



FLATIRON  
INSTITUTE

Center for Computational  
Astrophysics



# **Stellar binaries and explosions:** how to form neutron stars and black holes

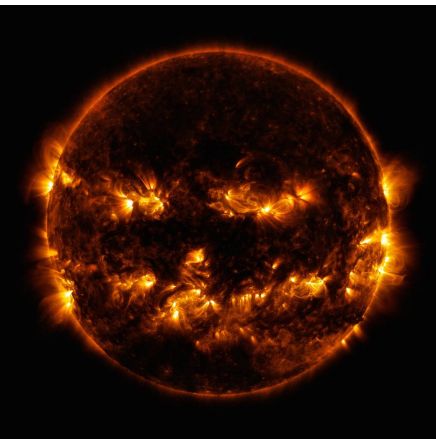
Mathieu Renzo

**What is a star?**

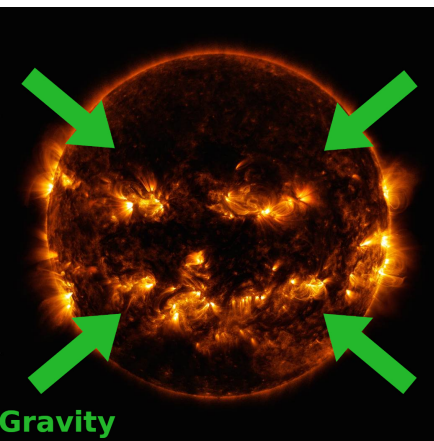
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## The nearest star to us is the Sun

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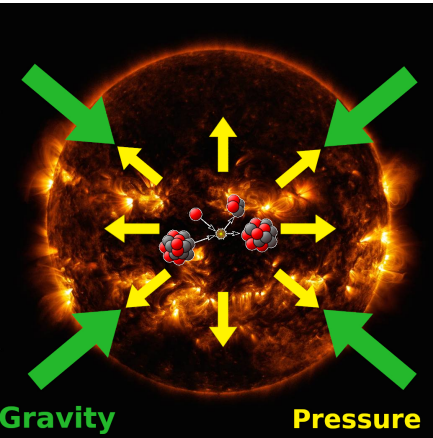


# Stars are large balls of matter that “resist” their own weight



Pushing against gravity  
costs energy

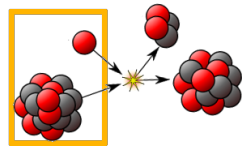
# Stars produce their own energy by nuclear fusion



Pushing against gravity  
costs energy



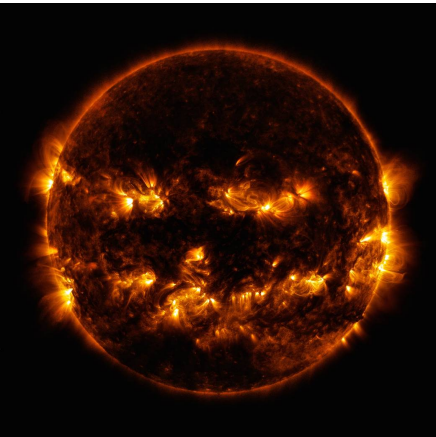
To produce energy, stars  
create new elements



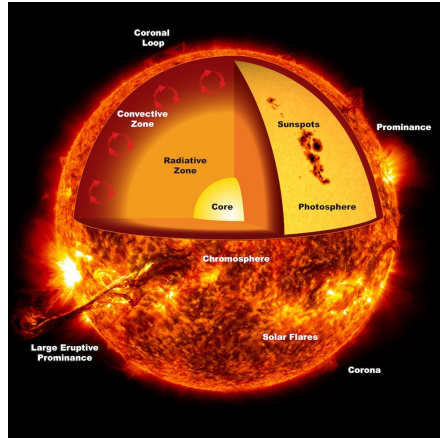
They run out of "fuel"  
and are forced to evolve

## How can we “look” inside a star?

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# How can we “look” inside a star?



We simply can't!

