Astrophysical Sources of Gravitational Waves

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Compton Lectures
University of Chicago

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

Gravity (a review)

Newton says

- Objects that are in motion stay in motion unless acted upon by an external force
  - ***Newton's First Law***
- All objects fall at the same rate, regardless of their mass
  - ***Principle of Equivalence***
- There is an universal attractive ***Force of Gravity*** between all objects that is proportional to their mass.

Einstein says

- Objects that are in motion stay in motion unless acted upon by an external force
  - ***Geodesic Motion***
- All objects follow the same geodesics
  - ***Principle of Equivalence***
- Gravity is described by the ***Geometry of Space-time***, which is determined by the distribution of mass and energy in the universe
- No information can travel faster than the ***speed of light***

Gravitational Waves

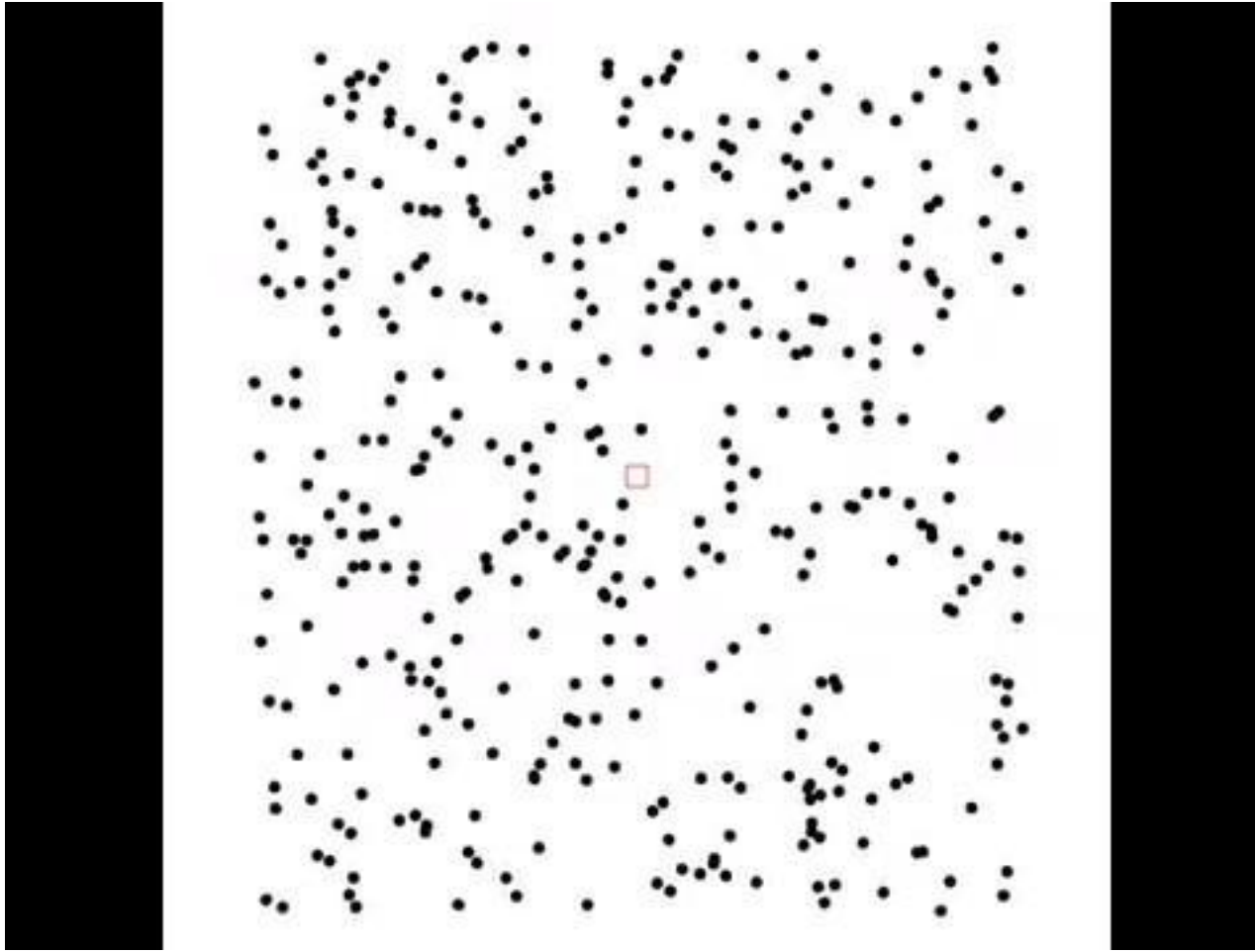
In General Relativity,

Space tells matter how to move and matter tells space how to curve

Gravitational waves (wiggles in space-time) are caused by changes in the motion of matter (accelerations)

Gravitational Waves

Fundamentally, ***Gravitational Waves are traveling wiggles in the Gravitational potential*** just like Electromagnetic Waves (light) are traveling wiggles in the Electromagnetic potential.



Gravitational Waves

- Radiation carrying information about gravitating systems
- Travel at the speed of light
- Create extremely tiny changes in length between objects

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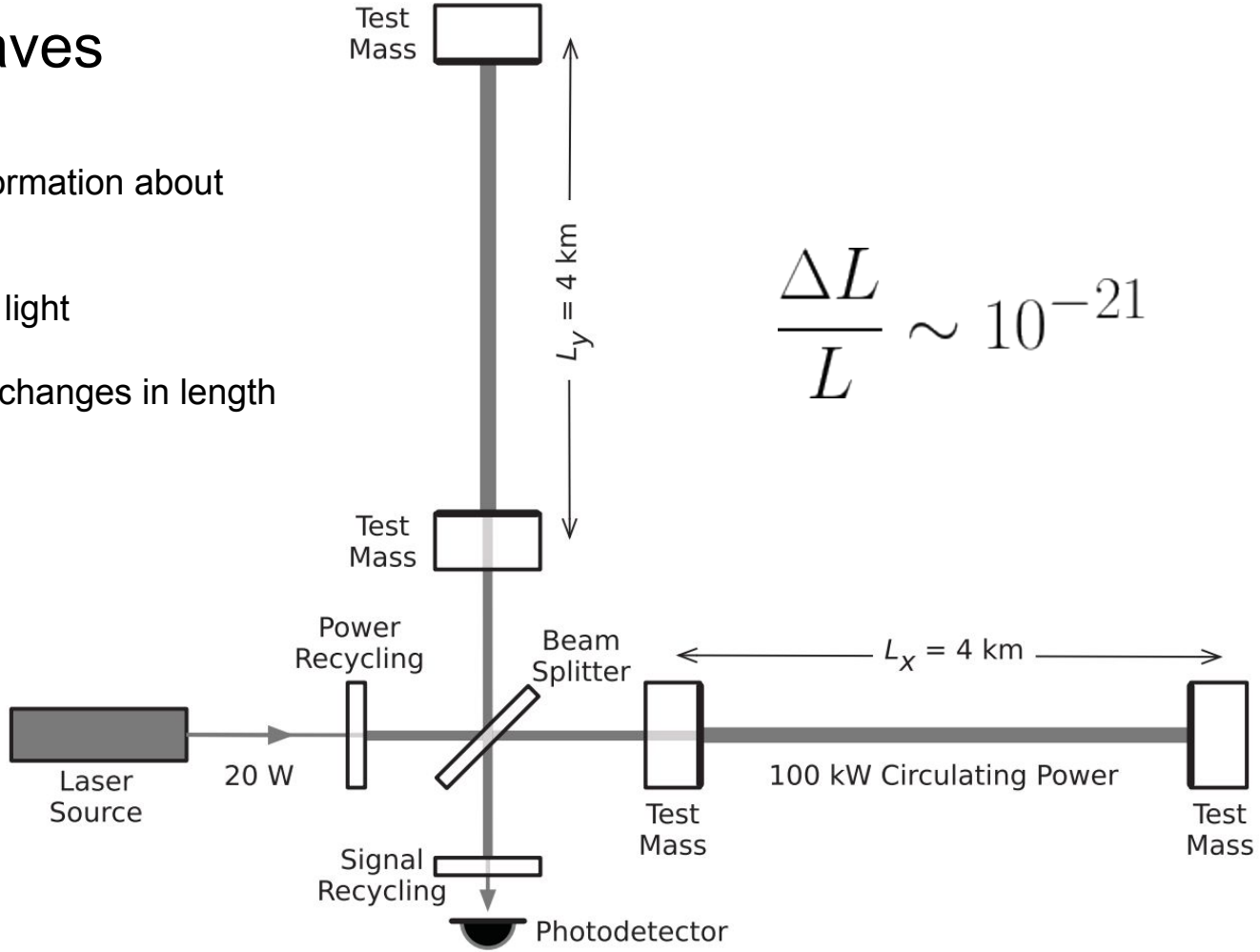

