The SOHO-Stellar Connection: Update

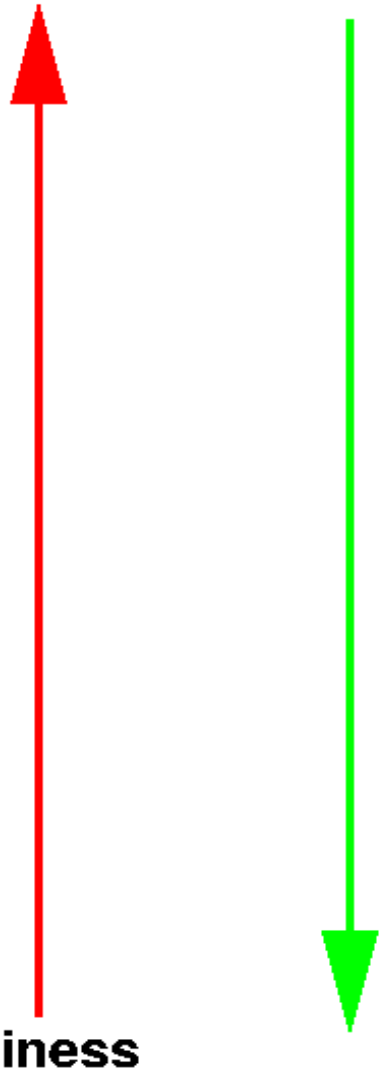
TR Ayres (CASA)

- With the help of: A. Brown, G. Harper, S. Redfield, J. Linsky, et al.

Ultraviolet and X-ray observations of coronal activity in late-type stars

Stellar Coronae in Astrophysical Context:

The Cosmic Sexiness Ladder



J.J. Drake

On heating mechanism in AGN X–ray emitting accretion disk coronae:

"We are going to have to borrow from the Sun"

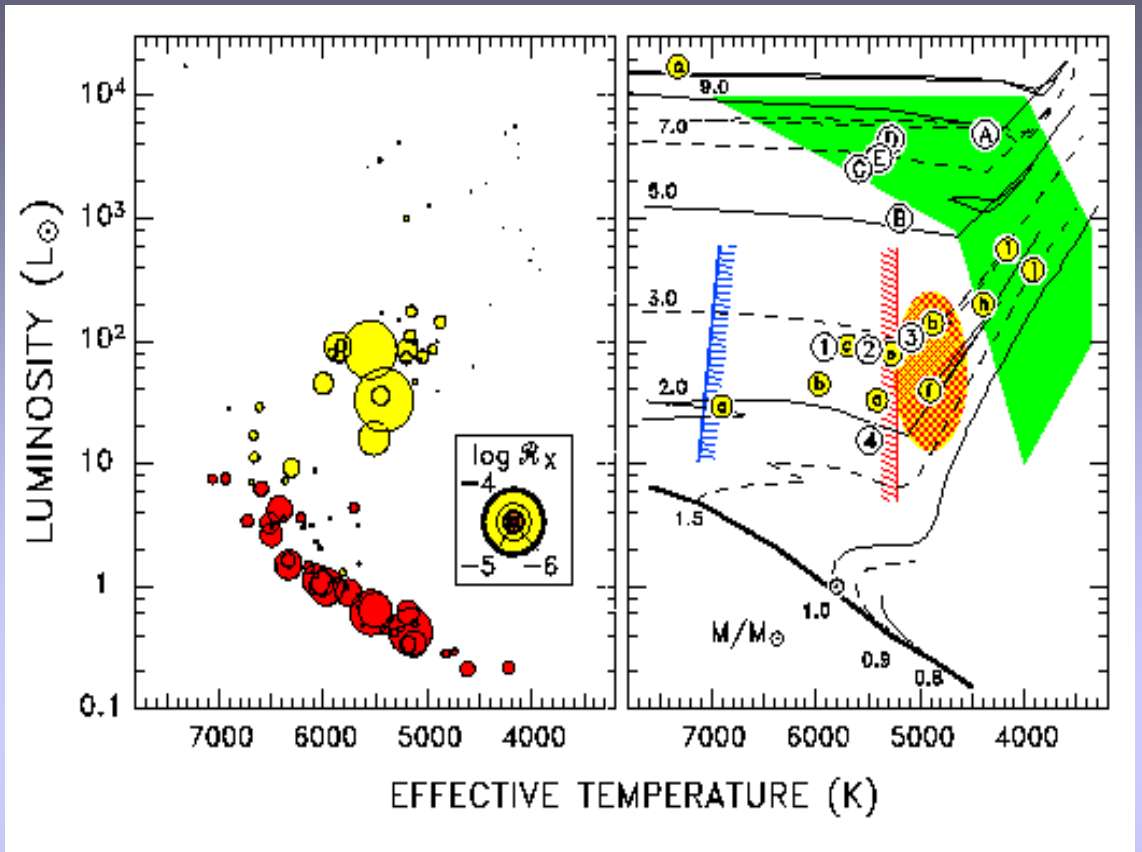
A. Fabian, COSPAR (2000)

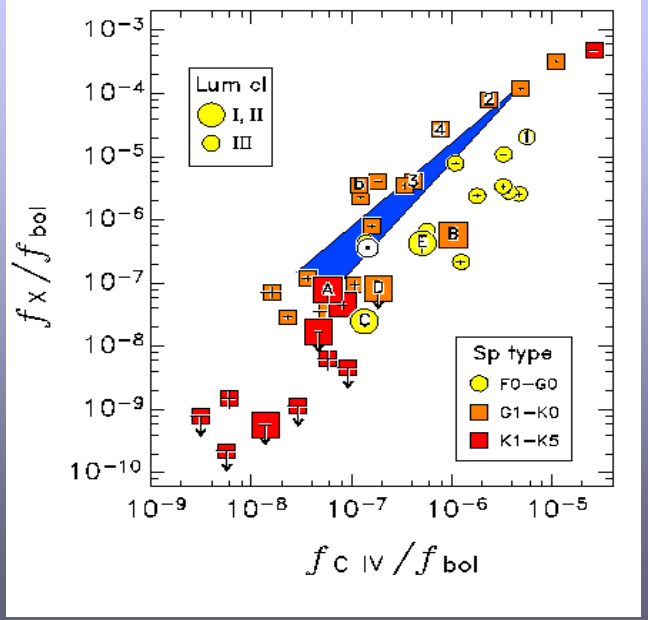
Issues in Cool-Star Astronomy

- Coronae in the H-R diagram: where?
- Heating mech's: steady vs. flares? (Role of dynamics: origin of broad & narrow components?
- Cool Winds vs. Coronae?
- Death of coronae at extremes of evolution?

The Conventional Wisdom:

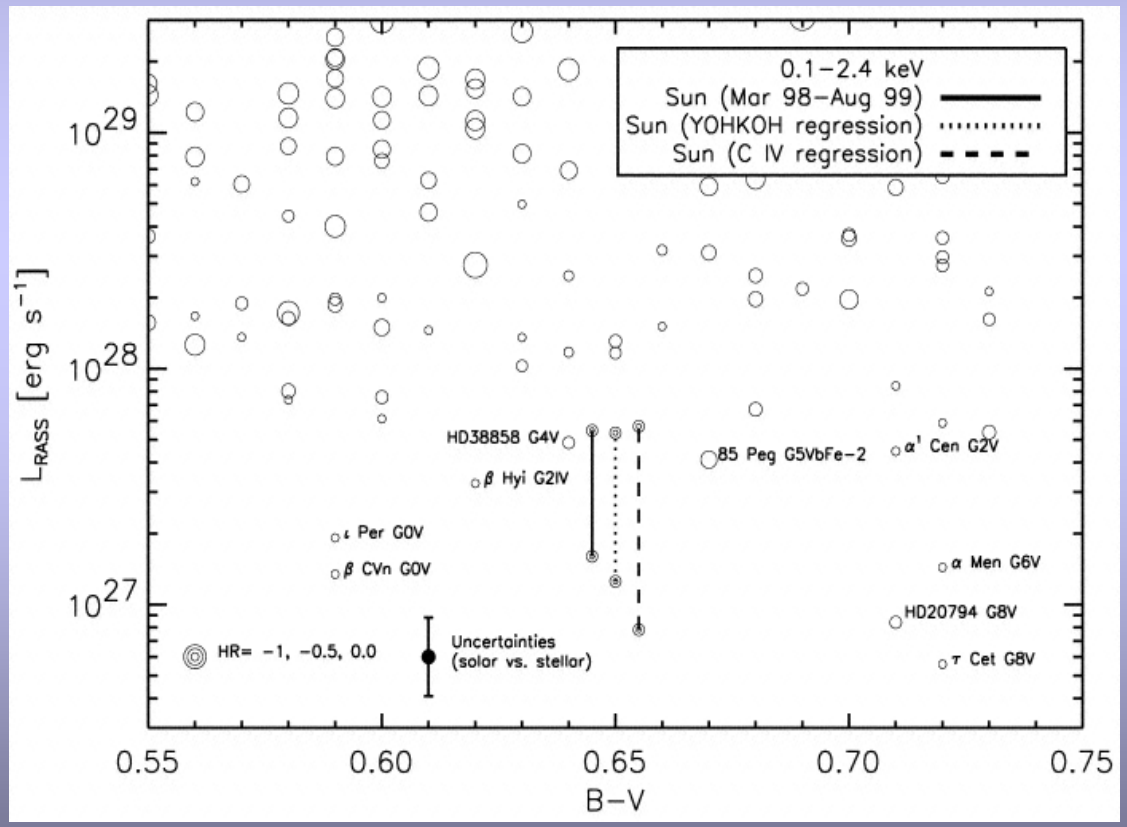
- Rotation – through "dynamo" action – is major determinant of the level of magnetic coronal activity. Convection is other key ingredient; thus activity is confined mainly to cool stars.
- Activity acts back on rotation through stellar wind braking; the moment of inertia depends sensitively on evolutionary status; thus, time and evolution play central roles in controlling coronal properties of stars.





- Main sequence dwarfs: diversity o activity levels due to age (and cycles)
- Hertzsprung gap giants: rapid rotation, shallow CZ, X-ray deficien
- Rapid braking zone: intense, hot corona sources; spindown
- Red giant branch: winds, spindown, coronal graveyard

