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Frontier Research in Astrophysics: Old and New Results

Franco Giovannelli[*†]
INAF - Istituto di Astrofisica e Planetologia Spaziali, Roma
E-mail: franco.giovannelli@iaps.inaf.it

Lola Sabau-Graziati
INTA-Dpt Cargas Utiles y Ciencias del Espacio, Madrid
E-mail: sabaumd@inta.es

In this paper – a short updated version of our review paper about "*The impact of space experiments on our knowledge of the physics of the Universe* (Giovannelli & Sabau-Graziati (2004) (GSG2004) – we will briefly discuss old and new results obtained in astrophysics, that marked substantially the research in this field. Thanks to the results, chosen by us following our knowledge and feelings, we can describe the main pillars that support the "Bridge between the Big Bang and Biology". We will remark the importance of the joint venture of 'active physics experiments' and 'passive physics experiments' ground– and space–based that, with their results, are directed towards the knowledge of the physics of our universe. New generation experiments open up new prospects for improving our knowledge of the aforementioned main pillars. We will discuss about the

- Big Bang Theory,
- Background in the Universe,
- Problem of the Flatness of the Universe,
- Extragalactic Background Light,
- Determination of the Hubble Constant,
- Re-ionization Epoch
- Unified Scheme for Collapsed Objects,
- Jets,
- Gamma-Ray Bursts,
- Star Formation,
- Cross Sections of Nuclear Reactions in Stars,
- Galactic Compact Sources,
- Habitable Zone in the Milky Way and Exoplanets,
- Conclusions

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1. Introduction

The birth of the universe and its present status constitute the two banks of a river in which the life of the universe is slowly flowing. Undoubtedly the two banks are joined by a bridge that Giovannelli (2001a) nicknamed "The Bridge between the Big Bang and Biology" that constituted the title of the workshop held in Stromboli (Aeolian Archipelago, Sicily, Italy) in 1999.

In this paper we will briefly discuss the main pillars of this bridge by using the huge amount of experimental data coming from "*Active Physics Experiments (APEs)*" and from "*Passive Physics Experiments (PPEs)*" ground– and space–based. The APEs try to reproduce in laboratory the physical conditions of our Universe at the beginning of its life and later, while the PPEs try to observe our Universe after the epoch of recombination, when the Cosmic Microwave Background (CMB) gives witness of the conditions of the primeval Universe, and later – after the epoch of reionization, when the first stars appear – for providing information about the formation of galaxies, "active" and "normal", quasars (QSOs), and all the processes giving rise to Gamma Ray Bursts (GRBs), stellar evolution and Supernovae explosions. These latter phenomena are responsible of the injection of heavy elements in the interstellar medium, condition necessary for the formation of rocky planets, and then maybe the flowering of the life.

Figure 1 shows schematically the temperature of the Universe versus its age. The light–red and the light–indico rectangles indicate the domains of APEs and PPEs, respectively (after Denegri, 2006). The positions in the Fig. 1 of the various LHC (Large Hadron Collider) experiments are indicated.

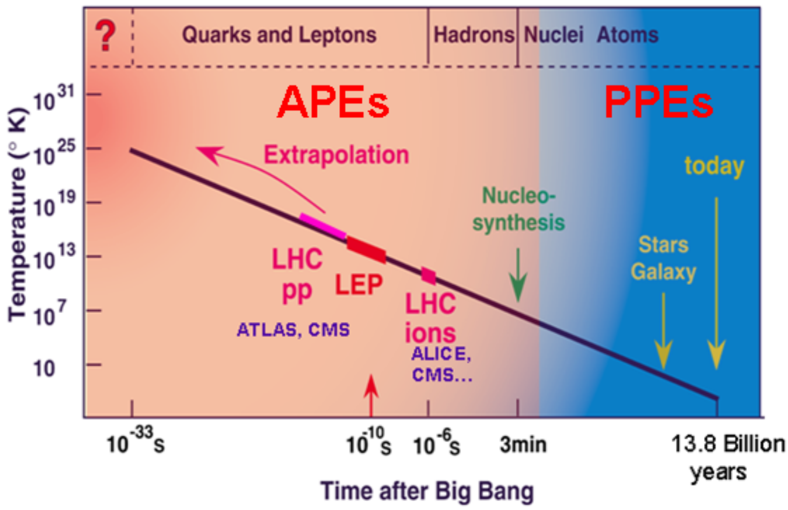

Figure 1: Schematic diagram of the temperature of our Universe versus its age. The domains where APEs and PPEs operate are marked with the light–red and the light–indico rectangles (after Denegri, 2006).

For describing the origin of our Universe, the Big Bang model (BBM) is generally accepted, but it is not complete. Indeed, the BBM is based on the Cosmological Principle which assumes that matter in the universe is uniformly distributed on all scales. This is a very useful approximation

*Speaker.

†A footnote may follow.

that allows one to develop the basic Big Bang scenario, but a more complete understanding of our Universe requires going beyond the Cosmological Principle. Many cosmologists suspect that the inflation theory may provide the framework for explaining the large-scale uniformity of our universe and the origin of structure within it.

Figure 2 (Shellard, 2003) shows the evolution of our Universe from the Big Band till today: Quantum gravity wall (10^{-43} s), Grand unification transition (10^{-35} s), Electroweak transition (10^{-11} s), Quark-hadron transition (10^{-6} s), Nucleosynthesis (3 minutes), Matter domination ($\sim 5 \times 10^3$ yr), Recombination ($\sim 4 \times 10^5$ yr), Galaxy formation Era (start at $\sim 7 \times 10^8$ yr), Star formation peak ($\sim 3 \times 10^9$ yr), Solar system formation ($\sim 9.4 \times 10^9$ yr), Earth formation ($\sim 9.7 \times 10^9$ yr), Acceleration ($\sim 11 \times 10^9$ yr), Life on Earth ($\sim 11.5 \times 10^9$ yr), Today ($\sim 14 \times 10^9$ yr).

Spergel et al. (2003) by using the first year data from WMAP derived for the age of the Universe 13.7 ± 0.2 Gyr. The WMAP determination of the age of the universe implies that globular clusters form within 2 Gyr after the Big Bang, a reasonable estimate that is consistent with structure formation in the ΛCDM cosmology. Recent measurements from WMAP provide an age of our Universe of $(13.77 \pm 0.059) \times 10^9$ yr (Komatsu & Bennett, 2014).

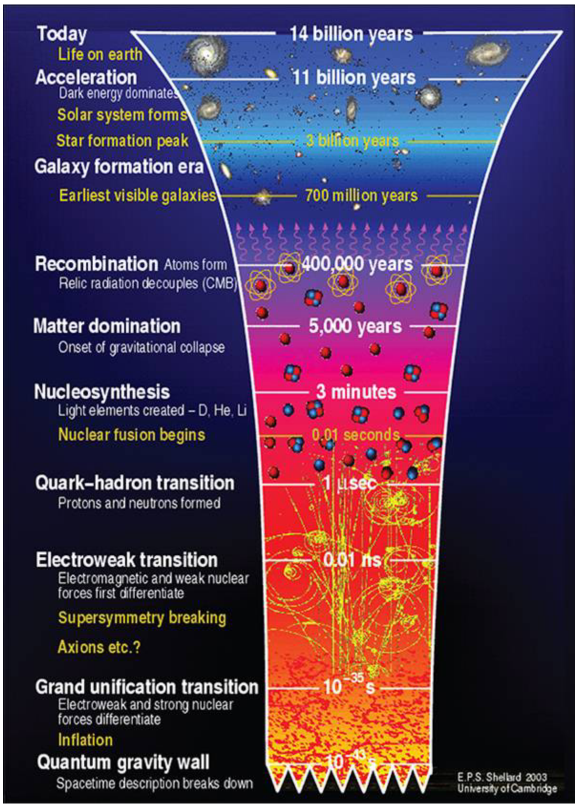

Figure 2: Evolution of our Universe from the Big Bang till today (courtesy of Shellard, E.P.S., 2003).

2. Big Bang

We will briefly discuss the state of art of the BBM by using the recent results coming from APEs and PPEs.

2.1 APEs

As we can see from Fig. 1, the different experiments of LHC can provide information about the first moment of the life of the Universe. LHC is a complementary tool for HE observatories looking directly to the Universe.

From ATLAS results, a 5.0 σ excess at $\sim$ 126.5 GeV has been detected. This value is compatible with the expected mass of Higg's boson (Gianotti, 2012). If this result would be confirmed, a remarkable step in supporting the BBM would be reached.

2.2 PPEs

Recently the collaboration of the BCEP2 experiment claims the detection of E-mode and B-mode polarization of the CMB (Ade et al., 2014). If B-mode polarization would be confirmed, the inflationary model of the Universe would be definitively confirmed. However, big discoveries need big confirmations.

In the last decade several experiments provided results confirming the validity of the BBM. In Fig. 3 one can see: i) (left panel): red star - the experimental confirmation of the content of the primordial light elements (de Bernardis et al., 2000) superimposed to the theoretical curves (Burles et al., 2001); ii) (central panel): red line - the temperature of the Cosmic Microwave Background Radiation (T_{CMBR}) at redshift z = 2.34, ranging between 6 and 14 K (Srianand, Petitjean & Ledoux, 2000), in agreement with the theoretical temperature law T_{CMBR}= $T_{CMBR}(0)(1+z)$, which gives at z = 2.34 a temperature of 9 K; iii) (right panel): the CMB radiation temperature (2.726 ± 0.010 K) (Bartelmann, 2008, after Mather et al., 1990).

