QUARK-NOVA AND THE MECHANISM BEHIND DOUBLE HUMPED SUPERLUMINOUS SUPERNOVA

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Supervisor: Dr. Rachid Ouyed

CSQCD 2016


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Forbes / Tech

JAN 15, 2016 @ 06:32 AM 119,182 VIEWS

Superluminous Supernova Is The Brightest Ever Seen

Brid-Aine Parnell
CONTRIBUTOR

I write about science, technology and the wonders of the universe

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Astronomers have been left stunned by a superluminous cosmic explosion that outshines the entire output of the 100 billion stars in the Milky Way.

The aptly named ASASSN-15lh, spotted by the Automated Survey for Supernovae (ASAS-SN), is a ball of hot gas billions of light years away that radiated energy 570 billion times more powerful than our Sun at its peak.

At the centre of this cosmic event is a superluminous supernova, a record-breaking explosion more than twice as bright as the previous record-holder. But scientists are stumped as to what kind of stars or stellar events lead up to these exceptionally rare, extreme explosions.

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Superluminous Supernova Are a New, Strange Way for Stars to Die

Mika McKinnon
1/14/16 3:03pm · Filed to: SCIENCE

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Universe's most luminous supernova was 50 times brighter than the Milky Way

By Daniel Clery | Jan. 14, 2016 , 2:00 PM

Kaboom! Astronomers have found the most violently explosive supernova so far detected in the history of the universe. Supernovae are already some of the brightest events out there but in recent decades astronomers have seen a rare new class of blasts, superluminous supernovae (SLSNe)—sometimes dubbed hypernovae. The new discovery was spotted last June by the All Sky Automated Survey for SuperNovae (ASAS-SN), a system of eight small 14-centimeter telescopes at two sites in Chile and Hawaii that can **scan the entire sky every 2 to 3 days**. At its peak, ASAS-SN-15lh, as the new supernova is known, was twice as luminous as any previously seen, thousands of times brighter than a normal supernova, and outshone our entire Milky Way galaxy by 50 times. (The artist's impression above shows what it would look like from an exoplanet 10,000 light-years away in its home galaxy.) But, as the ASAS-SN team describe online today in *Science*, more detailed study of the object and its surroundings with larger telescopes **is confounding theorists**. ASAS-SN-15lh appears to fall into a class called a hydrogen-poor SLSN which theorists believe occurs when an old star, run out of fuel, creates a supernova blast while collapsing into a highly-magnetized neutron star, known as a magnetar. The magnetic energy from the magnetar—so the theory goes—then powers up the still-expanding supernova making it unusually bright. However, this sort of SLSN is expected to form in small, dim dwarf galaxies full of young stars but ASAS-SN-15lh is in a large, bright galaxy with little star formation. So, back to the drawing board.

Forbes / Tech

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Found: The Most Powerful Supernova Ever Seen

A stellar explosion almost 600 billion times brighter than the sun pushes the limits of physics

By Lee Billings on January 14, 2016

What are superluminous supernovas?

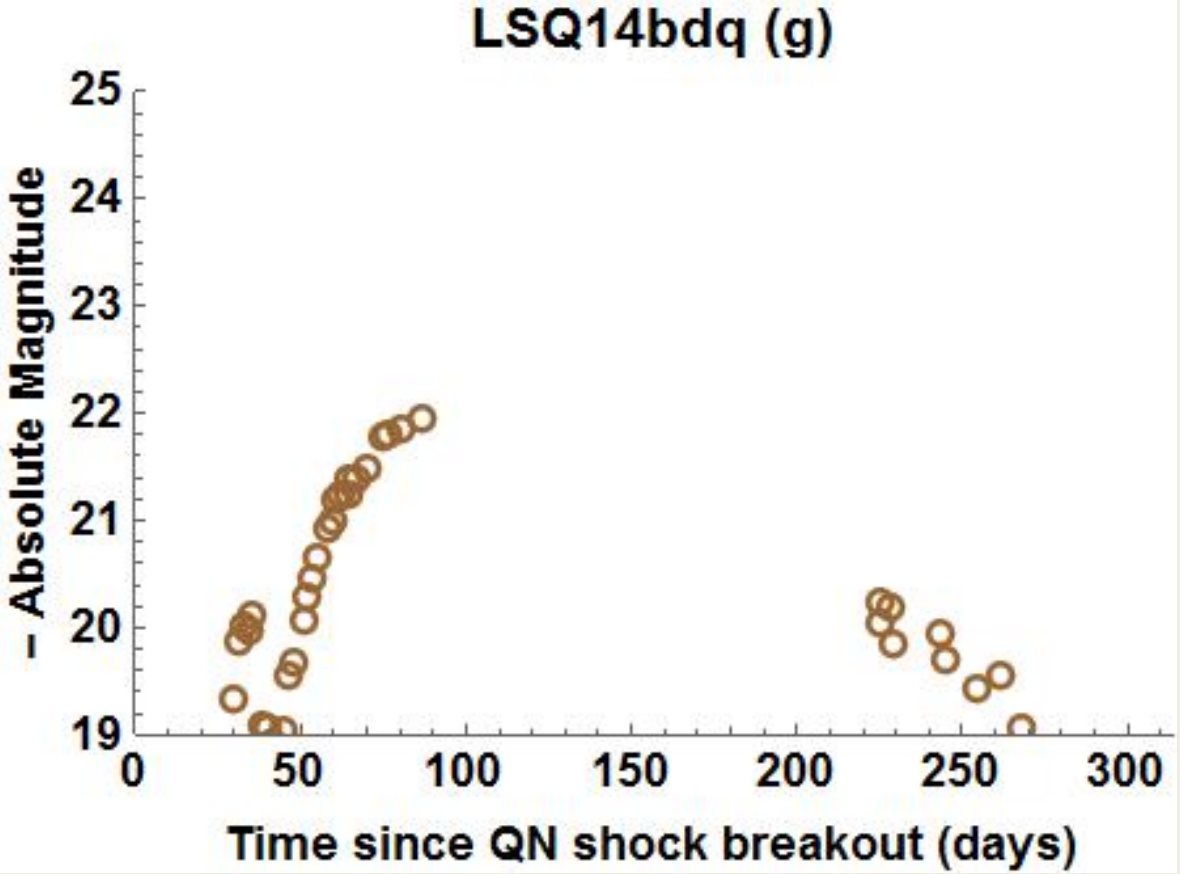
- Key aspects
- Current models
- Stellar evolution 101
- The Quark-Nova model
- Results
- Conclusion

A superluminous supernova

- 10 to 100 times brighter than normal core-collapse supernovae.
  - *50 times brighter than the Milky Way*
- Unknown mechanism
- Hydrogen poor and associated with low-metallicity environment/galaxies
- Ideal to get information about the early universe and use as standard candles

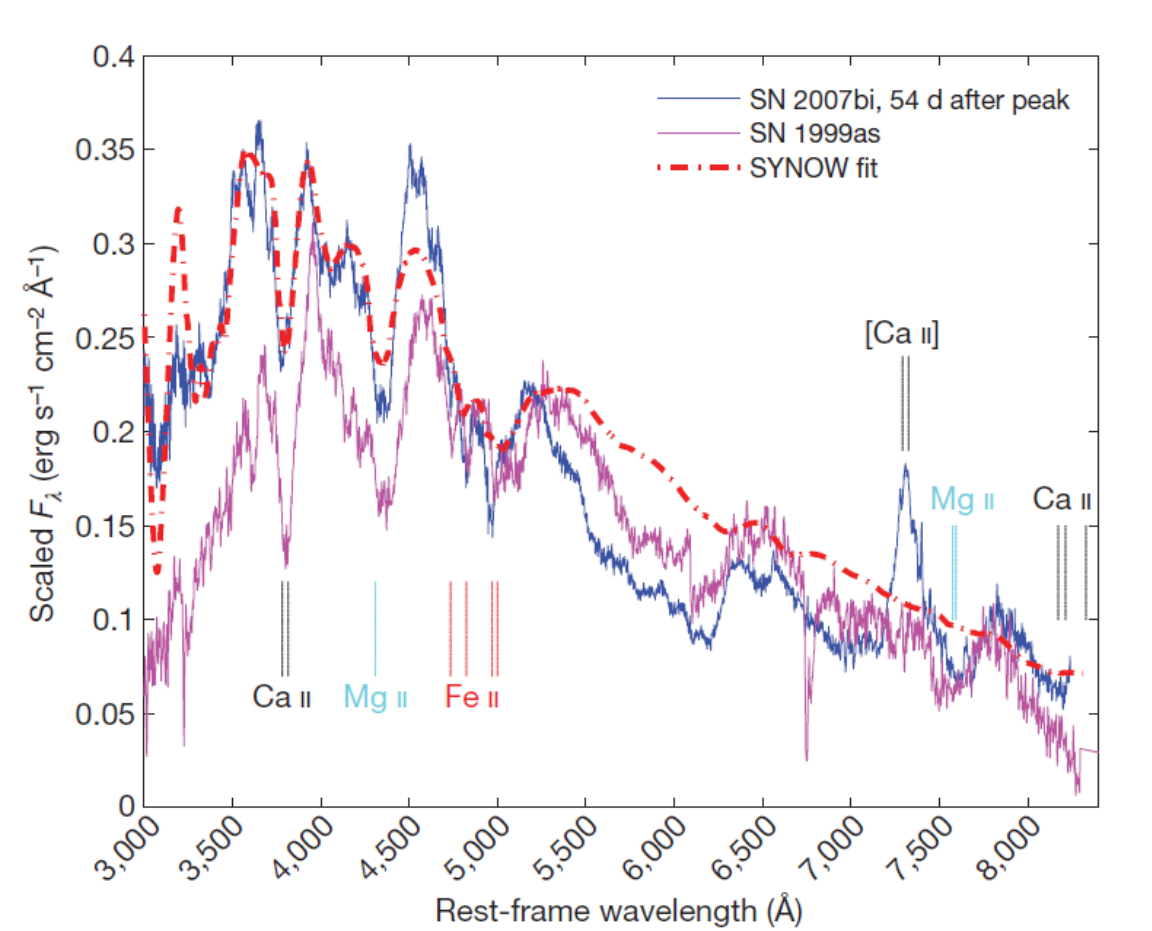
Credit: Beijing Planetarium / Jin Ma

What does it look like?



- Double hump
- Bright
- Lack of hydrogen in the spectrum

What does it look like?



