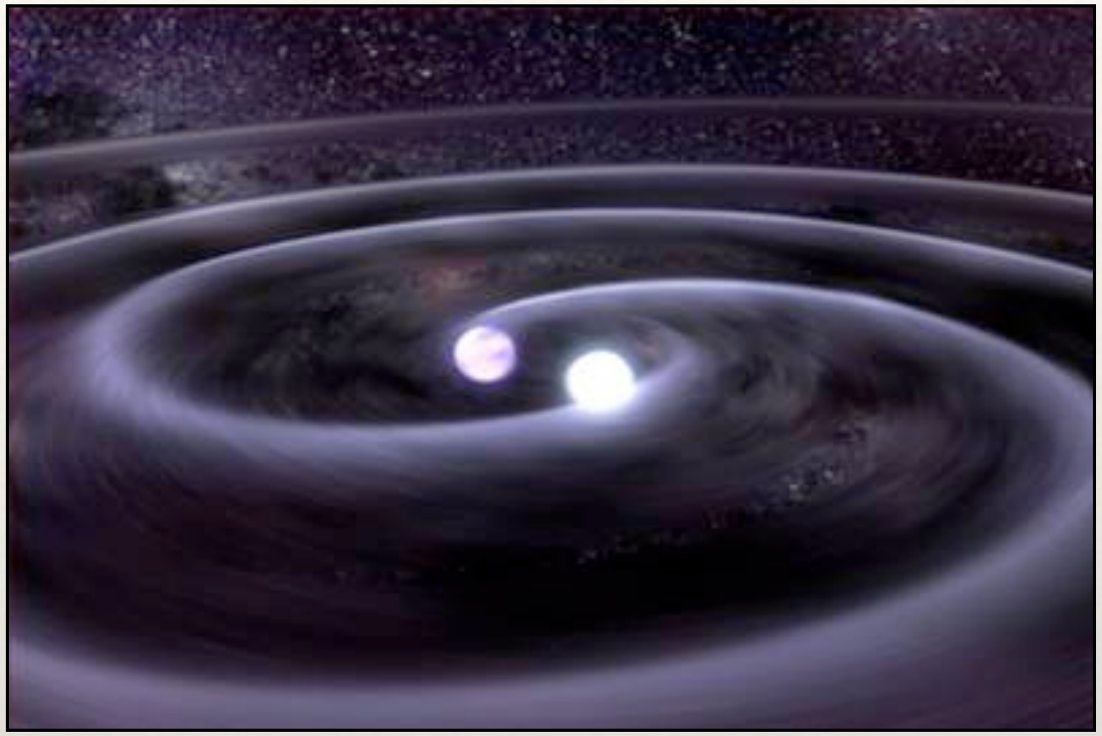
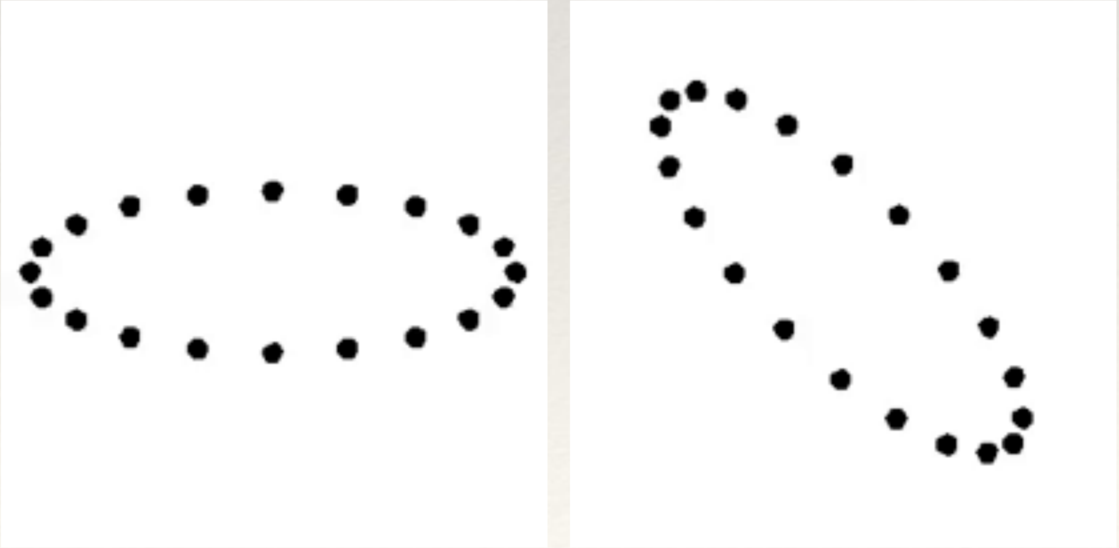
Future directions in gravitational physics

