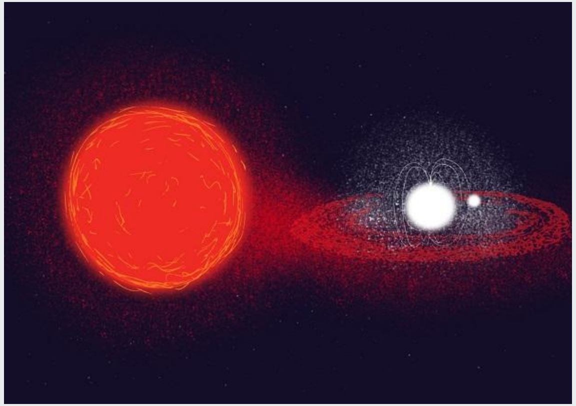
Still in the Hunt: Ongoing Searches for Continuous Gravitational Wave Sources



Ansel Neunzert on behalf of the LIGO-Virgo Scientific Collaboration

LIGO DCC number: G2101211

Outline

1. Continuous waves: key information
2. LSC CW publications on O3 data
3. LSC CW pre-prints on O3 data
4. Things to look for in the future

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Title slide image credit: European Space Agency (ESA)

Links to all papers discussed will be available during the Q&A, and are therefore not included on the slides.

Continuous waves: key information

Continuous waves: key information

- Most promising source: **non-axisymmetric** spinning neutron stars.
- Signals are **persistent**, **weak**, and **near single frequency.**
- Searches are often limited by **computational cost.**
- **No detections... yet.**

Continuous waves: key information

- Most promising source: **non-axisymmetric** spinning neutron stars.
  - Often characterized in terms of the ellipticity (ϵ) of a rotating triaxial ellipsoid.
  - Many proposed mechanisms for non-axisymmetry in neutron stars (accretion, crustal deformation, internal oscillation modes, etc)
  - Other possible sources for CWs as well!

- Signals are **persistent**, **weak**, and **near single frequency.**

- Searches are often limited by **computational cost.**

- **No detections... yet.**

Continuous waves: key information

- Most promising source: **non-axisymmetric** spinning neutron stars.
- Signals are **persistent**, **weak**, and **near single frequency.**
    - Need to analyze weeks, months, or years of data at once.
    - “Near single frequency” != “single frequency”.
        - Spin-down, Doppler modulation, glitches, etc.
- Searches are often limited by **computational cost.**
- **No detections... yet.**

Continuous waves: key information

- Most promising source: **non-axisymmetric** spinning neutron stars.
- Signals are **persistent**, **weak**, and **near single frequency.**
- Searches are often limited by **computational cost.**
  - Different searches probe different ranges of parameter space, source types, etc.
  - Multiple mature search techniques with different strengths
- **No detections... yet.**

Continuous waves: key information

- Most promising source: **non-axisymmetric** spinning neutron stars.
- Signals are **persistent**, **weak**, and **near single frequency.**
- Searches are often limited by **computational cost.**
- **No detections... yet.**
  - Non-detections are getting more interesting as search sensitivity improves!
  - Setting upper limits and constraining theoretical models.

Continuous wave search terms

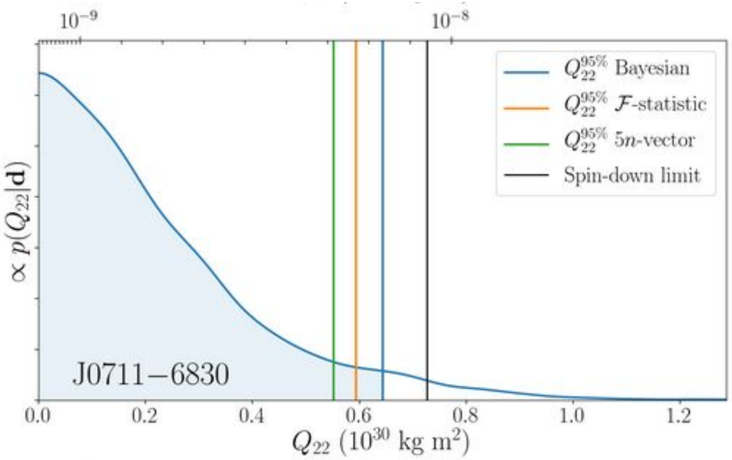
"Targeted"	"Directed"	"All-sky"
Sky location: known Spin frequency: known	Sky location: known Spin frequency: unknown	Sky location: unknown Spin frequency: unknown
Typically most sensitive	Typically have intermediate sensitivity	Typically least sensitive
Requires the most information about the source	Requires intermediate knowledge about the source (sky location)	Requires the least information about the source(s)

"Spin-down limit": maximum signal if all rotational kinetic energy lost during spin-down was due to GW emission.

