Convection and Turbulence

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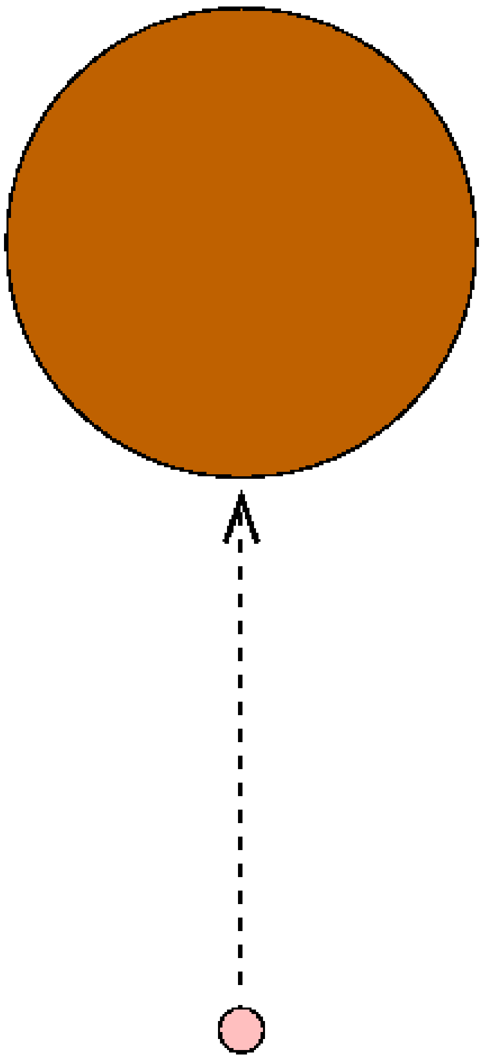
Convection and turbulence

- Effects the atmosphere of A stars and cooler.
- Visible as Solar Granulation
  - Surface convection cells
- Indirectly inferred via
  - Microturbulence
  - Macroturbulence
  - Line bisector curvatures
- Free parameters in 1-d models
  - Can vary with depth in atmosphere

Mixing-Length Theory

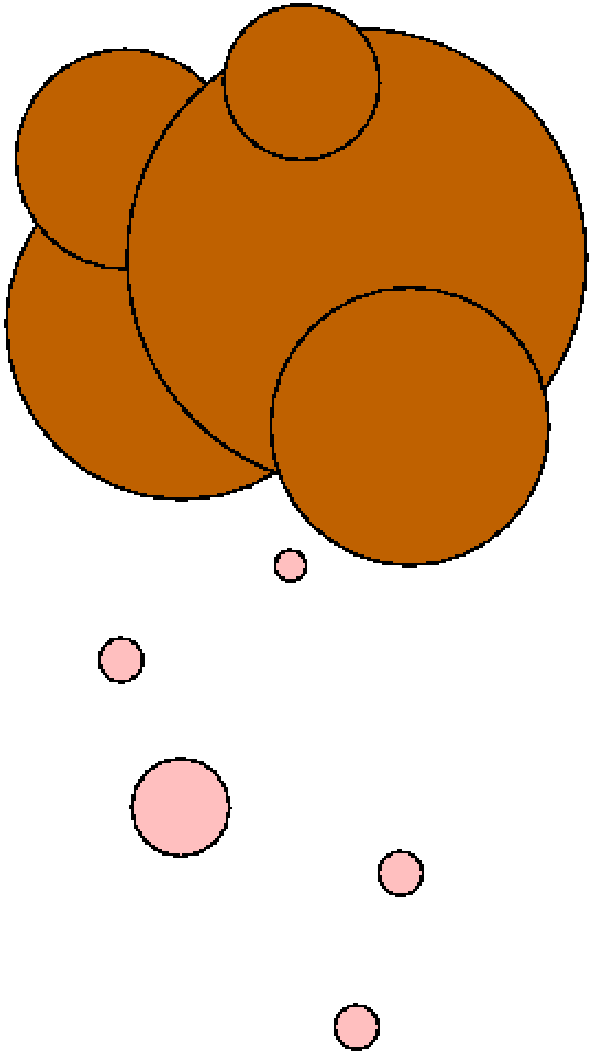
- A single bubble of rising gas
  - Rises a certain length before dispersing
- Problems:
  - Too simple!
  - No prescription for mixing-length
    - pick your own value!

Böhm-Vitense 1958, ZA, 46, 108

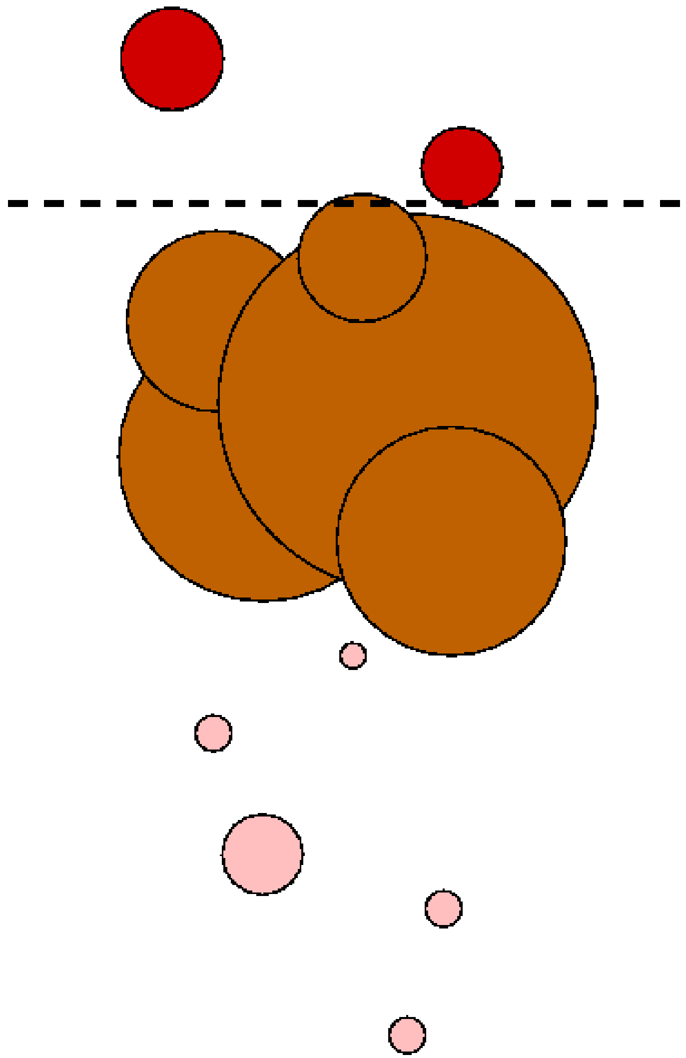


Turbulent Convection

- Canuto & Mazzitelli Model (1991, ApJ, 370, 295; 1992, ApJ, 389, 724)
  - Using full range of bubble sizes and dispersion lengths
  - No free parameters!
- Implemented in
  - ATLAS9 (Kupka, 1996, ASPC, 108, 73)
  - LL models (Shulyak et al., 2004, A&A, 428, 993)



Convective Overshooting



- Bubbles rise above the convections zone into the stable regions
  - overshooting
  - should be present in our models

Approximate Overshooting

“convective models use an overshooting approximation that moves flux higher in the atmosphere above the top of the nominal convection zone. Many people do not like this approximation and want a pure unphysical mixing-length convection instead of an impure unphysical mixing-length convection”

(http://kurucz.harvard.edu)

The ATLAS CONVECTION Card

e.g. CONVECTION OVER 1.25 0 36

Defaults before **CONVECTION** card: MIXLTH = 1; OVERWT = 1

CONVECTION OFF

- MIXLTH is set to 1, but OVERWT is not changed.

CONVECTION ON MIXLTH

- MIXLTH is set, but OVERWT is not, in this case OVERWT will be 1 and so overshooting by default.

CONVECTION OVER MIXLTH OVERWT NCONV

- Smooths over a scale height. Assumes overshooting by 0.5 scale height if convection is strong, but none if convection is weak.
- Setting OVERWT = 0 turns off overshooting.

See Smalley 2005, MSAIS, 8, 155

NCONV

- ATLAS puts the constraint that the convective flux (F_{conv}) must be zero above layer NRHOX/2
  - introduced to remove numerical artefacts
  - usually a good number, except for coolest models
    - constraint generates a jump in T-τ_{ross} for Teff $\leq 4000\mathrm{K}$
  - If NRHOX is 72, NRHOX/2 = 36
  - NCONV introduced by Castelli to allow user to specify the layer above which F_{conv} is surely zero
    - Default is 36

See Smalley 2005, MSAIS, 8, 155

The CM/CGM routines

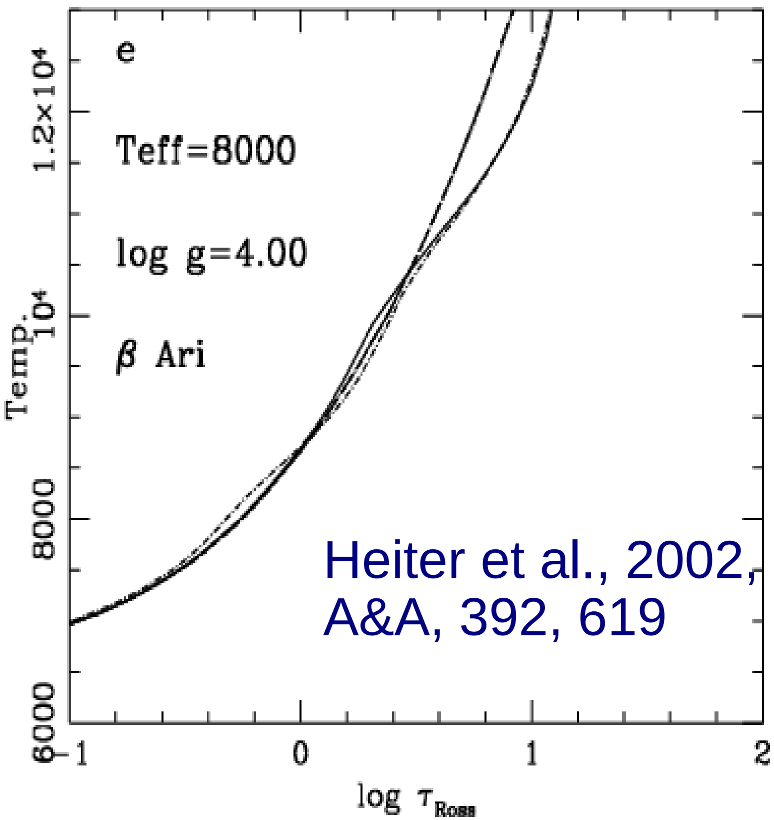
- Drop-in replacements for CONVEC and TCORR
  - implemented by Kupka 1996, ASPC, 108, 73
  - Not part of the Linux version of ATLAS

