Measuring Curvature, Mass of Black Holes, + Frame-Dragging

By:

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It is not hard to measure the mass of a black hole

- The conventional way to determine the mass of black holes

  - - By measuring the speed of the stars as well as the size of the orbits.

  - - Mainly applied to measuring the nearby black holes.

  - - Errors will occur if apply to the supermassive black holes(SMBH).

A new measurement is more productive!

- Distant galaxies lie so far away that telescopes cannot resolve the stars and the clouds of the material around the black hole.

- A method called reverberation mapping has made it possible for astronomers to measure the mass of the outlying black holes.(by examining 'Quasars').

- The process of this measurement was slow in the beginning, finally boosted by employing the wide-view telescope to collect data of a wider sky area.

The evolution of the new method

- over last 20 years, astronomers only managed to measure only 60 SMBHs using the reverberation mapping.
- with a wide-view telescope, approximately 850 quasars can be examined at once in a patch of the sky.

- The new measurement reveals SMBHs mass from further back in time to when the universe was half its current age.
- We are able to now understand how the supermassive black holes grow and evolve.

Possible ways of measuring the curvature of spacetime?

- Measuring the curvature of spacetime due to gravity
  - Think about how you might design an experiment to measure the strength of the gravitational force at any location in space.
- At every point, you can infer the force of gravity or the amount of spacetime curvature.
  - But experiments like this are limited. They only give information about gravitation along one direction, Towards the center of the Earth.
- take an object at rest, release it so it's in free-fall, and observe how it accelerates.
- Measuring the change in velocity over time, we get the acceleration.

To get a multidimensional picture

- We perform an experiment that's sensitive to changes in the gravitational field as an object changes its position.

