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# A multifrequency review of Galactic and Extragalactic Novae

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Novae show emission over the whole electromagnetic spectrum and have been suggested as possible neutrino sources. The present paper is an update to the previous review about the multifrequency observations of novae presented at The Golden Age of Cataclysmic Variables and Related Objects V workshop.

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[*] Speaker

## 1. Introduction

Novae are cataclysmic variables where a white dwarf (WD) is accreting material from a secondary star [14, 21, 136]. The nova outburst is produced by a ThermoNuclear Runaway (TNR) on the surface of the white dwarf [62, 150, 192–194]. Novae are generally discovered thanks to the rapid increase in optical brightness, that can achieve $M_V$ = -10 mag, but the emission ranges from radio to X-rays and gamma rays. Novae play a crucial over a broad range of science topics, being laboratories for investigating accretion physics, contributors to the chemical evolution of galaxies, showing sometimes high energy emission and, in the case of recurrent novae, as possible SN Ia progenitors. The recent years have witnessed the deployment of a broad range of high time cadence, all sky surveys, that are contributing both to discoveries of new novae and to the monitoring of their evolution. The present paper reviews the multi-frequency observations of Galactic and extragalactic novae and discusses their impact.

## 2. Optical Observations

Historically novae have been and are being discovered by citizen astronomers. The optical all-sky surveys presently in operation are playing an increasing role in Galactic and extragalactic nova discovery and monitoring, providing densely sampled light curves that can extend before the maximum. Optical observations of novae, including both photometry and spectroscopy, are still the workhorse of the observing effort.

### 2.1 Photometry

After the maximum, novae enter a decline stage that is not necessarily smooth, but can show a variety of features, such as dips, flares or oscillations. The photometric features are linked to spectroscopic features that will discussed below. According to [196], the decline curves of novae can be classified into seven classes: (Fig. 1): F-class with flat top (2% of all novae); C-class with a cusp (1%); J-class with jitters (16%); P-class with a plateau (21%); O-class with oscillations (4%); S-class with a featureless decline (38%); D-class with dips (18%).

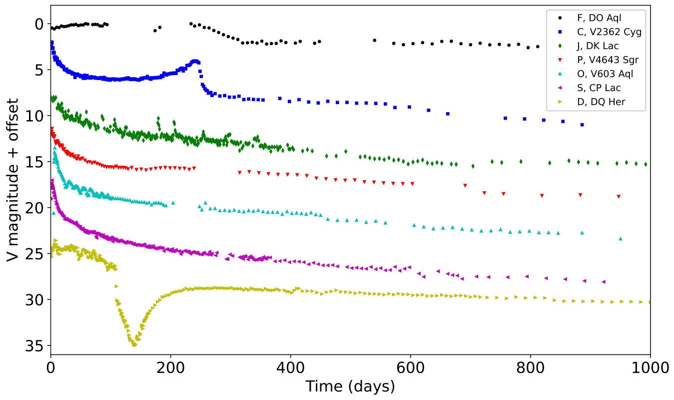

**Figure 1:** The classification of nova light curves [196]; data from [196]

### 2.2 Spectroscopy

The spectroscopic evolution of nova explosions involves various stages linked to the photometric evolution, with a rich pattern of emission and absorption lines and varying expansion velocities of the ejected material [112, 136]. The initial rise to the maximum, the pre-maximum stage, is linked to the free expansion of ejecta. This stage is generally missed, since it can last from hours to a few days, but it is now detected more often thanks to the all sky surveys. Some novae exhibit also a pre-maximum halt, with spectra similar to F supergiant spectra showing lines with P Cyg profiles. The maximum is associated to the shrinking of the pseudo-photosphere, with the dominant contribution from free-free emission. High energy UV radiation is converted into less energetic radiation, prompting the appearance of low ionization transitions, including those from heavy elements [212] and O I 8446 [16]. The principal spectrum later switches to a diffuse enhanced spectrum, with P Cyg profiles, while density of the ejecta is decreasing. The transition stage is achieved when optical thickness switches from thick to thin, leading to the Orion spectrum, with high ionization helium, nitrogen, oxygen lines and the CIII/NIII Bowen blend. During the later decline the density keeps decreasing with the disappearance of the absorption components and the onset of nebular stage, marked by the appearence of forbidden lines [111, 136]. Usually nebular lines show flat or split/saddle shaped profiles that provide information about the ejecta morphology, with equatorial rings and/or polar caps. During the nebular stage novae can show the maximum level of excitation, when the hot whited dwarf surface appears as a bright source in soft X-rays, due to the burning of hydrogen rich remnant material [126]. Soft X-rays and UV radiation produce the photoionization of heavy elements, that can appear as high excitation coronal lines, such as [Fe VII], [Fe X], [Ar X]. On time scales of the order of years after the outburst classical novae develop the post-nova spectrum, with a gradual fading of the coronal and forbidden lines, due to the decreasing ionization level, with H$\alpha$, He II 4686 and N III 4640 remaining visible on longer time scales [68].

