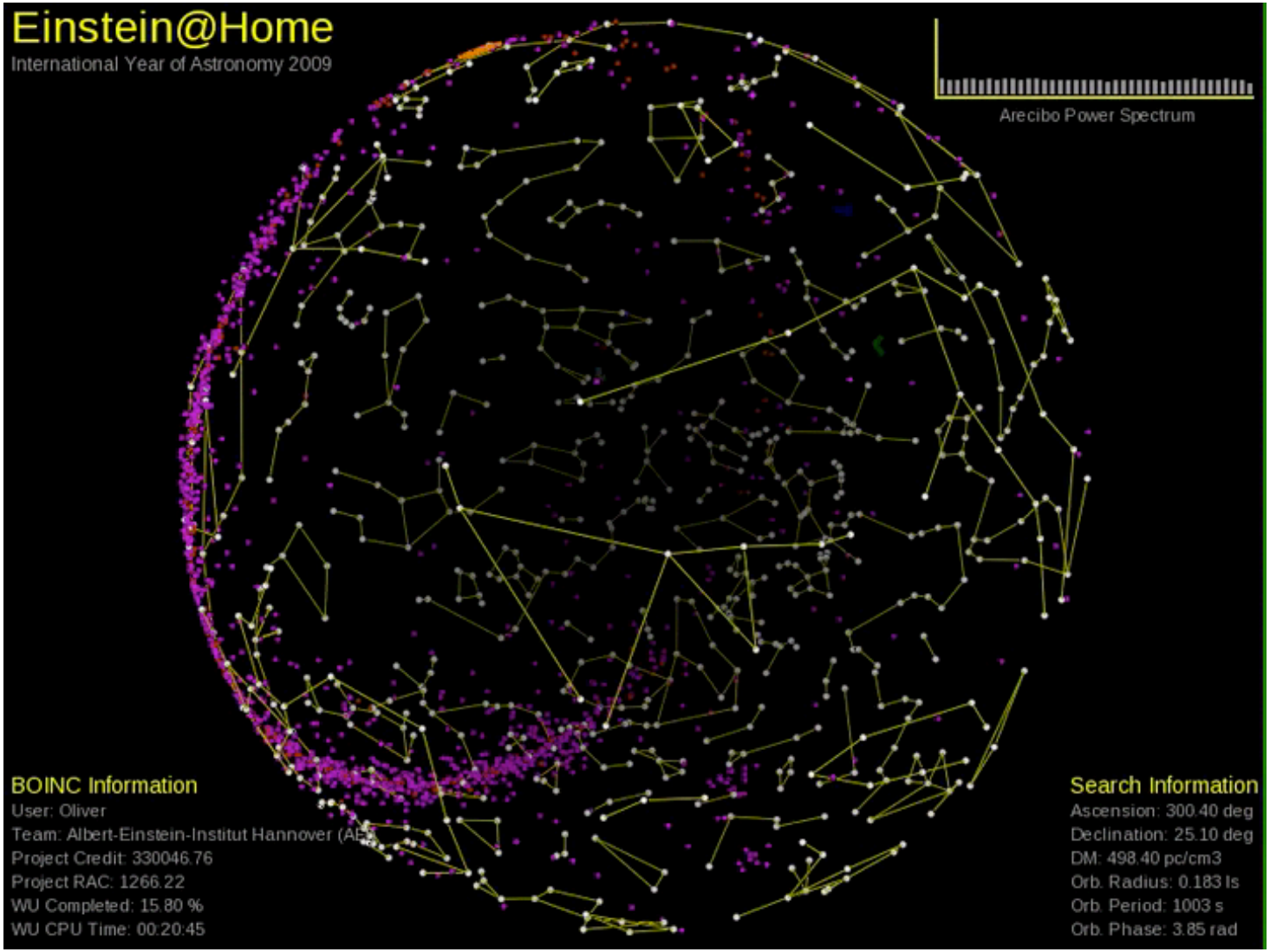
Einstein@Home



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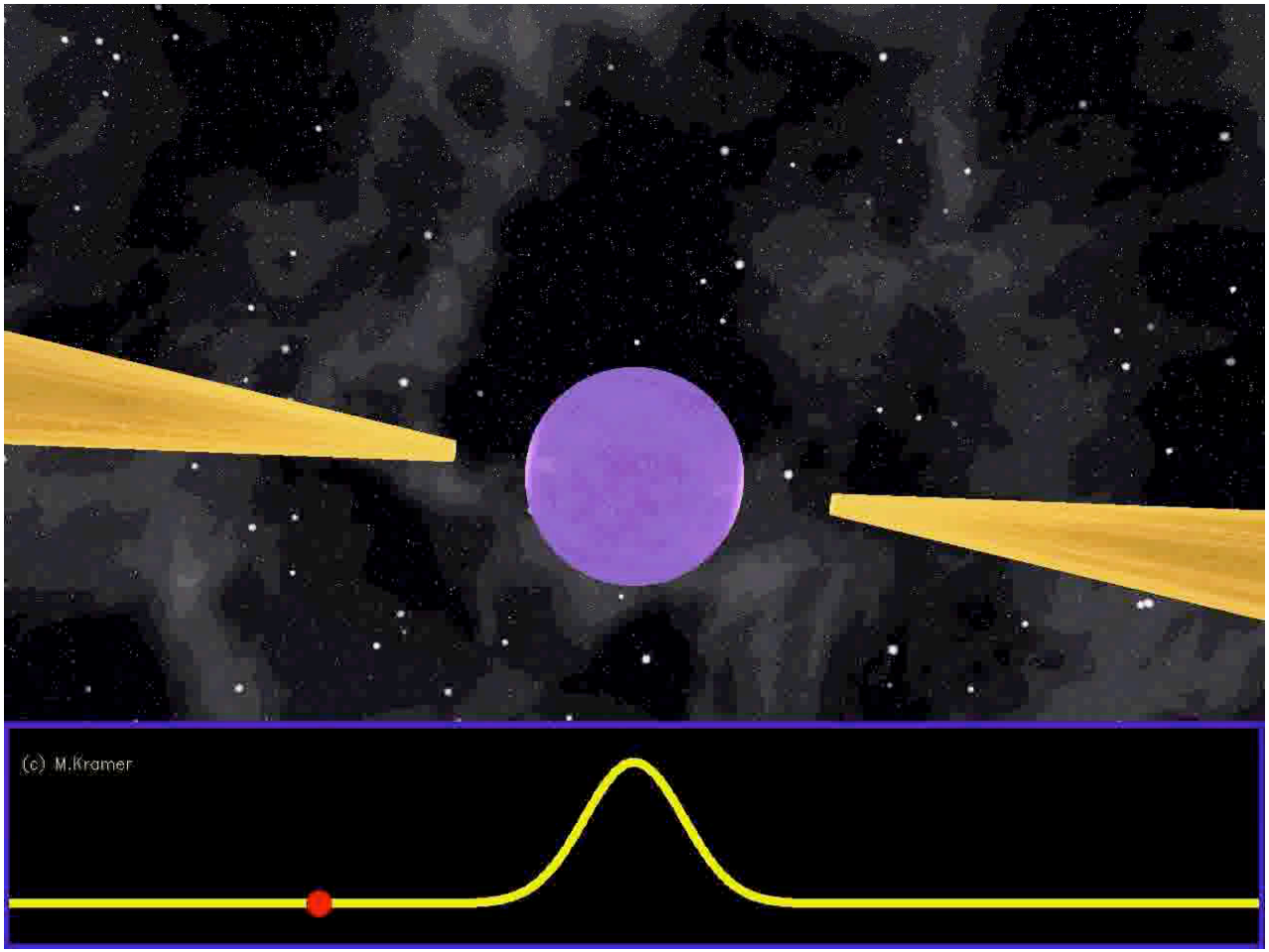
Neutron Stars



Copyright: Michael Kramer

- Discovered 1967
- About 2000 known
- Radius 8-12 km
- Up to 40 000 rpm
- 1 cm^3 weights 10^{15} g (mountain)
- Very strong magnetic fields (10^8 - 10^{16} Gauss)
- Emit (weak) radio waves, X-rays, gamma-rays. Should also emit (weak) gravitational waves

The idea for Einstein@Home

- Lunch at the Caltech Athenaeum with Stuart Anderson (now head of computing for the LIGO laboratory)
- That morning we had both read this LA Times article

Universe Wide Web

August 19, 1999|SARAH YANG | SPECIAL TO THE LOS ANGELES TIMES

An ambitious project is enlisting the help of 1 million computer users worldwide to analyze radio signals from outer space in the search for extraterrestrial intelligence.

