Chemical composition of Exoplanet-host stars

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Outline

1- The chemical composition of Exoplanet-host stars

2- Influence of the accretion of planetary matter onto stars
and hydrodynamical consequences

3- The fate of planetary systems:
accretion of debris disks onto white dwarfs

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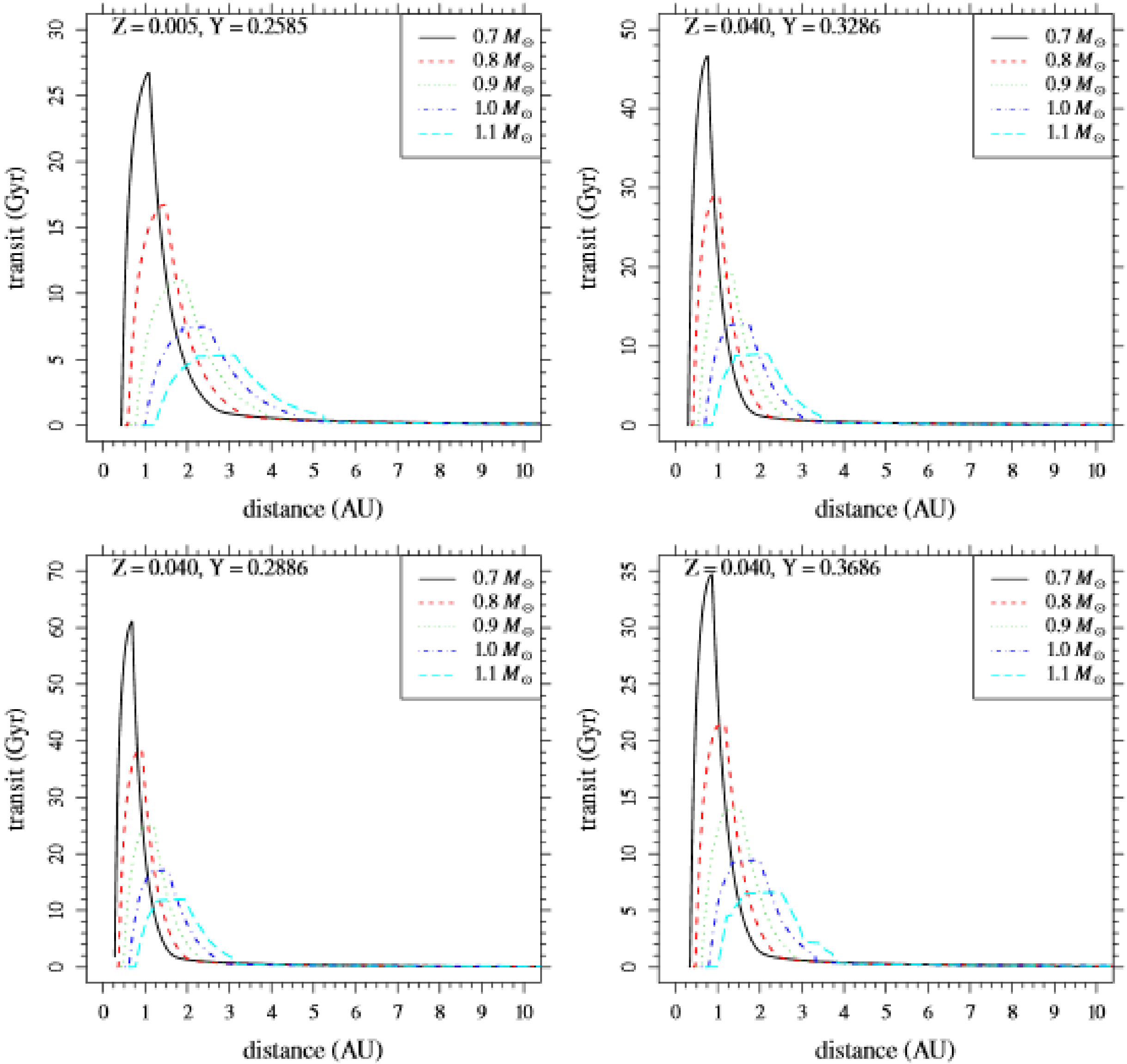


Fig. 3. (Top row): duration of habitability (transit) as a function of the distance from the host star, for different masses M and chemical compositions of the host star for a fixed value of $\Delta Y/\Delta Z = 2$ and two metallicities $Z = 0.005$ and $Z = 0.040$. (Bottom): same as the top row, but for a fixed metallicity $Z = 0.040$ and two values of $\Delta Y/\Delta Z$, namely 1 (left panel) and 3 (right panel).

