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Cosmic future of nuclear and particle physics

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Abstract Astronomy and nuclear or particle physics are often considered as two opposite extremes, but in fact their common part is not empty and still enlarging. In this brief review we trace their common roots and we look for their common future. We predict that soon they will *de facto* merge in terms of phenomena being studied, theories used to describe them as well as experimental techniques. We gave several examples, devoting special attention to the "Pi of the Sky" project searching for optical flashes of astrophysical origin.

Key words astronomy • nuclear physics • particle physics • astroparticle physics

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Introduction

The two realms

Astronomy and elementary particle physics seem to be the opposite poles of science. Astronomy is dealing with large objects ranging from 10^3 m (asteroids) to 10^{21} m (galaxies) and even with the entire Universe as a whole (cosmology). At such scales, the only important force is gravity and the ruling theory is Einstein's general relativity. On the contrary, particle physics describes phenomena on subnuclear scale of 10^{-14} m, which involve particles considered as point-like objects (e.g. electron). Gravity could be neglected, compared to electroweak and strong nuclear forces governed by formulae of quantum field theories. However, it turns out that these two domains have very much in common. In the following sections we are going to review these commonalities and we predict that in the near future the overlap will increase both in the subject of interest and in experimental techniques.

History of nuclear and particle physics

Discoveries on radioactivity by Becquerel in 1896, as well as by Maria and Piotr Curie in following years, are commonly considered as the birthday of nuclear physics. The α, β and γ rays emitted by radioactive elements were studied by Rutherford, who in 1911 correctly described the atom as consisting of positively charged nucleus surrounded by electrons. Further experiments led him to conclusion that the nucleus itself is composed of positively charged particles called protons (which escape nucleus while bombarded by α rays) and hypothetical neutral particles called neutrons. The existence of neutron was confirmed in 1932 by Chadwick.

This could be the end of the story. All ordinary matter is composed of atoms. Each atom has a small nucleus surrounded by electrons. The atomic nuclei consist of protons and neutrons. The entire Universe could be described by these three elementary particles: electron, proton and neutron. However, this nicely closed picture was delightful for no more than one year. The shock came from space. A positron, i.e. anti-electron, was found among cosmic rays. This was the first evidence for antimatter. Four years later another exotic particles, today called muons (μ^+ and μ^-), were discovered. This was followed by discovery of pions (π^+ and π^-) and strange mesons K^+ and K^-.

All these new particles were discovered in the cosmic rays. In the fifties accelerators took over the leading role in experimental particle physics and they keep it till today. Will this be the case forever? I expect we will see another turn-over quite soon. We will discuss this in the following sections.

History of the Universe

First cosmological models describing the Universe as a whole were created in 1917, two years after Einstein formulated General Theory of Relativity. In order to obtain stable solutions he introduced the famous constant Λ. When Hubble discovered in 1929 that the galaxies are receding from each other with a speed proportional to their distance it became evident that the Universe is expanding. Later Einstein called Λ the biggest mistake in his life. Recently, measurements of supernovae exploding 5–10 billions years ago [13, 14] (combined with measurements of cosmic microwave background [15, 17]) have indicated that the Universe expansion is accelerating. This can be explained by $\Lambda > 0$. Einstein was wrong, that he was wrong.

If the Universe is expanding today, it means that in the past it was denser and hotter. Solving cosmological equations one can find that it begun its existence about 14 billion years ago in the state of infinite density and temperature. The theory of expanding Universe was called ironically by its opponents a "Big Bang", but the experimental evidence in its favor soon became so strong, that even the name "Big Bang" acquired serious scientific meaning.

