Detecting Gravitational Waves on Earth

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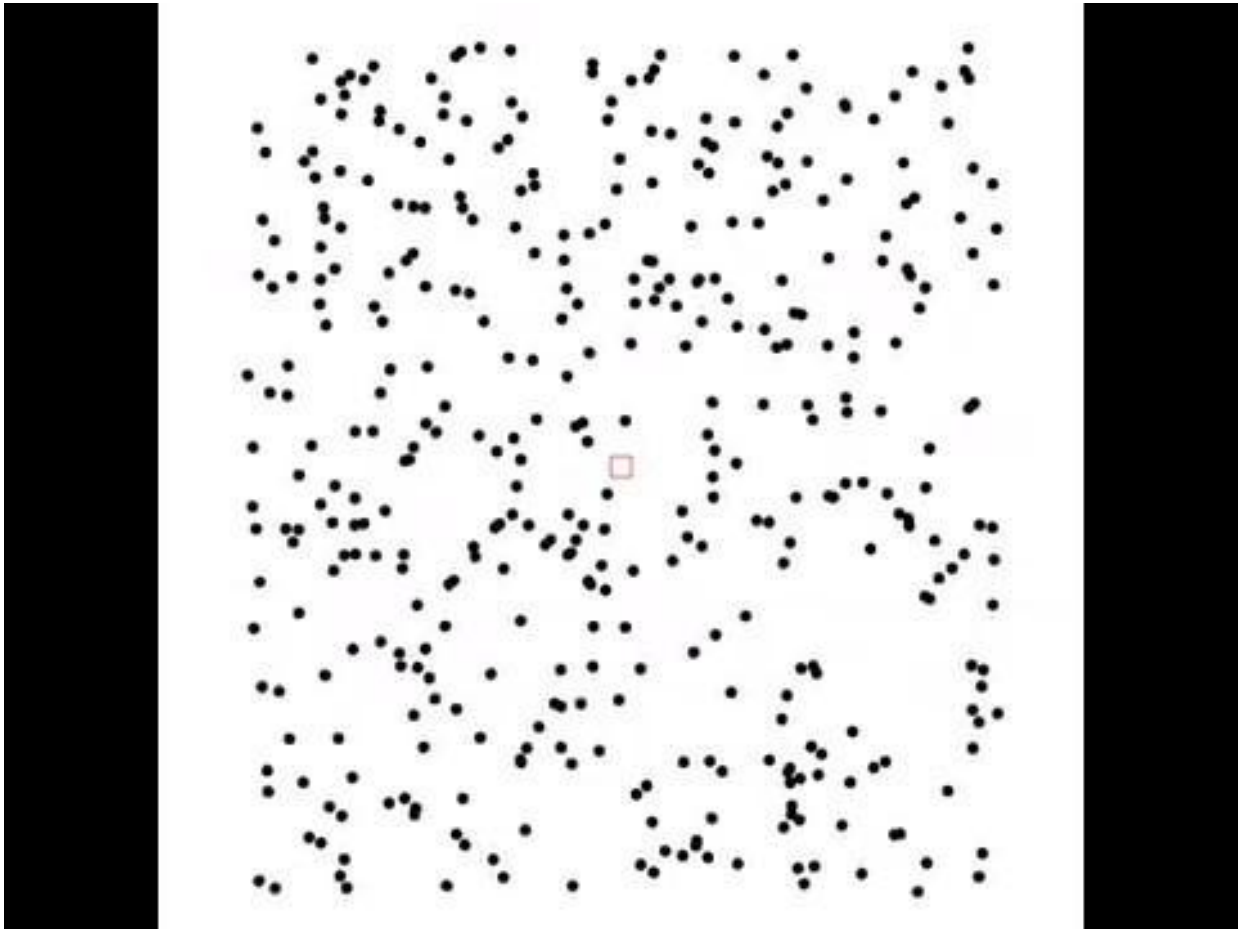
Compton Lectures
University of Chicago

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

Gravitational Waves and Astrophysical Sources (a review)

Gravitational waves change the physical distances between objects by stretching and squeezing the space between them.



Gravitational Waves and Astrophysical Sources (a review)

Why are Astrophysical Objects needed?

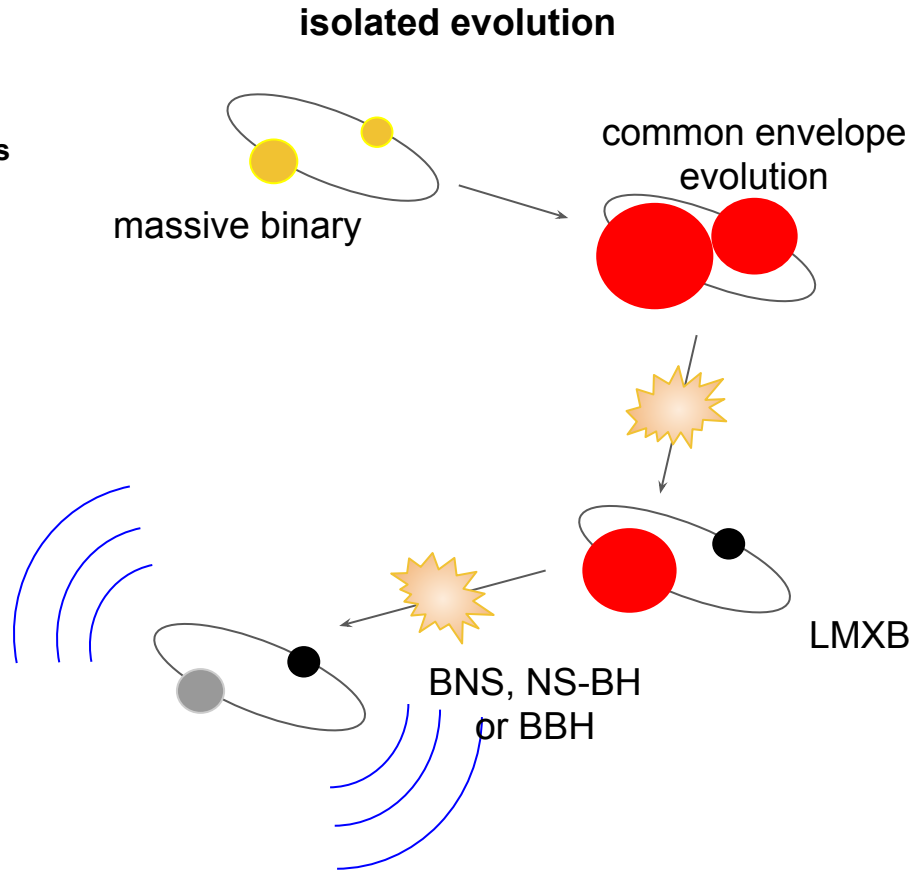
Dimensional analysis:

$$h \sim \frac{G}{c^2}\left(\frac{m}{D}\right)\left(\frac{v}{c}\right)^n$$
$$\sim 5 \times 10^{-22}\left(\frac{m}{M_\odot}\right)\left(\frac{100\,\mathrm{Mpc}}{D}\right)\left(\frac{v}{c}\right)^n$$

