Probing alternative theories of gravity with gravitational wave detection from pulsar timing arrays

Sydney J. Chamberlin and Xavier Siemens

Outline

- What can gravitational wave physics do for cosmology?
- Gravitational waves in alternative gravity theories
- Schematic: how to detect gravitational waves with pulsar timing arrays
- Pulsar timing arrays have increased sensitivity to scalar-longitudinal and vector gravitational waves that appear in some alternative gravity theories

arXiv: 1111.5661

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- How can we test these theories against observation?
  - Test general relativity (GR) in strong field regime
  - Gravitational waves (GWs): excellent way to test GR

What can gravitational wave physics do for cosmology?

Detect GWs

↓

Use observations to test GR & place constraints on gravity theories

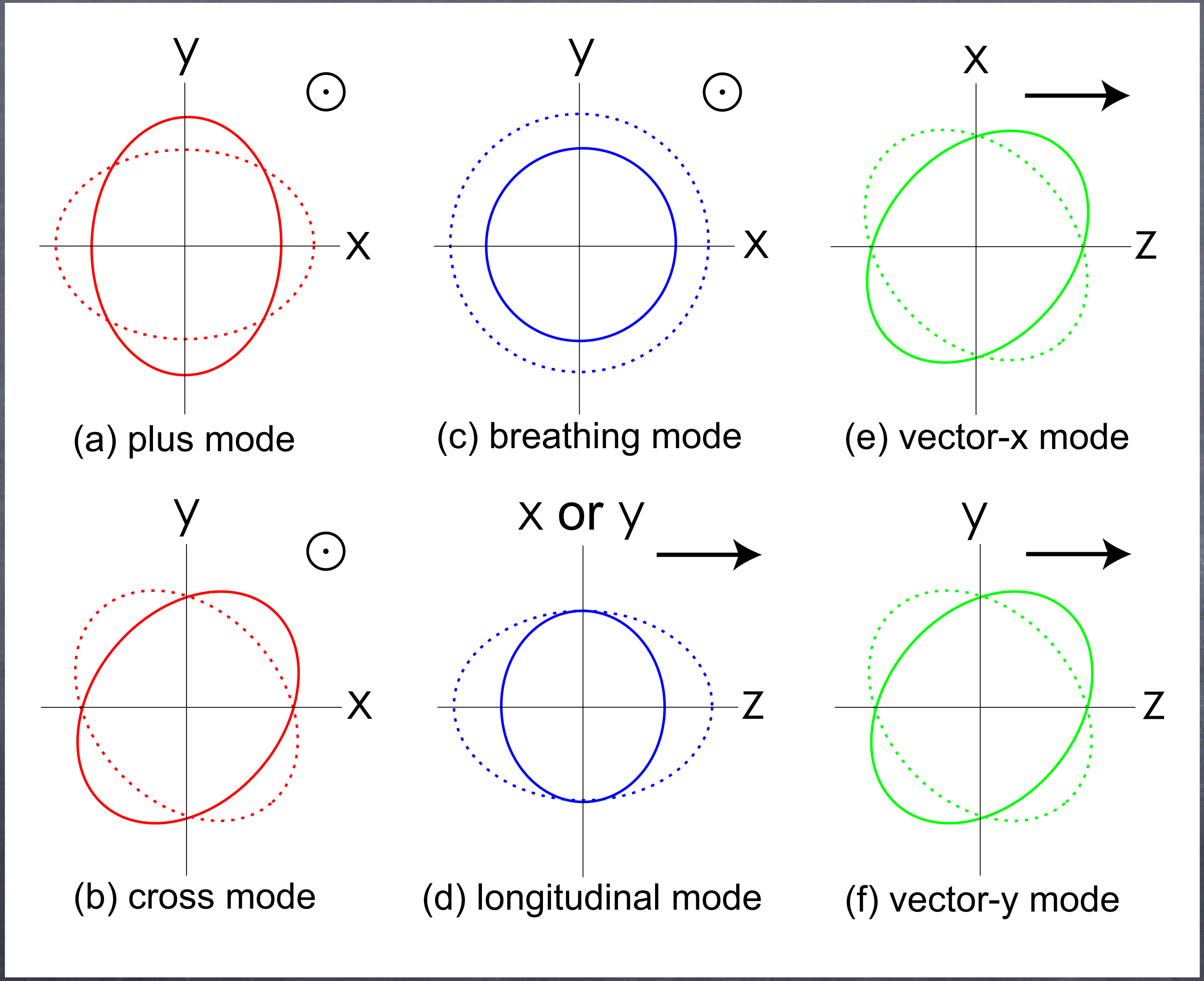
↓

Apply to various models of cosmology

GWs in alternative theories of gravity

Metric theories of gravity: 6 GW polarizations instead of 2

Tensor Scalar Vector



Transverse: +, x, breathing

Non-transverse: longitudinal, vector

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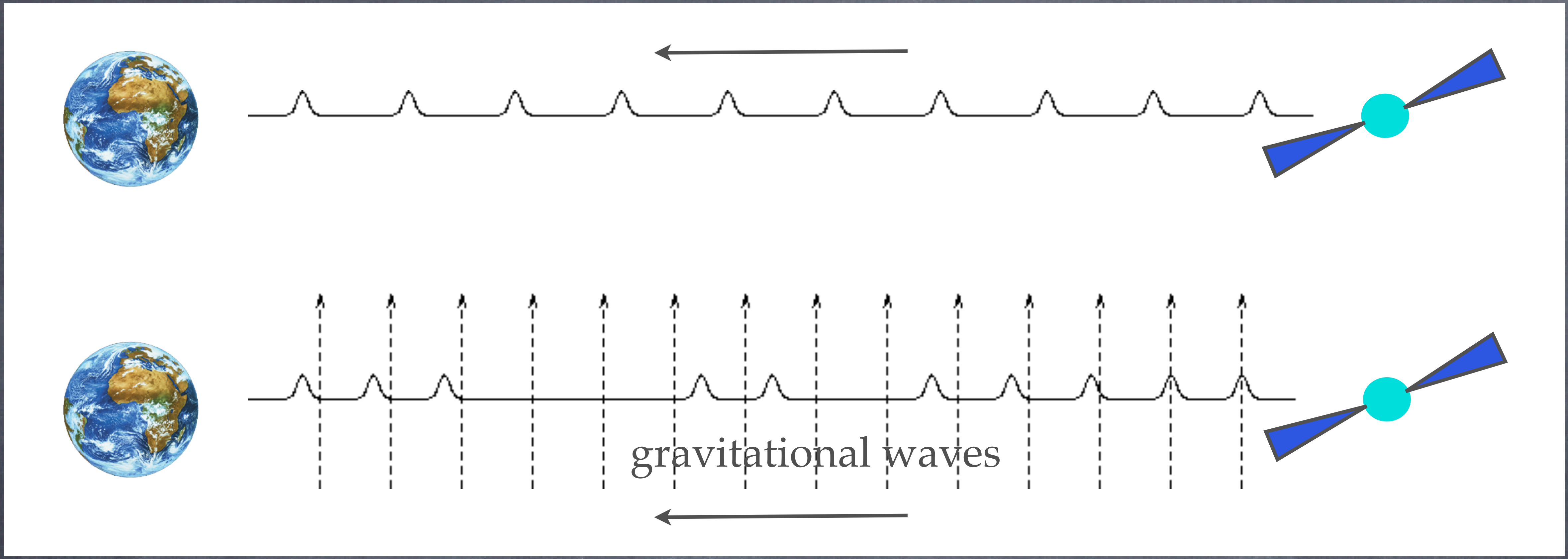
Claim: Pulsar timing arrays (PTAs) ideal for this physics

So... how do pulsars come into the picture?

A GW induces a redshift in the pulsar's signal:



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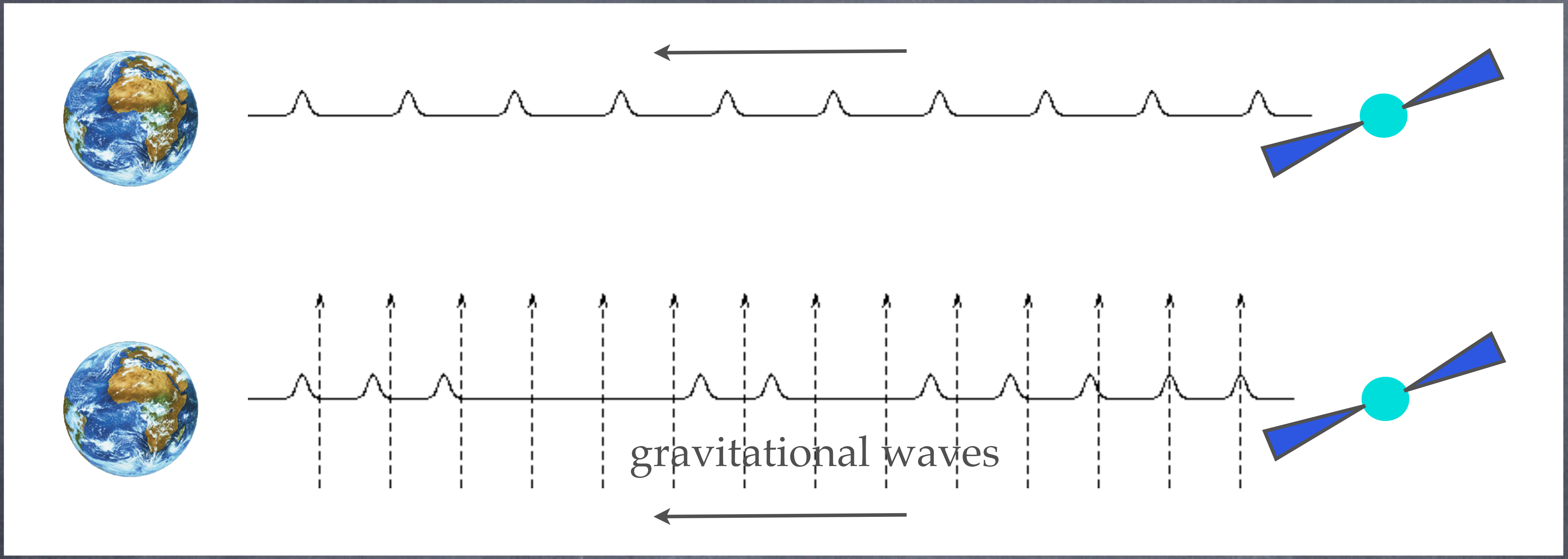


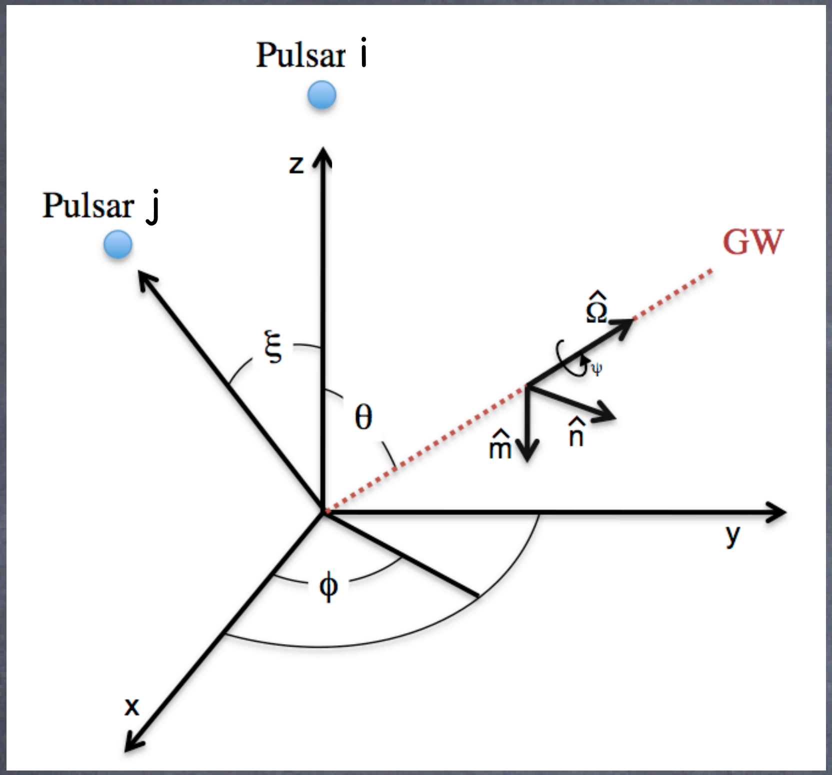
We measure the timing residual, R(t)

$$R(t) = \mathrm{TOA}_{\mathrm{actual}} - \mathrm{TOA}_{\mathrm{expected}}$$

where

$$R(t) = \int_0^t dt' z(t')$$

Ideal to cross correlate signals from different pulsars (hence the term "pulsar timing array"):



Pulsar positions:

$$p_1 = (0, 0, 1), \quad p_2 = (\sin\xi, 0, \cos\xi)$$

GW propagation direction: $\hat{\Omega}$

Expected cross-correlation:

$$\langle \tilde{z}_i^*(f)\tilde{z}_j(f')\rangle \propto \Omega_{gw}(f)\delta(f-f')\Gamma_{ij}(f)$$

source spectrum ($\Omega_{gw}(f)$)

overlap reduction function ($\Gamma_{ij}(f)$):
a geometrical factor, characterizes sensitivity and polarization properties

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PTAs see increased sensitivity to scalar-longitudinal and vector GWs!

