3

Matter-Antimatter Asymmetry and States in the Universe

F. L. Braghin
Instituto de Física, Universidade Federal de Goiás, GO
Brazil

1. Introduction

Dirac's interpretation of the negative and positive energy eigenvalues of relativistic free fermions equation became a sound paradigm widely and continuously articulated in particle, nuclear physics and modern astrophysics and cosmology. The foundations of the theories for elementary particles and fields rely deeply in symmetries, including those relating particles and antiparticles. In spite of that, observed cosmic rays (CR), diffuse gamma ray spectra and fluctuations of Cosmic Microwave Backgound (CMBR) do not allow to conclude there is a meaningful amount of antimatter in the Universe. If the exact symmetries of particle physics are considered to give rise to macroscopic scenarios that evolved towards the current Universe a clear contradiction appears with the observed matter-antimatter asymmetry.

Although electric charge $U(1)$ and baryon number $U(1)$ have strict conservation laws, GUT and SUSY-GUT predict baryon nonconservation via proton decay: $p \to \pi^0 + e^+$ and $p \to \bar{\nu}_\mu + K^+$, and the current lower bound for these processes is of the order of 10^{34} years (69). From the point of view of quantum field theories, a local hermitian quantum field theory in the Minkowski space with Lorentz covariance produces the same mass, lifetime and magnetic moment for particles and their antiparticles with opposite charges according to the CPT theorem (55; 94). This theorem establishes a sound framework on which (most of) particle and cosmological theories have been worked out. Nevertheless, in the scope of the CPT theorem, mechanisms for baryogenesis can be envisaged since C and CP are broken in Nature, at least by weak interactions. Whereas breaking of CP is invoked very often for describing baryogenesis, CPT might not have been valid anymore in the extreme conditions of the Early Universe, and the consequences can be very rich for the cosmo evolution. Tests of the validity of the CPT theorem become an important task (32), and actually there is evidence of CPT violation from neutrino oscillation (3).

Standard Big-Bang theory (88) predicts an equal amount of baryons and photons produced in the Early Universe which is well reduced nowadays. Estimations based on the standard Big Bang nucleosynthesis (98) taking into acount CMBR fluctuations (90) yield the current value for the ratio of the baryon density to the photon density to be around (93):

$$\omega = \frac{\rho_B - \rho_{\bar{B}}}{n_\gamma} = (6.1 + .3 - .2) \times 10^{-10} \tag{1}$$

where $\rho_B, \rho_{\bar{B}}$ are the baryon and antibaryon densities and n_γ the photon density. Other similar estimations provide: $\omega = (4.7 + 0.1 - 0.8).10^{-10}$ (97) and $(5.0 \pm 0.5).10^{-10}$ (27). Baryons seem to represent only nearly 5% of total energy density of the Universe while dark matter would correspond to at least 23% of this total energy density (34). Therefore one of the first natural candidates to constitute dark matter was (hidden) antimatter. However this hypothesis did not show to be really reasonable due to the absence of the corresponding particle-antiparticle annihilations in the regions where dark matter is expected to be. The current bound on matter-antimatter asymmetry is nearly $n_{\bar{B}}/n_B < 3.10^{-6}$ (93) basically from the absence of gamma rays from annihilation processes, and that goes along with observation of cosmic rays. In the last years several high precision cosmic ray observatories outside the atmosphere were built and launched (PAMELA, BESS, AMS-2,PEBS), (diffuse) gamma ray spectra in different energies are also continuously improved (EGRET, FERMI and others).

There are different possible solutions for the contradiction between the fundamental elementary particle symmetries of particles and antiparticles and the apparent absence of antimatter in the Universe: (1) there was at least one reasonably efficient mechanism of producing more matter than antimatter (baryogenesis) , (2) antimatter continuously existed and currently it is somehow hidden (either in some different place(s), domains or state(s)), or (3) antimatter would not have been as stable as matter and it could have been annihilated or decayed in some other way that was not the usual particle-antiparticle annihilation. In particular, mainly (but not only) for the solutions (2) or (3) antimatter may be distributed non homogeneously in the Universe within the so-called "islands" (or domains) of antimatter. The picture of matter dominated Universe is corroborated by estimations on the minimum distance to the nearest antimatter dominated galaxy or cluster that could agree with CMBR fluctuations, and which is expected to be farther than around $10-20$Mpc (31; 57; 92; 93). Within this scenario one usually is left with the problem of efficient baryogenesis in the Early Universe, although the domains of symmetric Universe still might have this size. The most well known mechanism was proposed by Sakharov (79) and it relies in non-equilibrium dynamics and breaking of CP, although in some models it is not enough to produce the expected asymmetry (34). However there are other mechanisms that have been invoked to explain such matter-antimatter asymmetry, mainly for solutions (1) and (2), as discussed in Sections 3 and 4. Among them, one can consider the existence of very dense antimatter objects, such as primordial (anti)black holes (PBH) in larger number than matter objects (anti-black holes). Often, models accounting for any of the three solutions are not compatible with other aspects of Standard Big Bang theory (such as nucleosynthesis) and CMBR fluctuations. However, antimatter still might be somehow hidden from observations, and an eventual realistic estimation of the possible location(s) or states, for example in the form of anti-stars or Galaxies, depends on several hypothesis, being subject of theoretical and experimental investigation. In any case, eventually one can expect to find effects that could prevent the corresponding annihilation of matter and antimatter in different phases of the Universe evolution, such as discussed in Section 4.

The Chapter is organized as follows. In the next Section, a short review of observations related to antimatter in the Universe is presented, mainly referring to cosmic rays and diffuse gamma rays. In Section 3, we discuss the current constraints for the existence of large domains of antimatter that would be expected in a $B - \bar{B}$ symmetric Universe and the usual baryogenesis conditions proposed by Sakharov (79). Some of the most successful scenarios in which the Sakharov conditions work are quoted, besides some other alternative models for baryogenesis. In Section 4, we discuss few different models that can also allow for symmetric baryon-antibaryon Universe. Some dynamical effects that might make possible these less usual scenarios are discussed. Some aspects of relevance for dense antimatter bound systems, such as dense antistars, are also presented. In the last Section, there is a brief summary of the ideas presented in the Chapter. The amount of works about these subjects is large and this Chapter is not intended to provide a complete exhaustive review of them. Given the large number of possible mechanisms involving production or dynamics of antimatter some of the most often considered will be shortly described. This work was, in part, based in some good reviews on aspects of the antimatter problem available in the literature (15; 28; 34; 36; 38; 54; 78; 84).

2. Observational constraints: results and plans

There are two main types of observations for detecting antimatter in the Universe: gamma rays spectra and cosmic rays (CR). However, as it will be noted, these observations must be considered not only as resulting from the processes involving primary production of antimatter or its annihilation but also from secondary interactions of both antimatter and matter. Besides these observables, we mention other possible signatures of antimatter, such as isocurvature perturbations for which there still are uncertainties (61). Isocurvature fluctuations do not exclude the possibility of antimatter objects in not far distances from us (39; 61). Neutrinos (and antineutrinos) from supernovae are observed in Earth observatories, therefore one could also expect to observe antineutrinos from anti-supernovae with typical flux but seemingly these events have never been observed (39; 77). Gravitational lensing for halo compact objects is considered by the MACHO project (*Massive Compact Halo Objects*). White dwarfs or even black holes can be searched (7) and the association of these observations with gamma rays can also provide information on the presence of antimatter in this region of the Milk Way.

