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Multifrequency behaviour of high energy cosmic sources

A review

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Abstract. In this paper we want to discuss the status of the high energy astrophysics taking into account the new very interesting results coming from space– and ground–based multifrequency experiments and their theoretical interpretation, as mostly discussed in the review paper by Giovannellli (2011). Several old open points have been solved, but in the same time new hints for the scientific community born. All the arguments presented in this review will be objects of deeper discussions during this workshop, and then most of them will appear in details in these proceedings. We will briefly discuss also the prospects of the multifrequency astrophysics which is now in its golden age without any pretension of completness.

Key words. Experimental Astrophysics: multifrequency – Theoretical Astrophysics: multifrequency – X-ray Binaries – Cataclysmic Variables – Jets – Gamma-ray Bursts – Cosmology: Background – Reionization – Clusters of Galaxies – Dark energy – Dark matter

1. Introduction

After the epoch of recombination (last scattering), the universe experienced the so–called *Dark Ages*, where the dark matter halos collapsed and merged until the formation of the first sources of light that determined the end of such Dark Ages and the beginning of the *Reionization Era*: population III stars were born and as feedback the first SNe and GRBs. This occurred between $\approx (2 - 5) \times 10^8$ yr (z $\approx 20-10$). Soon after population II stars started to form and probably the second wave of reionization occurred and stopped at $\approx 9 \times 10^8$ yr (z ≈ 6) after the Big Bang, and then the evolution of galaxies started. (e.g. Djorgovski, 2004, 2005).

Reionization is the last global phase transition in the Universe. The reionization era is thus a cosmological milestone, marking the appearance of the first stars, galaxies and quasars.

The search of the epoch of reionization is one of the most important open problems discussed by Panagia (2011). Recently Ouchi et al. (2010) conclude that the major reion-

Send offprint requests to: F. Giovannelli ization process took place at z >∼ 7. And, it is around such values of redshift that our ground– and space–based experiments can provide important results for a better knowledge of the physics of our universe (e.g. review by Giovannelli & Sabau-Graziati, 2004). These, together with cosmic microwave background (CMB) experiments, that are exploring the universe until the epoch of the last scattering, are going in the direction of linking up with the results coming from LHC.

It is in this context that we can remark that all the cosmic sources emit photons and particles and neutrinos which can be detected on the Earth, or in Space or Underground, by means of different techniques and methods. It is obvious that photons coming from cosmic sources arrive directly onto the Earth detectors, space– or ground–based, apart the absorption due to interactions with the crossed media (dust and radiation). On the contrary, particles emitted by the cosmic sources are scattered by the presence of magnetic fields in function of their energy, which generally prevent the direct recognition of their original direction, and react with the CMB. A discussion on cosmic ray directions and sources is reported in the paper by Clay (2000). Particles arriving to the top of the Earth atmosphere experience nuclear reactions with air molecules which give rise to three different cascade channels: muonic component and neutrinos, hadronic component, and electromagnetic component (e.g. De Roeck, 2008). Neutrinos also arrive directly from the production sources, which are presumably the same producing VHE photons, but because of their very low cross section, their detection is extremely difficult (e.g. Kappes et al., 2007).

Then photonic, particle and neutrino experiments must converge for the same objective: the knowledge of the physics of the Universe. This is the new long way undertaken by the new field of physics, namely *Astroparticle Physics*. Multifrequency observations – possibly simultaneous – are fundamental in astroparticle physics.

In spite of the enormous jumps in our knowledge of the physics of our Universe, many *old* problems are still open and many *new* problems are arising with the new data. They foment the most exciting race in which humans are pursuing *mother nature* in order to unveil its deepest secrets.

2. Gamma-rays: production mechanisms and detection history

Acceleration of electrons to high energies and interactions with magnetic fields and CMB are the mechanisms producing X-rays and γ-rays via synchrotron and Inverse Compton Scattering (ICS), respectively. High energy proton-proton reactions produce $\pi^{\pm}$ and π°. The former decays into neutrinos and the latter decays into 2γ-rays. Energy γ-ray spectra from such processes have been computed and discussed by many authors (e.g. Giovannelli et al., 1982a,b; Bednarek et al., 1990; Bednarek, 2009a,c; Sitarek & Bednarek, 2010), and energy neutrino spectra by e.g. Giovannelli et al. (1983), Bednarek (2009b).

Gamma-ray astronomy really born around the middle 1970-ies with the results from SAS-2 (Fichtel et al., 1975). SAS-2 provided the first detailed information about the gamma-ray sky and demonstrated the ultimate promise of gamma-ray astronomy. SAS-2 revealed that the galactic plane gamma-radiation was strongly correlated with galactic structural features, especially when the known strong discrete sources of gamma-radiation were subtracted from the total observed radiation. The SAS-2 results clearly established a high energy (> 35 MeV) component to the diffuse celestial radiation. High-energy gamma-ray emission was also seen from discrete sources such as the Crab and Vela pulsars.

Later COS-B satellite detected 25 discrete γ-ray sources (Swanenburg et al., 1981). A jump in the knowledge of HE sky has been obtained with the CGRO (Gehrels, Chipman & Kniffen, 1993) and in particular the EGRET experiment detected 276 discrete γ-ray sources (Hartman et al., 1999). But at that time the γ-ray sky had a severe limitation in the range $\approx 10-300$ GeV. The space– and ground–based experiments were able to observe below and above this range, respectively. This gap, owing to technological limitations, was discussed by Saggion & Bastieri (2002), and recently has been filled up by GLAST observatory (renamed FERMI). As of 2010 March 25, there are 98 sources known: 38 extragalactic and 60 galactic for E > 100 MeV (Wagner, 2010).

The First Fermi-LAT catalog (1FGL) contains 1451 sources detected and characterized in the 100 MeV to 100 GeV (Abdo et al., 2010a).

3. Background in the Universe

After the Big Bang the Universe started to expand with a fast cooling. The cosmic radiation observed now is probably a melting of different components which had their origin in different stages of the evolution as the results of different processes. This is the Diffuse Extragalactic Background Radiation (DEBRA), which, if observed in different energy ranges, allows the study of many astrophysical, cosmological, and particle physics phenomena.

It is possible to consider the DEBRA as a radiation produced by a cosmic source: the whole Universe. Such a background radiation from radio to HE γ-ray energy bands has been deeply discussed by Ressel & Turner (1990), Henry (1999, 2002), Hasinger, Miyaji & Schmidt (2000), and in the review paper by Giovannelli & Sabau-Graziati (2004). The analysis of the different components of DEBRA leads to the Grand Unified Photon Spectrum (GUPS), covering 29 orders of magnitude of the electromagnetic spectrum, from 10^{-9} to 10^{20} eV. The GUSP is continuously being updated, thanks to results coming from the many experiments in different energy regions. Henry (1999, 2002) thoroughly discussed the experimental situation of the cosmic background. DEBRA is the witness of the whole history of the Universe from the Big Bang to present time.

Such history is marked by three main experimental witnesses supporting the Big Bang theory (e.g. Giovannelli & Sabau-Graziati, 2008): the light element abundances (Burles, Nollett & Turner, 2001); the CMBR temperature at various redshifts as determined by Srianand, Petitjean & Ledoux (2000), and the references therein; the CMB at z = 0 as result of COBE ($T_{CMBR}(0)$ = 2.726±0.010 K), which is well fitted by a black body spectrum (Mather et al., 1994). At z≃ 2.34, the CMBR temperature is: 6.0 K < $T_{CMBR}(2.34)$ < 14.0 K. The prediction from the Hot Big Bang: $T_{CMBR} = T_{CMBR}(0) \times (1 + z)$ gives $T_{CMBR}(2.34)$ = 9.1 K, which is consistent with the measurement.

