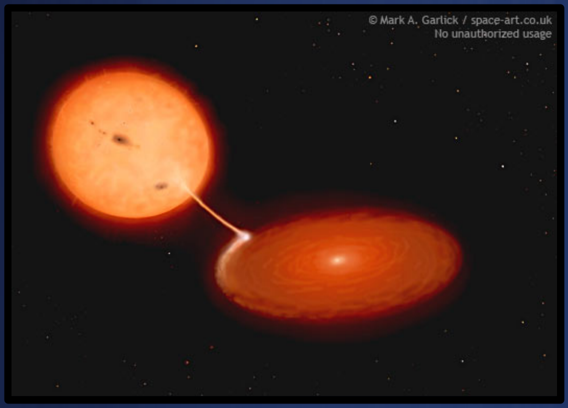
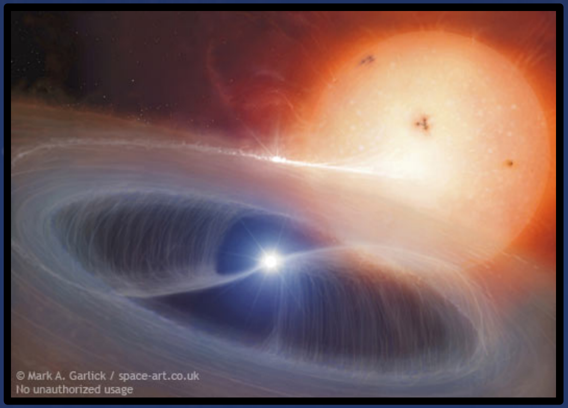
Moderate Resolution NIR Spectra and Modeling **the Secondary Stars** of Cataclysmic Variables





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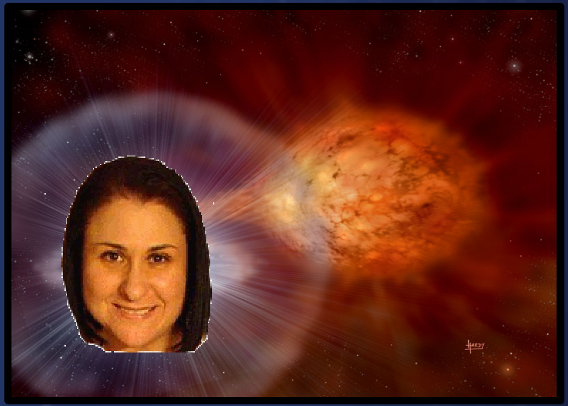
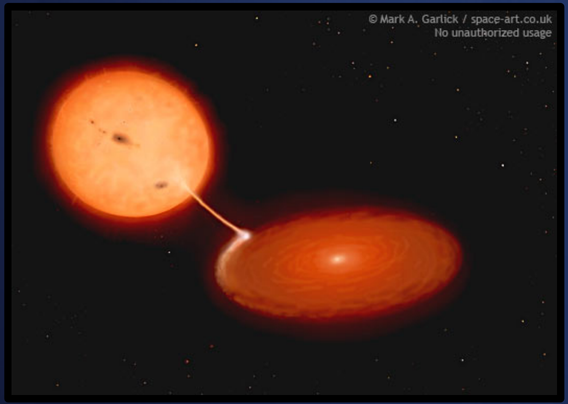
Talk Outline

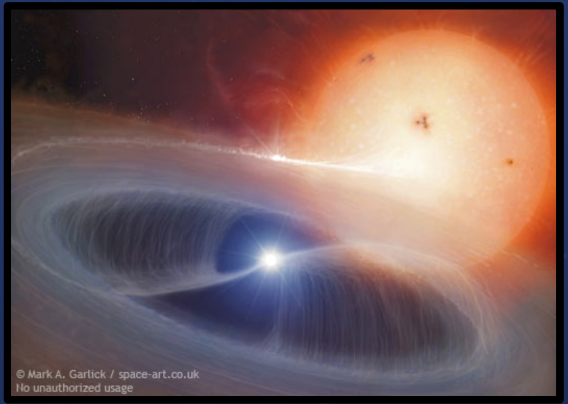
- (Very Brief) Introduction
  - Why Bother? Secondaries should be dull...
  - UV C IV/N V ratios
  - Recent NIR Observations
- UV-NIR Link and implications
- Description of Ph.D. thesis work
  - Very much a work-in-progress and just getting up and running
    - Results coming soon :)

Intro: CV Menagerie

- One progenitor pop., but HUGE variety!
- Appear in all shapes, sizes, and flavors
  - Classical Novae
  - Non-Magnetic Systems
  - Nova-Like Systems
  - Magnetic Systems

