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An Updated Catalogue of High-Energy Observations of Galactic Supernova Remnants

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We present an update to the University of Manitoba's catalogue of high-energy observations of all known Galactic supernova remnants (SNRs), that we publicly released in 2012. We recall the rationale for our work, which aims at bridging the existing census of Galactic SNRs (primarily made at radio wavelengths) with the ever-growing and diverse observations of these objects at high-energies (in X-rays and γ-rays). We share some insights on the sustained and worldwide use of our online resource that is maintained regularly at www.physics.umanitoba.ca/snr/SNRcat. We give updated statistics on the SNR data collected to date, which provide a summary of our current view of Galactic SNRs. Finally, we present two upcoming extensions of our catalogue: one regarding a dedicated database for pulsar wind nebulae, the other related to the bilateral SNR subclass with an imaging component to the catalogue. We plan to keep this resource complete and up-to-date with high-energy observations, and continue to welcome feedback by the community.

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1. Introduction

The broad-band emission from supernova remnants (SNRs) can be used to probe the physics of collisionless shocks and particle acceleration at the shell, in link with the production of high-energy cosmic-rays in the Galaxy, as well as the extreme physics of the compact objects and their outflows often created following a core-collapse explosion. Over the past decades, the development of various new space- and ground-based instruments has produced a surge of observations in the high-energy domain of the electromagnetic spectrum: X-rays and γ-rays. This prompted us to make a systematic census of these observations for all known Galactic SNRs.

2. Background

Details on the making of our catalogue can be found in our paper [2]. In this section we briefly outline the rationale and objectives for our approach, and highlight its usage by the community.

2.1 Rationale and Objectives

Our work was developed with a few key goals in mind:

• Focus on high-energies: the well-known catalogue of SNRs by Dave Green[1] [4, 5] focuses on identification and typing from the radio perspective,[2] our catalogue completes it by focusing on the X-ray and γ-ray emission.

• Provide a unified view of all SNRs: some websites offer dedicated resources per instrument or per energy domain, we present all the relevant observations of a given object together and in a complete way.

• Be up-to-date: Green's catalogue is updated once every several years (the last two updates were released in 2009 and 2014, with the most recent one [5] including references up to the end of 2013), our catalogue is updated regularly to provide a live view of SNRs at high energies, with typically weekly updates (as indicated by the date at the bottom of any page of our website).

• Be easy to manipulate: data are stored in a relational database, that was made (partly) accessible from a web interface.

2.2 Release and Reception

The public website[3] for the catalogue was released on 2012 February 1. It consists of a list of all SNRs with summarized properties and observations, plus an individual record for each SNR with more details and all references. The dynamic main page allows for sorting and filtering of the data, as well as somewhat complex searches using boolean operators. Explanations on the content and use of the catalogue are indicated in the header of the main webpage, and more details can be found in its companion paper [2].

[1] www.mrao.cam.ac.uk/surveys/snrs

[2] Note that we label the radio shells with interior thermal X-ray emission (often called 'mixed morphology' SNRs in the literature) as being (thermal) 'composite' SNRs, while Green does not make this distinction and simply uses the 'shell' terminology (so that his 'composite' SNRs are all plerionic (non-thermal) 'composite' SNRs).

