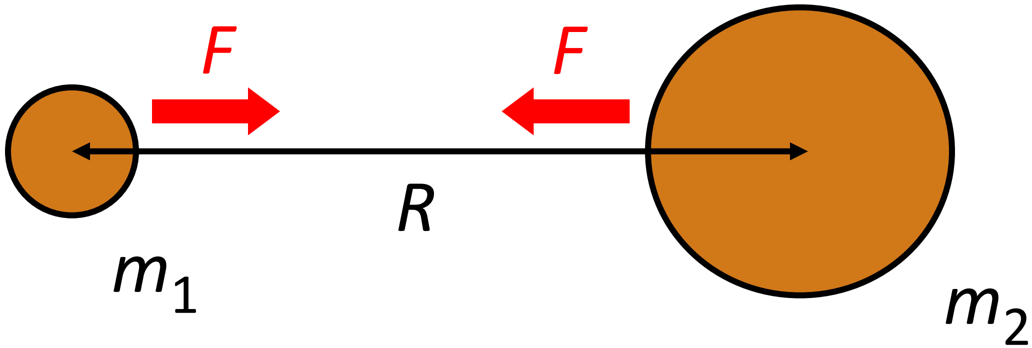
Newton’s Universal Law of Gravitation



$$F = G \frac{m_1 m_2}{R^2}$$

Clicker Question

What are the forces acting on an astronaut orbiting the Earth?

A. His weight is canceled by the centrifugal force, so he is weightless.
B. Since he is weightless, there are no forces.
C. His weight provides the centripetal force.
D. Gravity pulls him down. In addition, the centripetal force also pulls him down.
E. His weight is canceled by the centripetal force.

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Clicker Question

A child twirls a rock tied to a string in a circle above her head. What are the forces acting on the rock?

A. The tension in the string, and gravity.
B. The tension in the string, and the centripetal force.
C. Gravity, the tension in the string, and the centripetal force.
D. Gravity, the centripetal force, and the centrifugal force.
E. Since the speed is constant, the net force is zero.

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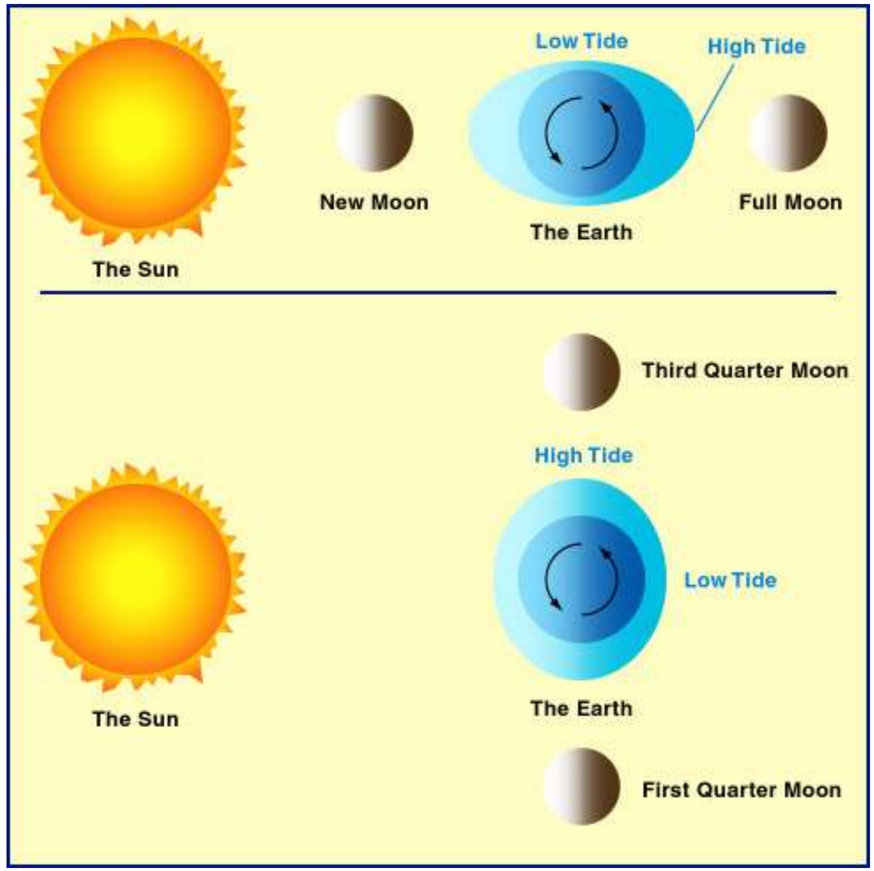
E. Since the speed is constant, the net force is zero.