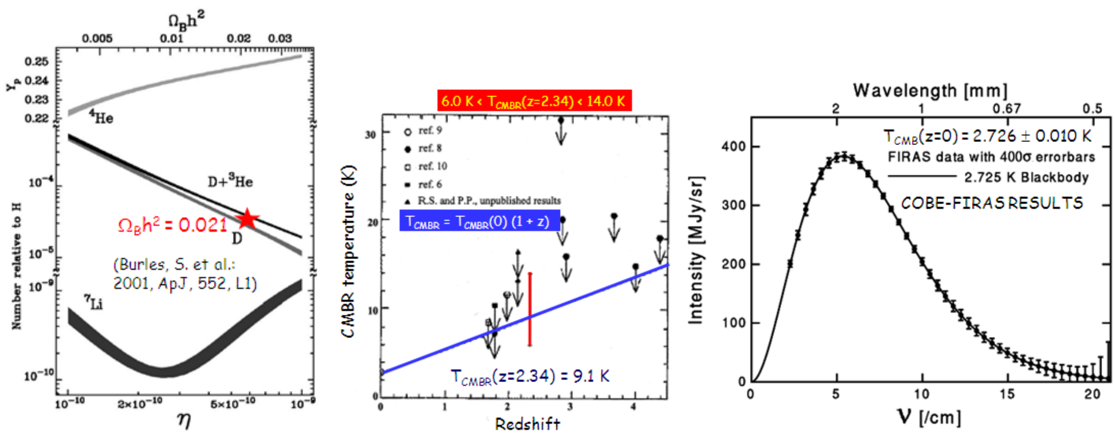

Figure 3: Three experimental results in favour of the BBM (see text for explanation).

3. Background Radiation in the Universe

The Diffuse Extragalactic Background RAdiation (DEBRA) permeates through the whole electromagnetic spectrum, and it is peaked in the microwave region. It is possible to consider the DEBRA as a radiation produced by a cosmic source: the whole Universe. Such a background radiation from radio to HE γ-ray energy bands has been deeply discussed by Ressell & Turner

(1990), and in GSG2004 and the references therein. The analysis of the different components of DEBRA leads to the Grand Unified Photon Spectrum (GUPS), covering 29 orders of magnitude of the electromagnetic spectrum, from 10^{-9} to 10^{20} eV, as shown in Fig. 4 (after Ressell & Turner, 1990). The light–red and the light–indico rectangles indicate the domains with energies less or greater than $\approx$ 10 GeV, respectively. The domain at higher energies is now explored by numerous experiments space–based, like Fermi LAT observatory (up to 300 GeV) and ground–based, like Whipple, Veritas, HESS, Magic, and the coming CTA (Cherenkov Telescopes Array). All these experiments will provide to fill the zone of the GUPS diagram prepared by Ressell & Turner (1990) where only upper limits were reported.

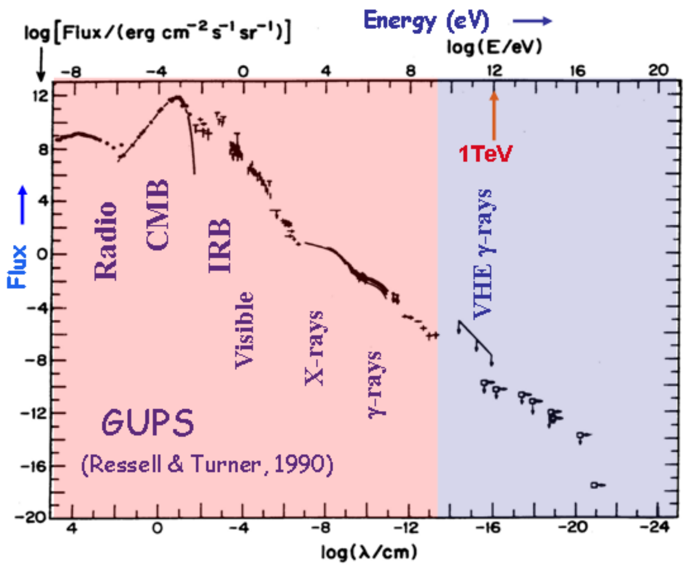

Figure 4: The Grand Unified Photon Spectrum of the Diffuse Extragalactic Background Radiation (after Ressell & Turner, 1990).

Henry (1999, 2002) thoroughly discussed the updated experimental situation of the cosmic background.

4. Problem of the Flatness of the Universe

One of the most critical points about our Universe is the problem of its flatness. The present state of the cosmological tests is illustrated in Fig. 5. The left panel of Fig. 5 shows the results obtained with the BOOMERanG (Balloon Observations Of Millimetric Extragalactic Radiation and Geomagnetics) experiment (de Bernardis et al., 2000). They are fully consistent with a spatially flat Universe. The right panel of Fig. 5 shows the combination of the likelihood contours obtained with three different observational approaches: i) type-Ia SNe (Tonry et al., 2003; Riess et al. 2004); ii) CMB (Spergel et al. 2003; Bennett et al. 2013); iii) galaxy clusters (Schuecker et al. 2003; Schuecker, 2005). One can see that the cosmic matter density is close to Ω_m = 0.3, and that the normalized cosmological constant is around Ω_Λ = 0.7. This sums up to unit total cosmic energy density and suggests a spatially flat universe. However, the density of cosmic matter growths with redshift like $(1 + z)^3$ whereas the density ρ_Λ related to the cosmological constant Λ is independent

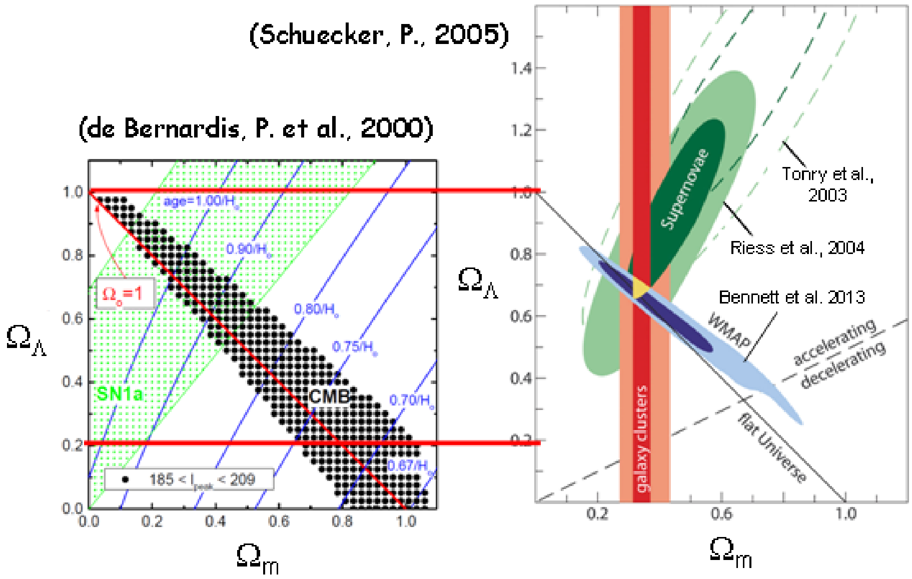

Figure 5: Constraints of cosmological parameters (after de Bernardis et al., 2000; Schuecker, 2005, Bennett et al., 2013).

of z. The final results from WMAP (Bennett et al., 2013) shows a little misalignment with the line of "flat Universe". Thus it is necessary to be careful in the conclusions.

5. Extragalactic Background Light

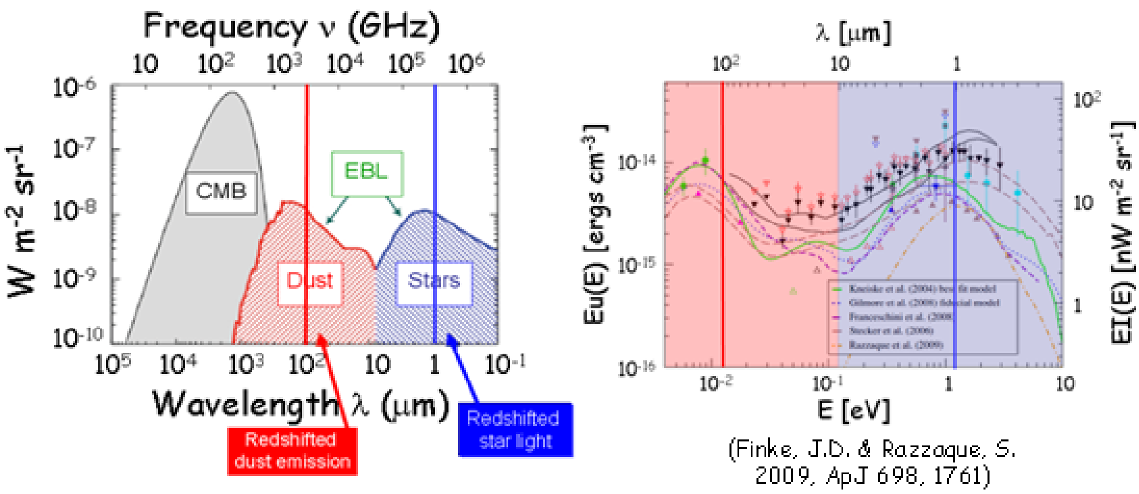

Figure 6: Extragalactic Background Light (EBL): left panel – the contribution to EBL of redshifted dust emission and redshifted star light; right panel – experimental data clearly reproducing the shape of the former contributions (after Finke & Razzaque, 2009). For a comparison of the two plots, red and blue vertical lines mark 100 and 1 μm wavelength, respectively.

The intergalactic space is filled with the light produced by all the stars and accreting compact objects that populated the observable Universe throughout the whole cosmic history. This relic cosmic background from IR to UV is called the diffuse Extragalactic Background Light (EBL). Figure 6 shows: (left panel) – the contribution to EBL of redshifted dust emission and redshifted star light; (right panel) – experimental data clearly reproducing the shape of the former contributions (Finke & Razzaque, 2009). The light–red and light–indico rectangles show the zones of redshifted dust emission and redshifted star light, respectively.

Direct measurements of the EBL are difficult due to bright local foregrounds. A powerful approach for probing these diffuse radiation fields in the UV to far-IR bands is through γ–γ absorption of high-energy photons. Actually pair production (e^+ e^-) against EBL photons with wavelengths from ultraviolet to infrared is effective at attenuating γ–rays with energy above $\sim$ 10 GeV. This process introduces an attenuation in the spectra of γ–ray sources above a critical energy (Buson, 2015 – these proceedings).

Thanks to measurements of the quasar 3C 279 ($z \simeq 0.54$) obtained with the MAGIC experiment (Albert et al., 2008), and with the many sources at high redshift, including Gamma Ray Bursts (GRBs) measured with the Fermi LAT observatory (Abdo et al., 2010), it has been demonstrated that the Universe is more transparent to γ–rays than before believed (Coppi & Aharonian, 1997).

