Constraining Photospheric Abundances of Donor Stars in Cataclysmic Variables

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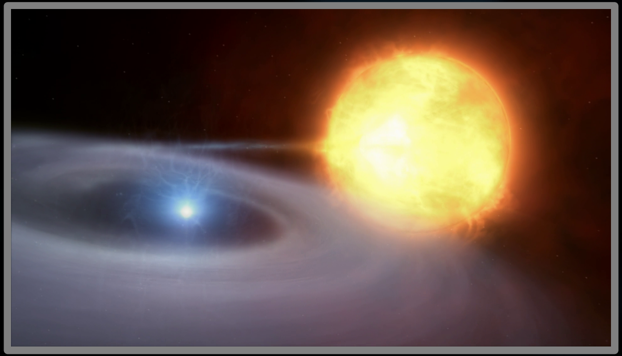
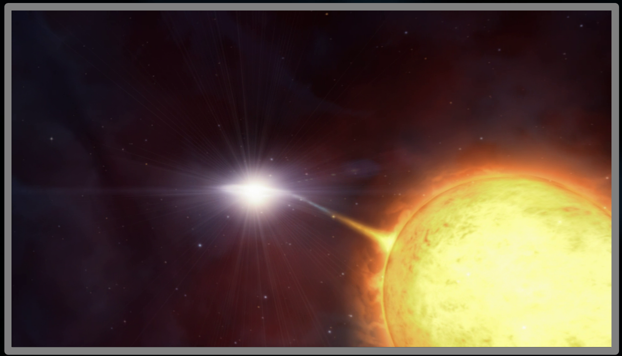
+ Many More!

Motivation

- Interacting binary evolution important!
  - All go through common envelope (CE) phase
    - CVs, [L,H]MXB, Algols, W UMas, microquasars...
      - Zoo of interacting types, progenitors uncertain!
- CVs (AM CVns? Magnetics?) may be SN Type-Ia's!
  - (Wheeler 2012; requires magnetics, but still CVs)

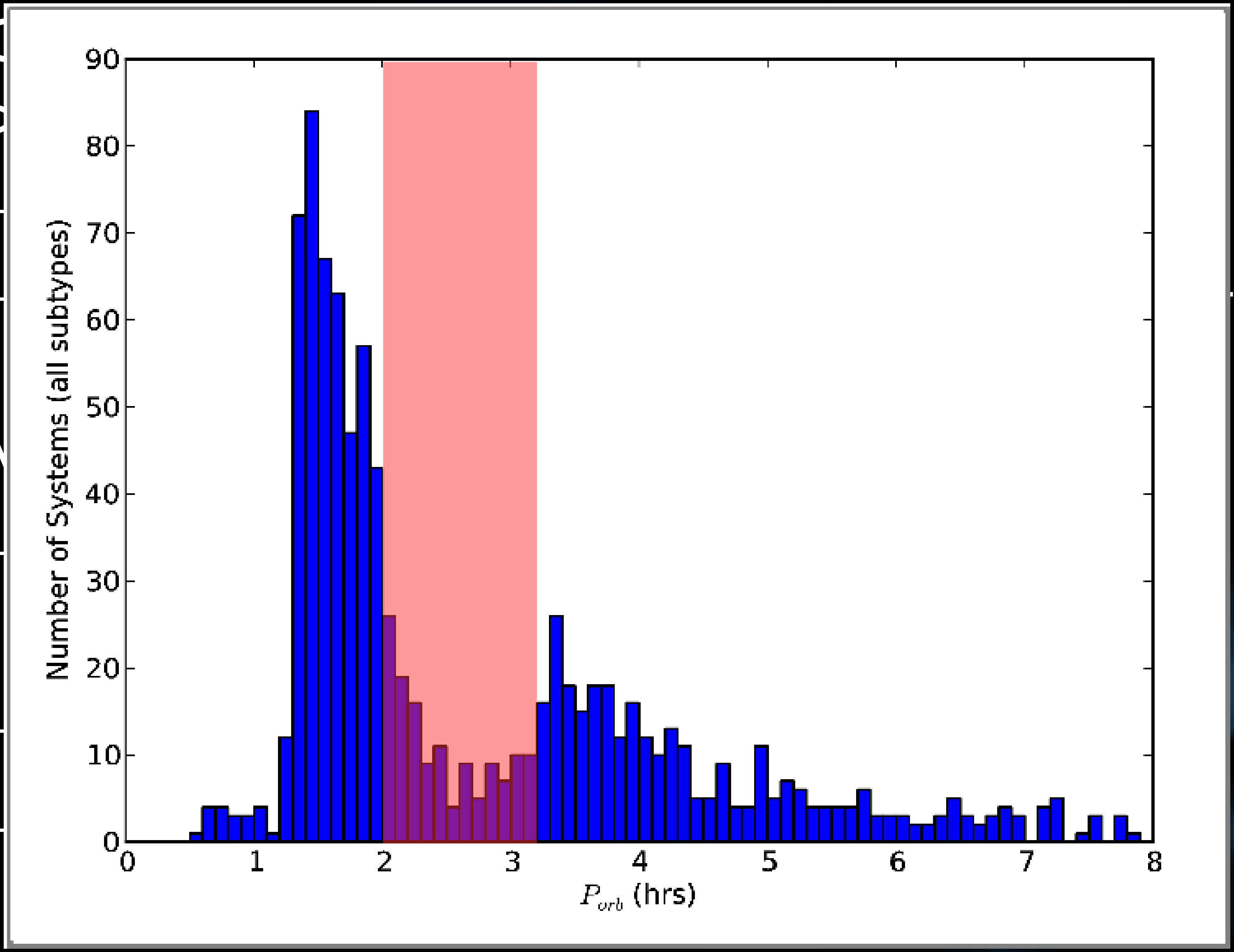




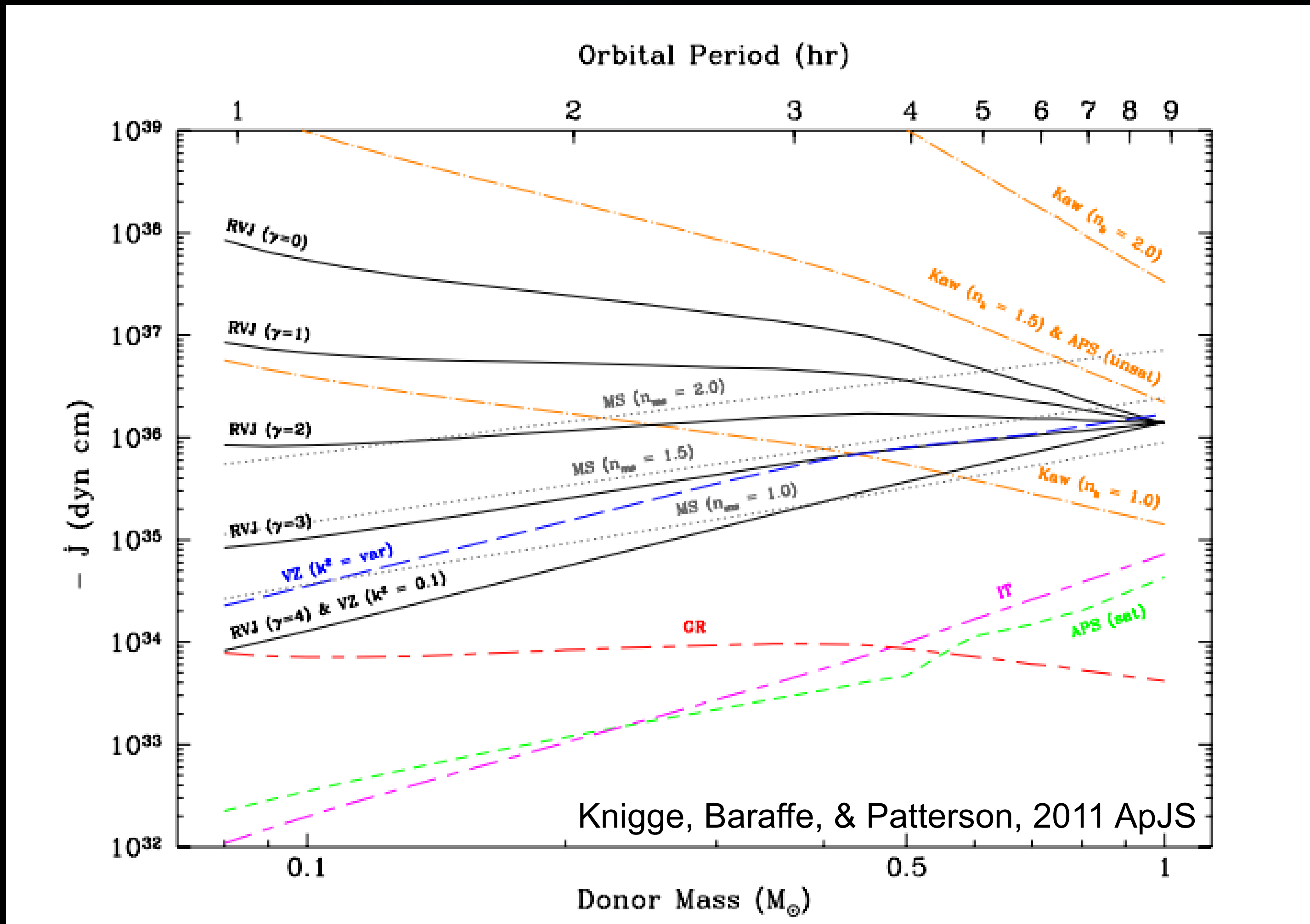
Introduction: System Evolution

- Close binaries w/unequal masses experience common envelope (CE) as larger star leaves MS
  - Ritter 2010, Knigge, Baraffe, & Patterson 2011
  - After CE ejection, orbit shrinks and CV is born w/3 to 10 hr orbital period
- Mass transfer until secondary fully convective
  - Donor shrinks, mass xfer stops
  - $P_{orb} \sim 3$ hr, $M_2 \sim 0.2\text{-}0.3\ M_{sun}$
  - "magnetic braking" disrupted?
    - Main source of angular momentum loss

Introduction: System Evolution



Angular Momentum Loss Rates



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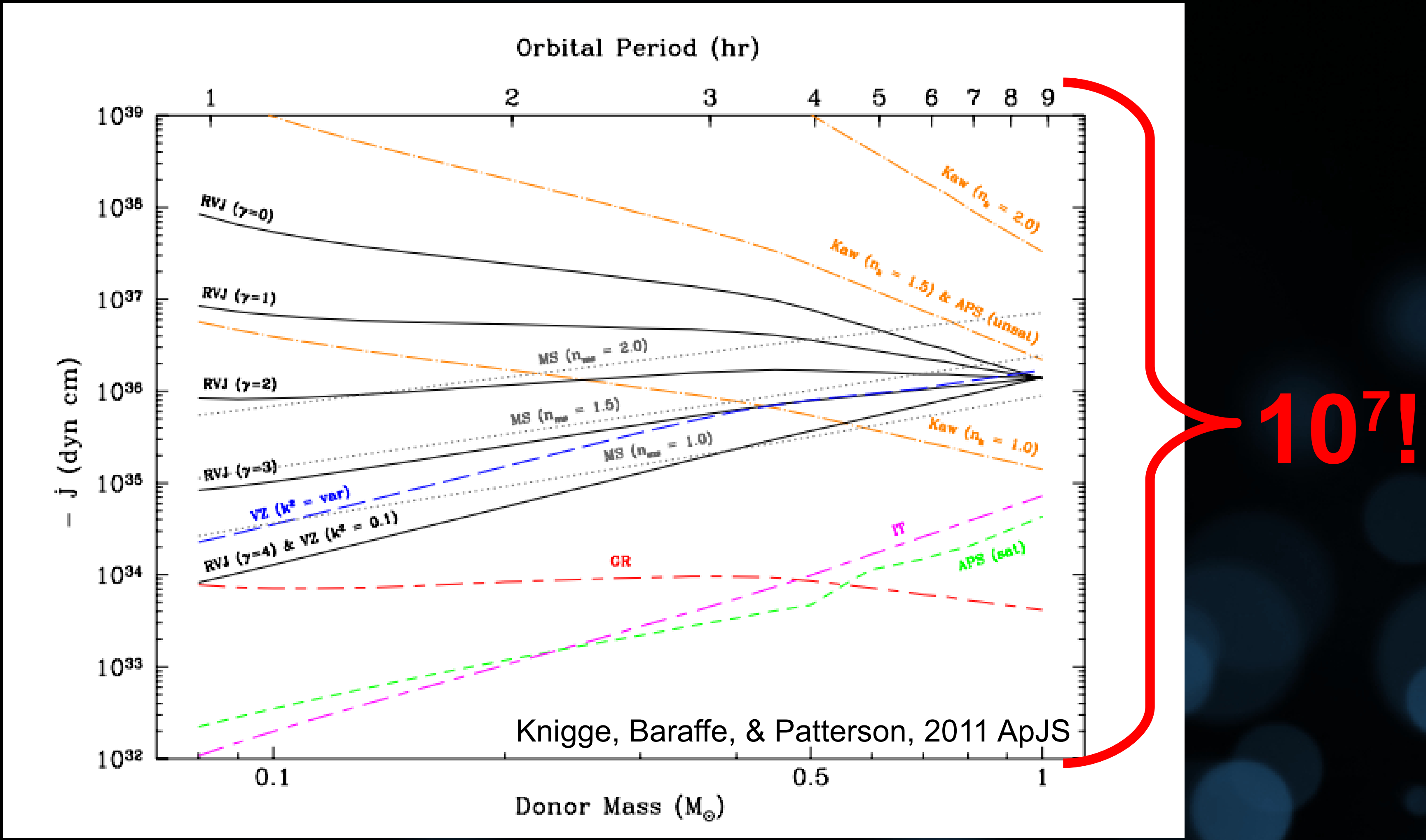
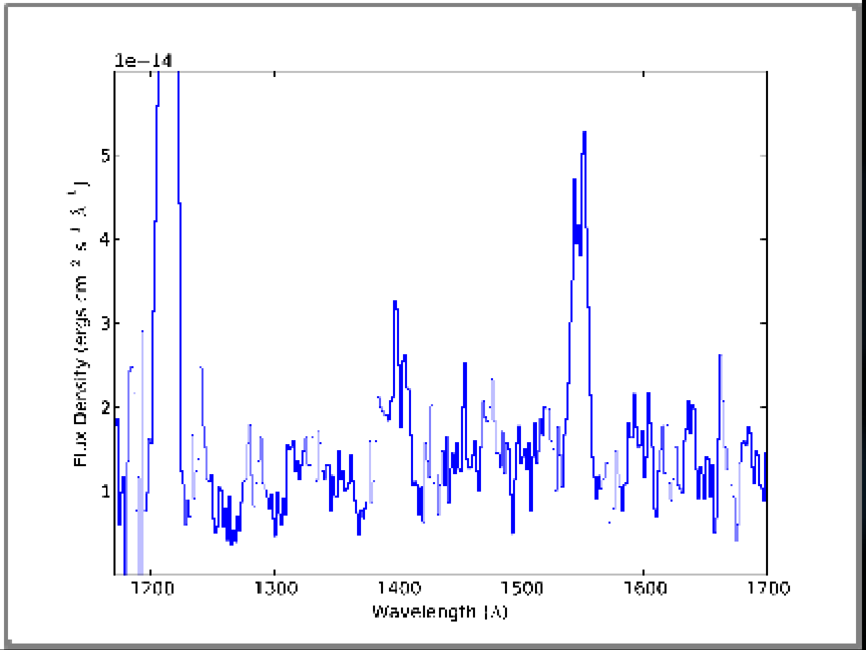