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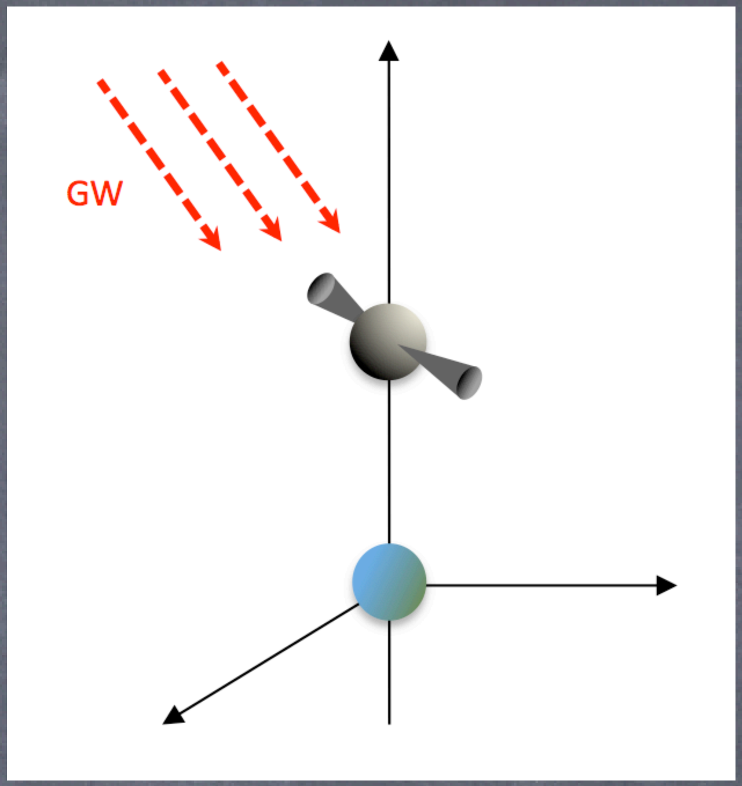

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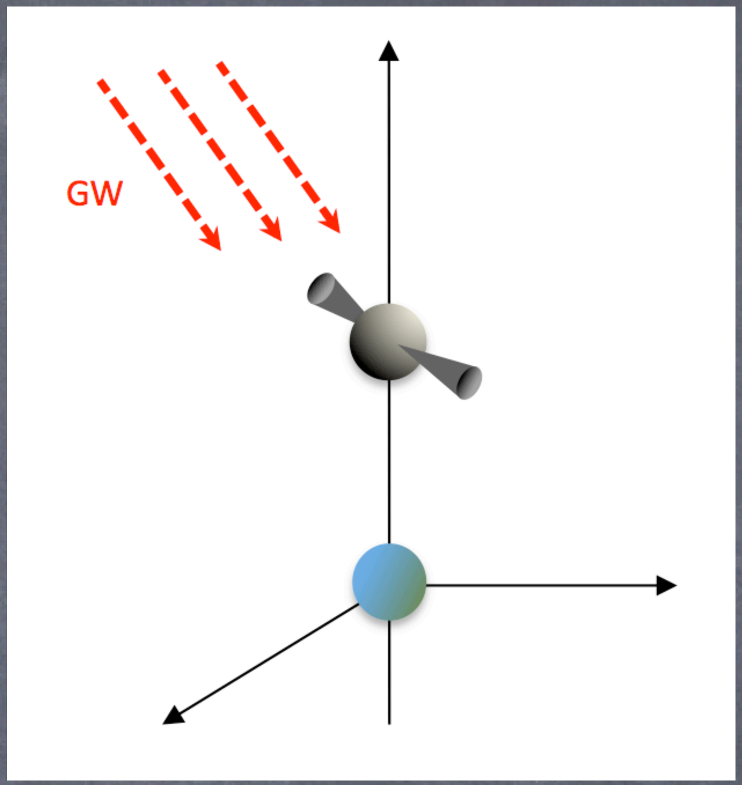

