Extragalactic Novae

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Chris Pritchet -- U Victoria
Kamil Hornoch -- Ondrejov Obs.
Chris Curtin -- SDSU

Outline of Talk

I. Recent Results on Extragalactic Nova Rates

- *Dependence on Hubble Type*
- *Virgo Cluster Elliptical Galaxy Nova Survey*

II. Properties of Novae in Local Group Galaxies

- *Spectroscopic and Speed Classes in M31, M33, and the LMC*

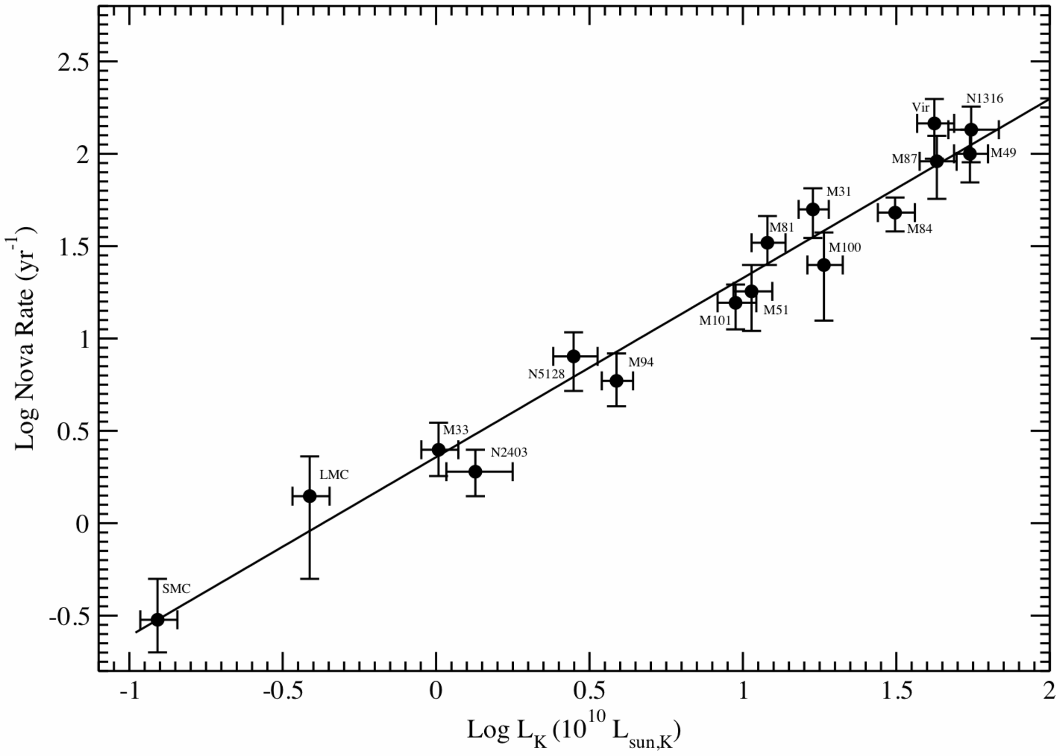
III. The Recurrent Nova Population in M31

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

$$\text{Log } R = a \log L_K + \log b$$



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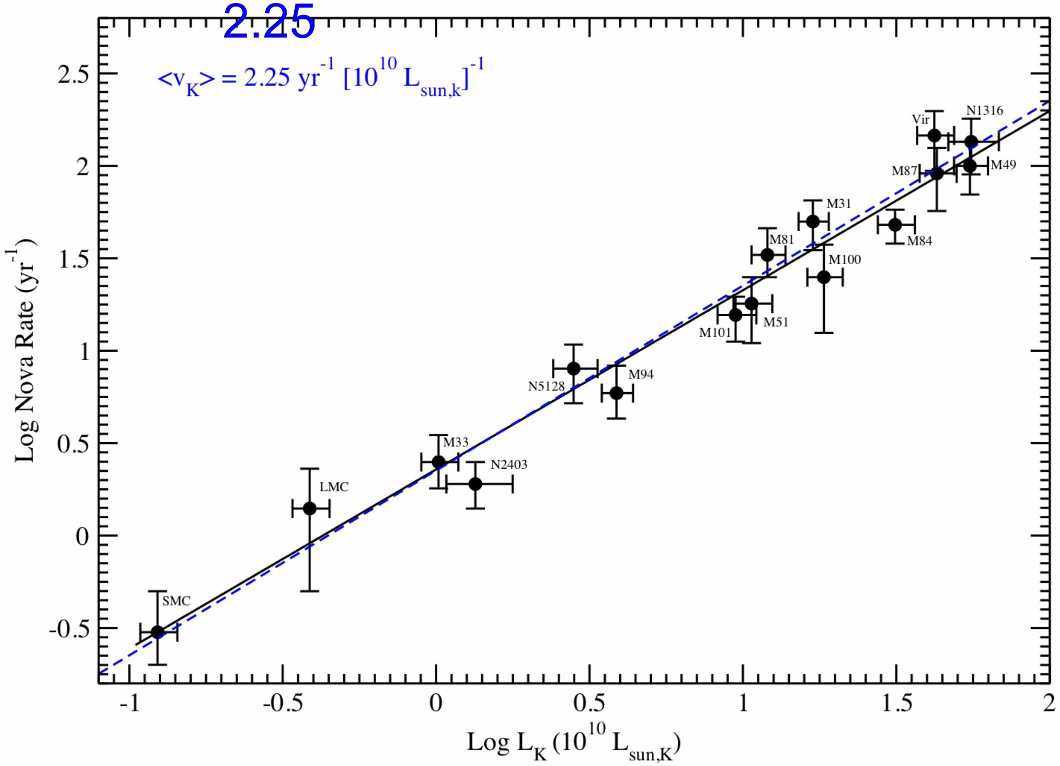
$\text{Log } R = a \log L_K + \log b$

$a \approx 1 \text{ --> } R = b\, L_K$ with $b \approx 2.25$



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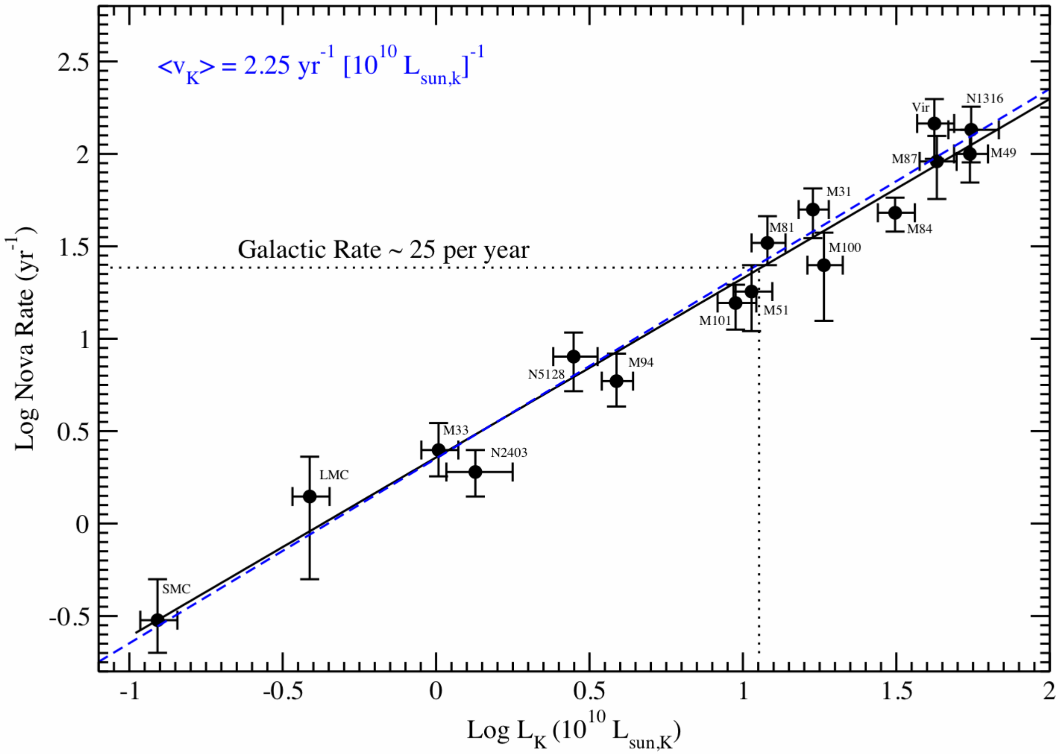
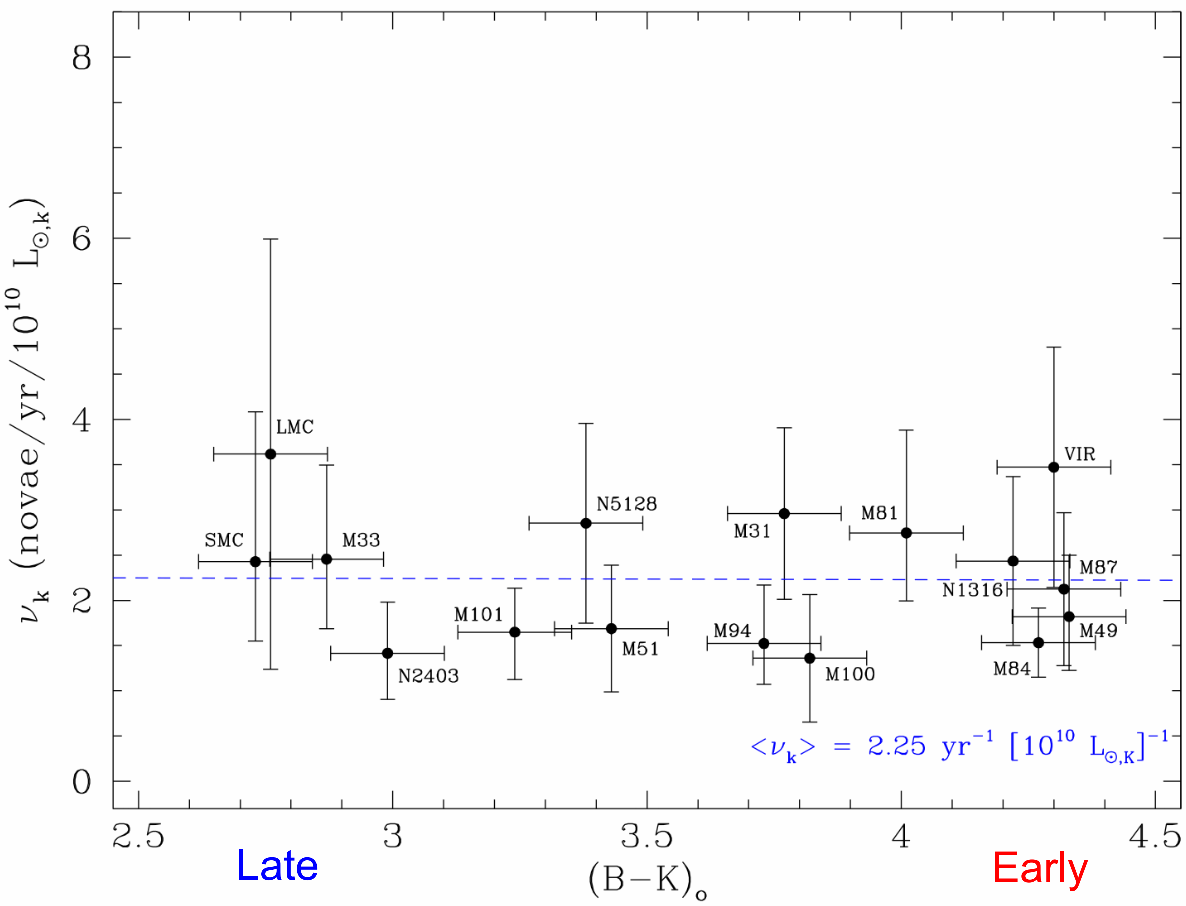


