GEMINI OBSERVATORY

observing time request summary

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

Instruments: GMOS North

Time Awarded: NaN **Thesis:** Yes

Band 3 Acceptable: No

Title:	**Observations of SU Tauri While In Deep Decline**
Principal Investigator:	**Edward Montiel**
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Reviewer:	Edward Montiel
Mentor:	Geoffrey Clayton

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

		PI Request		NTAC Recommendation			
Partner	**Lead**	**Time**	**Min**	**Reference**	**Time**	**Min**	**Rank**
	Total Time	*0.6 hr*	*0.6 hr*		*0.0 hr*	*0.0 hr*	

Abstract

The R Coronae Borealis (RCB) stars are rare hydrogen-deficient carbon-rich supergiants. Two evolutionary scenarios have been suggested, a double degenerate merger of two white dwarfs (WDs), or a final helium shell flash. Evidence pointing toward a WD merger or a final flash origin for RCB stars is contradictory. The RCB star SU Tau is currently about 9 magnitudes below its maximum V-band brightness of 9.5 mag. We are proposing for Gemini/GMOS imaging to resolve the nebulosity close to the central star, which is normally hidden when the star is bright. This will be accomplished by taking advantage of the natural coronagraph provided by SU Tau while in its deep decline. The unpredictable nature of these declines make these observations ideal for the new Fast Turnaround Observing Mode. We will also use Monte Carlo radiative transfer models to investigate the dust scattering in the shell to help determine its origin. If the progenitors of RCB stars are close WD binaries, then they may be low-mass analogs of more-massive binaries destined to become Type Ia SNe.

TAC Category / Keywords

Galactic / Circumstellar matter, Dust

Potential Problems

The submitted proposal has 1 observation with a low probability of suitable guide stars.

Scheduling Constraints

These observations must be scheduled between March 9 and March 11.

Observation Details (Band 1/2)

Observation	**RA**	**Dec**	**Brightness**	**Total Time** *(including overheads)*
SU Tau	05:49:03.731	19:04:21.872	10.72 B Vega, 9.10 V Vega, 9.80 R Vega, 9.17 J Vega, 8.27 H Vega, 7.09 K Vega	0.6 hr

Potential problems: Some PAs do not have suitable guide stars (64%)
Conditions: CC Any, IQ Any, SB 50%/Dark, WV Any
Resources: GMOS-N Imaging None g (475 nm)+r (630 nm)+i (780 nm)+z (925 nm)

Scientific Justification

We would like to obtain deep Gemini/GMOS of the R Coronae Borealis (RCB) star SU Tau and its circumstellar environment while it is currently in deep decline. The presence or absence of circumstellar material, as well as the morphology of any present material, provides a fossil record of previous evolutionary stages. At present, SU Tau is at V∼18.5 mag, about 9 magnitudes below maximum light. When SU Tau is near maximum light its apparent magnitude is ∼9.5 mag, which makes detecting faint nebulosity near the star impossible. However, the thick clouds of dust that cause the dramatic declines in brightness seen in RCB stars act as "natural coronagraphs, allowing us to study reflection nebulosity seen near these stars. We have already used this technique very successfully with Gemini/GMOS on R CrB, itself, and UW Cen. See Figure 1. The RCB declines occur at irregular intervals that cannot be predicted, so previously this kind of proposal would have been a Target of Opportunity. But the new Fast Turnaround Observing Mode is ideal for catching RCB stars in decline events which may only last a few months. No visible light imaging exists for SU Tau while in a deep decline. These proposed images will complement already existing *Spitzer* and *Herschel* images showing a large (∼2 arcmin) IR shell, seen in Figure 2, around SU Tau.

The RCB stars are a small group of carbon-rich, hydrogen-deficient, post-AGB supergiants. Only about 150 RCB stars are known in the Galaxy and the Magellanic Clouds (Clayton 1996, 2012; Tisserand et al. 2013). Their defining characteristic is unusual variability – RCB stars undergo massive declines of up to 8 mag due to the formation of carbon dust at irregular intervals. Two scenarios have been proposed for the origin of an RCB star: a white dwarf (WD) merger or a final helium-shell flash (FF) models (Iben et al. 1996). The former involves the merger of a CO- and a He-WD (Webbink 1984). In the latter, a planetary nebula central star is blown up to supergiant size by a FF (Renzini 1979).

Most amazingly, in the last decade RCB stars were found to have unique chemical abundances. They have been found to be enriched in both ^{18}O and ^{19}F, which are both by-products of partial He-burning (Clayton et al. 2007; Pandey et al. 2008). These unusual abundances indicate that some nucleosynthesis must have occurred during the formation of the RCB stars (Menon et al. 2013). In addition, several RCB stars show significant Li in their atmospheres making an explanation even more difficult (e.g., Asplund et al. 2000). The production of ^{18}O and ^{19}F requires temperatures large enough to completely destroy any Li present. Hence, the simultaneous enrichment of Li, ^{18}O, and ^{19}F is not expected in the WD merger or FF scenarios.

