Accrete, accrete, accrete... Bang! (and repeat):
The remarkable recurrent novae

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Novae: “Vital Statistics”

• **Primary: White Dwarf**
  – 0.5 – ~1.4 Solar Masses (Chandrasekhar mass)
  – CO or ONe(Mg)
  – Plus He and H layers

• **Secondary: ‘Late Type’ MS star**
  – Typically Solar-ish composition
  – Orbital period 1.5 – 8 hrs – Roche lobe filling

• **Mass Accretion:**
  – Solar material – Hydrogen rich
  – Accretion rate: $10^{-9}$ Solar masses / year

• **Luminosity:**
  – Quiescence: ~ Solar Luminosity
  – Eruption: ~$10^4$ Solar – Eddington luminosity

• **Ejected Mass:**
  – $10^{-5} – 10^{-4}$ Solar Masses
  – Composition: depleted H, enhanced He/N
  – Possible Ne enhancement is ONe WD

• **Recurrence Period:**
  – 1,000 – 1,000,000 years
  – 1,000s of eruptions per system

• **Recurrent Novae:**
  – >1 observed eruption
  – Secondary: Evolved
  – Orbital period: >1 day
  – High accretion rate (up to $10^{-7} M_{\text{sun}} / yr$
  – High mass WD (>1.2 $M_{\text{sun}}$)
Nova mechanism
Classical vs Recurrent Novae

Classical Novae
- Only one observed eruption
- Recurrence timescales few thousand – million years (predicted)
- Secondaries – main sequence stars
- Low mass transfer/accretion rates
- Range of WD masses
- Range of evolution speeds
- Range of ejection velocities
- Mix of Fe II and He/N spectra
- 400 Galactic systems (1000 M31)
- WD mass decreasing

Recurrent Novae
- >1 observed eruption
- Recurrence timescales 10 – 100 years
- Secondaries – sub-giants (U Sco) or red giants (RS Oph)
- High mass transfer/accretion rates
- High WD Masses
- Rapid eruption evolution
- High ejection velocities
- He/N spectra
- 10 Galactic systems (16 M31, 3 LMC)
- WD mass increasing ➜ SN Ia (?)
Classical Novae

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The Liverpool Telescope – The World’s Largest *Fully Robotic* Telescope

- The first extragalactic nova to be observed in optical, UV and X-rays, and spectroscopically confirmed

- Initially thought to be recurrent due to positional “coincidence” with 1969-08a

- X-ray observations and optical spectra consistent with recurrent nova

- HST archival data revealed progenitor system – red giant secondary

- First recovery of a nova progenitor beyond the Milky Way
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Galactic Progenitors – Darnley+ 2012

- The problem with Galactic nova studies is the distance ... the problem with extragalactic studies is the distance(!)
- Can we carry out a statistically significant survey of extragalactic progenitors
- Assumption: the colour & magnitude of a quiescent nova can be used to determine secondary type
- Colour-mag position is determined by the secondary – accretion disk shifts emission blue-wards and luminosity upwards
- Blue – MS-novae (CNe); Green – SG-novae; Red – RG-novae
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Extragalactic novae
Extragalactic Progenitors – Darnley+ 2013
M31 Nova Survey – Shafter & Darnley et al. (2011), Williams & Darnley et al. (2014, 2016)

- Extensive follow-up survey of M31 novae: August 2006 – ?? (Sala+ 2016 in prep)
- Lead facilities: Liverpool Telescope (phot +spec), HET (spec), HST (archive)
- Photometric, spectroscopic, astrometric follow-up survey of almost 100 novae (3x the spectroscopically confirmed sample)
- As with M31N 2007-12b, utilising the HST archive for quiescent detection
M31 Quiescent Nova Survey – Williams & Darnley et al. (2014)
M31 Quiescent Nova Survey – Williams & Darnley et al. (2016)

- Progenitor Survey Highlights
  - 30±12 % of M31 nova eruptions occur in RG-nova systems
  - The traditional Galactic proportion is ~3 %
  - Order of magnitude increase in the RG-nova population size – same affect to their SN Ia contribution(?)
  - RG-novae are associated with the disk (young) stellar population of M31
  - Result is consistent with all the RG-novae being disk novae
  - No nova SN Ia contribution from novae in early-type galaxies(?)
**RNe / RG-novae  ➚ SNe Ia (?)**

- Many models now show RN WD mass is growing with time
- He-flashes on high mass WDs may not cause significant mass loss
- High mass WD and high accretion rate drive shorter recurrence times
- Short recurrence times drive WD mass growth rates
- Predictions limit recurrence periods to 50 days as approach Chandrasekhar limit

- Minor question about the WD composition – CO vs. ONe

- But we need to find the extreme system(s)

- Galactically
  - RG-nova: RS Oph – 20 yrs
  - SG-nova: U Sco – 10 yrs

- LMC
  - LMCN 1968-12a – 6 years (as of 2016)

- M31
  - M31N 1963-09c – 5 years

- But wouldn't it be nice to find something more extreme?!