6. Hubble Constant

The Hubble constant (H_0) is one of the most important numbers in cosmology because it is needed to estimate the size and age of the universe. The important problem of determination of H_0 value is one of the most exciting. Indeed, in the literature it is possible to find many determinations coming from different experiments using different methods. However, it is very complicate to obtain a true value for H_0. It is necessary to have two measurements: i) spectroscopic observations that reveal the galaxy's redshift, indicating its radial velocity; ii) the galaxy's precise distance from Earth (and this is the most difficult value to determine). Reliable "*distance indicators*" such as variable stars and supernovae (SNe), must be found in galaxies. The value of H_0 itself must be cautiously derived from a sample of galaxies that are far enough away that motions due to local gravitational influences are negligibly small. The history of the determination of the Hubble constant is long and full of controversial debates. Indeed, from the first evaluation of H_0 = 500 km s^{-1} Mpc^{-1} made by Hubble himself (Hubble, 1927, 1929a,b; Hubble & Humason, 1931). Baade (1952) pointed out that there were two different types of Cepheid, so Hubble's calibration had been incorrect. This reduced H_0 to 200 km s^{-1} Mpc^{-1}. Sandage (1958) recognized that objects that Hubble had thought were the brightest stars in some of his galaxies were in fact clouds of hot gas and he arrived at the first recognizably modern value of 75 km s^{-1} Mpc^{-1}. There was an acute disagreement between Sandage (1968) and Sandage and Tammann (1990), on the one hand, favoring H_0 = 50 km s^{-1} Mpc^{-1}, and de Vaucouleurs & Peters (1986), on the other, favoring H_0 = 109 $\pm$ 4 km s^{-1} Mpc^{-1}, and de Vaucouleurs (1993) who determined H_0 = 88.8 $\pm$ 5.7 km s^{-1} Mpc^{-1}. Giovannelli & Sabau-Graziati (1999a) in their review paper noted that observations with ROSAT satellite have shown that rich clusters of galaxies have mass fraction $\sim 0.3 \times (h_0)^{-3/2}$ of hot X-ray gas (Mushotzky, 1992). Since $\Omega_{\rm cluster} \sim 0.2$, this yields $\Omega_b \sim 0.06$ for these clusters, in reasonable agreement with the BBN, but only if $h_{50} = H_0/50 \sim 1$. This result strongly favors a value of H_0 = 50 km s^{-1} Mpc^{-1}. Moreover, a prediction of the inflation is a flat universe, roughly confirmed by BOOMERanG and WMAP results, that implies $\Omega = 1$. The age of the universe is T_U

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= 2/3 H_0 for a matter dominated universe ($\Omega = 1$). On the other hand, the age of globular clusters is 15 $\pm$ 3 Gyr (Schramm, 1990). This is consistent with a universe with $\Omega = 1$ only if H_0 = 60 km s^{-1} Mpc^{-1} (Giovannelli & Sabau-Graziati, 1999b). Panagia (1999) gave a value H_0 = 59 $\pm$ 6 km s^{-1} Mpc^{-1} by using SNIa as standard candles and HST observations of Cepheids in parent galaxies of SNIa.

Professor Livio Gratton (1990) in "*Reflections on Hubble constant*", his last unpublished paper, critically discussed and compared the many evaluations of the Hubble constant giving as result 52 > H_0 > 45 km s^{-1} Mpc^{-1}. Giovannelli & Sabau-Graziati (1997) analyzing all the available data in that epoch concluded that H_0 = 56 $\pm$ 6 km s^{-1} Mpc^{-1}. Van den Bergh (1989) in his review – that he defined perhaps "*the last large review on the scale of distances before that the true value of H_0 be determined*" – concluded that the most probable value of the Hubble constant is H_0 = 67 $\pm$ 8 km s^{-1} Mpc^{-1}, that a posteriori seems to be the proper one. Indeed, in 2001 the HST Key Program team, led by Wendy Freedman, announced their final result: H_0 = 72 $\pm$ 8 km s^{-1} Mpc^{-1} (Freedman et al., 2001). Again van den Bergh (1992) critically reviewed the distance determinations to individual galaxies, groups, and clusters and derived a value H_0 = 76 $\pm$ 9 km s^{-1} Mpc^{-1}. A large summary about the methods used for H_0 determination, and its derived values can be found in the Proceedings of the Fall 2004 Astronomy 233 Symposium on "*Measurements of the Hubble constant*" (Damon et al., 2004). Sandage et al. (2006), by using the Hubble Space Telescope (HST) to determine the Hubble constant from the Cepheid-calibrated luminosity of Type Ia supernovae, found H_0 = 62.3 $\pm$ 1 (random) $\pm$ 5 (systematic) km s^{-1} Mpc^{-1}.

So that it appears very clear the difficulty in determining the value of the Hubble constant, which seems to be the "*most variable constant of the whole Universe*".

Later Riess et al. (2011) with the HST determined a value of H_0 = 73.8 $\pm$ 2.4 km s^{-1} Mpc^{-1}. This value agrees with the WMAP results: H_0 = 71.0 $\pm$ 2.5 km s^{-1} Mpc^{-1} (Komatsu et al., 2011). Does this determination, finally, close the history about the search of the "true" value of H_0?

7. Reionization Epoch

Ground-based observations of the CMB on subdegree angular scales suggest that the gas content of the universe was mostly neutral since recombination at z$\sim$ 1000 until about z$\sim$ 100 (Gnedin, 2000 and the references therein) because earlier reionization would have brought the last scattering surface to lower redshift, smoothing the intrinsic CMB anisotropy. At the same time, we know that the universe is highly ionized, since z$\approx$ 5, from observations of the spectra of quasars with the highest redshifts (e.g. Giallongo et al. 1994). This change of the ionization state of the universe from neutral to highly ionized is called "*reionization*". How large is the redshift to which the reionization started and stopped is object of strong debate.

The formation of the first stars and quasars marks the transformation of the universe from its smooth initial state to its clumpy current state. In current cosmological models, the first sources of light began to form at a redshift z$\sim$ 30 and reionized most of the hydrogen in the universe by z$\sim$ 7 (see review by Loeb & Barkana, 2001).

The argument for an extended period of reionization is now proved by measurements. Indeed, the WMAP has detected the correlation between temperature and polarization on large angular scales (Kogut et al., 2003) that has an amplitude proportional to the total optical depth of CMB

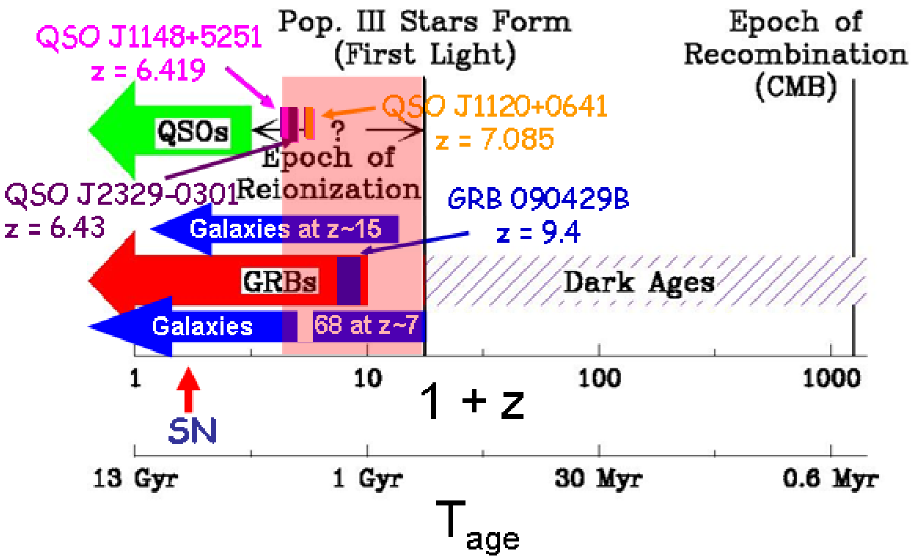

Figure 7: A sketch of reionization epoch (after Xiangping Wu's Talk at the Summer School on "Cosmic Reionization" at the KIAA-PKU , Beijing, China, July 1-11, 2008).

photons to Thomson scattering, τ (Kaplinghat et al., 2003; Sunyaev & Zeldovich, 1980; Zaldarriaga, 1997).

Modeling reionization with a single sharp transition at z_{ri}, a multi–parameter fit to the WMAP data gives $z_{ri} = 17 \pm 5$ (Spergel et al., 2003). On the other hand, the evolution of quasar spectra from $z \approx 7$ and $z \approx 6$ shows a rapid decrease in the amount of neutral Hydrogen, indicating the end of reionization (Fan et al., 2003). A simple interpretation to explain these two very different datasets is that reionization started early, $z_{ri} \sim 20$, but did not conclude until much later ($z \sim 6$) (Knox, 2003).

The WMAP detection of reionization (Kogut et al. 2003) implies the existence of an early generation of stars able to reionize the universe at $z \sim 20$. Panagia et al. (2005) in deep HST/VLT/Spitzer images found that the source UDF 033238.7-274839.8 – a post–starburst galaxy with a mass $\sim 6 \times 10^{11}$ $M_{\odot}$ placed at $z \geq 6.5$ – may be capable of reionizing its surrounding region of the universe, starting the process at a redshift as high as $z = 15 \pm 5$.

Figure 7 shows schematically the updated experimental situation about cosmic sources (galaxies, GRBs, QSOs, SNe) detected at high redshifts. The light–red rectangle marks the possible range of z during which the reionization occurred.

However, although there is rather good agreement about the epoch of re-ionization, how really re-ionization occurs is still object of debate. Indeed, Dopita et al. (2011), considering that recent observations show that the measured rates of star formation in the early universe are insufficient to produce re-ionization, suggest the presence of another source of ionizing photons. This source could be the fast accretion shocks formed around the cores of the most massive haloes.

8. A Unified Scheme for Collapsed Objects

The argument of the possibility of describing all the collapsed objects with a unique scheme have been discussed since long time by many authors. In their review paper, Begelman, Blandford & Rees (1984) discussed the theory of extragalactic radio sources and in particular the unified model of active galactic nuclei (AGNs).

