Spectroscopic analysis of giants and red supergiants

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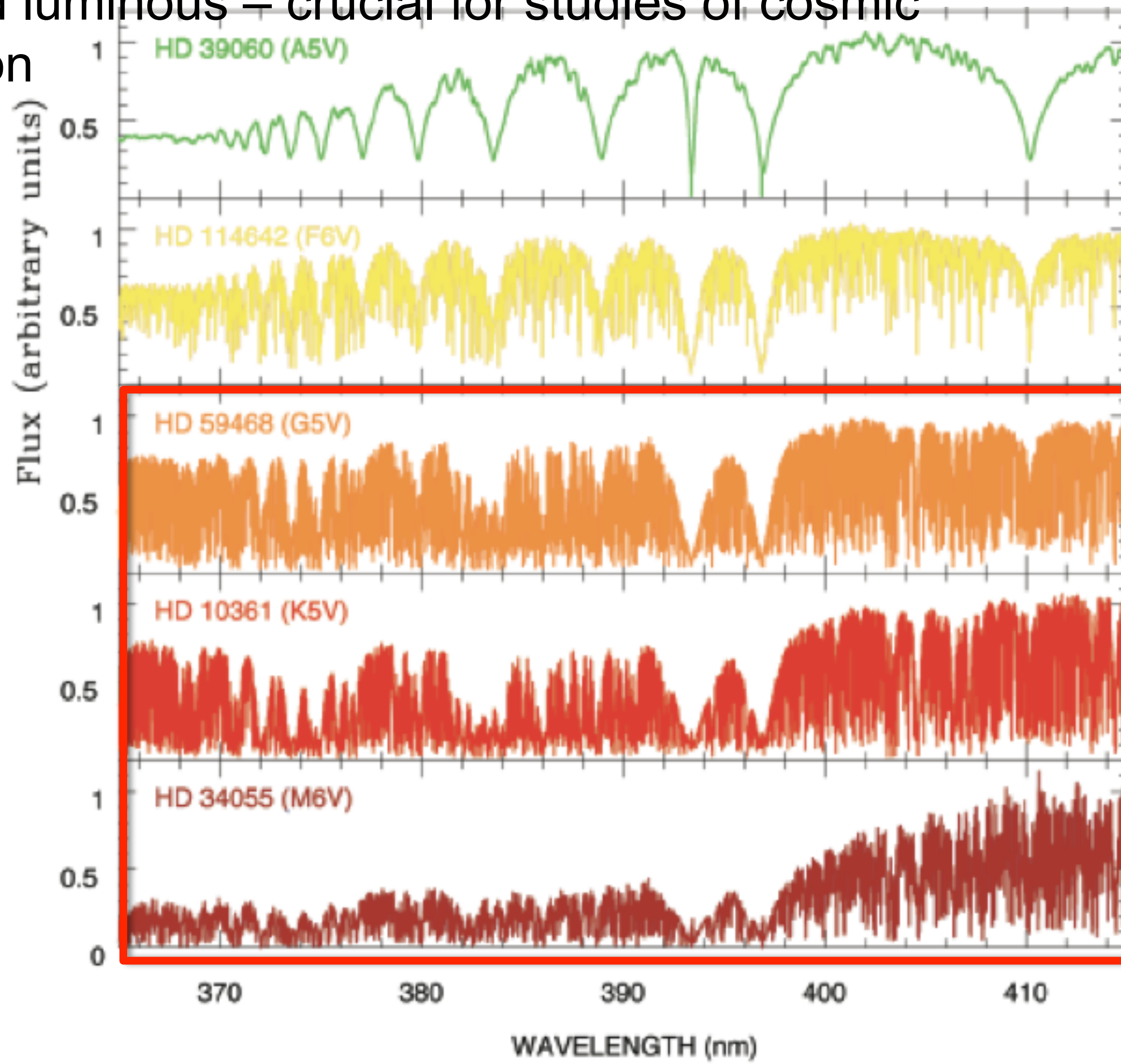
Red giants, AGB, Red Supergiants (RGB)

L: 10 - 10^3 $L_\odot$ … 10^2 - 10^3 … 10^4 - 10^6

extremely bright and luminous – crucial for studies of cosmic chemical composition



Red giants

- low-mass, $M < 2\ M_{Sun}$
- old → trace composition of the ISM **now and in the past**

- T_{eff} : 4500 ... 5500
- $L \sim 10 - 10^3\ L_\odot$

luminous → can be observed across the Milky Way and its satellites

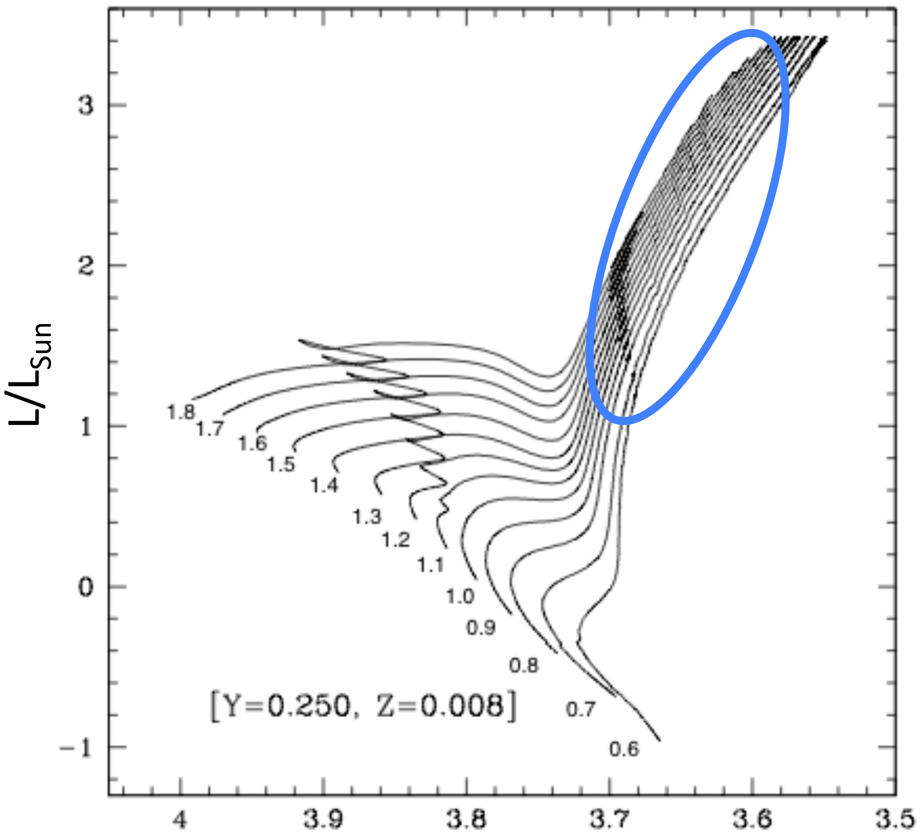


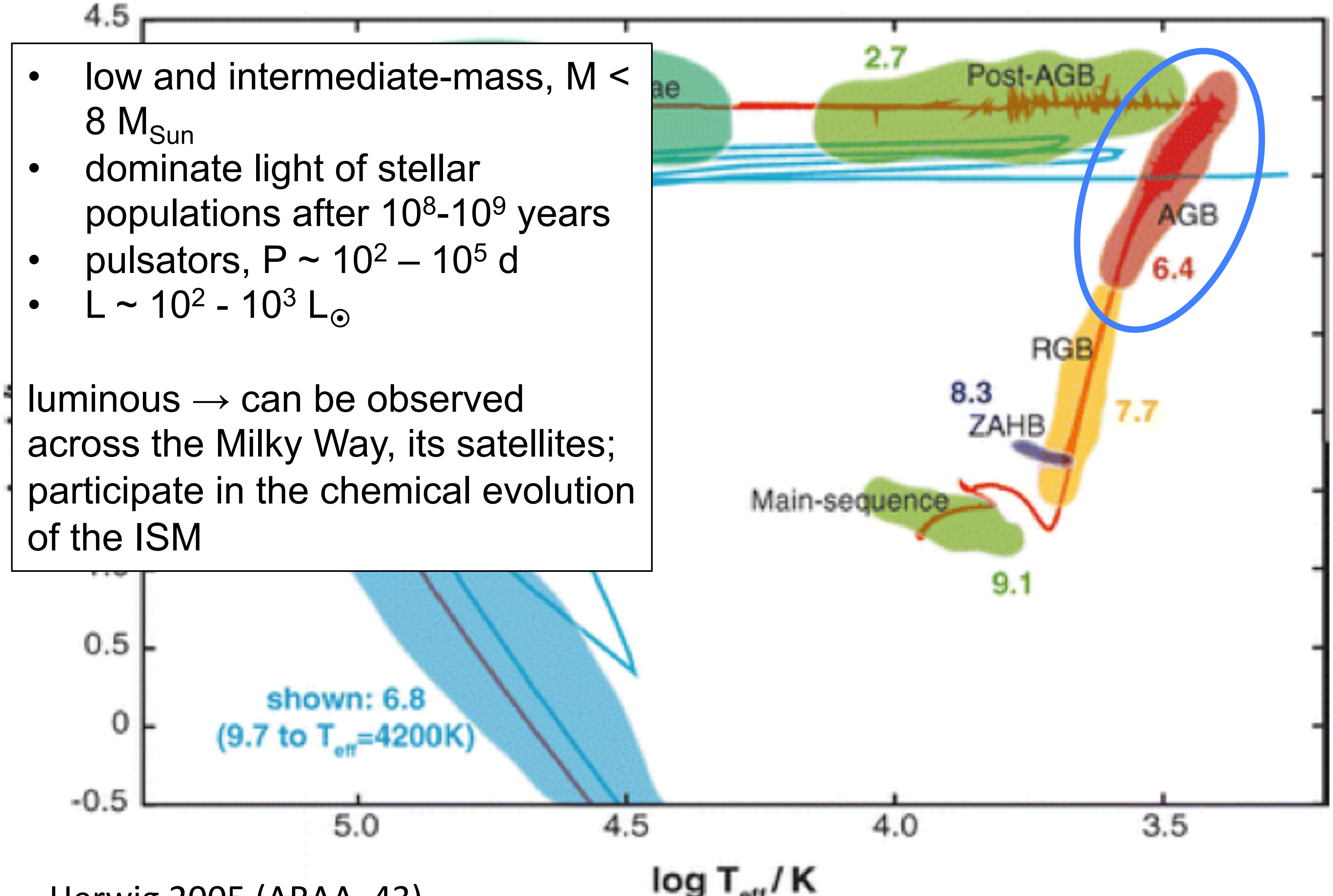
Fig. 5. Evolutionary tracks (same composition as Fig. 4) for low-mass models up to the RGB-tip.

Salasnich et al. (2000)

Asymptotic giant branch (AGB)

- low and intermediate-mass, $M < 8\ M_{Sun}$
- dominate light of stellar populations after 10^8-10^9 years
- pulsators, $P \sim 10^2 - 10^5$ d
- $L \sim 10^2$ - $10^3\ L_\odot$

luminous → can be observed across the Milky Way, its satellites; participate in the chemical evolution of the ISM



Herwig 2005 (ARAA, 43)

Red supergiants

- massive stars ($10 < M_{Sun} < 30$) → evolve and explode quickly
- young (< 50 Myr) → trace composition of the **present-day ISM**

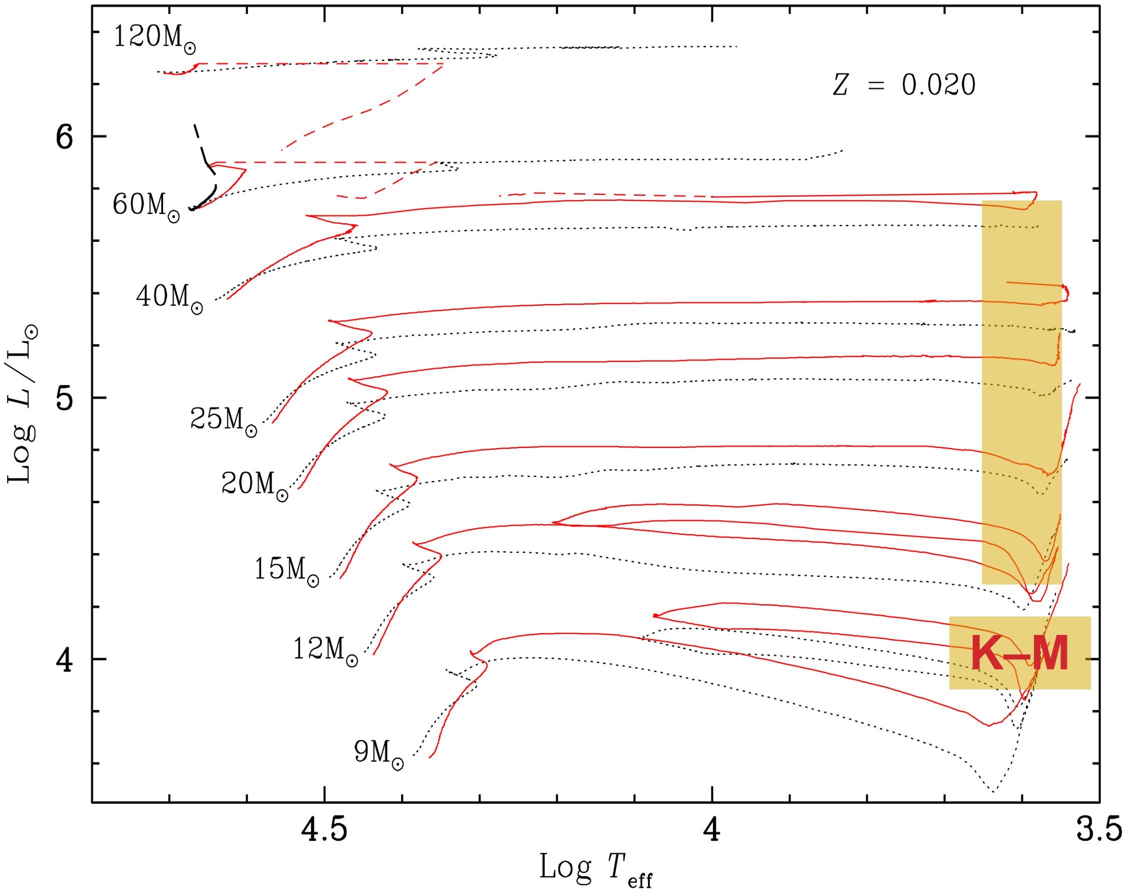
- $L \sim 10^4 - 10^6 L_\odot$

huge luminosities → RSG's observable with modern instruments to distances of few Mpc
(outside the Local Group)

integrated light of young stellar populations in star forming galaxies → out to few 10's Mpc