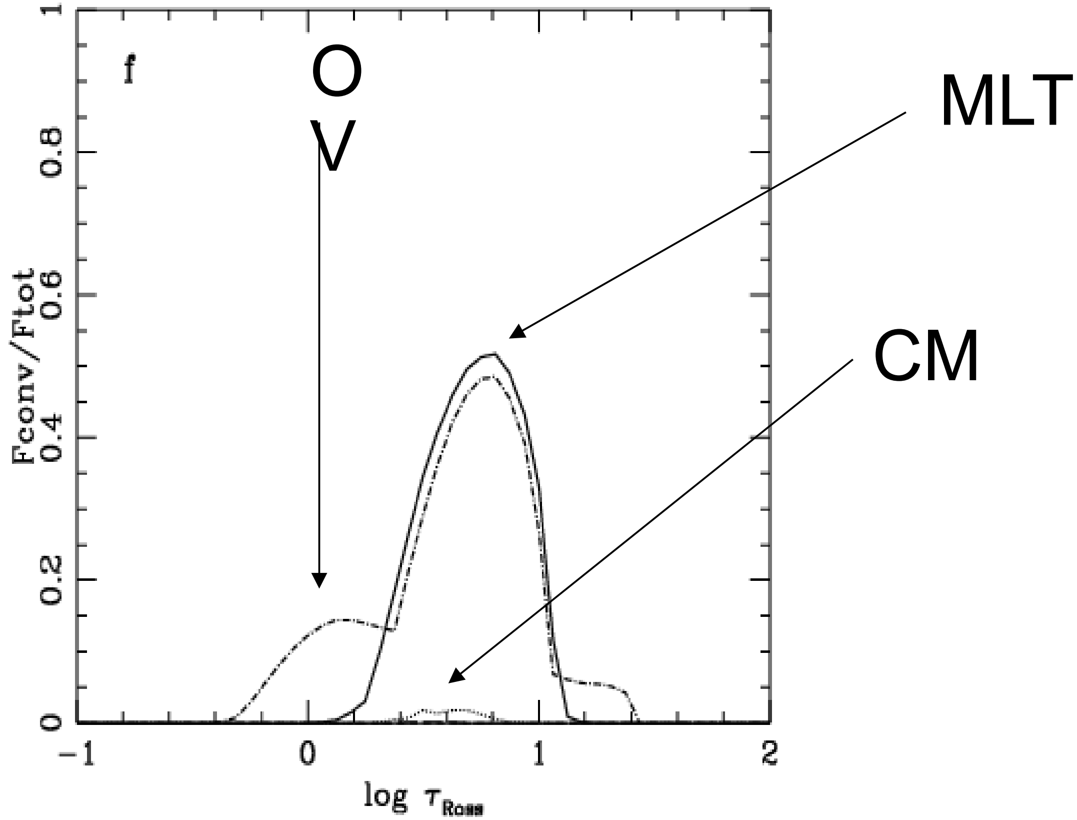
Usage: **CONVECTION ON** MIXLTH

- CM
  - MIXLTH not used, but must be > 0 in input
- CGM
  - MIXLTH in CGM has the meaning of "α^*", (see Canuto et al. 1996, ApJ, 473, 550), standard value used is 0.09

See Smalley 2005, MSAIS, 8, 155

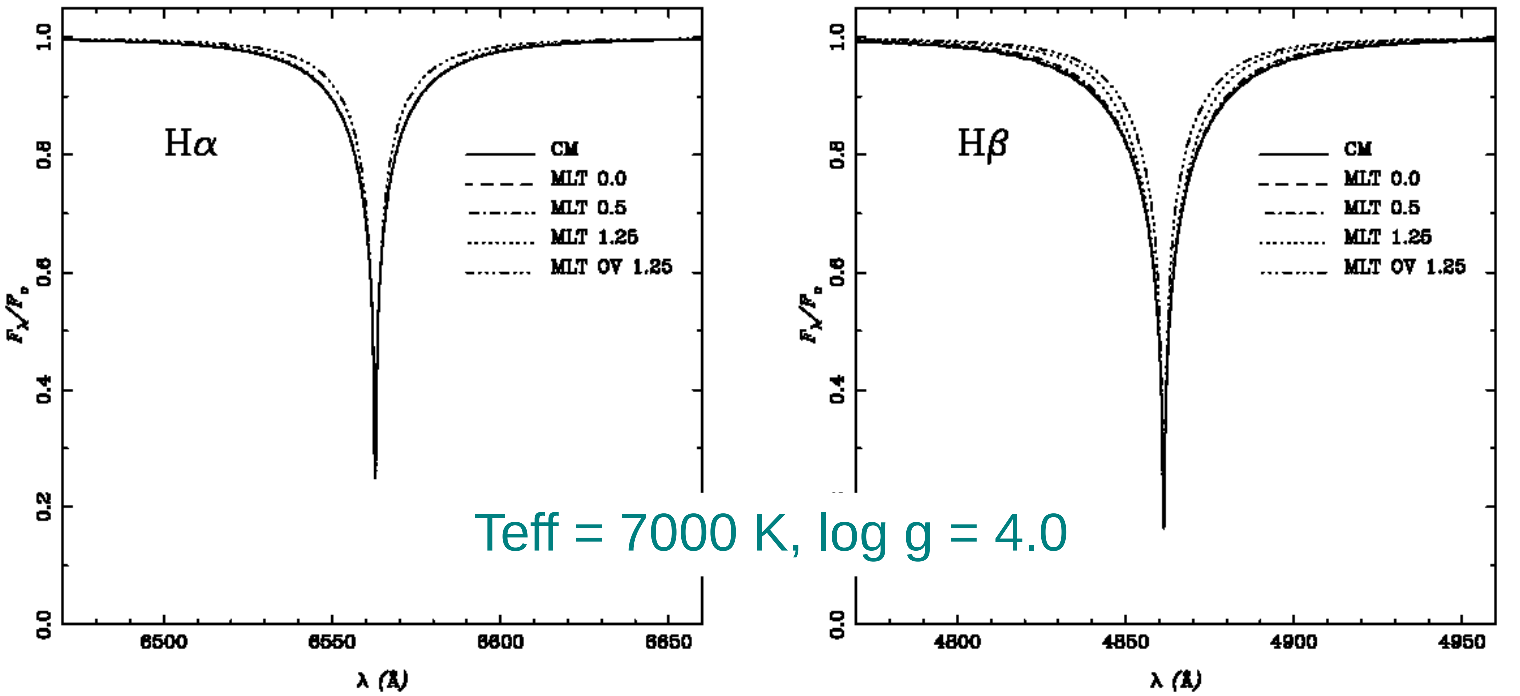
Atmospheric Structure





- At T_{eff} = 8000K CM gives essentially radiative temperature gradient
  - less convective flux than MLT
- Overshooting introduces flux in higher layers

Balmer profile variations



Teff = 7000 K, log g = 4.0

- Formed at different depths within atmosphere
  - probe differing parts of atmospheric structure
- Changing the efficiency of convection, by increasing mixing length, has significant effect on computed profile

Balmer profile sensitivities

- Hα insensitive to mixing-length
- Hβ sensitive to mixing-length
- Both lines affected by overshooting
  - sensitive to temperature and metallicity
  - surface gravity sensitivity for hotter stars

Van't Veer & Megessier, 1996, A&A 309, 879

What to use in ATLAS?

- Detailed comparison between CM and MLT:
  - Both CM and MLT good overall agreement with observations.
    - **But with no overshooting**
  - Suggestions that *l/H* = 0.5 better for A stars, and *l/H* = 1.25 for cooler F and G stars.

Smalley & Kupka, 1997, A&A 293, 446;
Gardiner et al., 1999, A&A 347, 876;
Smalley et al., 2002, A&A 395, 601

Recommended ATLAS models for general use are Castelli et al. 1997 (A&A, 318, 841) with no overshooting and *l/H* = 1.25

