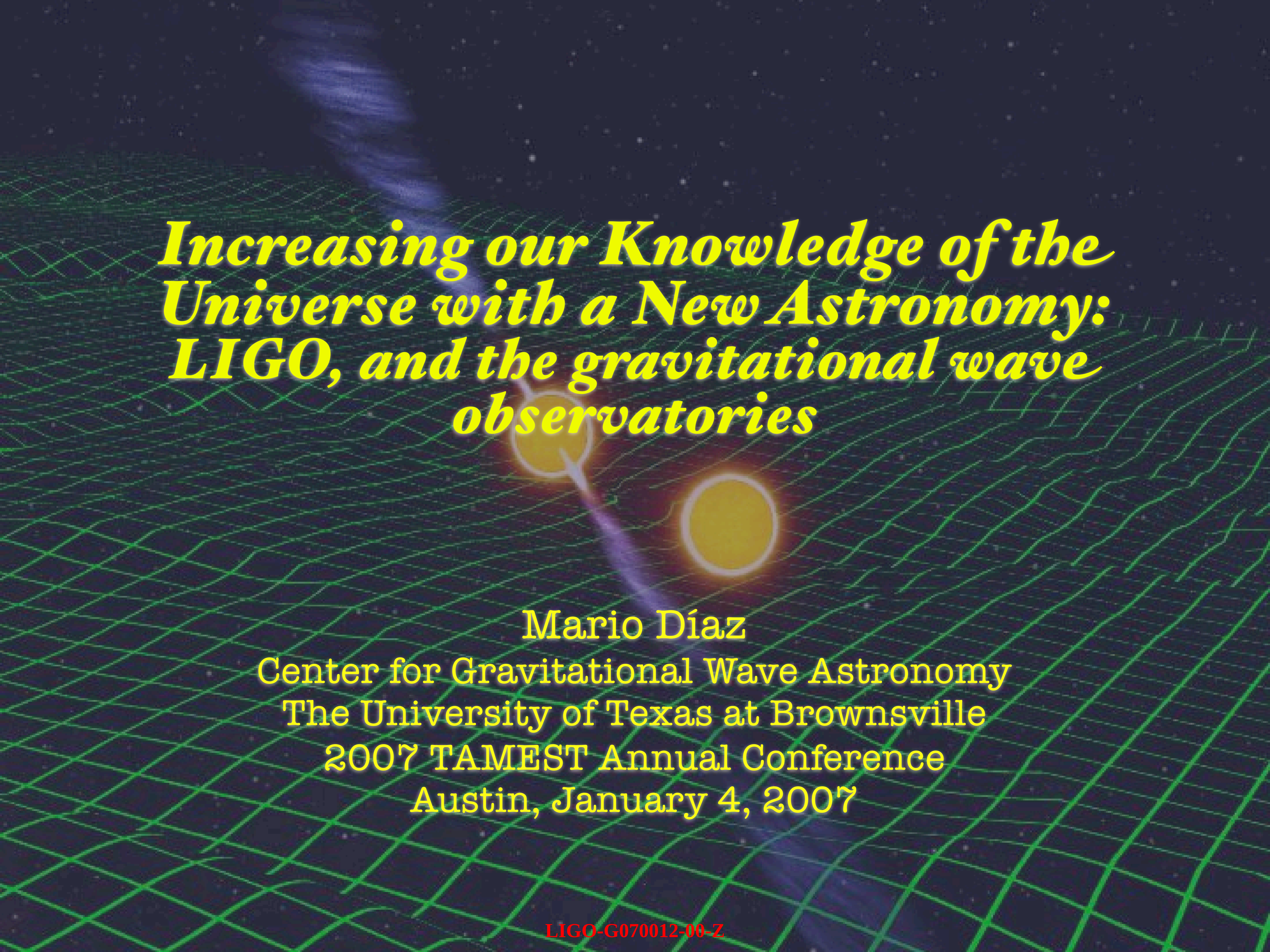

Increasing our Knowledge of the Universe with a New Astronomy: LIGO, and the gravitational wave observatories

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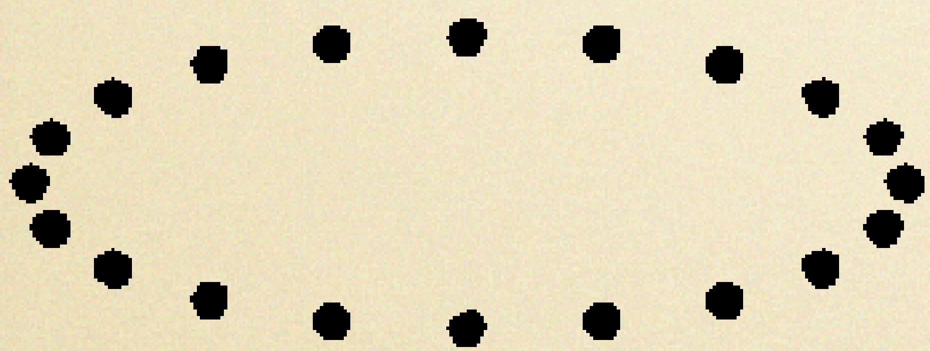
LIGO-G070012-00-Z

Gravitational Waves

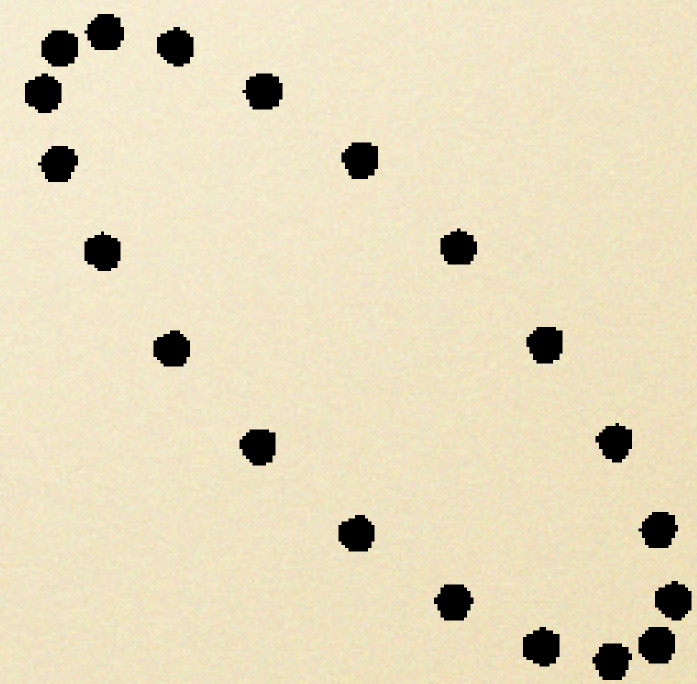
- What kind of waves?
- Which are the sources?
- What information do they provide?
- How do we detect and study them?

- They are different from EM waves.
- Ripples in the fabric of space-time
- Carry information about the dynamics of very compact, very massive astrophysical systems.

