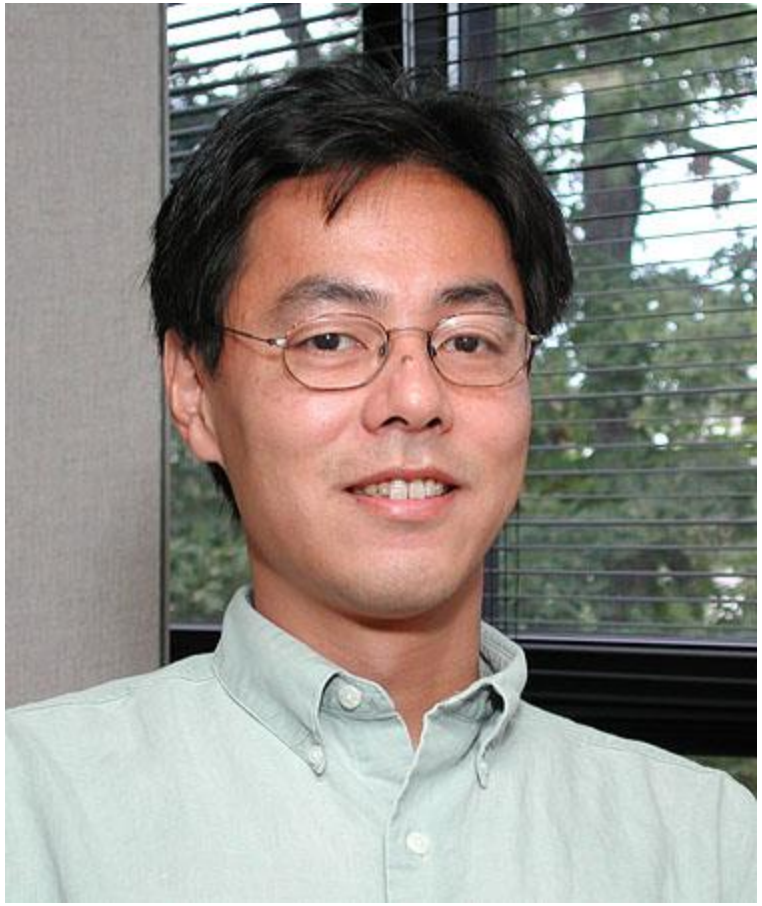
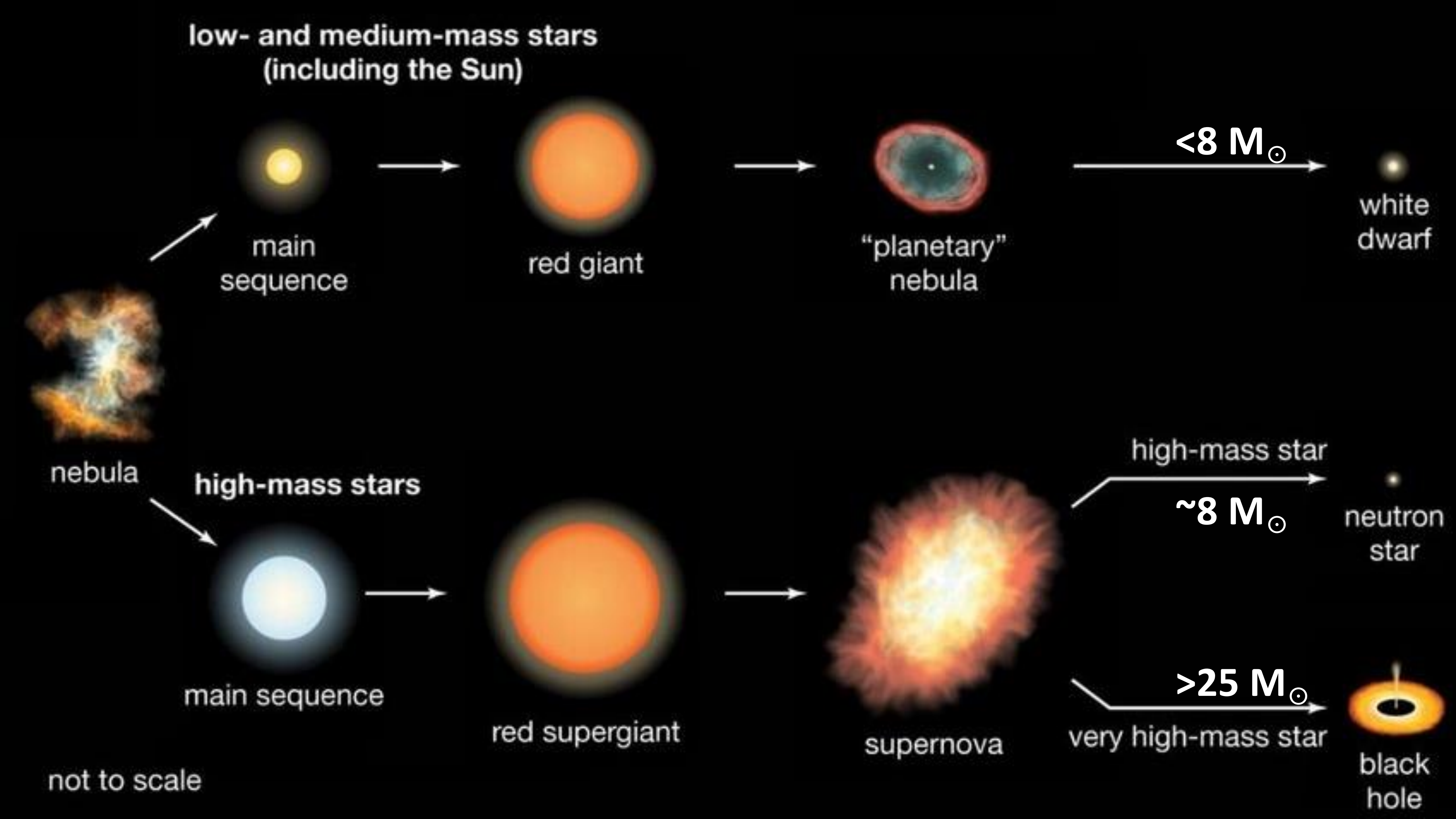
Cataclysmic Variables/Novae/ White Dwarfs

Jeremy Hare

Thanks to Koji Mukai for providing material!

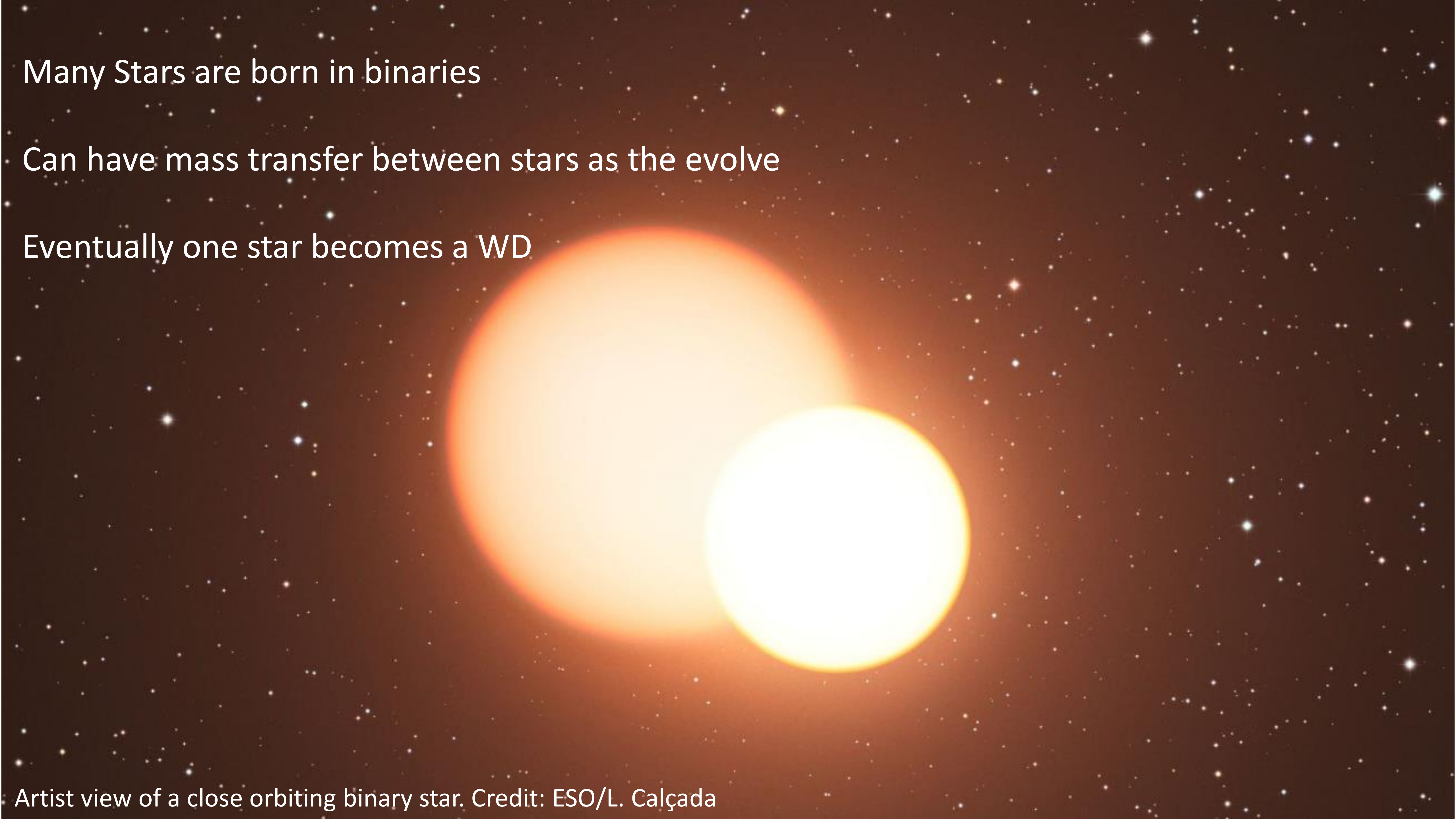



low- and medium-mass stars
(including the Sun)
main
sequence
red giant
"planetary"
nebula
$<8\ M_\odot$
white
dwarf
nebula
high-mass stars
main sequence
red supergiant
supernova
high-mass star
$\sim 8\ M_\odot$
neutron
star
$>25\ M_\odot$
very high-mass star
black
hole
not to scale