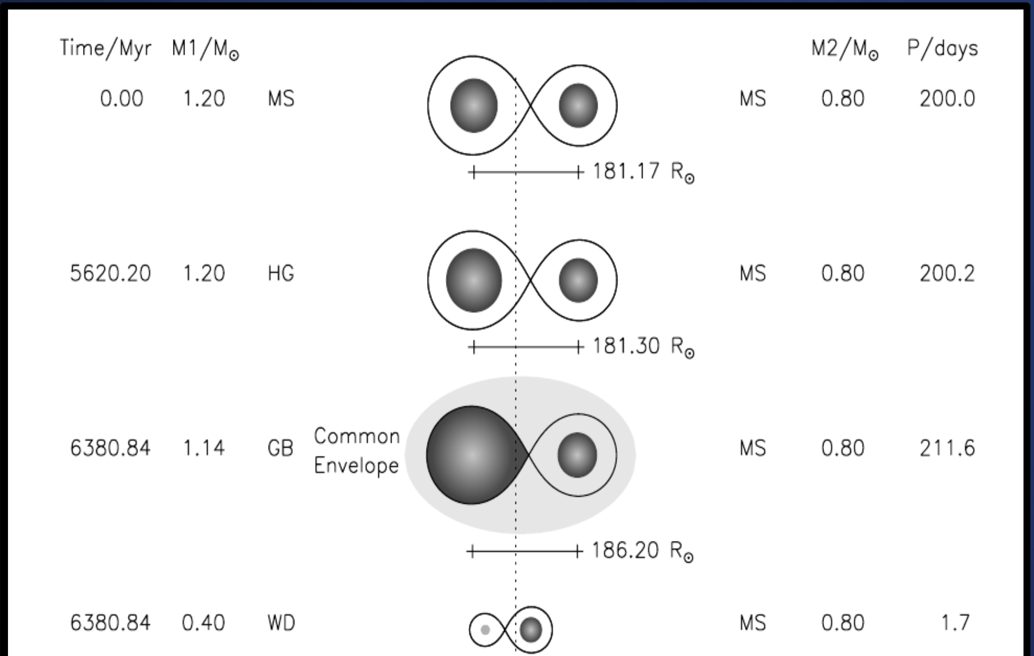




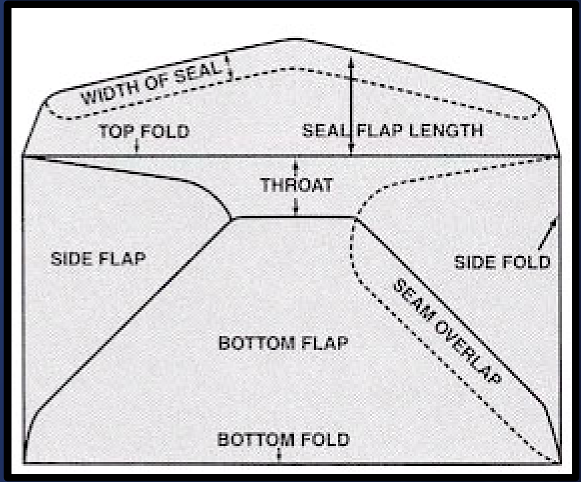


Intro: “Standard” CV Scenario

- Start with wide binaries of moderate orbital period and unequal masses
  - Ritter 2010 review & references therein
  - Also everyone who talked yesterday