In 1948, Alpher, Bethe and Gamov (the famous $\alpha\beta\gamma$ trio) published a theory of creation of elements, which predicted existence of huge number of very soft photons in the Universe. 380,000 years after the Big Bang the temperature of the Universe was above 6000 K and all the atoms were ionized. The large number of charged ions and electrons caused that the space was not transparent to photons. When the Universe got cooler it became neutral because of recombination of electrons and ions. All the photons became free and they travel through the space till today forming so-called cosmic microwave background. This radiation was discovered in 1964 by Penzias and Wilson, which provided a strong confirmation for the theory of Big Bang.

If we go back in the history of the Universe we see that 3 min after the Big Bang the temperature reaches 10^9 K and only the lightest elements like helium and lithium can exist. One second after the Big Bang at 10^{10} K no nucleus can exist and we see only free neutron and protons. At the earlier times, we could observe all kinds of elementary particles interacting with each other. The Universe became the largest ever laboratory of particle physics.

Astroparticle physics

As we have seen in the previous section, it turned out that the particle physics is necessary to understand the evolution of the Universe. A new discipline was born, called astroparticle physics. It is a common ground for exchanging information between astronomy (cosmology) and particle physics. Particle physics describes physics laws, which govern the matter at the very fundamental level, whereas cosmology makes use of these laws to describe the evolution of the Universe. Experiments in particle physics study conditions similar to those in the early Universe, but even today's Universe contains many sources of high energy particles. Experimental results in particle physics give input to cosmological models, while astronomical observations provide tests of particle physics laws. A few specific examples of this mutual exchange will be given in the following sections.

Messengers from space

What is the Universe made of?

The answer seems to be obvious: the Universe consists of nothing but stars with a little addition of planets, asteroids, comets and some interstellar dust. Surprisingly enough, according to best estimations of today, stars account for only 0.5% of the total density of the Universe [18]. About 4% can be attributed to the rest of baryonic matter (neutrons and protons) in form of Jupiter-like objects or interstellar gas and dust. Above 70% of the Universe density, called dark energy, is associated with the cosmological constant Λ [5]. Its physical nature is not yet known. Roughly 22% is "reserved" for so-called cold dark matter. Most probably, these are elementary particles of new kind, not yet discovered. One of more serious candidates are neutralinos, predicted by supersymmetric theories of elementary particles. Last but not least, about 0.3% (an amount comparable to that of the stars!) is carried by neutrinos.

Neutrino telescopes

Neutrinos are so important in modern astroparticle physics that they deserve a dedicated article (next one in this issue). Here, we only briefly mention their meaning.

One of the most important discoveries in recent years for both particle physics and astronomy was observation of neutrino oscillations [6] by Super-Kamiokande[1] experiment. For particle physics, because it gave evidence that neutrinos have a mass. For astronomy,

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[1] Super-Kamiokande: http://www-sk.icrr.u-tokyo.ac.jp

because it confirmed that the standard solar model is accurate down to about 10%.

Super-Kamiokande belongs to the family of experiments called neutrino telescopes. These are huge water tanks (or ice cubes) surrounded with thousands of photomultipliers, which detect photons emitted by charged products of neutrino reactions. To some extent they can measure the energy and direction of neutrinos. First detectors of this kind were built to search for proton decay, which is predicted by some theories unifying weak and strong nuclear forces. So far, no decays were observed, which gives the limit on the proton lifetime above 10^{33} years.

The name "neutrino telescopes" was coined after detection of neutrinos from supernova explosion in 1987 [3, 7]. In total 24 neutrinos were observed. It was a very spectacular discovery – an astronomical observation done by particle detector. Since then, several neutrino detectors were designed especially to study neutrinos coming from space. AMANDA[2] uses the ice near the South Pole to catch neutrinos. Over 2000 m deep holes are drilled in the ice to hang strings with phototubes. A new version of this detector called the Ice Cube[3] is being prepared. It will use as much as 1 cubic km of the ice. The ANTARES[4] detector is based on a similar concept, but instead of ice it uses ocean water. The first prototype was constructed at the bottom of the Mediterranean See near the French city of Toulon.

