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Hot Points in Multifrequency Astrophysics Today

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Abstract This paper reproduces the introductory talk of the workshop in which we presented several hot points of today astrophysics, which have been discussed in details during the workshop. We would like to demonstrate that the improvement on knowledge of the physics of the Universe is strictly related with multifrequency studies of diffuse and discrete cosmic sources.

Key words: Multifrequency Astrophysics: cosmology – clusters of galaxies – AGNs – X-ray binary systems

1 INTRODUCTION

In the last few decades, cosmic-ray physics and high energy astrophysics strongly developed thanks to ground- and space-based experiments. Higher and higher capabilities in reproducing extreme conditions in which the nature demonstrates, and better and better sensitivities of the detectors used have been the key of such a development.

However, in spite of the enormous jumps in the knowledge of the physics of the 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.

In this paper we present a selection of hot-problems remarking those that can be considered highlights of the updated astrophysics by most of the participants actively attending this workshop. Of course the selection, far to be complete, was born by our knowledge and feelings.

2 COSMOLOGY

Modern physical cosmology has now converged on the Big Bang framework. Such a framework is supported by four principal pillars:

- Hubble expansion
- microwave background
- light element abundances
- inflation

The first pillar is a necessary condition for the Big Bang, but hardly sufficient since alternative cosmologies such as the steady state also include it. The second and third pillars do indeed tend to force us to an early universe which was hot and dense: this can be nicknamed a Big Bang universe (e.g. Schramm, 1993, 1998; Steigman, Hata & Felten, 1998; Rees, 1998; Walker, 1998). The fourth pillar is necessary for a flat universe (e.g. Kellerman, 1993).

Giovannelli & Sabau-Graziati (1997; 1999) and Giovannelli (2001; 2003) discussed on the four pillars of cosmology. Therefore we address the reader to those papers and the references therein.

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The many determinations of the Hubble constant H_0 with different techniques have given discrepant results on its value, as discussed in the latter cited papers. The 'ultimate' value of the Hubble constant, discussed by Panagia (2005) is $H_0 = 65 \pm 5$ km s^{-1} Mpc^{-1} which is a compromise between the value $H_0 = 59 \pm 6$ km s^{-1} Mpc^{-1} (Sandage's group: e.g. Saha et al., 2001) and $H_0 = 72 \pm 7$ km s^{-1} Mpc^{-1} (Freedman's group: e.g. Freedman et al., 2001).

Such a flat Universe can be described by the so-called *Cosmic Triangle*, whose sides represent the three key cosmological parameters $\Omega_{\rm m}$, $\Omega_{\rm k}$ and Ω_Λ (Bahcall, 1999). Each point of the triangle, shown in Figure 1 (left), obey to the law:

$$1 = \Omega_{\rm m} + \Omega_{\rm k} + \Omega_\Lambda$$

Figure 1 (right) shows the observed cosmic triangle. The allowed bands are coming from the study of cosmic structures at different values of redshift: clusters of galaxies at low redshift, supernovae at intermediate redshift, and Cosmic Microwave Background at high redshift. It appears evident that the intersection amongst bands favors a cold dark matter model of an expanding Universe ($\Lambda_{\rm CDM}$).

COBE results from FIRAS instrument give for the CMBR a best fit to a black body spectrum within 3.4×10^{-8} erg cm^{-2} s^{-1} sr^{-1} cm over the range 5–0.5 mm (2–20 cm^{-1}). These measurements imply stringent limits on energy release in the early Universe after $t \sim 1$ yr and redshift $z \sim 3 \times 10^6$. The deviations are less than 0.03% of the peak brightness. The temperature of the CMBR is 2.726 ± 0.010 K at 95% confidence level. Such a value is corresponding to redshift equal zero in a Big Bang model of the Universe (Mather et al., 1994).

Figure 2 shows in the upper panel a sketch of the evolution of the Universe from the Big Bang to present time; in the lower left panel: the light element abundances (Burles, Nollett & Turner, 2001); in the lower center panel: the CMBR temperature at various redshifts as determined by Srianand, Petitjean & Ledoux (2000), and the references therein. The point at $z = 0$ is the result of COBE ($T_{\rm CMBR}(0) = 2.726 \pm 0.010$ K), which is well fitted by a black body spectrum, as shown in the lower right panel. At $z = 2.1394$ there is an upper limit. At $z = 2.33771 \simeq 2.34$, the CMBR temperature is: 6.0 K $< T_{\rm CMBR}(2.34) < 14.0$ K (vertical bar). The dashed line is the prediction from the Hot Big Bang: $T_{\rm CMBR} = T_{\rm CMBR}(0) \times (1 + z)$. Such a prediction gives $T_{\rm CMBR}(2.34) = 9.1$ K, which is consistent with the measurement.

However, the background radiation is present not only in the microwave band, but practically across all the electromagnetic spectrum. Such a background radiation from radio to HE γ-ray energy bands has been deeply discussed by Henry (1999) and by Hasinger (2000).

2.1 Converging evidence for Standard Model

Gravitational force compresses the primordial plasma until resistance from photon pressure reverses the motion, leading to acoustic oscillations. Because compression raises the temperature, this results in *hot spots* and *cold spots* that are visible in the microwave sky today. Flat models ($\Omega_m + \Omega_\Lambda = 1$) produce an acoustic peak at Legendre multipole $l = 200 (\sim 1^\circ$ on the sky). Open models have a peak that is shifted to smaller scales (larger *l* values. The height of the peak depends on additional parameters, including $\Omega_m, \Omega_\Lambda, \Omega_b, H_o$, and tilt.

Before the BOOMERanG (Balloon Observations Of Millimetric Extragalactic Radiation and Geomagnetism) data (de Bernardis et al., 2000), all the evidence pointed towards a model of the Universe that is flat and lightweight (low dark-matter density), with an initial spectrum of density fluctuations whose power is constant across all length scales (Bahcall et al., 1999). This standard model is strongly inconsistent with the observed lack of prominent second peak in the power spectrum of the CMB. The possible explanations for the missing peak are:

i) the initial density fluctuations could actually increase with length scale, thereby suppressing small-scale fluctuations. This is the so-called *tilted* model. This solution would have important implications for the particle physics of inflation and observations of gravitational waves;

ii) the baryon density is as much as 50% than the value implied by the abundance of light elements in the Universe as the nucleosynthesis theory predicts. Any extra baryons cannot be in the stars we see today.

If this were the solution, the question of where most of the baryons are today becomes even more puzzling (Fukugita, Hogan, & Peebles, 1998).

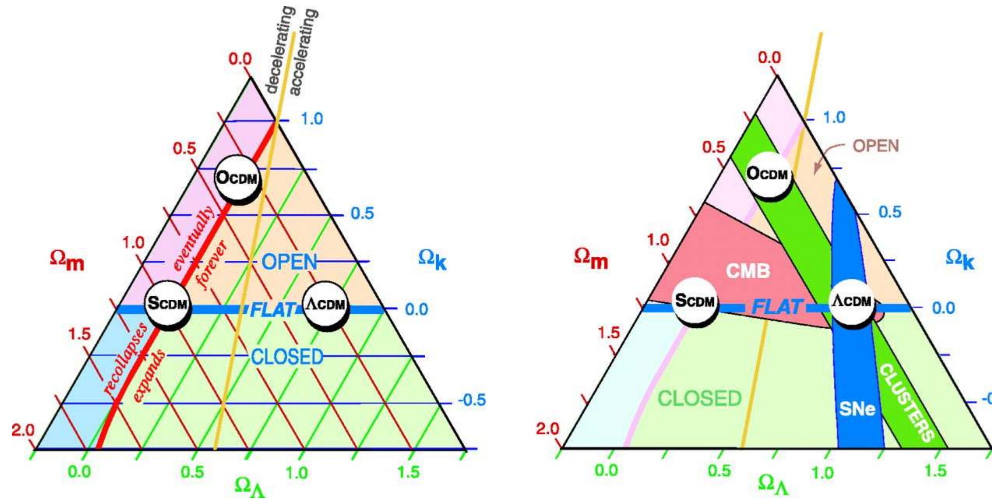

Fig. 1 Cosmic triangle: predicted (left), observed (right) (Bahcall, 1999).

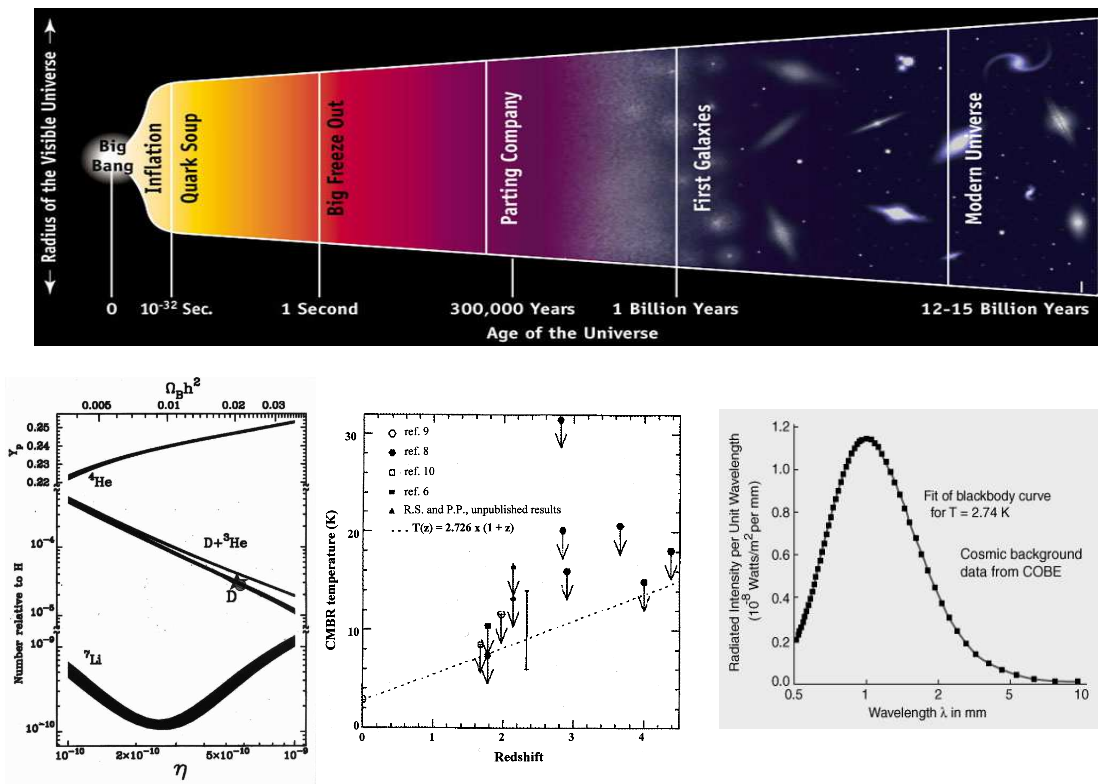

Fig. 2 Upper panel: Sketch of the evolution of the Universe with the main steps. Lower panel: Left - Light element abundances (Burles, Nollett & Turner, 2001). Derived points from experiments are overlapped: ⋆ (Netterfield et al., 2002), ○ (de Bernardis et al., 2000). Center - CMBR temperature versus redshift (Srianand, Petitjean & Ledoux, 2000). Right - COBE 2.726 K black body spectrum (Mather et al., 1994).

