The Universe

Sultana N. Nahar

Department of Astronomy, The Ohio State University, Columbus, OH 43210, USA

E-mail: `nahar@astronomy.ohio-state.edu`

Abstract. We are part of the universe. Creation of matter through primordial nucleosynthesis and formation of some astronomical objects, such as stars, blackholes, incidents such as supernova explosion are briefly described for a general picture of our universe. Knowledge about them can be aquired through spectroscopy of the light and other forms of radiation emitting from them.

1. INTRODUCTION

Studies beyond our earth in to the space have always been of interest and crucial to us since the astronomical objects provide us information relevant to our existence in the universe. We ourselves are travelling in space riding on the the planet earth belonging to a medium size star, the sun. The following sections provide some details of our universe.

2. CREATION OF THE UNIVERSE

Observations suggest that our universe had a beginning about 13.7 billion years ago and has gone through phases of evolution. Big Bang (BB) theory can explain the beginning and evolution that are supported by discoveries and present day understanding. The earliest phases of the Big Bang are subject to much speculation. The universe started as an infinitesimally small, infinitely hot, infinitely dense, energy source, with one force supergravity and in a state called a singularity. Science has yet to explain from where this source appeared. The singularity started expanding rapidly when supergravity broke into gravity and electroweak forces. Soon the universe started to inflate in an exponential manner, which is the Big Bang, and a phase transition occured. The universe was filled with high energy photons in an extreme dense condition and

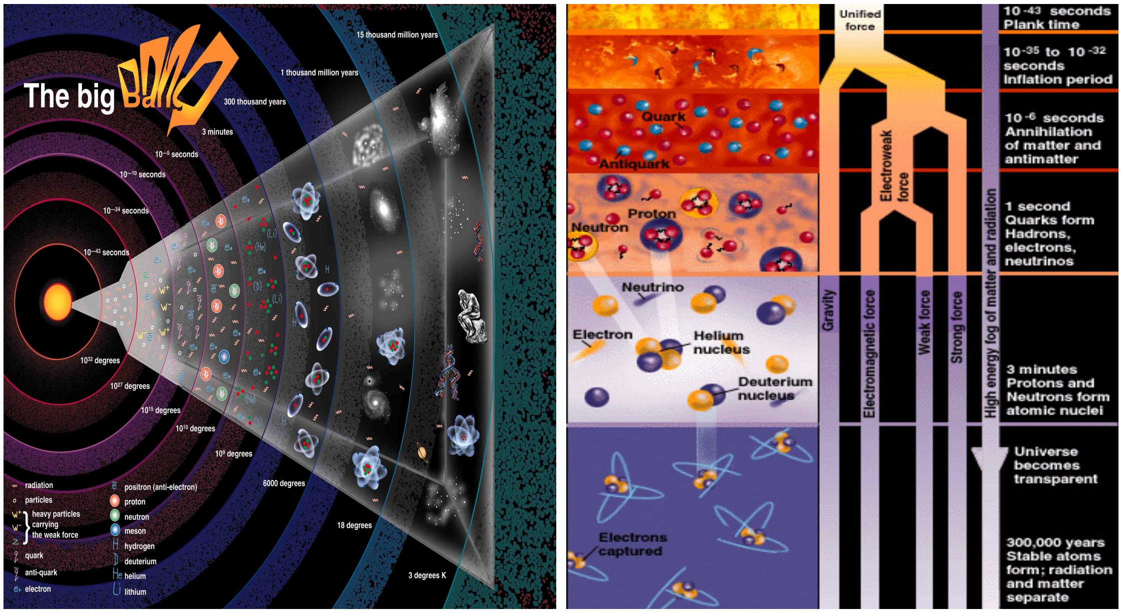

Figure 1. Timeline of our universe: left (schoolnet.gov.mt/earth_universe) - evolution of radiation and matter, right (www.redorbit.com) - evolution with fundamental forces.

high temperature. Collisions of these photons produced particles, such as quakrs, gluons, and other elementary particles. The dense ensemble of particles in the early hot universe is often called the "particle soup" of the Big Bang.