For the high precision CMBR fluctuations and diffuse gamma ray spectrum several observatories are working and being planned, such as: WMAP (103), Cosmic Background Imager (29), Planck mission (44) and FERMI (43). Planck mission, for example, will measure the CMB with very high angular resolution and high sensitivity, improving the COBE resolution. We just mention further FERMI observatory (Fermi Gamma-ray Space Telescope, formerly GLAST) that is a high precision observatory to analyse high energy events in the Cosmos (43): black hole dragging matter, emission of jets with high speeds, signals of dark matter, gamma ray bursts, origin of cosmic rays, pulsars, among others. Certainly the corresponding gamma ray spectra is expected to provide valuable information on the contribution of antimatter components via annihilation processes in such high energy events. Differences on the spectrum with respect to previous observations have appeared but deserves further investigation (2; 108). It is assumed that proton-antiproton annihilation via π^0 is the most important baryon annihilation process for the cosmic diffuse gamma spectrum (91). Given that there is an average of four γ per $p - \bar{p}$ annihilation and two γ from e^+e^- annihilation (with $E = 0.511$keV in the restframe) the resulting spectra would be quite peculiar and quite strong (both lines: from e^+e^- and π^0 decay due to $p - \bar{p}$ annihilation) and this is not observed. One obtains an upper limit on the antimatter/matter fraction to be around 10^{-15} in Galactic molecular clouds, 10^{-10} in the Galactic halo, and 10^{-5} within our cluster (75). However, the line of $E = 0.511$keV (e^+e^-) is quite bright and visible from the Galactic center, from Galactic bulge and possibly even in the halo (76; 100; 101). It is not settled whether and to what extent they are fingerprints of antimatter in these places. Diffuse gamma rays and CMBR fluctuations help to put a constraint on the minimum size of our matter dominated region out of which it could appear an antimatter dominated "island", and it is nearly 20 Mpc (31). Taking into account the pressure of such radiation, with dragging effect from diffusion of protons and antiprotons, the scale of matter dominated region in the Universe would be extended to 1 Gpc depending on the model considered (39). Unless new dynamic effect(s) provide a well defined separation of large antimatter domains during the Universe evolution these domains are rather ruled out as considered so far. However, several of the observations cannot be considered as proofs of antimatter absence, Earth fortunately seems to be deep in a matter dominated region that prevents antimatter (or, to some extent, its fingerprints) to reach us.

On the other hand, the gamma ray spectra coming from annihilation of antimatter in astrophysical objects (or anti-objects themselves) are easier to interpret. Annihilation of proton flux towards an anti-object is given for bulk and surface regions in Ref.(15) resulting in very high luminosity events. Punctual annihilation of antimatter (either in the form of free propagating antiparticles, small objects or antistars) in gas clouds as well as collisions of antistars with stars of different types were also considered in (15). By examining the collision of two galaxies, the presence of matter-antimatter can be detected by annihilation which emits the characteristic gamma rays yielding a maximum relative amount of antimatter in our Galaxy of the order of 3.10^{-6} (93). These last events can be extremely energetic and maybe providing gamma bursts.

2.1 Cosmic rays

Cosmic rays CR can provide one of the direct fingerprints of antimatter structures in the Universe, in spite of the interaction with the interstellar medium (ISM). In any case, the need of observations outside the atmosphere is undeniable. Primary sources have been proposed to be galactic and extragalactic. Firstly one can expect that antimatter objects can emit antiparticles (antiprotons, positrons and eventually anti-nuclei) in the same proportion as matter objects emit particles, however interaction with ISM can well contribute for the CR spectrum as well as other primary sources: evaporation of micro BH (64; 106) or annihilation of dark matter from the galactic halos (eg. neutralinos) (18). On the other hand antiprotons and positrons can be produced in secondary reactions in the ISM with known cross sections. Some of the most relevant processes for understanding all the antimatter components in the CR are: (1) diffusion in the magnetic fields of the galaxy and of the Sun, (2) reacceleration, after the movement of scattering centers, (3) antiparticles can loose energy by Coulomb scattering or ionization in the interstellar medium (ISM), (4) convection can expel antiparticles from galactic disc or solar system, (5) they can simply annihilate on ISM, usually with H or He (67). The influence of several of these processes on the resulting spectra depend on theoretical predictions and observational astrophysical data. Therefore although CR provides an important source of information about antimatter in the Universe its understanding must include several other aspects. Protons from usual matter can form a massive positively charged BH which produces strong enough electric field to generate pairs of e^+e^-. It should follow a strong absorption of the electrons and ejection of positrons becoming a source of antimatter (16). Dark matter scalar singlet model, for example, predicts annihilation of scalar dark matter into positrons and antiprotons that might be in part those observed in high energy CR (48). although the mass of such scalar is not measurable not even in LHC. Galactic halos might contain substructures (clumps) and may enhance dark matter annihilation. Basically, the current upper bounds of antimatter from CR can be considered to be nearly 10^{-4} for $\bar{p}/p$ and 3.10^{-8} for $\bar{He}/He$, which might settle nearly the scale of maximum amount of antimatter in the galaxy. There are several on going projects intended to clarify the antimatter components of CR (positron / antiproton/

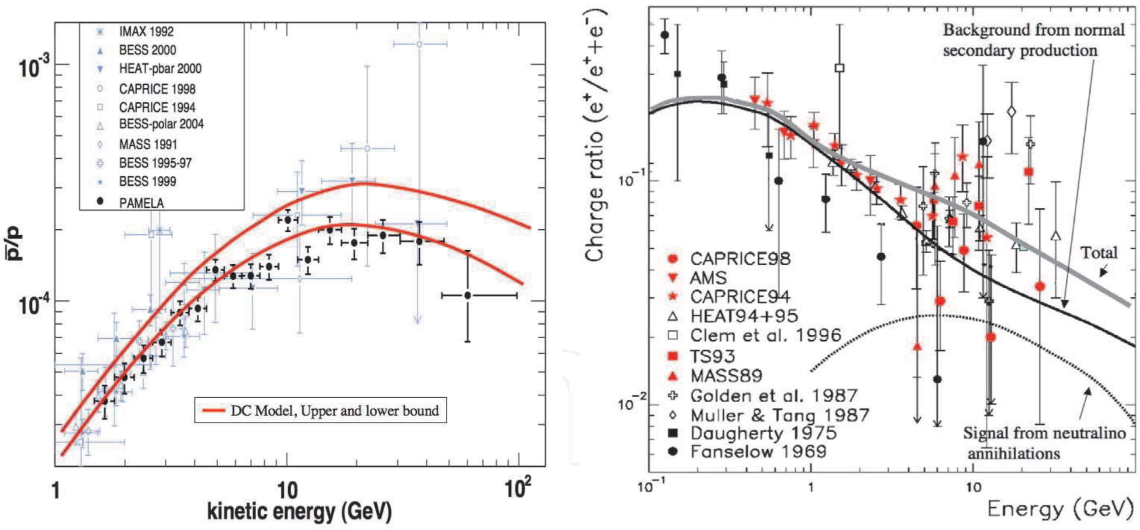
antinuclei): PAMELA2006 (72; 74), AMS02-2009 (11), BESS (19), PEBS-2010 (46), GAPS-2013 (65).