Stephen Fairhurst
Cardiff University

Gravitational Waves

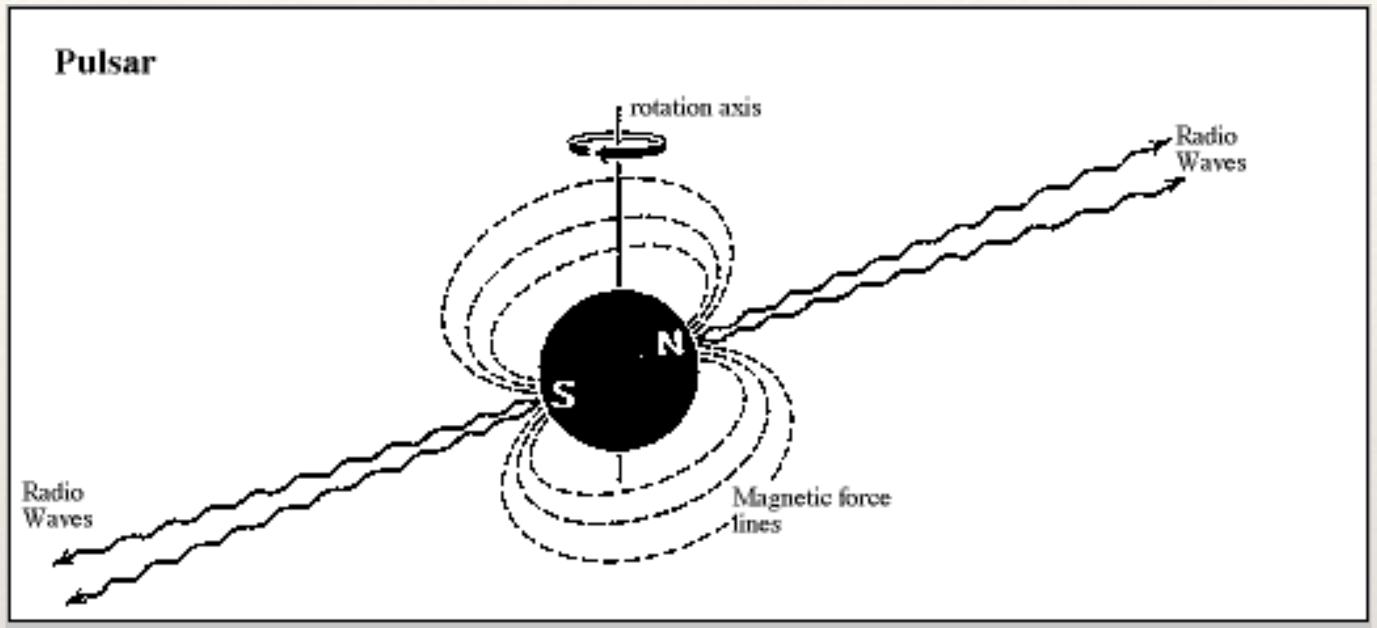


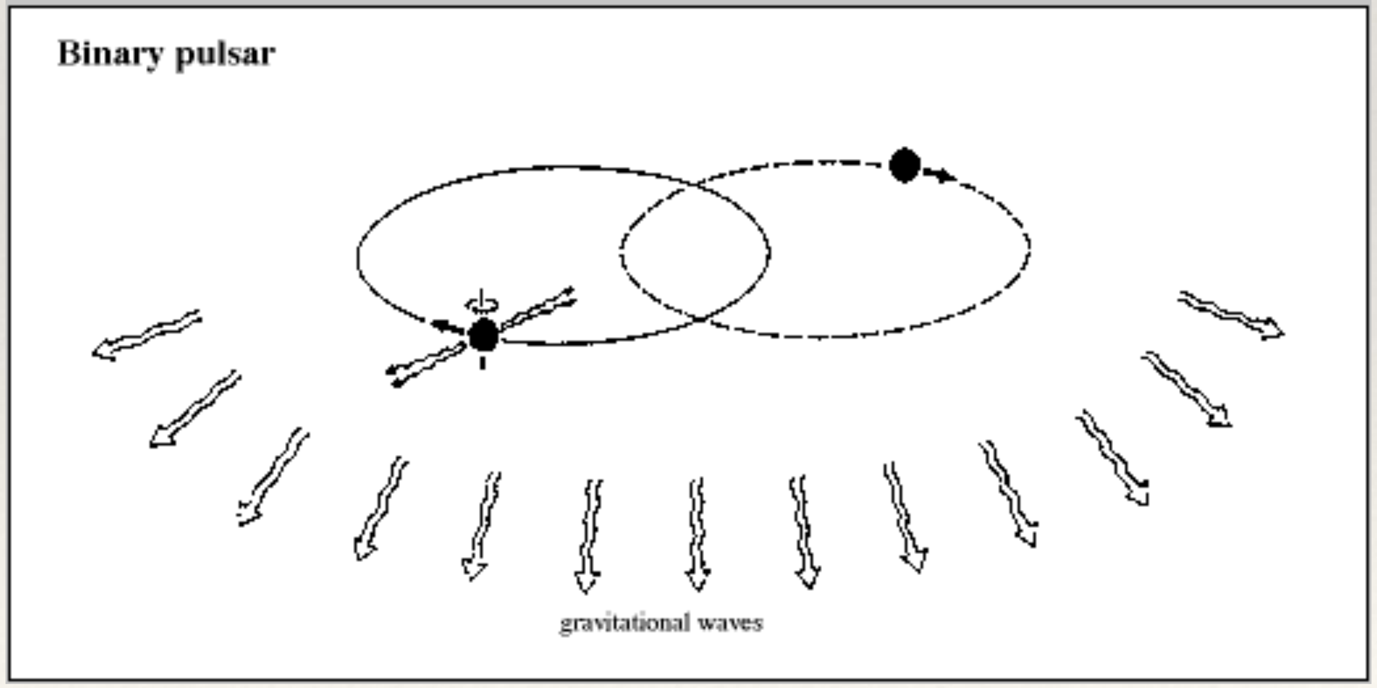
- Gravitational waves are a feature of Einstein's general theory of relativity
- Accelerating mass emits gravitational waves
- "Ripples in space-time" propagate away from source at the speed of light



Evidence for Gravitational Waves

- PSR 1913+16 found by Hulse and Taylor in 1974
- It is part of a binary system and the companion is also a neutron star
- Measuring pulse arrival time gives precise measurement of orbital period





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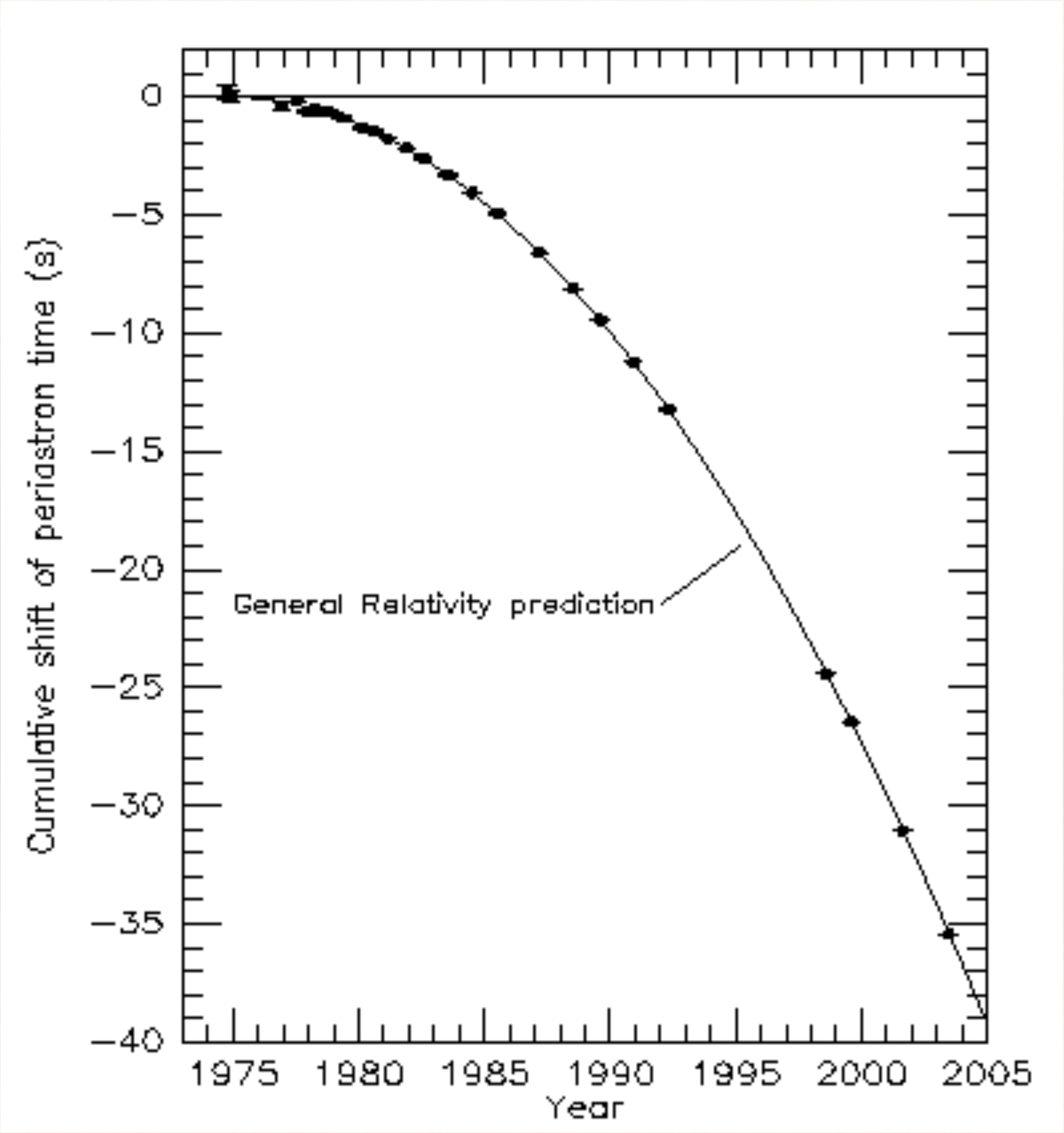
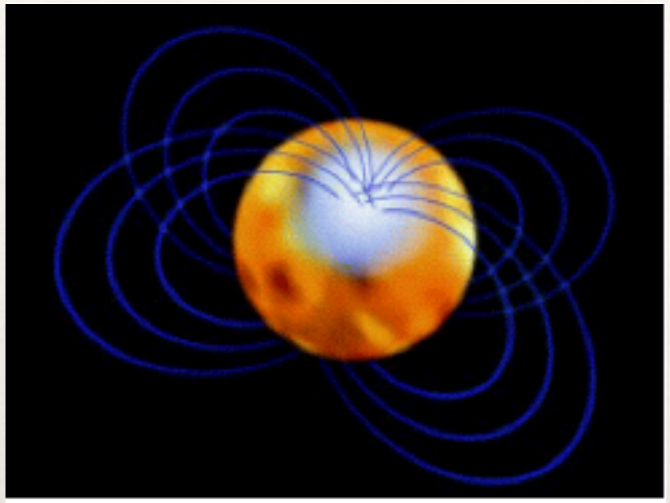
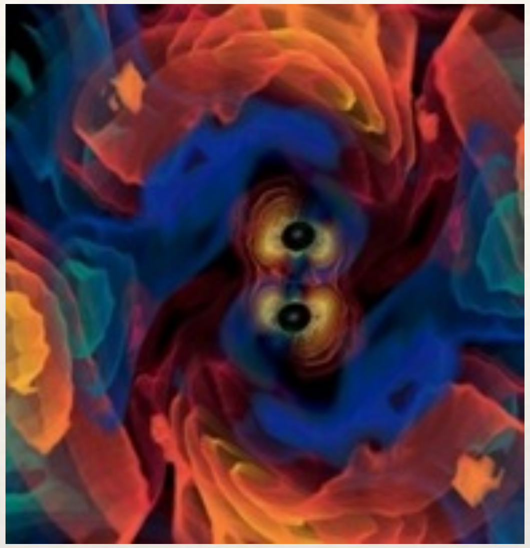


From Weisberg & Taylor (2004)

