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

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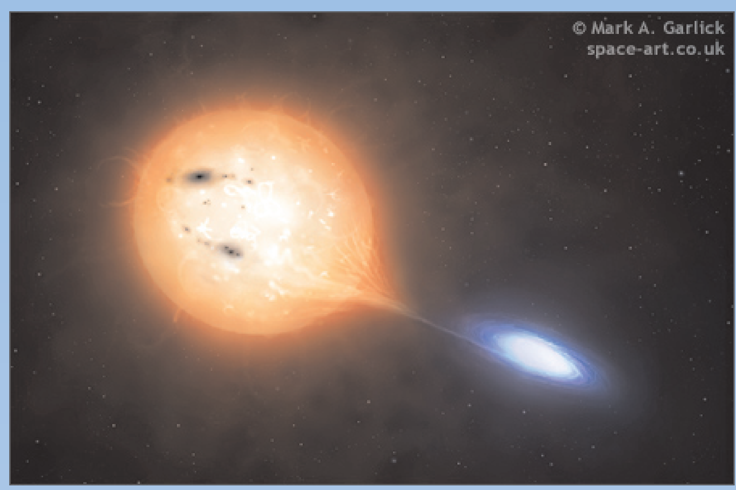
Abstract

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 variety of variability.

Given their low masses, the evolutionary paradigm developed for CVs suggests that the secondaries should be relatively unevolved. Recent observations, however, seem to indicate otherwise: near-IR spectroscopy 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 show C deficits, in stark contrast to the perfectly normal secondaries in highly 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 than is currently accepted. We describe our program that 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, the ESO CPL via the Gasgano interface, or 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 telluric standard stars observed and the number of arc frames available, calibration frames were chosen to match closest in time and most similar in airmass. Orbital "smearing" was taken into account before median combining the observations.

Systems & Data

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 CV's, four M dwarf stars were observed for comparisons. 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.

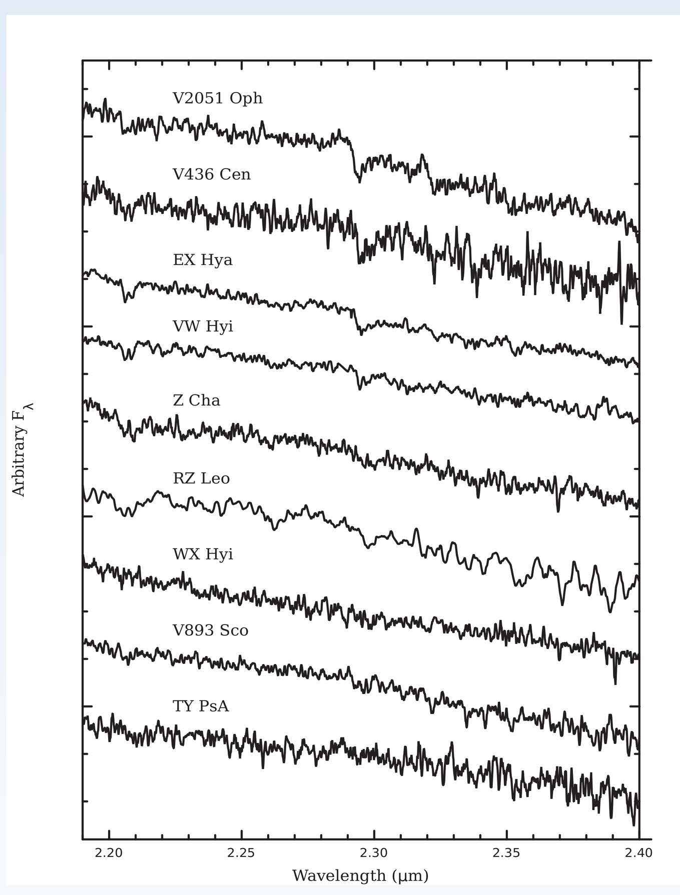
System Name	Orbital Period (hours)	Magnitude (mk)	Primary Mass (Msun)	Secondary Mass (Msun)	Sp Type (Published)	Inclination (degrees)
V2051 Oph	1.4982	13.53	0.78 ± 0.06	0.15 ± 0.03	…	83 ± 2
V436 Cen	1.5	13.526	0.7 ± 0.1	0.17	…	65.± 5.0
EX Hya	1.6376	11.69	0.790 ± 0.026	0.108 ± 0.008	M5-6	77.8 ± 0.4
VW Hyi	1.7825	11.702	0.67 ± 0.22	0.11 ± 0.03	L0	…
Z Cha	1.788	13.314	0.84 ± 0.09	0.125 ± 0.014	M5.5	81.1 ± 0.14
WX Hyi	1.7955	12.961	0.9 ± 0.3	0.16 ± 0.05	…	40 ± 10
V893 Sco	1.8231	12.68	0.89	0.17	…	72.5
RZ Leo	1.8249	15.387	…	…	M5	…
TY PsA	2.02	13.583	…	…	…	…