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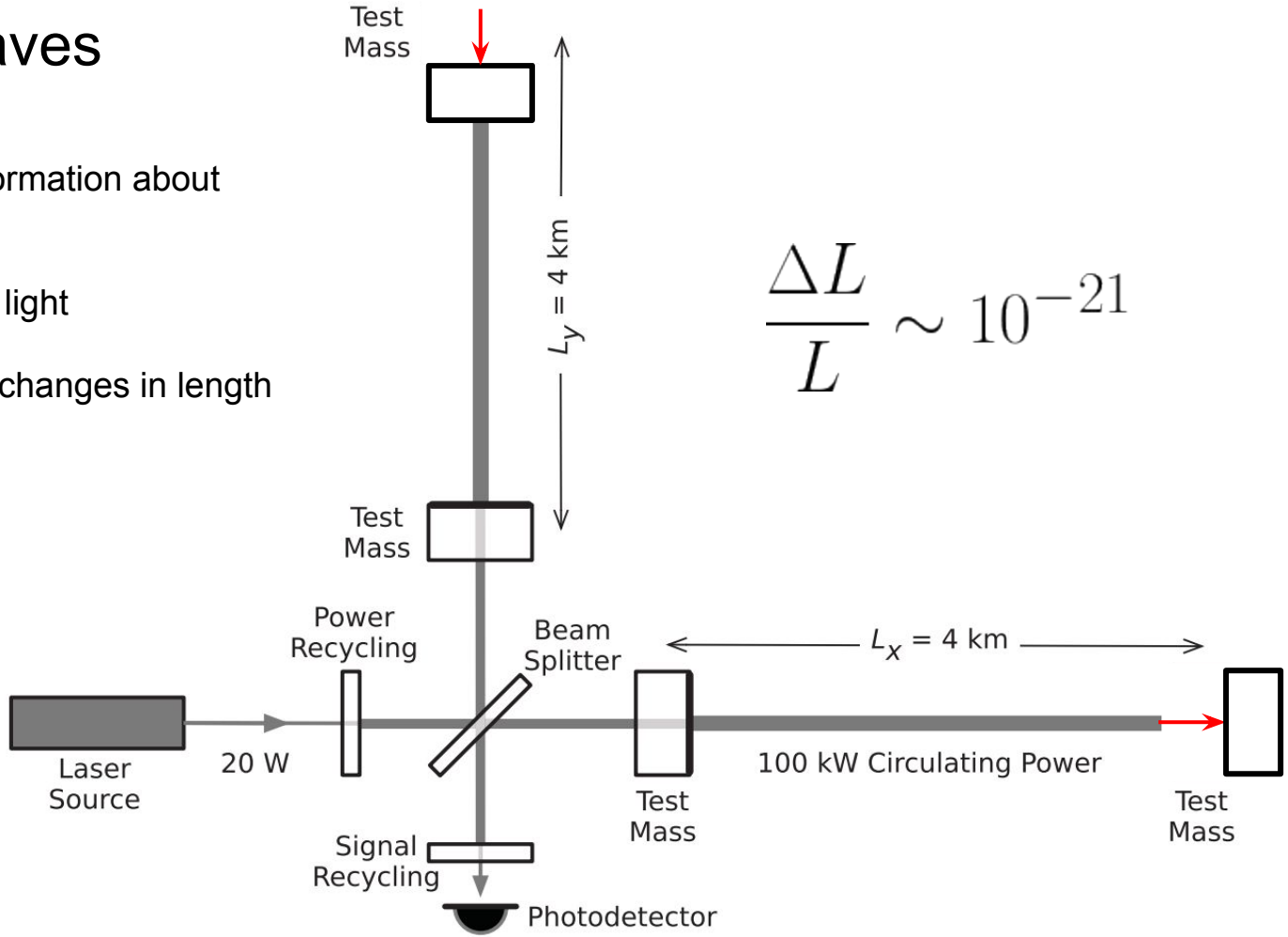

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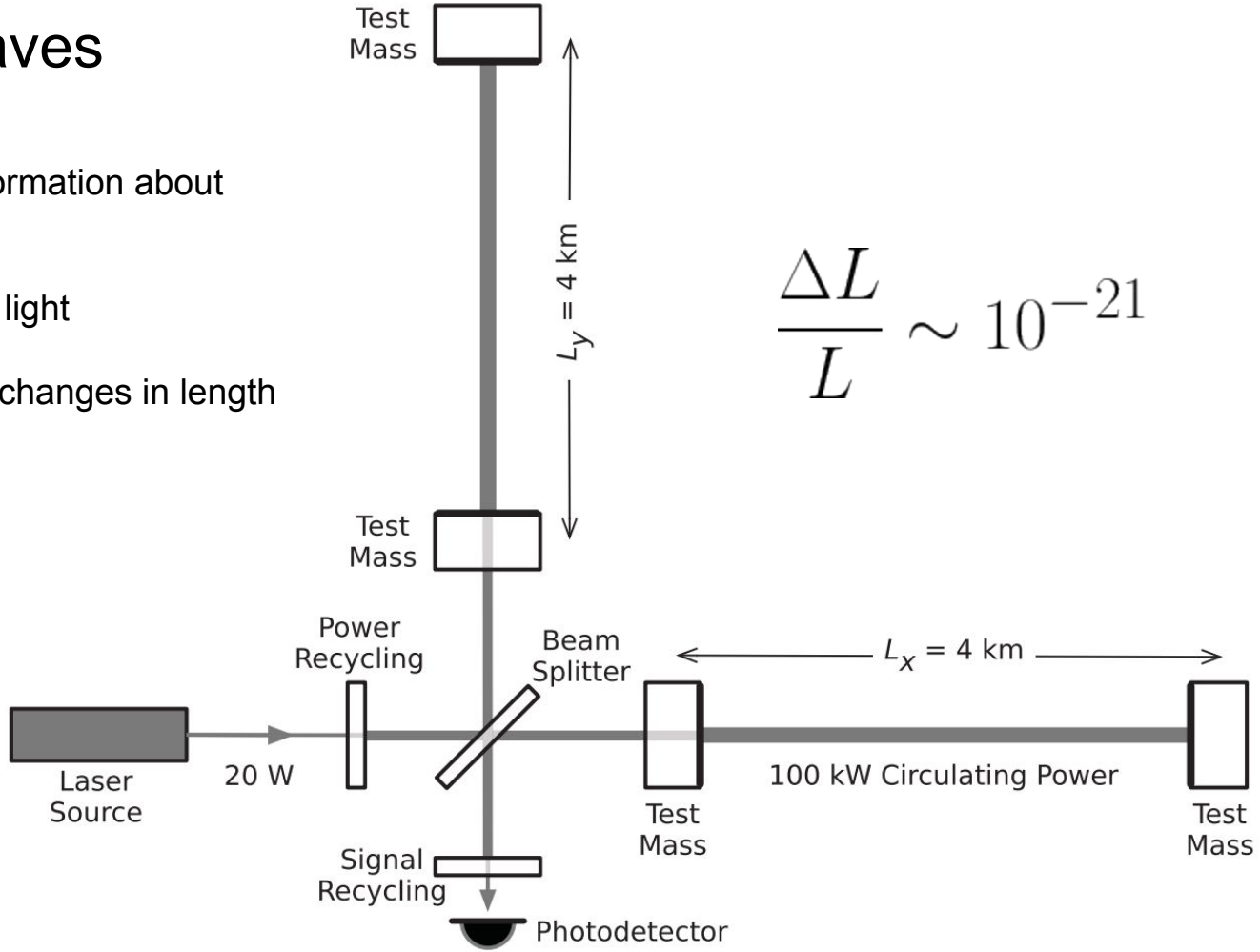