Space and time started with Big Bang. It is believed that there was no space before BB and it started at zero time. Hence the space itself is expanding, carrying galaxies with it. Figure 1 presents timeline of the phases of evolution of our universe.

3. PRIMORDIAL NUCLEOSYNTHESIS

Soon after the creation of matter the era of primordial nucleosynthesis, also known as the Big Bang Nucleosynthesis (BBN), for formation of nuclei began. This period is generally considered to have started about 0.01 second after the Big Bang and stopped around 3 minutes later. Of the quarks in the early universe, the up quark carried a positive charge of 2/3, while the down quark carried a negative charge of 1/3. Prior to BBN, the temperature was too high, that is, the particles were moving too fast to form nucleons. In the later part of BBN, the temperature was too low to form nucleons, that is, there was simply not enough energy. As the universe cooled the strong force seperated from the electroweak force which again would later seperate into the electromagnetic and weak forces. Nuclear forces were then able to pull two up quarks and one down quark together to form a proton, and two down quarks and one up quark to form a neutron. Protons and neutrons are referred to as nucleons. Baryons also refer to protons and neutrons. Particles were at random motions at relativistic speeds and particle-antiparticle pairs of all kinds were being continuously created and destroyed in collisions. The process continued until radiation and matter were in thermal equilibrium as temperature dropped with expansion of the universe. An unknown reaction called *baryogenesis* violated the conservation of baryon number, resulting in a small excess of quarks and leptons over antiquarks and anti-leptons of the order of 1 part in 30 million. At approximately 1 second after the Big Bang neutrinos decoupled and begun traveling freely through space. The expansion of the universe had caused the temperature to drop when photons no longer had the energy to create proton anti-proton pairs. Protons and neutrons are now frozen out of thermal equilibrium with radiation. By 4-10 seconds, the temperature had fallen further to the point at which electrons were frozen out.

Given a fixed baryon-to-photon ratio in the first three minutes of origin, a few *primordial* nuclear species made of baryons appeared. The atomic nuclei created were predominantly protons and helium nuclei, with very small trace amounts of deuterium (heavy hydrogen), tritium and lithium (Li^7). At two minutes, the temperature of the universe fell to the point when protons and neutrons begin to combine into atomic nuclei through nuclear fusion. First deuterium was formed, then Helium, and after a while Lithium and Beryllium. However, this nucleosynthesis only lasted for about 17-30 minutes after which drop of the temperature and density could no longer support nuclear fusion. At the end of nucleosynthesis period, all of the neutrons had paired with protons to mainly form helium which is 24% of the primordial light elements. There is about three times more protons than helium ion by mass. The relative numbers of protons, neutrons, deuterium etc. were fixed by the thermal environment and the time allotted. The current abundances of the light elements reflect what occurred during the epoch of BBN and therefore place strong constraints on the state of the universe and the baryon density during BBN.

BBN is supported by the "standard model" of particle physics which relates the three of the four known fundamental interactions or forces and the elementary particles that take part in these interactions. The model implies that most visible matter in the universe is made of baryons.

4. EPOCHS OF RADIATION AND RECOMBINATION

The energy of the universe continued to be dominated by photons which interacted frequently with charged protons, electrons and nuclei for the next 300,000 years. Photons were scattered from free plasma particles via Thomson or Compton scattering and had short mean free paths. All radiation energy was thus "trapped" and plasma was opaque to radiation. This era is known as the radiation dominated or *photon* epoch. The temperature of the radiation dominated the temperature of matter.

During photon period, recombination process for ions and later for neutral atoms started. Atomic physics determines that singly ionized helilum He^+ (*not* hydrogen) would have been the first atoms(ions) formed. The electron-ion recombination process is: $He^{2+} + e \rightarrow He^+ + h\nu$. The reason that He^+ was the first atomic species was due to the extremely hot plasma when nuclei and electrons were free in fully ionized state. The atomic species that would form first is the one with the highest ionization potential (E_{IP}). E_{IP} for (He^+) = Z^2 = 4 Ryd = 54 eV, as opposed to E_{IP} (He) = 1.8 Ryd = 24.6 eV, and E_{IP} (H) = 1 Ryd $\equiv$ 13.6 eV. It follows that He^+ can exist at much higher temperatures, i.e. at earlier hotter times, than either neutral He or H. It took about 240,000 years before the neutral helium and then hydrogen formed.