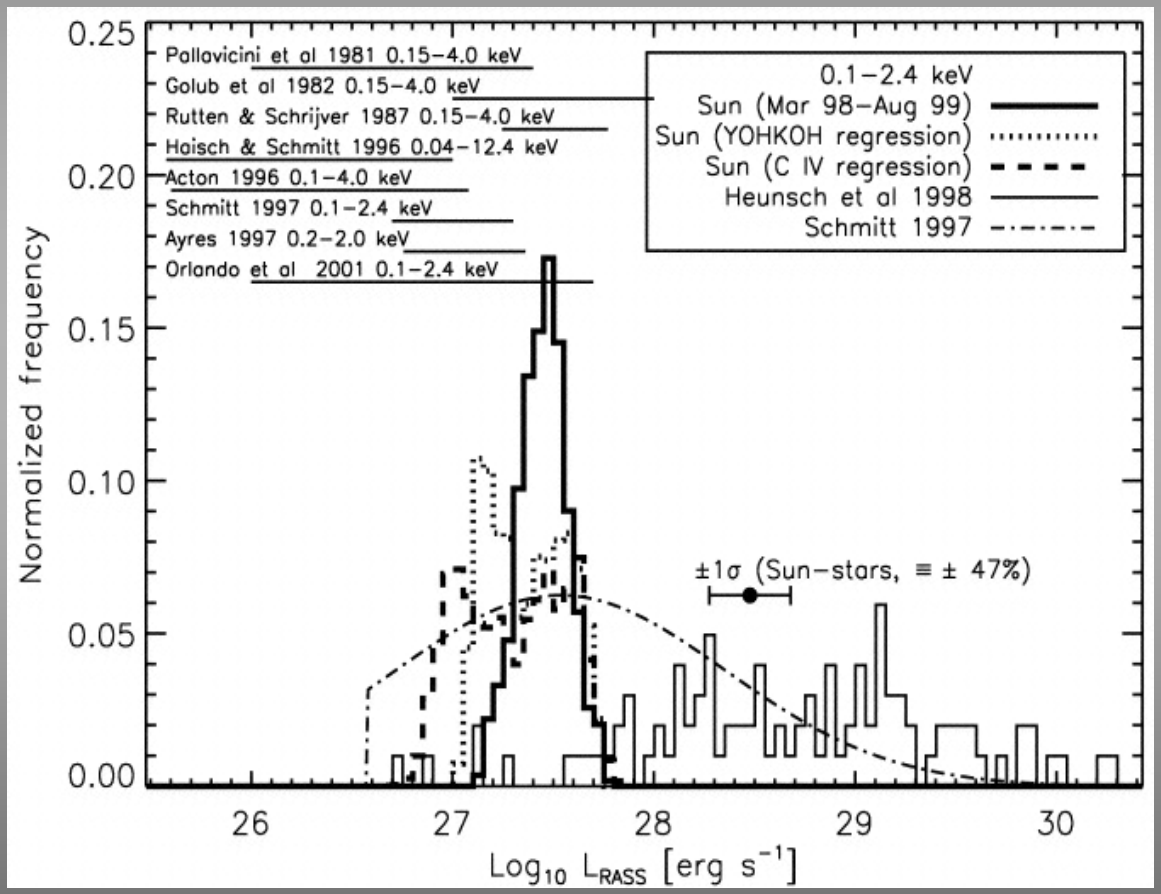
The Sun's Place in the X-ray Universe



- **Judge, Solomon, & Ayres (2003):**

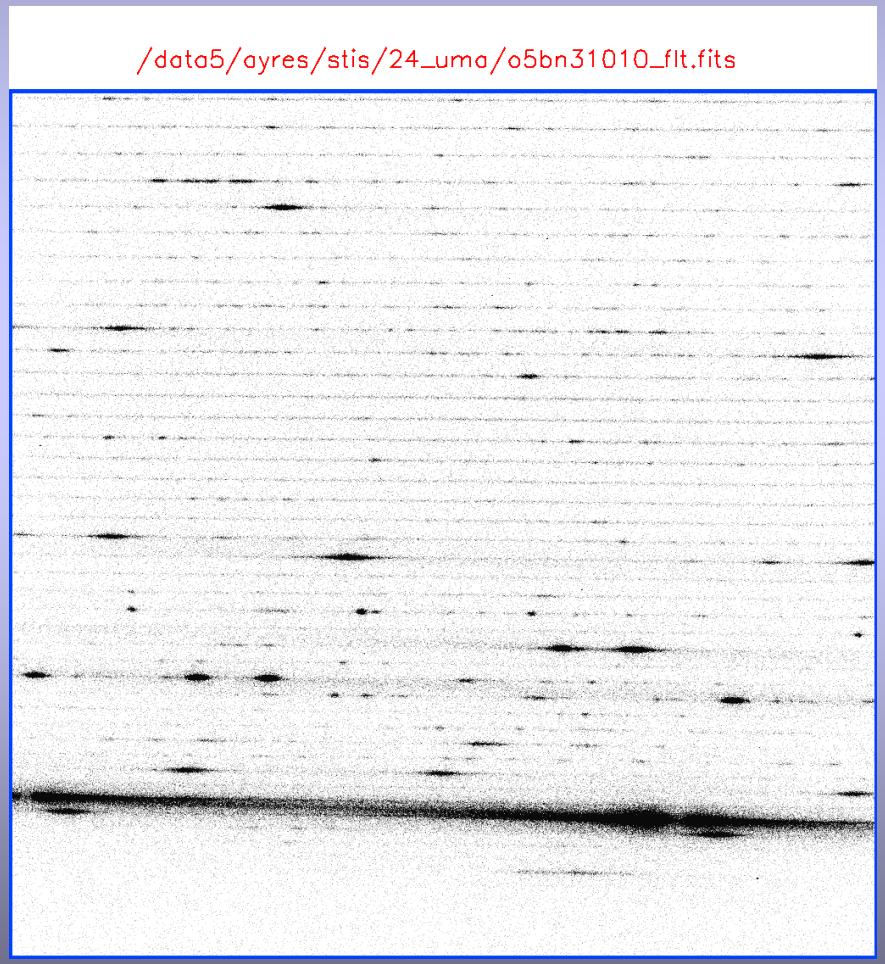
The Sun fits in wel as a normal, low-activity middle-age G-type dwarf; nothing funny going on…

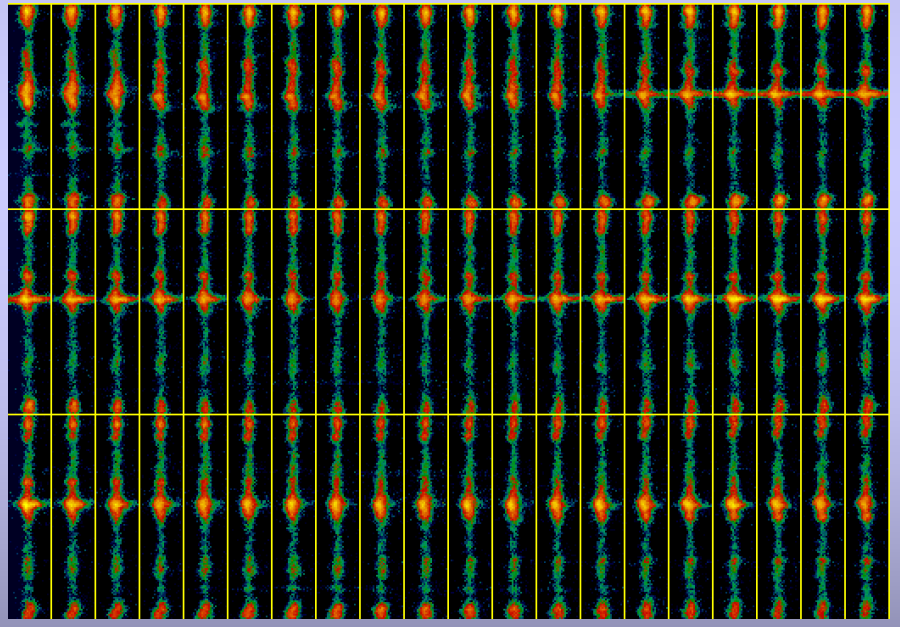
The Sun's Activity Cycle in the Stellar Context



The solar activity cycle, as seen in soft X-rays, is in no way exceptional compared with other G dwarfs of the field, although the solar L_X is lower than most.

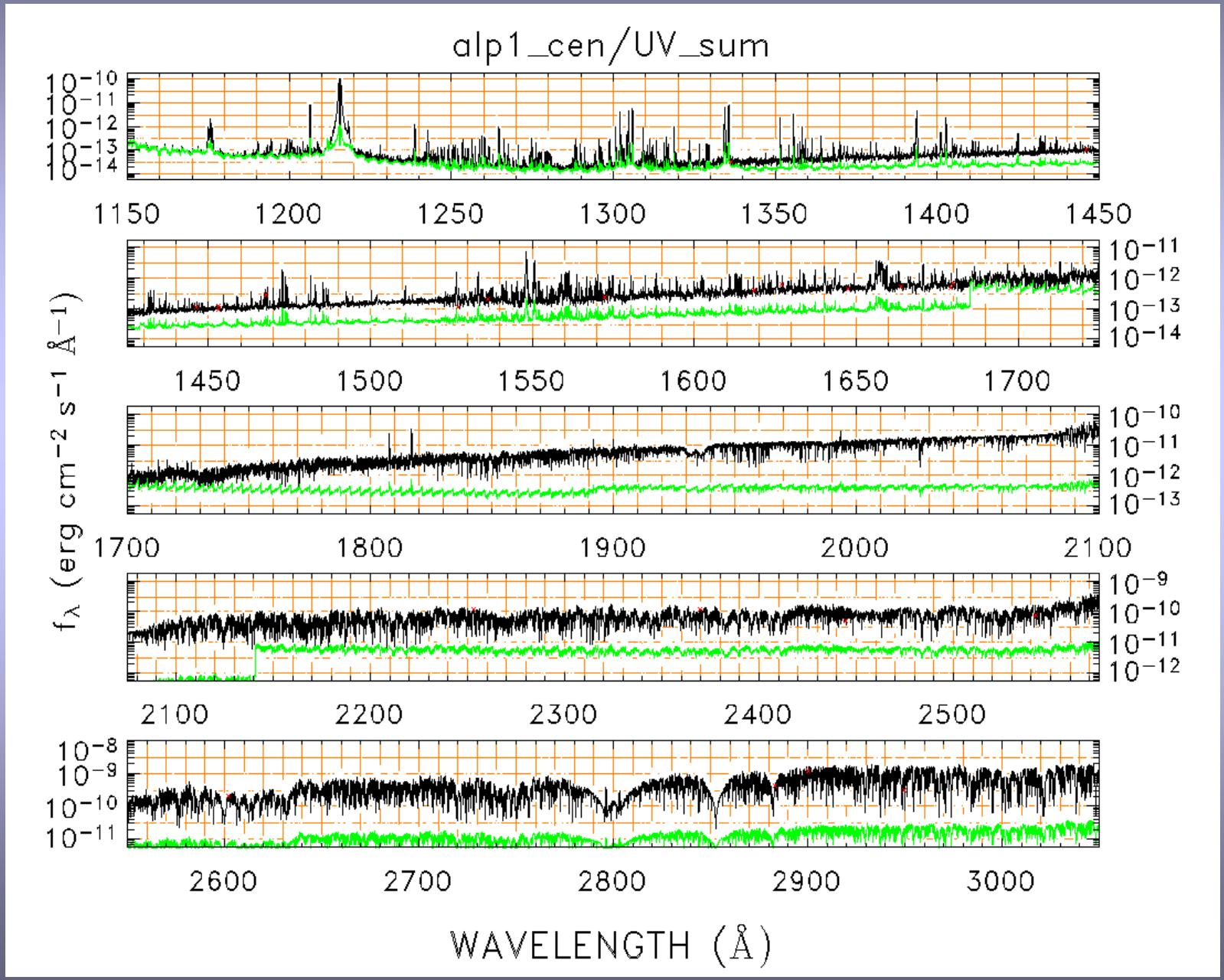
UV observations of the Sun and stars: STIS E140M spectrum (left); SUMER FUV timeslices (right)



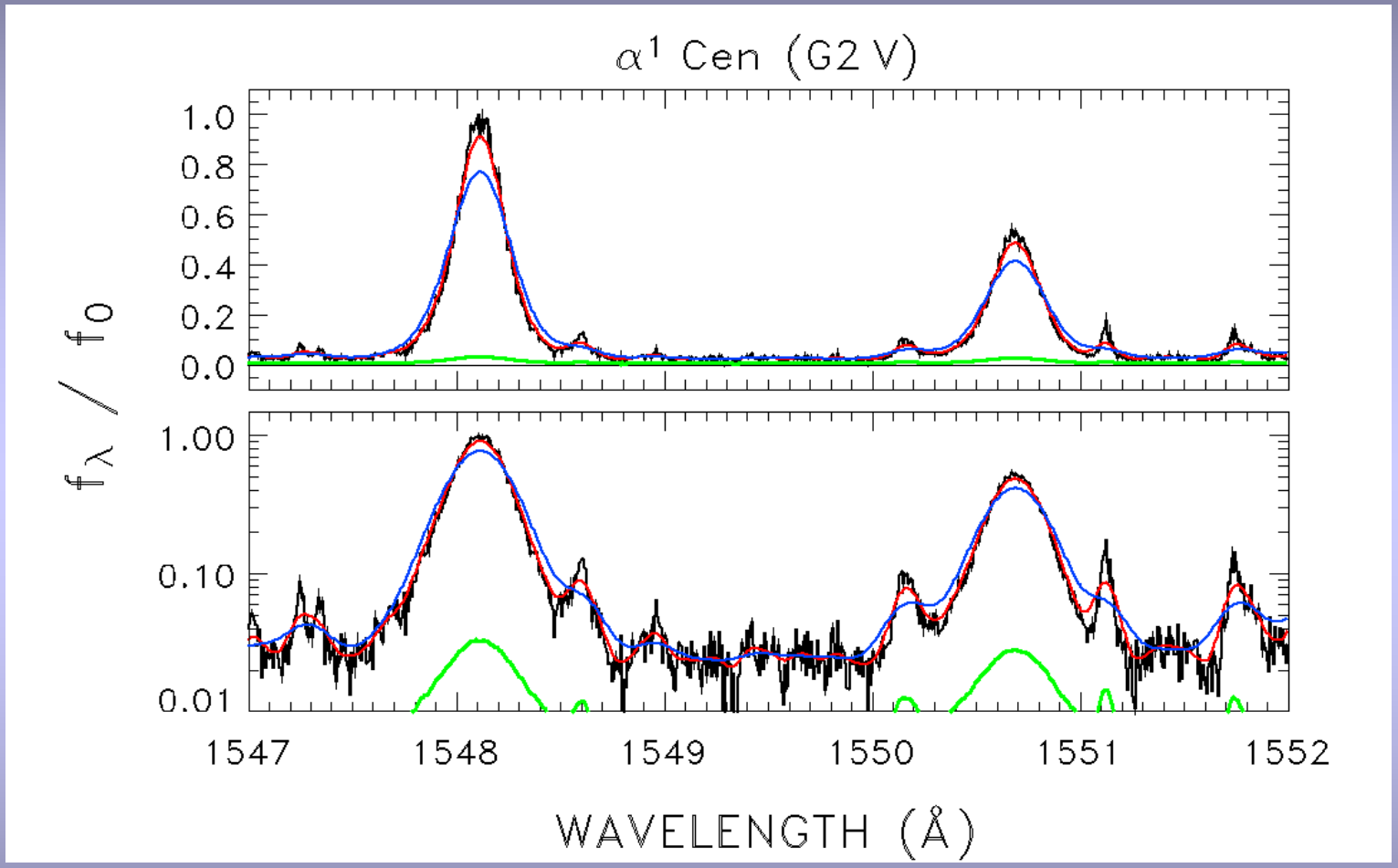


HST STIS UV spectrum of solar-twin Alpha Cen A

(http://origins.colorado.edu/~ayres/CoolCAT)



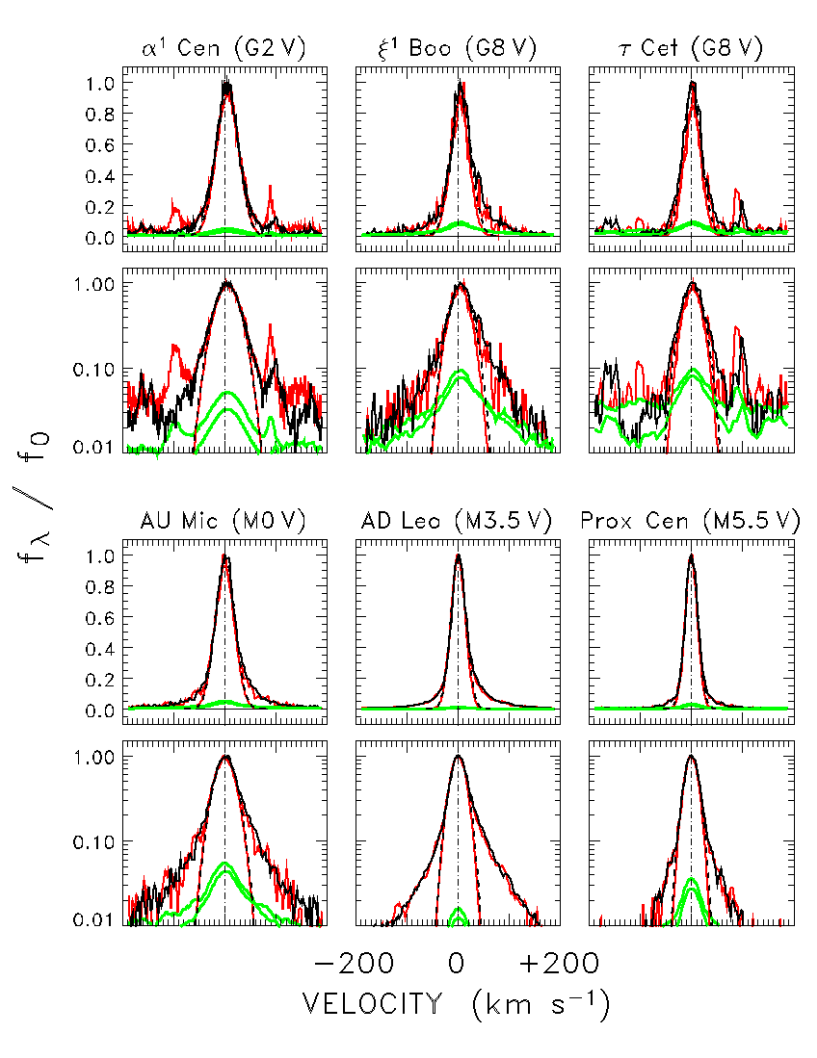
R=110,000 (black), 20,000 (red), 10,000 (blue)

