2002MmSAI..73.1066M

# X-Ray Spectral Properties of the $\gamma$-ray Pulsars PSR B0656+14 and PSR B1706-44

E. MASSARO[1,2], T. MINEO[3], G. CUSUMANO[3], B. SACCO[3], W. BECKER[4]
[1] *Istituto di Astrofisica Spaziale, CNR, Via Fosso del Cavaliere, I-00113, Roma, Italy*
[2] *Dipartimento di Fisica, Universitá La Sapienza, P.le A. Moro 2, I-00185, Roma, Italy*
[3] *Istituto di Fisica Cosmica con Applicazioni all'Informatica, CNR, Via U. La Malfa 153, I-90146, Palermo, Italy*
[4] *Max-Planck-Institut für Extraterrestrische Physik, D-85740 Garching bei München, Germany*

**ABSTRACT.** BeppoSAX observed PSR B0656+14 and PSR B1706-44 in March 1999. Both sources were clearly detected in the LECS and MECS images, but no modulation at the radio periods of both pulsars was found. In this contribution we present the results of the spectral analysis which confirms the multicomponent energy distribution of PSR B0656+14, while that of PSR B1706-44 can be well fitted by a single power law.

## 1. Introduction

X-ray observations of $\gamma$-ray emitting pulsars are useful to gain more information about the particle acceleration and high energy emission in the magnetosphere. Several pulsar models predict the production of a huge number of electron-positron pairs originated by primary high energy curvature photons interacting with the intense magnetic field. These pairs are expected to radiate X rays via the synchrotron mechanism. However, other X-ray emission processes must be taken into account like the thermal (blackbody) radiation from the polar caps, heated by the impinging of high energy particles, and the inverse Compton effect. In young pulsars, X rays can be also emitted by a compact synchrotron nebula surrounding the neutron star. The X-ray spectra are then expected to show several components with different spectral and modulation properties.

In this contribution we present some preliminary results of the spectral analysis of the X-ray emission from two EGRET $\gamma$-ray pulsars observed by the Italian-Dutch satellite BeppoSAX.

PSR B0656+14, having a period of 0.385 s, was discovered in the radio band by Manchester et al. (1978) and in the optical by Shearer et al. (1997) and Pavlov et al. (1997). It was observed in the X-ray band by Cordova et al. (1989), while its $\gamma$-ray emission has been reported by Ramanamurthy et al. (1996). The X-ray spectrum has been modelled by means of superposition of two or three components: two blackbodies (Finley et al. 1992, Wang et al. 1998), a blackbody plus a power law (Finley et al. 1992), and two blackbodies plus a power law (Greiveldinger et al. 1996).

PSR B1706−44 is a young pulsar with a period of 0.102 s. It was discovered in the radio band by Johnston et al. (1992) and an unpulsed X-ray emission was first detected by Becker et al. (1995) with ROSAT-PSPC. In more recent observations with ASCA (SIS+GIS) (Finley et al. 1998) and RossiXTE (Ray et al. 1999) again 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 around 1.75 and column densities of (1.3–2.2) $10^{21}$ $\mathrm{cm}^{-2}$, but these values are poorly constrained because of their quite large (1 standard deviation) uncertainties of about 0.3 and 1.3 $10^{21}$ (and even more), respectively. A $\gamma$-ray source was early detected by COS B (Swanenburg et al. 1981) and the pulsation above 50 MeV was first observed by EGRET-CGRO (Thompson et al. 1992). A detection at TeV energies has been obtained with the air Cerenkov telescope by the CANGAROO collaboration (Kifune et al. 1995). McAdam et al. (1993) proposed the association of PSR 1706−44 with the SNR G343.1-2.3, but the VLA images by Frail et al. (1994) indicated that this pulsar may be located inside a plerionic nebula. Evidence for an X-ray compact nebula (with a radius of about 27") was also found by Finley et al (1998) in a ROSAT-HRI image.

## 2. Observation and Data reduction

BeppoSAX observed PSR B0656+14 and PSR B1706-44 in March 1999: the former from March 9 to 11 and the latter from March 29 to 31. The images in the LECS and MECS instruments 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. Background was estimated from annular regions in the same fields and from a collection of blank field images. We also considered an ASCA observation performed on 1998 October 11 and available from the archive, and added these data to those of BeppoSAX.

