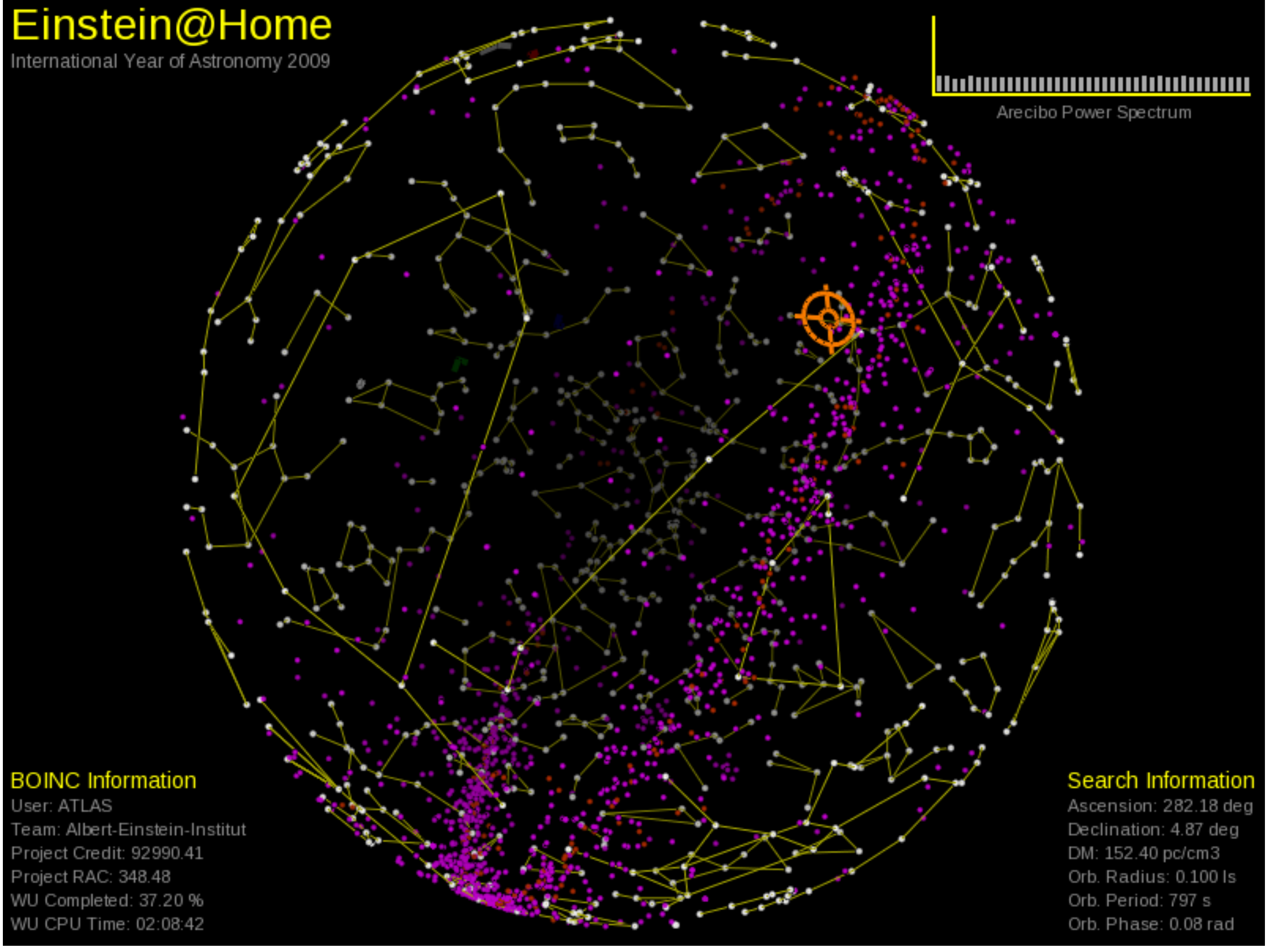
Einstein@Home – gravitational waves for everybody

Informations about how you personally can help with the search for gravitational wave – by donating processing time on your private computer

An article by Reinhard Prix und Bernd Machenschalk

For tens of thousands of computer users world-wide, the hunt for gravitational waves is anything but a remote scientific endeavour – it takes place right on their personal computers. Whenever they are not otherwise in use, these computers analyze data packets from the LIGO detectors and GEO600. A screen saver (see below) keeps the user up to date and shows in which celestial region his or her computer is currently searching for gravitational waves.



All this is made possible by the project "Einstein@Home". (Eager to join right away? Click on Einstein@Home!)

There is a solid scientific reason for involving so many people and computers: The hunt for gravitational waves calls for immense computing power. This is because in current gravitational wave detectors (see our spotlight topic Listening posts around the globe), typical gravitational wave signals are expected to be very weak compared with all the noise from thermal motion to seismic tremors present in the detector output. A good way to find out whether a given detector is listening to a gravitational wave or merely to noise is by a systematic search for well-known gravitational wave signals. This search – looking for characteristic patterns buried deep within large amounts of data – requires an inordinate amount of computing power and time.

