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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, GRBs, radio pulsars, millisecond pulsars, cosmic counterparts of γ-ray sources

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

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– 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) discussed on the four pillars of cosmology. The situation can be summarized as follows:

2.1 Hubble expansion

The absolute magnitude M of the galaxies can be determined through the measurement of the apparent magnitude m and redshift z. This allows the use of an equation between the module of the distance m-M and redshift z, in which H_0 (the Hubble constant) and Ω_0 (present average mass density of the Universe) appear as parameters (Matting, 1958, 1959). However the experimental determination of Hubble constant remains one of the fundamental problems in cosmology in spite of the numerous attempts also through the most powerful observatories such as Hubble Space Telescope (HST).

Until now, the many determinations of H_0 with different techniques have given discrepant results on its value. How the value of the Hubble constant influences cosmology was largely discussed in the concluding remarks of the Vulcano Workshop 1996 by Lipari (1997).

Taking into account all the literature, **a critical evaluation of the Hubble constant** is $H_0 = 56 \pm 6$ km s^{-1} Mpc^{-1} (Giovannelli & Sabau-Graziati, 1997).

From HST data on SNe, the value of $H_0 = 59 \pm 6$ km s^{-1} Mpc^{-1} seems the most probable (Panagia, 1999).

Supposing that the Universe has close to the critical density in light ($\sim$ 30 eV) neutrinos which decay radiatively with a lifetime of $\sim 10^{23}$ s, Sciama (1997) derived the parameters of the decaying hot dark matter cosmology rather precisely, namely:
$m_\nu = 27.4 \pm 0.2$ eV $\longrightarrow \Omega_\nu h^2 = 0.293 \pm 0.003$, $\tau_\nu \cong (1-2) \times 10^{23}$ s, $h = 0.548 \pm 0.003$, for $\Omega_\nu + \Omega_\mathrm{b} = 1$, where Ω_ν and Ω_b denote the fraction of the critical density in neutrinos and baryons, respectively, and h the Hubble constant in units of 100 km s^{-1} Mpc^{-1}. This shows that the Hubble constant must be $\sim$ 55 km s^{-1} Mpc^{-1}.

From such a universe, an expected UV line at 13.7$\pm$0.1 eV should be detected (Sciama, 1998) by the EURD (Espectrógrafo Ultravioleta extremo para la Radiación Difusa) detector (Bowyer, Edelstein & Lampton, 1997) aboard the Spanish MINISAT-01, described by Giménez & Sabau-Graziati (1996). On the contrary, the EURD data appear to be completely incompatible with the Sciama model of radiatively decaying massive neutrinos (Bowyer et al., 1999).

2.2 Microwave background

Small spatial anisotropy could indicate that the matter was not homogeneously distributed when CMBR originated, and small deviations with respect to the black body spectrum should indicate the presence of high energy sources in the primeval Universe. Sometimes this is noted with the analogy that *you cannot make an omelet without cracking eggs; i.e., you cannot make galaxies without disturbing the microwave background.*

The CMBR temperature in the Rayleigh-Jeans region was determined before COBE (COsmic Background Explorer) as 2.73 ± 0.05 K (Smoot et al., 1985). This value is better than 2% with respect to that from COBE.

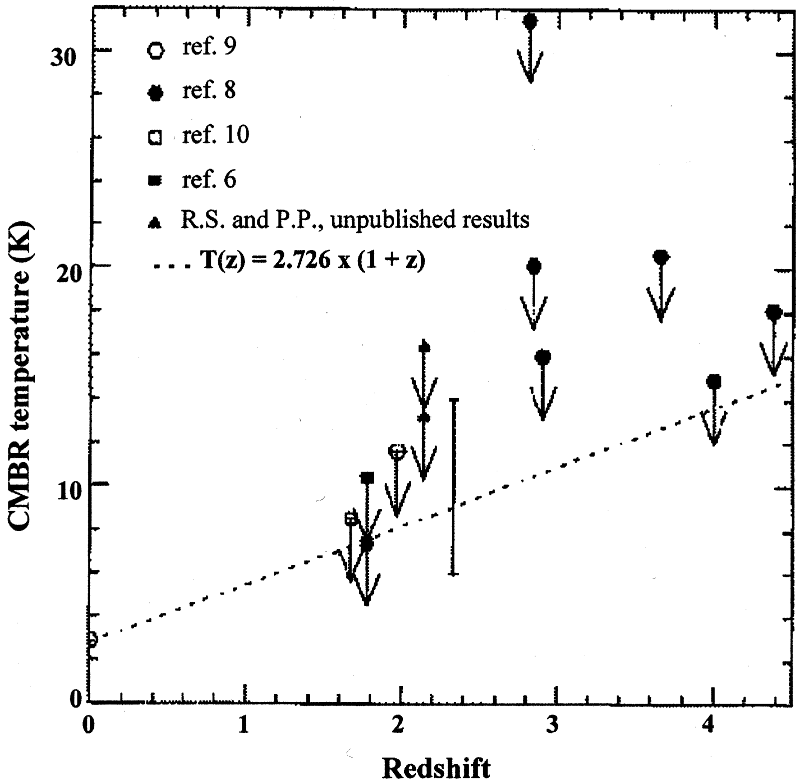

Fig. 1 CMBR temperature versus redshift (Srianand, Petitjean & Ledoux, 2000).

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 1 shows 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 ($T_{\mathrm{CMBR}}(0) = 2.726 \pm 0.010\,K$). At $z = 2.1394$ there is an upper limit. At $z = 2.33771 \simeq 2.34$, the CMBR temperature is: 6.0 K $< T_{\mathrm{CMBR}}(2.34) <$ 14.0 K (vertical bar). The dashed line is the prediction from the Hot Big Bang: $T_{\mathrm{CMBR}} = T_{\mathrm{CMBR}}(0) \times (1 + z)$. Such a prediction gives $T_{\mathrm{CMBR}}(2.34) = 9.1$ K, which is consistent with the measurement.

However, the background radiation is present not only in the microwave band, but practically along all the electromagnetic spectrum. Figure 2 shows such a background radiation from radio to HE γ-ray energy bands (Henry, 1999).