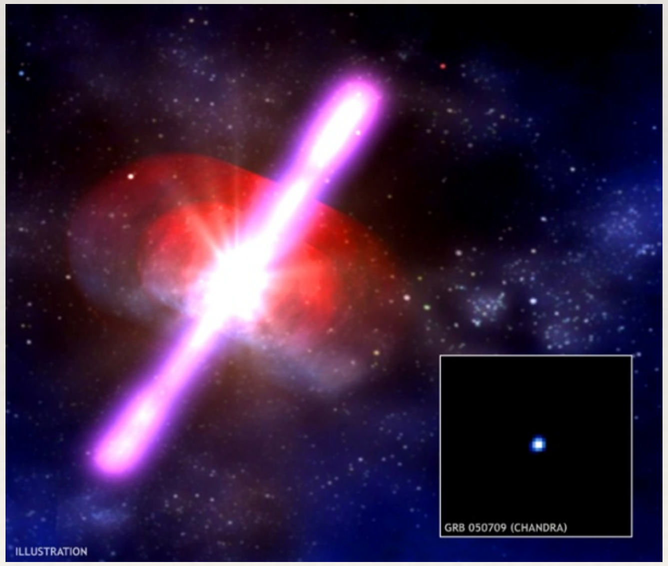
Sources of Gravitational Waves



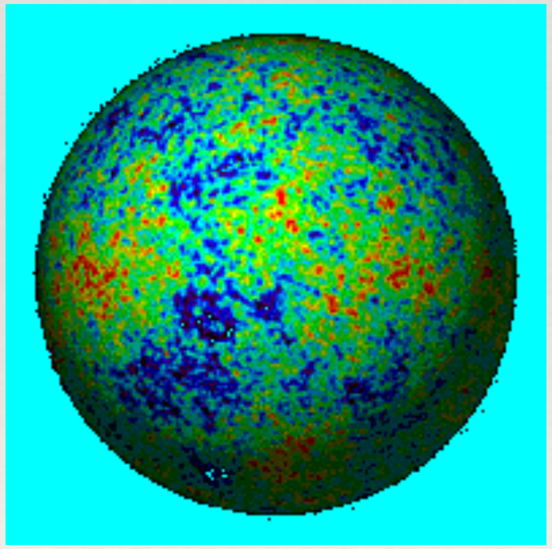
Continuous Waves:
Spinning Neutron Stars



Coalescing Binaries:
Merging black holes and neutron stars



Short Bursts:
Supernovae,
Gamma Ray Bursts



Stochastic Sources:
GW from the Big Bang

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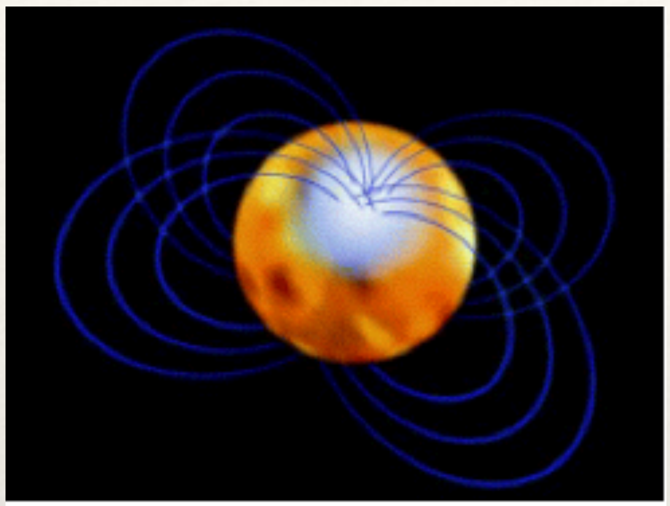

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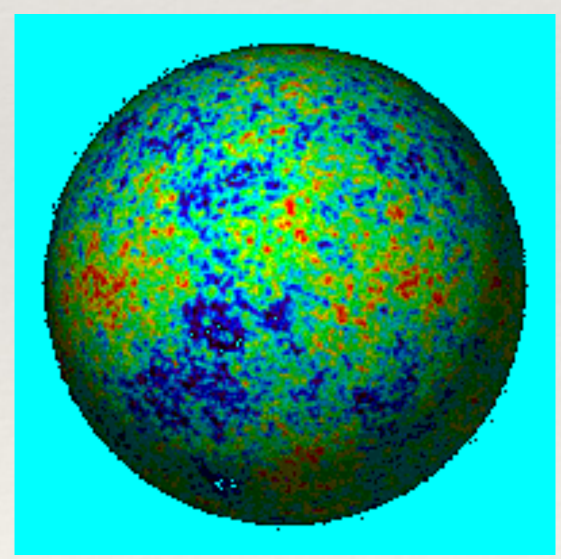

Stochastic Sources:
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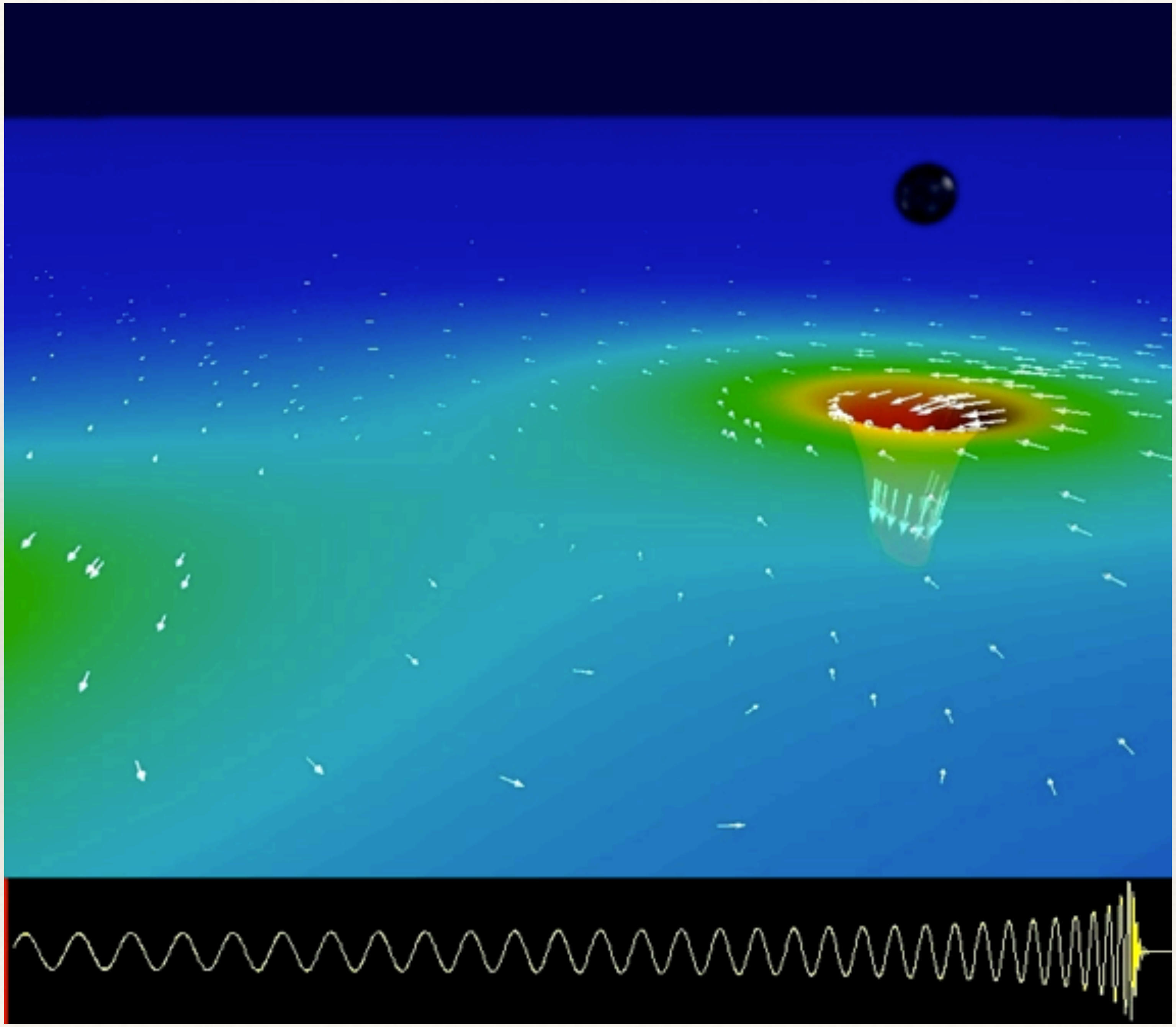
Modelling black hole collisions

