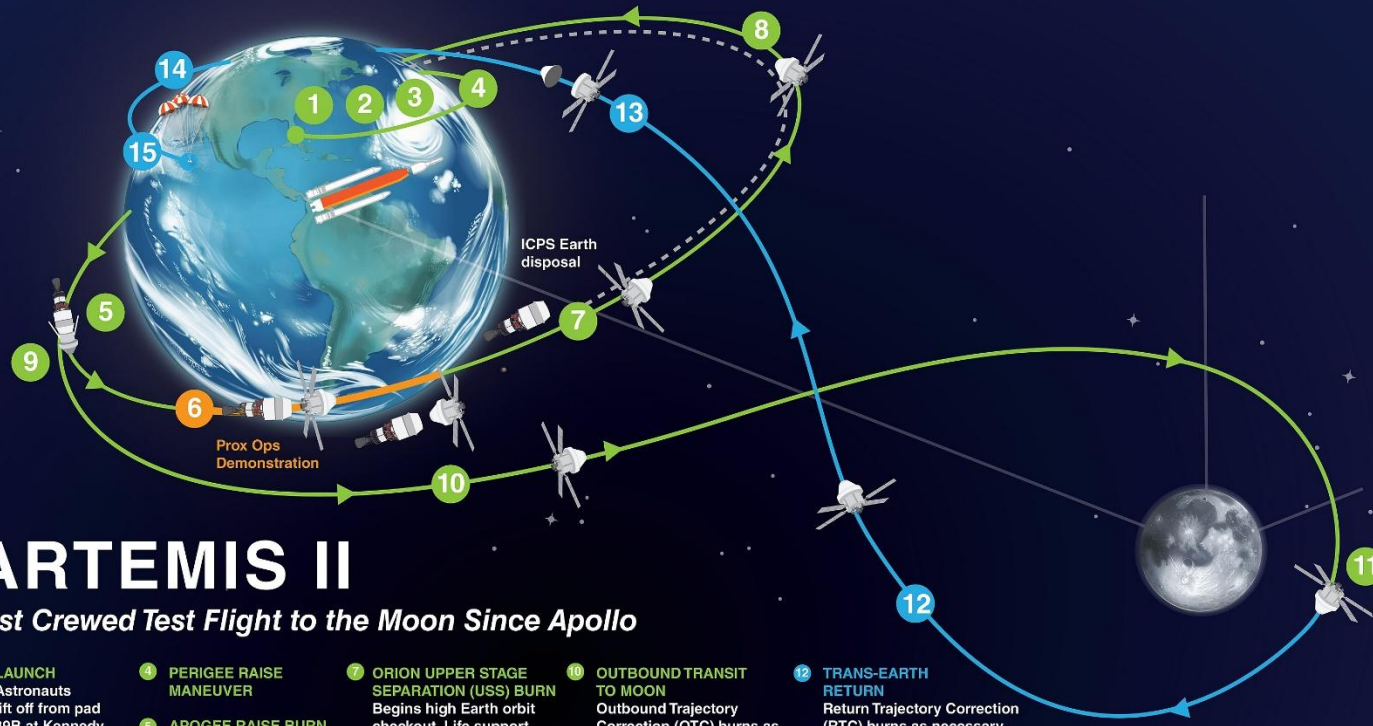


TODAY @ 6:24 pm EST

ARTEMIS II Launch to the MOON



ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

- 1 LAUNCH**
Astronauts lift off from pad 39B at Kennedy Space Center.
- 2 JETTISON SOLID ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
- 3 CORE STAGE MAIN ENGINE CUT OFF**
With separation.
- 4 PERIGEE RAISE MANEUVER**
- 5 APOGEE RAISE BURN TO HIGH EARTH ORBIT**
Begin 23.5 hour checkout of spacecraft.
- 6 ORION SEPARATION FROM INTERIM CRYOGENIC PROPULSION STAGE (ICPS) FOLLOWED BY PROX OPS DEMO**
Plus manual handling qualities assessment for up to 2 hours.
- 7 ORION UPPER STAGE SEPARATION (USS) BURN**
Begins high Earth orbit checkout. Life support, exercise, and habitation equipment evaluations.
- 8 PERIGEE RAISE BURN**
- 9 TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE**
Lunar free return trajectory initiated with European service module.
- 10 OUTBOUND TRANSIT TO MOON**
Outbound Trajectory Correction (OTC) burns as necessary for Lunar free return trajectory; travel time approximately 4 days.
- 11 LUNAR FLYBY**
6,479 miles / 10,427 km (mean) lunar farside altitude.
- 12 TRANS-EARTH RETURN**
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.
- 13 CREW MODULE SEPARATION FROM SERVICE MODULE**
- 14 ENTRY INTERFACE (EI)**
Enter Earth's atmosphere.
- 15 SPLASHDOWN**
Ship recovers astronauts and capsule.



