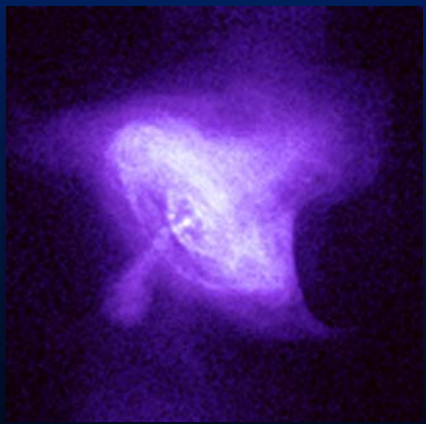
Gravitational Waves From Rotating Neutron Stars

Xavier Siemens
Caltech



(NASA/CXC/SAO)

G060531-00-M

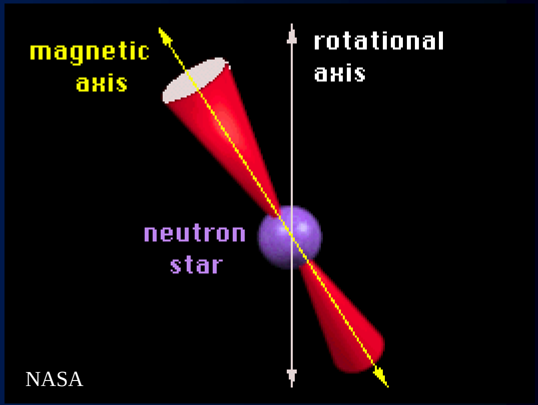
Rotating neutron stars

Neutron stars can form from the remnant of stellar collapse

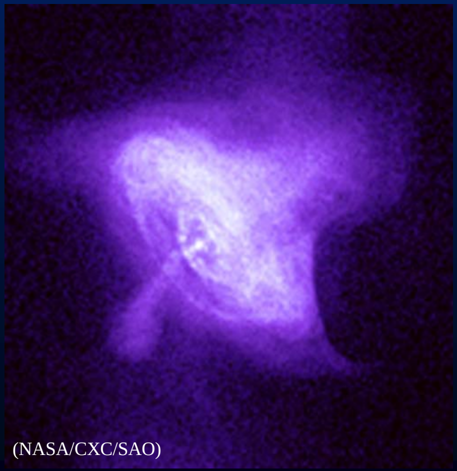
Typical size of 10km, and are about 1.4 solar masses

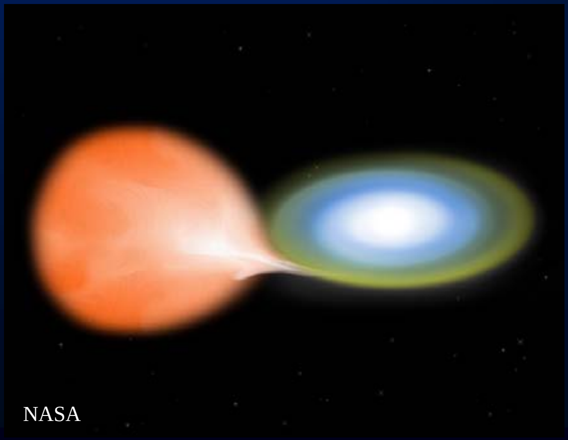
Some of these stars are observed as pulsars

Gravitational waves from neutron stars could tell us about the equation of state of dense nuclear matter



NASA


(NASA/CXC/SAO)


NASA

Gravitational waves from rotating neutron stars

- We search for rotating neutron stars with deviations from axi-symmetry

- Model the neutron stars as tri-axial ellipsoids

- Rotational frequency f_{ROT}, gravitational wave emission frequency $f_{GW} = 2 f_{ROT}$

