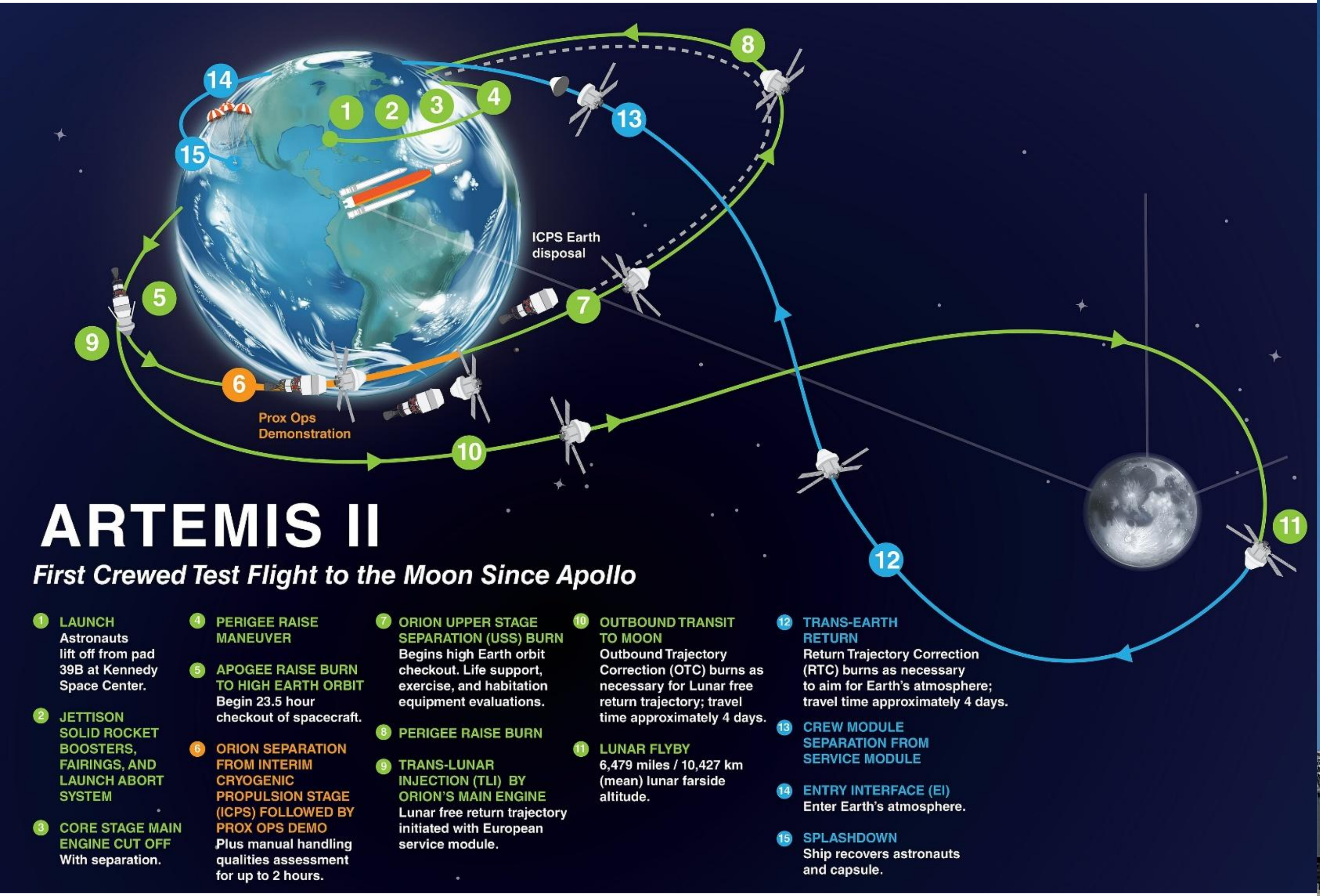
TODAY @ 6:24 pm EST
ARTEMIS II Launch to the MOON



Today's Topics

Wednesday, April 1, 2026 (Week 9, lecture 26) – Chapter 24.

A. Review of Midterm Topics

A. Gravitational Waves.

B. Black holes.

Problem Set #8 is due on ExpertTA on Friday, April 3, 2026, by 9:00 AM

Midterm #2 will be on Monday, April 6, 2026.

Midterm #2 topics

Midterm #1 background physics

1. Scientific units, notations, exponents, trigonometry
2. Kepler's Laws + Newton's vers. of 3^{rd} law
3. Newton's laws and gravity
4. Conservation laws: Energy, momentum, angular momentum
5. Kinetic & Potential Energy
6. Circular Motion
7. Escape velocity
8. Electromagnetic spectrum
9. Blackbody radiation
10. Photons & Spectroscopy
11. Doppler effect
12. Nuclear particles & P-P chain fusion

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MAIN TOPICS

A. Telescopes, angular resolution
B. Our Sun, P-P chain fusion
C. Luminosity, magnitude
D. Luminosity vs mass, H-R diagram
E. Main sequence stellar evolution
F. Red giant, planetary nebula, white dwarf
G. Pauli exclusion principle
H. Evolution of massive stars
I. Type 2 supernova physics, neutrinos
J. Neutron stars, pulsars
K. Origin of the elements
L. Special relativity: length contraction, time dilation
M. General relativity, gravitational waves
N. Black holes

Gravitational Waves

- Accelerating and ***orbiting*** masses will emit gravitational waves.

