CLOUDS ON ΛCDM SKY
and/or
NEW PHYSICS
and
COSMOLOGICAL ANTIMATTER

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There is large amount of astronomical data, collected during the last few years, strongly indicating that the standard ΛCDM cosmology, very well describing gross features of the universe, encounters serious problems in numerous details. As the saying goes:

"The Devil is in the detail"

maybe this is not the Devil but God (as it was originally), i.e. New Physics.

Expansion regime of the contemporary universe may be different: ”Power-law cosmology, SN Ia, and BAO”, A.D., V. Halenka, I. Tkachev, JCAP 1410 (2014) 10, 047.

Observational constraints on modified gravity models, which at low redshifts lead to a power-law cosmology are analyzed, using data on Supernova Ia and on baryon acoustic oscillations. It is shown that the expansion regime $a(t) \sim t^\beta$ with $\beta \approx 3/2$ in a spatially flat universe is a good fit to these data.

Recent confirmation, 1509.04924.

The tension between the Planck and traditional astronomical measurements: $h_{Pl} = 0.6727 \pm 0.0066$, $h_{astr} = 0.743 \pm 0.021$, may be resolved, if a new long-lived particle exists, decaying between the recombination and the present day, Z. Berezhiani, A.D., I.I. Tkachev, "Reconciling Planck results with low redshift astronomical measurements", arXiv:1505.03644; PRD in press.

There is an avalanche of observed early formed objects which could not be created in so young universe.
Moreover, the stars are observed which are "older than the universe".

"Something is rotten in the state of ~~Denmark~~ the Universe" (almost quote of Marcellus from "Hamlet")

These numerous data and a possible model which can explain them are discussed in this talk.

As a byproduct the model predicts plenty of antimatter in our neighborhood, even in the Galaxy. Still it can escape the existing observations.

The cosmological antimatter is actively searched for at the present time and there may be non-negligible chances for the discovery.

Universe age as a function of redshift:

$$t(z) = \frac{1}{H}\int_0^{\frac{1}{z+1}} \frac{dx}{\sqrt{1 - \Omega_{tot} + \frac{\Omega_m}{x} + x^2\Omega_v}},$$

Parameters:

$\Omega_{tot} = 1$, $\Omega_m = 0.317$, $\Omega_v = 0.683$;

$H = 67.3$ **km/sec/Mpc (Planck);**

$H = 74$ **km/sec/Mpc (direct).**

Origin of the tension?

Universe age (in Gyr):

$t_U \equiv t(0) = 13.8;\ 12.5.$

$t(12) = 0.37;\ 0.33;\quad t(10) = 0.47;\ 0.43$

$t(6.3) = 0.87;\ 0.79;\quad t(3) = 2.14;\ 1.94.$

I. Observed high-z objects which could not be created in so short time.

There is a large ”zoo” of astronomical objects formed in surprisingly short times. Several galaxies have been observed at high redshifts, with natural gravitational lens “telescopes, e.g. a galaxy at $z \approx 9.6$ which was created when the universe was about 0.5 Gyr old, (W. Zheng, *et al*, ”A highly magnified candidate for a young galaxy seen when the Universe was 500 Myrs old” arXiv:1204.2305).

Moreover a galaxy at $z \approx 11$ has been observed which was formed earlier than the universe age was 0.41 Gyr (or even shorter with larger H). D. Coe *et al* **"CLASH: Three Strongly Lensed Images of a Candidate $z \sim 11$ Galaxy", Astrophys. J. 762 (2013) 32; e-Print: arXiv:1211.3663.**

An observation of not so young but extremely luminous galaxy was recently reported: ”The most luminous galaxies discovered by WISE” Chao-Wei Tsai, P.R.M. Eisenhardt *et al*, arXiv:1410.1751, 8 Apr 2015.
$L = 3 \cdot 10^{14} L_{\odot}$; age $\sim$ 1.3 Gyr.
The galactic seeds, or embryonic black holes, might be bigger than thought possible. P. Eisenhardt: ”How do you get an elephant? One way is start with a baby elephant.” The BH was already billions of $M_{\odot}$, when our universe was only a tenth of its present age of 13.8 billion years.

Another example and even more striking example of early formed objects are quasars observed at high z. A quasar with maximum $z = 7.085$ has been observed i.e. it was formed at $t < 0.75$ Gyr. Its luminosity is $6.3 \cdot 10^{13} L_\odot$ and mass $2 \cdot 10^9 M_\odot$. D.J. Mortlock, *et al*, " A luminous quasar at a redshift of z = 7.085" Nature 474 (2011) 616, arXiv:1106.6088 The quasars are supposed to be supermassive black holes (BH) and their formation in such short time looks problematic by conventional mechanisms.

