OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jun **Proposal type:** long-term

MMT Optical Spectroscopy of Faint CNe

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Abstract of Scientific Justification

Novae (CNe) are important contributors to galactic chemical enrichment on local scales. Optical spectroscopy of novae provides information about the elemental abundances of the gas in the ejecta dispersing into the interstellar medium (ISM) as well as kinematic information related to the outburst. We propose to obtain optical spectra with the Blue Channel Spectrograph of faint novae returning to quiescence ([V]$\simeq$ 17), as well as recently discovered adolescent novae, to study the dynamics of the ejecta, to determine the temporal evolution of coronal lines, recombination lines (measuring their strength and velocity profiles), and to determine whether or not the [Fe X] 6374Å emission line is present – an indicator of the supersoft x-ray phase. The optical spectra, which will be supplemented with published and unpublished infrared, ultraviolet and x-ray spectra, are critical to determining accurate abundances of nova ejecta. These abundance solutions will help determine the importance of nova contributions to the ISM and, in particular, the roll that novae play in the abundances of certain intermediate mass elements observed in the ISM and meteorites. Sources selected for study include those targeted as part of our science programs awarded time on HST, Newton-XMM, SOFIA, and Swift. Our efforts are part collaborative program between investigators at ASU, the LBTO, and Minnesota. **The proposal is a U. Minnesota GTO request.**

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/9	Blue			2	dark	Jun	Jun	no	no

Scheduling constraints and unusable dates *(up to 4 lines)***:** Target visibilities (RAs 17-02 hrs) and low Decl (down to -33°) and lunar phase restrict observing windows to near dark time conditions in June 2015, near 17 June or after. The PI *is unavailable* 5-9 and 12-15 Jun due to meeting travel.

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A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	EG131	19:20:35.0	-07:40:06.0	12V
2	V745 Sco-γ	17:55:22.3	-33:14:58.5	14V
3	V339 Del-γ	20:23:30.7	+20:46:04.1	12V
4	NvCyg2014	20:21:42.3	+31:03:29.4	13V
5	NvCep2014	20:54:23.8	+60:17:06.9	17V
6	V809 Cep	23:08:04.7	+60:46:52.1	19V
7	NvSgr2014	18:25:08.6	-22:36:02.4	14V
8	V5558 Sgr-[FeX]	18:10:18.4	-18:46:51.0	17V
9	V5593 Sgr-[FeX]	18:19:37.0	-19:07:40.0	17V
10	V5590 Sgr	18:11:03.7	-27:17:30.2	17V
11	V458 Vul	19:54:24.0	+20:52:52.0	18V
12	V2491 Cyg	19:43:01.9	+32:19:13.8	15V
13	V2468 Cyg-[FeX]	19:58:33.6	+29:52:04.6	16V
14	V407 Cyg-γ	21:02:09.8	+45:46:33.0	14V
15	V1974 Cyg	20:30:31.6	+52:37:51.3	17V

Approval for Instrument Use from PI: ______________________________

*(have instrument PI signature appear on, or attach PI e-mail to, **all** copies)*

Graduate students *(provide the following information for **each** student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on **all** submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Amanda Wilber	SS, RMW, CEW		yes	no

Scientific Justification

Novae occur in close binary systems in which a white dwarf (WD) accretes hydrogen-rich material from a companion, either through a stream or a wind. Core material is mixed into the accreted material and is violently ejected (with velocities of $\simeq$ 100 km s^{-1} to $\gtrsim$1000 km s^{-1}) into space when a thermonuclear runaway (TNR) is initiated. Novae thus eject a mixture of material accreted from the companion star, core material from the underlying WD, and products of nucleosynthesis occurring during the TNR into the ISM; where the ejected mass ranges from 10^{-7} to 10^{-3} $M_{\odot}$ (cf., José 2013; Starrfield et al. 2012; Woodward & Starrfield 2011).

Initially the radiative output of a nova peaks in the optical. However, as the density in the ejecta drops from expansion and the mass loss rate from the WD surface declines, successively hotter layers of the WD ejecta are revealed (e.g., Metzger et al. 2014). The decline in the optical ([V]), generally measured as the time to decline 2 magnitudes from maximum (t_2) defines the nova speed class. The t_2 time has been assumed to be inversely related to the WD mass since a massive WD accretes less material before a TNR begins, leading to a smaller ejected mass. The composition in the TNR region is also important, ultimately affecting $\dot{M}$. The bolometric luminosity remains constant near the Eddington luminosity as long as hydrogen fuel remains on the WD. This energy powers the later spectral evolution and can be observed, once the ejected material has sufficiently cleared, as a bright and soft X-ray source. In novae, this evolutionary phase is designated as the SSS-phase due to the close observational resemblance to supersoft X-ray binaries (Kahabka & van den Heuvel 1997). In the optical, onset of this phase is associated with the presence of [Fe X] 6374Å emission (e.g., Ness et al. 2008). Once nuclear burning ends, the X-ray light curve fades as the WD cools and the system returns to quiescence.

