GEMINI OBSERVATORY

observing time request summary

Semester: 2015A **Observing Mode:** Fast Turnaround **Gemini Reference:**

Instruments: GMOS North

Time Awarded: NaN **Thesis:** No

Band 3 Acceptable: No

Title: **Gemini-N GMOS Observations of EU Cnc**

Principal Investigator: **Steve Howell**
PI institution: NASA Ames Research Center, , USA
PI status: PhD
PI phone/e-mail: / steve.b.howell@nasa.gov
Reviewer: Steve Howell

Partner Submission Details *(multiple entries for joint proposals)*

		PI Request		NTAC Recommendation			
Partner	**Lead**	**Time**	**Min**	**Reference**	**Time**	**Min**	**Rank**
	Total Time	*2.5 hr*	*2.0 hr*		*0.0 hr*	*0.0 hr*	

Abstract

We plan to obtain phase-resolved blue spectroscopic observations for the magnetic cataclysmic variable EU Cnc. This system contains a white dwarf with a 40 MG field in a 2.1 hr orbit with a low-mass M star. The Gemini-N observations are part of a multi-wavelength campaign on this star, lead by a continuous 83-day, 1-minute sampled K2 photometric observation. The GMOS spectra will yield high value science results as cornerstone data in this campaign.

TAC Category / Keywords

Galactic / White dwarfs, Variable stars, Binaries, Accretion

Scheduling Constraints

The spectra must be taken in a continuous manner over the 2-2.5 hours of time.

Observation Details (Band 1/2)

Observation	RA	Dec	Brightness	Total Time *(including overheads)*
EU Cnc	08:51:27.209	11:46:57.000	20.00 V Vega	2.5 hr
Conditions: CC 50%/Clear, IQ 70%/Good, SB 80%/Grey, WV Any **Resources:** GMOS-N LongSlit None B1200 None 0.75 arcsec slit				

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

This is a Fast Turnaround Program proposal.

The star EU Cnc is the first and only cataclysmic variable to be rigorously shown to be a member of an open star cluster (Williams et al., 2013). As such, its age, metal content, absolute luminosity, evolution time line, white dwarf progenitor mass, etc. can be well known due to the decades of work performed on Messier 67. These properties alone make EU Cnc a valuable target to observe. We were just awarded K2 mission, Campaign 5 observations of EU Cnc in Jan 2015. C5 starts on 26 April 2015 and we will obtain 1-minute sampled photometric observations of EU Cnc, continuously covering the entire 83-day campaign. No magnetic CV (polar) was known, discovered, or observed in the original Kepler field by the Kepler mission and, to date, none have been observed in the K2 mission. Thus, the K2 observations will provide an unprecedented photometric dataset and our proposed Gemini-N GMOS observations will do the same for spectroscopy.

EU Cnc consists of a magnetic white dwarf (WD) primary star (mass$\sim$0.7-0.8 M-sun) with a magnetic field strength of B=41MG. Its binary companion, an M5 star, co-orbits with a period of 2.1 hr. Mass is transferred from the M5 star to the primary and accretes onto the WD via accretion streams striking the WD surface at one or both of the magnetic poles. The pole regions are much higher in temperature than the surrounding surface due to the direct impact of material and vary as the accretion changes both rate and which pole(s) collect material. As the magnetic poles come into and out of view of the observer, the effects of cyclotron humps (lying in the visible band for a 40MG star) modulate the spectral continuum. These signatures of cyclotron cooling radiation near the magnetic poles (Fig. 1) provide fingerprint-like patterns allowing the magnetic field structure to be ascertained and the accretion dynamics to be measured. Spectroscopic changes occur continuously in both the continuum and in the lines.

Photometric modulation occurs in the light output of EU Cnc on various timescales. These timescales range from the orbital period (2.1 hr) to much shorter events such as cyclotron hump flux changes and accretion flare events as magnetically trapped plasma at the stagnation points in the streams fall onto the WD surface at velocities of up to 1200 km/sec. While we say the magnetic field strength of EU Cnc is 41 MG, it is actually different for each pole (41 MG is the pole-averaged value) and can be differentiated spectrally via measurement of each pole's cyclotron humps. The poles rotating in and out of view, cause the optical brightness to increase from the minimum value for EU Cnc (V$\sim$20-21) to 0.2 to 1.5 magnitudes brighter.