Thesis Description

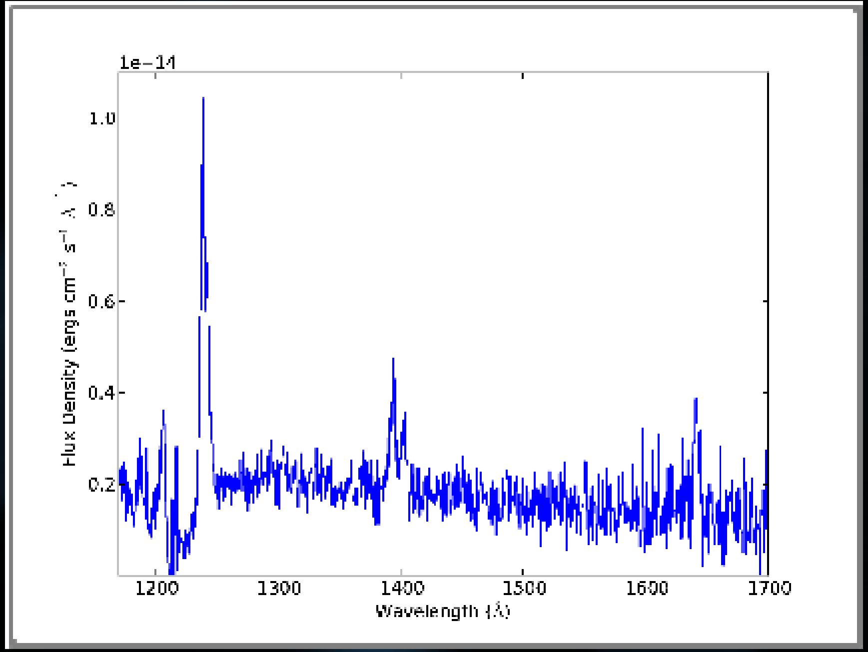
- Can we learn anything about progenitors of CVs?
  - Measure abundances in the atmosphere of the donor star in the NIR
    - No “bullet proof” measurements, though hints of weird abundances
  - Prior work in NIR on donors focused on spectral typing
    - Template matching/visual inspection, template subtraction
    - X-ray, UV, Optical almost completely dominated by WD + disk
- Use synthetic spectra to explore donor star spectra
  - Cool stars are fickle! Molecular features abundant
  - Need to be robust
    - Explore the large parameter grid

Prior Work (UV Observations)

- Some systems just plain weird as we begin to look in more (non-optical) bandpasses
  - UV systems that show high N/C ratios, indicate CNO processing coming from…somewhere (Gänsicke 2003)



AC Cnc: IUE SWP18731 P = 7.2 h, M_1=0.76 M_2=0.77, K1-3 V (MAST)



EY Cyg: STIS O6LI0V010   P = 11 h, M_1=1.10 M_2=0.50, K0 V (Gaensicke et al. 2003)

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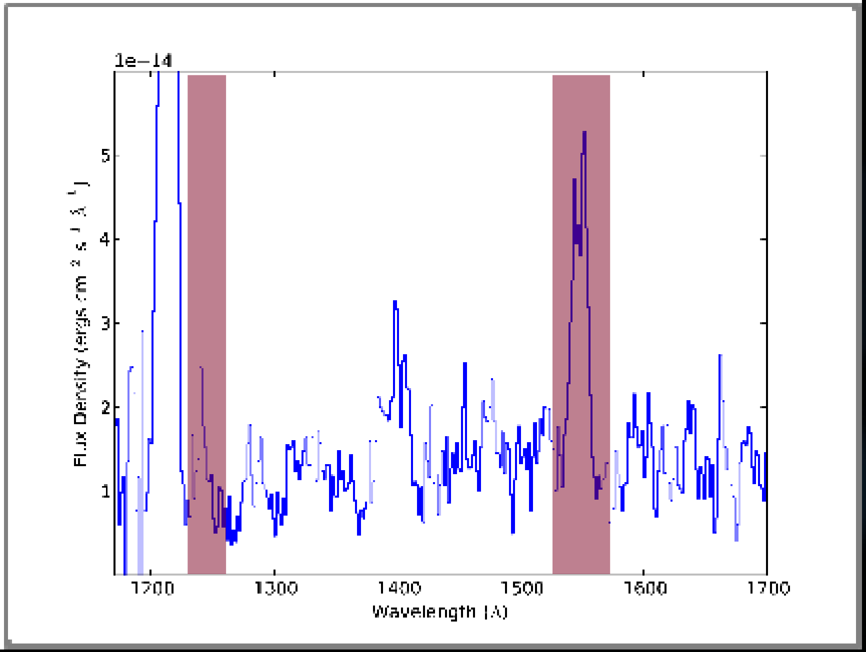

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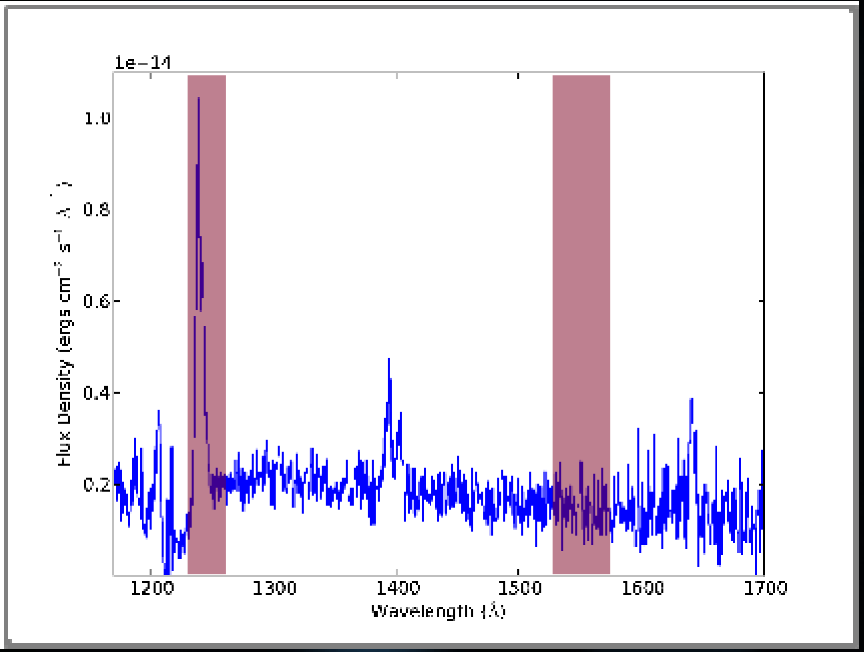

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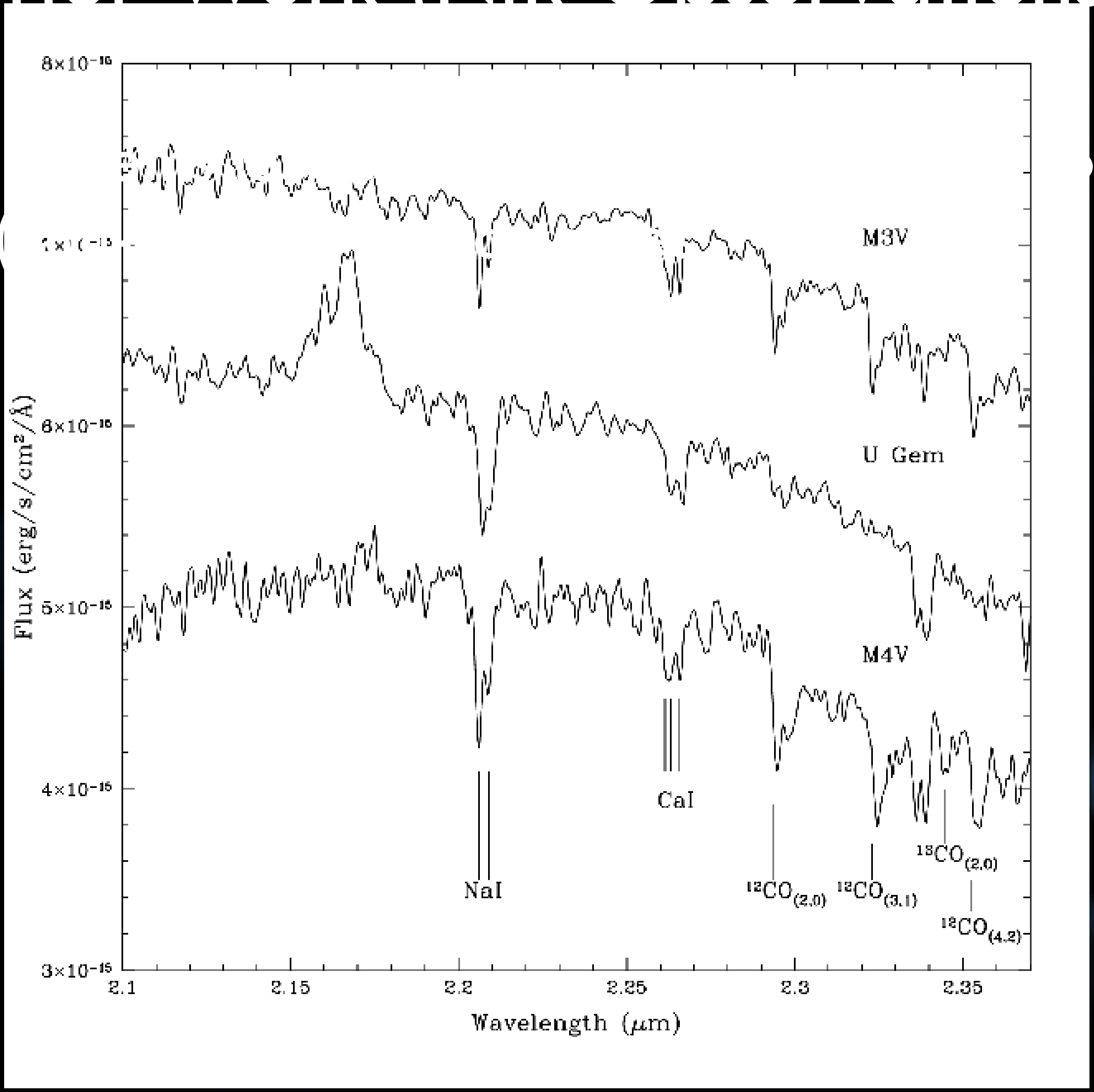
Prior Work (NIR Observations)

- Some [text hidden by figure] look in more ([text hidden by figure]



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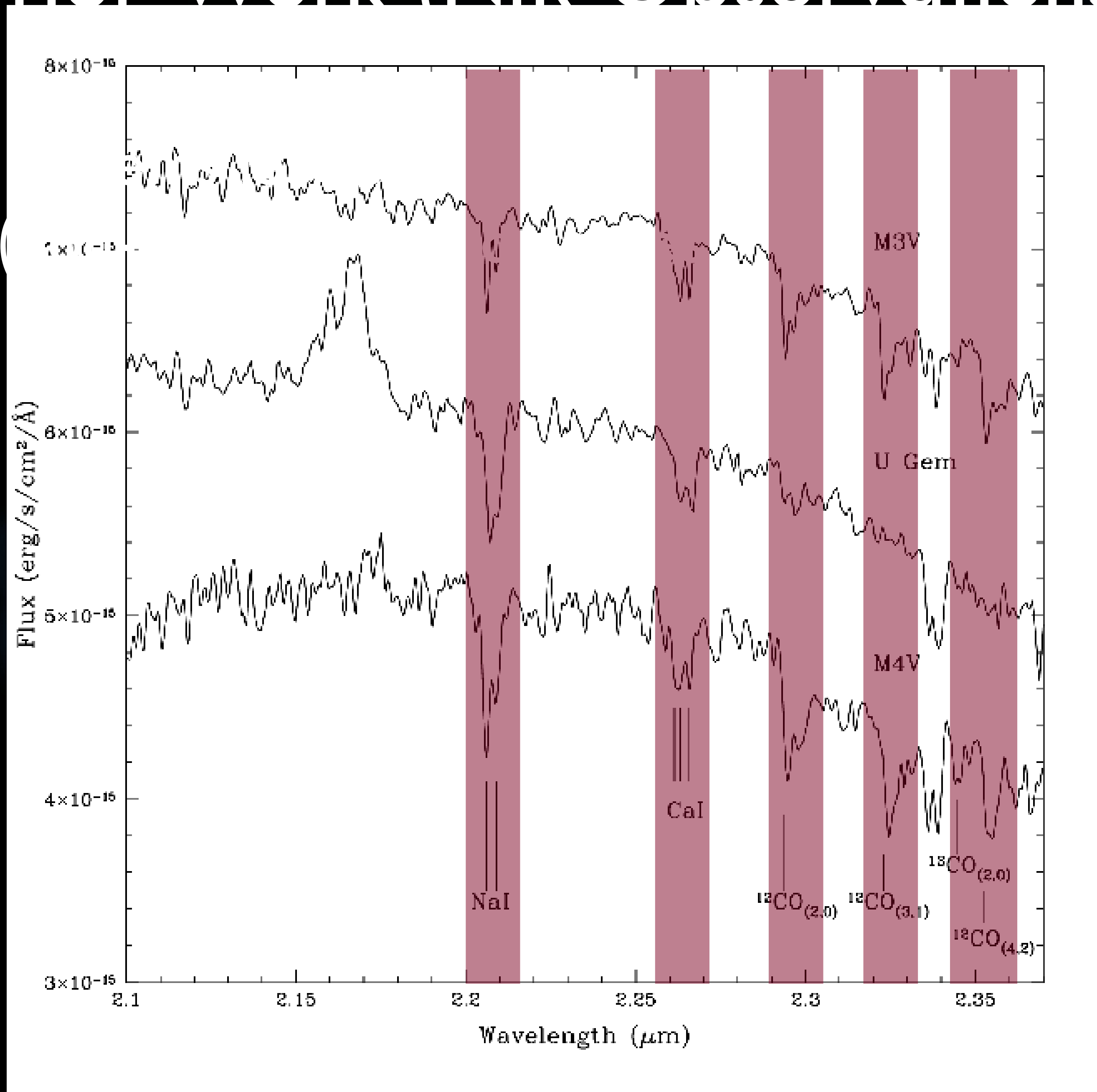


Prior Work (NIR Observations)

- Some systems just plain weird as we begin to look in more (non-optical) bandpasses
  - Many CVs show weak CO features! (Hamilton et al. 2011)
    - 0 "Pre-CVs" (heterogeneous; Silvestri et al. 2007)
    - 13/19 - Long Period Non-Magnetic (68%)
    - 3/12 - Short Period Non-Magnetic (25%)
    - 3/11 - Magnetic, includes IPs (27%)

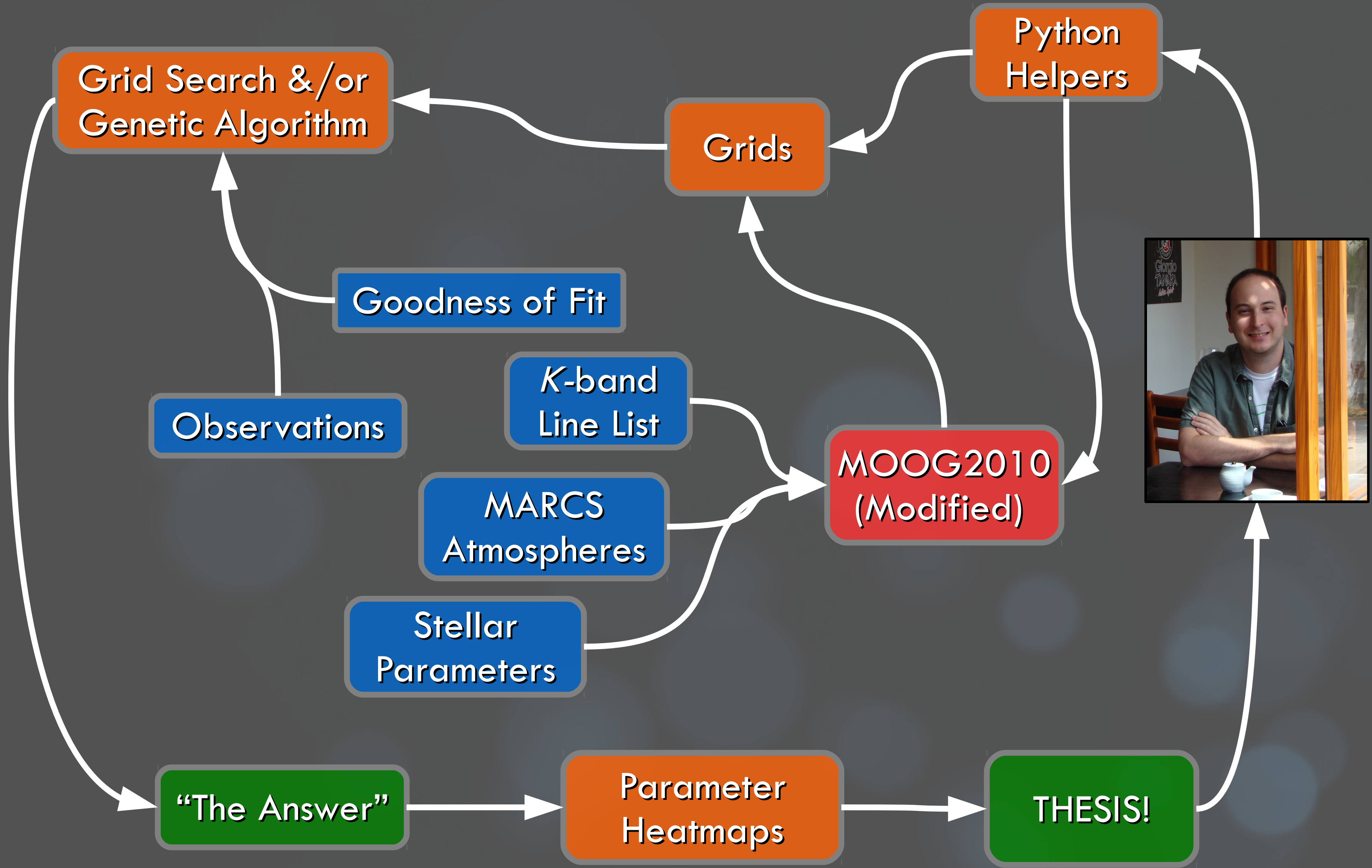
UV + NIR?

