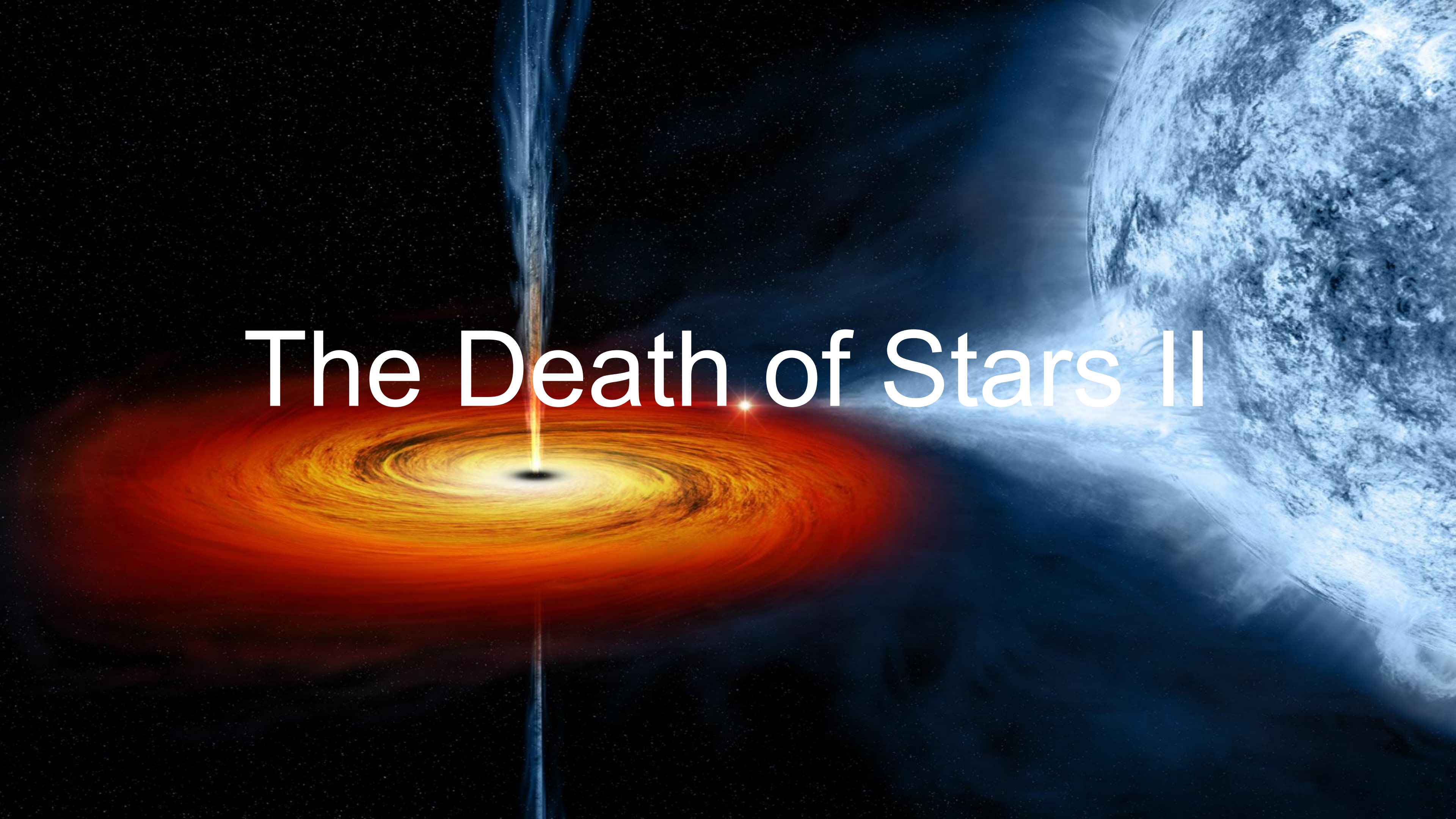
# The Death of Stars II



# Binary systems?

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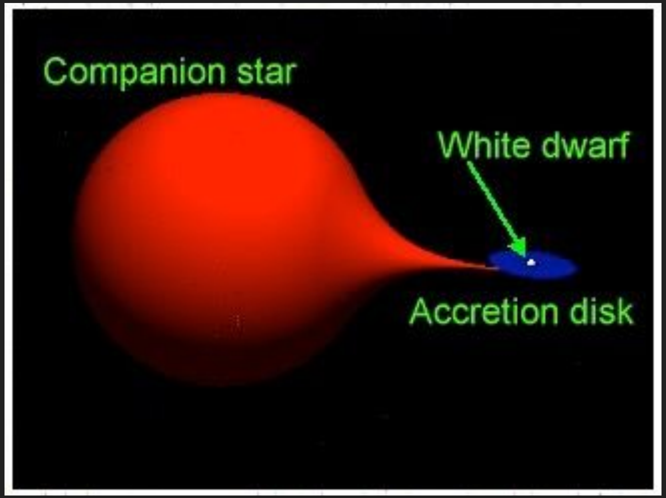
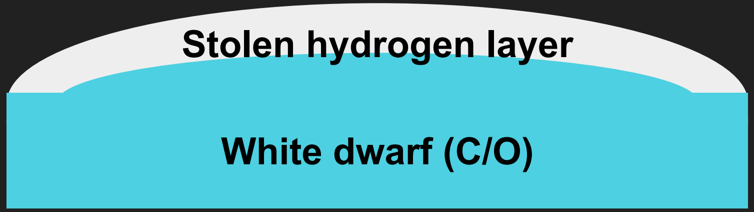
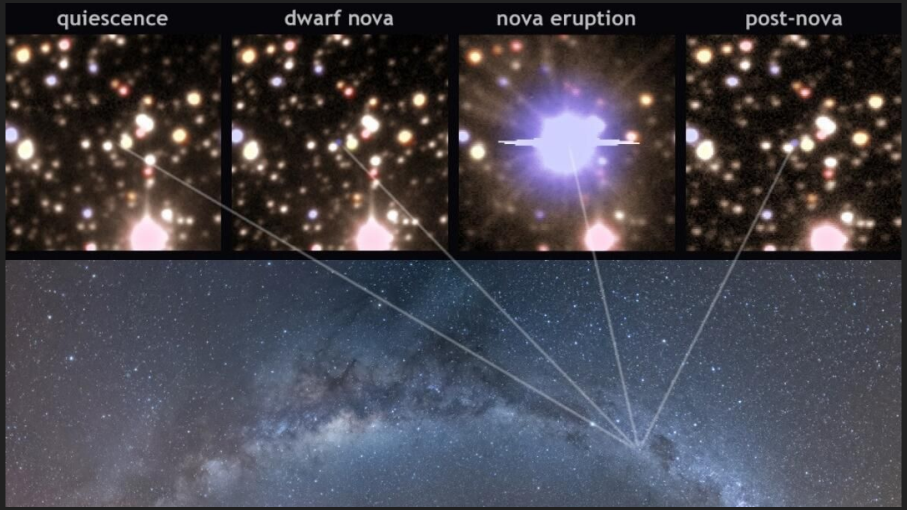
- In close binary pairs with different masses, the higher mass star evolves into a white dwarf first
- Later, the other star evolves into a red giant
- The white dwarf steals mass from its companion