Possible Sources

Compact Binary Coalescences

- **Binary systems containing Black Holes and Neutron Stars**



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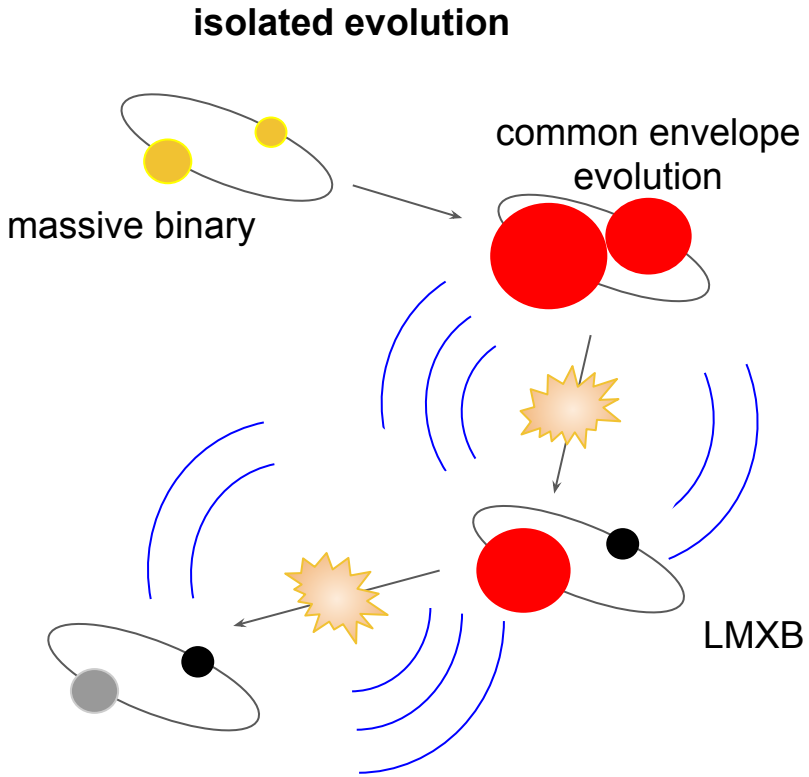
Compact Binary Coalescences

- Binary systems containing Black Holes and Neutron Stars

Bursts

- **Core-Collapse SuperNova (CCSN)**
- General “other stuff”



Possible Sources

Compact Binary Coalescences

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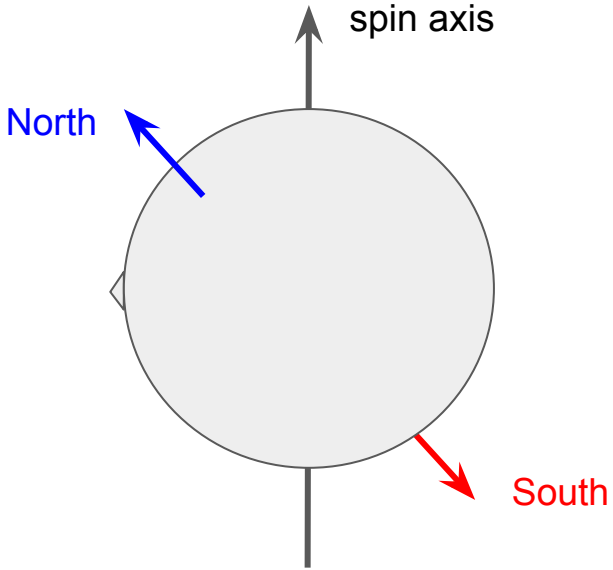
Continuous Sources