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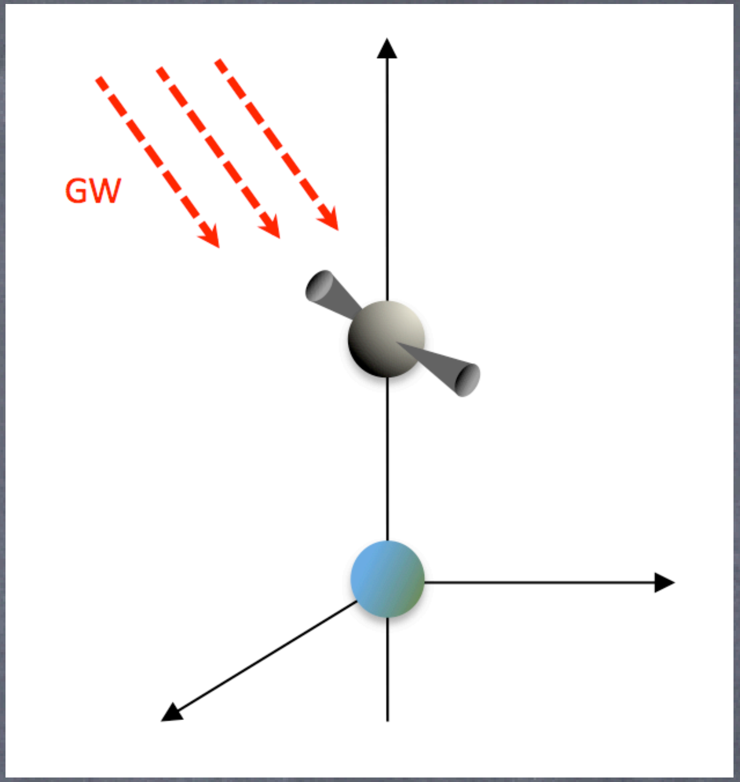

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$$\tilde{z}_+(f,\hat{z}) = \frac{-\sin^2\theta}{2(1+\cos\theta)}(e^{-2\pi i f L(1+\cos\theta)}-1)h_+$$ Tensor

$$\tilde{z}_y(f,\hat{z}) = \frac{-\cos\theta\sin\theta}{(1+\cos\theta)}(e^{-2\pi i f L(1+\cos\theta)}-1)h_y$$ Vector

$$\tilde{z}_l(f,\hat{z}) = \frac{\cos^2\theta}{2(1+\cos\theta)}(e^{-2\pi i f L(1+\cos\theta)}-1)h_l$$ Scalar

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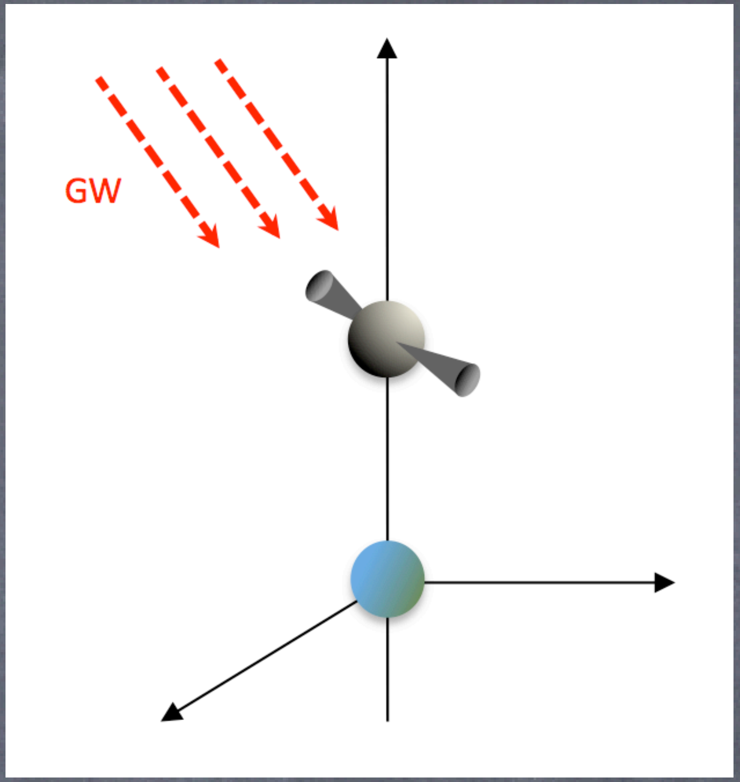