- Gravitational waves are a consequence of the **finite speed of gravity** *(speed of light)*.

  → a change in gravity's strength propagates at the speed of light.
  (i.e. it's not instantaneous.)

- Only large masses emit significant gravitational waves.

  → Orbiting **black holes** and **neutron stars.**
  → Masses must be close together (i.e. fast moving) for significant emission.

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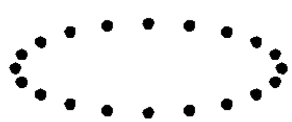
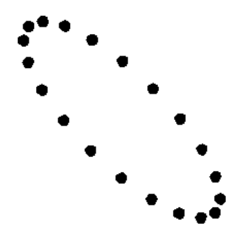
- A passing gravitational wave applies weak pulling & stretching forces along two perpendicular axes.



"+" polarization

or



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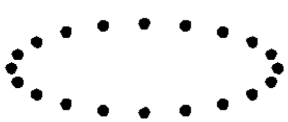

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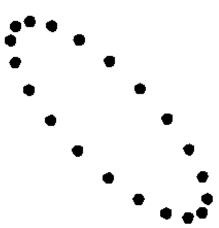


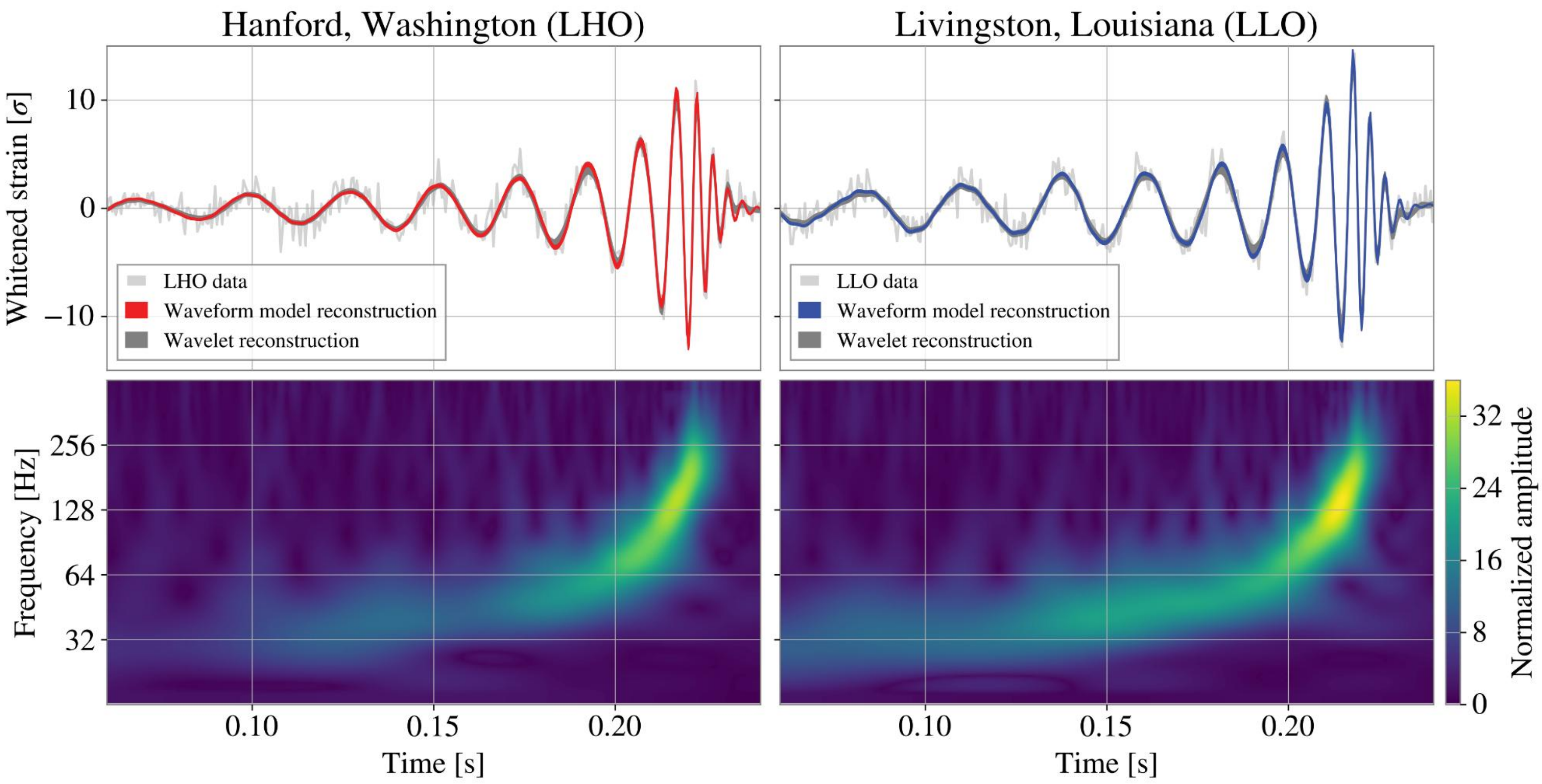
"×" polarization

Gravitational Wave "Telescope"

LIGO: Laser Interferometer Gravitational-Wave Observatory

