Classical and Recurrent Novae as Quintessential Panchromatic Transients

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Vision is the art of seeing what is invisible to others
– Jonathan Swift

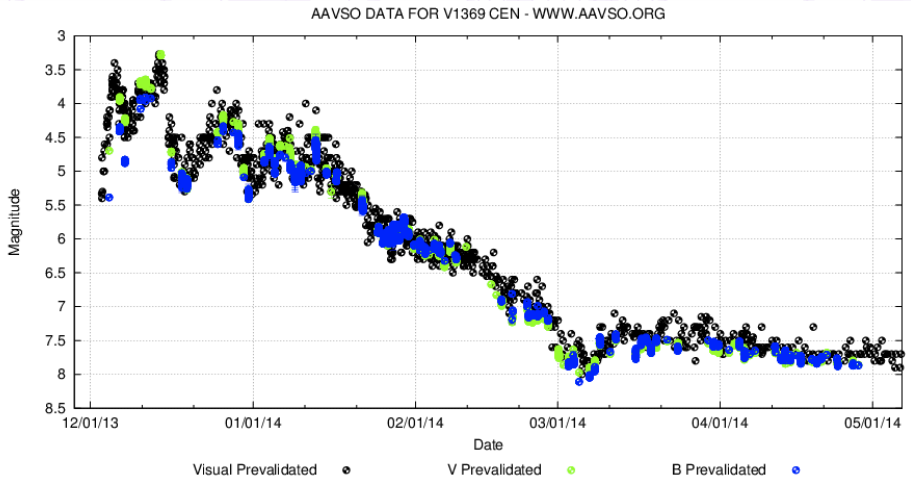
A definition of classical nova

A classical nova eruption is a thermonuclear runaway (TNR) on a white dwarf surface that impulsively ejects a large amount of accreted matter.

- By this definition, it is an event in, and not a type of, interacting binaries.
- Underlying binary could be a cataclysmic variable (CV) or a symbiotic star.
- Sufficiently specific to eliminate supernovae, dwarf novae, and X-ray novae.
- This definition de-emphasizes the difference between classical novae and recurrent novae.

Nova Eruption in the Optical

- During the rise and the maximum, T~10,000K pseudo-photosphere (warm phase; electron scattering opacity ~1) of red giant dimension dominates the visual light curve.
- Dust formation in many novae requires the existence of T~1,000 K, mostly neutral, cold phase.

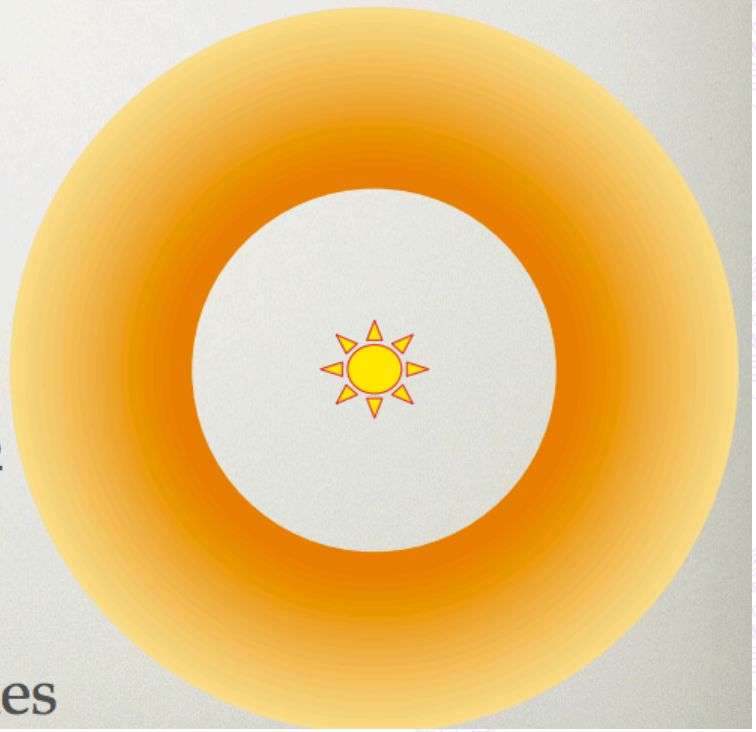


- Complex optical light curves seen in some novae (e.g., V1369 Cen shown left) probably require a complex ejection history which is currently not understood.

