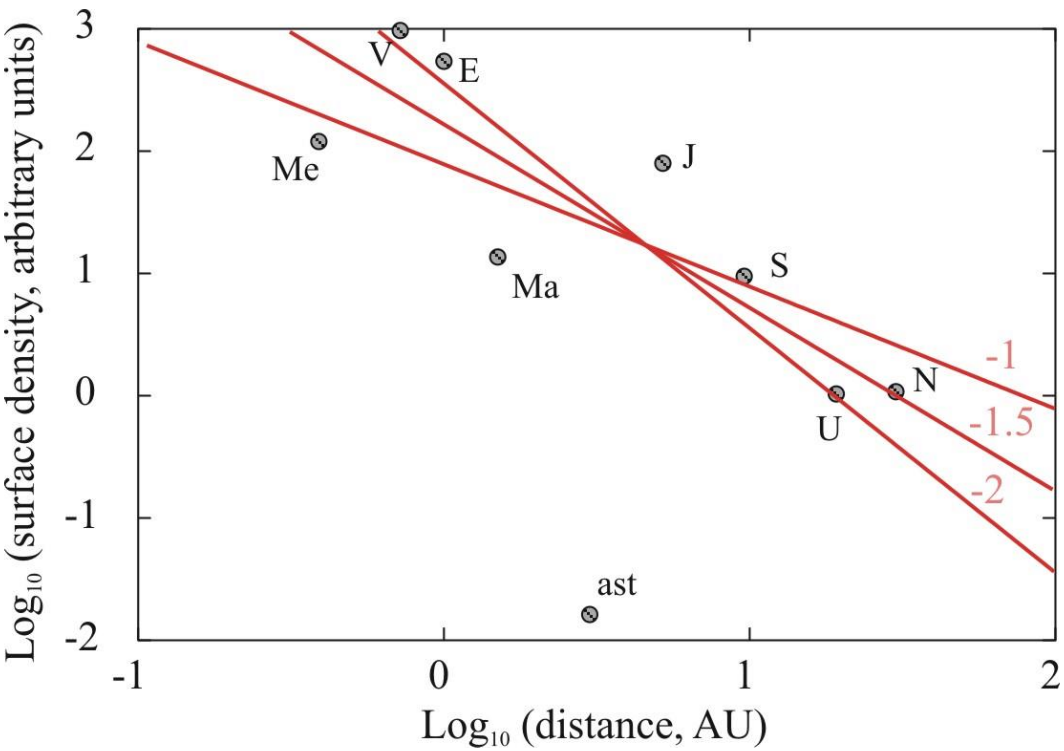
Observations (1)

- Early stages of solar system formation can be imaged directly – dust disks have large surface area, radiate effectively in the infra-red
- Unfortunately, once planets form, the IR signal disappears, so until very recently we couldn't detect planets (now we know of ~400)
- Timescale of clearing of nebula (~1-10 Myr) is known because young stellar ages are easy to determine from mass/luminosity relationship.



This is a Hubble image of a young solar system. You can see the vertical green plasma jet which is guided by the star's magnetic field. The white zones are gas and dust, being illuminated from inside by the young star. The dark central zone is where the dust is so optically thick that the light is not being transmitted.

Observations (2)



- We can use the present-day observed planetary masses and compositions to reconstruct how much mass was there initially – the *minimum mass solar nebula*

- This gives us a constraint on the initial nebula conditions e.g. how rapidly did its density fall off with distance?
- The picture gets more complicated if the planets have moved . . .
- The observed change in planetary compositions with distance gives us another clue – silicates and iron close to the Sun, volatile elements more common further out

Nebular composition

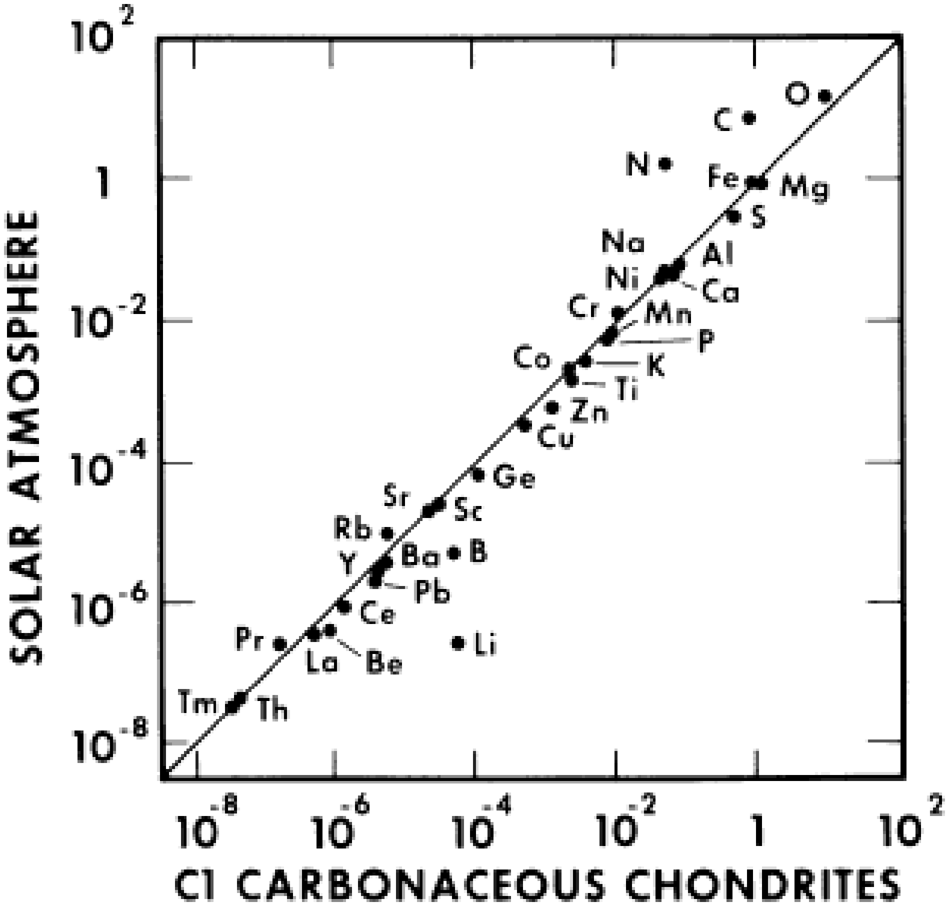
– Composition of the Sun (photosphere)

