The fingerprints of the stars …

High resolution Spectroscopy

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Hamburger Sternwarte

GrK 1351 -- October 2013

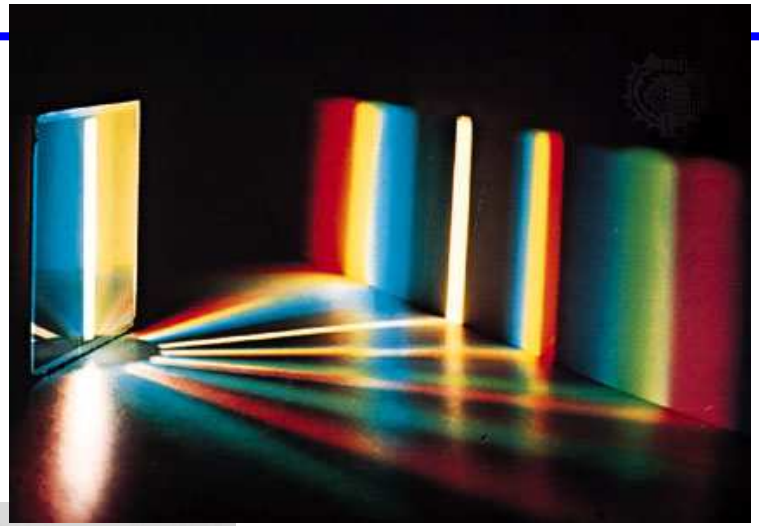
Outline

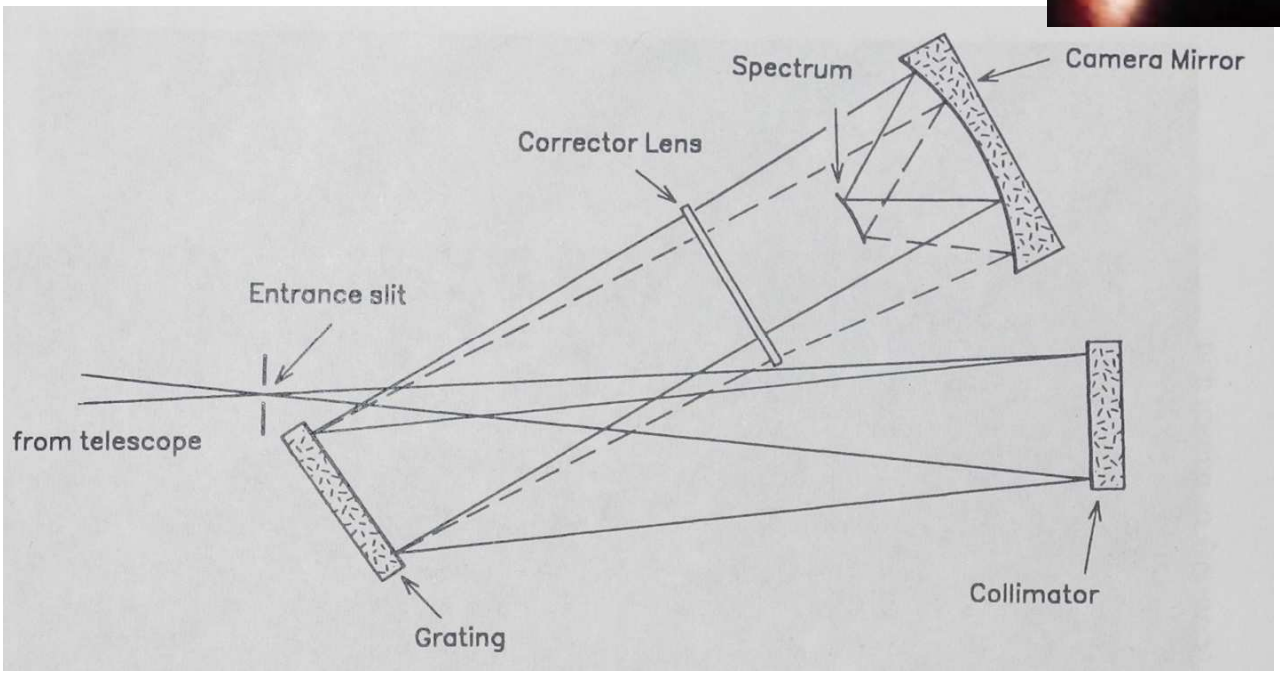
- CARMENES in high-resolution spectroscopy
- Stellar properties in optical spectra
- Stellar activity vs. radial velocity measurements

High resolution

Spectrographs & Spectra

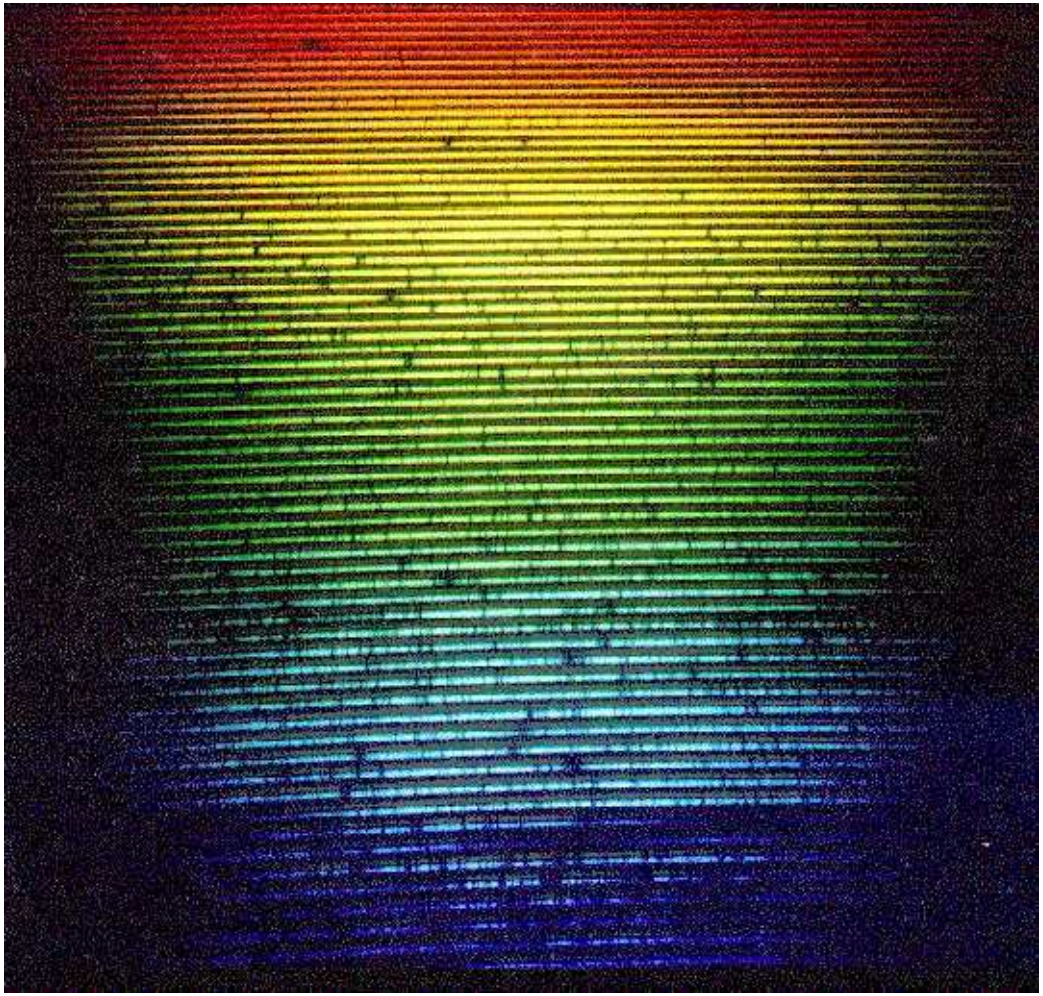
A reflection grating spectrograph in principle



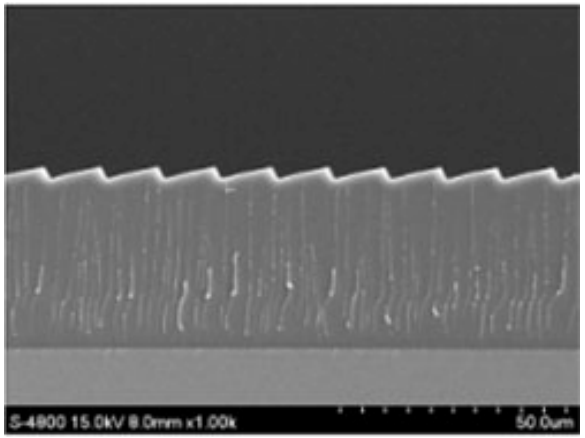


(**D. Gray 2nd edition, 2012**;
Grating project)

Attention: Echelle



(FOCES, T. Gehren, China Grating)



Spectral resolution
$R = \lambda / \Delta\lambda = n \cdot N$

n … order number
N … number of grooves

CARMENES in a nutshell

	VIS	NIR
	550-1050 nm	950-1700 nm
	29 orders	53 orders
Spectral resolution	82,000	
Fibre size	1.50 arcsec	
Mean sampling	2.8 CCD pixel	

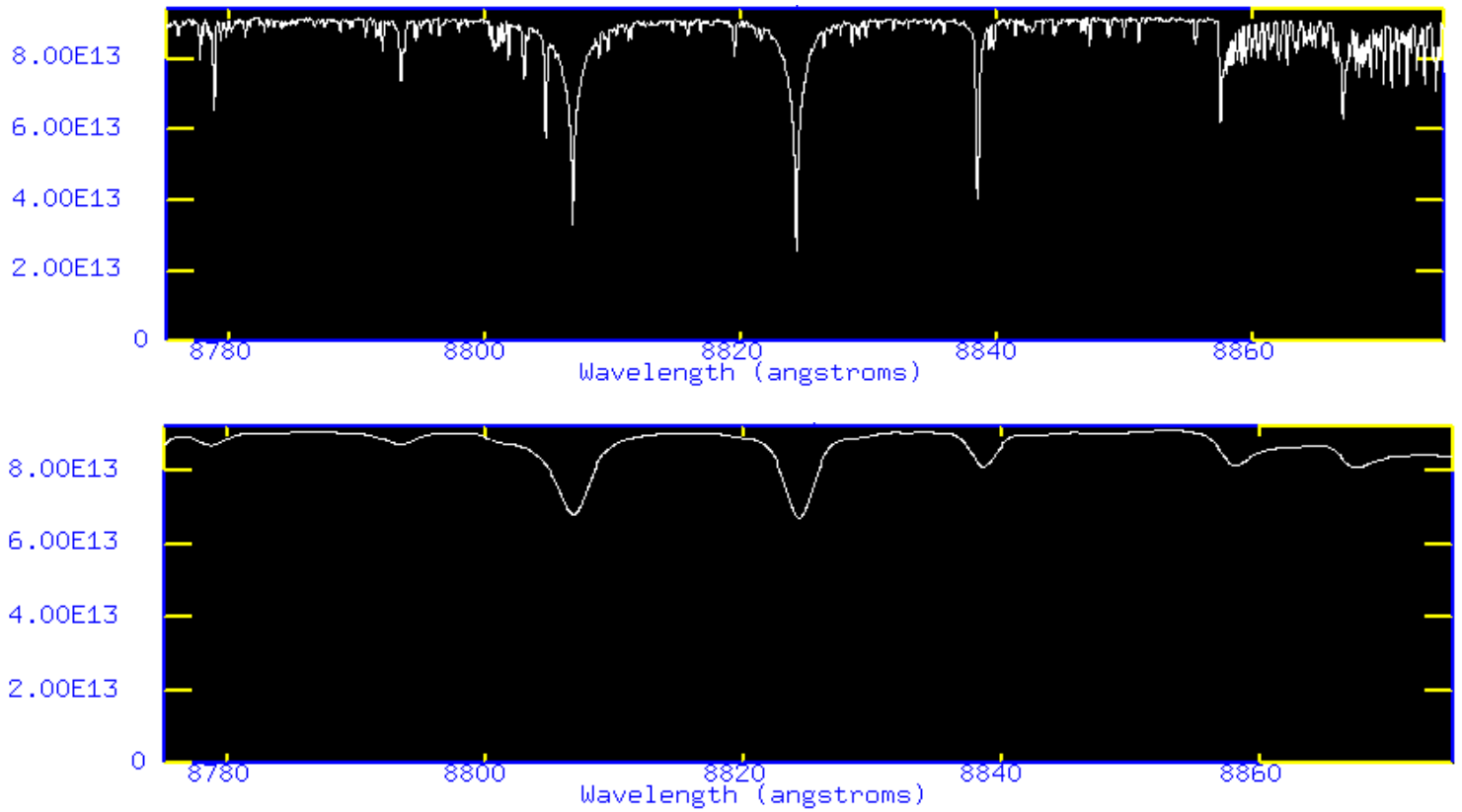
Wavelength stability better than 1 m/s

$R = \lambda / \Delta\lambda = 82\,000$

$\Delta v = c / 82000 = 3.7$ km/s

(Seifert et al. 2012, SPIE 8446)

