The Observation of Crab Nebula with PHENEX Polarimeter

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Abstract

We have been developing a hard X-ray polarimeter to open a new window for hard X-ray astronomy. The name of the project is called as PHENEX (Polarimetry For High ENERgy X rays). Constructing the flight model with small effective area, we have carried out balloon-borne experiment in Jun.13, 2006 to preliminarily observe the polarization of the Crab Nebula in hard X-ray band. The PHENEX accomplished the level flight at the altitude of 37.5 km over 6 hours and we succeeded in observing the Crab Nebula in one hour. The PHENEX polarimeter successfully operated on the level flight and safely was recovered on the sea. Analyzing the data on the observation of Crab Nebula and the background region, we investigated the degree and the direction of the polarization. Though the statistical accuracy is not enough for the shortage of observation time and the smallness of the effective area, we found a modulation curve to indicate the polarization of the Crab Nebula. In near future, we will carry out the balloon-borne experiment for the Crab Nebula again by the flight model with moderate effective area.

1 Introduction

X-ray astronomy has been much advanced by three observations of spectroscopy, timing, and imaging. Also in hard X-ray region, the three observations will be realized by NeXT, Con-X, and XEUS. However, the observation of the polarization is left out to date in spite of the potential usefulness. This is because of the difficulty of developing polarimeters with high sensitivity. Since the origin of the polarization is often due to non-thermal radiation processes such as synchrotron radiation, observations in the hard X-ray region are possibly more important than that for the soft-X-ray region; it is expected that the degree of polarization in the hard X-ray region would be higher than that at lower energies. For the above reasons, we have been developing a hard X-ray polarimeter with high sensitivity, called PHENEX (Polarimetry for High ENERgy X rays) polarimeter. We carried out balloon-borne experiment with the prototype flight model in Jun.13, 2006 to investigate the performance. We chose the Crab Nebula as observation target because the Crab Nebula is only the stellar object which degree of polarization is measured in X ray region at accuracy. In this poster, we will report the preliminary results for the polarization of the Crab Nebula.
2 PHENEX Polarimeter

For the detail of the PHENEX polarimeter and the DAQ system, please look at the poster of No.217 by Kishimoto and No.221 by Morimoto.

Figure 1: The left figure shows the whole system of the PHENEX. The detector rotates along the axis for the line of the sight. It is effective to reduce spurious modulation. The right figure shows the detector system installed in pressure vessel. It consists of four unit counters and one monitor counter. On these counters, collimators with opening angle of 4.8 degrees (FWHM) are mounted.

3 Observation of Crab Nebula

Though PHENEX polarimeter operated well on the level flight, the attitude control system did not function correctly. Even so we succeeded in observing the Crab Nebula in one hour. The left figure shows the count rates. The excess of the count rates is seen on the

Figure 2: The left figure shows the count rates of four unit counters. The right figure shows the line of the sight for the PHENEX polarimeter on the observation of the Crab Nebula.
observation of Crab Nebula. The right figure shows the line of the sight on the observation. For the later analysis of Crab Nebula, we used only the data of the blue-shaded region. For the balloon borne-experiment, please look at the poster of No.217 by Kishimoto, too.

4 Analysis Methods for Polarization

We carried out the analysis of the polarization according to the following procedure. The abstract of the procedure is shown in Figure 3.

1. In case that the plastic scintillator with energy deposit above a certain threshold is only one and that the CsI(Tl) scintillator with energy deposit above a certain threshold is only one, the events are selected.

2. For the coordinates of the detector system, the scattering angle is determined from the positions of the plastic scintillator and the CsI(Tl) scintillator.

3. Taking account of the rotation angle of the polarimeter’s pressure vessel and the line of sight of the polarimeter, the scattering angle on the coordinates of the detector system is transformed to that on the equatorial coordinates.

![Diagram](image)

Figure 3: Explanation for the analysis methods.

5 Preliminary Results for the polarization

We observed a blank region of the sky for about one hour. The region of the blank sky corresponds to the same elevation and azimuth as that of the Crab Nebula during its observation period. For the data, the analysis of the polarization was carried out. The figure 4 shows the results. The x-axis and y-axis correspond to the scattering angle on equatorial coordinates and the counts, respectively. The histograms are real data and the red line is the fitting by the following function.

\[
y = A + B \times \sin(2x + C)
\]
The best fitting parameters are as follows; $A=145.85$, $B=6.61$, $C=17.235$. The confidence level of the fitting was 0.3 and the modulation was 4.5%. From the results, we confirmed that the PHENEX polarimeter does not show strong anisotropy for the scattering angle.

Figure 4: The distribution of the scattering angle for the equatorial coordinates on the observation of background region.

As well as the analysis for the blank region, we analyzed the data on the observation of Crab Nebula. The left figure 5 shows the results. The histograms are real data and the red line is the fitting by the same function. The best fitting parameters are as follows; $A=254.31$, $B=-12.31$, $C=48.186$. The confidence level of the fitting was 0.8 and the modulation was 4.8%. Though the modulation is as low as that for the blank region, the histograms are better fitted than that for the blank region. The histograms for the blank region were subtracted from those for the Crab Nebula, taking account of the difference of the observation time. The subtracted data are shown in the right figure. The red line is the fitting. The best fitting parameters are as follows; $A=52.33 \pm 6.67$, $B=20.43 \pm 9.46$, $C=214.17 \pm 26.28$. The confidence level of the fitting was 0.8 and the modulation was 39 ± 19%. From these results, we calculated the degree and the direction of polarization. The results are as follows. The degree of polarization was 74 ± 36% and the direction of polarization was 207 ± 26deg. In the X-ray region, the degree and the direction of the polarization were measured by Weisskopf and Novick with OSO8 and a sounding rocket. The results are summarized in the table 1.

Figure 5: The left figure shows the distribution of the scattering angle for the equatorial coordinates on the observation of the Crab Nebula. The right figure is subtraction of the figure 4 from the left figure 5.
Table 1: Summary of the observation in X-ray region by M. Weisskopf et al.

<table>
<thead>
<tr>
<th>Energy</th>
<th>Degree</th>
<th>direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6 keV</td>
<td>19.2%</td>
<td>156°</td>
</tr>
<tr>
<td>5.2 keV</td>
<td>19.5%</td>
<td>152°</td>
</tr>
</tbody>
</table>

6 Conclusion

To open the new window for hard X-ray astronomy, we have been developing hard X-ray polarimeter called PHENEX polarimeter. In Jun. 2006, we carried out the balloon-borne experiment to investigate the performance of the PHENEX polarimeter and to observe the polarization of the Crab Nebula. The PHENEX polarimeter operates well on the level flight over 6 hours and safely was recovered on the sea. Though the attitude control system did not function correctly, we succeeded in observing the Crab Nebula and the blank region of the sky over each 1 hour. At first, we carried out the analysis of the polarization for the blank region to confirm that the PHENEX polarimeter does not show strong anisotropy for the scattering angle. Secondly, we analyzed the data on the observation of Crab Nebula and subtracted the data for the blank region from those for the Crab Nebula. In the subtracted data, we found a modulation curve to indicate the polarization of the Crab Nebula though the statistics of the data is not good enough to determine the degree and the direction of the polarization in accuracy.