Home computers discover gamma-ray pulsars

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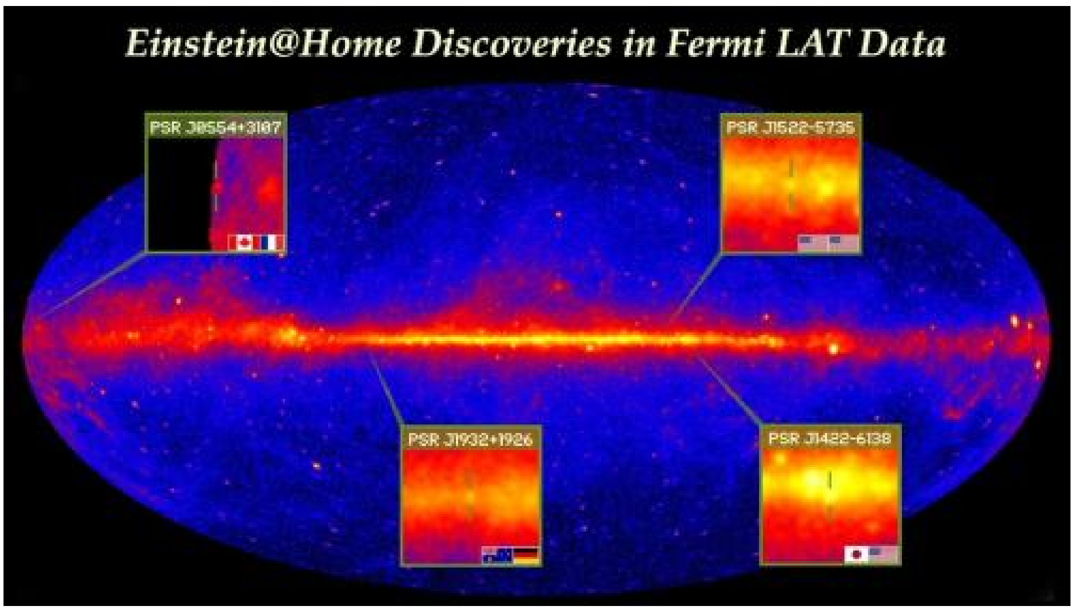


All four gamma-ray pulsars discovered by Einstein@Home lie in the plane of our Milky Way, as shown in this sky map using data from Fermi's Large Area Telescope (LAT). The plane is apparent as an area of particularly intense gamma radiation; brighter colors indicate more intense radiation. The insets show the four pulsars as point sources. The flags indicate the nationalities of the Einstein@Home volunteers whose computers made the discoveries. Credit: © Knispel/Pletsch/AEI/NASA/DOE/Fermi LAT Collaboration

The combination of globally distributed computing power and innovative analysis methods proves to be a recipe for success in the search for new pulsars. Scientists from the Max Planck Institutes for Gravitational

Physics and Radio Astronomy together with international colleagues have now discovered four gamma-ray pulsars in data from the Fermi space telescope. The breakthrough came using the distributed computing project Einstein@Home, which connects more than 200,000 computers from 40,000 participants around the world to a global supercomputer. The discoveries include volunteers from Australia, Canada, France, Germany, Japan, and the USA.

Since its launch in 2008, the Fermi satellite has been observing the entire sky in gamma-rays. It has discovered thousands of previously unknown gamma-ray sources, among which are possibly hundreds of yet undiscovered pulsars – compact and rapidly rotating remnants of exploded stars. Identifying these new gamma-ray pulsars, however, is computationally very expensive – wide parameter ranges have to be "scanned" at very high resolution.

"Our innovative solution for the compute intensive search for gamma-ray pulsars is the combination of particularly efficient methods along with the distributed computing power of Einstein@Home," says Holger Pletsch, Independent Research Group Leader at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute/AEI), and lead author of the study. "The volunteers from around the world enable us to deal with the huge computational challenge posed by the Fermi data analysis. In this way, they provide an invaluable service to astronomy," says Pletsch.

