Testing General Relativity with Gravitational Waves

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Compton Lectures
University of Chicago

https://github.com/reedessick/compton-lectures-2019

Review

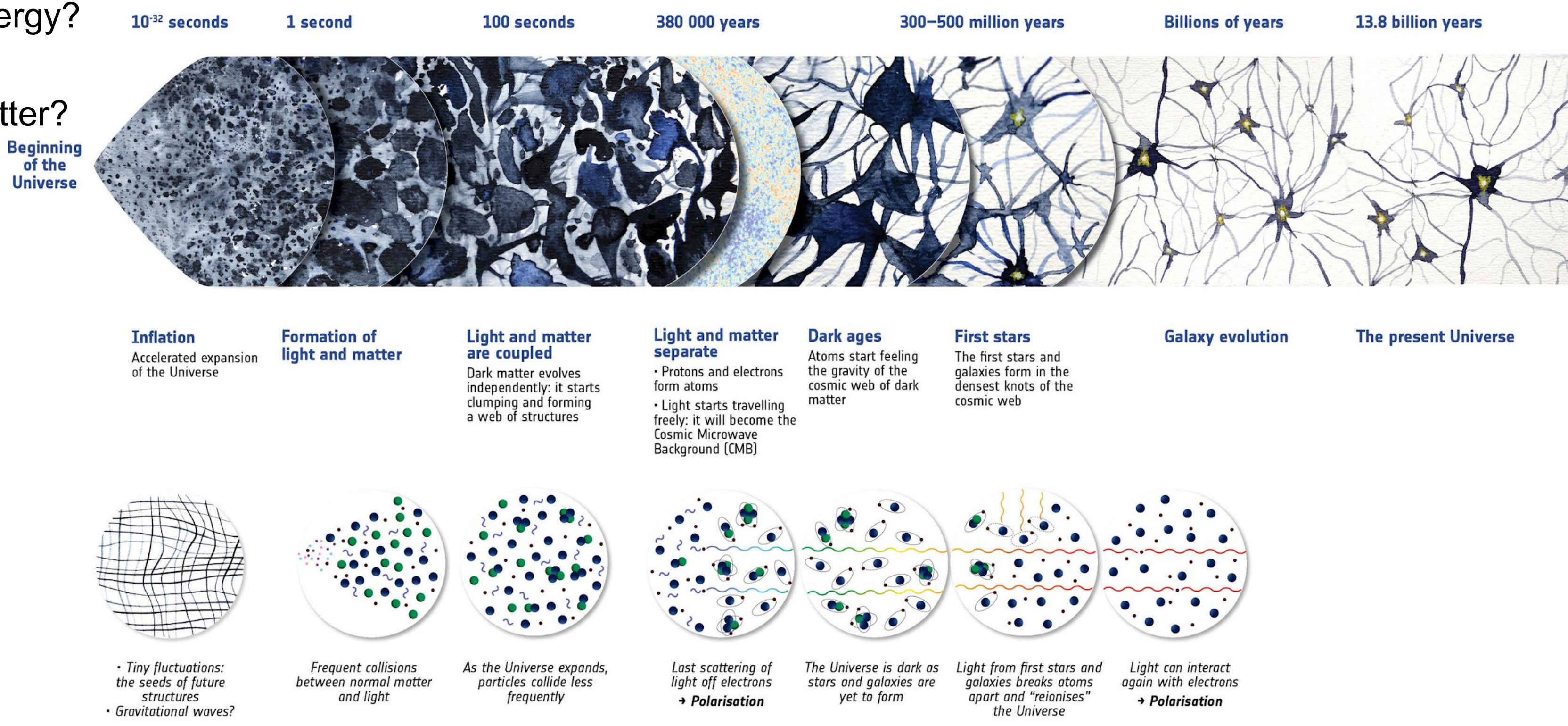
General Relativity Basics

- Equivalence principle
- GWs travel at speed of light
- 2 polarizations

Review

Why test General Relativity?

- Dark Energy?
- Dark Matter?



Review

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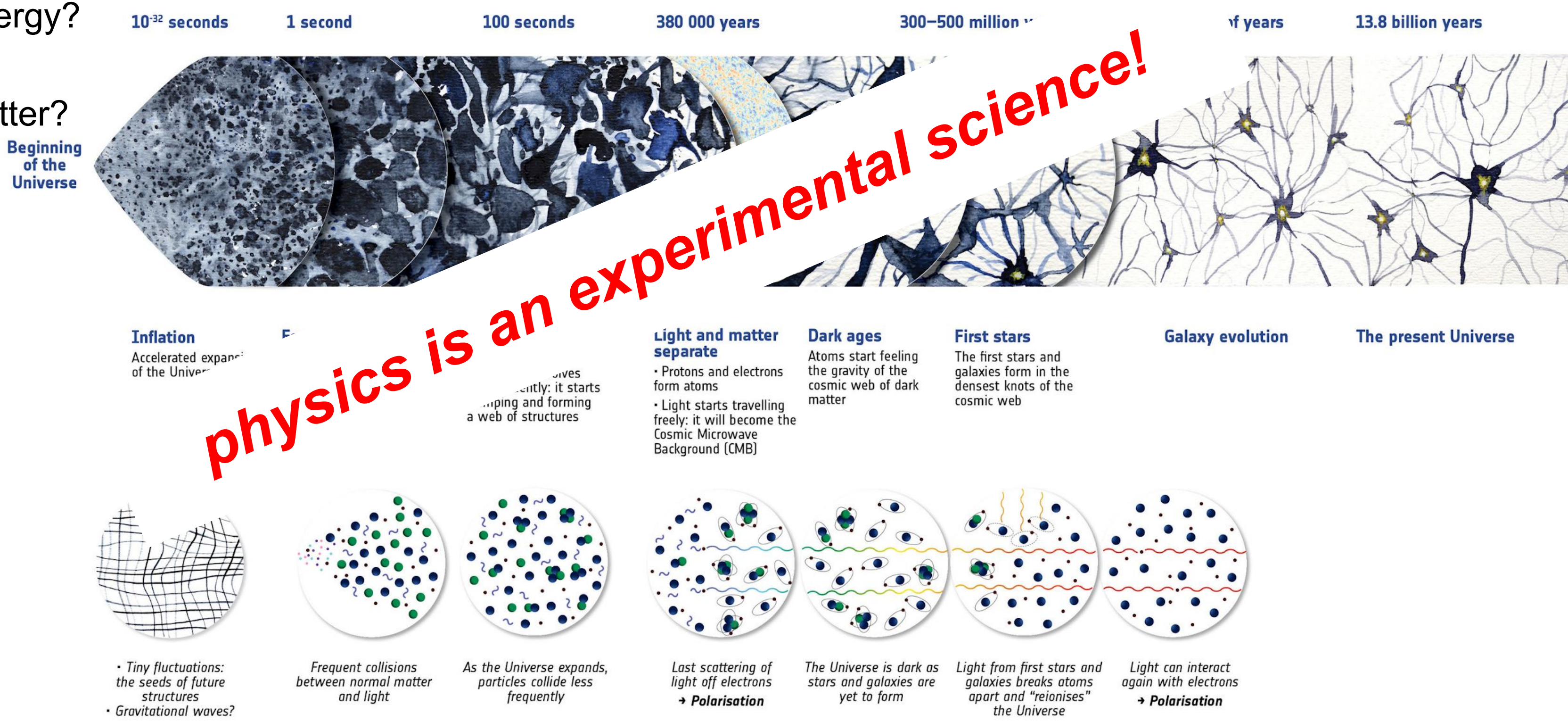
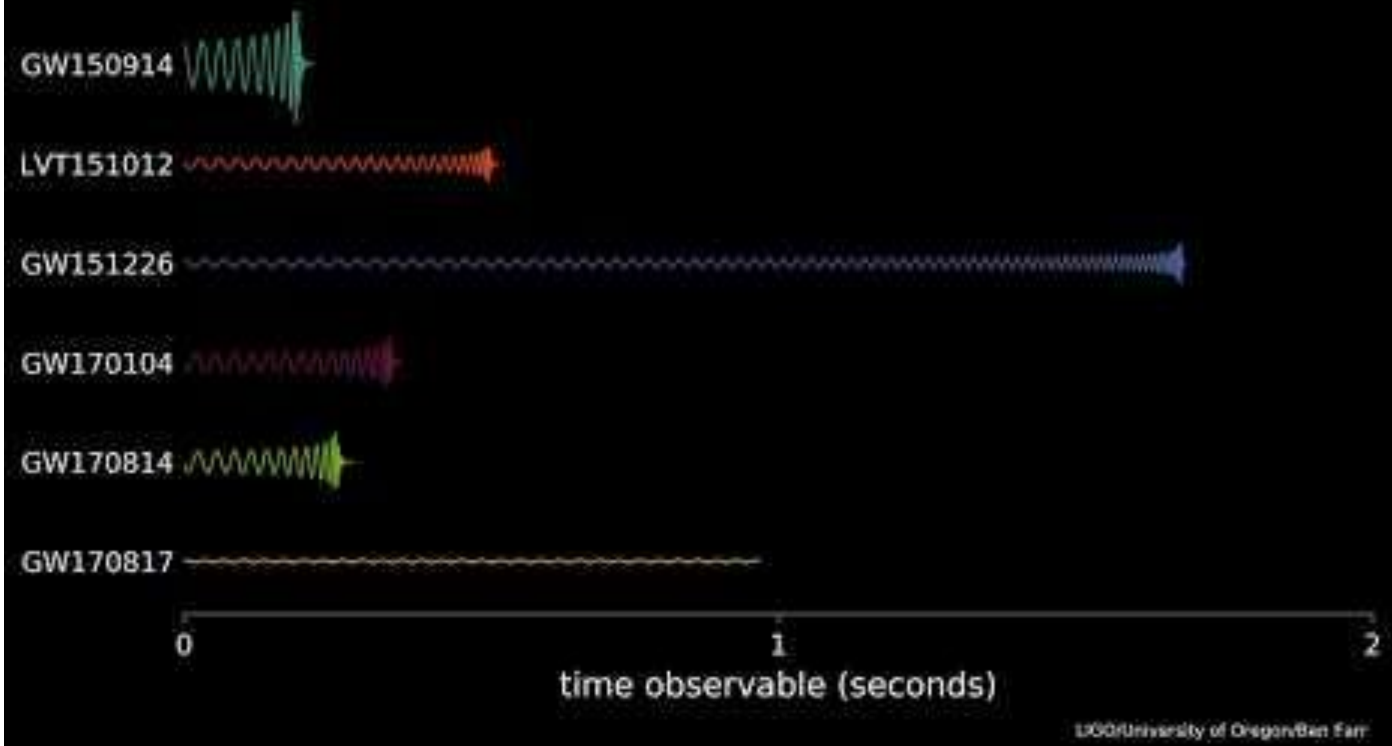
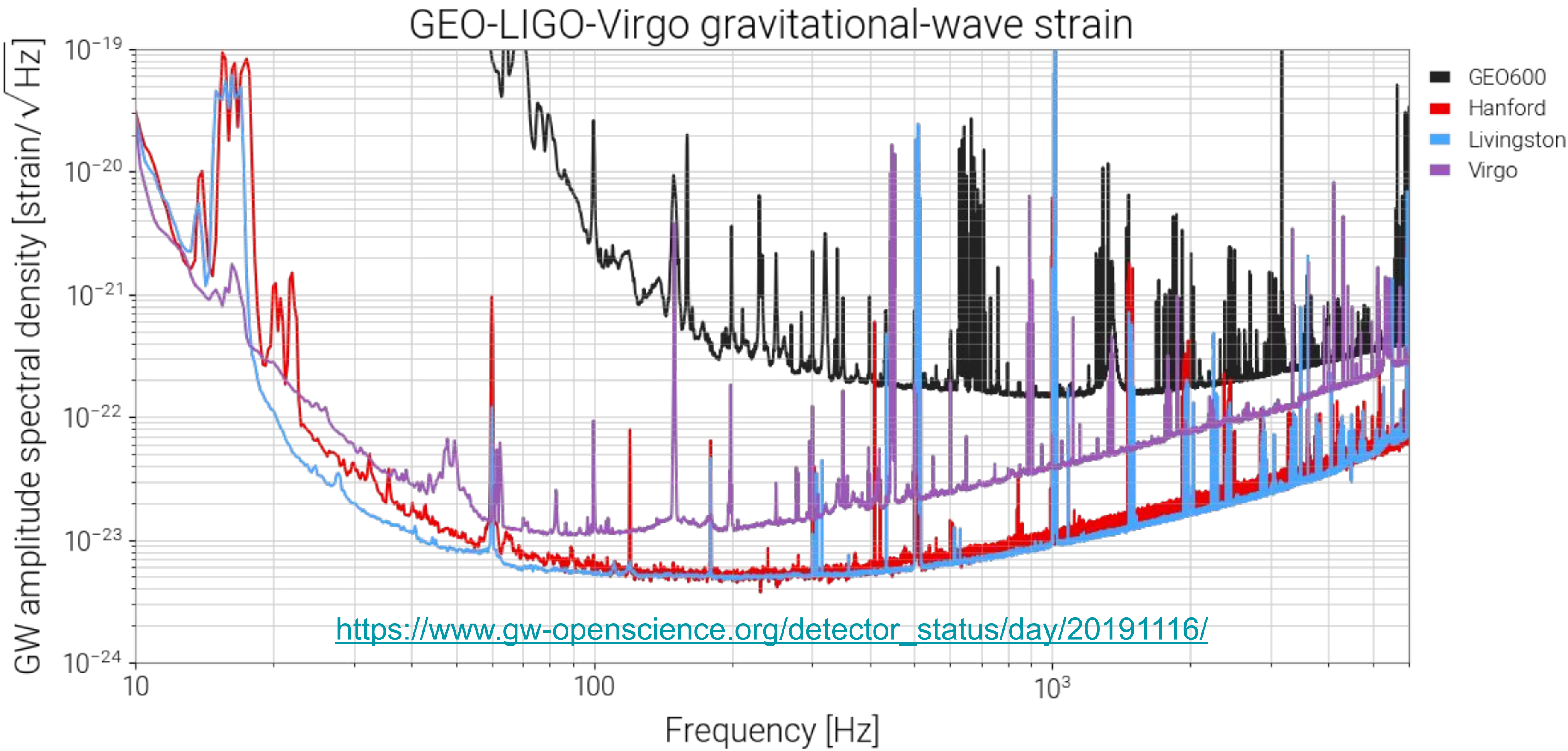


