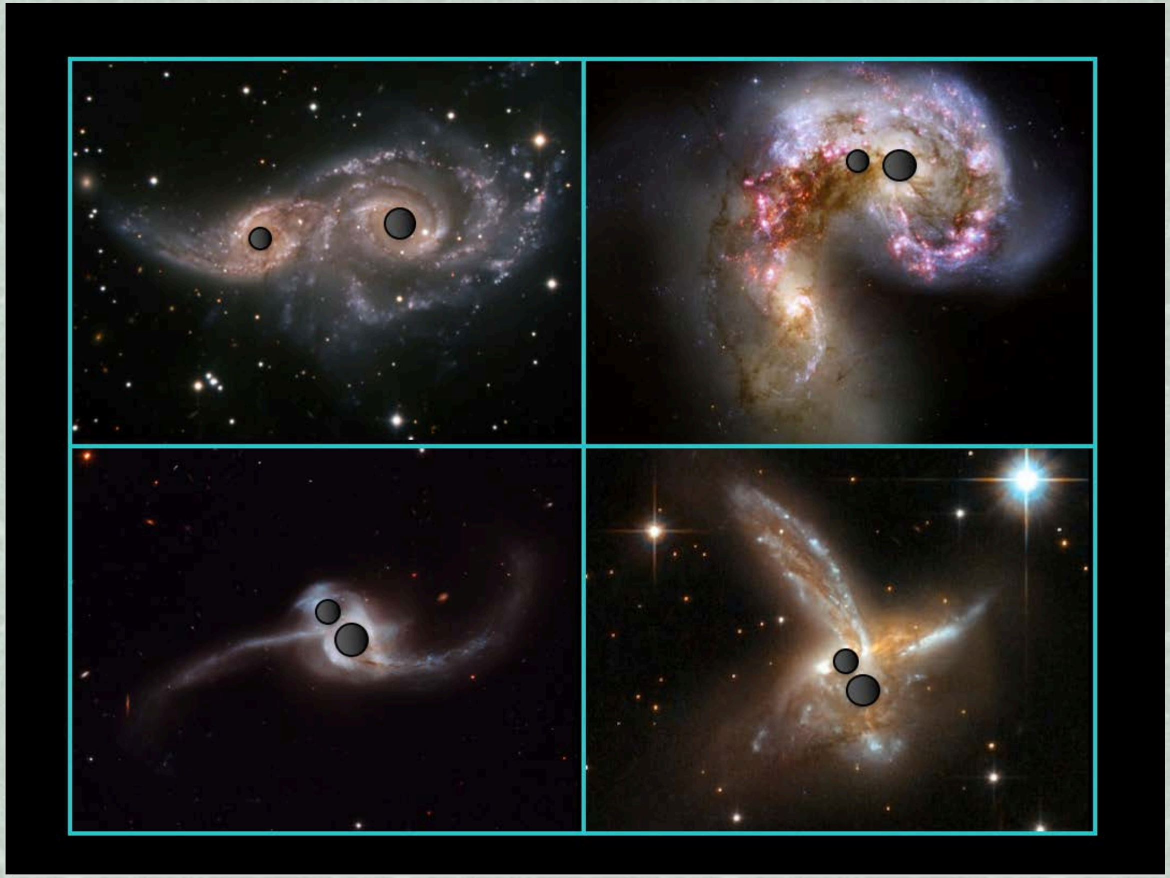
NANOGrav
Physics Frontiers Center

Measuring the Ripples from Galaxy Collisions



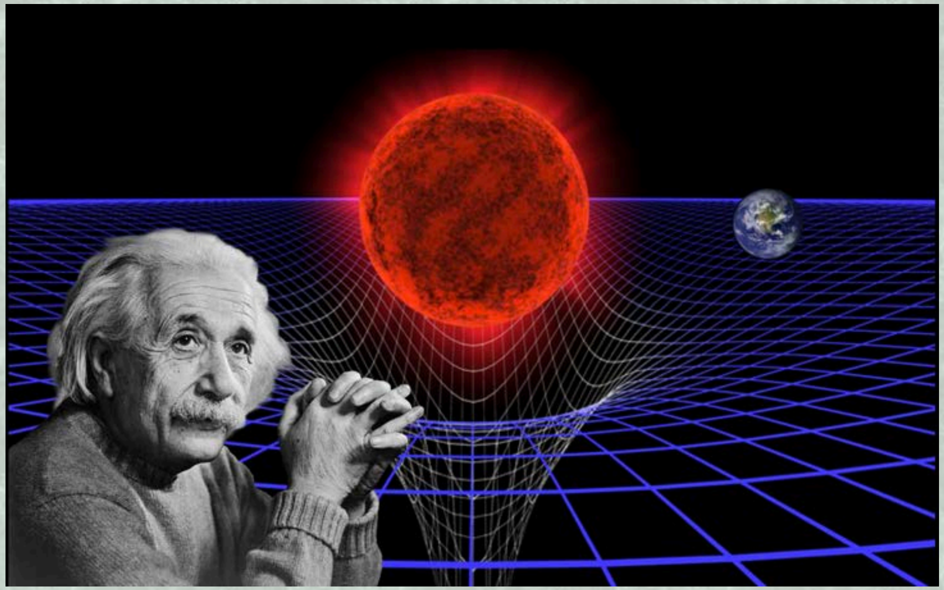
Topic: Gravitational Waves and Pulsar Timing