- Dense layer of hydrogen collects on the white dwarfs surface



# Novae

- If enough material piles up onto the surface of the white dwarf, the hydrogen layer can ignite and undergo nuclear fusion
- White dwarf ejects accreted material and brightens by 100–1000 times
- Fades over months
- Called a nova (Latin for new)
- Common event, about 20 per year in our galaxy



# Evolution of stars

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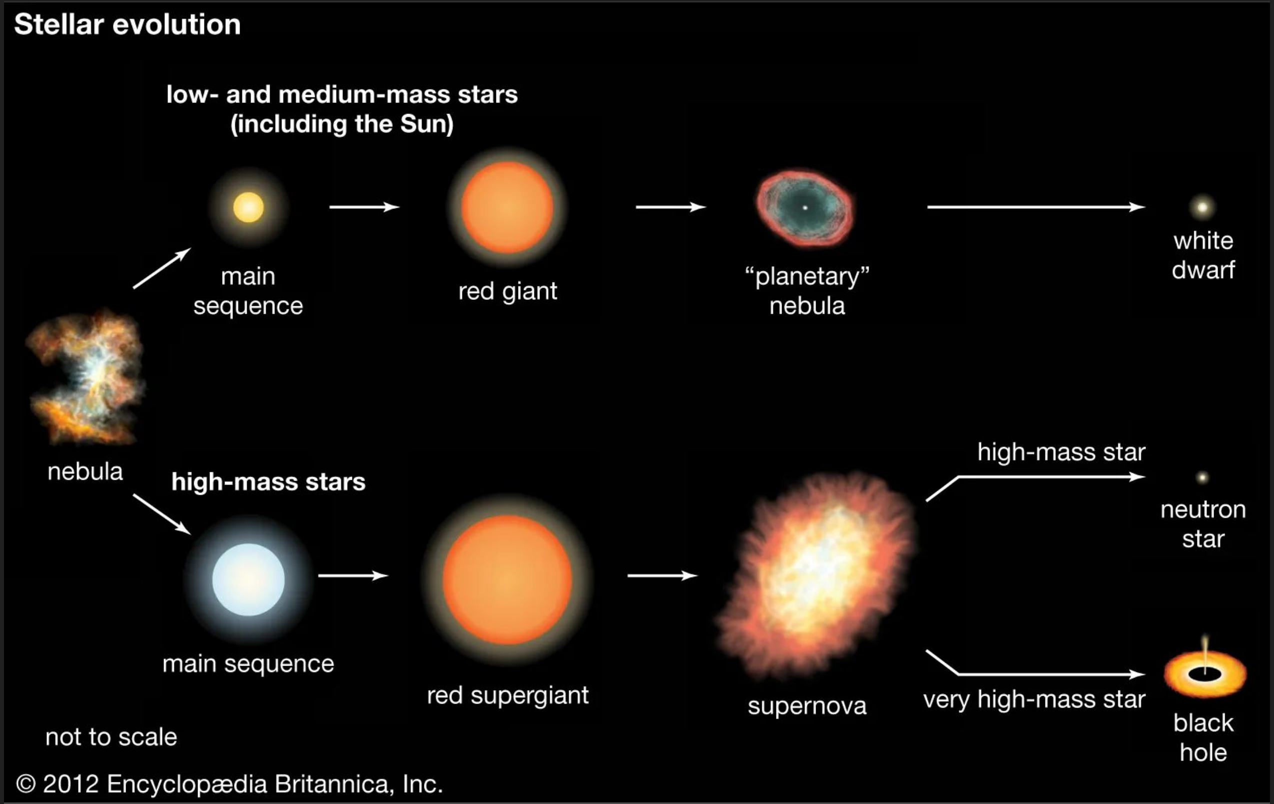