Effect on a ring of particles

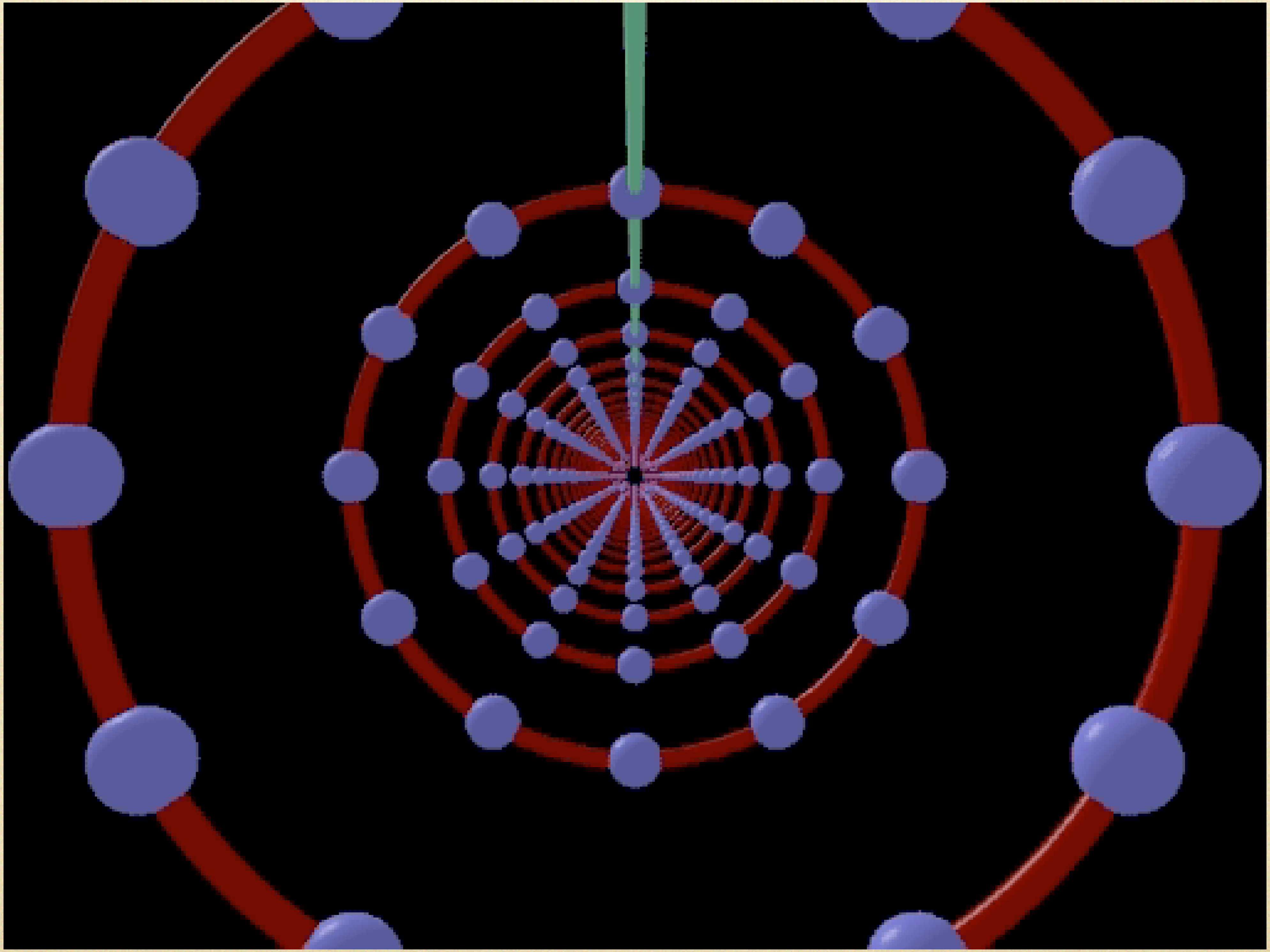


Plus polarization



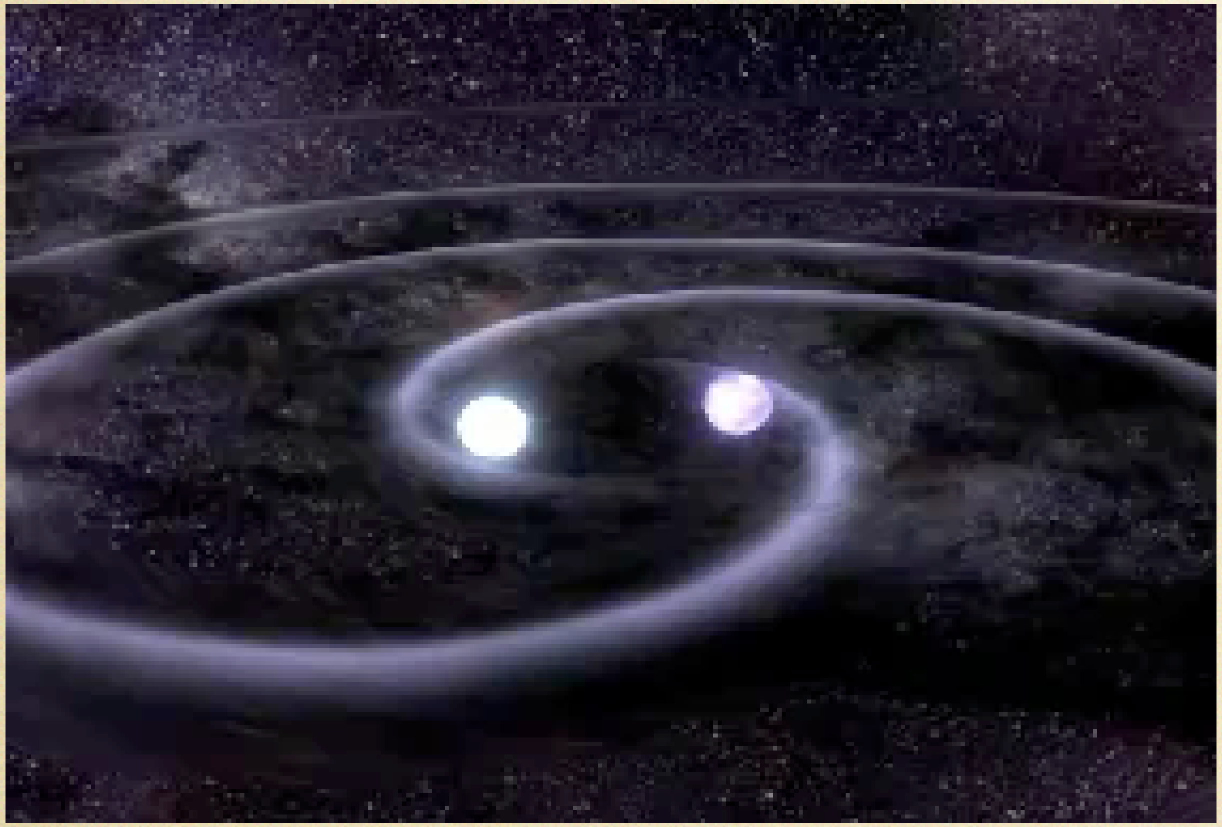
Cross polarization

A 3-D perspective



Animation credit Michael R. Gallis

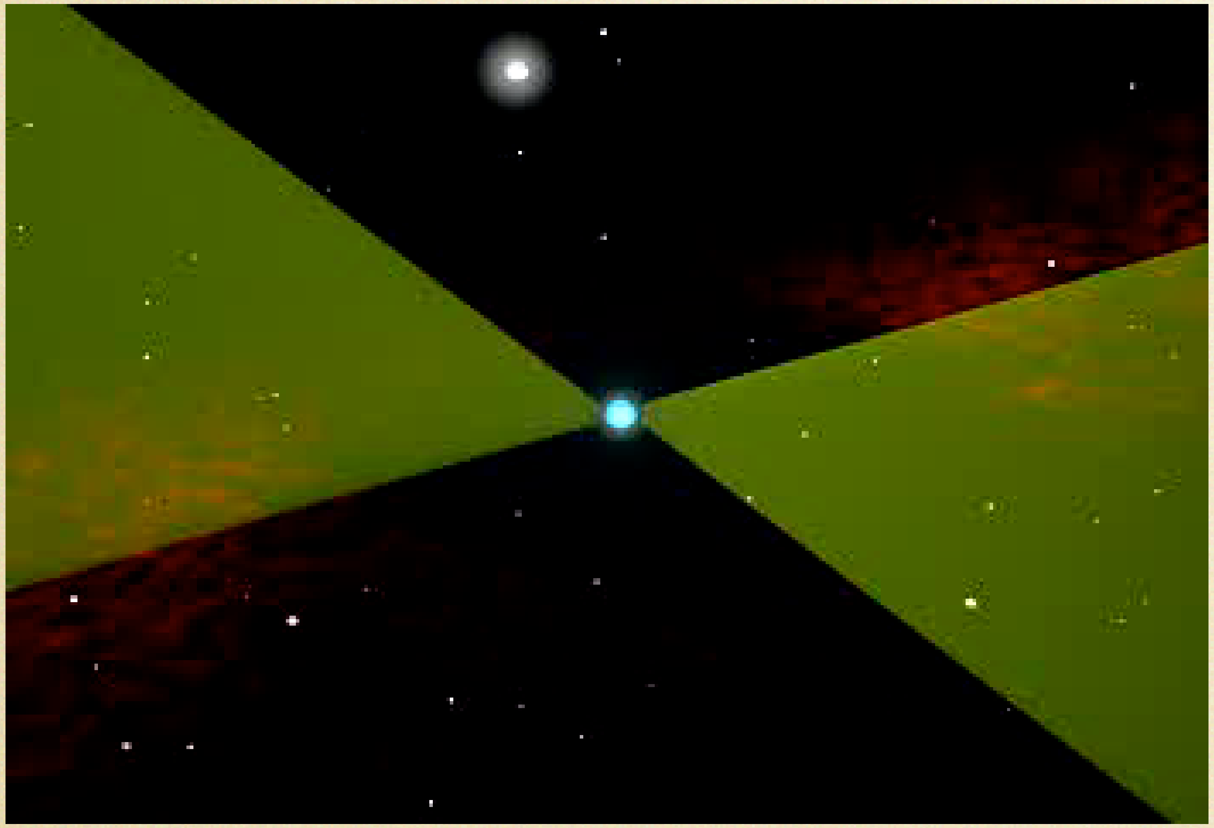
What are the sources?