Luminosity-Specific Nova Rates Across Hubble Type



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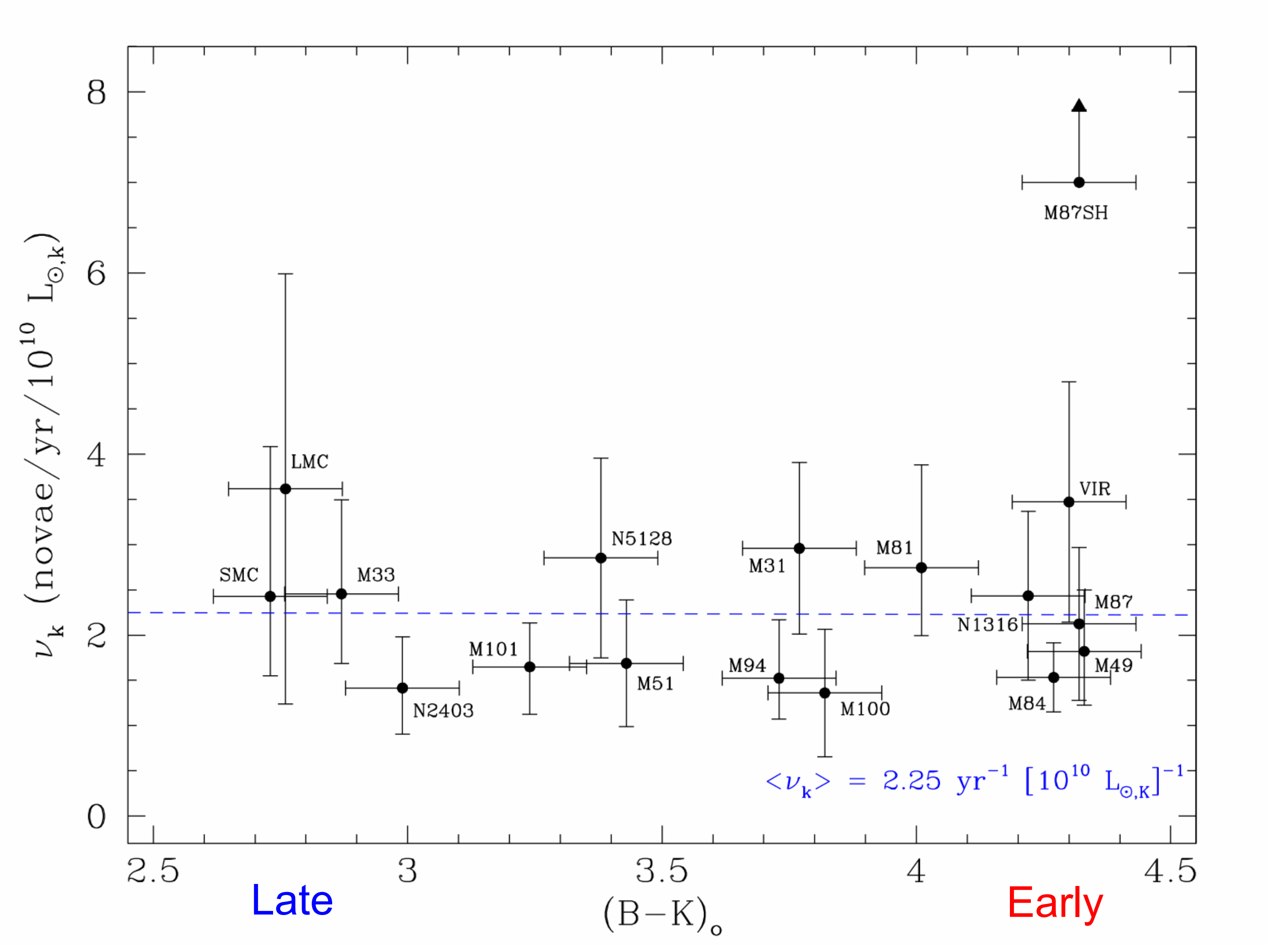


The Nova Rate in M87

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?

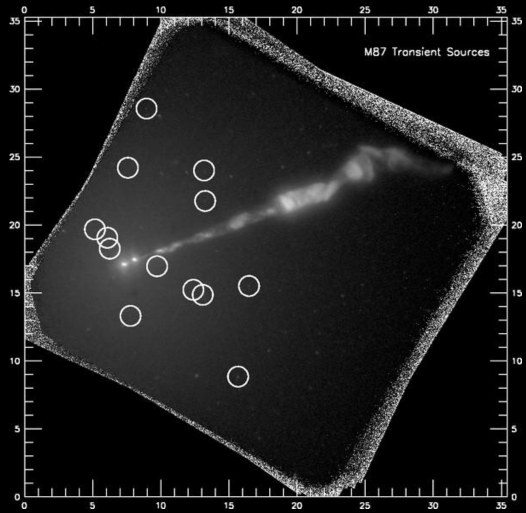
Two ways to form novae:
-- Common envelope evolution
-- Captures in GC cores

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?

The Nova Rate in M87



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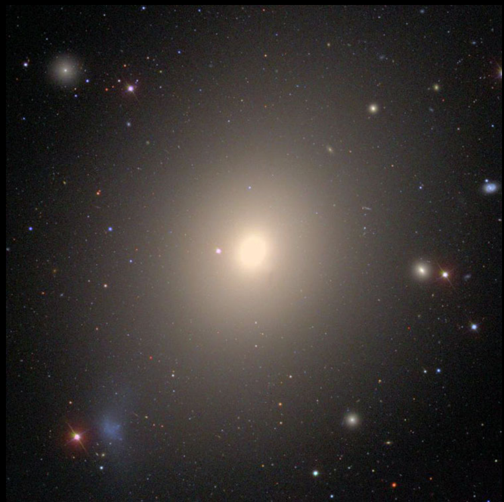

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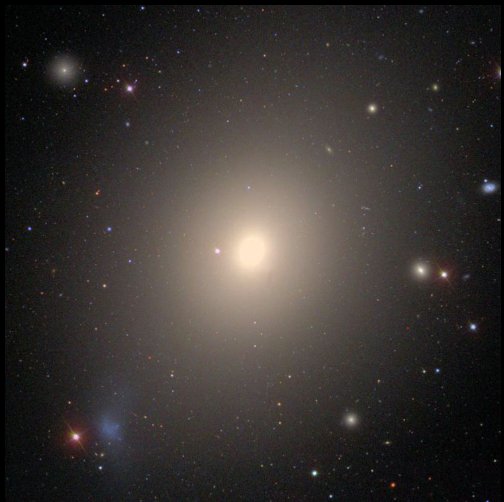

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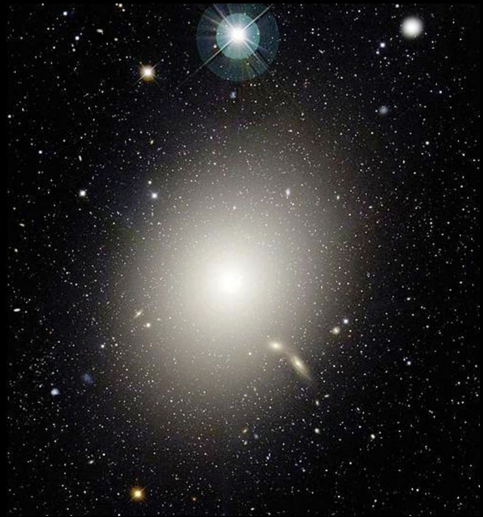

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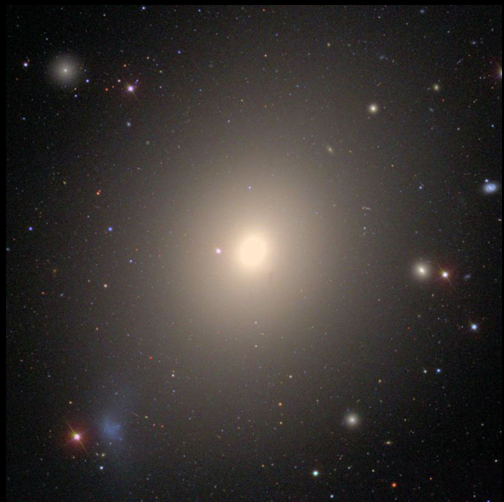

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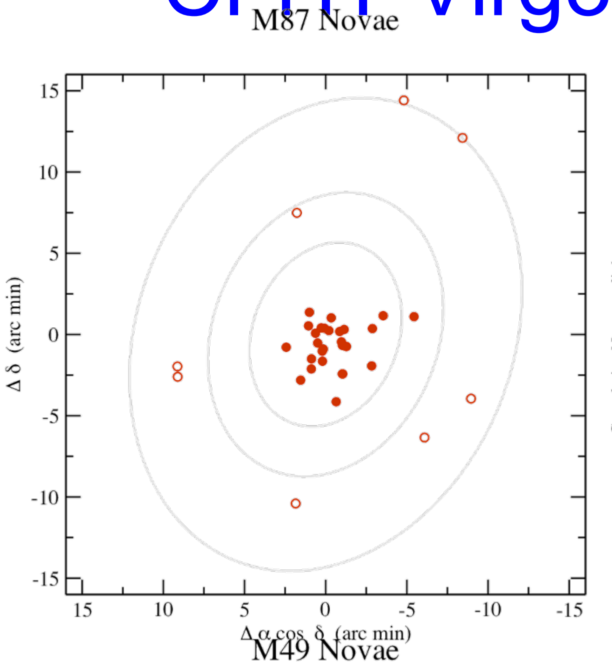
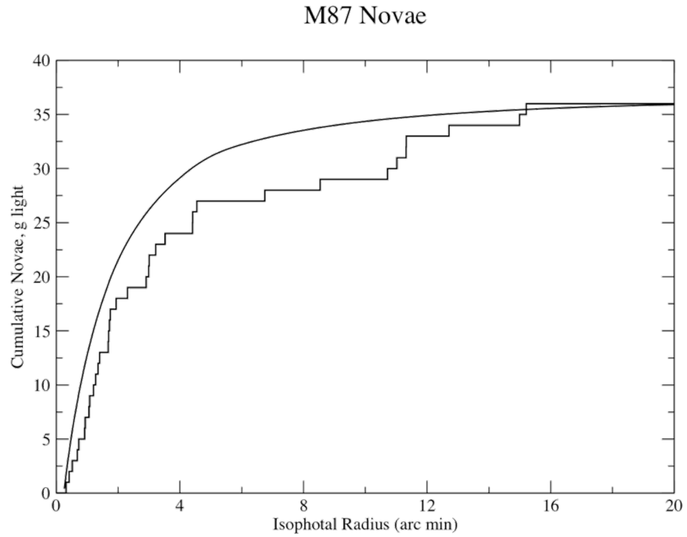
CFHT Virgo Nova Survey: M87 & M49