Cosmic rays

Apart from neutrinos, Earth is bombarded from space by an other kind of stable particles: electrons, protons and nuclei, as well as their antiparticles. Together with hard photons they are often called cosmic rays. They usually interact in the atmosphere and create cosmic showers. One can easily detect muons, which are the end-product of such showers and live sufficiently long to travel through the atmosphere. The flux of cosmic muons approaches 100 Hz/m^2 at the sea level. Apart from being the subject of dedicated studies, muons serve as invaluable tool for calibrating particle detectors.

The number of particles in a cosmic shower is proportional to the energy of the initial particle. Therefore, it is important to cover large area of the ground by detectors and to detect as many particles as possible. The largest projects like CASA[5], KASCADE[6], AGASA[7] or AUGER[8] cover many square km with sparse particle detectors connected together.

Particle detectors built to work with accelerators can also be used for cosmic ray study. They have usually smaller size, than dedicated air shower detectors, but instead they have tracking capability and good angular resolution. Interesting results were obtained by CosmoLEP[9] project at CERN. For example, the L3 detector at LEP measured the ratio of protons and antiprotons coming from space [10]. Looking at protons with energy of 80–100 GeV one can see the shadow of the Moon. Because of bending in the Earth magnetic field the proton and antiproton shadows should be shifted. Hence, one can distinguish protons from antiprotons.

It would be interesting to study the particles coming from space as they are before interaction in the atmosphere. So far, the only attempt for such study was the AMS[10] detector flying in the Space Shuttle. It is a small size spectrometer with some capabilities of particle identification. The new version of this detector is planned to be installed at the International Space Station Alpha.

Cosmic and human made accelerators

Where do the cosmic rays come from? Some of them come from the Sun and other stars. However, these are rather soft. High energy particles are produced in more violent environment such as supernovae explosions, gamma ray bursts, active galaxy nuclei, microquasars, pulsars, etc. Charged particles can be further accelerated in intergalactic magnetic fields. The energies can by far higher than those achievable in human built accelerators.

The Large Hadron Collider[11] being build at CERN in Geneva will collide protons with the energy of 14 TeV. It is expected to start in 2007. Hopefully, it is not the Last Hadron Collider. The Very Large Hadron Collider[12] is considered in the US. It would have a circumference of 100–600 km and the energy up to 200 TeV. More advanced are 0.5–1 TeV e^+e^- linear colliders: Tesla[13] in Germany, NLC[14] in the US and JLC[15] in Japan. A 5 TeV e^+e^- collider CLIC[16] is investigated at CERN. But what next? Around-the-Earth or on-the-orbit colliders sounds too fantastic to became true in the next 50 years. I think that we will never give up and we will always look for new ideas, but in the near future we may have no choice, but to use cosmic accelerators. Anyway, they are already there and they are for free.

Cosmic photons

The easiest way to detect photons coming from space is… to look at the night sky. For hundreds of years astronomy was based just on this kind of detection. A new window has been open with the invention of radiotelescopes. Today, all energies E and wavelengths λ of electromagnetic radiation are used in astronomy, ranging from long radio waves of $\lambda = 10^3$ m and $E = 10^{-8}$ eV to the hardest gamma rays of $\lambda = 10^{-23}$ m and E

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[2] AMANDA: http://amanda.berkeley.edu