$$h = \frac{4\pi^2 G}{c^4} \frac{I f_{GW}^2}{d} \varepsilon$$

G - Newton's constant

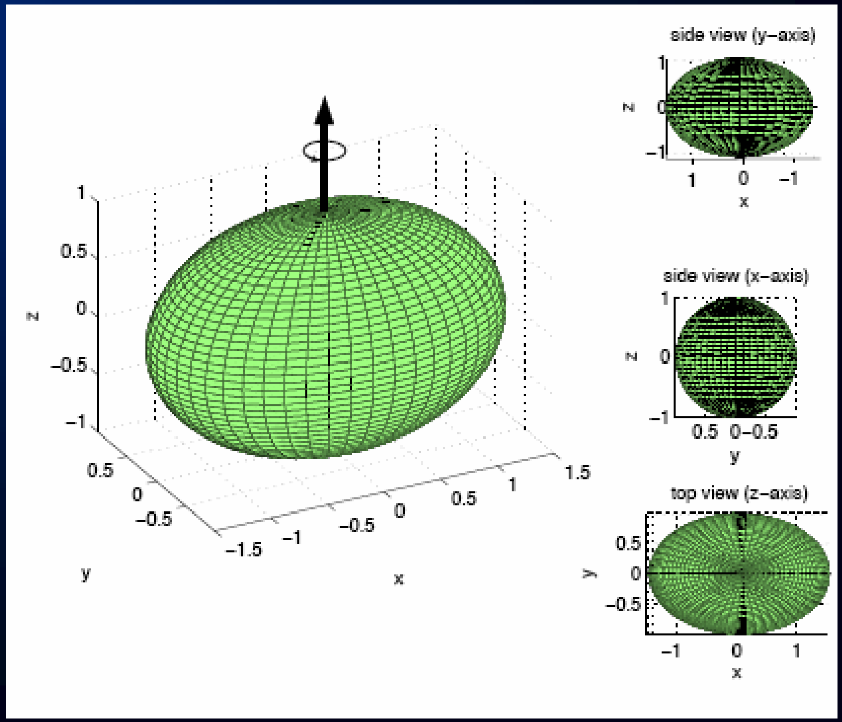
c - speed of light

I - Moment of inertia about rotation axis

f - GW frequency

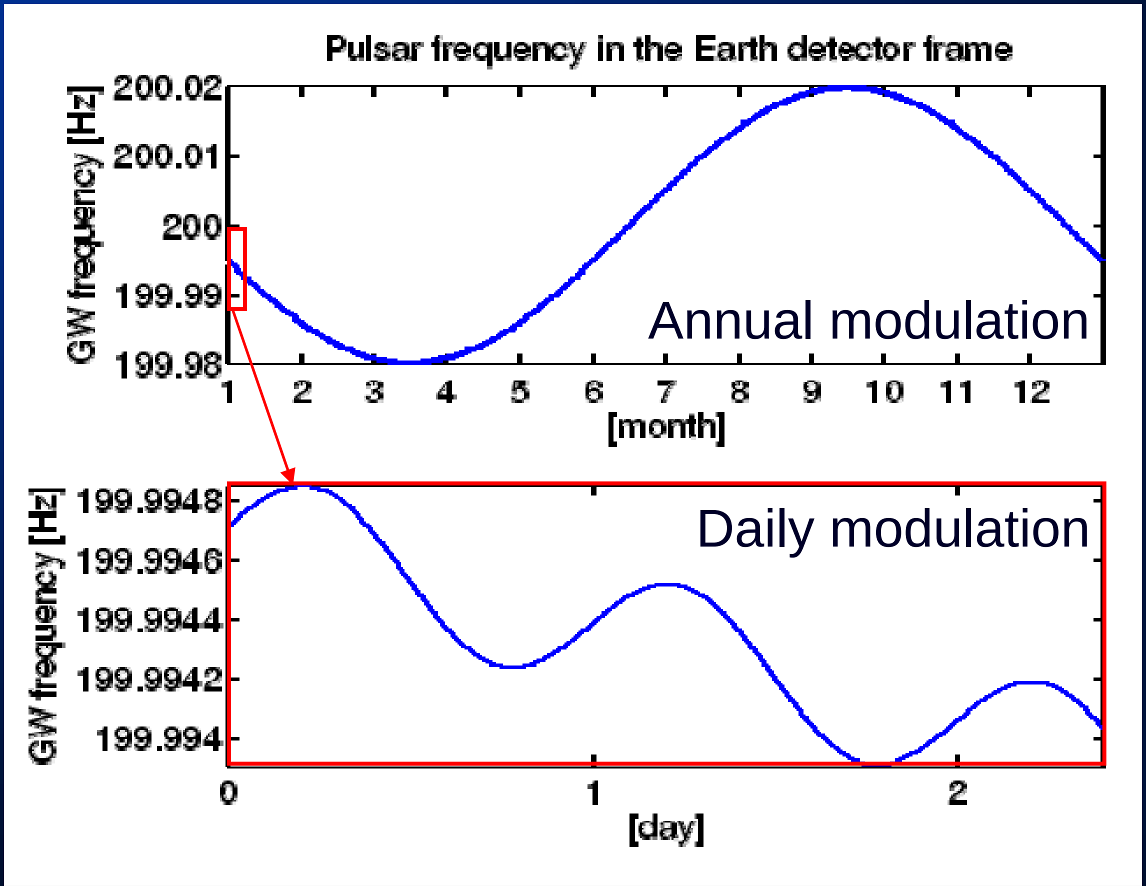
d - distance to source

ε - ellipticity



Gravitational waves from rotating neutron stars

Signal is essentially monochromatic:



Doppler modulation depends on sky location

Matched-filtering

Suppose we have a monochromatic signal $s(t) = n(t) + A\sin(2\pi ft)$

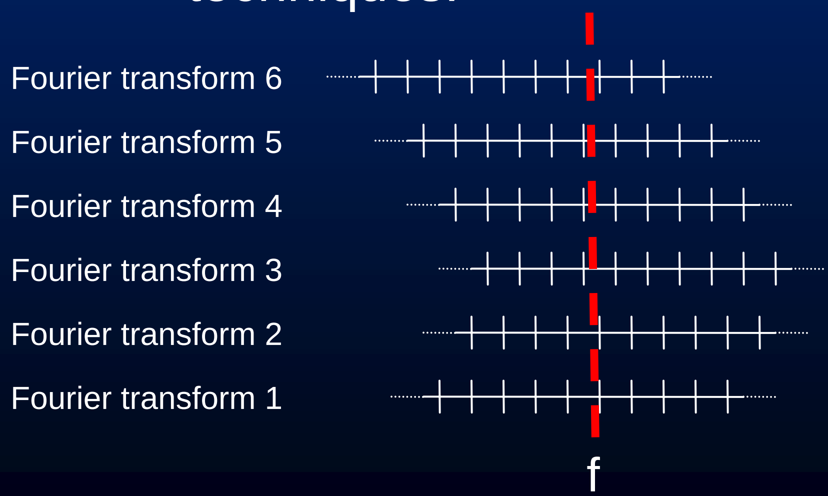
and we look for it via

$$\int_0^T dt s(t)\sin(2\pi f't) = \int_0^T dt n(t)\sin(2\pi f't) + A\int_0^T dt \sin(2\pi f't)\sin(2\pi ft)$$

$\propto \sqrt{T}$ $\qquad$ $\propto T$

The signal to noise of a monochromatic signal grows like $\propto \sqrt{T}$

Real signals are Doppler shifted. Frequency domain search techniques:



Combine incoherently: Excess Power

Combine coherently: Keeps track of phase

Looks straight-forward, computationally non-trivial for coherent searches

LIGO

Coherent searches:

- Time-domain:
  - Targeted
  - Markov Chain Monte Carlo

Searches over narrow parameter space

- Frequency-domain:
  - Isolated (e.g. Einstein@Home)
  - Binary, Sco X-1

Searches over wide parameter space

Semi-coherent searches:

- Hough transform
- Stack-Slide
- Powerflux

Fast Robust Excess power searches

Ultimately, will combine these in a hierarchical scheme

Summary of LIGO publications for periodic GWs:

Setting Upper Limits on the Strength of Periodic GW from PSR J1939+2134 Using the First Science Data from the GEO600 and LIGO Detectors, PRD 69, 082004 (2004) .

Limits on Gravitational-Wave Emission from Selected Pulsars Using LIGO Data, PRL 94, 181103 (2005).