[http://ligo.caltech.edu: LIGO Livingston, LA]

Gravitational Waves
from
Black Hole Merger



GW250114 event

Black Holes

Black hole

A celestial object whose gravity is so strong that even light cannot escape from it.

→ Light emitted outside of the **event horizon** (i.e. **Schwarzchild radius**) can escape.

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→ The **event horizon** / **Schwarzchild radius** defines the size and surface of a black hole.

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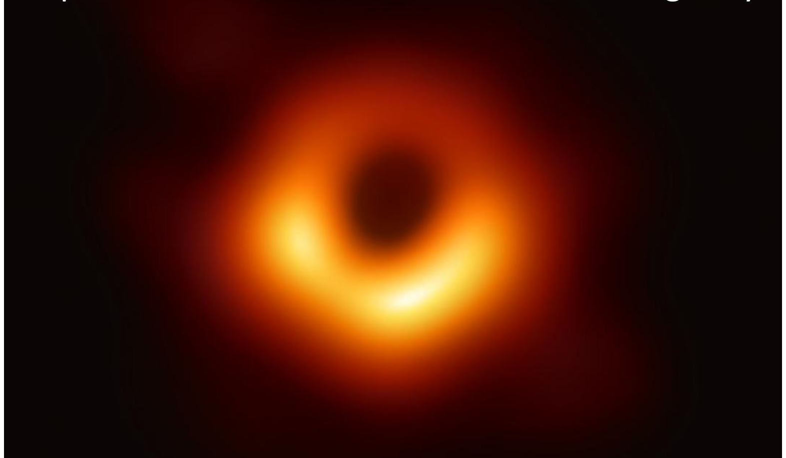
$$\text{Schwarzchild radius} = R_S = \frac{2GM}{c^2}$$

*The **event horizon** is about 2-3 times smaller than the black shadow.*

Supermassive black hole at center of M87 galaxy.



[Event Horizon Telescope, www.eso.org, λ=1.3 mm]

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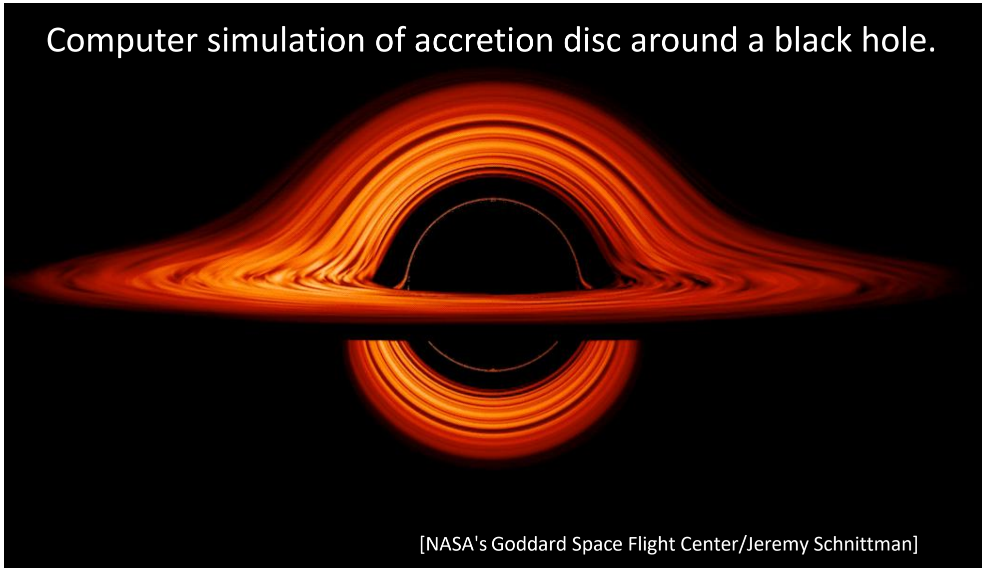

Computer simulation of accretion disc around a black hole.