- If have both UV and NIR spectra, see CNO material
  - UV: High N V, Weak C IV → N/C increased
  - NIR: Weak CO, enhanced ^{13}C → $^{12}C/^{13}C$ decreased
- Tracing CNO processed material from the donor to WD/disk
  - Requires more massive donor stars than current evolutionary picture allows!
    - Also allows for CVs to be potential Type 1a progenitor systems, with $M_{total} > 1.4\ M_{sun}$

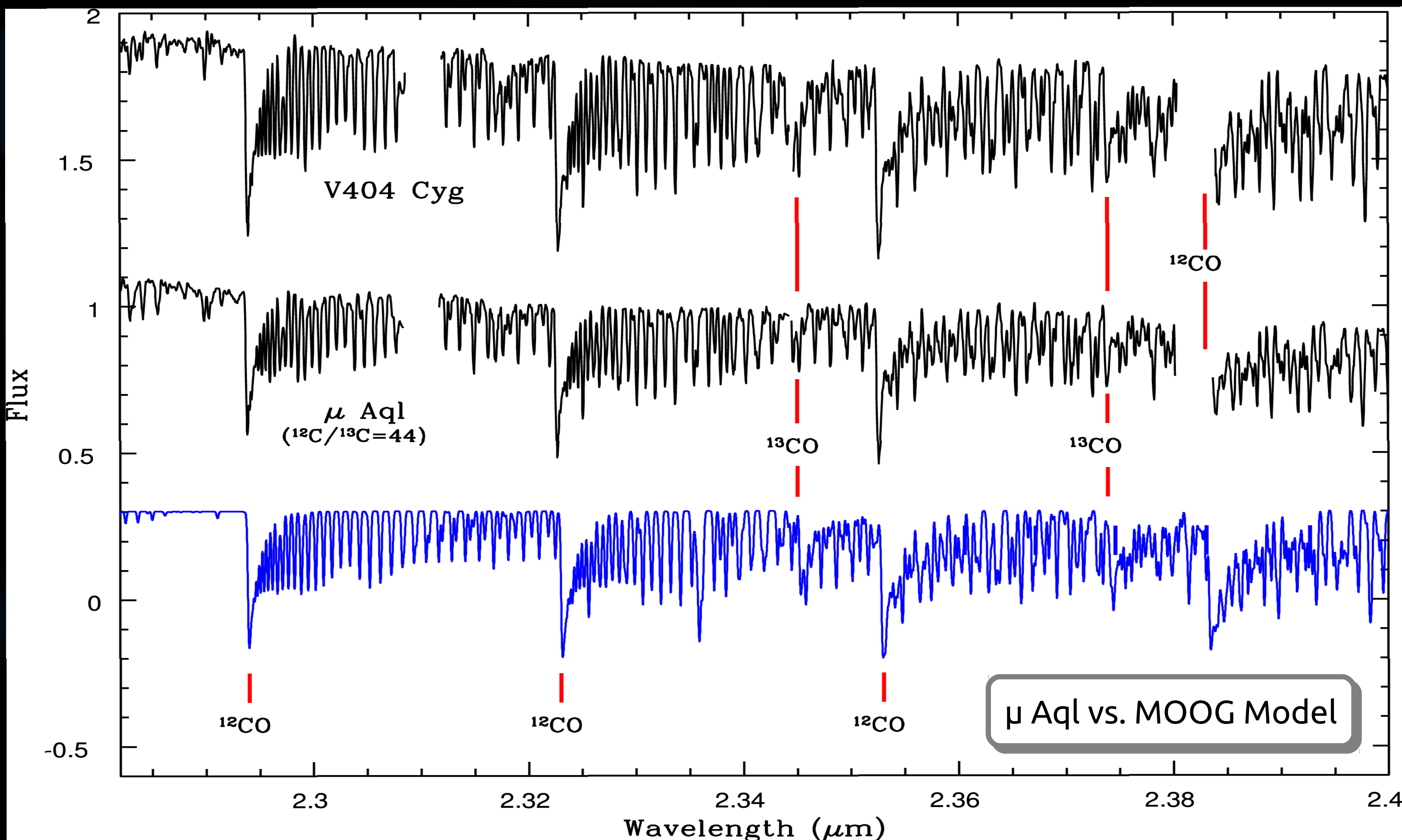
Thesis Walkthrough

- Use MOOG
  - Widespread use, freely available (and modifiable)
  - NO M DWARFS since no H_2O
    - Could probably do earlier than M2, needs testing though
    - PHOENIX available through F. Allard's web interface, but not reliable/fast enough for a thesis
      - (Some other options in the works)
- Modify code directly for easier interactions
  - Not described here, but lots of changes to make MOOG easier to deal with and parallelizable

Algorithm & Code Flow



High Resolution Synthetic CO Spectra



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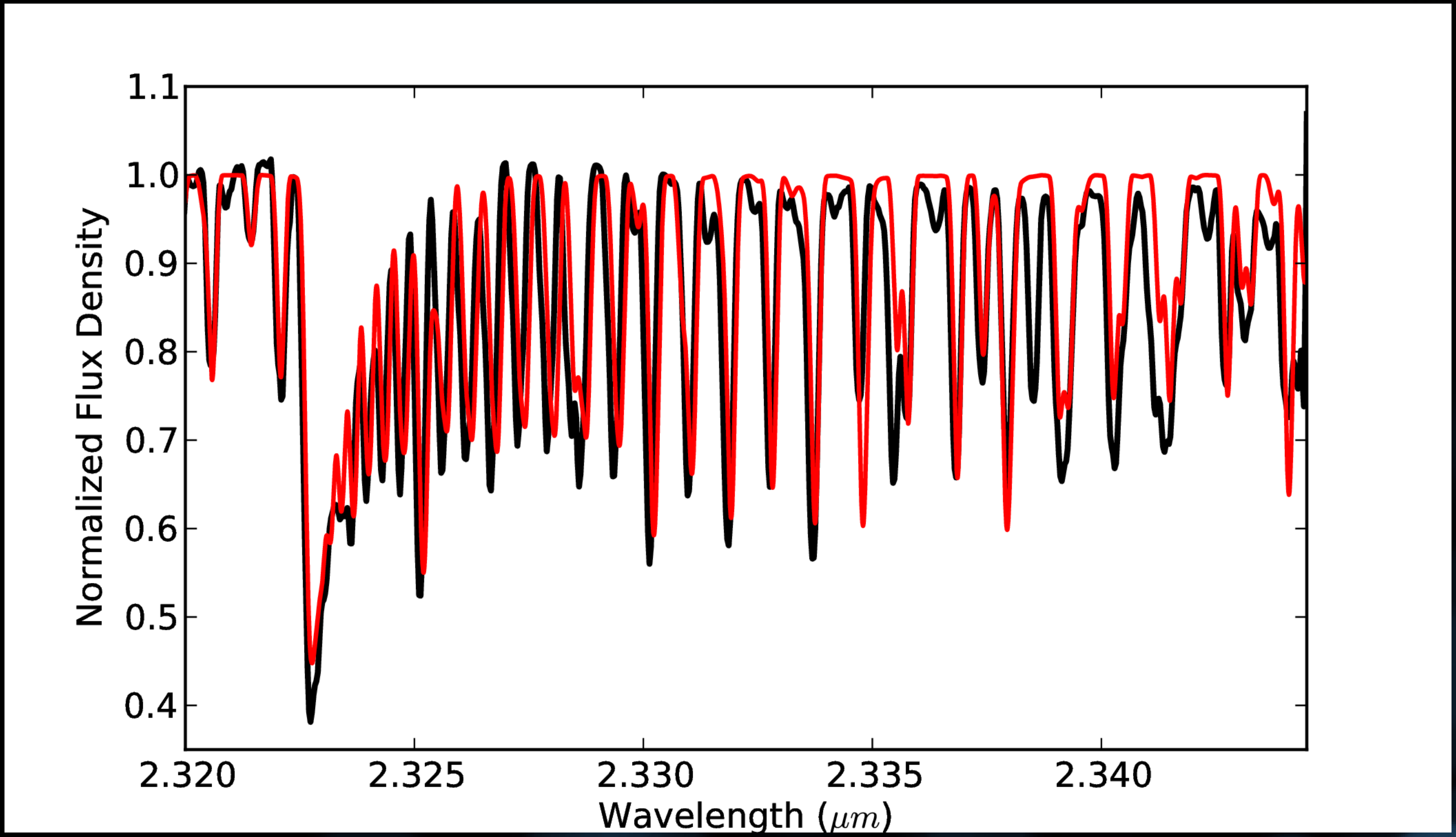
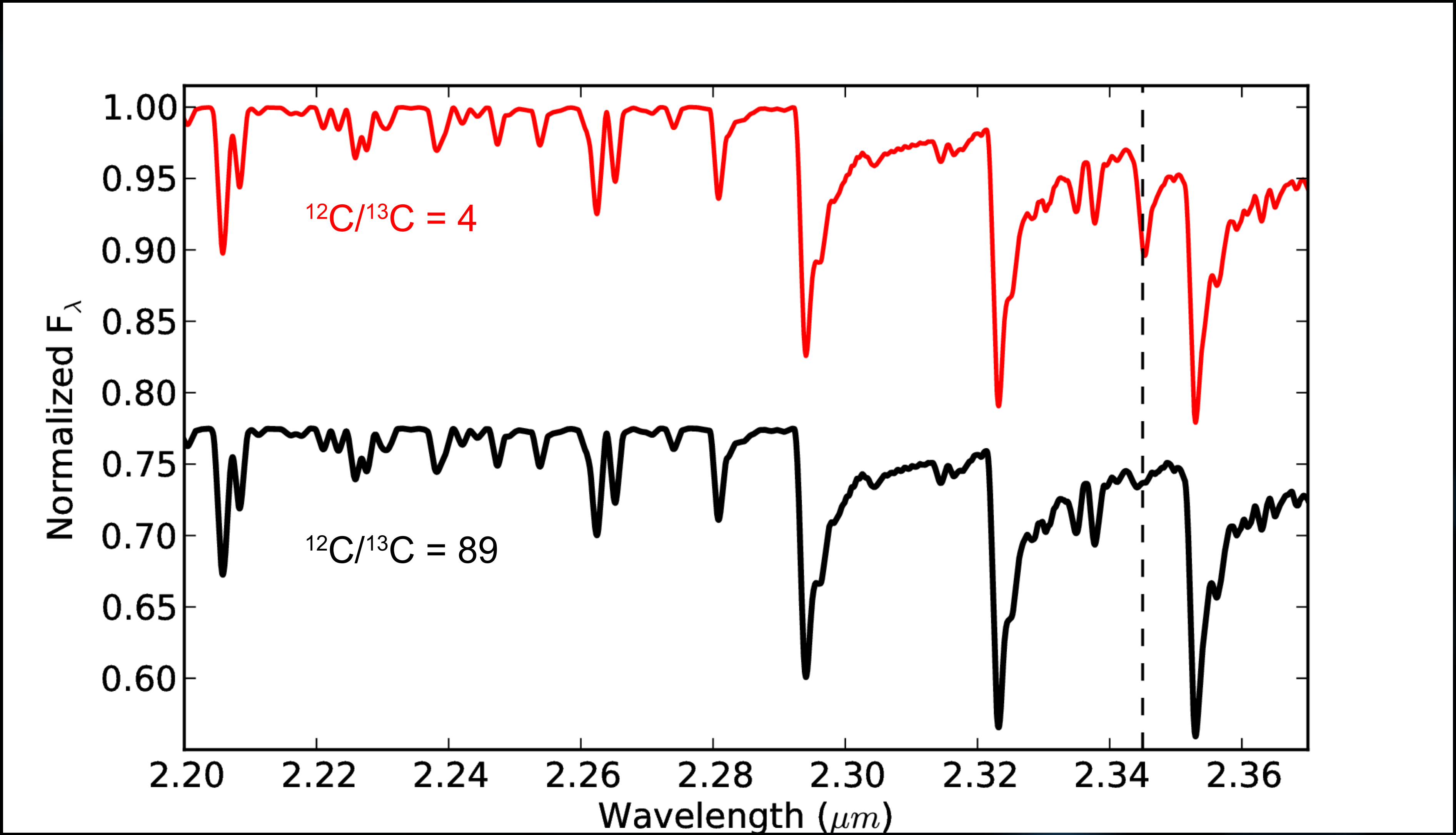
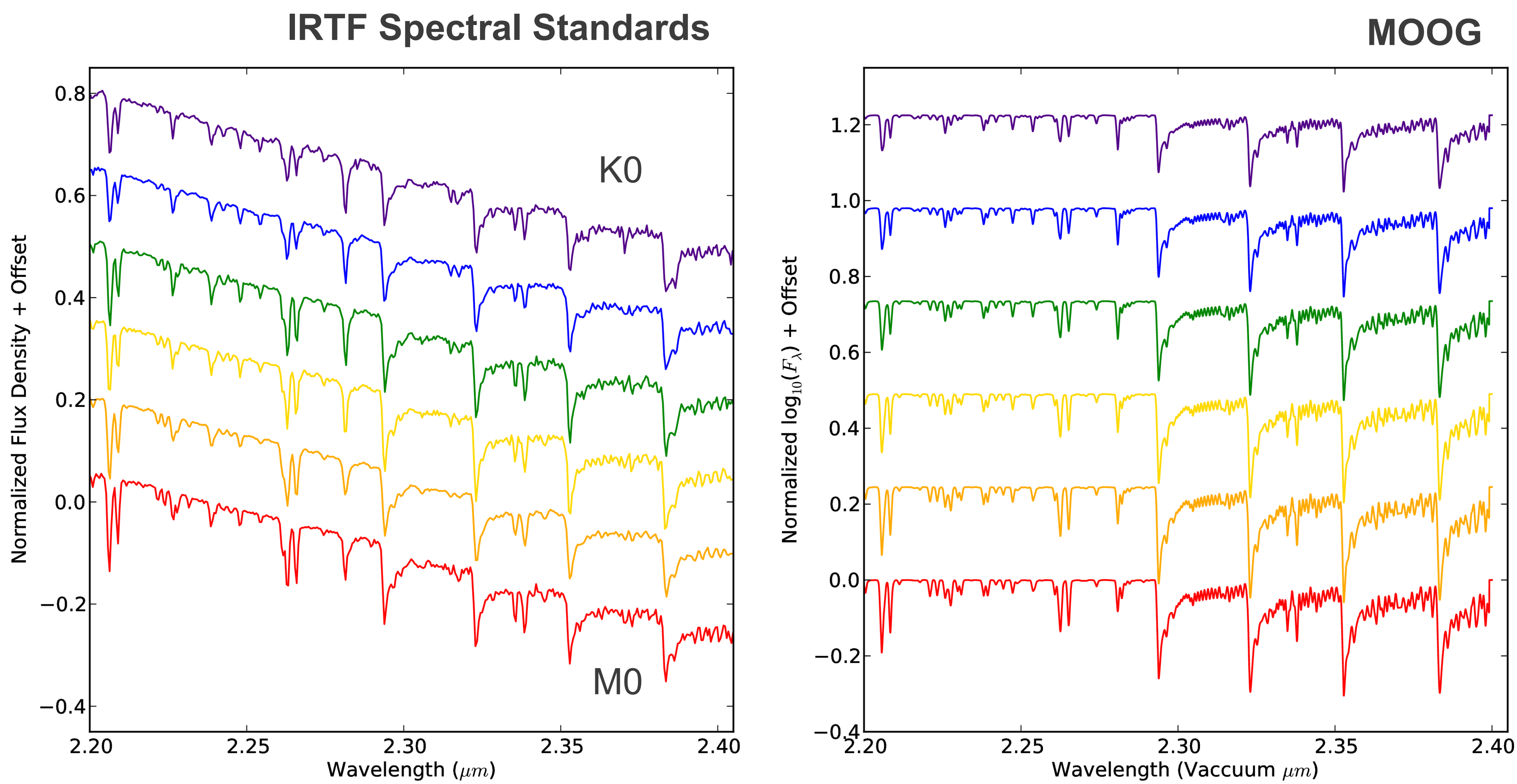