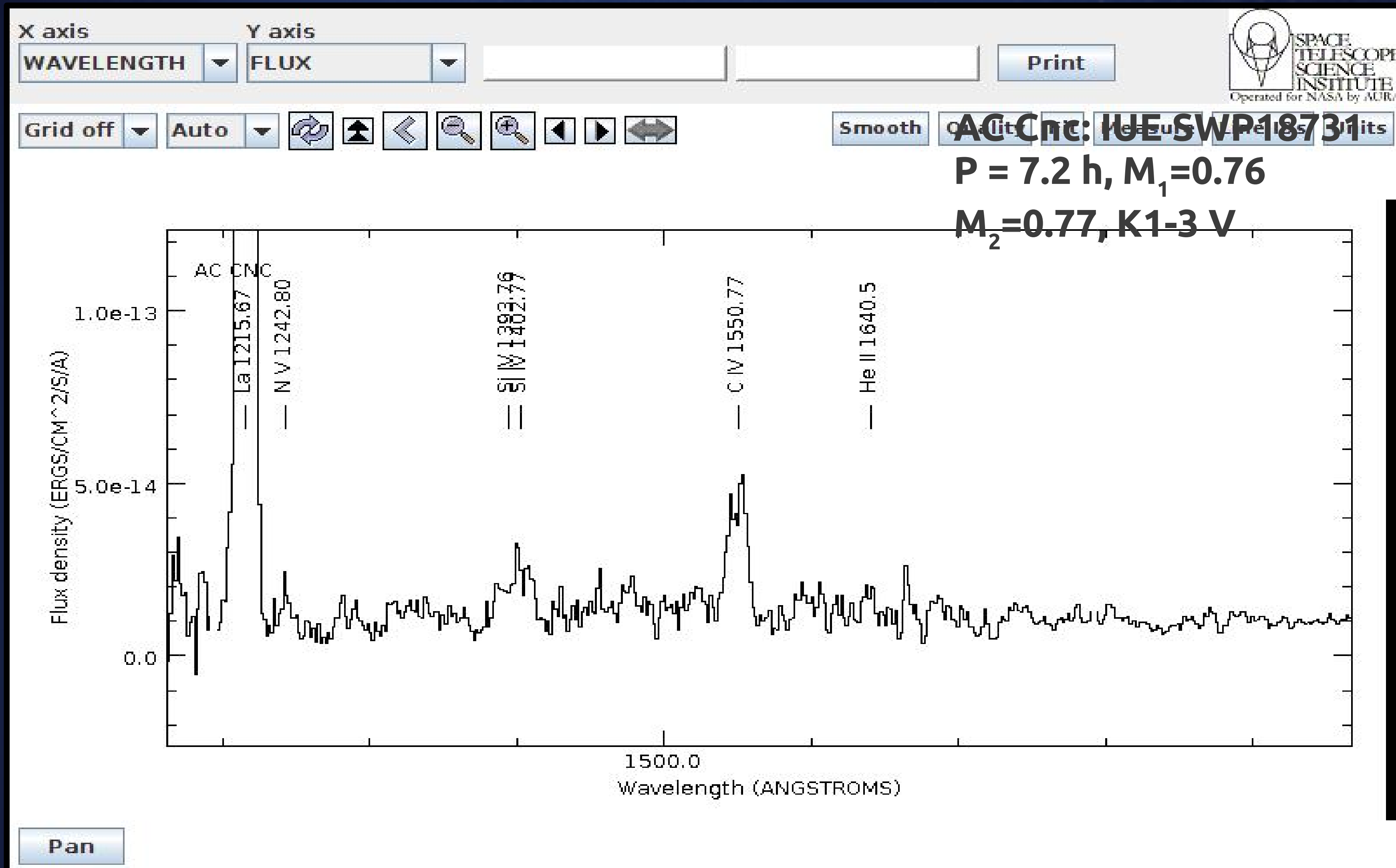
Willems & Kolb 2004



Intro: UV Observations

- Increasing number of strange C/N ratios seen in UV spectra (~13-15 currently)
  - Presence of CNO processed material!
  - Gänsicke et al. 2003; Gänsicke 2004; de Martino and Gänsicke 2009; Sanad 2011
- Really strong N V, very weak C IV
  - C IV can be completely absent!
  - (seen in other lines as well, e.g. C III 1247Å)