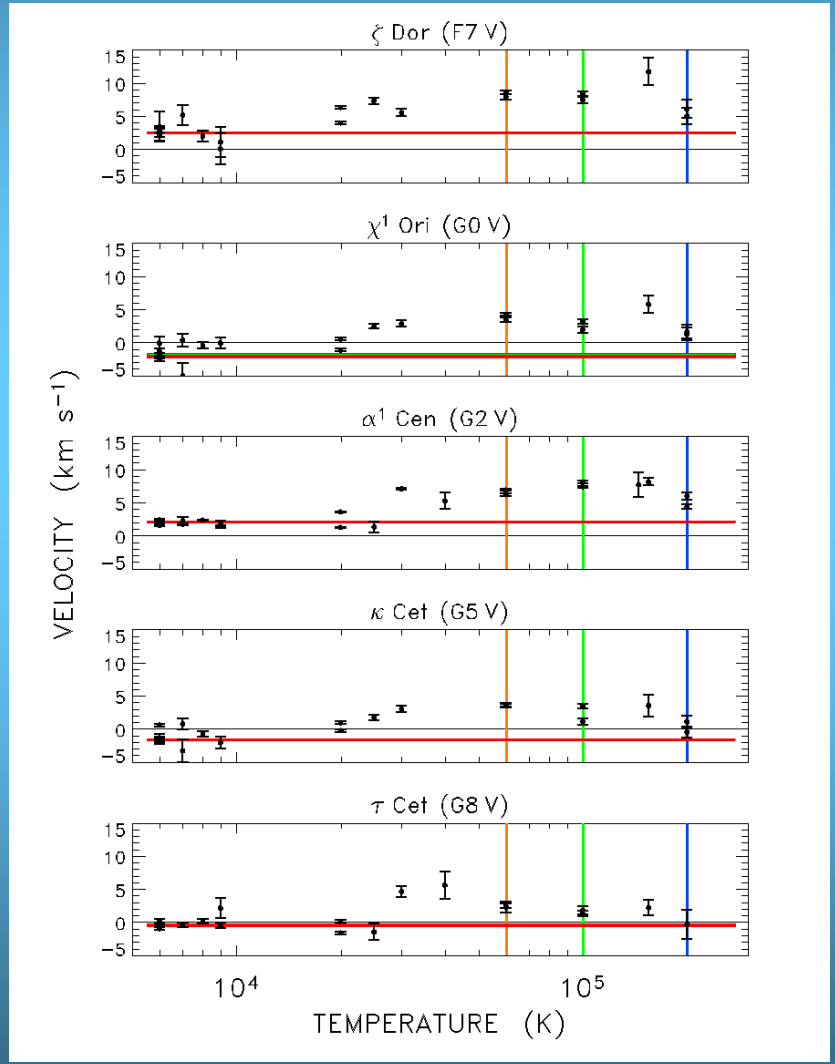


- **A resolution of about 20,000 preserves most of the dynamical information, and guards against blends, for the TZ lines.**

Stellar Transition Zone Dynamics

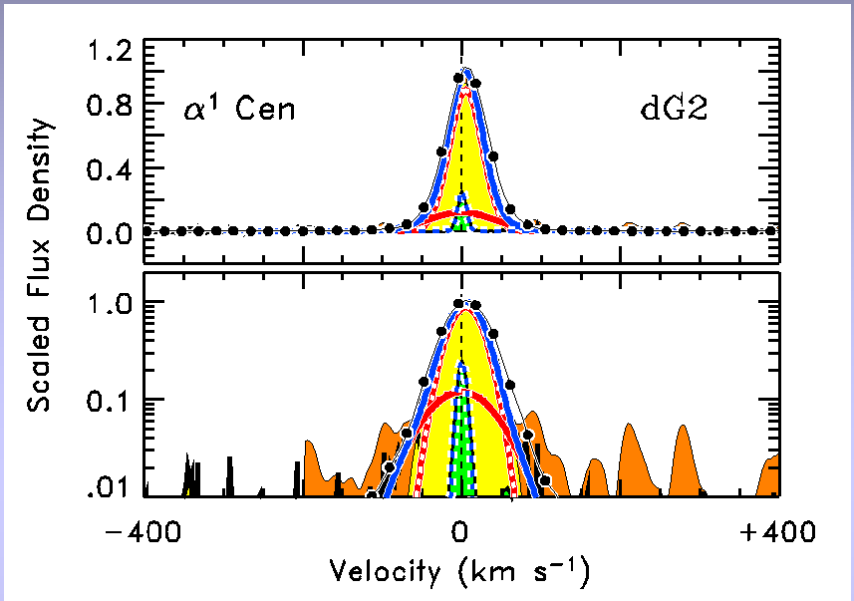
Left: C IV 1548 (black), 1550 (red);
Right: Si IV (orange), C IV (green), N V (blue)

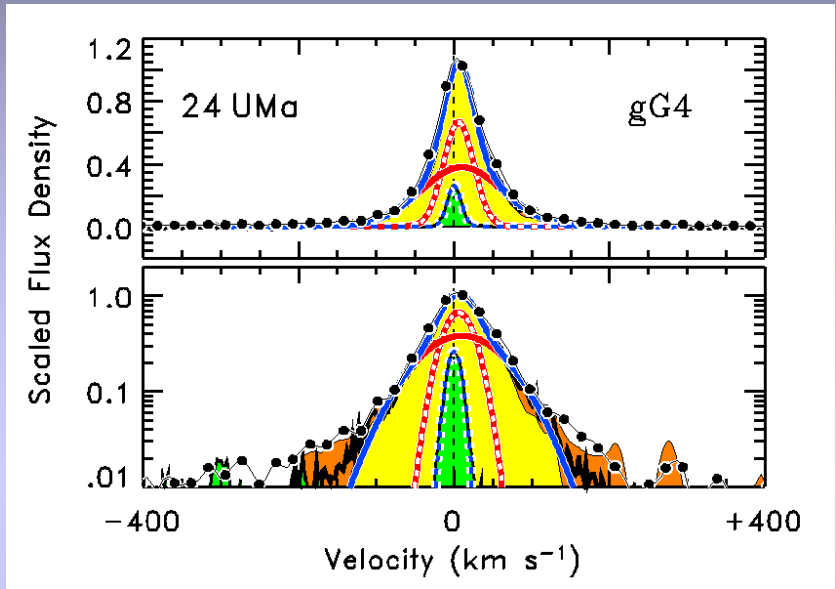


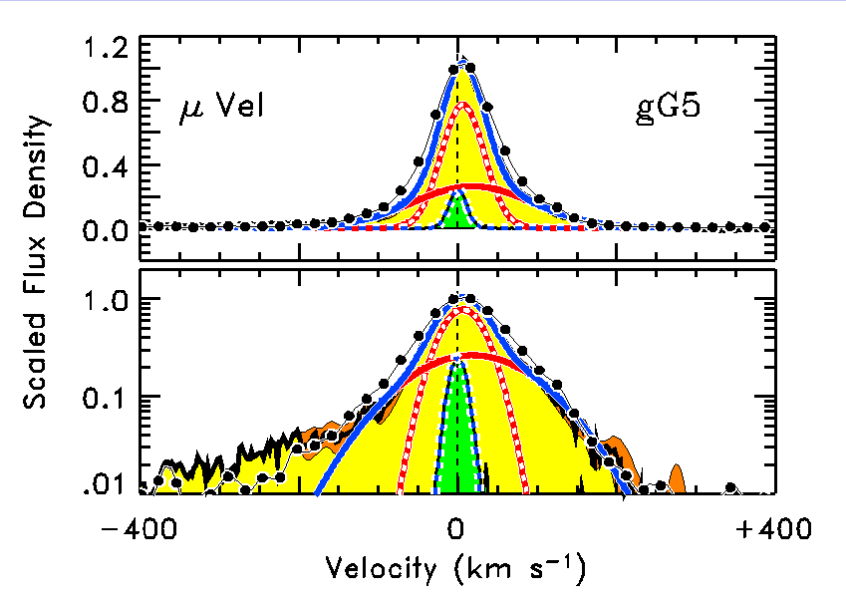


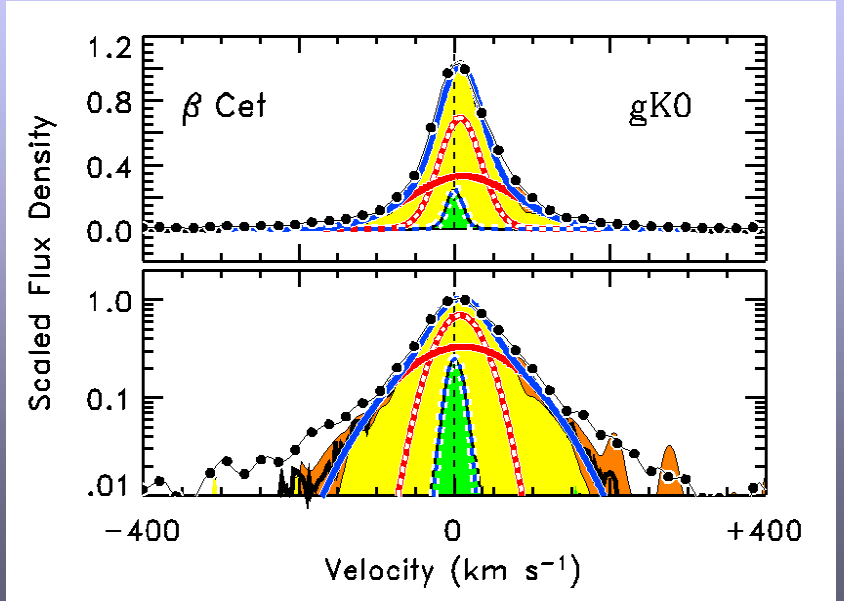
- **low-ex chromospheric O I + C I close to v=0**

STIS Si IV+C IV+NV
FUSE O VI (dots)