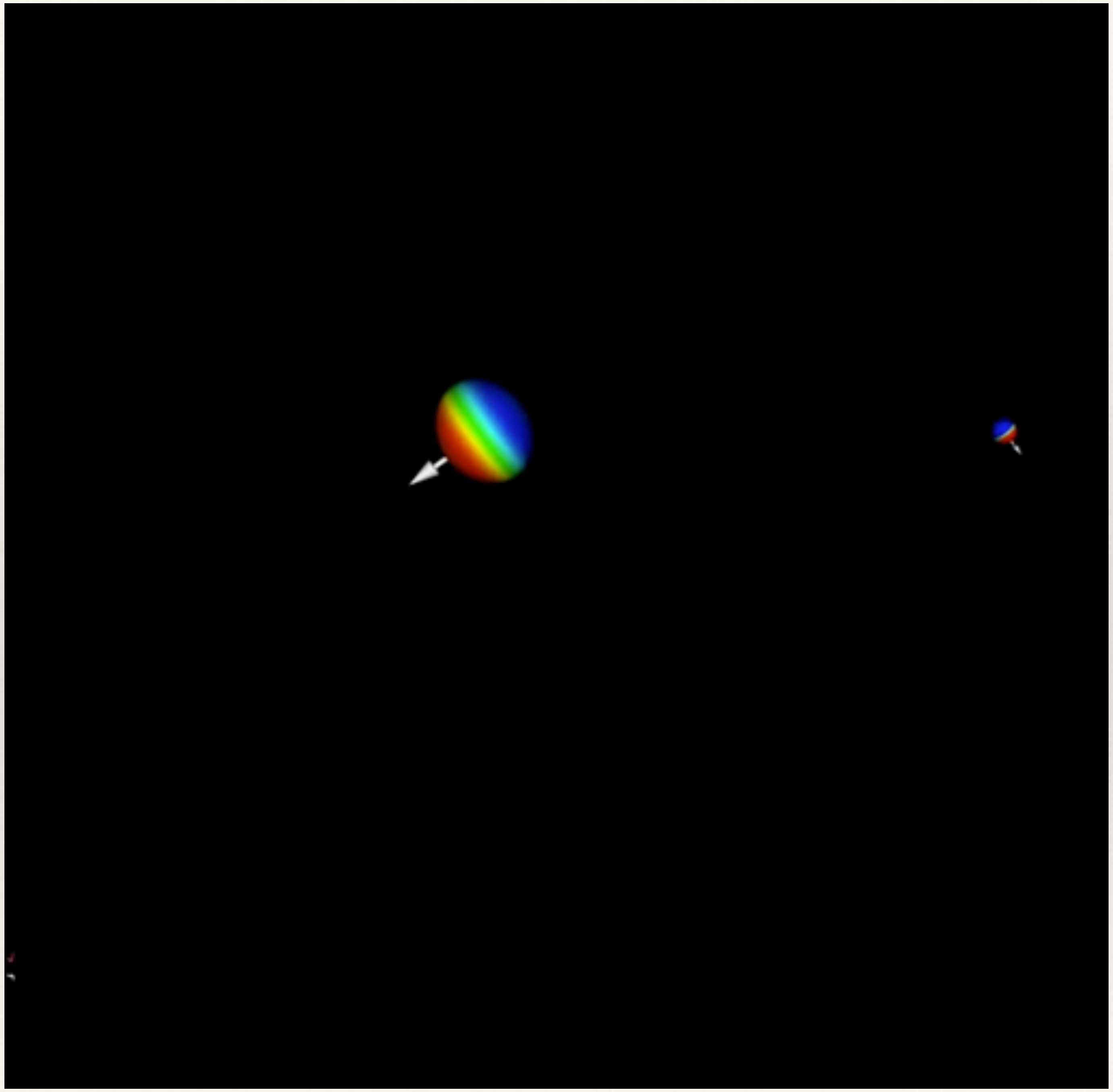
- When black holes are far apart, calculate waveforms analytically
- Close to merger, need to solve non-linear Einstein equations numerically
- Calculate binary evolution and gravitational wave emission



Simulations of Extreme Spacetimes (black-holes.org)

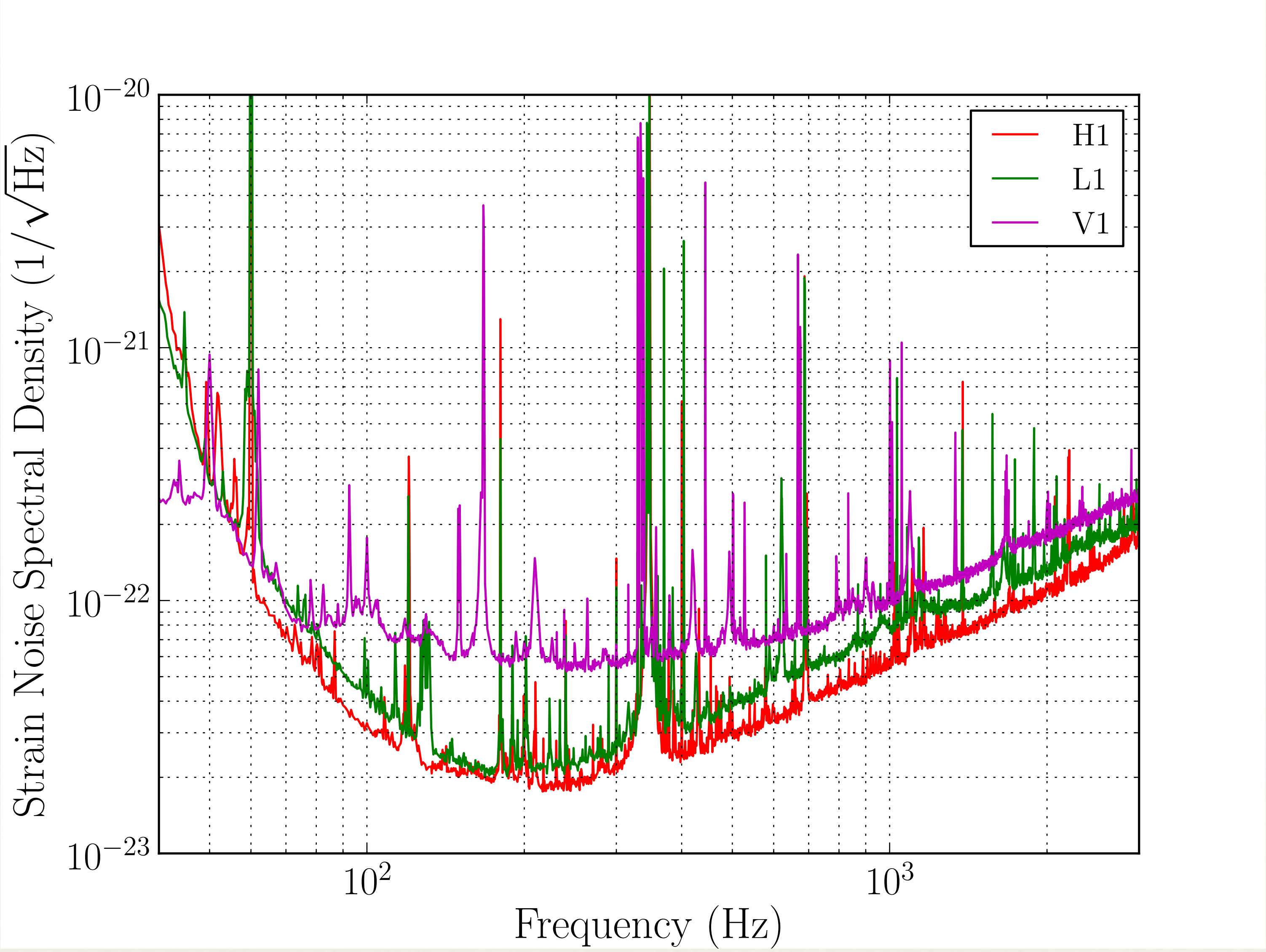
Future Challenges

- Black hole spins complicate matters: cause system to precess
- Naive coverage of parameter space would require ~10,000 simulations
- Typical simulation takes a month on 256 cores



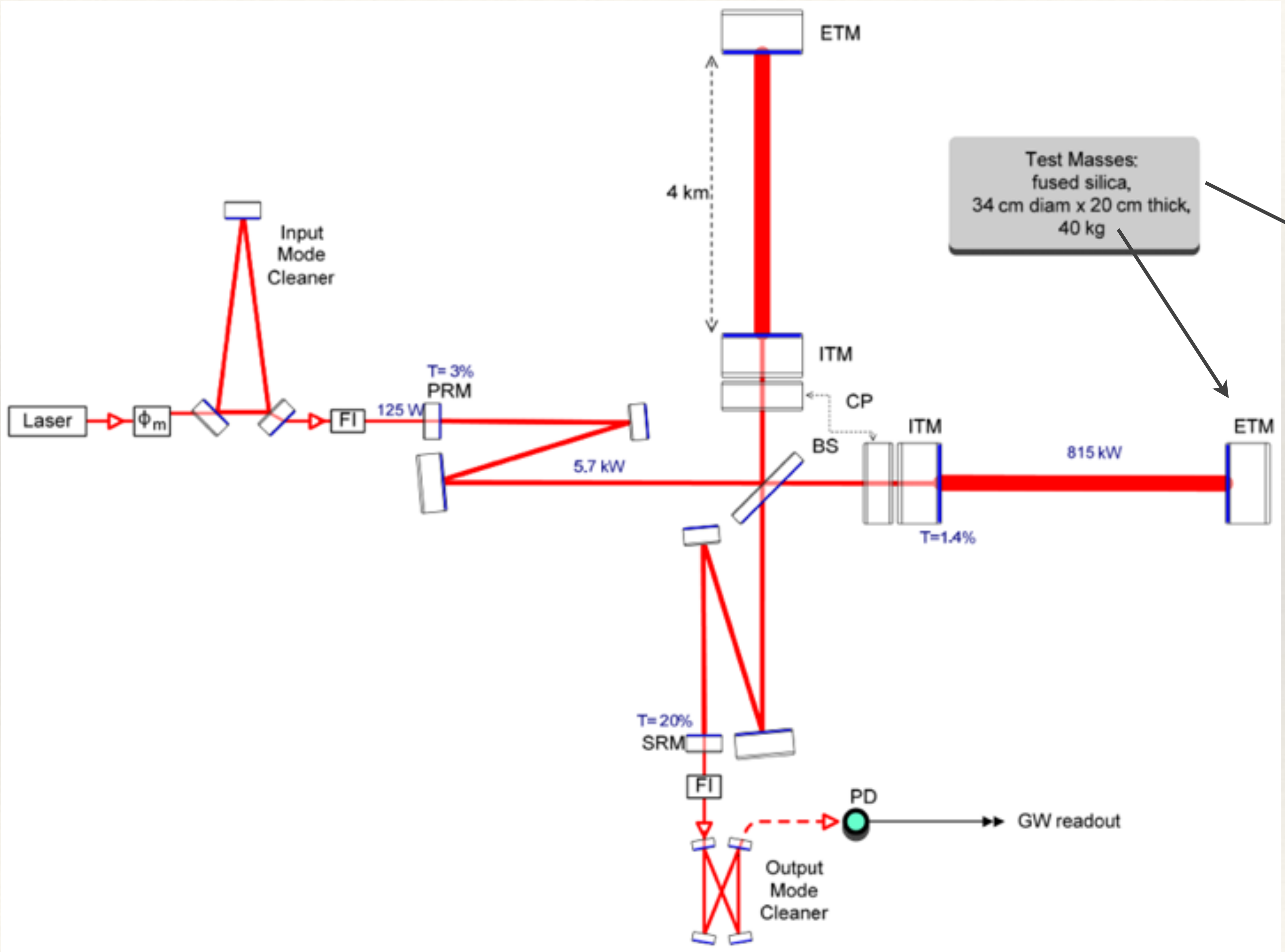
Simulations of Extreme Spacetimes (black-holes.org)