The centripetal force is not an additional force. Rather it is the net force acting on the rock (string tension + gravity).

Ocean Tides

[Video]



spring tide

neap tide

Clicker Question

The ocean tides are due to

A. the gravitational pull, mainly of the sun
B. the gravitational attraction of the other planets
C. ocean water being pushed around by wind
D. the centripetal force of the Earth's rotation
E. the gravitational pull, mainly of the moon

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Clicker Question

If the length of a day was 6 hours instead of 24, how many high tides would there be every day?

A. 1
B. 2
C. 4
D. 8
E. None of the other answers.

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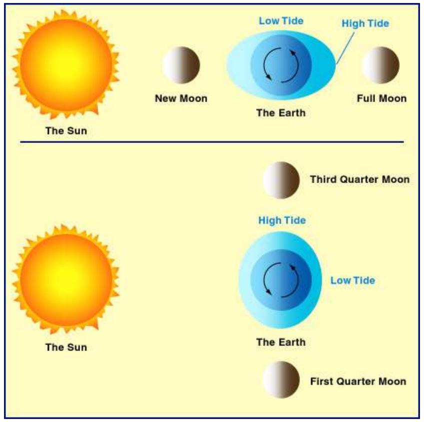

Clicker Question

During a full moon, the ocean tides are

A. at a maximum, because the tidal effects of the moon and the sun add up.
B. smallest, because the moon is opposite the sun, so their tidal effects partially cancel.
C. zero, because the tidal effects of the sun and the moon cancel.
D. about the same as during other phases of the moon, since the moon's gravity doesn't depend on which side of the moon is illuminated.
E. None of the other answers

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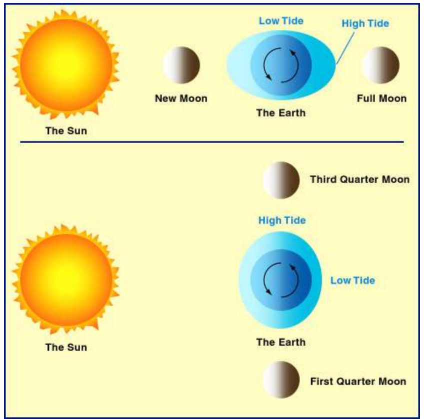

Clicker Question

During a new moon, the ocean tides are

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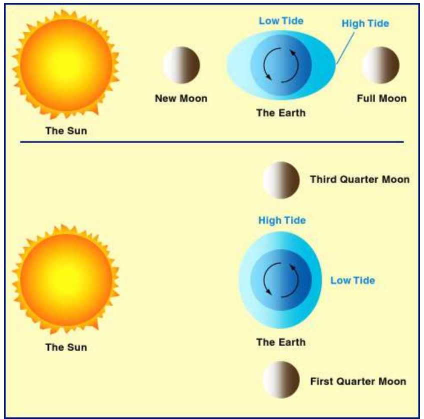


In Newton's time:

Unknown

$$g = G\frac{m_{\text{Earth}}}{R_{\text{Earth}}{}^{2}}$$

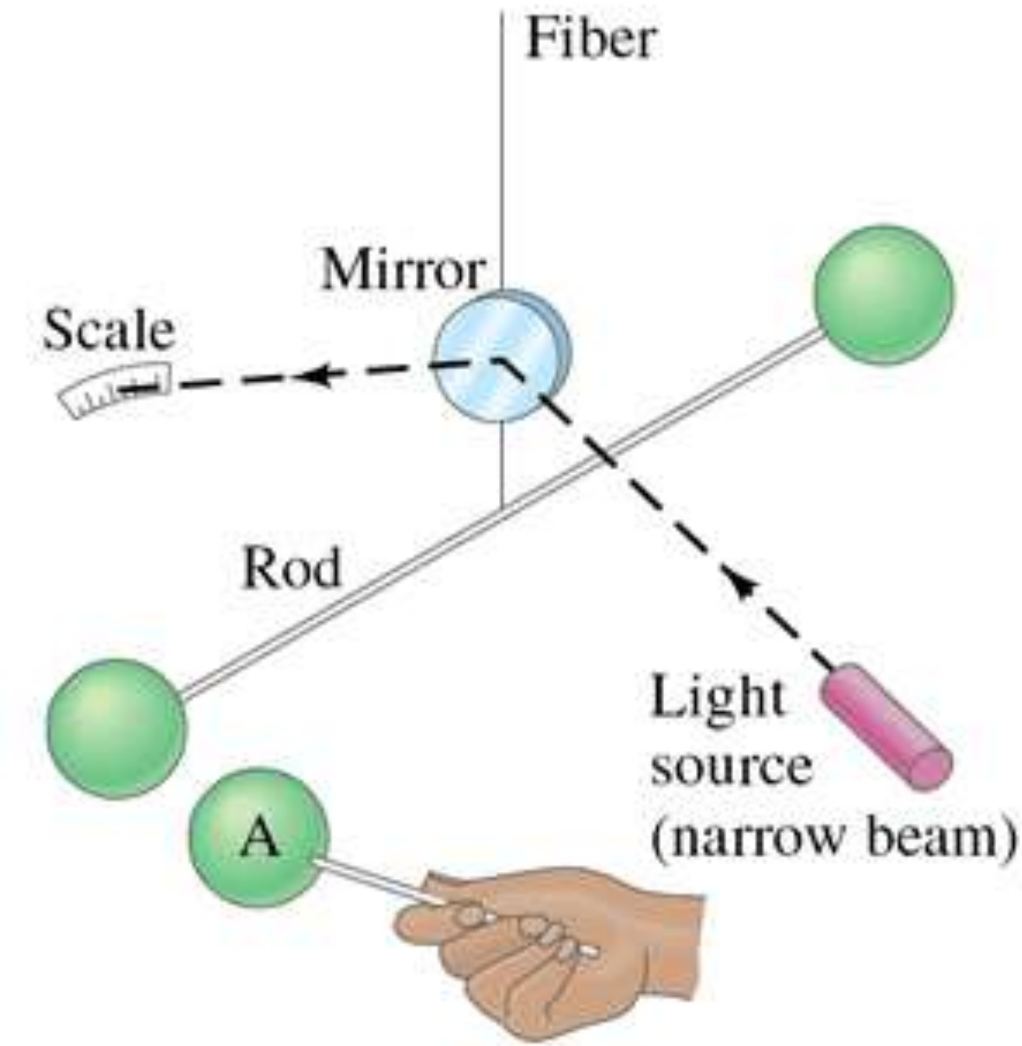
Known

Rearrange:

$$g\,(R_{earth})^{2} = G\,m_{Earth}$$

- Newton did not know G and m_{Earth} separately.
- He could now figure out their product, though.
- How can we determine what they are separately?

