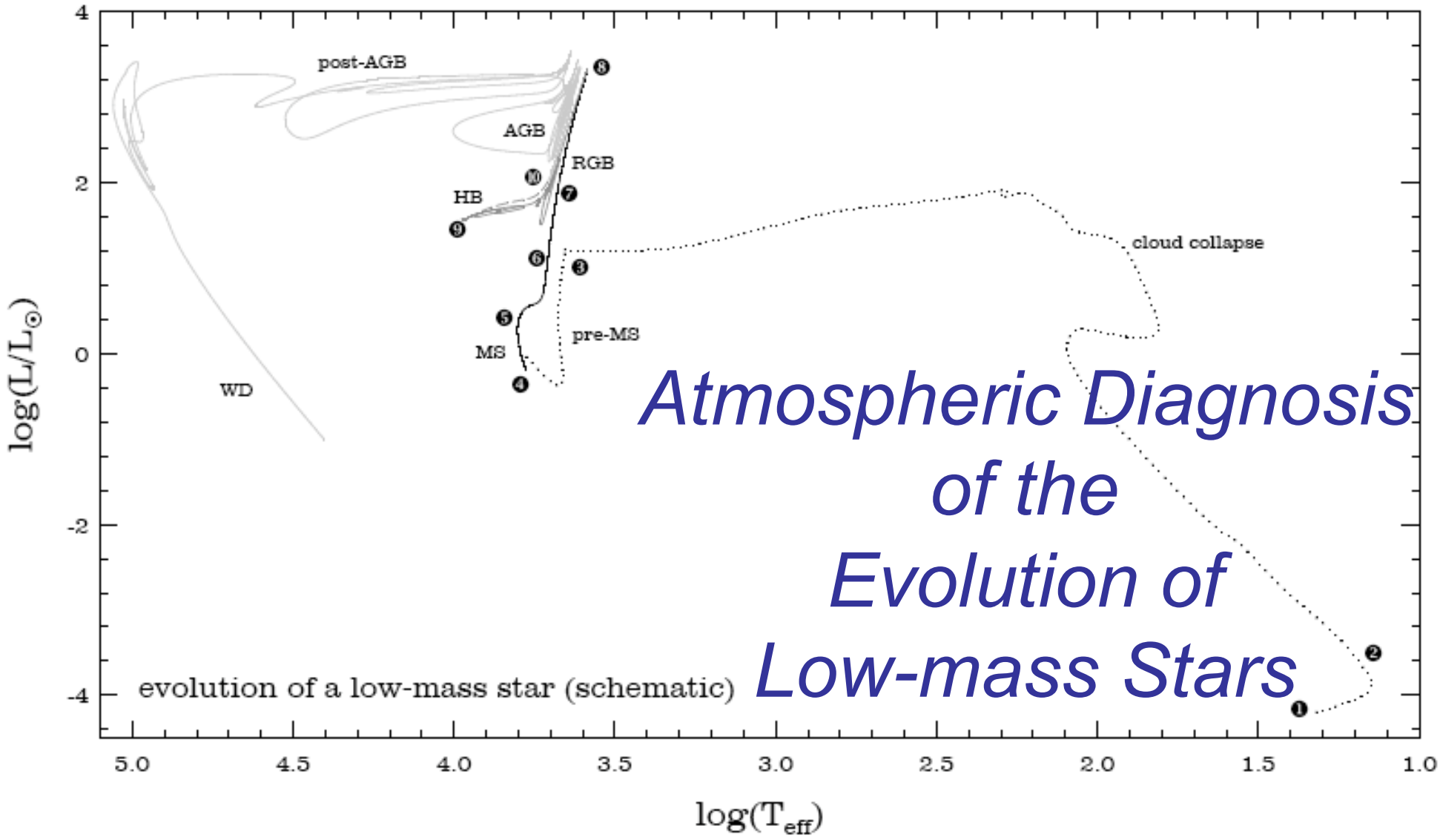

Atmospheric Diagnosis of the Evolution of Low-mass Stars

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Dept of Physics and Astronomy

Uppsala University

UPPSALA UNIVERSITET

Fig. from Catelan (2007)

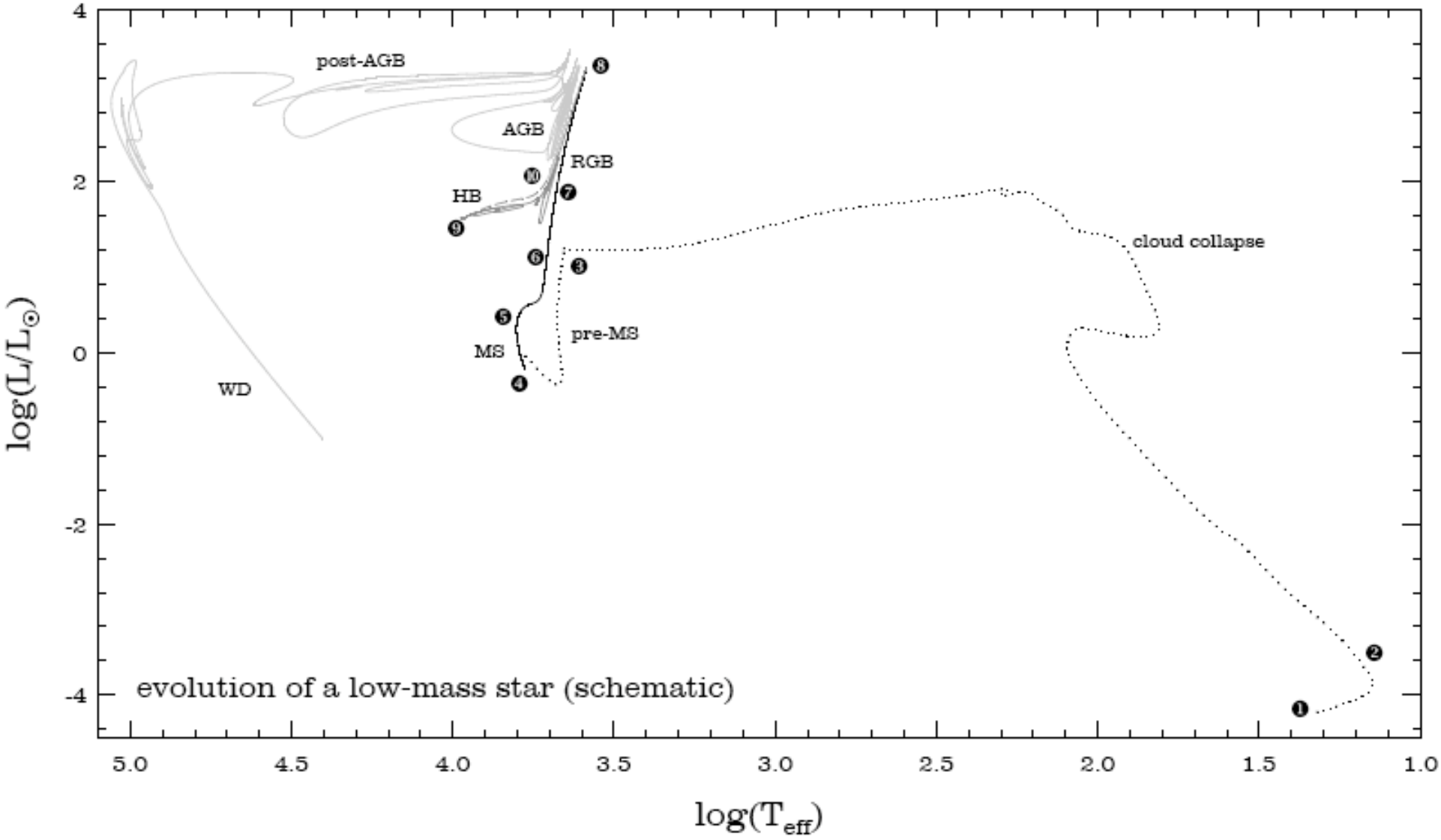


Fig. from Catelan (2007)

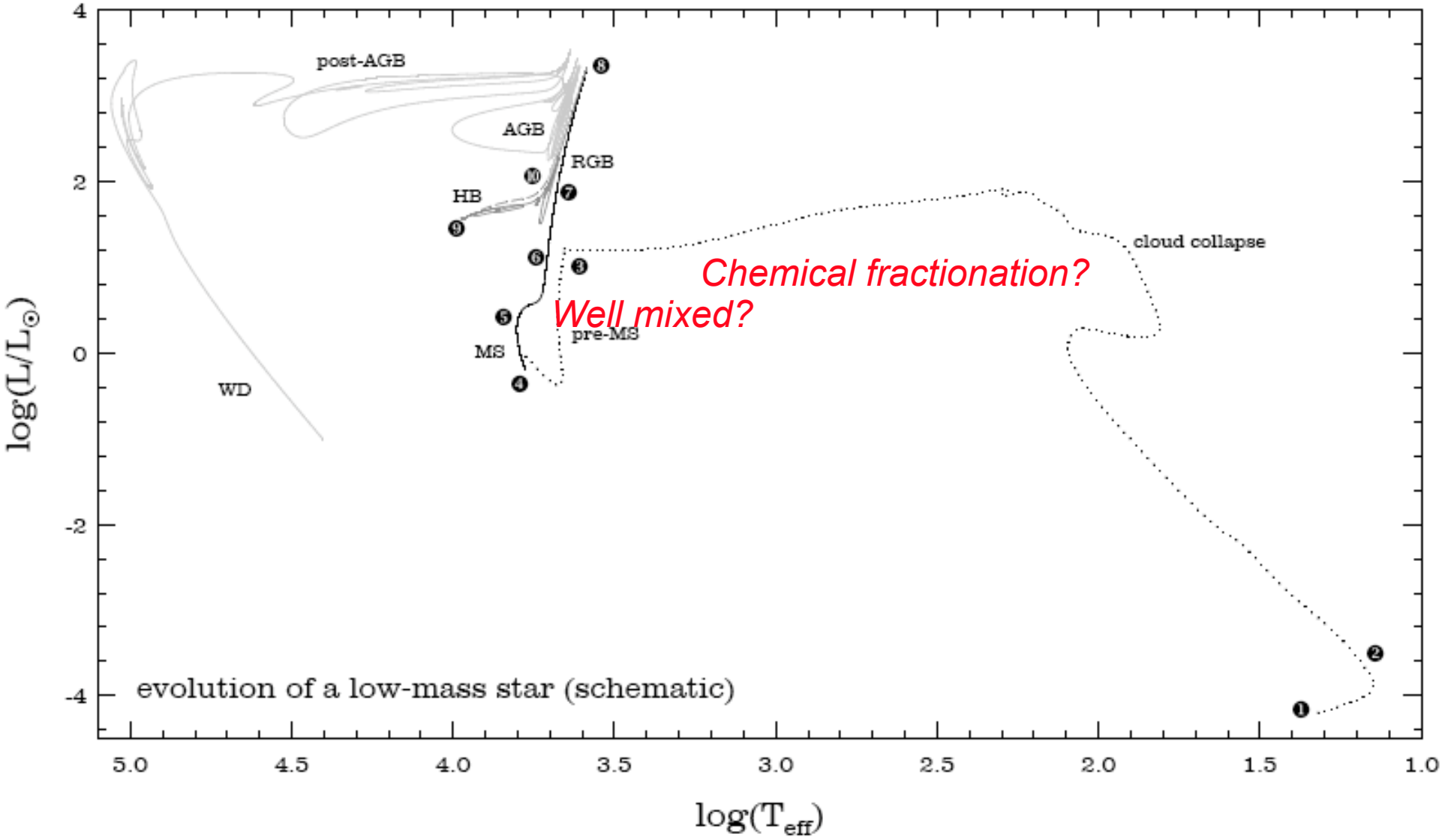


Fig. from Catelan (2007)

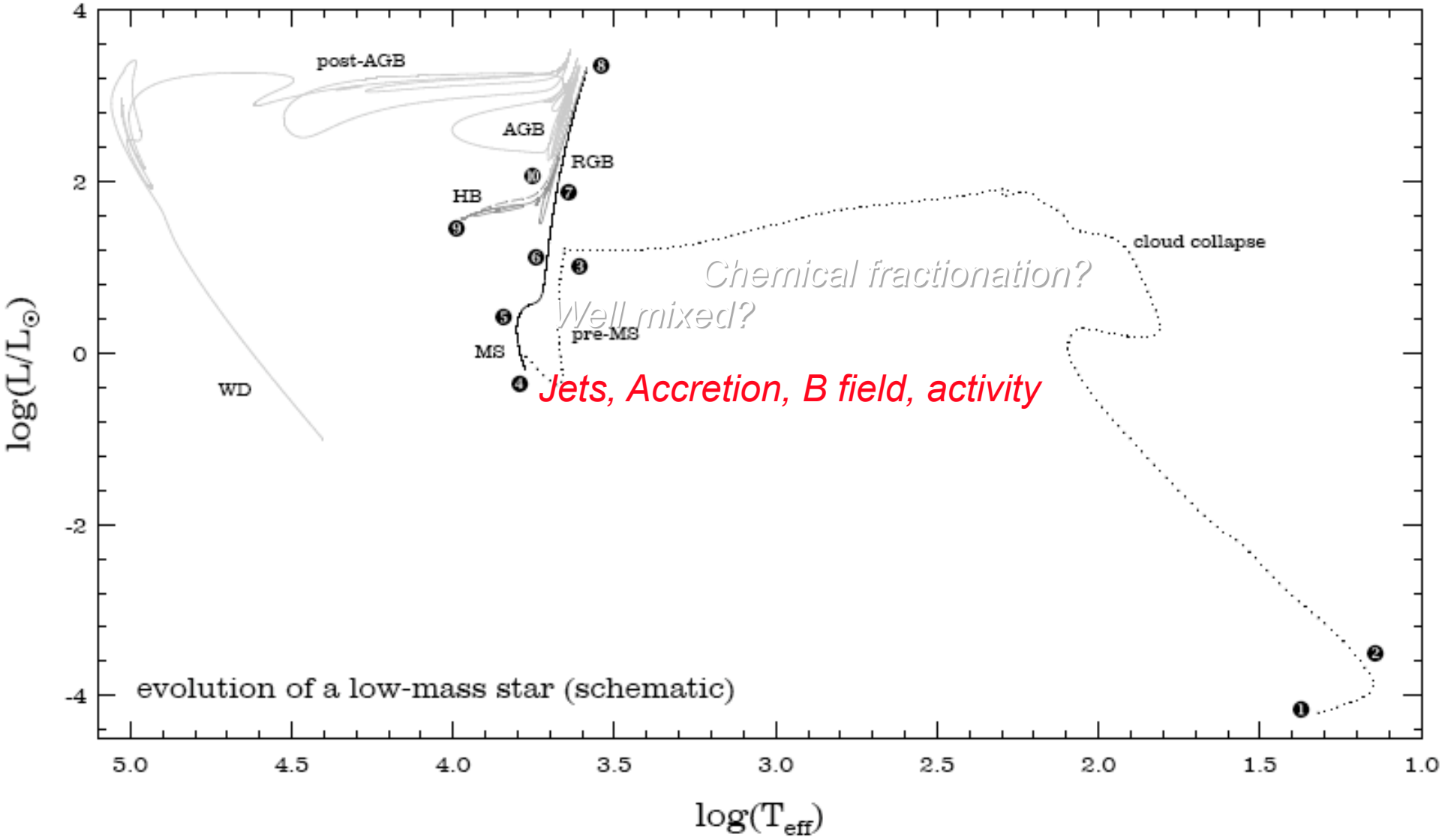


Fig. from Catelan (2007)

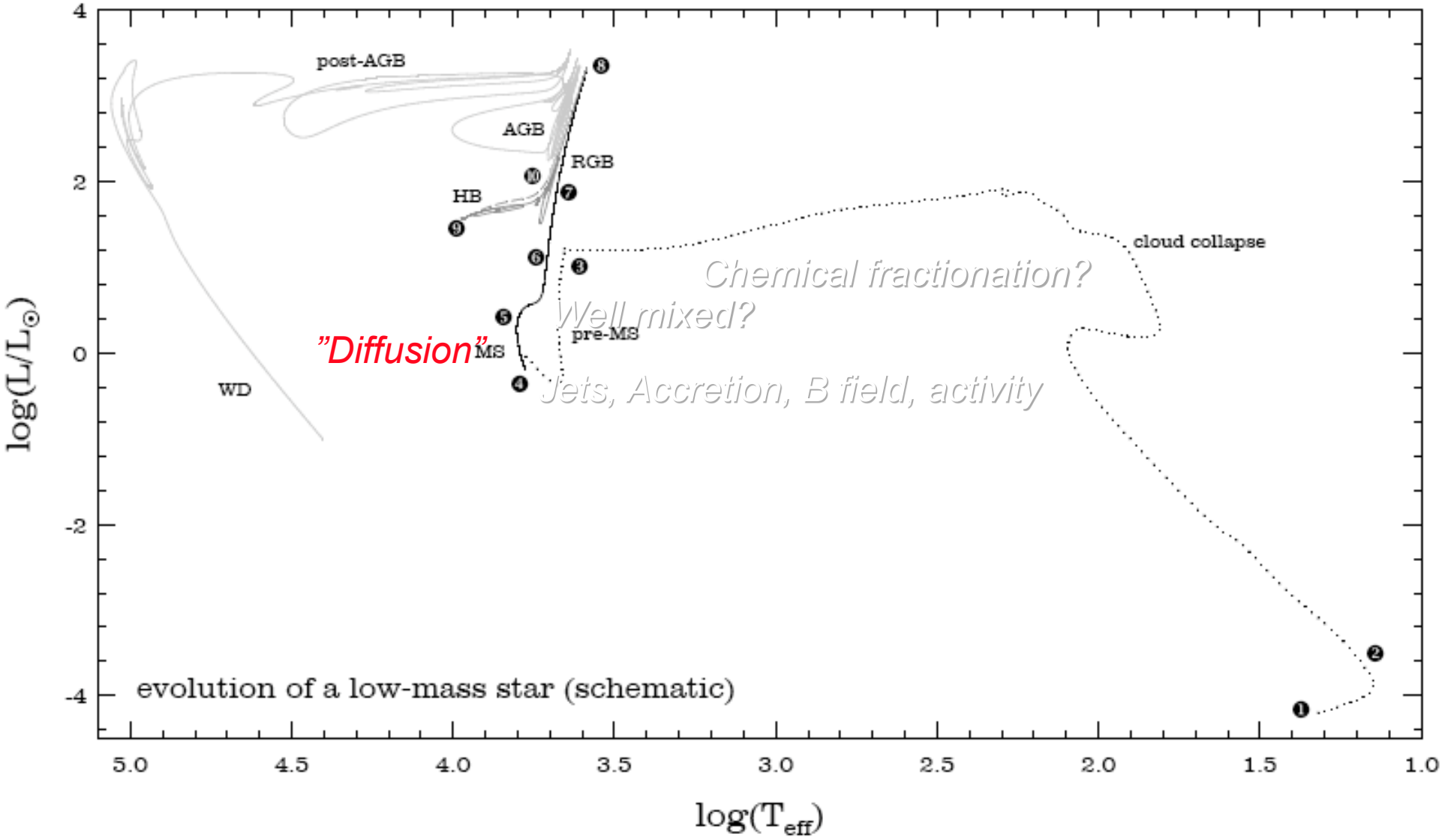


Fig. from Catelan (2007)

