

Title: Red Supergiants: A Magnifying Glass for Stellar Theory

Date: Mar 07, 2018 02:00 PM

URL: <http://pirsa.org/18030068>

Abstract: <p>Red supergiants (RSGs) are the helium-fusing evolved descendants of moderately massive (10-25Mo) stars, the result of a near-horizontal evolution across the top of the Hertzsprung-Russell diagram following their time on the main sequence. As the coldest and largest (in physical size) members of the massive star population, these stars represent a significant evolutionary extreme and serve as ideal "magnifying glasses" for scrutinizing our current understanding of massive stars and their role in the universe. RSGs are significant dust producers in young stellar populations, the observationally-confirmed progenitors of core-collapse supernovae, and a crucial step in the formation and population statistics of massive interacting binaries (including those that will ultimately produce compact object binaries and gravitational waves). Observations of RSGs can also be used to test stellar evolution and population models and as metallicity indicators in nearby galaxies. This talk will provide an overview of our field's knowledge of RSGs, identify some of the most pressing current questions about these stars, and consider the importance of RSGs in the coming decade as the next generation of observatories - including JWST, WFIRST, and the ELTs - comes online.</p>

Red Supergiants: A Magnifying Glass for Stellar Theory

Emily Levesque
University of Washington

 @emsque

Red Supergiants: A Magnifying Glass for Stellar Theory

UW Massive Stars group



Jamie Lomax
(postdoc)



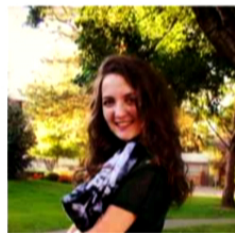
Trevor Dorn-
Wallenstein (grad)



Kathryn Neugent
(grad)



Locke Patton
(undergrad)



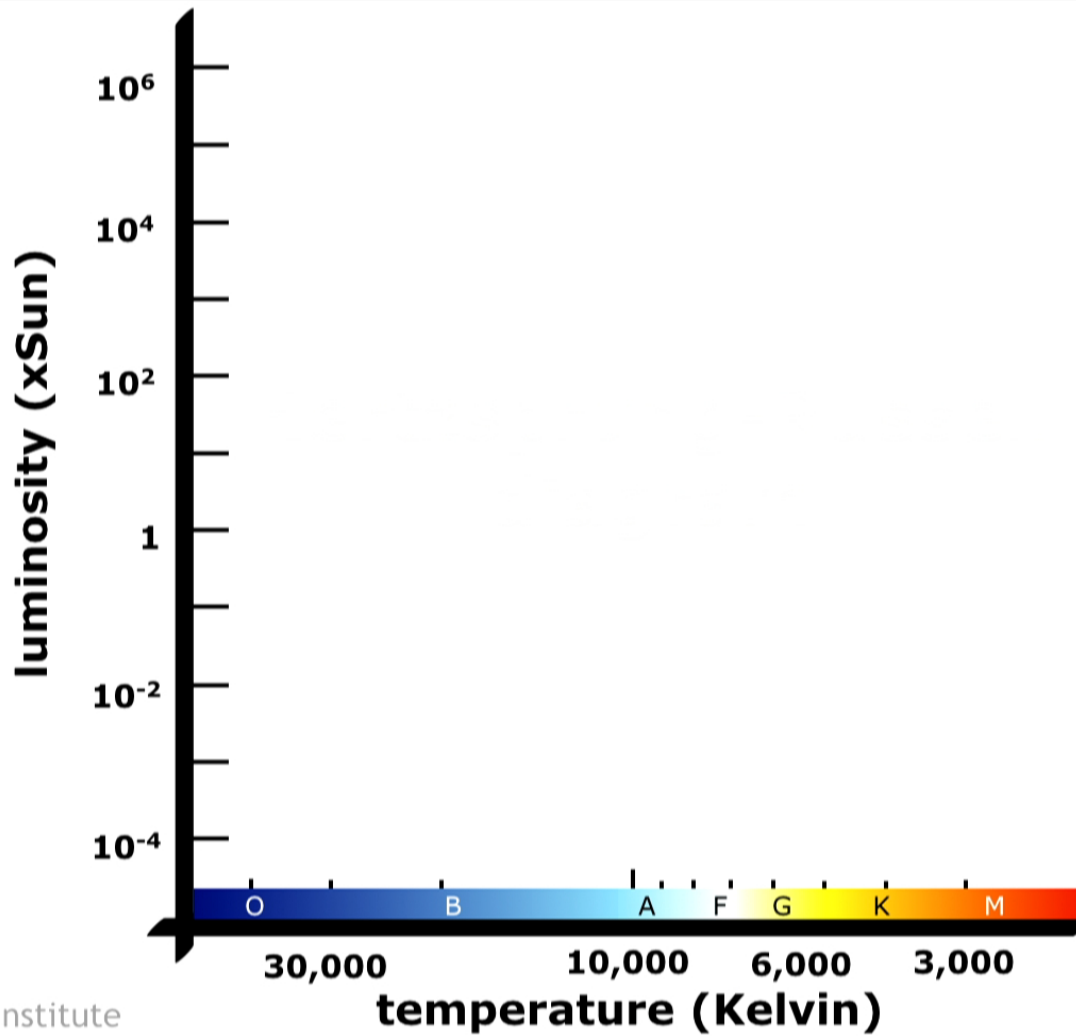
Brooke Dizenzo
(undergrad)



Emily Levesque
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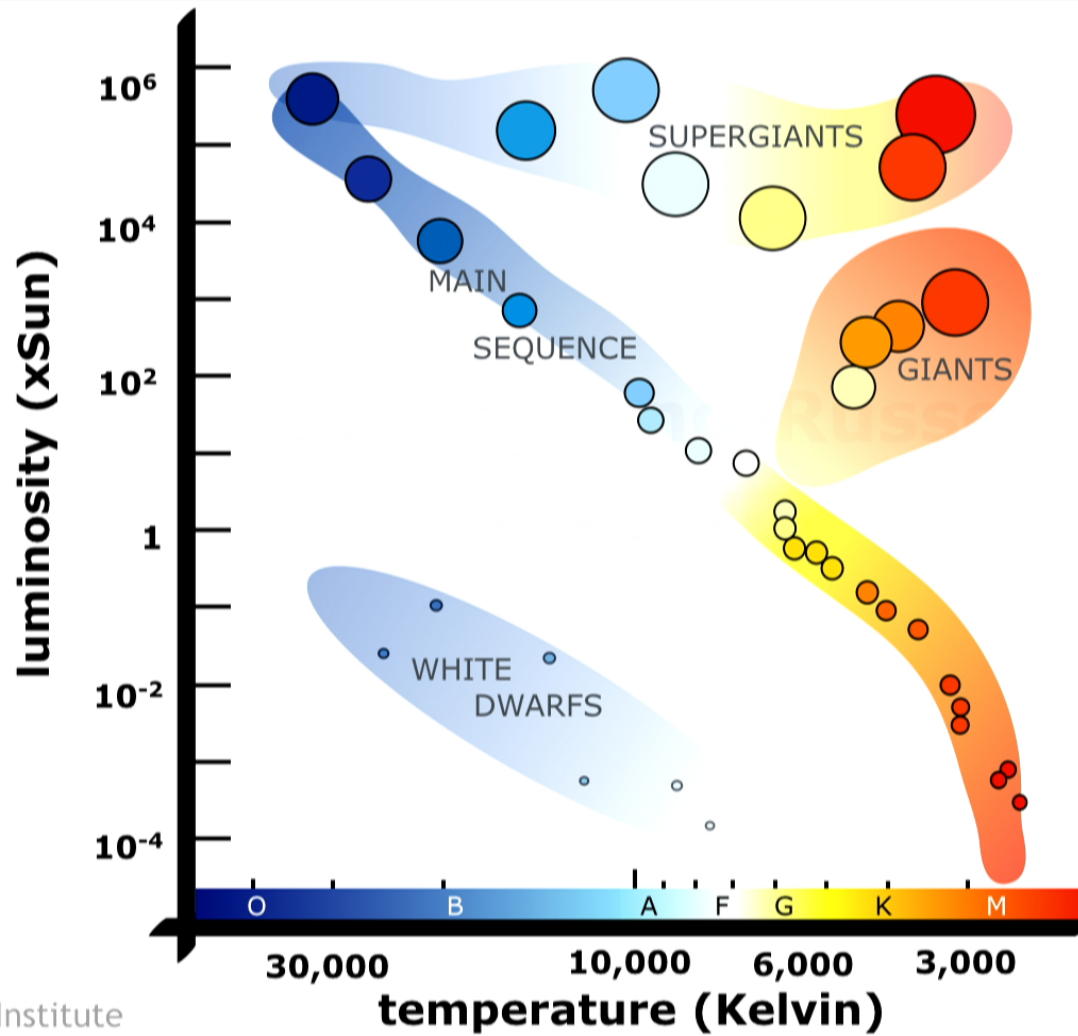
What are red supergiants?



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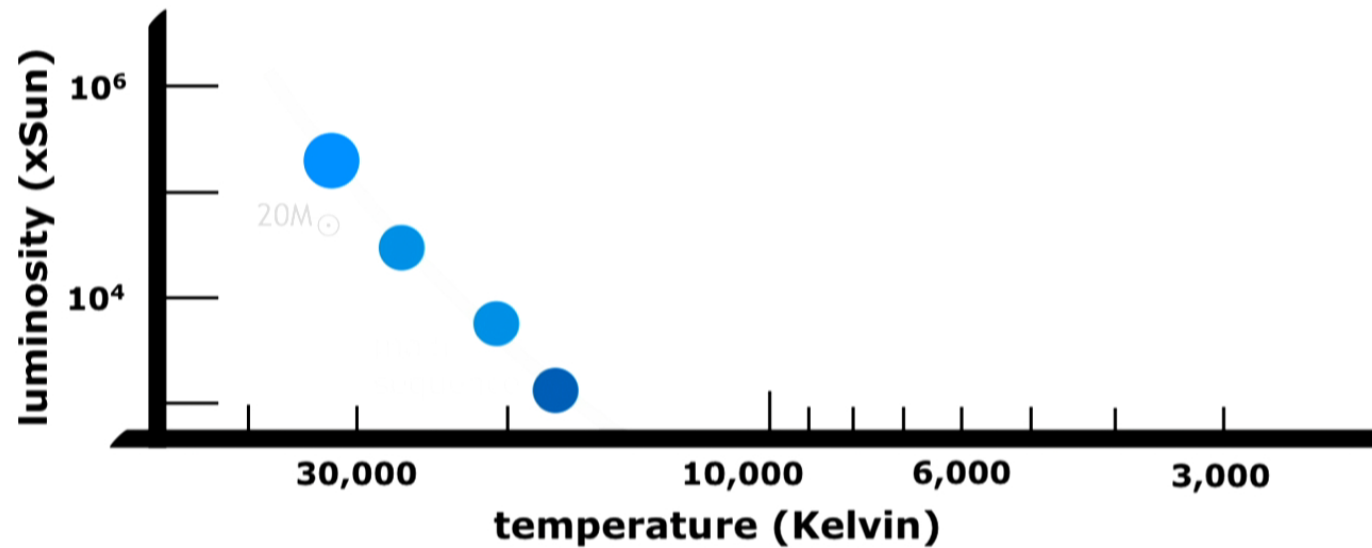


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What are red supergiants?

RSGs are the helium-fusing evolved descendants of moderately massive (~8-40 M_{\odot}) main sequence stars.



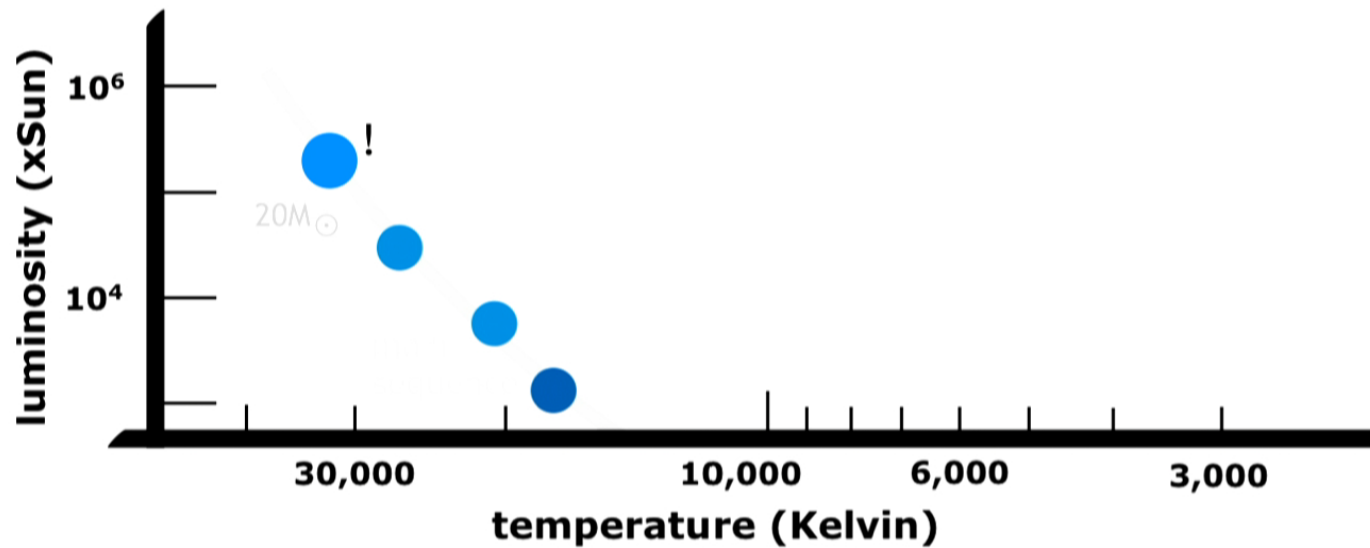
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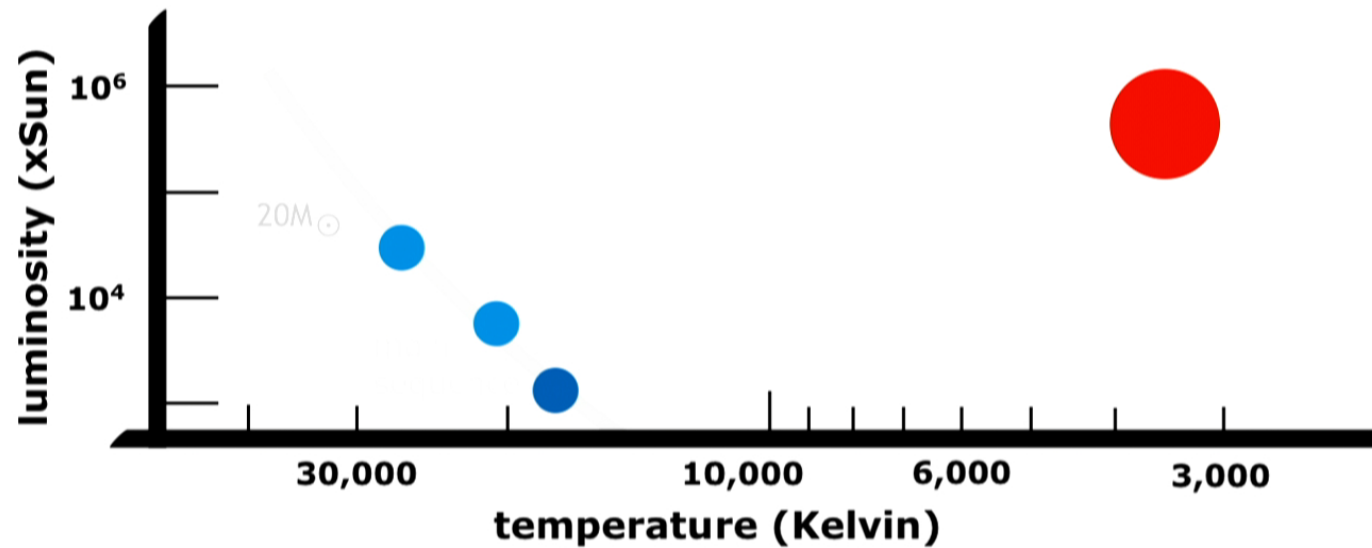
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$$L \propto R^2 T^4$$



What are red supergiants?

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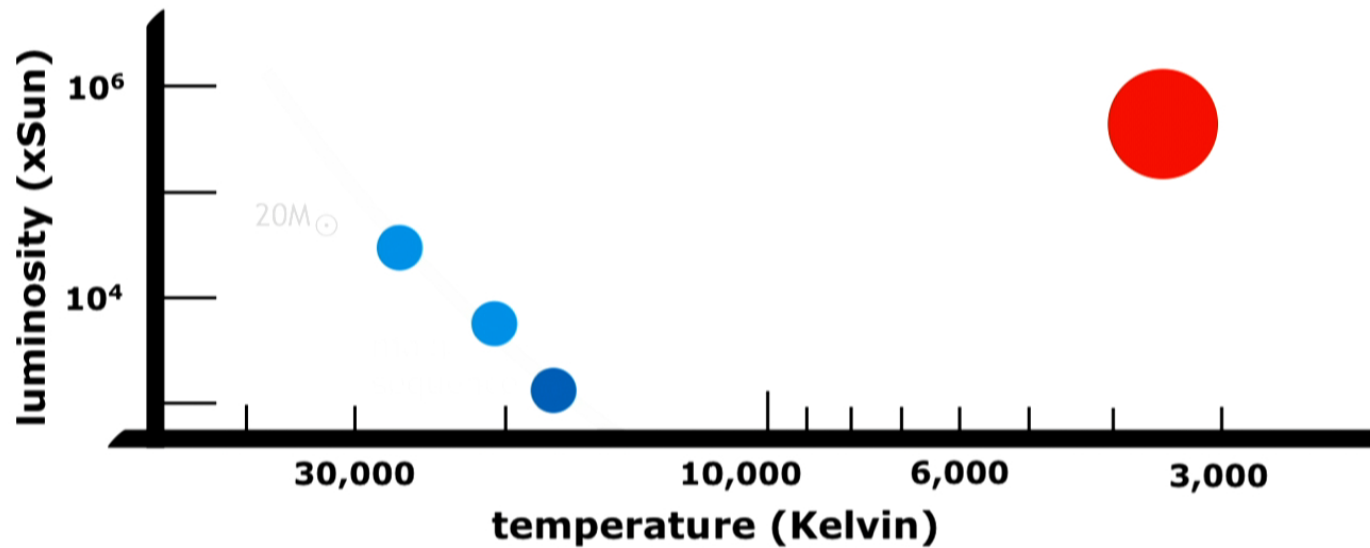
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What are red supergiants?

RSGs are the helium-fusing evolved descendants of moderately massive ($\sim 8\text{-}40M_{\odot}$) main sequence stars.

- coldest and physically largest massive stars
- distinct from red *giants*; (higher M_i , shorter lifetimes, different evolutionary pathways)
- end phase *or* intermediate phase in massive star evolution



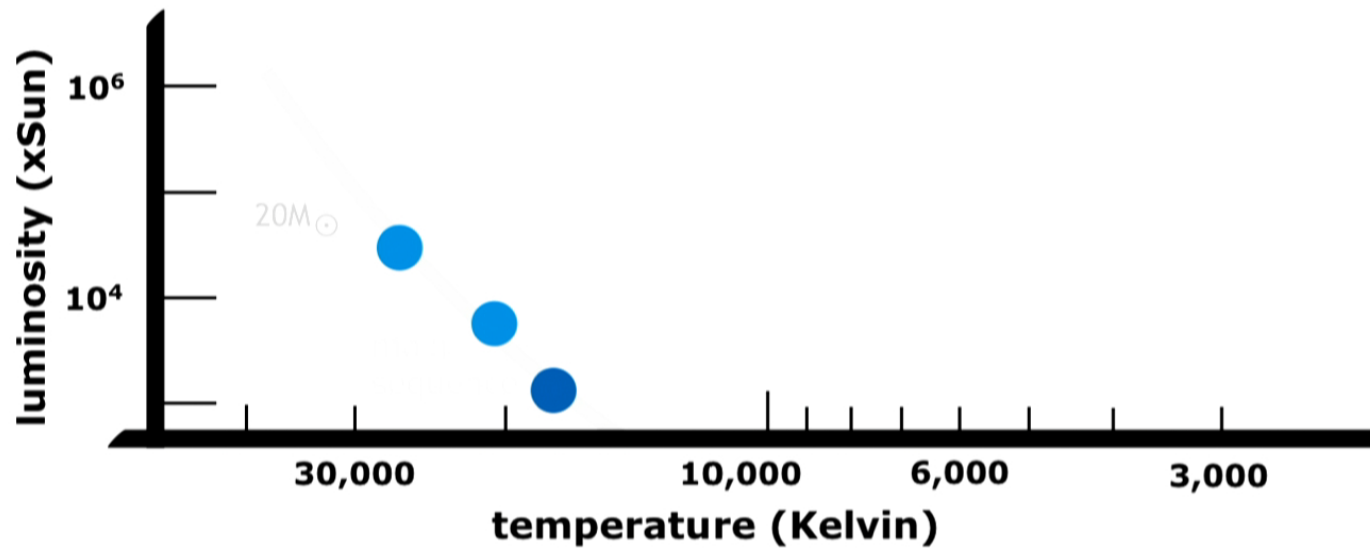
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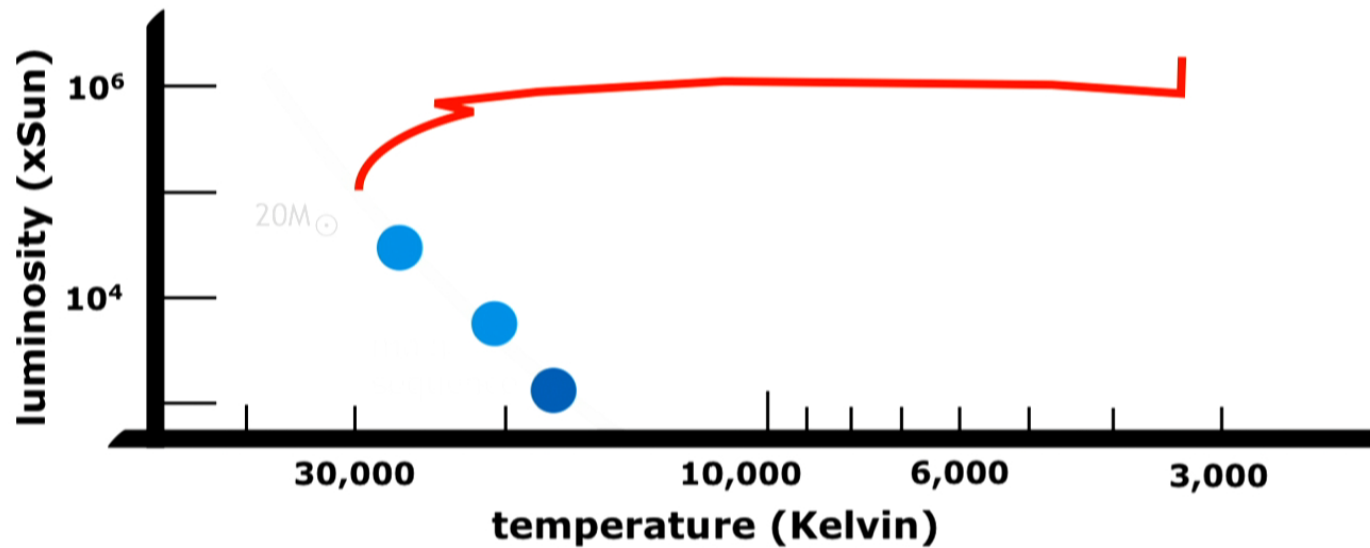
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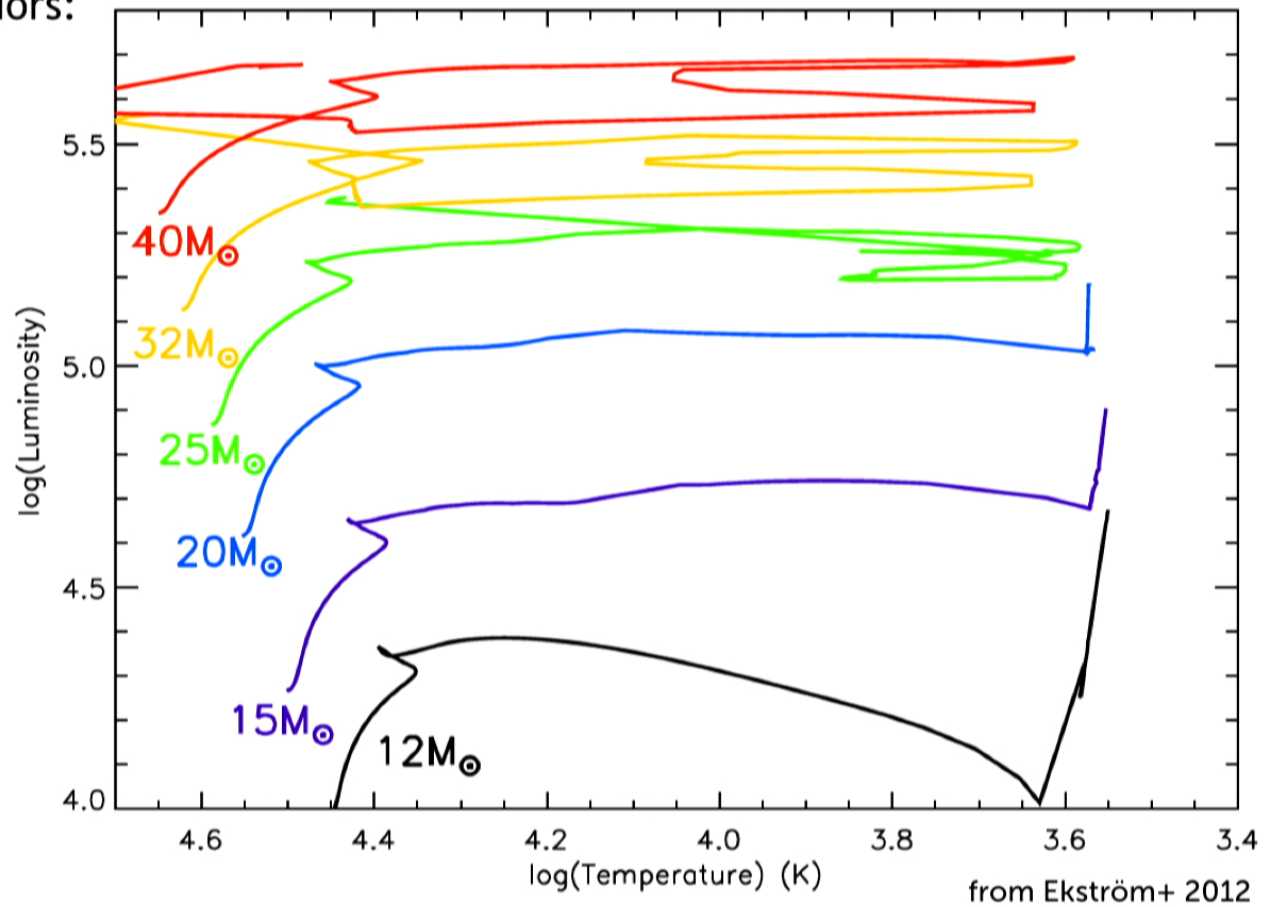


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What are red supergiants?