[3] Ice Cube: http://icecube.wisc.edu

[4] ANTARES: http://antares.in2p3.fr

[5] CASA: http://hep.uchicago.edu/~covault/casa.html

[6] KASCADE: http://ik1au1.fzk.de/KASCADE_home.html

[7] AGASA: http://www-akeno.icrr.u-tokyo.ac.jp/AGASA/

[8] AUGER: http://www.auger.org

[9] CosmoLEP: http://alephwww.cern.ch/COSMOLEP/

[10] AMS: http://ams.cern.ch

[11] LHC: http://www.cern.ch

[12] VLHC: http://www.vlhc.org

[13] Tesla: http://tesla.desy.de

[14] NLC: http://www-project.slac.stanford.edu/nlc/home.html

[15] JLC: http://www-jlc.kek.jp

[16] CLIC: http://ps-div.web.cern.ch/ps-div/CLIC/

$= 10^{17}$ eV. The most energetic γ-rays ($E > 10^{14}$ eV) can be detected by air shower detectors, as it was described earlier. The γ-rays in the range of 10^{11} eV $< E < 10^{15}$ eV are studied by ground based detectors called γ-telescopes. Those in the range of 10^{9} eV $< E < 10^{11}$ eV can be studied only with detectors placed on satellites.

The visible sector, first covered by human eye and later by photographic emulsion, today is dominated by the CCD cameras. Modern CCD sensors have quantum efficiency above 50% and thus they are just very good photon detectors. Similarity to other particle detectors gives prospect for using in the future some techniques developed in experimental particle physics. We will discuss it in more detail in the following sections.

The microwave radiation is especially interesting because of the presence of the cosmic microwave background (CMB). It was first discovered by a ground based antenna, but today it is studied in much cleaner conditions by balloons and satellites. The CMB map obtained by the COBE[17] satellite [2] can be considered as the first photograph of the "Baby Universe" 380,000 years after the Big Bang. Measurements by Boomerang[18] [15] and Maxima[19] [8] balloons established that the Universe is almost flat. Data obtained by the satellite missions WMAP[20] [17] were accurate enough to extract values of cosmological parameters with the precision of a few percent. This will be soon still improved by the Planck[21] satellite.

In the domain of radiowaves, the most impressive device is a very long base interferometer (VLBI)[22], which consists of several radiotelescopes placed in distant locations at the Earth and thus having a base of thousands of kilometers.

Astro-nuclear and astro-particle phenomena

Stars as nuclear reactors

When we say "astronomy" we usually think – "stars" and we mean ordinary shining stars like our Sun. The gallery of cosmic objects and processes is, however, much richer. We will mention a few examples in the following sections, but we cannot begin from anything but Sun-like stars.

The stars shine. The question "why" was awaiting for the answer for many millennia. Only in 1920 Eddington made the right suggestion that the energy of stars comes from nuclear fusion of hydrogen atoms into helium. And only in 1938 Bethe came with the first set of correct nuclear reactions. Today we can predict quantitatively details of processes in the Sun with a precision better than 10%. The Earth receives from the Sun the power of 1340 W/m^2. The total power emitted by the Sun is 4×10^{26} W. It is equivalent to 4,200,000 tons of solar mass converted into energy within a second. For comparision – all the power stations in Poland produce "only" 9×10^{10} W. Thus, stars are nothing but gigantic nuclear fusion reactors. In fact, so far these are the only stable nuclear fusion reactors we know. It is worth to note that we make an extensive use of one.

Neutron stars – gigantic nuclei

One of the most striking discoveries in astronomy was observation of pulsars – objects emitting radiowave pulses with a period of milliseconds to seconds. Later, it was understood that pulsars are, in fact, neutron stars, composed of densely packed neutrons. They can be considered as gigantic nuclei with a radius of the order of 10 km. It is obvious that understanding neutron stars require the input from particle physics and *vice versa*, neutron stars are very interesting test ground for particle physics theories. There are speculations that the density in the core of a neutron star is so high that the neutrons lose their identity and form a state, which would be better described as a quark gluon plasma. Such state of matter is predicted by quantum chromodynamics (QCD). Some evidence for the existence of such state in high energy heavy nuclei collisions was collected [16] at the CERN (Geneva) and is being further studied in RHIC[23] collider in Brookhaven.

It is not *a priori* excluded that there might exist extremely dense stars composed just of quarks. If such quark stars indeed exist, they can stand for a wonderful laboratory of particle physics. They can also help us to understand very early stages of the evolution of the Universe, before 10^{-10} s after the Big Bang. Unfortunately, no experimental evidence was found that such stars exist and there is even no good idea of how to search for such objects.