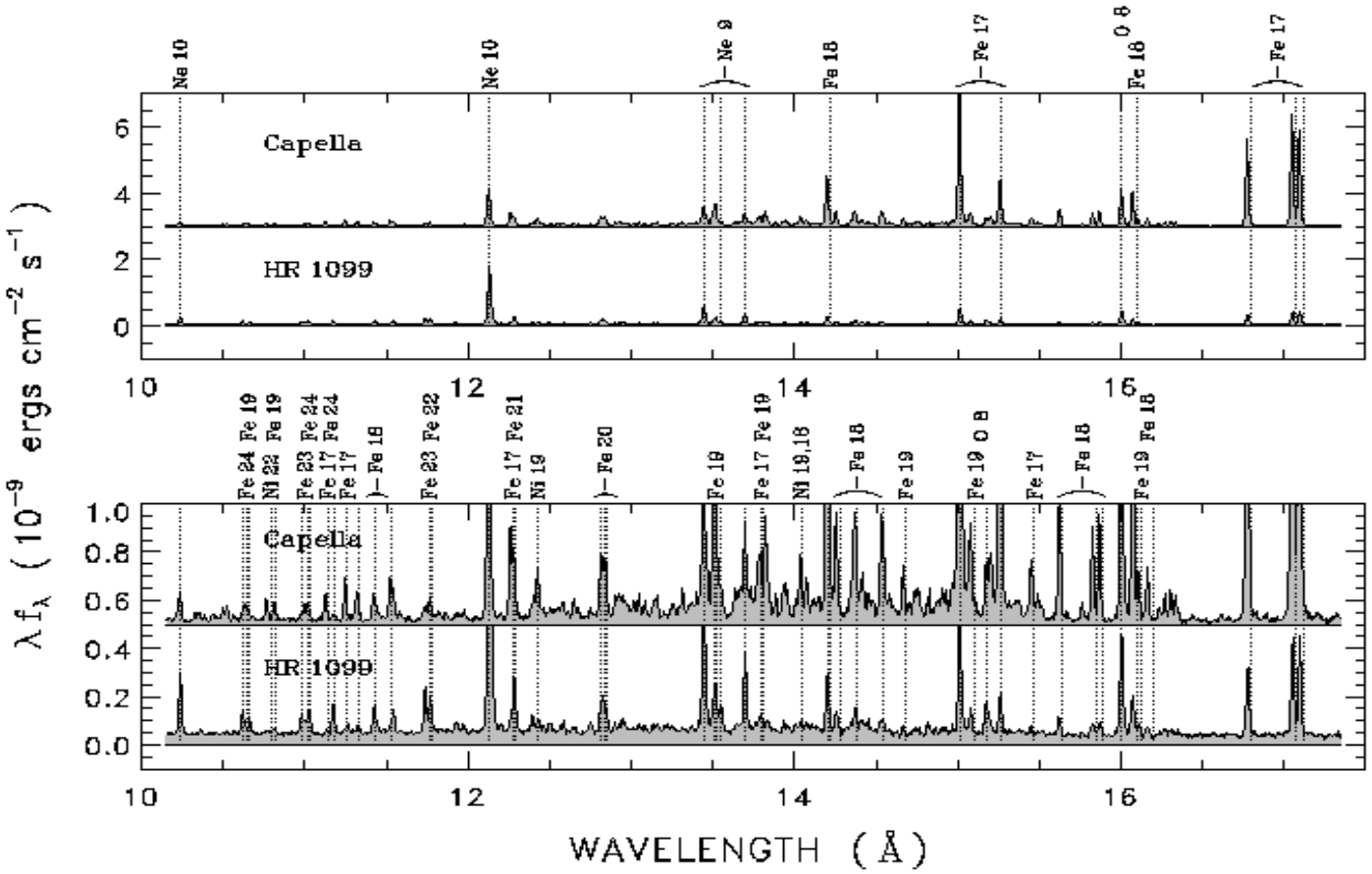


Narrow & Broad components in Dwarfs and Giants

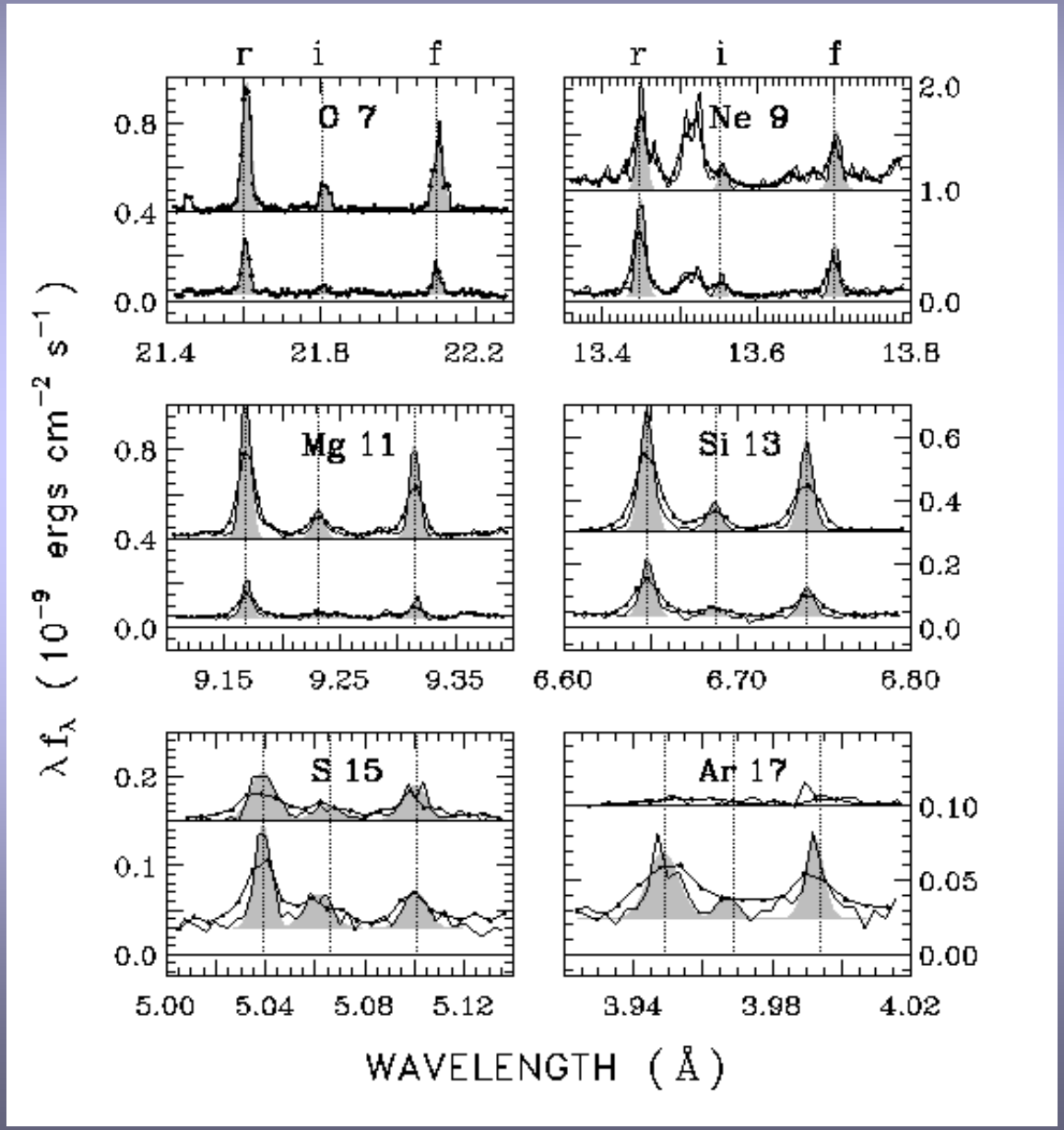
Group	N*	v_{nar}	W_{nar}	v_{brd}	W_{brd}	f_{brd}/f_{tot}
G V	5	+4.3	43	+5.9	103	0.22-0.54
K V	3	+2.2	32	+6.8	78	0.46-0.56
M V	4	+1.6	32	+8.0	105	0.35-0.42
G III	4	+6.5	59	+12.2	156	0.49-0.61

- Doppler shifts (v) and FWHM (W) in km/s

Chandra HETGS spectra of two active binary systems: Capella and HR 1099

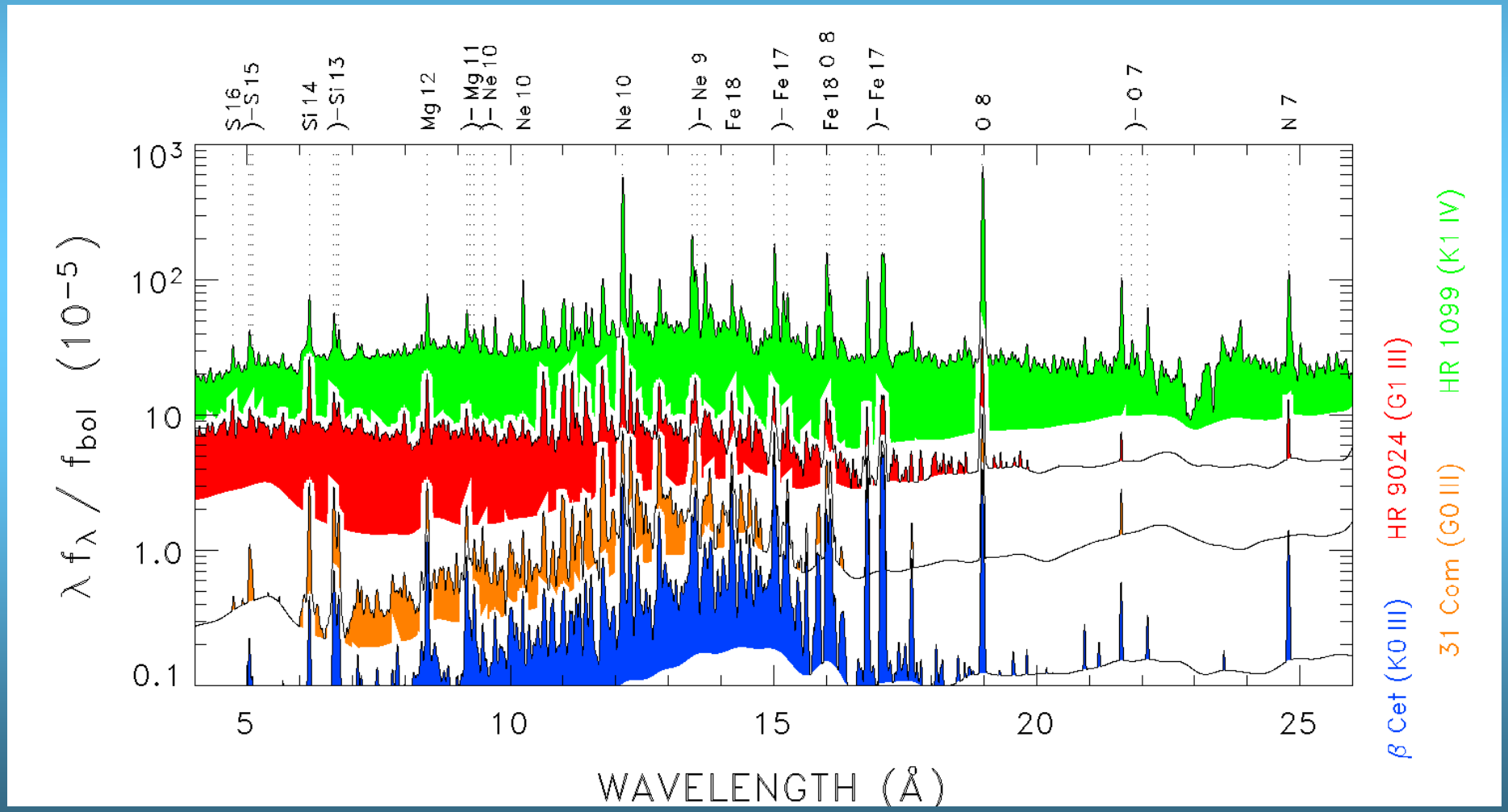


He-like triplets in Capella (top trace) and HR 1099 (bottom)

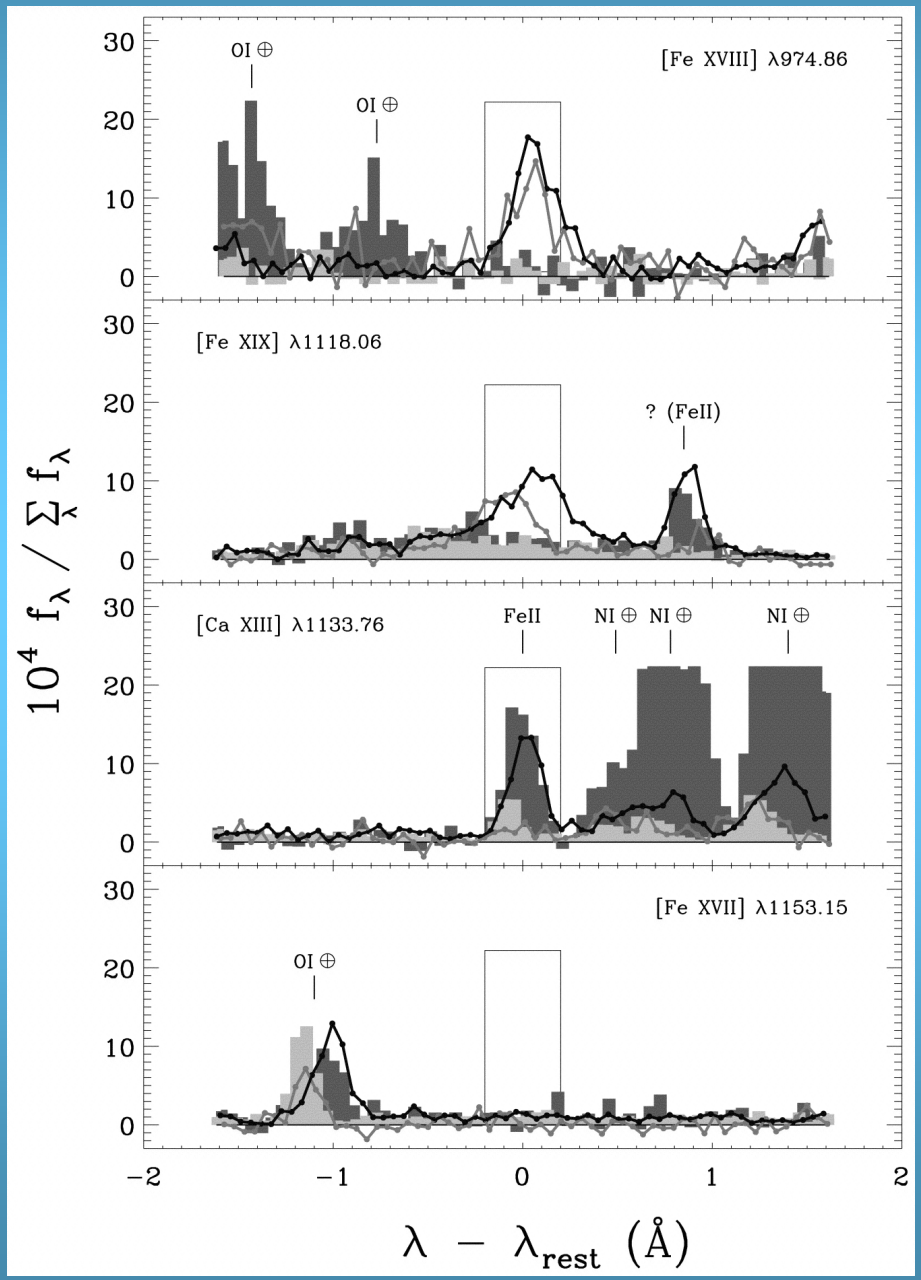


- Ratio of forbidden to intercombination line is sensitive to density.
- Ratio of He-like to H-like r is sensitive to temperature.