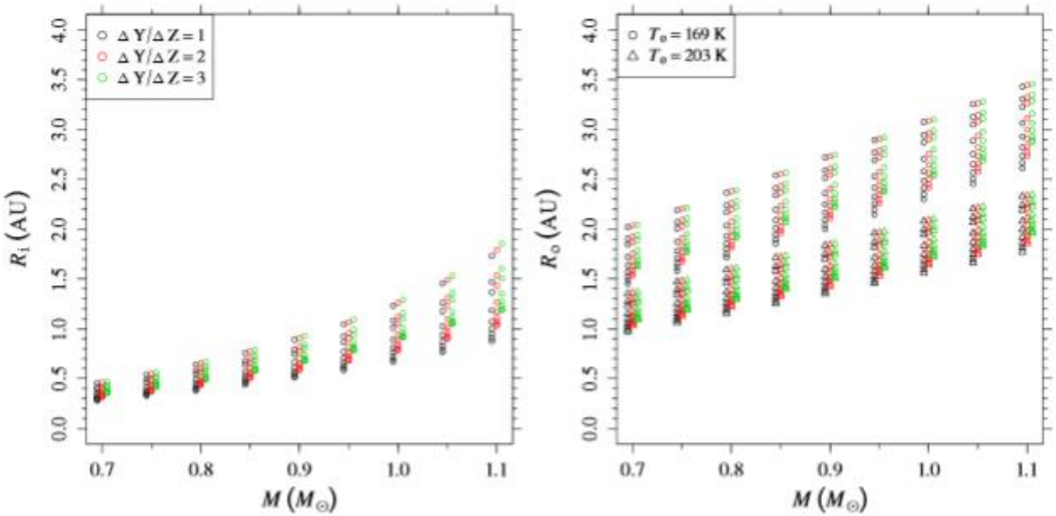


Fig. 7. (Left): position (in AU) of the 4 Gyr CHZ inner boundary as a function of the host star mass for the labelled $\Delta Y/\Delta Z$ values. For each set of mass and $\Delta Y/\Delta Z$, the metallicity Z runs from 0.04 at the upper point to 0.005 at the lower one. The initial helium content is obtained from Z and $\Delta Y/\Delta Z$ as in Eq. (4). To show the effect of the initial helium content, the abscissa of models with high (low) $\Delta Y/\Delta Z$ are shifted by adding (subtracting) 0.005 $M_\odot$. (Right): same as the left panel, but for the outer boundary. The circles correspond to the computations with T_o = 169 K, while the triangles correspond to those with T_o = 203 K.