- **Pulsars**

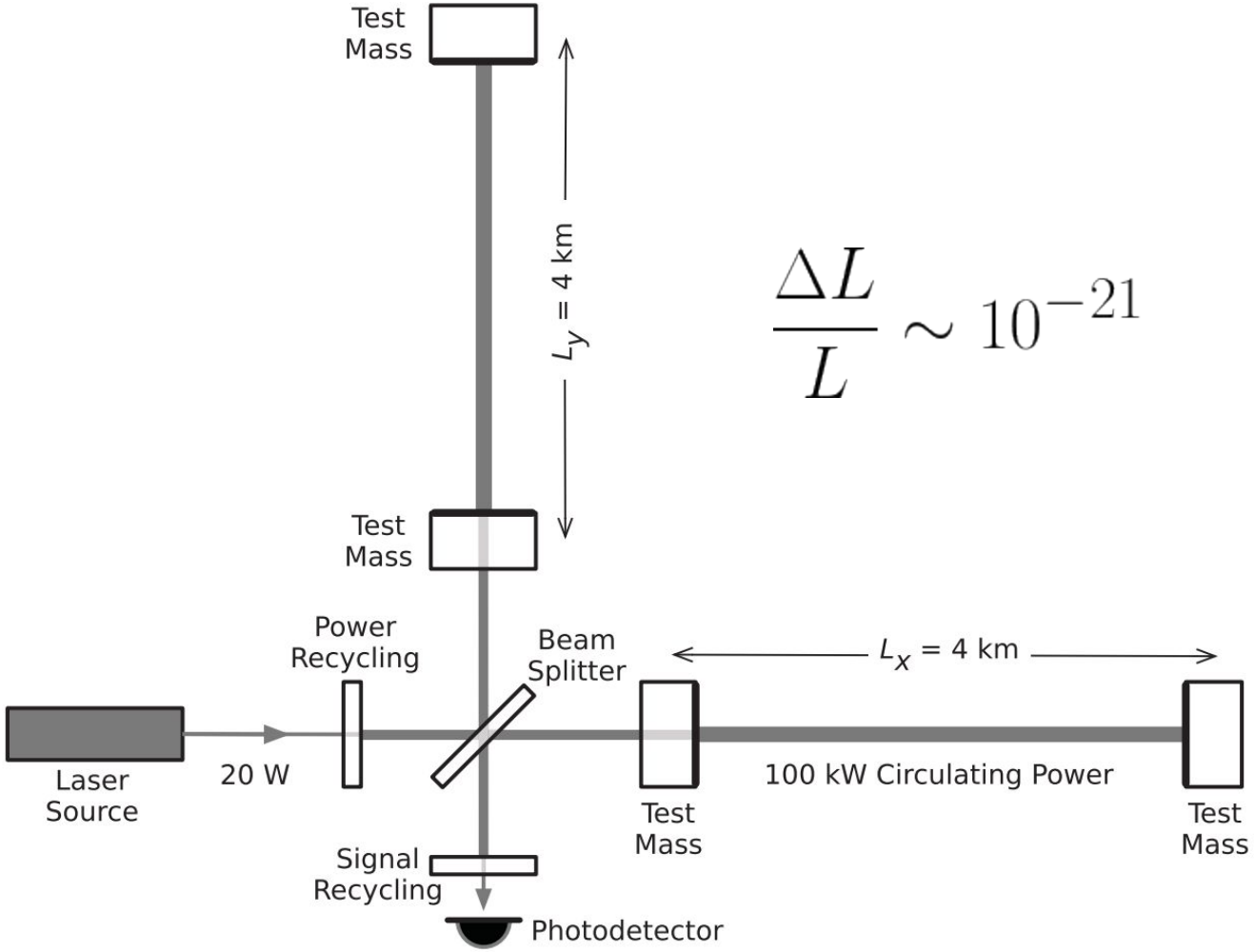
Stochastic Sources

- Unresolved sources
- Primordial backgrounds



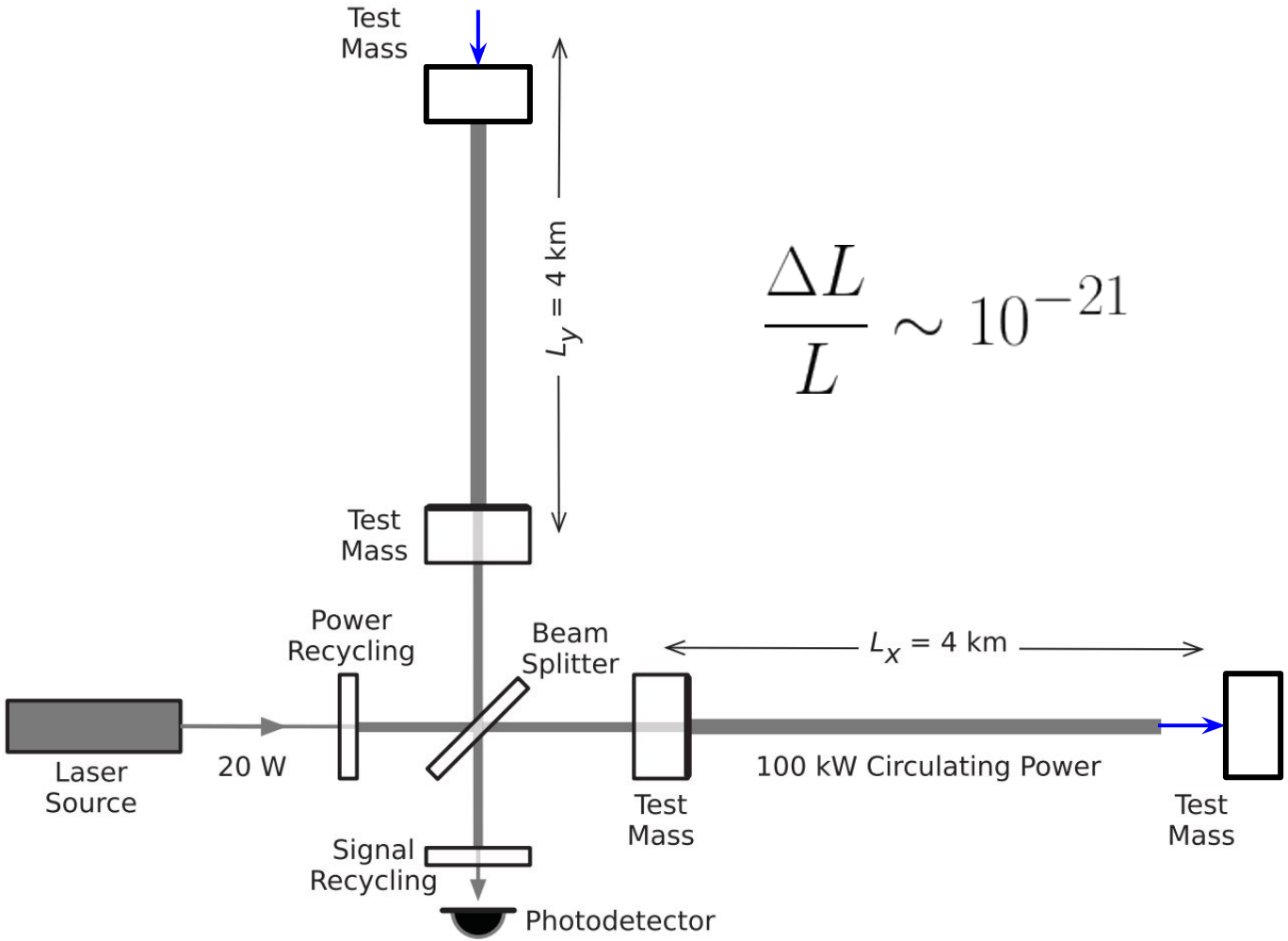
must be a perfect sphere
to ~ **1 part in 10,000**

Interferometers



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

Interferometers



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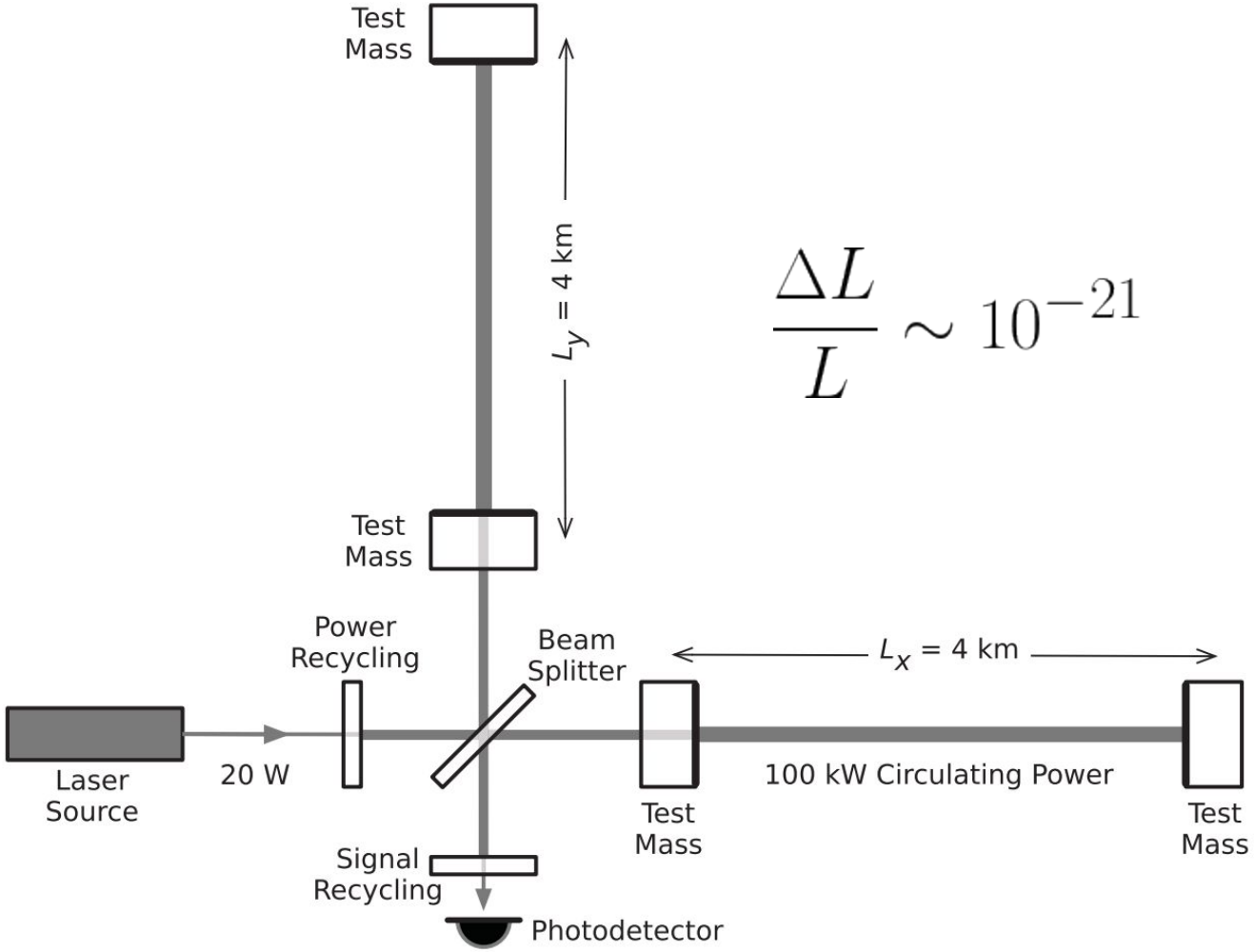