Chandra HETGS spectra of active giants

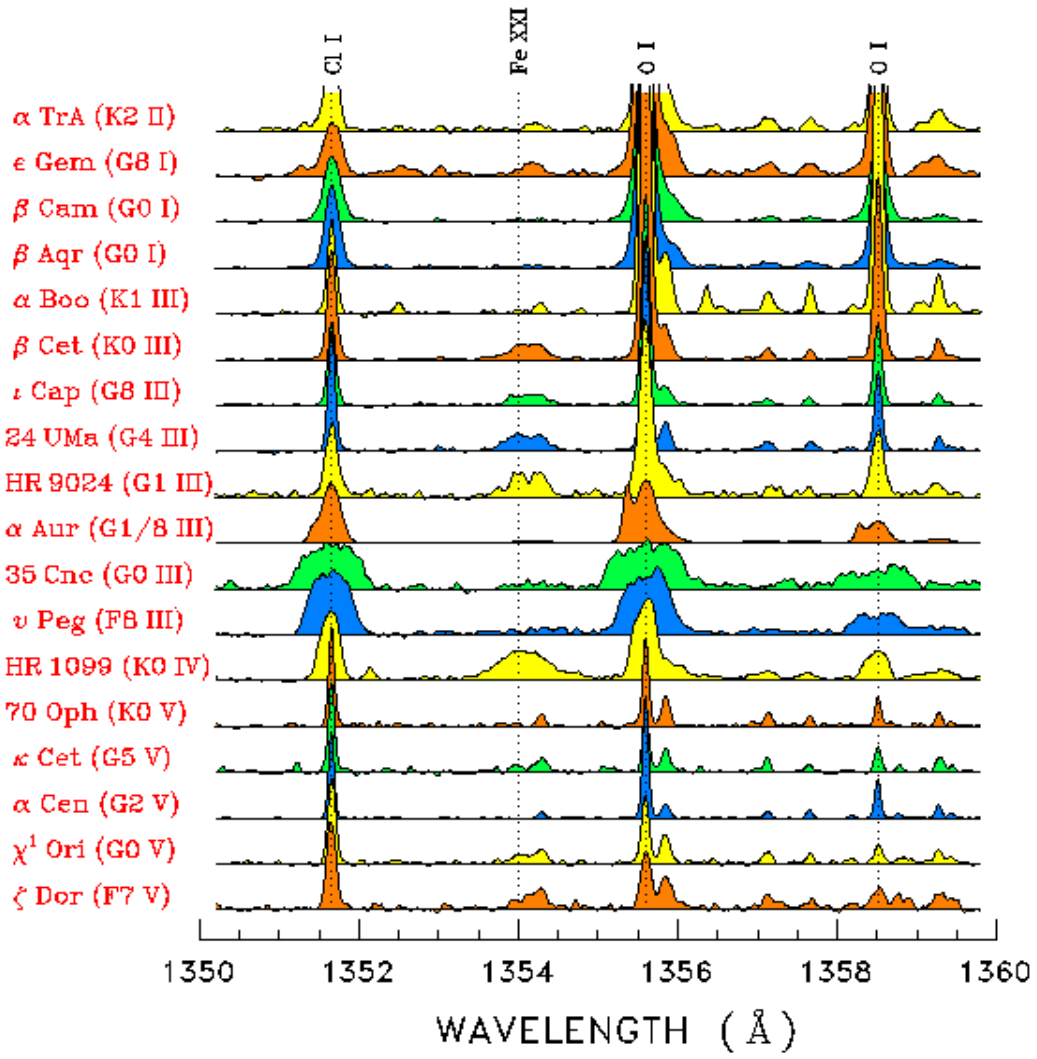


FUV Coronal Forbidden Lines



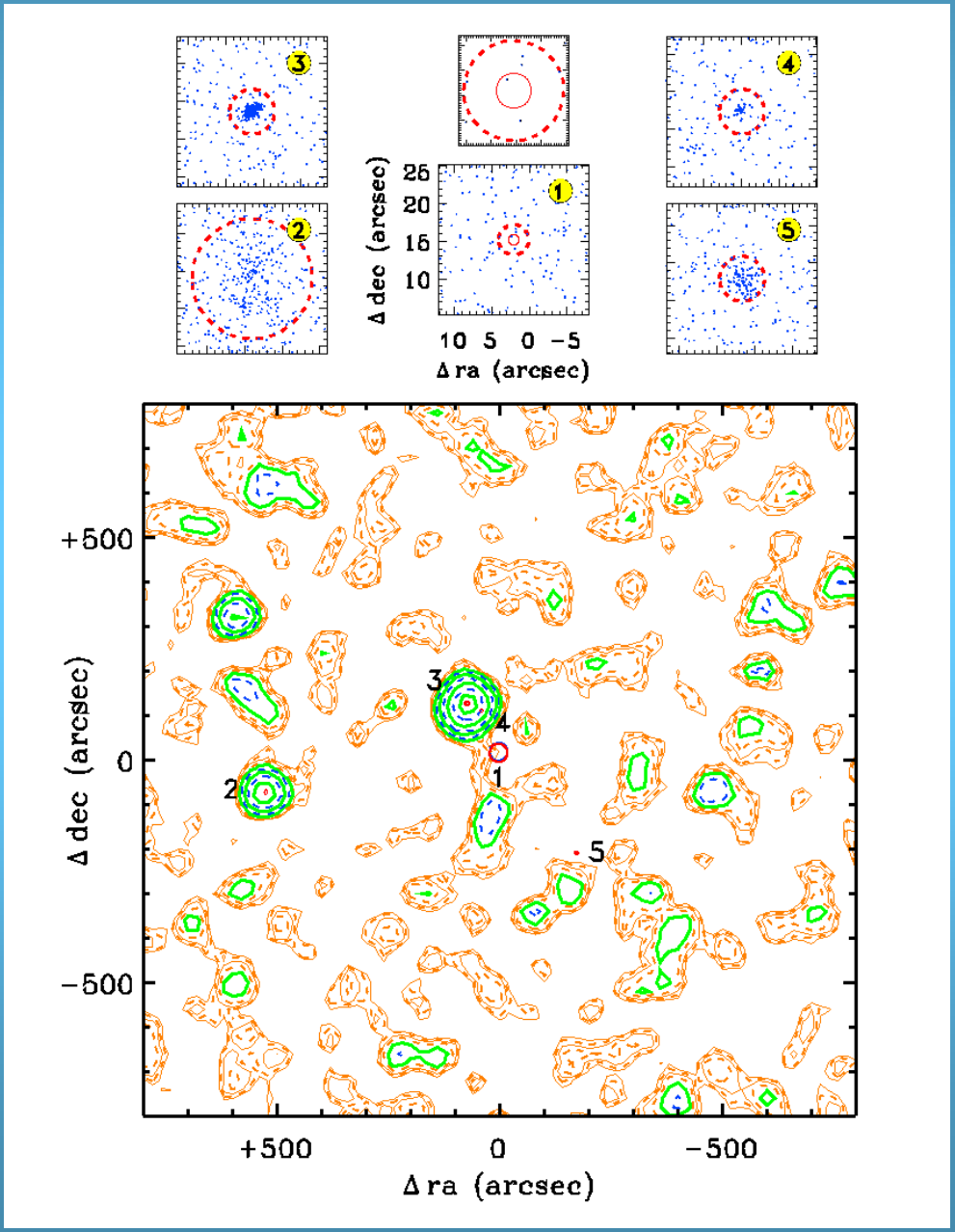
- from Redfield et al. (2003)

Fe XVIII forms near peak EM distribution of active K-type giants (Brickhouse, Dupree, et al.). For *dynamics studies*, FUSE has 10-20X the spectral resolution of Chandra L/HETGS.

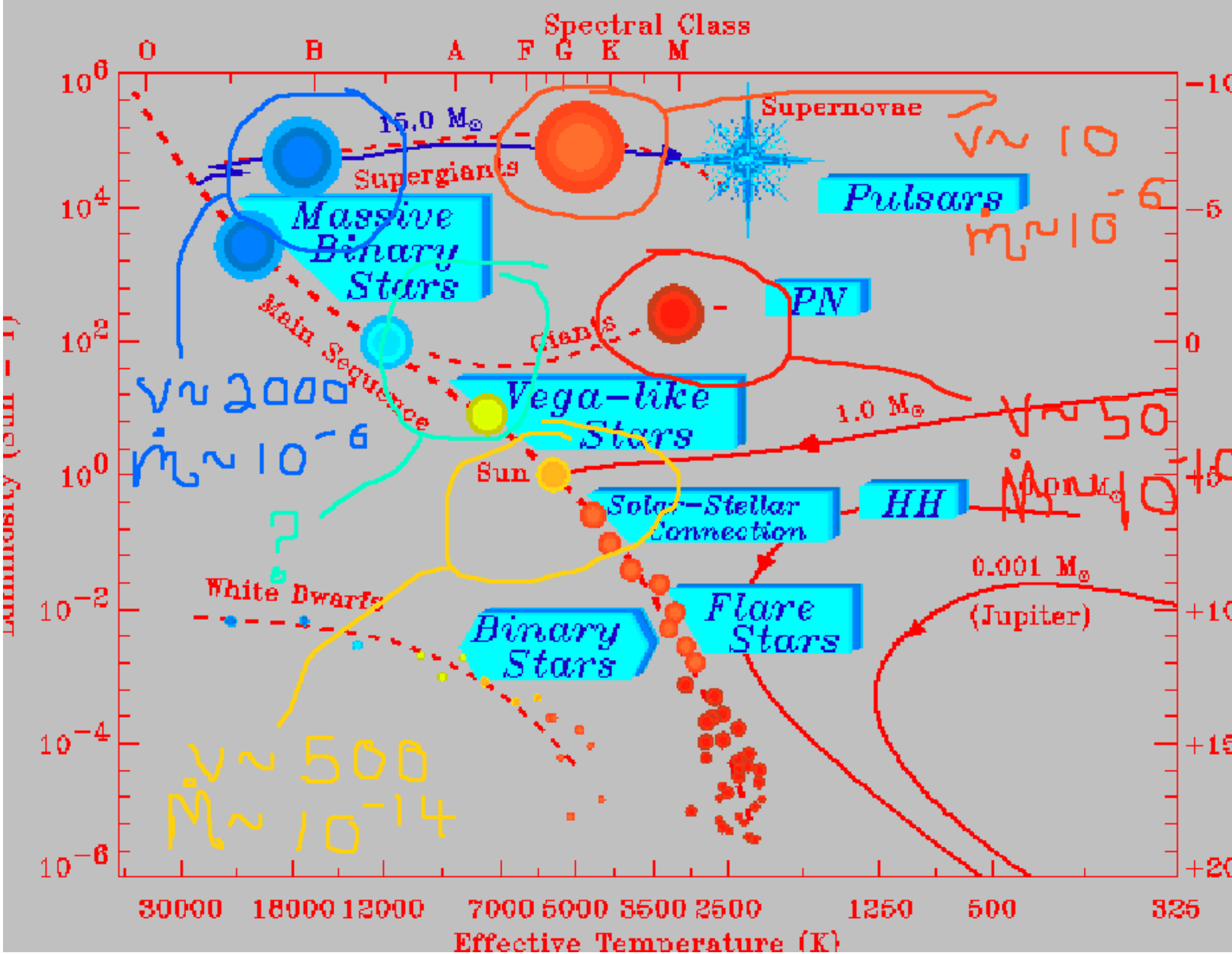


- *STIS E140M can record Fe XXI 1354 and Fe XII 1242, 1349***
- *STIS resolution is 40X Chandra*

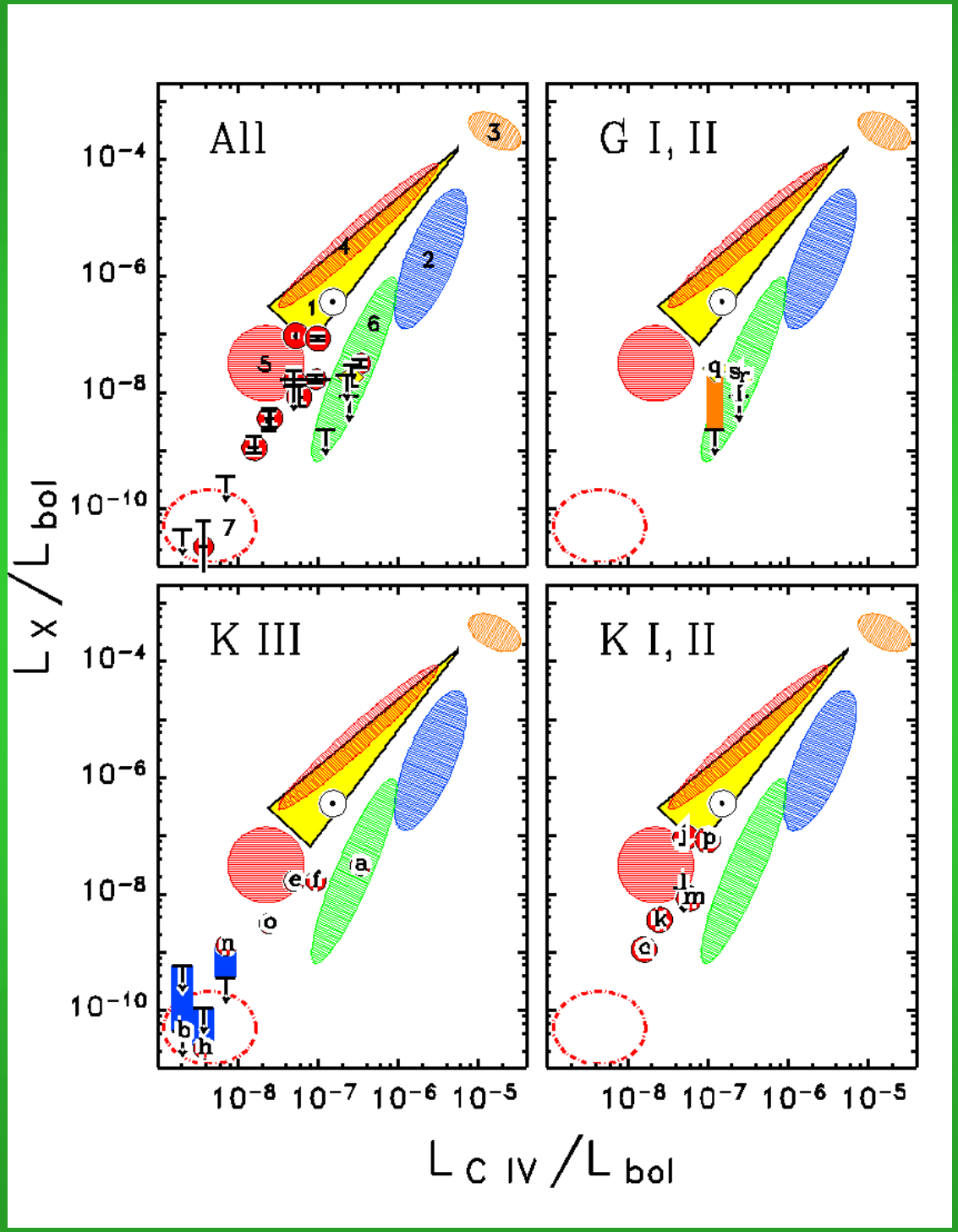
Buried Alive in the Coronal Graveyard?



Chandra HRC 19 ks exposure of Aldebaran (small red dots); contours are from earlier ROSAT PSPC observation; no source detected at position of red giant.