Exteriors:

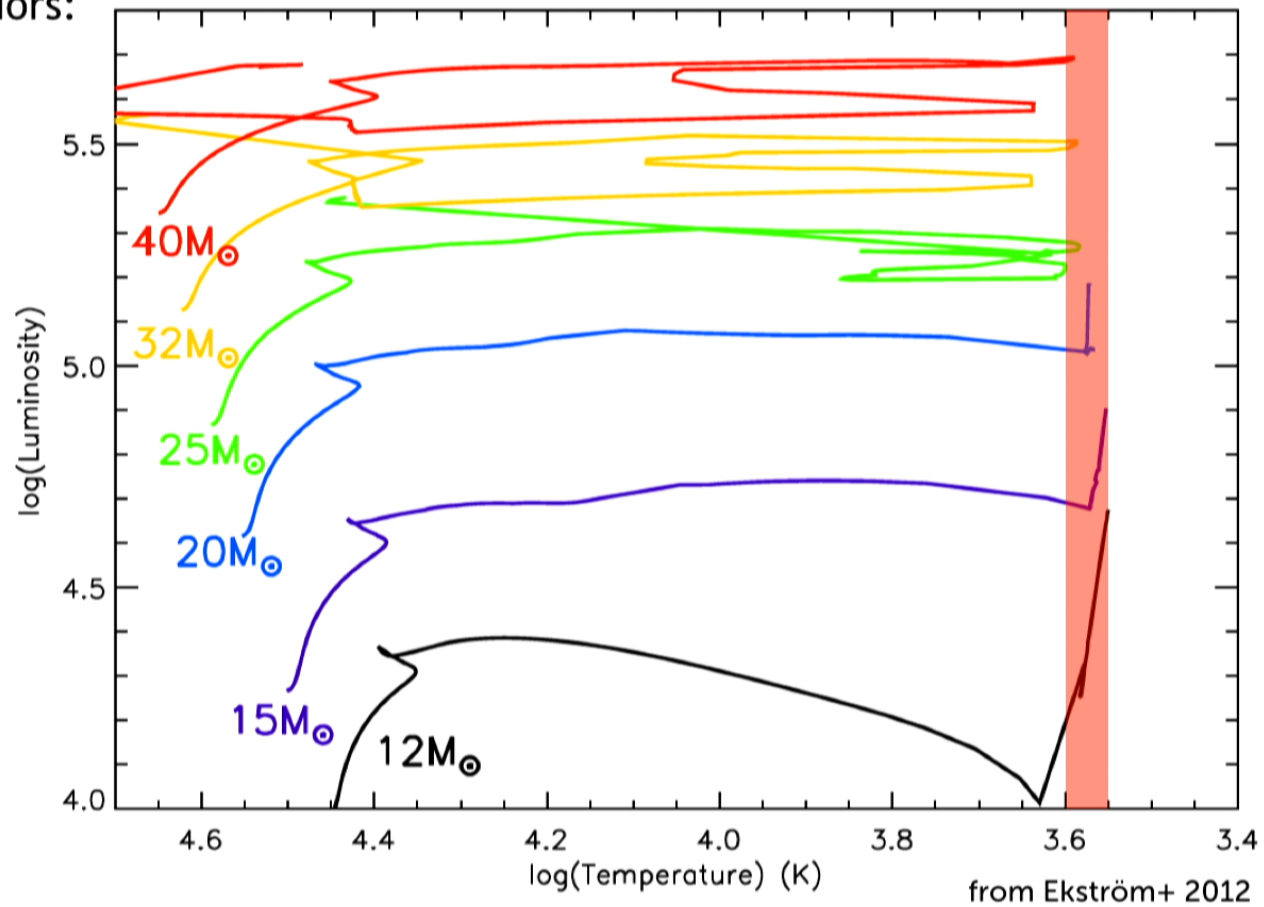


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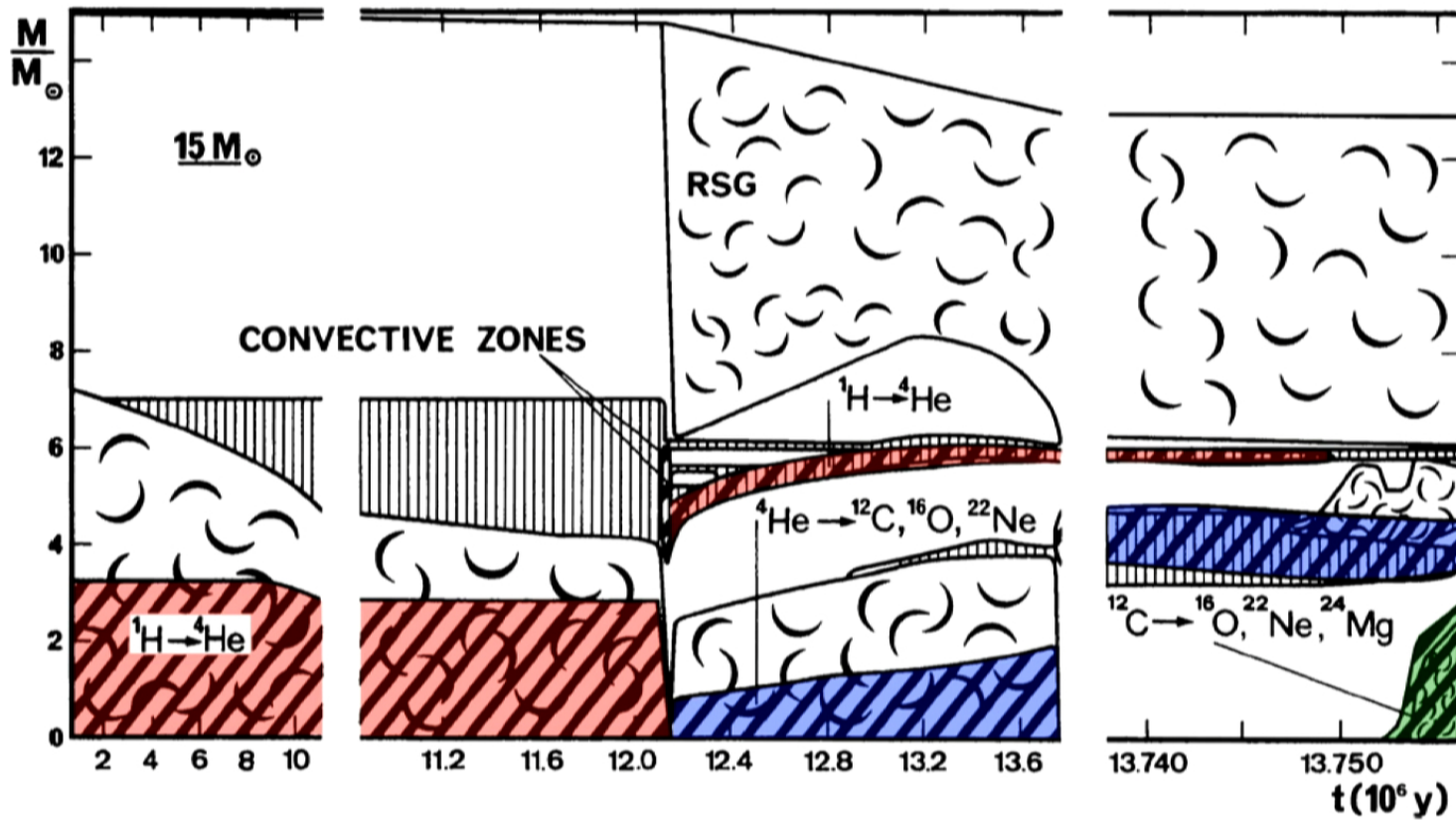


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What are red supergiants?

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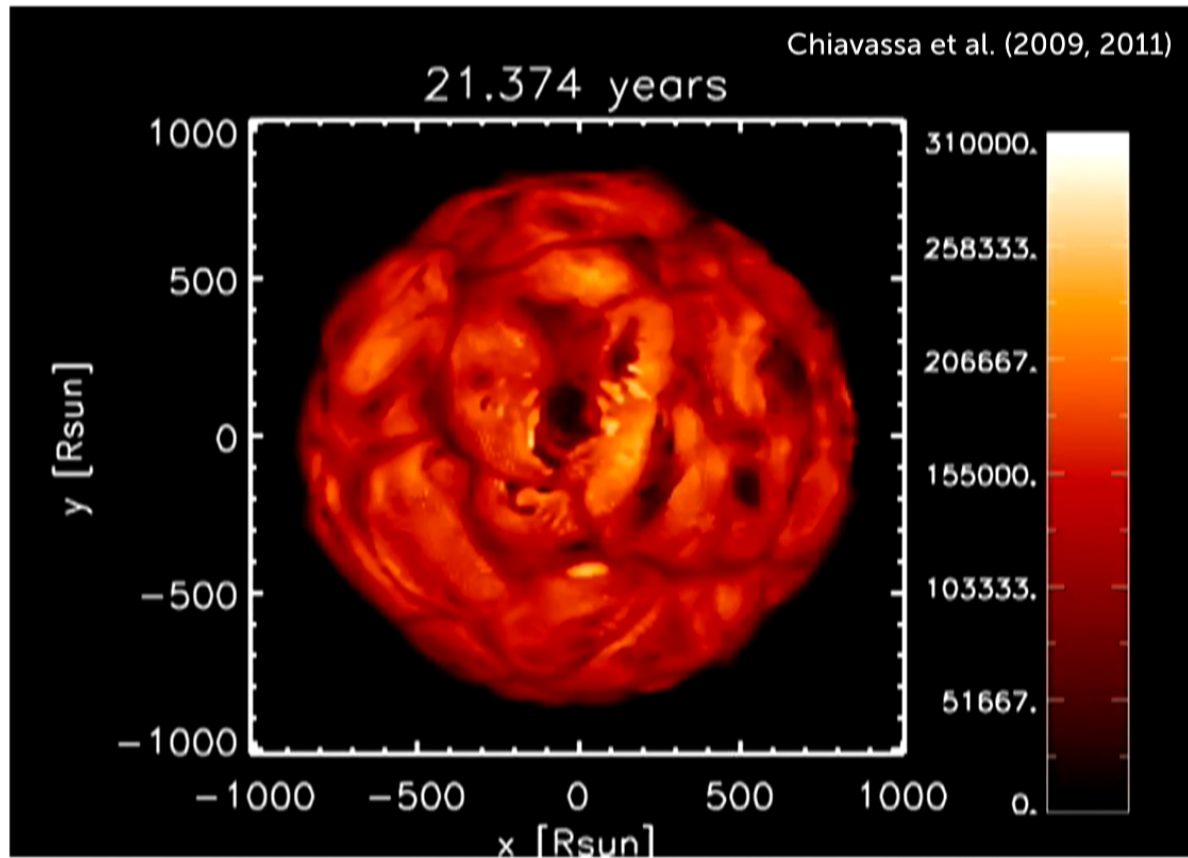


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What are red supergiants?

Interiors+Exteriors:

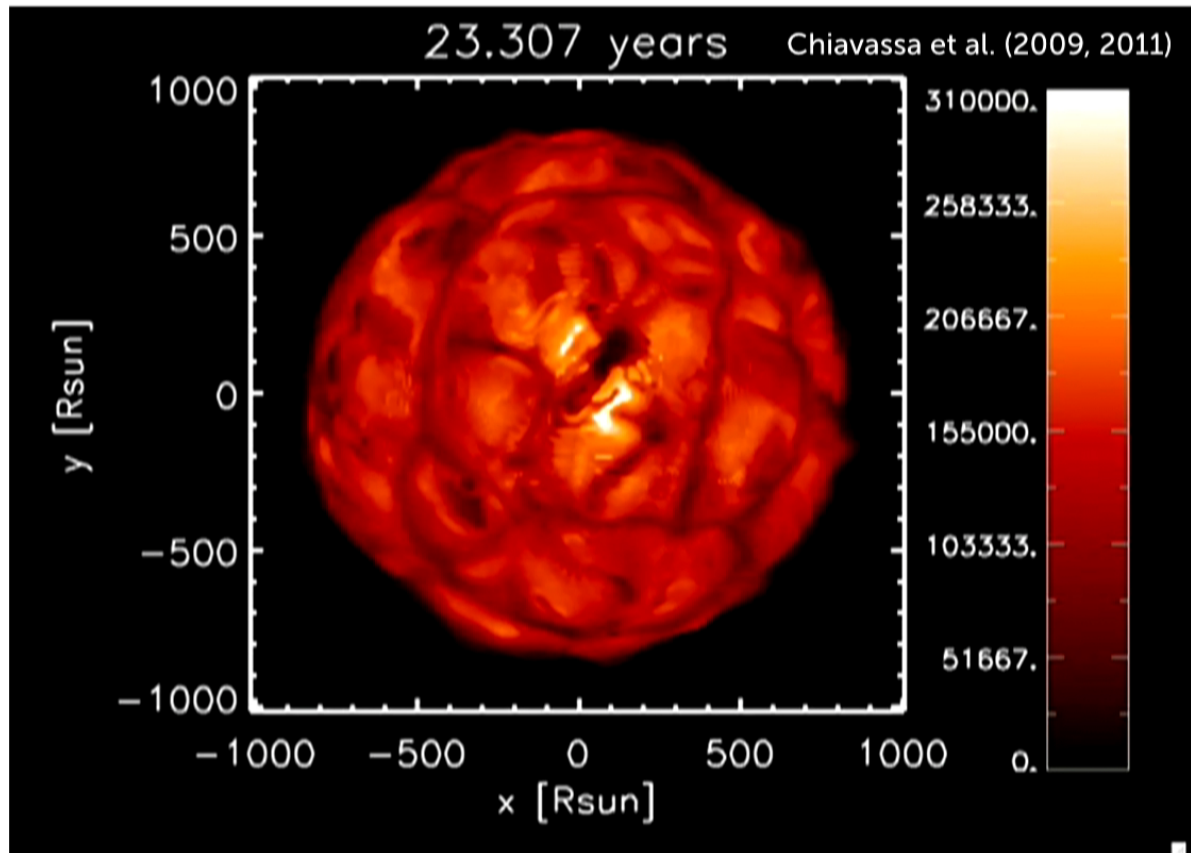


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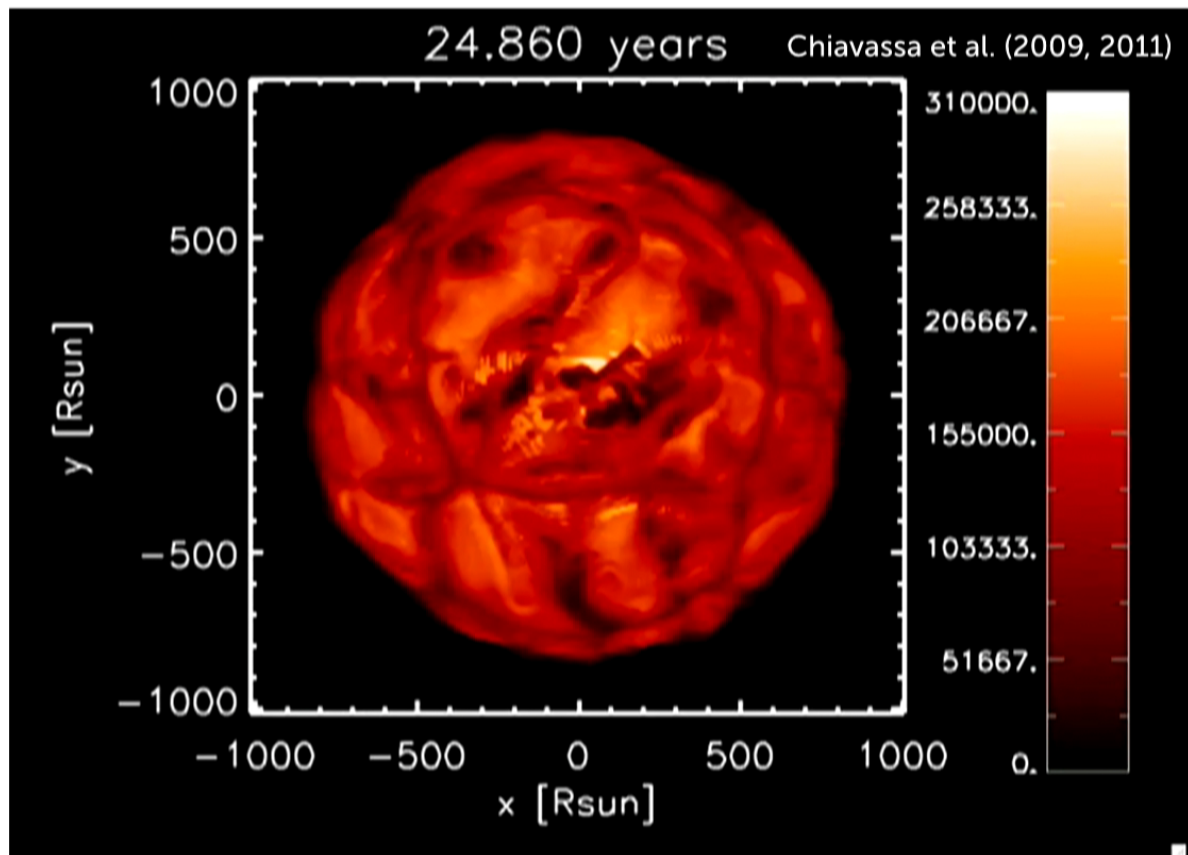


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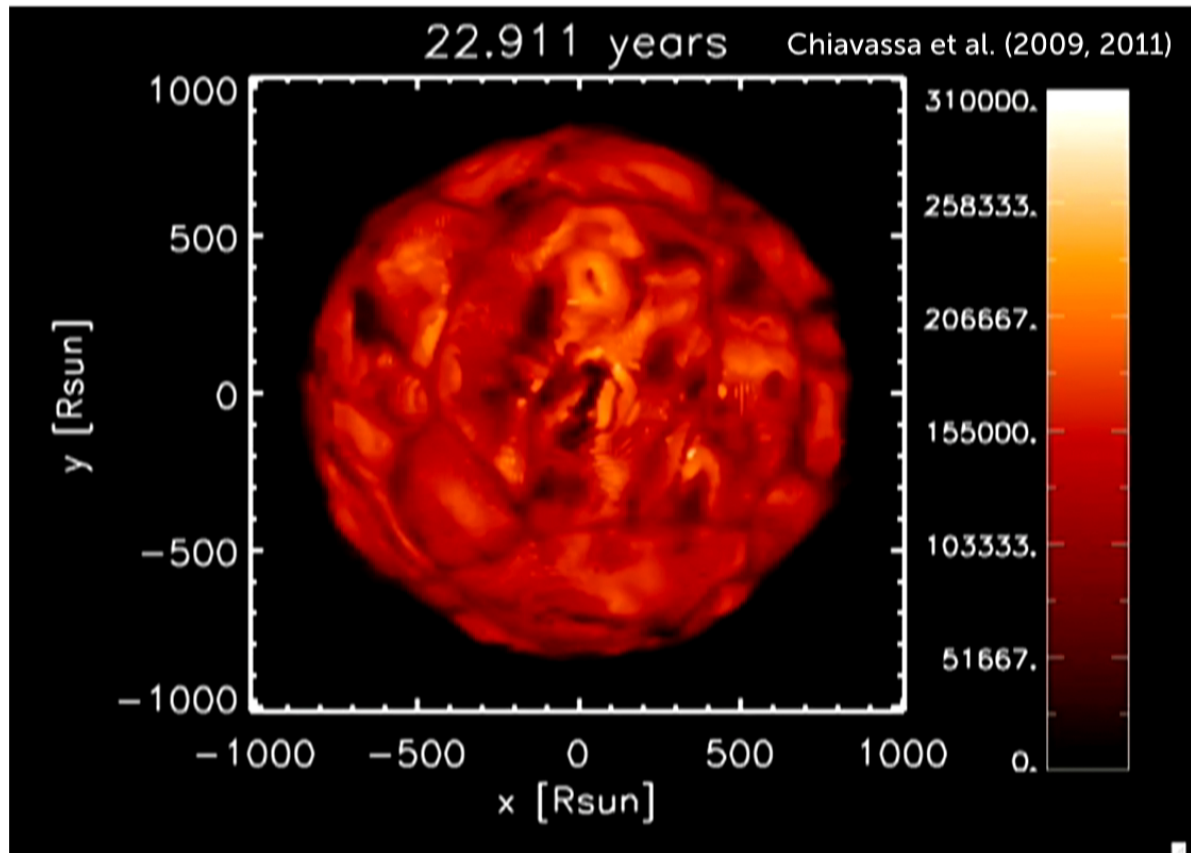