– Primitive meteorites

An important result is that the solar photosphere and the primitive meteorites give *very* similar answers: this gives us confidence that our estimates of nebular composition are correct

Meteorites vs. Photosphere

- This plot shows the striking similarity betwe meteoritic and photospheric compositic
- Note that volatiles (N,C, are enriched in photosphere relative to meteorites
- We can use this information to obtain a best-guess nebular composition



Basaltic Volcanism Terrestrial Planets, 1981

Co-formation of Sun and planets

The sun and the planets of our solar system formed at the same time and from the same material reservoir:

- ▷ Elementary abundances
- ▷ Age of the meteorites = age of the sun
- ▷ Parallel angular momentum of sun and planets

Radiometric dating:

Material	Age
Earth (Zircon, Australia)	4.40 Gyr
Moon (highland rocks)	4.1-4.4 Gyr
Meteorite (oldest from Mars)	4.5 Gyr
Meteorite (chondrules)	4.564 Gyr
Meteorite (CAI)	4.567 Gyr

Age determination of the sun (evolutionary models and helioseismology data):

Authors	Age
Guenther & Demarque 1997	4.5±0.1 Gyr
Bonnano, Schlattl & Paterno 2002	4.57±0.11 Gyr
Houdek & Gough 2007	4.68±0.02 Gyr

Nebular Composition

- Based on solar photosphere and chondrite compositions, we can come up with a best-guess at the nebular composition (here relative to 10^6 Si atoms):

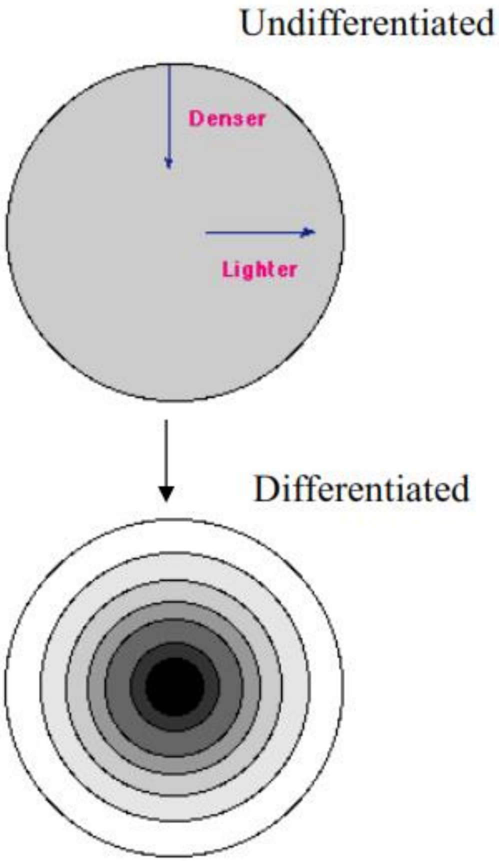
Element	H	He	C	N	O	Ne	Mg	Si	S	Ar	Fe
Log_{10} (No. Atoms)	10.44	9.44	7.00	6.42	7.32	6.52	6.0	6.0	5.65	5.05	5.95
Condens. Temp (K)	180	--	78	120	--	--	1340	1529	674	40	1337

- Blue are volatile, red are refractory
- Most important refractory elements are Mg, Si, Fe, S

Data from Lodders and Fegley, *Planetary Scientist's Companion*, CUP, 1998
This is for all elements with relative abundances > 10^5 atoms.

Differentiation

- After planet formation, planets were homogeneous.
- For bodies with diameters >few km, internal temperatures were large enough to cause partial or total melting of the interiors => allowed materials to separate according to density.
- "Heavy" materials are those that bond to iron, forming iron-bearing minerals (*siderophiles*, i.e., "iron-lovers"). Siderophiles sink to center of planet, forming core.
- "Light" materials are those the bond to silicates; called the *lithophiles*. Rise to upper layers of planet.
- Separation of materials according to density allows a complicated layered structure to form inside a planet.