[3] www.physics.umanitoba.ca/snr/SNRcat

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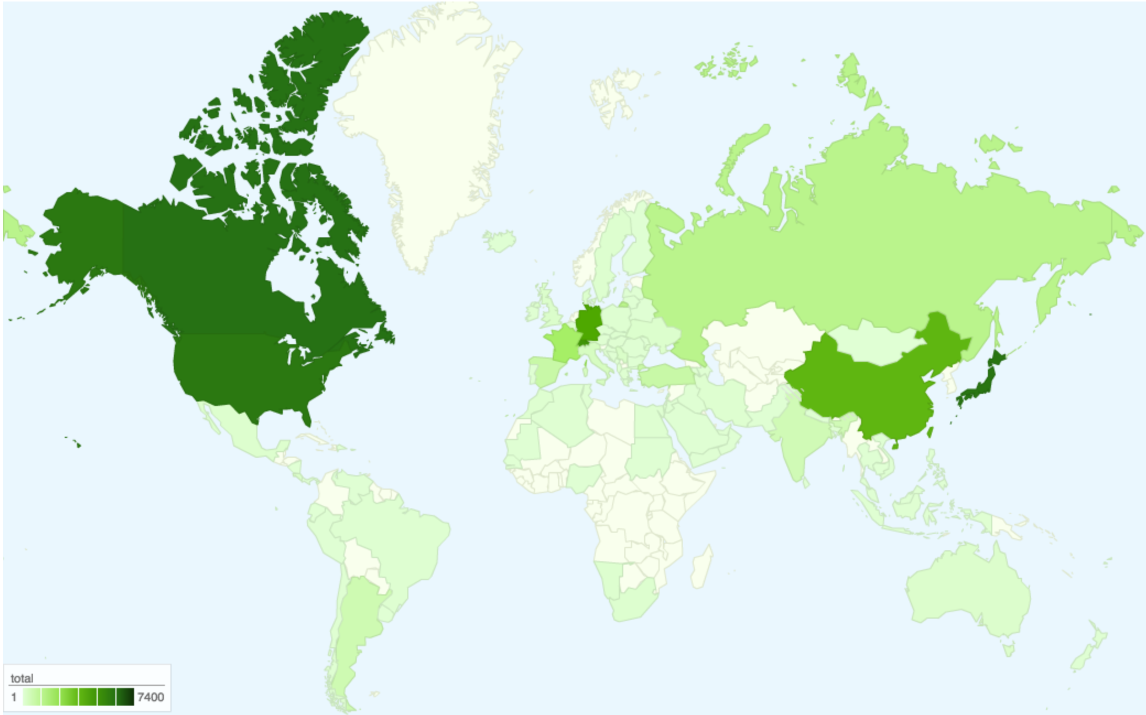

Figure 1: Total accesses (web bot excluded) to the webpages by country, cumulated as of 2014 October 1.

Monitoring of the web traffic has shown the heavy use of our catalogue. Over the first 2.7 years of existence (that is, until 2014 October 1), we recorded nearly 50,000 accesses to our pages, from more than 5,000 unique IP addresses.[4] Most of them can be geo-localised, which reveals that our website has been visited from about a hundred countries all over the globe, as shown in Figure 1, with geographic coverage still expanding. The three most frequent user countries are Canada, Japan, and the USA, followed in the top ten by Switzerland, Germany, China, France, Russia, Spain and Turkey. Accesses are fairly steady over time, with an average of about 100 hits per week for the main page.[4] So this resource obviously answered a need in the community.

3. Current Status

In this section we provide some simple statistics on the content of the catalogue, highlighting the improvements with respect to the initial release. Note that these statistics are updated regularly (typically a few times per year, depending on the level of activity) and posted on the website.[5] As of 2014 October 1, the database contains:

[4]These numbers exclude the robots from search engines. As of now, these 'web crawlers' make only ∼15% of all the IP addresses, but ∼40% of all the page accesses.

[5]Follow the link 'statistics' in the header of the main page, which points to a pdf file dated with the latest update.

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• 329 SNR records, up by 8% from 302 in the initial release (and some recent SNR candidates are still being considered for inclusion). This list includes all of the 294 objects of Green's catalogue as of May 2014 [5],[6] plus 35 other objects (confirmed or candidates): several filled-centre remnants, and some shells or composites that were added in the light of recent observations. 108 records mention a neutron star (NS) or NS candidate, 90 being identified as a pulsar (PSR), including 6 anomalous X-ray pulsars (AXPs). These 6 AXPs plus 2 soft γ-ray repeaters (SGRs) and 2 other high-B objects make 10 magnetars candidates. There are also 15 central compact objects (CCOs) or CCO candidates. All these numbers have only slightly increased since the first release. Also, a pulsar wind nebula (PWN) is now detected or suggested in 87 cases, with only 63 SNRs associated with both a PWN and a NS/PSR. Finally interaction of the shell with a molecular cloud is reported in 68 cases, with varying levels of confidence.

Since the initial release, we made an effort to include all the age and distance estimates we could gather for all the SNRs.[7] As of this writing, we have 160 SNRs with a distance estimate (48%), 115 SNRs with an age estimate (35%), and 111 SNRs with both (34%). These estimates are commonly given as a range of possible values (which can be quite large), or sometimes as only lower or upper limits. In any case, we would like to warn the reader that most of these estimates are model-dependent, and should therefore be used with caution.

• 14 records of the sighting of a supernova, that are referred to by 14 SNRs records (in a non-bijective way, and with varying levels of confidence). This is unchanged from the initial release (and unlikely to change dramatically in the future).