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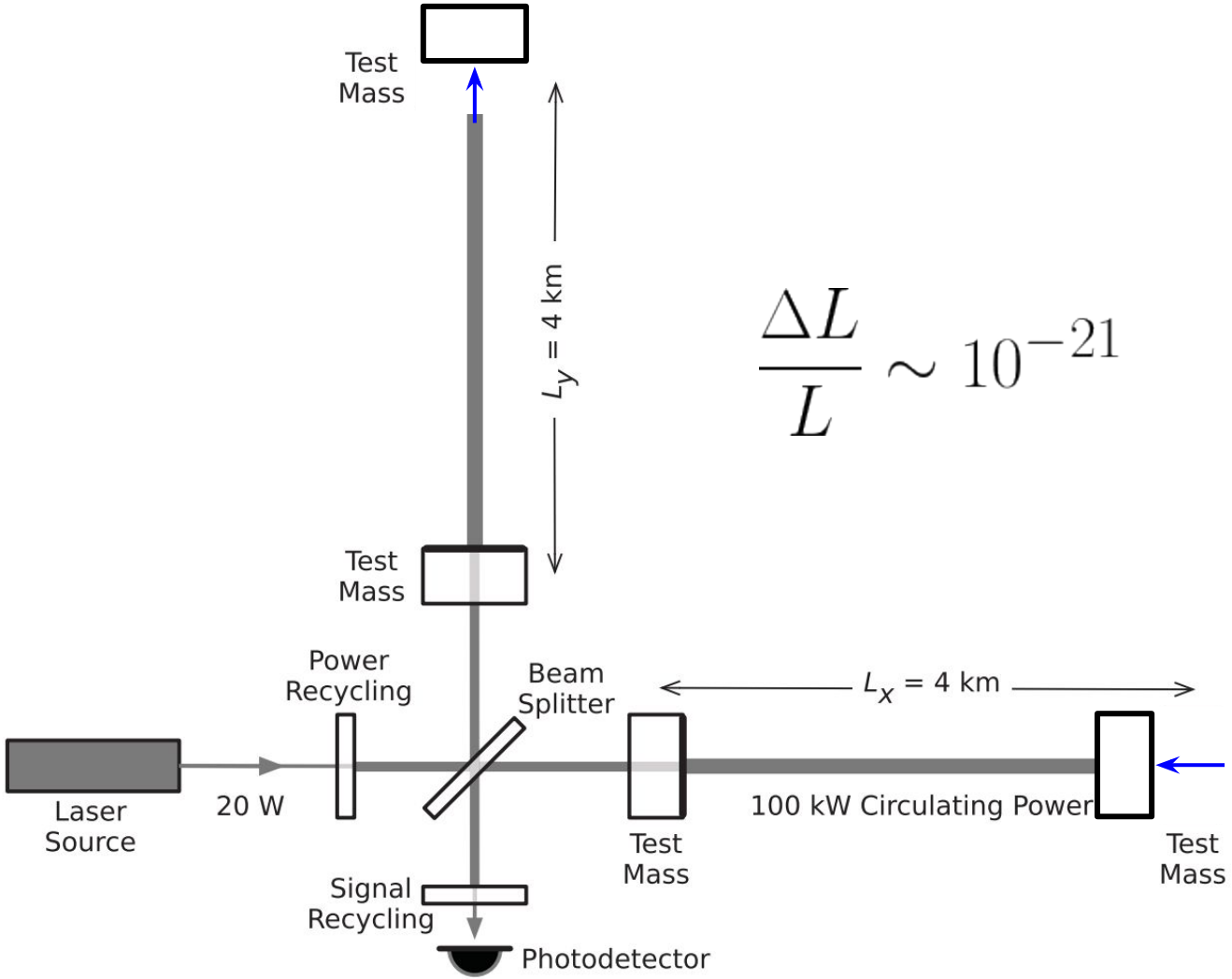

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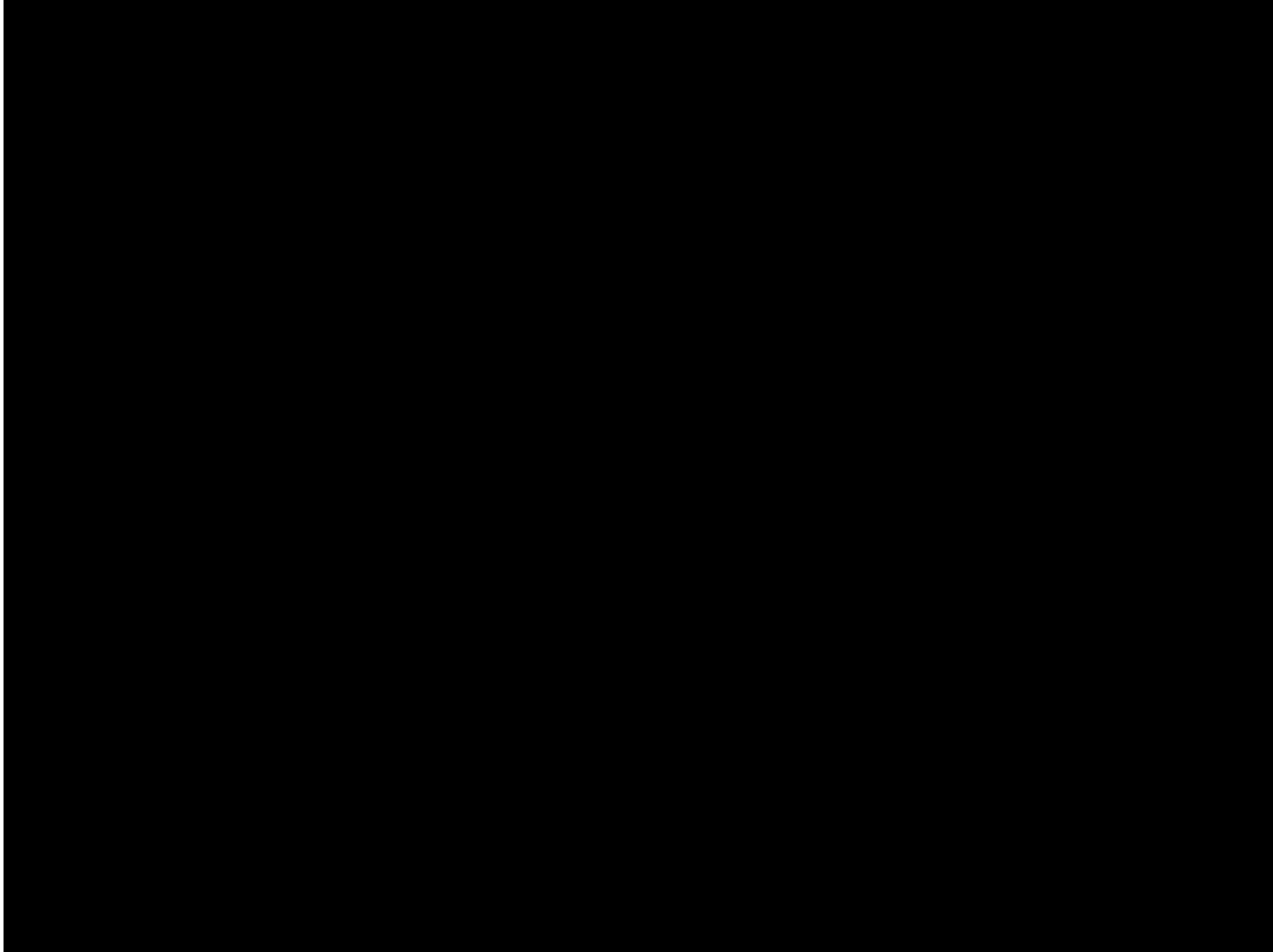
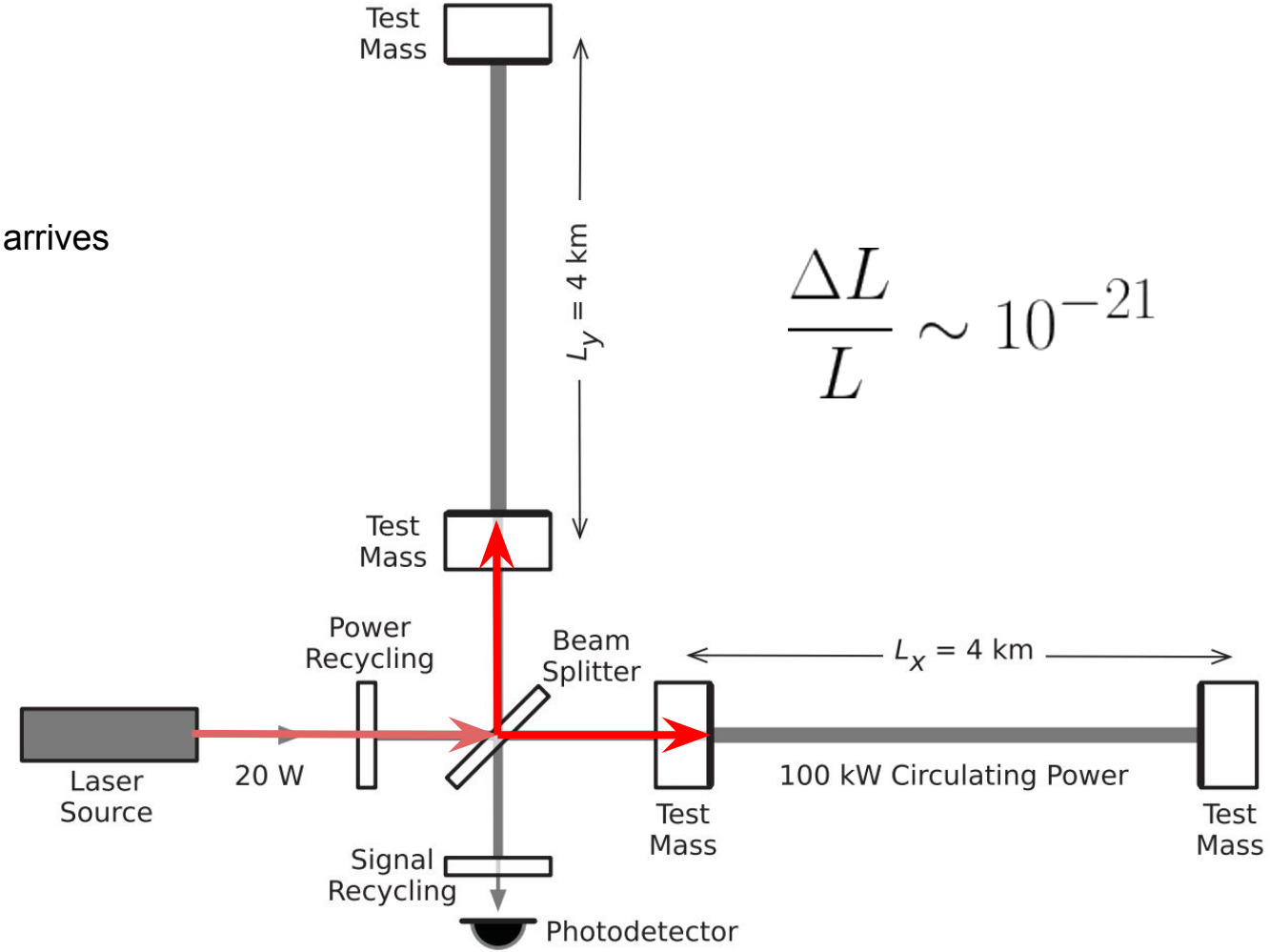


