The life and death of stars, and how having company can make a difference

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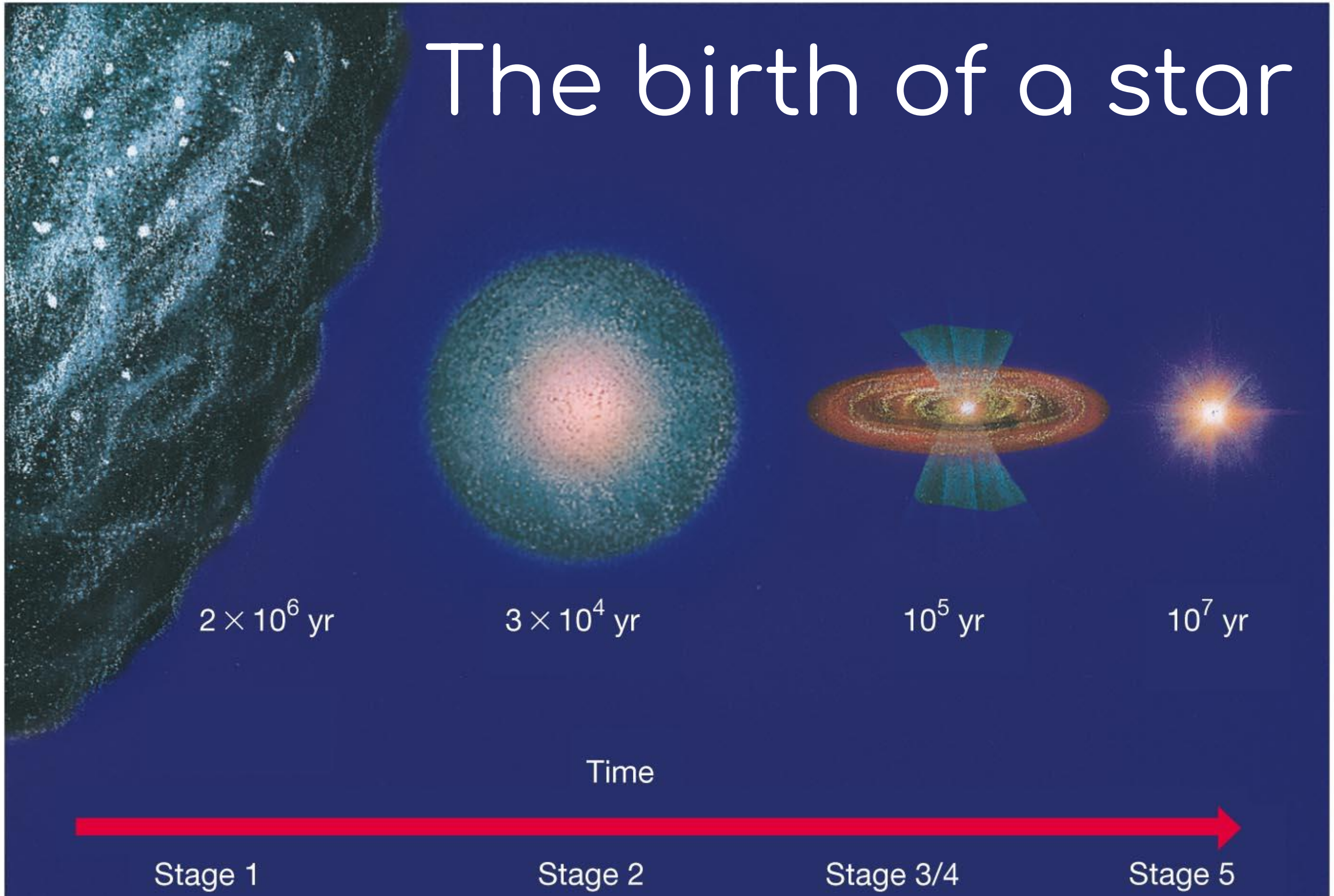
Warwick Astro Society, 14 February 2022

Research fellow (postdoc) in the Astronomy & Astrophysics Group here at Warwick

Before: research fellow at U. Potsdam (Germany), PhD at UFRGS (Brazil).

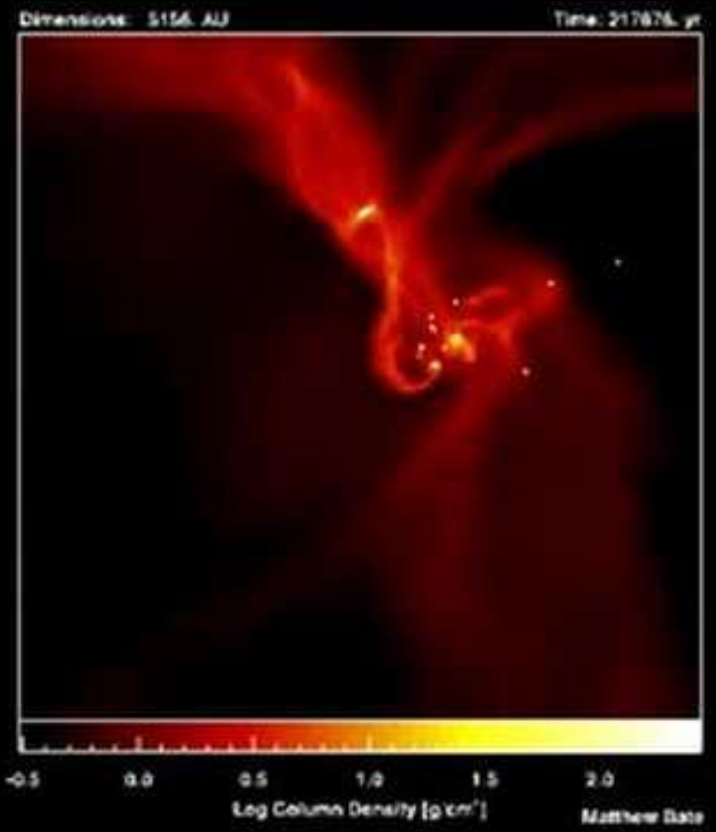
Main research interest: **white dwarfs** and other compact stars formed by **binary evolution.**

The birth of a star



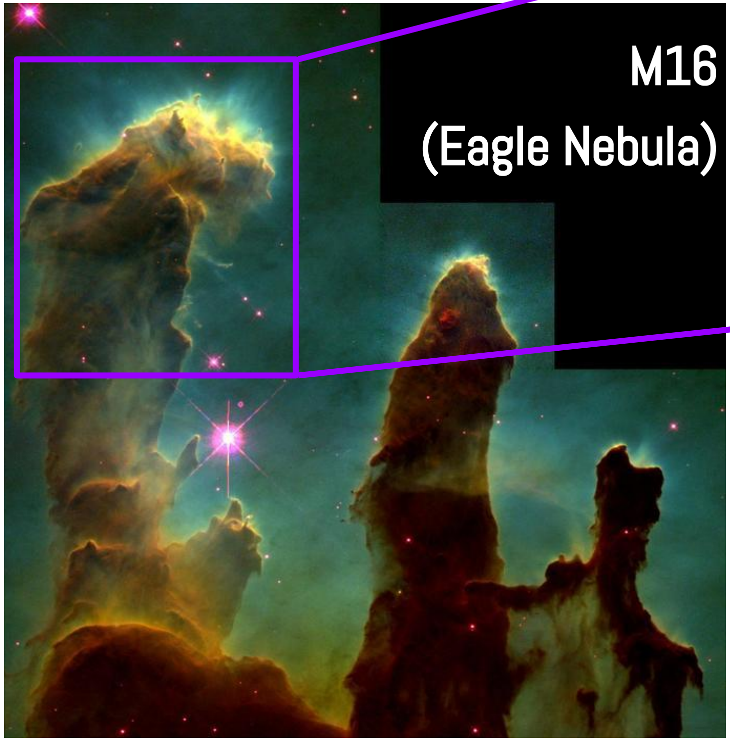
From a giant molecular cloud to a star

We can do computer simulations of this process!



https://youtu.be/YbdwTwB8jtc

The birth of a star



And also see it happen with our own ~~eyes~~ telescopes!

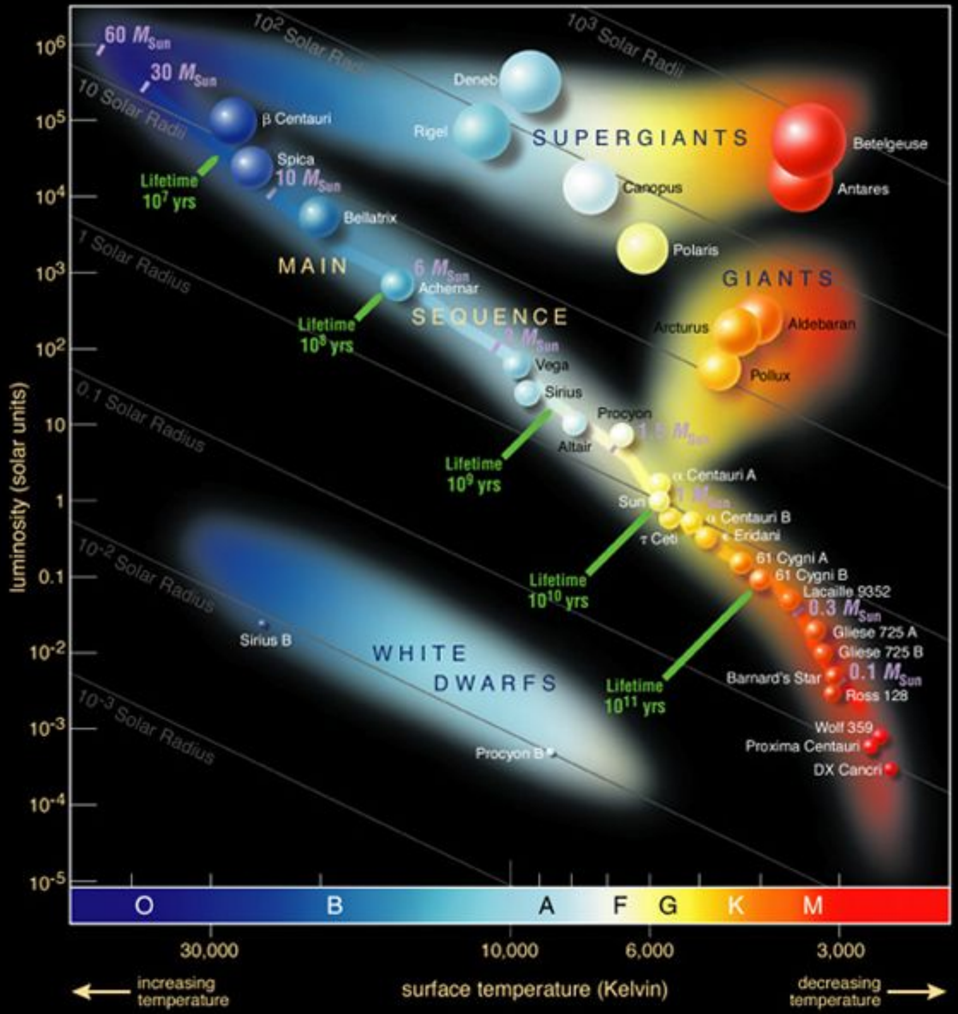
The birth of ~~a~~ many stars

NGC602

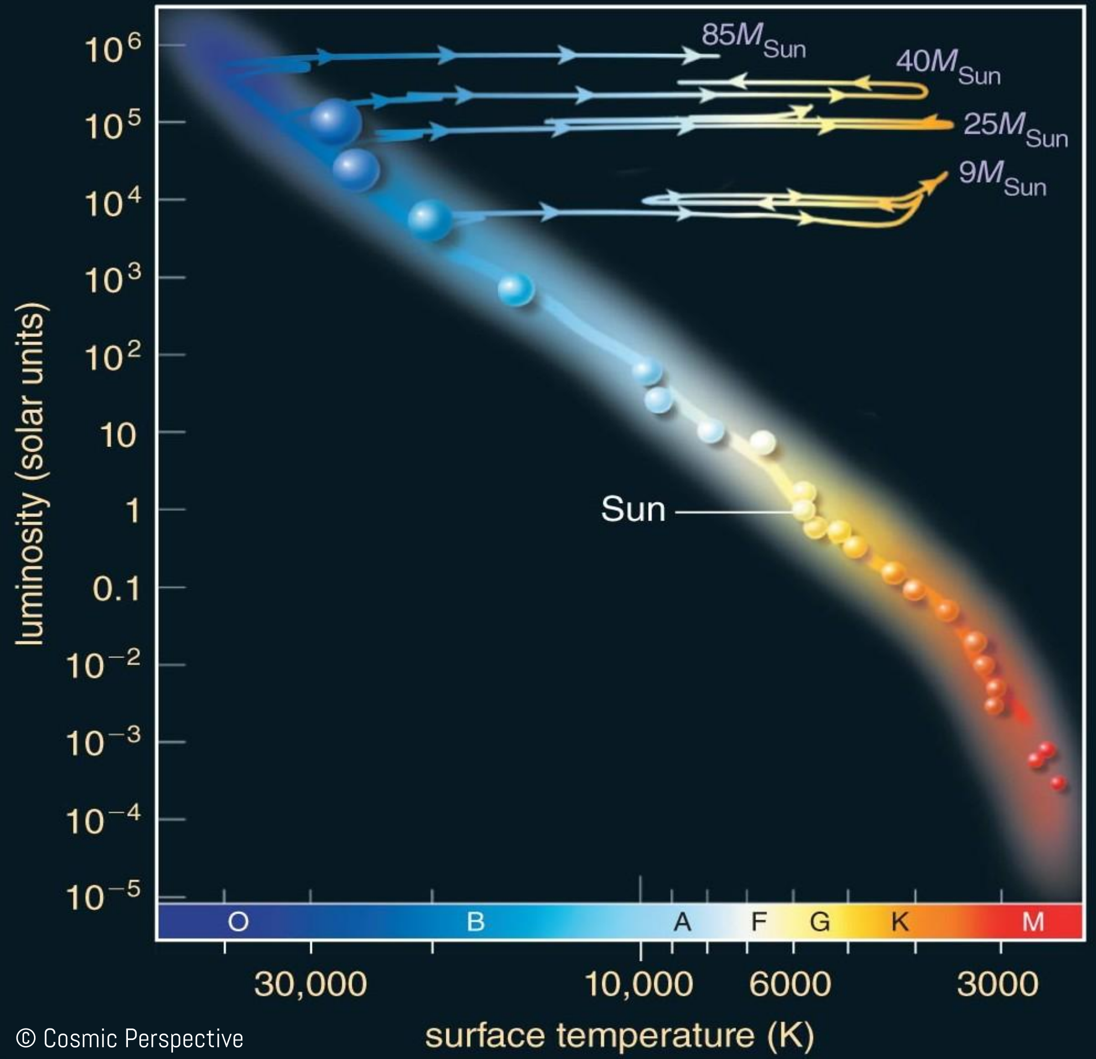
Credits: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration

Stars are typically born in groups.

The Hertzprung-Russel diagram

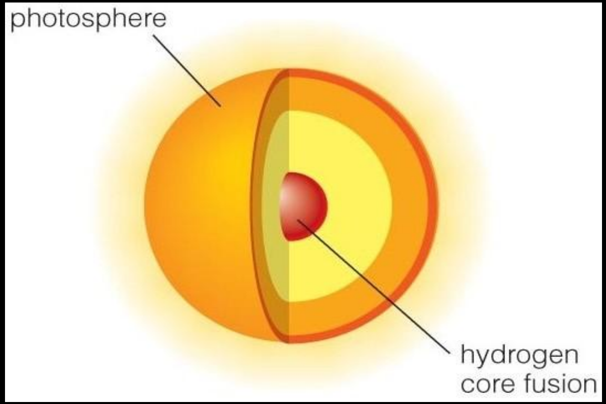


Stars can't have any temperature, mass, radius: there are equilibrium conditions.



