Extragalactic Novae

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Outline of Talk

I. Recent Results on Extragalactic Nova Rates
   - Dependence on Hubble Type
   - Virgin Cluster Elliptical Galaxy Nova Survey

II. Properties of Novae in Local Group Galaxies
   - Spectroscopic and Speed Classes in M31, M33, and the LMC

III. The Recurrent Nova Population in M31
I. Rates in Different Hubble Type Galaxies

- Nova rates have been measured in more than a dozen galaxies.

- The population synthesis models of Yungelson et al. (1997) predict that the luminosity-specific nova rate (LSNR) should be higher in galaxies with a recent history of active star formation (e.g. spirals and irregulars, particularly low mass systems).

- Nelson et al. (2004) suggest that the nova frequency should be lower in an older population containing CVs with cooler white dwarfs.

- Thus, the LSNR was predicted to vary with the Hubble type of the galaxy.
Nova Rates vs Galaxy K-band Luminosity

Log $R = a \log L_K + \log b$
Nova Rates vs Galaxy K-band Luminosity

\[ \log R = a \log L_K + \log b \]

or

\[ a \approx 1 \rightarrow R = b L_K \] with \[ b \approx 2.25 \]

\[ \langle v_K \rangle = 2.25 \text{ yr}^{-1} \left[ 10^{10} L_{\text{sun},K} \right]^{-1} \]
Nova Rates vs Galaxy K-band Luminosity

\[ \log R = a \log L_K + \log b \]

If \( a \ll 1 \) then \( R = b L_K \) with \( b \approx 2.25 \).
Luminosity-Specific Nova Rates Across Hubble Type

\[ \langle \nu_k \rangle = 2.25 \text{ yr}^{-1} [10^{10} L_{\odot, K}]^{-1} \]
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\[ \langle \nu_k \rangle = 2.25 \text{ yr}^{-1} \left(10^{10} L_{\odot,k}\right)^{-1} \]
The Nova Rate in M87

- GB: Shafter et al. (2000): 91+/- 34 yr\(^{-1}\)
- HST: Shara & Zurek (2002): >300? yr\(^{-1}\)
- HST: Madrid et al. (2007) >1100!? yr\(^{-1}\)
- HST: Mizusawa et al. (2013) >200 yr\(^{-1}\)
- M49: HST Rate of ~100 yr\(^{-1}\) Ferrarese et al. (2003)

Is rate in M87 >> M49?

Two ways to form novae:
- Common envelope evolution
- Captures in GC cores

What if a significant fraction of novae are formed in GCs?

Globular cluster specific frequencies
M87: \(S_n = 14\)
M49: \(S_n = 3.6\)

Is M87 rate enhanced relative to M49?
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CFHT Virgo Nova Survey: M87 & M49

M87: 36 nova candidates over 4 epochs.
Monte Carlo simulation nova rate: \( 109 \text{ yr}^{-1} \)
LSNR = 2.6
GCSF = 14

M49: 33 nova candidates over 4 epochs.
Monte Carlo simulation nova rate: \( 100 \text{ yr}^{-1} \)
LSNR = 1.9
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CFHT Virgo Nova Survey: M87 & M49

M87: 28 nova candidates over 4 epochs.
Monte Carlo simulation nova rate: $85 \text{ yr}^{-1}$

LSNR = 2.0
GCSF = 14

M49: 32 nova candidates over 4 epochs.
Monte Carlo simulation nova rate: $97 \text{ yr}^{-1}$

LSNR = 1.8
GCSF = 3.6
II. Nova Populations in the Local Group

- Photometric and Spectroscopic studies of novae in:
  - M31
  - M33
  - The LMC

- Dominant Speed Class (e.g., $t_2$ time)
- Mix of Spectroscopic Classes (e.g., Fe II vs He/N)
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Spectral Classification of Novae

- Williams (1992) proposed that novae can be divided into two principal classes: “Fe II” and “He/N”, based on the observed emission line properties.

- He/N novae have higher expansion velocities (line widths), and higher levels of ionization compared with the Fe II novae.

- A third class of “hybrid” or broad-lined Fe II novae (Fe IIb) exist, and usually evolve into He/N systems.

- He/N (and Fe IIb) novae represent only ~20% of the total in M31 and the Galaxy.