Supernovae

The origin of neutron stars is well known today. It turned out to be the same as the one of supernovae explosions. When the nuclear fuel of hydrogen is nearly over, the star begins to "burn" helium into carbon and oxygen. The process is then continued through heavier and heavier elements till iron. When everything but iron is used, there is no more energy to sustain giantic preasure of gravity. Within a fraction of a second the iron core which has the mass of the Sun and the size of the Earth collapses to a 10 km diameter ball. The preasure in the ball is such that iron nuclei are pressed together and even the electrons are pressed into protons. Remains nothing but neutrons. This is the birth of a neutron star.

In the meantime, the vacuum created by the iron collapse sucks the matter around. After accelerating to the 2/3 of the speed of light the matter collides with the neutron star and spread through the Universe with enormous flash called by us a supernova.

Human beings, whenever they find something new they always try to taste it and use it as some kind of tool. The same happen to supernovae. Recently they

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[17] COBE: http://lambda.gsfc.nasa.gov/product/cobe/

[18] Boomerang: http://cmb.phys.cwru.edu/boomerang/

[19] Maxima: http://cosmology.berkeley.edu/group/cmb/

[20] WMAP: http://map.gsfc.nasa.gov/

[21] Planck: http://www.rssd.esa.int/Planck/

[22] VLBI: http://www.jb.man.ac.uk/vlbi/

[23] RHIC: http://www.bnl.gov/rhic/

have been used [13, 14] as “standard candles” to study the properties of the early Universe. We have already mentioned it earlier.

Gamma ray bursts

Some hope for quark star proponents came recently with the discovery of gamma ray bursts (GRB) [9], which stands for one of the most difficult and most interesting puzzles of today’s astrophysics. These are short (0.01 s – 100 s) pulses of γ-rays with intensity lager than any other processes seen in the Universe so far. Energy of typical burst is estimated to be of the order of 10^{51} erg. Intensity of the burst is often higher than the total background from all other sources in the sky taken together. They are distributed isotropically and came from cosmological distances, reaching 13×10^9 light years (redshift $z = 4.5$).

The mechanism of γ-ray emission seems to be well understood in terms of explosion shockwave traversing interstellar matter [21]. However, the nature of the central engine of the explosion providing the energy is still a subject of hot discussion. There are two leading hypothesis, which both may be true. Longer (>2 s) bursts can be created by a collaps of a massive star, called – depending on the details of the model – a collapstar or a hypernova. It might be similar to a supernova, but it would not stop at the stage of a neutron star. It could collaps further and end up with a black hole. An important argument in favour of this two-step collapse scenario is observation of a supernova in coincidence with a few GRB’s. The best known was GRB 030329[24] [19]. Shorter bursts (<2 s) are suspected to be caused by a merger of two neutron stars or a neutron star and a black hole. Again, the final state would be a black hole.

In order to proceed with understanding the physics of GRB, one needs to observe them also in wavelengths different than gamma rays. It is natural to expect that GRB should be accompanied by bright optical flashes [11]. Systematic study of optical flashes accompanying GRB could impose important limits for theories explaining bursts mechanism and their energy engines. Perhaps not every GRB is accompanied by a bright optical flash. If GRB originates from a very distant region of the Universe, its light might be strongly red-shifted and/or absorbed by an interstellar gas. Thus, studying cosmic flashes influence our knowledge of fundamental interactions and the early Universe – the very dramatic experiment which follows the basic laws of physics.

