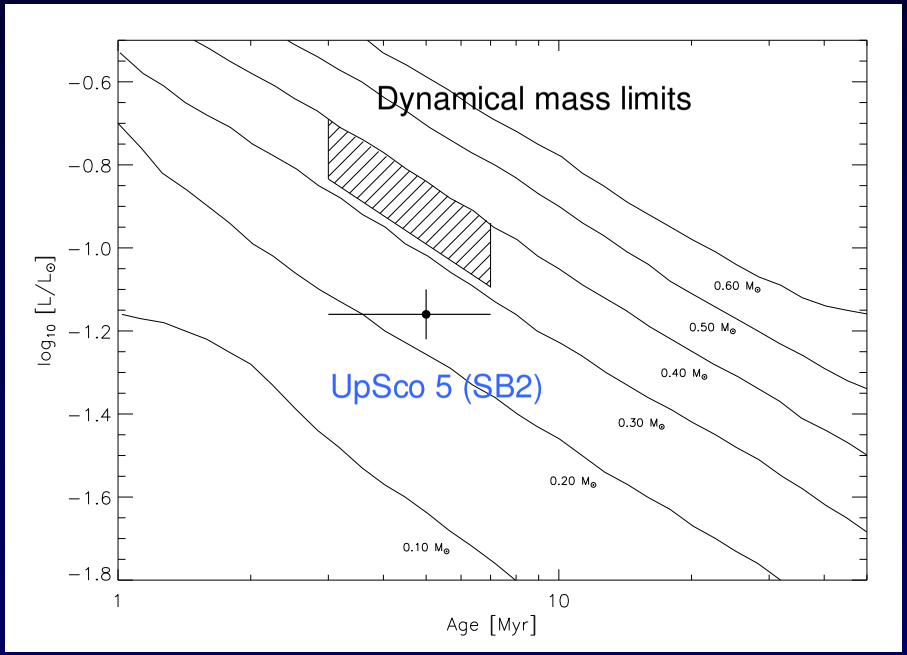
Calibrating models of ultra low-mass stars

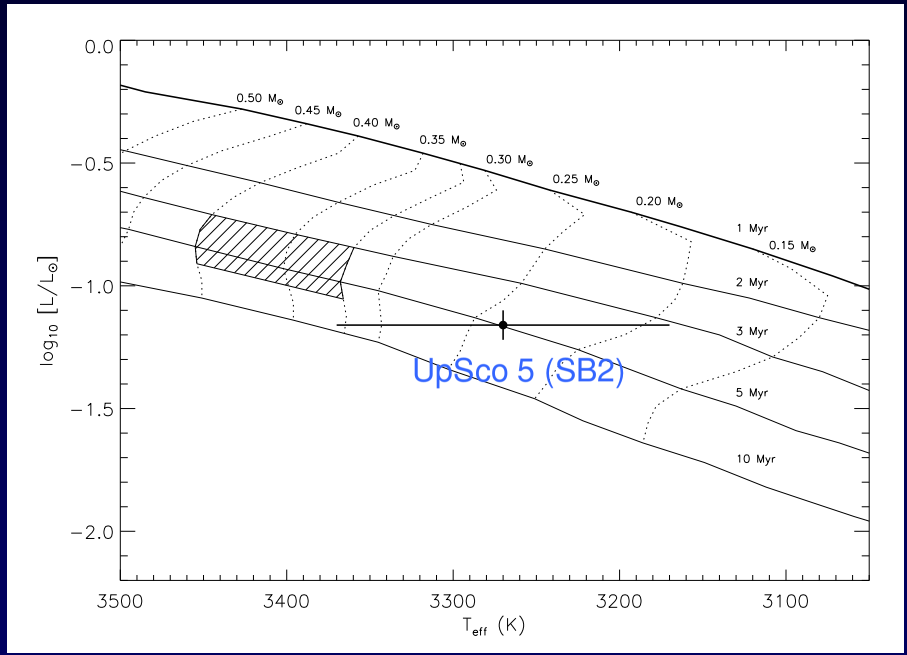
Ansgar Reiners
University of California, Berkeley
Hamburger Sternwarte

European Commission - Marie Curie Actions

Gibor Basri (UCB), Subhanjoy Mohanty (CfA), Peter Hauschildt (HStwB)

Calibrating models in luminosity, temperature, radius, and mass is one of the critical problems facing studies of ultra low-mass forming objects





(Reiners, Basri & Mohanty, ApJ, accepted)

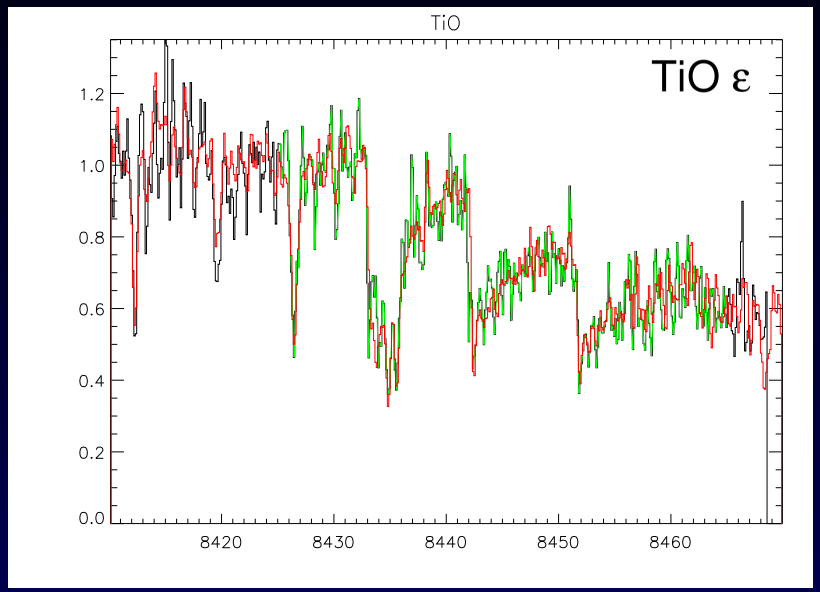
Deriving Fundamental Physical Parameters

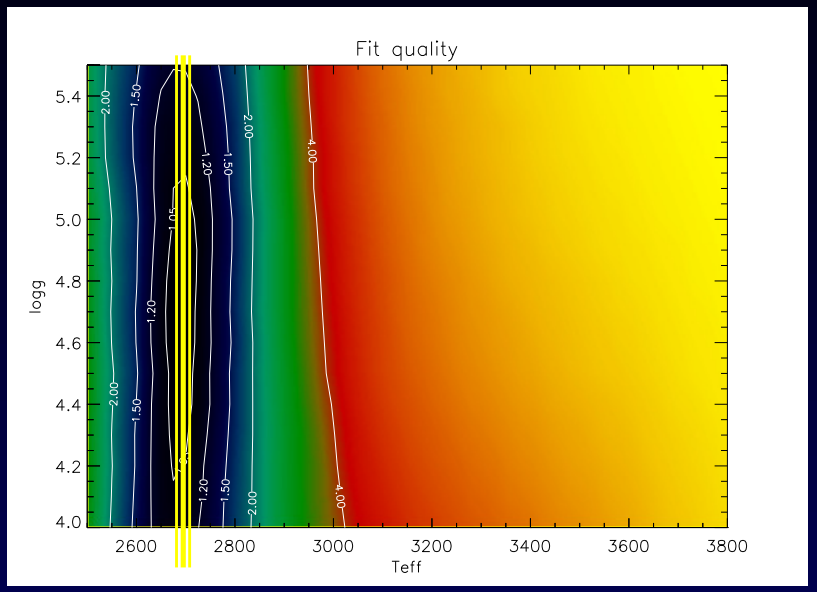
Radius, Mass and *Luminosity* can be derived
from photometry and parallax,
if temperature and surface gravity are known.