Interferometers

before the GW arrives



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Interferometers

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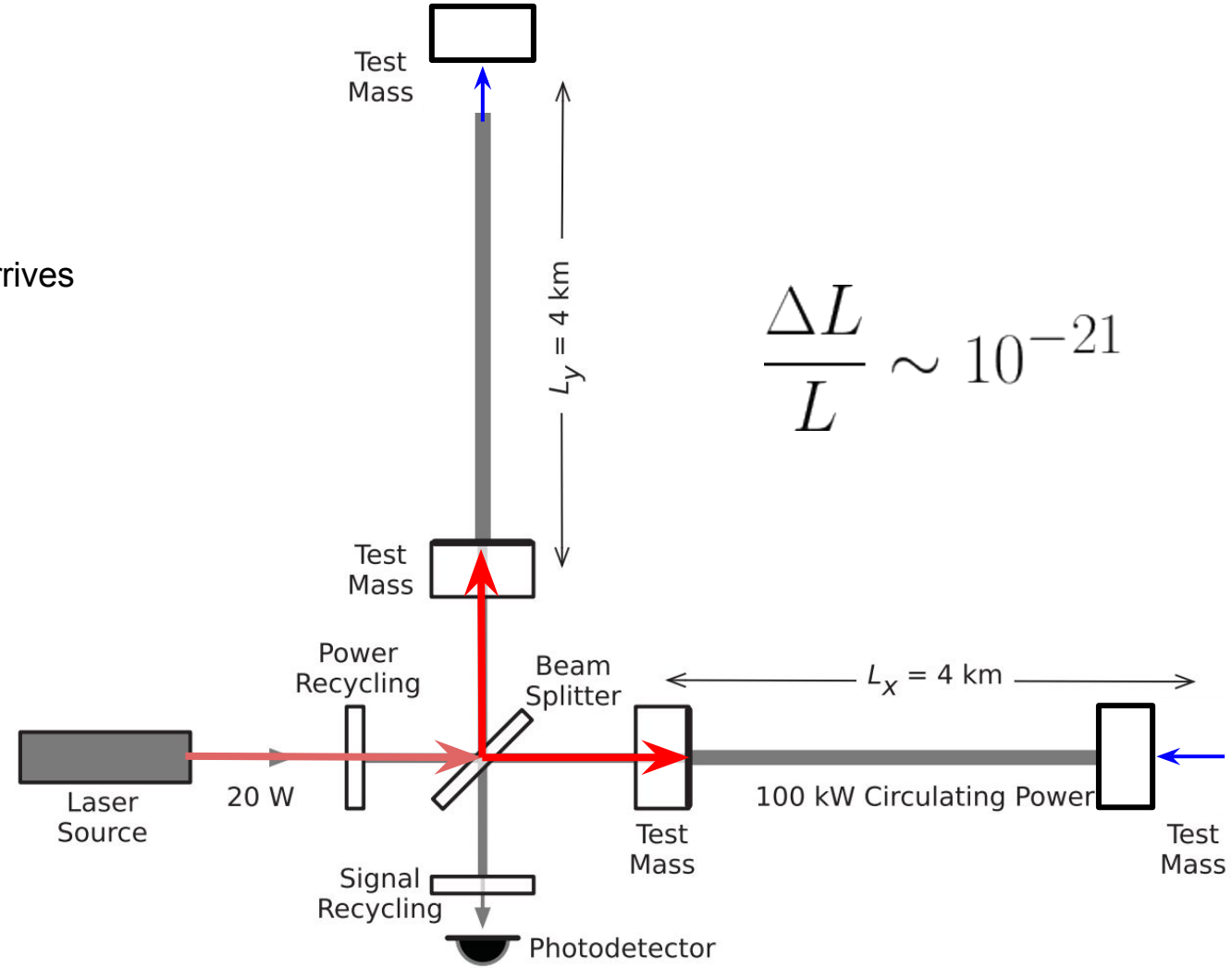

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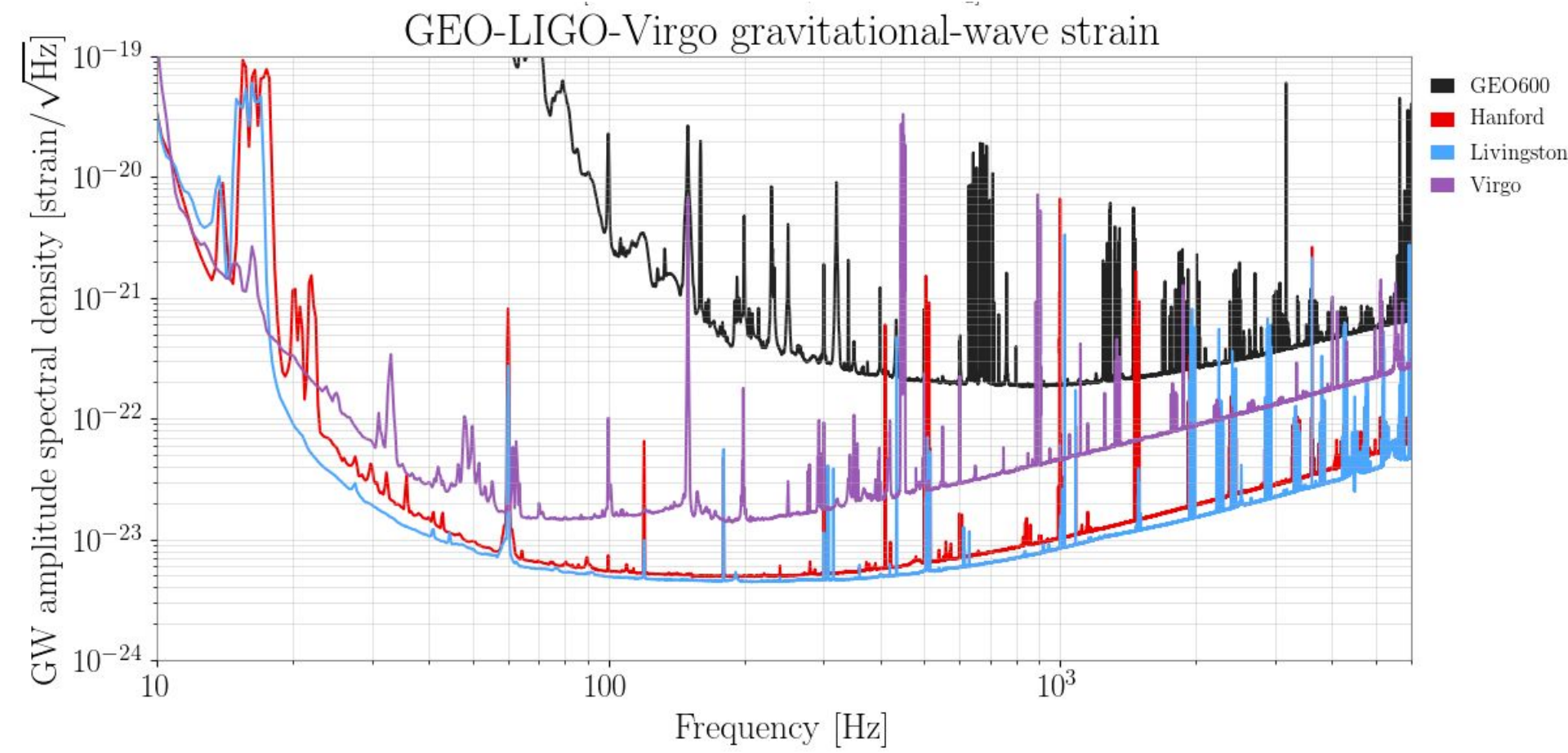
(Gaussian) Noise Sources