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Interiors+Exteriors:



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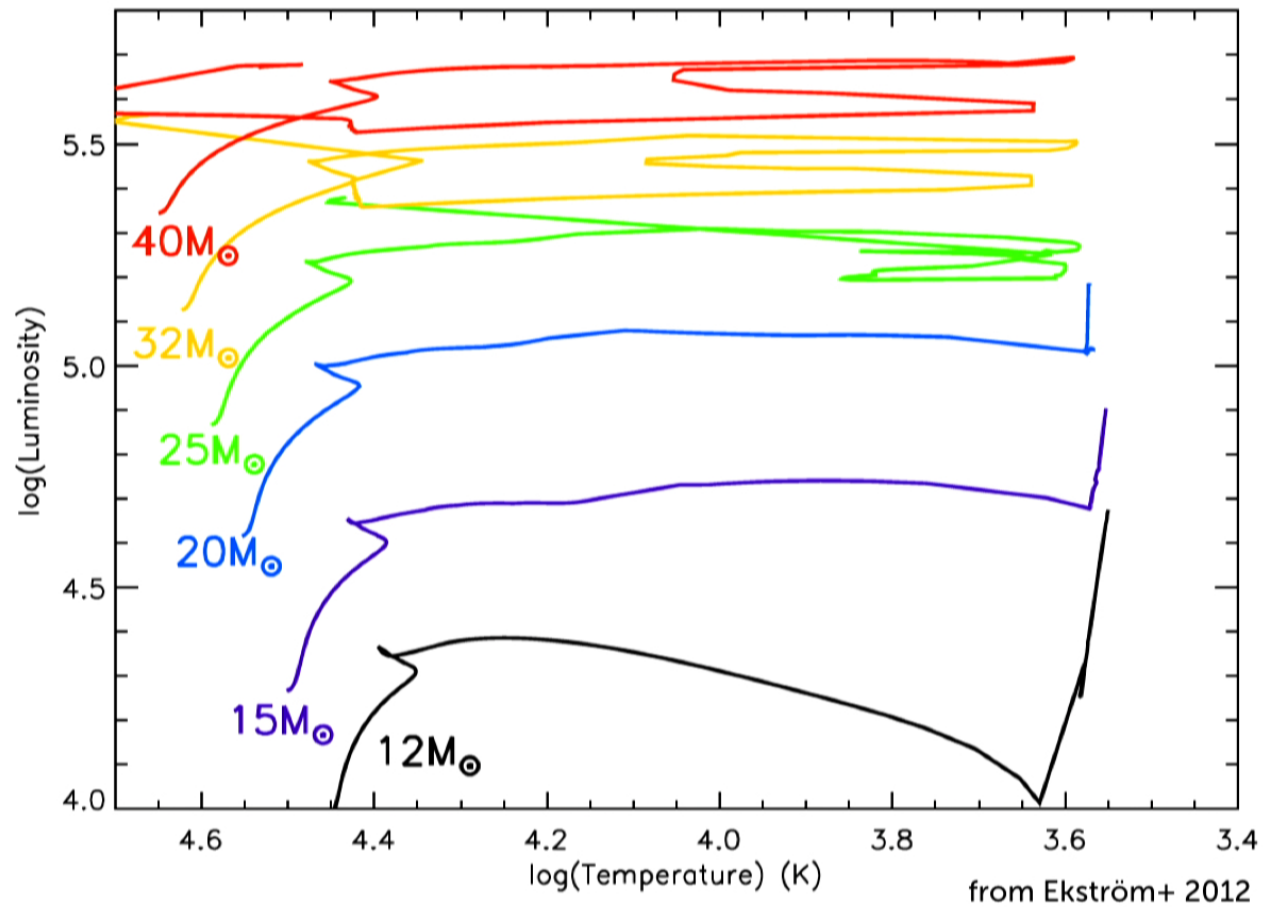
Who *cares* about red supergiants?

massive star formation
early universe chemistry
gravitational waves
massive star evolution
stellar populations
galaxy compositions
strange and variable stars
time-domain astronomy
infrared astronomy

mass loss in cool stars
stellar magnetic fields
YOU DO!
supernova progenitors
stars in the early universe
compact objects

dust production
massive binary fraction
mass loss in massive stars
mass-transfer binaries
stellar rotation
nucleosynthesis

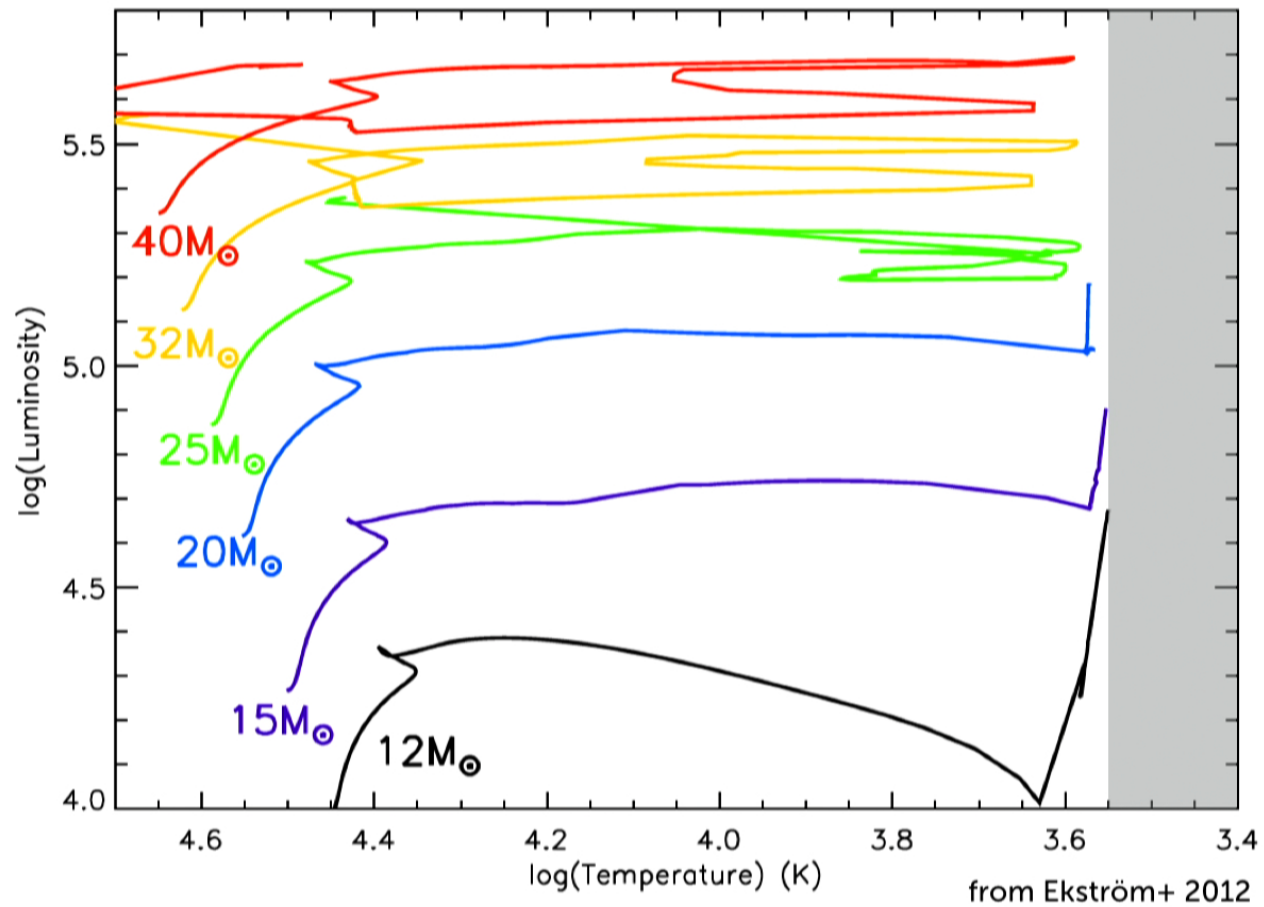
Challenges: RSG temperatures



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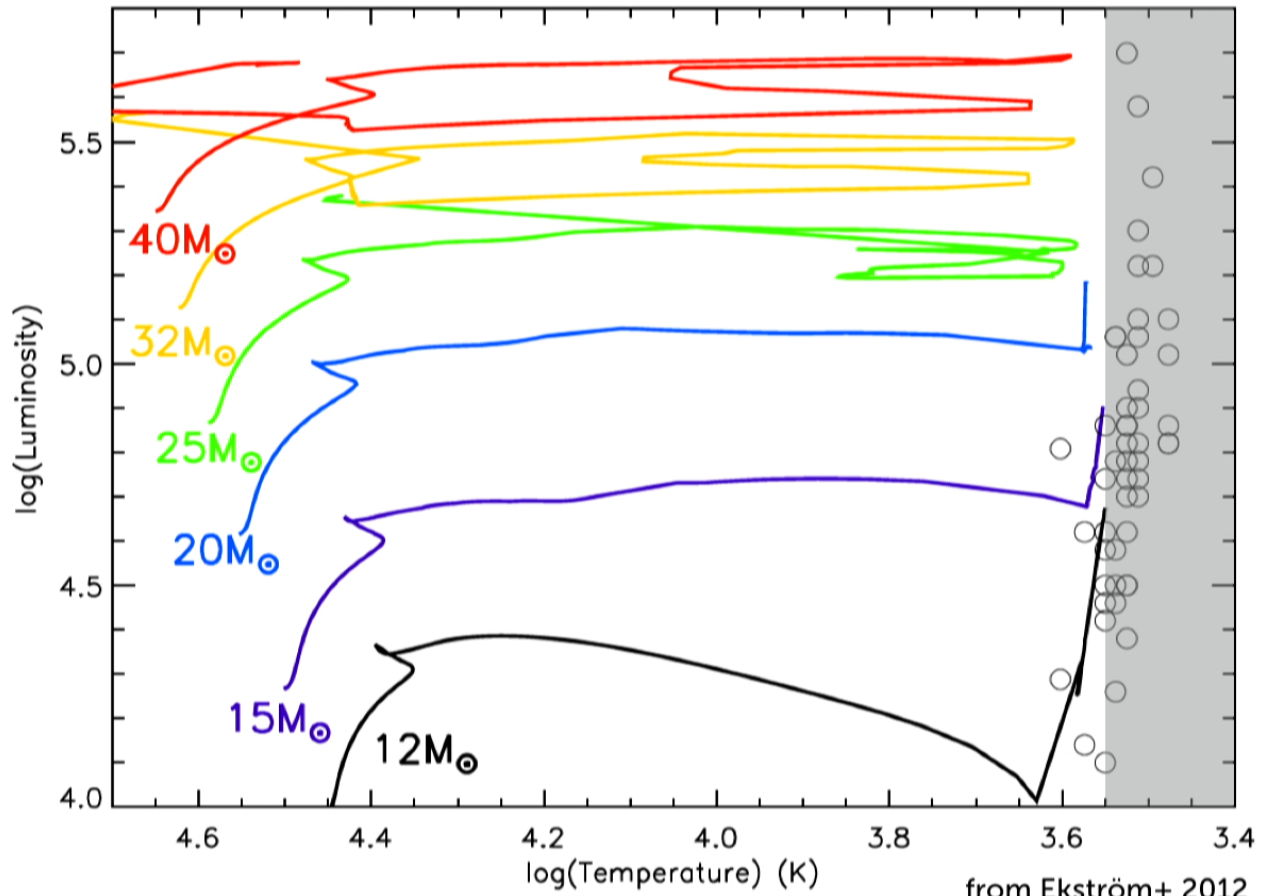
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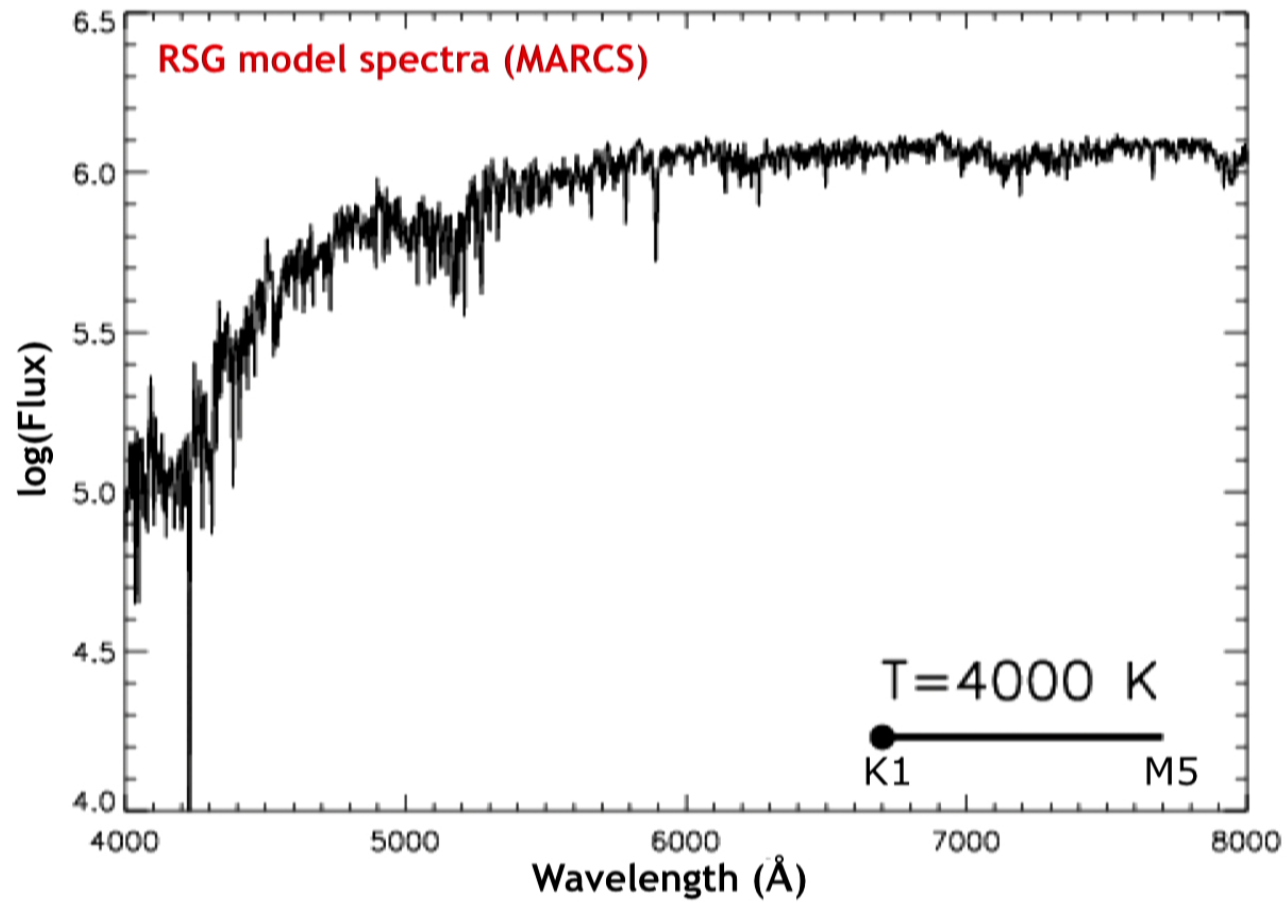


from Ekström+ 2012
from Levesque+ 2005

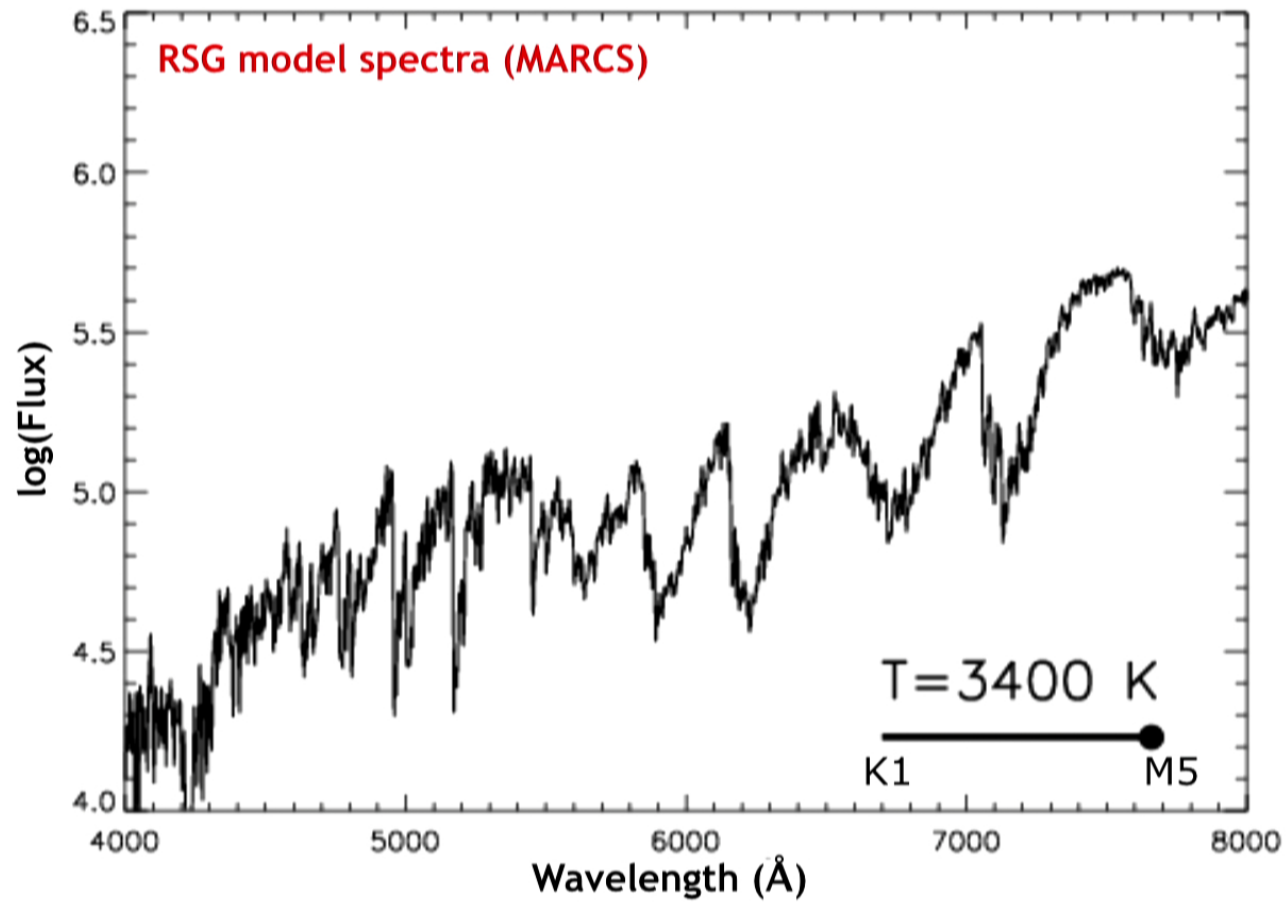
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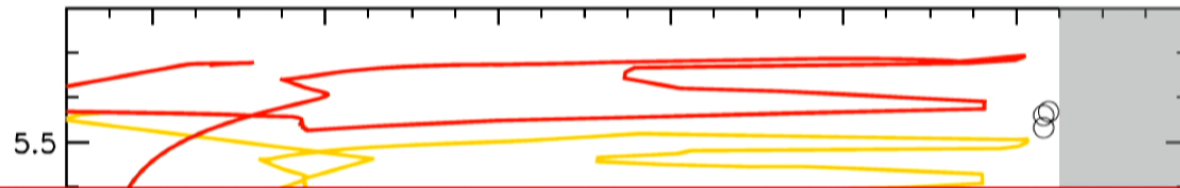
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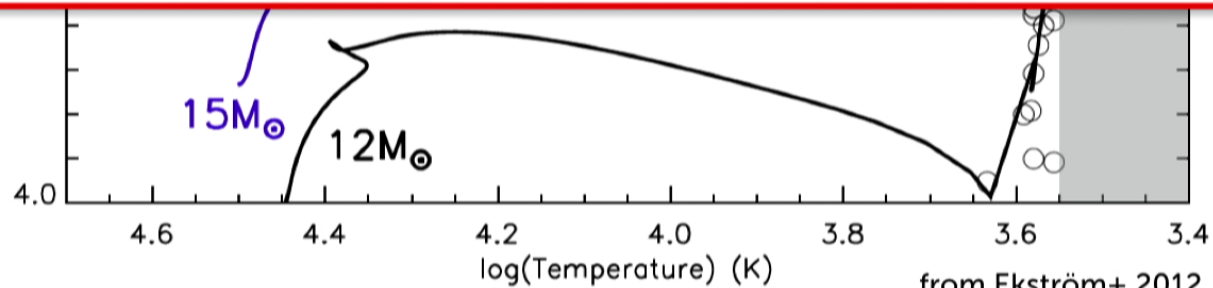


Challenges: RSG temperatures



BUT...

- breaks down in galaxies with different chemical composition
- technique is limited to optical data; IR data doesn't (quite) match
- spectra are observationally costly; are there other ways?



from Ekström+ 2012
from Levesque+ 2005

Challenges: RSGs in other galaxies

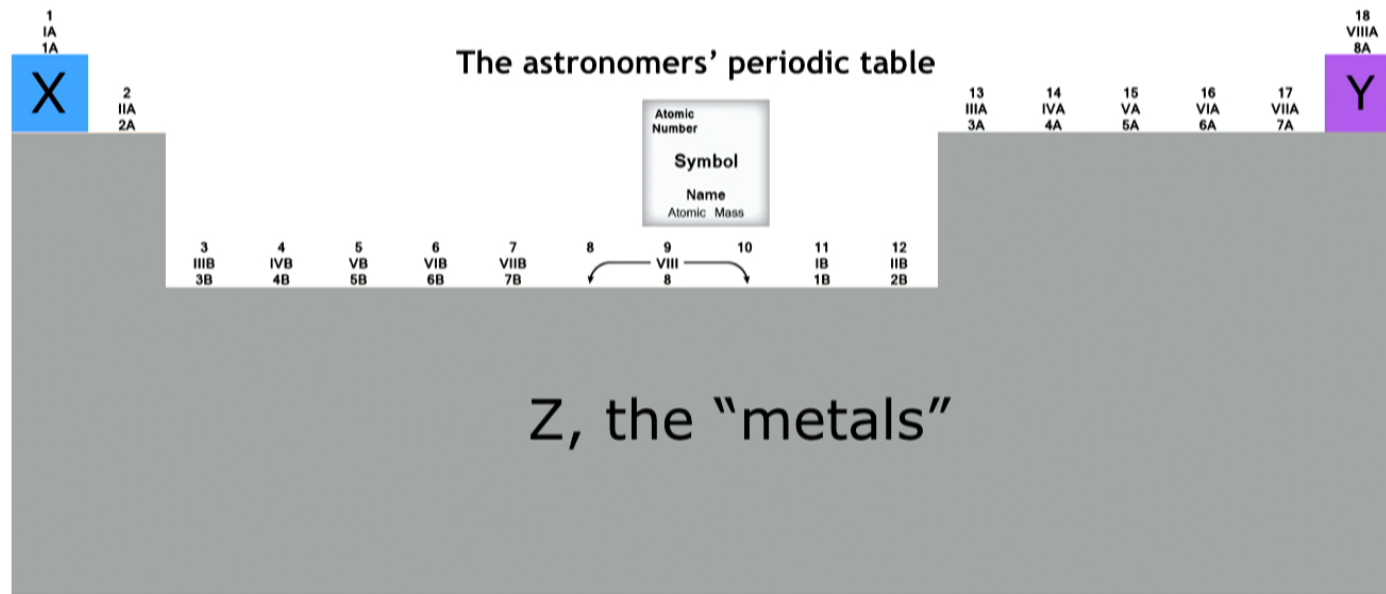
This is one of the key appeals of studying RSGs! So where do we start?