Red supergiants

the largest stars in the Universe! R > 500 R_{Sun}



Meynet & Maeder (2000)

T_{eff} : 3500 ... 4500 K

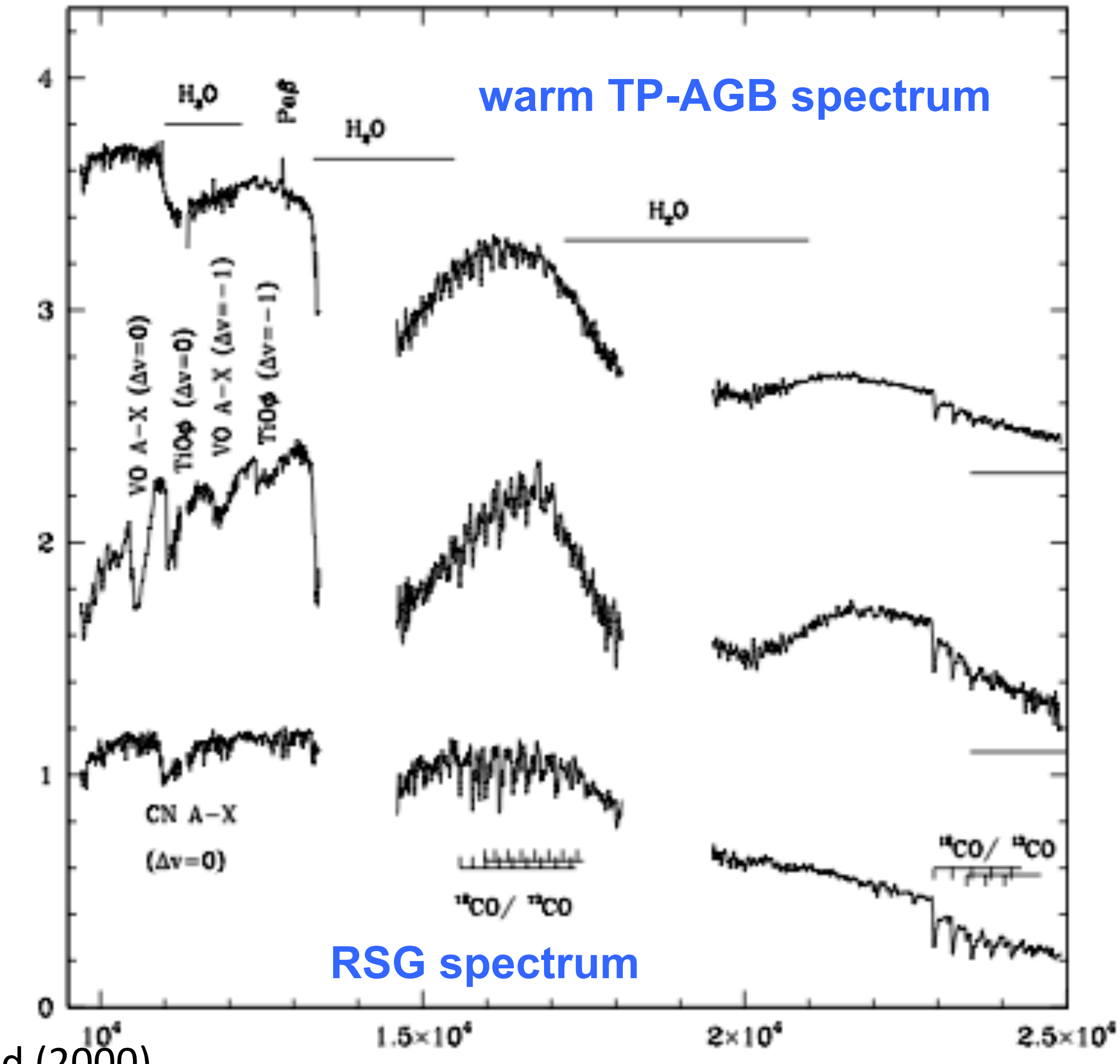
log g : -0.5 ... 0.5

[Fe/H]: about solar

very low T_{eff}, log g, and solar [Fe/H] →

worst situation for spectral analysis

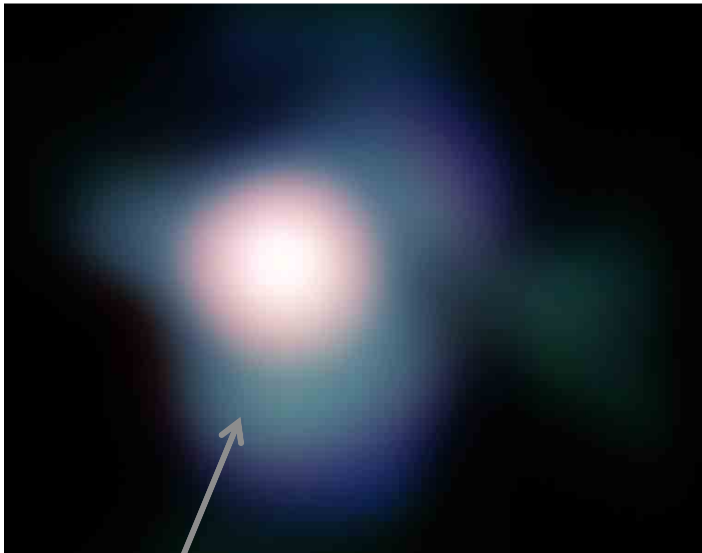
Observations: spectroscopy



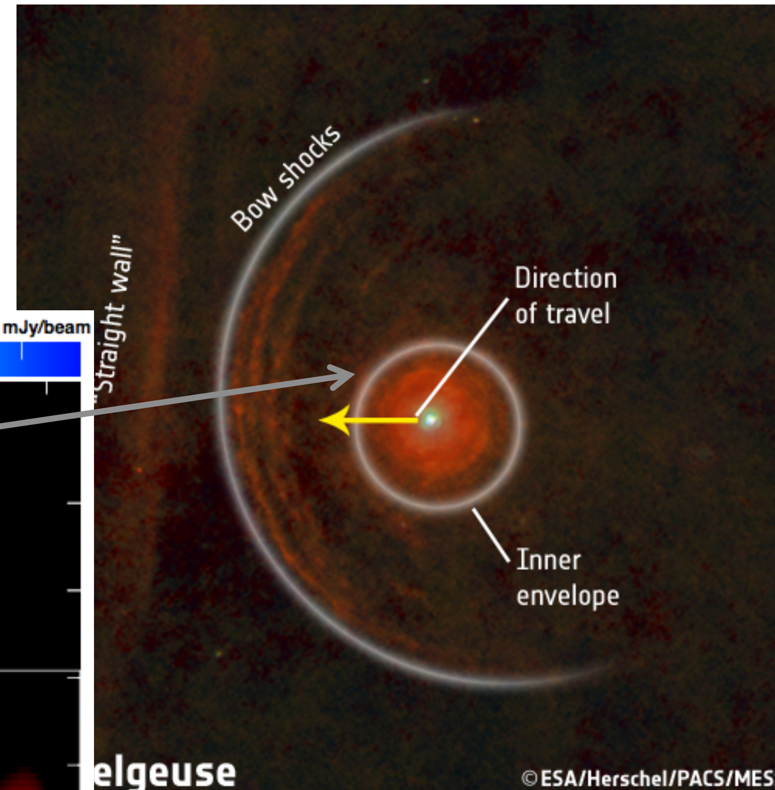
Lancon & Wood (2000)

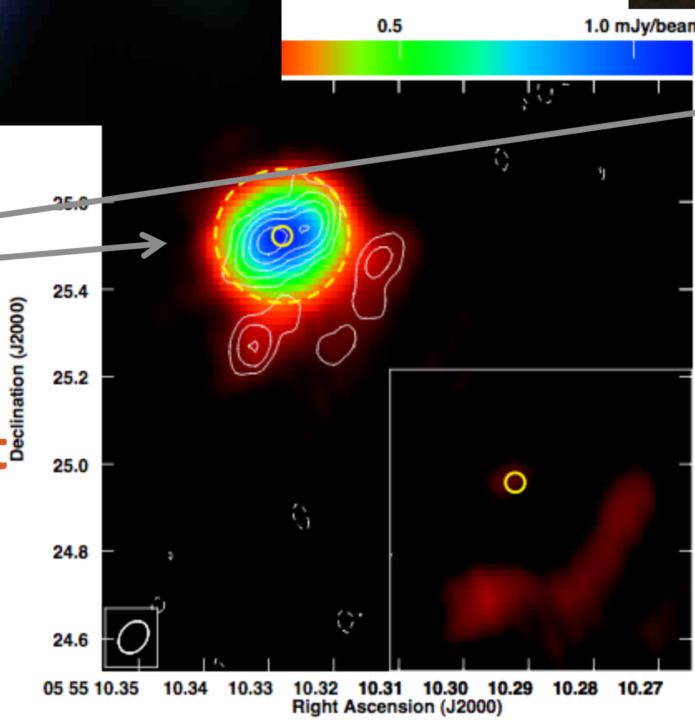
Observations: imaging

ESO VLT



Herschel Space Observatory
(observations @ 60 – 600 mikron)





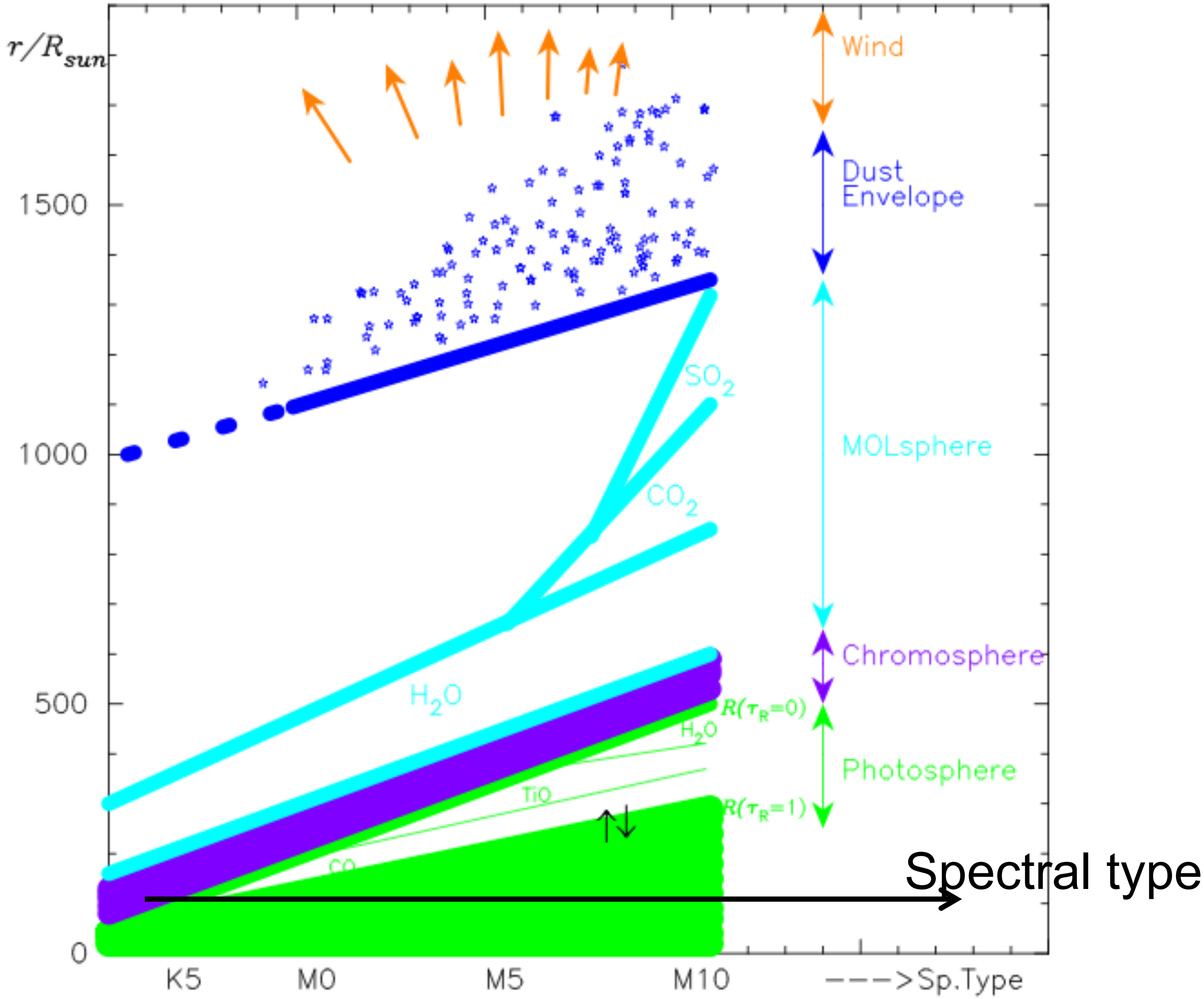
e-MERLIN
radio interferometry (5 cm)