Intro: “Normal” CV in UV

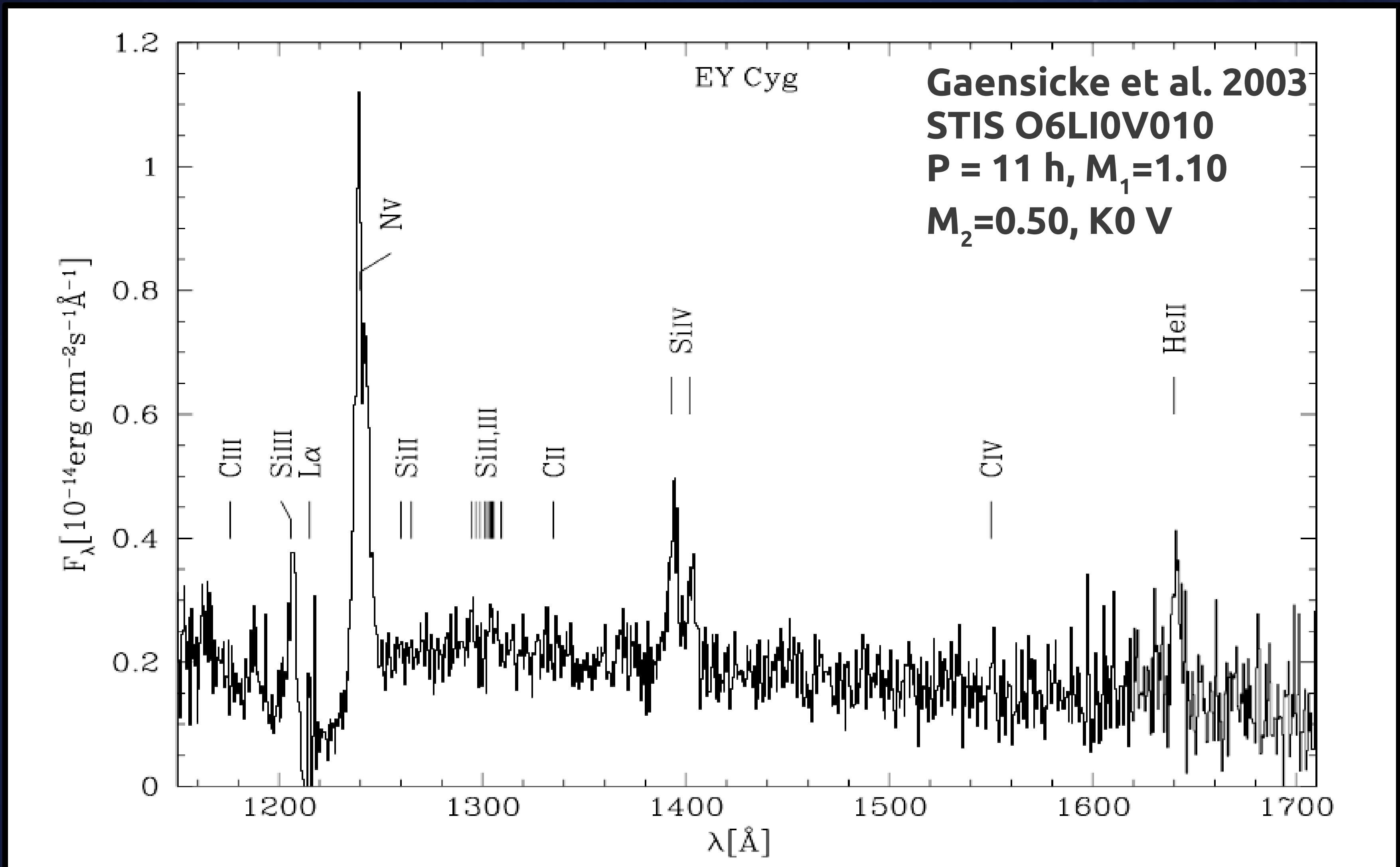


AC Cnc: IUE SWP18731

P = 7.2 h, M_1=0.76

M_2=0.77, K1-3 V

Intro: "Weird" CV in UV

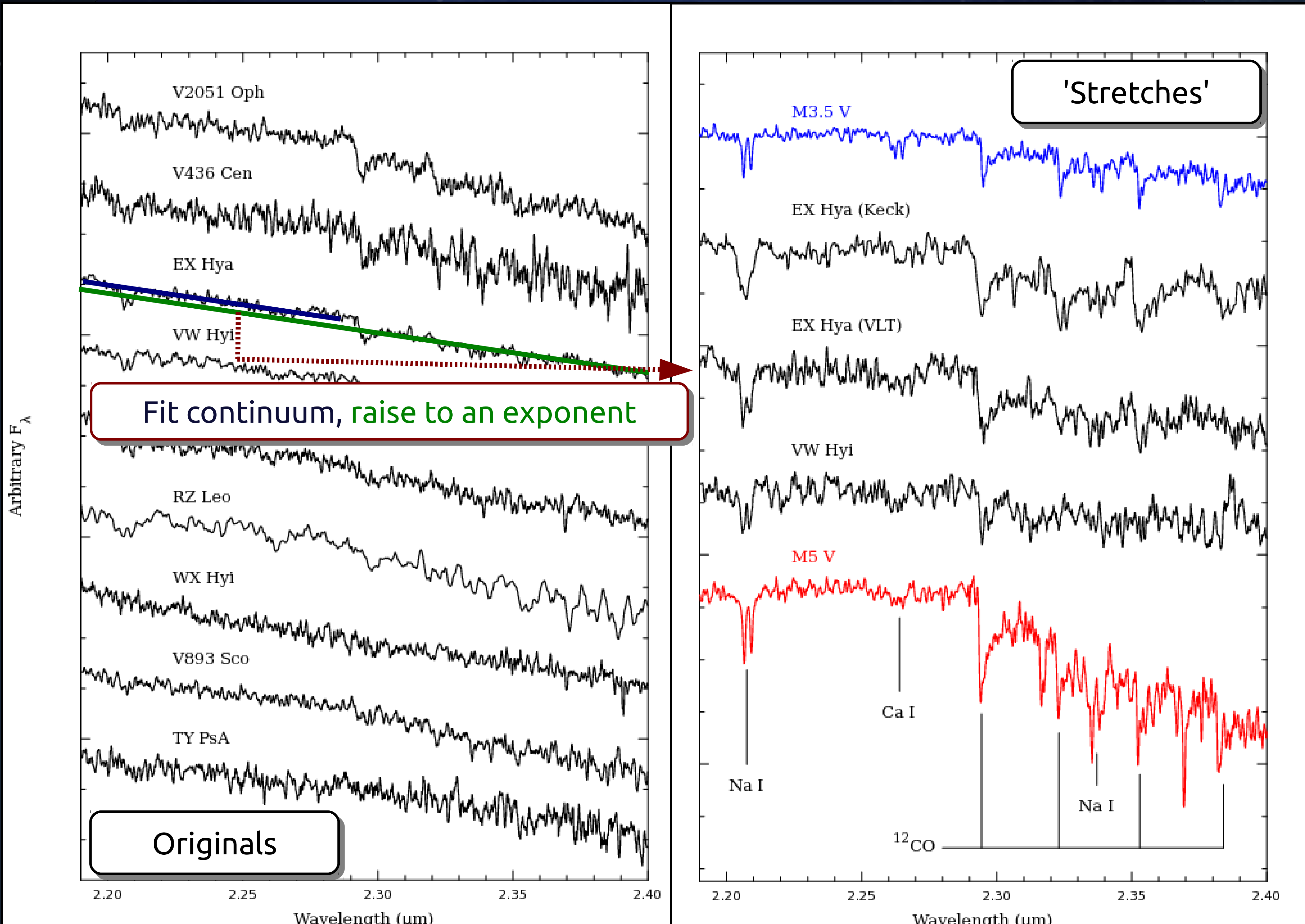


Intro: NIR Observations

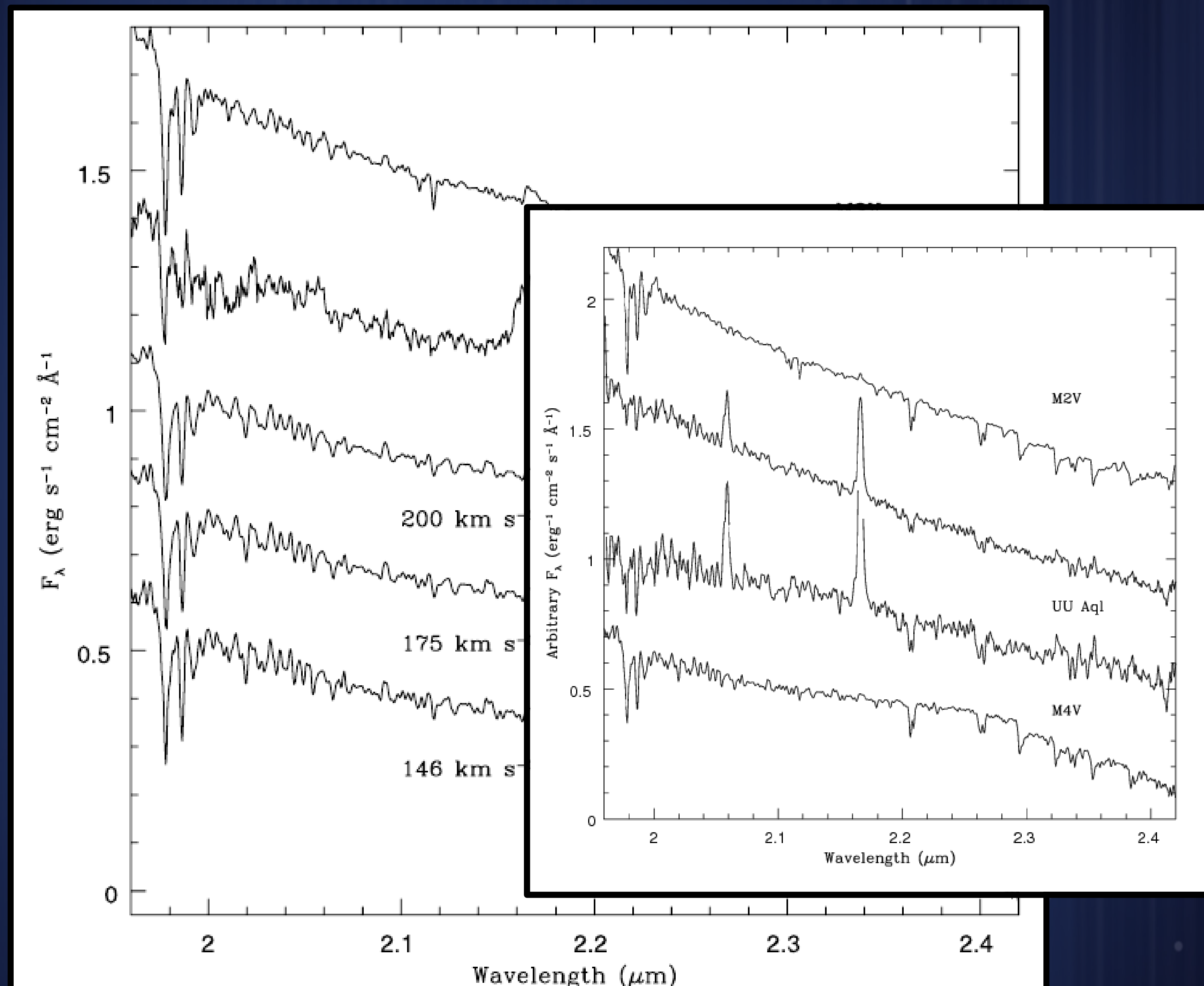
- Increasing number of strange CO bands seen in NIR spectra
  - CO bands weaker than expected for given spectral type or just not there
    - Especially in long period systems above gap
  - Deficit of C, O, or something else?
- ^{13}C enhancements seen as well
  - More ^{13}C means the secondary star had nuclear processed material before contact!

Intro: “Normal” CVs in NIR

- Taken from Hamilton et al. 2011
- Doubled the sub-gap NIR sample
- Systems below period gap harder to detect
    - Faint, later type secondaries than systems above the gap
    - Short P_{orb} makes it difficult since K_2 is so high
    - Need short exposures (LARGE telescopes) to resolve anything of use



Arbitrary F$_\lambda$
V2051 Oph
V436 Cen
EX Hya
VW Hyi
RZ Leo
WX Hyi
V893 Sco
TY PsA
Originals
Fit continuum, raise to an exponent
2.20
2.25
2.30
2.35
2.40
Wavelength (µm)
'Stretches'
M3.5 V
EX Hya (Keck)
EX Hya (VLT)
VW Hyi
M5 V
Na I
Ca I
Na I
^{12}CO
2.20
2.25
2.30
2.35
2.40
Wavelength (µm)



F$_\lambda$ (erg s^{-1} cm^{-2} Å^{-1})
200 km s
175 km s
146 km s
Wavelength (μm)
Arbitrary F$_\lambda$ (erg^{-1} cm^{-2} s^{-1} Å^{-1})
M2V
UU Aql
M4V
Wavelength (μm)