LSC/LVK CW publications on O3 data

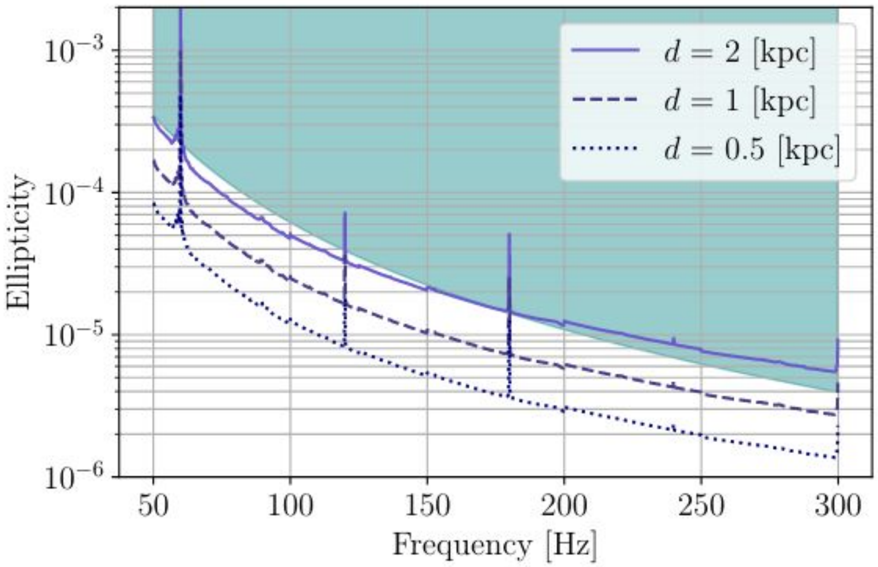
“Gravitational wave constraints on the equatorial ellipticity of millisecond pulsars” October 2020, ApJL

- Targeted: searched for 5 radio pulsars (2 recycled millisecond pulsars, 1 mildly recycled, 2 young)
- Three search methods, three observing runs worth of data (O1, O2, O3)
  - Methods: time-domain Bayesian, F/G statistic, 5n-vector (O3 only)
  - Considered GWs at 1x and 2x spin frequency, plus narrow-band searches
- **First time matching or surpassing spin-down limits on a recycled pulsar.**
- **Equatorial ellipticities constrained to ~1e-8 .**



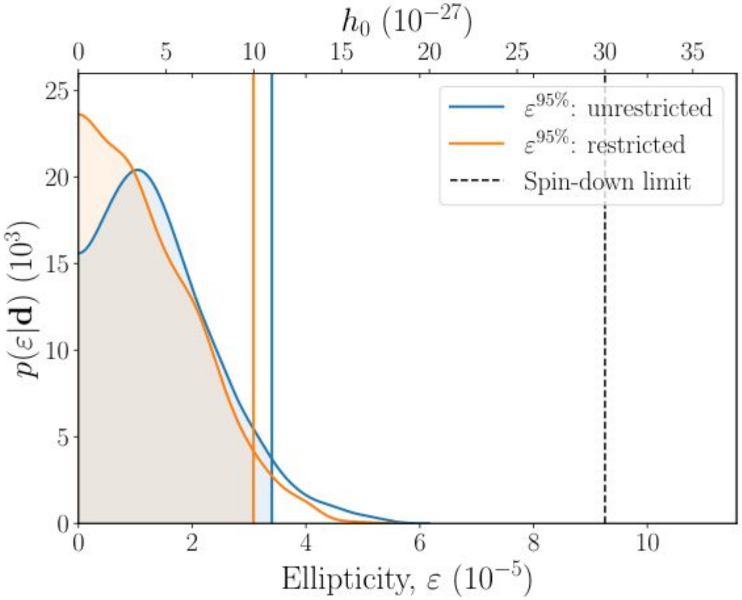
“All-sky search in early O3 LIGO data for continuous gravitational-wave signals from unknown neutron stars in binary systems” (March 2021, PRD)

- All-sky search, with a large parameter space due to unknown binary orbital parameters.
- Method: semicoherent templated search in O3a data (Livingston and Hanford only).
- Maximum spindown limit implies maximum range.
- **Ellipticity constraints approaching expected allowed maximum.**



“Diving below the spin-down limit: Constraints on gravitational waves from the energetic young pulsar PSR J0537-6910” (May 2021, ApJL, includes Kagra authorship)

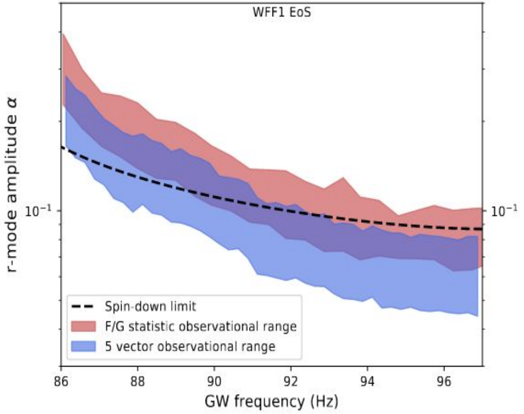
- Targeted search for a promising source: largest spin-down luminosity, fastest spinning young pulsar, glitches, braking index may suggest GW radiation
  - NICER observations provide detailed information on spin frequency and evolution
- Time-domain Bayesian method in a combination of O2 and O3 data.
- Searched 1x and 2x spin frequency, but did not consider r-modes.
- **Upper limits surpass spin-down limit by more than factor of 2 - no signal found.**

