TESTING GENERAL RELATIVITY WITH BLACK HOLE-PULSAR BINARIES

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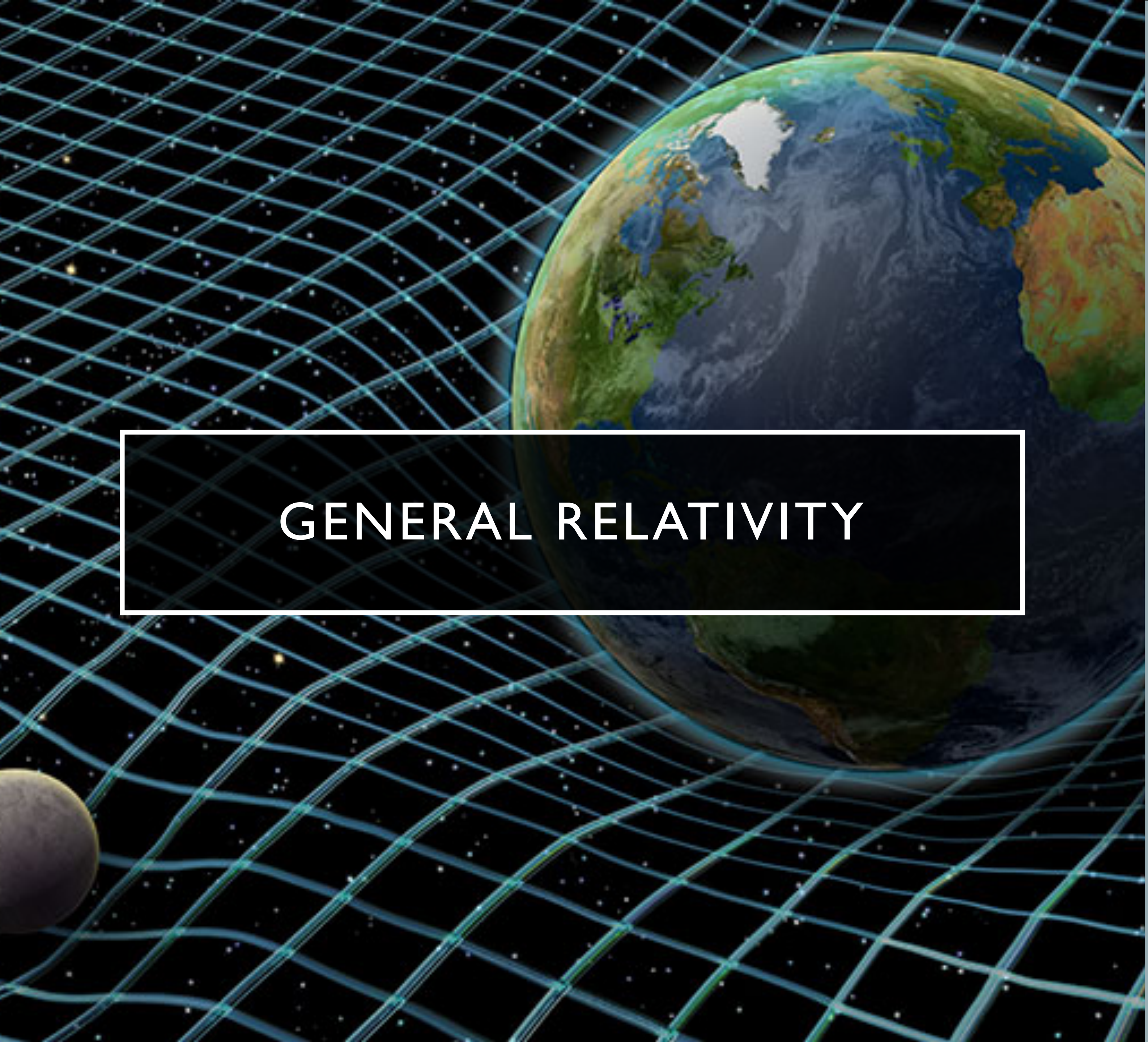
OUTLINE

1. Testing General Relativity
2. Observing a Black Hole-Pulsar Binary with Pulsar Timing
3. Applying Methodology to a Specific theory: Varying Gravitational Constant
4. Conclusion