According to F. Melia, "The Premature Formation of High Redshift Galaxies", 1403.0908: "Rapid emergence of high-z galaxies so soon after big bang may actually be in conflict with current understanding of how they came to be. This problem is very reminiscent of the better known (and probably related) premature appearance of supermassive black holes at $z \sim 6$. It is difficult to understand how $10^9 M_\odot$ black holes appeared so quickly after the big bang without invoking non-standard accretion physics and the formation of massive seeds, both of which are not seen in the local Universe."

Very recently another monster was discovered "An ultraluminous quasar with a twelve billion solar mass black hole at redshift 6.30". Xue-BingWu et al, Nature 518, 512 (2015)
About 40 quasars with $z > 6$ are known, each quasar containing BH with $M \sim 10^9 M_\odot$. Such black holes, when the Universe was less than one billion years old, present substantial challenges to theories of the formation and growth of black holes and the coevolution of black holes and galaxies.
Now we have $10^{10}\mathrm{M}_\odot$!!!

There is already a serious problem with formation of lighter and less luminous quasars which is multifold deepened with this new "creature". About 40 quasars with $z > 6$ are known, each containing BH with $M \sim 10^9 M_\odot$. Such black holes, when the Universe was less than one billion years old, present substantial challenges to theories of the formation and growth of black holes and the coevolution of black holes and galaxies. The new one with $M \approx 10^{10} M_\odot$ makes it absolutely impossible in the standard approach.

The universe at $z \sim 10$ is quite dusty, L. Mattsson, "The sudden appearance of dust in the early Universe",1505.04758

The medium around the observed early quasars contains considerable amount of "metals" (elements heavier than He). According to the standard picture, only elements up to ^{4}He and traces of Li, Be, B were formed by BBN, while heavier elements were created by stellar nucleosynthesis and dispersed in the interstellar space by supernova explosions.

If so, prior to or simultaneously with the QSO formation a rapid star formation should take place. These stars could produce plenty of supernovae which enriched interstellar space by metals.

Another possibility is a non-standard BBN, as is discussed below.

Observations of high redshift gamma ray bursters (GBR) also indicate a high abundance of supernova at large redshifts. The highest redshift of the observed GBR is 9.4 and there are a few more GBRs with smaller but still high redshifts. The necessary star formation rate for explanation of these early GBRs is at odds with the canonical star formation theory.

"Back to the future".
"Quasar quartet embedded in giant nebula reveals rare massive structure in distant universe", J.F. Hennawi et al, Science 15 May 2015, 348 p. 779, discovered in a survey for Lyman- emission at redshift $z \approx 2$.
Quasars are rare objects separated by cosmological distances, so the chance of finding a quadruple quasar is $\sim 10^{-7}$.
It implies that the most massive structures in the distant universe have a tremendous supply ($\sim 10^{11} M_\odot$) of cool dense ($n \approx 1/\mathrm{cm}^3$) gas, in conflict with current cosmological simulations.

Present days: it seems that every large galaxy and some smaller ones contain a central supermassive BH whose masses are larger than $10^9 M_\odot$ in giant elliptical and compact lenticular galaxies and $\sim 10^6 M_\odot$ in spiral galaxies like Milky Way.

The mass of BH is typically 0.1% of the mass of the stellar bulge of galaxy but some galaxies may have huge BH: e.g. NGC 1277 has the central BH of $1.7 \times 10^{10} M_{\odot}$, or 60% of its bulge mass. This fact creates serious problems for the standard scenario of formation of central supermassive BHs by accretion of matter in the central part of a galaxy. An inverted picture looks more plausible, when first a supermassive black hole was formed and attracted matter serving as seed for subsequent galaxy formation.
Bosch et al, Nature 491 (2012) 729.

More examples: F. Khan, K. Holley-Bockelmann, P. Berczik arXiv:1405.6425. Although supermassive black holes correlate well with their host galaxies, there is an emerging view that outliers exist. Henize 2-10, NGC 4889, and NGC1277 are examples of SMBHs at least an order of magnitude more massive than their host galaxy suggests. The dynamical effects of such ultramassive central black holes is unclear.

A recent discovery of an ultra-compact dwarf galaxy older than 10 Gyr, enriched with metals, and probably with a massive black in its center seems to be at odds with the standard model J. Strader, *et al* Astrophys. J. Lett. 775, L6 (2013), arXiv:1307.7707.

