Gravitational Waves

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What are Gravitational Waves?

Linear Approximation

Albert Einstein in his general theory of relativity, showed that moving masses produce gravitational waves that are ripples in the curvature of space-time.

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Field equations of linearized general relativity.

Introducing slightly perturbed Minkowski metric.

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \quad (|h_{\mu\nu}| \ll 1)$$

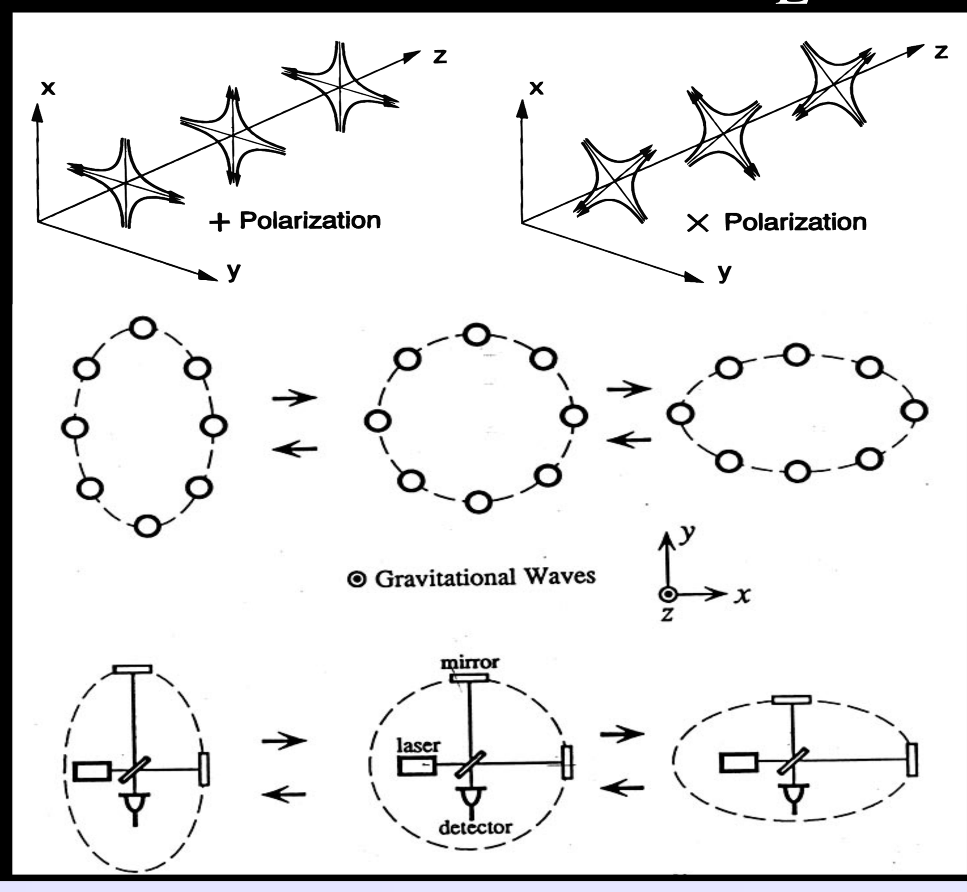
$$\Box h_{\mu\nu} = \left(-\frac{\partial^2}{\partial t^2} + \nabla^2\right) h_{\mu\nu} = -\frac{16\pi G}{c^4} T_{\mu\nu}$$

(= 0 in Vacuum)

$h_{\mu\nu}$ - Transverse plane wave propagating with speed of light.

Interferometer as GW Detector

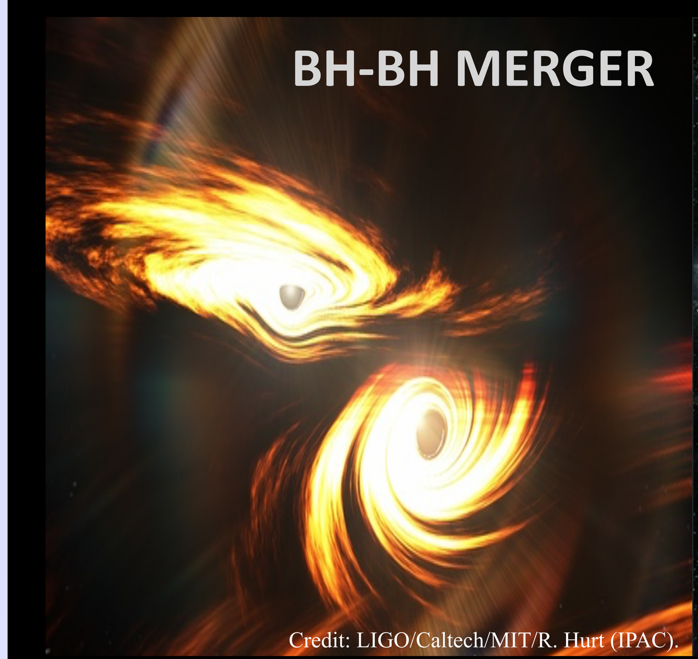
- GW as amplitude : $h(t) = \frac{\Delta L_x - \Delta L_y}{L}$



