Einstein@Home

search for periodic gravitational waves in early S5 LIGO data

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The first **Einstein@Home** search in S5 LIGO data

- **All-sky** broad-band search for **periodic** gravitational waves,
  such as from rotating non-axisymmetric neutron stars:

  » Searched frequency range: 50 Hz < f < 1500 Hz
  » Searched range of frequency derivatives: $-f/\tau < \dot{f} < 0.1f/\tau$,
    with τ = 1000 yrs for f < 400Hz and τ = 8000 yrs for f > 400Hz.
  » Goal: high-confidence detection (not upper limits).

- **Input data:** 840 hours selected from 66 days of early **S5 LIGO** run:

  » **H1 4-km detector:** 22 x 30-hour segments,
  » **L1 4-km detector:** 6 x 30-hour, segments. } **28 30-hour segments**
  » Removed understood instrumental lines from the data.

- **Huge** parameter-space search: Distributed over more than
  100 000 computers volunteered by the general public
  via **BOINC** (Berkeley Open Infrastructure for Network Computing).

- Details: `http://arxiv.org/abs/0905.1705`

Coherent matched-filtering over each 30-hour segment ($\mathcal{F}$-statistic)

» Data is convolved with a set of signal **template** waveforms corresponding to all possible sources.

Same methods as previous E@H S4 search: Phys. Rev. D 79, 022001 (2009).

- Templates in **4D** parameter space ($\mathbf{f}, \dot{\mathbf{f}}, \boldsymbol{\alpha}, \boldsymbol{\delta}$)
  - » placed at approximately equal distance,
  - » distance measure (metric) defined from fractional loss in expected $\mathcal{F}$-statistic.

- Template **grid** of maximum possible loss in $\mathcal{F}$ (mismatch m):
  - » m = 15% for **f** < 400Hz, m = 40% for **f** > 400Hz.

- Template **grid** is a Cartesian product of a uniformly spaced grid in frequency **f**, uniformly spaced grid in $\dot{\mathbf{f}}$ and metric-based grid on the sky (different for each data segment).
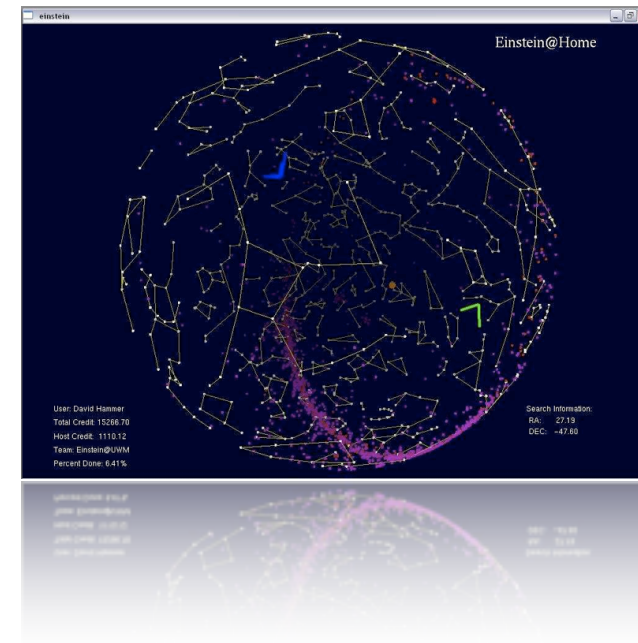
» In total: ≈10^{16} templates!

Einstein@Home screensaver

Einstein@Home:

Uses idle computing cycles volunteered by the general public, based upon BOINC.

- **Divide huge parameter space into small workunits:**
  - » Each workunit has computing time of order 1 day.
  - » Workunits sent to out to participating hosts.
  - » Hosts return finished work in a top-list of most significant events (in $\mathcal{F}$-statistic).
  - » Validation: same work done on hosts owned by two different users, then results automatically compared.
  - » In total 16 446 454 workunits.

- **Total processing time on E@H project:**
  - » 6 months.
  - **Total result data volume to post-process:**
  - » 0.6 TB compressed, 2.5 TB uncompressed.

- **About 100 000 active participants:**
  - » About 100 Tflops.

Goal: Find candidates from the **28** different data segments which cluster closely together in the 4D parameter space ($\mathbf{f}, \dot{\mathbf{f}}, \alpha, \delta$).

- **Steps:**
  - » Shift candidate event frequencies to a fixed fiducial time so they can be compared
  - » 'Bin' candidate events into 4D cells
  - » Search for cells which have candidate events from **many** of the 28 data segments

- **Cells are chosen to be as small as possible consistent with:**
  - » Cell size in sky > largest sky-grid separations (use metric-based model in declination)
  - » Cell size in frequency > frequency-grid spacing + (spin-down grid spacing) x 30 hours
  - » Cell size in spin-down > spin-down grid spacing

- **Veto regions of parameter space**
  - » Exclude regions where stationary instrumental lines tend to appear due to global correlations. Physically: regions of minimum Doppler modulation.
  - » In this search, about 13% of total search parameter-space is vetoed.