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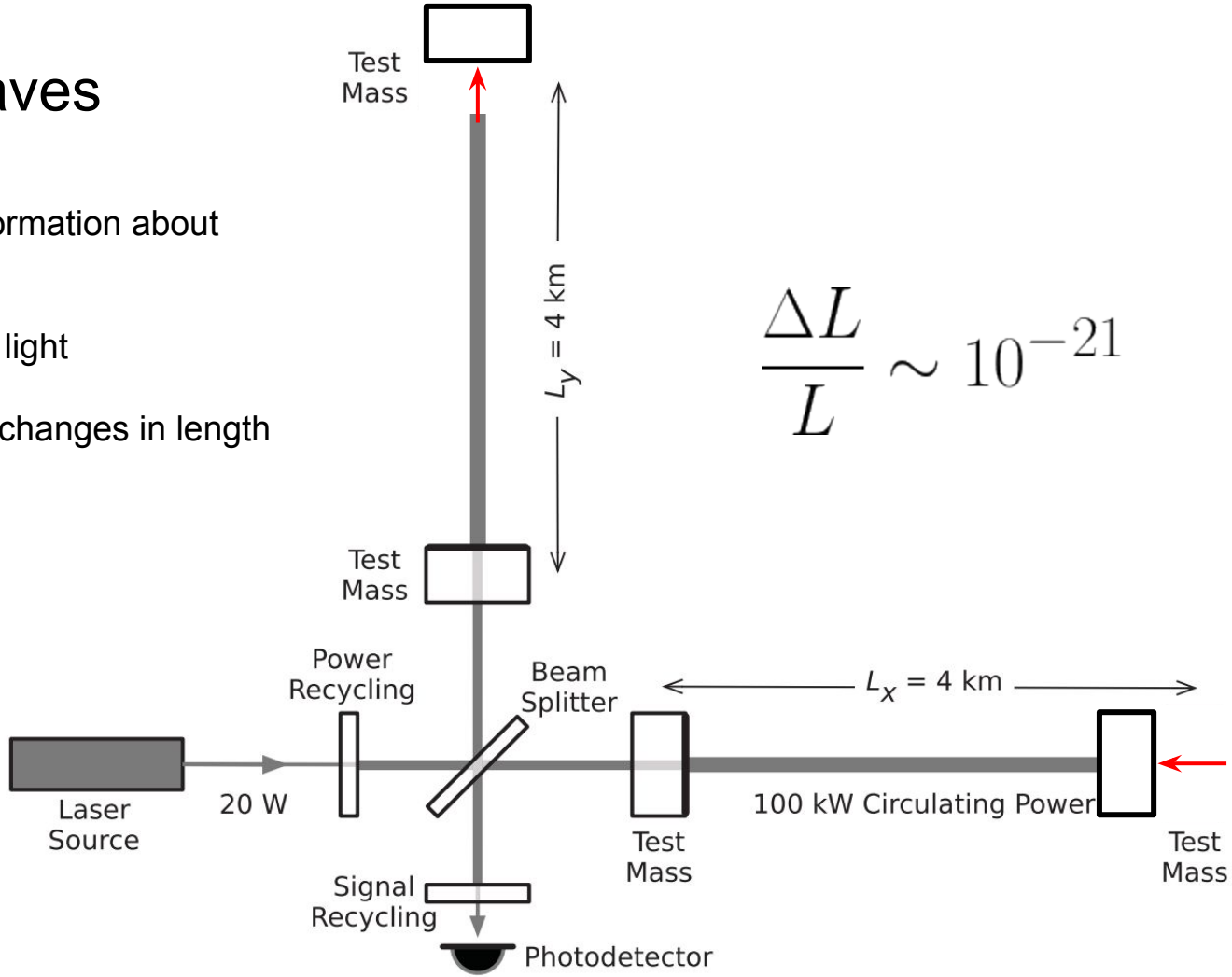

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Gravitational Wave Sources

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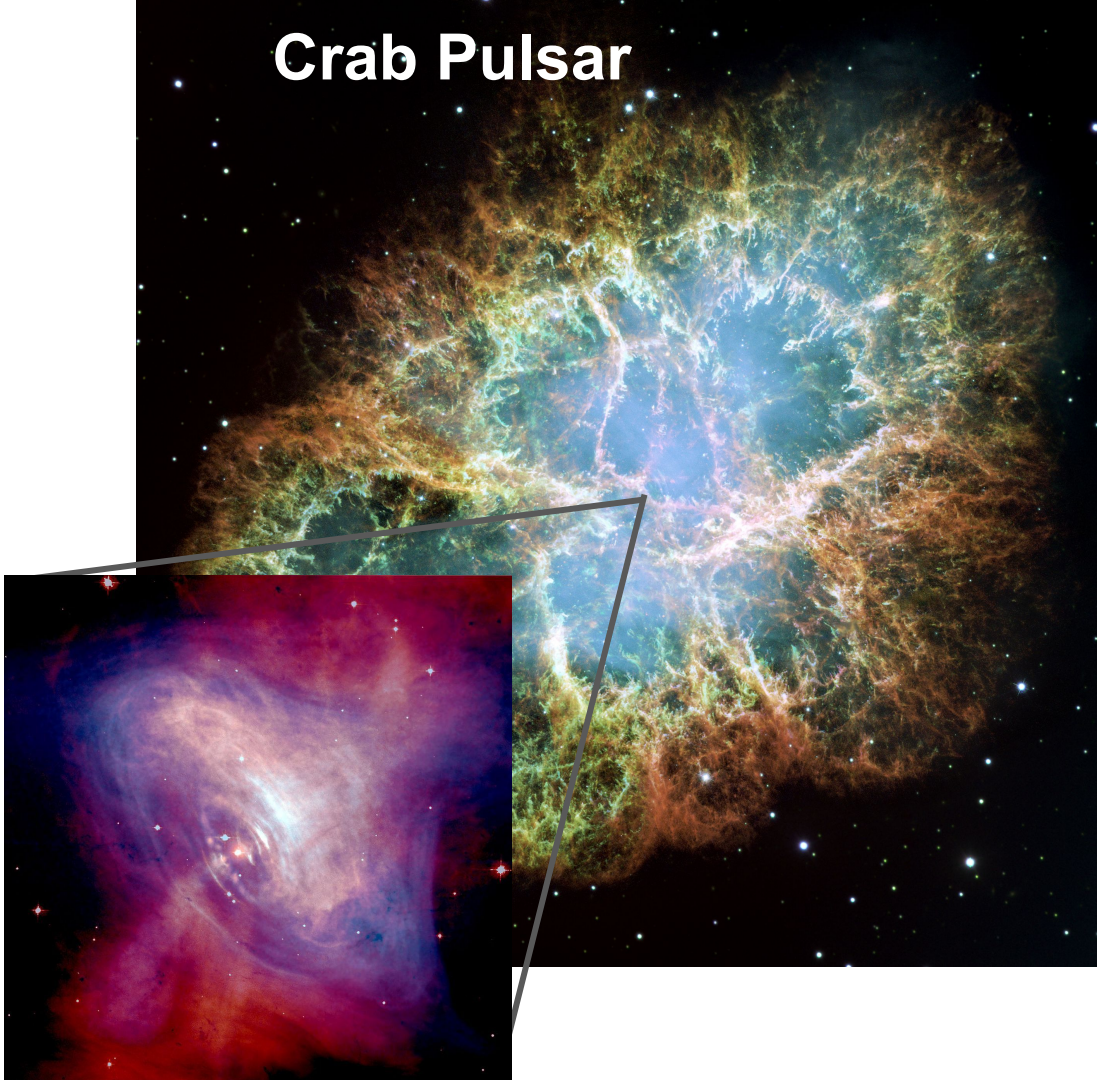
- Symmetries limit the type of radiation
  - Mass/Energy is conserved → no monopole radiation
  - Momentum is conserved → no dipole radiation
  - *Quadrupolar radiation is the leading-order term*