# Life of a low-mass star

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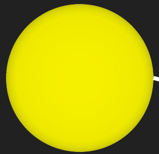
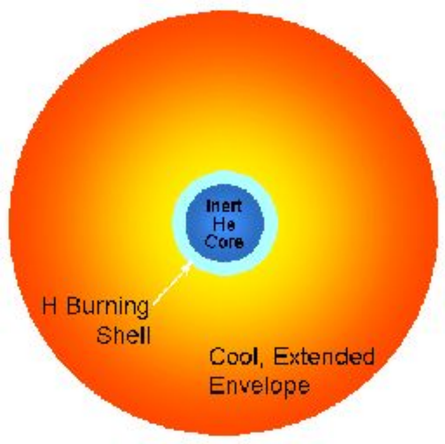
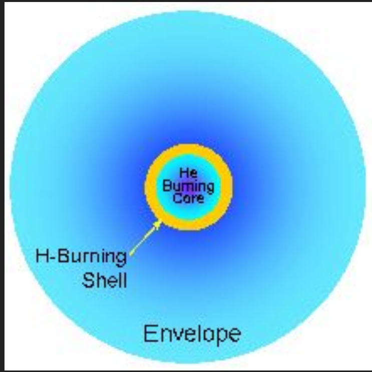


**Main sequence**
Core hydrogen burning
$T_{core}$ ~ 15 million K

**Red giant**
Hydrogen shell burning

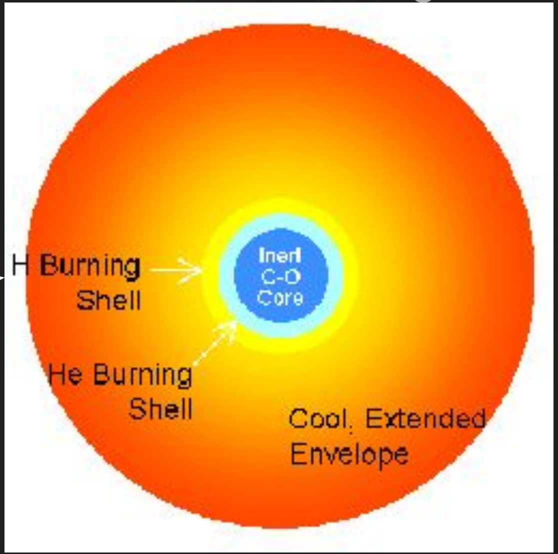







**Horizontal branch**
Core helium burning
$T_{core}$ ~ 100 million K

**Asymptotic giant branch**
Shell helium burning



# Death of high-mass (> 8 M_Sun) stars

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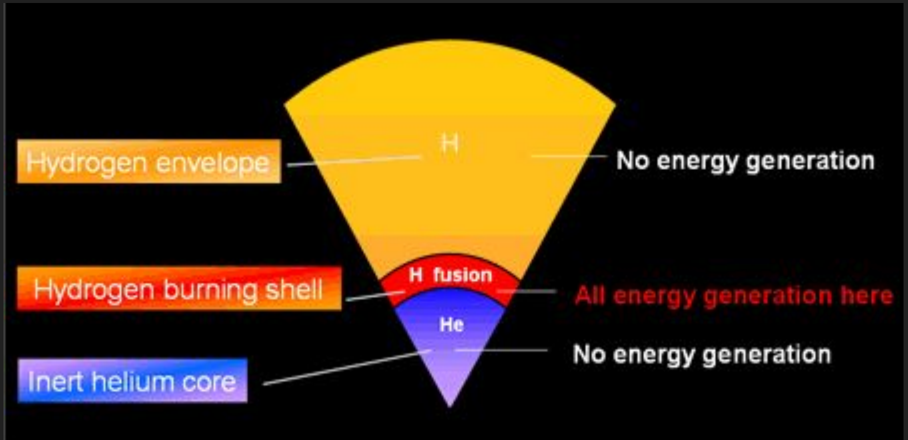
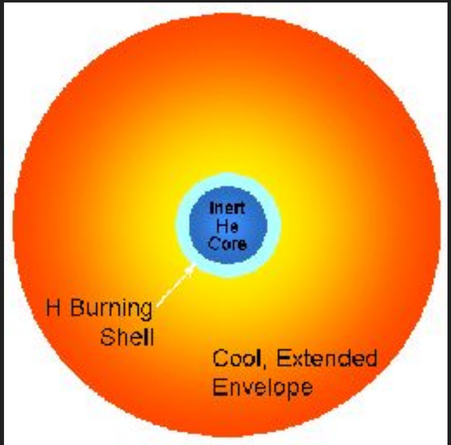
- Similar to lower-mass stars in the first few stages.
- When the hydrogen supply in the core runs out, the core starts to contract
- Hydrogen shell burning around the large helium core
- The outer atmosphere expands quickly and the star becomes a red supergiant

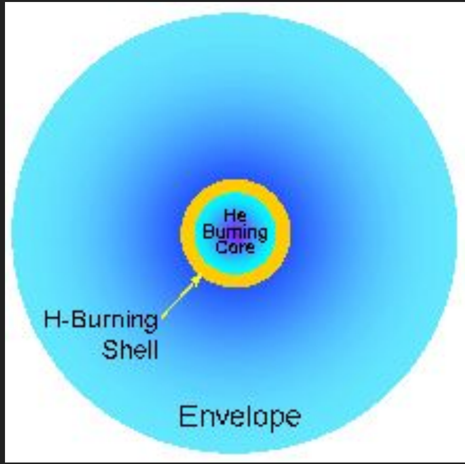


# The supergiant phase



- The outer atmosphere of the star grows larger
- More than 5 AU (the orbit of Mars)
- The surface cools because it is far from the hot core
- The star's core contracts and heats up
- Eventually hot enough for helium fusion (triple alpha)
- The star heats back up, blue supergiant