Gal-Yam, et al 2009

- Double hump
- Bright
- Lack of hydrogen in the spectrum

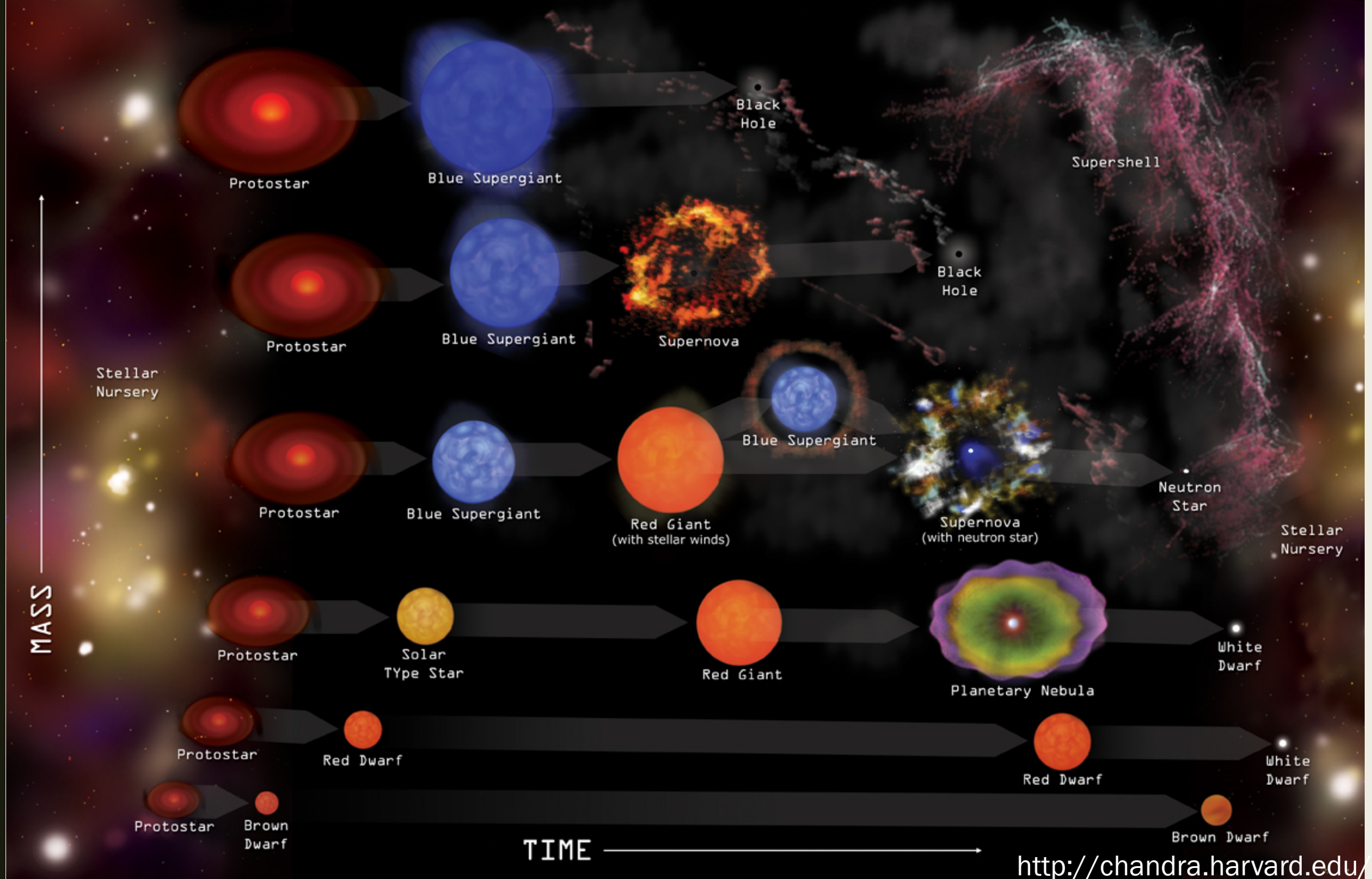
Current models

- Accreting black hole that launches relativistic jets.
- Interaction of a supernova with a dense circumstellar material.
- Rapidly-rotating neutron star (NS) that loses rotational energy (magnetar)

BUT….

- *What about the lack of hydrogen?*
- *What is the reservoir of energy?*

- *Let's look at Astrophysics 101*


Black Hole
Protostar
Blue Supergiant
Supershell
Black Hole
Protostar
Blue Supergiant
Supernova
Stellar Nursery
Protostar
Blue Supergiant
Blue Supergiant
Red Giant (with stellar winds)
Supernova (with neutron star)
Neutron Star
Stellar Nursery
MASS
Protostar
Solar TYpe Star
Red Giant
Planetary Nebula
White Dwarf
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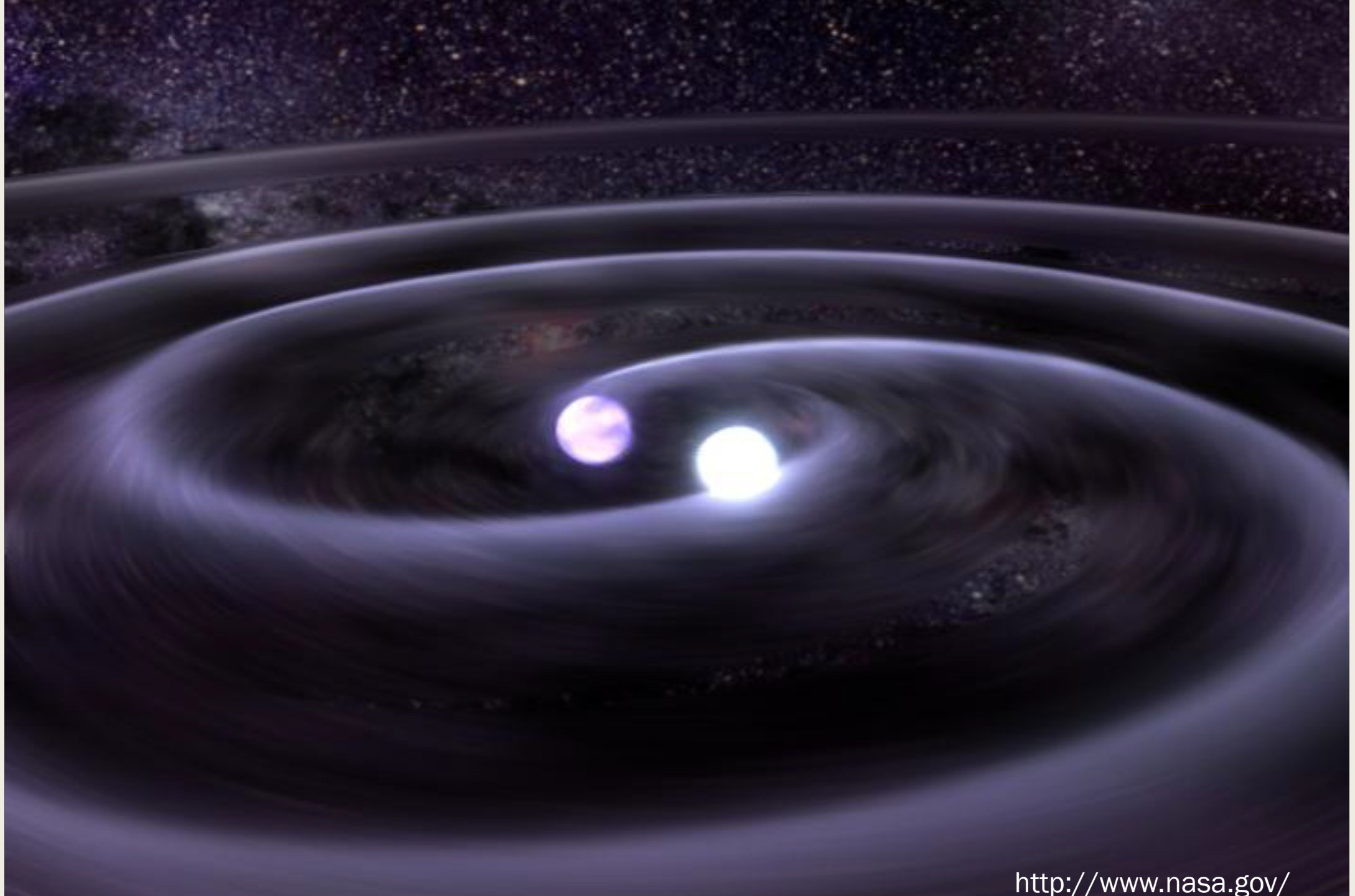
TIME
http://chandra.harvard.edu/

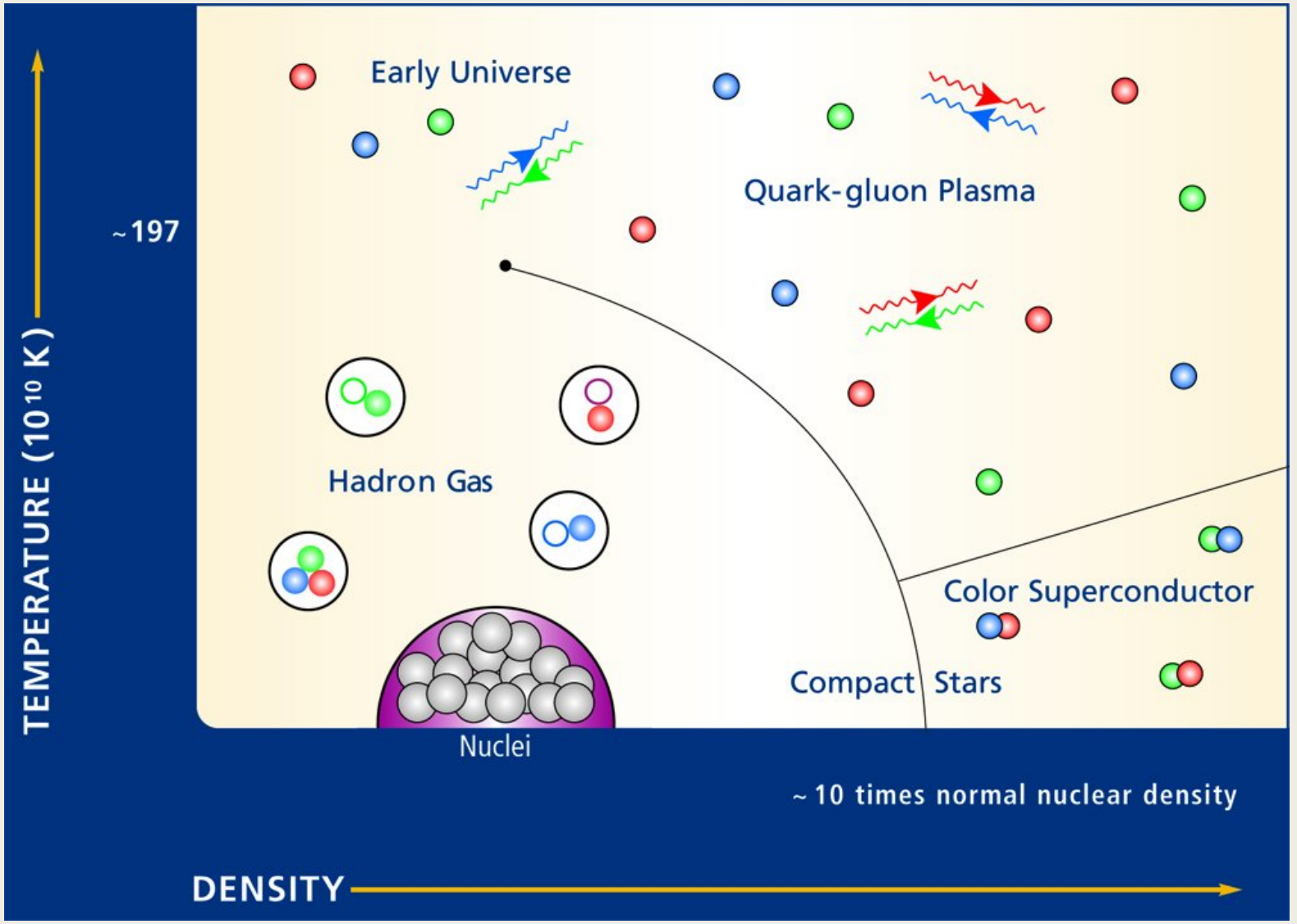

http://www.nasa.gov/

The binary

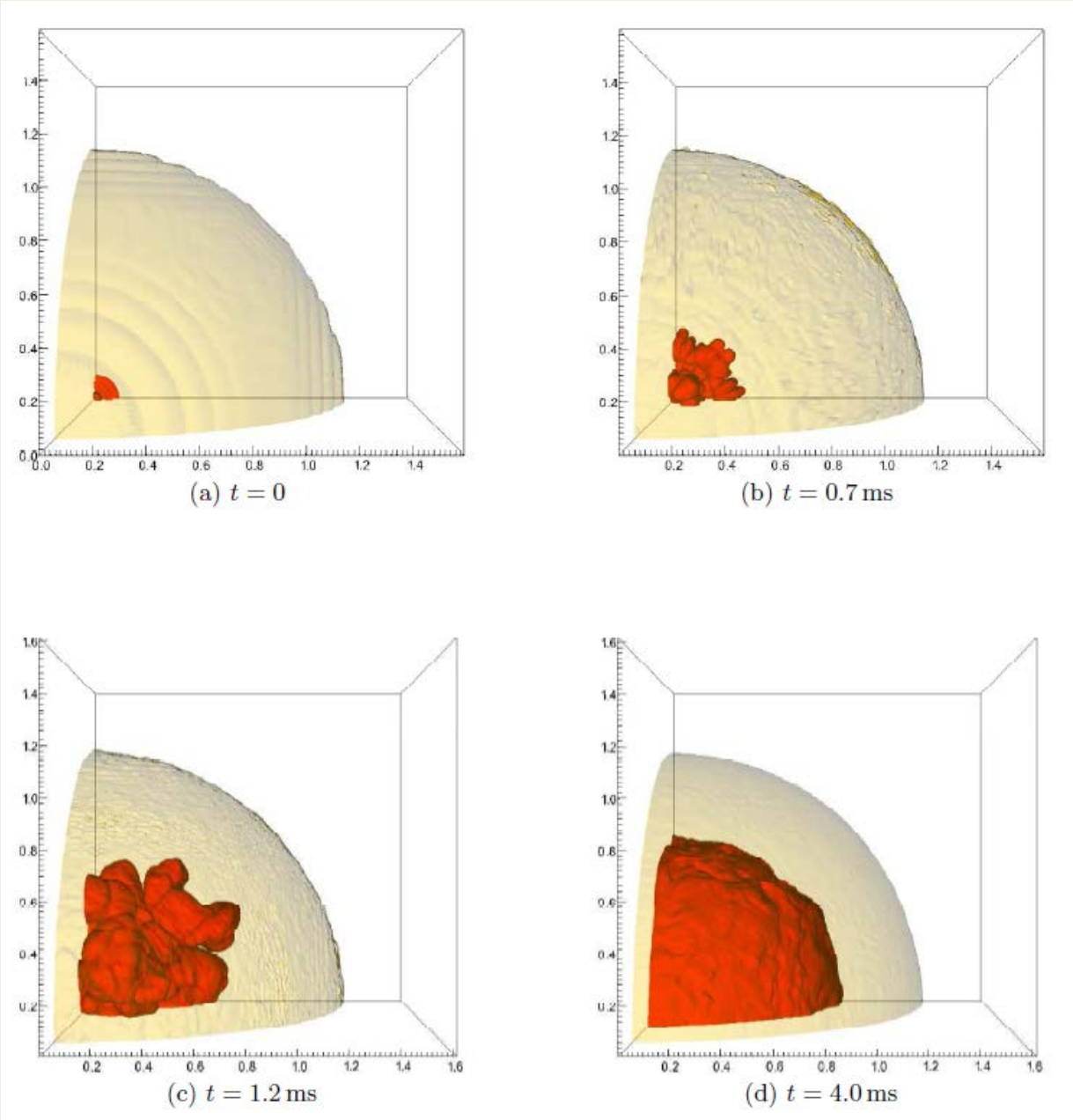
- There is an exchange of matter.
- Matter is expelled.
- Now you have an undergrad degree in astrophysics!