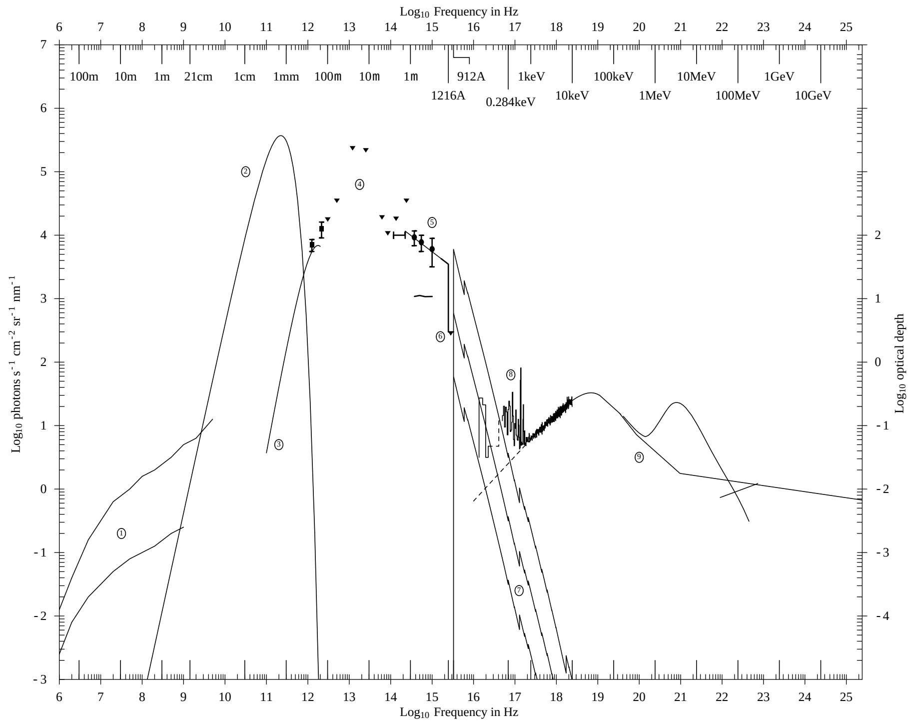

Fig. 2 The background (BKGD) radiation in the Universe: 1. Radio BKGD, 2. MW BKGD, 3. FIRAS Excess, 4. DIRBE BKGD, 5. Optical BKGD, 6. UV BKGD, 7. Ionization Optical Depth of ISM, 8. Soft X-Ray BKGD, 9. HE γ-ray BKGD (Henry, 1999).

2.3 The abundances of light elements

The Big Bang Nucleosynthesis (BBN) provides a quantitative experimental tests to standard and non-standard cosmological models. Nuclear reactions took place in the primordial plasma during the first minutes after the Big Bang, starting at $t \sim 1$ s, when the temperature was $\sim 10^{10}$ K.

The predicted abundance of light elements depend mainly on the universal baryonic density, which may be considered the only free parameter in the nucleosynthesis calculations. Measurements of the primordial abundance of the light elements test the consistency of primordial nucleosynthesis and in turn set very valuable constraints on the baryonic density $\eta = n_{\rm b}/n_{\gamma}$. η remained constant since the positron-electron annihilation epoch to the present day. This topic has been reviewed by Rebolo (1996).

The abundance of these light elements have all been accurately determined to be in impressive agreement with the Big Bang predictions to the accuracy of the measurements. Furthermore, the Big Bang model predicts that the abundance would fit well only if there were no more than three families of neutrinos, and this was exactly what was observed at LEP (Large Electron-Proton collider). So, the light elements with abundance ranging from 76% for H to 10^{-10} for Li all fit with the cosmological predictions with the one adjustable parameter being the baryon density $\Omega_{\rm b} \sim 0.05 \pm 0.03$. So, if one *prefers* a universe with $\Omega_{\rm tot} = 1$, one must also

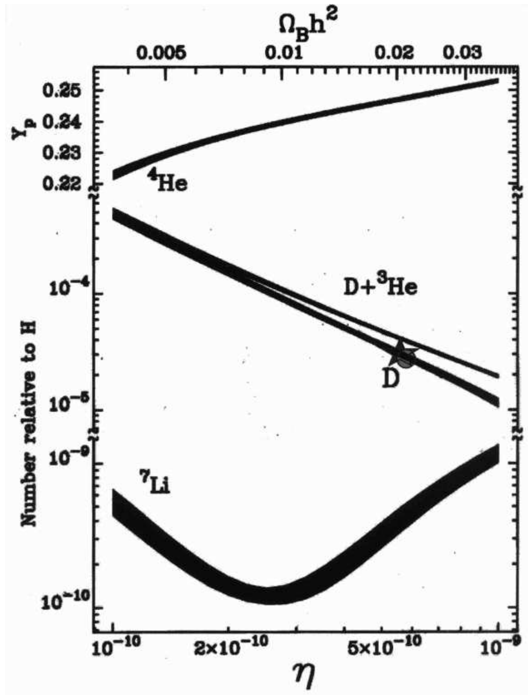

Fig. 3 Light element abundances (Burles, Nollett & Turner, 2001). Derived points from experiments are overlapped: $\star$ (Netterfield et al., 2002), $\circ$ (de Bernardis et al., 2000).

demands that the bulk of the matter in the universe ($\geq$ 90%) be something other than baryons (Schramm, 1993).

Recent evaluations of light element abundances (Burles, Nollett & Turner, 2001) allow to infer $h^2\Omega_b = 0.020\pm0.002$ (95% confidence level) (Netterfield et al., 2002). From BOOMERanG data (de Bernardis et al., 2000) a value of $h^2\Omega_b = 0.021$ has been derived. These two points are overlapped to the predicted curves for ^{4}He, D + ^{3}He, D, and ^{7}Li, shown in Figure 3.

The determination of the mass fraction of the hot gas in clusters of galaxies, obtained through the measurements performed with ROSAT and ASCA satellites, can provide the baryonic content and then a test for the BBN, or alternatively an indirect determination of the Hubble constant assuming that the baryonic content is in agreement with the BBN, as discussed e.g. by Giovannelli (2001).

Observations with the ROSAT satellite have shown that rich clusters of galaxies have a mass fraction ($\sim 0.3 \times h_{50}^{-3/2}$) of hot X-ray gas (Mushotzky, 1992). Since $\Omega_{\rm cluster} \sim 0.2$, this yields $\Omega_b \sim 0.06$ for these clusters in reasonable agreement with BBN, but only if $h_{50} = H_0/50 \sim 1$. This result strongly favors a value of the Hubble constant H_0 = 50 km s^{-1} Mpc^{-1}, which is roughly in agreement with the determinations already discussed.

Then, open problems are both the determination of the Hubble constant and the mass content in clusters of galaxies, strictly related each other.

2.4 Inflation

It is well known that inflation predicts a flat universe and produces gaussian density fluctuations with a power spectrum

$$\left(\frac{\partial\rho}{\rho}\right)^2_{\mathrm{K}} \sim \mathrm{K}^n$$

with $n \sim 1$. K is the wave number of the fluctuation (K $= 2\pi/$L, where L is the length scale). Standard inflaction yields the flat ($n = 1$) Harrison-Zeldovich spectrum with equal power on all scales.

COBE satellite has given results consistent with a gaussian spectrum and yields $n = 1.2^{+0.5}_{-0.6}$ (Smoot et al., 1992). Fluctuations detected by COBE are on angular scales $\theta \geq 7°$, which are greater than the causal horizon ($\theta \sim 2°$) at the time of radiation decoupling; then the observed fluctuations support the need for inflation. In fact, minimal fluctuations, existing on the scales of the observed galaxies and structures, would roughly incoherently add all together on larger scales and give rise to a power spectrum $\propto K^4$. COBE results clearly contradict this fact.

Then, the primordial spectrum is not a simple superposition of the fluctuations produced by galaxies, clusters and other observable structures. In other words, this means that some larger scales primordial fluctuations must exist. It is still necessary to check eventual other additional seeds, maybe non-gaussian, but in any case, **COBE results are consistent with inflation.**

However, this consistency is necessary but not sufficient. Indeed the idea of a flat spectrum ($n = 1$) exists prior the inflation hypothesis. Then, although obtaining such a spectrum, the unicity of inflation is not proved.

Another prediction of the inflation is a flat universe ($\Omega = 1$). This is supported by the angular size versus redshift measurements of compact radio jets measured with very long baseline interferometry (Kellerman, 1993).