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 ~1.20 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.

What do we See and Why do we Care?

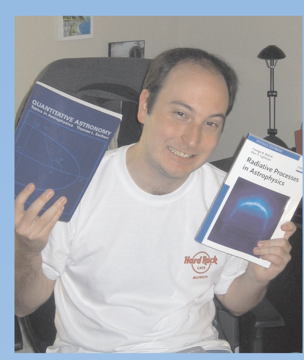
Including these systems, this brings the total number of CV systems observed in the IR at moderate resolution to 48. Though it is a small sample size, a few general trends are clear; pre-CVs, sub-gap systems, and highly magnetic polars all do not show any surprising CO band strengths. Among the long period systems, thirteen 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 braking mechanisms were less efficient than is currently believed, then the secondary would have additional time to undergo nuclear evolution. For CVs the magnetic breaking is said to almost switch off entirely at the convective boundary. While Schreiber et al. (2010) find evidence of this magnetic breaking mechanism in a survey of SDSS PCEBs, studies in field stars show no such evidence. This result has only been strengthened with additional data for low mass stars in clusters (c.f. 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 uncertian. 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 in fully convective stars. Much of the stellar activity is located closer to the poles of later-type objects. In some CVs polar spots are seen, while in others the spots are more equatorial (Watson et al. 2006, 2007). Cohen et al. (2009) show that if a spot is located near the pole, the stellar wind structure is dramatically affected, and that total mass and angular momentum loss is substantially higher than if the spots were equatorial. Unless it is found that the spots on CVs are preferentially located near the equatorial regions, this explanation seems unable to produce the desired result.