Microturbulence

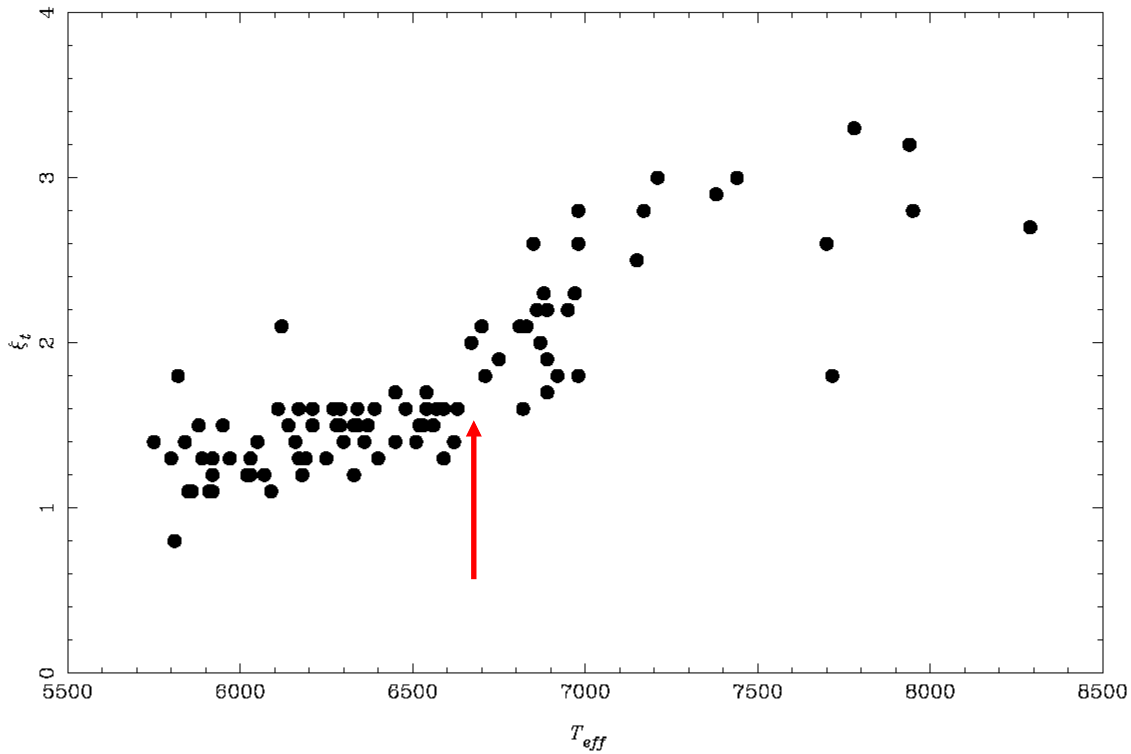
- A ***free*** parameter introduced to ensure that abundances from weak and strong lines agree
- Extra source of broadening
  - added to thermal broadening
- Small scale motions within the atmosphere

Is it caused by incomplete physics in model atmospheres?

OR

Intimately related to convective motions within the atmosphere?

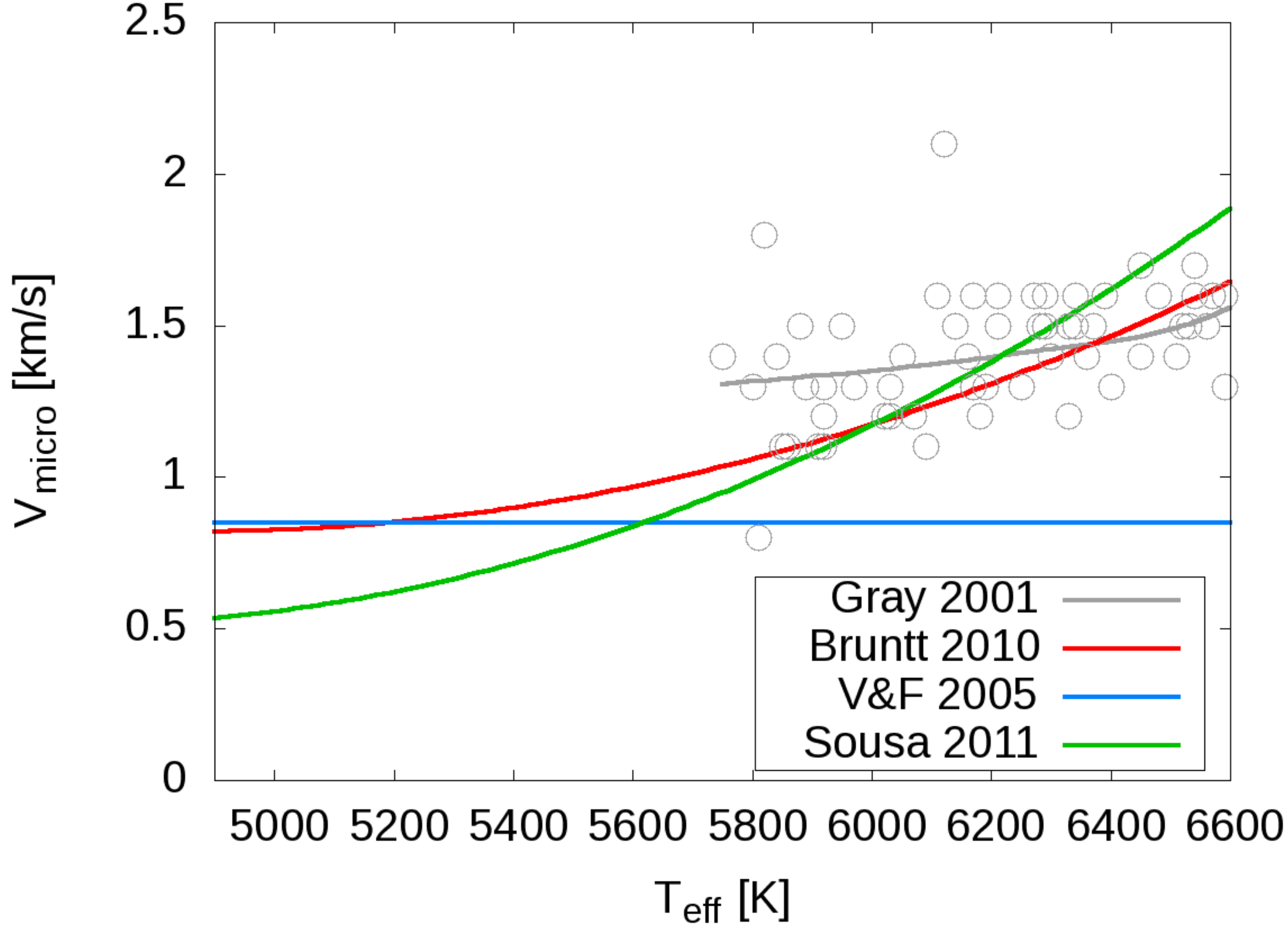
Microturbulence Variations



Smalley 2004, IAUS 224, 131 based on Gray et al. 2001, AJ, 121, 2159

- Microturbulence varies with T_{eff}
  - increases with increasing temperature
    - peaking around mid-A type

Microturbulence Calibrations

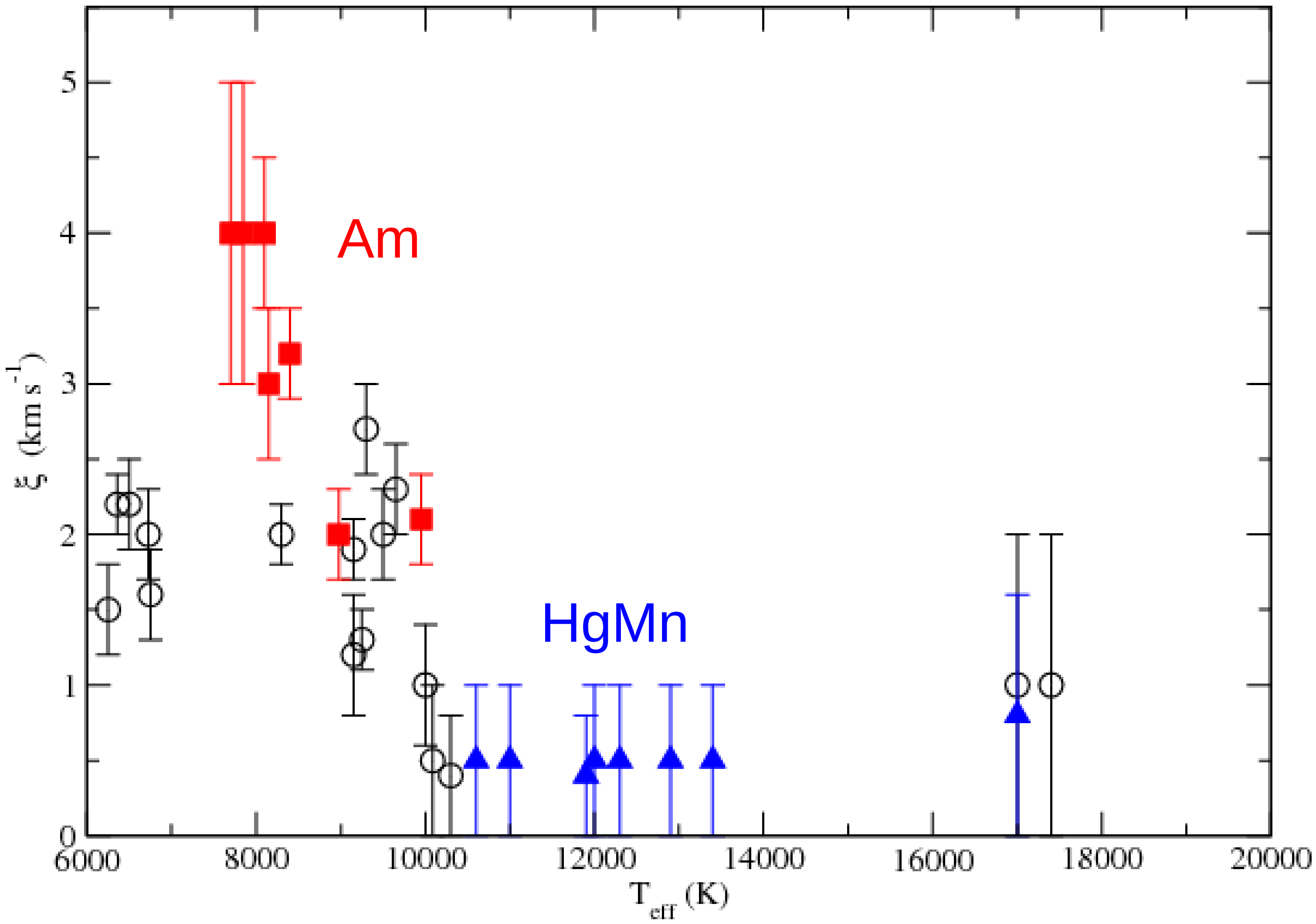


Valenti & Fischer 2005 found: "strongly correlated values of v_{mic} and [M/H], suggesting that v_{mic} and [M/H] are partially degenerate." Adopted fixed value.

