Pulsar investigations with Arecibo - the world's largest radio telescope

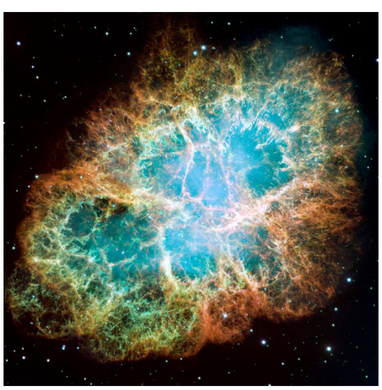
Pulsars are city-sized stars with as much material as the Sun. They typically rotate many times per second and are surrounded by enormous magnetic fields. They emit radio signals from regions above their magnetic poles much as do light houses. These "almost black holes" generate powerful beams of radio energy by processes similar to the Earth's aurorae, but unimaginably more intense. Key to understanding how pulsars work is the measurement of the polarization state (orientation) of the electromagnetic signals, and not just their intensity. The physical conditions near and within pulsars are some of the most "exotic" in the cosmos; thus their study provides key tests of the fundamental principles of physics. The Arecibo telescope's unrivaled sensitivity has kept it at the forefront of pulsar investigations for the past four decades.

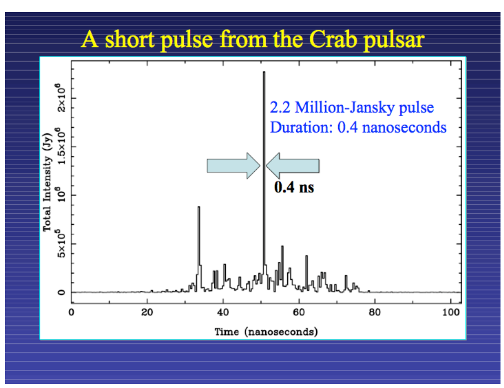
Arecibo is providing most of the key discoveries about how pulsars work, including:

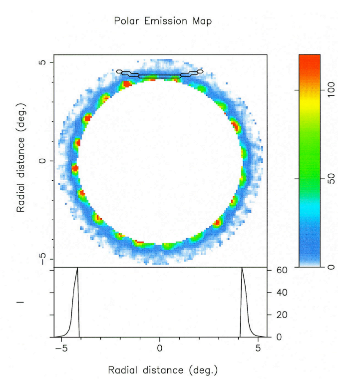
- discovery of fundamental emission phenomena: "drifting" subpulses, pulse nulling, and microstructure.
- identification of the double-cone and core characteristic pulsar beam forms.
- confirmation that the emission cones are comprised of multiple subbeams that precess around a pulsar's magnetic pole.
- the primary importance of the orthogonal polarization modes and null periodicities.
- nano-arc-second imaging of pulsar emission beams using both natural interferometers in the interstellar medium and subbeam-circulation mapping
- ultra-wide-band observations of pulsars revealing basketball-sized emission elements

Pulsars' enormous magnetic, electric and gravitational fields provide "exotic" conditions for testing physical principles that occur nowhere else in the universe. Only Arecibo can:

- conduct investigations of important WEAK and DISTANT PULSARS (*e.g.*, B0943+10 below).
- obtain sensitive measurements of the DYNAMIC POLARIZATION OF PULSAR SIGNALS.
- carry out DETAILED OBSERVATIONS of the properties of BRIGHT PULSARS.



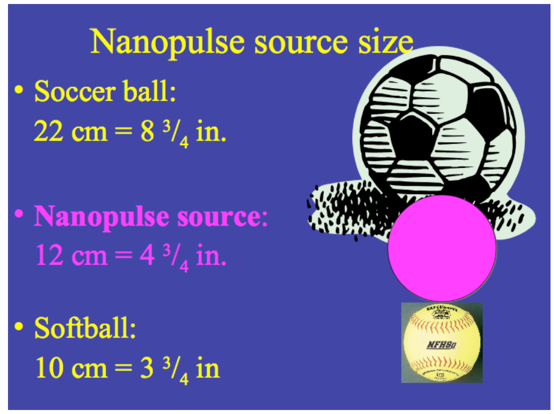




Left: Optical image of the Crab Nebula, a nearby supernova in 1054, where Arecibo identified the then fastest spinning pulsar in 1968. **Center**: A giant pulse from the Crab pulsar, over extremely short times the brightest signal known. **Right**: Subbeam emission "carousel" of pulsar B0943+10 that rotates around its magnetic axis every 43 seconds producing its "drifting" subpulses, identified using Arecibo.

