SEARCH FOR GRAVITATIONALLY REDSHIFTED 2.2 MEV LINE FROM 4U 1820-30

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ABSTRACT

We have analyzed 1.7 Ms of the *INTEGRAL* data of the Low Mass X-Ray Binary (LMXB) 4U 1820-30 and searched for the redshifted 2.2 MeV neutron capture gamma-ray line. This source is unique in that it is thought to be accreting pure Helium and might be a powerful 2.2 MeV line source. If detected, this line would strongly constrain the neutron star equation of state, motivating this search. The line is expected to be redshifted to 1.30-1.72 MeV so we scanned the 1-2 MeV region. Although we failed to detect the redshifted 2.2 MeV line, mainly due to the intense background noise to which *INTEGRAL* is exposed, we placed upper limits on the source's flux for different line widths. We plan to do analysis on the rest of the data (over 8 Ms) in the future.

1. INTRODUCTION

As matter accretes onto a neutron star from the accretion disk, its temperature rises well above nuclear binding energies, resulting in the production of many free, energetic neutrons. These neutrons, located quite close to the surface of the neutron star, can undergo several processes, one of which is the H(n,γ)D reaction, where a neutron incident on Hydrogen results in Deuterium and a 2.223 MeV gamma-ray. This line is expected to be gravitationally red-shifted and broadened, in addition to the broadening due to the NS spin [1]. If this red-shifted emission line is observed and studied, important information regarding the neutron star can be obtained (including the mass to radius ratio M/R and the spin), constraining the star's nuclear equation of state. Determination of the M/R ratio (potentially within an error of 0.05%) and thereby strongly ruling out different equations of state of a neutron star is the motivation of this research.

The neutron star we focused on is 4U 1820-30, which is an accreting LMXB. It is located in the globular cluster NGC 6624, and has an orbital period of 685 seconds, the shortest orbital period known to date [2]. Although the spin period is still unknown, high-frequency QPO's have been observed from 4U 1820-30 [3]. The constant peak frequency separation, compared with other bursting binaries of similar behavior, suggests a 275 Hz (or 550 Hz) spin frequency.

4U 1820-30 has a white dwarf companion and is therefore believed to be accreting pure Helium. The neutrons required for the H(n,γ)D reaction are produced mainly during the spallation of ^{4}He through ^{4}He(p, pn)^{3}He. Hence a high concentration of accreting He nuclei makes 4U 1820-30 a good candidate for a powerful 2.2 MeV line source, even though it is not exceptionally bright in X-rays. In order to calculate where the redshifted and broadened 2.2 MeV line would be in the spectrum, we used the possible neutron star equations of state and the equation

$$\frac{R}{M} = \frac{2G}{c^2\left[1-(E/E_0)^2\right]} \tag{1}$$

where E and E_0 are the observed and rest-frame line energies and M and R are the mass and radius of the star respectively [1]. The expected energies for different equations of state are given in Table 1.

Table 1. The expected energies of the 2.2 MeV line for different equations of state. The equations of state are as follows: π: Pion condensate, R: Reid's, BJ: Bethe-Johnson, TNI: 3-Nucleon Interaction Approximation, TI: Tensor Interaction, MF: Mean Field Approximation [4]

EOS	$M_{max}/M_{\odot}$	R (km)	M_{max}/R ($M_{\odot}$/km)	E (MeV)
π	1.5	7.5	0.20	1.41
R	1.6	8.5	0.19	1.47
BJ	1.9	10.5	0.18	1.50
TNI	2.0	9	0.22	1.30
TI	2.0	12-15	0.13-0.17	1.56-1.72
MF	2.7	13.5	0.20	1.41

Proc. 6th INTEGRAL Workshop 'The Obscured Universe', Moscow, 3-7 July 2006 (ESA SP-622)

2. ANALYSIS

The data used in this research consisted of 1.7 Ms and we used the *INTEGRAL* data analysis software OSA 5.1 for the imaging, timing and spectral extraction steps. The science windows were divided into 3 groups:

Group 1: Revolutions 1 – 140
Group 2: Revolutions 141 – 214
Group 3: Revolutions 215 – 250

The reason for this grouping is the loss of detector 2 during revolution 140 and the loss of detector 17 during revolution 214. For now, we analyzed only Group 1 (with a total of 1.7 Ms of data), using the empty field observation from revolution 72 as background.

Before generating the histograms for the source and background, we checked the dead times, ACS rates and GEDSAT rates of all science windows. We removed any anomalous cases from our data set.

After the histogram generation, we generated the background files from the flat field revolution 72. Finally, we performed the imaging task and scanned the 1-2 MeV energy band with 22 keV, 44 keV, 100 keV, 150 keV and 170 keV line widths [5]. We searched for 2 sources in addition to 4U 1820-30 and later checked the significance of 4U 1820-30 in the interval 1-2 MeV.

In the spectral timing step, we scanned the 1-2 MeV region with 100 bins. We set the brightest 3 sources found in the imaging step as constants (Ginga 1826-24, H 1705-250 and GX 1+4) and allowed 4U 1820-30 to vary in each scw.

3. RESULTS

4U 1820-30 generally was not detected significantly in any of the energy bins we used for imaging. In Table 2 we present the 3σ upper limits for the redshifted 2.2 MeV line in the 1-2 MeV range using the imaging results. The limits are given as a range instead of a single value, due to the strong background lines present in the 1-2 MeV region. In Fig. 1 and Fig. 2 we present two example images that show the location of the 2 brightest sources detected as well as 4U 1820-30 in a given energy range. In Fig. 3 we present the spectrum of 4U 1820-30 in the 1-2 MeV range.