Chemical differentiation/fractionation

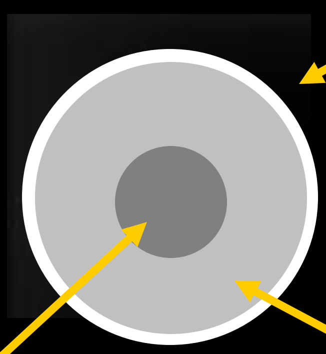
- Large planets (Earth/Venus) are molten long enough for a Fe and Ni core to form.
- Smaller planets (Mars) cool faster and solidify before heavier elements sink to the core => elements like Fe are over abundant in the soil, giving Mars its red color.
- Large planets cool slower, and have thinner crusts. High cooling rates also determine the interior structure.
- Slow cooling rates imply some planets still have warm interiors => more diversified structure (inner core, outer core, semi-solid mantle, etc.)
- Earth is differentiated or layered; highest density in center, lower densities progressively outward
  - Crust - rocky outer layer, brittle (5-40 km)
  - Mantle - solid rocky layer, dense, high pressure, flow
  - Outer Core - molten Fe-rich
  - Inner Core - solid Fe, Ni

- **Differentiation**

Since gravity is directed towards the centre of a planet, the molten material tried to fall inwards ...

… and so the planets took roughly spherical shapes, then cooled gradually to form brittle outer skins (crusts):

(this is not to scale - the crust would be ***much*** *thinner than shown here)*

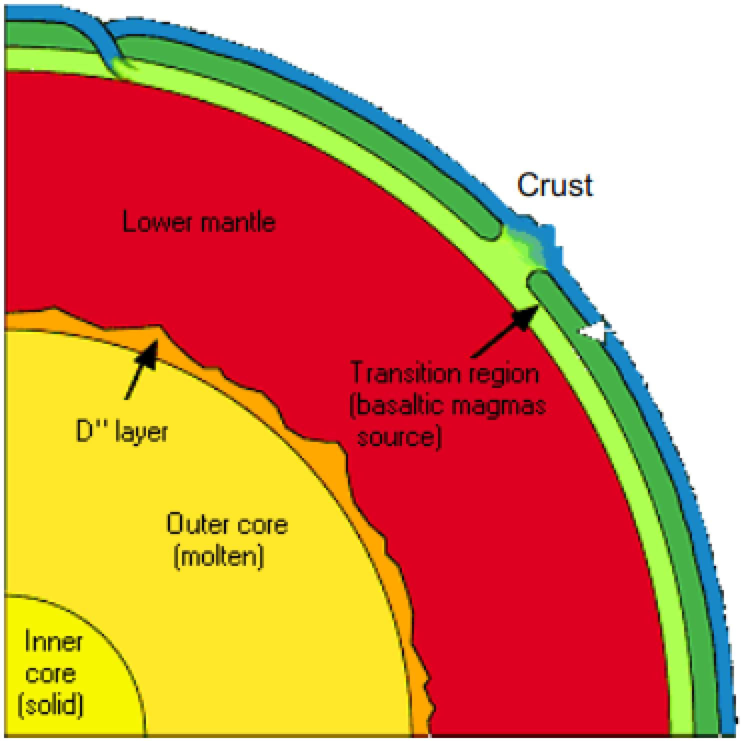


Denser (iron-rich) material settles in the centre (core)

Lighter (silicon-rich) material rises towards the surface (mantle)