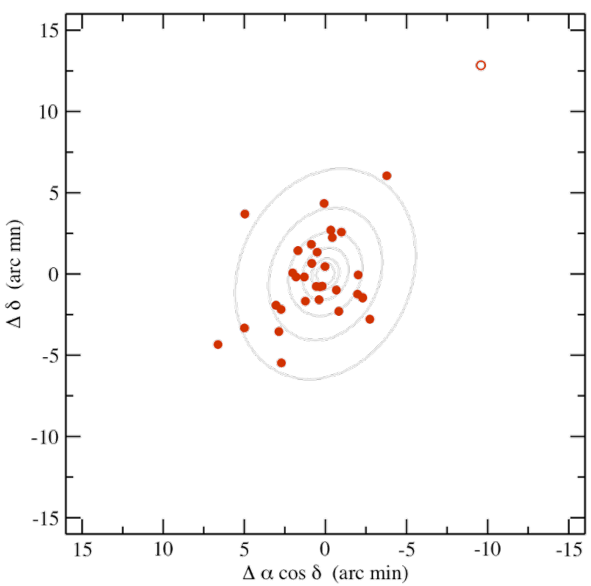


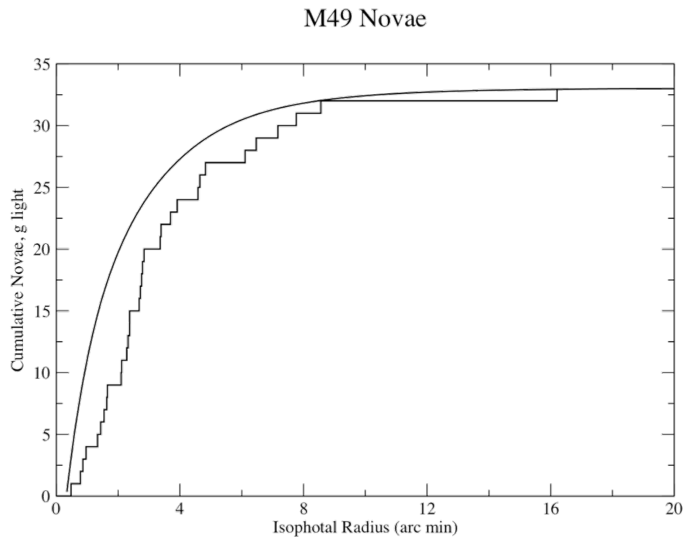


M87: 36 nova candidates over 4 epochs.
Monte Carlo simulation nova rate: 109 yr^{-1}

LSNR = 2.6

GCSF = 14



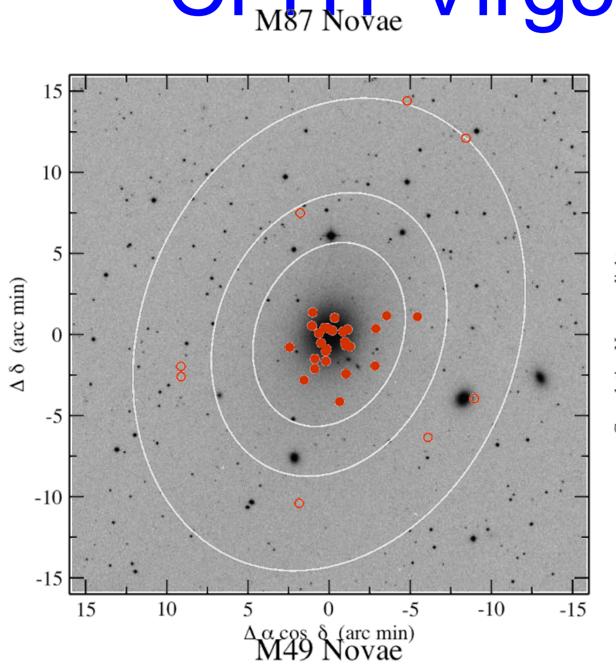


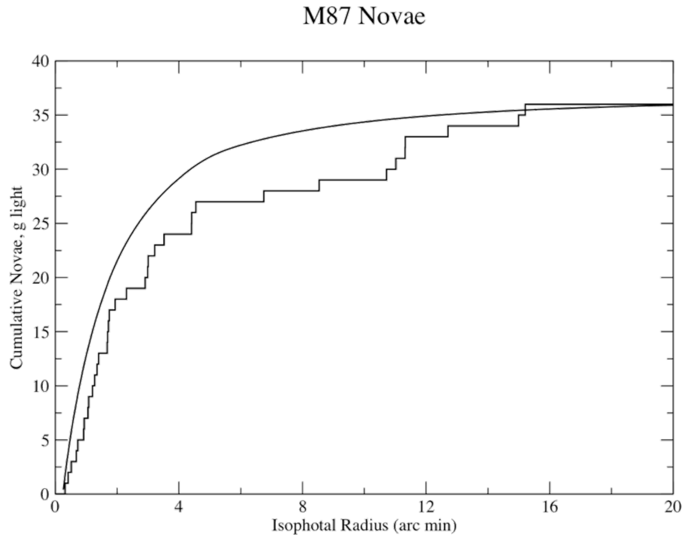
M49: 33 nova candidates over 4 epochs.
Monte Carlo simulation nova rate: 100 yr^{-1}

LSNR = 1.9

GCSF = 3.6

CFHT Virgo Nova Survey: M87 & M49





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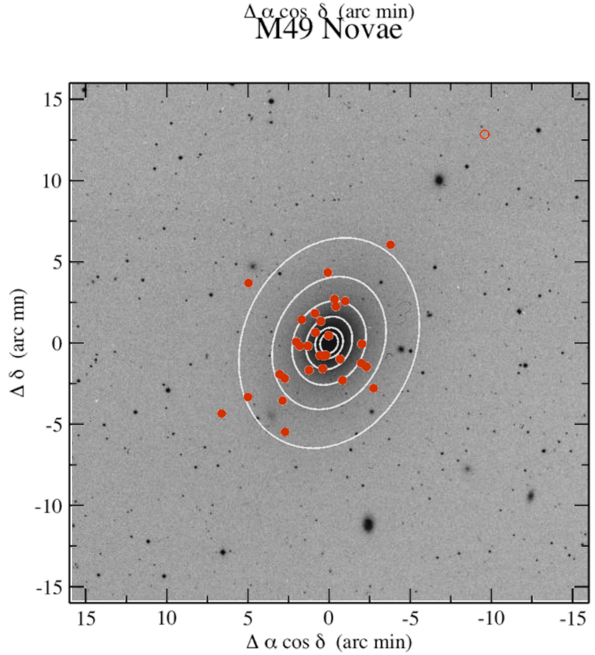

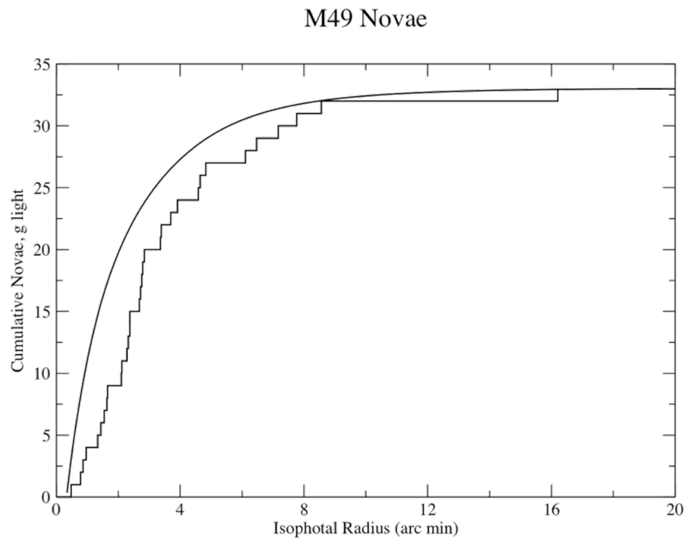

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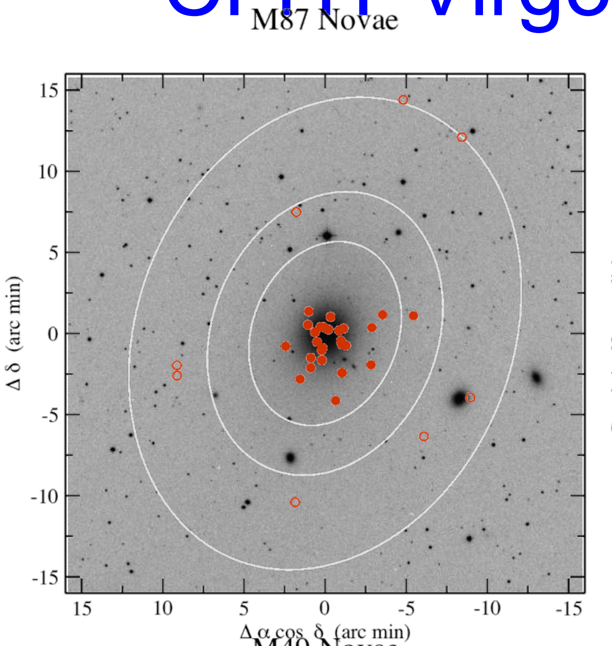
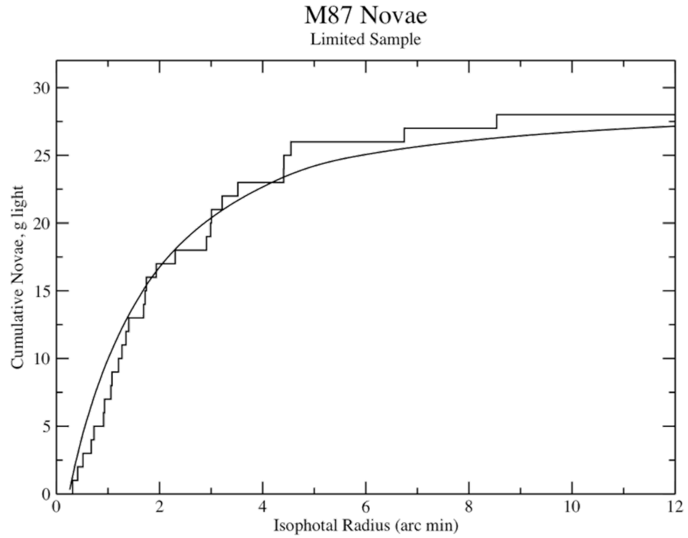
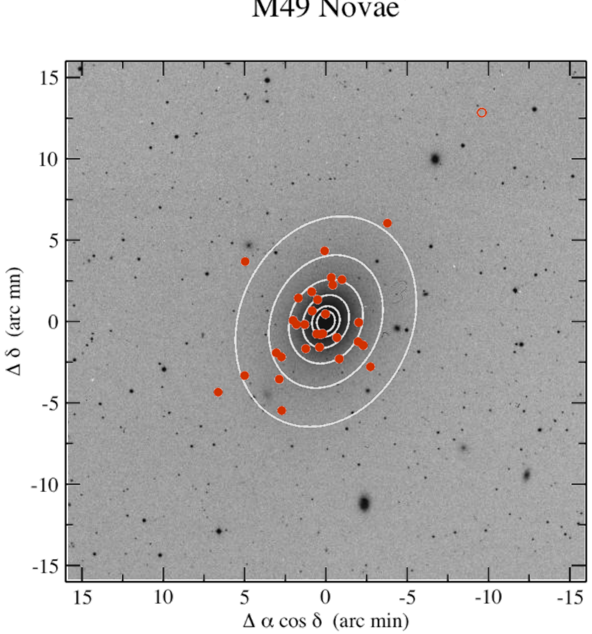


