Title: Red Supergiants: A Magnifying Glass for Stellar Theory

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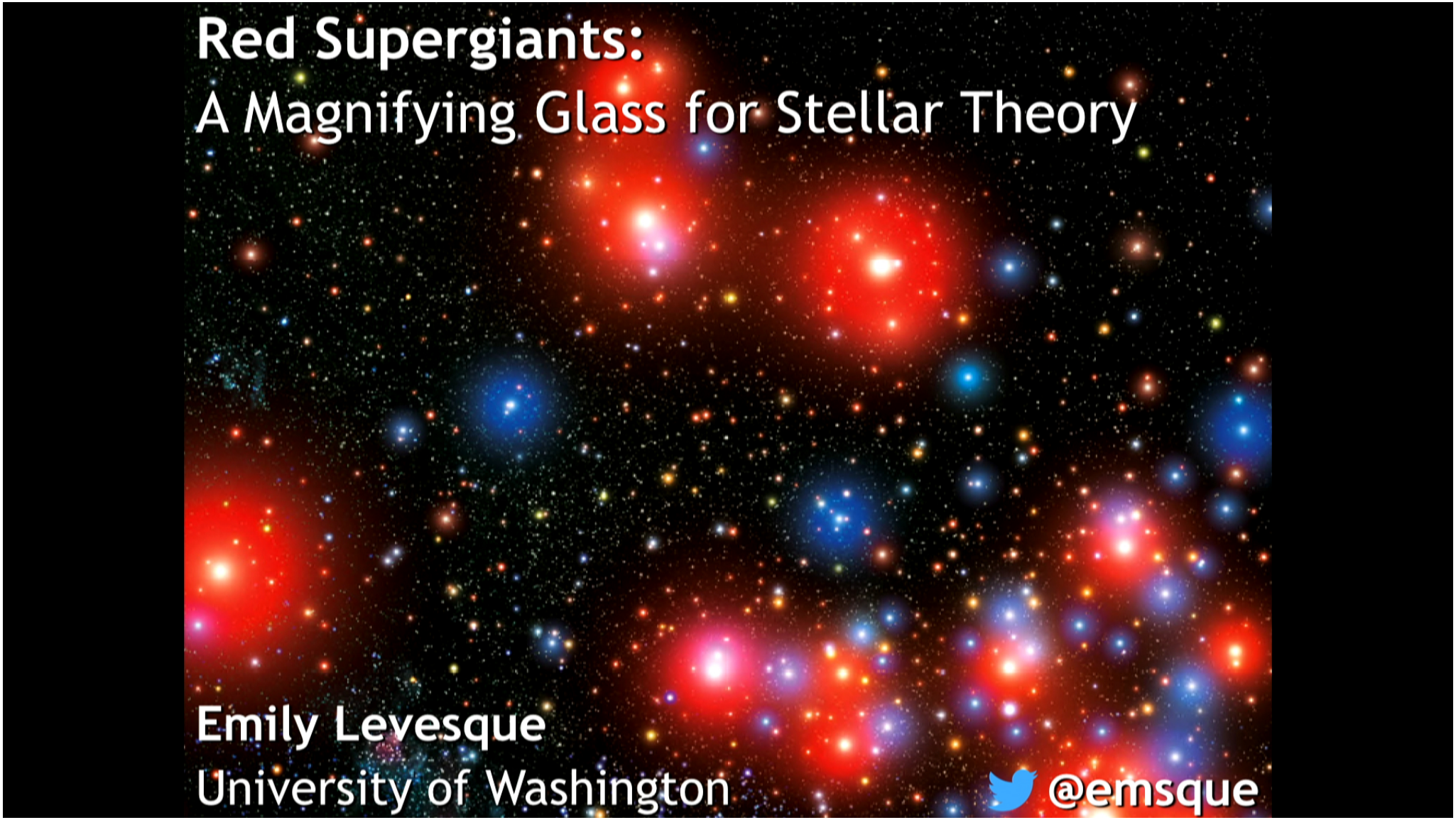
Abstract: Red supergiants (RSGs) are the helium-fusing evolved descendants of moderately massive (10-25Mo) stars, the result of a near-horizontal evolution across the top of the Hertzsprung-Russell diagram following their time on the main sequence. As the coldest and largest (in physical size) members 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.


Red Supergiants:
A Magnifying Glass for Stellar Theory
Emily Levesque
University of Washington
@emsque

Red Supergiants:
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Brooke Dicenzo
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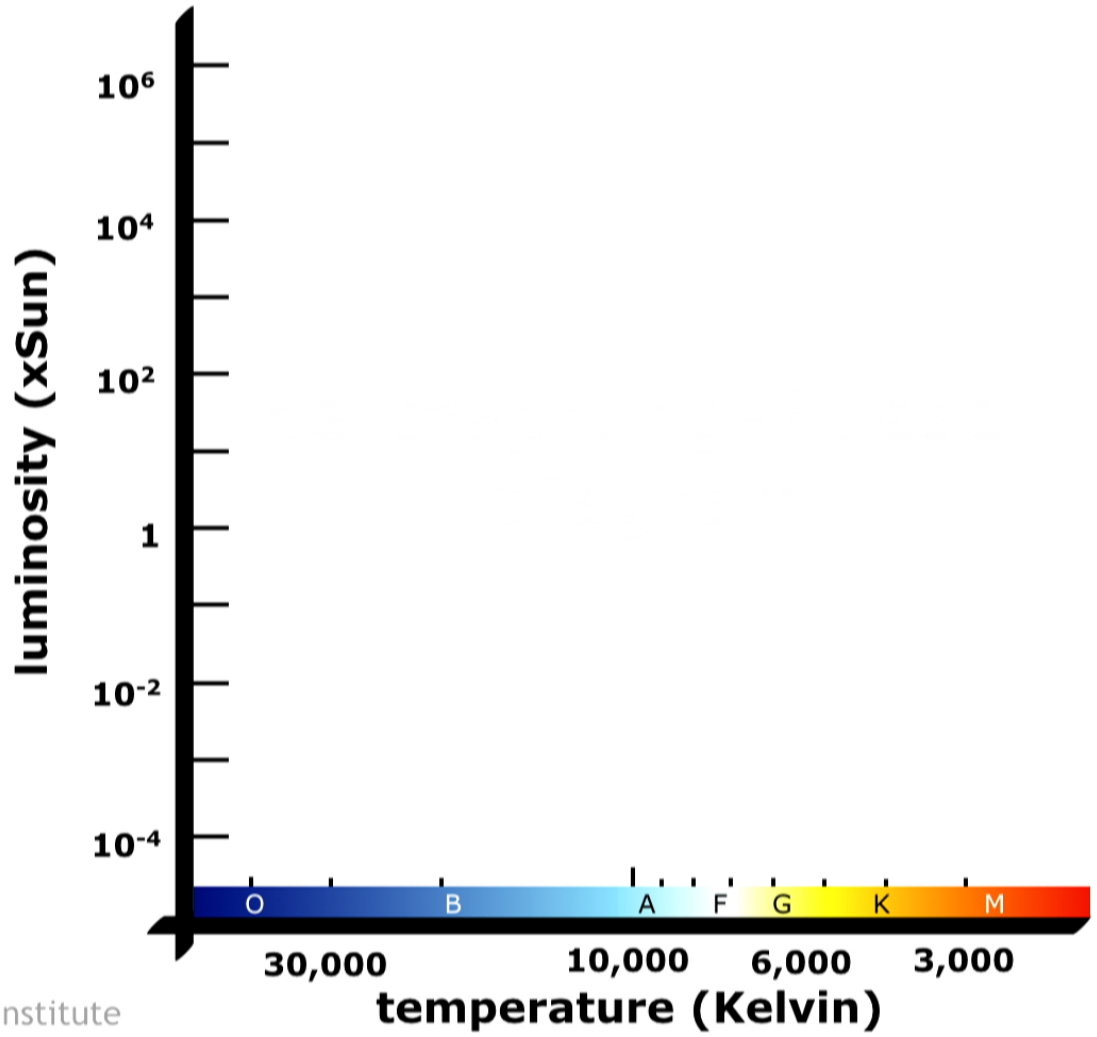
What are red supergiants?



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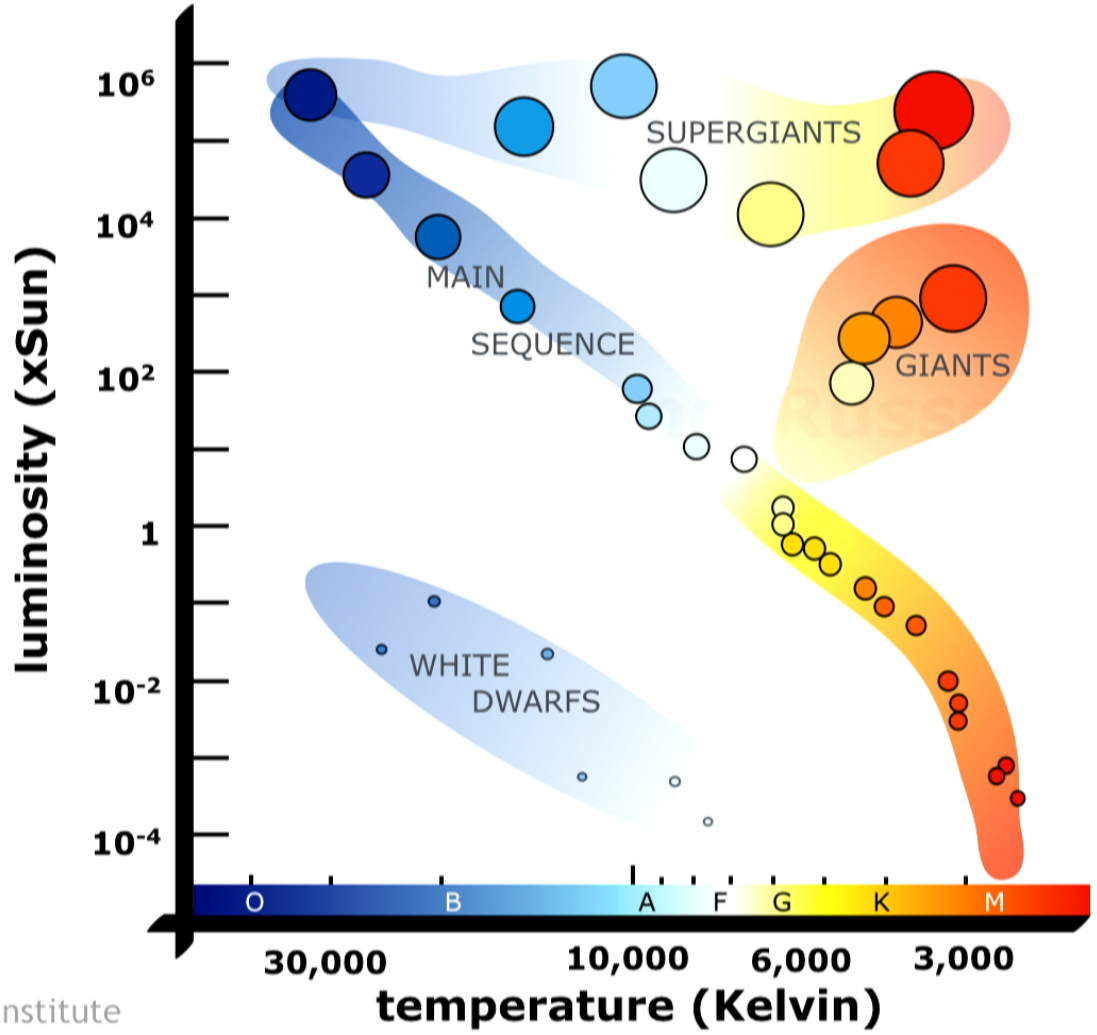

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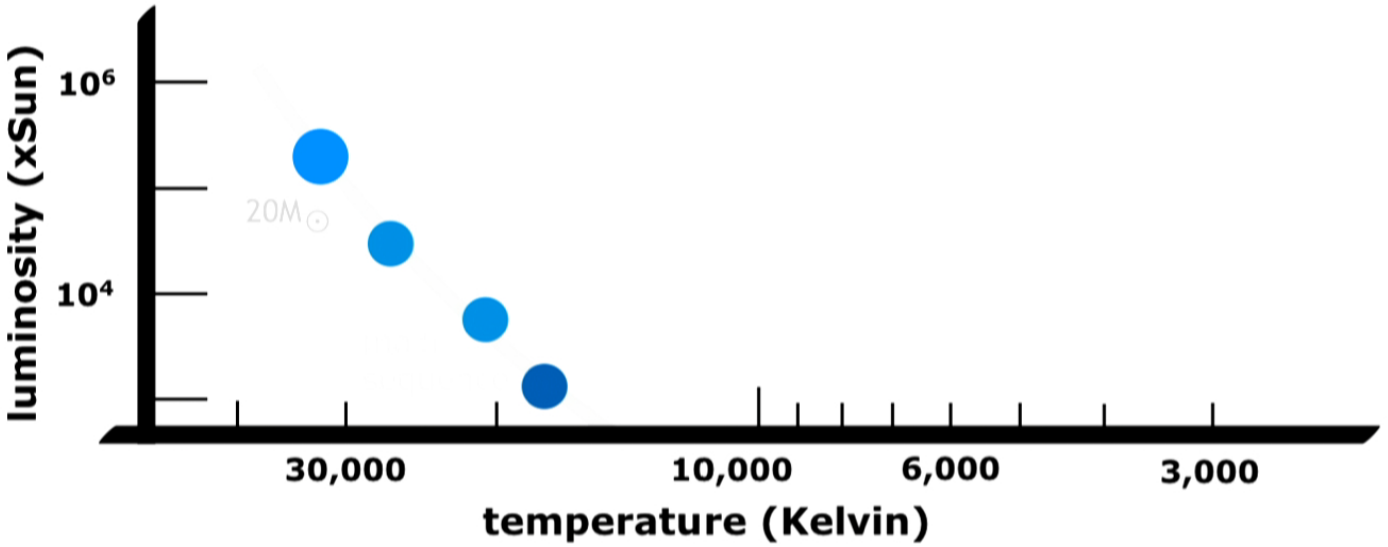
RSGs are the helium-fusing evolved descendants of moderately massive (~8-40$M_\odot$) main sequence stars.



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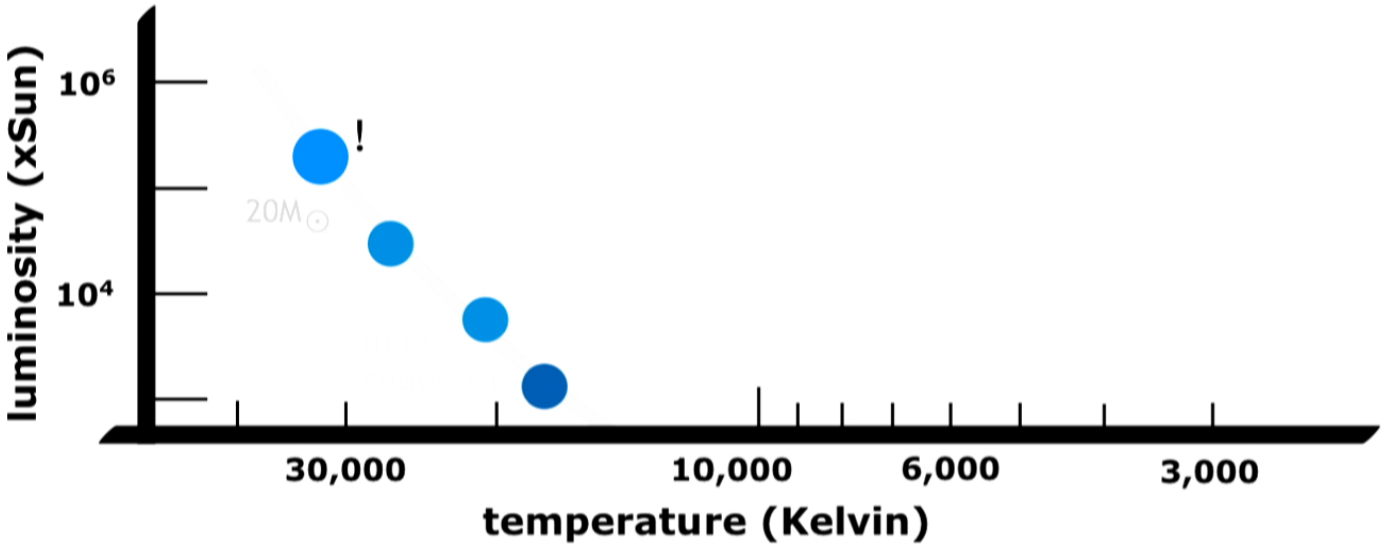
$$L \propto R^2 T^4$$



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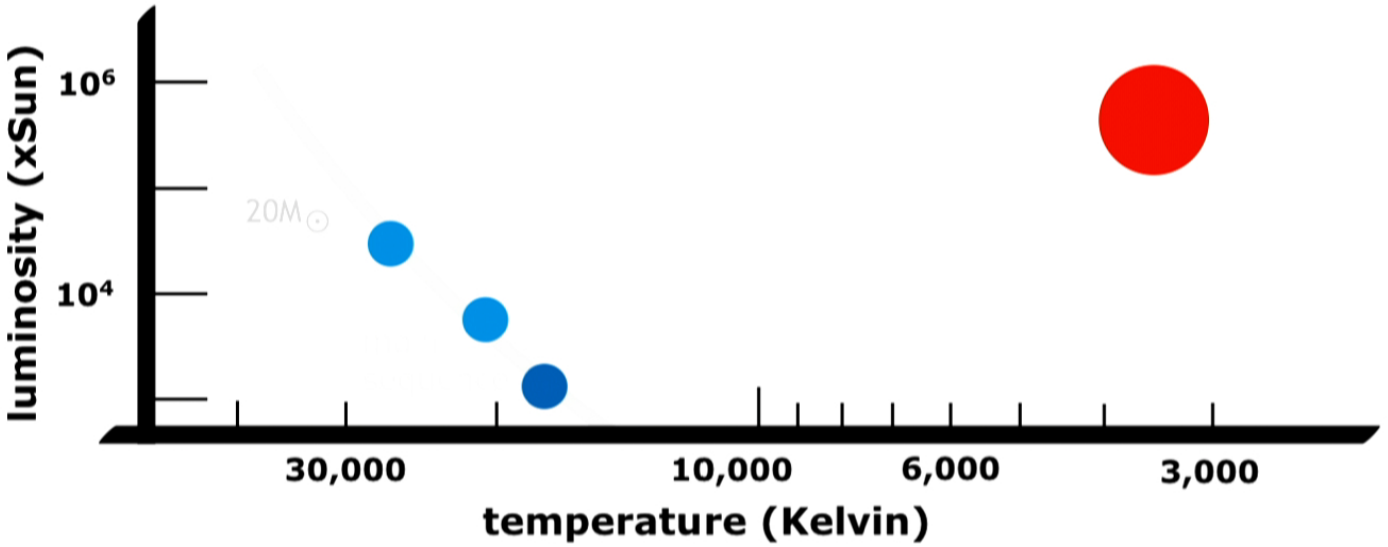

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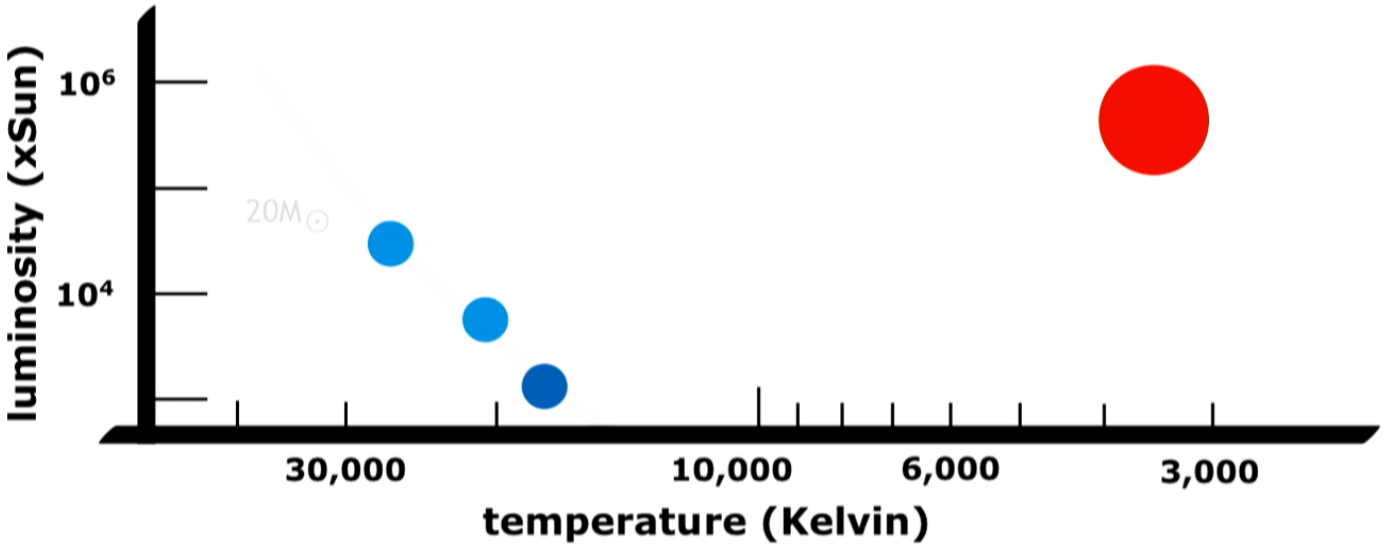
RSGs are the helium-fusing evolved descendants of moderately massive (~8-40$M_\odot$) main sequence stars.