Periodic Table of the Elements

1 IA 1A	2 IIA 2A											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanide	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinide	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

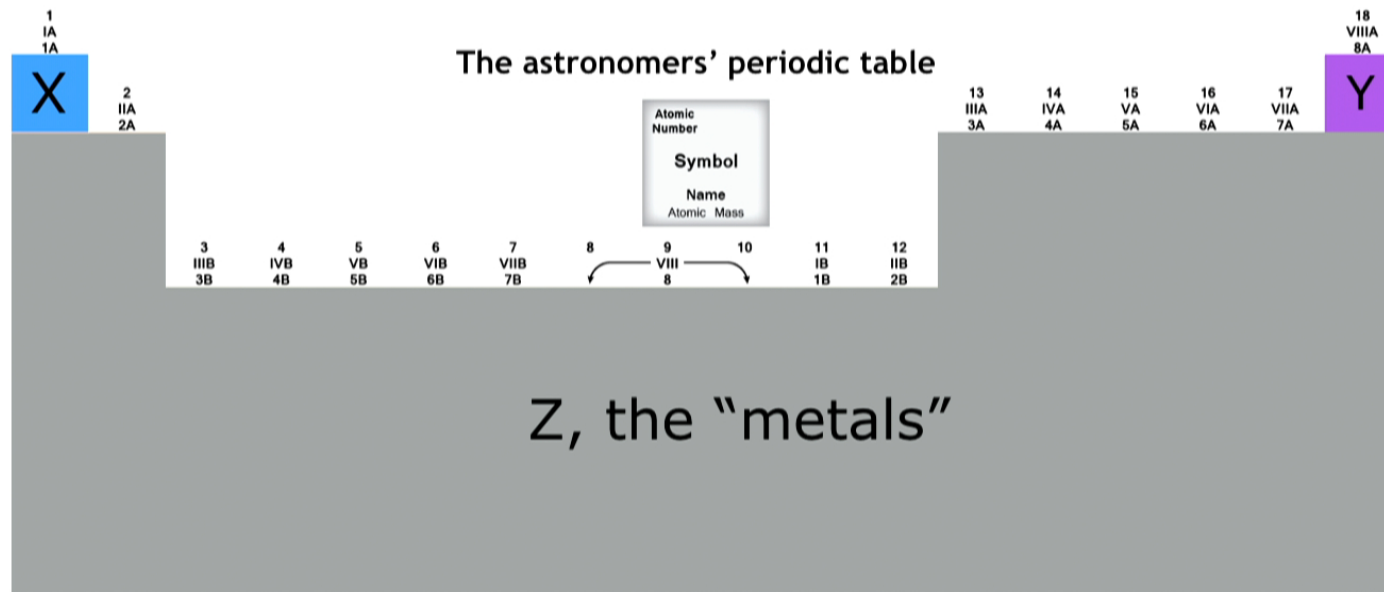
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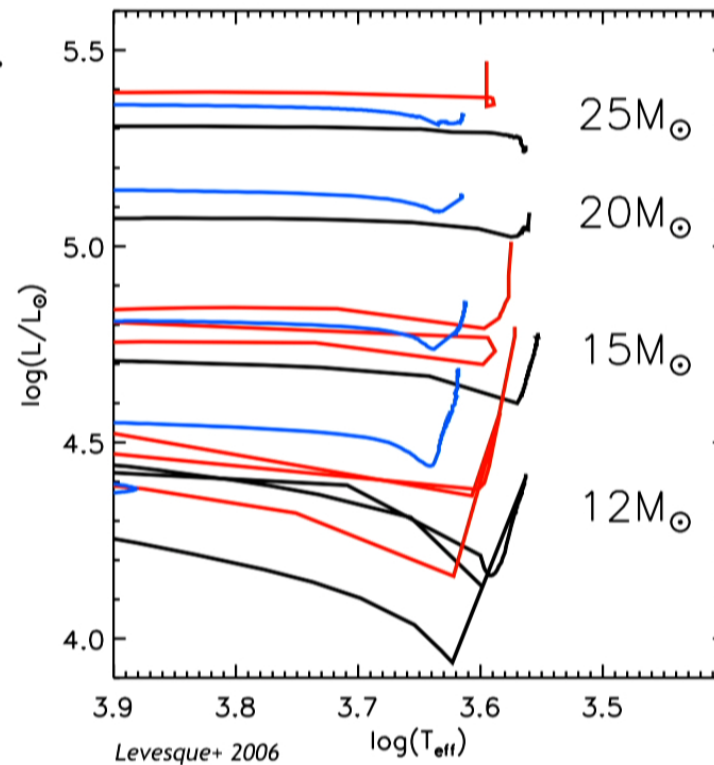


“metallicity”: non-H-and-He chemical composition of a star or galaxy

Challenges: RSGs in other galaxies

What range of colors (e.g. temperatures) should we be looking for?

The **Hayashi limit** shifts to warmer temperatures at lower metallicities.



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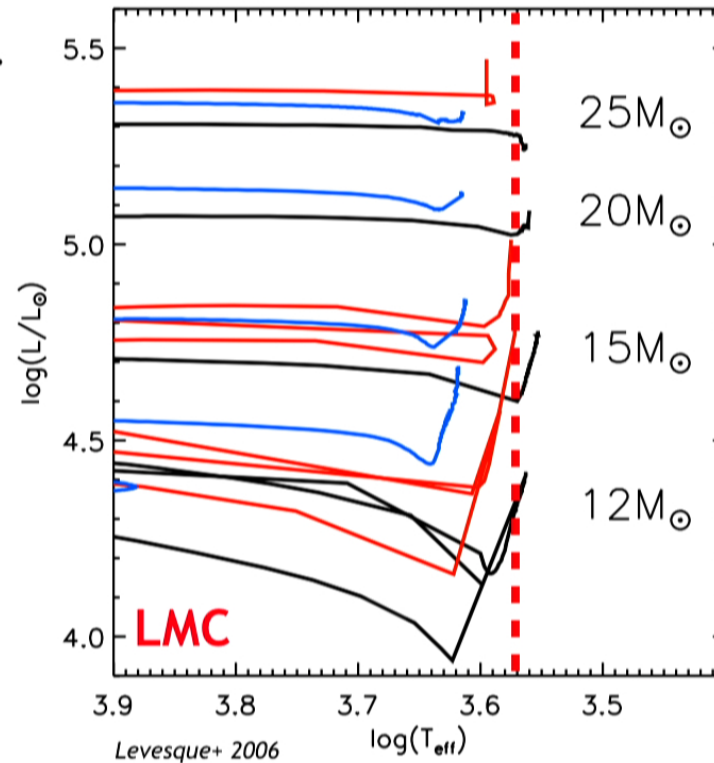
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Challenges: RSGs in other galaxies

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(effect comes from more free e^- at higher metallicity, which leads to a higher abundance of H^- , the main opacity source in cool star atmospheres with $\kappa \propto T^9$)

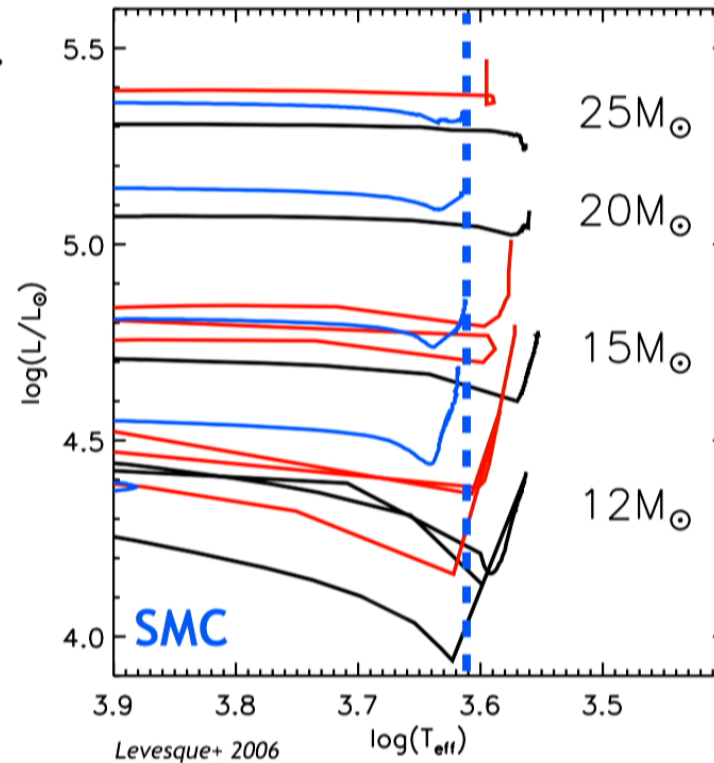


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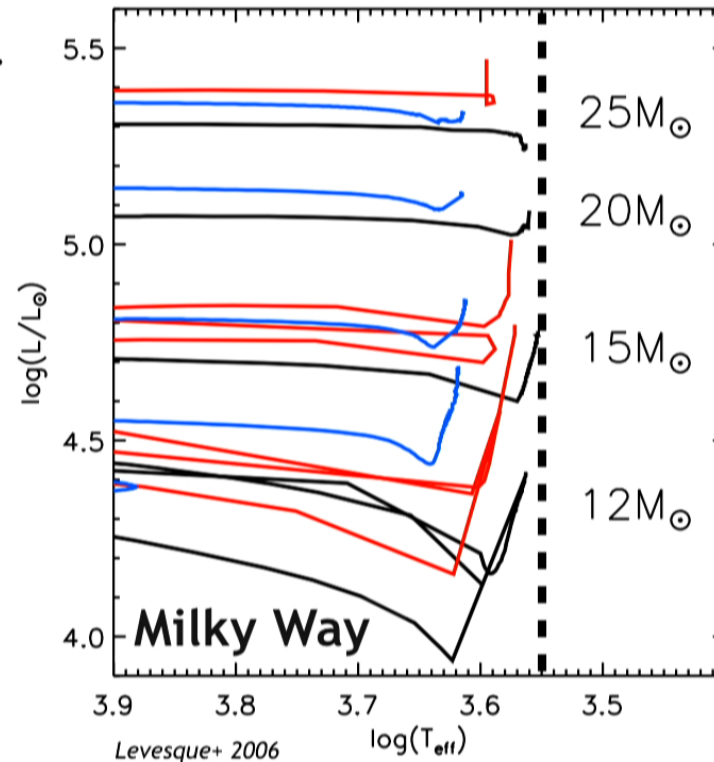
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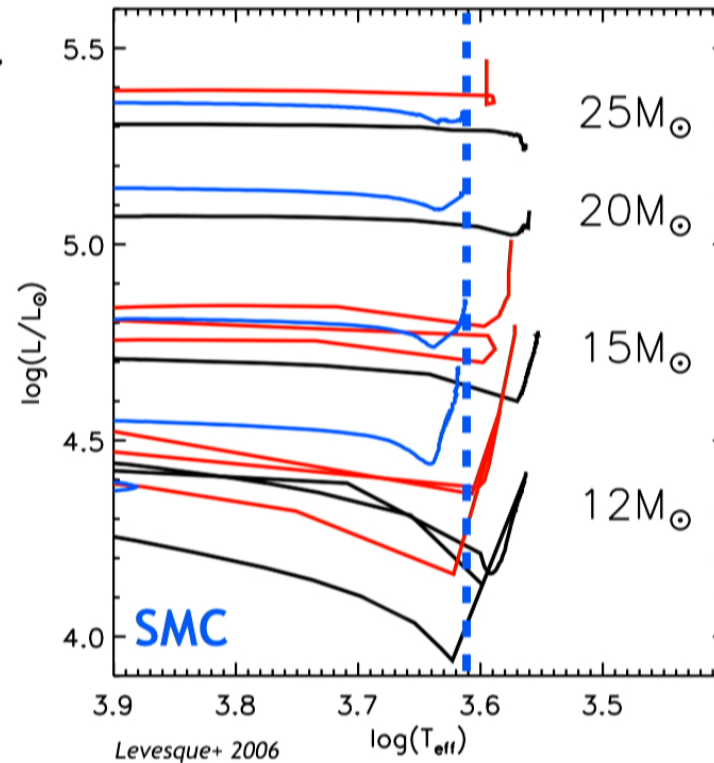
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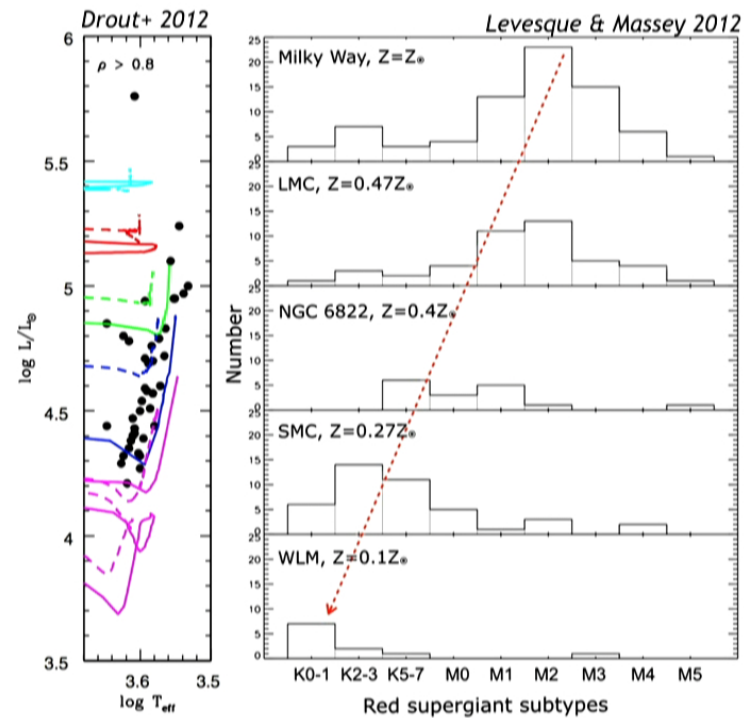
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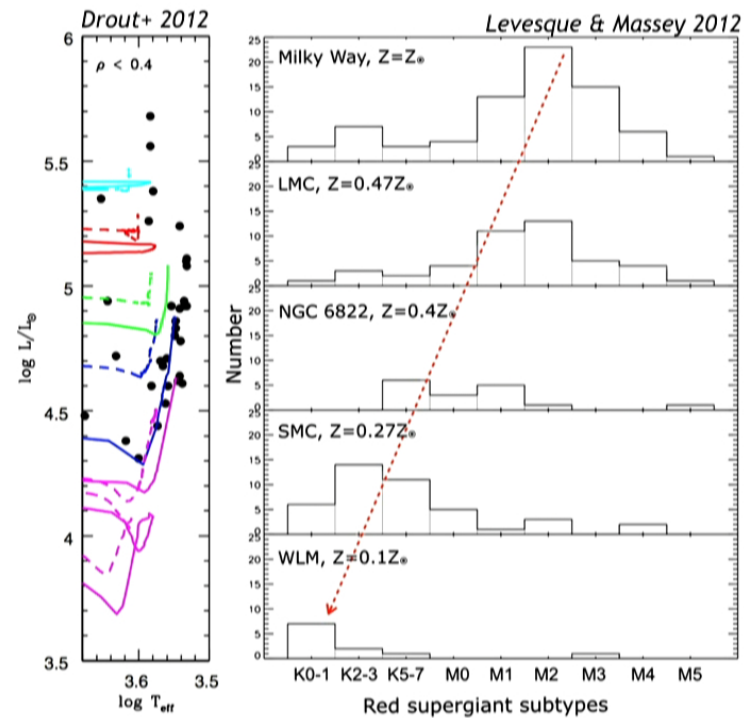
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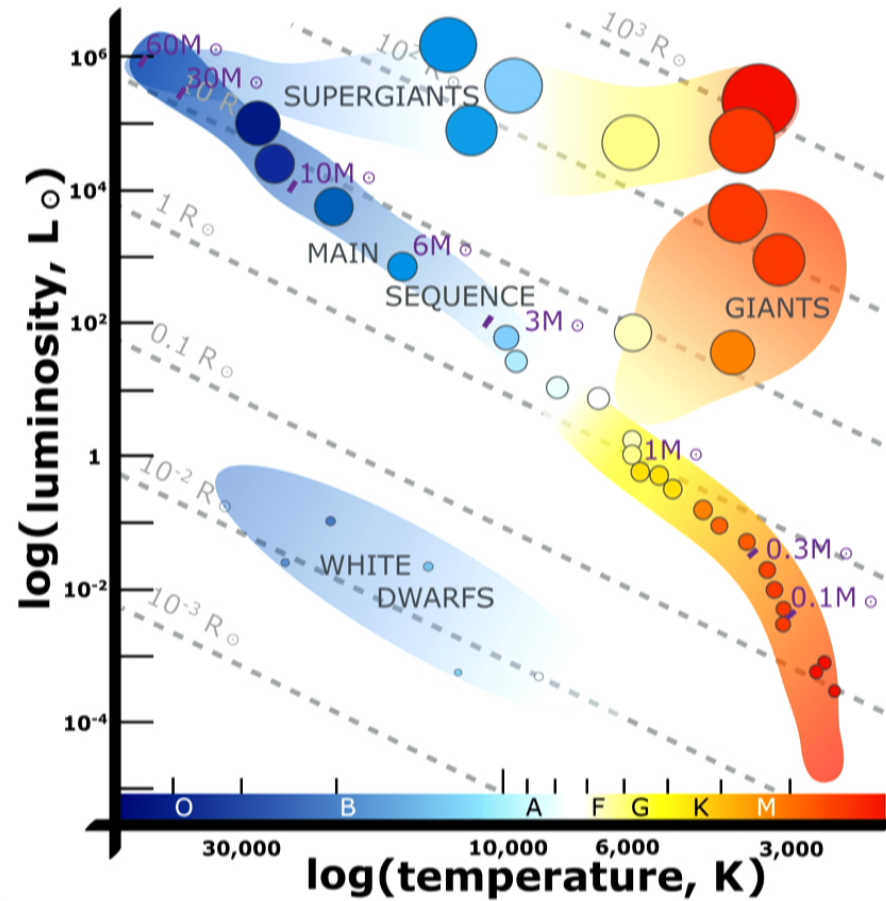
(effect comes from more free e^- at higher metallicity, which leads to a higher abundance of H^- , the main opacity source in cool star atmospheres with $\kappa \propto T^9$)

This leads to a warmer average T_{eff} - and a bluer average color - for RSG populations at low metallicity!



Challenges: RSGs in other galaxies

What range of luminosities (e.g. masses) should we be looking for?



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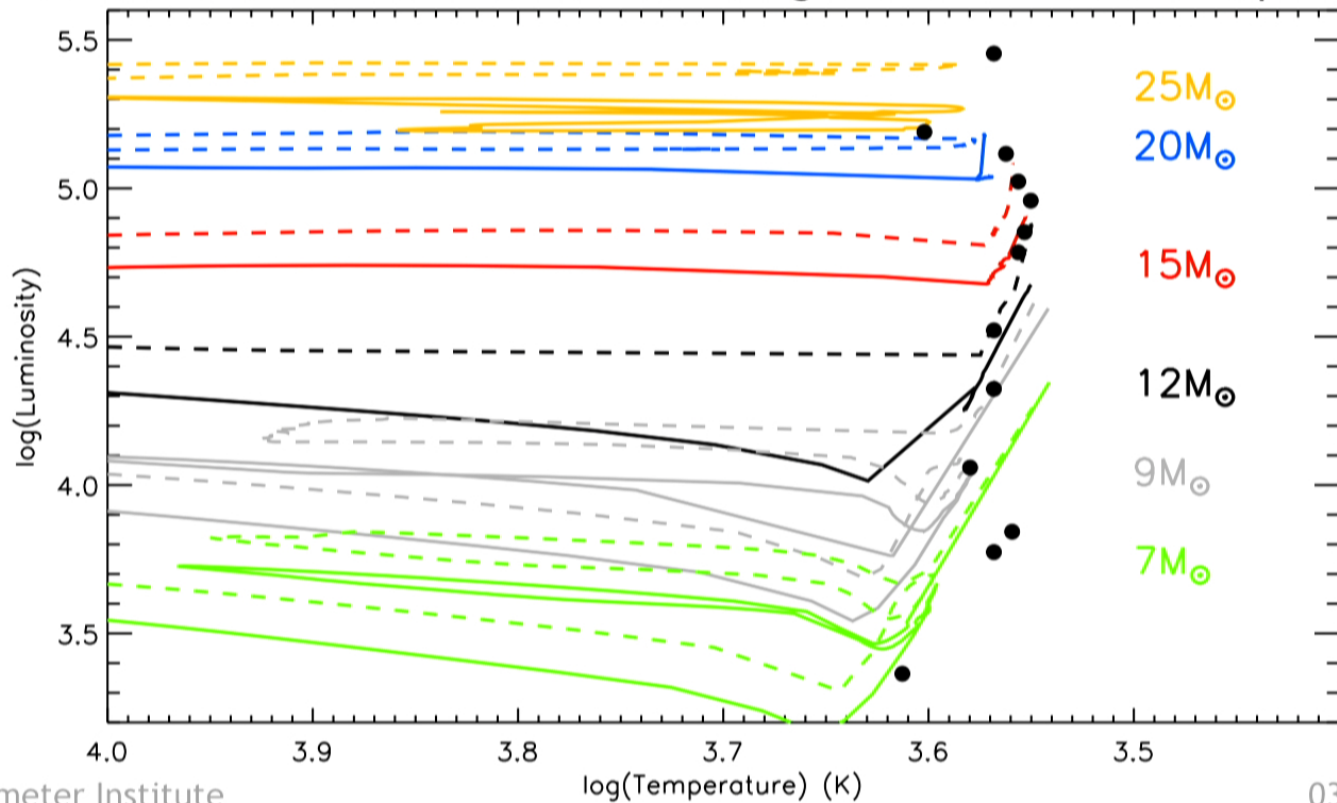
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Challenges: RSGs in other galaxies

What range of luminosities (e.g. masses) should we be looking for?

Should be straightforward to get a complete sample down to $\sim 8M_{\odot}$

...but contamination from the low-mass giant branch becomes a problem.