Novae as Radio Transients

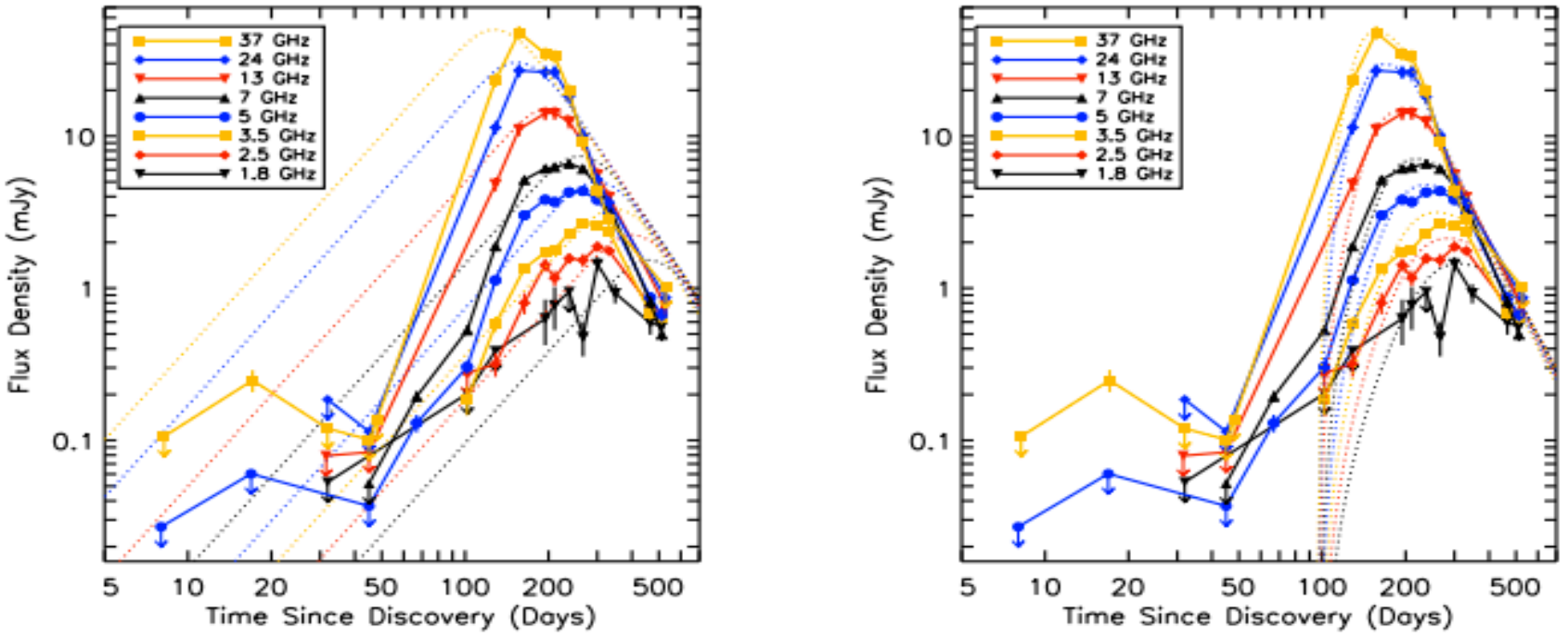
Radio Emission from Novae

- Thermal Free-Free Emission
- Spherical Shell
- smooth density $\propto 1/r^2$
- Constant $T_e \sim 10^4$ K
- distribution of velocities



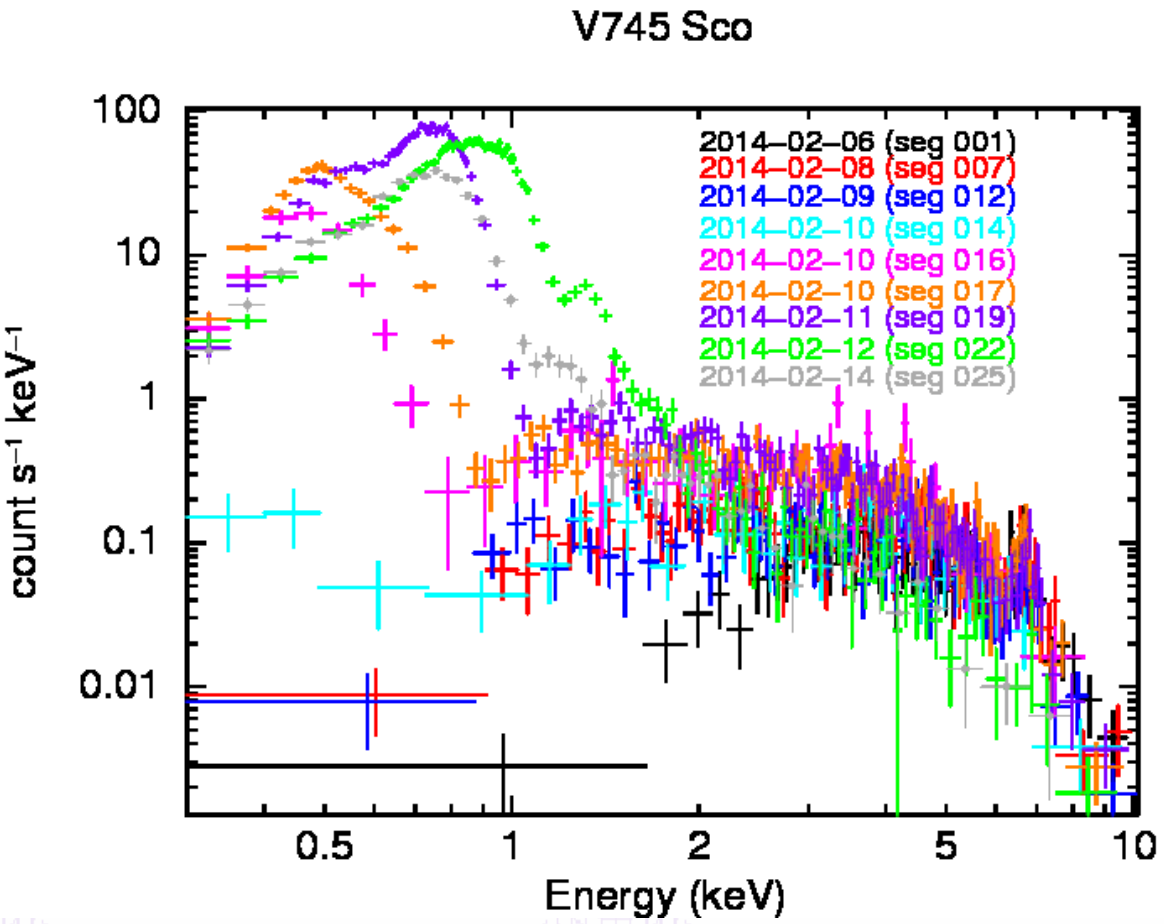
Multi-frequency radio light curves can then used to estimate the total ejecta mass, distance and other parameters of interest: hence the E-Nova project https://sites.google.com/site/enovacollab/ . However, there are complications.

