The search for gravitational waves

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University of Mississippi
LIGO Scientific Collaboration

The University of Mississippi

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LIGO-G070613-00-Z

Background picture from http://cgwp.gravity.psu.edu

What is a gravitational wave?

A gravitational wave is:

$$Mr\,(h_+ - ih_\times)_{2\,,2} = 8\sqrt{\frac{\pi}{5}}\eta(M\Omega)^{2/3}\left[1+\frac{55\eta-107}{42}(M\Omega)^{2/3}+2\pi(M\Omega)-\frac{2173+7483\eta-2047\eta^2}{1512}(M\Omega)^{4/3}\right.$$
$$\left.+\left(\frac{-107+34\eta}{21}\pi+\frac{56}{5}i\eta\right)(M\Omega)^{5/3}\right]e^{-im(\int\Omega dt-2M\Omega\ln\Omega/\Omega_0)}\,.$$

$$\frac{dE}{dt} = \lim_{r\to\infty}\left[\frac{r^2}{16\pi}\int_\Omega\left|\int_{-\infty}^{t}\Psi_4 d\tilde{t}\right|^2 d\Omega\right], \qquad \Psi_4 = \ddot{h}_+ - i\ddot{h}_\times$$

$$\frac{dP_i}{dt} = -\lim_{r\to\infty}\left[\frac{r^2}{16\pi}\int_\Omega \ell_i\left|\int_{-\infty}^{t}\Psi_4 d\tilde{t}\right|^2 d\Omega\right],$$

$$\frac{dJ_z}{dt} = -\lim_{r\to\infty}\left\{\frac{r^2}{16\pi}\mathrm{Re}\left[\int_\Omega\left(\partial_\phi\int_{-\infty}^{t}\Psi_4 d\tilde{t}\right)\left(\int_{-\infty}^{t}\int_{-\infty}^{\hat{t}}\overline{\Psi_4}d\tilde{t}d\hat{t}\right)d\Omega\right]\right\},$$

…OK, I'll try to keep it simple!

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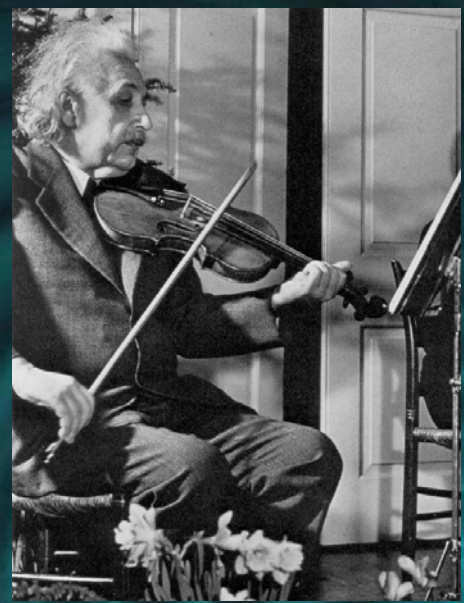
A gravitational wave is a propagating disturbance of the spacetime

Einstein's General Relativity

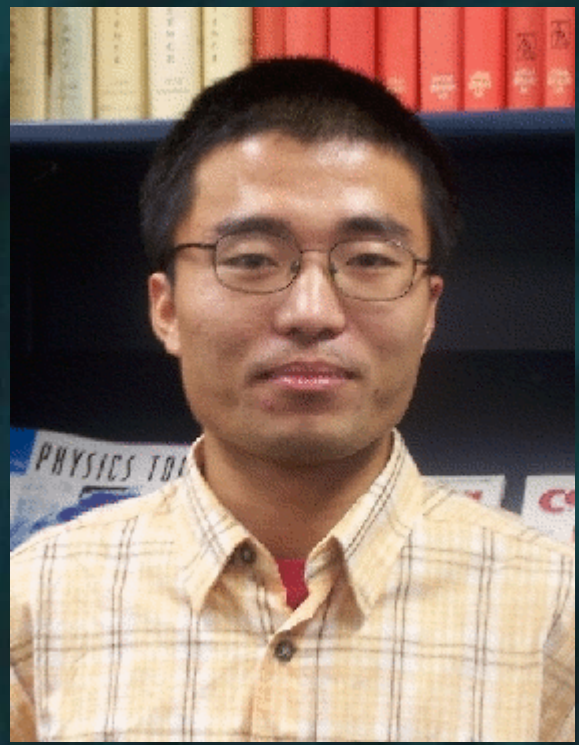
The spacetime geometry is continuously distorted by the presence of mass (=energy).

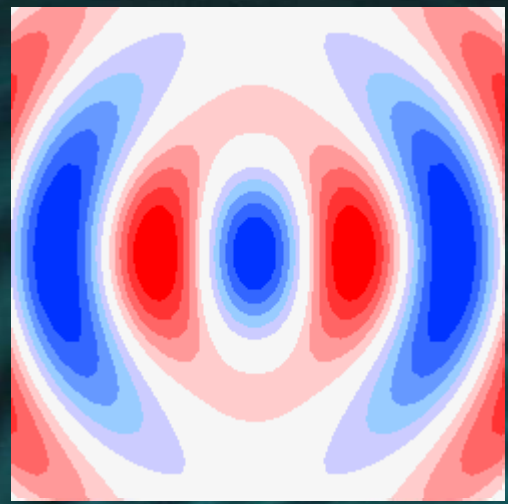
When masses move rapidly, the spacetime becomes stirred by their motion: *ripples* start travelling outward with the speed of light



What is the effect of a gravitational wave?