- This is where QCD gets into the picture!

The Quark Nova model



The Quark Nova model



Drago & Pagliaria, 2015

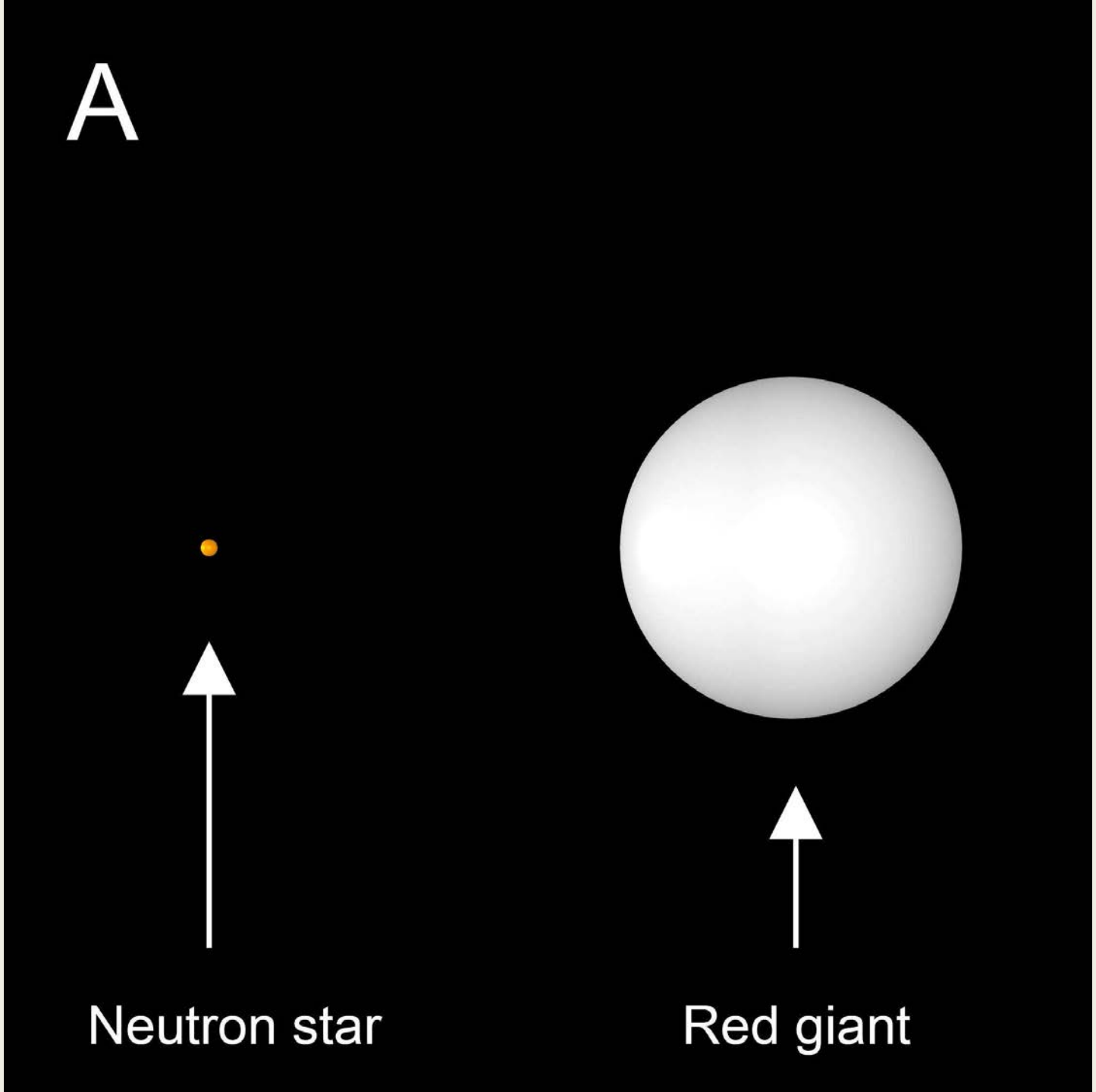
The Quark-Nova in a massive binary

- A mechanism for superluminous supernovas
- It offers:
  - *Hydrogen poor environments*
  - *An energy reservoir*

- Start with a supernova in a binary…

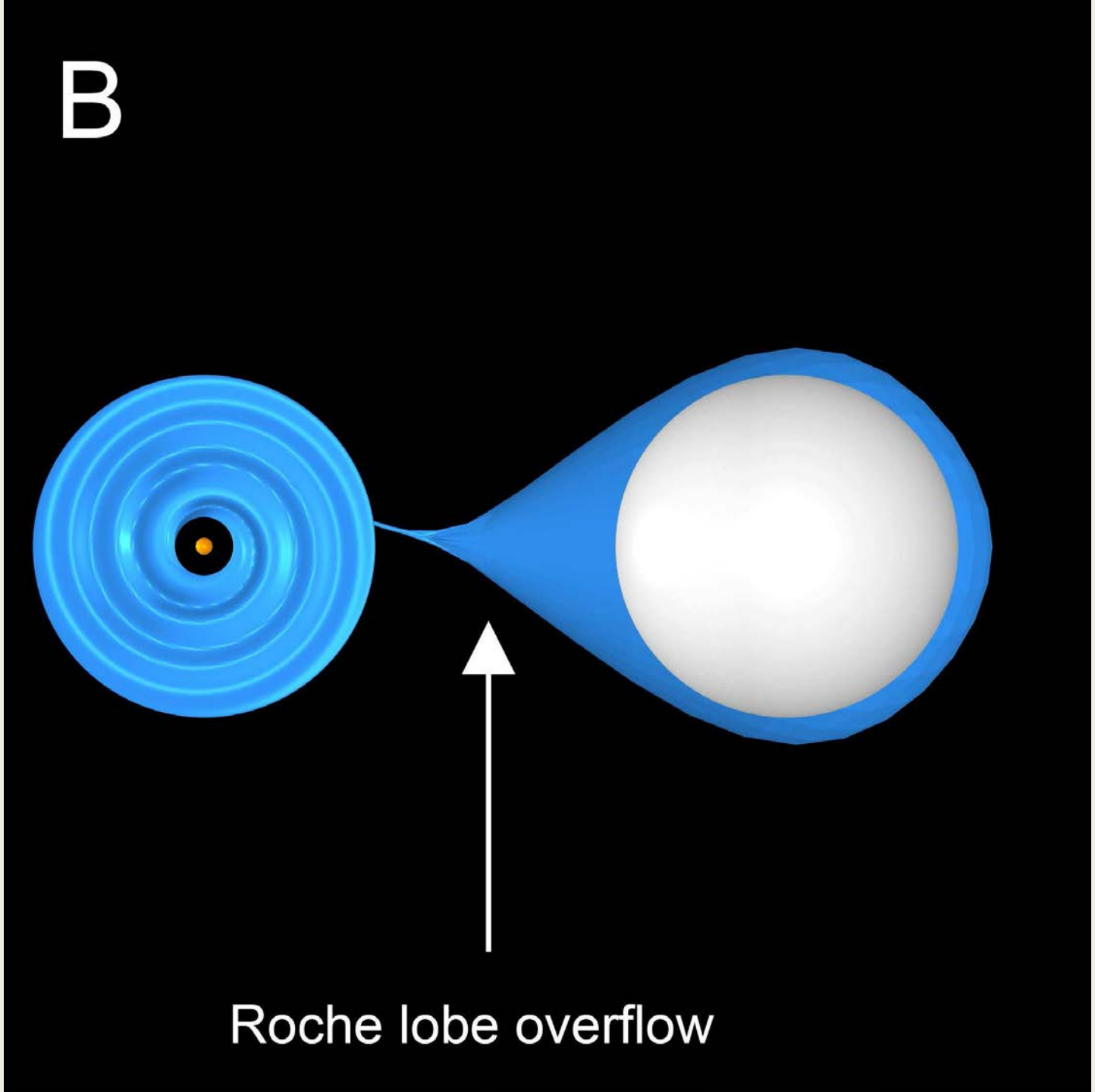
- ~20- 25 Mo
- NS ~ 1.4Mo
- Separation

  ~ 200Ro



Ouyed, Leahy and Koning. 2015

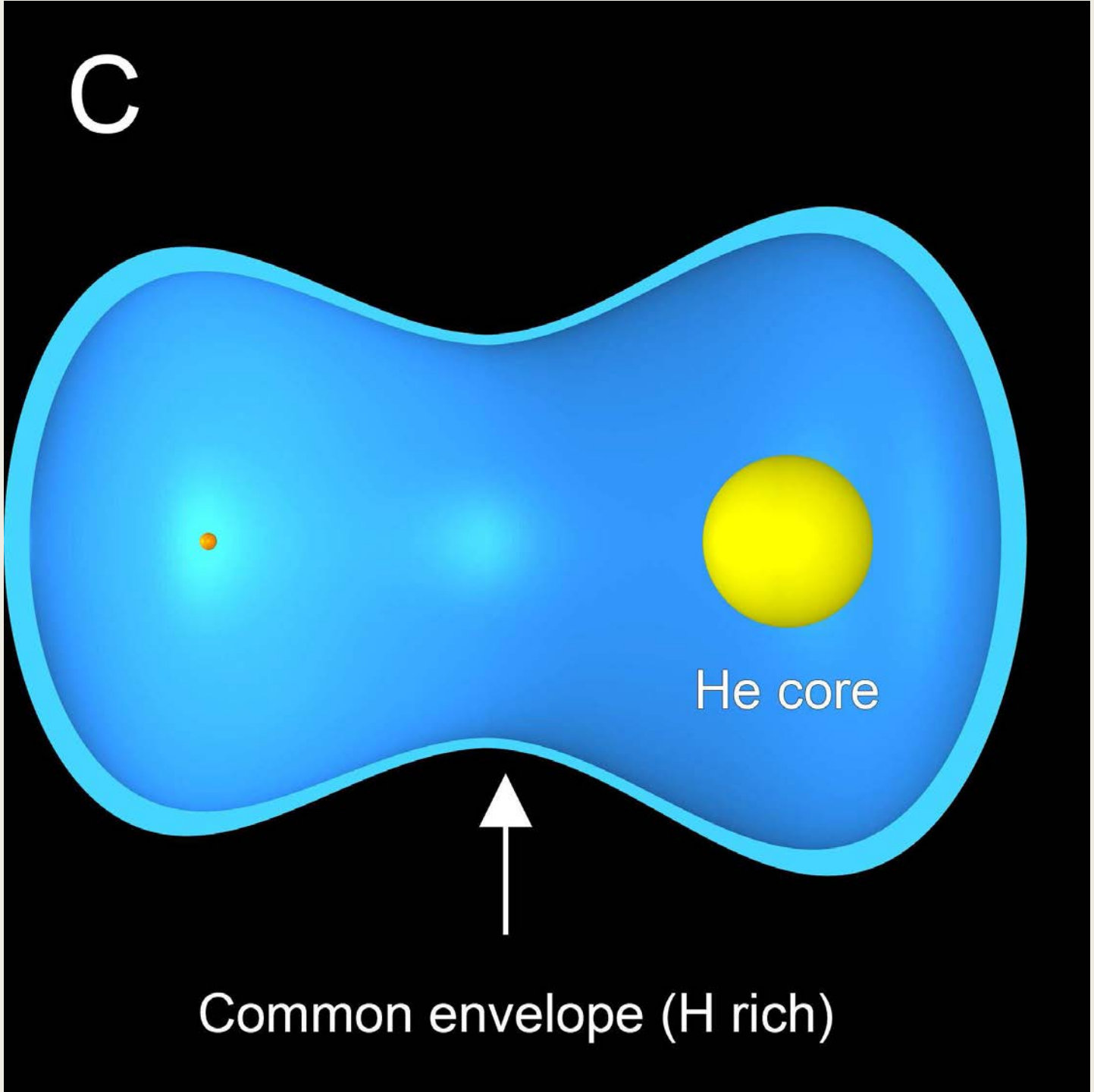
- Giant phase, Developed He core
- H envelope is ejected by in-spiralling NS.