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 3rd 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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“+” polarization

or



“x” polarization

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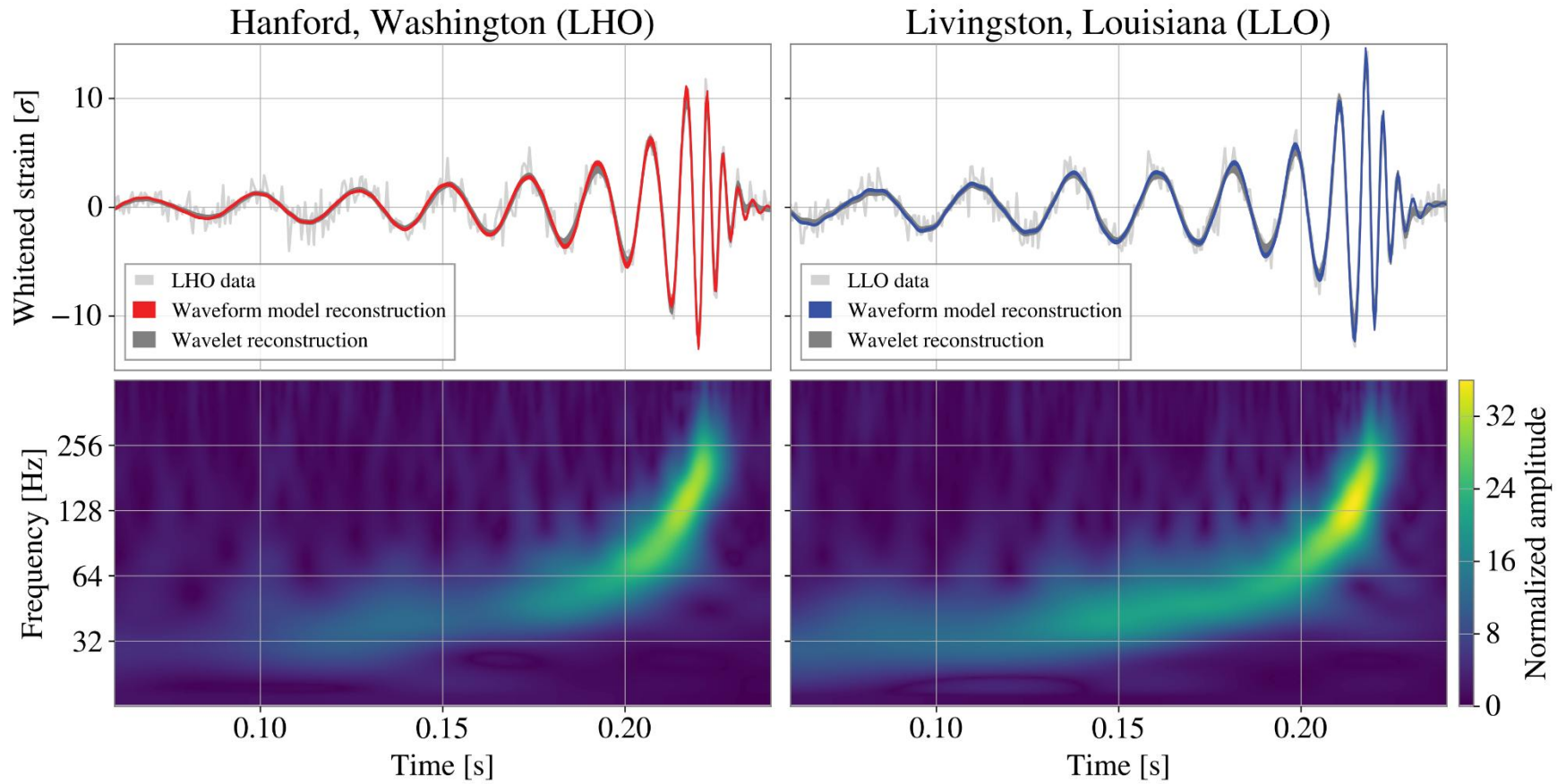
Gravitational Wave “Telescope”