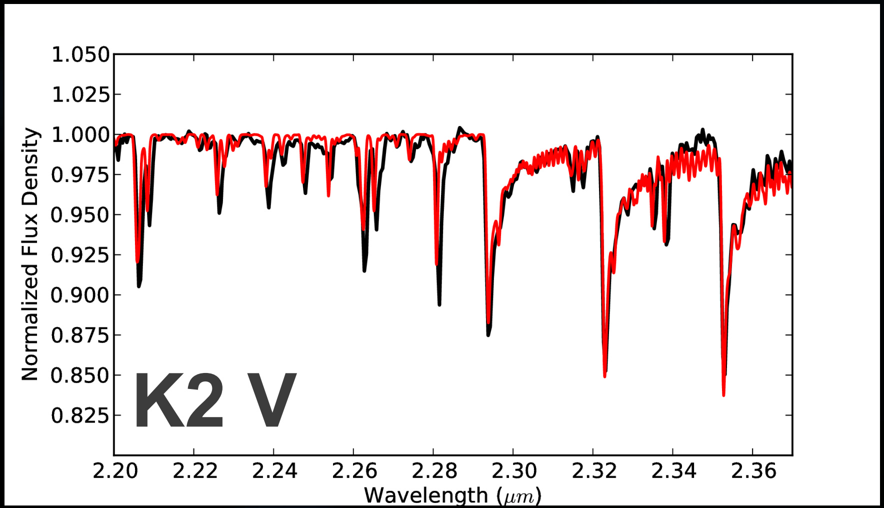
Appearance of ^{13}CO

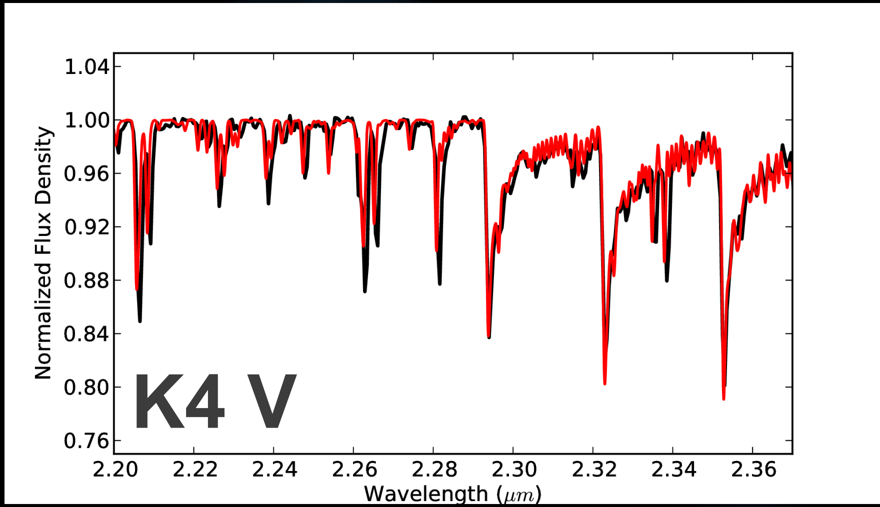


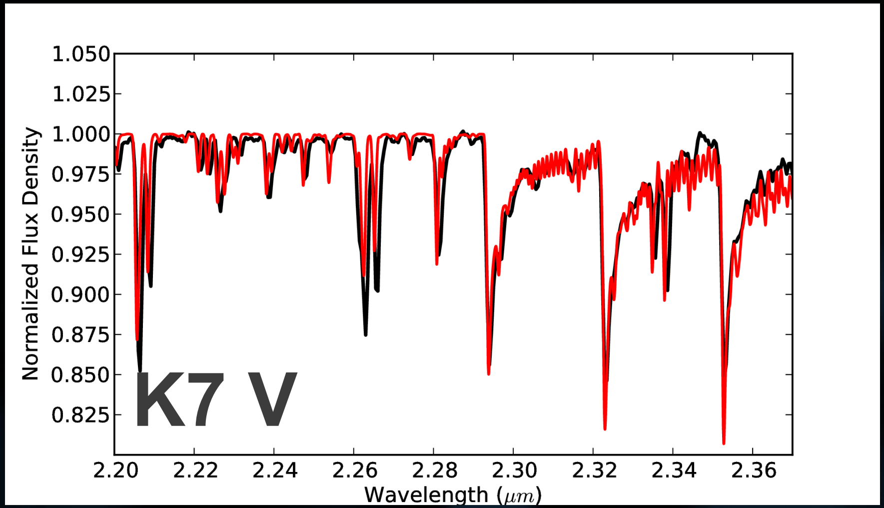
Spectral Sequences: K Dwarfs



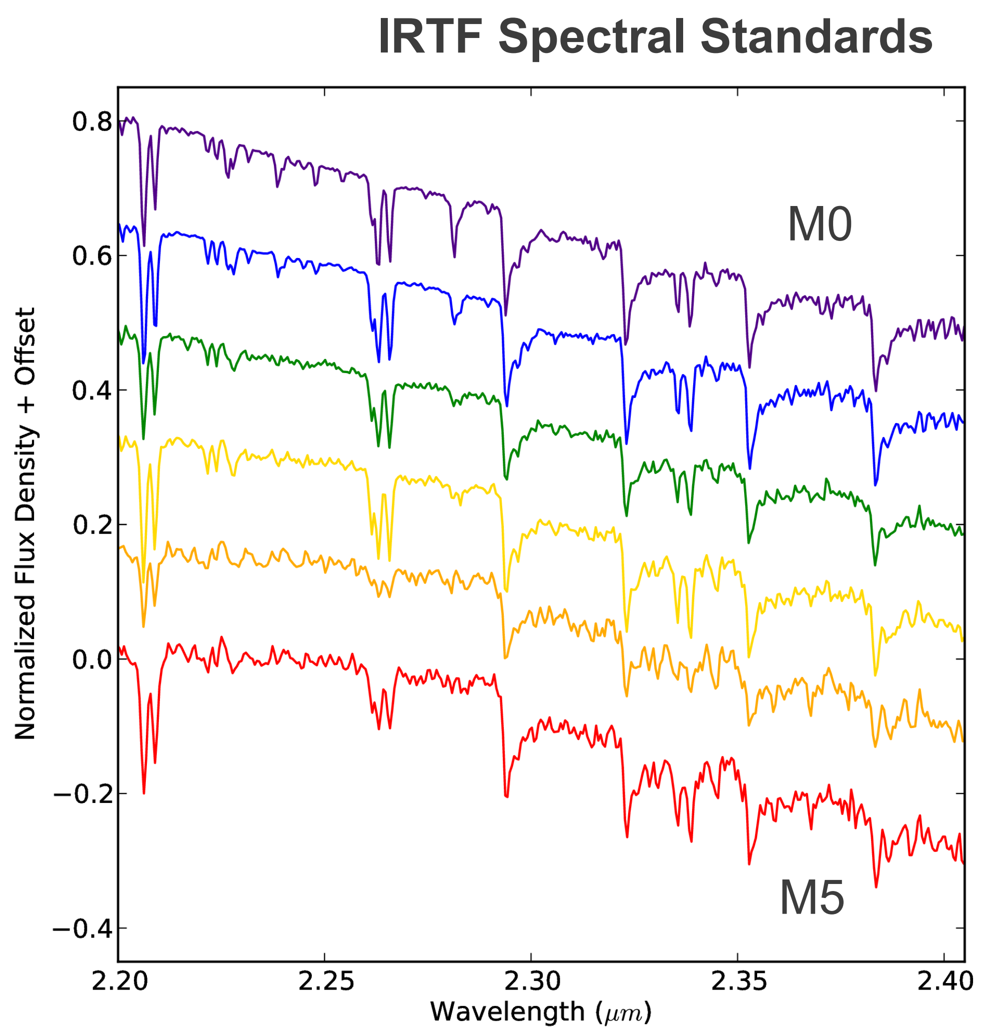
Matching Spectral Class Standards

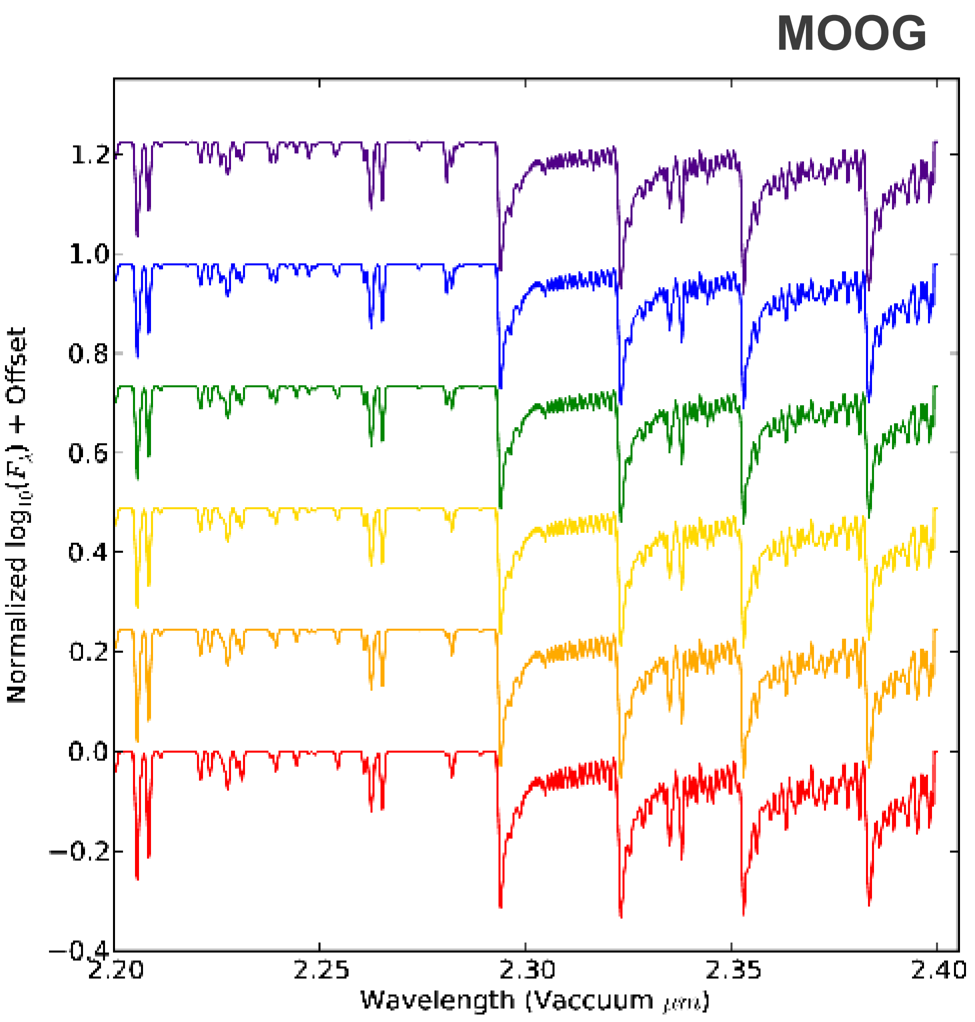




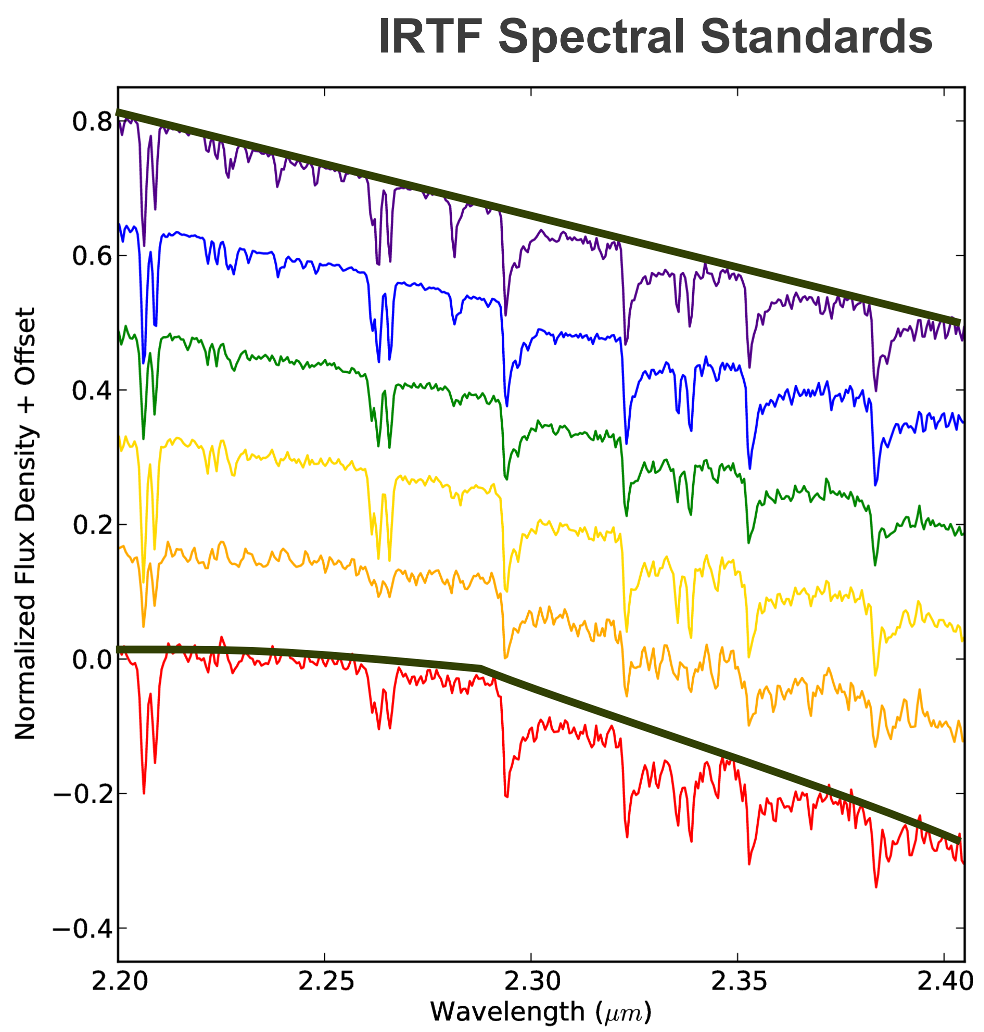


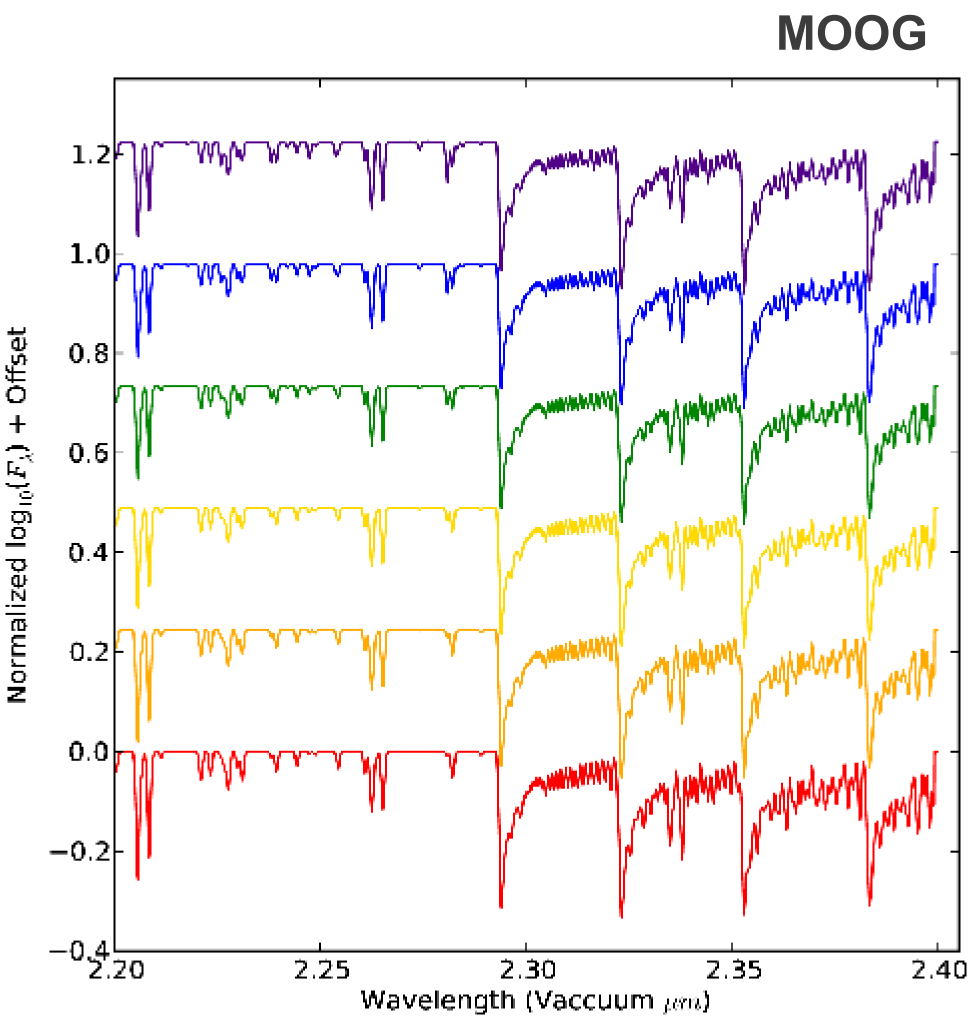
Spectral Sequences: M Dwarfs