Review

CBC signal types

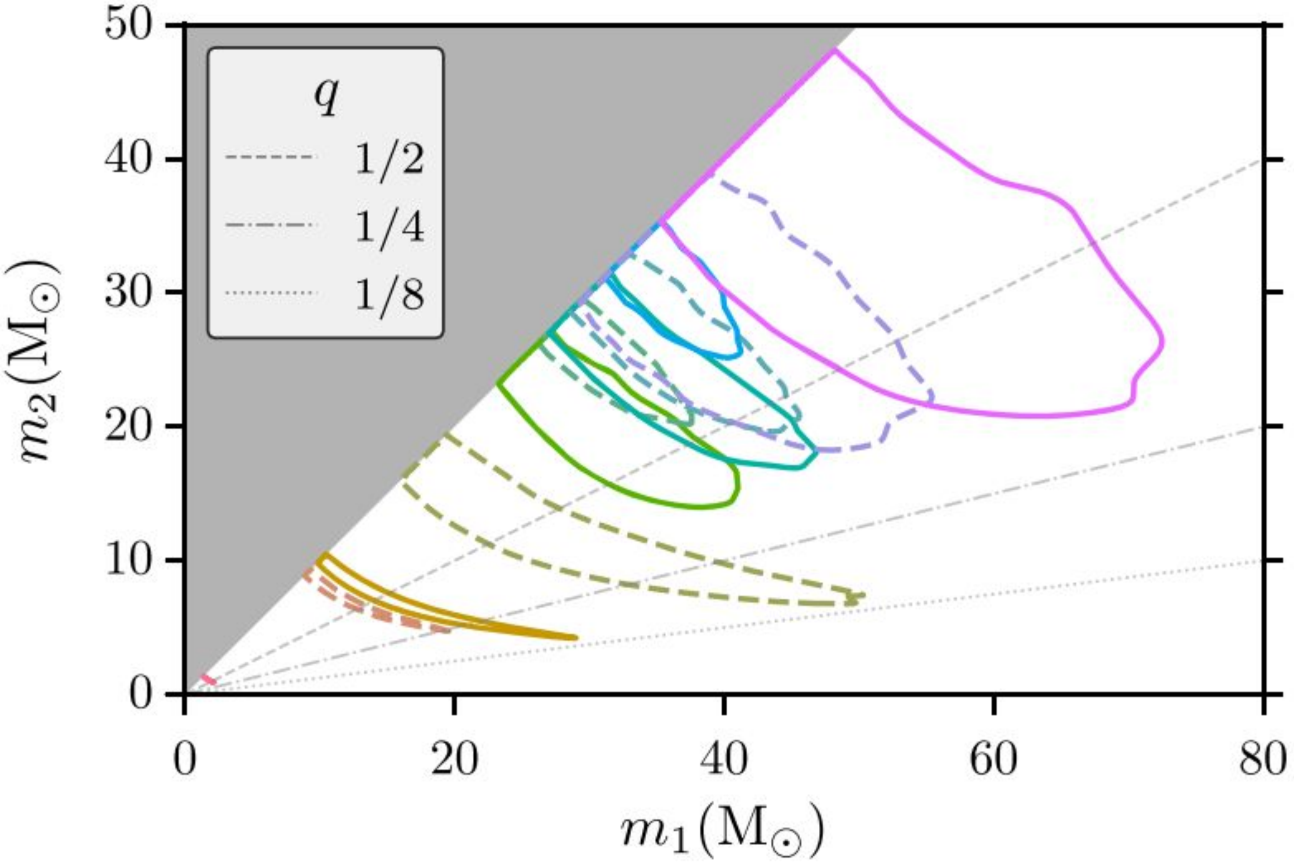


Review



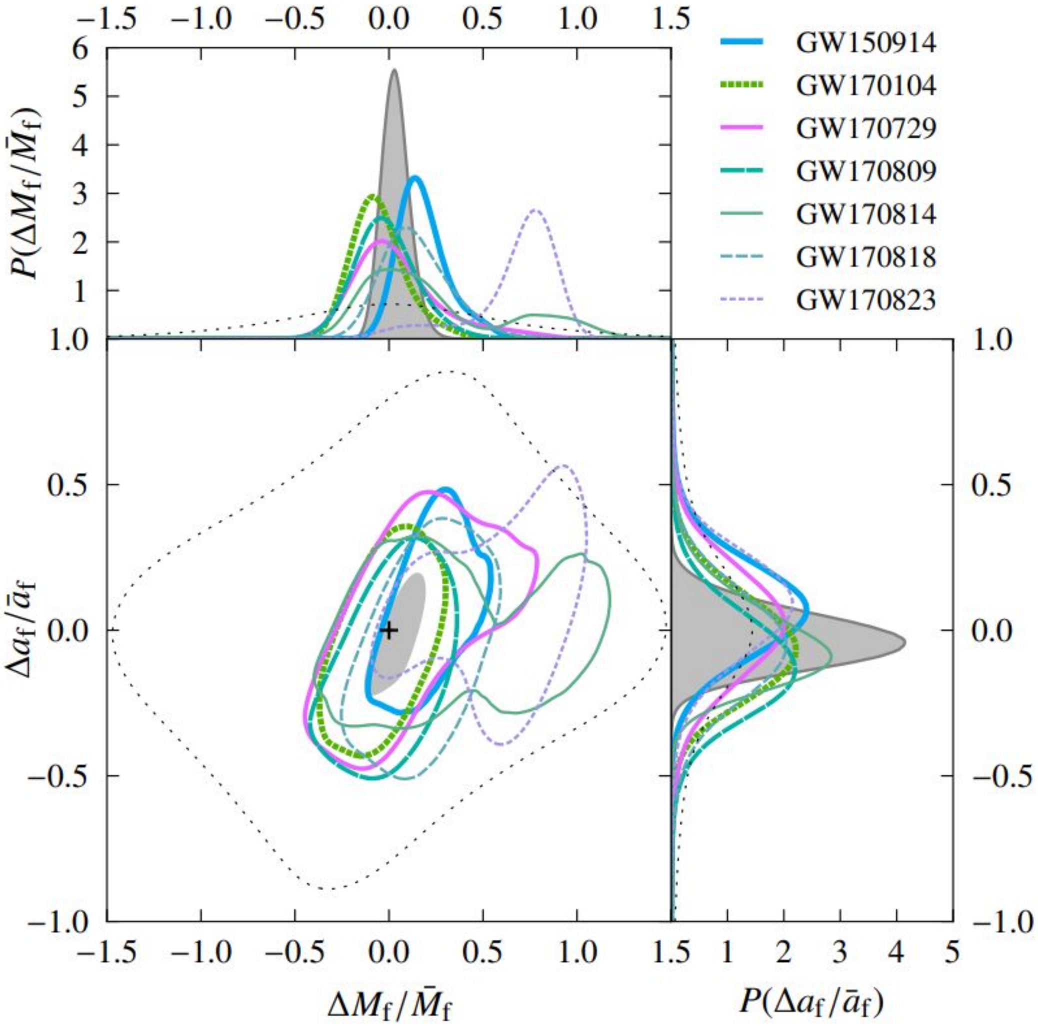
https://www.gw-openscience.org/detector_status/day/20191116/

