THE BOLOGNA SUBMILLISECOND PULSAR SURVEY

NICHI D'AMICO[1]
[1] *Osservatorio Astronomico di Bologna, Bologna, Italy*

ABSTRACT.
Almost all the searches for millisecond pulsars carried out so far were strongly biased against the detection of periodicities near or below the period value ($\simeq$ 1.5 ms) of the original millisecond pulsar PSR1937+21. The coincidence of the minimum observed period with the lower limit predicted by the so called "stiff" equation of state of the ultradense matter is rather intriguing. On the other hand, other realistic equations of state, such as the "soft" one, predict a much lower limiting spin period ($\simeq$ 0.6 ms) for a rotating neutron star, a range that was never searched by radioastronomers. So, a sensitive search for pulsars in the submillisecond period range is important in order to put constraints on the equation of state of matter at nuclear densities. Following these considerations, we constructed a pulsar equipment, specifically designed to undertake a large scale survey of the galactic field for submillisecond pulsars. In this paper we discuss the main characteristics of the experiment and the survey plan.

1. Introduction

The problem of the stability of a rotating neutron star, is extensively discussed in the literature (Friedman, Ipser and Parker, 1984; Cook, Shapiro and Teukolky, 1994), and a wide range of realistic equations of state of the ultradense matter is available. Almost all the accredited equations of state converge towards the same relation for the limiting spin period (Phinney and Kulkarni, 1994):

$$p_{min} > 0.77 \cdot \left(\frac{R_{NS}}{10km}\right)^{3/2} \cdot \left(\frac{1.4M_{\odot}}{M_{NS}}\right)^{1/2} \qquad ms \tag{1}$$

From the observational point of view, one of the macroscopic differences between the various equations of state is the predicted value of the limiting spin period of the neutron star. If the equation of state is very "stiff" this value is $\simeq$ 1.5 ms, on the other hand, if the equation adopted is the very "soft" one, the limiting spin period can be as short as $\simeq$ 0.6 ms.

So, as pointed out by D'Amico (1996) and by Burderi & D'Amico (1997), the discovery of a submillisecond pulsar, or more generally a sensitive search of the critical period range (0.6 ms $\leq$ P $\leq$ 1.5 ms), would be invaluable in order to probe the equation of state of the nuclear matter. Indeed, Burderi & D'Amico (1997), Colpi, Possenti, D'Amico & Burderi (1997) and Possenti, Colpi, D'Amico & Burderi (1998) have shown that in the context of the most widely accepted recycling scenarios, the existence of submillisecond pulsars might be not so rare. In spite of the importance of this issue, almost all the surveys and searches performed so far were strongly biased against the detection of ultra short periodicities.

2. The new Bologna experiment

The capability of a pulsar–search experiment to probe a given volume of the pulsar parameters space depends on various experiment characteristics. One of the main factor affecting the sensitivity limit in a search for ultra short periodicties is the effective pulse width W_e resulting from propagation in the interstellar medium and convolution with the instrument resolution (D'Amico 1996). This is given by:

$$W_e = \sqrt{W^2 + (\beta\delta t)^2 + (\delta t_{DM})^2 + (\delta t_{scatt})^2} \tag{2}$$

where W is the intrinsic pulse width, δt is the sampling time, β is a parameter that takes into account the application of the post-detection time constant and anti-aliasing filter (typically $\beta \simeq 2$) and δt_{DM} is the broadening of pulses due to dispersion: $\delta t_{DM} \propto$ DM $\nu^{-2}(\delta\nu/\nu)$ (were $\delta\nu$ and ν are the width of a single frequency channel and the center observing frequency). The last term δt_{scatt} is the pulse broadening due to multi-path scattering in the interstellar medium, and is usually negligible at high Galactic latitudes.