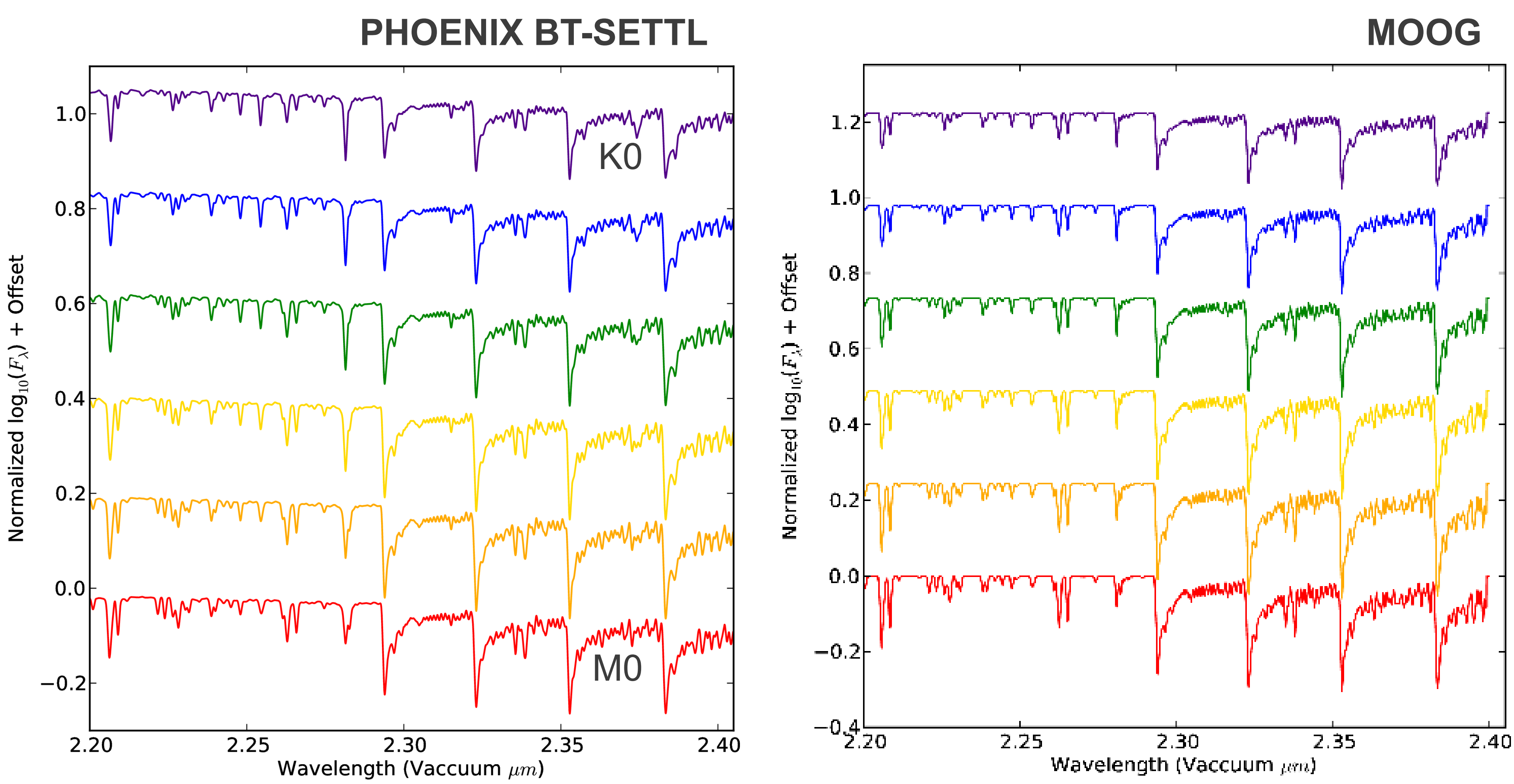


Spectral Sequences: M Dwarfs

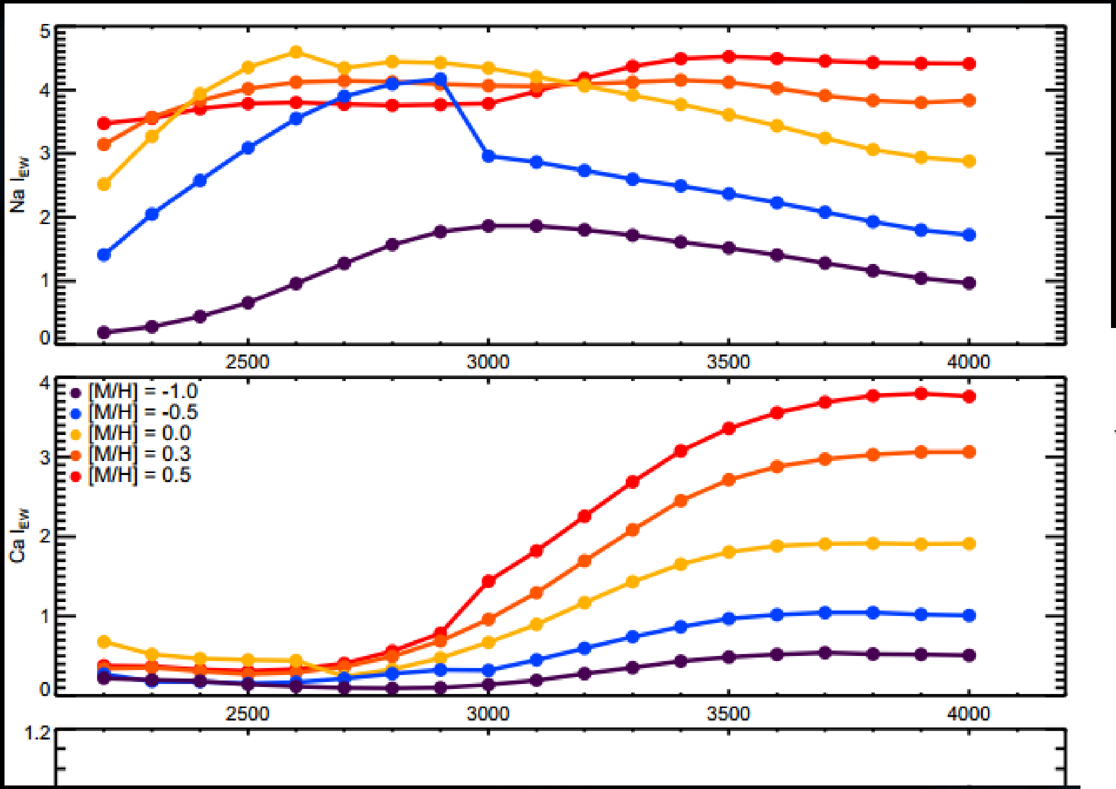




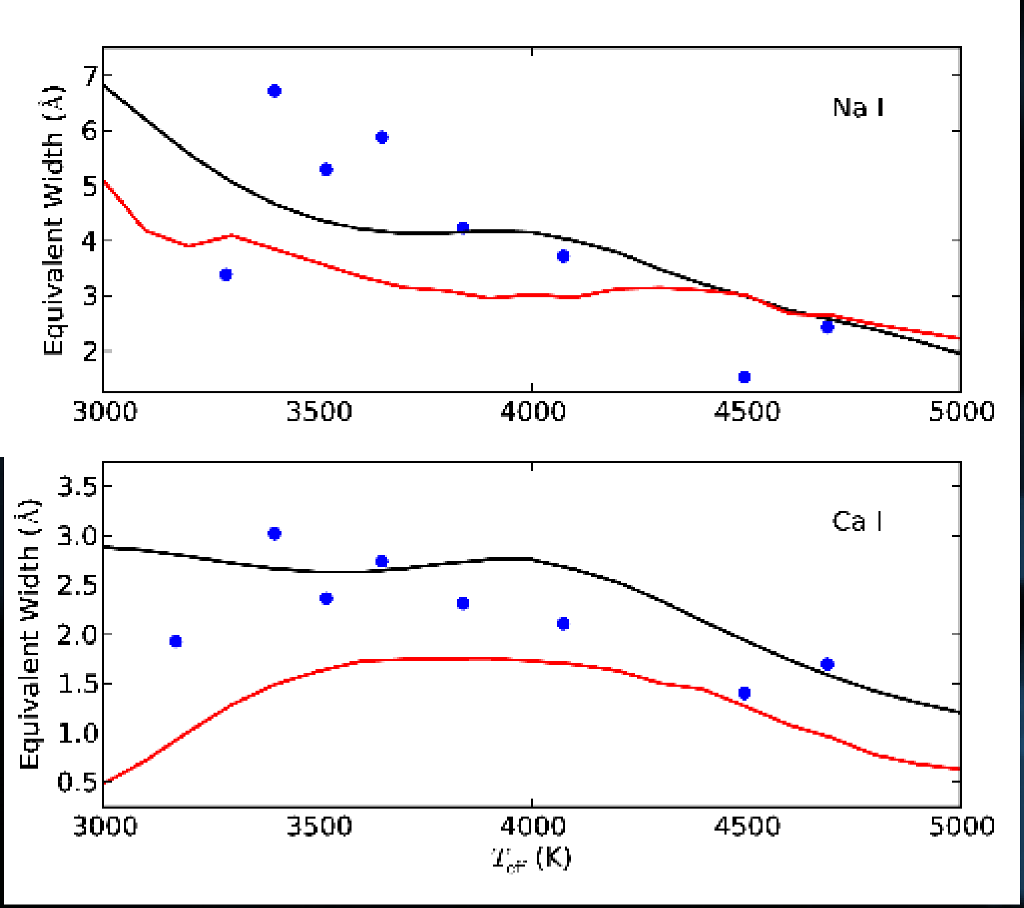
Comparing Synthetic Spectra



Equivalent Width Comparisons

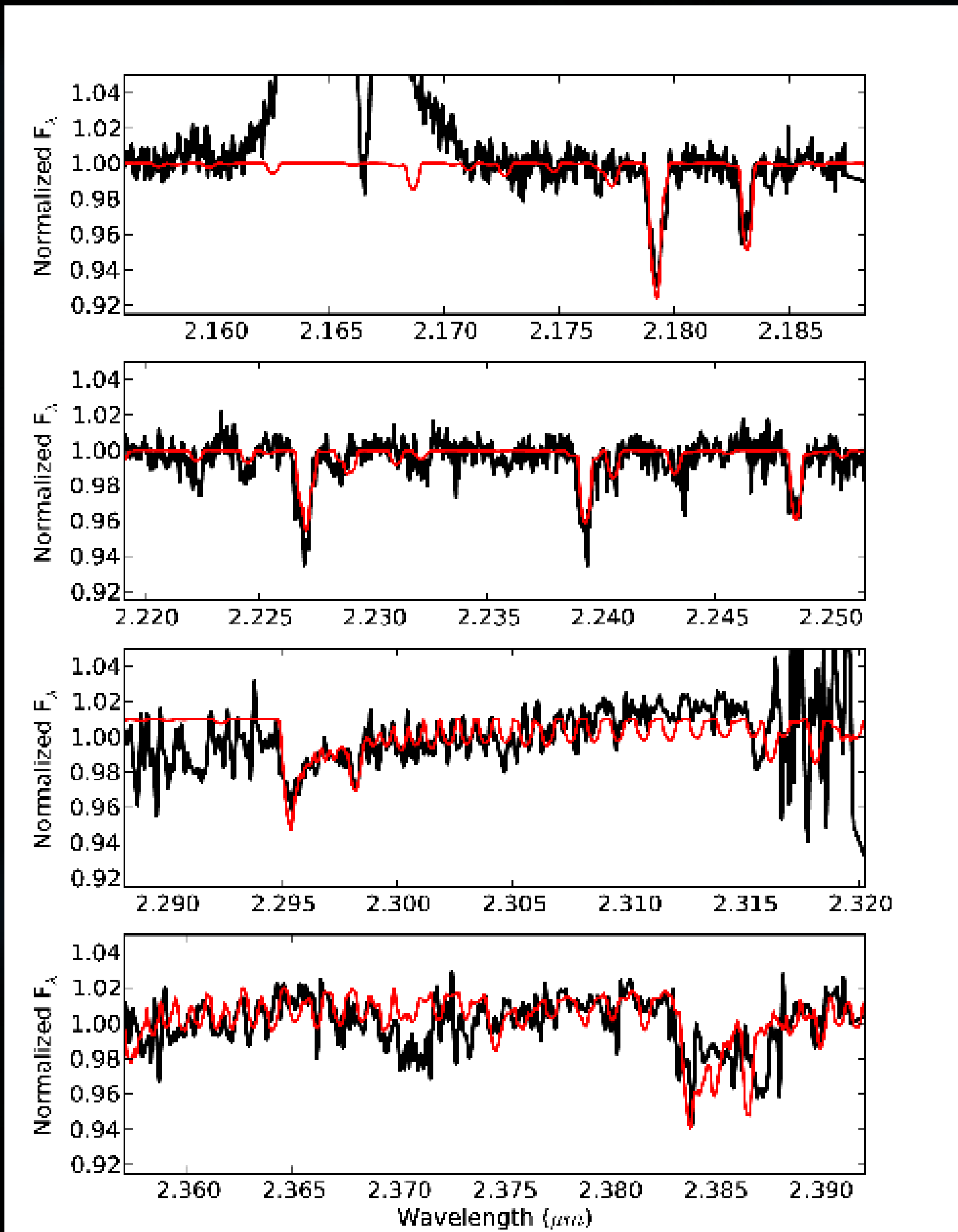


Rojas-Ayala et al. 2012
PHOENIX BT-SETTL



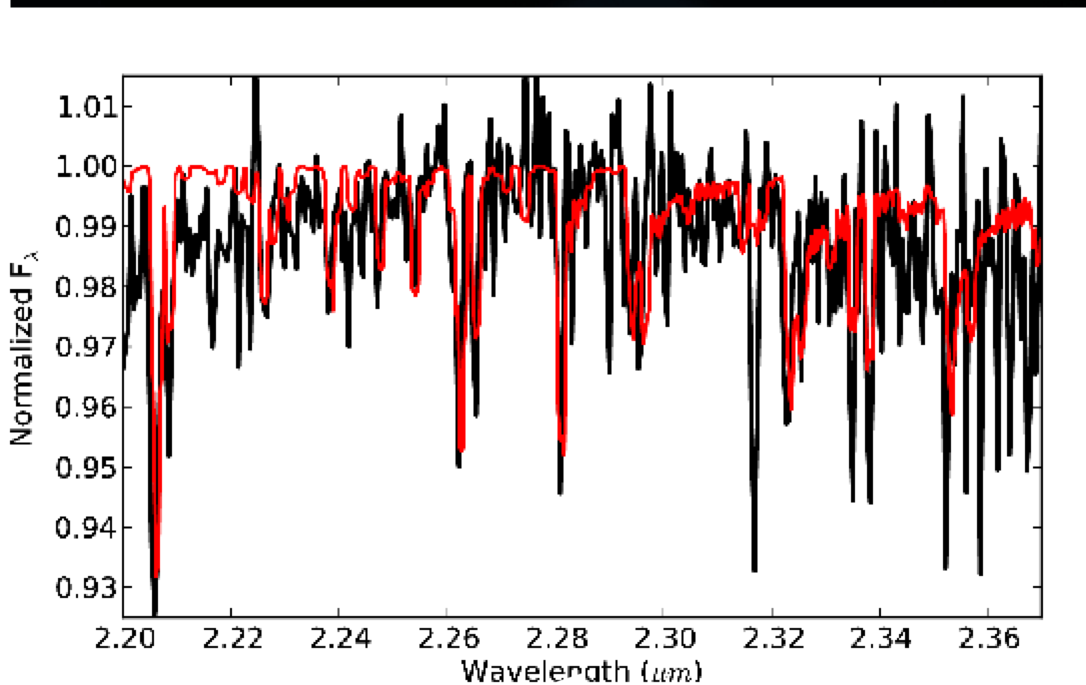
Red: PHOENIX BT-SETTL
Black: MOOG