Review



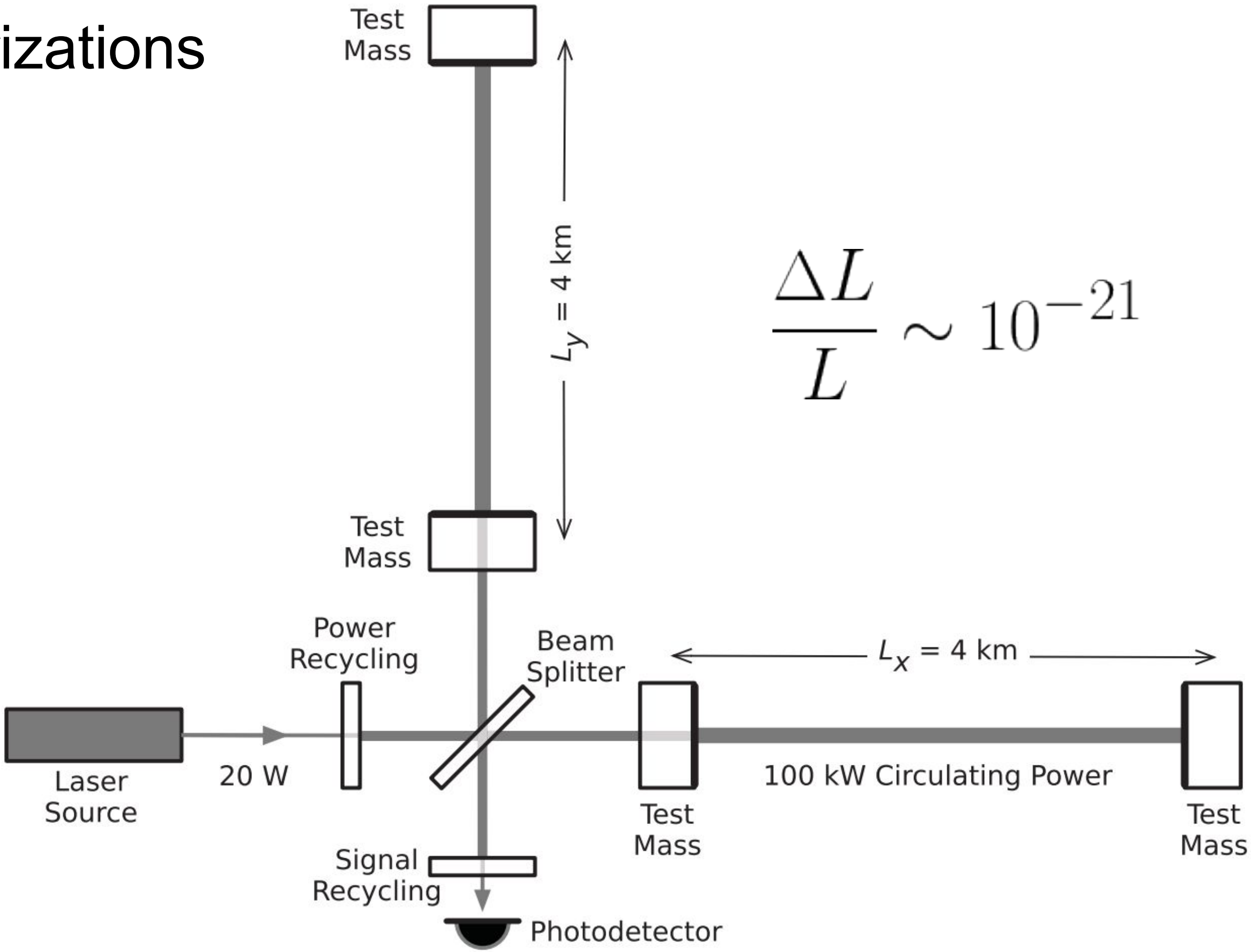
q
1/2
1/4
1/8
50
40
30
20
10
0
0
20
40
60
80
$m_2(\mathrm{M}_\odot)$
$m_1(\mathrm{M}_\odot)$

Masses+Spins



Number of Polarizations

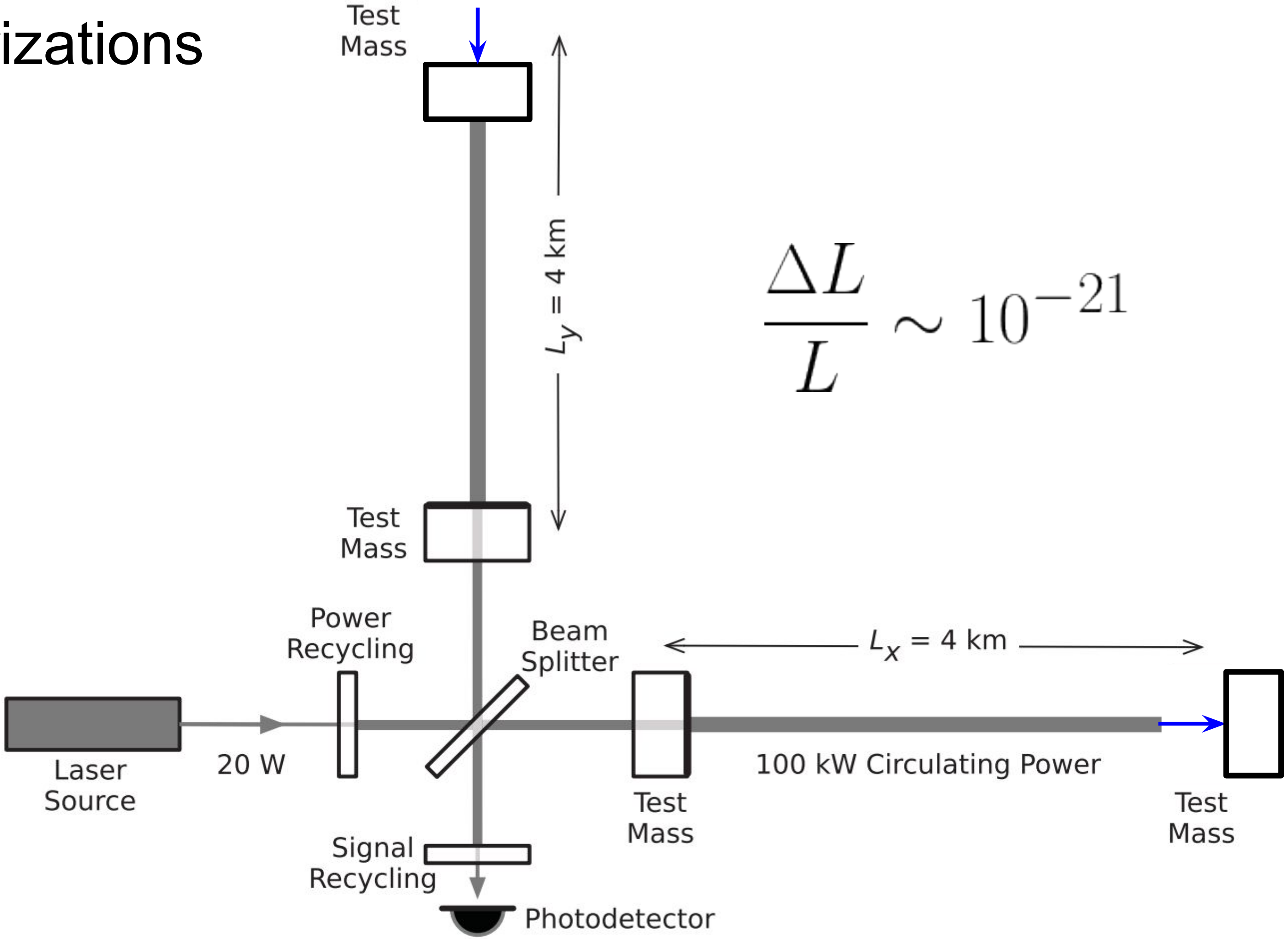
Tensor Modes



$$\frac{\Delta L}{L} \sim 10^{-21}$$

Number of Polarizations

***Tensor* Modes**



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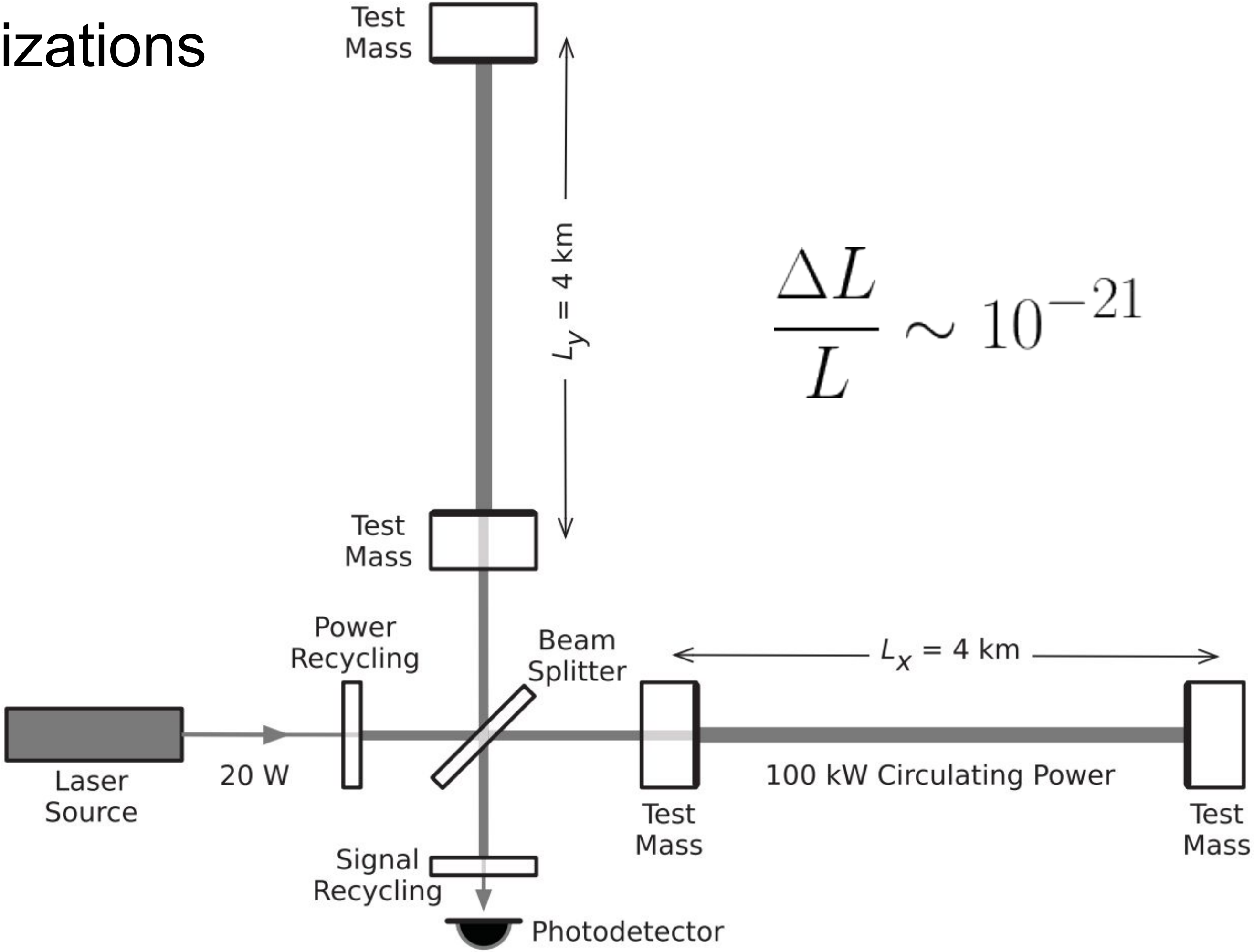