Figure 2 shows the light curve of EU Cnc and the large modulation due to orbital motion. Accretion events last seconds to minutes and their shape and duration can tell us about the physical location of magnetic entraining above the WD surface. Here the material is temporarily held in the so-called stagnation region before magnetic forces collapse it, causing the material fall to the WD surface. Additionally, as the magnetic poles rotate in and out of view, the white dwarf limb emitting the cyclotron emission acts as a "knife-edge" and allows the size and location of the poles to be precisely measured (Sirk and Howell 1998).

We are carrying out a multi-wavelength campaign of EU Cnc in order to collect high time and high spectral resolution observations. The AAVSO will be providing multi-color photometric observations, K2 will provide high time sampled, white light photometric observations (1-minute, 83 days), SWIFT will provide a few binary star orbits of X-ray and UV observations, and here we are proposing for phase-resolved optical spectral observations. We plan to obtain phase-resolved GMOS spectra that will be of higher S/N and higher spectral resolution than the one previous study (Williams et al., 2013) and contemporaneous with our K2 program.

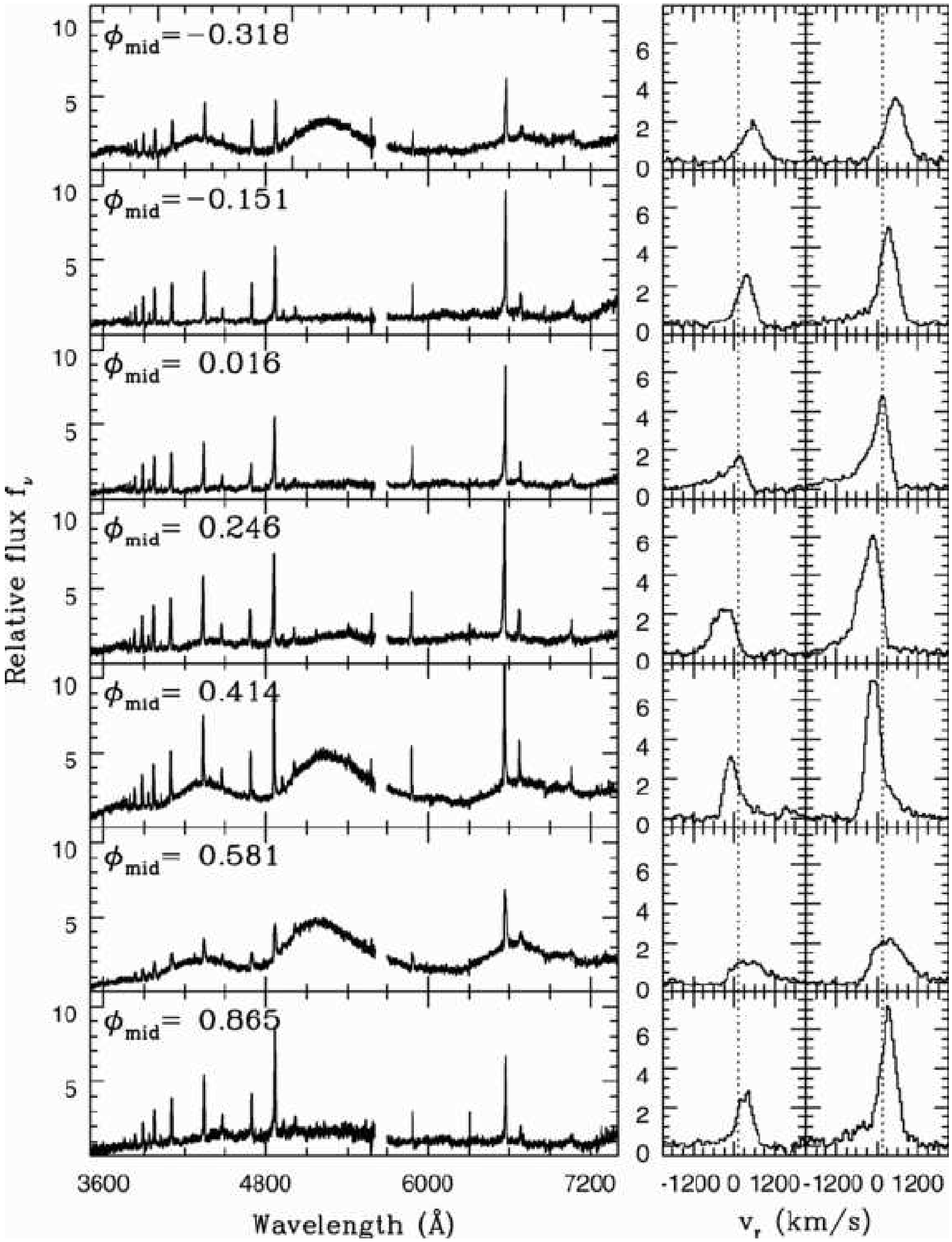

Figure 1: Time-ordered spectroscopy of EU Cnc from Keck I & LRIS. The left panels contain the entire spectrum; the break near 5650Å is the gap between the blue and red arms of the spectrograph. Note the changing spectral continuum due to cyclotron emission from the highly magnetic (41 MG) white dwarf as the magnetic poles rotate in and out of view. The right panels contain close-ups of the He II 4686 line (left) and Hβ line (right); the radial velocity variations and variable line asymmetries are clearly visible. Phase 0 indicates the negative zero crossing of the narrow-line component (secondary star) of the emission lines. (From Williams et al. 2013.)

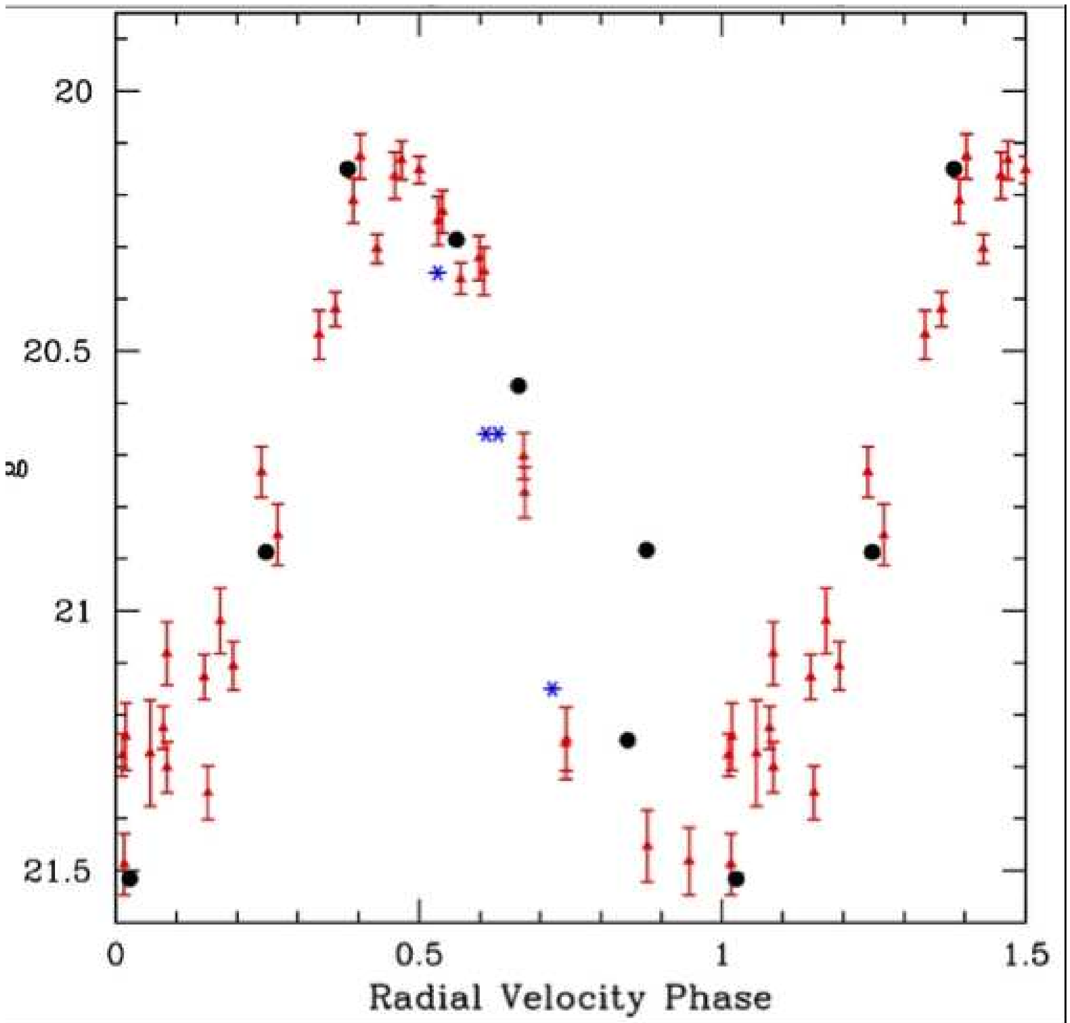

Figure 2: The light curve for EU Cnc. Filled circles are photometric data from WIYN; error bars are not included but are approximately 0.03 mag. Filled triangles with error bars are data from Nair et al. (2005), shifted in phase by an arbitrary offset. Blue stars are spectropolarimetric data from Williams et al. (2013). EU Cnc varies by 1-2 magnitudes over its 2.1-hr orbit.