From the evidence that the shapes of SEDs (Spectral Energy Distributions) of different kind of AGNs (Cen A, NGC 4151, and 3C 273) are practically the same (e.g. Ramaty & Lingenfelter, 1982), Giovannelli & Polcaro (1986) (GP86), by using experimental data coming from the EINSTEIN observatory, constructed the maximum luminosity diagram for extragalactic objects, independent of the current classification of those objects. Indeed, those extragalactic objects have the same engine producing energy (supermassive black hole with accretion disk and jet) and they are classified as blazars, or radio-loud QSOs, or radio galaxies depending on the angle between the line of sight and the jet axis. The attenuation in the emission of a cosmic source containing a black hole in function of such an angle and the beam Lorentz's factor of the particles have been calculated by Bednarek et al. (1990).

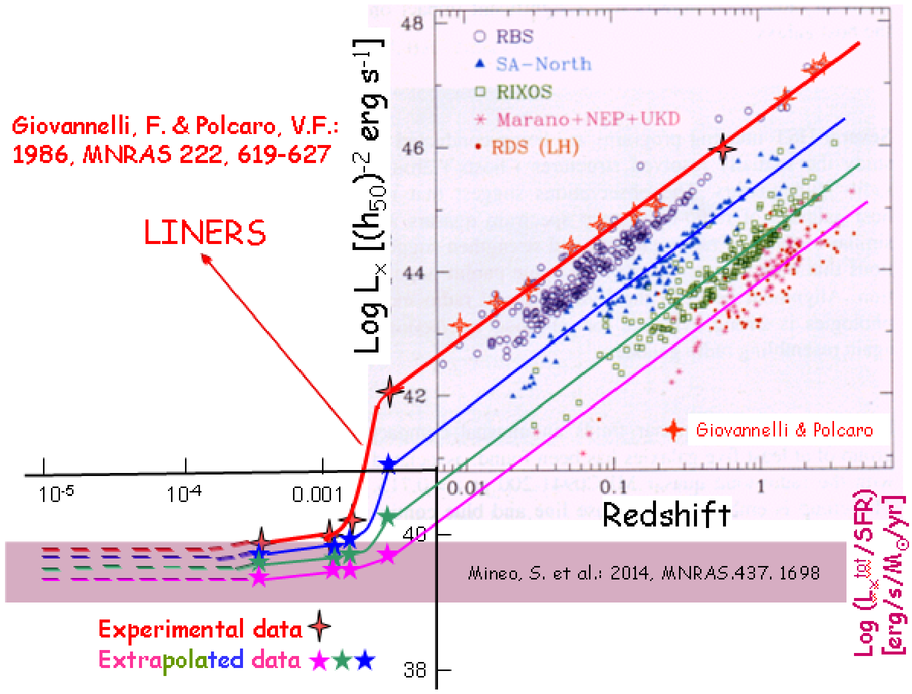

Figure 8: L_{xmax} versus z for extragalactic X-ray emitters. Red crosses and red line represent GP86 diagram. The deeper surveys shown in the diagram are indicated with different colors. The light plum-colored band indicates the range of Mineo et al. (2014) results.

The emission of the extragalactic X-ray sources can be expressed as $L_{TOT} = L_{NUC} + L_{HG}$, where, L_{NUC} is the nuclear luminosity and L_{HG} is the host galaxy luminosity, formed by the integrated emission of its discrete sources. Such components can be derived by using the GP86 diagram. In the long review paper GSG2004 there is a discussion about the GP86 diagram using also the data coming from X-ray surveys of extragalactic objects at higher sensitivities (Hasinger et al., 1999).

Taking the brightest objects for an arbitrary binning of redshift (Δz) one obtains the upper part of the GP86 diagram, $L_{xmax}(z)$, as shown in the Figure 86 of GSG2004. If the choice of the brightest object for an arbitrary Δz is repeated for each survey with higher sensitivities one obtains a family of curves parallel to that of the aforesaid diagram. This means that the conclusions discussed by GP86 are still valid, namely, there is a physical continuity between the different classes of compact extragalactic X-ray sources. This strongly indicates the existence of a unique kind of central X-ray source. The numerical continuity of the whole $L_{xmax}(z)$ function should be interpreted as owed to an evolution of the central X-ray source from a very active to a more quiet status. Moreover, the part of GP86 at lower redshifts converge to the level of emission due to the discrete sources within the galaxies. This was recently supported by the results of Mineo et al. (2014) that provide a range of possible emission of discrete sources in the galaxies between $\approx 10^{39}$ and $\approx 10^{40}$ erg s^{-1} M$_{\odot}^{-1}$ yr^{-1}. Figure 8 shows the GP86 diagram (red crosses) and the deepest surveys (as clearly shown in the figure), and the allowed band of Mineo et al. (2014) (light plum-colored).

9. Jets in Astrophysics

Every object rotating with adequate energy produces a jet. Relativistic jets have been found in numerous galactic and extragalactic cosmic sources at different energy bands. They can be formed by electrons and protons – accelerated up to relativistic energies – which through interactions with the matter and/or photons generate high energy radiation. The spectra of such a radiation are strongly dependent on the angle formed by the beam axis and the line of sight, and obviously by the Lorentz factor of the particles (e.g. Bednarek et al., 1990 and the references therein; Beall, Guillory & Rose, 1999; Beall, 2002, 2003; Beall et al., 2006, 2007).

Jets are thought to be produced by the powerful electromagnetic forces created by magnetized gas swirling toward a collapsed object (i.e. black hole). Although most of the material falls into the collapsed object, some can be ejected at extremely high speeds. Magnetic fields spun out by these forces can extend over vast distances and may help explain the narrowness of the jet (e.g. Clarke et al., 2008).

However, highly collimated supersonic jets and less collimated outflows are observed to emerge from a wide variety of astrophysical objects. They are seen in young stellar objects (YSOs), proto-planetary nebulae, compact objects (like galactic black holes or microquasars, and X-ray binary stars), and in the nuclei of active galaxies (AGNs). Despite their different physical scales (in size, velocity, and amount of energy transported), they have strong morphological similarities. What physics do they share? These systems are either hydrodynamic or magnetohydrodynamic (MHD) in nature and are, as such, governed by non-linear equations. An important review on this topic was published by de Gouveia dal Pino (2005). Very interesting discussion has been published about the role of magnetic reconnection on jet/accretion disk systems, valid in different kind of cosmic sources, like from microquasars to low luminous AGNs, till YSOs (de Gouveia Dal Pino, Piovezan & Kadowaki, 2010).

Several examples of jets can be seen in the Chandra X-ray images. Such jets are coming from different sources, such as the radio galaxies Pictor A, Cyg A and Cen A, the Crab and Vela pulsars and nebulae, and several Herbig Haro objects: HH 30, HH 34, HH 47, as shown in Figure 9.

Therefore, following the very interesting paper by Beall et al. (2007), astrophysical jets are a remarkable laboratory for a number of important physical processes. They provide a confirmation

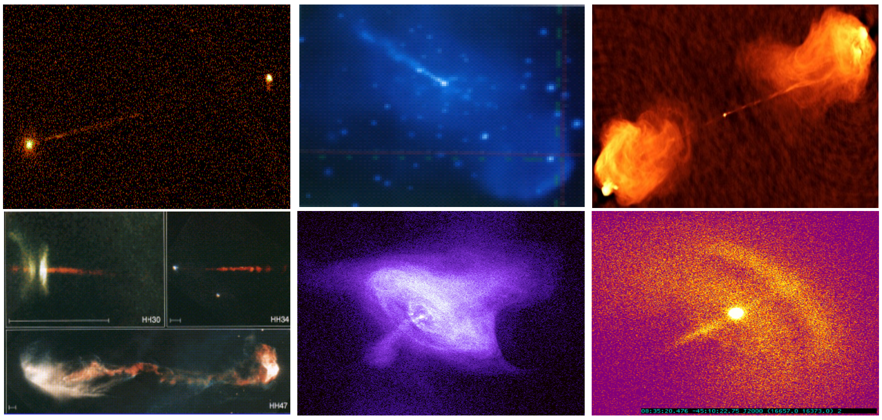

Figure 9: Clockwise from left upper panel the spectacular jets emanate from i) the center of the radio galaxy Pictor A; ii) Cen A radio galaxy; iii) Cygnus A radio galaxy; iv) Vela pulsar; v) Crab Nebula; vi) Herbig Haro objects: HH 47, HH 34, and HH 30 (NASA/Chandra X-ray Observatory ACIS Images).

of special relativity in terms of relativistic Doppler boosting, superluminal motion, and time dilation effects. When coupled with their black-hole/neutron-star origins, jets have implications for testing general relativity. Over the course of two decades of astrophysical research, we have become aware that jets are ubiquitous phenomena in astrophysics. Extended linear structures now associated with jets can be found in star–forming regions, galactic binaries, microquasars, active galaxies and quasars, clusters of galaxies, and γ-ray bursts. The presence and evolution of these jet–like structures is of course a testament to the principle of conservation of angular momentum.

The association of jets with accretion disks strengthens the case for similar physical processes in all these phenomena (e.g., Beall, 2003; Marscher, 2005), and it has become plausible that essentially the same physics is working over a broad range of temporal, spatial, and luminosity scales. Jets have, therefore, become a ‘laboratory’ or perhaps an anvil, that we can use to help us forge our understanding of the physical processes in the sky.

In 1992 the first so-called microquasar, *annihilateur*, was identified (Mirabel et al., 1992). This source was exhibiting bipolar radio jets spread over several light-years. This was the first such observation in our Galaxy, however jets had been already observed emanating from distant galaxies. Therefore this observation made clear the existence of a morphological analogy between quasars and microquasars. Indeed, Mirabel & Rodríguez (1994) detected from the black hole candidate GRS 1915+105 – discovered by Castro Tirado et al. (1994) – apparent superluminal motions, while frame velocity was v$\sim$ 0.92c. It became then rapidly clear that the advantages of microquasars compared to quasars were that i) they are closer, ii) it is possible to observe both (approaching and receding) jets, and iii) the accretion/ejection timescale is much shorter. After this observation of superluminal motions, the morphological analogy with quasars became stronger, and the question was then: is this morphological analogy really subtended by physics? If the answer is yes, then microquasars really are “micro”–quasars. For instance, there should exist microblazars (microquasar whose jet points towards the observer), in order to complete the analogy with quasars.