- 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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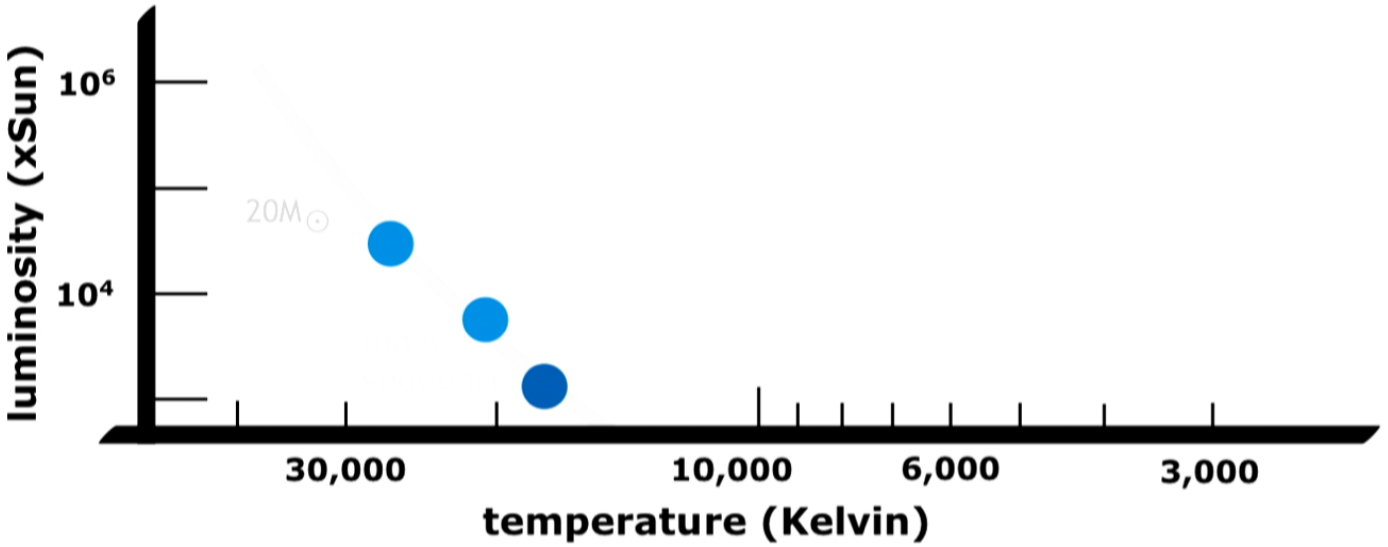

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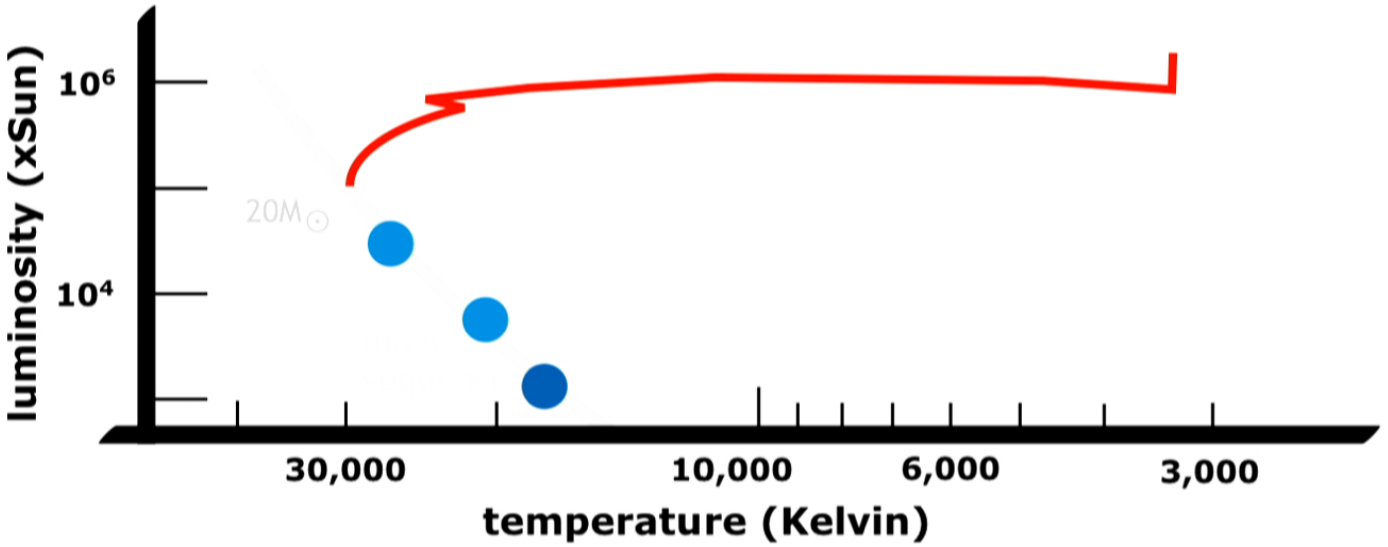

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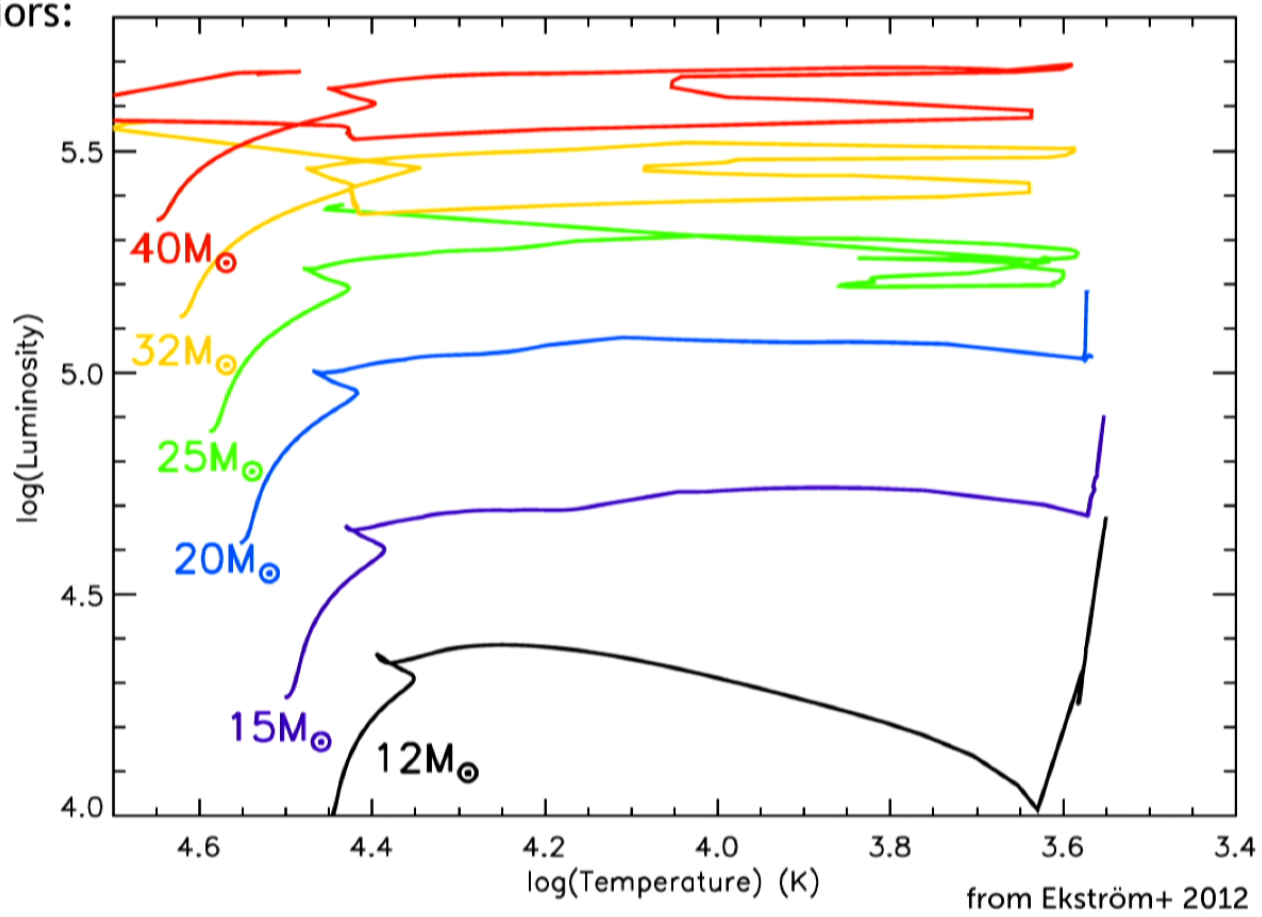

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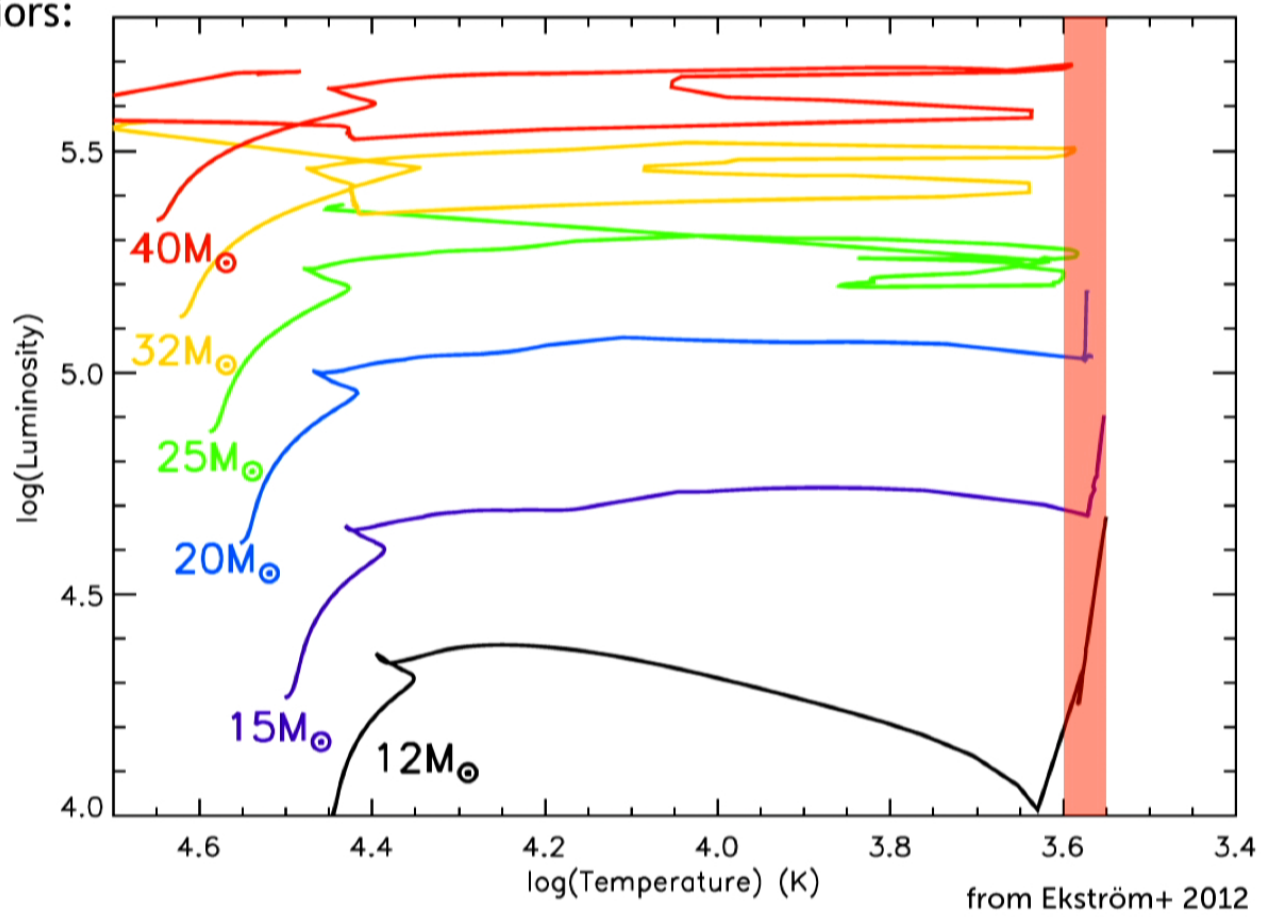

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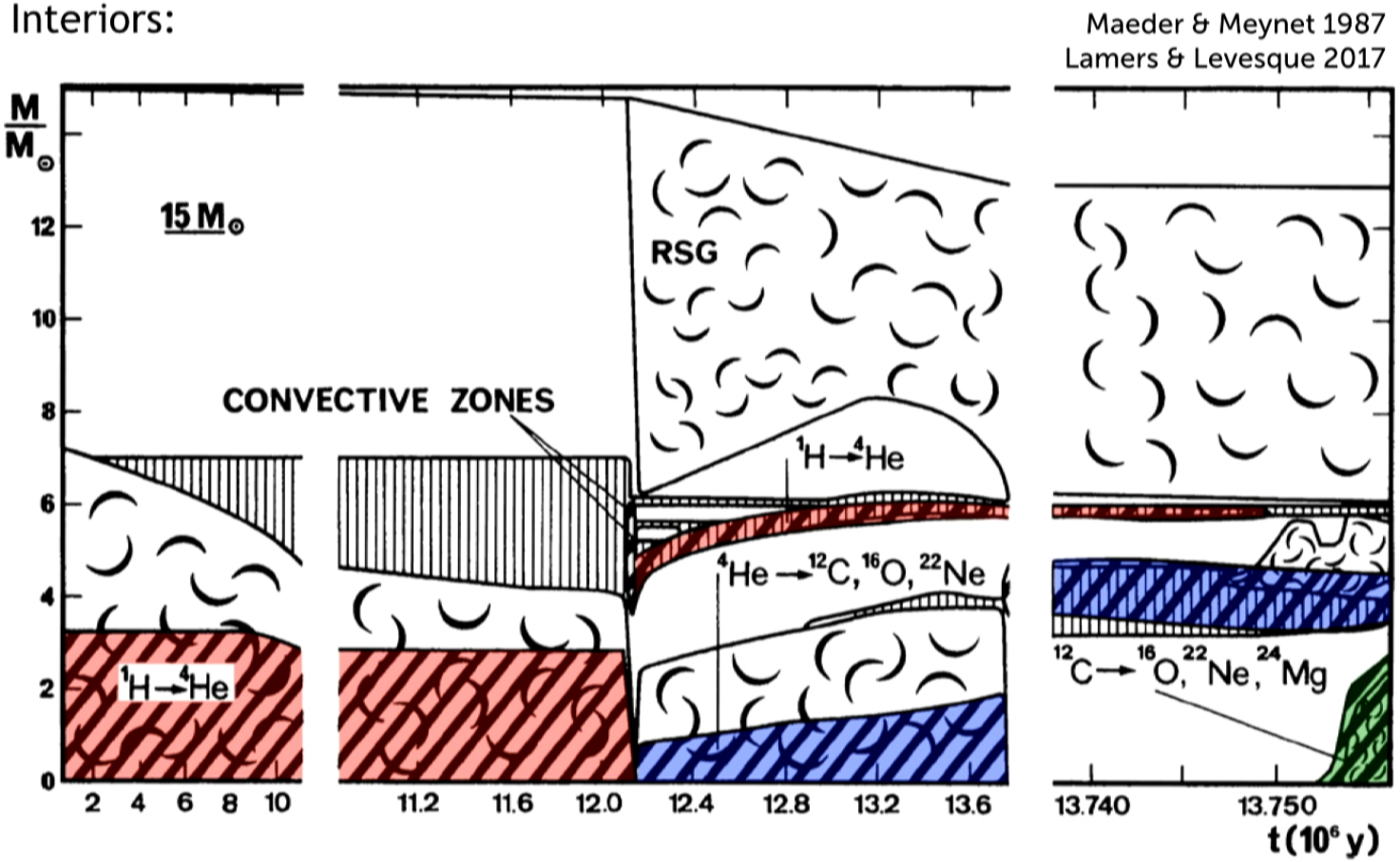

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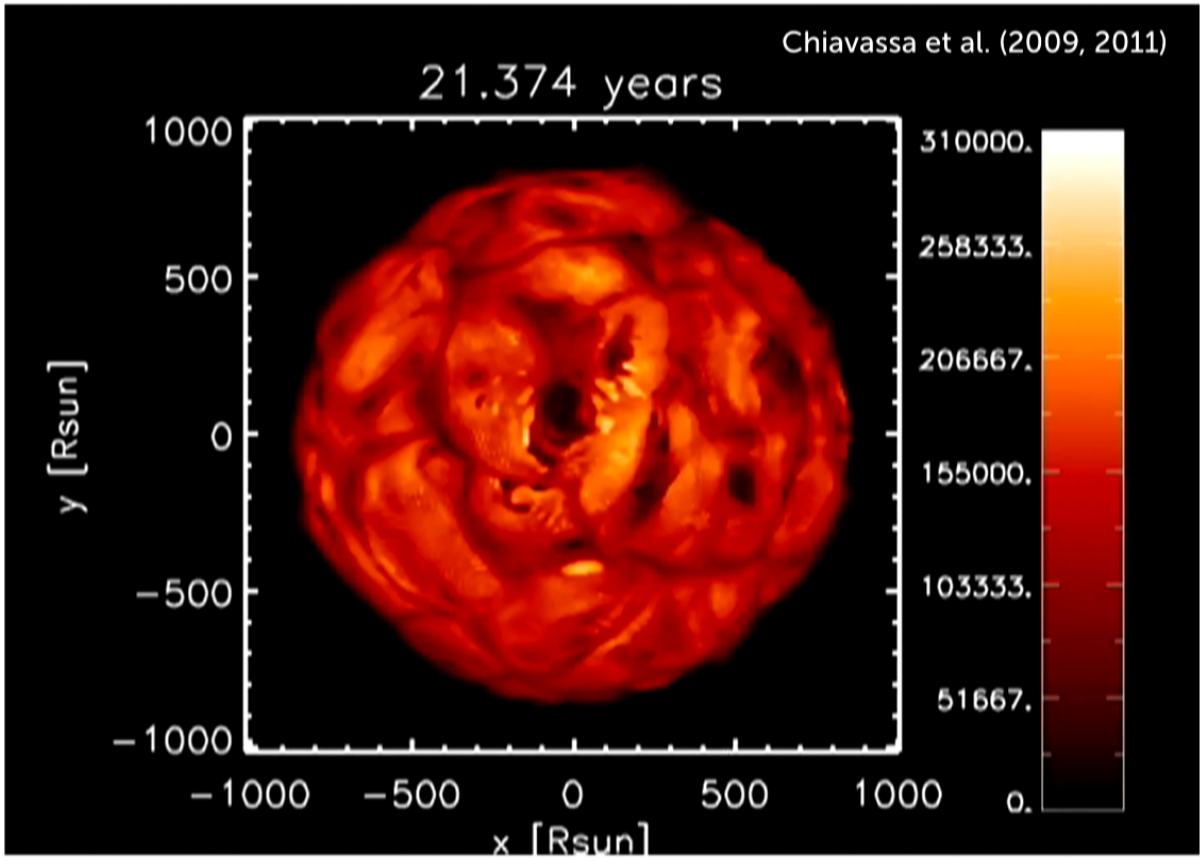

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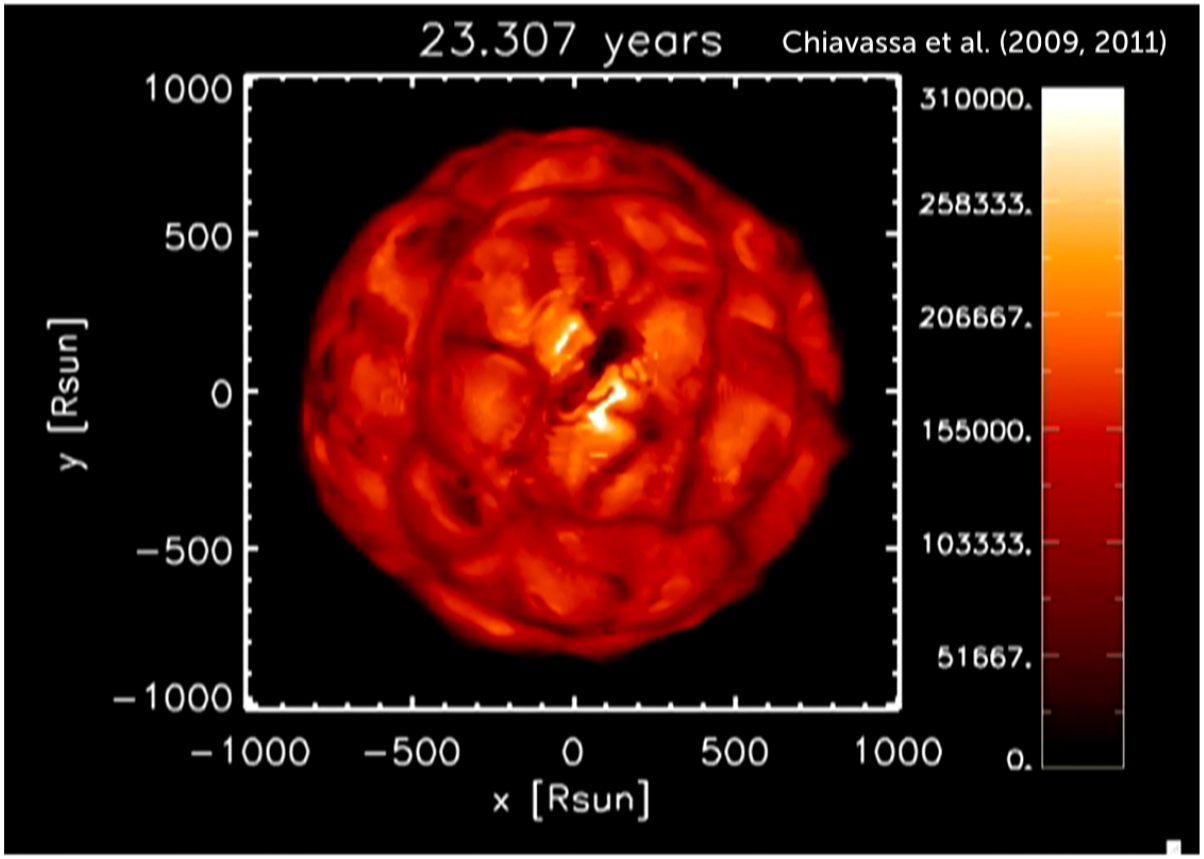

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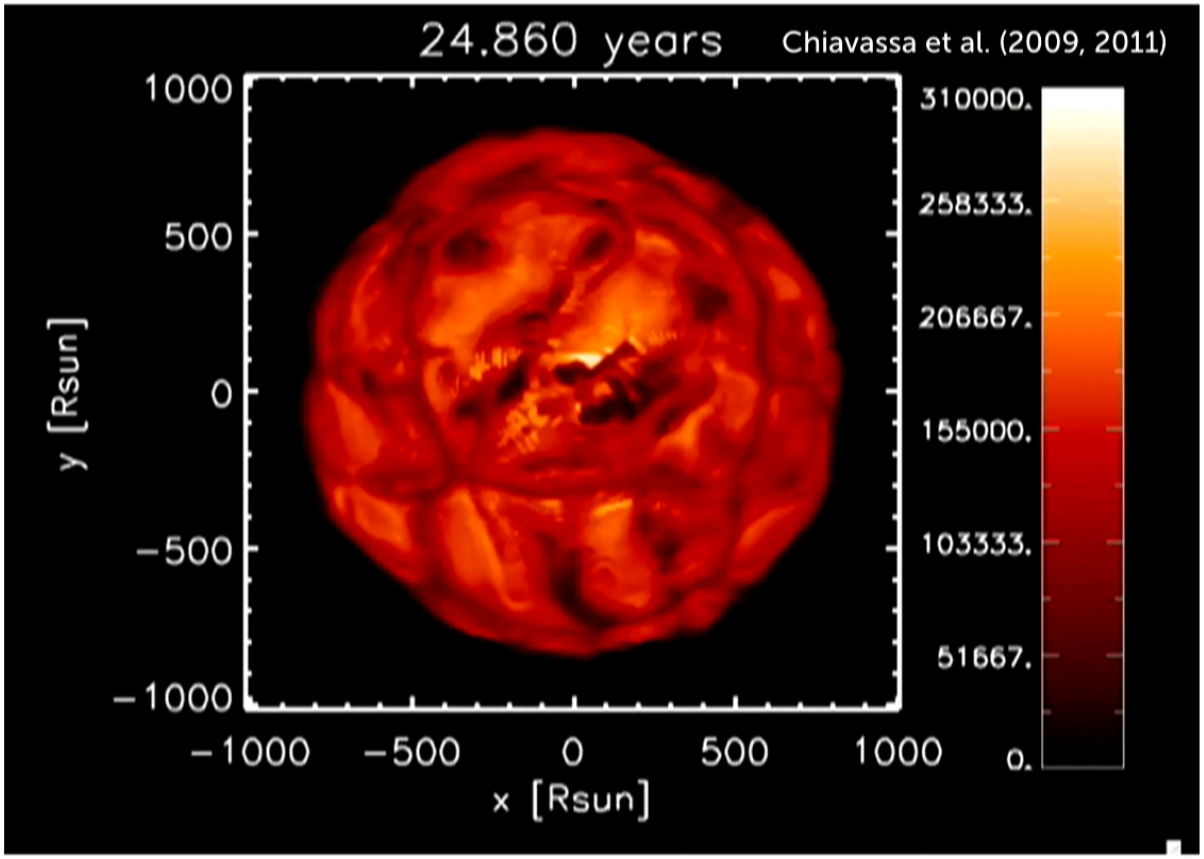

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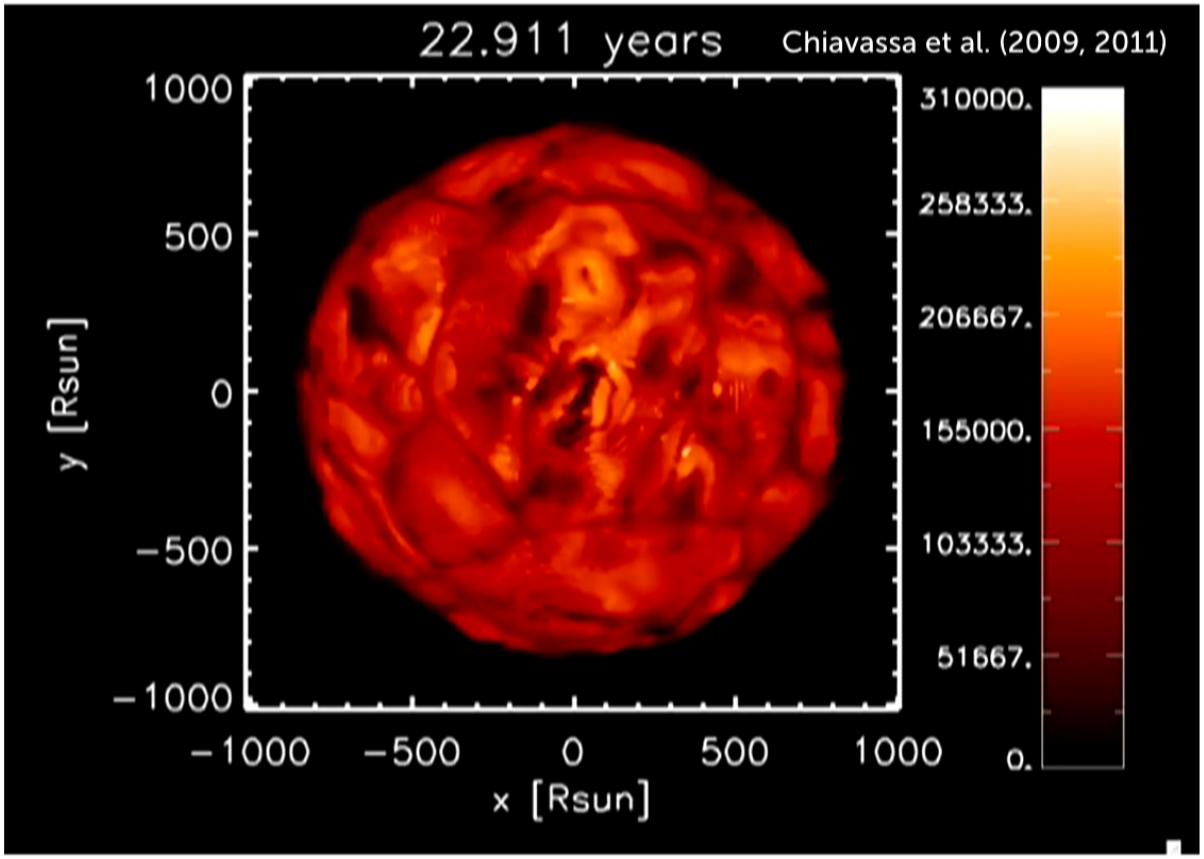