T_{eff} can be derived from SEDs,
but is only marginally sensitive to log(g)

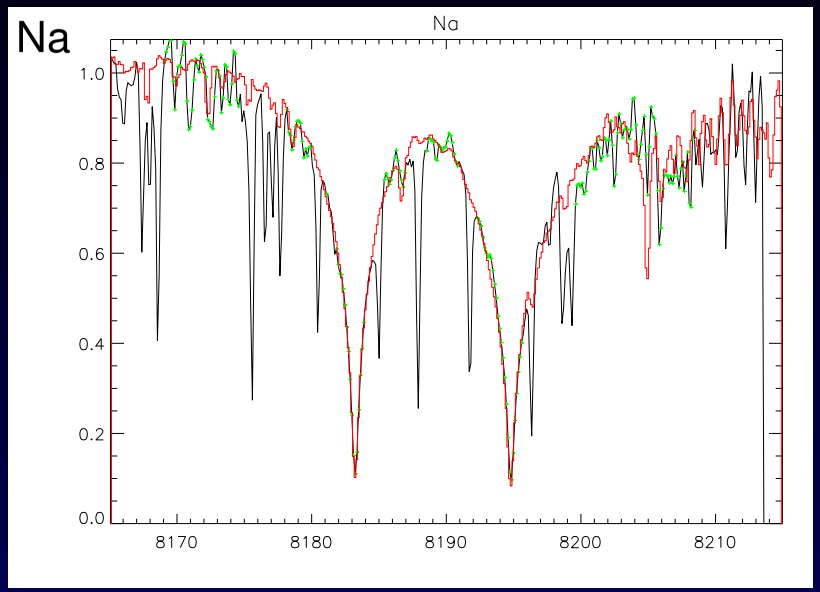
In principle, T_{eff} and log(g) can be determined from high resolution spectra, since atomic lines and molecular bands are very sensitive to T_{eff} and log(g)

