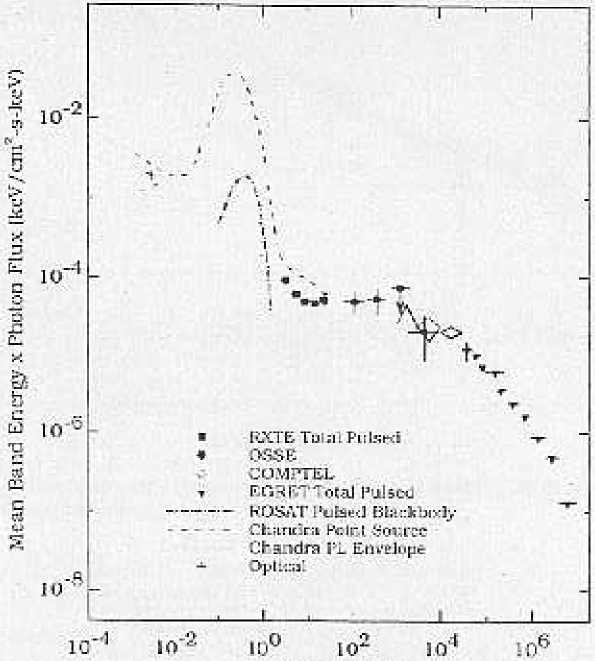

FIGURE 3. Total pulsed spectrum of the Vela Pulsar.

other spectral features will pose an important constraint on physical parameters such as emission altitude. None of the existing models are yet sufficiently refined to make predictions concerning phase-resolved spectrum behavior in this band, but these observations will supply an impetus to move in that direction.

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BeppoSAX observations of the γ-ray pulsars PSR B0656+14 and PSR B1706−44

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Abstract. The Italian-Dutch satellite for X-ray astronomy BeppoSAX observed the two γ-ray pulsars PSR B0656+14 and PSR B1706-44 in March 1999. Both sources were detected in the LECS and MECS images. No evidence of modulation with the pulsars' period was found. The X-ray spectrum of PSR B0656+14 is complex and requires a three component model, while that of PSR B1706-44 can be fitted by a single power law.

INTRODUCTION

The study of the X-ray emission of γ-ray pulsars is important for the understanding the physical processes occurring in the magnetosphere of these sources. Several models predict the production of a large number of secondary electron-positron pairs originated by the interaction of primary high energy curvature photons with the intense magnetic field. These pairs are expected to radiate X rays via the synchrotron mechanism. Other important emission processes of X-ray photons are the thermal (blackbody) radiation from the polar caps, heated by the impinging of high energy particles, and the inverse Compton effect. Finally, in the case of young pulsars, X rays can be emitted in a compact synchrotron nebula surrounding the neutron star. In order to discriminate among these possibilities it is important to perform very detailed and precise observations of several sources of this class. In this contribution we present the preliminary results of the spectral analysis of the X-ray emission from two EGRET γ-ray pulsars observed by the Italian-Dutch satellite BeppoSAX.

PSR B0656+14 was discovered by Manchester et al. (1978) and, in the X-ray band, a pulsed signal at the radio period was observed by Cordova et al. (1989). γ-ray emission in the EGRET band has been reported by Ramanamurthy et al. (1996). ROSAT PSPC observations (Finley et al. 1992) showed that the 0.1–2.4 keV spectral distribution can be well fitted by two blackbodies or by a blackbody plus a power law. Greiveldinger et al. (1996), on the basis of ASCA and ROSAT data, proposed a three component model (two blackbodies plus a power law), while Wang et al. (1998) found that only two blackbodies without a power law are sufficient to have a satisfactory spectral fit.

PSR B1706−44, a young pulsar with a period of 0.102 s was discovered in the radio band by Johnston et al. (1992) and an unpulsed X-ray was first detected by Becker et al. (1995) with ROSAT PSPC. In the more recent X-ray observations performed with ASCA