There are some compilations of nova spectra observed with high time cadence. The historical Tololo nova atlas reported several novae in different stages of evolution [215, 216]. The SMARTS Consortium [208, 209] has built a living spectral atlas of novae observable from Southern hemisphere at the SMARTS 1.5 m telescope. The atlas comprises about one hundred novae and has been used to perform investigations of the relations of He II 4686and the X-ray super-soft stage in He/N novae and of the $K_s$ band flux and dust formation [208].

I have been performing the monitoring of Northern novae at the Cassini 1.5m telescope, with the BFOSC Imager/Spectrograph [146], since 2005. I have secured optical spectra at the highest temporal cadence allowed by telescope observing time and weather conditions. The observed sample comprises more than twenty Galactic novae and a few extragalactic novae: V1663 Aql [137], V1722 Aql, V809 Cep, V962 Cep, V2362 Cyg [141], V2467 Cyg [142], V2468 Cyg, V2491 Cyg, V2659 Cyg, V407 Cyg, V339 Del, KT Eri, V959 Mon, V2615 Oph, V2670 Oph [140], V2944 Oph, V496 Sct, V612 Sct (ASASSN-17hx) [149], V556 Ser, V5558 Sgr [138, 143], V5584 Sgr [145, 148], V458 Vul [139], V459 Vul [144], the extragalactic novae M31 2009-10b, M31 2010-07a, M31 2011-07 and M33 2010-07a [147]. Some observed novae have shown a peculiar photometric and spectroscopic behavior: V458 Vul is an hybrid nova switching from Fe II to He/N class [139]; V2467 Cyg showed oscillations during the initial decline and an early appearance of nebular transitions [142]; V5558 Sgr is a very slow nova with a white dwarf whose mass is just at the limit to trigger the outburst [138, 143]; V2362 Cyg showed a cusp during the decline, explained by a secondary mass ejection [141]; V612 Sct (ASASSN-17hx) is a slow nova with a long pre-maximum stage [149]; M31 2009-10b is one of the brightest novae ever observed in M31 [147]; M33 2010-07a is the first nova in M33 showing a secondary mass ejection [147].

### 2.3 Nova Classes

The original classification of nova spectra devised two classes, Fe II novae and He/N novae [213–216], according to the presence of Fe II multiplets and He/N, respectively, with the members of Fe II class being fainter and slower than He II class novae [50, 56]. The mechanisms operating in the two classes are wind ejection for the more common Fe II novae (about 80% of Galactic novae) and shell ejection in He/N novae. Hybrid novae switch from the Fe II class to the He/N class before the appearance of forbidden lines, e.g. V458 Vul [139, 201]. Example spectra of Fe II, He/N, hybrid novae are reported in Fig. 2. Other novae, such as T Pyx [63, 93] and V5558 Sgr [138, 143, 199], show the opposite evolution, switching from He/N to Fe II class.

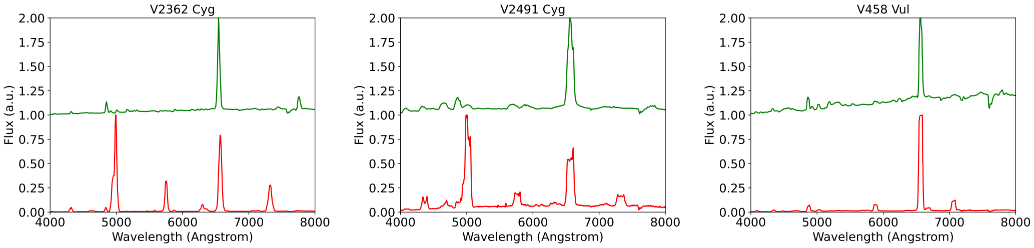

**Figure 2:** Optical spectra of the Fe II nova V2362 Cyg [141], He/N nova V2491 Cyg (Poggiani, in preparation), hybrid nova V458 Vul [139] secured during the initial decline (top curves) and the late stages (bottom curves)

The original Fe II, He/N classification has been recently revised [211], suggesting that the Fe II and He/N nova spectra are produced in the white dwarf ejecta and in the circumstellar envelope around the secondary star, respectively. The observation of either kind of spectrum is explained by the relative contribution of the two processes that changes during the evolution [211].

Some Galactic and extragalactic novae have shown a much higher luminosity than usual, e. g. Nova LMC 1991 [48, 161], V1500 Cyg, SN 2010U in NGC 4214 [36], M31 2007-11d [176], M31 2009-10b [147]. The majority of superluminous novae belongs to Fe II class, with the possible exception of the hybrid nova V1500 Cyg.

### 2.4 Abundances and Contribution to Nucleosynthesis

Chemical abundances in the nova ejecta show an enrichment in helium and/or heavy elements [69, 73, 98, 106, 136], since the thermonuclear runaway develops in the accreted hydrogen rich envelope through the CNO burning chain. A compilation of abundances in the optically thin shells of 11 classical novae have been presented by [7], who combined UV and optical spectroscopy secured during the nebular stage.