Although there is no clear definition of a microquasar, we can characterize it as a galactic binary system – constituted of a compact object (stellar mass black hole or neutron star) surrounded by an accretion disk and a companion star – emitting at high-energy and exhibiting relativistic jets. A schematic view of a microquasar, compared with quasars, is given in Figure 10 (Chaty, 1998). Taking this broad definition, nearly 20 microquasars in our Galaxy have been observed.

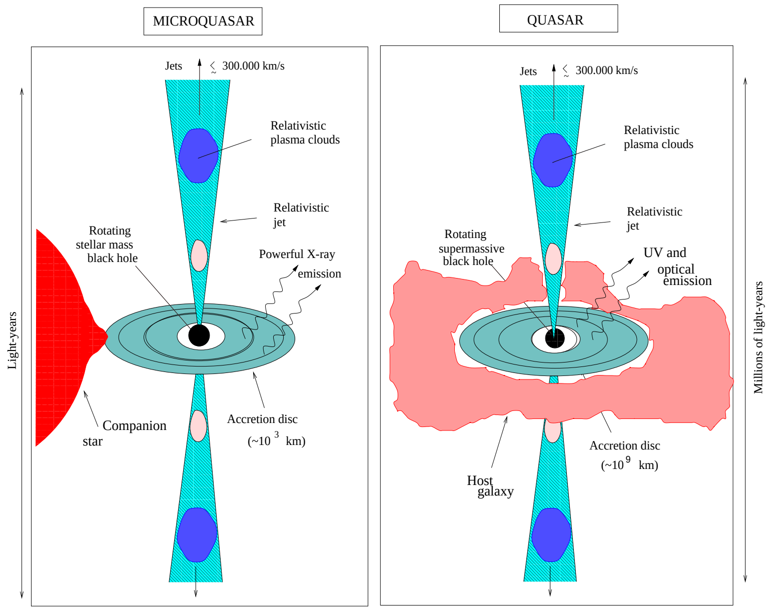

Figure 10: Sketch showing analogies between quasars and microquasars. Note the different mass and length scales between both types of objects (Chaty, 1998).

Microquasars are among the best laboratories for high energy phenomena and astroparticle physics. They are good candidates to be emitters of astroparticles: very high energy photons, cosmic rays and neutrinos. For these reasons the study of microquasars is one of the main goal of current space missions. Since each component of the system emits at different wavelengths, it is necessary to undertake multifrequency observations in order to understand phenomena taking place in these objects.

Theoretical and observational works show that jets from AGN can trigger star formation. However, in the Milky Way the first – and so far – only clear case of relativistic jets inducing star formation has been found in the surroundings of the microquasar GRS 1915+105. Mirabel et al. (2015) discussed jet-induced star formation by a microquasar. Although star formation induced by microquasar jets may not be statistically significant in the Milky Way, jets from stellar black holes may have been important to trigger star formation during the re-ionization epoch of the universe (Mirabel et al. 2011).

A recent review about jets in astrophysics has been published by Beall (2014).

10. Gamma Ray Bursts

Gamma-ray burst (GRBs) were discovered in 1967 – thanks to the four VELA spacecrafts, originally designed for verifying whether the Soviet Union abided the 1963 Limited Nuclear Test Ban Treaty – when 16 strong events were detected (Klebesadel, Strong & Olson, 1973). Since then

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GRBs have remained a puzzle for the community of high energy astrophysicists. For this reason the problem of GRBs originated thousands articles most of them devoted to their physical interpretation (e.g. the review by Mazets & Golenetskii, 1988; the review by GSG2004 and the references therein). BATSE/CGRO experiment detected 2704 GRBs from 1991 to 1999. This number increased with new generation satellites (BeppoSAX, RossiXTE, HETE, INTEGRAL, SWIFT, and Fermi LAT). From the BATSE and KONUS isotropic distribution of GRBs, their cosmological origin have been demonstrated. GRBs may be classified into two groups depending on their duration: ~ 0.2 s (25%), and ~ 30 s (75%) (e.g. Kouveliotou et al., 1993). The counterparts for all bursts can be observed in all wavelengths (X, UV, opt, IR, radio): the afterglow (e.g. Kann et al., 2010; Perley et al., 2014).

Theoretical description of GRBs is still an open strongly controversial question as discussed elsewhere (e.g. Giovannelli & Sabau-Graziati, 2008; Giovannelli, 2013). Many review papers have been published about GRBs. Among them we can cite those published in the last decade (Piran, 2004; Meszaros, 2006); Woosley & Bloom, 2006; Granot, 2007, 2009; Granot & Ramirez-Ruiz, 2010; Inoue et al., 2013). Recently an interesting review about short GRBs has been published by Berger (2014).

Important implications on the origin of the highest redshift GRBs are coming from the detection of the GRB 080913 at z = 6.7 (Greiner et al., 2009), GRB 090423 at z $\sim$ 8.2 (Tanvir et al., 2009), and GRB 090429B at z = 9.4 (Cucchiara et al., 2011). This means that really we are approaching to the possibility of detecting GRBs at the end of Dark Era, where the first Pop III stars appeared. Izzo et al. (2010) discussed successfully a theoretical interpretation of the GRB 090423 within their fireshell model. Wang & Dai (2009) studied the high-redshift star formation rate (SFR) up to z $\simeq$ 8.3 considering the Swift GRBs tracing the star formation history and the cosmic metallicity evolution in different background cosmological models including ΛCDM, quintessence, quintessence with a time-varying equation of state and brane-world models. ΛCDM model is the preferred which is however compared with other results.

Although big progress has been obtained in the last few years, GRBs theory needs further investigation in the light of the experimental data coming from old and new satellites, often coordinated, such as BeppoSAX or BATSE/RXTE or ASM/RXTE or IPN or HETE or INTEGRAL or SWIFT or AGILE or Fermi LAT or MAXI. Indeed, in spite of thousands papers appeared in the literature since the discovery of GRBs, the problem of their energy emission is still elusive: i) what is jet's composition? (kinetic or magnetic?); ii) where is dissipation occurring? (photosphere? deceleration radius?); iii) how is radiation generated? (synchrotron, Inverse Compton, hadronic?) (Zhang et al., 2013).

For this reason we believe useful to read the very interesting scientific-social remark made by Arnon Dar at the end of the paper discussed by Guido Barbiellini at the Vulcano Workshop 2002 (Barbiellini & Longo, 2003).

The idea that GRBs could be associated to gravitational waves (GWs) emission is now popular. Indeed, short GRBs are believed to be produced by the mergers of either double NSs or NS-BH binaries (Nakar, 2007) and the recent observation of a kilonova associated with GRB130603B (Tanvir et al., 2013; Berger, Fong & Chornock, 2013) lends support to this hypothesis. Such compact binary coalescences generate strong GWs in the sensitive frequency band of Earth-based gravitational wave detectors (Blanchet, Iyer & Joguet, 2002; Blanchet & T. Damour, 1989). Recently, Aasi et al. (2014) searched for gravitational waves associated with 223 GRBs detected by the InterPlanetary Network (IPN) in 2005-2010 during LIGO's fifth and sixth science runs and Virgo's first, second, and third science runs. No evidence of a gravitational wave signal associated with any of the IPN GRBs in the sample, nor evidence for a population of weak gravitational wave signals associated with the GRBs has been found.

11. Star Formation

In his splendid review, Robert C. Kennicutt, Jr. (1998) discussed the observations of star formation rates (SFRs) in galaxies that provide vital clues to the physical nature of the Hubble sequence and showing that these observations are key probes of the evolutionary histories of galaxies. Kennicutt, Jr & Evans II (2012) reviewed the progress over the previous decade in observations of large-scale star formation, with a focus on the interface between extragalactic and Galactic studies. Methods of measuring gas contents and star-formation rates have been discussed, and updated prescriptions for calculating star-formation rates were provided. They reviewed relations between star formation and gas on scales ranging from entire galaxies to individual molecular clouds.

The key dynamical processes involved in star formation – turbulence, magnetic fields, and self-gravity – are highly nonlinear and multidimensional. Therefore, it is extremely difficult a complete quantitative description of the physics involved in the process of star formation. McKee & Ostriker (2007) attempted to review the theory of star formation. For this reason they divided star formation into large-scale and small-scale regimes and reviewed each in turn. Large scales range from galaxies to giant molecular clouds (GMCs) and their substructures. Important problems include how GMCs form and evolve, what determines the star formation rate (SFR), and what determines the initial mass function (IMF). Small scales range from dense cores to the protostellar systems they beget. They discussed formation of both low– and high–mass stars, including ongoing accretion. The development of winds and outflows is increasingly well understood, as are the mechanisms governing angular momentum transport in disks. However, they concluded that a comprehensive theory of star formation will be tested by the next generation of telescopes.

Fumagalli et al. (2012) investigated the evolution of the H_α equivalent width, EW(H_α), with redshift and its dependence on stellar mass, using the first data from the 3D-HST survey, a large spectroscopic Treasury program with the HST-WFC3. Combining these data with those from ground-based telescopes, they found that at all masses the characteristic EW(H_α) is decreasing towards the present epoch, and that at each redshift the EW(H_α) is lower for high-mass galaxies.

The cosmic history of star formation, heavy element production, and reionization of the Universe from the cosmic "dark ages" to the present epoch has been discussed in the recent review paper by Madau & Dickinson (2014). A consistent picture is emerging, whereby the star-formation rate density peaked approximately 3.5 Gyr after the Big Bang, at $z \approx 1.9$, and declined exponentially at later times, with an e-folding timescale of 3.9 Gyr. Half of the stellar mass observed today was formed before a redshift z = 1.3. About 25% formed before the peak of the cosmic star-formation rate density, and another 25% formed after z = 0.7. Less than $\sim$ 1% of today's stars formed during the epoch of reionization.

