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Follow-up of FAST pulsar discoveries

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Context

Pulsars are strongly magnetized neutron stars detected mainly through the pulses of electromagnetic radiation emitted from their poles. They have become a fascinating research area since their discovery in 1967, as they provide an outstanding laboratory for a wide variety of physics, ranging from a better understanding of stellar evolution, to map the electron content in our Galaxy, to test theories of gravity and placing limits on the equation-of-state (EoS). The most stable pulsars, who's precision approaches that of atomic clocks, are our only window into the extremely low-frequency (10e-8 Hz) gravitational waves expected from supermassive black hole binaries, which are not detectable by LIGO or LISA (Zoltan et al. 2017).

With the aim of finding the most exciting pulsars, the Chinese Academy of Science (CAS), the Max-Planck Institute for Radioastronomy (MPIfR) and the Australia Telescope National Facility (ATNF) have started a major pulsar survey using the giant "Five-hundred-meter Spherical-dish Telescope" (FAST), the world's biggest radio-telescope. Since first light in September 2016, FAST has been undergoing commissioning observations. Already at this early stage, the pulsar survey is producing exciting science by finding new pulsars, demonstrating FAST's unprecedented sensitivity.

1. The Commensal Radio Astronomy FAST Survey

The survey using FAST is one of the key science projects at the telescope. FAST's unrivaled collecting area has two major benefits for pulsar surveys. The first is simply raw sensitivity, the second is the binary parameter space that can be searched. In most pulsar surveys a large number of trial accelerations need to be searched to account for the apparent change in period of the pulsar during the observation. The tighter the binary, the greater the Doppler shift and the larger the acceleration range that must be searched.

FAST's main characteristics (Nan et al 2011):

- It is a 500 meters aperture as spherical reflector but it can be deformed to create a 300 meters parabolic dish. This makes tracking possible for longer in comparison with normal a static radio-telescope.
- Frequency coverage from 70 MHz to 3 GHz is possible with the 19-beam receiver.
- Allows zenith angle of 40º. The sky view is showed in fig. 1.
- The sensitivity in the L-band (1-2 GHz) is ~18 K/Jy. By comparison Parkes has 0.65 K/Jy, Effelsberg 1.4 K/Jy and Arecibo 9-11 K/Jy.
- It is located in the large karst depressions in south Guizhou province (southwest China).

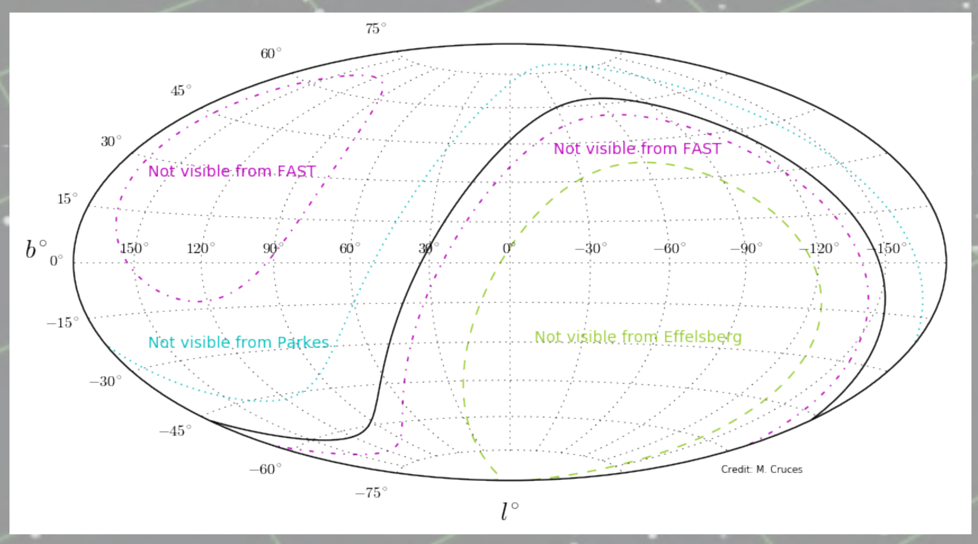


Fig 1. Sky coverage of FAST, Effelsberg and Parkes radio-telescopes in galactic coordinates.

2. Early stage of the survey

So far, the survey is making use of the drift-scan mode and a wide-band receiver made for the commissioning phase. The best candidates have been found in the 500 MHz band, where a source passes through the beam in about 50 seconds.

