Swift Observations of Novae

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and the nova community at
http://www.swift.ac.uk/nova-cv/
Novae: SN1a progenitors?

SN1a are key to measuring the acceleration of the Universe
- Thermonuclear explosion of a CO WD
- Progenitors are unknown (large literature!)
- Wang & Han 2012 review:
  - Single degenerate models:
    - WD+MS/RG/He
  - Double degenerate model:
    - WD+WD
- Gonzales-Hernandez+ 2012: lack of bright survivors means giant & subgiant companions excluded in SN1006
- Dilday+ 2012: PTF11kx circumstellar shells imply symbiotic nova prog.
- Broersen+ 2014: RCW86 is a remnant of a 1a that exploded in a 30 pc wind-blown cavity - requires an accretion wind, ie SD model
- Graur+ 2014: no HeII em before SN2011fe ➔ no high acc rate WD
Novae:
• Thermonuclear runaway burning of accreted material on a WD
• Orbital period can be hours to decades
• Recurrent novae have human timescale eruption cycle
• Unclear if $M_{WD}$ grows or declines over many eruptions

Potential sources of X-ray emission from novae:
• Thermal emission from hot white dwarf
  • shock breakout
  • residual nuclear burning after ejecta dispersal
• High velocity shocks
  • internal shocks within the ejecta
  • shock of ejecta with shell from previous nova or planetary nebula
  • shock of later fast wind with earlier slower wind
• Re-established accretion
Pre-Swift novae X-rays

V1974 Cyg
16 ROSAT observations
Krautter et al. 1996

V382 Vel
5 ASCA observations
Mukai & Ishida ’01
Swift novae stats

- Swift has observed 73 Galactic & MC novae within 11 years of outburst, of which:
- 43 detected in X-rays
- 12 novae have >100 ksec each: V1535 Sco, V745 Sco, V339 Del, N Mon 2013, T Pyx, U Sco, KT Eri, N LMC 2009, HV Cet, V2491 Cyg, V458 Vul & RS Oph
- Observations can start promptly: ~9 hrs from discovery for V339 Del (pre-nova for V2491 Cyg, U Sco, T Pyx & M31N 2008-12a)
- M31, M33 novae also observed
RS Oph

X-ray (0.3-10 keV) light curve shows:

- Cooling hot gas emerging from red giant wind
- Noisy onset of super-soft phase, which lasts ~64 day in total
- Turnoff time \( \rightarrow M_{WD} \sim 1.35 \, M_\odot \)

Osborne et al 2011
RS Oph

Osborne et al 2011

XRT count s\(^{-1}\) (0.3–10 keV)

day since outburst

Osborne et al 2011
RS Oph

Ness et al 2009
A quasi-periodic modulation

RS Oph (0.3 - 10.0 keV) 1024 bins/interval

Day 33-45

Day 45-58

Period near 35s in soft X-rays between days 33-59

WD spin?

Nuclear burning instability?
Super Soft novae QPO

(a) RS Oph
- $M = 122$
- $d_t = 13.18$ (s)
- $T_0 = 1230.3$ (s)
- $N_{\text{real}} = 1249$
- $\alpha = 1.86 \pm 0.07$
- $\nu_{\text{QPO}} = 0.09853 \pm 0.00007$ Hz
- $\tau_{\text{QPO}} = 0.0343 \pm 0.0129$
- $Q = 30.6 \pm 2.4$

(b) KTe1
- $M = 148$
- $d_t = 0.018$ (s)
- $T_0 = 1230.3$ (s)
- $N_{\text{real}} = 1249$
- $\alpha = 1.91 \pm 0.34$
- $\nu_{\text{QPO}} = 0.09858 \pm 0.00007$ Hz
- $\tau_{\text{QPO}} = 0.0343 \pm 0.0129$
- $Q = 30.6 \pm 2.4$

(c) V339 Del
- $M = 71$
- $d_t = 0.026$ (s)
- $T_0 = 1230.3$ (s)
- $N_{\text{real}} = 1249$
- $\alpha = 1.89 \pm 0.34$
- $\nu_{\text{QPO}} = 0.09853 \pm 0.00007$ Hz
- $\tau_{\text{QPO}} = 0.0343 \pm 0.0129$
- $Q = 30.6 \pm 2.4$