We will experiment on a graduate student (Mr. Jun-Qi Guo)





Sources of gravitational waves

- Coalescing binary neutron stars or black holes
- Spinning neutron stars
- Gravitational bursts (e.g. supernovae)
- Big bang gravitational echo

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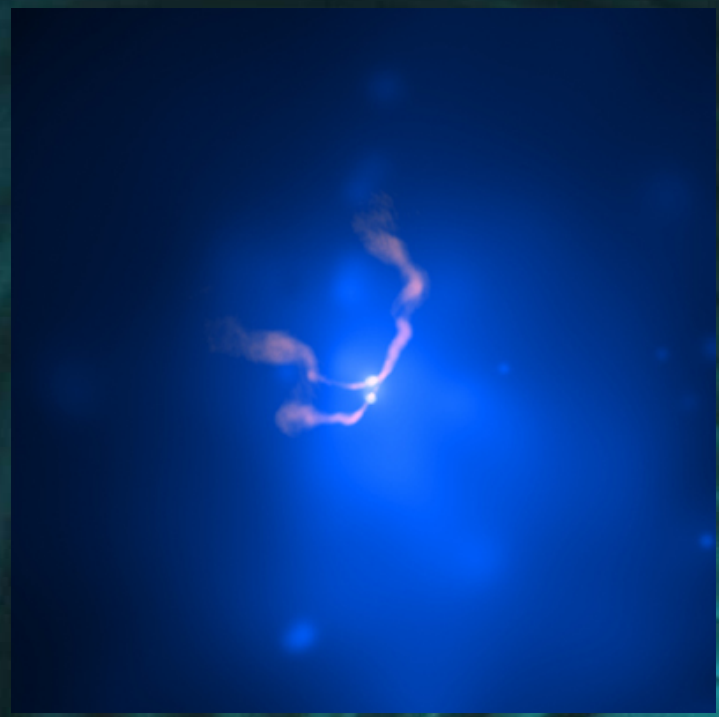

Picture credit: NASA/CXC/AIfA; NRAO/VLA/NRL

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Picture credit: NASA/HST/STScI

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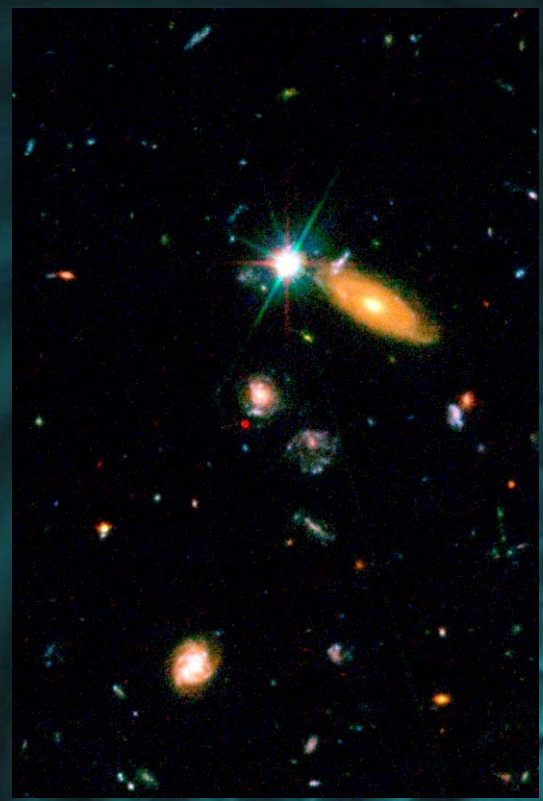

Picture credit: NASA/HST/STScI

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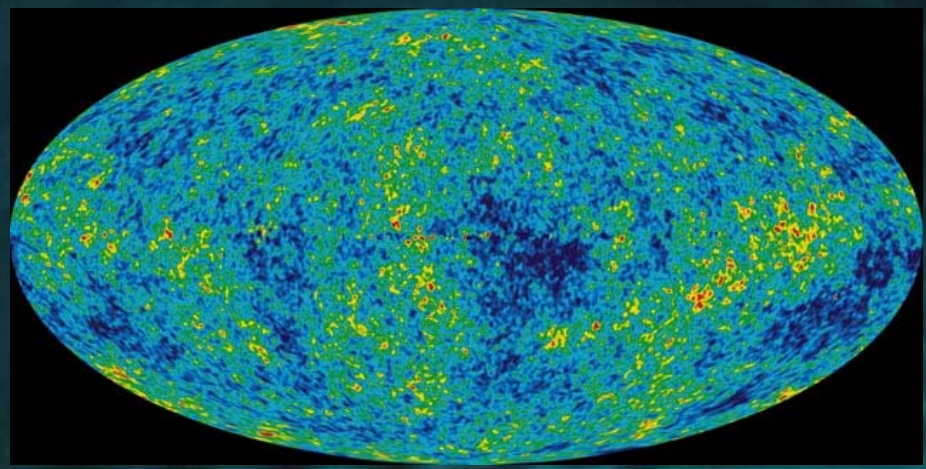
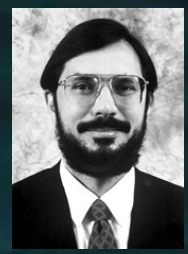


Picture credit: **NASA/WMAP**

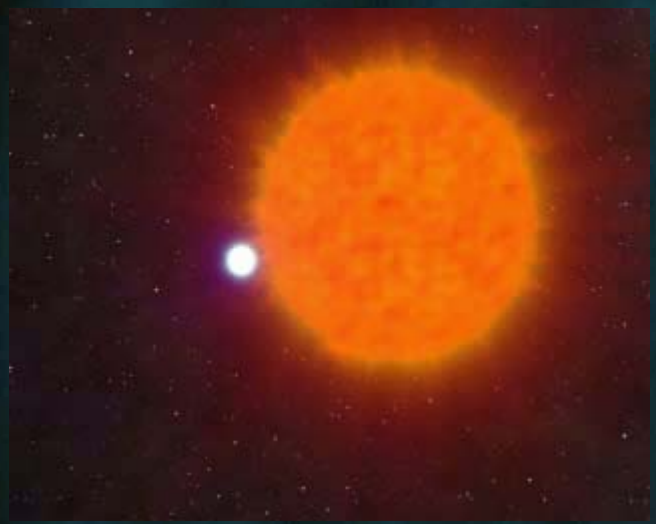
How do we know that gravitational waves exist?