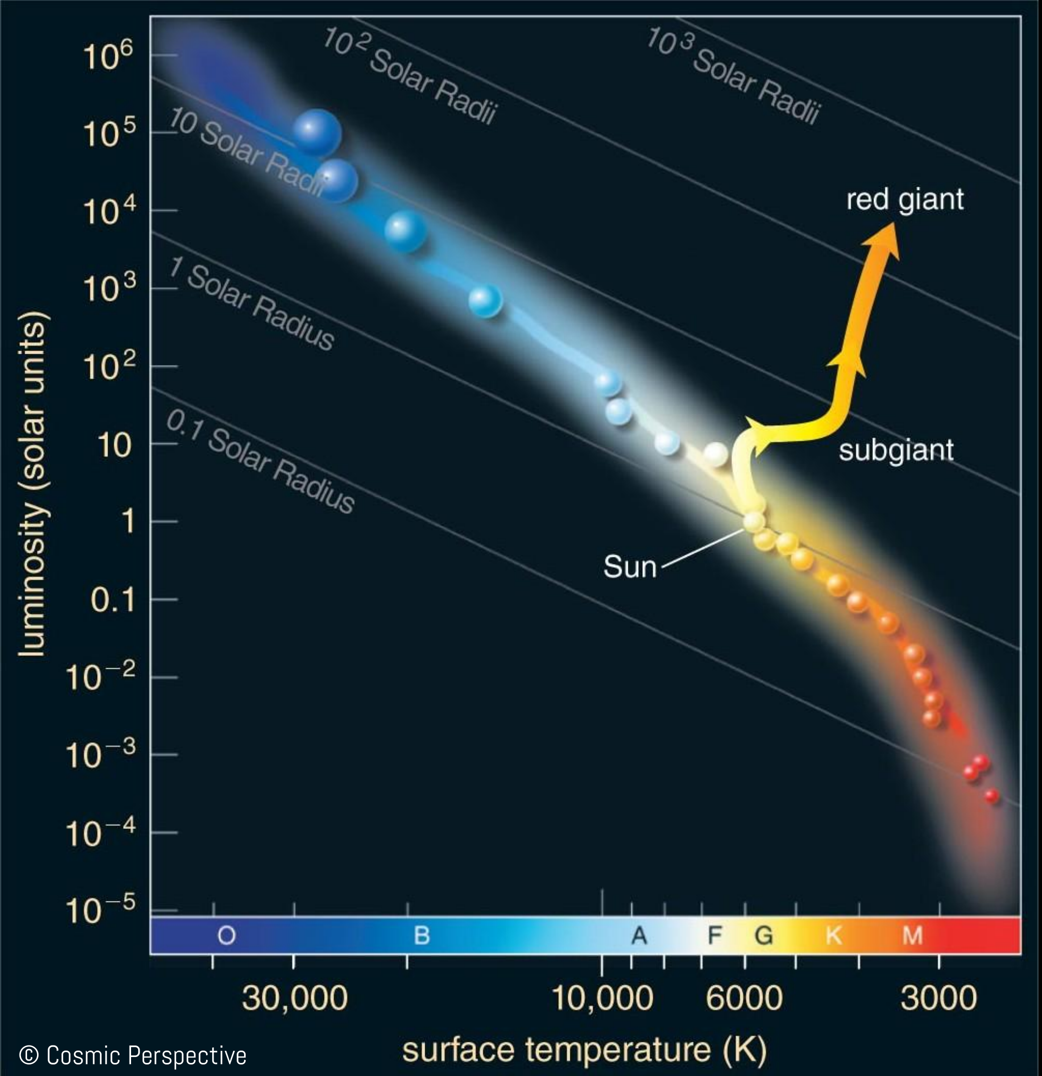
Main sequence

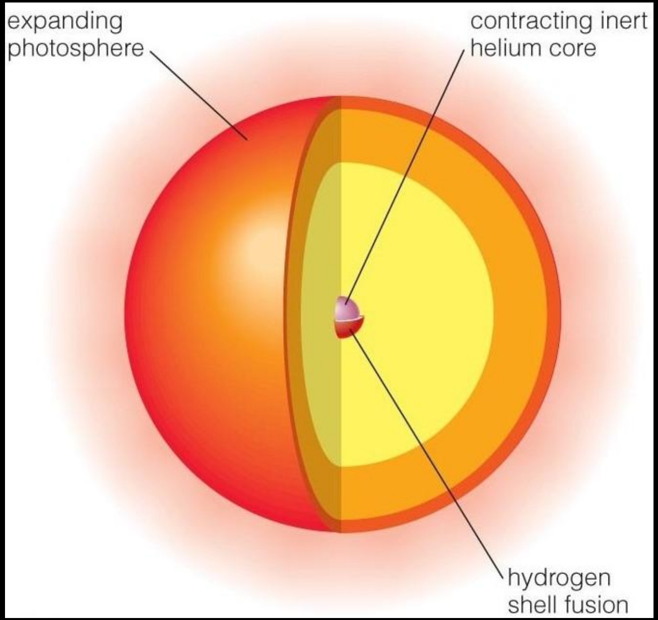
H ⟶ He in the core releasing energy that counteracts gravity

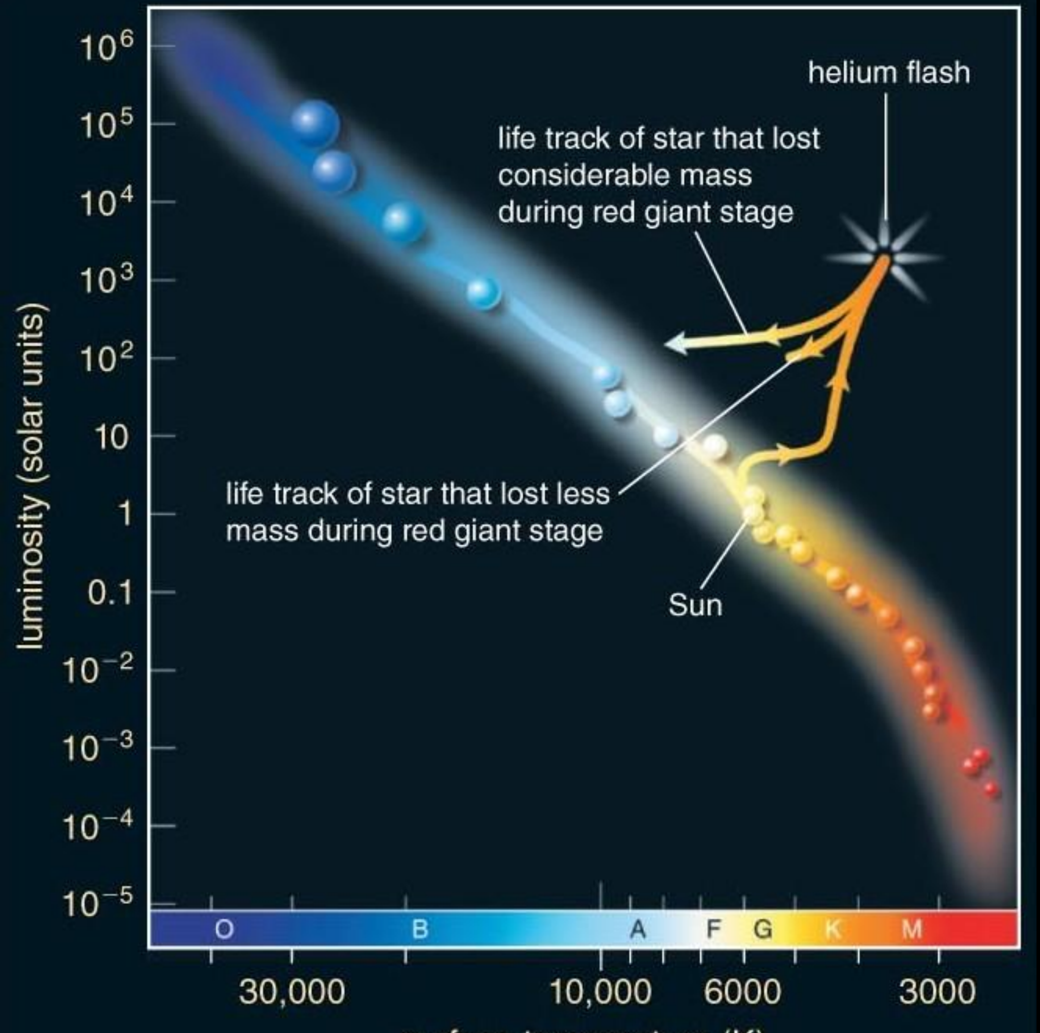


Red giant

No more H fuel, core contracts and exterior expands.

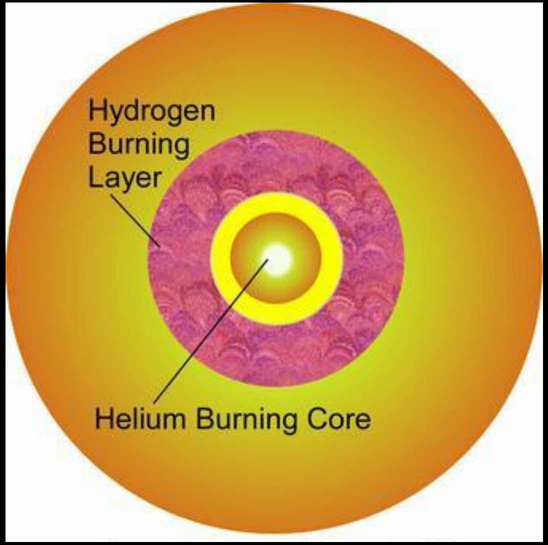


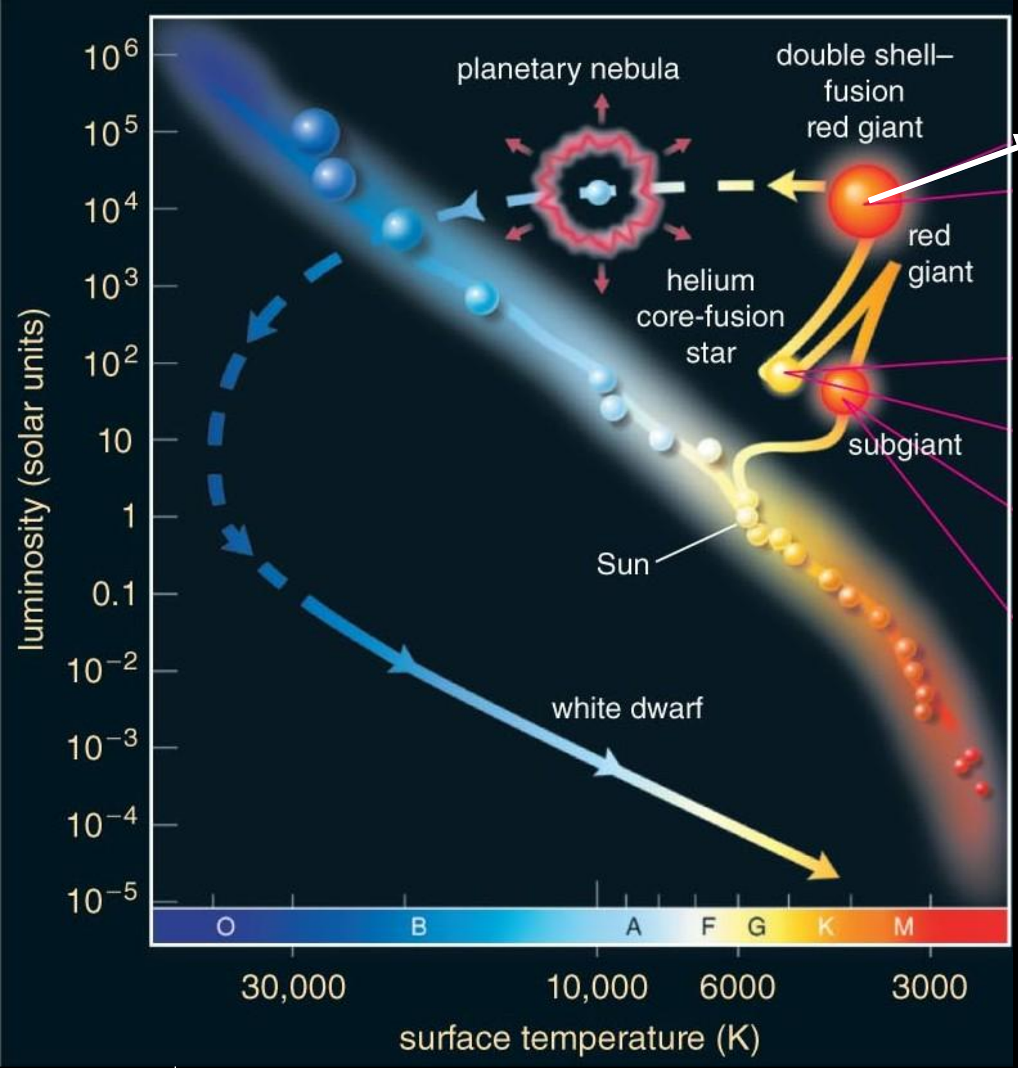




He-burning phase

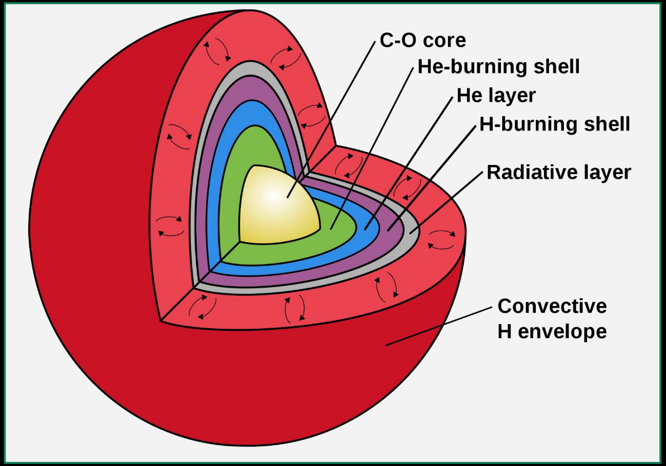
Core contracts enough to ignite He, now He ⟶ C/O gives equilibrium conditions



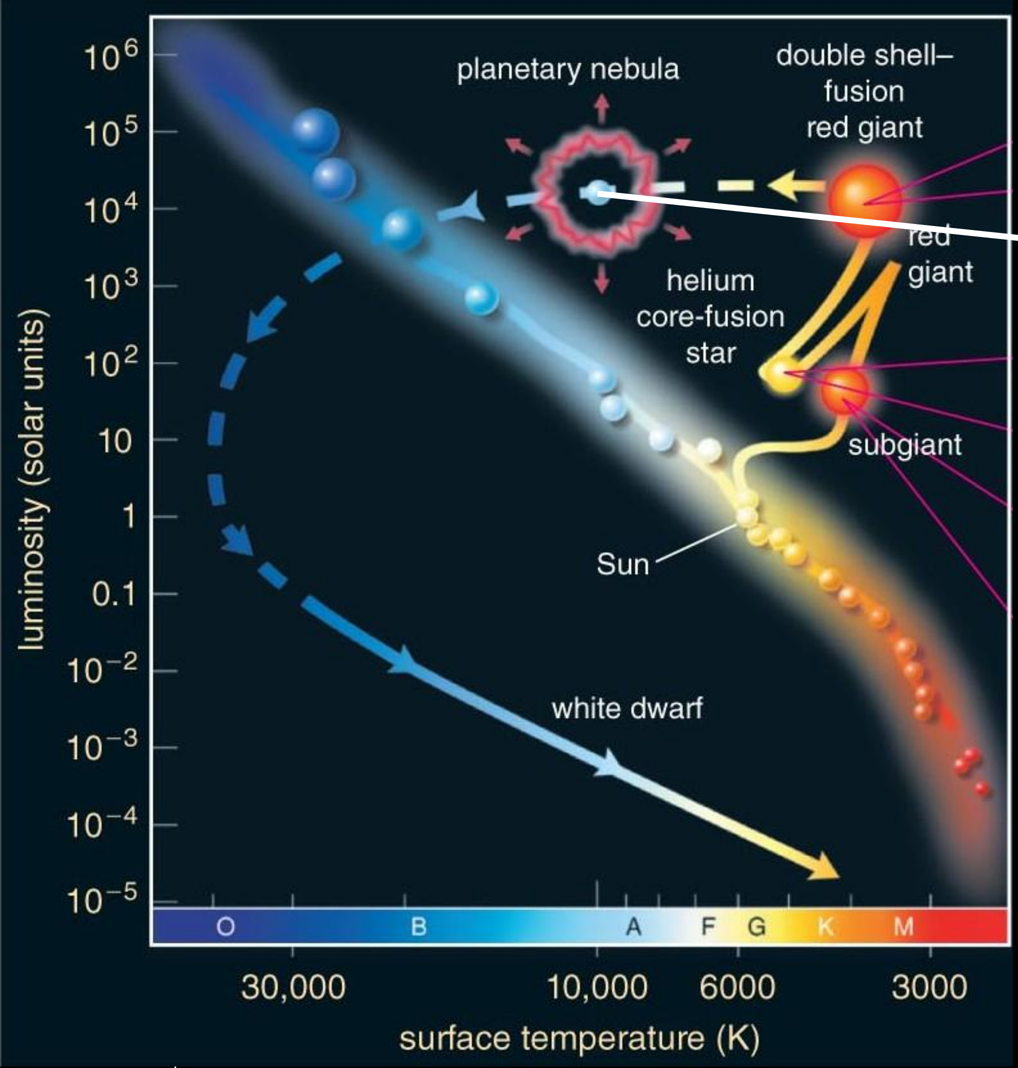


Asymptotic giant branch

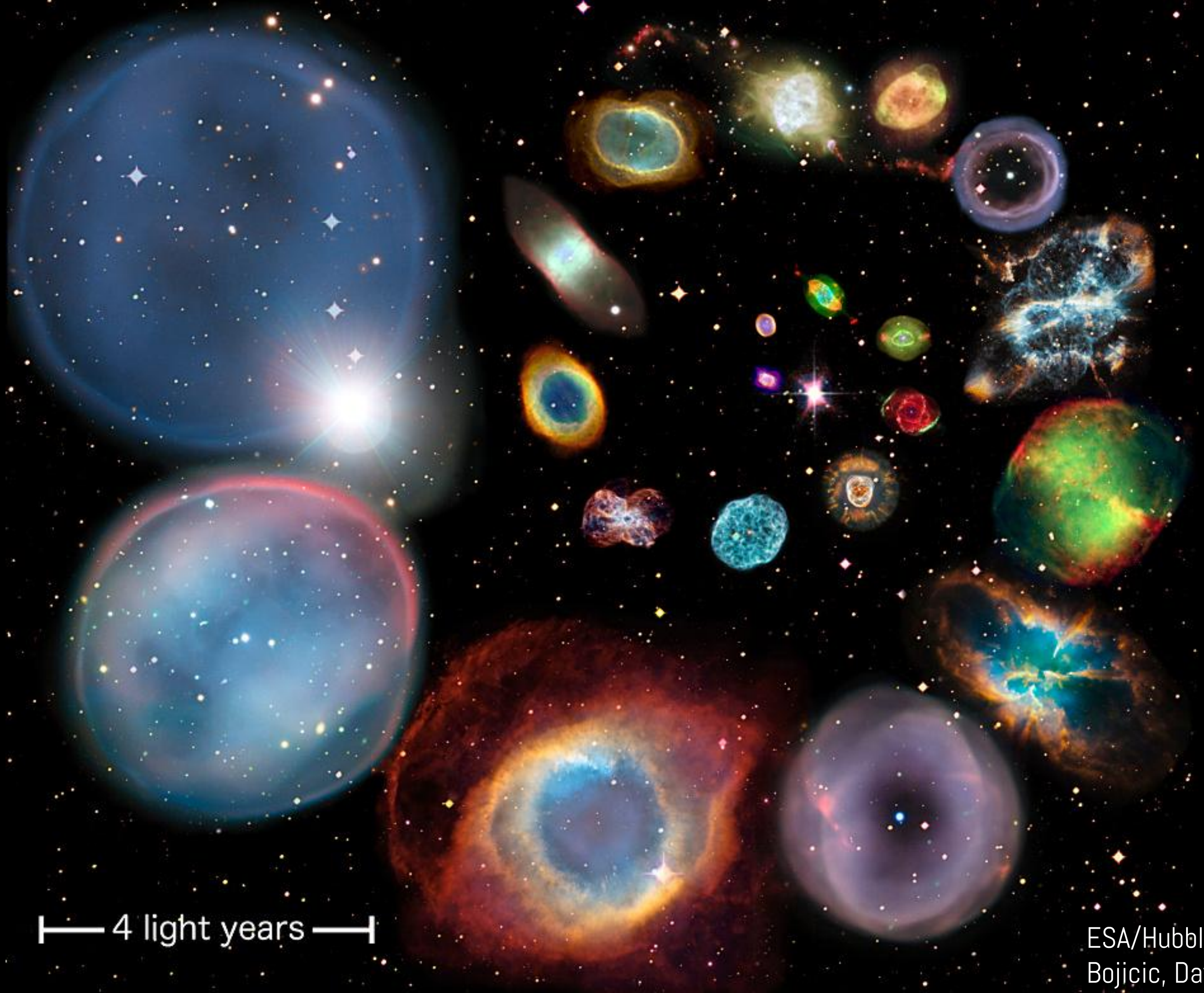
No more He fuel, core contracts and exterior expands.