Many Stars are born in binaries

Can have mass transfer between stars as the evolve

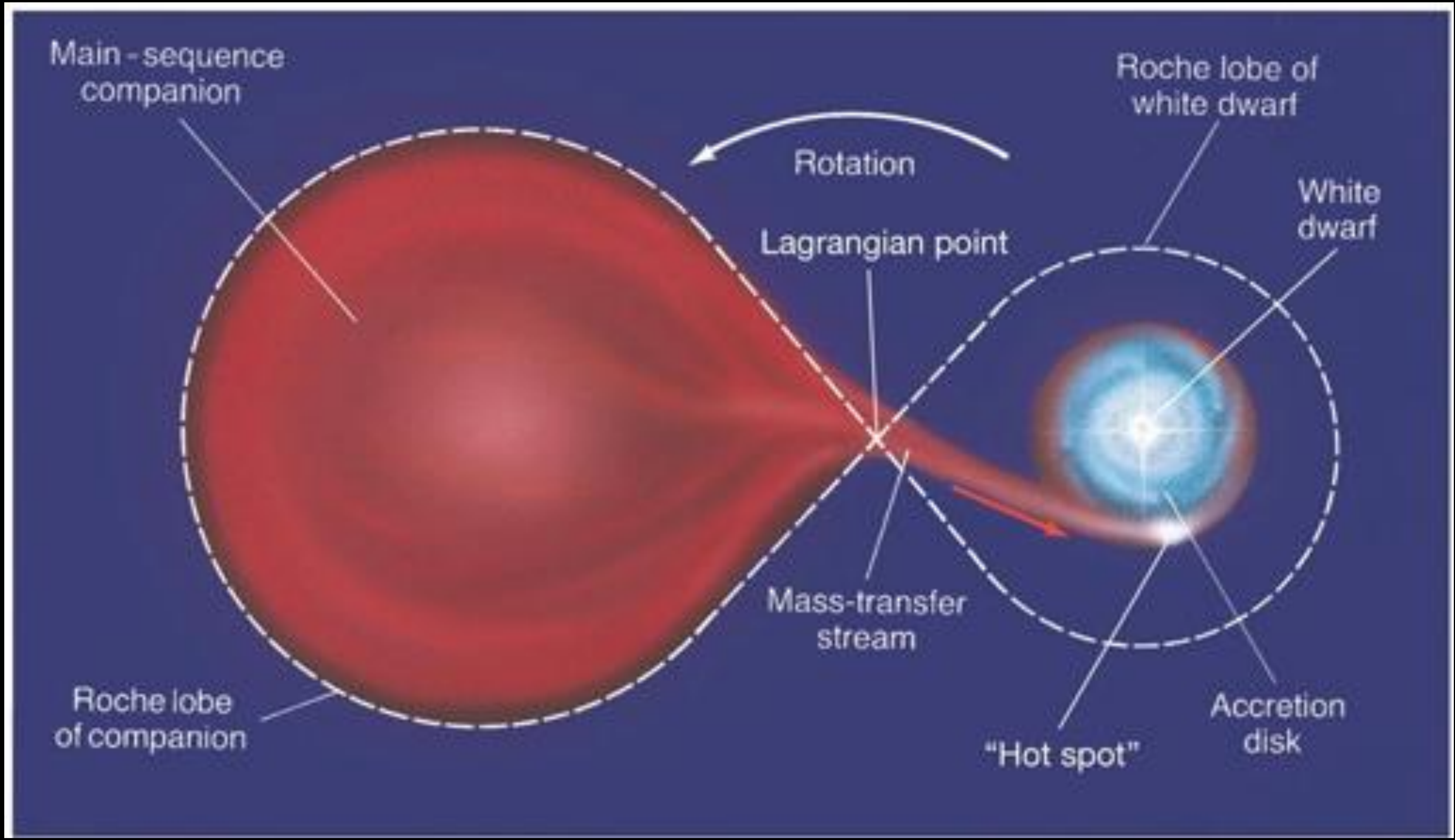
Eventually one star becomes a WD



Artist view of a close orbiting binary star. Credit: ESO/L. Calçada

Why should you care about WDs and CVs?

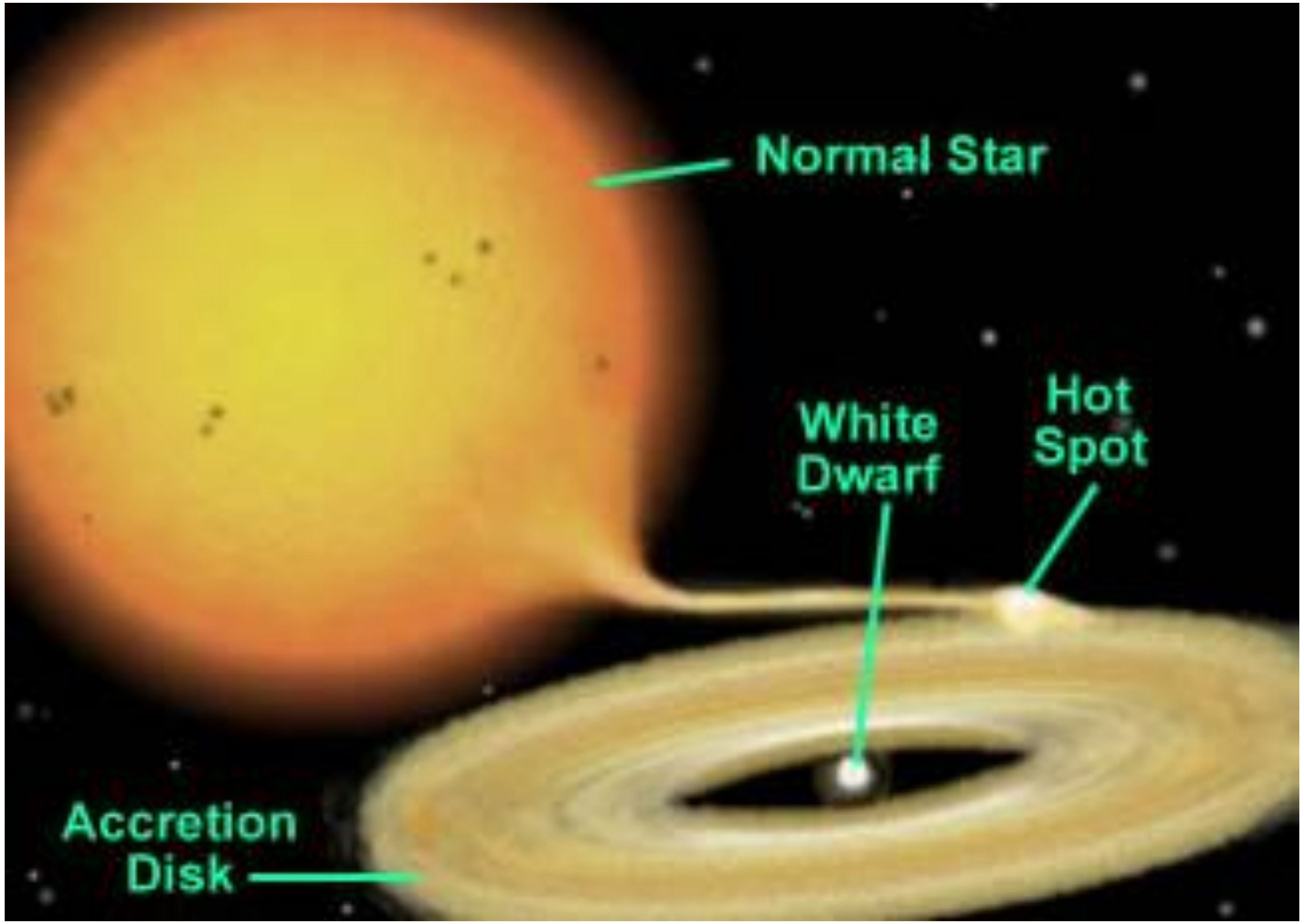
- Provide a less complicated environment to study accretion (i.e., relativistic effects can mostly be ignored)
- Can help constrain binary evolution and mass transfer
- Type Ia supernova progenitors and evolutionary channels still not well understood (Hubble constant biases)
- Frequently found as transient/variable sources
- Major contributor to X-ray background in Galactic bulge and ridge



Types of WD systems: Cataclysmic Variables (CVs)

Magnetic CVs: Intermediate Polars

- Magnetic fields of 1-10 MG
- Form an accretion disk that is truncated by B field
- Orbital periods of 80 min to 10 hrs



Magnetic CVs: Polars

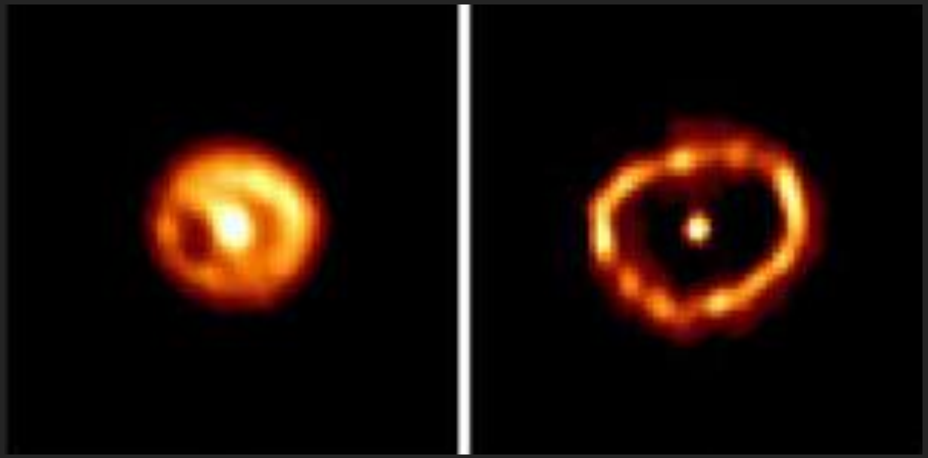
Picture credit: M. A. Garlick © 1998

Polars

- Strong magnetic fields 10-230 MG
- Strongest B field produced in a lab ~0.5 MG
- Accretion stream flows directly from companion to B field, no accretion disk formed
- Synchronizes the spin with the orbital period
- Some Asynchronous polars exist, where spin and orbital period differ by <1%

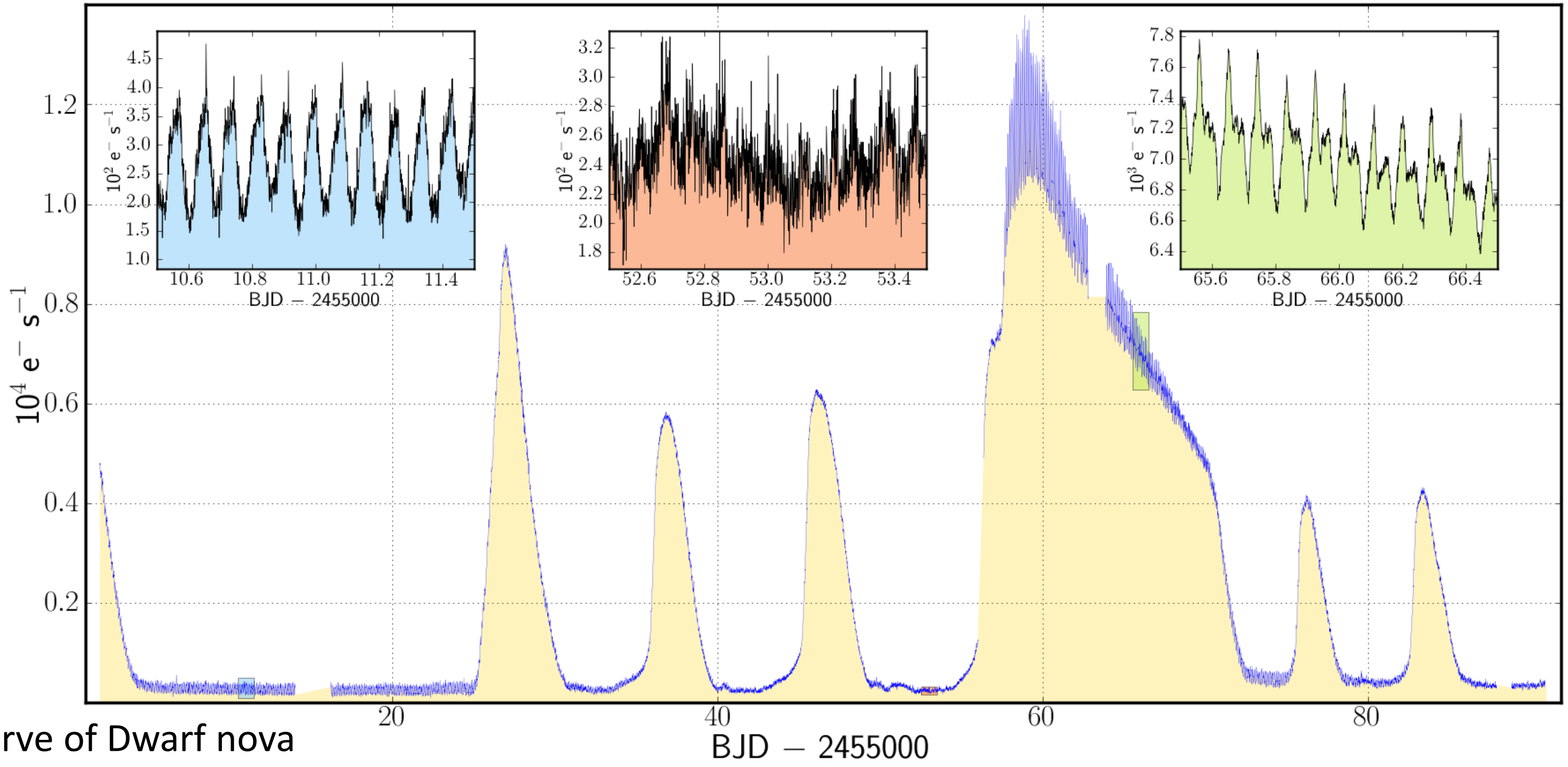
Non-Magnetic CVs: Classical Novae

- Form an accretion disk, but no B field so material can accrete on entire surface
- Ignites nuclear fusion on surface
- Ejects outer layers or hydrogen