Who *cares* about red supergiants?

massive star formation

dust production

mass loss in cool stars

early universe chemistry

massive binary fraction

gravitational waves

stellar magnetic fields

massive star evolution

mass loss in massive stars

YOU DO!

stellar populations

mass-transfer binaries

supernova progenitors

galaxy compositions

stellar rotation

stars in the early universe

strange and variable stars

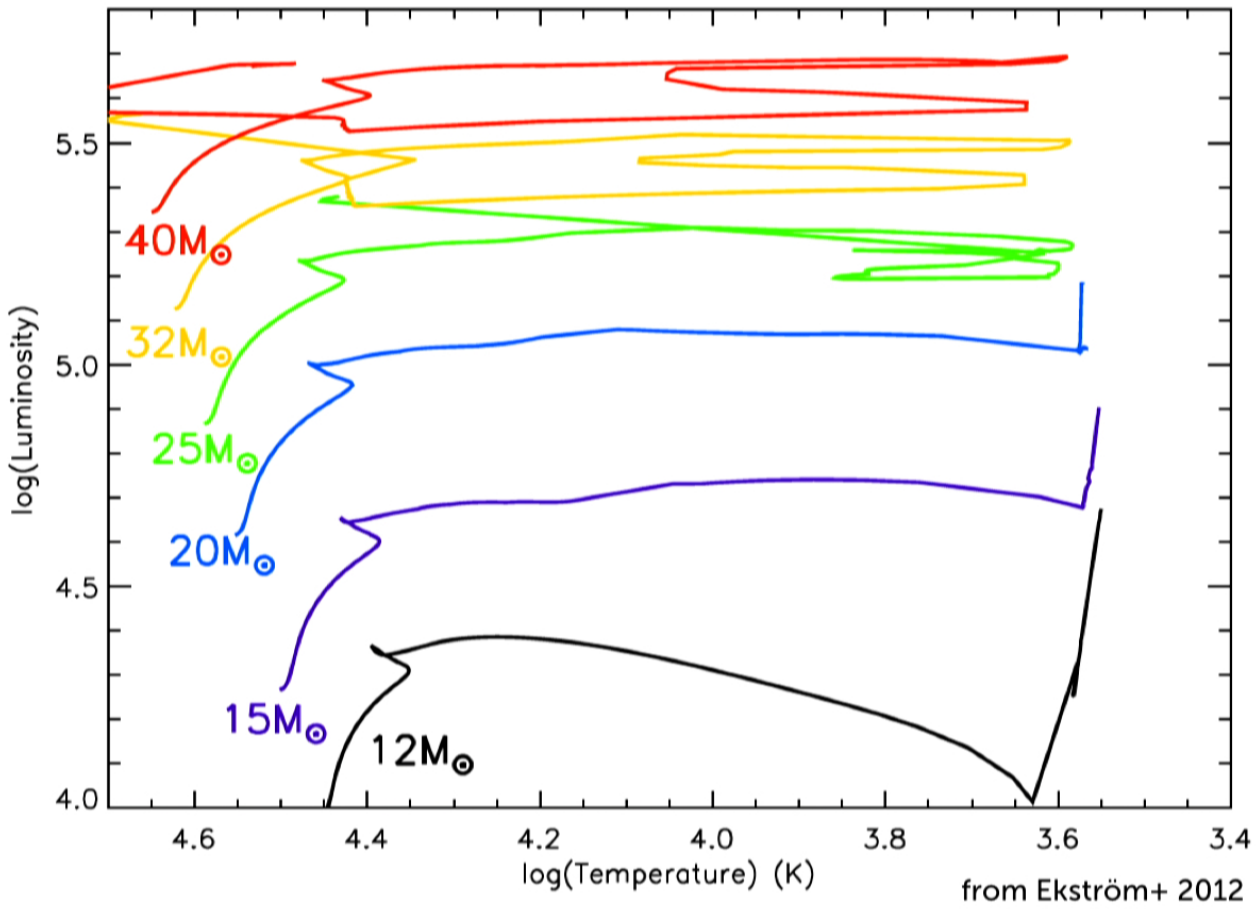
compact objects

time-domain astronomy

nucleosynthesis

infrared astronomy

Challenges: RSG temperatures



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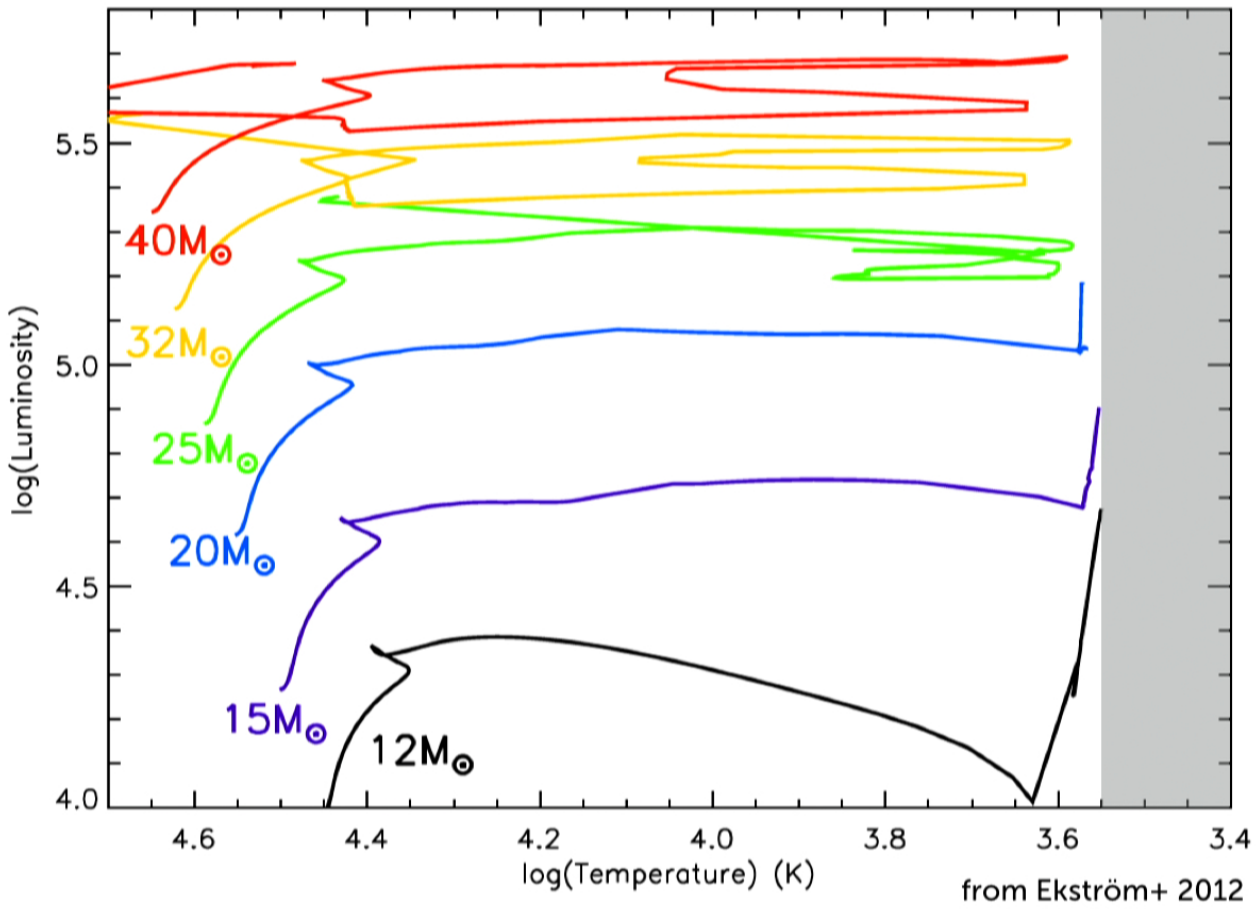

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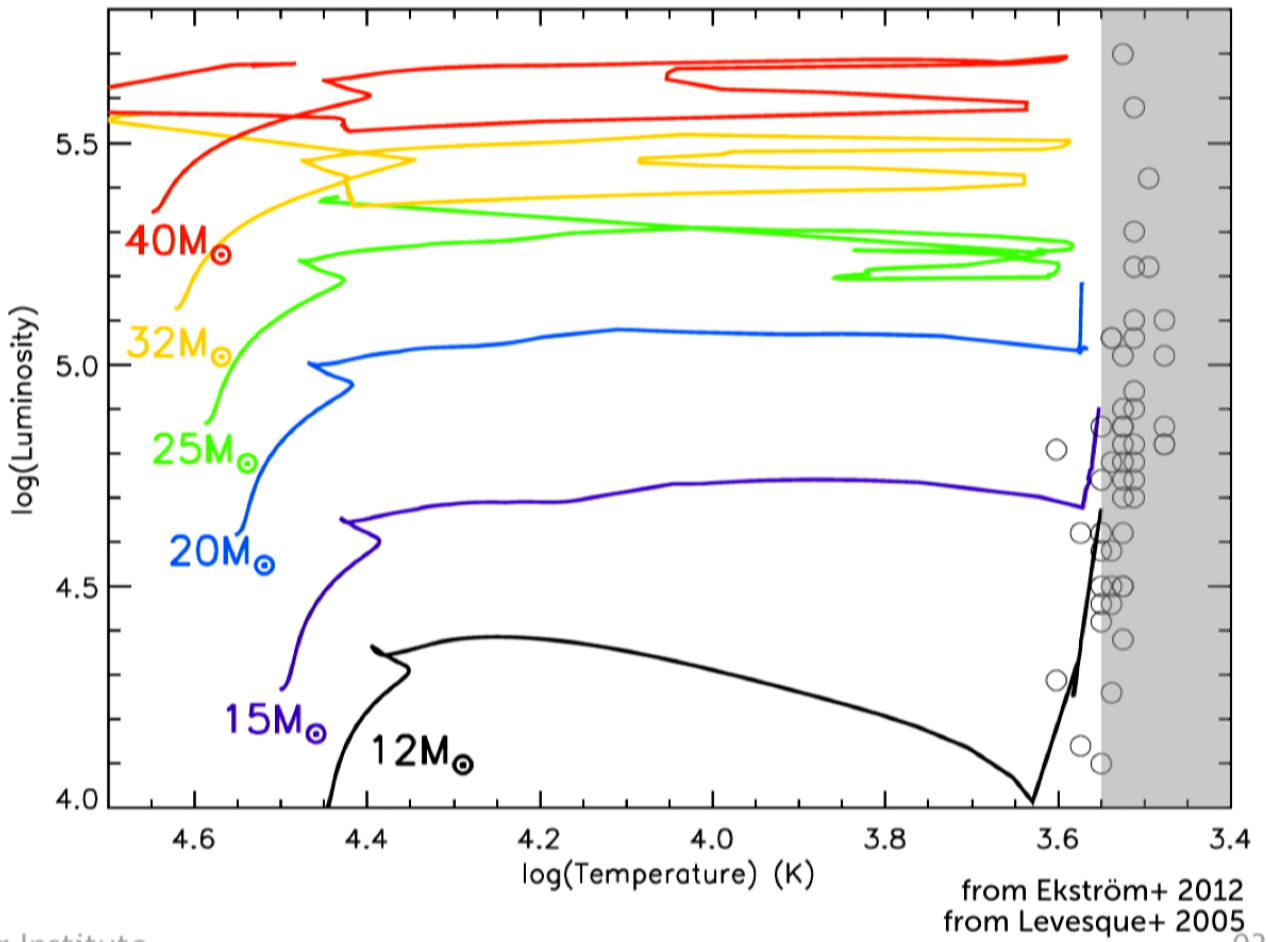

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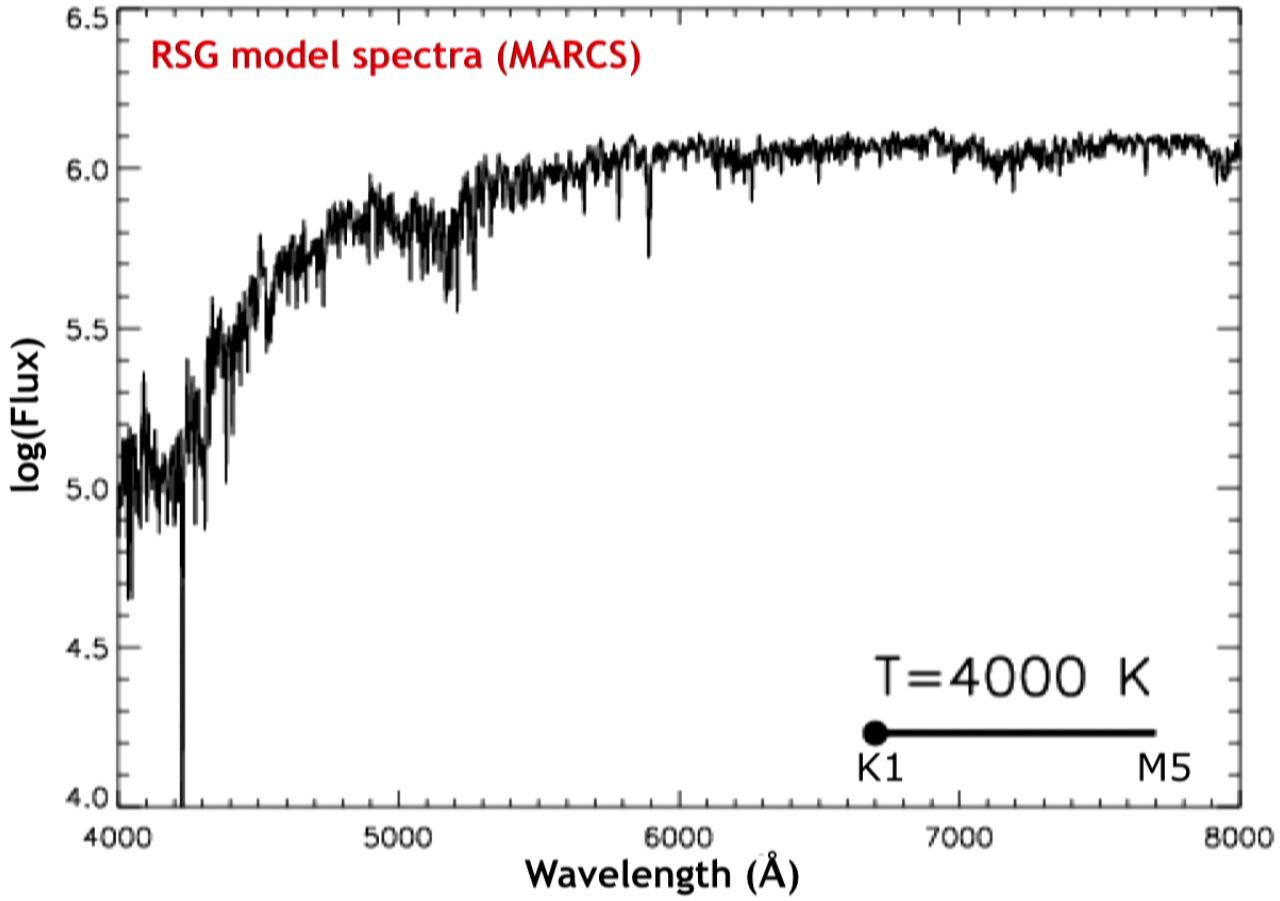

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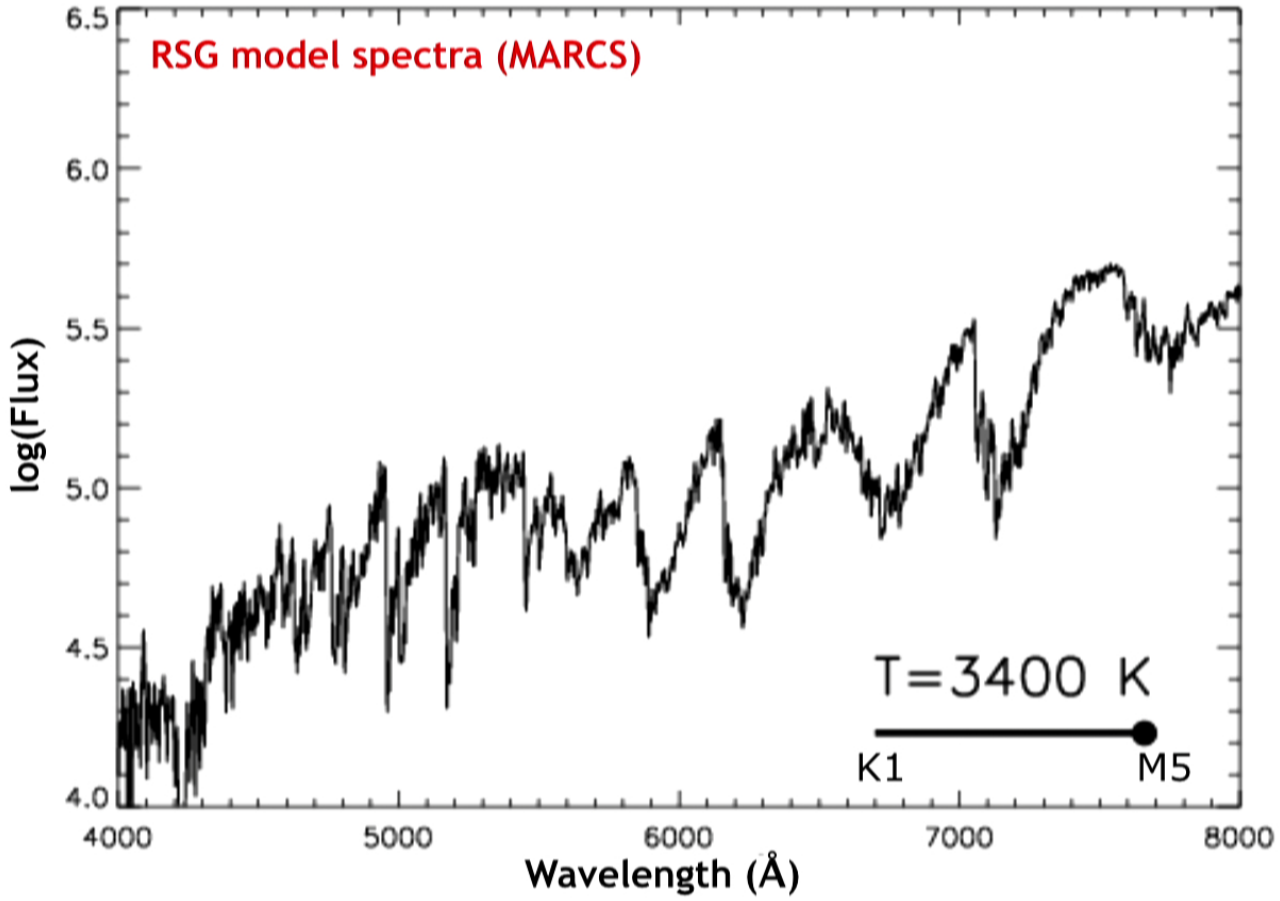

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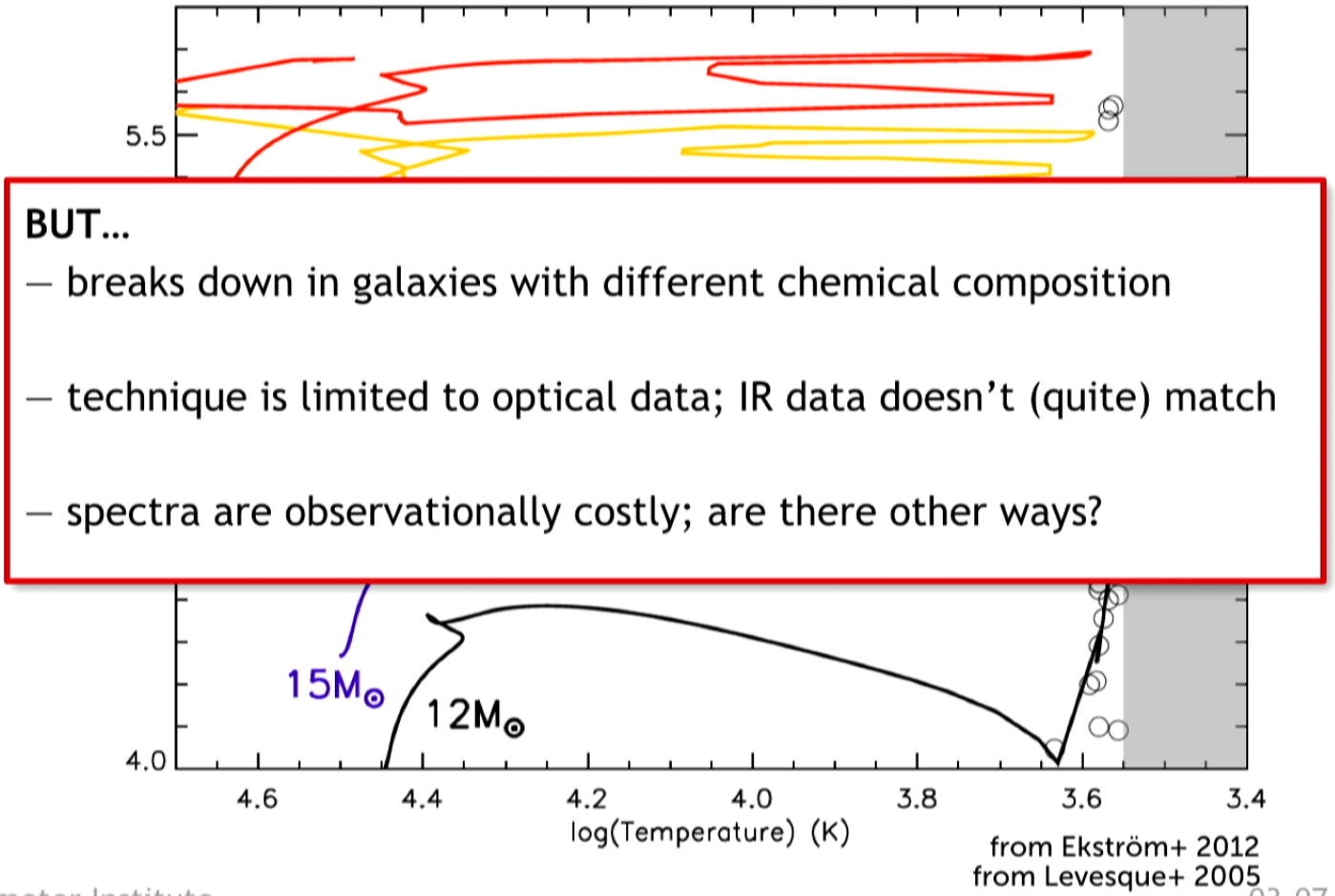


BUT…

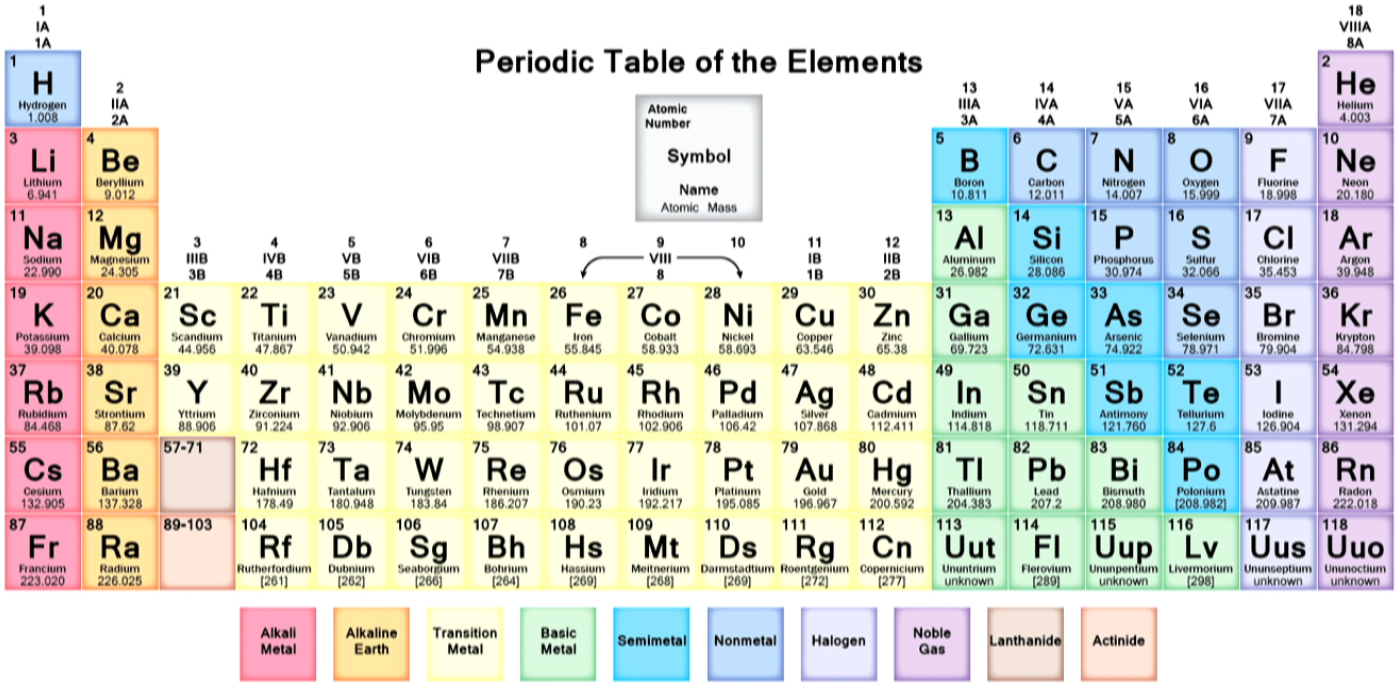
– breaks down in galaxies with different chemical composition

– technique is limited to optical data; IR data doesn't (quite) match

– spectra are observationally costly; are there other ways?