„High resolution“:
What spectral resolution does to you



PHOENIX 3700 K (M1 V) R= 100000 vs. 4500

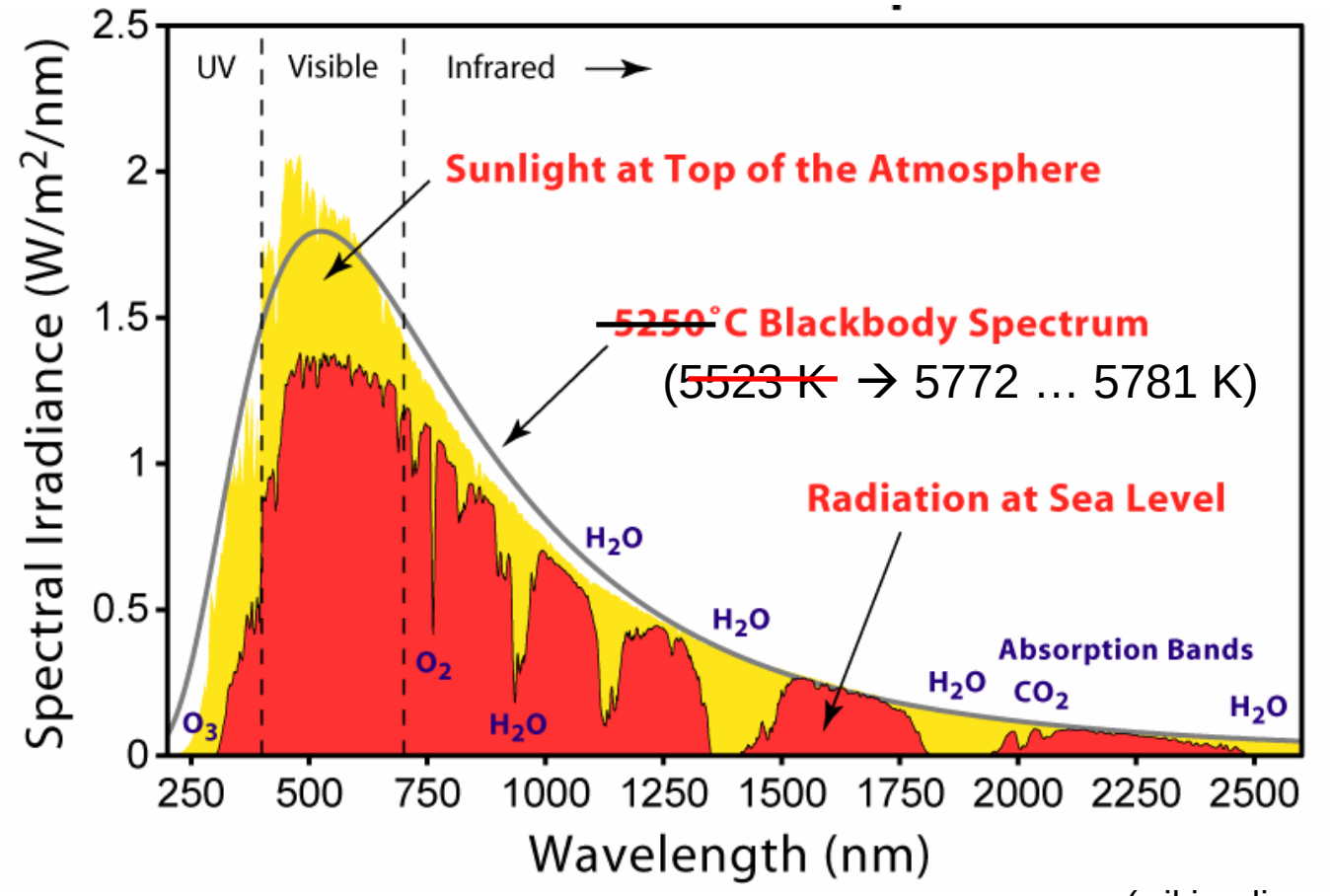
→ Husser et al. 2013, A&A 553

Effective

Temperature

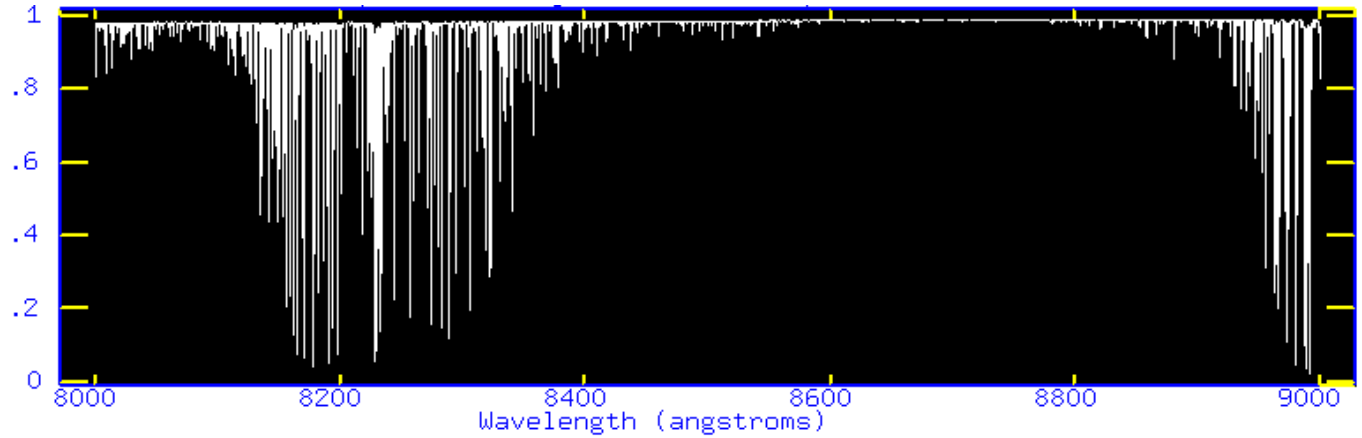
… and line depths

Our host star



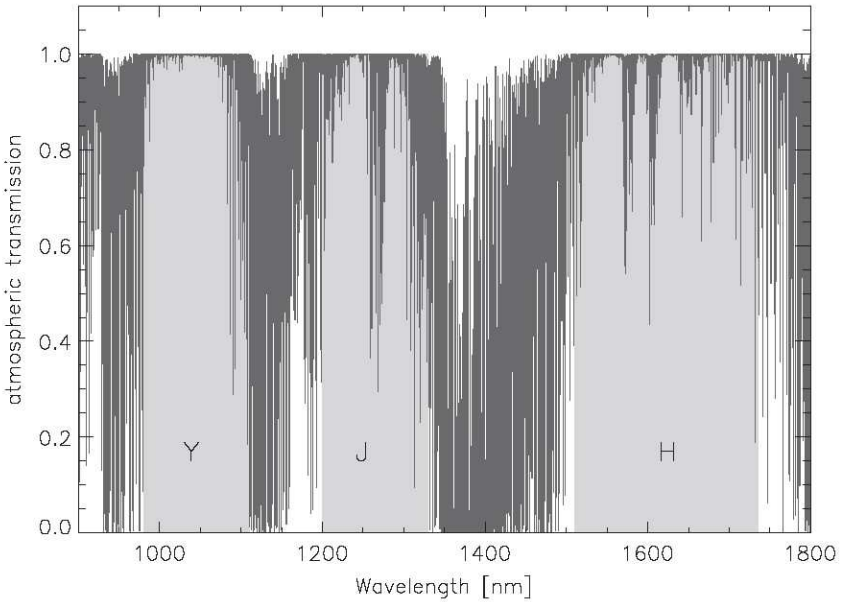
(wikipedia.org,
Bessel et al. 1998, A&A 333
www.pas.rochester.edu/~emamajek)

Telluric lines -- what the air does to you



LBRTM

(Clough et al. 1992, J. Geophys. Research)



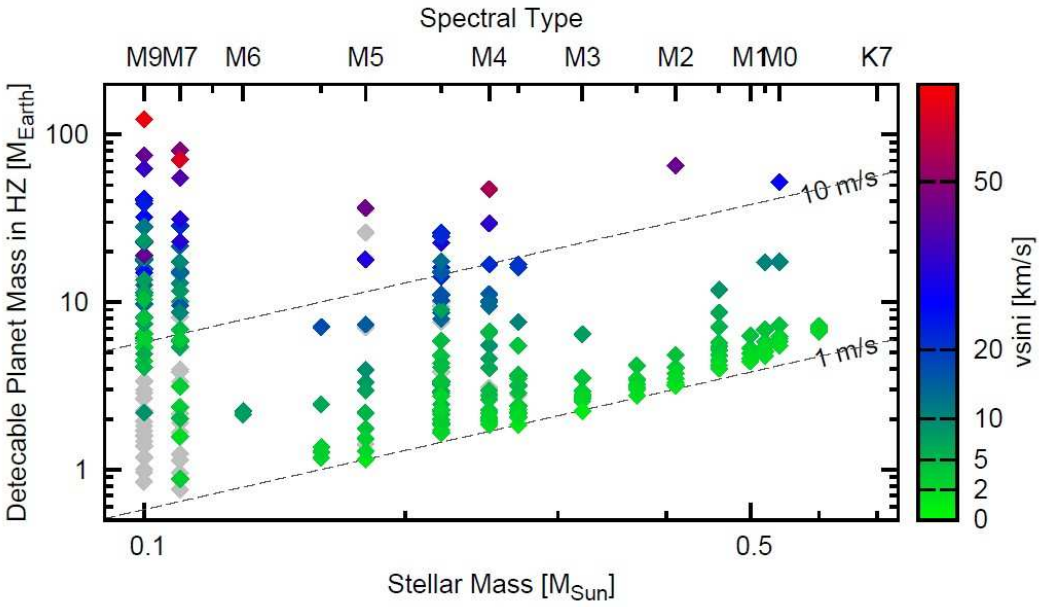
(Reiners et al. 2010, ApJ 710)

What effective temperature does to your spectrum (low resolution)