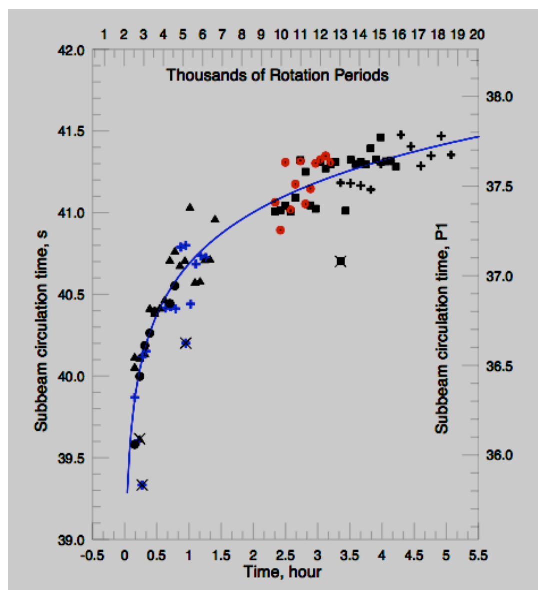
Arecibo continues to reveal unique and exotic aspects of pulsar radiation that illuminate fundamental physics and are beyond the reach of all current and planned telescopes.

The Brightest Pulses in the Galaxy



"What is the physics behind the conversion of a pulsar's rotational energy to the radio emission we see as regular pulses similar to what one sees from the rotating beam of a lighthouse?" One hypothesis is that violent turbulence in the highly charged pulsar atmosphere produces bursts of radiation, which could then be seen as very short radio pulses. Using a technique to remove the distortion of pulsar radio signals due to propagation through the huge distance of interstellar space, the predicted short pulses have been found in signals recorded with ultra-high time resolution at the Arecibo Observatory. To produce a short pulse, an emitter can be no larger than the distance light travels in the duration of the pulse. "Nanopulses" as short as 4 ten-billionths of a second (0.4 ns, see above) have been detected from the Crab Nebula pulsar. With instantaneous energies as powerful as the Sun (whose radio intensity is a million Janskys—though typical radio sources are only a few Janskys), but a billion times further away, these nanopulses are the brightest cosmic signals ever measured. Thus, the emitter must be larger than a softball and smaller than a basket ball—*i.e.*, about 12 cm (see above). The next challenge for understanding pulsar emission physics is to determine if other pulsars have similar characteristics. Ultra-high time resolution measurements made with the Arecibo telescope are required to test this hypothesis.

The Physics of Carousel Subbeam Systems



Pulsars' characteristic cones of emission, Arecibo studies now show, are produced by "carousels" of rotating subbeams that also produce their "drifting" subpulses and most "null" pulses (see above figure). Typical circulation times are a minute or more, and these probe the physically crucial high field regions just above a pulsar's magnetic polar cap. After onset, the "drift" circulation time in pulsar B0943+10 has been found to decay with a characteristic time of about one hour—the longest orderly behavior seen in any pulsar phenomenon. This result may reflect the changing temperature in the polar cap regions of the pulsar (perhaps some 500,000 degrees), again a fundamental property for understanding pulsar radiation physics.

For pulsar investigations, it is crucial to keep Arecibo operational because it is:

- able to study the emission dynamics of the weakest and most distant pulsars currently known. Therefore, many exciting investigations can only be pursued using Arecibo.
- the only telescope currently capable of investigating pulsar polarization in detail.
- the most sensitive telescope for studying high time resolution phenomena, which are often the most exciting for tests of fundamental physics.