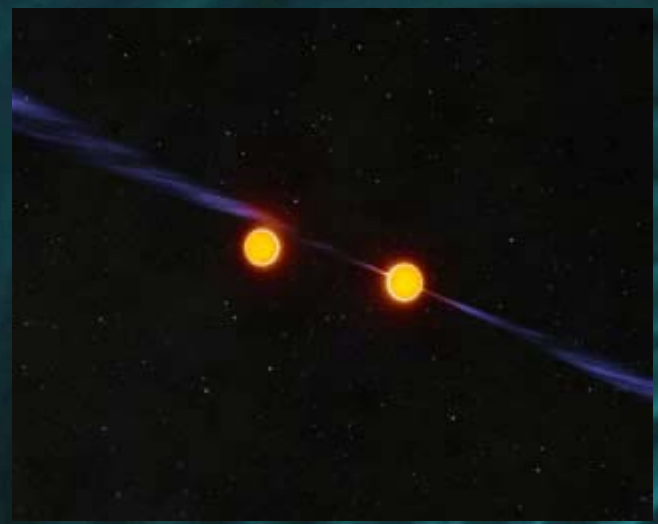
Indirect detection: slow down of a binary pulsar



R. Hulse

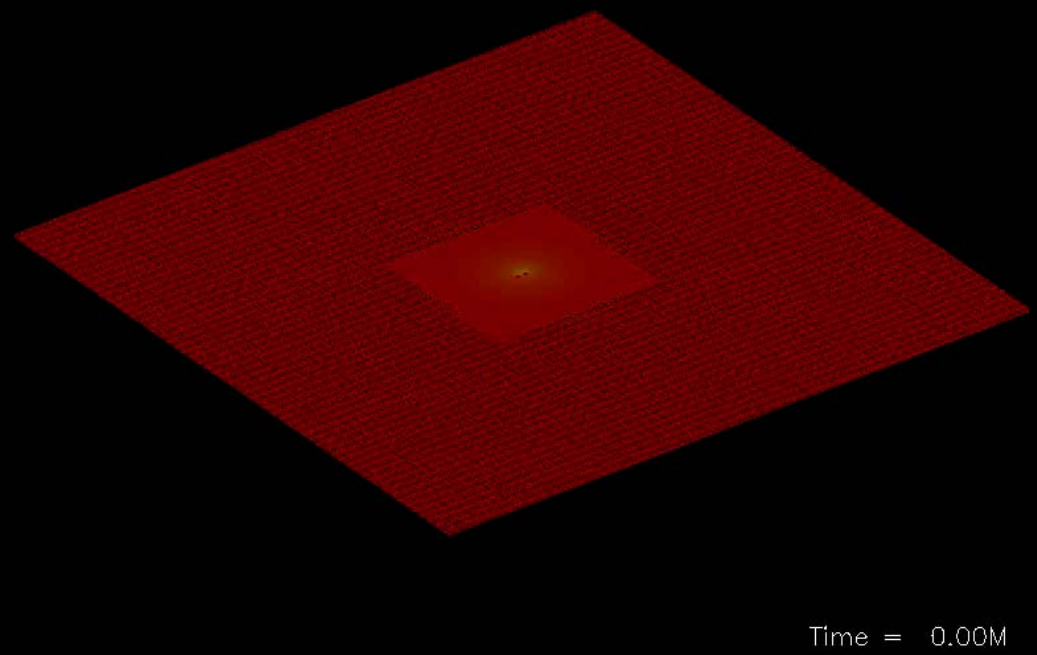
J. Taylor





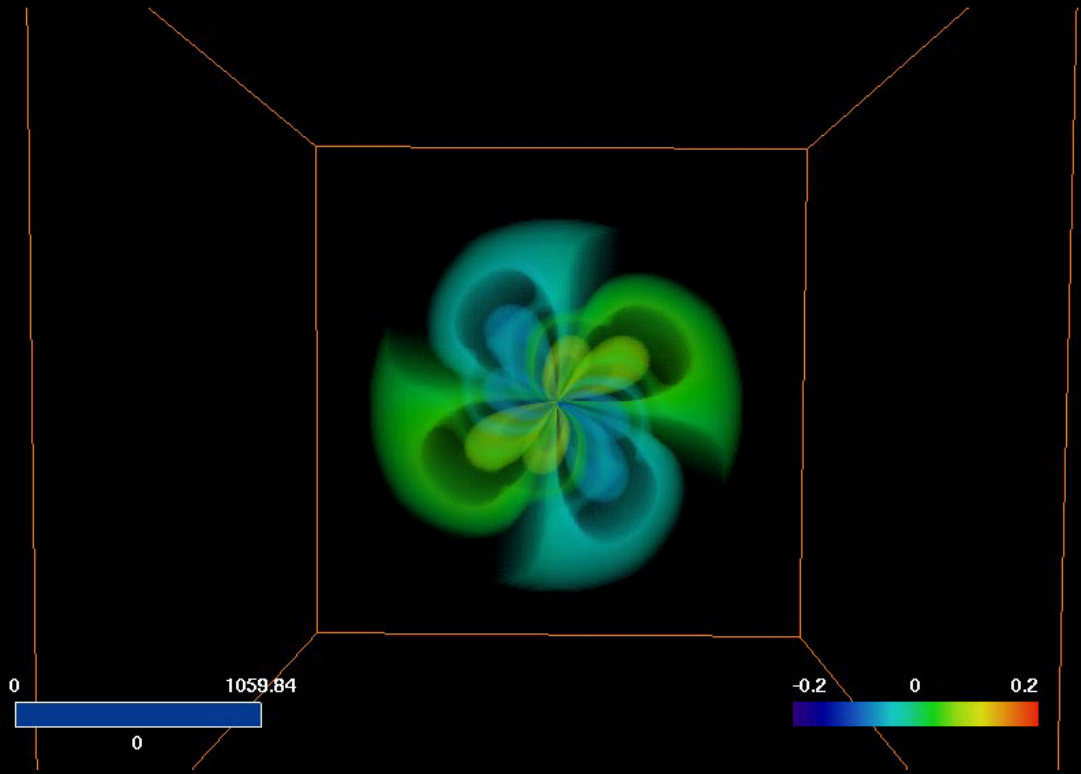
John Rowe Animation/Australia Telescope National Facility, CSIRO

Merger of a binary black hole system (equal-mass, unequal-spin black holes)



(Picture credit: L. Rezzolla, Albert-Einstein Institute, Golm, Germany)

Merger of a binary black hole system (equal-mass, zero-spin black holes)



(Courtesy of L. Rezzolla, Albert-Einstein Institute, Golm, Germany)

What is LIGO?