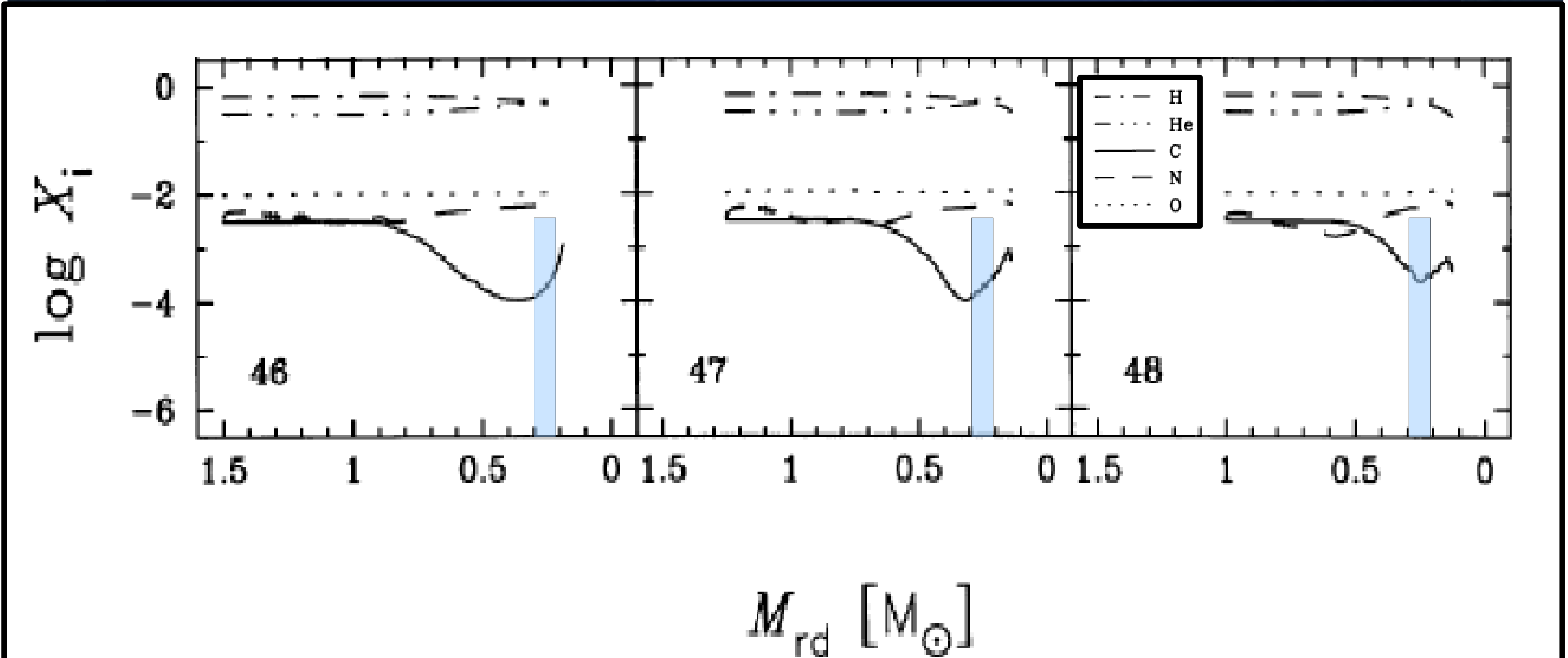
UV-NIR Connection

- Cases where have both UV and NIR spectra, see CNO material
  - UV: High N V, Weak C IV → CNO material
  - **NIR: Weak CO, enhanced ^{13}C → CNO material**
- **Tracing CNO processed material from the secondary to the WD/disk**
  - Require initially more massive secondaries
    - Different progenitor population? **Thermal-Timescale Mass Transfer (TTMT)**?
    - Schenker et. al (2002)

More Massive Secondaries…?

- If secondary initially r… has time to chemicall…
  - Marks & Sarna 1998

Model	M_{1i} [M$_\odot$]	M_{1f} [M$_\odot$]	M_{2i} [M$_\odot$]	M_{2f} [M$_\odot$]	P_i [d]	P_f [d]
46	1.2	1.068	1.5	0.185	1.166	1.092
47	1.0	0.864	1.25	0.138	0.909	0.127
48	0.8	0.692	1.0	0.126	0.709	0.080



So What Will We Do?

- Abundances:
  - Weak CO → C deficit? Is ^{13}C really enhanced?
  - Synthetic spectra to answer
    - Use two different codes/models
  - Find best match to given observations in a robust and repeatable way
- Need to understand systematics, biases, and uncertainties in the sample
  - Require homogeneous data reductions?

