# SEARCHING FOR THE CONTINUOUS SOUNDS OF UNKNOWN NEUTRON STARS IN BINARY SYSTEMS

We have conducted the first ever search for the continuous gravitational waves emitted by spinning neutron stars in binary systems that have not yet been observed. Neutron stars are expected to be fairly smooth and symmetric, but perhaps not perfectly symmetric. If there is a small asymmetry in the neutron star (like a small bump on the surface), then as it spins, the star will emit continuous gravitational waves. The presence of such an asymmetry is scientifically interesting because it tells us about the behavior of matter at extremely high densities and pressures, under conditions that are impossible to replicate in laboratories on Earth

Often, the neutron star will be alone in space, but sometimes it is located in a binary system with a companion star or planet. Binary systems are very attractive to look for because the potential for accretion of material from the companion gives rise to a natural mechanism to create asymmetries of the neutron star. When the neutron star is in a binary system, however, the problem of finding the gravitational waves from an unknown system becomes computationally daunting because the unknown orbit causes variations in the signal. We have devised and developed new analysis techniques to search for the gravitational waves from unknown sources in binary systems. The new techniques reduce the computational burden by reducing the dimensionality of the search and utilize massive clusters of computers to process data in parallel within a manageable amount of time.

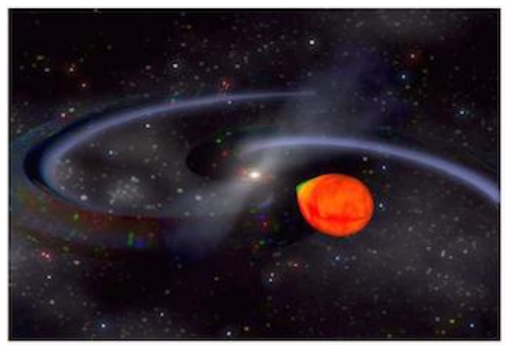


*Image from a video depicting a neutron star (the small, central object), circled by a companion star, that accretes material and emits gravitational waves. Courtesy of NASA Goddard: As the pulsar picks up speed through accretion, it becomes distorted from a perfect sphere due to subtle changes in the crust, depicted here by an equatorial bulge. Such slight distortion is enough to produce gravitational waves. Material flowing onto the pulsar surface from its companion star tends to quicken the spin, but loss of energy released as gravitational radiation tends to slow the spin due to the principle of conservation of energy. This competition may reach an equilibrium, setting a natural speed limit for millisecond pulsars beyond which they cannot be spun up.*

*Video available at* http://www.ligo.org/science/Publication-S6VSR23TwoSpect/index.php

Recently collected data from the Laser Interferometer Gravitational wave Observatory (LIGO) detectors, located in the United States, and the Virgo detector, located in Italy, were analyzed using the newly developed TwoSpect analysis technique to search for evidence of continuous gravitational wave signals from neutron stars in binary systems. No evidence for gravitational waves was found in any of the detector data. Even the absence of a signal, however, is scientifically interesting. Since the asymmetry is directly proportional to the gravitational wave amplitude emitted by the neutron star, the lack of signal means that nearby neutron stars in binary systems must not be too asymmetric. The analysis provides an upper limit value on the amplitude of continuous gravitational waves impinging on the LIGO and Virgo detectors from unknown neutron stars in binary systems. Thus, the absence of a signal may allow physicists to rule out some models describing the behavior of matter in neutron stars.

In addition to looking for unknown sources, the recently collected data were analyzed in a directed search using the same TwoSpect algorithm to look for continuous gravitational waves from a very interesting low-mass x-ray binary system containing a neutron star: Scorpius X-1. This source has the potential to be one of the strongest sources of continuous gravitational waves detectable on Earth. While no gravitational waves were detected in the data, this recent analysis allows physicists to place new upper limits on the possible amplitude of gravitational waves emitted by the neutron star in Scorpius X-1.

In the future, second-generation gravitational wave detectors--such as advanced LIGO and advanced Virgo-- will enable even more sensitive searches. The methods developed by TwoSpect and used for the all-sky search will also be employed in directed searches for particular sources (like Scorpius X-1). We anticipate an exciting era of gravitational wave searches for neutron stars in binary systems.

## GLOSSARY

• **Neutron star**: The relic of a massive star that has reached the end of its life. When a massive star has exhausted its nuclear fuel, it dies in a catastrophic way--a supernova--that often results in the formation of a neutron star: an object so massive and dense that atoms cannot sustain their structure as we normally perceive them on Earth. Some neutron stars are observed as pulsars by radio astronomers, as depicted in the first figure.

• **Directed search**: A search for a continuous gravitational wave signal when something is known about a potential source and included in the search method, but not all parameters of the potential source are known with high precision. This type of analysis lies between searches for unknown sources (all-sky searches) and targeted searches (all parameters are well-constrained).

• **Strain**: The fractional change in the distance between two measurement points due to the deformation of space-time by a passing gravitational wave.

• **Upper limit**: A statement on the maximum value some quantity can have while still being consistent with the data. Here, the quantity of interest is the maximum intrinsic gravitational wave strain amplitude of a given continuous wave signal arriving at Earth. We use a 95% degree-of-belief limit, i.e. given the data, there is a 95% probability that the quantity is below this limit.