Concepts: General Relativity, Compact Objects

Coordinated By: The NANOGrav Education and Public Outreach Team

Gravitational Waves – “Listening” to the Universe

- Gravitational Waves (GW) are a way of observing the Universe without electromagnetic phenomena (i.e. light, telescopes).
- These waves are a direct consequence of Einstein’s Theory of General Relativity which says accelerating masses will generate ripples in the fabric of spacetime.
- GW propagation stretches and shrinks the space around it. Therefore relative distance between objects that GW pass through changes.



Recipe for Gravitational Waves

Ingredients:

(i) Matter (or Energy -- they are equivalent, after all)

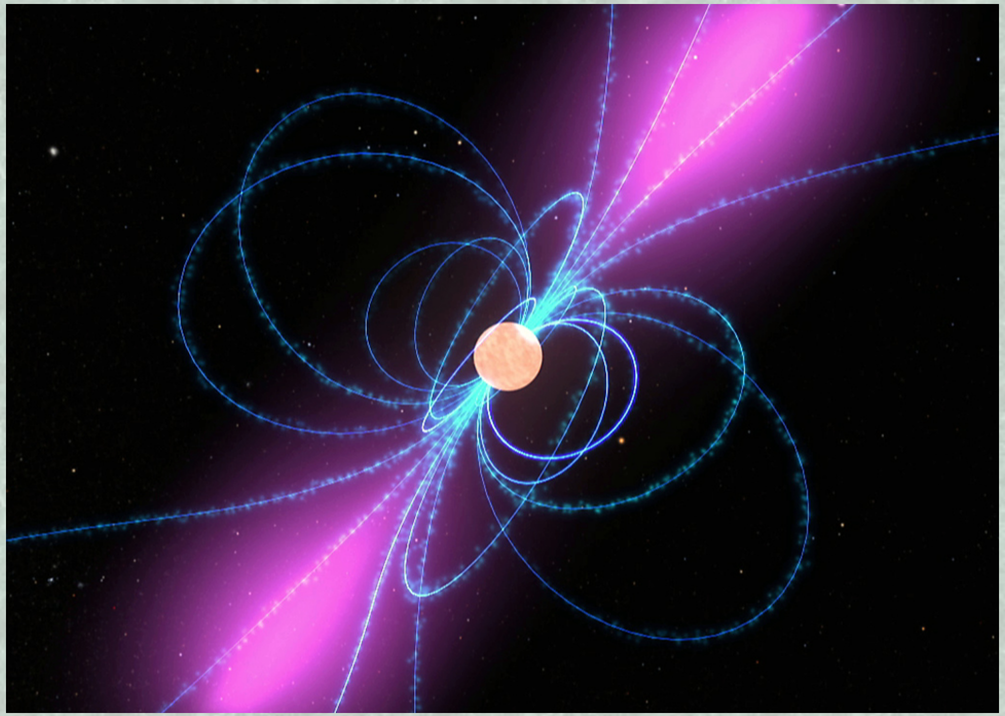
Directions:

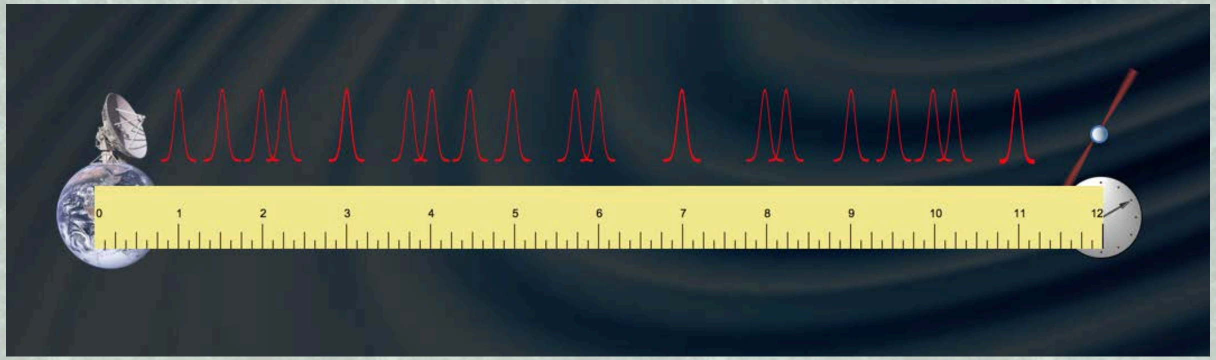
(i) Compress matter into high-density lump.

One lump is OK, two works better.

(ii) Shake/Stir the lump(s)

Pulsar Timing





- Pulsars are neutron stars that emit light from jets at regular predictable intervals. Periodicity in the pulses allow us to determine expected arrival times for pulses.
- Since GW change the distance between objects, they can be detected through changes in distances to pulsars by differences in arrival times of the pulses.
- North American Nanohertz Observatory for GW (NANOGrav) monitors a network of radio-frequency emitting pulsars to search for GW.

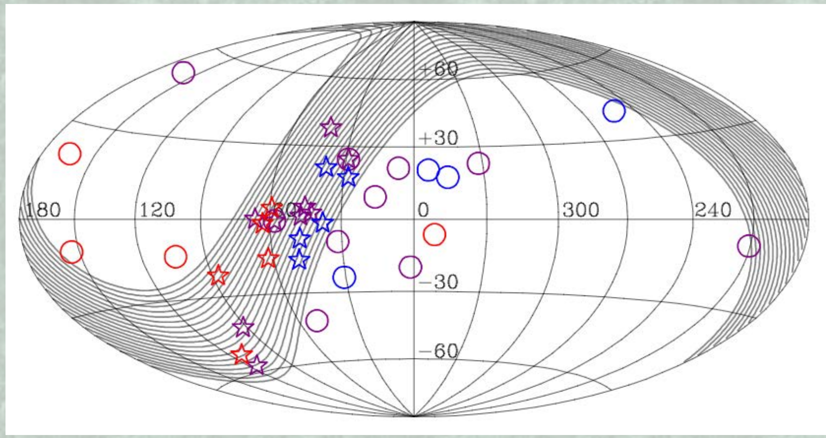
NANOGrav

- Collaboration of hundreds of scientists from institutions throughout the US and Canada, working together to detect low-frequency gravitational waves by timing an array of millisecond pulsars.
- Two radio observatories are used to study the pulsar light curves in Arecibo Observatory in Puerto Rico and the Green Bank Telescope at Green Bank Observatory (GBO) in Green Bank, WV.

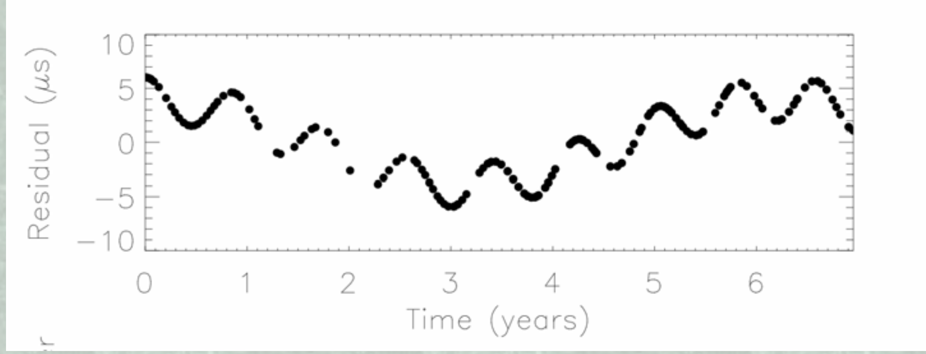
Arecibo image credit: NAIC
Green Bank Image Credit: NRAO