Delayed ejection in T Pyx



In the optical, T Pyx remained at maximum for ~2 month, probably in a quasi-static, red-giant-like configuration. Radio etc. data suggest the end of that phase coincided with the main mass ejection (Nelson et al. 2014; Chomiuk et al. 2014)

X-ray Emissions in Novae



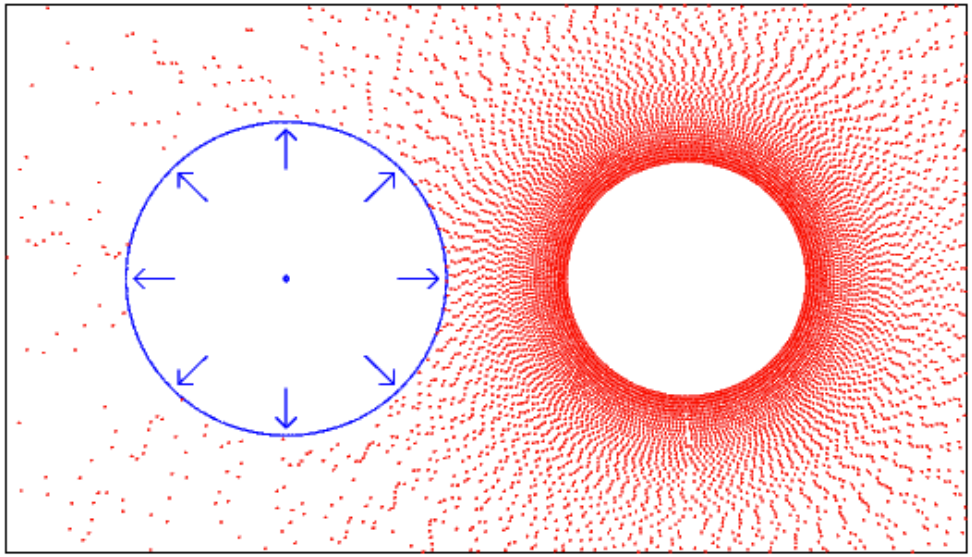
Supersoft emission from the surface of the nuclear-burning WD and optically thin thermal component from the shocked ejecta are seen in different novae at different times.

Figure by Kim Page (Leicester)

External Shocks in Embedded Novae

The majority of known novae occur in CVs – compact binaries (P<a few days) with Roche-lobe filling mass donor.

A small subset happen in symbiotic stars – wide binaries (P~a few years) with late type giant mass donors.

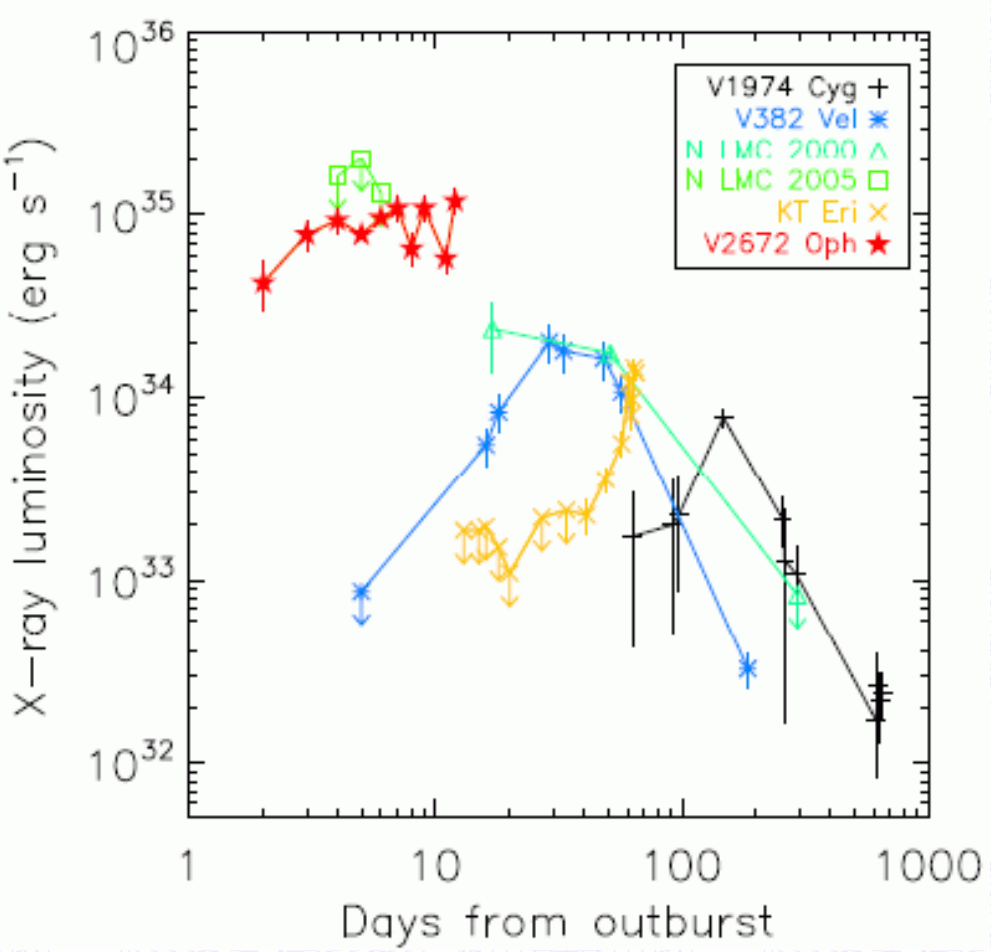


In such systems, the nova is embedded in the wind of the mass donor: the nova blast wave immediately hits the wind and is shocked. Such external shocks can lead to early, luminous, hard X-ray emission: high velocity differentials and high density of the wind results in high emission measures.