The outcome of optical searches has been rather limited so far. Only about 60 GRB (out of about 3000 detected by satellites) were identified with optical sources. Most of them were observed by large telescopes, many hours after the GRB. On this time scale the observed afterglow of the order of 20^{m} faints at the rate of 1^{m} per several hours. Only twice a bright optical flash was observed, a few seconds after GRB trigger. The GRB 990123 was caught by ROTSE[25] group [1] equipped with a small robotic telescope. A flash was observed as bright as 8.6^{m}, i.e. one could see it even through a binonocular.

For the second time, the optical flash was observed even a few seconds before the gamma emission GRB041219 [20]. It was possible, because the main gamma emission was preceeded by a weak “precursor”. Paczynski and Haensel [12] interpreted the precursor as a sign of creation of a quark star. We have to keep in mind, however, that this is only one of many proposed hypothesis.

Thus, the central engine of GRB remains a mystery. Whatever it is, most probably it involves extreme high density states which are of primary interests for nuclear and particle physics. In fact, in any kind of collapse of a stellar mass object to a black hole the matter must go through denser and denser states such as, e.g. quark-gluon plasma. Some of these states might even be stable and form a new kind of macroscopic objects. Today, we can only speculate about this, but the future of – let us call it – “particle astrophysics” looks very exciting.

Experimental techniques

Differences and similarities

Experimental techniques of astronomy and nuclear or particle physics at first glance seem to be very different. Telescopes searching the sky seem to have very little to do with Geiger counters or scintillators, and even less with wire chambers, sampling calorimeters or other particle detectors. This is, however, quite misleading.

Particle physics begins with photographic emulsions. The invention of the first electronic detector – a wire chamber – was such an important breakthrough that it was appreciated by the Nobel Committee giving the prize to George Charpak. Larger speed and higher compactification of electronic elements made it possible to collect more and more data. Data storage became soon a bottle-neck. It was necessary to reduce significantly the amount of data on-line, making partial analysis in real time. Modern particle detectors acquire data from millions of events (particle collisions) per second and only small fraction of events can be stored on disks or tapes. Selection mechanism, called trigger, recognizes potentially interesting events and rejects uninteresting ones. Usually, the trigger is organized in consecutive levels, each one reducing the data volume by a certain factor using more and more sophisticated algorithms.

Introducing CCD sensors made a similar impact on astronomy. First, CCD sensors were used as a substitute for photographic films. Much higher quantum efficiency enabled photographing fainter objects with the same exposure time. Immediate availability of photometric measurement and convenience of computer processing made the measurement process more and more automatic. The number of objects studied by a single project increased from thousands to millions. The

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[24] GRB’s are denoted by their observing date in the format “yymmdd”.

[25] ROTSE: http://www.rotse.net/

precision of measurements was also enormously improved. Automatic data acquisition increased dramatically the amount of available data. Rapid progress in electronics causes the data streams so huge that the analysis becomes the bottleneck. We are simply not able to analyze all the data, which we could collect. Multi-terabyte archives of "virtual telescopes" will soon become too large to be handled.

One can predict what will be the next step of astronomy looking at an analogy with experimental particle physics. Here, sophisticated selection techniques were developed in order to reduce the amount of data on-line, in real time. Only a small fraction of the most interesting measurements is "triggered", the rest being immediately deleted. It seems that astronomy is also approaching this phase. One can predict that solutions similar to those in particle physics will be soon adopted also in astronomy. Multilevel triggers and on-line data reduction will become widely used in astronomical observations.

As a result, more and more particle physicists get involved in astronomical experiments. Experience gained with large data streams and on-line analysis is highly valuable. Just to give two examples: the EROS[26] project searching for microlensing events is lead by Michel Spiro from the Orsay Laboratory in France. The Robotic Optical Transient Search Experiment (ROTSE) has been created by Carl Akerlof of Los Alamos National Laboratories.

Large particle physics laboratories opens astroparticle divisions. It happened recently to Fermilab in the US. Also the Los Alamos National Laboratories are known for their space related projects. The CERN in Geneva has open a cathegory of "recognized experiments" which, although not placed at the CERN site, can use some CERN resources. Among them are several astroparticle and astronomy related projects. Last, but not least, the importance of astronomy and particle physics interactions has been well recognized in the UK, where the Particle Physics and Astronomy Research Council (PPARC) has been created.