# What I do:

Theoretical model

+



Supercomputer

=

Simulation



# Simulations are never as good as reality...



simulation in Minecraft

# Simulations are never as good as reality...



simulation in Minecraft

≠



real picture

...but they are useful tools to understand how reality works



simulation in Minecraft

≈



real picture

...but they are useful tools to understand how reality works



≈



**Nature does not have the limitations of simulations**

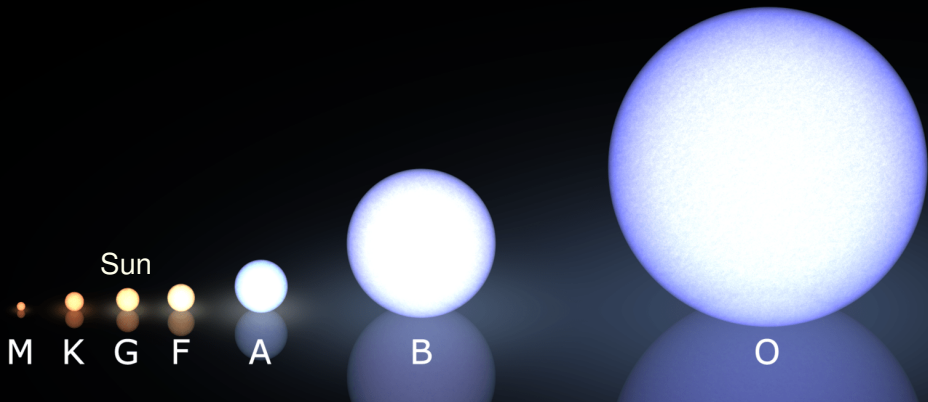


Comparing with observations is  
crucial not to fool ourselves!

# Massive stars

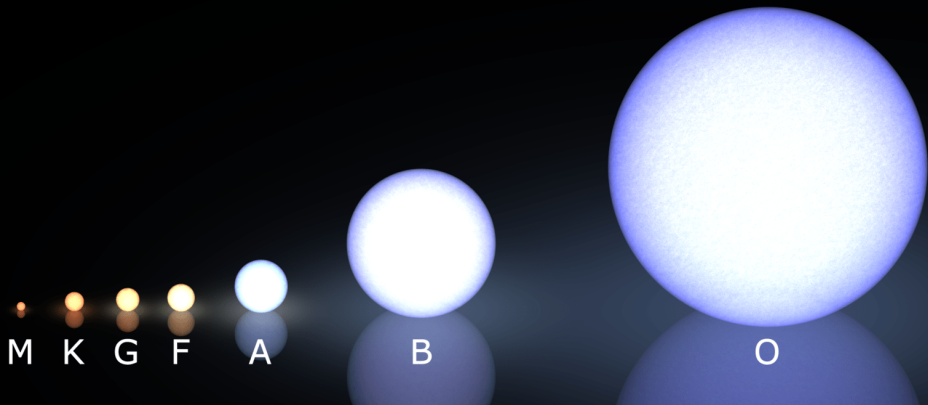
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# The mass of star determines how they live