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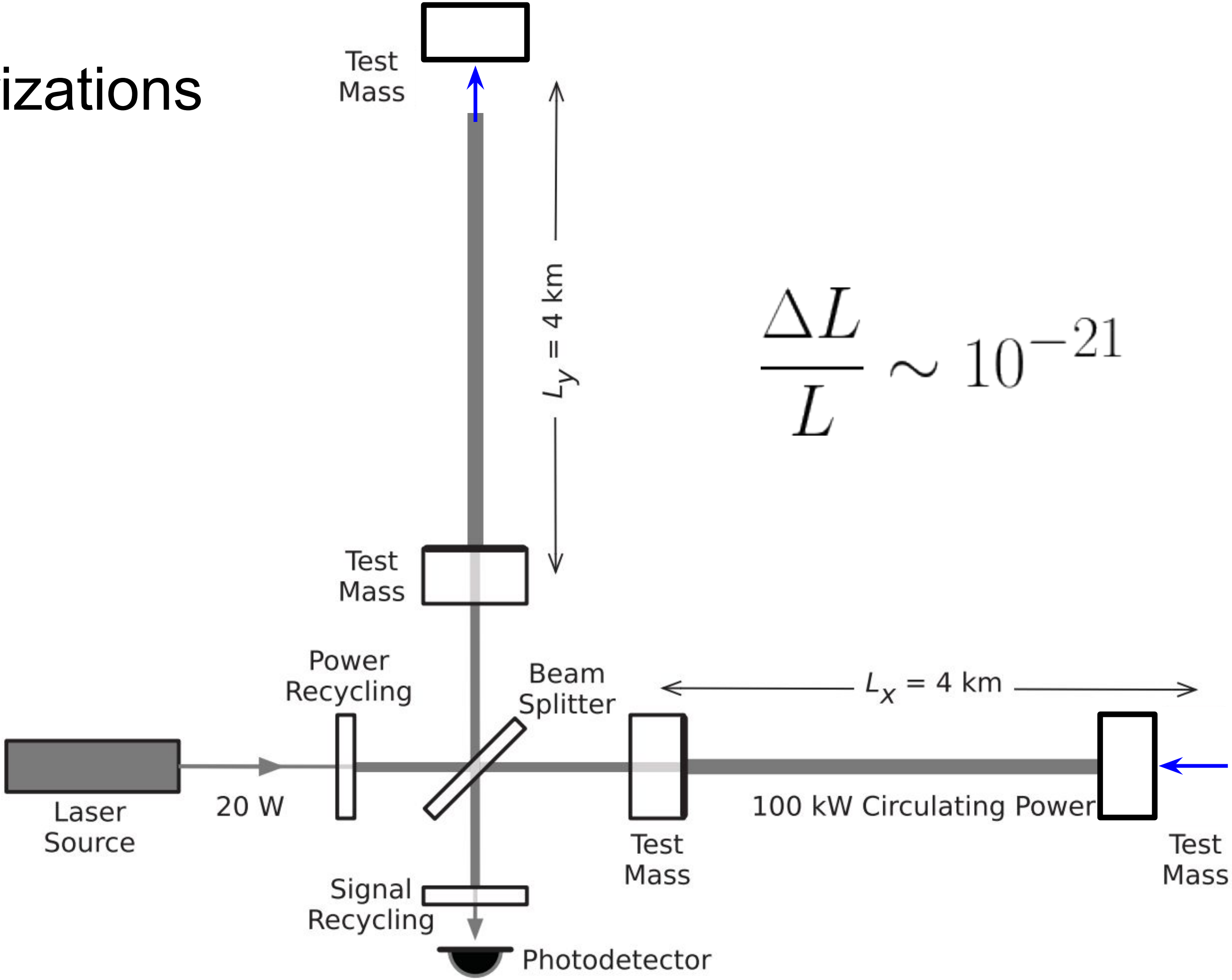

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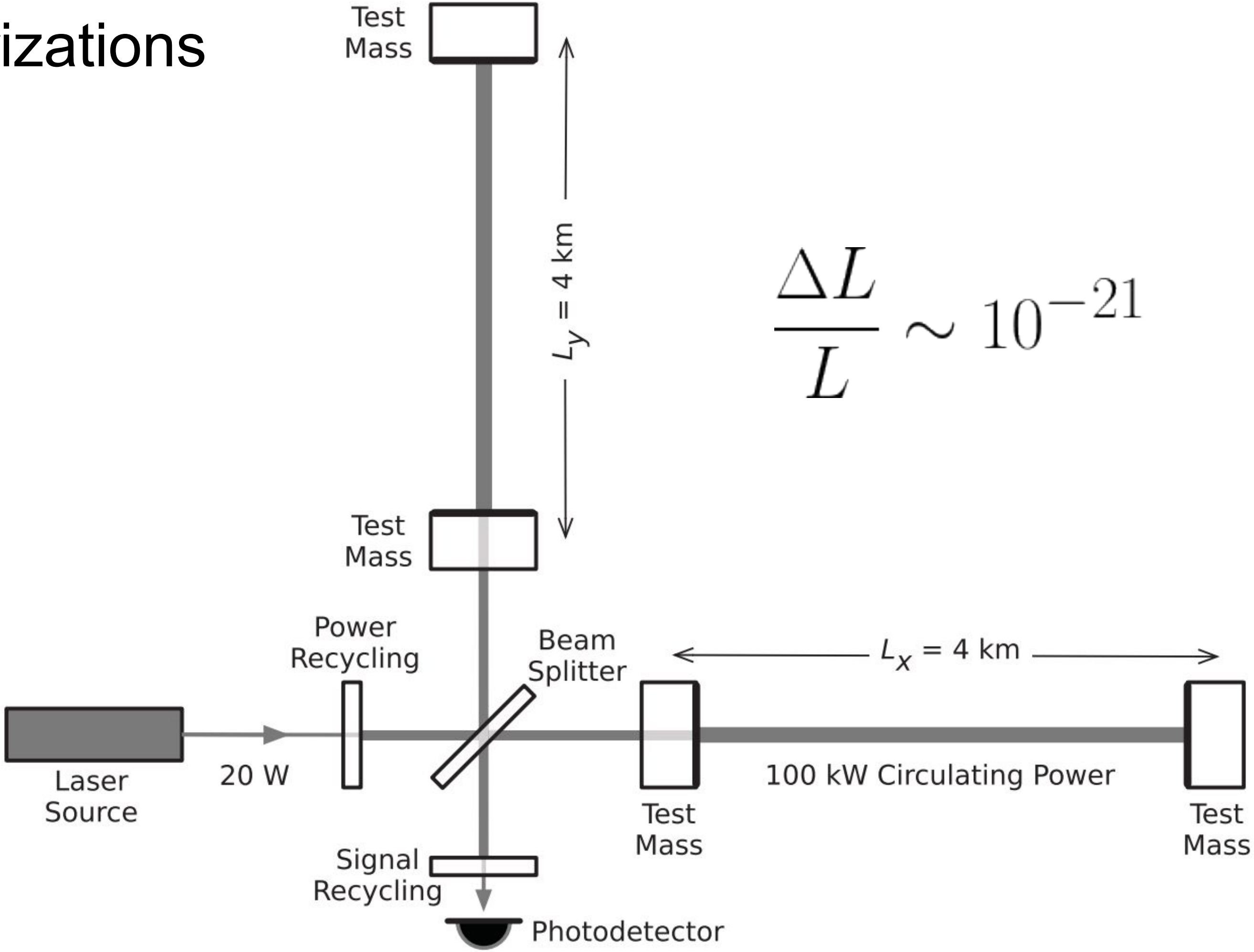
Number of Polarizations

Vector Modes



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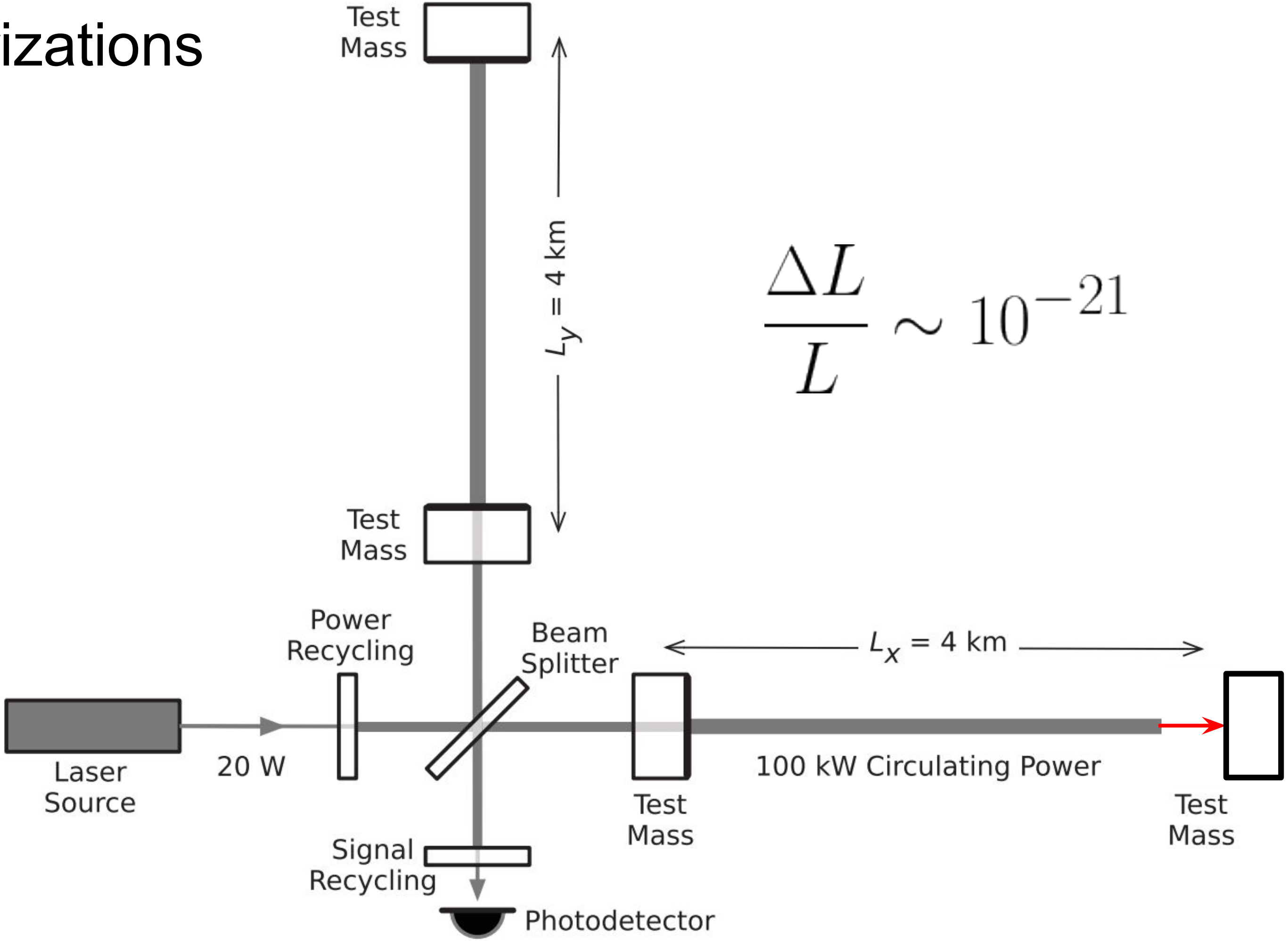