(Gaussian) Noise Sources

What noise sources could disturb our measurements?

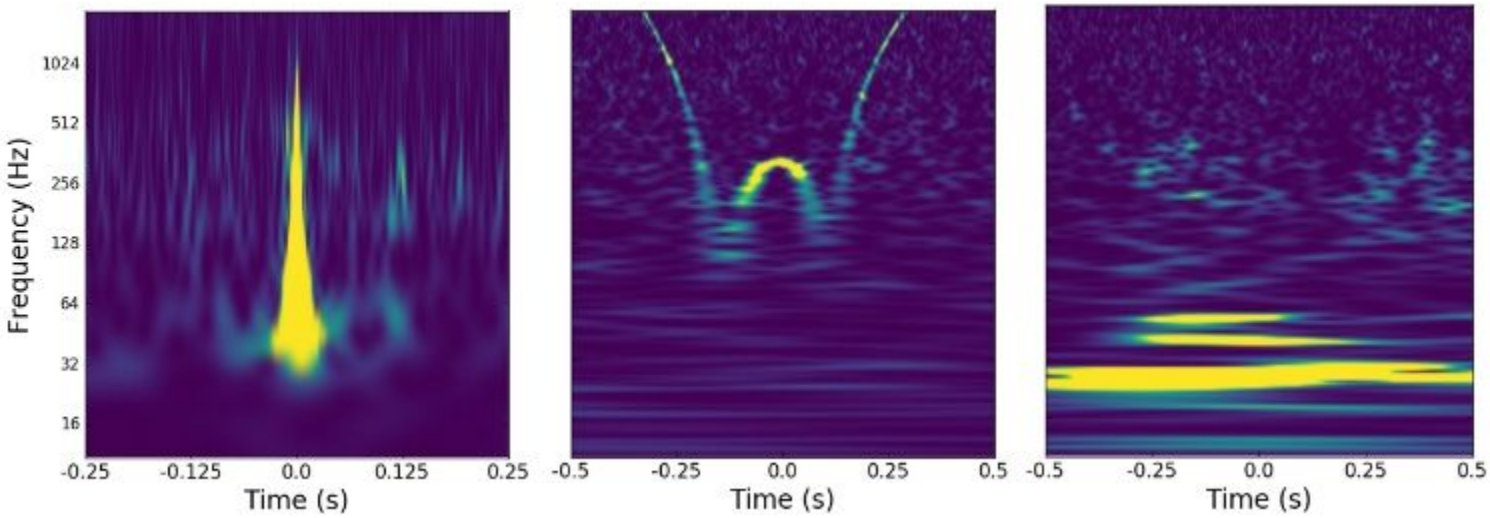
public summary pages!

Ground motion?
Magnetic fields?
High winds/storms?
Dust/gas in the laser's path?
Defects in the mirrors?
Domino's Pizza?

(non-Gaussian) Noise Sources

Often called “Glitches”

- Typically *shorter* but ***louder*** than Gaussian noise
- May not be random, i.e. may have predictable time-domain waveforms



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gravity spy!

Thirsty ravens?
Cutting Down Trees?
Wiggling Surfaces?
Radio Frequency Interference?
Domino’s Pizza?
else?

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Often called “Glitches”

- Typically *shorter* but ***louder*** than Gaussian noise
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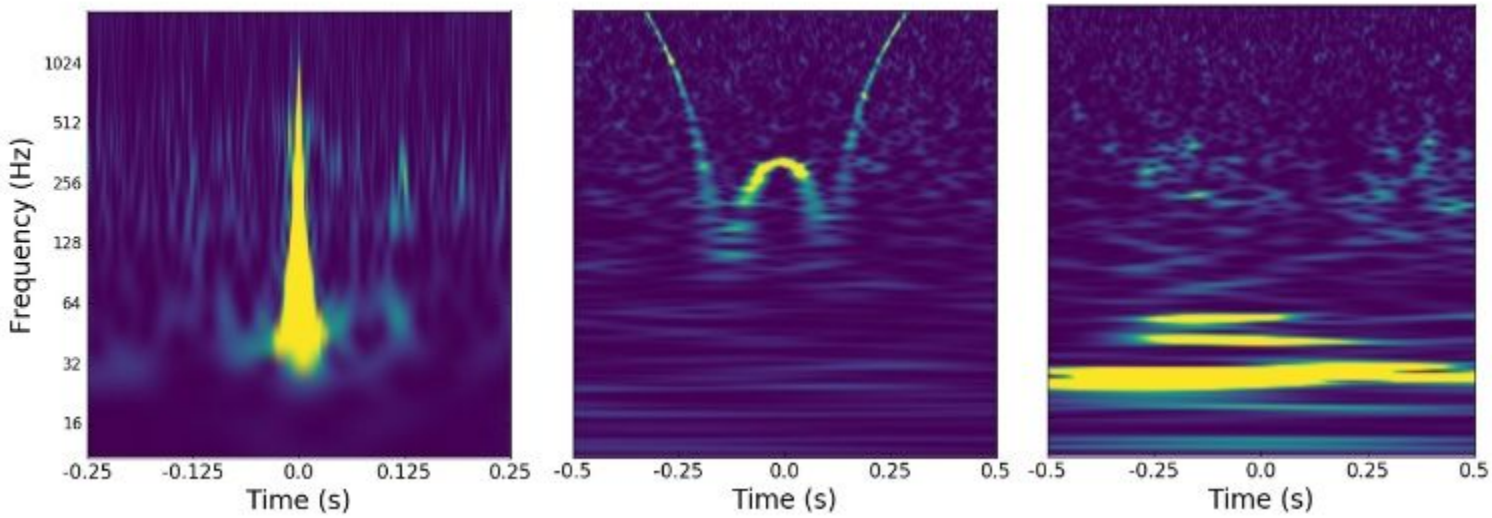
How do we identify and remove glitches?