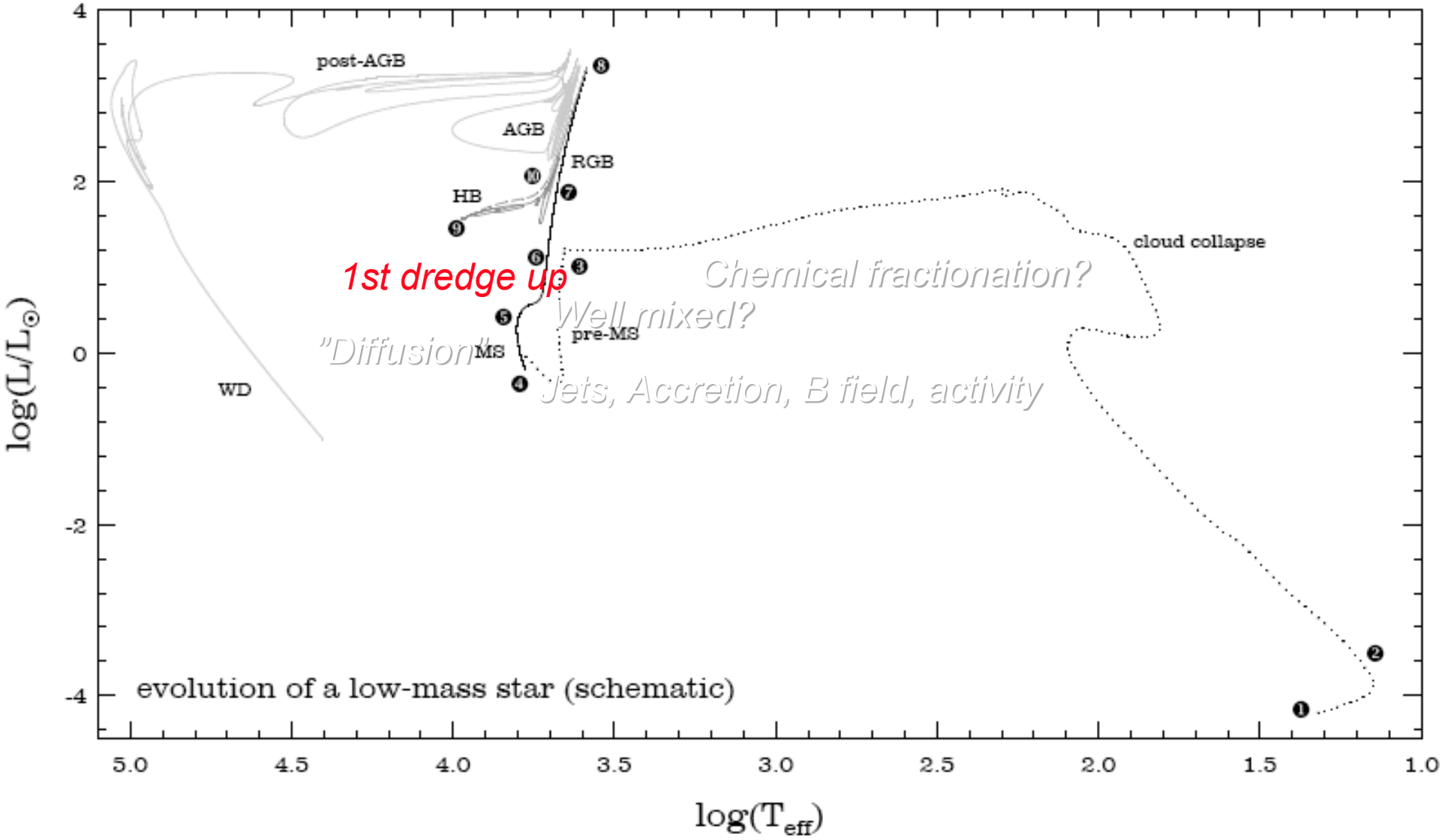


Fig. from Catelan (2007)

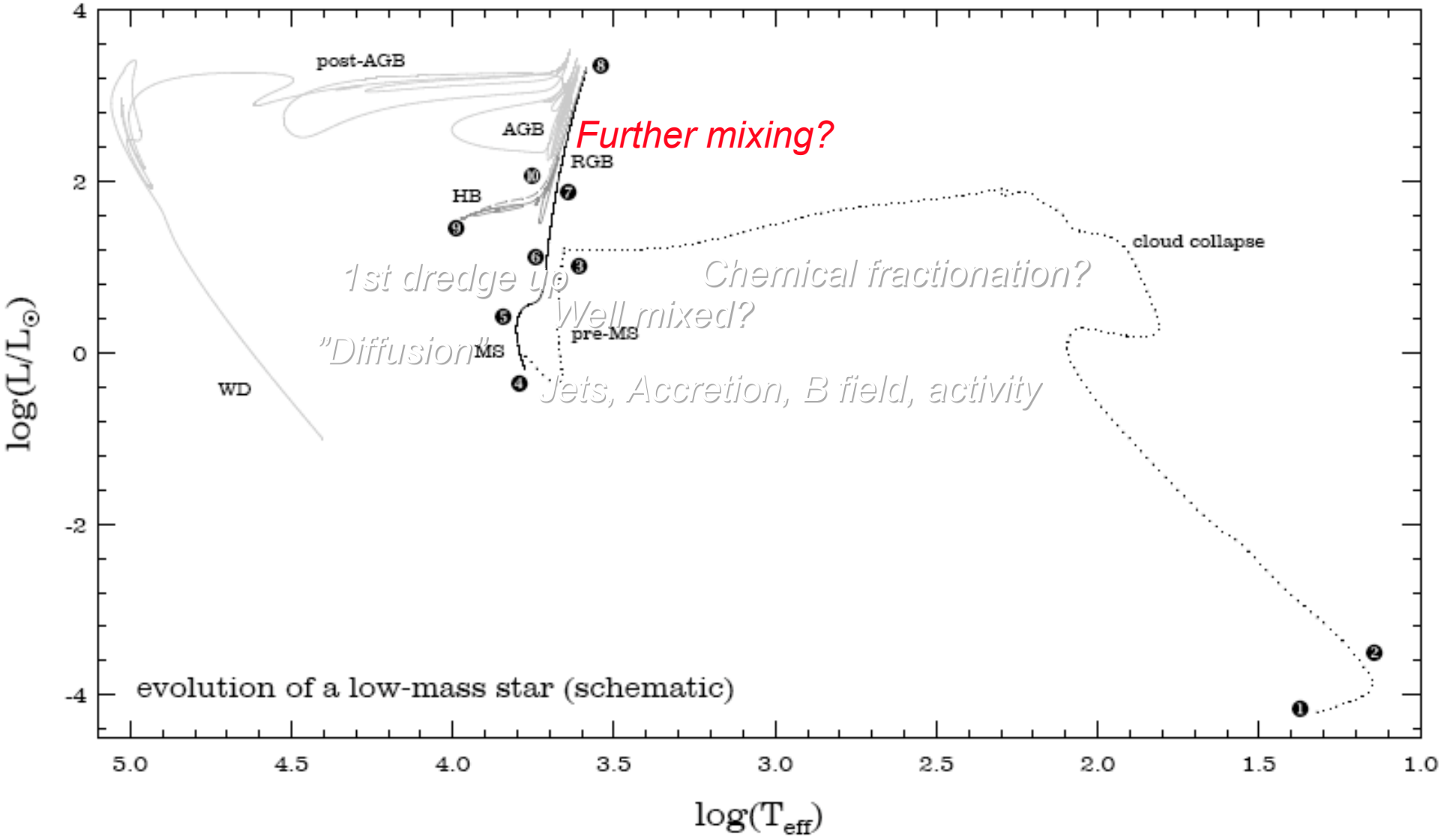


Fig. from Catelan (2007)

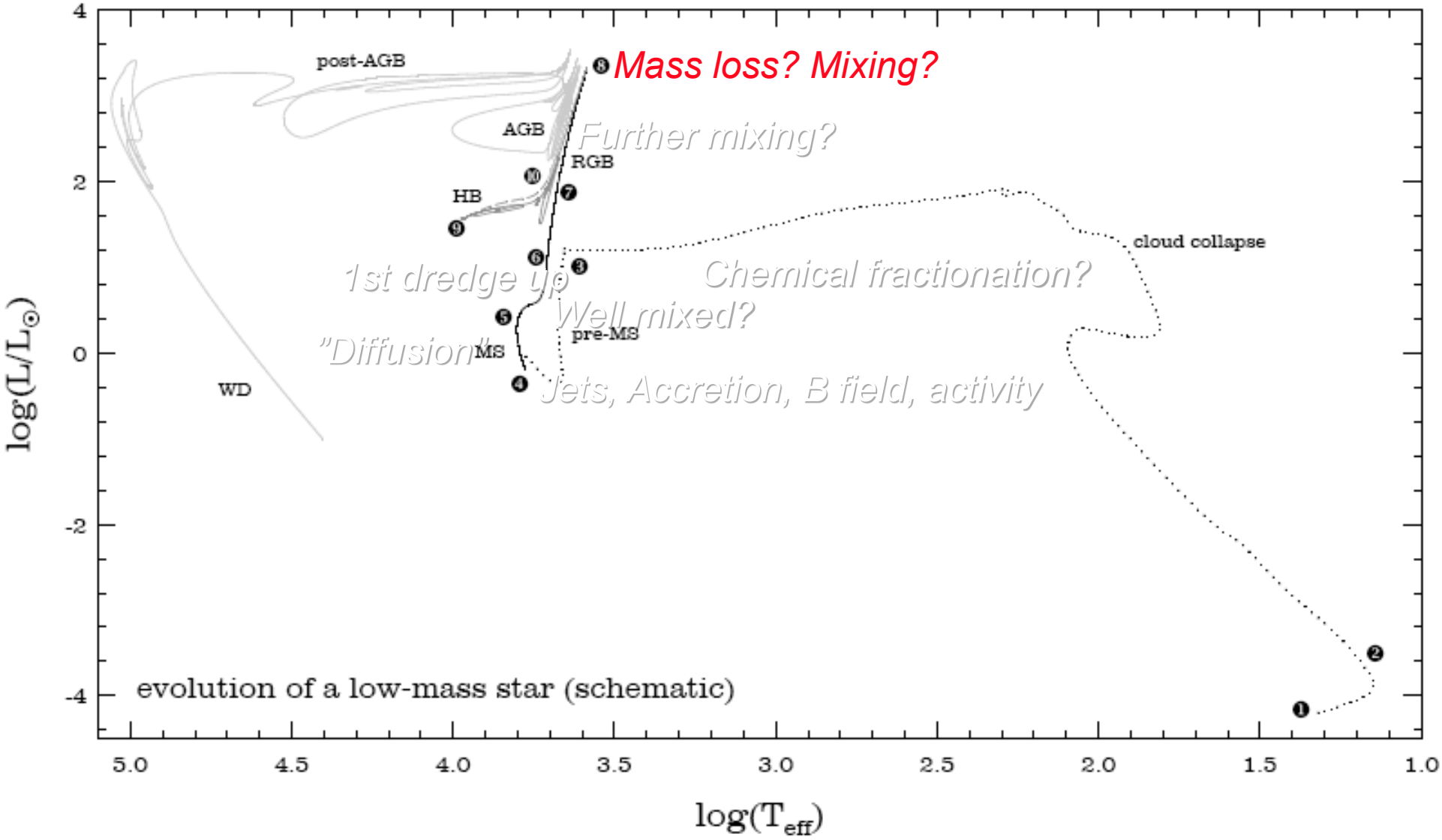


Fig. from Catelan (2007)

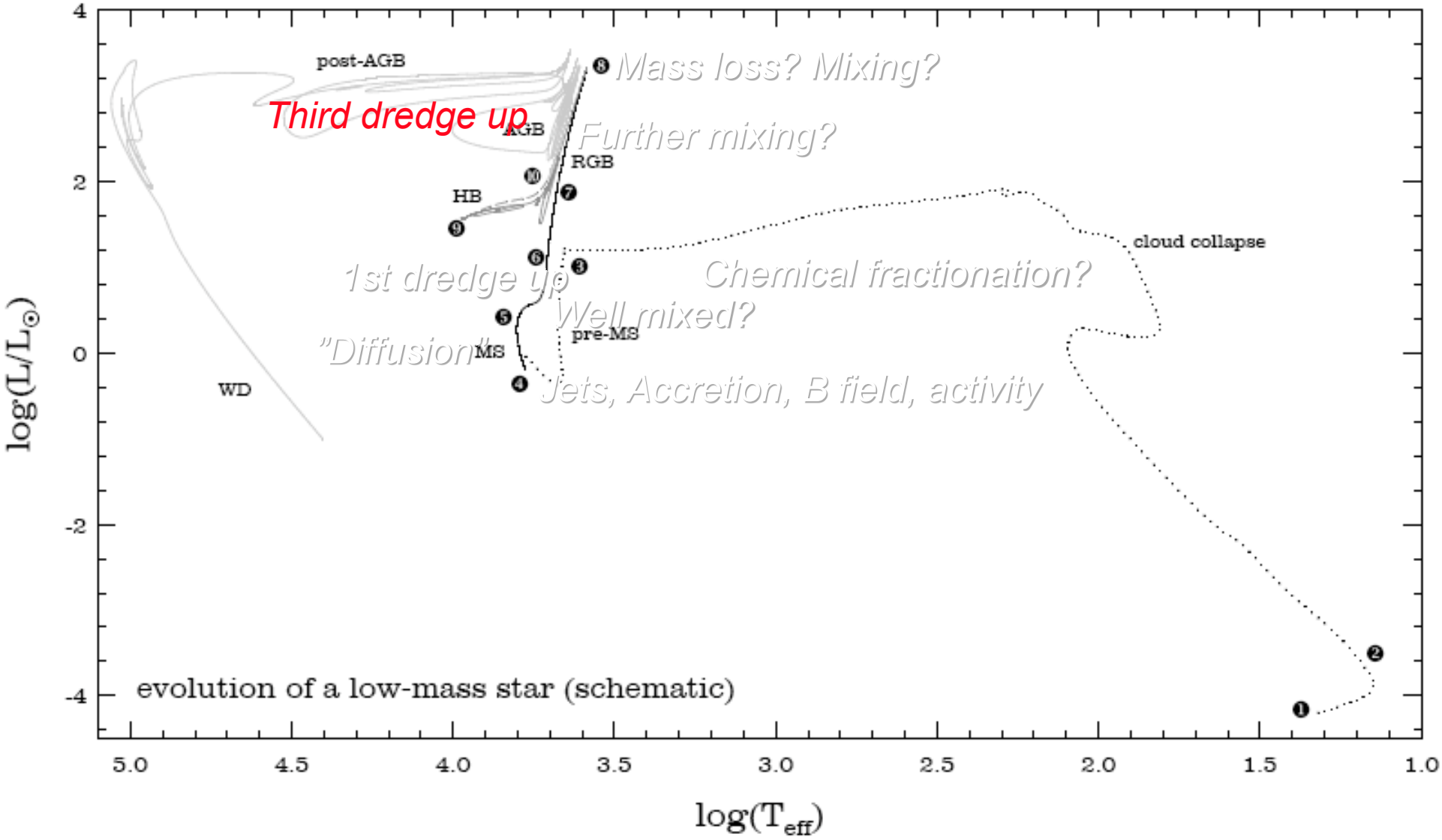


Fig. from Catelan (2007)

