Search for High-Energy Gamma-ray Emission from an Anomalous X-ray Pulsar, 4U 0142+61

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SUMMARY

We estimated upper limits to the persistent and pulsed high-energy gamma-ray emission from anomalous X-ray pulsar 4U 0142 + 61. In turn, we calculated an upper limit to the spectral break energy and evaluated the existing physical models in terms of our results.

INTRODUCTION

Until 2004, AXPs have been known as bright soft X-ray emitters. An important observational development was the discovery of hard X-ray emission from AXPs (Kuiper et al. 2004, den Hartog et al. 2004, Revnivtsev et al. 2004). The physical mechanism of the hard emission component still has not fully resolved. In order to understand the nature of the hard emission component of AXPs, it is crucial to establish their spectral shapes on a wide range in the energy domain. In particular, it is crucially important to determine where their spectral energy distribution peak.

Here, we present our results of detailed search for persistent and pulsed high energy gamma-ray emission from AXP 4U 0142+61 using Fermi/LAT observations.

OBSERVATIONS & ANALYSIS

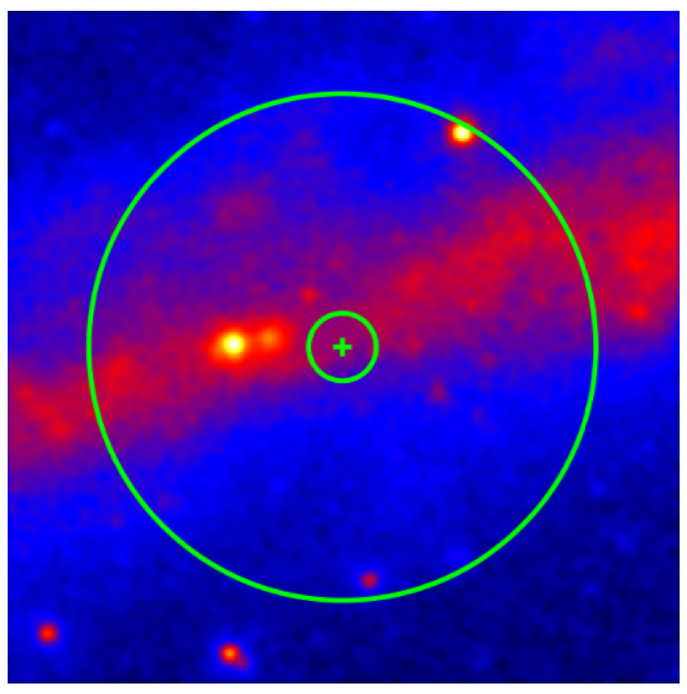

Figure: 1. Smoothed Fermi/LAT count map around 4U 0142+61 in the energy range 0.2-100 GeV. Big circle and small circle inside represent 15° and 2° radius extraction regions, respectively. Plus sign indicates the position of AXP 4U 0142+61.

Fermi/LAT

To search for persistent emission we accumulated Fermi/LAT data within a 2° and 15° radius around 4U 0142+61, collected from 2008 August 4 to 2010 April 29 with an exposure time of, ~31.7 Ms. We performed our unbinned likelihood analysis using ScienceTools v9r15p2. Standard event selection procedure was applied to the data. The spectral fits and flux calculations were done with the python version of gtlike, pyLikelihood.

As evident from Figure 1, 4U 0142+61 is clearly not detected in the LAT energy passband. A point source search using the filtered event list with gtfindsrc tool of ScienceTools results in a potential source whose coordinates are inconsistent with that of 4U 0142+61, therefore yields no detection. We fitted the data from 2° with power-law with an index of 3 plus the galactic diffuse and extragalactic isotropic diffuse emission. Model yields a Test Statistics (TS) value of ~3 corresponding to a detection significance less than 2σ. For flux calculations 0.2−1.0 GeV and 1.0−10.0 GeV energy bands are chosen. For 15° radius region we also added bright cataloged sources [a] and recently discovered blazar (Vandenbroucke et al. 2010) in this region of interest into the model and left their model parameters free. TS value of ~0.23 implies a detection significance less than 1σ.

RXTE

To search for pulsed high energy gamma-ray emission from 4U 0142+61, we obtained the precise spin ephemeris of the source using contemporaneous Rossi X-ray Timing Explorer (RXTE)/Proportional Counter Array (PCA) observations. We have selected 53 RXTE observations that were performed between 2008 August 4 and 2010 April 30. Individual pointings are typically between 3 and 4 ks long and the total exposure time of all selected observations is about 196 ks. For each observations, we extracted events in the 2−10 keV range collected with the PCA and converted their arrival times to the solar system barycenter using faxbary tool of HEASoft 6.8. We employed a Fourier based epoch folding technique to obtain the spin ephemeris of 4U 0142+61 using RXTE/PCA observations covering the time span of the LAT exposure of the source.