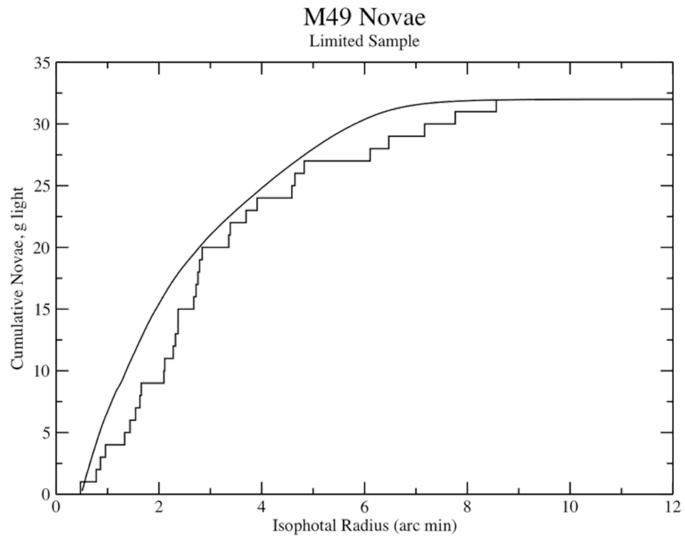


M87: 28 nova candidates over 4 epochs.
Monte Carlo simulation nova rate: 85 yr^{-1}

LSNR = 2.0

GCSF = 14





M49: 32 nova candidates over 4 epochs.
Monte Carlo simulation nova rate: 97 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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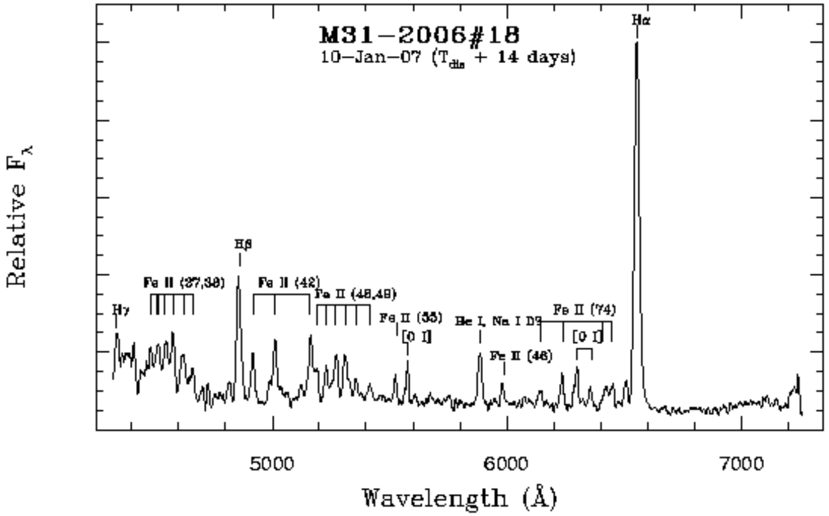
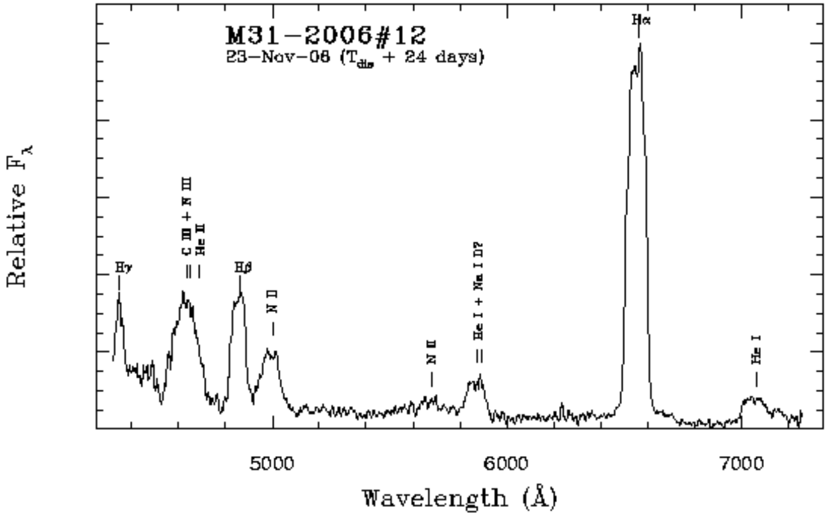
Spectral Classification of Novae





- 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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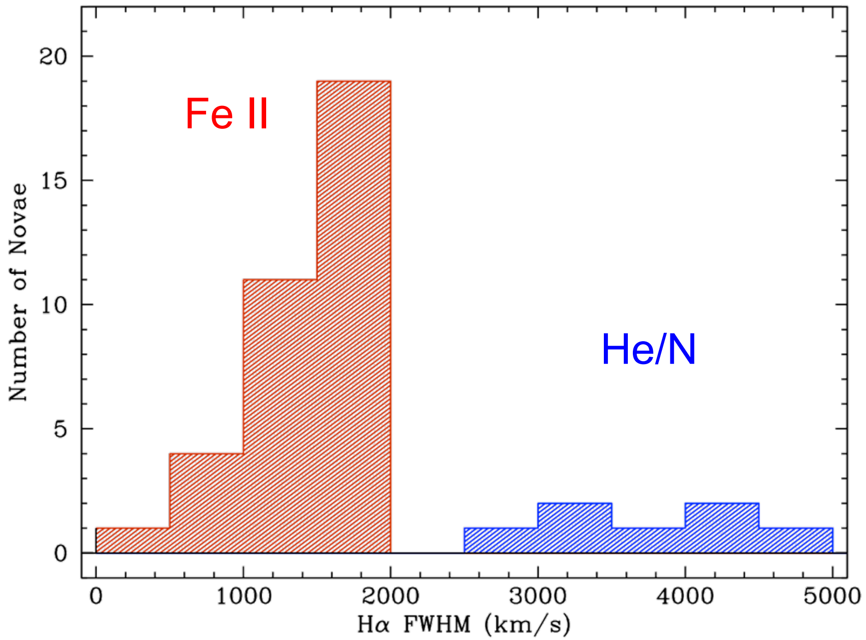
M31 Novae



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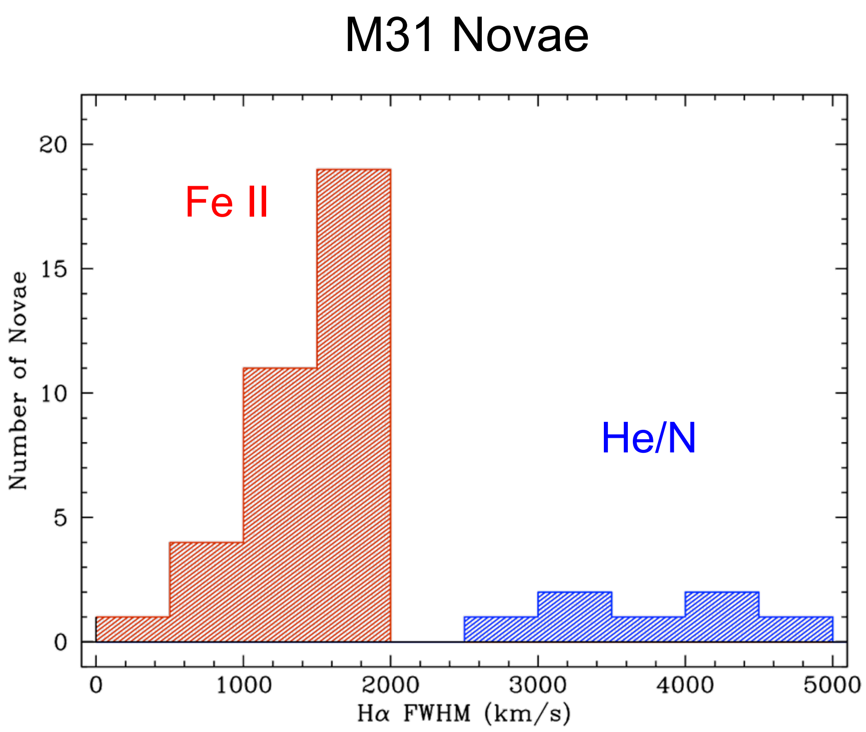

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M31: Principal Historical Target

Major Studies:	Novae
• 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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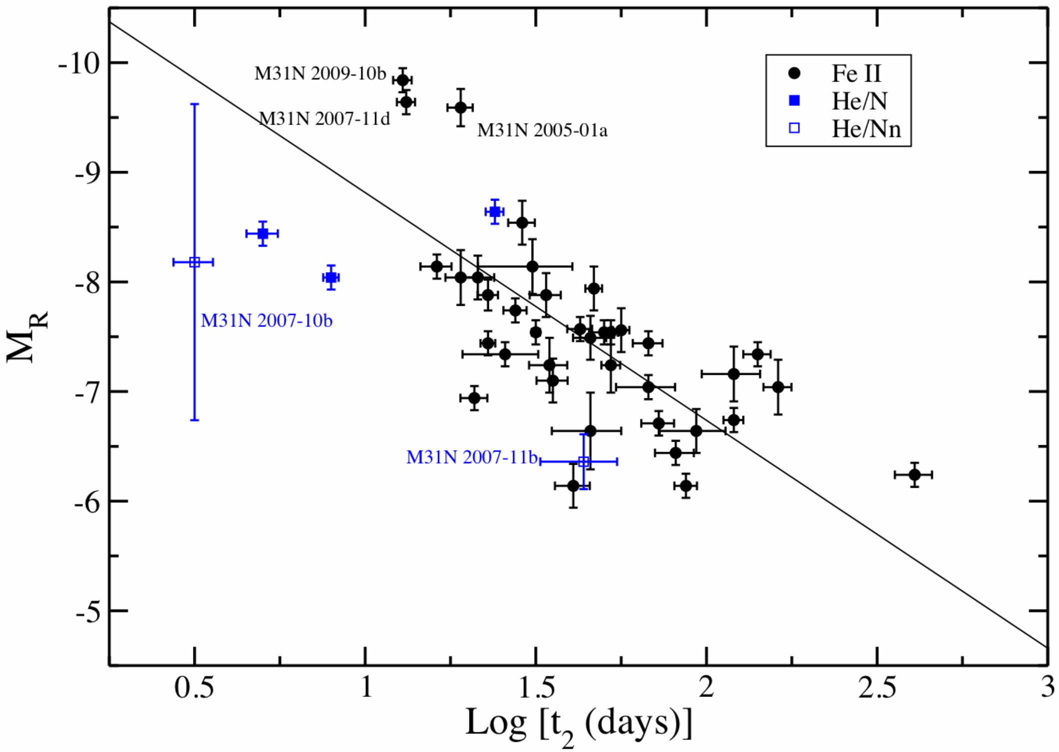
Principal Conclusions:

- Nova Rate ~ 50 +/- 15 yr^{-1}
- ***Appear consistent with a mainly bulge population!***

M31 R-band MMRD

Shafter et al. (2011)



- Significant scatter in the MMRD relation, but a general trend persists.