PAMELA (A Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) (72; 74) offers high statistics and sensitivity for the composition of the spectrum at high energies. Positron flux are measured with energies from 50 MeV to 270 GeV (previous limits were $0.7 - 30$ GeV), antiproton flux from 80 MeV to 190 GeV (previous limits $0.4 - 50$ GeV) and antinuclei ($\bar{H}e/He$) with flux of nearly 10^{-8} (previous limit about 10^{-6}). Besides that, matter will be observed in a wider range of energies as well.

AMS02 collaboration is a worldwide collaboration (11; 89) that will search for positron, antiproton, anti-helium and heavier antinuclei (up to anti-iron) with energies up to 1 TeV with higher statistics and sensitivity than AMS.

BESS (Balloon-borne Experiment with Superconducting Spectrometer) (19) offers a much lower cost than space missions by long duration polar ballon flights. It is suitable to detecting low energy antiprotons, antideuterons and antihelium (19; 71; 82). However it is GAPS that offers the best apparatus for detecting antideuteron (65).

The relative antiproton flux $\bar{p}/p$ observed in different satellites/observatories is presented in Fig. 1 (figure from Ref. (66),*Morselli, Moskalenko, Status of indirect searches in the PAMELA and FERMI era* Proceedings of Science, PoS, *http://pos.issa.it (IDM2008) 025)*). Antiproton flux is similar from the different observations (BESS, CAPRICE, MASS, PAMELA, IMAX, HEAT) In solid lines lower and upper limits on the contribution for pure secondary component from Ref. (95). Secondary interactions are overestimated by usual codes (75; 87; 95). Therefore the peak in the low energy around 2GeV presents the behavior described by secondary interaction component of the ISM although it is probably not described only by these interactions.



(a) Figure 1 (b) Figure 2

Fig. 1. Antiproton flux from the different observations (BESS, CAPRICE, MASS, PAMELA, IMAX, HEAT) and with estimations for secondary ISM interactions from (95). Figure from (66). **Fig. 2**: The relative positron flux, $e^+/(e^+ + e^-)$, from Ref. (75) with data from several experiments and two theoretical curves (model with pure secondary interaction in ISM (in black solid line) and a model in which neutralino annihilates producing positrons)

The relative positron flux, $e^+/(e^+ + e^-)$, from different observations, is shown in Fig. 2 (figure from Ref. (75), *Picozza, Morselli, (2008)* Journal of Physics: Conference Series *120,042004, IOP Publishing*), where the total flux is in grey solid line. Since these particles are light they must loose energy considerably in interaction with interestellar matter. On the other hand positrons might also originate from secondary interaction in such interstellar medium (from $\pi+$ and K^+). Two theoretical curves are included: model with pure secondary interaction in ISM (in black solid line) and a model in which neutralino annihilates producing positrons (in dotted line (14)) There is a slightly reduced decrease of the total flux for energies around 10GeV.
From the different observations in the last years the upper limit of the relative flux for heavy anti-nuclei to nuclei (Z>2) is around 1 among 10^4 nuclei and the current bound on the ratio of anti-helium/helium is of the order of 3.10^{-7} from BESS-Polar and BESS-TeV (82). These observations already shows an improvement compared to the previous AMS upper bound that was 10^{-6} (10). The absence of light antinuclei (mainly $\bar{He}$) emitted by antistars could be (at least partially) explained by interaction in the matter dominated ISM and eventually dragging by their electric (or magnetic) fields. At a first look, one usually expects nearly the same proportionality of particles and antiparticles observed in CR and the relative abundance of matter and antimatter mainly in the Galaxy, i.e. composing the emitting sources of CR. Following this reasoning Dolgov and Bambi (15) have found an upper bound on the number of antistars in the galaxy considering the total number of stars is of the order of 10^{11}. Besides that, considering the current bound on the ratio of anti-He/He content of the CR one has (15):

$$N_{antistars} \leq 10^3. \tag{2}$$

It reduces to a extremely small fraction and its relative amount is far from being enough to justify a matter-antimatter symmetric picture of the galaxy.

2.2 Current tests on antimatter

In spite of the evidences for the need of baryogenesis mechanisms it is important to testify further antimatter, the properties and fundamental symmetries we assume to be valid, such as CPT and its consequences. Not only the current validity of these symmetries must be verified but also their behavior along the evolution of the Universe should be investigated, in particular in the Early Universe, when the extreme conditions could be responsible for modifications of matter/antimatter properties. Whereas the first of these aspects can usually (but not always) be tested in laboratories, the second remains rather an open field that continuously receives more input from theories and observations. The equivalence between inertial and gravitational mass for antimatter (anti-nuclei) is tested in the AEGIS experiment at CERN (4; 40) ("Antimatter Experiment: Gravity, Interferometry, Spectroscopy") through positronium/ antihidrogenium measurements. Different tests on CPT will be done in CERN: by ALPHA experiment (6) will consider spectral lines of anti-hydrogen atoms, ASACUSA will test the hyperfine splittling (12), ATRAP will perform accurate laser spectroscopy on anti-hidrogen (13).
An interesting recent test on CPT has appeared in neutrino physics from MINOS experiment (3). Oscillations of neutrino and antineutrinos have been found to be compatible with a violation of CPT although one expects to have more precise results from forthcoming experiments.
Some other tests on antimatter interactions and bound states will be done by FAIR-GSI (42).
Although there is no available way of testing some further issues we mention that besides the possible CPT breaking that could have modified deeply the expected dynamics of the Early

Universe, some other modified gravitation theories which lead to effective repulsion between matter and antimatter in the Early Universe have also been envisaged (50). There are several theories yielding antimatter behavior different from matter, just as example we quote Ref. (86) with theories of supergravity for which Kaluza-Klein graviscalar and gravivector components may provide different couplings between matter/antimatter.

3. Cosmological baryogenesis

CMBR fluctuations and diffuse gamma ray spectrum are compatible with matter dominated Universe. If the Universe presented the same amount of matter and antimatter the most probable realisation would appear with whole domains of antimatter (anti-galaxies, anti-clusters). However, the best established theoretical estimations for this scenario indicates that if there were boundary walls of matter and antimatter dominated regions ("islands") they would have strong annihilation effects in the borders already in the phase of hydrogen recombination that would distort the CMBR anisotropies and polarization (31; 68; 93). After recombination it would be difficult to prevent annihilation for different domains of matter and antimatter. If the Universe contains a sizeable (even if not large) baryon excess one is left with the problem of understanding the mechanisms that yielded the corresponding symmetry breakings of particle Physics. Given that at very high temperatures, and more generally high energy densities, the symmetries usually have the tendency of being rather restored (58), even if this is not always expected (20), a scenario that copes such opposite expectations may become a still more difficult task. In this section we discuss aspects of particles field theories and dynamics relevant for the investigation not only of the matter-antimatter asymmetric scenario in the Early Universe but also for different pictures (less asymmetric) of the Universe and antimatter states.