Distributed Computing for Astronomy

Einstein@Home is a joint project of the Center for Gravitation and Cosmology at the University of Wisconsin–Milwaukee and the AEI in Hannover. It is funded by the National Science Foundation and the Max Planck Society. Since mid-2011, Einstein@Home has been searching for signals from gamma-ray pulsars in Fermi data. The project was founded in 2005 to search for gravitational-wave signals in data from the LIGO detectors – still the main task of Einstein@Home. Since early 2009, the project has also been conducting successful searches for new radio pulsars.

"The first-time discovery of gamma-ray pulsars by Einstein@Home is a milestone – not only for us but also for our project volunteers. It shows that everyone with a computer can contribute to cutting-edge science and make astronomical discoveries," says co-author Bruce Allen, director at the AEI and principal investigator of Einstein@Home. "I'm hoping that our enthusiasm will inspire more people to help us with making further discoveries."

Pulsars for everyone

The volunteers who contributed to the discoveries are thrilled. "At first I was a bit dumbfounded and thought someone was playing a hoax on me. But after I did some research everything checked out. That someone as insignificant as myself could make a difference was amazing," says Thomas M. Jackson from Kentucky in the USA, who runs Einstein@Home on his quad-core processor.

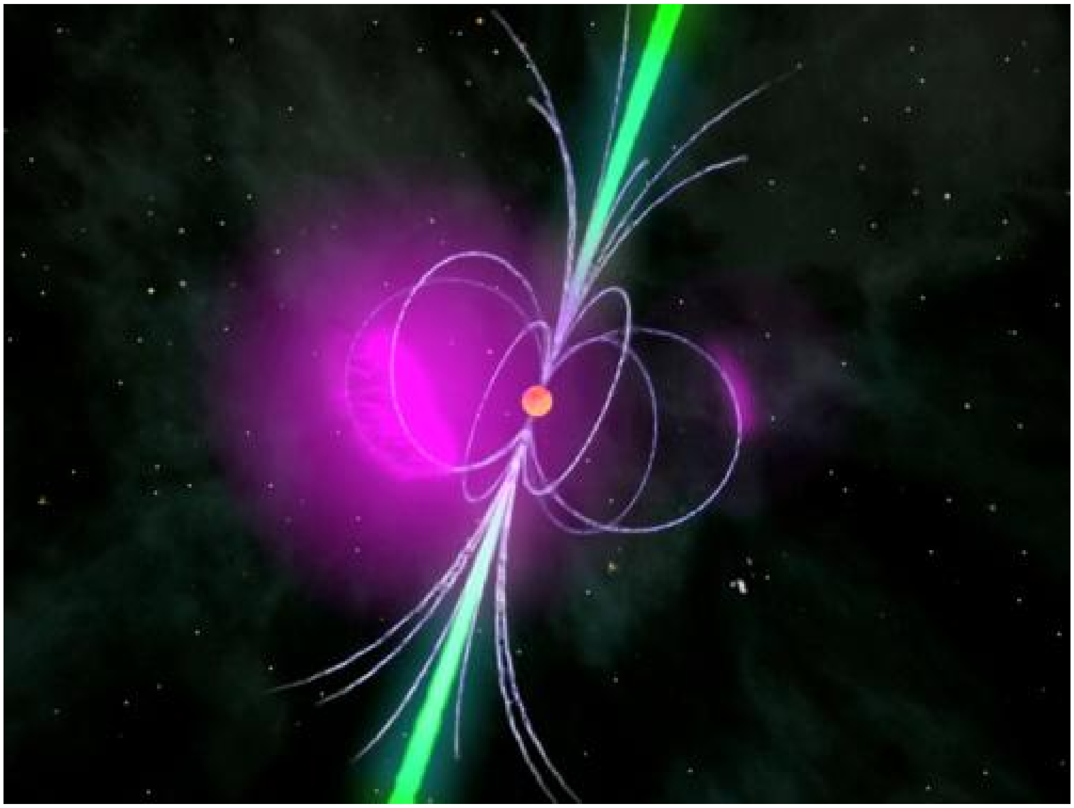
Hans-Peter Tobler from Rellingen, Germany, has been participating in Einstein@Home since 2005 and has now helped in the discovery of a gamma-ray pulsar: "I'm fascinated by astronomy. Einstein@Home allows me to contribute to this field of science, even though I'm not a professional astronomer myself." With hundreds of thousands of computers teaming up, he never expected that his PC would discover anything.