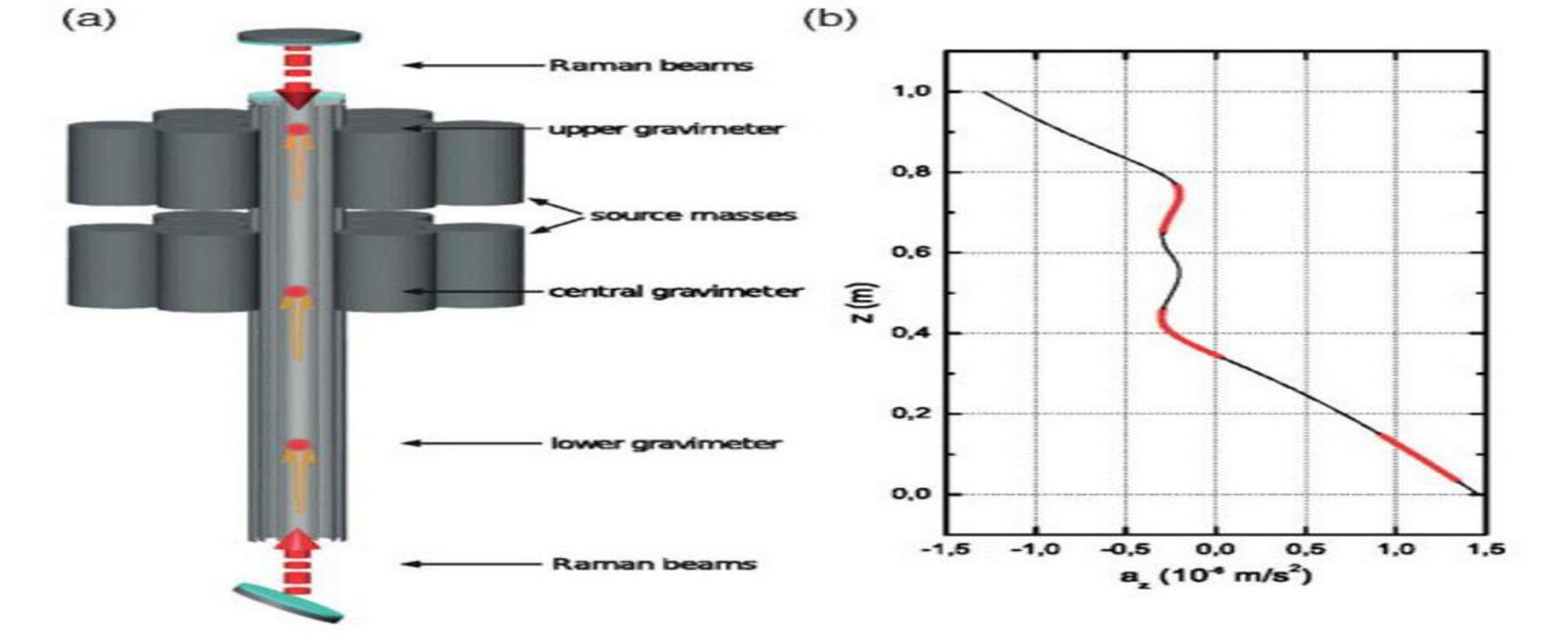
1950s the Pound-Rebka experiment

- First cause a nuclear emission at a low elevation
  a. Then, note that the corresponding nuclear absorption didn't occur at a higher elevation
  b. presumably due to gravitational redshift, as predicted by Einstein.
- If you gave the low-elevation emitter a positive boost to its speed
  a. that extra energy would balance the loss of energy thats traveling upwards in a gravitational field extracted as a result, the arriving photon has the right energy, and absorption occurs.

atomic clocks

- Raising an atomic clock by barely a foot above another one caused a measurable frequency shift in what the clock registered as a second.
- Taking these two clocks to any location on Earth, and adjusting the heights as we see fit, we could understand how the gravitational field changes as a function of elevation.
- Not only can we measure gravitational acceleration, but the changes in acceleration as we move away from Earth's surface.

Measurement of the Gravity-Field Curvature by Atom Interferometry (2015)



- conjugate three atom interferometers simultaneously
- Instead of using just two locations at different heights
- Get the mutual differences between three different heights at a single location on the surface
- We get change in the gradient as a function of distance
- Exploring how the gravitational field changes as a function of distance

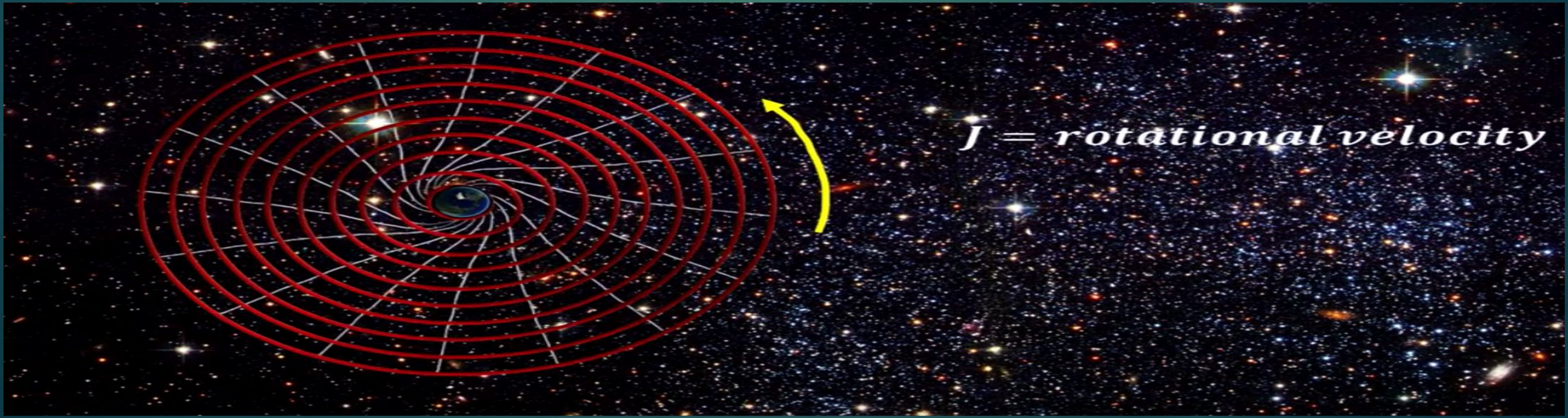
  => We understand the shape of change in spacetime curvature
- We determine:
  - The gravitational force,
  - how it changes with elevation,
  - and how the change in the force is changing with elevation all at once.