Non-magnetic CVs: Dwarf Novae (DNe) and Nova-like CVs

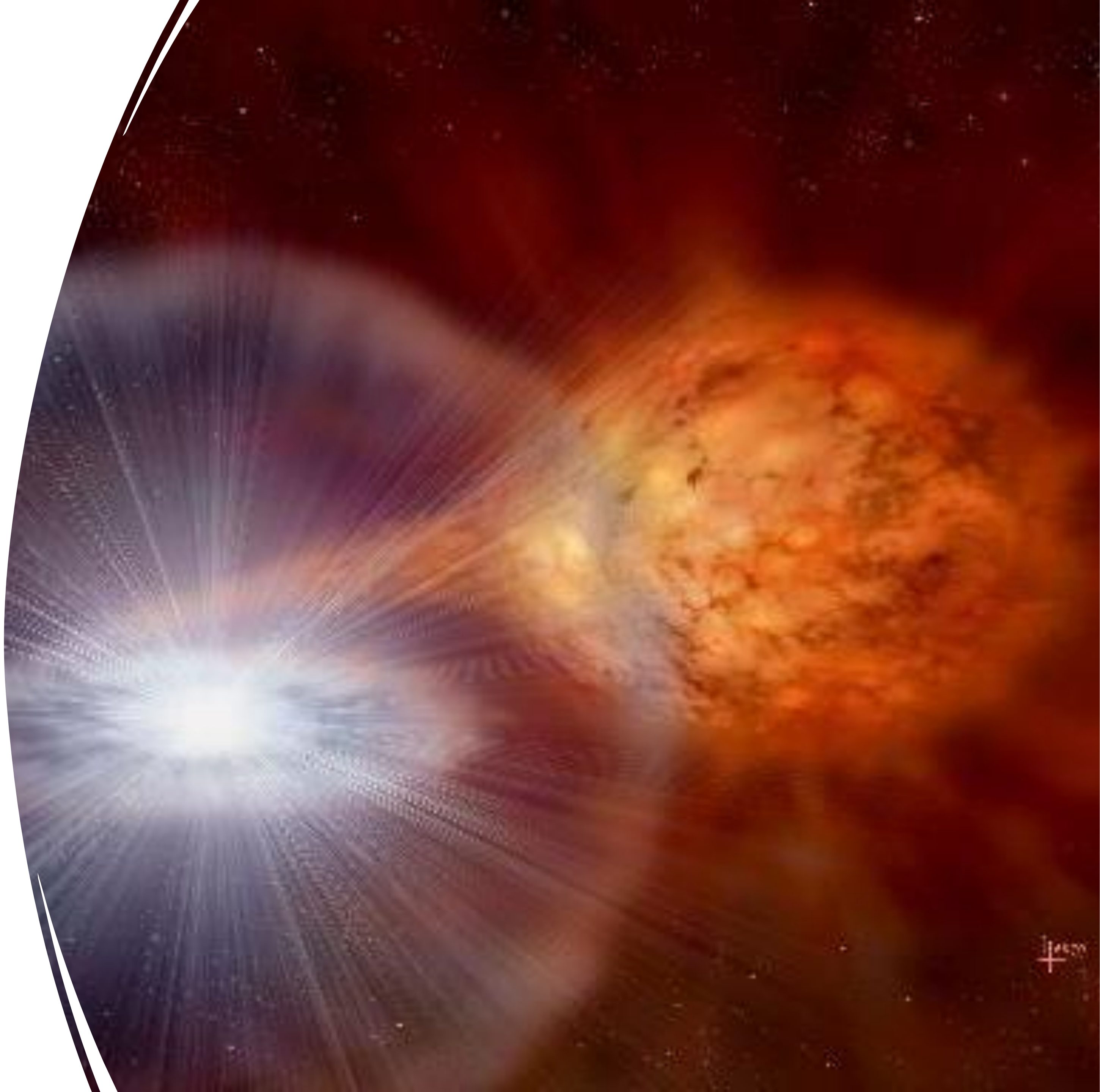
- DNe systems exhibit strong optical variability driven by changing mass accretion rate
- NL are in a persistent "high" state, but do not show nova like outbursts



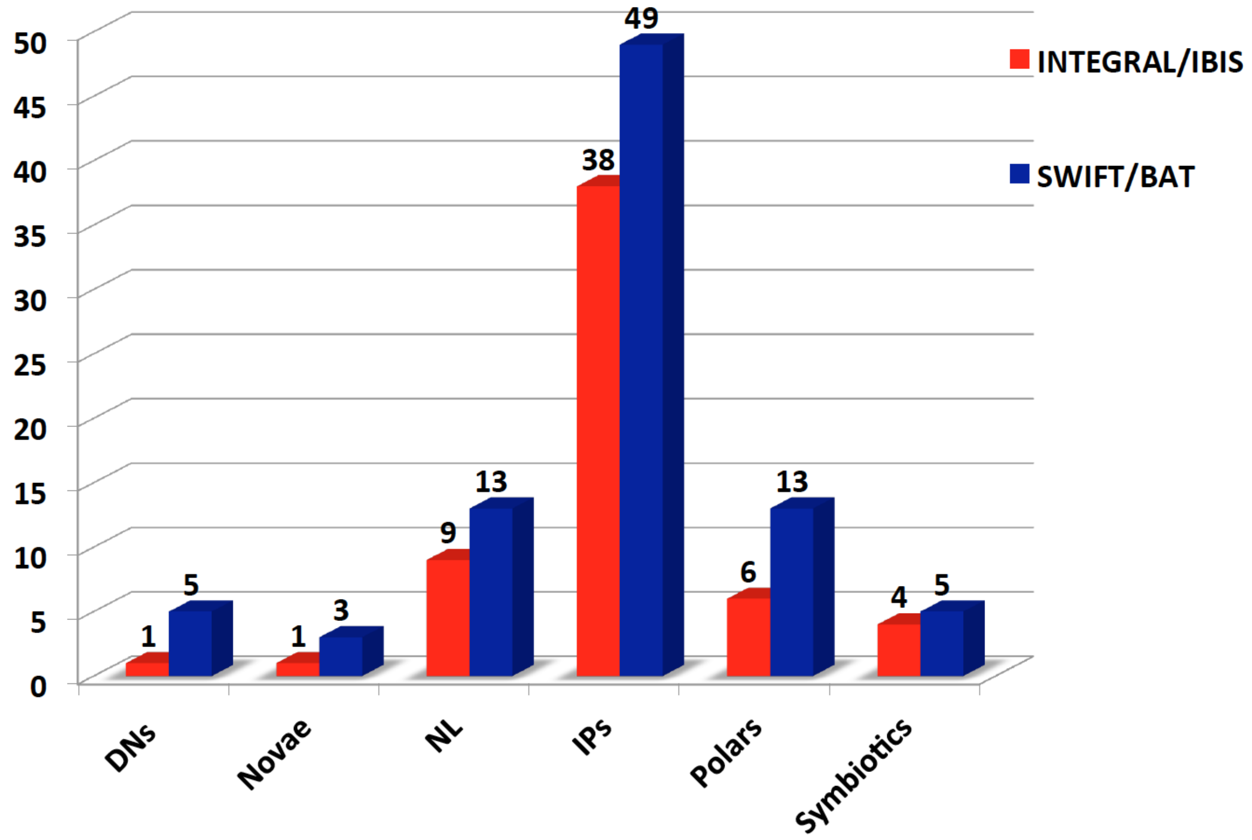
Kelper light curve of Dwarf nova

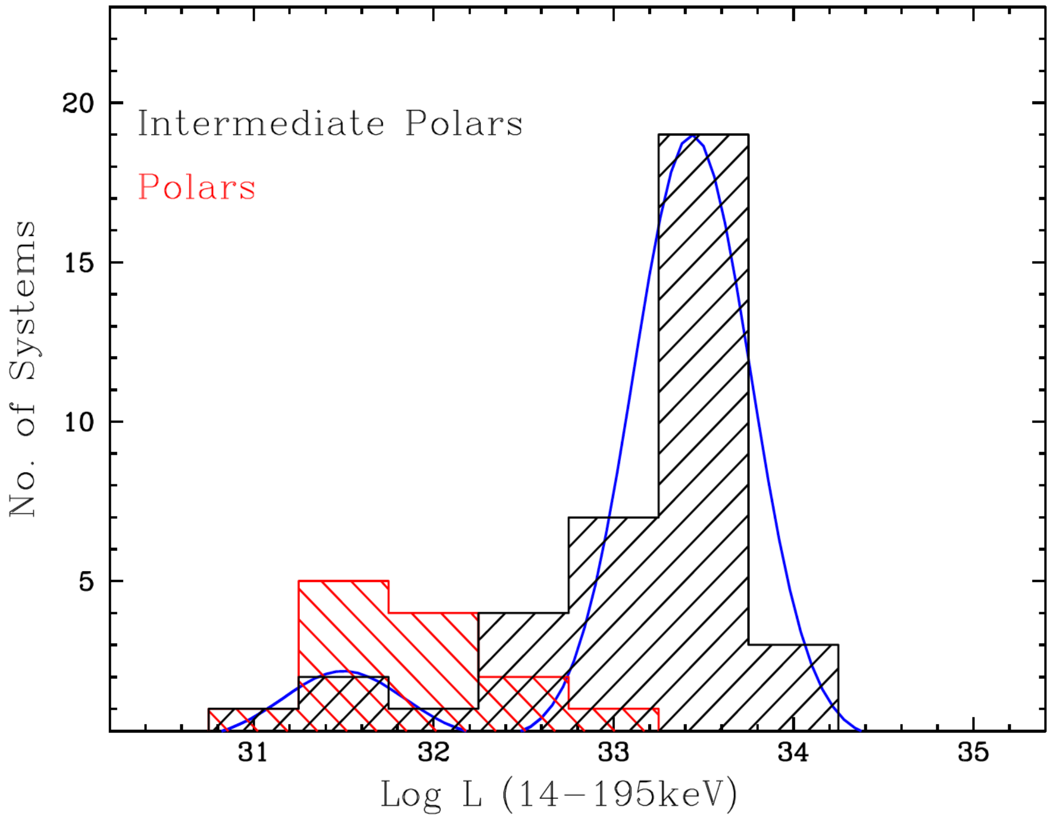
Symbiotic Stars

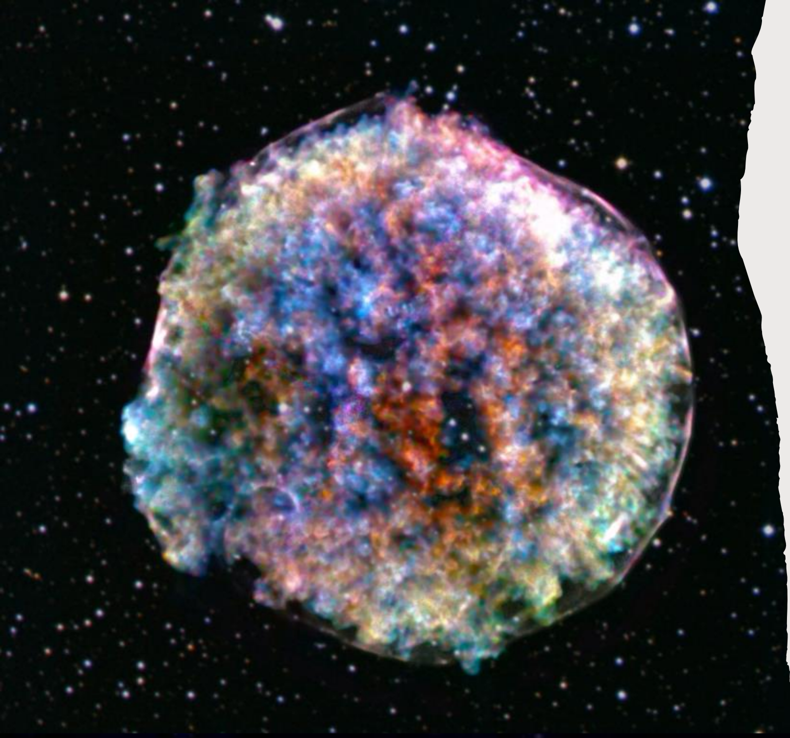
- Contain a WD accreting from red giant donor
- Orbital periods of hundreds of days to 10s of years
- Evolution of symbiotic stars are driven by the nuclear evolution of the donor.
- Many are powered by shell nuclear burning. Some are powered by accretion alone.
- Can also undergo classical novae