All Einstein@Home volunteers are acknowledged for their contributions in the scientific publication. The astronomers particularly mention the eight volunteers whose computers made the discoveries. The volunteers are from Australia, Canada, France, Germany, Japan, and the USA. As a token of appreciation, they receive special certificates of discovery.

New Window for the Discovery of Neutron Stars

Not only are the four gamma-ray pulsars the first to be found with a distributed volunteer computing project, but also the pulsars are special, too. "It is exciting that all four pulsars are in the plane of our Milky Way," says co-author Michael Kramer, director at the Max Planck Institute for Radio Astronomy (MPIfR). Earlier surveys with radio telescopes have been thoroughly searching this part of the sky, but the four new pulsars had remained hidden and only one comparable neutron star had been found.

Apparently, the pulsars are only visible in gamma-rays. The radio and gamma-ray emission are produced in different regions around the pulsar. Depending on the orientation of the pulsar, the narrow radio beam might miss Earth, while the wider beam of gamma-ray photons could be detectable. Dedicated follow-up observations of all four new discoveries with the MPIfR's 100-meter Effelsberg radio telescope and the Australian Parkes Observatory confirm the absence of any detectable radio emission.



A gamma-ray pulsar is a compact neutron star that accelerates charged particles to relativistic speeds in its extremely strong magnetic field. This process produces gamma radiation (violet) far above the surface of the compact remains of the star, for example, while radio waves (green) are emitted over the magnetic poles in the form of a cone. The rotation moves the emission regions across the terrestrial line of sight, making the pulsar light up periodically in the sky. Credit: © NASA/Fermi/Cruz de Wilde

"With the successful blind searches for gamma-ray pulsars, we use a new window for the discovery of neutron stars," says Kramer. The new searches employ methods inspired by gravitational-wave data analysis. Using these, astronomers around Pletsch discovered all of the eleven gamma-ray pulsars found in the last three years of blind searches in Fermi data.

Young Neutron Stars with a Hiccup

Two of the newly discovered pulsars exhibited a sudden change in their otherwise perfectly regular rotation – they suffered a so-called pulsar glitch. During a glitch, the neutron star's rotation suddenly speeds up, then gradually becomes slower and returns to the initial rotation period after a few weeks. "We don't know the exact cause of these glitches yet, but measuring them can provide new insights into the incompletely understood neutron star interior," says co-author Lucas Guillemot, who worked as a researcher at MPIfR when the discoveries were made and has recently taken up a position at the LPC2E in Orléans.

Glitches mostly happen in newly born pulsars. According to the measurements of the astronomers, the four pulsars discovered now are between 30,000 and 60,000 years old – youngsters among neutron stars.

Discovery Potential

In the future, the efficient search methods will become increasingly important, since Fermi is scheduled to take data for at least another five years. The longer the measurement time, the weaker the pulsars the scientists can discover. With increasing measurement time, however, the computational costs grow quickly. Conventional methods are already too costly at present, but there is still headroom for the new methods.

"Only our methods will enable efficient blind pulsar searches in Fermi data in the future. Using the distributed computing power provided by the Einstein@Home volunteers, we hope to discover gamma-ray pulsars that are particularly far away or faint," says Pletsch.