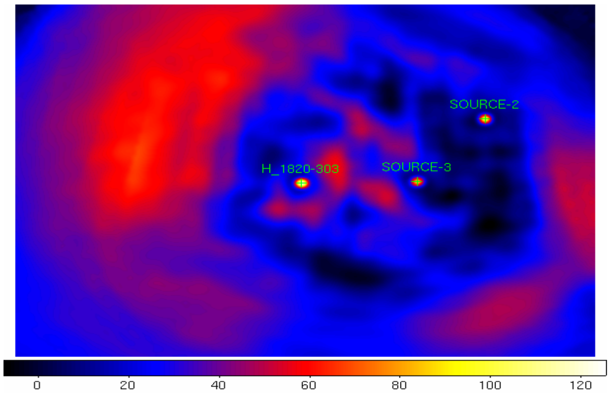

Fig. 1. The result of 1484-1528 KeV imaging, in which 4U 1820-30 is found to be the brightest of the three sources (with a 124σ significance, however this is possibly due to incorrect background subtracting), whereas Source 2 (H 1705-250) and Source 3 (4U 1730-335) have 102.0σ and 87.1σ respectively.

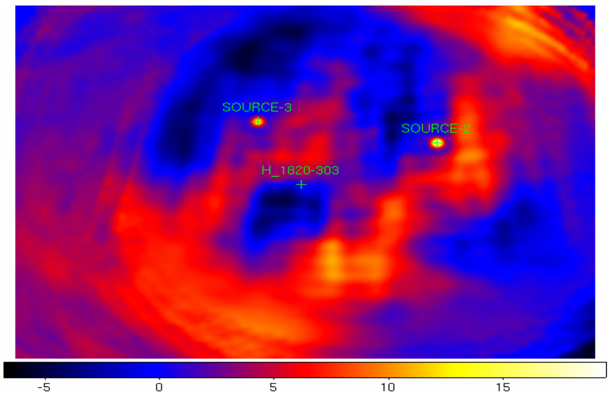

Fig. 2. The result of 1500-1600 KeV imaging, in which 4U 1820-30 has a significance of 0.4 σ, with Source 2 (GX 1+4) and Source 3 (Ginga 1826-24) have 19.5σ and 14.5σ respectively.

Table 2. The 3σ upper limits for the redshifted 2.2 MeV line.

ΔE (keV)	**Flux (photons cm^{-2} s^{-1})**
22	$4.0 \times 10^{-5} - 5.6 \times 10^{-5}$
44	$5.8 \times 10^{-5} - 9.0 \times 10^{-5}$
100	$9.0 \times 10^{-5} - 1.1 \times 10^{-4}$
150	$1.1 \times 10^{-4} - 1.6 \times 10^{-4}$
170	$1.2 \times 10^{-4} - 1.8 \times 10^{-4}$

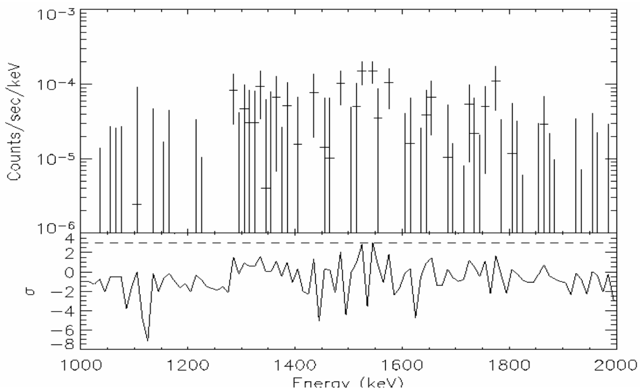

Fig. 3. The upper panel is the spectrum of 4U 1820-30. The lower panel shows the signal to noise ratio.

4. DISCUSSION

While we couldn't observe a significant redshifted 2.2 MeV line in this research, we were able to place upper limits on its flux in different line widths. 4U 1820-30 is not a particularly bright neutron star, and the immense background noise to which *INTEGRAL* is exposed makes it even harder to locate and identify important emission lines. In addition to this, the spin frequency may be of the order of a few hundred Hz, potentially producing significant broadening in spectral lines [1], making it even harder to detect them.

The 1.5 MeV peak produced in the imaging step is very possibly due to undersubtraction of the background in the region of a blend of several background lines, the most dominant being the 1525.5(1) KeV line formed by 69Ge(EC)69Ga [6]. It is very unlikely that all 3 sources have very strong emission at the same energy region. In order to overcome this problem, we are working on different background methods, such as GEDSAT and GEDRATE.

Although the 2.2 MeV line failed to show in the analysis of this group of data, there will be over 8 Ms of data from this source at the end of AO-4. We will continue to analyze the data and either find a line or very stringently constrain the upper limit from this source in the near future.

5. REFERENCES

1. Ozel, F., Psaltis, D., 2003, *ApJ*, 582: L31-L34.
2. Stella, L. et al., 1987, *ApJ*, 312: L12-L21.
3. Smale, A.P. et al., 1997, *ApJ*, 483: L119-L122.
4. Shapiro, S. L., Teukolsky, S. A., *Black Holes, White Dwarfs and Neutron Stars: The Physics of Compact Objects,* 1983.
5. Boggs, S. E., Smith, D. M., 2006, *ApJ*, 637: L121-L124.
6. Weidenspointer, G., et al. 2003, *A&A*, 411: L113-L116.

6. ACKNOWLEDGEMENTS

Ş. Ç. and E. K. are supported by the European Commission through an FP6 Marie Curie International Reintegration Grant (INDAM). E. K. acknowledges partial support of TUBITAK and E. K. and S. E. B. acknowledge NASA grants NAG 5-13142 and NAG 5-13093.