A problem for the inflation could be the value of the Hubble constant. Indeed the age of the Universe is $t = \frac{2}{3H_0}$ for a value $\Omega = 1$, matter dominated universe. But the age of globular clusters is $t_{\mathrm{GC}} = 15 \pm 3$ Gyr (Schramm, 1990), which can be consistent with an $\Omega = 1$ universe only if $H_0 \leq 60$ km s^{-1} Mpc^{-1}.

Then, once more a value of the Hubble constant consistent with those previously reported and discussed is indirectly coming out under the hypothesis that the inflation is valid. Vice versa, since a value of $H_0 = 59 \pm 6$ km s^{-1} Mpc^{-1} has been determined, the inflation idea is proved.

The converging proofs for Standard Model have been reported by Giovannelli (2001) by discussing the CMB anisotropy after BOOMERanG and Charge-Parity (CP) violation.

3 CLUSTERS OF GALAXIES

The knowledge of magnetic field intensity in clusters of galaxies (CGs) is fundamental for understanding the properties of the intercluster plasma. CGs with extended radio halo (1 Mpc scale, probably associated with the compenetration of clusters-subclusters) 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 intercluster 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 intercluster 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 could solve such problems. With the launches of AXAF/Chandra and XMM/Newton observatories at the end of nineties some of these problems are going to the solution.

A very impressive image of colliding galaxies, shown in Figure 4, 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). They are placed at about 60 million light years from Earth in the 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.

4 ACTIVE GALACTIC NUCLEI AND GALACTIC COLLAPSED OBJECTS: UNIFIED SCHEMES

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: $L_{\rm TOT} = L_{\rm NUC} + L_{\rm HG}$, where, $L_{\rm NUC}$ is the nuclear luminosity and $L_{\rm HG}$ 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.

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 $\log L_{\rm x}$ vs $\log z$. Getting the brightest objects for an arbitrary binning of redshift (Δz) one obtains the upper part of the Giovannelli & Polcaro (1986) diagram, $L_{\rm xmax}(z)$, as shown in the Figure 5. 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 5 where the points of the upper part of Giovannelli & Polcaro diagram have been superimposed to those of Hasinger, Miyaji & Schmidt (2000).

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 ($L_{\mathrm{NUC}} = L_{\mathrm{IS}} + L_{\mathrm{BEAM}}$) with the non-evolutionary galactic luminosity, (L_{HG}), predicts the appearance of a source as a radio galaxy if $L_{\mathrm{HG}} > L_{\mathrm{NUC}}$.

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.

5 RELATIVISTIC JETS

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.

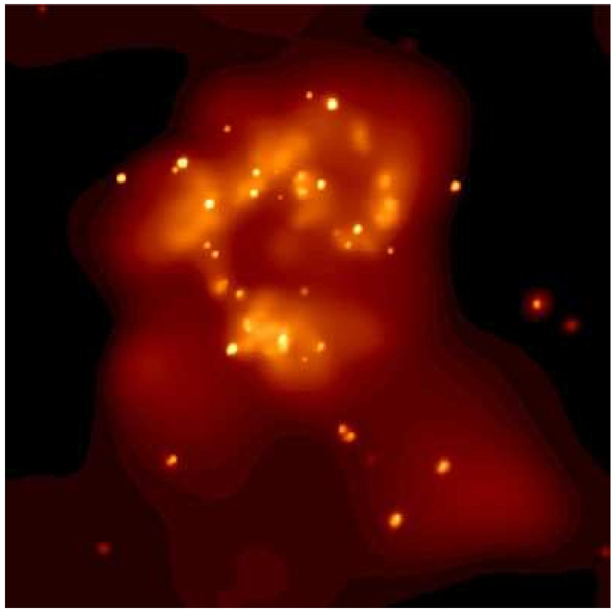

Fig. 4 Image of the Antennae colliding galaxies obtained with the Chandra observatory. It shows superbubbles produced by the combined effect of thousands of supernovae, as well as dozens of bright point-like sources produced by neutron stars and black holes (NASA/SAO/Fabbiano, Zezas & Murray, 2001).

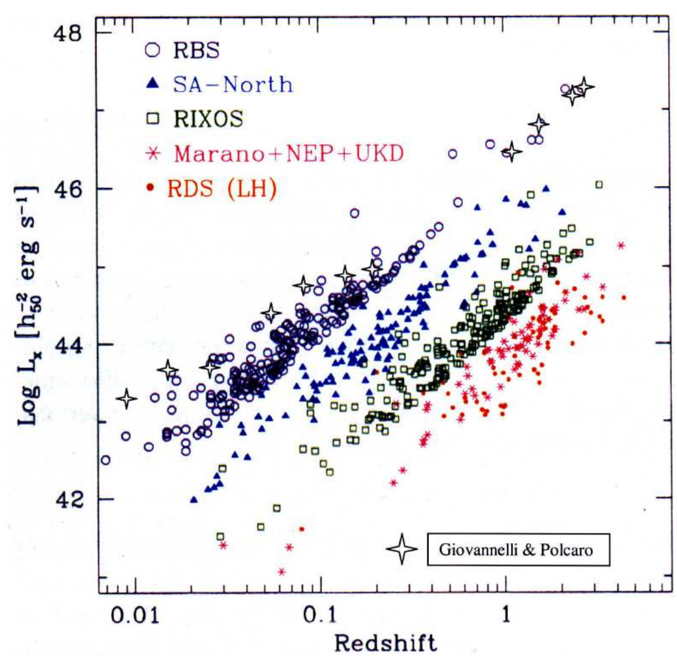

Fig. 5 X-ray luminosity of different samples of extragalactic emitters versus redshift (Hasinger, Miyaji & Schmidt, 2000)). Stars indicate the points of the maximum luminosity diagram of Giovannelli & Polcaro (1986).

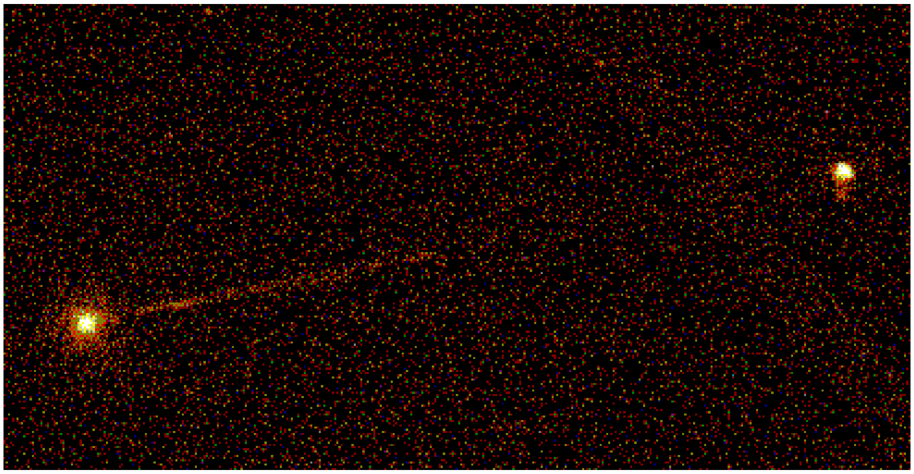

Fig. 6 The spectacular jet that emanates from the center of the galaxy Pictor A (left) and extends across 360 thousand light years toward a brilliant hot spot, which is at least 800 thousand light years (Chandra X-ray Observatory ACIS Image Credit: NASA/UMD).