Often discovered in Hard X-ray Surveys







CVs and Symbiotic Stars: hottest thermal X-ray sources

- Astrophysical X-ray sources may be due to
  - Non-thermal processes (pulsars, certain supernova remnants)
  - Comptonization ("accretion disk corona") in AGN and X-ray binaries (the "corona" may be thermal or non-thermal)
  - Optically thick thermal emission (the disk in X-ray binaries, neutron star surface; the disk in AGN is probably not hot enough)
  - Optically thin thermal emission from stellar coronae, stellar winds, SNR, clusters of galaxies, CVs and symbiotic stars
- Hottest examples of optically thin thermal X-rays: ~3 keV in stellar coronae and colliding winds, ~5 keV in SNR, ~10 keV in clusters of galaxies
  - In CVs and symbiotic stars, the hottest temperature is determined by the gravitational potential of the accreting white dwarf
  - In CVs and symbiotic stars, kT~10-20 keV is common, kT in excess of 50 keV is possible

IPs and Polars – and non-magnetic CVs

- In magnetic CVs (both IPs and Polars), accreting matter can be considered in vertical free-fall – strong shock ensues. If the shock is near the white dwarf surface, the shock temperature encodes the white dwarf mass.
- In the subclass of polars, the magnetic field is so strong that cyclotron cooling can compete with Bremsstrahlung cooling. This will reduce both the X-ray temperature and luminosity.
- For high X-ray luminosity, high accretion rate is also necessary.

- In non-magnetic CVs and symbiotic stars, accretion occurs from Keplerian disk (itself too cool to emit X-rays).