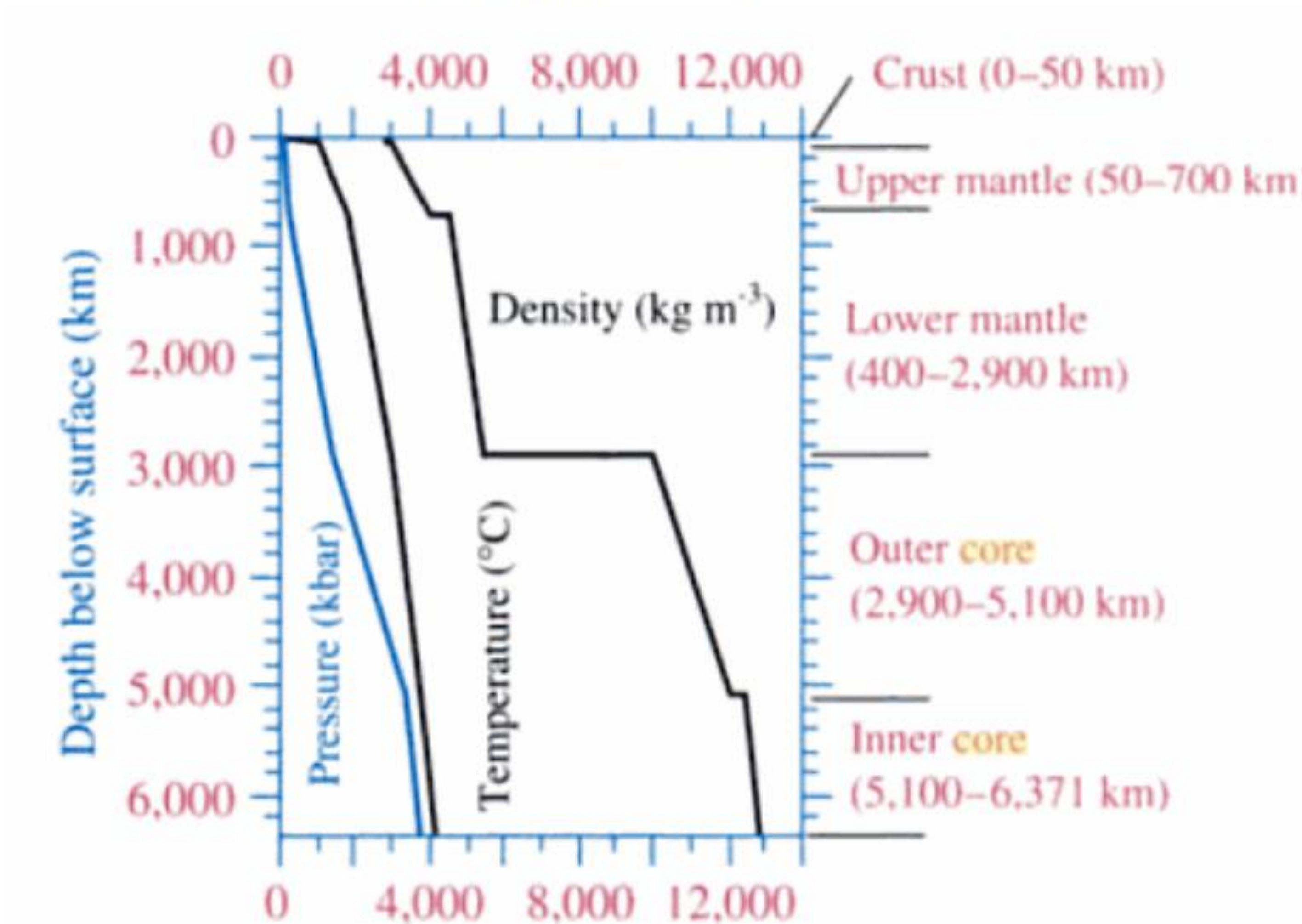
Differentiation within Earth

- Composed of layers:
  - ***Core:*** Earth central portion. Thickness ~3,470 km and temperature ~6,000K. Pressure so high core is solid.
  - ***Pasty Magna:*** Portion below crust. Divided into mantle (thickness of 1200km) and intermediary layer (called external nucleus, thickness of 1700 km).
  - ***Crust or Lithosphere:*** Earth's external layer. Thickness of 60 km in the mountainous areas and 5 to 10 km in the oceanic basins.



Conditions within Earth

Density (kg/cm-3)



Temperature (°C)

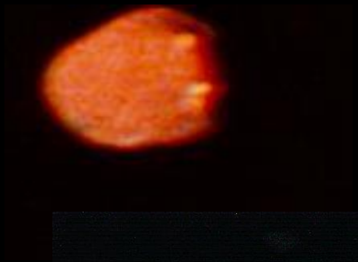
The idea that planet-sized rocky objects can “melt” due to their own internal energy is pretty surprising, until we remember that the Earth has a molten core, and we see the heat released from the Earth’s still hot mantle in volcanic activity.

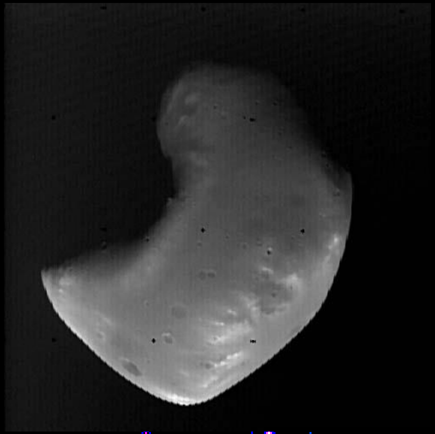
There is another particularly clear piece of evidence for this:

if we take a census of Solar System objects, we find that ...

– rocky bodies with diameters greater that 200 km are roughly spherical:

– whereas bodies with diameters less than 130 km are usually irregular:



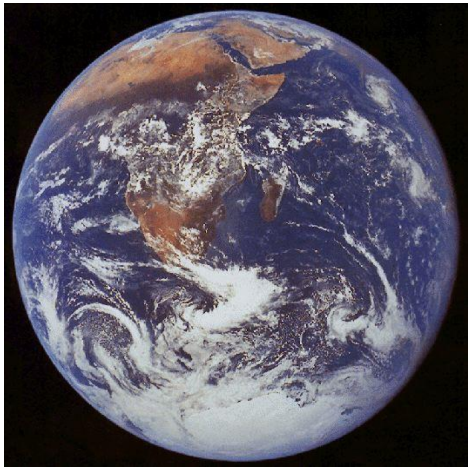


– which agrees quite well with calculations of how large an accreting object can become before it differentiates.

Once the planet has differentiated, the interior then gradually cools (though radioactive decay still acts as an internal heating source in the terrestrial planets) and the upper crust solidifies.