The standard value can also be made to work by lowering the predicted height of the peaks relative to the COBE measurements at the 10° scale by anyone of several effects. A testable consequence of either-baryon-density solution is that the third peak should be higher in amplitude than the second;

iii) the final and perhaps most speculative solution is the formation of atomic hydrogen were to be delayed until the Universe was nearly 30% older, either with an unknown source of energy or through a chance in our understanding of atomic physics at early times. This would increase the time available for the acoustic oscillations to dissipate and hence suppress the smaller peaks.

A combination of some or all of these solutions may also provide the answer and perhaps avoid any extreme departures from the Standard Model (Hu & Peebles, 2000).

2.1.1 CMB anisotropy after BOOMERanG

BOOMERanG data (de Bernardis et al., 2000) place a lower limit on the baryon density that is comparable to the nucleosynthesis estimate. A value for the dark-matter density higher that the standard one-third of the critical density also helps fits the power spectrum better (three times as much dark matter and 50% more baryons: red curve of the Figure 3 (Bahcall et al., 1999), at the expense of agreement with other cosmological data. The multiple l corresponds roughly to an angular scale of π/l radians.

Flat models ($\Omega_{\rm m} + \Omega_\Lambda = 1$) produce an acoustic peak at $l = 200$, corresponding to $\sim 1^\circ$ on the sky. Open models have a peak that is shifted to smaller scales (larger l values). The height of the peak depends on the additional parameters, including $\Omega_{\rm m}$, Ω_Λ, $\Omega_{\rm b}$, H_0, and tilt. The best fit is for $\Omega_{\rm m} = 1/3$, $\Omega_\Lambda = 2/3$, $\Omega_{\rm k} = 0$ (flat universe), $H_0 = 65$ km s^{-1} Mpc^{-1}, tilt = 1, Age = 14.1 Gyr. The observational data points (1σ error bar) include the COBE measurements on large scale (small l values) and other multifrequency ground and balloon based observations.

The first images at four frequencies of resolved structure in the CMB anisotropies clearly distinguish the CMB from foreground emission. The angular power spectrum of the CMB gives a peak at $l_{\rm peak} = 197 \pm 6$, with an amplitude $\Delta T_{200} = 69 \pm 8$ μK. This is consistent with that expected for cold dark matter models in a flat Euclidean Universe, as favored by standard inflationary model.
But recently, the analysis of WMAP source catalog has shown that the vast majority of bright foreground extragalactic sources detected in CMB maps are blazars. Giommi & Colafrancesco (2004) calculated the contamination of CMB anisotropy maps by this type of flat-spectrum, strongly variable and polarized extragalactic radio sources using up-to-date results from deep multifrequency surveys. They found that more than 50 known blazars (or blazars candidates) expected to be above the sensitivity limit of BOOMERanG are included in its 90/150 GHz anisotropy maps, a factor ≥ 15 larger than previously reported. Figure 4 shows the 150 GHz CMB fluctuation map obtained from BOOMERanG with the position of known and candidate high galactic latitude ($|b| \geq 20^\circ$) blazars and radio galaxies, whose expected flux at 150 GHz is over the detection threshold of BOOMERanG.

These sources induce an average sky brightness of 0.4 Jy deg^{-2}, corresponding to an average temperature of $\approx 4 - 8$ μK. The associated level of fluctuations is of the order of $C_{l,\rm blazar} = 2 \times 10^{-2}$ μK^2 sr at 41 GHz, and $C_{l,\rm blazar} = 1 \times 10^{-3}$ μK^2 sr at 94 GHz. Blazars variability causes the detection of some sources – whose emission is at the border of the sensitivity threshold of the detectors – during the long exposure time of the satellite experiments; the many steep-spectrum radio sources flatten at high frequencies; also radio galaxies give a contribution. Then, the residual fluctuation due to discrete extragalactic foreground sources could be a factor approximately 2–3 higher than the latter estimates.

The blazar induced fluctuations, calculated by Giommi & Colafrancesco (2004), contaminate the CMB spectrum at a level of $\approx 30\% - 90\%$ at $l = 500$ and $\approx 80\% - 100\%$ at $l = 800$. Figure 5 shows: (left panel) the contribution of blazars to the CMB fluctuation spectrum in the WMAP Q channel at 41 GHz (solid line). By adding an estimate of possible contribution of radio sources with steep spectrum at low radio frequencies which flatten at higher frequencies one obtains the dashed line curve, and with the inclusion of the effects of spectral and flux variability one obtains the dotted line curve. A typical CMB power spectrum evaluated in a ΛCDM cosmology with $\Omega = 0.3$ $\Omega_\Lambda = 0.65$, and $\Omega_{\rm b} = 0.05$, which best fits the experimental data is also shown; (right panel) the ratio $C_{l,\rm blazar}/C_{l,\rm CMB}$ between the blazar power spectra and the CMB power spectrum at 41 GHz.

Therefore, such fluctuations cannot be neglected in the derivation of the primordial CMB fluctuation spectrum. Then, a hearty warning of danger is mandatory before firm conclusions about weak features, like

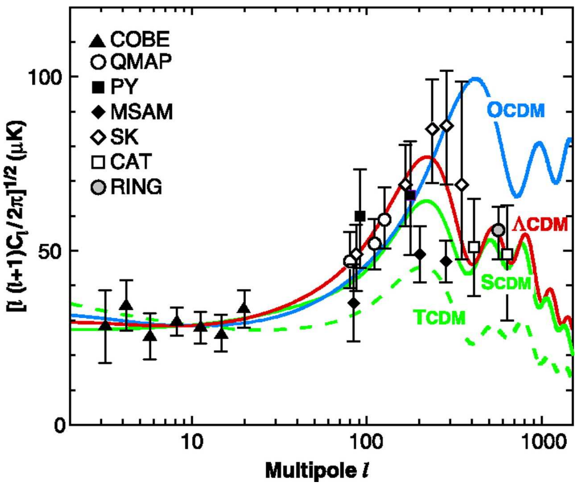

Fig. 3 The CMB temperature anisotropy as function of angular scale. The multiple l corresponds roughly to an angular scale of π/l radians. The observational data points (1 σ error bar) include the COBE measurements on large scale (small l values) and other multifrequency ground and balloon based observations. (Bahcall et al., 1999).

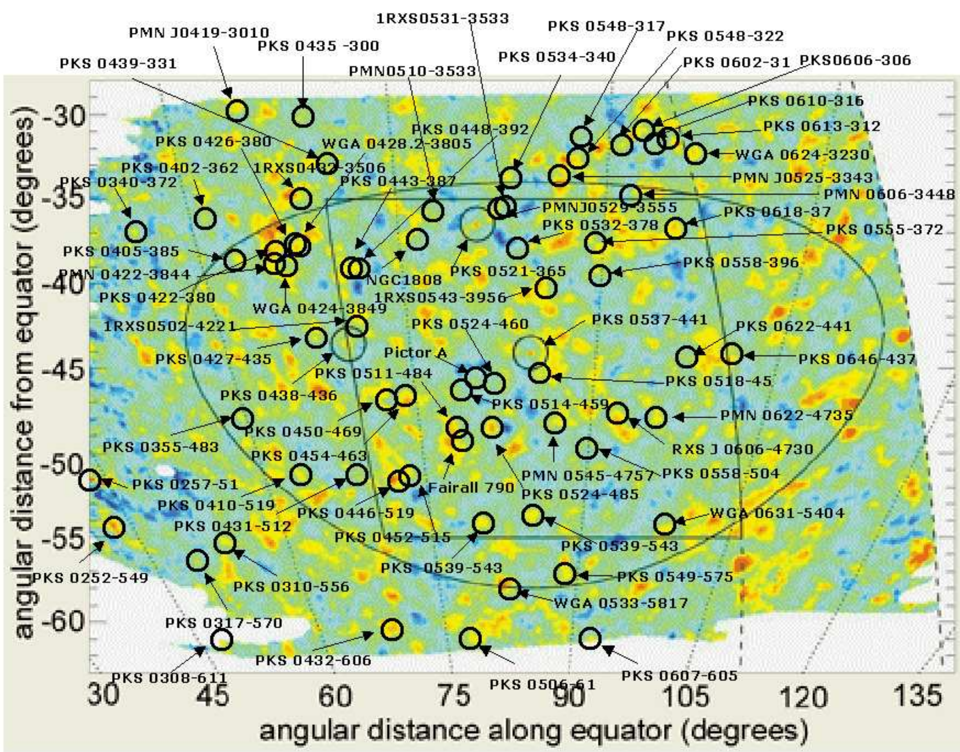

Fig. 4 The 150 GHz CMB fluctuation map obtained from BOOMERanG, correlated with the positions of known and candidate high galactic latitude ($|b| \geq 20^{\circ}$) blazars and radio galaxies enough bright to be detected by BOOMERanG experiment (Giommi & Colafrancesco, 2004).

the secondary high l peaks of the CMB power spectrum or very weak signals like those coming from CMB polarization.

3 COSMIC COUNTERPARTS OF γ-RAY SOURCES

After EGRET experiment on board CGRO satellite, more than 250 γ-ray sources have been discovered to populate the sky. The number is similar to that we had after UHURU for the X-ray sources, at the beginning of 1970s. Now the X-ray sources detected are of order hundreds thousands, thanks to the strong increase of sensitivities. Then, probably, increasing the sensitivity of the γ-ray detectors, the number of γ-ray sources could follow the same trend of the X-ray ones.

The second COS B catalog (Swanenburg et al., 1981) was formed by 25 γ-ray sources, most of them not recognized with known cosmic sources. When the 3rd EGRET catalog was published most (170) of the 271 γ-ray sources were not associated with known astrophysical objects (Hartman et al., 1999). Among them, 66 were associated with BL Lac objects, 27 with blazars, 5 with pulsars, 1 with the radiogalaxy Cen A, 1 with the LMC, and 1 with a solar flare. So, nearly two thirds of the sources are hiding in the Galaxy, awaiting the identification.

Many of these sources concentrate towards the galactic plane and correlate with the spiral arms of the Milky Way, which indicates a significant contribution from population-I objects (e.g. Romero, Benaglia & Torres, 1999; Romero, 2001).

Figure 6 shows the cosmic ray spectrum from 10^2 to $\sim 10^{12}$ GeV (courtesy of Todor Stanev). Curve 1 shows the contribution of SNRs whilst curve 2 shows the contribution of unknown galactic sources; curve 3 limits the contribution of extragalactic sources.