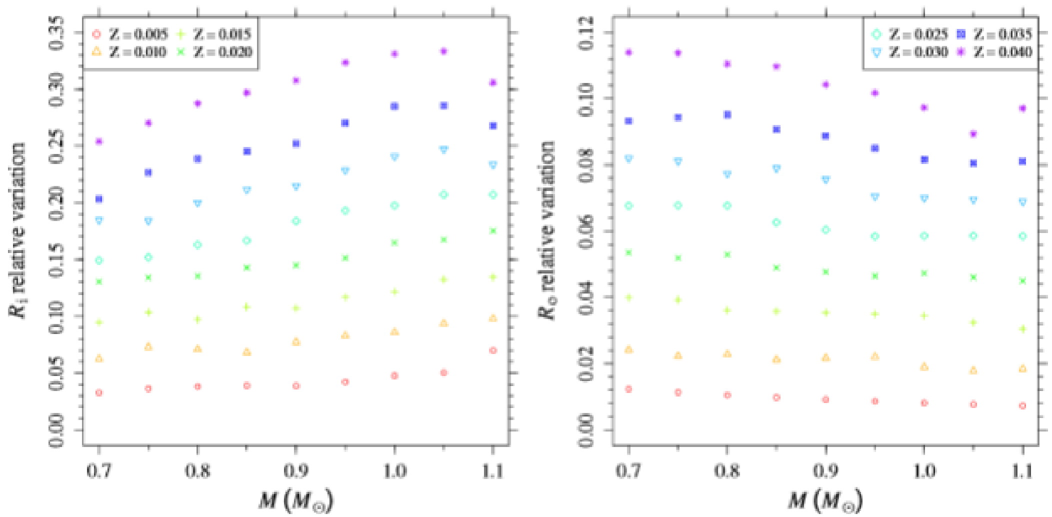
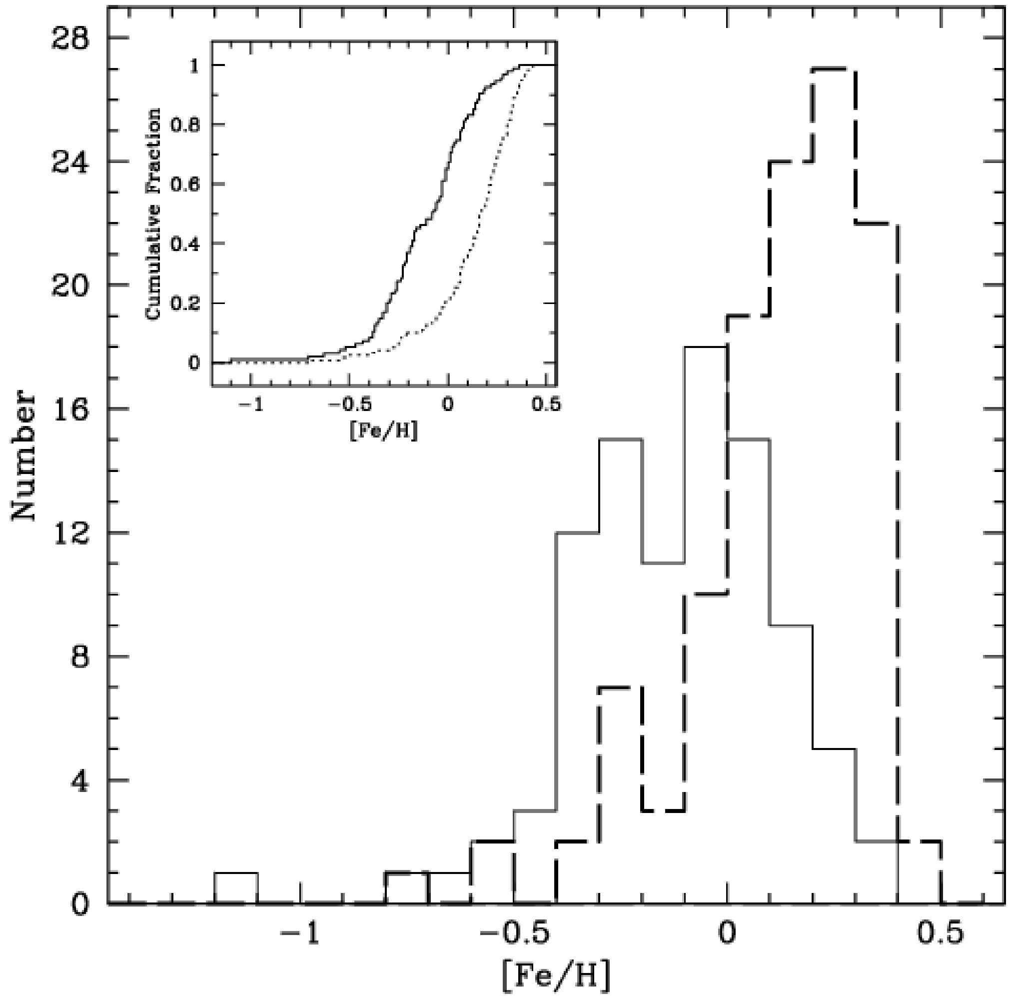