Two burning layers ⇒ thermal pulses.

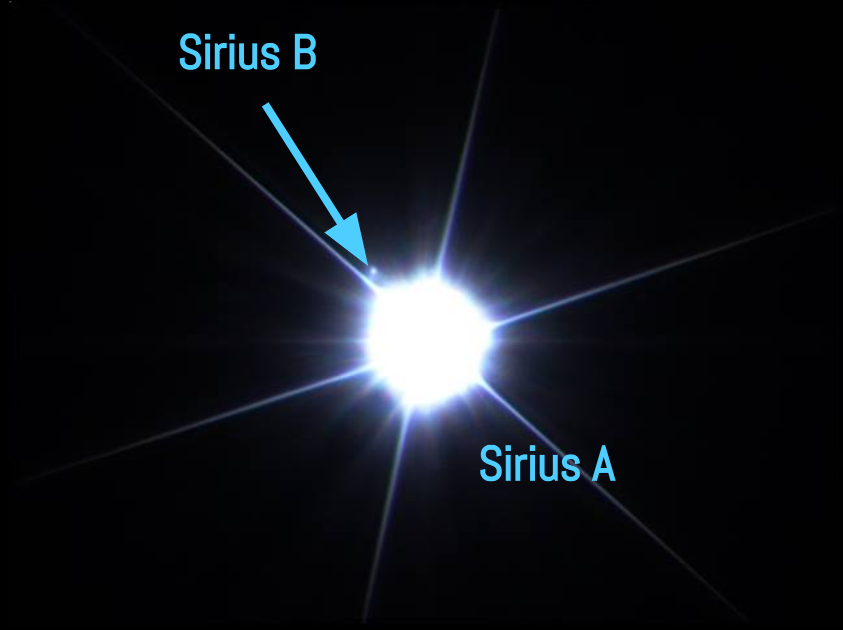


Outer layers are shed due to thermal pulses: a planetary nebula is formed

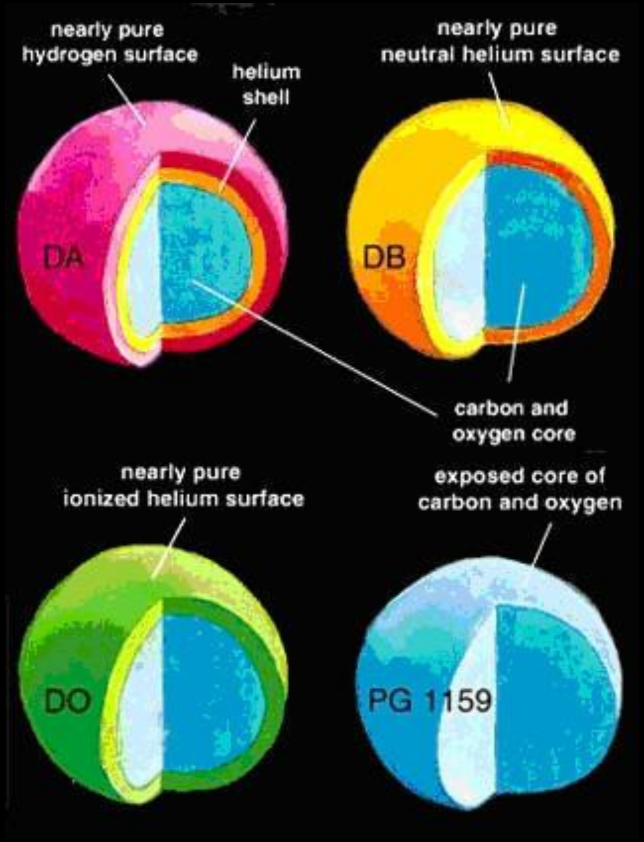


ESA/Hubble & NASA, ESO, Ivan Bojicic, David Frew, Quentin Parker.

The planetary nebula fades away, a **white dwarf** is revealed



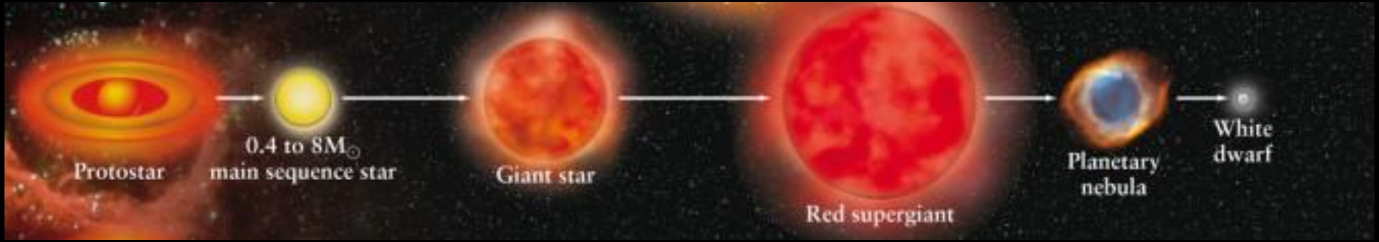
White dwarfs: rich laboratories



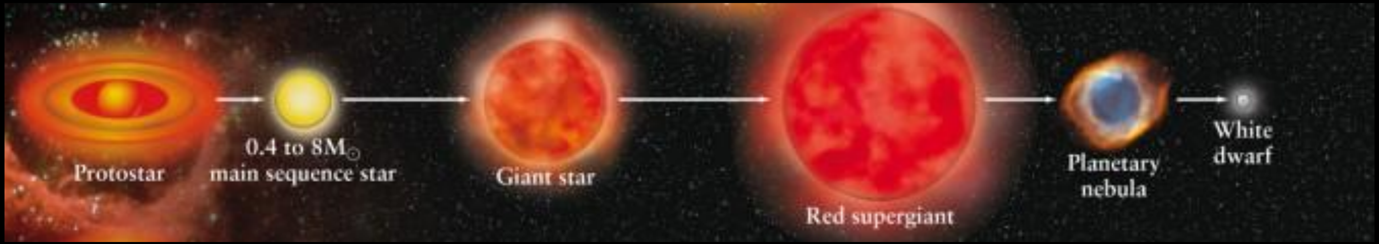
- **Simple** (compared to other evolutionary stages)
- **Abundant** (final state of over 95% of stars)
- **Old**

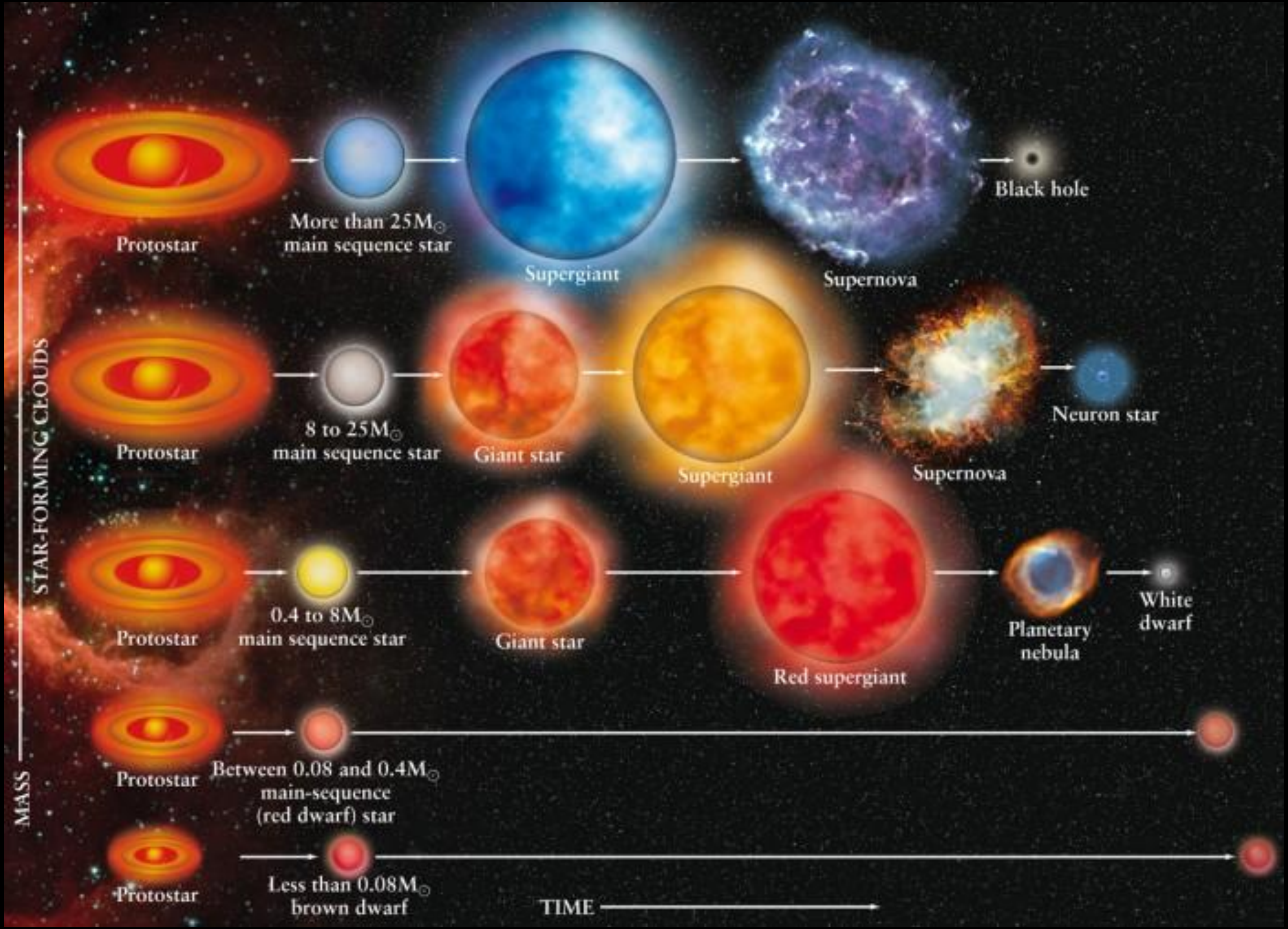
Excellent laboratories for astronomy and physics!

In summary: the life and death of 95 % of single stars



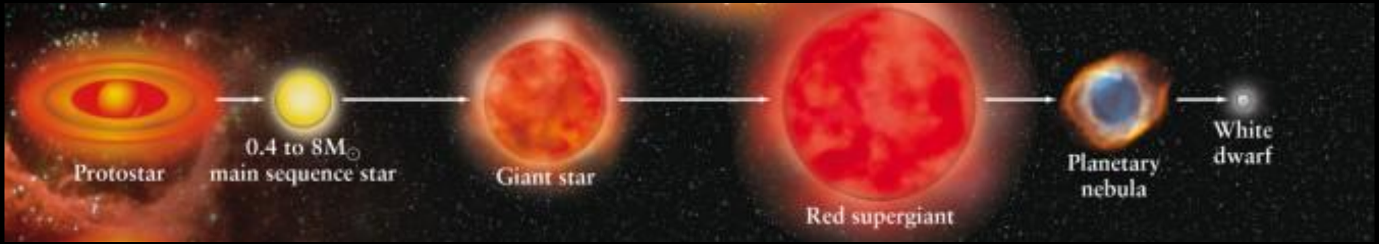
In summary: the life and death of 95 % of single stars





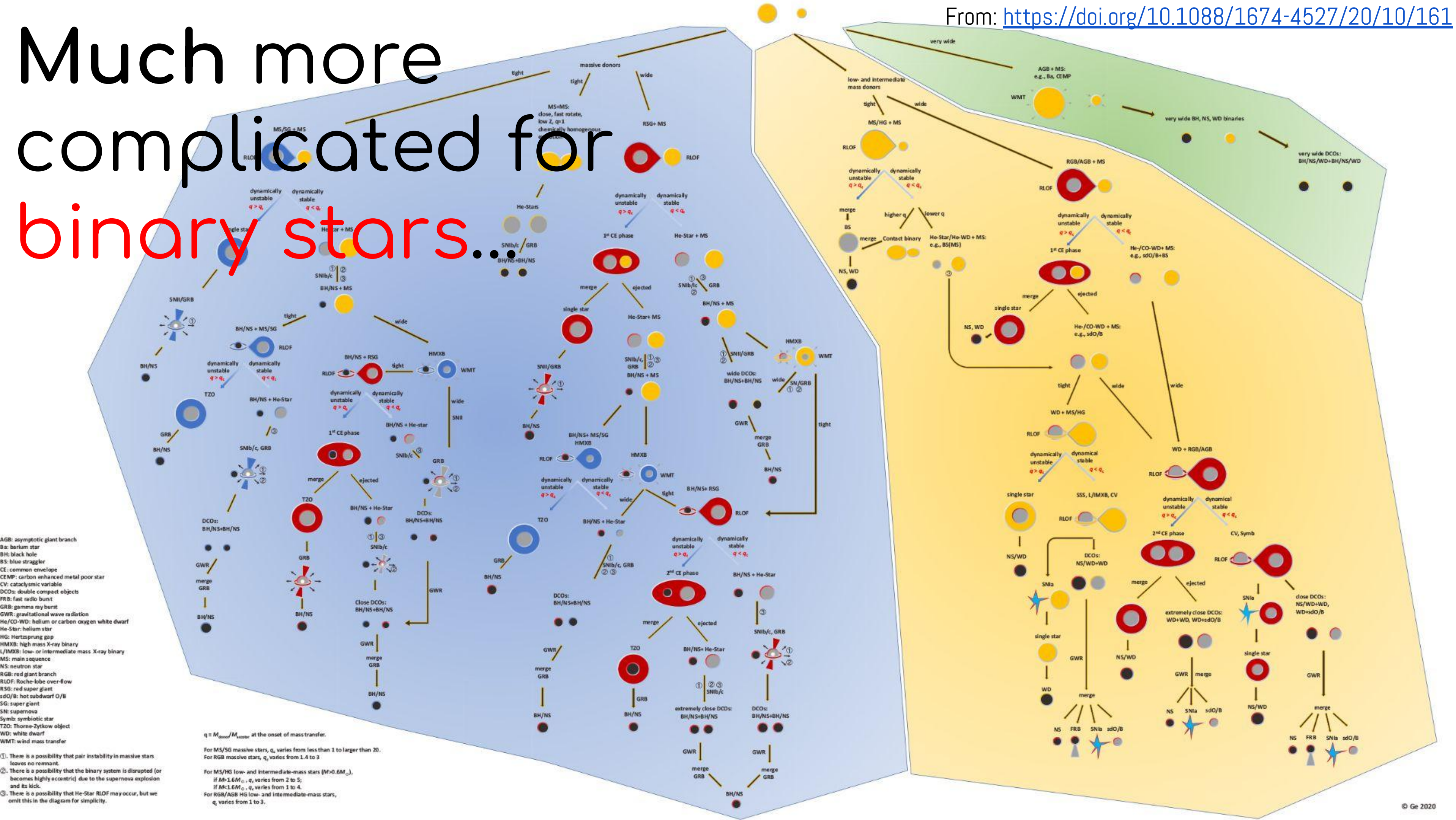
STAR-FORMING CLOUDS
MASS
Protostar
More than 25M$_\odot$ main sequence star
Supergiant
Supernova
Black hole
Protostar
8 to 25M$_\odot$ main sequence star
Giant star
Supergiant
Supernova
Neuron star
Protostar
0.4 to 8M$_\odot$ main sequence star
Giant star
Red supergiant
Planetary nebula
White dwarf
Protostar
Between 0.08 and 0.4M$_\odot$ main-sequence (red dwarf) star
Protostar
Less than 0.08M$_\odot$ brown dwarf
TIME

In summary: the life and death of 95 % of single stars



From: https://doi.org/10.1088/1674-4527/20/10/161

Much more complicated for binary stars...



How can we make sense of all of this?!

How can we make sense of all of this?!

⇒ By characterising different types of systems and trying to model them!