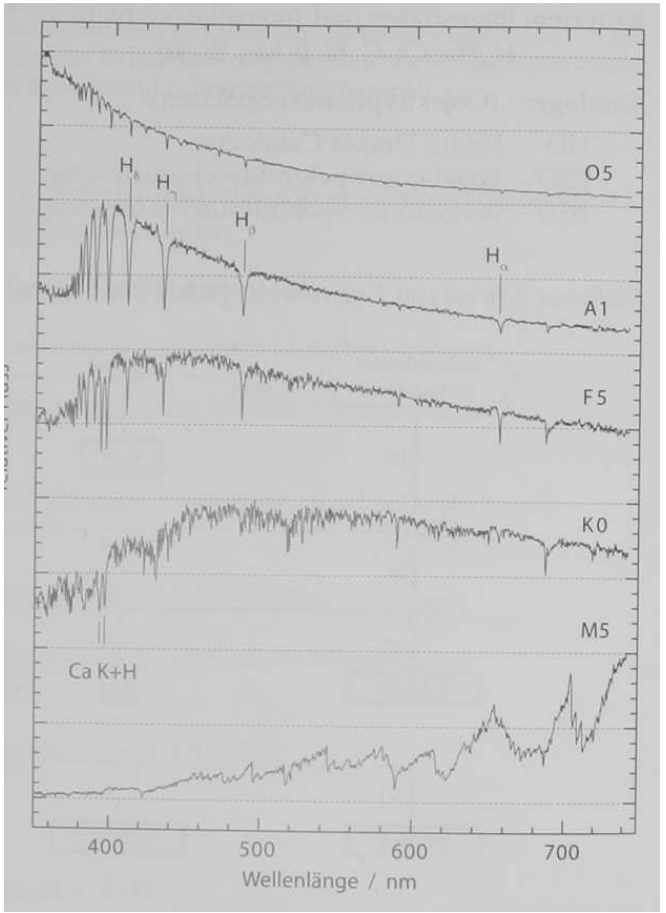
UVES POP

CRIRES POP

ftp://phoenix.astro.physik.uni-goettingen.de

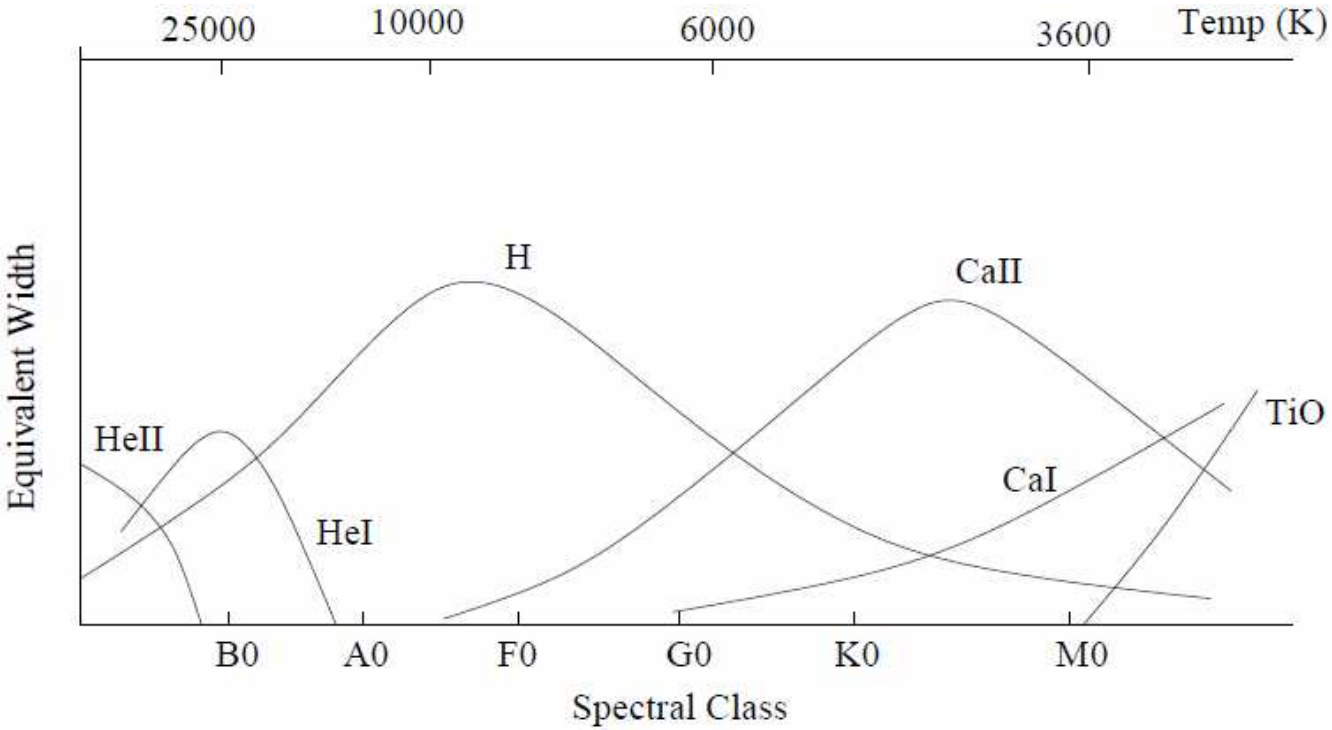


(Quirrenbach et al. 2012, SPIE 8446)



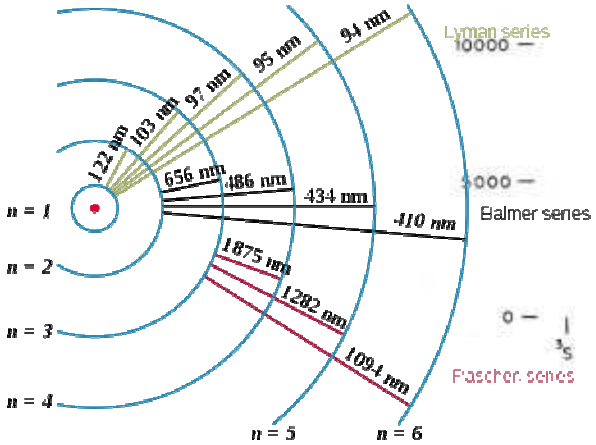
(H.-H.Voigt ed., 6th edition, 2012)

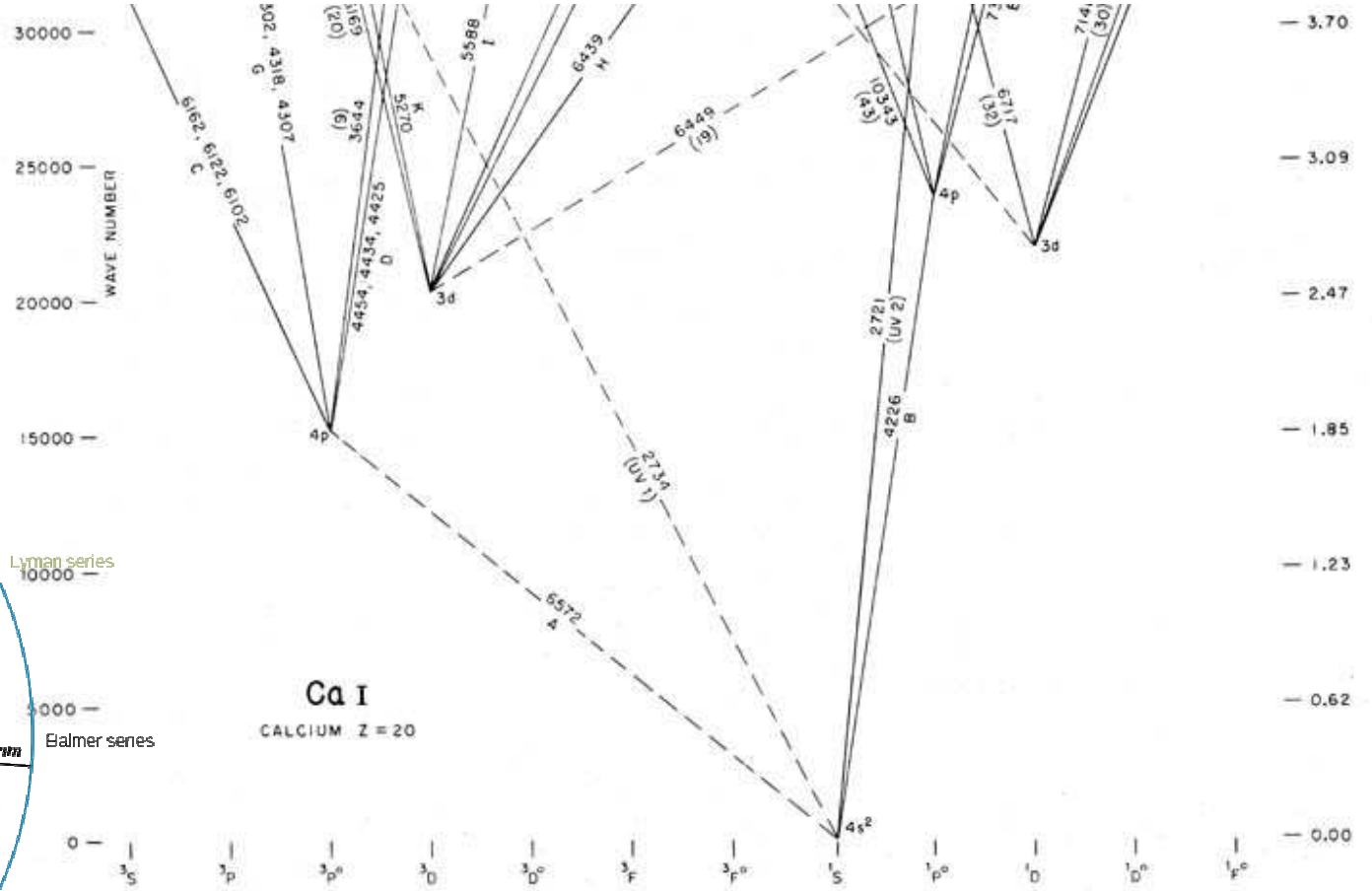
Why effective temperature does it



Saha equation
*** Boltzmann population of the ground level**
*** Molecular dissociation energy**

Why effective temperature does it

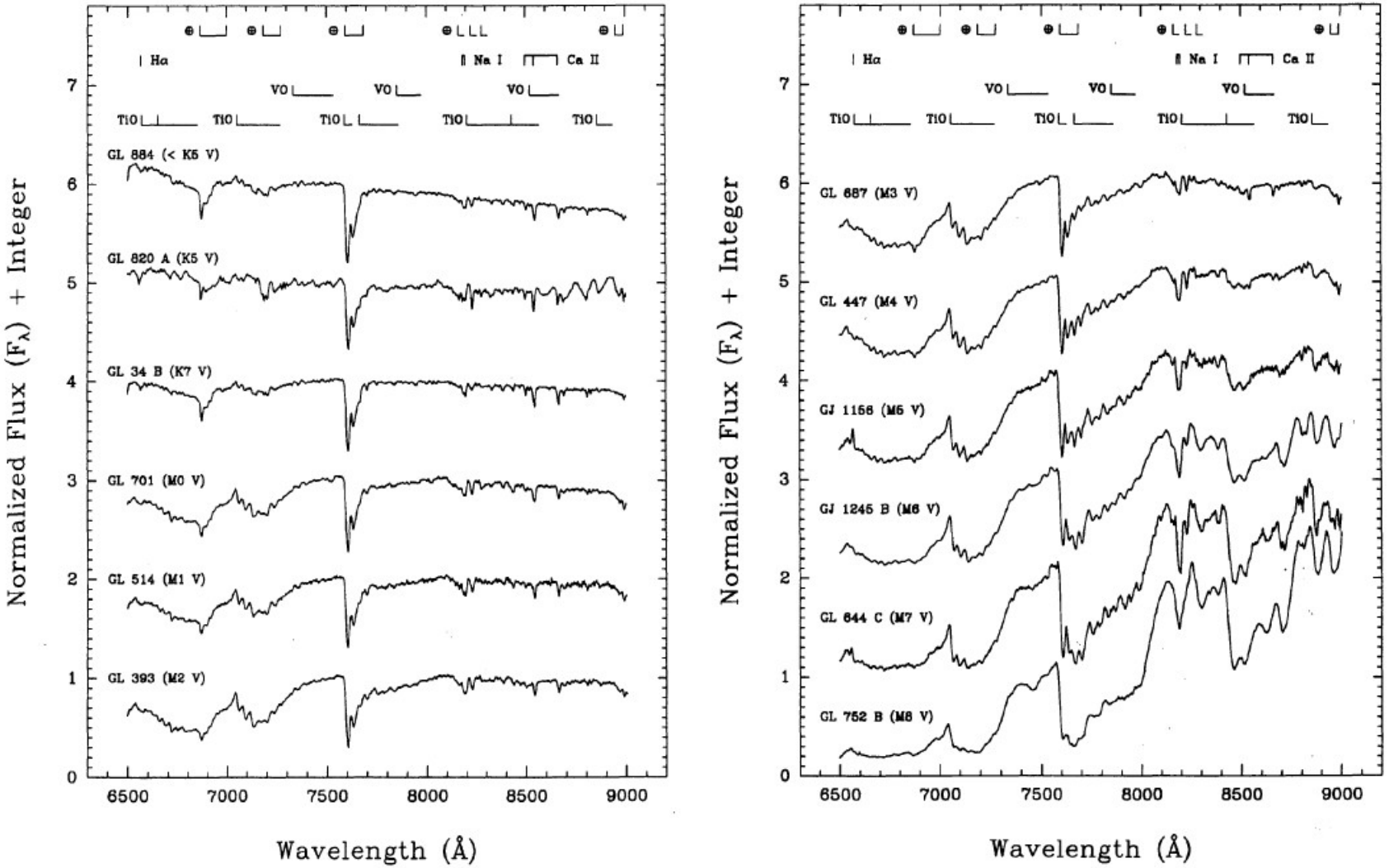




→ **www.nist.gov** **(closed down Oct. 2013)**

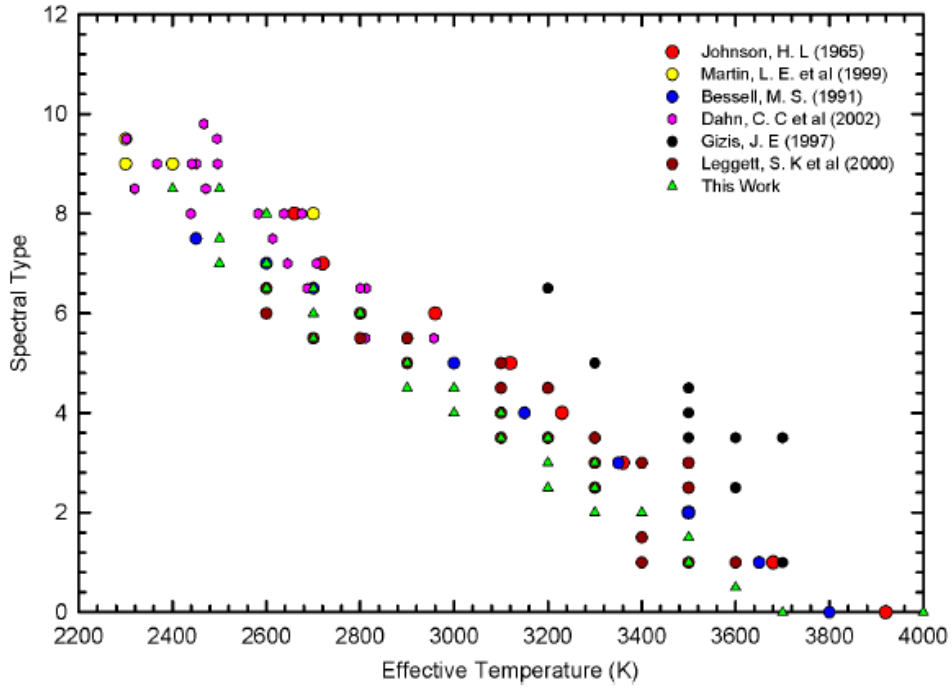
vald.inasan.ru/~vald3

The spectral regime of M-dwarfs



(Henry et al. 1994, AJ 108)