4. Reionization of the Universe

After the epoch of recombination (last scattering) between $\approx 3.8 \times 10^5 - \approx 2 \times 10^8$ yr (z $\approx$ 1000 − 20), the universe experienced the so–called *Dark Ages*, where the dark matter halos collapsed and merged until the appearance of the first sources of light. This ended the Dark Ages. The ultraviolet light from the first sources of light also changed the physical state of the gas (hydrogen and helium) that fills the Universe, from a neutral state to a nearly fully ionized one. This was the *Reionization Era* where the population III stars formed and as feedback the first SNe and GRBs. This occurred between $\approx (2-5)\times 10^8$ yr (z $\approx 20-10$). Soon after population II stars started to form and probably the second wave of reionization occurred and stopped at $\approx 9 \times 10^8$ yr (z $\approx$ 6) after the Big Bang, and then the evolution of galaxies started (e.g. Djorgovski, 2004, 2005). Quasars – the brightest and most distant objects known – offer a window on the reionization era, because neutral hydrogen gas absorbs their ultraviolet light.

Reionization drastically changes the environment for galaxy formation and evolution and in a hierarchical clustering scenario, the galaxies responsible for reionization may be the seeds of the most massive galaxies in the local Universe. Reionization is the last global phase transition in the Universe. The reionization era is thus a cosmological milestone, marking the appearance of the first stars, galaxies and quasars.

Recent results obtained by Ouchi et al. (2010) give an important contribution for solving such a problem. Indeed, from the the Lyα luminosity function (LF), clustering measurements, and Lyα line profiles based on the largest sample to date of 207 Lyα emitters at z = 6.6 on the 1 deg^2 sky of Subaru/XMM-Newton Deep Survey field, Ouchi et al. (2010)

found that the combination of various reionization models and observational results about the LF, clustering, and line profile indicates that there would exist a small decrease of the intergalactic medium's (IGM's) Lyα transmission owing to reionization, but that the hydrogen IGM is not highly neutral at z = 6.6. Their neutral-hydrogen fraction constraint implies that the major reionization process took place at z >∼ 7.

The W. M. Keck 10-m telescope has shown the quasar SDSS J1148+5251 at a redshift of 6.41 ($\approx$ 12.6 $\times$ 10^9 yr ago) (Djorkovski, 2004), and MegaCam imaging at the Canada-France-Hawaii Telescope (CFHT) detected the quasars CFHQS J1509-1749 at z = 6.12 and CFHQS J2329-0301 at z = 6.43 (Willott et al., 2007), that are currently the most distant quasars known. An analysis of the sizes of the highly-ionized near-zones in the spectra of two quasars at z = 6.12 and z = 6.43 suggest the IGM surrounding these quasars was substantially ionized before these quasars turned on. Together, these observations point towards an extended reionization process, but we caution that cosmic variance is still a major limitation in z ¿ 6 quasar observations. These measurements does not contradict the result found for the epoch of reionization. However, the search of the epoch of reionization is still one of the most important open problems for understanding the formation of the first stars, galaxies and quasars. This problem has been discussed by Panagia (2011).

5. Dark energy and dark matter

By using different methods to determine the mass of galaxies it has been found a discrepancy that suggests ∼ 95% of the universe is in a form that cannot be seen. This form of unknown content of the universe is the sum of *Dark Energy (DE)* and *Dark Matter (DM)*. Colafrancesco (2003) deeply discussed about *New Cosmology*.

The discovery of the nature of the dark energy may provide an invaluable clue for understanding the nature and the dynamics of our universe. However, there is ∼ 30% of the matter content of the universe which is dark and still requires a detailed explanation. Baryonic DM consisting of MACHOs (Massive Astrophysical Compact Halo Objects) can yield only some fraction of the total amount of Dark Matter required by CMB observations. WIMPs (Weakly Interacting Massive Particles) (non-baryonic DM) can yield the needed cosmological amount of DM and its large scale distribution provided that it is "cold" enough. Several options have been proposed so far like: *i)* light neutrinos with mass in the range $m_\nu \sim 10 - 30$ eV, *ii)* light exotic particles like axions with mass in the range $m_{axion} \sim 10^{-5} - 10^{-2}$ eV or weakly interacting massive particles like neutralinos with mass in the range $M_\chi \sim 10 - 1000$ GeV, this last option being favored at present (see, e.g., Ellis 2002).

There are two ways for attempting an explanation of the nature of dark matter: the first is to think DM formed by MACHOs, and the second to think that DM is formed by WIMPs. Alternatively, DM could be formed by both MACHOs and WIMPs. MACHOs are the big, strong dark matter objects ranging in size from small stars to super massive black holes. WIMPs are the little weak subatomic dark matter candidates. Astronomers search for MACHOs and particle physicists look for WIMPs. The investigation about DM is therefore a battle field where the two communities apparently fight on equal terms. This battle generated different experiments which are running and producing results that have been during the Vulcano 2010 workshop (Giovannelli & Mannocchi, 2011).

Modern astronomical methods yield a variety of independent information on the presence and distribution of dark matter. For our Galaxy, the basic data are the stellar motions perpendicular to the plane of the Galaxy (for the local dark matter), the motions of star and gas streams and the rotation (for the global dark matter). Important additional data come from gravitational microlensing (Paczyński, 1986) by invisible stars or planets. In nearby dwarf galaxies the basic information comes from stellar motions. In more distant and giant galaxies the basic information comes from the rotation curves and the X-ray emission of the hot gas surrounding galaxies. In clusters and groups of galaxies the gravitation field can be determined from relative motions of galaxies, the X-ray emission of hot gas and gravitational lensing. Finally, measurements of fluctuations of the CMB radiation in combination with data from type Ia supernovae in nearby and very distant galaxies yield information on the curvature of the Universe that depends on the amount of Dark Matter and Dark Energy. For a long updated discussion about Dark Matter see the review by Einasto (2009).

EROS and MACHO, two experiments based on the gravitational microlensing, were developed. Two lines of sight have been probed intensively: the Large (LMC) and the Small (SMC) Magellanic Clouds, located 52 kpc and 63 kpc respectively from the Sun (Palanque-Delabrouille, 2003).

With 6 years of data towards the LMC, the MACHO experiment published a most probable halo fraction between 8 and 50% in the form of 0.2 $M_\odot$ objects (Alcock et al., 2000). Most of this range is excluded by the EROS exclusion limit, and in particular the MACHO preferred value of 20% of the halo.

Among experiments for searching WIMPs dark matter candidates there is PAMELA devoted to search for dark matter annihilation, antihelium (primordial antimatter), new matter in the Universe (strangelets?), study of cosmic-ray propagation (light nuclei and isotopes), electron spectrum (local sources?), solar physics and solar modulation, and terrestrial magnetosphere. A comparison of PAMELA expectation with many other experiments has been discussed by Morselli (2007). Bruno (2011) discussed some results from PAMELA.

Finkbeiner & Weiner (2007) proposed a dark matter candidate with an excited state 12 MeV above the ground state, which may be collisionally excited and de–excite by e^+e^- pair emission. By converting its kinetic energy into pairs, such a particle could produce a substantial fraction of the 511 keV line observed by the INTEGRAL/SPI in the inner Milky Way (Knödlseder et al., 2003; Weidenspointner et al., 2006). Then they propose that dark matter is composed of WIMPs which can be collisionally excited and de–excite by e^+e^- pair emission, and that this mechanism is responsible for the majority of the positronium annihilation signal observed in the inner Milky Way.

