Novae with Gaia

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Gaia Alerts, Liverpool 10-13 November
When pressure at bottom of accreted layer (mostly H) is $P > 10^{19}$ dyne cm$^{-2}$

- violent TNR
- accreted shell ejected ($v \sim 1000-5000$ km s$^{-1}$)

All novae are recurrent at intervals of $\sim 10^1 - \sim 10^6$ yr.

$$\Delta m_{\text{acc}} \sim R_{\text{WD}}^4/M_{\text{WD}}$$
<table>
<thead>
<tr>
<th>Why Novae?</th>
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<tbody>
<tr>
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<td><img src="#" alt="List" /></td>
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<tr>
<td>• White dwarf structure</td>
<td>• Dust Formation</td>
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<td>• Nuclear reactions</td>
<td>• Mass of the ejecta</td>
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<td>• Hydrodynamics of explosive mass loss</td>
<td>• Abundances</td>
</tr>
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<td>• Common envelope structures</td>
<td>• Distance Indicators</td>
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</tbody>
</table>
Summary

Novae as Distance Indicators

Novae and the MW nucleosynthesis

1993

1994

0.32 arcsec
Nova as distance indicators

The usage of novae as distance indicators is based on the pioneering studies of McLaughlin (1945) in the MW and Arp (1956) and Rosino (1964, 1973) in M31. They found that the absolute magnitude of novae at maximum correlates with the rate of decline.
Nova Vel 1999

XX Tau 1927
Novae are observed in extragalactic systems (M31, MCs, M33, M81, M101, Virgo, Fornax), calibrated via Cepheids and then used as secondary distance indicators.
## The Galactic MMRD

**maximum magnitude vs. rate of decline relation**

<table>
<thead>
<tr>
<th>Equation</th>
<th>Authors and Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M = 2.2 \times \log t^3 - 10.5$</td>
<td>McLaughlin (1945)</td>
</tr>
<tr>
<td>$M = 2.0 \times \log t^3 - 10.1$</td>
<td>Vorontsov-Velyaminov (1947)</td>
</tr>
<tr>
<td>$M = 3.7 \times \log t^3 - 13.8$</td>
<td>Kopylov (1952)</td>
</tr>
<tr>
<td>$M = 2.3 \times \log t^3 - 10.9$</td>
<td>Buscombe &amp; de Vaucouleurs (1955)</td>
</tr>
<tr>
<td>$M = 2.5 \times \log t^3 - 11.8$</td>
<td>Schmidt 1957</td>
</tr>
<tr>
<td>$M = 1.8 \times \log t^2 - 11.5$</td>
<td>Pfau 1976</td>
</tr>
<tr>
<td>$M = 2.4 \times \log t^3 - 11.3$</td>
<td>de Vaucouleurs 1978</td>
</tr>
<tr>
<td>$M = 2.41 \pm 0.23 \times \log t^2 - 10.70 \pm 0.30$</td>
<td>Cohen 1985</td>
</tr>
<tr>
<td>$M = 2.54 \pm 0.35 \times \log t^3 - 11.99 \pm 0.56$</td>
<td>Downes &amp; Duerbeck 2000</td>
</tr>
</tbody>
</table>
MMRD

M31+LMC

Della Valle & Livio 1995
Are Novae good enough?

Novae are bright. They can reach an absolute magnitude at max of ~ -9 $\rightarrow$ 2-3 mag brighter than Cepheids of large periods.

Cepheids are detected only in Spirals whereas novae can be detected also in Es $\rightarrow$ calibration of SN-Ia.