Ouyed, Leahy and Koning. 2015

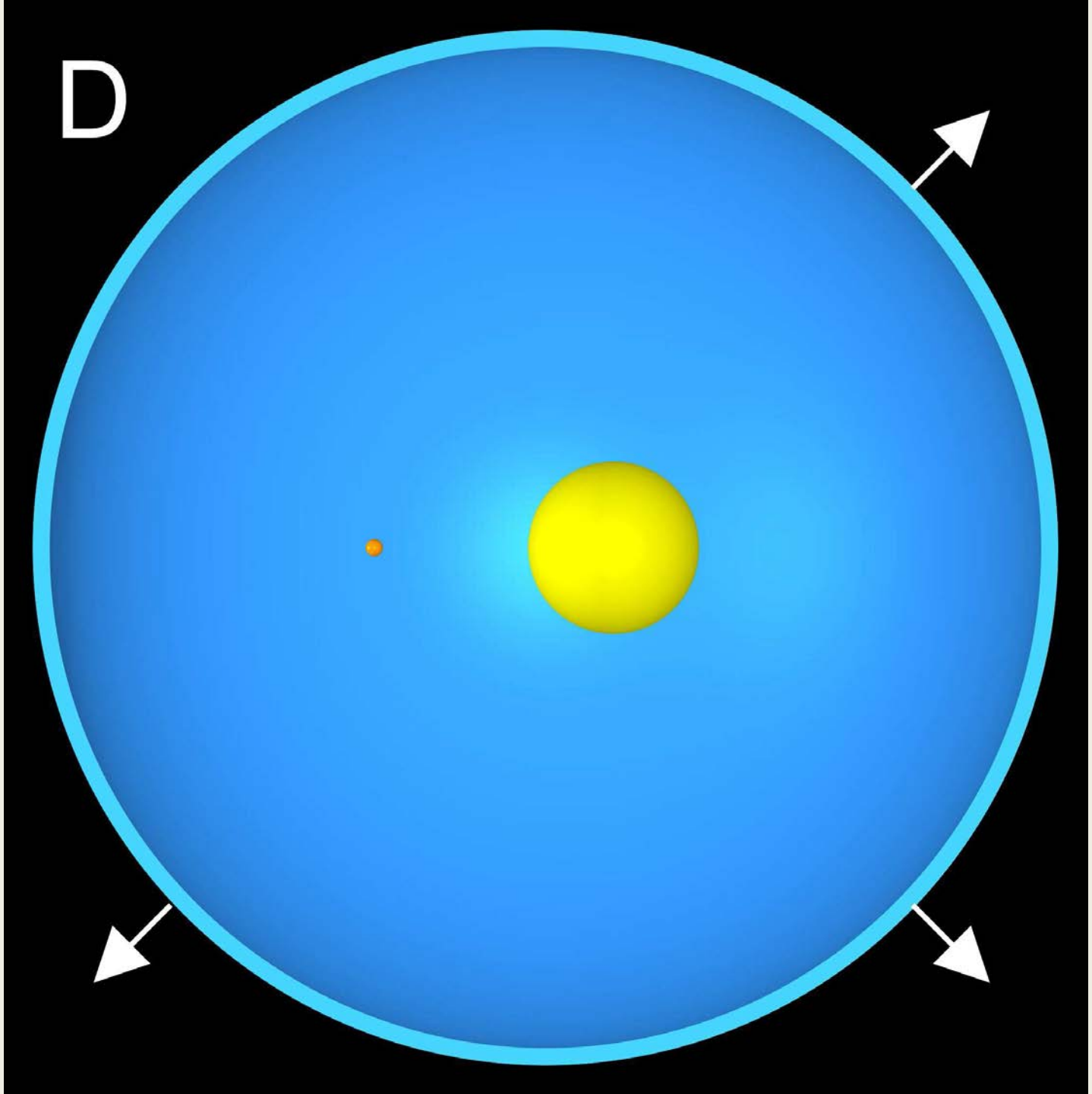
- Red giant

  engulf NS



Ouyed, Leahy and Koning. 2015

- NS accretes matter.
- NS ~ 1.5Mo



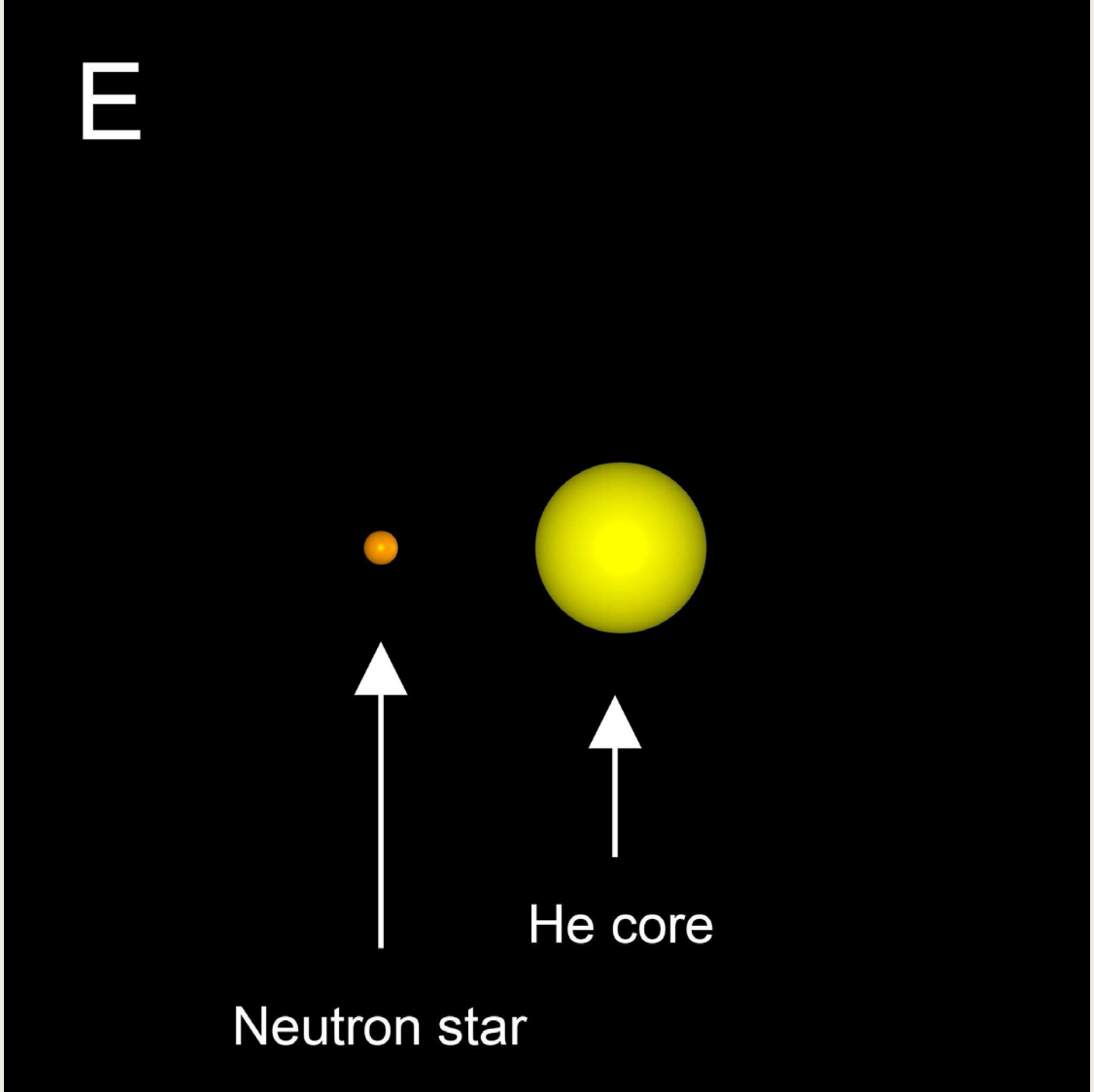
We still need 0.5Mo in the NS!