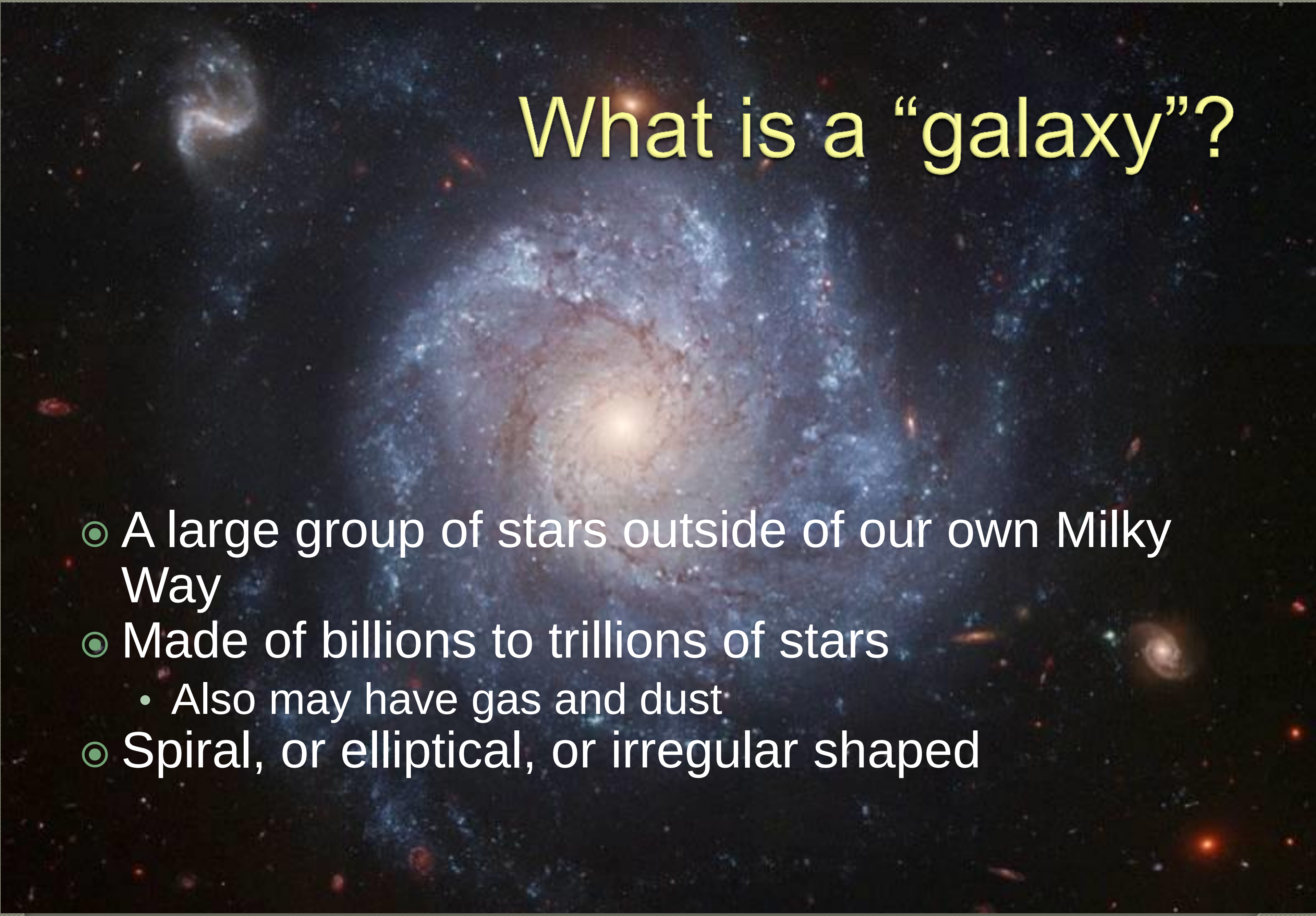
In some planets, the mantle and even the core slowly solidifies. The smaller the planet, the quicker it can radiate its internal heat, cool down and finally solidify.

The process of planetary differentiation also leads to *outgassing*, whereby internal gasses escape to the surface of the planet and form its outer atmosphere and – in the case of the Earth – oceans. The atmospheres and oceans (of the Earth) are also added to by impacting icy comets in the early history of the Solar System.



So… Big Bang & Solar Nebular? How are they related?

- The Big Bang Theory considers the creation of all the matter and energy that exists in the universe.. Anywhere..
- The Solar Nebula theory uses that matter and energy, to create galaxies and solar systems.



What is a "galaxy"?

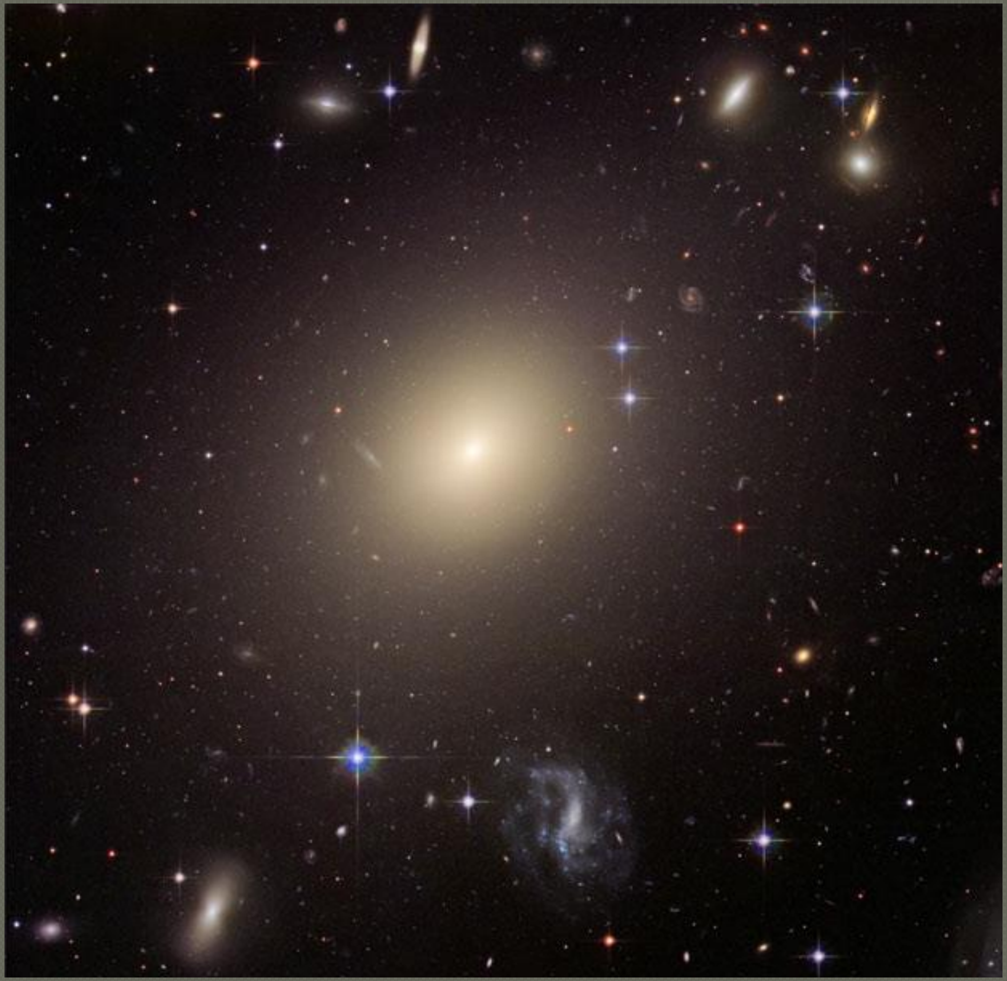
- A large group of stars outside of our own Milky Way
- Made of billions to trillions of stars
  - Also may have gas and dust
- Spiral, or elliptical, or irregular shaped