Challenges: RSGs in other galaxies

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



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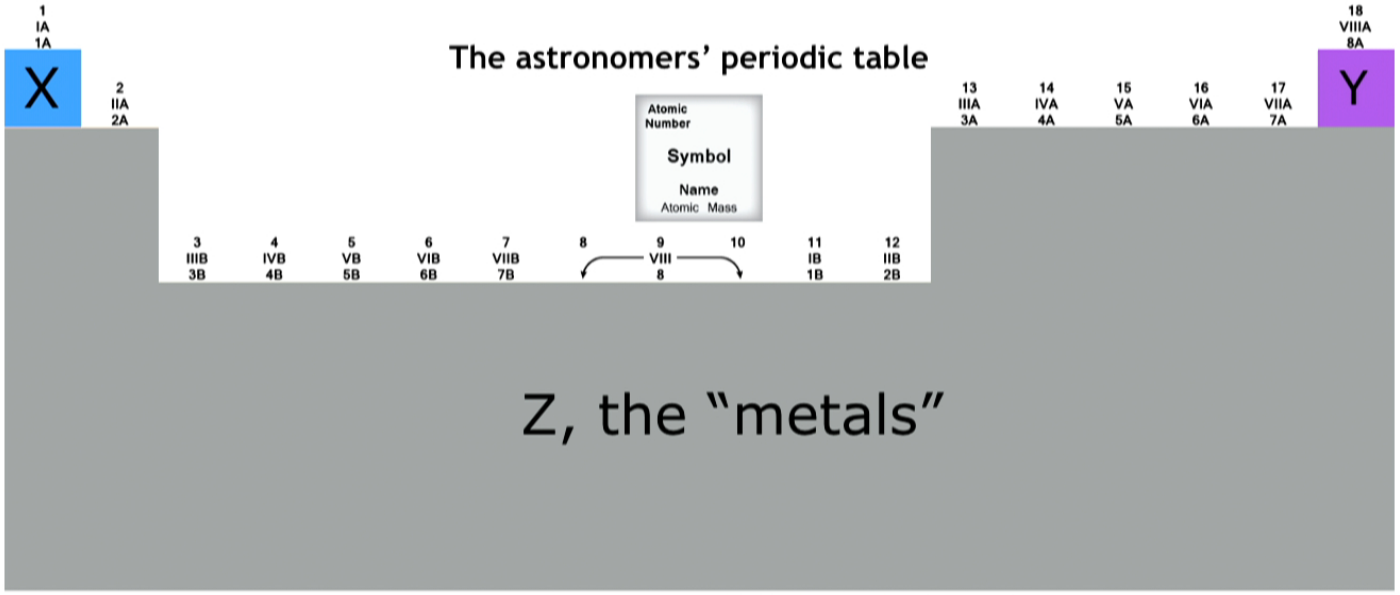

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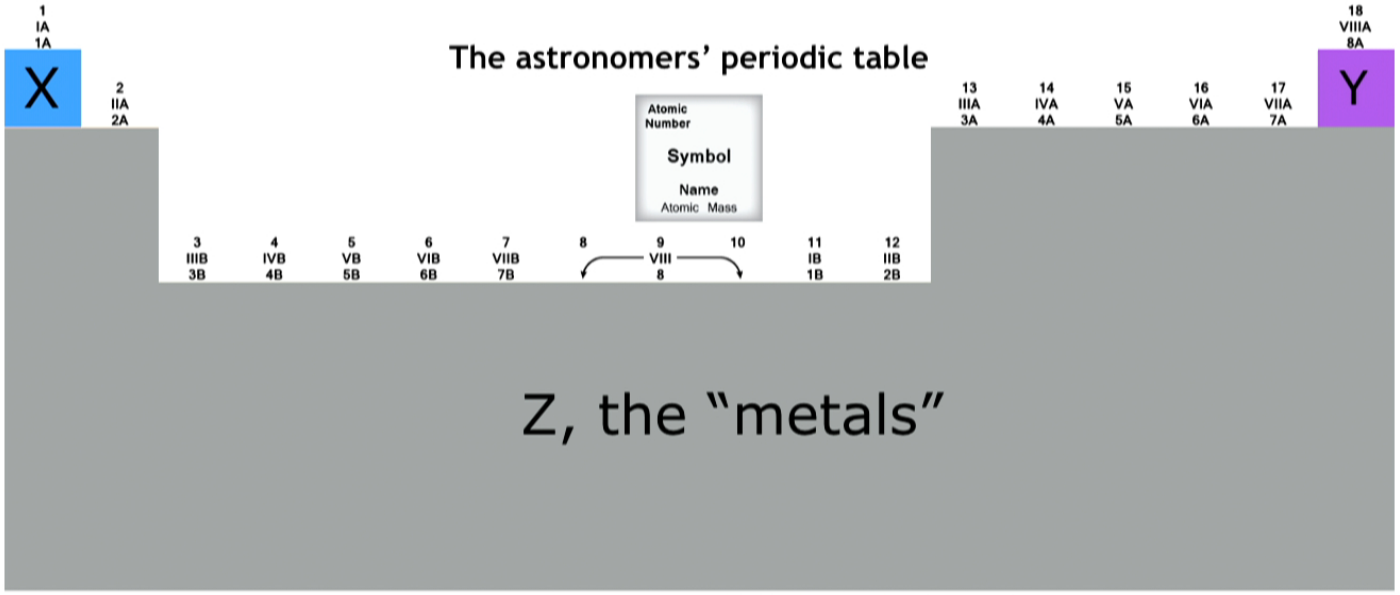

"**metallicity**": non-H-and-He chemical composition of a star or galaxy

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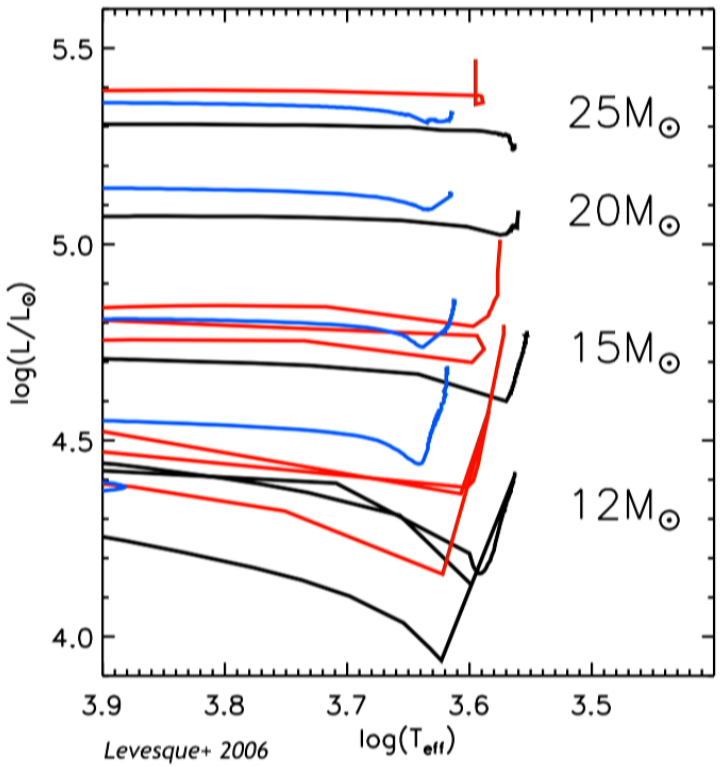
What range of colors (e.g. temperatures) should we be looking for?

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



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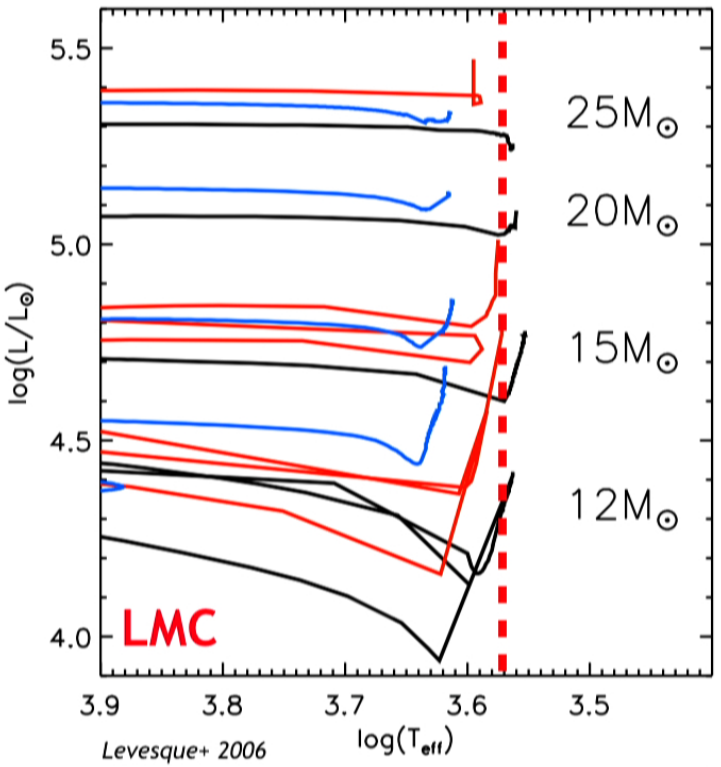

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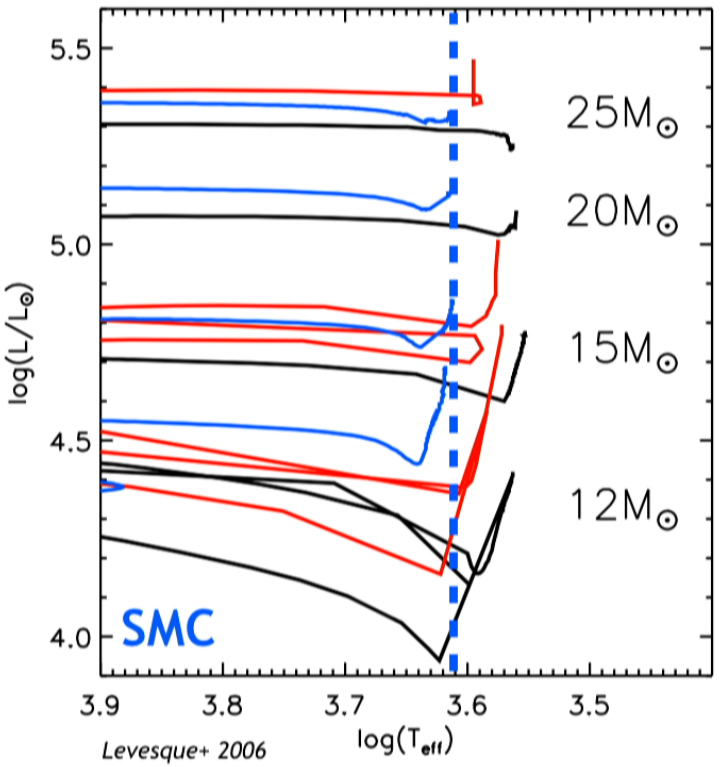

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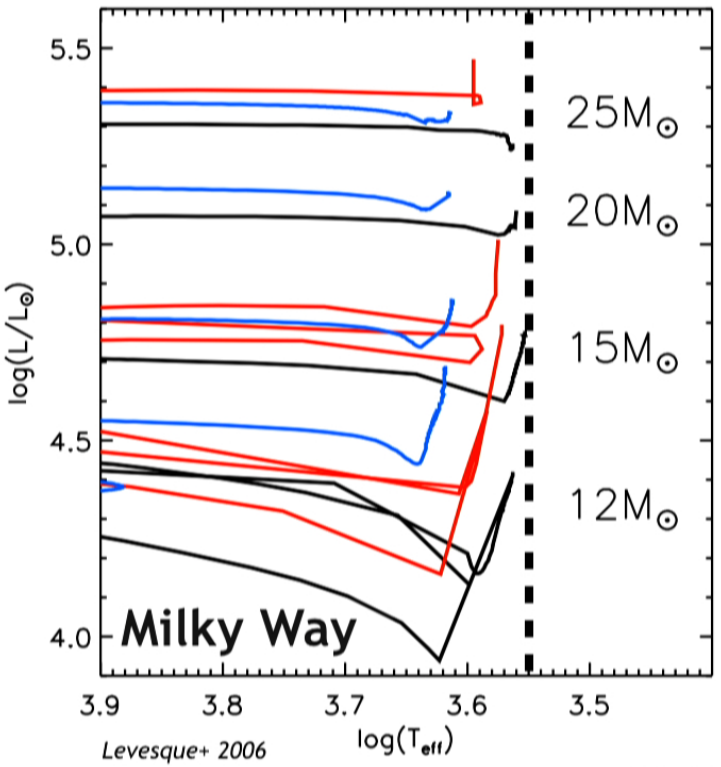

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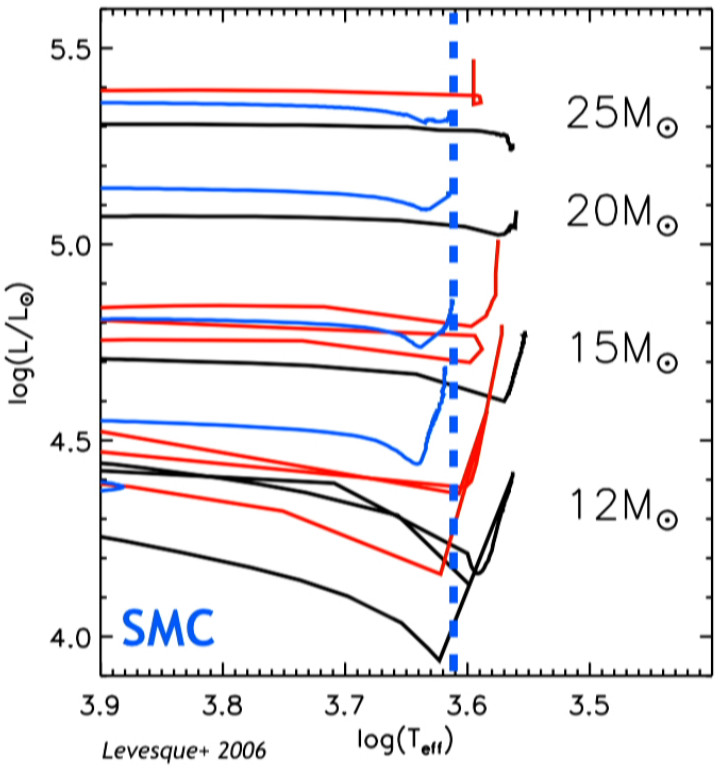

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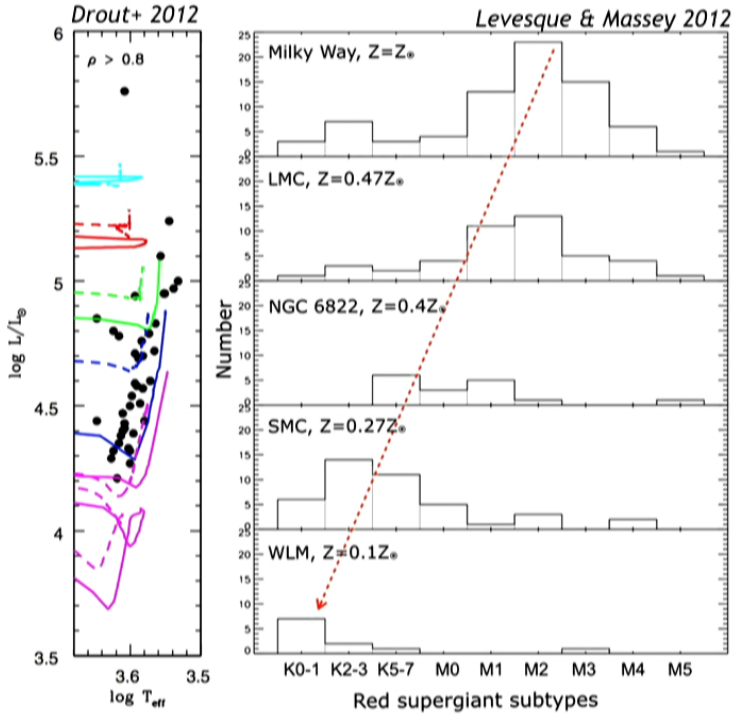

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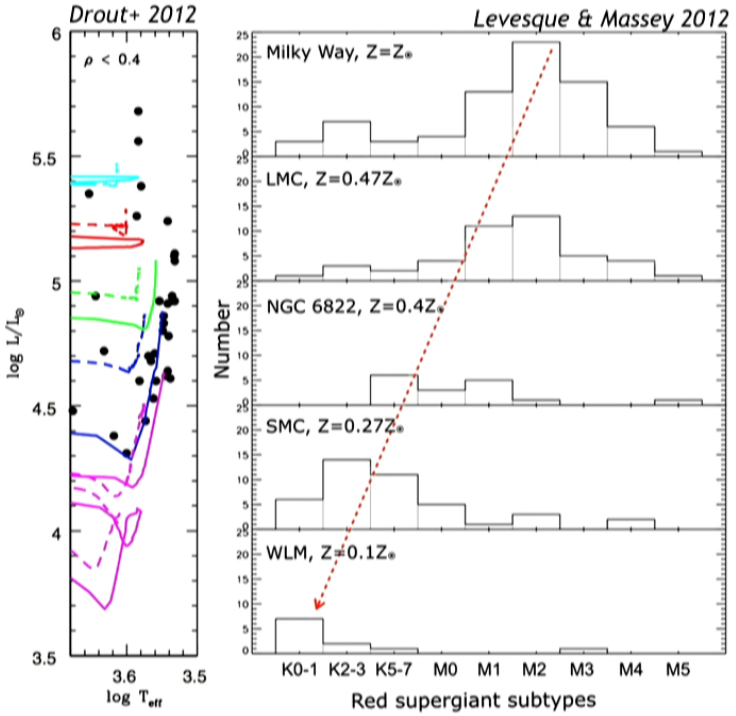
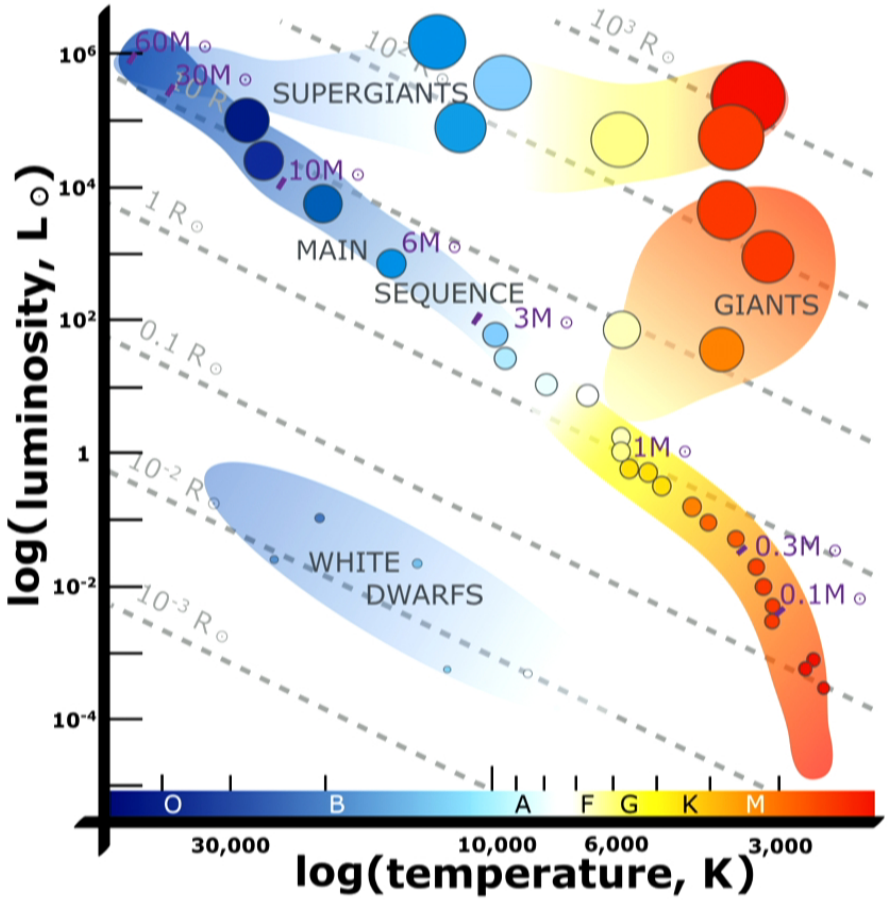
This leads to a warmer average T_{eff} - and a bluer average color - for RSG populations at low metallicity!