The event selection and the local background evaluation for PSR B1706−44 was much more difficult because of the presence of the near bright LMXB 4U 1705-44. To get a reliable 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 a simple analytical formula to these values , excluding the region containing the pulsar, and the interpolated value at its position was taken as the proper background estimate. The same procedure applied to the LECS data, which have a much poorer statistics and a wider PSF, shows a detectable signal only in the channels corresponding to energies lower than 1.5 keV, and all these events were included in a single bin from 0.1 to 1.5 keV.

We searched for pulsed emission from both sources using either a period folding with the radio ephemeris extrapolated at the observations epochs and a period search using the $Z^2$ statistics with one and two harmonics. No statistically significant signal was detected for the two pulsars, even considering different energy ranges.

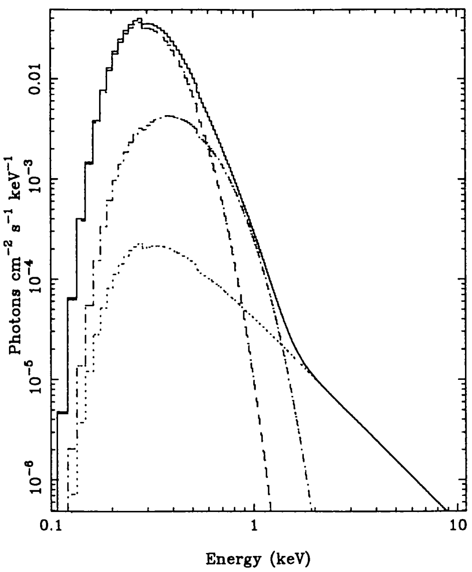

Fig. 1. The three spectral components of PSR B0656+14 according our best fit model (Table 1.)

## 3. Spectral analysis

### 3.1. PSR B0656+14

We used three spectral models to fit the LECS and MECS data. The fits with an absorbed blackbody + power law and with two blackbodies failed to give acceptable values of the reduced $\chi^2$ (greater than 3), while a fit with a power law plus two blackbodies gave a signifcant improvement. 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 improved the statistics adding to the BeppoSAX data a 153 ks long ASCA (GIS) observation and performed a joint spectral analysis. Again, an acceptable fit was reached only using two blackbodies plus a power law: the best fit values of the parameters are listed in Table 1 while these spectral components are shown in Fig. 1. These results are generally in an acceptable agreement with previous literature. 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 $N_H$ 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 an earlier ROSAT observation.

**Tab. 1 - Spectral Parameters of the 3 component model for PSR B0656+14**

| Parameter (unit) | Value |
|---|---|
| $N_{\rm H}$ ($10^{20}$ cm$^{-2}$) | 3.4±1.1 |
| kT$_1$ (keV) | $(5.89\pm0.48)\times10^{-2}$ |
| BB$_1$Norm (erg s$^{-1}$ kpc$^{-2}$) | $(3.64\pm0.11)\times10^{-4}$ |
| kT$_2$ (keV) | 0.12 ±0.01 |
| BB$_2$Norm (erg s$^{-1}$ kpc$^{-2}$) | $(4.26\pm0.13)\times10^{-5}$ |
| Photon Index | 2.10 ±0.23 |
| PL Norm. | $(6.61\pm0.86)\times10^{-5}$ |

### 3.2. 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 gave a photon index of 1.66 ± 0.13 and a column density $N_{\rm H}$ = (2.6 ± 1.5) $10^{21}$ cm$^{-2}$ (reduced $\chi^2$ = 1.2; 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. On the other hand, using two times wider energy bins, this scatter disappears, the reduced $\chi^2$ lowers to a value smaller than unity but the spectral parameters remain unchanged. We also evaluated a power law fit with the $N_{\rm H}$ fixed at the value of 5 $10^{21}$ cm$^{-2}$ obtained from a ROSAT-PSPC observation (Becker et al. 1995), and obtained a photon index of 1.72 ± 0.12 (reduced $\chi^2$ = 1.25, 16 d.o.f.), statistically not different with that reported above. Furthermore, to be more confident that this result was independent of the local background, we used different estimates of its intensity and spectrum all derived from the model used to fit the LMXB contribution: in all cases the best fit spectral parameters changed less than their statistical uncertainties. Other fits computed changing the LECS to MECS intercalibration factor (inside the acceptance range for a point source) gave again fully compatible photon index values. This result provides likely the best available representation of the spectral distribution of PSR B1706−44. In particular, we obtained a statistical error for the photon index about a factor of 3 smaller than that given by Finley et al. (1998).