What kind of objects could be the counterparts of the γ-ray sources?

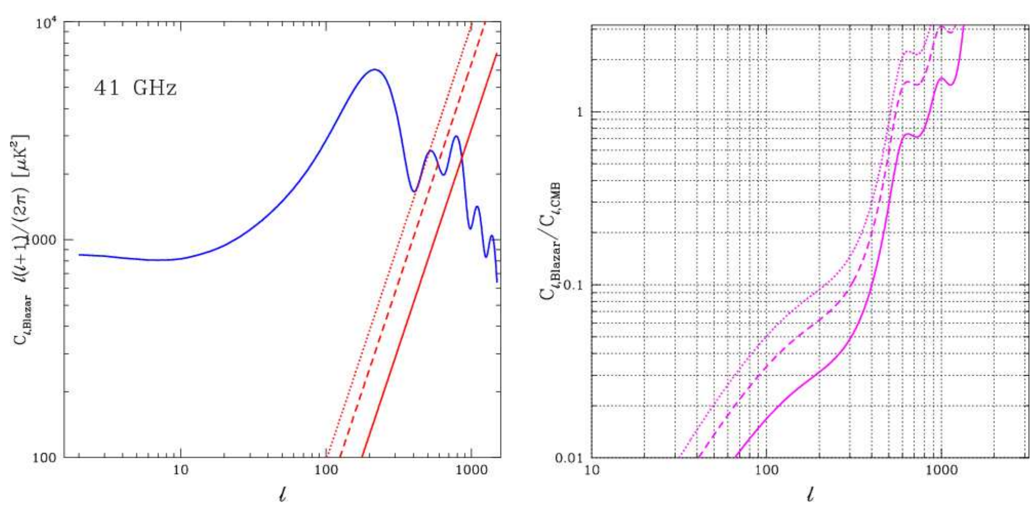

Fig. 5 Left: The contribution of Blazars to the CMB fluctuation spectrum in the WMAP Q channel at 41 GHz (solid line). It is also shown the angular power spectrum for the Blazar population by adding an estimate of the possible contribution of radio sources with steep-spectrum at low radio frequencies which flatten at higher frequencies (dashed line). The dotted line includes also the effect of spectral and flux variability. Although this additional contamination may be substantial a precise estimation can only be done through simultaneous high resolution observations at the same frequency. A typical CMB power spectrum evaluated in a CDM cosmology with which best fits the available data is shown for comparison. Right: The ratio between the Blazar power spectra and the CMB power spectrum for 41 GHz. (Giommi & Colafrancesco, 2004).

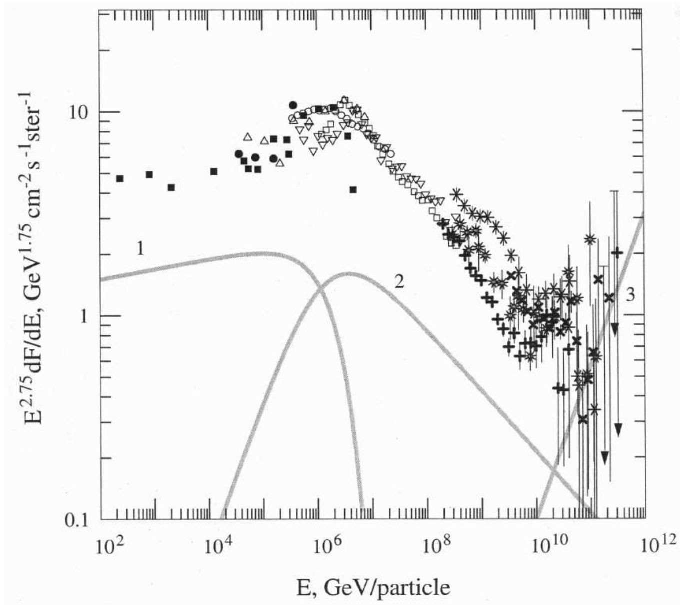

Fig. 6 The contributions of the spectra of SNRs (curve 1), unknown sources (curve 2) and extragalactic sources (triangle 3) to the cosmic ray spectrum (courtesy of Todor Stanev, 2003).

3.1 Galactic Sources as γ-ray Emitters

One interesting paper (Giovannelli, 1997), preceding the 3rd EGRET catalog discussed about the emissivity of the whole Galaxy as compound by different contributions due to different class of cosmic sources and the result was that the experimental emissivity measured by the SAS II is completely in agreement with the sum of the different contributors, namely:

- Young Open Clusters (YOCs): starting from the measured emissivity of Berkeley 87, $N_{\gamma \mathrm{Berk}} \sim 10^{38}$ photons s^{-1}, and from the extrapolated number ($\leq 10^3$) of YOCs in the Galaxy, the total emissivity of YOCs is $N_{\gamma \mathrm{YOCs}} \sim 10^{41}$ photons s^{-1}.
- Radio Pulsars (RPs): within 2.5 kpc there are ~ 1000 radio pulsars, which means that in the Galaxy the expected number of such pulsars is $\sim 3 \times 10^4$. Considering the average emissivity of a radio pulsar, the expected total contribution is $N_{\gamma \mathrm{RPs}} \sim 10^{40}$ photons s^{-1}. The contribution of the recycled pulsars is negligible (Lipunov, 1995).
- Isolated Black Holes (IBHs): The luminosity and emissivity of isolated black holes were calculated by Giovannelli, Karakuła & Tkaczyk (1982). With a reasonable number of such black holes in the Galaxy (2×10^4) and the calculated emissivity of a single black hole of ~ 10 M$_\odot$ equal to $\sim 2 \times 10^{37}$ photons s^{-1}, the expected total contribution of IBHs is $N_{\gamma \mathrm{IBHs}} \sim 10^{41}$ photons s^{-1}.
- Supernova Explosions and Supernova Remnants (SNRs): In the present cosmological epoch, statistical properties of radiopulsars in the Galaxy implies a formation of a neutron star of about one per each 30 years. This implies an expected contribution of $N_{\gamma \mathrm{SNR}} \sim 6 \times 10^{41}$ photons s^{-1} (Lipunov & Postnov, 1988).
- Black Holes and Neutron Stars in Binary Systems (BH,NS-BS): In the evolutionary Scenario Machine developed by Lipunov & Postnov (1988), the matrix of binary systems states gives a number of black holes and neutron stars of the order of a few units $\times 10^4$. Then the expected contribution of these systems to the total Galaxy emissivity is $N_{\gamma \mathrm{BH,NS-BS}} \sim 2 \times 10^{41}$ photons s^{-1}.

Therefore, the expected total Galaxy γ-ray emissivity is:

$$N_{\gamma \mathrm{tot}} = N_{\gamma \mathrm{YOC}} + N_{\gamma \mathrm{RPs}} + N_{\gamma \mathrm{IBH}} + N_{\gamma \mathrm{SN}} + N_{\gamma \mathrm{BH,NS-BS}} \cong 1.3 \times 10^{42} \text{ phot s}^{-1}$$

which is coincident with the total emissivity of the Galaxy, above 100 MeV, measured by SAS II.

Thus, the sources suggested by Giovannelli (1997) could be a good set of γ-ray counterpart candidates.

For sure, the following: EGRET AGNs, EGRET pulsars, EGRET LMC, COMPTEL sources (750 KeV–30 MeV), OSSE blazars (50 KeV–10 MeV), TeV sources (300 GeV–3 TeV), and Young Open Clusters (YOCs) are γ-ray sources. Romero (2001 and references therein) suggested a list of γ-ray counterpart candidates, like early-type stars, accreting neutron stars, radio-quiet pulsars, interacting SNRs, and black hole candidates, most of them already suggested by Giovannelli (1997). Paredes et al. (2000), Grenier (2001) and Romero (2001) have suggested the possibility of having microquasars as γ-ray counterparts of the 3^{rd} EGRET Catalog sources.

From a statistical point of view, two populations can be identified: one associated with the Gould belt, a nearby star forming region, and the other formed by higher luminosity sources at lower latitudes. Indeed, it has been suggested (Grenier, 2000) that a number of unidentified γ-ray sources could lie in Gould's belt: a lane of massive stars, most of which are less that 20–30 million years of age, arches across the sky. This starburst disk dominates our cosmic neighborhood up to a thousand light years away, and includes many of the brightest, most conspicuous stars in the sky. Most of the stable unidentified EGRET γ-ray sources, at mid-latitudes closely follow the curve and apparent width of the belt. It has been shown (Gehrels et al., 2000) that these mid-latitude sources are distinct from the population of unidentified sources in the Galactic Plane, and are likely to be associated with Gould's belt.

The microquasar LS 5039, which is a massive X-ray binary with persistent non-thermal radio emission, has been physically associated with the γ-ray source 3EG J1824–1514 (Paredes et al., 2000). Romero et al. (2001) suggested the association of the 3EG J0542+2610 with the transient X-ray source A0535+26/HDE245770 - the best studied system of such a class (Giovannelli & Sabau-Graziati, 1992) - suggesting that this Be/accreting pulsar can produce variable hadronic γ-ray emission through the mechanism originally proposed by Cheng & Ruderman (1989), where a proton beam accelerated in a magnetospheric electrostatic gap impacts the transient accretion disk. Giovannelli & Ziółkowski (1990) discussed on the possibility of the formation of a temporary accretion disk at the periastron passage of the neutron star around the Be star and Finger, Wilson & Harmon (1996) observed an accretion disk around the neutron star during a giant outburst of the system. So, the association could be really true. However, more direct measurements, especially simultaneous in different energy ranges, are necessary in order to definitively clarify such an association.

The possibility of having high energy γ-ray emission from close binary systems has been discussed by Bednarek & Giovannelli (1999) and the references therein.

Kaufman-Bernadó, Romero & Mirabel (2002) suggested a model for galactic variable γ-ray sources based on the idea of precessing microblazars, which have been proposed by Mirabel & Rodriguez (1999) as microquasars with jets forming a small angle with the line of sight, by analogy with the unified model for AGNs. Thus, microblazars are sources with highly variable and enhanced non-thermal flux due to Doppler boosting. Taking into account that more than 130 HMXRBs have been detected (Liu, van Paradijs & van den Heuvel, 2000) and that this number should be a small fraction of the total number of these systems in the Galaxy, Kaufman-Bernadó, Romero & Mirabel (2002) concluded that *it is not unreasonable to expect the existence of a few tens of microblazars at mid and low galactic latitudes that could be responsible of the variable galactic γ-ray sources detected by EGRET*. The discovery of the X-ray transient V 4641 Sgr, which has a $\sim 9\,M_\odot$ black hole and shows extreme superluminal velocities (Orosz et al., 2001), could be a microblazar. The best way of detecting microblazars is to measure the electron-positron annihilation feature in their spectra. This will be possible with the INTEGRAL-IBIS.