Novae are unique laboratories in which several poorly-understood processes are observed (e.g., mass transfer, TNR, optically thick winds, common envelope evolution, shocks, non-spherical ejection geometries, etc.) – many in real time. Therefore, the physics involved in novae outbursts has direct applications to many areas of astrophysics including deciphering the progenitors and evolution of Supernova Ia's (Dilday et al. 2012). Recently, Fermi/LAT has discovered transient γ-ray emission ($E \gtrsim$ GeV) coincident with six recent novae, two of which are symbiotic systems (cf., Ackermann et al. 2014). These latter detections have opened a new process to study in CNe. Contemporaneous optical observations, combined with Swift/HST/Chandra/XMM-Netwon observations of Fermi/LAT detected novae enable an unparalleled opportunity to identify the origins of the γ-ray photons. However, to achieve this objective and to understand other surprising phenomena requires dedicated, multi-wavelength monitoring to fully capture the underlying physics (e.g., Schwarz et al. 2014). Synoptic optical spectroscopy of these systems enable exploration of the temporal evolution of CNe which tightly constrains models describing the fundamental physics of these events (e.g., Shore et al. 2011).

Our MMT program continues our long-term observational studies of CNe. *Specific outcomes of our panchromatic study of the CNe event address: (i) the evolution of the stellar remnant and the ejected material by virtue of the changing states of ionization of the ejecta; (ii) the nascent shaping of the ejecta, as revealed by the evolving structure in the emission lines (filling factor, structured line profiles, etc.); and (iii) the temporal processing of dust (if present) in the environs of a hard UV or X-ray radiation field.*

One of our key targets is V339 Del (Nova Delphinus 2013). V339 Del (a CO-nova) was one of the 30 brightest novae ever discovered. We have an extant, long-term Swift GI-ToO (CY10) programs, complemented by approved campaigns including HST (+STIS) ToO and SOFIA programs to observe the long term evolution of this source. These data, combined with contemporaneous extensive ground-base optical monitoring will enable a transformative study of this source. V339 Del is archetype for our MMT activities, satisfying observational criteria including: detection by Fermi/LAT, high expansion velocity FWHM $\gtrsim$1800 km s^{-1} and low extinction (measured E(B-V) = 0.182).

References

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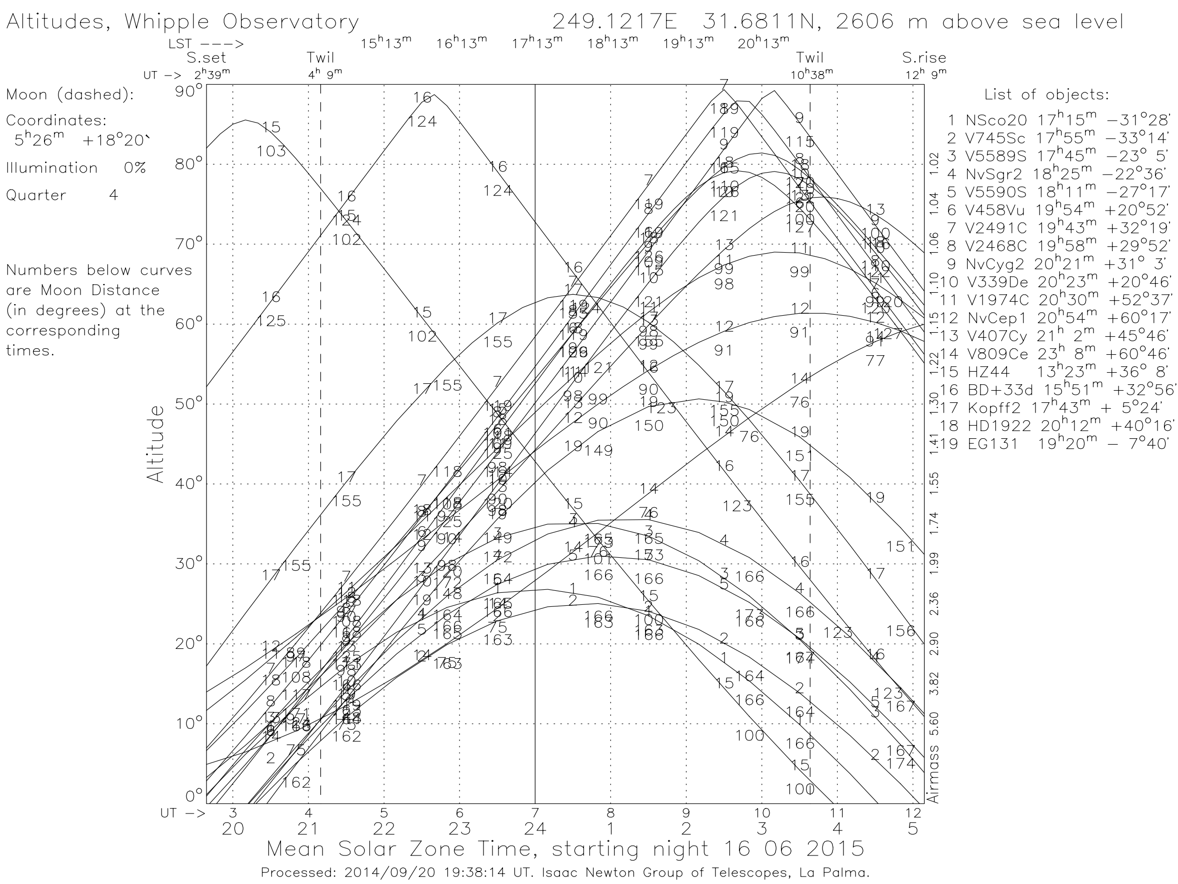