• 1301 records of high-energy observations, up by 50% from 869 in the initial release. These were made with 39 observatories, as shown in Table 1. This is more than 2 times more observatories than in the initial release. In the keV range, we added several legacy instruments: Einstein, EXOSAT, Ginga, HEAO-1, CGRO/OSSE, Uhuru, as well as a new instrument: NuSTAR. In the MeV range, we added the new instrument: NCT. In the GeV range, we added the legacy instruments: COS-B, CGRO/EGRET, SAS-2. In the TeV range, we added several legacy instruments: CAT, CELESTE, GT-48, HEGRA, STACEE, TACTIC, THEMISTOCLE, the Whipple observatory, as well as some recent instruments: AS-γ, ARGO-YBJ, HAGAR, PACT, ShALON. So we believe we have now reached our aim of being complete in the high-energy domain – and we intend to remain so.

Finally, we note that 312 of the observations (24% of the total, slightly down from 29% before) are actually non-detections. Also, we recall that the emission might not be coming from the SNR per se, as seen in Table 2.

• 1803 references in the form of SAO/NASA ADS bibcodes, plus hundreds of other URLs. These are provided as web links, to quickly access the relevant sources of information.

[6]From his 2009 list [4], Green added 21 SNRs, 12 that were already present in our list and 9 that we added, and removed 1 (shown to be a HII region), that we removed too.

[7]Excluding distance estimates based solely on the $\Sigma - D$ relation, the meaning and reliability of which is unclear.

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domain		**instrument**	**records by instrument**	**records by domain**	
X-rays	keV	ASCA	$122 + 3 = 125$	$720 + 37 = 757$	
		BeppoSAX	$19 + 0 = 19$		
		Chandra	$130 + 2 = 132$		
		Einstein	$55 + 7 = 62$		
		EXOSAT	$20 + 0 = 20$		
		Ginga	$19 + 0 = 19$		
		HEAO-1	$19 + 2 = 21$		
		INTEGRAL	$23 + 7 = 30$		
		NuSTAR	$8 + 0 = 8$		
		CGRO/OSSE	$5 + 0 = 5$		
		ROSAT	$89 + 4 = 93$		
		RXTE	$22 + 5 = 27$		
		Suzaku	$55 + 1 = 56$		
		SWIFT	$15 + 2 = 17$		
		Uhuru	$10 + 0 = 10$		
		XMM	$109 + 4 = 113$		
γ-rays	MeV	CGRO/COMPTEL	$4 + 0 = 4$	$6 + 3 = 9$	$269 + 275 = 544$
		INTEGRAL	$1 + 3 = 4$		
		NCT	$1 + 0 = 1$		
	GeV	AGILE	$9 + 0 = 9$	$146 + 215 = 361$	
		COS-B	$7 + 0 = 7$		
		CGRO/EGRET	$26 + 19 = 45$		
		Fermi	$101 + 196 = 297$		
		SAS-2	$3 + 0 = 3$		
	TeV	AS-γ	$1 + 0 = 1$	$117 + 57 = 174$	
		ARGO-YBJ	$4 + 0 = 4$		
		CANGAROO	$6 + 8 = 14$		
		CAT	$1 + 0 = 1$		
		CELESTE	$1 + 1 = 2$		
		GT-48	$2 + 0 = 2$		
		HAGAR	$1 + 0 = 1$		
		HEGRA	$4 + 8 = 12$		
		H.E.S.S.	$55 + 11 = 66$		
		MAGIC	$8 + 12 = 20$		
		Milagro	$10 + 0 = 10$		
		PACT	$1 + 1 = 2$		
		ShALON	$6 + 0 = 6$		
		STACEE	$1 + 1 = 2$		
		TACTIC	$1 + 0 = 1$		
		THEMISTOCLE	$1 + 0 = 1$		
		VERITAS	$12 + 6 = 18$		
		Whipple	$2 + 9 = 11$		
ALL		**TOTAL**	$989 + 312 = 1301$	$989 + 312 = 1301$	

Table 1: Number of observational records in the database, by energy domain and by instrument (numbers are the sum of successful observations and non-detections). Statistics shown as of 2014 October 1.

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	ejecta / shock	compact object / wind	other (unrelated)	unknown
X-rays	$306+\ 63=369$	$266+\ 98=364$	$21+\ 11=\ 32$	82
γ-rays	$42+\ 55=\ 97$	$89+\ 50=139$	$0+\ 6=\ 6$	58
TOTAL	$348+118=466$	$355+148=503$	$21+\ 17=\ 38$	140

Table 2: Nature of the high-energy emission source for all observational records in the database (for the first three columns, numbers are the sum of confident and uncertain identifications). Note that the four columns are not exclusive. Statistics shown as of 2014 October 1.