Astrophysical Sources of Gravitational Waves

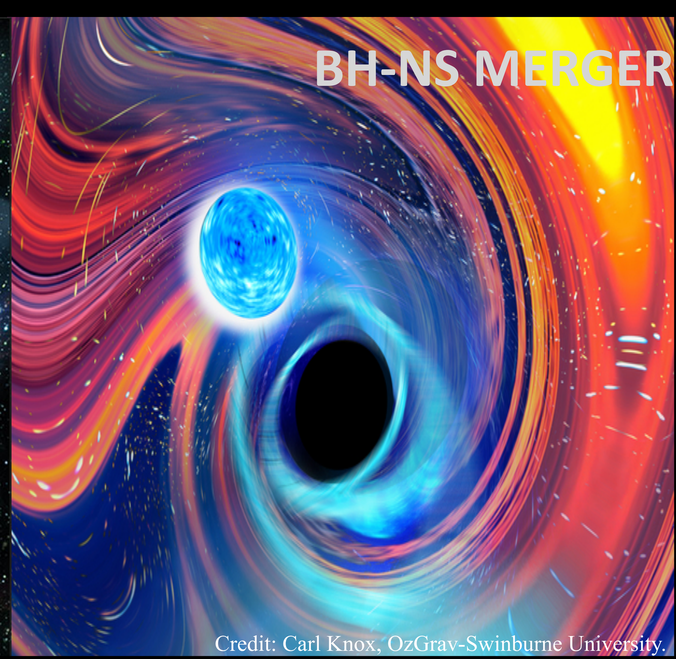
Coalescing Compact Binaries

Gravitational waves are generated during the end-of-life stage of binary systems, where two compact objects merge into one. The three subclasses of "compact binaries" are binary black holes, binary neutron stars, or neutron star-black hole binaries. The pairs of dense compact objects rotate around each other, emitting gravitational waves, which decreases their orbital distance. This causes the binary system to orbit each other faster, increasing the frequency of the gravitational waves until the moment of coalescence.



Credit: LIGO/Caltech/MIT/R. Hurt (IPAC)

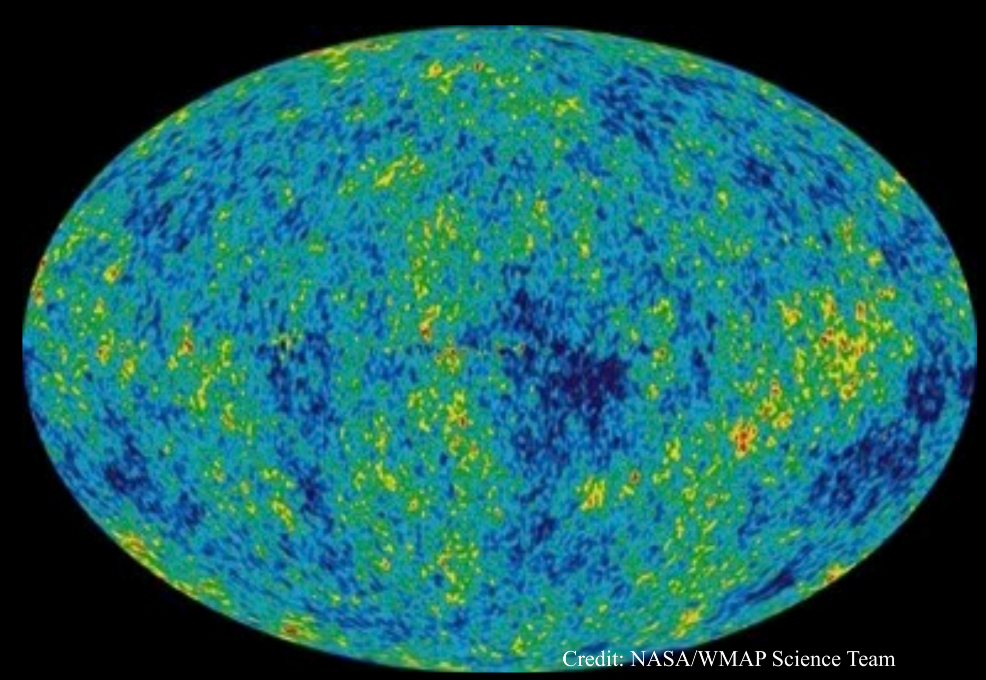
Credit: Dana Berry/Skyworks Digital, Inc./The Kavli Foundation.