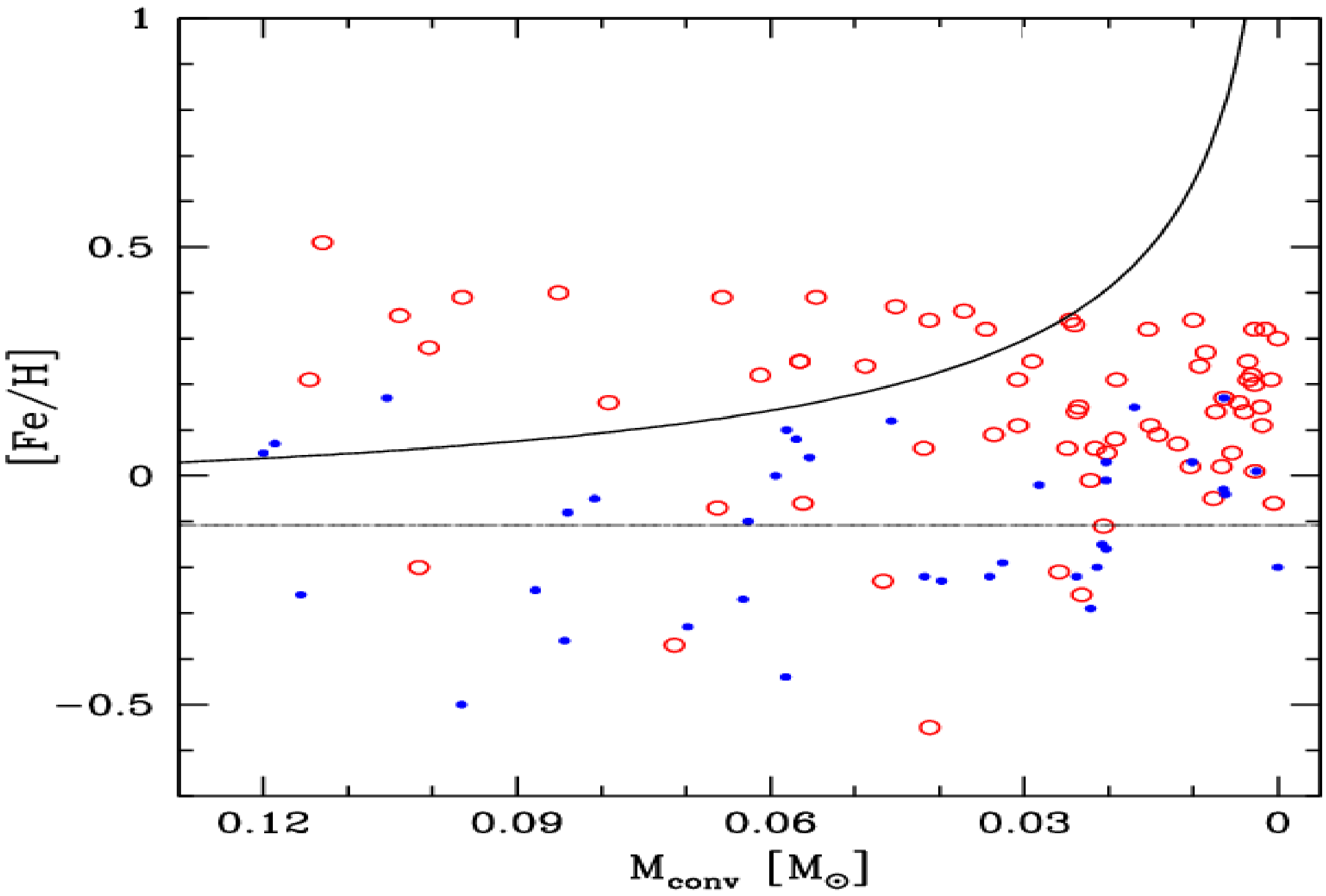
Fig. 8. (Left): relative variation for a change from $\Delta Y/\Delta Z$ = 3 to $\Delta Y/\Delta Z$ = 1 of the 4 Gyr CHZ inner boundary as a function of the host star mass for the labelled Z values. (Right): same as the left panel, but for the outer boundary. The adopted outer boundary temperature is T_o = 169 K.