Effective temperatures (of M-dwarfs) -- CAVEAT

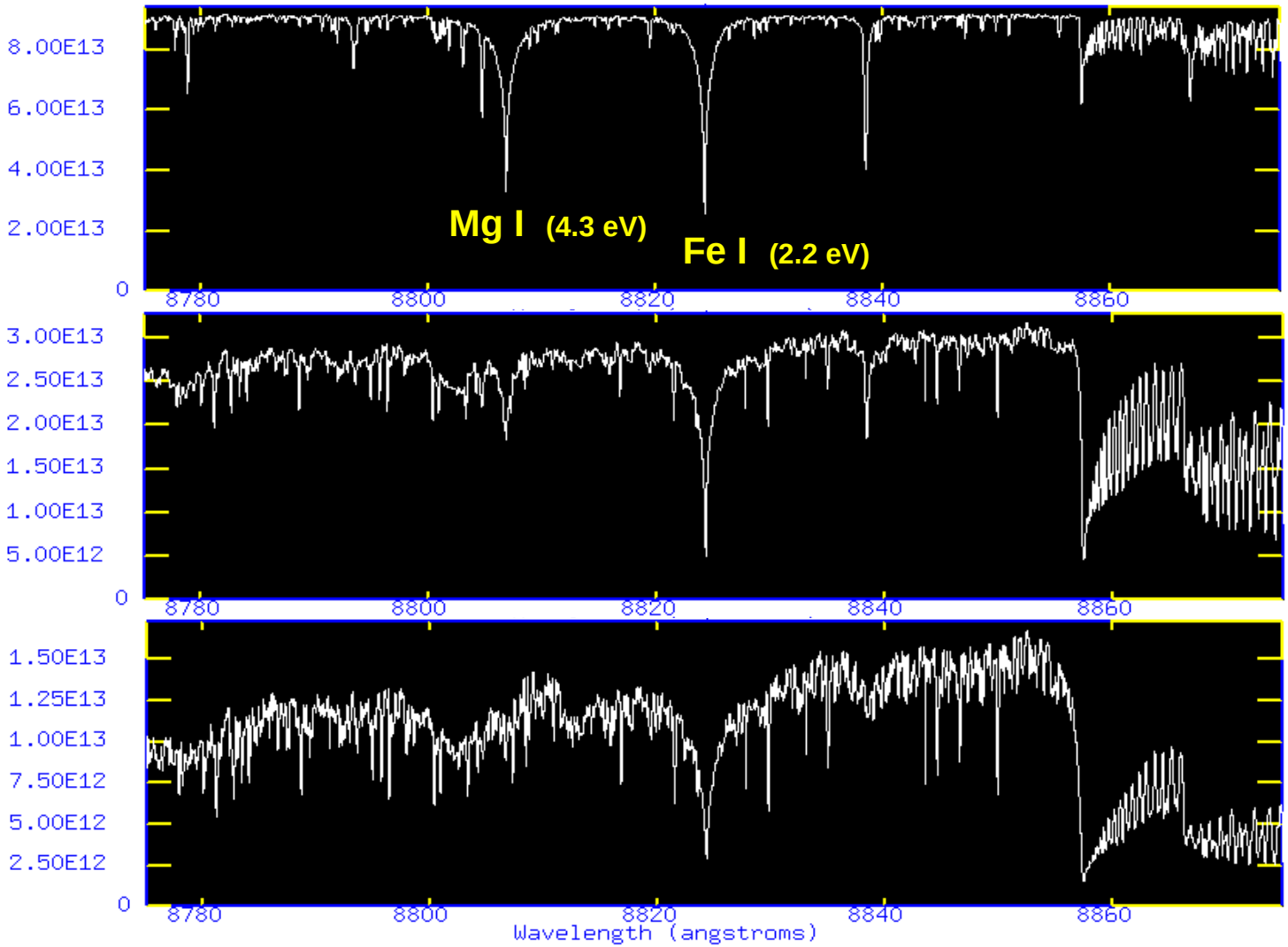


(Reylè 2011, ASPC 448)

M0V: 3800 K (0.5 $M_\odot$) -- M5V: 2900 K -- M9V: 2300 K (0.1 $M_\odot$)

→ www.pas.rochester.edu/~emamajek/

What effective temperature does to your M-star spectra (High resolution)



→ VALD3

vald.inasan.ru/~vald3

→ Schäfer et al. 2013 (in prep.)

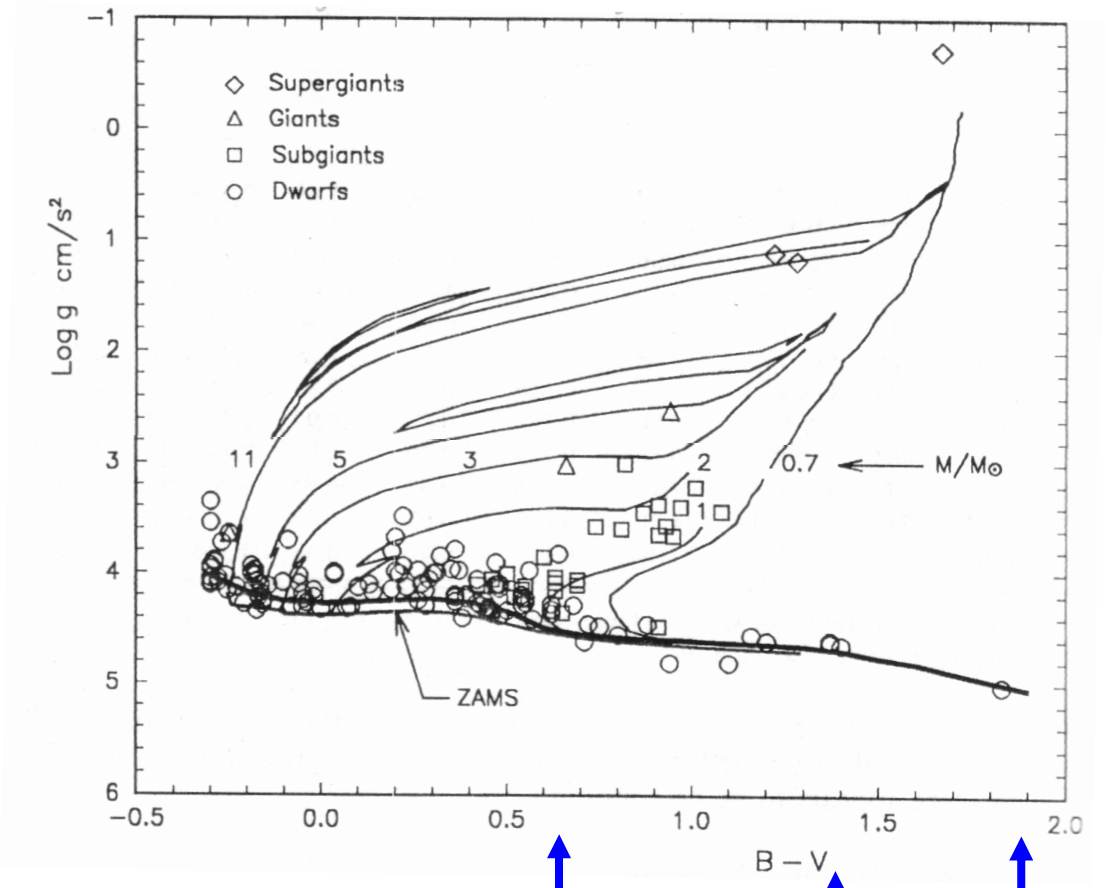
PHOENIX 3700K (M1) 2800K (M6) 2400K (M8)

Surface

Gravity

and line broadening

Surface gravity: „log g“



Sun (G2 V)

M0 V

M5 V

M0 V

0.61 $M_\odot$

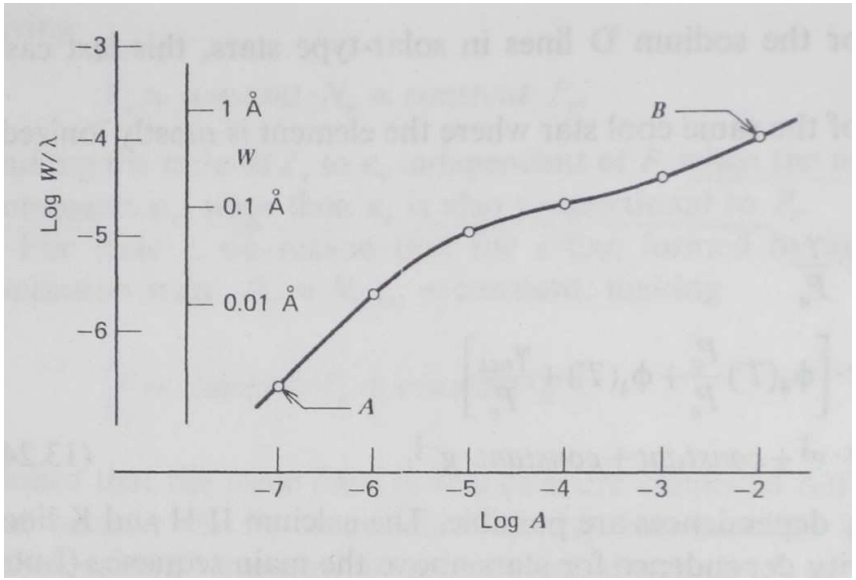
(Delfosse et al. 2000, ApJ 364)

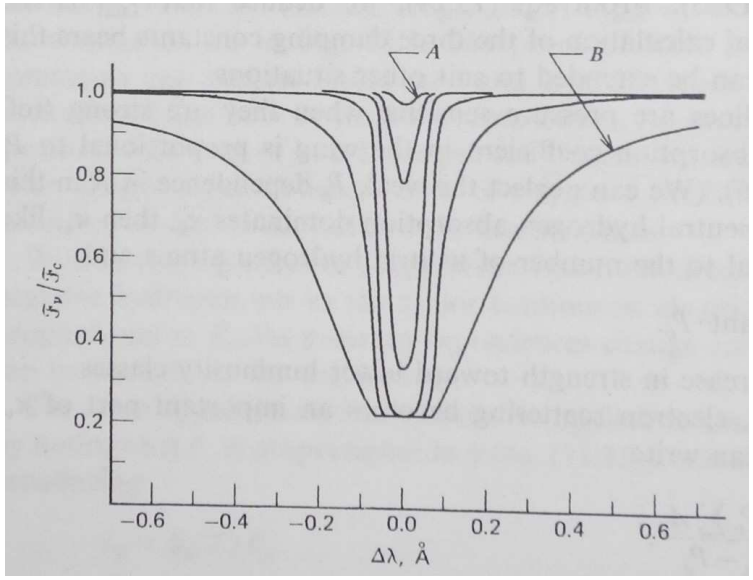
Mira -- M1-9(III)e

1.2 $M_\odot$

(Wyatt & Cahn 1983, ApJ 275)

Line broadening: Microscopic





Line absorption coefficient α

α(total) = α(natural) * α(Stark) * α(Van-der-Waals) * α(thermal) * α(micro)