In our opinion the problem of the identification of the unknown EGRET sources is very difficult to solve, since for their position around the very crowded galactic plane the sources — which in principle can be discrete or diffuse — cannot be resolved with the present generation of instruments, although EGRET greatly improved the angular resolution with respect to COS B. Only attempts can be performed in this sense. Indeed, for instance, Manchanda et al. (1996) suggested as a possible class of γ-ray diffuse emitters the young open clusters containing peculiar objects with hypersonic stellar winds (> 2500 km s^{-1}). In this way it is possible to account for 7 sources which were, of course, contained in the COS B catalog as well: NGC 6514 (2CG 006–00); Berk 87 (2CG 075+00); NGC 6910 (2CG 078+01); IC 1808 (2CG 135+01);

Tr16/Tr18 (2CG 288–00); and NGC 6193 and NGC 6231, associated with two regions of diffuse emission reported by COS B.

Although considering these identifications, most of the EGRET sources still remain unidentified. Are they mostly point sources from compact objects like neutron stars? Are they related to SNRs where one would expect an enhanced cosmic ray density? Do they correspond to matter enhancements like giant molecular clouds being bombarded by cosmic rays of ordinary density? Are they Supernova–OB associations (SNOBs)?

Six or seven of the unidentified EGRET sources are sufficiently near to catalogued shell-like SNRs that at least some of them may be casually linked.

Indeed, Romero, Benaglia & Torres (1999) discussed the possible association of unidentified γ-ray sources in the 3EG catalog with three classes of cosmic sources, namely SNRs, OB associations, and Wolf–Rayet stars. Their conclusion is that there seem to exist more than a single population of galactic γ ray sources. The large number of unidentified EGRET sources, free of any positional coincidence with luminous objects, encourage further studies to find whether there exist a population of exotic objects yet undetected at higher energies. In fact, VHE γ-ray astronomy can help in this identification process in several ways.

In the first place they can be detected in the VHE range. Several of the EGRET sources which may be identified with SNRs have relatively hard spectra which extrapolate to flux levels that are easily detectable in VHE range. The expected γ-ray fluxes from SNR of shell type have been calculated by Drury, Aharonian & Voelk (1994). Their values support those extrapolated from EGRET energies. Similar extrapolation of the EGRET data from Berk 87 (CGRO J 2021+37) to VHE range has been performed by Giovannelli, Bednarek & Karakuła (1996). The expected fluxes can be detected by the present generation of VHE experiments.

One of the long standing prime objectives for VHE γ-ray astronomy is the desire to establish direct evidence for the sources of cosmic rays. If the source of very high and ultra high energy cosmic rays are extragalactic at distances more than twice the distance to the Virgo cluster (20 Mpc), then the photon window for their exploration effectively closes above 10^{14} eV. Thus VHE γ-ray astronomy has the potential to view the highest photon energy at which distant extragalactic cosmic ray sources may be studied directly.

It is well established that cosmic ray spectrum extends to 10^{20} eV (see Figure 6), yet the origins of such spectacularly high energy particles remains obscure. Particle energies of this magnitude imply that near their acceleration sites a range of elementary particle physics phenomena is present which is beyond the ability of present day particle accelerators to explore. VHE γ-ray astronomy may catch a glimpse of such phenomena.

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?

Several papers appeared for searching the unidentified EGRET sources in the Milky Way (e.g. Grenier, 2003; Harding et al., 2004; Romero et al., 2004; Gonthier et al., 2005; Grenier, Kaufman Bernad & Romero, 2005) and the problem of the identification appears now closer to the solution. Indeed, for instance, Mattox, Hartman & Reimer (2001) searched for the association of the unidentified EGRET sources with radio sources. They found 46 associations with a high probability of being correct, 37 associations with a 'plausible identification' and 15 more plausible identifications, which were not suggested previously at all.

Recently, many VHE γ-ray sources have been detected. HEGRA (High Energy Gamma Ray Astronomy) observations, from 1997 to 2002, of the CRAB Nebula between 500 GeV and 80 TeV have provided a good experimental spectrum whose best fit is given by $dN/dE = (2.83 \pm 0.04) \times 10^{-11} (E/\mathrm{TeV})^{-2.62 \pm 0.02}$ photons cm^{-2} s^{-1} TeV^{-1} (Aharonian et al., 2004). A new TeV HEGRA source J2032+4130 has been detected, being its flux $F(E > 1\,\mathrm{TeV}) = (5.9 \pm 3.1) \times 10^{-13}$ photons cm^{-2} s^{-1}, which is ~ 0.03 Crab (Horns, & Rowell, 2004). HESS (High Energy Stereoscopic System) discovered 8 new VHE galactic sources. These 8 sources plus J1745–290 and SNR RX J1713.7–3946, already known, can form a new population of VHE gamma-ray sources in the Galaxy (Aharonian et al., 2005).

Which kind of open problems still survive?

One is the problem of knowing the behavior of γ-ray sources in the energy range $\approx$ 10–300 GeV; indeed, such a range is above that measurable with the space-based detectors and below that measurable with the ground-based detectors. So, this is essentially a technological and/or physical problem. The technological problem is self-evident; the physical problem could be related to the eventuality of discovering new form of detection of photons of such energies.

Another problem is that connected with the cutoffs at high energies of the γ-ray sources, not yet completely known, and moreover not yet measured but few exceptions.

Finally, the last problem is related to the origin of γ-rays, once they are detected from a cosmic source; in other words, from which physical part of the cosmic source γ-rays are coming? (i.e., i) from jets, where electrons and positrons are interacting with the surrounding matter and/or radiation, giving rise to X- and γ-rays via bremsstrahlung or to a formation of neutral and charged pions, which decay into γ-rays and neutrinos; ii) from spherical accretion of matter onto collapsed objects?

3.2 Extragalactic Sources as γ-ray Emitters

Most of the unknown EGRET sources far from the galactic plane are probably extragalactic in origin. The problem of their association with known classes of objects is not yet completely solved.

3.2.1 Clusters of galaxies as γ-ray emitters

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 has 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.

ASCA measurements (Ohashi et al., 1996) show constancy in the Fe abundance in CGs. If the amount of metals in the ICM is proportional to the total mass in CGs, the constant abundance of Fe would imply that the mass ratio between galaxies and primordial intergalactic gas is the same between rich and poor clusters. Then, the efficiency of the galaxy formation should be constant for different richness of clusters. This contradicts the popular correlation of Fe abundance with the gas temperature.

Which open problems in 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.

A very impressive image of colliding galaxies, shown in the left panel of Figure 7, has been obtained with the AXAF/Chandra satellite. This image of colliding galaxies shows superbubbles produced by the combined effect of thousands of supernovae, as well as dozens of bright point-like sources produced by neutron stars and black holes. This Chandra X-ray image shows the central regions of two colliding galaxies known collectively as *The Antennae* (Fabbiano, Zezas & Murray, 2001). The galaxies are located $\approx$ 30 Mpc away in the southern constellation Corvus. They got their nickname from the wispy antennae-like streams of gas seen by optical telescopes. These wisps are believed to have been produced by the collision between the galaxies that began about 100 million years ago and is still occurring.

Right panel of Figure 7 shows the HST high resolution image in the NIR of the same Antennae galaxies (NGC4038/NGC4039), which are clearly colliding. On the left is shown a ground based telescopic view of the Antennae galaxies, formed by the gravitational tidal forces of their encounter, resembles an insect's antennae. On the right are shown the respective cores of the twin galaxies as the orange blobs, left and right of image center, crisscrossed by filaments of dark dust (photo STScI-PRC97-34a). This natural color image is a composite of four separately filtered images taken with the Wide Field Planetary Camera 2 (WFPC2), on January 20, 1996. The resolution is 15 light years per pixel (picture element). A wide band of chaotic dust, called the overlap region, stretches between the cores of the two galaxies. The sweeping spiral-like patterns, traced by bright blue star clusters, show the result of a firestorm of star birth activity which was triggered by the collision. While stars can be expelled from the disk by elastic collisions during the merger, thereby forming the tidal arms, the interstellar matter experiences inelastic collisions and concentrates mainly in the joint central region. There it is compressed, and as a consequence millions of new stars are forming within in the region of most violent interaction in both galaxies. As many of these star formation regions are still deeply embedded within dust they are not visible in optical light but only at mid-IR wavelengths, where the dust becomes transparent. From the color and luminosity of the dust emission in the FIR and sub mm range, conclusions can be drawn about hidden star forming processes (Staude & Rix, 2001).

Deep studies on the clusters during a merger have been performed by Blasi (2001, 2003) and Gabici & Blasi (2003, 2004) and the references therein. The luminosity coming from the process of merging is $L_{\rm merg} \approx 1.6 \times 10^{45}$ erg s^{-1}(M/$10^{14}\,M_\odot$)^2 (d/1.5 Mpc)$^{-1}$ and the gamma ray luminosity is $L_\gamma \approx \varepsilon L_{\rm merg}$, where $\varepsilon \sim 10^{-2}$.

There are several theoretical motivations for expecting γ-ray emission from clusters of galaxies. Indeed, γ-rays are coming from the decay of neutral pions, produced either in the interaction of cosmic ray protons with the ICM protons ($pp \longrightarrow X + \pi^0 \longrightarrow \gamma + \gamma$) (e.g. Colafrancesco & Blasi, 1998; Völk & Atoyan, 1999) or in the annihilation of dark matter particles ($\chi\chi \longrightarrow X + \pi^0 \longrightarrow \gamma + \gamma$) (Colafrancesco & Mele, 2001).

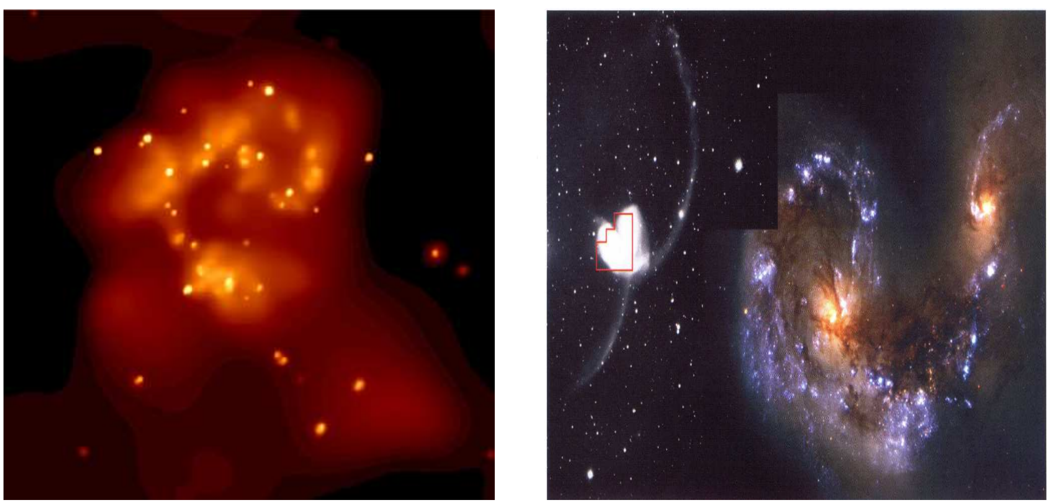

Fig. 7 Left panel: Image of the Antennae colliding galaxies obtained with the Chandra observatory. It shows superbubbles produced by the combined effect of thousands of supernovae, as well as dozens of bright point-like sources produced by neutron stars and black holes (NASA/SAO/Fabbiano, Zezas & Murray, 2001). Right panel: The Antennae in the optical range. The HST image on the right hand side (detail) clearly shows colliding dust clouds and numerous nests of young blue stars (image NASA/ESA).

