A data base of targets for searches of continuous gravitational wave from rotating neutron stars

Alberto Vecchio
Max Planck Institut für Gravitationsphysik
Albert Einstein Institut
14473 Potsdam, Germany

I. BASICS OF DIRECTED SEARCHES

The continuous gravitational waveform (CW) emitted by a rotating neutron star can be written in the general form $h(t; \boldsymbol{\lambda})$, where $\boldsymbol{\lambda}$ is a vector – defined in the N_λ-dimensional parameter space $\boldsymbol{\Theta}_\lambda$ – containing all the parameters that describe the signal h; $\boldsymbol{\lambda}$ includes the coordinates of the source in the sky, its emission frequency and time derivatives (at some reference time), the orbital elements if the compact object is in a binary system and possibly other additional parameters (we refer the reader to the section about sources and data analysis algorithms for a more detailed discussion of this issue).

A *directed or targeted search* samples not the whole parameter space $\boldsymbol{\Theta}_\lambda$ – which corresponds to an all-sky/all-frequency survey – but only some parameter values ($\boldsymbol{\lambda}_a$, $\boldsymbol{\lambda}_b$,..) or a parameter subset $\boldsymbol{\Theta}'_\lambda \subset \boldsymbol{\Theta}_\lambda$, chosen on the basis of our astrophysical knowledge and theoretical understanding of neutron stars as sources of gravitational waves (GW). Such search requires the set up of a *data-base of targets*, where the values of known $\boldsymbol{\lambda}$'s are stored and then retrieved by the CW search algorithm; the catalog also contains additional parameters useful for a posteriori cross-checks if any candidate event is found.

The targets can be classed into two fairly large categories: (1) individual sources, and (2) sky areas. As the searched area gets larger and the frequency band wider, category (2) merges into the all-sky/all-frequency survey. A tentative list of relevant objects for directed CW searches is the following (we would like to underline that this list can not be regarded as a complete one, but, as of this writing, only a reasonable summary of interesting candidates; the theoretical picture about CW sources has significantly evolved over the last year and shall change again):

1. Individual sources:

    - know pulsar and, generally, neutron stars detected in any electromagnetic frequency band;
    - Low Mass X-Ray Binaries (LMXRB's) and , in general, accreting neutron stars;
    - sources not yet identified with known objects – usually detected with X-ray or γ-ray observations – that might be neutron stars;

2. Areas of the sky:

    - supernovae remnants;

- globular clusters;
- molecular clouds;
- our galactic plane.

Based on the structure of the GW target catalog, it is convenient to divide category (1) in two additional subgroups, as they require a rather different way of exchanging information between the data base itself and the data processing code: (1.a) sources for which $\boldsymbol{\lambda}$ is fixed and constant for the whole period of GW observations; (1.b) sources for which some parameters need to be continously monitored and passed in a sort of "real time" (although we still do not know exactly the optimal time scale) fashion to the GW data analysis algorithms. For sake of simplicity, we shall refer to the catalog required by (1.a) and (2) as *Target Identification Data Base* and to the one necessary for (1.b) as *Source Tracking Data Base*. In the following, we briefly describe the main features of both of them.

- *Target Identification Data Base*: As we have seen, a rather broad class of objects – as of this writing, all but the LMXRB's – share the property of being described by a fixed set of parameters, that do not vary over the time scale of gravitational wave observations, and are simply required as inputs by the data analysis algorithm. The targeted values are retrieved from the catalog and used right at the beginning of the search for CW signals; in principle, the target catalog is never interrogated once the GW searching procedure has started.

- *Source Tracking Data Base*: For LMXRB's, our present theoretical understanding suggests that the time evolution of the gravitational wave emission frequency depends – in a rather complex way – (at least) on the mass accretion rate $\dot{M}$ onto the surface of the neutron star (see the section about sources for more details) [1]; as $\dot{M}$ varies on a time-scale much shorter than the integration time for CW searches, one needs to keep updating this value (and possibly others); in particular one needs to track the evolution of $\dot{M}$ as a function of the so-called s_z parameter along the standard X-ray color-color, or Z-, diagram [2]. For this class of sources, the data base can not be a simple look-up table, which is the case for the "target identification data base", but is much more similar to a communication protocol that transfers the relevant information from some astronomical facilities, possibly X-ray and Ultra-Violet telescopes, to the CW data analysis codes, after suitable manipulation of the variables.