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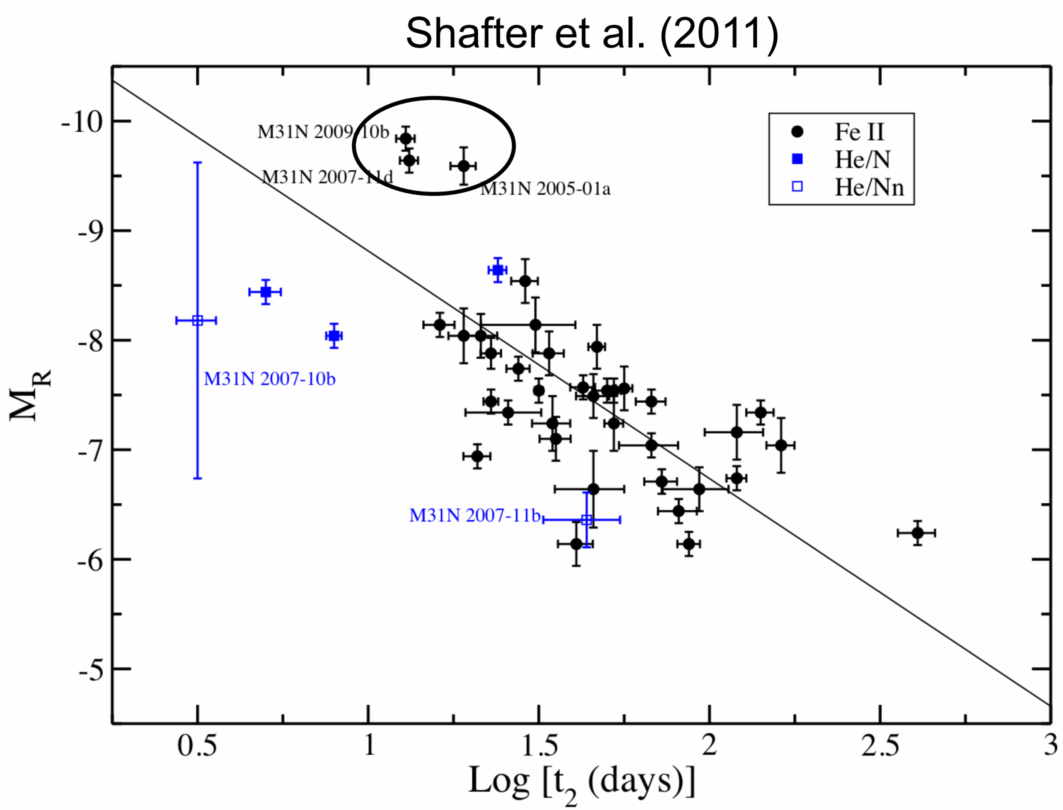
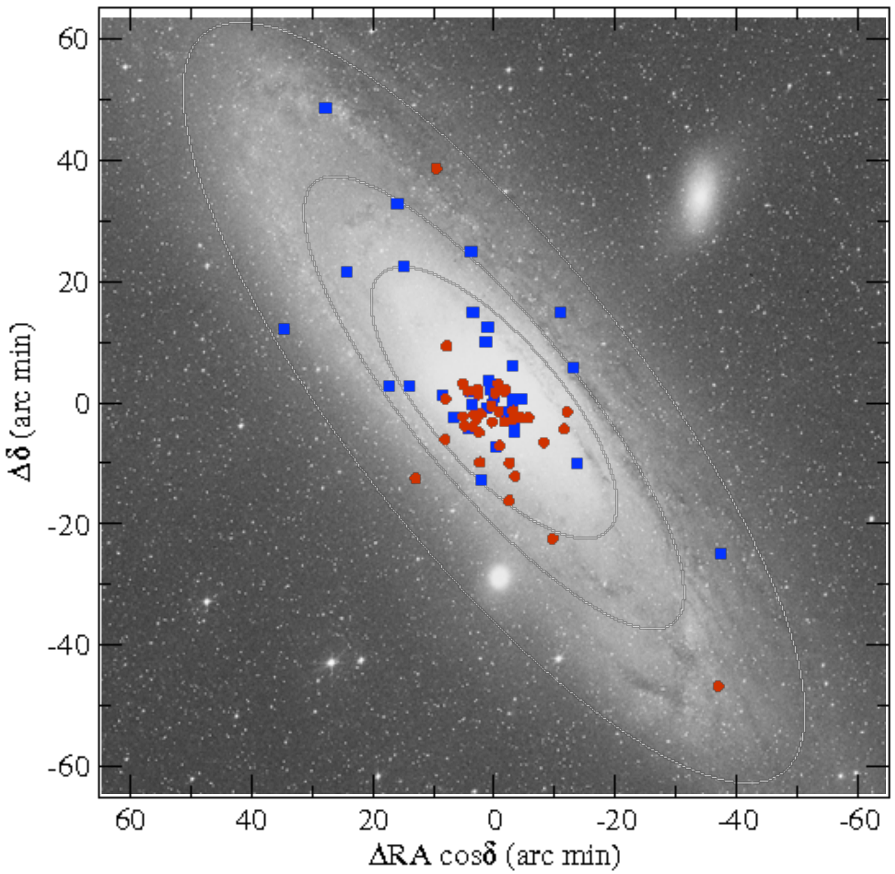
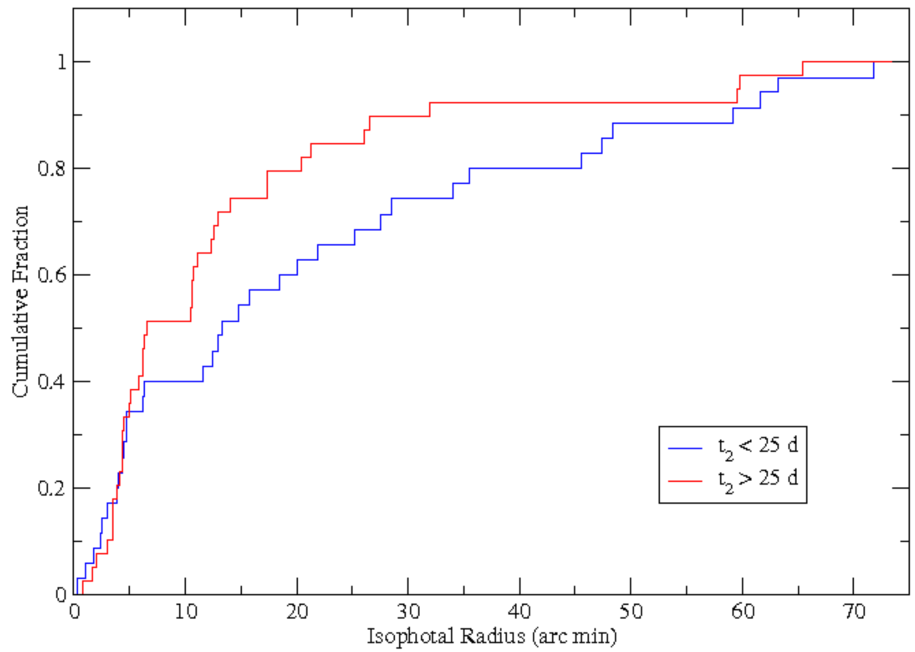


- Significant scatter in the MMRD relation, but a general trend persists.
- Note the three luminous Fe II novae.

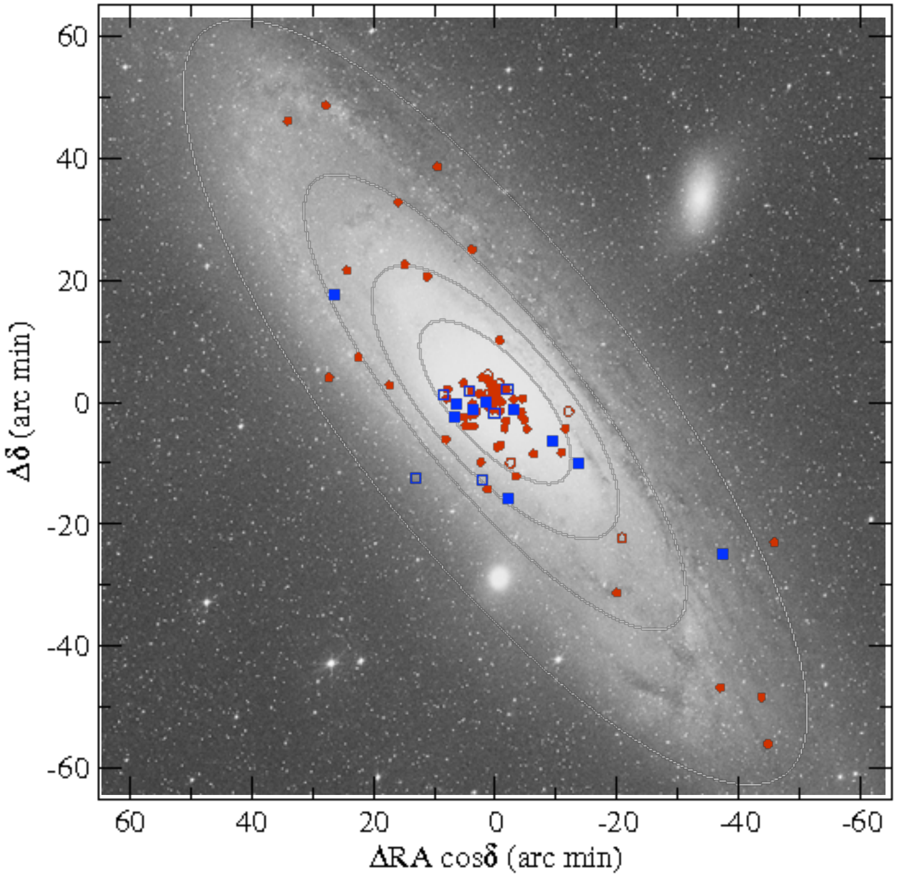
Variation of Speed Class with Spatial Position