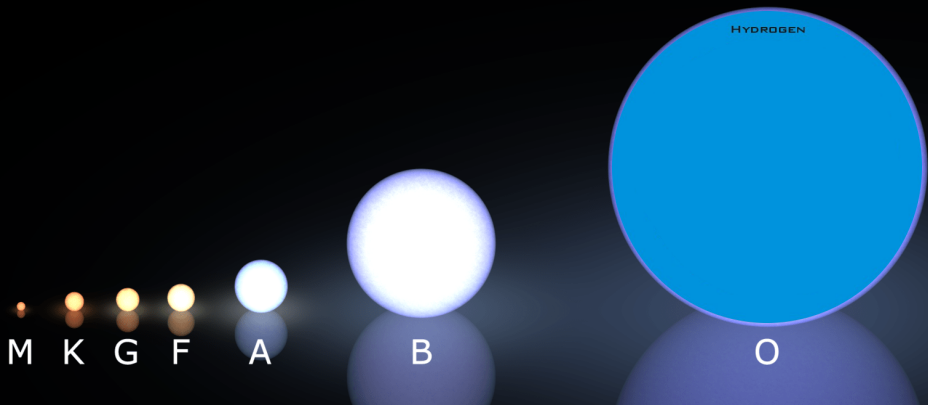


Massive stars:  $10 \times$  Sun

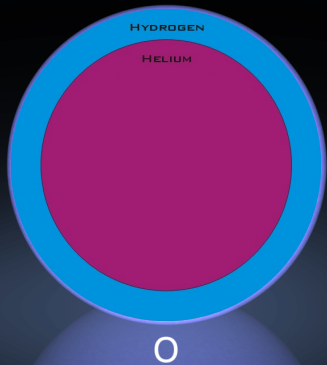
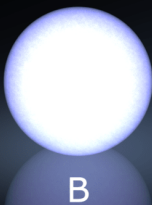
What are stars (mostly) made of?

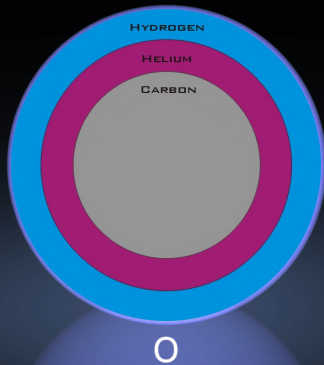
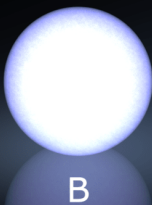
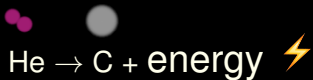


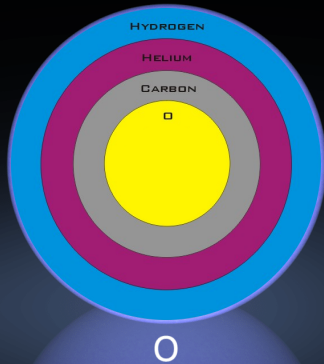
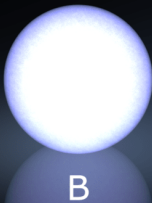
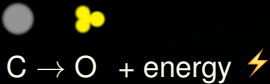
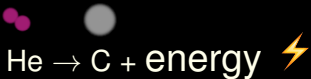
What are stars (mostly) made of?

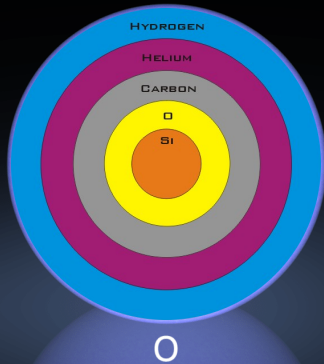
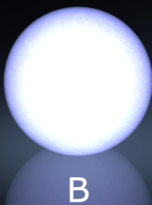
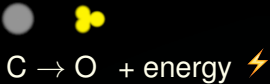
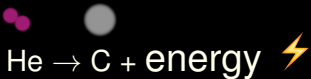


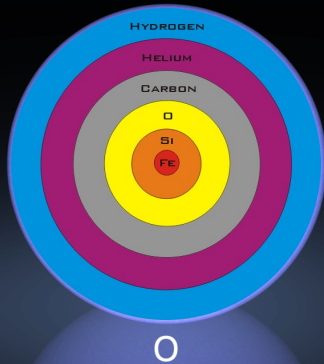
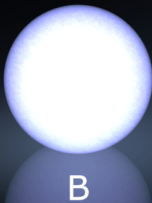
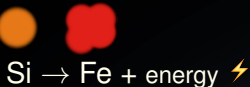
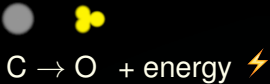
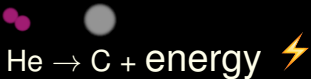