There exists a good theoretical understanding of the MMRD relation.
The physical parameters of the outburst are primarily determined by the:

- Mass of the WD
- Accretion rate
- Temperature of the WD
- Magnetic Field
- Composition of the accreted material
- Mixing Process between accreted envelope and underlying WD
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- Mass of the WD
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The “tool”

“... the more massive is the WD the more powerful is the outburst”

Della Valle & Livio 1995
Livio 1992
De Bruijne & de Marchi (2011)
1. Calibration of the Galactic MMRD based on the brightest “historical” Novae ($m_V^{\text{min}} < 10^{-12}$) + “new objects” ~ 5-6/yr that can be observed at maximum (and during the early decline) → novae turn to “primary indicators”
2. GAIA Calibration of the MMRD$^\text{MW}$ + E-ELT observations of Novae in galaxies with (m-M) $\sim$ 36 $\rightarrow$ $H_0$ measurements
74±3%  
Ia+NIR Cep  
Freedman et al. 2012

74±8%  
HII  
Chavez et al. 2012

74±5%  
Ia+Cep  
Riess et al. 2009

72±6%  
water maser  
Reid et al. 2012

66±8%  
Lensing  
Paraficz et al. 2010

63-73 km s$^{-1}$ Mpc$^{-1}$  
WMAP- LAMBDA data product

### Table 1

<table>
<thead>
<tr>
<th>$H_0$ (km s$^{-1}$ Mpc$^{-1}$)</th>
<th>Technique</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>81 ± 8</td>
<td>Cepheids in 4 Virgo spirals</td>
<td>van den Bergh (1995a)</td>
</tr>
<tr>
<td>80 ± 12</td>
<td>SB fluctuations</td>
<td>Jacoby et al. (1992)</td>
</tr>
<tr>
<td>78 ± 11</td>
<td>Globulars in M87</td>
<td>Whitmore et al. (1995)</td>
</tr>
<tr>
<td>76 ± 7</td>
<td>PN in Virgo Cluster</td>
<td>Jacoby (1996)</td>
</tr>
<tr>
<td>75 ± 8</td>
<td>PN in Fornax cluster</td>
<td>McMillan et al. (1993)</td>
</tr>
<tr>
<td>74 ± 14</td>
<td>Tip of RG branch</td>
<td>Sakai et al. (1996)</td>
</tr>
<tr>
<td>73 ± 6 ± 7</td>
<td>SNe II exp. photospheres</td>
<td>Kirshner (1996)</td>
</tr>
<tr>
<td>73 ± 6</td>
<td>$D_n$ - $\sigma$ (Vir, For, Leo)</td>
<td>Mould (1996)</td>
</tr>
<tr>
<td>70 - 74</td>
<td>Tully-Fisher</td>
<td>Giovanelli (1996)</td>
</tr>
<tr>
<td>66 ± 12</td>
<td>IR Tully-Fisher</td>
<td>Malhotra et al. (1996)</td>
</tr>
<tr>
<td>65 ± 6</td>
<td>SN Ia lightcurves</td>
<td>Riess et al. (1996)</td>
</tr>
<tr>
<td>64 ± 3</td>
<td>4 SNe Ia</td>
<td>Hamuy et al. (1996)</td>
</tr>
<tr>
<td>55 ± 17</td>
<td>Sunyaev - Zel'dovich effect</td>
<td>Birkhanshaw &amp; Hughes (1994)</td>
</tr>
<tr>
<td>55 - 60</td>
<td>SNe Ia (theory)</td>
<td>van den Bergh (1995b)</td>
</tr>
<tr>
<td>52 ± 9</td>
<td>SNe Ia (1937C)</td>
<td>Saha et al. (1994)</td>
</tr>
<tr>
<td>52 ± 8</td>
<td>SNe Ia (1972E)</td>
<td>Saha et al. (1995)</td>
</tr>
<tr>
<td>43 ± 11</td>
<td>Galaxy diameters</td>
<td>Sandage (1993a)</td>
</tr>
</tbody>
</table>
2. GAIA Calibration of the MMRD$_{MW}$ + E-ELT observations of Novae in galaxies with $(m-M) \sim 36 \rightarrow H_0$ measurements

$(m-M) \sim 30$

Infall correction toward Virgo $\sim 100/400$ km s$^{-1}$

Average recession velocity of the cluster $\sim 900/1200$ km s$^{-1}$

$\rightarrow \Delta H_0/H_0 \sim 30\%$

$(m-M) \sim 36 \rightarrow \sim 11000$ km s$^{-1} \rightarrow \Delta H_0/H_0 \sim 3\%$
3) Independent Calibration (from Cepheids) of the peak luminosity of SNe-Ia in Es/Ss

→ Distance
→ Progenitors (systematic differences at maximum light of SNe-Ia)
4. Direct measurement of the distance to LMC with nova parallaxes and calibration of the LMC MMRD
Why Novae?