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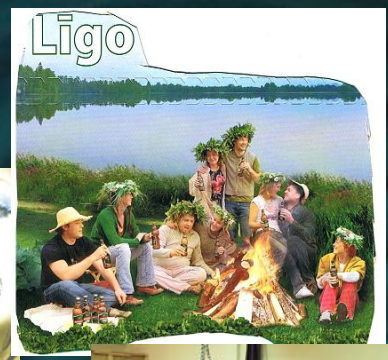
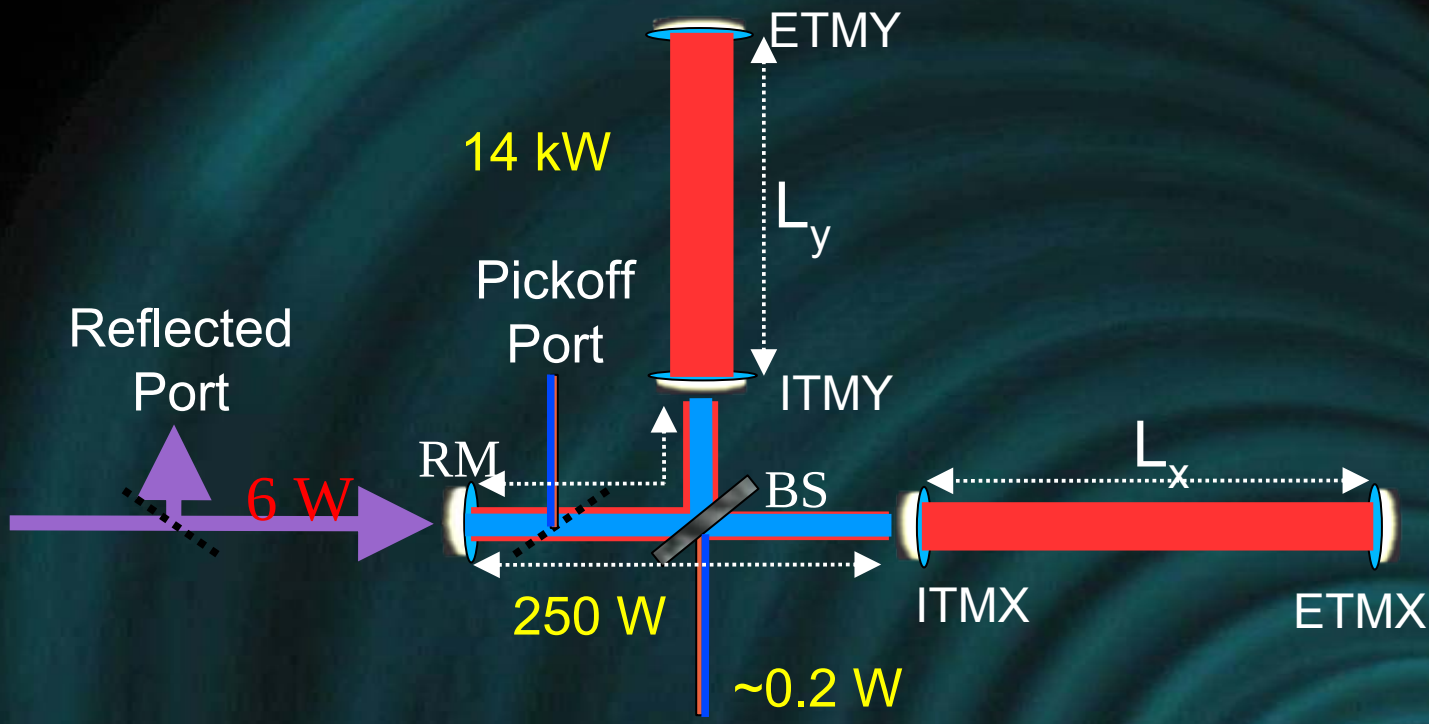
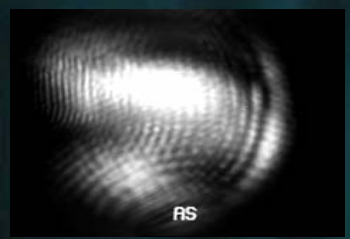
A way to answer is to use the most incredible scientific tool of the new millennium:



LIGO is an interferometer

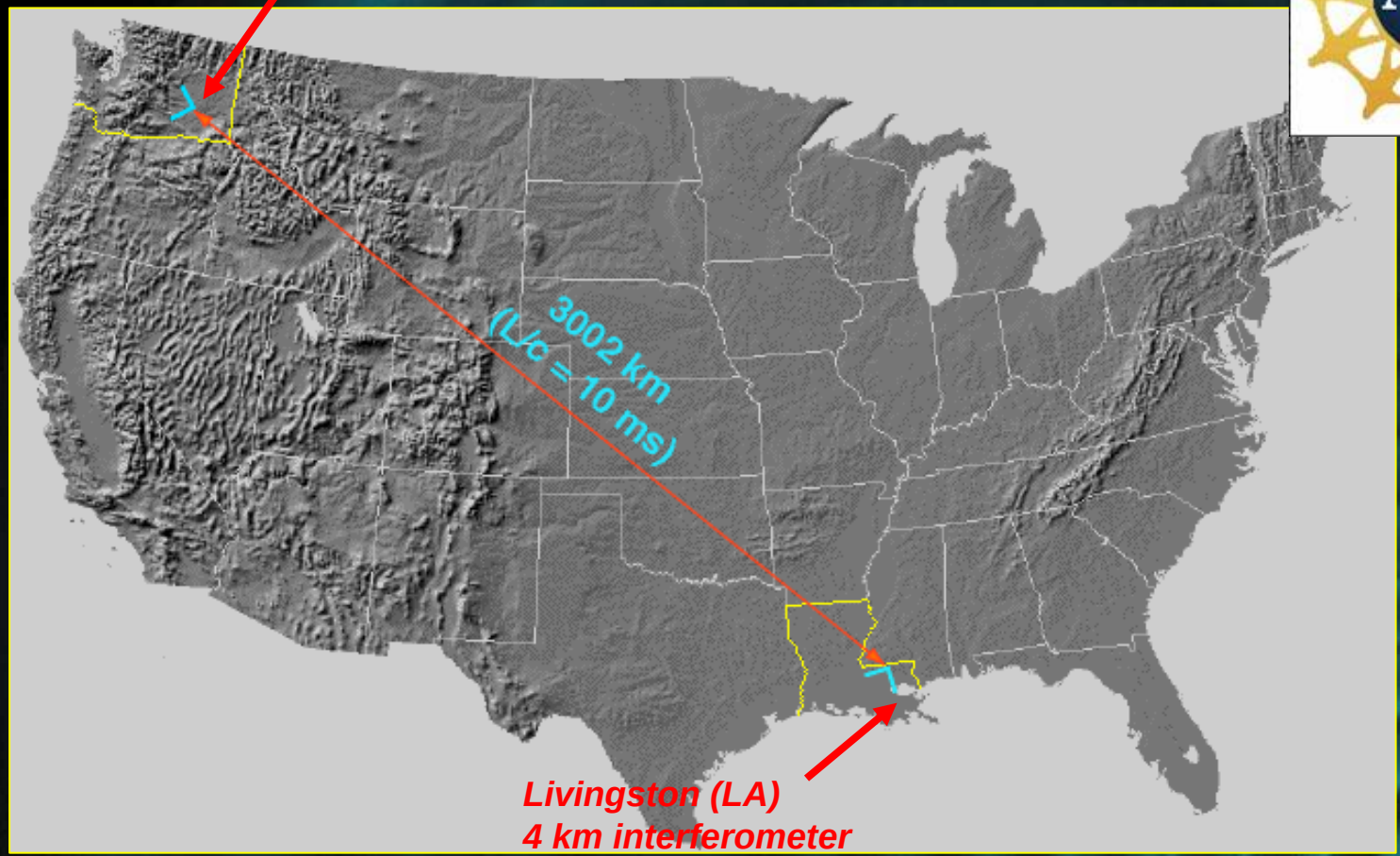


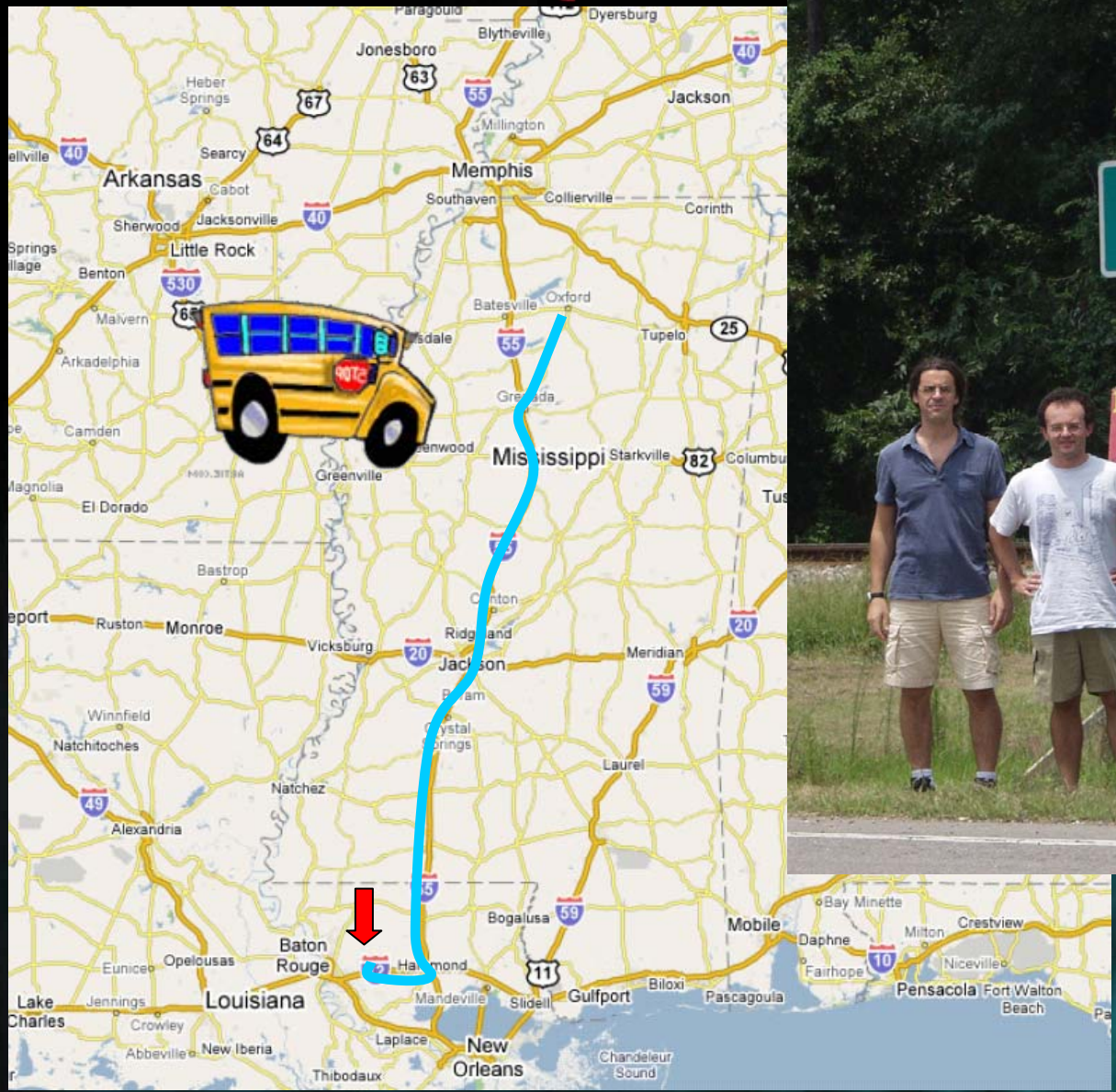
Strain
Readout
(L_y-L_x)