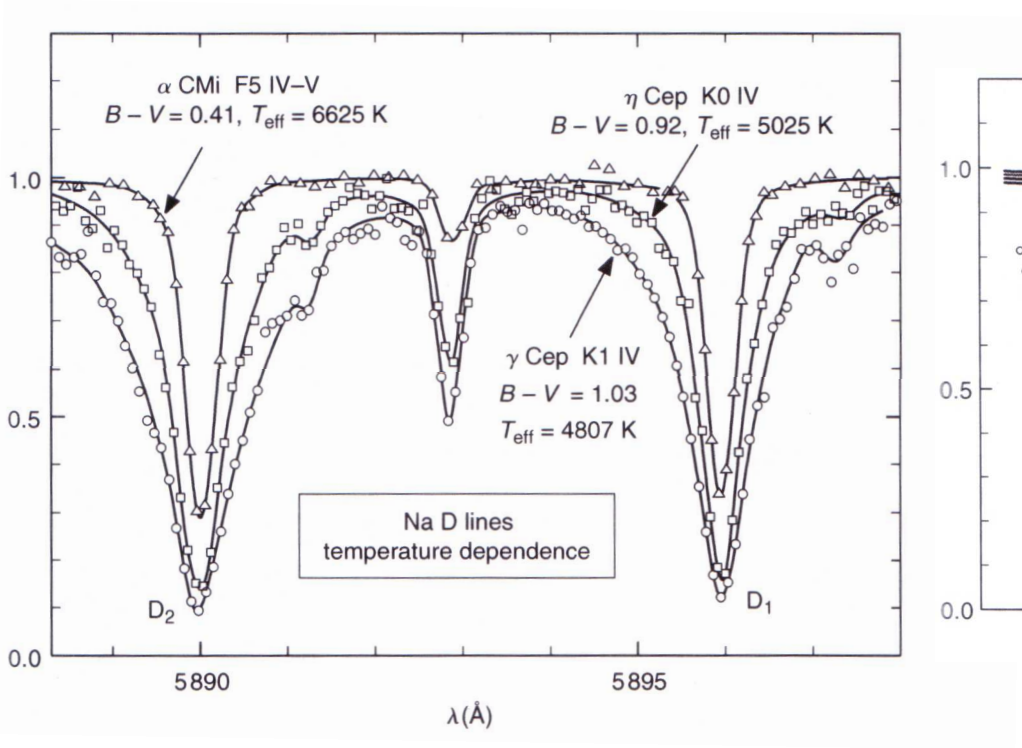
Lorentz — **Gaussian**

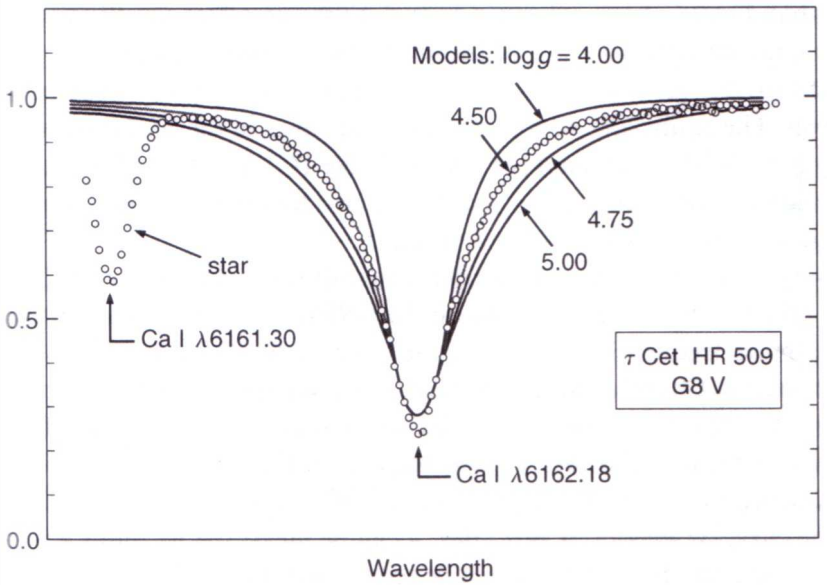
≈ 10^{-4} Å

≈ 1 km/s (e.g. Ca 3000 K)

≈ 1 km/s (M-dwarfs)

log g and Teff get entangled -- Caution





„MOOG“ (for F-G-K stars, Sneden 1973, PhDT)
„SME“ (Valenti & Piskunov 1996, A&AS 118)

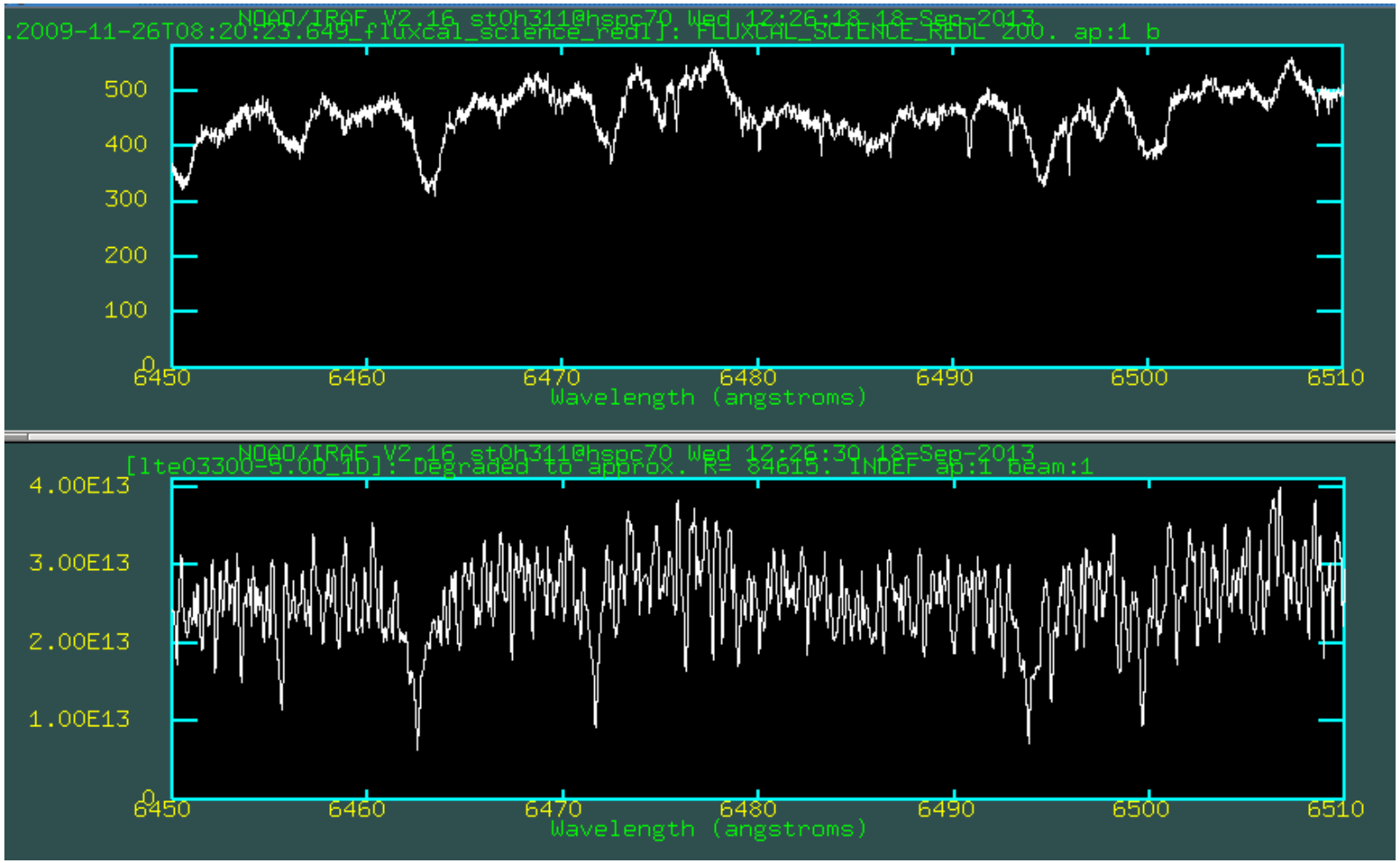
→Ammler - von Eiff et al. 2009, A&A 507
→ Schröter et al. 2011, A&A 532

Stellar

Rotation

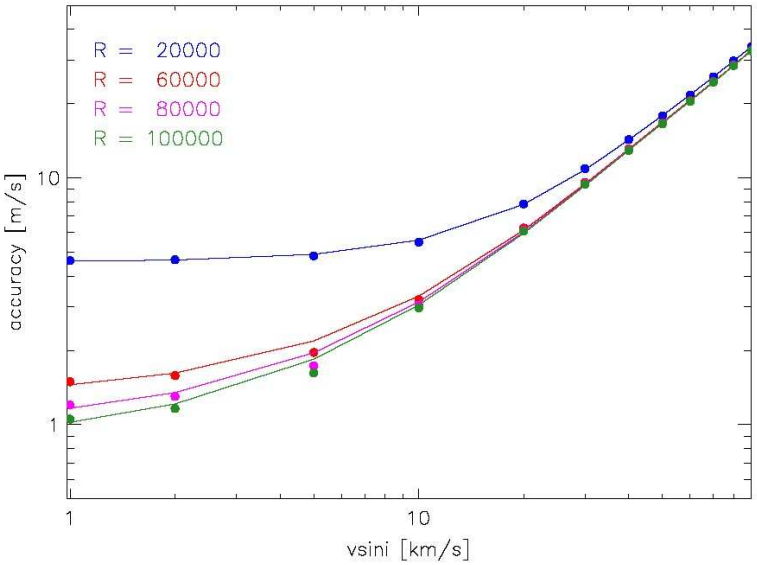
and line broadening

Rotational broadening – the effect of *projected* rotation
$v_{eq} \cdot \sin i$



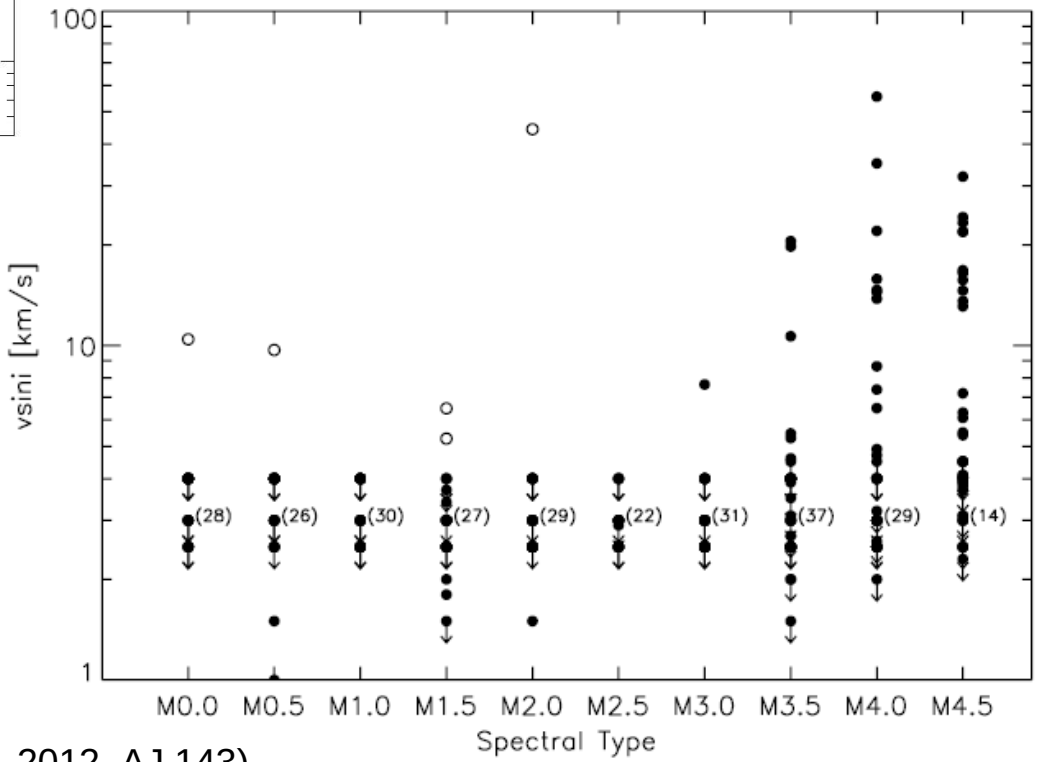
v sini = 40 km/s vs. 0 km/s (ca. M4 V, e.g. CaI 6463 Å)