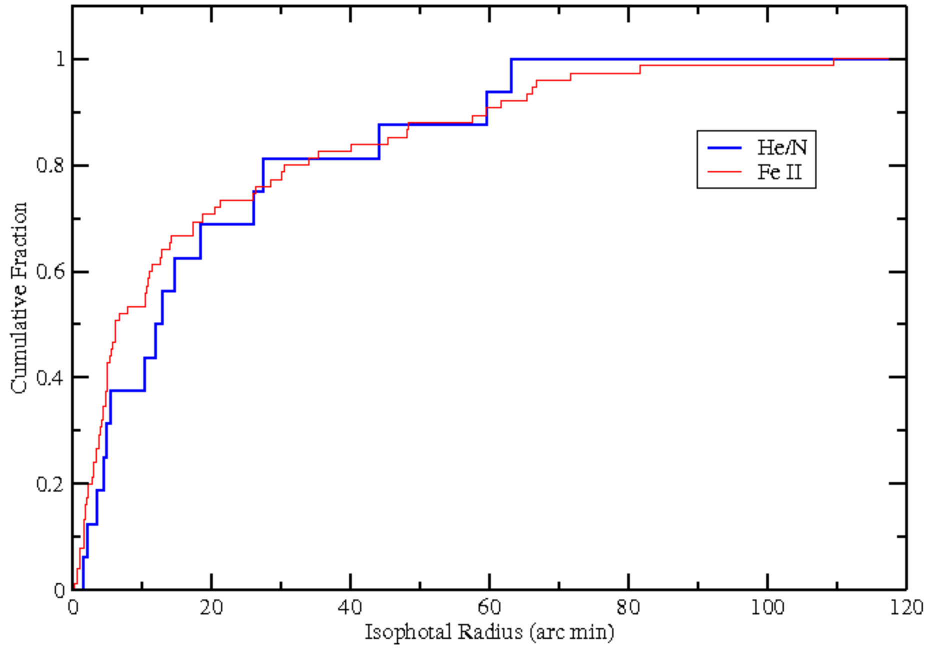




Light curve data from the Shafter et al. (2011) nova sample reveals a weak dependence of speed class on spatial position in M31. Fast novae appear to be slightly more extended than their slower counterparts.

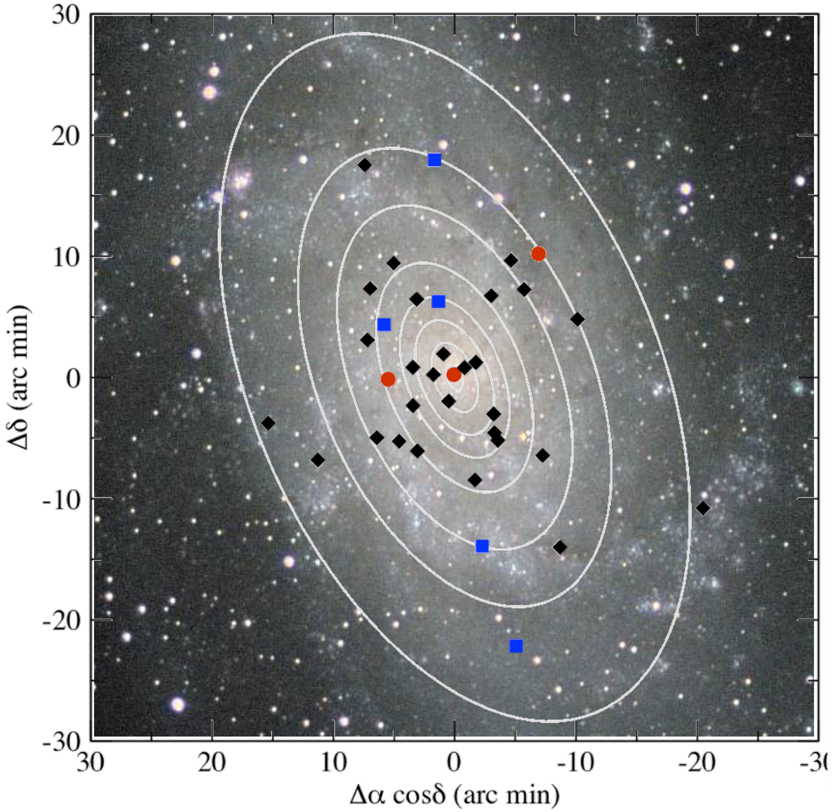
Radial Dependence of Nova Spectral Class in M31

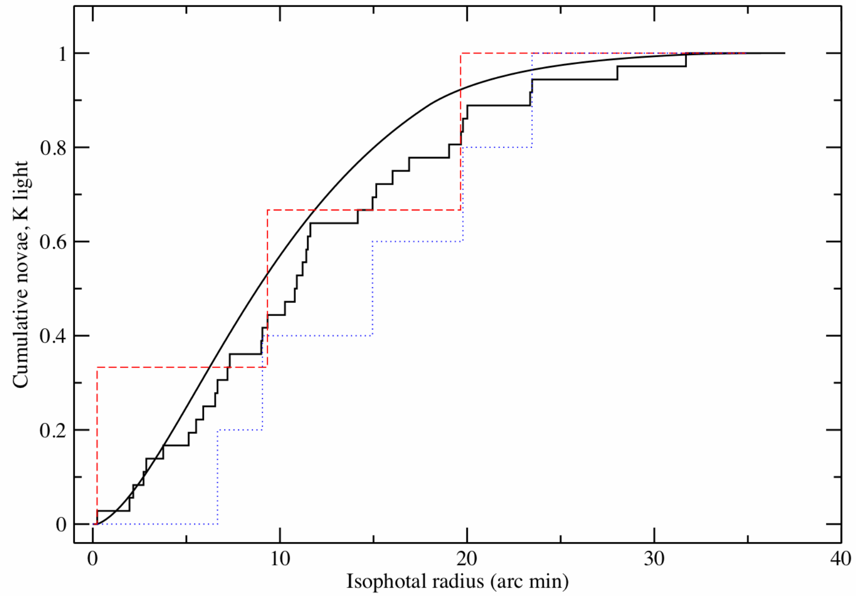




- The data from Shafter et al. (2011) suggest that the distribution for the He/N novae are **no** more extended than that for the Fe II novae.
- Spectroscopic classifications for additional novae in additional galaxies will be required before definitive conclusions can be reached.

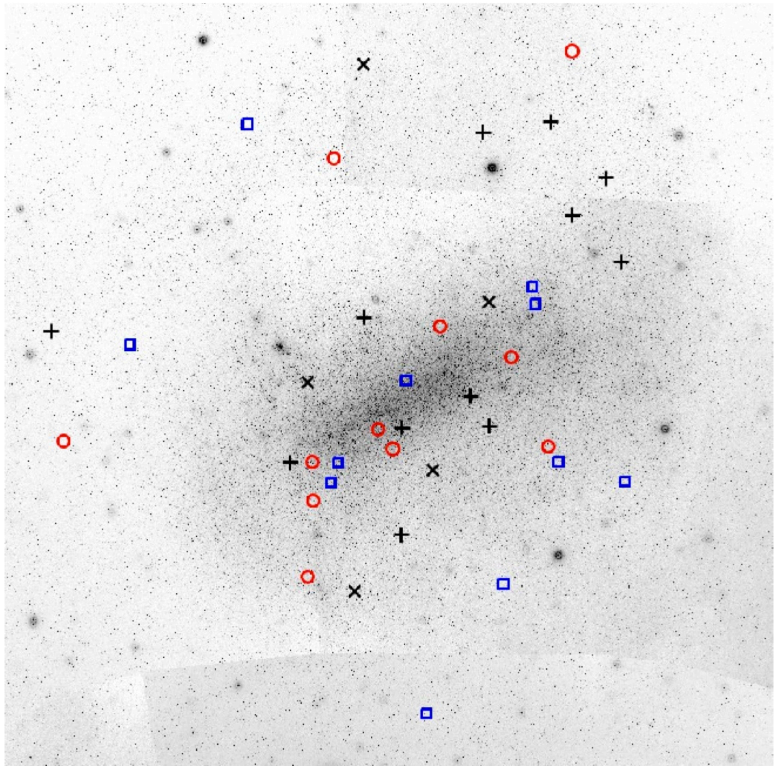
Novae in M33

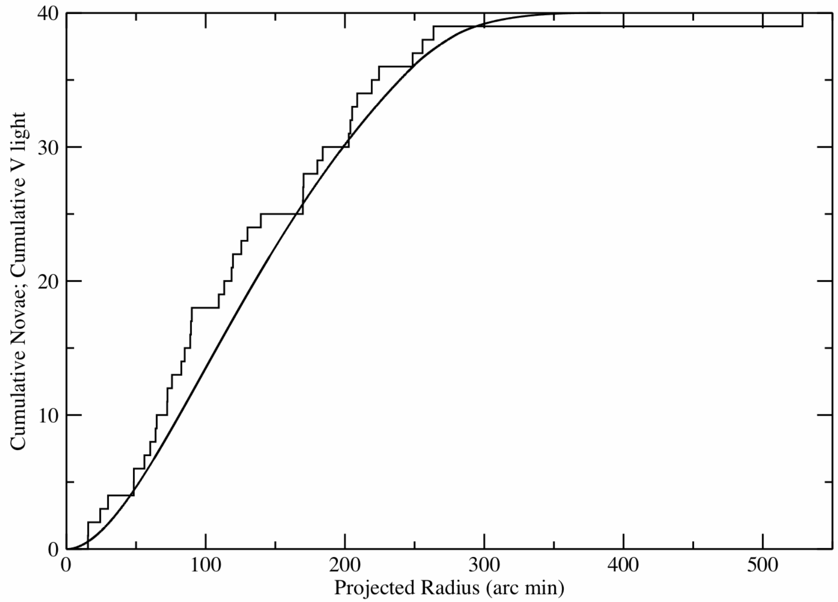




- 38 nova candidates in M33 1919 - present, with no Recurrent Nova Candidates…
- Only ~50% of the 10 novae are Fe II type (red circles), with He/N novae (blue squares) being more common than in M31 or the Galaxy (97% confidence).
- Cumulative distribution of novae consistent with background light.