Image at

Spiral galaxy--Andromeda

NOAO/AURA/NSF Images at
http://www.noao.edu/image_gallery/html/im0606.html and

Elliptical Galaxies



Images at
http://hubblesite.org/newscenter/archive/releases/galaxy/elliptical/2007/08/image/

Irregular Galaxies

NASA and NOAO/AURA/NSF Images at
http://hubblesite.org/newscenter/archive/releases/galaxy/irregular/2005/09/res

Our Galaxy: the Milky Way

- has about 200 billion stars, and lots of gas and dust
- is a barred-spiral (we think)
- about 100,000 light-years wide
- our Sun is halfway to the edge, revolving at half a million miles per hour around the center of the Galaxy
- takes our Solar System about 200 million years to revolve once around our galaxy

The Milky Way

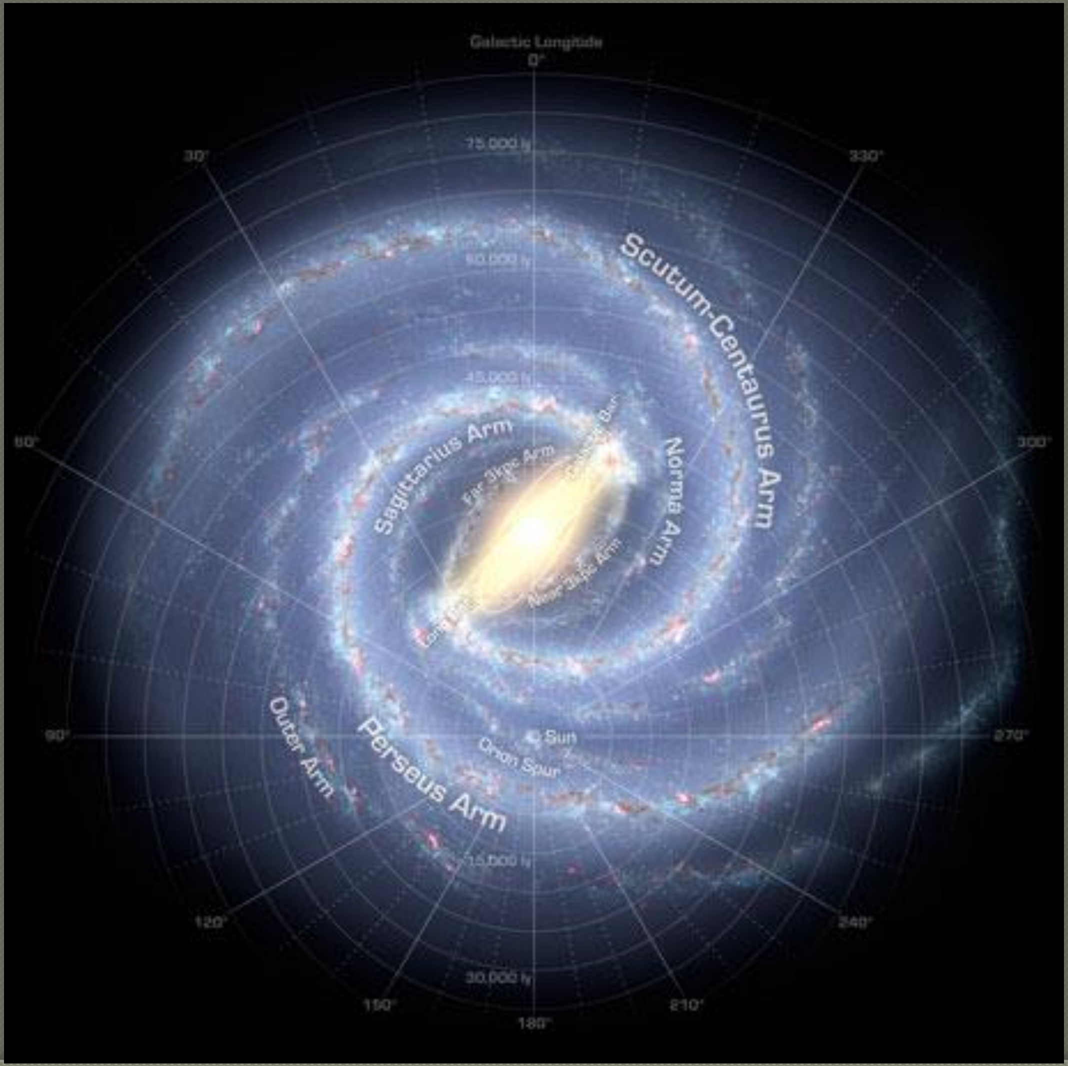
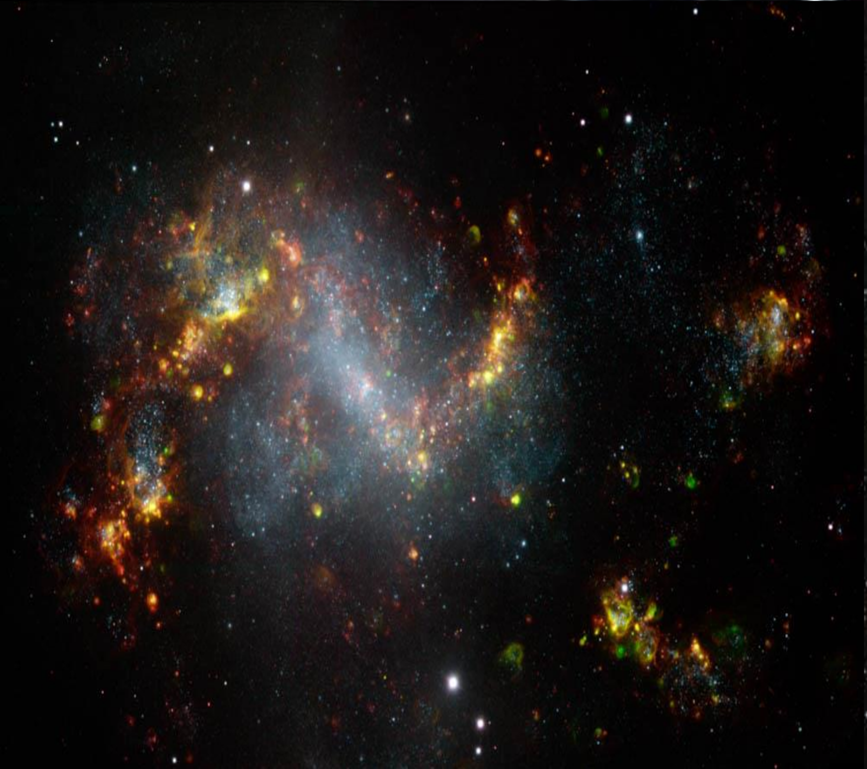
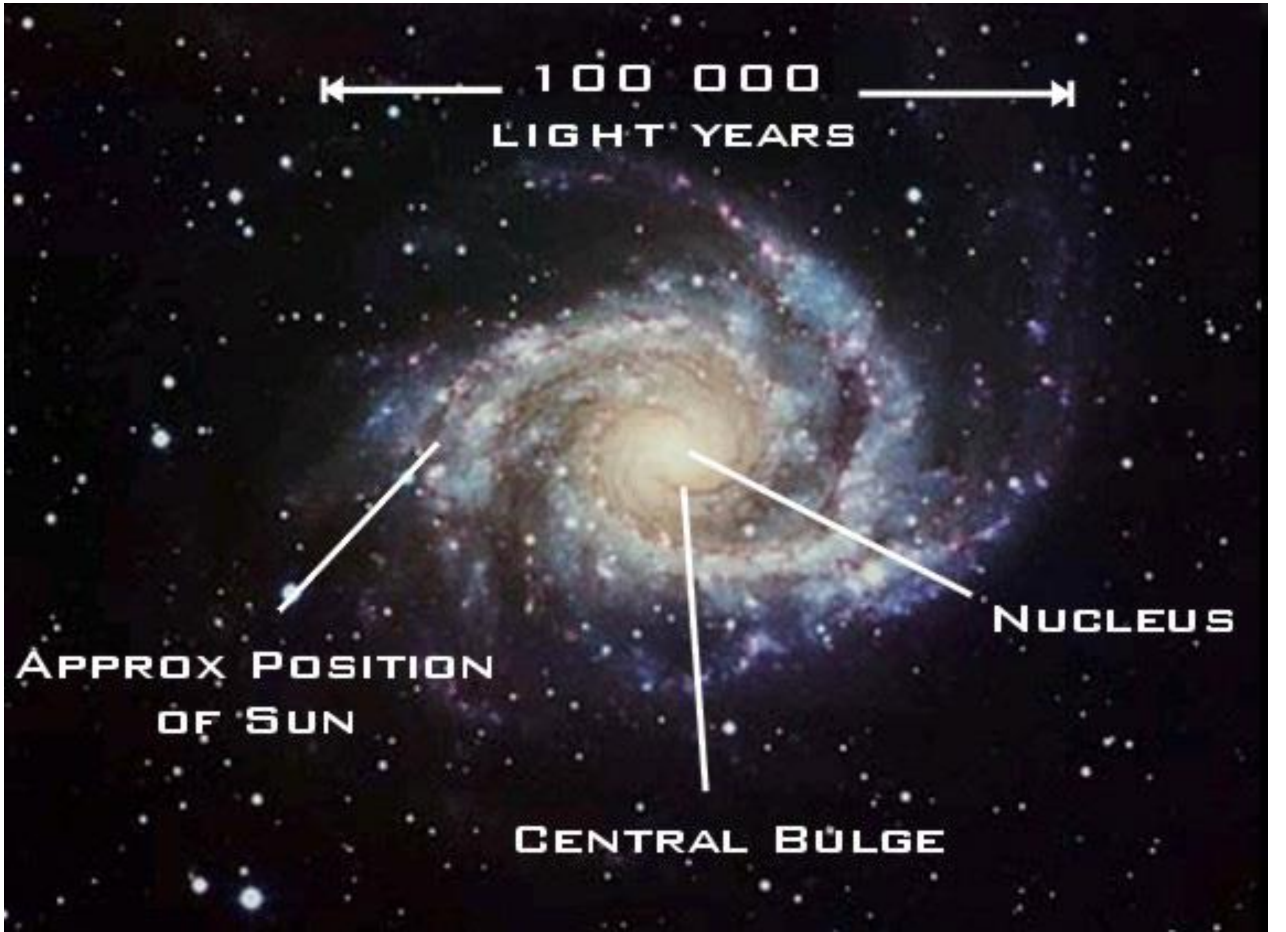