Gravitational Wave Sources



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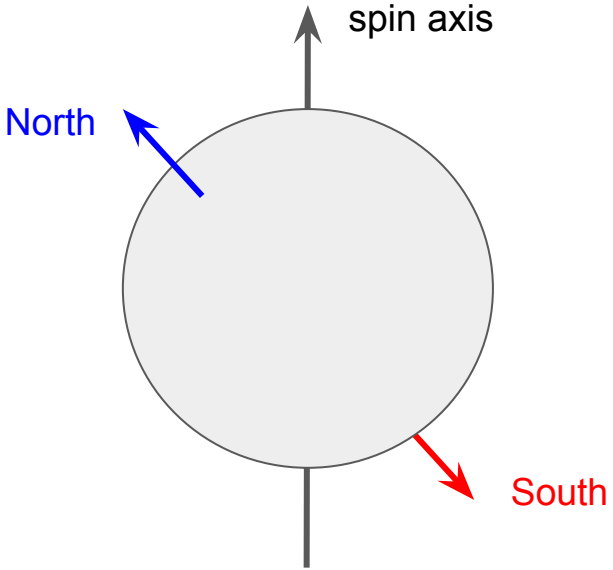
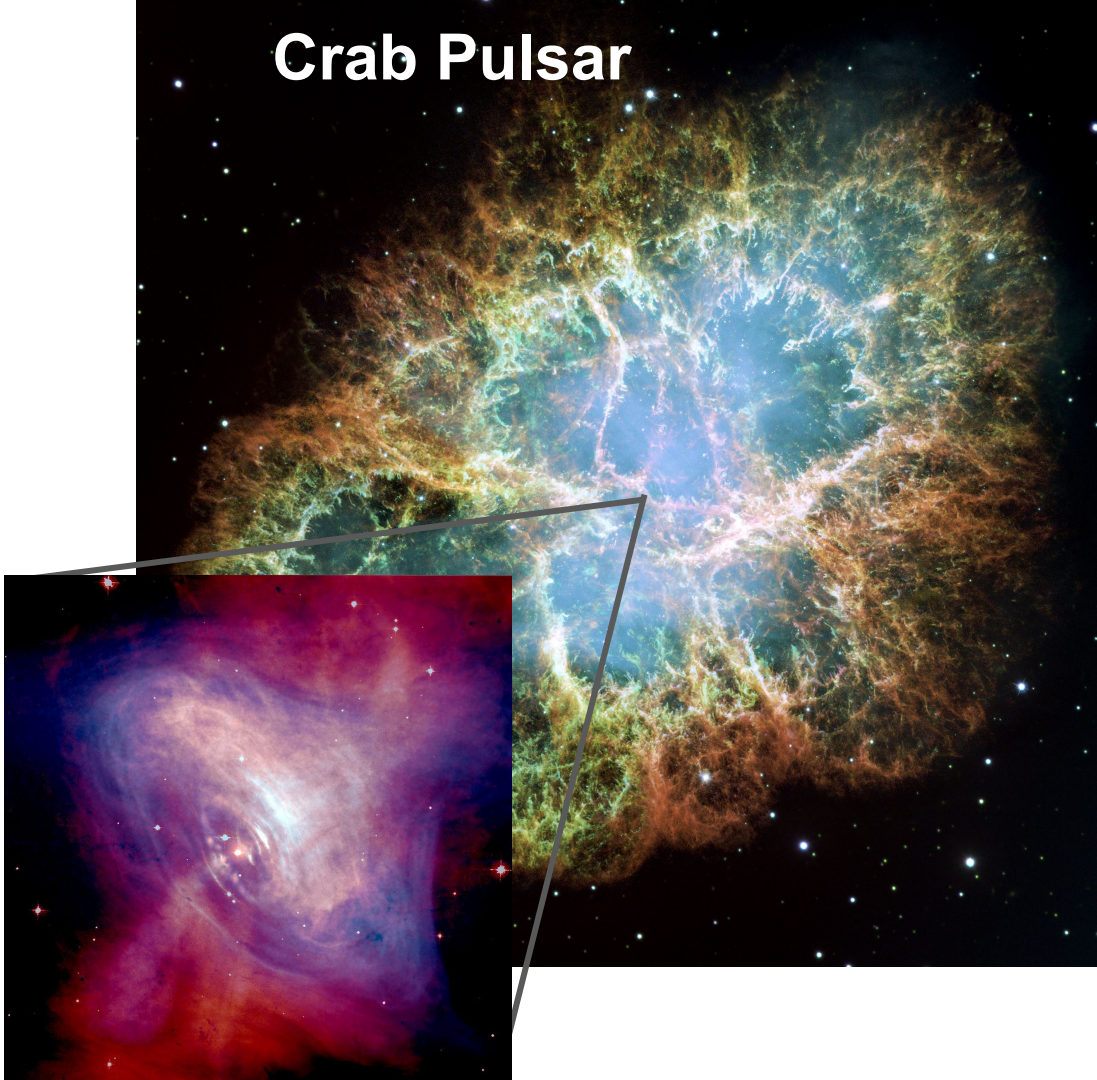


spin period of *33ms*
slowing down by *38ns/day*



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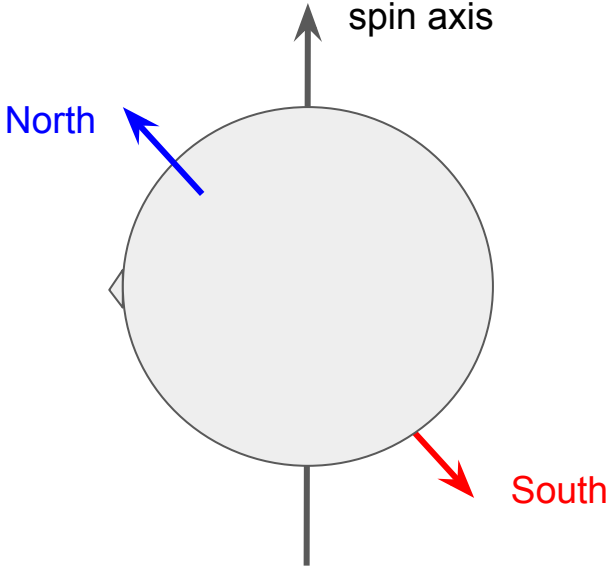