Some of the things binaries can do

HD265435: a close binary that will go supernova

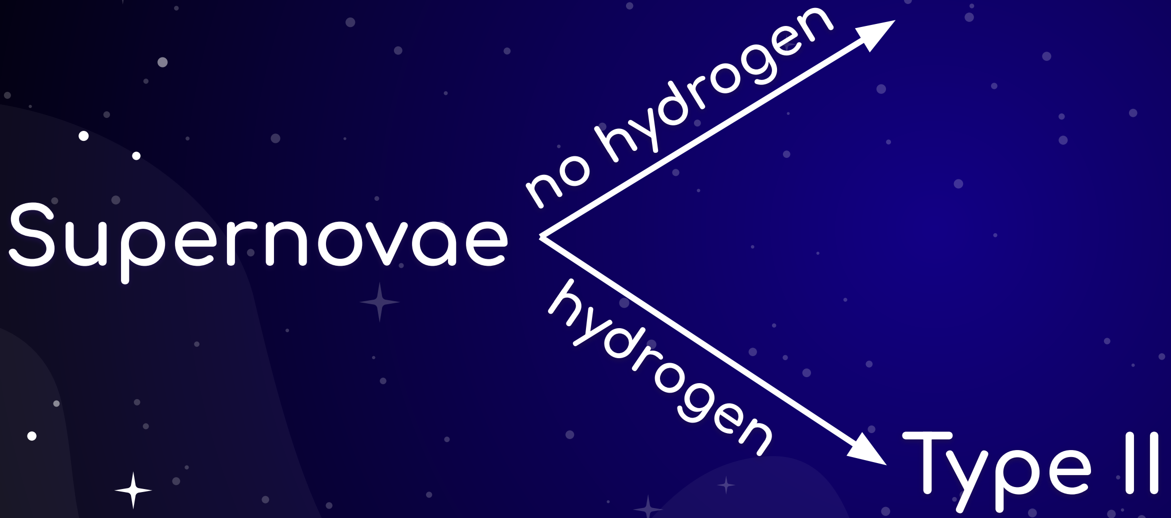
J0240+1952: the fastest spinning white dwarf

Supernovae

Supernovae

hydrogen →

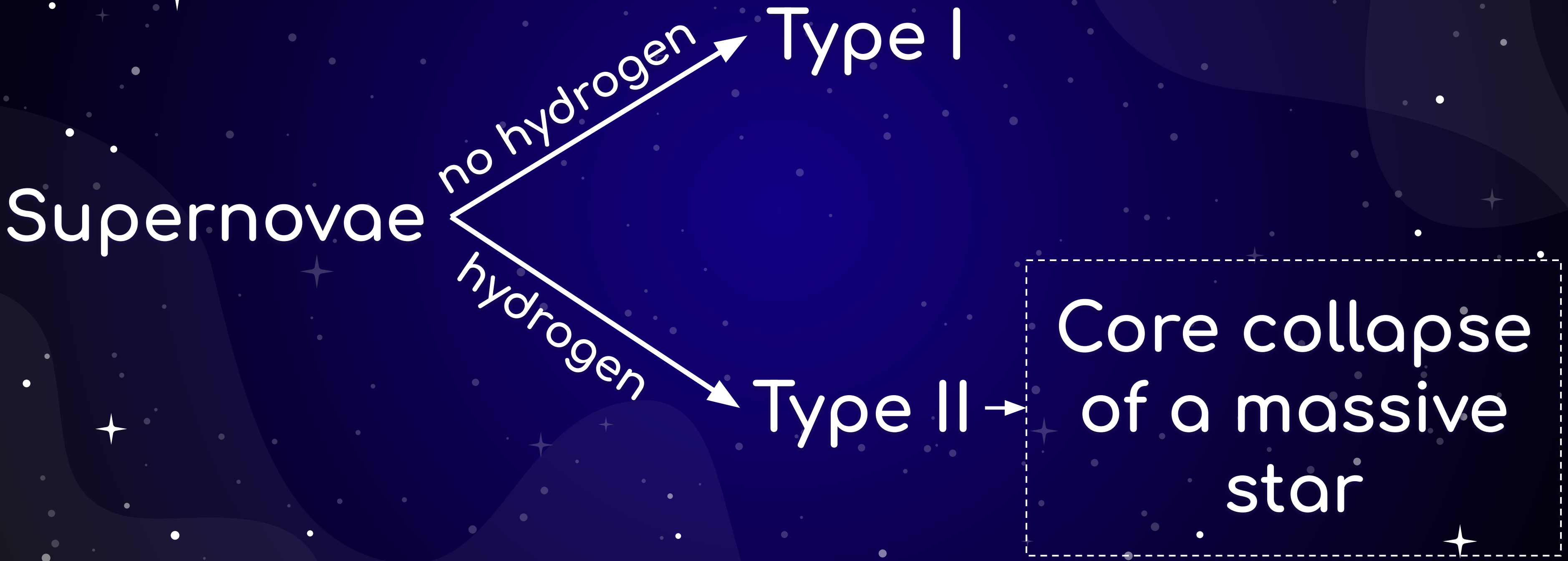
Supernovae


Supernovae
no hydrogen
hydrogen
Type II

Supernovae

no hydrogen →

hydrogen → Type II → Core collapse of a massive star


Supernovae
no hydrogen
Type I
hydrogen
Type II
Core collapse of a massive star

Supernovae

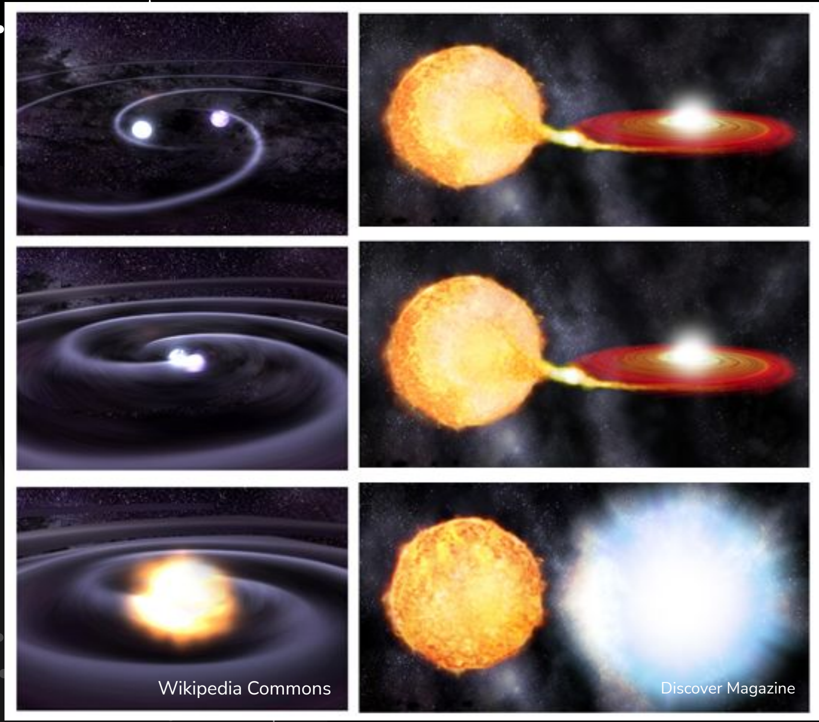
- no hydrogen → Type I → Different types, different origins.
- hydrogen → Type II → Core collapse of a massive star

Supernovae

no hydrogen → Type I → Type Ia = white dwarf detonation

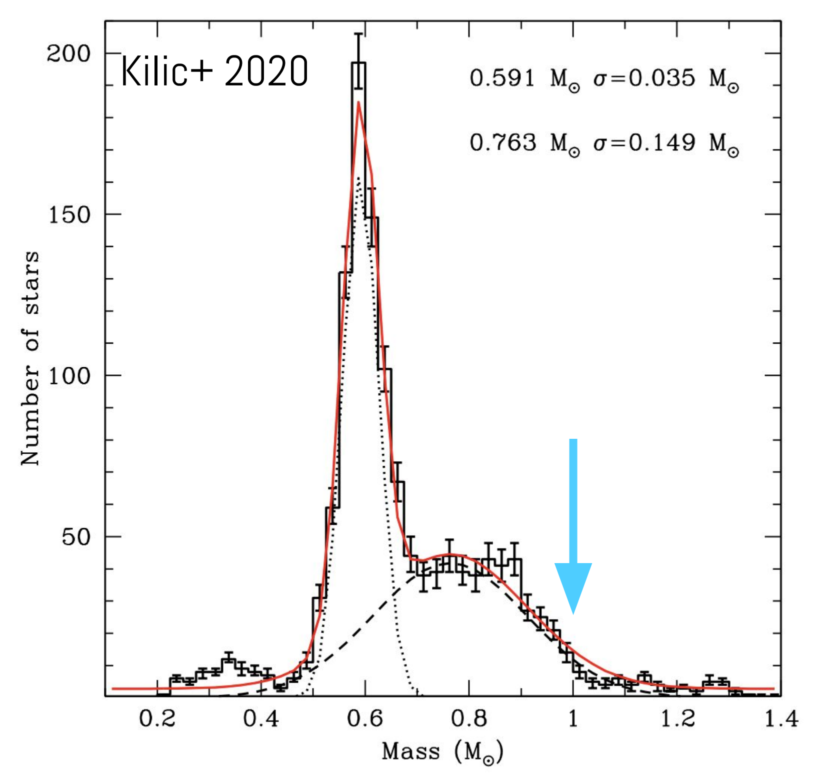
hydrogen → Type II → Core collapse of a massive star

SN Ia = white dwarf reaches Chandrasekhar limit



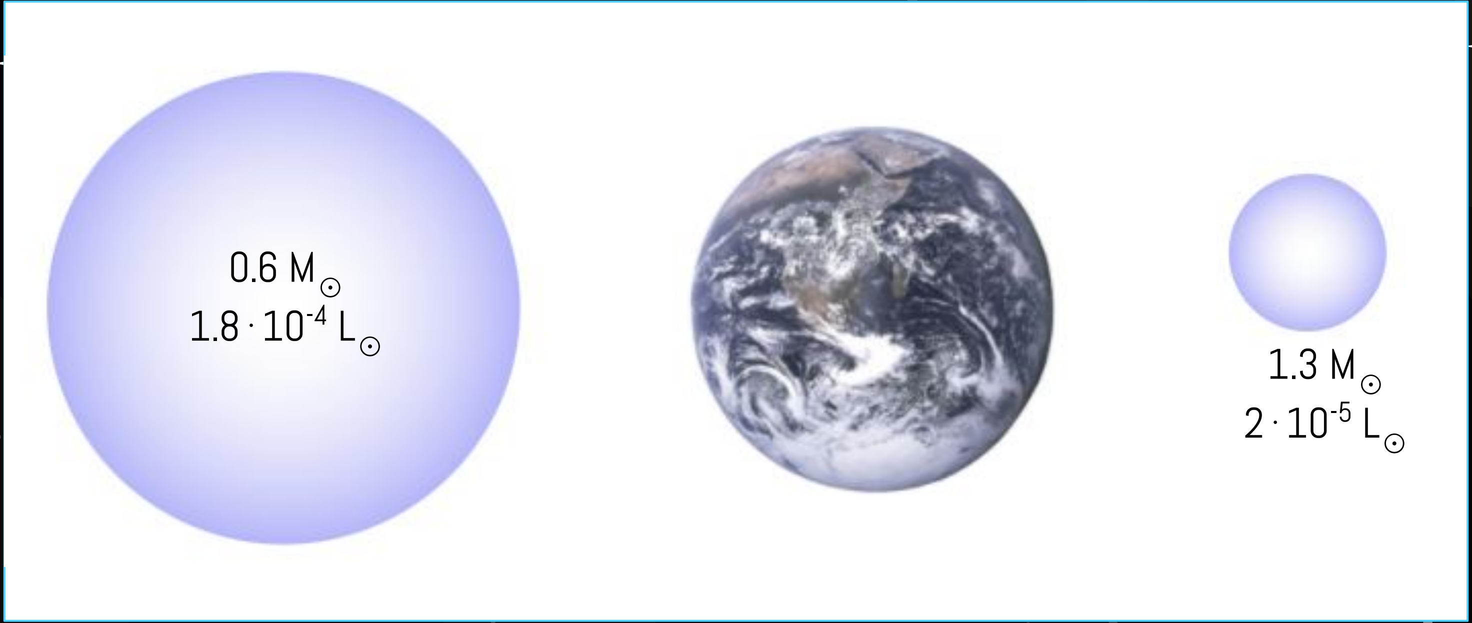
- Double degenerate vs. single degenerate
- Allow us to measure the expansion of the Universe
  (Nobel Prize in Physics 2011)
- Galactic SN rate = ~1 every 1000 years

...but where are the progenitors?

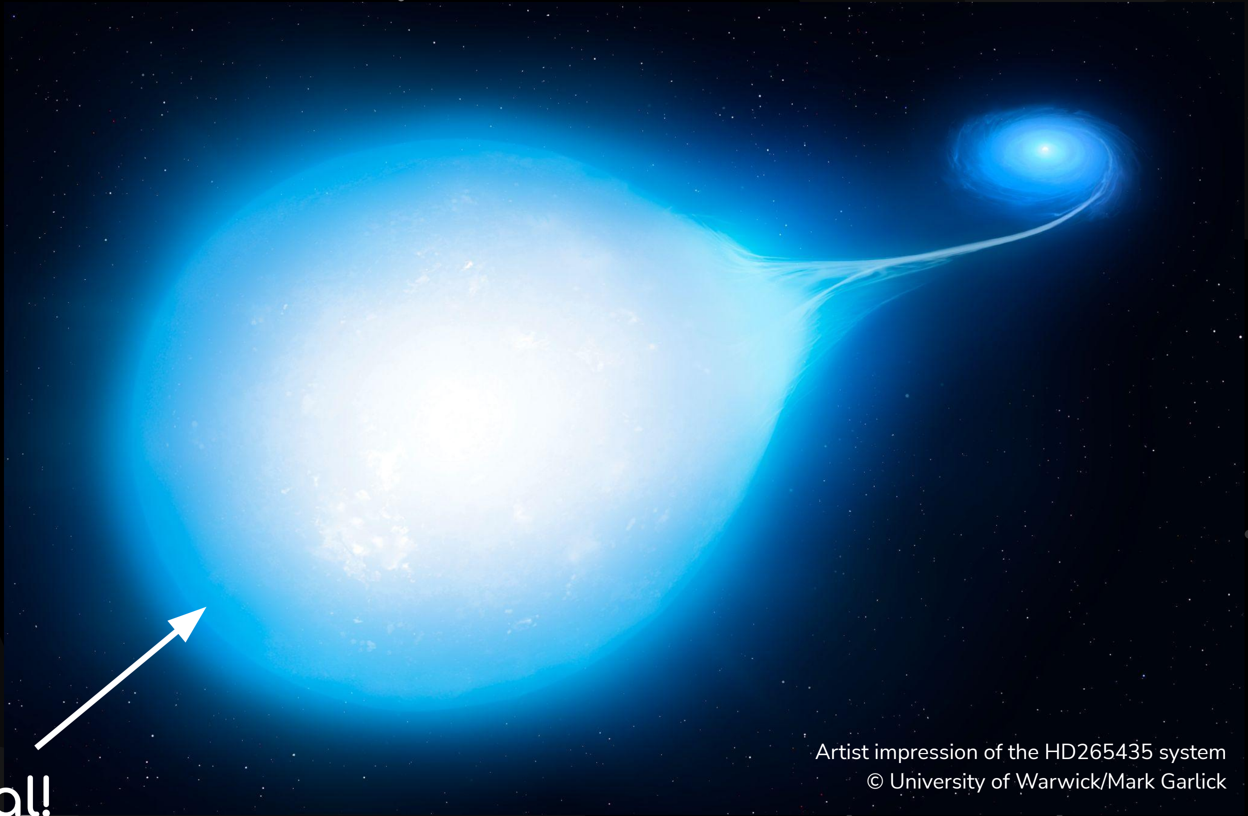


- Single degenerate:
  - Massive white dwarfs are rare, and often produced by mergers
- Double degenerate:
  - dedicated survey found only two possible progenitors (Napiwotzki+ 2020)
- Double degenerate SN rate = 1 every 100,000 years

Massive white dwarfs are faint, challenging to directly detect...



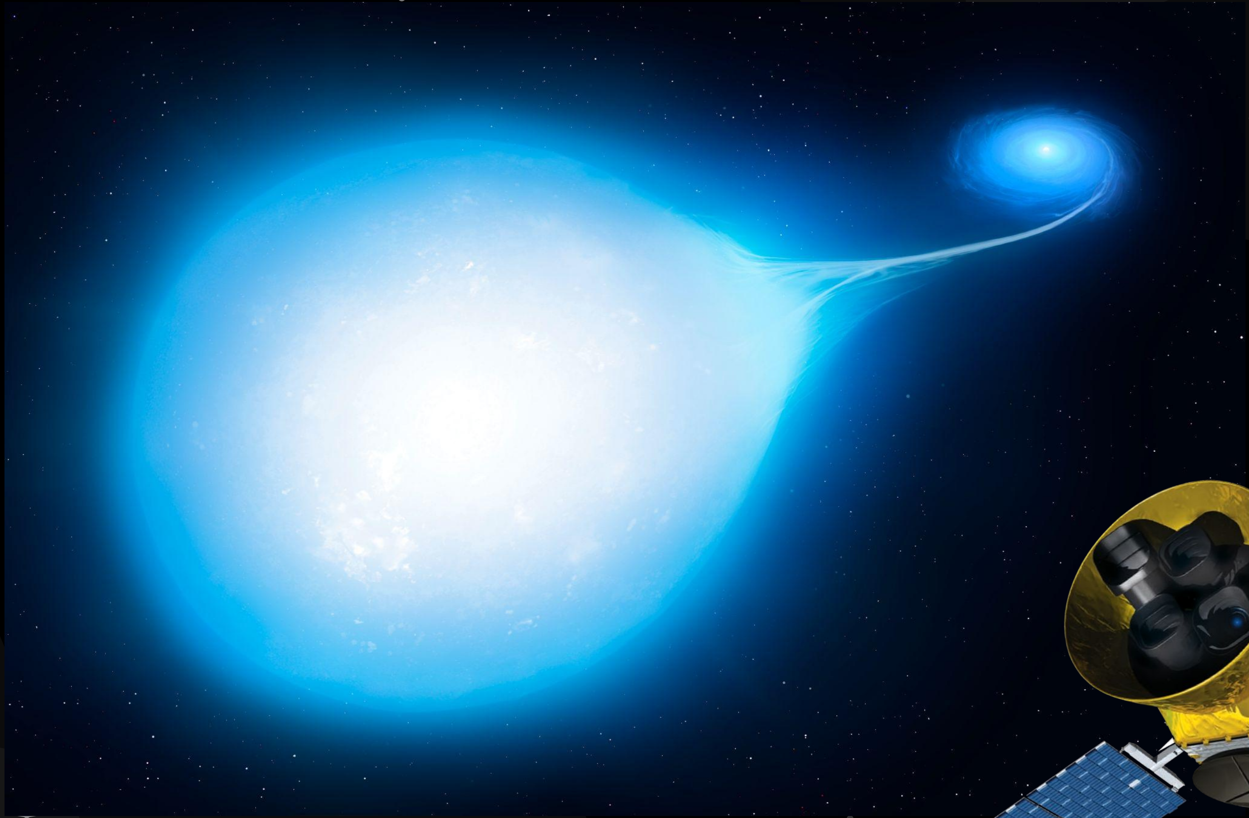
...but the high gravity will tidally distort the companion.



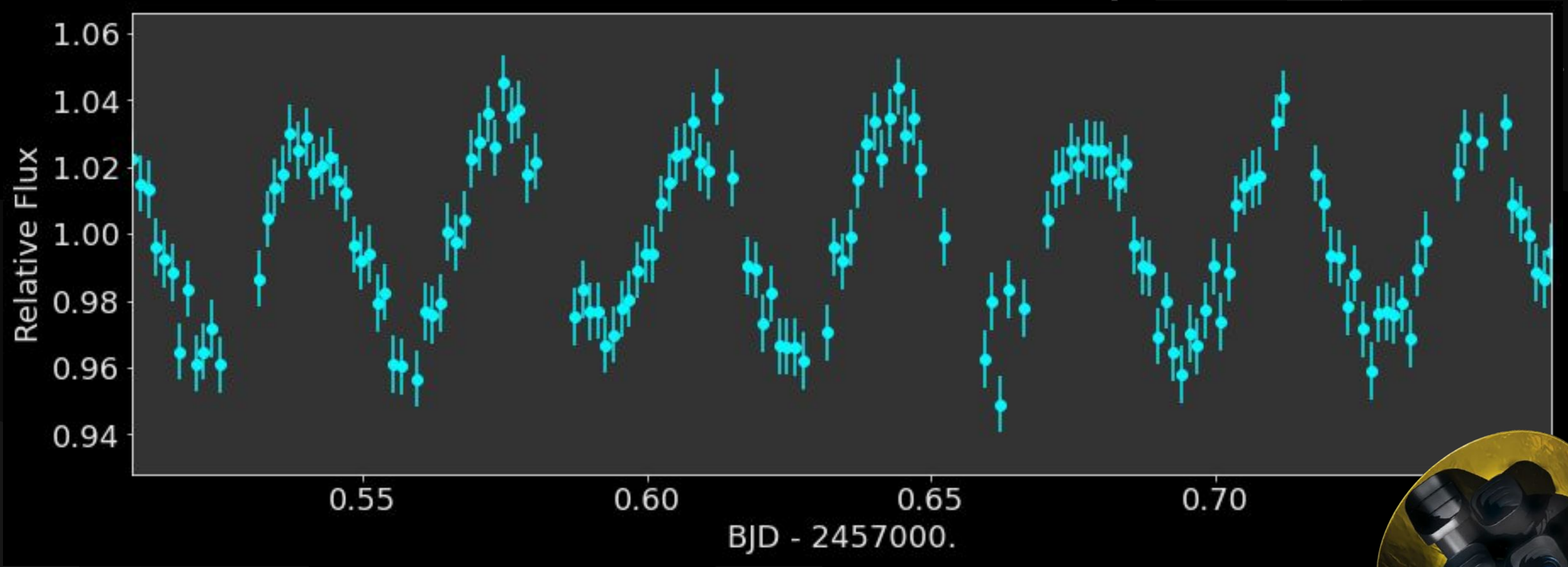
Artist impression of the HD265435 system
© University of Warwick/Mark Garlick

Not spherical!