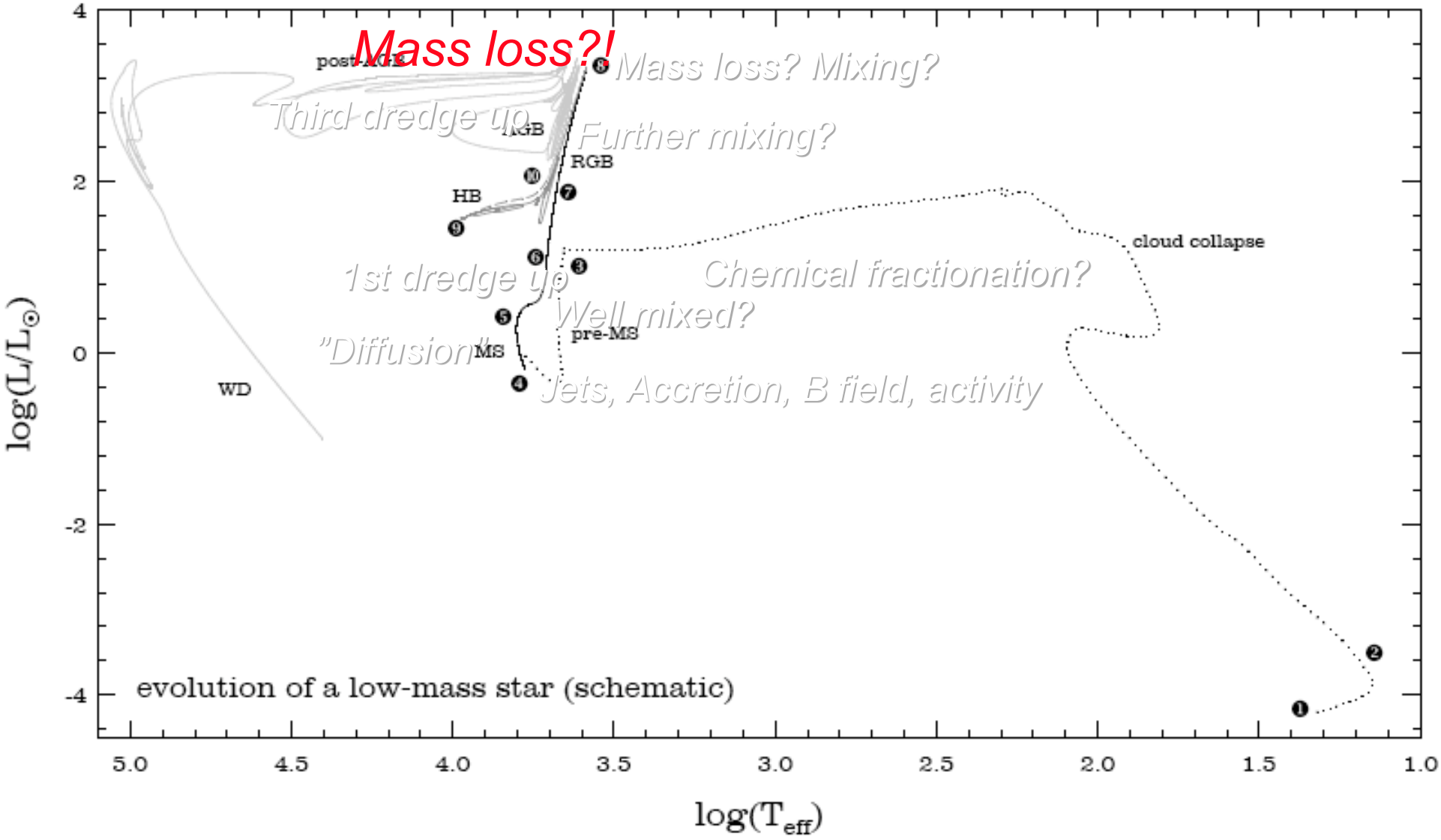
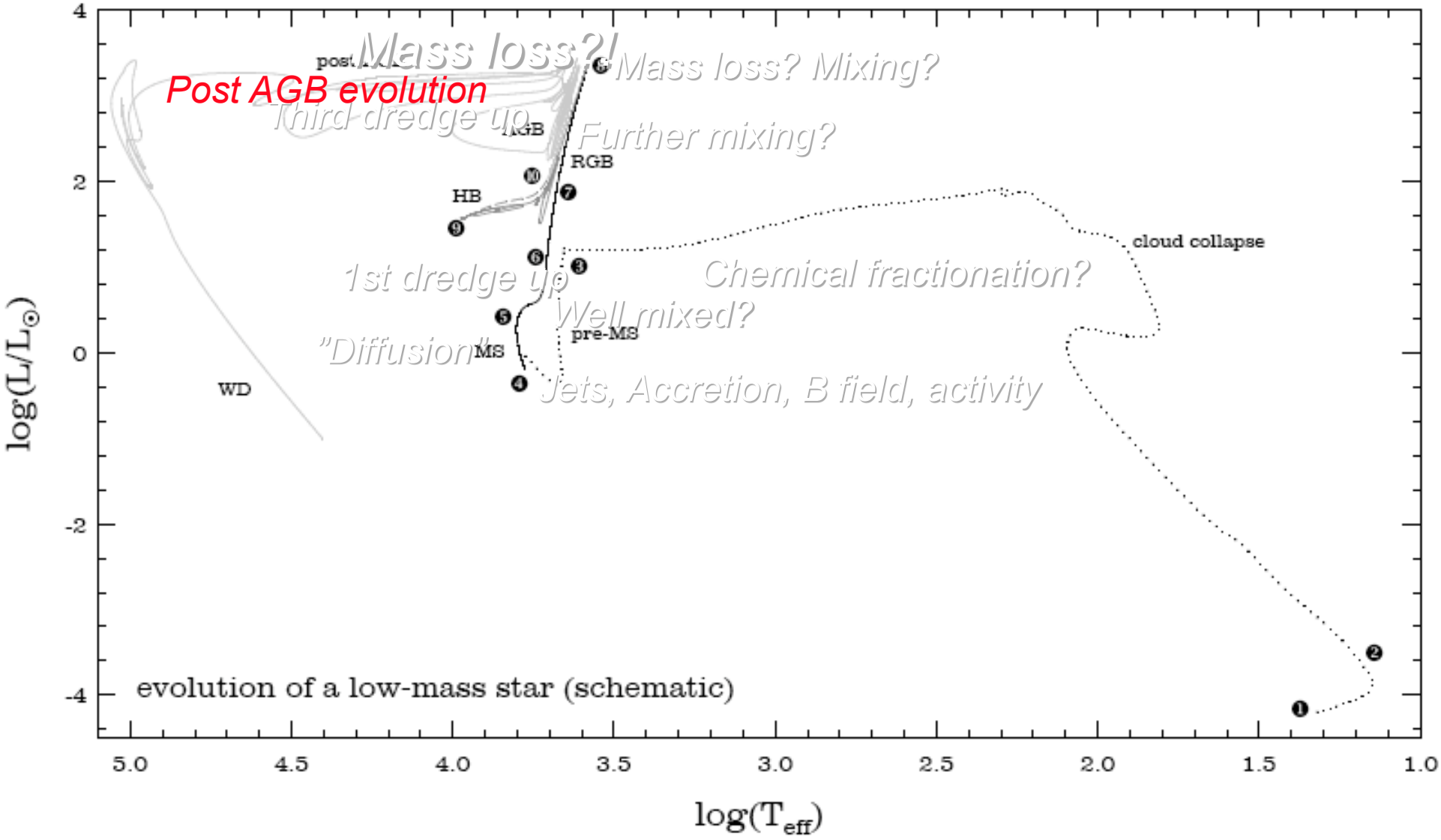


Fig. from Catelan (2007)



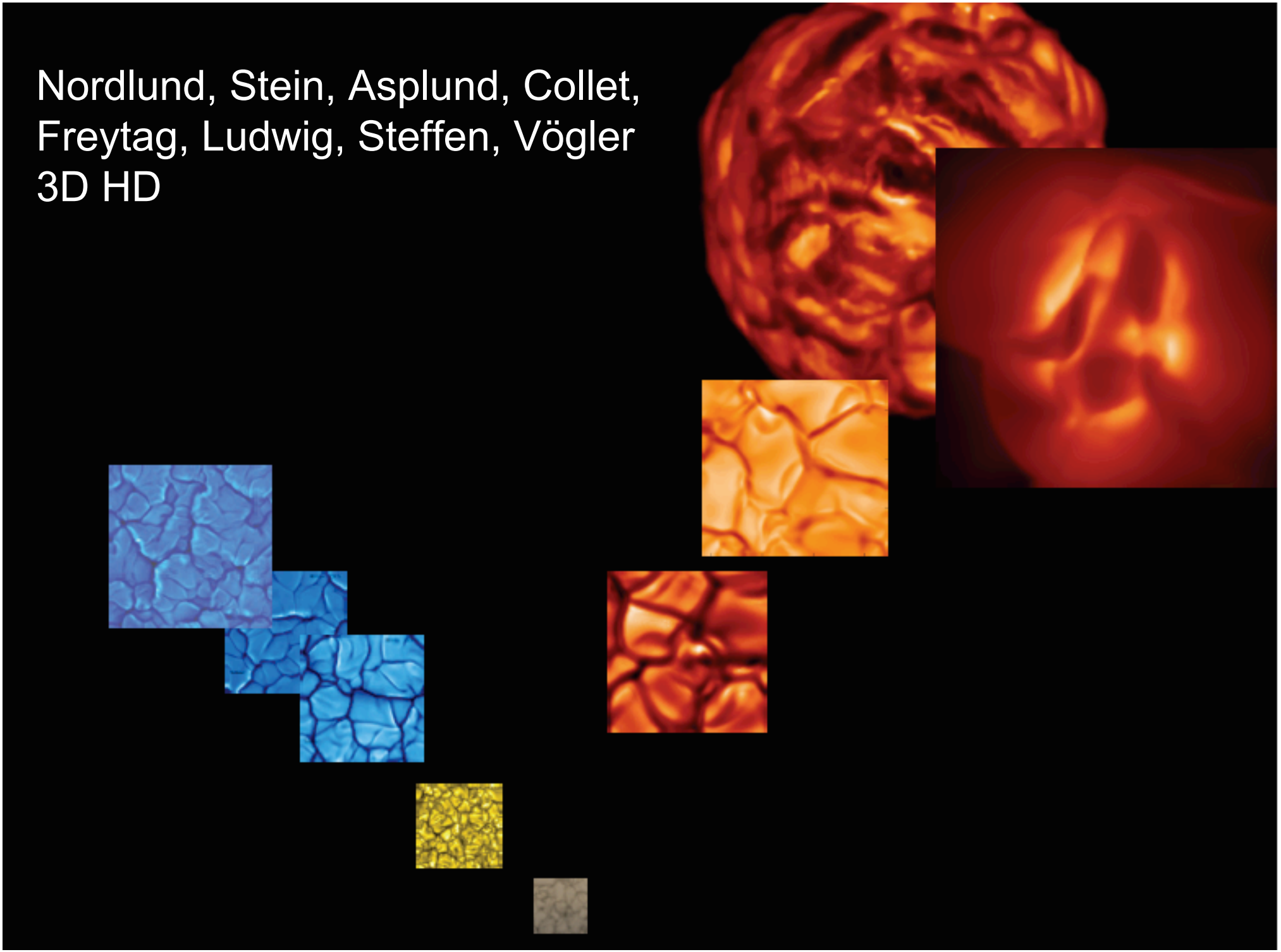
Model atmospheres with synthetic spectra:
standard tools for analysis of stellar spectra

- Basic assumptions: ~~1D, HE, LTE, MLT~~

  3D, (M)HD, SE

Cf: BG, IAU 265

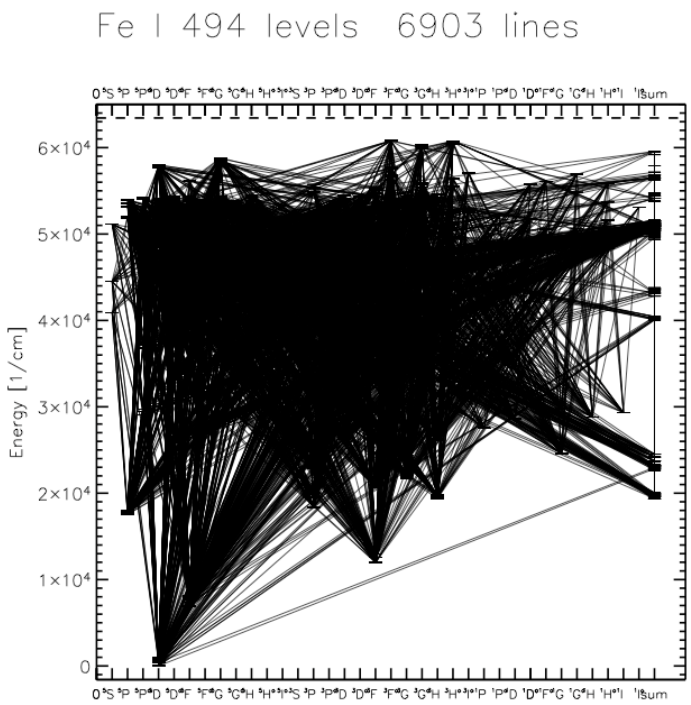
Nordlund, Stein, Asplund, Collet,
Freytag, Ludwig, Steffen, Vögler
3D HD



SE (non-LTE)

- For individual atoms in given model atm: 2000-2010:
  > 20 elements studied for solar-type stars
- Collision-rates improving
- Full SE model atmospheres: Anderson (1989), Hauschildt & Short (2005, …)

24 elements in SE
6 ion. stages
464 states, 6903 Fe I lines
617 / 13 600 Fe II
1 600 / 35 000 Ti+Mn+Co+Ni



Consistent 3D + HD + SE

- ***Still missing!***

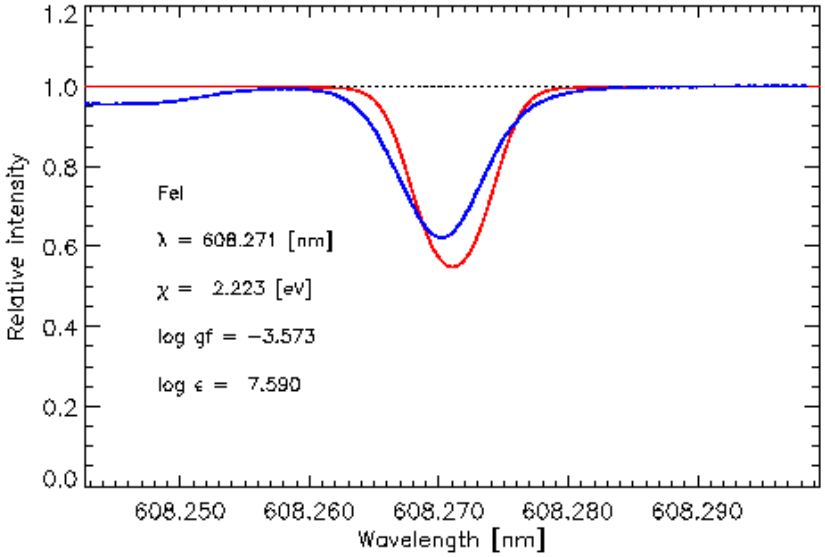
Consistent 3D + HD + SE

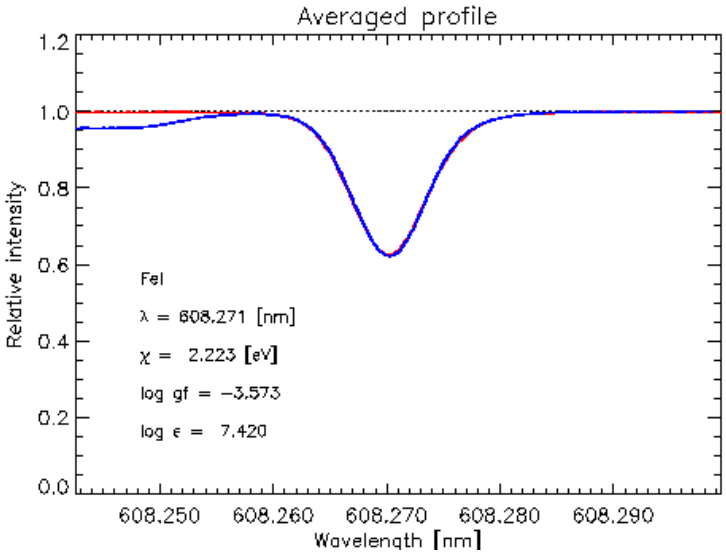
- ***Still missing!***

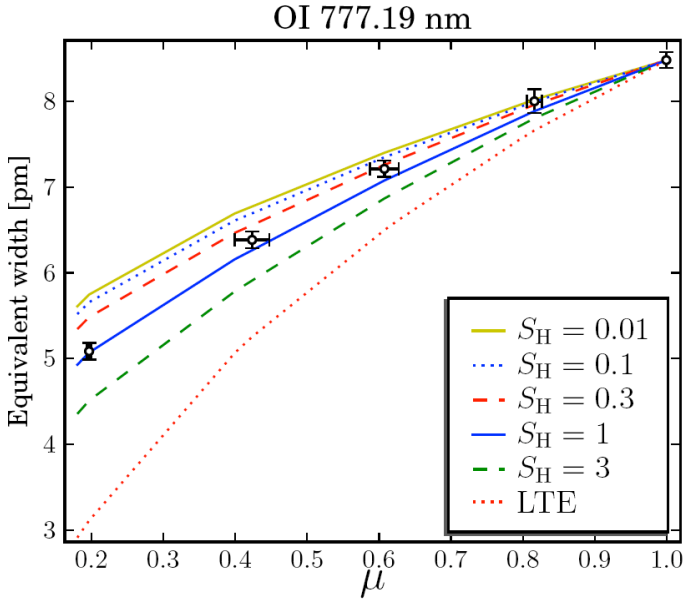
But probably needed.