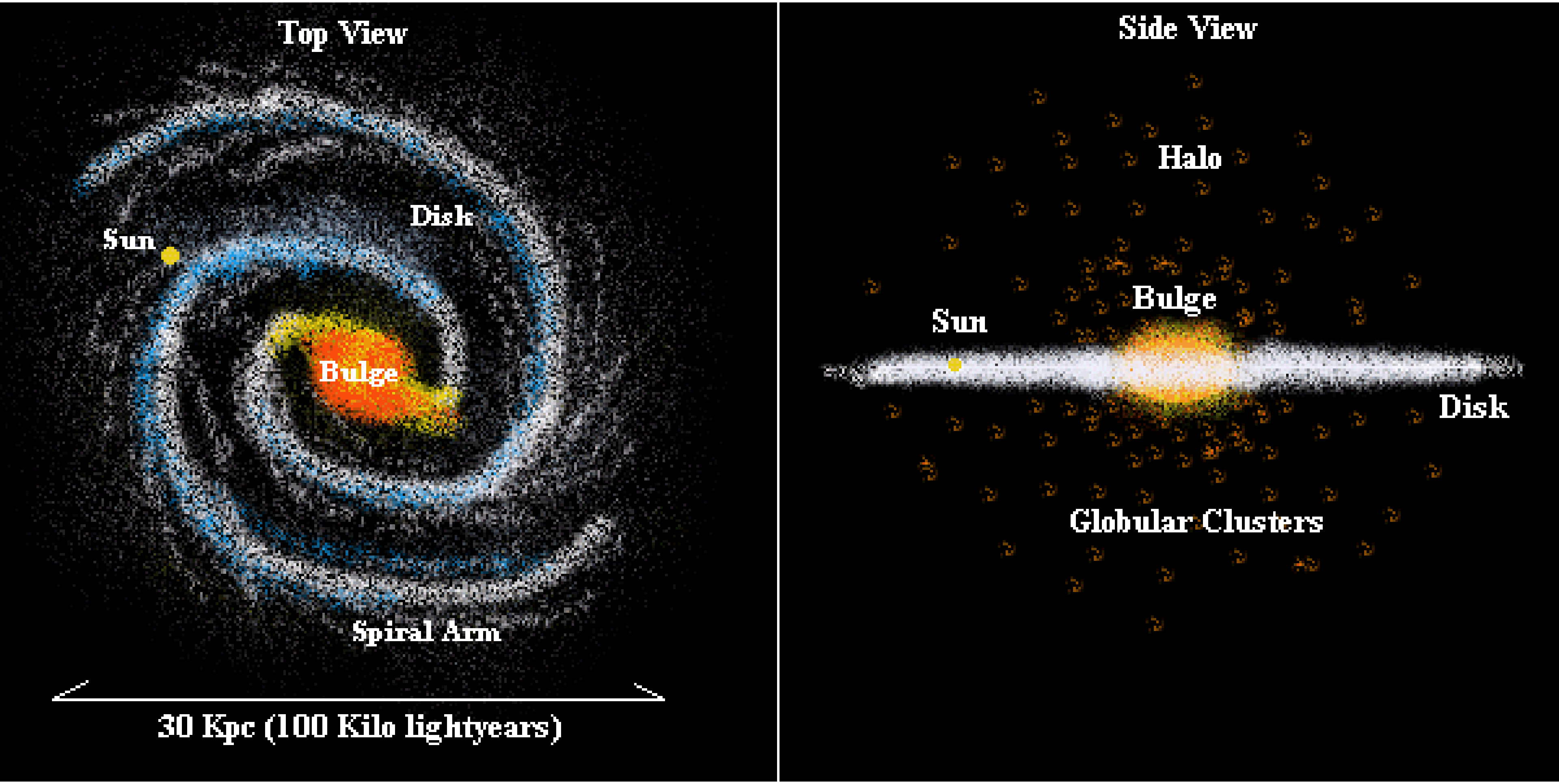
Image at
http://news.nationalgeographic.com/news/bigphotos/104



Our Galaxy

- Our solar system is part of the Milky Way Galaxy.
- The Milky Way Galaxy is a spiral shaped galaxy.





Top View
Disk
Sun
Bulge
Spiral Arm
30 Kpc (100 Kilo lightyears)
Side View
Halo
Bulge
Sun
Disk
Globular Clusters