Pulsar at Arecibo: The Next 15 years.

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Abstract

Research goals for the Arecibo Observatory for the next 15 years.

1 Searching for pulsars with ALFA

Over the next few years, the main pulsar project at Arecibo will continue to be the *ALFA pulsar survey.* I am particularly optimistic about the prospects for finding a large number of Galactic millisecond pulsars (MSPs), and the scientific relevance of these new discoveries:

1. The recent *discovery of the first millisecond pulsar by the ALFA pulsar survey*, PSR J1903+03 (a 2.15-ms pulsar at a DM of 297 pc cm^{-3}, the highest ever for this class of pulsar[1]) demonstrates that the ALFA pulsar survey can discover previously hidden MSPs deep within the Galactic interstellar medium.

   Recent simulations by D. Lorimer indicate that, with this capability, there is the potential of finding ~120 MSPs in the sky area being probed by the survey at the sensitivity provided by the WAPPs, more if one is to use the new spectrometers. This means that *the ALFA pulsar surveys could triple the number of Galactic MSPs.* PSR J1903+03 was found after searching 1440 beams (about 4 square degrees), the ALFA pulsar survey will eventually cover 420 square degrees; this is consistent with the prediction of $\sim 10^2$ new MSPs.

2. The short pointings needed to achieve the unprecedented sensitivity of the ALFA pulsar survey mean that it is sensitive to pulsars in tight binary systems. A great example of this is the *discovery of PSR J1906+0746, the second most relativistic and the youngest binary pulsar known* [1].

   This means that the ALFA pulsar survey can find systems with fast spin periods *and* tight orbits - the sort of object that is likely to be a great physics laboratory.

3. The PSR J1903+03 binary system is itself an interesting object, deserving of a publication on its own: it is the first binary MSP in the Galactic disk to have an eccentric (e = 0.44) orbit and a massive companion. This system seriously challenges our present understanding of stellar evolution in binary systems

Timing the interesting objects found in the ALFA pulsar survey will take many years. That long-term timing program will extract the science out of the most interesting new objects, the end objective of the ALFA pulsar survey. Some systems might even be worthy of study for centuries to come. To start the timing of these objects, *the Arecibo telescope will be needed at least until the SKA is commissioned.*

However, over the next decade or so the study of radio pulsars at Arecibo *will become even more scientifically compelling.* The main reason for this is that several space missions will start probing new regions of the electromagnetic spectrum and even of the gravitational wave spectrum. The high sensitivity of the Arecibo radio telescope *will be essential for the follow-up of many discoveries that will be made by these new instruments.* We present two examples of such space missions below.

2 A revolution in the γ-ray sky

The next generation of γ-ray satellites, AGILE (Astro-rivelatore Gamma a Immagini LEggero) and particularly the Gamma-ray Large Area Space Telescope (GLAST), will revolutionize our understanding of the γ-ray (> 20 MeV) Universe. Previous all-sky surveys at these wavelengths, notably those made with EGRET and other instruments on board of the Compton Gamma Ray Observatory (CGRO), could not determine source positions to better than ~ 1 degree (slightly less for higher energies). The Large Area Telescope (LAT) on board of GLAST will be able to locate γ-ray sources with a spatial precision of 30 arcseconds to 5 arcminutes, i.e., sky

[1] see http://www2.naic.edu/~pulsar/highlights/highlights_ALFA_1903+03.shtml

maps will have thousands of time the level of detail they have at present. Furthermore, LAT it will be able to time the photons it receives with a precision of the order of $3\mu s$[2].

The implications of this capability are staggering:

1. The high spatial resolution of LAT will be able to determine exactly if a given photon came from the direction of any known pulsar. Seven pulsars are known to pulse in γ-rays, all of them are young [2]: Crab, Vela, Geminga, three more Southern pulsars and one further object in the Arecibo sky, PSR B1951+32. Geminga has never been convincingly detected at radio wavelengths. A few other young pulsars are spatially associated with EGRET γ-ray sources, but to date it has been technically impossible to prove the association. This happens because of the low spatial resolution of EGRET's sky maps; this means that a pulsar could be merely aligned with a background emitter. There is one case (EGRET source 3EG J1928+1733) where two young, energetic pulsars (PSR J1928+1746 and PSR J1930+1852) have been proposed as counterparts [3, 4]. The former, found recently with ALFA, is the most likely candidate, but the association remains unproven. The much higher spatial resolution provided by LAT will remove these ambiguities once and for all.

