Gamma-ray novae

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on behalf of
the Fermi-LAT collaboration
Novae

Thermonuclear runaway burning of electron-degenerate material accreted on a WD

Violent $10^{-7}$-$10^{-4} \ M_\odot$ ejection followed by continued burning at $L_{\text{Edd}} \sim 10^{38} \ \text{erg/s}$

Recurrent over $1$-$10^4$ yrs time scales

$50$ ($+30/-20$) novae/yr in Galaxy

Wolf et al. (2013), Shafter (2016)

Multi-wavelength transient from radio to X-rays (now gamma-rays)

Variety of observed behaviors, at all stages
A new gamma-ray source class

Week/month-long transient
Most spectra cutting off at few GeV

Ackermann et al. (2014)
## Current gamma-ray detection record

<table>
<thead>
<tr>
<th>Year</th>
<th>Object</th>
<th>Discoverer</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>V407 Cyg</td>
<td>Nishiyama/Kabashima</td>
</tr>
<tr>
<td>2012</td>
<td>V1324 Sco</td>
<td>MOA</td>
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<td></td>
<td>V959 Mon</td>
<td>Fermi</td>
</tr>
<tr>
<td>2013</td>
<td>V339 Del</td>
<td>Itagaki</td>
</tr>
<tr>
<td></td>
<td>V1369 Cen</td>
<td>Seach</td>
</tr>
<tr>
<td>2014</td>
<td><strong>V745 Sco</strong></td>
<td>Stubbings</td>
</tr>
<tr>
<td>2015</td>
<td>V5668 Sgr</td>
<td>Seach</td>
</tr>
<tr>
<td>2016</td>
<td><strong>V407 Lup</strong></td>
<td>ASASSN</td>
</tr>
<tr>
<td></td>
<td>V5855 Sgr</td>
<td>Itagaki</td>
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<td></td>
<td><strong>V5856 Sgr</strong></td>
<td>ASASSN</td>
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<tr>
<td>2017</td>
<td>V549 Vel</td>
<td>ASASSN</td>
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<tr>
<td>2018</td>
<td>Nova Mus 2018</td>
<td>Kaufman</td>
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<td></td>
<td><strong>Nova Car 2018</strong></td>
<td>ASASSN</td>
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<td></td>
<td>V392 Per</td>
<td>Nakamura</td>
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</tbody>
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Classical and **symbiotic novae**

**Low significance objects**
(+2 from revisiting data with Pass 8)

**High significance objects**
Variety of gamma-ray novae

- Symbiotic and classical
- Very fast to slow, variety of optical lightcurves
- Gamma-ray luminosities vary by >20, distances 1-7kpc
- Some very bright optical novae not detected in gamma-rays

Ackermann et al. (2014)
Cheung et al. (2016)
A first population study (Franckowiak et al., A&A, 2018)

Search for gamma-rays from 75 optical novae in 7.4 yrs of Pass 8 data

- 2 novae candidates at \( \sim 2\sigma \) (V679 Car 2008, V1535 Sco 2015)
- Sub-threshold population at \( 3\sigma \)
- Constraining gamma-ray emissivity distribution from population model
- Excluded: constant or correlated with maximum magnitude
- Favored: broader uncorrelated distributions

![Graphs showing the distribution of peaks in apparent magnitude and log10 flux over various energy levels.](image-url)
A first population study (updated approximately)
Novae as particle accelerators – symbiotic systems

WD + RG companion
(RS Oph, V407 Cyg, V745 Sco)

Shock in dense stellar wind
Scaled-down SN/SNR
($10^{44}$ erg, 3000 km/s, weeks)

Pan et al. (2015)
Novae as particle accelerators – symbiotic systems

- LAT data reproduced from typical assumptions for shock acceleration
- Mass amount and distribution are key to reproduce the light curve
- Martin & Dubus (2013)

V407 Cyg: (if) shock propagating in matter accumulated around WD gamma-rays mostly inverse-Compton in nova+RG light
Novae as particle accelerators – classical novae