Blue Points: IRTF Spectral Standards

Results! GK Per



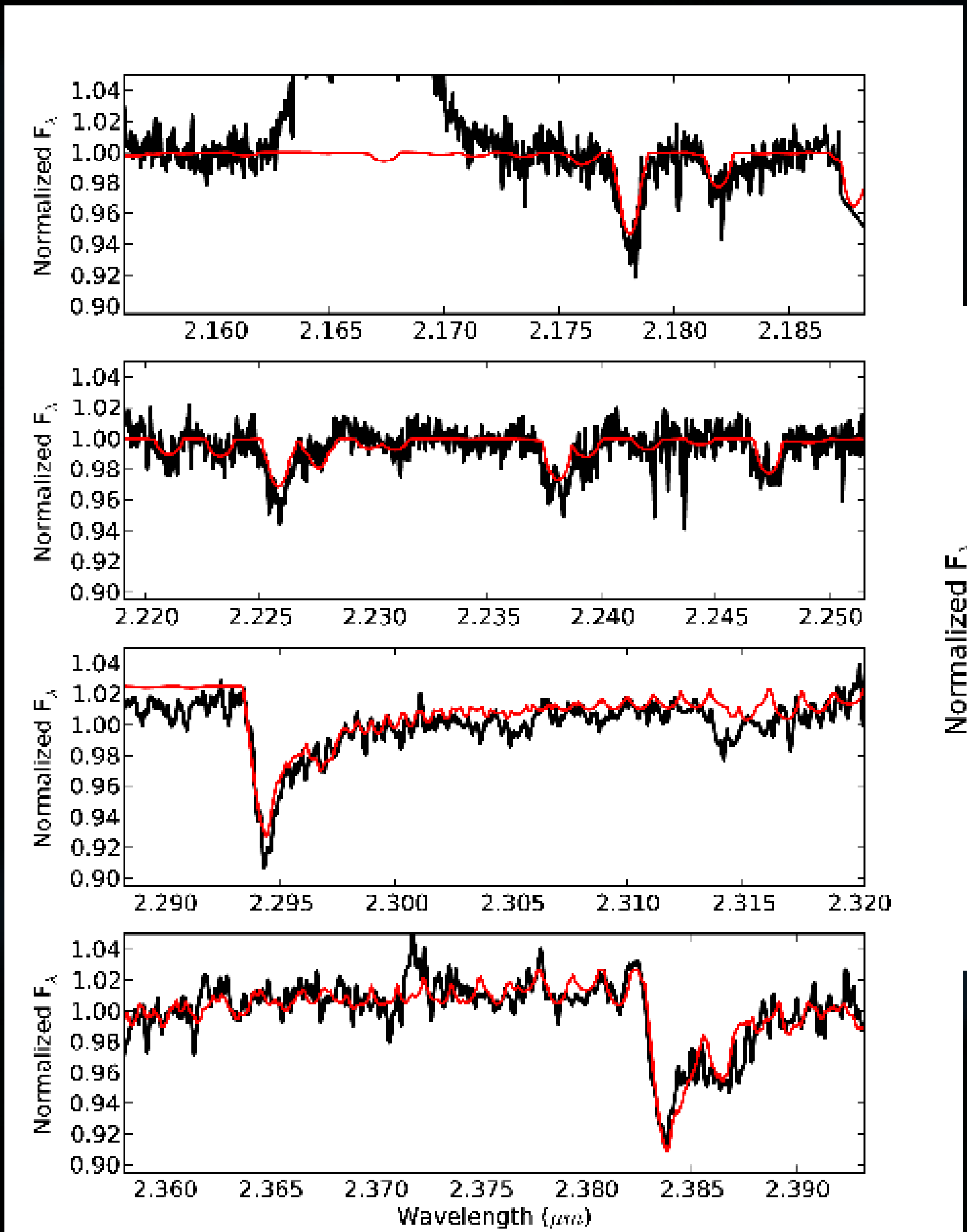
NIRSPEC @ Keck II

T_{eff} = 5100 K, *log(g)* = 4.50,
[Fe/H] = -0.5, [C/H] = -0.50 *(0.3 solar)*



SpeX @ IRTF

Results! RU Peg



NIRSPEC @ Keck II

T_{eff} = 4600 K, *log(g)* = 4.50,
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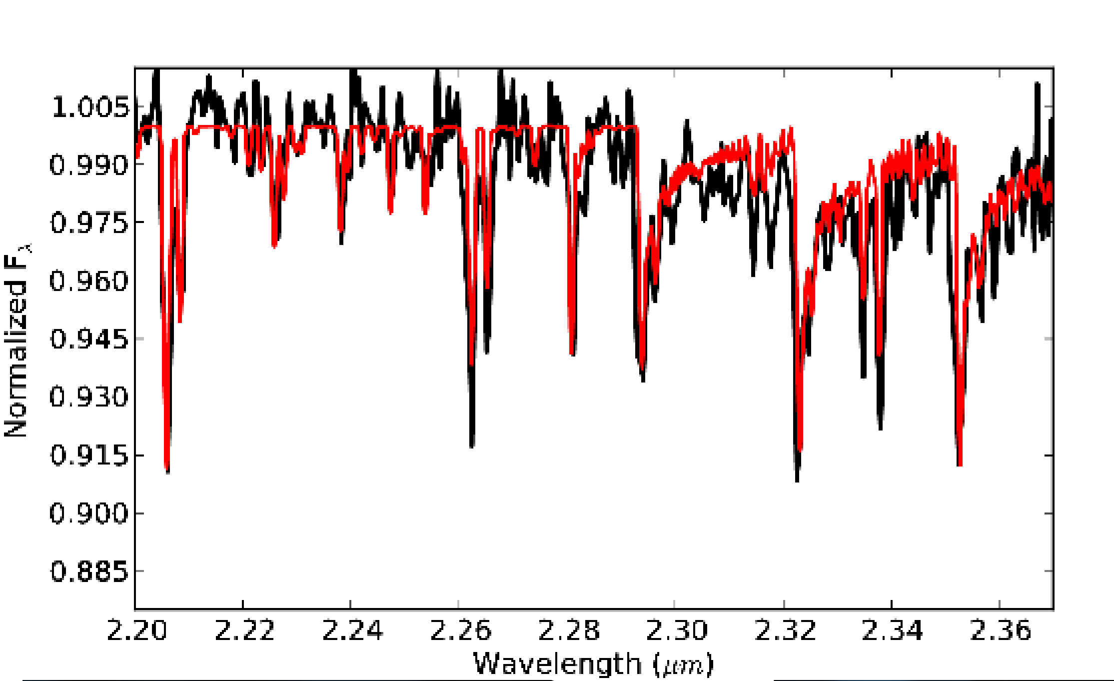
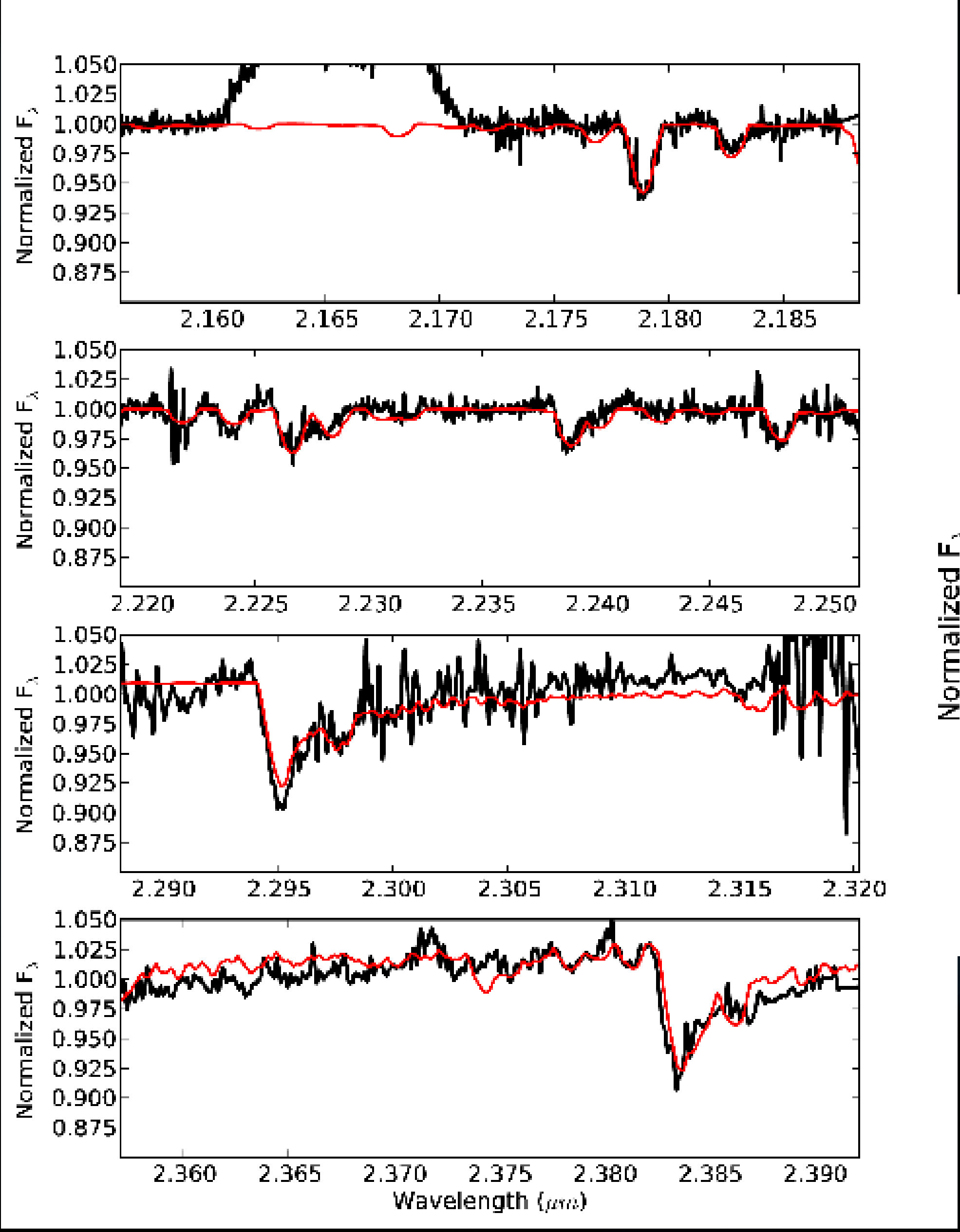