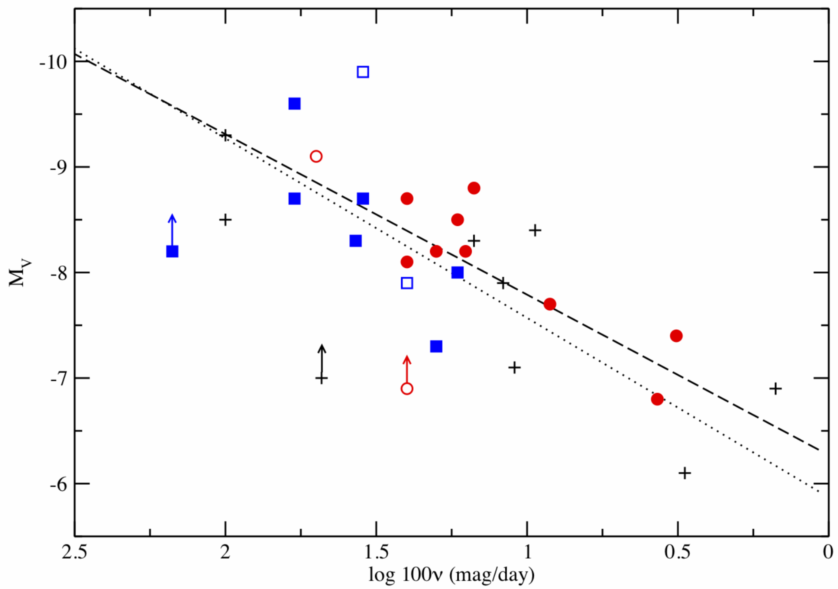
Novae in the LMC





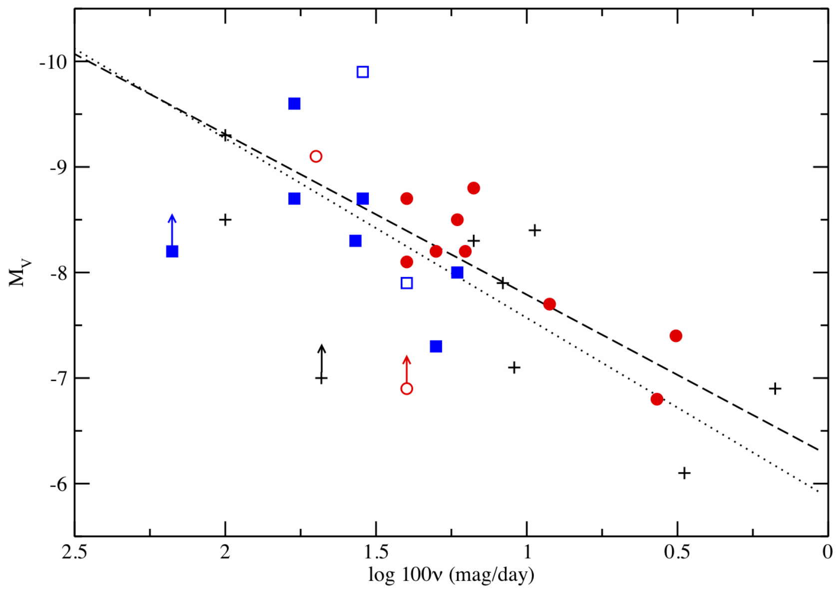
- 43 nova candidates (35 confirmed) in the LMC 1926 - 2012 with 3 RNe Candidates.
- Like M33, only ~50% of the 18 novae with known type are Fe II type (red circles), with He/N novae (blue squares) being more common than in M31 or the Galaxy (99% confidence).
- Cumulative nova distribution is consistent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

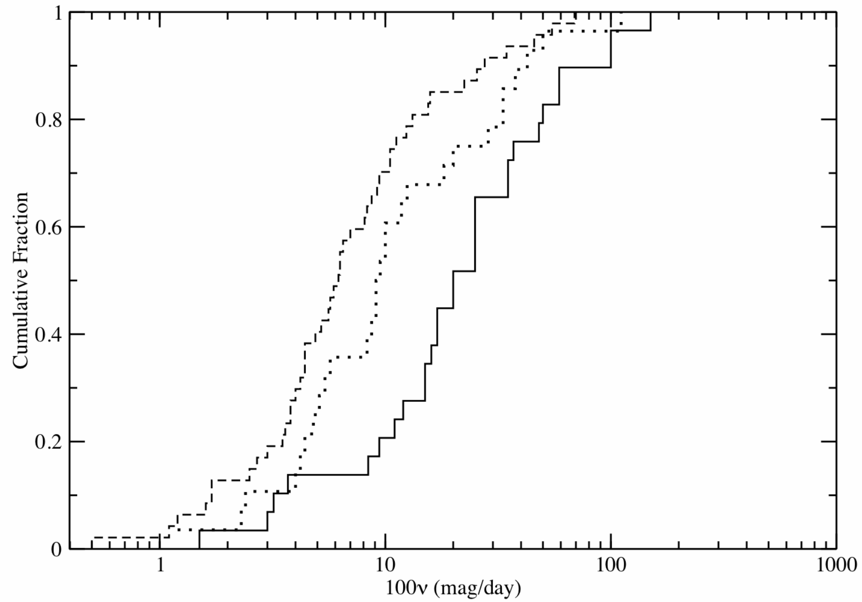
Novae in the LMC



- 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 (+)

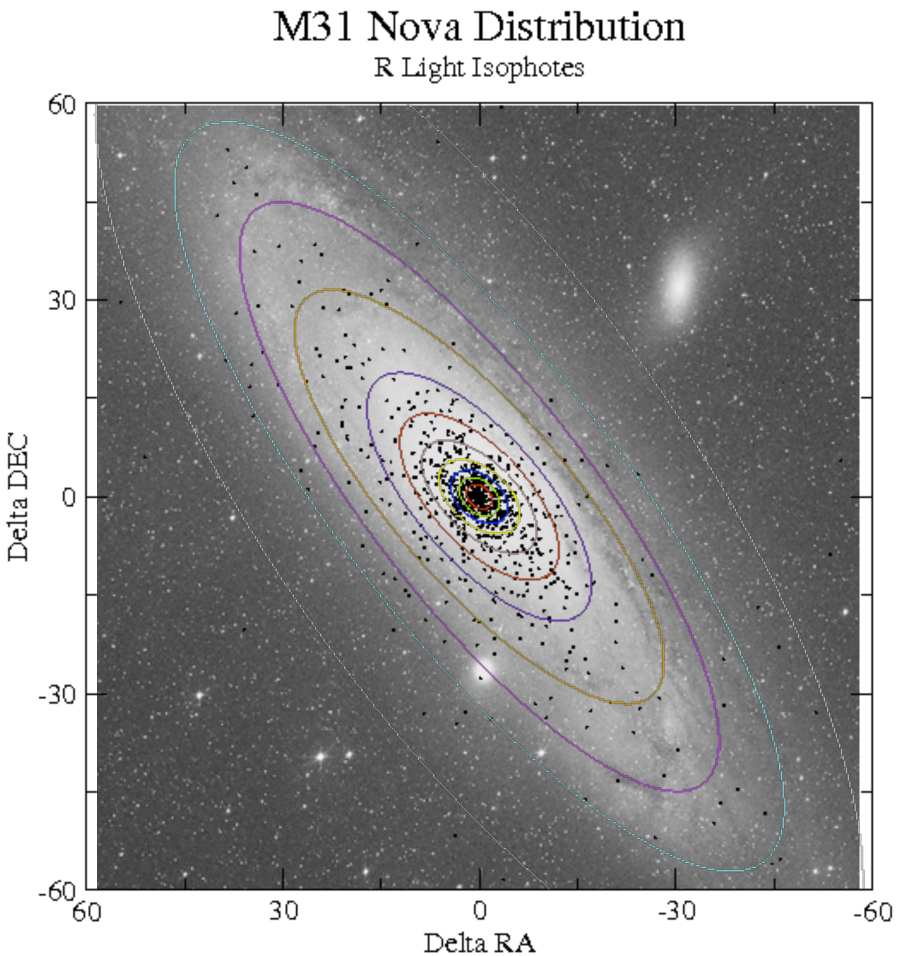
Novae in the LMC





- 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).

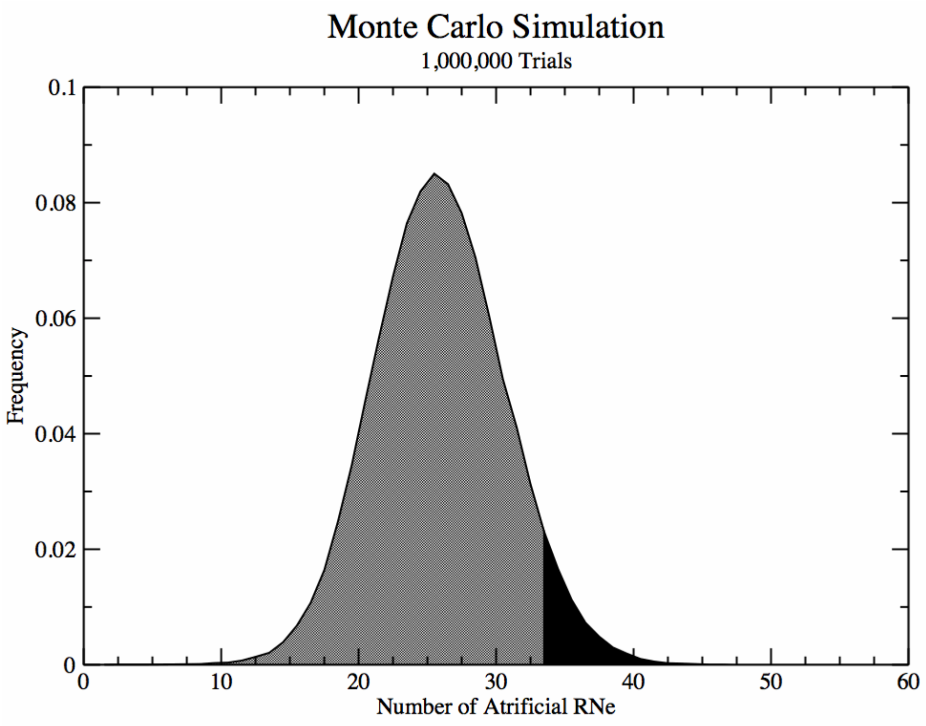
III. Estimating the RNe population in M31

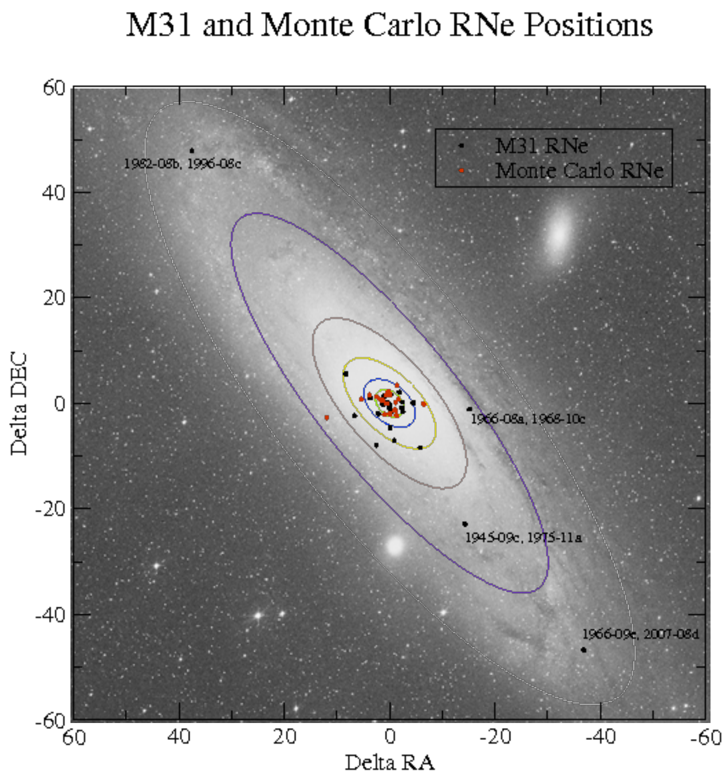


- W. Pietsch et al. have compiled the positions of >900 M31 novae.
- From these there are a total of 28 pairs, 3 triples, and 2 quads with separations < 5’’.
- Of these 33 RNe candidates, many are likely chance positional coincidences.
- To estimate what fraction, we have conducted a Monte Carlo simulation.