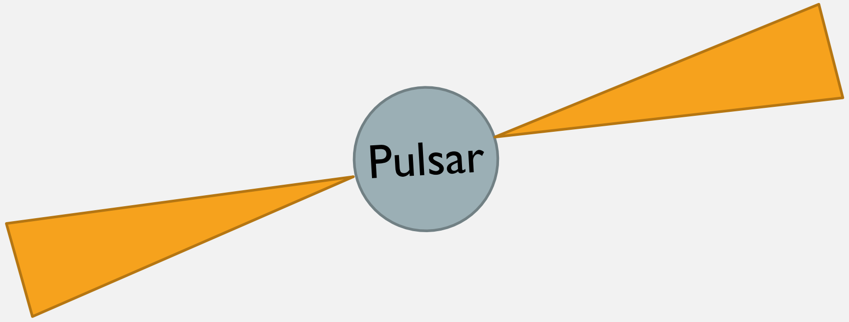
GENERAL RELATIVITY

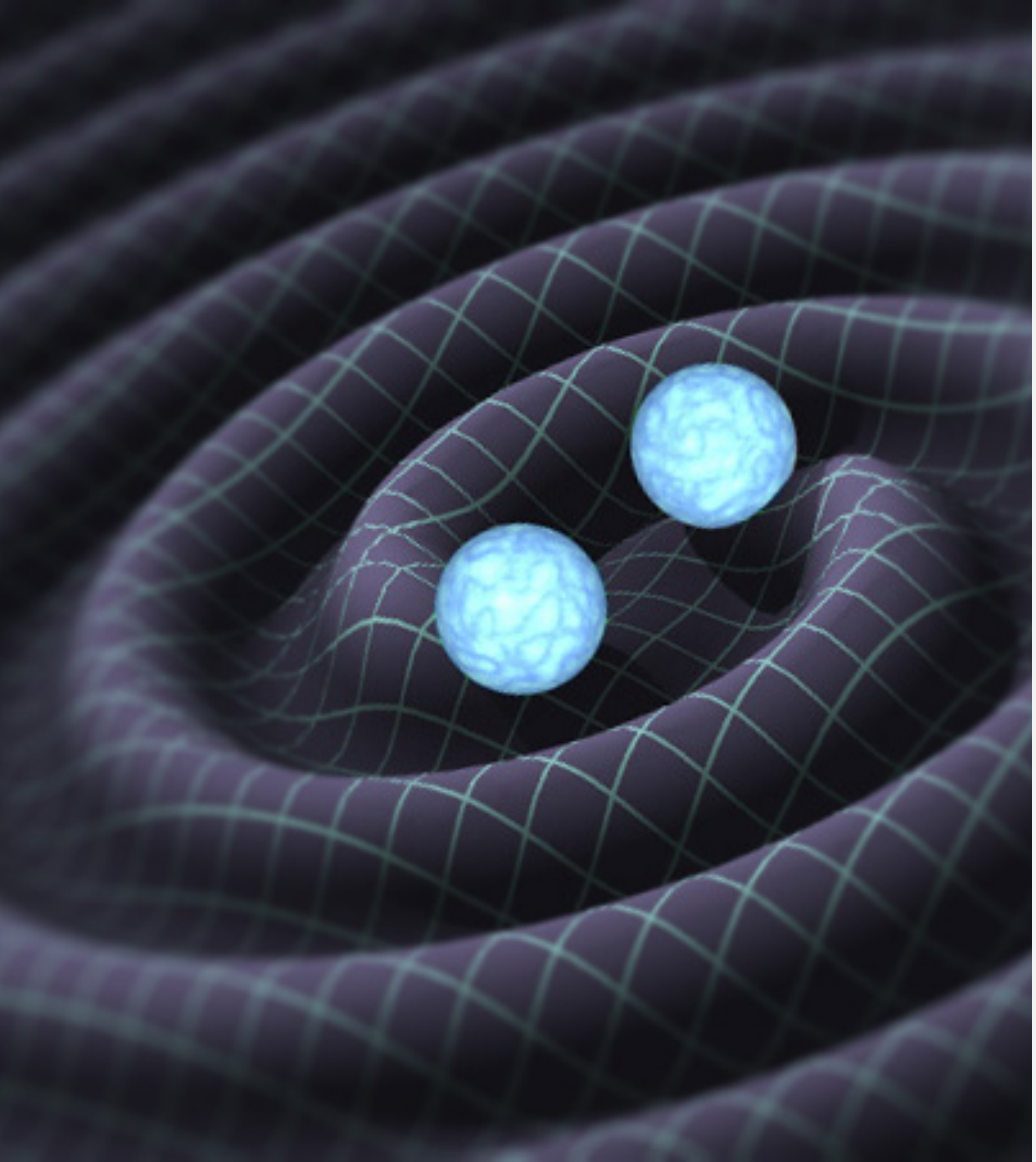


- Einstein's general relativity improved Newtonian gravity to deal with relatively strong-field experiments.
- Gravitational force is caused by curvature of spacetime.
  - Mass distorts spacetime
  - Spacetime distortion moves matter

