Pulsar Discovery by Global Volunteer Computing

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Einstein@Home (*1*) (E@H) is a volunteer distributed computing project (*2*). Members of the public sign up their home or office computers (hosts), which automatically download work units from the servers, carry out analyses when idle, and return results. These are automatically validated by comparison with results for the same work unit produced by a different volunteer's host. More than 250,000 individuals from 192 countries have contributed; each week about 100,000 different computers download work. The aggregate computational power (0.25 Pflop/s) is on par with the largest supercomputers. E@H's primary goal is to detect gravitational waves from rapidly spinning neutron stars in data from Laser Interferometer Gravitational-Wave Observatory (LIGO) and VIRGO (*1*).

Since 2009, about 35% of E@H compute cycles have also been used to search for pulsars in radio data from the Pulsar ALFA (PALFA) project [supporting online material (SOM)] at the 305-m Arecibo Telescope (Puerto Rico). Data disks are sent to Cornell University's Center for Advanced Computing (United States), where data are archived. For E@H, data are transferred to Liebniz Universität (Hannover, Germany), dedispersed for 628 different dispersion measures (DM $\in$ [0, 1002.4] pc cm^{-3}), and resampled at 128 µs. Hosts receive work units containing time series for four DM values for one beam. Each is 2 MB in size, covering 268.435456 s. A host demodulates each time series (in the time domain) for 6661 different circular orbital templates with periods greater than 11 min (our Galaxy has even shorter period binaries). The grid of templates is spaced so that, for pulsar spin frequencies below 400 Hz, less than 20% of signal-to-noise ratio is lost. Fourier algorithms sum up to 16 harmonics. A total of 1.85% of the power spectrum is removed to eliminate well-known sources of radio frequency interference. A significance ($S = -\log_{10}p$, with p the false-alarm probability in Gaussian noise) is calculated at each grid point. After ~2 central processing unit hours, the host uploads the 100 most significant candidates to the server.

When all work units for a given beam are complete, the results are postprocessed on servers at Hannover. Candidates with $S > 15$ are identified by eye, then optimized with PRESTO (www.cv.nrao.edu/~sransom/presto/) (SOM). To date E@H has searched 27,000 of 68,000 observed beams. It has redetected 120 pulsars, most in the past 4 months, because code and algorithm optimizations sped up the search by a factor of ~7.

On 11 July, the 24-ms PSR J2007+2722 was discovered with a significance of $S = 169.7$ (Fig. 1) in survey data from February 2007. It was later re-detected in another PALFA survey observation. Follow-up observations were done by the Green Bank Telescope (GBT, United States), the Lovell Telescope at Jodrell Bank Observatory (United Kingdom), the radio telescope at Effelsberg (Germany), the Westerbork Synthesis Radio Telescope (WSRT, Netherlands), and Arecibo. The period-averaged flux density is 2.1 mJy (1 Jy = 10^{-26} W m^{-2} Hz^{-1}) at 1.5 GHz. Gridding observations using Arecibo and WSRT unambiguously associate the pulsar with a source in an archival Very Large Array (VLA) C-array observation, having 1.2 mJy flux density at 4.86 GHz, at right ascension (RA) $20^h07^m15^s.77$ and declination (Dec) 27°22′47″.7 (J2000) with uncertainty $\lesssim 1''$. The pulsar is not in a supernova remnant or globular cluster and has no counterpart in x-ray or gamma-ray point-source catalogs. The DM of 127 pc cm^{-3} implies a distance of 5.3 kpc (*3*). The full pulse width between the outer half-maxima is $W \approx 224°$. The wide pulse and initial polarization observations indicate that the pulsar likely has nearly aligned magnetic and spin axes.

The pulsar's barycentric spin frequency (*4*) is 40.820677620(6) Hz at MJD 55399.0. With the VLA position, the 2010 data give limits $|\dot{f}| < 3 \times 10^{-14}$ s^{-2}, magnetic field $B < 2.1 \times 10^{10}$ G, and spin-down age $> 21 \times 10^6$ years. These limits and lack of a companion mean that J2007+2722 is likely the fastest-spinning disrupted recycled pulsar yet found (*5*). However we cannot rule out it having been born with low B (*6*). Either way, PSR J2007+2722 is a rare, isolated low-B pulsar, which contributes to our understanding of pulsar evolution.

This result demonstrates the capability of "consumer" computational power for realizing discoveries in astronomy and other data-driven science.

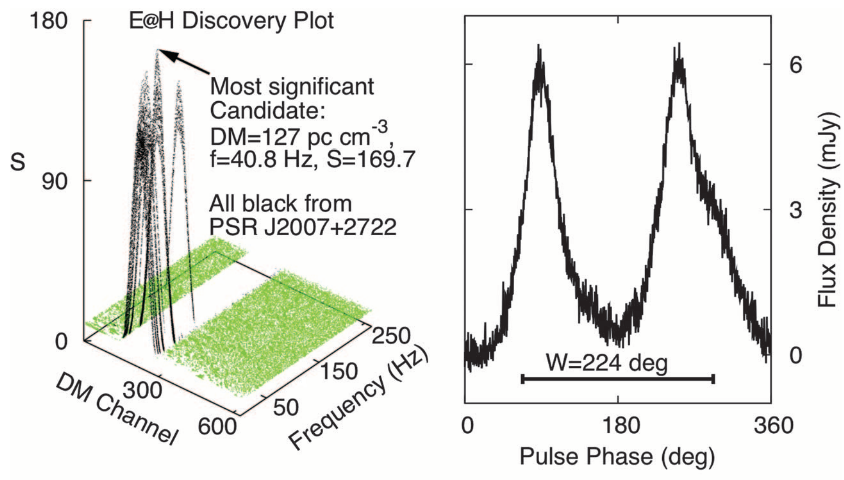

Fig. 1. (**Left**) Significance S as a function of DM and spin frequency (all E@H results for the discovery beam). (**Right**) The pulse profile at 1.5 GHz (GBT). The bar illustrates the extent of the pulse.

References and Notes

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7. We thank Einstein@Home volunteers, who made this discovery possible. The computers of C. and H. Colvin (Ames, Iowa, USA) and D. Gebhardt (Universität Mainz, Musikinformatik,Germany) identified J2007+2722 with the highest significance. This work was supported by Canada Foundation for Innovation, Canadian Institute for Advanced Research, fonds québécois de la recherche sur la nature et les technologies, Max Planck Gesellschaft, National Astronomy and Ionosphere Center, National Radio Astronomy Observatory, Natural Sciences and Engineering Research Council (of Canada), NSF, and Netherlands Organization for Scientific Research, Science and Technology Facilities Council; see the SOM for details.

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Supporting Online Material

www.sciencemag.org/cgi/content/full/science.1195253/DC1
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References

16 July 2010; accepted 5 August 2010
Published online 12 August 2010;
10.1126/science.1195253
Include this information when citing this paper.

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