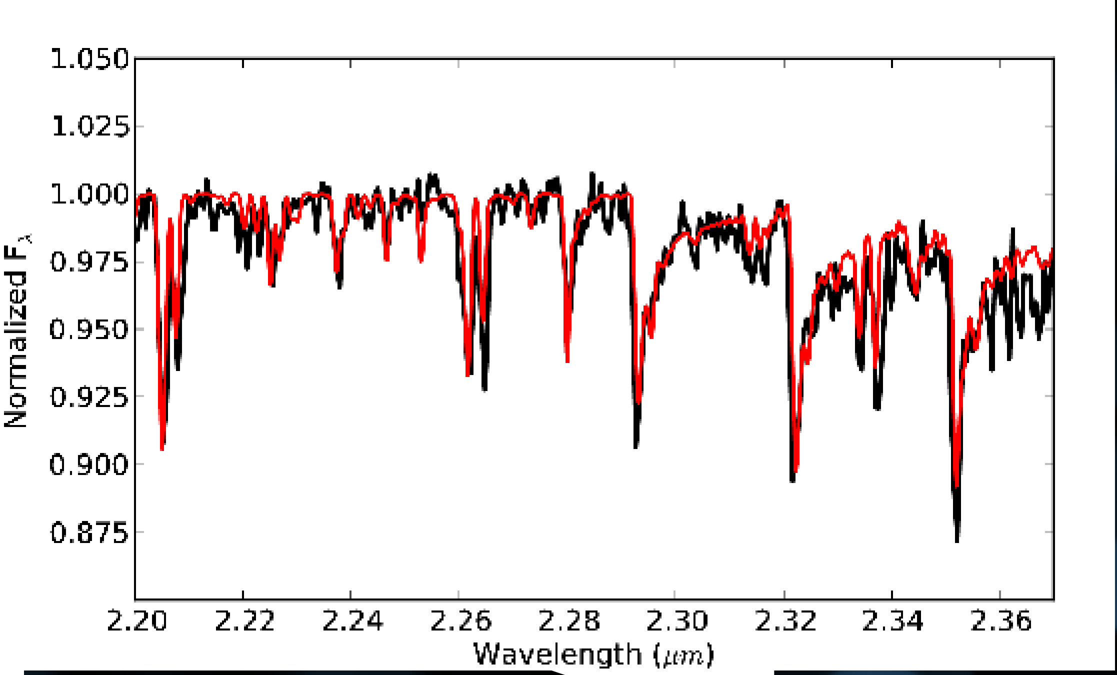
SpeX @ IRTF

Results! SS Cyg



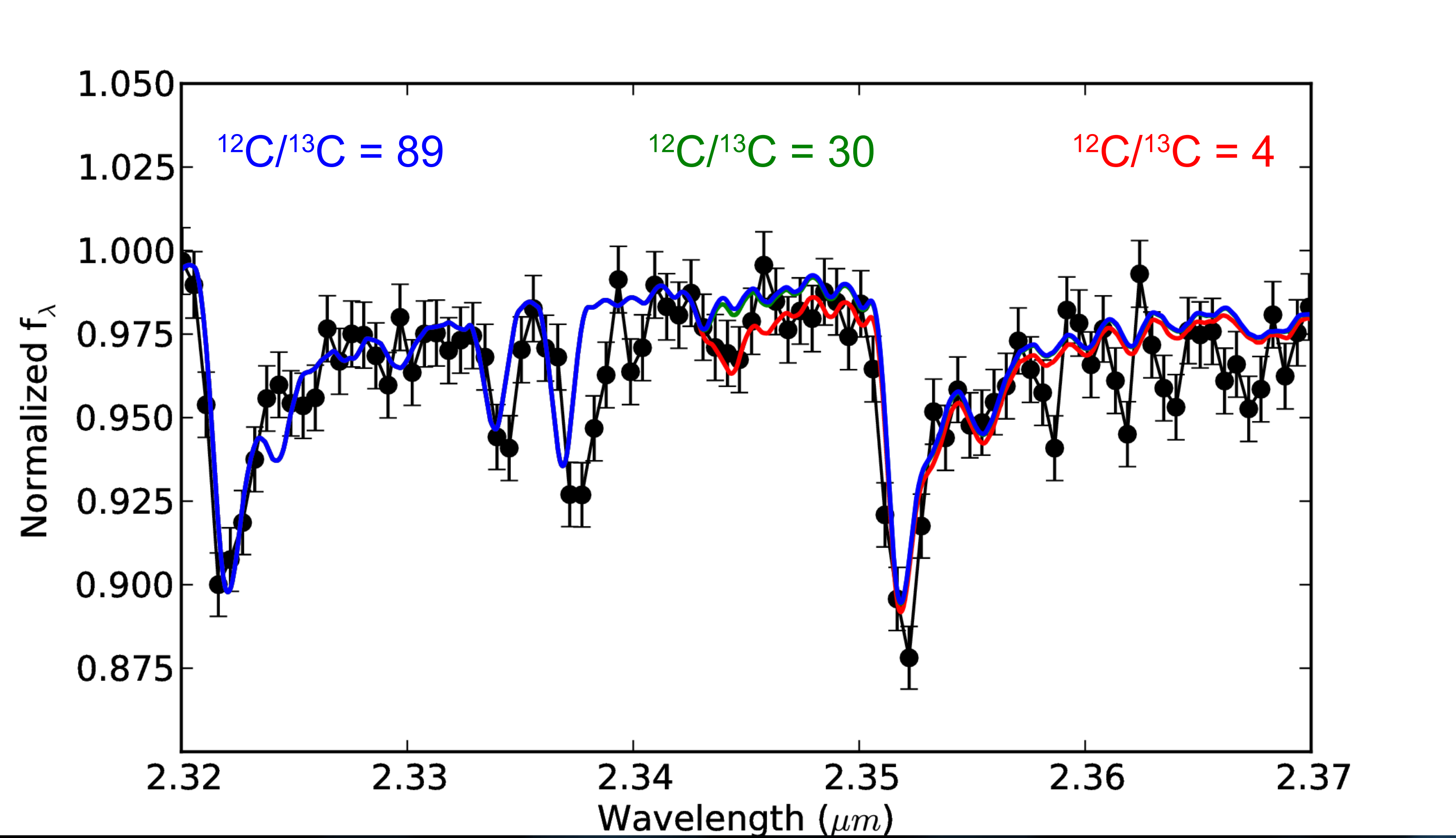
NIRSPEC @ Keck II

T_{eff} = 4700 K, *log(g)* = 4.25,
[Fe/H] = -0.25, [C/H] = -0.25 *(0.6 solar)*

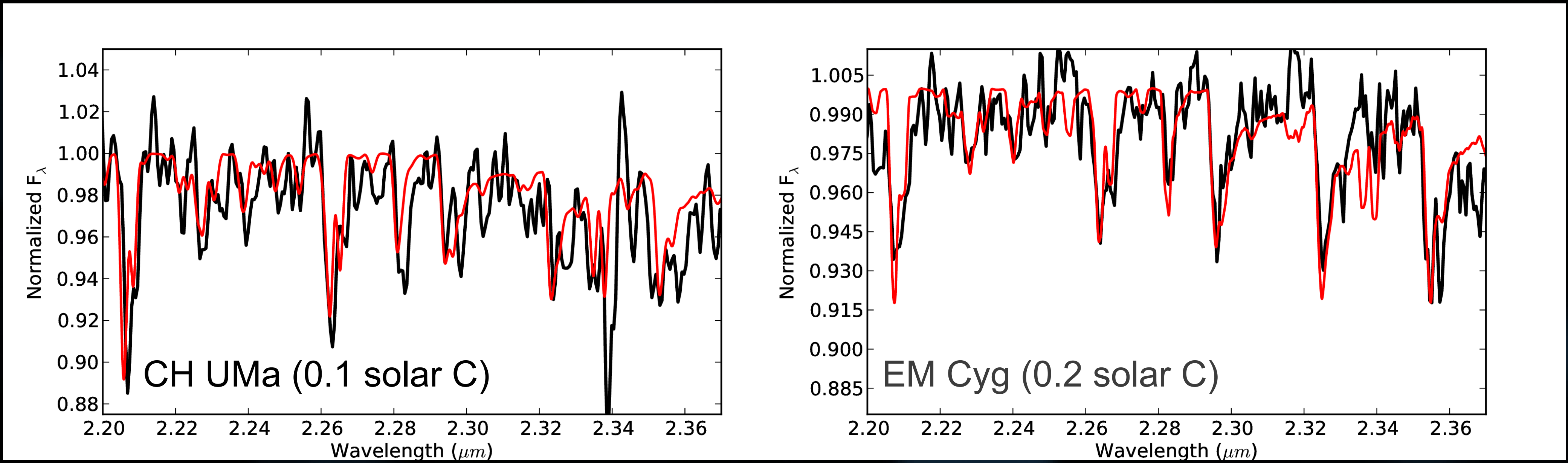


SpeX @ IRTF

SS Cyg: ^{13}CO Enhancement

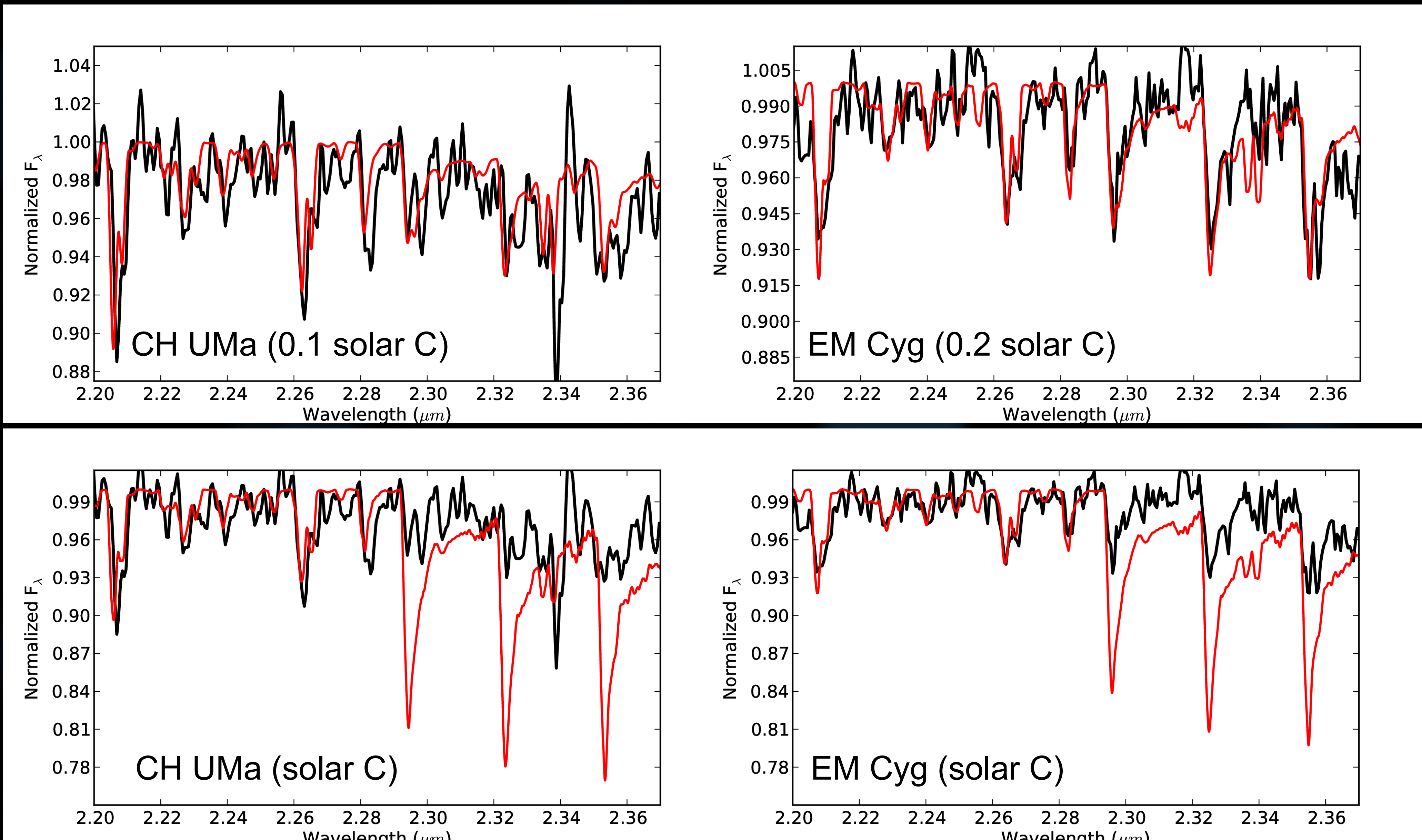


CH UMa & EM Cyg



Normalized F$_\lambda$
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0.88
CH UMa (0.1 solar C)
2.20
2.22
2.24
2.26
2.28
2.30
2.32
2.34
2.36
Wavelength (μm)
Normalized F$_\lambda$
1.005
0.990
0.975
0.960
0.945
0.930
0.915
0.900
0.885
EM Cyg (0.2 solar C)
2.20
2.22
2.24
2.26
2.28
2.30
2.32
2.34
2.36
Wavelength (μm)

CH UMa & EM Cyg



CH UMa (0.1 solar C)
EM Cyg (0.2 solar C)
CH UMa (solar C)
EM Cyg (solar C)
Normalized F_λ
Wavelength (μm)
1.04
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0.930
0.915
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0.96
0.93
0.90
0.87
0.84
0.81
0.78
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2.32
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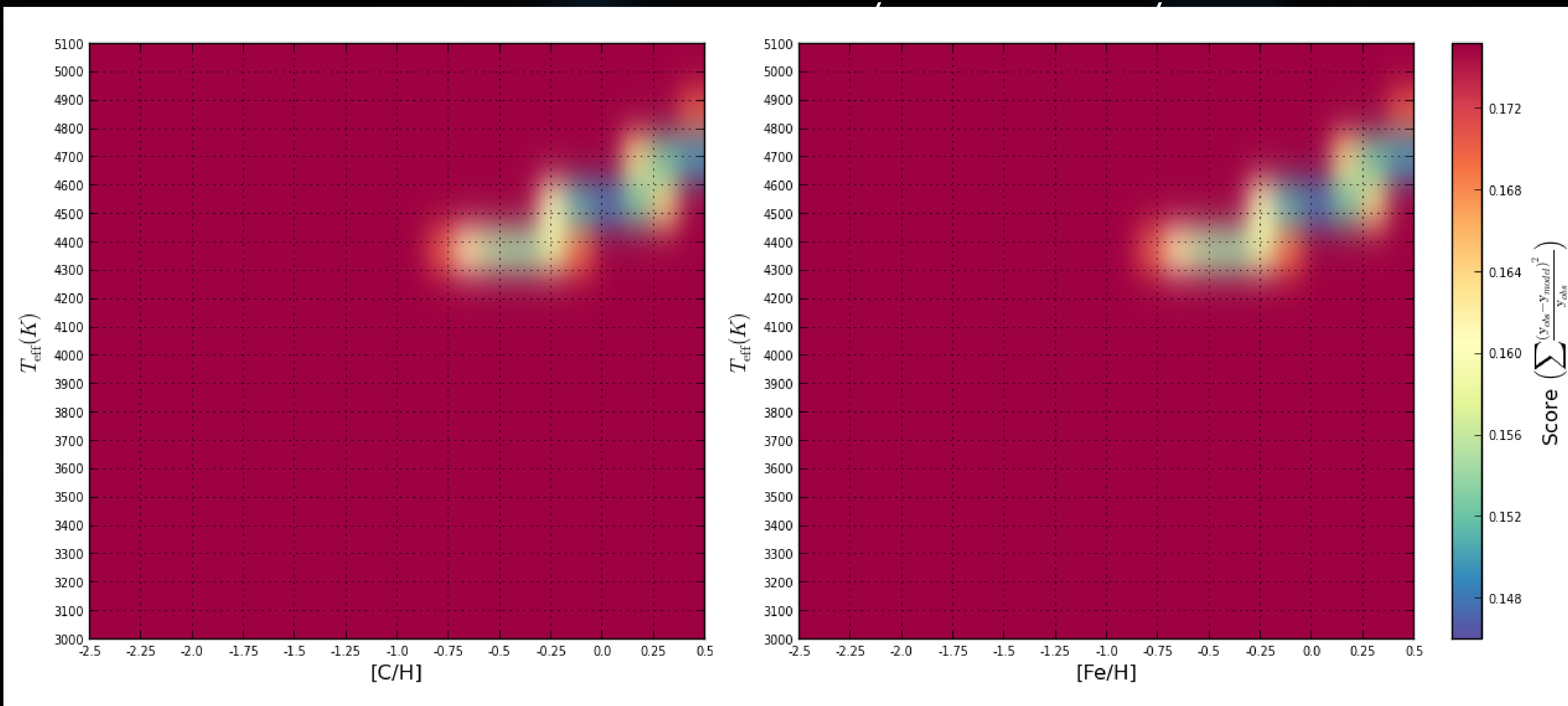
2.36

Assessing Parameter Variations

- Take slices in param space, plot vars as contours of χ^2
  - Due to T_{eff} dependence of CO strength, degeneracies between T_{eff}, [C/H], and [Fe/H]

Assessing Parameter Variations

- Take slices in param space, plot vars as contours of χ^2
  - Due to T_{eff} dependence of CO strength, clear