Anti-Symmetric
Port

The LIGO Observatory



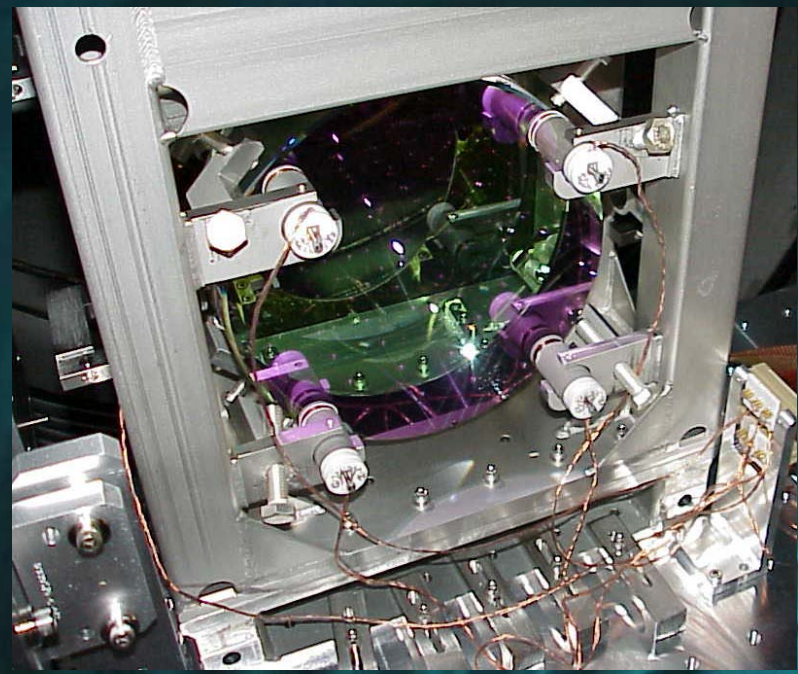

Jonesboro
Blytheville
Dyersburg
Jackson
Heber Springs
Searcy
Arkansas
Cabot
Memphis
Millington
Southaven
Collierville
Corinth
Sherwood
Jacksonville
Little Rock
Benton
Malvern
Arkadelphia
Batesville
Oxford
Tupelo
Camden
Greenville
Mississippi
Starkville
El Dorado
Bastrop
Ruston
Monroe
Vicksburg
Jackson
Meridian
Winnfield
Natchitoches
Natchez
Laurel
Alexandria
Bogalusa
Mobile
Bay Minette
Daphne
Milton
Crestview
Fairhope
Niceville
Pensacola
Fort Walton Beach
Baton Rouge
Opelousas
Eunice
Hammond
Louisiana
Lake Charles
Jennings
Crowley
Abbeville
New Iberia
Mandeville
Slidell
Gulfport
Biloxi
Pascagoula
Laplace
New Orleans
Thibodaux
Chandeleur Sound