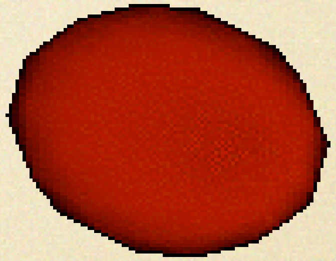


Binary systems

Supernovae explosions

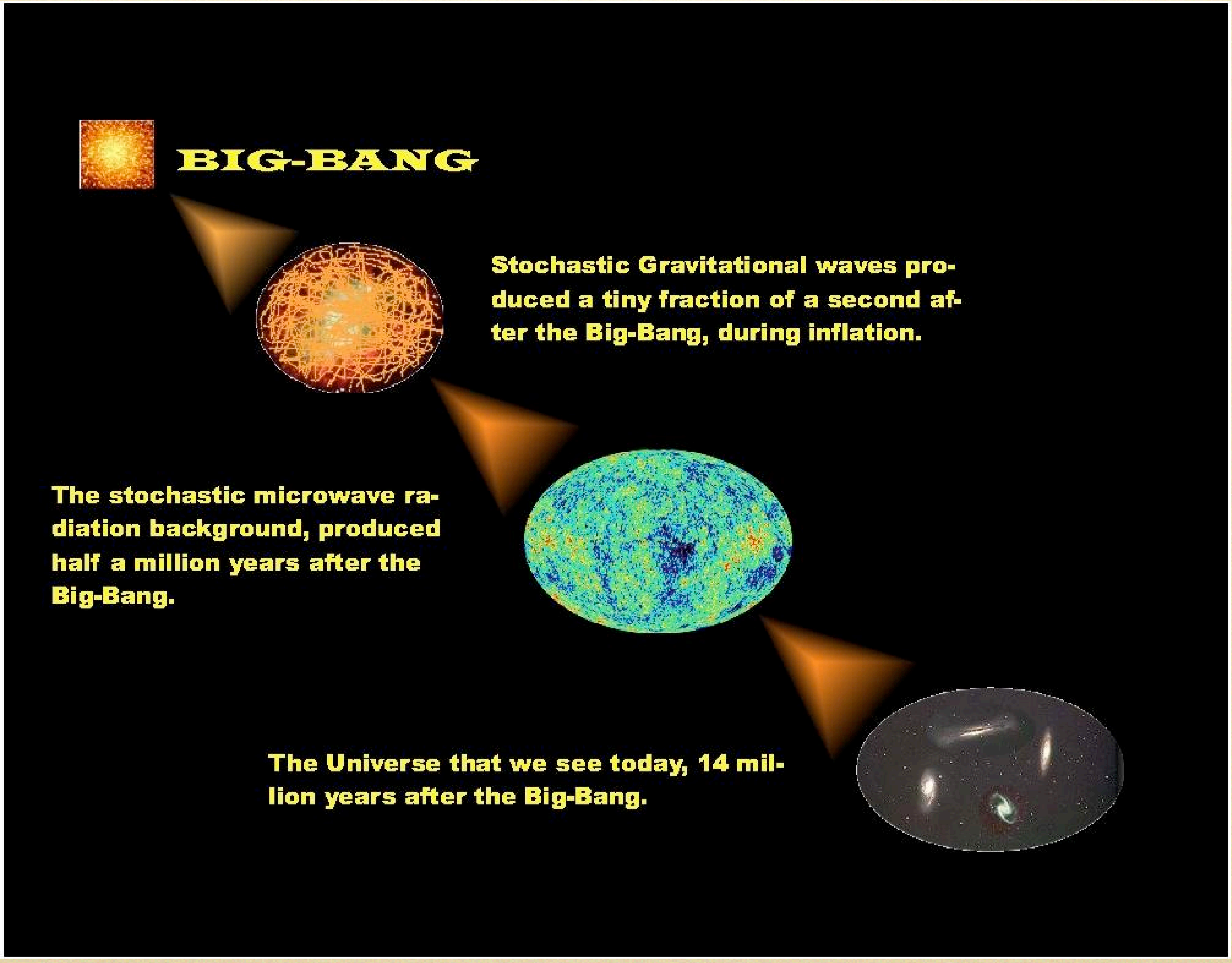
More sources





A non-spherical pulsar

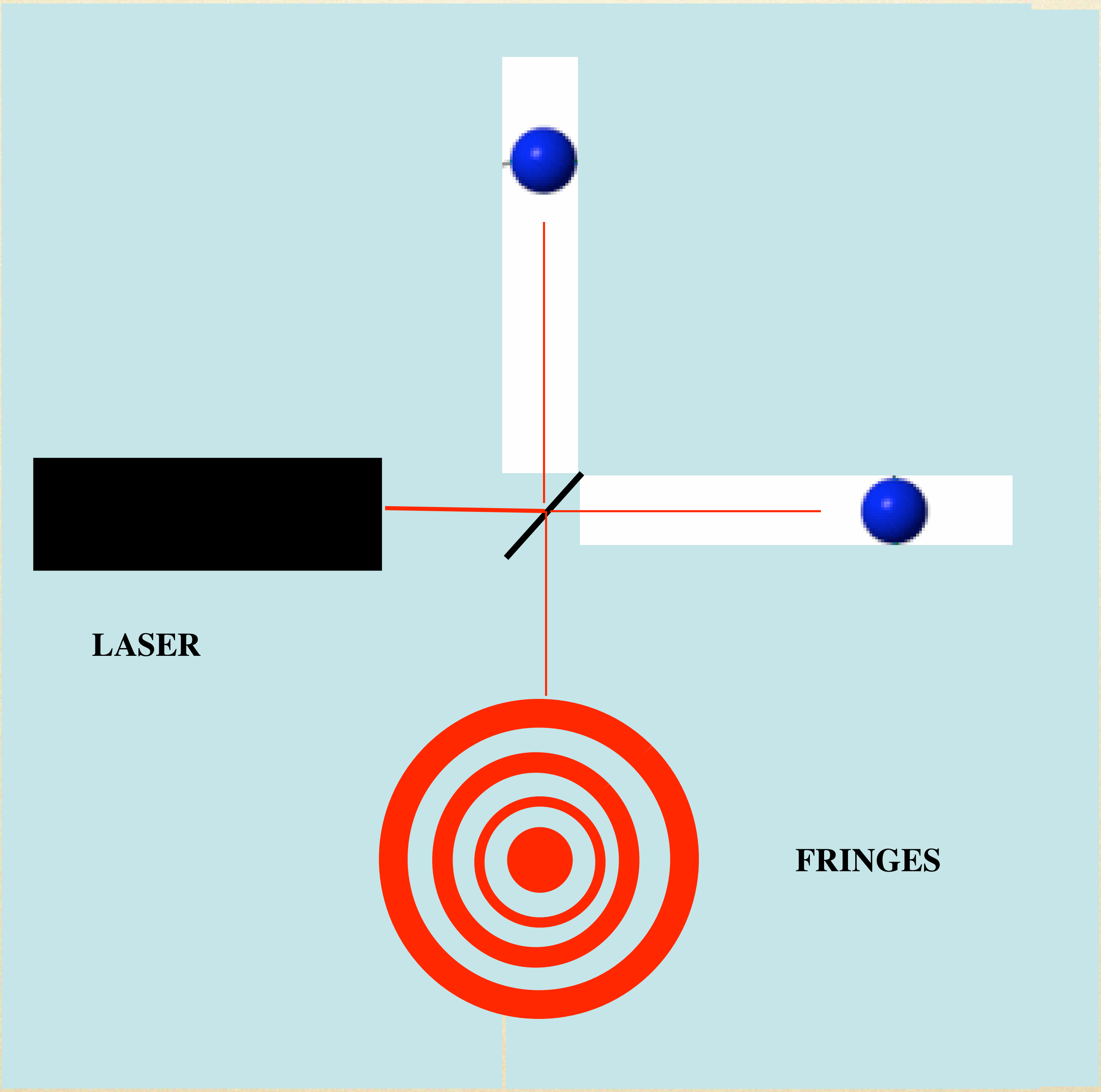
The Big-Bang


BIG-BANG
Stochastic Gravitational waves produced a tiny fraction