Waves from rotating neutron stars

A prime example concerns a very simple class of gravitational wave signal: waves emitted by rotating neutron stars which are not completely rotationally symmetric (for instance stars that have tiny bumps on their surface). Astronomers should see a number of these stars as pulsars. The others can only be detected by measuring the gravitational waves they emit. These waves have a very simple structure – they are emitted as regular sine waves with a frequency twice as large as that of the star's rotation.

Even though the signal is simple, searching for it in the detector data is not. First of all, such waves will generically be very weak. Only a long-term search covering long periods of observation can tell for sure whether or not such weak signals are present in the data. The weaker the signal, the longer the required observation time. For current gravitational wave detectors, observation times are of the order of a few months, minimum.

Such long observation times lead to the next set of difficulties: During that time, the Earth (with the detector on it) is turning, as well as moving in orbit around the sun. With this motion of the detector relative to the source, the Doppler effect becomes important: relative motion between a wave source and a receiver changes the frequency measured at the receiver. Correspondingly, the gravitational wave frequency changes slightly over time – with the exact nature of the change depending on the position of the gravitational wave source in the sky.

This has an upside and a downside. The upside: One can use the Doppler shift to pinpoint the object’s position in the night sky. The downside: the Doppler shift makes the search for signal patterns much more complicated. When looking for the signal from an unknown neutron star, it is not sufficient to look for all the possible different frequencies. In addition, one needs seperate search patterns for all possible positions of the source in the sky, which incorporate the possible Doppler shifts. (There is, in fact, one further parameter that hasn’t been mentioned so far: For many neutron stars, the rotation decelerates over time. In a search, one must look for all different possible values of such a deceleration, as well.)

The bad news: The resulting number of patterns is so large that even with a supercomputer, a complete search would take an inordinate amount of time. In fact, computing power for the data analysis is currently one of the major factors limiting the sensitivity of such gravitational wave searches.

The good news: By its very nature, the search for a great number of different pattern is a problem that can be easily split up and distributed to a great number of computers, each of which then works on its own subset of patterns. This brings us back to the Einstein@Home project.

Harnessing the power of private computers

World-wide, there are millions of computers in private or commercial use, from privately owned single computers to the computer pools of large companies. Almost none of them are in continual use – typically, there are many idle periods in which these computers remain unused. A huge potential source of computational power, and largely untapped. Whoever manages to put even a fraction of that idle time to good use commands a total computing power much larger than that of the world's supercomputers.

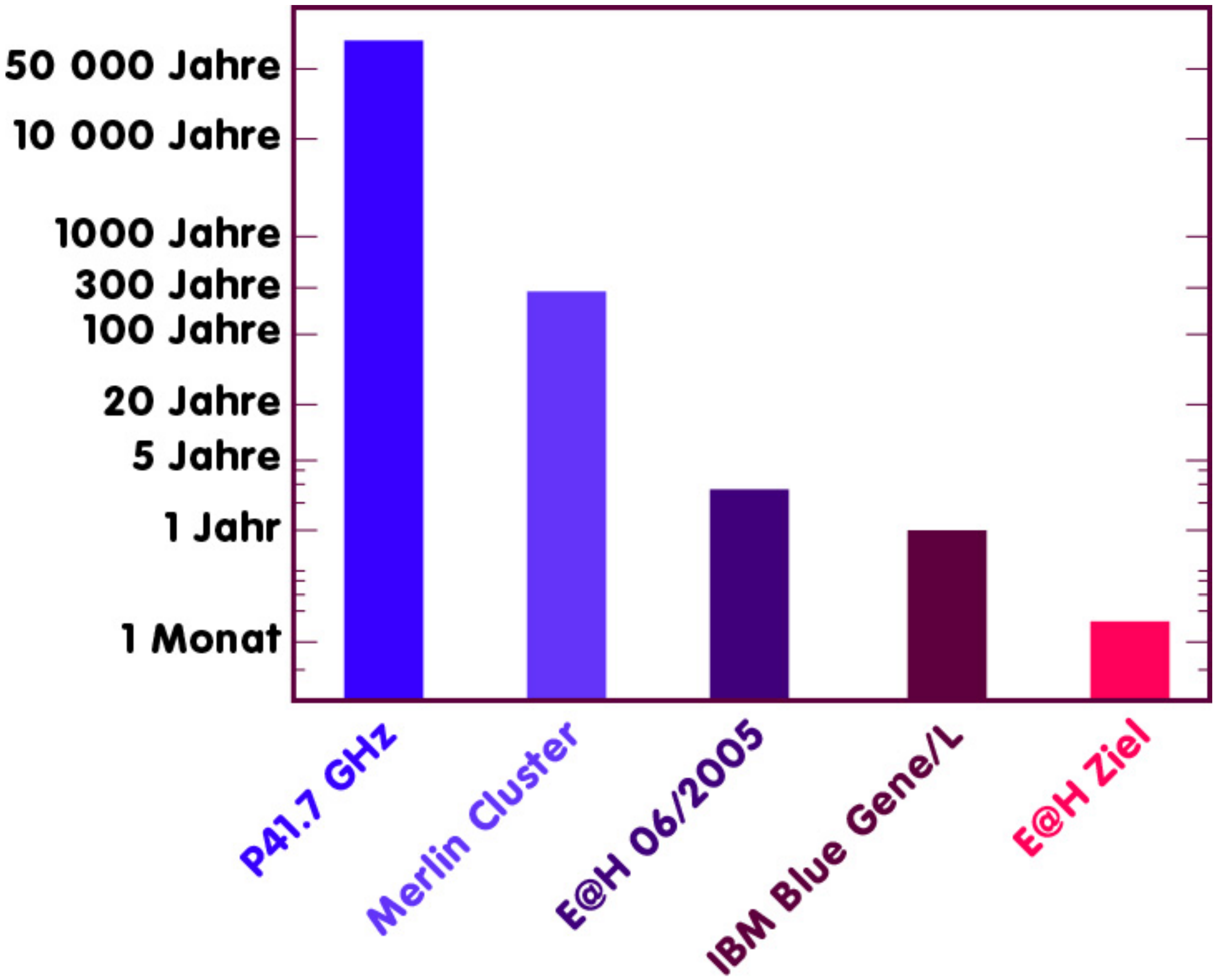
The first project to implement this ingenious idea on a large scale was "SETI@Home" – the search for radio signals sent by intelligent extraterrestrial beings. Its great success led to the development of a free library named BOINC. Einstein@Home combines BOINC with the search algorithms for the gravitational wave signals of rotating neutron stars. The necessary software was mainly developed at the University of Wisconsin-Milwaukee in the US and at the Albert Einstein Institute in Potsdam, Germany. It is one of the projects of the American Physical Society for the World Year of Physics 2005.