The dynamical mass is $2 \times 10^8 M_\odot$ and $R \sim 24$ pc - very high density.

Chandra: variable central X-ray source with $L_X \sim 10^{38}$ erg/s, which may be an AGN associated with a massive black hole or a low-mass X-ray binary.

Old stars in the Milky Way:

Employing thorium and uranium in comparison with each other and with several stable elements the age of metal-poor, halo star BD+17^o 3248 was estimated as 13.8 ± 4 Gyr.
J.J. Cowan, C. Sneden, S. Burles, *et al* Ap.J. 572 (2002) 861, astro-ph/0202429.

The age of inner halo of the Galaxy 11.4 ± 0.7 Gyr, J. Kalirai, "The Age of the Milky Way Inner Halo" Nature 486 (2012) 90, arXiv:1205.6802.

The age of a star in the galactic halo, HE 1523-0901, was estimated to be about 13.2 Gyr. First time many different chronometers, such as the U/Th, U/Ir, Th/Eu and Th/Os ratios to measure the star age have been employed.

"Discovery of HE 1523-0901: A Strongly r-Process Enhanced Metal-Poor Star with Detected Uranium", A. Frebe, N. Christlieb, J.E. Norris, C. Thom Astrophys.J. 660 (2007) L117; astro-ph/0703414.

Metal deficient high velocity subgiant in the solar neighborhood HD 140283 has the age 14.46 ± 0.31 Gyr.

H. E. Bond, E. P. Nelan, D. A. VandenBerg, G. H. Schaefer, D. Harmer, Astrophys. J. Lett. 765, L12 (2013), arXiv:1302.3180.

The central value exceeds the universe age by two standard deviations,

if $H = 67.3$ and $t_U = 13.8$;

if $H = 74$, then $t_U = 12.5$.

X. Dumusque, *et al* **"The Kepler-10 Planetary System Revisited by HARPS-N: A Hot Rocky World and a Solid Neptune-Mass Planet". arXiv:1405.7881; Ap J., 789, 154, (2014).**

Very old planet, $10.6^{+1.5}_{-1.3}$ Gyr.

(Age of the Earth: 4.54 Gyr.)

A SN explosion must must precede formation of this planet.

Summary: many objects in the universe were formed much earlier than allowed by the standard theory.
Among them: stars in the Milky Way, older than the Galaxy and even older than the universe (within two sigma); distant high redshift ($z \sim 10$) staff: galaxies, QSO/supermassive BHs, supernovae, gamma-bursters, evolved chemistry and a lot of dust.
The universe is much more developed at early times than it was expected.

A simple model can explain all that and more, e.g. mysterious MACHO's, quite strange, unexpected, mass distribution of BHs in the galaxy and predict abundant cosmological anti-matter in our neighborhood, i.e. in the Galaxy and its halo.

The model: Supersymmetric (Affleck -Dine = AD) baryogenesis with an additional general renormalizable coupling of AD-field to inflaton.

Baryogenesis with SUSY condensate, Affleck and Dine (AD). **SUSY predicts existence of scalars with B $\neq$ 0. Such bosons may condense along flat directions of the quartic potential:**

$$U_\lambda(\chi) = \lambda|\chi|^4 \left(1 - \cos 4\theta\right),$$

and of the mass term, $m^2\chi^2 + m^{*\,2}\chi^{*\,2}$**:**

$$U_m(\chi) = m^2|\chi|^2[1 - \cos\left(2\theta + 2\alpha\right)],$$

where $\chi = |\chi|\exp\left(i\theta\right)$ **and** $m = |m|e^\alpha$**.**

If $\alpha \neq 0$, C and CP are broken.

In GUT SUSY baryonic number is naturally non-conserved - non-invariance of $U(\chi)$ w.r.t. phase rotation.

Initially (after inflation) χ is away from origin and when inflation is over starts to evolve down to equilibrium point, $\chi = 0$, according to Newtonian mechanics:

$$\ddot{\chi} + 3H\dot{\chi} + U'(\chi) = 0.$$

Baryonic charge of χ:

$$B_\chi = \dot{\theta}|\chi|^2$$

is analogous to mechanical angular momentum. χ decays transferred baryonic charge to that of quarks in B-conserving process. AD baryogenesis could lead to baryon asymmetry of order of unity, much larger than 10^{-9}.

If m $\neq 0$, the angular momentum, B, is generated by a different direction of the quartic and quadratic valleys at low χ. If CP-odd phase α is small but non-vanishing, both baryonic and antibaryonic regions are possible with dominance of one of them.