(d) V745 Sco
- $M = 72$
- $d_t = 0.018$ (s)
- $T_0 = 1230.3$ (s)
- $N_{\text{real}} = 1249$
- $\alpha = 1.89 \pm 0.34$
- $\nu_{\text{QPO}} = 0.09858 \pm 0.00013$ Hz
- $\tau_{\text{QPO}} = 0.0343 \pm 0.0129$
- $Q = 30.6 \pm 2.4$

Beardmore et al 2015
What can we learn?

- $kT_{\text{max}}$ gives $M_{\text{WD}}$
- $T_{\text{recurr}}$ gives $M_{\text{WD}},$ acc rate
- $T_{\text{SS}}$ gives $M_{\text{WD}}$
- Ejecta abundances give level of WD mixing, and so whether WD is gaining or loosing mass

Sala & Hernanz 2005

Hachisu & Kato 2006

Wolf et al 2013

Starrfield et al 2012
What can we learn?

NLTE expanding solar abundance nova atmosphere (scaled)

Different mass loss rates

Van Rossum 2012
Super Soft Swift Novae

Expansion velocity FWHM (km/s)

Schwarz et al 2011
Super Soft Swift Novae

SS (& prob SS) defined as $S = 2H$
where $S=0.3$-1.0 keV c/s, $H=1.0$-10 keV c/s

- High expansion velocity $\Rightarrow$ high WD mass
- High expansion velocity $\Rightarrow$ early & short SS phase
  - Absorption & a strong hard component can be confusing
- The fastest novae have an early hard phase
  - Internal shocks in ejecta: $kT_{\text{shock}} = (3/16)<m>V^2$
- Lack of SSS in previous samples due to observations being insufficiently early or late
SS novae turn-on times

The fastest novae eject the least mass
They become SSS early as the ejecta thin out quicker

Schwarz et al 2011
SS novae turn-off times

Hachisu & Kato 2010
Predicted end of nuclear burning from optical LC break time
Not well supported by Swift data

Days to decline 2 magnitudes

Schwarz et al 2011
SS novae turn-off times

Ejecta velocity

Derived from 4 SS turn-offs

Greiner+ 03

Schwarz et al 2011
SSS = optical plateau?

Hachisu+ 08: “RNe optical plateau due to fading ejecta revealing irradiated accretion disk which ends when nuclear burning ends”

Our data agree with this, even for 2 of the 3 unconfirmed RNe

A proxy for SSS (as is [Fe X] 6375Å)
CSS 081007... = HV Ceti

- Beardmore et al 2010: initial summary in AN

- $\Delta V > 4$
- H$\alpha$ vel $\sim$ 1500 km/s
- Strong [Ne V]
- Pre-o/b rise $\sim$ 1-2 mag
- Gal latitude = -44°
- Time of optical peak poorly constrained
HV Ceti

- 1.77 day modulation: orbital (cf GK Per) or poss precession
  - Broad modulation suggests large emission region
  - UV peak dips like SSS Cal 87 (bright inner accretion disk?)
HV Ceti

- Tri-peaked optical emission lines - which move
- Also seen in some Compact Binary SSS
- ‘jet emission’ / bipolar ejecta / accretion disk ??
- Hard to get both disk edge and high velocity jets in line of sight (unless they are broad)

Wagner et al 2011
HV Ceti

Galex spectra:

- no spectral variation
- few thousand times extrapolated X-ray spectrum
- but we know UV is modulated at 1.77 d like X-rays
- UV must come from inside accretion disk
• Suggests we see only scattered X-rays ($\tau << 1$), while UV reflector sees hot WD directly.

• Helps to explain $R \sim$ few $10^7$ cm from X-ray spectral fits (Rauch atmosphere model) - Well below expected $\sim 10^9$ cm.
HV Ceti

• What about the trend in the periodic X & UV photometric variation?
  