Observations by the Wilkinson Microwave Anisotropy Probe (WMAP) experiment have identified an excess of microwave emission from the center of the Milky Way (Hooper et al., 2008). It has previously been shown that this WMAP haze could be synchrotron emission from relativistic electrons and positrons produced in the annihilations of dark matter particles. If dark matter annihilations are in fact responsible for the observed haze, then other annihilation products will also be produced, including gamma rays. If the dark matter particles annihilate mostly to electrons or muons will GLAST/Fermi be unable to identify the gamma ray spectrum associated with the WMAP haze.

Arkani-Hamed et al. (2009) proposed a comprehensive theory of dark matter that explains the recent proliferation of unexpected observations in high-energy astrophysics. Cosmic ray spectra from ATIC and PAMELA require a WIMP with mass $M\chi \sim$ 500–800 GeV that annihilates into leptons at a level well above that expected from a thermal relic. Signals from WMAP and EGRET reinforce this interpretation.

Possible multifrequency tests for searching dark matter sources have been discussed by Morselli (2010).

Ackermann et al. (2010a) discussed the results of the Fermi LAT galaxy cluster monitoring program. In the first 11 months of operations no γ-ray emission from any of the monitored galaxy clusters has been detected. The non-observation of a signal from the Fornax cluster allows to constrain a large range of dark matter models predicting a stable particle based on the theory of Supersymmetry. In addition, models predicting dark matter annihilating/decaying dominantly into leptons can be constrained quite severely, even with conservative assumptions on the dark matter substructure present in the galaxy clusters. Such models are favored to explain the Fermi LAT cosmic-ray electron spectrum as well as the PAMELA electron/positron fraction without violating constraints from the measurements of anti-protons in the cosmic rays.

Then the search for DM is one of the main open problems of today's astroparticle physics.

6. Clusters of galaxies

The knowledge of magnetic field intensity in clusters of galaxies (CGs) is fundamental for understanding the properties of the intracluster plasma. CGs with extended radio halo (1 Mpc scale, probably associated with the clusters-subclusters penetration) should have a non-thermal emission of hard X-rays, due to Compton diffusion of relativistic electrons in the CMB.

The coordinated detection of radio and hard X-ray radiation directly provides some of the basic properties of the intracluster magnetic field and cosmic ray electrons. These determinations are based on observable quantities, contrary to the only radio measurements, by which is possible to determine the magnetic field and electron density model dependent. Before BeppoSAX, only upper limits in the hard X-ray emission from CGs were known. Thanks to its sensitivity, BeppoSAX measured such a hard emission, removing the previous uncertainties (Fusco Femiano et al., 1999).

The mass determination in CGs is a fundamental task in understanding the nature of the dark matter and cosmological origin of structures in the Universe. X-ray spectra are fundamental in determining the abundance of heavy elements in the intracluster medium (ICM). The knowledge of metal abundance is crucial for the knowledge of the origin and evolution of ICM, the history of star formation and the chemical evolution of CGs.

Several open problems about the comprehension of CGs still survive in spite of many important results coming from satellites of the last decade. The problems of the production and transport of heavy elements, the hierarchical distribution of the dark matter, and the role of the intergalactic magnetic fields in CGs are still open. Multifrequency simultaneous measurements, with higher sensitivity instruments, in particular those in hard X-ray and radio energy regions and optical- near infrared (NIR) could solve such problems. The AXAF/Chandra and XMM/Newton observatories, launched at the end of nineties, are contributing to the solution of some of these problems, as well as HST.

XMM-Newton observatory results are extremely important. From X-ray spectra, it is evident that the ICM contains metals (Fukazawa et al., 1998). As heavy elements are only produced in stars, the processed material must have been ejected by cluster galaxies into the ICM. Possible transport processes are ram pressure stripping (Gunn & Gott, 1972), galactic winds (De Young, 1987), galaxy-galaxy interactions or jets from AGNs.

Publications on galactic winds (McKee & Ostriker, 1977) found that mass outflow occurs only at very high gas temperatures of several 10^6 K. For non-starburst galaxies, like our Milky Way, the temperature of the hot interstellar medium (HIM) is below several 10^6 K, therefore radiative cooling prevents a continuous mass loss. This would lead to the conclusion that only active galaxies with an ongoing starburst can enrich the ICM with metals due to thermally driven galactic winds.

High resolution spectroscopy of CGs performed by Peterson et al. (2003) gave the derived abundances as a function of ambient temperature for several elements, such as Fe, O, Mg, Ne, and Si. The abundance of iron declines slightly with more massive clusters, as indicated in earlier ASCA observations (Mushotzky et al. 1996; Fukazawa et al. 1998). The amount of metals in the ICM is at least as high as the sum of the metals in all galaxies. This means that a lot of gas must have been transported from galaxies into the ICM. Tozzi et al. (2003) obtained a robust measurement of the average ICM metallicity as a function of cosmic epoch. The behaviour of metallicity in CGs, undoubtedly different for high and low mass CGs. This result needs a confirmation with a larger sample of CGs.

Ajello et al. (2010) discussed the contribution of SWIFT/BAT experiment on the knowledge of several CGs concluding that the hard X-ray emission is most likely thermal in origin. Weratschnig (2010) discussed new results about CGs in the era of XMM-Newton and

Chandra observatories, like the measurement of the Hubble parameter, a probable detection of warm-hot matter in the filament between two clusters, new constraints on the nature of dark matter and some others.

There are several theoretical motivations for expecting γ-ray emission from clusters of galaxies (e.g. Sreekumar et al., 1996; Colafrancesco & Blasi, 1998; Völk & Atoyan, 1999; Colafrancesco & Mele, 2001). Moreover there is also the γ-ray emission from individual 'normal' galaxies (Berezinsky et al., 1990; Dar & De Rújula, 2001) and from 'active' galaxies (Urry & Padovani, 1995) contained in the cluster.

Other possible process for producing γ-rays is the merging of CGs. Deep studies about such a process have been performed by Blasi (2001, 2003), Gabici & Blasi (2003, 2004), Blasi, Gabici & Brunetti (2007) and the references therein.

EGRET seems to have detected such γ-ray emissions from clusters of galaxies. Indeed, Colafrancesco (2002) reported evidence for an association between galaxy clusters and unidentified γ-ray sources of high galactic latitude ($|b| > 20°$) in the Third EGRET catalog.

However, in the first 11 months of operations of the Fermi LAT monitoring program of CGs no γ-ray emission from any of the monitored CGs has been detected (Ackermann et al., 2010b).

Is the lack of γ-ray emission from CGs due to the small sample until now observed or due to physical reasons not yet clear?

7. Gamma-ray bursts

Gamma-ray burst (GRBs) were discovered in 1967 – thanks to the four VELA spacecrafts, originally designed for verifying whether the Soviet Union abided the 1963 Limited Nuclear Test Ban Treaty – when 16 strong events were detected (Klebesadel, Strong & Olson, 1973). Since then GRBs have remained a puzzle for the community of high energy astrophysicists. For this reason the problem of GRBs originated thousands articles most of them devoted to their physical interpretation (e.g. the review by Mazets & Golenetskii, 1988; the review by Giovannelli & Sabau-Graziati, 2004 and the references therein). BATSE/CGRO experiment detected 2704 GRBs from 1991 to 1999 (Paciesas et al., 1999). This number increased with new generation satellites (BeppoSAX, RossiXTE, HETE, INTEGRAL, SWIFT, and FERMI). In spite of this, the problem of their origin is still alive, at least for a part of them.

As of 2010 May 18 there are more than 250 claimed association of GRBs with the host galaxies at high redshift (Greiner, 2011). This fact strongly push toward the extragalactic origin of GRBs. However, extragalactic origin would necessitate an extremely high amount of energy for each event, that probably only invoking *ad hoc* models could be justified. If a γ-ray burst should produce a very high collimated relativistic beam in the direction of us, the amount of energy associated ($\approx 10^{53}$ erg) could be justified.