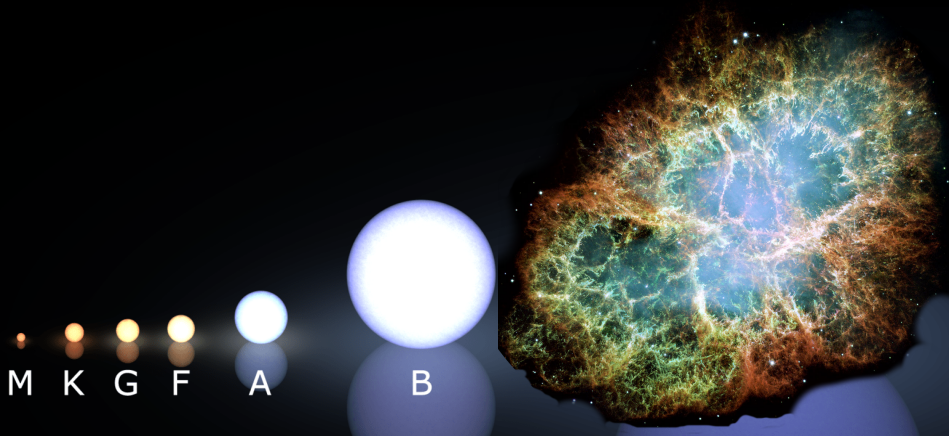






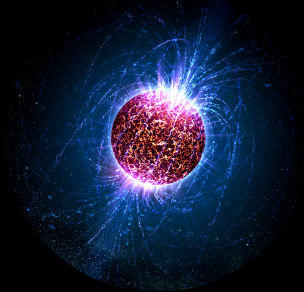
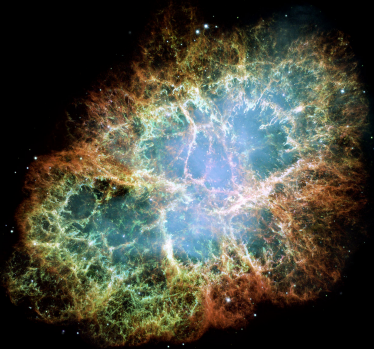


... and then they explode!

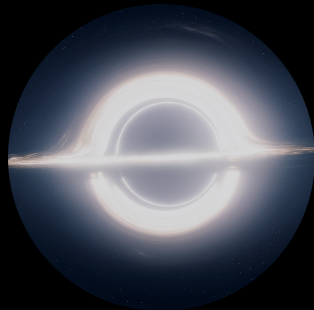


# Supernovae:

The outside is ejected,  
while the core becomes...



... a neutron star



... or a black hole

**Could you have been an  
astronomer in ancient greece?**

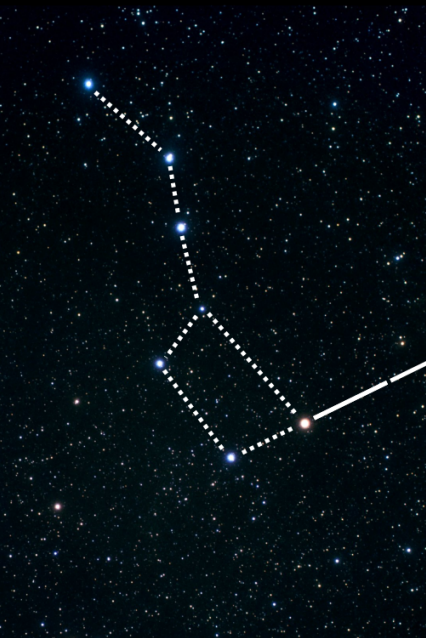
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The big dipper