Rotation: The price you pay -- part 1/3: line broadening



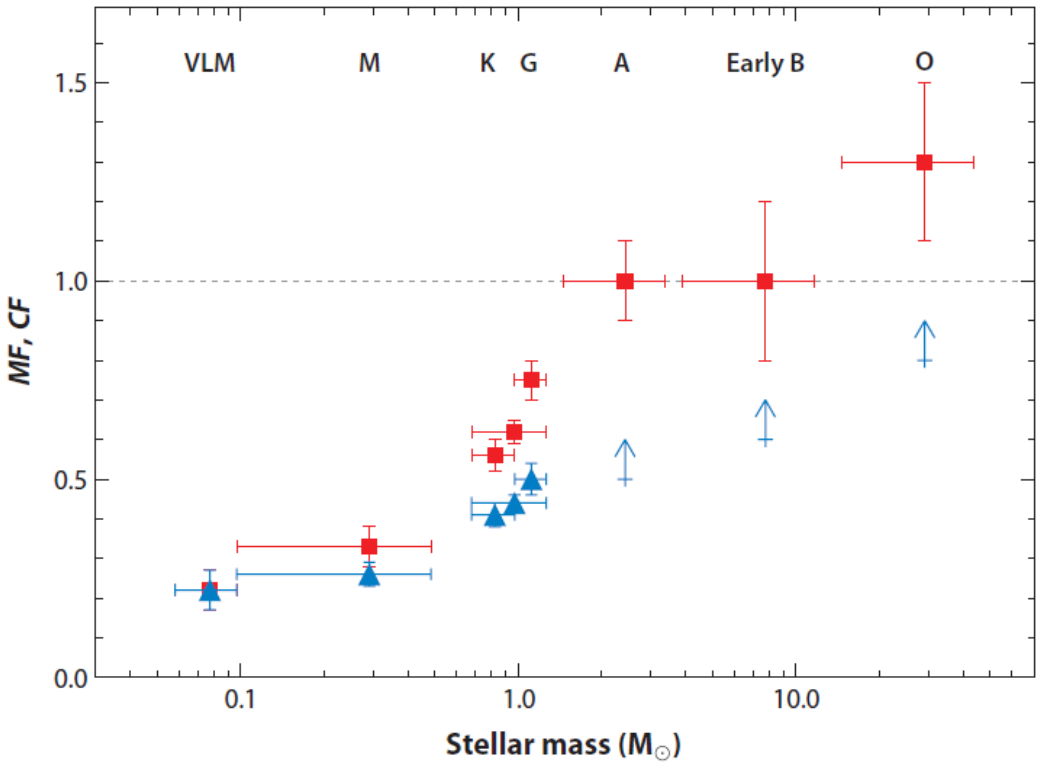
e.g. T_{eff} = 3000 K observed at 10000 Å

(Reiners et al. 2010, ApJ 710)

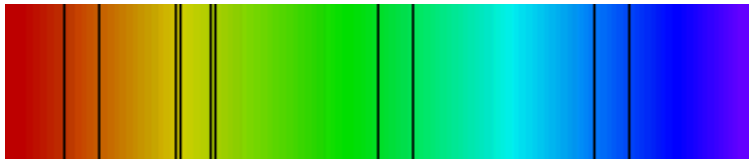


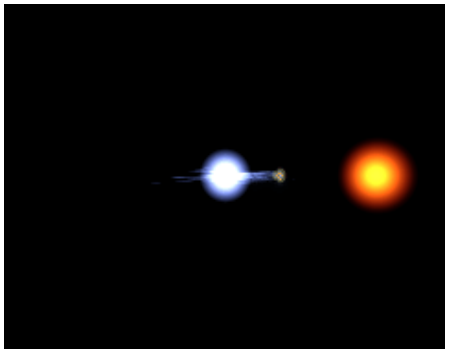
(Reiners, Joshi & Goldman. 2012, AJ 143)

Interlude: Beware of binaries !



(Duchène 2013, ARA&A 51)

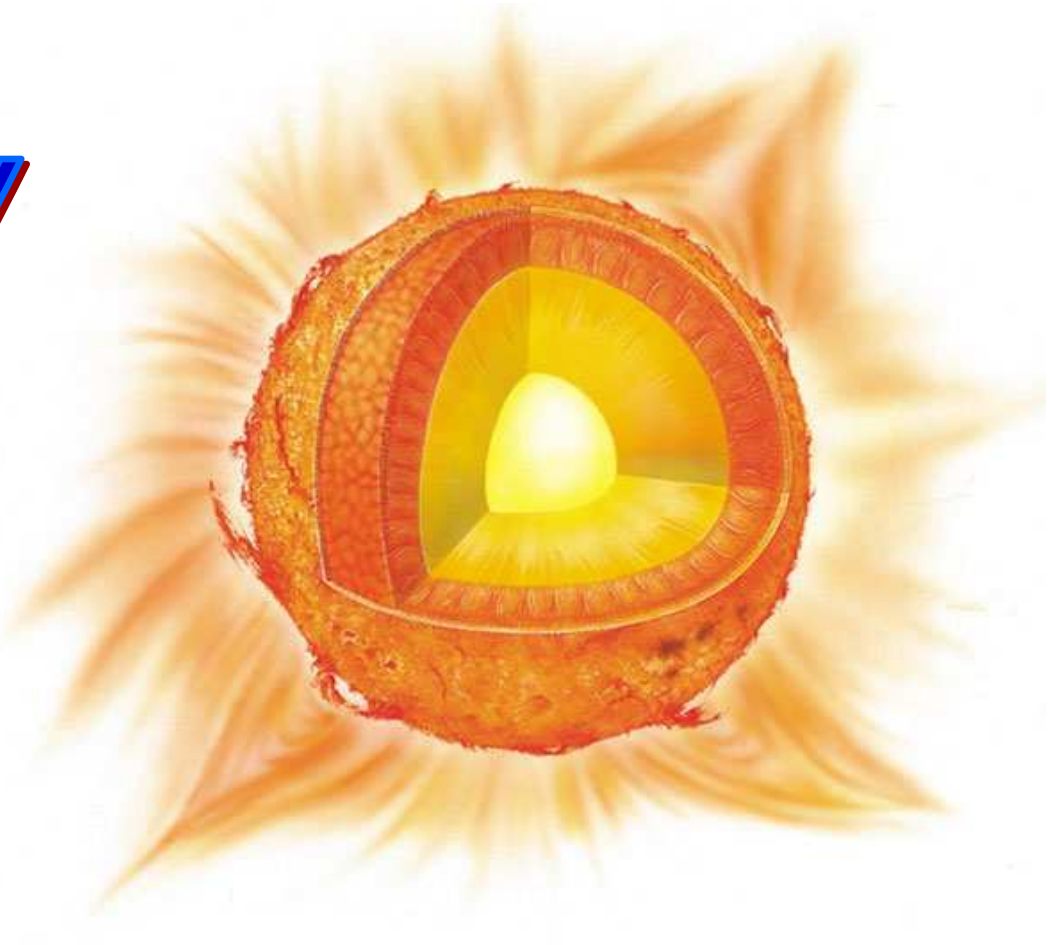




(Freedman, Geller, Kaufmann; Universe)

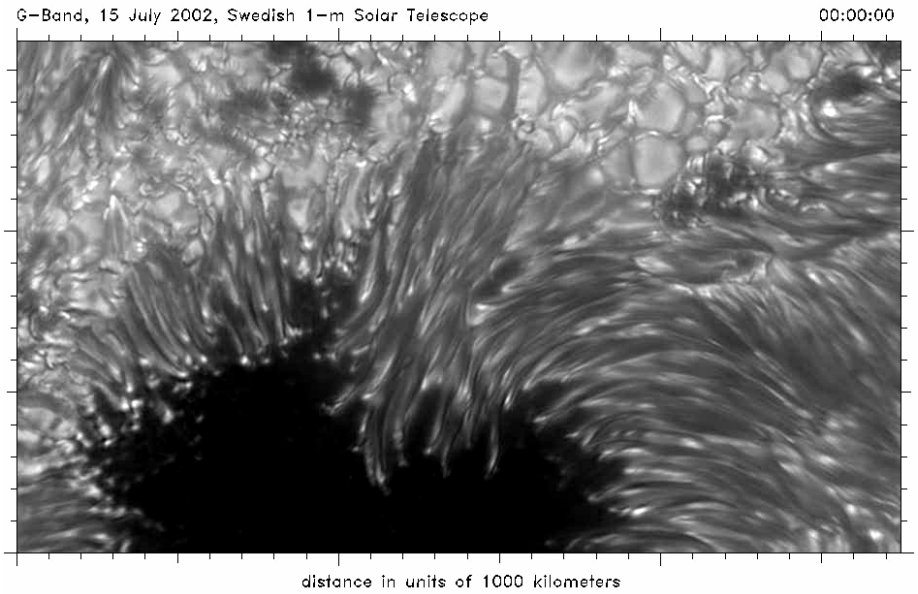
Stellar

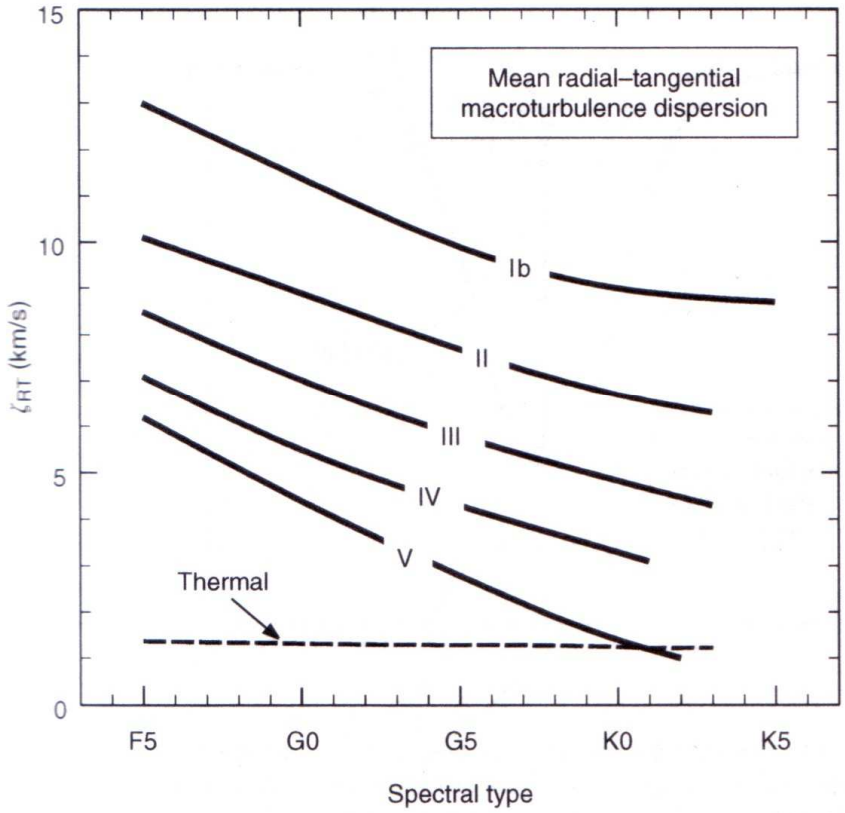
Activity



(Oxford University Press)

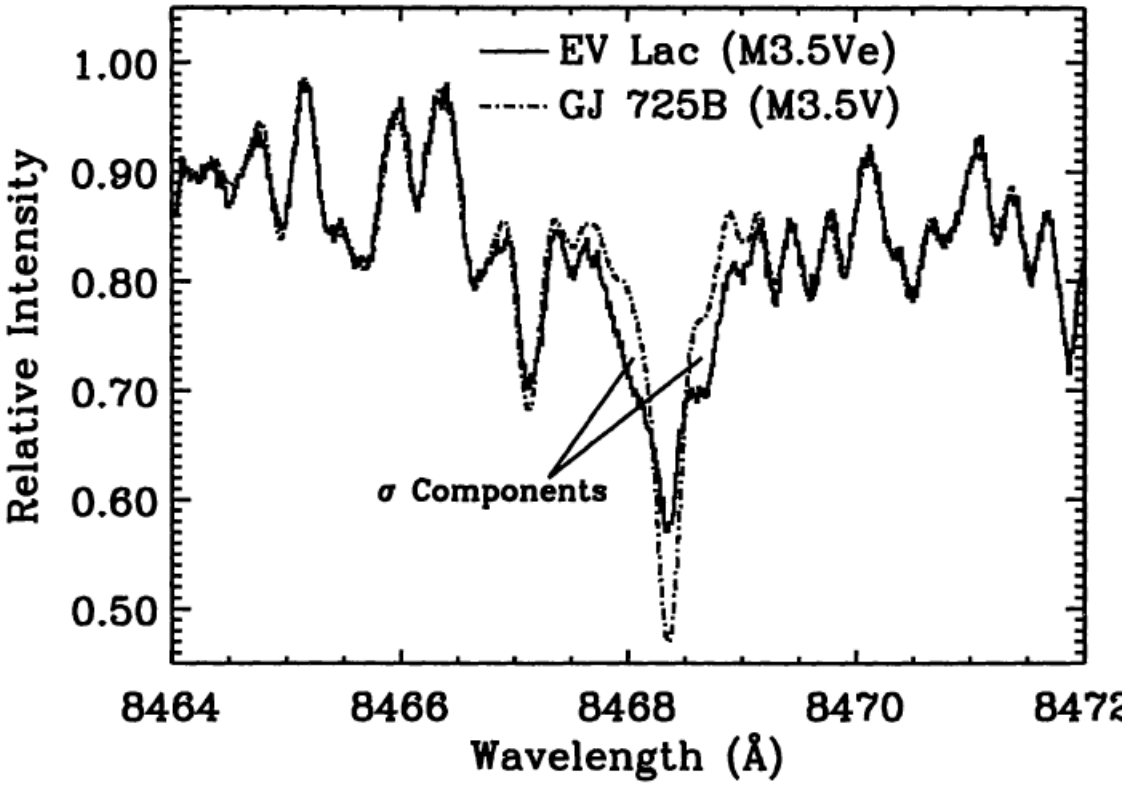
Surface convection („Macroturbulence“) – invisible in M-dwarfs