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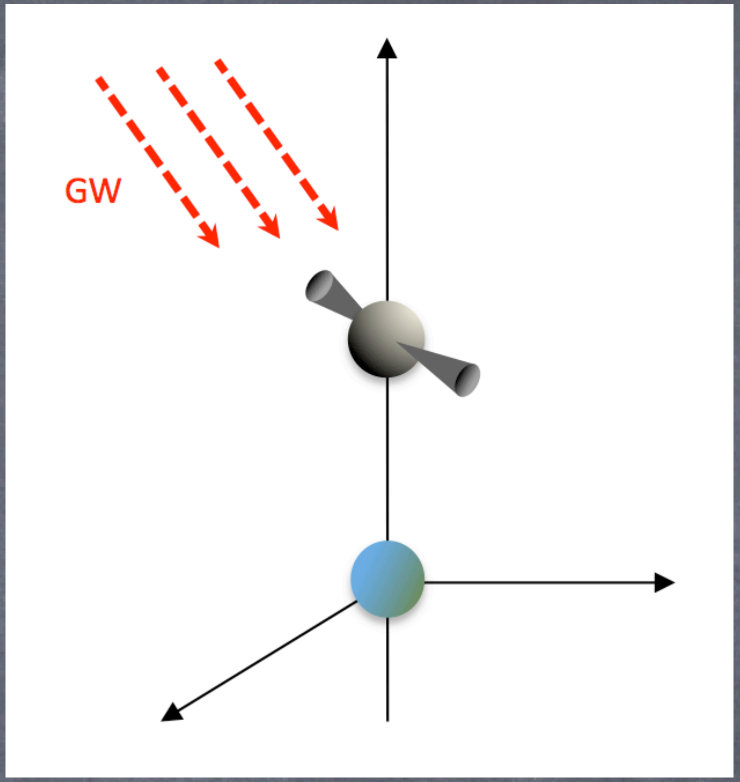
what happens when $\theta \approx \pi$?

Can Taylor expand the exponential terms:



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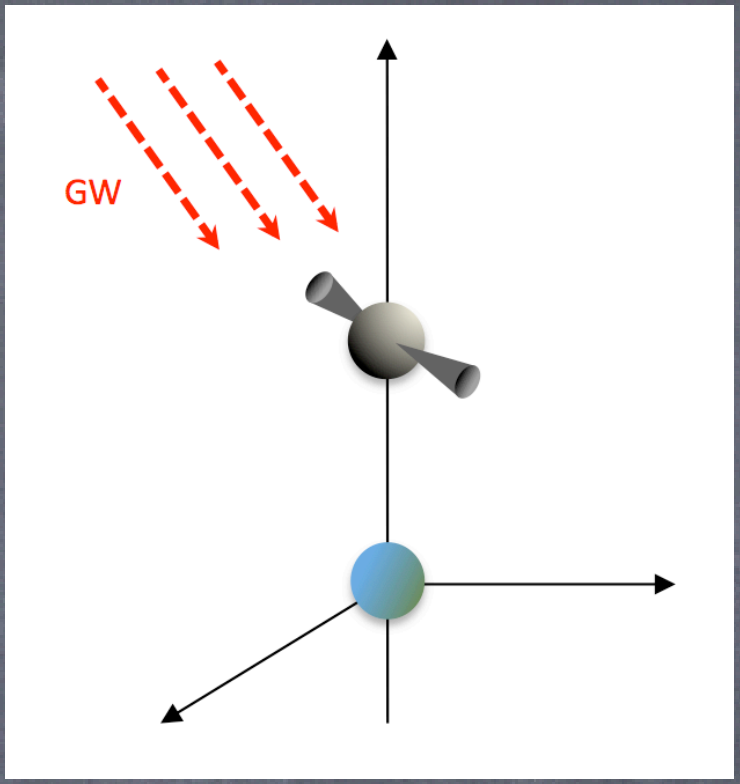

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We get:

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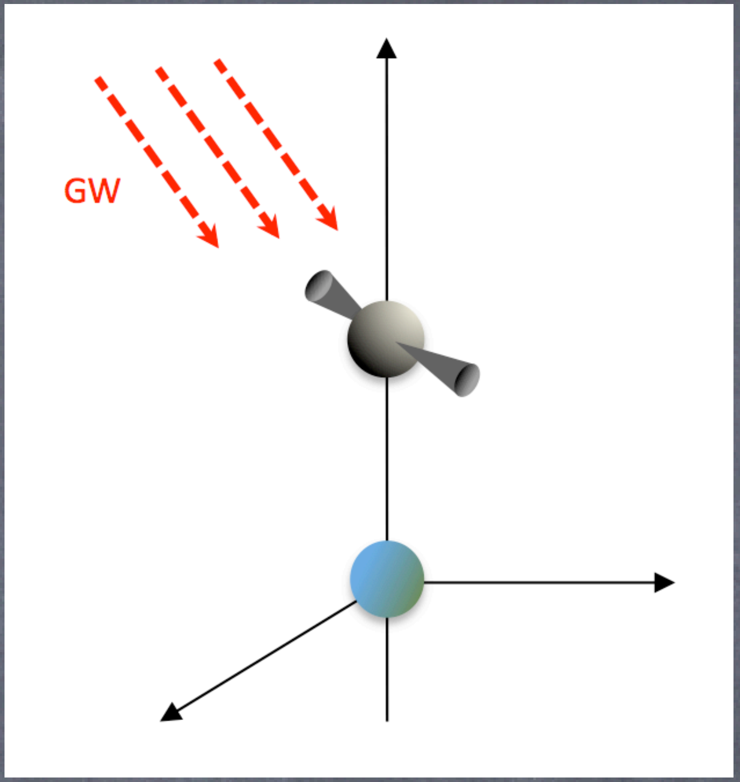