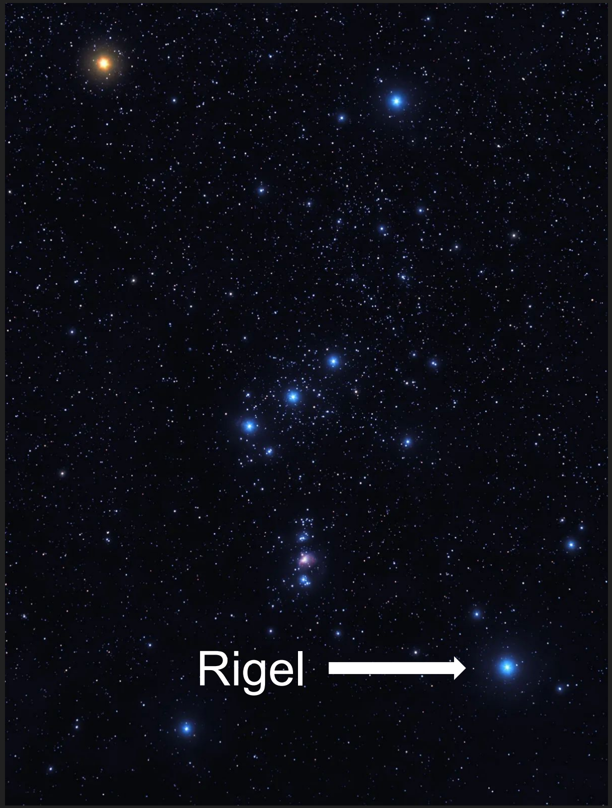


# Blue supergiant



- More mass means more gravitational contraction
- When Helium fusion stops, the inert Carbon/Oxygen core stars to collapse under gravity and create really high temperatures
- Temperatures high enough to ignite carbon fusion



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# Massive stars: layers

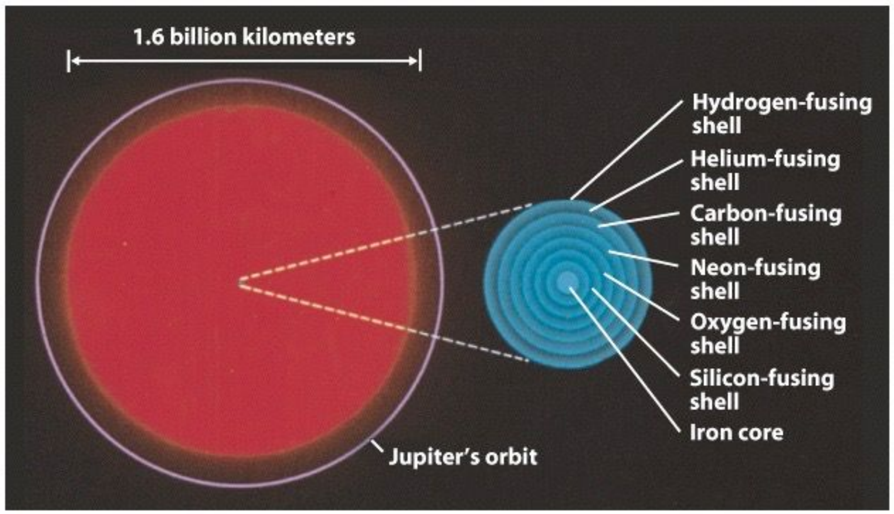
- Helium to carbon is not the end
- Cycles of core contraction, heating, then ignition
- Ash of one cycle becomes fuel for next

$^{12}_{6}C + ^{4}_{2}He \longrightarrow ^{16}_{8}O + \text{energy}$

$^{12}_{8}O + ^{4}_{2}He \longrightarrow ^{20}_{10}Ne + \text{energy}$

and so on…

- Onion-like structure to core



# Iron—the end of the road

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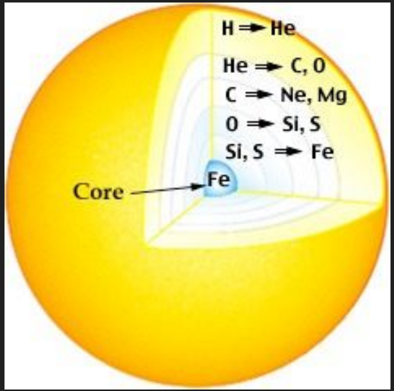
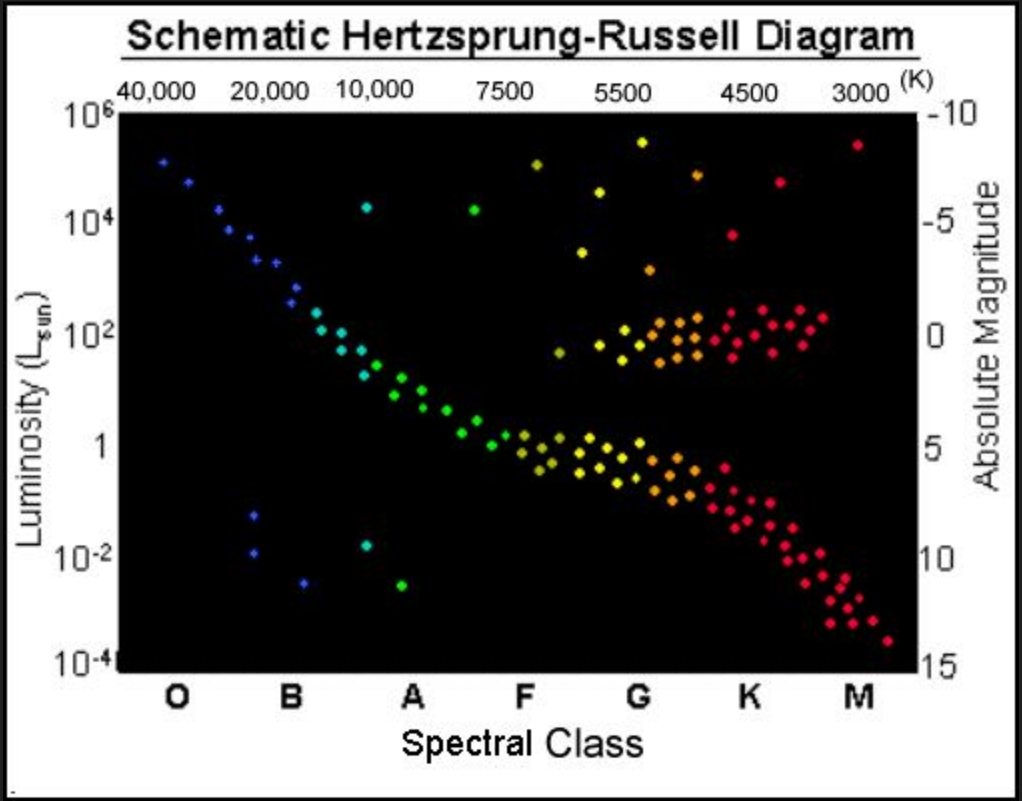
- Supergiants burn heavier and heavier atoms in the fusion process
- Creates shells with different elements
- Each stage is faster than the last
- This process stops at iron