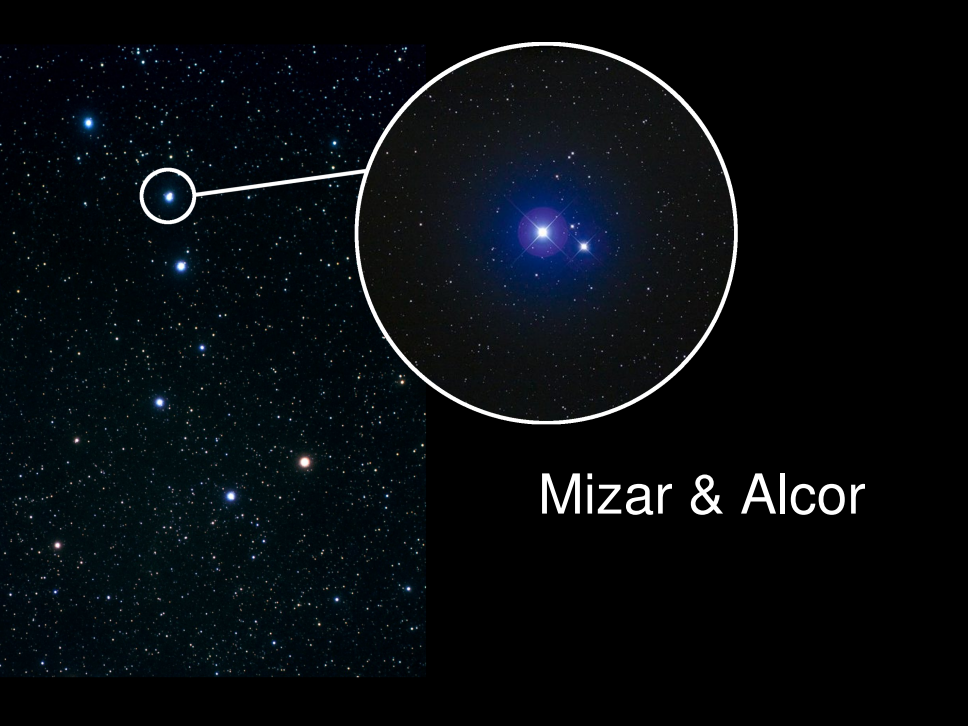
North Star



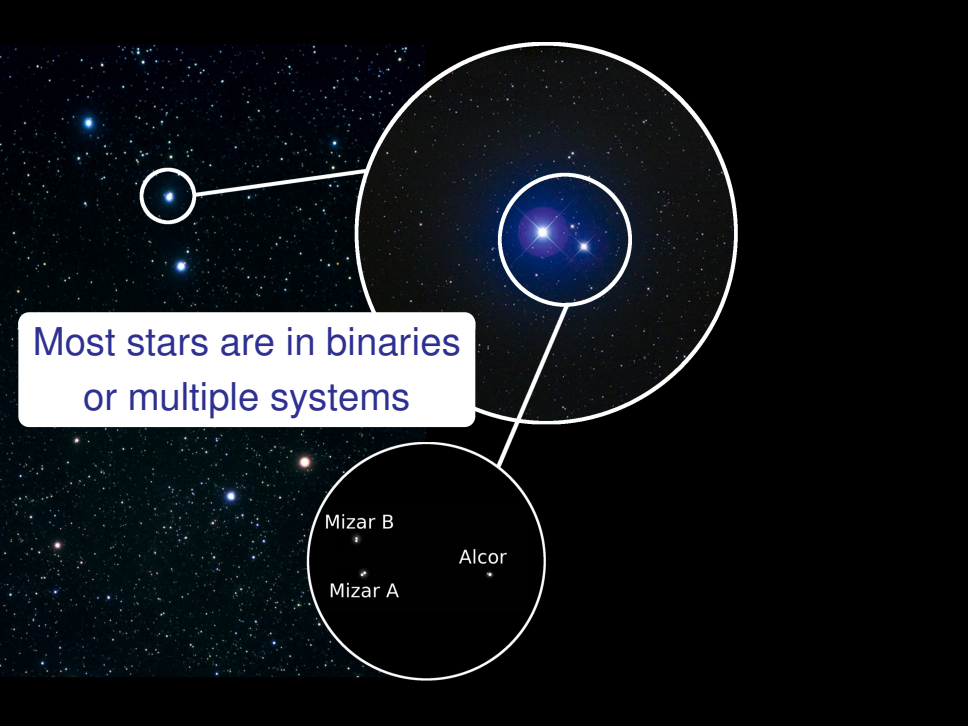
The big dipper



The big dipper



Mizar & Alcor

A diagram illustrating star systems against a starry night sky background. A large white circle highlights a binary star system. A smaller white circle is connected to it by a line, pointing to a single star. Another white circle is connected to the large circle by a line, pointing to a specific star in a larger system. A third white circle is connected to the large circle by a line, pointing to a group of stars labeled Mizar B, Alcor, and Mizar A. A white rounded rectangle contains the text 'Most stars are in binaries or multiple systems'.