Experimental Design *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. (Limit text to one page)*

The K2 observations of EU Cnc will cover the time period of 26 April to 11 July 2015. Simultaneous ground-based observations of K2 fields are hard to impossible, as the satellite is in an Earth-trailing orbit, currently about 0.5 AU away and observes a different sky than our night time. Thus, we wish to get "near in time" observations from the ground while the target star is still well placed for observation. The 9-10 March 2015 Fast Turnaround Program dates are best for this observation, early April dates would be fine as well.

Figure 1 shows that qualitatively, the spectra of EU Cnc appear fairly typical for a magnetic-type interacting binary system in a low accretion state. Cyclotron humps (the cooling mechanism of the accreted material near each magnetic pole) are visible and variable in strength throughout the orbit. The largest modulation effect is the geometric line of sight to each magnetic pole with detailed changes being due to individual pole strength and accretion rate variations (e.g., Sirk and Howell, 1998). Emission lines of H and He are observed and appear to have at least two components, a narrow (unresolved) component and a broad component (Fig. 1, right panels). The higher spectral resolution of GMOS will allow much to be learned from these components such as the detailed emission line work presented in Robertson, Howell, et al., (2008).

The emission lines have variable radial velocities, and the radial velocities of the two line components are not in phase. This type of emission line component behavior is often seen in polars, for example VV Pup (Mason et al. 2008), whereby the narrow line component phases with the motion of the secondary star (Mason et al. 2008; Howell et al. 2008). Study of the line components in this low-accretion rate magnetic system will allow mass estimates for both the primary white dwarf and the low-mass secondary - a rare thing in cataclysmic variables.

The stellar and accretion properties of EU Cnc as a function of orbital phase (accretion pole location on the white dwarf) will be exposed to study by our multi-wavelength campaign. Photometric observations will provide good time resolution for accretion events (e.g., flares) and to assess the detailed size and shape of the near-surface pole regions (Sirk & Howell 1998). Our K2 observations will provide photometric coverage of nearly 950 orbits of the binary to both co-add and temporally assess. SWIFT X-ray and UV observations (led by P. Boyd) will yield outer accretion corona structures and allow energy partitioning to be studied as cool material moves along the streams, become heated and shocked, and falls onto the WD surface. The GMOS phase-resolved spectroscopic observations will yield velocity (i.e., mass) values for the two stars as well as gas stream motion between the stars. Temperature and electron densities for the plasma regions can be determined and a general picture of the process formulated. Accretion pole region size (i.e., the plasma region size vs. the WD surface footprint size) can be evaluated as well.

Being a member of M67, the mass of the white dwarf becomes an important piece of information to allow both the progenitor star mass to be determined as well as the evolution of EU Cnc itself. Using CV evolution tracks (Howell et al., 2001), the binary evolution of EU Cnc can be known from main sequence time and orbital period to the present state.

We plan to make all our reduced data public as soon as possible to allow the community to make the best use of the (public) K2 photometry and the Gemini GMOS observations. We will, of course, publish a scientific paper(s) on the entire multi-wavelength campaign, with the Gemini-N GMOS observations being the cornerstone data for detailed interpretation of the binary and its accretion mechanisms.

Proprietary Period: 0 months

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-Gemini facilities, including those available through NOAO. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?*

The EU Cnc campaign will make use a few ground-based telescopes: The AAVSO network of 18 to 36-inch telescopes will obtain phase-resolved multi-color photometric observations and Gemini-N will provide phase-resolved optical spectroscopy. Space-based observations will be provided by SWIFT (X-ray and UV) and K2 (83-continuous days of 1-minute optical photometric observations). All our data will be made public as soon as reduced.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

I have had numerous photometric, spectroscopic, and visitor instrument runs at Kitt Peak (4-m, WIYN) and Gemini-N in the past five years. Most of these data are already published and all are publicly available. I have not proposed for or used GMOS before.