Chemical composition of exoplanet host stars



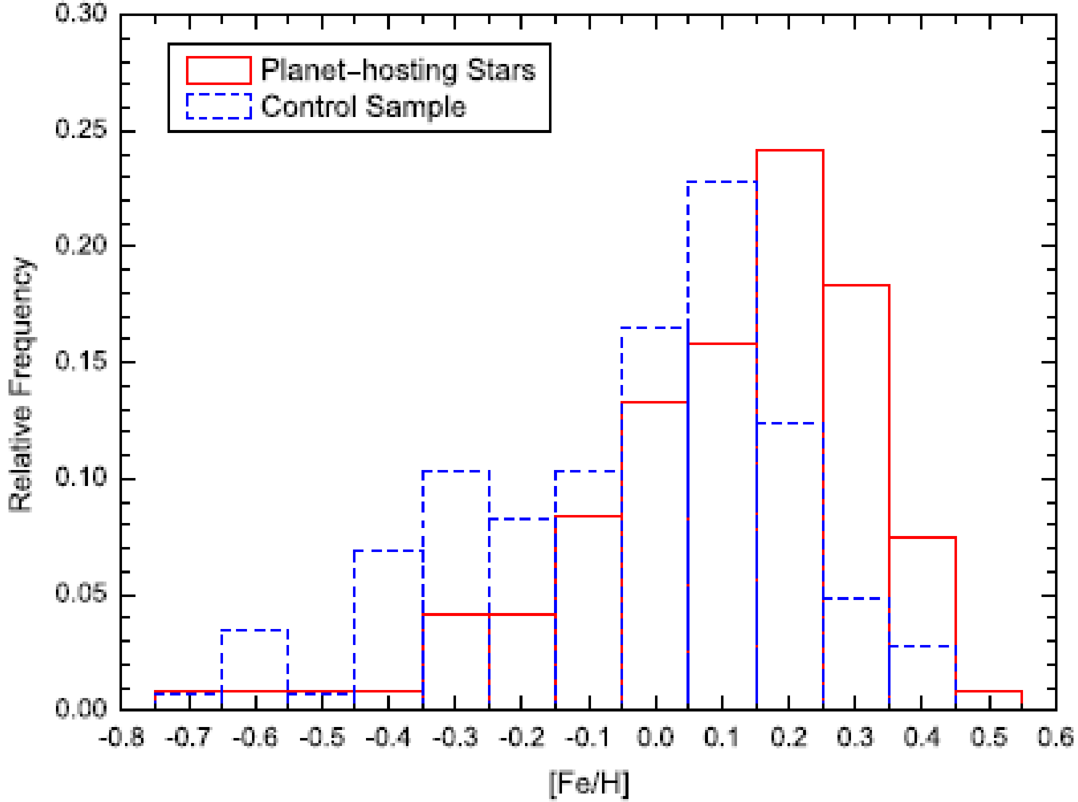
119 planet-host stars (dashed) ;
94 comparison stars (solid)