• **Polarization**: Circularly polarized means the star's rotation axis is pointing along the line of sight to Earth. This is the best case because there are more gravitational waves emitted in this direction than in others. Randomly chosen polarizations produce less signal, all else being equal.

## READ MORE

Freely readable preprint of the paper describing the full details of the analysis and the results: http://arxiv.org/abs/1405.7904

An introduction to gravitational waves: http://www.ligo.org/science/GW-GW2.php

Wikipedia page on binary systems: http://en.wikipedia.org/wiki/Binary_system

Wikipedia page on accretion: http://en.wikipedia.org/wiki/Accretion_%28astrophysics%29

LIGO Scientific Collaboration homepage: http://www.ligo.org

Virgo collaboration homepage: http://www.ego-gw.it/virgodescription/

Wikipedia page on parallel computing: http://en.wikipedia.org/wiki/Parallel_computing

Freely readable preprint on the TwoSpect analysis technique: http://arxiv.org/abs/1103.1301

Wikipedia page on amplitude: http://en.wikipedia.org/wiki/Amplitude

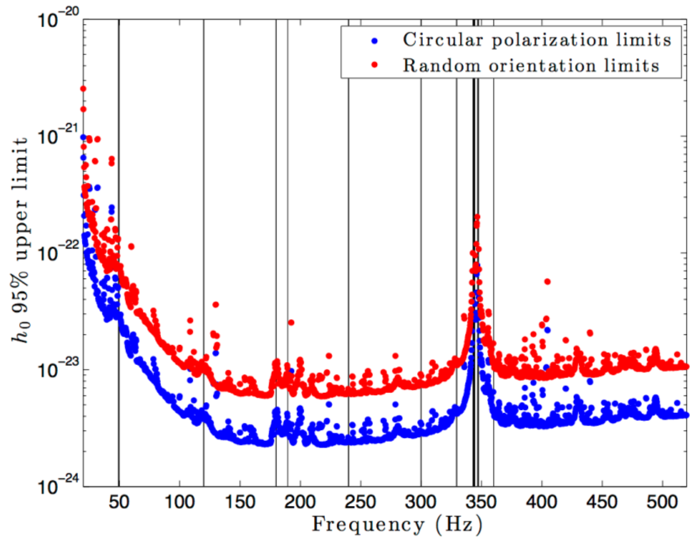
Wikipedia page on low mass X-ray binary systems: http://en.wikipedia.org/wiki/X-ray_binary#Low-mass_X-ray_binary

Wikipedia page on Scorpius X-1: http://en.wikipedia.org/wiki/Scorpius_X-1

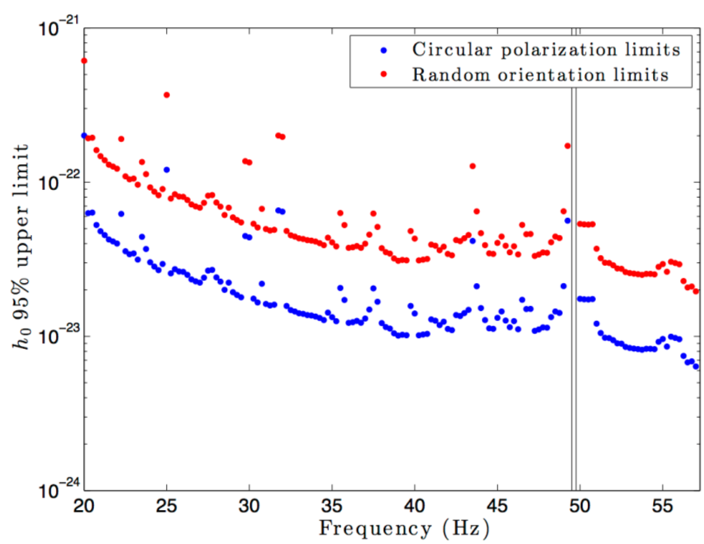
**Visit our website at http://www.ligo.org/**

## FIGURES FROM THE PUBLICATION

*For more information on how these figures were generated and their meaning, see the preprint at arxiv.org/abs/1405.7904*




*The blue dots in this plot show the upper limits on the circularly polarized gravitational wave strain amplitude from unknown spinning neutron stars in binary systems over the range of parameters searched using the TwoSpect algorithm. The red dots show the upper limit on the randomly polarized gravitational wave strain amplitude from unknown spinning neutron stars in binary systems over the range of parameters searched using the TwoSpect algorithm. This indicates that the gravitational wave strain coming at these frequencies from binaries is less than 2 x $10^{-24}$ in the most optimistic case.*




*The blue dots in this plot show the upper limits on the circularly polarized gravitational wave strain amplitude from the neutron star in the low mass x-ray binary system Scorpius X-1 using the TwoSpect algorithm. The red dots show the upper limit on the randomly polarized gravitational wave strain amplitude from the neutron star in the low mass x-ray binary system Scorpius X-1 using the TwoSpect algorithm. This indicates that the gravitational wave strain coming at these frequencies from Scorpius X-1 is less than 6 x $10^{-24}$ in the most optimistic case.*