NEW STARS IN GENERAL RELATIVITY

- New types of special compact stars emerge such as black holes and pulsars.
- A black hole bends space so much that nothing, including light, can escape it.
- A pulsar is as heavy as the sun but around the same width as Washington DC.





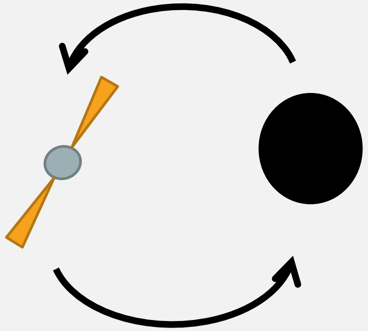
GRAVITATIONAL WAVES IN ASTROPHYSICAL BINARIES

- General relativity also predicted that orbiting heavy objects emit gravitational waves (ripples of spacetime).
- Gravitational waves emit energy, so stars spiral together.
  - This decreases the orbital period.
- 2017 Nobel Prize awarded to LIGO for first direct gravitational wave detection!

PULSAR TIMING

- Radio telescopes and gravitational wave observatories have found double black hole and double pulsar binaries and are actively searching for a black hole – pulsar binary.
- When one is found, observations of orbital period change will be powerful for testing general relativity.

Radio Telescope



Black Hole-Pulsar Binary

ORBITAL DECAY RATE

- Orbital energy is lost through gravitational radiation.
- Orbital decay rate is defined to be the time derivative of the orbital period.
- For completeness, I include the equations for the values of the orbital decay rate in general relativity.

$$\left.\frac{\dot{P}}{P}\right|_{GR} = -\frac{96}{5} G^{5/3} \mu M^{2/3} \left(\frac{P}{2\pi}\right)^{-8/3} F_{GR}(e)$$

$$F_{GR}(e) \equiv \frac{1}{(1-e^2)^{7/2}} \left(1 + \frac{73}{24}e^2 + \frac{37}{96}e^4\right)$$

ORBITAL DECAY RATE MODIFICATION

- Future radio telescopes such as FAST or SKA may detect a black hole-pulsar binary and measure its orbital decay rate.
- Orbital decay rate measurements can place bounds on theory parameters.

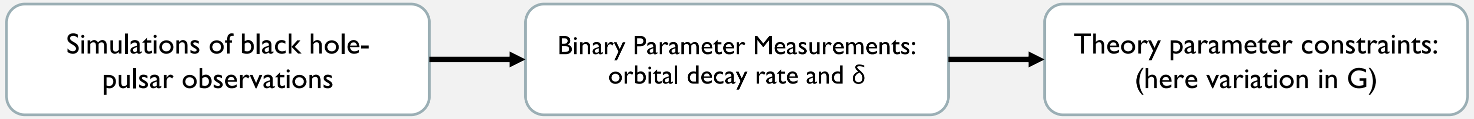
$$\left| \frac{\frac{\dot{P}}{P}(\text{th. param.}) - \frac{\dot{P}}{P}\Big|_{GR}}{\frac{\dot{P}}{P}\Big|_{GR}} \right| < \delta$$

VARYING GRAVITATIONAL CONSTANT

- The gravitational constant is fundamental part of general relativity (and Newtonian gravity).
- G is assumed to be the constant in time.
- **How can we constrain the time derivative of G to be 0?**