3.1 Sakharov's conditions

The Sakharov's conditions were proposed in the 60's (79) and remain the most well established framework to describe baryogenesis. They assume CPT symmetry along the whole Universe evolution. The conditions are the following:

- Non conservation of baryon number B,
- C , CP and T violation,
- Out of equilibrium environment.

Consider only the first condition that is the essential one for any mechanism. There is no experimental evidence of B non conservation up to 10^{34} years (69), so B number is a conserved quantity in the Standard model Lagrangian although quantum effects might break such symmetry and GUTs also predict its breaking. If C is conserved then a reaction $(X_1 \rightarrow X_2 + B)$ produces a baryon B and the conjugated reaction $(\bar{X}_1 \rightarrow \bar{X}_2 + \bar{B})$ would also take place producing the same amount of $\bar{B}$ over a long period of time. Therefore one needs to break invariance over C to produce (reasonable amount) of B asymmetry. If CPT is considered to be an exact symmetry, the masses of particles and antiparticles are equal $(m_X = m_{\bar{X}}\ ,\ m_B = m_{\bar{B}})$, then an initial baryon asymmetry (from the first two conditions above) would, in thermal equilibrium, be compensated by other processes which would generate pairs of particle-antiparticle so that B would be conserved over a, not necessarily long, period of time. Therefore it is required that during some time B is nonconserved outside equilibrium and when restoring thermal equilibrium this asymmetry remains. Therefore time reversal must also be broken which means that if CPT theorem is intact by the time of such particle production, CP must be broken as well. If these processes take place out of thermodynamic equilibrium one can expect that the reverse reactions of those breaking B and CP occur with different widths. By the way, one is left with one of the most fundamental links for relating microscopic symmetric world, with the corresponding symmetries, and the macroscopic thermodynamic Universe. Nowadays there are several known mechanisms of CP breaking, although in the Early Universe CP breaking could had taken place by means of mechanisms probably, at least in part, different from those observed in laboratory nowadays (26). However any fraction of matter excess might have been produced by combined mechanisms of spontaneous and explicit breaking of CP (60). It is also plausible that the amount of matter generated by the fundamental processes was simply larger than the amount of antimatter, due to some other mechanism of baryon number violation.

3.2 Some scenarios for Sakharov conditions and other mechanisms

There are many proposals for alternative scenarios to explain the baryon asymmetry in the Universe, we mention few of them in the following and the reader can find more in reviews available in the literature, for example in Refs. (15; 28; 34; 36; 38; 54; 78; 84). In GUT, baryogenesis can be realized from condensation of scalar SUSY-fields in the Affleck-Dine scenario. Scalar superpartners of baryons or leptons (χ) undergo condensation by spontaneous symmetry breaking and their decay involve B-nonconserving processes that can bring a large baryon asymmetry (although this scenario also can favor matter/antimatter domains) (9). The decay of Higgs or gauge bosons X ($m_X \sim 10^{16}$GeV) in GUT might also generate baryon excess (47). Combination of the above processes could be realised, for example through baryogenesis after leptogenesis (45) at the energy scale of $T \sim 10^{10}$GeV. SUSY models can yield baryogenesis resulting from thermal leptogenesis, although usually producing wrong primordial abundance of elements. Some works try to mend this probelm (33). Assuming a SSB of a global $U_A(1)$ gauge symmetry the decay of a Goldstone field can yield baryogenesis in the broken phase (30). However these models easily produce large deviation from isocurvature density fluctuations. Some other models consider interactions violating R-parity which yields an excess of baryons over antibaryons, besides explaining the dark matter with good agreement with current estimations of relative abundance of elements (59).

Some of the processes that could have provided CP- breaking in the Early Universe are not expected to take place anymore nowadays. We remind some mechanisms of CP breaking and the reader will find further details in reviews available in the literature (15; 36; 38; 99). Some CP breaking mechanisms come from an explicit Lagrangian term and others from spontaneous symmetry breaking (63; 99). However this last mechanism yields rather a symmetric universe with equal amounts of matter and antimatter (105). Several of the known mechanisms were proposed within the electroweak theory, sphalerons undergo a tunneling between the degenerated vacuum of different baryonic number yielding B non conservation. Strong-CP violation (96) might contribute to yield sizeable baryon excess if there is large deviation from thermal equilibrium. However the massive Higgs can favor a second order phase transition with small deviation from thermal equilibrium, besides that this CP violation is seemingly weak (36). It is also possible to have dynamical or stochastic CP breaking due to complex scalar field out of equilibrium for which one would have generated a meaningful amount of antimatter (35; 36). A possible solution for the difficulty in producing a correct amount of CP breaking would be TeV - high energy scale gravity (8). In some other models the neutrino mass generation is related to the baryogenesis (81) that also describes dark matter in a seesaw-like model (51). One has also proposed that although quarks/antiquarks have been created without an asymmetry, dynamics of the early Universe would have found a way of store antiquarks in lumps of color antiquark condensates within (small or not) compact antimatter objects (24; 70).

4. Further ideas

In spite of the (strong) observational evidences discussed above for an asymmetric $B - \bar{B}$ Universe discussed above there still are other possible scenarios, in particular with less asymmetric Universe. For instance considering a complex scalar field, undergoing spontaneous symmetry breaking, and acquiring a vacuum expectation value it provides a mechanism that allows for separating matter and antimatter domains (62). Models for inhomogeneous baryogenesis within Affleck-Dine scenario were discussed in Ref.(37) which give rise to some ways of accommodating antistars from early Universe dynamics considering the decay of scalar baryon condensate χ into quarks (and antiquarks) (37). The order of the phase transition can have strong effects on the resulting distribution of antimatter and it is not known (37). An analysis based in the Coleman-Weinberg potential for the evolution of the χ condensate is given in Ref.(38). In such model, CP is unbroken but B is broken. These scenarios would have to cope with the high energy gamma ray background (31) and with the known "matter" domain wall (107).

Besides the usual picture of antimatter islands discussed above, other related configurations may arise, for instance, antimatter dominated region in the edges of the observed Universe. This scenario could emerge if matter and antimatter interactions have had strongly repulsive interaction in the Early Universe. This scenario is allowed by constraints on CMBR homogeneity. Differently, if the early Universe dynamics allowed for the formation of localized massive antimatter objects (black-holes, B-balls, droplets, nuggets, lumps) they could carry (at least part of) the primordial antimatter (17; 24; 70). Among the localized objects, primordial anti-black holes could be candidates to contain a sizeable amount of antimatter from the Early Universe, therefore, in spite of the difficulties, it would be very interesting to try to distinguish them from matter BH, for example by annihilation processes in the hair. There is no specific limit on the PBH masses, but they might be as small as $10^{-14} M_{sun}$ (solar mass) and reach many times the solar mass. B-balls might also be objects or anti-objects (15), originated from a bubble in the Affleck-Dine mechanism with scalar baryon field χ which decays into baryons/quarks. A different form of bound states of antimatter could be the (anti)lumps formed when quarks and antiquarks were produced in different bubbles in the QCD phase transition (70). They could contain superconducting state anti-quarks (23; 24; 70).