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. **Schwarzschild radius**) can escape.
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- The **event horizon / Schwarzschild radius** defines the size and surface of a black hole.

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

*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, $\lambda=1.3$ mm]

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[Event Horizon Telescope, www.eso.org, $\lambda=1.3$ mm]

Computer simulation of accretion disc around a black hole.

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

PolleEv Quiz: PolleEv.com/sethaubin

2020 Nobel Prize in Physics

Black Hole Physics & Astronomy



Roger Penrose
(U. of Oxford)



Reinhard Genzel
(Max Planck Inst.)



Andrea Ghez
(UC Los Angeles)

2020 Nobel Prize in Physics

Black Hole Physics & Astronomy



[Source: Cirone-Musi, Festival della Scienza, CC BY-SA 2.0]

Roger Penrose
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Black hole
physics & mathematics



[Source: Max Planck Institute for Extraterrestrial Physics]

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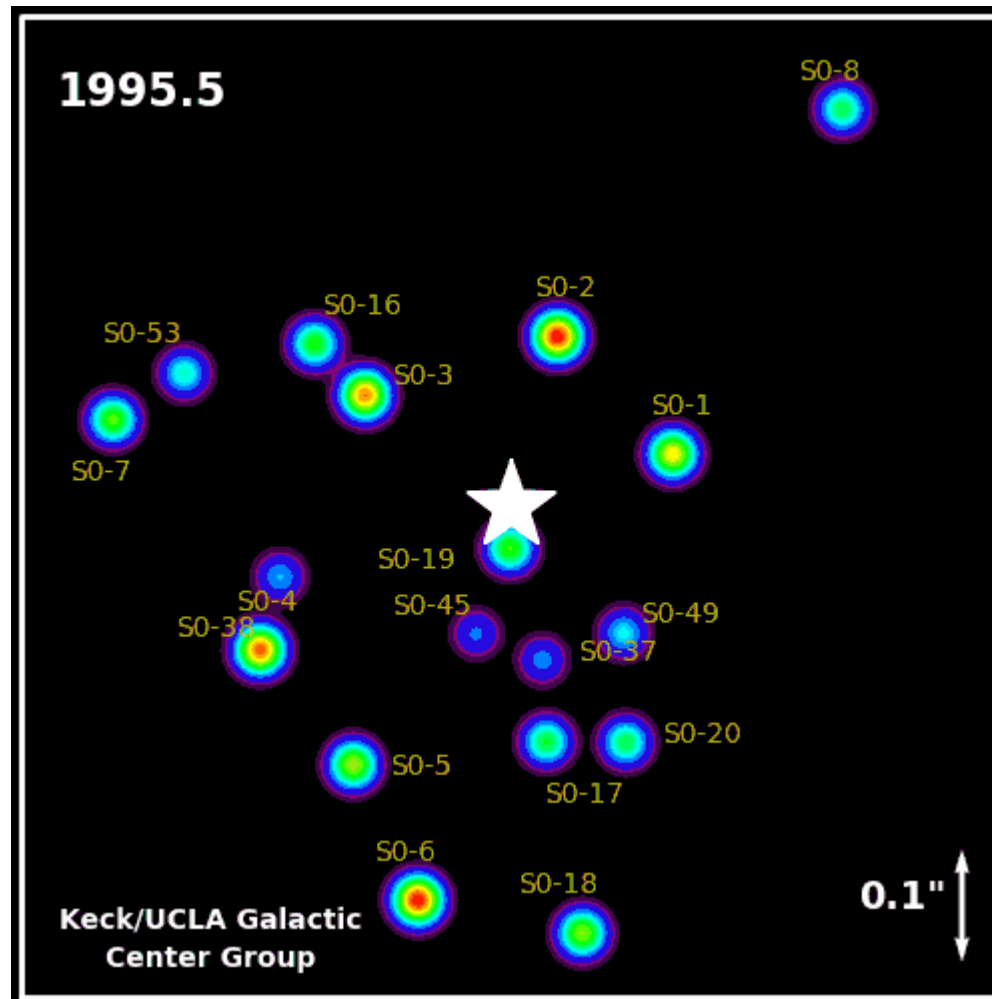
[Source: Christopher Dibble]