Advantages:

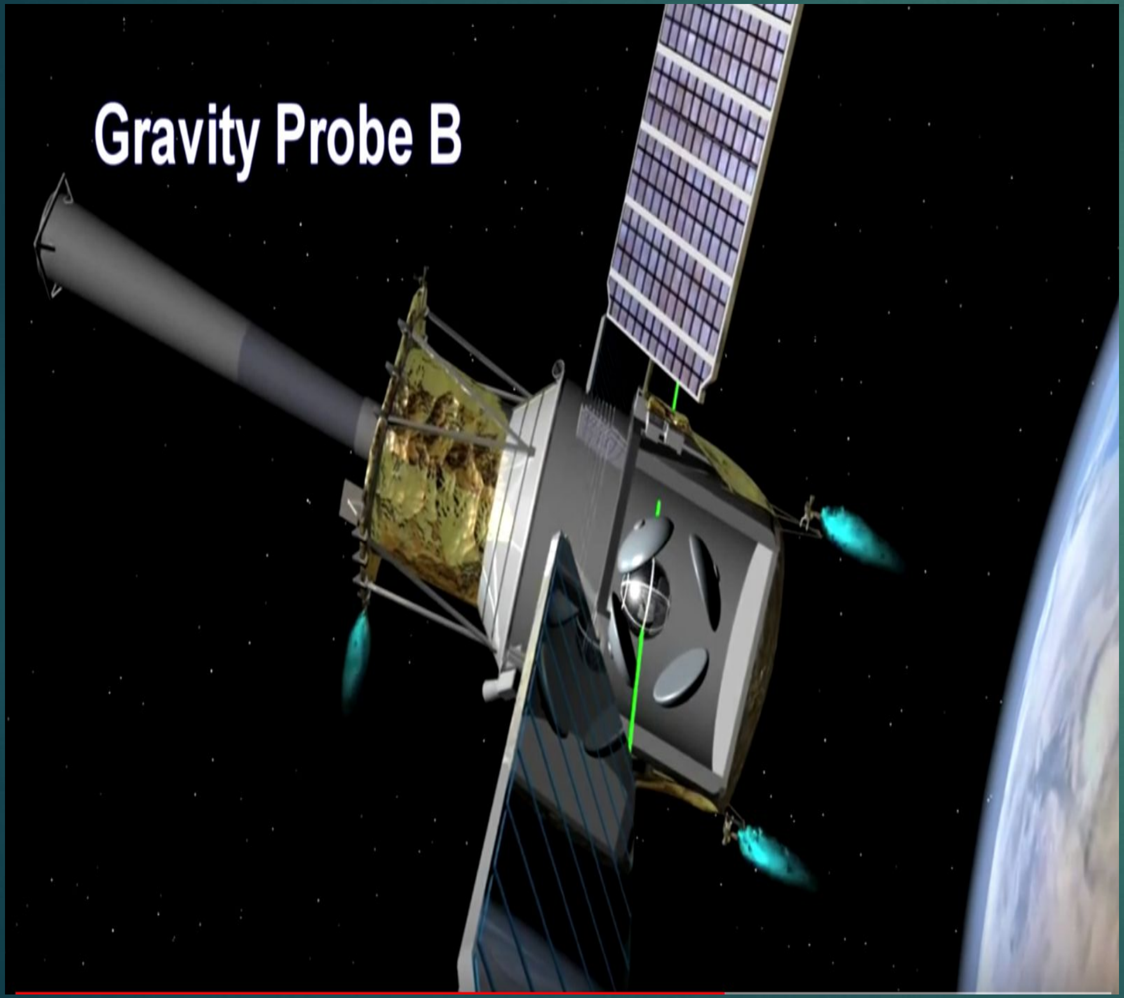
- Making multiple measurements of the field gradient simultaneously allows us to measure G between multiple locations that eliminates a source of error.
- Get three differences (between 1 and 2, 2 and 3, and 1 and 3) rather than just 1 (between 1 and 2).
- we can better understand our planet's interior simply by making measurements at the surface.
- If we want to do asteroid mining, this could be the ultimate prospecting tool.
- Applied to technology on upcoming spacecrafts, it could help correct for Newtonian noise