Credit: Carl Knox, OzGrav-Swinburne University.

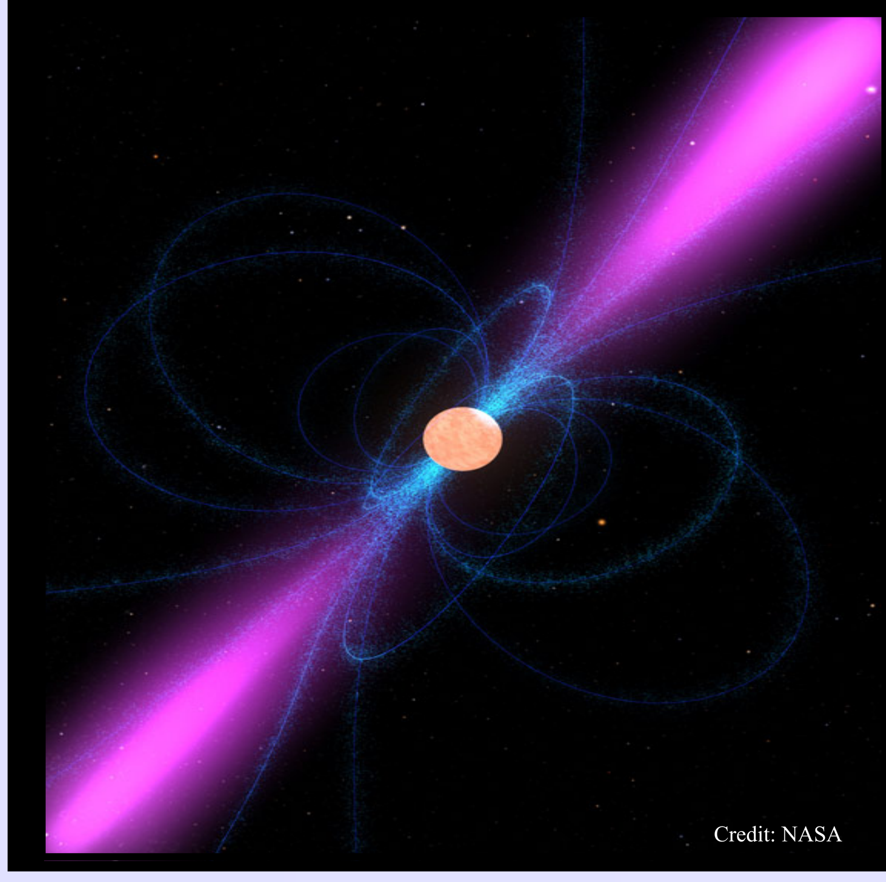
Stochastic Background

The stochastic background of gravitational waves arises from the superposition of a large number of random, independent sources. It is expected that the Big Bang may be a prime candidate for producing this stochastic signal, which may carry information about the origin and history of the Universe.



Credit: NASA/WMAP Science Team

Rotating Stars (Pulsars)



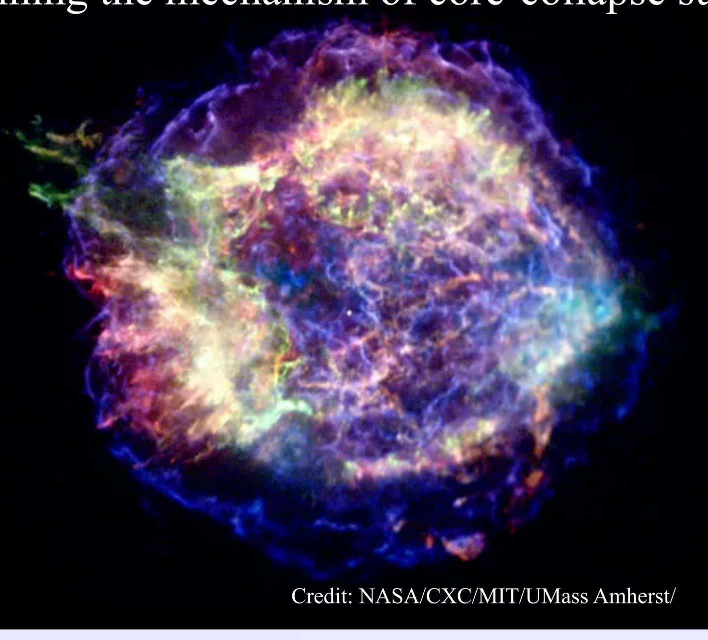
Credit: NASA

Rotating isolated neutron stars are known to show transient excitations measured by electromagnetic observations. These involve glitching pulsars and magnetar bursts. The glitches can emit short-duration transient gravitational wave signals as f-modes at frequencies between 1−3 kHz and damping times of less than a few seconds. There could be a population of isolated neutron stars in our galaxy which are not seen by telescopes, but can produce gravitational wave bursts of short duration.