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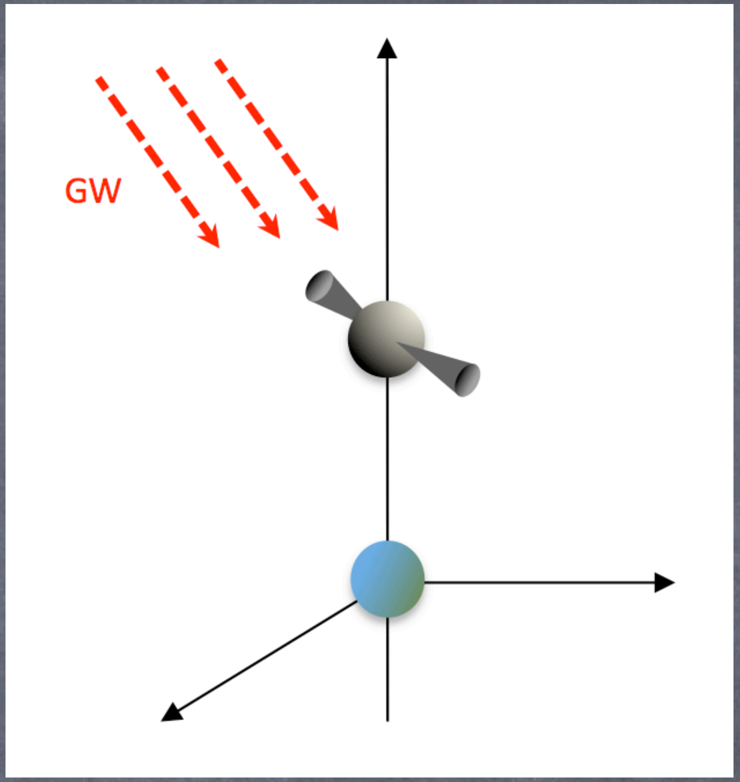

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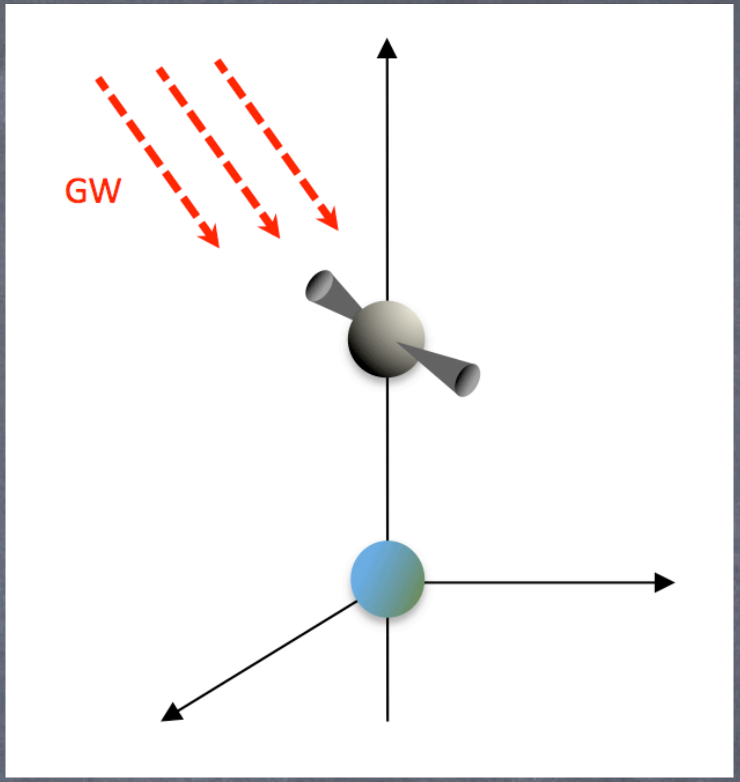

