**INTEGRAL OBSERVATIONS OF THE $\gamma$-RAY BINARY 1FGL J1018.6-5856**

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**ABSTRACT**

The *Fermi* Large Area telescope (*Fermi*-LAT) collaboration has recently reported that one of their detected sources, namely, 1FGL J1018.6-5856, is a new gamma-ray binary similar to LS 5039. This has prompted efforts to study its multi-frequency behavior. In this report, we present the results from 5.78 Ms *International Gamma-Ray Astrophysics Laboratory (INTEGRAL)* IBIS/ISGRI observations on the source 1FGL J1018.6-5856. By combining all the available *INTEGRAL* data, a detection is made at a significance level of 5.4$\sigma$ in the 18–40 keV band, with an average intensity of 0.074 counts s$^{-1}$. However, we find that there is non-statistical noise in the image that effectively reduces the significance to about 4$\sigma$ and a significant part of the signal appears to be located in a 0.2-wide phase region, at phases 0.4–0.6 (where even the corrected significance amounts to 90% of the total signal found). Given the scarcity of counts, a variability is hinted at about 3$\sigma$ at the hard X-rays, with an anticorrelation with the *Fermi*-LAT periodicity. If this behavior were true, it would be similar to that found in LS 5039 and prompt observations with TeV telescopes at phases anticorrelated with the GeV maximum.

**Key words:** X-rays: binaries -- X-rays: individual (1FGL J1018.6-5856)

**Online-only material:** color figure

1. INTRODUCTION

The *Fermi* Large Area telescope (*Fermi*-LAT) is a pair-production detector with large effective area (≈ 8000 cm$^2$ on axis for $E > 1$ GeV) and field of view (≈ 2.4 sr at 1 GeV), sensitive to gamma rays in the energy range from 20 MeV to >300 GeV (Atwood et al. 2009). Precisely because of its capability of covering a wide region of the sky, its normal mode of operation is surveying, which facilitates serendipitous discoveries and simultaneous observations of many sources. The *Fermi*-LAT collaboration has recently released (Corbet et al. 2011) the results for continuing data analysis of the gamma-ray emission from 1FGL J1018.6-5856, for which earlier information was also reported in the *Fermi*-LAT source catalog (Abdo et al. 2010). The considered data, obtained between MJD 54682 and 55627 in the energy range 100 MeV–200 GeV, show the presence of periodic modulation with a period of 16.58 ± 0.04 days and an epoch of maximum gamma-ray flux at MJD 55403.3 ± 0.4 (Corbet et al. 2011). A coincident X-ray flux was found using *Swift* X-ray telescope (XRT) observations, which also features a high degree of variability, with the 0.3–10 keV count rates ranging from approximately 0.01 to 0.05 counts s$^{-1}$, as well as a star of magnitude B2 which in turn coincides with the *Swift*-XRT detection. Based on all of the previous studies, Corbet et al. (2011) reported that 1FGL J1018.6-5856 is a new gamma-ray binary-like, for instance, LS 5039 (see Abdo et al. 2009). In this Letter, we present the results of the analysis of 5.78 Ms *International Gamma-Ray Astrophysics Laboratory (INTEGRAL)* IBIS/ISGRI data on the source 1FGL J1018.6-5856.

2. OBSERVATIONS AND DATA ANALYSIS

*INTEGRAL* (Winkler et al. 2003) is optimized to work between 15 keV and 10 MeV. Its main instruments are the IBIS (15 keV–10 MeV; Ubertini et al. 2003) and the Spectrometer on board *INTEGRAL* (SPI; 20 keV–8 MeV; Vedrenne et al. 2003). At the lower energies (15 keV–1 MeV), the cadmium telluride array ISGRI (Lebrun et al. 2003) of IBIS has a better continuum sensitivity than SPI below ~300 keV. The *INTEGRAL* observations were carried out per pointing, called individual Science Windows (SCWs), with a typical time duration of about 2000 s each. The data reduction was performed by using the standard Online Science Analysis (OSA) version 9.0. The results were obtained by running the pipeline from the raw to the image level. In this analysis, only IBIS/ISGRI public data are taken into account. The available *INTEGRAL* observations when 1FGL J1018.6-5856 had offset angle less than 14° comprise about 2014 SCWs, adding up to a total exposure time of 5.78 Ms. Our data set covers revolutions 30–867 from 2003 January 11 to 2009 November 20 (MJD 52650–55155). This large amount of data allow for an in-depth investigation of the hard X-ray emission from 1FGL J1018.6-5856.