  • X-ray max declines, min stays constant while
  • UV max stays constant, min declines

• Cannot be due to changes in disk rim height or size of inner scattering region

• No explanation to hand: worry about scattering cloud - UV reflection - disk obscuration concept?
Mostly novae

- High inclination SSSs are emission line dominated
- Low inclination systems dominated by continuum & absorption lines

Ness et al 2014
Sources are:
- continuum dominated when bright
- emission line dominated when faint
- More luminous sources are continuum dominated
- Less Luminous source are emission line dominated

Line of sight to WD is blocked at \( i > \sim 70^\circ \)
- Residual continuum seen via scattering
- Emission lines stronger where continuum is stronger \( \rightarrow \) photo-excitation
- Accretion disk exists at time of SS in novae
Nova LMC 2012

- Very fast decline: $t_2 \sim 2$ days (~fastest ever seen)
- $P_{\text{UV, opt, NIR}} = 19.2$ hr, not present in X-rays
- Emission line Chandra grating spectrum & optical emission line modelling suggests inclination $\sim 55^\circ$

- Very low hard X-ray L ($\sim 1e31$ erg/s) points to low $M_{\text{ej}}$ ($\sim 1e-6 M_\odot$)
- Short $T_{SS} (= 50$ d) at 1MK, high $V_{\text{ej}}$ ($\sim 5000$ km/s), low $M_{\text{ej}}$ all point to a high $M_{\text{WD}}$
Optical/UV & X-ray spectroscopy constrain Rauch WD and Cloudy ejecta models, leading to the need for a 2nd UV/optical source:

- Consistent with illuminated secondary, T ~ 20,000 K
- Optical light curve is not due to ejecta
- Probable RN, gaining mass: SN1a progenitor - hard to find with t_2 ~ 2 days
Fermi-LAT novae

- 6 >100 MeV novae
- V407 Cyg: red giant ($P_o \sim 40-50$y)
- N Sco = ?
- N Mon = K dwarf
- Emission peaks a few days after optical
- Discovery not widely expected: MeV line emission predicted, but not GeV continuum
- 1st had dense companion wind, good target for shock
  - photo-pion or IC origin
  - LAT novae would be rare
- No wind in N Mon 2012
Fermi-LAT novae

- N Mon 2012 seen in VHE-$\gamma$ before optical
- 7.1 hr period in phase in X-ray, UV & I-band
  - Modulation due to disk rim obscuration?
- Presumed orbital period $\Rightarrow$ Msec $\sim 0.8 M_\odot$, rules out wind shock VHE-$\gamma$
- Martin & Dubus 2013 model: shock in gas around accretion disk
Fermi-LAT novae

GeV emission as fast-late wind shocks on slower-denser material in orbital plane

Cheung/LAT+ Science 2014

Chomiuk+ Nature 2014
M31 nova: $T_{\text{recurr}} \sim 1$ yr

- Shortest Galactic nova $T_{\text{recurr}} \sim 8$ yr (U Sco)
- Very fast V-band decline ($t_2 \sim 4$ days)
- Very high $M_{\text{WD}}$ ($\sim 1.4 \, M_\odot$) and accretion rate ($\log M_{\text{dot}} \sim -7$ to -8)
- Very short SS phase seen by Swift ($T_{\text{SS}} \sim 20$ days) $\Rightarrow$ high $M_{\text{WD}}$
- $T_{\text{BB}} \sim 97$ eV $\Rightarrow$ very high $M_{\text{WD}}$
- Also found by Rosat as SSS in 1992/2 & 1993/1 and by Chandra HRC in 2001/9
- If this is a CO WD, it is a good SN1a progenitor candidate

Darnley et al 2014
Henze et al 2014
M31 nova: $T_{\text{recurr}} \sim 1$ yr

- $M_{\text{WD}} > 1.3$ M & acc rate $> 1.5 \times 10^{-7}$ Msun/yr
- Min poss $T_{\text{recurr}} \sim 2$ months (for non-rot 1.38 $M_{\text{WD}}$)