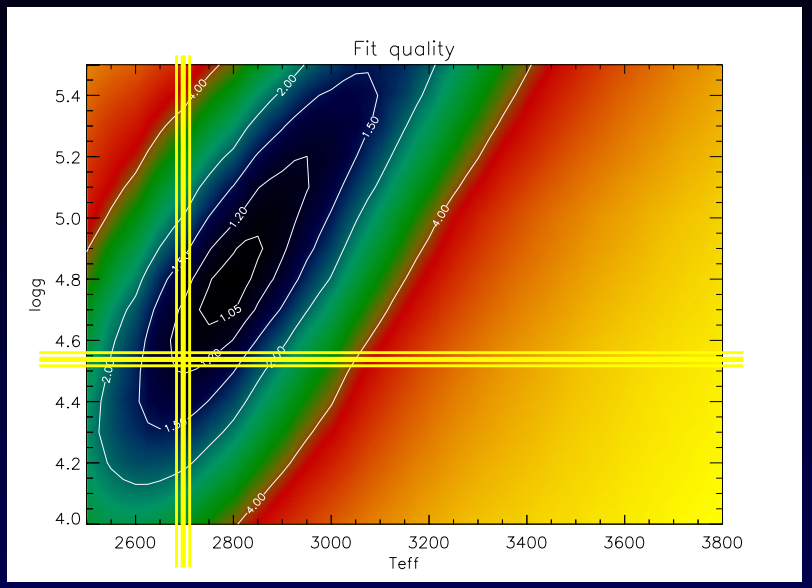
Get temperature from TiO

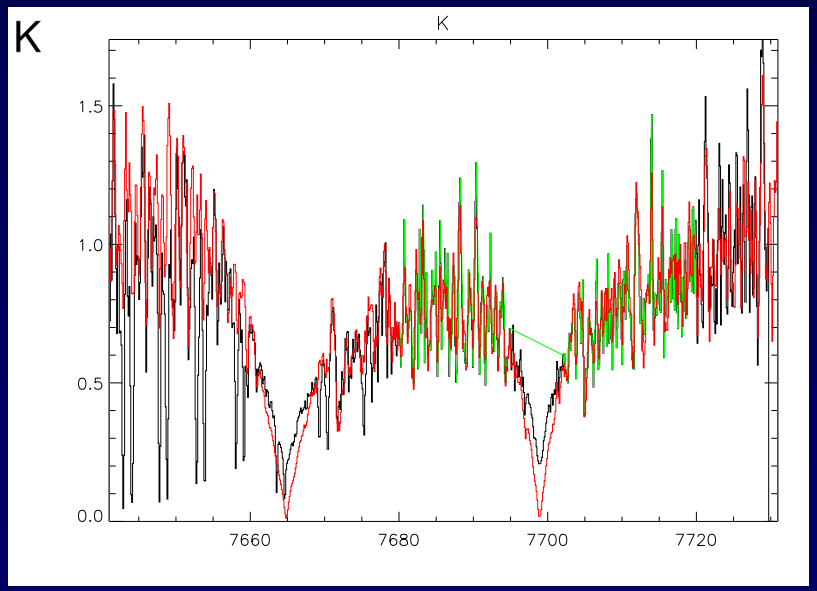


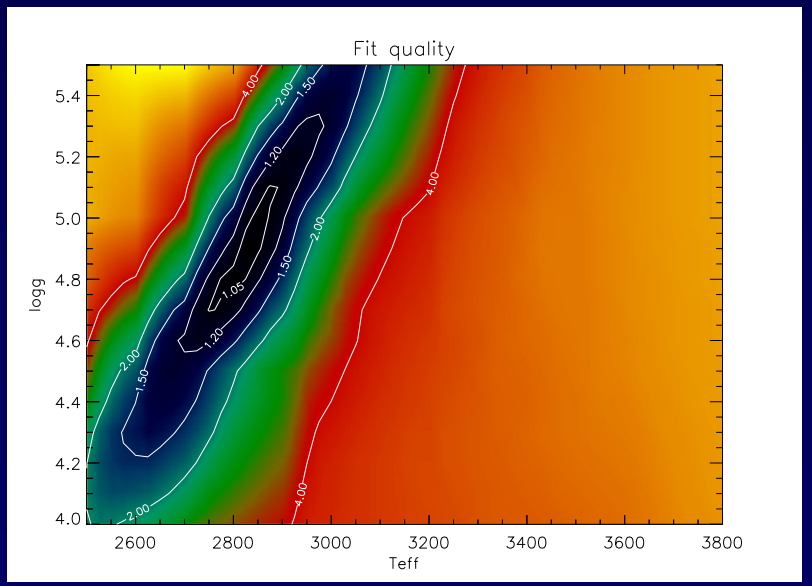


Temperature / gravity sensitivity in K and Na

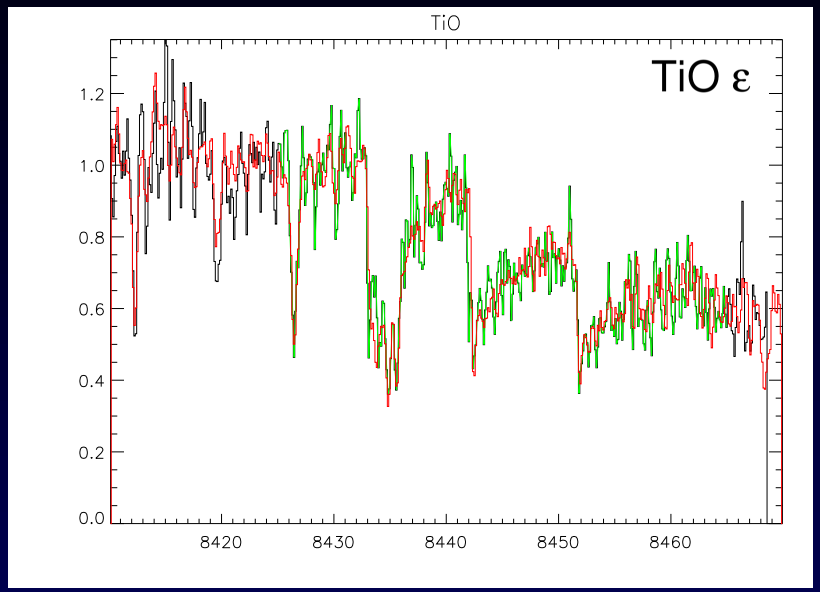


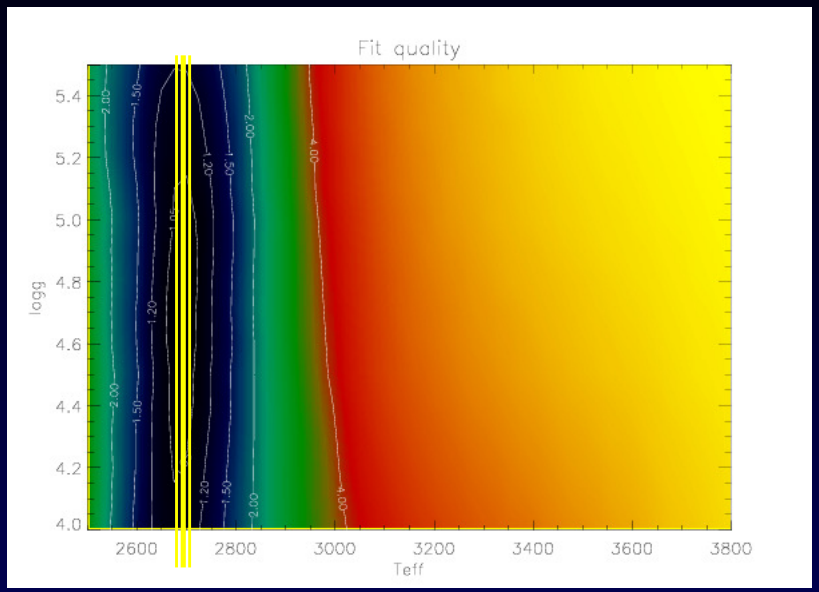


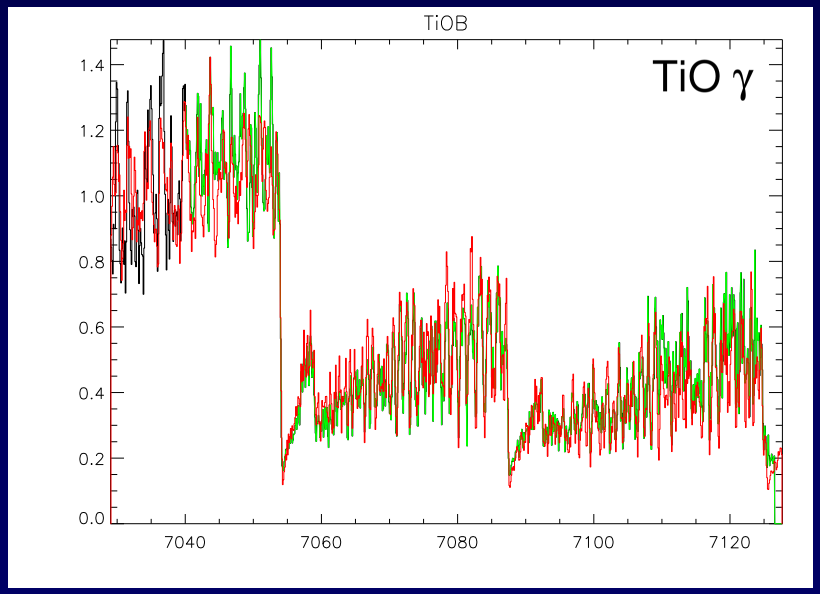


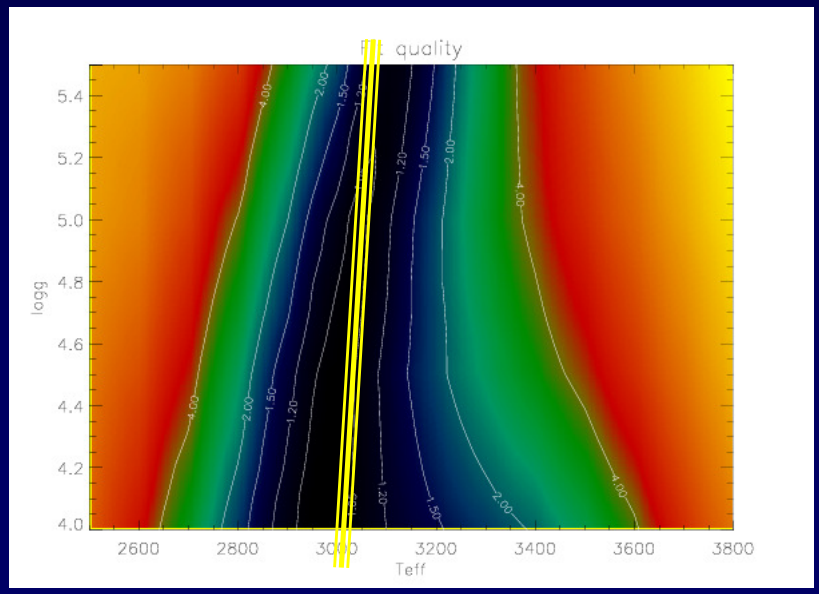


Temperature from TiO, but…





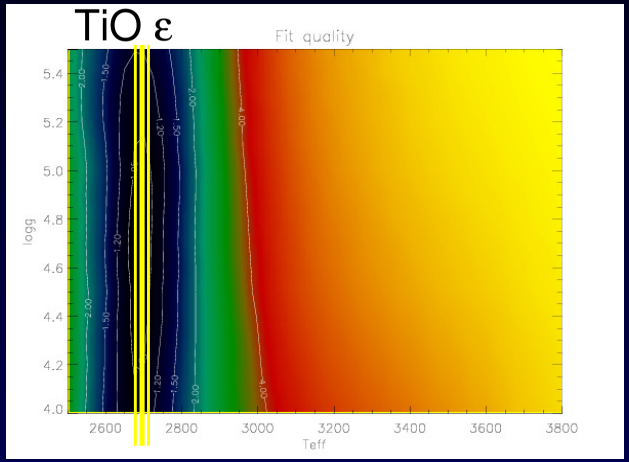


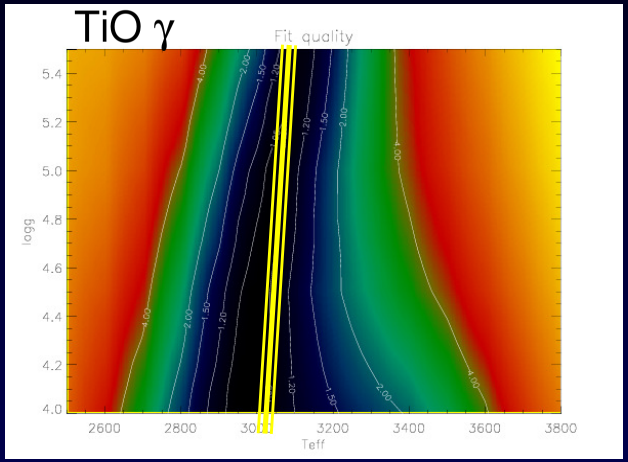


Temperatures from TiO-bands at
7040Å (γ-band) and 8450Å (ε-band)
are inconsistent in current models!