Optical spectroscopy of novae has allowed to understand their contribution to Galactic nucleosynthesis. When TNR starts, the first reaction is the proton-proton chain, while with increasing temperature convective motions transport material from the interior of the white dwarf into the burning zone, igniting the CNO cycle. The reaction increases the production of $\beta$-unstable isotopes, finally leading to the outburst [191]. Helium can produce $^7$Be that later decays into $^7$Li (half-life of about 53 days) [18]. Convective motion can move $^7$Be to the external layers, where $^7$Li is ejected in the thermonuclear runaway. Despite the early predictions of lithium production by novae its detection has been elusive for a long time [8, 67, 195]. The expected signature of lithium is the resonance transition of its neutral state, an absorption doublet centered at $^7$Li I 6707.8 Å. Recent observations have detected the presence of lithium and beryllium. V1369 Cen showed an absorption feature at 6695.6 Å, a blue shifted $^7$Li I 6708 Å transition at different epochs [95]. V5668 Sgr exhibited an absorption line corresponding to the blue shifted Li I 6708 Å transition [207]. The blue shifted resonance lines of the singly ionized isotope of $^7$Be has been observed in the NUV spectra of nova V339 Del [197]. It has been estimated that contribution from novae can explain the amount of $^7$Li observed in the Galaxy [117]. Evidence for the presence of $^7$Be has been presented by [96, 97, 116, 164, 197, 198].

## 3. Infrared Observations

Infrared observation of novae provide information about abundances, in analogy to optical observations, but also about dust production and the ejecta geometry [23]. The observations in the J, H, K bands are used to classify novae [10, 74]. The separation of Fe II and He/N classes holds also in the near infrared: carbon lines appear only in Fe II novae, but not in He/N novae, while hydrogen Paschen and Brackett lines appear in both classes. CO emission in the first overtone has been used to estimate the $^{13}$C yield and the impact on Galactic chemical evolution [10]. Infrared observations support the bipolar nature of the ejection of nova shells [24, 25]. The first infrared observation of a nova, FH Ser, showed an infrared brightening in coincidence with an optical fading, suggesting that dust formation had occurred [75]. Novae are relevant producers of dust grains [71, 72, 92, 108, 109], whose composition includes silicates, amorphous carbon, SiC, hydrocarbons [64]. Dust formation is often associated to a dip in the optical light curve and an infrared brightening due to heating and re-emission of dust particles, as observed in Nova V705 Cas, whose optical and infrared light curves are reported in Fig. 3. The dip in the optical light curve coincident with the maximum in the infrared light curve is caused by the formation of an optically thick carbon dust shell [109].

## 4. Radio Observations

The evolution of the radio emission in novae occurs over time scales of the order of years, larger than the typical optical time scale [28, 155]. The first detection of radio emission from novae occurred in novae HR Del and FH Ser [87]. The dominant mechanism in the radio emission is thermal bremsstrahlung from the ejecta, unless explosion occurs in a dense environment and a contribution from synchrotron emission arises. Thermal emission from a spherical and isothermal shell of ionized gas with a power law density gradient has been used to model the radio light curves of novae [14, 88]. However, ejecta could be non spherical and show localized clumps and non uniform temperatures. The analysis of radio emission is used to estimate the mass of the ejecta [155, 162]. Radio interferometric observations provide high resolution and high sensitivity

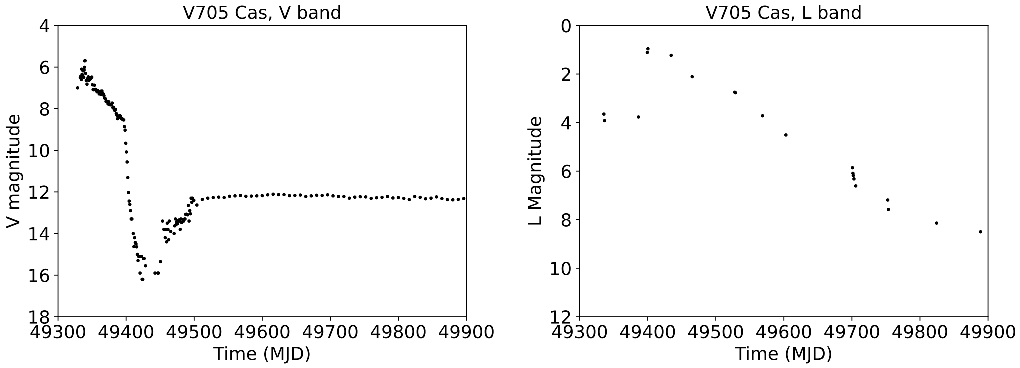

**Figure 3:** The V band light curve (left, data from [196]) and the L band light curve (right, data from [109])

observations, allowing detection of radio emission since the early stages. The E-Nova team at the Very Large Array (VLA) has monitored 36 novae [28], showing that radio emission is a mixture of thermal and synchrotron emission, with non thermal emission detected at earlier times. The early synchrotron peak was sometimes in temporal coincidence with the dust dip in the optical light curve, suggesting a common location for particle acceleration and dust formation. The search for radio counterparts of novae with the Australian Square Kilometer Array Pathfinder (ASKAP) found counterparts for four novae [79].