[a] http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr_catalog

RESULTS

Persistent Emission

For 2° radius region we find 3σ upper limits to the source flux with a power-law index 3 as 5.72 × 10^{-6} MeV cm^{-2} s^{-1} in 0.2−1.0 GeV band and 1.29 × 10^{-6} MeV cm^{-2} s^{-1} in 1.0−10.0 GeV band. For 15° radius region, 3σ flux upper limits with a power-law index 2.5 are 2.32 × 10^{-6} MeV cm^{-2} s^{-1} in the 0.2−1.0 GeV band and 1.28 × 10^{-6} MeV cm^{-2} s^{-1} in the 1.0−10.0 GeV band. In Figure 2, we present the high-energy gamma-ray flux upper limits of 4U 0142+61 in the νF_ν representation along with its low energy gamma-ray behavior (data constructed from den Hartog et al. 2008).

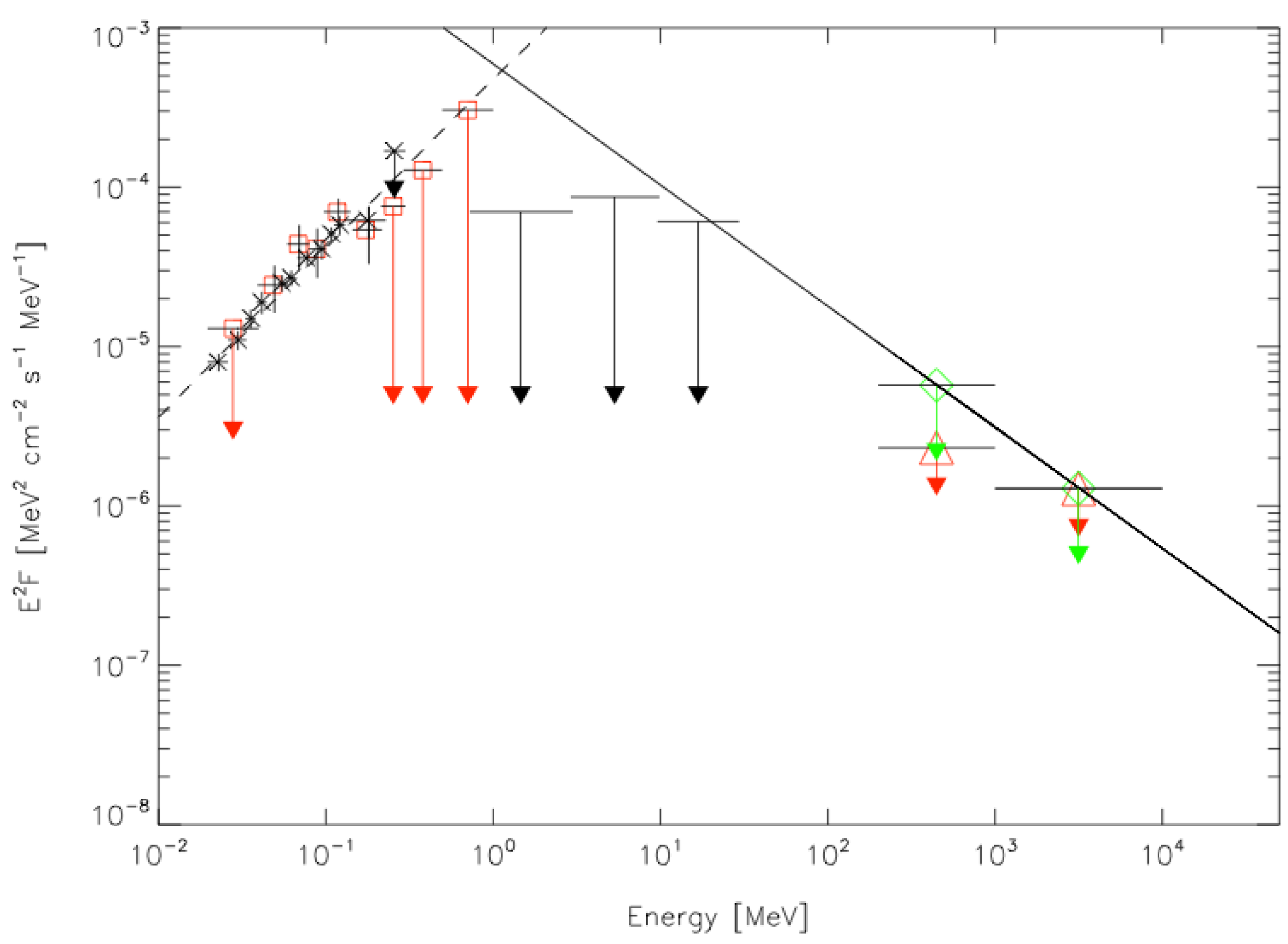

Figure: 2. A wide band νF_ν spectrum of 4U 0142+61: INTEGRAL /ISGRI (20-300 keV) in black (stars), INTEGRAL /SPI (20-1000 keV) in red (open square) and CGRO/COMPTEL (0.75-30 MeV) upper limits in black (data constructed from den Hartog et al. 2008). Fermi/LAT upper limits (in the 0.2−1.0 GeV and 1.0−10.0 GeV bands) obtained using power-law