With the expansion, the temperature and the density of the universe fell making the environment for neutral helium and hydrogen atoms to form by electron captures. The process is relatively faster for the helium than for the hydrogen due to energy differences. The time from 240,000 to 310,000 years is known as the *recombination* epoch. The study of this epoch is important to ascertain the primordial abundances, such as, a percentage abundance ratio for H:He of ~93:7 by number, and ~76:24 by mass. All the helium produced continuously in stars is still significantly less than those produced in the first three minutes after the BB. During that era, conditions was just right to produce 98% of the helium in the universe today. The universe has 1 helium nucleus for 9 hydrogen nuclei. Had the conditions been different, present ratio would have been different. It is known that most of the hydrogen in the universe is in its natural form, not as its heavier isotopes deuterium or tritium. Deuterium is not produced in stars; it is only destroyed. Therefore the abundance of deuterium today places a lower limit on the amount of deuterium produced in the epoch of primordial nucleosynthesis, and thus on the density of baryons. Current abundance of the elements must be explained by any model of what happened in the early universe. The hot Big Bang does explain what we see today, and the abundances place a very firm constraint on the baryon density in the universe.

The atomic nuclei joined with electrons many years later would eventually become the seeds of stars. All of the other elements from the carbon, nitrogen, and oxygen upon which life is based, to metals like iron, copper and gold were forged in repeating cycles of starbirth and death. Astronomical objects, such as galaxiex, novae, black holes, stars, planets are being formed as more materials are created.

5. THE EXPANDING UNIVERSE

The discovery by Edwin Hubble that universe is expanding (known as Hubble law) supports Big Bang that the universe was once a point source, and started and continues to expand to cosmos and cool to this day.

Uniform expansion of the isotropic and homogeneous universe implies that radiation from far away objects recede from an observer with constant velocity v. Empirical observations lead to Hubble's Law

$$v(t) = H_o \times d(t), \tag{1}$$

where d is the distance at an epoch t (look-back time) and H_o is the *Hubble Constant.* The commonly accepted value of $H_o \sim 67$ km/sec/Mpc. Since the linear Hubble relation has the slope H_o its inverse $1/H_o$ has the dimension of time and directly yields the age of the universe. However, it should be noted that Hubble's law assumes uniform velocity expansion whereas (i) actual velocity is determined by the amount of matter owing to gravity and (ii) observations show a net acceleration of present day galaxies. Both of these quantities depend on cosmological parameters, particularly the matter and energy density in the universe. The ultimate fate of the universe, whether it will continue to expand, or eventually reach a steady state, or collapse in one big crunch, depends on the density of baryonic matter.

6. COSMIC MICROWAVE BACKGROUND

The cosmic microwave background (CMB) radiation is known as the relic radiation from the creation of the universe. It fills the space in all directions regardless of presence of other astronomical objects. The radiation can be seen as a faint background glow.

CMB is the result of transperent universe after the recombination era when neutral atoms formed. The temperature of the universe dropped to about 3000K in the recombination period. Neutral atoms can not absorb thermal radiation. This made the matter in the universe transparent to radiation. Matter and radiation of photon era began to follow separate thermal histories. Photons present at that time have been propagating ever since, though growing fainter and less energetic, since the exact same photons fill a larger and larger universe. This is CMB radiation or CMBR. Hence the CMB is a picture of the universe at the end of the recombination epoch. The CMBR has a thermal black body spectrum at a temperature of 2.725 K. It causes the spectrum to peak in the microwave range frequency of 160.2 GHz, corresponding to a 1.9 mm wavelength. The CMB's discovery in 1964 by radio astronomers Arno Penzias and Robert Wilson was the culmination of work initiated in the 1940s, and earned them the 1978 Nobel Prize.