The new Bologna survey is carried out at 408 MHz. Observations are made using the Northern Cross E-W arm, which allows to track a source for about 1 min around transit. The survey plan includes as a first goal a complete coverage of the northern sky ($\delta \geq 0^o$), but observations could be extended also to $\delta \geq -28^o$. The high resolution adopted both in the frequency and time domains ($\delta\nu = 32$ KHz and δ t $= 64$ μs respectively) give good sensitivity in the ultra short period range. Fig. 1 shows the experiment sensitivity compared with that of the recent Parkes survey (Manchester et al 1996), which led to the discovery of 17 new millisecond pulsars and 84 new ordinary pulsars in the southern emisphere. As can be seen from the figure, the intrinsic sensitivity, or the sensitivity for long period pulsars, of the Bologna system is not very high. This is due to system limitations such as transit time and bandwidth. So, the Bologna experiment is not expected to discover new "normal" pulsars. In fact, the main goal of the experiment is a sensitive search of the millisecond period range and particularly of the critical period range (P $<$ 1.5 ms). A total of 128 frequency channels is used, corresponding to a bandwidth of 4MHz, and the integration time is 67 sec. The experiment requires the acquisition of 128 x 10^6 samples per beam position, and the entire survey project calls for the observation of about 150,000 beams.

Given the high volume of data, the raw data are processed online by a powerful multiprocessor system. Fig 2 shows the block diagram of the system. The raw data collected by the data acquisition subsystem are transferred to a local bus. Raw data available on the local bus can be copyed onto a DLT tape for offline analyses, or can be moved directly to the Dedispersor machine. The Dedispersor produces for each data set a given number of dedispersed times series, corresponding to a set of trial DM values, and makes them available on the same local bus. Any CPU board connected to the same

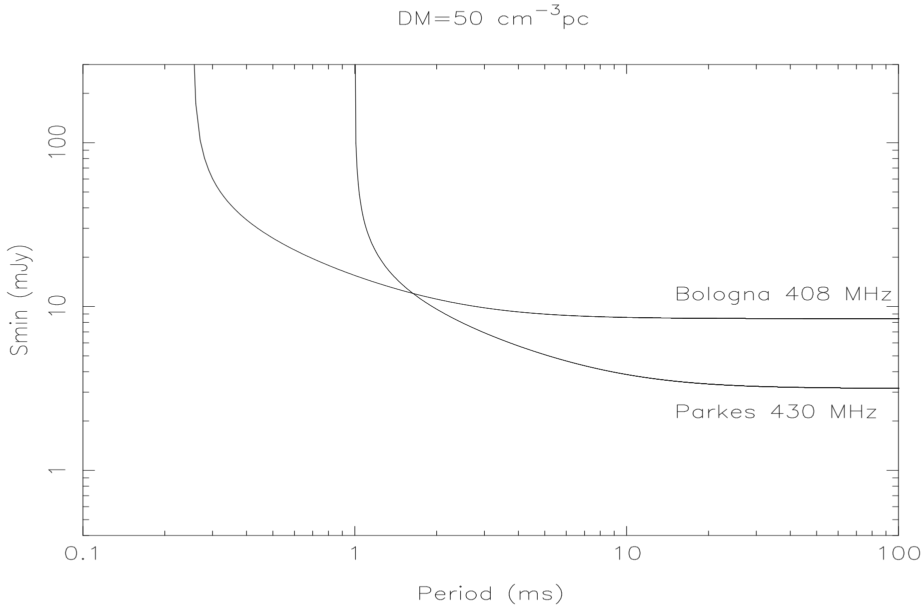

Fig. 1. Minimum detectable pulsar mean flux density for the Bologna survey, compared with that of the Parkes survey.

bus can then read a given dedispersed time series and search for pulsations. Relevant pulsar suspects at any trial DM are automatically stored in a database for future sorting, visual inspection and confirmation.