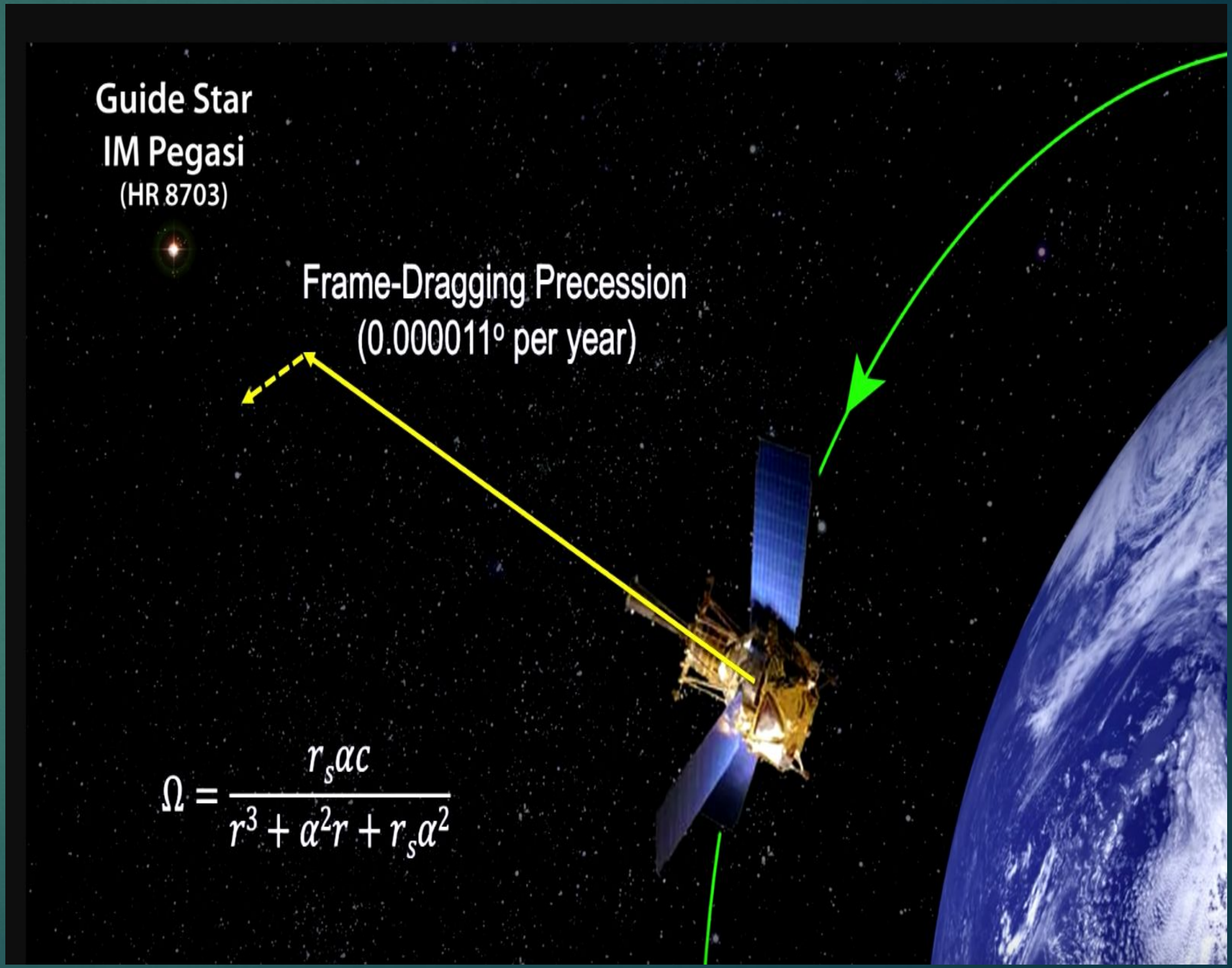
Frame-Dragging

- Frame-dragging is an effect on spacetime, predicted by Einstein
- Caused by non-static stationary distributions of mass–energy
- joseph lens and hans thiering test