Andrea Ghez
(UC Los Angeles)

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

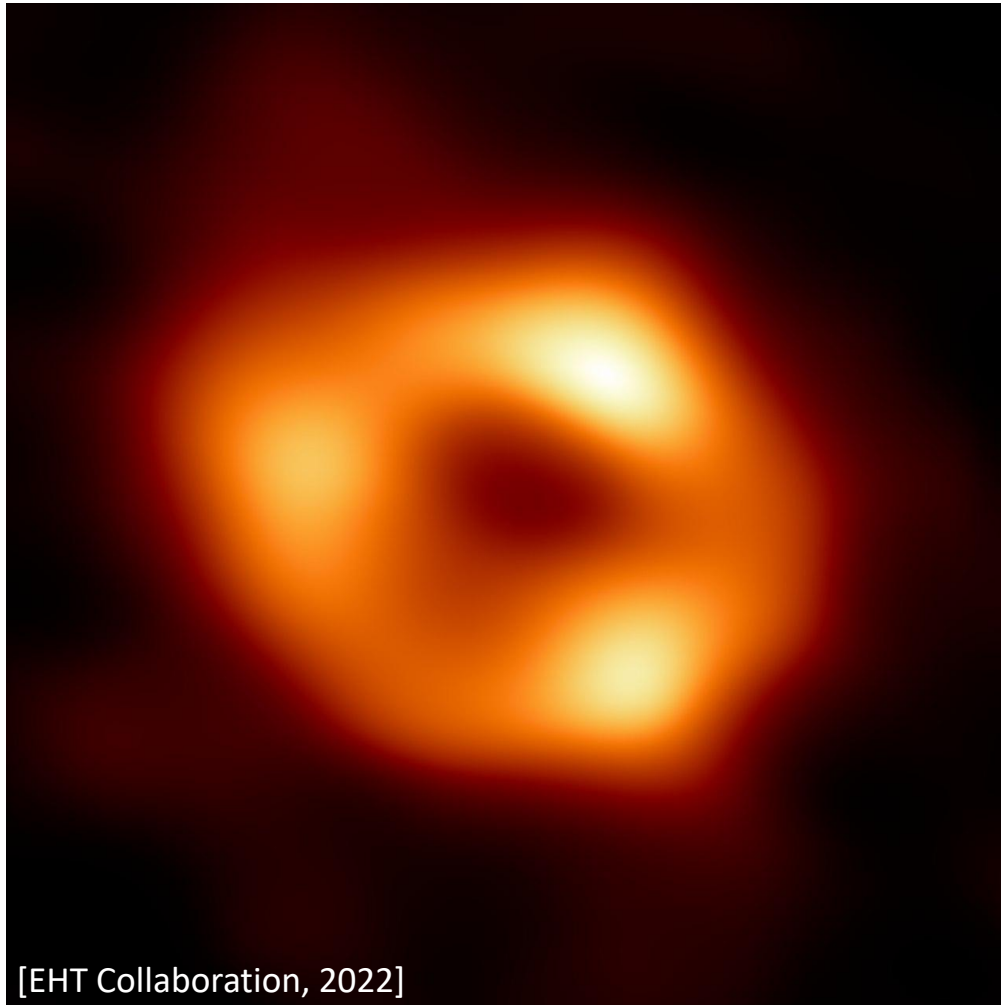
Black Hole at center of Milky Way

The Sagittarius A* supermassive black hole



Black Hole at center of Milky Way

The Sagittarius A* supermassive black hole



[EHT Collaboration, 2022]

Mass = 4 million M_{Sun}

What happens if you fall into a Black Hole?