Betelgeuse:
the nearest
Red supergiant

Atmospheres of giants/supergiants

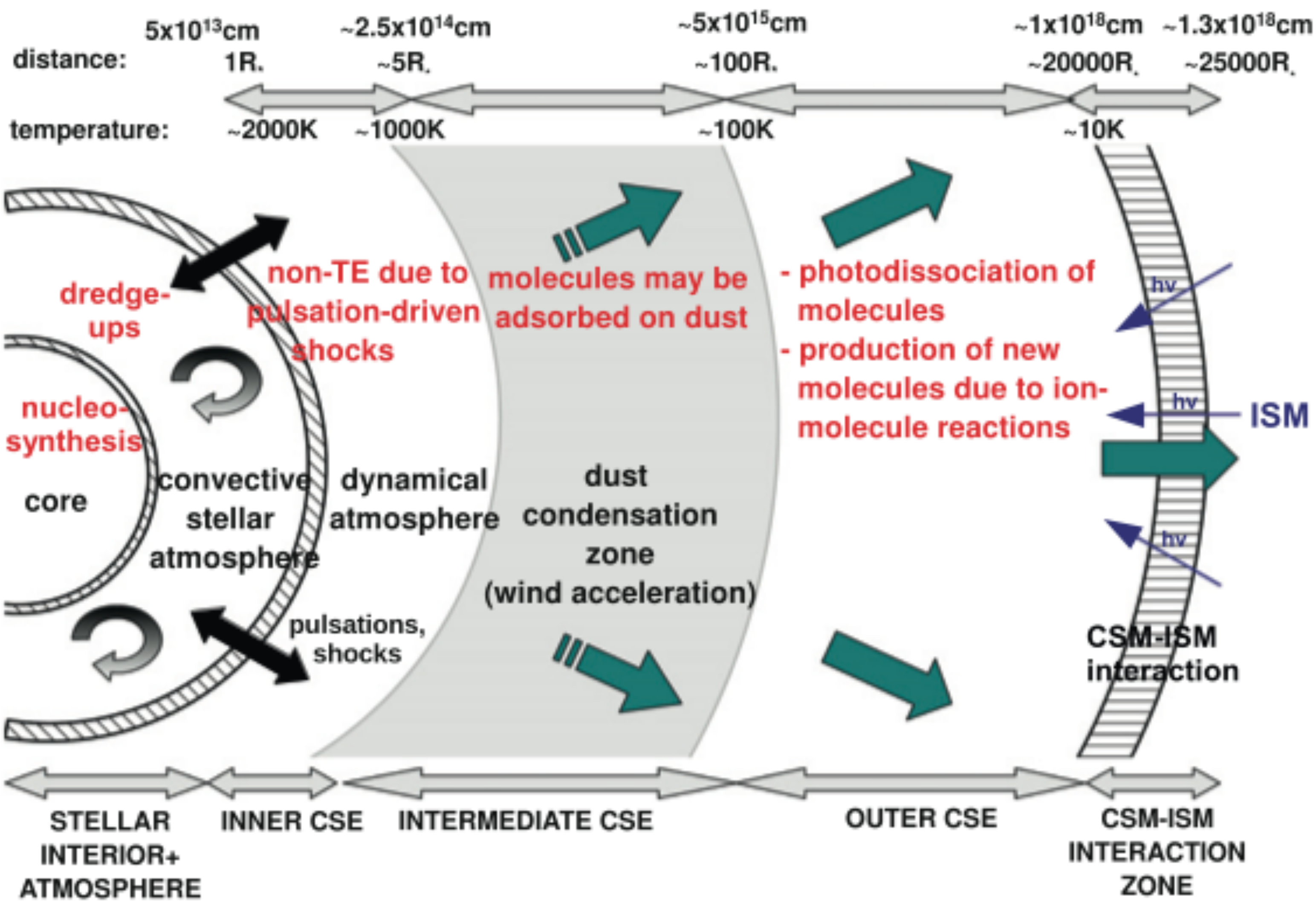
1. Molecular opacities
2. Asymmetric shapes with ‘hot spots’ and mass loss
3. MOLsphere (H_2O, SiO)
4. Deviations from hydrostatic equilibrium and giant convective cells
5. Deviations from **local thermodynamic equilibrium (LTE)**
6. Chromospheres

RGB: atmospheres



Tsuji (2002)

AGB stars: atmospheres



Decin (2013)

Atmospheres of giants/supergiants

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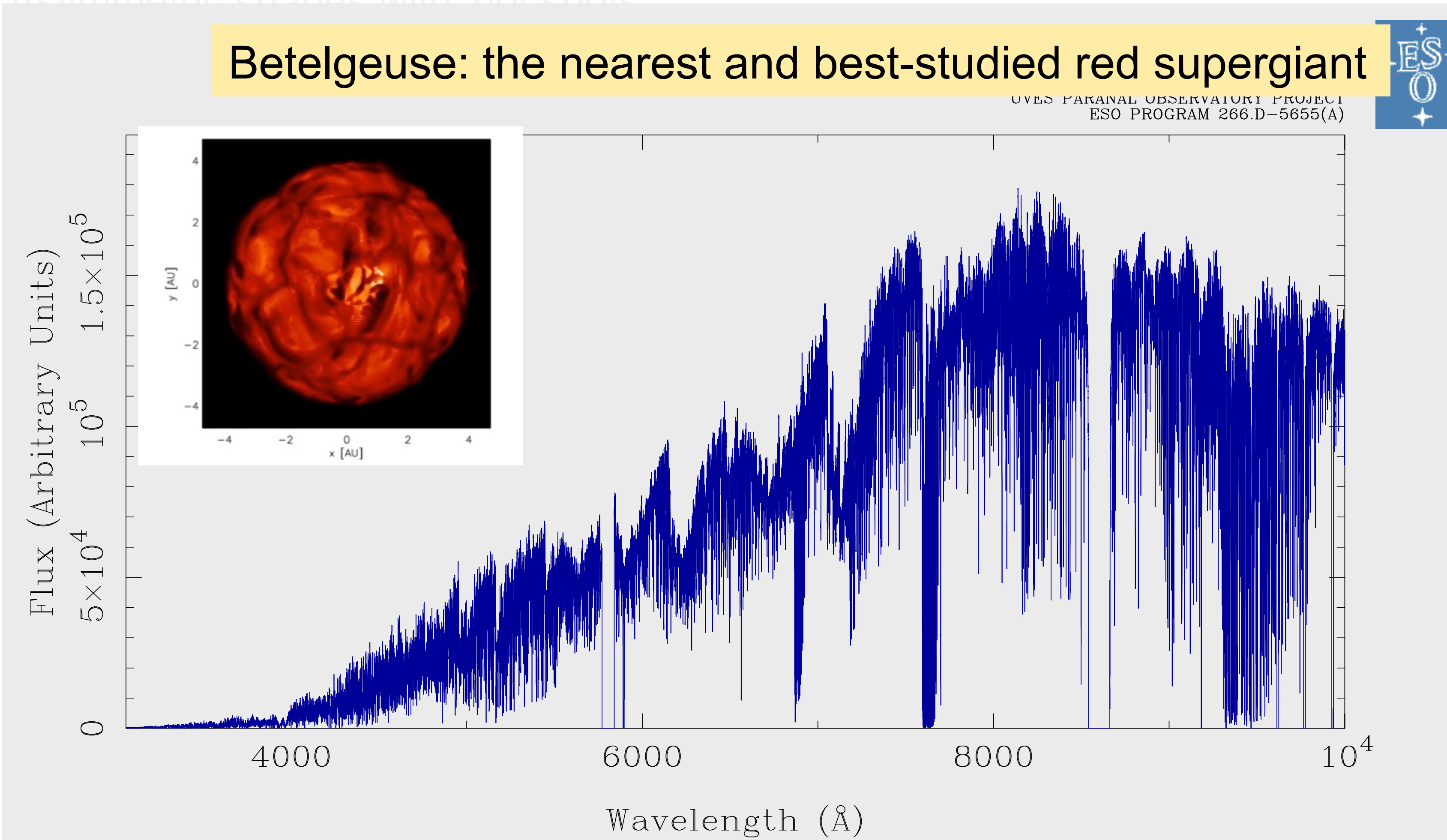
Modeling complexities

1. Molecular opacities
2. Asymmetric shapes with 'hot spots'
3.
4.
5.



Modeling complexities

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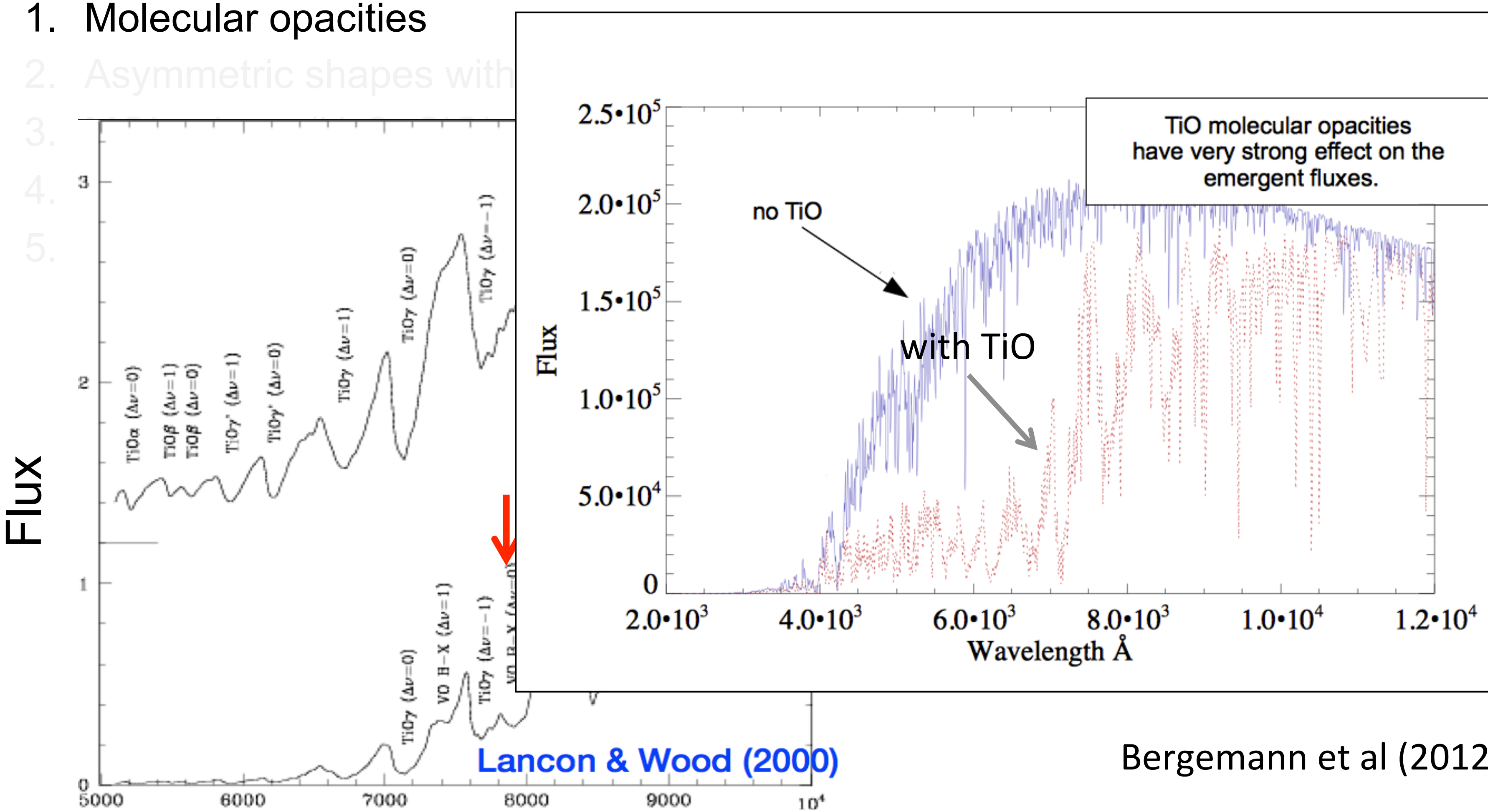


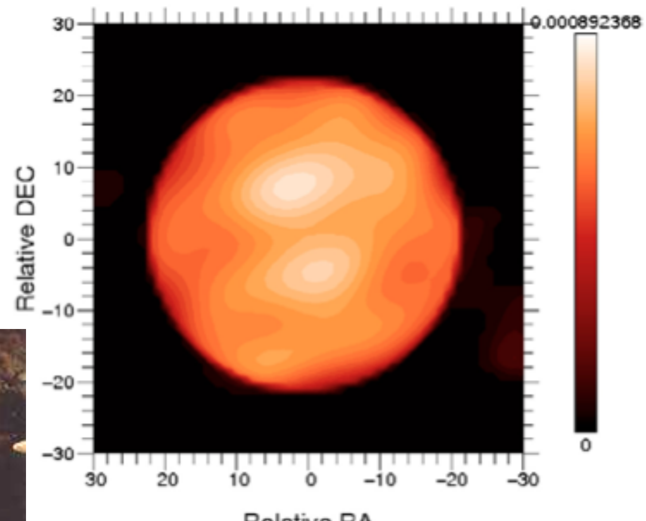
Lancon & Wood (2000)

Bergemann et al (2012)

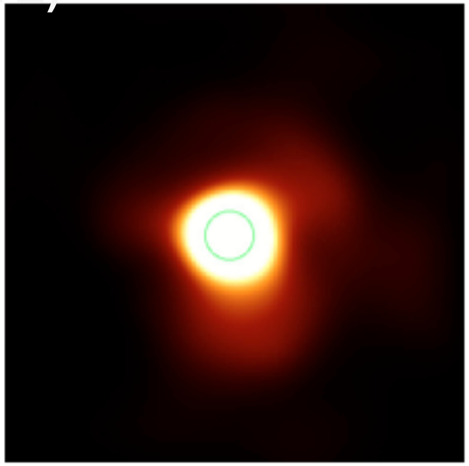
Modeling complexities

1. Molecular opacities
2. Asymmetric shapes with ‘hot spots’

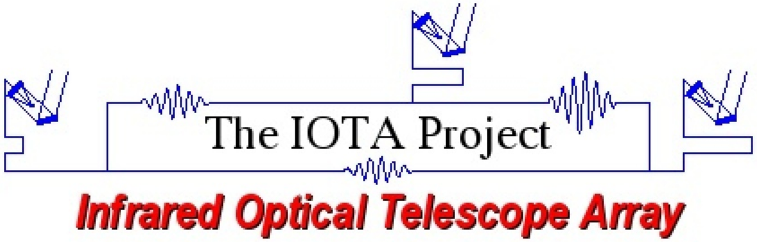
Interferometric observations resolve structure on Betelgeuse: hot spots, ‘plumes’ and giant convective cells



Haubois et al. (2009)