LIGO
QUALITY SOD

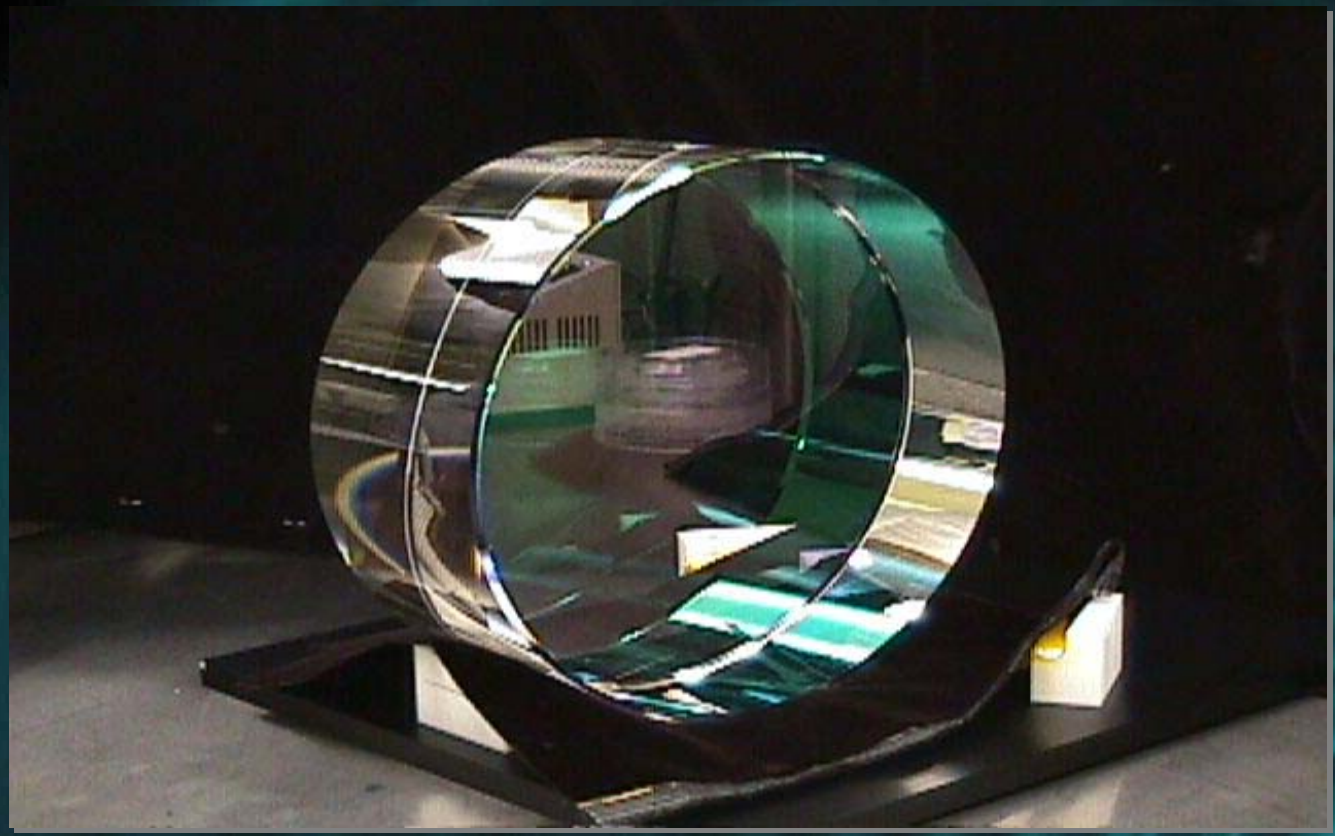

Livingston,
Louisiana

Vacuum equipment

Core optic suspensions

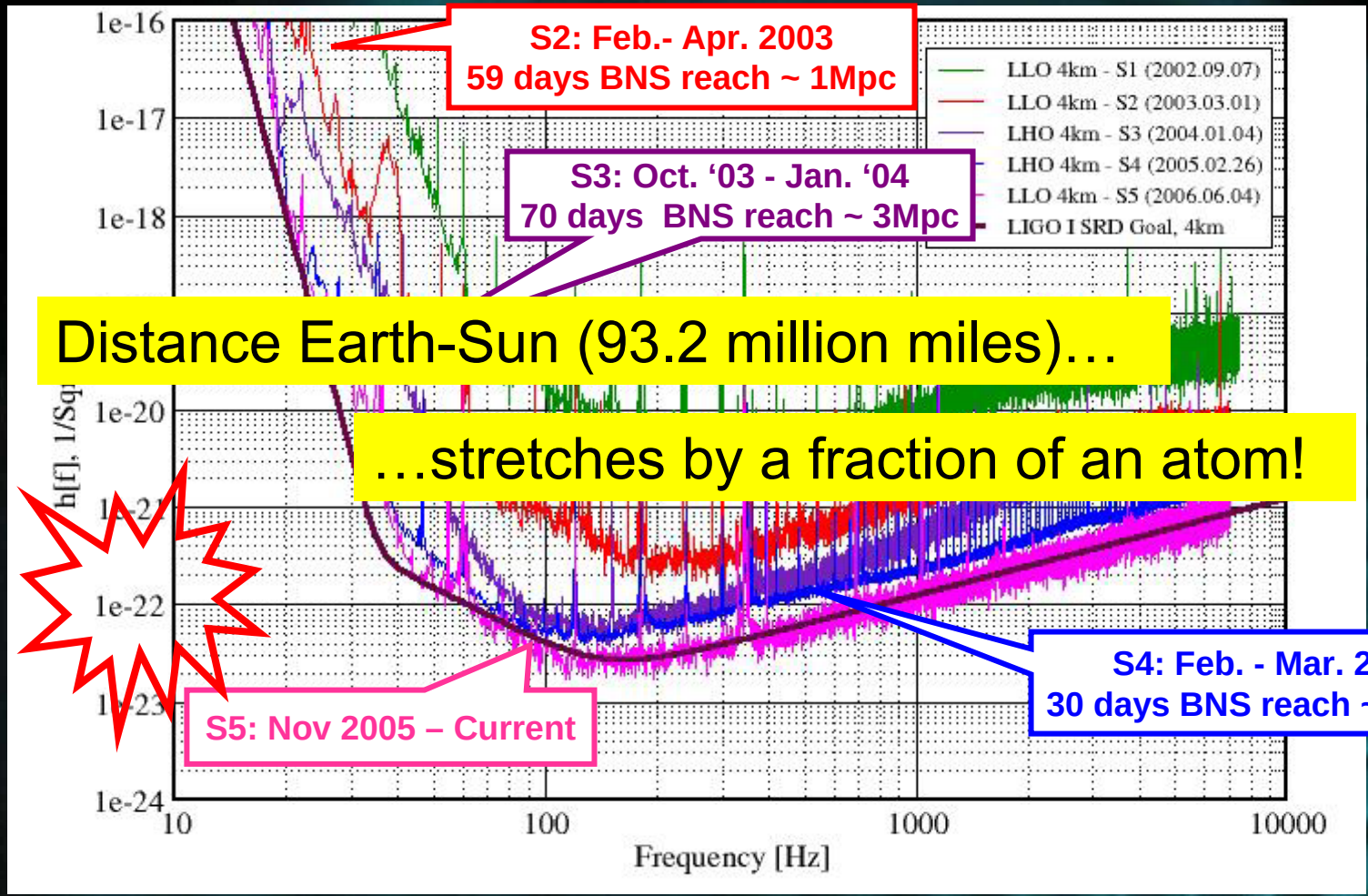


Core optics



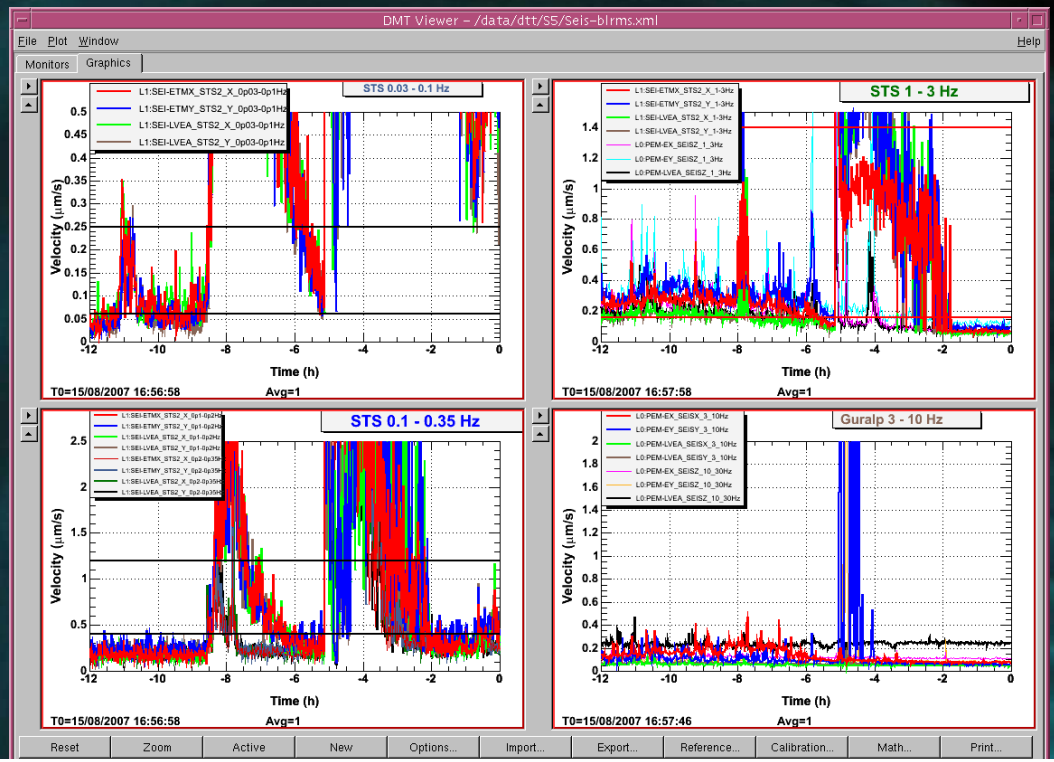
The control room

LIGO sensitivity



LIGO is so sensitive that it feels…

- Cars and trucks
- Airplanes
- Sea waves
- Earthquakes…



MAP	7.9	2007/08/15 23:40:57	-13.358	-76.522	30.2	NEAR THE COAST OF CENTRAL PERU
MAP	5.3	2007/08/15 23:20:36	35.335	140.389	38.9	NEAR THE EAST COAST OF HONSHU, JAPAN
MAP	6.5	2007/08/15 20:22:14	50.568	-177.507	21.2	ANDREANOF ISLANDS, ALEUTIAN IS., ALASKA

LIGO

Australian Consortium
for Interferometric
Gravitational Astronomy
The Univ. of Adelaide
Andrews University
The Australian National Univ.
The University of Birmingham
California Inst. of Technology
Cardiff University
Carleton College
Charles Stuart Univ.
Columbia University
Embry Riddle Aeronautical Univ.
Eötvös Loránd University
University of Florida
German/British Collaboration for
the Detection of Gravitational Wav
University of Glasgow
Goddard Space Flight Center
Leibniz Universität Hannover
Hobart & William Smith Colleges
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Physics