Gray 2001 fit by Smalley 2004 IAUS 224, 131
Sousa 2011 is fit given in 2013arXiv1302.6115G

Valenti & Fischer, 2005, ApJS,159, 141
Bruntt et al., 2010, MNRAS, 405, 1907

Microturbulence in A and B stars



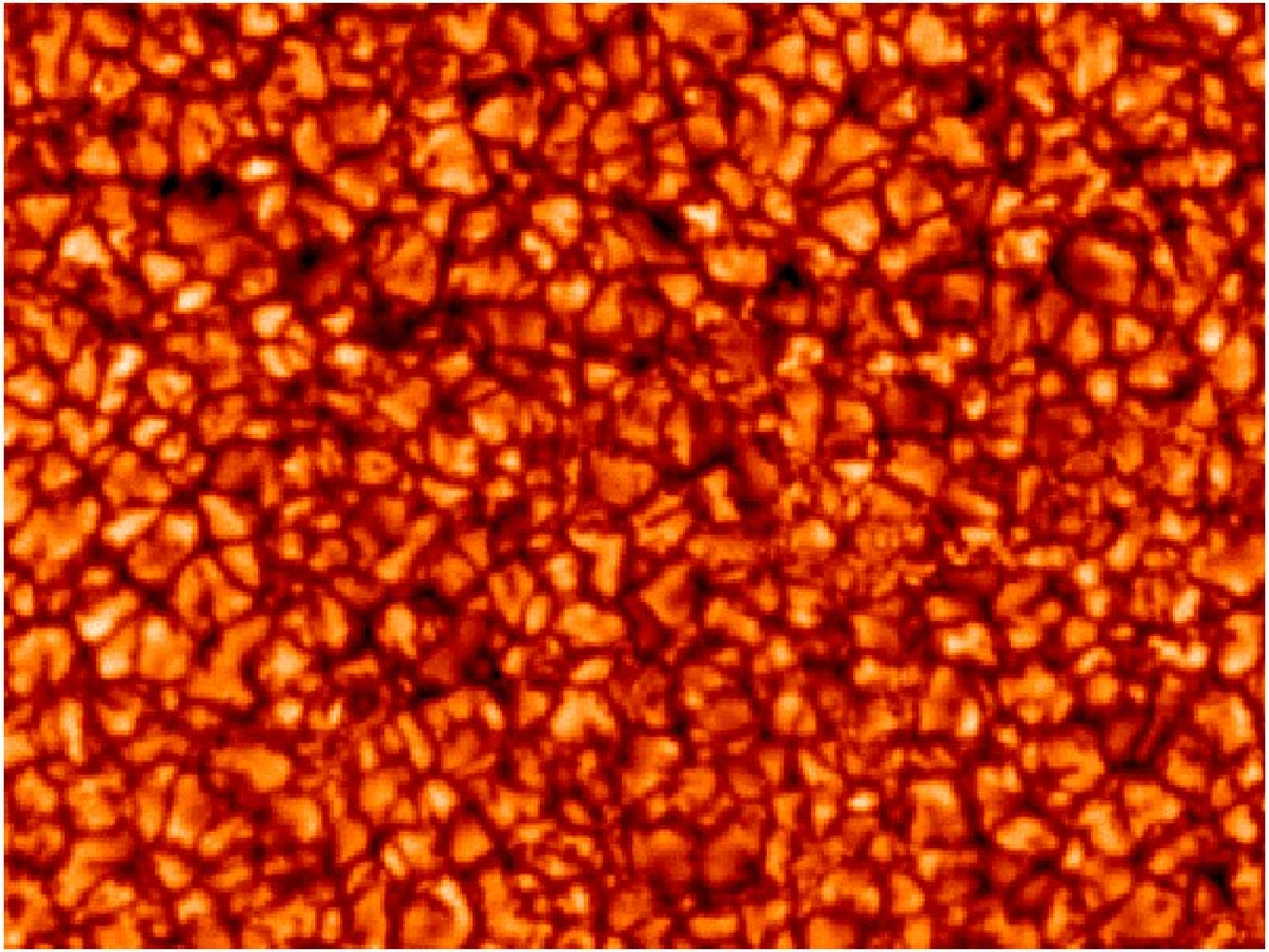
Landstreet et al., 2009, A&A, 503, 973

No need for microturbulence?

- Numerical simulations avoid the need for such a free parameter (Asplund et al., 2000, A&A 359, 729)
  - de-saturating effects
    - not turbulent motions, but velocity gradients

No longer a free parameter and should be constrained when using 1-d models

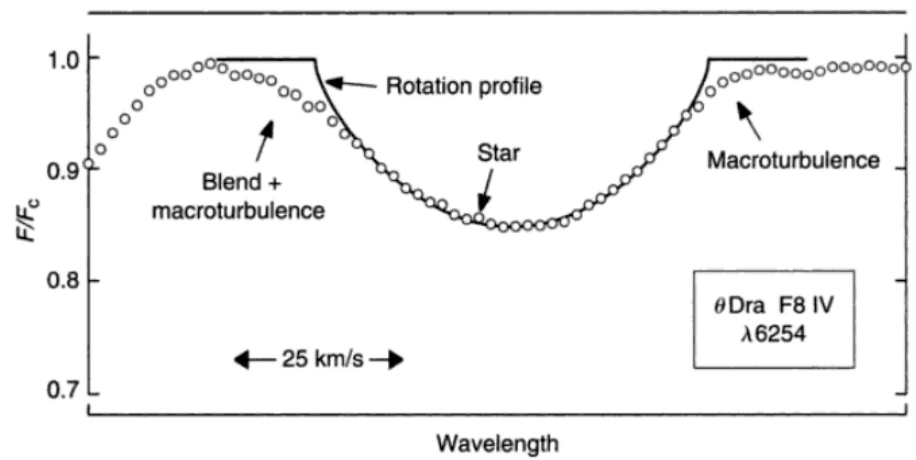
Solar Granulation

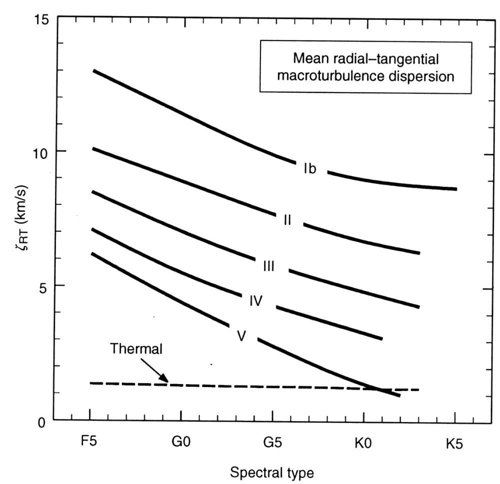


http://zeus.nascom.nasa.gov/~dmueller/gran_intro.htm

Macroturbulence

- Extended shallow wings
- Strong in giants and supergiants
- Seen in A-type stars
- Even B supergiants
  - Przybilla et al., 2006, A&A, 445, 1099
- Large-scale velocities within atmosphere





Gray 2008 Book

Gray's Radial-Tangential Model

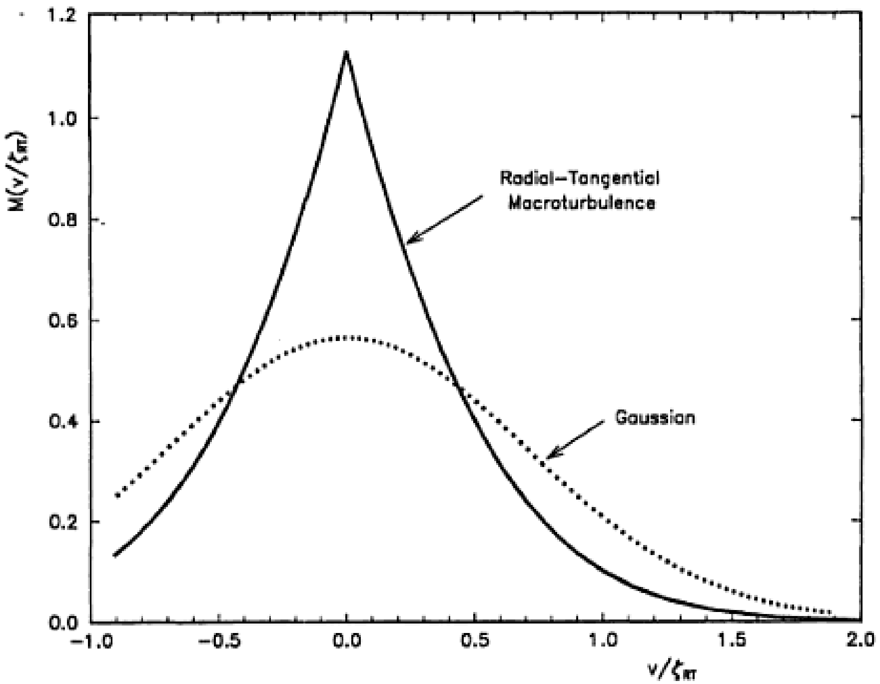
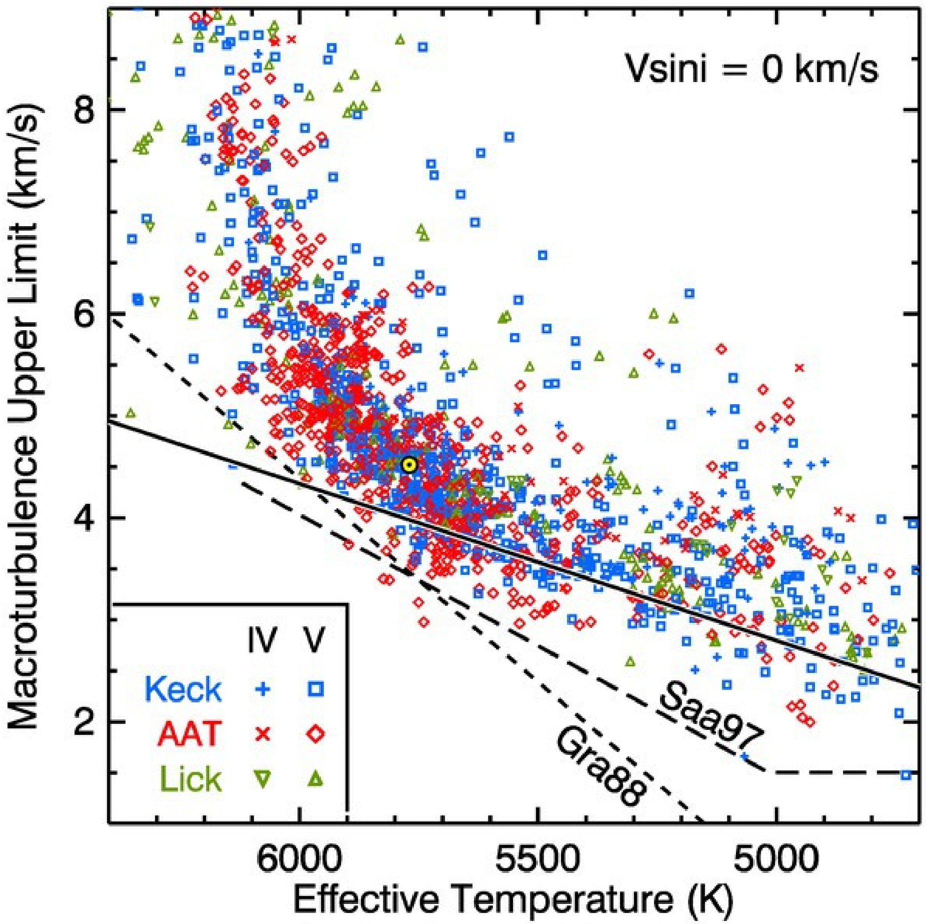