- White dwarf structure
- Nuclear reactions
- Hydrodynamics of explosive mass loss
- Common envelope structures

- Dust Formation
- Mass of the ejecta
- Abundances
- Distance Indicators
Novae contribute to the chemical enrichment of galaxies.
Mass of ejected shell

$10^{-4/-5} \ M_\odot$

DV et al. 2002
24 novae/yr DV & Livio 1995
35 novae/yr Shafter 1997

$\times 10^{-4} \times 100 \text{ yr} \rightarrow \sim 0.3 \, M_\odot$

cf. $\sim 1.4 \, M_\odot$ from SNe-Ia

Fig. 1. The nova rate as a function of H-Luminosity of the parent galaxies
Novae can produce interesting concentrations of rare isotopes (100-1000 times solar values)

- $^{13}\text{C};\; ^{15}\text{N}$
  - Sparks, Starrfield, Truran (1978);
  - Williams (1985);
- $^7\text{Li}$
  - Arnould and Norghard (1975);
  - Starrfield et al. (1978);
  - D’Antona and Matteucci (1991)
- $^{22}\text{Na};\; ^{26}\text{Al}$
  - Hillebrandt and Thielemann (1982);
  - Kolb and Politano (1997)
- Ne
  - Livio and Truran (1994)
First Detection of Lithium from an Exploding Star

The chemical element lithium has been found for the first time in material ejected by a nova. Observations of Nova Centauri 2013 made using telescopes at ESO's La Silla Observatory, and near Santiago in Chile, help to explain the mystery of why many young stars seem to have more of this chemical element than expected. This new finding fills in a long-missing piece in the puzzle representing our galaxy's chemical evolution, and is a big step forward for astronomers trying to understand the amounts of different chemical elements in stars in the Milky Way.
Galactic Li enrichment by novae
Observations

AAVSO light curve

Time (days from 2 Dec 2013)

V Magnitude

PUCHEROS
FEROS

0.50m @PUC
2.2m @La Silla
319 ID of singly-ionized heavy-elems with $E_{\text{in}} < 6\text{eV}$
The case of Li I 6708

Ca I 4226

K I 7699
Estimate of mass ejected

$$\text{Mass Li} = 0.3 - 4.8 \times 10^{-10} \text{ Msun}$$
Direct measurements of the distance of Nova Systems will improve (~ 40%) the accuracy on abundances estimates (not only for Li !)
Fig. 1. The nova rate as a function of H-Luminosity of the parent galaxies

24 novae/yr DV & Livio 1995
35 novae/yr Shafter
Rebirth of Novae as Distance Indicators Due to Efficient, Large Telescopes