- **Technical info of the observations:**
  - Receiver covering from 270 MHz to 1.6 GHz
  - Temperature of the system is ~ 60 K
  - Gain of ~6 K/Jy
  - Rate of discoveries of ~10/month

Pointing is achieved by moving the suspended focus cabin. The position is monitored using laser ranging systems and the pointing model is being developed.
In order to aid commissioning by confirming the pointing and sensitivity, the 100m Effelsberg and 64m Parkes radio-telescopes in addition to be one of the few telescopes large enough to follow FAST discoveries, have excellent pointing precision, positional and frequency agility. This makes them the ideal northern and southern hemisphere telescopes for this project.

3. The Effelsberg follow-up

Upon the discovery of a good candidate by FAST, the confirmation campaign starts. As the pipelines are not required to search the whole sky and the full parameter space like in a blind survey, they are expanded to include novel search techniques that would be too computationally expensive to use otherwise.

Pulsar's amazing rotational stability allows its signal to be detected on Earth as regular and precisely timed pulses. With regular timing observations a phase coherent solution for the pulsar can be created which accounts for every rotation of the pulsar from the discovery to the latest observation.

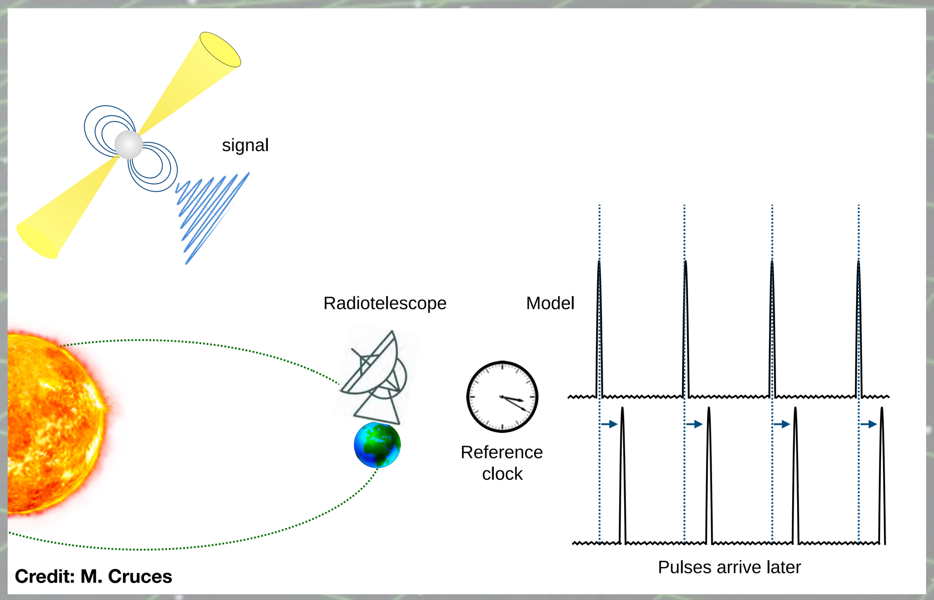


Fig 2. Sketch of Pulsar timing method.

Such a model can then be used to measure the pulsar mass and to place limit on EoS (ex: Antoniadis et al. 2013)., or to detect irregularities in the time of arrival in the pulses of an array of pulsars, which might indicate the passing of gravitational waves (Manchester 2010).

4. Results

For the observations we use Effelsberg's 7-beam receiver at 1.4 GHz. In order to match FAST's sensitivity and to account for the expected decrease in flux density at higher frequencies, we observe every candidate for 30 to 60 minutes.

- To date 6 pulsars have been confirmed by Effelsberg. Their discovery plot are presented in figures 3-8.
- With every pulsar confirmation feedback in the positioning of the source is provided which feeds back into the position modeling of FAST.
- Currently we are monitoring 7 pulsars and we expect to obtain a phase connected solutions within the coming months.