...but the high gravity will tidally distort the companion.



Tidal distortion => variability in the observed flux with time



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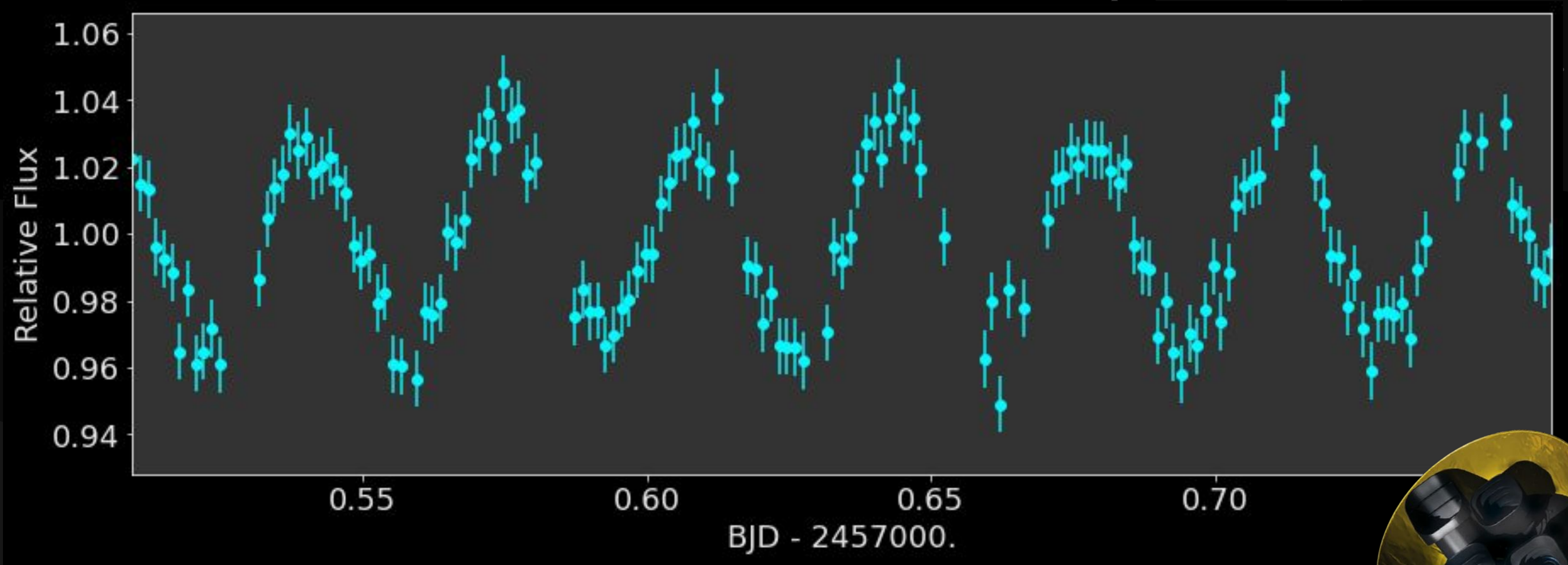
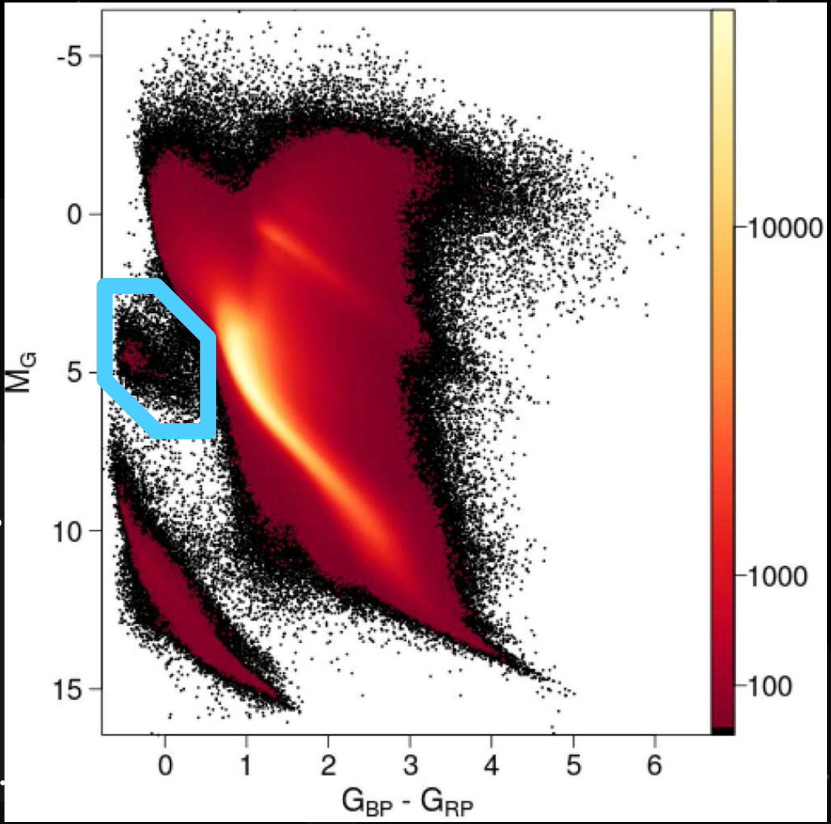


We can find supernova progenitors by searching for short-period ellipsoidal variables!

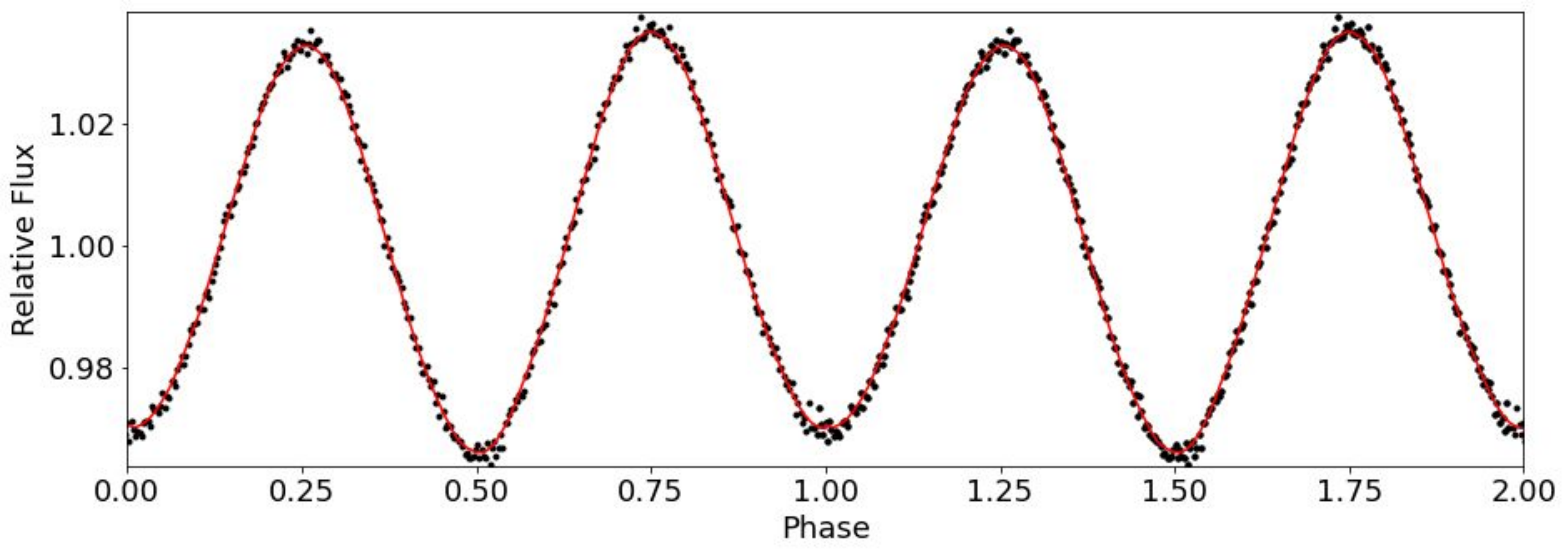
Where should we be looking?

Hot subdwarfs: the ideal companions!

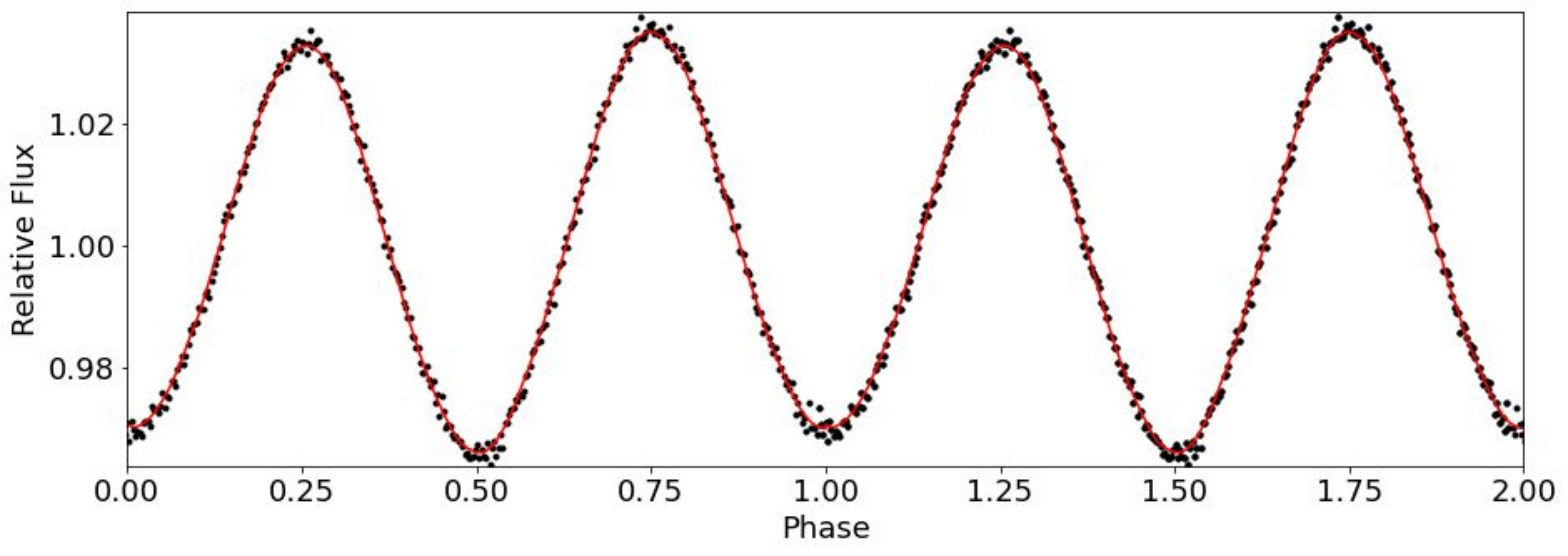


- Formed by binary evolution, often found in close binaries.
  (Han+ 2002, 2003; Maxted+ 2001, Pelisoli+ 2020)
- Typically bright enough for us to detect the light variations.

After looking at thousands of light curves, this one came up...



The light curve of HD265435



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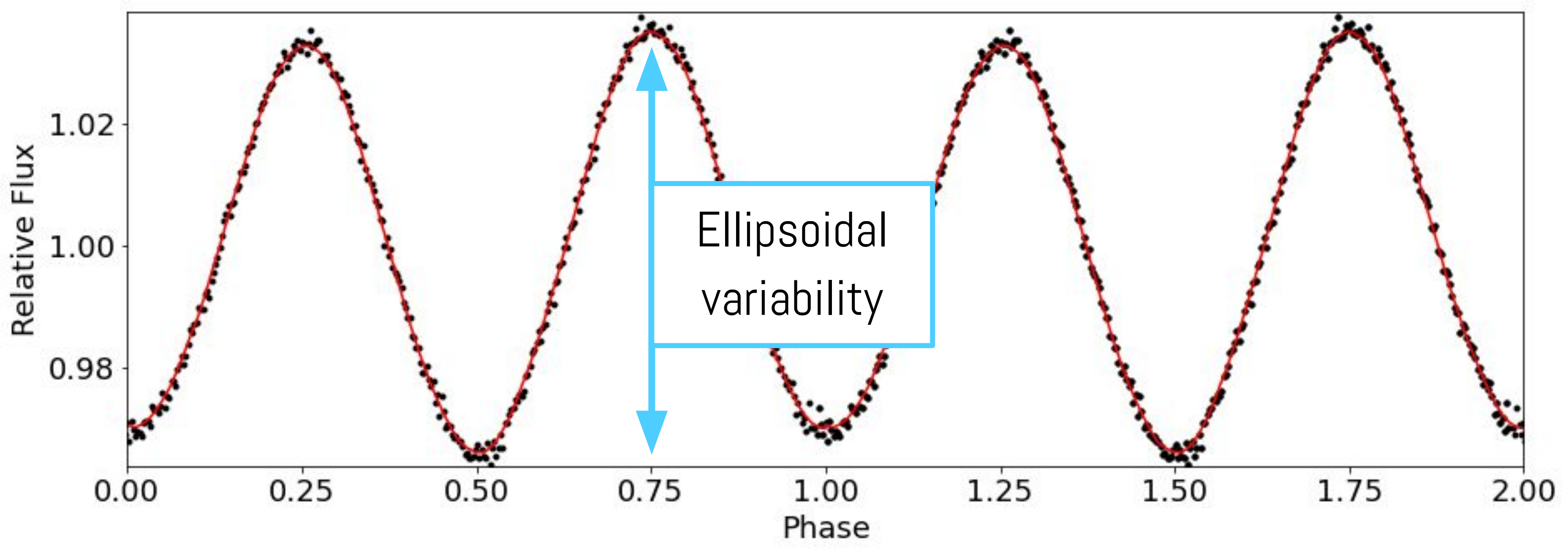
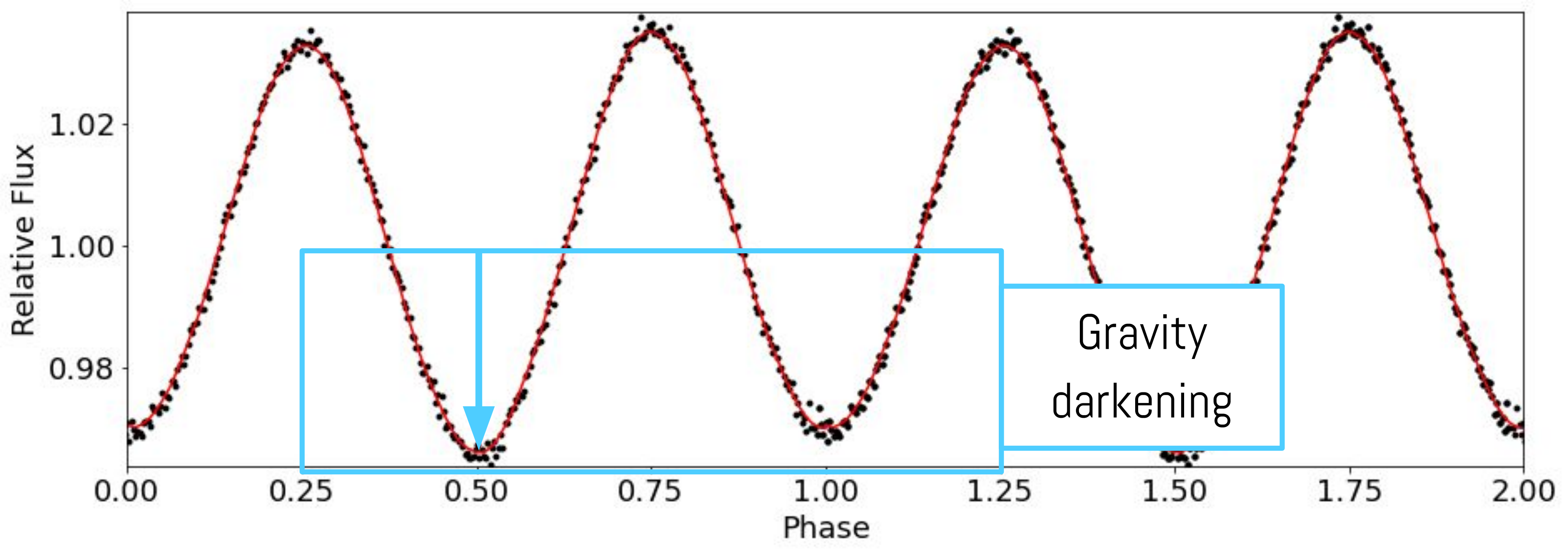
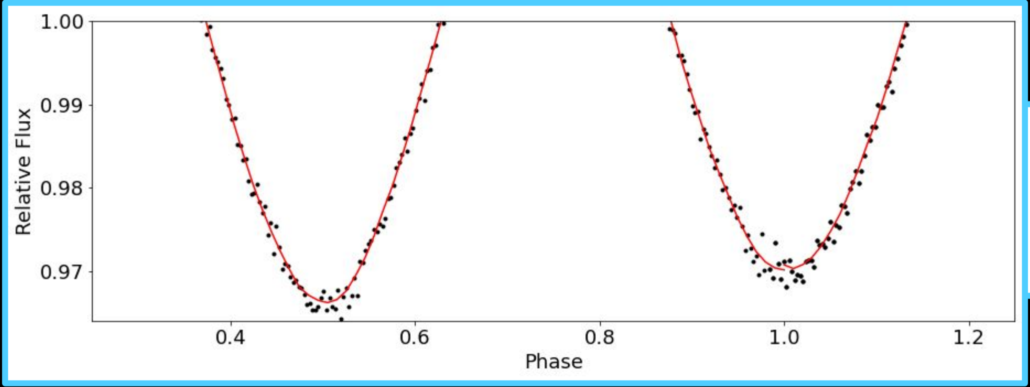