of a second after the Big-Bang, during inflation.
The stochastic microwave radiation background, produced half a million years after the Big-Bang.
The Universe that we see today, 14 million years after the Big-Bang.

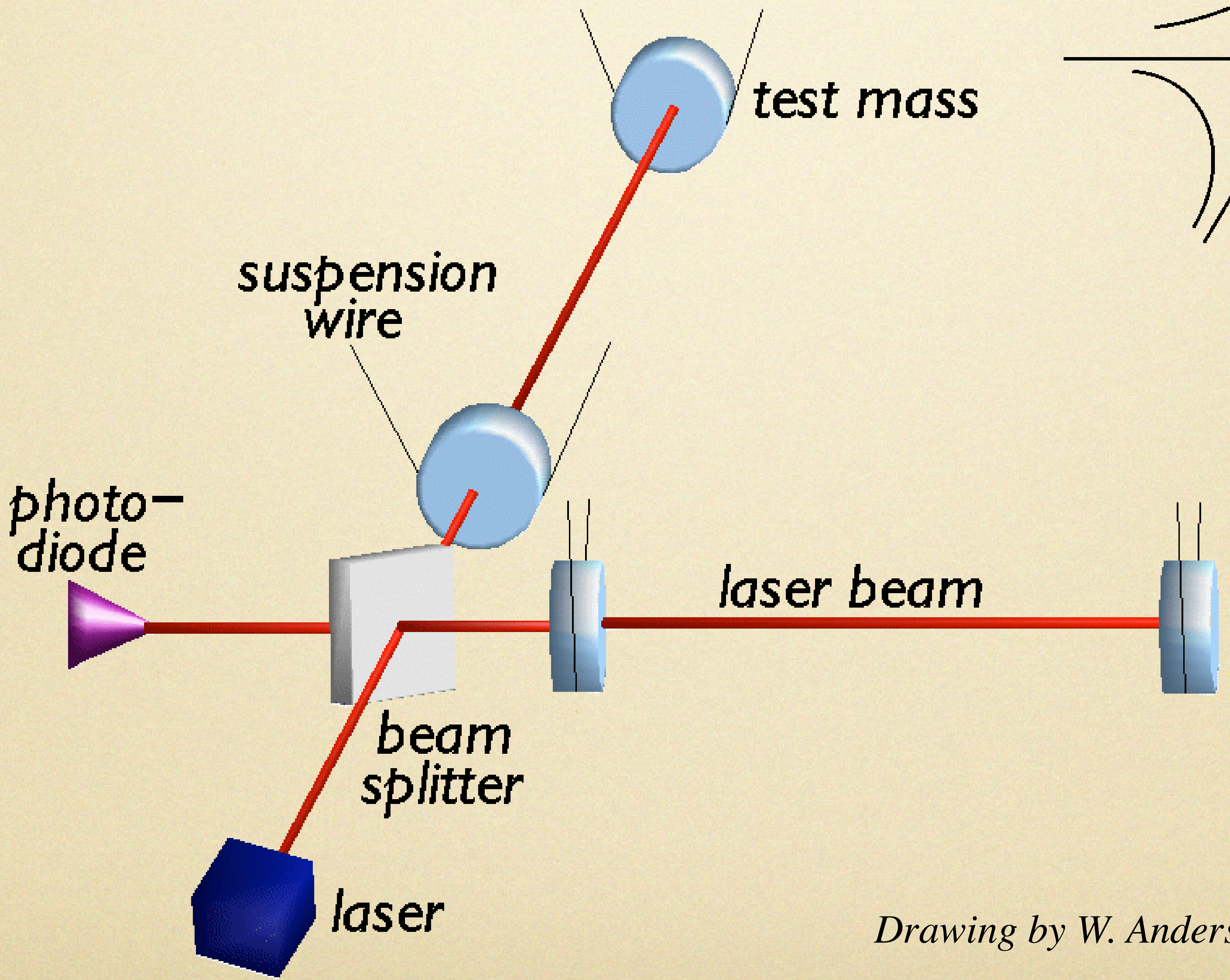
How to detect them?