$$L = \frac{GM_1\dot{m}}{R_1}$$

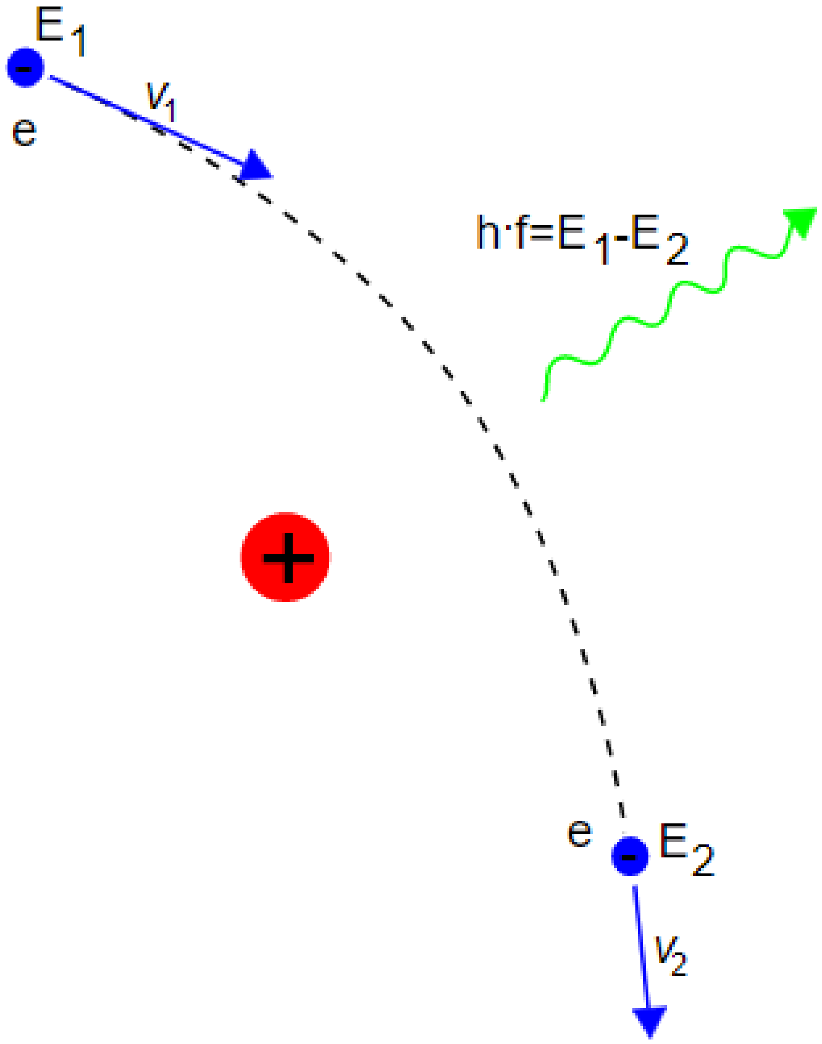
$$v_{ff} = \sqrt{\frac{2GM_1}{R_1}}$$

$$kT_{s,ff} = \frac{3}{8}\frac{GM_1\mu m_{\mathrm{H}}}{R_1}$$

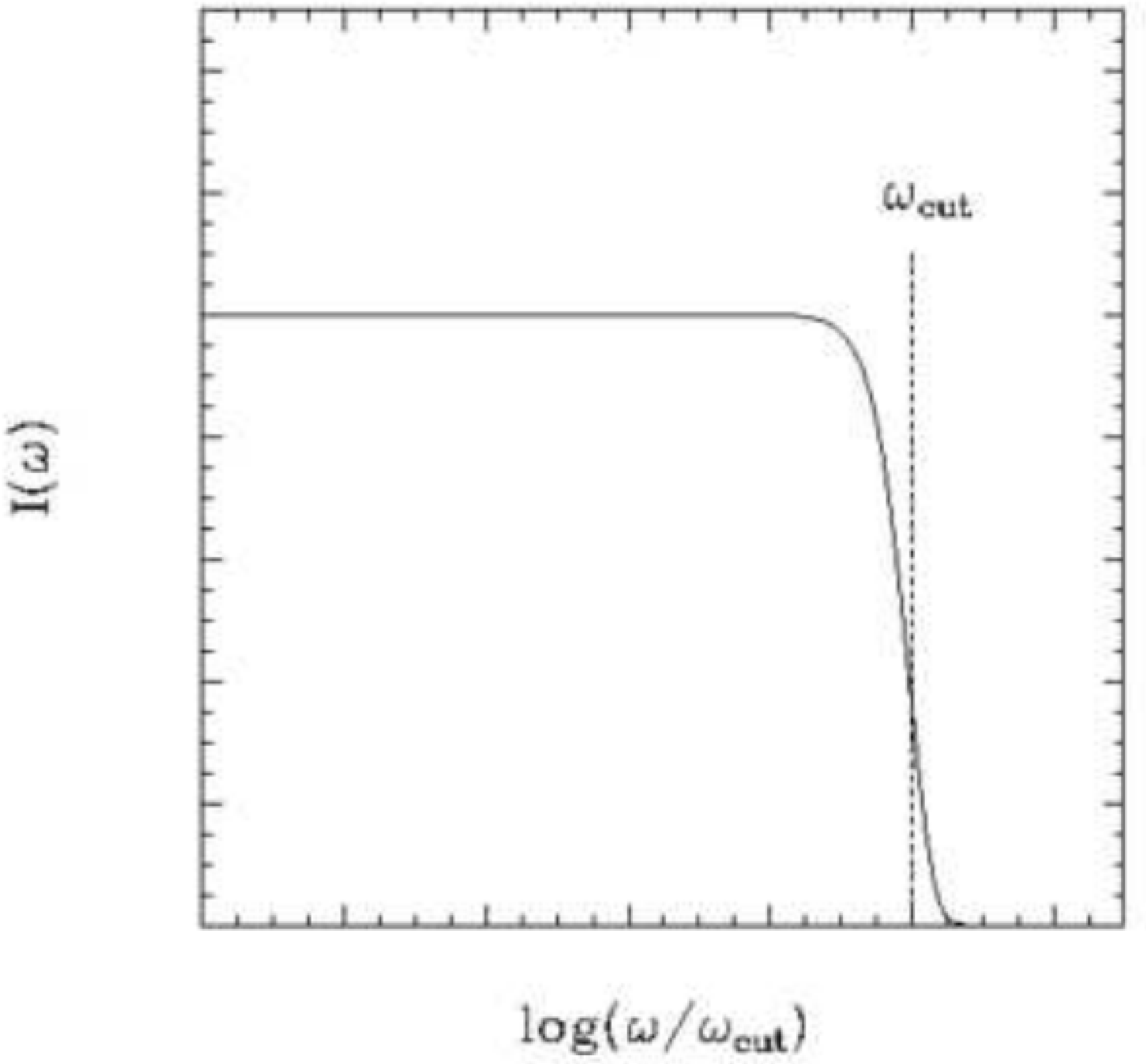
$$v_{Kep} = \sqrt{\frac{GM_1}{R_1}}$$

$$kT_{s,Kep} = \frac{3}{16}\frac{GM_1\mu m_{\mathrm{H}}}{R_1}$$

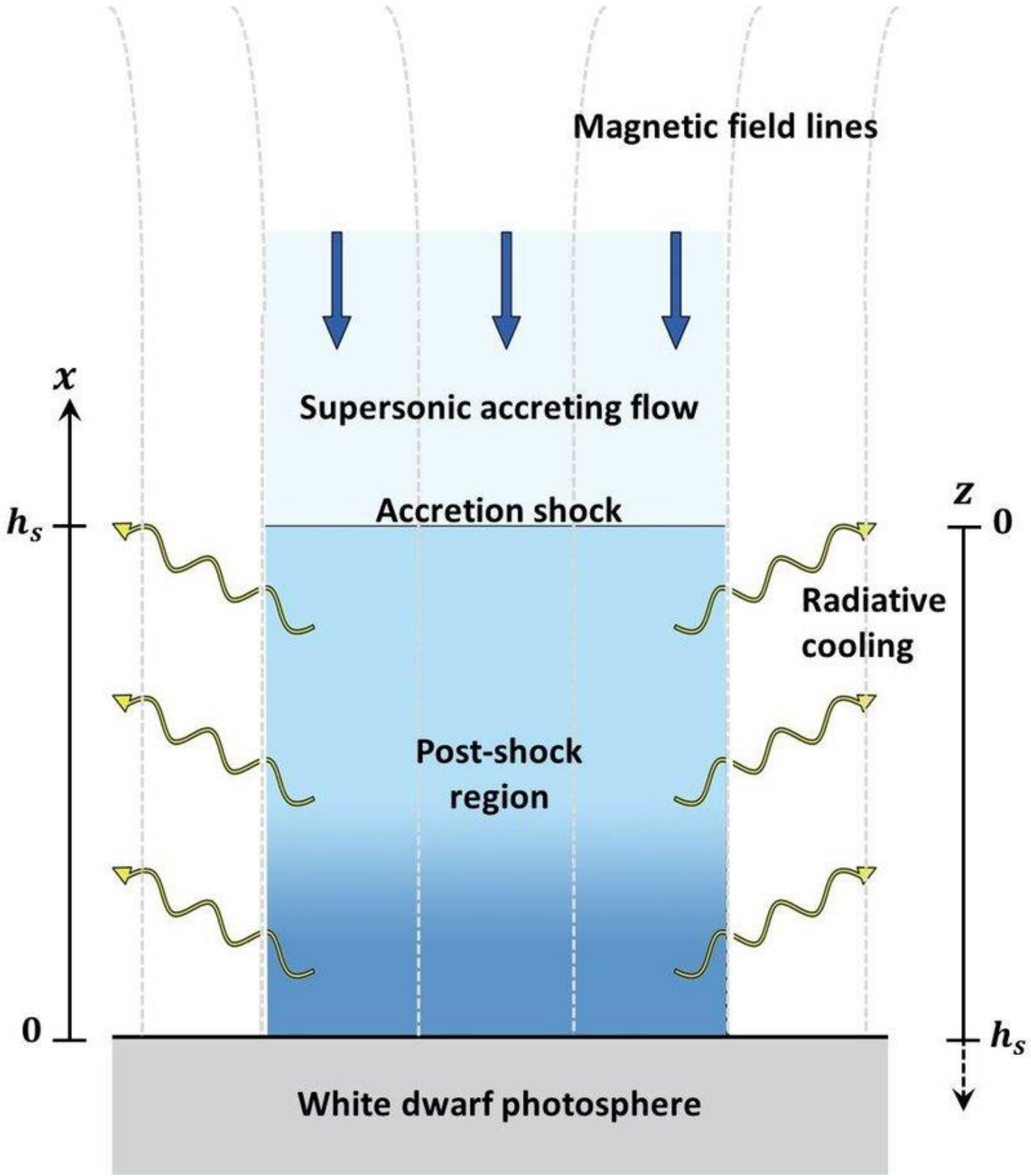
An aside on thermal Bremsstrahlung



Wikipedia



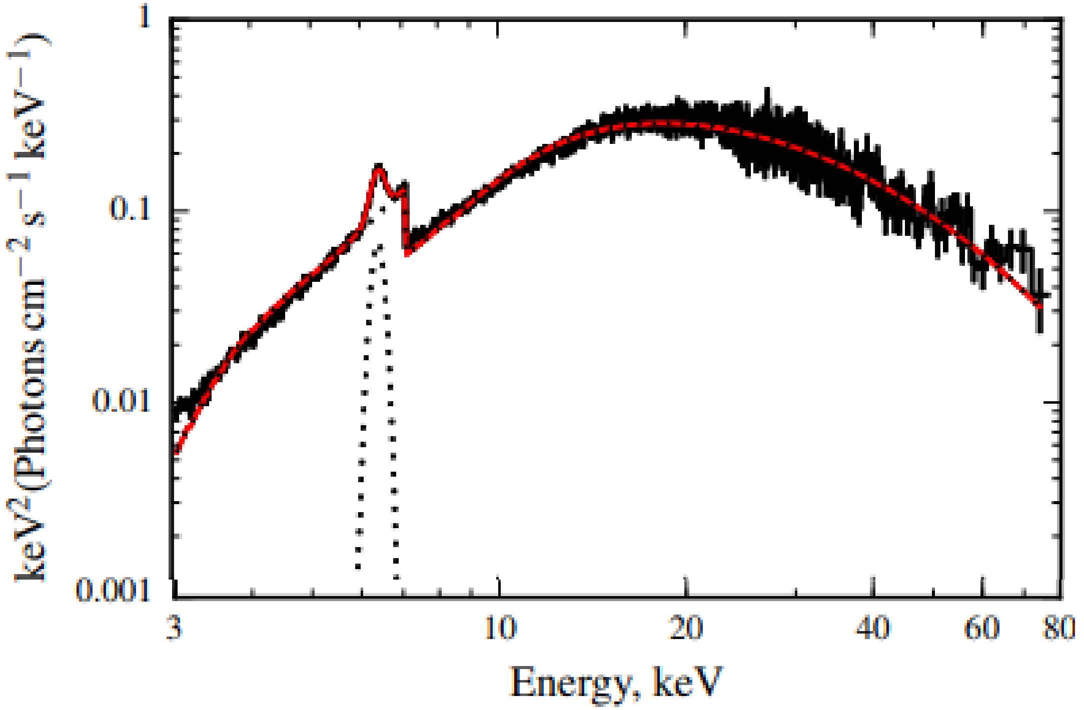
Shock schematic



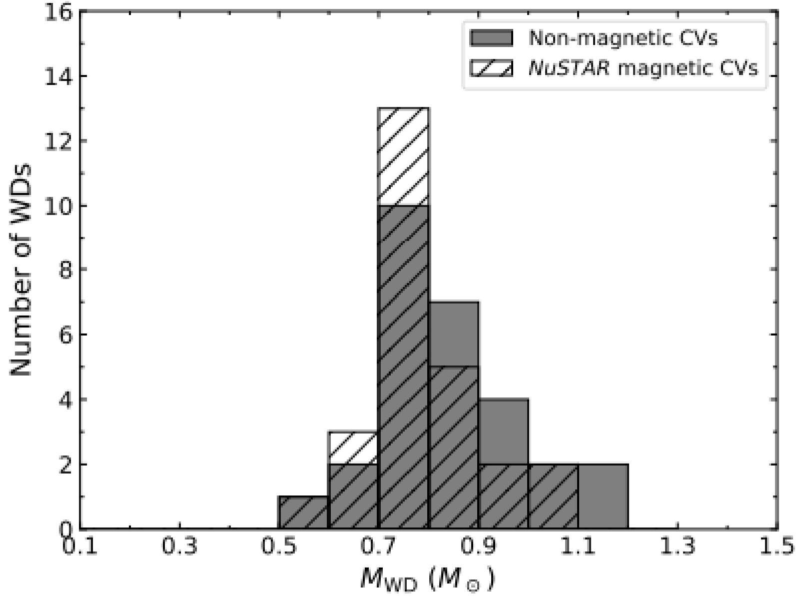
NuSTAR CV Science!