Fig 17.5 Gray (2008)

- Dopper broadening in both radial and tangential directions
  - ½ surface radial
  - ½ surface tangential
- Assume same velocity for both (ζ_{RT})
- A ***free*** parameter

Valenti & Fischer 2005

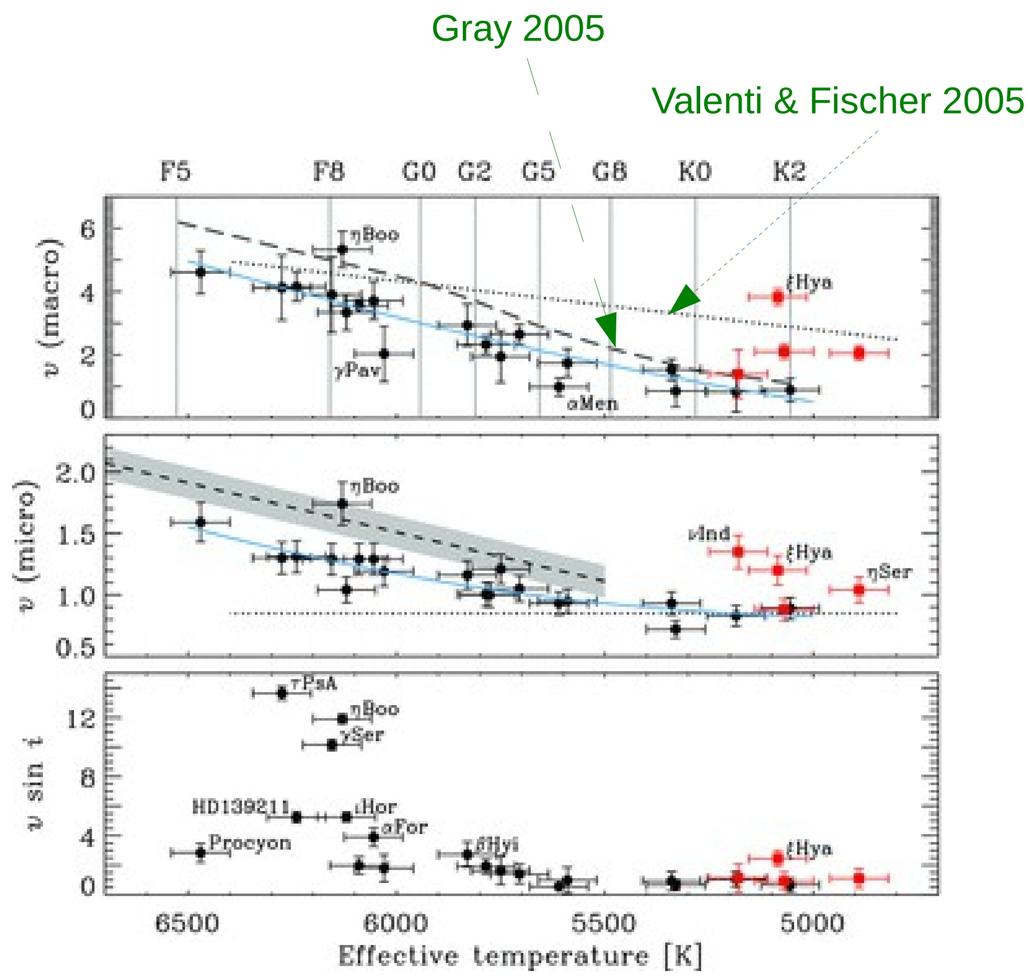


Valenti & Fischer, 2005, ApJS,159, 141

- Determined V_{macro} assuming $v \sin i = 0$
  - An *upper limit*
- But might underestimate above ~5800K

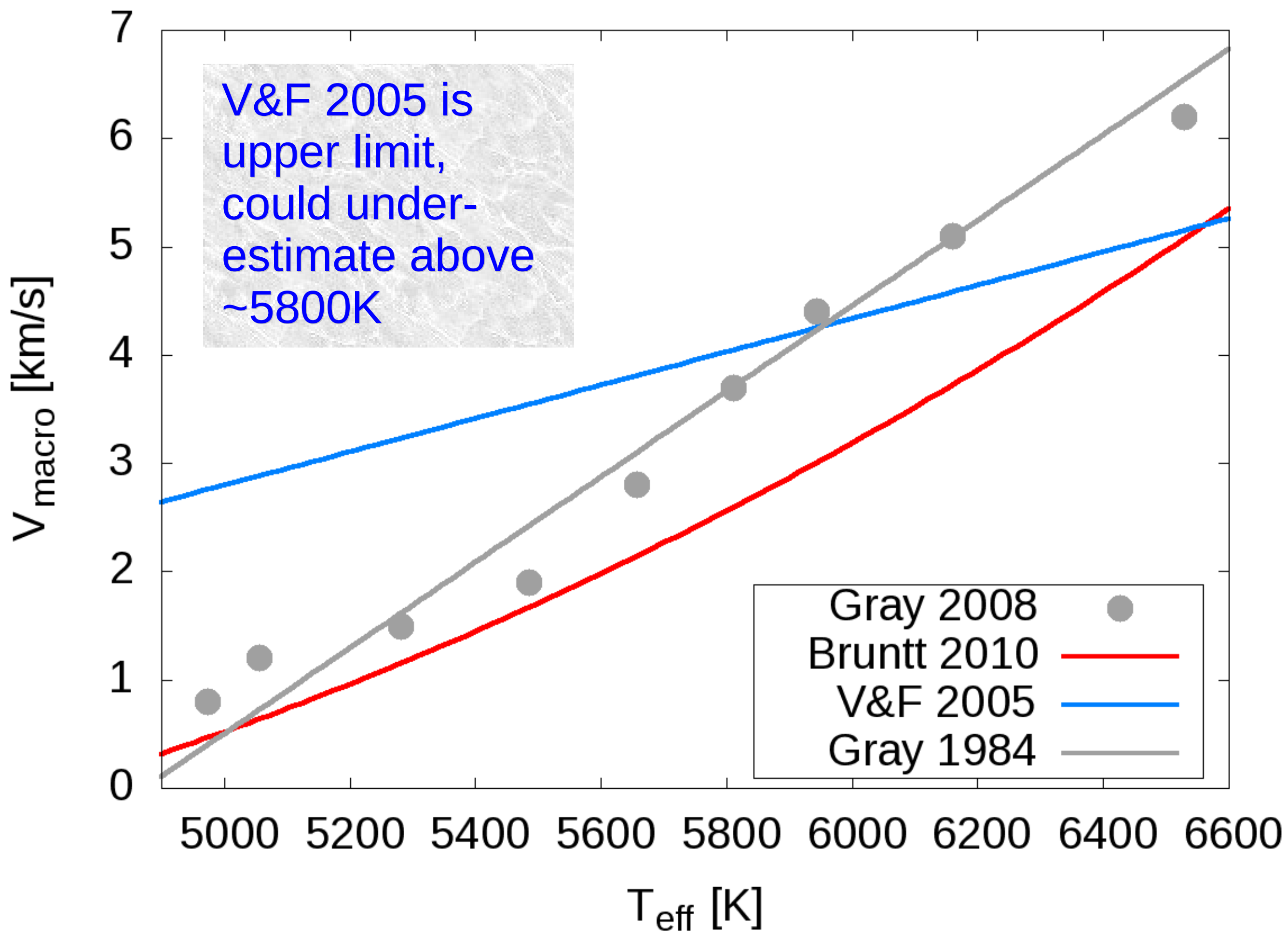
Bruntt et al.

