STARS & COSMOLOGY
A REVIEW

1. Stars are composed mostly of H and He and a few percent heavier elements; they are entirely gaseous.
2. Stars are incandescent bodies, that is, they shine or emit light because they are hot.
3. The surface brightness of a star, B_*, is the amount of Energy radiated by each unit area of a star's surface per second.

   B_* is proportional to the fourth power of the surface temperature:

   $$B = \sigma T^4 ,$$

   where "σ" is a constant of proportionality. This is called the **Stefan-Boltzmann Law.**
4. Cool stars appear reddish in color and hotter stars are Bluer in color. (**Wien's Law**: $WL_{max} = a / T$), where "a" is a of constant of proportionality.
5. Stars form from dense clouds of gas and dust in the Interstellar medium of the galaxy
6. As stars gravitationally contract, they heat up as gravitational potential energy is converted into thermal energy.
7. The evolution of a star is determined mainly by its initial mass and secondarily by its chemical composition. The more massive the star, the faster it evolves.
8. Objects that have an initial mass that is less than 0.06 times the Sun's mass (Kumar Limit) achieve a balance between gas pressure and gravity before the central temperature is sufficiently high to initiate thermonuclear fusion reactions (TNF) in the core. It then begins to cool off and forms what is called a **Brown Dwarf.**

   New evidence indicates that a large fraction of a galaxy's mass may exist as brown dwarfs.

9. If the object's mass is great enough, gravitational contraction continues to the point where the core of the star reaches 5 million K. Then thermonuclear fusion (TNF) of H into He begins in the core plus the release of energy that keeps the star shining.

   Now the star has become a **Main Sequence** star.

10. Main Sequence stars are characterized by TNF of H into He in the core and **hydrostatic equilibrium** throughout the star.

    They also obey the "**mass- luminosity law**": the more massive the star, the brighter it is.

11. When the H in a M-S star's core is exhausted, the core shrinks and gets hotter but the outer layers expand, making the star very large, that is, a red giant (RG) or supergiant (SG) star. Exactly which it becomes depends on the mass of the star.

12. Eventually, other TNF reactions begin in the core to convert He into heavier elements, such as, C, Ne, O, Mg, Si, and Fe.

13. The cores of very massive stars collapse when they run out of nuclear fuel. This in turn leads to a catastrophic explosion in the upper layers of the star. This explosion is called a Type II supernova event. Other stars loose mass by giving off strong winds.

    Therefore, stars are causing a slow change in the chemical composition of the interstellar medium of a galaxy and, hence, new stars that form have a higher abundance of heavy elements. This is how the age of a star may be determined.

14. Planets and people were not possible at first, since the galaxy originally consisted only of H and He.

15. The exact sequence of evolutionary stages of a star depends on its mass. The following are some possible sequences:

    A. For very massive stars, the evolutionary sequence is protostar, M-S, Red SG, SN, and finally: WD/NS/BH, depending on the remaining mass of the star.

B. For stars like our Sun and less massive: protostar, T Tauri star, MS, RG, SG and finally WD.

16. White dwarf (WD) stars have gravitationally contracted to the point where the mutual repulsion between free electrons (degenerate electron pressure) balances gravity. Such stars are about a hundredth the size of the Sun or smaller (about the size of a large planet), and are very dense. They have masses less than the **Chandrasekhar Limit** of 1.4 solar mass units.

    White dwarfs are dying stars.

    They cannot generate any energy and are slowly cooling, by emitting radiation into space according to the laws of radiation.

    But, it will take about 50 billion years for a white dwarf to cool to a temperature such that it no longer emits any visible light. When this does happen, a white dwarf becomes a black dwarf. However, the universe is too young for any white dwarfs to have become black dwarfs.

17. Neutron Stars (NS) are stars that have gravitationally collapsed to the point where all electrons are forced to combine with all the protons to form a star made entirely of neutrons and nothing else.

    Such stars are very small; they rotate very fast, and have strong magnetic fields.

    Because of their very strong magnetic fields, these stars emit intense radiation from their magnetic poles. As the star rapidly spins with its magnetic axis not aligned along its rotational axis, such intense beams may sweep by an observer so that pulses of radiation are detected. Such phenomena are called **Pulsars.**

18. Black Holes (BH) are stars that have collapsed to the point where the escape velocity at the surface of the star is greater than the velocity of light. Hence, nothing can ever escape from the star, not even light. The gravitational field of such a star is described as a severe curving of the space-time continuum around the star in such a way that it is like a dark hole in space. The star is said to have collapsed inside of its **Schwarzschild or Critical Radius**.