BERKELEY — Every day, every few seconds, some of the world's most powerful radio telescopes scan millions of channels in outer space in an effort to detect signs of extraterrestrial communication. No alien signals have been detected thus far. But is that because no one is out there contacting us, or are we just not listening hard enough?

Scientists are coming closer to the answer as legions of computer users around the world donate their PCs' otherwise idle time to help in the Search for Extraterrestrial Intelligence, or SETI. Scientists at UC Berkeley's Space Sciences Laboratory have been running the project, called SETI@home, for three months, in an ambitious hunt for signs of alien civilizations.

Earlier this week, the project passed a milestone by logging in its millionth participant.

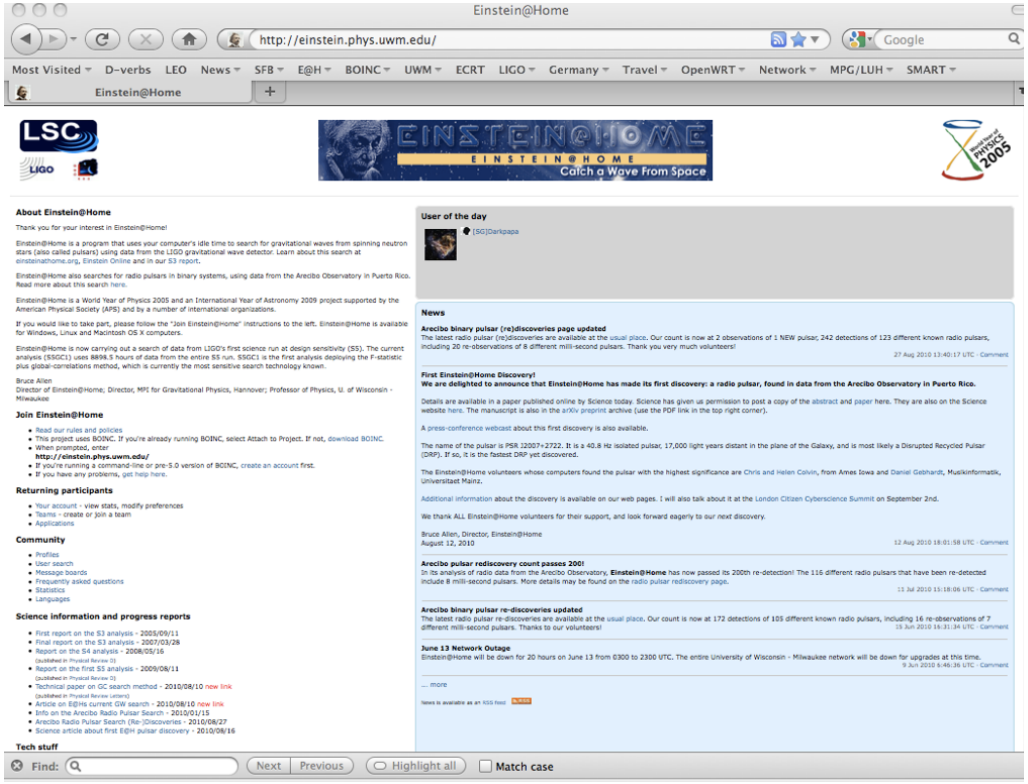
"There are very few science projects out there that you can be a part of," said Dan Werthimer, chief scientist for SETI@home. "This is the first program where people can participate in a global science project. It's also a great way to get kids interested in science."