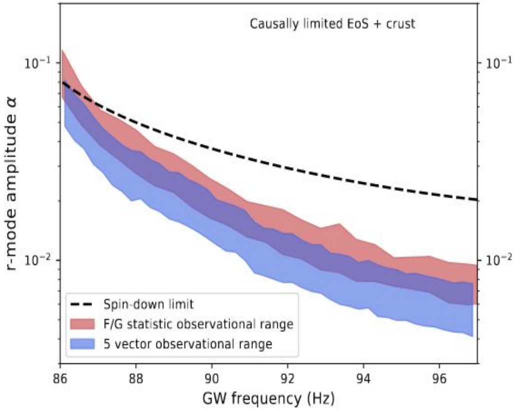


LSC/LVK CW pre-prints on O3 data

“Constraints from LIGO O3 data on gravitational wave emission due to r-modes in the glitching pulsar PSR J0537-6910” (pre-print, released April 2021, includes Kagra authorship)

- R-modes are toroidal fluid oscillations within a neutron star
- NS equation of state (EoS) is uncertain → requires narrow-band search
- Method: both F/G statistic and 5-vector method in O3 data
- Results: ***if*** **r-mode GW emission drives entire spin-down of the pulsar, this requires a soft EoS or a NS below ~2 solar masses.**





“Searches for continuous gravitational waves from young supernova remnants in the early third observing run of Advanced LIGO and Virgo” (pre-print, released May 2021)

- Wide-band **directed searches for 15 young supernova remnants**
  - Sources elected from the Green supernova catalog and SNRcat
- Using 3 different search methods (Band Sampled Data, single-harmonic Viterbi, dual-harmonic Viterbi) in O3a
- Constraints improve on O1 searches by more than a factor of ~2, and on O2 searches by a factor of ~1.4

Source	Minimum t_{age} (kyr)	D (kpc)	T_{coh} (hours)	f (Hz)	$\dot{f}$ (Hz/s)
G1.9+0.3	0.10	8.5	1.0	[31.56, 121.7]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$
G15.9+0.2	0.54	8.5	1.0	[44.03, 657.1]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$
G18.9–1.1	4.4	2	1.9	[31.02, 1511]	$[-1.507 \times 10^{-8}, 1.507 \times 10^{-8}]$
G39.2–0.3	3.0	6.2	2.8	[62.02, 459.2]	$[-1.968 \times 10^{-8}, 1.968 \times 10^{-8}]$
G65.7+1.2	20	1.5	4.7	[35.10, 1128]	$[-3.149 \times 10^{-9}, 3.149 \times 10^{-9}]$
G93.3+6.9	5.0	1.7	1.9	[30.00, 1668]	$[-1.335 \times 10^{-8}, 1.335 \times 10^{-8}]$
G111.7–2.1	0.30	3.3	1.0	[25.71, 365.1]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$
G189.1+3.0	3.0	1.5	1.4	[26.13, 2000]	$[-1.968 \times 10^{-8}, 1.968 \times 10^{-8}]$
G266.2–1.2	0.69	0.2	1.0	[18.36, 839.6]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$
G291.0–0.1	1.2	3.5	1.0	[31.97, 1460]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$
G330.2+1.0	1.0	5	1.1	[36.57, 1039]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$
G347.3–0.5	1.6	0.9	1.0	[21.74, 1947]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$
G350.1–0.3	0.60	4.5	1.0	[31.96, 730.1]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$
G353.6–0.7	27	3.2	10	[77.86, 318.3]	$[-2.295 \times 10^{-9}, 2.295 \times 10^{-9}]$
G354.4+0.0	0.10	5	1.0	[25.72, 121.7]	$[-3.858 \times 10^{-8}, 3.858 \times 10^{-8}]$

“Constraints on dark photon dark matter using data from LIGO's and Virgo's third observing run” (pre-print, released May 2021, includes Kagra authorship)

- Dark photons could cause time-dependent oscillations in the mirrors of the LIGO-Virgo detectors.
  - **Not gravitational waves! This is a direct DM experiment.**
  - But it’s quasi-monochromatic, and uses LIGO data and CW analysis tools.
- Two search methods: Band Sampled Data, and cross correlation, both used in CW searches.
- Uses LIGO and Virgo O3 data, improves on previous O1 results by a factor of ~100.
- Limits surpass those of existing dark matter experiments.

Q&A