Critics to this origin have been discussed by several authors, such as Kundt (2001, 2002, 2003) and Bisnovatyi-Kogan (2003a,b). Indeed, some points need to be clarified, namely: i) Redshift is measured only in long-duration bursts. Do short bursts have different nature? ii) Origin of hard gamma ray (20-20000 MeV) afterglow, lasting up to 1.5 hours. iii) Hard X-ray absorption features. iv) Influence of a strong GRB explosion on the host galaxies, which is not (yet) found. v) Absence of the expected correlations connected with properties of GRBs at large and small redshifts.

In order to settle the controversy, it is crucial to monitor the sky with the goal of searching for the behaviour of GRBs in the whole electromagnetic spectrum, possibly with simultaneous measurements.

The SWIFT observatory is strongly improving our knowledge about GRBs. The average redshift of the host galaxies for the long GRBs is a factor ~ 2 greater than the average redshift for the GRBs detected in the pre–SWIFT era: ~ 2.8 and ~ 1.4, respectively (Jakobsson et al., 2006). Moreover, this spacecraft has detected few dozens short bursts at cosmological distances at average redshift $\bar{z} = 0.5$. They are located mostly in elliptical galaxies outside of the star formation regions.

Therefore, they must be connected to the old population and not to the young massive stars (as the long bursts are). The most likely explanation is that at least large part (majority?) of these events are due to mergers of compact objects (e.g. Ziółkowski, 2007).

Important news about GRBs at very high redshift are coming from optical observations of long-duration GRBs made over a three-year period with the robotic Palomar 60 inch telescope (P60) (Cenko et al., 2009). They found that a significant fraction (∼ 50%) of Swift events show a suppression of the optical flux with regard to the X-ray emission (the so-called "dark" bursts). Their multicolor photometry demonstrates this is likely due in large part to extinction in the host galaxy. Then, the previous studies, by selecting only the brightest and best-sampled optical afterglows, have significantly underestimated the amount of dust present in typical GRB environments.

Recent observations of the short GRB090510 performed by the Fermi and Swift observatories show an extended emission detected in the GeV range. Furthermore, its optical emission initially rises, a feature so far observed only in long bursts, while the X-ray flux shows an initial shallow decrease, followed by a steeper decay. This exceptional behavior enables authors to investigate the physical properties of the gamma-ray burst outflow, poorly known in short bursts and discussing internal and external shock models for the broadband energy emission of this object (De Pasquale et al., 2010).

Theoretical description of GRBs is still an open strongly controversial question. Fireball (FB) model (Meszaros & Rees, 1992; Piran, 1999), cannon ball (CB) model (Dar & De Rújula, 2004), spinnin-precessing jet (SPJ) model (Fargion, 2003a,b; Fargion & Grossi, 2006), fireshell (Izzo et al., 2010) model — directly coming from electromagnetic black hole (EMBH) model (e.g. Ruffini et al. 2003 and the references therein) — are the most popular, but each one against the others. In our opinion the most promising could be the fireshell model since it fits very well each kind of GRBs. However, this model deserves meticulous controls.

Important implications on the origin of the highest redshift GRBs are coming from the detection of the GRB 050904 at z = 6.39 (Haislip et al., 2006) with the BOOTES INTA–CSIC–ASU, the GRB 080913 at z =6.7 (Greiner et al., 2009) and GRB 090423 at z ∼ 8.2 (Tanvir et al., 2009). Izzo et al. (2010) discussed successfully a theoretical interpretation of the latter GRB 090423 within their fireshell model. Such detections of high z GRBs mean that really we are approaching to the possibility of detecting GRBs at the end of Dark Era (z ∼ 25), where the first light appeared and Pop III stars formed (Lamb & Reichart 2000; Ciardi & Loeb 2000; Bromm & Loeb 2002). The recent detection of the GRB090429B at z ≃ 9.4 (Cucchiara et al., 2011) plays a role in favour of the possibility of detecting GRB until the epoch of Pop III stars formation.

Wang & Dai (2009) studied the high-redshift star formation rate (SFR) up to z ≃ 8.3 considering the Swift GRBs tracing the star formation history and the cosmic metallicity evolution in different background cosmological models including ΛCDM, quintessence, and quintessence with a time-varying equation of state and brane-world models. ΛCDM model is the preferred which is however compared with other results.

Although big progress has been obtained in the last few years, GRBs theory needs further investigation in the light of new experimental data,

8. Extragalactic background light

Space is filled with diffuse extragalactic background light (EBL) which is the sum of starlight emitted by galaxies through history of universe. High energy γ-rays traversing cosmological distances are expected to be absorbed through their interactions with the EBL by: $\gamma_{\rm VHE} + \gamma_{\rm EBL} \longrightarrow e^{+}\ e^{-}$. Then the γ-ray flux Φ is suppressed while travelling from the emission point to the detection point, as $\Phi = \Phi_0 e^{-\tau(E,z)}$, where τ(E,z) is the opacity. The e–fold reduction [τ(E,z) = 1] is the Gamma Ray Horizon (GRH) (e.g. Blanch & Martinez, 2005; Martinez, 2007).

The direct measurement of the EBL is difficult at optical to infrared wavelengths because of the strong foreground radiation originating in the solar system. However, the measurement of the EBL is important for VHE gamma-ray astronomy, as well as for astronomers modelling star formation and galaxy evolution. Second only in intensity to the CMB, the optical and infrared (IR) EBL contains the imprint of galaxy evolution since the Big Bang. This includes the light produced during formation and reprocessing of stars. Current measurements of the EBL are reported in the paper by Schroedter (2005, and references therein). He used the available VHE spectra from six blazars. Later, the redshift region over which the gamma reaction history (GRH) can be constrained by observations has been extended up to z = 0.536. Upper EBL limit based on 3C 279 data have been obtained (Albert et al., 2008a). The universe is more transparent to VHE gamma rays than expected. Thus many more AGNs could be seen at these energies.

Indeed, Abdo et al. (2009a) observed a number of TeV-selected AGNs during the first 5.5 months of observations with the Large Area Telescope (LAT) on–board the Fermi Gamma-ray Space Telescope. Redshift–dependent evolution is detected in the spectra of objects detected at GeV and TeV energies. The most reasonable explanation for this is absorption on the EBL, and as such, it would represent the first model–independent evidence for absorption of γ-rays on the EBL. Abdo et al. (2010b) by using a sample of γ-ray blazars with redshift up to z $\sim$ 3, and GRBs with redshift up to z $\sim$ 4.3, measured by Fermi/LAT placed upper limits on the γ-ray opacity of the universe at various energies and redshifts and compare this with predictions from well–known EBL models. They found that an EBL intensity in the optical-ultraviolet wavelengths as great as predicted by the "baseline" model of Stecker, Malkan & Scully (2006) can be ruled out with high confidence.

9. Relativistic jets

Relativistic jets have been found in numerous galactic and extragalactic cosmic sources at different energy bands. The emitted spectra of jets are strongly dependent on the angle formed by the beam axis and the line of sight, and obviously by the Lorentz factor of the particles (e.g. Bednarek et al., 1990 and the references therein; Beall, Guillory & Rose, 1999, 2009; Beall, 2002, 2003, 2008, 2009; Beall et al., 2006, 2007). So, observations of jet sources at different frequencies can provide new inputs for the comprehension of such extremely efficient carriers of energy, like for the cosmological GRBs. The discovered analogy among μ–QSOs, QSOs, and GRBs is fundamental for studying the common physics governing these different classes of objects via μ–QSOs, which are galactic, and then apparently brighter and with all processes occurring in time scales accessible by our experiments (e.g. Chaty, 1998). Chaty (2007) remarked the importance of multifrequency observations of jet sources by means of the measurements of GRS 1915+105.