model to 2° extracted region (green diamonds) and 15° extracted region (red triangles). Dashed line is the best fit power-law model to the ISGRI data-points presented in den Hartog et al. (2008). Solid line shows the upper limit curve to the Fermi/LAT 2° region data.

Pulsed Emission

In Figure 3, we present the phase shift and the best fitting model, that is a 3^{rd} order polynomial (χ^2/degrees of freedom = 59.6/42). We find that both LAT profiles are consistent with random fluctuations with respect to its mean. We calculate a 3σ upper limit to the RMS pulsed amplitude as 1.5% in the 0.2−1.0 GeV band and 2.3% in the 1.0−10.0 GeV band. We also investigated the lower energy part of the LAT passband (30−200 MeV) which resulted with no evidence of pulsed emission either; the 3σ RMS pulsed amplitude upper limit is 1.6%.

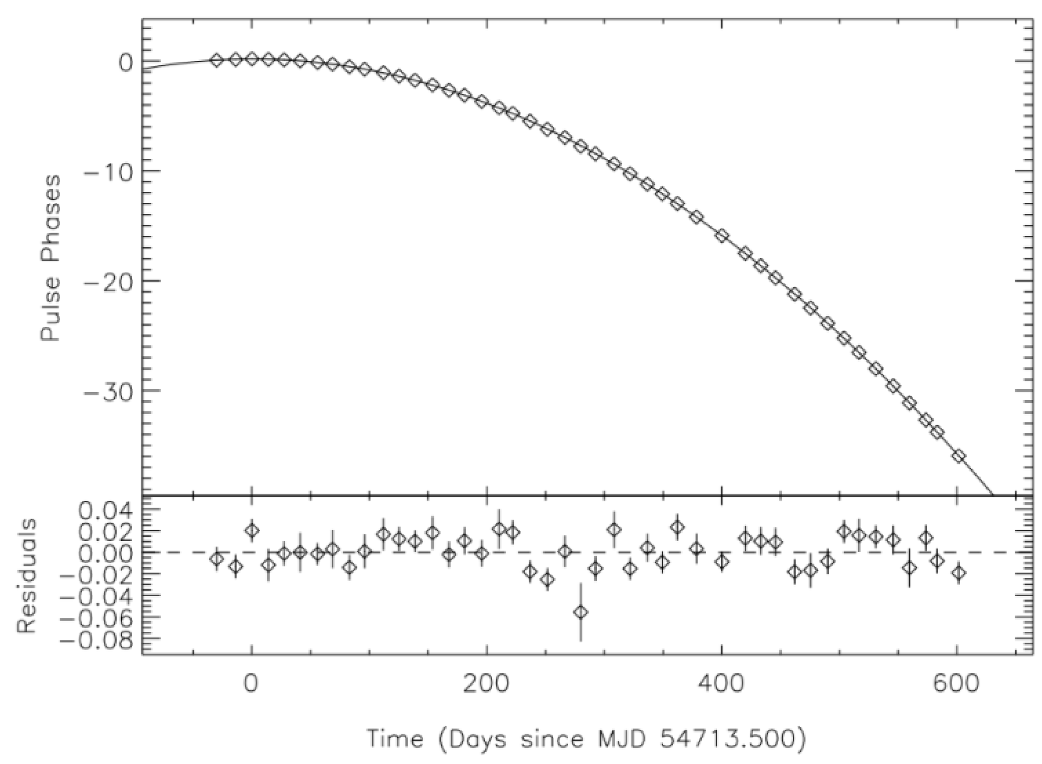

Figure: 3. (top) Spin phase shifts of RXTE/PCA observations of 4U 0142+61with respect to the epoch. The solid line is the best fitting model, that is a 3^{rd} order polynomial. (bottom) Residuals of the fit.