Matter and antimatter domain may exist but globally B $\neq 0$.

A minor modification of AD-scenario can lead to very early formation of compact stellar-type objects and naturally to a comparable amount of antiobjects, such that the bulk of baryons and (equal) antibaryons are in the form of compact stellar-like objects or PBH, plus sub-dominant observed homogeneous baryonic background, the amount of antimatter may be comparable or even larger than of KNOWN baryons, but such "compact" (anti)baryonic objects would not contradict any existing observations.

Affleck-Dine field χ with CW potential coupled to inflaton Φ (AD, Silk, 1993; AD, Kawasaki, Kevlishvili, 2009):

$$U = g|\chi|^2(\Phi - \Phi_1)^2 + \lambda|\chi|^4 \ln\left(\frac{|\chi|^2}{\sigma^2}\right)$$

$$+\lambda_1\left(\chi^4 + h.c.\right) + (m^2\chi^2 + h.c.).$$

Coupling to inflaton is the general renormalizable one.

If the window to flat direction, when $\Phi \approx \Phi_1$ is open only during a short period, cosmologically small but possibly astronomically large bubbles with high β could be created, occupying a small fraction of the universe, while the rest of the universe has normal $\beta \approx 6 \cdot 10^{-10}$, created by small χ.

Phase transition of 3/2 order.

The distributions of high baryon density bubbles over length and mass have log-normal form:

$$\frac{dN}{dM} = C_M \exp\left[-\gamma \ln^2(M/M_0)\right]$$

where C_M, γ, and M_0 are constant parameters.

Spectrum is practically model independent, it is determined by inflation.

INHOMOGENEITIES.

1. After formation of domains with large χ due to different equations of state inside and outside of the domains: some nonrelativistic matter inside the bubbles and relativistic outside.

2. Second period of $\delta\rho$ generation after the QCD phase transition at $T \sim 100$ MeV when quarks made non-relativistic protons. BH masses from a few $M_\odot$ to $10^{6-7} M_\odot$.

Compact objects (not BH) with smaller masses could be formed too.

The log-normal mass distribution naturally explains some features of stellar mass black holes in the Galaxy. It was found that their masses are concentrated in the narrow range $(7.8 \pm 1.2) M_\odot$ (1006.2834)
This result agrees with another paper where a peak around $8M_\odot$, a paucity of sources with masses below $5M_\odot$, and a sharp drop-off above $10M_\odot$ are observed, arXiv:1205.1805. These features are not explained in the standard model.

A modifications of U_{int} leads to a more interesting spectrum of the early formed stellar type objects, e.g., if:

$$U_{\rm int} = \lambda_1 |\chi|^2 \, (\Phi - \Phi_1)^2 \, (\Phi - \Phi_2)^2 \, ,$$

we come to a two-peak mass distribution of the PBHs and compact stars, which is probably observed, but not explained up to now.
ArXive: 1011.1459: "sample of black hole masses provides strong evidence of a gap between the maximum neutron star mass and the lower bound on black hole masses" - maybe lower mass BH are created by a normal mechanism of stellar collapse.

FAVORABLE FEATURES

On the tail of the distribution very heavy BH may be created, $\sim 10^7 M_\odot$.

A mechanism of early quasar formation with evolved chemistry - one of the mysteries of the standard model.

Superheavy PBH are seeds for structure formation!?

At the moment there is no satisfactory mechanism for formation of the observed superheavy BH.

An explantation of high-redshift SN, gamma-bursters, stars older than the universe (observed in the Milky Way),...

Cut-off BH distribution at $\sim 6 M_\odot$.

Impact on BBN.

If $\beta \equiv \eta \gg 10^{-9}$, light (anti)element abundances would be anomalous: much less anti-deuterium, more anti-helium.

Look for clouds with anomalous chemistry. However, with 50% probability it may be the normal matter with anomalous n_B/n_γ.

If such a cloud or compact object is found, search for annihilation there.

Evolved chemistry in the so early formed QSOs can be explained, at least to some extend, by more efficient production of metals during BBN due to much larger ratio $\beta = N_B/N_\gamma$. The standard BBN essentially stops at ^{4}He due to very small β. However, in the model considered here β is much larger than the canonical value, even being close or exceeding unity.

The suggested mechanism leads to creation of compact stellar-like objects and equal number of compact anti-objects in the early universe at $t = 0.01 - 1$ sec.

So the universe may be full of early formed and by now dead or low luminosity stars (and antistars).

Natural explanation of MACHOS(??) - invisible stellar mass objects observed by gravitational micorlensing; too many for usual stars.