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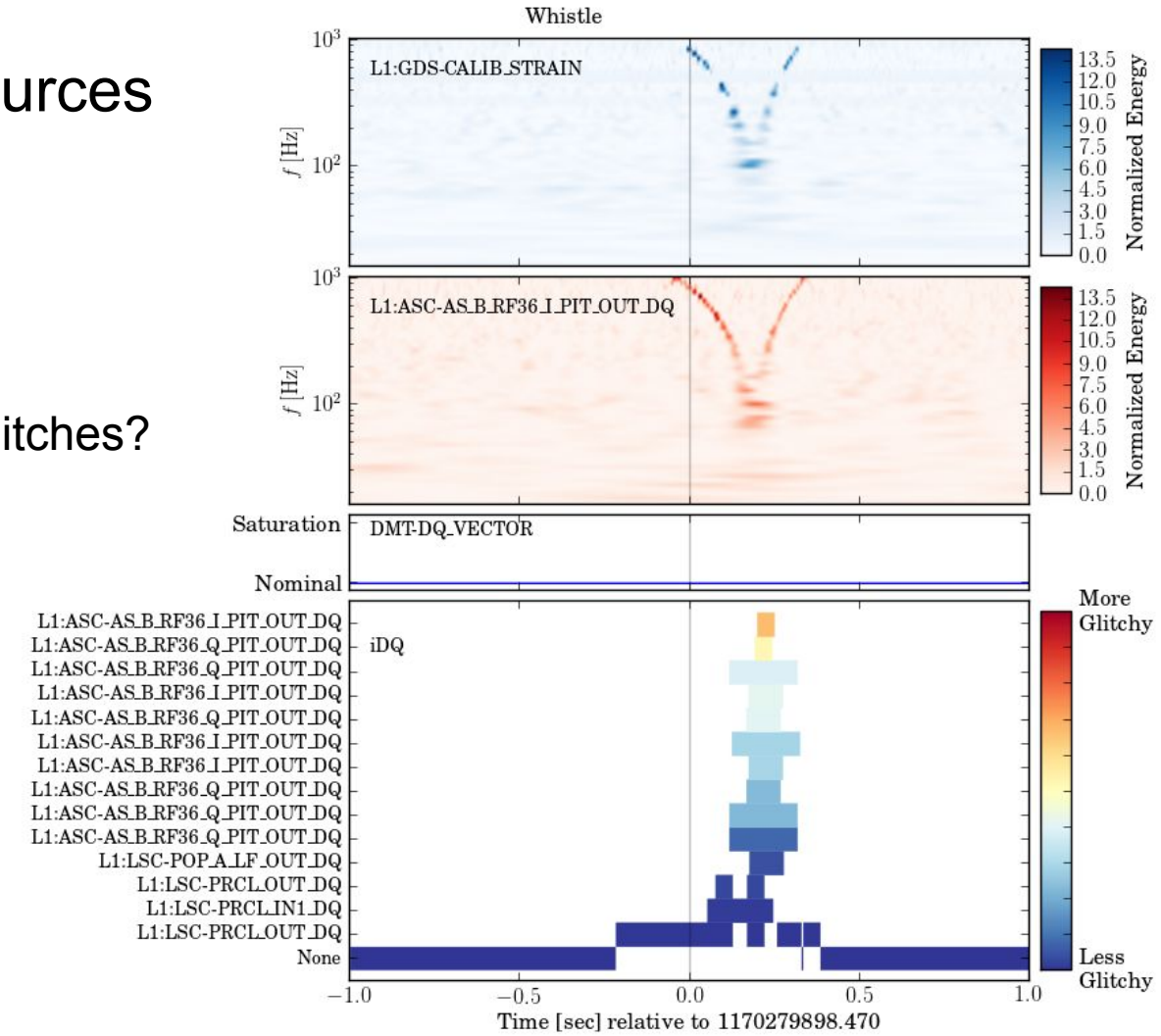
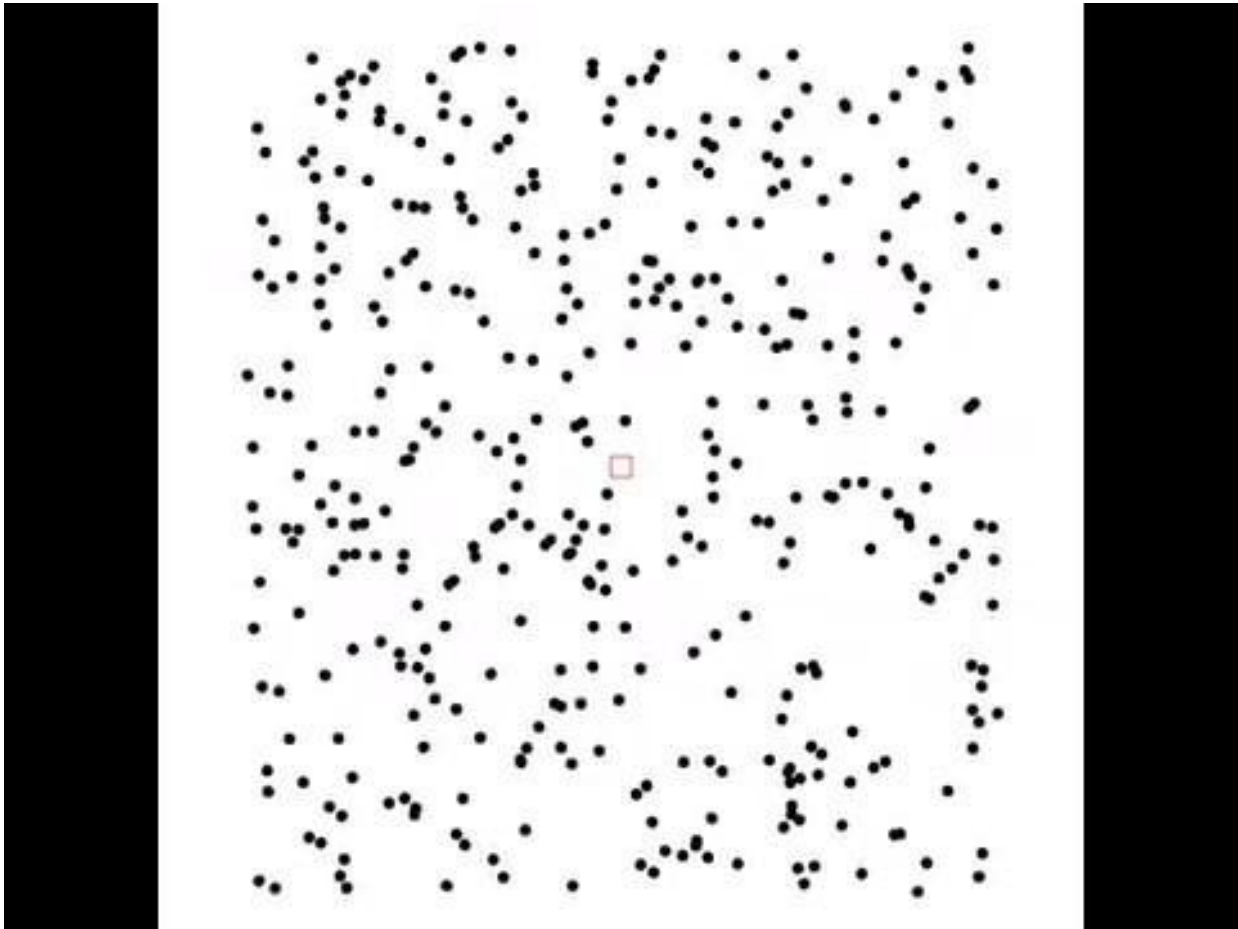
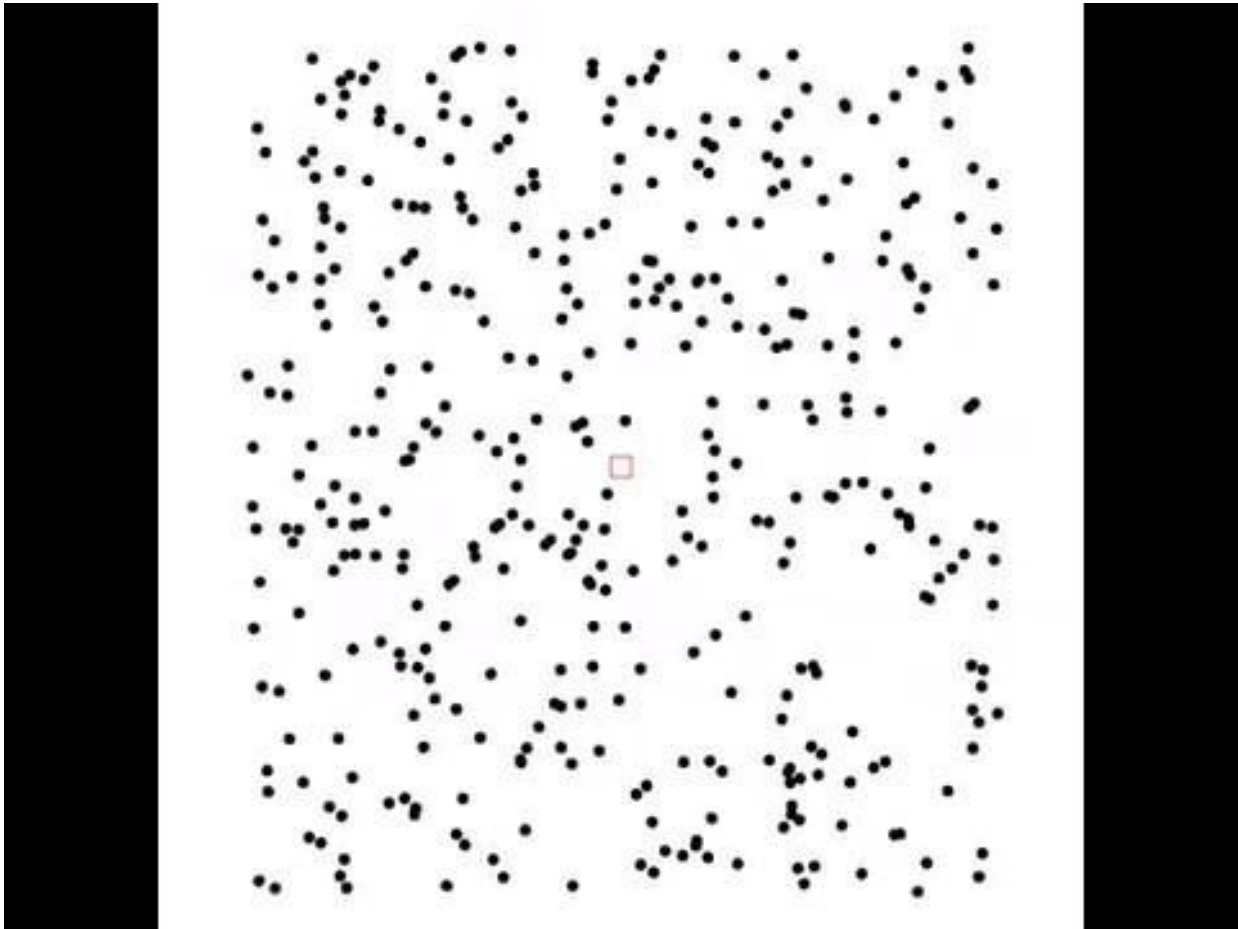