However, these results were already largely discussed and presented by Hopkins & Beacom (2006), and summarized in the Fig. 11. The light–red rectangle marks the range of redshift where

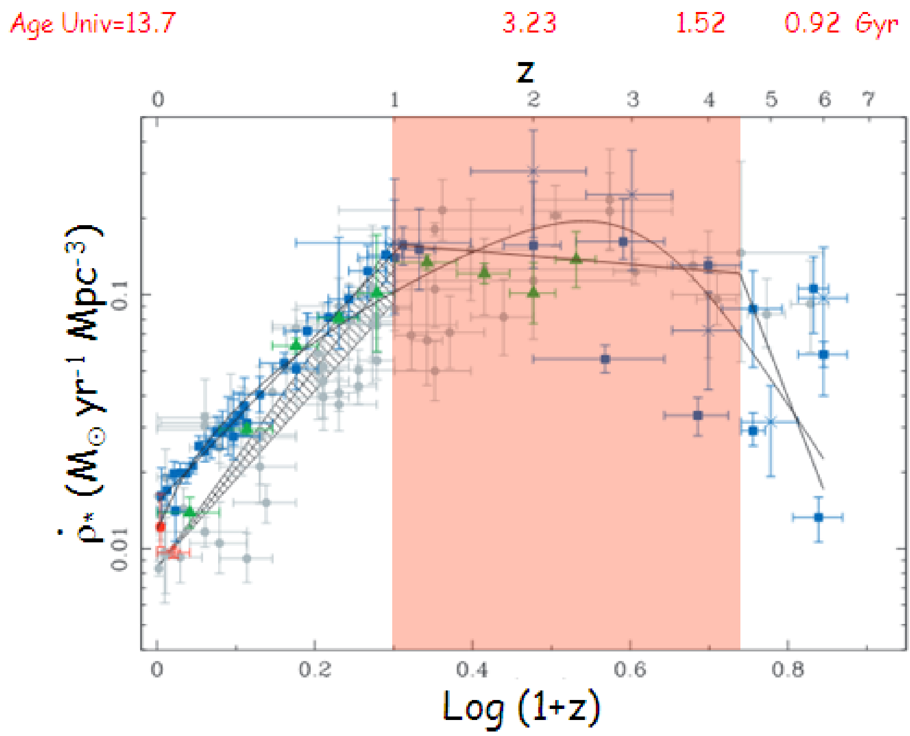

Figure 11: Evolution of SFR density with redshift (after Hopkins & Beacom, 2006).

the star formation density had the maximum. This will be better understood when the supernova rate density evolution, the ranges of stellar masses leading to core-collapse and type Ia supernovae, and the antineutrino and neutrino backgrounds from core-collapse supernovae will be known thanks to the next generation experiments both ground– and space–based.

12. Cross Sections of Nuclear Reactions in Stars

Most stars derive their luminosity from the conversion of hydrogen to helium. The rest mass of one ^{4}He atom is about 0.71% less than the combined rest masses of four hydrogen atoms (note that the electrons are included in the atomic masses here). The difference, or about 26.7 MeV/c^2, is released as heat, except for $\approx$ 0.6 MeV worth of neutrinos (in the *pp* chain). There are two paths from 4^{1}H to ^{4}He: the *pp*–cycle, which predominates in the Sun and cooler stars, and the *CNO*–cycle, which predominates in stars with slightly higher central temperatures. Figure 12 shows the main channels of the *pp*– and *CNO*–cycles (Bahcall, 1989).

The knowledge of the cross-sections of nuclear reactions occurring in the stars appears as one of the most crucial points of all astroparticle physics. Direct measurements of the cross sections of the ^{3}He(^{4}He,γ)^{7}Be and ^{7}Be(p,γ)^{8}Be reactions of the *pp* chain and ^{14}N(p,γ)^{15}O reaction of the *CNO*–cycle will allow a substantial improvement in our knowledge on stellar evolution.

The LUNA (Laboratory for Underground Nuclear Astrophysics) is devoted to measure nuclear cross sections relevant in astroparticle physics. It is the most valuable experiment running underground in the Gran Sasso Laboratory of the INFN. The LUNA collaboration has already measured with good accuracy the key reactions D(p,γ)^{3}He, ^{3}He(D,p)^{4}He and ^{3}He(^{4}He,γ)^{7}Be. These

pp	CNO
$p + p \rightarrow {}^{2}\mathrm{H} + e^{+} + \nu_e$	${}^{12}\mathrm{C} + p \rightarrow {}^{13}\mathrm{N} + \gamma$
${}^{2}\mathrm{H} + p \rightarrow {}^{3}\mathrm{He}$	${}^{13}\mathrm{N} \rightarrow {}^{13}\mathrm{C} + e^{+} + \nu_e$
${}^{3}\mathrm{He} + {}^{3}\mathrm{He} \rightarrow {}^{4}\mathrm{He} + 2p$	${}^{13}\mathrm{C} + p \rightarrow {}^{14}\mathrm{N} + \gamma$
	${}^{14}\mathrm{N} + p \rightarrow {}^{15}\mathrm{O} + \gamma$
	${}^{15}\mathrm{O} \rightarrow {}^{15}\mathrm{N} + e^{+} + \nu_e$
	${}^{15}\mathrm{N} + p \rightarrow {}^{12}\mathrm{C} + {}^{4}\mathrm{He}$

Figure 12: The main channels of the *pp*– and *CNO*–cycles (Bahcall, 1989).

measurements substantially reduces the theoretical uncertainty of D, ^{3}He, ^{7}Li abundances. The D(^{4}He,γ)^{6}Li cross section – which is the key reaction for the determination of the primordial abundance of ^{6}Li – has been measured (e.g. Gustavino, 2007, 2009, 2011, 2012, 2013), as well as that of ^{2}H(α,γ)^{6}Li (Anders et al., 2013), and ^{2}H(α,γ)^{6}Li (Anders et al., 2014).

Other reactions fundamental for a better knowledge of stellar evolution have been studied by the LUNA experiment: e.g. ^{17}O(p,γ)^{18}F (Scott, D.A. et al. 2012); ^{25}Mg(p,γ)^{26} (Strieder, F. et al., 2012) ^{25}Mg(p,γ)^{26} (Straniero et al., 2013); ^{17}O(p,γ)^{18}F (Di Leva, A. et al., 2014).

A general data base for Experimental Nuclear Reaction Data (EXFOR) can be found in: https://www-nds.iaea.org/exfor/exfor.htm.

13. Galactic compact sources

In the Galaxy there are different kinds of compact sources: white dwarfs (WDs), neutron stars (NSs) and black holes (BHs), both isolated and in binary systems. Thousand papers about these cosmic sources are available in the literature. We mention the last available exhaustive review by Postnov & Yungelson (2014) about "*The Evolution of Compact Binary Stars Systems*" in which they review the formation and evolution of compact binary stars consisting of WDs, NSs, and BHs. Merging of compact-star binaries are expected to be the most important sources for forthcoming gravitational-wave (GW) astronomy. In the first part of the review, they discuss observational manifestations of close binaries with NS and/or BH components and their merger rate, crucial points in the formation and evolution of compact stars in binary systems, including the treatment of the natal kicks, which NSs and BHs acquire during the core collapse of massive stars and the common envelope phase of binary evolution, which are most relevant to the merging rates of NS-NS, NS-BH and BH-BH binaries. In the second part of the review, they discuss the formation and evolution of binary WDs and their observational manifestations, including their role as progenitors of cosmologically-important thermonuclear SN Ia. They also consider AM CVn-stars, which are thought to be the best verification binary GW sources for future low-frequency GW space interferometers.

In the following we are going to briefly discuss the main characteristics of the galactic compact sources.

13.1 Cataclysmic Variables

The detection of CVs with the INTEGRAL observatory (Barlow et al., 2006) have recently renewed the interest of high energy astrophysicists for such systems, and subsequently involving once more the low–energy astrophysical community. The detection of CVs having orbital periods inside the so-called *Period Gap* between 2 and 3 hours, which separates polars – experiencing gravitational radiation – from intermediate polars – experiencing magnetic braking – renders attractive the idea about physical continuity between the two classes. Further investigations are necessary for solving this important problem.

For a recent reviews on CVs see the papers by Giovannelli & Sabau-Graziati (2012; 2015).

13.2 High Mass X-Ray Binaries

For general reviews see e.g. Giovannelli & Sabau-Graziati (2001, 2004, 2014) and van den Heuvel (2009) and references therein.

HMXBs are young systems, with age $\leq 10^7$ yr, mainly located in the galactic plane (e.g., van Paradijs, 1998). A compact object – the secondary star –, mostly a magnetized neutron star (X-ray pulsar) is orbiting around an early type star (O, B, Be) – the primary – with $M \geq 10$ $M_\odot$. The optical luminosity of the system is dominated by the early type star.

Such systems are the best laboratory for the study of accreting processes thanks to their relative high luminosity in a large part of the electromagnetic spectrum. Because of the strong interactions between the optical companion and collapsed object, low and high energy processes are strictly related. In X-ray/Be binaries the mass loss processes are due to the rapid rotation of the Be star, the stellar wind and, sporadically, to the expulsion of casual quantity of matter essentially triggered by gravitational effects close to the periastron passage of the neutron star. The long orbital period ($>$ 10 days) and a large eccentricity of the orbit ($>$ 0.2) together with transient hard X-ray behavior are the main characteristics of these systems. Among the whole sample of galactic systems containing 114 X-ray pulsars (Liu, van Paradijs & van den Heuvel, 2006), and 128 HMXBs in the Magellanic Clouds (Liu, van Paradijs & van den Heuvel, 2005), only few of them have been extensively studied. Among these, the system A 0535+26/HDE 245770 is the best known thanks to concomitant favorable causes, which rendered possible thirty nine years of coordinated multifrequency observations, most of them discussed by e.g. Giovannelli & Sabau-Graziati (1992, 2008), Burger et al. (1996).

Accretion powered X-ray pulsars usually capture material from the optical companion via stellar wind, since this primary star generally does not fill its Roche lobe. However, in some specific conditions (e.g. the passage at the periastron of the neutron star) and in particular systems (e.g. A 0535+26/HDE 245770), it is possible the formation of a temporary accretion disk around the neutron star behind the shock front of the stellar wind. This enhances the efficiency of the process of mass transfer from the primary star onto the secondary collapsed star, as discussed by Giovannelli & Ziolkowski (1990) and by Giovannelli et al. (2007) in the case of A 0535+26.