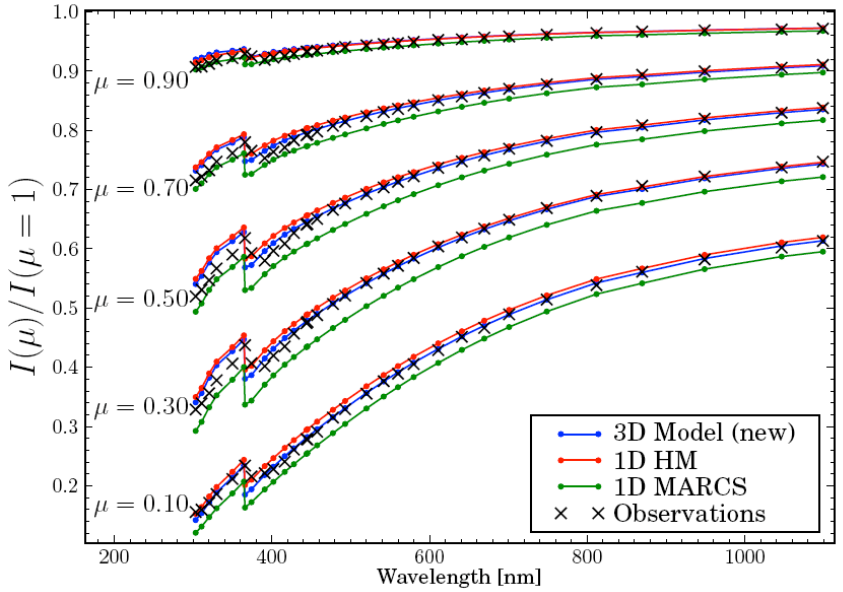
Checks of 3D and SE needed for stars!

(Cf work on Sun by Asplund, Allende-Prieto, Dravins, Kiselman, Koesterke, Nordlund, Pereira, Stein, ….)









Model atmospheres with synthetic spectra: standard tools for analysis of stellar spectra

- Basic assumptions: ~~1D, HE, LTE, MLT~~
  3D, (M)HD, SE

Dramatical improvements:

- basic consistency
- error control
- accuracy (?)

(limitations: physical data, observations, resolution in models, remaining simplifications)

Observations $\Longleftrightarrow$ Model atmospheres

Main results

- T_{eff}, log g, (M, L, R), $\{A_i\}_{i=1,N}$
- V_{atm}, V_{rot} sin i, $V(\phi)$
- $\langle \underline{B} \rangle$
- Surface distribution of T, A_i , $\underline{B}$, …

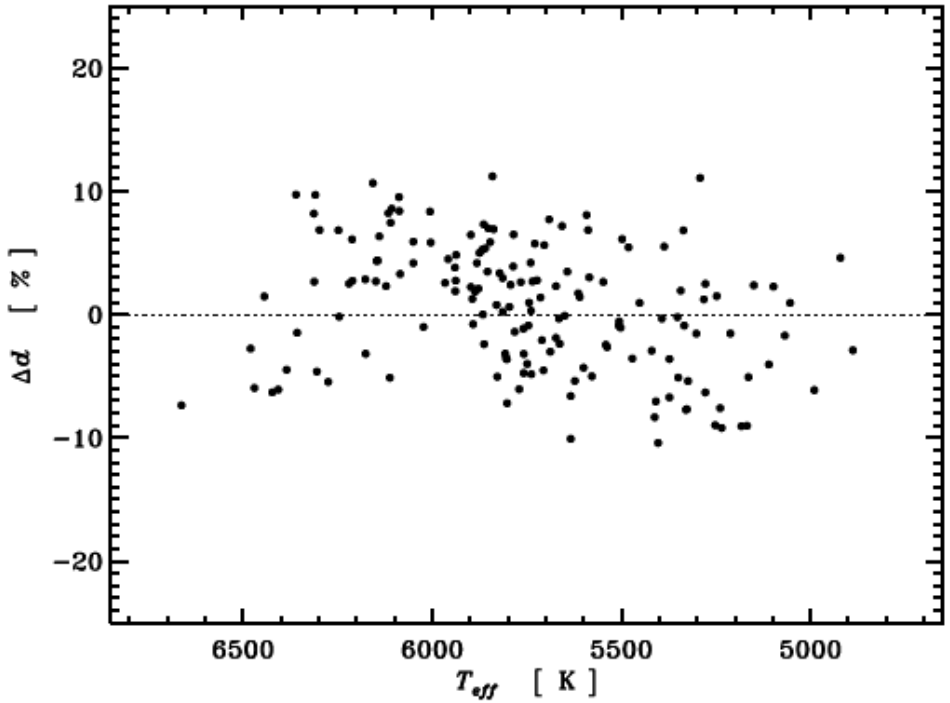
To which extent do these constrain models of stellar evolution? How accurate are they?

What can they be used for?

Spectral diagnostics

- T_{eff}, solar - type stars: $\varepsilon \sim 100$ K (cf. Casagrande et al. 2010)
- red giants: 100 - 200 K
- ***log g***, solar-type stars: $\varepsilon \sim 0.05$ (Fuhrmann 2004), red giants ~0.2
- Cf. Asteroseismology
  (CoRoT, Kepler)
  $\varepsilon(\boldsymbol{R}) \sim 3\%$, $\varepsilon(\boldsymbol{M}) \sim 5\%$
  => ε (log g) ~ 0.03 dex!

see Kallinger et al. (2009)
Stello et al. (2009)



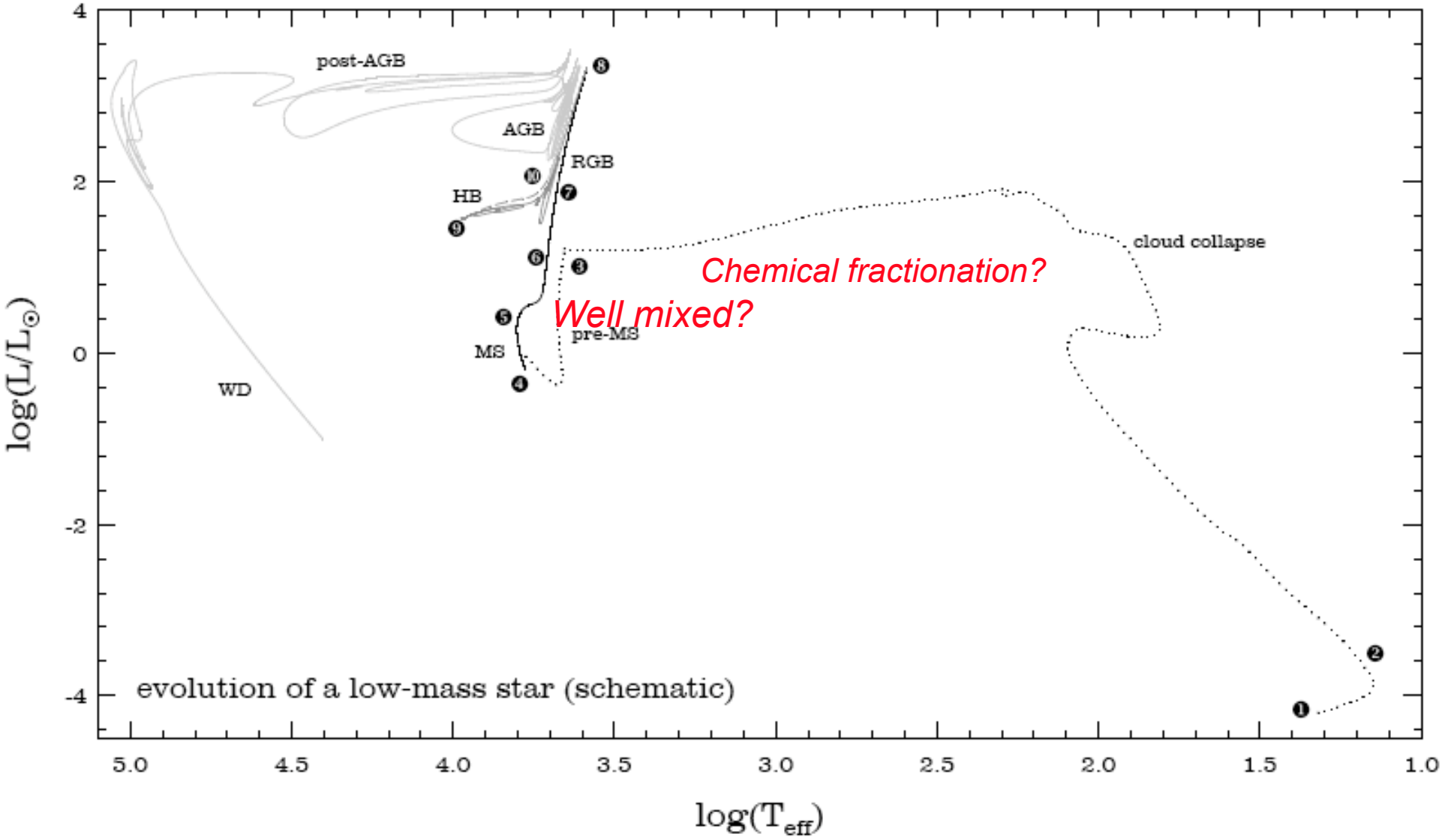
Chemical composition

- log A_i ; Errors ~ 0.1 dex (sun, solar-type stars)
- [X/Fe] ~ 0.1 dex, RGB: 0.1 - 0.2
  AGB: 0.2 - 0.4

Possibilities to decrease errors:

- Improved obs. data (R, S/N, Spectral range)
- Improved phys. data (ident, gf, D_e , $\{\sigma_i\}$, …)
- Improved model atm.
- Differential analysis

Fig. from Catelan (2007)



Ex. 1. Was the proto-Sun completely mixed?

- Melendez et al. (2009):
  Sun vs 11 solar twins ε [X/Fe] ~ 0.01

Sun dust-depleted

Disk only prevails ~ 10 Myr, but conv. zone deep until ~ 30 Myr (stand. models). However, Wurchtel, Klessen, Tscharnuter (2002, 2003) suggest Sun was never fully convective!

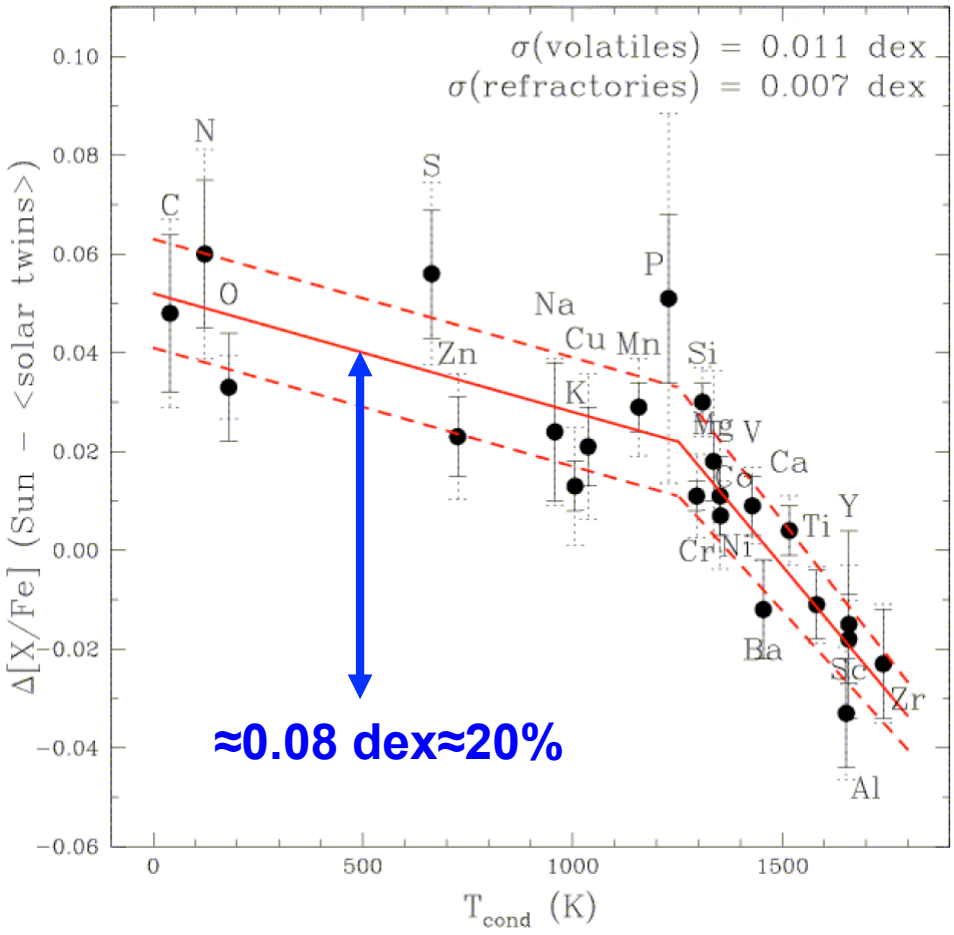
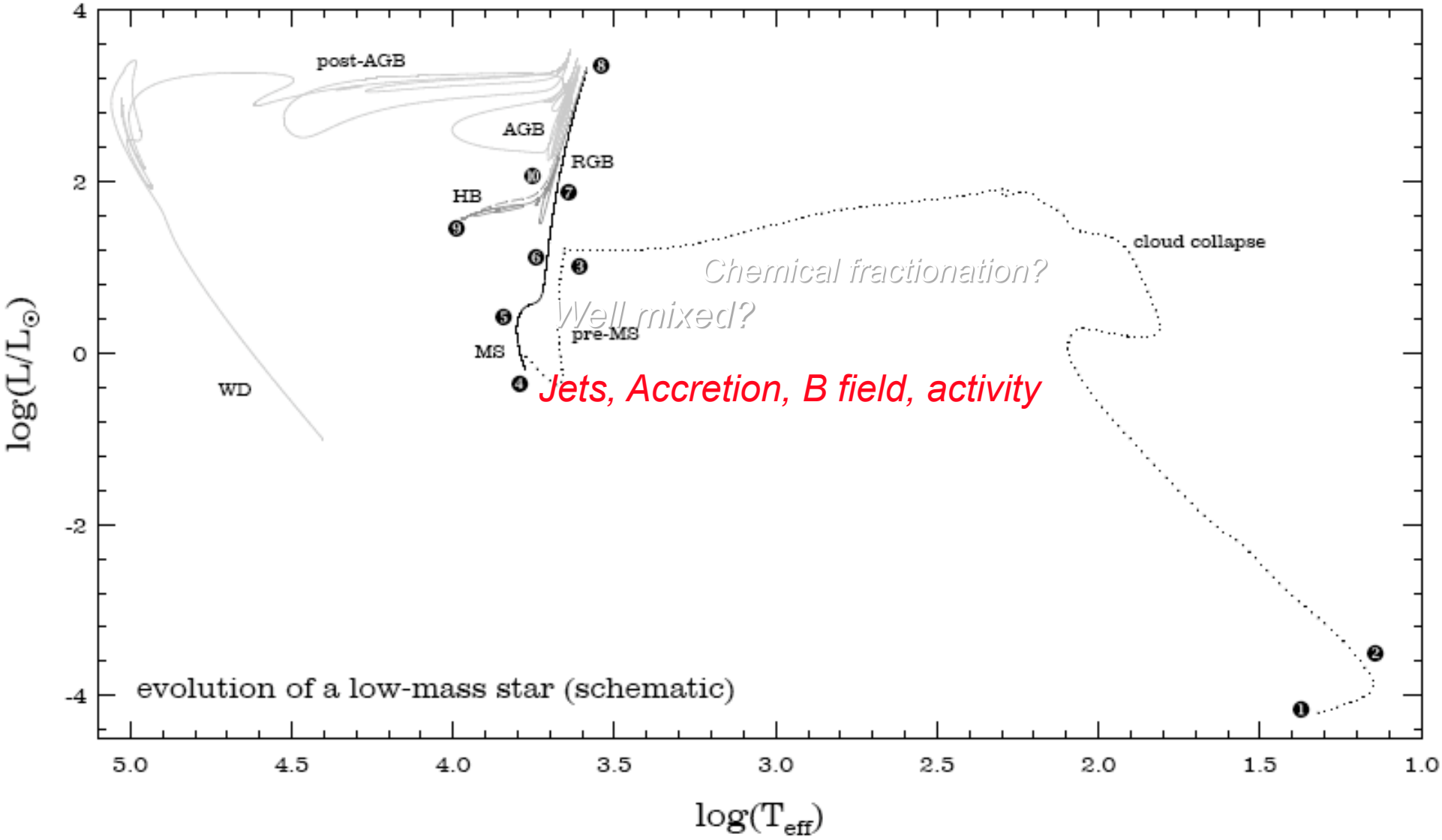


Fig. from Catelan (2007)