The secondary electrons turned out in the previous mechanisms can produce additional γ-rays through bremsstrahlung and inverse Compton scattering (ICS) (e.g., Blasi & Colafrancesco, 1999; Colafrancesco & Mele, 2001) in the interactions with the CMB photons. Also primary cosmic ray electrons can produce a diffuse γ-ray emission via non thermal bremsstrahlung (e.g. Sreekumar et al., 1996) and ICS of the CMB photons. In addition to this diffuse emission, 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.

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. All the clusters probably associated with the EGRET sources have a strong radio emission either because they host radio galaxies or radio sources in their environment or because they have a radio halo or relic inhabiting their intracluster medium. The cluster radio emission suggests that the relativistic particles which are diffusing in the intracluster medium might be also responsible for their γ-ray emission. Beyond the spatial associations of clusters with unidentified EGRET sources, Colafrancesco (2002) found a correlation between the radio flux at 1.4 GHz of the cluster's brightest source and the γ-ray flux, $F(> 100\,\mathrm{MeV})$, of the associated EGRET source. Moreover, there is a further correlation between the X-ray luminosity of galaxy clusters and the γ-ray luminosity of the associated γ-ray source under the hypothesis that the EGRET sources have the same redshift of clusters. Such correlations are consistent with theoretical expectations.

The possible association of the EGRET source 3EG J1337+5029 with the cluster of galaxies Abell 1758A is shown in Figure 8 as example. The rich cluster Abell 1758A falls within 95% confidence level position error contour of the source very close to the center of the EGRET source map. No other γ-ray source counterpart is found in the field of this EGRET source. The Abell 1758A cluster has a redshift $z = 0.279$ and is associated with the X-ray source RXJ 1332.7+5032 (Boehringer et al., 2000).

The γ-ray/radio correlation found for the nine most probable EGRET–clusters associations is $F(> 100\ \mathrm{MeV}) \sim S_{1.4}^{0.19\pm0.09}$ at $\approx 2.05\sigma$ confidence level (only statistical uncertainties). The γ-ray/X-ray correlation is $L_\gamma \propto L_{\mathrm{X}}^{0.59\pm0.12}$ at $\approx 4.9\sigma$ confidence level (only statistical uncertainties) (Colafrancesco, 2002).

3.2.2 *Active Galactic Nuclei as γ-ray emitters*

The main idea in order to explain the emission from extragalactic X-ray emitters, now very popular, was suggested many years ago (Giovannelli & Polcaro, 1986): the *engine* producing high energy radiation is of the same kind for all extragalactic emitters. Mass and mass accretion rates are the unique parameters differentiating extragalactic emitters, containing central black holes, by the galactic black holes.

The emission of the extragalactic X-ray sources can be expressed as: $L_{\mathrm{TOT}} = L_{\mathrm{NUC}} + L_{\mathrm{HG}}$, where, L_{NUC} is the nuclear luminosity and L_{HG} is the host galaxy luminosity, formed by the integrated emission of its discrete sources. Such components can be derived by using the Giovannelli & Polcaro (1986) diagram (GPd).

Hasinger, Miyaji & Schmidt (2000) from the combined X-ray surveys from All-Sky Survey (RBS) to the Deepest Surveys (RDS) of AGNs obtained a diagram $\log L_{\mathrm{x}}$ vs. $\log z$ (Figure 9). Getting the brightest objects for an arbitrary binning of redshift (Δz) one obtains the upper part of the GPd, $L_{\mathrm{xmax}}(z)$. If the choice of the brightest object for an arbitrary Δz is repeated for each survey with higher sensitivities one obtains a family of curves parallel to that of the aforesaid diagram. This means that the conclusions discussed by the latter authors are still valid, namely: there is a physical continuity between the different classes of compact extragalactic X-ray sources. This strongly indicates the existence of a unique kind of central X-ray source. The numerical continuity of the whole $L_{\mathrm{xmax}}(z)$ function should be interpreted as due to an evolution of the central X-ray source from a very active to a more quiet status. And now, this is definitively proved thanks to the surveys obtained from lower luminosity objects at different redshifts as shown in the Figure 9 where the points of the upper part of GPd have been superimposed (red crosses) to those of Hasinger, Miyaji & Schmidt (2000). In Figure 9 is also reported the position (blue star) in which the new quasar J1148+5251 at $z = 6.1$ discovered with a 10 m Keck telescope (Fan et al., 2003) would lie in the GPd. So, such a diagram predicts the 2 keV X-ray luminosity of that quasar as $L_{\mathrm{x}} \sim 7 \times 10^{47}$ erg s^{-1}. This is a good test for the GPd goodness.

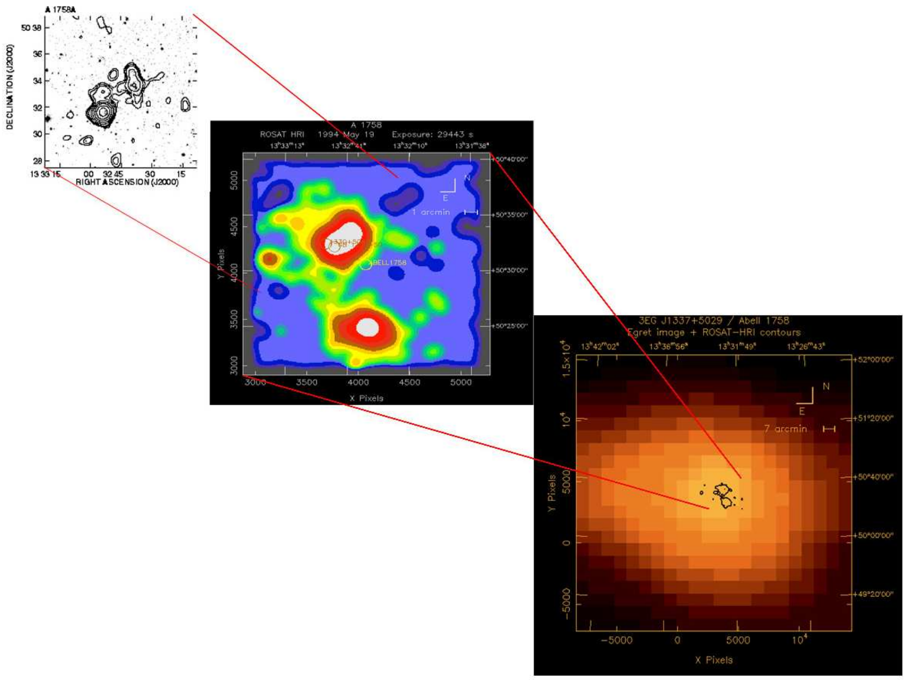

Fig. 8 Optical image of the Abell 1758A cluster, EGRET image of the 3EG J1337+5029, and ROSAT-HRI contour (Colafrancesco, 2002).

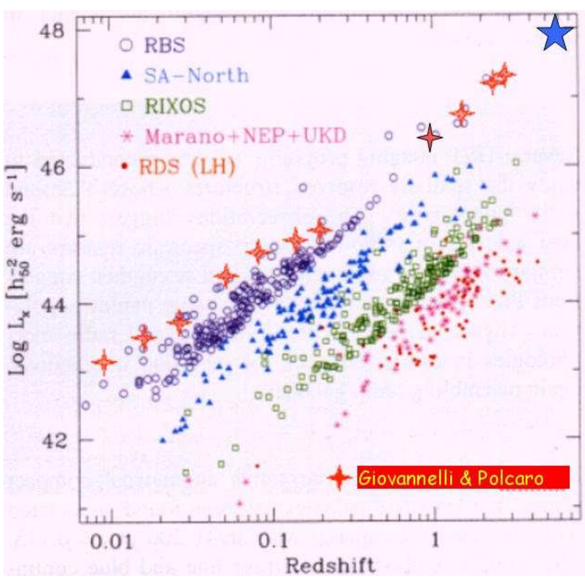

Fig. 9 X-ray luminosity of different samples of extragalactic emitters versus redshift (Hasinger, Miyaji & Schmidt, 2000). Red crosses indicate the points of the maximum luminosity diagram of Giovannelli & Polcaro (1986)(GPd). Blue star indicates the position in which the new discovered quasar J1148+5251 at $z = 6.1$ would lie in the GPd.

The way in which AGNs appear to the observers strongly depends on their orientation: classes of apparent different AGNs might be intrinsically similar (same kind of *engine*), only seen at different angles with respect to the line of sight (e.g. Urry & Padovani, 1995; Padovani, 1998).

More detailed unified schemes have been produced. For instance, in Vagnetti, Cavaliere & Giallongo (1991) and Vagnetti & Spera (1994) and in the references therein, the evolutionary unified scheme is based on the changing balance among three optical luminosities, namely:

– nuclear isotropic component;
– relativistic beam component;
– host galaxy component.

The intrinsic jet luminosity is assumed to have the same cosmic evolution as the nuclear isotropic component. The bulk Lorentz factor of the beam is able to account for the slower evolution of flat-spectrum QSOs. The comparison of the total nuclear luminosity ($L_{\rm NUC} = L_{\rm IS} + L_{\rm BEAM}$) with the non-evolutionary galactic luminosity, ($L_{\rm HG}$), predicts the appearance of a source as a radio galaxy if $L_{\rm HG} > L_{\rm NUC}$.

In order to test the unified scheme for representing AGNs it is necessary to enhance the statistics of the measured objects in order to clearly understand the influence of the beam Lorentz factor, the beam axis orientation versus the line of sight - as already discussed in the case of electron and proton relativistic beams interacting with the matter and/or radiation around (Bednarek et al., 1990)- and the contributions of the nuclear isotropic component, host galaxy component, as well as that of the beam component. To do this, it is necessary to explore experimentally a large sample of AGNs in different wavelength regions.

The open problem in this case is probably not due to the physics governing such sources, which seems, now, rather well known, but to the methodology of measurements most suitable to obtain indirectly the physical parameters necessary to test the theory of unification. These parameters are the beam Lorentz factor, the inclination of the system with respect to the line of sight, fundamental to derive the actual emission of the source at different energies, which on the contrary can appear largely altered when observed from the Earth with ground- or space-based experiments.