2. The precise timing capability of LAT means that we can attribute to each photon a precise rotational phase; we can therefore determine the pulse profile in γ rays, in case this emission if magnetospheric (it could instead be generated in the pulsar wind nebula). Apart from the extra confirmation of the association, this allows the study of pulsar emission mechanisms at γ-ray wavelengths. This is important because, apart from the dipolar radiation emitted at the pulsar's spin frequency, γ-rays carry away most of the electromagnetic luminosity; much more than radio waves. They are therefore more direct probes of the emission/particle-acceleration mechanism. To date, the few pulse profiles studied tend to have two sharp features connected by a bridge of low-level emission. Because of these sharp features, it is very important to have good rotational ephemerides for the radio pulsars, otherwise the γ-ray pulse profiles will be smeared.

   However, most of the youngest and most energetic pulsars known, the prime candidates for detection by GLAST, have very unpredictable rotational phases, these are affected by timing noise and, in some cases, glitches. For this reason, any given ephemeris will quickly degrade with time. The problem is further compounded by the way LAT collects data: during Phase 1 of the mission (starting 60 days after launch, and lasting one full year), *and likely through the remaining 4-10 years of mission time*, the satellite will spin in space while it conducts a deep whole-sky survey. This will therefore be the integration time for *all* pulsars in the sky. Even low-amplitude timing noise can create a significant drift in the rotational phase relative to the prediction of the ephemeris, thus smearing the γ-ray pulse profile. Hence the need to monitor the rotational phase of these pulsars at radio wavelengths during this period, and *only Arecibo can do this effectively for the faintest pulsars*.

3. After completing its all-sky survey, GLAST will detect many γ-ray pulsars, but the estimates vary widely, depending on the assumed beam geometry. McLaughlin and Cordes[2] estimate that it will detect 750 objects, of these about 120 will be known radio pulsars. Gonthier et al. (2002)[5] estimate the discovery of $\sim$76 known radio pulsars and $\sim$74 "radio quiet" pulsars. Although some of the new pulsars will be immediately recognized as such through the immediate detection of γ-ray pulsations, or the coincidence with known radio pulsars, most will appear only as steady sources of hard ($>$ 100 MeV) γ rays with no known radio counterparts. Investigating the nature of these confirmed or suspected pulsars will require follow-up at radio wavelengths. The Arecibo Observatory will be the ideal place to make a deep search for radio pulsations from the supposed "radio quiet" objects; the spatial accuracy provided by LAT is well matched to Arecibo's L-band beam. Past surveys for pulsars in EGRET sources had to spread the observing time in large sky areas, therefore not much depth could be achieved. We will now be able to search for the radio counterpart of γ-ray sources *knowing exactly where to point.* This will lead to the discovery of many new, energetic radio/γ-ray pulsars.

4. As for the previously known pulsars, timing these sources with Arecibo will then allow the folding of the γ-ray photons, and determine the γ-ray pulse profiles, starting what is, in effect, a symbiotic relationship. Most of the new objects will be faint, *only Arecibo will be likely to be able to monitor their rotation effectively.*

[2] For details on the mission, check http://glast.gsfc.nasa.gov/

3 LISA

Expected to launch in the middle of next decade, the Laser Interferometer Space Antenna (LISA) will be able to detect gravitational waves with periods ranging from many hours to a fraction of a minute. It has guaranteed sources of gravitational waves, but the most interesting sources will probably be those we don't know about yet.

One particular feature of this mission is very relevant to our purposes; is its ability to detect extremely compact systems. If there is a binary radio pulsar with a massive neutron star companion in a tight orbit (less than 30 minutes or so), then there are serious selection effects against the detection of such a system in radio searches. If the binary is close to us, these might be removed by the aforementioned short integrations of the ALFA pulsar survey if coupled with an acceleration search procedure; a similar technique has recently been used by some of us to discover large numbers of MSPs in globular clusters (e.g., [6]). However, such massive, tight binaries have short lifetimes, since they are losing energy fast because of emission of gravitational waves. Therefore, there are few of them in out Galaxy, i.e., they are not likely to be close to the Sun.

Fortunately, LISA, being sensitive to the *amplitude* of gravitational waves (not their intensity), has a sensitivity to such systems that decreases solely as $1/r$, not $1/r^2$. This means that it will definitly find the most compact systems containing neutron stars in our Galaxy. Assuming a signal-to-noise ratio (S/N) of 10, a source with an orbital period of 1 hour will be located by LISA with a spatial accuracy of about 0.06 sr (about 200 square degrees) [7], if the orbital period is 1000s, the spatial location will be of the order of 100 square degrees, and a 5-minute binary would have an error ellipse of about 20 square degrees. The surface of these error ellipses would decrease inversely to the square of the S/N. The areas might be small enough to motivate deep surveys for radio pulsars, Arecibo will be more at an advantage compared to other telescopes the better the location is. Finding a pulsar - neutron star binary with an orbital period of tens of minutes or shorter would represent a great step forward in the study of gravitation. Another exciting possibility would be the detection of a pulsar-black hole binary, which might allow the study specetime near these objects. There is clearly much potential for an Arecibo/LISA partnership, much of which is still not recognized today.

References

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