OBSERVING REQUEST
University of Arizona Observatories

Year: 2017 **Term:** Jul–Dec **Proposal type:** long-term

MMT Recconaissance Optical Spectroscopy of Faint CNe

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Abstract of Scientific Justification

Classical Novae (CNe) are important contributors to Galactic chemical enrichment. Optical spectroscopy of novae provides information about the elemental abundances of the gas in the ejecta dispersing into the ISM as well as kinematic information related to the outburst. For example, high resolution optical spectroscopy of V339 Del and V1369 Cen show the presence of Be II and Li I spectral lines, respectively, originating through the nuclear decay of 7Be to 7Li in the expanding nova ejecta. The amount of Li is sufficient to account for the overabundance of Li observed in young stellar populations given the observed Galactic nova rate. We propose to obtain optical spectroscopy (Blu/Red Channel) of recent faint CNe (V 17-20) and gamma-ray emitting CNe in particular as they return to quiescence. We will investigate the dynamics of the ejecta, determine the temporal evolution of both coronal and recombination lines (measuring their strength and velocity profiles), and assess whether or not the [FeX] 6374A emission line is present – an indicator of the super–soft X-ray phase. **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/Red			2	grey/dark	Sept	Sept-Oct	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: Target visibilities (RAs 17-19 hrs) and low Decl (down to -33°) and lunar phase restrict observing windows to near grey/dark time conditions in mid-Sept to early-Oct 2017. The PI *is unavailable* in 6-9 Sept (first week of academic year).

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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	V5668Sgr-[FeX]	18:36:57.0	-28:55:42.0	14V
4	V339 Del-γ	20:23:30.7	+20:46:04.1	12V
5	V2491 Cyg	19:43:01.9	+32:19:13.8	15V
6	V2468 Cyg-[FeX]	19:58:33.6	+29:52:04.6	16V

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 if student is PI on the cover page or if this is a 2nd-year or Thesis program. Send confirmation email to TAC chair in place of signature.)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis

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} $M_{\odot}$ (Starrfield et al. 2012, BASI 40,419; Woodward & Starrfield 2011, CanJPhys 89, 333).

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. The optical ([V]) decline, the time (days) to decline 2 mags from maximum (t_2) defines the nova speed class and is 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 sufficient 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. In the optical, onset of this phase is associated with the presence of [Fe X] 6374Å emission (Ness et al. 2008, AJ 135, 1328). 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, Science 337, 942). High resolution optical spectroscopy of V339 Del and V1369 Cen showed the presence of Be II and Li I spectral lines respectively originating through the nuclear decay of 7Be to 7Li in the expanding nova ejecta. The amount of Li is sufficient to account for the overabundance of Li observed in young stellar populations given the observed Galactic nova rate. Transient γ-ray emission ($E \gtrsim$ GeV) is detected in many novae with Fermi/LAT (cf., Cheung et al. 2016, ApJ 826, 142). These latter detections have opened a new process to study in CNe. Ground-based optical observations, combined with space-based 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 (Schwarz et al. 2015, AJ 149, 95). Optical spectroscopy enables exploration of the temporal evolution of CNe which tightly constrains models describing the fundamental physics of these events.

Our MMT program targets recent faint CNe (V $\simeq$ 17–20) and γ-ray emitting CNe currently under study in our Swift/Newton-XMM/SOFIA programs that are poorly accessible from northern observatories. With these data we will address: (i) the evolution of the stellar remnant and the ejected material by measurement of the states of ionization of the ejecta; (ii) the nascent shaping of the ejecta, as revealed by the structure in the emission lines (filling factor, structured line profiles, etc.); (iii) the temporal processing of dust (if present) in the environs of a hard UV or X-ray radiation field (especially for systems exhibiting the [Fe X] emission line which is indicative of the SSS x-ray phase of evolution); and (iv) the ejecta mass of the shell (e.g., [O III] 4363, 4959, 5007 Å emission lines to determine the column densities).