Temperatures from model TiO-bands…

T_{eff} = 2700K

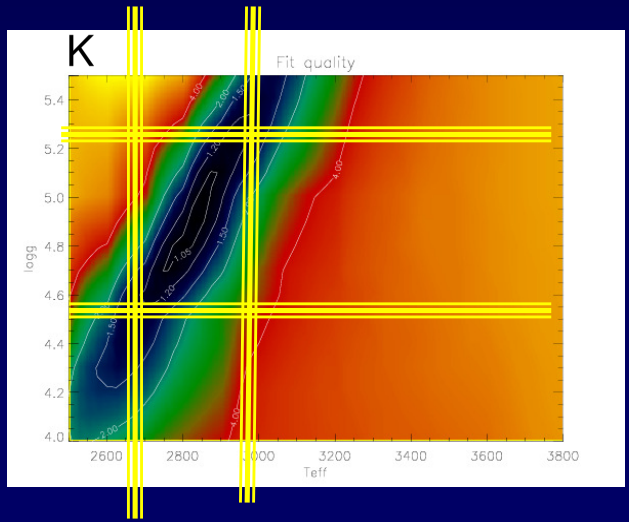




T_{eff} = 3000K

…also determine the gravity.

log(g) = 4.6



log(g) = 5.2

Temperature (and thus gravity) from the two TiO-bands are significantly different!

Calibrate TiO-band strengths using stars for which T_{eff} and log(g) are known.

Calibrator Stars have become available from interferometric radius measurements:

Star	other name	Sp Type	T_{eff}	log(g)	[Fe/H]	Data Source
GJ 191	Kapteyn's Star	M1V	3570 ± 156*	4.96 ± 0.13*	-0.86*	ESO-Archive
GJ 205	HD 36395	M1.5V	3520 ± 170*	4.54 ± 0.06*	-0.45*	ESO-Archive
GJ 411	HD 95735	M2V	3570 ± 42*	4.85 ± 0.03*	-0.40*	Hamilton
GJ 699	Barnard's Star	M4V	3134 ± 102*	5.04 ± 0.10*	-0.75*	ESO-Archive
GJ 551	Proxima Cen	M5.5V	3042 ± 117*	5.20 ± 0.23*	≥0.0	ESO-Archive

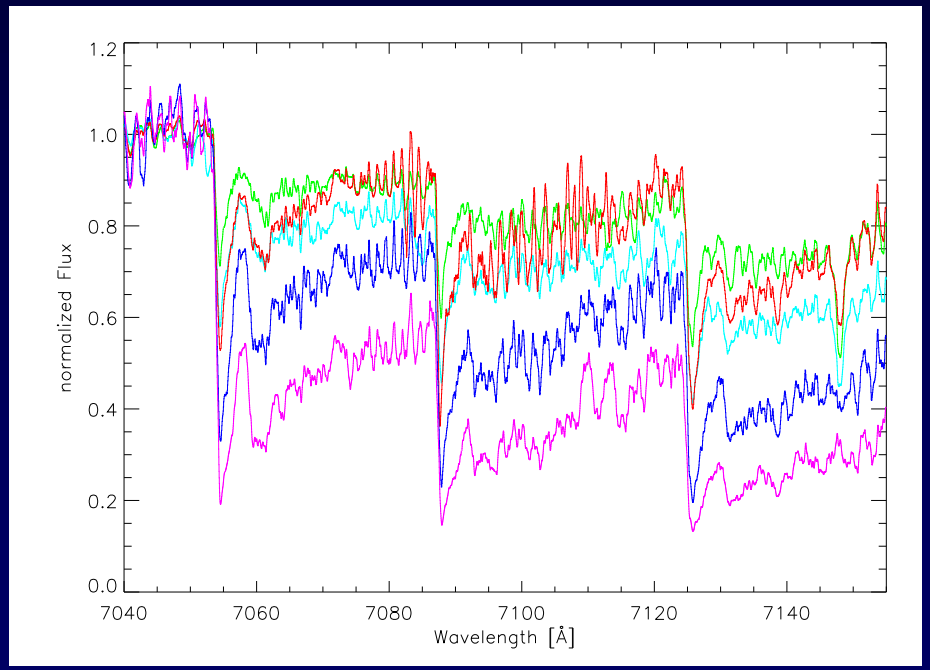
*Ségransan et al., 2003

*Dawson & Robertis, 2004

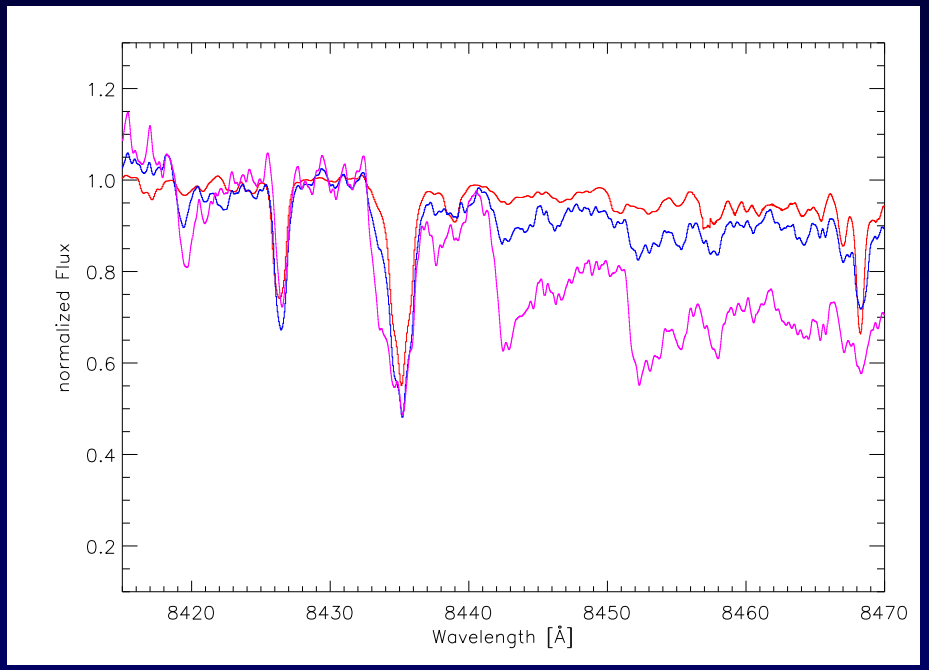
*Woolf & Wallerstein, 2005

Calibration sequence in both TiO-bands

Star	Sp Type	T_{eff}	logg	[Fe/H]
GJ 191	M1V	3570	4.96	-0.86
GJ 205	M1.5V	3520	4.54	-0.45
GJ 411	M2V	3570	4.85	-0.40
GJ 699	M4V	3134	5.04	-0.75
GJ 551	M5.5V	3042	5.20	0.0