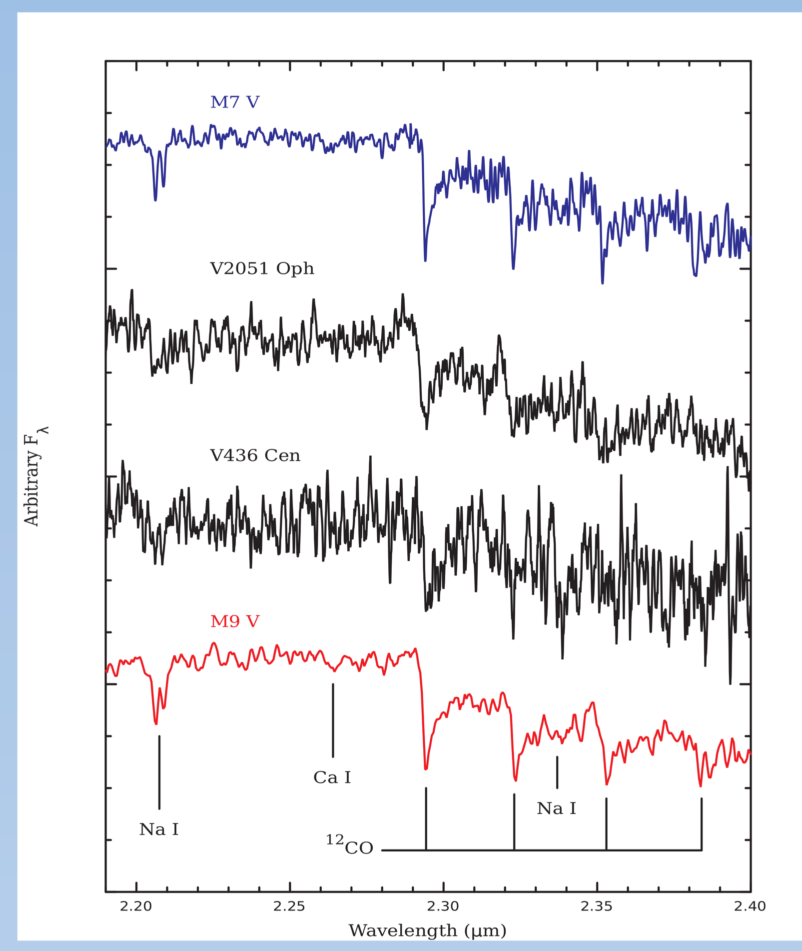
Future Work & Contact Info



- Modeling of M stars: needed to fully assess and understand CO weaknesses seen
  - PHOENIX ?
  - $^{12}C/^{13}C$ ratio also seen as indicative of CNO processing in some observations
- The UV-IR Connection
  - Do *all* systems that show CNO material in the UV show weak CO bands?
  - Requires large aperture telescope time & matching (archival?) UV observations
- Questions or comments? Come find me!
  - Email contact: rthamilt@nmsu.edu

V2051 Oph

- First direct constraint on its spectral type
- First overtone CO feature is stronger than Na I doublet
- Ca I triplet not clearly detected
  - Suggests a very late spectral type
- IRTF spectral templates matches best with an M7±1
- Knigge (2006) suggests spectral type near M7V

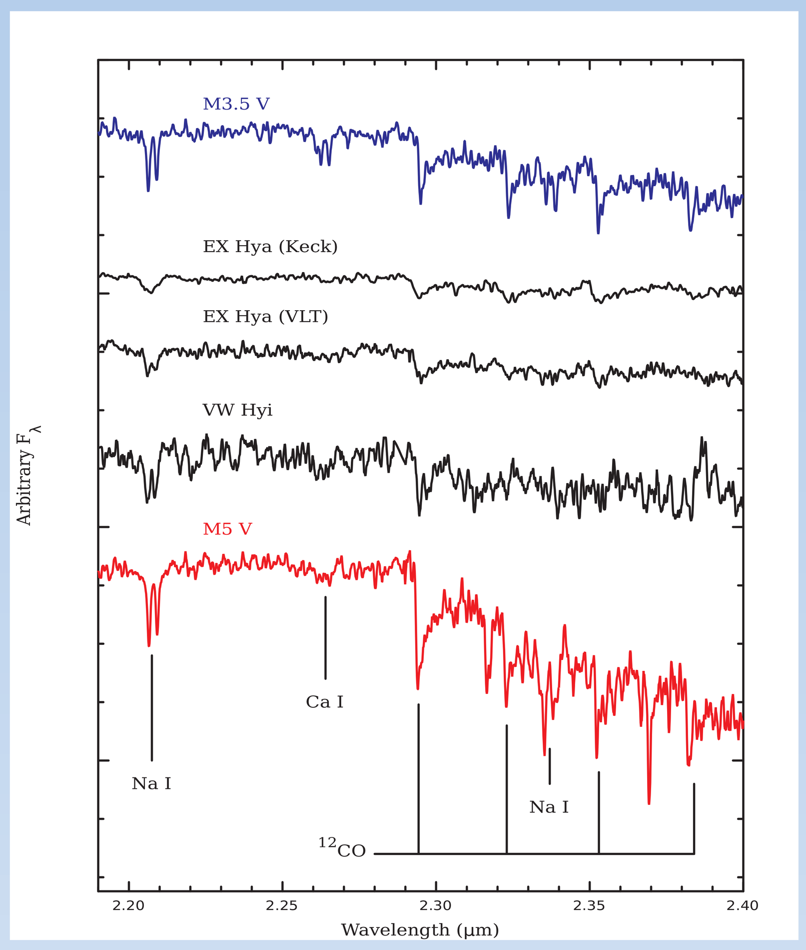


V436 Cen

- First direct detection of secondary in V436 Cen
- Previous work suggested a low mass secondary
  - Patterson 2001; Knigge 2006
  - Fits between q and superhump and Porb
- Should be very similar to V2051 Oph
  - P_{orb}, K_{2MASS}, M_2, etc.
- Knigge (2006) predicts an M7 dwarf donor
- Na I, Ca I, and CO features best match M8±1
- Data reduction problematic b/c of no good telluric std.

