Polarized X-rays emitted from a magnetar[†]

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Magnetars are neutron stars with ultra-strong magnetic fields. Magnetars exhibit steady X-ray pulsed emissions with a luminosity of approximately 10^{33}–10^{35} erg s^{-1}, spin period P of approximately 0.1–12 s, and large spin-down rates $\dot{P}$ of approximately 10^{-14}–10^{-10} s s^{-1}. This translates into magnetic fields of up to B approximately 10^{15} G, assuming a conventional spin-down model. The external magnetic field of magnetars is expected to have a toroidal component that twists the field lines. Because charged particles must flow along the closed magnetic field lines to sustain the field, the star magnetosphere becomes optically-thick during resonant Compton scattering (RCS).[1)] Because of its strong magnetic field, magnetar X-ray emission is linearly polarized in two normal modes, namely, the ordinary (O) and extraordinary (X) modes, and upon reprocessing via RCS, X-mode photons become dominant.

4U 0142 + 61 is the brightest persistent magnetar with an unabsorbed flux of 6×10^{-11} erg s^{-1} cm^{-2} in the 2–10 keV range. Here, we report on the polarimetric observation of 4U 0142 + 61 conducted by the Imaging X-ray Polarimetry Explorer (IXPE) from January 31, 2022 to February 27, 2022 for a total on-source time of 840 ks.

Results are shown in Fig. 1 in the form of a polar plot where the polarization degree (PD) is the radial coordinate and polarization angle (PA) the azimuth. The measured PD is 15 ± 1% at low energies (2–4 keV). At 4–5 keV PD becomes consistent with zero and then increases to 35 ± 7% at 5.5–8 keV. The PA is approximately 50° East of North at energies below 4 keV and swings by 90°, settling at 40° West of North, above 5 keV.

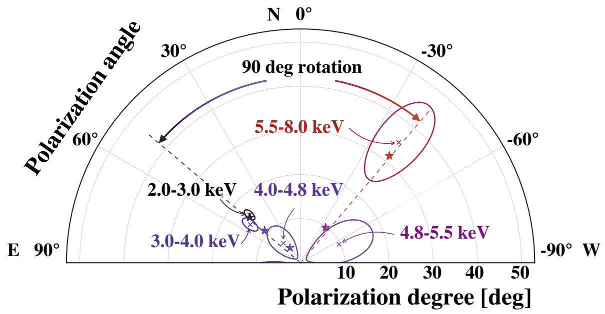

Fig. 1. Polar plot showing the energy dependence of the measured PD and PA. Contours enclose the 68.3% confidence level regions. Stars indicate the corresponding PD and PA calculated using the RCS model.

The polarization pattern as a function of energy, with a minimum of PD and swing of PA by 90° at approximately 4–5 keV, suggests that the X-ray emission from 4U 0142 + 61 is characterized by two distinct components polarized in two different normal modes. The low-energy component is thought to be produced by thermal surface emission while the high-energy component by photons up-scattered in the magnetosphere. The measured polarization fraction at high energies (35% at 5.5–8 keV) is indeed compatible with the theoretical expectations of the RCS model and suggests that X-mode photons dominate. Although the measured polarization fraction at low energies (2–4 keV) differs from the predictions of published theoretical models,[2)] we found that the radiation emitted from a condensed[3)] equatorial belt results in a predominance of O-mode photons with PD of approximately 15%.

In conclusion, the positive detection of polarized emission from 4U 0142 + 61 by IXPE further supports the magnetar model. In particular, the distinctive energy-dependent pattern can be explained by assuming emission from the bare condensed surface reprocessed by RCS in the twisted magnetosphere.

References

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