"π of the Sky" experiment – a remarkable example

The concept

An interesting example of an experiment using particle physics expertises in astronomy is "π of the Sky"[27] [4]. Its main goal is to search for optical couterparts of gamma ray bursts. As we have already mentioned earlier, the traditonal approach is to wait for an alert from a satellite and then point the telescope towards the alert's target. Several robotic telescopes have been constructed especially for this purpose in order to minimise the reaction time. It is impossible, however, to observe with this method an optical emission during or before the gamma burst, which might be very important to discriminate between various possible mechanisms.

Traditional astronomical approach:

- chose an object,
- point the telescope and observe,

needs to be changed with the one more familiar in particle physics

- observe everything,
- automaticaly select interesting objects and study them in detail.

The "π of the Sky" project is a practical attempt to this approach.

The design assumes that a large part of the sky is observed continuously. This is achieved by two sets of 16 CCD cameras, with each camera covering 20° × 20° Field of View (FoV). The total FoV of the system is thus 2×2 steradians. The original plan was to cover 2π steradians, justifying the name of the project. The two sets observe the same part of the sky from distant (~100 km) locations to enable rejection of near-Earth objects by parallax. Each camera has a CCD of 2000 × 2000 pixels of 15 μm × 15 μm. Cameras are equipped with CANON EF $f = 85$ mm, $f/d = 1.4$ photo lenses. This gives the pixel scale of 0.6 arcmin/pixel. The expected limiting magnitude for 10 s exposures is 12^m and for 20 exposures added together it is 14^m. The apparatus is currently under construction.

Such limiting magnitude does not guarantee that all GRB's optical counterparts will be observed. Several GRB's detected by a Swift BAT gamma detector have not been observed by its UVOT telescope having limiting magnitude of 17. On the other hand, a few afterglows have been found quite bright. The recently observed are:

- GRB041219: 14.9^m (infrared) after 0.8 h by the Palomar 200-inch Hale Telescope,
- GRB050502: 14.3^m after 23 s by ROTSE,
- GRB050525: 14.7^m after 6 min by ROTSE.

Extrapolation to the first minute suggests that at least two of them would be visible by "π of the Sky". In the past, the two brightest bursts were

- GRB990123: 8.6^m after 20 s by ROTSE,
- GRB030329: 13^m after 1 h by telescopes at Riken and Kyoto.

These would be certailny visible, even by the current "π of the Sky" prototype.

Working prototype

A prototype consisting of two cameras has been built and installed at the Las Campanas Observatory (LCO) in Chile. Each camera has a CCD of 2000 × 2000 pixels of 15 μm × 15 μm. Cameras are equipped with Carl Zeiss Planar T* photo lenses of $f = 50$ mm, $f/d = 1.4$. The limiting magnitude for 10 s exposures is $10–11^m$ and for 20 exposures added together it is $12–13^m$ depending on the Moon phase etc. The cameras are installed on a robotic mount controlled by a computer.

The apparatus is controlled by a PC located inside the dome. Second PC, located in a nearby control room is used for off-line data analysis. The system is fully autonomous, but also fully controllable via Internet. During the normal operation the system runs autonomously according to the preprogramed schedule. Dedicated script language has been developed to make the schedule programing easy and flexible. For most of

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[26] EROS: http://eros.in2p3.fr/

[27] π of the Sky: http://grb.fuw.edu.pl/

the time, the cameras follow the field of view of the HETE satellite[28]. Its position is read out from the Internet at regular intervals and the mount position is automatically corrected accordingly. If the HETE FOV is not visible, another location in the sky is programmed. The system is also listening to GCN alerts. Should an alert located outside the current FOV arrive, the mount automatically moves towards the target and exposures are being taken. Twice a night an all sky scanning is performed, which lasts 2 × 20 min.

