Front-Line Recurrent Nova Science Requires Century-Old Data
Bradley E. Schaefer (Louisiana State University)

Perennial problem: WHAT IS THE PROGENITOR SYSTEM FOR TYPE Ia SUPERNOVAE?

Suddenly a Vital Big-Money Problem:
• Must know progenitor to calculate change in SN Ia $M-\Delta t_{15}$ relation
• Evolution of metallicity in old Universe change Hubble Diagram shape
• SNAP cannot achieve goal without progenitor/evolution solution
PROPOSED PROGENITORS:

- Recurrent Novae
- Symbiotic stars
- Super-soft sources
- Double White Dwarf Binaries

RECURRENT NOVAE ARE LIKELY SOLUTION:

To recur with $\tau_{\text{rec}} < 100$ years, RNe must have:

- High WD mass ($1.2M_\odot < M_{\text{WD}} < M_{\text{Chandra}}$)
- High accretion rate ($M \sim 10^{-7} M_\odot/\text{yr}$)

$M_{\text{WD}}$ will exceed $M_{\text{Chandra}}$ any year now…

SN Ia

TWO PROBLEMS:

- Does the White Dwarf eject more mass each eruption than it gains between eruptions?
  \[ M_{\text{ejecta}} < \tau_{\text{rec}} \dot{M} \]

- Are there enough RNe to produce the observed Type Ia SN rate?
  \[ R_{\text{RNdeath}} = R_{\text{SNIa}} \]
  \[ R_{\text{RNdeath}} = N_{\text{RN}} / (0.2M_\odot) \]
RN DEMOGRAPHICS REQUIRED TO ANSWER THE FRONT-LINE QUESTIONS:

- $\tau_{rec}$: recurrence time scale
- $N_{RN}$: number of RNe in Milky Way
- $\dot{M}$: mass accretion rate onto white dwarf
- $M_{\text{ejecta}}$: mass ejected in eruption

CAN GET THESE ONLY FROM HISTORICAL/ARCHIVAL DATA:

- $\tau_{rec}$: can only look in archival plate collections
- $N_{RN}$: archival plates and AAVSO data only way to measure discovery efficiency
- $\dot{M}$: changes on all time scales, but we need average over the last century
- $M_{\text{ejecta}}$: must have pre-eruption eclipse timings
\( \tau_{\text{rec}} = \text{Average Recurrence Time Scale:} \)

Most RN eruptions are not discovered:

- Undirected searches:  \(<\text{efficiency}> = 4\% \ (0.6\%-19\% \text{ full range})\)
- Directed searches:  \(<\text{efficiency}> = 60\% \ (30\%-100\% \text{ full range})\)

Missed eruptions make for errors of \( \sim 3X \) in \( \tau_{\text{rec}} \):

- **CI Aql:** Old \( \tau_{\text{rec}} = 83 \text{ years \ [2000-1917]} \)
  - But I found 1941 eruption
  - Steady brightness 1941-2000 shows eruption \( \sim 1975 \) missed
    \[ \Rightarrow \tau_{\text{rec}} = 27 \text{ years} \ (3X \text{ error}) \]

- **U Sco:** Old \( \tau_{\text{rec}} = 24 \text{ years \ [6 eruptions since 1863]} \)
  - But I found 1917, 1945, & 1969 eruptions
  - Steady eruptions every 10\pm2 \text{ years (lost behind Sun in 1927 and 1957)}
    \[ \Rightarrow \tau_{\text{rec}} = 10\pm1 \text{ years} \ (2.4X \text{ error}) \]

- **V2487 Oph:** Naive \( \tau_{\text{rec}} = 98 \text{ years \ [1998-1900]} \)
  - But \(<\text{efficiency}> = 30\% \ 1890-2008 \) with two eruptions found
    \[ \Rightarrow \tau_{\text{rec}} = 18 \text{ years} \ (5.4X \text{ error}) \]

- **RS Oph:** Old \( \tau_{\text{rec}} = 23 \text{ years \ [5 eruptions since 1890]} \)
  - But new-found eruptions in 1907 & 1945 plus new eruption in 2006
    \[ \Rightarrow \tau_{\text{rec}} = 14 \text{ years} \ (1.6X \text{ error}) \]
\[ N_{RN} = \text{Number of RN in our Milky Way:} \]

(and in M31 and LMC)

\[ N_{RN} = \frac{N_{\text{known}}}{F_{\text{discoverable}} \cdot \varepsilon_{RN}} \]

- \( N_{\text{known}} = 10 \)
- \( F_{\text{discoverable}} \approx 0.2 \) (Shafter 2002)
- \( \varepsilon_{RN} = \text{Discovery efficiency for finding 2-or-more nova eruptions} \)

Most never seen at all

\(<\varepsilon_{\text{discovery}}>=4\% \)

\{ A few with 1 event (labeled ‘CN’) \}

- 3 eruptions
- 88.5%

- Rarely, 2 or more events seen
- 11%

For one event

\( \varepsilon_{RN} = 1/200 \)

\( \sim 10 \times N_{\text{known}} \) RNe are hiding as cataloged ‘Classical Novae’

\[ N_{RN} = 10 / (0.2/200) = 10,000 \] RNe in our galaxy!

• TEST: Seek old eruptions of ‘Classical Novae’: Success - Nova Oph 1998 erupted in 1900

(Pagnotta, Schaefer, & Xiao; 2008)
\( \dot{M} = \text{Average Mass Accretion Rate:} \quad \dot{M} \propto F_{\text{blue}}^{1.5} \)

- \( \dot{M} \) varies by 10X on all timescales
- Archival data (from Harvard & AAVSO) allow for correct measures
$M_{\text{ejecta}} = \text{Mass ejected by nova eruption}$:

Orbital period change across an eruption ($\Delta P$) will give the ejected mass:  
$$M_{\text{ejecta}} = 0.91 \, M_{\text{WD}} (\Delta P / P)$$

Need $pre$-eruption eclipse times:
- Harvard plates
- AAVSO archives
- Archival light curves (mine and Roboscope)

Results for CI Aql:
$$\Delta P = (8 \pm 4) \times 10^{-7} \text{ days}$$
$$M_{\text{ejecta}} = (1.5 \pm 0.7) \times 10^{-6} \, M_\odot$$
RESULTS: [see also my Poster 491.04 on Wednesday]

- \( R_{\text{RNdeath}} \sim R_{\text{SNIa}} \) for Milky Way, M31, & LMC

- \( M_{\text{ejecta}} \ll \tau_{\text{rec}} \dot{M} \) for CI Aql and U Sco

LESSONS:

- Most nova events are missed \( \Rightarrow \) Great opportunity for observers
  \( \Rightarrow \) \(~30\%\) of ‘Classical Novae’ are RNe with multiple eruptions in the last century

- Harvard plates should be digitized
  [see Poster 427.07 by Tang, Grindlay, Los, & Laycock]

- Front-line science is laying around in archival data
- Science unique and unobtainable with modern telescopes
  [cf. Special Session on Monday]