Three explanations for the origin of this material has been explored by Montiel et al. (2015). These are, 1) fossil Planetary Nebula (PN) shells, which would exist if RCB stars are the product of the FF scenario, 2) material left over from the white-dwarf merger event which formed the RCB stars, or 3) they are material lost from the star during the present RCB-star phase. Prior observations of R CrB, itself, and UW Cen in decline with GMOS, as seen in Figure 1, revealed a morphology similar PNe like the Eskimo or Helix nebula (Clayton et al. 2011). Further, if these envelopes are fossil PNe then they should contain neutral Hydrogen. Montiel et al. (2015) found an upper limit of neutral Hydrogen of $\sim 10^{-1}$ $M_\odot$ based on 21-cm observations for the R CrB shell. They concluded that based on the mass of the dust in the R CrB shell that the dust envelope was most likely constructed from multiple puff ejections during the current RCB phase of the star.

What is needed are observations of a significant sample of RCB stars while in deep declines. However, these declines happen unpredictably and may only last every few years. The Fast Turnaround Observing Mode will enable us to catch these enigmatic stars when they are faint so their shells may be studied in detail. These new data will help us to understand the evolution of the RCB stars and WD mergers.

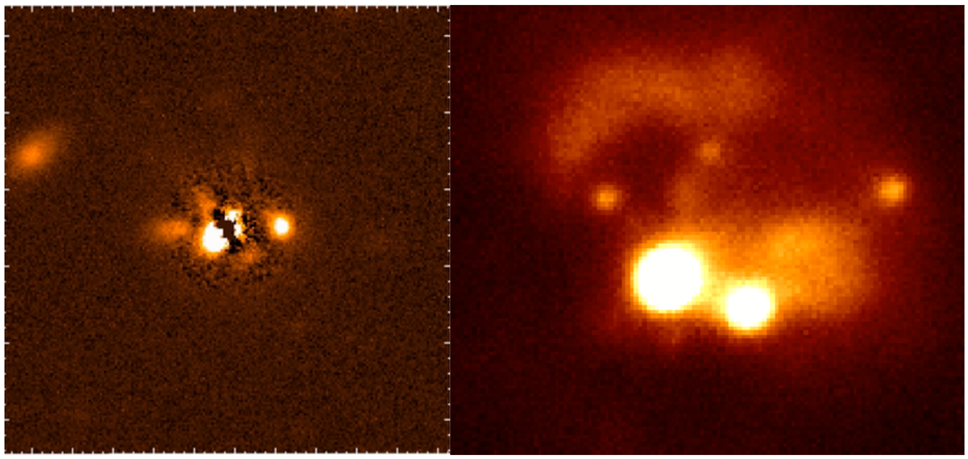

Figure 1: Two panel Gemini/GMOS image of the RCB stars R CrB (left) and UW Cen (right). The R CrB panel has had a stellar PSF subtracted to highlight the surrounding nebulosity. The UW Cen panel has not yet been PSF subtracted, but the surrounding reflection nebula is clearly visible (Clayton et al. 2011, 2015, in prep.).

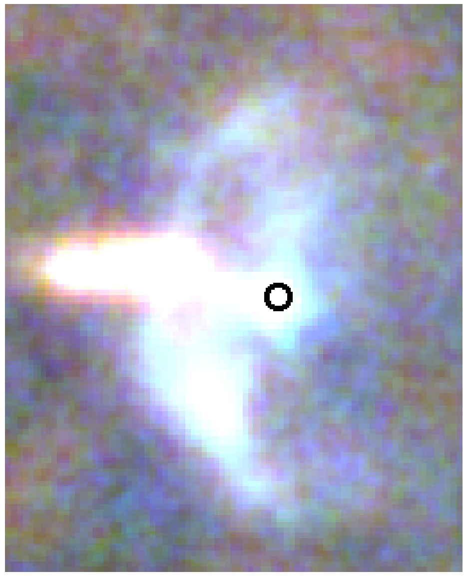

Figure 2: *Herschel* PACS 3-color image of SU Tau with blue, green, and red represented by 70, 100, and 160 μm, respectively. The black circle is 10" in radius and represents the position of SU Tau. We assume that the emission in blue to be associated with SU Tau, while the redder emission is a background galaxy that lies along the line of sight. The field shown is 2.0' $\times$ 2.5' (Montiel et al. 2015, in prep).