Challenges: RSGs in other galaxies

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



Challenges: RSGs in other galaxies

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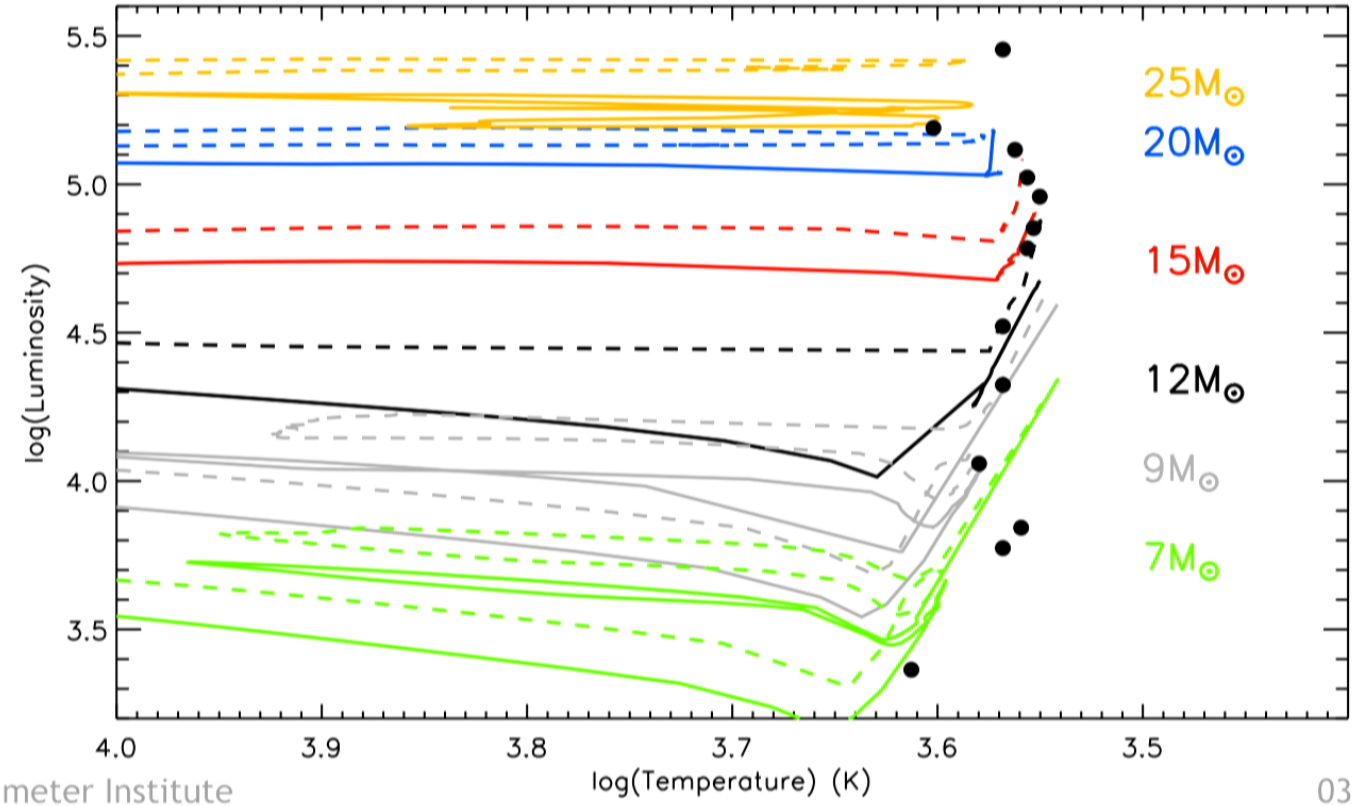
Should be straightforward to get a complete sample down to ~8$M_\odot$

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



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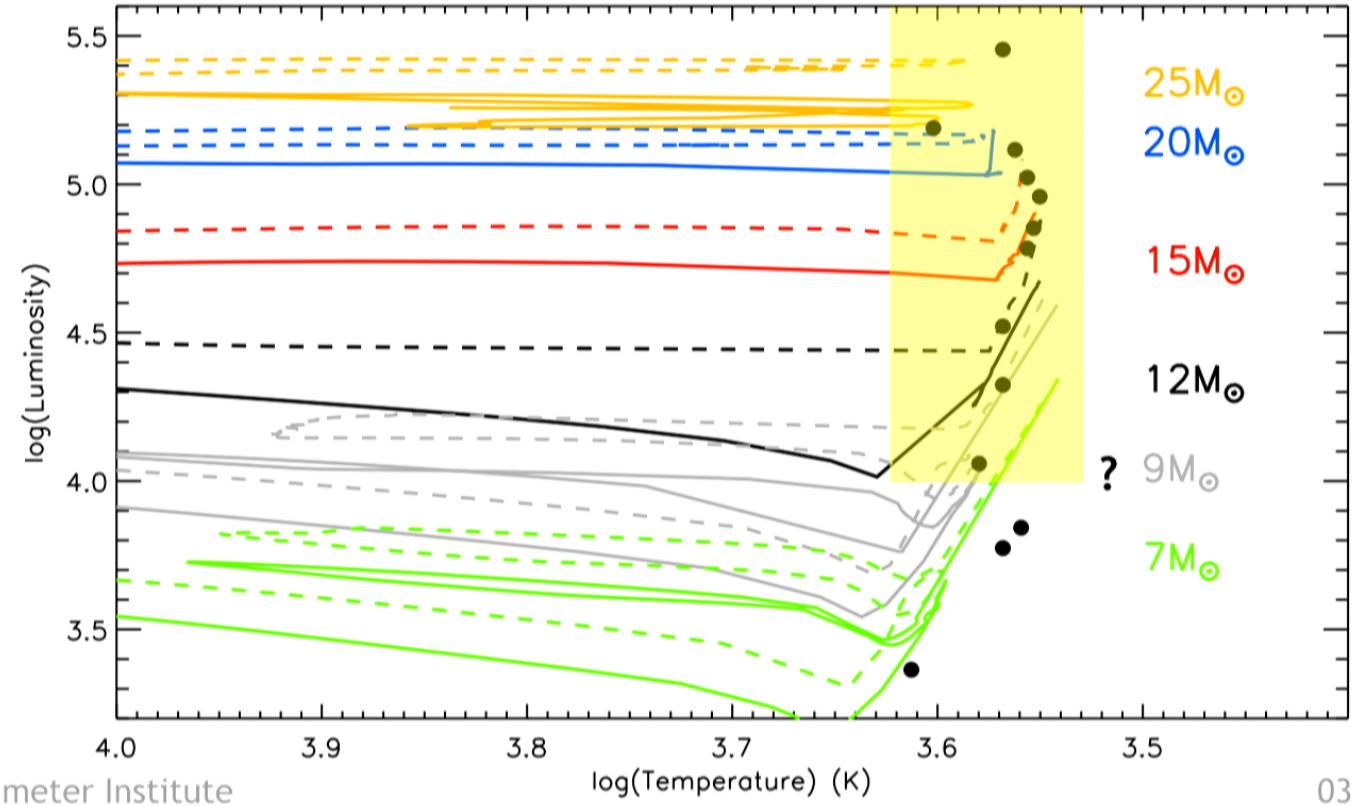
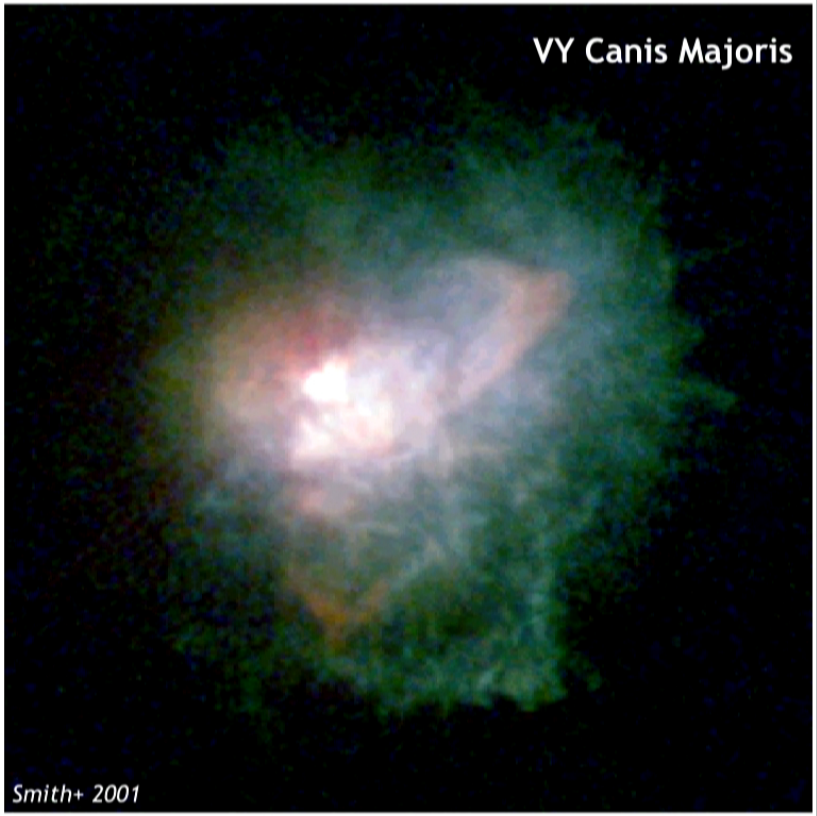


Challenges: RSGs in other galaxies

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



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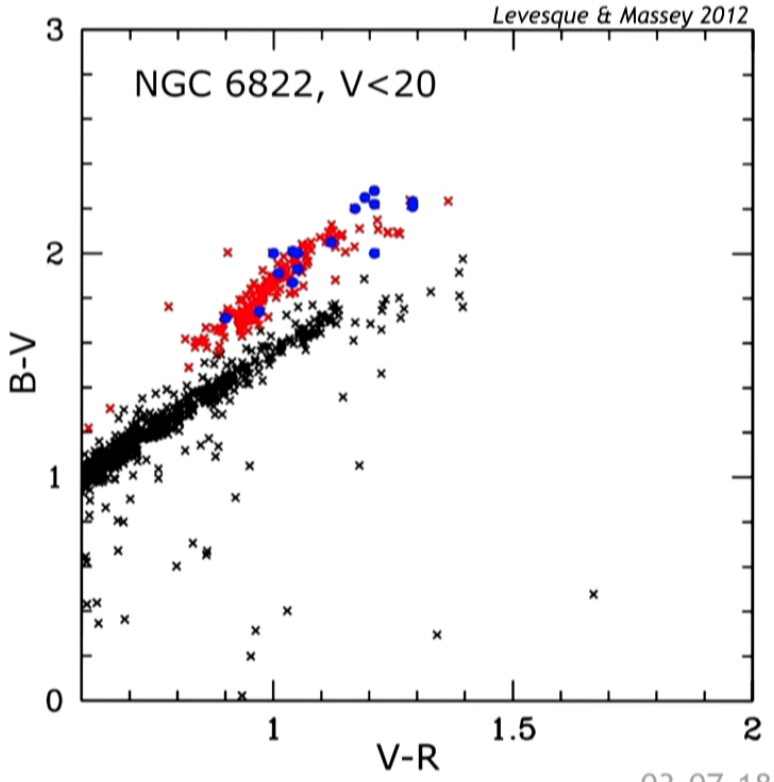
How can we distinguish actual RSG members from…

- foreground dwarfs?
  - colors
  - kinematics



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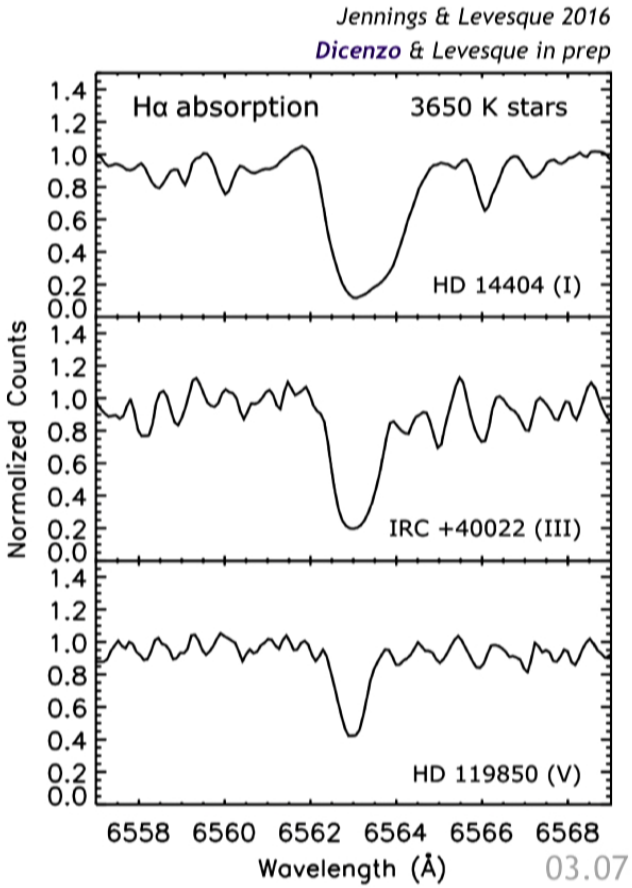

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How can we distinguish actual RSG members from…

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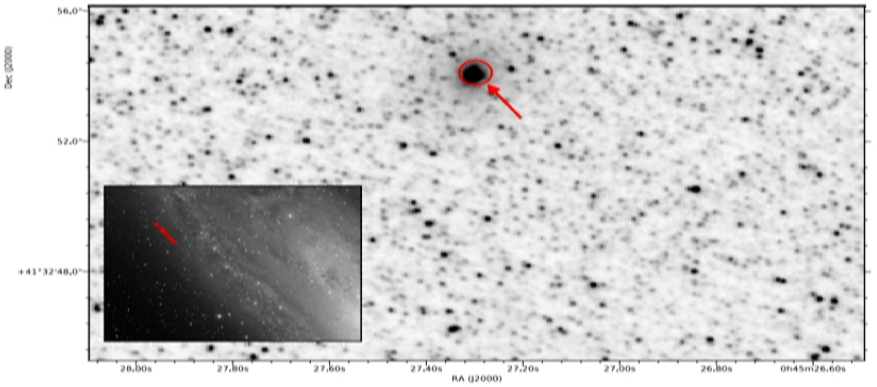
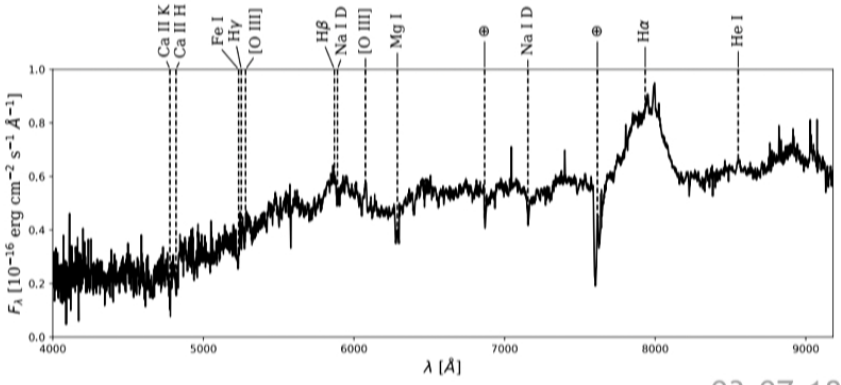
  - surface gravities
- background galaxies?
  - deep/resolved imaging
  - spectroscopy

Dorn-Wallenstein+ 2017





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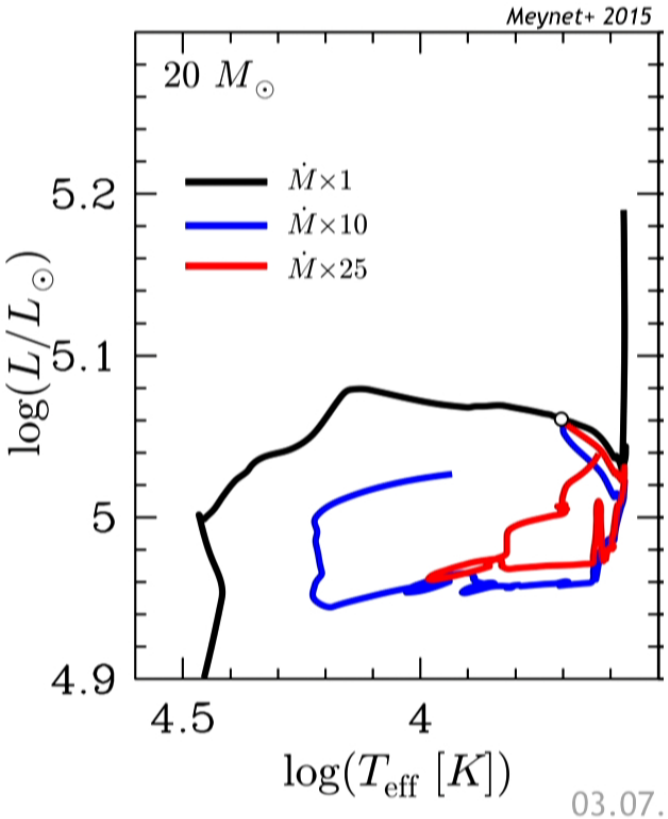

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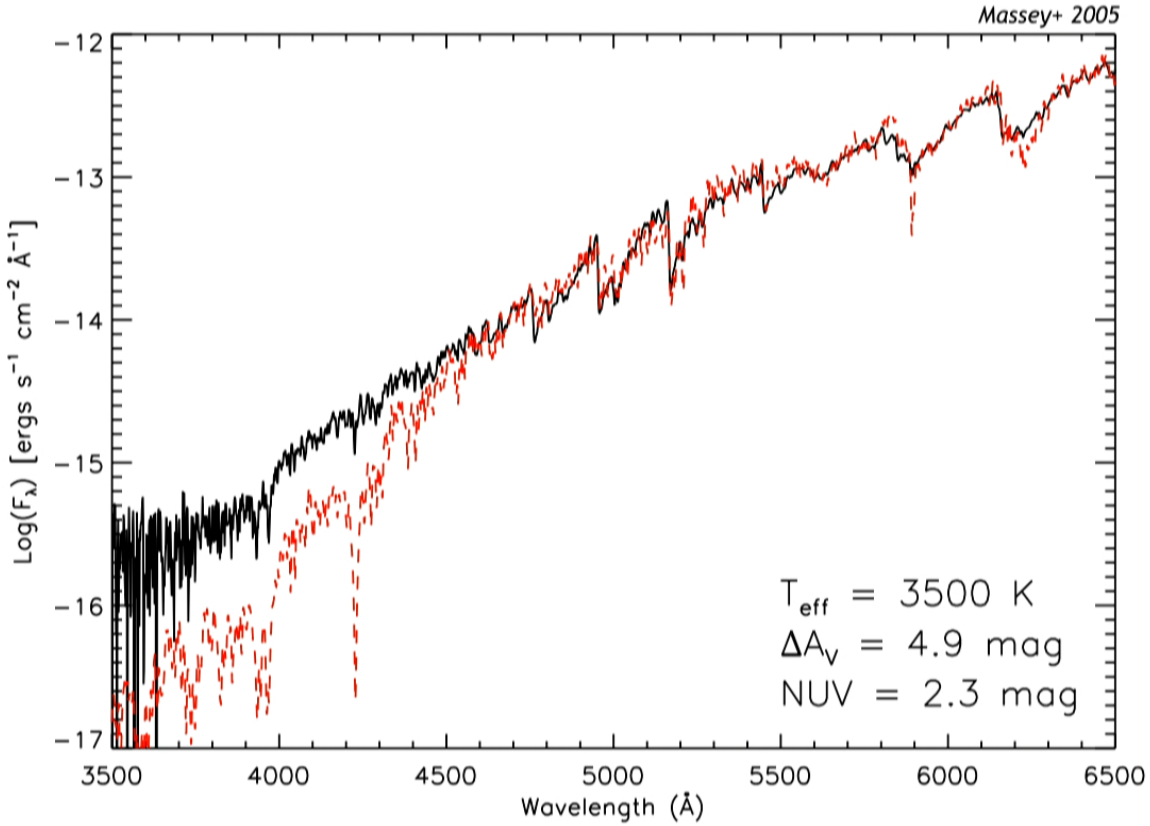

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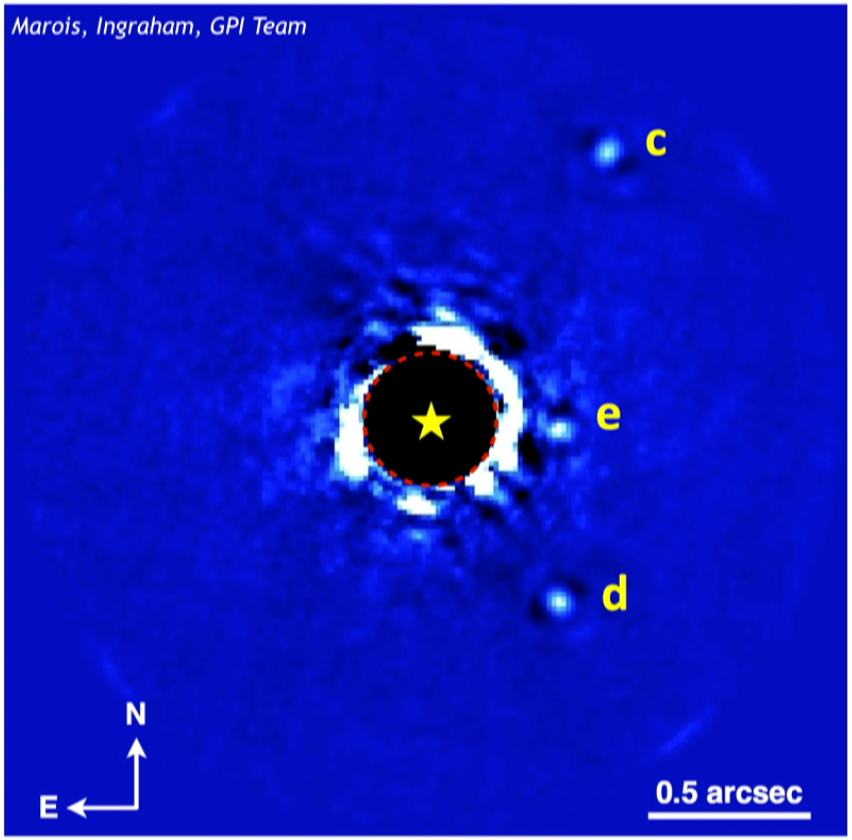

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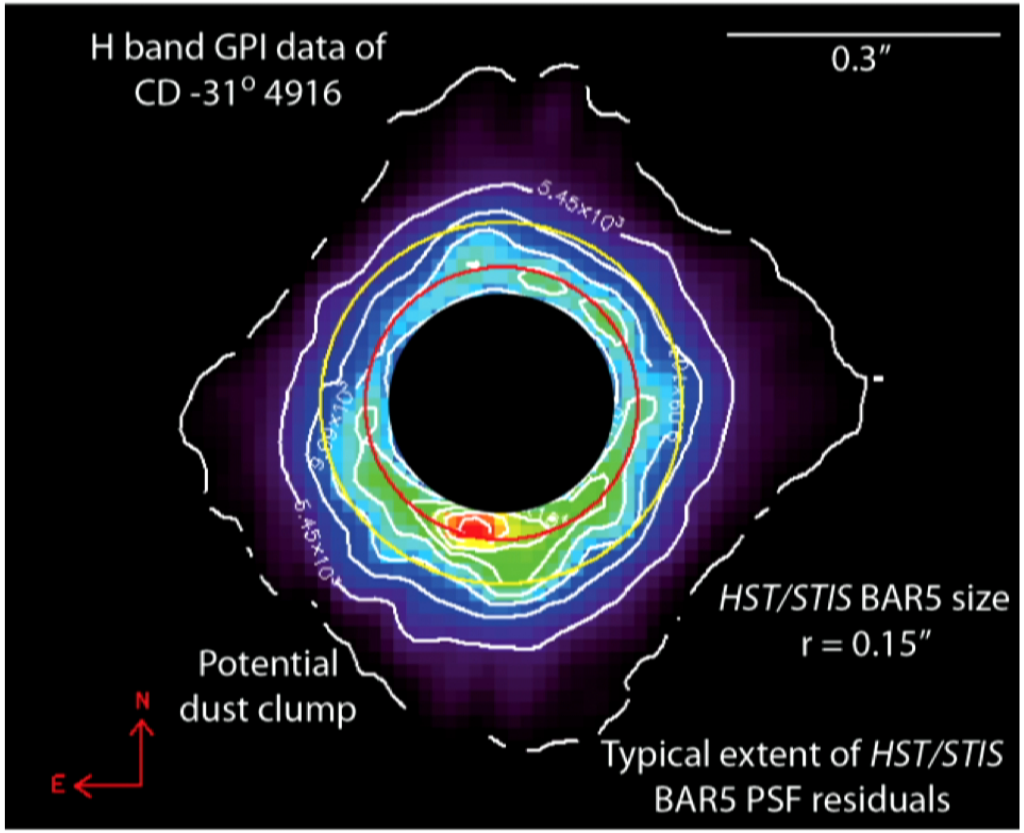
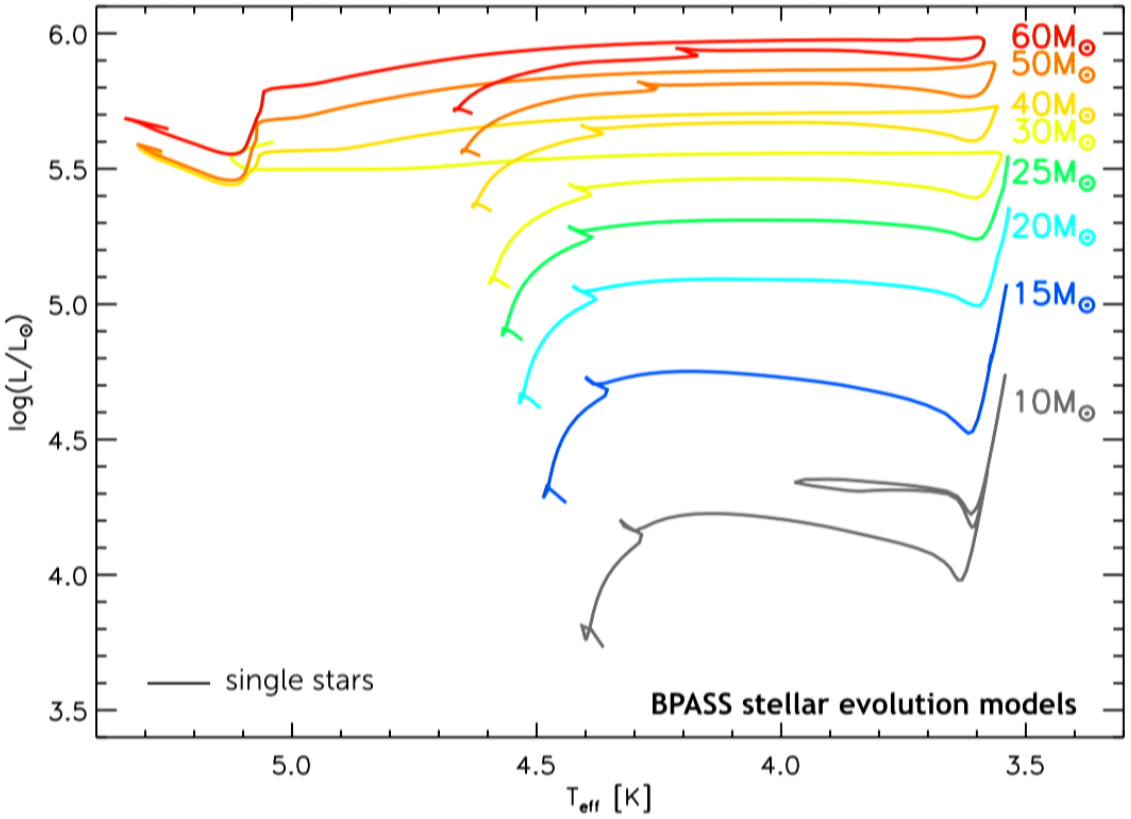


