Recent and Ongoing Searches for Continuous-Wave GW Signals

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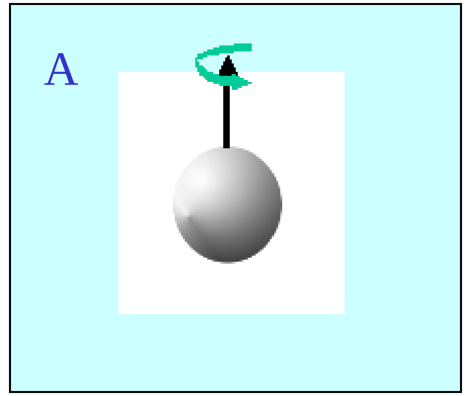
Sources of CW GW Signals

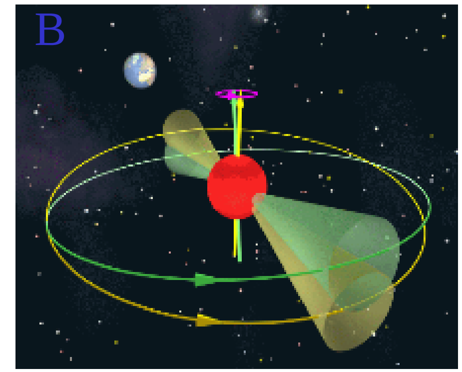
Target: rapidly-spinning neutron star with some sort of asymmetry or dynamics that emits GW

Can detect a very weak signal by integrating over long data periods

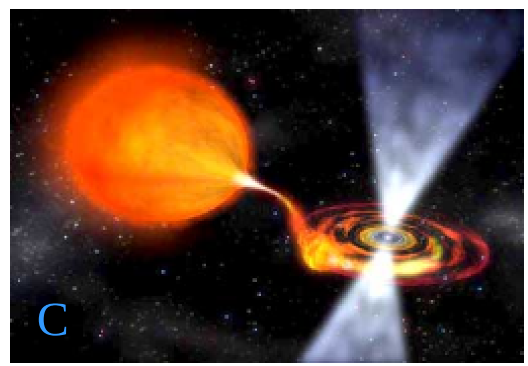
… but have to correct for Doppler and amplitude modulation at the detector



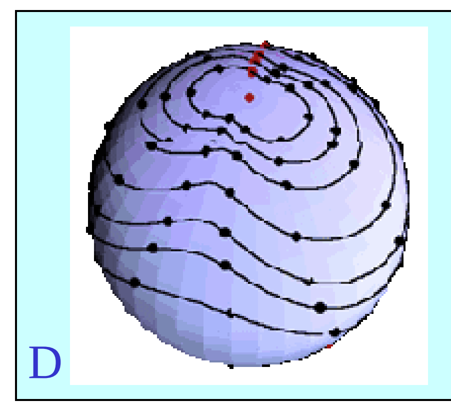
Mountain on a star



Wobbling star



Accreting star



Oscillating star

Credits:

A. image by Jolien Creighton; LIGO Lab Document G030163-03-Z.

B. image by M. Kramer; Press Release PR0003, University of Manchester - Jodrell Bank Observatory, 2 August 2000.

C. image by Dana Berry/NASA; NASA News Release posted July 2, 2003 on Spaceflight Now.

D. image from a simulation by Chad Hanna and Benjamin Owen; B. J. Owen's research page, Penn State University.

Types of CW GW Searches

Several cases to consider:

Candidates

- Sky position and spin frequency known accurately — Radio pulsars
- Sky position and spin frequency known fairly well — X-ray pulsars
- Sky position known, but frequency and/or binary orbit parameters unknown — LMXBs
- Search for unknown sources in favored sky regions — Supernova remnants, Galactic center, Globular clusters
- Search for unknown sources over the whole sky — Unseen isolated neutron stars