The multifrequency radio curves of V1500 Cyg [88] and V5667 Sgr [28] are reported in Fig. 4.

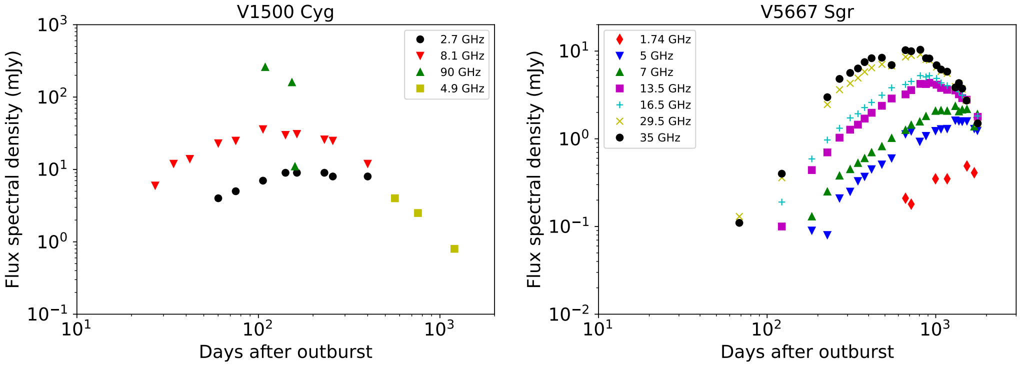

**Figure 4:** The multifrequency radio light curves of V1500 Cyg (data from [88]) and V5667 Sgr (data from [28])

The high resolution radio observations have detected the morphology of the ejecta for some novae, showing deviations from spherical symmetry and possiblr bipolar geometry, as observed in V1974 Cyg [65], RS Oph during the 2006 outburst [124], [15], V959 Mon [28].

## 5. X-ray Observations

The X-ray emission in novae is produced via thermal emission from the white dwarf, when ejecta become optically thin in the SuperSoft X-ray Source phase (SSS) and undergo shock on the surrounding material or from accretion during the quiescence stage. The first X-ray observations of novae with EXOSAT [125] and ROSAT [101] showed the evolution of X-ray flux during the outburst and the approach to the supersoft phase. The X-ray hard and soft components are associated to shocks within the ejecta and to the nuclear burning on the white dwarf surface, respectively. The super-soft phase, often associated to the presence of the optical [Fe X] 6374 Å line, has been detected in several novae [160]. Fast novae in the Galaxy and in M31 show high ejection velocities and early turn-on and turn-off of the SSS phase [85]. The turn on and off times of the SSS phase have been discussed by [80, 81].

The Swift-XRT instrument has monitored a large numbers of Galactic novae and novae in M31, LMC, SMC [123, 129], providing light curves with high cadence. As an example, the 0.3-10 keV light curves of RS Oph and HV Cet [160] are reported in Fig. 5.

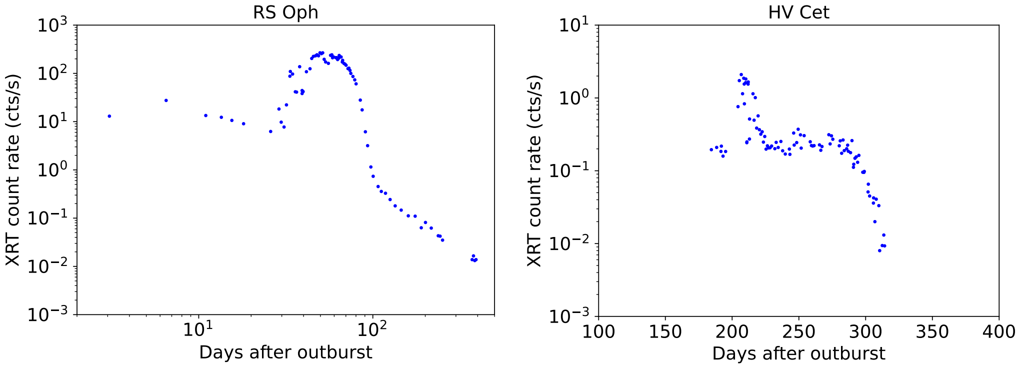

**Figure 5:** The 0.3-10 keV light curves of RS Oph and HV Cet; data from [160]

The 2006 outburst of RS Oph is a showcase of multi-frequency observations that revealed the presence of shocks in the ejecta [13, 130, 190], with radio [124] and HST observations [15] suggesting a bipolar geometry with an equatorial ring. After the outburst, the keV X-ray flux decreased and later achieved a peak at about day 30, when SSS phase started, the burning ended by day 80 and X-rays faded.