Cavendish Experiment: Direct measurement of *G*



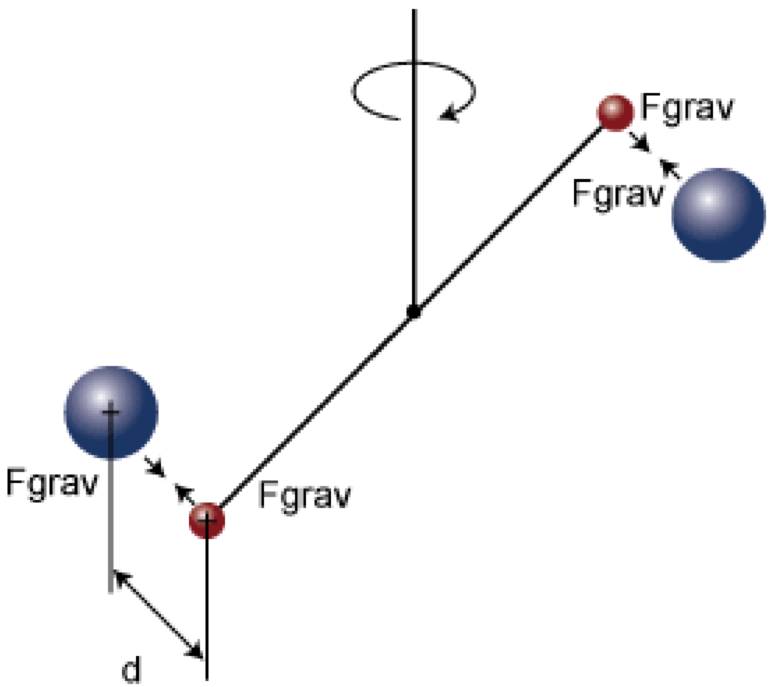
Henry Cavendish
1797

[Cavendish Experiment Video]

(skip to 11:20 for time lapse footage)

Cavendish Experiment to Measure G

Newton's 2nd law for the little ball: $F_1 = m_1 a_1$



$$G \frac{m_1 m_2}{R^2} = m_1 a_1$$

cancel m_1: $G\frac{m_2}{R^2} = a_1$

solve for G: $G = \frac{a_1 R^2}{m_2}$

Cavendish Experiment: Direct measurement of G

This experiment yields G = 6.7 x 10^{-11} N m^2/kg^2

$$g\,(R_{earth})^2 = G\, m_{Earth}$$

Now we can also determine the mass of the earth:

6 x 10^{24} kg

Clicker Question

To increase the sensitivity in a Cavendish experiment, you double the stationary masses. The measured acceleration will

A. stay the same.
B. be reduced by half.
C. double.
D. quadruple.
E. none of the other answers

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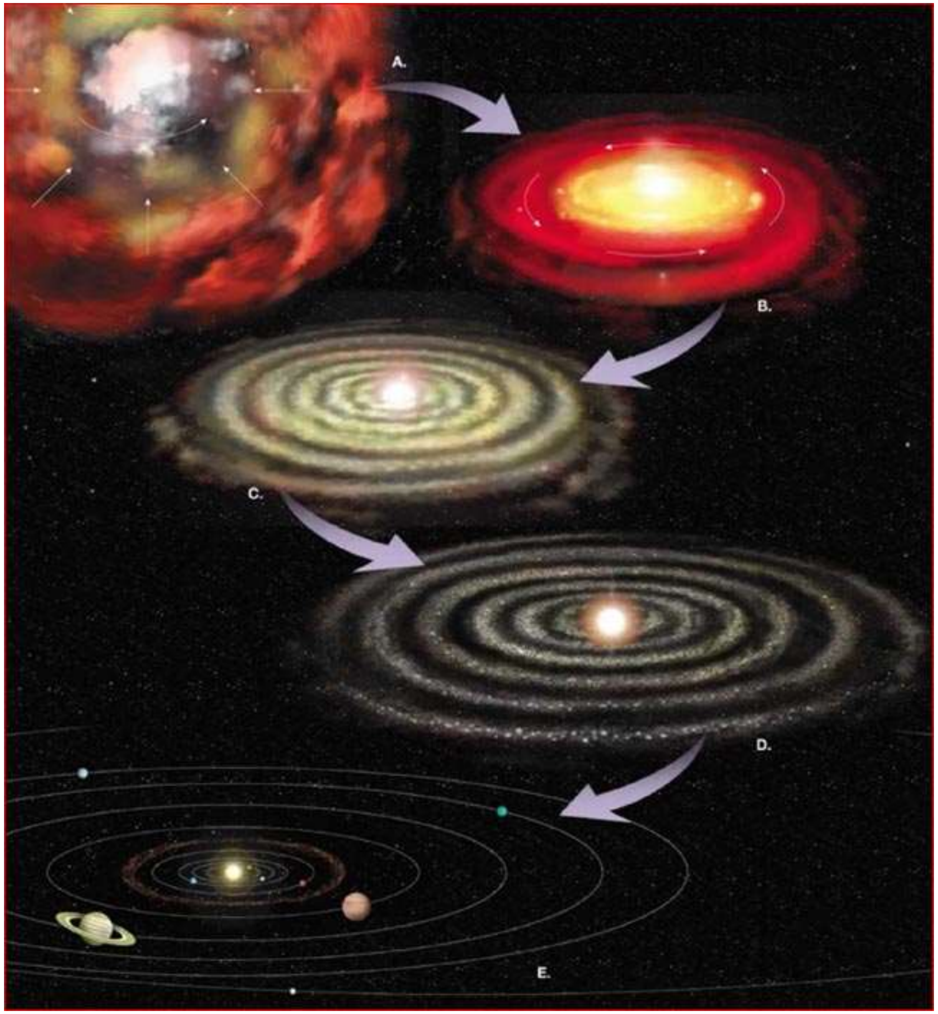
Gravitational Collapse: Formation of the Solar System



