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MULTI-WAVELENGTH PULSARS STUDY : LONG-TERM TIMING OF XMM, HESS AND GLAST SOURCES WITH THE NANCAY RADIOTELESCOPE

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Abstract. We present here the current Nançay observing program gathering the pulsar french community around the radio follow-up of X- and gamma-ray pulsars for the building of a complete multi-wavelength sample. The goal of this project is double : 1) provide strong constraints on the physics and emission mechanisms of pulsars , 2) guarantee the success of pulsar harvest at high energy by providing good and contemporaneous ephemerides for folding the few gamma and X-ray photons . The community is well involved in the last generation of gamma-ray and X-ray detectors and the availability of the NRT and its dedicated backend BON represents a very good opportunity for acquiring the necessary and complementary radio data.

1 Introduction

Of the over 1500 pulsars known (Hobbs et al., 2004) the large majority have been detected in the radio domain only. The high-energy emission is the result of highly accelerated particles in a strongly magnetized environment. Thermal emission may be from the cooling neutron star or a heated region, most likely the polar cap, which is bombarded by high-energy particles. Non-thermal emission, characterized by hard power law spectra, is thought to arise from the magnetosphere. Alternatively, the emission can be from a pulsar driven synchrotron nebula or the interaction of relativistic pulsar winds with either a wind from a close companion star or the companion star itself. Several models have been proposed which describe the origin of the high-energy emission, the most supported being the polar cap model (Daugherty & Harding, 1996) and the outer gap model (Cheng, Ho & Ruderman, 1986). However, it is still unclear today, almost 40 years after the discovery of pulsars, which of these models ultimately describes the emission mechanisms and thus the nature of pulsars. The energy spectra obtained through multi-wavelength observations will help to understand the physical mechanisms that accelerate charged particles and help to identify the interaction processes that produce the pulsed radiation.

2 High energy emission

Besides aspects concerning their physics or their emission mechanism, the study of pulsars in X- or gamma-rays requires especially regular radio observations, for determining the exact period and phase of the pulsations. The follow-up problem of these high energy radiation emitters is that X- or gamma photons arrive very sparsely in time. For the Crab pulsar, though among the brightest objects, GLAST will capture for example only one photon every 500 rotations of the star. The faintest pulsars will then require 5 to 10 years to integrate a signal, with a need for follow-up radio observations throughout this long period. Moreover, gamma-ray candidates are the young unstable pulsars suffering from glitches and timing noise. They are also those with the largest spin decay. Consequently, they need regular and frequent timing observations and new ephemerides, which means that they need to be regularly observed in radio.

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Predictions of
Slot gap (Gonthier et al. 2004) and Outer gap model (Jiang & Zhang 2006) models

	Normal pulsars		Millisecond pulsars	
	Radio-loud	Radio-quiet	Radio-loud	Radio-quiet
EGRET	25 8	9 24	1	2
GLAST	304 78	258 740	27	79

Fig. 1. Predictions of the number of pulsars potentially detectable for two different emission models (Harding 2006) for GLAST along with comparison with EGRET results.

2.1 HESS

Joint gamma-radio observations have already been carried out with the Nançay antenna i.e. for regularly following pulsars observed with the ground-based gamma-ray detector CELESTE. As a continuation, a first list of target which is a small, selected sample of eight pulsars expected to be observed by HESS in the coming years was settled. HESS (High Energy Stereoscopic System), an array of atmospheric Cherenkov telescopes located in Namibia, is currently the most sensitive gamma-ray detector operating in the energy range from 100 GeV to several tens of TeV. While most models of the main component of pulsar gamma-ray emission predict sharp spectral cutoffs somewhat below this energy range, some models predict detectable gamma-ray emission in the energy range of HESS, e.g. by the Inverse Compton process, or possibly by curvature radiation in the case of low-magnetic-field (millisecond) pulsars.

The observations of these eight pulsars will provide the ephemerides necessary to search for pulsed gamma-ray emission with HESS, and thereby provide constraints for our understanding of the pulsar emission processes. Given the uncertain state of model predictions at these energies, these pulsars were for the most part selected by their very high spin-down power, Edot/d2, where Edot is the decay with time of the rotational energy and d is the pulsar distance.