Most stars are in binaries  
or multiple systems

Mizar B

Alcor

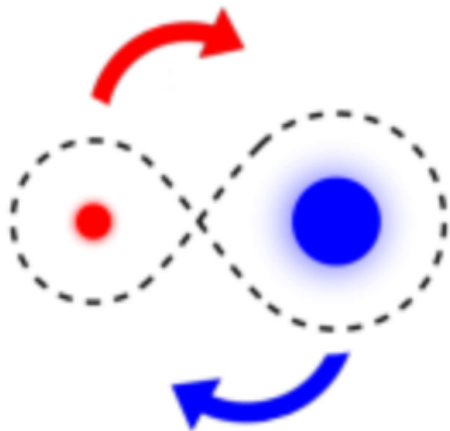
Mizar A

**What happens when two stars  
evolve together in a binary?**

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## The two stars orbit each other

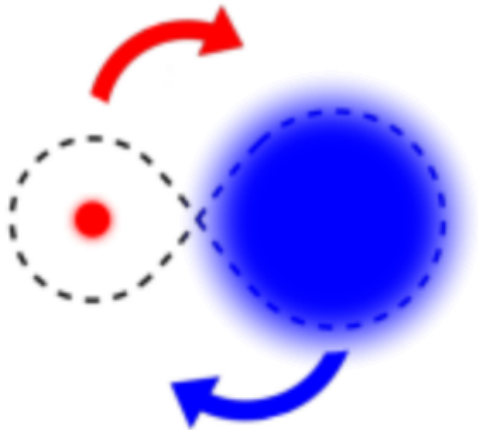
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**The bigger star evolves first...**

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**... but there is a limit to how much it can grow**

**Two massive stars together will interact**



Artist's impression

## About 1/3 of all massive binaries merge



The last “nearby” stellar explosion was from a stellar merger



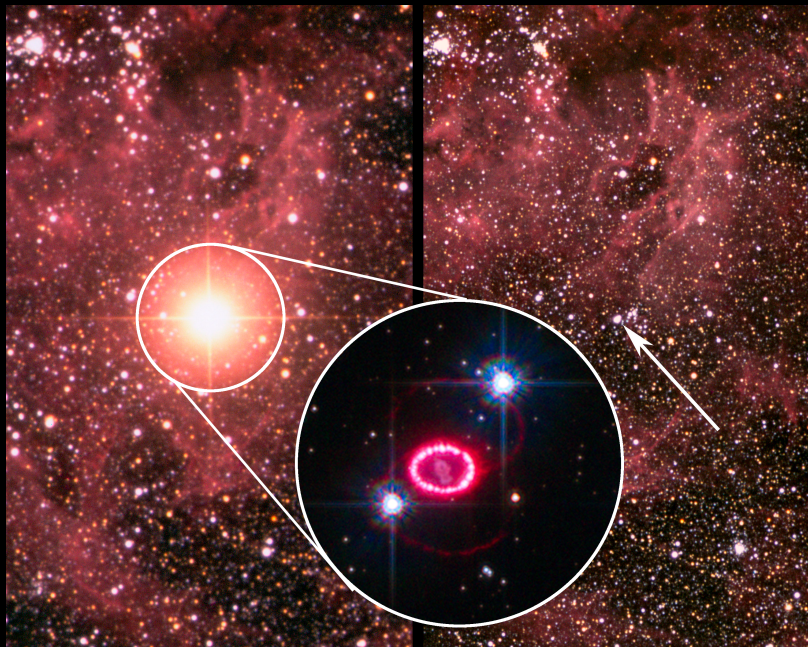
# The last “nearby” stellar explosion was from a stellar merger

Supernova 1987A



# The last “nearby” stellar explosion was from a stellar merger

Supernova 1987A



**When one star explodes,  
what happens to the other?**

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An artist's impression of a black hole. A bright blue and white jet of light and gas is being ejected from the left side of the black hole. The black hole is surrounded by a glowing orange and yellow accretion disk. A bright star is visible in the background.

