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Rapid X-ray Variations of the Geminga Pulsar Wind Nebula

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Abstract

We have discovered the X-ray variabilities from various components of the pulsar wind nebula (PWN) powered by Geminga (PSR J0633+1746) on timescales from a few days to a few months (Hui et al. 2017). The fastest variation occurred at a rate of 80% of the speed of light in the circumstellar environment. On the other hand, a light-year long tail is found to wiggle at a rate of 20% of speed of light. Also we have found the evidence of X-ray spectral hardening along this tail. The properties of the highly twisted feature can be a result of a propagating torsional Alfv́en wave along it.

1 Introduction

Through a deep *XMM-Newton* observation, X-ray extended features associated with PSR J0633+1748 (Geminga) of light-year long (referred as outer tails hereafter) were first discovered by Caraveo et al. (2003). With high-angular resolution observations of *Chandra*, an axial tail which is extended up to ∼25" behind its proper-motion direction was subsequently discovered (Sanwal et al. 2004; Pavlov et al. 2006). Recently, Posselt et al. (2017) have reported a detailed study of Geminga PWN with multi-epoch *Chandra* Observations from

2012 November to 2013 September. While their study has confirmed the variability of the axial tail, neither the spectral and morphological variabilities of the other PWN components have been examined. To have a more detailed investigation on the X-ray variabilities of this interesting system, Hui et al. (2017) have carried out painstaking searches with the same set of multi-epoch *Chandra* data used by Posselt et al. (2017). In the proceeding, we would like to give a highlight of these results.

2 Variability analysis of various PWN components

In the image with all data merged, we have found the axial tail has a length of ∼42" behind the proper-motion direction of Geminga. We have discovered the spectral and morphological variation of this tail from the observationd in 2013 August/September. We found that its variabilities took place on a timescales as short as few days (cf. Figures 5 and 7 in Hui et al. 2017).

On the other hand, we have confirmed the existence of a variable diffuse component in the circumstellar environment from the observations on 2013 August 25, 2013 August 30, 2013 September 16, 2013 September 20 (see the left panel in Figure 1). The feature appeared as a southeastern protrusion which connects Geminga and its southern outer tail. There is an apparent variation in its length of ∼2.5" within 5 days (Left panel in Figure 1). At a distance of 250 pc, this corresponds to a change in its physical size of $\sim 9.4\times 10^{15}$ cm. Such results implies that such variability occurred at a rate of $\sim 0.8c$ which c is the speed of light.

For the outer tails, we suggest that these features can be the jets launched from the pulsar which are significantly bent by the ram pressure. By comparing the images obtained from the observations in 2012 November-December (referred as Epoch 3 in Hui et al. 2017) and that obtained from 2013 August-September (referred as Epochs 7+8 in Hui et al. 2017), we found that the southern outer tail shows significant wiggling (see right panel in Figure 1). . The maximum deviation of the feature in these two frames are found to be ∼0.5'. This corresponds to a physical length of $\sim 10^{17}$ cm at distance of 250 pc. This implies that such variation occurred at a rate of $\sim 0.2c$. Moreover, we have found evidence for spectral hardening of the southern outer tail from 2013 January to August (see Table 3 in Hui et al. 2017). We further pinpointed that the spectral hardening occurred at the rear end of the tail (see Figures 1 and 14 in Hui et al. 2017).

All theses results can be interpreted in the context of a model that consists of a torus around the pulsar with jets (i.e. outer tails and the southeastern protrusion) launched along the spin axis. On the other hand, the axial tail can be interpreted as a synchrontron nebula resulting from the postshock flow. The morphological and spectral variability of the southern outer tail can be a result of torsional Afv́en waves. For a better understanding of the physical processes involved in the variabilities, a detailed MHD modeling is encouraged.

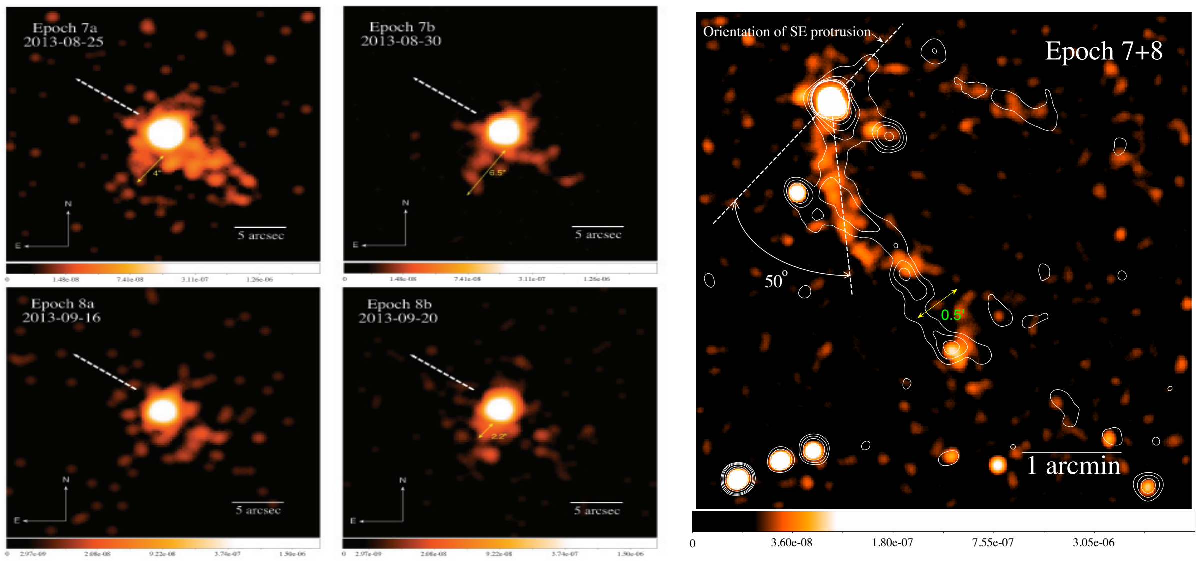

Figure 1: (Left) Exposure-corrected images in 0.5-7 keV of the circumstellar environment around Geminga at different epochs. (Right) Exposure-corrected image with data obtained from 2013 August-September that covers the outer tails and it is compared with the contours obtained from the 2012 November-December.

3 Summary

We investigated the X-ray variabilities of PWN associated with Geminga and here we summarized our major results:

1. Discovery of spectral and morphological variations of axial tail in 2013 August/September, which took place at a timescale as short as a few days.

2. Confirming the existence of the variable southeastern protrusion that connects the pulsar and the southern outer tail.

3. Discovery of the wiggling and spectral hardening of the southern outer tail that took place at a timescale of few months.

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