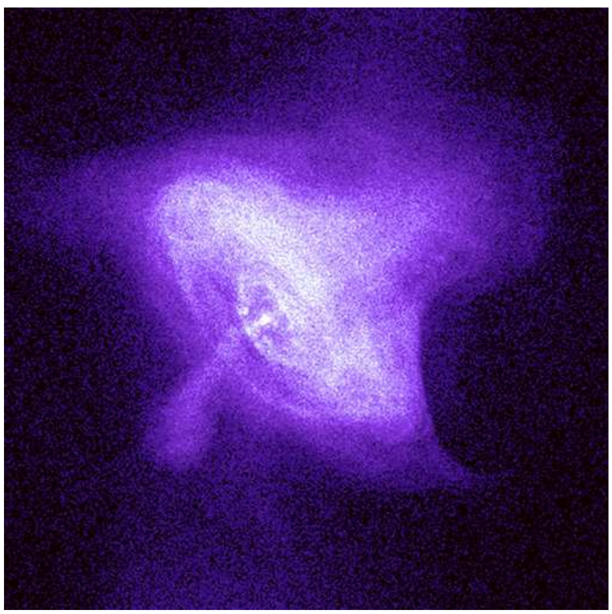

Fig. 7 The central Crab pulsar surrounded by tilted rings of high-energy particles. Perpendicular to the rings, jet-like structures produced by high-energy particles blast away from the pulsar (NASA/CXC/SAO).

Two astonishing examples are reported by the Chandra X-ray images of Pictor A (Fig. 6) and the Crab Nebula (Fig. 7). Figure 6 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 7 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).

6 GAMMA-RAY BURSTS

Gamma-Ray Bursts (GRBs) constitute the hottest argument of modern astrophysics. Indeed, in spite of 2704 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. Such an updated isotropic, but not homogeneous, distribution is shown in Figure 8, where 2704 GRBs are represented. The number of GRBs has further increased thanks to the detections of the BeppoSAX, RossiXTE, and HETE satellites and in the near future will increase too because of the measurements of the INTEGRAL mission.

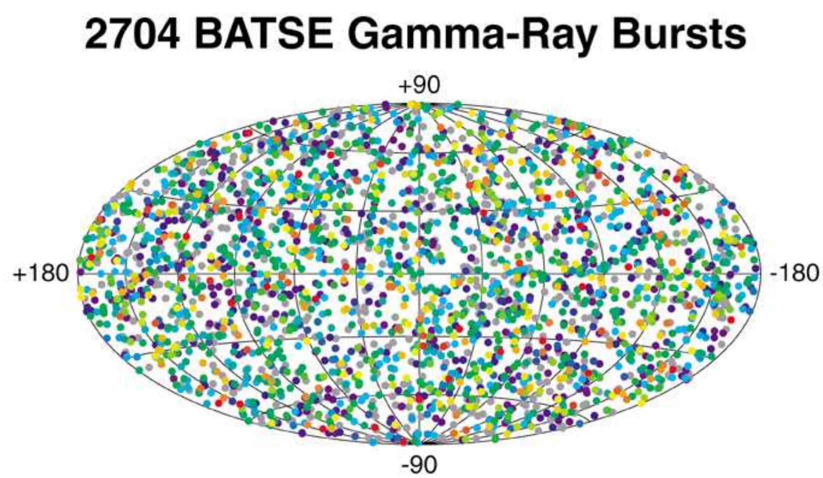

Fig. 8 Distribution of 2704 GRBs detected by the BATSE experiment on board the CGRO from 1991 to 1999. (http://www.batse.msfc.nasa.gov/data/grb/skymap)

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), and Pian (2002) 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 ($1.7 \pm 0.2\%$) ~ 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 28 GRBs detected by different satellites, for which the redshifts of the *host galaxies* have been determined (Djorgovski et al., 2001; Greiner, 2002).

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).

Figure 9 shows the energy spectrum of an extragalactic GRB compared with the spectra of Crab Nebula & Pulsar, an X-ray burst and an X-ray binary (courtesy of Kevin Hurley, 2002): left panel shows the flux vs energy; right panel shows the energy per decade vs energy.

High resolution GRB spectroscopy may reveal more details and, consequently, new surprises: This will be possible very soon with the INTEGRAL mission, like discussed by Hurley (2001). He commented also 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

Table 1 Gamma-ray bursts, detected by different satellites and the redshifts of the host galaxies (Djorgovski et al., 2001; Greiner, 2002)

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

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 future experiments such as Milagro.

In spite of the enthusiasm in accepting the cosmological nature of GRBs, our opinion is, at the moment, that the extragalactic origin of GRBs has not yet definitively demonstrated, at least for most of them. The problem in explaining the origin of the immense amount of energy associated to extragalactic GRBs is still under discussion. 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. Bisnovatyi-Kogan (2002) and Kundt (2001, 2002).

7 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

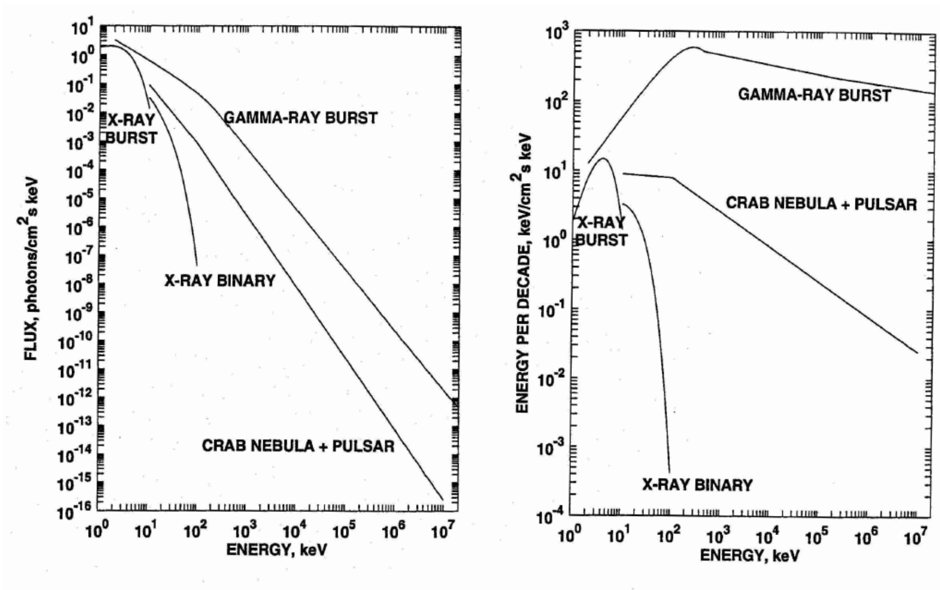

Fig. 9 GRB energy spectrum compared with those of Crab Nebula & Pulsar, an X-ray burst and an X-ray binary (courtesy of Kevin Hurley, 2002).

strictly related to high energy processes and vice versa. We jump here the discussion on X-ray binary systems, inviting the reader to see the specific paper *X-Ray Binary Systems: A Laboratory for Frontier Physics* (Giovannelli & Sabau-Graziati, this volume, and the references therein).