Any bumps on or imperfections in the spherical shape of a spinning isolated neutron star will generate continuous gravitational waves with almost perfectly constant frequency and amplitude.

Supernova Explosions

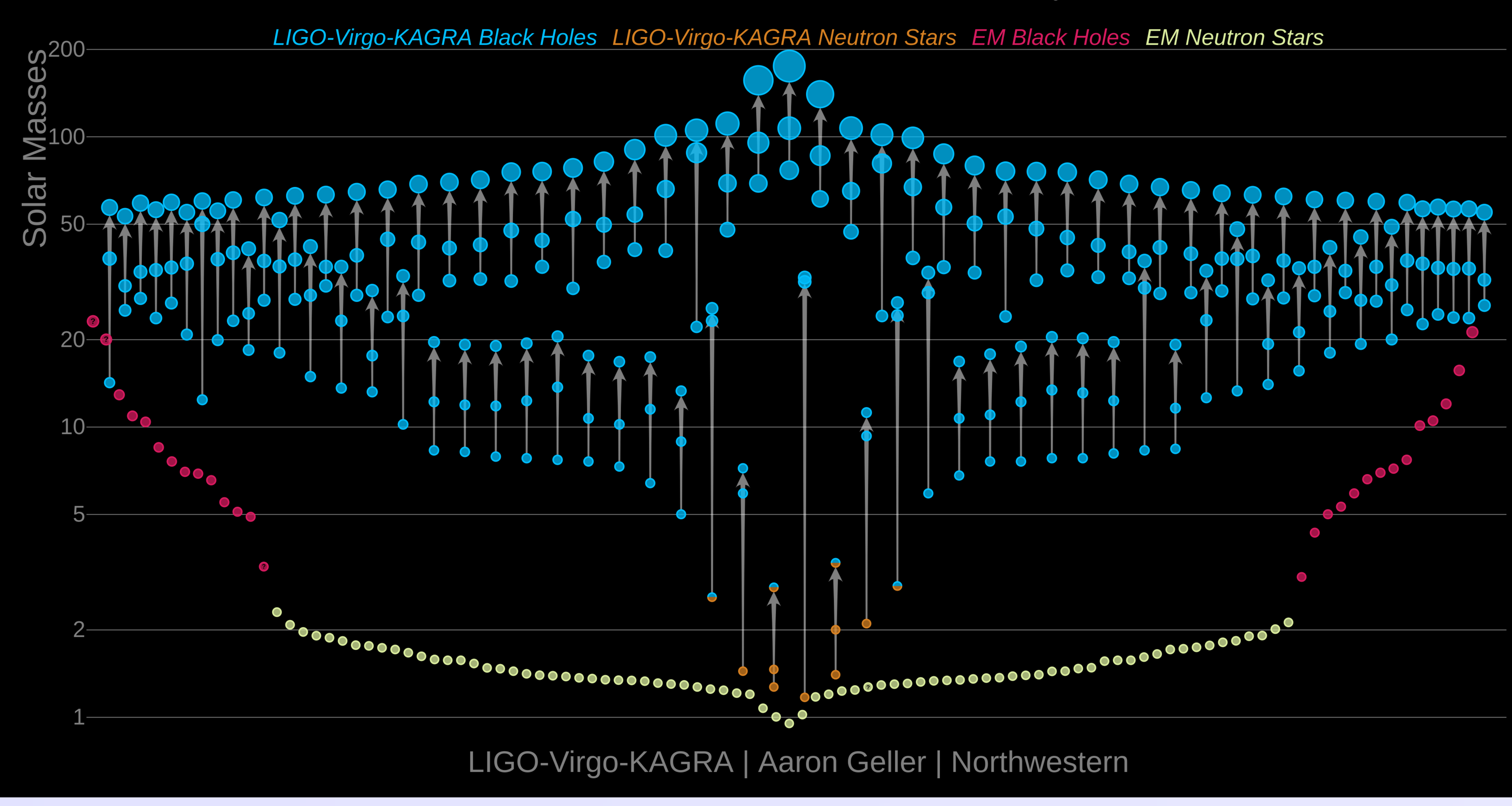
Core-collapse supernovae are potential sources of not well-modeled ("bursts") transient gravitational waves by aspherical mass-energy dynamics. Such dynamics are expected to be present in the pre-explosion stalled-shock phase. The emitted gravitational waves can probe the character of these asymmetries and thus may help in constraining the mechanism of core-collapse supernovae.



Credit: NASA/CXC/MIT/UMass Amherst/

Gravitational Wave Detections

Masses in the Stellar Graveyard



Growth in the Number of Detected Candidates