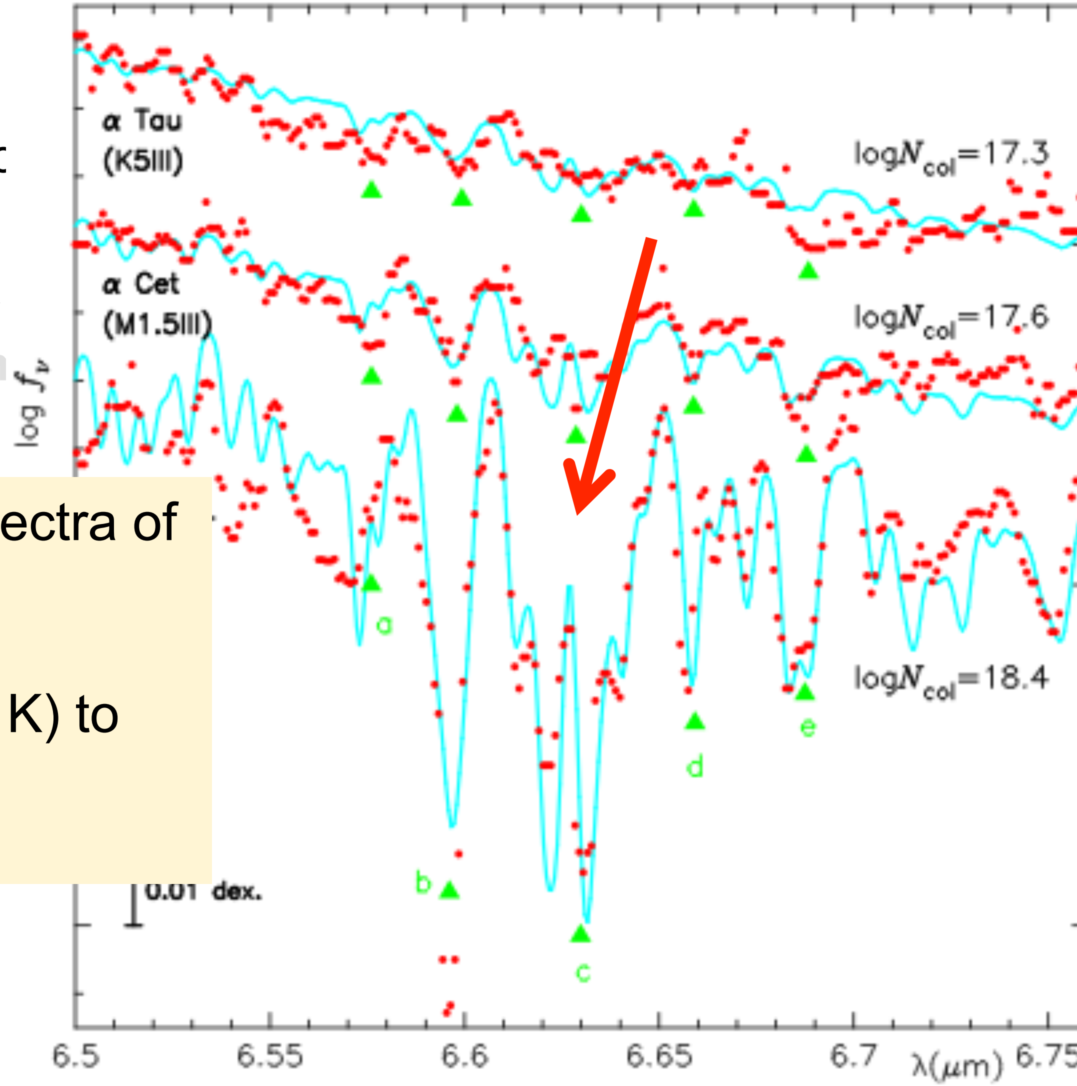


Kervella et al. (2009)



Modeling complexities

1. Molecular opacities
2. Asymmetric shapes with ‘hc
3. MOLsphere (H_2O, …)
4. Deviations from hydrostatic
5. Deviations from **local thern**



H_2O: detected in the IR spectra of giants and supergiants

need very low T_{eff} (~ 2000 K) to explain the observed spectral features

Tsuji (2002)

Modeling complexities

1. Molecular opacities
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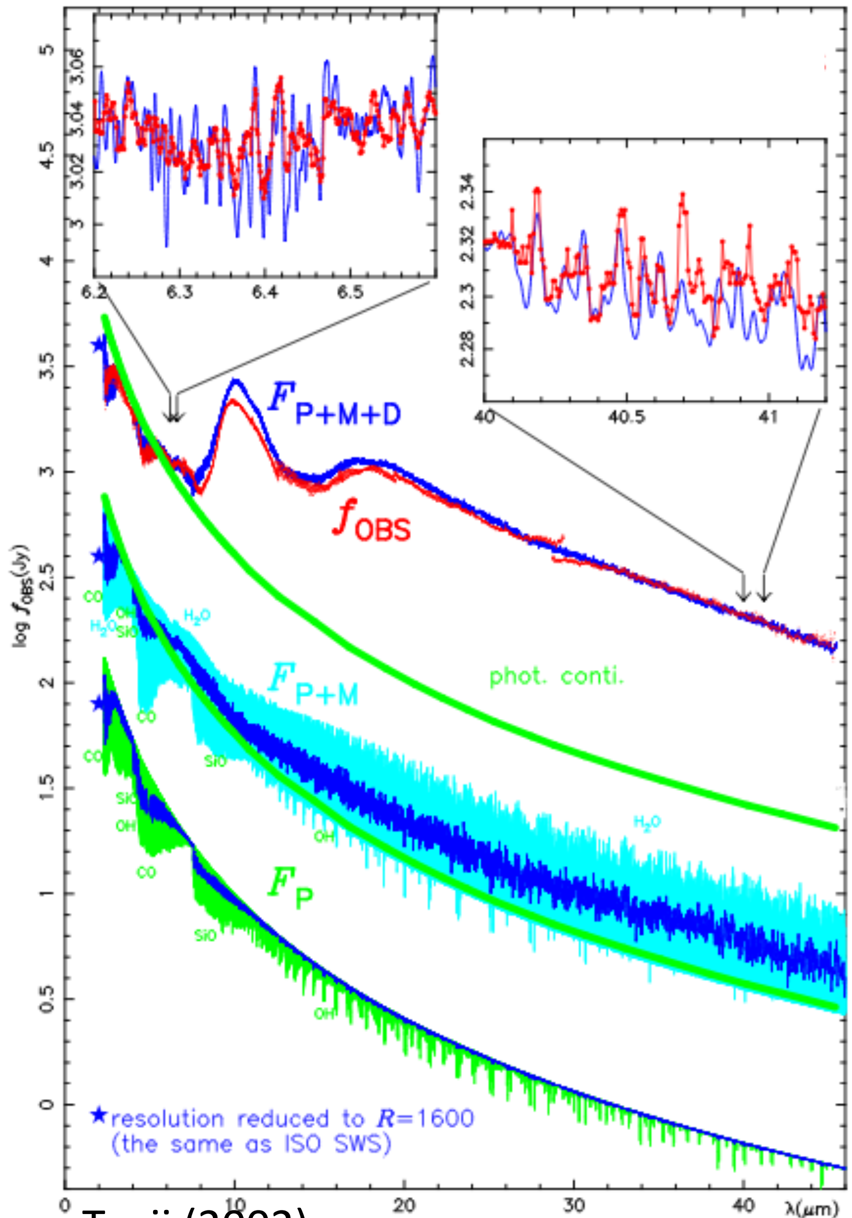
5. Deviations from **local thermodynami**

H_2O: in absorption at $\lambda < 5$ µm but in emission at $\lambda > 5$ µm

Where does the emission come from?

Idea 1: a layer at R ~ 0.3 R_* above the photosphere with T_{eff} ~ 2000 K + a dust shell to explain the IR excess

Idea 2: the models are very wrong



Tsuji (2002)

Modeling complexities

1. Molecular opacities
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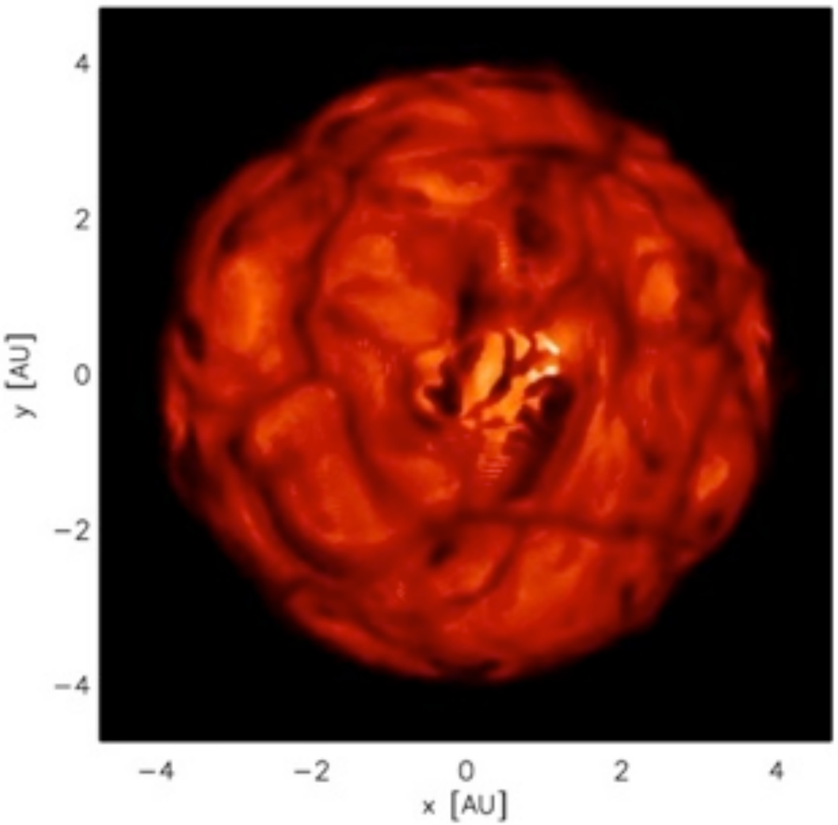
4. Deviations from hydrostatic equilibrium and giant convective cells

equilibrium (LTE)



Models of red supergiants

radiative hydrodynamics in 3D
but
simplified radiative transfer LTE

Chiavassa et al. (2011)

Modeling complexities

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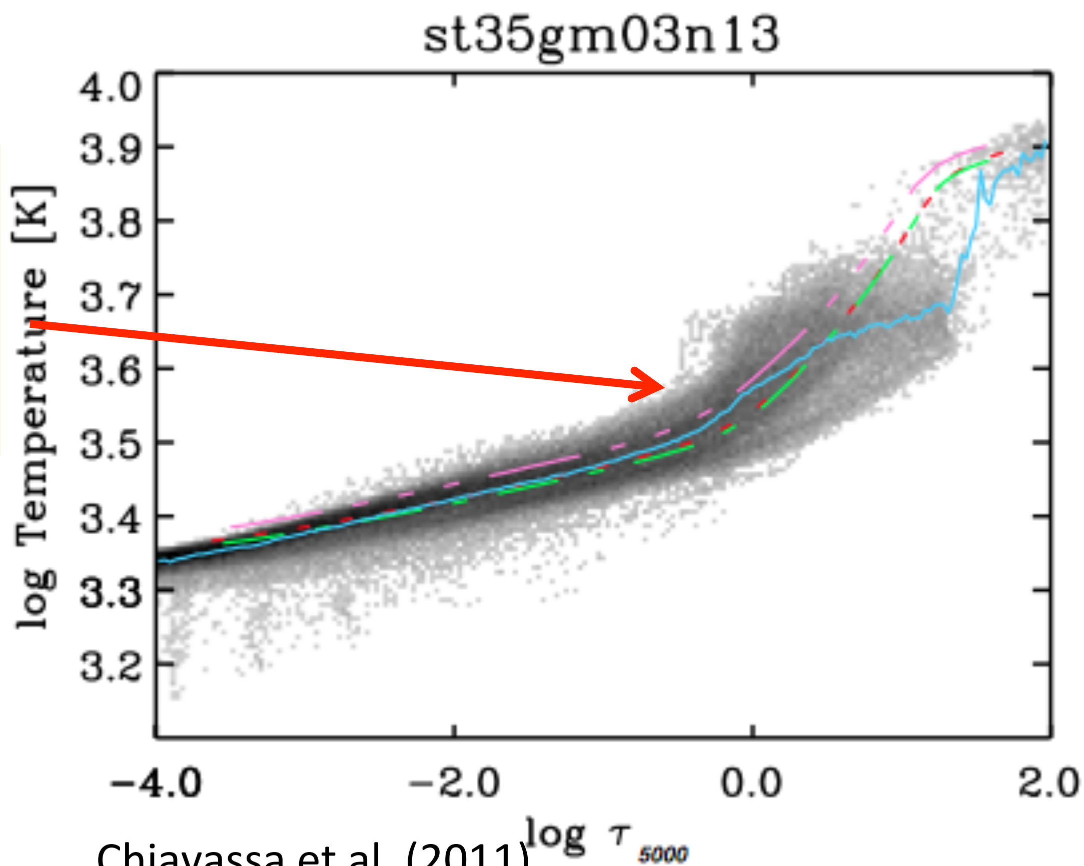
4. Deviations from hydrostatic equilibrium and giant convective cells
5. Deviations from **local ther**

Convective over-shoot into the photosphere →
the concept of a ‘mean’ 1D hydrostatic structure is meaningless



Chiavassa et al. (2011)

Modeling complexities

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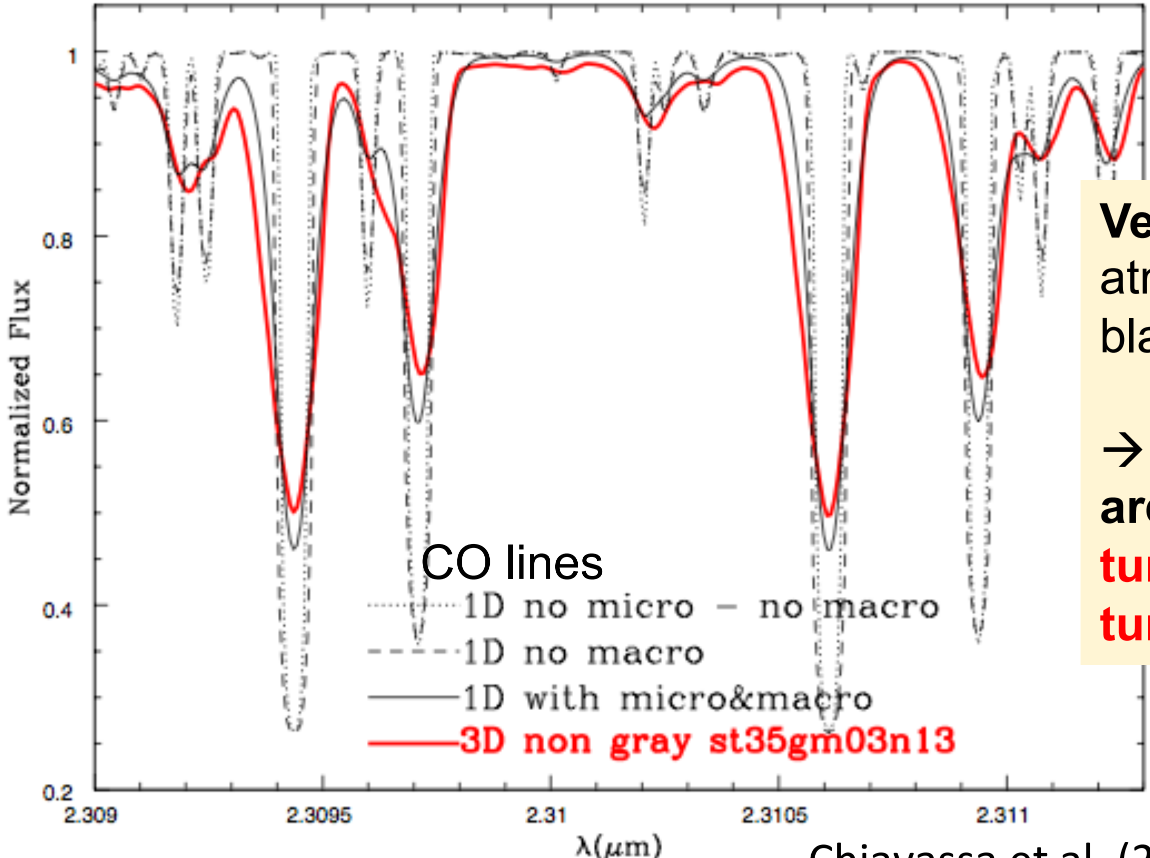