Different computational challenges ⇒ Different approaches

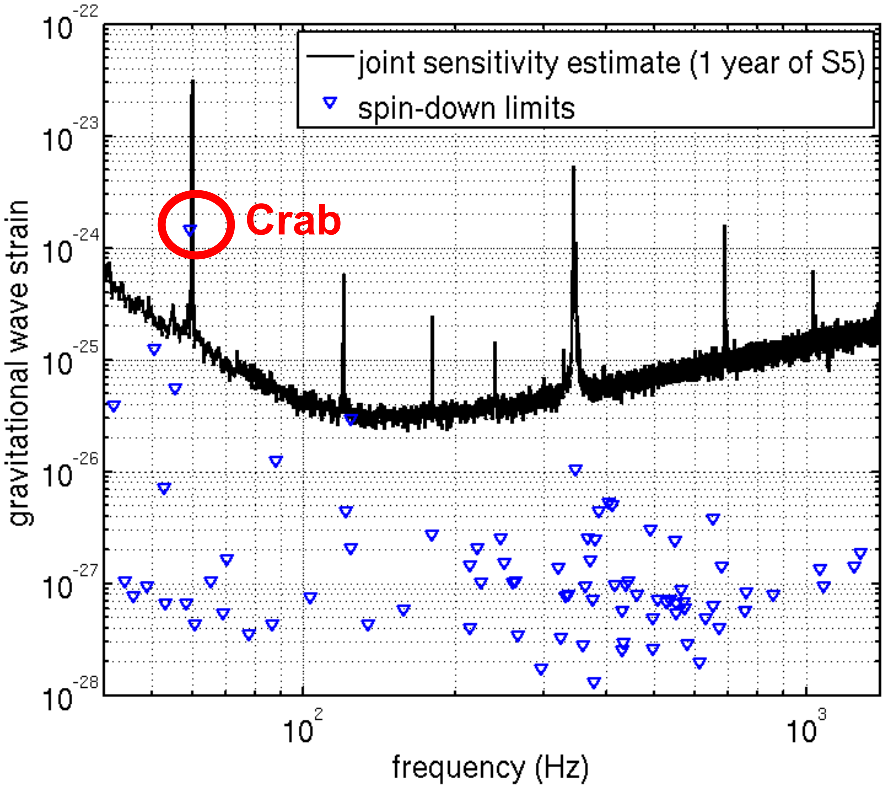
Searches for GW from Known Pulsars

Straightforward demodulation

Have an *a priori* limit on GW energy emission from observed spin-down rate

Crab pulsar has largest known spin-down rate

- EM emission and accelerating expansion account for at least some of the spin-down…
- But GW emission could contribute a significant fraction *!*



LIGO data from first ~9 months of the S5 run has been searched for a GW signal from the Crab pulsar

- Fully coherent searches, based on radio pulse timing information from Jodrell Bank Observatory

Crab Pulsar Searches

Two complementary searches

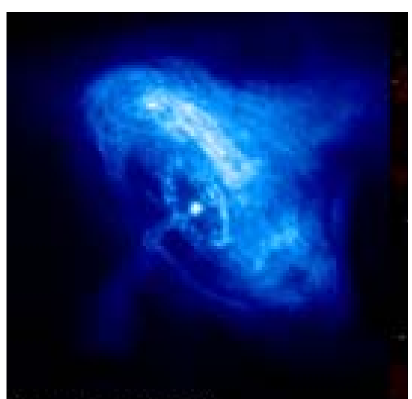
- Single template at twice the rotation frequency determined from radio
- Multi-template search ***near*** twice the rotation frequency
  - Allow EM and GW signals to differ by up to 10^{-4} (relative) in f and f-dot
  - Total of 3×10^{7} templates

Bayesian analysis with 4 unknown parameters (besides template)

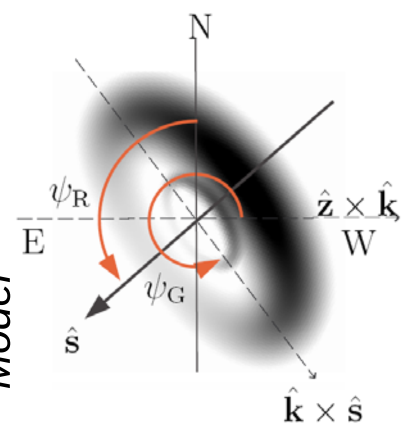
Two different priors for neutron star spin orientation

- Uniform
- Restricted using X-ray observations [Ng and Romani, ApJ 601 (2004) 479]