[NASA's Goddard Space Flight Center/Jeremy Schnittman]

PollEv Quiz: PollEv.com/sethaubin

2020 Nobel Prize in Physics
Black Hole Physics & Astronomy

Roger Penrose
(U. of Oxford)

Reinhard Genzel
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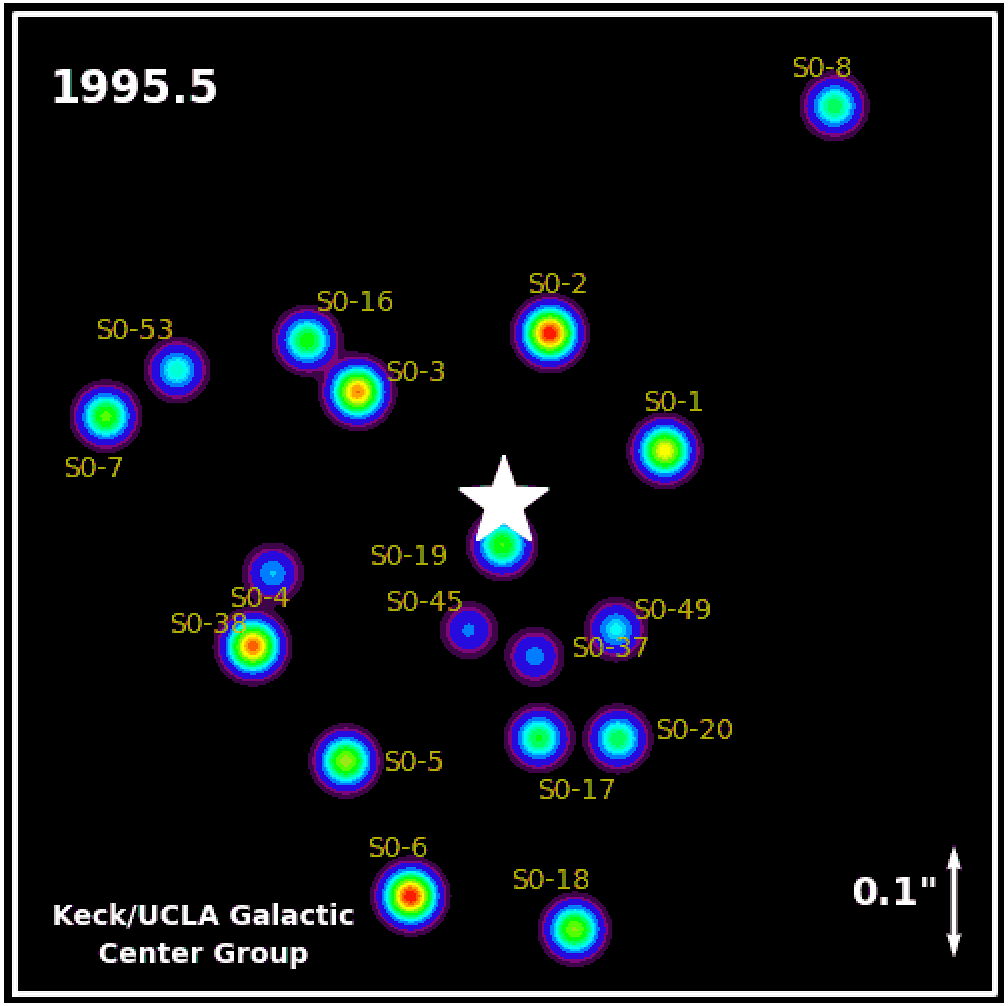
Black hole
physics & mathematics