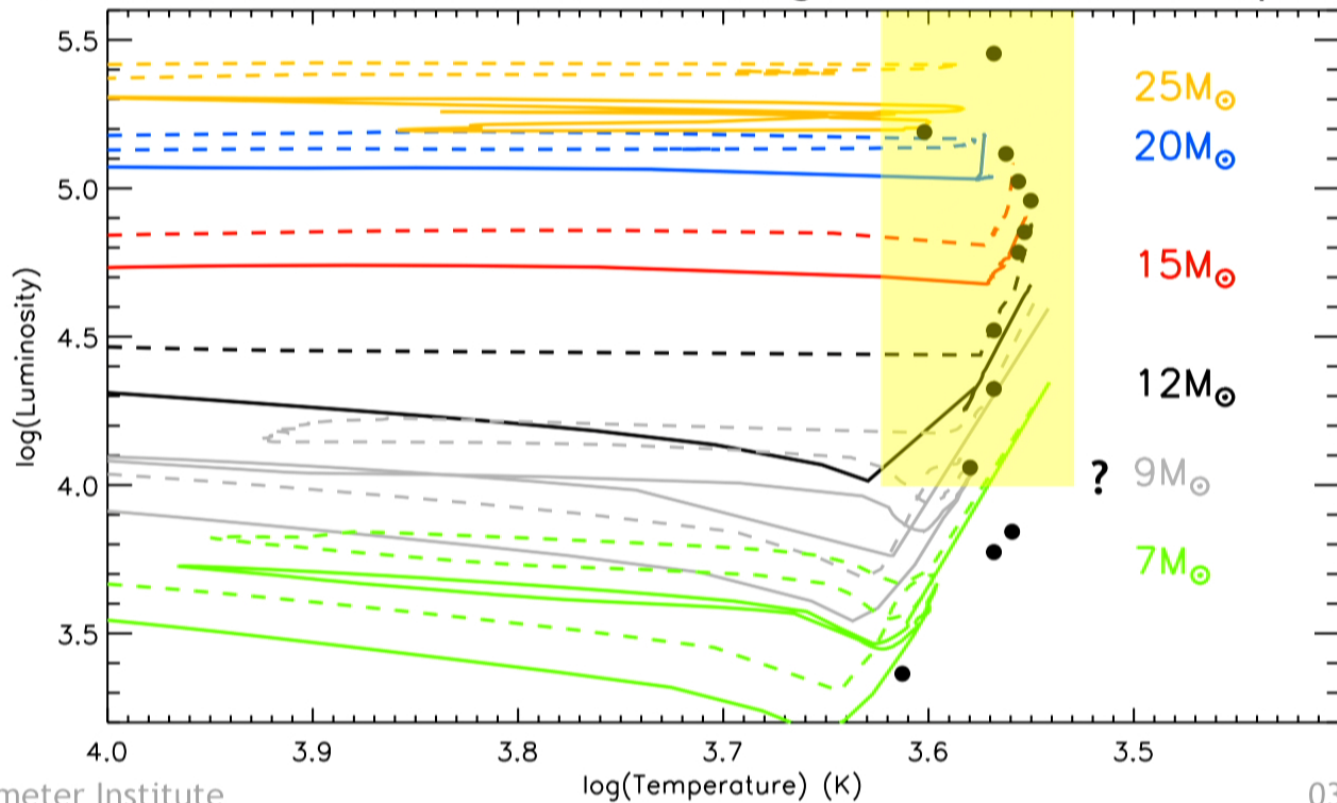


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Challenges: RSGs in other galaxies

What range of luminosities (e.g. masses) should we be looking for?

Other parameters can also impact the RSG luminosity range:

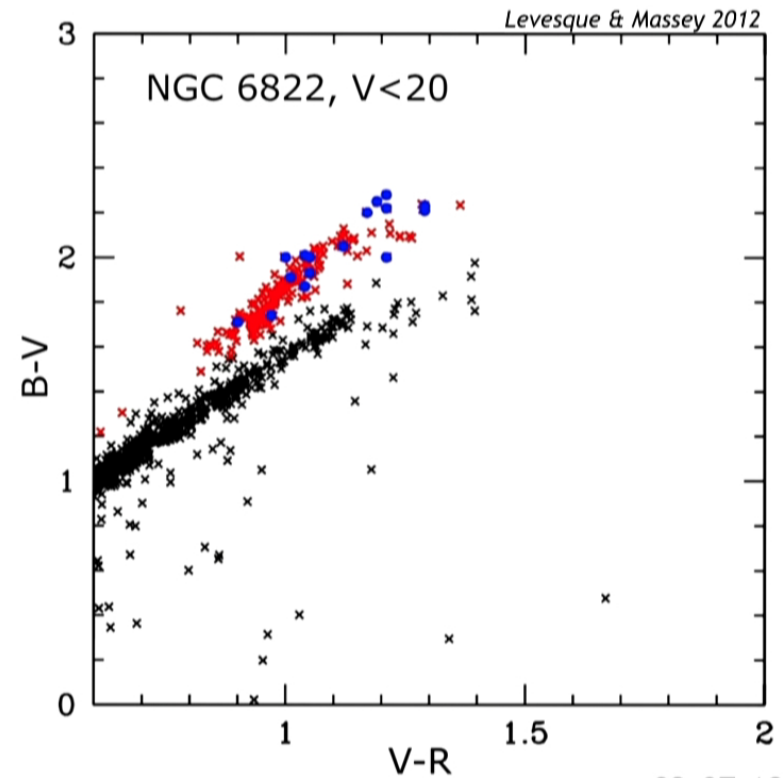
- distance accuracy
- metallicity
- circumstellar dust
- photometric variability



Challenges: RSGs in other galaxies

How can we distinguish actual RSG members from...

- foreground dwarfs?
 - colors
 - kinematics



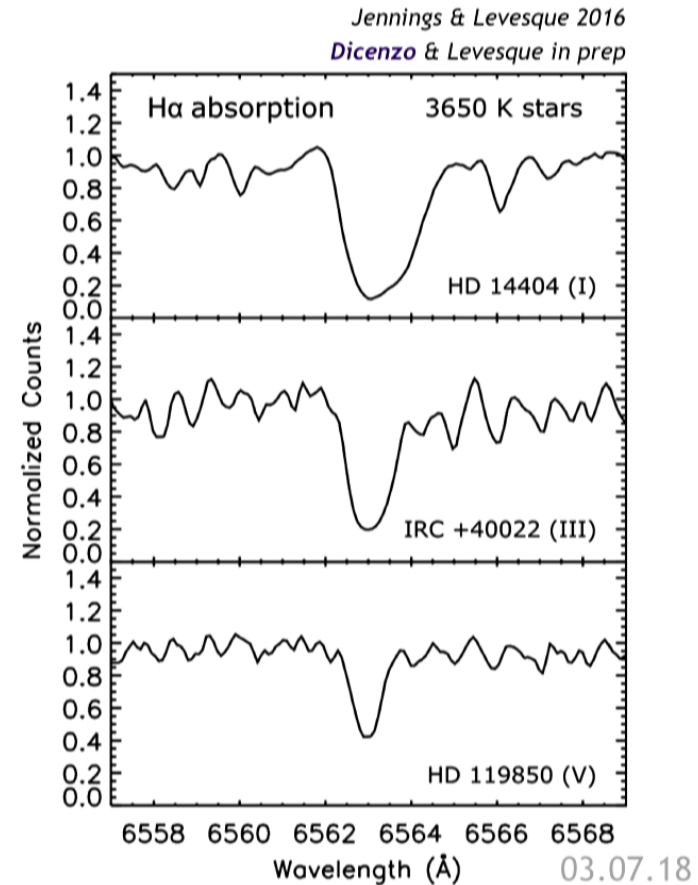
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Challenges: RSGs in other galaxies

How can we distinguish actual RSG members from...

- foreground dwarfs?
 - colors
 - kinematics
- foreground giants?
 - kinematics
 - surface gravities

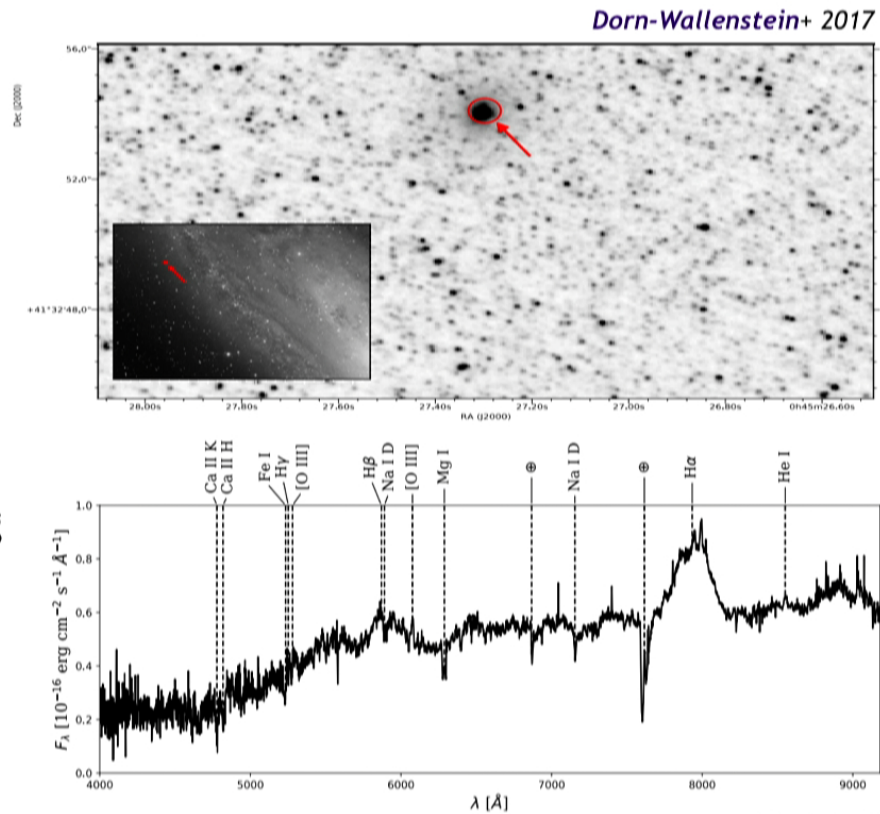


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Challenges: RSGs in other galaxies

How can we distinguish actual RSG members from...

- foreground dwarfs?
 - colors
 - kinematics
- foreground giants?
 - kinematics
 - surface gravities
- background galaxies?
 - deep/resolved imaging
 - spectroscopy



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Challenges: RSG mass loss

RSGs shed an enormous amount of mass from their outer layers during their lifetimes...



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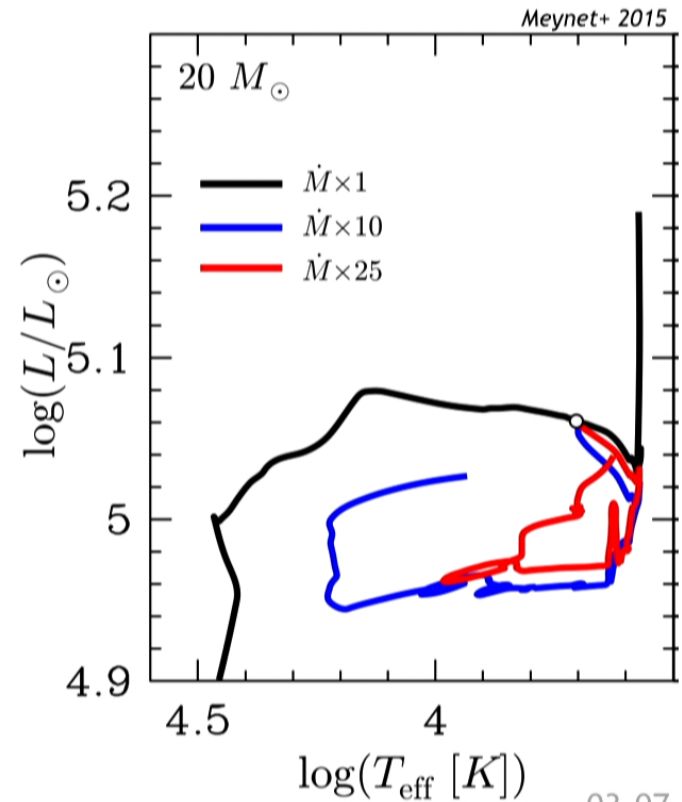
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Challenges: RSG mass loss

RSGs shed an enormous amount of mass from their outer layers during their lifetimes...which can dramatically impact their evolution.



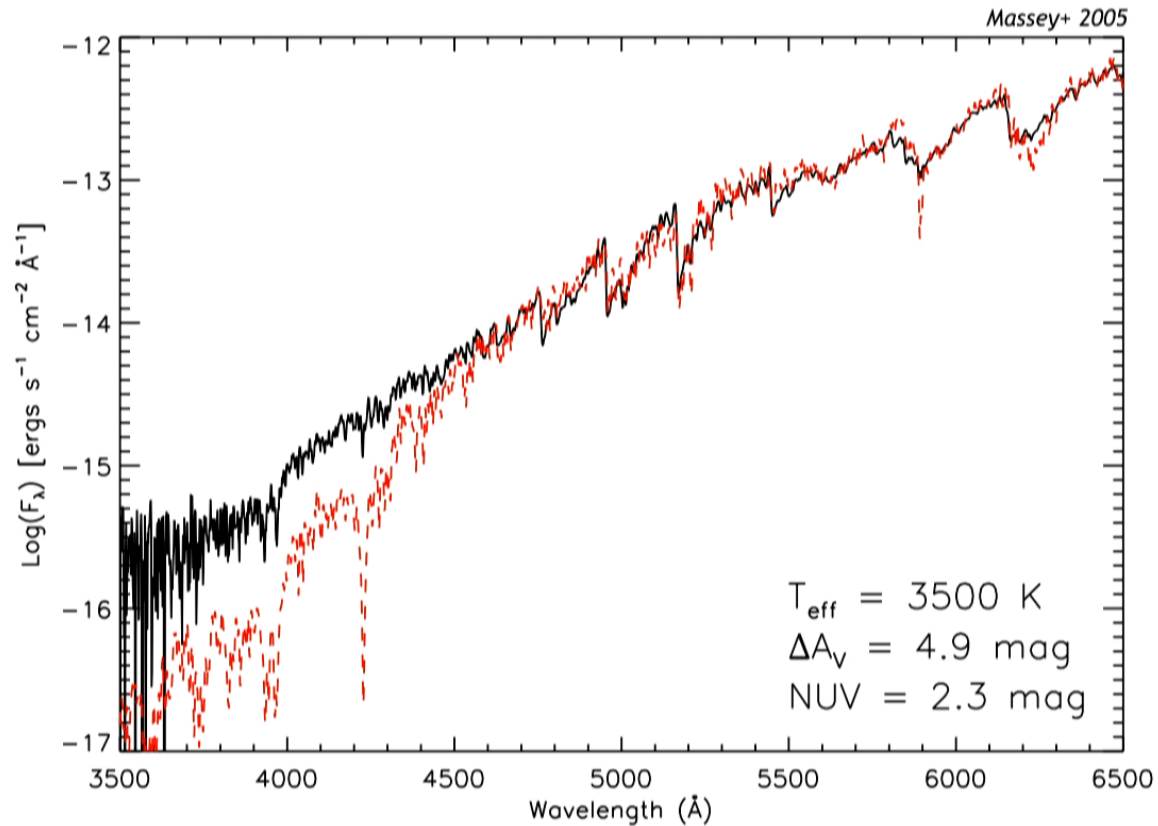
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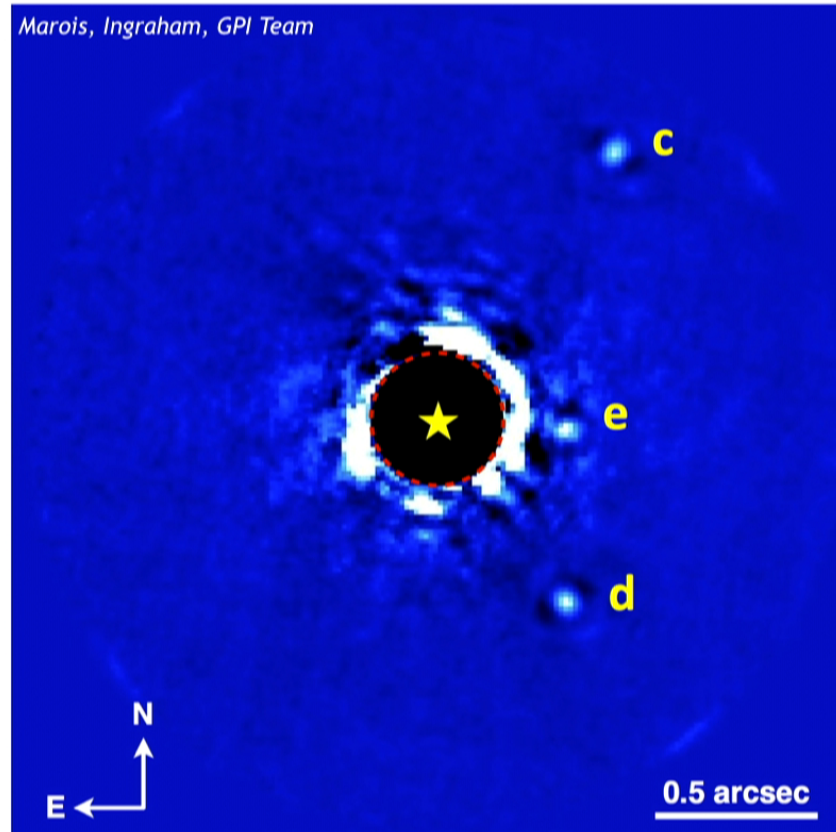


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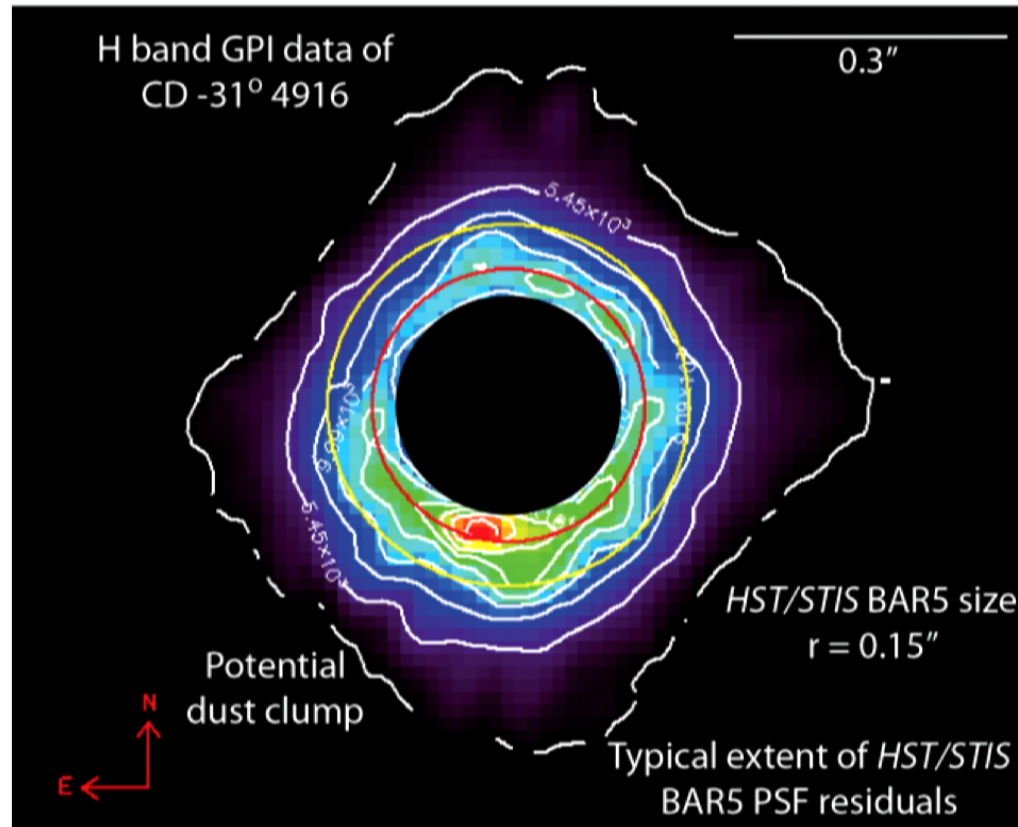


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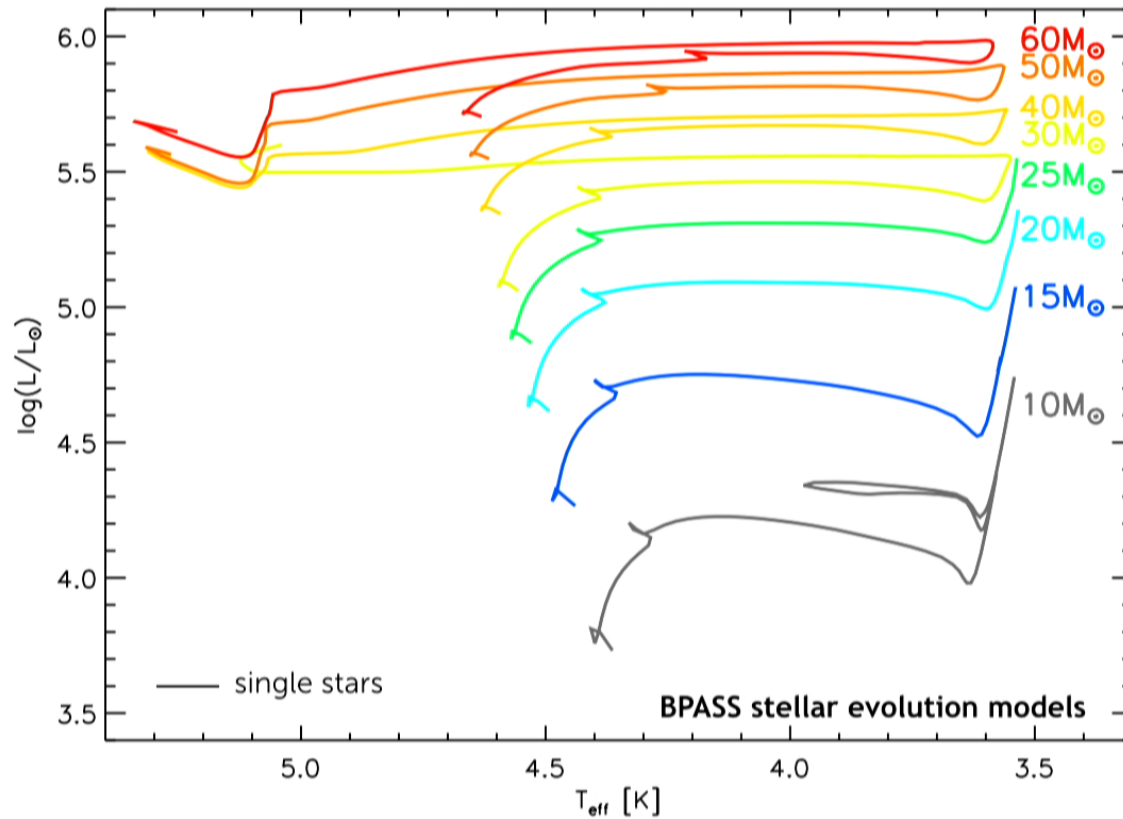
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Lomax+ in prep

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Challenges: RSGs in binaries

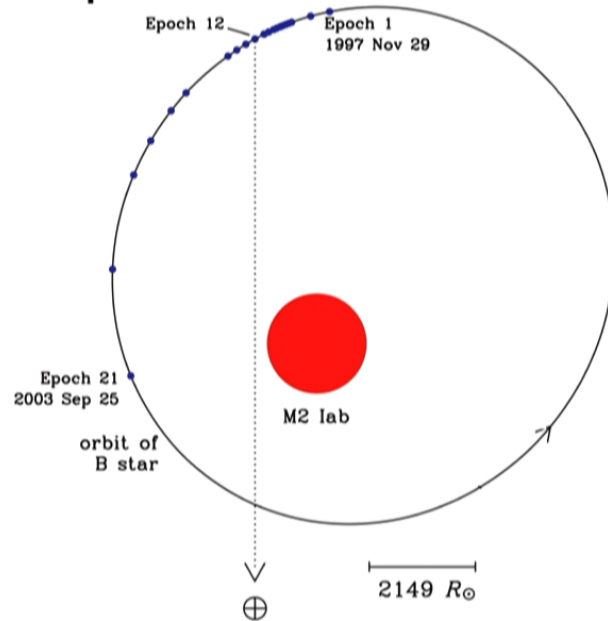
Binary evolution can also *dramatically* impact how RSGs lose mass, evolve, and die...



Challenges: RSGs in binaries

Binary evolution can also *dramatically* impact how RSGs lose mass, evolve, and die...but we know almost nothing about binary RSGs.