M31 novae: Henze+14

(a) turn-off time [d] vs turn-on time [d]

(b) blackbody kT [eV] vs uncertainty

(c) turn-on time [d] vs time [d]

(d) expansion velocity [km/s] vs uncertainty

Unobservable region: turn off < turn on
• 4 observations a day to search for shock breakout
• only upper limits found
Dust in V339 Del

• N Del 2013 (V339 Del) was one of the brightest novae in the last century (Vmax ~ 4.3)
• LAT VHE gamma-ray source
• MS donor star, bipolar ejecta
• Filling factor ~0.1 derived from ratio of H beta luminosity to electron density from [O III]
• Ejecta mass 2-3e-5 Msun
• Taranova+14 discovered IR dust peak at ~ 1 month
• Relationship between dust & X-rays not well established

Shore+16 A&A 590 A123
Dust in V339 Del

Dust-driven decline?

Day since detection

Mag

AAVSO-B
AAVSO-V
AAVSO-R
AAVSO-I
Swift-w2
Dust in V339 Del

Evans+17 MNRAS 466 4221
Dust in V339 Del

- No obvious sign of dust effect in X-ray light curve
Dust in V339 Del

Evans+17 MNRAS 466 4221
Dust & X-rays

• CO novae may produce C dust
• C K absorption edge is at 0.27 keV
  • probably too low to be of interest
• Frucuter+01 argues that dust grains smaller than ~1 micron
  are optically thin to X-rays
  • X-ray absorption will be unaffected by whether C is
    in dust or gas at these grain sizes
The observed soft X-ray rise around the times of the end of the dust events is not caused by dust destruction.

The dust destruction may be caused by the X-ray rise.

X-rays destroy dust by:
- thermal evaporation
- electron ejection causing strong Coulomb repulsion

V5668 Sgr has $\log(E/D^2) > 5$

Its X-ray energy density easily destroys the grains.
Hernanzfest, 15-16 Jun 2017, Tossa de Mar
LMC 2009a: 1.19d period

UV

X-rays

Bode+16 ApJ 818 145
1.19 day period is too long to be WD spin

Smooth modulation over the whole orbit implies an emitting structure size comparable to the orbit

- scattering cloud around WD?

UV or X-rays modulated, but not both simultaneously

X-ray modulation lags UV by 0.28P

- UV modulation source must be distinct from X-ray (also implied by overall light curve)

- azimuthally structured raised disk rim?
• 1st obsn at 3.7 hrs after discovery announcement
V745 Sco: Swift

- V745 Sco kT 25 eV below that of M31 N (curve shifted up): WD mass lower
- Much shorter X-ray timescales than M31N 2008-12a: WD mass higher
- WD mass is not the only important parameter
- e.g. burnt & ejected mass with $T_{\text{rec}}$ gives accretion rate ~5% that of M31N
V745 Sco: Swift+NuSTAR

- 2-3 sigma Fermi LAT detection on day 1-2
- Swift & NuSTAR observations on day 10
• Chomiuk+14 proposed that hard X-ray emission arises from shocks between fast polar and slower equatorial ejecta.

• Metzger+15 proposed that significant optical emission is powered by absorbed X-ray shocks.

• M+15 propose a search for these absorbed shocks with NuSTAR at the time of VHE gamma-ray emission and optical peak.

• The V745 Sco observation was unfortunately too late (due to the exceptional speed of this nova).

• This test has yet to be performed AFAIK.

Metzger+15 MNRAS 450 2739
Summary

• High-energy nova observations have revealed surprises

• Not really understood:
  - Large amplitude variability of early super-soft phase (‘clumps’?)
  - 30-60 sec QPO (WD spin or oscillation?)
  - GeV emission origin

• Perhaps understood:
  - High mass WDs lead to fast novae
  - Irradiation can play a large role in optical light curve formation
  - Accretion disk can be present in residual nuclear burning phase
  - X-rays from inner regions can be scattered into line of sight
  - Completeness of fast novae may be very poor

• Swift has contributed answers, questions & motivation for observations elsewhere; and can continue to do so