Discovery of the black hole at the center
of our Milky Way galaxy

Black Hole at center of Milky Way

The Sagittarius A* supermassive black hole



Black Hole at center of Milky Way

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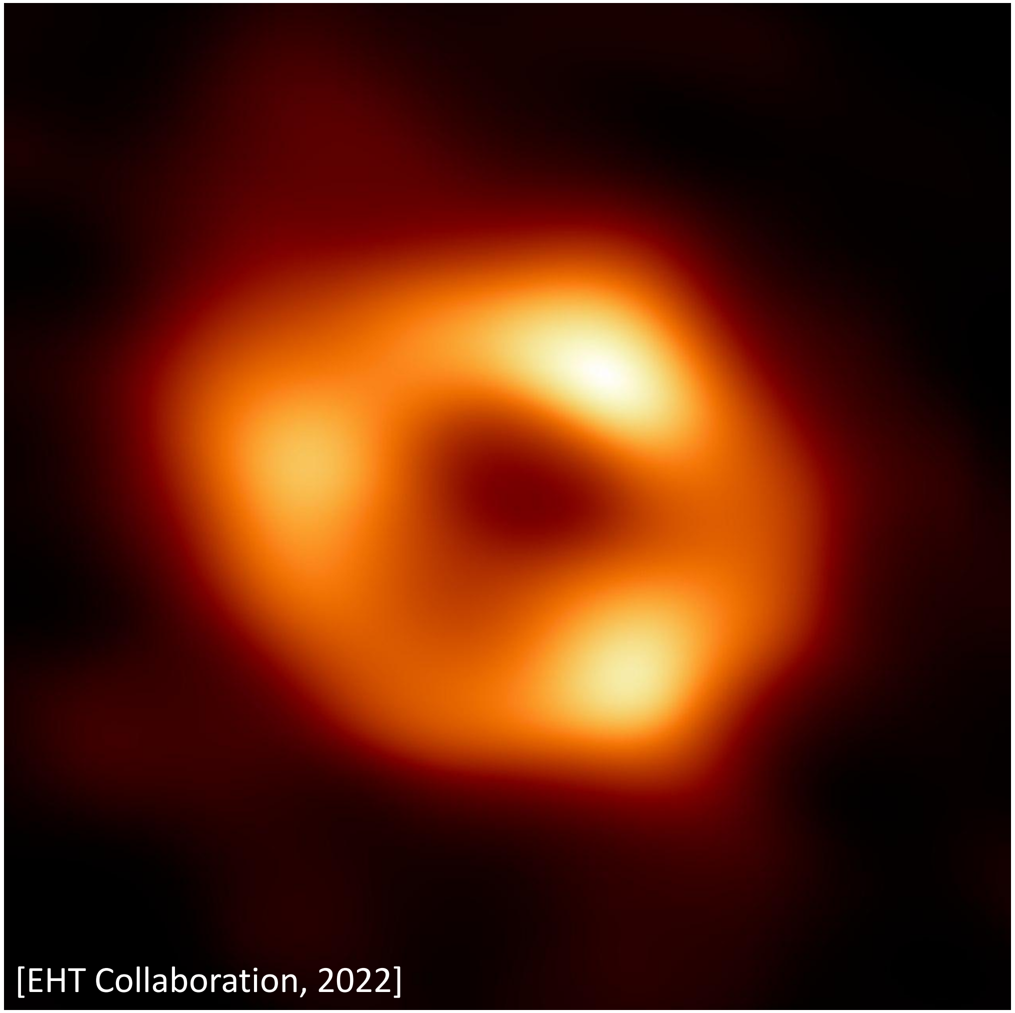


Mass = 4 million M_{Sun}

What happens if you fall into a Black Hole?

Stellar mass black hole

- The **Roche limit** is well outside of the event horizon.
- Any object falling towards the event horizon is **pulled apart** (spaghettified) by the strong **gravity gradient** (tidal force) of the black hole.