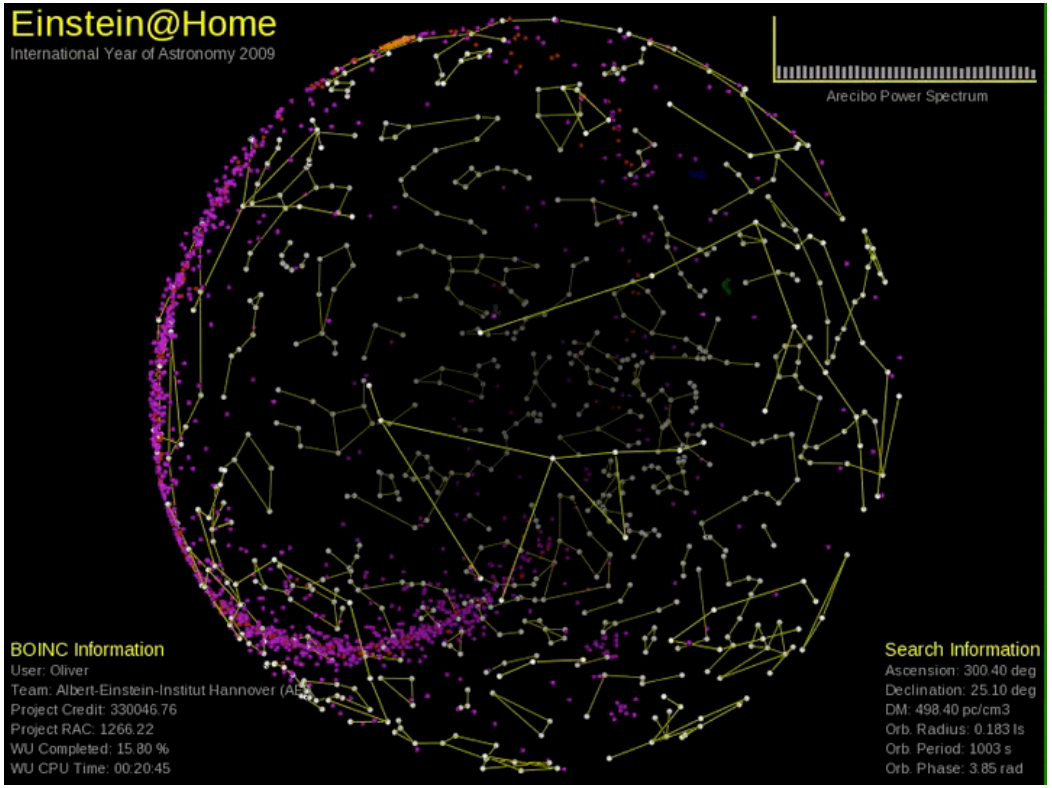
Einstein@Home: a volunteer supercomputer

TARGET SOURCE:
Rapidly-spinning neutron stars

LAUNCH: 2005 (Einstein Year)

THREE DISTINCT SEARCHES:
- Gravitational Wave Data
- Radio Data (since 2009)
- Gamma Ray Data (since 2011)





Einstein@Home Publications

[Related papers on "methods" are not listed]

Einstein@Home discovery of four young gamma-ray pulsars in Fermi LAT data, H. J. Pletsch, L. Guillemot, B. Allen, et al., Astrophysical Journal Letters, 779, L11 (2013)

The Einstein@Home search for radio pulsars and PSR J2007+ 2722 discovery, B Allen, B Knispel, JM Cordes, JS Deneva, et al., Astrophysical Journal 773, 91 (2013)

Einstein@Home all-sky search for periodic gravitational waves in LIGO S5 data, LSC, Physical Review D 87, 042001, 2013.

Einstein@Home Discovery of 24 Pulsars in the Parkes Multi-beam Pulsar Survey, B Knispel, RP Eatough, H Kim, EF Keane, B Allen, et al., Astrophysical Journal 774, 93 (2013)

Arecibo PALFA Survey and Einstein@ Home: Binary Pulsar Discovery by Volunteer Computing, B Knispel, P Lazarus, B Allen, et al., The Astrophysical Journal Letters 732 (1), L1 (2011); P. Lazarus et al., Timing of a young mildly recycled pulsar with a massive white dwarf companion. MNRAS, 437, 1485-1494 (2014)

Pulsar discovery by global volunteer computing, B Knispel, B Allen, JM Cordes, JS Deneva, et al., Science 329 (5997), 1305-1305 (2010)