**Values for a 20 $M_\odot$ star**

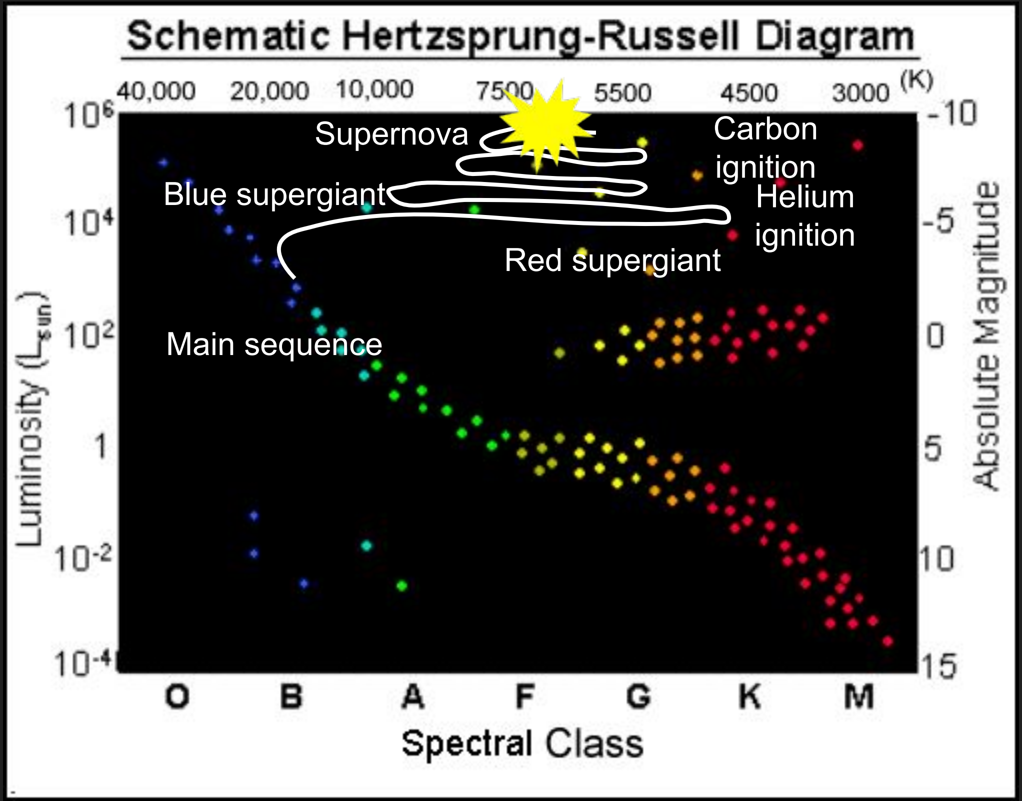
| Stage | Temperature | Duration |
|---|---|---|
| H | 40 million K | 7 million years |
| He | 200 million K | 500,000 years |
| C | 600 million K | 600 years |
| Ne | 1.2 billion K | 1 year |
| O | 1.5 billion K | 6 months |
| Si | 2.7 billion K | 1 day |