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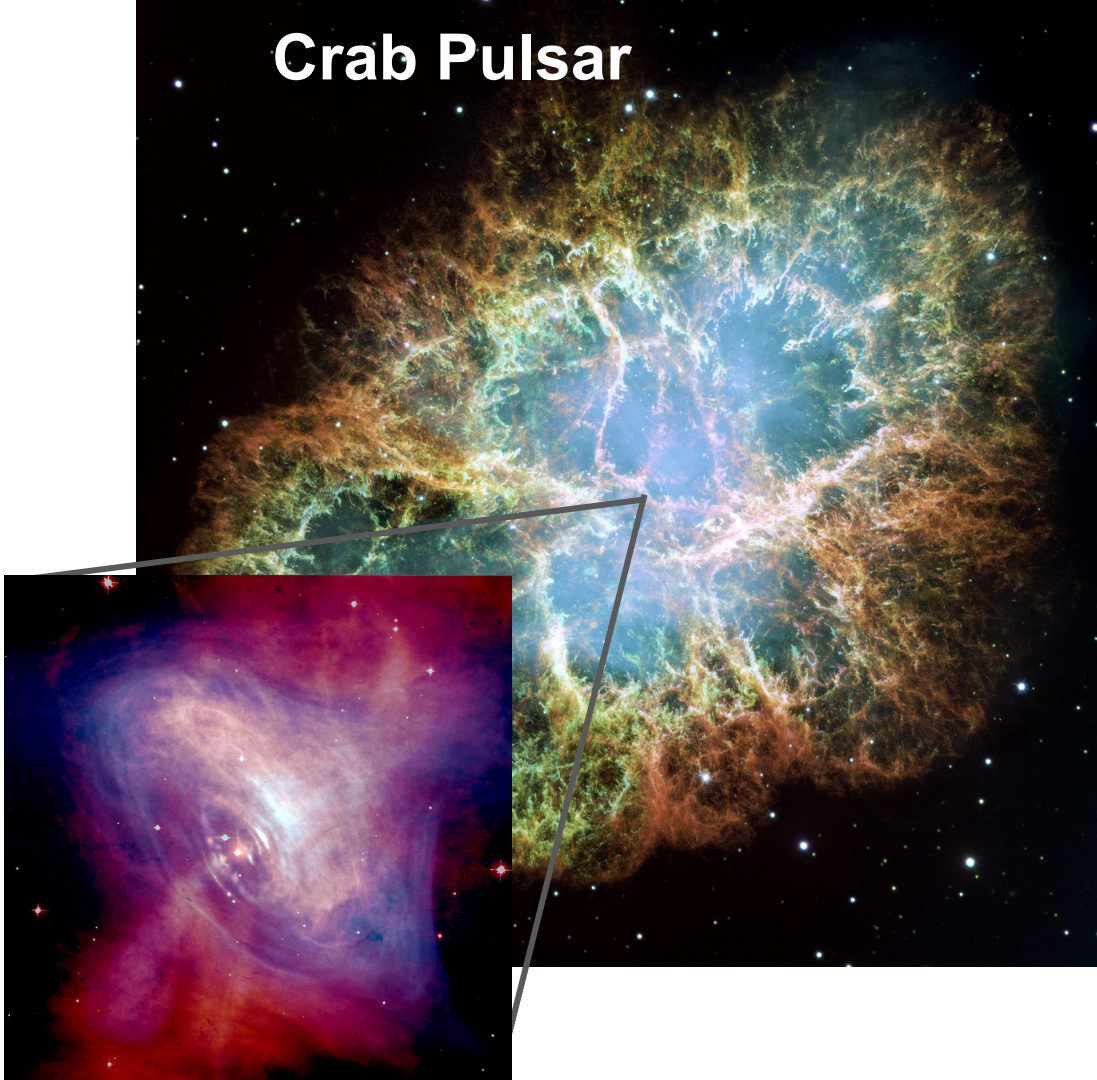
to ~ **1 part in 10,000**



Why are Astrophysical Objects Needed?

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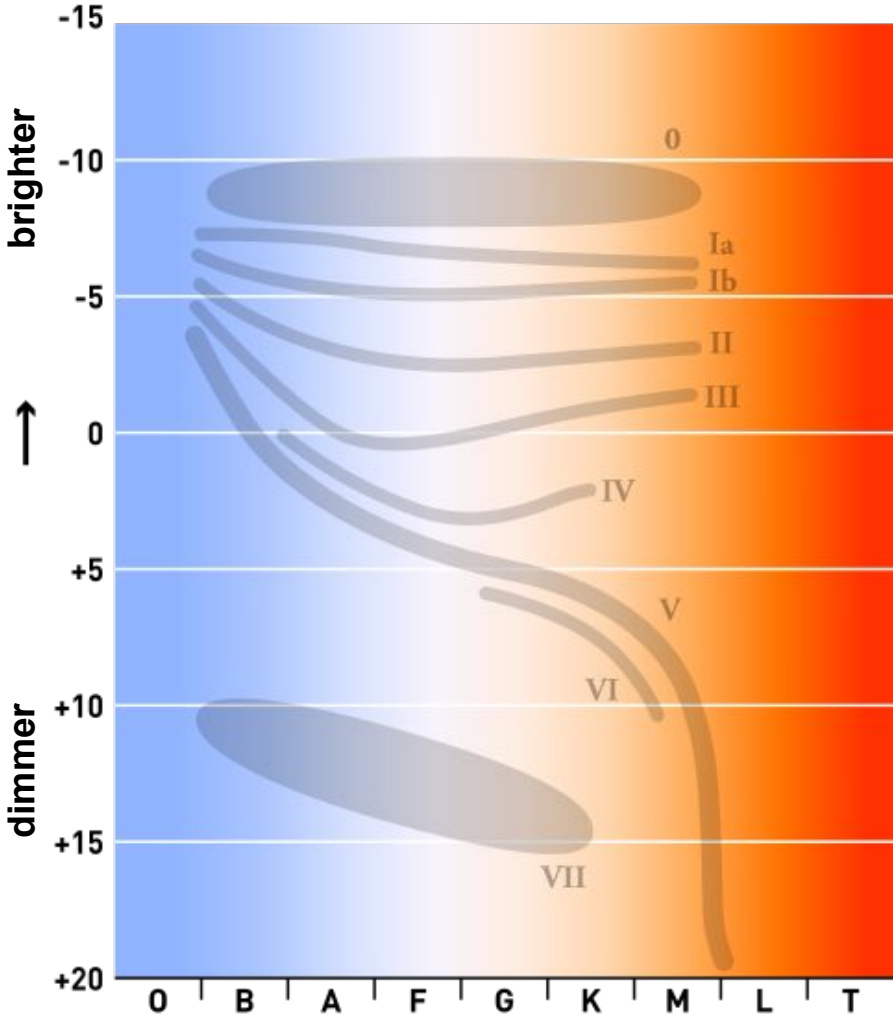
Why do they need to be compact?