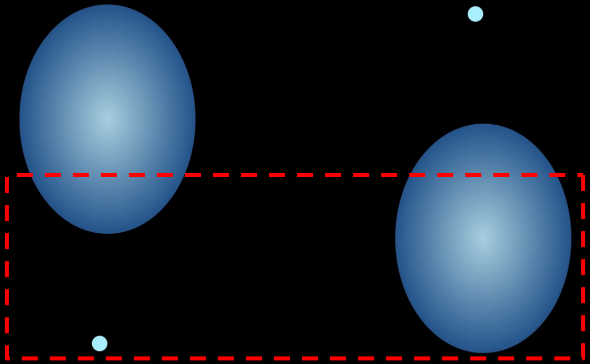
The light curve of HD265435



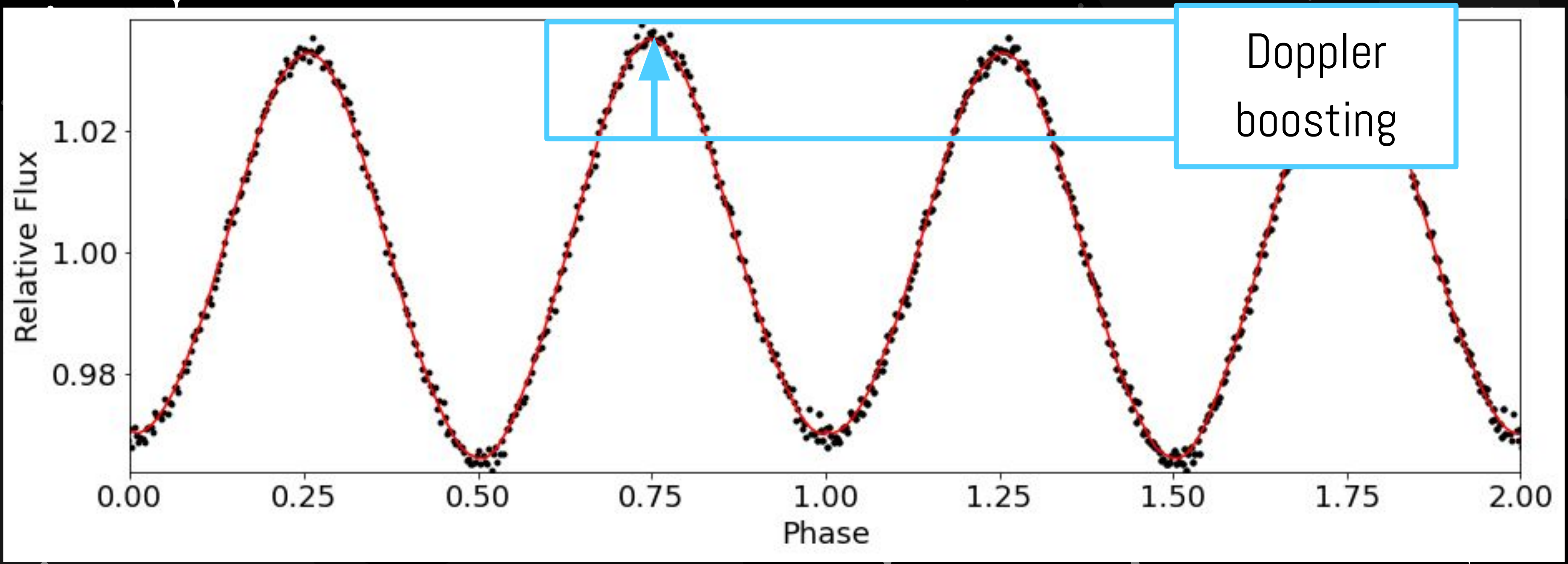
The light curve of HD265435



Gravity darkening



The light curve of HD265435



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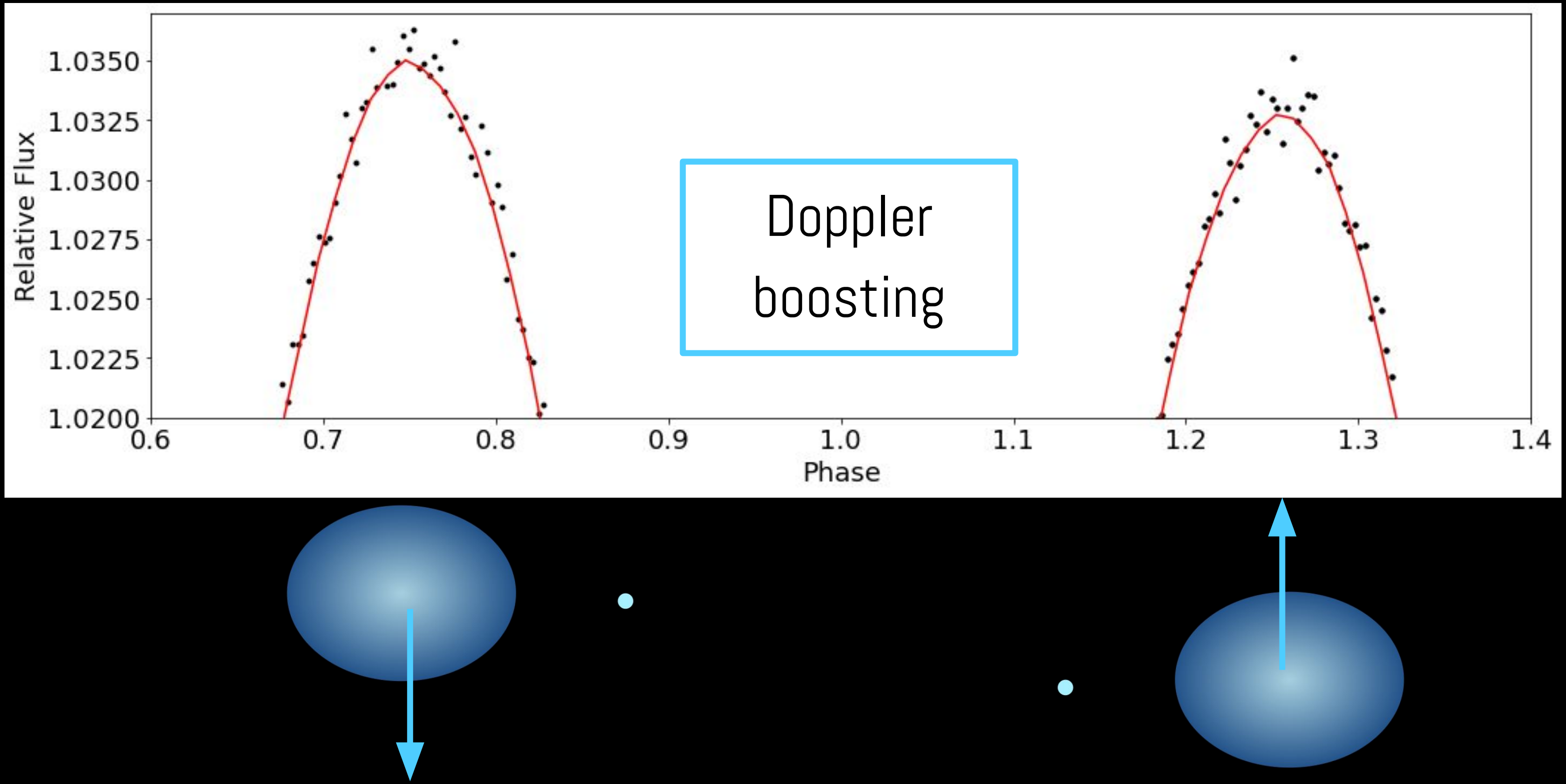
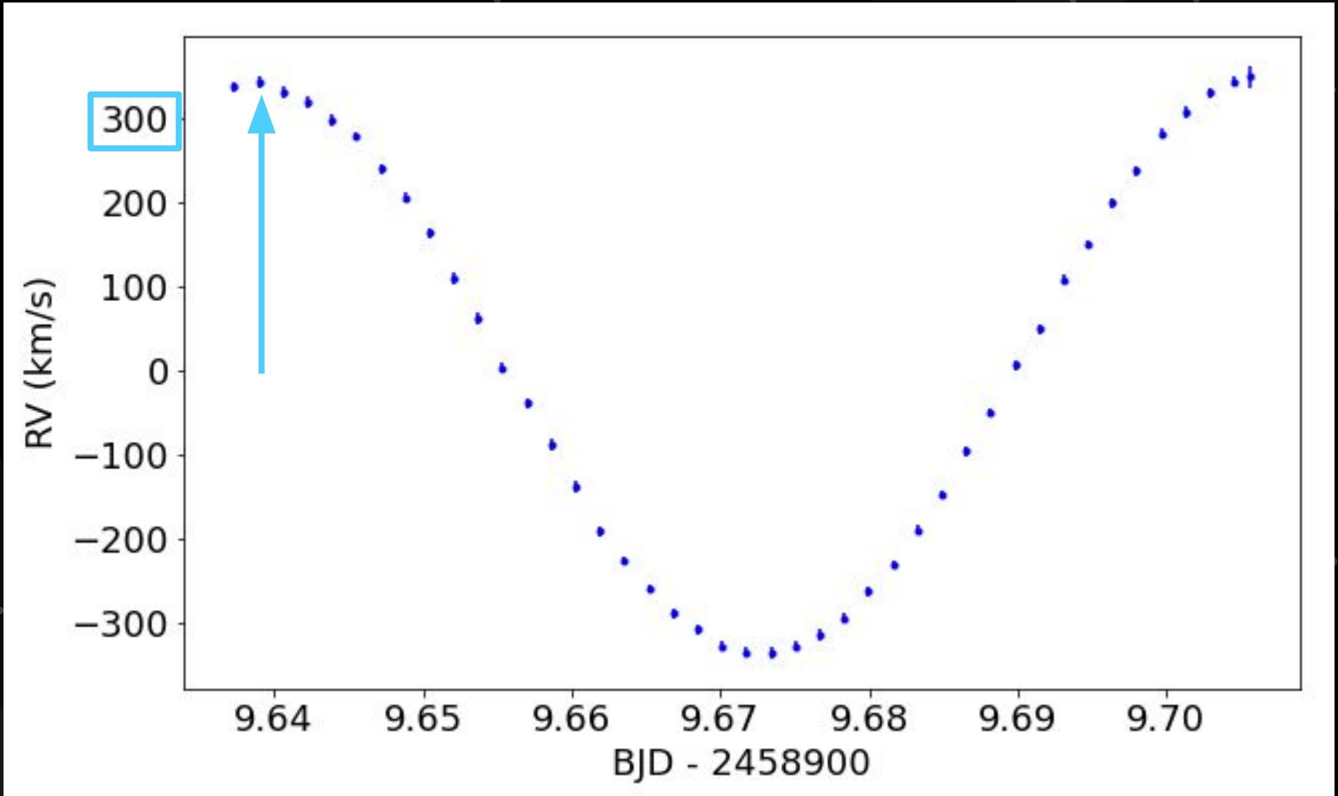
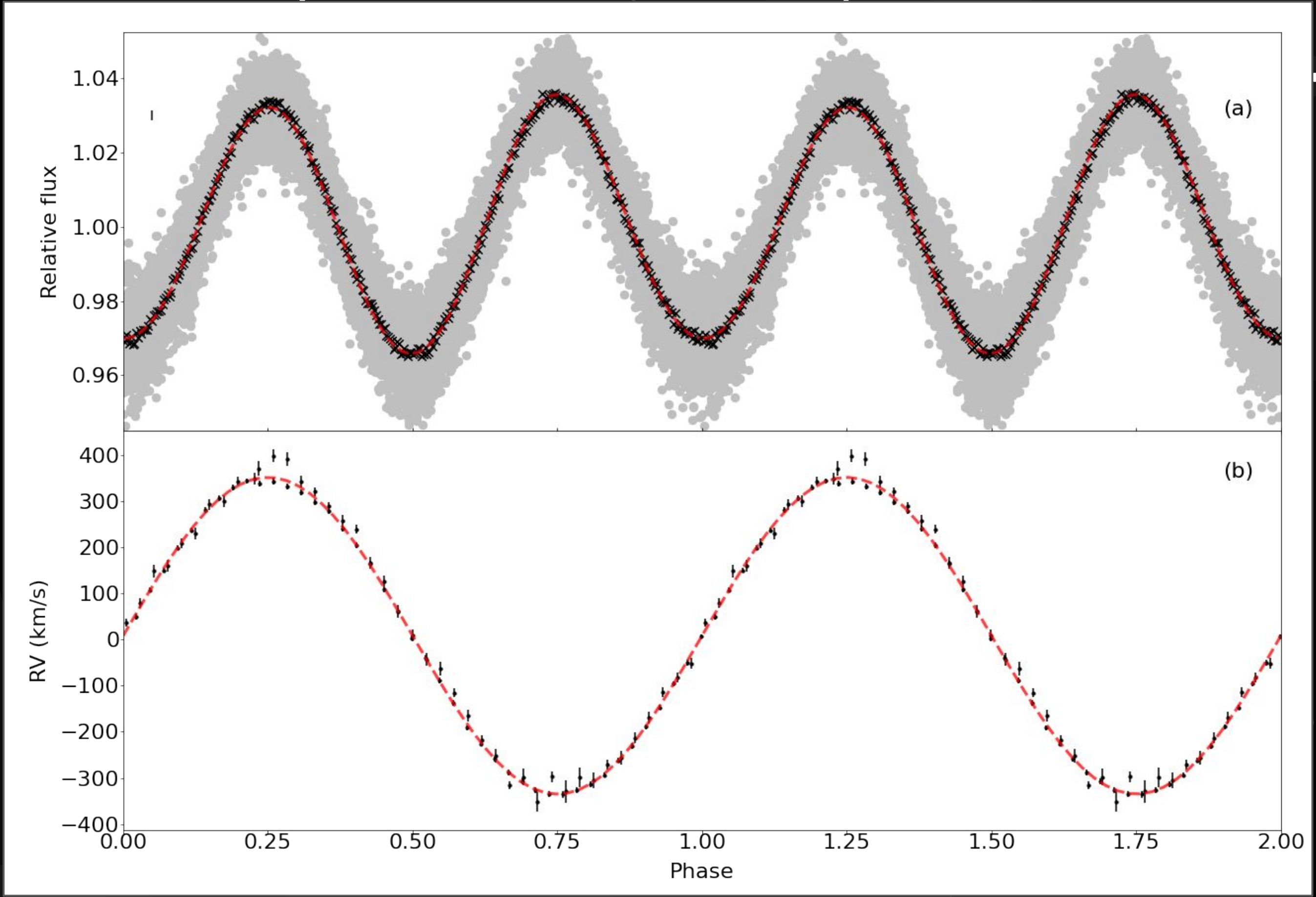


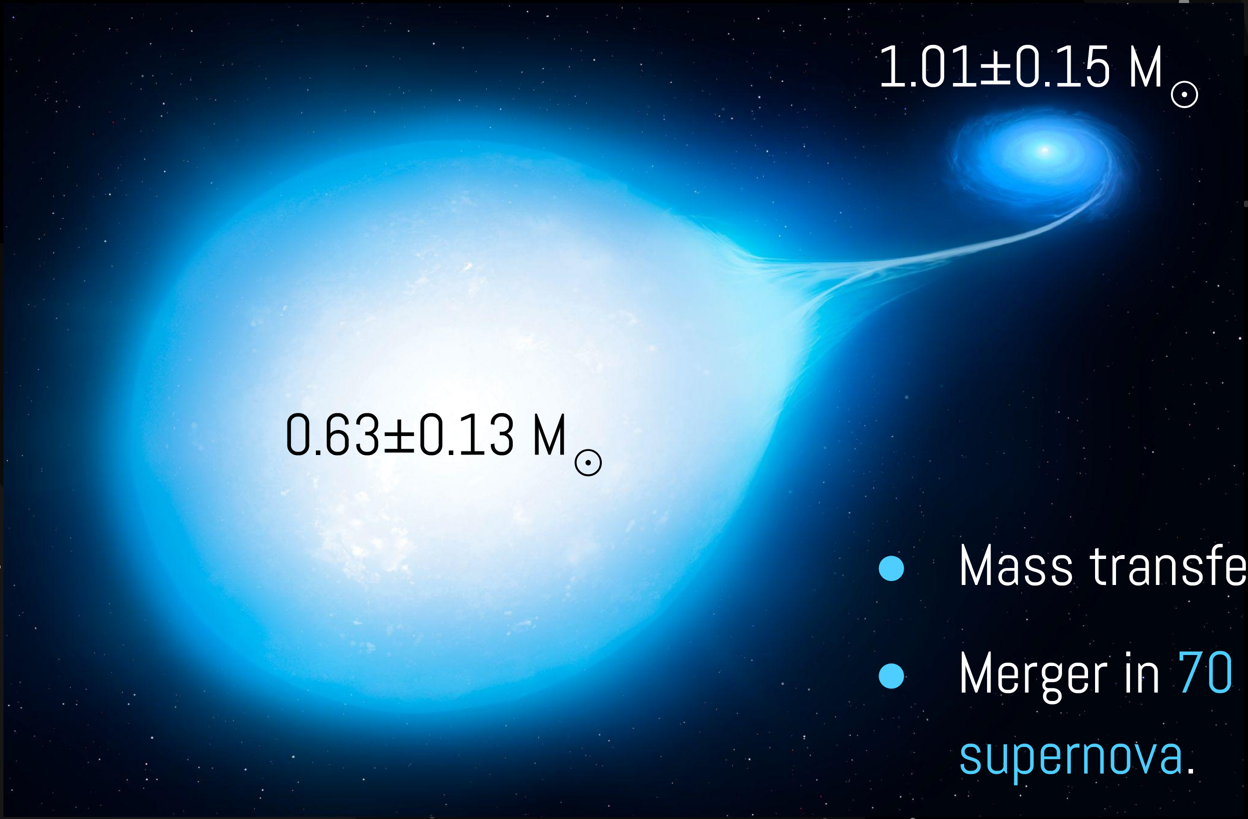
The velocity of HD265435





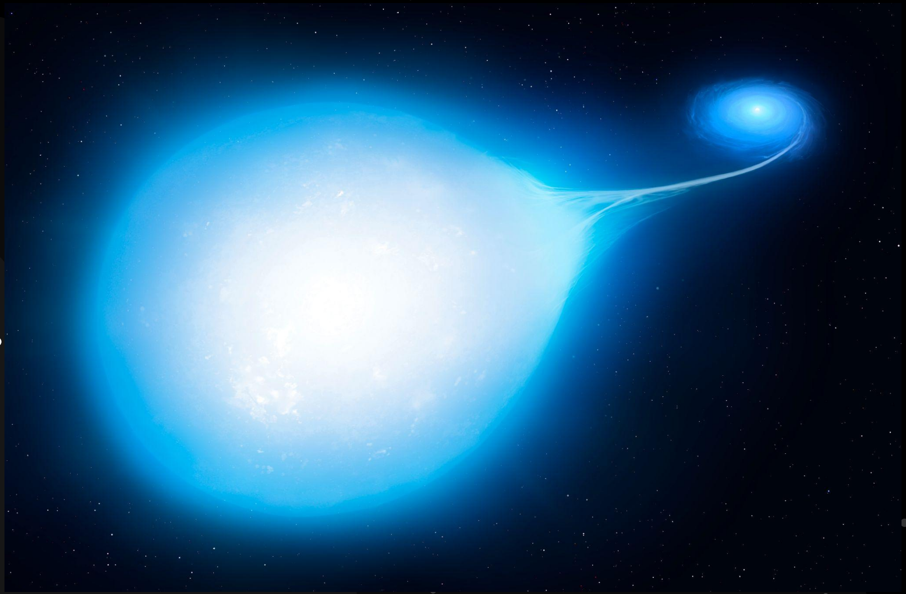
HD265435: light curve + radial velocity + modelling

System properties & evolution



- Mass transfer will begin in 30 Myr.
- Merger in 70 Myr leading to a supernova.