EX Hya

- A bright and well studied Intermediate Polar (IP)
- Only magnetic CV in our sample.
- Previous observations showed an M5.5±0.5 dwarf
  - Beuermann ○ Reinsch 2008
- Observed w/ISAAC @ the VLT and NIRSPEC @ Keck
  - Secondary star was prominent in both datasets
- Find a 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, M5V ~44% of the K-band flux

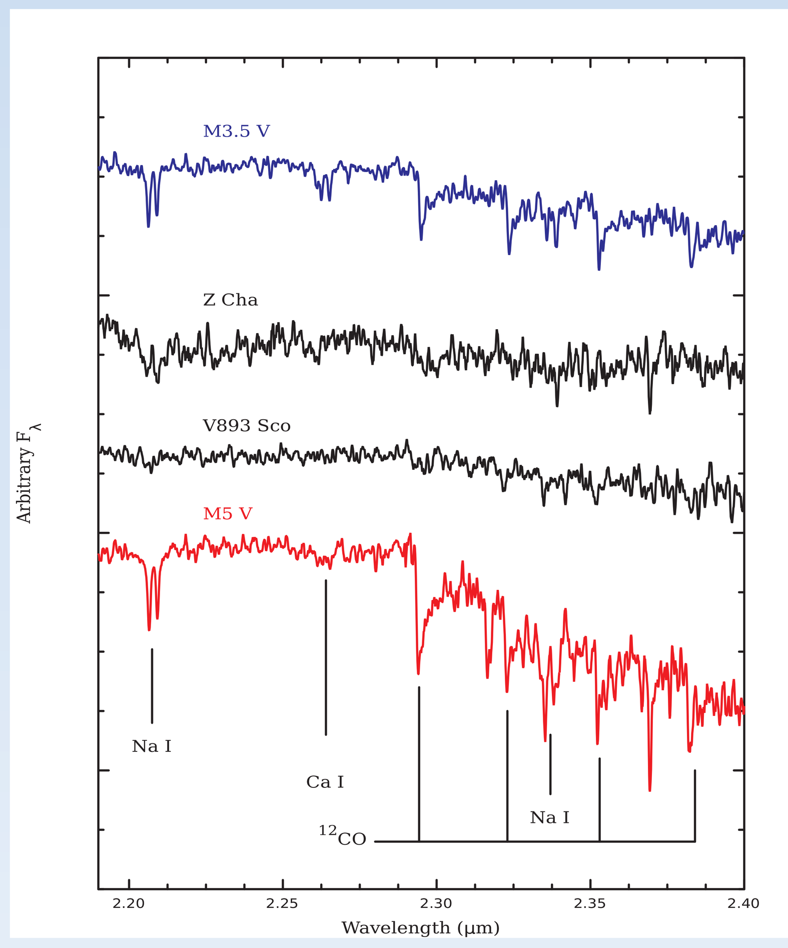


VW Hyi

- Previously examined by ISAAC
- Mennickent et al. (2004), low resolution work
- Found evidence for an L0±2 dwarf
  - Fit 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 & Horne (1988) saw an M5.5 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
- Spectrum is heavily contaminated by accretion disk
  - Spectral type of the secondary star highly uncertain
  - M5 consistent with both Ca I and Na 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 CO 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
- Faintest in this survey by two magnitudes
  - Donor star is easily seen however
- M4±1 with normal CO features
  - Based on Na I and the Ca I
- Similar to the M5 seen by Mennickent & Diaz (2002)
  - SED fitting of lower resolution ISAAC spectra
- Recently presented by Howell et al. (2010)
- Knigge (2006) predicts an M5 dwarf