Lomax+ in prep

Challenges: RSGs in binaries

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



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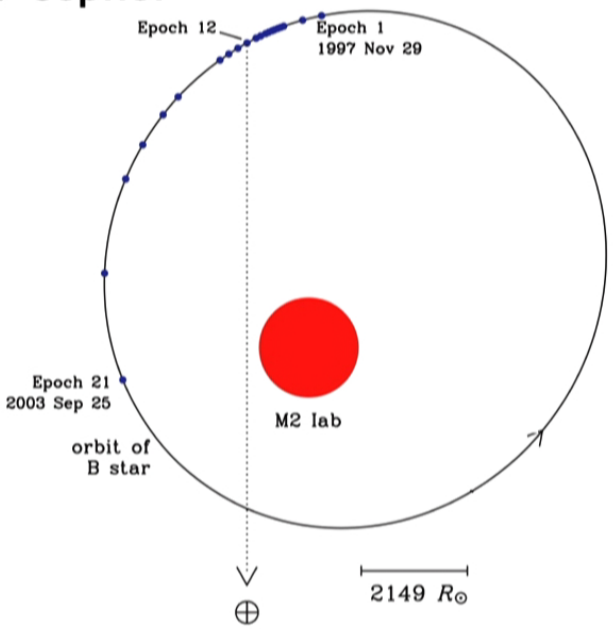
VV Cephei



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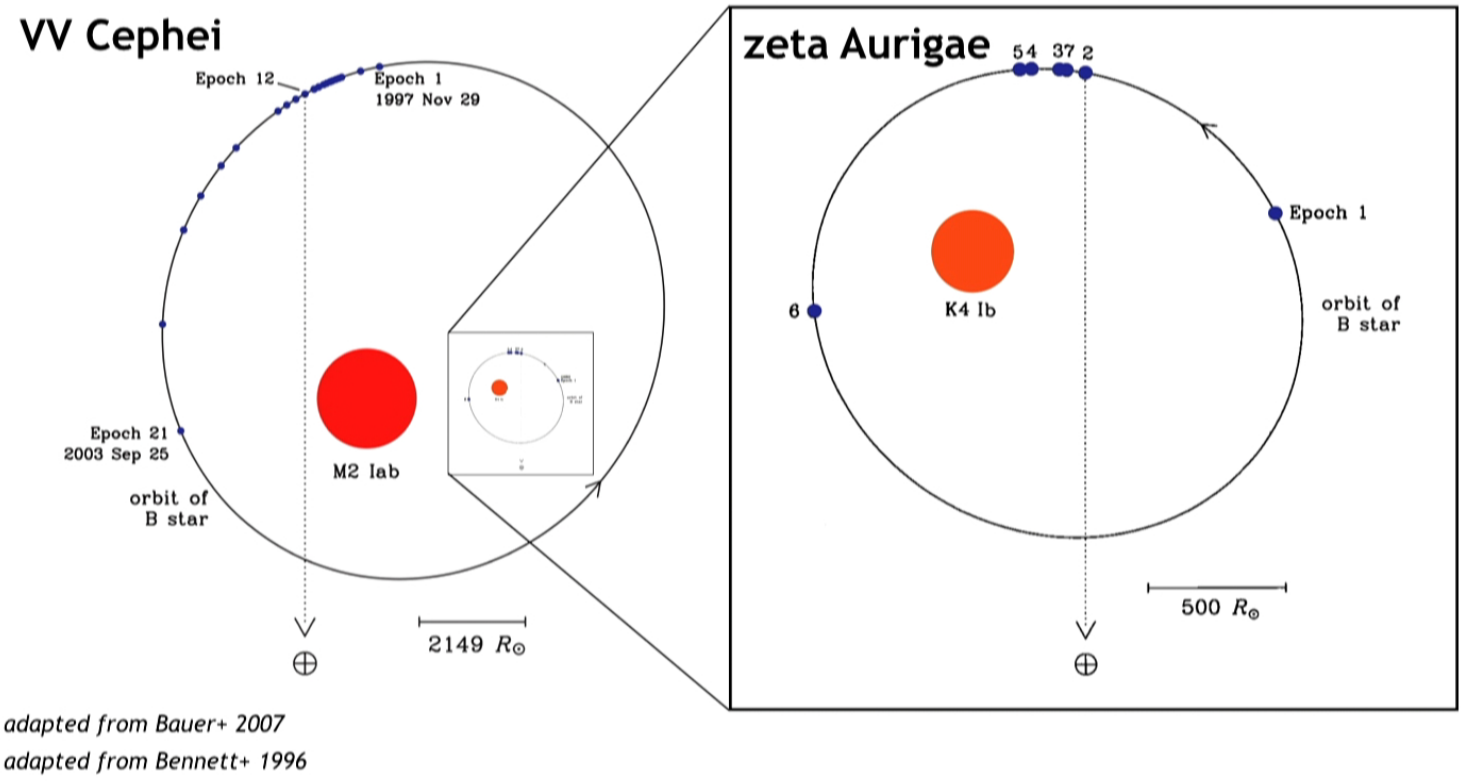

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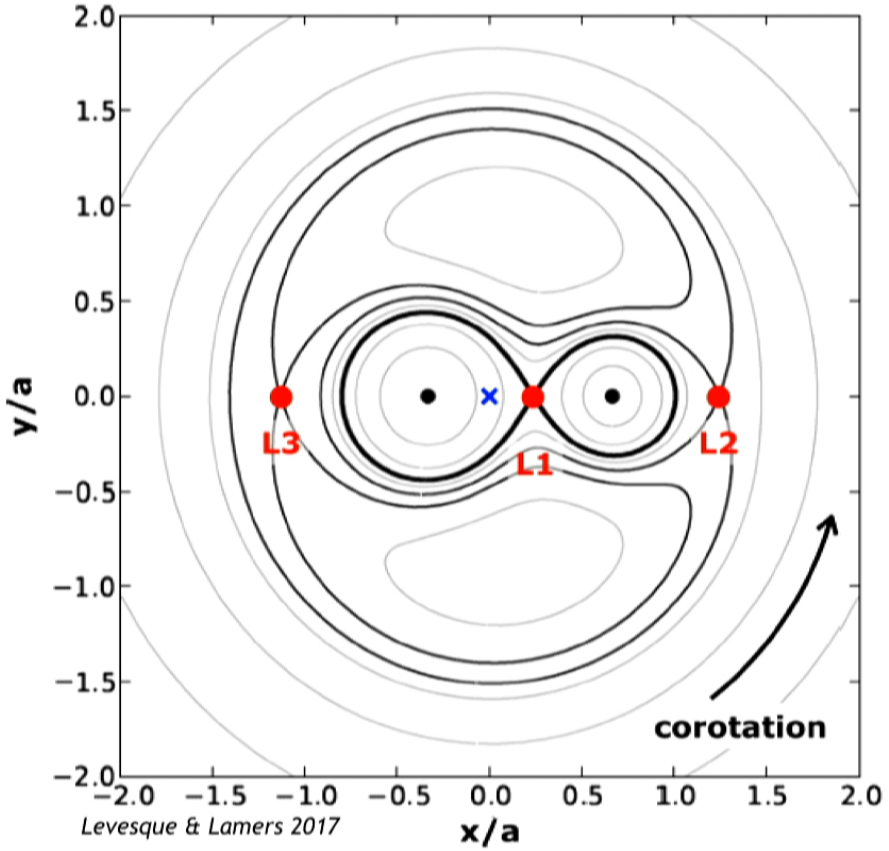

Levesque & Lamers 2017

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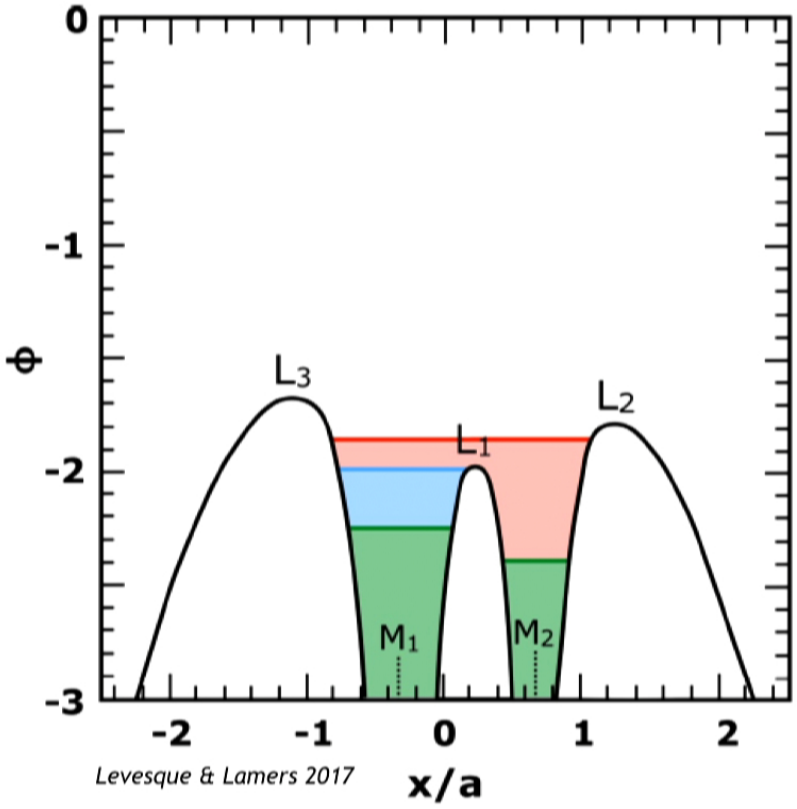

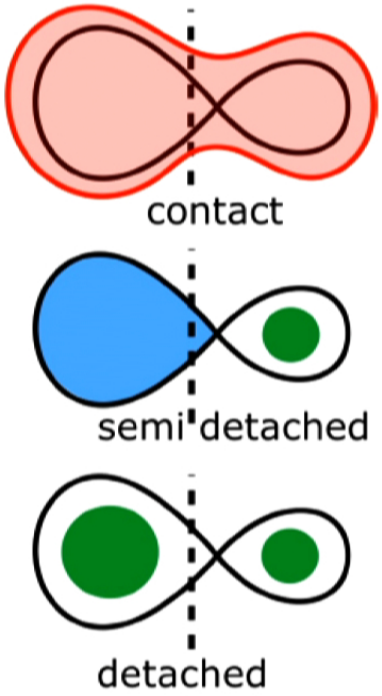

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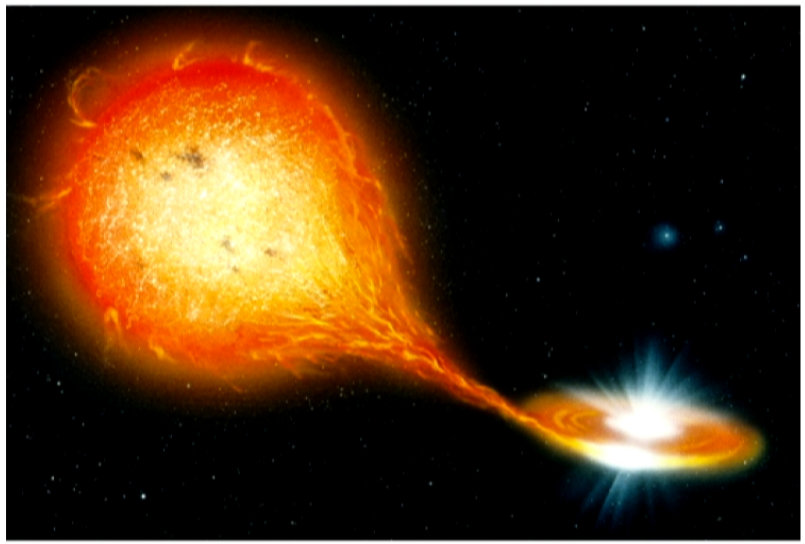

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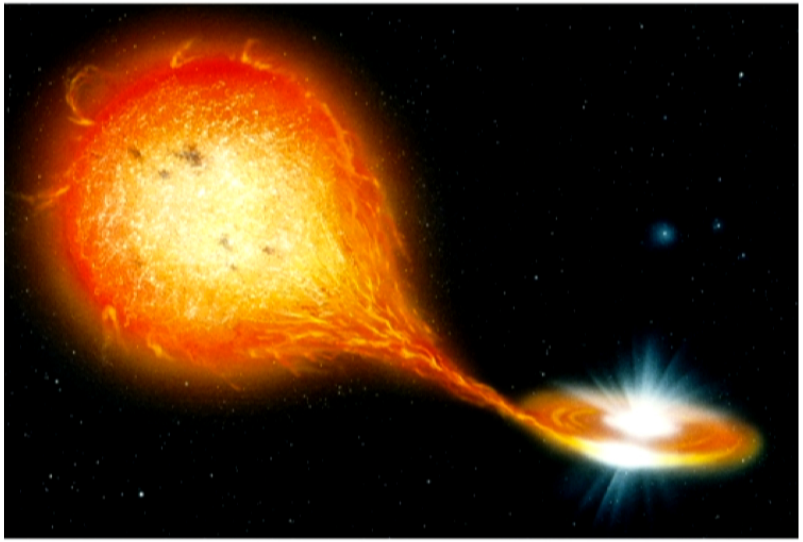
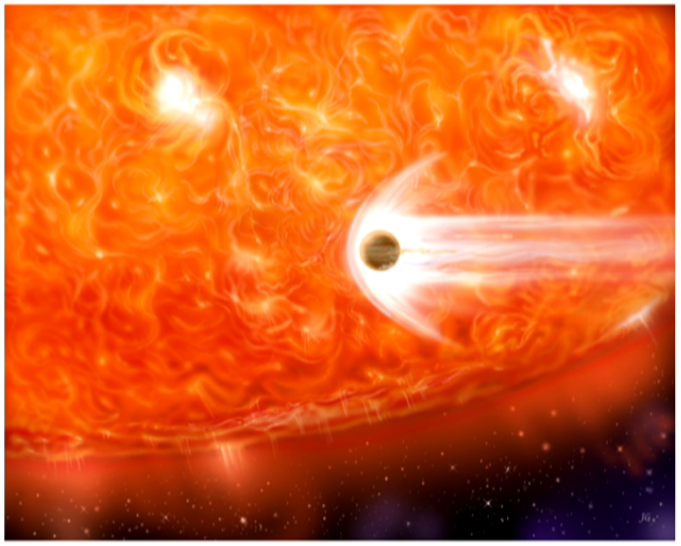
Thorne-Żytkow Objects (TŻOs) are a theoretical class of star: a neutron star "core" surrounded by a large diffuse envelope.

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





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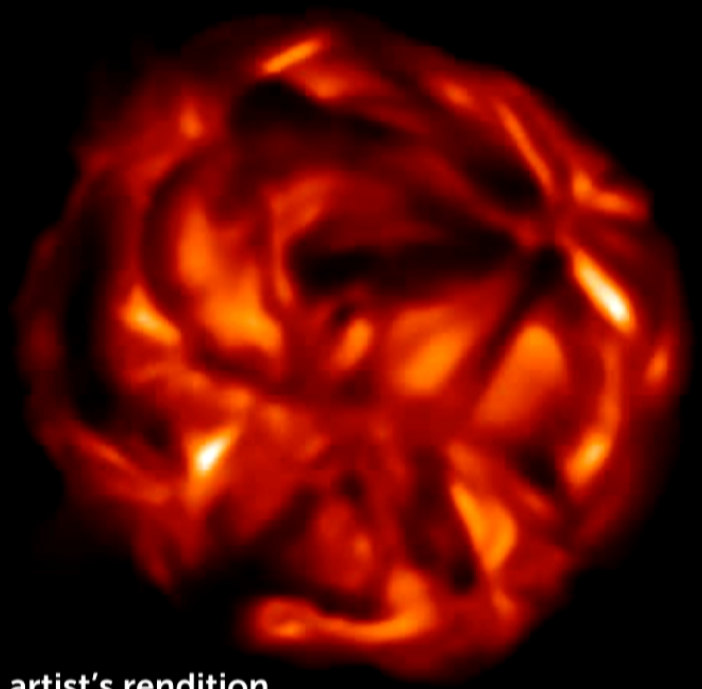

artist's rendition

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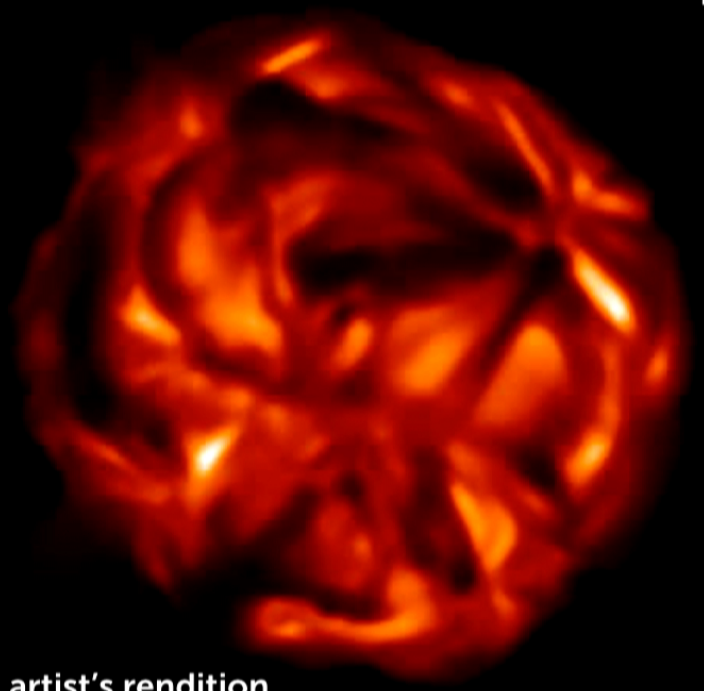

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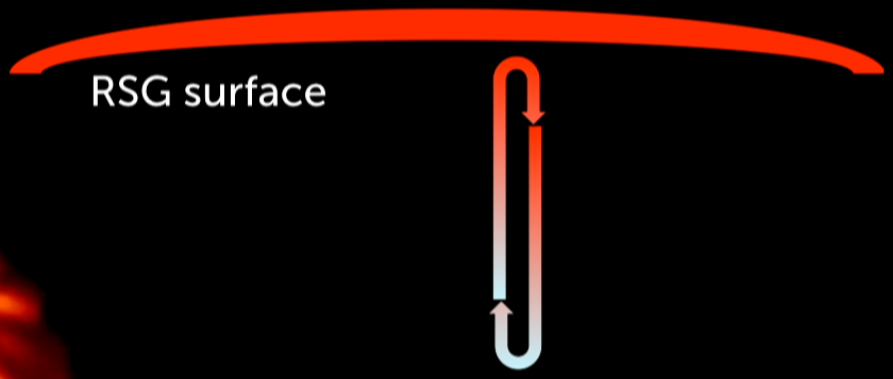

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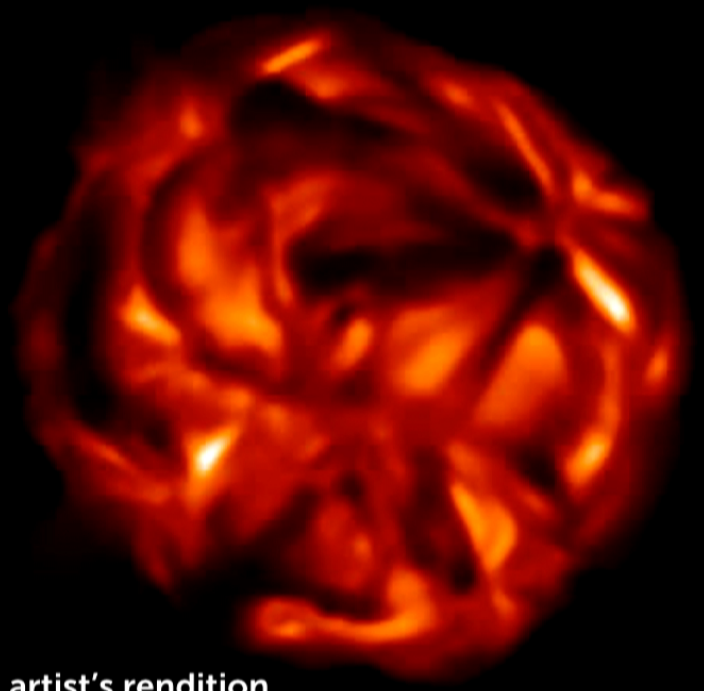

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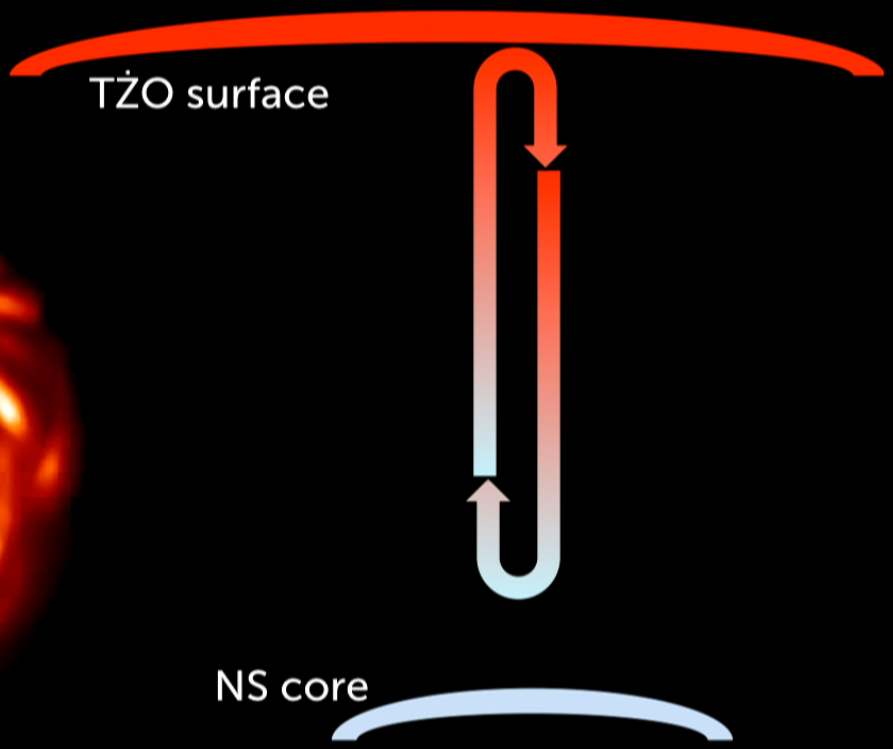