And what can this system teach us?



- Combined with other data about hot subdwarfs, we can derive how much this type of system contributes to the SN Ia rate: ~1 every 100,000 years.

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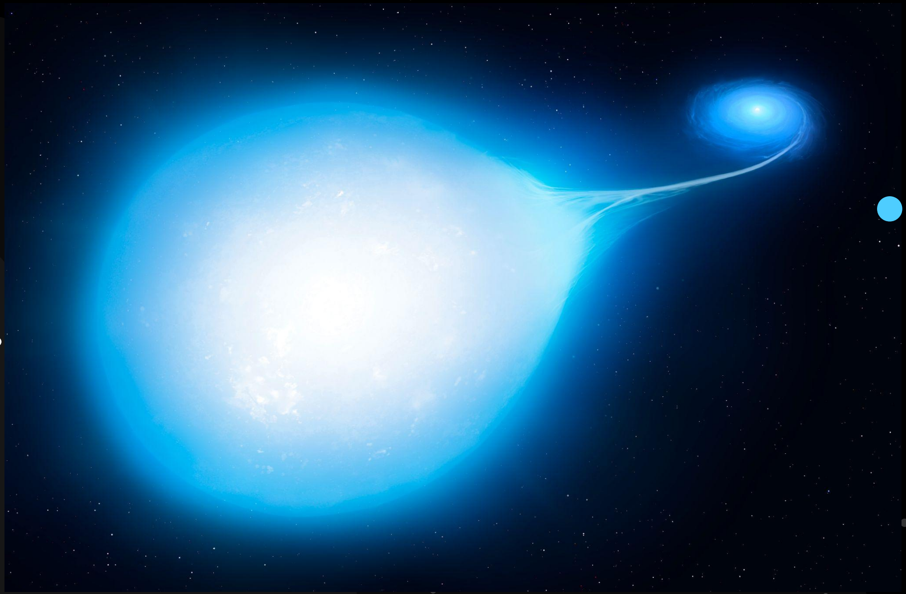

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- Same order as the contribution from classical white dwarf + white dwarf!

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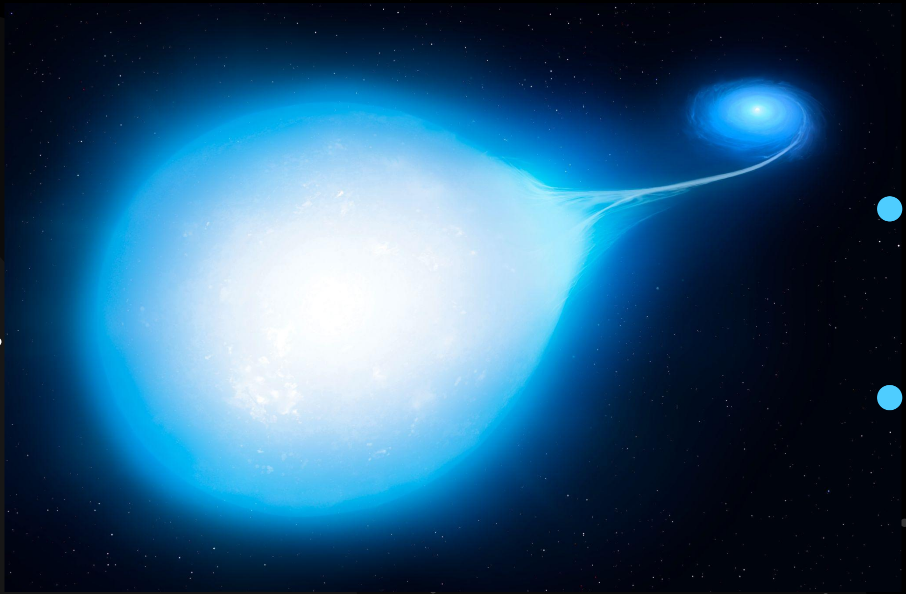
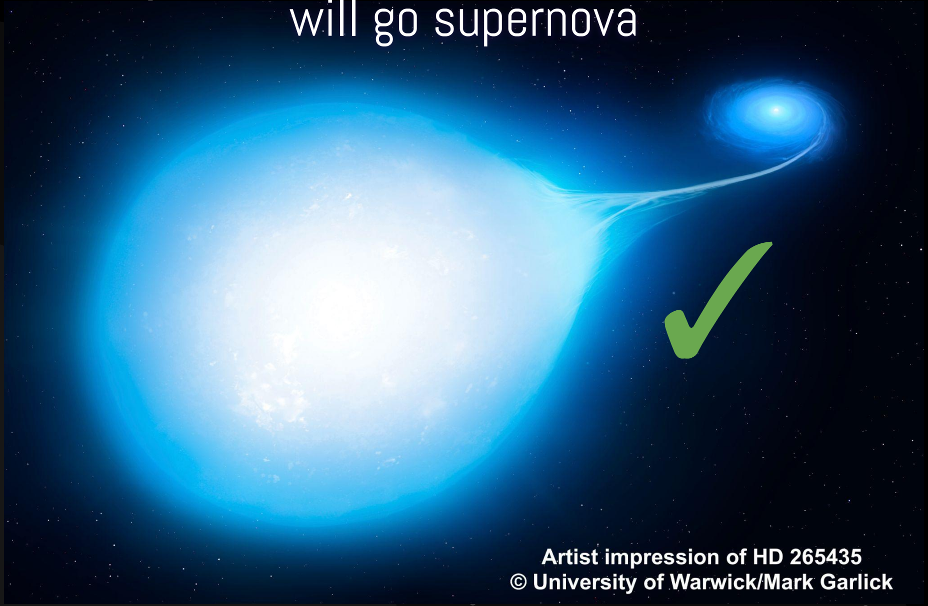


- Combined with other data about hot subdwarfs, we can derive how much this type of system contributes to the SN Ia rate: ~1 every 100,000 years
- Same order as the contribution from classical white dwarf + white dwarf!
- But still much lower than the Galactic rate...

Some of the things binaries can do

HD265435: a close binary that will go supernova

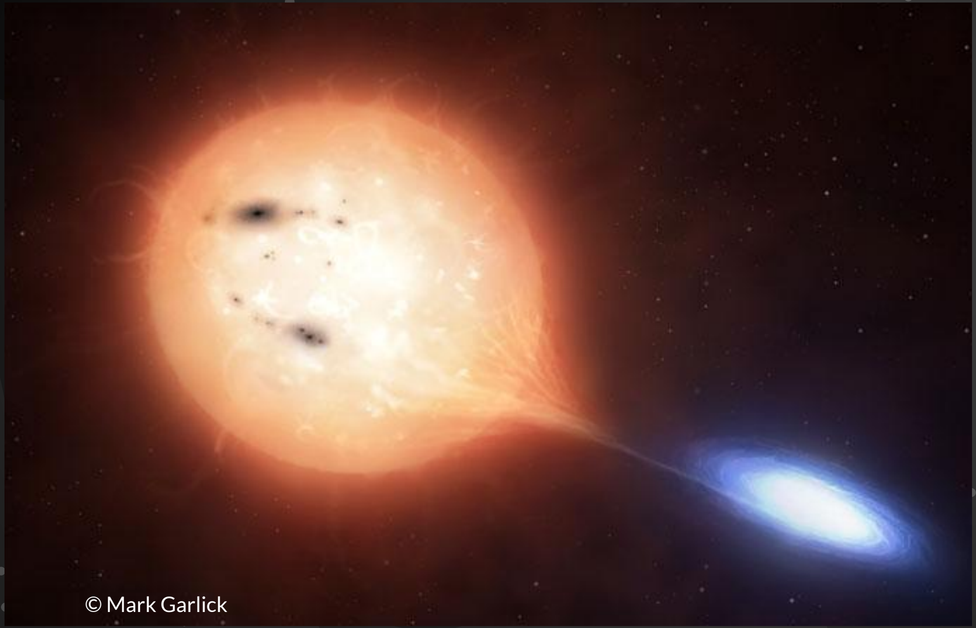


Artist impression of HD 265435
© University of Warwick/Mark Garlick

J0240+1952: the fastest spinning white dwarf

Artist impression of J0240+1952
© University of Warwick/Mark Garlick

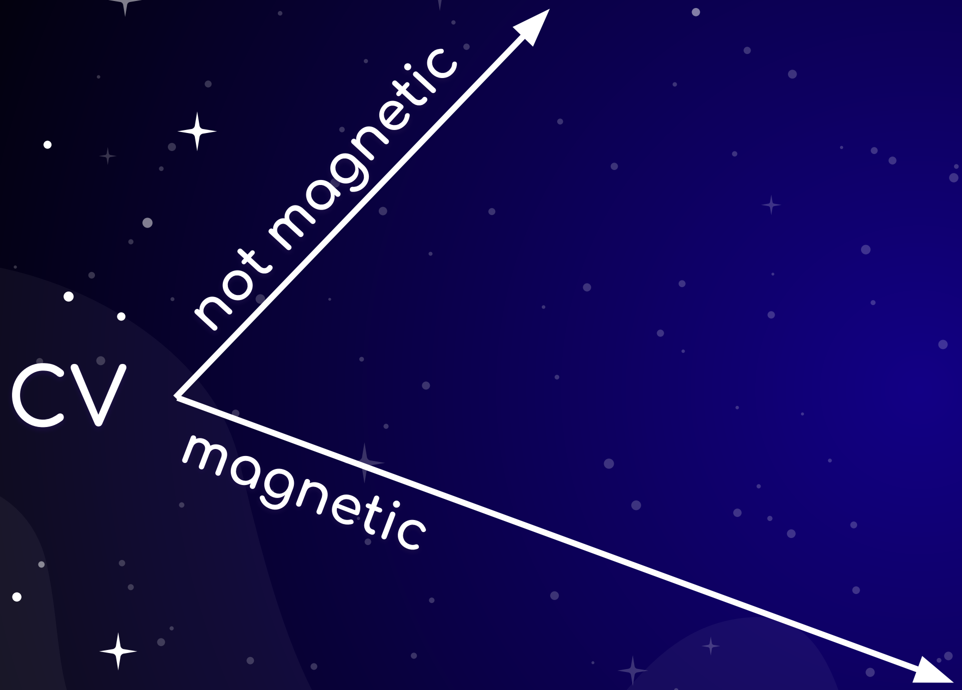
Accreting white dwarfs can have a (somewhat) peaceful life: cataclysmic variables (CVs)



CV = white dwarf accretes mass from a main sequence companion.

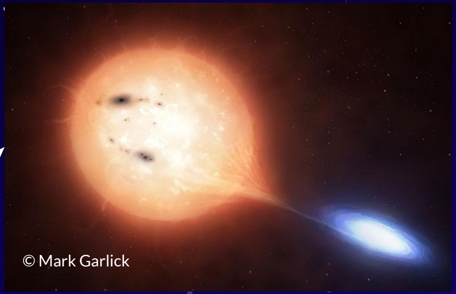
CV


CV
not magnetic


CV
not magnetic
magnetic

CV

not magnetic



Accretion occurs via a disc extending to the white dwarf's equator.

magnetic

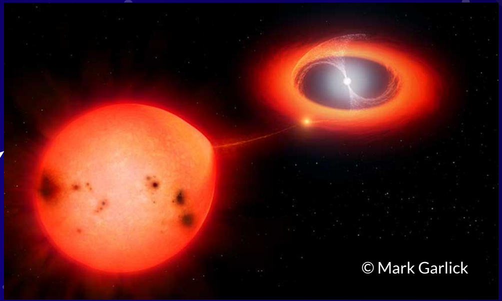
CV

not magnetic

Accretion occurs via a disc extending to the white dwarf's equator.

magnetic

Intermediate field



Intermediate polars (IPs)

Inner accretion disc is disrupted.

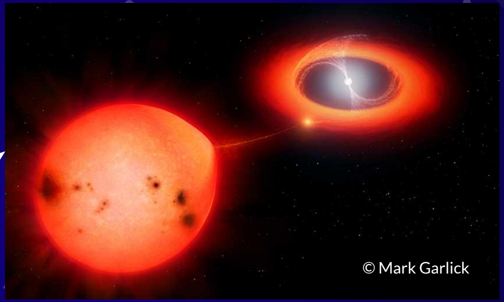
CV

not magnetic

Accretion occurs via a disc extending to the white dwarf's equator.

magnetic

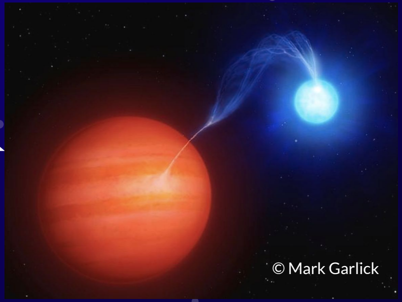
Intermediate field



Intermediate polars (IPs)

Inner accretion disc is disrupted.

Strong field



Polars

Disk fully disrupted, accretion occurs along magnetic field lines.

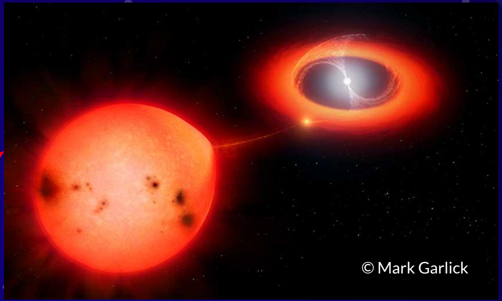
CV

not magnetic

Accretion occurs via a disc extending to the white dwarf's equator.

magnetic

Intermediate field



Intermediate polars (IPs)

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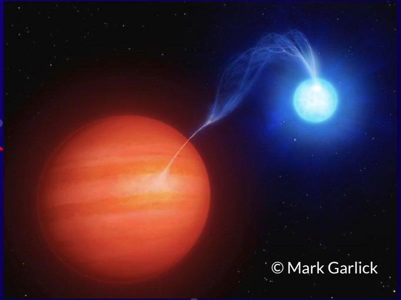
Strong field

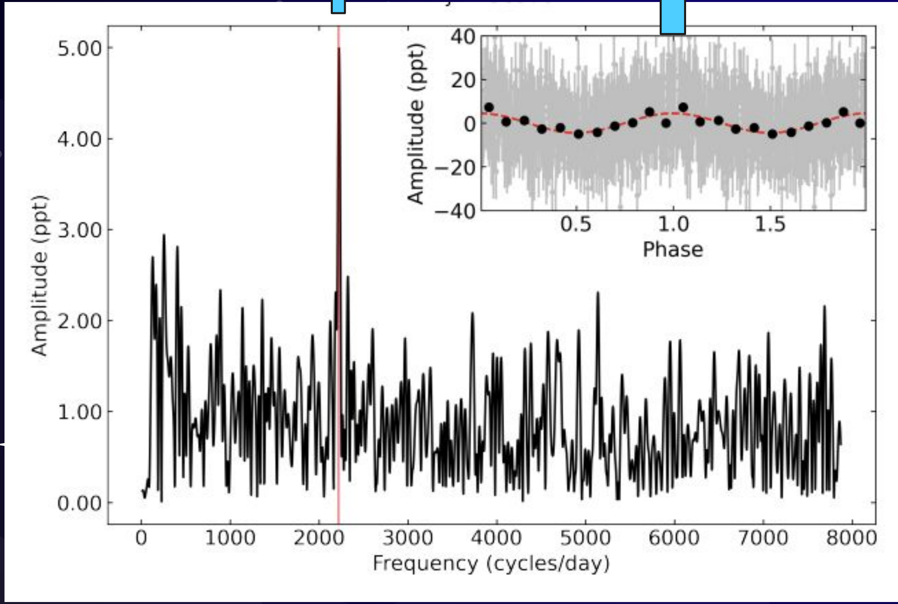


Polars

Disk fully disrupted, accretion occurs along magnetic field lines.

Magnetic CVs reveal their rotation period in their light curves

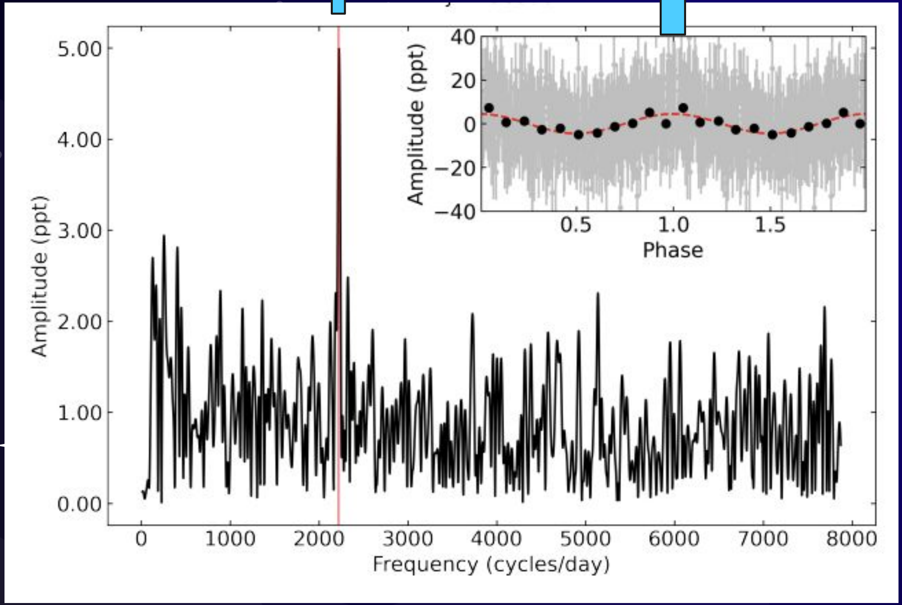
Spin period



Modulation caused by accretion-induced spot.