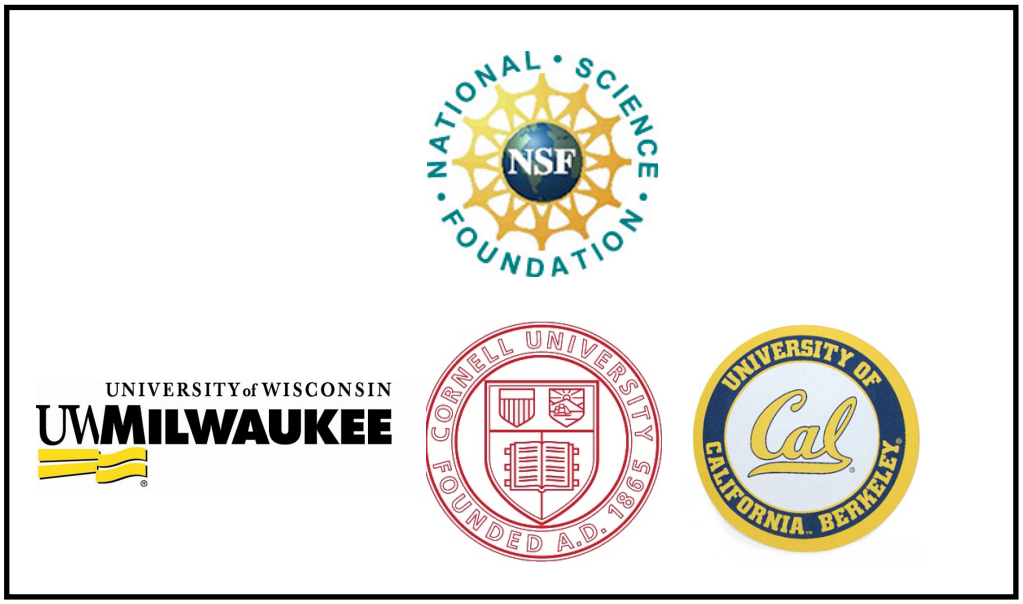
Einstein@ Home search for periodic gravitational waves in early S5 LIGO data, LSC, Physical Review D 80, 042003 (2009)

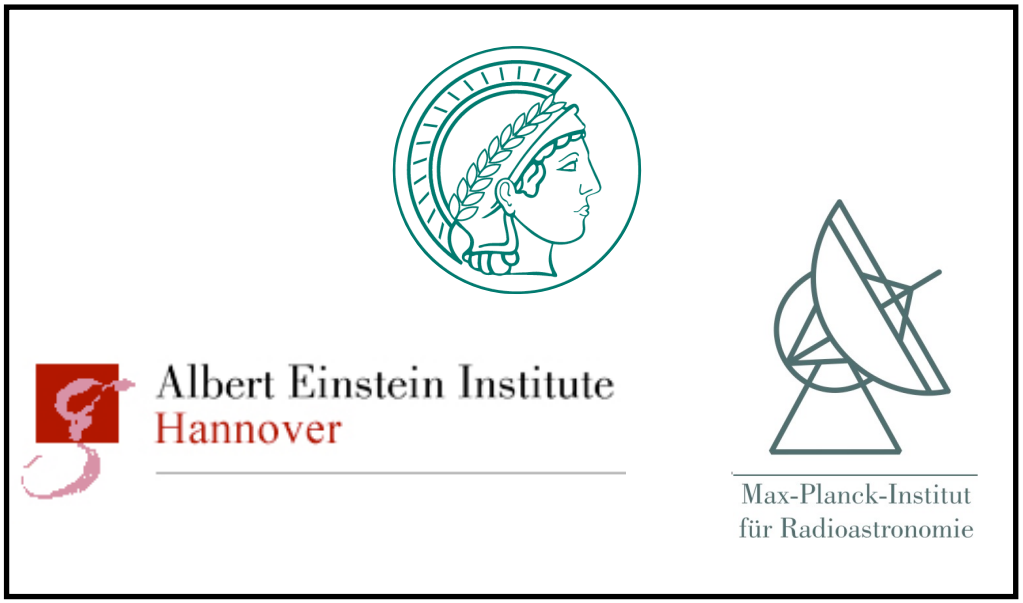
Einstein@ Home search for periodic gravitational waves in LIGO S4 data, LSC, Physical Review D 79, 022001 (2009)

Einstein@Home Support

National Science Foundation
through the UWM, Cornell,
and UC Berkeley

Max Planck Society
through the AEI and MPIfR





- BOINC development (UCB)
- Gravitational wave searches (UWM)
- Server/data infrastructure (UWM)
- PALFA data preparation (Cornell)

- Programming
- Radio searches
- Gamma-ray searches
- Gravitational wave searches