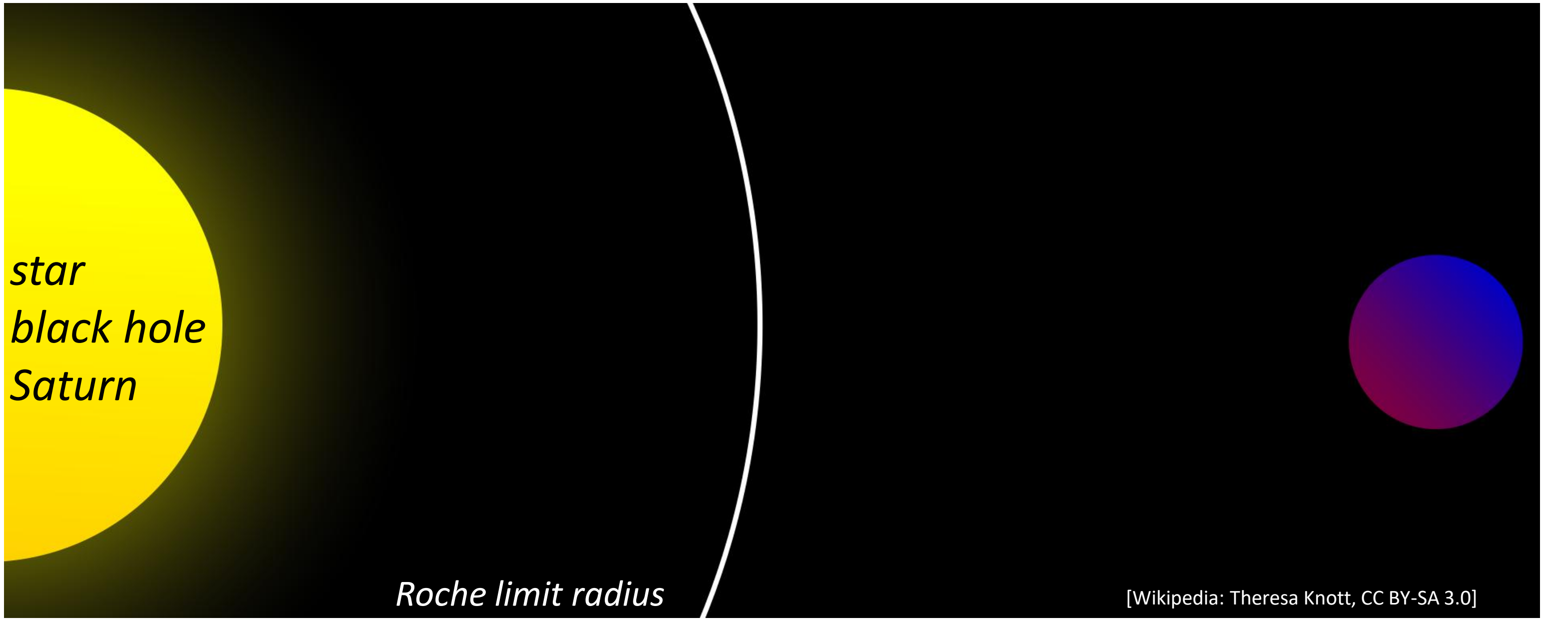
The Roche Limit

The Roche limit is the orbital radius at which a gravitational bound object will be **pulled apart** by the **tidal force** from the central mass (i.e. Sun, Saturn, black hole, etc).

(gravity gradient)

→ The Roche limit depends on nature of body (solid, fluid, density).

→ Proposed by Eduard Roche in 1848 (French astronomer).



Far outside the Roche limit radius, the tidal force and deformation are **weak**.

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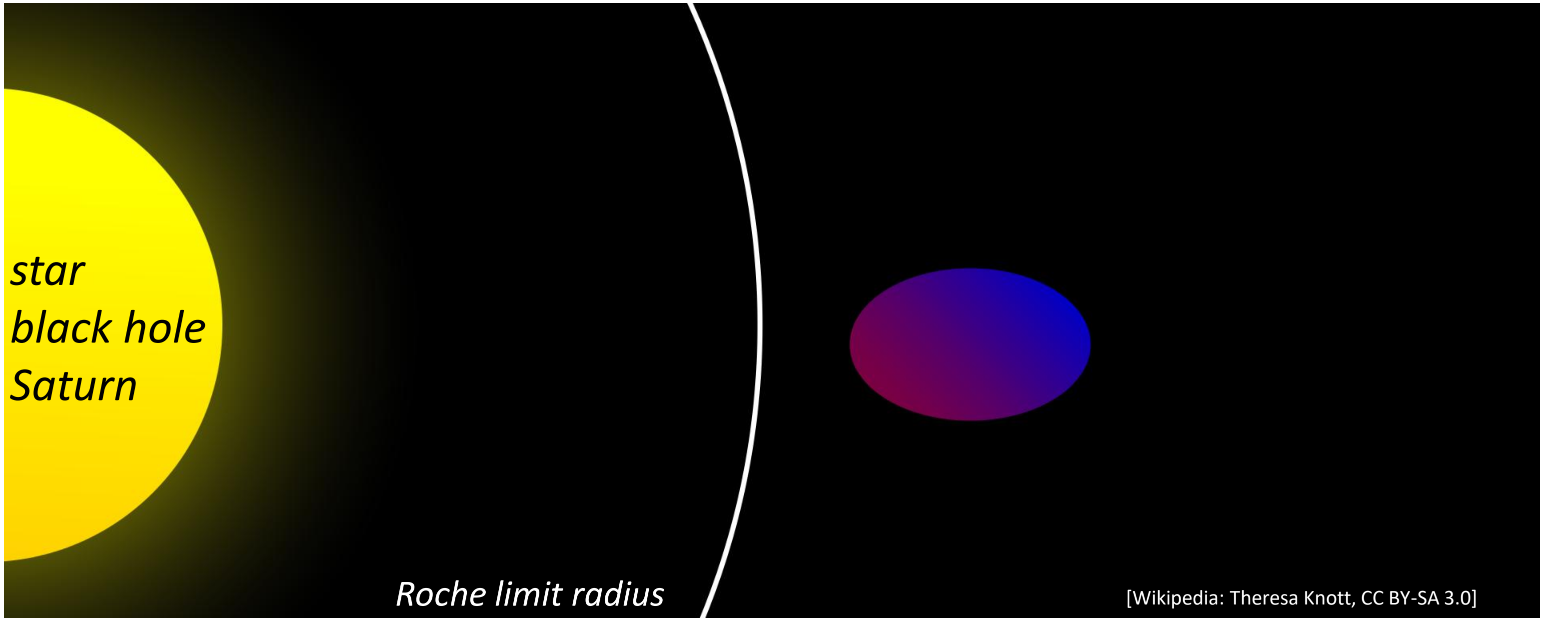

Close to the Roche limit radius, the tidal force and deformation are **strong**.