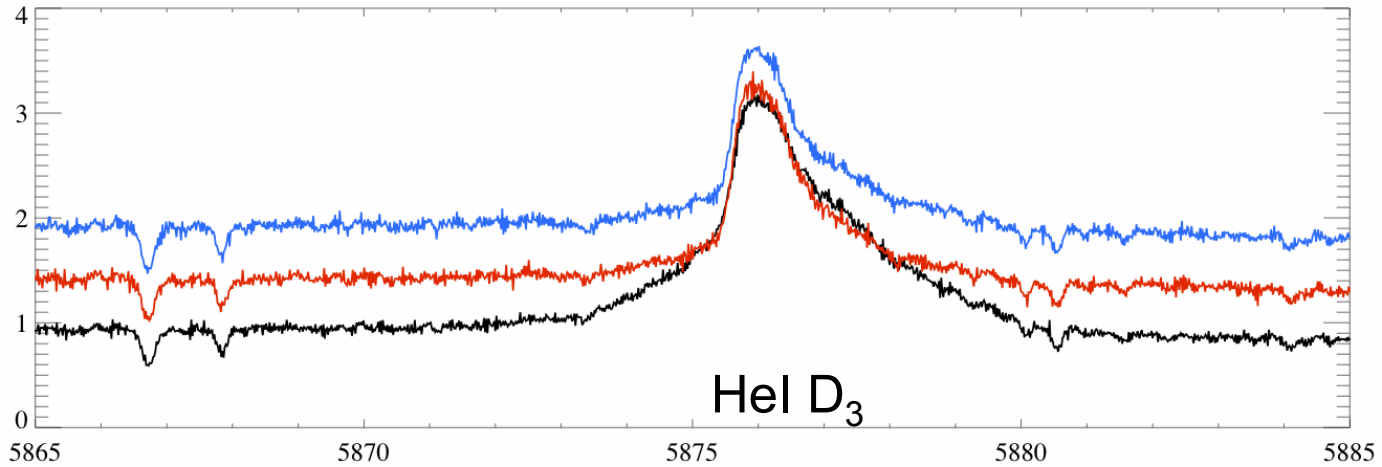


Ex. 2. Magnetic-field distribution on T Tauri stars

- V2129 Oph, BP Tau (Donati et al. 2207, 2008), mapped fields
- Piskunov et al. (in prep): TW Hya, V=11.1, ESO 3.6m + HARPS

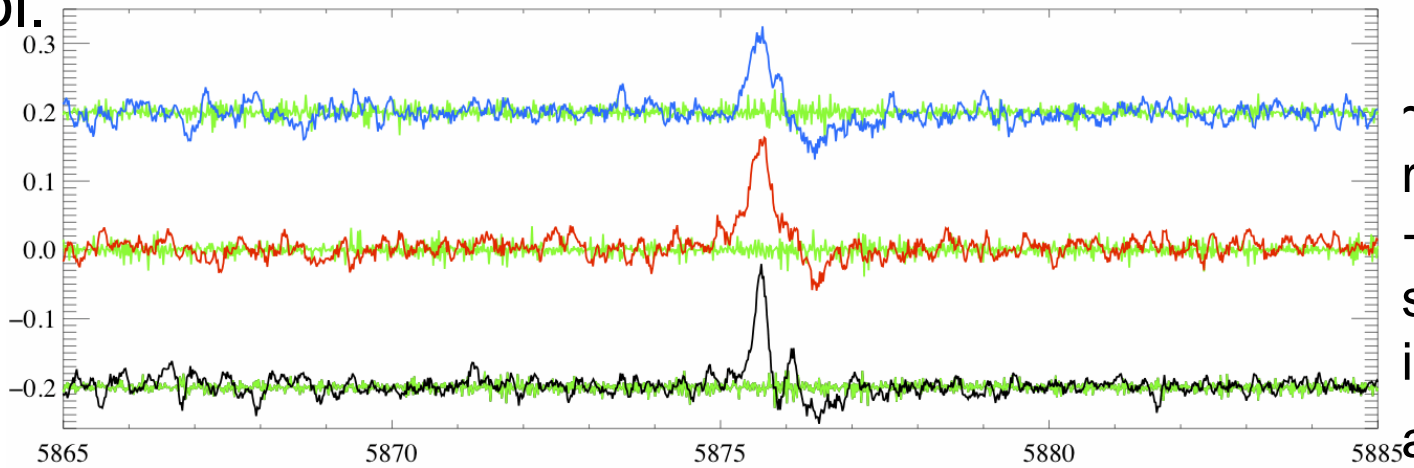
  v sin i = 6 km/s

Intensity



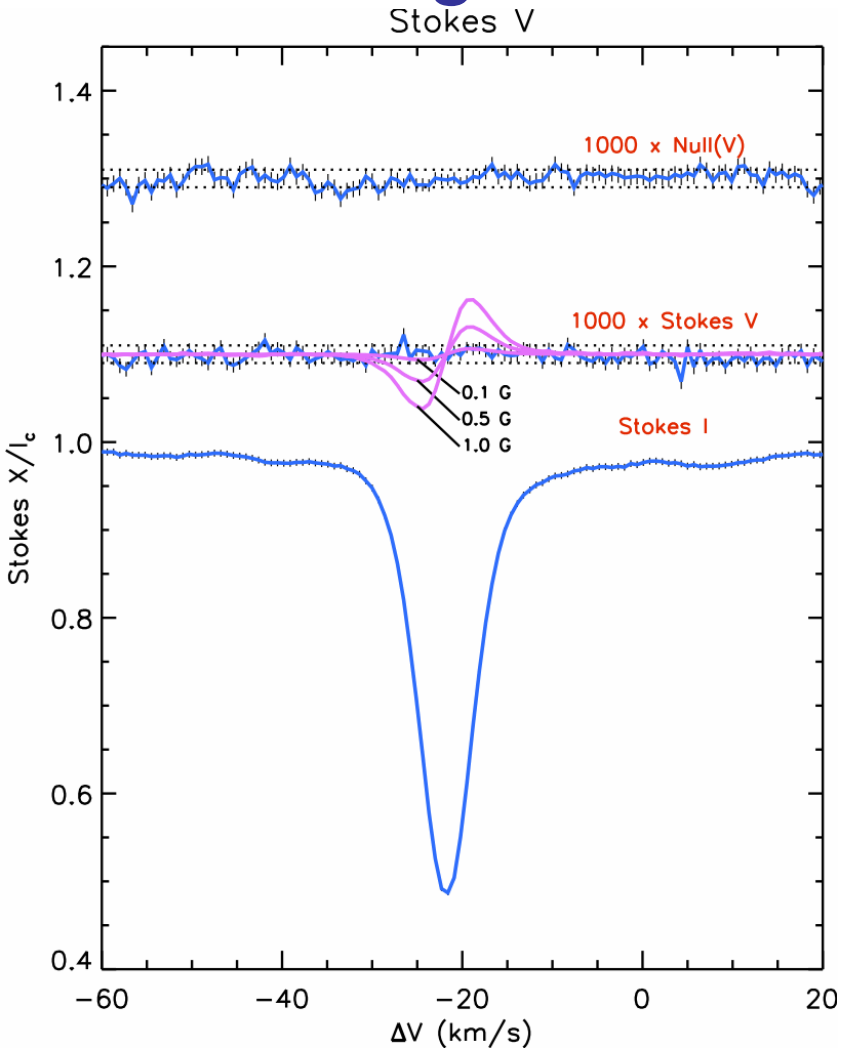
Jan 10, 2010
Jan 6, 2010
Jan 2, 2010

Circ. Pol.



~10^2 gauss,
rot. mod. field
+
stronger field
in variable
accretion flow

Magnetic field on α Cen A

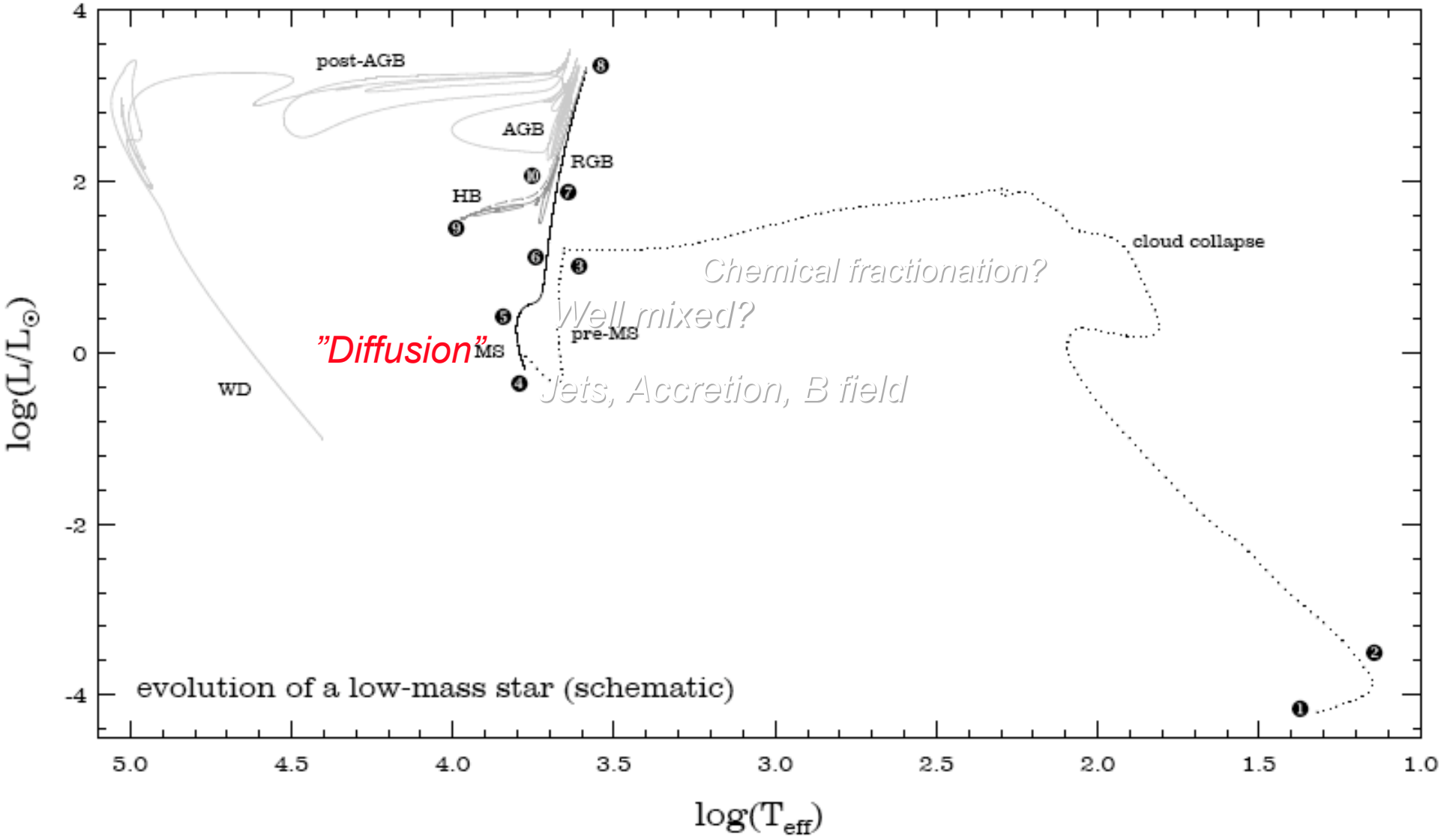


For Sun, at maximum:
2 gauss.

Cf. Donati & Landstreet (Ann. Rev. A&A 2009)

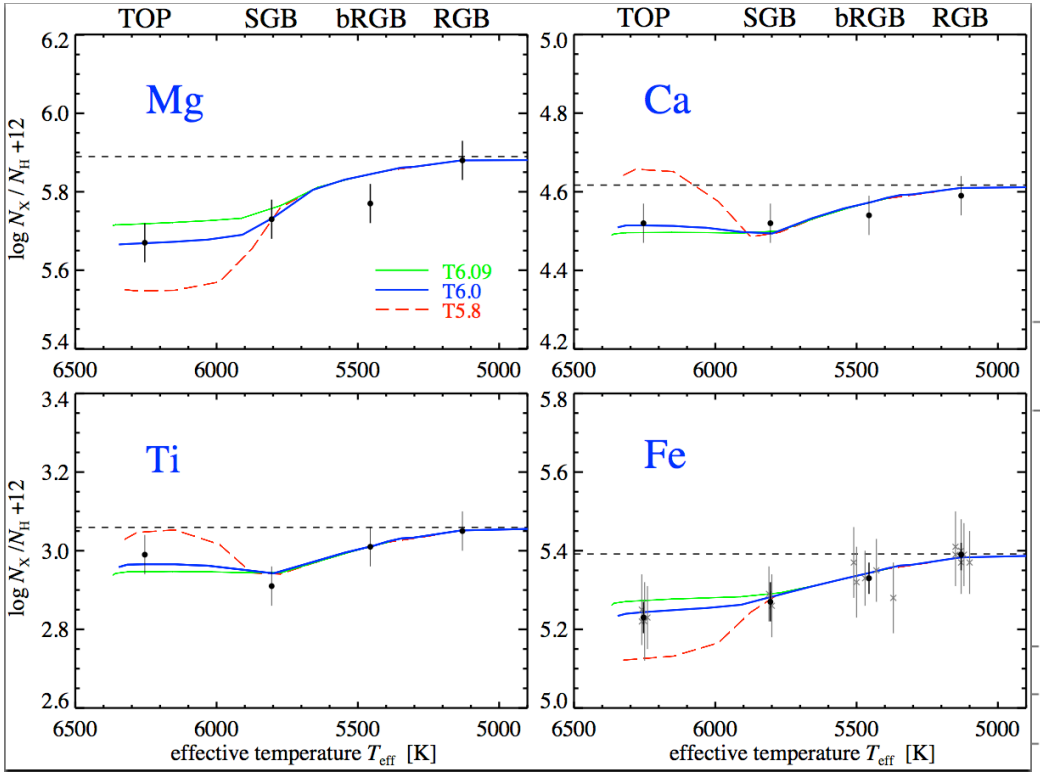
e.g. τ Boo (F7), polarity switches 2x in two year

Fig. from Catelan (2007)



Ex. 3: "Diffusion" in solar-type stars

- Korn et al. (2006), Lind et al. (2008): NGC 6397, [Fe/H] ~ -2



- Expected for M67 ~ solar (O. Richard):

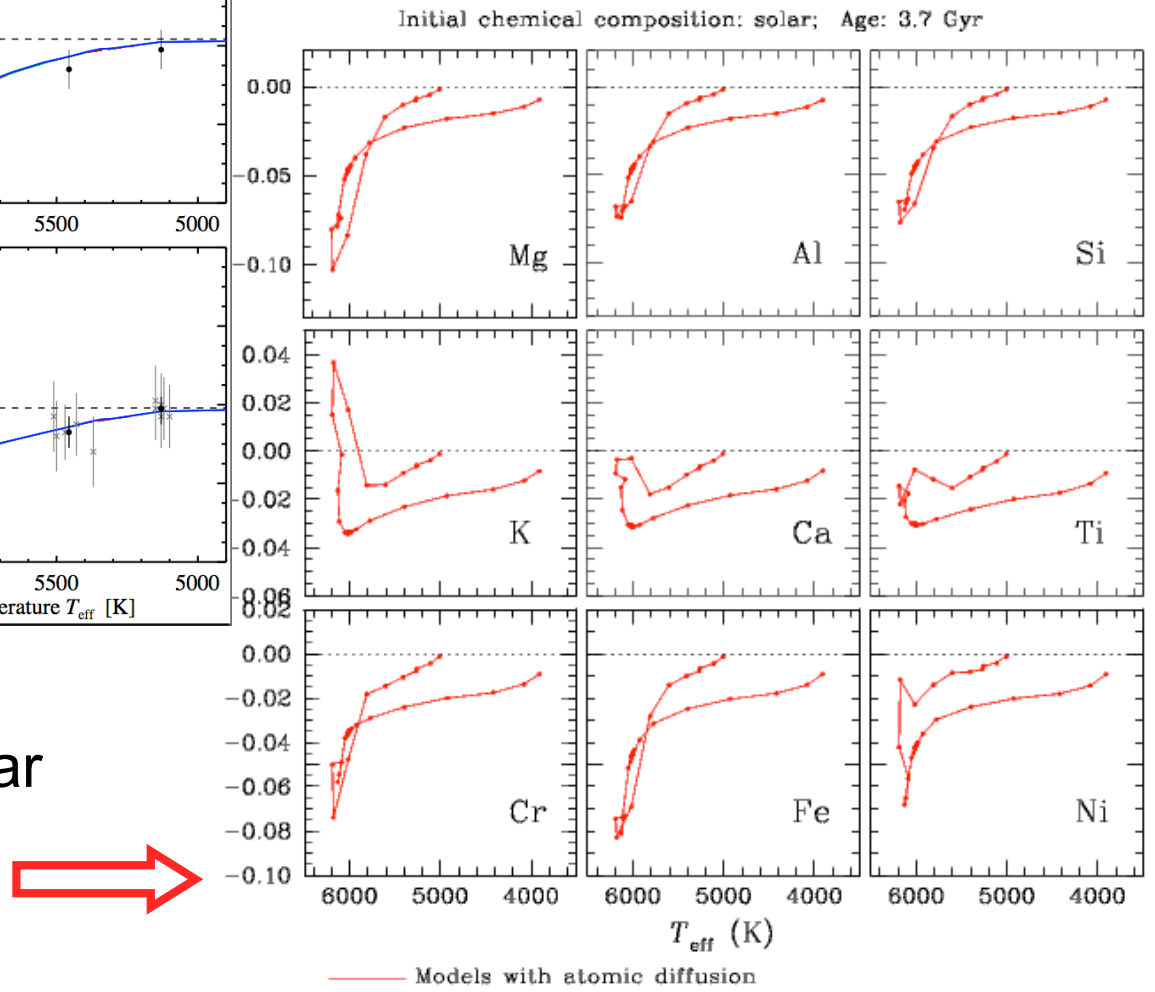
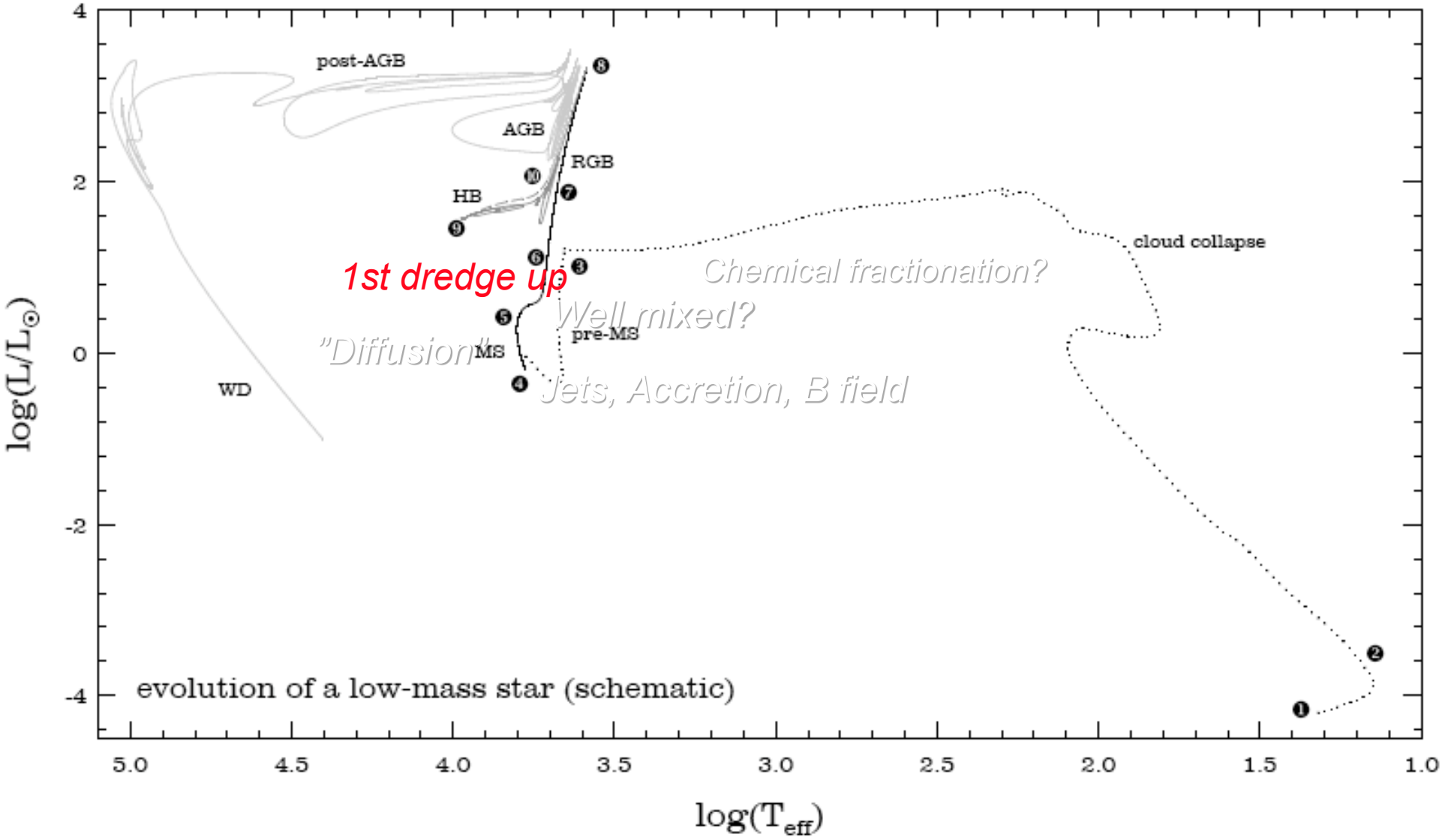