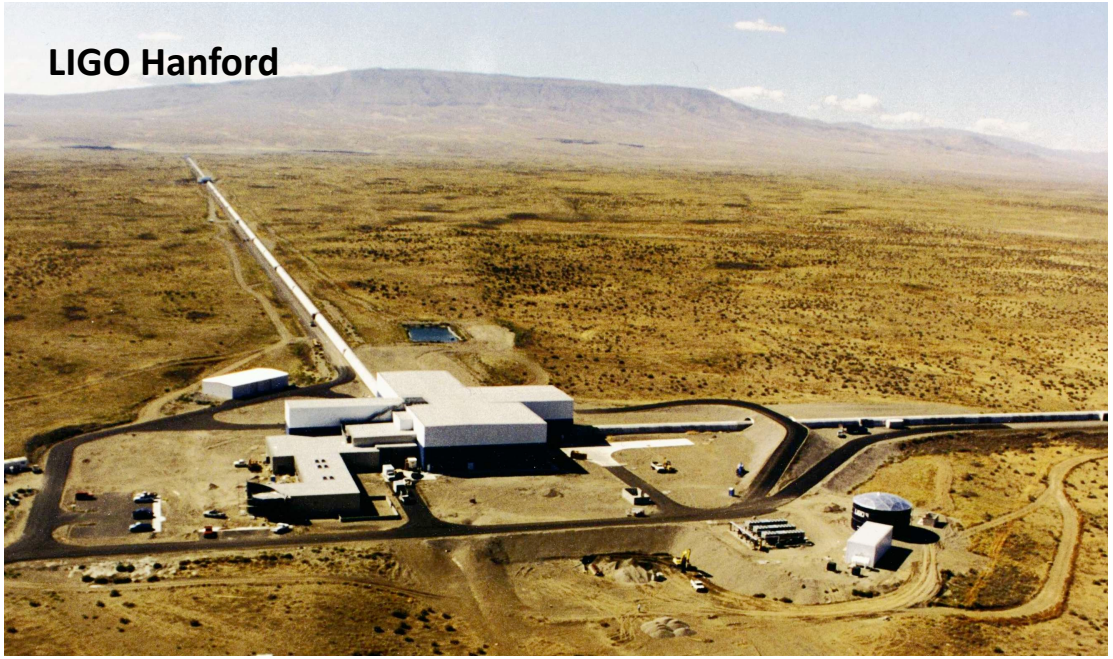
Einstein@Home Computing

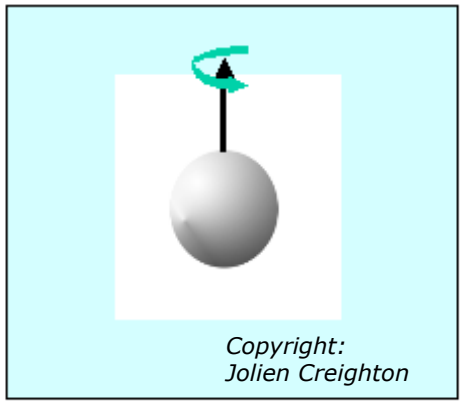
- 3 different CPU search apps (radio, gamma-ray, gravitational wave)
- CUDA and OpenCL GPU versions for radio and gamma-ray search
- Android version of the radio search
- Past 9 years:
  377 000 volunteers
  193 UN countries
- Past two weeks:
  64 526 computers got work
- 10 393 active GPUs (NVIDIA/AMD/Intel)
- Currently 1232 Teraflops