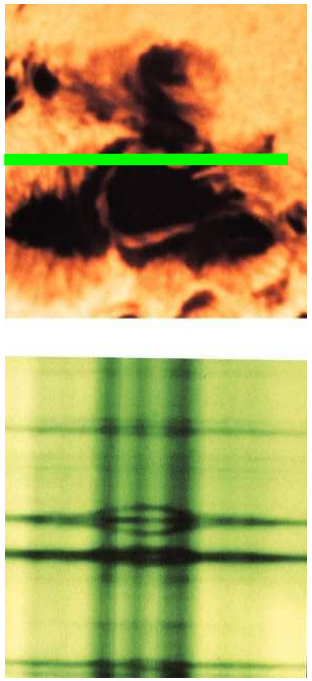




(**D. Gray 3rd edition, 2012**;
P. Foukal 3rd edition, 2013)

Magnetic line deformation – requires close inspection



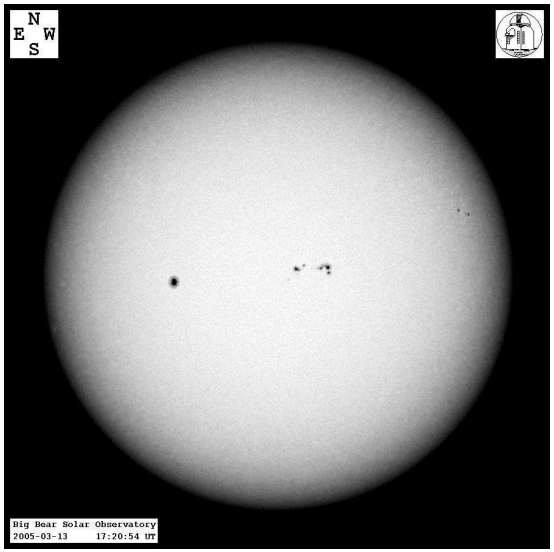


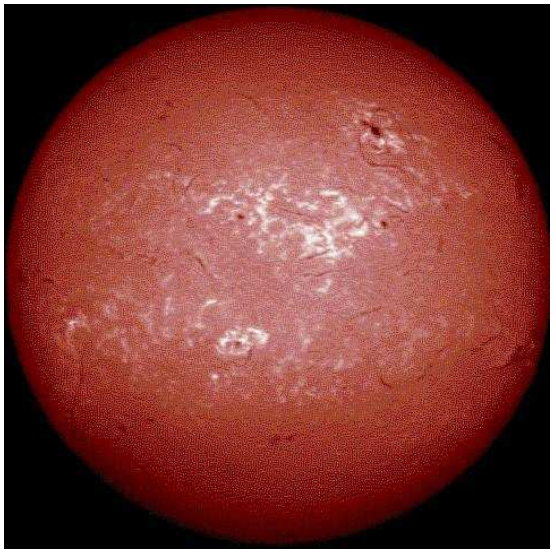
(Johns-Krull & Valenti 1996, ApJL 459
Johns-Krull & Valenti 2000, ASPC 198)

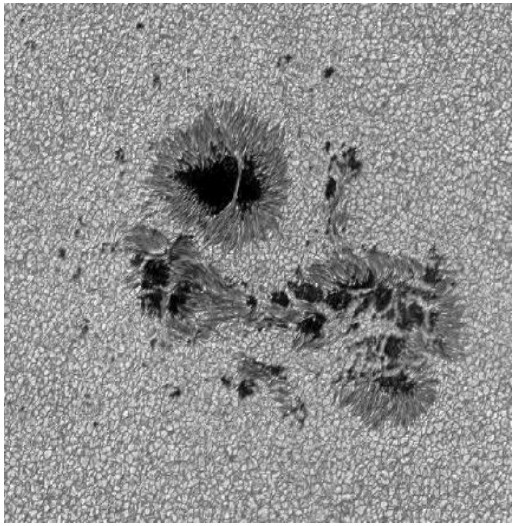
(Reiners & Basri 2010, ApJ 710)

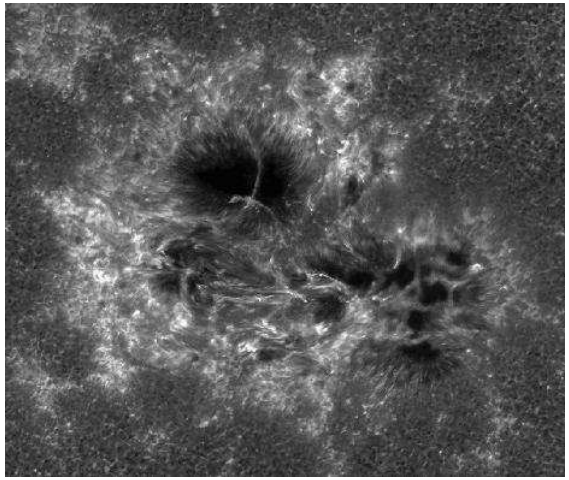
(Freedman, Geller, Kaufmann; Universe)

Solar spots and plages



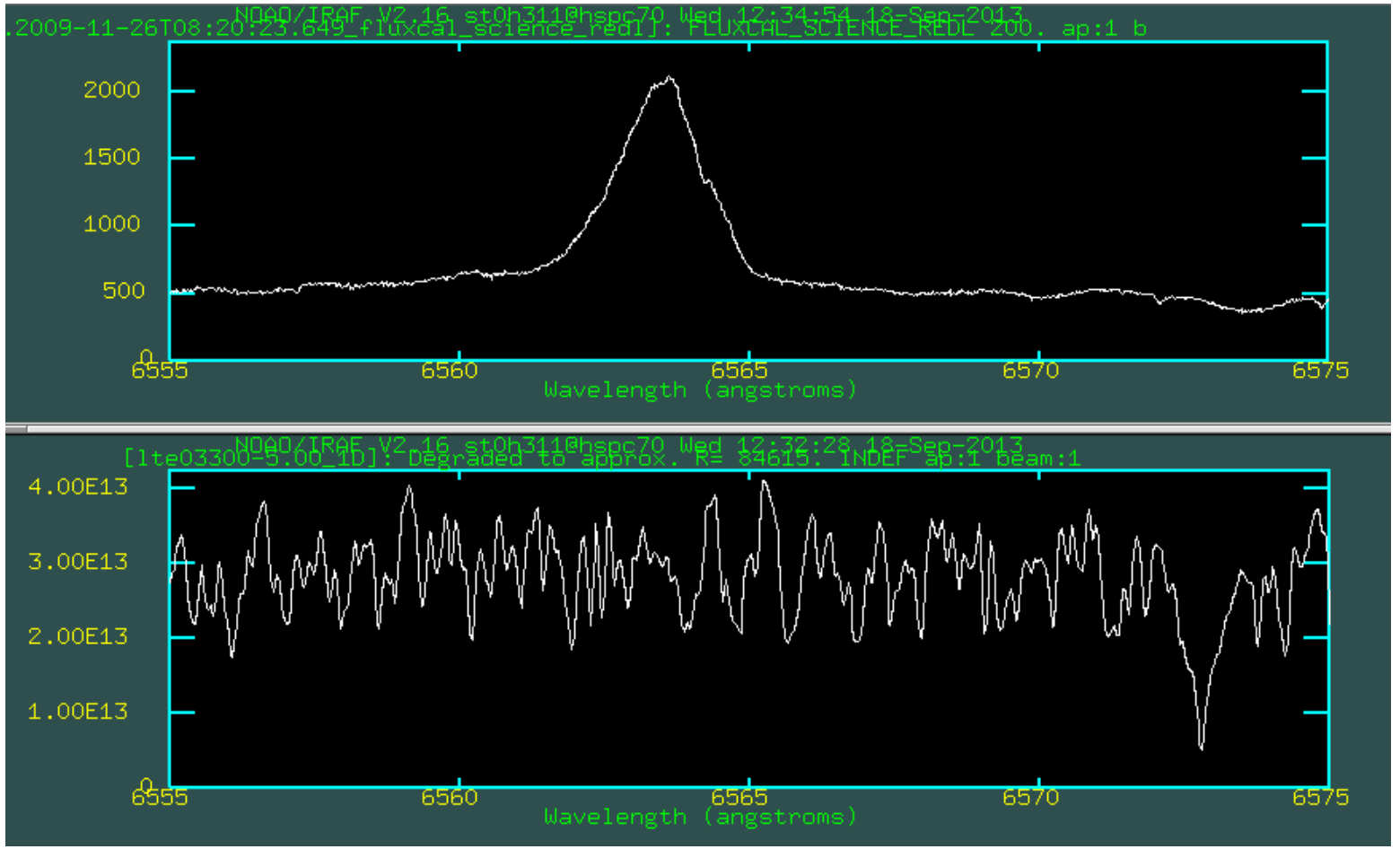






(Big Bear Observatory, Swedish solar telescope, NASA)

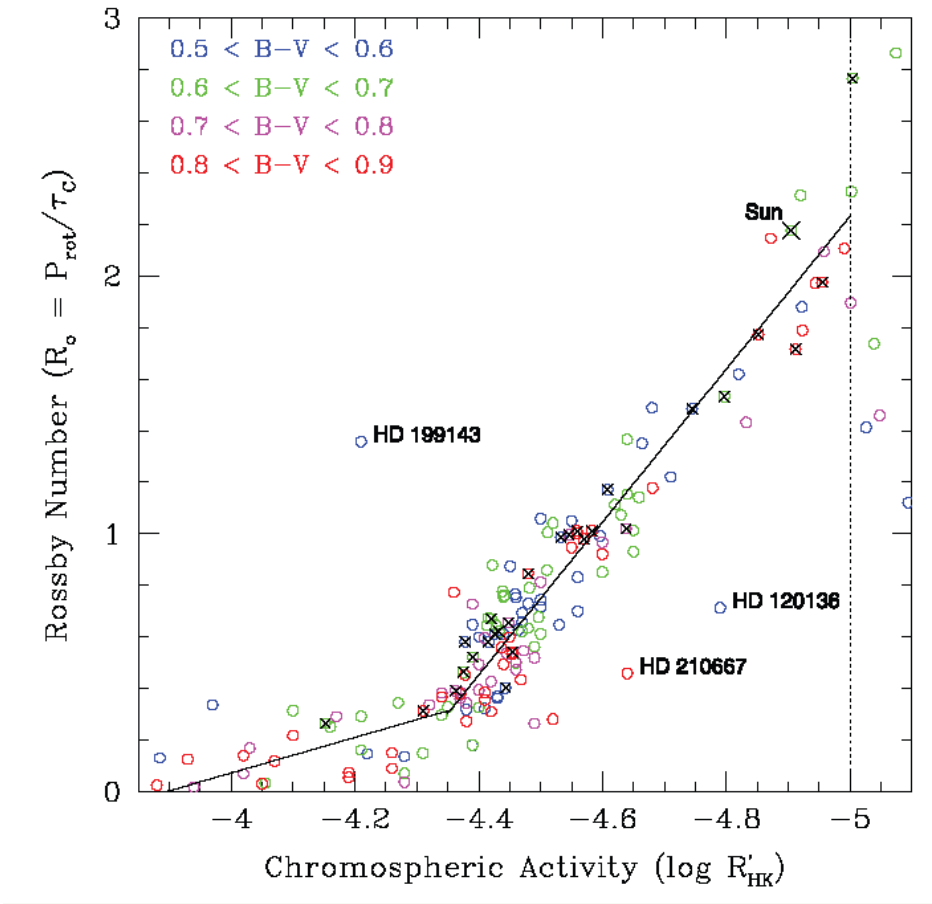
Rotation: The price you pay -- part 2/3: chromospheric emission