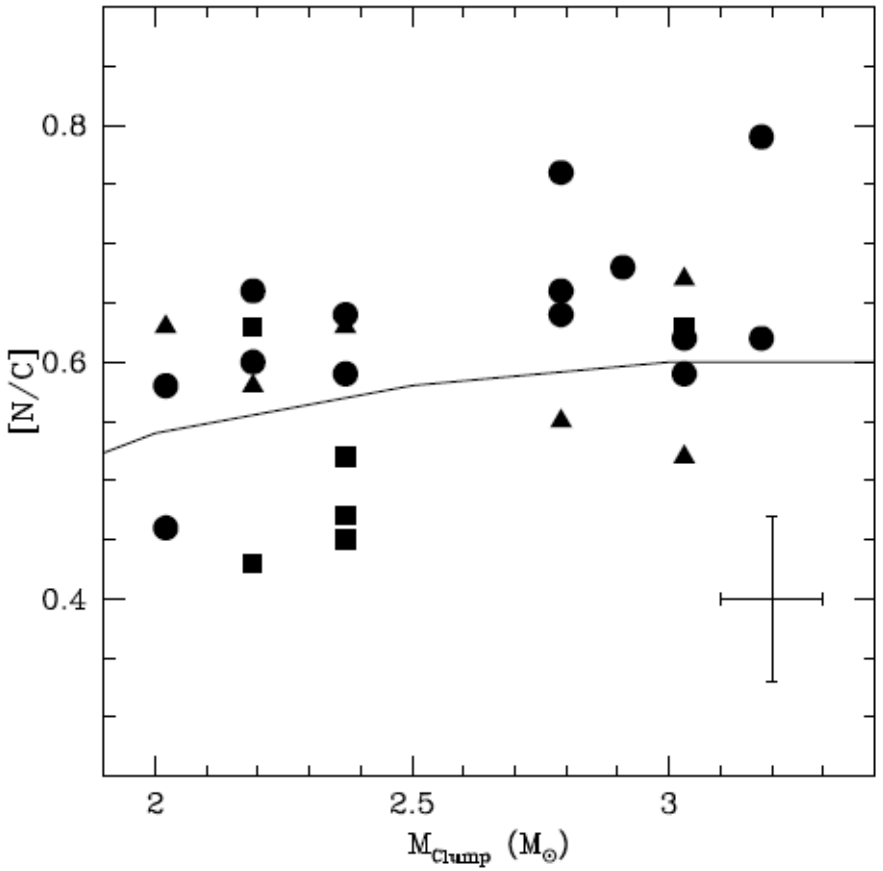
Fig. from Catelan (2007)



Ex. 4. 1:st dredge up

Smiljanic et al. (2009) 10 open clusters

——— Shaller et al. (1992), Molawi et al. (1999) models



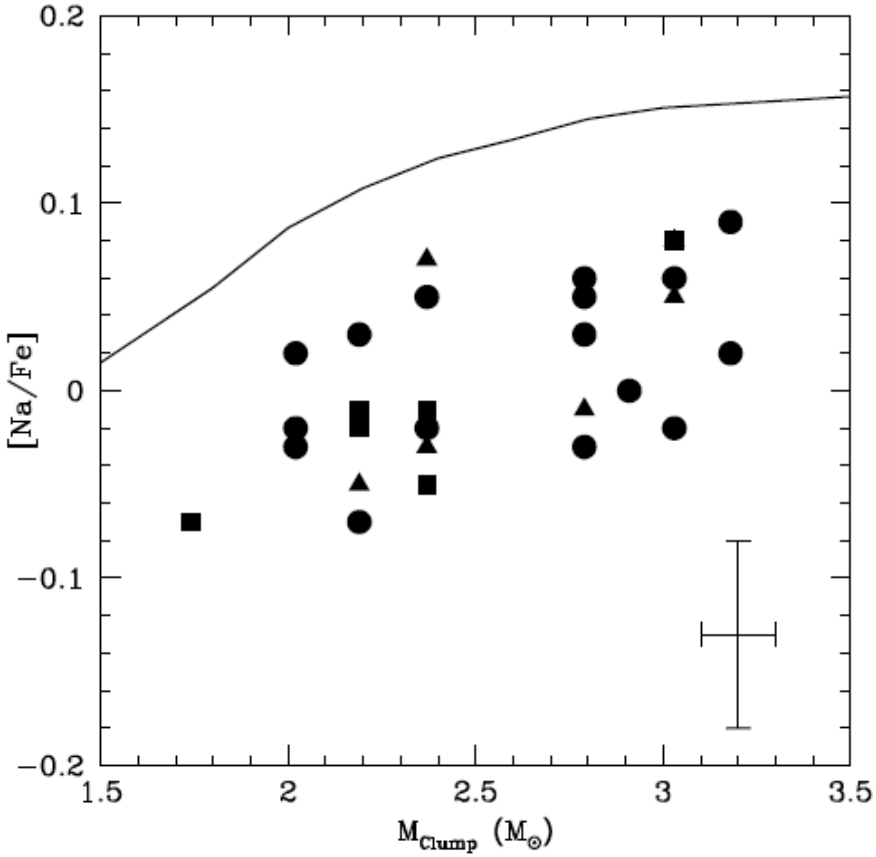
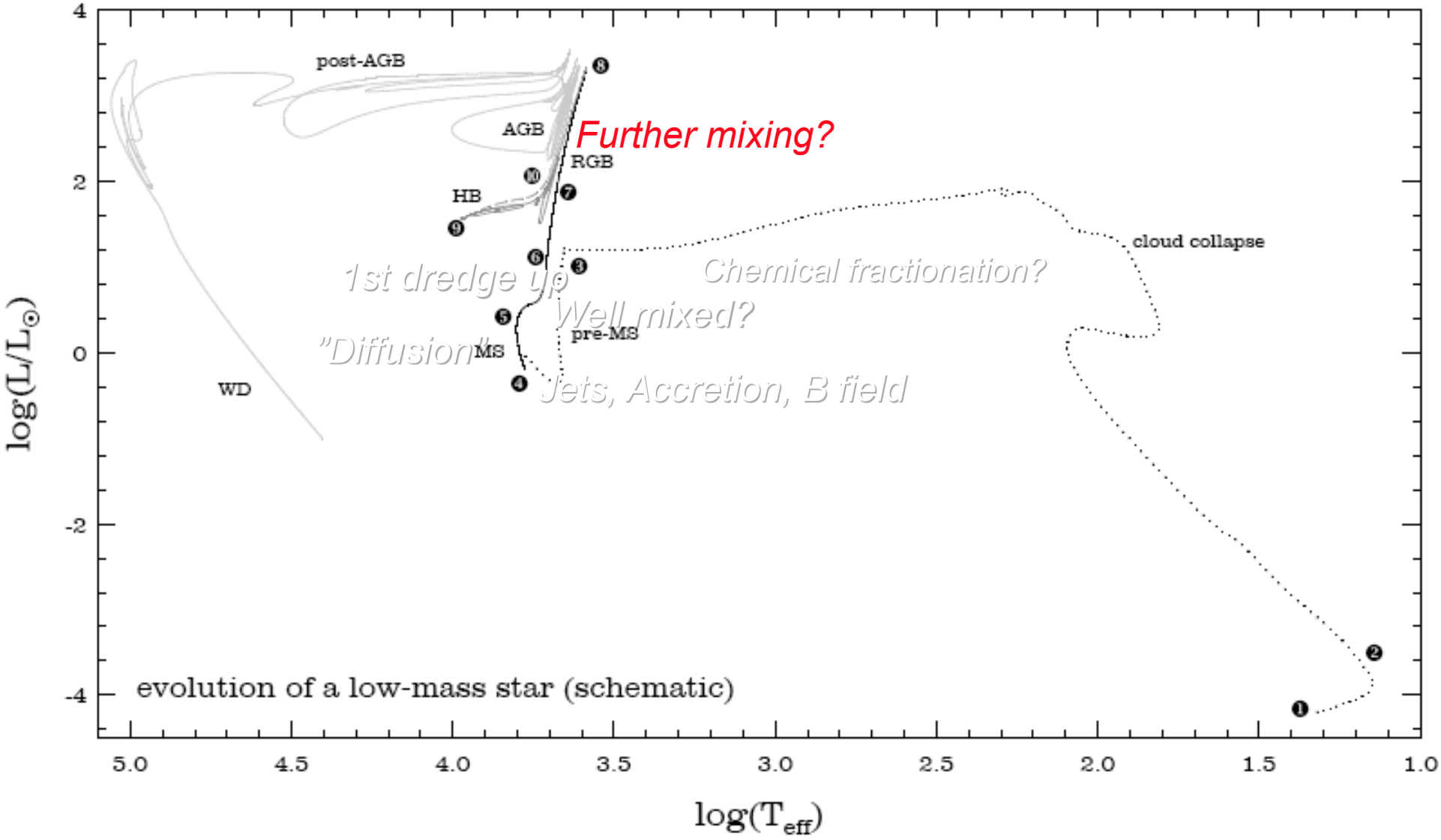


Fig. from Catelan (2007)



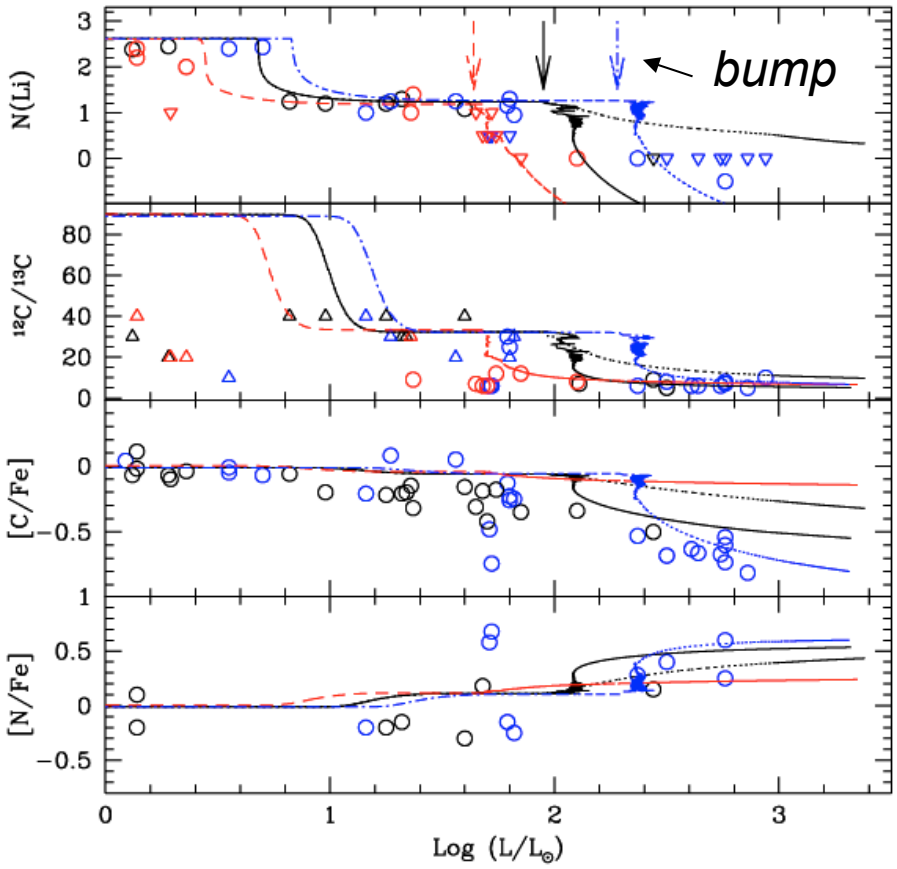
Ex. 5. More mixing on RGB

μ- or thermohaline mixing

Eggleton et al. (2006, …)

Charbonnel & Zahn (2007)

[Fe/H] = -1.8 -1.3, -0.5

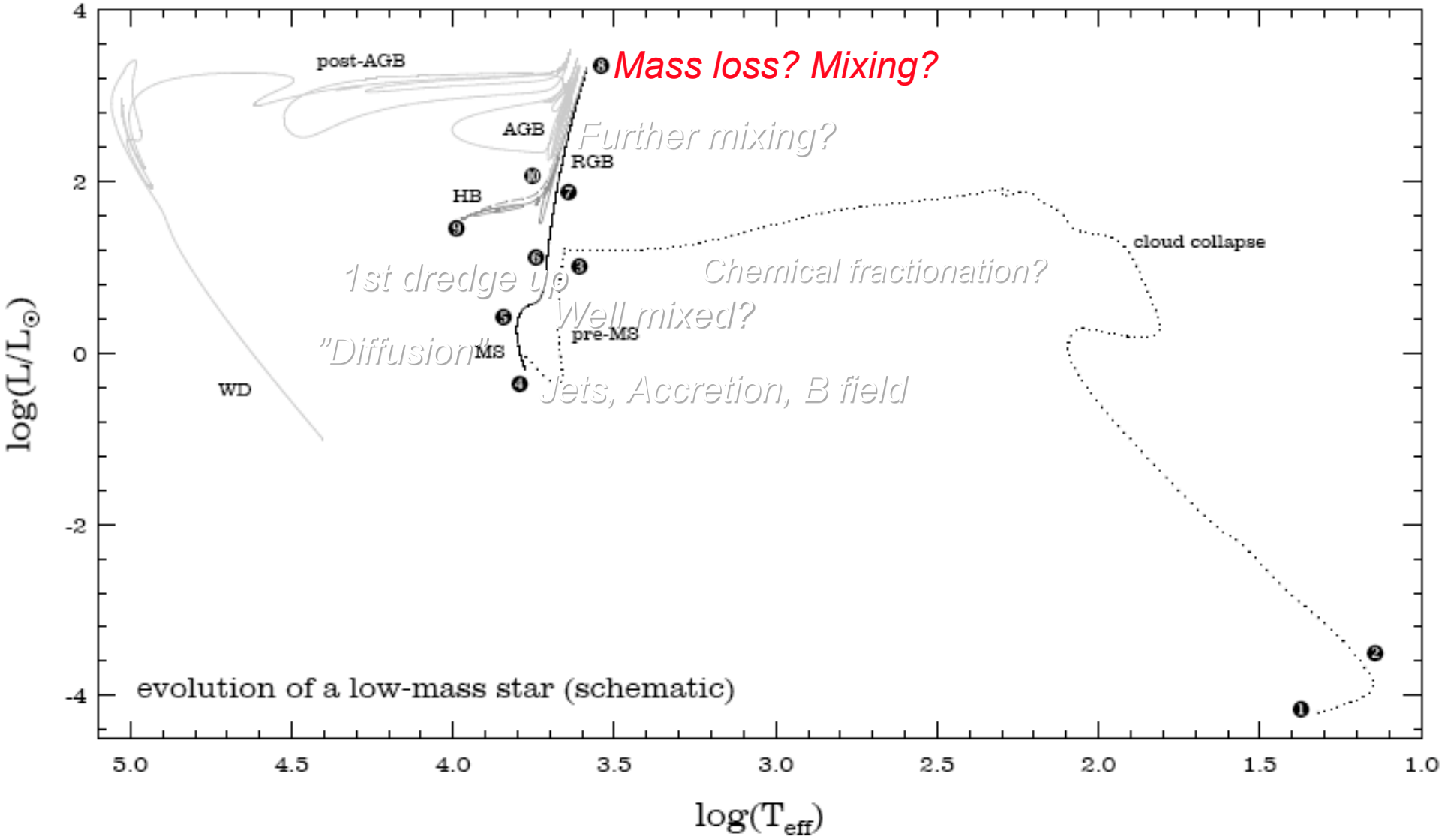


Also interacts with ***rotational mixing***!