The high resolution grating X-ray spectra secured with XMM-Newton and Chandra have allowed to measure, in addition to the continuum, the white dwarf absorptions or emission lines or a combination of both [122, 127]. Collisional plasmas are responsible for the spectra outside the super-soft phase, while shocks produce emission before the start of the SSS stage and the later emission is due to the radiatively cooling thin ejecta [122].

## 6. Gamma-ray Observations

Gamma ray emission in novae was expected to occurr at MeV energies, associated to positron annihilation and nuclear de-excitation of nitrogen, oxygen and sodium [31, 86]. However, the first detection of gamma rays from a nova occurred at GeV energies, when the Fermi-LAT instrument observed the emission of the symbiotic nova V407 Cyg [2]. The gamma ray emission is produced by the interaction of the nova shell with the environmental medium of the secondary star: being V407 Cyg a symbiotic nova, ejecta expand in a circumstellar wind and particle acceleration occurs in a blast wave. Fermi-LAT detected GeV gamma ray emission in other novae, among them: V959 Mon, V1324 Sco and V339 Del [5], V5668 Sgr and V1369 Cen [26], V1324 Sco [66], ASASSN-16ma [103],V906 Car [103], V549 Vel [104], RS Oph [27], FM Cir [210].

The GeV light curve of V959 Mon and V1324 Sco are shown as an example in Fig. 6.

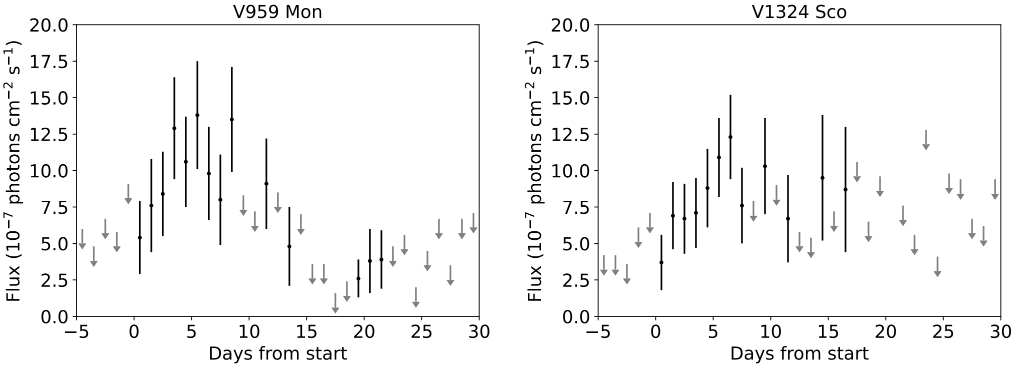

**Figure 6:** Fermi-LAT light curves (above 100 MeV) of V959 Mon and V1324 Sco; data from [5]

While the number of novae observed at GeV energies is steadily increasing, novae at large distance could show fluxes below the detection threshold of current instrument. For example, Fermi-LAT detected gamma rays from 6 novae out of 69 novae discovered during the same interval [118]. Bright and close novae with a magnitude R≤12 and closer than 8 kpc can be potentially detected by Fermi-LAT [118].

Both hadronic and the leptonic models have been proposed to explain GeV emission in novae [5]. In hadronic models nova ejecta interact with nuclei in the environment (novae) or with the stellar wind (symbiotics), producing neutral pions that decay into photons. In leptonic models gamma rays are produced through the interaction of accelerated electrons and photons via Inverse Compton or with atoms via bremsstrahlung.

Novae with gamma ray emission involve the acceleration of relativistic particle at shock sites [113]. The ratio of gamma ray to optical luminosity governs the fraction of the shock power involved in the acceleration of relativistic particle. X-ray emission in the NuSTAR sensitivity band is expected to appear in coincidence with GeV emission [113], falling [206]. On the other hand, generally there is no clear correlation between gamma ray emission and optical emission [121].

Potentially, shocks and relativistic particle acceleration can produce gamma ray emission in the TeV region [114], that is observed with ground based atmospheric Cherenkov detectors. Recently, MAGIC [4] and H.E.S.S. [46] have observed high energy gamma rays from RS Oph, with a temporal profile similar to that of GeV emission [27], suggesting a common origin.

## 7. Novae as possible Neutrino Sources

High energy gamma ray emission in novae could be associated with high energy neutrinos [12, 78, 152, 188]. The observation of GeV emission from novae suggests that shocks are strongly contributors and they are hadron accelerator sites. The IceCube collaboration has performed a search of neutrinos from novae in the energy range from GeV to 10 TeV [1]. The search for correlations between gamma-rays and neutrino emission and between optical and neutrino emission did not find any evidence for neutrino emission from novae [1] which is expected given the low occurrence rate of such events, likely one per decade or even less [78].