Giovannelli & Sabau-Graziati (2011) discussed the history of the discovery of optical indicators of high energy emission in the prototype system A0535+26/HDE 245770 $\equiv$ Flavia' star, updated to the March–April 2010 event when a strong optical activity occurred roughly 8 days before the X-ray outburst (Caballero et al., 2010) that was predicted by Giovannelli, Gualandi &

Sabau-Graziati (2010). This event together with others occurred in the past allowed to Giovannelli & Sabau-Graziati (2011) to conclude that X-ray outbursts occur ~ 8 days after the periastron passage. Giovannelli, Bisnovatyi-Kogan & Klepnev (2013) developed a model for explaining such a delay by the time of radial motion of the matter in a non–stationary accretion disk around the neutron star, after an increase of the mass flux in the vicinity of a periastral point in the binary. This time is determined by the turbulent viscosity, with the parameter $\alpha = 0.1 - 0.3$.

However how X-ray outbursts are triggered in X-ray pulsars constitute one important still open problem giving rise to controversy within astrophysicists.

Important news are coming also from GeV observations of HMXBs. Indeed, Abdo et al. (2009) presented the first results from the observations of LSI + 61°303 using Fermi LAT data obtained between 2008 August and 2009 March. Their results indicate variability that is consistent with the binary period, with the emission being modulated at 26.6 days. This constitutes the first detection of orbital periodicity in high–energy γ-rays (20 MeV-100 GeV).

13.2.1 Obscured Sources and Supergiant Fast X-Ray Transients

Relevant are INTEGRAL results about a new population of obscured sources and Supergiant Fast X-ray Transients (SFXTs) (Chaty & Filliatre, 2005; Chaty, 2007; Rahoui et al., 2008; Chaty, 2008). The importance of the discovery of this new population is based on the constraints on the formation and evolution of HMXBs: does dominant population of short-living systems – born with two very massive components – occur in rich star-forming region? What will happen when the supergiant star dies? Are primary progenitors of NS/NS or NS/BH mergers good candidates of gravitational waves emitters? Can we find a link with short/hard γ-ray bursts?

Thanks to the INTEGRAL observatory that has roughly quadrupled the number of supergiant X-ray binaries known in the Milky Way, new questions about the formation and evolution of such sources has arisen. Coleiro & Chaty (2011) made a statistical analysis of the distribution of HMXBs in the Galaxy. They showed that HMXBs are clustered with star forming complexes (SFCs), with a typical size of 0.3 kpc and a characteristic distance between clusters of 1.7 kpc. Chaty (2011) described the nature, formation and evolution of the three kinds of HMXBs population, namely: i) Be/X-ray systems; ii) supergiant stars/X-ray systems (sgHMXBs) that accrete matter via stellar wind; iii) supergiant stars overflowing their Roche Lobe. The new observations suggest the existence of evolutionary links between Be and stellar wind accreting supergiant X-ray binaries.

13.3 Ultra–Compact Double–Degenerated Binaries

Ultra–compact double–degenerated binaries (UCD) consist of two compact stars, which can be black holes, neutron stars or white dwarfs. In the case of two white dwarfs revolving around each other, the orbital period is $P_{orb} \leq 20$ min. The separation of the two components for a UCD with $P_{orb} \approx 10$ min or shorter is smaller than Jupiter's diameter (e.g. Wu, Ramsay & Willes, 2008; Wu, 2009).

These UCD are evolutionary remnants of low–mass binaries, and they are numerous in the Milky Way. The discovery of UCD is foreboding interesting hints for gravitational–wave possible detection with LISA observatory.

13.4 Magnetars

The discovery of magnetars (Anomalous X-ray Pulsars – AXPs – and Soft Gamma-ray Repeaters – SGRs) is also one of the most exciting results of the last years (Mereghetti & Stella, 1995; van Paradijs, Taam & van den Heuvel, 1995; and e.g. the review GSG2004 and the references therein). Indeed, with the magnetic field intensity of order $10^{14} - 10^{15}$ G a question naturally arises: what kind of SN produces such AXPs and SGRs? Are really the collapsed objects in AXPs and SGRs neutron stars? (e.g. Hurley, 2008). With such high magnetic field intensity an almost 'obvious' consequence can be derived by the Hillas (1984) diagram (magnetic field intensity versus dimension of the source): the correspondent dimension of the source must be of ~ 10 m (Giovannelli & Sabau-Graziati, 2006). This could be the dimension of the acceleration zone in supercompact stars. Could they be quark stars (QSs)?

Indeed, transformations of NS to QS or to pion- or kaon-condensed stars have been studied since long time (e.g. Migdal et al., 1979; Bhattacharyya et al., 2006,2007; Drago & Lavagno, 2010; Mishustin et al., 2014).

Mallick & Sinha (2011a,b) – starting from recent results and data suggesting that high magnetic fields in NSs ($\geq 10^{14}$ G) strongly affect the characteristics (radius, mass) of the star – discussed the effect of such a high magnetic field on the phase transition of a NS to a quark star (QS). They studied the effect of magnetic field on the transition from NS to QS including the magnetic–field effect in the equation of state (EoS).

Therefore, the problem of the eventual transition from a NS to a QS is very attractive. However, Mallick, Ghosh & Raha (2009) showed that the presence of high magnetic field, an essential feature of neutron stars, strongly inhibits the conversion of neutron stars to bare quark stars.

Ghosh (2009) and Nag et al. (2009) discussed some of the recent developments in the quark star physics along with the consequences of possible hadron to quark phase transition at high density scenario of neutron stars and their implications on the Astroparticle Physics.

Important consequences could be derived by the continuity among rotation-powered pulsars, magnetars, and millisecond pulsars, experimentally demonstrated (Kuiper, 2007). However, it is not yet clear which is the physical reason of such a continuity.

Safi-Harb & Kumar (2013) discussed about the environments and progenitors of supernova remnants associated with highly magnetized neutron stars. They studied two SNRs: G292.2Ű0.5, associated with the HBP J1119-6127, and Kes 73, associated with the AXP 1E 1841-045, and summarized the current view of the other high magnetic field pulsars (HBPs)/magnetar-SNR associations.

Recently a discussion about magnetars have been published in the White Paper for ASTRO-H Space X-ray observatory (Kitamoto et al., 2014).

14. Habitable Zone in the Milky Way and Exoplanets

Once scientists understood that the stars in the sky are other suns, and that the galaxies consist of billions of stars, it appeared a near certainty that other planets must orbit other stars. And yet, it could not be proven, until the early 1990's. Then, radio and optical astronomers detected small changes in stellar emission which revealed the presence of first a few, and now many, planetary systems around other stars. We call these planets "exoplanets" to distinguish them from our own solar system neighbors (http://science.nasa.gov/astrophysics/focus-areas/exoplanet-exploration/).

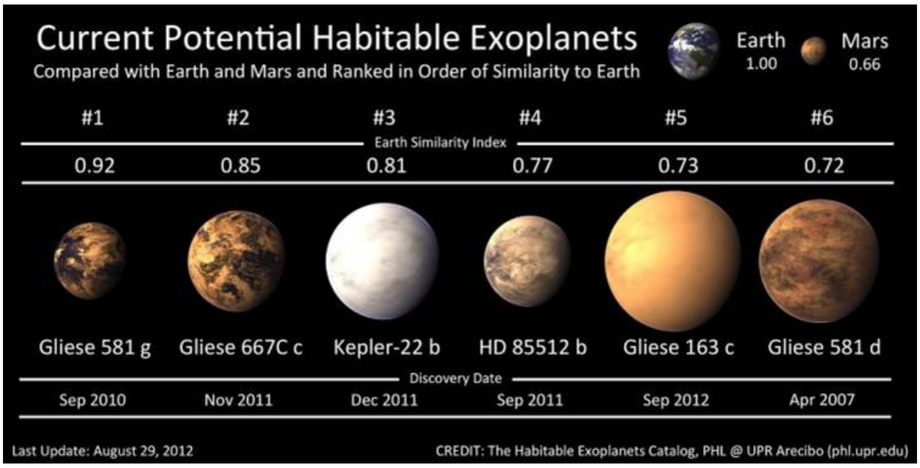

Figure 13: Current potential habitable exoplanets (2012, credit: PHL@UPR Arecibo).

The research of potential habitable exoplanets has been strongly supported during last two decades. Indeed, this field of astrophysics is now probably the most exciting since the discovery of planets Earth-like could open a serious debate about the possibility of life outside of solar system. Fig. 13 shows the potential habitable exoplanets updated to 29th August 2012 (Planetary Habitable Laboratory - PHL - University of Puerto Rico at Arecibo, 2012). This list is continuously updated, and the number of such exoplanets is rapidly increasing. Fig. 14 shows the distribution of Kepler planet candidates by size as of January 2015 (Image Credit: NASA Ames/W Stenzel). As we can see there are 808 Earth-like planets in the neighbourhood of solar system.

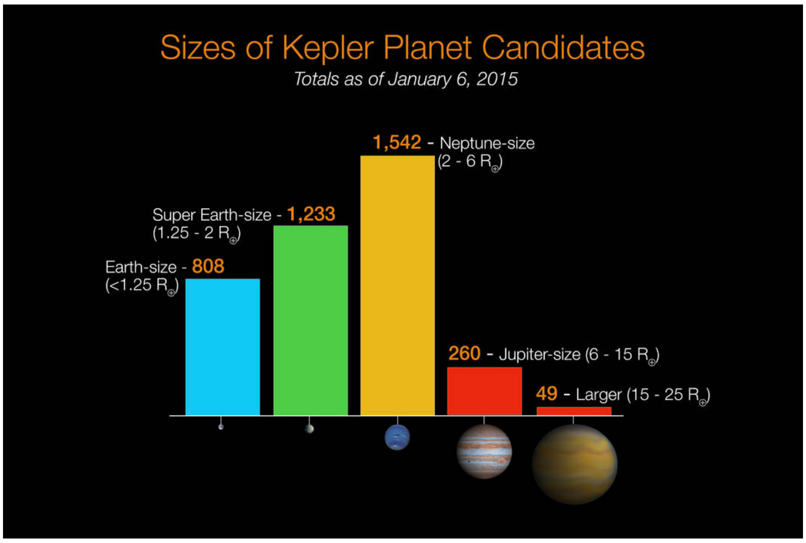

Figure 14: The distribution of Kepler planet candidates by size as of January 2015 (Image Credit: NASA Ames/W Stenzel).