TABLE 3
^{12}C/^{13}C RATIOS

Mass	$X = 0.70$, FDU	$Z = 0.02$ Final	$X = 0.738$, FDU	$Z = 0.001$ Final	$X = 0.74$, FDU	$Z = 0.0004$ Final
0.80.....	36.9	15.9	34.1	5.3	35.0	4.2
0.85.....	34.0	15.3	31.5	5.0	31.8	4.0
0.90.....	32.2	14.5	29.6	4.9	30.0	4.0
1.00.....	29.5	13.4	27.3	4.9	27.4	4.0
1.25.....	25.6	13.0	24.3	5.0	24.3	4.1
1.50.....	23.6	13.7	24.3	5.2	22.7	4.6
2.00.....	22.3	17.0	21.2	14.2	21.0	21.0

Fig. from Catelan (2007)



Ex. 6. Mass loss at He-core flash

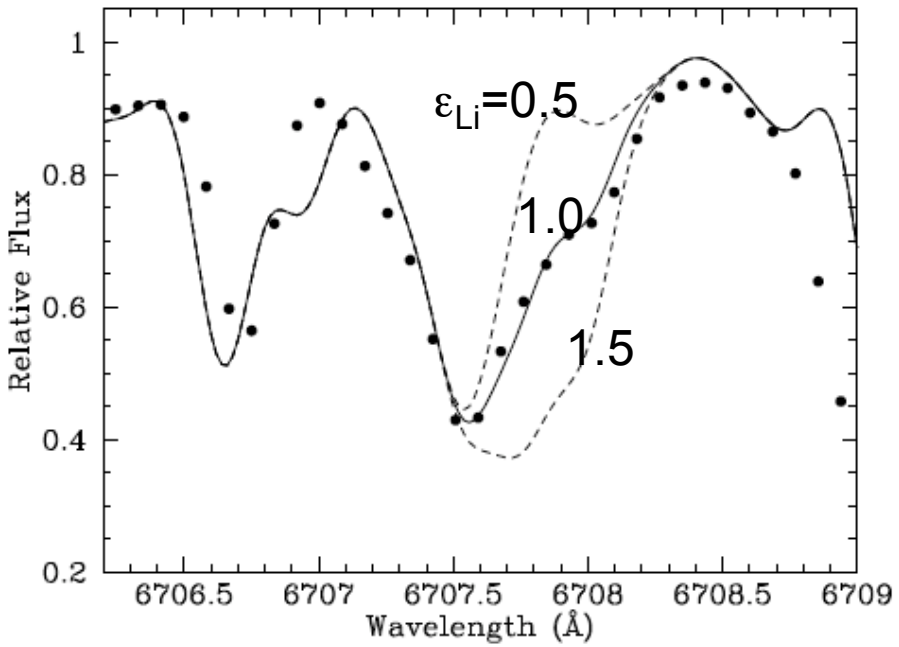
Massloss? $\Delta M \sim 0.2\ M_{sun}$(Lee et al. 1994,Caloi & D'Antona 2008)

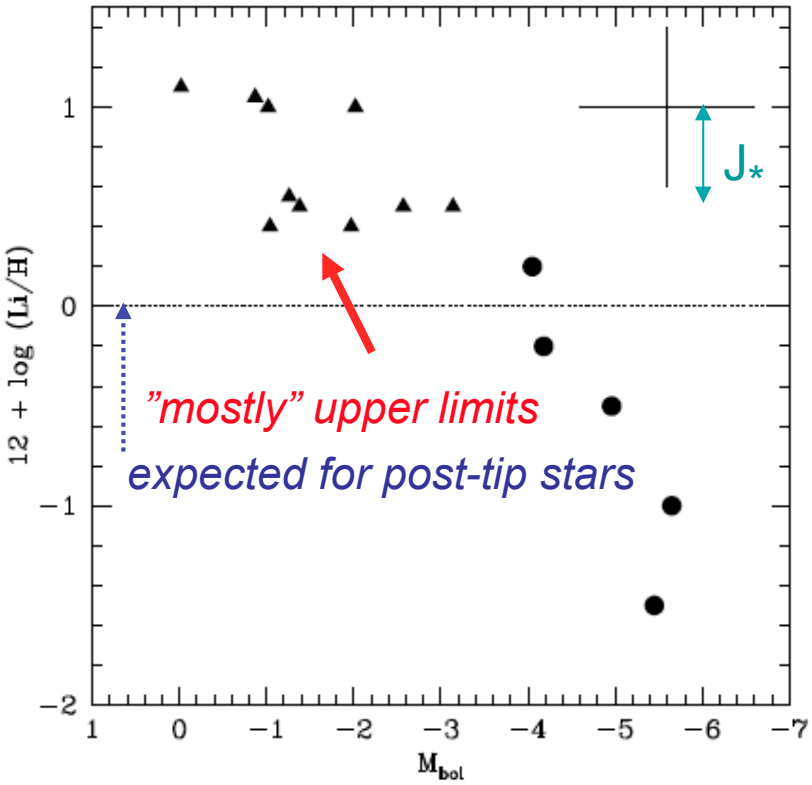
- Spectrocopically (log g) very difficult
- Asteroseismology -- possible

Mixing?

- Early R-type stars, at clump, C enriched, no s-enrichment
- Zamora et al. (2009):

Errors in [X/Fe] 0.2-0.5 dex



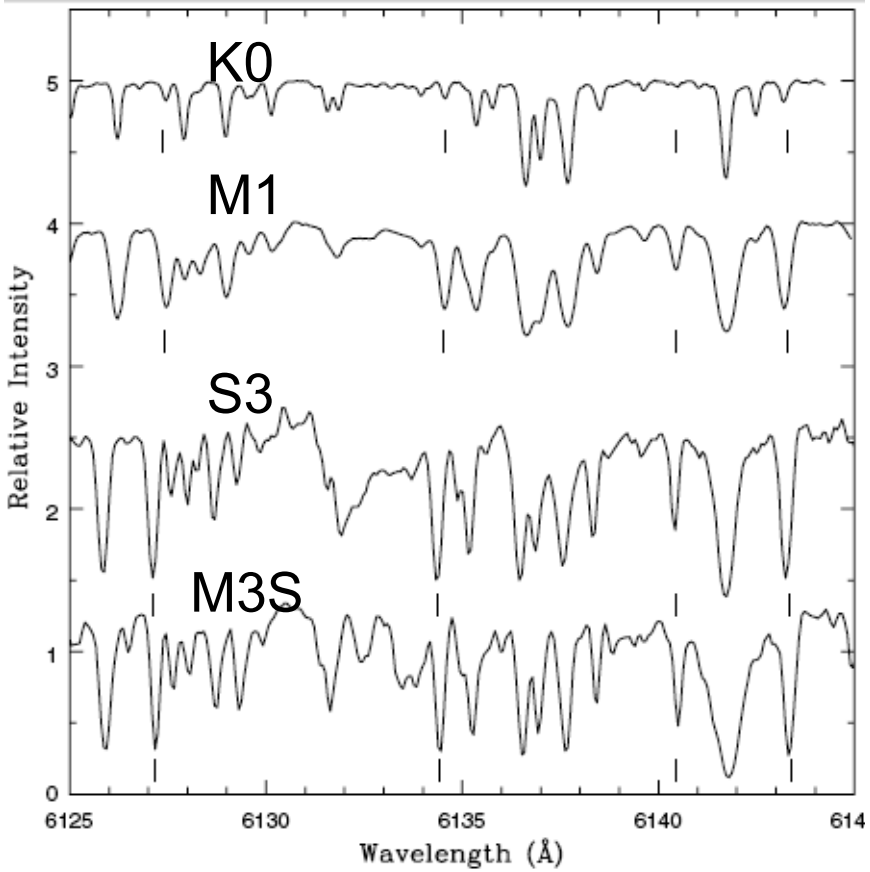


Ex. 7. ***3:rd dredge up on AGB***

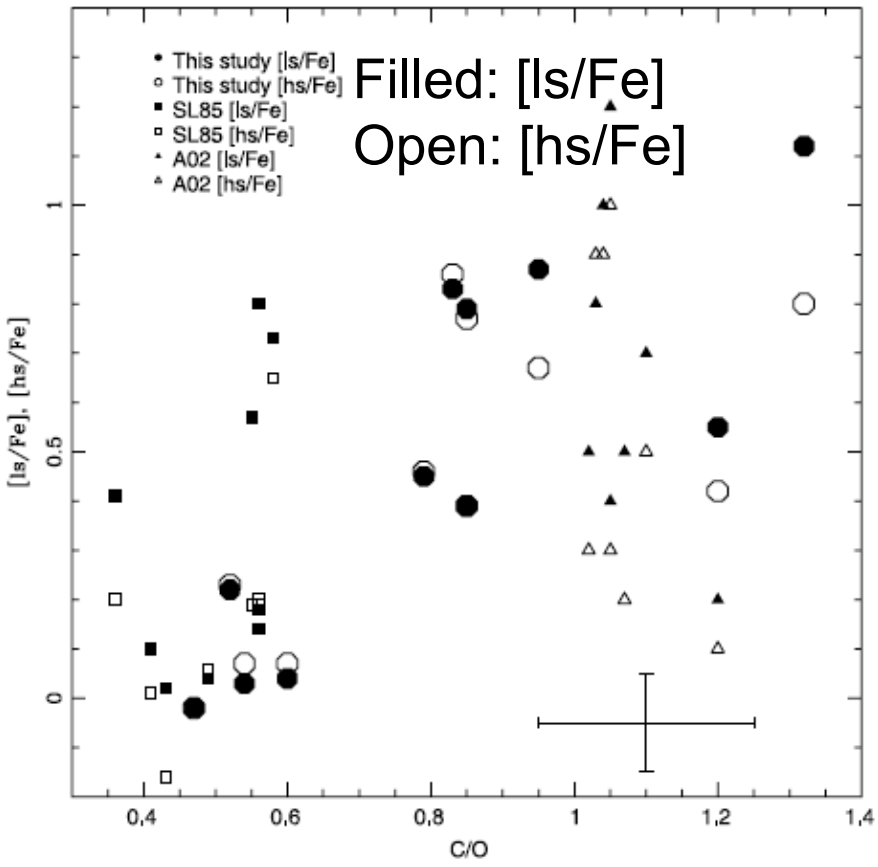
Satisfactorily consistent picture. C increasing, s elements produced, for low mass stars by $^{13}C(\alpha,n)^{16}O$.
Still considerable errors. IR+better line lists. Also problems (e.g. CH)
Note testing of reaction rates, 3α, $^{12}C(\alpha,\gamma)^{16}O$, …

From Wylie-de Boer & Cottrell (2009)

Zr lines: |



[s/Fe]



F in N stars (Abia et al. 2009)

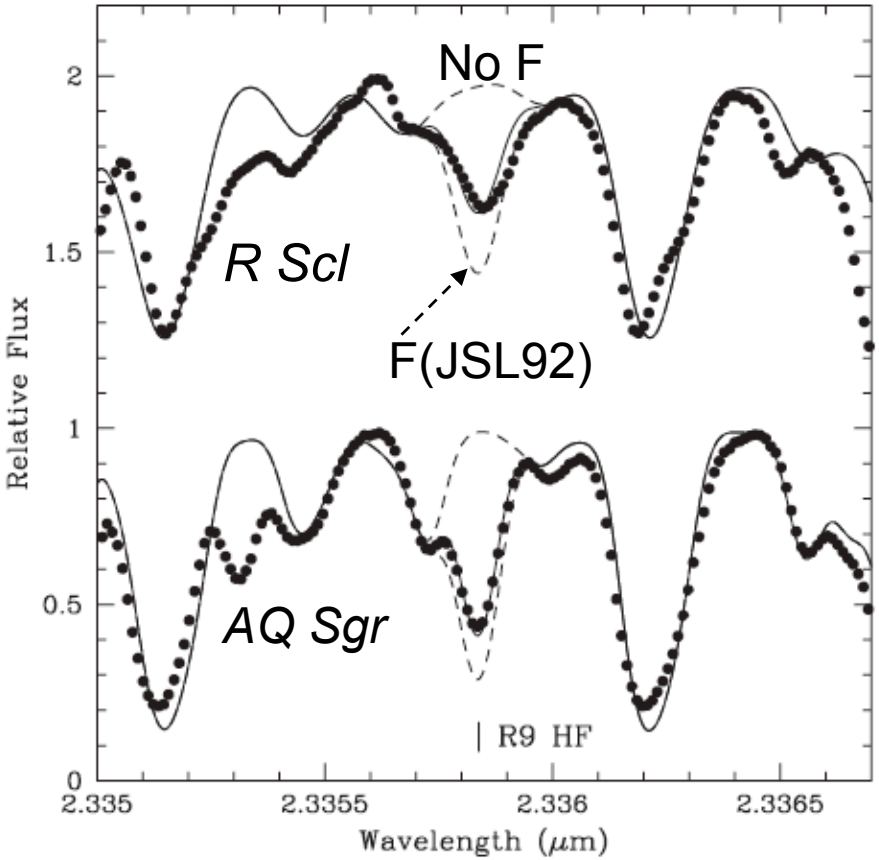
$^{14}N(\alpha,\gamma)^{18}F(\beta^{+})^{18}O(p,\alpha)^{15}N(\alpha,\gamma)^{19}F$

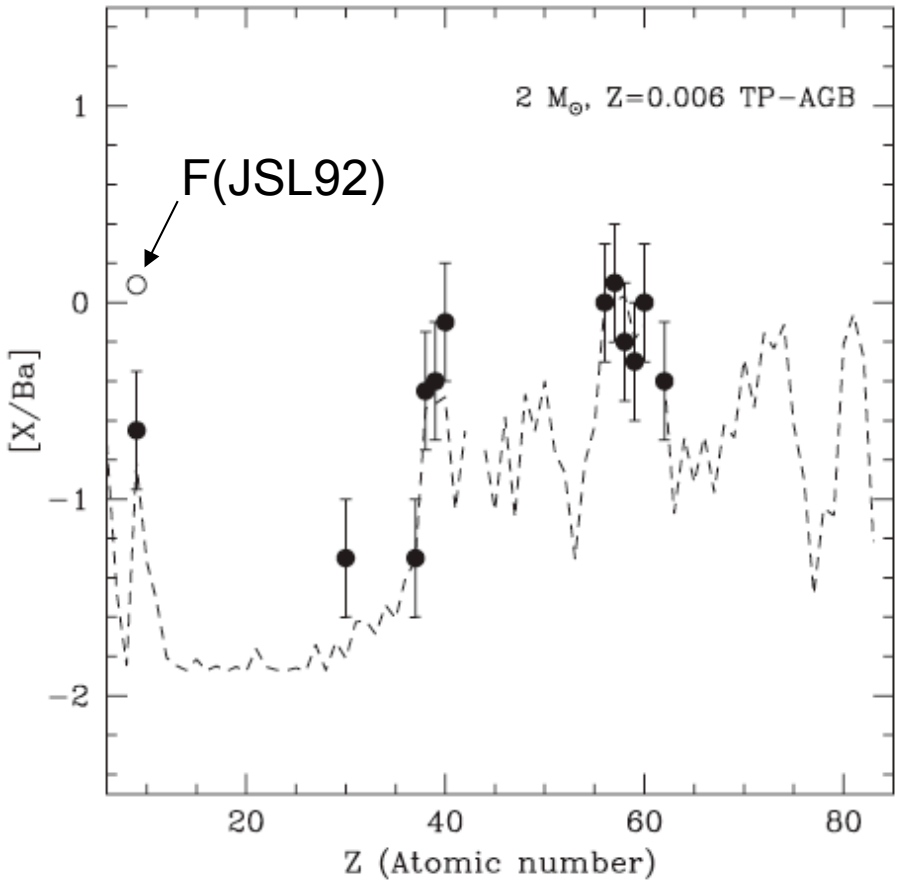
$^{14}N(n,p)^{14}C$

$^{13}C(\alpha,n)^{16}O$

Should correlate with s elem.