- Calibration of both microturbulence and macroturbulence



Bruntt et al., 2010, MNRAS, 405, 1907

Macroturbulence Calibrations

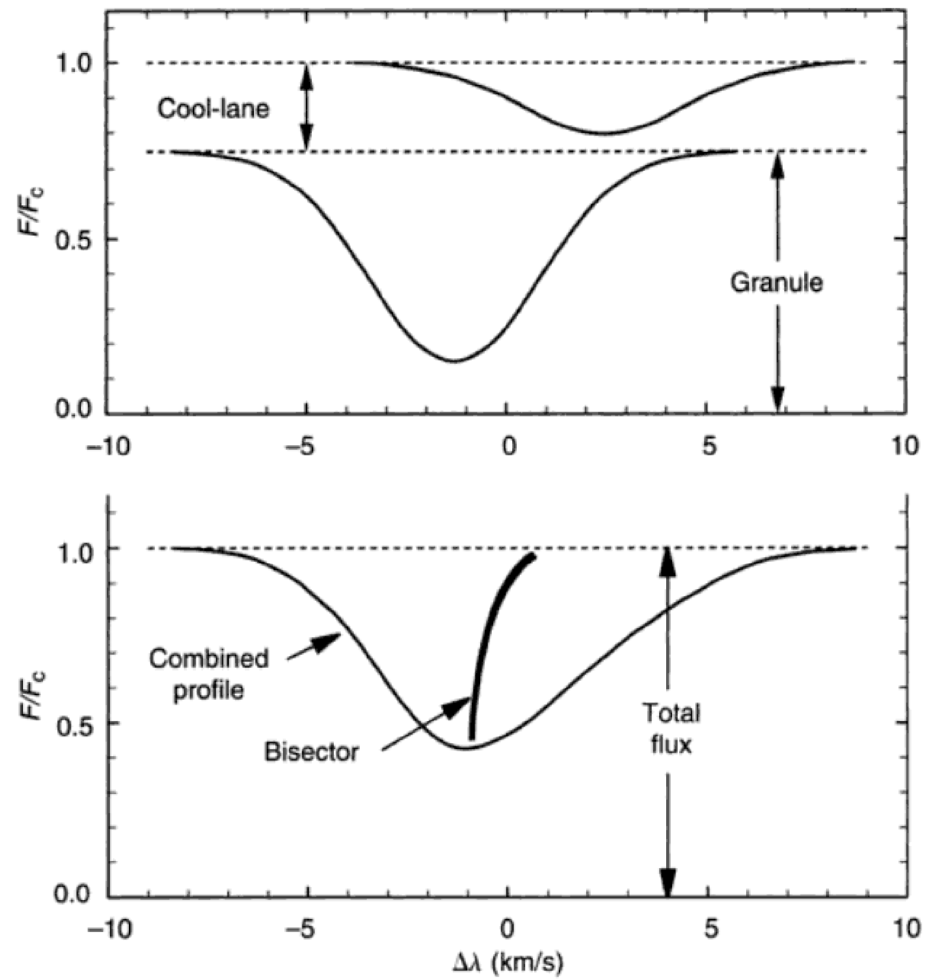


Gray, 1984, ApJ, 281, 719

Line Asymmetries

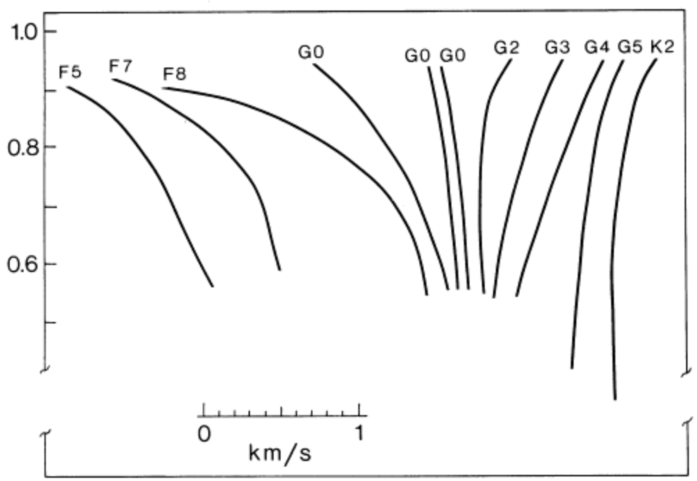
- Line Bisectors
- Velocity fields in atmosphere
  - Rising elements blue shifted
  - Falling elements red shifted
- A-type Stars
  - small rising columns of hot gas
  - larger cooler downdrafts
  - velocities consistent with microturbulence

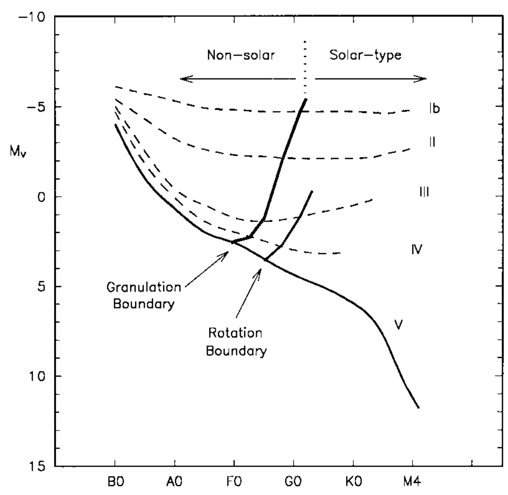
Landstreet, 1998, A&A, 338, 1041



Gray (2008) Book

Line Bisector Variations



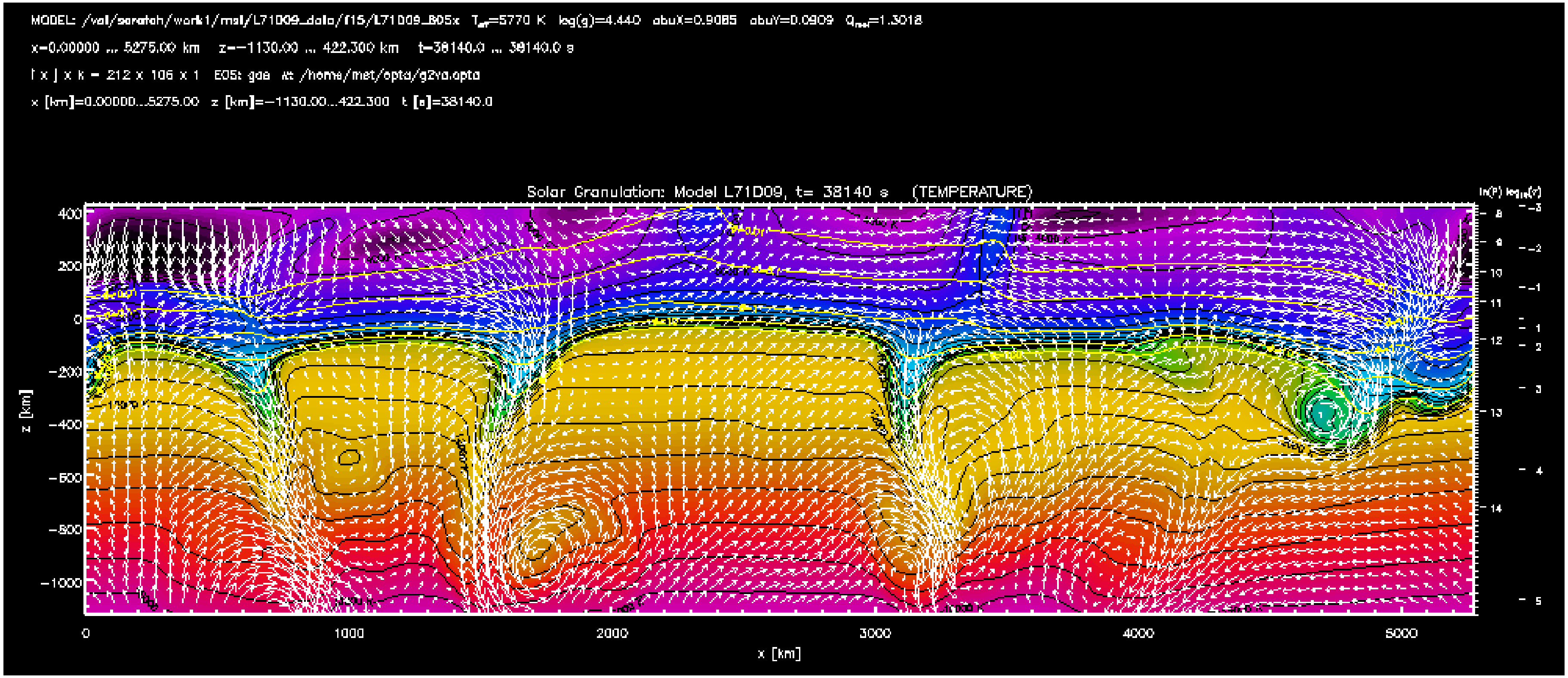


Gray 2008 Book

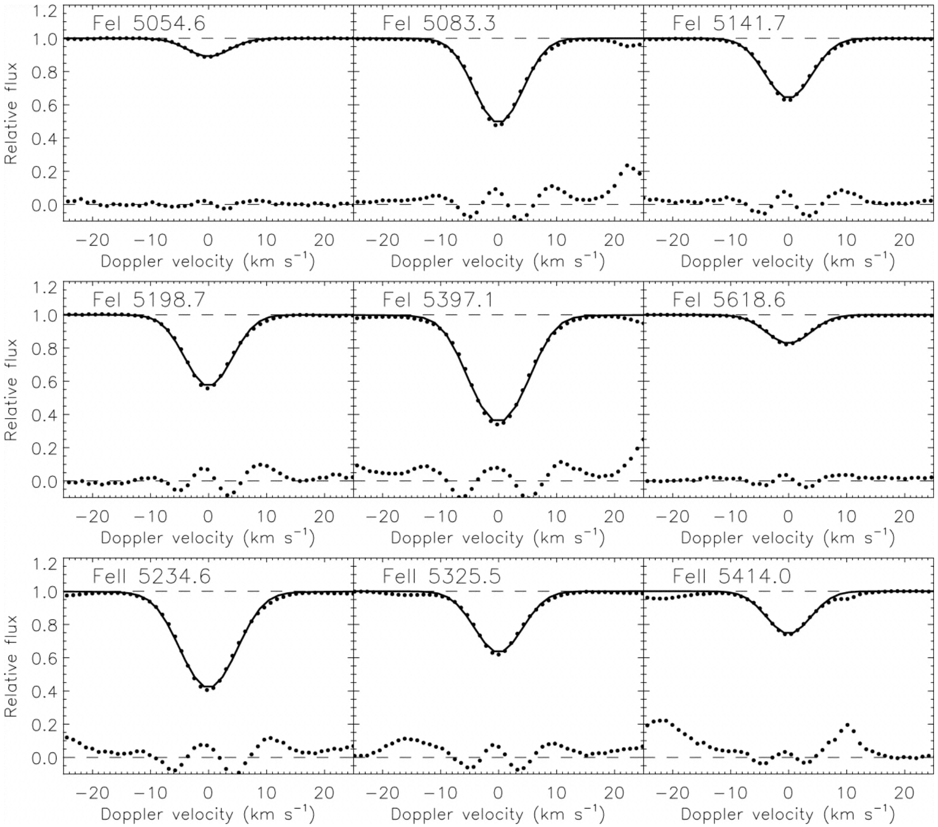
- Bisectors are reversed for early-F and A stars
  - No curvature in B stars
- Granulation Boundary
  - Changing from fully convective to weak subsurface convection