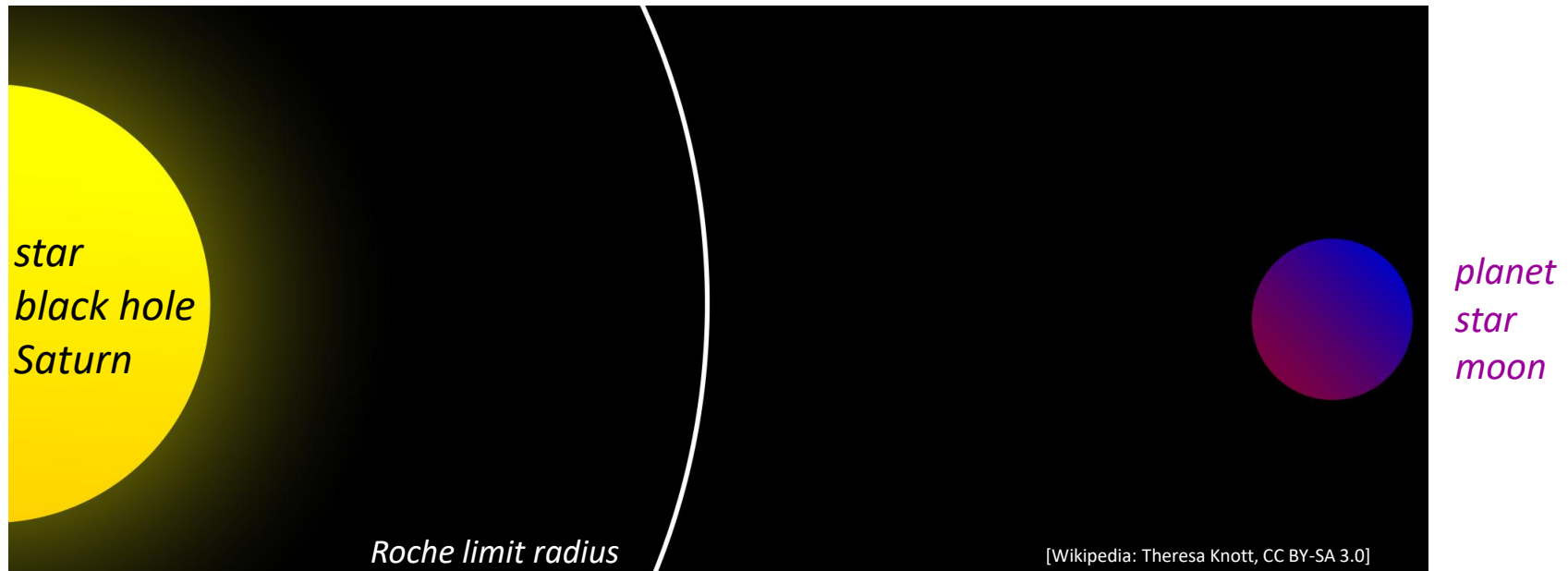
Stellar mass black hole

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- 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)