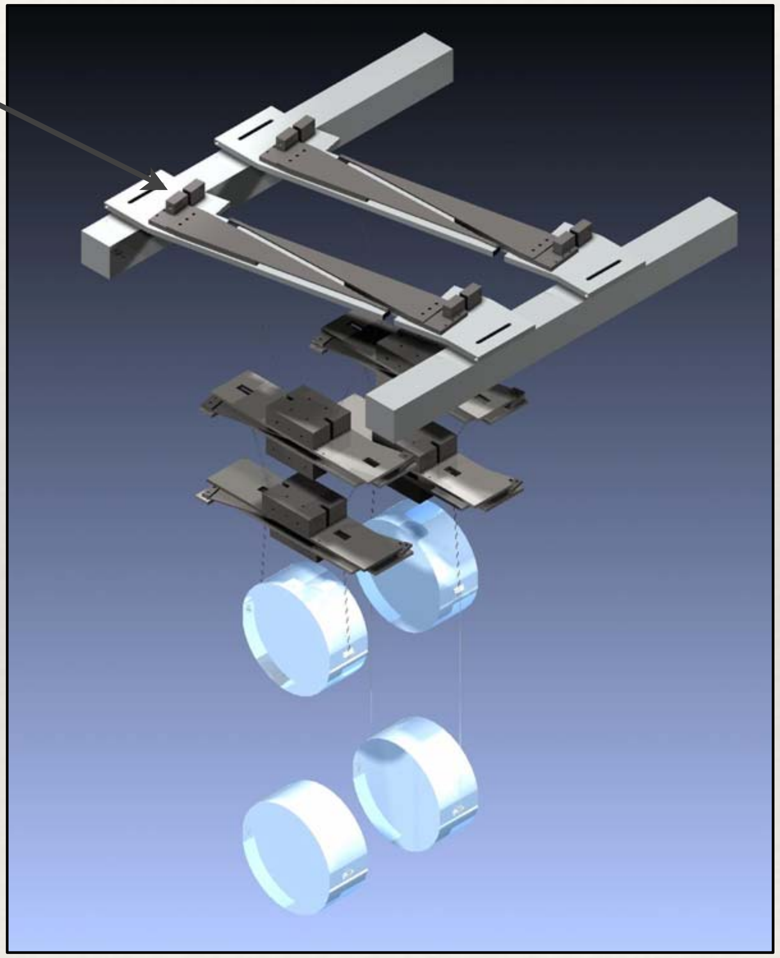
The detectors



From Abadie et al, PRD (2012)

Advanced LIGO Detector



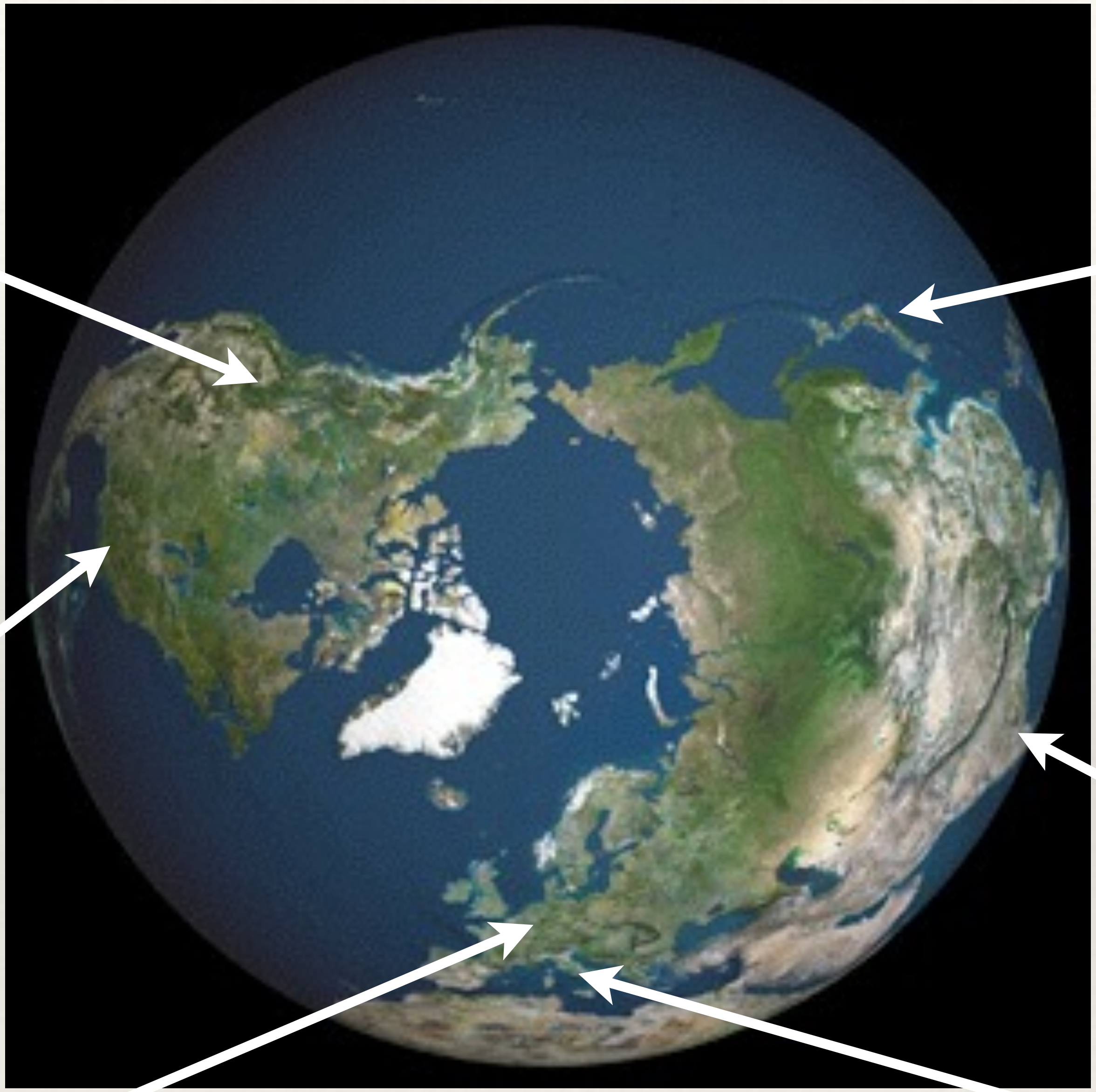


From Harry et al, CQG (2010)