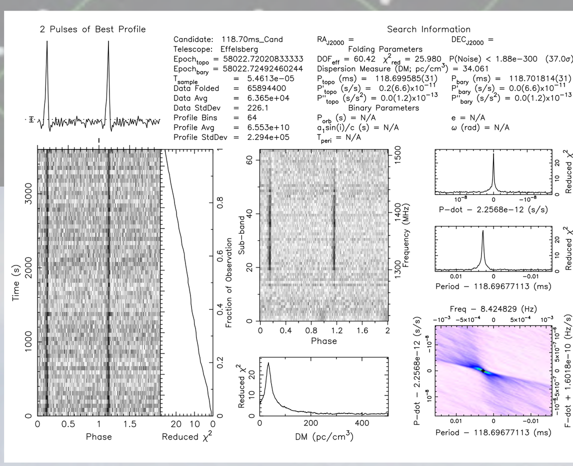


Fig 3. Confirmation of a pulsar with spin period 118.701 milliseconds at DM of 31.061 pc/cm^3.

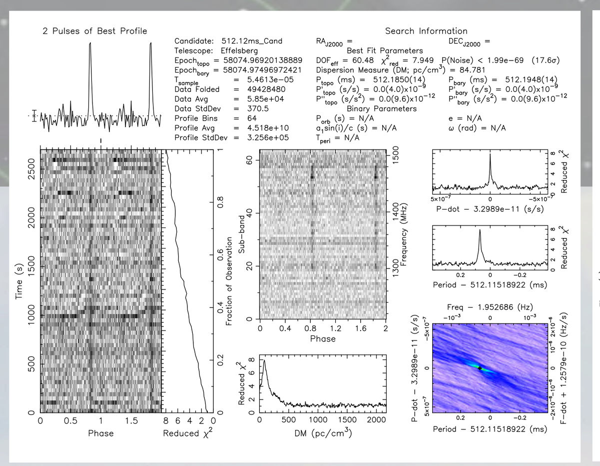


Fig 4. Confirmation of a pulsar with spin period 512.194 milliseconds at DM of 84.781 pc/cm^3.

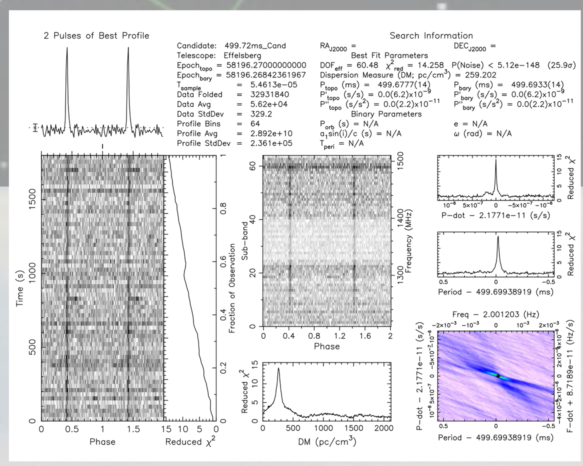


Fig 5. Confirmation of a pulsar with spin period 499.693 milliseconds at DM of 259.202 pc/cm^3.

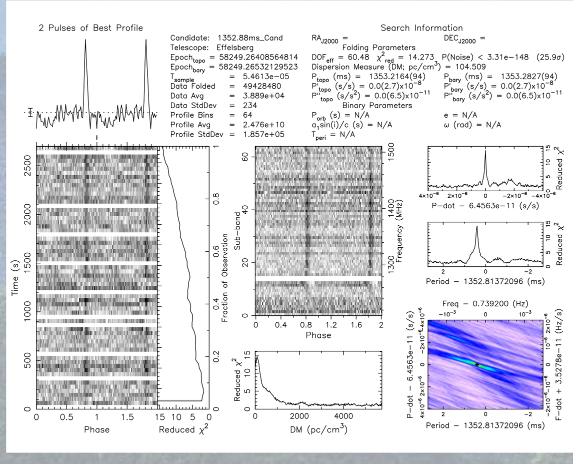


Fig 6. Confirmation of a slow pulsar with spin period 1353.28 milliseconds at DM of 104.509 pc/cm^3.

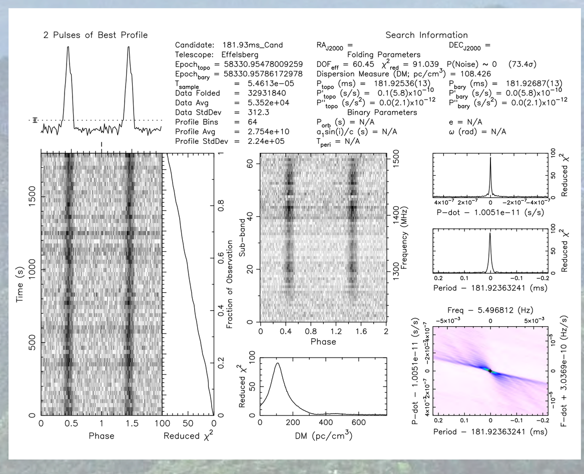


Fig 7. Confirmation of a pulsar with spin period 181.926 milliseconds at DM of 108.426 pc/cm^3.