## 8. Recurrent Novae

Recurrent novae are a subset of novae showing outbursts with recurrence times of the order of several years or decades [14, 37]. The recurrence time is determined by the white dwarf mass and by the accretion rate [218]. Recurrent novae show an high mass transfer rate and has been proposed as possible progenitors of type Ia supernovae [55, 174]. To date, the statistics of recurrent novae includes 10 systems in the Galaxy (out of more than four hundreds Galactic novae) [157], 4 in LMC [42, 167], about twenty in M31 [174]. There also some classical novae that are recurrent nova candidates, since they have showed a single eruption, but with the same properties of recurrent novae [134]. Galactic recurrent novae are classified into three classes: RS Oph, V745 Sco, T CrB, V3890 Sgr have orbital periods of several hundreds days; U Sco, CI Aql, V394 CrA, V2487 Oph have orbital periods of the order of one day; IM Nor and T Pyx have orbital periods of the order of fractions of days. The historical photometry of the Galactic recurrent novae has been discussed by [157]. The light curves of RS Oph, T CrB, V3890 Sgr, T Pyx are reported in Fig. 7.

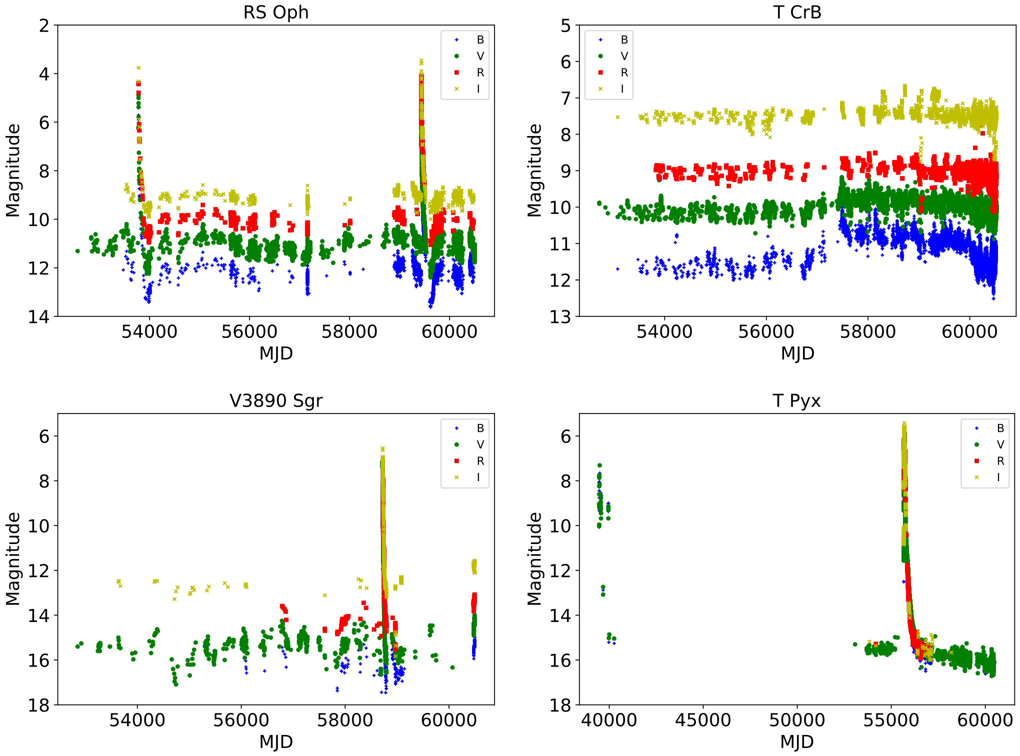

**Figure 7:** The historical light curves of RS Oph, T CrB, V3890 Sgr, T Pyx; data from AAVSO

Recently, the Galactic systems RS Oph, T Pyx, V745 Sco and V3890 Sgr underwent outbursts that triggered a large number of multifrequency observations (see e.g. [13, 15, 43, 63, 94, 124, 128, 130, 132, 190].

The fraction of recurrent novae in M31 is of the order of a few percent, higher than in our Galaxy [174]. The short recurrence time of Nova M31 2008-12a, about one year, makes it an ideal laboratory to study recurrent novae. Several outbursts have been recorded [11, 40, 41, 84]. The object is considered a supernova Ia progenitor candidate [83].

## 9. Novae as Cataclysmic Variables

The orbital period is known only for a fraction of observed novae. The distribution of measured periods is reported in Fig. 8, after excluding novae with evolved secondaries and periods larger than 10 hours. The distribution has a peak between 3 and 4 hours, above the period gap of cataclysmic variable population.