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

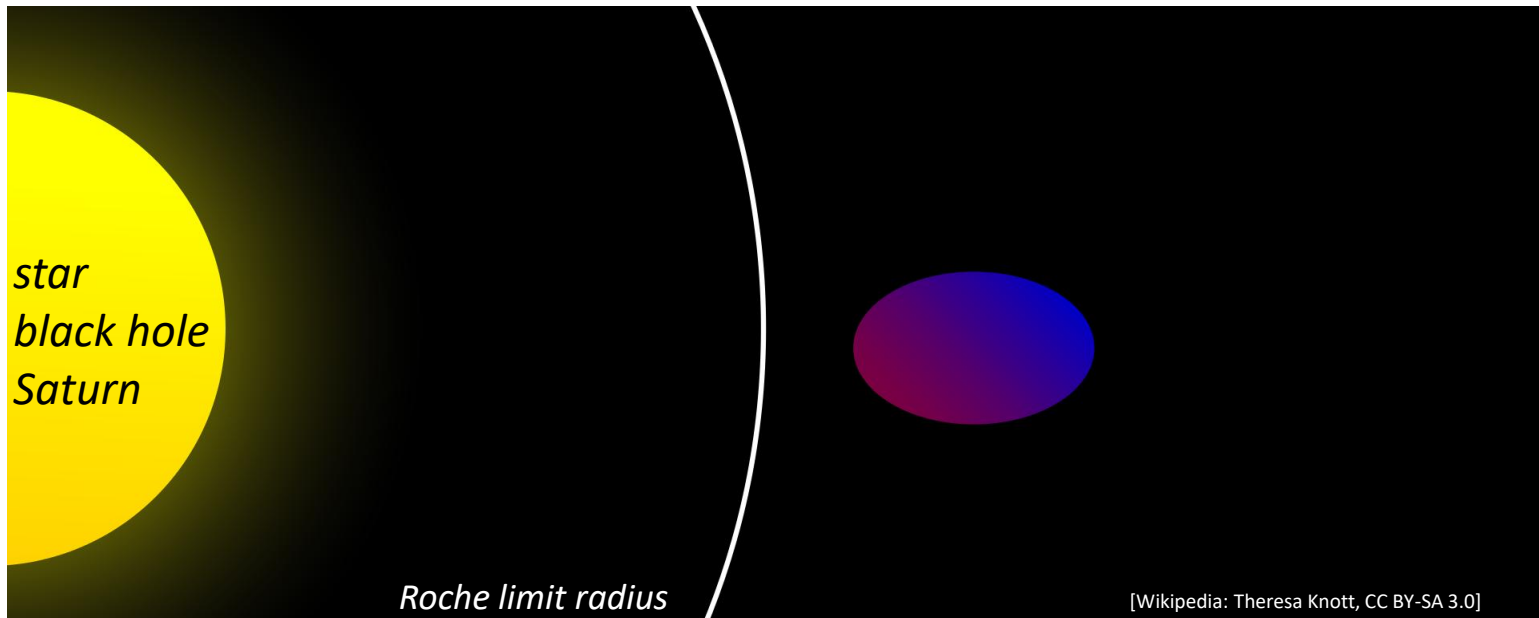


Far outside the Roche limit radius, the tidal force and deformation are **weak**.

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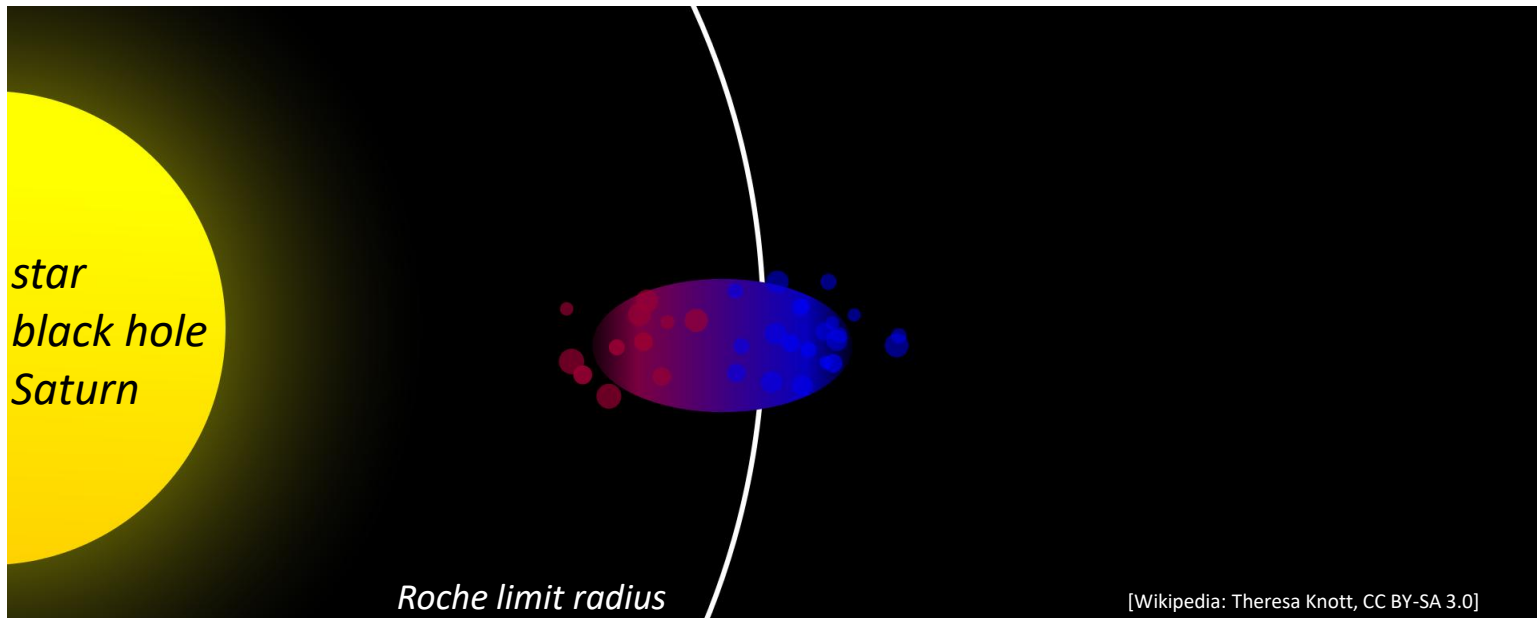