First All-sky Upper Limits from LIGO on the Strength of Periodic Gravitational Waves Using the Hough Transform, PRD 72, 102004 (2005).

Coherent searches for periodic gravitational waves from unknown isolated sources and Scorpius X-1: results from the second LIGO science run, gr-qc/0605028, submitted to PRD

Einstein@home online report for S3 search: http://einstein.phys.uwm.edu/PartialS3Results

Upper limits on gravitational wave emission from 76 radio pulsars, Undergoing internal review process

All-sky LIGO (semi-coherent) search for periodic gravitational waves in the S4 data run, Undergoing internal review process

S1

S2

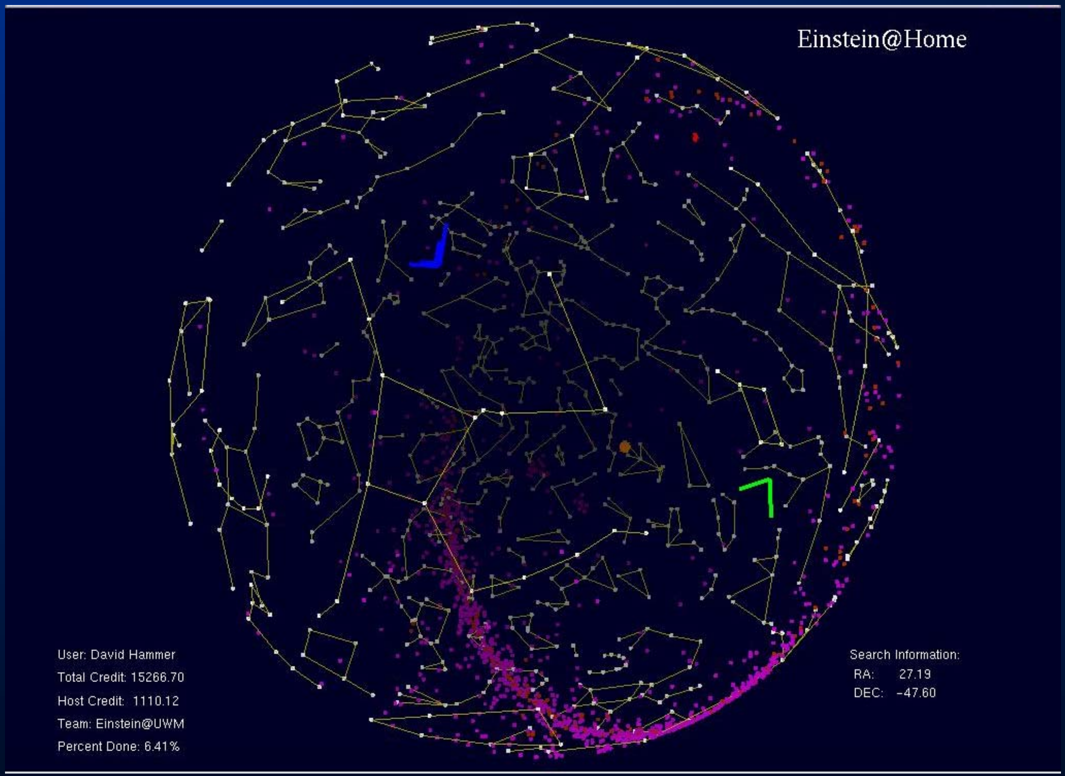
S3

S4

Neutron star search results

Einstein@Home

Screen saver a la SETI@Home that searches for neutron stars using your computer's spare CPU cycles



http://einstein.phys.uwm.edu

Neutron star search results

Einstein@Home

- ~50 Tflops

- Makes use of coherent frequency domain method

S3:
- 60 10 hour segments
- No evidence of strong pulsar signals
- Outliers are consistent with instrumental artifacts or bad bands. None of the low significance remaining candidates showed up in follow-up on S4 data.