Velocity fields: affect on the atmosphere through the line blanketing

→ **in 1D static models, V fields are represented by 'micro-turbulence' and 'macro-turbulence'**

Chiavassa et al. (2011)

Modeling complexities

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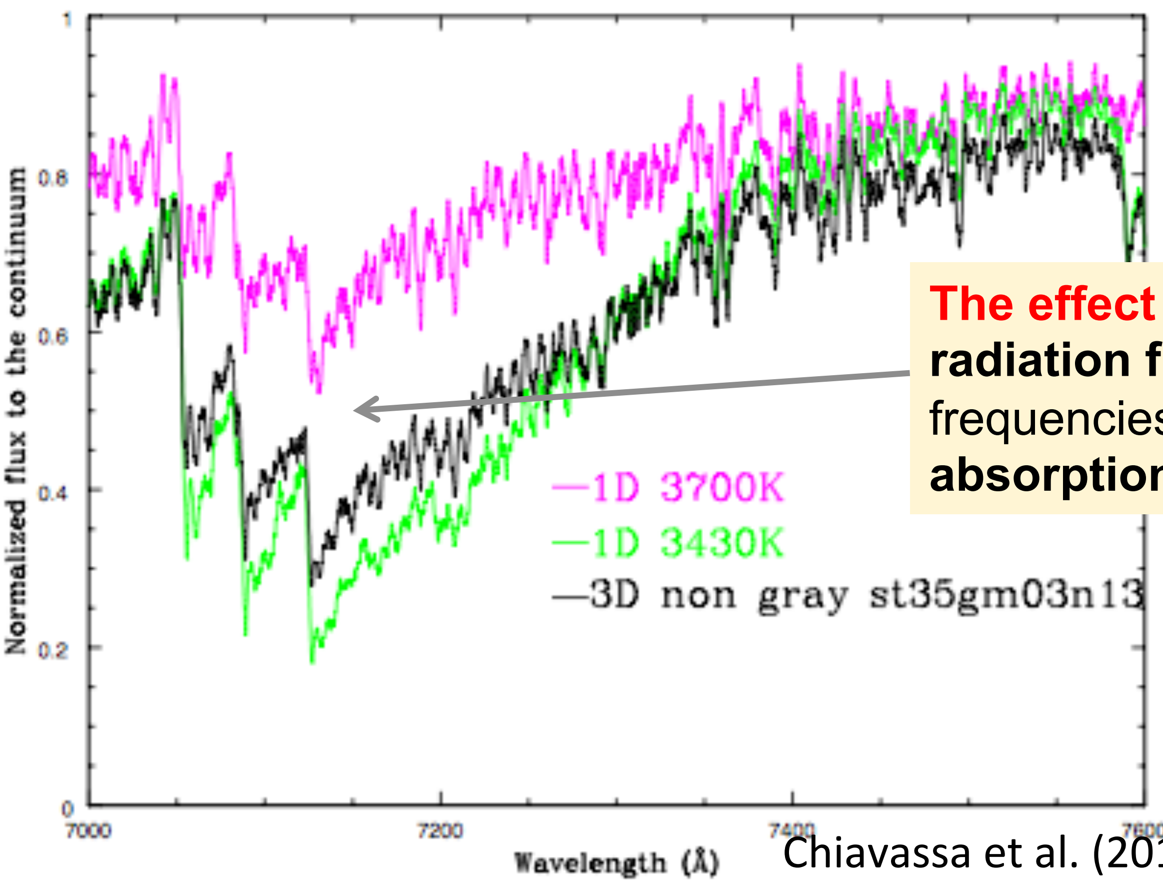
n (LTE)

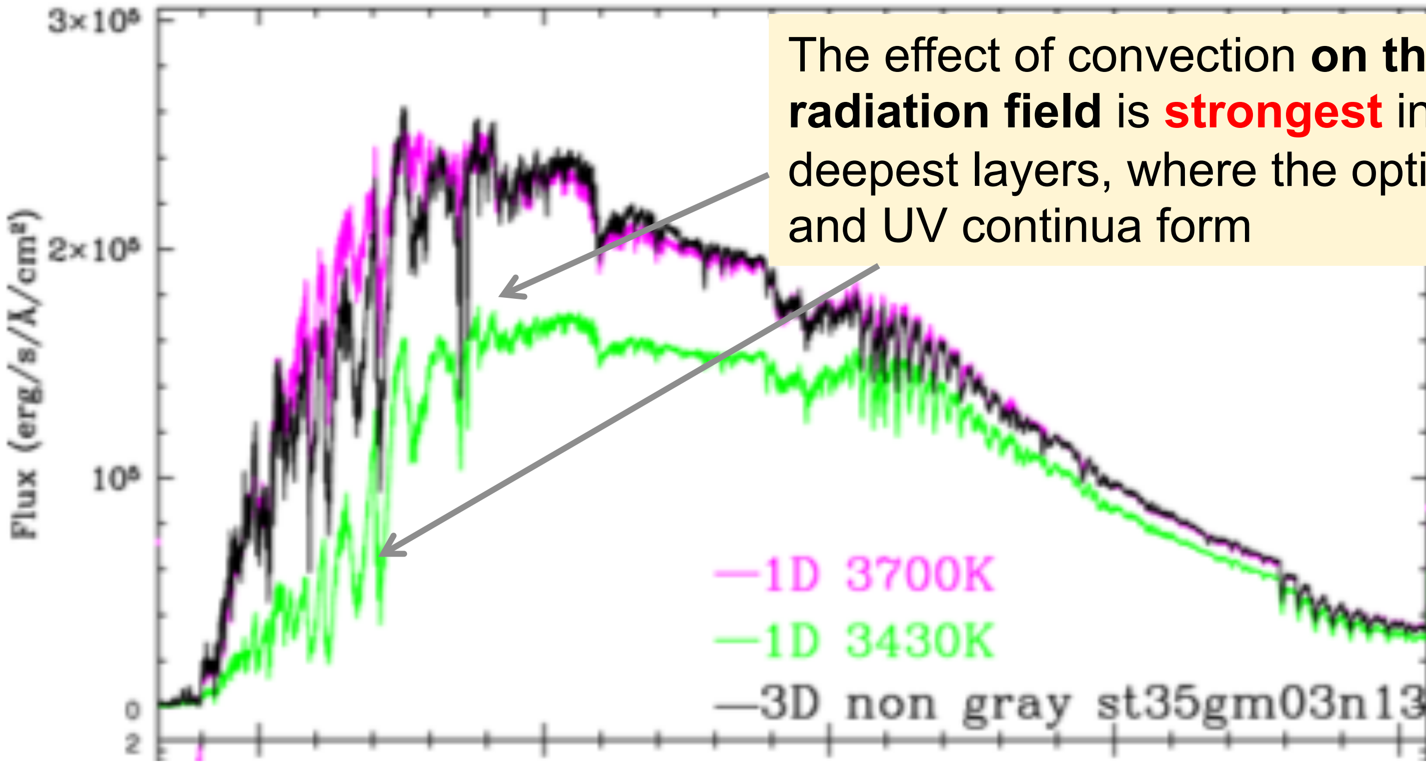


The effect of convection on the radiation field is huge in the frequencies of **strong molecular absorption** (e.g TiO)

Chiavassa et al. (2011)

Modeling complexities

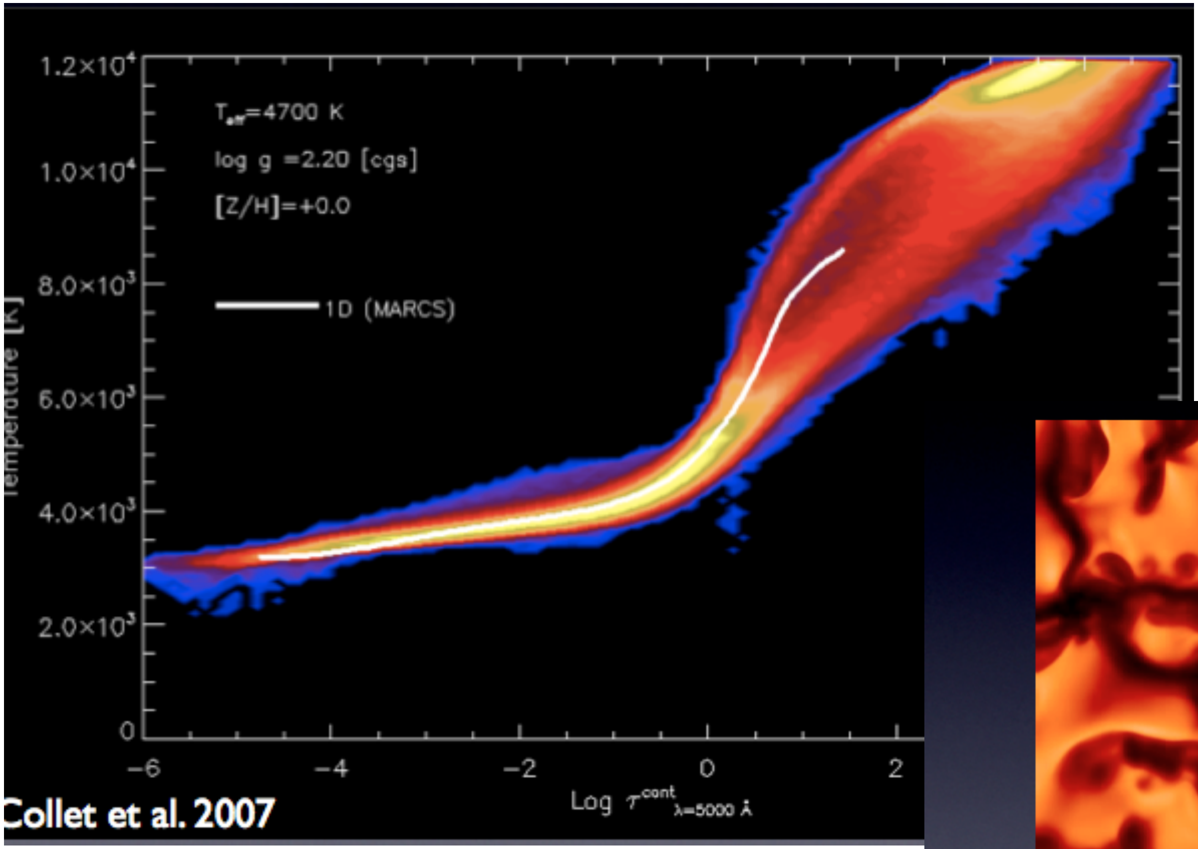
1. Molecular opacities
2. Asymmetric shapes with ‘hot spots’
3. MOLsphere (H_2O, SiO)
4. Deviations from hydrostatic equilibrium and giant convective cells
5. Deviations from **local thermodynamic equilibrium (LTE)**

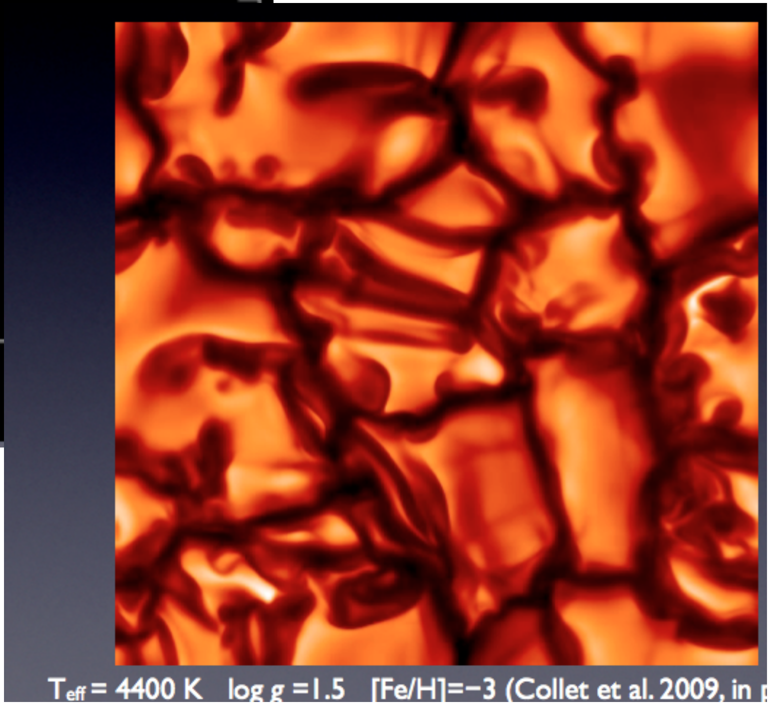


The effect of convection **on the radiation field** is **strongest** in the deepest layers, where the optical and UV continua form