8 RADIO PULSARS, MILLISECOND PULSARS

Radio pulsars discovered by Hewish et al. (1968) are rotating magnetic neutron stars (Pacini, 1967) whose radio emission is highly directional. Radio beams are generally not aligned with the rotational axis and therefore their rotation produces a "lighthouse" effect observed on Earth as radio pulses. Then, the rotating magnetic pulsar emits a magnetic dipole radiation at the rate (Ostriker & Gunn, 1969):

$$L_{\rm mdr} = 2/3c^3 (B^2 R^6 \Omega^4 \sin^2\alpha)\,, \tag{8.1}$$

where B is the polar field strength at the neutron star' surface, R and Ω are the radius and the angular rotational velocity of the neutron star, and α is the angle between the angular momentum axis and the spin axis. The magnetic dipole radiation is emitted at the expense of the rotational energy of the pulsar, which is the cause of the apparent spin-down, corresponding to the rotational energy loss:

$$\dot{E} = -I\Omega\dot{\Omega}\,, \tag{8.2}$$

where I is the moment of inertia of the neutron star. If the observed spin-down is indeed caused by magnetic dipole radiation, the two formulas can be equated. Then, $\dot{E} = L_{\rm mdr}$.

The observable quantities are the rotational period P and the spin-down rate $\dot{P}$. Then substituting these quantities to Ω and $\dot{\Omega}$, it is possible to express the pulsar magnetic field in terms of the observable quantities, by using typical values for the moment of inertia and the radius of the neutron star (Ziółkowski, 1997):

$$B = 3.2 \times 10^{19} (P\dot{P})^{1/2} \text{ G} . \tag{8.3}$$

The rate of energy loss is (Thompson, 2000):

$$\dot{E} \simeq 4 \times 10^{46} \dot{P} P^{-3} \text{ erg s}^{-1} . \tag{8.4}$$

The line open field line voltage is (Thompson, 2000):

$$V \simeq 4 \times 10^{20} \dot{P}^{1/2} P^{-3/2} \, V \simeq \dot{E}^{1/2} . \tag{8.5}$$

Another important parameter expressed in terms of the observable quantities is the apparent age of the pulsar $\tau = P/2\dot{P}$. The value of τ gives the present time scale of the spin-down of the pulsar; then it is called the "spin-down" age of the pulsar. If the magnetic field of the pulsar is not substantially changed since its birth, τ gives the true age of the pulsar. Another estimate of the age is possible through the age of the associated SNR. This is the "kinematic age" based on the proper motion and the distance to the galactic plane. Similarly, the estimate of the magnetic field strength based on the cyclotron lines detected in X-ray pulsars or the spin-up and spin-down properties of X-ray pulsars provide results in reasonable agreement with those obtained from the equation (8.3). Then, this equation and the spin-down age are useful tools for estimating magnetic fields and ages of pulsars, but with the hypothesis of the constancy of the magnetic field intensity.

Pulsars born with a fast period (order of few tens of millisecond) and strong magnetic fields ($B \geq 10^{12}$ G). The Crab pulsar is the most popular example: $P = 33$ ms, $\log B(\text{G}) = 12.6$, $\log \tau(\text{yr}) = 3.1$, true age is 949 yr. Due to spin-down, the pulse period is increasing, so that an "old" pulsar, with age of $\sim 10^7$ yr, has a rotation period of order of seconds. According to the classical picture, the magnetic field of a neutron star decays on a similar timescale (Gunn & Ostriker, 1970). Due to both processes, the efficiency of the radio emission mechanism is expected to decrease and after reaching the critical value of the ratio B/P^2 the mechanism switches off completely (Sturrok, 1971). In the $\log B - \log P$ diagram, the line $B \propto P^2$, along which the switch off condition is satisfied, is called the "death line". After crossing such a line, the neutron star is no longer a pulsar and this part of diagram is called "graveyard". It occurs at age of $\sim 10^7 - 10^8$ yr. The pulsars in the graveyard are not only radio quiet, but are unobservable also in other energy regions. The exception are dead pulsars that are members of binary systems and receive now the matter transferred from their binary companions. Such systems are seen as low mass X-ray binaries (LMXBs).

The first millisecond pulsar PSR 1937+21 discovered by Backer et al. (1982) became immediately a sensation because of its unusually fast rotation ($P = 1.56$ ms). Soon after two more millisecond pulsars were discovered: PSR 1953+29 ($P = 6.13$ ms) and PSR 1855+09 ($P = 5.36$ ms). These new fast pulsars had very weak magnetic fields ($\log B(\text{G}) \sim 8.5$) and very long spin-down ages ($\tau \sim 2 \times 10^8 - 5 \times 10^9$ yr). Their properties seemed paradoxical, since weak magnetic fields and long spin-down ages would indicate very old objects. At the same time, the very rapid rotations would indicate very young aged objects. The apparent paradox was solved soon (Radhakrishnan & Srinivasan, 1984) under the hypothesis that these new objects were descendants of the old dead pulsars, which were spun-up and so resurrected to a new life due to reprocessing through a binary evolution. Therefore the term "recycled pulsars" was coined.

Then, recycled radio pulsars are very old neutron stars, which spent some time in the graveyard, but were resurrected due to spin-up associated with the accretion of matter from their binary companions. Their progenitors were, therefore, LMXBs. For reviews on this topic, see the papers by Ziółkowski (1997, 1999). The spin periods of recycled pulsars are similar to those observed in LMXBs and are consistent with the expected outcome of the accretion spin-up process. A magnetized neutron star, which accretes matter from the companion is expected to adjust its rotation to the so-called *equilibrium period*. This period is defined as a period at which the accelerating accretion torque (spin-up torque) and the braking propeller torque (spin-down torque) balance each other, and the spin period, in the first approximation, remains constant (e.g. Ghosh & Lamb, 1979). In a simplified description, this corresponds to the situation when the outer edge of the magnetosphere rotates with Keplerian velocity. The equilibrium period is directly related to the magnetic field strength and to the accretion rate (e.g. Ziółkowski, 1999 and references therein). By using the Eddington limited accretion rate $\approx 10^{18}$ g s^{-1}, one obtains the expression for the shortest rotational period to which a neutron star of a given B could be spun-up by accretion:

$$P_{\rm eq} \approx 0.7 B_{12}^{6/7} \text{ s} \,. \tag{8.6}$$

This equation defines the so-called "spin-up line" in the $\log B - \log P$ diagram.

There is a strong observational evidence (Bhattacharya, 1995; Ziółkowski, 1997) that magnetic fields decay in the neutron stars accreting the matter during the binary evolution. Figure 10 shows the magnetic field versus the spin period for known radio pulsars (Ziółkowski, 1999).

In spite that about 1000 "second" pulsars are known, after the recent discovery of few hundreds new pulsars (D'Amico, 2000) and the class of millisecond pulsars (e.g. Bailes & Lorimer, 1995) is becoming rather populated, the problem of the continuity between the two classes still deserves further studies both experimental and theoretical, as well as the problem of the so-called *death line* whose slope is model dependent. Indeed, the idea of the *death line* was coming from the experimental evidence on the complete absence of radio pulsars with periods exceeding few seconds. In this picture, beyond this boundary, pulsars with low spin rate cannot accelerate particles above the stellar surface to high enough energies to initiated pair cascades trough curvature radiation, and the pair creation needed for radio emission is strongly suppressed. But this line has been violated at least once; then a re-consideration of such a picture is mandatory.

Baring & Harding (1997) postulate the existence of another pulsar *death line* corresponding to high magnetic field $B \sim 10^{13}$ G in the upper part of the $\dot{P} - P$ diagram, a domain where few radio pulsars are observed. The origin of this high B boundary is due to the suppression of magnetic pair creation $\gamma \rightarrow e^+e^-$. Above this boundary, pulsars are expected to be radio quiet, but perhaps still X-ray and γ-ray bright.