Examples: RS Oph (2006), V407 Cyg (2010), V745 Sco (2014), and Nova Sco 2014
Possibly related: CI Cam, MAXI J0158-744 (postulated WD – early type star binaries)

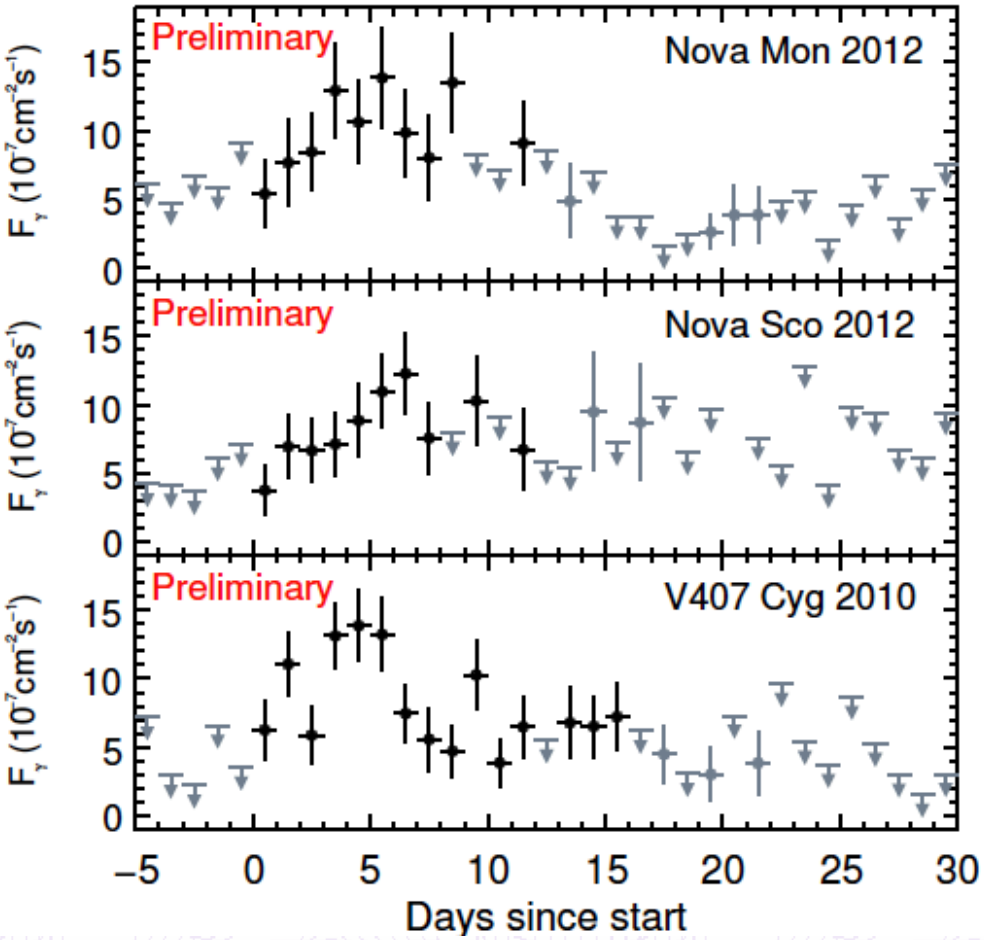
X-rays from Shocked Ejecta

- Such X-rays from shocked ejecta are common, if not universal, even in unembedded novae
  - RS Oph up to ~10^{36} erg/s
  - Unembedded novae in 10^{33} to 10^{35} erg/s range
- Typical interpretation: "internal shock" – variations in velocity and other parameters within the nova ejecta lead to shock(s).
- 10^7K shocked gas represents the third (hot) phase of nova ejecta.



Gamma-Ray Emission in Novae

- MeV emission from novae has been predicted from nuclear decay, but has never been detected.
- Fermi/LAT has detected GeV emission from novae, first V407 Cyg and now five more – they should not be called "gamma-ray novae"
- This requires diffusive shock acceleration (DSA) – either of electrons followed by Compton up scattering, or of protons followed by pion production.