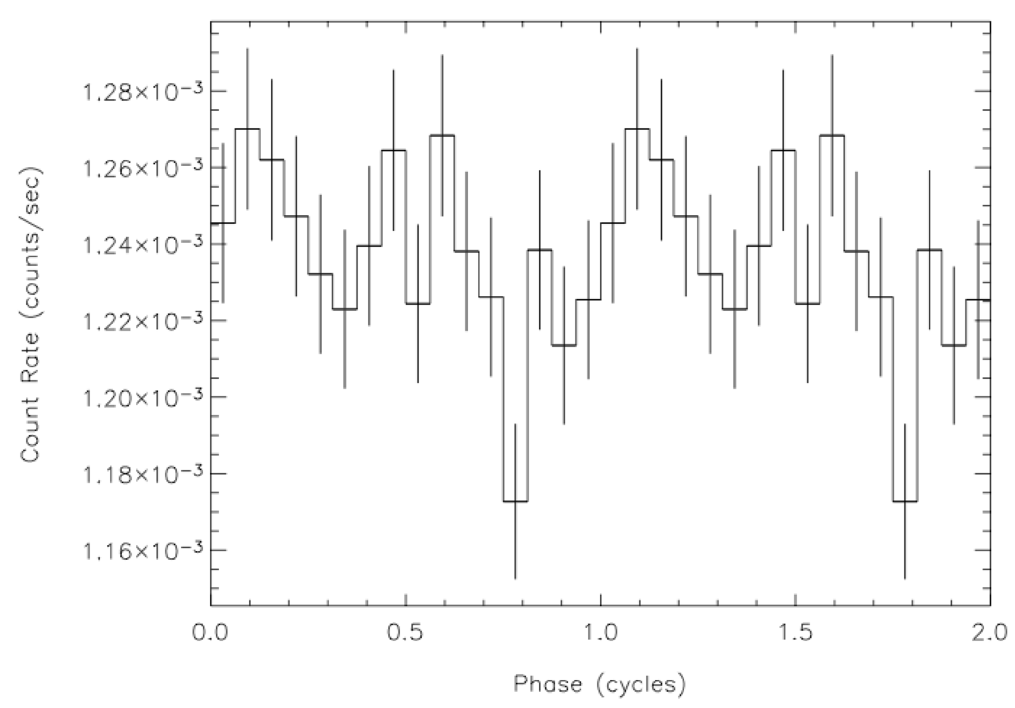

Figure: 4. Pulse profile of 4U 0142+61 by folding the Fermi/LAT data with the precise spin ephemeris obtained with contemporaneous RXTE/PCA observations. A 3σ upper limit to the RMS Pulsed Fraction is 0.03

DISCUSSION & CONCLUSION

- We searched for both persistent and pulsed high energy emission from the magnetar 4U 0142+61 using Fermi LAT data. We found no significant detection in neither of the two objectives.
- We constructed the νF_ν spectrum of the source in the 15 keV - 10 GeV by using the hard X-ray spectrum presented in den Hartog et al. (2008) and employing the upper limits calculated in this work. den Hartog et al. (2008) fitted the Integral/ISGRI data with a simple power-law model of index -0.93 ± 0.06. We present this fit with dashed lines in Figure 2.
- We placed an upper limit curve, which is the line connecting the two LAT upper limit measurements (as shown with solid line in Figure 2), is also a power-law with an index of 0.76. These two curves intersect with each other at ~1.1 MeV which is an upper limit to the spectral break energy. Note that the spectral break upper limit is consistent with den Hartog et al. (2008) measurement of 279^{+65}_{-41} keV obtained by fitting a log-parabolic function.
- Our estimated upper limit to the spectral break energy is in accordance with both Heyl & Hernquist (2005a, 2005b) and Beloborodov & Thompson (2007). According to the corona model of Beloborodov & Thompson (2007), photons with energies in excess of $\gtrsim$1 MeV would be trapped in the ultrastrong magnetic fields (B $\gtrsim 10^{14}$ G). In such a case photons would either split into two photons or they would create an electron-positron pair, therefore, suppressing the emission from inner corona above ~1 MeV. According to the quantum electrodynamics model by Heyl & Hernquist (2005), the lower limit to the break energy is expected to be around 1 MeV. They also claim that if a source has a significant excess emission in optical wavelengths, as in the case of 4U0142+61 (Hulleman et al. 2000), its νF_ν spectrum should continuously increase in the 10 − 200 MeV range. However, the origin of the excess optical emission is not clear. It can be originated from the neutron star itself (Kern & Martin 2002; Dhillon et al. 2005) and from a disk around 4U 0142+61 (Wang et al. 2006; Ertan & Çalışkan 2006). If the excess optical emission originates from the compact object, our results place constraint, although not stringent, on the quantum electrodynamics model due to the lack of increase in the 10 − 200 MeV range in the νF_ν spectrum. On the other hand, if the disk provides a significant contribution to the observed emission, then the optical radiation from the neutron star itself would not be excessive and the quantum electrodynamics model would still remain feasible.

References

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