Summary:

1. Compact anti-objects mostly survived in the early universe, especially if they are PBHs.

2. A kind of early dense stars might be formed with initial pressure outside larger than that inside.

3. Such "stars" may evolve quickly and, in particular, make early SNs, enrich the universe with heavy (anti)nuclei and reionize the universe.

4. Early formation of superheavy BHs, i.e. QSO with enriched chemistry.

5. Energy release from stellar like objects in the early universe is small compared to CMBR.

6. Not dangerous for BBN since the volume of B-bubbles is small.

One can always hide any undesirable objects into black holes.

ANTIMATTER. A little history. P.A.M. Dirac, Proc. Royal Soc. London, A117 (1928) 610, predicted “with the tip of his pen” a whole world of antimatter (not just a small planet). He assumed initially that positively charged ”electron” was proton!? Critics by Oppenheimer: hydrogen instability (if proton is a hole in negative continuum), forced Dirac to conclude that ”anti-electron” is a NEW particle with the same mass as e^- (1931). At that time a hypothesis about a new particle was not as blameless as today.

Carl Anderson, discovery of positron, 1933; Nobel prize in 1936. According to the Anderson words: it was not difficult, simply nobody looked for that.

Dirac's Nobel prize in 1933 immediately after the experiment.

Paul A.M. Dirac: "Theory of electrons and positrons", Nobel Lecture, December 12, 1933: "It is quite possible that... these stars being built up mainly of positrons and negative protons. In fact, there may be HALF the stars of each kind. The two kinds of stars would both show exactly the same spectra, and there would be no way of distinguishing them by present astronomical methods."

It seems that now we know ways to distinguish stars from a antistars by observations from the Earth.
The spectra are not exactly the same, even if CPT is unbroken and polarization of radiation could be a good indicator or the type of emitted neutrinos/antineutrinos from supernovae.

Dirac was the second person to talk about antimatter. In 1898, 30 years before Dirac and one year after discovery of electron (J.J. Thomson, 1897) Arthur Schuster (another British physicist) conjectured that there might be other sign electricity, ANTIMATTER, and supposed that there might be entire solar systems, made of antimatter, INDISTINGUISHABLE from ours.

Schuster's wild guess: matter and antimatter are capable to annihilate and produce VAST energy.
He believed that they were gravitationally repulsive having negative mass.
Two such objects on close contact should have vanishing mass!?

A. Schuster, Nature, 58 (1898) 367.

Potential Matter. Holiday Dream.

“When the year’s work is over and all sense of responsibility has left us, who has not occasionally set his fancy free to dream about the unknown, perhaps the unknowable?”

”Astronomy, the oldest and yet most juvenile of the sciences, may still have some surprises in store. May antimatter be commended to its case”.

Antiparticles are predicted and observed in experiment, but it is unknown if antimatter, i.e. antistars, antiplanets, antigalaxies exist anywhere in the universe.

Maybe Dirac and Schuster were right saying that antiworlds exist!?

Presently cosmological antimatter (the real one not just antiparticles) is actively searched for by several groups; more sensitive detectors are proposed for future observations.

Astronomical search for antistars.

If CPT is broken and $\Delta m \neq 0$, spectra of anti-atoms might be different in irregular way, not described by a red-shift. However, CPT may be broken but masses remain equal.

Still, with CPT or without it, there are chances for distant observation of antiworlds.

If CPT is respected:
Atomic spectra with broken C and CP (AD, Khriplovich, Rudenko). The positions of levels of atoms and antiatoms are probably the same, but partial decay widths are different. Unfortunately, for hydrogen the effect is tiny (accidental cancelation?):

$$\Delta\Gamma/\Gamma \sim 10^{-28}.$$

An amplification, in particular, in heavier atoms and in external magnetic or electric fields might be possible.

Some other ways to see an antistar (AD, Novikov, Vysotsky). Through communication with inhabitants: it is usually supposed that to this purpose CP-violation is to be used. If the light charged leptons in the shells of their atoms are more frequently produced in K_L decays $K_L \to \pi^{\pm} e^{\mp} \nu$, then we communicate with anti-people.

Polarized radiowaves can be used in the communication asking if the polarization of charged lepton emitted in neutron β decay is the same?
CP-violation is not necessary, breaking of P is enough.
However, the stellar system may be non-inhabited and even if it is, this process would take an extremely long time and is more proper for a science fiction. We need to find methods independent on intelligent life in the system under scrutiny.