S4:
- Using segment lengths of 30 hours
- Analysis took ~ 6 months
- Currently in post-processing stage

S5:
- Faster more efficient application
- Estimated time to completion 6-12 months

USERS	Approximate #
in database	220,560
with credit	139,297
registered in past 24 hours	252
HOST COMPUTERS	**Approximate #**
in database	524,205
registered in past 24 hours	1,095
with credit	285,285
active in past 7 days	72,246

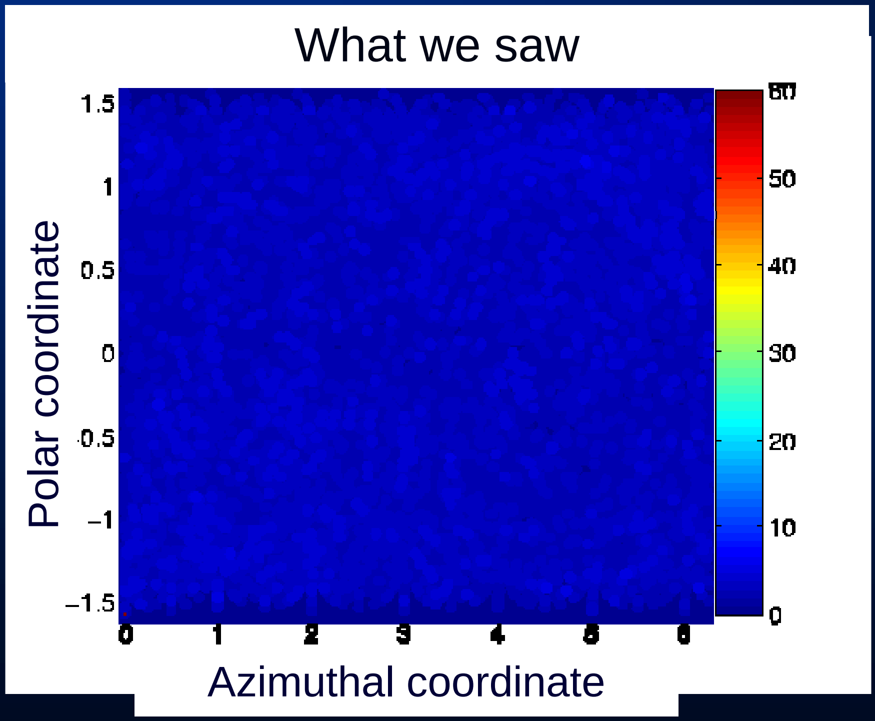
S5 search progress

Total needed	Already done	Work still remaining
16,446,454 units	6,411,114 units	10,035,340 units
100 %	38.982 %	61.018 %
302.6 days	118.0 days	184.6 days (estimated)

Neutron star search results

Einstein@Home

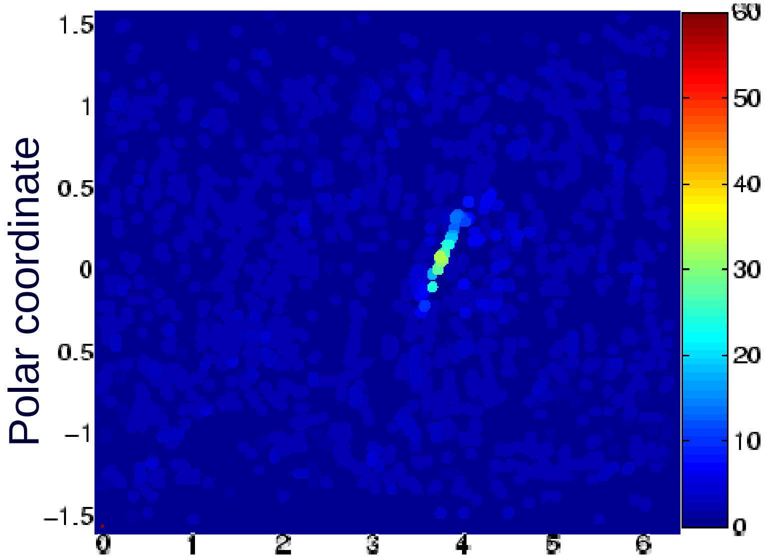
S3 run data: Did 60 10 hour coherent searches, band of 1500Hz, over entire sky. Then counted values of signal power above some threshold consistent (in frequency and sky location) among the 60 searches.