19. The Kerr solution of Einstein's General Relativity equations indicates that a rotating black hole will bend the space-time continuum in such a way that a direct connection or bridge (called a wormhole) is formed between the location of the black hole and another location in the space-time continuum that may be far away in either space or time. The actual meaning of this is not certain, but it has given rise to a lot of science fiction.

20. In 1917, H. Shapley applied the period-luminosity law to find the distances of the globular clusters and hence their distribution around the Sun.

    This resulted in our present understanding of the structure of our galaxy and the location of the Sun.

21. The structure of a typical spiral galaxy like ours consists of the disk, the halo, the nuclear bulge, and the nucleus.

22. Another advance in understanding our Galaxy was made in 1943 by W. Baade, who showed that there are two distinct stellar populations comprising a galaxy.

    Population I stars:

    1. These stars are found in the spiral arms of a galaxy.
    2. They are young stars.
    3. The brightest stars are the hot blue stars of the upper main sequence or blue giants.
    4. Often found in open clusters
    5. Associated with nebulosity.
    6. Have higher metal abundances.

    Population II stars:

    1. These stars are in the globular clusters, the halo stars, and the nuclear bulge.
    2. Stars are very old, more than 10 billion years old.
    3. They are not associated with clouds of gas & dust.
    4. This population has no blue giants and the brightest stars are red giants and supergiants.
    5. The main sequence for such stars is truncated with a turnoff point indicative of their old age.
    6. The stars have low metal abundances.

23. Stars are located within galaxies and galaxies are the basic building blocks of the universe.

We now realize that the universe contains billions of galaxies extending to the limit of visibility (13.7 billion ly).

24. It is now realized that, in general, large galaxies grow larger by absorbing, "eating," cannibalizing, or ingesting smaller galaxies through gravitation interaction.

Although a collision of two galaxies will wreak havoc on the large scale structure of the galaxies, it has no effect on the stars they contain. This is because stars are spaced about a parsec apart, which is millions of times greater the size of a typical star. So the stars in the galaxies just glide past one another.

25. The galaxies aggregate into variously sized clusters which are arranged in a frothy or lace-like distribution throughout the universe.

The Local Group is such a cluster, but a small one.

26. In1929, E. Hubble discovered that we live in an expanding universe.

This is a conclusion based on Hubble's Law: The farther away a cluster of galaxies is, the greater its recessional velocity (the faster it is moving away from us).

The slope of the line in the Hubble Diagram is called the Hubble Constant and is the rate of expansion of the universe.

27. Recent studies of Type Ia supernovae in distant galaxies indicate the universe is accelerating in its rate of expansion. So the Hubble constant is not a fixed value.

28. The acceleration of the universe's expansion is the result of dark energy, which is energy stored in the S-T continuum.

29. Studies of the motions of stars in galaxies indicate that galaxies have a lot of unseen matter or non-luminous matter. This is called "dark matter." One of the frontiers of investigation today is to determine what

the form of this dark matter is and how much is present. Some matter may not really be dark, but just intrinsically faint so that it is not detectable at great distances.

30.

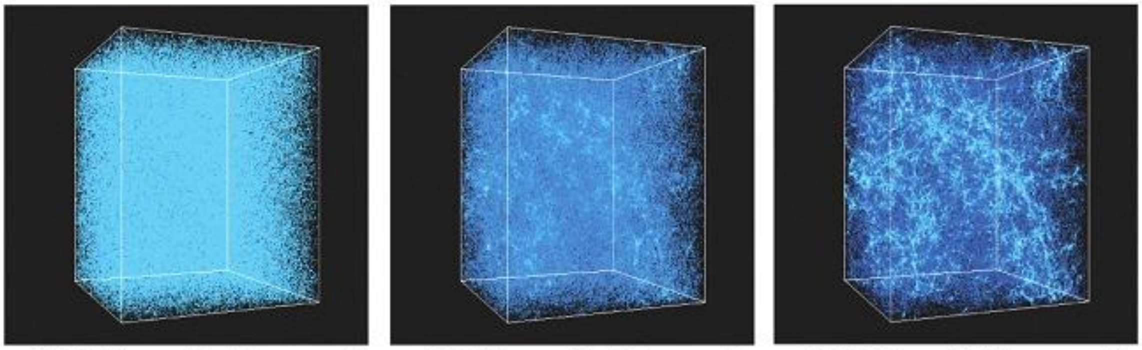
Properties of Quasars

Galactic nuclei have different degrees of activity in the sense they emit variable and intense radiation.