Instead of discussing issues very commonly addressed, such as macroscopic hydrodynamics in expanding geometries, we go through some aspects of interest of quantum fields with focus on approximative solutions with qualitative interesting effects. Although the particles are the dynamical variables that constitute the whole Universe, it is an impossible task to perform any calculation or simulation of the Universe evolution, including the formation of structures, considering a time dependent quantum field theory with all the relevant fields and particles. Instead, a hydrodynamic model must be considered in the corresponding curved space time background (31; 102) and the underlying field theories can be considered for the determination of relevant microscopic effects and initial conditions. Even if the initial conditions have shown to not produce relevant effects as discussed in Ref.(31), the microscopic dynamics may introduce further input in the macroscopic scenario. Furthermore, instead of picking up a specific model and analyzing the efficiency of the processes allowed by their symmetries, we analyze effects that might be present in different theories, and the understanding of the quantitative reach is not addressed. Commonly these results can be implemented with some plausible modification of the former model. Consider a local field theory with fermions (ψ), gauge/vector fields (A_μ, V_μ), scalar field(s) (ϕ, χ). In a curved space-time background with non minimal coupling of gauge and scalar fields to gravitational field one can write the following action (21; 55):

$$S = \int d^4x \sqrt{-g} \left\{ \frac{i}{2} \left[\bar{\psi}\gamma_\mu \nabla^\mu \psi - (\nabla_\mu \bar{\psi})\gamma^\mu \psi \right] - M\bar{\psi}\psi - a_1\phi\bar{\psi}\psi - (m^2 + \xi_1 R(\mathbf{x}))\phi^2(\mathbf{x}) \right.$$
$$\left. + R(\mathbf{x}) + \mathcal{L}_{\phi,A_\mu}[\phi,\chi] + \xi R(\mathbf{x}) A_\mu A^\mu \right\}, \tag{3}$$

where $\sqrt{-g}$ is the square root of the determinant of the metric, ξ_i are couplings of gravitational field, $R(\mathbf{x})$ is the Ricci scalar,$\mathcal{L}_{\phi,A_\mu}[\phi,\chi]$ is the Lagrangian density of the scalar fields with interactions, including self-interacting terms for scalar fields $V[\phi,\chi]$, and their dynamical equations are not written. In a curved space-time background the Dirac equation for fermions $\psi(\mathbf{x})$ and the corresponding $\bar{\psi}(\mathbf{x})$ interacting with scalar and vector fields can be written as:

$$\left(i\gamma_\mu(\nabla^\mu + igA^\mu) - M - a_1\phi\right)\psi(\mathbf{x}) = 0, \quad \left(-i\gamma_\mu((\nabla^*)^\mu - igA^\mu) + M + a_1\phi\right)\bar{\psi}(\mathbf{x}) = 0, \tag{4}$$

where the covariant derivative ∇_μ includes the spin connection (21; 73). In Minkowski space for free fermions the eigenvalues of these equations are $E_0 = \pm\sqrt{k^2 + M^2}$. For the high energy environment of the Early Universe, we assume that the boson fields of this model can acquire a non zero classical value, typical from spontaneous symmetry breakings (55; 80). From these expressions, effective masses can be defined for the bosons and fermions. For example for the fermions (and anti-fermions): $M^* = M - a_1\bar{\phi}$ in terms of a classical counterpart of the scalar $\phi(\mathbf{x})$. The eigenvalues of the Dirac equation with a classical counterpart of V_μ and scalars ϕ, as external fields, become:

$$E_i^\pm = g_V V_0 \pm \sqrt{(\mathbf{p} - g_V\mathbf{V})^2 + (M_i^*)^2} \tag{5}$$

where the coupling to scalar field was incorporated in the effective mass. In particular little attention has been given to the formation of antimatter and matter-antimatter bound states, (104). Such states hardly would be responsible for absorbing antimatter excess, although they may be envisaged to produce new forms or structures of matter/antimatter eventually coexisting at least for some time in the Universe, maybe also contributing to the radiation spectra. More realistic cases appear when these external fields are not homogeneous quantities, i.e., when $V_0 = V_0(r)$. One can envisage different geometries for the dynamics of the creation of particles and antiparticles such that inhomogeneous configurations can arise that modify the matter-antimatter annihilation ratio or even preventing large annihilation ratio. For the sake of the argument, suppose that dynamics of (strongly interacting) fermions/anti-fermions are such that in a given direction x_i

$$\partial_{x_i}\psi(\mathbf{x}) \sim ik_i F_i(k)\psi(\mathbf{x}), \qquad \partial_{x_i}\bar{\psi}(\mathbf{x}) \sim -ik_i G_i(k)\bar{\psi}(\mathbf{x}), \tag{6}$$

where F_i and G_i can be functions of momenta and depend on the boson fields. Although one would expect solutions with the similar profile for both $\psi, \bar{\psi}$ it is perfectly reasonable that their momentum dependences may have different or even opposite behavior. Besides that the particle/antiparticle effective masses may become different dynamically by a solution such as those resulting from expressions (6). The hermiticity of Dirac Hamiltonian is not necessarily kept in curved spacetimes due to the time dependence of the metrics that brings time dependence of the spatial position eigenstates (53). Together with the kinetic effects discussed above we just mention topologically non trivial configurations. For the sake of simplicity consider a flat spacetime for which the fermions and antifermions have spatial wavefunctions spherically symmetric with two components: $f(r) = Asech(r/R)h(r)$ and $g(r) = Atanh(r/R)h(r)$, where A is a normalization, $h(r)$ is an overall function that also depends on the other fields, and these two components correspond to the leading terms respectively of the fermion (positive energy) and antifermion (negative energy) solutions. The negative and positive energy solutions could exhibit a topological property similar to the usual scalar field kink, which may guarantee fermions and antifermions to remain separated. Other solutions of the Dirac equation share similar properties (52).

Equations (6,4) do not account for any mechanism of explicit CPT breaking. If CPT breaking (32) took place in the extreme conditions of the early Universe different consequences might be expected, but current observational bounds must be observed in particular CMBR and matter homogeneity. An eventual separation of matter and antimatter was also proposed to occur in different branes which could be close in the higher dimensional space (41).

4.1 Dense systems of antimatter

An usual field theoretical formalism suitable for describing nuclear equation of state in dense stars (56; 83) should also be suitable for dense antimatter physics (24; 49). Similar effective models at the nuclear level are expected to be suitable for describing finite nuclei and hopefully should be suitable for describing the light antinuclei observed recently in relativistic heavy ions collisions of STAR-RHIC and ALICE-CERN (1; 85), although so far one did not have access for the detailed investigation of its structure. These observations just corroborates the expectation of anti-nucleosynthesis in the Early Universe. The energy is not as high as in the early universe GUT scales and baryogenesis is not expected to take place in the same scale. Nevertheless it has been suggested that bubbles of P-violating content of baryons and antibaryons might form in such collisions (5), what might be a preliminar sign for the Sakharov's conditions. However, instead of providing an extensive discussion on these relativistic models for dense baryon equation of state, we present some issues of relevance for finite density anti-baryon systems eventually going beyond usual developments (24). We will refer generally to fermions since the framework is valid, in general lines, for both (anti)baryons or (anti)quarks.