Pletsch, PRD 78, 102005 (2008).

- Average false alarm probability per 0.5Hz band in Gaussian noise of
  - » obtaining 10 (of 28) coincidences: 10^{-3} ➡ expect a few in 1.5 kHz of Gaussian noise.
  - » obtaining 20 (of 28) coincidences: 10^{-21} ➡ confident detection.

At what strain h_0 would 90% of sources be **confidently** detected?

» Determined by MC simulations in each 0.5Hz band.

- Simulated source population probed for detection
  - » Uniformly distributed over the sky.
  - » Uniformly distributed in the nuisance parameters.

- In most sensitive band 125 - 225Hz, > 90% of sources with $h_0 \geq 3 \times 10^{-24}$ were confidently detected.

- Comparison to previous Einstein@Home S4 analysis:
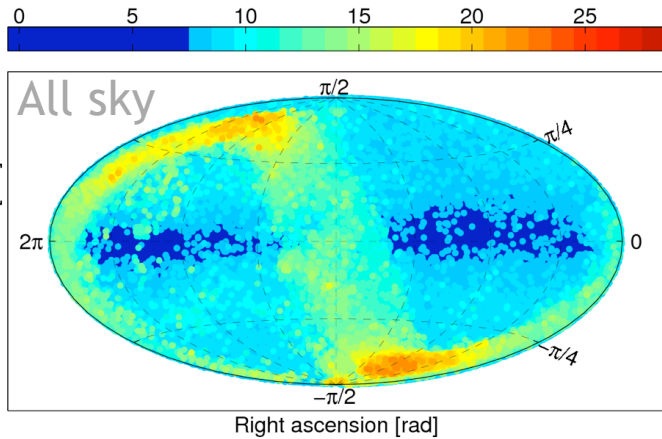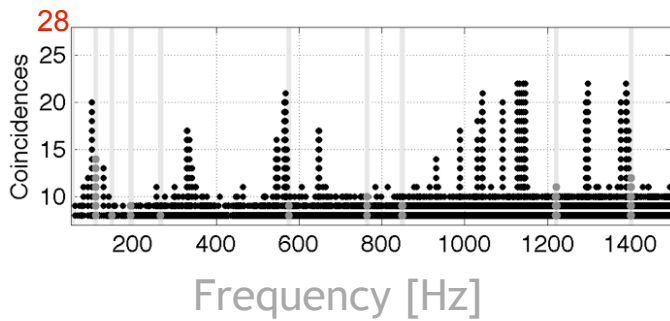 - » Improved sensitivity by a factor ≈ 3.

Resulting sensitivity estimates

LIGO

LSC
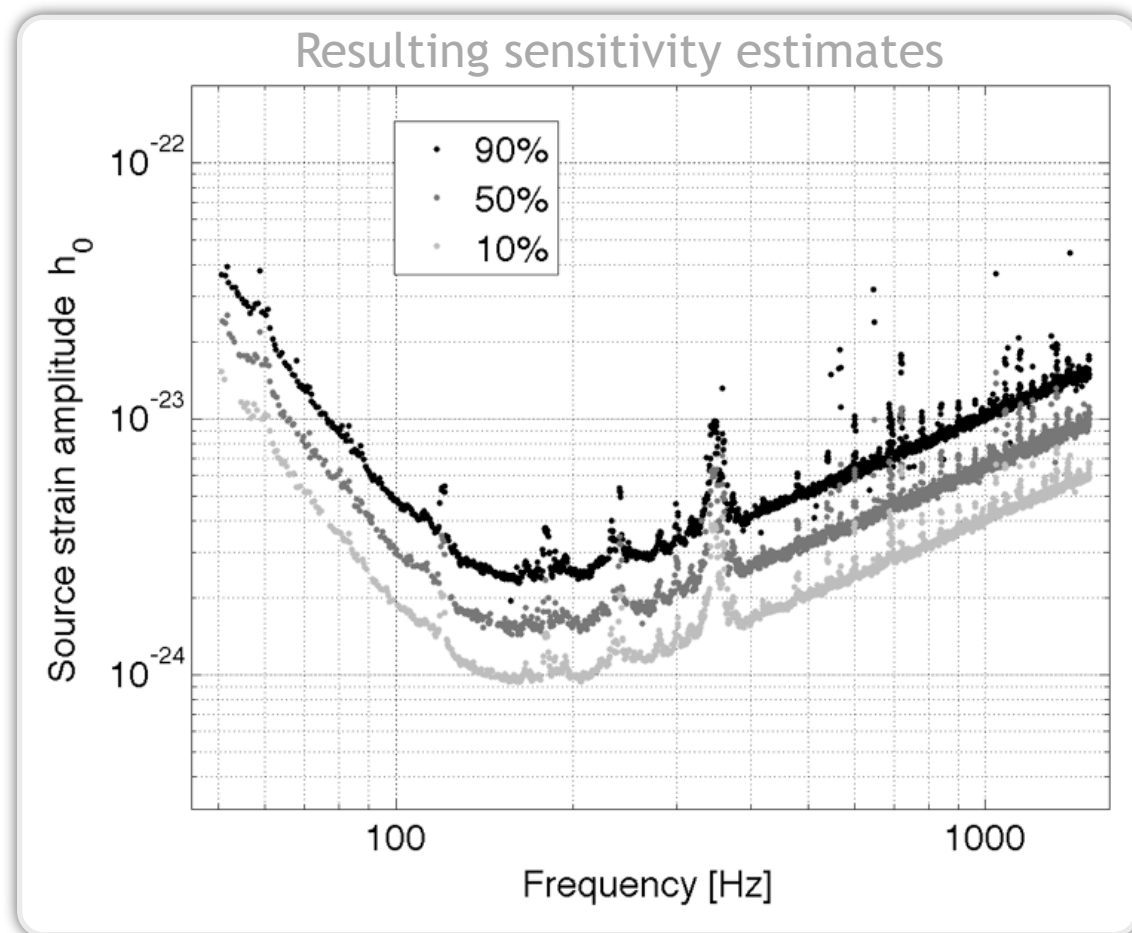
Coincidence analysis results:

Further post-processing steps:

1. **A posteriori cleaning**
   » Removing instrumental lines of *known* origin.

2. **Parameter-space veto**
   » Discriminating parameter-space regions of Doppler stationarity.

3. **Detector coincidence veto**
   » Discriminating candidates whose coincidences come from a single detector only.

Final results:

» Left: 10 coincidences of 28 possible (but 10 also expected by chance).

» **No credible signal found.**
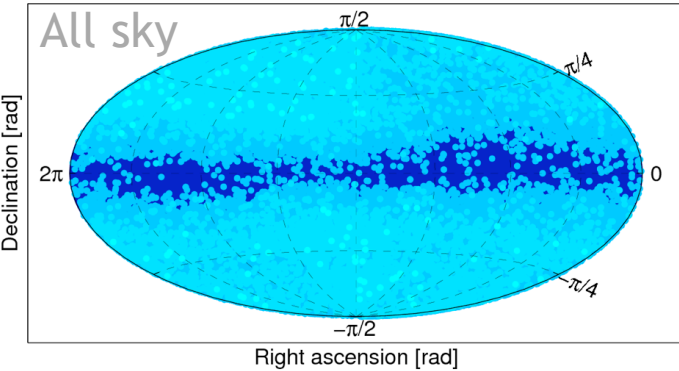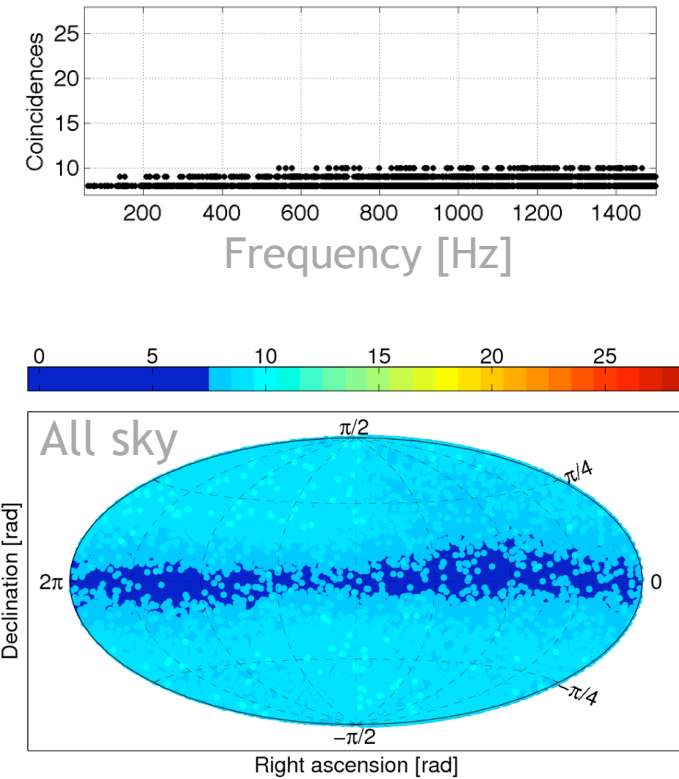
- **Einstein@Home** now running a hierarchical search in later S5 LIGO data using the **Hough transform** method.
  - » Incoherent combination step done on hosts,
  - » 121 data segments of 25 hours each (from H1 and L1),
  - » Increase in sensitivity by a factor ≈ 4.

> Krishnan et al., PRD 70, 082001, (2005).

- A **more sensitive method** currently under development:
  - » "Global-Correlation Transform" technique,
  - » Substantial increase in sensitivity by a factor ≈ 6,
  - » Planned for search of future LIGO S6 data.

> Pletsch and Allen, ArXiv:0906.0023, (2009).

- Those of you who run Einstein@Home: THANK YOU!

- Everyone else, sign-up to join at:

http://einstein.phys.uwm.edu