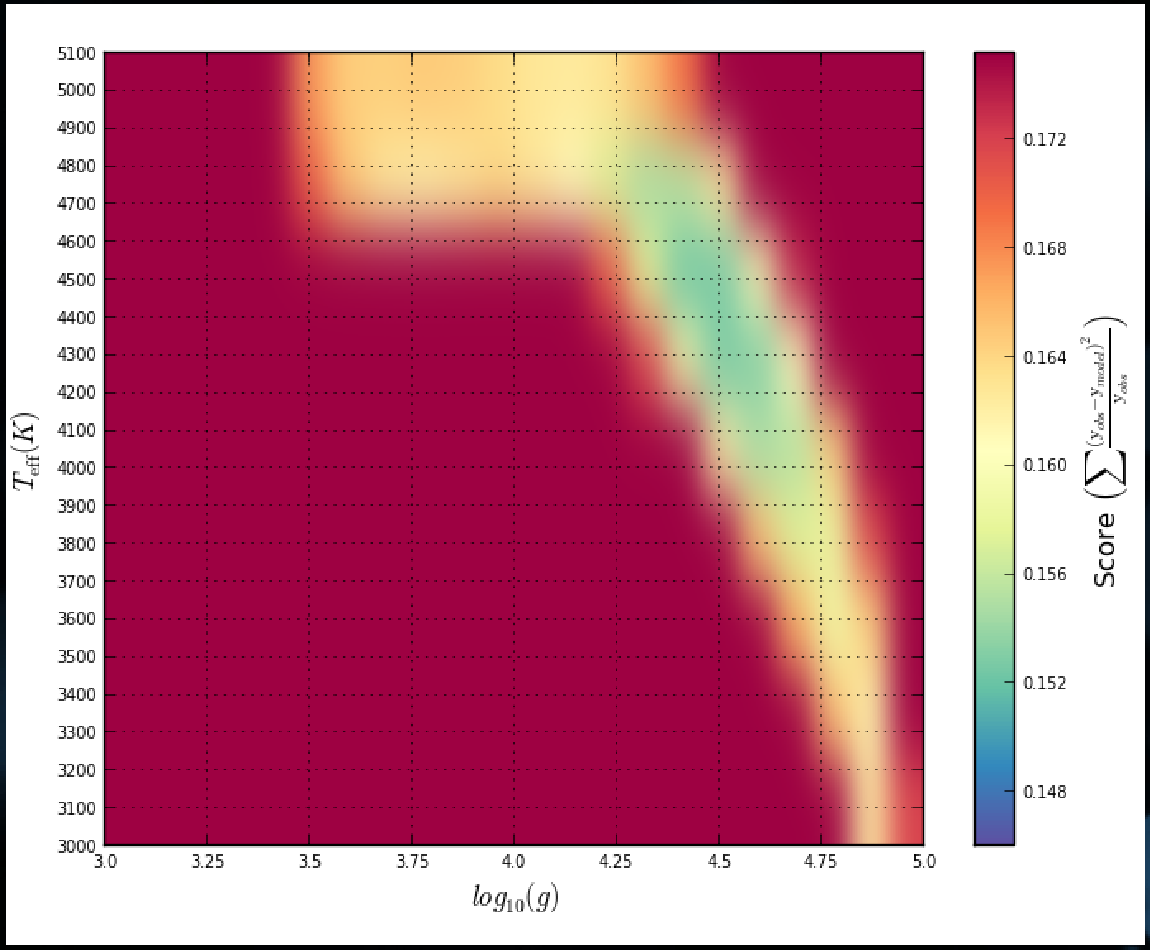


Assessing Parameter Variations

- *log(g)* generally poorly constrained, need more gravity sensitive lines!

Adopted Errors:

- T_{eff}: ± 75, 125 K
- log(g): ± 0.25 dex
- [Fe/H]: ± 0.25 dex
- [C/H]: ± 0.25 dex
- $^{12}C/^{13}C$: upper limit



Results Summary

Table 4.2. Derived System Parameters

System	$T_{\rm eff}$ (K)	$log_{10}(g)$	$[Fe/H]$	$[C/H]$	$^{12}C/^{13}C$
GK Per	5100 ± 75	4.50 ± 0.25	-0.50 ± 0.25	-0.50 ± 0.25	...
RU Peg (Keck)	4600 ± 75	4.50 ± 0.25	-0.50 ± 0.25	-0.50 ± 0.25	...
RU Peg (IRTF)	4400 ± 125	4.50 ± 0.25	-0.50 ± 0.25	-0.50 ± 0.25	...
SS Cyg (Keck)	4700 ± 75	4.25 ± 0.25	-0.25 ± 0.25	-0.50 ± 0.25	...
SS Cyg (IRTF)	4700 ± 125	4.25 ± 0.25	-0.25 ± 0.25	-0.50 ± 0.25	< 30
CH UMa	4100 ± 125	4.50 ± 0.25	$+0.00 \pm 0.25$	-1.00 ± 0.25	...
MU Cen	4400 ± 125	4.50 ± 0.25	$+0.00 \pm 0.25$	-0.75 ± 0.25	...
EM Cyg	4500 ± 125	4.50 ± 0.25	$+0.00 \pm 0.25$	-0.75 ± 0.25	...

Note. — Both $[Fe/H]$ and $[C/H]$ in columns four and five are the logarithmic ratio of Fe and C respectively compared to the sun, such that

$$[X/H] = \log(N_X/N_H)_{\rm star} - log(N_X/N_H)_{\rm solar}$$

where N_X and N_H are the absolute abundances of element X and H respectively.

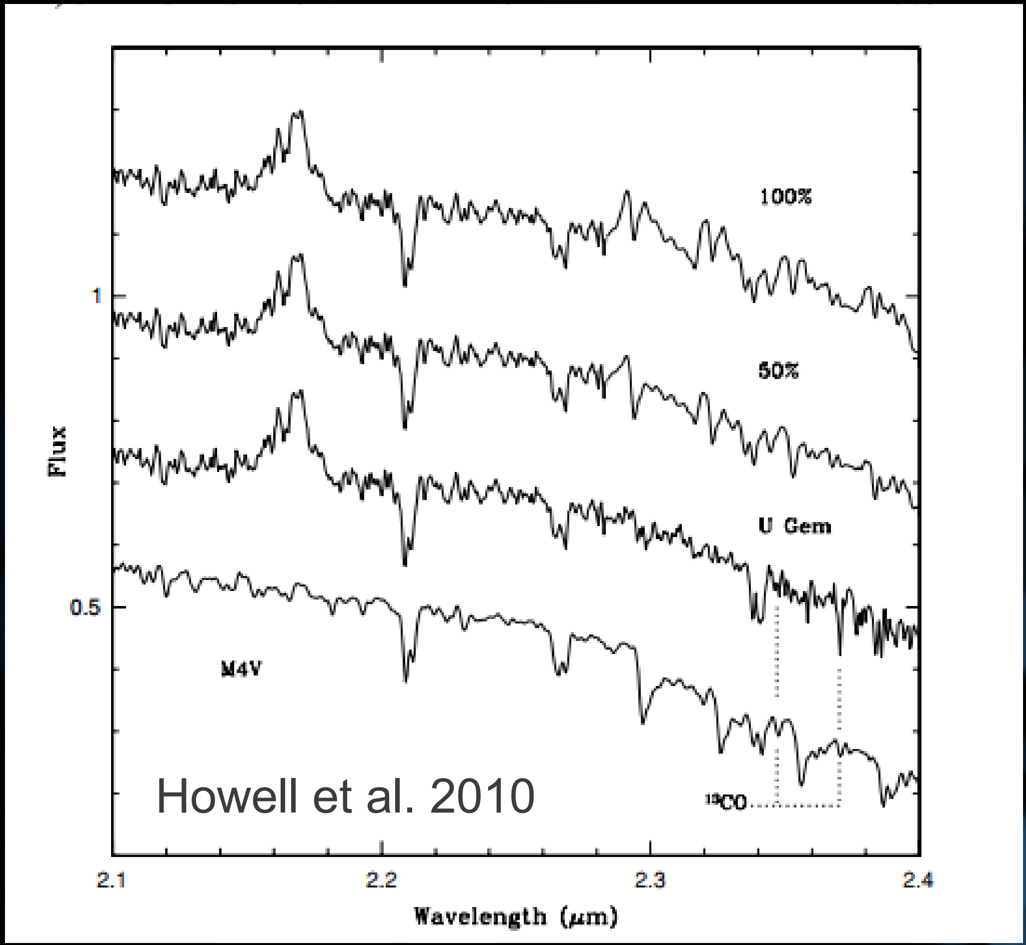
System	Fe/H	C/H
GK Per	0.3	0.3
RU Peg	0.3	0.3
SS Cyg	0.6	0.3
CH UMa	1.0	0.1
MU Cen	1.0	0.2
EM Cyg	1.0	0.2

Note. — Fe/H and C/H are relative to solar such that $X/H = 10^{[X/H]}$

Spectral types/$T_{\rm eff}$ match previous estimates. All are clearly C deficient! Some indication of enhanced ^{13}CO and lower *log(g)* in SS Cyg as well.

What Are These Systems?

- C is definitely depleted
  - Emission filling not suitable, different velocity components
- Accretion from WD novae CNO material would be efficiently mixed into secondary quickly
- Evolved? Subgiants?
  - Would be more massive secondary stars
  - Beuermann 1998, Baraffe & Kolb 2000, Marks & Sarna 1998



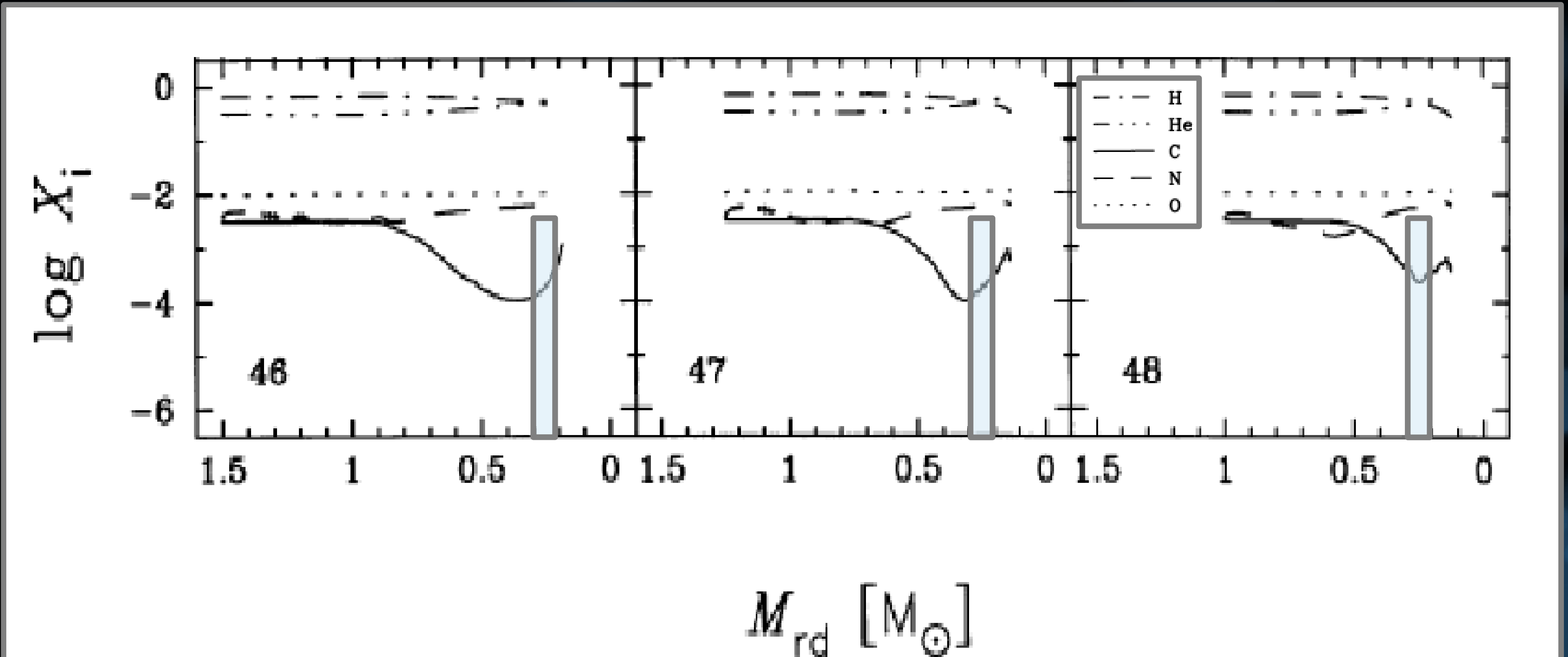
More Massive Secondary Stars

- If secondary initially more massive, then it has time to chemically evolve
  - Marks & Sarna 1998

More Massive Secondary Stars

- If secondary initially mo… time to chemically evolv…
  - 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



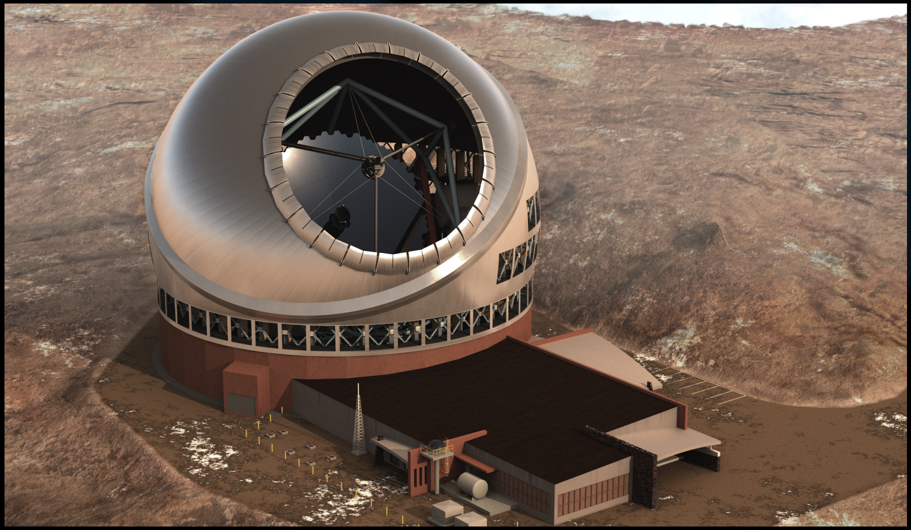
Conclusions

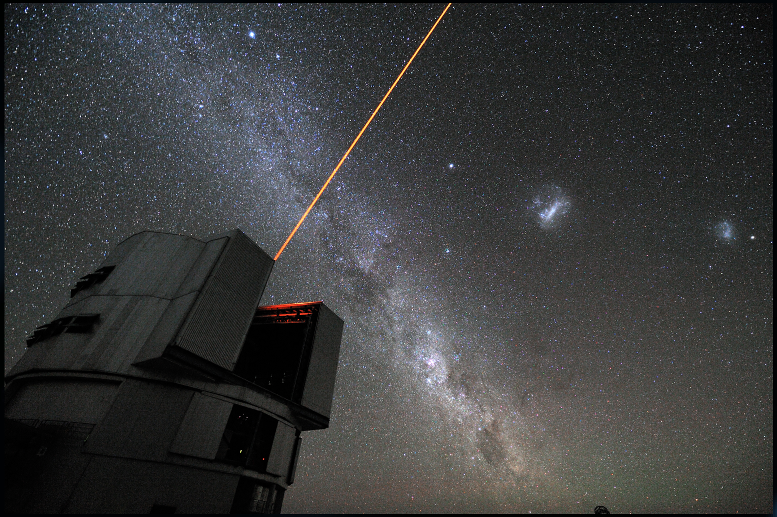
- Provide first abundance measurements of CV donors
  - All are C deficient relative to solar
- High resolution is best (R > 20000) (duh)
  - Can still compare CO strength at R 2000, though, especially if have high S/N
- CV donors being C deficient requires larger mass donors!
  - Some expected by pop. synthesis, but not this many!

Thesis Future Work & Plans

- Accretion disk contamination
- Finish push towards fully modeling M stars
  - Collect small grid of nonsolar C abundance PHOENIX models
- Phase resolved spectroscopy!
  - Need more real, reliable, dynamical masses!
  - Check to see if pre/post gap systems really have the masses that we expect
- Gently nudge theoretical folks to give new abund. predictions

Future Prospects (For Some of Those)





Backup Slides