The 10 s exposures are being taken continuously. The images are immediately analyzed, while in the computer RAM in search for flashes with a rise time of the order of seconds. Then, they are temporarily stored on a disc and can be reexamined in case of late arrival of an external alert. If a flash candidate is found, the 100 × 100 pixel samples of ±7 frames are stored permanently for the record. In the meantime, the images are copied to the second PC, which superposes the images and searches for optical transients with a rise time of minutes. During the day, two analyses are performed in parallel on the temporarily stored data. The first PC runs fast photometry on individual frames, which can be used later to study rapidly varying objects. The second PC performs precise photometry on images superposed by 20. This could be used to study variable stars etc. The results are stored permanently on a disc. Out of almost 30 GB of data taken every night, about 2 GB of results is stored permanently. After 2–3 months, a 200 GB removable disc with the results is replaced and taken to Warsaw for further analysis.

Firsts results

The prototype is in operation since July 2004. During almost one year of running the system detected about 100 optical flashes of unknown origin, which are visible by two cameras, but only in a single frame. One cannot exclude that they are caused by Sun light reflexes from rotating artificial satellites, which are not present in available databases. Four flashes have been observed which are visible in at least two consequtive frames. It is rather improbable that these are also caused by satellites. One case was unambiguously identified with an outburst of the CN Leo flare star. The brightness of the star has risen by a factor of 100 in seconds and then it gradualy faded away during several minutes. This observation confirms that the system is capable of automatic discovery of true optical flashes.

Between 1 July 2004 and 16 June 2005 as much as 70 GRB have been observed by satellites and their positions have been established. Most of them happened during the day or below the horizon at LCO. Only 2 occurred within "π of the Sky" FoV: GRB 040825A and 050412. In several other cases the system has slewed to the target shortly after the alert. No new optical sources have been found. Limits have been given and published for the cases, when "π of the Sky" was faster than others: GRB 040916B, 041217, 050123, 050326, and 050607.

The brightness of thousands of stars has been monitored. A large data base with their light curves is being built. Quick look reveiled many variable stars, some of them not yet known as variables. We hope that the systematic analysis of all the collected data may bring interesting discoveries in the field of fast variating stars.

Merging experimental techniques

We have already mentioned about similarities between CCD cameras and particle detectors. In both domains, introducing electronic readout was a real breakthrough.

But all in all, what is the difference between the astronomical observations and particle physics experiments? In the past, the difference was evident. An astronomer looked through a telescope at a celestial body, whereas a particle physicist looked at a particle track in a cloud chamber. Today, an astronomer is counting photons coming from space to his electronics device (CCD), and a particle physicist is counting particles entering his electronics device. One can say, that still there is a difference: one is counting visual photons, the other one – elementary particles. However, also in particle physics one of the most effective ways of detecting particles was found to force them to produce visible light (by scintillation or Cerenkov radiation) and detect resulting photons.

Thus, the typical scheme of particle physics experiment is the following. A phenomenon is being observed. The only information about it is carried by particles produced in this phenomenon. In order to detect them effectively we place a medium, which cause the traversing particles to emit visual photons. These photons are finally detected by some photosensitive electronic device.

Now imagine that the phenomenon in question is the GRB engine (whatever it might be), the media is the interstellar matter and the detecting device is a CCD camera. Precisely, such an experiment is described above as "π of the Sky". Is it astronomy or particle physics?

Conclusions

Astronomy and particle physics both extends to infinity. Astronomy attempts to describe larger and larger structures, including the Universe as a whole. Nuclear and particle physics explore the opposite direction resolving smaller and smaller bilding blocks of matter. As we have seen, surprisingly enough, it turned out that they go heads-on towards each other. This is well illustrated by the infinity symbol ∞. It is a snake eating his own tail.

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