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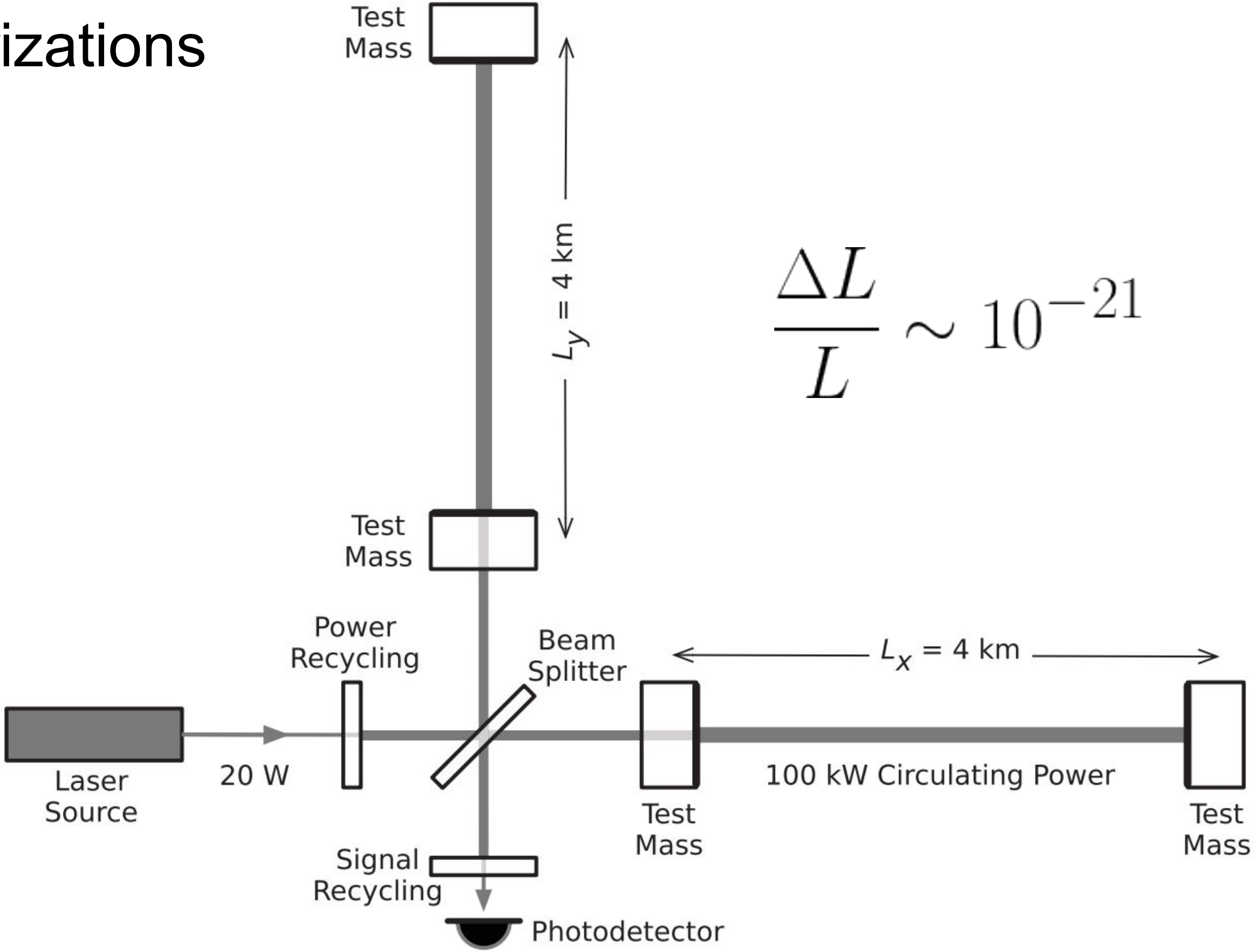

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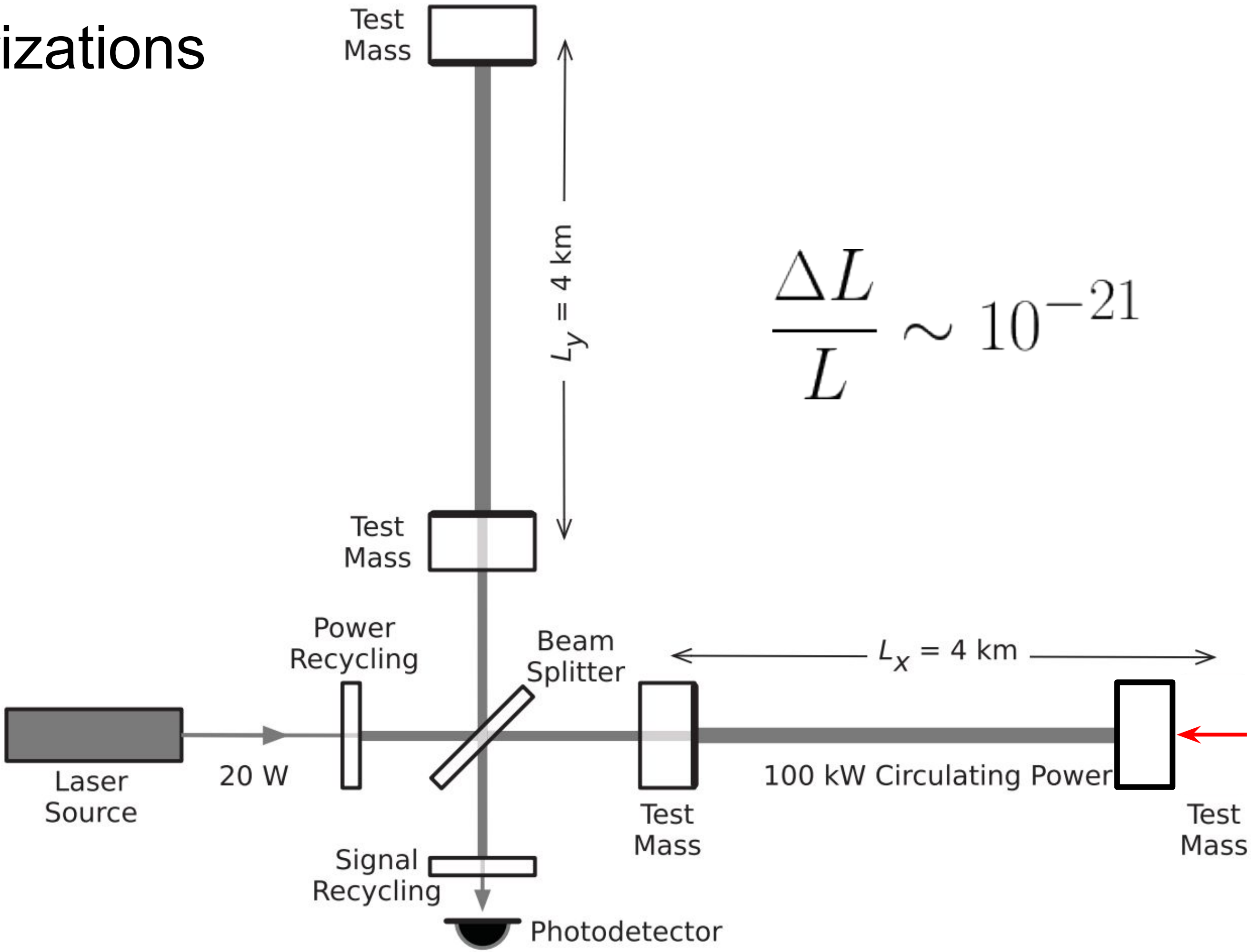

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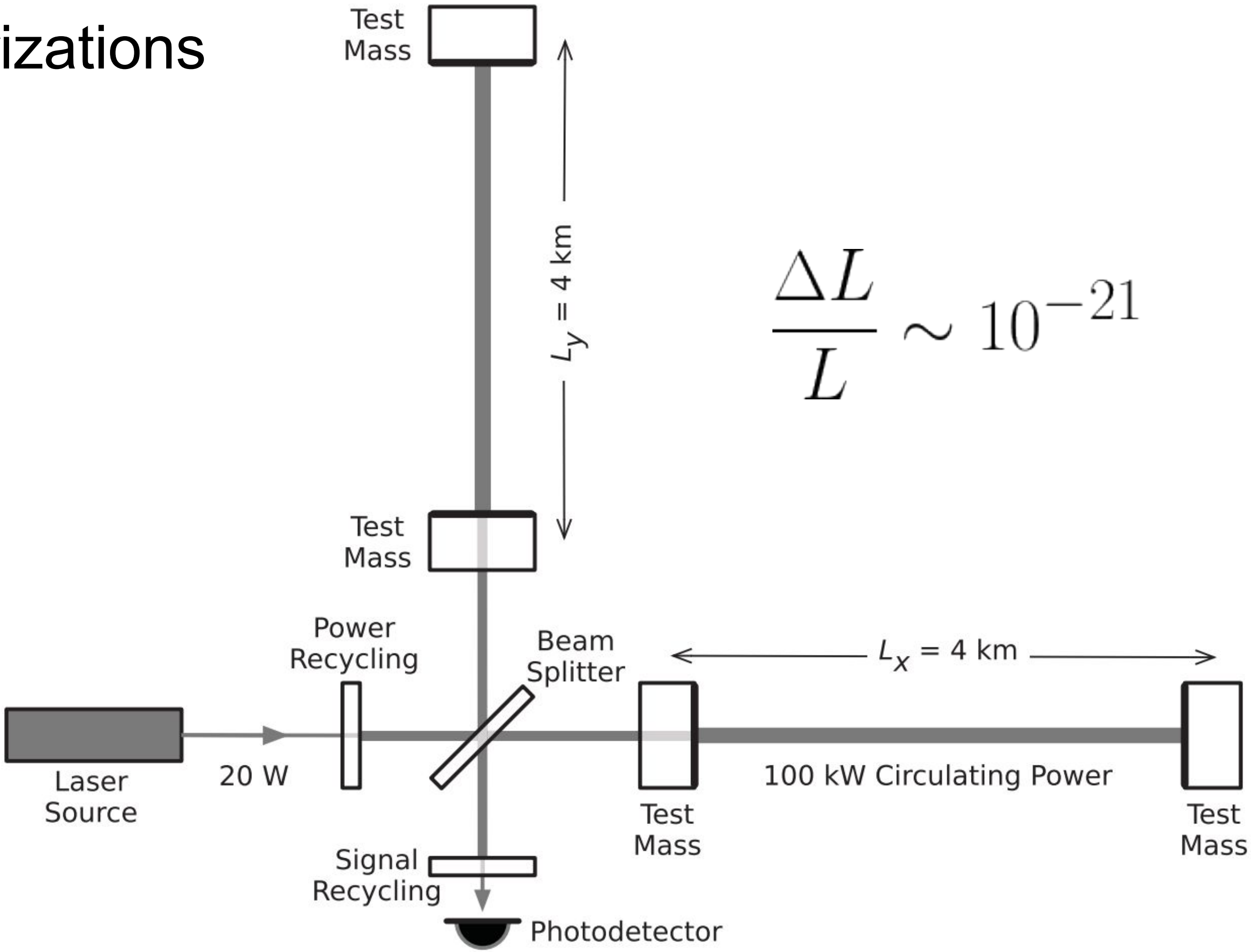
Number of Polarizations

