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

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What is a star?
The nearest star to us is the Sun
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?
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...
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simulation in Minecraft ≠ real picture
...but they are useful tools to understand how reality works.
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Nature does not have the limitations of simulations

Comparing with observations is crucial not to fool ourselves!
Massive stars
The mass of star determines how they live

Massive stars: $10 \times \text{Sun}

$$\text{H} \rightarrow \text{He} + \text{energy}$$

$$\text{He} \rightarrow \text{C} + \text{energy}$$

$$\text{C} \rightarrow \text{O} + \text{energy}$$

$$\text{O} \rightarrow \text{Si} + \text{energy}$$

$$\text{Si} \rightarrow \text{Fe} + \text{energy}$$

Massive stars: $10 \times \text{Sun}$
What are stars (mostly) made of?

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Si → Fe + energy
... and then they explode!

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$\text{Si} \rightarrow \text{Fe} + \text{energy}$
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?
The big dipper
The big dipper
Mizar & Alcor
Most stars are in binaries or multiple systems
What happens when two stars evolve together in a binary?
The two stars orbit each other
The bigger star evolves first...

... but there is a limit to how much it can grow
Two massive stars together will interact
About 1/3 of all massive binaries merge
The last “nearby” stellar explosion was from a stellar merger
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When one star explodes, what happens to the other?
Sometimes they stay together and interact again.
The vast majority of explosion break the binary
The nearest massive star is running away from an explosion.
What can we observe to understand massive stars?
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

“Ashes”: supernova remnants

Neutron stars
Things we can observe: the stars themselves

The explosions: supernovae

“Ashes”: supernova remnants

Neutron stars

We cannot see black holes...

...but we can see matter falling into them!
Things we can observe: the stars themselves

- The stars themselves
- The explosions: supernovae
- "Ashes": supernova remnants
- Neutron stars

We cannot see black holes...

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Gravitational waves
Betelgeuse is either a merger or a widowed star.
Extra Slides
What happens to massive stars in binaries?

Credits: ESO, L. Calçada, M. Kornmesser, S.E. de Mink