Magnetic CVs reveal their rotation period in their light curves

Spin period



Modulation caused by accretion-induced spot.

Opportunity to understand the interplay between different mechanisms acting during binary interaction, which can cause spin-up or spin-down torques.

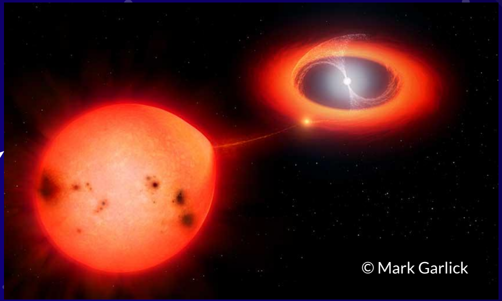
CV

not magnetic

Accretion occurs via a disc extending to the white dwarf's equator.

magnetic

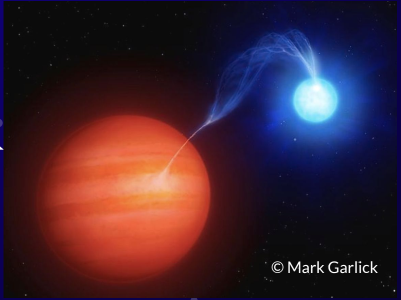
Intermediate field



Intermediate polars (IPs)

Inner accretion disc is disrupted.

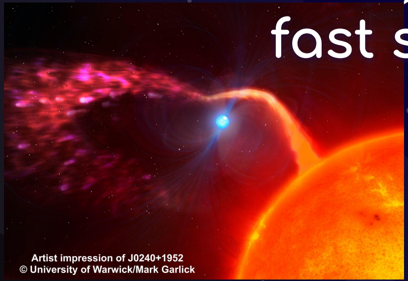
Strong field



Polars

Disk fully disrupted, accretion occurs along magnetic field lines.

+ fast spin

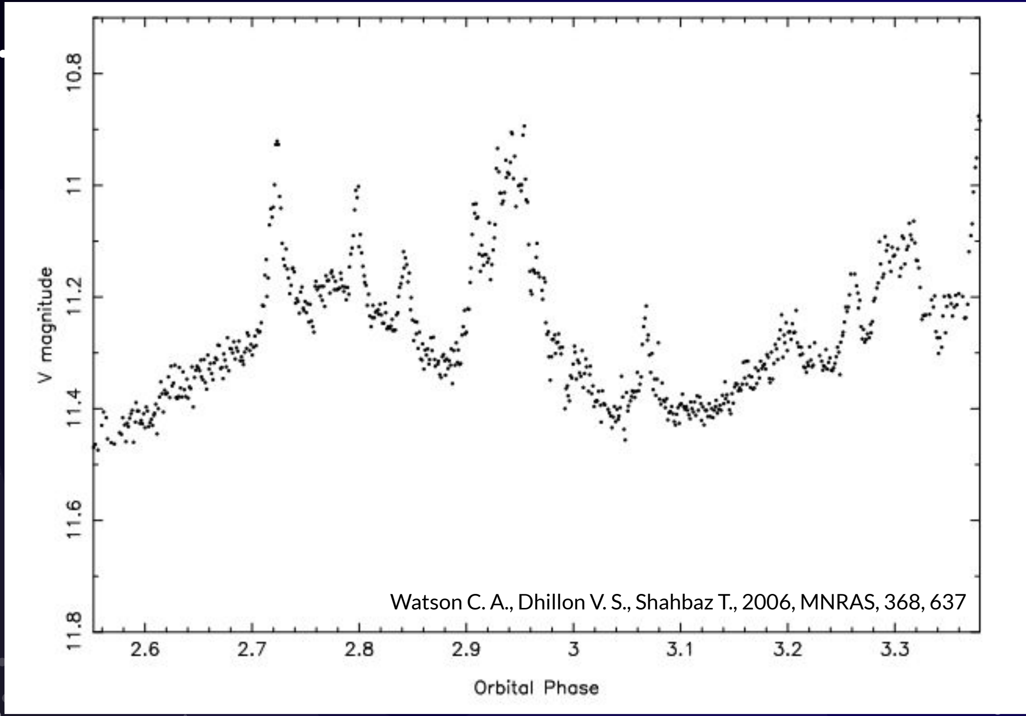


Artist impression of J0240+1952
© University of Warwick/Mark Garlick

Magnetic propeller

Material is ejected from the system.

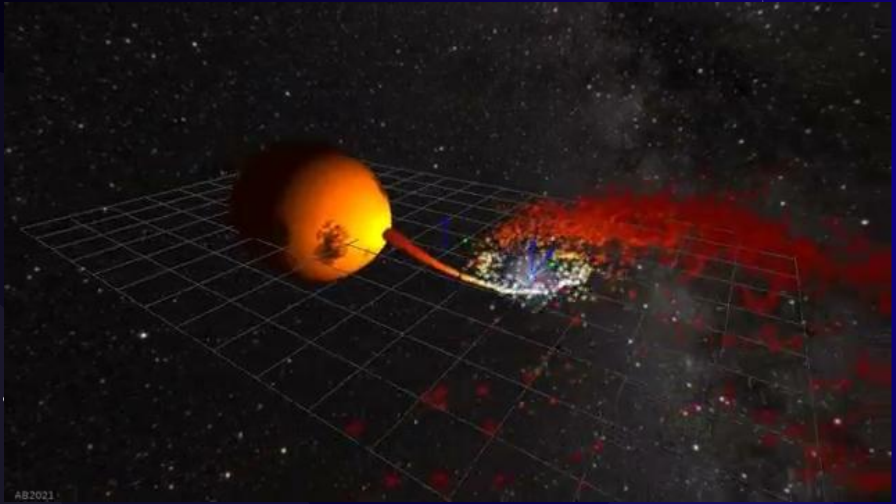
AE Aqr: the only magnetic propeller (until last year)



Watson C. A., Dhillon V. S., Shahbaz T., 2006, MNRAS, 368, 637

- Known as a CV since 1943!
- Shows very strong irregular flaring in the light curve.

AE Aqr: the only magnetic propeller (until last year)



Animation by Andy Beardmore (U. Leicester)

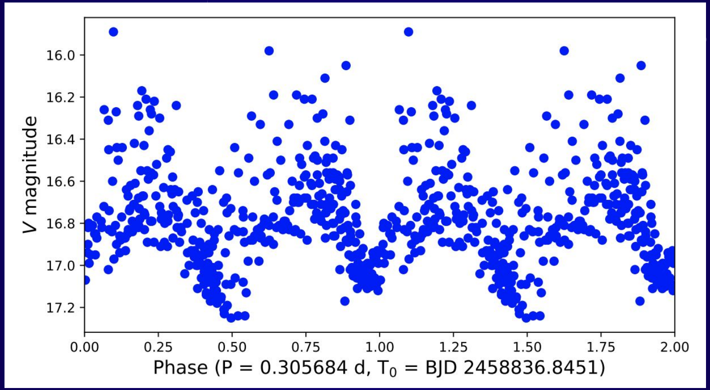
Very short (33 sec) spin period discovered in 1979.

Model: the majority of the mass transferred from the secondary star is ejected as it interacts with the white dwarf's magnetic field.

Rotation rate is reducing on a timescale of ~10 million years.

LAMOST J024048.51+195226.9: very similar properties to AE Aqr

- Thorstensen (2020) noted flaring activity.



- Garnavich+ (2021) confirmed material was being ejected.

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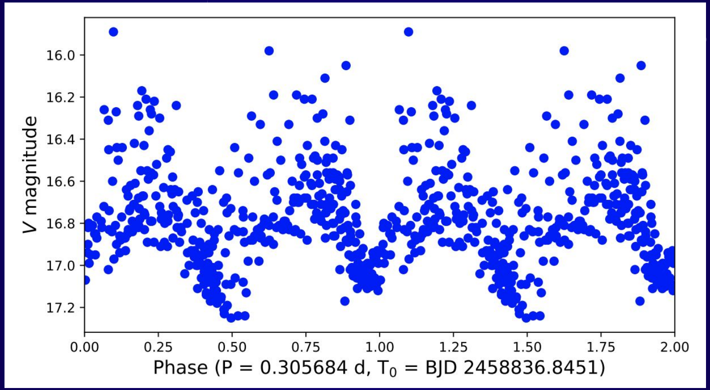
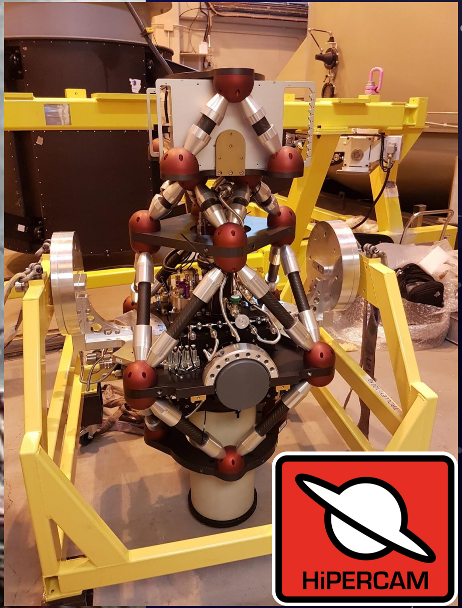


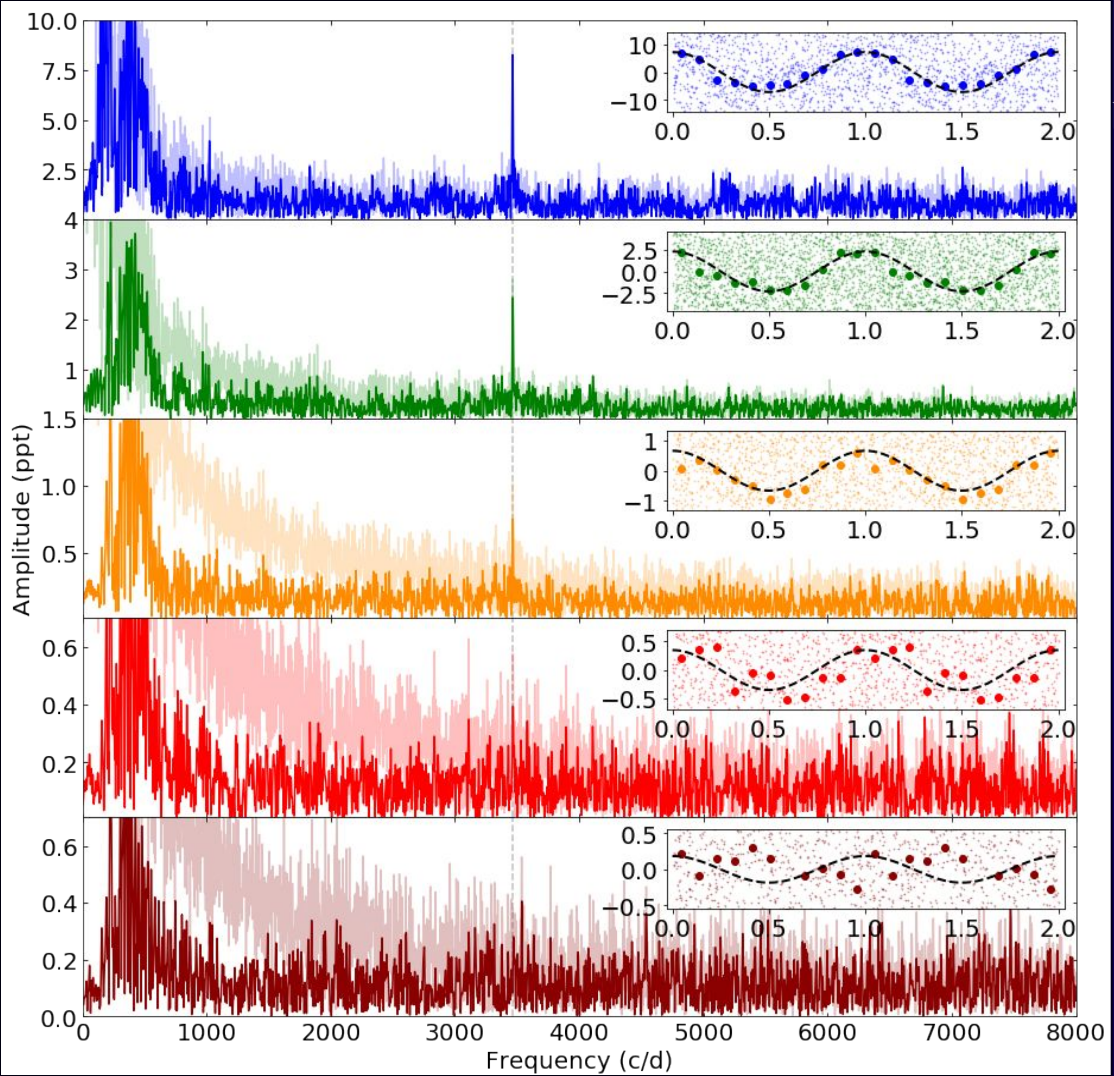
but no fast spin detected...

- Garnavich+ (2021) confirmed material was being ejected.

In comes the largest telescope…

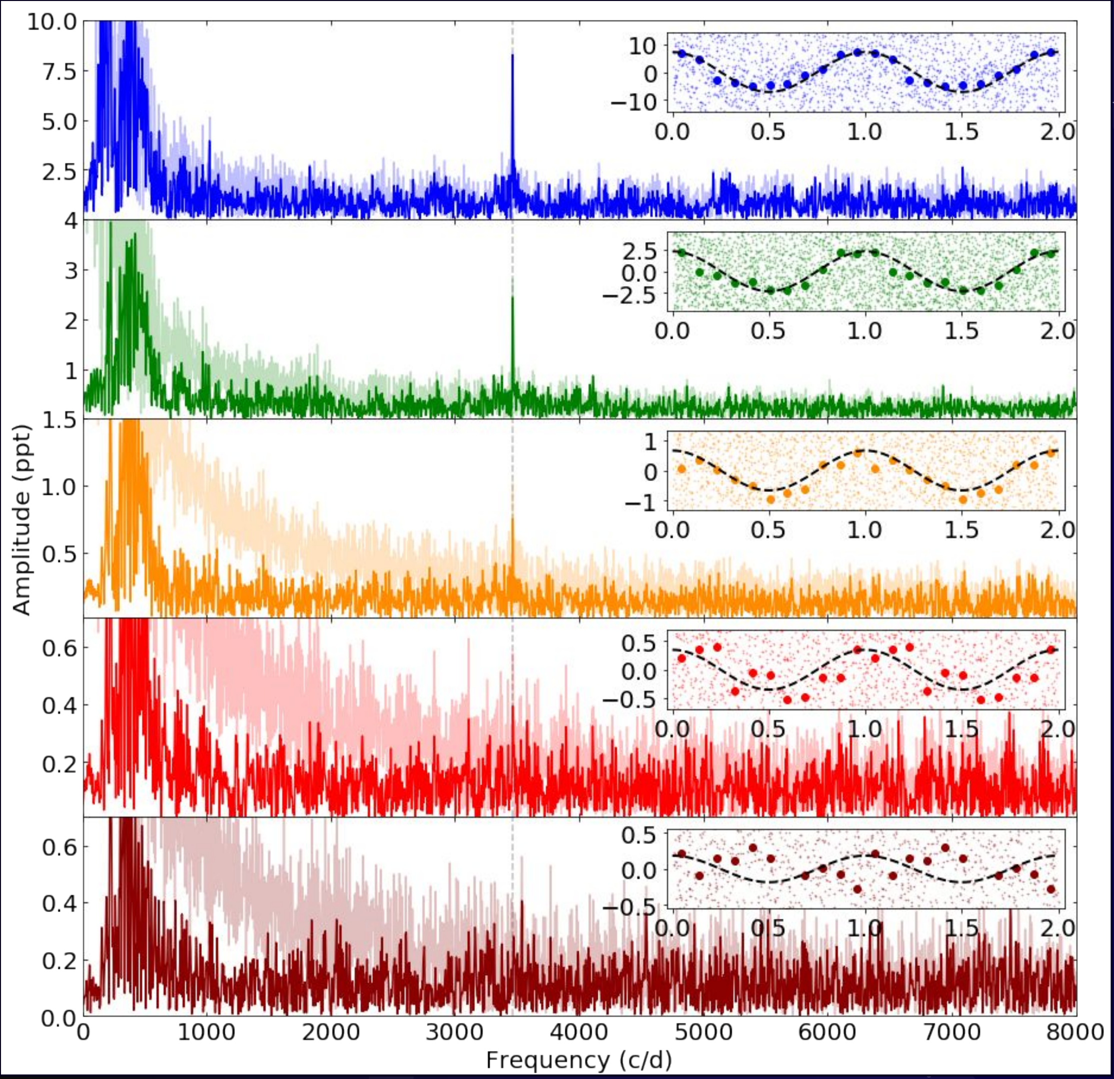
...with the most efficient photometer...





...et voilà!

Detection of a **24.9 second** spin!



...et voilà!

Detection of a **24.9 second** spin!

J0240+1952 became only the **second ever known magnetic propeller** and the **fastest spinning confirmed white dwarf**!

SUMMARY

The **evolution of single stars** is fairly well understood, and the **most common result is a white dwarf**, which can thus reveal the history of formation and evolution of the Galaxy.

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Massive white dwarfs can go supernova if they accrete enough mass, like HD265435

Accretion can also occur more peacefully, like for cataclysmic variables – though **magnetic fields can lead to peculiar behaviour**, like J0240+1952.

PRESS RELEASES

HD 265435: *Teardrop star reveals hidden supernova doom*

https://warwick.ac.uk/newsandevents/pressreleases/teardrop_star_reveals/

J0240+1952: *High-speed propeller star is fastest spinning white dwarf*

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Thanks!