Ouyed, Leahy and Koning. 2015

- Separation

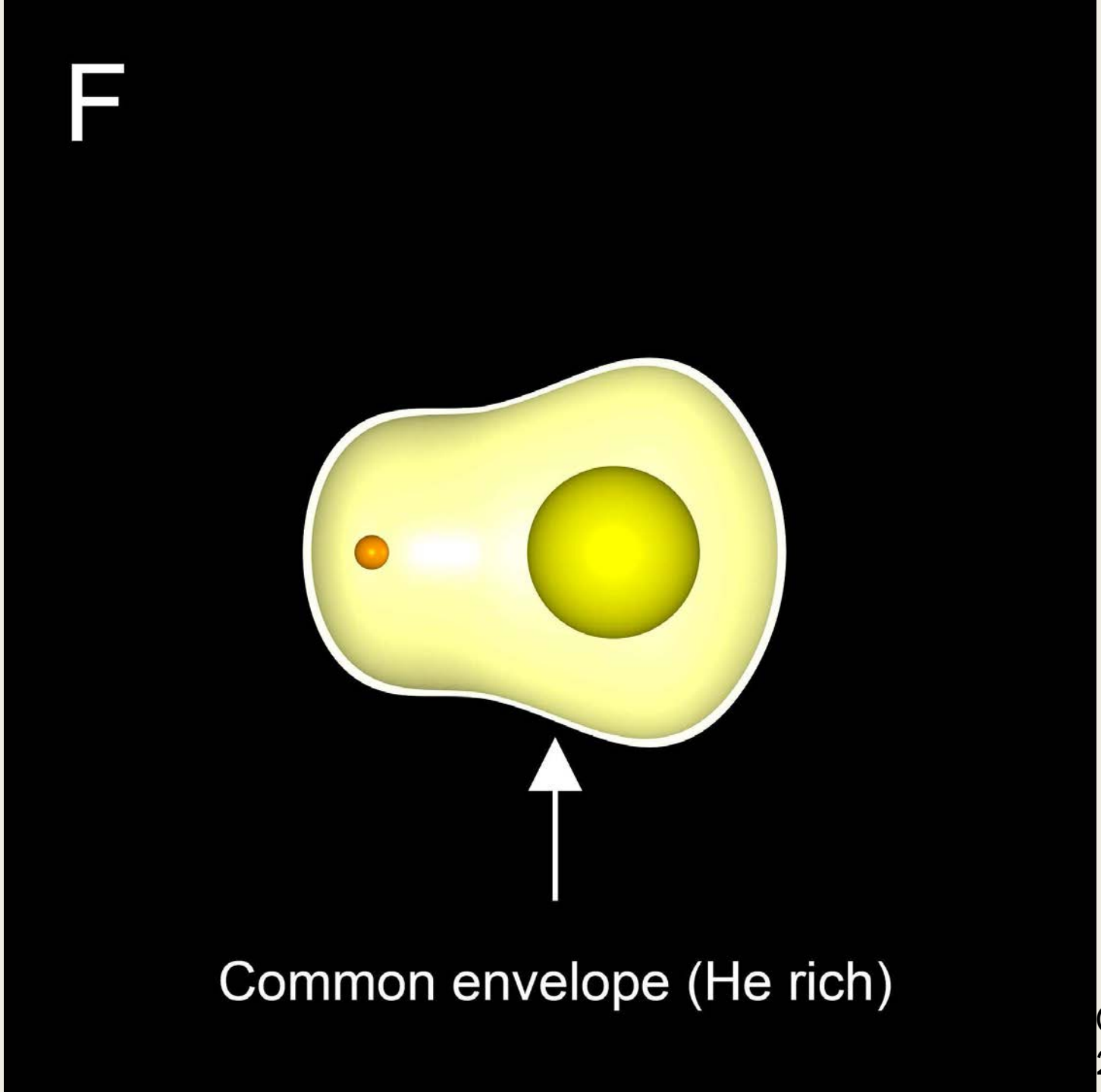
  ~ 3Ro
- He core continues

  evolving
- Mass ~6-8 Mo



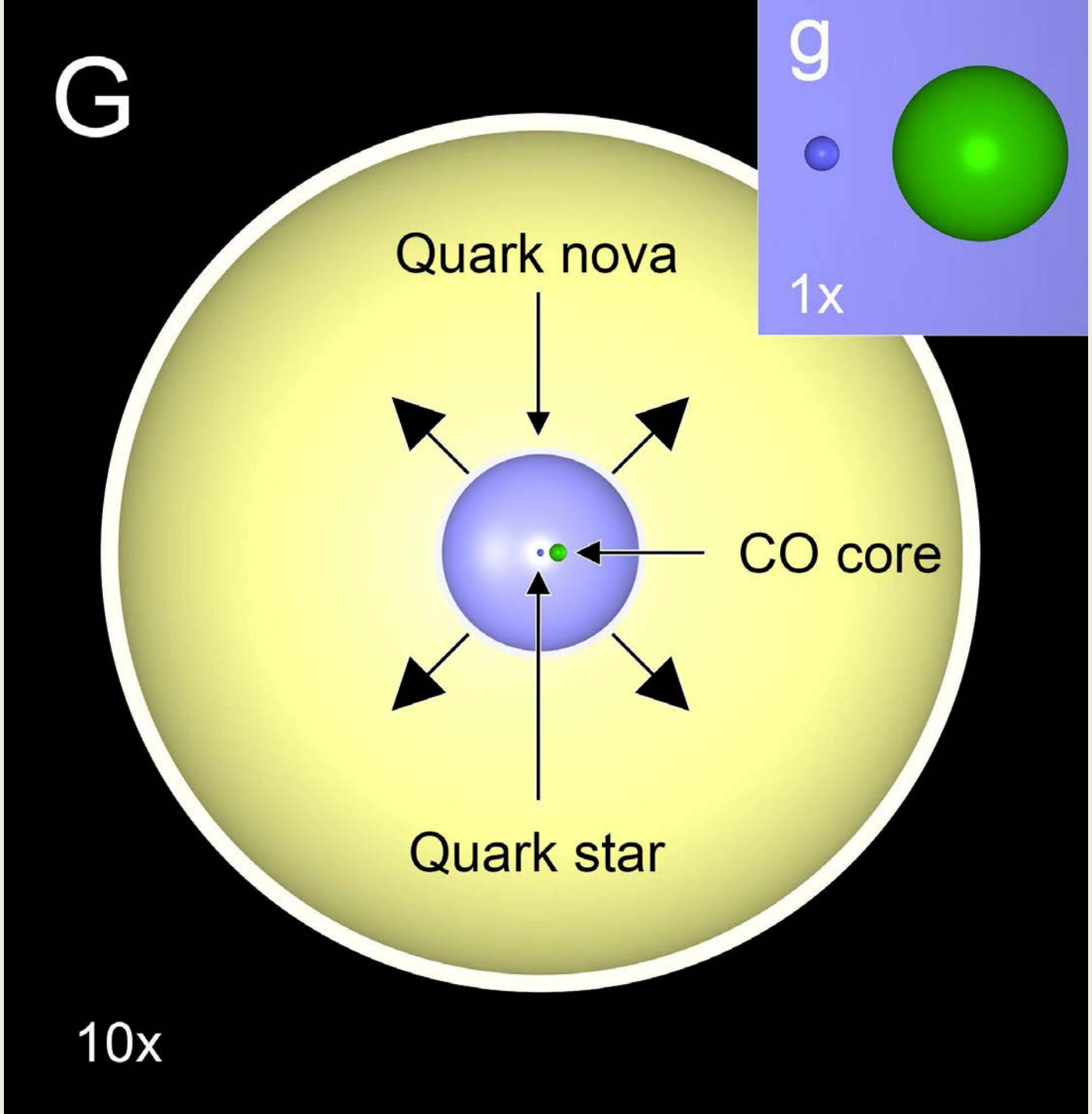
Ouyed, Leahy and Koning. 2015

- Second common envelope (CE).
- Accretion by NS.
- CE evolves and NS spirals accreting mass



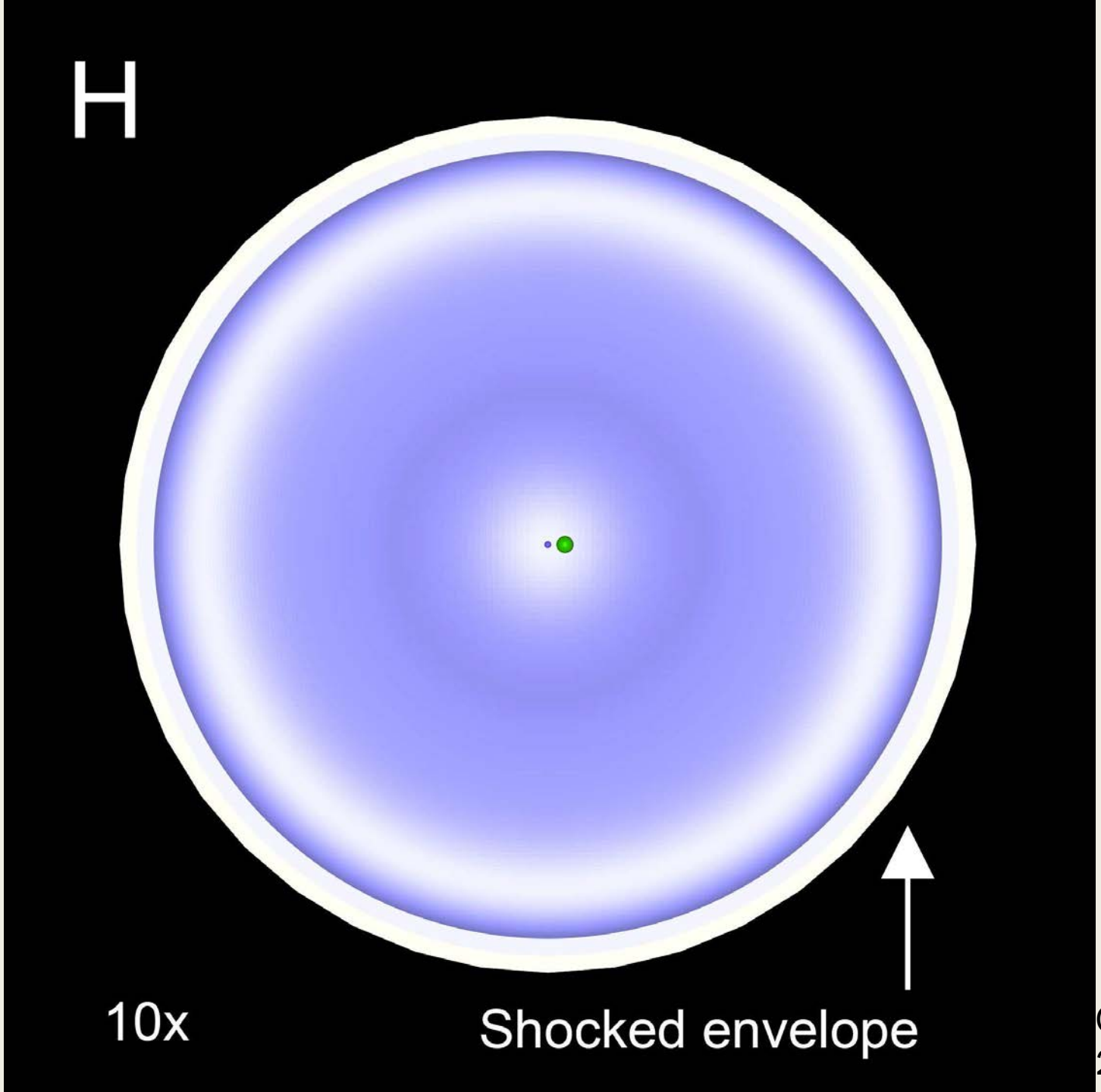
Ouyed, Leahy and Koning. 2015

- NS reaches critical mass ~2 Mo
- We get a QN event.
- CE ~ 900 Ro



Ouyed, Leahy and Koning. 2015

- Shock helps eject CE
- ~10^{52} erg of QN kinetic energy is harnessed



WE GET OUR FIRST HUMP!

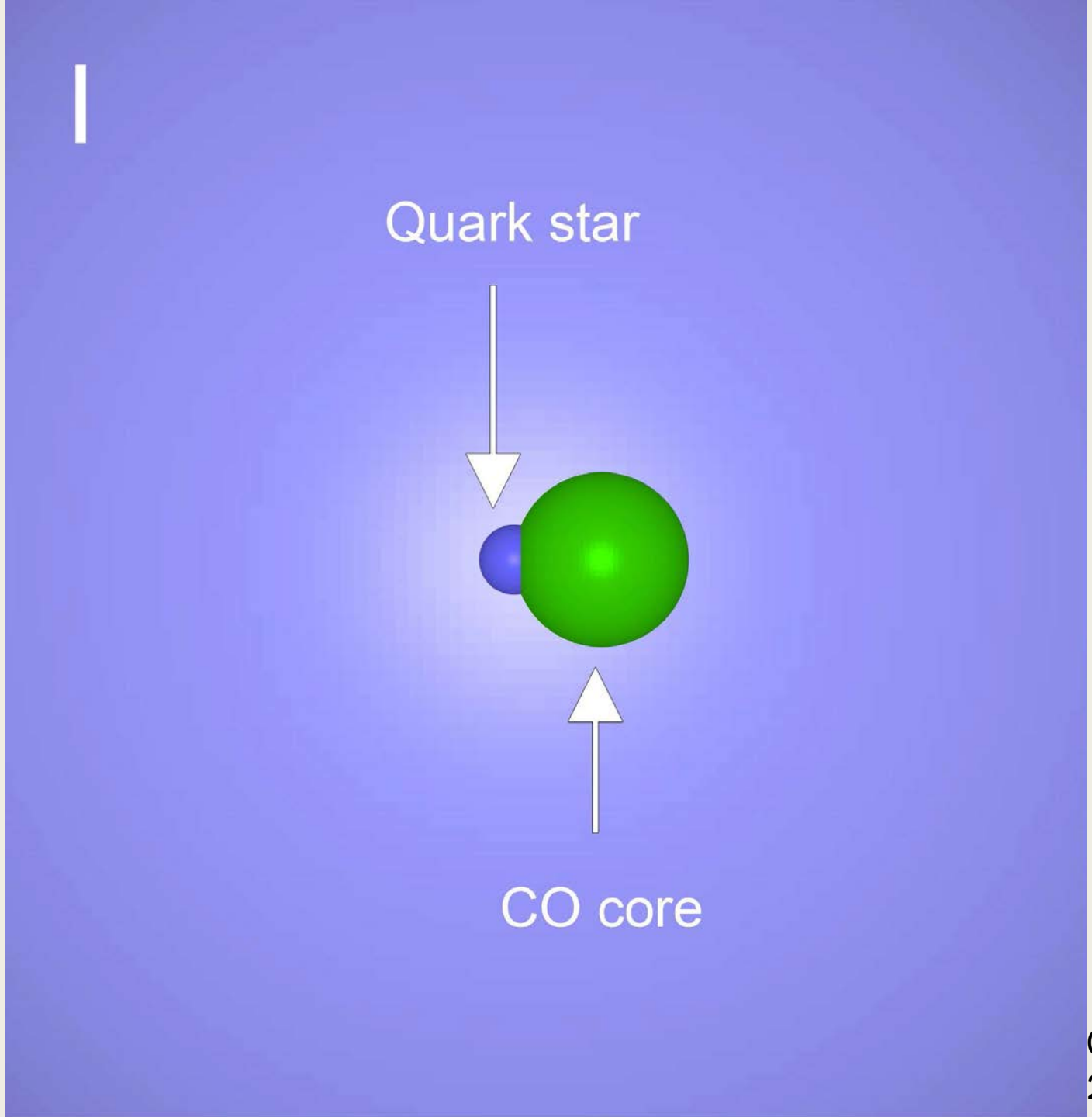
Ouyed, Leahy and Koning. 2015

- Mass of core ~ 2Mo
- Size of core <0.1 Ro

- Orbital period:

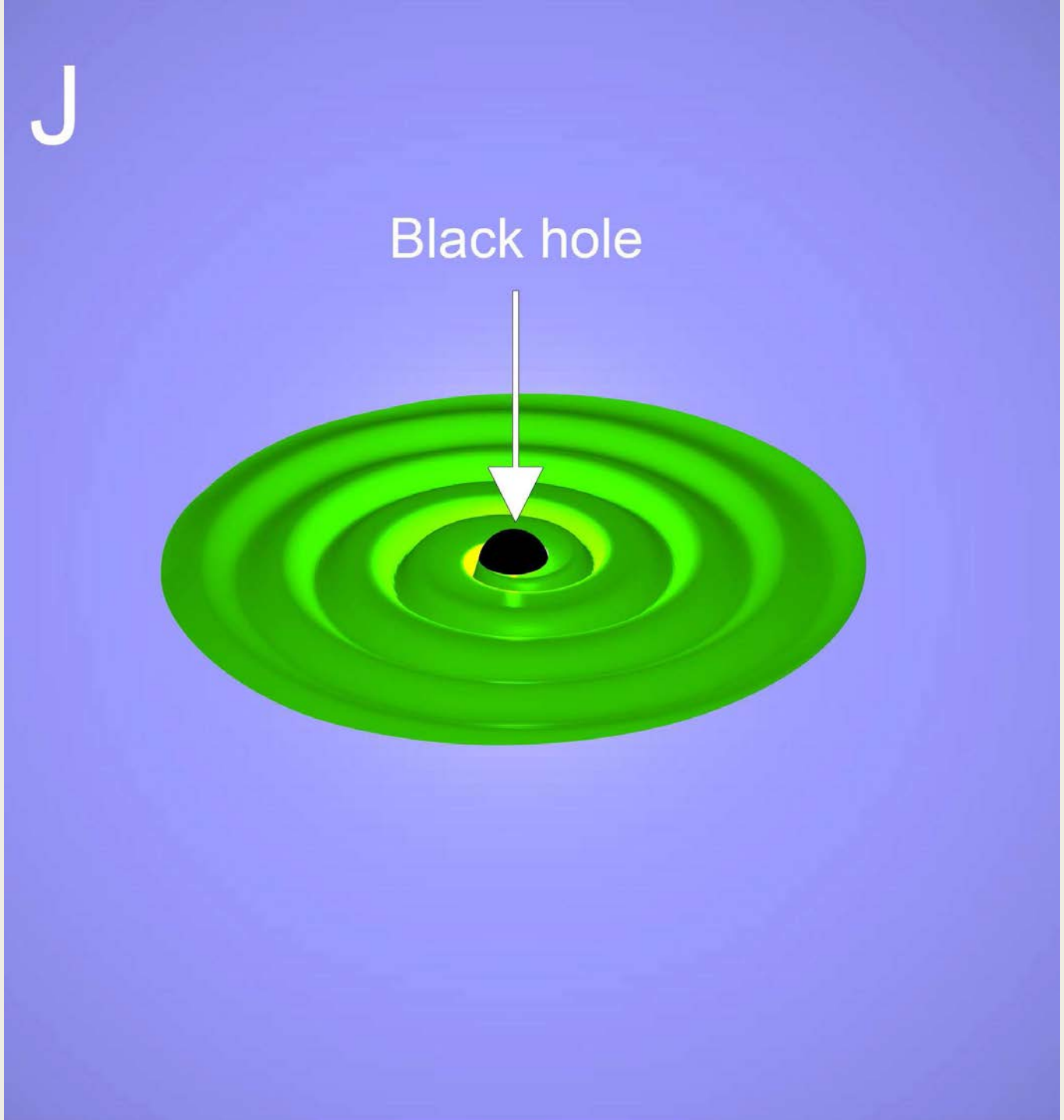
  minutes
- Merging occurs in a

  few hours.



Ouyed, Leahy and Koning. 2015

- The merger has enough mass to make a Black Hole.
- CO core forms a disk around the black hole and accretes onto it.



Ouyed, Leahy and Koning. 2015

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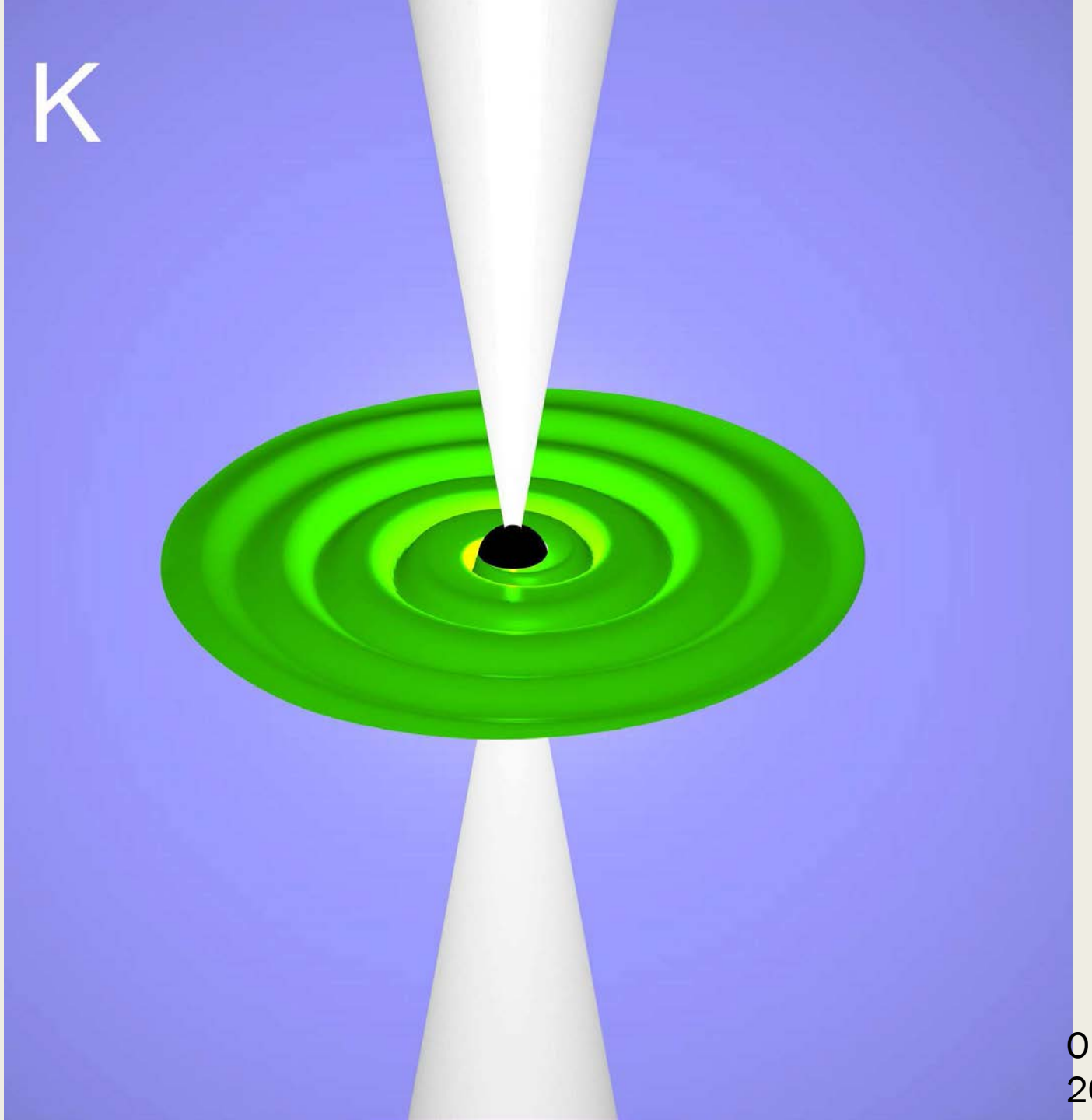
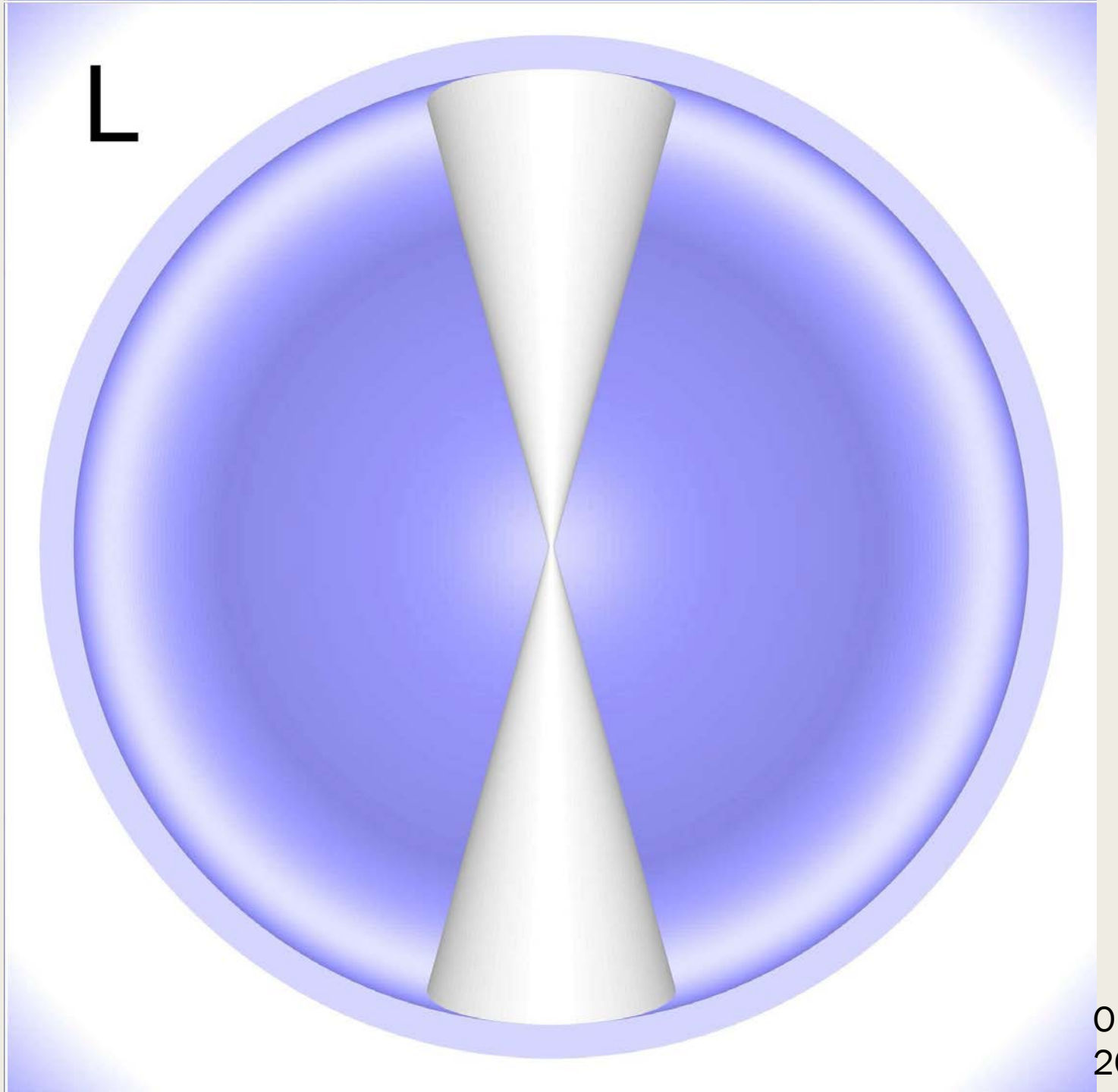