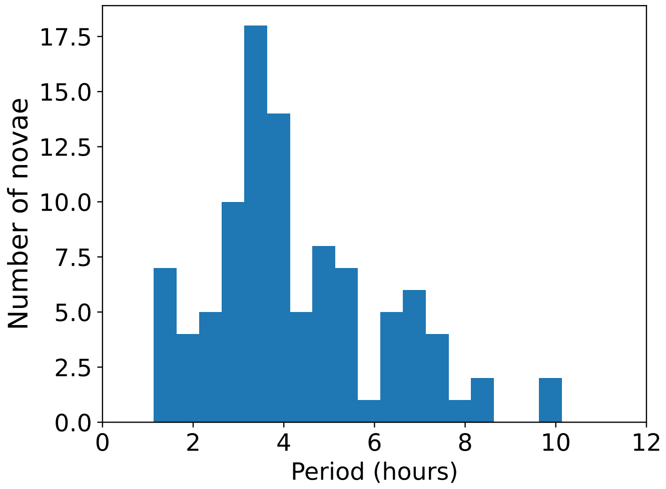

**Figure 8:** Distribution of the orbital periods of Galactic novae; data from [153]

It has been suggested that novae can enter hibernation with a low mass transfer rate [183]. The combination of magnetic braking and gravitational wave emission during the hibernation stage causes an orbit shrinking. The irradiation of white dwarf maintains an high brightness level on time scales of decades after the outburst, followed by fading and variations of the accretion rate, that produce dwarf nova outbursts [183]. Novae are predicted to show a periodic evolution between low and high mass transfer stages [183]. The hibernation stage can last hundreds thousands years. The predictions of the hibernation model are consistent with the observed decline rates of old novae [61] and the observation of shells around cataclysmic variables of different types. Shells have been observed around the dwarf novae Z Cam [184] (that is surrounded also by a second shell [182]), AT Cnc [185] (that underwent a nova eruption about three centuries ago [178]), the dwarf nova in Te 11 associated to nova 483 CE in Orion [115], the nova-likes V1315 Aql [156] and IPHASX J210204.7+471015 [77]. On the other hand, novae can exhibit dwarf nova outbursts: V1213 Cen [181], V1047 Cen [70], Nova Sco 1437 AD [181]. The evolution of novae over long time scales has been discussed by [135]. The pre-outburst light curves of novae show that the quiescent magnitude of the majority is almost identical before and after the outburst [34, 154].

The search for old novae in cataclysmic variable catalogs and observatory plates is often hampered by the lack of spectroscopic classification [90, 91, 133, 200]. Selection criteria combine multicolour photometry and spectroscopic observations when available.

## 10. Galactic and Extra-galactic Nova Rates

### 10.1 Galactic Nova Rates

To date, more than four hundreds Galactic novae are known [59, 60, 153], mostly concentrated around the Galactic plane. The Galactic nova rate plays a relevant role for the Galactic chemical evolution and the nature of progenitors of type Ia supernovae. The Galactic nova rate has been recently reviewed by [168], who proposed a rate of $50^{+31}_{-23}$ yr$^{-1}$. The compilation of estimated Galactic nova rates is reported in Table 1. The discovery rate of Galactic novae is of the order of a few per year, well below the published estimates that are of the order of some tens.

| Authors | Rate (yr$^{-1}$) |
|---|---:|
| Lundmark 1935 [107] | 50 |
| Allen 1954 [6] | 100 |
| Kopylov 1955 [100] | 50 |
| Sharov 1972 [186] | 260 |
| Liller and Mayer 1987 [105] | 73±24 |
| Della Valle 1988 [47] | 15±5 |
| Ciardullo et al. 1990 [29] | 11-46 |
| van den Bergh 1991 [203] | 16 |
| Della Valle and Livio 1994 [53] | 15-24 |
| Hatano et al. 1997 [82] | 41±20 |
| Shafter 1997 [165] | 35±11 |
| Shafter 2002 [166] | 36±13 |
| Matteucci et al. 2003 [110] | 25 |
| Darnley et al. 2006 [38] | $34^{+15}_{-12}$ |
| Mroz et al. 2015 [119] | 13.8±2.6 |
| Shafter 2017 [168] | $50^{+31}_{-23}$ |
| De et al. 2021 [44] | $43.7^{+19.5}_{-8.7}$ |
| Kawash et al. 2022 [99] | 26±5 |
| Zuckermann et al. 2023 [220] | $47.9^{+3.1}_{-8.3}$ |

**Table 1:** Galactic nova rates

### 10.2 Extragalactic Nova Rates

The observations of Galactic novae are affected by the interstellar absorption, that is a lesser concern when observing novae in other galaxies. The properties of extragalactic nova populations have been reviewed by [169, 171]. The nova rates for a selection of close galaxies will be discussed below.