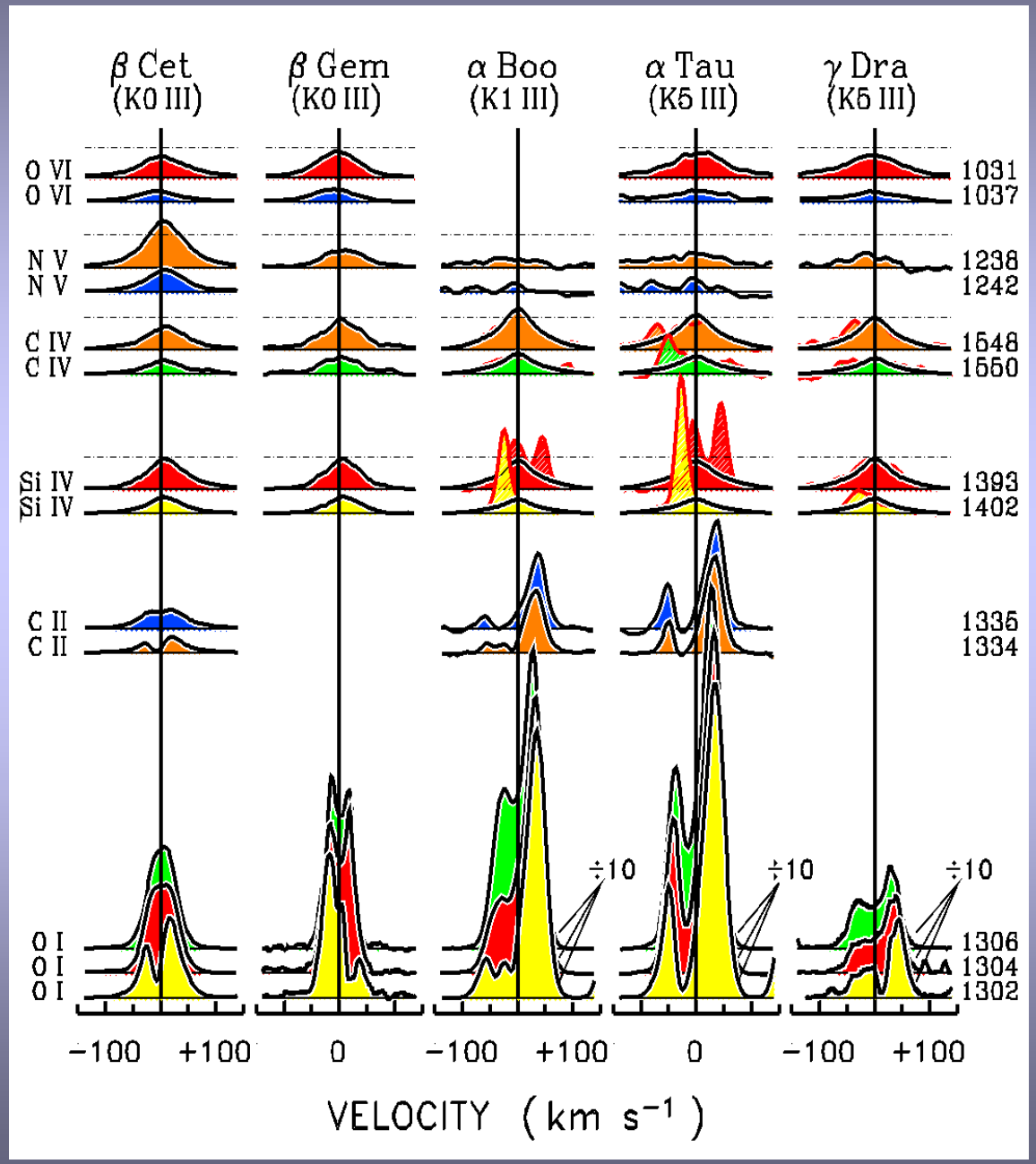

Spectral Class
O
B
A
F
G
K
M
15.0 M⊙
Supergiants
Supernovae
Massive Binary Stars
Pulsars
PN
Main Sequence
Giants
Vega-like Stars
1.0 M⊙
Sun
Solar-Stellar Connection
HH
White Dwarfs
Binary Stars
Flare Stars
0.001 M⊙
(Jupiter)
Luminosity (Sun = 1)
Effective Temperature (K)
30000
18000
12000
7000
5000
3500
2500
1250
500
325


Helium Flas
Clump
3 Msun
Coronal
Graveya
1 Msun

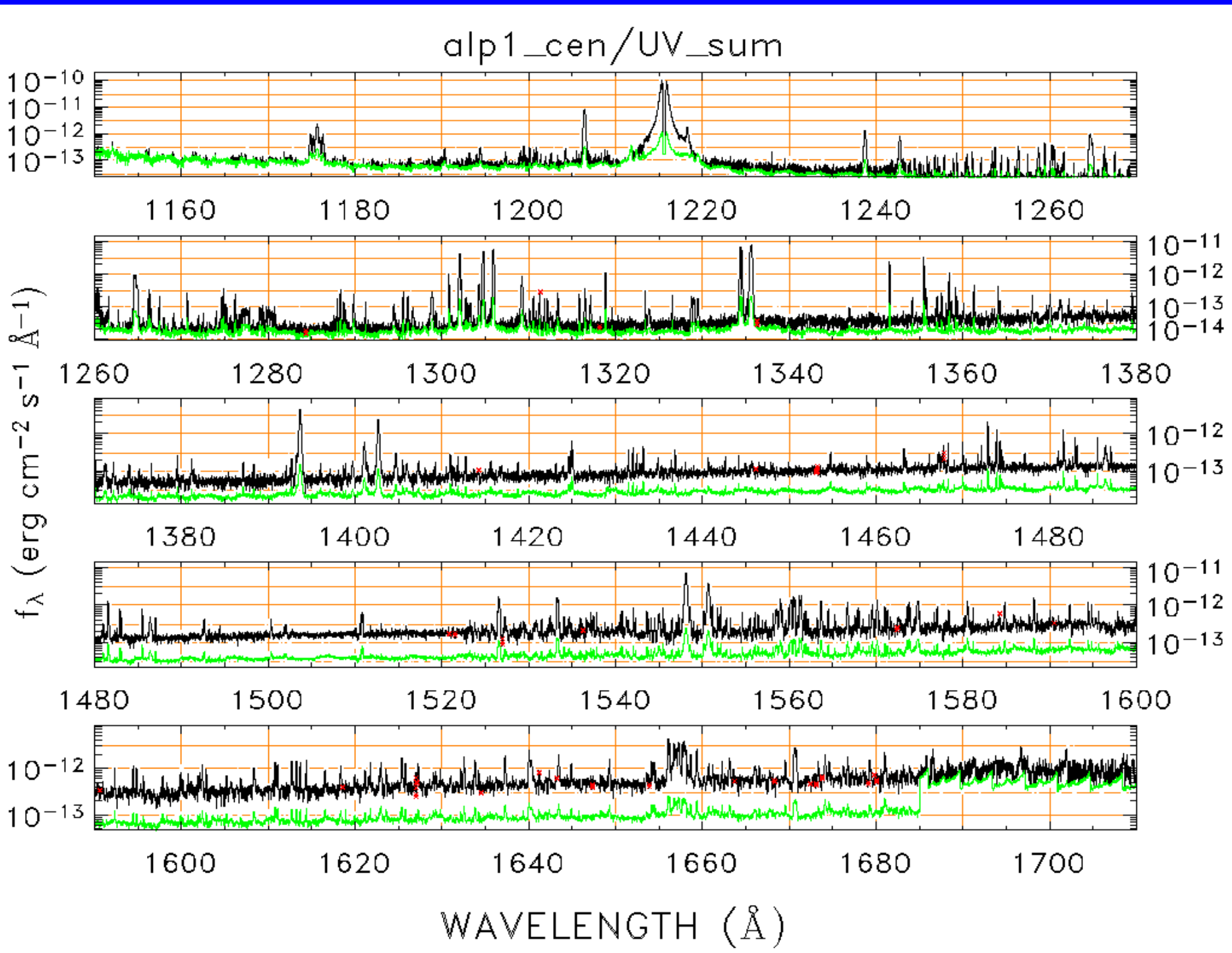


New study with Chandra and ROSAT; several previous X-ray detections of red giants replaced by upper limits; evolved stars underluminous in X-rays.

UV Line Profiles of Red Giants



- N strong; O, C weak in active clump giants
- N V weak in red giants; but O VI still present
- Si IV affected by H_2 fluorescence
- X-rays very weak; C IV/O I ratios very small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1480
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1600
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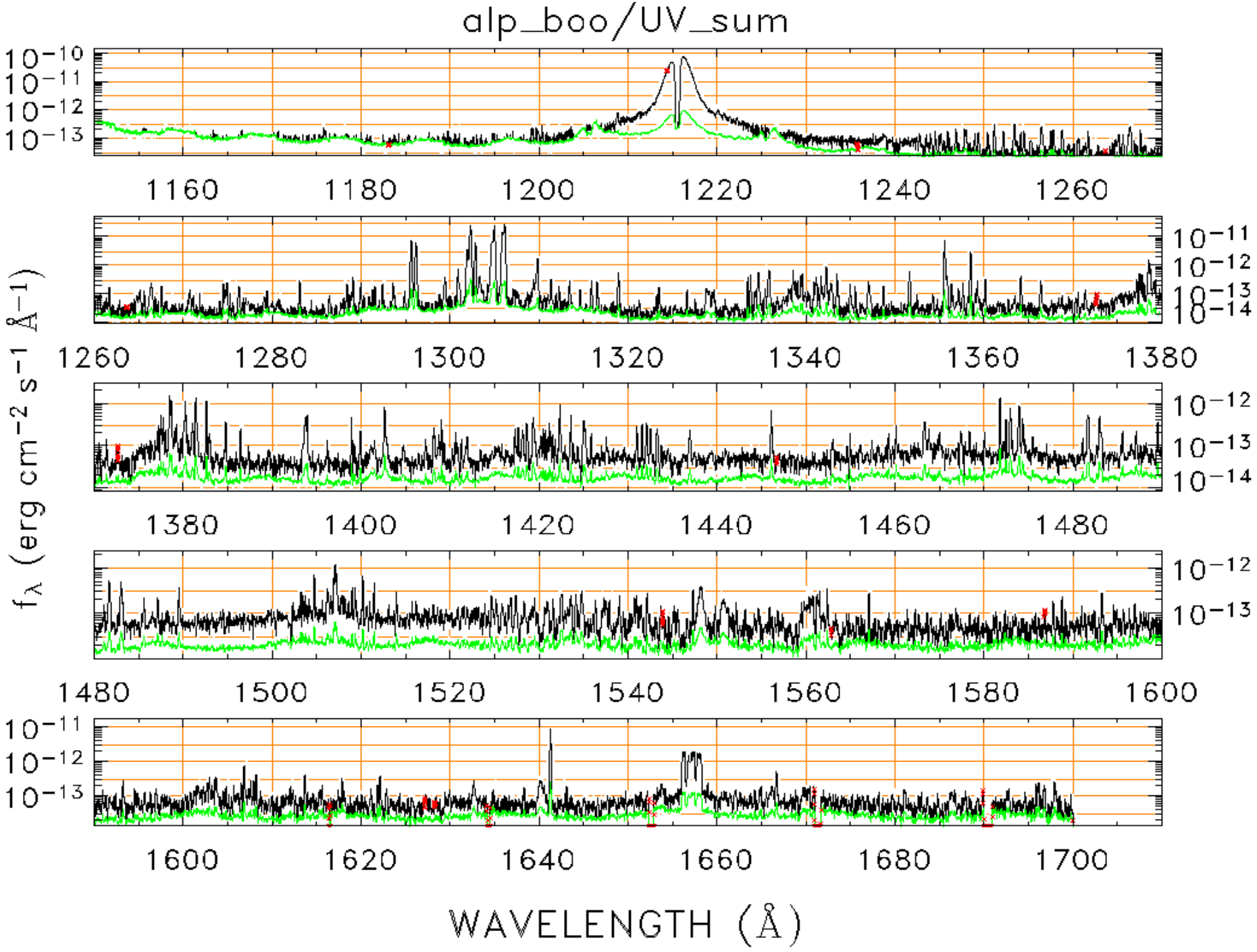
1680
1700
f_λ (erg cm^{-2} s^{-1} Å^{-1})
WAVELENGTH (Å)