Realistic Convection Models

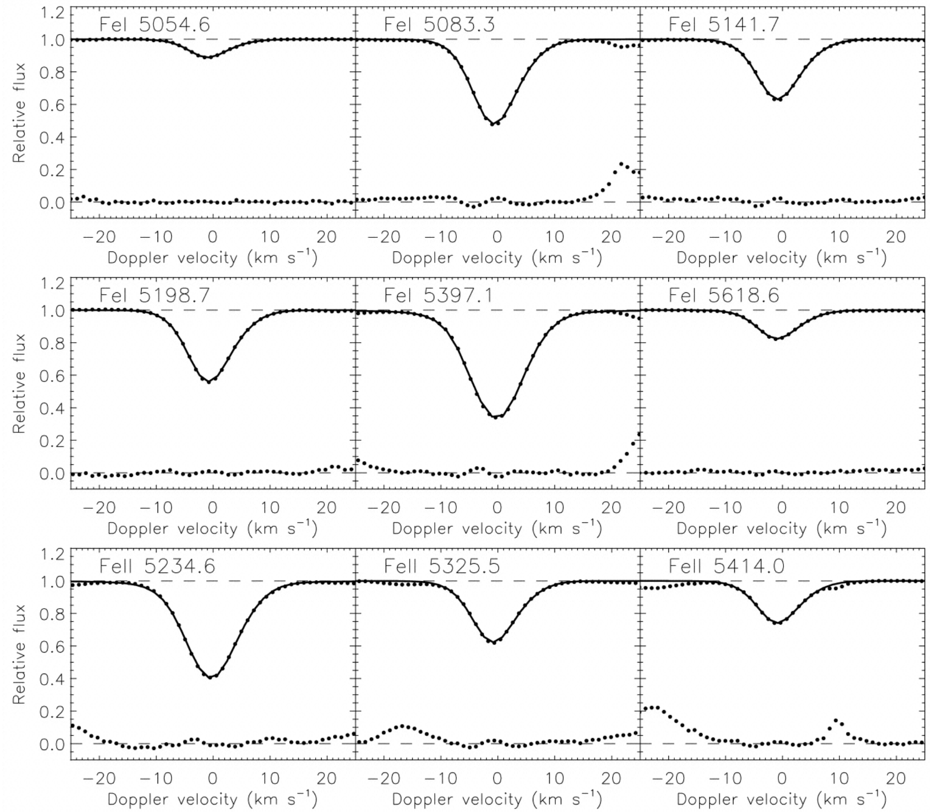
- None of the current 1d models of convection are totally satisfactory
  - What do 2d & 3d hydrodynamic simulations reveal?



Procyon Line profiles (1-d vs 3-d)



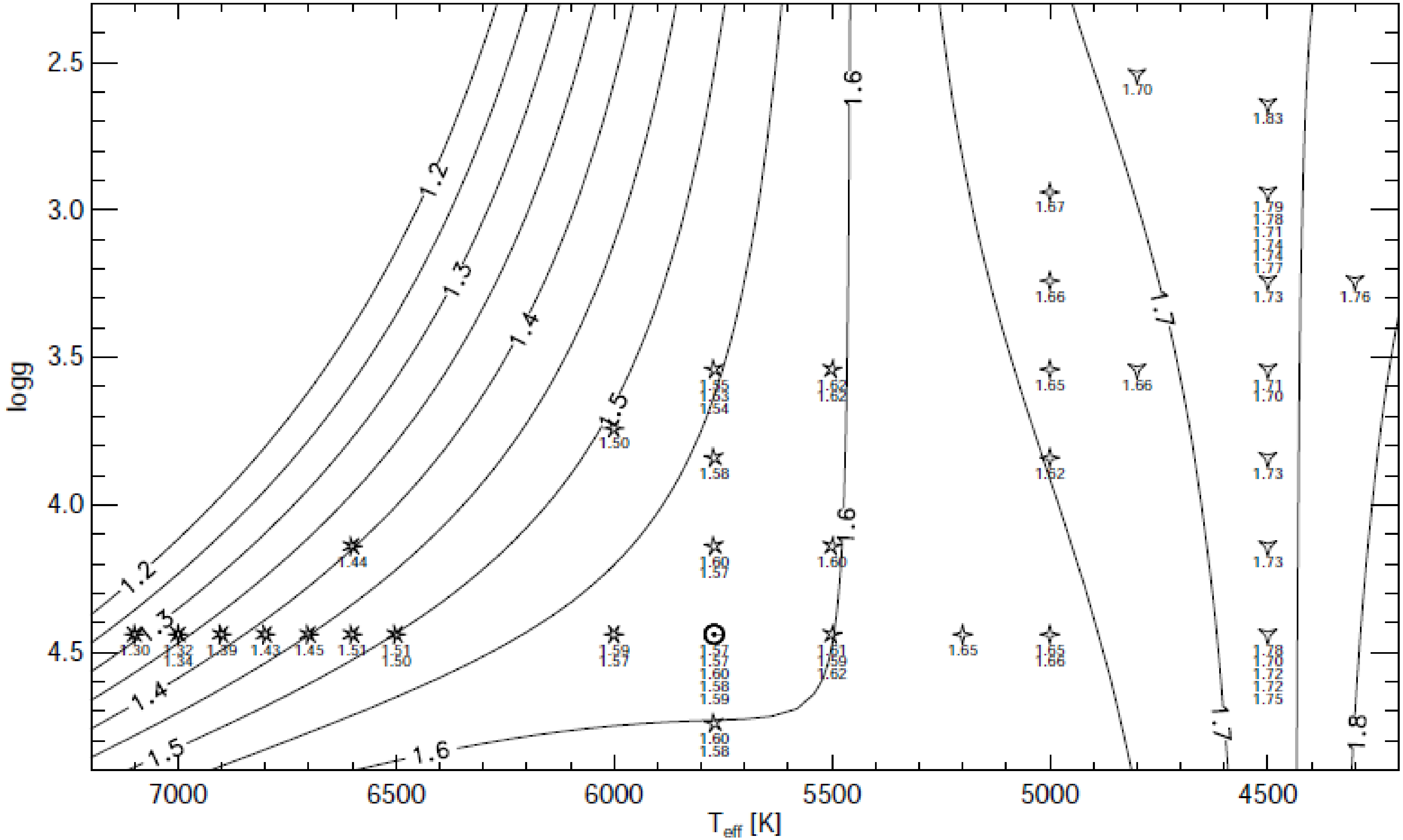
1-d



3-d

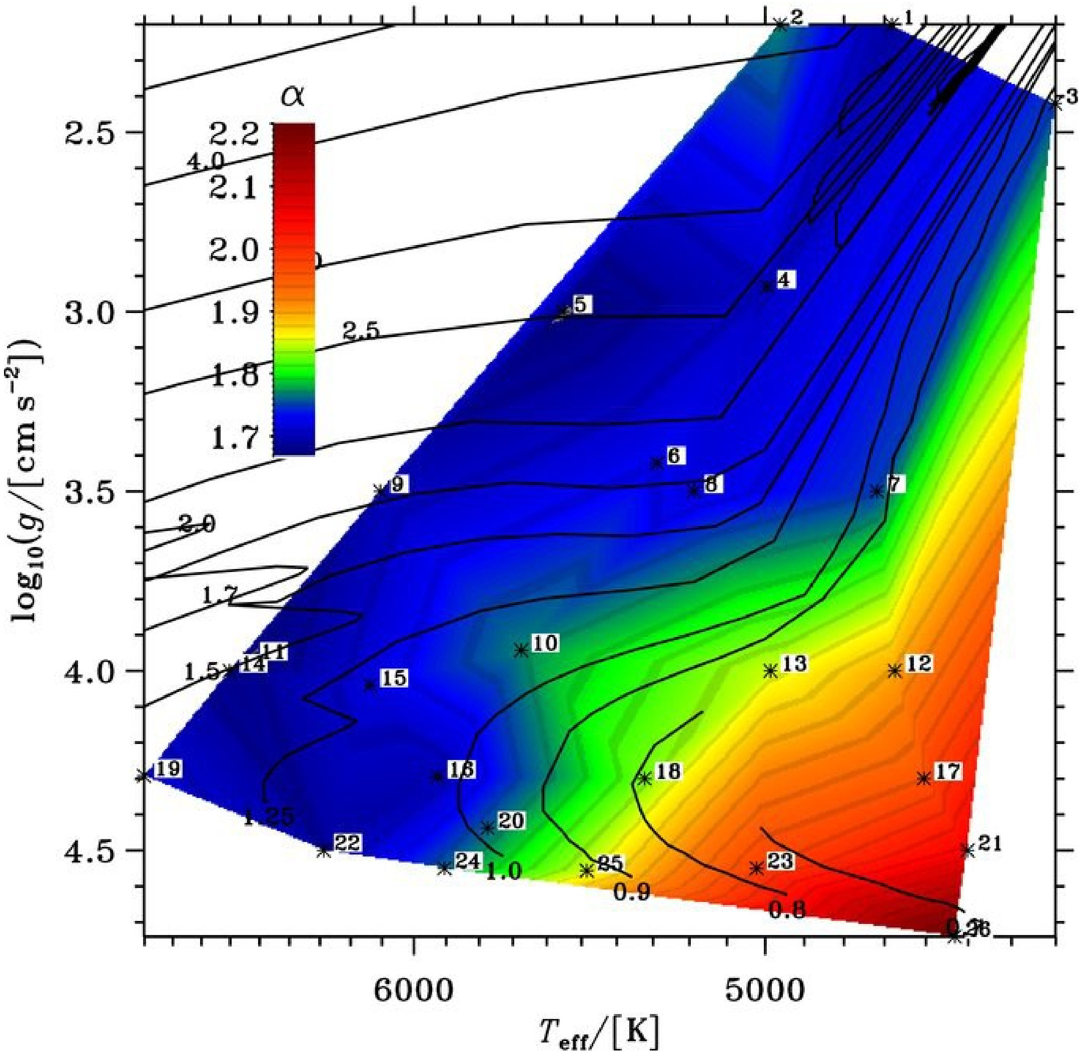
Allende Prieto et al., 2002,ApJ, 567, 544