Scalar Modes



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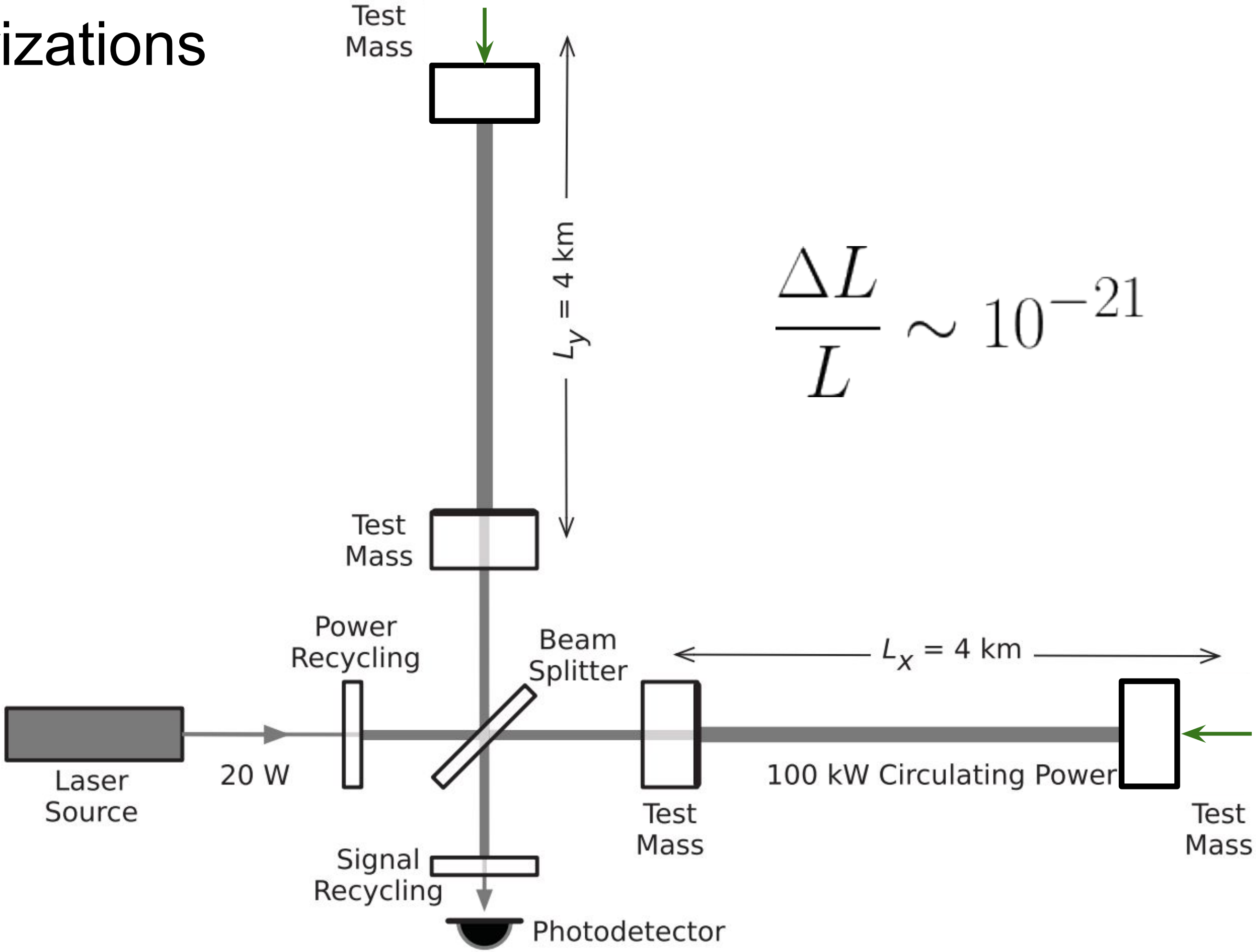

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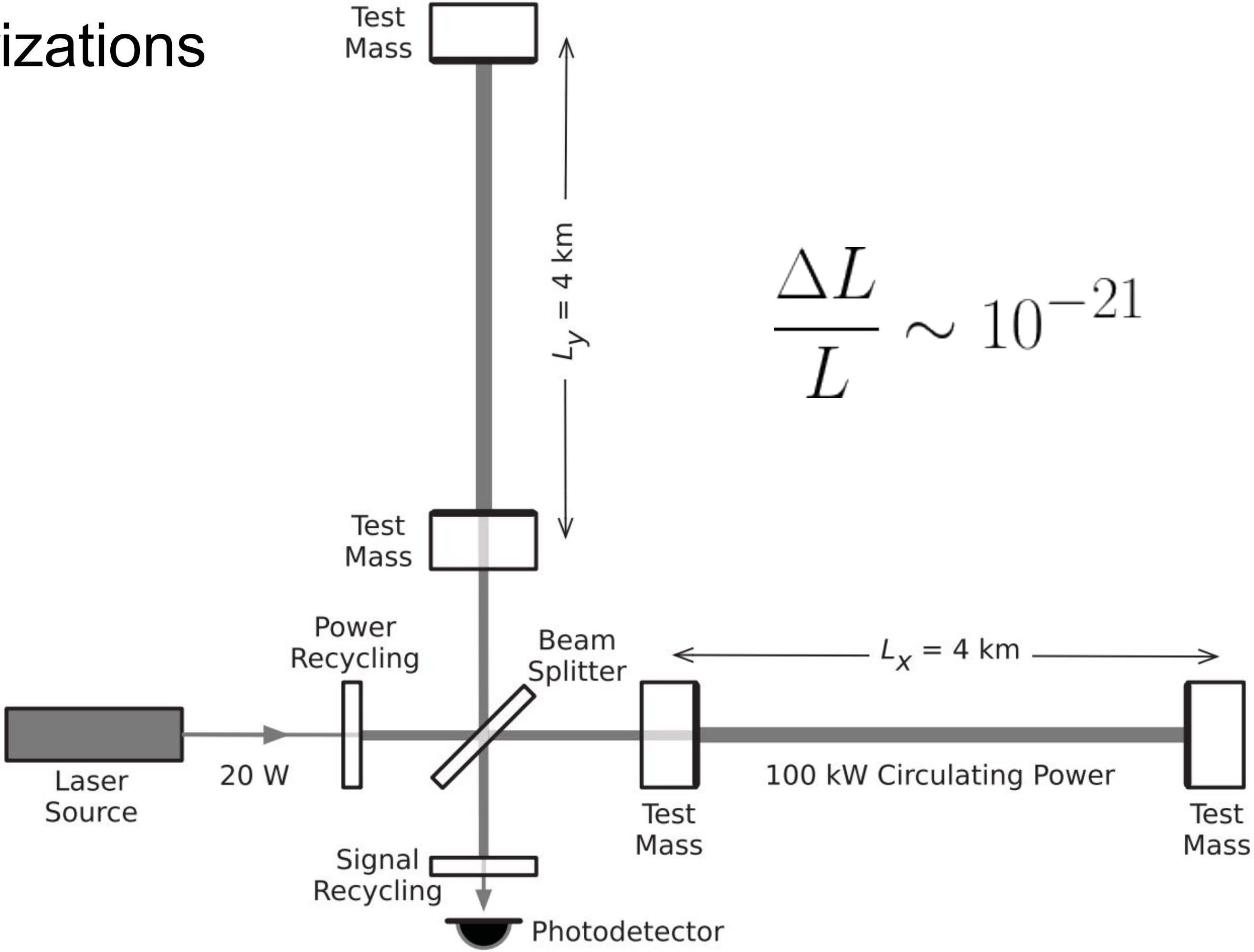

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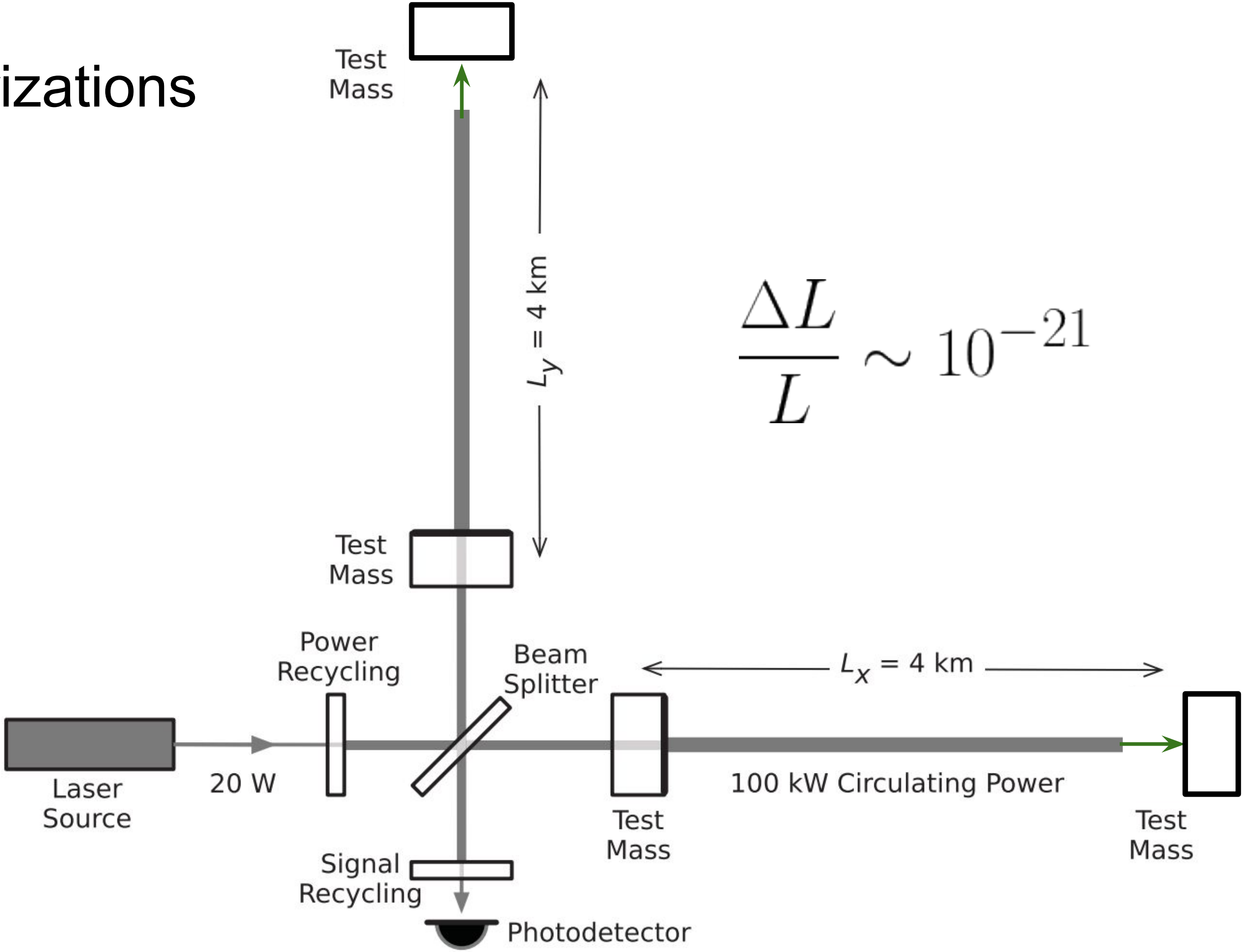