- He/N novae are generally “faster” and more luminous than Fe II novae, and likely arise in systems with more massive white dwarfs.
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M31: Principal Historical Target

Major Studies:  

- Hubble (1929) 85
- Arp (1956) 30
- Rosino (1964;1973) 142
- Ciardullo et al. (1987) 40
- Shafter & Irby (2001) 82
- Darnley et al. (2006) 20
- Others (e.g. amateurs) >400

Total: ~900
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**Total:** ~900

**Principal Conclusions:**

- Nova Rate ~ 50 +/- 15 yr\(^{-1}\)
- *Appear consistent with a mainly bulge population!*
Significant scatter in the MMRD relation, but a general trend persists.
M31 R-band MMRD

- Significant scatter in the MMRD relation, but a general trend persists.
- Note the three luminous Fe II novae.

Shafter et al. (2011)
Light curve data from the Shafter et al. (2011) nova sample reveals a weak dependence of speed class on spatial position in M31. Fast novae appear to be slightly more extended than their slower counterparts.
The data from Shafter et al. (2011) suggest that the distribution for the He/N novae are no more extended than that for the Fe II novae.

Spectroscopic classifications for additional novae in additional galaxies will be required before definitive conclusions can be reached.
Novae in M33

- 38 nova candidates in M33 1919 - present, with no Recurrent Nova Candidates…
- Only ~50% of the 10 novae are Fe II type (red circles), with He/N novae (blue squares) being more common than in M31 or the Galaxy (97% confidence).
- Cumulative distribution of novae consistent with background light.
Novae in the LMC

- 43 nova candidates (35 confirmed) in the LMC 1926 - 2012 with 3 RNe Candidates.
- Like M33, only ~50% of the 18 novae with known type are Fe II type (red circles), with He/N novae (blue squares) being more common than in M31 or the Galaxy (99% confidence).
- Cumulative nova distribution is consistent with background light.
Novae in the LMC

- MMRD: Estimates of maximum magnitude and fade rate available for 29 novae.
- Fe I novae (red circles); He/N + Fe IIb (blue squares); unknown spectroscopic type (+)
Novae in the LMC

- MMRD: Estimates of maximum magnitude and fade rate available for 29 novae.
- Fe I novae (red circles); He/N + Fe IIb (blue squares); unknown spectroscopic type (+)
- As first shown by Della Valle & Duerbeck (1993), the cumulative distribution of fade rates shows that LMC novae are “faster” than M31 (broken line) or the Galaxy (dotted line).
III. Estimating the RNe population in M31

- W. Pietsch et al. have compiled the positions of >900 M31 novae.
- From these there are a total of 28 pairs, 3 triples, and 2 quads with separations < 5''
- Of these 33 RNe candidates, many are likely chance positional coincidences.
- To estimate what fraction, we have conducted a Monte Carlo simulation.
Monte Carlo RNe Simulations

- We randomly distribute artificial novae with the same spatial distribution as the observed nova distribution and check for chance positional coincidences.
- The most likely number of chance coincidences is 25, suggesting that ~8 of the RNe candidates are likely real (~6% chance none are).
- Not surprisingly, the chance coincidences are concentrated near the nucleus where the nova density is highest.
# M31 Recurrent Nova candidates