Red giants

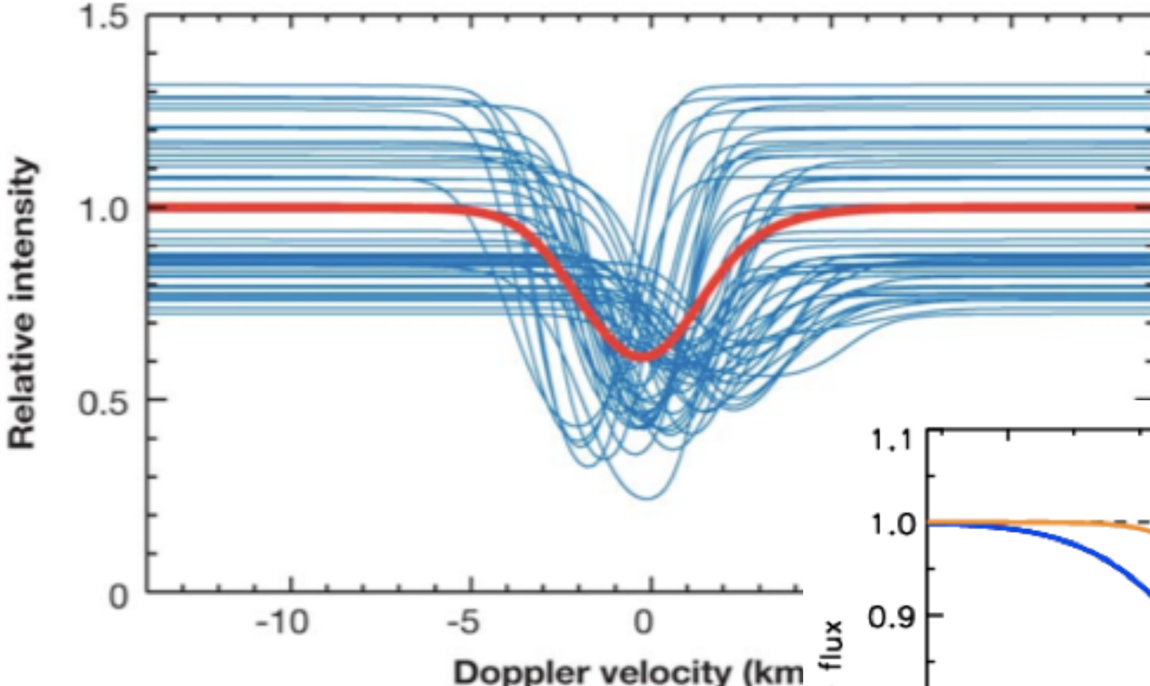
3D hydrodynamics models



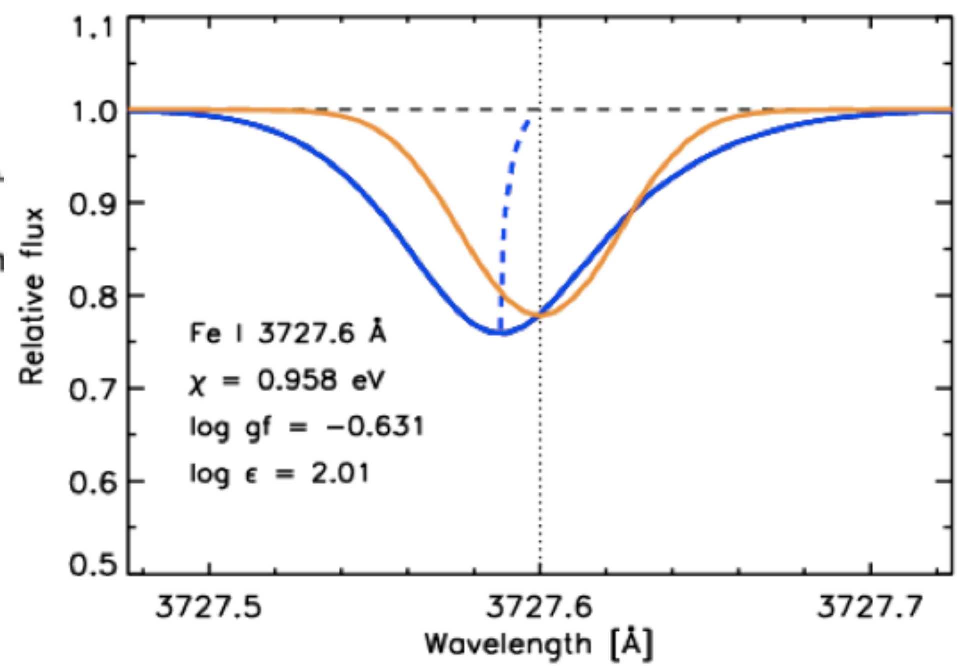


Red giants

3D hydrodynamics models

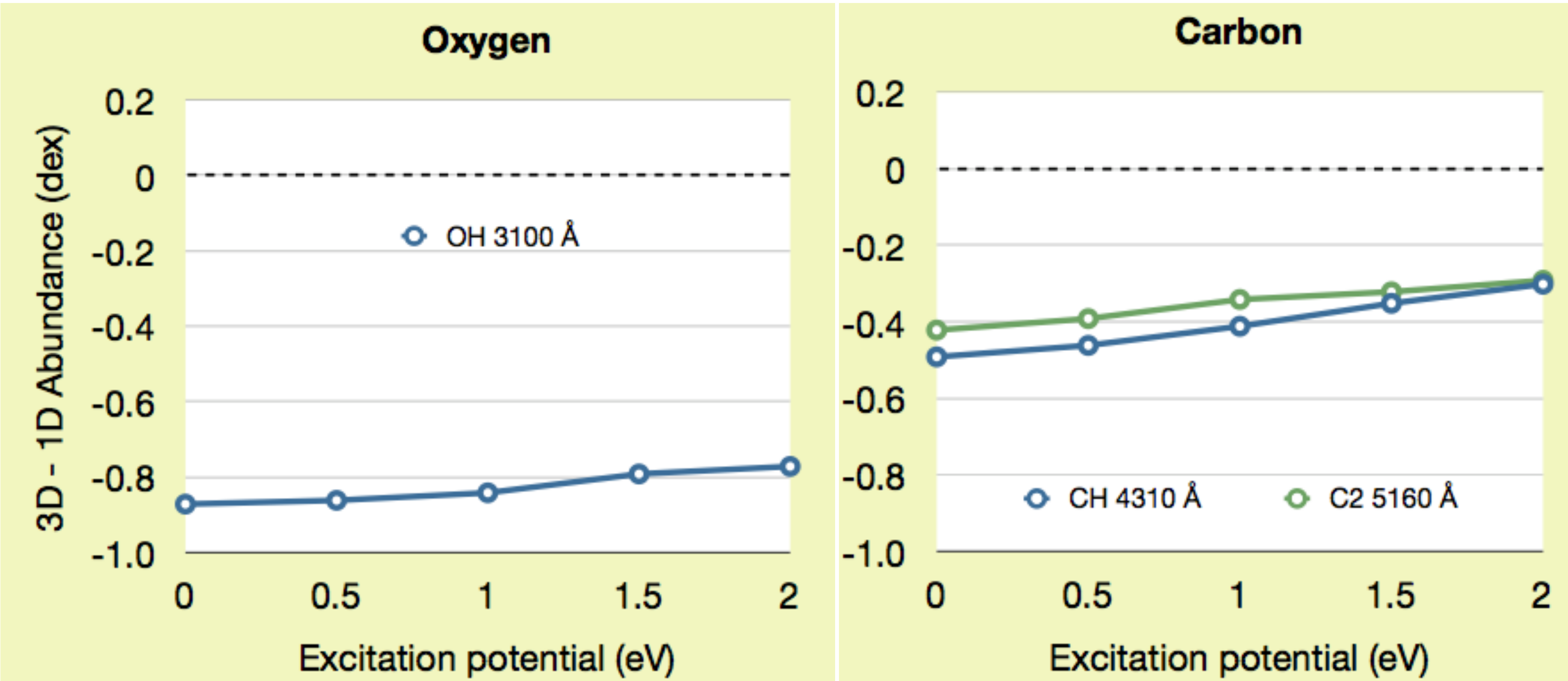


Asplund 2005 (ARAA)



Effect on abundances

The abundances derived with 3D hydro models are lower



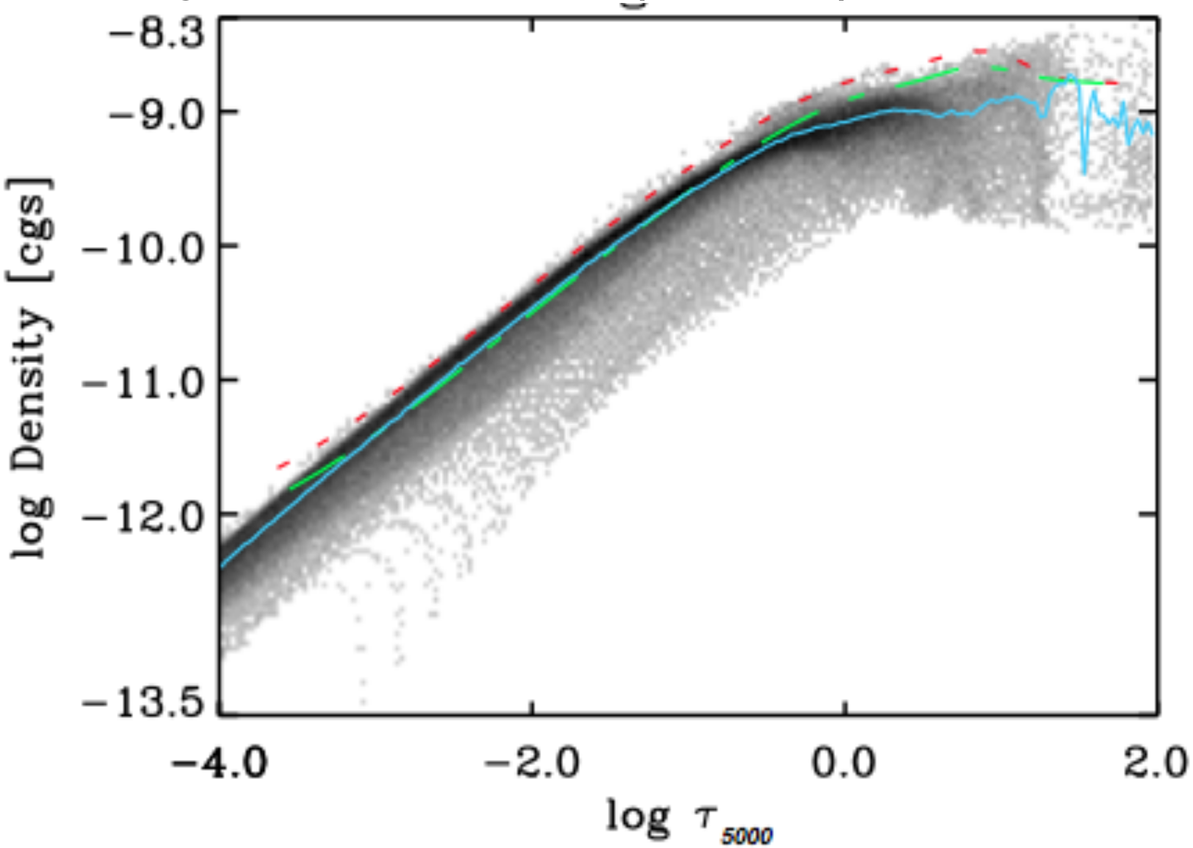
Collett 2009

Modeling complexities

1. Molecular opacities
2. Asymmetric shapes with ‘hot spots’
3. MOLsphere (H_2O, SiO)
4. Deviations from hydrostatic equilibrium and giant convective cells
5. **Deviations from local thermodynamic equilibrium (non-LTE)**

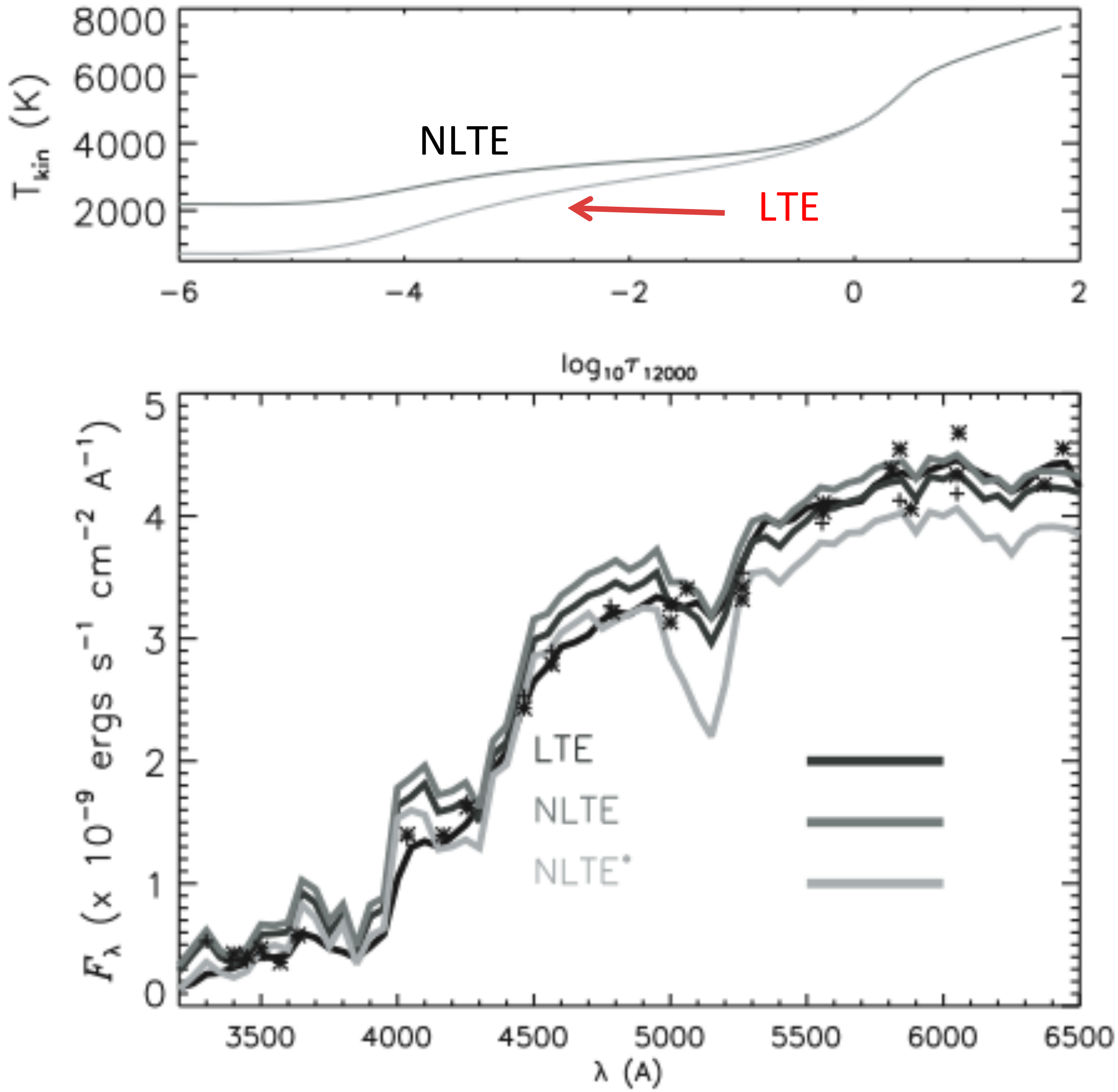
densities 10^{-4} that of the Sun:

collisions are too weak to establish LTE



NLTE

- atmospheric structure
- flux distribution



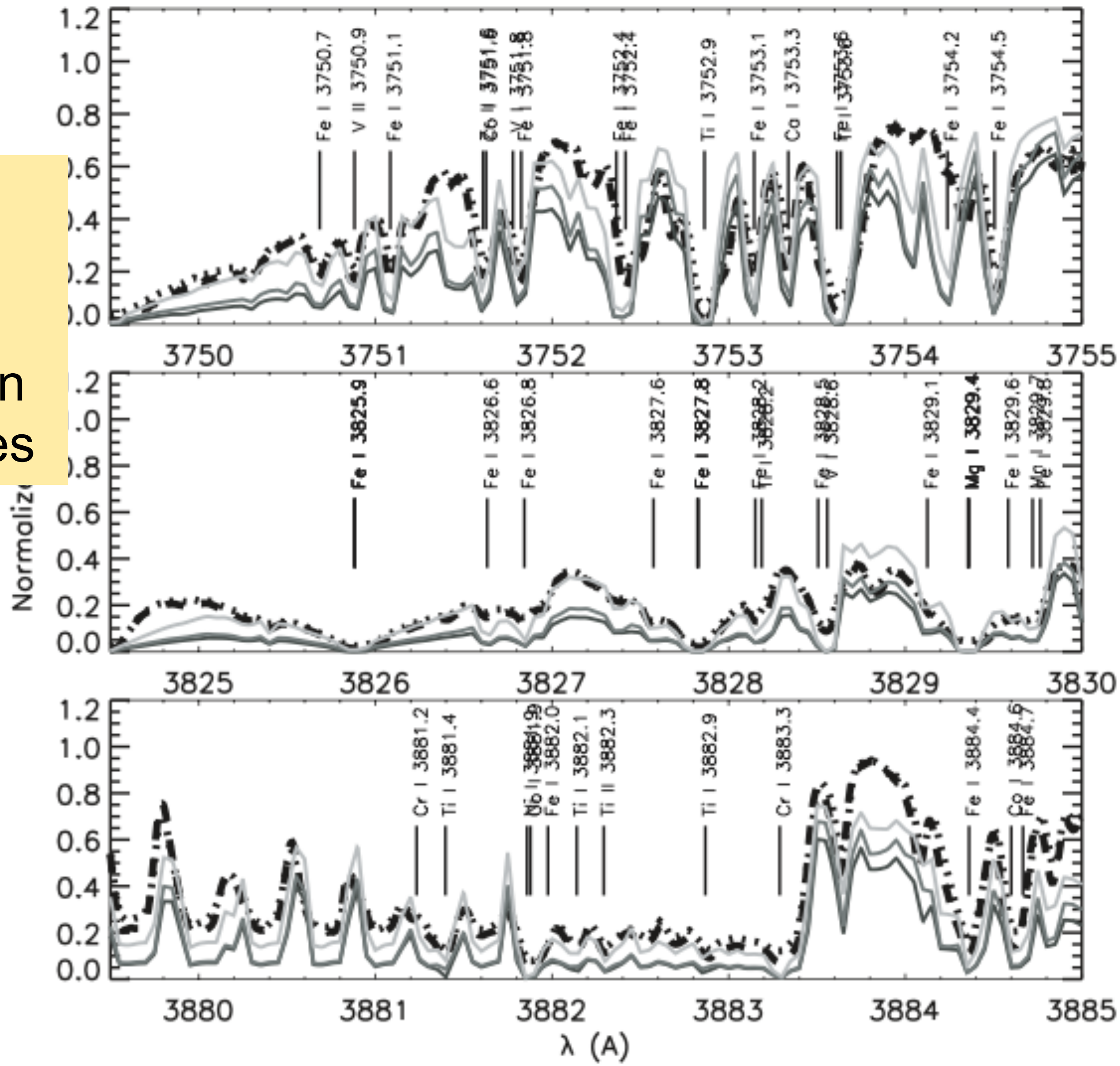
Short & Hauschildt (2009)

Figure 7. Arcturus: upper panel: atmospheric $T_{kin}(\log \tau_{5000})$ structure. Theoretical models: NLTE: dark line; NLTE-cool: lighter line. Lower panel: same as

NLTE

Arcturus:

NLTE alone is not sufficient to explain the observed fluxes

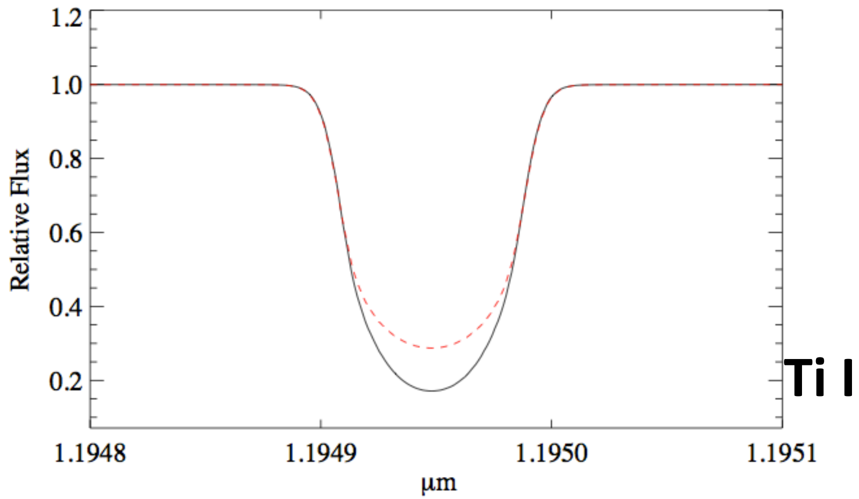


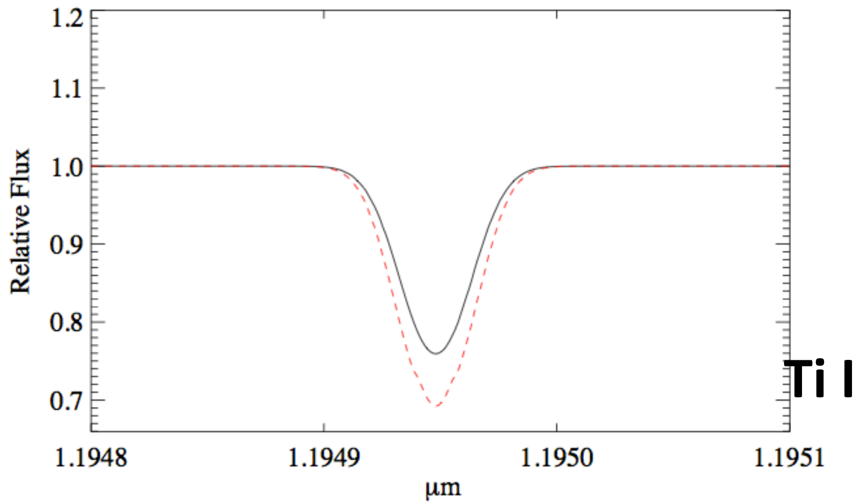
NLTE

Δ = log A (non-LTE) – log A (LTE)

- Fe I: - 0.05 < Δ < + 0.10 – small
- Ti I : - 0.30 < Δ < + 0.30 – important
- Si I: - 0.40 < Δ < - 0.10 – important

- NLTE abundance corrections are mainly a function of T_{eff} and metallicity

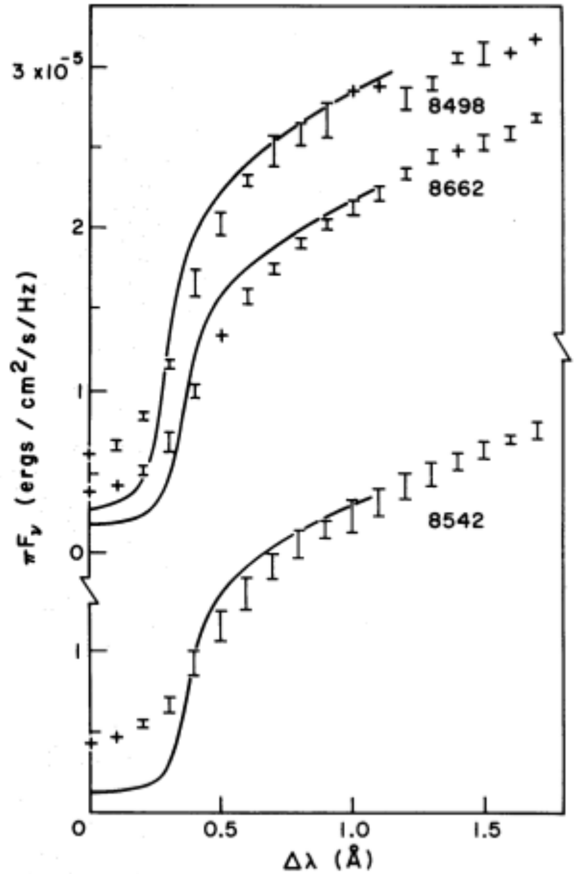


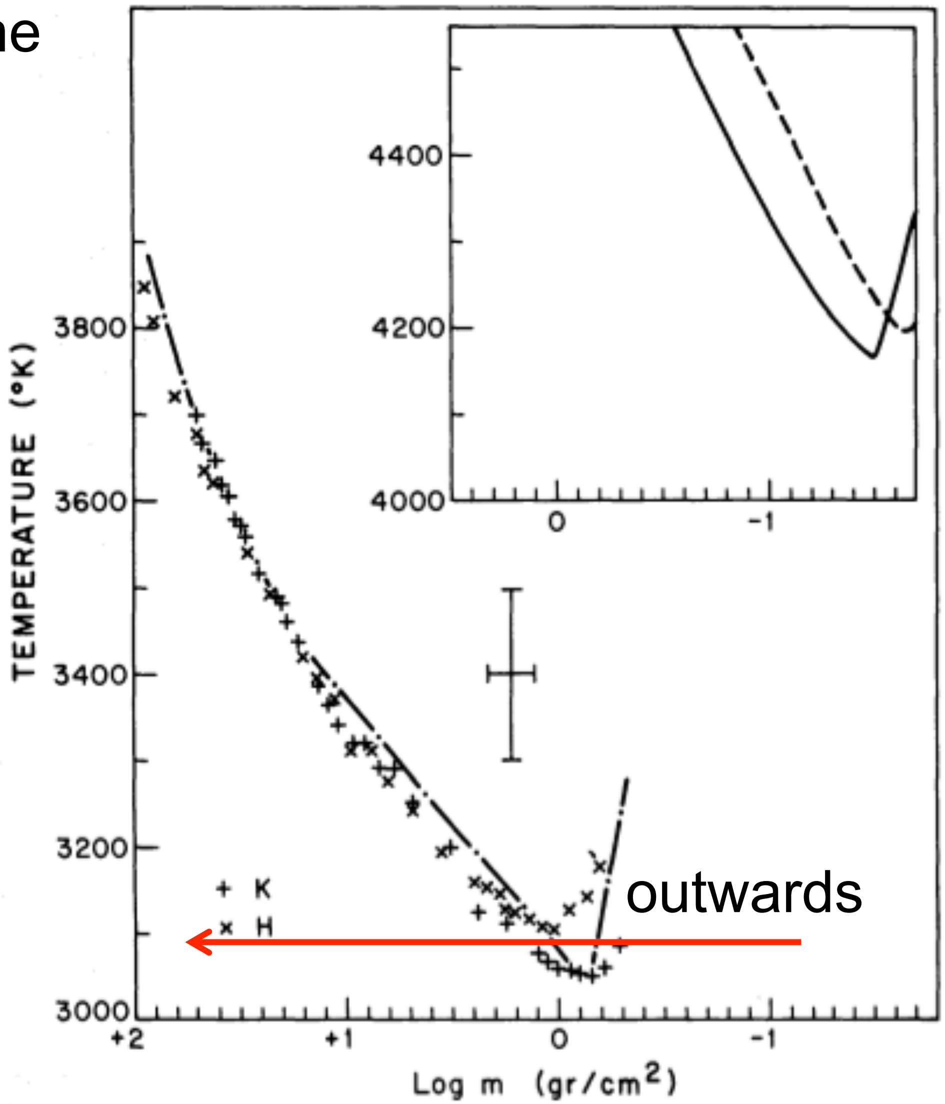


Bergemann et al (2012)