- Circumbinary medium mostly **empty**
- …the ejecta is the mass reservoir!
- Internal shocks revealed by hard X-rays (ROSAT…Swift)
- Multiple ejecta components from lines

Impulsive ejection followed by fast radiatively driven wind

**Radiative** forward and reverse **shocks** separated by cold dense shell

Variations on the geometry
Metzger et al. (2014,2015)
Martin et al. (2018)
Novae as particle accelerators – classical novae

- Diffusive shock acceleration with values typical of SNRs
  - Particle injection fraction $\sim 10^{-4}$ and $e/p$ ratio $\sim 10^{-2}$
  - Amplified upstream magnetic field $= 10^{-4}$-$10^{-2}$ the ram pressure
  - Particles diffusing in Bohm limit

Protons accelerated $<\text{TeV}$
Electrons exhausted by synchrotron losses
Gamma-rays $> 100\text{MeV}$ dominated by pion decay
Novae as particle accelerators – classical novae

- Gamma-rays as a **probe of mass ejection**
- LAT data favour nova wind $< 2000$ km/s
- Poor prospects for detection at TeV energies (CTA)

Martin et al. (2018)

Most other parameters of internal shock scenario **poorly constrained**

**Need additional information** on shock dynamics from X-rays/optical
The light from novae

- Internal shocks dissipate $10^{37-38}$ erg/s at peak, primarily in X-rays
- Observed $L_X \leq 10^{35}$ erg/s
- High X-ray opacity in early stages…reprocessing into optical light!

- Additional contribution to optical lightcurve (secondary maxima, plateaus)

Metzger et al. (2015)
The light from novae

- ASSASN-16ma = V5856 Sgr (Li et al. 2017)
The light from novae

- ASSASN-16ma = V5856 Sgr (Li et al. 2017)
The light from novae

- Another possible example V5855 Sgr (Munari et al. 2017)
The light from novae

- Another possible example V5855 Sgr (Munari et al. 2017)
  - Wavelength-dependent maximum time for fireball component
  - …not the case for gamma component: different origin!
Novae as cosmic-ray sources?

- Globally, negligible
  - Kinetic energy $= 10^{44-45}$ erg/nova
  - Eruption rate $50\sim$ novae/yr
  - At least 2000x below SNe
Novae as cosmic-ray sources?

- Possible local effects?
  - Kamae et al., PASJ, 2018
  - Higher WD density in solar neighborhood
  - CR trapping in local bubble
  - Explains hardening in CR spectra (and GeV hump in inner Galaxy)
Open issues (personal selection)

- Mass ejection in nova eruptions
  - What is the typical pattern for mass ejection in novae (if any) ?
  - Role of asymmetry/inhomogeneities/geometry ?
  - Which progenitor properties drive the mass ejection sequence ?

- Radio emission
  - Can we fully account for the early non-thermal radio emission ?
  - Radiation from secondaries from hadronic interactions ?
  - See Justin Linford’s talk

Relation of gamma-ray novae to the whole population
- What drives the gamma-ray sample selection ?
- Can we predict gamma-ray emission from other bands ?
The way forward

• Radiation transfer calculations
  • What kind of outflow can result from steady nuclear burning on the WD?
  • What fraction of the internal shock power is reprocessed into optical?

• Fermi-LAT
  • Expanding the detected population
  • More high significances objects à la ASASSN-16ma and Nova Car 2018
  • Eruption of nearby symbiotic RS Oph and TCrB in mid-2020!

• Associated multi-wavelenth coverage
  • X-rays (Swift, Nustar,…)
  • High cadence optical follow-up
  • Early and late radio follow-up
  • Mid-term: MeV and TeV exploration

Fermi-LAT shed a new light on the nova phenomenon
  … by probing the heart of the mass ejection process
  … and helping connect various observables into a coherent picture

Vurm et al. (2018), Metzger et al. (2016)
Nova Car 2018
Most significant
Highest-energy photons

8th Fermi symposium - Oct 2018