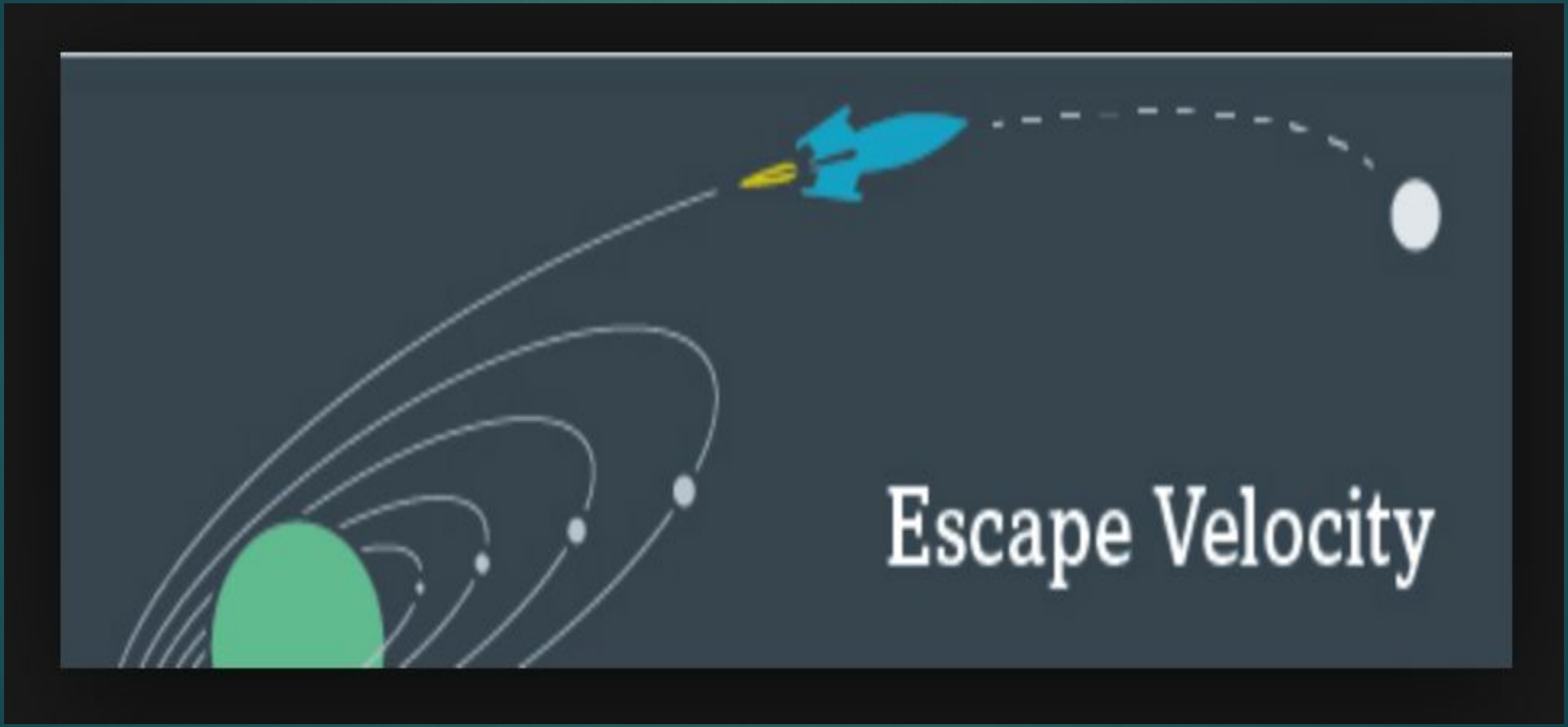


Measuring Twisting of Space





Escape Velocity



Some fun facts about these constant

- Planck constant - h (e = hv)
- Planck Length - 1.616*10^-35m
- Planck Temperature -1.4168*10^32k