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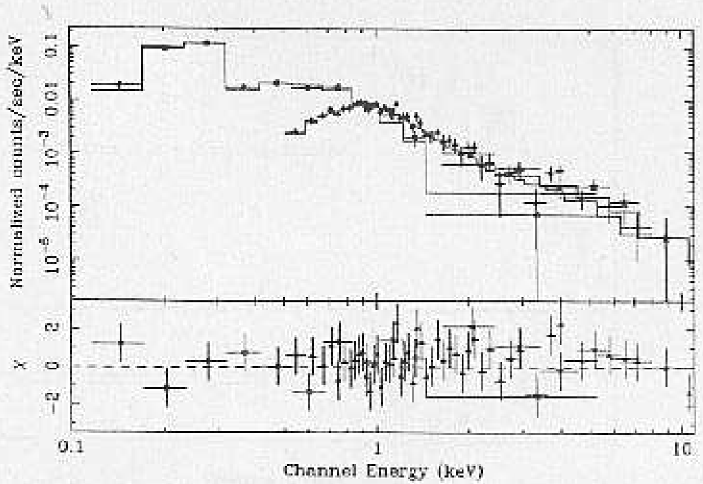

FIGURE 1. Spectral fit of the LECS (open circles), MECS (stars) and ASCA GIS (triangles) spectra of PSR B0656+14 with two blackbody plus power-law model

TABLE 1. Best fit values for the three component spectrum of PSR B0656+14

Parameter (unit)	Value
N_H (10^{20} cm^{-2})	3.4±1.1
kT_1 (keV)	$(5.89\pm0.48)\times10^{-2}$
$Norm_1$ (erg s^{-1} kpc^{-2})	$(3.64\pm0.11)\times10^{-4}$
kT_2 (keV)	0.12 ±0.01
$Norm_2$ (erg s^{-1} kpc^{-2})	$(4.26\pm0.13)\times10^{-5}$
Photon Index	2.10 ±0.23
PL Norm.	$(6.61\pm0.86)\times10^{-5}$

(SIS+GIS) (Finley et al. 1998) and RossiXTE (Ray et al. 1999) no pulsed emission was detected. SIS and GIS spectra in the (0.5–5) keV range were fitted by a power law with a photon index ranging from 1.6 to 1.9 and column densities of (1.3–2.2) 10^{21} cm^{-2}, but these values are poorly constrained because of their quite large (1 standard deviation) uncertainties of about 0.3 and 1.3 10^{21} cm^{-2} (and even more), respectively. A spectral fit with the higher column density fixed at 5 10^{21} cm^{-2} gave the steeper photon index of 2.3 ± 0.3. A γ-ray source was detected by COS B (Swanenburg et al. 1981) and the pulsation at energies greater than about 50 MeV was found by EGRET-CGRO (Thompson et al. 1992). An unpulsed source at TeV energies has been detected by the CANGAROO collaboration (Kifune et al. 1995). McAdam et al. (1993) proposed a possible association of PSR 1706−44 with SNR G343.1-2.3, but the VLA images by

Frail et al. (1994) indicated that it may be located inside a plerionic nebula. Evidence for a X-ray compact nebula (with a radius of about 27") was also found by Finley et al. (1998) in a ROSAT-HRI image.

OBSERVATIONS AND DATA REDUCTION

BeppoSAX observed PSR B0656+14 and PSR B1706−44 in 1999: the former from March 9 to 11 and the latter from March 29 to 31. The LECS and MECS images show sources at positions fully compatible with the radio coordinates. In the case of PSR B0656+14 the events for the time and spectral analysis were selected within circular regions, centred at the radio position, with radii of 4' and 3' for the LECS and MECS, respectively. The background was estimated from annular regions in the same fields and from a collection of blank field images. The the local background evaluation for PSR B1706−44 was more difficult because of the presence of the near bright LMXRB 4U 1705-44. In order to get a reliable evaluation of the local background in the MECS image, we computed the count level in a series of adiacent small circular regions, radially located with respect to the binary source in the pulsar direction. Then we fitted these values with an analytical formula excluding the pulsar region, and we assumed the value interpolated at its position as the background estimate. The same procedure applied to the LECS data, which have a much poorer statistics and a wider PSF, gives a detectable signal only in the energy channels up to about 1.5 keV. We therefore considered only the low energy photons included in a single bin from 0.1 to 1.5 keV.

We also searched for pulsed emission from both sources. We used the folding technique with extrapolated radio ephemeris to the observations epochs and also a period search using the Z^2 statistics with one and two harmonics, but no significant signal was detected, even considering various energy ranges.