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.



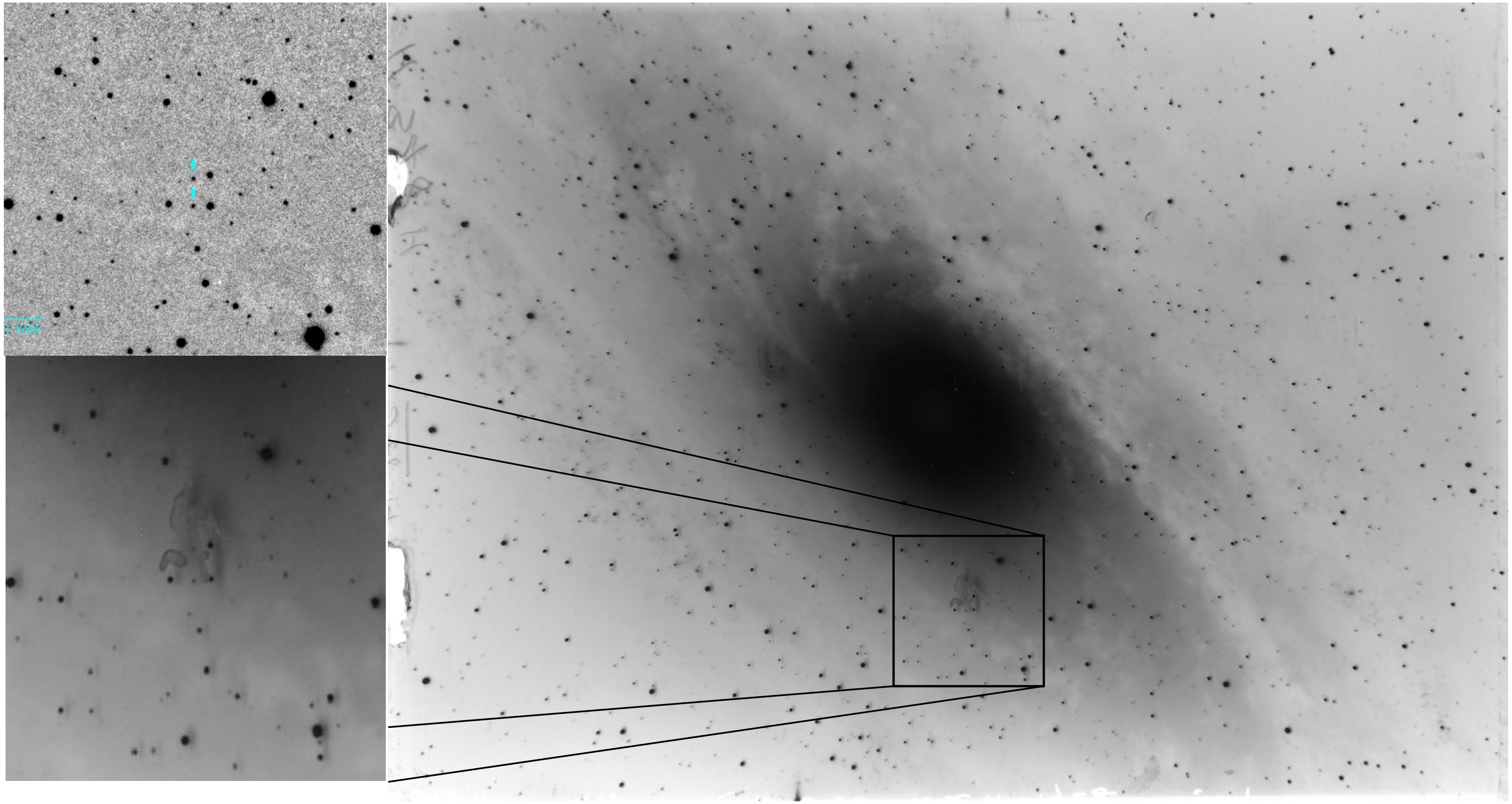


M31 Recurrent Nova candidates

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

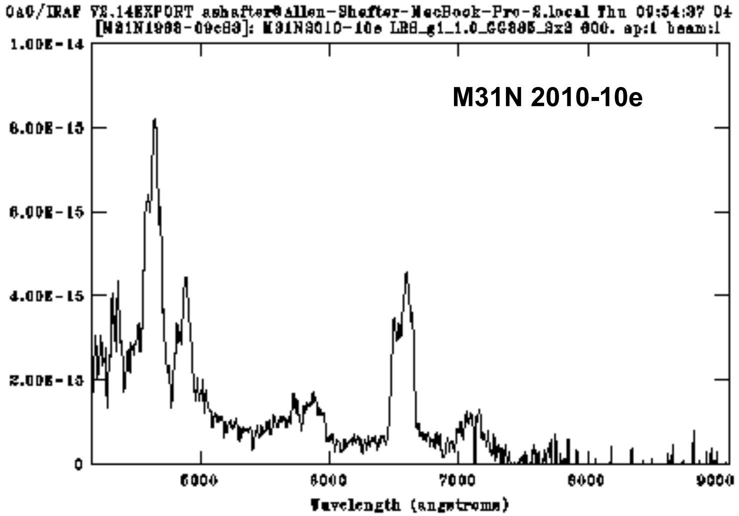
#	1st Eruption	2nd Eruption	Int (yr)	Sep (″)	Prob	Comments
1	**M31N1919-09a**	**M31N1998-06a**	**79**	**1.80**	**0.027410**	**RN (Shafter)**
2	**M31N1923-12c**	**M31N2012-01b**	**89**	**5.55**	**0.378976**	**RN; He/N (Shafter)**
3	**M31N1926-06a**	**M31N1962-11a**	**26**	**5.73**	**0.171649**	**RN (Shafter)**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

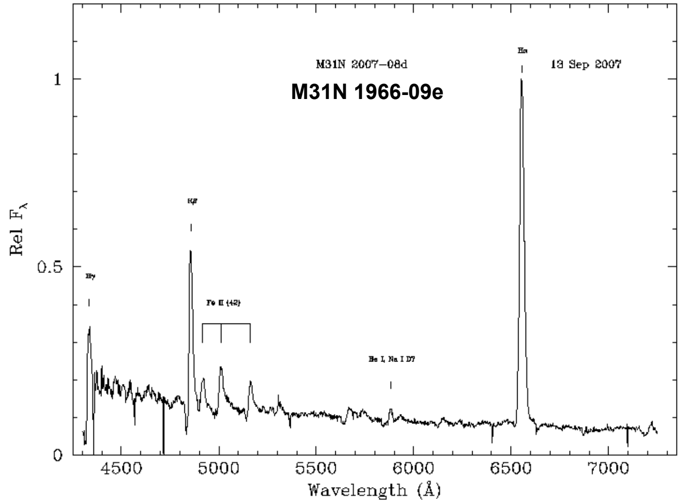
M31N 1923-12c and M31N 2012-01b

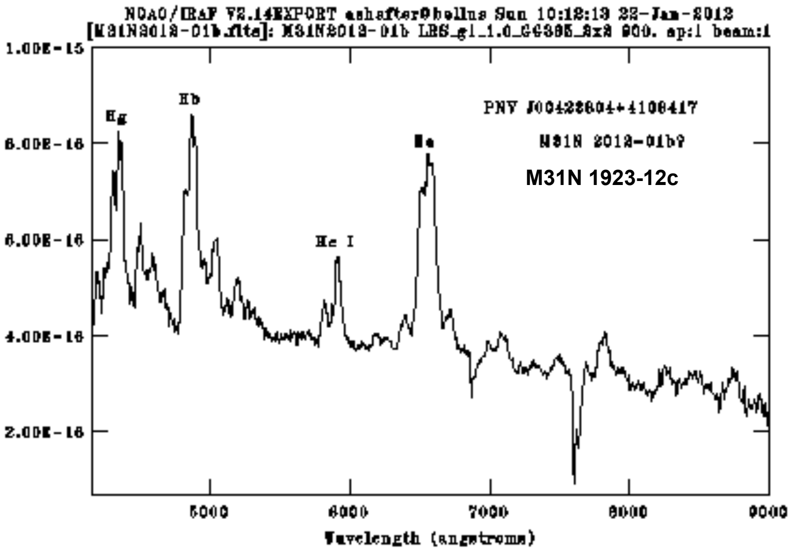


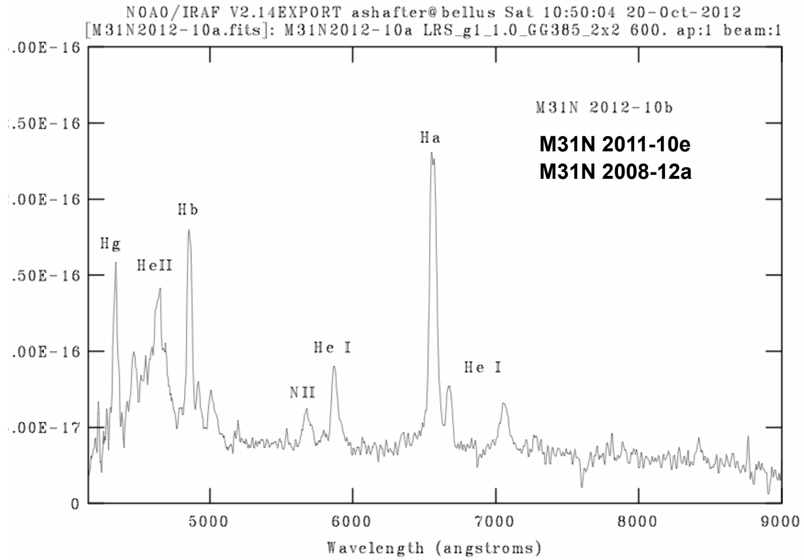
- Positions agree to 1”

Spectra of M31 RNe Candidates









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!