**Sometimes they stay together  
and interact again**



The vast majority of explosion break the binary



Artist's impression

The nearest massive star is running away from an explosion



**What can we observe to  
understand massive stars?**

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**Things we can observe: the stars themselves**



## Things we can observe: the stars themselves

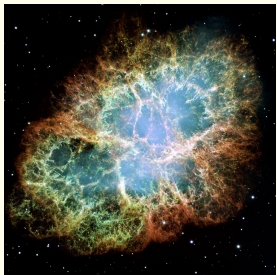


The explosions: supernovae

## Things we can observe: the stars themselves



The explosions: supernovae

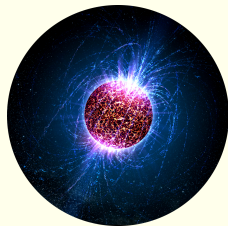


“Ashes”: supernova remnants

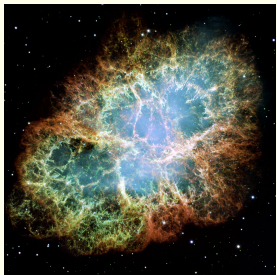
# Things we can observe: the stars themselves



The explosions: supernovae



Neutron stars

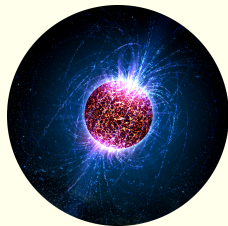


“Ashes”: supernova remnants

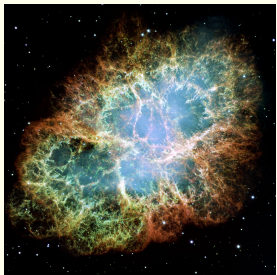
# Things we can observe: the stars themselves



The explosions: supernovae

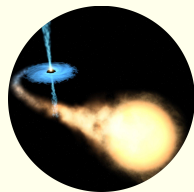
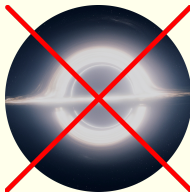


Neutron stars



“Ashes”: supernova remnants

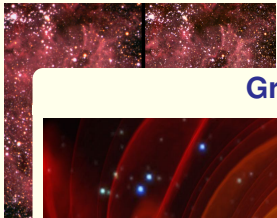
**We cannot see black holes...**



...but we can see matter  
falling into them!

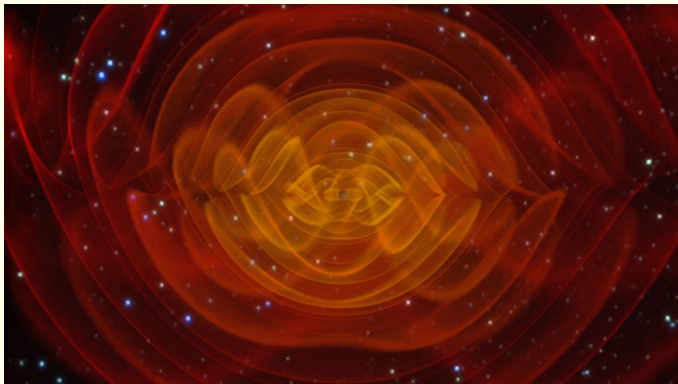


# Things we can observe: the stars themselves

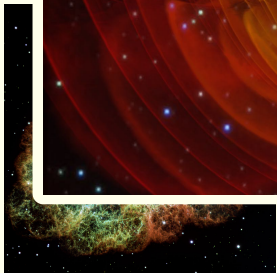


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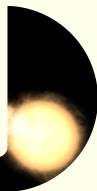
## Gravitational waves