Jorissen et al. (1992)
HF IR lines
High log A(F) ~ 5.5
Abia et al. x 1/10!
Blends!





Are present N-star model atmospheres realistic enough?

- Non-LTE, 3D, convection, magnetic fields?
- Extended -- by turbulence
  and pulsations
- Seriously affected by dust

”V-R CH problem” of Lambert et al. 1986!

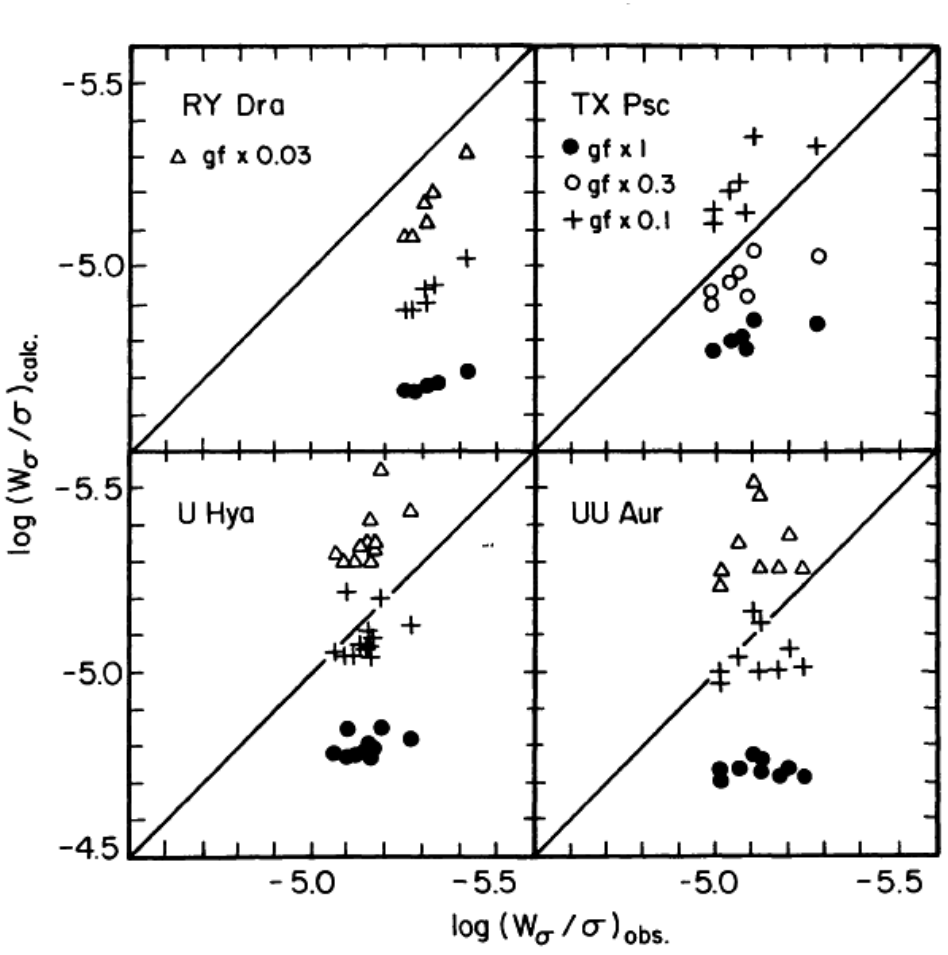
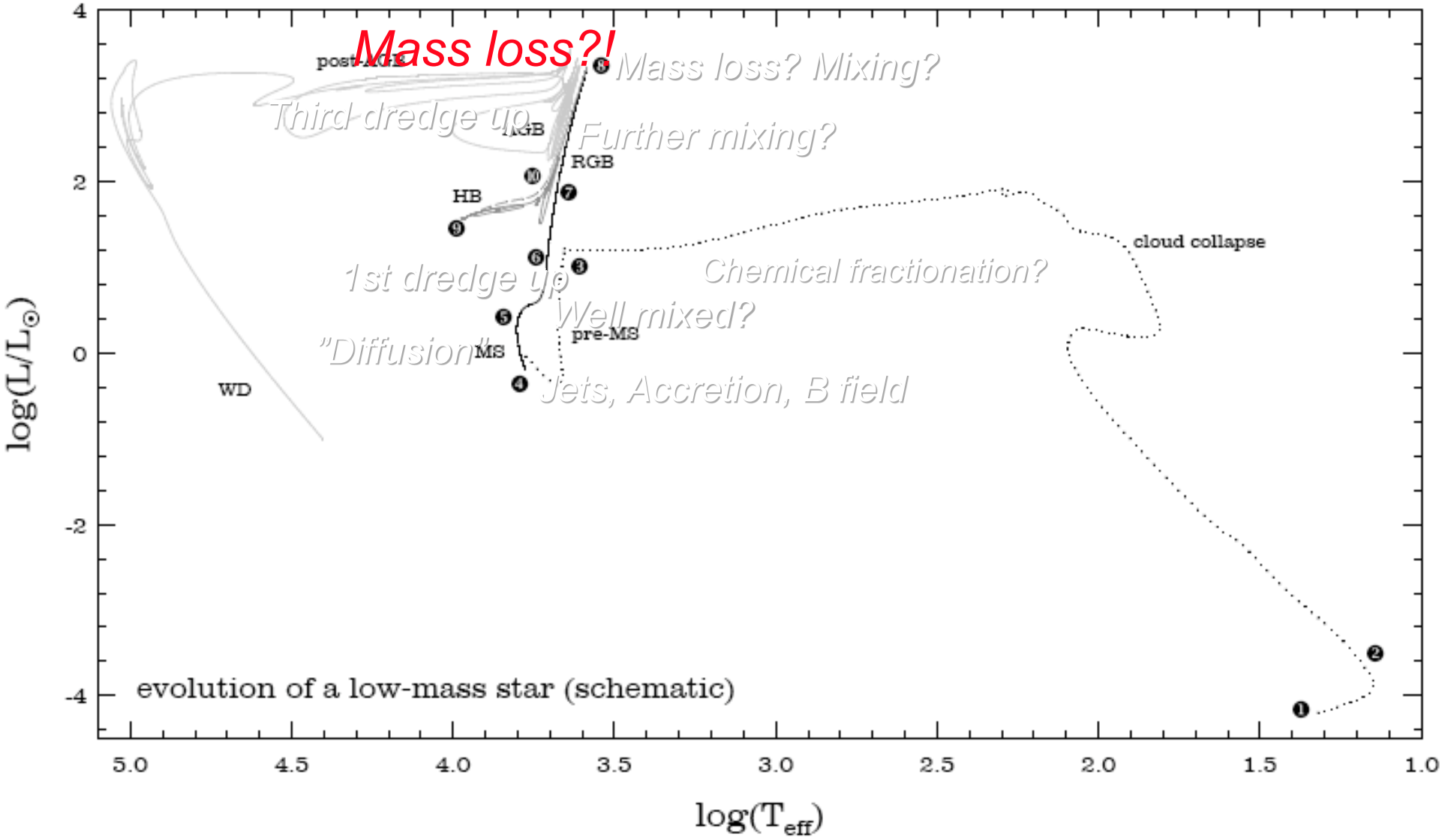
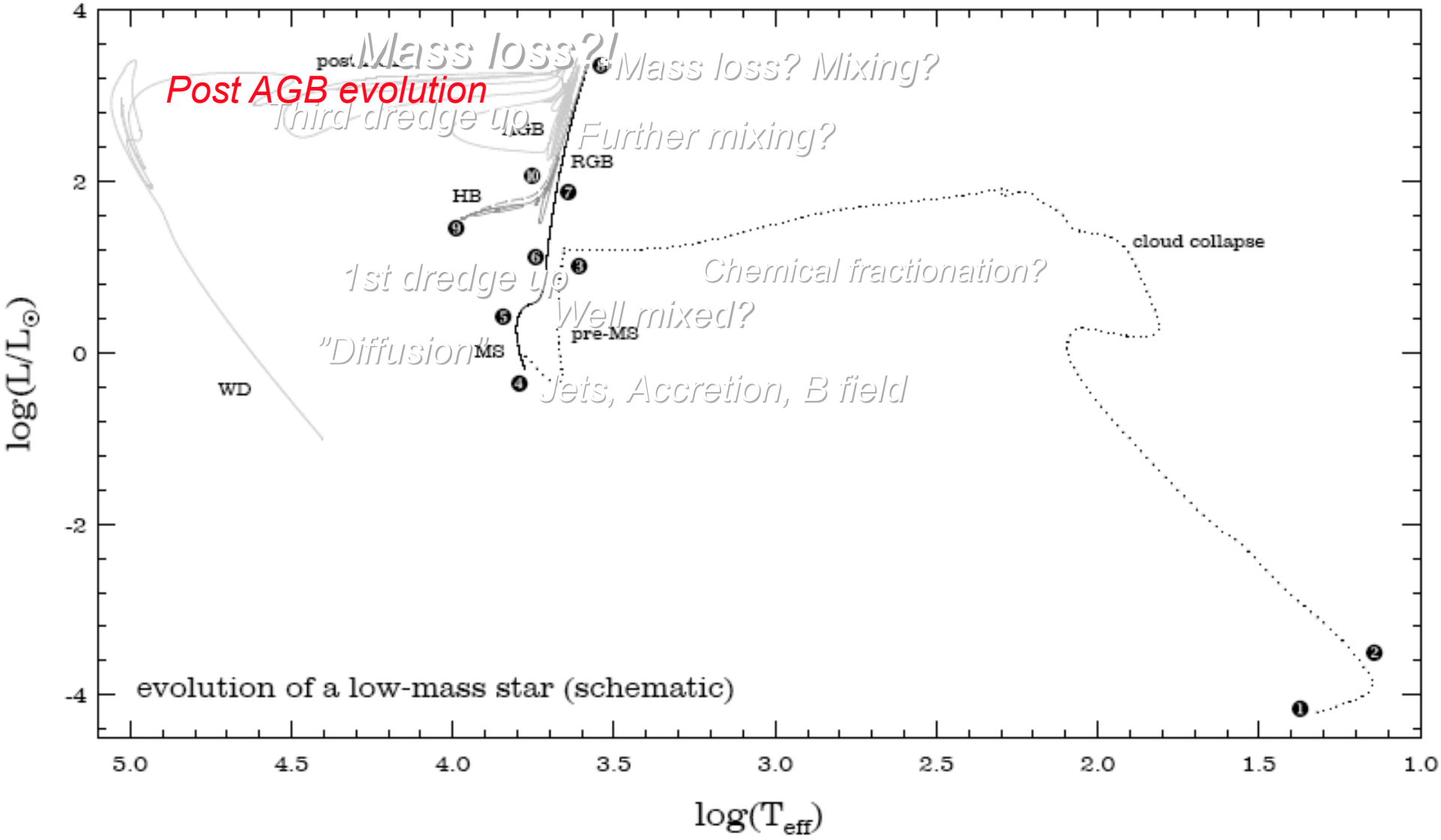


Fig. from Catelan (2007)



See talks by Höfner and Ramstedt!

Fig. from Catelan (2007)



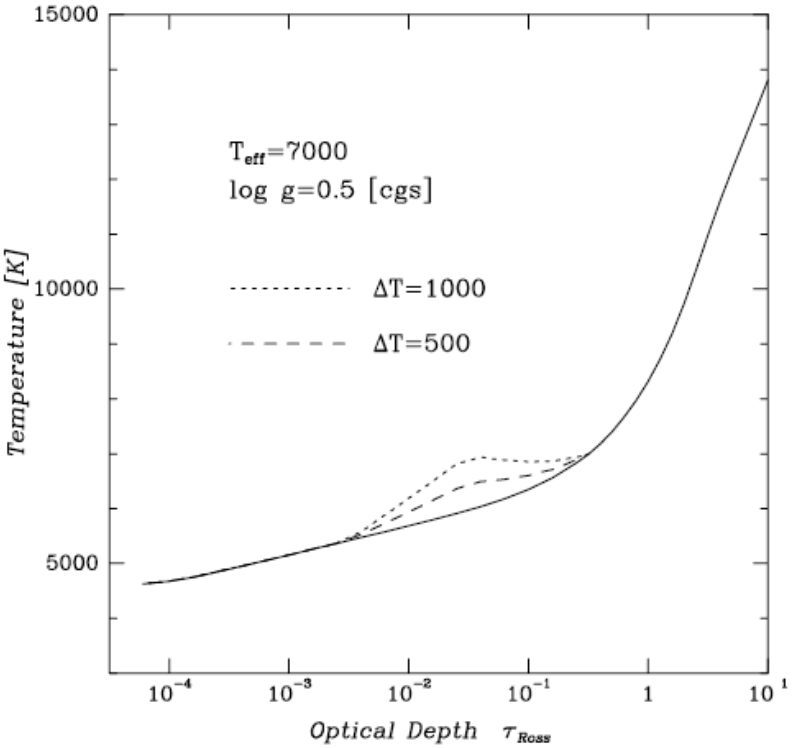
Ex. 8. *R CrB stars and H-deficient C stars*

- Asplund et al. (2000): abundances for 18 stars.

Double Degenerate *or* Final Flash?

"C problem"

CI lines vs CI continuum x4!



Ex. 8. *R CrB stars and H-deficient C stars*

- Asplund et al. (2000): abundances for 18 stars.

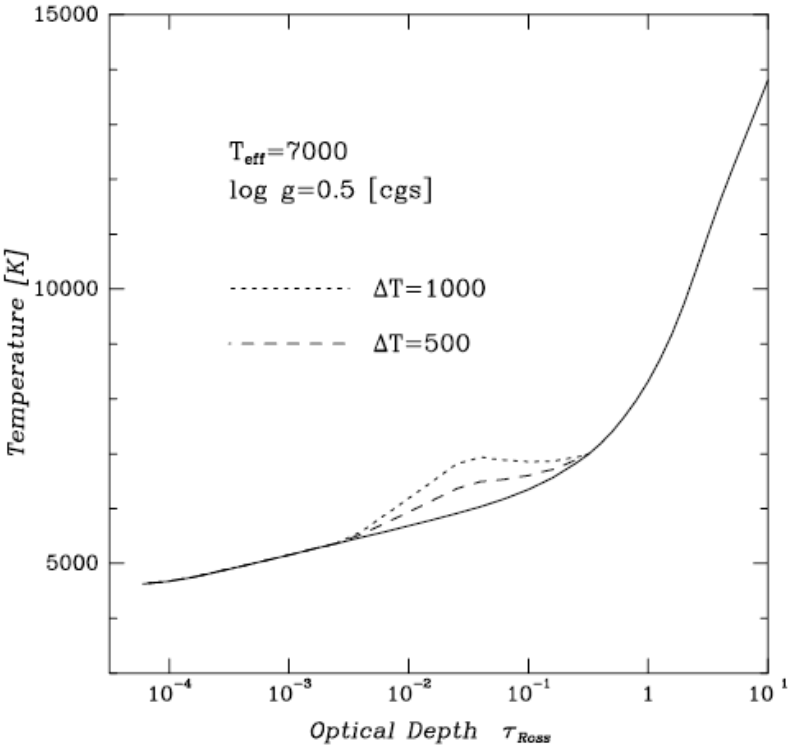
Double Degenerate *or* ~~Final Flash~~

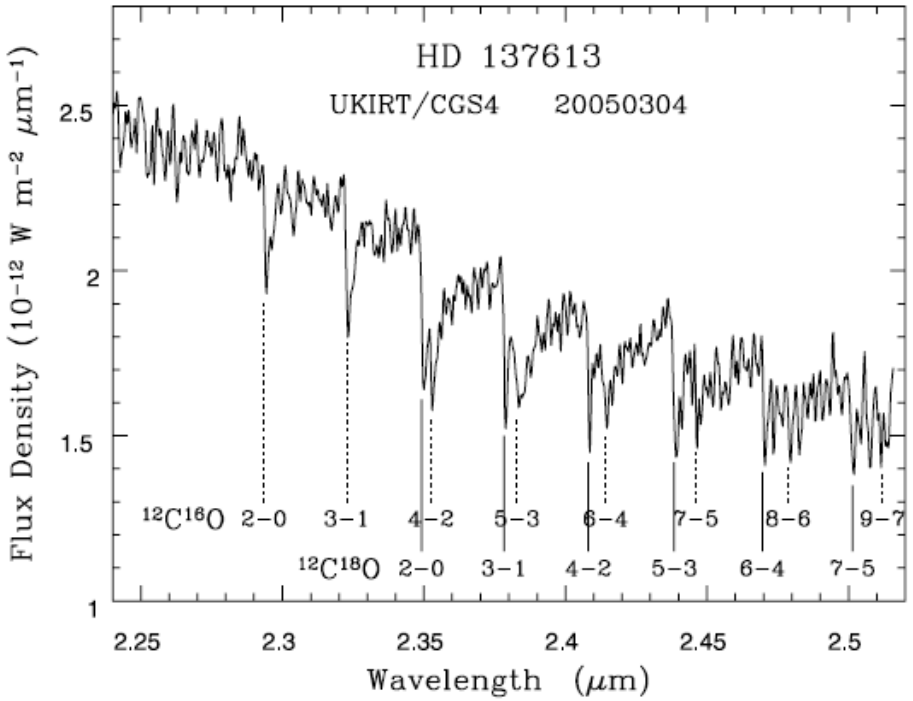
"C problem"

CI lines vs CI continuum x4!

But: $^{18}O/^{16}O$ very high!! (Clayton et al. 2006 ...)

and A(F) very high (Pandey et al. (2006 …)





Sakurai and FG Sge may be FF (cf poster by Herwig et al.)

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