$$F_{gravity} = G\frac{M_1 \, M_2}{r^2}$$

BOUNDING A VARYING GRAVITATIONAL CONSTANT

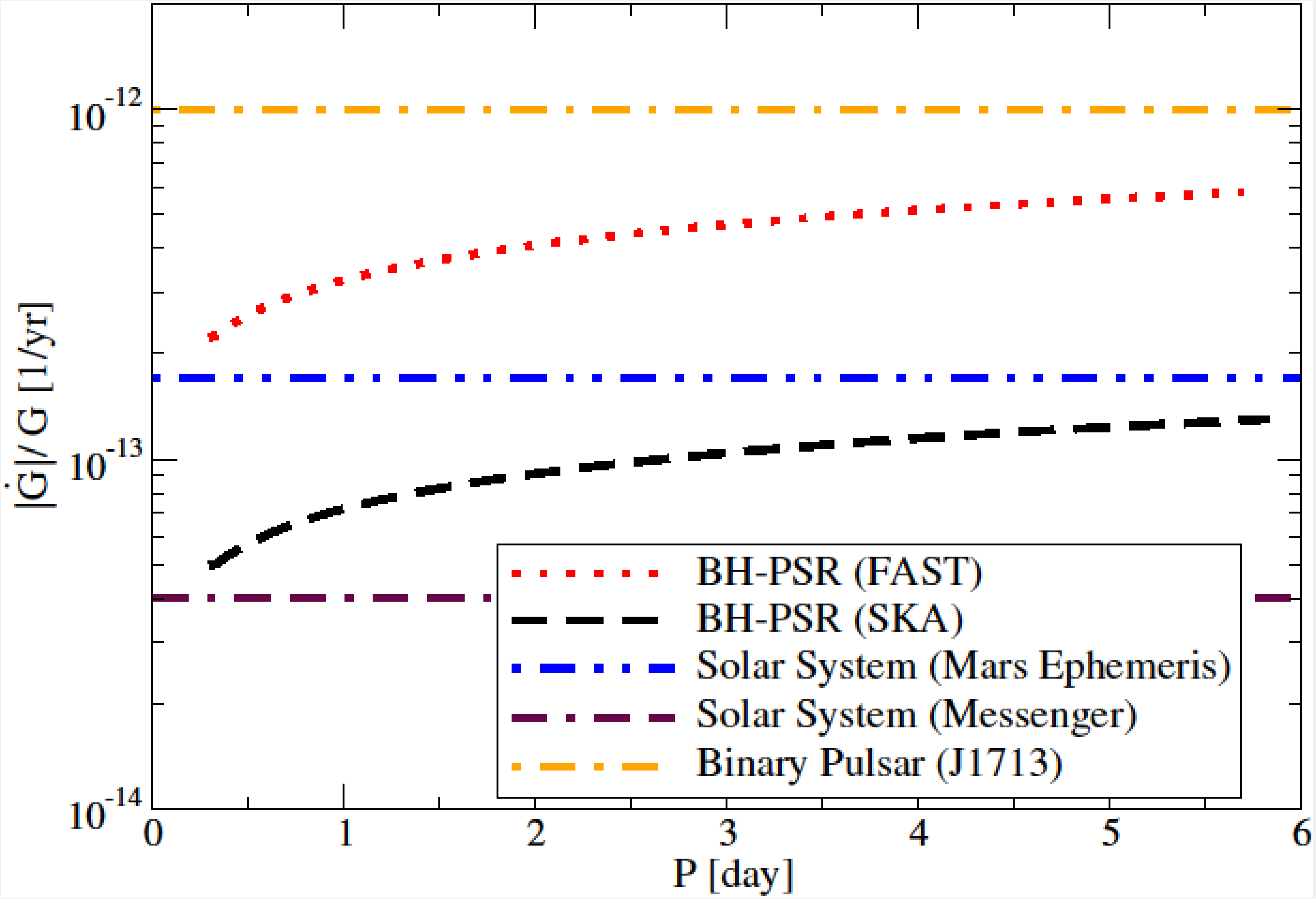


- One can derive an equation that describes the orbital decay rate in a theory where the gravitational constant varies.
- Using techniques from the last slide, we can construct a bound on the variation in G with a measurement of the orbital decay rate.

$$\frac{\dot{P}}{P} = \left.\frac{\dot{P}}{P}\right|_{GR} - 2\frac{\dot{G}}{G}\left[1 - \left(1 + \frac{m_c}{2M}\right) s_p - \left(1 + \frac{m_p}{2M}\right) s_c\right]$$

$$\frac{|\dot{G}|}{G} < -\frac{1}{2}\left.\frac{\dot{P}}{P}\right|_{GR} \frac{\delta}{1 - \left(1 + \frac{m_c}{2M}\right) s_p - \left(1 + \frac{m_p}{2M}\right) s_c}$$

BOUNDS ON A CHANGING GRAVITATIONAL CONSTANT



CONCLUSION AND FUTURE WORK

- General relativity is the best current theory of gravity.
- Gravitational waves have a promising powerful future for understanding our universe.
- A black hole – pulsar binary will present new ways to test modifications of general relativity.