Consider a general finite density environment in Minkowski space in which fermions, either nucleons and eventually hyperons or quarks for quark stars, interact mainly with meson fields, in particular a vector and scalar fields, V_μ, ϕ (49; 83). By considering the Dirac equation for such fermion fields with its eigenvalues and eigenfunctions as functions of the classical counterparts of the meson fields, the energy densities associated to the fermions (anti-fermions) can be calculated straightforwardly $\rho_f[V_0] = Tr\bar{\psi}\hat{H}\psi$. Depending on the truncation of the fermion eigenstates the resulting energy density might exhibit different behaviors. In particular, if the eigenstates of the Dirac equation coupled to the background mean fields (5), it is found that they do not have necessarily the symmetry of the matter-antimatter in the vacuum if V_0 does not change sign. Comparing the behavior for the different densities we notice that antifermion density can be favored for some ranges of V_0, mainly for $V_0 < 0$ as it should be expected (24). It is also interesting that depending on the profile of the solution for $V_0[\rho_B]$, the resulting equation of state can be stiffer or softer.

The resulting expressions for ρ_f might not have the same behavior of those for Fermi liquids (25). Experimental investigation of antinuclei structure will settle further the relevant degrees of freedom and the eventual correspondence of the states of a nucleus and its corresponding anti-nucleus.

As discussed in Section 3, in the same way as quarks can form superconducting high density states, antiquarks might also form color superconducting states with di-antiquark condensation ($< \bar{q}\bar{q} >$) and it could take place in dense antiquark stars (23; 70). Some effects of classical tensor and vector fields, eventually associated to classical gluon configurations (which could be relevant for the time of the quark production), are usually considered for the formation of superconductive states at very high densities (22).

5. Summary

Observational Cosmology is coming to a new era where large observatories start to provide much more precise data. Antimatter asymmetry and states in the Universe have been investigated for short period of time and much has to be done to establish deeper knowledge about them. At the end we remain deeply inside a matter dominated region of the Universe, even if antimatter objects might be not so far. CMBR fluctuations are the most well established observables that induce constraints in the evolution of structures and diffuse gamma ray spectra can provide direct fingerprint of antimatter annihilation and therefore is suitable for investigating anti-objects and their interaction with matter. Cosmic rays are currently measured with high precision and sensitivity, although the corresponding interpretation is not obvious and depends strongly on further models for matter-antimatter interactions in the interstellar medium.

Most observables favor a highly asymmetric $B - \bar{B}$ Universe for which there is a difficulty of establishing the realistic mechanisms which allowed for the baryogenesis according to Sakharov conditions, even if other scenarios have been proposed. In particular the mechanism(s) of CP breaking that really contributed in the Early Universe are not fully elucidated, and several of them cannot be tested in laboratories. If there is hidden antimatter, or islands of antimatter not observed so far, so that the Universe is rather (or nearly) symmetric, then mechanisms that provided the formation of anti-structures (different or not from the known matter structures) or such spatial separation between matter and antimatter must be understood. CPT, gravitational interaction of antimatter eventually with the formation of primordial anti-black holes, among other objects, are some of the issues deserving further theoretical and observational investigation.

6. Acknowledgements

The author thanks Aldo Morselli as well as Igor Moskalenko for kindly sending the Figures 1, 2 from References (66; 75).

7. References

[1] Abelev, B.I. et al, (2010). *Science* 2, Vol. 328, pp. 58-62. Agakishiev, H. et al, STAR-RHIC Collaboration, arXiv:nucl-ex/1103.3312.
[2] Abdo, A. A. et al, (2009) *Phys. Rev. Lett.* 103, 251101 (2009),
[3] Adamson, P. et al. (MINOS Collaboration), (2010) *Phys. Rev. Lett.* 105, 151601. Engelhardt, N. , Nelson, A. E., Walsh, J. R., arXiv:hep-ph/1002.4452.
[4] AEGIS Collaboration, URL: http://aegis.web.cern.ch/aegis

[5] Aggarwal, M. M., et al. (STAR Collaboration) *Phys. Rev. Lett.* 106 (2011) 62002.
[6] Madsen N. (2010) Philosophical Transactions of the Royal Society A 368, vol 1924, 3671.
[7] Alcock , et al., (1997) *Astrophys. J.* 486, 697. MACHO project, URL http://www.macho.mcmaster.ca/
[8] Arkani-Hamed. N, Dimopoulos. S, Dvali. G, (1998) *Phys. Lett.* B 429 (1998) 263; Antoniadis. I, et al, *Phys. Lett.* B 436 (1998) 257. Dolgov.A. D, Urban.F.R, (2006) *Nucl. Phys.* B752 , 297; hep-ph/0605263; Bambi.C, Dolgov.A. D, Freese. K, (2007) *Journal of Cosmology and Astroparticle Physics* 04, 005; hep-ph/0612018.
[9] Affleck. I, Dine. M, (1985) *Nucl. Phys.*, B249 , 361.
[10] AMS Collaboration, *arXiv:hep-ex/0002048v1*; URL: http://ams.cern.ch.
[11] AMS-2, URL: http://ams-02project.jsc.nasa.gov .
[12] ASACUSA, URL: http://asacusa.web.cern.ch/ASACUSA/
[13] ATRAP, URL: http://public.web.cern.ch/public/en/research/ATRAP-en.html
[14] Baltz, E. and Edsjo J., (1999) *Phys. Rev.* D 59, 023511.
[15] Bambi. C, Dolgov. A. D, (2007) *Nucl. Phys.* B 784, 132, astro-ph/0702350.
[16] Bambi. C, et al, (2009) *JCAP* 9, 013. Treves. A., Turolla. R,(1999) *Astrophys. J.* 517 , 396.
[17] Belotsky. K. M, Golubkov.Yu.A, Khlopov. M.Yu,. Konoplich. R.V., Sakharov. A.S, (2000) *Phys. Atom. Nucl.* 63, 233; Golubkov. Y. A, Khlopov. M. Y, (2001) *Phys. Atom. Nucl.* 64, 1821; astro-ph/0005419; Fargion. D, Khlopov. M, (2003)*Astropart. Phys.* 19, 441, hep-ph/0109133; Casadei D., *astro-ph*/0405417, revised version in 2008.
[18] Bergstrom. L, Edsjo. J and Ullio. P, (1999) *Phys. Rev.* D 59, 43506. G. Jungmamn and M. Kamionkowski, (1994) *Phys. Rev.* D, 49 , 2316.
[19] BESS Collaboration URL: http://www.universe.nasa.gov/astroparticles/programs/bess/
[20] See for example: Bimonte G., Lozano G., (1996) *Phys. Lett.* B 366, 248.
[21] Birrell. N. D and Davies. P. C. W, (1982) *Quantum fields in curved space*, Cambridge Univ. Press, Cambridge. Fulling. S. A, (1996) *Aspects of Quantum Field Theory in Curved Space-Time*, London Math Society, S.T. 17, C. U. P., Cambridge.
[22] See for example Blaschke, D et al., (2005) *Phys. Rev.* D 72, 065020.
[23] Braghin, F.L.,(2007) *Nucl. Phys.* A 790, 546c, hep-ph/0611390.
[24] Braghin, F.L. (2007) *Int. Journal of Mod. Phys.* D 16, 96.
[25] Braghin, F.L. (2010) *Int. Journal of Mod. Phys.* D 19, 1505.
[26] Brown. R. W and Stecker. F. W, (1979)*Phys. Rev. Lett.*, 43 , 315.
[27] Burles, S., Nollett, K. M., Turner, M. S., (2001) *The Astrophysical Journal*, 552.
[28] Casadei,D., astro-ph/0405417. Golubkov,Y.A., Khlopov, M.Y., (2001) *Phys. Atom. Nucl.* 64, 1821; astro-ph/0005419.
[29] CBI: URL: http://www-astro.physics.ox.ac.uk/research/expcosmology/groupcbi.html
[30] Cohen. A. G, Kaplan. D. B, .Nucl. Phys., B308 (1988) 913.
[31] Cohen A. G, de Rújula. A, Glashow. S. L, (1998) *The Astrophys. Journ.* 495, 539 . Auriemma. G, (2003) *Chin. J. Astron. Astrophys.* 3, 30.
[32] See for example: Kostelecky, A., Russell, N., (2008) Data Tables for Lorentz and CPT Violation, hep-ph, arXiv:0801.0287v3 Mavromatos, N. E., (2005) hep-ph/0504143. Russell, N., (2005) hep-ph/0511262.
[33] De Simone A, et al, (2010) *Journ. of Cosmology and Astroparticle Phys.* 7, 17.
[34] Dine M., Kusenko. A, (2003) *Rev. of Mod. Phys.* 76 1 and references therein.
[35] Dolgov. A. D, (1992) Phys. Repts 222, No. 6.
[36] Dolgov. A. D, (2005) *Lectures presented at Varenna* Varenna, Italy, hep-ph/0511213.
[37] Dolgov,A.D., Kawasaki, M., Kevlishvili, N. (2008) hep-ph/arXiv:0806.2986v2