Dermer et al. (2009) suggest that ultra-high energy cosmic rays (UHECRs) could come from black hole jets of radio galaxies. Spectral signatures associated with UHECR hadron acceleration in studies of radio galaxies and blazars with FERMI observatory and ground–based γ-ray observatories can provide evidence for cosmic-ray particle acceleration in black hole plasma jets. Also in this case, γ-ray multifrequency observations (MeV–GeV–TeV) together with observations of PeV neutrinos could confirm whether black-hole jets in radio galaxies accelerate the UHECRs.

Despite their frequent outburst activity, microquasars have never been unambiguously detected emitting high-energy gamma rays. The Fermi/LAT has detected a variable high-energy source coinciding with the position of the X-ray binary and microquasar Cygnus X-3. Its identification with Cygnus X-3 is secured by the detection of its orbital period in gamma rays, as well as the correlation of the LAT flux with radio emission from the relativistic jets of Cygnus X-3. The gamma-ray emission probably originates from within the binary system (Abdo et al., 2009b). Also the microquasar LS 5039 has been unambiguously detected by Fermi/LAT being its emission modulated with a period of 3.9 days. Analyzing the spectrum, variable with the orbital phase, and having a cutoff, Abdo et al. (2009c) concluded that the γ-ray emission of LS 5039 is magnetospheric in origin, like that of pulsars detected by Fermi. These experimental evidences of emission in GeV region of microquasars open an interesting window about the formation of relativistic jets.

10. TeV sources

The most exciting results of the last decade have been obtained in the field of VHE astrophysics from different experiments (e.g. CGRO/EGRET, Wipple, HEGRA, CANGAROO, Celeste, Stacee, Tibet, HESS, VERITAS, MILAGRO, MAGIC) that detected many VHE cosmic sources. The VHE sky, practically empty at the beginning of 1990s, is populated as of 2010 March 25 by 98 sources, thanks to the contribute of the Fermi observatory (Wagner, 2010). About 61% of these sources are galactic since their fluxes are greater than those extragalactic, although the intrinsic luminosities of the latter are much greater than the former. Increasing the sensitivities of the experiments — stereoscopic arrays of imaging atmospheric Cherenkov telescopes in the range 10^{10} – 10^{15} eV — the extragalactic sky will become even more populated than the galactic one.

One of the most interesting results has been the determination of the Spectral Energy Distribution (SED) of the Crab nebula, thanks to many measurements obtained by different HE–VHE experiments (Albert et al., 2008b).

Another exciting result has been the detection of the first variable galactic TeV source, namely the binary pulsar PSR B1259-63 (Aharonian et al., 2005). They found that the radio silence occurs during the time in which the pulsar is occulted by the excretion disk of the Be star. TeV γ-ray astronomy has been reviewed by Santangelo (2007), Ribó (2008), Bartko (2008) and De Angelis, Mansutti & Persic (2008).

The many detected sources representing different galactic and extragalactic source populations are supernova remnants (SNRs), pulsar wind nebulae (PWNe), giant molecular clouds (GMCs), star formation regions (SFRs), compact binary systems (CBSs), and active galactic nuclei (AGNs). Paredes & Persic (2010) reviewed the results from MAGIC Cherenkov telescope for most of the former class of sources. Models of TeV AGNs have been discussed by Lenain (2010).

Abdo et al. (2009a) observed a number of TeV-selected AGNs during the first 5.5 months of observations with the Fermi/LAT. In total, 96 AGNs were selected for study, each being either (i) a source detected at TeV energies (28 sources) or (ii) an object that has been studied with TeV instruments and for which an upper-limit has been reported (68 objects). The Fermi observations show clear detections of 38 of these TeV-selected objects, of which 21 are joint GeV-TeV sources and 29 were not in the third EGRET catalog. Most can be described with a power law of spectral index harder than 2.0, with a spectral break generally required to accommodate the TeV measurements. Based on an extrapolation of the Fermi spectrum, sources, not previously detected at TeV energies, have been identified and are promising targets for TeV instruments.

Indeed, a search of the Milagro sky map for spatial correlations with sources from a subset of the recent Fermi Bright Source List (BSL) has been performed (Abdo et al., 2009d). The BSL consists of the 205 most significant sources detected above 100 MeV by the Fermi/LAT. The authors selected sources based on their categorization in the BSL, taking all confirmed or possible Galactic sources in the field of view of Milagro. Of the 34 Fermi sources selected, 14 are observed by Milagro at a significance of 3 standard deviations or more. Milagro is sensitive to gamma rays with energy from 1 to 100 TeV with a peak sensitivity from 10-50 TeV depending on the source spectrum and declination. These results extended the observation of these sources far above the Fermi energy band. With the new analysis and additional data, multi–TeV emission is definitively observed associated with the Fermi pulsar, J2229.0+6114, in the Boomerang Pulsar Wind Nebula (PWN). Furthermore, an extended region of multi–TeV emission is associated with the Fermi pulsar, J0634.0+1745, the Geminga pulsar.

The First LAT AGN Catalog (1LAC) includes 671 gamma-ray sources located at high Galactic latitudes ($|b| > 10°$) (Abdo et al., 2010a). Some LAT sources are associated with multiple AGNs, and consequently, the catalog includes 709 AGNs, comprising 300 BL Lacertae objects (BL Lacs), 296 flat-spectrum radio quasars (FSRQs), 41 AGNs of other types, and 72 AGNs of unknown type. The blazars have been classified based on their SEDs as archival radio, optical, and X-ray data permit. In addition to the formal 1LAC sample, the authors provide AGN associations for 51 low-latitude LAT sources and AGN affiliations (unquantified counterpart candidates) for 104 high- latitude LAT sources without AGN associations. The overlap of the 1LAC with existing γ-ray AGN catalogs (LBAS, EGRET, AGILE, Swift, INTEGRAL, TeVCat) is evident.

Abdo et al. (2010c) discuss the dramatic increase in the number of known gamma-ray pulsars detected by the Fermi/LAT. The catalog summarizes 46 high-confidence pulsed detections using the first six months of data taken by the Fermi/LAT instrument. Sixteen previously unknown pulsars were discovered by searching for pulsed signals at the positions of bright gamma-ray sources seen with the LAT, or at the positions of objects suspected to be neutron stars based on observations at other wavelengths. The dimmest observed flux among these gamma-ray-selected pulsars is 6.0×10^{-8} ph cm^{-2} s^{-1} (for E > 100 MeV). Pulsed gamma-ray emission was discovered from twenty-four known pulsars by using ephemerides (timing solutions) derived from monitoring radio pulsars. Eight of these new gamma-ray pulsars are millisecond pulsars. The dimmest observed flux among the radio-selected pulsars is 1.4×10^{-8} ph cm^{-2} s^{-1} (for E > 100 MeV). The remaining six gamma-ray pulsars were known since the CGRO mission, or before. The pulsed energy spectra can be described by a power law with an exponential cutoff, with cutoff energies in the range $\sim$ 1–5 GeV. The rotational energy loss rate ($\dot{E}$) of these neutron stars spans 5 decades, from $\sim 3 \times 10^{33}$ erg s^{-1} to 5×10^{38} erg s^{-1}, and the apparent efficiencies for conversion to gamma-ray emission range from $\sim$ 0.1% to $\sim$ unity, although distance uncertainties complicate efficiency estimates. The pulse shapes show substantial diversity, but roughly 75% of the gamma-ray pulse profiles have two peaks, separated by $>\sim$ 0.2 of rotational phase. For most of the pulsars, gamma-ray emission appears to come mainly from the outer magnetosphere, while polar-cap emission remains plausible for a remaining few. Spatial associations imply that many of these pulsars power PWNe. Finally, these discoveries suggest that gamma-ray-selected young pulsars are born at a rate comparable to that of their radio-selected cousins and that the birthrate of all young gamma-ray-detected pulsars is a substantial fraction of the expected Galactic supernova rate.