Pulsars

Neutron stars are exotic objects. They are made up of matter much more densely packed than normal, giving the entire star a density comparable to an atomic nucleus. The diameter of our sun would shrink to less than 30 km if it was that dense.

Neutron stars also have extremely strong magnetic fields. Charged particles accelerated along the field lines emit electromagnetic radiation in different wavelengths. This radiation is bundled into a cone along the magnetic field axis. As the neutron star turns about its rotational axis, the cones of emitted radiation sweep through the sky like a lighthouse beam because the rotational axis is usually inclined relative to the magnetic field axis. The neutron star is then visible as a pulsar. Pulsars rotate with cycles of a few seconds up to only milliseconds with a precision that makes them the most accurate clocks in the world.

These cosmic lighthouses were first discovered in 1967 by Jocelyn Bell Burnell and identified as radio pulsars. X-ray and gamma-ray pulsars are also known to exist today. Even though not all pulsars are observable in all wavelengths, scientists assume that they still emit radiation in the entire electromagnetic spectrum. However the mechanisms which govern radiation emission in different frequency ranges are not yet completely understood.

A neutron star is the densest object astronomers can observe directly, crushing half a million times Earth's mass into a sphere about 20 kilometers across. This illustration compares the size of a neutron star to the area around Hannover, Germany, hometown of the Albert Einstein Institute Hannover. Credit: © NASA's Goddard Space Flight Center

Gamma-ray Pulsars and Radio Pulsars

A plausible explanation could be that lower-energy radio waves are bundled in a tighter cone at the magnetic poles than high-energy gamma-radiation. Since radiation is mainly emitted along the surface of the cone and different wavelengths are emitted in cones with a different spread, radio waves and gamma waves would leave the neutron star in different directions. A pulsar might thus become visible as a gamma-ray or radio pulsar to a distant observer (depending on which cone sweeps across the observers position). Another model has gamma radiation originating not in the polar regions of the magnetic field but rather the equatorial plane where the field lines are disrupted. It is therefore very important to observe as many pulsars as possible in all wavelengths to better understand these mechanisms.

Data Analysis

When analyzing data from gravitational wave detectors, scientists have to rely on very effective algorithms and high computing power. This is necessary, because a possible gravitational wave signal would be scarcely stronger than the background noise at the current measurement accuracy.

The data is analyzed in several steps. First, the astrophysicists scan large areas of the sky for signals. If there is a conspicuous signal in one direction, they investigate the vicinity with an algorithm which has a narrower search grid and thus requires more computing time. If the signal is confirmed, the scientists analyse its temporal characteristic and examine whether it can be assigned to a specific pulsar period, for example. The Hanover scientists have modified the algorithm to search for continuous sources of gravitational waves and used it successfully to search for gamma-ray pulsars in Fermi data.

Einstein@Home

This project for distributed volunteer computing connects PC users from all over the world, who voluntarily donate spare computing time on their home and office computers. So far more than 350,000 volunteers have participated and it is therefore one of the largest projects of this kind. Scientific supporters are the Center for Gravitation and Cosmology at the University of Wisconsin-Milwaukee and the Max Planck Institute for Gravitational Physics (Albert Einstein Institute, Hanover) with financial support from the National Science Foundation and the Max Planck Society. Since 2005, Einstein@Home has examined data from the gravitational wave detectors within the LIGO-Virgo-Science Collaboration (LVC) for gravitational waves from unknown, rapidly rotating neutron stars.

As of March 2009, Einstein@Home has also been involved in the search for signals from radio pulsars in observational data from the Arecibo Observatory in Puerto Rico and the Parkes Observatory in Australia. Since the first discovery of a radio pulsar by Einstein@Home in August 2010, the global computer network has discovered more than 50 new radio pulsars.

A new search for gamma-ray pulsars in data of the Fermi satellite was added in August 2011. It made the four discoveries reported now. The project is looking for, among other things, the first millisecond pulsar, visible only in the gamma-ray range.

Provided by Max Planck Society