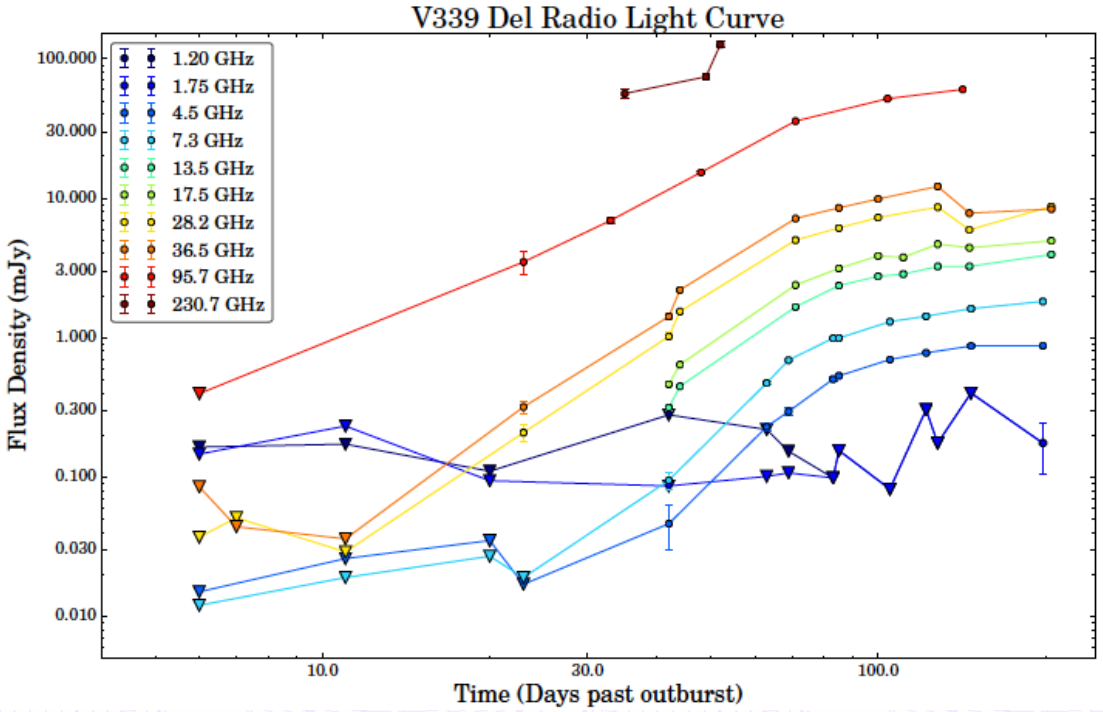


Are there special gamma-ray novae?

- As of 2014 April, there are 58 known Galactic novae since the launch of Fermi on 2008 June 11, and 6 have been detected with the LAT.
- Judging by the published distance estimates, 4 of them are quite nearby (d<4 kpc); conversely, most (if not all) nearby (d<4 kpc) novae have been detected with Fermi/LAT.
- Conjecture: all classical novae have peak GeV luminosity of order 10^{35} ergs s^{-1}
- All nearby ones, and some more distant, gamma-ray bright ones, are detected with Fermi/LAT.

V339 Del

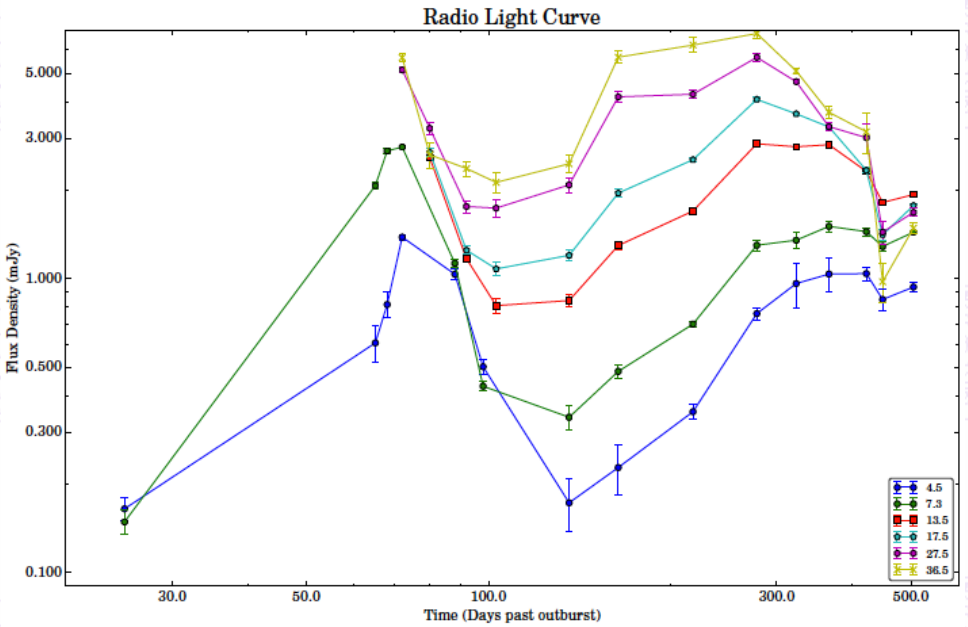
- Bright (V~4.3 at peak) nova discovered in 2013 August
- Detected with Fermi/LAT in pointed observations.
- For its optical brightness, it remained only a weak hard X-ray source.



Multi-frequency radio light curves show a slow, single-peaked evolution, perhaps consistent with a single thermal ejecta. Despite the Fermi/LAT detection, other signatures of shock in V339 Del are weak at best.