2-d calibration of mixing-length



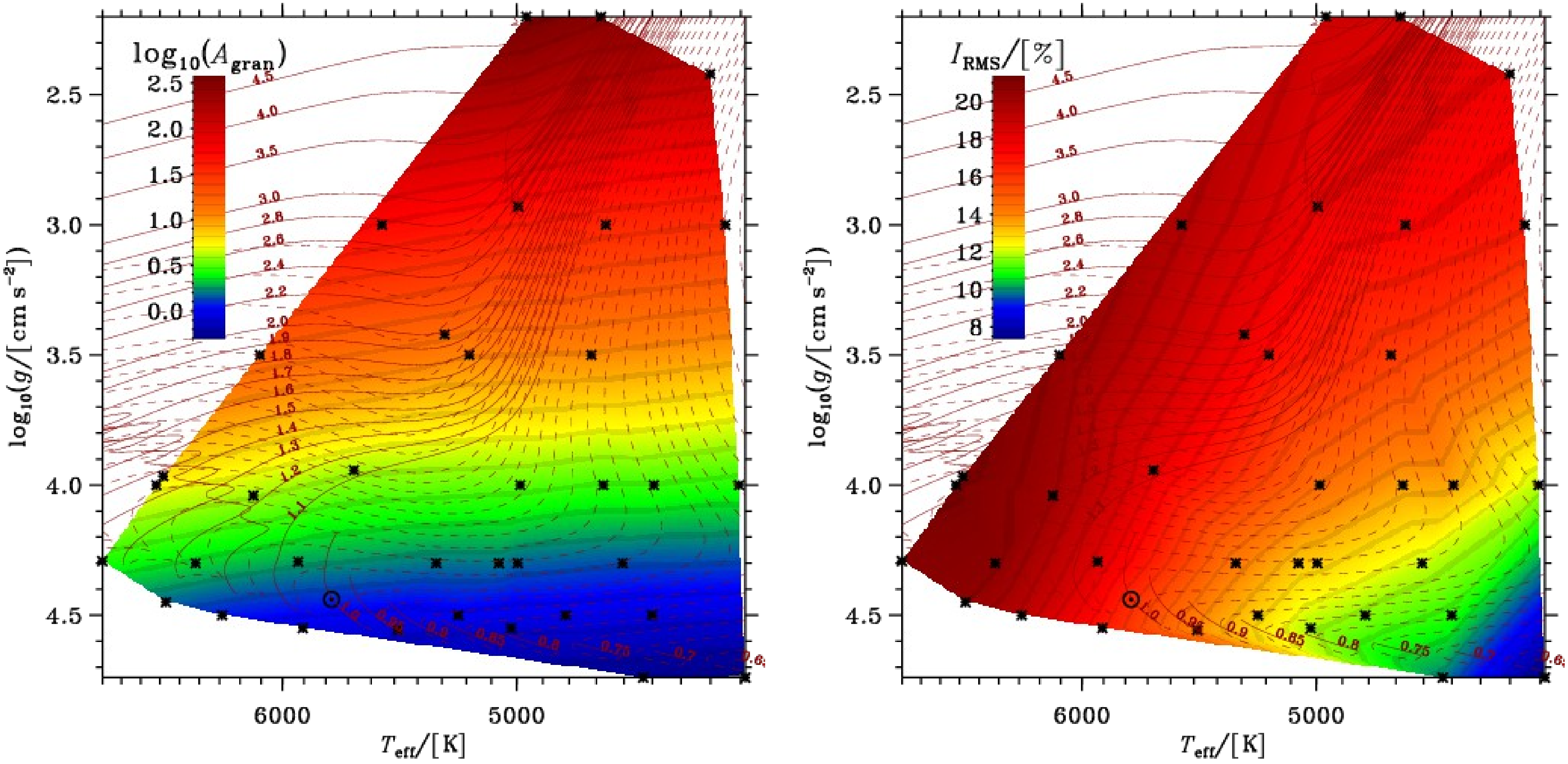
Ludwig et al, 1999, A&A, 346, 111

Mass Mixing-length variations



Trampedach & Stein 2011,ApJ, 731, 78

Granulation: size and contrast



Trampedach et al., 2013, arXiv1303.1780

3D CO5BOLD turbulence

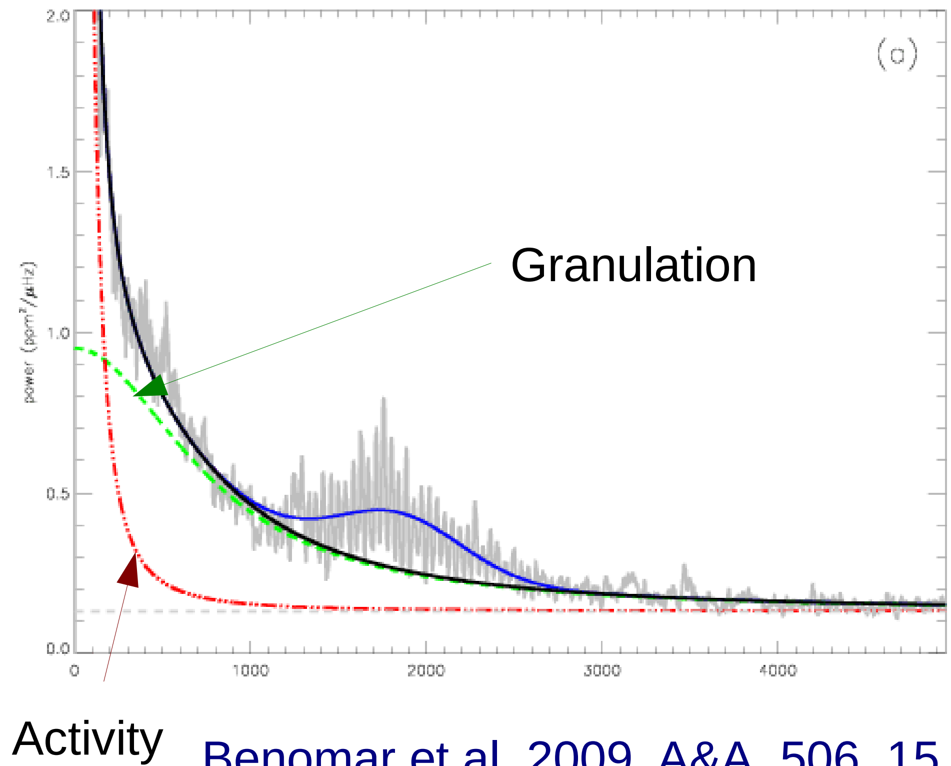
Atmosphere	$\xi_{\rm mic}$ [km/s]		$\xi_{\rm mac}$ [km/s]		$v_{\rm turb} = \sqrt{(\xi^2_{\rm mic} + \xi^2_{\rm mac})/2}$ [km/s]	
	disk-center	full-disk	disk-center	full-disk	disk-center	full-disk
Sun, observed[a]	1.00 ± 0.15	1.35 ± 0.15	1.63 ± 0.15	1.90 ± 0.15	1.35 ± 0.10	1.65 ± 0.10
3D solar model (gt57g44n58)	0.70 ± 0.10	0.95 ± 0.15	1.85 ± 0.45	2.40 ± 0.30	1.40 ± 0.30	1.80 ± 0.20
Procyon, observed[b]	—	2.10 ± 0.30	—	4.20 ± 0.50	—	3.30 ± 0.30
3D Procyon model (d3t65g40mm00n01)	0.95 ± 0.25	1.45 ± 0.25	3.10 ± 0.40	4.40 ± 0.30	2.30 ± 0.30	3.30 ± 0.20

Steffen et al., 2009, MmSAI, 80, 731

- Preliminary results:
- Overall turbulence agrees, but
  - microturbulence is underestimated
  - macroturbulence overestimated.

Asteroseismology

- Kepler analyses may yield improved understanding of convection and turbulence.
  - Mixing length l/H lower than Sun and increases with [M/H]
    - Bonaca et al., 2012, ApJ, 755, L12



Benomar et al. 2009, A&A, 506, 15

Granulation in A stars

Kallinger & Matthews 2010, ApJ, 711, L35
Balona, 2011, MNRAS, 415, 1691

A Convection Recipe

No convection		Weak convection (sub-surface)	Strong convection (surface)
$l/H = 0$	$l/H = 0$	$l/H \simeq 0.5$	$l/H \simeq 1.25$
$\xi_{\rm t} = 0$	$\xi_{\rm t} \sim 2 {\rm km\,s^{-1}}$	$\xi_{\rm t} \sim$ 2-4 ${\rm km\,s^{-1}}$	$\xi_{\rm t} \sim$ 1-2 ${\rm km\,s^{-1}}$
A0V 10 000 K	A5V 8500 K	F0V 7000 K	

Smalley, 2004, IAUS 224, 131

- Schematic variation of microturbulence and mixing length with $T_{\rm eff}$
  - The two appear to be intimately linked

Summary

- Convection and Turbulence
  - Parameterized in 1-d models using:
    - Mixing-length
    - Microturbulence
    - Macroturbulence
  - They are free parameters, but should not be
- 3-d models and detailed observations should be able to provide prescriptions for these 1-d parameters