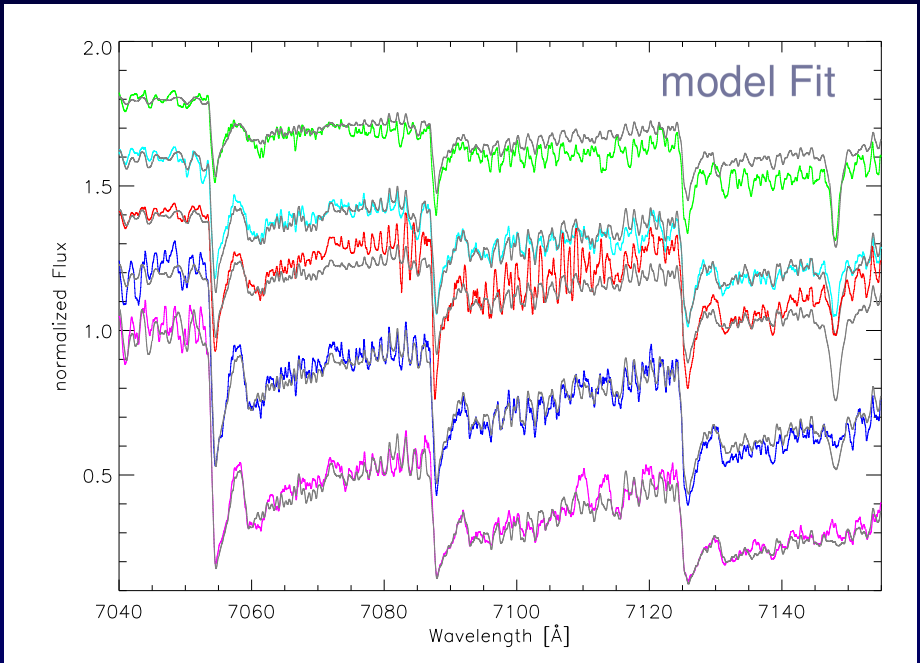
γ-Band

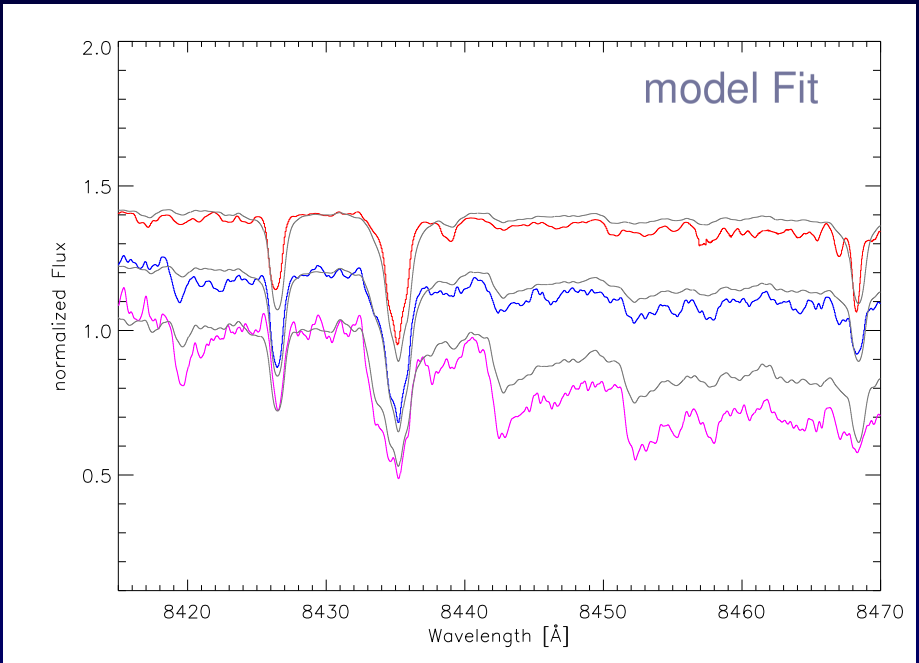


ε-Band

Model fits using PHOENIX spectra

Star	Sp Type	T_{eff}	logg	[Fe/H]
GJ 191	M1V	3570	4.96	-0.86
GJ 205	M1.5V	3520	4.54	-0.45
GJ 411	M2V	3570	4.85	-0.40
GJ 699	M4V	3134	5.04	-0.75
GJ 551	M5.5V	3042	5.20	0.0



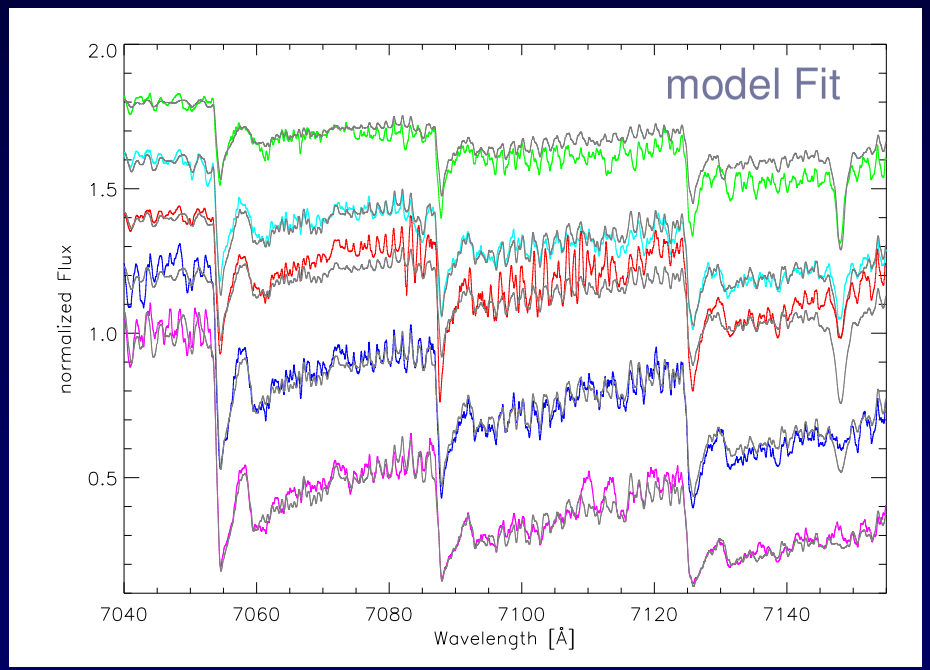


γ-Band fits!

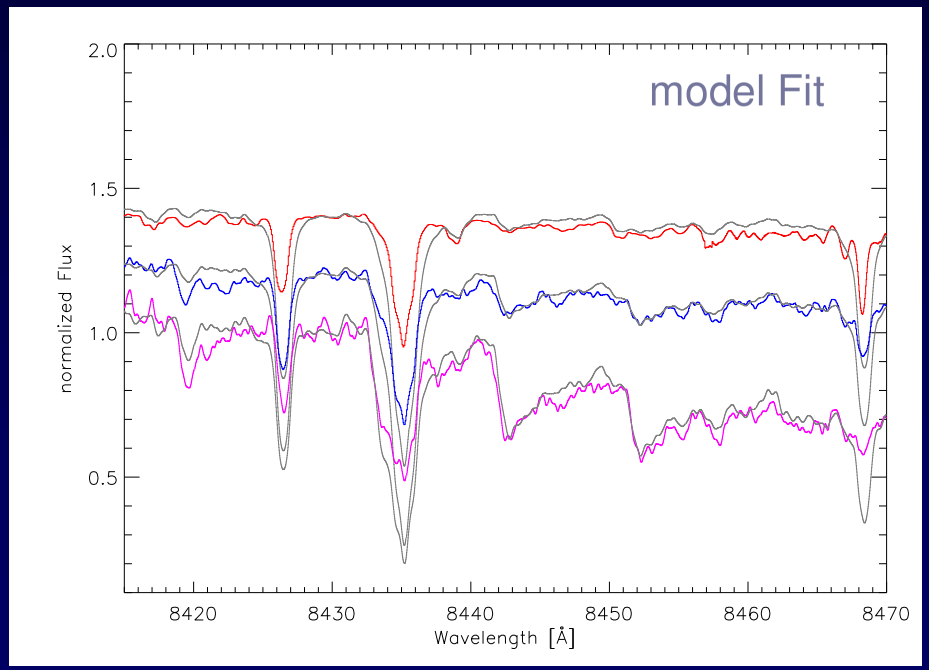
ε-Band is systematically too weak

Consistency achieved with “modified oscillator strength”

Star	Sp Type	T_{eff}	logg	[Fe/H]
GJ 191	M1V	3570	4.96	-0.86
GJ 205	M1.5V	3520	4.54	-0.45
GJ 411	M2V	3570	4.85	-0.40
GJ 699	M4V	3134	5.04	-0.75
GJ 551	M5.5V	3042	5.20	0.0



