The Nature of the Low-Mass Secondary Stars in Cataclysmic Variables

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Abstract

Cataclysmic Variables (CVs) are interacting binary systems containing a white dwarf primary and a low mass secondary star. Typically, the secondary stars have spectral types ranging from early K to late M, though there is evidence for brown dwarf secondaries in some systems. There are two broad subclasses of CVs: magnetic and non-magnetic. In non-magnetic CVs, an accretion disk is formed around the white dwarf to conserve angular momentum, and processes within the disk give rise to a wide range of variability.

Given their low masses, the evolutionary paradigm developed for CVs suggests that the secondaries should be relatively unaffected by their short orbital periods. We present new IR spectroscopy that reveals that a number of secondary stars have peculiar abundance patterns, especially deficits of C. Most of the secondary stars in long period non-magnetic systems appear to be related to the perfectly normal secondaries in high magnetic systems. It is difficult to reconcile these results in the currently accepted evolutionary scenario, in which the histories of magnetic and non-magnetic systems are identical. Using UV data, there is some indication that CNO enriched material is being transferred from the secondary star. This requires, however, secondary stars that are initially more massive that is currently accepted. We describe our program, which will measure the abundance patterns in the secondary stars in CVs in order to identify their progenitors.

Method

These data were obtained with the ESO 8.2m Very Large Telescope (VLT) Antu in Cerro Paranal, Chile, with ISAAC as well as NIRSPEC at the W.M. Keck Observatory in Hawaii. Standard reductions were carried out using IRAF, ESO Image Processing Pipeline, and the REDSPEC IDL package. Telluric corrections were carried out using the IRAF telluric task, scaling and shifting an appropriate standard spectrum at a “similar” time and airmass and then dividing it into the object spectrum to best remove atmospheric lines. Due to limitations in both the number of tellurics stars observed and the number of arc-frames available, calibrated frames were chosen to match closest in time and most similar in airmass. Orbital “smearing” was taken into account before median combining the observations.

Data & Systems

A large sample of moderate or high resolution IR spectra (R ≥ 2000) for systems below the 2-3 hour period gap does not exist in the literature due to the competing effects of the brightness of the accretion disk, the very hot white dwarf, and the low mass secondary star. We present IR spectra for nine such systems below the period gap. In addition to the CVs, four M dwarf stars were observed for comparison. The observed properties of each system are shown in the table below. Three M star standards were also observed, LHS 427, LHS 2347, and LHS 3003.

For the VLT data, we used a medium resolution grating and a 0.6" slit, giving a resolving power of ~4400 and a dispersion of 0.20 angstroms per pixel. EX Hya and RZ Leo, when observed with NIRSPEC, used a 0.380" slit and a low resolution grating with a dispersion of ~4.27 angstroms per pixel.

For what do We See and Why do We Care?

Including these systems, this brings the total number of CV systems observed in the IR at moderate resolution to 48. Though it is a small sample size, a few general trends are clear: pre-CVs, sub-giant systems, and highly magnetic CVs do not show any surprising CO band strengths. Among the long period systems, thirty out of nineteen systems that either show absent or weakened CO features. In all the cases where we see weak or non-existent CO absorption in the atmosphere of the secondary star, we interpret this as a deficit in the C abundance on the surface of the secondary star. It is a challenge to completely explain the how pre-CV, short period, and magnetic systems appear to have normal C abundances, and how long period systems do not. The models of Marks & Sarna (1998) where the secondary has evolved off of the main sequence before contact show that the surface C abundance in the secondary star declines throughout the lifetime of the CV until the star becomes fully convective. After this point the surface C abundance returns to normal as material from deeper layers is convected to the surface. If the angular momentum breaking mechanisms were less efficient than assumed in the model, then the secondary would have additional time to undergo nuclear evolution. For CVs the magnetic breaking is said to almost offset entirely at the convective boundaries. While Schröder et al. (2010) find evidence of this magnetic breaking mechanism in a survey of SBDS PCEBs, studies in field stars show no such evidence. This result has only been strengthened with additional data for low mass stars in clusters (cf. Scholz et al. 2009).

While observations of the magnetic field structures and magnetic dynamos in low mass stars is improving, the extension of this knowledge to explain the evolution of CVs is uncertain. Since there is only one property that all CVs at the top of the period gap must share, a three hour rotation period, it must be that rotation somehow quenches the efficient magnetic dynamo generation of magnetic stars. Much of the stellar activity is located closer to the poles of later-type objects. Donor stars are easily seen however M4I with normal CO features - Based on Na and the Ca I similar to the M5 seen by Mennekert & Diaz (2002) -SED fitting of lower resolution ISAAC spectra Recently presented by Howell et al. (2010) Knigge (2006) predicts an M5 dwarf

EX Hya

A bright and well studied Intermediate Polar (IP)

- Only magnetic CV in our sample.
- Previous observations predict an M5.5±0.5 dwarf
- Beuermann ▶Reinsch 2000
- Observed with ISAAC at the VLT and NIRSPEC @ Keck
- Secondary star was prominent in both datasets
- Find 2 spectral type of M5 for this secondary star
- Also has high precision HST parallax, 64.5±1.2 pc
- Beuermann et al. 2003
- At this distance, MV ~44% of the K-band flux

VW Hvi

- Previously examined by ISAAC
- Mennekent et al. (2004), low resolution work
- First evidence for a M0.5 dwarf
- Fe J-band with power-law disk and stellar template
- Strength of the Na I & Ca I points to mid-M sp. type
- Good agreement with an M4 dwarf
- CO features close to their expected strength
- Absorption features between 2.21 and 2.26 μm
- Fe I? Consistent with a very late M-type dwarf
- Each has the correct depth and width
- Overall spectrum is clearly inconsistent with L0 dwarf

Z Cha

- Wade & Home (1988) saw an M5 secondary star
- Based on TIO band strengths
- Knigge (2006) predicts an M5 dwarf for this Porb
- Blue and red portion of K-band observed separately
- VLT scheduling constraints, 4 mo. apart
- Spectral type of the secondary star highly uncertain
- M5 consistent with both Na I and Ca I
- CO features are much weaker than they should be

V893 Sco

- Knigge (2006) predicts an M5 dwarf
- Na I doublet and first overtone of G0 are visible
- Quality of these data are low
- Ca I triplet remains undetected
- Does show a water vapor break
- Later type secondary, M6

RZ Leo

- Taken using NIRSPEC @ Keck
- Fainter star by two magnitudes
- Donor star is easily seen however
- M4I with normal CO features
- Based on Na and the Ca I
- Similar to the M5 seen by Mennekent & Diaz (2002) -SED fitting of lower resolution ISAAC spectra
- Recently presented by Howell et al. (2010)
- Knigge (2006) predicts an M5 dwarf