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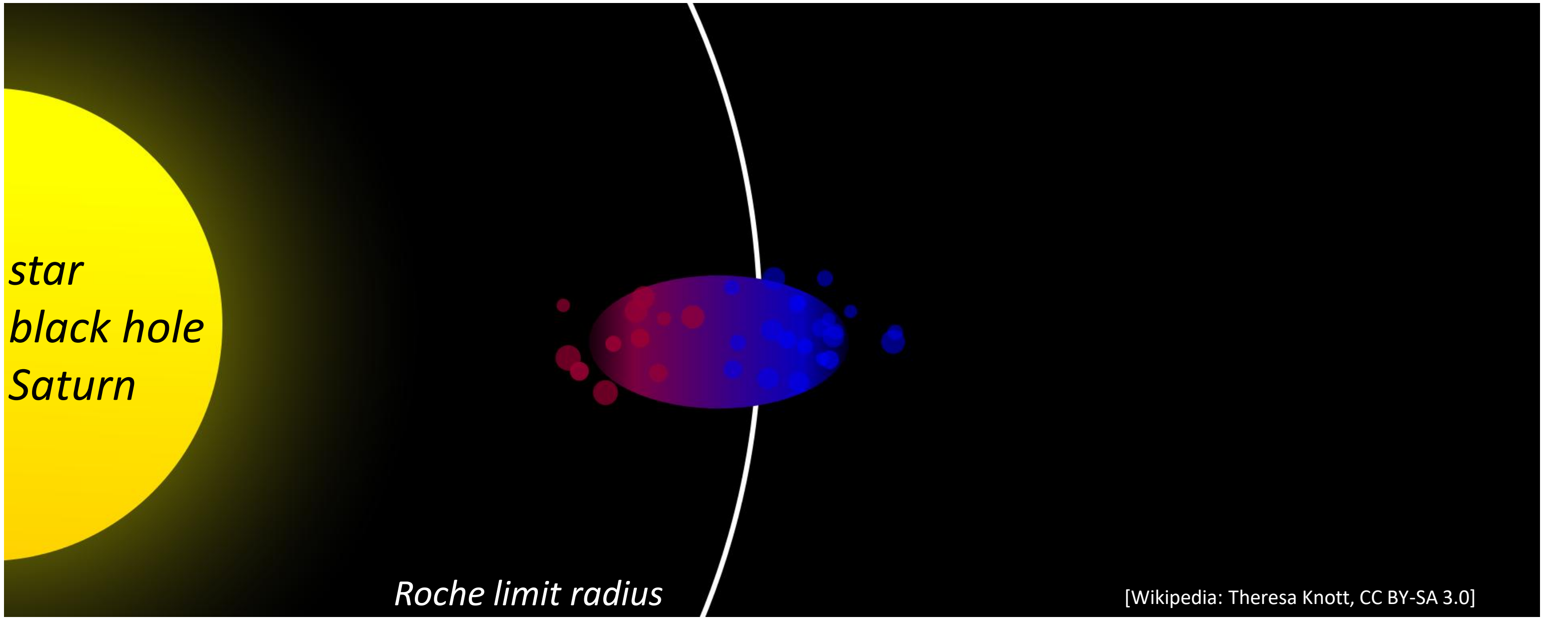

At the Roche limit radius and within it, the tidal force and deformation **pull the planet/moon/star apart**.

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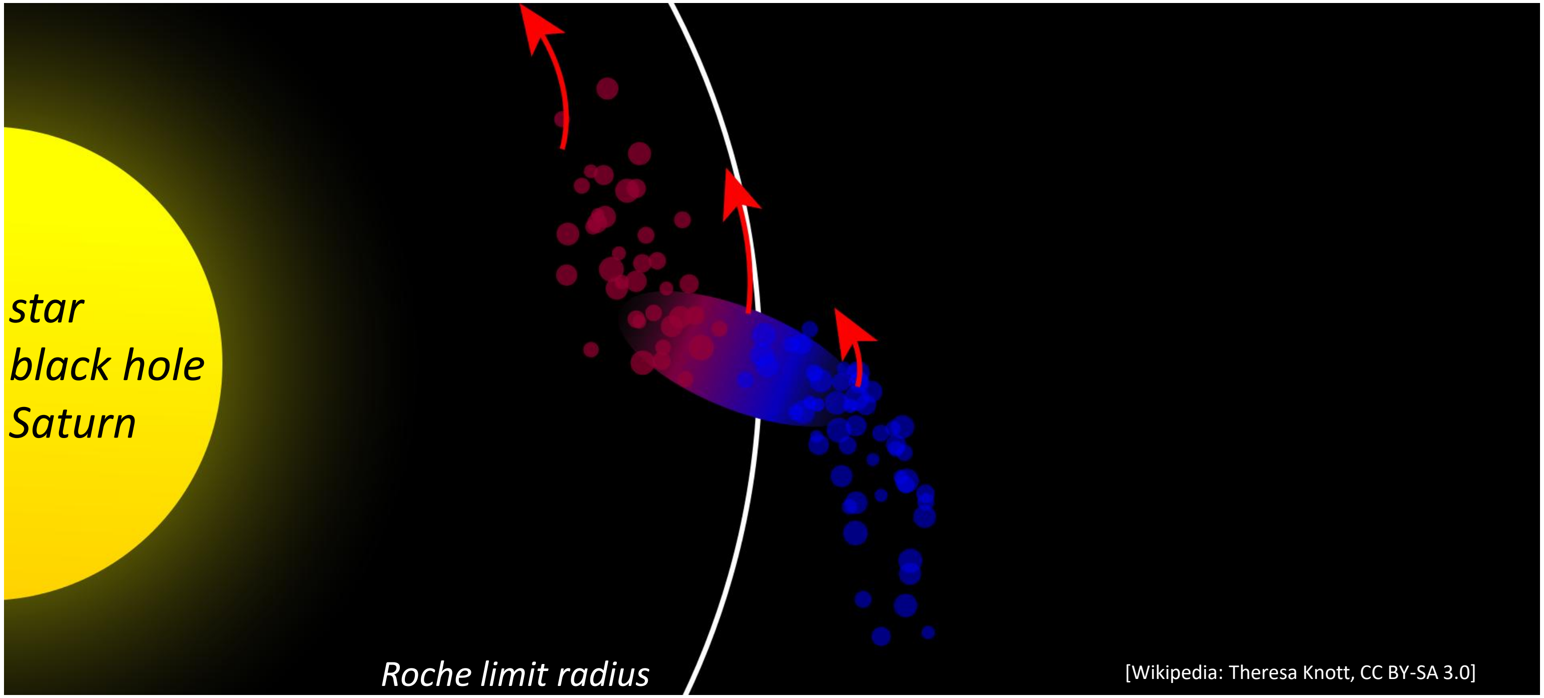