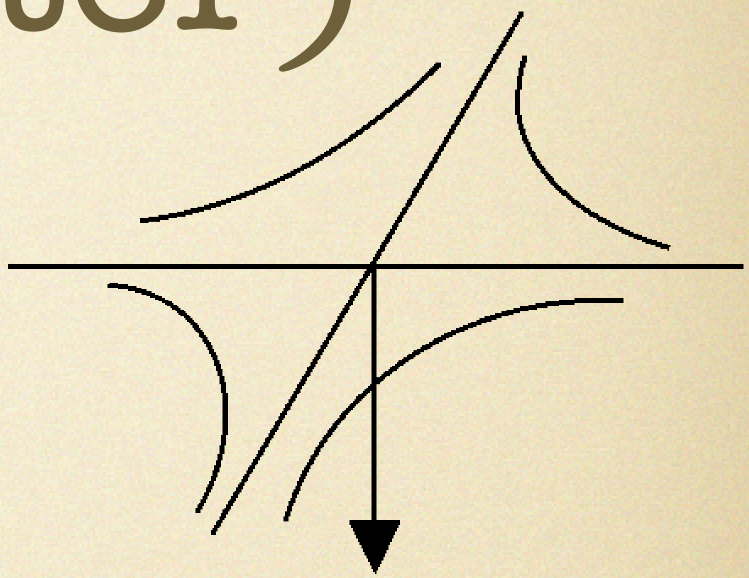
The first detector

Interferometer cartoon



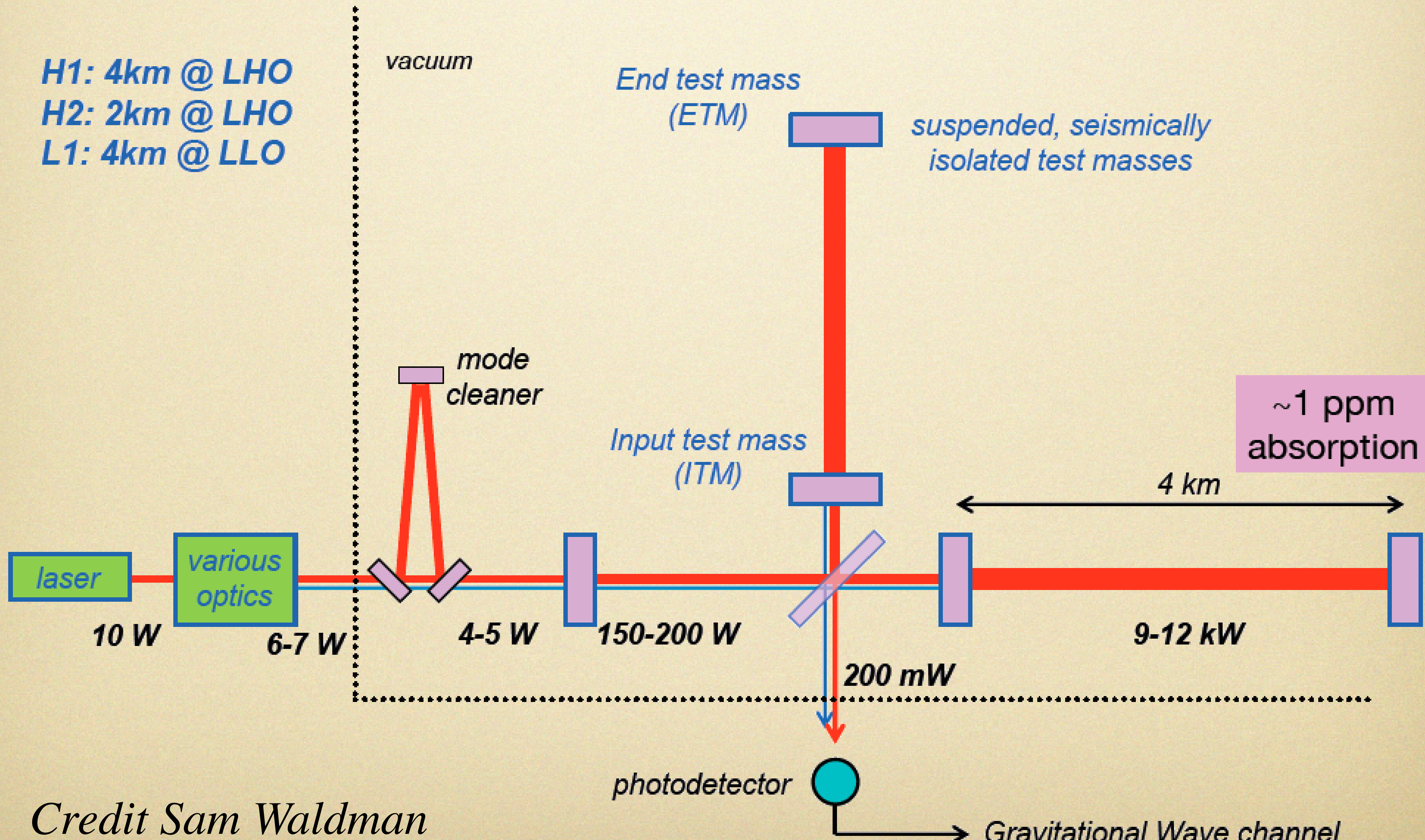
IFO cartoon (better)