V1324 Sco

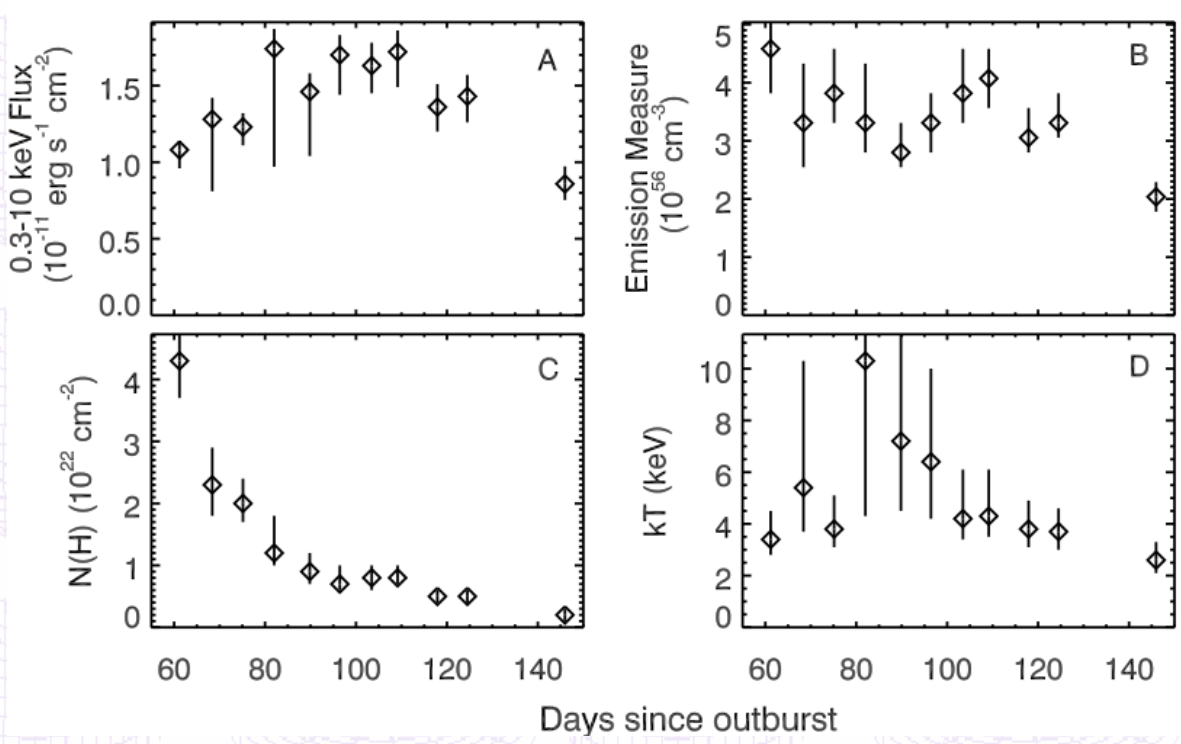
- Discovered in a microlensing survey and showed a very complex optical light curve, including simultaneous drop in optical and IR brightness which may or may not be due to dust formation
- It has never been detected in X-rays
- d~8 kpc from ISM absorption
- Progenitor likely a CV



- Radio light curves are highly complex with two distinctive peaks. The spectral index of the initial detection indicates a synchrotron origin, the only other signature of shocks for this nova with a high GeV luminosity.

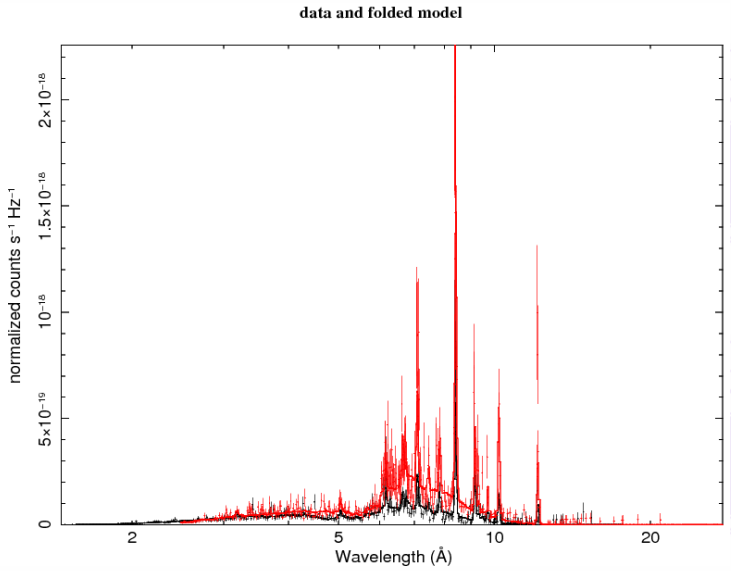
V959 Mon

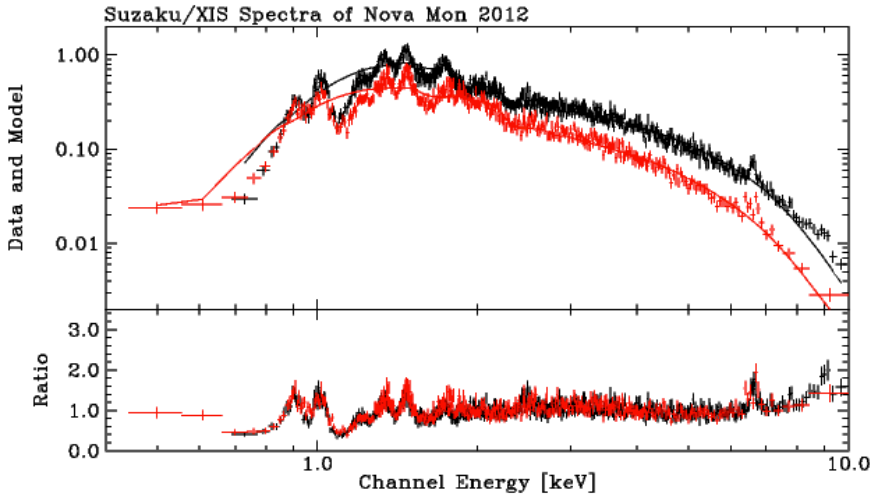
- Discovered as a Fermi transient near the Sun, the optical nova was discovered ~2 month later
- Inferred peak optical magnitudes in the V~4-5 range



- Strongly detected in X-rays with N_H evolution typical of internal shocks
- P=7.1 hr orbital period detected in supersoft X-rays and in the optical – definitely a CV