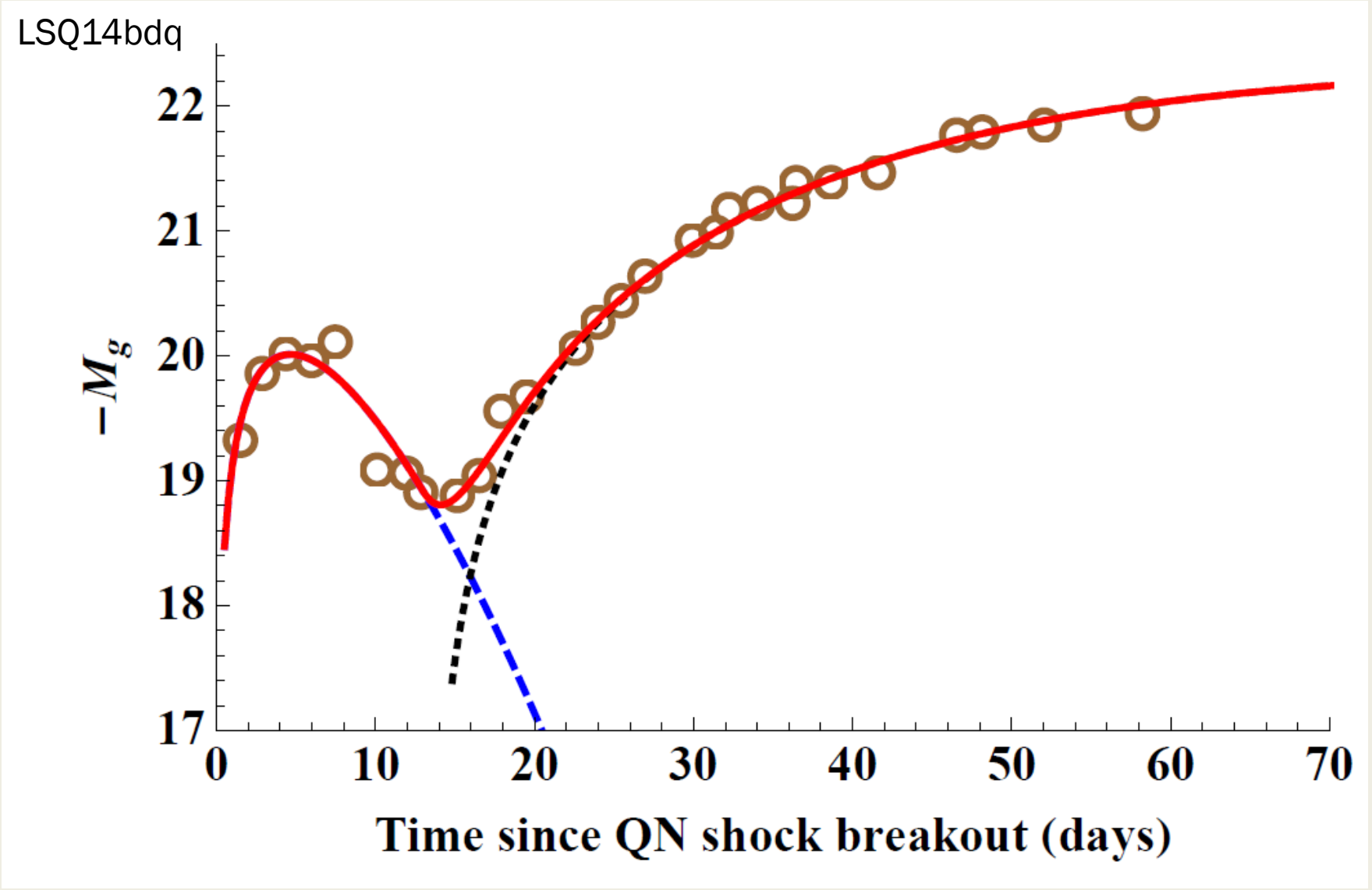
Ouyed, Leahy and Koning. 2015

- Second hump comes from BH accretion



Ouyed, Leahy and Koning. 2015

So, does the model work?



Ouyed, Leahy and Koning. 2015, 2016

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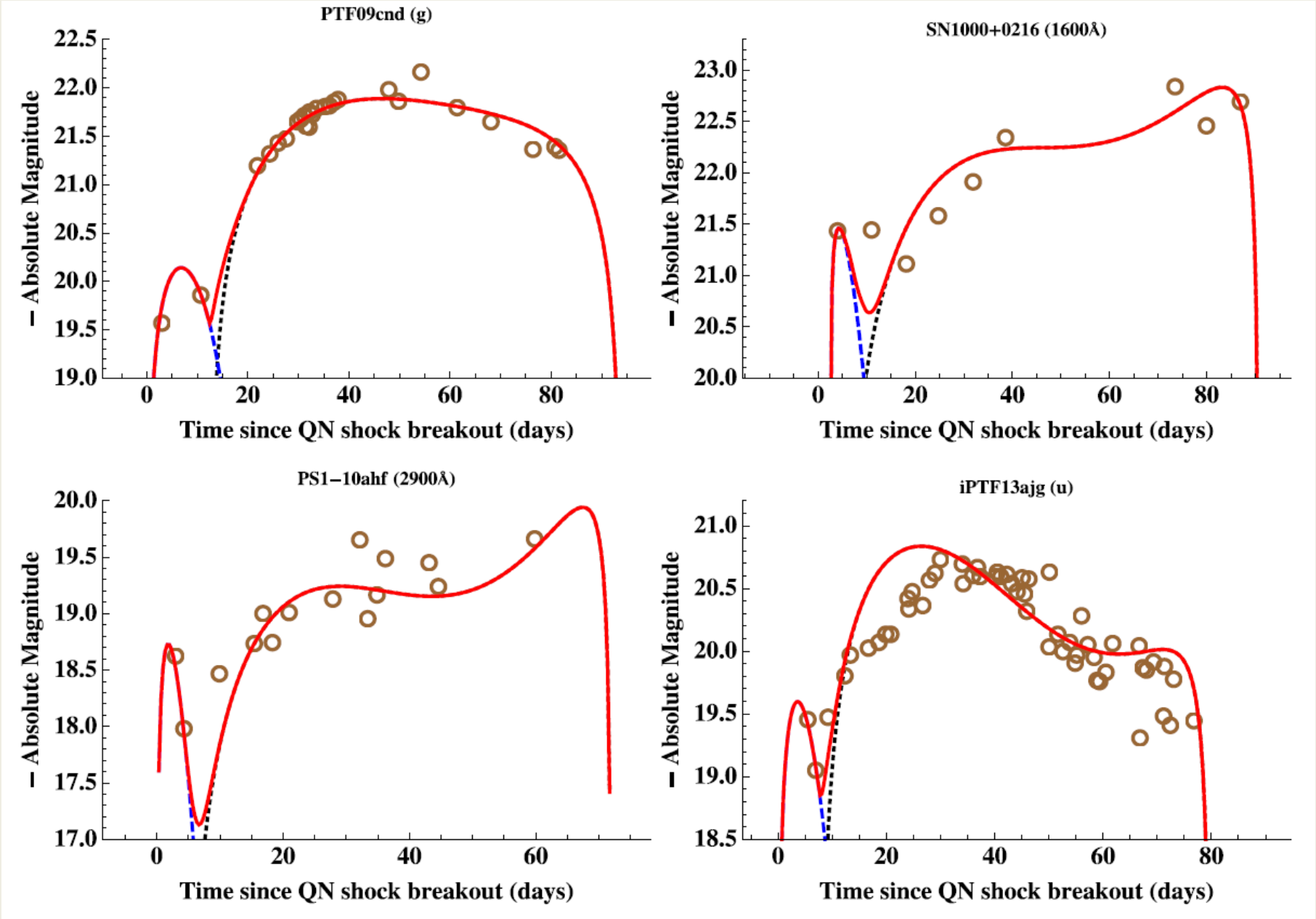

Ouyed, Leahy and Koning. 2015, 2016

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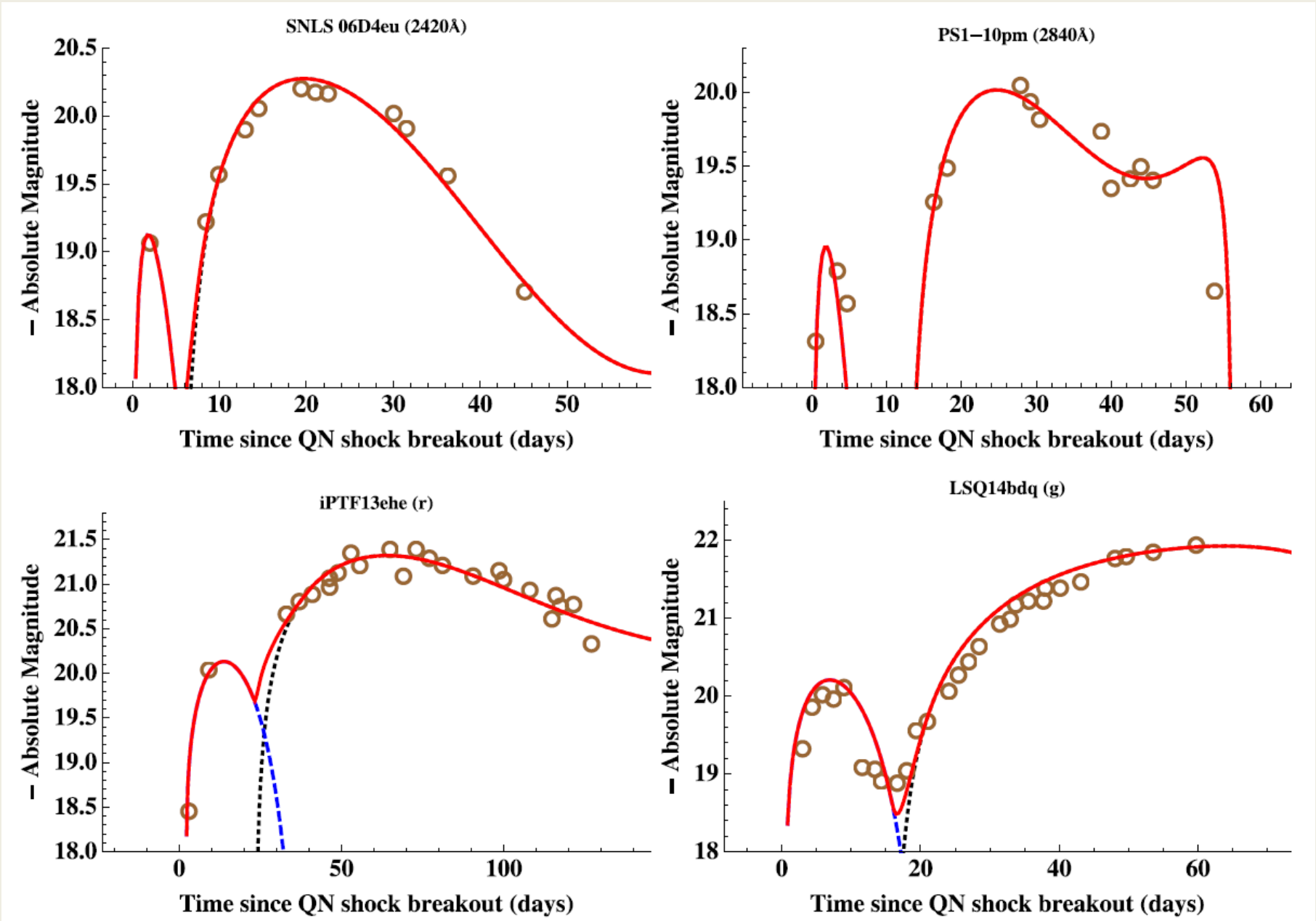
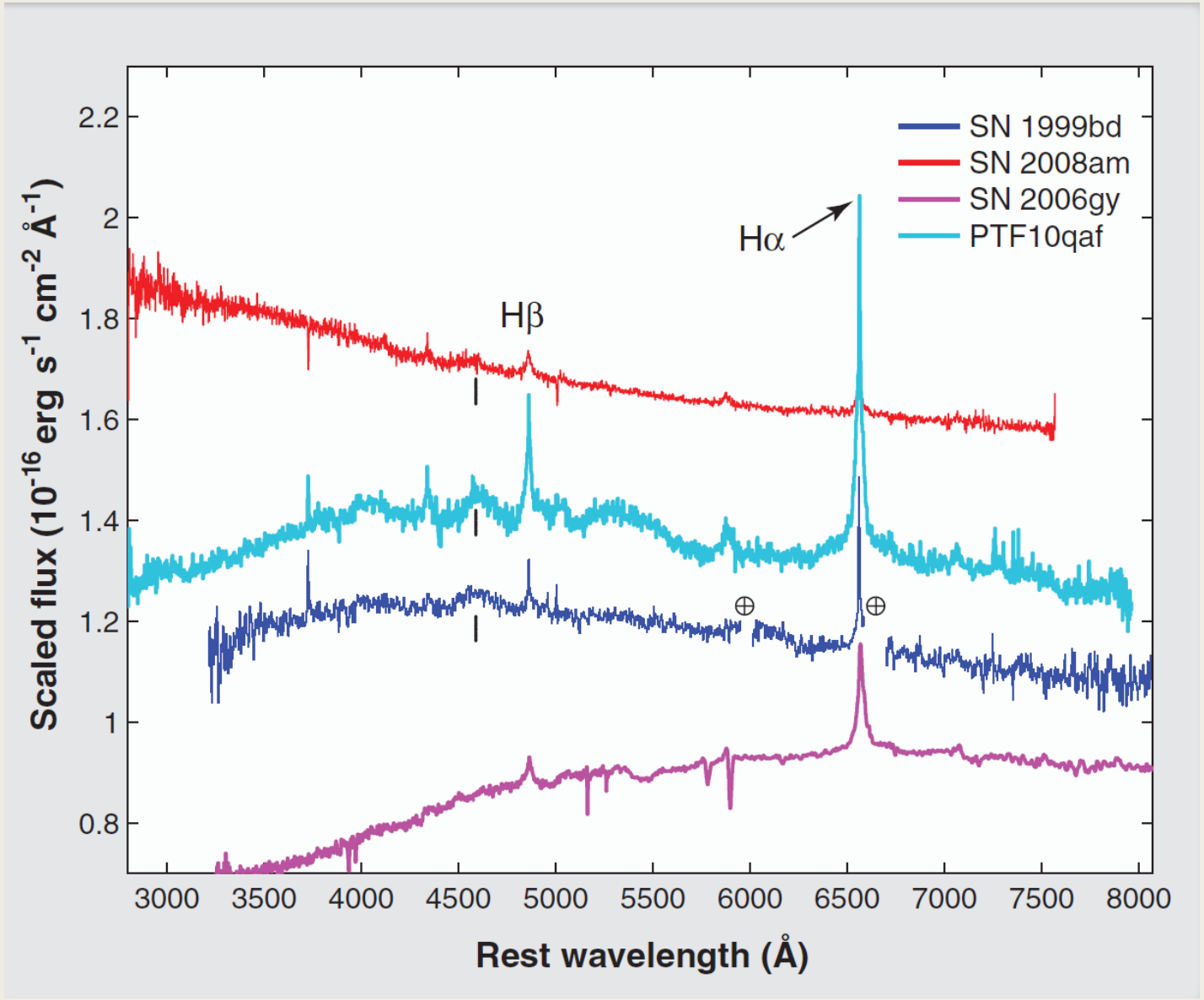


