Searching for gravitationalwaves in PTA data







Rutger van Haasteren (Jet Propulsion Lab)





Outline

- 1. Pulsars and pulsar timing
- 2. Gravitational-wave sources
- 3. Pulsar Timing array searches
- 4. Outlook and current sensitivity





Similar to interferometers



Credit: Advanced Technology Center, NAOJ

Emit light, and reflect back

Essentially: time the propagation of the beam



LASER has precise frequency \rightarrow equivalent to clock

Interferometry for detection



Need precise frequency/clock





Could say that LIGO uses a LASER as an accurate frequency standard What about pulsar's spin frequency?

Period of PSR B1937+21: T = 0.00155780644887275 s



Strain sensitivity per frequency

Energy density function of wavelength Electromagnetic waves: $\Omega \propto |E|^2 + |B|^2$ Gravitational waves: $\Omega \propto |\dot{h}|^2 = f^2 h(f)^2$







Pulsar Timing



Parkes Radio Telescope





Pulse profiles

70
A A

Some typical numbers

- Pulse period: 5 ms
- Pulse width: 0.5 ms (~10% of period)
- Timing accuracy: 100 ns
- Pulsar distance: several kpc (3 * 10^19 m)

 \rightarrow sensitivity to distance variations of 30 m (< 1 part in 10^18)

Map relative motion very accurately Can account for every not-observed pulsar rotation!

Timing residuals

Effect of pulsar position RAJ = 0.602600905734 +/- 1.7e-09

A lot of power is absorbed by the fitting process. Most comes from fitting a quadratic shape (spindown) and pulsar position.

The effect of fitting

Red timing noise

Random walk in torque plus extra effects?

Timing noise severe in canonical pulsars \rightarrow use millisecond pulsars (MSPs)

Not very prominent in our MSPs. For now...

The Pulsar Timing Arrays

Parkes Pulsar Timing Array: Parkes radio telescope (64m). Oldest fully organised PTA effort. Best timing residuals to date. Southern Hemisphere

European Pulsar Timing Array: Effelsberg (100m), Westerbork synthesis (14x25m), Nancay (94m), Lovell (76m), Sardinia (64m). Most dishes.

NANOGrav: GreenBank (100m), Arecibo (300m). Biggest dishes.

Antenna pattern response

a: + or x polarisationb: breathing modec: vector x,y modesd: longitudinal mode

Most efforts focus on the usual +,x polarisations.

 $\frac{\delta \mathbf{v}}{\mathbf{v}} = e_{ab}^{A}(\hat{\mathbf{\Omega}}) \frac{1}{2} \frac{\hat{p}^{a} \hat{p}^{b}}{1 + \hat{\mathbf{\Omega}} \cdot \hat{p}} \left(h_{e}(t_{e}) - h_{p}(t_{p}) \right)$ Earth-term Pulsar-term

Antenna pattern response

Primary signal in PTAs

Ensemble of supermassive black-hole binaries, (somewhat) isotropically distributed.

(Taylor and Gair, 2013)

At low frequencies: background

Sesana et al. (2008), Ravi et al. (2012): Theory and simulations suggest there is a non-zero probability that individual sources have SNR above the background.

Primary signal in PTAs

Stochastic isotropic signals are correlated between pulsars according to the overlap reduction function (Hellings & Downs curve). Due to quadrupolar nature of Gws.

Need many, many pulsars!!!

Searching for the H&D curve

Jenet et al. (2005), Demorest et al. (2012), many others...

Also: for alternative theories of gravity, or massive gravitons

What we have...

Our cross correlation power estimate is still consistent with zero amplitude. Most stringent published upper limit: $h_c < 2.4e-15$

Modeling anisotropies

H&D curve is pre-integrated. Here we divide the sky in an arbitrary number of 'pixels', and search for an amplitude in each pixel.

Preliminary work (Neil Cornish and myself, in parallel)

Prospects for detection

Siemens et al. (2013)

Assumptions: keep observing all pulsars, and add 3 per year

Note: red noise estimate is quite uncertain

Other applications

Hobbs et al. (2012)

Pulsars can be used to construct a timescale, independent from atomic clocks

Other uses include: studying the solar system ephemeris (planet masses), cosmic strings, interstellar navigation, ...

Conclusions

•Pulsars can be used as sensitive instruments

•Lots of fundamental science done

Observing GWs in the near future with pulsar timing arrays: this decade?
Unknown: noise level
Unknown: signal amplitude

•New IPTA datasets coming soon. What will it bring?