Neutrinos versus antineutrinos produced by thermonuclear reactions in a star. However, the fluxes are too low for the present day sensitivity. Neutrinos from SN explosions have better chance to be registered. At the first stage of SN explosion neutrinos from the neutronization reaction $pe^- \to n\nu$ are emitted and antineutrinos from anti-SN.

Detection of anti-stars by photons produced in weak interaction processes. These photons are longitudinally polarized and their energy can be well defined if they are created in two body decays. Mono-energetic photons produced e.g. in $B \to K^\star\gamma$ should be left-handed because of dominance of $b \to s\gamma$ penguin transition with left-handed s-quark.

However, one can hardly imagine noticeable abundance of B-mesons in stars, and most probably there is an equal amount of B and $\bar{\mathrm{B}}$ mesons.

Stars with abundant strange quarks look more promising. The outer shell of such stars is populated by Σ-hyperons and the polarization of photons emitted in $\Sigma^+ \rightarrow p\gamma$ decay could indicate if the photons are emitted by hyperon or anti-hyperon. The polarization is large, $\alpha = -0.76 \pm 0.08$ and the branching ratio is nonnegligible $(1.23 \pm 0.05) \times 10^{-3}$.

Circular polarization of photons in the γ-transitions of nuclei was observed in the terrestrial experiments:

$P_\gamma = (4 \pm 1) \cdot 10^{-5}$ in ^{175}Lu transition with the emission of 395 keV photon,

$P_\gamma = -(6 \pm 1) \cdot 10^{-6}$ for 482 keV photon emitted in ^{181}Ta transition,

$P_\gamma = (1.9 \pm 0.3) \cdot 10^{-5}$ for 1290 keV photon emitted in transition of ^{41}K.

Measurement of circular polarization of such photon lines is ideally suited for search of antistars.

Traditional ways to search for cosmic anitmatter.

Indirect: astronomical manifestations of antimatter: 0.5 MeV or 100 MeV gamma-rays, distortion of CMB, impact on BBN and LSS formation.

Direct: registration of antimatter which cannot be secondary produced, mainly cosmic anti-nuclei, and anomalous antiprotons and positrons in cosmic rays.

Nowadays, burst of experimental activity for direct search of cosmic antimatter:

Existing missions for the direct search:

1. BESS: Japanese Balloon Borne Experiment with Superconducting Solenoidal Spectrometer.

2. PAMELA (Italian-Russian space mission): Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics.

3. AMS: AntiMatter Spectrometer (Alpha Magnetic Spectrometer), CERN-MIT-NASA.

Planned missions:

PEBS (Positron Electron Balloon Spectrometer,) search for cosmic positrons and antiprotons.

GAPS (Gaseous Antiparticle Spectrometer), search for X-rays from de-excitation of exotic atoms, may reach 2 orders of magnitude better sensitivity than AMS for $\bar{H}e/He$.

Search for cosmic anti-helium, existing bounds:

BESS: $\bar{H}e/He < 3 \times 10^{-7}$.

Expected:
PAMELA: $\bar{H}e/He < 3 \times 10^{-8}$;
AMS-2: $\bar{H}e/He < 10^{-9}$.

Observed flux of cosmic helium at $E <$ **10 GeV/nuclei:**
$dN/dE = 10^2/m^2/str/sec/GeV$.

Expected secondary produced anti-nuclei

Anti-deuterium is produced in $\bar{p}\,p$ or $\bar{p}\,He$ collisions (Duperray et al, 2005)
The predicted flux of anti-deuterium:
$\sim 10^{-7}/m^2/s^{-1}/sr/(GeV/n)$,
i.e. 5 orders of magnitude lower than the observed flux of antiprotons.

The expected fluxes of secondary produced $^3\bar{H}e$ and $^4\bar{H}e$ are respectively 4 and 8 orders of magnitude smaller than the flux of anti-D.

Observations and bounds, summary.

$\bar{p}/p \sim 10^{-5} - 10^{-4}$, observed, can be explained by secondary production;
$He/p \sim 0.1$;
Upper limit: $\bar{H}e/He < 3 \times 10^{-7}$;
Theoretical predictions: $\bar{d} \sim 10^{-5}\bar{p}$, ${}^{3}\bar{H}e \sim 10^{-9}\bar{p}$, ${}^{4}\bar{H}e \sim 10^{-13}\bar{p}$.
From the upper limit on $\bar{H}e$: the nearest single antigalaxy should be further than 10 Mpc (very crudely).

Search for antinuclei at LHC.