Close to the Roche limit radius, the tidal force and deformation are **strong**.

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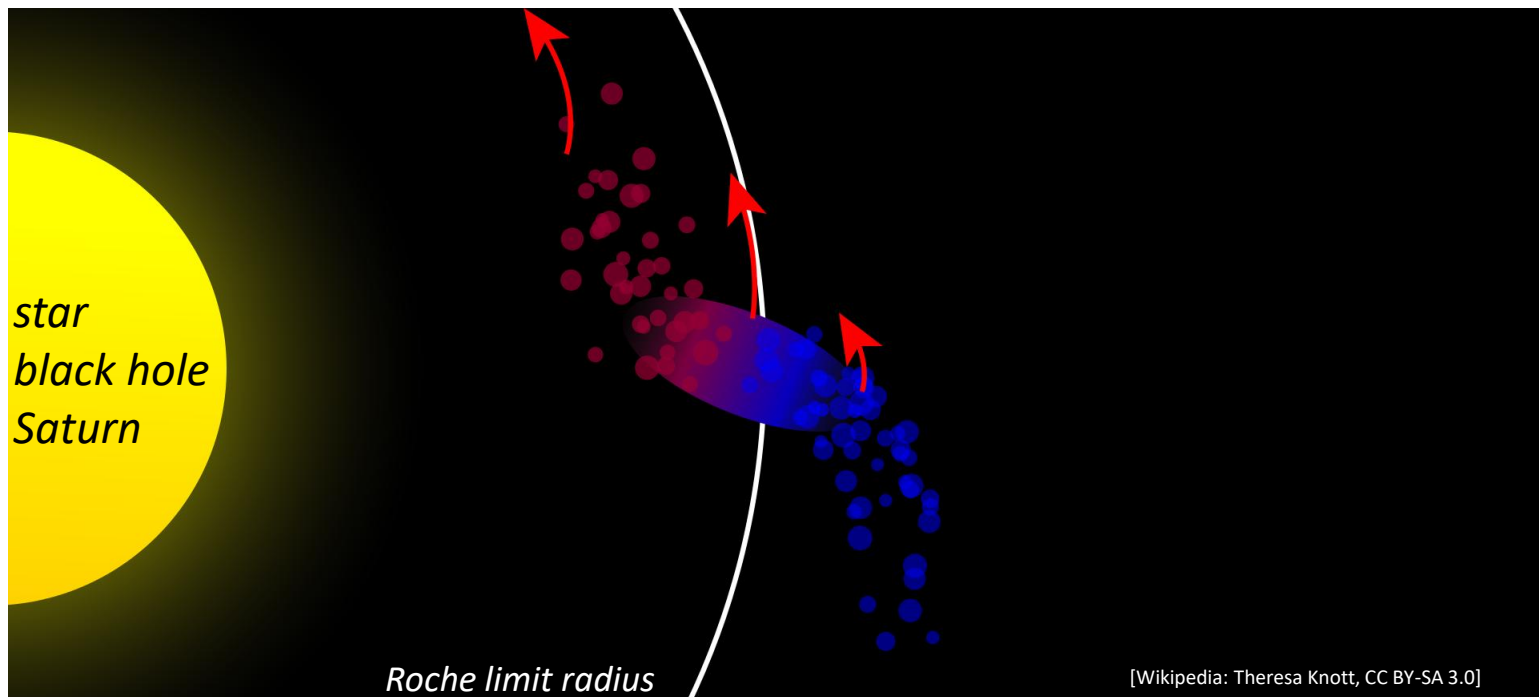