γ-Band



ε-Band

$f_{el,new} \approx 1.7 * f_{el,old}$

Stronger TiO-band at 8450 Å

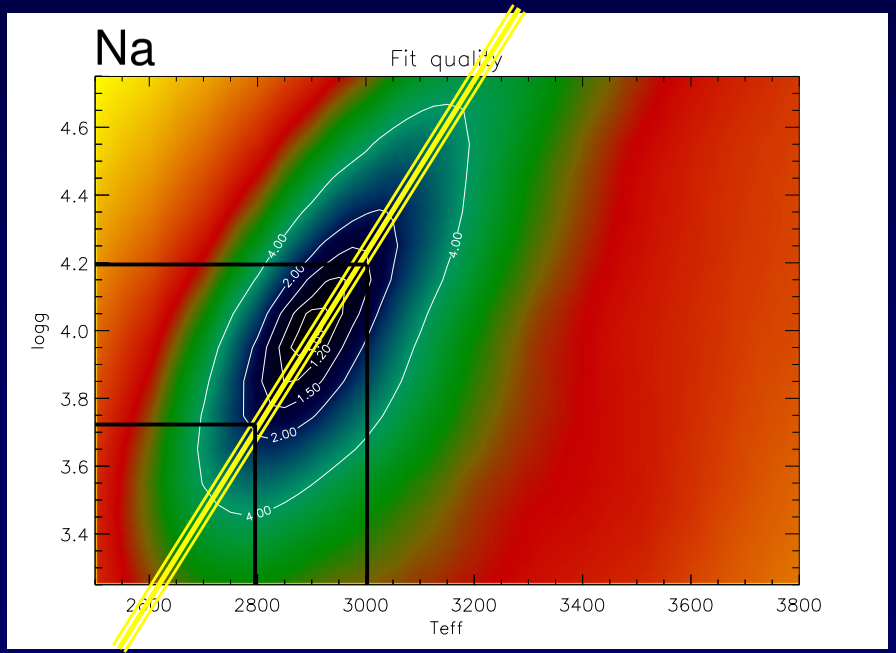
⇓

$T_{eff} \approx 150 - 200$ K higher in young objects

⇓

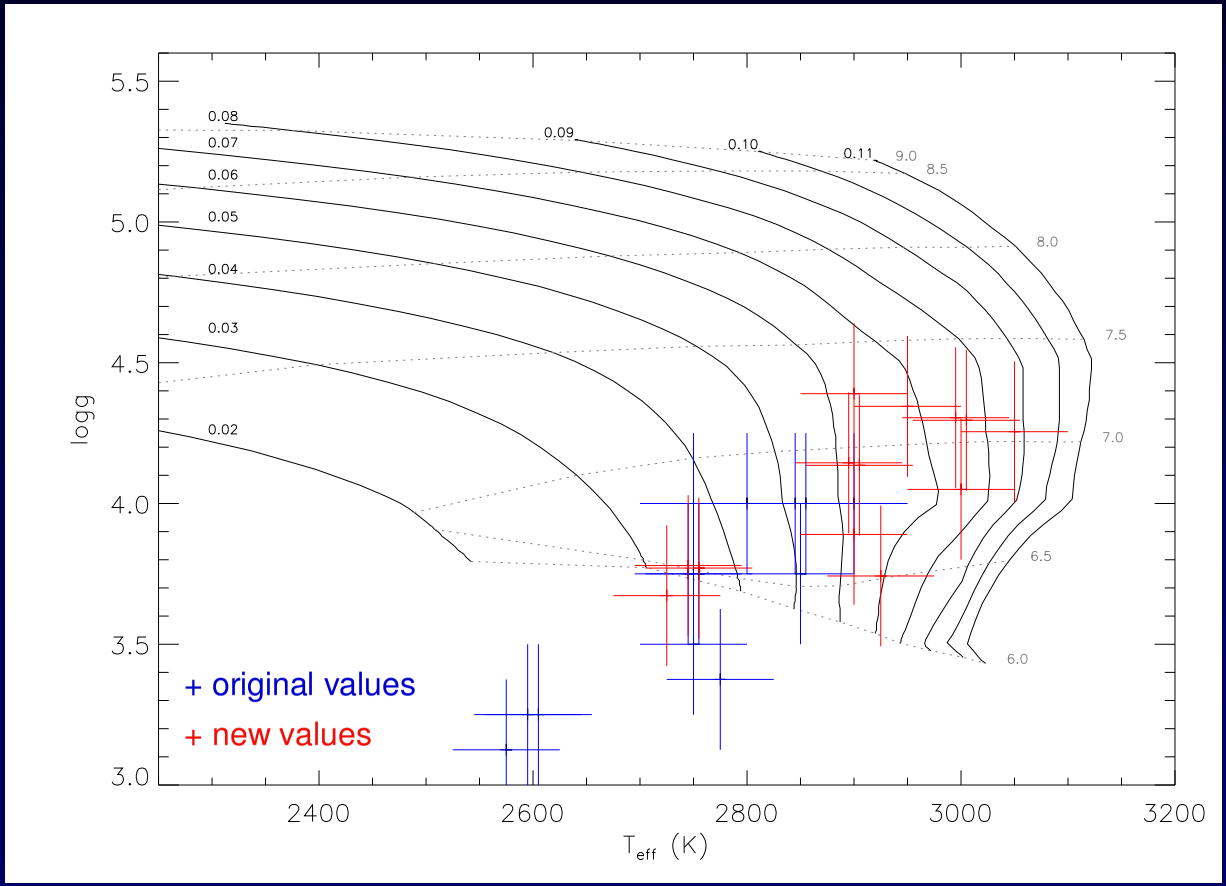
log(g) from Na (and K) changes as well

Δ log(g) ≈ 0.4

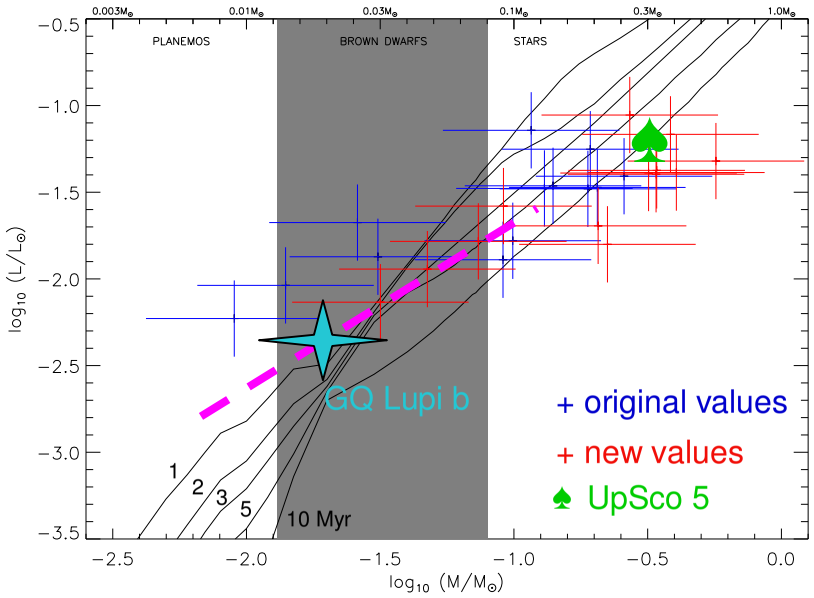


How does this change recent results?

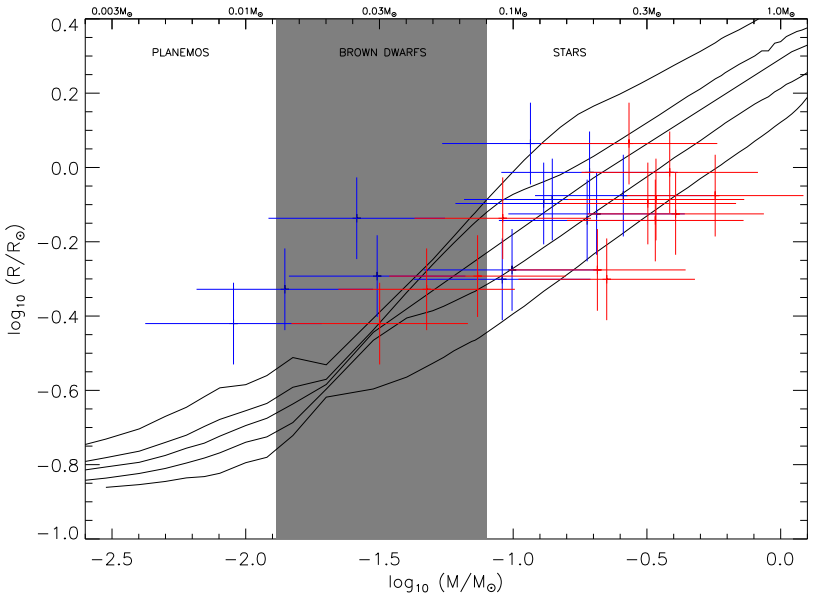
UpSco sample (~ 5 Myr)
(Mohanty et al., 2004)