3.3 Relativistic Jets as γ-ray Emitters

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

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

Two astonishing examples are reported by the Chandra X-ray images of Pictor A (Figure 10) and the Crab Nebula (Figure 11). Figure 10 shows a spectacular jet that emanates from the center of the galaxy (left) and extends across 360 thousand light years toward a brilliant hot spot. The hot spot is at least 800 thousand light years (8 times the diameter of our Milky Way galaxy) away from where the jet originates. The hot spot is thought to represent the advancing head of the jet, which brightens conspicuously where it plows into the tenuous gas of intergalactic space (Chandra X-ray Observatory ACIS Image Credit: NASA/UMD). Figure 11 shows the central Crab pulsar surrounded by tilted rings of high-energy particles that appear to have been flung outward over a distance of more than a light year from the pulsar. Perpendicular to the rings, jet-like structures produced by high-energy particles blast away from the pulsar (NASA/CXC/SAO).

4 GAMMA-RAY BURSTS

Gamma-Ray Bursts (GRBs) constitute the hottest argument of modern astrophysics. Indeed, in spite of ~ 3000 events recorded, their origin and nature is still controversial. Greiner (1999) presented and discussed the sky distribution of 1869 GRBs detected with CGRO-BATSE instrument, their localization and origin. An updated isotropic, but not homogeneous, distribution has been shown in many papers (e.g., Figure 8

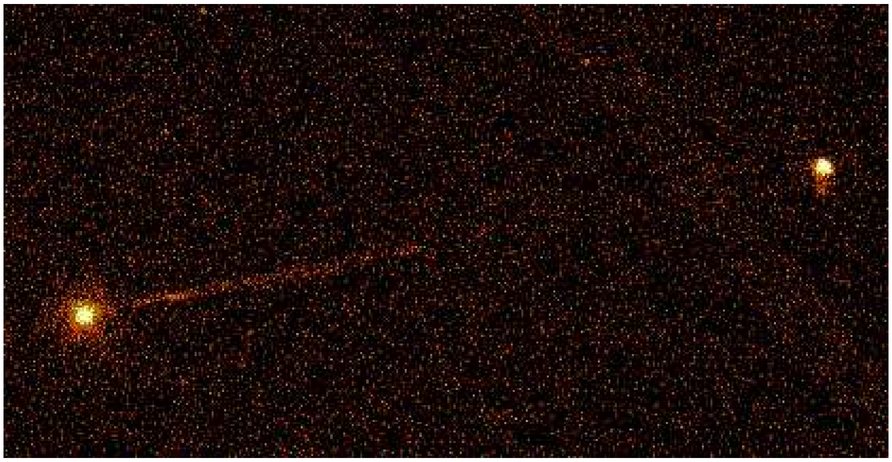

Fig. 10 The spectacular jet that emanates from the center of the galaxy Pictor A (left) and extends across 360 thousand light years toward a brilliant hot spot, which is at least 800 thousand light years (Chandra X-ray Observatory ACIS Image Credit: NASA/UMD).

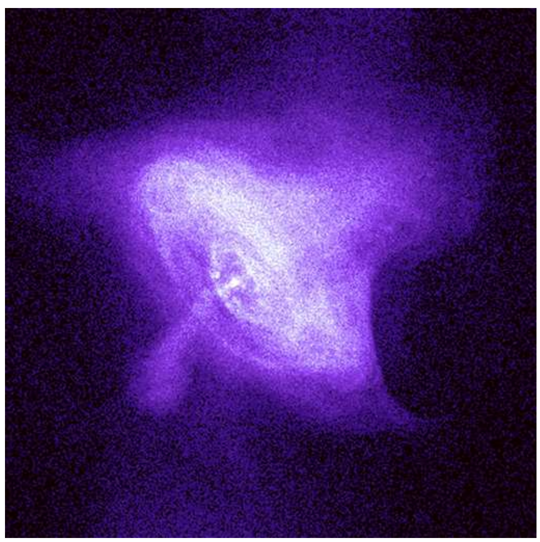

Fig. 11 The central Crab pulsar surrounded by tilted rings of high-energy particles. Perpendicular to the rings, jet-like structures produced by high-energy particles blast away from the pulsar (NASA/CXC/SAO).

of the paper by Giovannelli & Sabau-Graziati, 2003b or Figure 143 of the review paper by Giovannelli & Sabau-Graziati, 2004) where 2704 GRBs are represented. The number of GRBs further increased thanks to the detections of the BeppoSAX, RossiXTE, HETE and the INTEGRAL mission. Recently such a number started to increase rapidly because of the measurements of the SWIFT Observatory launched at the end of 2004.

GRBs are few seconds duration sudden events, different from each other both for intensity and duration. The same GRB manifests in different energy ranges with some delays (e.g. Nicastro et al., 2001). They emit an amount of energy, which can eclipse even a giant galaxy. Their origin is still a mystery. Are they galactic or extragalactic in origin? No one strong argument against the complete isotropic distribution has been given. The majority of GRBs has a rather complex temporal structure: in particular their variability time scale is significantly shorter than the duration.

After the launch of the RXTE and BeppoSAX it has been possible to perform multifrequency observations of the probable counterparts associated with the GRBs just within a few hours of occurrence. Indeed, the BeppoSax measurements allowed to detect the fading X-ray emission, which follows the higher energy photon emission associated to the GRB in its highest state. Such an emission has been called *afterglow* (Costa et al., 1997) and extends at lower energy ranges, where the first Optical-IR-Radio counterparts were detected since 1997 (e.g. reviews of Piran (1999, 2000), Feroci (2001), Castro-Tirado (2002), Pian (2002), Hurley (2003), Frontera (2003) and references therein). The first X-ray afterglow detected was that related to the GRB 970228 (Costa et al., 1997). This was one of the most important measurements performed in the space.

The precise X-ray position (1') triggered the research for the eventual optical afterglow (OA), which was actually detected by Pedichini et al. (1997) and Guarnieri et al. (1997) in the rising phase of the light curve. The optical maximum ($V \sim 21.3$ mag was reached ~ 20 hours after the GRB maximum emission (Groot et al., 1997) and the power-law decay was best fitted by $F \propto t^{-1.2}$ (Galama et al., 1997; Bartolini et al., 1998). An extended source was seen at the OA position by ground-based and HST observations (van Paradijs et al., 1997; Sahu et al., 1997). Six months later, HST detected in the position of the OA an object having $V = 28$ mag as well as the extended source with $V = 25.7$ mag (Fruchter et al., 1997). The extended source surrounding the point-source was interpreted as a galaxy. Later, the redshift of such a galaxy was determined as $z = 0.695$ (Djorgovski et al., 1999).

After this important discovery the number of papers devoted to GRBs exploded, especially those proposing models for explaining the physics of the events. With the detection of the afterglow of the GRB 970228, the so-called Afterglow Era for GRBs started.

For the GRB 990510, following the BeppoSAX/WFC detection, Vreeswijk et al. (1999a,b) found the optical counterpart placed at $z = 1.619$. This is the first GRB for which polarized optical emission was detected $(1.7 \pm 0.2\%) \sim 18.5$ hr after the maximum emission (Covino et al., 1999) and later on by Wijers et al. (1999). This confirms the synchrotron origin of the blast wave itself and represents the second case for jet-like outflow (Stanek et al., 1999), being the first that of the GRB 970228.

Table 1 shows 50 GRBs detected by different satellites, for which the redshifts of the *host galaxies* have been determined (Djorgovski et al., 2001; Greiner, 2005). The number of such GRBs is increasing because of dedicated observatories, such as HETE and SWIFT: 11 GRBs with known z out of 79 from May 2004 to May 2005, whilst from May 2002 to May 2004 they were 11 out of 68.

In the case of extragalactic origin of GRBs, their energy, emitted during the burst, is an immense amount: e.g. the combination of the detection of the GRB 971214 by the BeppoSAX and the measurements of its X-ray afterglow (dal Fiume et al., 2000) and the observations with the Keck Telescope on December 16, 1997 and January 10, 1998 in the optical R band of the afterglow source, allowed to determine its distance at $z = 3.41$ (Kulkarni et al., 1998). With such a redshift the energy released during the burst was $\sim 10^{54}$ erg. The energetic afterglow of such a GRB was discussed by Ramaprakash et al. (1998). Many models have been developed for explaining the cosmological origin of GRBs (e.g. Fargion, 2003; Barbiellini & Longo, 2003; Dado & Dar, 2005;

High resolution GRB spectroscopy may reveal more details and, consequently, new surprises: this is object of investigation with the INTEGRAL, HETE and SWIFT missions. Hurley (2001) commented on the detection of emission from GRBs at energies greater and greater with steps occurring about every 5 years since 1980. Indeed, emission above 200 GeV coming from Milagrito ground-based experiment, is probably associated with GRB 970417 (Atkins et al., 2000). This energy is more than one order of magnitude greater than the previous record (Hurley, 1994) and it is close to or greater than the opacity limit for sources at $z > 0.3$ due to pair production on extragalactic starlight. Thus, this suggests that if all GRBs are cosmological and their redshifts are $z \geq 1$, the emission record at 200 GeV may stand for some time. Such an idea will be tested by experiments such as Milagro and GLAST.

In spite of the popular enthusiasm in accepting the cosmological nature of GRBs, the problem in explaining the origin of the immense amount of energy associated to extragalactic GRBs is still under discus-

Table 1 Gamma-ray bursts, detected by different satellites and the redshifts of the host galaxies (Djorgovski et al., 2001; Greiner, 2005)