Chromospheres

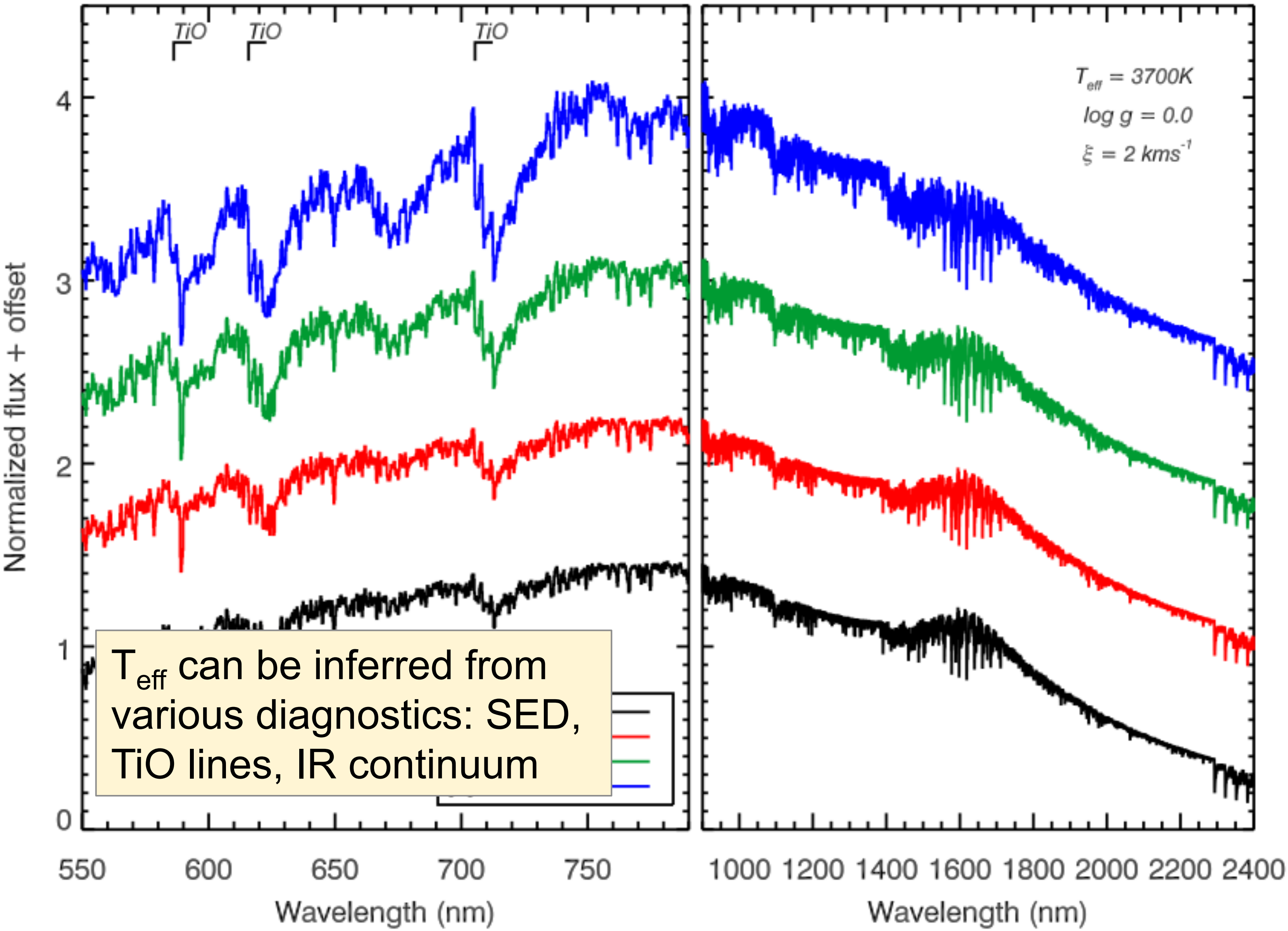
reconstruction by fitting the observed line profiles





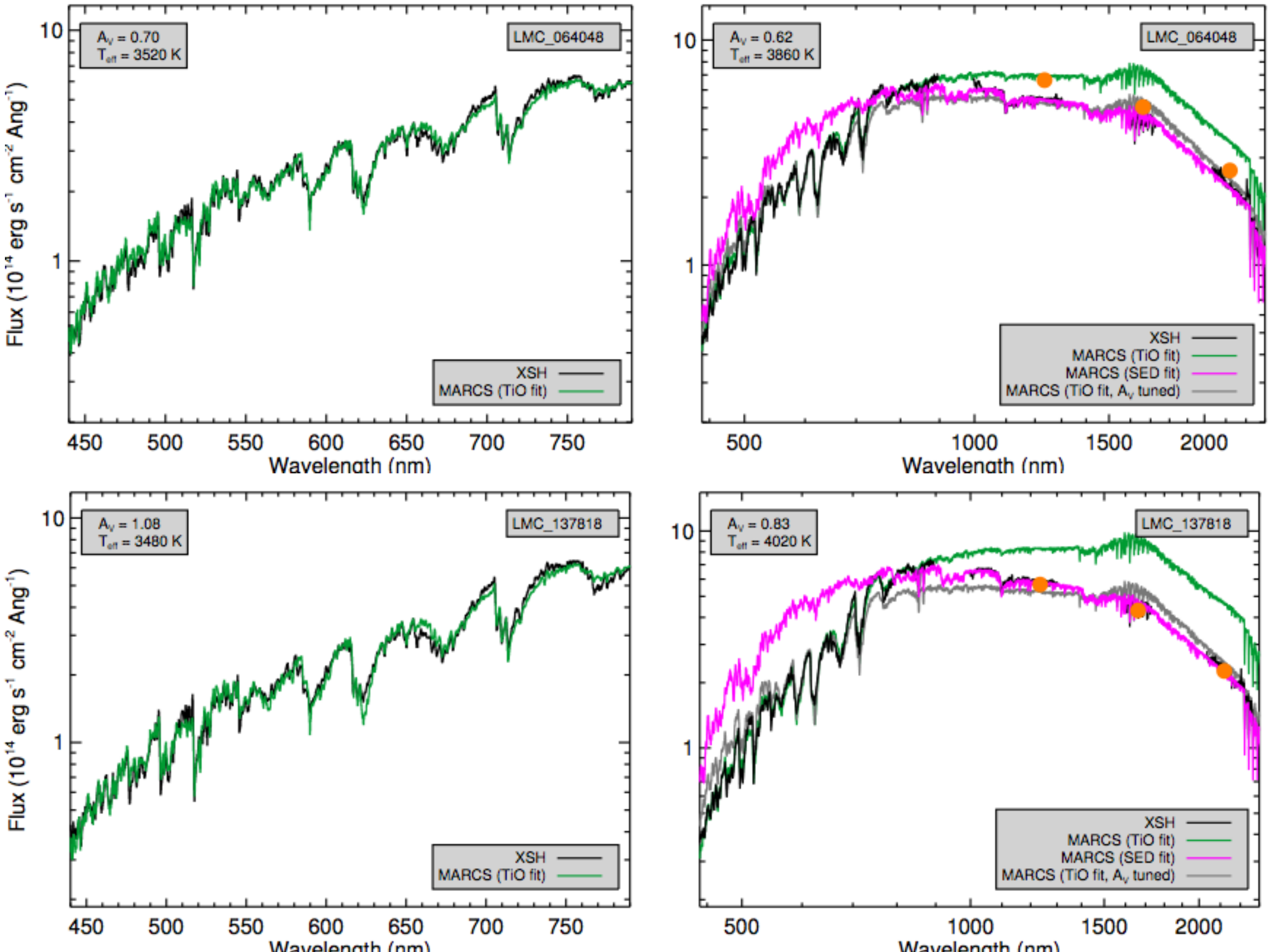
Ayres & Linsky (1975)

How to determine T_{eff}?

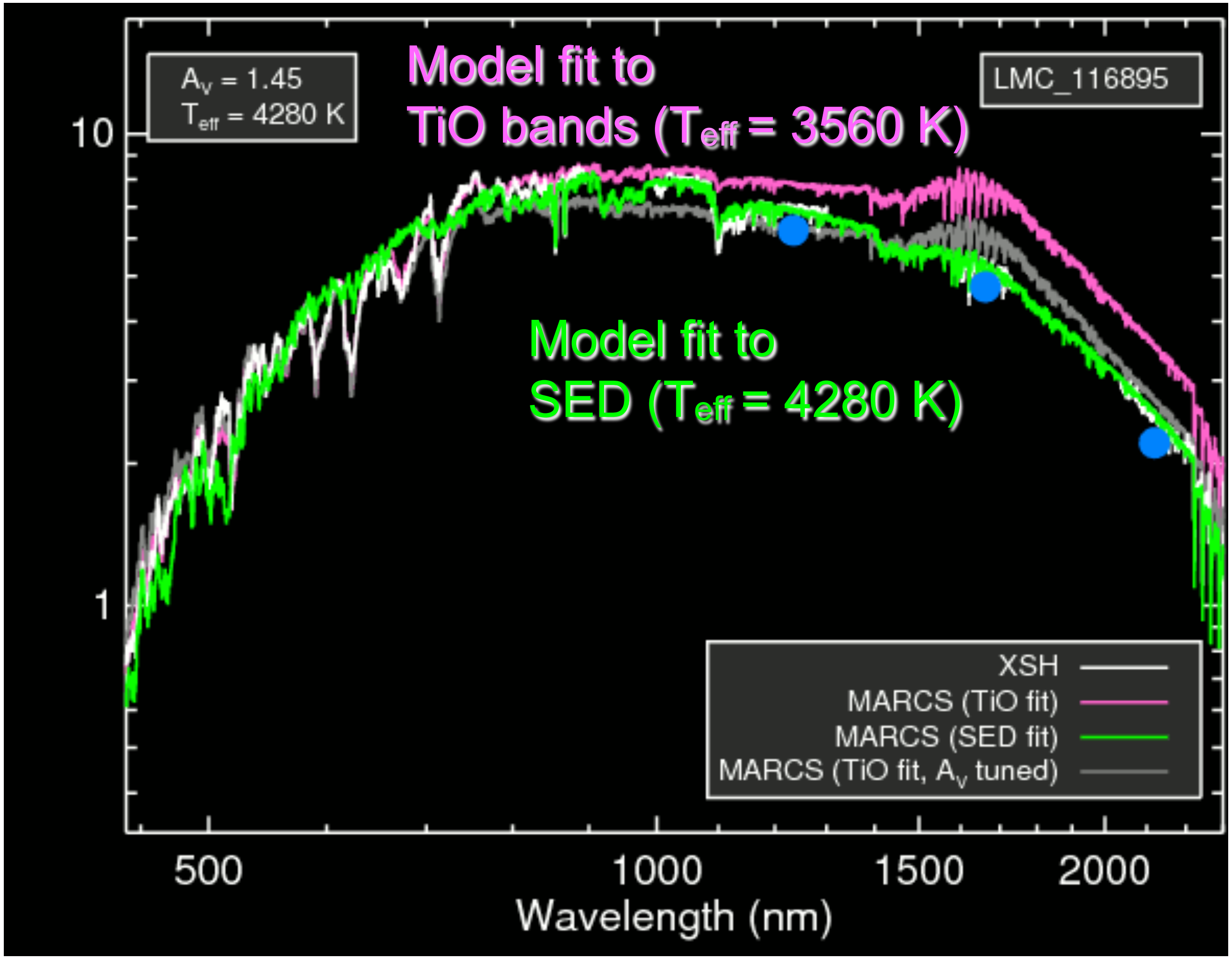


T_{eff} can be inferred from various diagnostics: SED, TiO lines, IR continuum

Temperature scales



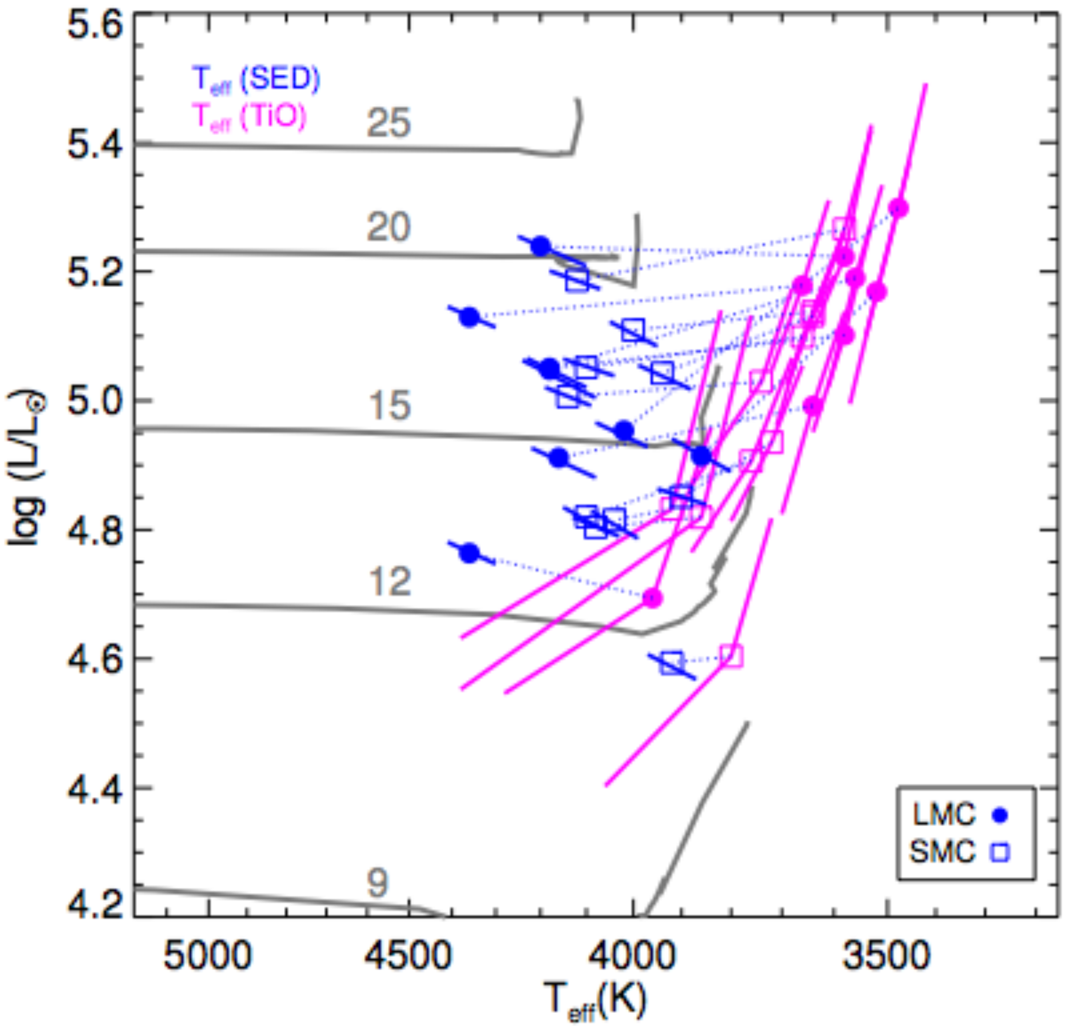
Davies et al. (2013)



- fits to the TiO region overestimate the flux in the near IR.
- fits to the featureless regions of the SED under-predict the TiO strengths

Fundamental discrepancy between T_{eff} (TiO) and T_{eff} (SED-IR)

Position on the HRD



Davies et al. (2013)

Summary

Analysis of giant and supergiant spectra

- Molecular opacities
- Asymmetric shapes with ‘hot spots’ and mass loss
- MOLsphere (H_2O, SiO)
- Deviations from **hydrostatic equilibrium** and giant convective cells
- Deviations from **local thermodynamic equilibrium (LTE)**
- Chromospheres

global effect on the SED and ratio of fluxes in different wavelength bands

1D LTE hydrostatic models are meaningless