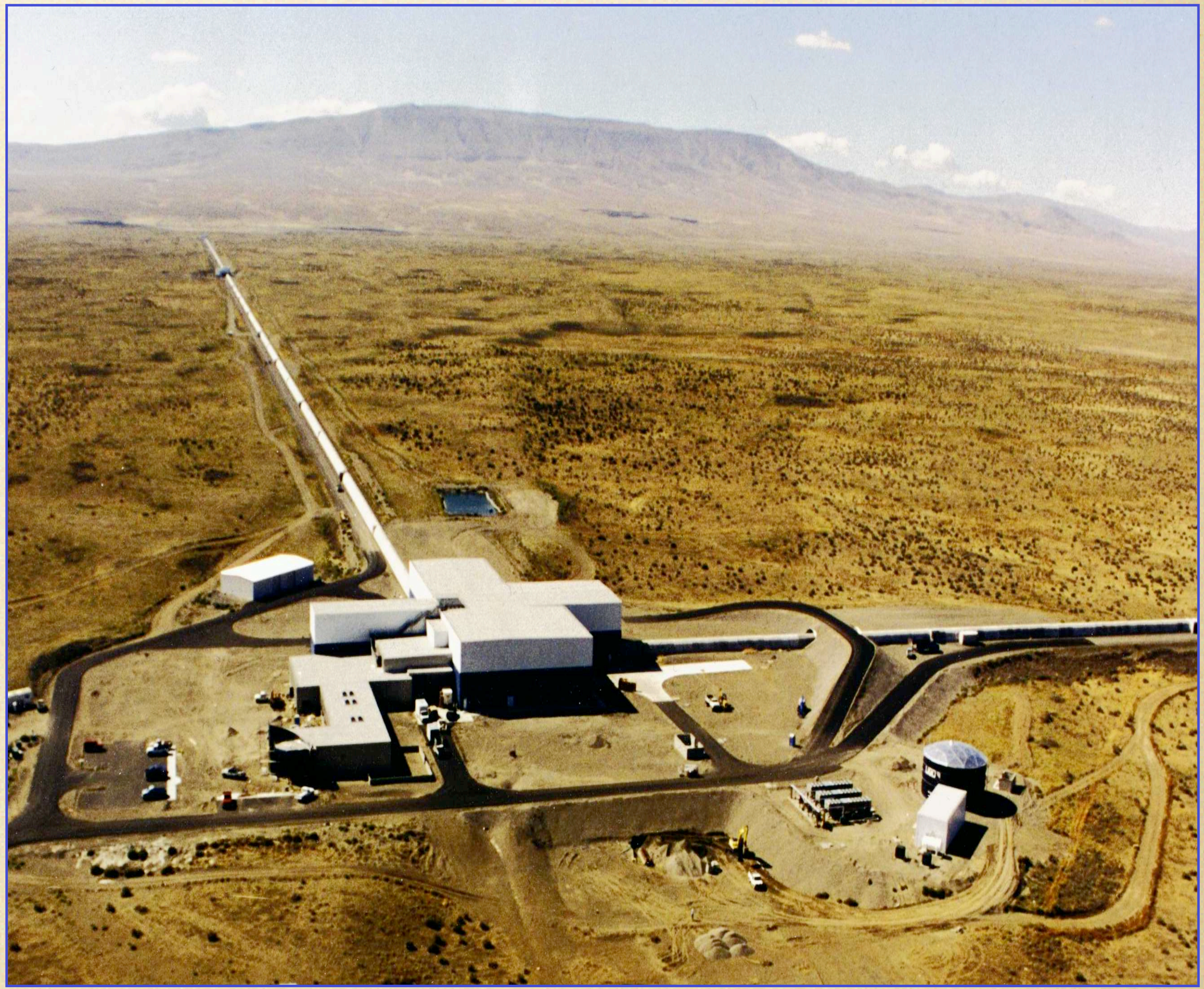
Drawing by W. Anderson

An even better cartoon



Credit Sam Waldman

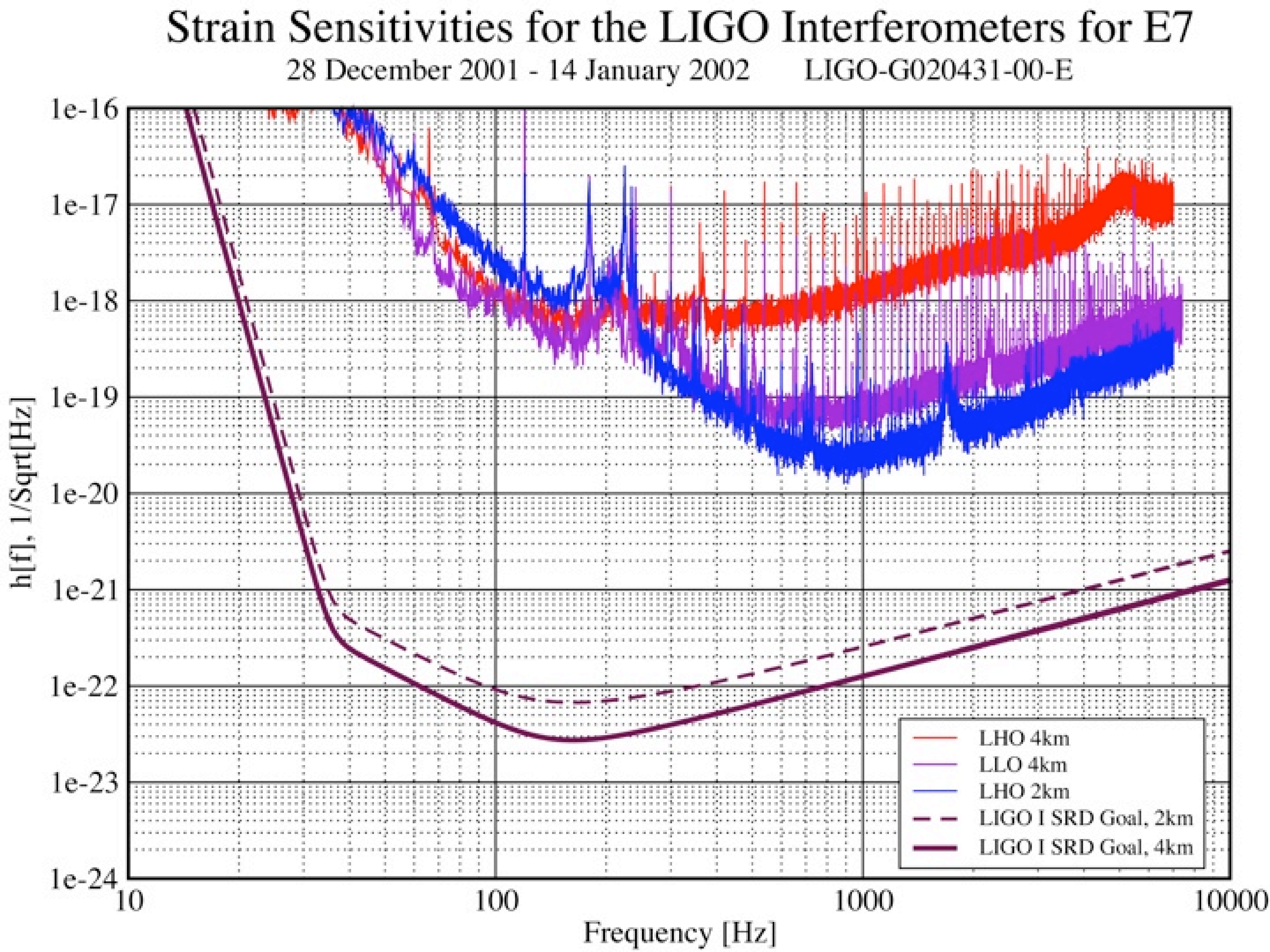
The LIGO observatories

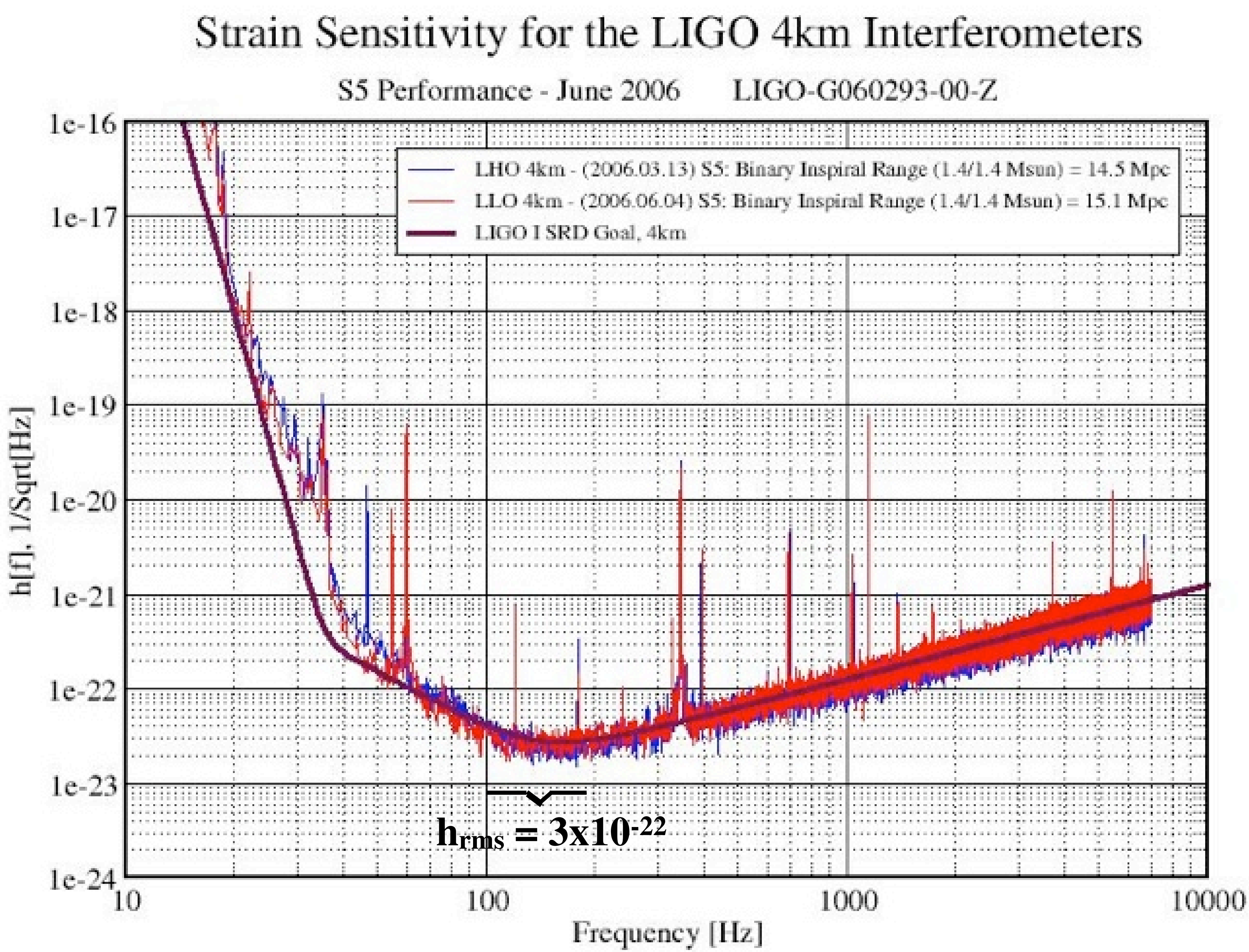


Scientific Data

Started taking Engineering Data in 2000.

Science Run 5	10/20/2005-ongoing	>9000 hs
Science Run 4	2/22/2005-3/23/2005	708 hs
Science Run 3	10/31/2003-1/9/2004	1680 hs
Science Run 2	2/14/2003-4/14/2003	1415 hs
Science Run 1	8/23/2002-9/9/2002	408 hs


Strain Sensitivities for the LIGO Interferometers for E7
28 December 2001 - 14 January 2002
LIGO-G020431-00-E
h[f], 1/Sqrt[Hz]
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
1e-23
1e-24
10
100
1000
10000
Frequency [Hz]
LHO 4km
LLO 4km
LHO 2km
LIGO I SRD Goal, 2km
LIGO I SRD Goal, 4km



Strain Sensitivity for the LIGO 4km Interferometers
S5 Performance - June 2006
LIGO-G060293-00-Z