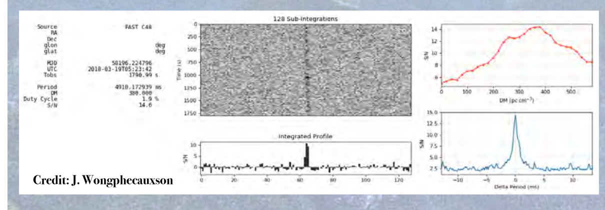
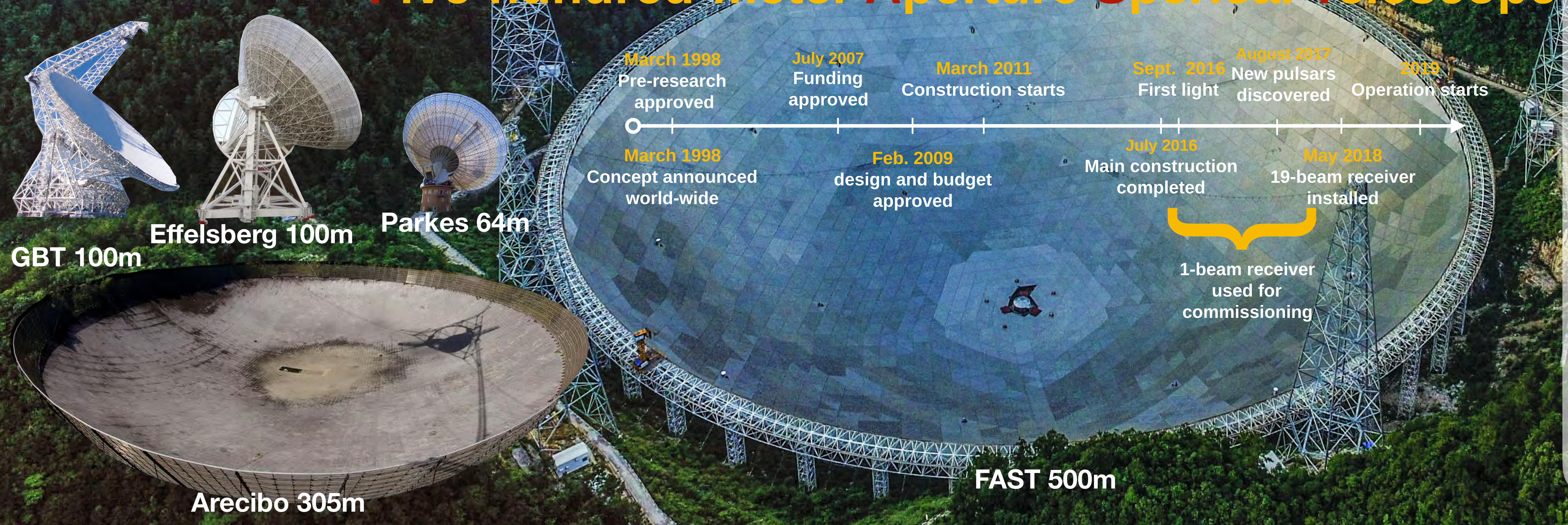


Fig 8. Confirmation of a slow pulsar with spin period 4910.172 milliseconds at DM of 380 pc/cm^3. So far, the only one confirmed through *fast folding algorithm* (see Cameron et al. 2017).

The Radiotelescope Family
sizes into perspective
Credit: M. Cruces

Five-hundred-meter Aperture Sperical Telescope



DID YOU KNOW THAT...?

- The fastest spinning pulsar rotates 716 times per second.
- Pulsar's core is denser than the atom nucleus.
- In China FAST is known as 天眼, which means **Sky Eye**.
- FAST saw first light from a pulsar 1351 Ly. away during the opening ceremony.
- One of the key science projects at FAST is SETI.
- Effelsberg is the second largest steerable radio-telescope.
- Parkes is the largest dedicated radio-telescope in the southern hemisphere.