White Dwarf Accretion and Shell Burning

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X-Rays from White Dwarfs

Shock heating of accretion flows:

\[ T_{ps} = \frac{3}{16} \frac{\mu m_p}{k_B} v_s^2 = 4 \times 10^7 \left( \frac{v_s}{1700 \text{ km s}^{-1}} \right)^2 \frac{\mu}{0.6} \text{ K} \]

In outflows or innermost accretion regions

Shell burning: \( E_{\text{burn}} / E_{\text{nuc}} \sim 50 \)

Novae

Quasi-steady burning

Before we dive into any discussion of symbiotics, symbiotic outbursts, or known population, we need to clarify one feature of WD symbiotics that effects almost everything — the presence or absence of quasi-steady shell burning.

In contrast to neutron stars, white dwarfs produce more energy from nuclear burning than accretion (for a given amount of fuel).

Much of what is known about magnetic accretion and the accretion-disk BL in CVs comes from X-ray observations, including CCD and grating observations with Chandra. Chandra has been particularly impactful when its high spatial resolution has been used to observe populations e.g., in GCs and other galaxies (as by, e.g., Dave Pooley and Rosanne).
White dwarfs produce $\gamma$-rays!??

It [is/would be] hard for me to exaggerate the degree to which this finding that novae produce gamma-rays has surprised the nova and high-energy communities.
Fermi Detects Normal Novae

**Unexpected:** Flow speeds non-relativistic. Radioactive decays → lines with $E \sim \text{MeV}$. 

*L_{g} = \text{few } \times 10^{35} \text{ erg/s}

Think about Tommy's statement that there is not enough power in the forward shock to power gamma ray emission.
Finding the $\gamma$-ray shocks: V959 Mon

X-rays probe the same shocks that accelerate particles.
Direct Imaging

Need to image sub-arcsec scales to uncover internal shocks in \( \gamma \)-ray novae.

See also Mukai & Still (2003).
Invest in Nearby Novae

- Fermi detects one nova/yr.
- Assume it will operate for 10 yr.
- We have about 10 chances to understand nova \( \gamma \)-rays.
- We may only get one we can image.
- We should be aggressive.

Result: origin of \( \gamma \)-rays and solutions to long-standing questions of mass ejection and binary stellar evolution.
Shell burning makes some symbiotic stand out.
Wide white dwarf binaries

- Half of low-mass stars are in binaries. The distribution of initial orbital periods peaks around 1000 yr.

- Where are all the wide, interacting, low-mass binaries?
X-rays from non-burning symbiotics

SU Lyn
Mukai+ 2016

X-ray emission from $>10^{-9} \ M_\text{sun}/\text{yr}$ accreting onto a $1 \ M_\text{sun}$ white dwarf.

d=650 $\pm$ 10% parsec (Mukai+2016)

Detected serendipitously with Swift during an X-ray high state.

Mention RT Cru? <- How my interest in this population began: with a 25 ks DDT Chandra observation (and a 25k grant that supported then-SAO predoc Juan Luna). We found: …

Swift XRT+BAT
Insight from a new population

- UV excess, X-rays, variability, astrometric wobble.
- More non-burning than burning symbiotics (Mukai +16). Total space density could rival that of CVs.
- Elucidate binary stellar evolution, accretion physics, disk winds and jets.

**R Aqr**
Kellogg+ 07, Nichols+ 07

**CH Cyg**
Karovska+ 2010

Number non-burning SS vs CVs? Sion webpage estimates few times 10^6 CVs in Gal (from space density of few x 10^{-5} per parsec^3).

From Mukai+ 16: number of nearby, serendipitously detected non-burning symbiotic suggests that they have a higher space density than burning symbiotics. Taking Munari+ xx estimate of symbiotic (as previously defined; 3e5 total in Gal), the space density could rival that of CVs. Given the brevity of the interaction phase compared to that of CVs, wide WD binaries (that interact at some point) could be the dominant population of (evolved only?) interacting low-mass stars in the Galaxy. (! Is this really true?)

More non-burning than burning symbiotics (Mukai+16). Total space density could rival that of CVs.

Distances for R Aqr and CH Cyg??
Conclusions

• Working closely with other observatories, Chandra is poised to make multiple, major discoveries relating to accreting white dwarfs.
• One will almost certainly relate to shocks, γ-ray production, and how novae erupt, especially if Chandra observes nearby novae aggressively.
• Chandra is also likely to help find, and probe accretion physics with, a new population of interacting, jet-producing white dwarf binaries.
Nova $\gamma$-rays

1. Overturns old picture of novae.

$L_{\text{LAT}} \sim 10^{35}$ erg/s $\rightarrow$ $L_{\gamma} \sim 10^{36}$ erg/s $\rightarrow$ $L_{\text{Shock}} \sim 10^{38}$ erg/s $\sim L_{\text{opt/UV}}$ (Metzger+ 2014, 2015)