The theoretical understanding of LMXRB's as gravitational wave sources is still poor in order to draw any final conclusion about the requirements for the set up of a "source tracking data base"; however theoretical investigations are currently been carried out and likely to provide the necessary (or at least some more solid) information quite soon [3]; when they will be available, it will be possible to tackle effectively the issue of setting up a data base for LMXRB's, which will be addressed in a future version of this document. In the following we shall deal therefore only with the "target identification data base".

II. PRACTICAL ISSUES

There are several excellent resources on the World-Wide-Web and/or anonymous ftp sites that are suitable in order to build up a catalog of CW targets. Here we give reference to two of them:

- the *Astronomical Data Center* (ADC) [4];
- the *High Energy Astrophysics Science Archive Research Center* (HEASARC) [5].

They seem to be complete for our purposes, but contain also hyper-links to several other astronomical data centers that could provide additional information. The (hundreds of) data sets, which can be easily downloaded, are written in various formats, depending on the instrument and the research team that collected the data; they are up-dated on a quite variable time scale, which translates into the issue of maintaining the data base for GW searches. They also contain a rather extensive reference list of publications and people related to each catalog. Of course, no catalog can be used directly as "target identification data base" because the final format would not be homogeneous and would not fit at all into the GW data analysis algorithms.

The work required is therefore the translation of each relevant astronomical data base (the total number of those useful for the GW community is around 20) into a common format. Such work – likely to be repeated a few times per year during GW observations in order to be updated – can be done by designing a script for each catalog that automatically downloads the relevant files and convert them into the desired format. The very final structure of the data base for GW data analysis and its software implementation crucially depend on the GW search code that retrieves the parameter values. At present, the CW searching algorithms are still under construction and therefore I would advise to set up a preliminary data base with a very simple structure (for example a large table in the form of text file), that can be easily read and, in future, rearranged according to the project needs.

Some general criteria can be identified and guide the construction of the catalog. The data base will be interrogated in three basic ways: (i) one can target one specific source (e.g. Vela, 47-Tuc, SN1987a); (ii) one can target a class of objects (e.g. radio pulsars, globular clusters); (iii) one can target a specific parameter range, say all the known objects with $\boldsymbol{\lambda}^{(0)} \leq \boldsymbol{\lambda} \leq \boldsymbol{\lambda}^{(1)}$, where $\boldsymbol{\lambda}^{(0)}$ and $\boldsymbol{\lambda}^{(1)}$ are given by the observer (particular cases are a region of the sky and/or a frequency range). Each line of the data base (that refers to each specific object that can be targeted) shall contain the name of the object, its class, and all the known parameters required for GW observations (with confidence levels!) sorted out in a specific and fixed order; in addition, the list of know parameters not necessary to search for GW's (typical example is the source distance) should be kept; they could be very useful if a candidate GW event is detected in correspondence of a particular target in order to establish consistency between observations carried out in the GW band and in other electromagnetic frequency windows. It is also important to maintain a detailed documentation about each entry of the data base, e.g. the astronomical data base where the target comes from, related publications and the last time the parameters were updated.

In Figure 1 we report a simple example/implementation regarding a data base for radio pulsars. The radio pulsar data base was assembled using the Princeton catalog published by Taylor and co-workers [6]. It is available from the Princeton ftp (or web) server and includes so far 706 pulsar (notice that about a hundred of newly discovered pulsars are already missing!). Based on this catalog, which consists on ASCII and binary files and is provided with some basic Fortran77 subroutines in order to read it, I have designed some very simple Fortran routines that return the whole set of know parameters (and the associated errors) relevant for gravitational waves searches.

We conclude with some general remarks useful in order to organize and prioritize future work. The set up of the target identification data base does not involve any particular problem of data storage and/or handling; the software implementation should be rather straightforward once the format is decided on the basis of the GW data analysis algorithm; a preliminary data base for CW sources in a (very) simple form, with some basic routines in any software language that can retrieve the information, would be very helpful, in particular to implement and test a semi-automatic procedure to access to the relevant astronomical data centers; in fact maintaining and up-dating the data base is a very crucial issue. An extensive documentation with pointers to other astronomical catalogs and relevant papers/reports should be maintained. The issue of setting up the "source tracking data base" has not been discussed here: as we said, there is nothing we can do about it right now, but in a few months time we will be in a position of defining the general requirements and giving some basic guideline.