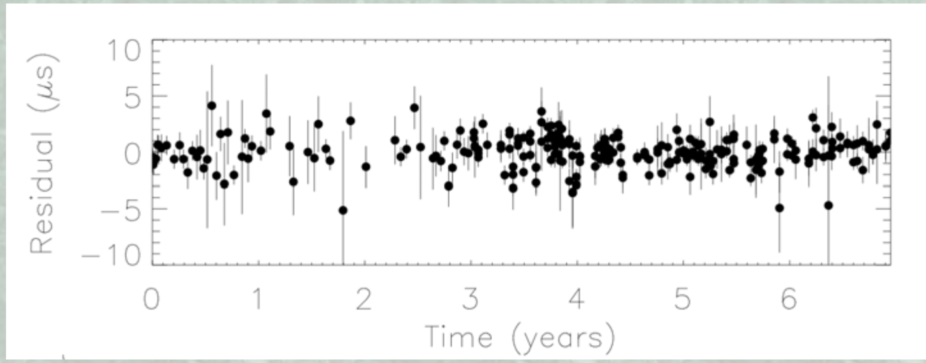
NANOGrav and PTAs

- "NANO" also stands for *nano*hertz, the detectable GW frequency range for pulsar timing arrays (PTA).
- The top image shows the array of millisecond pulsars used in the pulsar timing array projected on a sky map as of 2013 (an example).
- The middle image shows the theoretical residual that would appear due to GW.
- The bottom image shows an example of how the pulsar data analysis is done. The expected light curve from the pulsar's periodic emission is subtracted leaving the residual, allowing scientists to analyze it for a GW signature.



McLaughlin, 2013

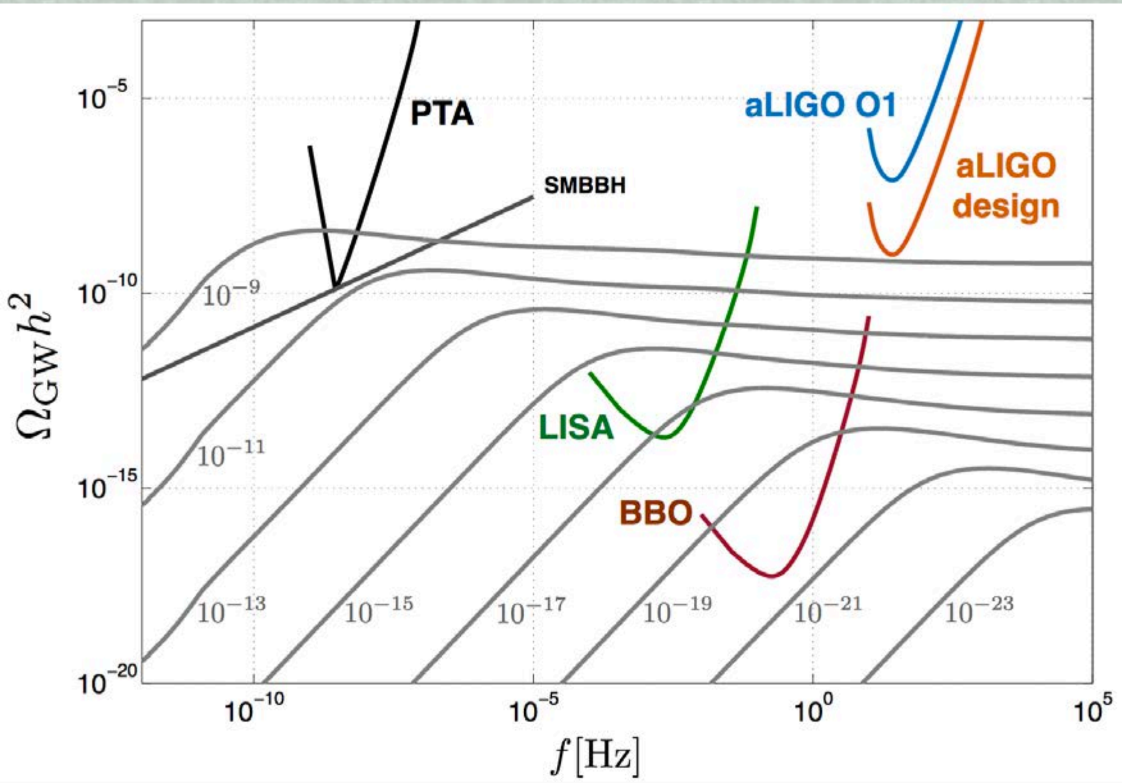




Jenet et. al 2003

What Can nHz GW Measure?

- Need most massive and compact objects to be detectable. But for long-period GW specifically, supermassive binary black holes and evidence for inflationary models in cosmology such as cosmic strings.



Blanco-Pillado et at. 2017