2. New regime for particle acceleration.

Both possible mechanisms for generating GeV emission require particle acceleration in shocks.
Hadronic scenario likely for γ-rays

If shocks radiative and $\varepsilon_\gamma < 0.2$:

**V1324 Sco**: $\varepsilon_{nth} > 0.1 - 0.01$

**V339 Del**: $\varepsilon_{nth} > 10^{-3}$

Since $\varepsilon_{nth} \sim 10^{-5} - 10^{-3}$ for leptonic scenario (e.g., Morlino & Caprioli 2012, Kato 2015, Park+ 2015), hadronic more likely.
Probing particle acceleration

Metzger+ (2014, 2015)

Shocks are radiative:
\[ t_{\text{cool}} < t_{\text{expansion}} \]

Shock power \( \rightarrow \) X-rays
\( \rightarrow \) optical/UV

\[ L_\gamma < L_{\text{opt}} \varepsilon_{\text{nth}} \varepsilon_\gamma \]
\[ \varepsilon_{\text{nth}} > (L_\gamma/L_{\text{opt}}) (1/\varepsilon_\gamma) \]

X-rays reprocessed because outer ejecta neutral (and post-FS gas dense and cool).

\[ \text{M15 eq19: protons experience > 1 collision on ave until after a time } t_{\text{pp}} = 8wks \left( \frac{M_{\text{ej}}}{1e-4} \right)^{1/2} \left( \frac{v}{1000 \text{ km/s}} \right)^{-3/2}. \]

\[ \text{V1324 Sco: } \varepsilon_{\text{nth}} > 0.01 \]
\[ \text{V339 Del: } \varepsilon_{\text{nth}} > 10^{-3} \]

\[ \varepsilon_{\text{nth}} \sim 10^{-5} - 10^{-3} \text{ for leptonic scenario (e.g., Morlino & Caprioli 2012, Kato 2015, Park+ 2015), so hadronic more likely.} \]
Diffusive shock acceleration

Inverse Compton scattering

Fermi 1949, PR; Bell 1978, MN

(Image courtesy Mark Pulupa.)

Two mechanisms -- as discussed by last week’s speaker!

π⁰ decay

current gamma-ray observations consistent with both mechanisms...
Fermi Detects Normal Novae

• **Ubiquity**: 3 out of 4 CN within 4 kpc
• **Similarity** of γ-rays: flux, spectrum, timing
• **Diversity**: 2/7 embedded, X-rays, radio and optical LCs

Think about Tommy's statement that there is not enough power in the forward shock to power γ-ray emission.
X-rays as Probe of Shell Burning

- Symbiotics without SBWDs can produce hard X-rays. In others, FUV flux from SBWD cools BL.

Correlation between X-ray hardness and UV flickering supports idea that SS with hard X-rays are accretion powered.

Luna+ 2013

Flickering associate with disk accretion, and some of the known accretion-powered symbiotics.
Swift Survey of Symbiotics

- 41 SS observed with XRT for ~10 ks each.
- 10 new X-ray sources detected, all with emission above 2 keV.
- Identification of hard X-ray emission from accretion.
- 2/3 of our detections from top 1/3 of distance-sorted list.
- XRT did not detect some nearby, optically bright targets.
Symbiotics as Nanoquasars

Jets spatially resolved in the radio, optical, and X-rays (e.g., Brocksopp+ '04).

Southwest inner jet (which appeared between 2000 and 2004) produced radio synchrotron emission, whereas outer knots are typically thermal. (Previous synch jet to the NE in 1987).

Between 2000 and 2004, when the new jet was produced, the hard x-ray emission from the boundary layer strengthened.

- $10^2 - 10^3$ km/s
- $10^3$ AU
- transient
- disk-jet link
- precessing
- thermal and non-thermal

(See also Galloway & Sokoloski '04; Sokoloski & Kenyon '03; Crocker+ '01, '03)

magenta contours are 6-7 keV emission; green contours are HST [OIII] flux; color is soft (0.2-2keV) X-rays
Large, wind-fed disks

$\sim 10^{10}$ cm

$10^{15} - 10^{16}$ cm

~$10^{13} - 10^{14}$ cm
Disk accretion in WD symbiotics

With X-rays and flickering UV emission, we are finally finding the disks (e.g., Luna+ 13).

X-rays:
- Flickering
- Cooling-flow
- Reflection (NuSTAR; Nelson, Mukai+)

UV:
Flickering

(See also Ezuka+ ’98, Luna & Sokoloski ’07, Nichols+ 07, Kennea+ 09, Eze+ ’10)
Key question: accretion rate
Is it high, as expected for ‘wind Roche lobe overflow’?

No. No evidence for pervasive accretion rates near wind loss rates. Typically $10^{-9}$ to $10^{-8}$ Msun/yr (e.g., Sokoloski & Bildsten ’10).