Bull. Astr. Soc. India (1999) 27, 181-184

Energy dependence of x-ray pulse profile of the Crab pulsar

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Abstract. We obtained pulse profiles of Crab pulsar in 4 different X-ray energy bands between 2 and 30 keV. We found that all the profiles in these energy ranges show two peaks occurring at the same phase joined by a lower but non zero flux region named as the bridge. Integrated flux or fluence of peak-2 and bridge show energy dependent variation with respect to peak-1. These fluence ratios increase with energy in a similar pattern indicating common origin for these changes. These increasing trends of the fluence ratios have different implications on current pulsar emission models and offer new challenges for refinement of existing models.

1. Introduction

The Crab Nebula pulsar (PSR 0531+21) is one of the best studied objects in almost all the energy bands of electro-magnetic spectrum in the span of last 30 years after its discovery. It is therefore an important object for the study of the nature of pulsars and their emission mechanism. The double peaked appearance of the pulse profile, the sharpness of the two peaks and their separation by 0.4 in phase are key parameters motivating researchers to develop theories to explain the observed shape of the pulse profile by a single model of pulsar emission mechanism (Eikenberry et al., 1997, 1996). The Crab pulsar was observed by pointed mode proportional counters (PPC's) of Indian X-ray Astronomy Experiment (Agrawal et al., 1996) on board IRS-P3 satellite, in the energy band of 2 to 30 keV. We present here pulse profiles of the Crab nebula pulsar at different energies in 2 to 30 keV band and the measured integrated flux or fluence of peak-2 and bridge at various energies with respect to peak-1 as tabulated in Table-1.

Table 1. Fluence ratios of bridge(I) and peak-2(P2) with respect to peak-1(P1) at different measured energy

Energy(keV)	Log E	I/P1	P2/P1
0.43 ± 2.0	2.97 ± 0.33	0.125 ± 0.005	0.872 ± 0.005
2.0 ± 3.5	3.42 ± 0.12	0.28 ± 0.02	1.11 ± 0.06
3.5 ± 7.0	3.69 ± 0.15	0.24 ± 0.01	0.99 ± 0.03
7.0 ± 10.5	3.93 ± 0.08	0.25 ± 0.02	1.19 ± 0.05
10.5 ± 30.0	4.25 ± 0.23	0.31 ± 0.04	1.72 ± 0.13
53.3 ± 10^4	5.86 ± 1.14	0.47 ± 0.03	1.39 ± 0.06

The entries in the first and the last rows of this table are obtained from ROSAT HRI for soft X-rays and CGRO OSSE for gamma-rays published by Stephen et al. Astrophysical Journal, 476:281-290, February 1997.

2. Data Analysis

The source was observed in Pulsar mode of operation where 16 bit information is recorded for each registered event in the PPC's. The 16-bit data contains 10-bit arrival time, 3-bit PHA, 2-bit layer identification and 1-parity bit. Relevant time based events were sorted out from above data and XRONOS software was used to get "Power Spectrum Density" and then "Pulse Profiles" at various energies, shown in Fig. 1. The fluences were measured with respect to the minimum level of the pulse profile in the range starting from end of peak-2

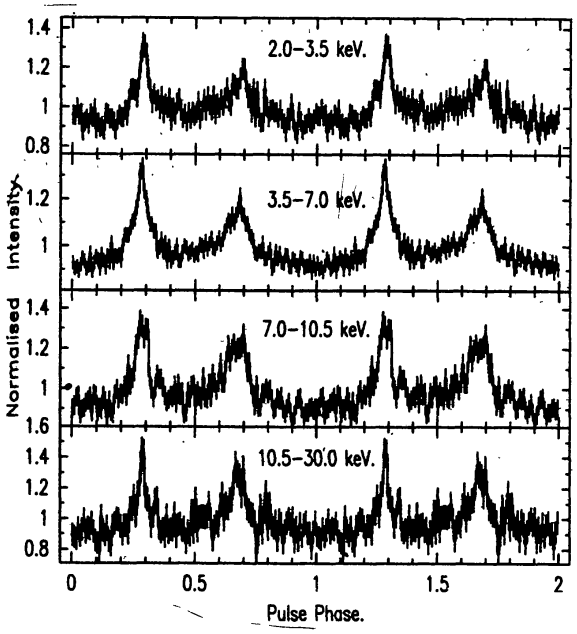

Figure 1. Pulse profiles of the Crab Pulsar at different X-ray energy bands.

to beginning of peak-1 and the region is termed as valley. The Peak-1, bridge and peak-2 of the pulse profiles were considered in the phase range of 0.2 to 0.4, 0.4 to 0.55 and 0.55 to 0.9 respectively. The errors in Fig. 2 represent resultant propagated errors in the determination of the ratios and include errors in determining the reference level.

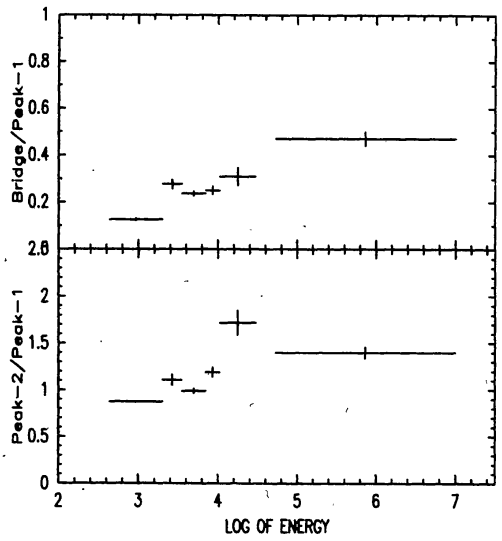

Figure 2. Fluence ratios of bridge and peak-2 relative to peak-1 versus energy.

3. Results

1. We obtained four pulse profiles for the Crab pulsar in 4 different energy bands in X-ray energy range of 2 to 30 keV.

2. Pulse profiles in these energy ranges show two peaks occurring at the same phase joined by non zero flux region (bridge) and separated by 0.4 in phase.

3. Integrated flux or fluence of peak-2 and bridge with respect to peak-1 show previously known trend, i.e., the fluence ratio increase with energy.

4. Conclusion

The overall trend for the increase in fluence with energy of the bridge and peak-2 with respect to peak-1 has differing implications for each of the models of Crab pulsar emission namely, two-gap outer gap model, one gap outer gap model and Polar Cap (PC) gap model. Although the first model can explain the observed rise of peak-2 with energy relative to peak-1, this model does not offer any explanation for the existence of the bridge. The unlimited azimuthal extent as per the second model does, however, predict the existence of a bridge between the two peaks but does not predict any pulse shape variation with energy. The third model is a composite model which provides the remedy for the bridge emission from the PC gap along with the two peaks in two-gaps outer gap model. While in PC-model a hollow cone geometry

for particle distribution can also reproduce crab like profile but again it cannot provide explicit prediction of pulse shape variation with energy. Therefore these measured parameters of pulse profile of the Crab pulsar demands further refinement of the existing emission models.

Acknowledgements

We acknowledge all the engineers and technical staff of TIFR, MUMBAI and ISRO, BANGALORE for successful completion of the X-ray astronomy Satellite Experiment and its operations.

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