Table 1. **M31 RNe (+ strong candidates)**

<table>
<thead>
<tr>
<th>#</th>
<th>1st Eruption</th>
<th>2nd Eruption</th>
<th>Int (yr)</th>
<th>Sep (&quot;)</th>
<th>Prob</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M31N1919-09a</td>
<td>M31N1998-06a</td>
<td>79</td>
<td>1.80</td>
<td>0.027410</td>
<td>RN (Shafter)</td>
</tr>
<tr>
<td>2</td>
<td>M31N1923-12c</td>
<td>M31N2012-01b</td>
<td>89</td>
<td>5.55</td>
<td>0.378976</td>
<td>RN; He/N (Shafter)</td>
</tr>
<tr>
<td>3</td>
<td>M31N1926-06a</td>
<td>M31N1962-11a</td>
<td>26</td>
<td>5.73</td>
<td>0.171649</td>
<td>RN (Shafter)</td>
</tr>
<tr>
<td>4</td>
<td>M31N1945-09c</td>
<td>M31N1975-11a</td>
<td>30</td>
<td>0.87</td>
<td>0.000347</td>
<td>RN (Henze)</td>
</tr>
<tr>
<td>5</td>
<td>M31N1957-10b</td>
<td>M31N2010-12a</td>
<td>53</td>
<td>1.02</td>
<td>0.000028</td>
<td>PT AND (Galactic DN)</td>
</tr>
<tr>
<td>6</td>
<td>M31N1963-09c</td>
<td>M31N1968-09a</td>
<td>5</td>
<td>0.54</td>
<td>0.001535</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>M31N2001-07b</td>
<td>33</td>
<td>0.22</td>
<td>0.000262</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>M31N2010-10e</td>
<td>9</td>
<td>0.35</td>
<td>0.000643</td>
<td>RN; He/N (Shafter)</td>
</tr>
<tr>
<td>7</td>
<td>M31N1966-08a</td>
<td>M31N1968-10c</td>
<td>2</td>
<td>0.00</td>
<td>0.000000</td>
<td>RN?</td>
</tr>
<tr>
<td>8</td>
<td>M31N1966-09e</td>
<td>M31N2007-08d</td>
<td>41</td>
<td>0.36</td>
<td>0.000021</td>
<td>RN; slow FeII</td>
</tr>
<tr>
<td>9</td>
<td>M31N1969-08a</td>
<td>M31N2007-12b</td>
<td>38</td>
<td>2.13</td>
<td>0.005168</td>
<td>Not RN; He/N (Bode)</td>
</tr>
<tr>
<td>10</td>
<td>M31N1977-12a</td>
<td>M31N1998-08a</td>
<td>21</td>
<td>2.07</td>
<td>0.047042</td>
<td>RN?; no spectra</td>
</tr>
<tr>
<td>11</td>
<td>M31N1982-08b</td>
<td>M31N1996-08c</td>
<td>14</td>
<td>2.99</td>
<td>0.001433</td>
<td>RN?; no spectra</td>
</tr>
<tr>
<td>12</td>
<td>M31N1990-10a</td>
<td>M31N1997-10b</td>
<td>7</td>
<td>2.26</td>
<td>0.459049</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>M31N2007-07a</td>
<td>10</td>
<td>0.81</td>
<td>0.072981</td>
<td>RN?; no spectra</td>
</tr>
<tr>
<td>13</td>
<td>M31N1997-10f</td>
<td>M31N2008-08b</td>
<td>11</td>
<td>0.45</td>
<td>0.034867</td>
<td>RN?; He/N?</td>
</tr>
<tr>
<td>14</td>
<td>M31N1997-11k</td>
<td>M31N2001-12b</td>
<td>4</td>
<td>1.00</td>
<td>0.010679</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>M31N2009-11b</td>
<td>8</td>
<td>0.83</td>
<td>0.007290</td>
<td>RN?; FeII (Kasliwal)</td>
</tr>
<tr>
<td>15</td>
<td>M31N2008-12a</td>
<td>M31N2011-10e</td>
<td>3</td>
<td>0.29</td>
<td>0.000023</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>M31N2012-10a</td>
<td>1</td>
<td>0.29</td>
<td>0.000023</td>
<td>RN; He/N (Shafter)</td>
</tr>
</tbody>
</table>
M31N 1923-12c and M31N 2012-01b

- Positions agree to 1"
Three of the four RNe have He/N spectra. M31N 2010-10e most recent of 4 eruptions!
Conclusions & Future Work

• The LSNRs of galaxies with differing Hubble types appear roughly constant, but uncertainties for individual galaxies are still large.
• Are a significant fraction of novae spawned in globular clusters? **No.** Luminosity-specific nova rates in M87, M49 and M84 are comparable.
• M33 and the LMC have a higher fraction of He/N and Fe IIb novae than seen in M31 and the Galaxy.
• Novae in the LMC are generally “faster” than novae in M31 and the Galaxy.
• A total of 7 confirmed RNe are now known in M31 with another 8 strong, but yet unconfirmed, candidates.
• Recurrent nova fraction (uncorrected for discovery efficiencies) in M31 (~15/900, ~2%); LMC (3/38, ~8%); Galaxy (10/300, ~3%)
• The frequent and deep surveying of nearby galaxies made possible by *Pan-Starrs* and the *LSST* will be of great help in addressing the above!