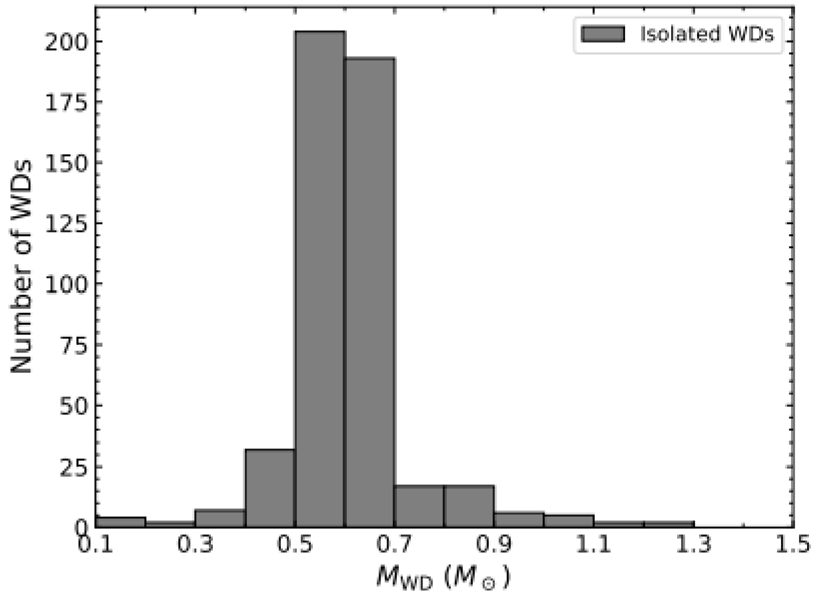
Shaw et al. 2020

$$kT_{s,ff} = \frac{3}{8}\frac{GM_1 \mu m_H}{R_1}$$

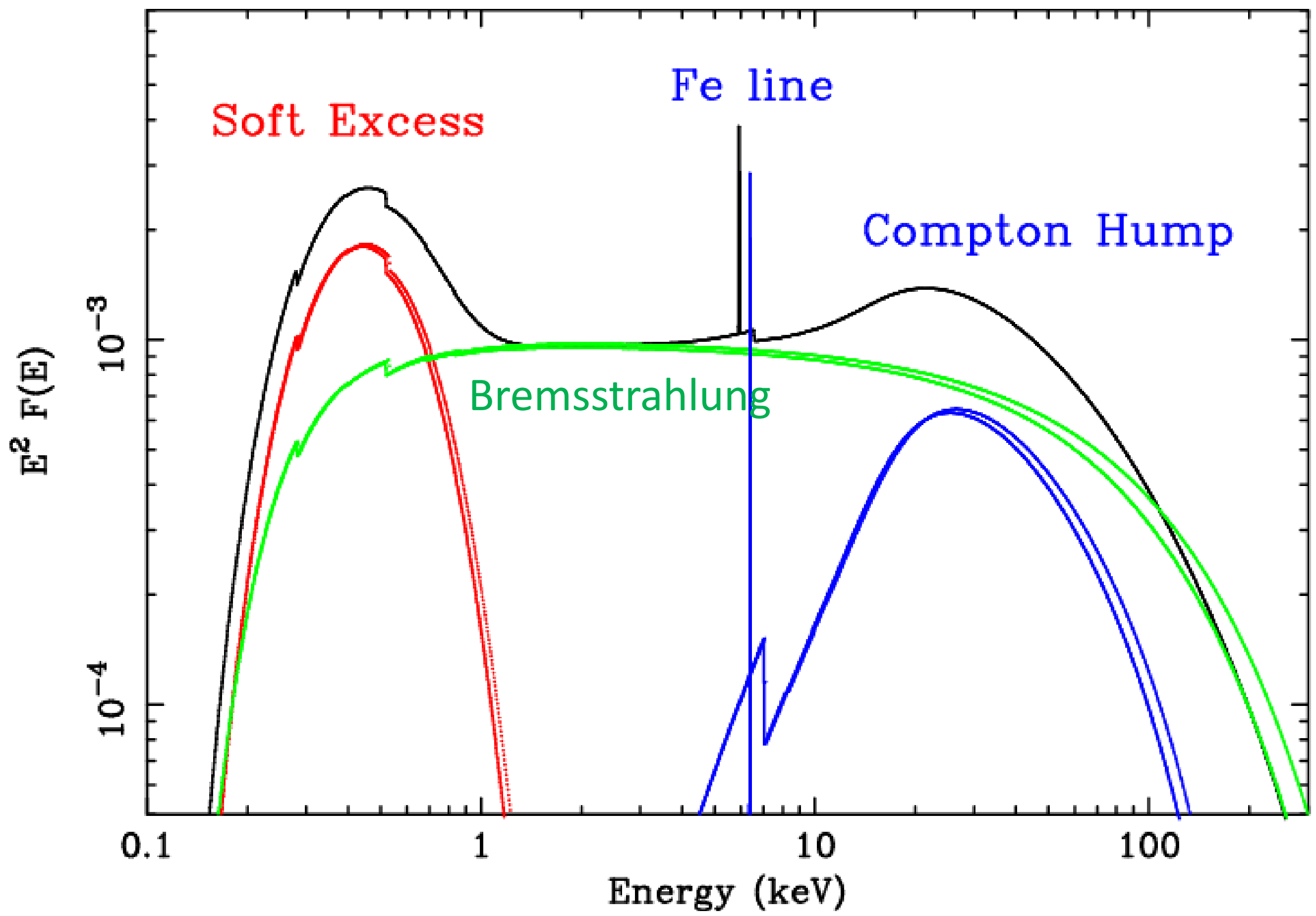


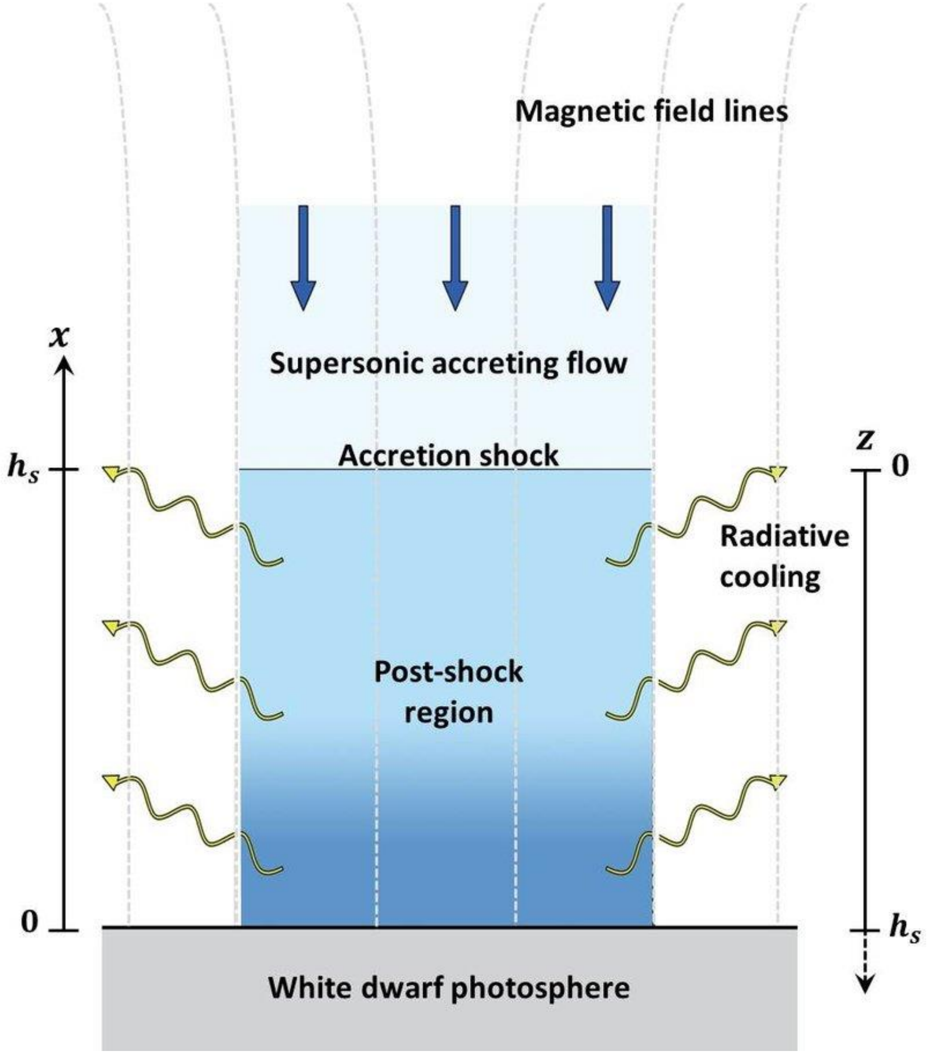
Suleimanov et al. (2016)



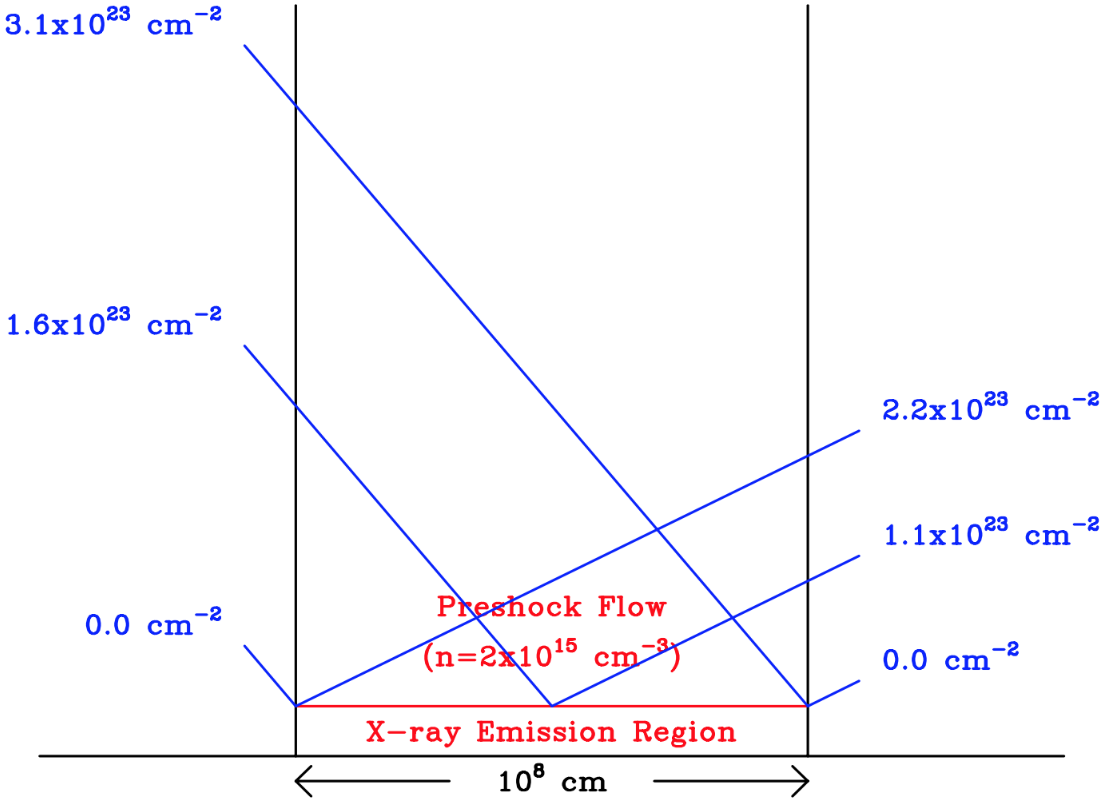


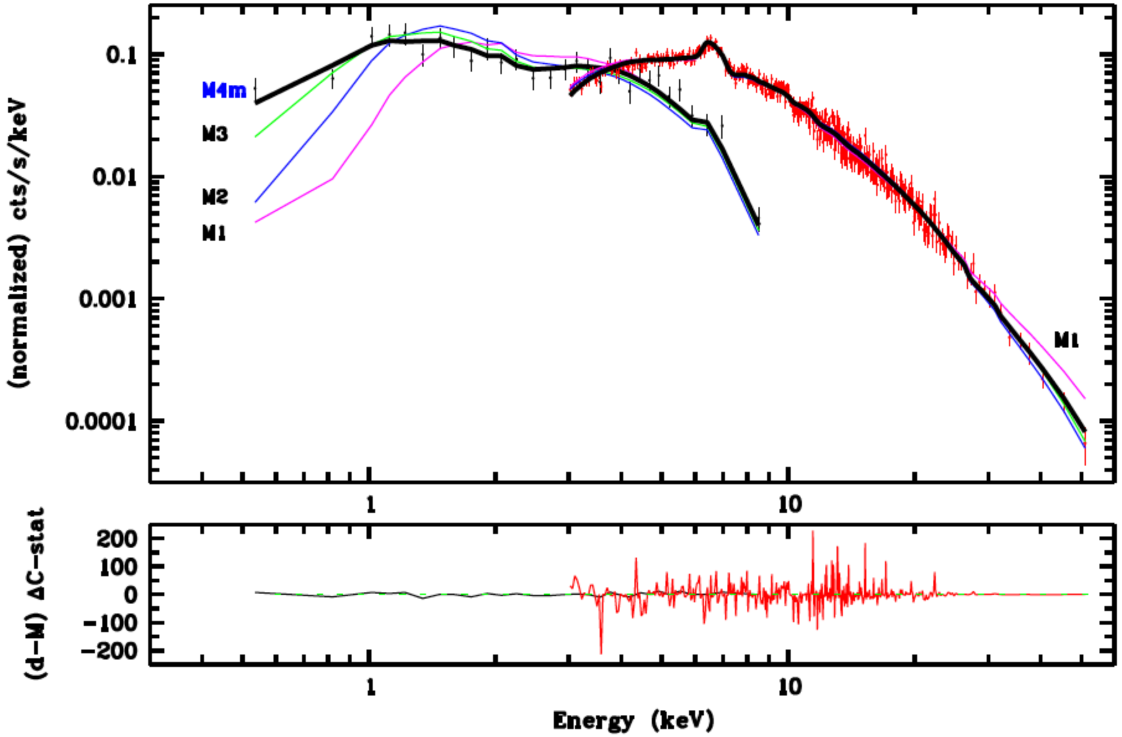
Reflection from WD surface/accretion stream





Complex absorbers





Lopes de Oliveira & Mukai 2019

Promise of High Resolution X-ray Spectroscopy

- XRISM and (maybe?) Athena will open up the power of high-resolution X-ray spectroscopy for CVs and Symbiotic Stars.
- Possible objectives include:
- Density diagnostics for magnetic CVs, allowing us to measure the size of the accretion column, hence that of the magnetospheric interaction region.
- Gravitational redshift of the 6.4 keV line from the surface of the white dwarfs.

Timing CVs: Spin and Orbital Period

Hare et al. (2021)