The X-ray observatories of 1990's, like ROSAT, ASCA, BeppoSAX and RXTE have achieved important progress in neutron star and pulsar astronomy. The identification of Geminga, the discovery of X-ray emission from millisecond pulsars and the identification of cooling neutron stars are only few of the fascinating results. Becker (2000) briefly review on the X-ray emission properties of rotation-powered pulsars and their wind nebulae as observed by the experiments aboard the former satellites.

Millisecond pulsars form a separate group among the rotational-powered pulsars. They are distinguished by their small spin period ($P \leq 20$ ms) and high rotational stability ($\dot{P} \approx 10^{-18} - 10^{-21}$) and consequently they are very old objects with spin-down ages up to $10^9 - 10^{10}$ yr and magnetic field strengths of order of $10^8 - 10^{10}$ G.

ROSAT, with a significant higher sensitivity compared with previous X-ray satellites, allowed for the first time to detect X-ray emission from objects as faint as millisecond pulsars. However, although 10 of the 34 detected rotation-powered pulsars belong to the small group

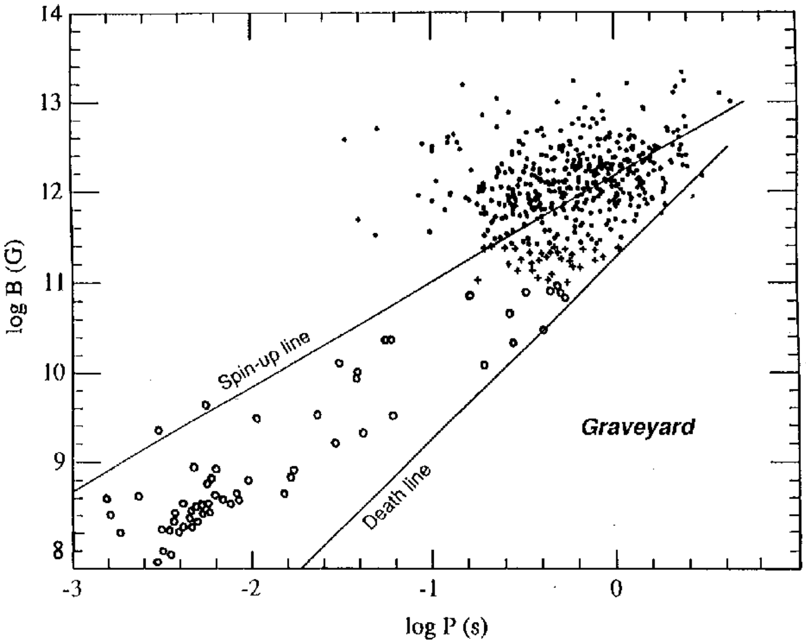

Fig. 10 The magnetic field B versus the spin period P for known radio pulsars. Young pulsars are shown with dots, recycled pulsars with open circles, possible recycled pulsars with crosses (Ziółkowski, 1999).

of millisecond pulsars, the origin of the detected X-ray emission for most of them is not yet known (for a review, see Becker & Trümper, 1998). Five of the ten millisecond pulsars (PSR 1957+20, PSR J10912+5307, PSR J0751+18, PSR J1744-1134, and PSR J1024-0719) are identified by ROSAT only by their positional coincidence with the radio pulsar, and in view of the low number of detected counts do not provide much more than a rough flux estimate. These objects are so faint that the sensitivity of AXAF-Chandra and XMM-Newton is needed to detect enough photons required for a detailed spectral and temporal study in the soft and hard bands beyond 2 keV. More detailed results have been found for the other 5 millisecond pulsars (PSR 1821–24 in M28, PSR 1937+21, PSR J0218+3242, PSR J0437–4715, and PSR J2124–3358), which all provide important empirical information on the pulsar's X-ray emission mechanisms, as discussed by Becker (2000).

However, putting the observed emission properties of the detected millisecond pulsars in a somewhat wider frame, Becker & Trümper (1997) found that the X-ray luminosity of the detected millisecond pulsars show the same linear relationship with the same X-ray efficiency as the Crab-like pulsars, as shown in Figure 11, indicating that the bulk of their emission is mainly due to non-thermal processes. As remarked by Becker (2000), the occurrence of power-law spectra in PSR 1821-24 and PSR J0437-4715 and the similarity between the radio/X-ray pulse profiles seen also for PSR J0218+3242 and PSR J2124-3358 may be considered as providing additional evidence for a non-thermal origin of the millisecond pulsars' X-ray emission.

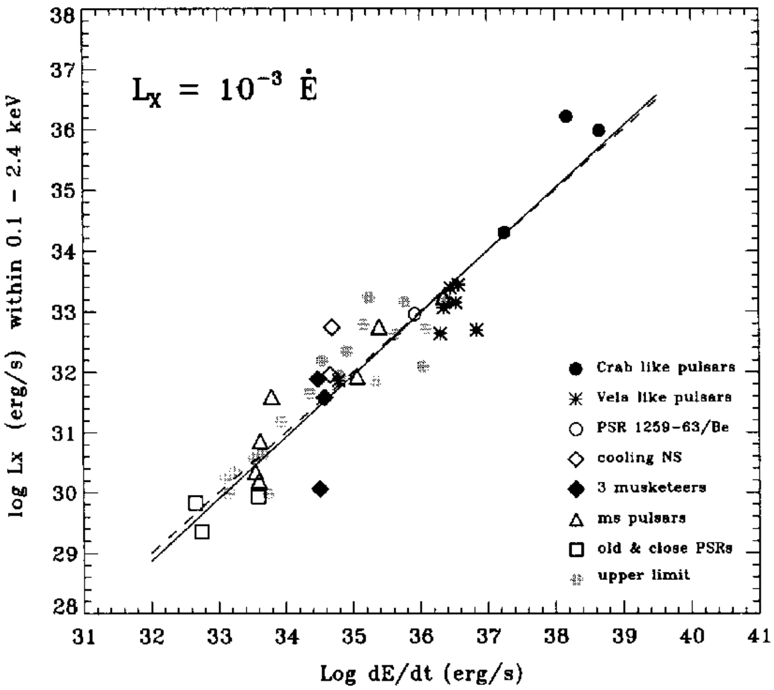

Fig. 11 X-ray luminosity of the ROSAT detected rotation-powered pulsars versus the pulsars' spin-down energy $\dot{E}$. Thermal spectral components have been subtracted. Although field pulsars and millisecond pulsars form well-separated populations, they obey the same X-ray efficiency (see Becker & Trümper, 1997 and discussion therein). The close correlation between $L_{\rm x}$ and $\dot{E}$ strongly suggest that the bulk of the observed X-rays is emitted at the expense of rotational energy, as it is observed for the radio and γ-ray emission (Becker, 2000).

Becker (2000) discussed also the other groups of rotation-powered pulsars and concluded that: the current findings of the pulsars' emission properties show that young pulsars with ages of less than $\sim$ 2000 yr appear Crab-like (i.e. bright synchrotron nebula, sharp X-ray pulses with high pulsed fraction), whereas $\sim 10^4 - 10^5$ yr old pulsars resemble more the emission properties observed for the Vela pulsar (i.e. X-ray emission beyond 0.5 keV dominated by the emission from the pulsar-driven synchrotron nebula, soft pulses only observable from the Vela pulsar). However, although these emission properties are found to fit very well for the young rotating-powered pulsars (i.e. radio pulsars) there is strong evidence that they are not representative for the whole sample of young neutron stars, which exist in our Galaxy. Topics, which are discussed in respect to this are soft γ-ray repeaters and anomalous X-ray pulsars.