Therefore, the hunt for discovery the association of the unknown TeV sources with known astrophysical objects is open through multifrequency observations of the objects in their error boxes.

11. The Galactic center

The Galactic Center (GC) is one of the most interesting places for testing theories in which frontier physics plays a fundamental role. There is an excellent review of Mezger, Duschl & Zylka (1996), which discusses the physical state of stars and interstellar matter in the Galactic Bulge ($R \sim$ 0.3–3 kpc from the dynamic center of the Galaxy), in the Nuclear Bulge ($R <$ 0.3 kpc) and in the Sgr A Radio and GMC Complex (the central $\sim$ 50 pc of the Milky Way). This review reports also a list of review papers and conference proceedings related to the Galactic Center with the bibliographic details. In the review paper by Giovannelli & Sabau-Graziati (2004, and the references therein) the multifrequency GC behaviour have been also discussed.

The luminosity contained in the radio-IR part of the spectrum is $\sim$ 300 $L_{\odot}$. The optical to UV luminosity ratio for Sgr A* is $L_{opt/UV} \leq$ 500 $L_{\odot}$. This is an upper limit if a standard accretion disk spectrum is fitted to the upper limit of the K-band flux density and a black hole mass of ~ (2–3)$\times10^6$ $M_\odot$ is adopted. The X-ray luminosity of Sgr A* is less than a few 10^2 $L_\odot$ (Mezger, Duschl & Zylka, 1996). Therefore, close to or at the dynamical center of the Milky Way there is a compact mass, which is probably a massive black hole. Such a mass is much lower than that inferred for the BHs in most of the active galaxies, but well in the range of dark masses detected in the centers of the Seyfert and normal galaxies. Indeed, if M81 radio–IR spectrum is scaled to 8.5 kpc, the distance to the GC, it is possible to directly compare it with that of the Sgr A*. This comparison, shown in Figure 139 of Giovannelli & Sabau-Graziati (2004) review, is in favor of the black hole hypothesis for the GC of the Milky Way (Mezger, Duschl & Zylka, 1996).

The GC, whose wonderful radio image was taken by LaRosa et al., 2000, is highly obscured in optical and soft X-rays; it shows a central compact object – a black hole candidate – with M ~ 3.6$\times10^6$ $M_\odot$ (Genzel et al., 2003a), which coincides with the compact radio source Sgr A* [R.A. 17 45 41.3 (hh mm ss); Dec.: -29 00 22 (dd mm ss)]. Sgr A* in X-rays/infrared is highly variable (Genzel et al., 2003b).

The GC is a good candidate source for indirect DM observations (Aharonian et al., 2006). It has been observed in VHE γ-rays by the Cangaroo (Tsuchiya et al., 2004), HESS (Aharonian et al., 2004), Whipple (Kosack et al., 2004), and MAGIC (Albert et al., 2006) telescopes. The EGRET telescope found evidence for a γ-ray source at the GC. Cesarini (2003) discussed the possibility that such an excess would be produced by neutralino annihilations in the dark matter halo, especially in the case of low neutralino masses, and that GLAST/Fermi will be able to measure much better this excess. The VHE spectrum of GC has been measured by several authors by using different telescopes. The VHE differential γ-ray flux of the spectrum of the GC (Albert et al., 2006) can be well described by a simple power law $\propto E^{-2.2}$.

Tsuchiya et al. (2004) detected sub-TeV gamma-ray emission from the direction of the GC using the CANGAROO-II Imaging Atmospheric Cerenkov Telescope. They detected a statistically significant excess at energies greater than 250 GeV. The flux was 1 order of magnitude lower than that of the Crab Nebula at 1 TeV with a soft spectrum proportional to $E^{-4.6\pm0.5}$. These data suggest that the GeV source 3EG J1746-2851 is identical to this TeV source, and associating these in turn with Sgr A East and/or Sgr A*, they found that the γ-rays can be naturally explained by π°–decay. In addition, they derived also upper limits to the CDM abundance in the GC region, assuming that the GeV and TeV emission is centered on Sgr A* and the emission region is a sphere with a radius of 47 pc. For an assumed weakly interacting, massive particle mass of 0.7, 1, 2, 4, and 6 TeV, the derived 2σ upper limits for the CDM densities are 9300, 7300, 5800, 5300, and 5800 GeV cm^{-3}, respectively.

Koyama et al. (2003) reported results of the HE activity of the GC found with observations performed by the GINGA, ASCA, and CHANDRA X-ray satellites. GINGA discovered the largely extended hot plasma around the GC, suggesting a violent activity of the GC within 10^5 year. ASCA found strong 6.4 keV line emissions from the molecular clouds near the GC, which is well explained by the fluorescent caused by strong X-ray irradiations from Sgr A* of ~ 100−300 years ago. CHANDRA observations on the GC have confirmed these previous results and moreover, with its unprecedented spatial resolution, have resolved a number of non-thermal/6.4-keV X-ray filaments and jet–like structures possibly caused by Sgr A*. They inferred that these complexities in morphology and spectrum of the GC X-ray are due to coupled actions of recent supernova explosions, a super massive black hole and giant molecular clouds. Koyama, Hyodo & Inui (2006) reported the diffuse X-ray emission from the Sgr A and B regions observed with SUZAKU. From the Sgr A region, they found many K-shell transition lines of iron and nickel.

Evidence of thermal and non–thermal X-ray emission from GC has been detected by the SUXAKU satellite (Yuasa et al., 2008).

The inner 10 pc of our Galaxy contains many counterpart candidates of the VHE (> 100 GeV) γ-ray point source HESS J1745-

290. Within the point spread function of the H.E.S.S. measurement, at least three objects are capable of accelerating particles to VHE and beyond and of providing the observed γ-ray flux. The best-fitting position of HESS J1745-290 with the position and morphology of candidate counterparts is, within a total error circle radius of 13 arcsec, coincident with the position of the supermassive black hole Sgr A* and the recently discovered pulsar wind nebula candidate G359.95-0.04. It is significantly displaced from the centroid of the supernova remnant Sgr A East, excluding this object with high probability as the dominant source of the VHE γ-ray emission (Acero et al., 2010).

12. Cataclysmic variables

One of the most exciting news from INTEGRAL has been the detection of HE emission from CVs (Barlow et al., 2006). Indeed, in the last decade, the production of γ-rays from CVs was experimentally proved. Acceleration of particles by the rotating magnetic field of the white dwarf in intermediate polars in the propeller regime – AE Aqr – was detected by ground-based Cherenkov telescopes in the TeV passband (e.g. Meintjes et al. 1992), as well as from the polar AM Her (Bhat et al. 1991). These measurements were never confirmed, but in spite of this they triggered the new interest for CVs. Therefore, it was possible to argue that magnetic CVs would have canned to be emitters in the keV – MeV passbands. Detection of emissions in such energy band would have been possible if the sensitivity of the instruments should have been sufficient: and that of IBIS/INTEGRAL was (Landi et al., 2009; Scaringi et al., 2010).

CVs are perfect laboratories for studying accretion processes for different values of magnetic fields at the white dwarf' surface (e.g. Giovannelli, 2008). The news from INTEGRAL have recently renewed the interest of high energy astrophysicists for CVs, and subsequently involving once more the low–energy astrophysical community.