Status 28.9.2014, taken from
http://einstein.phys.uwm.edu/server_status.php

Einstein@Home
Gravitational Wave Searches

Gravitational Wave Detectors

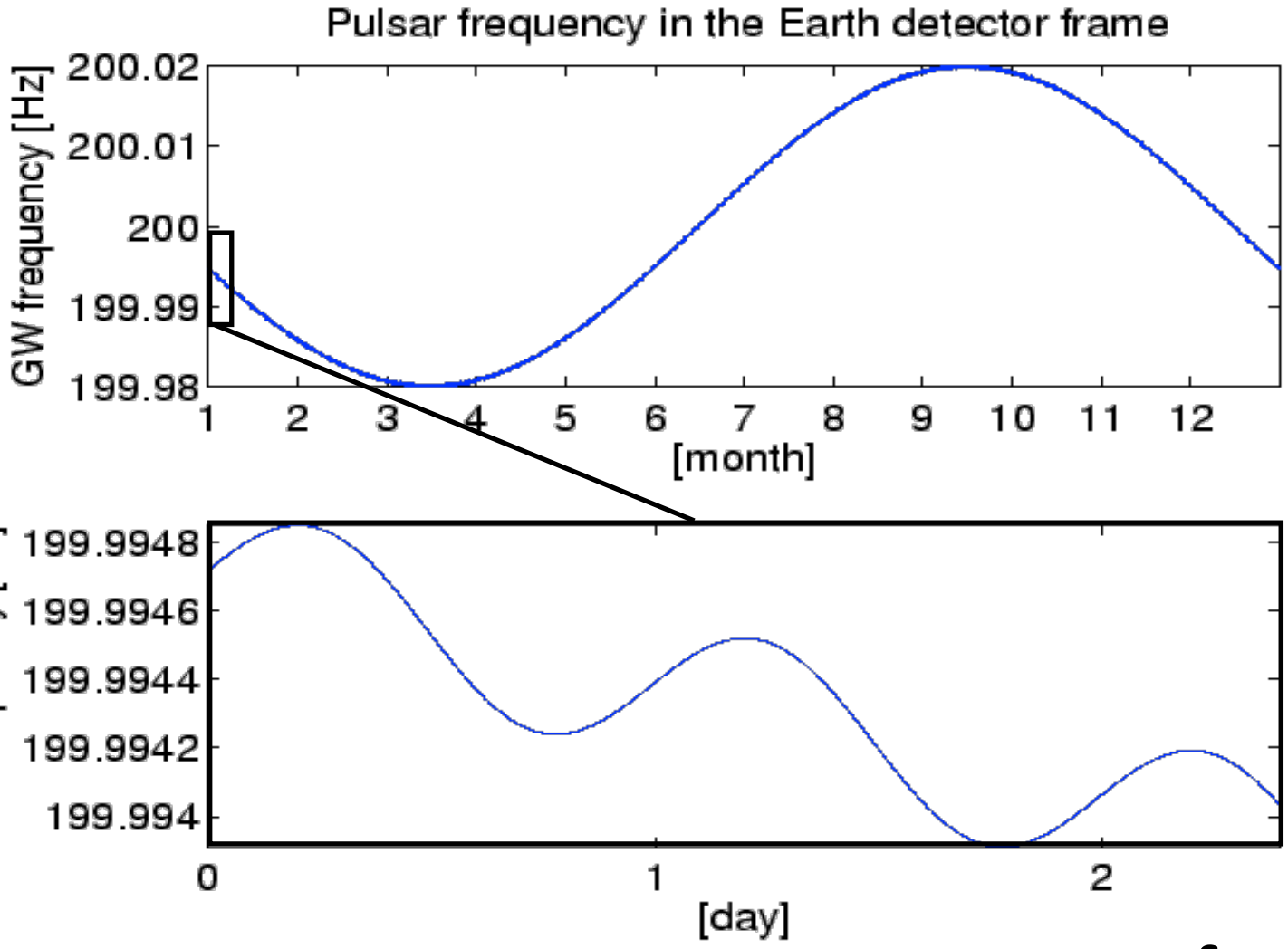


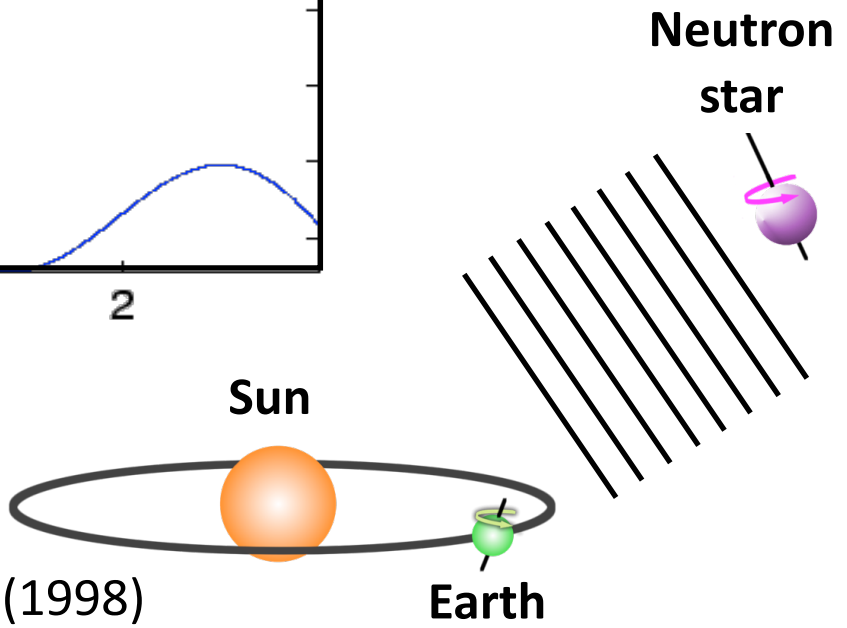


Mountain on a star

- Gravitational waves predicted by Einstein, 1916
- Observed indirectly, but not directly. Last remaining direct prediction of General Relativity
- Since mid-90s USA, France, Germany and UK building instruments to detect them
- In the USA, latest generation of the **L**aser **I**nterferometer **G**ravitational-wave **O**bservatories (**LIGO**) now starting commissioning: first extended science run expected in mid-2015

GW Blind-Search Challenge





- One year @ 200 Hz: 6×10^9 cycles
- Modulation pattern depends on sky position
- F-statistic, derived by Jaranowski, Krolak & Schutz (1998)

Einstein@Home
Radio Pulsar Search

Hunting for Radio Pulsars

- Began in 2009
- Data from ongoing Arecibo PALFA survey, and archival Parkes PMPS survey
- New part of parameter-space: binaries with short periods
- **Since mid-2010, Einstein@Home has discovered 48 new radio pulsars.** These include a number of exotic binaries and milli-second pulsars.

Arecibo (Puerto Rico)