The CMB glow is almost but not quite uniform in all directions. It shows a very specific characteristic expected if the inherent randomness of a red-hot gas is blown up to the size of the universe. While the universe remains generally isotropic, observations of the early universe contain information on anisotropies in the CMB radiation. Such anisotropies were detected in recent observations by the satellite *Wilkinson Microwave Anisotropy Probe* (WMAP). Compton scattering of particles with photons prior to recombination epoch would distort the otherwise isotropic CMB radiation to small extent, an effect known as the *Sunayev-Zeldovich effect*. A new space probe PLANCK has been launched in 2009 to measure anisotropies over the entire sky with higher precision.

The recessional velocity of all objects from one another (assuming isotropy) implies a wavelength shift in radiation from any object observed by any observer relative to restframe. The wavelength is given in analogy with Doppler effect. Since the observed wavelength would appear to be redder than the rest wavelength, there is a relation on redshift and temperature. We define the redshift as

$$z \equiv [\lambda(obs) - \lambda(rest)]/c = v/c. \qquad (2)$$

The effective temperature of the Universe at $z > 0$ is given by

$$T(z) = T_o(1 + z). \qquad (3)$$

The 3000K radiation from the recombination era can be seen today redshifted by a factor of 1000 to make up the 2.725 K cosmic microwave background as can be seen in the equation. In the above equation $T_o =$ 2.725 K is the background temperature at the present epoch $z = 0$. The radiation associated with a blackbody at this cold temperature is in the microwave region. As defined, the CMB temperature increases linearly with z. The transition from radiation to matter dominated universe is at $z \sim 35{,}000$, or T(z) $\sim 10^5$K. Cosmological models yield a corresponding timeframe of about 3000 years after the big bang.

7. ASTRONOMICAL OBJECTS

7.1. ORION NEBULA, THE BIRTHPLACE OF STARS

The conditions for formation of a star and its evolution is relevant to understanding the sun. The nearest birthplace of stars, 1,500 light years away, in the cosmic cloud called the Orion nebula has always been the subject of study. It is located below the three stars in the Orion constellation shown in Figure 2. Orion constellation is easily detecte in the sky because of these three lined up stars. For easy location of stars in the night sky, constellations of stars were imagined through various objects. The Orion constellations was imagined to be a hunter as drawn in Figure 2.

Orion nebula is seen as a reddish patch below the Orion belt. Detailed pictures of the nebula were taken by NASA's two space telescopes, Spitzer and Hubble. Figure 3 shows the combined pictures. The orange-yellow dots in the picture are the infant stars, over 1000, embedded in a cocoon of dust and gas. Various colors in the picture provide information on the constituents and physical conditions for formation of stars.

7.2. BLACKHOLES - CENTER OF IMENSE POWER

Among the astronomical objects, blackholes are of great interest as these hold immense power for sustaining a galaxy or cause drastic changes in