[38] Dolgov, A.D. (2009) arXiv:0901.2100v1.
[39] Dolgov,A.D., (2011) *Phys. of At. Nuclei* 74, 3, 462; hep-ph/1002.2940v1
[40] Doser, M. (AEGIS collaboration) (2010) *Journ. of Physics: Conf. Series* 199, 012009.
[41] Dvali. G. R, Gabadadze. G, Porrati. M, (2000) *Phys. Lett.* B485, 208, hep-th/0005016.
[42] FAIR/GSI facility: URL: https://www.gsi.de/portrait/fair$_e$.html
[43] FERMI Collaboration: URL: http://fermi.gsfc.nasa.gov/.
[44] Fixen. D.J et al., (1996) *Astrophys. J.* 473, 576. Mather . C.J et al., (1994) *Astrophys. J.* 420, 439. Bersanelli. M et al., (1994) *Astrophys. J.* 424, 517.
[45] Fukugita. M, Yanagita. T, (1986) *Phys. Lett.*, B174, 45. Buchmuller. W, Di Bari. P, Plumacher. M, (2004) *New J. Phys.*, 6 , 105.
[46] Gast H. et al, (2008) *Proceedings of the 30th International Cosmic Ray Conference*, ed by Caballero. R. et al Mexico City, Mexico, p. 293.
[47] Georgi. H ,Glashow. S L , (1974) *Phys. Rev. Lett.* 32, 438.
[48] Goudelis. A, Mambrini. Y and Yaguna. C, (2009) *JCAP*12 ,008
[49] Greiner, W., (2003) *AIP Conf. Proc.* 1323, 109; *Physics of Atomic Nuclei*, 66, 1009.
[50] Hajdukovc, D.S. , (2010) *Astrophys. and Space Science* 330, 1.
[51] Hu. P. H, Sarkar. U, (2010) *Phys. Rev. D* 81, 033001.
[52] Hirayama,M., Ninagawa,S. (1989) *Phys. Rev.* D 39, 1602 . A different approach in: Góźdź,M., Nakonieczny, L., Rogatko,M.(2007) *Phys. Rev.* D 81, 104027.
[53] Huang,X., Parker,L. (2009) *Phys. Rev.* D79, 024020.
[54] Several works for example in *Int. J. Mod. Phys.* D 17 (2002); and in Ref. (55). Santilli,R.M. , (1998) *Int. Journ. of Mod. Phys.* D 7, 351.
[55] Itzykson, C. and Zuber, J.-B. (1985) *Quantum Field Theory*, McGraw Hill, Singapore. Conditions for CPT violation, for example, in: Mavromatos, N. E., hep-ph/0504143. Tests on CPT, for example: N. Russell, hep-ph/0511262.
[56] Several contributions for the Proceedings of International Workshop on Relativistic Astrophysics, (2010) Int. Journ. of Mod. Phys. D 19. Ed. by J.E. Horvath, M.M.B.M. de Oliveira, B.E.J. Bodmann, C.A.Z. Vasconcellos, H. Stoecker, W. Greiner.
[57] Kinney, W.H. et al (1997) *Phys. Rev. Lett.* 79. A. G. Cohen, A. De Rujula, astro-ph/9709132.
[58] Kogut, J. et al (1983) *Phys. Rev. Lett.* 50, 393 Berges, J., Tetradis N., Wetterich C., (2002) *Phys. Rep.* 363, 223.
[59] Kohri,K., Mazumdar, A., Sahu, N., (2009) *Phys. Rev.* D 80, 103504.
[60] Kuzmin. V. A, Shaposhnikov. M. E, Tkachev. I. I, (1981) *Phys. Lett.* B105, 167; Kuzmin. V. A, Tkachev.I. I, Shaposhnikov. M. E, (1981) *Pisma Zh. Eksp. Teor. Fiz.* 33, 557.
[61] Langlois,D., C. R. (2003) *Physique* 4, 953.
[62] Lee,T.D. (1973) *Phys. Rev.*, D8 , 1226. Brown, R.W., Stecker, F.W. (1979) *Phys. Rev. Lett.* 43, 315.
[63] Lee, T.D., (1974) *Phys. Rept.* 9, 43. Brown, R.W. and Stecker, F.W. (1979) *Phys. Rev. Lett.* 43 315.
[64] Maki. K, Mitsui. T, T., and Orito. S, (1996) *Phys. Rev. Lett.* 76, 3474. Hawking,. S. W, (1971) *Monthly Notices Roy. Astron. Soc*, 152, 75. Kiraly. P et al., (1981) *Nature*, 293, 120.
[65] Mori. K, et al.,(2002) *Astrophys. Journal* 566 , 604 See e.g.:URL: http://www.cita.utoronto.ca/ kaya/gaps.html
[66] Morselli,A., Moskalenko, I.V., *Status of indirect searches in the PAMELA and FERMI era Proceedings of Science, PoS*, http://pos.issa.it (IDM2008) 025; arXiv:0811.3526

[67] Moskalenko. I. V., et al (2002) *Astrophys. J.* 565, 280. Tan. L. C and Ng. L. K , (1983) *J. Phys.* G 9, 227; (1983) *J. Phys.* G 9 , 1289.

[68] Naselsky P.D.,Chiang, L-Y (2004) *Phys. Rev.* D69, 123518.