alp_boo/UV_sum
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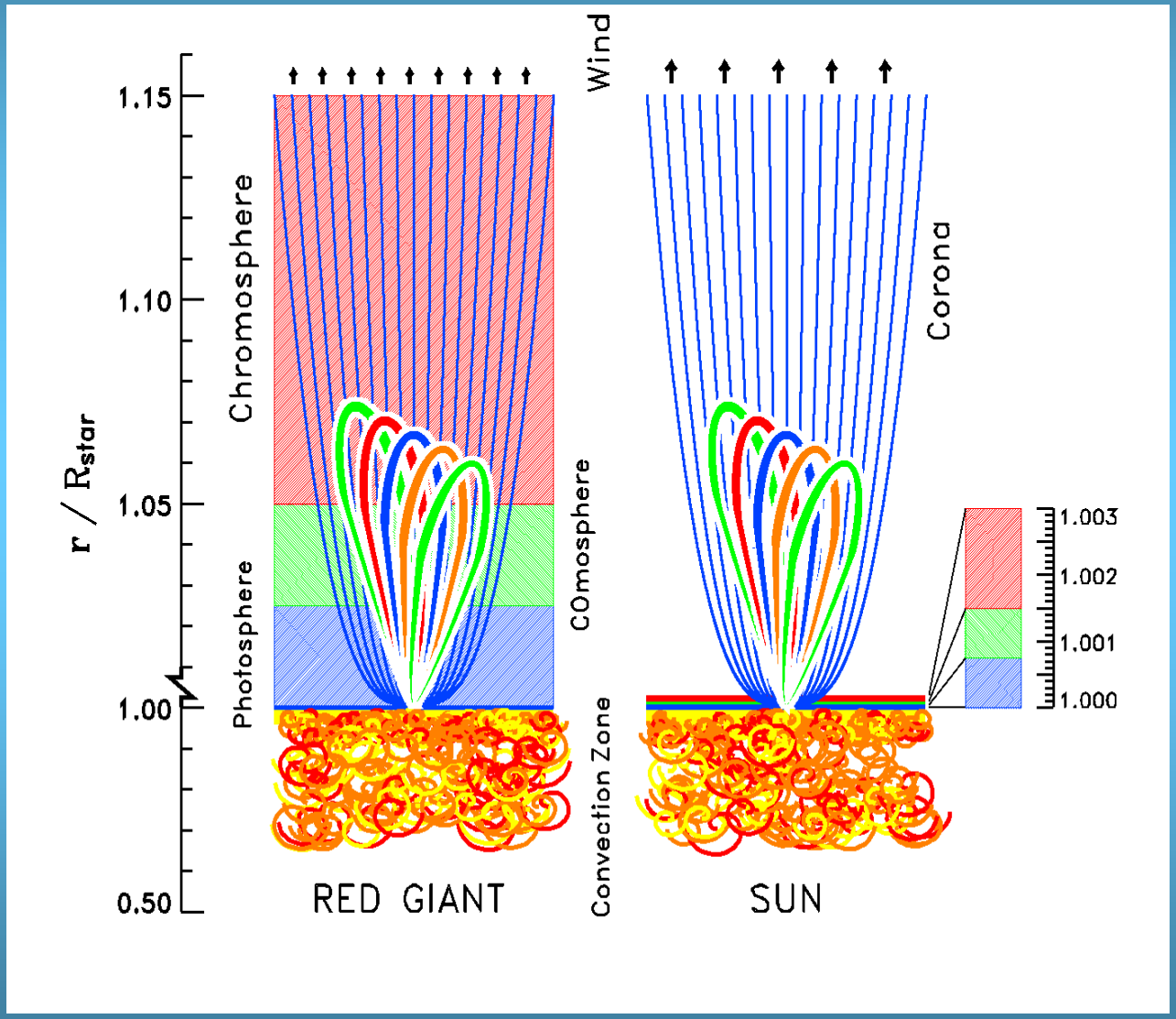
f_λ (erg cm^{-2} s^{-1} Å^{-1})
WAVELENGTH (Å)

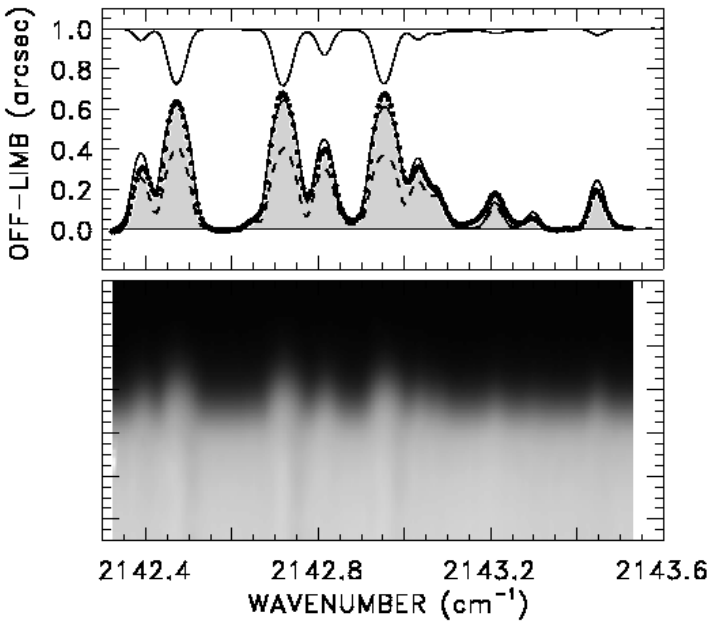
Buried Alive in the Coronal Graveyard

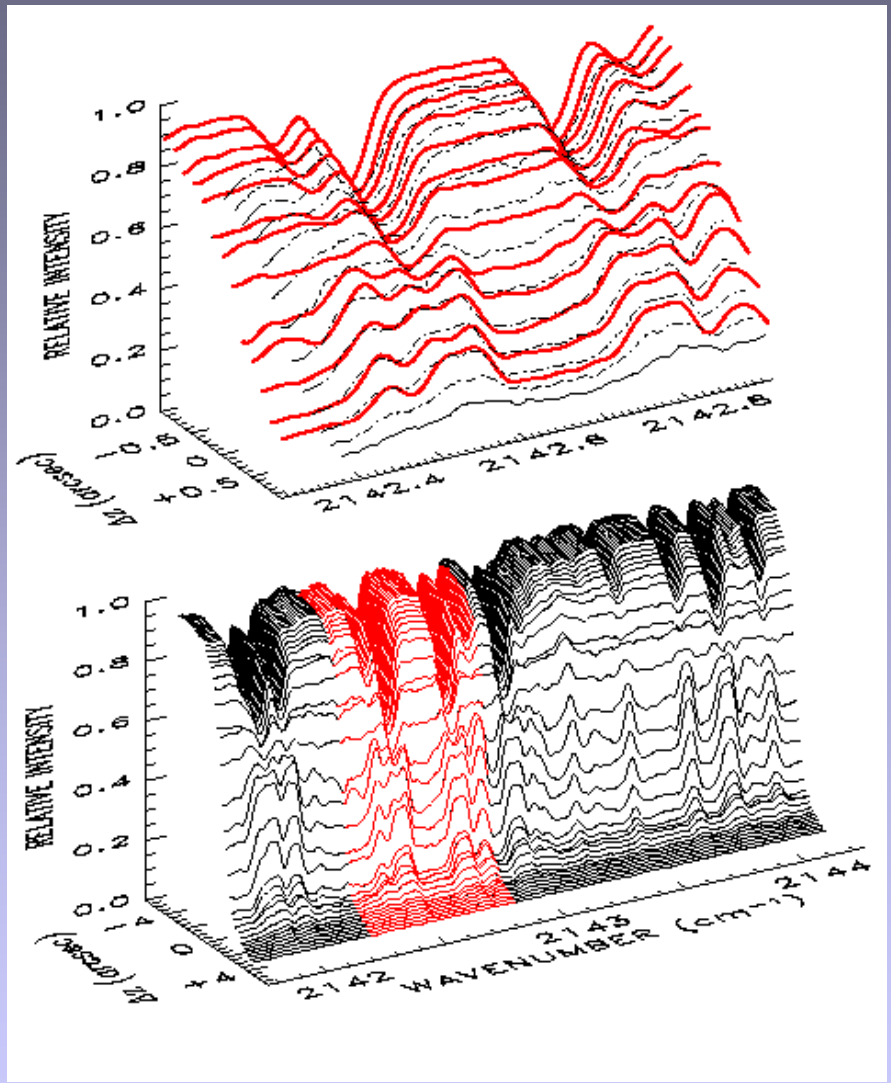


- Red giant atmosphere is much thicker than dwarf's owing to $H_p \sim R^2$
- $L_{loop} \sim R_{CZ} \sim R_{star}$

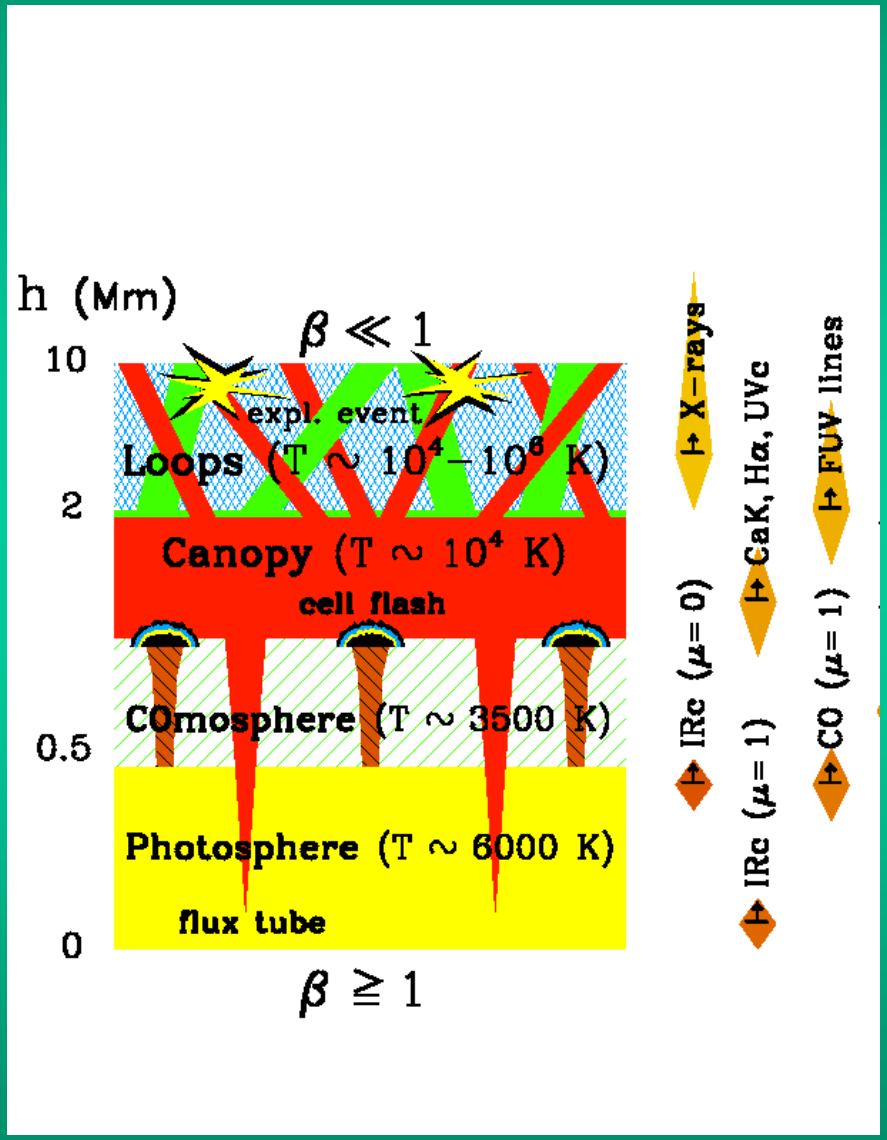
Winds???