# Path of a massive star



# Path of a massive star





# Core collapse

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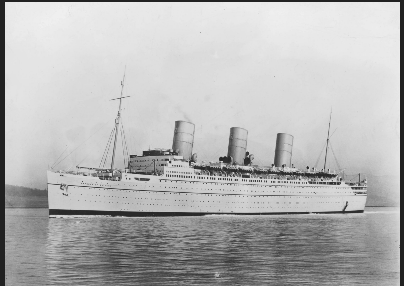
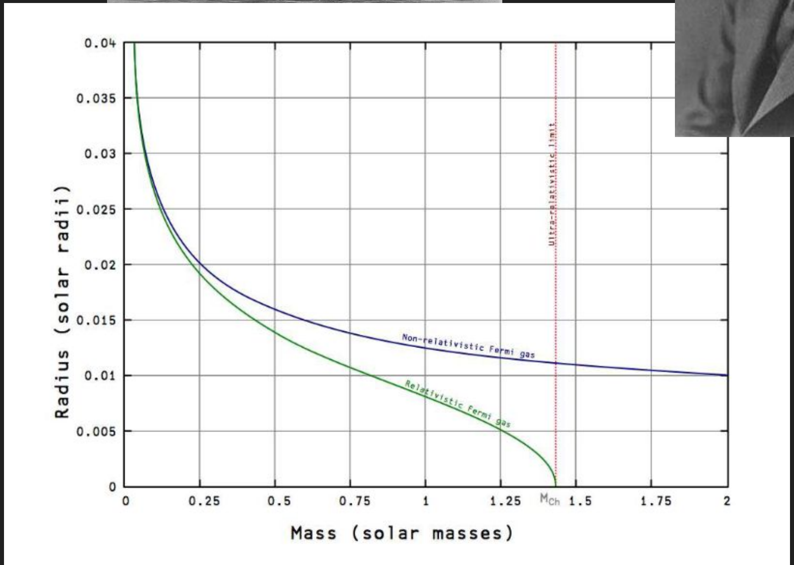
- The iron core is supported by electron degeneracy pressure
- Same pressure as white dwarf
- Core is so massive that gravity wins
    - Only when the core is 1.4 $M_{\odot}$ or greater (Chandrasekhar limit)
    - Need a massive star to get 1.4 $M_{\odot}$ in the core
- Over this limit = core collapse supernova





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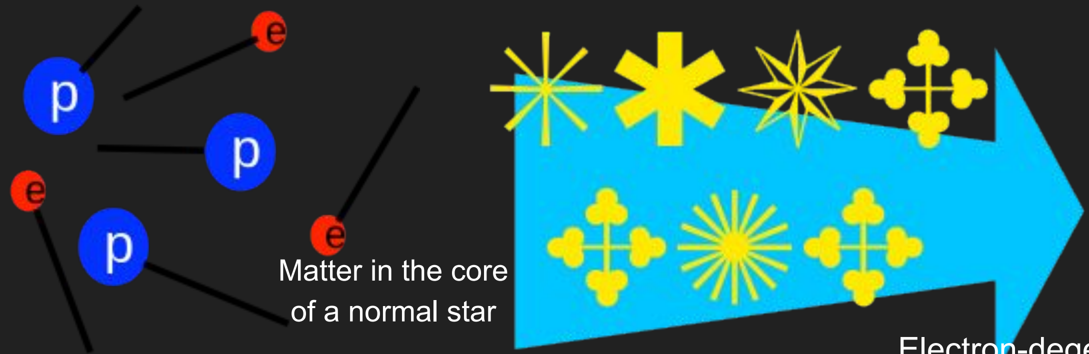
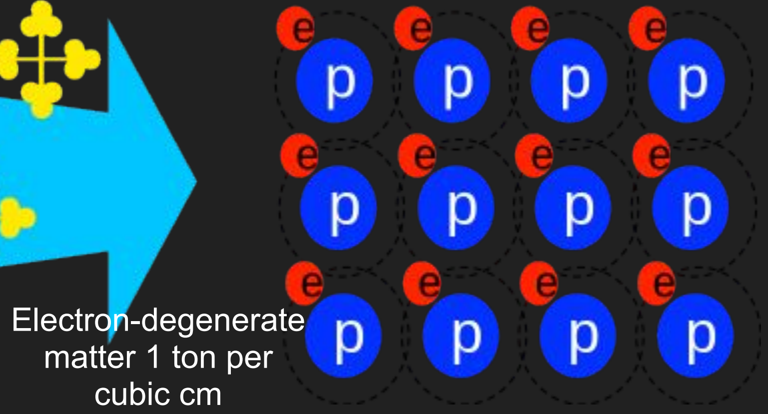
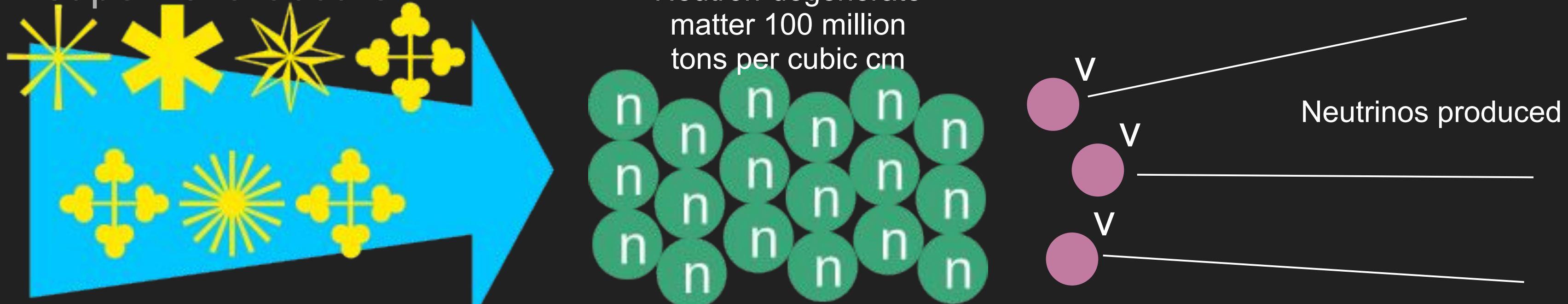
# When electron degeneracy breaks down