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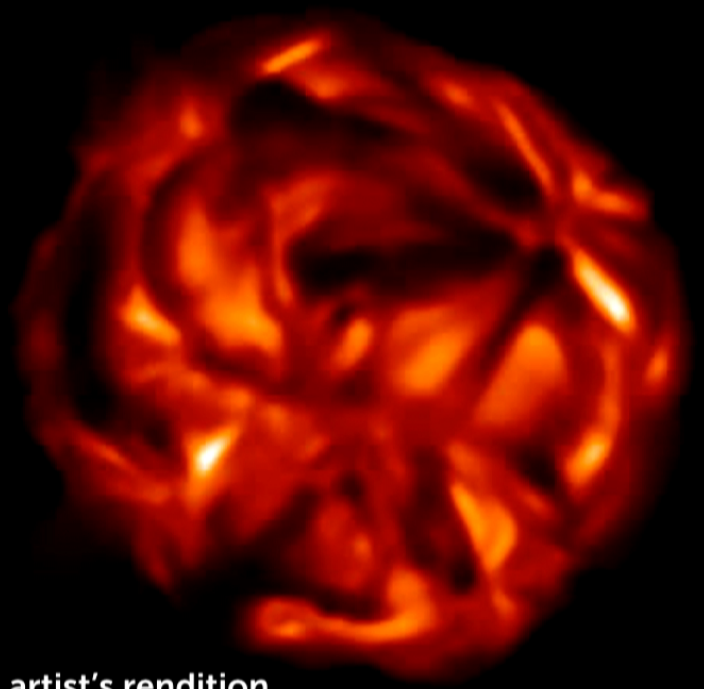

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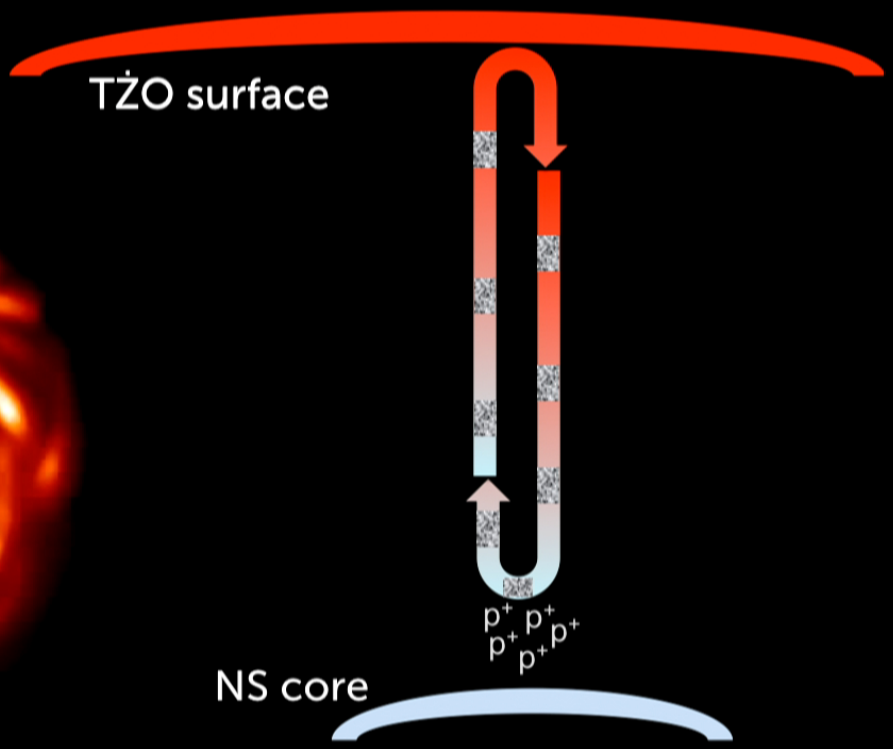

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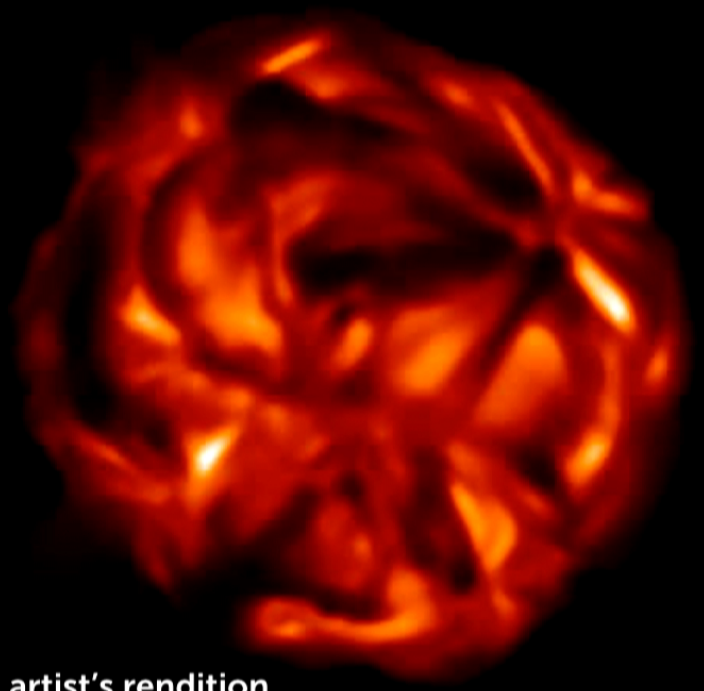

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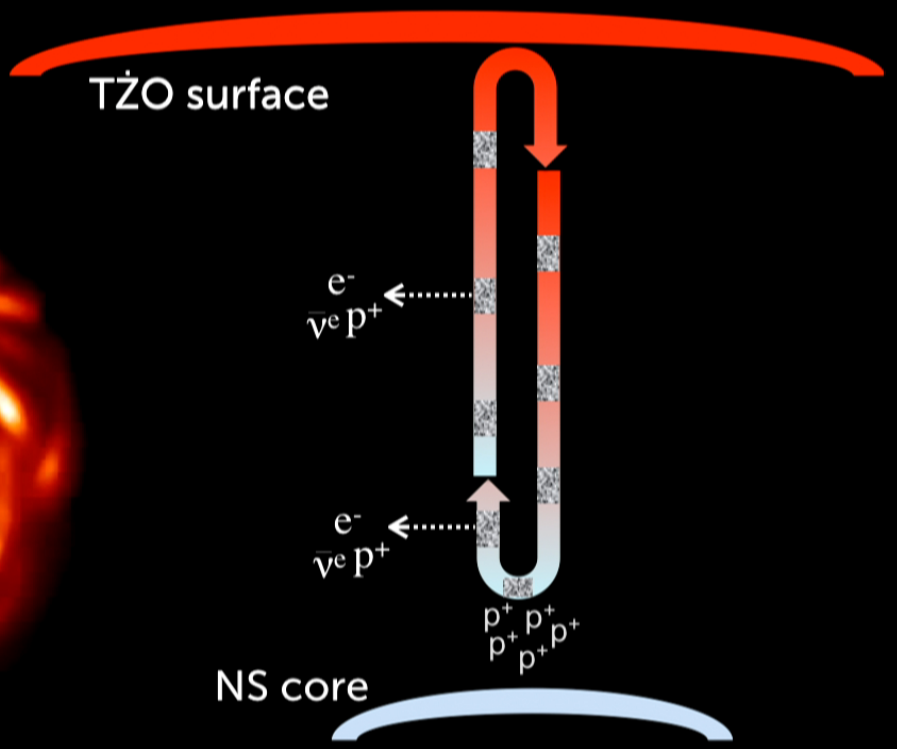

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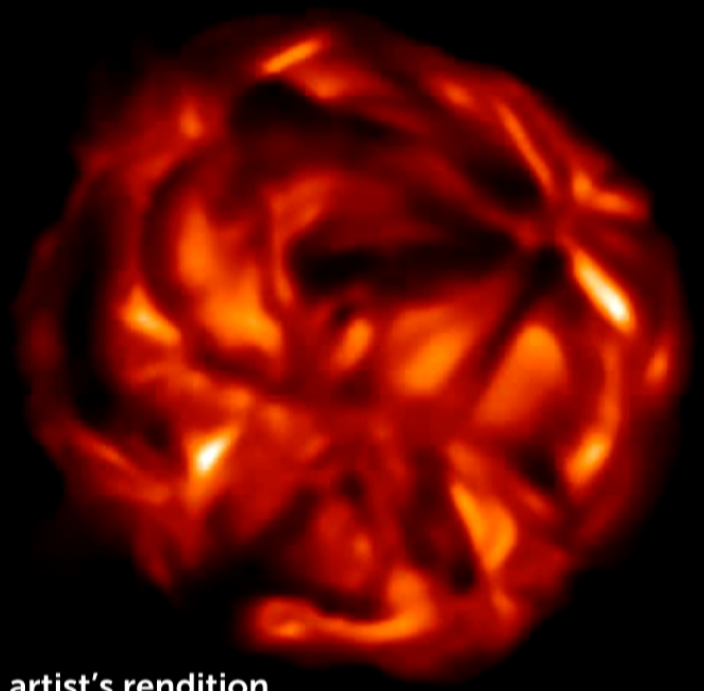

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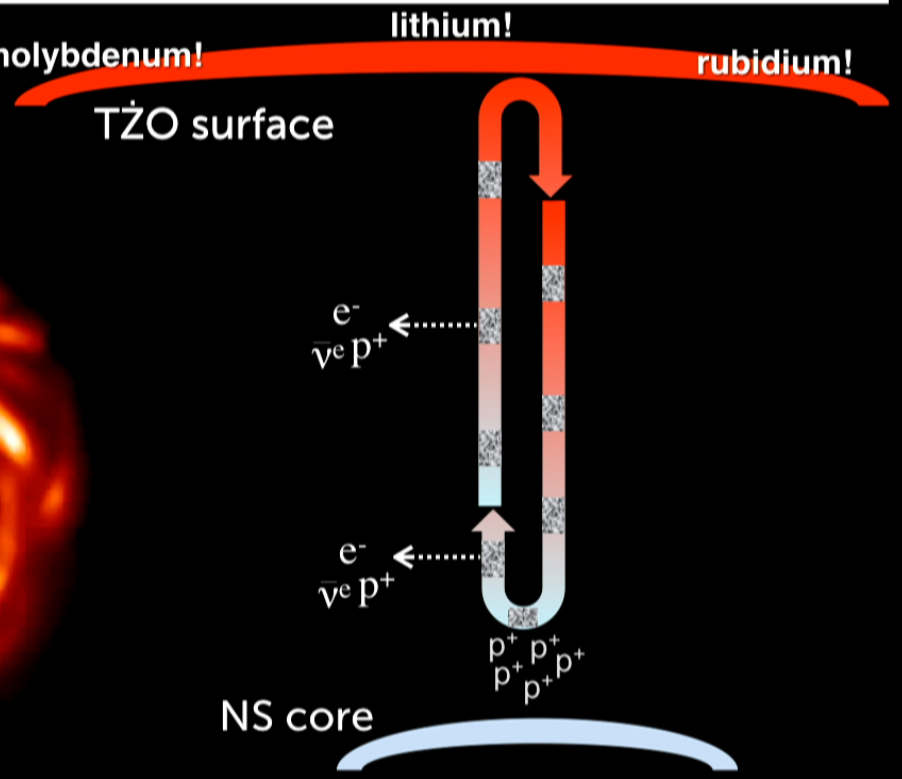

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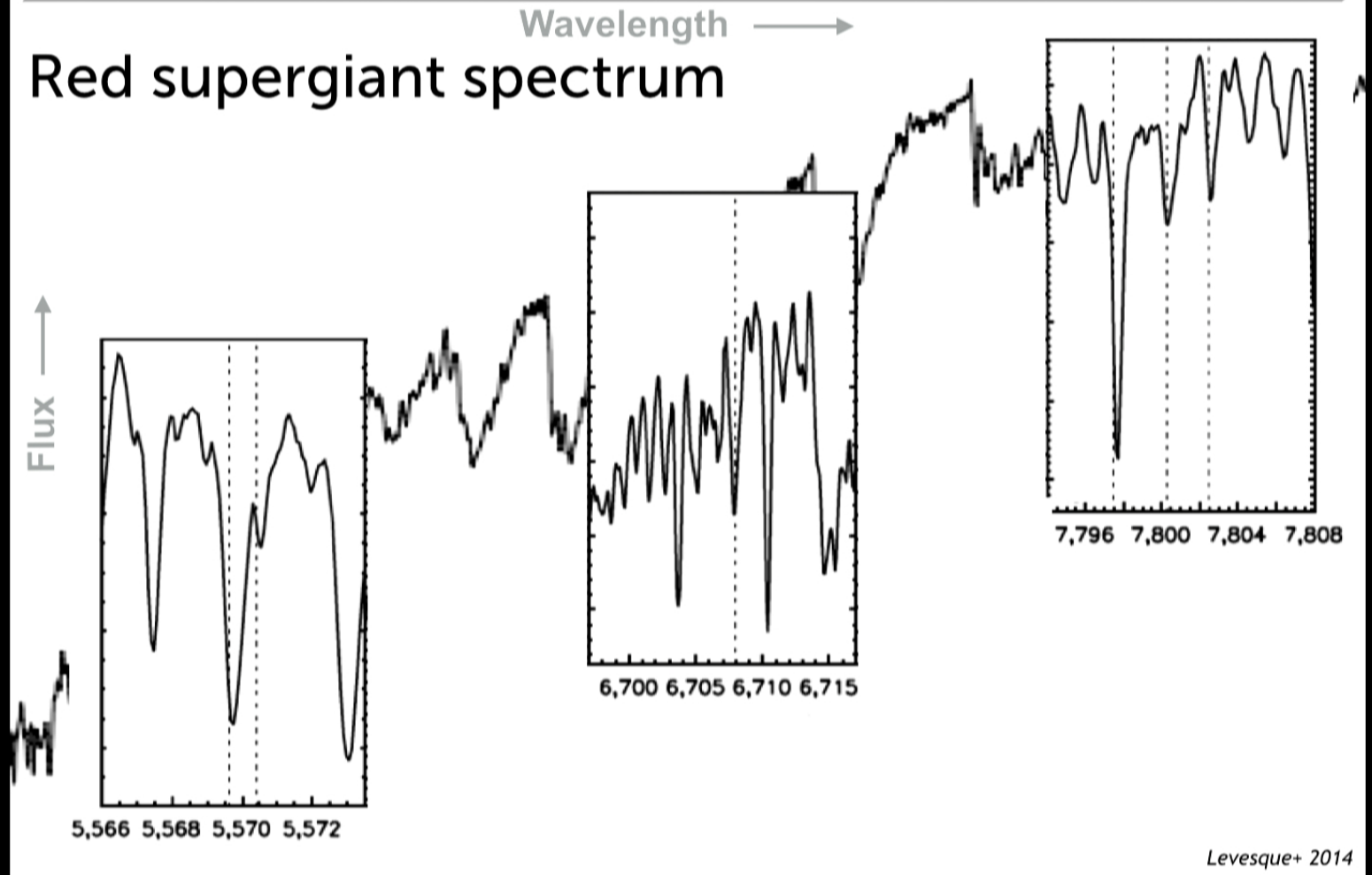

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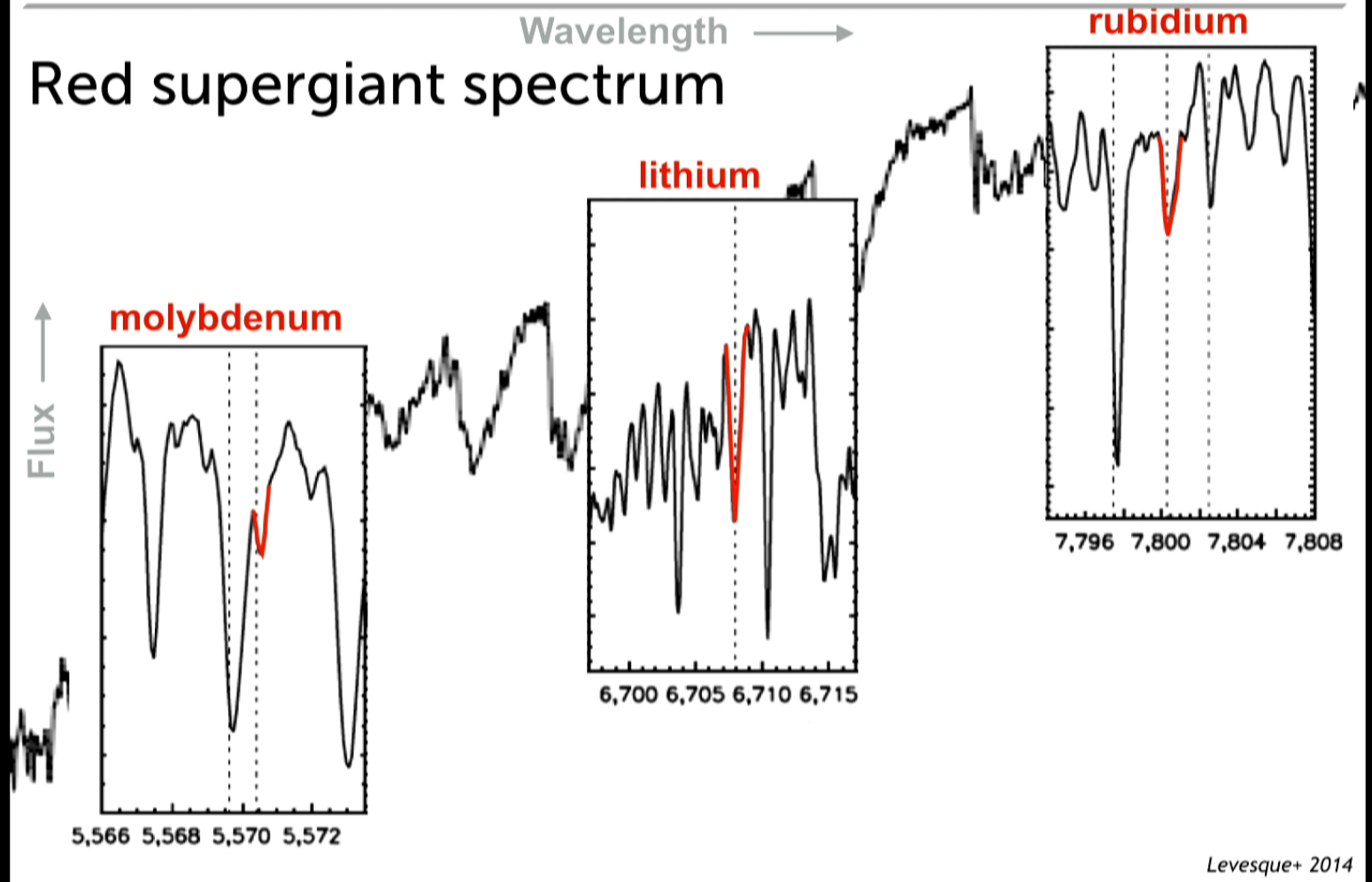

Levesque+ 2014

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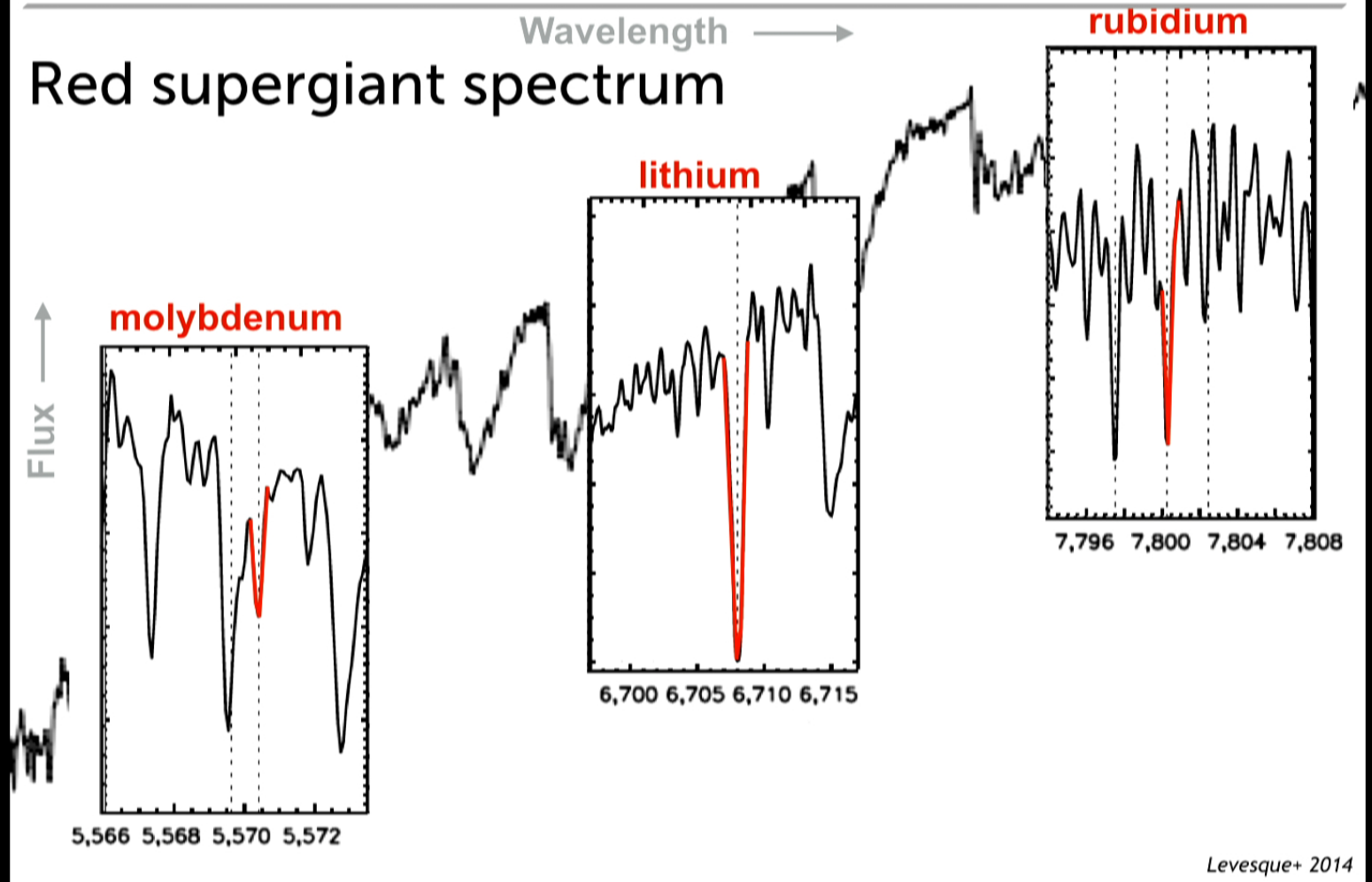