The presence of numerous exoplanets in the vicinity of solar system – within a distance of

~ 0.8 pc – plays an important role in speculating about the possible number of such exoplanets within the whole habitable zone of our galaxy. Such habitable zone has an internal radius of ~ 4 kpc and an external radius of ~ 11 kpc, as shown in Fig. 15 (after Lineweaver, Fenner & Gibson, 2004), where the habitable zone in a Milky Way-like galaxy is represented in green. The number of stars contained in this zone is $\approx 10\%$ of the total number of stars in the Galaxy. Taking into account that the thickness of the disk is ≈ 1 kpc, as evaluated by the differential rotation of the Galaxy, the habitable volume is ~ 330 kpc^3. Therefore, if in a volume of ≈ 2 pc^3 there are 808 Earth-like planets detected, in the habitable zone of our Galaxy we could expect $\approx 133 \times 10^6$ Earth-like planets. It is evident that the probability of finding numerous habitable planets becomes very high. Next generation instruments ground– and space–based will provide valuable information about this intriguing problem.

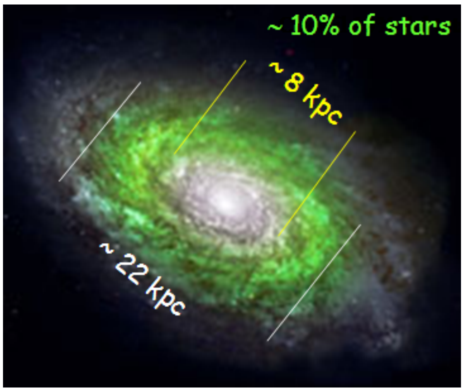

Figure 15: Habitable zone of a Milky Way-like galaxy (after Lineweaver, Fenner & Gibson, 2004).

Studies about exoplanet predictions around stars have been performed by Bovaird & Lineweaver (2013). Thy predict the existence of a low-radius ($R < 2.5\ R_\odot$) exoplanet within the habitable zone of KOI-812 and that the average number of planets in the habitable zone of a star is 1-2.

For life–forms like us, the most important feature of Earth is its habitability. Understanding habitability and using that knowledge to locate the nearest habitable planet may be crucial for our survival as a species. During the past decade, expectations that the universe could be filled with habitable planets have been bolstered by the increasingly large overlap between terrestrial environments known to harbor life and the variety of environments on newly detected rocky exoplanets. The inhabited and uninhabited regions on Earth tell us that temperature and the presence of water are the main constraints that can be used in a habitability classification scheme for rocky planets. Lineweaver & Chopra (2012) made a compilation and reviewed the recent exoplanet detections suggesting that the fraction of stars with planets is 100%, and that the fraction with rocky planets may be comparably large. They reviewed extensions to the circumstellar habitable zone (HZ), including an abiogenesis habitable zone and the galactic habitable zone.

Earth is located in a dangerous part of the universe. Threats to life on Earth are manifold and range from asteroid impacts to supernova explosions and from supervolcano eruptions to human-induced disasters. If the survival of the human species is to be ensured for the long term, then life on Earth has to spread to other planetary bodies. Mars is the most Earth-like planet we currently know and is the second closest planet; further it possesses a moderate surface gravity, an atmosphere, abundant water and carbon dioxide, together with a range of essential minerals. Thus, Mars is ideally suited to be a first colonization target. Here we argue that the most practical way that this can be accomplished is via a series of initial one-way human missions (Schulze-Makuch & Davies, 2013).

An intriguing question about the probability of finding a number of civilizations in the Galaxy arises. Frank D. Drake was the first in attempting an evaluation of this number. The history started long time ago. Seven months after the publication of the paper *Searching for Interstellar Communications* by Cocconi & Morrison (1959), Drake made the first systematic search for signals from extraterrestrial intelligent beings. Using the 25 meter dish of the National Radio Astronomy Observatory (NRAO) in Green Bank (WV, USA), Drake monitored two nearby Sun-like stars: Epsilon Eridani and Tau Ceti. In this project, which he called *Project Ozma* (Drake, 1961), he slowly scanned frequencies close to the 21 cm wavelength for six hours a day from April to July 1960. The project was well designed, inexpensive, and simple by today's standards. It was also unsuccessful. Soon thereafter, Drake hosted a "*Search for Extraterrestrial Intelligence*" meeting on detecting their radio signals. The meeting was held at the Green Bank facility in 1961. The equation that bears Drake's name arose out of his preparations for the meeting. He conceived an approach to bound the terms involved in estimating the number of technological civilizations that may exist in our galaxy. He wrote the very famous equation – later universally known as *Drake's formula* – on a blackboard of a room at the NRAO. A plaque now graces the wall of that room. The original Drake Equation gives the number of civilizations in the Galaxy that are able to communicate through electromagnetic waves. It is now evident that Drake's formula (Drake, 1962) must be object of a robust revision.

15. Conclusions

In this review we have discussed several of the most important pillars supporting the Bridge between the Big Bang and Biology, following our knowledge and feelings.

With the advent of new generation ground– and space–based experiments the BB theory is practically confirmed, thanks to the measurements of the CMB temperature, the temperature of a source placed at high redshift ($z \simeq 2.34$) and the content of primordial light elements. If B-mode polarization claimed by the BCEP2 collaboration would be confirmed, the inflationary model of the Universe would be definitively confirmed.

The GUPS is slowly completing even at the VHEs, thanks to the new more sensitive instruments.

WMAP data pose a warning about the flatness of the Universe.

Thanks to measurements of the quasar 3C 279 ($z \simeq 0.54$) obtained with the MAGIC experiment, and with the many sources at high redshift, including GRBs measured with the Fermi LAT observatory, it has been demonstrated that the Universe is more transparent to γ-rays than before believed.

With the discussion about the Hubble constant it appears evident the difficulty in determining its value. Hubble constant seems to be the "*most variable constant of the whole Universe*". However, with the last HST and WMAP results a value of $H_0 = 71.0 \pm 2.5$ km s^{-1} seems to be the most reliable. Does this determination, finally, close the history about the search of the "true" value of H_0?

It seems that we have an agreement about the epoch of reionization: it started early, $z_{ri} \sim 20$, but did not conclude until much later (z$\sim$ 6). However, how really re-ionization occurs is still object of debate. Indeed, considering that recent observations show that the measured rates of star formation in the early universe are insufficient to produce re-ionization, another source of ionizing photons could be present, namely the fast accretion shocks formed around the cores of the most massive haloes.

It has been demonstrated that there is a physical continuity between the different classes of compact extragalactic X-ray sources. This strongly indicates the existence of a unique kind of central X-ray source. The numerical continuity of the whole $L_{xmax}(z)$ function should be interpreted as owed to an evolution of the central X-ray source from a very active to a more quiet status.

The importance of jets in astrophysics has been recognized. Indeed, highly collimated supersonic jets and less collimated outflows are observed to emerge from a wide variety of astrophysical objects. They are seen in YSOs, proto-planetary nebulae, compact objects (like galactic black holes or microquasars, and X-ray binary stars), and in AGNs. Moreover, theoretical and observational works show that jets from AGN can trigger star formation. Despite their different physical scales (in size, velocity, and amount of energy transported), jets have strong morphological similarities. What physics do they share? These systems are either hydrodynamic or magnetohydrodynamic in nature and are, as such, governed by non-linear equations.

GRBs are physical phenomena in which an enormous amount of energy is emitted in a very short time. In spite of thousands papers appeared in the literature, the theoretical description of GRBs is still an open strongly controversial question. The recent idea that GRBs could be associated to GWs emission has become popular. Indeed, short GRBs are believed to be produced by the mergers of either double NSs or NS-BH binaries and the recent observation of a kilonova associated with GRB130603B lends support to this hypothesis. Such compact binary coalescences could generate strong GWs. This fact open a new interesting line of investigation.

The key dynamical processes involved in star formation – turbulence, magnetic fields, and self-gravity – are highly nonlinear and multidimensional. Therefore, it is extremely difficult a complete quantitative description of the physics involved in the process of star formation. The cosmic history of star formation, heavy element production, and reionization of the Universe from the cosmic "dark ages" to the present epoch is still object of debate. A consistent picture is emerging, whereby the star-formation rate density peaked approximately 3.5 Gyr after the Big Bang, at $z \simeq 1.9$, and declined exponentially at later times.

The knowledge of the cross-sections of nuclear reactions occurring in the stars appears as one of the most crucial points of all astroparticle physics. Direct measurements of the cross sections of the reactions of the *pp* chain and *CNO*–cycle will allow a substantial improvement in our knowledge on stellar evolution. The LUNA (Laboratory for Underground Nuclear Astrophysics) is devoted to measure nuclear cross sections relevant in astroparticle physics.

The formation and evolution of compact binary stars consisting of WDs, NSs, and BHs is one of the most important topic deeply studied by a large number of scientists. The formation and evolution of binary WDs and their observational manifestations, including their role as progenitors of cosmologically-important thermonuclear SN Ia, constitutes a crucial field of investigation.

Merging of compact-star binaries, and AM CVn-stars are expected to be the most important sources for forthcoming GW–astronomy.

The problem of the transition from NS to QS including the magnetic–field effect in the EoS is very attractive, and deserves further attention.

The presence of numerous exoplanets in the vicinity of solar system – within a distance of ~ 0.8 pc – plays an important role in speculating about the possible number of such exoplanets within the whole habitable zone of our galaxy, where we could expect $\approx 133 \times 10^6$ Earth-like planets. It is evident that the probability of finding numerous habitable planets becomes very high. Next generation instruments ground– and space–based will provide valuable information about this intriguing problem.

It is now evident that Drake's formula must be object of a robust revision. However, if we insist in looking for life which is like our own, why do we look for ... INTELLIGENT LIFE? (Giovannelli, 2001b).

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