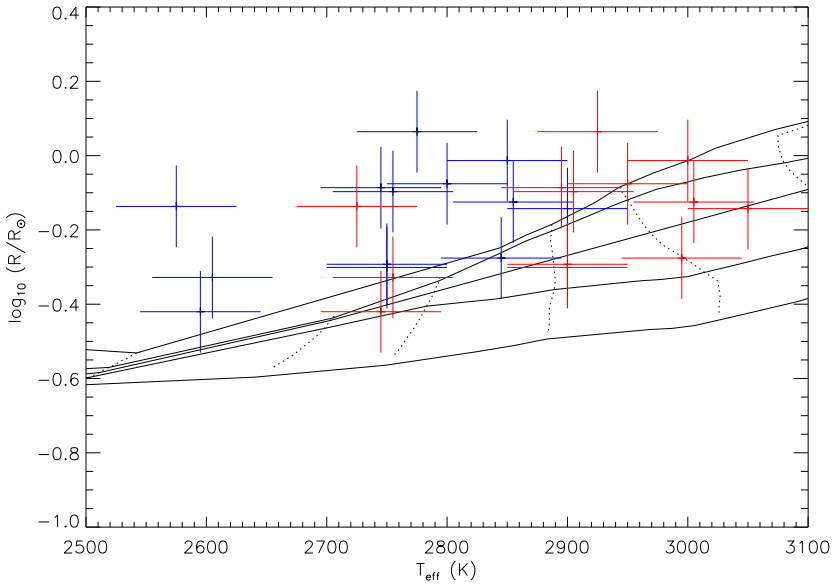
Luminosity / Mass



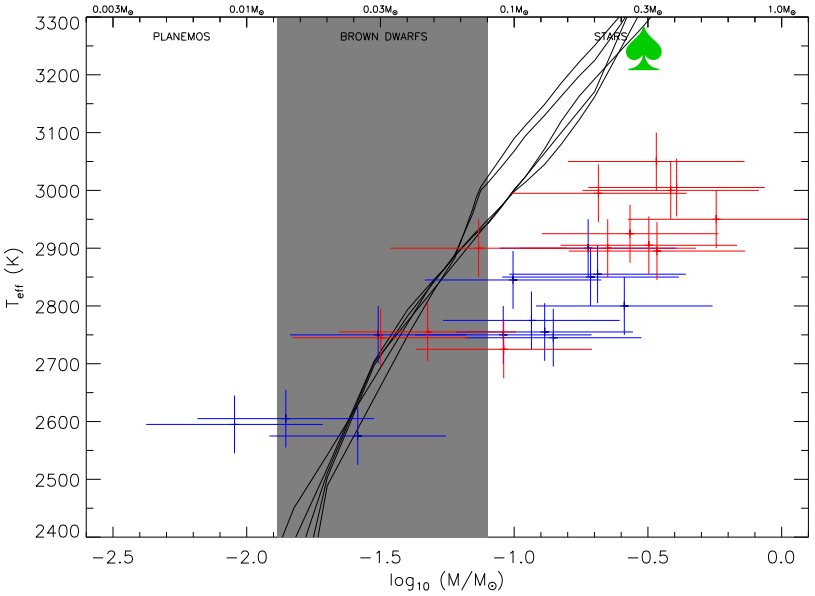
Radius / Mass



Radius / T_{eff}



T_{eff} / Mass



Conclusions

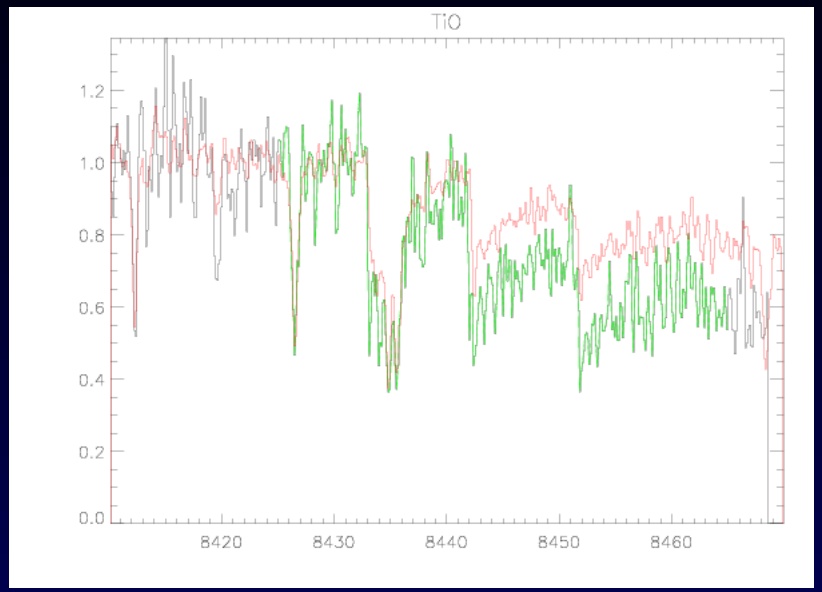
- Band strengths of TiO are inconsistent in current models
- The oscillator strength f_{el} of the ε-band (8450Å) has to be enhanced by $\approx$ 70% - this is consistent with calculations of f_{el} and gives better agreement to laboratory experiments
- Temperatures derived from the ε-band are then higher by $\approx$ 200K
- A first estimate shows that gravities derived from Na and K may be higher by about 0.4 dex
- Discrepancies between evolutionary models and spectroscopically derived parameters become smaller at very low masses (~M8), but too high masses may be derived for the hotter objects (~M5) – improved by the new grid of models?