Figure 12 shows the period versus the period derivative for many of the known pulsars, showing three of the derived parameters, namely spin-down age, surface magnetic field and open field line voltage, which are reported too (Thompson, 2000).

Thompson (2000) discussed the high energy emission from active pulsars. He found that non-thermal emission is seen from some pulsars across much of the electromagnetic spectrum, implying acceleration of particles to high energies. The power for this process usually comes from the rotation of the magnetized neutron star. The luminosity of these pulsars peaks in the

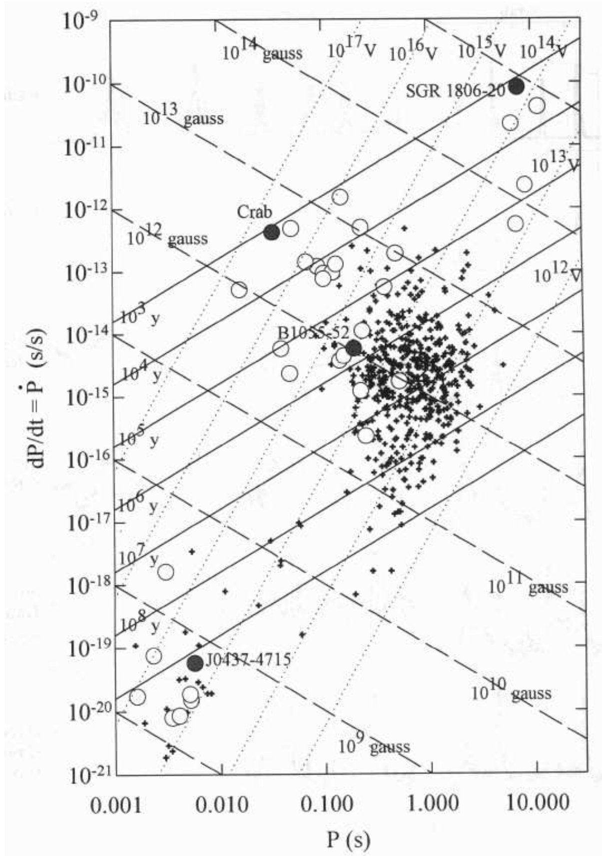

Fig. 12 Period versus the period derivative for many of the known pulsars, showing three of the derived parameters, namely spin-down age, surface magnetic field and open field line voltage are reported too (Thompson, 2000).

X-ray to γ-ray bands. The light curves for some of these pulsars suggest particle acceleration and radiation from a hollow surface above one magnetic pole of the star. Multifrequency observations have been used to construct and test models of high energy pulsar radiation. Although no single model for high-energy emission from pulsars has emerged, the observations with the present generation of high-energy telescopes have channelled all models in certain directions:

- the particle acceleration by the strong electric fields takes place somewhere above the magnetic poles;
- the principal high-energy emission processes are synchrotron radiation, curvature radiation, and inverse Compton scattering, with thermal-emission secondary contributor;
- the high-energy pulsed emission is probably associated with a single magnetic pole of the neutron star.

Thompson (2000) pointed out several open questions about spin-down pulsars:

- Where in the magnetosphere are the particles accelerated?

– What is the shape of the beam?
– Are there many more radio-quiet pulsars to be found in X-rays and γ-rays?
– How do these recent discoveries affect our thinking about supernovae and neutron star formation?

These open questions can be solved by improving the studies of the X-ray archives of the ROSAT, ASCA, BeppoSAX, and RXTE, while AXAF-Chandra, and XMM-Newton will give significant improvements in sensitivity and resolution. In the γ-ray range, the study of the CGRO archives and the new data from the INTEGRAL mission will help in filling some gaps in such a low-energy γ-ray band. The next major step in high-energy γ-rays will come with the GLAST experiment (e.g. Kamae, et al., 2000).

How pulsars born and if they are isolated or lie in binary systems, and what is the ratio between the number of isolated pulsars and the number of pulsars in binary systems still constitute open problems. Attempts in determining associations among pulsars and SNRs have been done by several authors in the case of isolated pulsars (e.g. Kaspi, 1998) and in that of X-ray pulsars in binary systems (Giovannelli et al., 1993a; 1994; Giovannelli & Sabau-Graziati, 2000).

It has been demonstrated that such associations exist; this proves theories predicting formation of pulsars by SN explosions in collapsing isolated progenitors or SN symmetric or asymmetric explosions in binary-system progenitors. Isolated pulsars are the remnants of a SN explosion of a collapsing isolated progenitor, or of a SN explosion in a binary-system progenitor with disruption of the binary system itself. Pulsars in low and high eccentricity binary systems are the remnants of symmetric or asymmetric SN explosions, without the disruption of the binarity of the systems.

In the latter two cases, a neutron star is orbiting around an early-type supergiant, giant or main sequence star.

This kind of association is very useful not only for the point of view of the evolution of binary systems, but also for calibrating the ages of the binary systems and associated SNRs: their ages must be of course the same. This allows to make a check of the theories of the evolution of binary systems, the braking of the pulsars and the development of a SNR after the explosion. Evolutionary theories of SNRs are mainly based on their radio behavior, while evolutionary theories of binary systems are mainly based on their optical and X-ray behavior. Therefore, so different methods of sounding so different cosmic objects are a powerful tool of cross-checking a lot of astrophysical problems.

However, for determining the veracity of most proposed associations, future proper motion and multi-frequency studies are needed.

9 COSMIC COUNTERPARTS OF GAMMA-RAY SOURCES

After EGRET experiment on board CGRO satellite, more than 200 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. Also most of the 271 γ-ray sources of the 3^{rd} EGRET Catalog (Hartman, et al., 1999) are still not associated with known cosmic sources. 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).

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

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) (still under discussion). 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. 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 already discussed by Bednarek & Giovannelli (1999) and the references therein.

Recently, 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 recent discovery of the X-ray transient V 4641 Sgr, which has a ~ 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.

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.

10 SOME IDEAS ON FUTURE MISSIONS

In the study of cosmic sources three resolutions are crucial for a better comprehension of the physics governing their behavior, namely (e.g. Giovannelli & Sabau-Graziati, 1997):

i) Resolution in Energy: better resolution allows the detailed studies of astrophysical plasmas and line profiles (e.g. the X-ray missions ASCA, BeppoSAX, CHANDRA, XMM, the X- and γ-ray missions INTEGRAL, and the future SPECTRUM X-Γ, if it will be launched);

ii) Resolution in Position: increasing this resolution it is possible to distinguish close sources in a crowded field (i.e. Galactic Center X-ray sources) (e.g. CHANDRA, XMM, INTEGRAL). Future X-ray experiments could discern protoclusters and protogalaxies and finally, with interferometric techniques, it will be probably possible to look at accretion disks and stellar surfaces;

iii) Resolution in Sensitivity: increasing this resolution it is possible: a) to detect weaker sources (i.e. ROSAT has detected more than 100,000 soft X-ray sources, most of them before ROSAT confused in the background radiation); b) to detect either flux variations at lower levels in a fixed Δt, or flux variations at higher levels but in shorter time scales (e.g. CHANDRA, XMM, RXTE, ASCA and INTEGRAL).