LHO 4km - (2006.03.13) S5: Binary Inspiral Range (1.4/1.4 Msun) = 14.5 Mpc
LLO 4km - (2006.06.04) S5: Binary Inspiral Range (1.4/1.4 Msun) = 15.1 Mpc
LIGO I SRD Goal, 4km
h[f], 1/Sqrt[Hz]
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
1e-23
1e-24
10
100
1000
10000
Frequency [Hz]
h_rms = 3x10^-22

2005: LIGO has achieved design sensitivity

- 1995: LIGO document E950015:

"initial LIGO detector strain sensitivity goal of 10^{-21} RMS, integrated over a 100 Hz bandwidth"

- 2005 NSF review panel agrees:

LIGO has reached design sensitivity

Astronomy?

LIGO achieved h_{rms} of 10^{-21} in a bandwidth of 100HZ and a peak sensitivity of $3\times 10^{-23}\ Hz^{-1/2}$ at 200 Hz. With this sensitivity it could detect:

★ A binary inspiral of 1.4 $M_{\odot}$ at 33 Mpc.

★ A supernova exploding at 15 Mpc with 10^{-3} conversion efficiency.

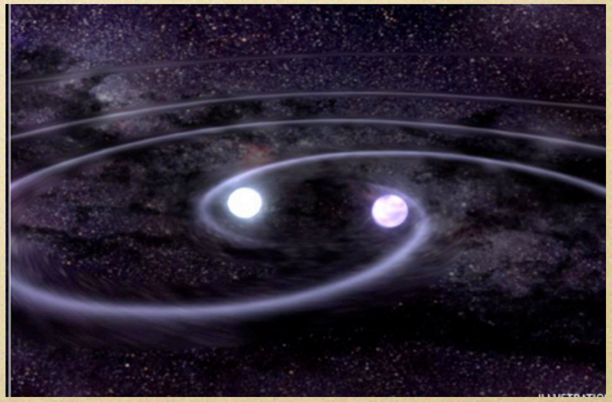
★ A 150 Hz pulsar at 15 kpc with an eccentricity of 10^{-5}.