“Ashes”: supernova remnants



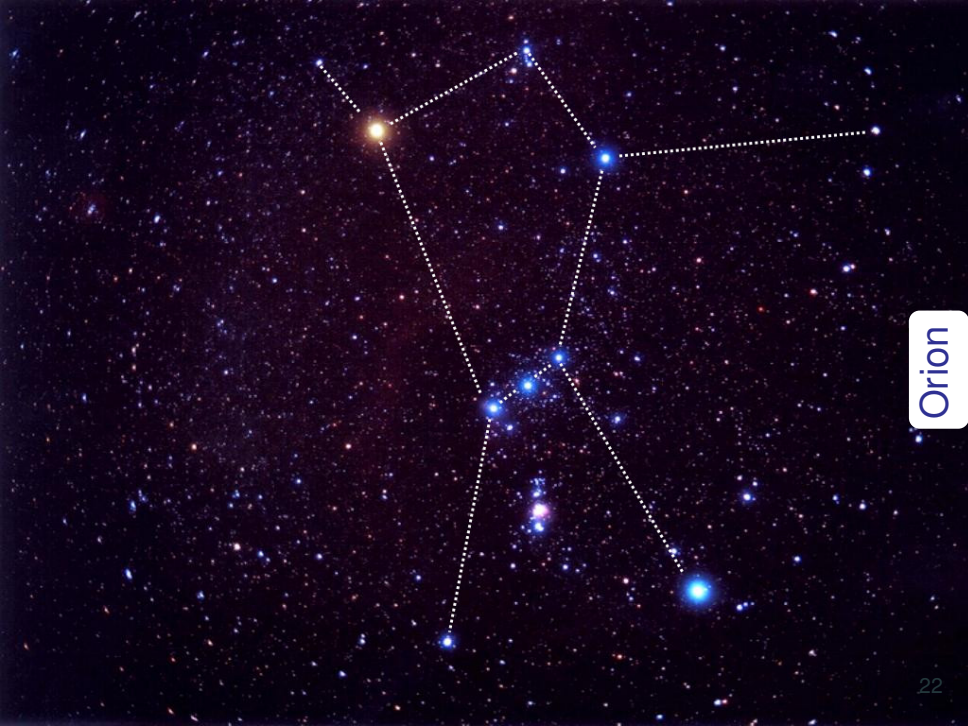
oles...



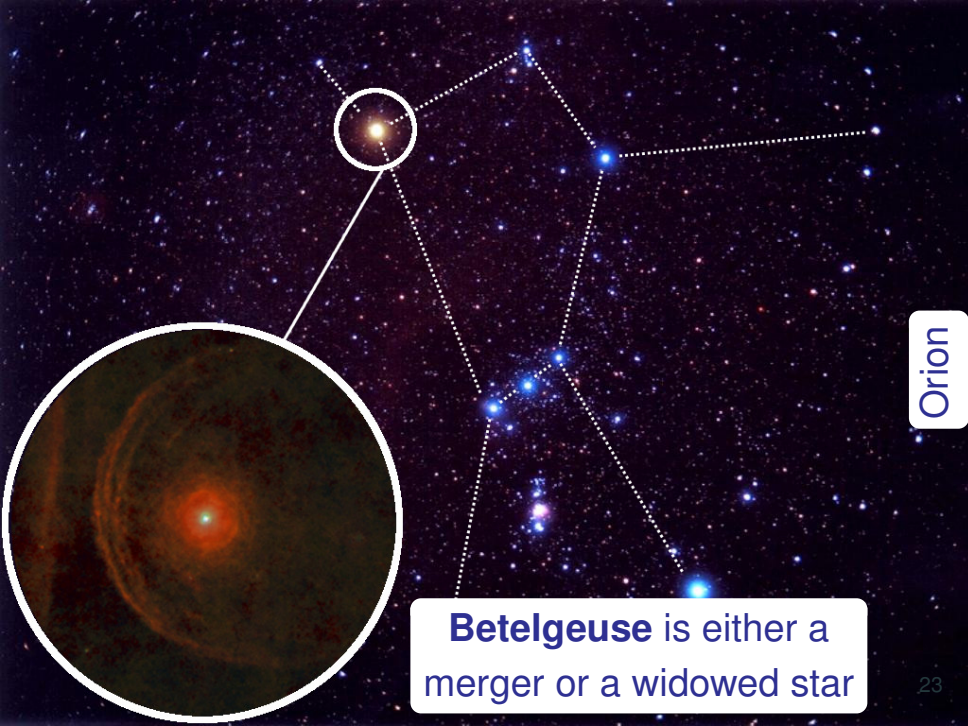
...but we can see matter  
falling into them!



Orion



Orion



Orion

**Betelgeuse** is either a merger or a widowed star

**Extra Slides**

# What happens to massive stars in binaries?