VV Cephei



adapted from Bauer+ 2007

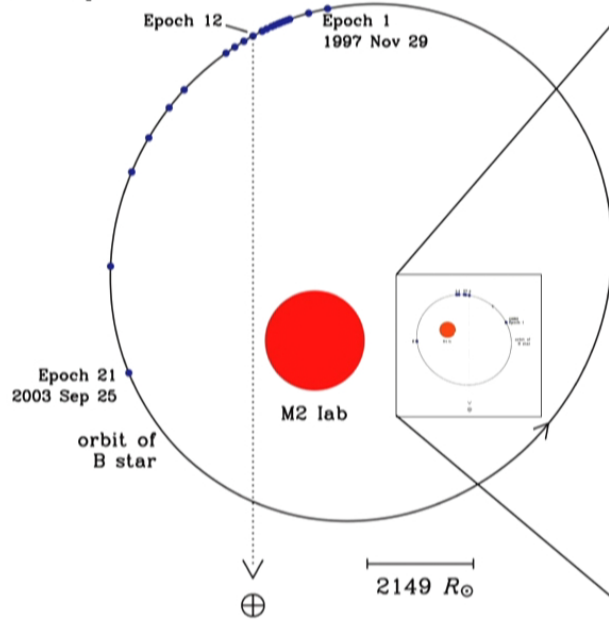
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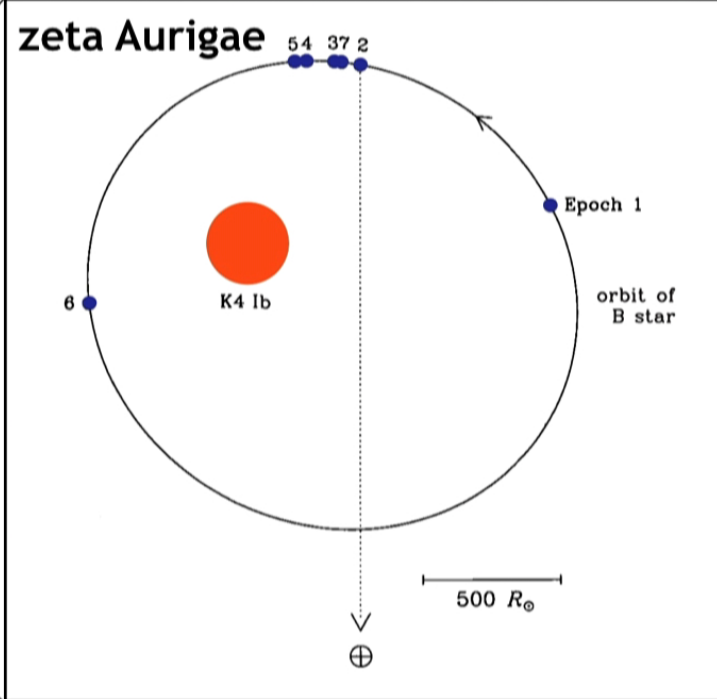
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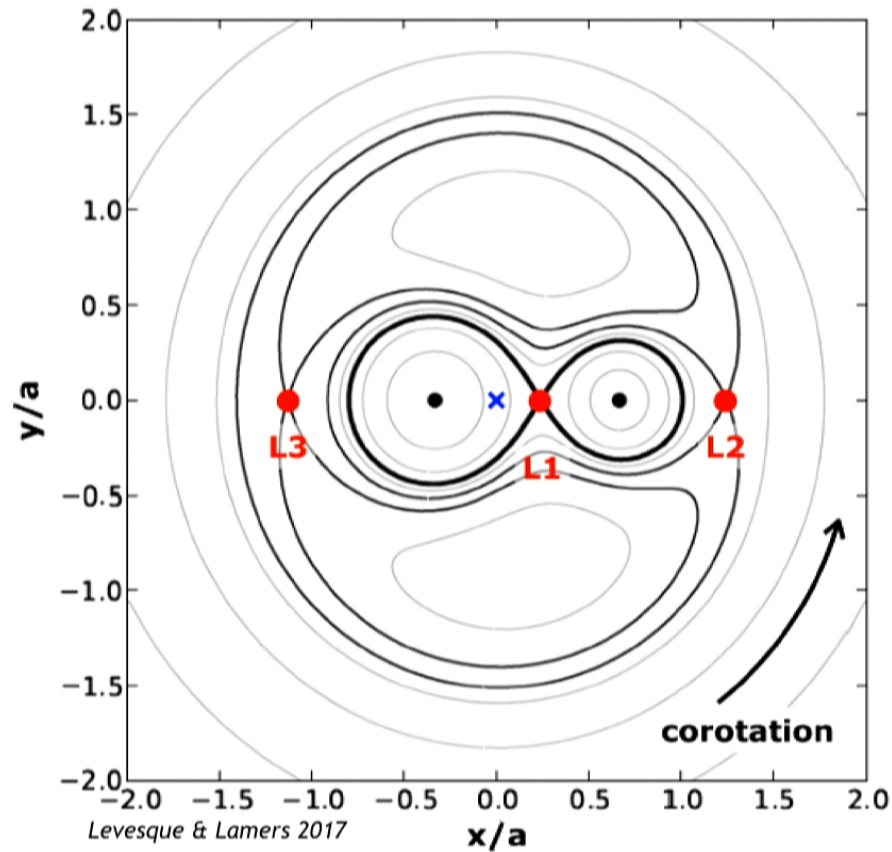


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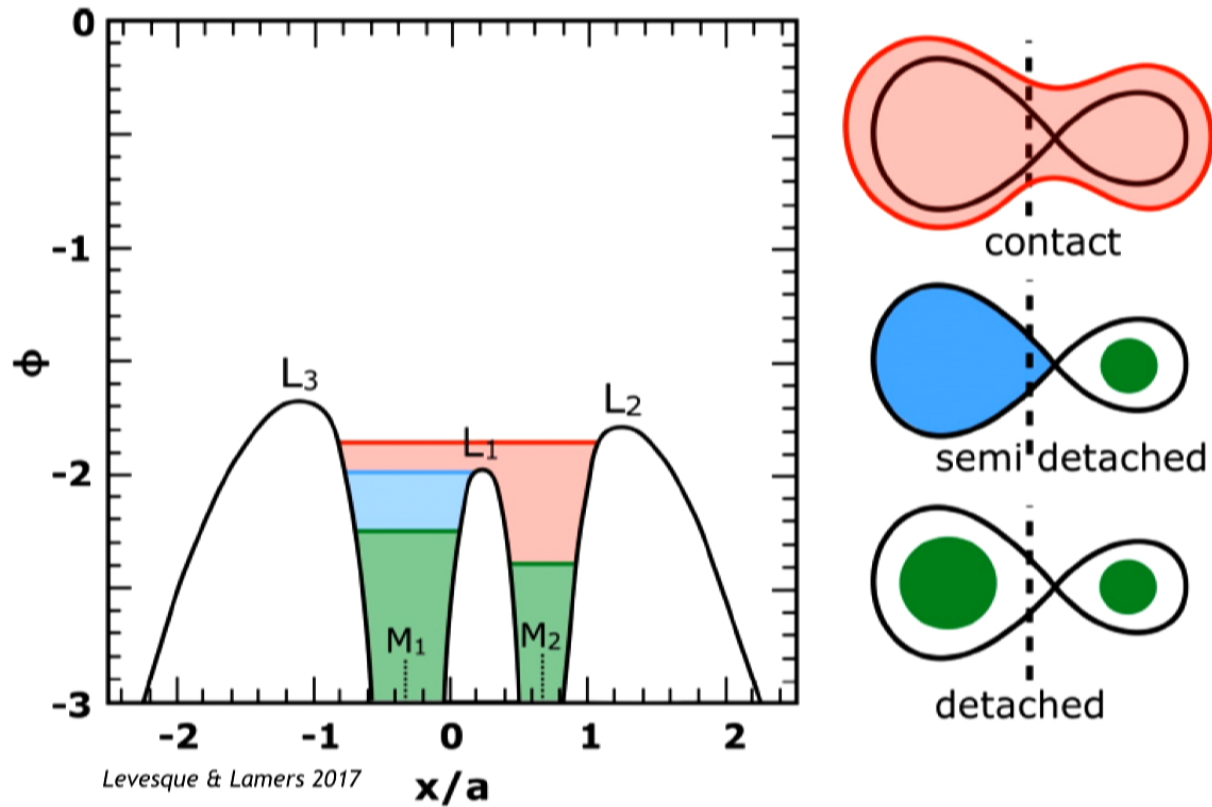
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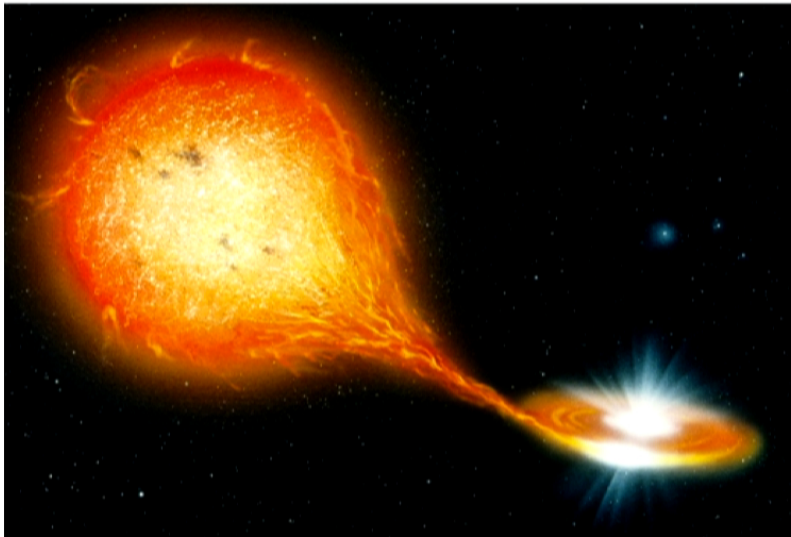
Challenges: RSGs in ~~binaries~~ ???

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Can form via engulfing



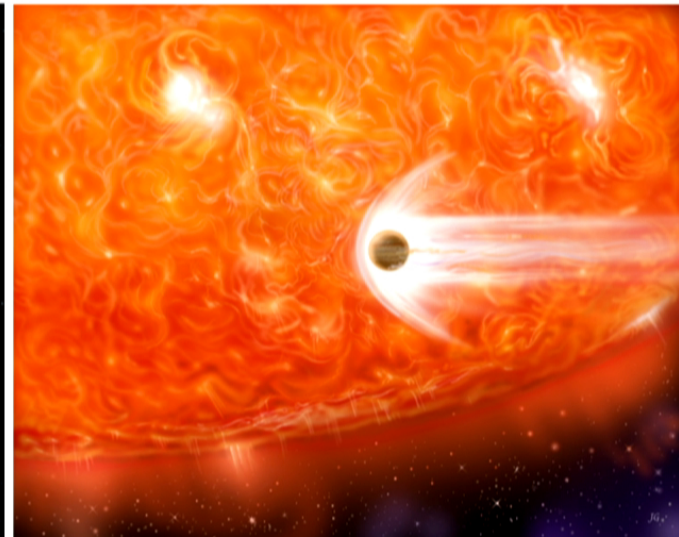
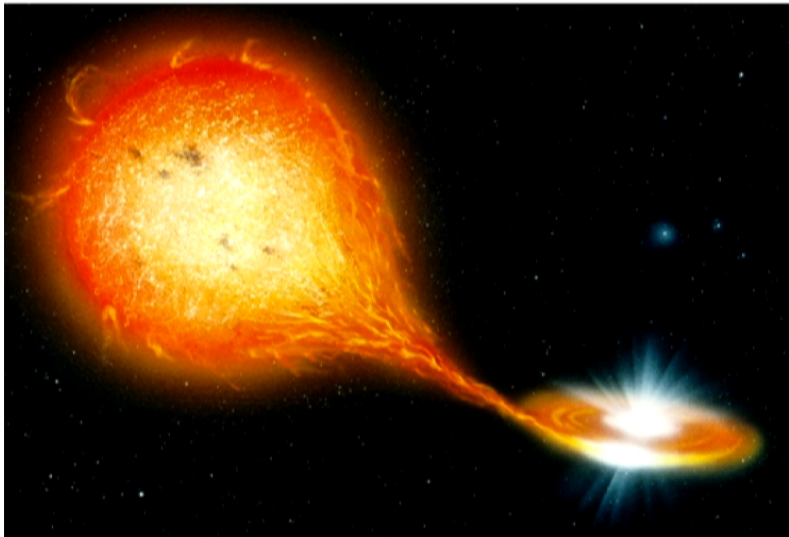
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Challenges: RSGs in ~~binaries~~ ???

Thorne-Żytkow Objects (TZO) are a theoretical class of star: a neutron star “core” surrounded by a large diffuse envelope.

Can form via engulfing or collision scenarios in massive binaries, and represent a new model for stable stellar interiors.

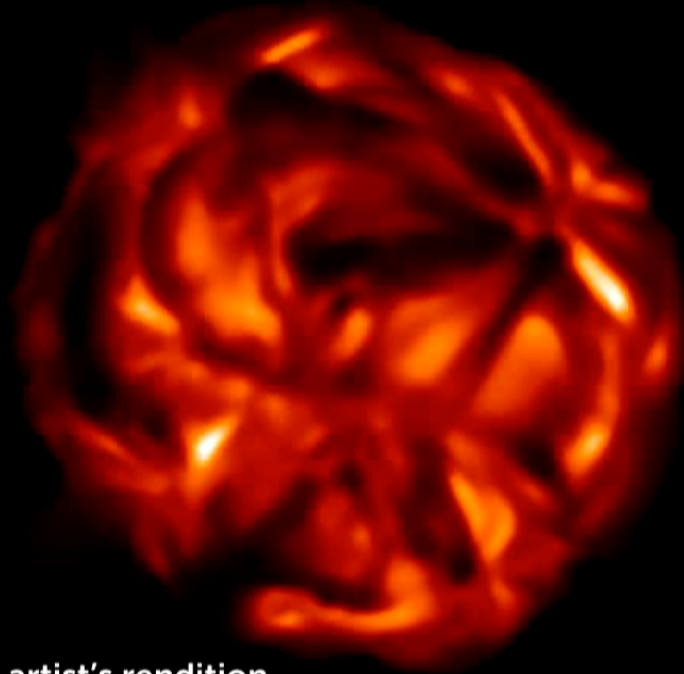


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Challenges: RSGs in ~~binaries~~ ???

TZO's look exactly like red supergiants...