- A system much closer to the 50 day “limit”? 
M31N 2008-12a

2008  M31 transient discovered
2009  Eruption announced  
       (PTF; Tang+ 2014)
2010  Eruption recovered  
       (Henze+ 2015)
2011  Erupted again
2012  Spectroscopically confirmed
2013  iPTF discover eruption
2014  LT detects predicted eruption (Darnley+ 2015)

• Transient X-ray detections:  
• At least one optical eruption in 1960s
M31N 2008-12a: The ‘missing’ 2010 eruption – Henze & Darnley et al. 2015
M31N 2008-12a: The recurrence period – Henze & Darnley et al. 2015

• The Optical Eruptions
  – 26 Dec 2008
  – 3 Dec 2009
  – 20 Nov 2010
  – 23 Oct 2011
  – 19 Oct 2012
  – 28 Nov 2013
  – 3 Oct 2014

• Extrapolated from X-ray detections
  – 5 Feb 1992 (ROSAT)
  – 11 Jan 1993 (ROSAT)
  – 8 Sep 2001 (XMM)
M31N 2008-12a: Recurrence period – optical eruptions – Henze & Darnley et al. 2015

\[ t_{\text{rec}} = 351 \pm 13 \text{ days} \]
M31N 2008-12a: The recurrence period – Henze & Darnley et al. 2015

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M31N 2008-12a: Recurrence period vs. X-ray detections – Henze & Darnley et al. 2015
M31N 2008-12a: Recurrence period vs. X-ray detections – Henze & Darnley et al. 2015
M31N 2008-12a: A recurrence period of 6 months? – Henze & Darnley et al. 2015

\[ t_{rec} = 175 \pm 11 \text{ days} \]
M31N 2008-12a: Where are the missing eruptions? – Henze & Darnley et al. 2015
M31N 2008-12a: The recurrence period – Darnley+ in prep

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  - 5 Feb 1992 (ROSAT)
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M31N 2008-12a: 2015 eruption r’-band – Darnley+ in prep
M31N 2008-12a: Always the same? – Darnley+ in prep
M31N 2008-12a: 2015 eruption optical spectra – Darnley+ in prep

![Graphs showing velocity vs flux with data from 2014 and 2015 compared.](image-url)

\[ H_\alpha \text{ FWHM [km s}^{-1}] \]

\[ \Delta t [\text{days}] \]

\[ \log (H_\alpha \text{ FWHM}) [\text{km s}^{-1}] \]

\[ \log (\Delta t) [\text{days}] \]
M31N 2008-12a: Supersoft X-ray source light curve – Darnley+ in prep

- No detection of SSS following 2012 eruption
- First X-ray detection followed 2013 eruption
- “Turn-on” detected by Swift 5.9 ± 0.5 days post eruption
- BB fit to X-ray spectra gives $kT = 120 ± 5$ eV (~1.4 million K)
- Count rate declined at day 16: turn-off 18.4 ± 0.5 days
M31N 2008-12a: Hubble Space Telescope Campaign
M31N 2008-12a: Hubble Space Telescope Campaign – Darnley+ in prep

- **Cycle 23 Proposal – Successful (yay)**
  - Rapid STIS NUV and FUV (low res spectroscopy; 1100-3200 Angstroms)
    - DToO – STIS FUV-MAMA – 4 orbits, 1 visit
    - DToO – STIS NUV-MAMA – 4 orbits, split over 2 visits
    - Visit 1 – 3 orbits - ~day 14
    - Visit 2 – 3 orbits - ~day 21
    - Visit 3 – 3 orbits - ~day 28
    - Visit 4 – 3 orbits - ~day 35 (~quiescence)
M31N 2008-12a: HST photometry (F336W – U-band) – Darnley+ in prep
M31N 2008-12a: HST photometry – Darnley+ in prep
Quiescent photometry – Darnley+ 2014
M31N 2008-12a: HST PHAT photometry – Darnley+ in prep
M31N 2008-12a: The remnant?!?!(?!?) – Darnley+ 2015
M31N 2008-12a: The remnant’s spectrum! – Darnley+ 2015

![Graph showing spectral lines with wavelengths and fluxes.]

![Image of a remnant's field with an ellipse and markers.]

0.5 arcmin
Models of M31N 2008-12a

- WD mass ≥ 1.35M☉, dM/dt > 1.5×10⁻⁷ M☉/yr (Kato+ 2014; based on 2013 data)

- Eruptions consistent with models of systems with >1.377M☉ & 1.358M☉ WDs (Henze+/Kato+ 2015; 2013/14 data)

- Accretion rate > 10⁻⁷ M☉/year
- Mass accumulation efficiency 0.64 (Kato+ 2015)

- Timescale to reach Chandrasekhar mass < 0.6 Myr (Tang+ 2014)
Conclusions / Implications / Questions

• A recurrent nova with an unprecedented 1 year (six months?) inter-eruption time

• M31N 2008-12a is the prime SN Ia SD-channel pre-explosion progenitor candidate

• Are such systems rare or common?

• Secondary type (RG vs. SG) still relatively uncertain – accretion mechanism?

• White dwarf composition (CO vs. ONe) unknown – can we ever know this?

• 1 sigma confidence periods for 2016 eruptions: 26th Feb – 19th Apr & 21st Aug – 13th Oct

• Detection and follow-up campaigns for the 2016 eruption(s) coming together – including LT, LCOGT, XMM (all confirmed), plus HST, Swift, GTC, Gemini, Keck, LBT + more ground-based