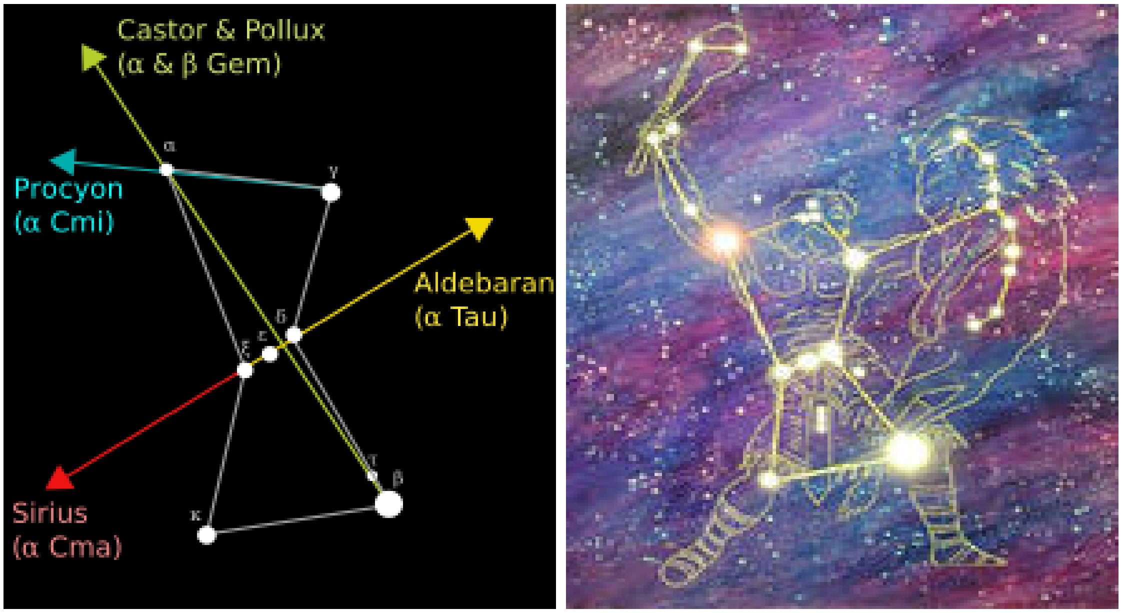

Figure 2. Imaginary figure of Orion constellation - "Orion the Hunter" where the three stars form his belt.

Figure 3. Orion nebula - the birthplace of over 1000 newborn stars (small dots) in a cocoon of dust and gas illuminated by other stars.

surrounding astronomical objects. By the power of intense gravity, these objects pull in not only materials, also the light passing nearby. Most of the galaxies are centered around a blakhole and their activities are driven by the center blackhole. The existence of a blackhole, from which light can not escape, is determined by the strong emission of X-rays around it or by the motion of the surrounding objects. The radiation is generated

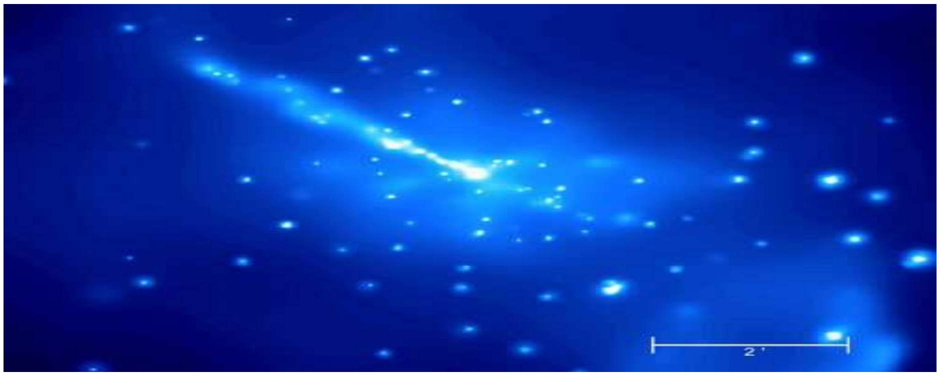

Figure 4. Centaurus A is the nearest galaxy to earth that contains a supermassive black hole actively powering a jet. Observed by Chandra space telescope.

by the superhot charged particles spiraling around and falling in to the hole. A blackhole can ejct a jet of energetic particles as seen in Figure 4. Astronomers think that such jets are important vehicles for transporting energy from the black hole to the much larger dimensions of a galaxy, and affecting the rate at which stars form there.

Blackholes are end products of stellar evolution of giant stars. Numerous smaller black holes in binary star systems exist in galaxies. One most spectacular one is GRO J1655-40 binary system observed by Chandra space telescope. Figure 5 shows materials from the large comparion star of the binary system is sucked in to the other companion blackhole. The materials form a wind as they spiral around the blackhole. The narrow-line X-ray spectra of the wind shows existence of highly charged elements Mg, Si, Fe, Ni.

7.3. SUPERNOVA REMNANTS - SOURCE FOR HEAVY ELEMENTS

Supernova remnants are important objects of study as they are related to planet formation. While most of the space is filled with hydrogren and helium, heavy elements are found in planets. These heavy elements, like ziconium, gold, uranium etc., are formed during supernova explosions. Our earth is rich in all kinds of elements because it formed from the debris of multiple generations of earlier supernova remnants. Figure 6 shows supernova remnant Cassiopia A observed by three telescopes: Spitzer (Infrared - red), Hubble (Visible - yellow), Chandra (X-ray -