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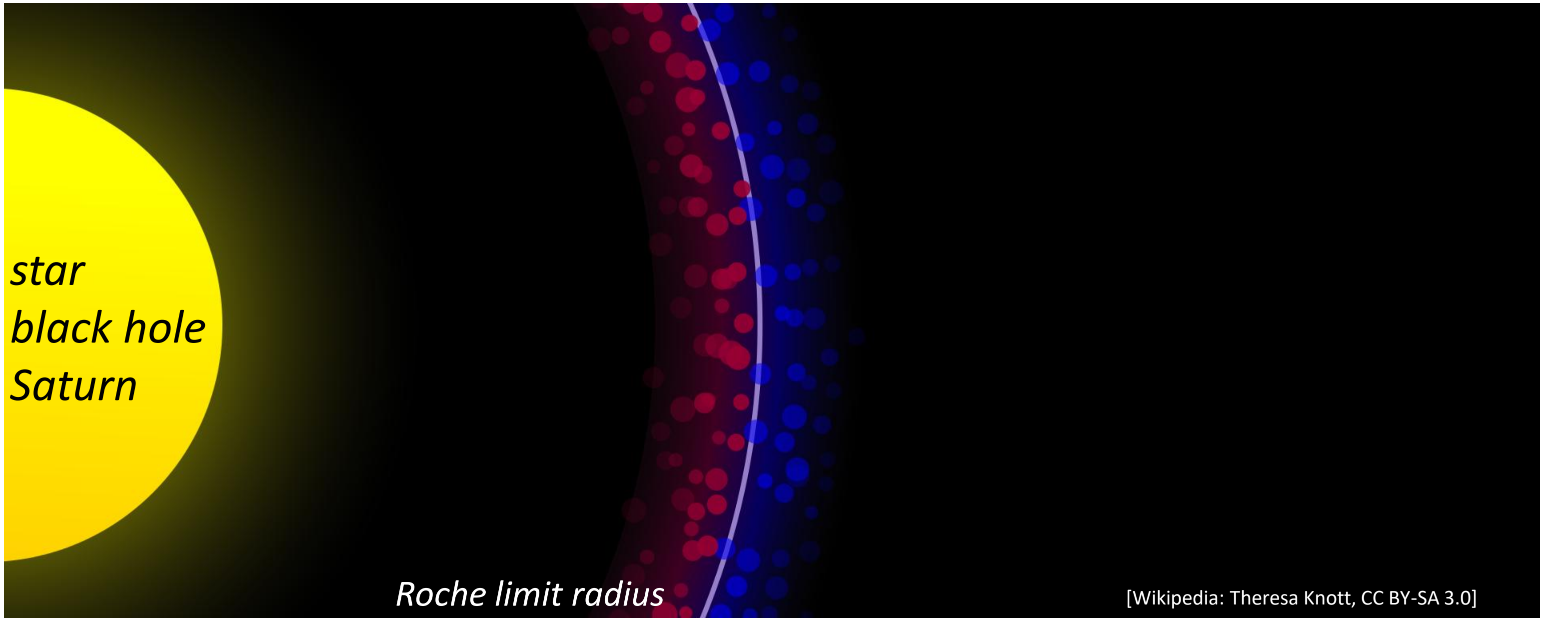

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→ Very close to the event horizon, the object becomes too redshifted to be well seen and also appears to come to a standstill.
(note: in frame of object, the object falls into black hole.)