[69] For example in Nishino, H. , et al. (Super-K Collaboration) (2009). *Phys. Rev. Lett.* 102, 141801.

[70] Oaknin. D. H, Zhitnitsky. A, (2005) *Phys. Rev.* D71, 023519, hep-ph/0309086; Oaknin. D. H, Zhitnitsky. A, (2005) *Phys. Rev. Lett.* 94 , 101301, hep-ph/0406146. K. Lawson and A.R. Zhitnitsky, arXiv:0704.3064

[71] Orito. S et al. (BESS Collaboration), (2000) *Phys. Rev. Lett.* 84, 1078; astro-ph/9906426.

[72] PAMELA Collaboration, URL: http://pamela.roma2.infn.it/index.php.

[73] Parker L. E, Toms. D. J, (2009) *Quantum Field Theory in Curved Spacetime*, Cambridge Univers. Press, Cambridge.

[74] Picozza. P et al., *Astroparticle Physics* 27 (2007) 296. Boezio M. et al, PAMELA Collaboration, (2008). *Journal of Physics: Conference Series*, 110, 062002.

[75] Picozza. P, Morselli. A, (2008) *Journal of Physics: Conference Series* 120,042004, IOP Publishing.

[76] Purcell. W. R et al., (1997) *Astrophys. J.* 491 , 725. Milne. P. A, et al (2002) *New Astron. Rev.* 46 , 553. Knodlseder. J. et al., (2005)*Astron. Astrophys.* 441, 513. Jean. P. et al., (2006) *Astron. Astrophys.* 445, 579.

[77] Raffelt, G. G., (2007) arXiv:astro-ph/0701677.

[78] Riotto, A., Trodden, M. (1999) Annu. Rev. Nucl. Part. Sci. 49:35.

[79] Sakharov. A.D, (1967) *JETP Lett.* 6, 24.

[80] Sannino. F and Schafer. W hep-ph/0111098.

[81] See for example Sarkar, U. (2000) *PRAMANA* Indian Academy of Sciences 54, 101.

[82] Sasaki. M *et al*, (2008) *Advances in Space Research* 42 , 450ï£¡454.

[83] Serot. B. D and Walecka. J. D, (1997) *Int. Jour. Mod. Phys.* E 6, 515 and references therein.

[84] Shaposhnikov. M, (2009) *Progr. of Theor. Phys.*122, 185.

[85] Sharma, N., ALICE Collaboration, arXiv: nucl-ex/1104.3311v2.

[86] Sherk. J, (1979) *Phys. Lett.* B 88 , 265.

[87] Simon. M, Molnar. A and Roesler.S, (1998) *Astrophys. Journal* 499 , 250. Bergstrom.L , et al, (1999) *Astrophys. Journal* 526 , 215

[88] See for example Singh. S, (2004) *Big Bang: The Origin of the Universe*, HarperCollins,.

[89] Spada. F., *hep-ex*/0810.3831v1.

[90] Spergel. D.N. et al., (2003) *Astrophys. J.* Suppl. 148, 175; astro-ph/0302209.

[91] Sreekumar, P. et al., (1998) *Astrophys. Journal* 494 , 523.

[92] Steigman. G, (1976) *Ann. Rev. Astron. Astrophys.* 14 , 339.

[93] Steigman G., (2008) *J. Cosmol. Astropart. Phys.* JCAP 10, 001. G. Steigman, arXiv:0808.1122.

[94] Streater, R. F., Wightman,A. S. (1964) *PCT, spin and statistics, and all that.* Benjamin/Cummings.

[95] Strong, A. W., Moskalenko, I. V., and Ptuskin, V. S., (2007) *Annu. Rev. Nucl. Part. Sci.* 57, 285.

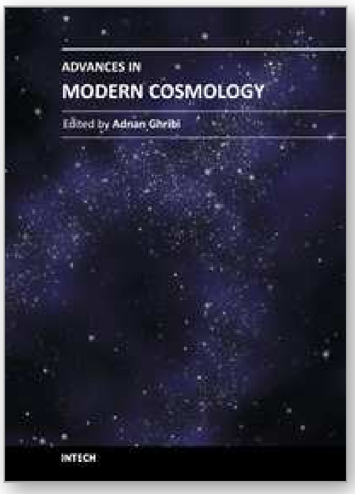
[96] t'Hooft. G, (1976) *Phys. Rev. Lett.* 37 8; (1976) *Phys. Rev.* D14 , 3432.

[97] Izotov, Y. I., Thuan, T. X., (1998) *Astrophys. J.* 500, 188.

[98] Yao et al, (2006) *Journal of Physics* G 33 , 1.

[99] Yokoyama J., et al, (1987) *Int. J. Mod. Phys.* A 2 , 1808; J. Yokoyama, et al (1988) Prog. Theor. Phys. 79 , 800. D. Grigoriev, hep-ph/0006115.

[100] Weidenspointner . G. et al., (2006) *Astron. Astrophys.* 450, 1013 ; astro-ph/0601673.
[101] Weidenspointner.G, et al., *astro-ph*/0702621.
[102] Weinberg, S., (1975) *Gravitation and Cosmology*, John Wiley & Sons, New York.
[103] WMAP Collaboration, URL: http://map.gsfc.nasa.gov/mission/ E. Komatsu, (2011) *Astrophys.J.Suppl.*192, 18; arXiv:astro-ph/1001.4538.
[104] See for example: Wong, C.-Y., Lee, T.G., arXiv:physics/1103.5774.
[105] Zeldovich, Ya.B., Kobzarev, I.Yu. Okun, L.B. , (1974) *Zh. Eksp. Teor. Fiz.* 67, 3; *Sov. Phys. JETP* 40 (1974) 1.
[106] Zeldovich Ya. B, (1976) *Pisma Zh. Eksp. Teor. Fiz.* 24, 29; Dolgov.A. D. (1981) *Phys. Rev.* D 24,1042.
[107] Zeldovich. Ya.B., Kobzarev. I.Yu, Okun. L. B, (1974) *Zh. Eksp. Teor. Fiz.*, 67, 3.
[108] Zhang, J., Yuan,Q., Bi, X.-J. (2010) *The Astrophysical Journal*, 720, 9.



Advances in Modern Cosmology

Edited by Dr. Adnan Ghribi

ISBN 978-953-307-423-8
Hard cover, 198 pages
Publisher InTech

Published in print edition August, 2011

The twentieth century elevated our understanding of the Universe from its early stages to what it is today and what is to become of it. Cosmology is the weapon that utilizes all the scientific tools that we have created to feel less lost in the immensity of our Universe. The standard model is the theory that explains the best what we observe. Even with all the successes that this theory had, two main questions are still to be answered: What is the nature of dark matter and dark energy? This book attempts to understand these questions while giving some of the most promising advances in modern cosmology.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

F. L. Braghin (2011). Matter-Antimatter Asymmetry and States in the Universe, Advances in Modern Cosmology, Dr. Adnan Ghribi (Ed.), ISBN: 978-953-307-423-8, InTech, Available from: http://www.intechopen.com/books/advances-in-modern-cosmology/matter-antimatter-asymmetry-and-states-in-the-universe

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821