GRB Name	Host-Galaxy Redshift	Localization Source
970228	0.625 ± 0.002	BeppoSAX
970508	0.835	BeppoSAX
970828	0.9579	RXTE/ASM
971214	3.418	BeppoSAX
980326	1 ?	BeppoSAX
980329	¡ 3.9	BeppoSAX
980425	0.0085	BeppoSAX
980613	1.0964 ± 0.0003	BeppoSAX
980703	0.9660 ± 0.0002	RXTE/ASM
990123	1.6004 ± 0.0005	BeppoSAX
990506	1.3	BATSE/PCA
990510	1.619 ± 0.002	BeppoSAX
990705	0.86	BeppoSAX
990712	0.430 ± 0.005	BeppoSAX
991208	0.7055 ± 0.0005	IPN
991216	1.020	RXTE/PCA
000131	4.50	Uly/KO/NE (IPN)
000214	0.37-0.47	BeppoSAX
000301C	2.0335 ± 0.0003	RXTE/ASM+IPN
000418	1.1185 ± 0.0007	IPN
000911	1.0585	IPN
000926	2.0369	Uly/KO/NE (IPN)
001109	0.37	BeppoSAX
010222	1.477	BeppoSAX
010921	0.45	HETE/Uly/BeppoSAX
011121	0.36	BeppoSAX
011211	2.14	BeppoSAX
020405	0.69	Uly/MO/BeppoSAX
020813	1.25	HETE
020903X	0.25	HETE
021004	2.3	HETE
021211	1.01	HETE
030226	1.98	HETE
030323	3.372	HETE
030328	1.52	HETE
030329	0.168	HETE
030429	2.65	HETE
031203	0.105	INTEGRAL
040511	2.63	HETE
040701X	0.2146	HETE
040924	0.859	HETE
041015	0.716	HETE
050126	1.29	SWIFT
050315	1.949	SWIFT
050318	1.44	SWIFT
050319	3.24	SWIFT
050401	2.90	SWIFT
050408	1.2357	HETE
050502	3.793	INTEGRAL
050505	4.3	SWIFT

sion. Such an enormous energy coming out from single events would be justified in a general way, avoiding *ad hoc* models. Physical restrictions on the models of GRBs have been discussed by e.g. Kundt (2001, 2002, 2003) and Bisnovatyi-Kogan (2002, 2003a,b). In the latter paper Bisnovatyi-Kogan discussed about the physical limits of different models of cosmological GRBs. The present common view about GRB origin is related to cosmology, what is based on statistical analysis, and on measurements of the redshift in the GRB optical afterglows of long GRBs. No correlation is found between redshift, GRB spectrum, and total GRB fluence. He made a comparison of KONUS and BATSE data about statistics and hard X-ray lines, and he noted some differences. There is no a fully consistent GRB model: neither for radiation, nor for explosion. It is not excluded, that short GRBs have galactic origin, and giant bursts in SGRs are connected with short GRBs (Mazets et al., 1982). Also Hurley (2003) in his general review about the big picture of GRBs lays stress on the fact that although one class of burst (the long bursts) can be attributed to the collapse of massive stars, the origin of another class (the short bursts) is still mysterious. A rather good summary on the knowledge of GRBs can be found in the review paper by Giovannelli & Sabau-Graziati (2004) and references therein.

Critical experimental evidences are needed: spectra of prompt optical afterglows; study of hard gamma-ray afterglows; search for orphans optical afterglows in all sky monitoring. Cosmological GRBs may come from collapse of massive rotating star followed by the formation of a Kerr black hole surrounded by a massive magnetized disk, and rapid accretion leading to a GRB; or from some exotic models.

Kundt (2003) discussed his own point of view about the origin of GRBs and updated his earlier conviction that a consistent interpretation of all the non-terrestrial GRBs can be obtained in terms of nearby Galactic neutron stars, at distances $10 < \mathrm{d/pc} < 500$. Indeed, Kundt in his long discussion against the extragalactic origin of GRBs takes as strong proof in favor of his conclusions the 'best case of a host-galaxy identification' for the GRB970508 (Bloom, Djorgovski & Kulkarni, 1998; Fruchter et al., 2000). The host is peculiar for its elongated shape, blue spectrum, and for housing the burst within < 70 pc of its center, without any extinction signature in the afterglow spectra. Its spectrum contains (only) two emission lines, 'identified' as [Ne III]3869 and [O II]3727, whose redshifts agree with those of the afterglow. But Allen's table of spectral lines tells that the line [Ne III]3342 should be 16 times stronger than the identified line; on the contrary it is absent. Then perhaps, the two lines should be re-interpreted as coming from nearby [Fe XV] and [Ni XV], and we see a glowing reflection nebula. And this is the strong reason why Kundt mistrusts all the 20 'host galaxies discussed by Bloom, Kulkarni & Djorgovski (2002) and by Masetti et al. (2003), which contain GRB970508 as their best case.

However, after the detection of a long (380 s) giant flare from SGR 1806–20, Hurley et al. (2005) argue that from a great distance, this event would appear to be a short-duration hard-spectrum cosmic GRB. Then, they conclude that at least a significant fraction of the mysterious short-duration GRBs may therefore come from extragalactic magnetars.

Our opinion is, at the moment, that the extragalactic origin of GRBs has not yet definitively demonstrated, at least for most of them, e.g. the short-duration ones. We would like to invite the scientific community to be extremely careful in considering all the possibilities in searching for the origin of GRBs, avoiding to follow the vogue. 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. Ideally, a GRB should commence as the burst starts, and continue throughout the afterglow phase, from radio to gamma-ray wavelengths.

5 X-RAY BINARIES

X-ray binary systems are a cauldron of physical processes and their multi-frequency studies improved a lot the knowledge of the accreting processes onto collapsed objects. They are still a precious font of information on plasma physics, on the physics of collapsed objects and their interactions with the optical companions. All the processes occurring in X-ray binary systems demonstrate in a wide range of the electromagnetic spectrum, then low-energy processes are strictly related to high energy processes and vice versa. In order to render lighter this long paper, we jump here the discussion on X-ray binary systems, inviting the reader to see e.g. the papers *X-Ray Binary Systems: A Laboratory for Frontier Physics* (Giovannelli & Sabau-Graziati, 2003c and the references therein) and *The Impact of Space Experiments on Our Knowledge of* *the Physics of the Universe* (Giovannelli & Sabau-Graziati, 2004 and the references therein) where X-ray binaries are deeply discussed also from an historical point of view.

A reader interested in this topic can find a good series of papers which appeared in the Special Volume (Vol. 3, 2003) of the Chinese Journal of Astronomy and Astrophysics devoted to the proceedings of the Frascati Workshop 2003 (Giovannelli & Sabau-Graziati, 2003a) and those reported in these proceedings.

However, we would like to remark several ideas that are coming from the analysis of the most recent results about the anomalous X-ray pulsars (AXPs) and soft gamma-ray repeaters (SGRs).

5.1 Anomalous X-ray Pulsars

In the last few years a new class of X-ray binaries has been recognized. They are X-ray pulsars with properties clearly different from those of the common HMXBs. These pulsars were recognized as presenting several characteristics similar to those of LMXBs, and for this Stella, Mereghetti & Israel (1996), in the proceedings of the 1995 workshop on *Highlights of European Astrophysics*, suggested that this new group of pulsars constitutes a subclass of the LMXBs, characterized by lower luminosities, higher magnetic fields and smaller ages than non-pulsating LMXBs. They tentatively called the systems of this new group Very Low Mass X-ray Binaries (VLMXBs). Soon after these objects have been called Anomalous X-ray Pulsars (AXPs) (Mereghetti & Stella, 1995; van Paradijs, Taam & van den Heuvel, 1995) and this is now the current accepted name.

Review papers on this topic are those by Mereghetti (2001a,b). A general review of accretion powered pulsars is that by Becker (2000). AXPs have spin periods ranging between ~ 6 and ~ 12 s, contrary to the larger spread of those of HMXBs (0.069–few $\times 10^3$ s). Spin periods of AXPs are monotonically increasing on timescales of $\sim 10^4$–4×10^5 yr. Six AXPs are currently known and three of them are associated with SNRs (Mereghetti, 2001a). Association of X-ray pulsars and SNRs have been claimed since 1993 by Giovannelli's group (Giovannelli et al., 1993a,b,c, 1994; Giovannelli & Sabau-Graziati, 2000). The nature of AXP as neutron stars is supported by their $P_{\rm spin}$ and $\dot{P}_{\rm spin}$. However, the corresponding rotational energy loss ($\sim 10^{45}\Omega\dot{\Omega}$) erg s^{-1}) is not sufficient to power the luminosity of the AXP, typically 10^{34}–10^{36} erg s^{-1}. This poses problems in understanding the accretion processes in these objects: e.g., binary models assuming weakly magnetized neutron stars ($B \sim 10^{11}$ G) rotating close to their equilibrium period. This requires accretion rates of few $\times 10^{15}$ g s^{-1}, which is consistent with the luminosity of AXPs (Mereghetti & Stella, 1995). Alternatively, the AXPs could involve isolated neutron stars accreting matter from a residual accretion disk (Corbet et al., 1995; van Paradijs, Taam & van den Heuvel, 1995; Ghosh, Angelini & White, 1997); AXPs result from the common envelope evolution of massive close X-ray binary systems. The formation of an accretion disk around an isolated neutron star could be possible through the falling material coming from the progenitor star after the supernova explosion (Chatterjee, Hernquist & Narayan, 2000).

Models based on strongly magnetized neutrons stars ($B \sim 10^{14}$–10^{15} G) have been developed in the last decade just in order to explain the behaviour of the Soft Gamma ray Repeaters (SGRs) (Duncan & Thompson, 1992; Thompson & Duncan, 1995, 1996). SGRs are transient very short (< 1 s) events, characterized by relatively soft bursts, peaked at ~ 20–30 keV, with super-Eddington luminosity. Up to now only four (perhaps five) SGRs are known (see reviews of Hurley, 2000a,b). Recent measurements of the spin down rates of SGRs and AXPs have been interpreted as evidence of very strong magnetic fields at the collapsed object poles, roughly two orders of magnitude greater than those of the 'normal' X-ray pulsars. However, this problem is one of the hottest in modern astrophysics. Indeed, for instance, Dar (2003a) argues that, instead, the observations support the hypothesis that SGRs and AXPs are neutron stars that have suffered a transition into a denser form of nuclear matter to become, presumably, strange stars or quark stars. Internal heat and slow gravitational contraction long after this transition can power both their quiescent X-ray emission and their star quakes, which produce 'soft' gamma ray bursts.

Reviews of observations of AXPs (Israel, Mereghetti & Stella, 2002), of the nature of SGRs and AXPs (Thompson, 2002), and of the general properties of recurrent bursts from SGRs (Aptekar et al., 2002) have been published in the proceedings of the Rome 2000 mini-workshop on *Soft Gamma Ray Repeaters* (Feroci & Mereghetti, 2002).

The optical counterparts of AXPs are not known, with the possible exception of 4U 0142+61, for which Hulleman, van Kerkwijk & Kulkarni (2000) reported the discovery of a faint ($R \sim 25$ mag) blue object in its error box. If such an association should be true, this faintness would rule out the presence of an accretion disk, thus favoring the magnetar interpretation. On the basis of the limits in the optical and IR wavelength regions, the presence of a massive early type companion star, such as OB super giants or Be stars, can be excluded in AXPs. Moreover, no orbital motion signatures are present in their X-ray light curves. However, with the CHANDRA observatory Wachter et al. (2004) provided a precise localization of the SGR 1627–41 and the AXP 1E 1841–045. For the first source they found an IR counterpart. For the second source, they found several sources located within the error circle. They discussed about the properties of their candidates to the detection and limits of other known AXP and SGR counterparts reported in the literature.

The Newton-XMM observation of the AXP 1E 1048.1–5937 has provided the first clear evidence for a spectral variation (soft excess during the pulse minimum and no variations during the pulse rise and decay) as a function of the pulse phase in this source (Tiengo et al., 2002). Such a behaviour is different from that of other AXPs which also show energy dependent pulse shapes like 1RXS J170849–4009 (Israel et al., 2001; Gavriil & Kaspi, 2002) and 4U 0142+61 (Israel et al., 1999).