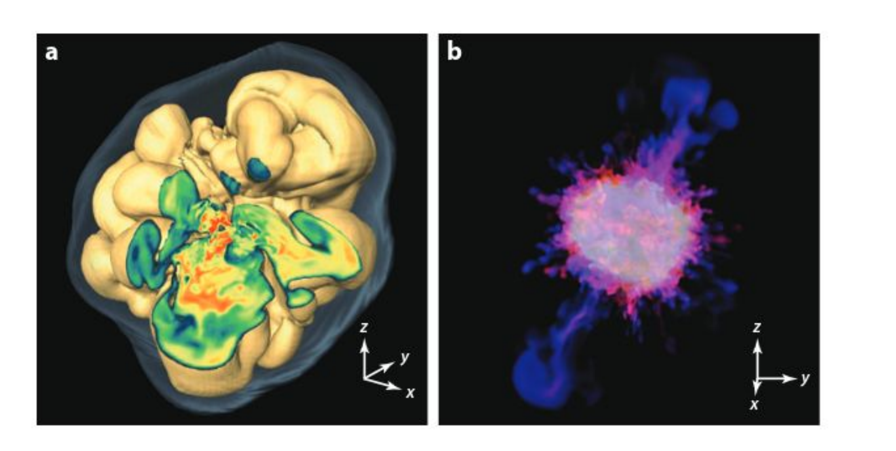




- If the core is 1.4 solar masses or more then a type II core collapse supernova occurs



# Supernova

- During the collapse, part of the core rebounds and produces a shock wave
- The material is so dense it even absorbs the neutrinos that are produced
- The neutrinos give the shock a “kick” and rip the outer layers apart
- The star explodes as a supernova
- Tremendous amount of energy, 99 % in the form of neutrinos




Janka, Hans-Thomas. ‘Explosion Mechanisms of Core-Collapse Supernovae’. *Annual Review of Nuclear and Particle Science*, vol. 62, no. 1, Nov. 2012, pp. 407–451, https://doi.org/10.1146/annurev-nucl-102711-094901. arXiv.

# Bright as a galaxy

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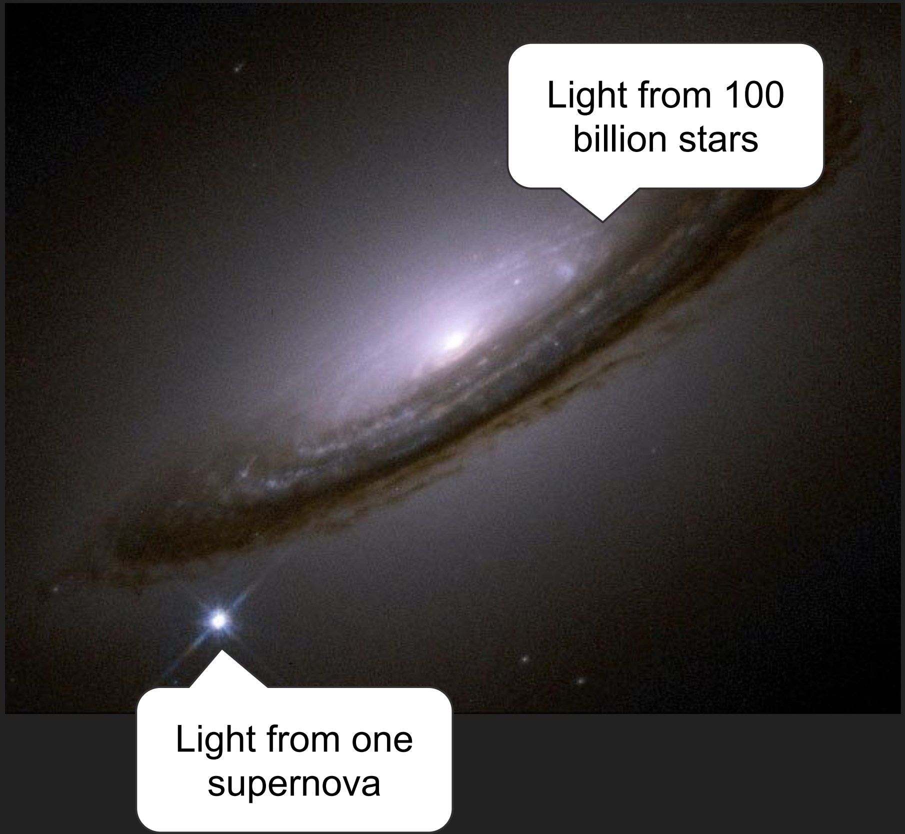
- Supernova are bright
- A star’s brightness increases by a factor of 10,000
- Almost outshines its host galaxy!
- Rigel, the (on occasion) brightest star in Orion has an apparent magnitude of 0. If Rigel went supernova, and brightened by 10,000 times, how bright would it appear in the sky?



# Poll everywhere



When poll is active respond at **PollEv.com/nikhilpatten355**

Send **nikhilpatten355** to **22333**

1. Rigel, the (on occasion) brightest star in Orion, has an apparent magnitude of 0. If Rigel went supernova, and brightened by 10,000 times, how bright would it appear in the sky?