- Our solar system began as such a gas and dust cloud. As it collapsed due to gravity, the cloud was heating up.
- Meanwhile, it was also rotating, and the outer regions flattened into a disk.
- The center of the cloud continued to collapse and heat up, forming the sun.
- The outer parts condensed into planets, asteroids, meteors, and comets.

Video

Gravitational Collapse:
Death of the Solar System

- In about another 5 billion years, the sun will exhaust its hydrogen fuel.
- As heavier elements start fusion reactions, the sun heats up and expands, eventually engulfing the earth.
- Finally, the sun exhausts all its fuel; the outer layers blow away and only the core is left, no longer generating energy.
  - Gravity takes over once again, and it continues to contract until it is as small as quantum mechanics will allow it to be – about the size of the earth, and incredibly dense.
  - A star in this stage of its existence is called a white dwarf.
  - It will gradually cool off and become invisible.

Video

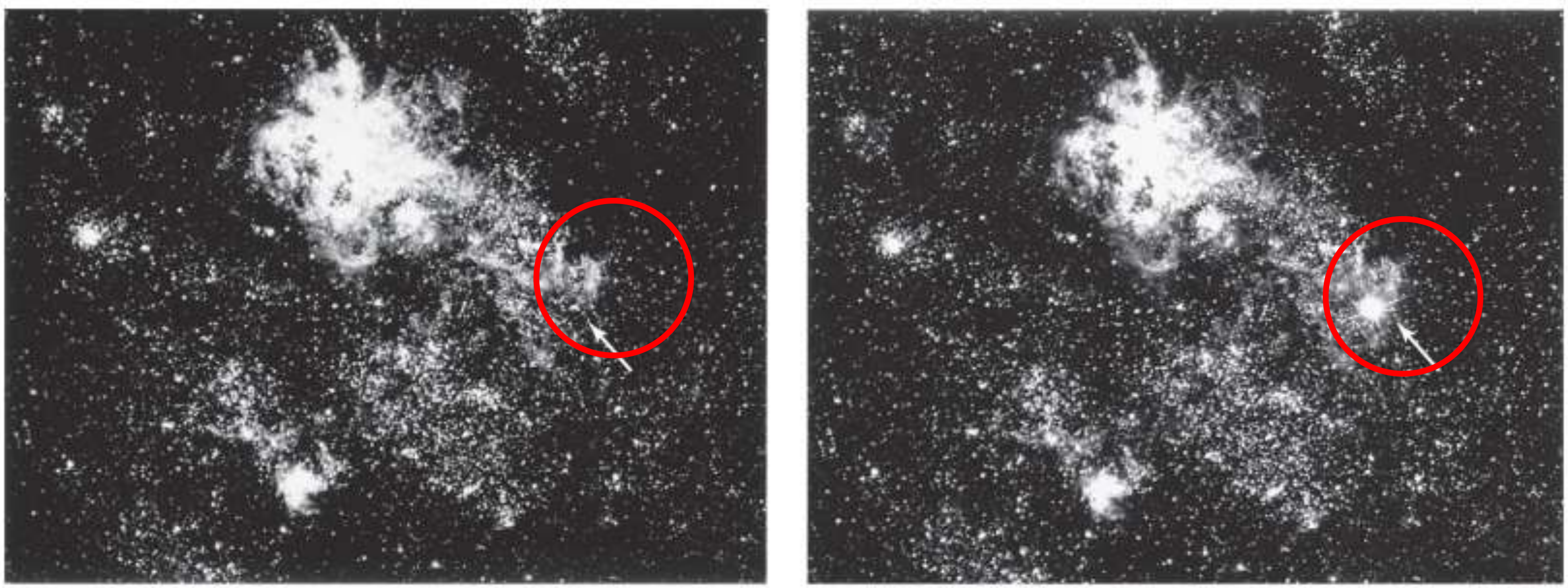
Gravitational Collapse: The Deaths of More Massive Stars