The spectra of all AXPs are well described by the sum of a power law and a blackbody. There are no reasons to attribute this spectral shape to the presence of two physically distinct emitting components (e.g., Ghosh, Angelini & White, 1997). The contribution to the total flux is a strong function of the energy (Özel, Psaltis & Kaspi, 2001), whilst the pulsed fraction at different energies does not change significantly. As noted by Tiengo et al. (2002), in the case of two physically distinct spectral components, this would require an *ad hoc* coupling in the pulse profiles of the black body and power law components. The fact that the pulsed emission from 1E 1048.1–5937 can be fitted by the same spectral shape at all phases also suggests that it originates from a single physical component having a spectrum more complex than a pure blackbody.

Thompson, Lyutikov & Kulkarni (2002), in their paper on the *Electrodynamics of Magnetars*, commented on the strength of the surface magnetic field in the SGR and AXP sources, as inferred from their measured spin down rates, and the implications of their model for the narrow measured distribution of spin periods.

With more data on spin periods of AXPs and measurements of magnetic field intensity it will be possible to discriminate amongst different possibilities. This probably will occur with the data from XMM-Newton and AXAF-Chandra still under acquisition. However, this problem could be solved with a proper experiment, like SIXE (Spanish Italian X-ray Experiment) (e.g., Giovannelli et al., 2001; Isern et al., 2001 and the references therein), dedicated to very long observations of selected sources ($A_{\rm eff} \times T_{\rm exp} \geq 10^{10}$ cm^2 s, where $A_{\rm eff}$ is the effective area of the X-ray detectors, and $T_{\rm exp}$ is the duration of the observation).

Giovannelli & Sabau-Graziati (2004) in their long review paper about *The Impact of Space Experiments on Our Knowledge of the Physics of the Universe* dedicated a section to AXP. Woods & Thompson (2004) discussed in an interesting review the properties of magnetar candidates: four SGR and eight AXP.

A long (380 s) giant flare from SGR 1806–20, which was much more luminous than any previous transient event observed in the Milky Way, was observed by Hurley et al. (2005). In the first 0.2 s, the flare release as much energy as the Sun radiates in 0.25 Myr. Its power can be explained by a catastrophic instability involving global crust failure and magnetic reconnection on a magnetar, with possible large-scale untwisting of magnetic field lines outside the star. From a great distance, this event would appear to be a short-duration hard-spectrum cosmic GRB. At least a significant fraction of the mysterious short-duration GRBs may therefore come from extragalactic magnetars.

In the magnetar model, SGRs are isolated neutron stars with teragauss exterior magnetic fields and even stronger fields within, making them the most strongly-magnetized objects in the Universe.

Table 2 reports the timing characteristics of AXPs and SGRs, derived by the literature (e.g. Woods & Thompson, 2004; Hermesen, 2005).

However, the nature of magnetar is not yet proved. Then we could speculate as follows: if magnetic fields of $\sim 10^{15}$ G can be expected in order to explain the behaviour of magnetars, an almost 'obvious' consequence can be derived from the diagram magnetic field intensity versus the dimension of the relative cosmic source, like shown in Figure 12 (courtesy of Todor Stanev, 2002 after Hillas, 1984). In this figure, we have extrapolated the value of B up to 10^{15} G. The correspondent dimension of the source is of ~ 10 m. This could be the dimension of the acceleration zone in a supercompact star, probably a quark star. *If you construct a trap, the rat falls into it!*

Table 2 Pulse Timing Properties of Magnetars

AXP & SGR (name)	Discovery (year)	$P_{\rm pulse}$ (s)	$\dot{P}_{\rm pulse}$ 10^{-11} s s^{-1}	B (10^{14} G)	Spin-down Age (10^3 yr)
1E2259+586 (CTB 109)	1981	6.98	0.048	0.6	220
1E1048–594	1985	6.45	1.3–10	5.0	4.3
4U 0142+614	1993	8.69	0.20	1.3	70
1RXS J1708–4009	1997	11.00	1.9	4.6	9.0
1E1841–045 (Kes 73)	1997	11.77	4.2	7.1	4.5
CXOU J0110–721 (SMC)	2001	8.02	?	3.9	?
AX J1845–026 (G29.6+586)	1998	6.97	?	?	?
XTE J1810–197	2003	5.54	1.5	2.6	5.7
SGR 0526–66	1979	8.0	6.6	7.4	1.9
SGR 1627–41	1998	6.4?	?	?	?
SGR 1806–20	1986	7.5	8.3–47	7.8	1.4
SGR 1900+14	1979	5.2	6.1–20	5.7	1.3

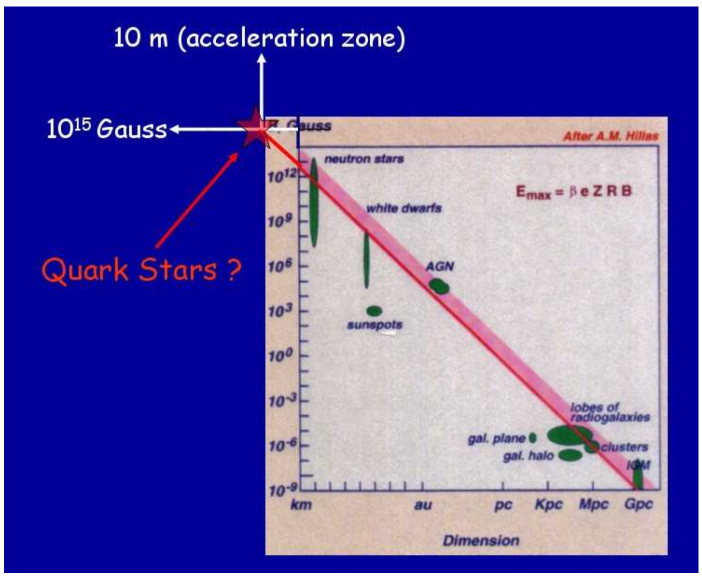

Fig. 12 Magnetic field intensity vs. dimensions of cosmic sources (courtesy of Todor Stanev, 2002, after Hillas, 1984). The extrapolation to 10^{15} G provides a dimension of $\sim$ 10 m: the acceleration zone in a supercompact star (quark star?).

6 CONCLUSIONS

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

(i) A warning in interpreting the measurements of the CMB. Indeed, the analysis of WMAP source catalog has shown that the vast majority of bright foreground extragalactic sources detected in CMB maps are blazars. More than 50 known blazars (or blazars candidates) expected to be above the sensitivity limit of BOOMERanG are included in its 90/150 GHz anisotropy maps. Blazars variability causes the detection of some sources – whose emission is at the border of the sensitivity threshold of the detectors – during the long exposure time of the satellite experiments. The blazar induced fluctuations contaminate the CMB spectrum at a level of $\approx$ 30%–90% at $l = 500$ and $\approx$ 80%–100% at $l = 800$.

Therefore, such fluctuations cannot be neglected in the derivation of the primordial CMB fluctuation spectrum. Then, a hearty warning of danger is mandatory before firm conclusions about weak features, like the secondary high l peaks of the CMB power spectrum or very weak signals like those coming from CMB polarization.

(ii) Important results are those of the association of several clusters of galaxies with EGRET sources. All the clusters probably associated with the EGRET sources have a strong radio emission. The cluster radio emission suggests that the relativistic particles which are diffusing in the intracluster medium might be also responsible for their γ-ray emission. Spatial associations of clusters with unidentified EGRET sources, a correlation between the radio flux at 1.4 GHz of the cluster's brightest source and the γ-ray flux, $F(> 100\,\mathrm{MeV})$, of the associated EGRET source, and a further correlation between the X-ray luminosity of galaxy clusters and the γ-ray luminosity of the associated γ-ray source under the hypothesis that the EGRET sources have the same redshift of clusters render this association virtually certain. Further investigations are necessary for closing this problem.

However, for the clusters of galaxies, 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.

(iii) A particular attention is necessary at the highest energies where the cosmic ray spectrum extends to 10^{20} eV (see Figure 6). Yet the origins of such spectacularly high energy particles remains obscure. Particle energies of this magnitude imply that near their acceleration sites a range of elementary particle physics phenomena is present which is beyond the ability of present day particle accelerators to explore. VHE γ-ray astronomy may catch a glimpse of such phenomena.

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?

(iv) In order to test the unified scheme for representing AGNs it is necessary to explore experimentally a large sample of them in different wavelength regions. The open problem in this case is probably not due to the physics governing such sources, which seems, now, rather well known, but to the methodology of measurements most suitable to obtain indirectly the physical parameters necessary to test the theory of unification. These parameters are the beam Lorentz factor, the inclination of the system with respect to the line of sight, fundamental to derive the actual emission of the source at different energies, which on the contrary can appear largely altered when observed from the Earth with ground- or space-based experiments.

(v) 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. 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.

(vi) In spite of the 50 claimed association of GRBs with the host galaxies at high redshit, at the moment, the extragalactic origin of GRBs has not yet definitively demonstrated, at least for most of them. Many observational features remain still unclear in the model of cosmological GRBs (Bisnovatyi-Kogan, 2003d), namely:

- Redshift is measured only in long-duration bursts. Do short bursts have different nature?
- Origin of hard gamma ray (20–20 000 MeV) afterglow, lasting up to 1.5 hours.
- Hard X-ray absorption features.
- Influence of a strong GRB explosion on the host galaxies, which is not (yet) found.

– Absence of the expected correlations connected with properties of GRBs at large and small redshifts.

Then, we would like to invite the scientific community to be extremely careful in considering all the possibilities in searching for the origin of GRBs, avoiding to follow the vogue. 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.

Critical experimental evidences are needed: spectra of prompt optical afterglows; study of hard gamma-ray afterglows; search for orphans optical afterglows in all sky monitoring. Cosmological GRBs may come from collapse of massive rotating star followed by the formation of a Kerr black hole surrounded by a massive magnetized disk, and rapid accretion leading to a GRB; or from some exotic models.

(vii) The problems connected with the AXPs and SGRs are extremely important. If magnetic fields of $\sim 10^{15}$ G can be expected in magnetars, an almost 'obvious' consequence can be derived: the correspondent dimension of the source must be of ~ 10 m. This could be the dimension of the acceleration zone in a supercompact star. Is this a quark star? *If you construct a trap, the rat falls into it!*.

(viii) The important problem for the next generation of experiments is a deep investigation of cosmic sources with experiments designed for higher and higher energies with sensitivities, spectral and spatial resolutions better and better. However this is in contrast with the sizes and costs of missions. Then, a compromise is mandatory.

Moreover, being HE cosmic sources producers also of neutrinos, next generation neutrino experiments should have to investigate about neutrino oscillations mainly in the region of $\Delta m^2 > 10^{-4}$ eV^2, in which at present there are indications in favor of oscillations.

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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