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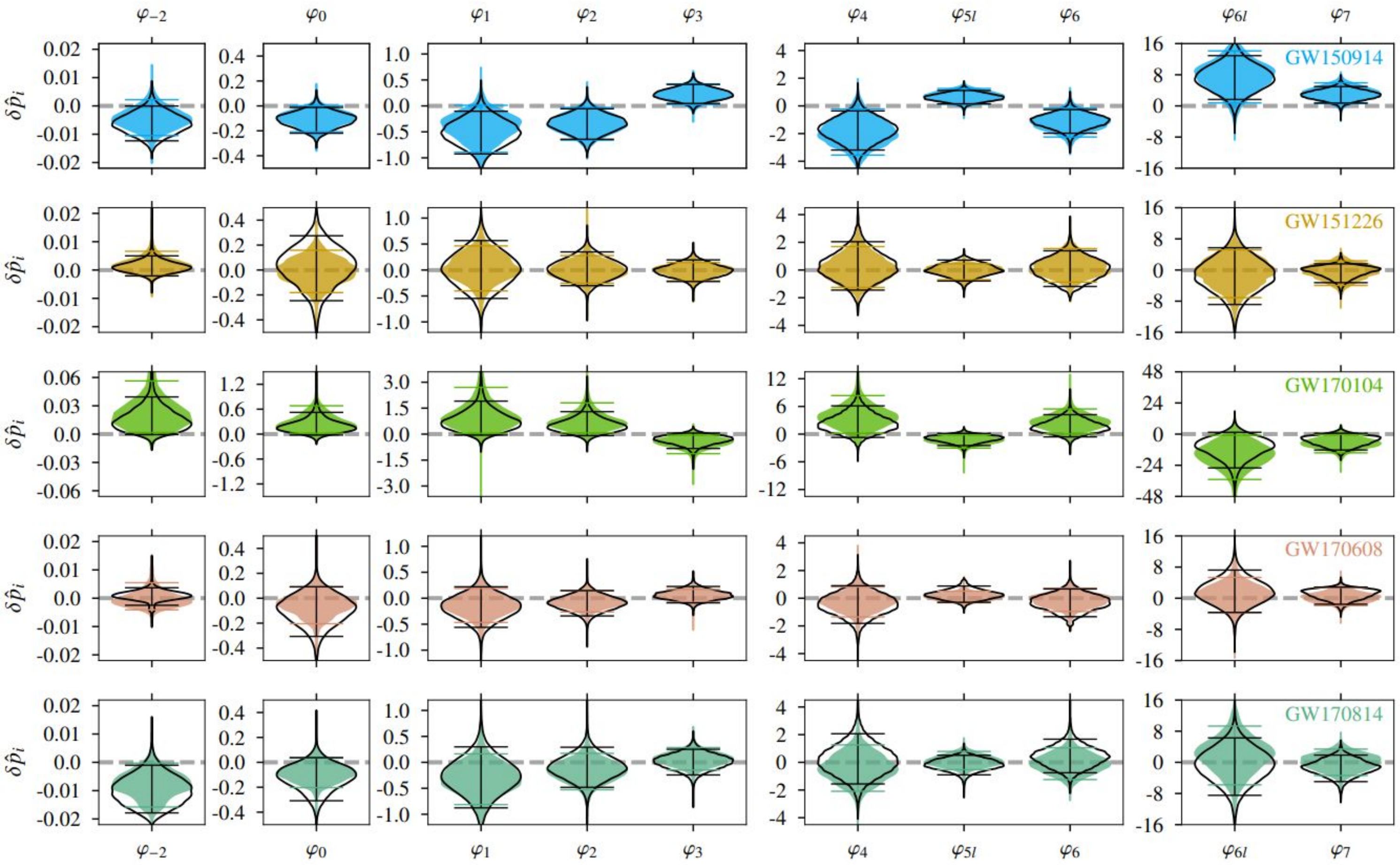
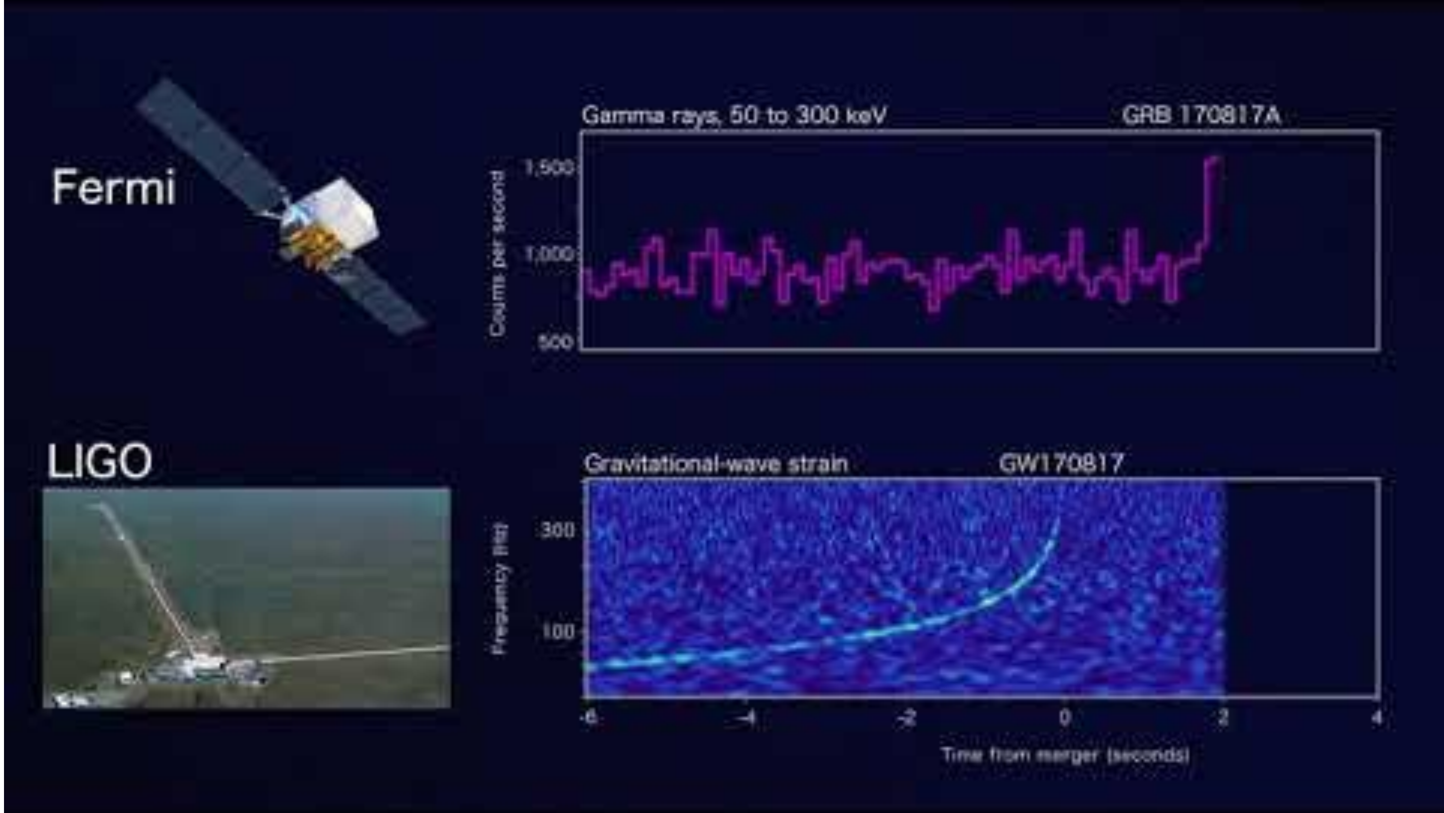
Orbital Evolution

Parameterized tests come up with an alternative model and see if the data matches it better



Speed of Gravity



Speed of Gravity

$$\Delta t = \frac{D}{c} - \frac{D}{c_{\mathrm{GW}}} \approx \frac{D}{c}\left(\frac{c_{GW} - c}{c}\right)$$

Speed of Gravity

Speed of gravity

Mass of the graviton

$$E^2 = m^2c^4 + c^2p^2$$

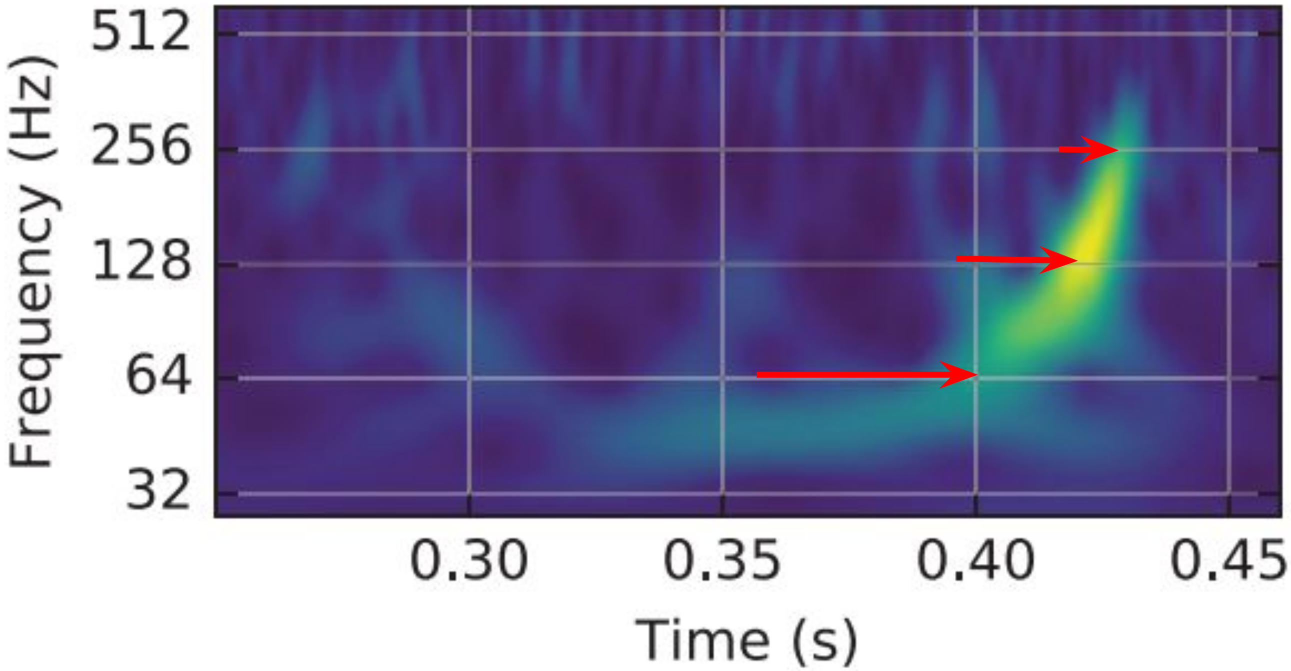
$$\left(\frac{\nu}{c}\right)^2 = \left(\frac{mc}{h}\right)^2 + \frac{1}{\lambda^2}$$

$$v_{\text{group}} \approx c - \frac{1}{2}\left(\frac{mc^2}{h\nu}\right)$$

Speed of Gravity

Speed of gravity

Mass of the graviton



$$m_g \leq 4.7 \times 10^{-23}\,\mathrm{eV}/c^2$$
$$\lambda_g \geq 1.64 \times 10^{13}\,\mathrm{mi}$$