A global network

LIGO Hanford, USA

LIGO Livingston, USA



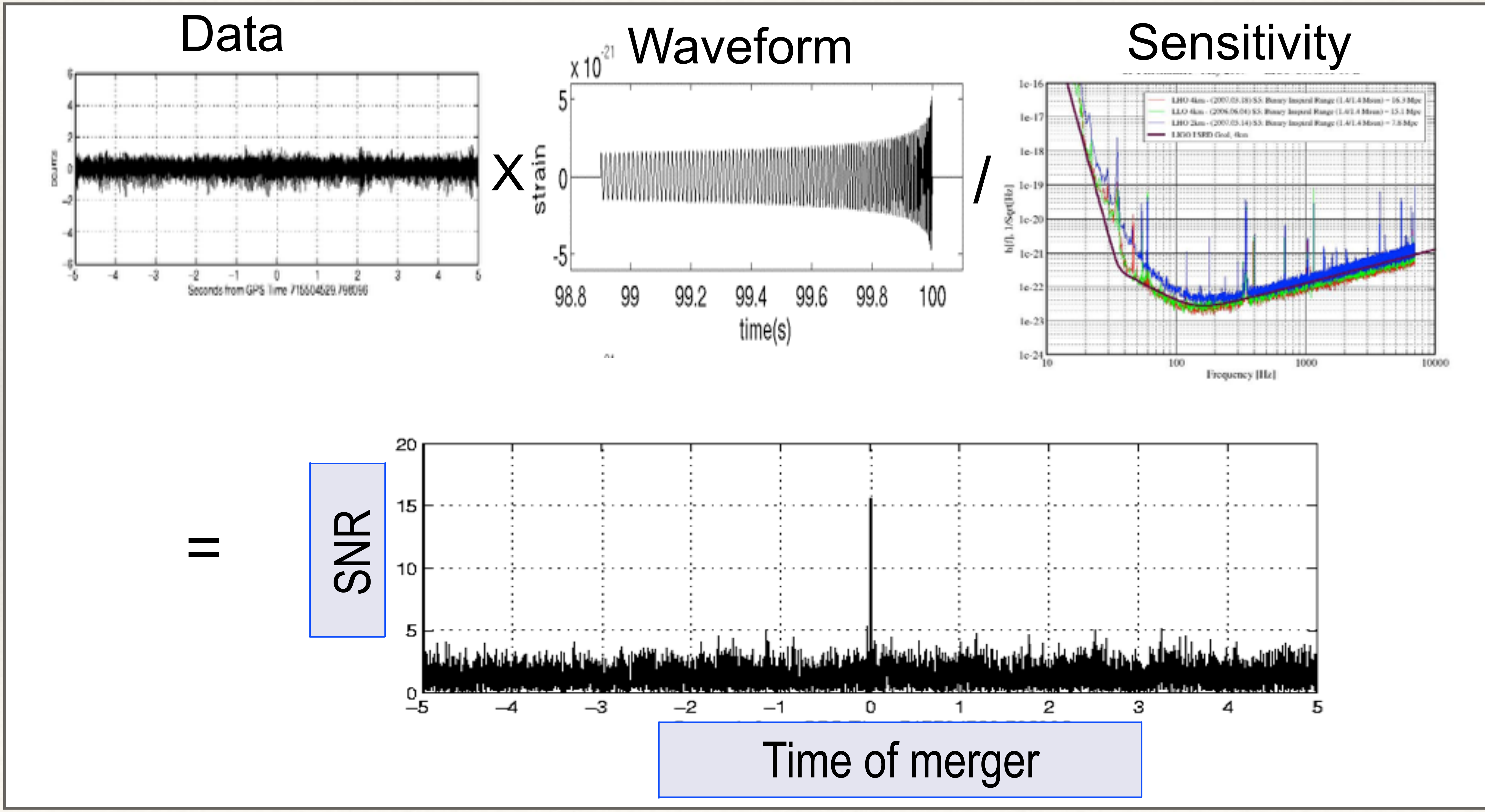
Japan

LIGO India

GEO 600, Germany

Virgo, Italy

Searching for gravitational waves



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"BLIND INJECTION" STRESS-TESTS LIGO AND VIRGO'S SEARCH FOR GRAVITATIONAL WAVES

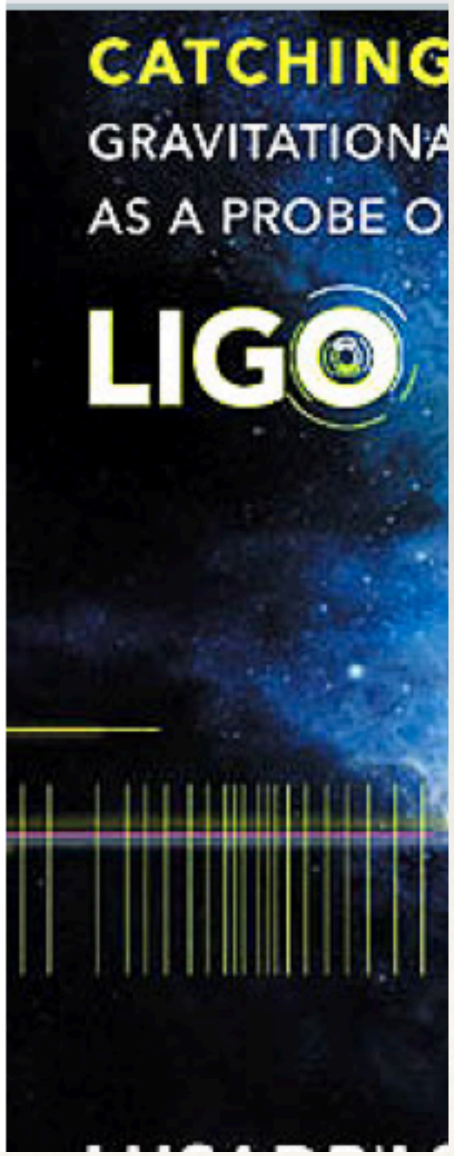
The LIGO Scientific Collaboration and the Virgo Collaboration completed an end-to-end system test of their detection capabilities at their recent joint collaboration meeting in Arcadia, CA. Analysis of data from LIGO and Virgo's most recent observation run revealed evidence of the elusive signal from a neutron star spiraling into a black hole. Shortly after the collaboration approved a scientific paper reporting the ground-breaking "discovery", LIGO and Virgo management revealed that the signal was a "blind injection" --- a fake signal secretly added to the data to test the detector and analysis.

While the scientists were disappointed that the discovery was not real (they knew that it could be a blind injection), the success of the analysis was a compelling demonstration of the collaboration's readiness to detect gravitational waves. LIGO and Virgo scientists are looking forward to observations with the advanced detectors which are expected to contain many real signals from the distant reaches of the universe.

GRAVITATIONAL WAVES:

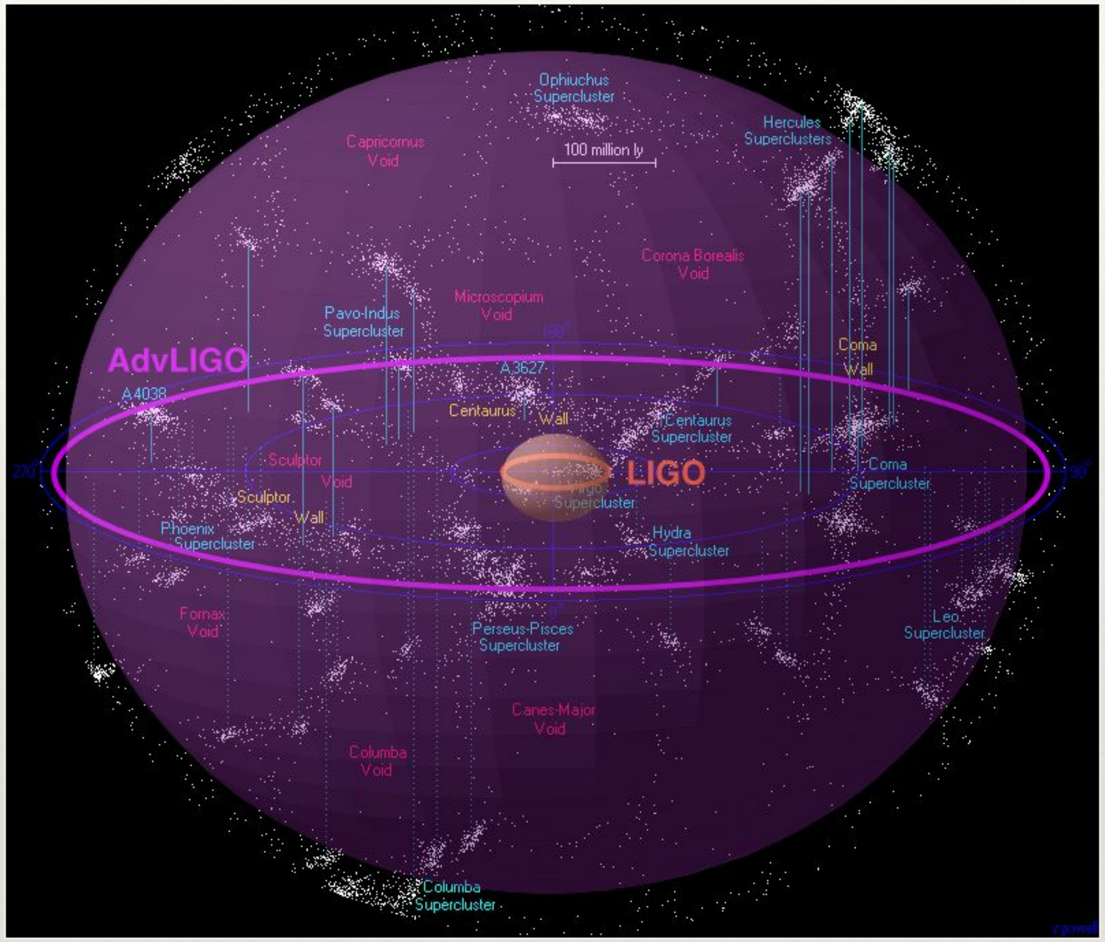
There's a lot at stake here. Gravitational waves, a firm prediction of Einstein's General Theory of Relativity, have never been directly detected, although there is convincing indirect evidence for their existence from precise timing of the orbits of binary pulsars in the Galaxy. The direct detection of these waves through the tiny distortions of space-time that they produce when they arrive at Earth from distant astrophysical sources would be a major scientific milestone, and would open up the new field of gravitational-wave astronomy.