3. RESULTS

An *INTEGRAL* detection of 1FGL J1018.6-5856 is derived by combining all the ISGRI data, with a significance level of 5.4$\sigma$ and an average intensity of 0.074 counts s$^{-1}$ in the 18–40 keV band (see Figure 1). 1FGL J1018.6-5856 is also consistently detected in the 18–60 keV; its map significance is reduced only to a fluctuation at higher energies. We only obtain 1.63$\sigma$ in the 40–100 keV. The significance and flux measurement of 1FGL J1018.6-5856 are obtained from the pixel comprising the most prominent position determined by *Swift*-XRT (Corbet et al. 2011), which is within *Fermi*-LAT 1FGL and 2FGL error circle. The pixel size of *INTEGRAL* is about 4.93 arcmin × 4.93 arcmin, whereas the uncertainty in position of *Fermi*, i.e., the 95% confidence radius, is ~1.76 arcmin and is thus fully...
Table 1

| Phase       | Exposure (Ms) | Width of Combined Sig. Map Distribution | Significance (in 18–40 keV) | Flux (counts s⁻¹) |
|-------------|---------------|----------------------------------------|-----------------------------|------------------|
| 0.0–1.0     | 5.4           | 1.40                                   | 5.78                        | 0.074 ± 0.014    |
| 0.0–0.2     | -0.0073 ± 0.032 | ...                                   | -1.16                       | -1.36            |
| 0.2–0.4     | 3.12          | 1.13                                   | 1.32                        | 0.094 ± 0.030    |
| 0.4–0.6     | 4.89          | 1.13                                   | 1.37                        | 0.154 ± 0.031    |
| 0.6–0.8     | 1.54          | 1.05                                   | 1.31                        | 0.050 ± 0.032    |
| 0.8–1.0     | 2.15          | 1.31                                   | 1.36                        | 0.061 ± 0.028    |

5856 varies along its 16.58 days orbit, we divide the INTEGRAL data into phase bins. The reference time at phase zero is set to the peak flux that was observed by Fermi-LAT at $T_{\text{max}} = \text{MJD} 55403.3 \pm n \times 16.58$ days, as reported at GeV energies in Corbet et al. (2011). We show the INTEGRAL results of 1FGL J1018.6-5856 for each phase bin in Table 1, where the flux, the corresponding exposure, and the significance are provided. Again, given that the pixel distribution has a Gaussian width of about 1.34 in each of the images (see Table 1), we conservatively consider that the significance should be lowered by this factor. Table 1 hints to a trend of having an anticorrelation between the hard X-ray emission and the Fermi-LAT periodicity. Actually, we find that a significant portion of the signal comes only from a 0.2 wide phase region, at phases 0.4–0.6 (where even the corrected significance amounts to about 90% of the signal found in total). However, the scarcity of counts makes it difficult to have a definitive proof of the variability: a constant fit to the count rate yields a reduced $\chi^2$ of 14.09/4, suggesting that the significance of variability is at 99.27% or only 2.7$\sigma$ level.

Though it is impossible to derive a light curve from standard reduction procedure, we could read pixels corresponding to 1FGL J1018.6-5856’s position and derive a light curve manually. To search for a periodic signal in the light-curve data, we used the Lomb–Scargle periodogram method. Power spectrum is generated for the light curve using the PERIOD subroutine (Press & Rybicki 1989). No significant signal is seen at an orbit period of 16.58 days beyond 90% white-noise confidence level. This is consistent with having only an overall weak detection of the source in our imaging analysis, and the orbit modulation is not apparent in light curve.

4. CONCLUDING REMARKS

We have carried out an analysis of all INTEGRAL data available for 1FGL J1018.6-5856, a new gamma-ray binary with a period of ~16.5 days discovered blindly by means of a power spectrum analysis of Fermi-LAT detection (100 MeV–200 GeV). The total effective exposure extracted on the source from the archive amounts to 5.78 Ms and leads to a credible detection of the source at hard X-rays (18–40 keV). The count rate is however very low, preventing us from extracting strong conclusions about orbital variability, although it hints at an anticorrelation with the gamma-ray emission detected by Fermi-LAT in 100 MeV–200 GeV. In fact, 1FGL J1018.6-5856 seems to significantly show up only during a small part of its orbital evolution, far from the gamma-ray maximum at 100 MeV–200 GeV. This would represent a more marked distinction with respect to what was obtained in the case of LS I +61°303 which presents a displacement of the maximum between hard X-rays (by INTEGRAL) and gamma rays (by Fermi-LAT and MAGIC),
without being completely anticorrelated (Zhang et al. 2010). Instead this is in line with the results for LS 5039 (see, e.g., Hoffmann et al. 2009) where the hard X-ray emission as measured with INTEGRAL is correlated with the TeV emission measured with the High Energy Stereoscopic System (HESS; Aharonian et al. 2006), and thus it is fully anticorrelated with the GeV emission as measured by Fermi-LAT (Abdo et al. 2009). The case of 1FGL J1018.6-5856 appears as another incarnation of this behavior, albeit with the conservative caveat of still a low significance for a strong claim—the maximum count rate of 1FGL J1018.6-5856 is about five times lower than that of LS 5039—emphasizing a possible physical similarity of the two sources. TeV observations at what appears to be the maximum of the hard X-ray light curve are thus encouraged.

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