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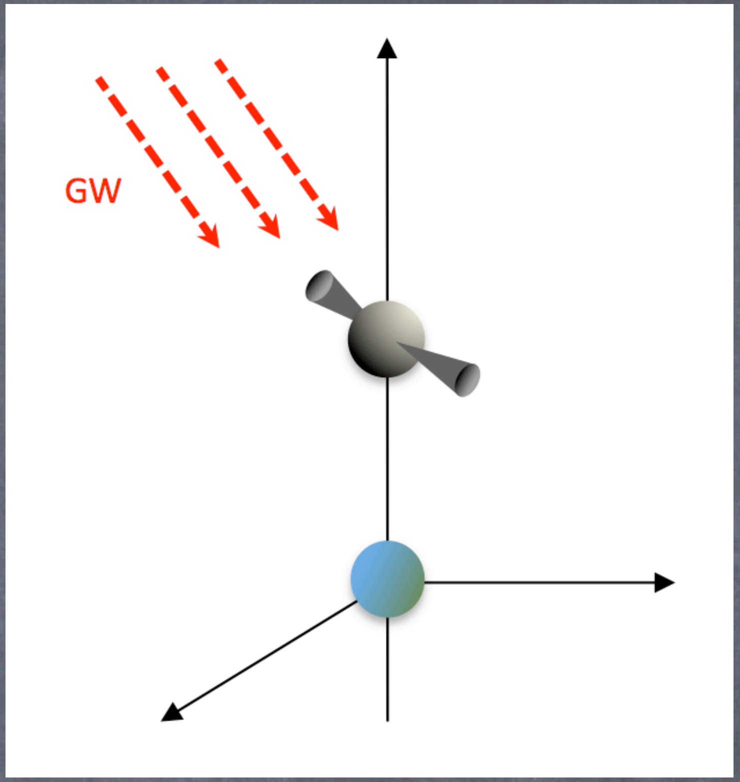

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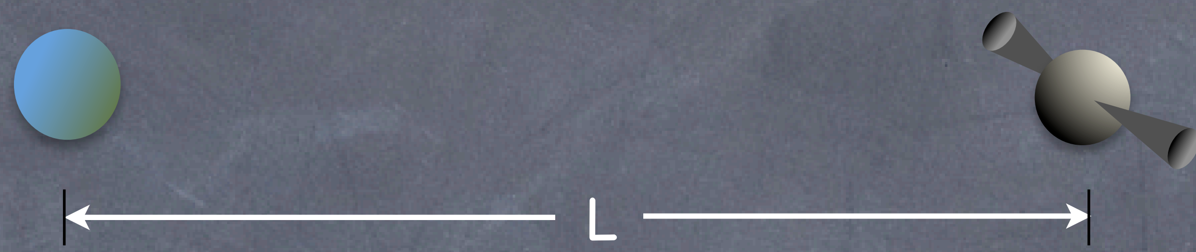
Response for the scalar-longitudinal mode doesn't vanish in this sky position!

In the time domain,

$$z_l(t, \hat{z}) \propto L\dot{h}$$



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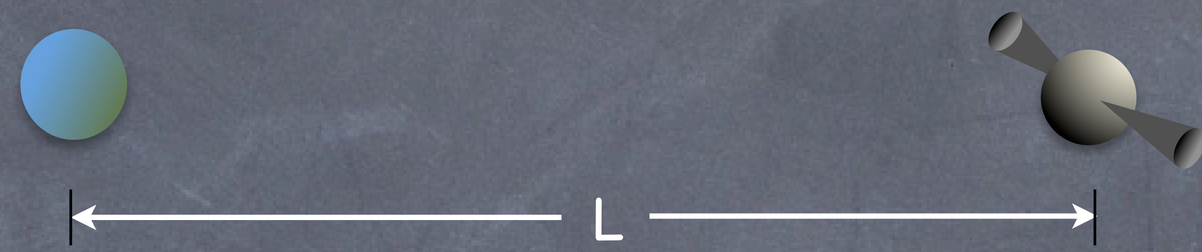

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PTAs see huge gains in sensitivity to scalar-longitudinal GWs for nearby pulsar pairs!
(effect also apparent at lesser scale for vector modes)

Conclusions

- Alternative theories of gravity are a promising solution to the problems facing cosmology
- Detection of GWs is an excellent (maybe the best) way to test these theories and place bounds on their parameters
- PTAs have increased sensitivity to the scalar-longitudinal and vector polarization modes that appear in some alternative theories (this could make testing GR even more feasible)

<u>Physics with PTAs complements current efforts in cosmology!</u>

For more details, see arXiv: 1111.5661