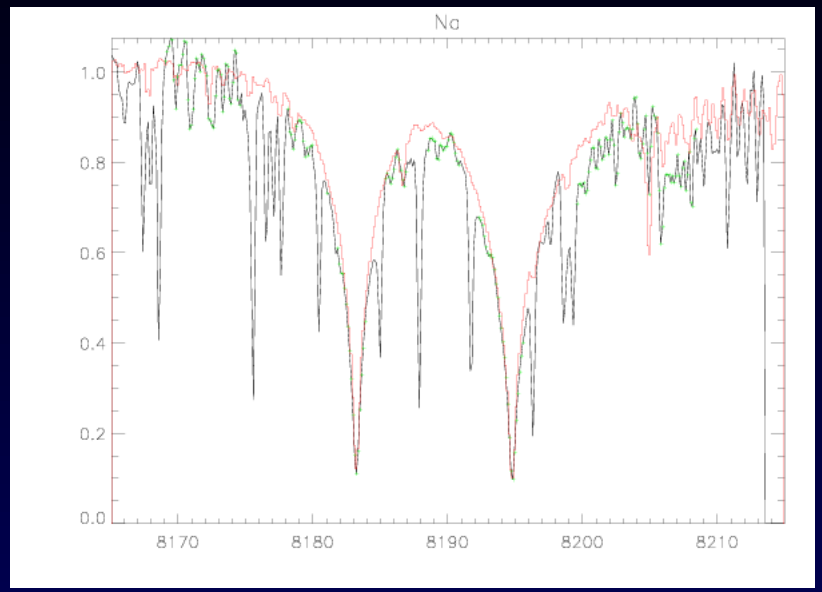
TiO oscillator strengths

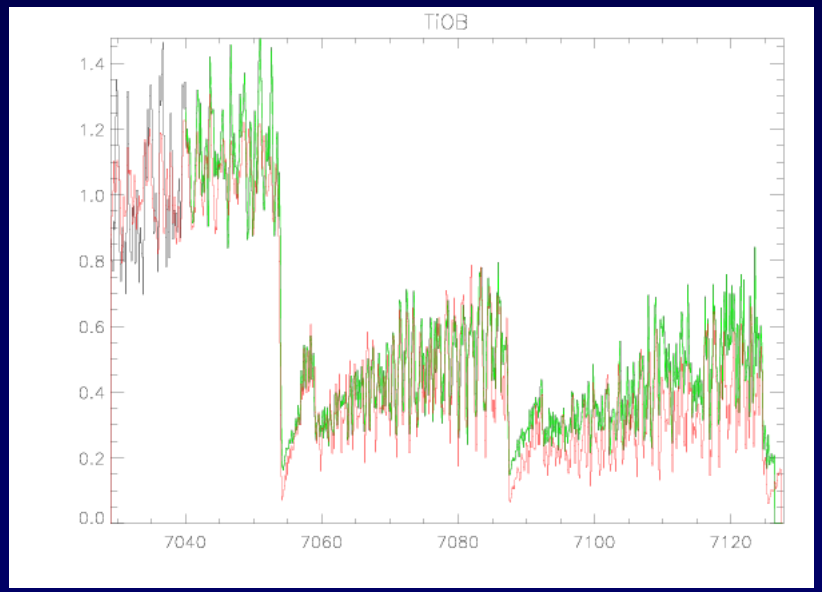
System	λ	B90 giant SEDs	J94/HNC95 laboratory	DLP86 sunspots	LP97 ab initio	AP98	adopted
α	5170.7	0.10	0.17	0.106	0.105	0.106	0.105
β	5605.2	0.15	0.28	0.125	0.176	0.125	0.176
γ'	6192.5	0.08	0.14	0.0935	0.108	0.0935	0.108
γ	7095.8	0.09	0.15	0.0786	0.092	0.0786	0.092
ε	8407.6	0.0024	0.014	<0.006	0.002	0.0023	0.002
δ	8870.9	0.02	0.048		0.096	0.048	
Φ	11044.8	0.02	0.052		0.018	0.0178	0.052

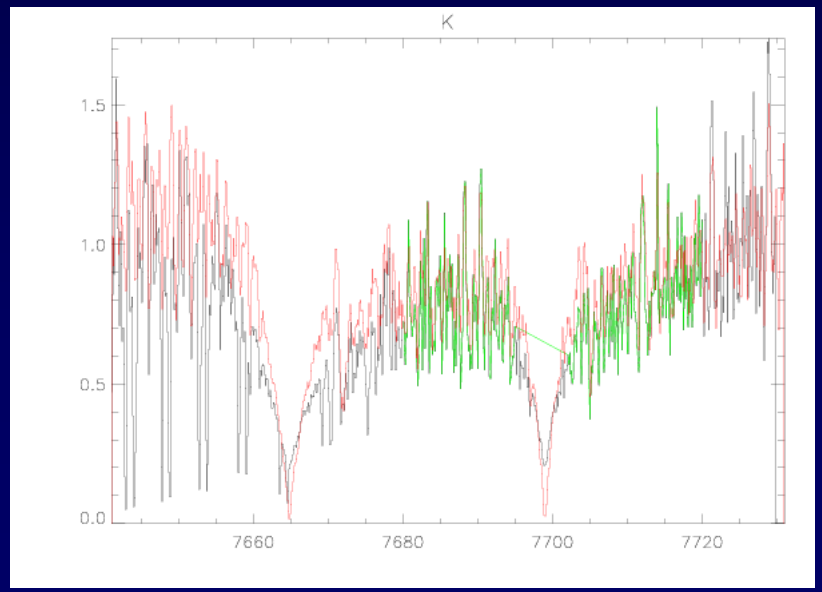
Allard, Hauschildt & Schwenke, 2000

Best simultaneous fit to CN Leo (M6)







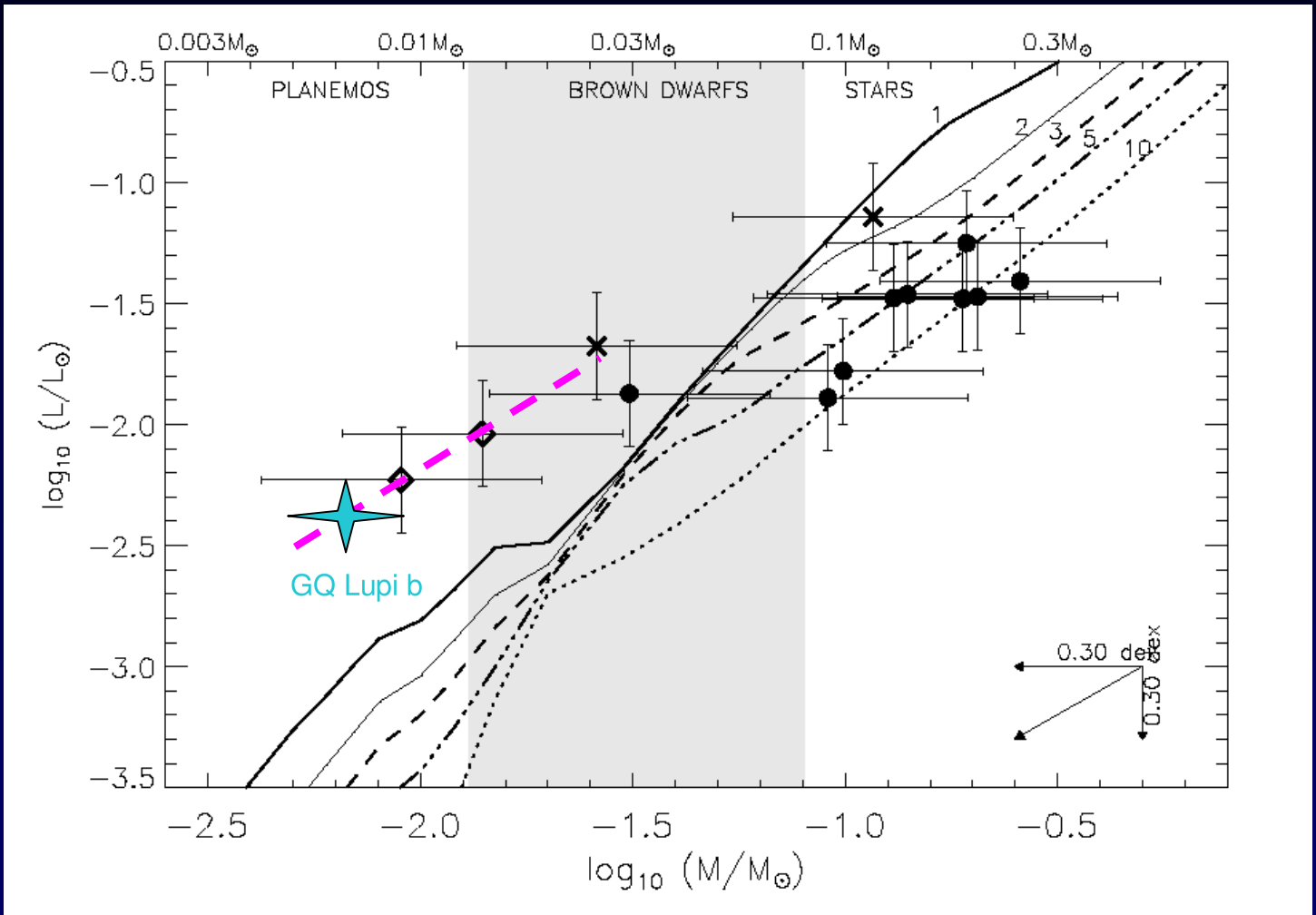


Deriving Temperature and Gravity *spectroscopically*

1. Find an *effective temperature* from TiO bands, which only depend on temperature

2. Find *surface gravity* from K/Na lines, which are degenerate in T_{eff} and log(g)

Spectroscopically derived fundamental parameters in UpSco



Mohanty et al., 2004