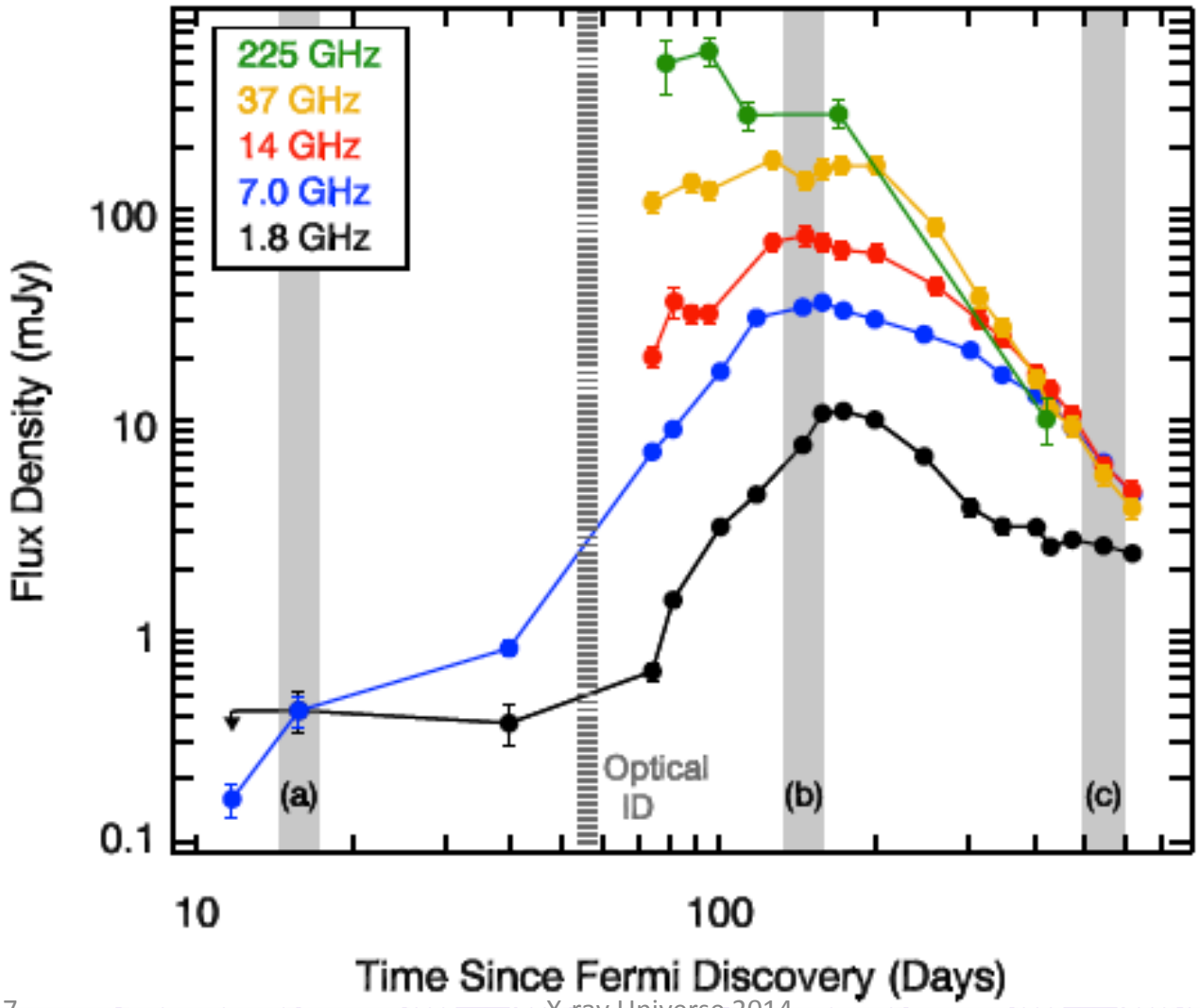
X-ray Spectra of V959 Mon





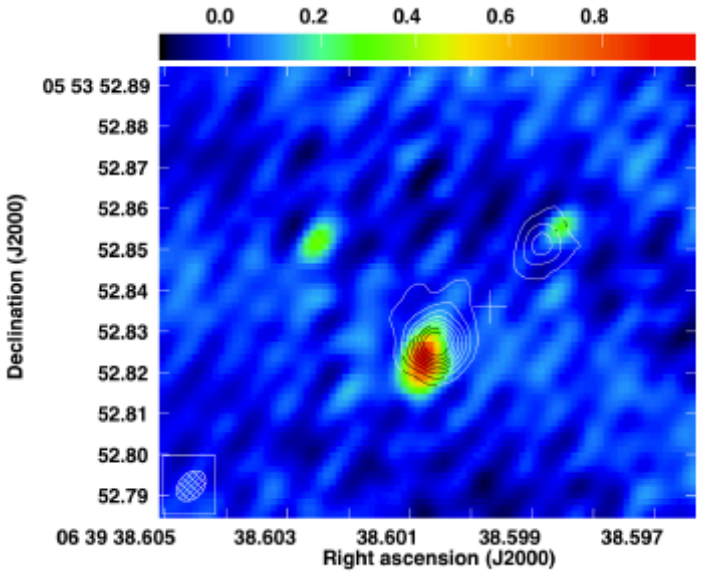
- The hard X-rays from V959 Mon was bright enough not only for a deep Suzaku observation but also for a Chandra/HETG observation.
- Continuum (above 2 keV) temperature: kT~4.8 keV, or v_{diff}~2000 km/s
- Ne and Mg lines are both extraordinarily strong, suggestive of overabundance.
- The H-like to He-like ratio of these ions indicate a much lower ionization temperature