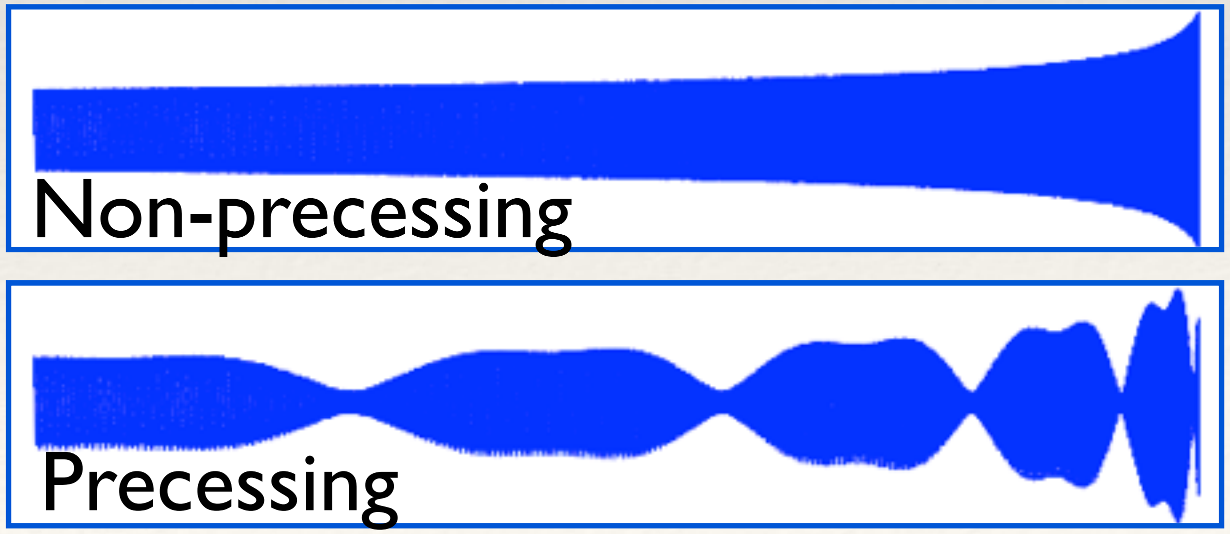
CATCH TH



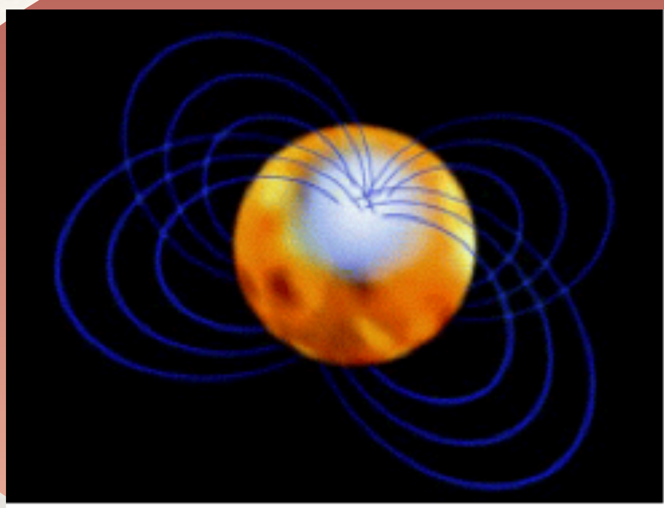
Future challenges

- Advanced detectors will have ten fold increase in sensitivity, expect to make first observations
- Need to search months or years of data using ~10,000 template waveforms for early runs (2015-16)
- Increases to millions of waveforms at final sensitivity (~2019), incorporating spin and precession effects
- Data is full of noise transients ("glitches") that can mask signals





Sources of Gravitational Waves



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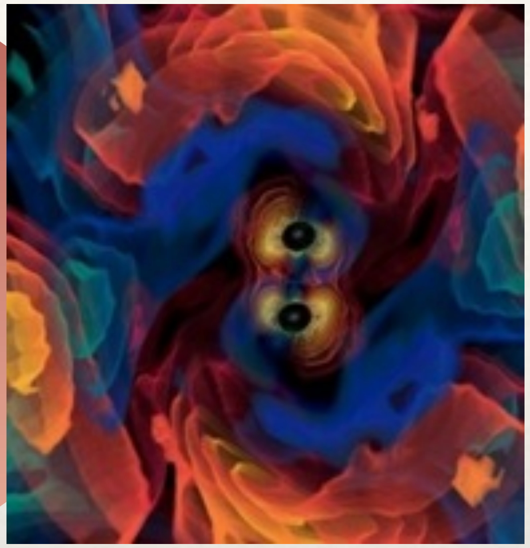

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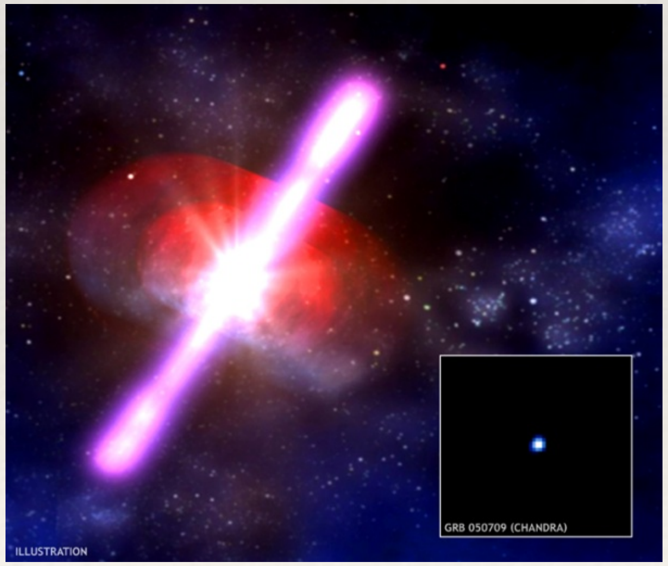

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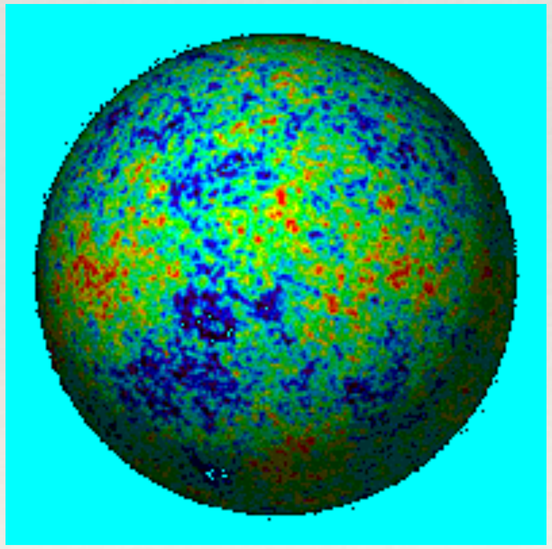