Chromospheric emission in Hα 6563 Å

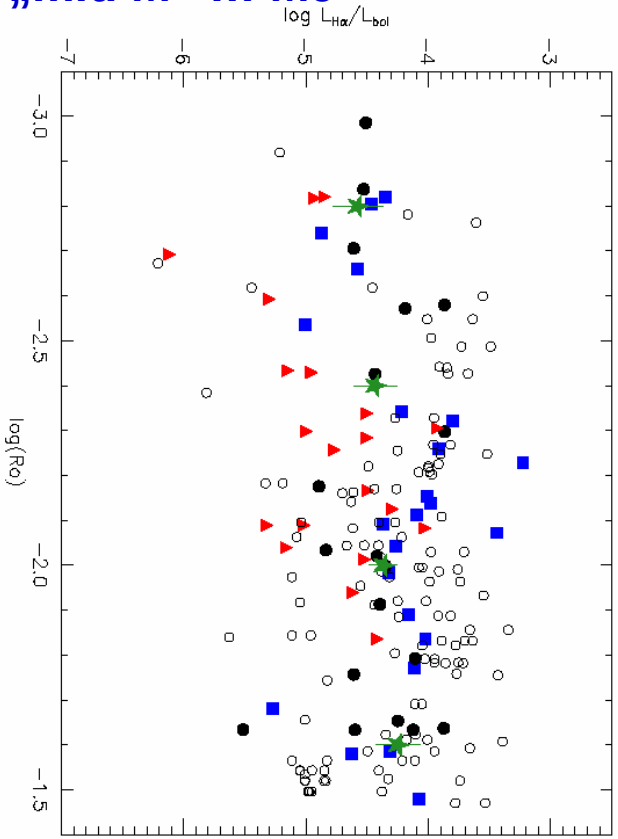
Rotation and activity – looking into the dynamo

F6 … K2



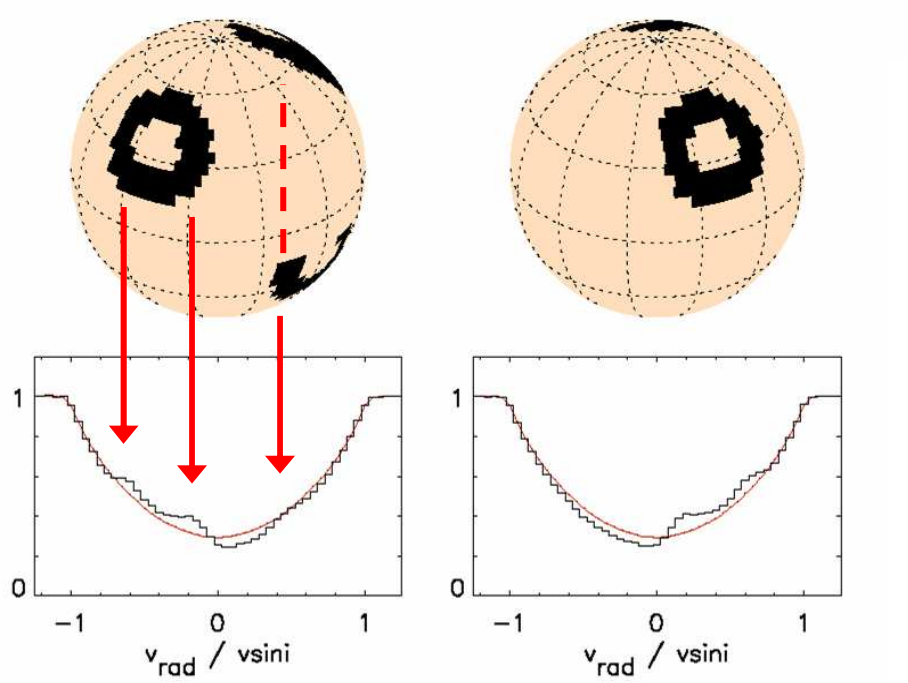
(Mamajek & Hillenbrand 2008, ApJ 687)

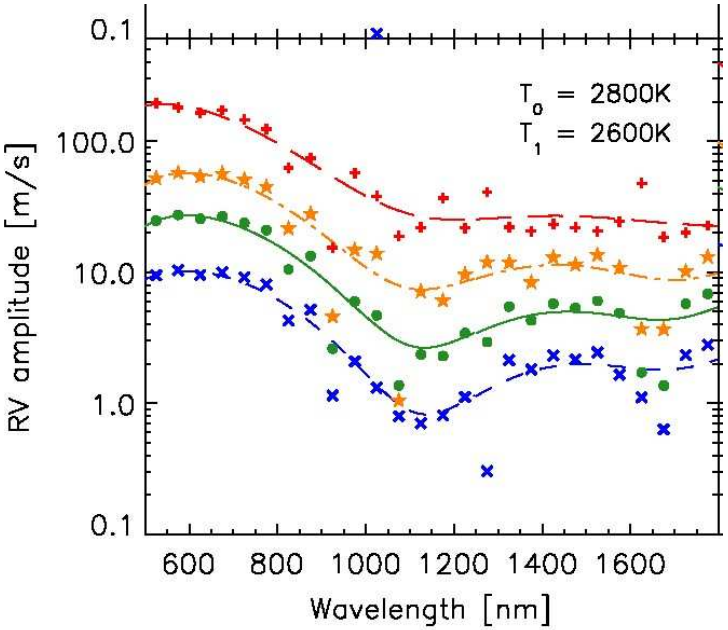
„mid M“ … M9



(Reiners & Basri 2010, ApJ 710)

Rotation: The price you pay -- part 3/3:
Rotational modulation of starspot signatures

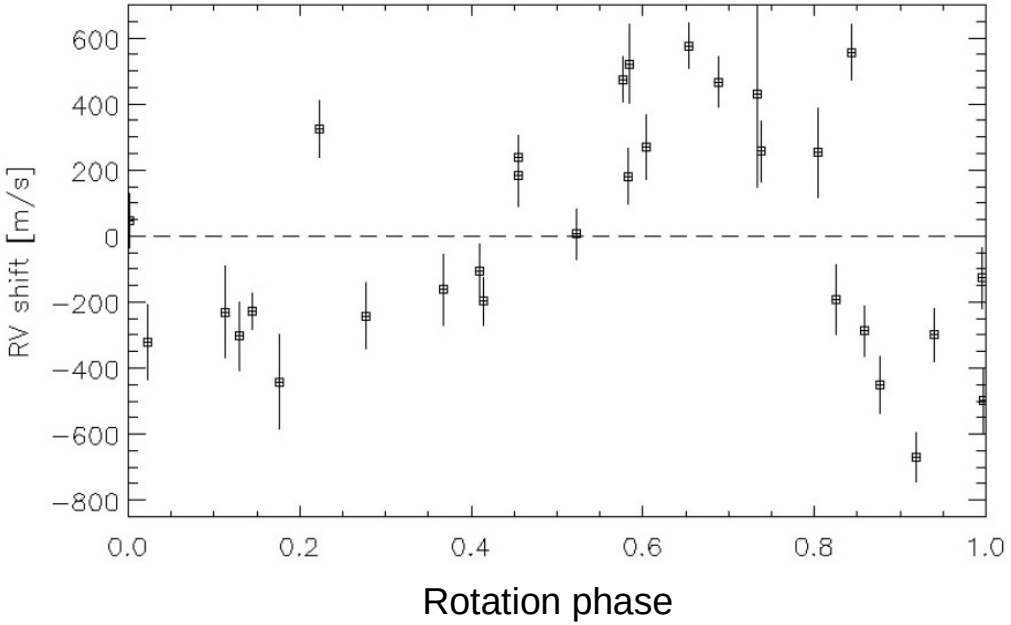


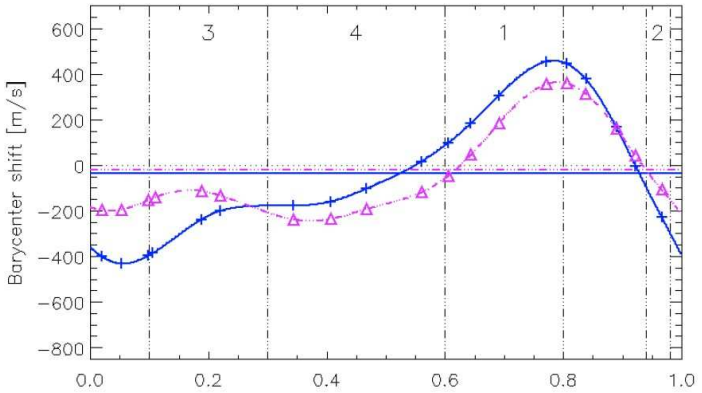


Deutsch 1958, Falk & Wehlau 1974, Goncharski et al. 1982
Vogt & Penrod 1983, Rice, Wehlau & Khoklova 1989
Donati, Semel & Praderie 1989; Piskunov & Kochukhov 1992
Kürster, Schmitt & Cutispoto 1994; Wolter & Schmitt 2005

(Reiners et al. 2010, ApJ 710)

The RV impact of starspots (extreme cases)



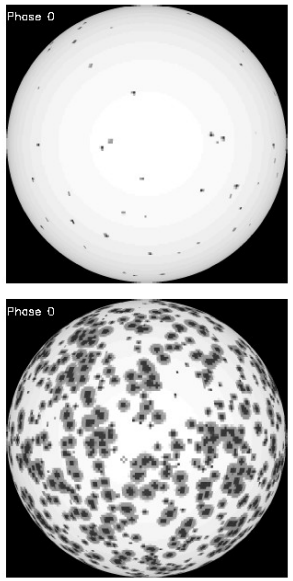


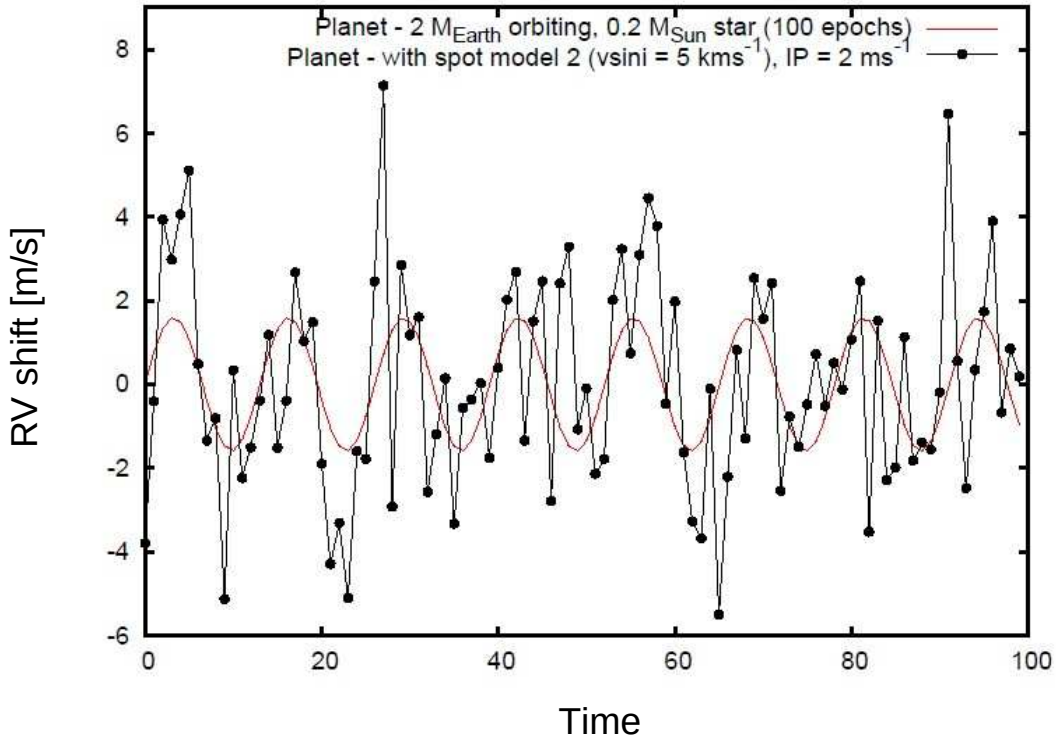
V889 Her (G0V, vsini = 39 km/s)

(Huber et al. 2009, A&A 501)

The RV impact of starspots (moderate cases)

„Solar maximum case“





(Barnes, Jeffers & Jones 2011, MNRAS 412)

Summary

- Host star properties and activitiy are well resolved by CARMENES‘ high resolution & spectral range

- Rotation and activity reduce achievable RV precision

- Think of activity, binaries, telluric features, **etc.** !