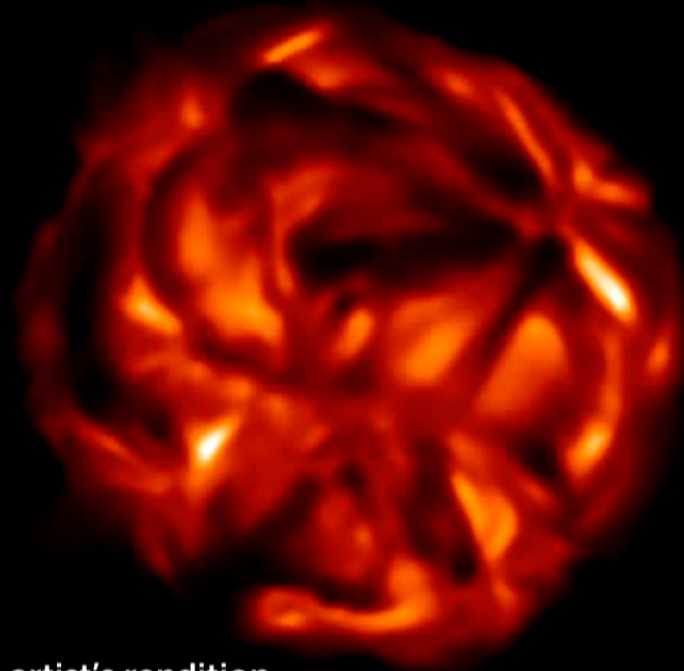


artist's rendition

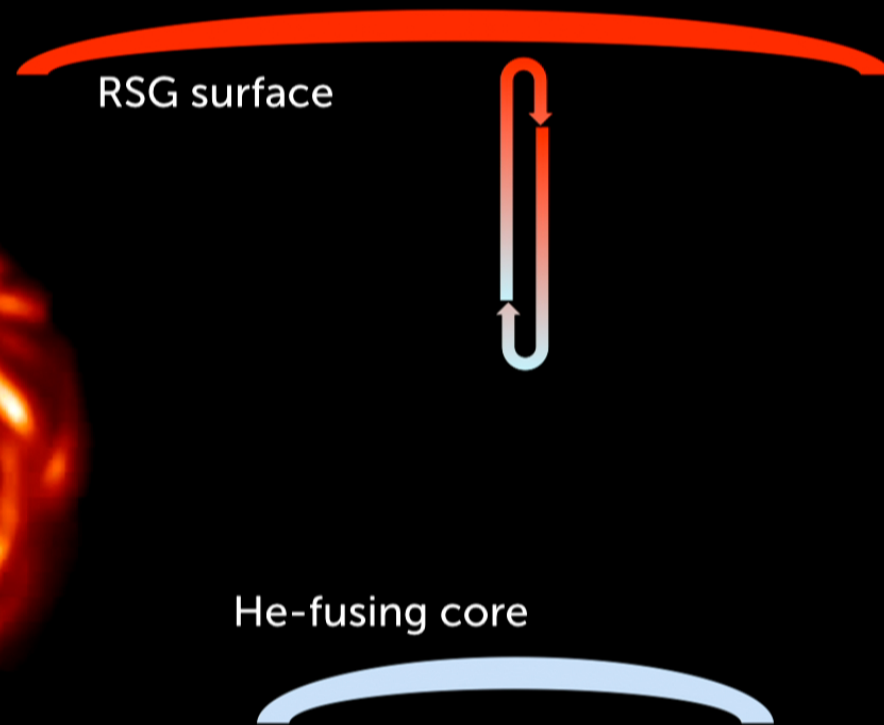
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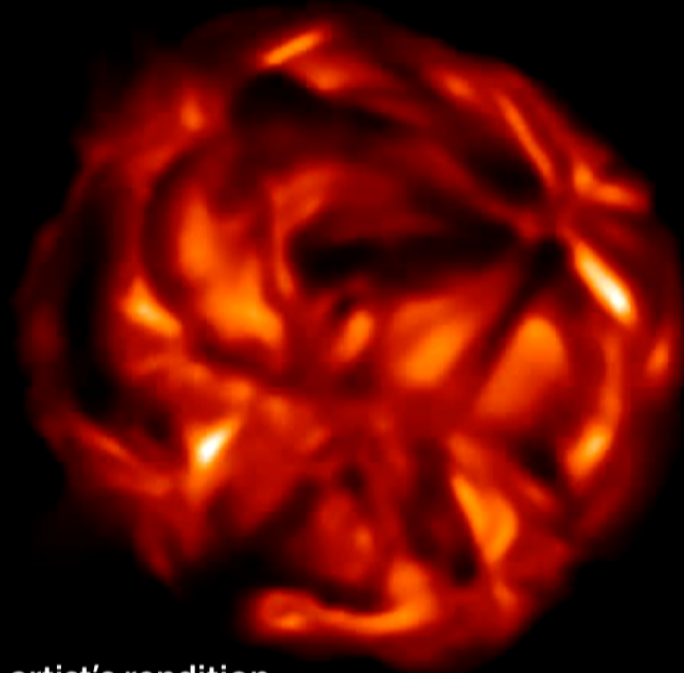
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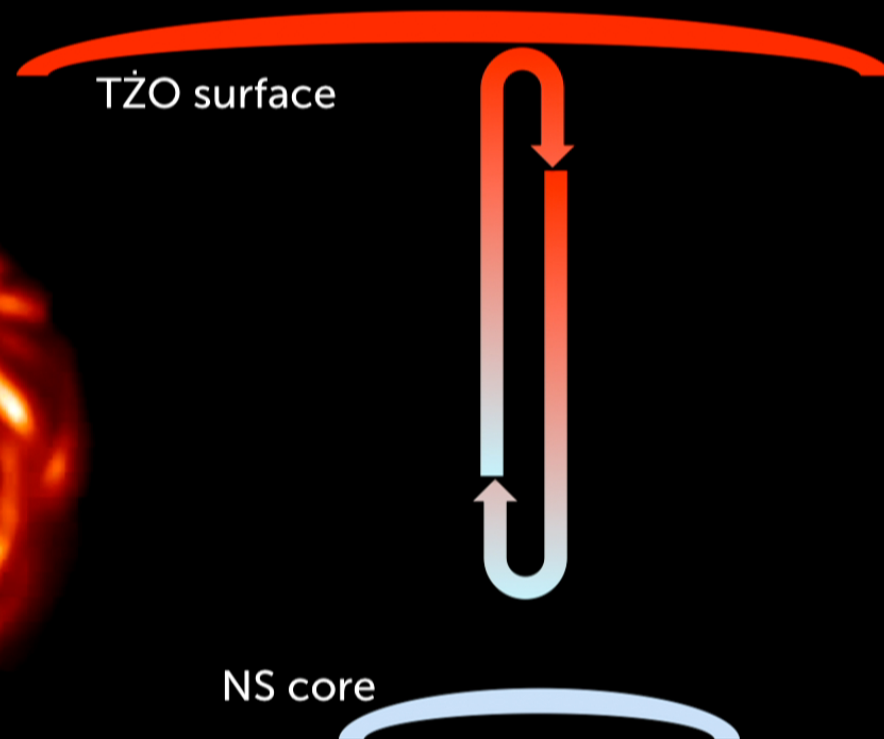
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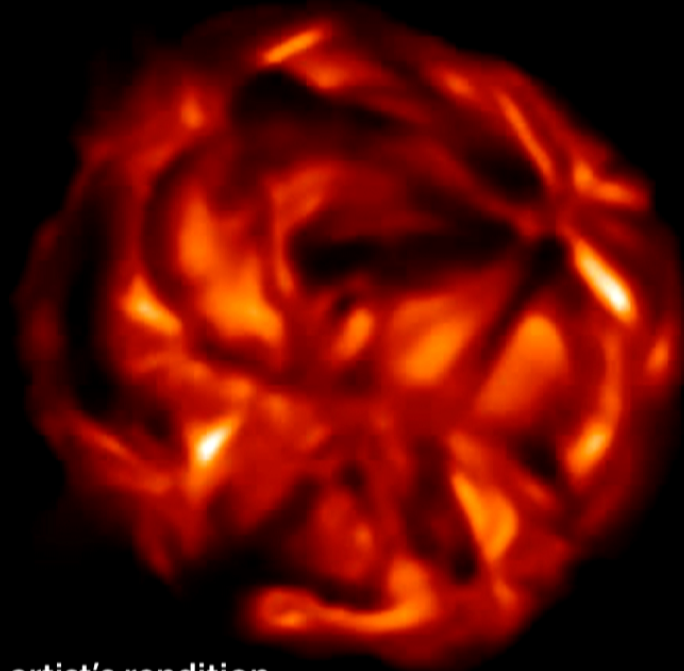
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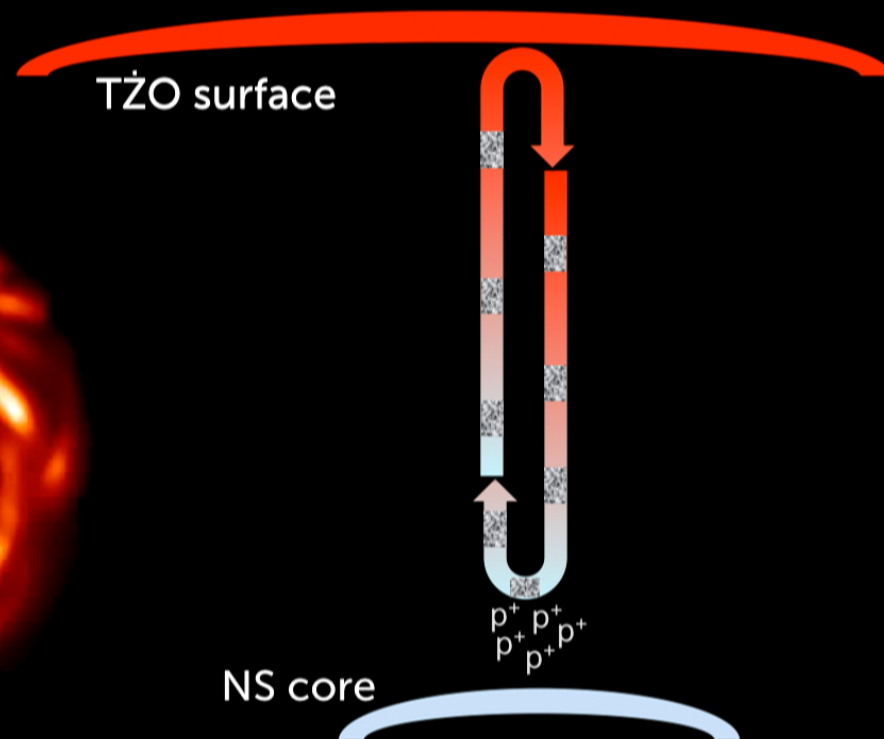
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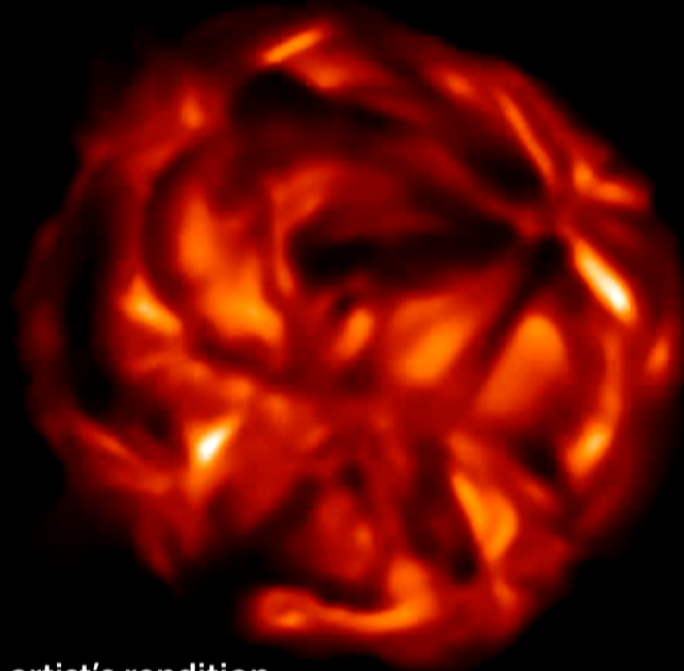
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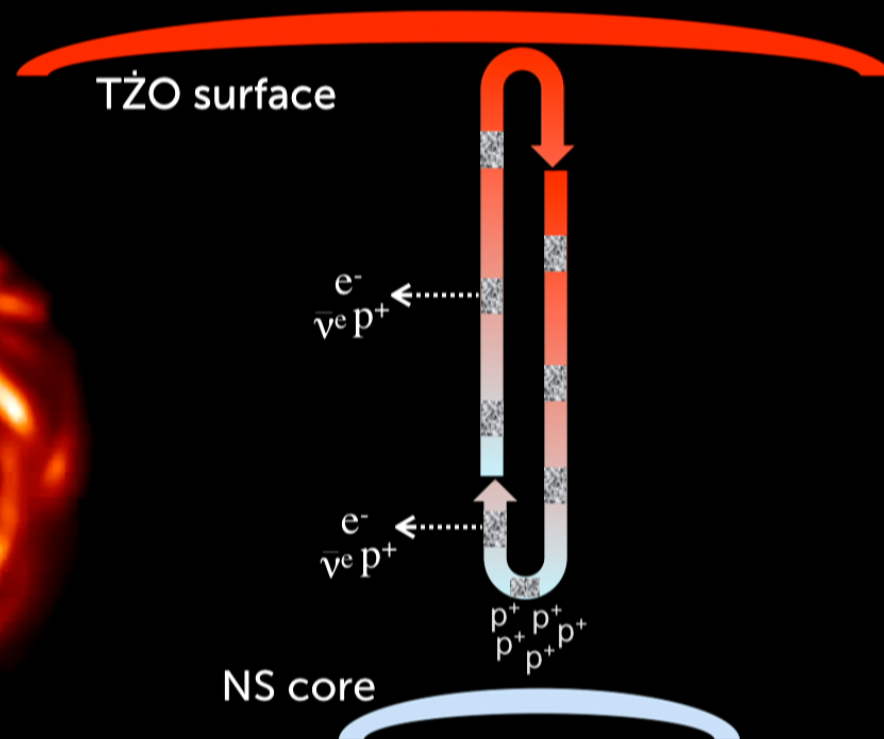
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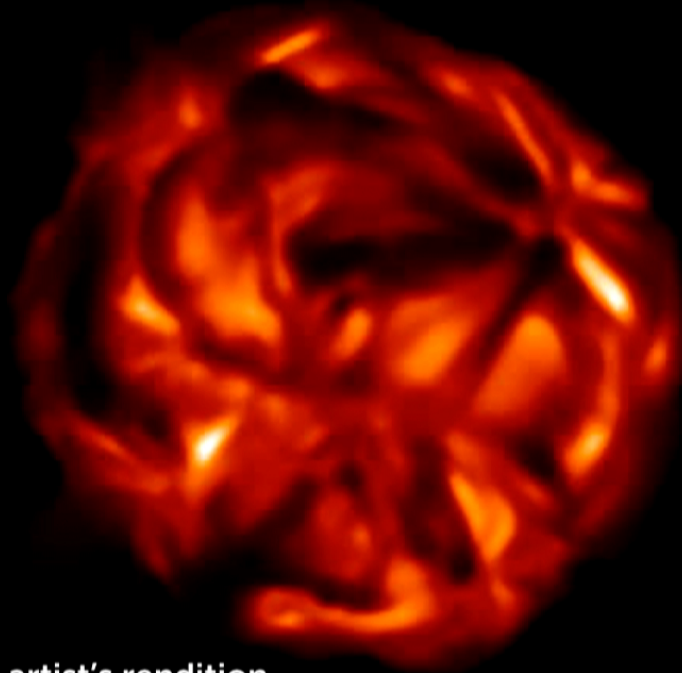
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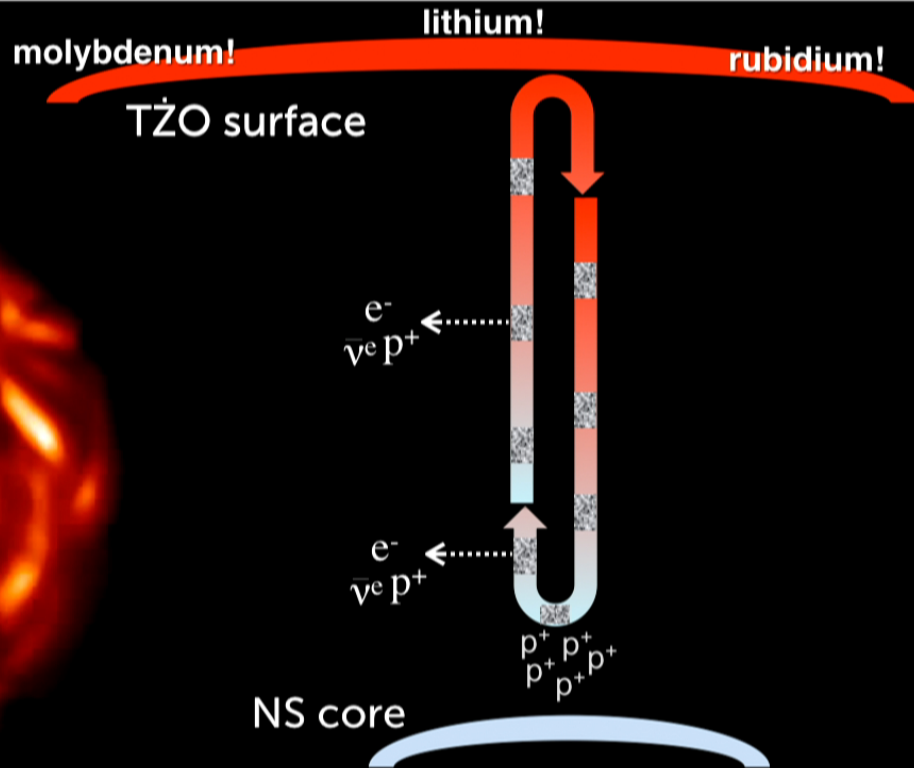
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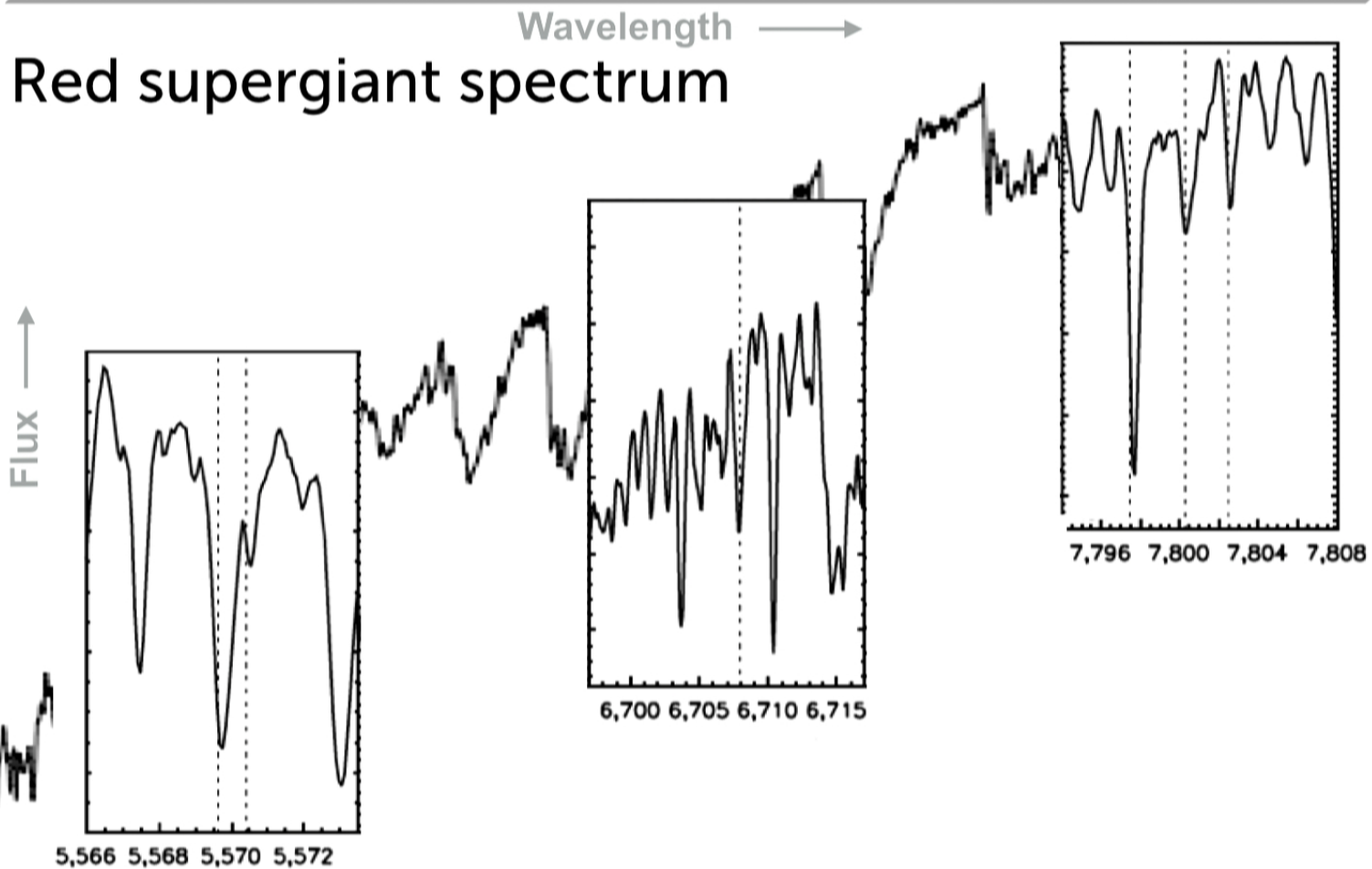
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artist's rendition



Challenges: RSGs in ~~binaries~~ ???

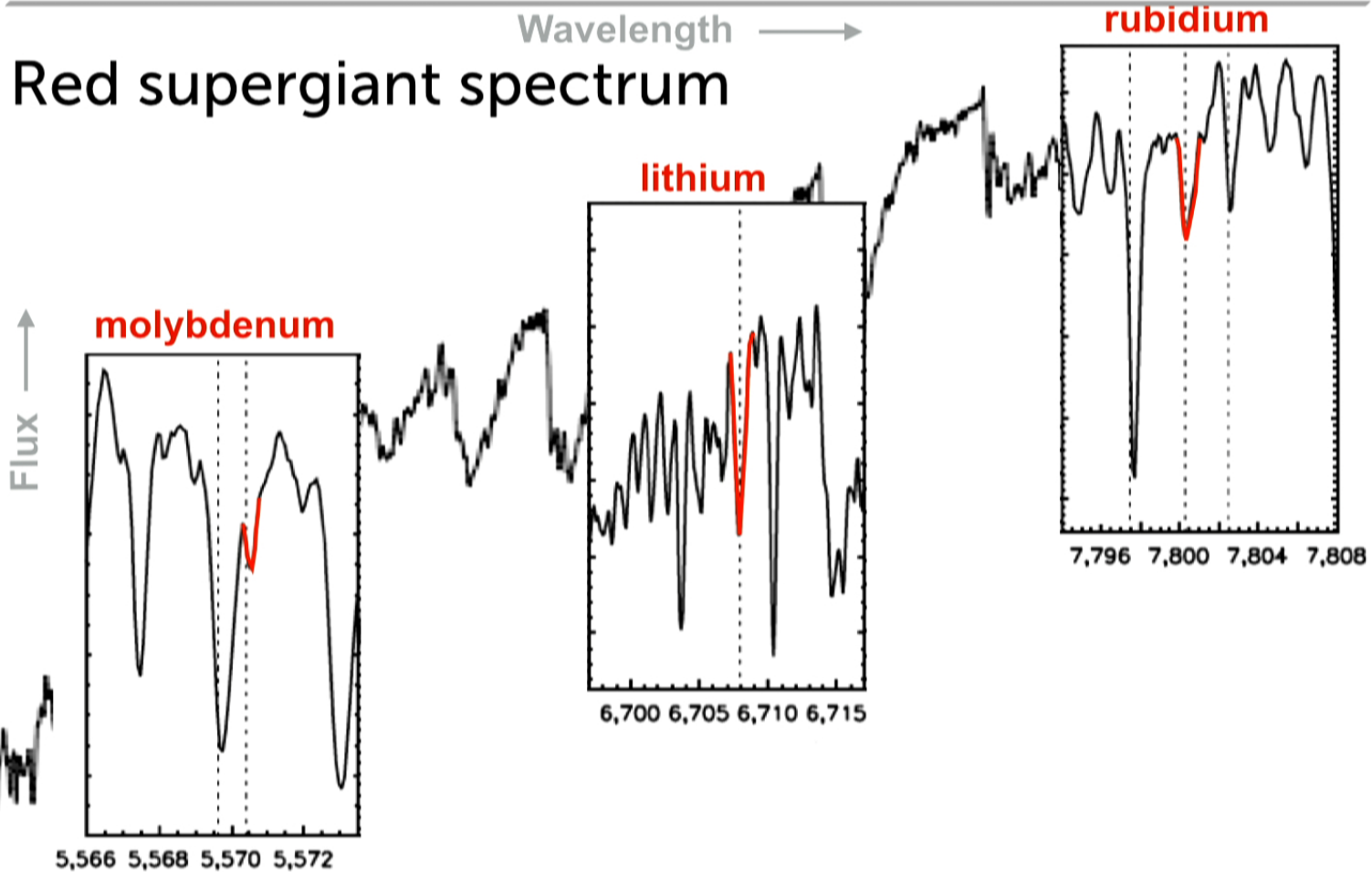


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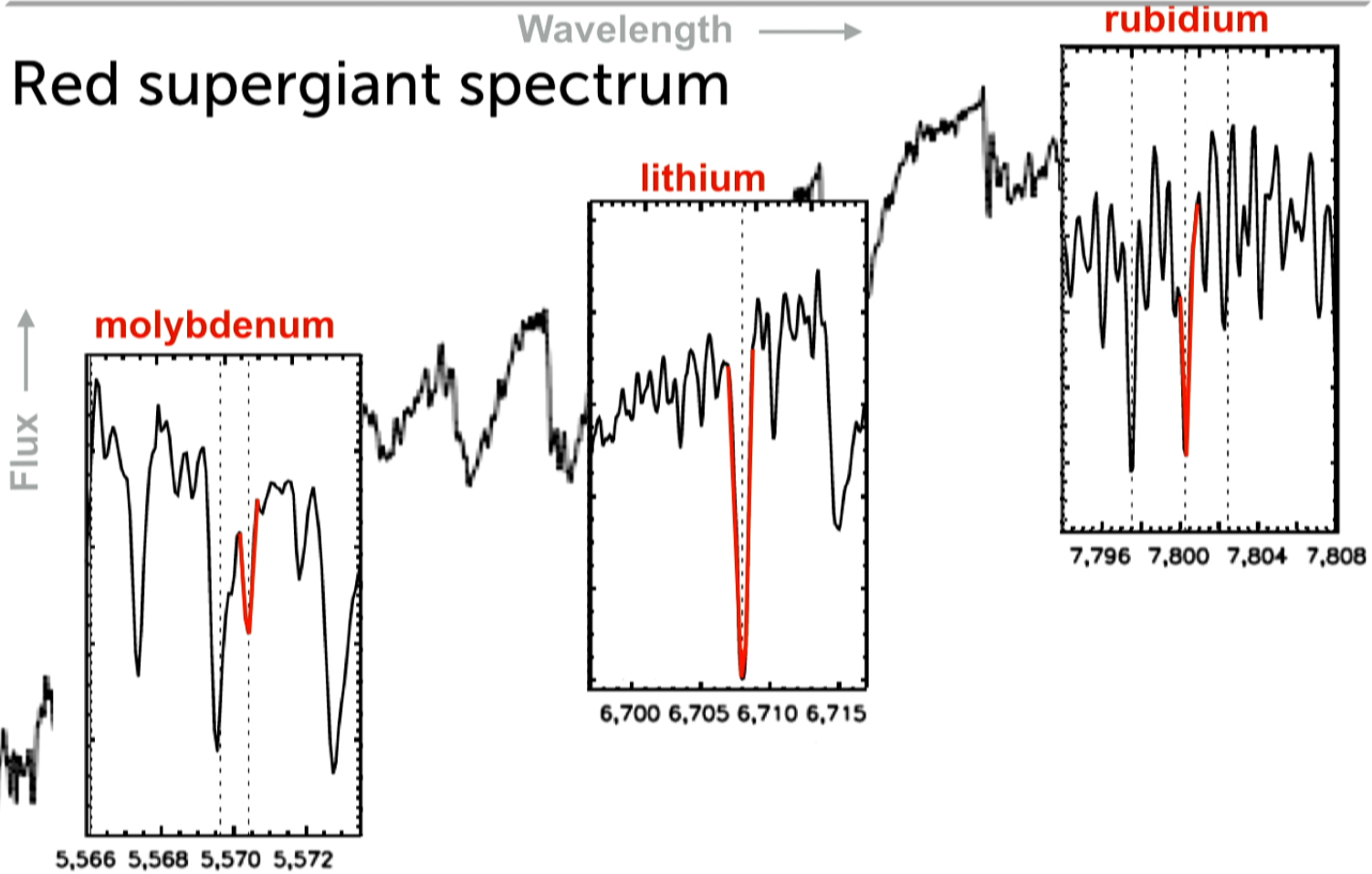


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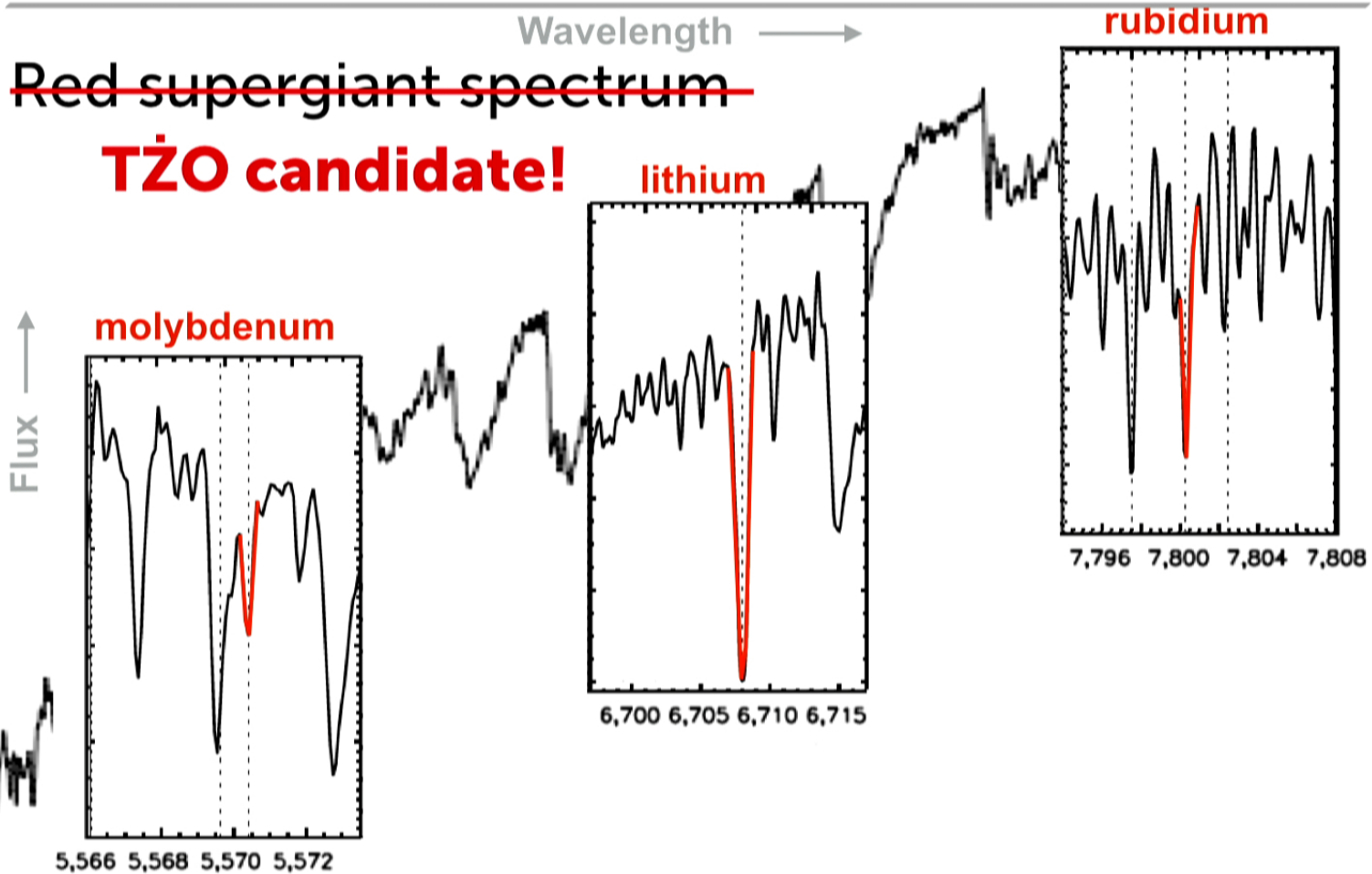


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Challenges: RSGs in ~~binaries~~ ???