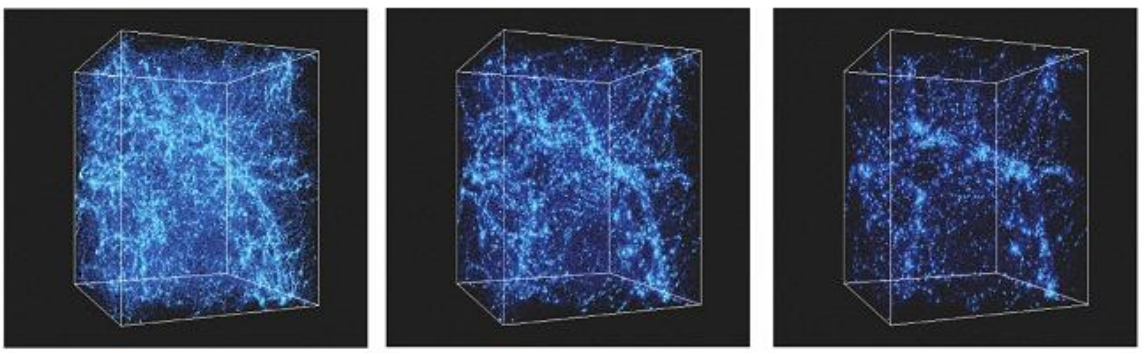
- Quasars are the brightest type of active galactic nucleus.
- The viewpoint now is that a supermassive black hole is consuming stars and gas and dust clouds in their near vacinity and creating an accretion disk of matter which is compressed and accelerated to near luminous speeds (the speed of light) as it spirals into the black hole.
- Compression of the gases in the disk would lead to the production of light and other types of radiation.
- In addition to radio waves and visible light, quasars emit ultraviolet rays, infrared waves, x-rays, and gamma-rays.

31.

Supercomputers have been used to simulate how the large-scale structure of the universe arose from primordial fluctuations in the density of the gas filling the universe.



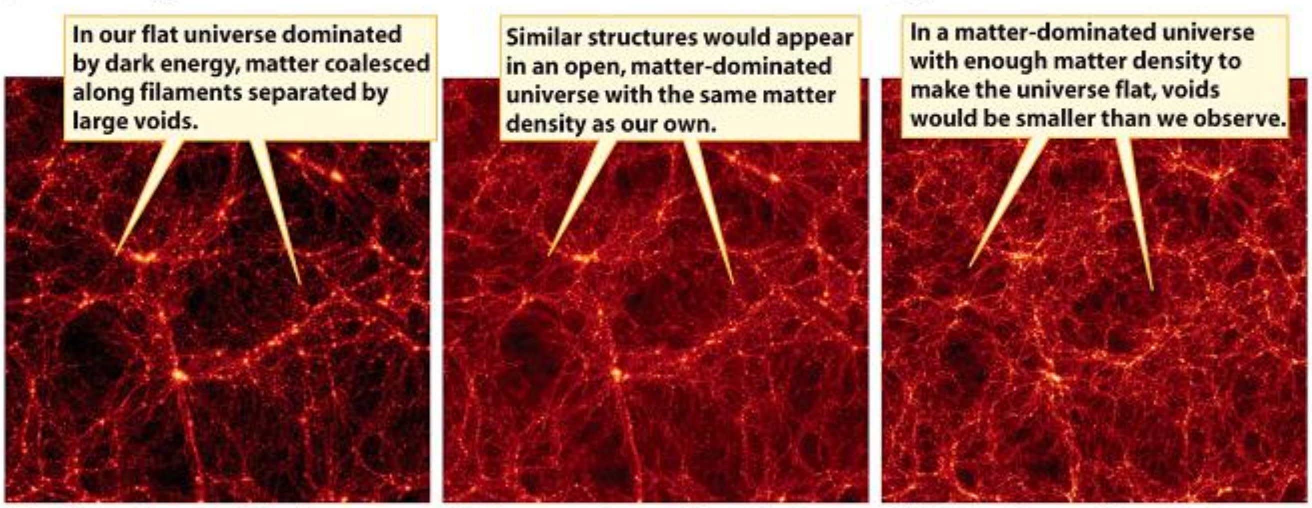
$z = 27.36$ Universe 120 million years old | $z = 9.83$ Universe 490 million years old | $z = 4.97$ Universe 1.2 billion years old



$z = 2.97$ Universe 2.2 billion years old | $z = 0.99$ Universe 6.0 billion years old | $z = 0.00$ Universe 13.7 billion years old

32.

Models based on dark energy and cold dark matter give good agreement with details of the large-scale structure



(a) A flat universe with dark energy: $\Omega_m = 0.3, \Omega_\Lambda = 0.7$

(b) A open universe without dark energy: $\Omega_m = 0.3, \Omega_\Lambda = 0$

(c) A flat universe without dark energy: $\Omega_m = 1.0, \Omega_\Lambda = 0$