References

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Experimental Design

We plan a Fast Turnaround (FT) program to observe the RCB star SU Tau while in deep decline with Gemini/GMOS with the g',r',i', and z' filters. These observations are well suited for the FT observing mode, since we already know that SU Tau is $\sim$ 9 mag below its maximum light and the observations need to be timely as the star may brighten at any time. In this state, the dust obscuring the central star behaves like a natural coronagraph. We will be able to seen the faint nebulosity around the star as the stellar photosphere will be effectively obscured. There are currently no deep optical observations of SU Tau while it is in decline. These proposed images are the only way that clouds close to the star can be examined in visible light reflected from the dust grains. These observations are particularly needed for SU Tau because it lies very close to a large background galaxy. This can be seen in Figure 2. This will enable us to distinguish the SU Tau shell from the nearby galaxy, as we currently lack the resolution in our spaced-based IR imaging. The four broadband filters will provide colors for the dust scattered light that, together with our observations in the mid- and far-IR with Spitzer and Herschel, will allow us to model the radiative transfer in the shell.

To investigate the distribution and nature of the dust, we will use the techniques we have developed in our studies of R CrB and UW Cen (Clayton et al. 1999, 2011, Montiel et al. 2015). We will construct a spectral energy distribution from the visible to the far-IR which we will model using Monte Carlo techniques to calculate the radiative transfer through arbitrary distributions of dust viewed from any angle (Gordon et al. 2001; Clayton et al. 1999, 2011). The new observations of the circumstellar shell around SU Tau will allow us to better distinguish between the three scenarios outlined above for its formation which will give us clues about the evolutionary history of the RCB stars and other WD dwarf merger objects such as Type Ia supernovae.

Technical Description

The GMOS field of view (5.5 square arcmin) is ideal since the nebulosity around SU Tau is $\sim$2? in diameter. We expect the V-band surface brightness of the shell to be about 20 mag arcsec^{-2}, assuming that it is similar in surface brightness to the shells already observed with GMOS observed around R CrB and UW Cen. We plan to take images with the g,r,i, z filters. With SU Tau currently experiencing a deep decline, it will be quite faint (<14 mag), and individual exposures can be 30 s each without saturating the detector. Each field should contain g,r,i standards provided by the AAVSO APASS database so that further photometric standard exposures will not be required. We plan to dither the individual images to fill in the chip gaps. We will use 2? 2 binning and use slow readout.

SU Tau is located at an RA of $\sim$ 5 hours 50 minutes, which means that it can be best observed during the first three scheduled nights for Fast Turnaround (March 9 – 11). It is observed best shortly after twilight for several hours when it will be at reasonable airmasses. This has the further advantage that the waning moon will not be rising until after 2 to 4 hours after the end of twilight, effectively giving us dark time, which will greatly increase our S/N. We expect to get a S/N $\sim$ 20-30 if the surface brightness is similar to the R CrB and UW Cen observations acquired previously with Gemini/GMOS. We will still be able to detect nebulosity even if it is 2 mag arcsec^{-2} fainter than expected. We plan 5 x 30s for the g' and r' filters, and 10 x 30s for the i' and z' filters. Therefore, including overheads, we request 38 minutes with Gemini/GMOS in imaging mode.

Band 3 Plan

While we can tolerate any cloud cover and water vapor, the time of the night sensitivity makes this program not suitable for band 3.

Classical Backup Program

This is not a classical request

Justify Target Duplications

The GSA search revealed no duplicate observations

Publications

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Use of Other Facilities or Resources

There are no non-Gemini related proposals.

Previous Use of Gemini

The PI for this program has had no prior awarded Gemini time.

ITC Examples

See below for the g' filter ITC.

Gemini Integration Time Calculator
GMOS version 5.0

Click here for help with the results page.
software aperture diameter = 1.12 arcsec
enclosed pixels = 47.30

derived image size (FWHM) for a point source = 0.94 arcsec.

Sky subtraction aperture = 5.0 times the software aperture.

Read noise: 3.6

S/N:

Contributions to total noise (e-) in aperture (per exposure):
Source noise = 49.48
Background noise = 127.77
Dark current noise = 1.03
Readout noise = 24.75

Total noise per exposure = 139.24
Total signal per exposure = 2449.16

Intermediate S/N for one exposure = 17.58

S/N for the whole observation = 36.28 (including sky subtraction)

Requested total integration time = 150.00 secs, of which 150.00 secs is on source.

The peak pixel signal + background is 396.

Output:
- Spectra autoscaled.

Input Parameters:
Instrument: GMOS-N

Source spatial profile, brightness, and spectral distribution:
The z = 0.0 extended source is a 20.0 mag_per_sq_arcsec G0I star in the V band.

Instrument configuration:
Optical Components:
- Filter: g_G0301
- Fixed Optics
- Detector - EEV DD array

Spatial Binning: 2
Pixel Size in Spatial Direction: 0.1454arcsec

Telescope configuration:

- silver mirror coating.
- side looking port.
- wavefront sensor: oiwfs

Observing Conditions:

- Image Quality: 70.00%
- Sky Transparency (cloud cover): 100.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 20.00%
- Airmass: 1.20

Frequency of occurrence of these conditions: 13.99%

Calculation and analysis methods:

- mode: imaging
- Calculation of S/N ratio with 5 exposures of 30.00 secs, and 100.00 % of them were on source.
- Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 5.00 times the target aperture.