Neutron star search results

Einstein@Home

What we might have seen (injection)



Injection:
signal of strain 1.6×10^{-23} at 574 Hz

So what?

Strain is: $$h = \frac{4\pi^2 G}{c^4}\frac{If^2}{d}\varepsilon$$

If we take M=1.4 solar masses, R=10 km, d=100 pc, then $\varepsilon=10^{-6}$

The ellipticity is the degree of deformation of the neutron star ➡ Can be connected with the equation of state of the nuclear matter of the star!

Neutron star search results

Directed searches – Crab pulsar

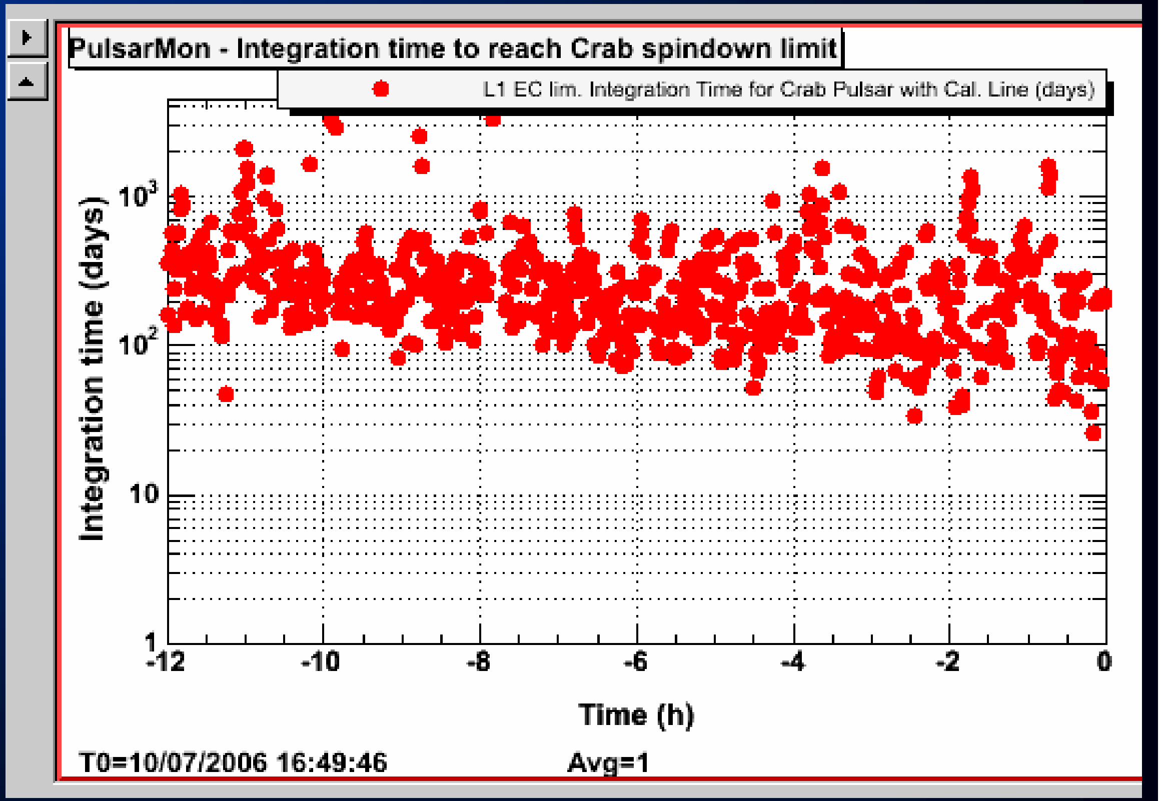
under internal review

Crab limit now below the 'spindown based' upper limit.