- *Most stars and stellar remnants touch before they are moving at interesting speeds!*

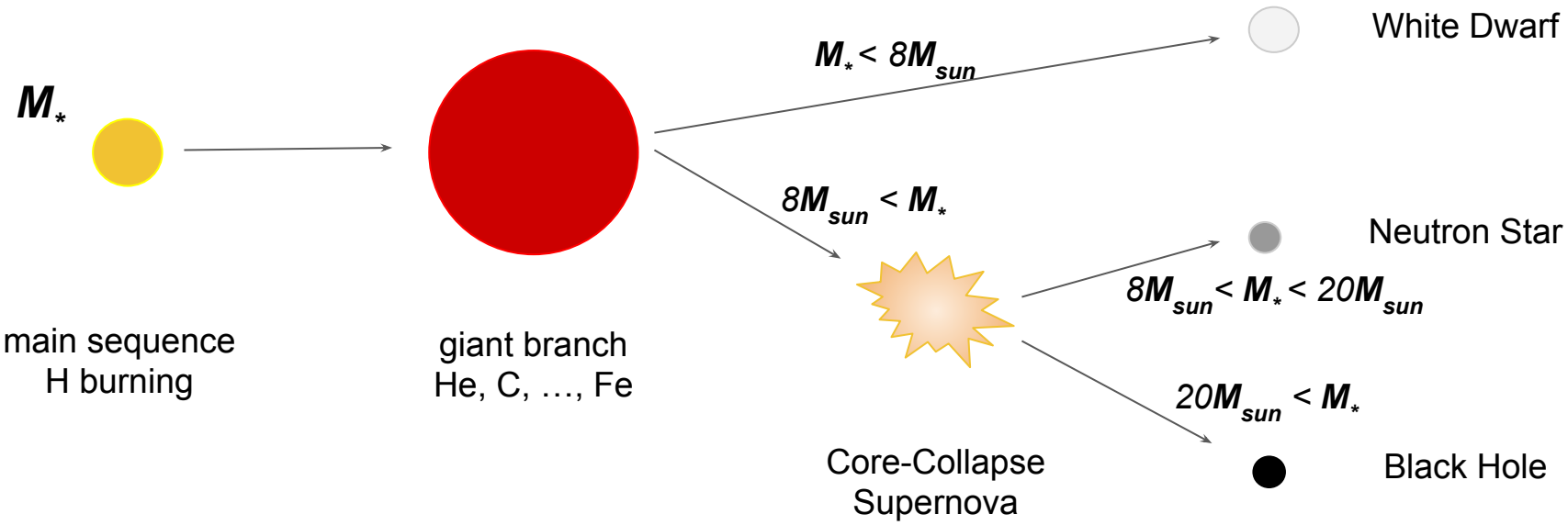
$$\left(\frac{v}{c}\right)^2 \sim \frac{Gm}{c^2 R}$$

Stellar Evolution



Compact Binary Coalescences (CBCs)

Neutron Stars and **Black Holes** are the end states of massive stars



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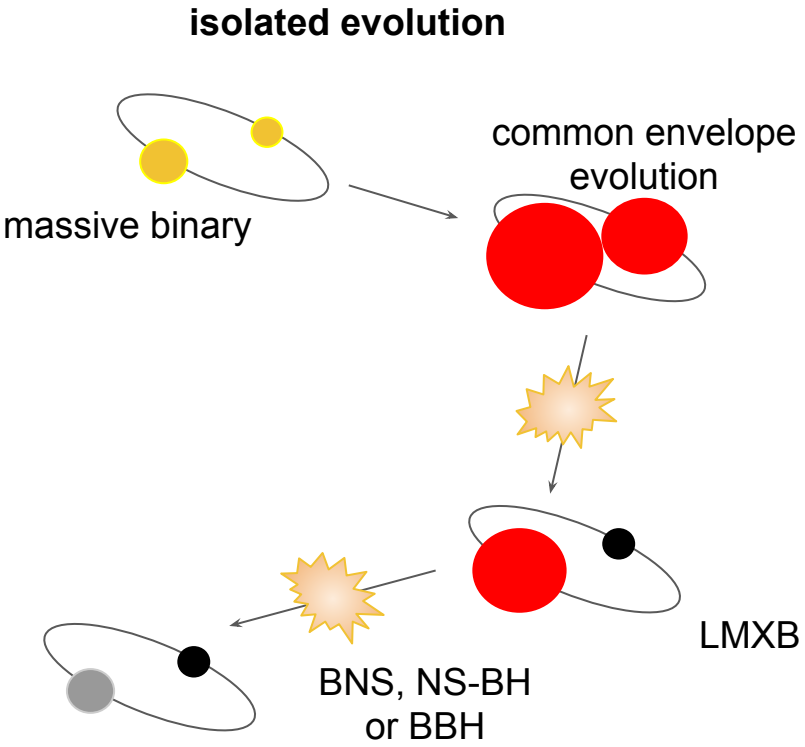
Binaries containing **Compact Objects** form through



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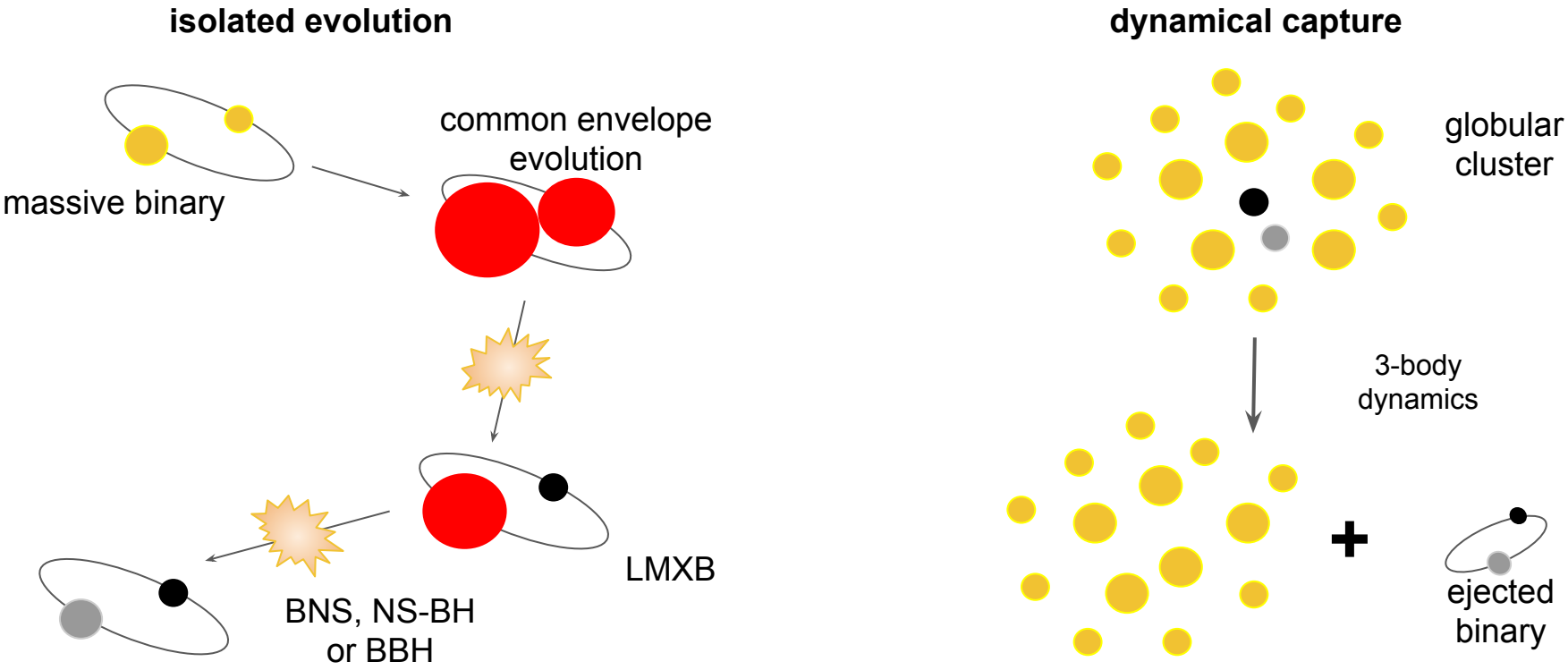

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- Why are CBCs such good sources?