## 4. Conclusion

The main results of the analysis of the BeppoSAX observations of PSR B0656+14 (in this case also joint to a long ASCA archive observation) and of PSR B1706−44 presented in this contribution can be summarized as follows.

1. No pulsation at the extrapolated radio periods was detected for both sources.
2. The spectral distribution of the X-ray emission from PSR B0656+14 is quite complex. Two component models are excluded by the high $\chi^2$ values while an acceptable model with one power law and two blackbodies, as early proposed by Greiveldinger et al. (1996), gives a good fit.
3. The X-ray spectrum of PSR B1706−44 is well fitted by a single power law with a photon index around 1.7. This value is just the one compatible with that connecting

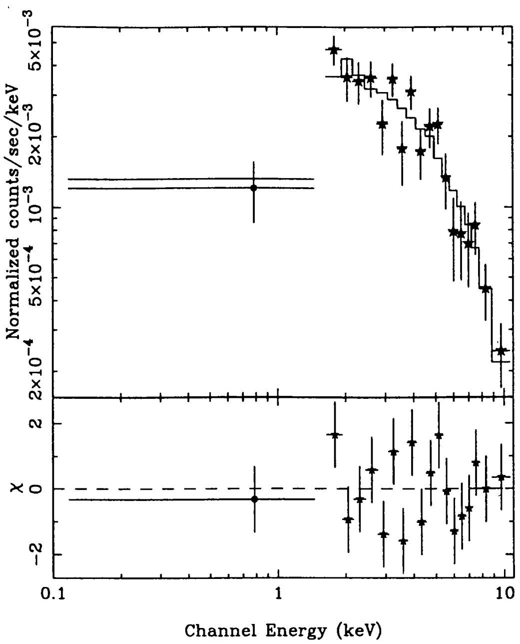

Fig. 2. The data and the best fit power law model for PSR B1706−44 (top panel), residuals (bottom panel).

the radio to X-ray flux (Finley et al. 1998) and seems then to confirm that this radiation is originated in the compact synchrotron nebula around the pulsar.

## Acknowledgements

This work was partially supported by the Italian Ministry of University and Scientific Research through the grant Cofin 99-02-02.

## References

Becker W. et al. 1995, A&A 298, 528
Cordova F.A. et al. 1989, ApJ 345, 451
Finley J.P. et al. 1992, ApJ 394, L21
Finley J.P. et al. 1998, ApJ 493, 884
Frail D.A. et al. 1994, ApJ 437, 781
Greiveldinger C. et al. 1996, ApJ 465, L35
Johnston M. et al. 1992, MNRAS 225, 401

Kifune T. et al. 1995, ApJ 438, 91
Manchester R.N. et al. 1978, MNRAS 185, 409
McAdam D. et al. 1993, Nature 361, 516
Pavlov G.G. et al. 1997, ApJ 489, L75
Ramanamurthy P.V. et al. 1996, ApJ 458, 755
Ray R.D. et al. 1999, ApJ 513, 919
Shearer A. et al. 1997, ApJ 487, L181
Swanenburg B.N. et al. 1981 ApJ 450, 784
Thompson D.J. et al. 1992, Nature 359, 615
Wang F.Y.-H. et al. 1998, ApJ 498, 373
Zavlin V.E. et al. 2001, preprint

## DISCUSSION

**W. KUNDT:** High-energy pulses can also be emitted beyond the speed-of-light cylinder, via Inverse-Compton scattering of the ambient photons bath; especially by the Crab pulsar.

**E. MASSARO:** The origin of high energy photons is still an open problem. Different models (inner gap, outer gap, etc..) have been proposed but none of them has been fully successful either in predicting the pulse shape or spectra. In the particular case of the Crab pulsar, the fine phase matching of pulses from radio to $\gamma$-rays suggests a unique emission region, likely in the inner magnetosphere. For other pulsars, like those observed by us, the interpretation is not simple because of the presence of several components.