In the present configuration, the system is able to process about 500 beam positions per day, and it can be used in three different configurations: a) *Online processing*: In this case the observing rate is limited by the data processing capabilities (500 pointings/day). The advantage is that results and data quality can be checked online; b) *Offline processing*: In this case continous observations ($\simeq$ 1200 pointings/day) are stored onto the DLT tape and processed offline by the data processing equipment; c) *Mixed configuration*: In this case observations are performed at the full rate ($\simeq$ 1200 pointings/day), about 500 pointings/day are processed online and the remaining data are stored onto a DLT tape and processed offline by the same machinery when the telescope is allocated to other projects. For each beam position, 6 "suspect periodicities" are generated by the analysis software. So, there is an average flow of about 3000 suspects/day. In order to keep track of all these suspects and classify them, we defined a database structure. The individual suspects archived in the database can be retrived and displayed on the basis of a combination of selection parameters, including: period range, S/N range, epoch etc. Typically, we display and manually classify only suspects with high S/N ($>$ 10). Suspects with low S/N will be automatically classified using a "pattern recognition" software which is still

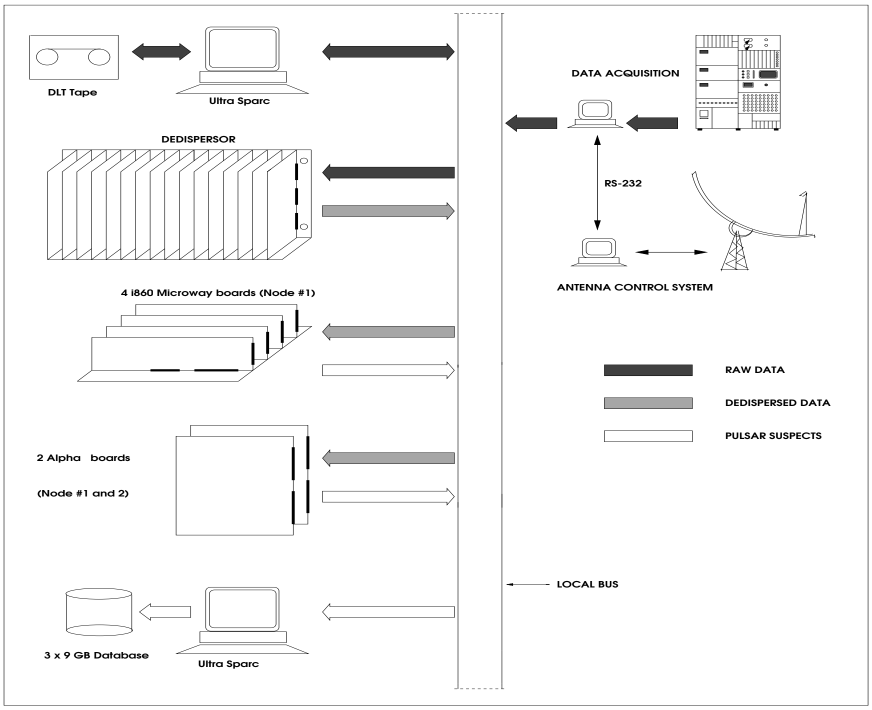

Fig. 2. The data acquisition and online processing system.

under development. We have already observed and processed about 75 % of sky region in the declination range $12^o \leq \delta \leq 38^o$. No pulsar suspects were confirmed so far.

References

Burderi and D'amico, 1997, ApJ 490, 343

Colpi, Possenti, D'Amico and Burderi, 1997, Proceedings of the International Conference on Neutron Stars and Pulsars held on November 1997 in Tokyo, Japan.

Cook, Shapiro and Teukolky, 1994 ApJ 423, L117

D'Amico, NATO/ASI Workshop *The many faces of neutron stars* Lipari, Italy, September 1996

Friedman, Ipser and Parker, 1984 Nat., 312, 255

Manchester et al, 1996, 279, 1235

Phinney and Kulkarni, 1994, ARAA, 32, 591

Possenti, Colpi, D'Amico, Burderi, 1998, ApJ, 497, L97