So how does this work? Once you have signed up and installed the software (to do this, go to the Einstein@Home homepage specified below), the Einstein@Home servers regularly send chunks of data and search codes to your computer. Whenever the computer is not otherwise in use, it spends its time applying the search algorithms to the data at hand. The results are sent back to the Einstein@Home servers. There is a credit system that allows users, or teams of users, to monitor their contribution to the project – lists of the top participants are maintained on the Einstein@Home website.

More powerful than the largest supercomputer

Although, as of June 2005, less than half a year has passed since the official start of Einstein@Home, public interest and participation have been overwhelming. Over 90,000 users with nearly 200,000 computers are registered, with a few hundred new users joining every day. This has brought the computational power of Einstein@Home to 48 trillion elementary computations per second – the power of a major-league supercomputer. (More precisely, the “elementary computations” are “floating point operations” – the elementary steps of every calculation done by computer. In computer lingo, this means that Einstein@Home now has 48 Teraflops.)

The following example demonstrates what this means. It considers the search for periodic gravitational wave signals from neutron stars of unknown frequency and position, using data from one week of observations in the frequency range between 100 and 600 Hertz. The following graph shows the approximate time needed by different computers or computer clusters to complete that search:



From left to right, the contenders are: a single computer with a Pentium 4 processor (it needs roughly 97,000 years to complete the job), the Merlin/Morgane computer cluster at Albert Einstein Institute (consisting of 180 dual-processor PCs), the current configuration of Einstein@Home in June 2005, IBM's supercomputer BlueGene/L with 138 trillion calculations per second, and finally the target configuration of Einstein@Home with a million participants.

So far, the Einstein@Home is working hard to reach its goal, constantly refining the search strategy and making ever better use of the substantial computing power involved. Chances are that, in the near future, Einstein@Home will become one of the most sensitive and powerful tools in the search for gravitational waves – and with some luck, you could be involved in the first ever detection of these elusive signals from outer space!

Further Information

Colophon

Reinhard Prix

is a scientist at the Albert Einstein Institute in Hannover. His research interests include neutron stars and the detection of gravitational waves. He is one of the developers of the Einstein@Home project; fittingly, he is co-author of our spotlight topic Einstein@Home – gravitational waves for everybody, written during his time as a post-doctoral researcher in the astrophysics group at Albert Einstein Institute in Potsdam.

Bernd Machenschalk

is a computer scientist at the Albert Einstein Institute in Hannover, where he works on the data analysis of the gravitational wave detectors LIGO and GEO600. He is a major contributor to the Einstein@Home project. During his time at the Albert Einstein Institute in Potsdam he was, unsurprisingly, co-author of the spotlight topic Einstein@Home – gravitational waves for everybody.

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