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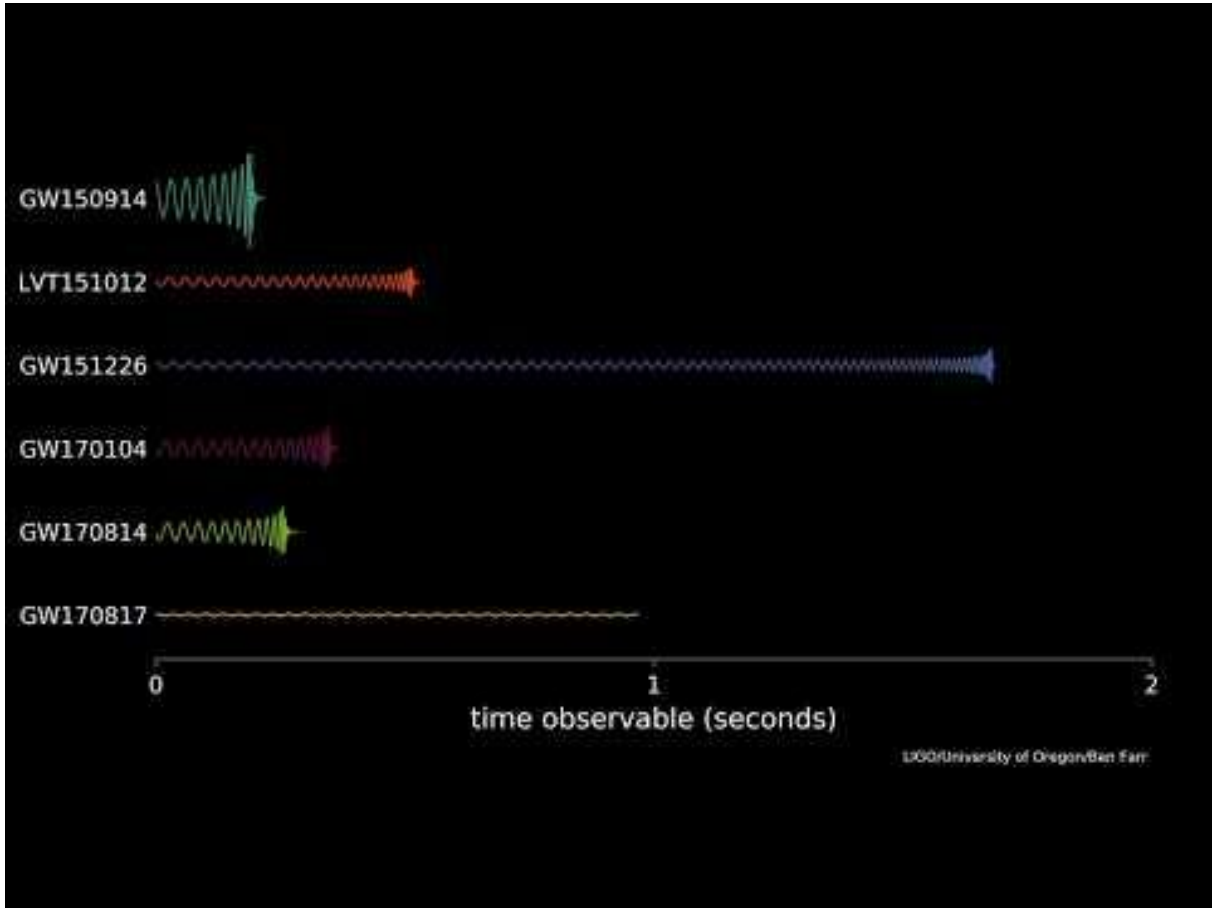
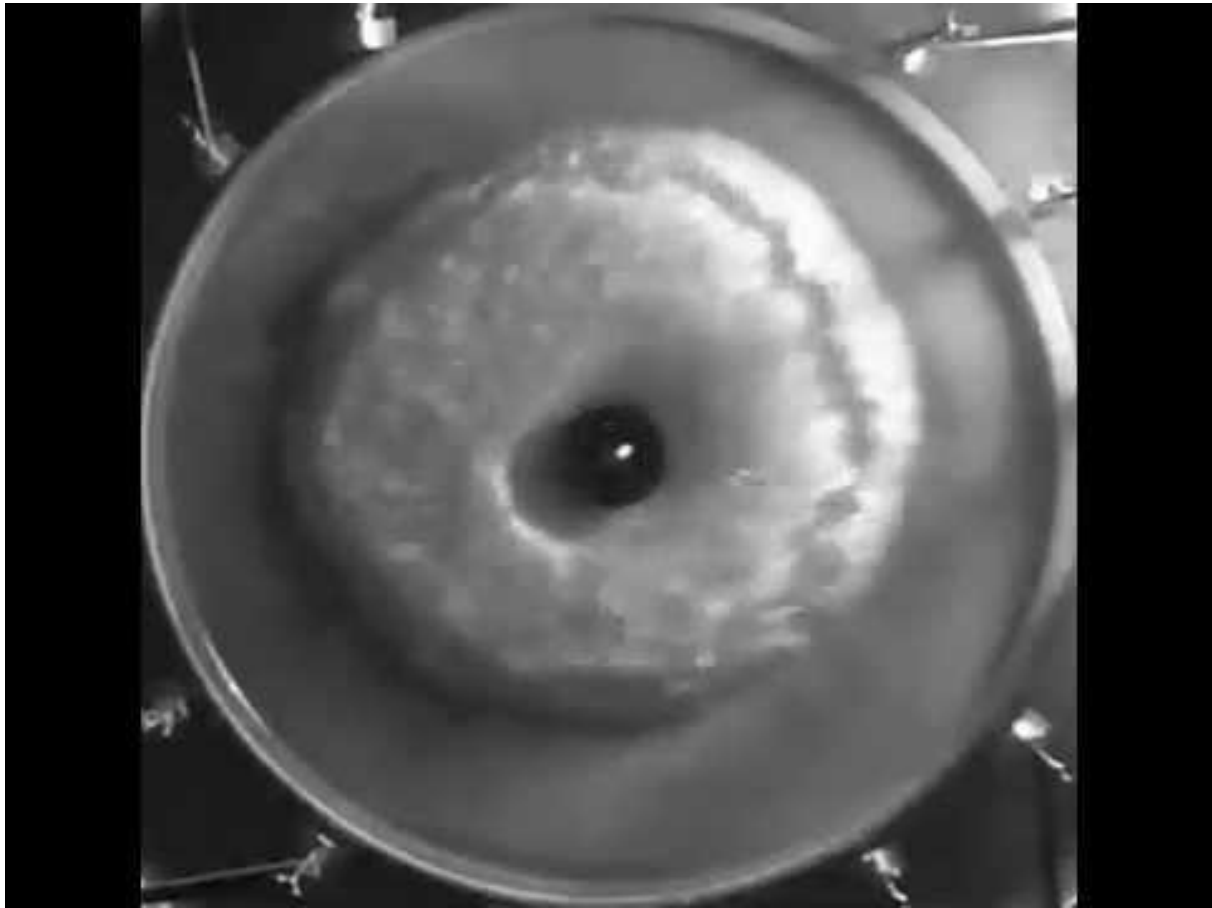
- Why are CBCs such good sources?
- What do CBC signals “sound like”?