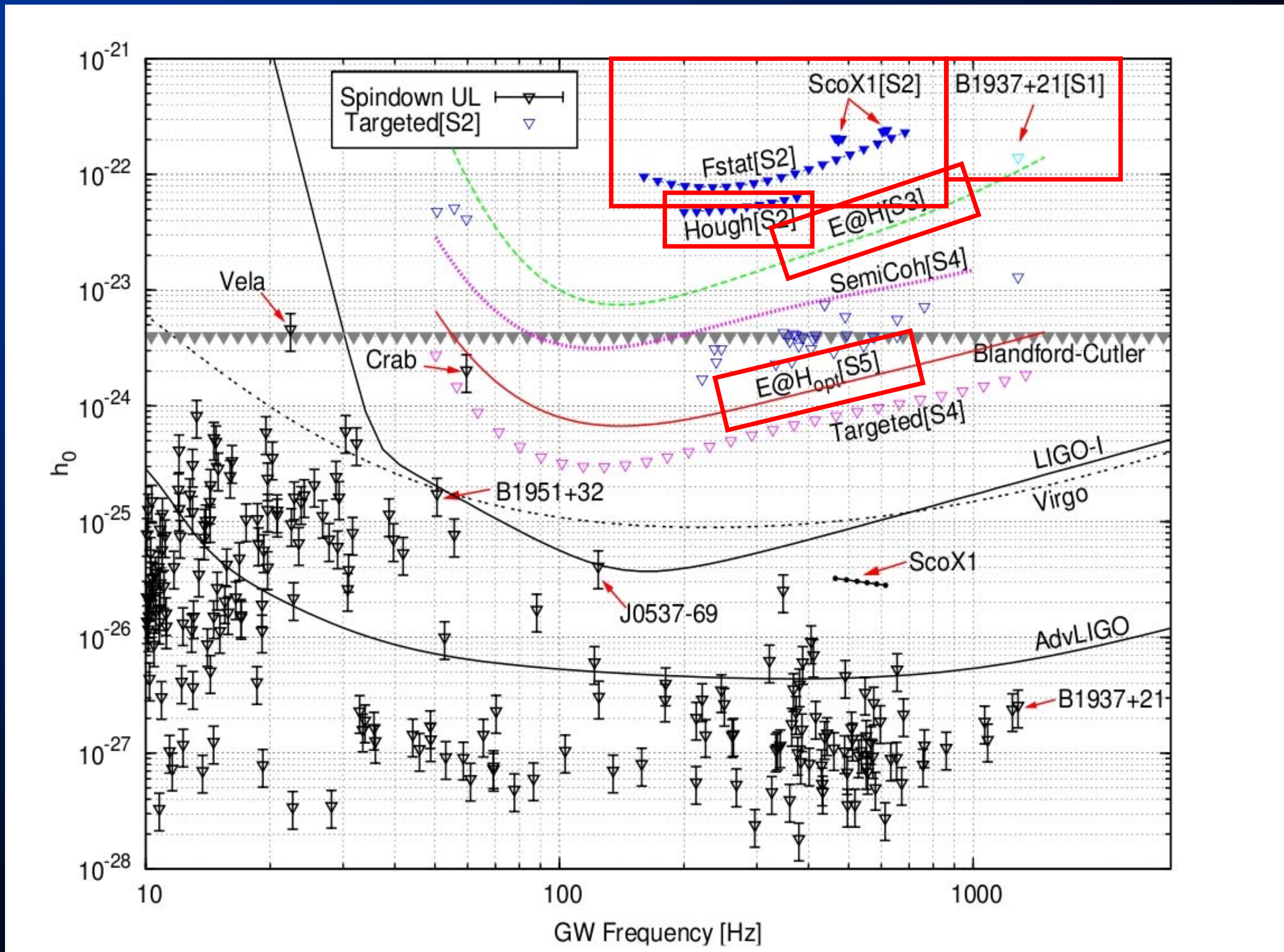
- $f_{GW} \approx 59.6$ Hz
- distance ≈ 2 kpc

22 Nov to 18 Apr:

- $h_0 < 1.3 \times 10^{-24}$
- $\varepsilon < 6.5 \times 10^{-4}$
- Spindown ratio 0.92



Past, Present, and Future



Summary

Neutron stars are a promising candidate for gravitational wave generation

We are involved in a variety of efforts to detect them

Can give insight into other fields of physics