Since most of the energy ranges are forbidden by ground-based observations, space-based experiments must be developed, following the general trend in increasing their sensitivities, compatibly with reasonable costs. But the spectral resolution in most of the energy bands is very close to the theoretical one. So, only by increasing the dimensions of the detectors it will be possible to reach lower threshold in intensities. An exception is the spatial resolution, that can be improved a lot by interferometric techniques.

Only genial ideas for new detectors could provide a significant step in the increase of their performances.

In Figure 13 the main high energy experiments from the beginning of 1990s to next decade are reported with their ranges of detection (Morselli, 2002). Most of these experiments are already operating since 2002. In Figure 14 the sensitivity of the past and future experiments is reported (Morselli, 2002).

Our opinion is that small satellites of the class of the Japanise ASTRO-Series, American-RXTE, Italian-AGILE, and Spanish MINISAT-Series can solve important astrophysical problems in the next decades, provided that they could be dedicated to specific missions, such as for instance the proposed payload SIXE (Spanish Italian X-ray Experiment) (Giovannelli et al., 1993b; Gómez-Gomar et al., 1999; Isern et al., 2001; Giovannelli et al., 2001,2002). Of course,

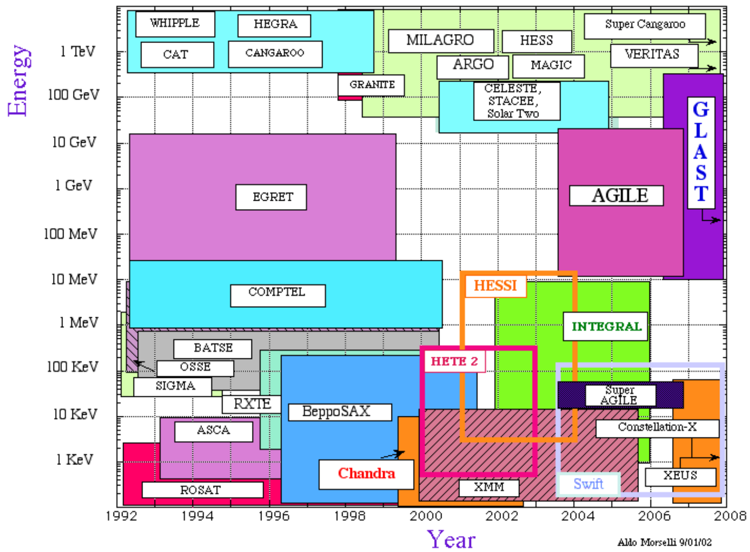

Fig. 13 Main high energy experiments and their ranges of detection from 1992 to 2008 (courtesy of Aldo Morselli, 2002).

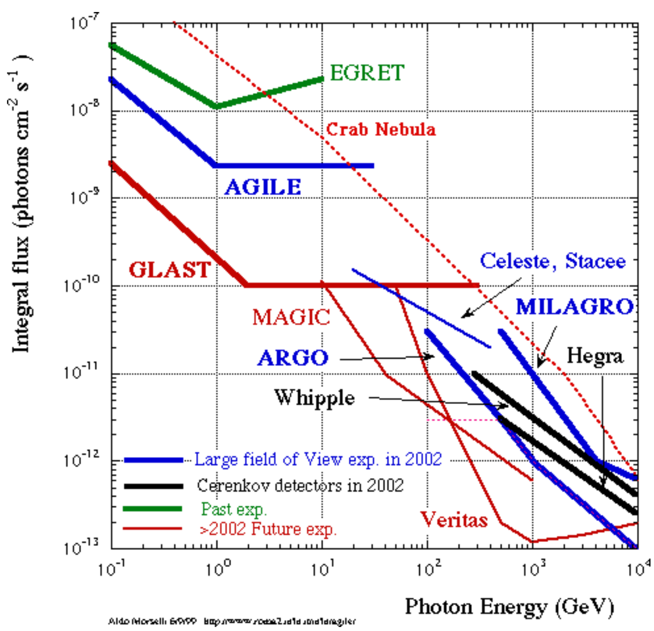

Fig. 14 Sensitivity of the past and future experiments. All sensitivities are at 5σ. Cerenkov-telescopes sensitivities (Veritas, MAGIC, Whipple, Hess, Celeste, Stacee, Hegra) are for 50 hours of observations. Large field of view detectors sensitivities (AGILE, GLAST, Milagro, ARGO) are for 1-year observation. MAGIC sensitivity is based on the availability of high efficiency PMT's (courtesy of Aldo Morselli, 2002).

this line of mini-satellites does not exclude bigger projects, provided that these could allow to different individual countries and Agencies to support also the smaller programs.

In general we believe that in the next decades the advances on the knowledge of the physics will necessarily pass through an improvement of passive-physics experiments both space- and ground-based. This is enforced also by the fact that the big ground-based active-physics experiments have already reached reasonable upper limits in dimensions, costs and complications.

11 CONCLUSIONS

In this paper we have discussed several of the most important problems of astrophysics today and the hot questions still open have been remarked.

Meaningful result is that on the Hubble constant. Its most probable value deduced from HST measurements is 59 ± 6 km s^{-1} Mpc^{-1}, while 56 ± 6 km s^{-1} Mpc^{-1} seems to be highly favored by a comparative analysis of all the determinations and indirectly by the necessity of this value in order to have agreement with the inflation and BBN theory.

Important example on the necessity of increasing the spectral and sensitivity resolutions in the next generation experiments is coming from ROSAT measurements, which allowed for the first time i.e. to detect X-ray emission from objects as faint as millisecond pulsars, but not to establish the origin of the detected X-ray emission for most of them. These objects are so faint that the sensitivities of AXAF-Chandra and XMM-Newton are necessary to detect enough photons required for a detailed spectral and temporal study in the soft and hard bands beyond 2 keV. However, in spite of the higher sensitivities of the latter satellites, only empirical information on the pulsar's X-ray emission mechanisms have been reached (Becker, 2000). So, for solving this problem, even higher sensitivities are needed.

We want to remark several more points, like those on: i) the power of X-ray measurements (e.g. from ASCA), which appeared evident for the knowledge of clusters of galaxies and then cosmology; ii) high time resolution measurements, like those of RXTE, which pointed out how it is possible to investigate on degenerate matter of neutron stars and on accretion processes. Then on the possibility of using the studies of the accretion processes in close binary systems for knowing those in cosmological active galaxies; iii) Beppo-SAX measurements, which provided a substantial improvement on knowledge of the GRB origin.

It is mandatory to remark on the importance of simultaneous multifrequency measurements, which can improve our knowledge on many problems of astrophysics and in particular on the accretion processes onto collapsed objects and then on plasma physics.

But, 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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DISCUSSION

JAMES H. BEALL: The picture of the jet you show in Pic A is one-sided for a significant distance. This appears to be a relativistic effect. Can you comment?

FRANCO GIOVANNELLI: It is true. Indeed, 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. One possible explanation for the X rays is that shock waves along the side and head of the X-ray jet are boosting electrons and possibly protons to ultra-relativistic energies. Jets are thought to be produced by the powerful electromagnetic forces created by magnetized gas swirling toward a black hole. Although most of the material falls into the black hole, 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. For details on the X-ray jet, detected by the CHANDRA satellite, see the papers by Schwartz et al.: 2000, ApJ **540**, 69. For the extended X-ray emission from the eastern radio lobe of Pic A, detected by XMM-Newton satellite, see the paper by Grandi et al.: 2003, ApJ **586**, 123.