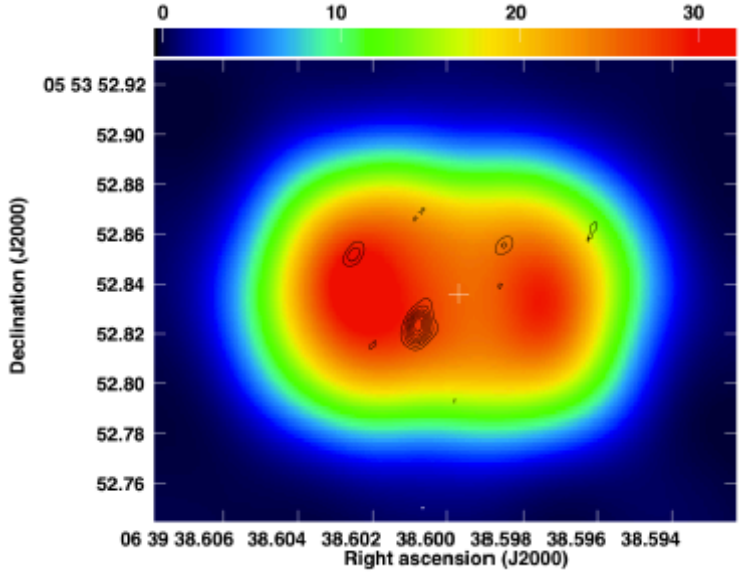
V959 Mon in the Radio



A Sneak Preview

- Initial detection probably due to synchrotron emission
- Later radio flux dominated by the thermal emission from the warm ejecta
- ...but we have images of the synchrotron hot spots at several epochs: location of shocks (Chomiuk et al. 2014, submitted to Nature today)



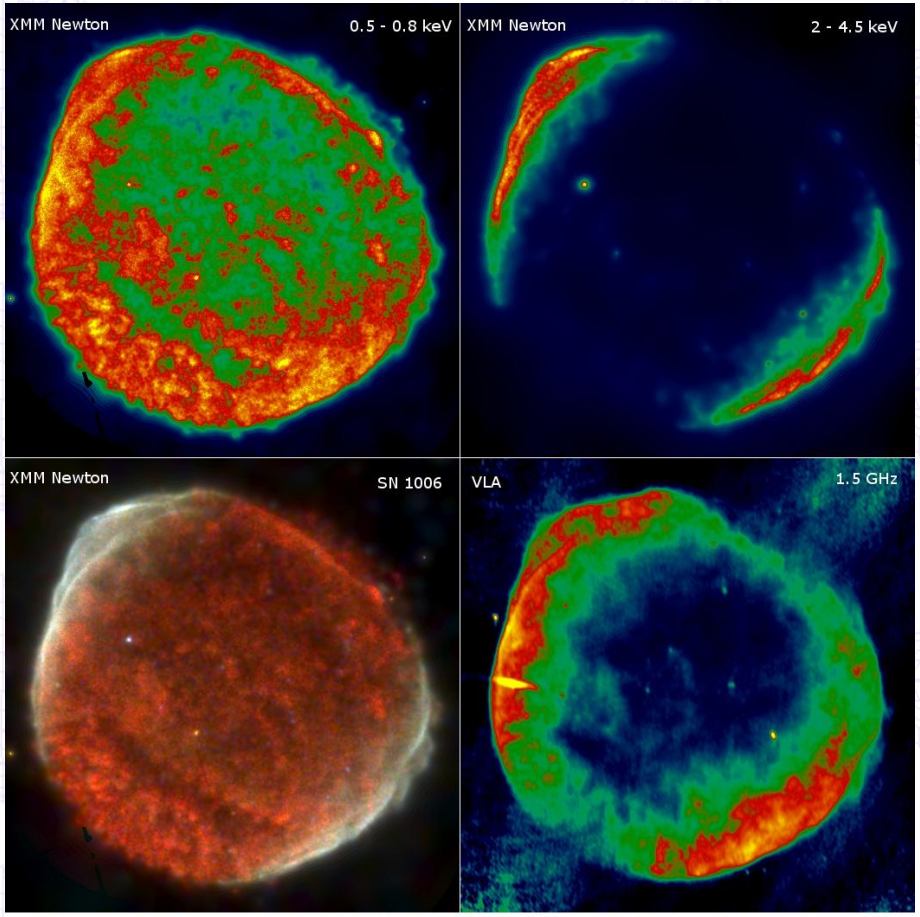


Fermi-detected Novae

Object	Shock X-rays	Note
V407 Cyg	Moderate	Symbiotic; embedded in Mira wind
V1324 Sco	Undetected	
V959 Mon	Strong	Optical detection delayed; 7.1-hr orbital period
V339 Del	Weak	
V1369 Cen	Undetected till late	Unusual optical light curve
V745 Sco	Strong	Symbiotic Recurrent; embedded in M giant wind

Fermi/LAT detection of these novae requires , followed either by pion decay (accelerated protons hitting a target, producing pions) or Compton scattering (accelerated electrons Compton up-scattering novae photons).
V407 Cyg and V745 Sco are in symbiotic systems, and external shocks resulted.
Others appear to be in CVs, so a different explanation is needed; also particle accelerating shocks do not necessarily produce strong hard X-rays.

Summary



- Nova ejecta have three phases: warm, cold and hot
- X-ray and multiwavlenegth data indicate many novae have complex mass ejection history; presently poorly understood.
- Hard X-rays are common in novae, embedded or otherwise. (Internal) shocks are ubiquitous.
- Particle accelerating shocks do not necessarily emint X-rays strongly (cf. SNR case)
- Shocks also emit synchrotron emission in the radio, which can be imaged.