M. Della Valle and R. Gilmozzi

A nova is a close binary system, where one component is a white dwarf. A nova exhibits a sudden and rapid increase in its brightness because of thermonuclear reactions on the surface of the white dwarf that is accreting hydrogen-rich material from its smaller mass companion star. These explosions liberate about $10^{34}$ ergs of energy within a few weeks, thus making novae some of the most luminous transient sources in the sky and, therefore, powerful standard candles for measuring intergalactic distances (1, 2). In addition, nova surveys in external galaxies can be used to determine the average number of nova outbursts per year, the nova rate, and this rate can be used to estimate the contribution of novae to the chemical evolution of the parent galaxy (3) and their potential to be gamma-ray producers (4). Despite the importance of novae, they are difficult to detect and observe in external galaxies with 2- to 4-m class telescopes. Here we used the 8.2-m Very Large Telescope (VLT) to search for novae in NGC 1316, the parent galaxy of the type Ia supernovae 1980N and 1981D. The observations were performed during nine nights between 25 December 1999 and 19 January 2000. They were carried out in service mode at the VLT equipped with the FORS-1 instrument (focal reducer/low-dispersion spectograph) and a 2048-by-2048 charged-coupled device (CCD) camera with a projected pixel size of 0.2 arc sec and a field of view of 6.8 by 6.8 arc min. Each 20-min exposure was imaged with filter B in the Bees photometric system, sometimes complemented by V and I. The background light due to the galaxy was removed by applying a median filter to each image, which was successively subtracted from the original frame. This procedure generates images containing only stars and the faint galaxy. The novae were discovered by comparing each background-subtracted B frame with the one obtained on 25 December. Photometric measurements have been performed with SExtractor (5), and the aperture photometry was corrected to account and $M_B \geq -19.10 \pm 0.35$ for supernova 1980N and supernova 1981D, respectively. This result is consistent with the existence of a ~0.2 to 0.3 mag deficiency in the luminosity at maximum of type Ia supernovae found in early type galaxies compared with supernovae found in spirals (6). Simulated VLT observations of novae in the Fornax cluster (7), where NGC 1316 is located, showed that our nova sample might be incomplete by as much as 20%. With this in mind and applying the control time technique (8), we estimate a nova rate for NGC 1316 of about 90 to 180 novae per year. After normalizing this rate to the infrared luminosity of the galaxy, we find that NGC 1316 tends to produce novae less prolifically than some type of spiral galaxies (9, 10). Novae can be used as distance indicators like cepheids by studying the Zwicky and Buscombe-de Vaucouleurs relationships in parent galaxies with well-observed type Ia supernovae. Novae that can be
Primordial lithium abundance

The primordial abundance of elements depends on the baryon/photon density ratio $\eta$:

Larger is the ratio, the more reactions there will be among baryons to produce deuterium, and consequently 4-helium, 3-helium and lithium via several channels.
Primordial lithium abundance

Calculated primordial abundances from Standard Big Bang Nucleosynthesis (and reaction rates) for:

- 4-Helium
- Deuterium
- 3-Helium
- 7-Lithium

From Planck observation of $\eta$:

<table>
<thead>
<tr>
<th></th>
<th>This work</th>
<th>Observations</th>
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<tbody>
<tr>
<td>$Y_p^*$</td>
<td>0.2461–0.2466</td>
<td>0.2465 ± 0.0097</td>
</tr>
<tr>
<td>D/H ($\times 10^{-5}$)</td>
<td>2.57–2.72</td>
<td>2.53 ± 0.04</td>
</tr>
<tr>
<td>$^3\text{He}/\text{H} \times 10^{-5}$</td>
<td>1.02–1.08</td>
<td>1.1 ± 0.2</td>
</tr>
<tr>
<td>$^7\text{Li}/\text{H} \times 10^{-10}$</td>
<td>4.56–5.34</td>
<td>1.58$^{+0.35}_{-0.28}$</td>
</tr>
</tbody>
</table>
The case of Li I 6708

Detection of a feature @ 6695.6 on Day 7
→ Li I 6708 expanding @ -550 km/s

Observed for about two weeks

ID of other neutral resonance lines as Ca I 4226
K I 7665-7699
... and Na I ...
Conclusions and Perspectives

- V1369 Cen still represents a perfect laboratory for many nova studies !!!

- Open questions: possible multiple ejecta, complete analysis of early narrow absorptions, origin of high-energy emission ...

- ...Li presence $\rightarrow$ physics of explosion: 1) efficiency of convection and 2) timescales of TNR

- The Li yield inferred from V1369 Cen, and extended to all slow novae, is sufficient to explain the overabundance of Li in young star populations
EARLY OPTICAL SPECTRA OF NOVA V1369 CEN SHOW PRESENCE OF LITHIUM

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CC-SNe + SNe-Ia
10-20 $M_\odot$ + 1.4 $M_\odot$/100yr

SNe-Ia 1.4 $M_\odot$/100yr
The “tool”

M31+LMC

Della Valle & Livio 1995