Stochastic Sources:
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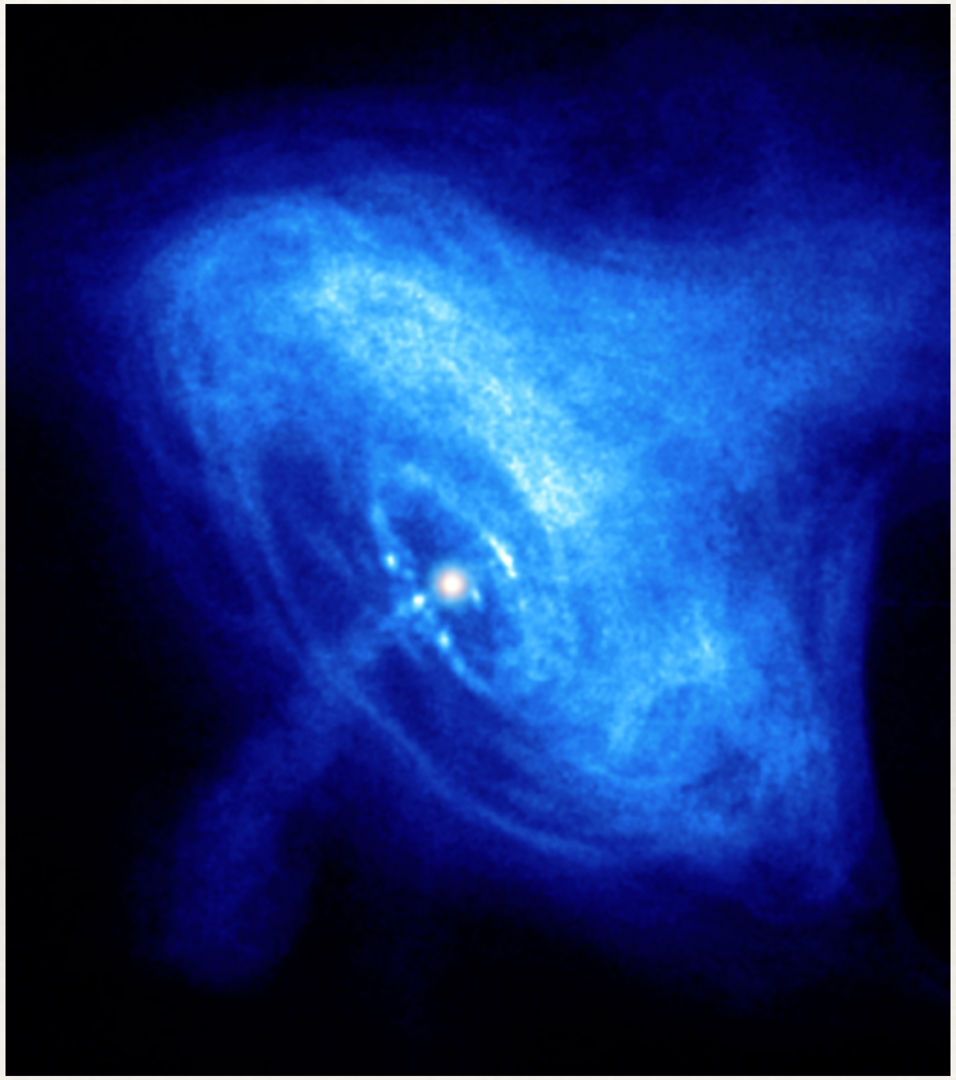
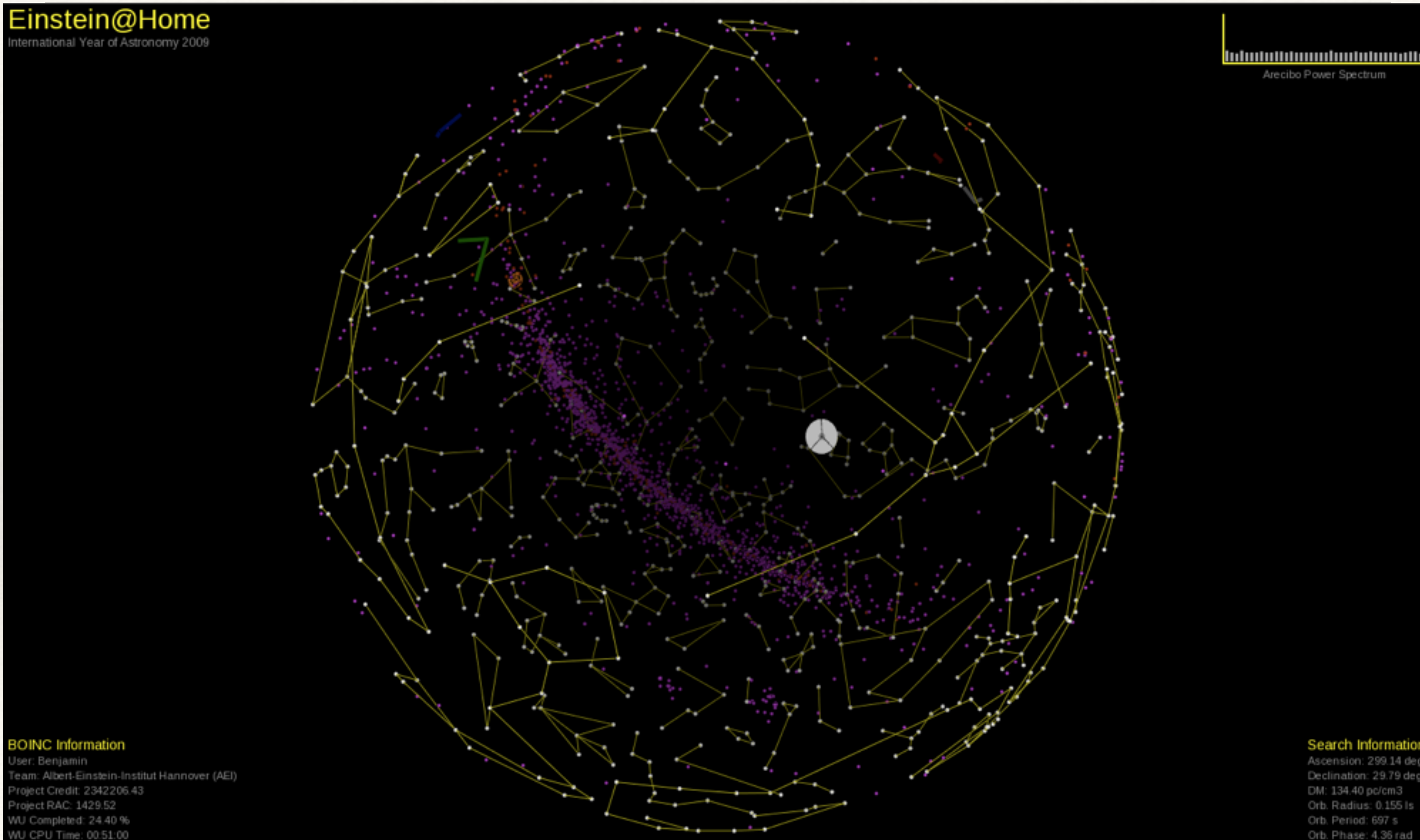
Spinning Neutron Stars

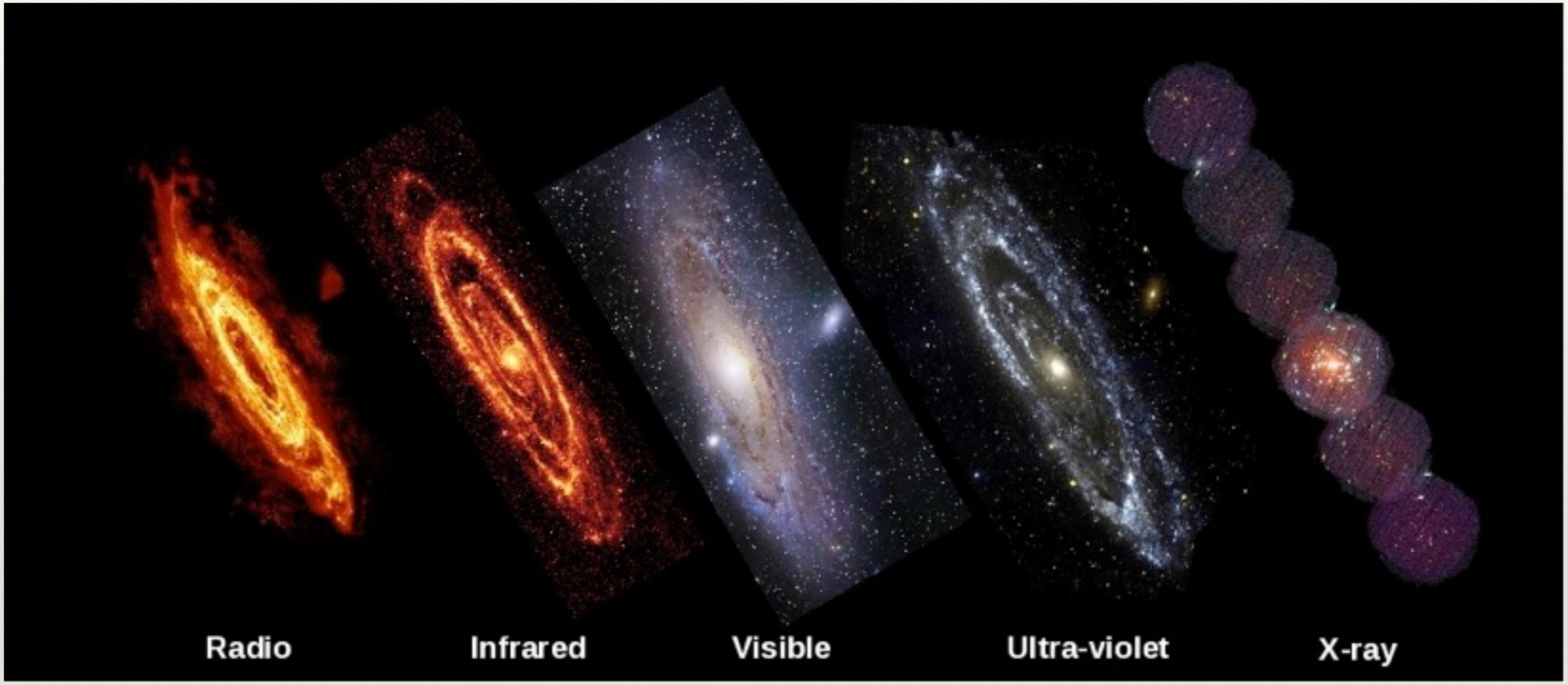
- Small "mountain" on a spinning neutron star gives a continuous gravitational wave signal
- Motion of earth modulates signal frequency
- Fully coherent search requires more computing than available



Einstein@Home



The payoff



- New insights provided by "multi-wavelength" astronomy
- Gravitational wave observations will provide "multi-messenger" astronomy