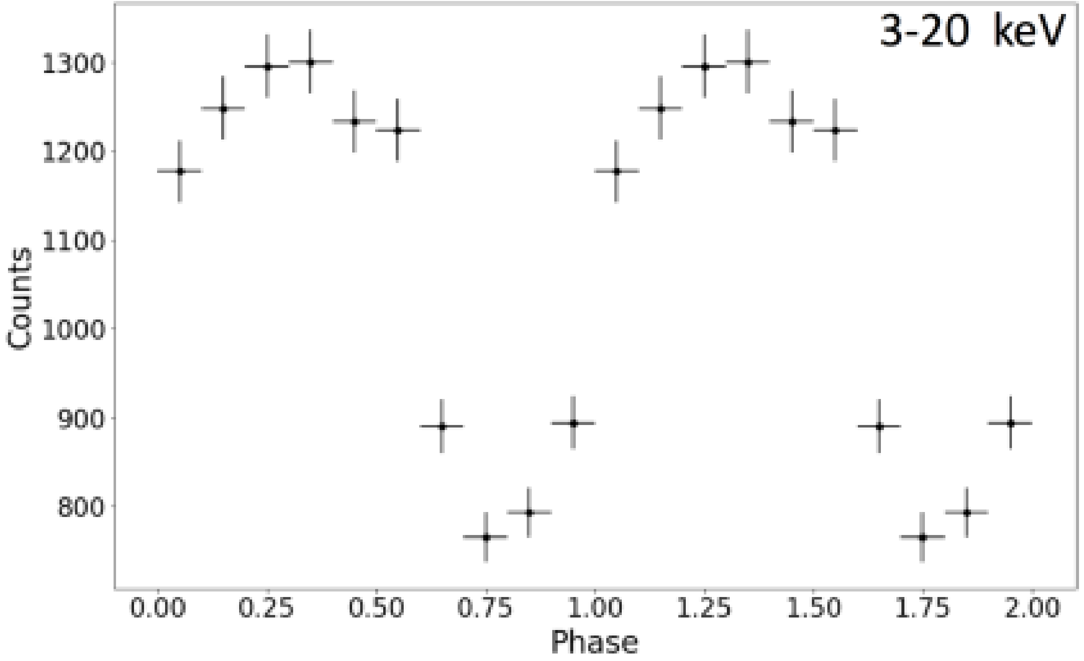
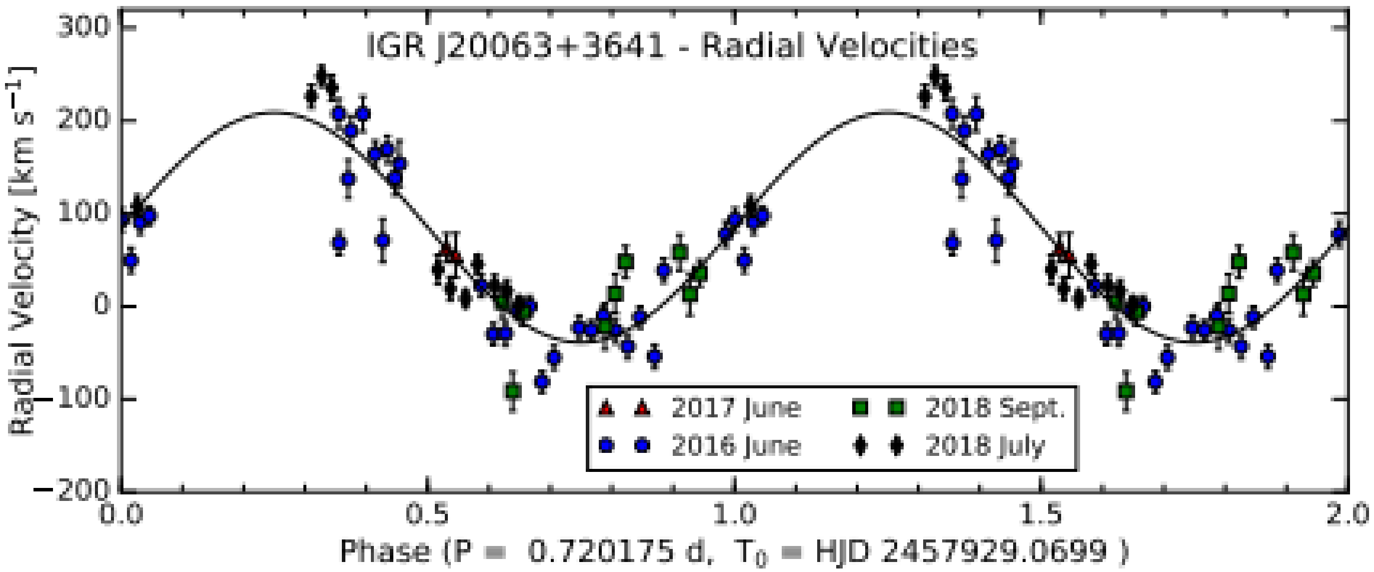
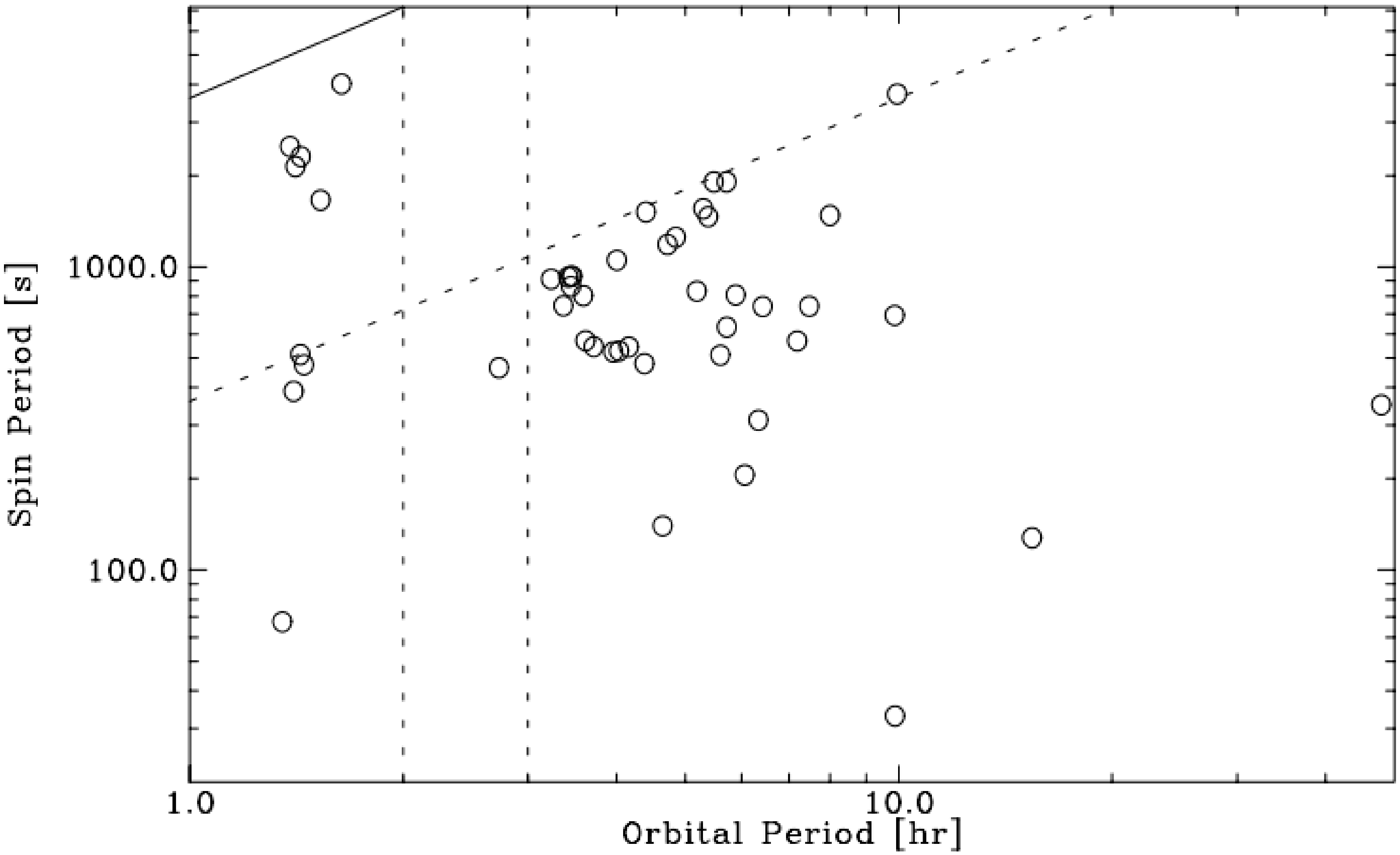
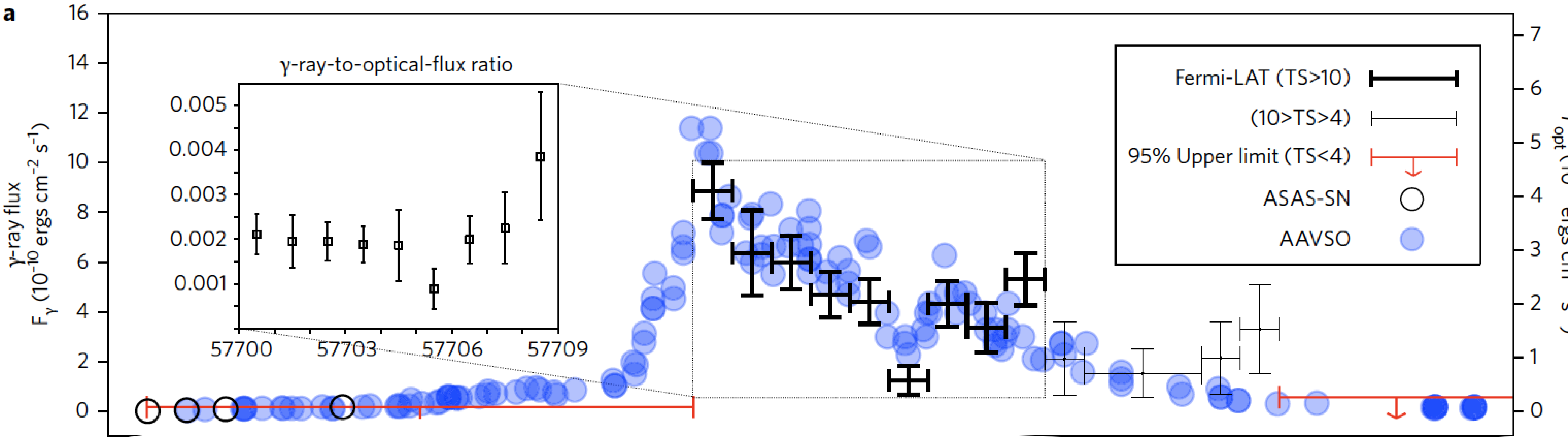


Figure 3. NuSTAR FPMA+FPMB pulse profile, folded at the $P_{\rm spin} = 172.46$ s period, of J20063 in the 3-20 keV energy range.



Timing CVs: Spin and Orbital Period

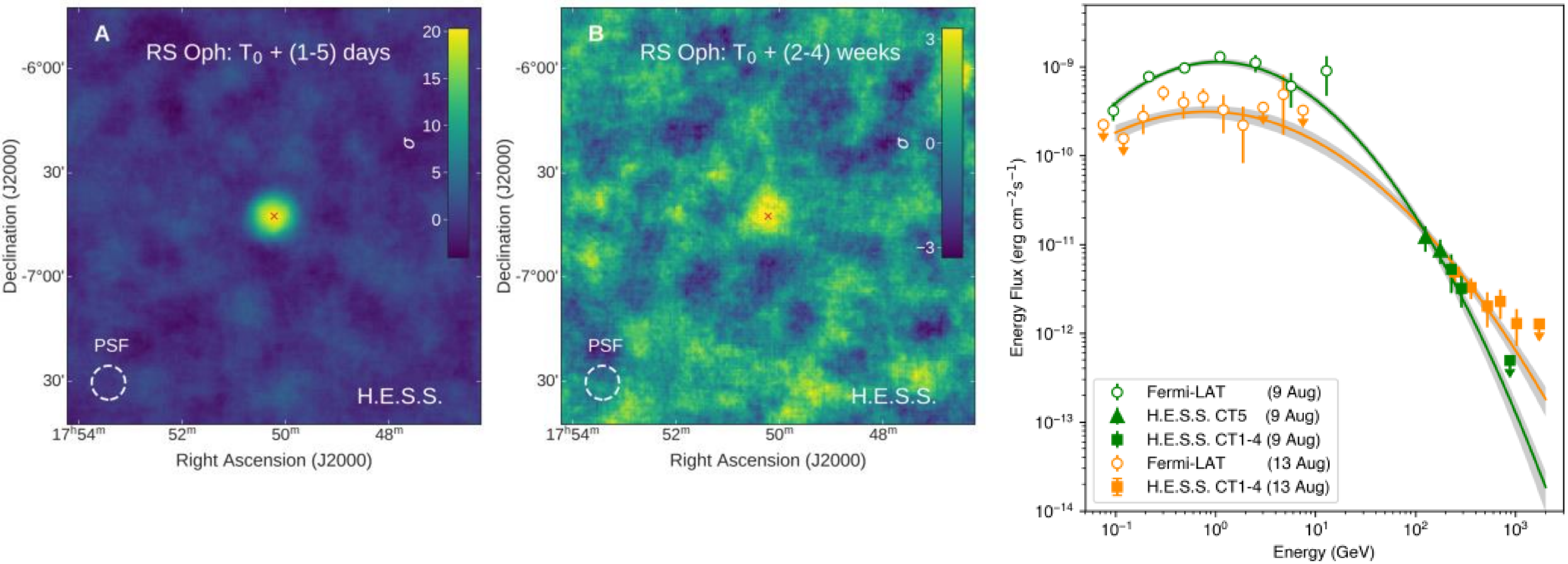




Novae as GeV gamma-ray sources

- Nova eruptions are the consequence of violent mass ejection due to thermonuclear runaway of material accreted on the white dwarf surface.
- Fermi/LAT has discovered 14 or so novae (depending on the significance threshold) as transient source of GeV gamma-rays.
- In one spectacular case of V5856 Sgr, Li et al. (2017, Nature Astronomy, 1, 697) reported a striking correlation between gamma-ray and optical flux of the nova, leading to the speculation that a significant part of the nova emission may be shock-powered.
- Such shocks should also emit thermal X-rays; non-thermal emission should extend down from GeV to hard X-ray energies.

H.E.S.S. Detection of RS Oph!