2.2 GLAST

Meanwhile, GLAST will be the next big step in gamma-ray pulsar observations. Its main instrument, the LAT (Large Area Telescope), will detect gamma-rays between 30 MeV and 300 GeV. The LAT field of view will be extremely wide, of the order of 2.4 sr, covering the whole celestial sphere in two orbits (3 hours). GLAST should allow the detection of the order of a hundred new gamma-ray pulsars. An important difference between the predictions of the two models mentioned above is in the shape of the spectral cutoff at high energies. The Polar Cap models predict a sharp break for energies above a few GeV, while Outer Gap models favour a much shallower behaviour extending up to a few 10 GeV. With better statistics in terms of pulsar population, the investigation of this energy range will help to constrain the location of high-energy particle acceleration. Gamma light curves compared to radio ones should also give a better understanding of the beam's geometry. Finally, neutron stars being produced in supernova explosions, at the end of the life of certain massive stars, a census of the population of neutron stars in the Milky Way provides also us with information about the star formation rate and the evolution of our Galaxy. Today, the statistics of neutron stars are only poorly known because we still do not know well the angular sizes of those radio and gamma emission beams.

From an observational point of view, and in particular from our experience with EGRET, the intensity of gamma rays is highly correlated with the spin-down of the neutron star induced by the rotation of the magnetic field. This spin-down is quantified by the parameter Edot/d2. The decay is stronger during the first tens of thousands of years after the birth of the neutron star. The deceleration in the pulsar 'childhood' has some consequences : the crust of the neutron star shows occasionally a change in its equilibrium state, resulting in a sudden change of its angular momentum and then observationally in a jump in rotational period (a glitch occurs). This leads to define a period of validity of the ephemerides of the order of the month for the most turbulent pulsars. Since the faintness of detected fluxes in the gamma domain requires an accurate folding over very long periods, sometimes extending up to the whole mission duration, a regular timing of these young pulsars is unavoidable.

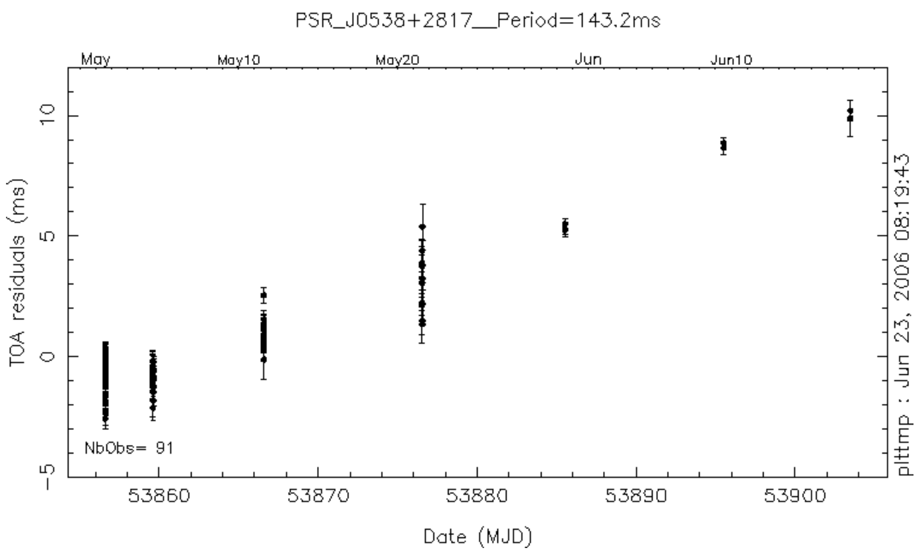

Fig. 2. Nançay PSR J0658+2817 observations processed with ATNF catalog parameters. A large drift produced by sligthly inaccurate parameters is easily visible and could preclude its detection at high energy if not improved.

To summarize, the phase of each single gamma photon has to be calculated with valid ephemerides, in order to be able to fold them into a unique light curve and get suitable statistics to detect, get a spectrum and finally a spectroscopy per phase interval for the most luminous ones. As a consequence of that, the availability of accurate and regular radio timing for large numbers of pulsars will clearly affect GLAST's pulsar yield.

To prepare this huge program of GLAST pulsar follow-up, we already started the building of the pulsar radio database that will be required at the date of the launch in late 2007. A preliminary list of candidates has been set up according to their probability of gamma emission. Two samples are then proposed : a test sample of 10 pulsars for which we sight a dense timing, with an observation every 2 or 3 weeks, and a more general catalog of 138 gamma source candidates extracted from the Parkes Pulsar catalog (http://www.atnf.csiro.au/research/pulsar/psrcat/) and sorted according to C1=sqrt(Edot)/d2, for which we aim to confirm the detection with the Nançay antenna and to update the spin parameters. For the latter, an amount of 4 meridian transits per object is necessary to build our database. Our goal here, with this preparatory study, is to do what was done for EGRET in the past by Arzoumanian et al 1994.