Indirect evaluations of magnetic field intensities in CV white dwarfs have been obtained through multifrequency observations for AM Her, U Gem, and SS Cyg (Fabbiano et al., 1981). Giovannelli & Sabau Graziati (2012a) discuss the case of SS Cyg and derive the magnetic field intensity at the surface of the white dwarf of the system (B = 2.2 ± 1.0 MG) in agreement with that evaluated by Fabbiano et al. (1981).

Our feeling is that the problem of magnetic fields in white dwarfs has been underestimated in the studies of CVs. Too many simplified models of disk accreting and magnetic CVs have been developed under the hypothesis that CVs can be sharply divided into three classes: Polar, IP, Non-Magnetic. Magnetic fields are smoothly varying in their intensities from one class to another, probably giving rise to misunderstandings in classifying CVs in the three classes mentioned, which probably contain systems which evolve from one class to another. Indeed, the discovery in some IPs of a circularly polarized optical emission suggests that these intermediate polars will evolve into polar systems (e.g., Mouchet, Bonnet-Bidaud & de Martino, 1998). Some evidence of the continuity between the IPCVs and PCVs is coming from the detection of the SW Sex systems. They have orbital periods just inside the so-called *period gap*, which separates the two classes of IPCVs and PCVs (e.g. Rodriguez-Gil, 2003). For details, see the review paper by Giovannelli & Sabau-Graziati (2012b).

13. High mass X-ray binaries

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

HMXBs are young systems, with age $\leq 10^7$ yr, mainly located in the galactic plane (e.g., van Paradijs, 1998). A compact object — the secondary star —, mostly a magnetized neutron star (X-ray pulsar) is orbiting around an early type star (O, B, Be) — the primary — with $M \geq 10\ M_\odot$. The optical luminosity of the system is dominated by the early type star. About 10% of the X-ray flux emitted in the vicinity of the compact star is intercepted by the primary star and reprocessed into optical radiation (e.g., Bradt & McClintock, 1983). As a function of the nature of the secondary star, HMXBs are usually divided into two subclasses, namely Be/X-ray binaries and O-B/X-ray binaries if the optical stars are Be or O-B supergiant stars, respectively (e.g., van Paradijs, 1983). Most of the HMXBs are X-ray/Be systems (see the catalog of Liu, van Paradijs & van den Heuvel, 2000), which contains 130 systems with orbital periods ranging from 4.8 hr to 187 d.

Such systems are the best laboratory for the study of accreting processes thanks to their relative high luminosity in a large part of the electromagnetic spectrum. Because of the strong interactions between the optical companion and collapsed object, low and high energy processes are strictly related. In X-ray/Be binaries the mass loss processes are due to the rapid rotation of the Be star, the stellar wind and, sporadically, to the expulsion of casual quantity of matter essentially triggered by gravitational effects close to the periastron passage of the neutron star. The long orbital period (> 10 days) and a large eccentricity of the orbit (> 0.2) together with transient hard X-ray behavior are the main characteristics of these systems. Among the whole sample of galactic systems containing 114 X-ray pulsars (Johnstone, 2005), only few of them have been extensively studied. Among these, the system A 0535+26/HDE 245770 is the best known thanks to concomitant favorable causes, which rendered possible thirty five years of coordinated multifrequency observations, most of them discussed by e.g. Giovannelli & Sabau-Graziati (1992, 2008), Burger et al. (1996), Giovannelli & Sabau-Graziati (2011).

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

Giovannelli & Sabau-Graziati (2011) discuss the history of the discovery of optical indicators of high energy emission in the prototype system A0535+26/HDE 245770 ≡ Flavia' star, updated to the March–April 2010 event when a strong optical activity occurred roughly 8 days before the X-ray outburst (Caballero et al., 2010) that was predicted by Giovannelli et al. (2010). This optical indicator of X-ray outburst together with the whole history of A0535+26 system allowed to conclude that the periastron passage of the neutron star is scanned every 110.856 days (optical orbital period), and the anomalous and casual X-ray outbursts are triggered starting from that moment and occur roughly after 8 days – the transit time of material expelled from the primary for reaching the secondary. On the contrary, the normal outbursts triggered by the 'steady' stellar wind of Be star — in a state of 'quiescence' — occur at the periastron.

Therefore, a continuous long–term monitoring of A0535+26/Flavia' star at least in optical and X-ray could definitively prove their conclusions. Giovannelli & Sabau-Graziati (2011) strongly believe that this behaviour of A0535+26/Flavia' star system is typical for all the X-ray/Be systems for which they wish methodical multifrequency monitoring. In conclusions, with their paper they give a hint to the community for thinking of mechanisms responsible of outbursts in X-ray pulsars, and of new overall models of X-ray/Be systems again.

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

Important news are coming also from GeV observations of HMXBs. Indeed, Abdo et al. (2009e) present the first results from the observations of LSI + 61°303 using Fermi/LAT data obtained between 2008 August and 2009 March. Their results indicate variability that is consistent with the binary period, with the emission being modulated at 26.6 days. This constitutes the first detection of orbital periodicity in high-energy gamma rays (20 MeV–100 GeV, HE). The light curve is characterized by a broad peak after periastron, as well as a smaller peak just before apastron. The spectrum is best represented by a power law with an exponential cutoff, yielding an overall flux above 100 MeV of $\simeq 0.82 \times 10^{-6}$ ph cm^{-2} s^{-1}, with a cutoff at ~ 6.3 GeV and photon index $\gamma \sim 2.21$. There is no significant spectral change with orbital phase. The phase of maximum emission, close to periastron, hints at inverse Compton scattering as the main radiation mechanism. However, previous very high-energy gamma ray (> 100 GeV – VHE) observations by MAGIC and VERITAS show peak emission close to apastron. This and the energy cutoff seen with Fermi suggest that the link between HE and VHE gamma rays is nontrivial. This is one open problem to be solved in future.

13.1. Obscured sources and supergiant fast X-ray transients

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

14. Ultra–compact double–degenerated binaries

Ultra-compact double-degenerated binaries (UCD) consist of two compact stars, which can be black holes, neutron stars or white dwarfs. Typically the orbital periods are $P_{orb} \leq 20$ min and the separation of the two components is given by (Wu, Ramsay & Willes, 2008). In the case of two white dwarfs revolving around each other with an orbital period $P_{orb} \approx 10$ min or shorter will have an orbital separations smaller than Jupiter's diameter.

These UCD are evolutionary remnants of low–mass binaries, and they are numerous in the Milky Way.

Many white–dwarf binaries show magnetism. The best known are the magnetic cataclysmic variables (MCV), in which the white dwarf has a magnetic field B that can reach 100 MG (e.g. Wickramasinghe & Ferrario 2000). This field strength implies a white–dwarf magnetic moment $\mu \sim 10^{34} - 10^{35}$ G cm^3. Given that white–dwarf magnetism is not exclusive to MCV, it is reasonable to expect some UCD to contain a magnetic white dwarf. If the white dwarf in a UCD has a magnetic moment $\mu_1 \sim 10^{34}$G cm^3, the magnetic field strength will exceed 10 kG at the position of its companion white dwarf. The compactness of UCD enables strong electro–magnetic interaction between their two white dwarfs. This leads to various exotic observational phenomena, such as: i) unipolar induction and spin–orbit coupling; ii) radiation from ultra–compact binaries (X-rays, gravitational waves, electron–cyclotron masers, and thus defines the characteristic of these interesting, extreme systems. A discussion about these observational phenomena is reported by (Wu, Ramsay & Willes, 2008). It is worthwhile doing a comment which can hint possible targets for the future gravitational–wave observatory LISA (e.g. Cutler, Hiscock & Larson, 2003). Indeed, the power (in erg s^{-1}) of the gravitational waves from a binary system with a circular orbit is

$$\begin{aligned}\dot{E}_{gw} &= -\frac{32}{5}\frac{G^4}{c^5}\frac{M_1^2 M_2^2 (M_1 + M_2)}{a^5} \\ &= -\frac{32}{5}\frac{G^{7/3}}{c^5} M_{chirp}^{10/3} \omega_{orb}^{10/3} \\ &= -1.2 \times 10^{36} \left[\left(\frac{M_{chirp}}{M_\odot}\right)\left(\frac{600\ s}{P_{orb}}\right)\right]^{10/3} \quad (1)\end{aligned}$$

where the chirp mass is: $M_{chirp} = \overline{M}^{3/5} (M_1 + M_2)^{2/5}$, and the reduced mass is: $\overline{M} = M_1 M_2 / (M_1 + M_2)$. A UCD with $P_{orb} < 600$ s therefore has a gravitational–wave power $\sim 10^{36}$ erg s^{-1}, which greatly exceeds the solar bolometric luminosity. This power is definitively over the detection thresholds of the LISA observatory.

