Testing alternative theories of gravity with gravitational waves: Continuous waves

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AltGrav Workshop
University of Wisconsin Milwaukee
26th - 27th May 2010
Outline

• Summary of on-going continuous wave searches
• Tests of alternative theories in the advanced interferometers era:
  1. Propagation velocity
  2. Polarisation properties
  3. Phase information
The present

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Continuous waves

- **Signal h(t):**
  - Deterministic
  - “Always” present in the data set
  - Slowly drifting \( (f/(df/dt) \gg T_{\text{obs}}) \)

\[
h(t) = \frac{1}{2} F_+ (t; \alpha, \delta, \psi) h_0 (1 + \cos^2 \iota) \cos \phi(t) + F_\times (t; \alpha, \delta, \psi) h_0 \cos \iota \sin \phi(t)\]

**Amplitude:**
\[ h_0 \propto \frac{I \epsilon}{D} f^2 \]

**Phase (in the source rest frame):**
\[ \phi(T) = \phi_0 + 2\pi \left[ f_0 (T - t_0) + \frac{1}{2} \dot{f}_0 (T - t_0)^2 + \frac{1}{6} \ddot{f}_0 (T - t_0)^3 + \ldots \right] \]

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Continuous waves

- Two flavours of searches/pipelines:
  1. *Fully coherent* over the whole observation time if source parameters, in particular position & frequency are known (e.g. radio/X-ray pulsars)
  2. *Semi-coherent* searches to look blindly over the whole sky (so far, search parameters \( \alpha, \delta, f, f_{\text{dot}} \)), e.g. Einstein@Home

http://einstein.phys.uwm.edu/
Sensitivity

- aLIGO (ZERO DET high P & High Freq)
- AdV, V+
- Vela
- Crab
- PSR J1952+3252 (CTB80)
- PSR J0537-6910 (LMC)
- J0437-4715

(signal strengths assume the pulsars are GRavitars)

GW frequency (Hz)

1y coherent

single detector

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S5 results: targeted search on radio pulsars

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S5 results: Crab

\[ \varepsilon = 0.237 h_{-24} r_{\text{kpc}} v^{-2} I_{38} \]

improvement on spin-down limit
Early S5 E@H results

Coincidence analysis

Final result
[after cleaning known instrumental lines, and performing parameter space coincidence tests]

Average false alarm probability over 0.5 Hz frequency band in Gaussian noise:
- 20 (out of 28) coincidences: $10^{-21}$ ➔ confident detection
- 10 (out of 28) coincidences: $10^{-3}$ ➔ expect a few in 1.5kHz band

Upper-limit on strain

Abbott et al, PRD 80, 042003 (2009)

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2015+

Summary of on-going continuous wave searches

Tests of alternative theories in the advanced interferometers era:

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Propagation velocity

- Goal: set a limit on $v_g/c$
- Need electro-magnetic counterpart

\[
\left| 1 - \frac{v_g}{c} \right| < \frac{\Delta t}{D}
\]

- Radio/X/gamma-ray pulsars in principle ideal (if we can detect them): provide both EM and GW time-stamps
- Improve with number of observed GW cycles (and number of pulsars):

\[
3 \times 10^4 \sqrt{\left( \frac{f}{100 \text{ Hz}} \right) \left( \frac{T}{10^7 \text{ s}} \right)}
\]
Comb of “delta’s” with different amplitudes (depend on geometry) and with phases that are locked (is this fully general?) throughout the observation.

Consistent with the same sky locations.

How many instruments are necessary to fully resolve the 6 polarisations?

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Phase evolution

- Analyses directly measure the phenomenological parameters, \( f, f\dot{}, f\ddot{}..., \)

\[
\phi(T) = \phi_0 + 2\pi \left[ f_0(T - t_0) + \frac{1}{2} \dot{f}_0(T - t_0)^2 + \frac{1}{6} \ddot{f}_0(T - t_0)^3 + \ldots \right]
\]

- Is there any reason to think that this model is not adequate in general?

- How many derivatives?

- Search range of \( f\dot{}, f\ddot{}, \) etc...?
Implications for pipelines

- Probably not much to change in terms of search strategies
- Radiometer/cross-correlation type of searches are promising approaches (see stochastic background session)
- What will change is the interpretation of the results if one relaxes the assumption that GR is correct: how to map fdot, fddot etc into physical parameters of an alternative theory of gravity?