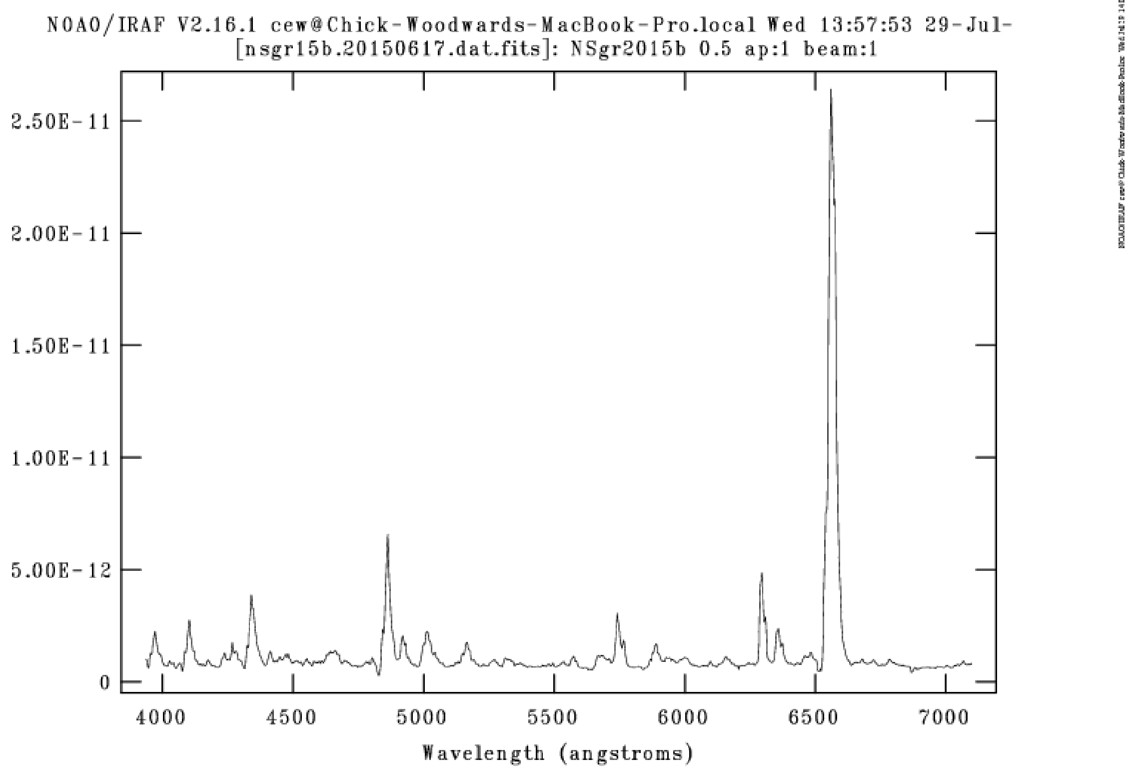

Figure 1: Example MMT spectra of PNV J18365700-2855420/Nova Sgr 2015 No. 2/V5668 Sgr which is also one of our Swift/SOFIA targets to study the supersoft X-ray phase i and dust formation in CNe (adopted from Gehrz et al. 2017, ApJ submitted).

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 mid-September 2017 is the optimal "grey/dark-time" window (required to balance UM usage of telescope time considering lunation) to conduct our observations.

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, C13.05 (Ferland et al. 2013, RMxAA 49, 137). 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. 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.

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, to obtain panchromatic synoptic and temporal monitoring of novae and other systems at a variety of ground-based facilities (e.g., MDM, LBT) available to the CoIs. MMT observations are necessary to obtain high quality SNR spectra of target faint nova whose declination's inhibit effective observations from northern facilities, and those targeted by Swift/HST/Newton-XMM/NASA SOFIA assets awarded time.

We are supported to conduct observations of nova systems through NASA grants through these latter facilities, as well as the NASA Theory programs to study and model the thermal nuclear runaway (TNR) associated with the CNe event. Our team has an extensive publication record related to the observational and theoretical study of classical novae systems.

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**)*

⋆ Finzell, T. and 33 colleagues 2017. A Detailed Observational Analysis of V1324 Sco, The Most Gamma-ray Luminous Classical Nova to Date. The Astrophysical Journal, in press.

⋆ Evans, A., and 18 colleagues 2017. Rise and fall of the dust shell of the classical nova V339 Delphini. Monthly Notices of the Royal Astronomical Society, in press.

⋆ Pavlenko, Y. V., Kaminsky, B., Rushton, M. T., Evans, A., Woodward, C. E., Helton, L. A., O'Brien, T. J., Jones, D., Elkin, V. 2016. Modelling the spectral energy distribution of the red giant in RS Ophiuchi: evidence for irradiation. Monthly Notices of the Royal Astronomical Society 456, 181-191.

Schlieder, J. E., and 23 colleagues 2016. The LEECH Exoplanet Imaging Survey: Orbit and Component Masses of the Intermediate-Age, Late-Type Binary NO UMa. The Astrophysical Journal 818, 1.

Skemer, A. J., and 41 colleagues 2016. The LEECH Exoplanet Imaging Survey: Characterization of the Coldest Directly Imaged Exoplanet, GJ 504 b, and Evidence for Superstellar Metallicity. The Astrophysical Journal 817, 166.

Woodward, C. E., and 10 colleagues 2015. SOFIA Infrared Spectrophotometry of Comet C/2012 K1 (Pan-STARRS). The Astrophysical Journal 809, 181.

Conrad, A., and 19 colleagues 2015. Spatially Resolved M-band Emission from Io's Loki Patera-Fizeau Imaging at the 22.8 m LBT. The Astronomical Journal 149, 175.

⋆ Raj, A., and 10 colleagues 2015. IR Study of Nova V2468 Cyg from Early Decline to the Coronal Phase. The Astronomical Journal 149, 136.

Maire, A.-L., and 38 colleagues 2015. The LEECH Exoplanet Imaging Survey. Further constraints on the planet architecture of the HR 8799 system. Astronomy and Astrophysics 576, A133.

⋆ Danilet, A. B., Holoien, T. W.-S., Wagner, R. M., Woodward, C. E., Starrfield, S., Wilber, A., Walter, F., Shore, S. 2015. Optical Spectroscopy of Nova Ophiuchi 2015 (PNV J17291350-1846120). The Astronomer's Telegram 7339, 1.

⋆ Wilber, A., Neric, M., Starrfield, S., Wagner, R. M., Woodward, C. E. 2015. Optical Spectroscopy of GK Per (Nova Per 1901) during the 2015 Outburst. The Astronomer's Telegram 7217, 1.