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4. Future extensions

Our catalogue has been focused on SNRs in our Galaxy[8]. We plan to enhance its usefulness and completeness by adding soon 1) a dedicated catalogue of PWNe and 2) a dedicated catalogue of bilateral SNRs, including SNR images. In this section we highlight these extensions currently developed in the University of Manitoba's SNR group.

4.1 Pulsar Wind Nebulae

Pulsar Wind Nebulae (PWNe, also called plerions), bubbles inflated by the relativistic winds of rotation-powered neutron stars, indicate the occurrence of a core-collapse supernova explosion. Such objects are therefore expected to be associated with SNR shells, produced by the interaction of the stellar ejecta with the interstellar medium (forming what are referred to as plerionic composite-type SNRs). However dozens of PWNe, including young ones like the Crab nebula, still currently lack a visible shell. We note that these apparently 'naked' (shell-less) PWNe are included in our catalogue under the 'filled-centre' SNRs class (but are not all included in Green's catalogue). A nice example of an elusive shell, finally revealed with a deep exposure in X-rays, is the SNR G21.5-0.9 [7, and references therein].

Currently under preparation in our group, with main contributions from Heather Matheson, is a dedicated catalogue of Galactic PWNe (be they isolated or parts of plerionic composite-type SNRs), with nearly a hundred objects currently listed. This catalogue, standing on its own yet fully integrated with the existing SNR catalogue, will provide a multi-wavelength view of PWNe, with focus on their X-ray properties (such as photon index, flux, column density).

4.2 Bilateral SNRs and a Visual Component

Even though SNR shells are commonly considered to be roughly spherical objects, their actual morphologies show a variety of shapes. Of particular interest are the 'bilateral' radio (and X-ray) shells: the geometry of the emission (which is synchrotron radiation in radio, and sometimes in X-rays as well) is directly connected to the geometry of the magnetic field, an important but poorly known ingredient. For SNRs sufficiently evolved, the question arises of the link between their appearance and the structure of the Galactic magnetic field [3, 8].

[8]See this online database (currently under development) for the Magellanic Cloud SNRs: www.mcsnr.org

Currently under preparation in our group, with main contributions from Jennifer West, is a dedicated catalogue of bilateral SNRs, with about two dozen objects currently listed. This catalogue, again standing on its own yet fully integrated with the existing one, will provide qualitative and/or quantitative descriptions of the morphology of the shell emission. To this end, we are in the process of gathering accessible radio and X-ray data (with also contributions from Yitchen Zhan), in order to produce images of the best possible quality to incorporate into our online catalogue. This extension brings us beyond our initial domain of high energies, although this radio-keV connection is of direct relevance for our studies of particle acceleration.

4.3 Long Term Perspectives

Our catalogue is to be updated regularly following new results, in particular from instruments having started operations (NuSTAR and H.E.S.S. II for a couple of years), satellites soon to be launched (ASTRO-H, eROSITA, and ASTROSAT in the next couple of years), and in the longer term planned next-generation observatories (such as CTA). Here we would like to highlight the fact that the H.E.S.S. experiment discovered the new SNR J1731-347 = G353.6-0.7 at TeV energies [6]; the upcoming CTA observatory is expected to detect $\sim$ 80 TeV SNRs [1]. We hope in the future to combine the radio and X-rays images with available γ-ray images.

5. Conclusion

SNRcat, publicly released in 2012, is targeted to benefit the SNR community, theorists and observers alike, and in helping plan future SNR observations. This catalogue complements existing resources, by providing an up-to-date and complete database of *high-energy* (X-ray and γ-ray) observations of all Galactic SNRs. This work was necessitated by the surge of modern high-energy missions and discoveries, and motivated by studying particle acceleration in SNRs. The public website has been widely accessed by the community worldwide, and feedback has been encouraged through an online form.[9] We continue to welcome corrections and updates on specific remnants, and suggestions for improvements of the website or evolutions of the catalogue.

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The database is hosted on the University of Manitoba's computing cluster funded by Canada's Foundation for Innovation and the Manitoba Research and Innovation Funds program.

[9] www.physics.umanitoba.ca/snr/SNRcat/SNRform.php

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