Figure 1: Representative target visibility and airmass for 16 June 2015, within the **optical dark time** window requested for MMT observations in 2015A.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

Target visibilities and lunar phase dictate that 2015 Jun 10 through 19 is the optimal "dark-time" window (required to balance UM usage of telescope time considering lunation) to conduct our observations, particularly spectroscopy of V339 Del (see Fig. 1).

CNe evolve temporally over periods of months. MMT data, complemented by deliberate, contemporaneous, and synoptic panchromatic observations conducted by our group (over the last 15 yrs), have shed new light on the post-eruption evolution of recurrent novae (RNe) and CNe, insight into the physics of the TNR, characteristics of the WD progenitor, and assessment of whether WD mass can potentially grow (via accretion) to exceed the Chandrasekhar Limit. The overall rationale for our integrated effort is to study the dynamical evolution of CNe, to determine absolute abundances (i.e., metals relative to H), to infer ejecta density, to estimate line of sight extinction (hence limits on system distance). We need and to acquire MMT spectra for inclusion in panchromatic data sets which are required for rigorously constraining models. Specific outcomes of this MMT effort address: (i) the elemental abundance pattern in the ejecta and especially the ejected mass, (ii) the nascent shaping of the ejecta, as revealed by the evolving structure in the emission lines (filling factor, structured line profiles, etc.); and (iii) the temporal processing of dust in the environs of a hard UV or X-ray radiation field.

Photoionization models provide estimates of ejecta abundances, ejected masses, and densities as well as source luminosities and temperatures. Modeling of multiple epochs also enables assessment of whether abundance patterns change as the ejecta evolve and the radiation field varies. Photoionization models become tightly constrained if panchromatic, contemporaneous spectra are available. Typically our analysis of the emission line spectra utilizes the Cloudy photoionization code, C07.02.02 (Ferland et al. 1998). Cloudy generates predictions of output spectra from non-LTE, illuminated gas clouds by solving the equations of thermal and statistical equilibrium for a given set of input parameters (i.e., observed emission line fluxes). In the early optically thin phases of evolution atmosphere models also can prove useful in interpreting the spectral energy distribution (cf., van Rossum 2012). The MMT spectra, combined with spectroscopy at UV through infrared wavelengths tightly constrains photoionization models of the radiating ejecta. These models provide guidance to interpret the evolution of the TNR, which is dependent upon the mass and luminosity of the WD, the rate of mass accretion, the composition of the accreted material, and the chemical composition in the reacting layers. The manner in which material is ejected and its relation to the properties of the central binary system can be deduced by following the evolution of the spectra through various phases (Woodward & Starrfield 2011, Shore et al. 2011, Helton et al. 2010, Lynch et al. 2008, Schwarz et al. 2007).

$\boxed{\textbf{Summary of Time Requested and Awarded}}$ *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

This proposal is part of an on-going collaborative project, requesting $\simeq 3$ nights per semester to suport synoptic and temporal monitoring of novae and other systems at a variety of facilities available to the CoIs. MMT observations are necessary to obtain high quality SNR spectra of target nova too faint for our synoptic "reconnaissance" spectroscopy conducted at the BoK or the MDM 2.4-meters. These optical observations also support our current HST (CoI-Woodward Cy21/20 Awarded Programs), Swift (PI-Woodward Cy10/09 Awarded Program), Chandra (PI, Starrfield; CoI-Woodward Cy15 Awarded Program), and SOFIA (CoI-Woodward Cy1/2 Awarded Programs).

A follow-on proposal will be submitted through the U. Arizona TAC for 2015B observing time at the MMT to match the night commitment in 2015A from the U. Minnesota by the ASU and LBTO CoIs for this science.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

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