NIR Sample Stats

- Most observed at $2000 \leq R \leq 6000$
- Few (6-7) observed at $R > 10000$
- 61 systems total:
  - 19 Pre-CVs
    - Some at $R \sim 1500$ but no disk contamination
  - 31 Non-magnetic systems
    - 19 above the gap, 12 below
  - 11 Magnetic systems
    - Includes IPs as well

The Big List

Table 4
CO Absorption Strength Across all CV Subtypes

Magnetic Systems				
GK Per	DN Na IP	47.9	W	3
AE Aqr	NL DQ	9.86	W[f]	7
V1309 Ori	NL AM	7.98	W[g]	8
MQ Dra	NL AM LA	4.39	Y	3
SDSS0837	NL AM LA	3.18	Y	8
AM Her	NL AM	3.09	Y	4
AR UMa	NL AM	1.93	Y	3

Non-magnetic Systems				
EY Cyg	DN UG	11.0	W[c]	9
BT Mon	NL SW	7.99	ND	8
SY Cnc	DN ZC	9.12	ND*	5
RU Peg	DN UG	8.99	W	5
CH UMa	DN UG	8.23	W	5
MU Cen	DN UG	8.21	W	5
AC Cnc	NL SW	7.21	Y ?	5
EM Cyg	DN ZC	6.98	W**	5
V426 Oph	DN ZC	6.85	Y	5

Summary of Strange Systems:
See Hamilton et al. 2011

0 Pre-CVs (0%)

13/19 - Long Period Non-Magnetic (68%)

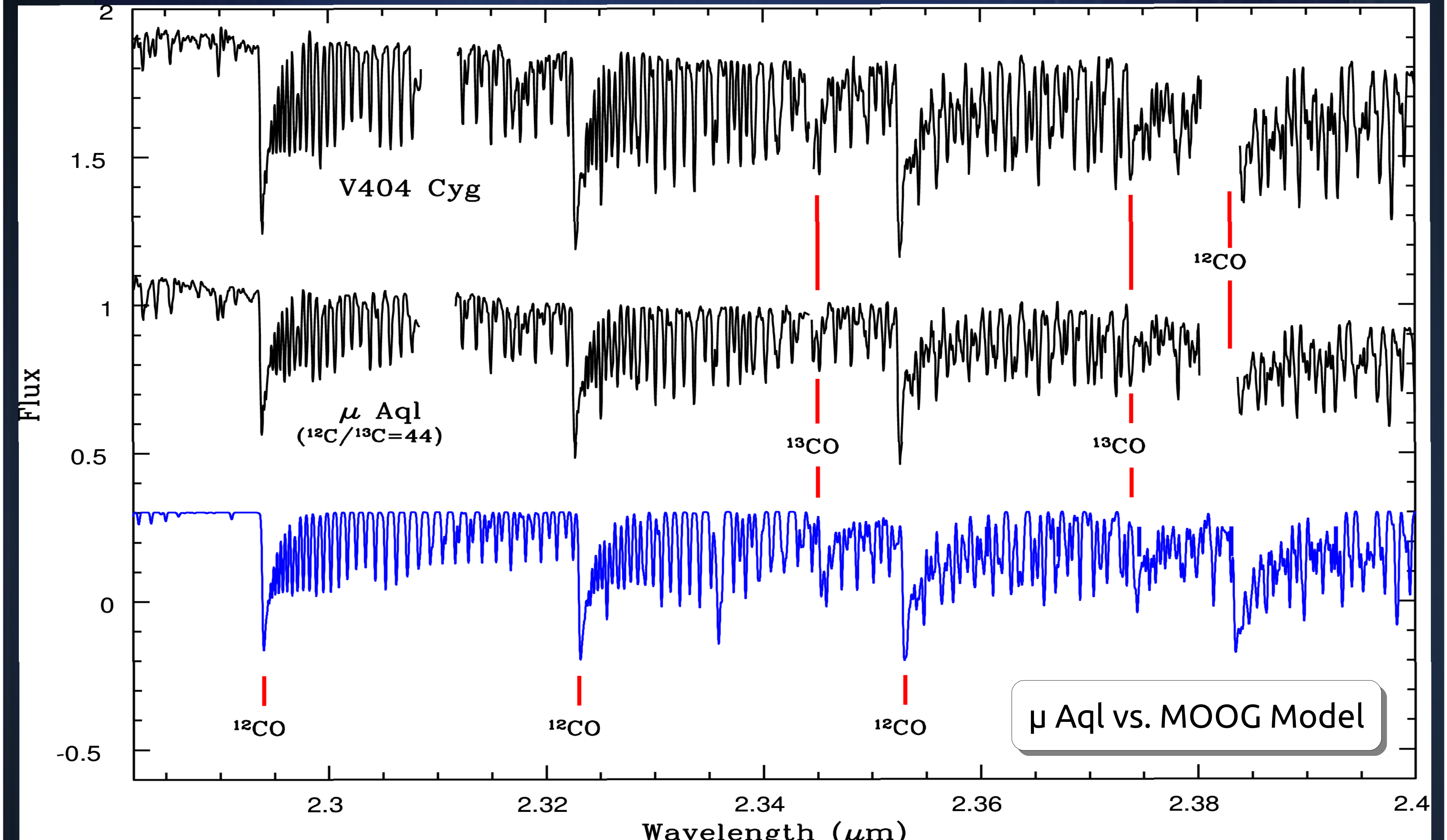
3/12 - Short Period Non-Magnetic (25%)

3/11 - Magnetic, includes IPs (27%)