# Apparent magnitudes of common objects

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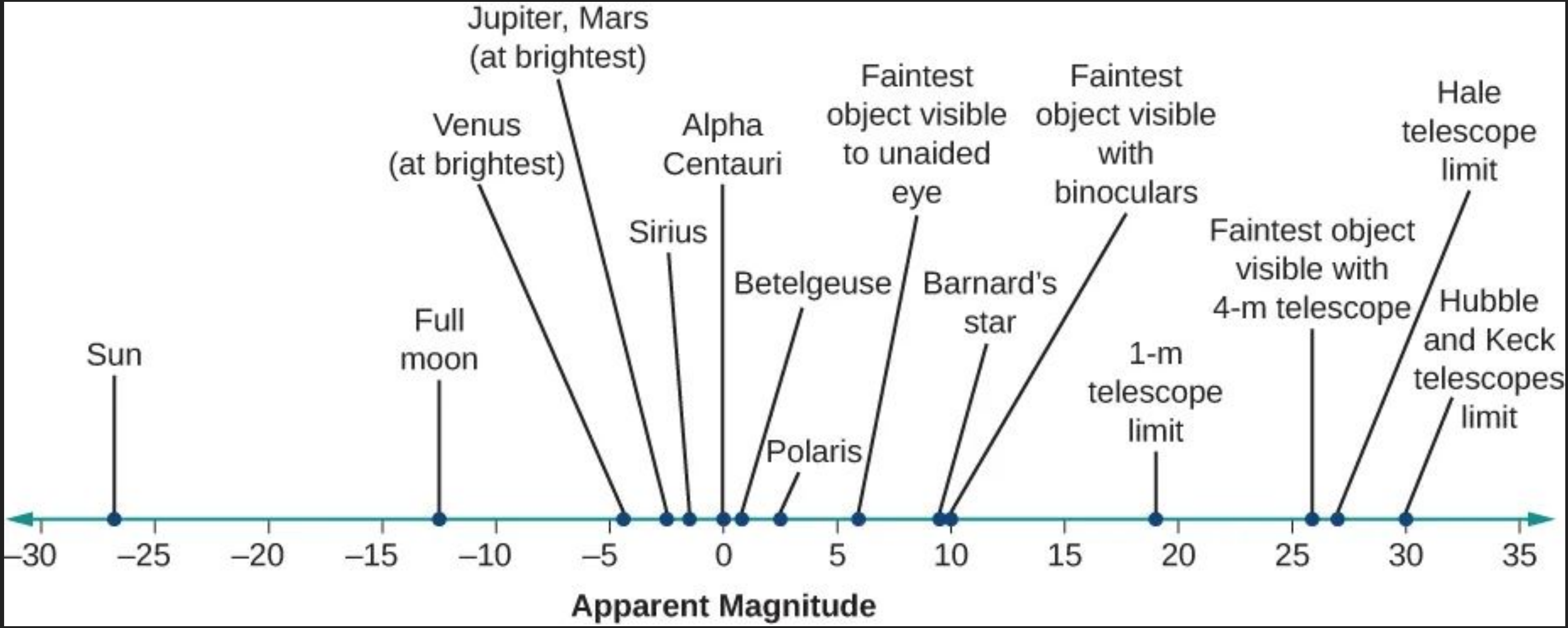

# Poll everywhere

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results

# Supernova 1987A in 1987

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Before

23 February, 1987

# Supernova 1987A in 1987

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Composite image of supernova today
JWST/HST/Chandra

# More than one way to supernova

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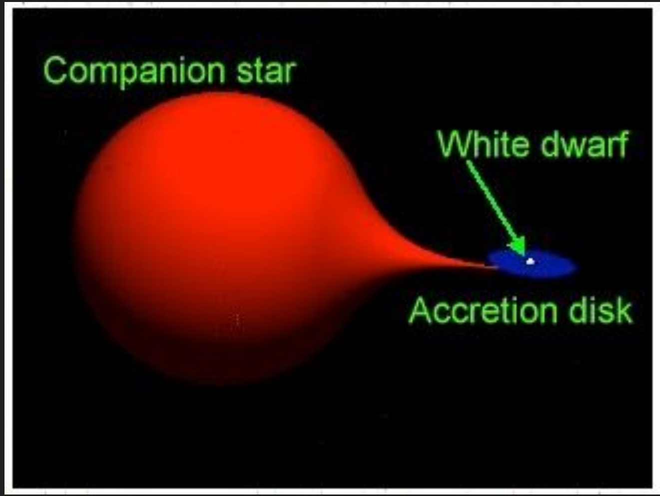
- If a white dwarf in a binary system steals enough matter, it can go over the Chandrasekhar limit
- Type 1A supernova
- White dwarf collapses under its own gravity
- Carbon and oxygen fuse into iron and nickel
- White dwarf is destroyed in a thermonuclear explosion



# Stellar evolution cycle

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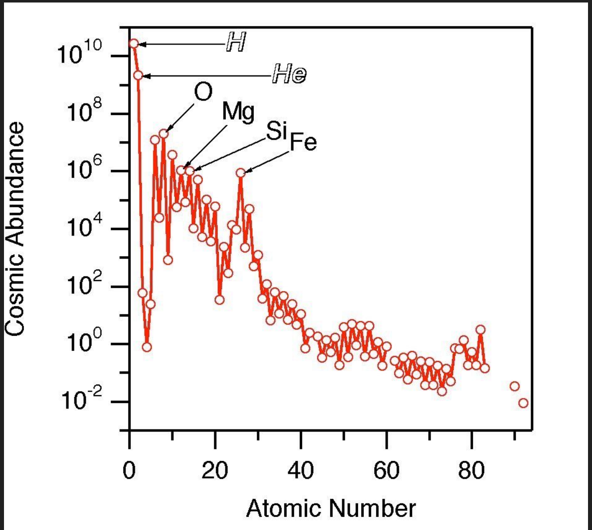
- Stars form out of the interstellar medium
- They make helium, carbon, oxygen in their interiors via fusion
- Heavier elements (iron, lead, uranium) are made by supernova
- Stars pass these processed materials back into the ISM when they die
- New ISM forms the next generations of stars
- We are the death of stars

# Heavy metals



- The dominant product of a supernova is iron (Z=26) in the final core of the high mass star
- During the explosion, there is so much energy that neutrons rapidly collide with iron nuclei
- Happens faster than fission can break up these elements
- Heavy elements up to plutonium (Z=94) produced
- By products are blasted into space and enrich the ISM



# Announcements

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- Exam 2 due today
- No lab this week

# Next time



- Exam 2 review