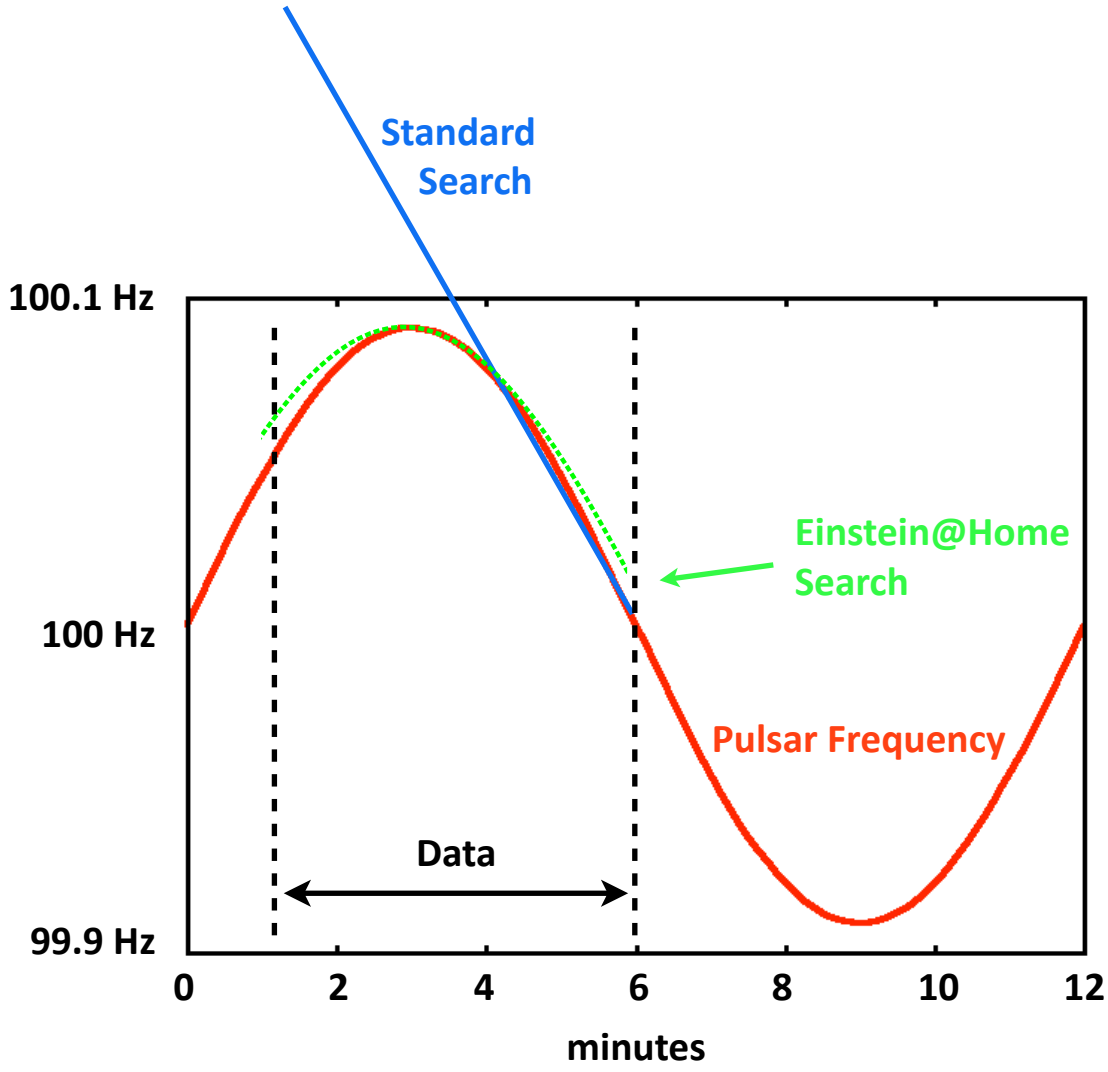
Copyright: Cornell University

Parkes (Australia)

Copyright: CSIRO Australia

Radio Pulsar Search

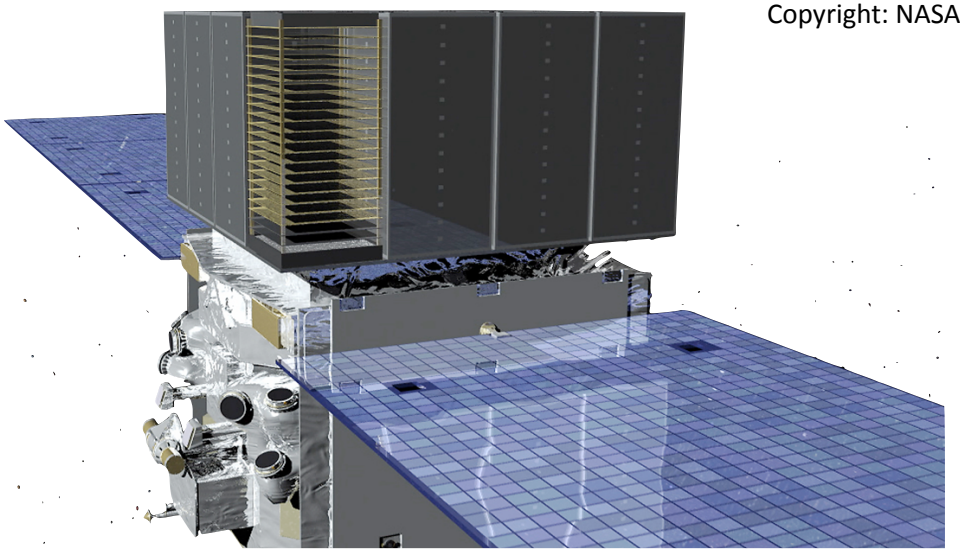
- **Einstein@Home does full orbital demodulation:** sensitive to orbital periods as short as P_{orbit} = 11 minutes
- "Standard search" looks for frequency changing linearly with time: loses sensitivity for P_{orbit} < 50 minutes
- Special interest: binaries with two neutron stars (double neutron stars = DNS. Shortest ~~known~~ published P_{orbit} are 2.5, 4.0, and 6.3 hours.
- Expectations for shortest-orbital period DNS in PALFA survey: 16 minutes (range 7 to 37 minutes)

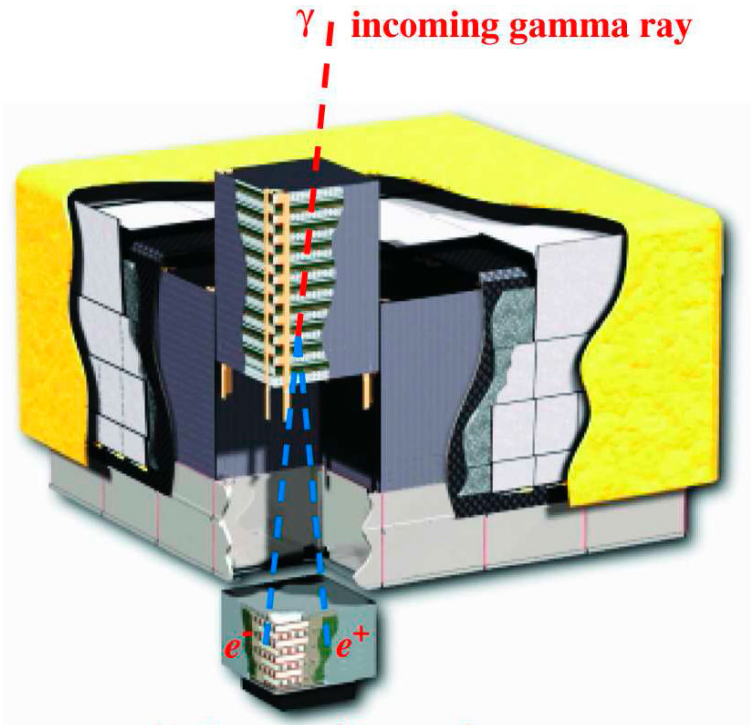


Einstein@Home Search for Gamma Ray Pulsars

Fermi Satellite Large Area Telescope (LAT)