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the exposure times, and the constraints requested (seeing, cloud cover, sky brightness, and, if appropriate, water vapor). If applying for instruments on both Gemini North and South, state the time request for each site. If a Band 3 allocation is acceptable, give the Band 3 time requested from each partner.*

Our previous observations of EU Cnc (Williams, et al, 2013; Fig. 1) represent the only set of detailed, phase-resolved spectral observations that exist for this star. They were collected on UT 2007 January 19 with the low-resolution imaging spectrometer (LRIS) on the Keck I telescope. We obtained simultaneous spectra with both blue and red sides of the spectrograph through a multi-object slit mask with slitlet widths of 10 arcsec. The gratings (600 l/mm) produced spectral resolutions of 7Å (blue) & 4.8Å (red) FWHM. Seven exposures, each of 20 minute integration, were taken over a 2.5 hr period, with two short breaks for mask re-alignment. During the final exposures, the flux dropped dramatically, indicating that the mask was slightly misaligned.

We plan to collect contemporaneous observations (a few months before the K2 observations) and to collect higher spectral resolution observations covering the blue portion of the spectrum. Fig. 1 shows that this region is rich in diagnostic spectral features. The observing plan is to obtain a time series of 8, 1000 sec exposures with GMOS, covering slightly more than one 2.1-hr orbit, covering a total time period of about 2.5 hr. We used the Gemini-N GMOS ITC (and discussions with Kathy Roth) to confirm the following values. The blue spectrum will be imaged using grating B1200, centered at 4500Å and covering 3800-5200Å. Our use of a 0.75 arcsec slit (to accommodate moderate seeing in this Fast Turnaround program) and 2X1 binning yields a S/N of 6-6.5/per pixel. This setting provides 1.4Å spectral resolution and access to the complete Balmer series (sans Hα) and highly diagnostic lines such as Ca II H&K, and He I, II lines (e.g., He II 4686). At this resolution, 4 times better than the LRIS data, we will be able to de-blend the narrow and broad emission line components and produce RV curves for each star, enabling system inclination determination and mass estimates for both stars.

In non-LTE conditions, such as those in a stellar chromosphere or the chromosphere-like regions typically surrounding the accretion poles or in ejected winds, the helium triplet levels are all over-populated due to collisional excitation compared with the singlet levels. The helium triplet lines are known to behave differently than the singlet lines, especially when the formation conditions are non-LTE. In hot (40,000-50,000 K), low-density (Ne=10^{11}) regions, the bifringent behavior in the helium emission lines can be used to assess the physical conditions present (Howell et al., 2013).

GMOS spectroscopy will be rich in scientific diagnostics associated with the Balmer (decrement) and He lines as well as providing RV information for both the secondary star (narrow line components) and the white dwarf (the accretion pole emission being a proxy for the WD motion). These same lines and others (Ca II, Fe, etc.) are well known as indicators for Teff, electron density, and local plasma conditions (Howell et al., 2013; Howell, et al., 2008; Robertson et al.; 2008, Mason, et al., 2008).

References:

Howell, S. B., Nelson, L. A., & Rappaport, S., 2001, ApJ, 550, 897
Howell, S. B., Harrison, T. E., & Huber, M. E., et al., 2008, AJ, 136, 2541
Howell, S. B., Rector, T., Walter, D., 2013, PASP, 125, 879.
Williams, K., Howell, S. B., Liebert, J., et al., 2013, AJ, 145, 129
Sirk, M., and Howell, S. B., 1998, ApJ, 506, 824
Mason, E., Howell, S. B., Barman, T., Szkody, P., & Wickramasinghe, D., 2008, A&A, 490, 279
Nair, P. H., et al., 2005, IBVS, 5585, 1
Robertson, J., Howell, S. B., Honeycutt, R. K., Kafka, S., & Campbell, T., 2008, AJ, 136, 1857

Band 3 Plan *If applying for queue time and it is acceptable for the proposal to be scheduled in Band 3, describe the changes to be made to allow it to be successful in Band 3 (limit text to half a page). Band 3 observations are used to fill the queue when no Band 1 or 2 programs are available. Successful Band 3 programs generally use poorer than median observing conditions, have targets away from the most popular regions of the sky, do not require strict timing or other constraints, and do not require special instrument configurations.*

There is no band three plan for this "Fast Turnaround Program".

Classical Backup Program *If applying for classically scheduled time, describe the program you will pursue should the weather be worse than the requested observing conditions (limit text to half a page).*

Justify Target Duplications *If your targets have been previously observed by Gemini using similar or identical setups to those proposed here, justify the duplication below. Duplicate observations can be identified through a search of the Gemini Science Archive.*

EU Cnc has never been observed by Gemini-N. Keck I phase-resolved observations were obtained in 2007 using LRIS. Phase-resolved GMOS observations will provide higher S/N and better spectral resolution.

ITC Examples *Attach representative Gemini ITC output for each instrument requested.*