Ouyed, Leahy and Koning. 2015, 2016

Results

- We have over a dozen positive fits and constantly increasing! http://quarknova.ca/LCGallery.html
- Parameter survey
  - *With a large enough sample, can we identify features that distinguish the QN in a binary?*
- Spectrum analysis. A *spectrum* of Superlumious Supernovae!
  - *We hypothesized traces of Hydrogen and we are starting to see them!*

Spectrum as a fingerprint



Gal-Yam, et al 2012

Conclusion

- Using our well known and understood model of binaries and our understanding of the QCD phase diagram we can formulate a *simple* and *elegant* model for superluminous supernovae.
- The use of the Quark Nova solves different unsolved issues: Lack of Hydrogen, time delay, luminosity, etc.
- The understanding of SLSN can give us signature for the understanding of QCD physics and standard candles.
- The implementation of physics into astrophysics as a communion.

Thank you

- Drago, A., & Pagliara, G. (2015). The scenario of two families of compact stars 2. Transition from hadronic to quark matter and explosive phenomena.*arXiv preprint arXiv:1509.02134*.
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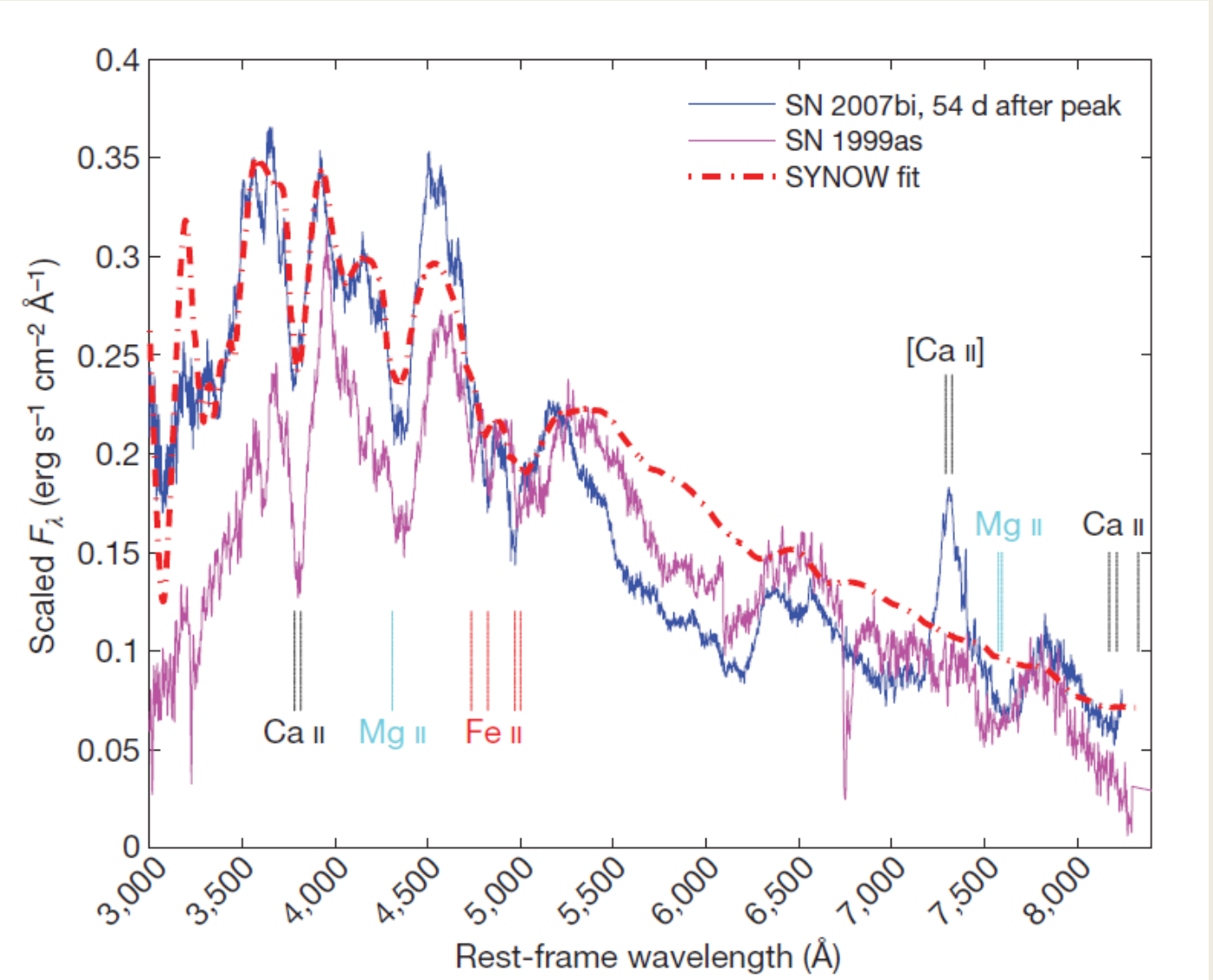
- Gal-Yam, A. "Luminous Supernovae." Science 337.6097 (2012): 927-932.
- Inserra, C., et al. "On the nature of Hydrogen-rich Superluminous Supernovae." *arXiv preprint arXiv:1604.01226* (2016).

Research outlook (II)

- Spectrum analysis
  - *Can we use the spectrum to create a spectrum of binaries?*
  - *Use radiative transfer to generate a synthetic spectrum.*

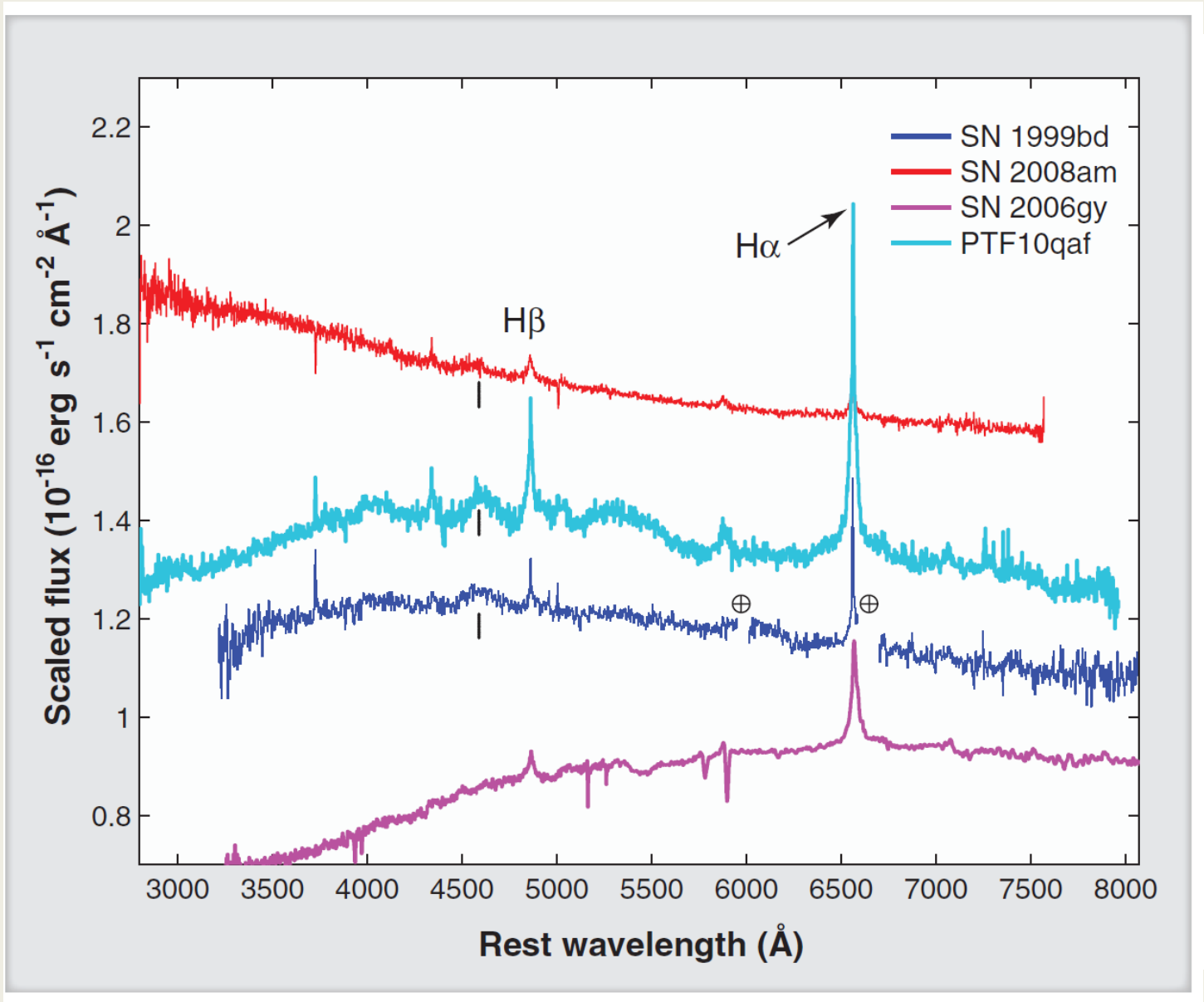
Hydrogen poor



SN2007bi

Inserra, et al 2016

Can there be Hydrogen?



Gal-Yam
2016

Research summary

- The QN model offers a viable solution to the super luminous supernova incognita.
  - *Apply the model to other SLSN*
  - *χ^2 analysis*
  - *Parameter survey*
  - *Spectrum analysis*
- Provide the community with enough evidence for them to decide.

Ongoing collaborations

- Help the rest of the research group with:
  - *Neutrino implementation into BURN-UD: Hydrodynamical combustion code.*
  - *Exploration of the conditions for the neutron star explosion.*
  - *Expansion of current software.*