Chandra image



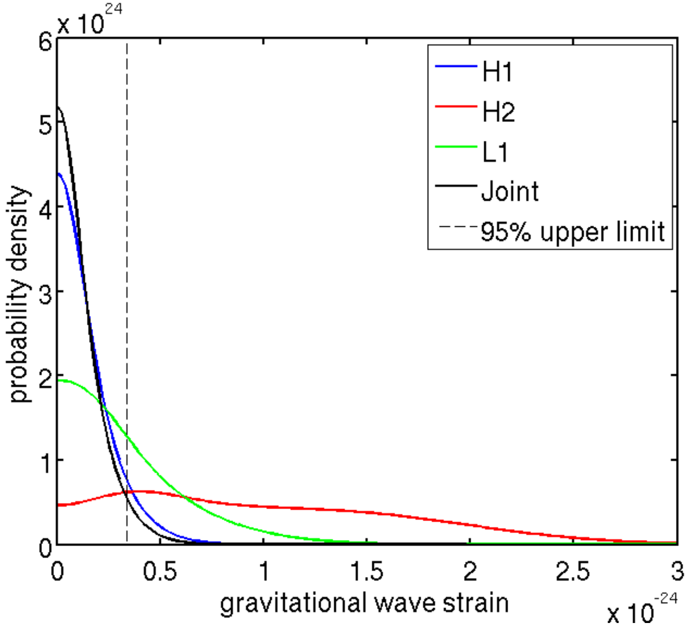
Model



Preliminary Crab Search Results

Consistent with Gaussian noise

- Individual and joint posterior pdfs assign large probability to zero amplitude
- Set upper limit by integrating area under pdf up to 95% of the total area



Upper limits on GW strain amplitude h_0

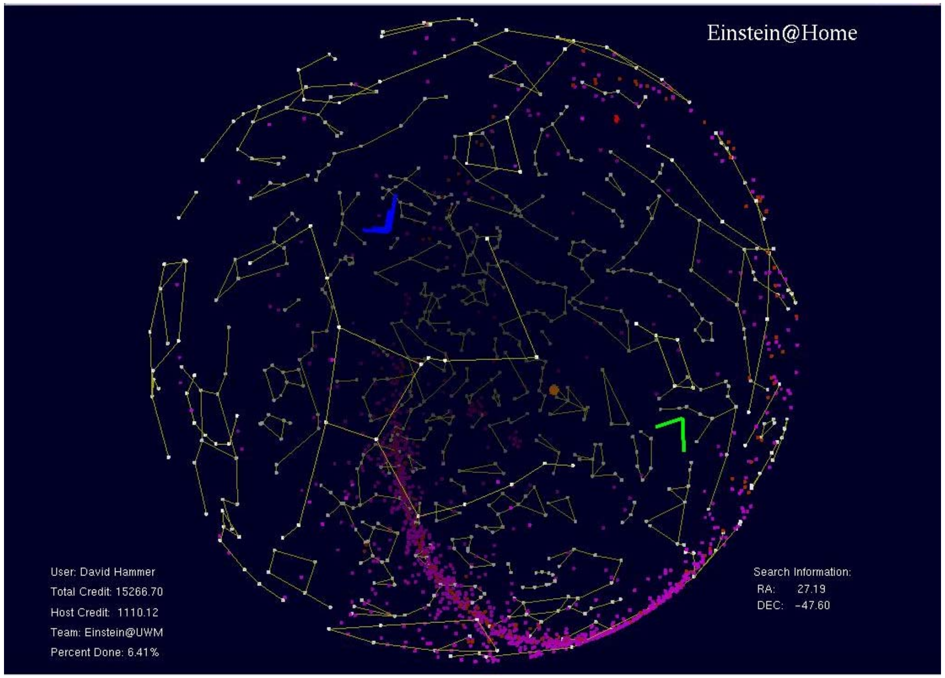
- Single-template, uniform prior: **3.4×10^{-25}**
- Single-template, restricted prior: **2.7×10^{-25}**
- Multi-template, uniform prior: **1.7×10^{-24}**
- Multi-template, restricted prior: **1.3×10^{-24}**

Implies that GW emission accounts for ≲ 4% of total spin-down power

These preliminary results have uncertainties of ±20%

- Calibration being finalized, etc.; preprint to be posted later this month

All-sky Search in LIGO S4 Data Using Einstein@Home



Einstein@Home is a public distributed computing project

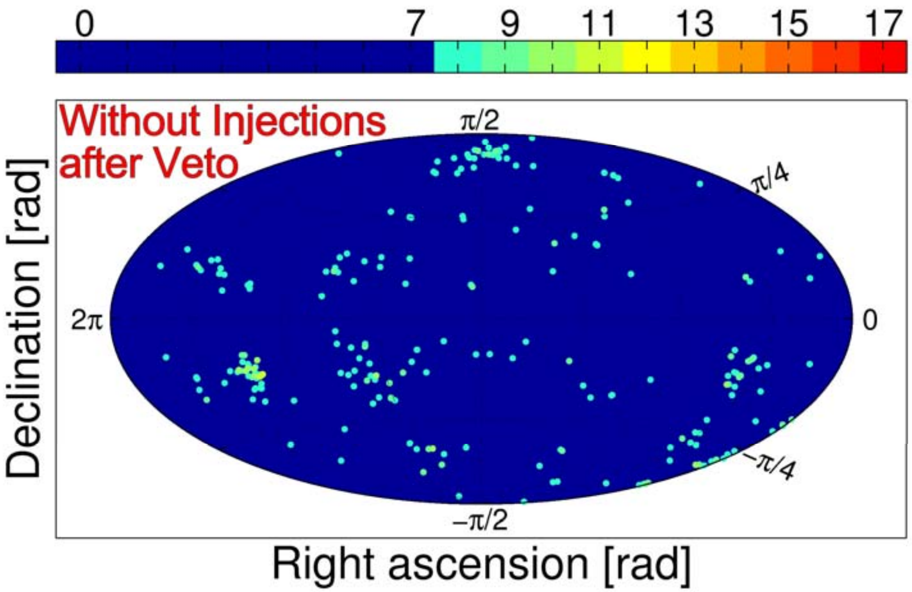
- Based on BOINC
- Hosts request "workunits", process data, return results
- Currently ~160,000 active participants, ~80 Tflops average
- Triple redundancy for validation