- A star's life cycle is determined primarily by its mass. Stars up to about ten times the sun's mass have a life cycle similar to the sun's, ending up as white dwarfs.
- Larger stars go through multiple cycles of core collapse and heating, fusing in turn helium, carbon, eventually producing iron.
- But now the star is in trouble – iron will not fuse. The core is no longer generating energy, and gravity takes over once again.
- The core collapses all at once, while the outer layers are blown off in a cataclysmic explosion called a supernova.
- The last supernova that occurred in our galaxy happened in 1604; it was bright enough to be seen with the naked eye during the daytime.

Video

Gravitational Collapse: The Deaths of More Massive Stars

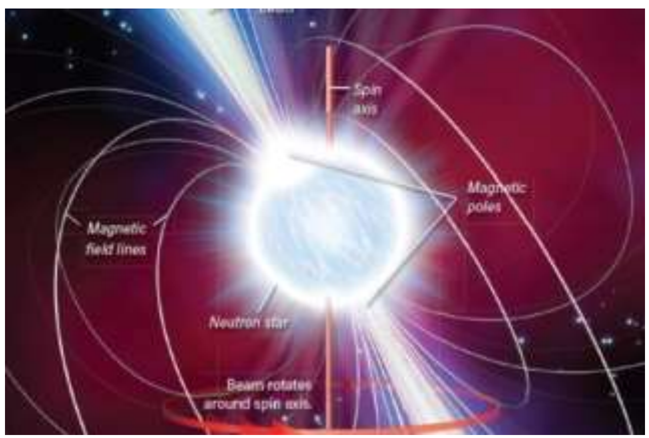
- In 1987, a supernova occurred in a galaxy near ours.
- Even at that great distance, it was visible to the naked eye.
- Below are before and after photographs of the galaxy.



(a) (b)

Gravitational Collapse:
The Deaths of More Massive Stars

- What remains after certain supernova explosions is a **neutron star**.
- **Neutron stars** are incredibly dense – a neutron star with the mass of the sun would be about 10 km in diameter!
- The star's rotation also speeds up as the collapse occurs, just as a skater's rotation speeds up as she pulls her arms in. Neutron stars typically rotate between 1 and 1000 times per second.