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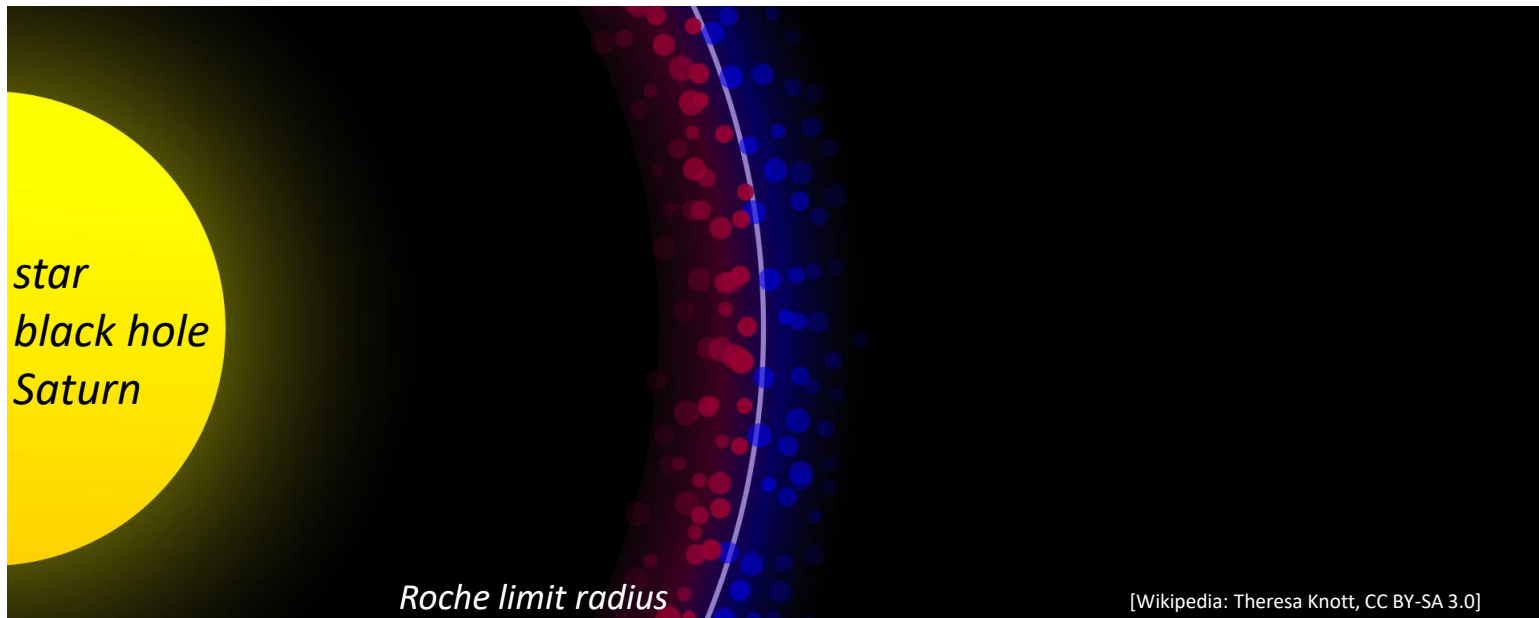


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Gravitational redshift: As the object falls its light becomes redder and eventually shifts into radio-waves.

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Gravitational time dilation: The object appears to slow down as it gets closer and closer to the event horizon.

→ 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.)