Other detection techniques



Other detection techniques

- LISA
  - LIGO *in space*



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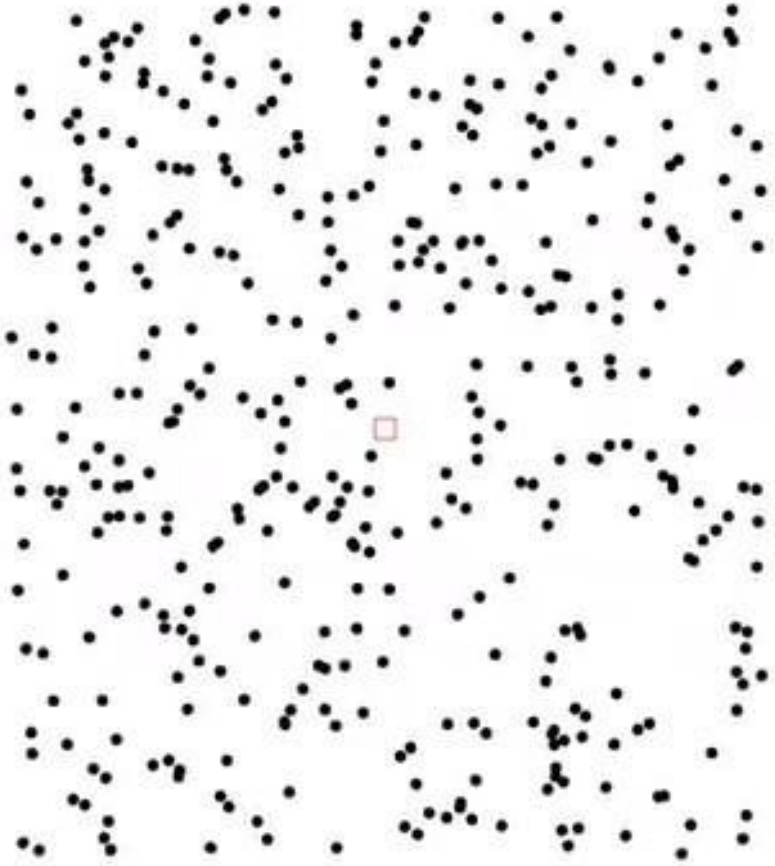
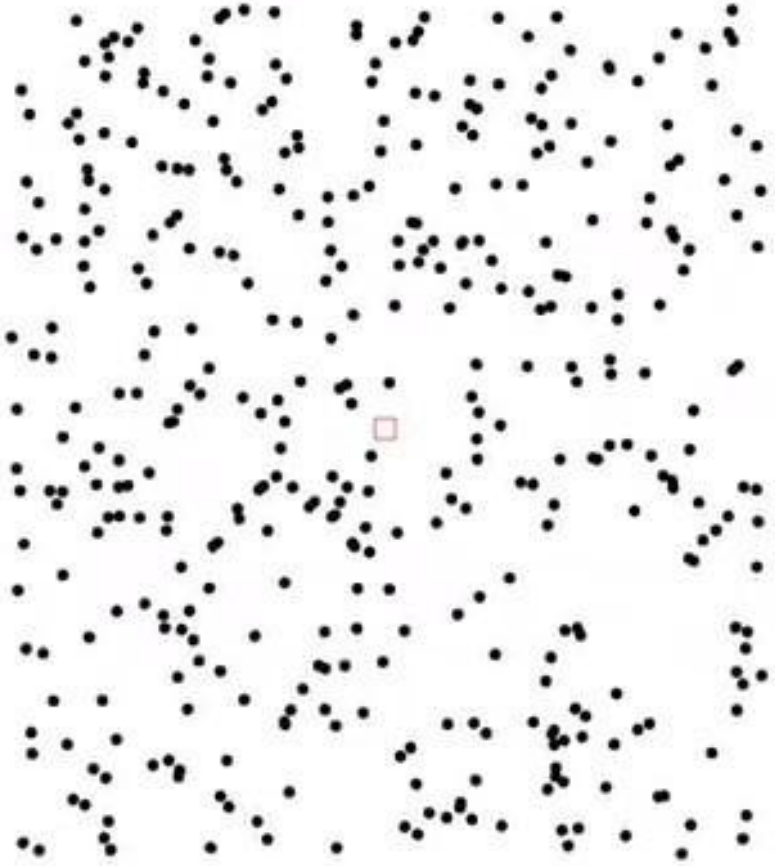
- Atom Interferometers
  - Other types of *flying clocks*



Other detection techniques

- LISA
  - LIGO *in space*
- Pulsar Timing Arrays
  - even bigger timing measurements
- Atom Interferometers
  - Other types of *flying clocks*
- Resonating bar detectors
  - ringing a bell



Next time

Searching for Gravitational Waves in Noisy Detector Data

- Search techniques
- Establishing detection confidence
- Parameter estimation

Suggested Reading

- *Gravitational Wave Detection: Principles and Practice* (https://dcc.ligo.org/LIGO-P1100131/public).
- *If light waves are stretched by gravitational waves, how can we use light as a ruler to detect gravitational waves? American Journal of Physics, 65, 501 (1997).*
- *Public LIGO-Virgo Summary Pages*. https://www.gw-openscience.org/detector_status/
- *Thirsty The Raven*. https://humansofligo.blogspot.com/2018/10/thirsty-raven.html
- *Gravity Spy. https://www.zooniverse.org/projects/zooniverse/gravity-spy*