The nova rate in M31 has been investigated by several authors. M31 hosts two nova populations, disk and bulge [38]. The survey of the M31 bulge by [202] was consistent with the Galactic nova population, as shown also by the observation of the fraction of Fe II and He/N novae [173]. The estimated nova rates in M31 are summarized in Table 2.

| Authors | Rate ($yr^{-1}$) |
|---|---:|
| Hubble 1929 [89] | 30 |
| Arp 1956 [9] | 26±4 |
| Capaccioli et al. 1989 [19] | 29±4 |
| Shafter and Irby 2001 [175] | $37^{+12}_{-8}$ |
| Darnley et al. 2006 [38] | $65^{+16}_{-15}$ |
| Chen et al. 2016 [22] | 97 |

**Table 2:** M31 nova rates

The estimates of the nova rate in M33 are reported in Table 3. The M33 rate is predicted to be higher than the M31 one [57]. Differently from Galactic and M31 novae, a survey reported a prevalence of He/N novae [172].

| Authors | Rate ($yr^{-1}$) |
|---|---:|
| Sharov 1993 [187] | <0.4 |
| Della Valle 1994 [57] | 4.7±1.5 |
| Williams and Shafter 2004 [217] | $2.5^{+1.0}_{-0.7}$ |
| Della Valle and Izzo 2020 [52] | $4.2^{+1}_{-0.8}$ |

**Table 3:** M33 nova rates

The rate of LMC novae is of the order of a few novae per year: 2-3 $yr^{-1}$ [76], 2±1 $yr^{-1}$ [20], 2.5±0.5 $yr^{-1}$ [49], 2.4±0.8 $yr^{-1}$ [120]. The survey of LMC novae by [167] found a comparable statistics for Fe II and He/N novae and faster decline times with respect to Galactic and M31 novae. The estimated rate of SMC novae is 0.9±0.4 $yr^{-1}$ [120]. The larger fraction of He/N novae in LMC and M33 is due to the young stellar population, leading to more massive white dwarfs and to an higher number of recurrent novae.

The estimations of the rate in M87 span a broad range: 91±34 $yr^{-1}$ [170]; $154^{+23}_{-19}$ $yr^{-1}$ [35]; $363^{+33}_{-45}$ $yr^{-1}$ [177]; $352^{+37}_{-437}$ $yr^{-1}$ [180]. The novae discovered in M87 recent surveys [177, 180] are concentrated along the galaxy jet [102].

The relation between the nova rate and the K-band luminosity of the host galaxy [57, 170] is investigated using the Luminosity Specific Nova Rates (LSNR) [110, 171, 219] (Fig. 9).

## 11. Maximum Magnitude Rate of Decline (MMRD) and Nova Distances

Despite their transient nature, novae are distance indicator candidates, since they can achieve a brightness much larger than that of other indicators, such as Cepheids. Novae have been suggested as possible standard candles in the extragalactic astronomical distance ladder [54, 204]. Searches for novae have been performed with the Very Large Telescope for in NGC 1316 in the Fornax cluster, at a distance of about 20 Mpc [51].

Nova distances have been historically determines using a broad range of methods: the Maximum Magnitude Rate of Decline (MMRD) relations [33, 45, 54, 58, 159, 205], the identity of the absolute

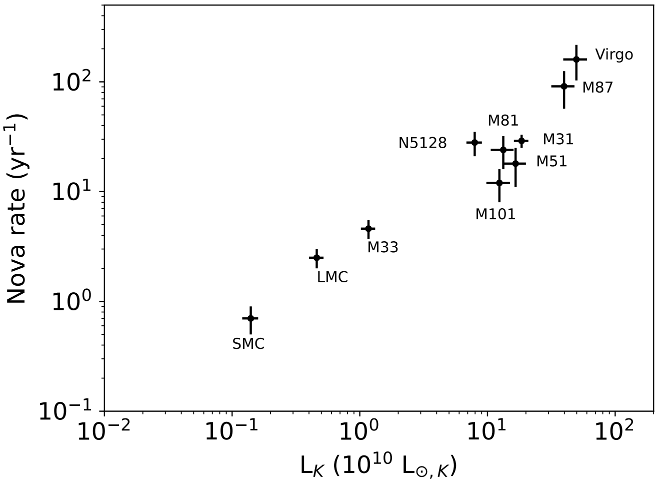

**Figure 9:** Nova rates versus K-band luminosity of host galaxies; data from [110]

magnitude achieved 15 days after the maximum [17, 19, 32, 205], nova expansion parallax [189], the location of the red clump giants in the infrared color-magnitude diagram [131].

The use of absolute magnitude at 15 days after maximum as a standard candle has been recently rediscussed and it is considered reliable for elliptical galaxies like M87 [179], but not for spiral galaxies like M31 due to the large scatter in nova magnitude [39, 179]. The investigation of a large sample of novae in M31 suggested that the peak luminosity of M31 novae are weakly correlated with the rates of decline, confirming previous observations [30]; in addition, the dispersion of the magnitudes measured after 15 days was not significantly smaller that the dispersion at maximum light.

The Gaia satellite has contributed to distance estimations for several novae [3, 151]. The work by [158] has compared the Gaia parallaxes of 41 novae with previous distance estimates. The Gaia DR2 distance estimations of 18 novae have been used by [163] to produce a new MMRD relation.

## 12. Conclusions

Novae are multifrequency sources whose observation can provide information on accretion processes and on cataclysmic variables. All sky high cadence surveys and high energy observatories are contributing to the understanding of physical processes occurring in novae.

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