Persistent and Transient Blank Field Sources

Abstract Blank field sources (BFS) are good candidates for hosting dim isolated neutron stars (DINS). The results of a search of BFS in the ROSAT HRI images are revised. We then focus on transient BFS, arguing that they belong to a rather large population. The perspectives of future research on DINS are then discussed.

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1 Introduction

Isolated neutron stars, which have overcome the pulsar phase are elusive sources. In principle they can shine from some residual internal energy (coolers), or because of their interaction with the interstellar medium (e.g. accretors). Their number in the Galaxy should be very high, about one percent of the total number of stars. Their significance as a population is of the utmost interest: they are the end-point of the evolution of a vast class of stars.

It is just because of these considerations that the discovery of dim isolated neutron stars by the ROSAT satellite has been a major achievement (see e.g. Treves et al. 2000, Haberl 2005, Zane et al. 2005).

DINS are one of the main attractions of this meeting, see in particular the presentations by Cropper and Popov. Their properties can be summarized as follows: softness $T \sim 100$ eV; closeness $d \sim 100$ pc; extremely dim optical counterparts ($V > 25$), periodicities of $5 - 10$ s; absorption features below 1 keV. The seven DINS discovered thus far are probably a mixed bag, in the sense that the above properties may not appear all together. For instance the prototype of the class 1856–37, has a perfect black body spectrum in the X-ray band with neither absorption lines nor indications of pulsations. Most likely they are all coolers (Neuhäuser & Trümper 1999, Popov et al. 2002).

In order to further improve our knowledge of DINS it is mandatory to enlarge their sample. The procedure followed up to now to discover new DINS has been to search the ROSAT images for the so called “Blank Field Sources” (BFS, Cagnoni et al. 2002), i.e. X-ray sources without counterparts in other spectral bands, and use the properties listed above to argue that the candidate belongs to the class. This line was pursued by a number of authors, we mention in particular the recent paper by Agueros et al. (2006) where the ROSAT PSPC images (RASS) are compared with the Sloan Digital Sky Survey.

Here we focus on progresses of our search of BFS in the ROSAT HRI images (Chieregato et al. 2005), concentrating on the possible detection of transient BFS.

2 The ROSAT-HRI Blank Field Sources

The ROSAT HRI fields cover $\sim 3\%$ of the sky but the advantage with respect to the PSPC is that the position of the source is much better determined, therefore the limit set by the absence of counterparts can be brought to a deeper level.

The $\sim 30000$ sources of the ROSAT HRI Brera wavelet catalogue (Panzera et al. 2003) have been searched for objects $a)$ with extreme $f_X/f_{opt}$, $b)$ not too faint, $c)$
with total number of photon above a given threshold. Excluding known sources, three objects have been found which have a statistical significance $> 4\sigma$, and with the closest counterpart at $> 4\sigma$ (see Table 1). With respect to Chieregato et al. (2005) 0433+15 was excluded since it was recognized as spurious.

The brightest source is 0421–57. It is close to a bright star (see Chieregato et al. 2005, Fig. 2). It has been detected with the PSPC at essentially the same level revealed by the HRI. The source is soft ($\sim 0.2$ keV, see also Section 3) but not as soft as other typical DINS. The two other sources are much weaker, and they have not been detected with HRI or PSPC when observed at different epochs. We will refer to them as transient BFS. Their light curve have been examined and we can exclude spike-like emission of duration of seconds or minutes.

### 3 New Observations

A program of X-ray observation of the three sources with the Swift XRT is ongoing (P.I. Moretti). We observed all three BFS: 0421–57 (11 ks), 1357+18 (9 ks) and 2007–48 (8 ks). The last two sources were not detected, resulting in $0.3–10$ keV $3\sigma$ upper limits of $1.8 \times 10^{-3}$ counts s$^{-1}$ and $2.2 \times 10^{-3}$ counts s$^{-1}$, respectively. Assuming a power law spectrum with photon index 2 and a Galactic column density (2.1 and $5.1 \times 10^{20}$ cm$^{-2}$) we obtain $5 \times 10^{-14}$ and $8 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ as upper limit on the unabsorbed flux in the 0.3–10 keV band.

In the case of 0421–57 we detect the source at a rate of $(2.2 \pm 0.2) \times 10^{-2}$ counts s$^{-1}$ (about 200 counts) but we are evaluating the contamination from a bright star closeby. The spectrum is very soft and consistent either with a black body (250 $\pm$ 30 eV) or a double Raymond-Smith model.

Several optical campaigns are now in progress. 1357+18 was observed with the $I$ and $R$ filters and the MiniMo camera with the 3.5 WIYN telescope in 10 minutes exposures on 2004 June (P.I. M. Orio). The seeing was about 1.2 arcsec. No optical counterparts were observed in the $3\sigma$ spatial error circle, with a $5\sigma$ upper limit $R > 23.4$. VLT ESO observations of 2007–48 were performed in May 2006 (P.I. R. Mignani), but are not yet analyzed.

### 4 Discussion

We consider in particular the two transient BFS (1357+18, 2007–48). Note that the statistical significance is formally $4\sigma$, and the total number of photons is $> 100$. It is obvious that one must be extremely cautious about the reality of the sources, and because they are supposedly transient, one can’t test with further observations.

In the following we suppose that the sources are real: the optical counterparts are dim indeed. What can transient BFS be? An extragalactic origin seems unlikely, because if they were some kind of BL Lac object, a persistent radio-emission would be expected. Gamma ray bursts are probably to be excluded too, because as noted above the light curves do not show short term variability. One should exclude also binaries with a non collapsed companion, because this should show up in the optical band. One is left to systems consisting of collapsed objects. The key point is that the population of which we have tentatively detected two members could be quite numerous. In fact the HRI field is $\sim 0.2$ deg$^2$, the total exposure time was $\sim 3 \times 10^5$ sec. If the distribution of sources were isotropic this would translate in a rate of $10^5$ transient BFS per year, otherwise the number should be scaled with the solid angle. The large parent population points to isolated neutron stars or white dwarfs. In particular one may wonder if transient BFS are related to a sudden release of the internal energy of a neutron star, a process which may be at work in the recently discovered transient radio pulsars (McLaughlin et al. 2006; Lyne, this conference).

### 5 Conclusions

In the fifteen years of research about DINS the progress was remarkable, yet there are two basic points that have not yet been achieved:

- There is still no example of a DINS which is convincingly powered by the accretion of the interstellar medium. While there are a number of arguments indicating that these objects should be much rarer than originally estimated (Treves & Colpi 1991, Blaes & Madau 1993, Perna et al. 2003 and references therein), these objects should finally show up, and their emission should be largely independent of the neutron star age. Neutron stars as old as the Galaxy could be a part of the lot.
- We have not yet any information on the cousins of DINS, i.e. isolated black holes (see e.g. Agol & Kamionkowski 2002).

The challenge for the future is obviously to explore the sky for DINS and their cousins, at a flux threshold which is an order of magnitude lower than that of ROSAT, and which is easily accessible to present generation X-ray telescopes. There is no doubt that the ac-
tivity up to now has been rather slow, since rich X-ray and optical archives are already available.

Let us summarize the hopes for the future, which can derive from a thorough study of the existing data:

– discovery of accretion fed DINS;
– establishing or excluding the existence of transient BFS;
– discovery of isolated black holes;
– discovery of intermediate mass black holes possibly related to ultraluminous X-ray sources (e.g. Mapelli, Ferrara & Rea 2006).

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