Search over sky position, frequency, and spin-down

- Used 510 hours of S4 data from H1 and L1, divided into 17 segments
- Frequency range: 50 to 1500 Hz
- Broad range of spin-down (and spin-up) rates
- Total of $6{\times}10^{13}$ templates !

S4 Einstein@Home Search Results

Set thresholds for each of the 17 segments;
Count number of segments with consistent templates above threshold



- Apply a "veto" to remove candidates consistent with stationary (instrumental) lines
- Exclude hardware-injected simulated signals

⇒ **No statistically significant candidates remain**

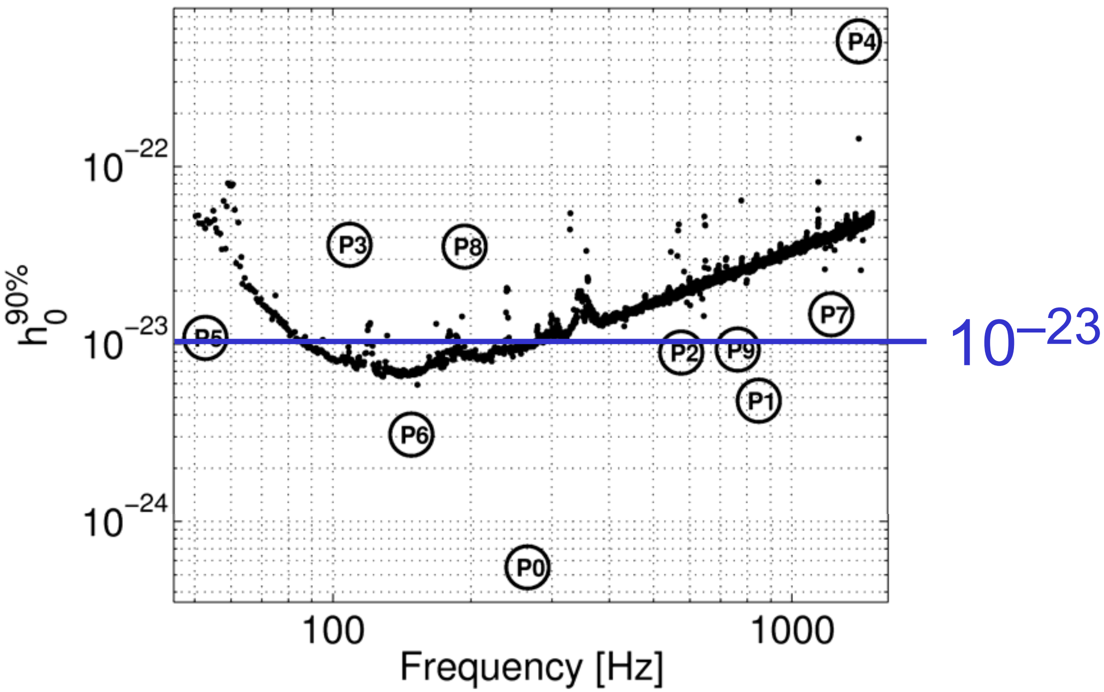
Preprint arXiv:0804.1747, to be submitted to Phys. Rev. D

Sensitivity of Einstein@Home Search

S4 search sensitivity vs. frequency:

$$h_0^{90\%} \sim 32\sqrt{\frac{S_h(f)}{30\text{ hours}}}$$

Three hardware-injected simulated pulsars were loud enough to be detected easily



Einstein@Home is now being used in a *hierarchical* search with LIGO S5 data

- S4 search sensitivity suffered from practical limit on number of candidates returned by hosts to server
- For S5 search, hosts do Hough transform search with fully coherent (not coincident) combination of data from H1 and L1