LSC

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Northwestern University
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Rutherford Appleton Lab
University of Rochester
San Jose State University
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and Univ. of Salerno
University of Sheffield
University of Southampton
Southeastern Louisiana Univ.
Southern Univ. and A&M College
Stanford University
University of Strathclyde
Syracuse University
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Univ. of Texas at Brownsville
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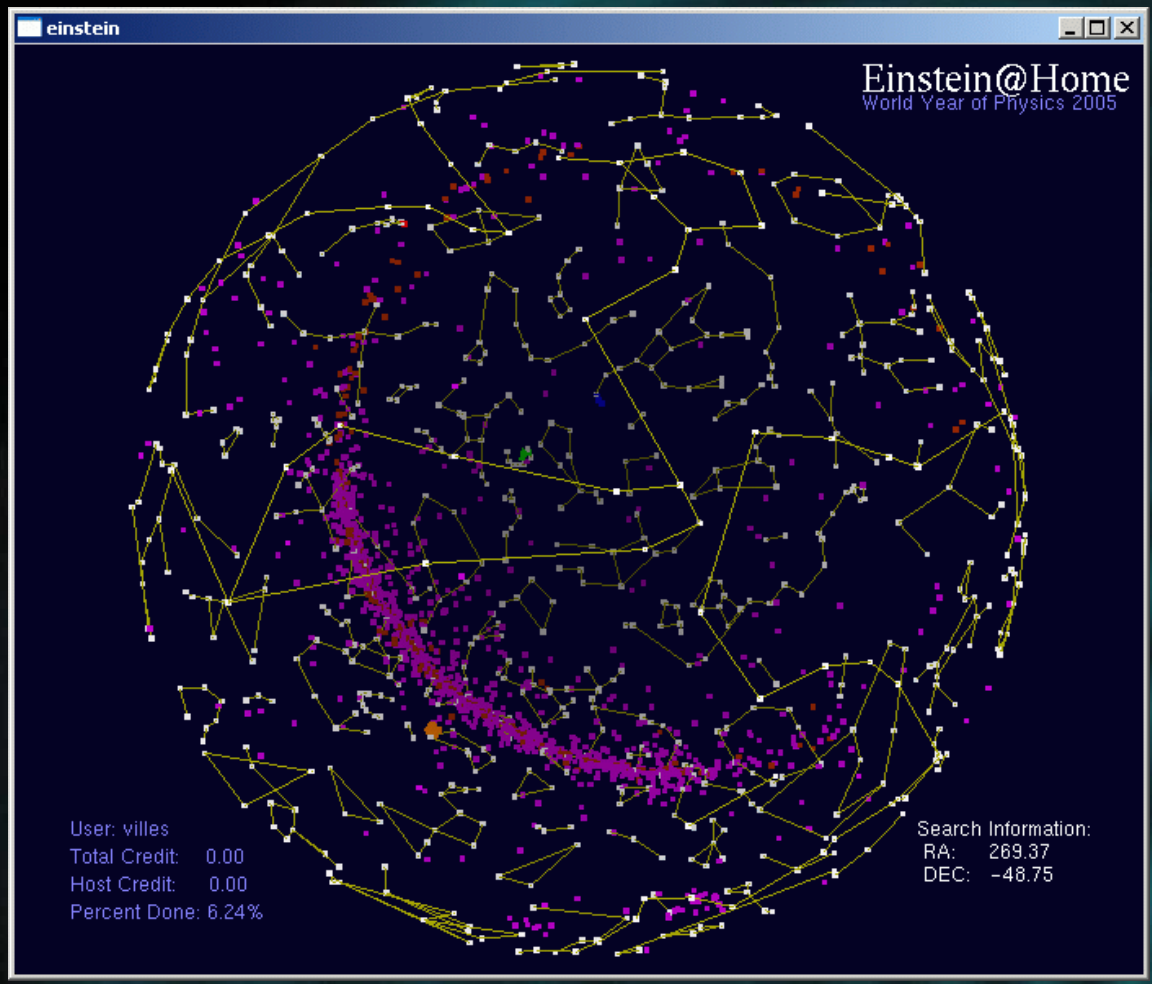
University of Western Australia
Univ. of Wisconsin-Milwaukee
Washington State University
University of Washington

You can also contribute!

The Einstein@home Project



Users and Computers

Sat Sept 8 2007 19:44 UTC

USERS	Approximate #
in database	280,419
with credit	175,444
registered in past 24 hours	358

HOST COMPUTERS	Approximate #
in database	758,499
registered in past 24 hours	1,038
with credit	397,527
active in past 7 days	57,190
floating point speed[1)]	70.9 TFLOPS

http://www.einsteinathome.org

Thank you!