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Who *cares* about red supergiants?

massive star formation
early universe chemistry
gravitational waves
massive star evolution
stellar populations
galaxy compositions
strange and variable stars
time-domain astronomy
infrared astronomy

mass loss in cool stars
stellar magnetic fields
YOU DO!
supernova progenitors
stars in the early universe
compact objects

dust production
massive binary fraction
mass loss in massive stars
mass-transfer binaries
stellar rotation
nucleosynthesis

Applications of RSGs

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gravitational waves

supernova progenitors

strange and variable stars

Applications of RSGs

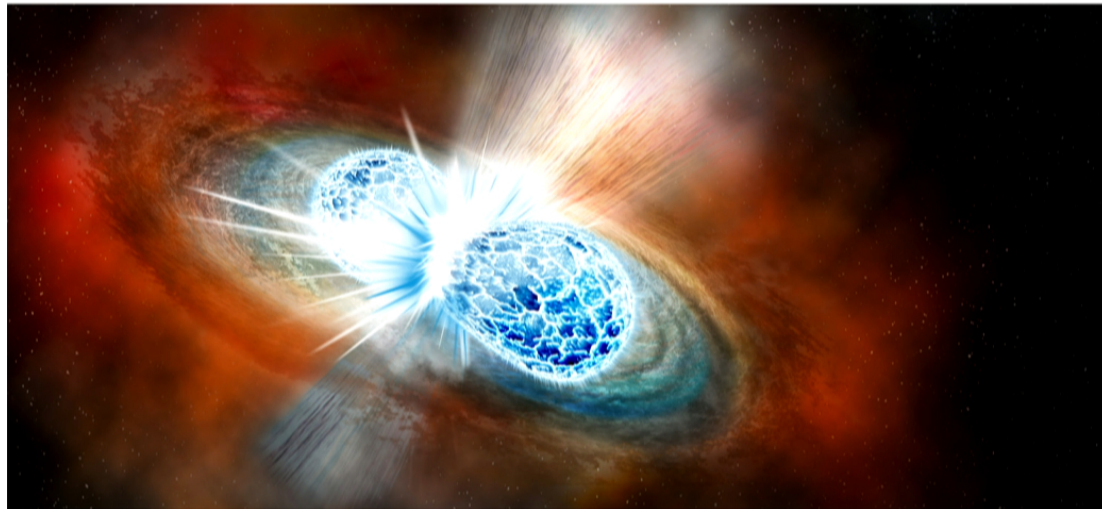
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gravitational waves - colliding neutron stars have evolved from RSGs in binaries

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Applications of RSGs

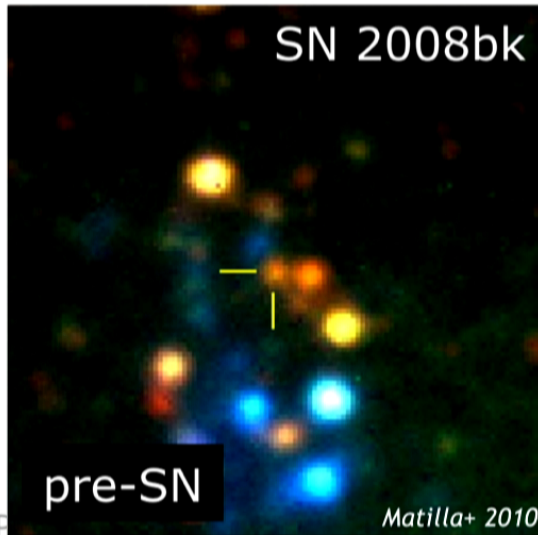
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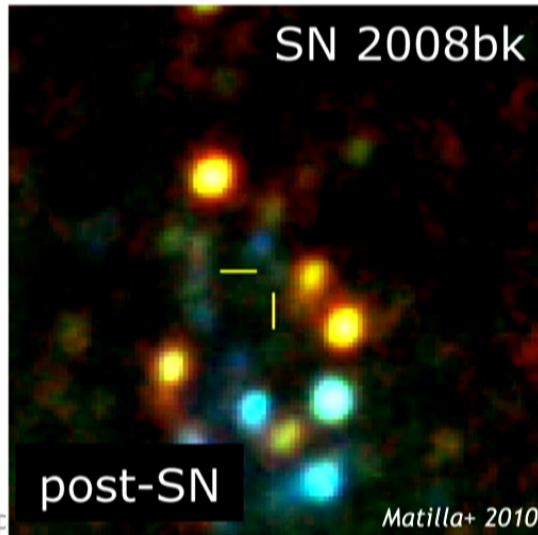
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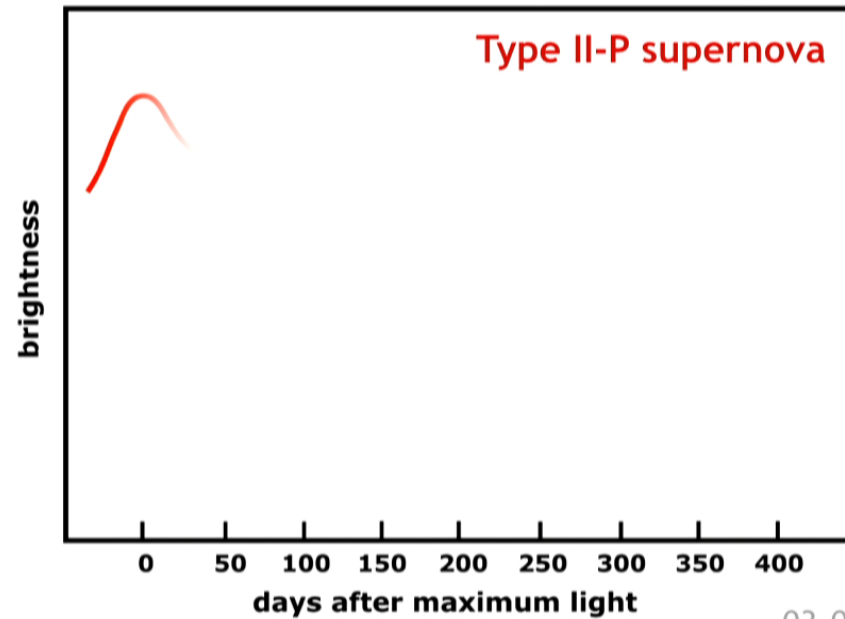
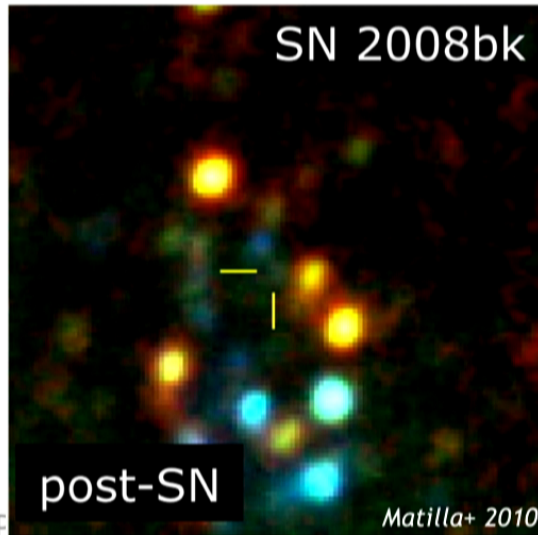
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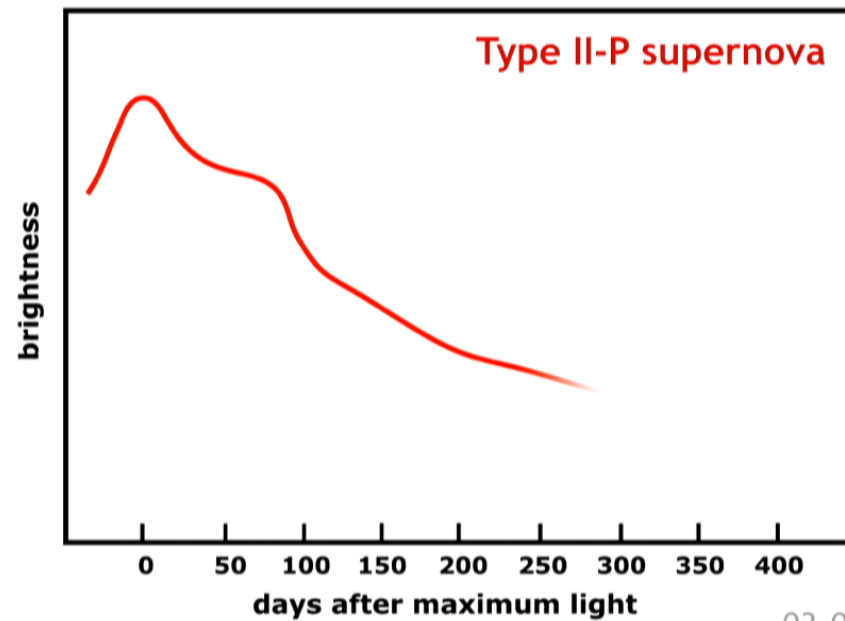
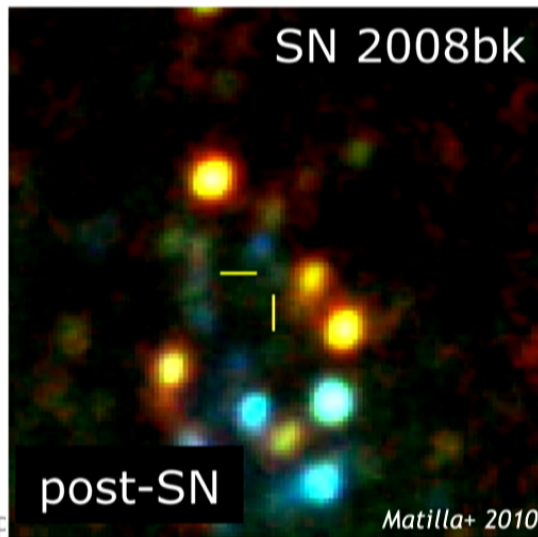
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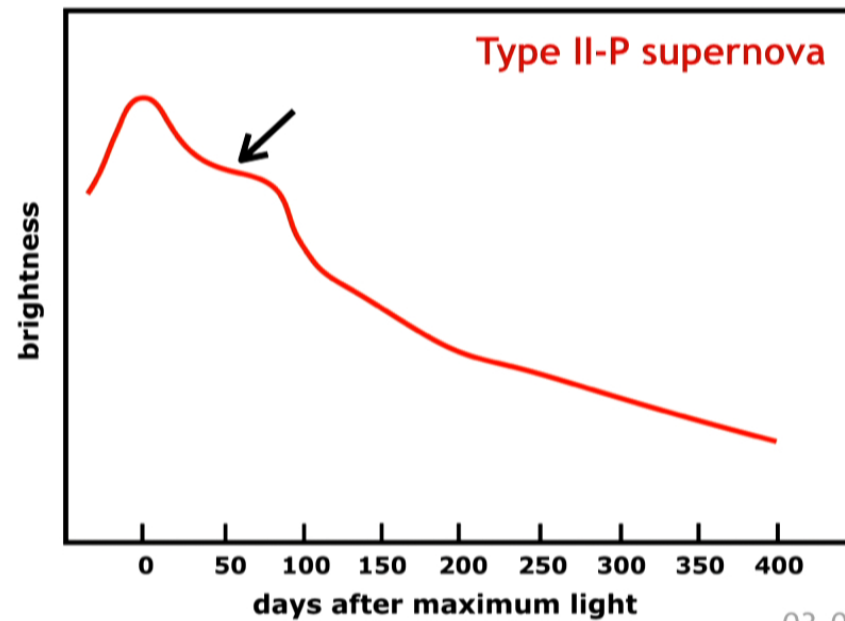
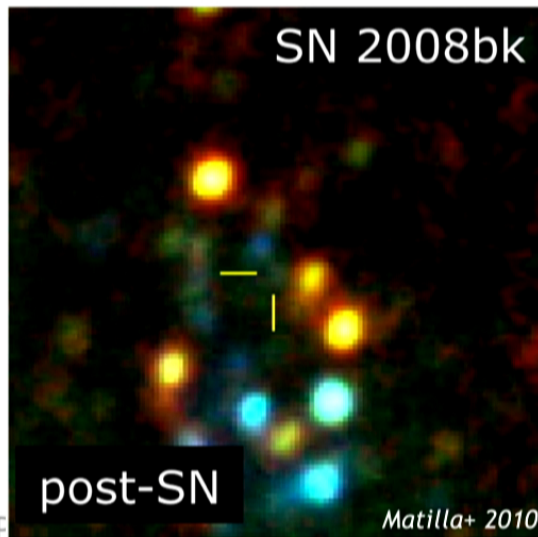
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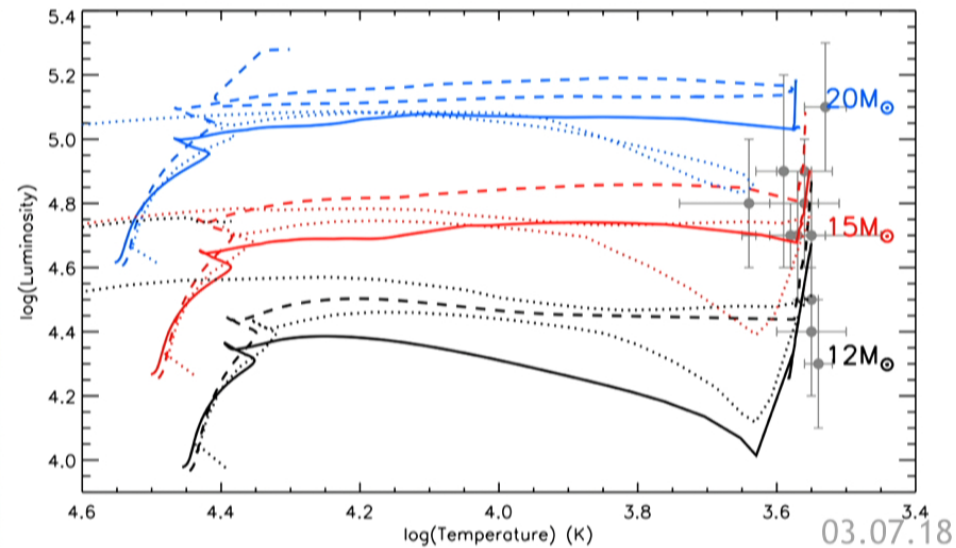
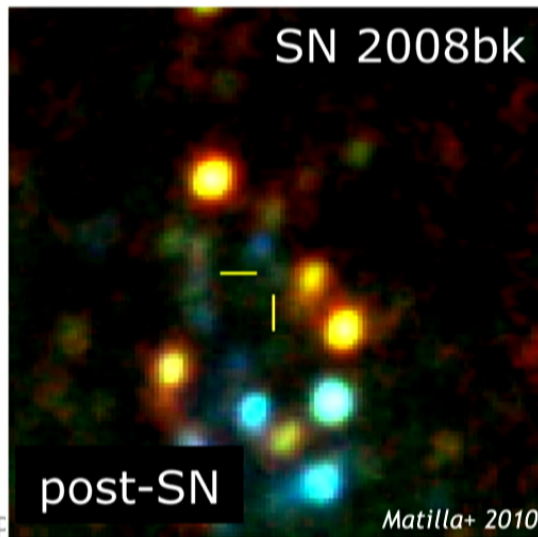
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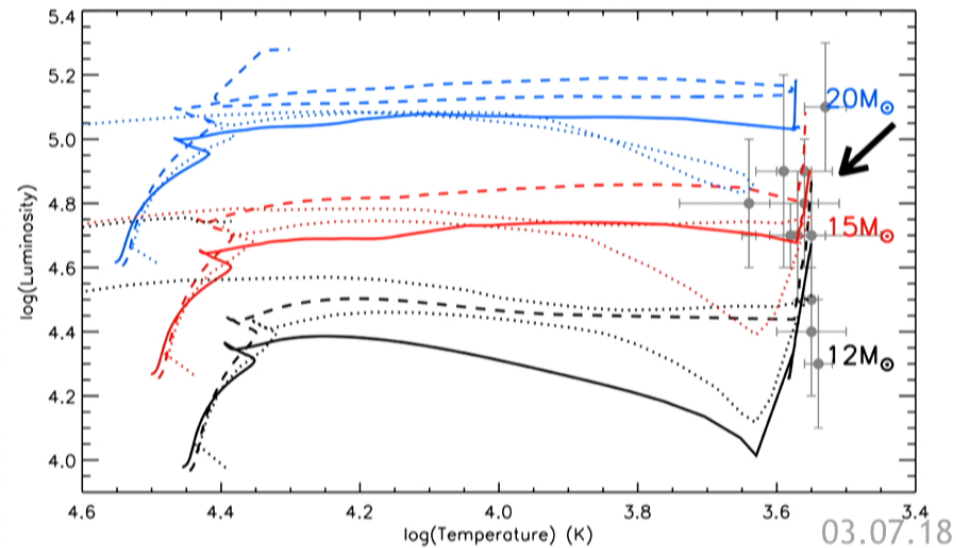
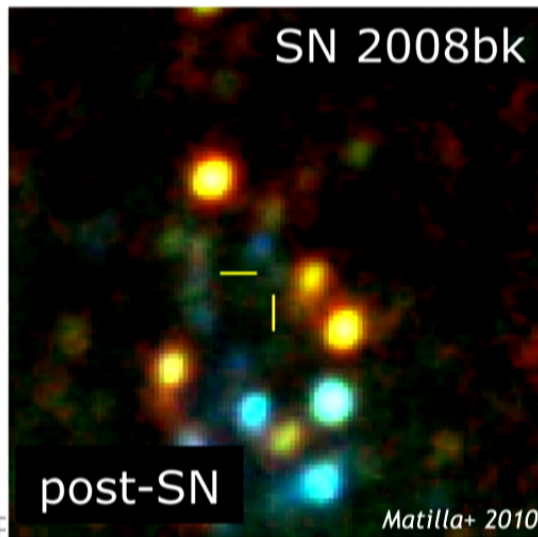
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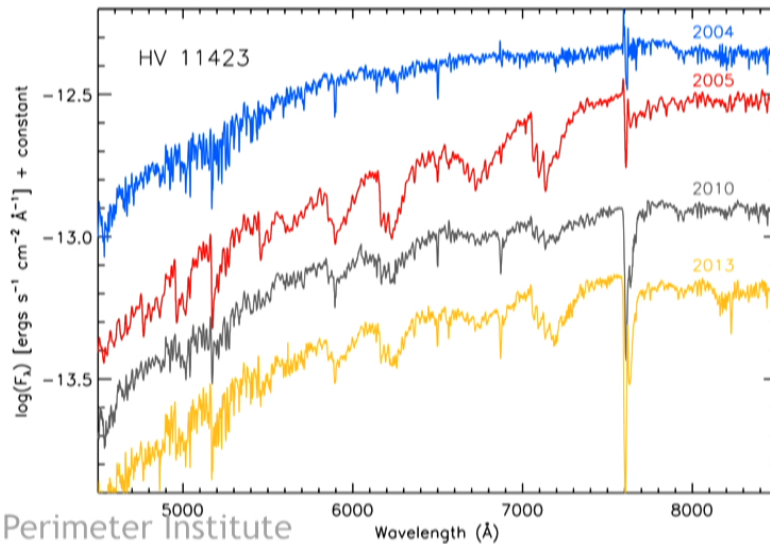
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strange and variable stars - photometric and spectroscopic variability

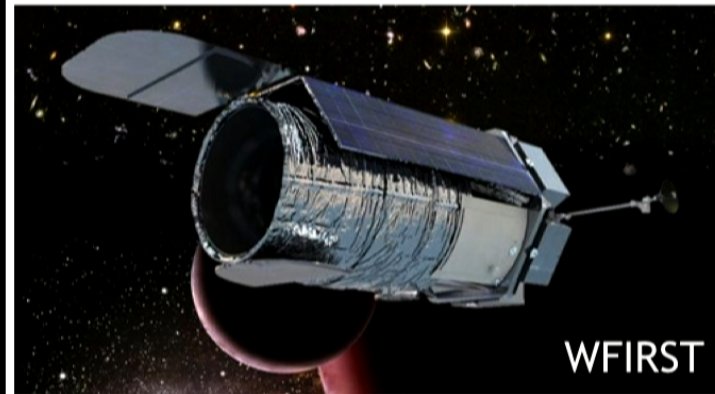
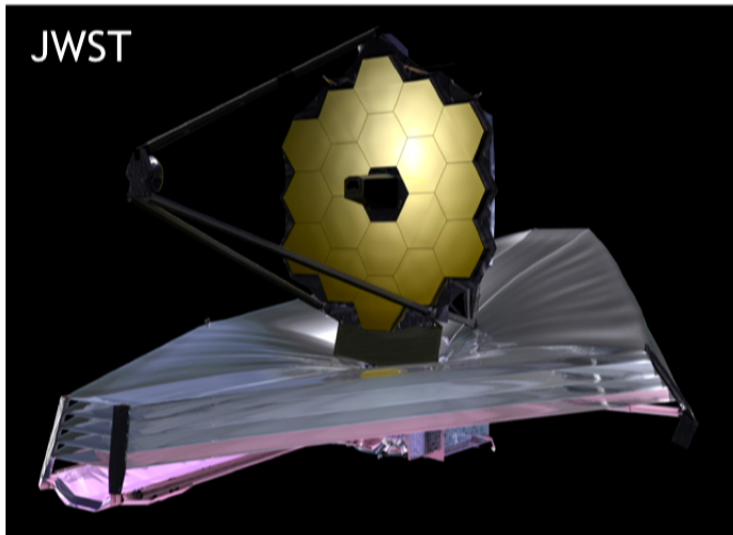


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What's next for RSGs?

- Upcoming space telescopes will be focused on IR observations...

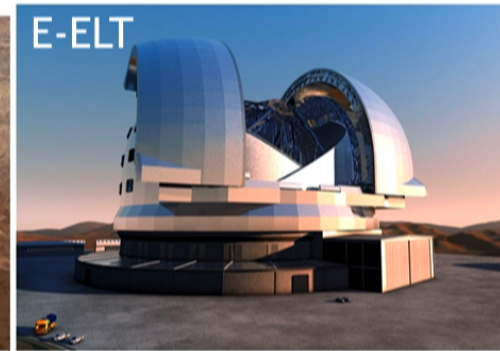
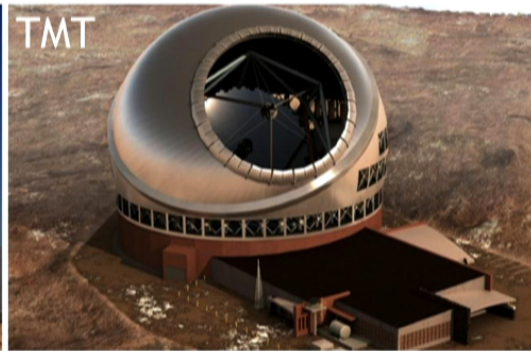
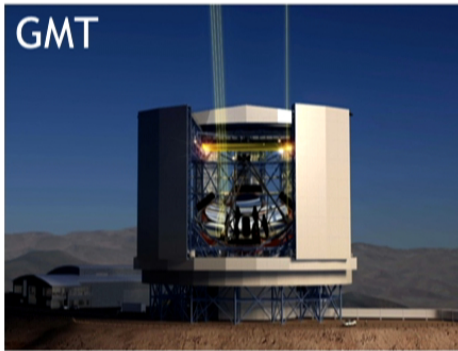


Ideal for:

- local and extragalactic RSGs (including pre-imaging SN progenitors!)
- observing RSG mass loss and dust production

What's next for RSGs?

- Upcoming space telescopes will be focused on IR observations...
- The ELTs will be excellent tools for stellar astrophysics...



Ideal for:

- spectra of extragalactic RSGs (stellar populations, stellar metallicities, etc.) out to ~50 Mpc!
- adaptive optics imaging of very distant RSG samples

What's next for RSGs?

- Upcoming space telescopes will be focused on IR observations...
- The ELTs will be excellent tools for stellar astrophysics...
- LSST will usher in a new era of transient astronomy...



Ideal for:

- observing RSG core collapse events (SNe, “disappearing” RSGs...)
- studying variability in RSGs

More about RSGs...



New ebook available FREE from IOP with an institutional subscription!



- Text is succinct (only ~100 pages!) and written at the advanced astronomy grad student level
- The book as a whole offers a complete primer on the current state of RSG astronomy
- For *anyone* with an interest in RSGs it can serve as a standing reference for answering questions about the physics of cool massive stars

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