Lots of work to still do in confirming systems!

https://asd.gsfc.nasa.gov/Koji.Mukai/iphome/catalog/wishlist.html

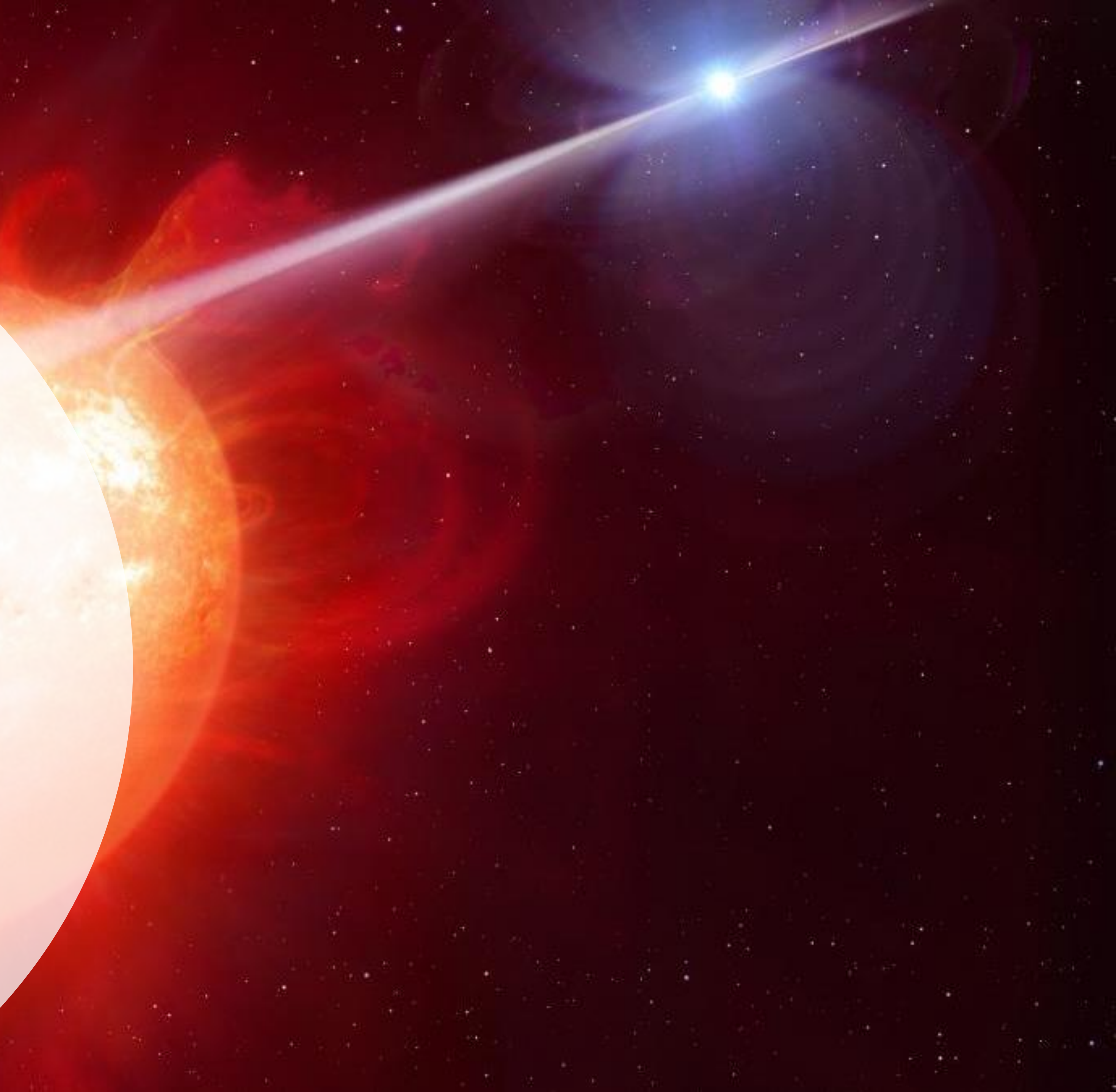
Systems needing dedicated optical observations

- 1RXS J015317.9+744641: In addition to X-ray data, more optical data are desirable.
- Swift J0525.6+2416: 20 hrs of optical photometry failed to reveal the X-ray detected spin period of 226.28 s or any other period, with a strong upper limit. Optical spectroscopy to detect the orbital period is needed, as well as another attempt at optical photometry.
- Swift J0535.2+2830: In addition to the X-ray confirmation of the spin, time-resolved spectroscopy is needed to measure the orbital period.
- Swift J061223.0+701243.9: There are no published optical studies beyond a description of the HET spectrum in an ATel.
- Swift J0746.2-1611: There is a hint of 2300 s X-ray period in a 9.4 hr binary, and the system was observed with XMM in high and low flux states. An independent confirmation of the potential spin period is highly desirable.
- 1RXS J080114.6-462324: It a 1308 s period seen in X-rays and the optical. Longer runs of optical photometry to beat down on alias patterns, and time resolved spectroscopy in search of the orbital period, are desirable.
- Swift J0820.6-2805: It has a possible 2485 s optical period. Longer runs of optical photometry, as well as time-resolved optical spectroscopy, are desirable.
- Swift J0958.0-4208: It has an X-ray spin period of 296.22 s, but there appears to be no published optical study beyond the identification spectrum.
- IGR J12123-5802: It is a hard X-ray detected CV. XMM observation failed to show a spin modulation. There appears to be no published optical study beyond the identification spectrum.
- IGR J14091-6108: It has a clear 576.3 s X-ray spin period. Optical photometry and time-resolved optical spectroscopy are required.
- IGR J14257-6117: It has no time-resolved optical observations in the literature, and its IP credential is based on one XMM observation.
- SDSS J144659.95+025330.3: It has a candidate spin period of 48.7 min from short XMM observations and

Source Catalog: https://asd.gsfc.nasa.gov/Koji.Mukai/iphome/catalog/alpha.html

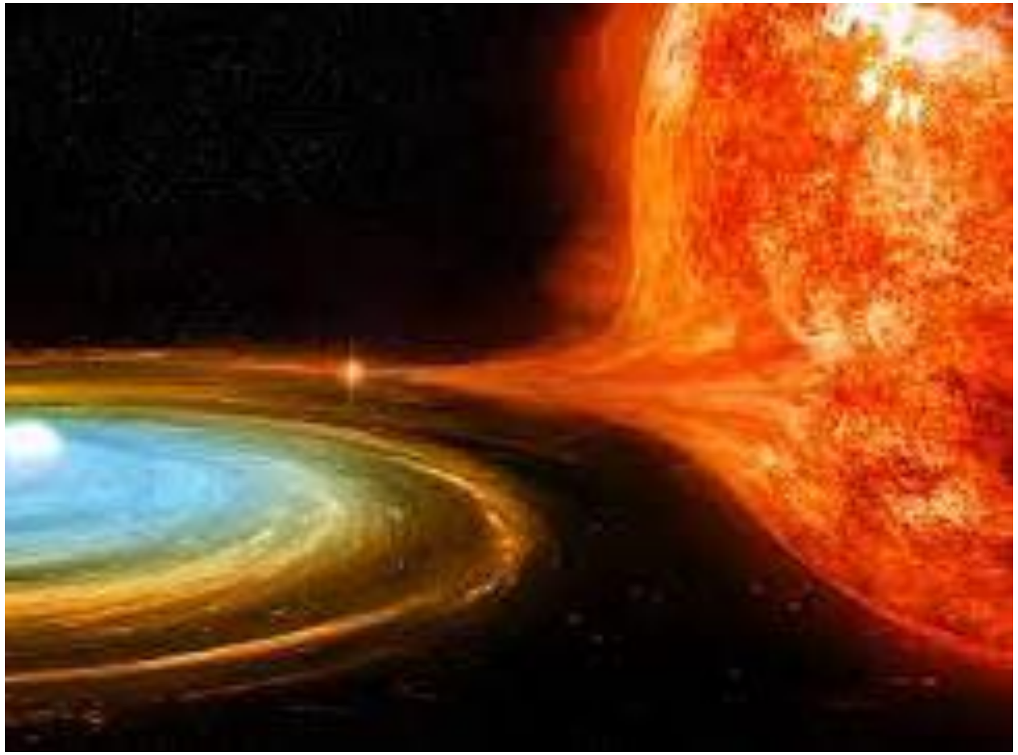
Rare WD Systems

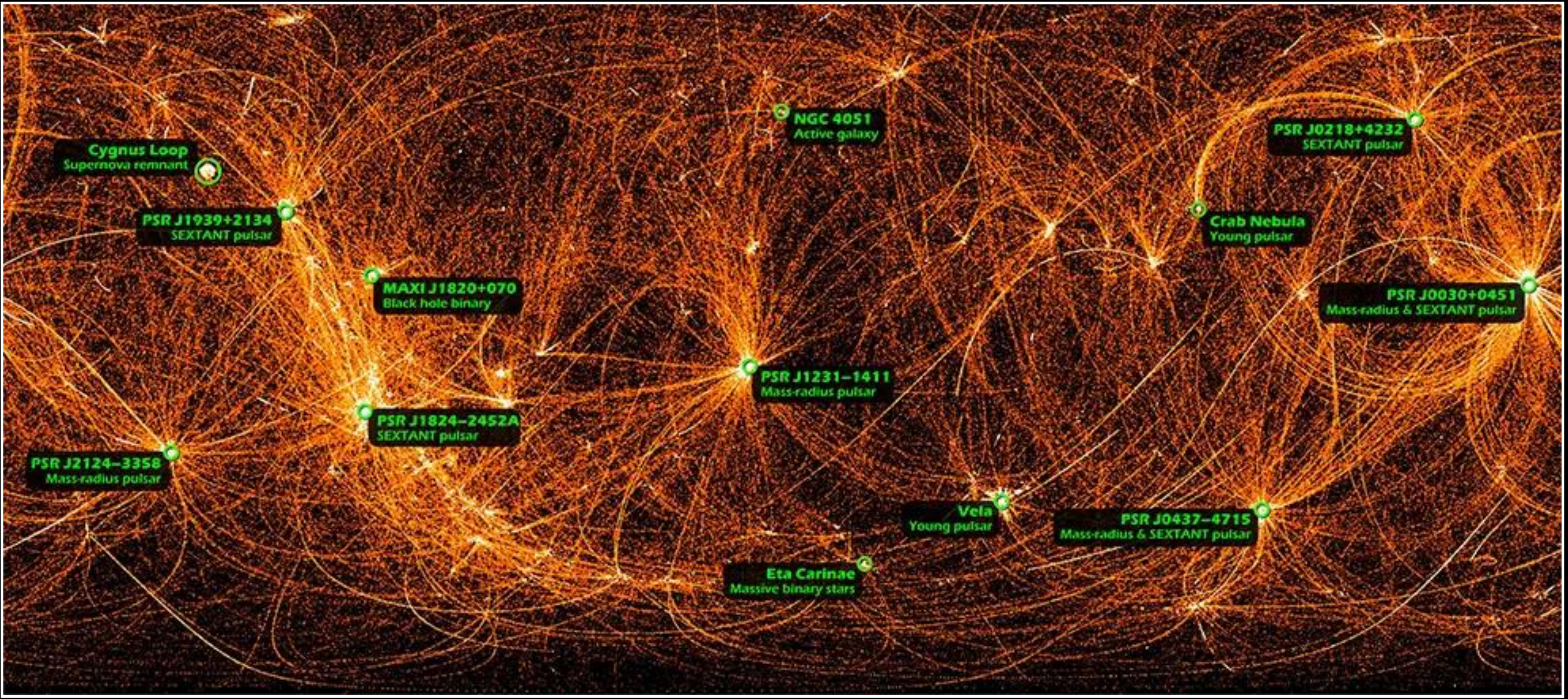
- WD pulsars, such as AR Scorpii ______
- Only 1 currently known
- Shows pulsations at radio frequencies similar to pulsars
- Also a relatively bright X-ray source



Be WD binaries

- Only a few known, found in SMC
- Must undergo uncommon mass transfer/binary evolution
- SALT involved in identifying Swift J011511.0-725611 as a new member of this class (Kennea et al. 2021)





Thank you for your time and attention!