According to the data of ALICE detector, production of an antinucleous with an additional antinucleon is suppressed only by factor about 1/300 which is much milder than the suppression factors presented above. Probably the difference is related to much higher energies at which data of ALICE are taken. The events with such energies are quite rare in cosmic rays.

From cosmic gamma rays:

Nearest anti-galaxy could not be closer than at ∼10 Mpc (Steigman, 1976), from annihilation with p in common intergalactic cloud.
Fraction of antimatter Bullet Cluster $< 3 \times 10^{-6}$ (Steigman, 2008).

CMB excludes LARGE isocurvature fluctuations at $d > 10$ Mpc.
BBN excludes large "chemistry" fluctuations at $d > 1$ Mpc.

Review: P.v. Ballmoos, arXiv:1401.7258

Bondi accretion of interstellar gas to the surface of an antistar:

$$L_\gamma \sim 3 \cdot 10^{35} (M/M_\odot)^2 v_6^{-3}$$

put a limit $N_{\bar{*}}/N_* < 4 \cdot 10^{-5}$ inside 150 pc from the Sun.

The presented bounds are true if antimatter makes the same type objects as the OBSERVED matter.

For example, compact faster objects made of antimatter may be abundant in the Galaxy but still escape observations (discussed below).

The puzzle of the observed predominance of matter over antimatter was resolved by Sakharov, (1967) on the basis of the conditions:

I. Nonconservation of baryons.

II. Violation of symmetry between particles and antiparticles, i.e. C and CP.

III. Breaking of thermal equilibrium.

(None of these three conditions is obligatory.)

Plethora of baryogenesis scenarios which can explain one number:

$$\beta_{observed} = \frac{N_B - N_{\bar{B}}}{N_\gamma} \approx 6 \times 10^{-10}\,.$$

The usual outcome: $\beta = const$, which makes it impossible to distinguish between models and does not leave space for cosmological antimatter.

NB: all the models, but one (Affleck and Dine) give rise to a small β but AD may create $\beta \sim 1$.

Natural generalizations of the simplest models of baryogenesis allow for a lot of antimatter almost at hand.

An observation of cosmic antimatter will give a clue to baryogenesis, to the mechanism of cosmological C and CP breaking, and present an extra argument in favor of inflation.

Since generalized scenarios predict a whole function $\beta(x)$, the models are falsifiable.

GREAT EXPECTATIONS:

Both a simple and probably unique, generalization of the theory, and available astronomical data allow for a lot of antimatter just "next door".

Maybe Dirac and Schuster were right saying that antiworlds exist!?

NB: interesting anti-objects should be astronomically large, so inflation is necessary and not too large to avoid problems with existing observations.

Phenomenology and bounds on compact antimatter objects and disperse anti-clouds (Bambi, AD, 2007; Blinnkov, AD, Postnov, 2015)

Possible astronomical objects:

1. Gas clouds of antimatter.
2. Isolated antistars.
3. Anti stellar clusters.
4. Anti black holes.
5. Stellar wind.
5. Antimeteorites.
6. What else?

WHERE:

Inside galaxies or outside galaxies?
Inside galactic halos or in intergalactic space?

Consider all the options.
New part: unusual compact objects, e.g. dead or half dead (anti)stars, (anti)BH with (anti)atmosphere.

OBSERVATIONAL SIGNATURES

1. **Gamma background.**
2. **Excessive antiprotons.**
3. **Positrons.**
4. **Antinuclei.**
5. **Compact sources of γ radiation.**
6. **Catastrophic phenomena.**
7. **Rapid change of stellar luminosity.**

Two types of objects (clouds and compact stars):

1. Gas clouds, mean free path of protons l_p is larger than the size of the (anti)cloud. Annihilation proceeds in whole volume.

Low density or small clouds would not survive in a galaxy. They would disappear during

$$\tau = 10^{15}\ sec\ \left(\frac{10^{-15} cm^3/s}{\sigma_{ann} v}\right)\left(\frac{cm^{-3}}{n_p}\right),$$

may survive in the halo.

The luminosity for volume annihilation:

$$L_\gamma^{(vol)} \approx 10^{35}\,\frac{\mathrm{erg}}{\mathrm{s}}\left(\frac{R_B}{0.1\,\mathrm{pc}}\right)^3 \left(\frac{n_p}{10^{-4}\,\mathrm{cm}^{-3}}\right)\left(\frac{n_{\bar p}}{10^{4}\mathrm{cm}^{-3}}\right).$$

Flux on the Earth at d=10 kpc: $10^{-7}\gamma/\mathrm{s}/\mathrm{cm}^2$ or $10^{-5}\mathrm{MeV}/\,\mathrm{s}/\mathrm{cm}^2$, to be compared with cosmic background $10^{-3}/\mathrm{MeV}/\mathrm{s}/\mathrm{cm}^2$, pointlike sources.