- Launched June 2008
- Field of view: 20% of the sky, 20 MeV - 300 GeV
- Surveys the entire sky every 3 hours
- Public data set (150 million photons) with microsecond accuracy, ~1 degree sky-position
- Starting in 2011, gravitional wave search methods have found 15 new pulsars via gamma-ray emissions. **Four of these from Einstein@Home**
- Challenge: 8000 photons in 4 years: ~1 photon per 100 000 revolutions



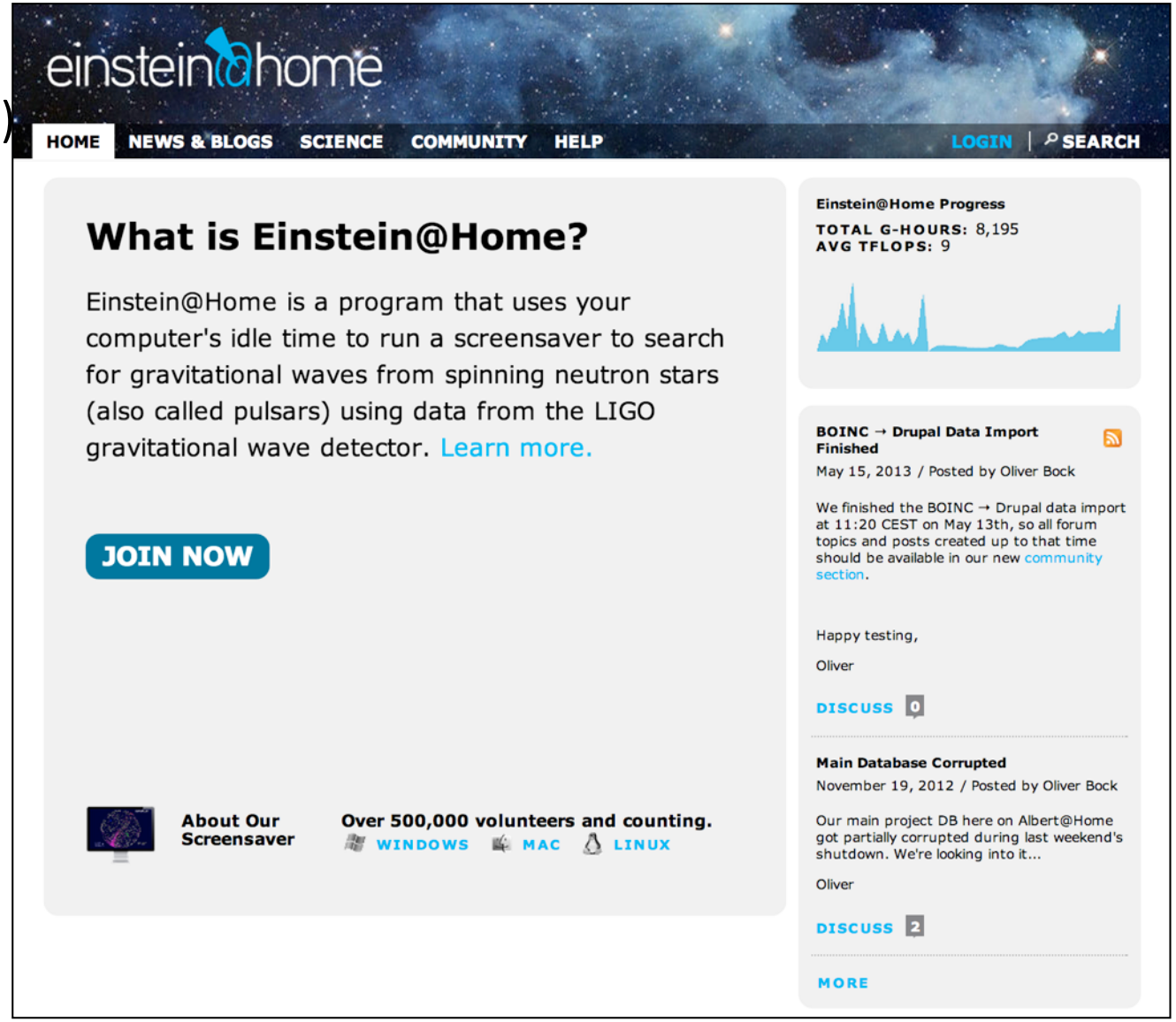


W. B. Atwood et al., *The large area telescope on the Fermi gamma-ray space telescope mission*, ApJ 697 (2009) 1071
doi:10.1088/0004-637X/697/2/1071

Outreach

Web Pages

- Hundreds of newspaper, magazine, radio and television stories (67 million Google hits!)
- Web site has community message boards, including a "Science" and "Tech" sections. Thousands of threads, including many detailed discussions with scientists.
- Web site also has "static" content about GWs, pulsars
- New Drupal-based web site in beta-test phase, hope to go public in some months. Will then add scientist and developer blogs, crowdsourcing



Discovery Certificates

- (Willing) volunteers are acknowledged by name in discovery papers
- They receive two formal framed “discovery certificates”, one in English, and one in their native language
- Currently we have English (USA, Australia, South Africa, UK), German (Switzerland, Germany), Dutch, Russian, Ukranian, Japanese, Polish, Finnish, Slovenian, Czech, Hungarian, Turkish, French (Switzerland), Italian

Conclusions

Einstein@Home Outlook

- Powerful tool for computationally-bound searches ***and*** a direct way for the public to contribute to scientific research.
- Gravitational wave searches will continue with improved methods and better data from Advanced LIGO
- Applying "GW technology" to radio and gamma-ray data is effective and will continue. Since mid-2010 we have found more than fifty new pulsars in radio data from Arecibo and Parkes, and gamma-ray data from Fermi LAT.
- Evolving with technology: support for NVIDIA and AMD/ATI GPUs and Android devices
- Future: crowdsourcing for post-processing, data storage AND computing (MeerKAT, SKA)