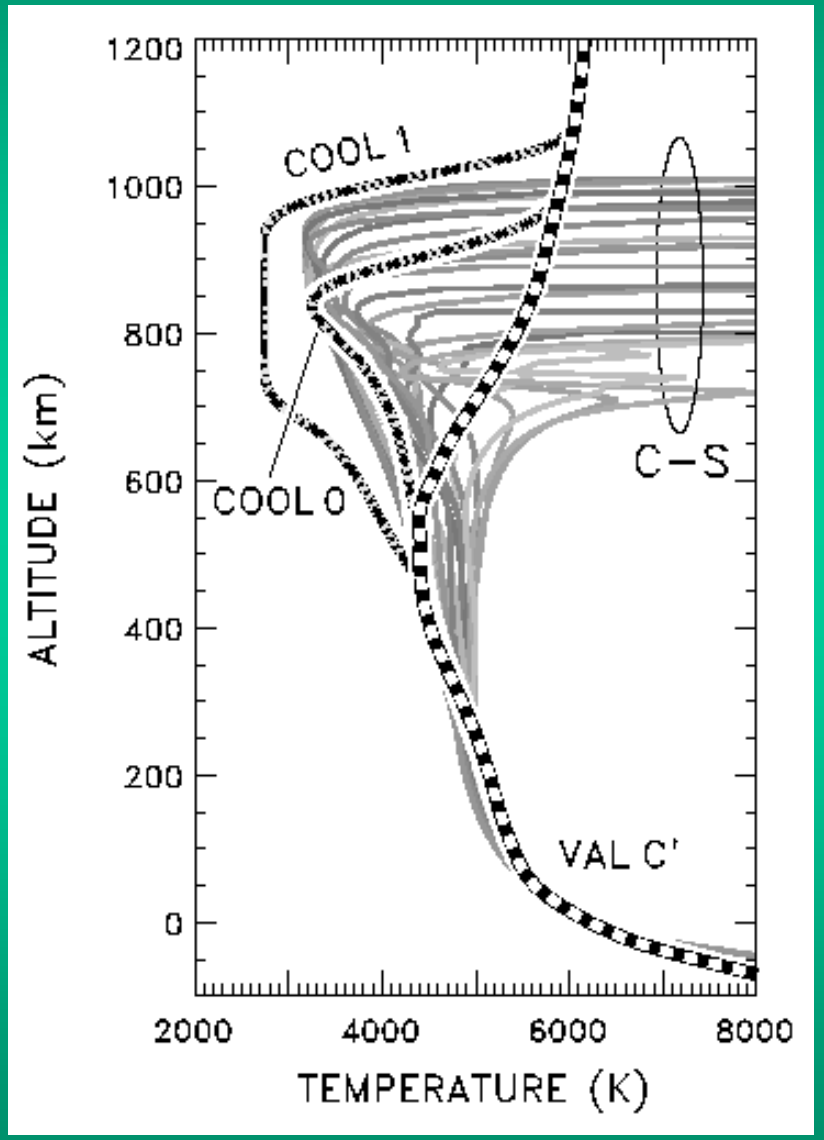
Off-Limb Emissions of CO

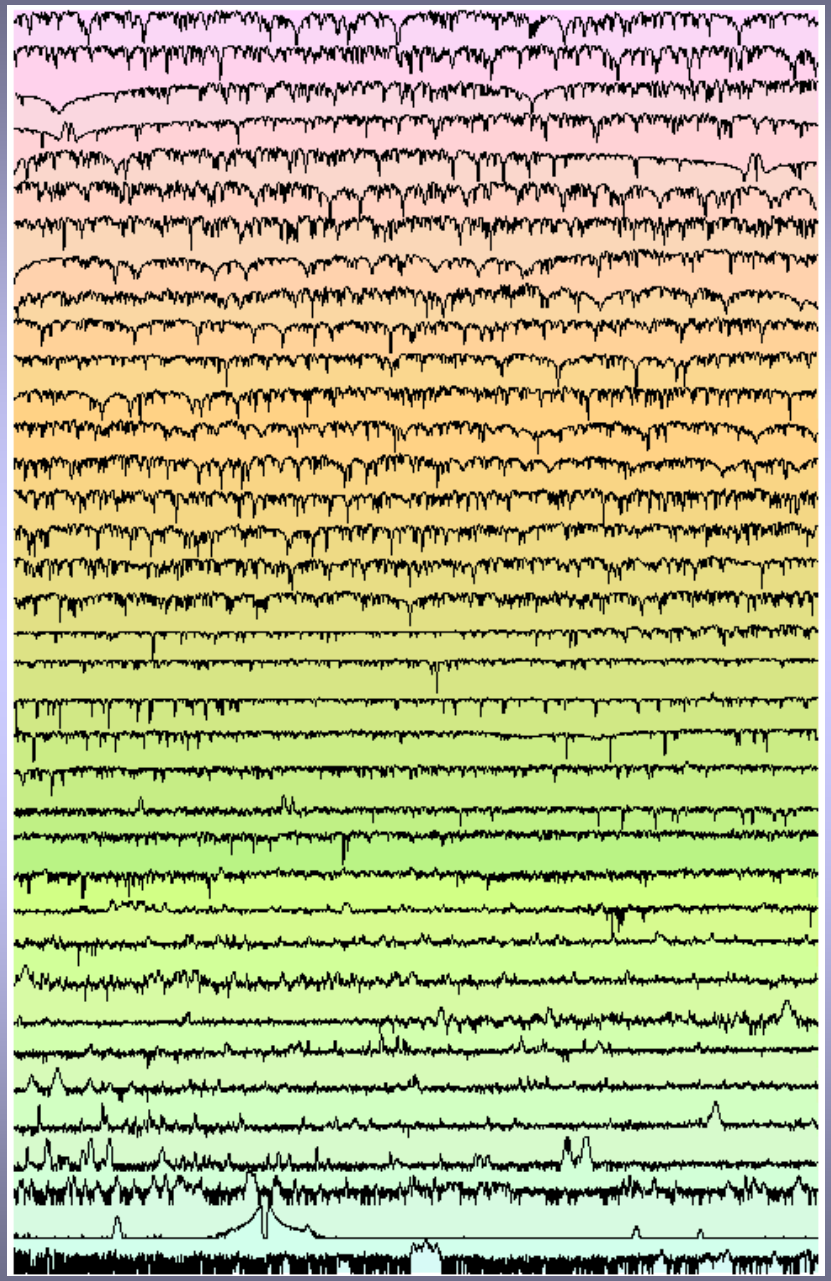


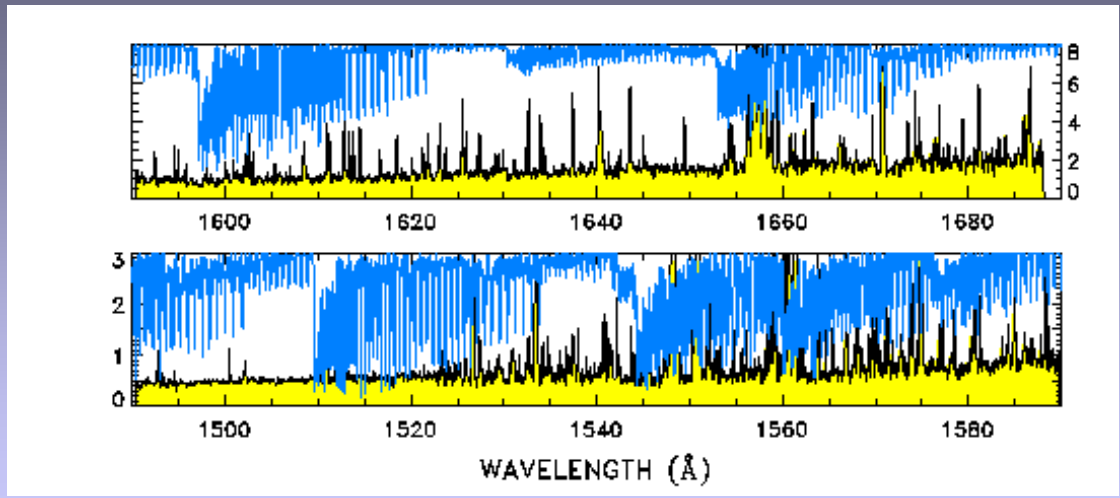


Cool Gas at High Altitudes







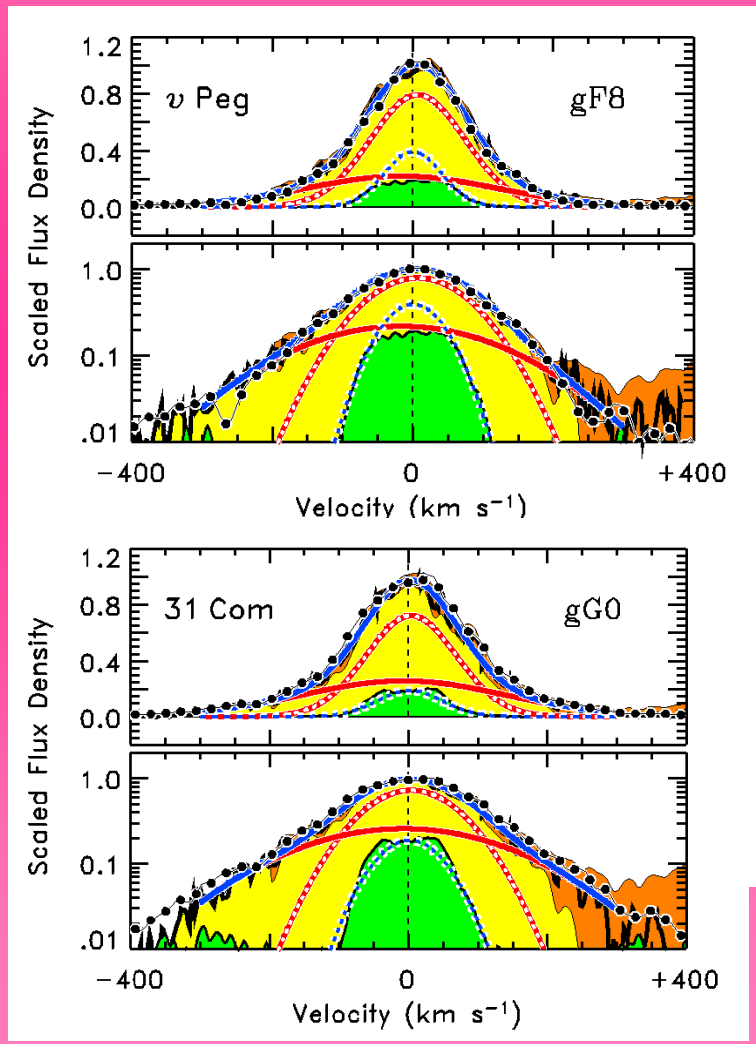


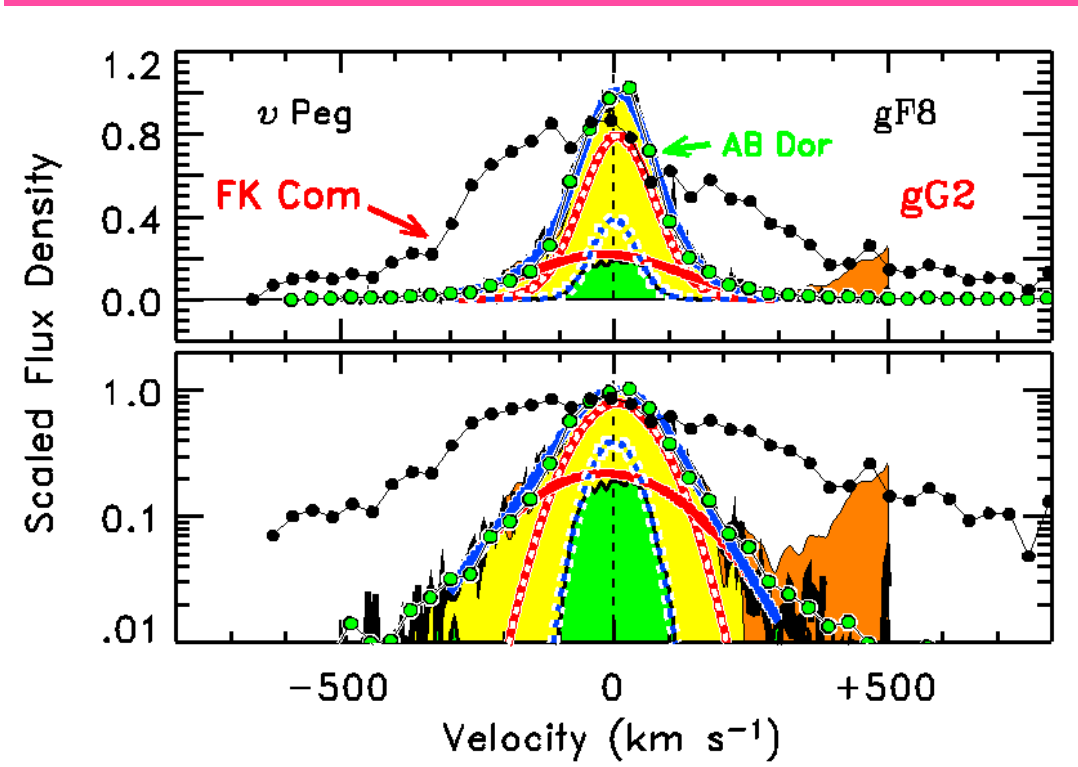
- *In the solar twin Alpha Cen spectrum we don't see any evidence of CO 4th- positive system absorption; ultraviolet continuum forms higher than COmosphere?*

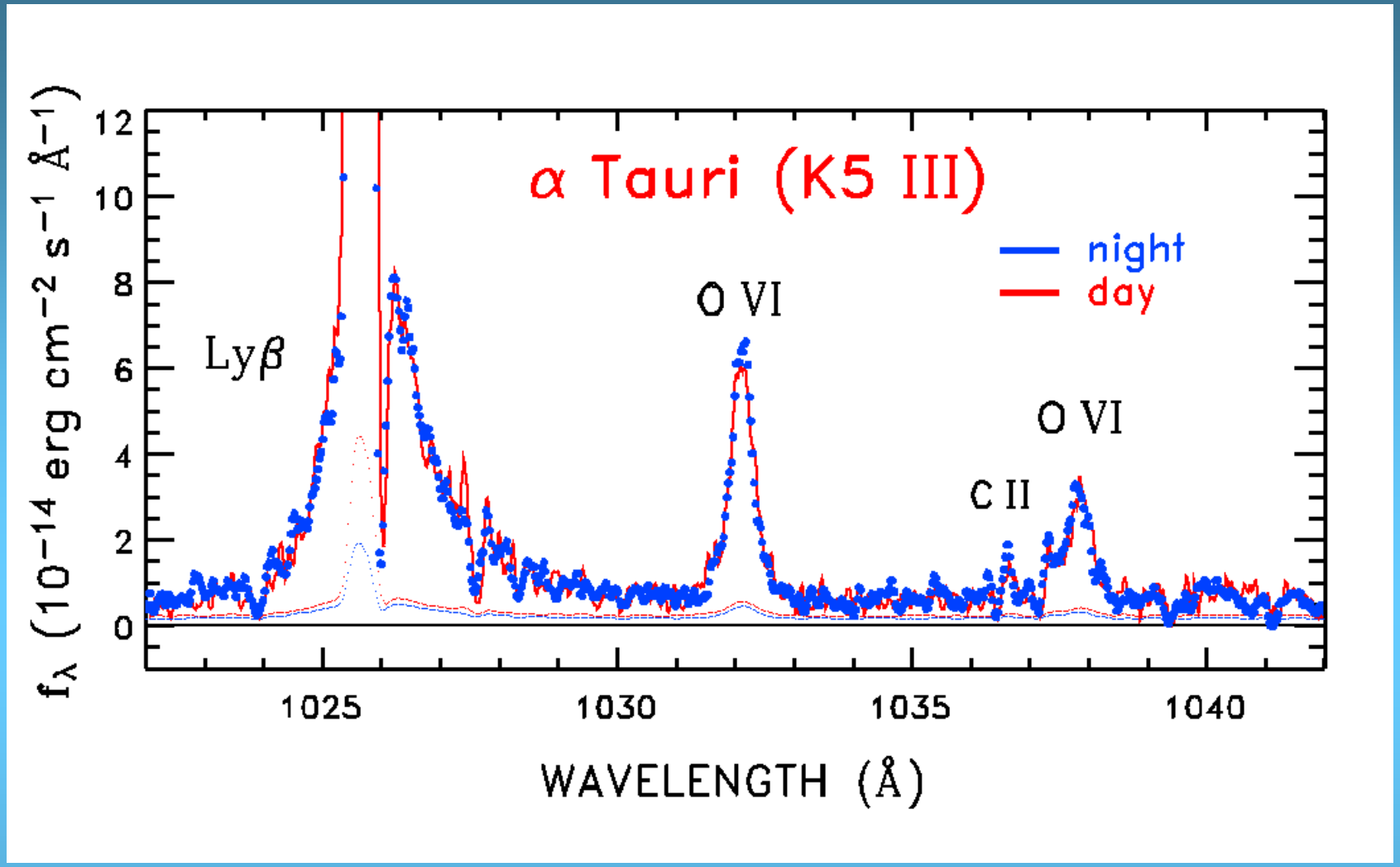
Tying it all together?

- The Sun is a very representative coronal star, yet near the bottom of the activity scale; so, potentially there is much to learn about extremes of solar activity from studies of the extreme X-ray stars.
- It's all about the dynamics…but need good wavelength zero point.
- The solar coronal graveyard?? Sometimes need to see below $\tau_{EUV}=1$ (coronal forbidden lines)…
- It is time to consider observing the Sun with the high-quality** UV/X-ray spectroscopy routinely applied to other stars. (**don't forget the wavecal lamp!)

Super-Rotational Broadening







O VI doublet clearly detected in 70 ks FUSE exposure; C II lines show affects of wind absorption; other abs in Lyβ.