Modeling the Big List

- MOOG
  - Chris Sneden, UT Austin
  - LTE only
    - Bring your own atmosphere and linelist
    - **Does Not Handle Triatomic Molecules (H_2O)**
  - Extremely common and well used
  - **FAST computations**

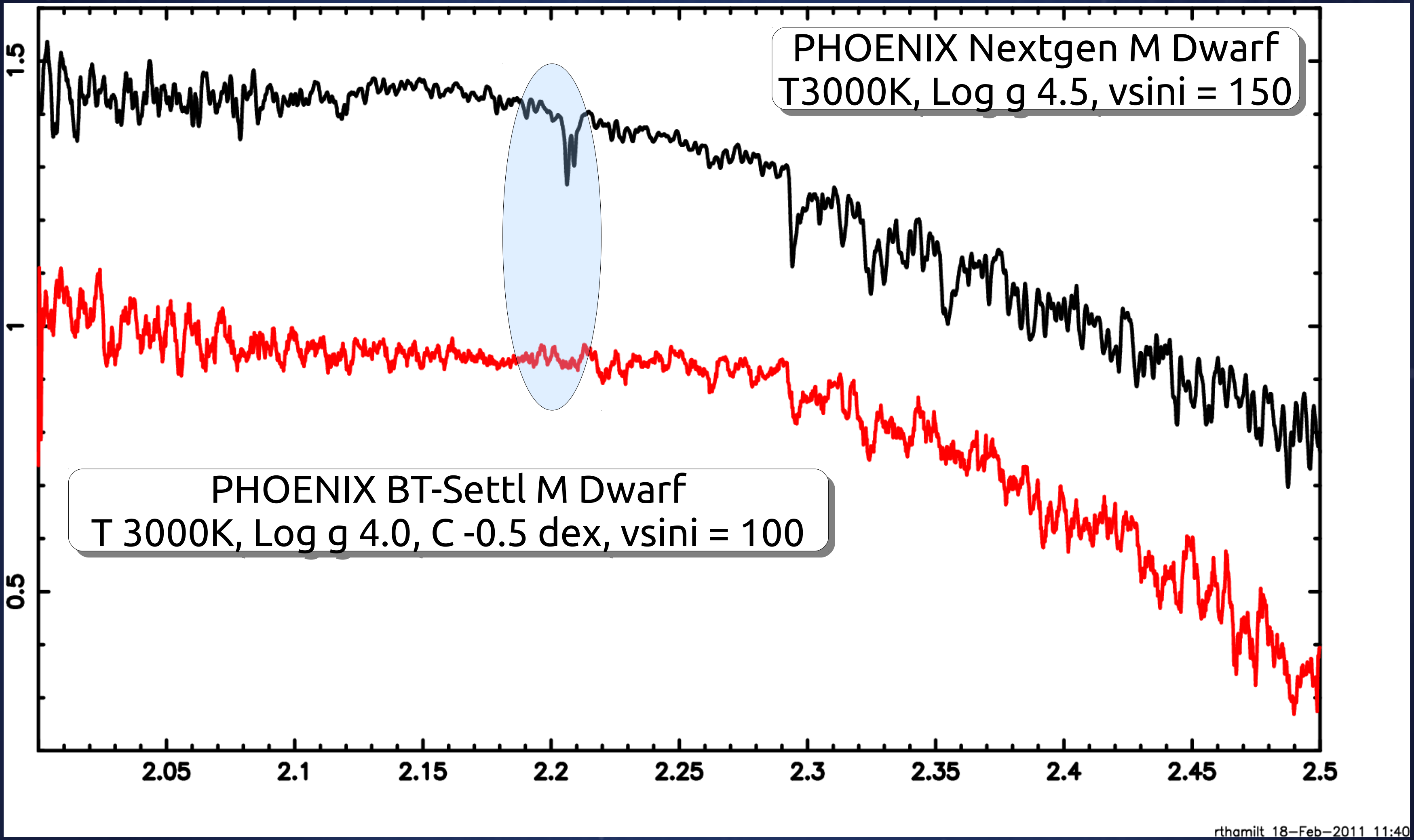
Sample MOOG Spectra



Modeling the Big List

- PHOENIX
  - Peter Hauschildt (et al.)
  - LTE/NLTE
  - Complete (complex) package
    - **Handles All Important Species/Molecules**
    - **Can include irradiation by other source (WD)**
  - **Gold standard for cool star community**
  - **SLOW computations (~days/weeks)**
    - Available through (buggy) web-based interface

Sample PHOENIX Spectra



(Very Near) Future Work

- Fit highest resolution spectra first
  - PHOENIX for mid-late M dwarfs, else MOOG
  - M-K dwarfs, CVs, IRTF templates w/ known parameters
    - Fit lower resolution observations of these same objects to sanity check
- Once sufficient agreement in fitting, move down the list in terms of resolution
- Results coming soon! Too early to show

Summary

- Short period systems mostly normal
- Pre-CV/Magnetic systems appear mostly normal as well
- Long period systems strange
  - 13/19 show weak/absent CO features (~70%)
  - Some enhanced ^{13}CO (Harrison et al. 2005)
- Synthetic spectra to play with
  - C abundance imply more massive secondary star progenitors?