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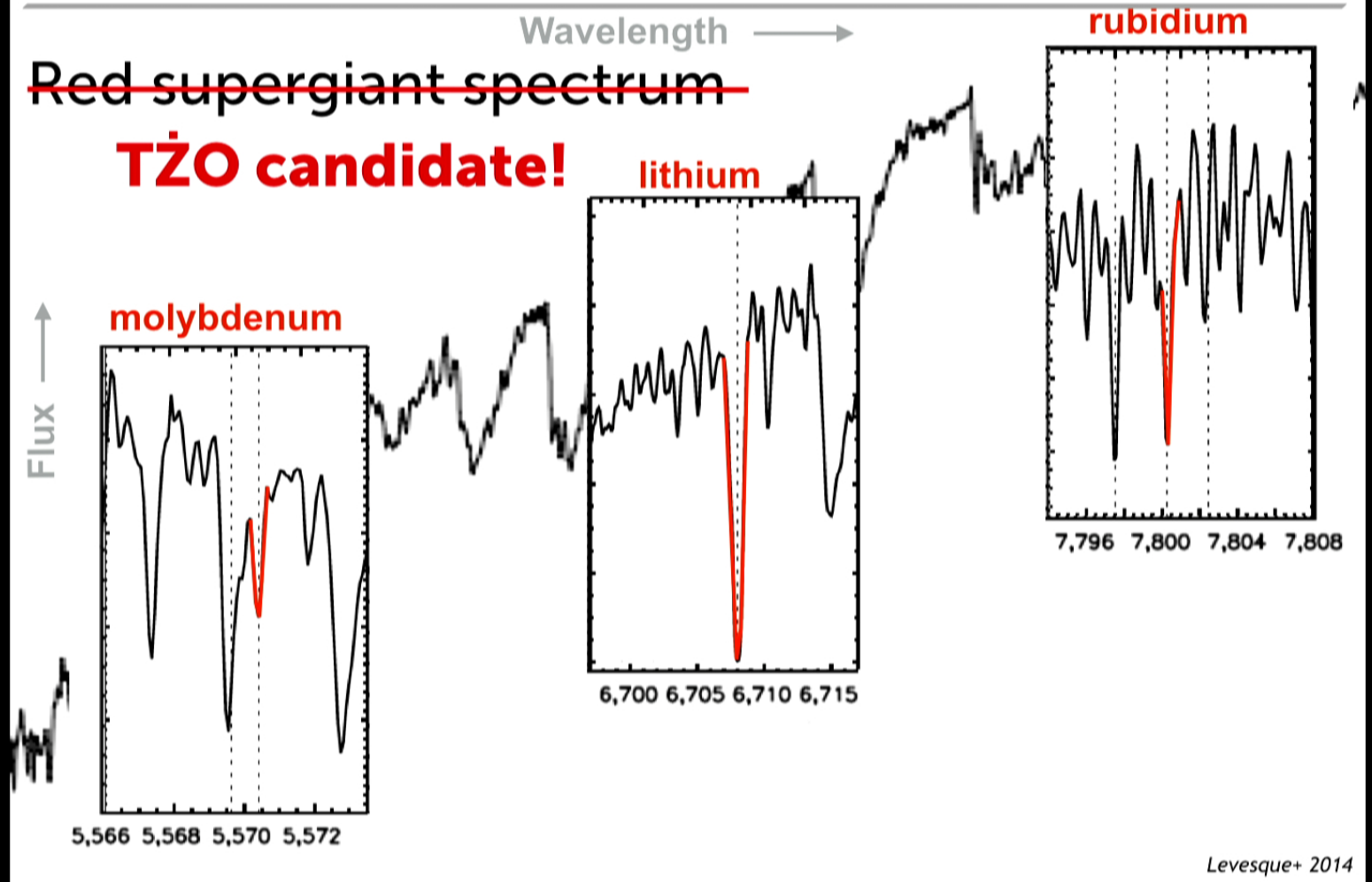

Who *cares* about red supergiants?

massive star formation

dust production

mass loss in cool stars

early universe chemistry

massive binary fraction

gravitational waves

stellar magnetic fields

massive star evolution

mass loss in massive stars

YOU DO!

stellar populations

mass-transfer binaries

supernova progenitors

galaxy compositions

stellar rotation

stars in the early universe

strange and variable stars

compact objects

time-domain astronomy

nucleosynthesis

infrared astronomy

Applications of RSGs

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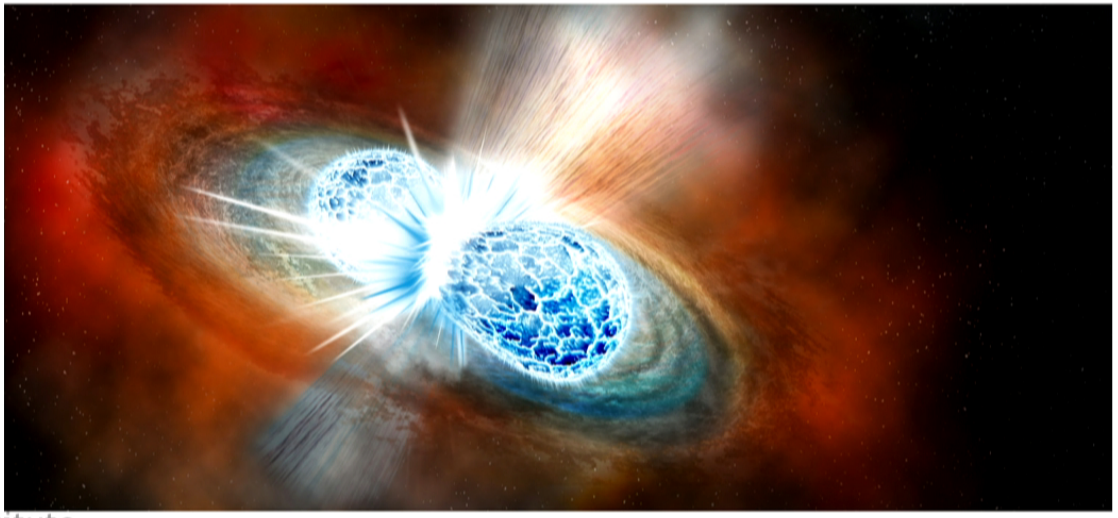

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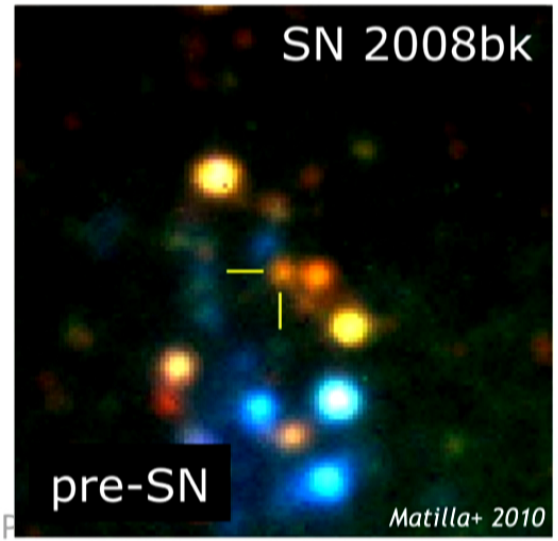

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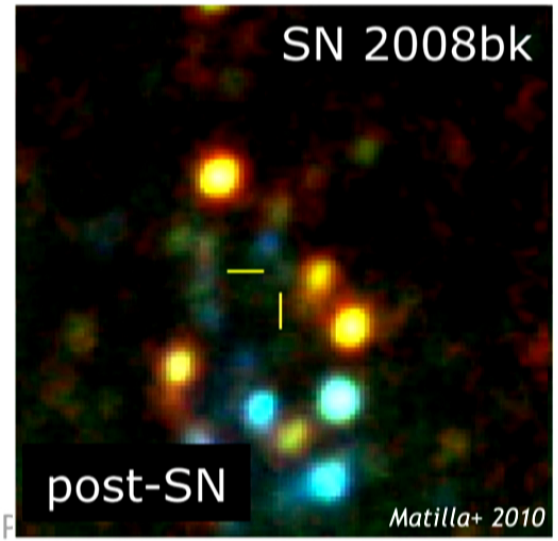

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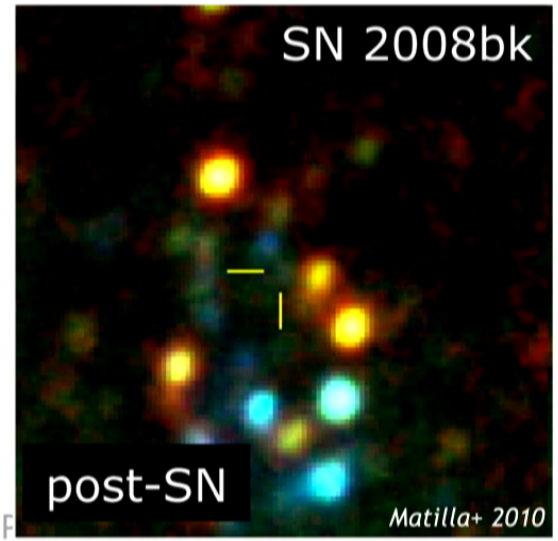

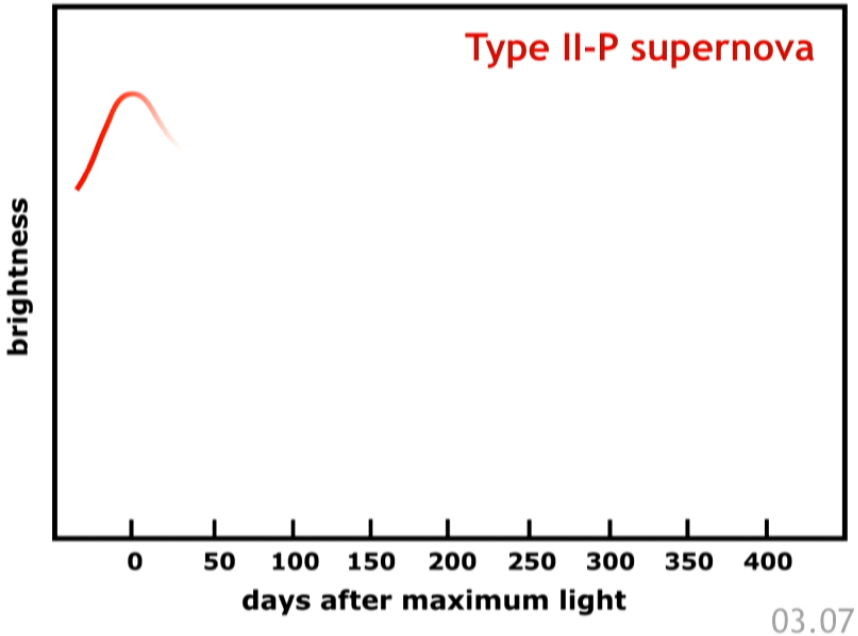

03.07.18

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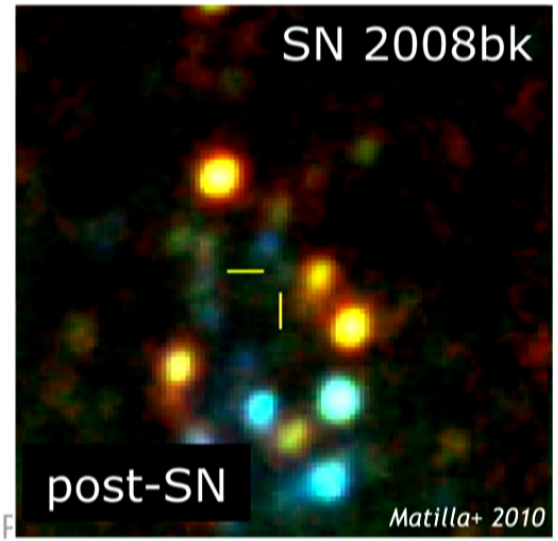

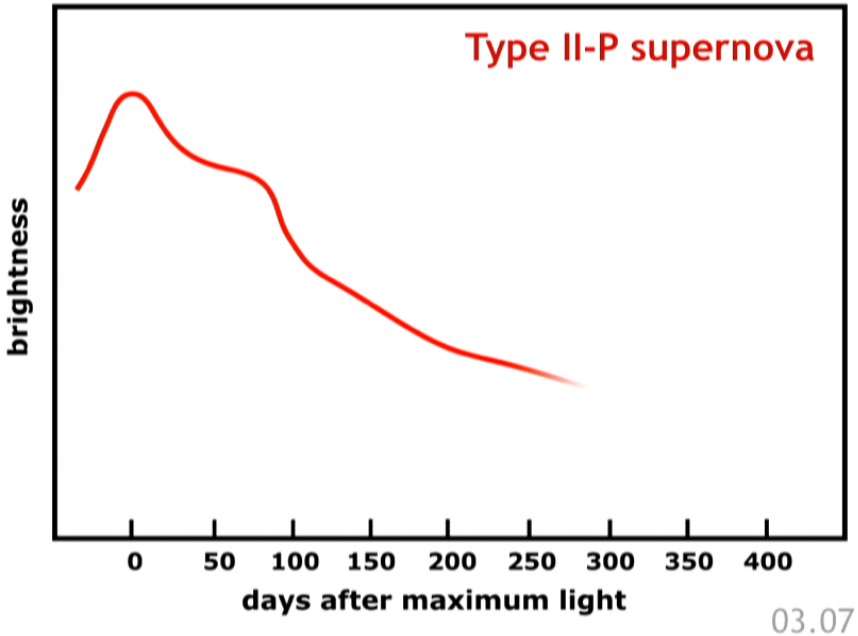

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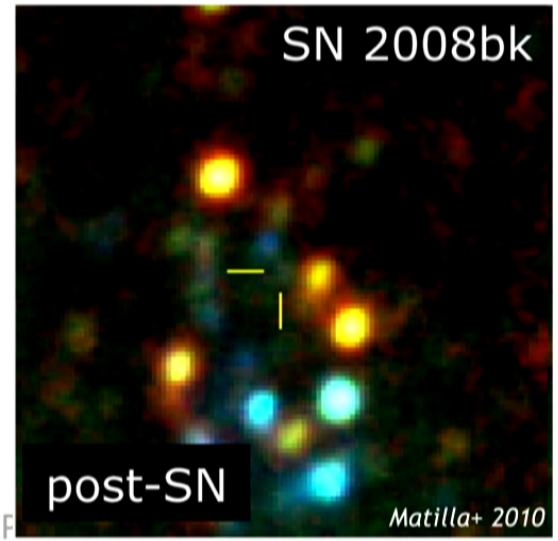

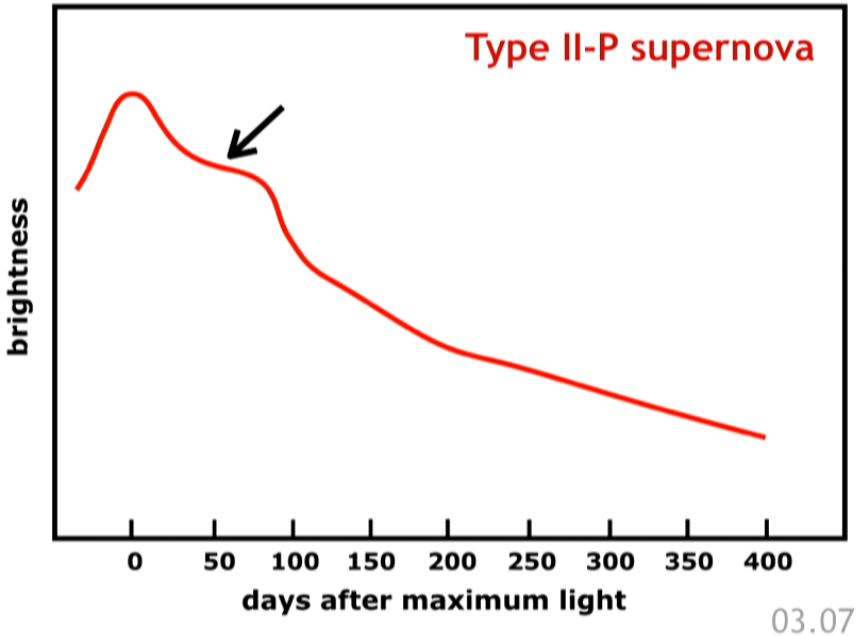

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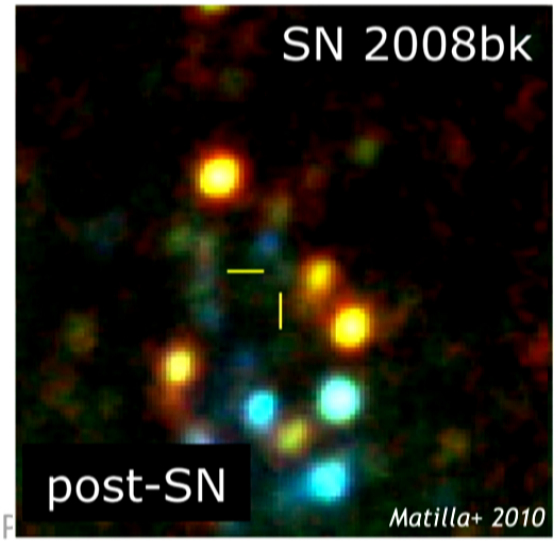

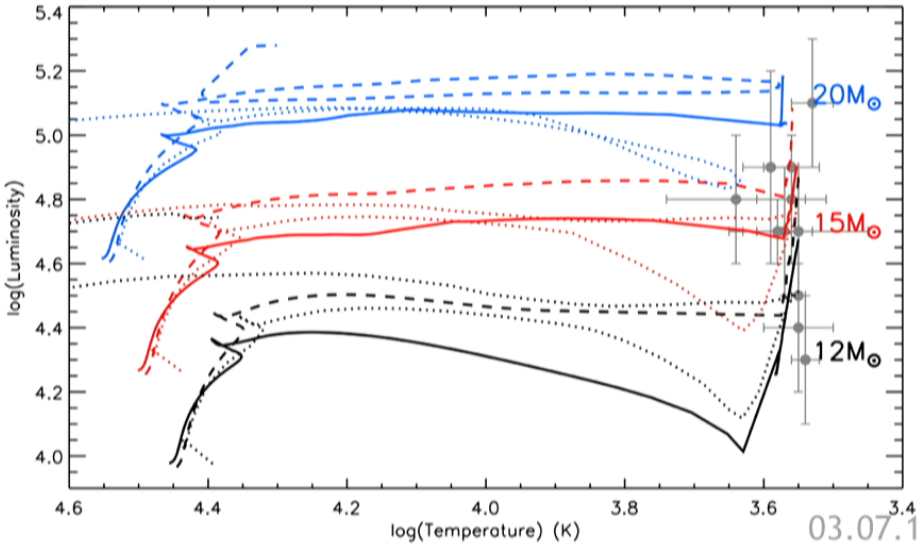

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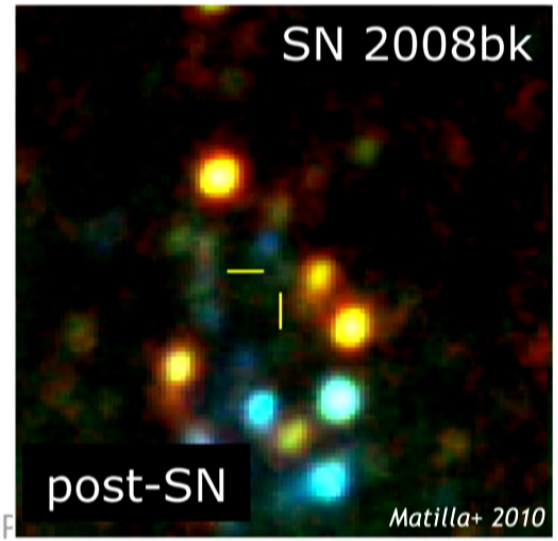

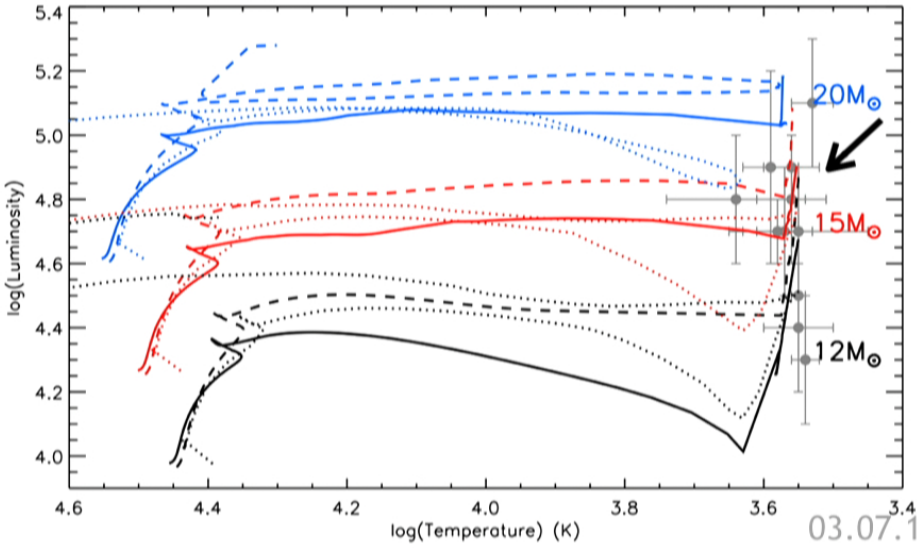

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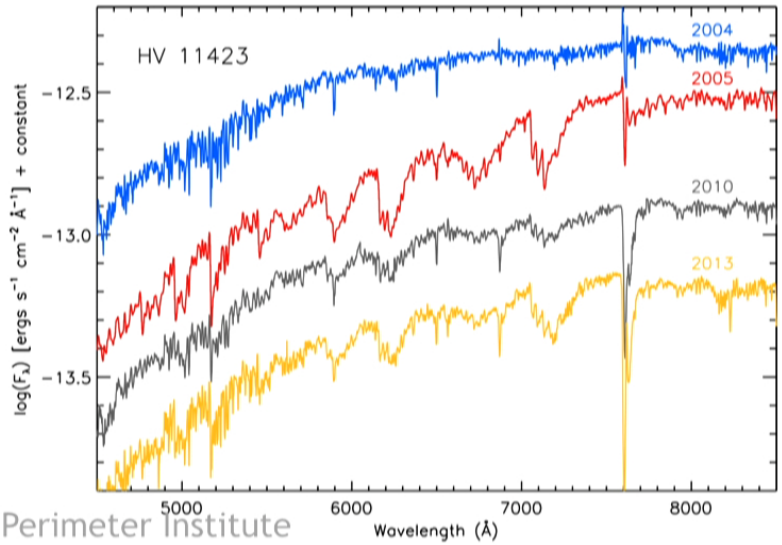
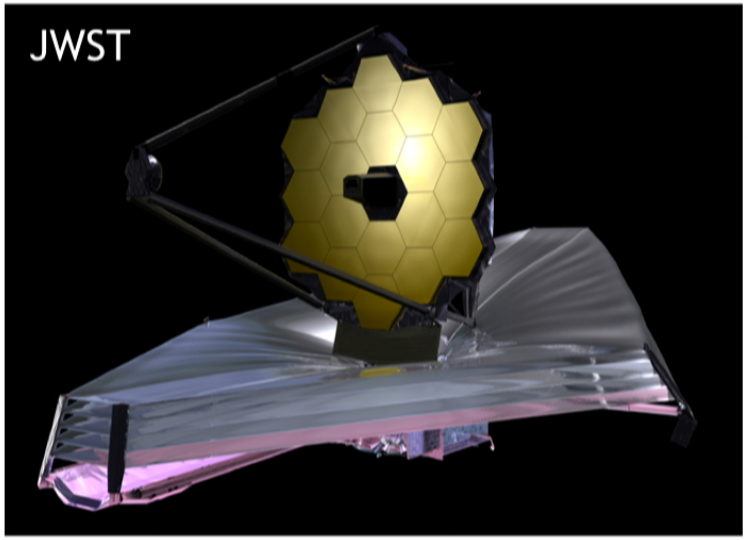
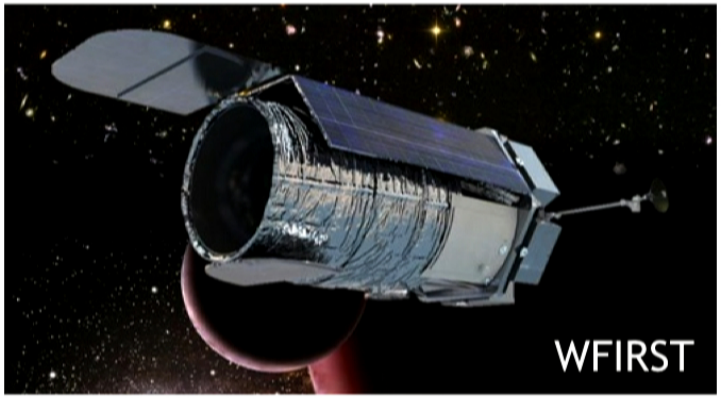


What's next for RSGs?

- 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

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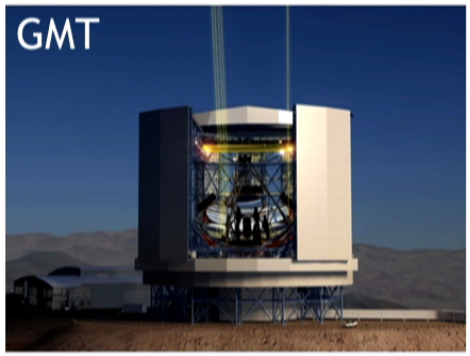
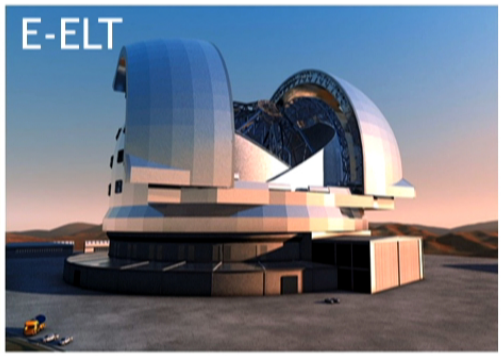
- The ELTs will be excellent tools for stellar astrophysics…





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