Finally, because the spectrum of PSR B0656+14 resulted quite complex, to obtain a more accurate estimate of the various components we considered another observation of this pulsar, performed by ASCA on 1998 October 11 and available from the archive, and joined it to our BeppoSAX data.

SPECTRAL ANALYSIS

PSR B0656+14

On the basis of literature results, we used multicomponent spectral models to fit the LECS and MECS data. The fits with an absorbed blackbody + powerlaw and with two blackbodies gave the not acceptable values of the reduced χ^2_r of 2.98 (13 d.o.f.) and 4.10 (12 d.o.f.), respectively, while a power law plus two blackbodies gave the better value of 1.21 (11 d.o.f.). The absorbing column density resulted equal to (3.1 ± 0.8) 10^{20} cm^2 and the photon index of the power law equal to 2.08 ± 0.41, while the blackbodies' parameters were poorly constrained because of the limited statistics. We, therefore, added to the BeppoSAX data set a 153 ks long ASCA (GIS) observation and performed a joint spectral analysis. Any attempt to obtain an acceptable fit with only two components

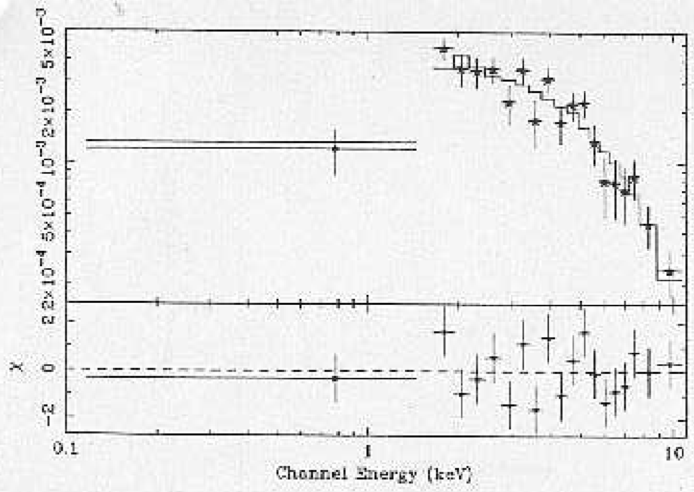

FIGURE 2. Spectral fit of the LECS and MECS spectrum of PSR B1706-44 with a power-law model

failed and a good fit was reached again with two blackbody distributions plus a power law ($\chi_r^2 = 0.97$, 55 d.o.f.), confirming that the X-ray spectrum of this source is complex (see Fig. 1). Our spectral results, reported in Table 1, are generally in agreement with the previous ones: typical differences in the blackbody temperatures are of the order of 20 % while a difference of a factor of two is between our estimate of N_H is and that of Greiveldinger et al. (1996). Similar results have been recently obtained by Zavlin, Pavlov and Halpern (2001) using the same ASCA data added to a ROSAT observation.

PSR B1706−44

The spectral analysis of the LECS and MECS data confirmed that the spectrum of this source can be well described by a single power law. The fit in the energy range 1.6–9 keV, for which the evaluation of the local background contribution due to the near LMXRB is easier, gave a photon index of 1.66 ± 0.13 and a column density $N_H = (2.6 \pm 1.5)\ 10^{21}\ cm^{-2}$, with a reduced $\chi^2 = 1.28$ (15 d.o.f.) (Fig. 2). The residuals show an irregular scatter with respect to the power law continuum, but this may be an effect of the model adopted for the local background evaluation. Using two times wider energy bins, this scatter disappears and the reduced χ^2 lowers to a value smaller than unity but the spectral parameters remain unchanged. The power law best fit with the N_H value fixed at the ROSAT-PSPC result of $5\ 10^{21}\ cm^{-2}$ (Becker et al. 1995) gave a photon index of 1.72 ± 0.12 (reduced $\chi^2 = 1.25$, 16 d.o.f.), practically coincident with the previous value. Furthermore, to be more confident that this result was independent of the local background, we used different estimates of its intensity and spectrum derived from the modified models for the LMXRB contribution. The changes of the best fit spectral

parameters' values were always smaller than the statistical uncertainties. We consider this result the best available information on the X-ray spectrum PSR B1706−44: in particular, the our statistical error of the photon index is about a factor of 3 smaller than that of Finley et al. (1998). Our result then confirms that this radiation is originated in the compact synchrotron nebula around the pulsar.

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