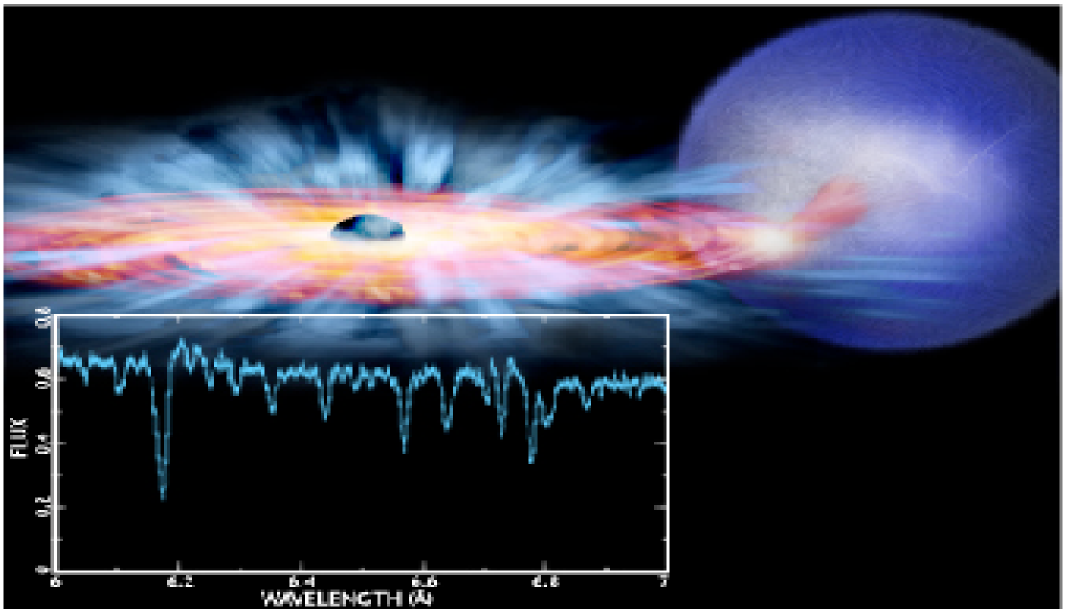

Figure 5. GRO J1655-40 binary star system where the materials from the large star (ballon shaped) is being sucked in to the blackhole companion (center point on the left). X-ray lines specturm of the wind by the falling particles near the blackhole tells the types of elements present in the wind.

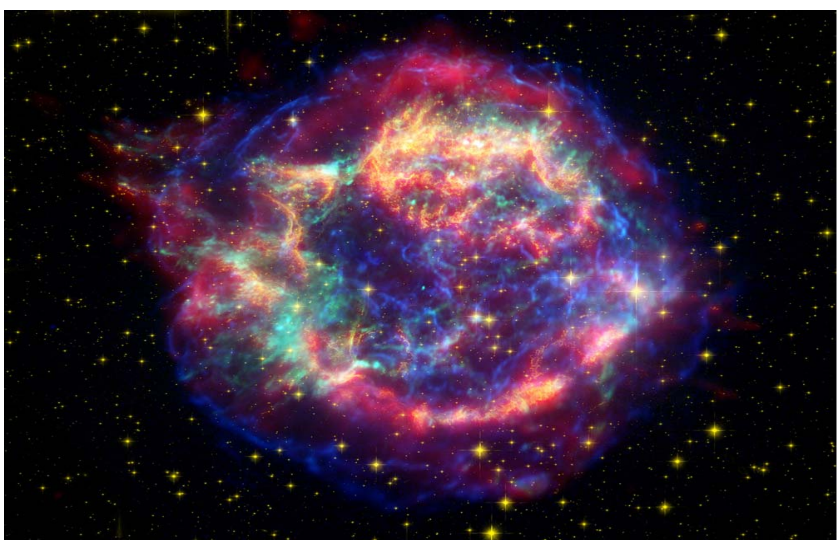

Figure 6. Supernova remnant Cassiopia A. Supernova remnants contain various heavy elements created during the explosion.

green blue). A supernova remnant like Cassiopeia A typically consists of an outer, shimmering shell of expelled material and a core skeleton of a once-massive star, called a neutron star.