2. Compact objects, $l_{free} \ll l_s$, surface annihilation, much less efficient. Total luminosity, $L = 2m_p \cdot 4\pi l_s^2 n_p v$:

$$L_{tot} \approx 10^{27} \frac{erg}{sec} \left(\frac{n_p}{cm^3} \right) \left(\frac{l_s}{l_\odot} \right)^2 .$$

Fraction into gamma-rays is about 20-30%.

Unidentified EGRET sources, from clouds or compact objects?

Stellar wind:

$$\dot{M} = 10^{12} W \; g/sec$$

where $W = \dot{M}/\dot{M}_\odot$.
If all "windy" particles annihilate, the luminosity per star:

$$L = 10^{33} W \text{ erg/sec.}$$

Mean free path of $\bar{p}$ in the galaxy is about 10^{23} cm (depending on their velocity). Gamma luminosity of the Galaxy: $L_\gamma \approx 10^{33} \bar{N} W \, erg/s$.

Number density of antinuclei is bounded by the density of "unexplained" $\bar{\mathrm{p}}$ and the fraction of antinuclei in stellar wind with respect to antiprotons.
It may be the same as in the Sun but if antistars are old and evolved, this number must be much smaller.
On the other hand, the relative amount of anti-nuclei could be larger because of explosions of the early SN.

Heavy antinuclei from anti-SN may be abundant but their ratio to $\bar{p}$ can hardly exceed the same for normal SN.

Explosion of anti-SN would create a large cloud of antimatter, which should quickly annihilate producing vast energy - a spectacular event.

However, most probably such stars are already dead and SN might explode only in very early galaxies or even before them.

COSMIC POSITRONS.

Gravitational proton capture by an (anti)star is more probable than capture of electrons, due to larger mobility of p. Antistar is neutralized by forced positron ejection.

It would be most efficient in galactic center where n_p is large.

0.511 MeV line (observed) must be accompanied by wide spectrum $\sim$ 100 MeV radiation.

Also: Schwinger process at Schwarzschild horizon.

EXOTIC EVENTS

Similar mass star-antistar collision, γ-bursters (???):

$$\Delta E \sim 10^{48}\, erg \left(\frac{M}{M_\odot}\right)\left(\frac{v}{10^{-3}}\right)^2$$

Annihilation pressure pushes the stars apart. Collision time $\sim$ 1 sec.

Radiation is emitted in the narrow disk but not jet.

Collision with RED GIANT: compact antistar travels inside creating an additional energy source. Change of color and luminosity(?).
$\Delta E_{tot} \sim 10^{38}$ erg and $\Delta t \sim$ month.

Transfer of material in binary system - hypernova explosion!?

OBSERVATIONAL BOUNDS.

I. Stellar wind:

$$\mathbf{N_{\bar{S}}/N_S \leq 10^{-6} W^{-1}},$$

from the total galactic luminosity in 100 MeV photons, $L_\gamma = 10^{39} erg/s$ and from the flux of the positron annihilation line $F \sim 3 \cdot 10^{-3}/cm^2/s$.

$W \ll 1$ is natural to expect because the primordial antistars may be already evolved.

II. Antihelium-helium ratio:

$$N_{\bar{S}}/N_S = (\bar{H}e/He) \leq 10^{-7},$$

if the antistars are similar to the usual stars, though most probably not.

CONCLUSION

1. The Galaxy may possess a noticeable amount of antimatter.

2. Theoretical predictions are vague and model dependent, but testable and may permit to distinguish between scenarios of BG.

3. Not only $^4\bar{He}$ is worth to look for but also heavier anti-elements. Their abundances should be similar to those observed in SN explosions.

4. Regions with an anomalous abundances of light elements are suspicious that there may be anti-elements.

5. A search of cosmic antimatter has nonvanishing chance to be successful.

6. Dark matter made of BH, anti-BH, and dead stars is a promising candidate. There is a chance to understand why $\Omega_{\rm B} = 0.05$ is similar to $\Omega_{\rm DM} = 0.25$.

7. Detection of $\bar{\nu}$ in the first burst from anti-SN explosion.

8. Measurement of polarization of electromagnetic radiation (?).

9. Existing signatures in favor:

May the observed positron 0.511 MeV line from the galactic bulge and especially (if confirmed) from the halo be a signature of cosmic antimatter!?

Unidentified EGRET sources.

THE END