Number of Spatial Dimensions

Number of spatial dimensions

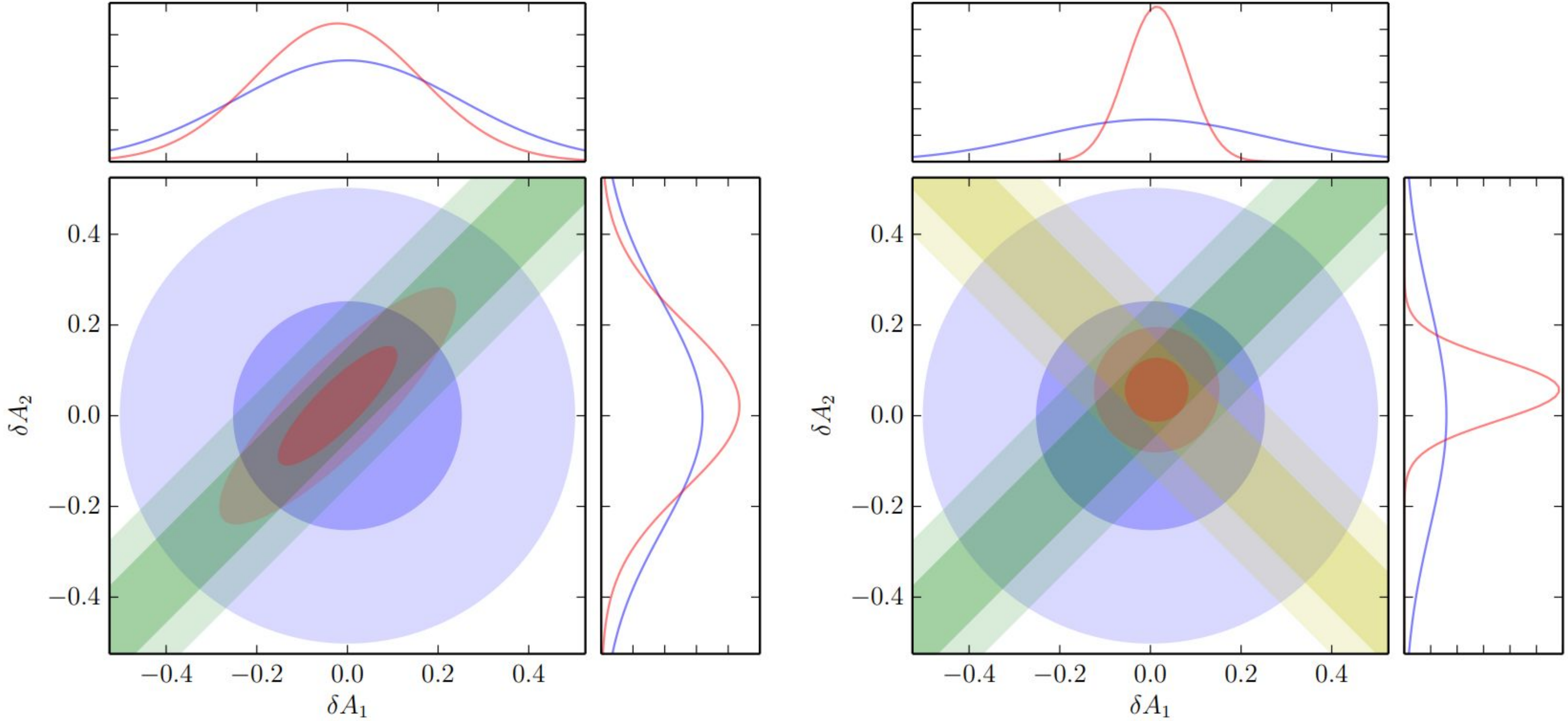
$$h \sim \frac{h_0}{D^{(n-1)/2}}$$

Astrophysical Calibration

What if GR is perfect?

Can we learn about our detectors?

Astrophysical Calibration



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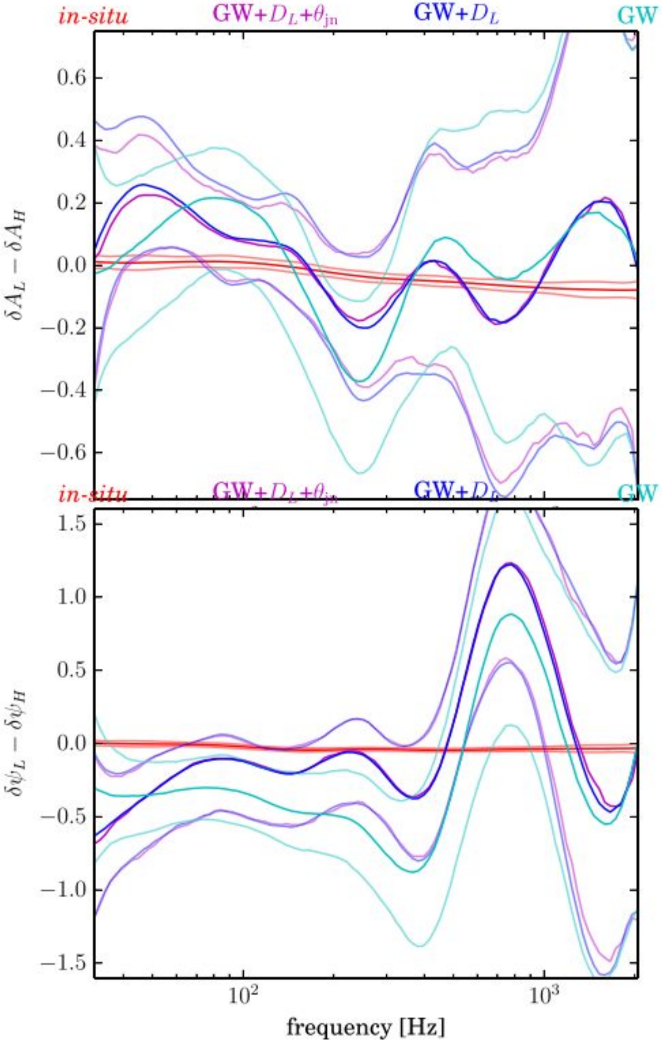

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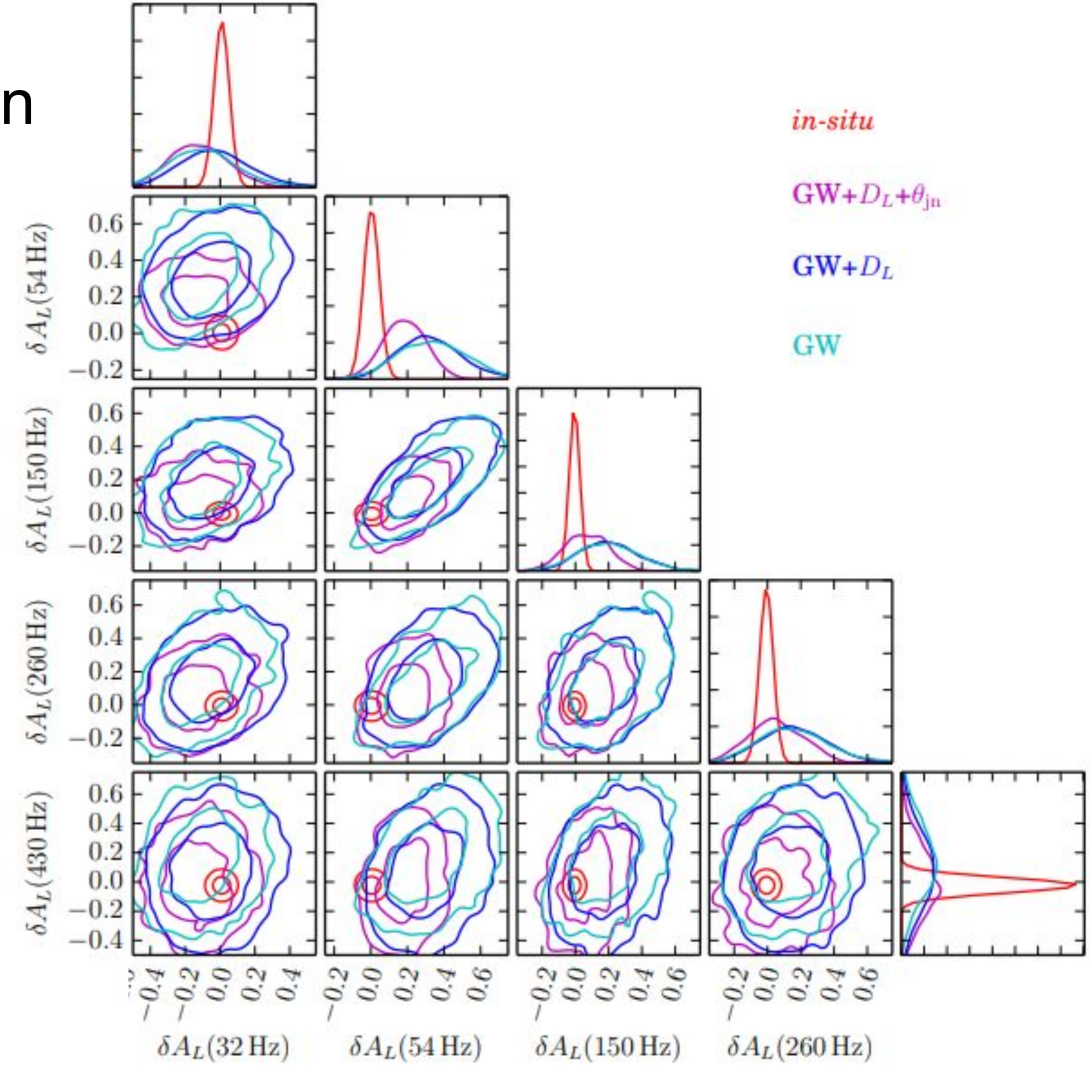

Next time

Gravitational Waves Over the Next 40 Years

- (Current) advanced detectors
- 3G detectors
- Space-based detectors, pulsar timing, and other missions

Suggested Reading

- Clifford Will. *Was Einstein Right? Putting General Relativity to the Test*. Basic Books (1993).
- https://www.ligo.org/science/Publication-GW170817TGR/index.php
- https://www.ligo.org/science/Publication-O2TGR/index.php