15. Magnetars

The discovery of magnetars (Anomalous X-ray Pulsars – AXPs – and Soft Gamma-ray Repeaters – SGRs) is also one of the most exciting results of the last years (Mereghetti & Stella, 1995; van Paradijs, Taam & van den Heuvel, 1995; and e.g. review by Giovannelli & Sabau-Graziati, 2004 and the references therein). Indeed, with the magnetic field intensity of order 10^{14} – 10^{15} G a question naturally arises: what kind of SN produces such AXPs and SGRs? Are really the collapsed objects in AXPs and SGRs neutron stars? (e.g. Hurley, 2008). With such high magnetic field intensity an almost 'obvious' consequence can be derived: the correspondent dimension of the source must be of $\sim$ 10 m (Giovannelli & Sabau-Graziati, 2006). This could be the dimension of the acceleration zone in supercompact stars. Could they be quark stars?

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

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

Bednarek (2009a) discussed a possible physical process occurring in a magnetar placed in a binary system. At a certain distance from the NS surface, the magnetic pressure can balance the gravitational pressure of the accreting matter, creating a very turbulent, magnetized transition region. This region provides good conditions for the acceleration of electrons to relativistic energies. These electrons lose energy due to the synchrotron process and inverse Compton scattering of the radiation from the nearby massive stellar companion, producing high-energy radiation from X-rays up to $\sim$ TeV γ-rays. The primary γ-rays can be further absorbed in the stellar radiation field, developing an IC $e^{\pm}$ pair cascade. He calculated the synchrotron X-ray emission from primary electrons and secondary $e^{\pm}$ pairs and the IC γ-ray emission from the cascade process. His results have been successfully used for explaining the quasi-simultaneous observations of the TeV γ-ray binary system LSI+61 303 in the X-ray and TeV γ-ray energy ranges.

Recently Hurley (2010) shortly reviewed SGRs in the context of magnetars models. Kanbach (2010) discussed the magnetar emission from optical to γ-ray energy bands.

Abdo et al. (2010d) report on the search for 0.1–10 GeV emission from magnetars in 17 months of Fermi Large Area Telescope (LAT) observations. No significant evidence for gamma-ray emission from any of the currently known magnetars is found. The most stringent upper limits to date on their persistent emission in the Fermi energy range are estimated between $\sim$ 10^{-12} and 10^{-10} erg s^{-1} cm^{-2}, depending on the source. They also searched for gamma-ray pulsations and possible outbursts, also with no significant detection. The upper limits derived support the presence of a cutoff at an energy below a few MeV in the persistent emission of magnetars. They also show the likely need for a revision of current models of outer–gap emission from strongly magnetized pulsars, which, in some realizations, predict detectable GeV emission from magnetars at flux levels exceeding the upper limits coming by the Fermi-LAT observations.

16. Cross sections of nuclear reactions in stars

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

The LUNA collaboration has already measured with good accuracy the key reactions $D(p,\gamma)^{3}He$, $^{3}He(D,p)^{4}He$ and $^{3}He(^{4}He,\gamma)^{7}Be$. These measurements substantially reduces the theoretical uncertainty of D, ^{3}He, ^{7}Li abundances. The D(^{4}He,γ)^{6}Li cross section, which is the key reaction for the determination of the primordial abundance of ^{6}Li , will be measured in the near future (Gustavino, 2007, 2009, and 2011).

17. Conclusions and reflections

Far from the completeness we can conclude with some comments about the topics discussed.

It is becoming increasingly clear that the energy régime covered by VHE γ-ray astronomy will be able to address a number of significant scientific questions, which include: i) What parameters determine the cut-off energy for pulsed γ-rays from pulsars? ii) What is the role of shell-type supernovae in the production of cosmic rays? iii) At what energies do AGN blazar spectra cut-off? iv) Are gamma blazar spectral cut-offs intrinsic to the source or due to intergalactic absorption? v) Is the dominant particle species in AGN jets leptonic or hadronic? vi) Can intergalactic absorption of the VHE emission of AGN's be a tool to calibrate the epoch of galaxy formation, the Hubble parameter, and the distance to γ-ray bursts? vii) Are there sources of γ-rays which are 'loud' at VHEs, but 'quiet' at other wavelengths?

In our opinion, the results obtained by Ruffini, Vereshchagin & Xue (2010) about the study of electron-positron pair formation in physics and astrophysics will give a strong impulse to the knowledge of frontier objects where frontier physics play a fundamental role. Indeed, such results can be tested in galactic and extragalactic black holes observed in binary X-ray sources, active galactic nuclei, microquasars and in the process of gravitational collapse to a neutron star and also of two neutron stars to a black hole giving rise to GRBs. What is important to recall at this stage is only that both the supernovae and GRBs processes are among the most energetic and transient phenomena ever observed in the Universe: a supernova can attain an energy of $\sim 10^{54}$ ergs on a timescale of a few months and GRBs can have emission of up to $\sim 10^{54}$ ergs in a timescale as short as a few seconds. The central role of neutron stars in the description of supernovae, as well as of black holes and the electron-positron plasma, in the description of GRBs, pioneered by Ruffini & Wilson (1975), are widely recognized. This will be a fundamental topic of investigation for the next decade.

The recent detection of GRBs at z = 6.7 an 8.2 with consequent theoretical explanation within the framework of the fireshell model and the input for recalibrating the SFR at high redshifts is one of the most promising topic for the near future for understanding the poor know epoch of the formation of the first Pop III stars soon after the end of the Dark Era (z $\sim$ 25). The detection of the GRB090429B at z $\simeq$ 9.4 plays a role in favour of the possibility of detecting GRBs until the epoch of Pop III stars formation.

It appears evident the importance of Multifrequency Astrophysics and Multienergy Particle Physics. There are many problems in performing simultaneous Multifrequency, Multienergy Multisite, Multiinstrument, Multiplatform measurements due to: i) objective technological difficulties; ii) sharing common scientific objectives; iii) problems of scheduling and budgets; iv) politic management of science.

In spite of the many ground- and space-based experiments providing an impressive quantity of excellent data in different energy regions, many open problems still exist. We believe that only drastically changing the philosophy of the experiments, it will be possible to solve faster most of the present open problems. For instance, in the case of space-based experiments, small satellites — dedicated to specific missions and problems, and having the possibility of scheduling very long time observations — must be supported because of their relative faster preparation, easier management and lower costs with respect to medium and large satellites.

We strongly believe that in the next decades passive–physics experiments space– and ground–based will be the most suitable probes in sounding the physics of the Universe. Probably the active physics experiments have already reached the maximum dimensions compatible with a reasonable cost/benefit ratio, with the obvious exception of the neutrino-astronomy experiments.

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