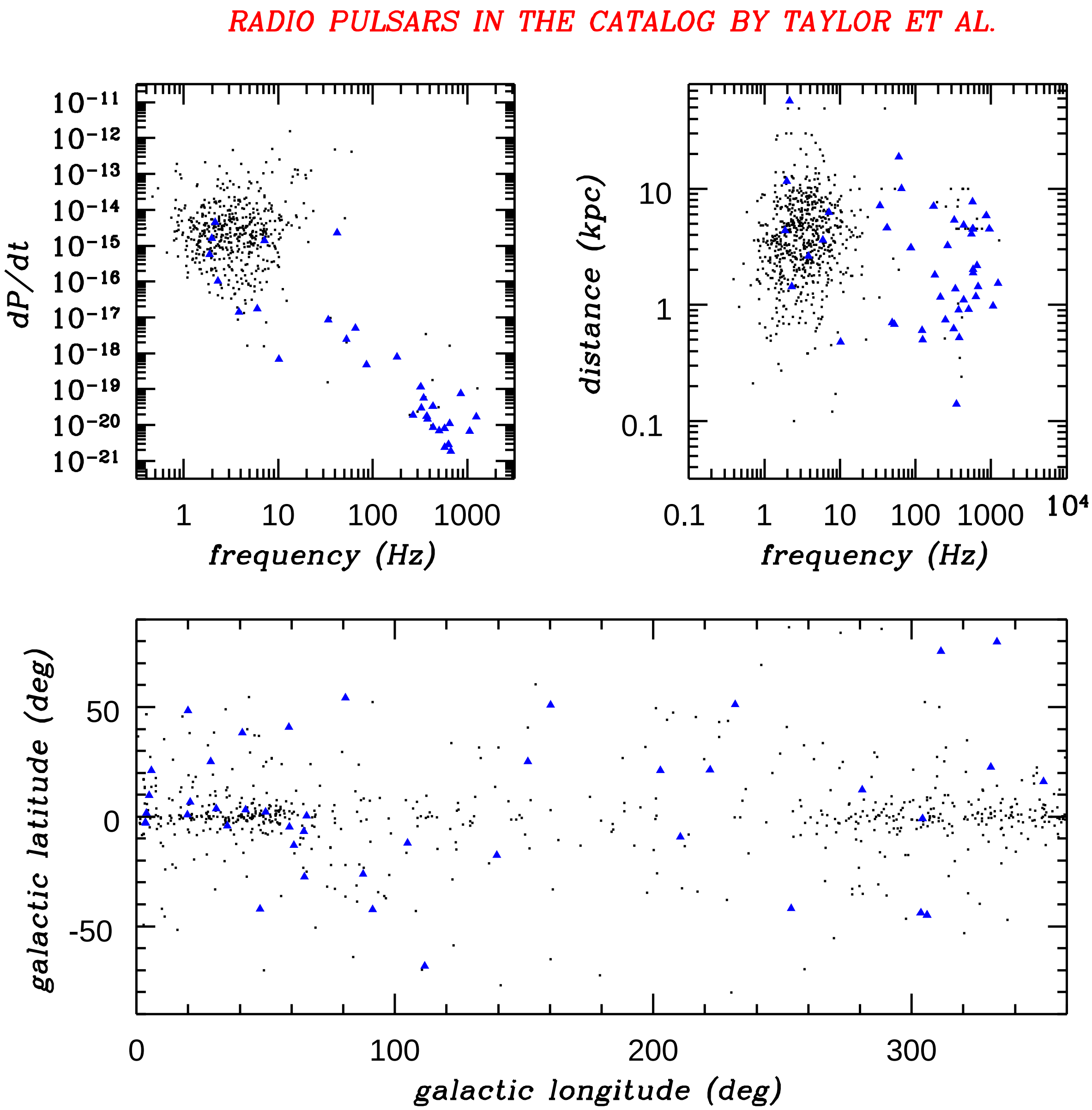

FIG. 1. Some parameters of the 706 radio pulsars contained in the Princeton catalog. The top panels show the first time derivative of the pulsar period P (left) and the distance in kpc (right) as a function of twice the pulsar radio frequency, in Hz. The bottom panel shows the location of the sources in the sky (we have used galactic longitude and latitude, in degrees). The dots and the triangles correspond to isolated neutron stars and pulsars in binary systems, respectively.

REFERENCES

[1] L. Bildsten, Ap.J. **501**, L89 (1998).

[2] P. Herz et al, Ap. J. **396**, 201 (1992).

[3] G. Ushomirsky, C. Cutler and L. Bildsten, paper in preparation.

[4] *Astronomical Data Center* (ADC) at the Goddard Space Flight Center, http://adc.gsfc.nasa.gov/

[5] *High Energy Astrophysics Science Archive Research Center* (HEASARC), http://heasarc.gsfc.nasa.gov/

[6] J.H. Taylor, R.N. Manchester, A.G. Lyne and F. Camillo, *Catalog of 706 Pulsar*, (1995); available at the anonymous ftp site *pulsar.princeton.edu*