2.3 XMM

In the continuation of the joint XMM-Newton/radio observational campaign carried out in 2004 for the three millisecond pulsars PSRJ0218+4232, PSRJ0751+1807 and PSRJ1012+5307, and in which Nançay contributed, radio/X-ray observations should happen regularly until the end of XMM-Newton's life, probably in 2010 or more likely in 2012. Those joint observations help in particular to understand how the surface magnetic field can evolve from high values (10^{11} - 10^{12} G) observed in the young population to the lower values (10^8 - 10^9 G) observed in recycled millisecond pulsars. Several mechanisms are ideed proposed. Mass accretion in the recycling phase, which is thought to spin up the pulsar, could also bury the magnetic field and then reduce the strength of the observed field (Romani, 1990). One should also observe an increase of the neutron star mass.

An other model states that during spin-up the surface magnetic field evolution could mirror some changes in the core magnetic field configuration. This model, known as the 'spin squeezed' model would result in a millisecond pulsar that would have either an orthogonal or an aligned magnetic field configuration. With the last XMM-Newton observations, one had for the first time enough counts to extract both spectra and light curves for the three millisecond pulsars : PSRJ0751+1807 shows evidence for being an aligned rotator while PSRJ1012+5307 appears to be an orthogonal rotator (Webb, Olive and Barret, 2005). The next observing run of parallel radio/X-ray follow-up, proposed by Webb et al. for the two pulsars PSR1909-3744 and PSR1911-1114, will take place at the end of 2006 or the beginning of 2007 (about ten days of integration per object are foreseen). Accurate ephemerides are required and regular follow-up throughout the X-ray observations.

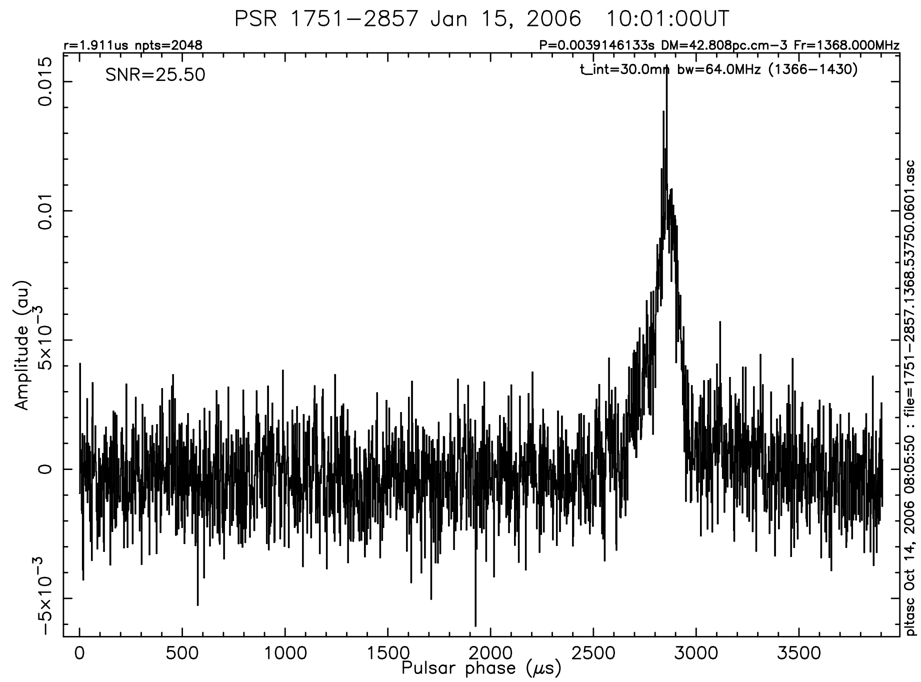

Fig. 3. Nançay observation of PSR J1751-2857, a faint millisecond pulsar and good candidate for high energy emission. This pulsar is quoted with a mean flux density of only 60 μJy, and a large collecting area like Nançay is needed.

3 Conclusion

Nançay observations are going forward for the more than 100 pulsars presently selected to fulfill the objectives we mentionned here. Profiles and Time Of Arrivals (TOAs) are now routinely obtained. Some preliminary ephemerides were already produced mainly for test purpose. In the future, observations will continue and the Nançay list of pulsars can of course be expanded if needed.

References

Arzoumanian, Nice, Taylor & Thorsett 1994, ApJ 422,671

Cheng, Ho, Ruderman 1986, ApJ 300,500

Daugherty & Harding 1996, A&AS 120, 107

Harding 2006, GLAST Data Challenge 2 : http://www-glast.slac.stanford.edu/software/DataChallenges/DC2/MarchWorkshop/

Hobbs et al. 2004, MNRAS 353, 131

Romani R. 1990, Nature 347, 741

Webb N. A. et al. 2004, A&A 417, 181

Webb N. A. et al. 2004, A&A 419, 269