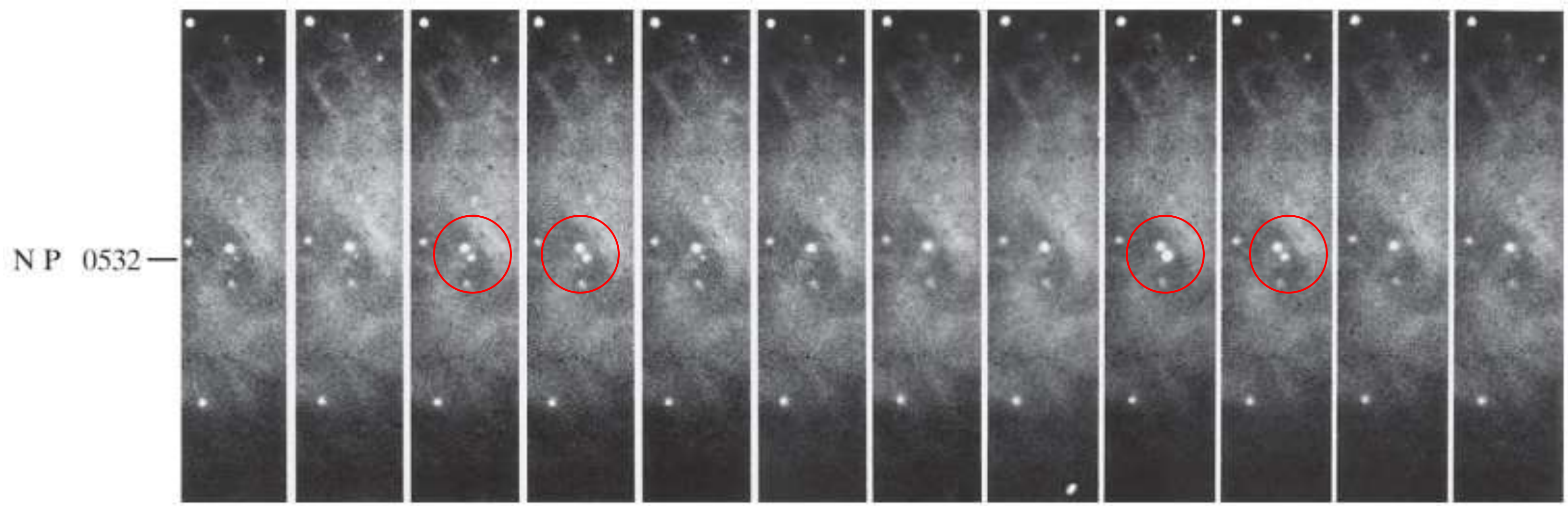
Video

Video

Gravitational Collapse: The Deaths of More Massive Stars

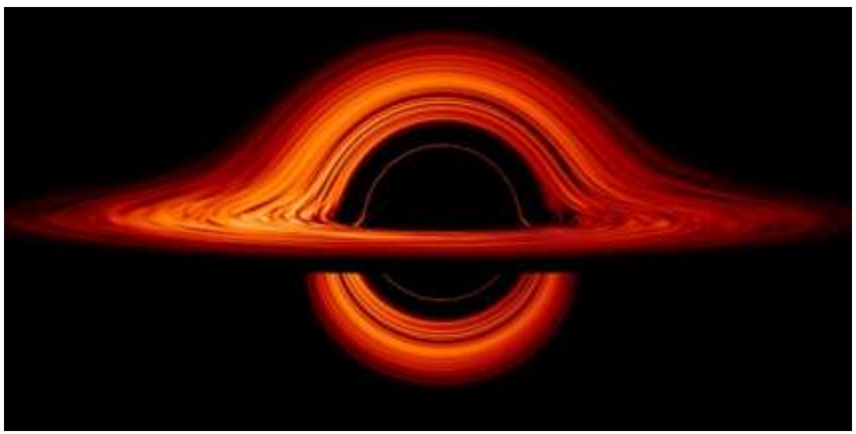
This spinning, along with very large magnetic fields, produces very intense radiation, which appears to blink on and off as the star rotates.

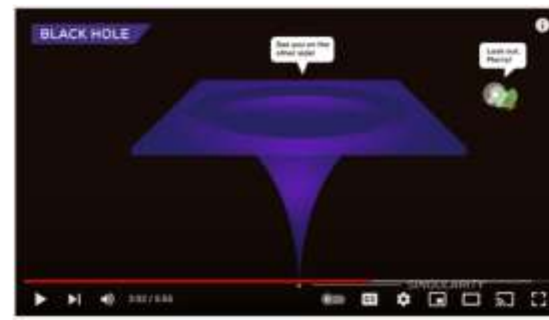
Pictures show a sequence of 1/20 second.



Gravitational Collapse:
The Deaths of More Massive Stars

- If the original star is more massive than about 30 times the sun's mass, even a neutron star cannot survive – the collapse results in a black hole.
- It is called a **black hole**, because nothing, not even light, can escape its gravitational pull.





[Video]

Powers of 10 video