Other Possible Sources

Bursts

- Core-Collapse SuperNova (CCSN)



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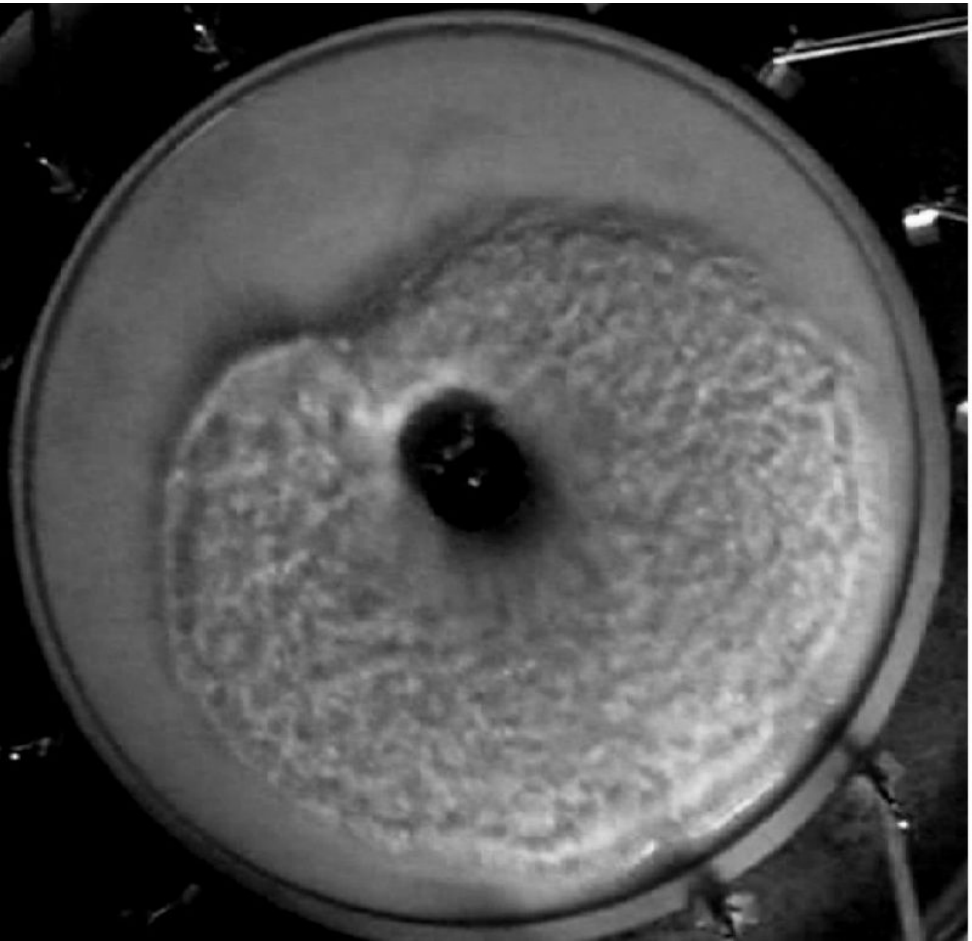

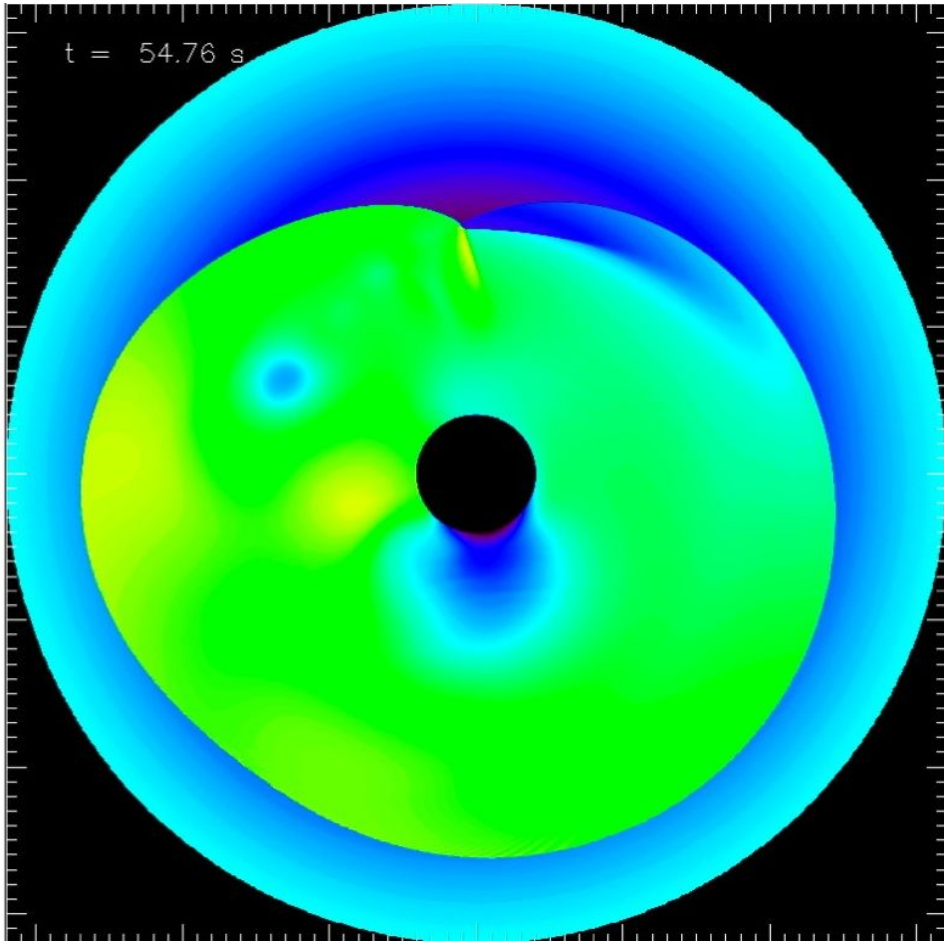

Other Possible Sources

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- Core-Collapse SuperNova (CCSN)

- General “other stuff”
  - Accretion disk instabilities
  - Pulsar glitches
  - Cosmic strings
  - …

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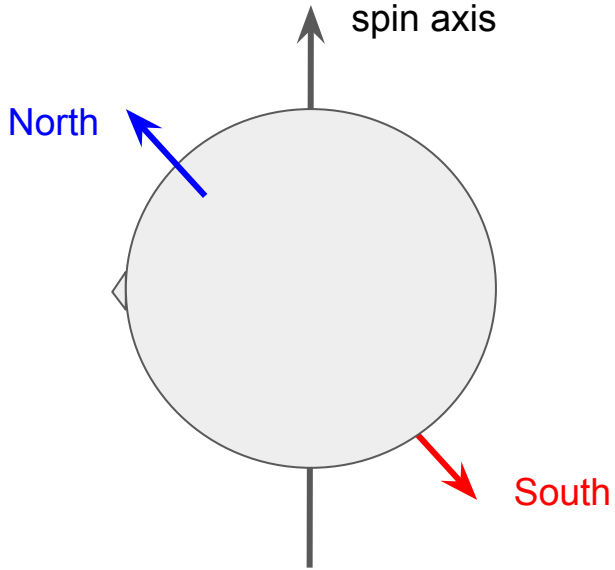

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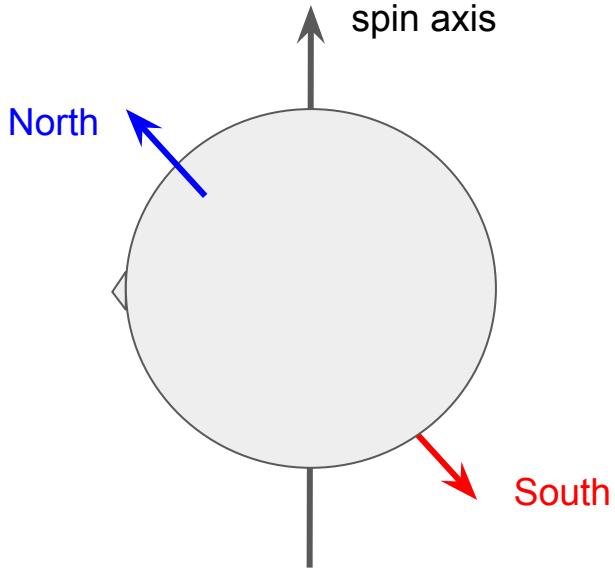
Stochastic Sources



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Next time

Detecting Gravitational Waves on Earth

- Laser interferometers
- Noise Sources
- Other detection techniques

Suggested Reading

- *Shallow Water Analogue of the Standing Accretion Shock Instability*. PRL 108, 051103 (2012).
- *A Carillon of Black Holes. arXiv:1803.08090 (2018).*