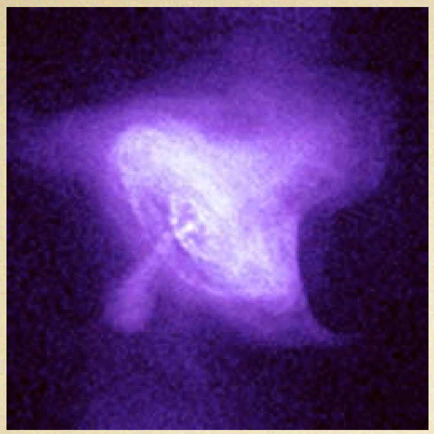
★ A stochastic GW with $\Omega = 10^{-6}$.

Results

Binary Inspirals: search using theoretical templates.

- S2: For BBH The search focused on binary systems with component masses between 3 and 20 M⊙. No events found that could be identified as gravitational waves in the 385.6 hours of data searched: $R90\% = 38\ \mathrm{year}^{-1}\ \mathrm{MWEG}^{-1}$. (PRD 72, 082002 (2005), PRD 73, 062001 (2006))
- S5 is expected to give BBH coalescence rate upper limits of less than $10^{-4}\ \mathrm{year}^{-1}\ \mathrm{MWEG}^{-1}$.

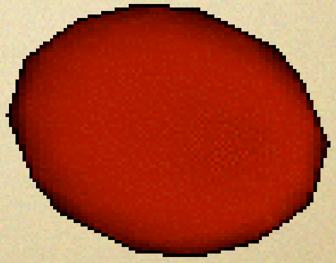




Results 2

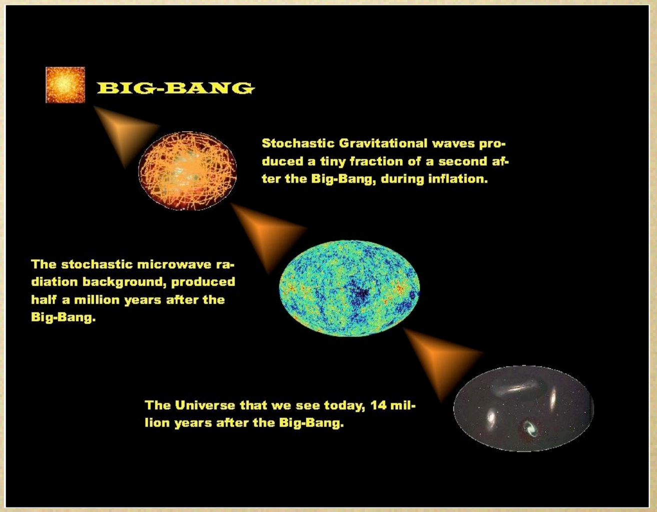
PULSARS: could produce GW if they are not spherical.

- Targeted searches for 73 known in S5: isolated pulsars, binary systems, pulsars in globular clusters…
- Best limit on ellipticity: PSR J2124-3358.(f_{gw} = 405.6Hz, r = 0.25kpc) $\epsilon = 4.0\text{x}10^{-7}$.
- We have beaten the spin-down limit for the Crab pulsar.



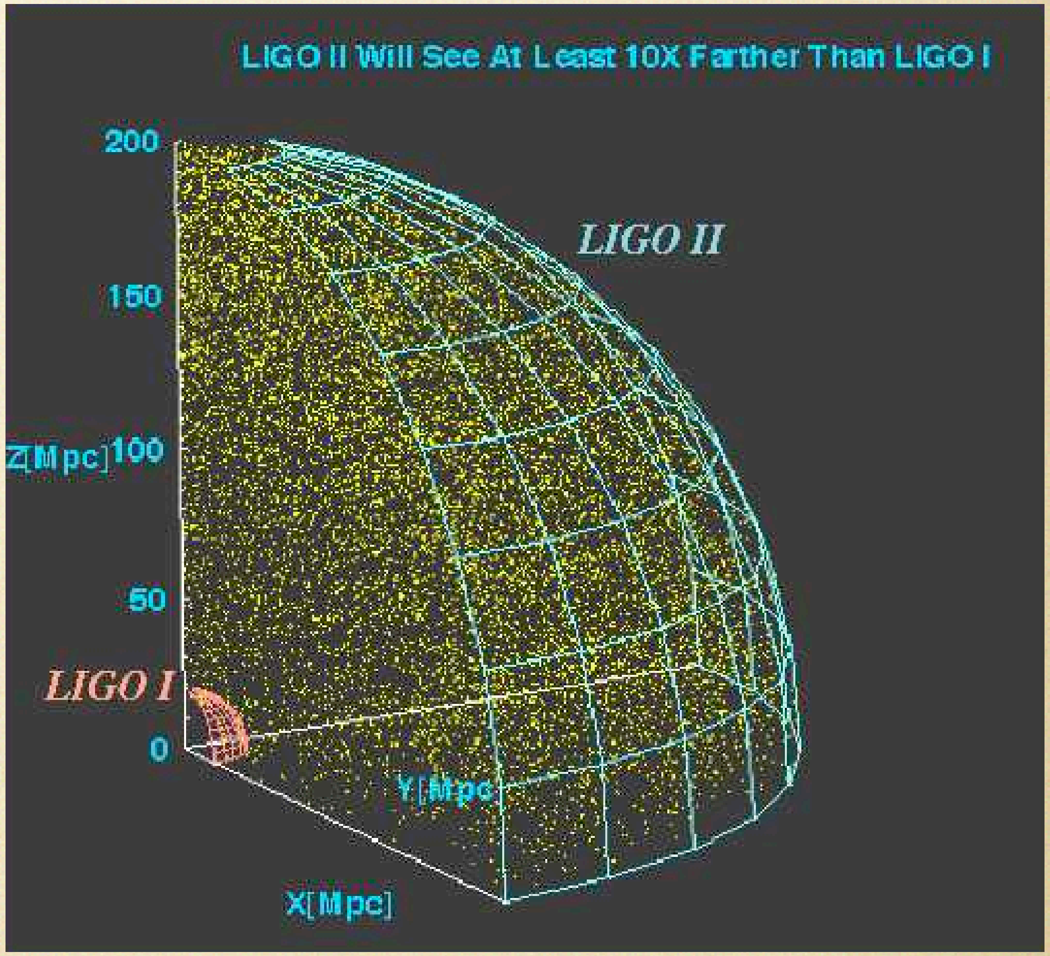
More results

- Most cosmological theories predict the emission of gravitational waves which would detected now as a more or less isotropic background.
- The signal, which is related to the energy density spectrum ($\Omega_{gw}[f]$)) can be searched from cross-correlations in different pairs of detectors: H1-L1 and H2-L1 Bayesian 90%
- S4 UL: $\Omega_{90\%} = 6.5 \times 10^{-5}$ (51-150 Hz)



The future (2014): Advanced LIGO

- NSB to 200-350 Mpc.
- BHB to 100 Mpc.
- 10x better amplitude sensitivity
- 1 year of initial LIGO will be 1 day of Ad. LIGO



From B. Allen