Santos et al. 2001

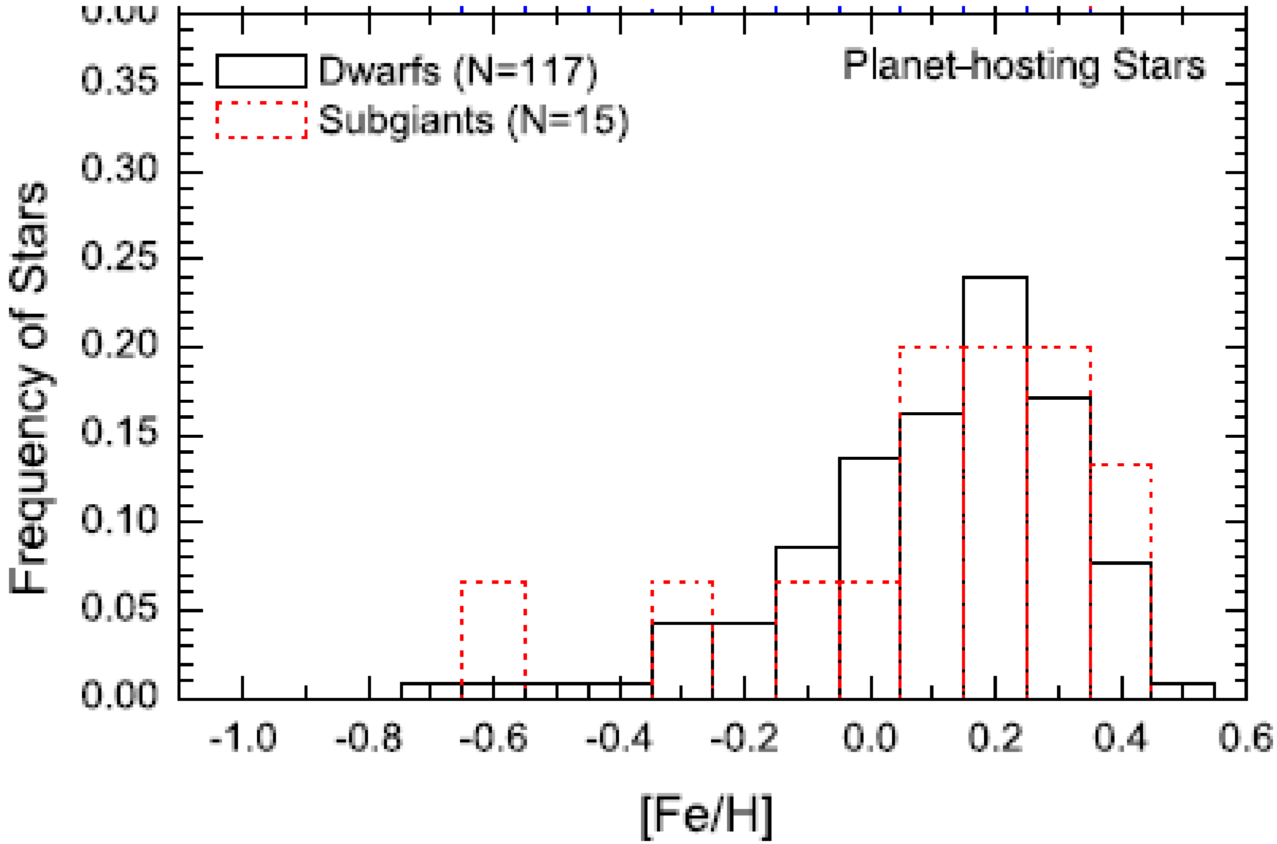


heavy elements in EHS: original abundances.

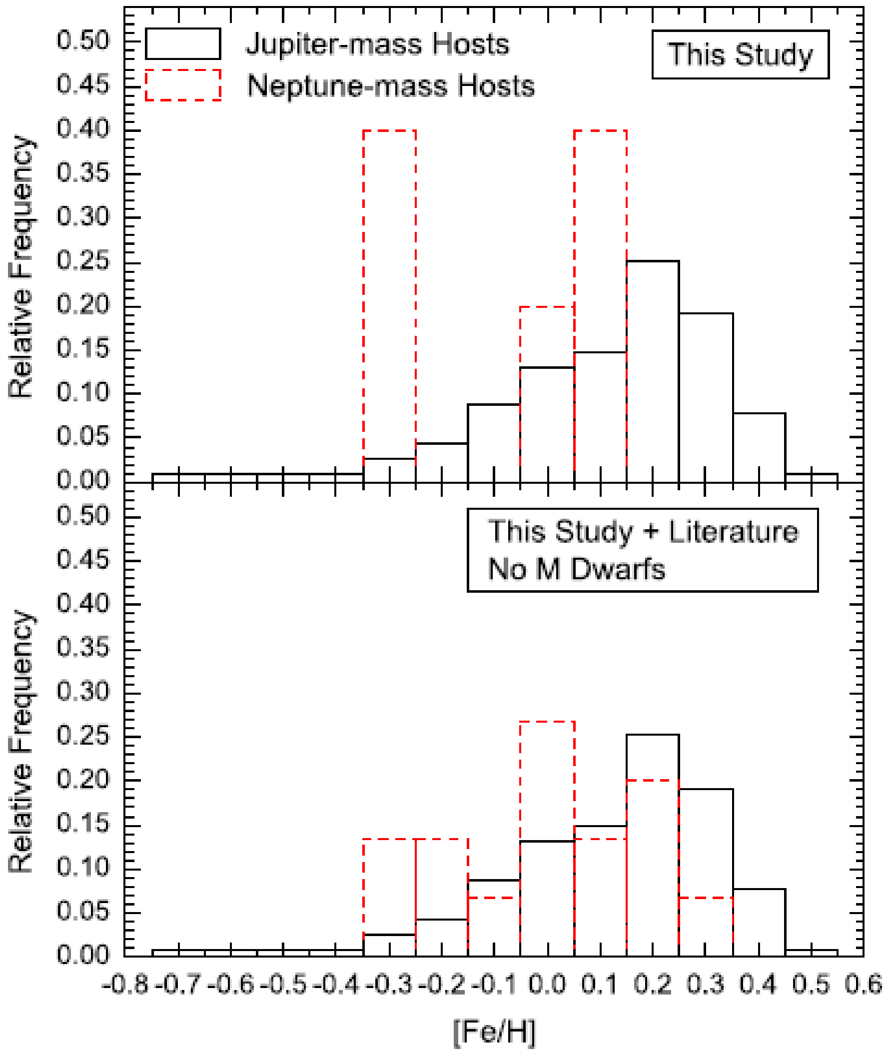
Observations: Santos et al. 2001 ; see Vauclair 2004; Garaud 2011, Théado and Vauclair 2012



Ghezzi et al. ApJ September 2010

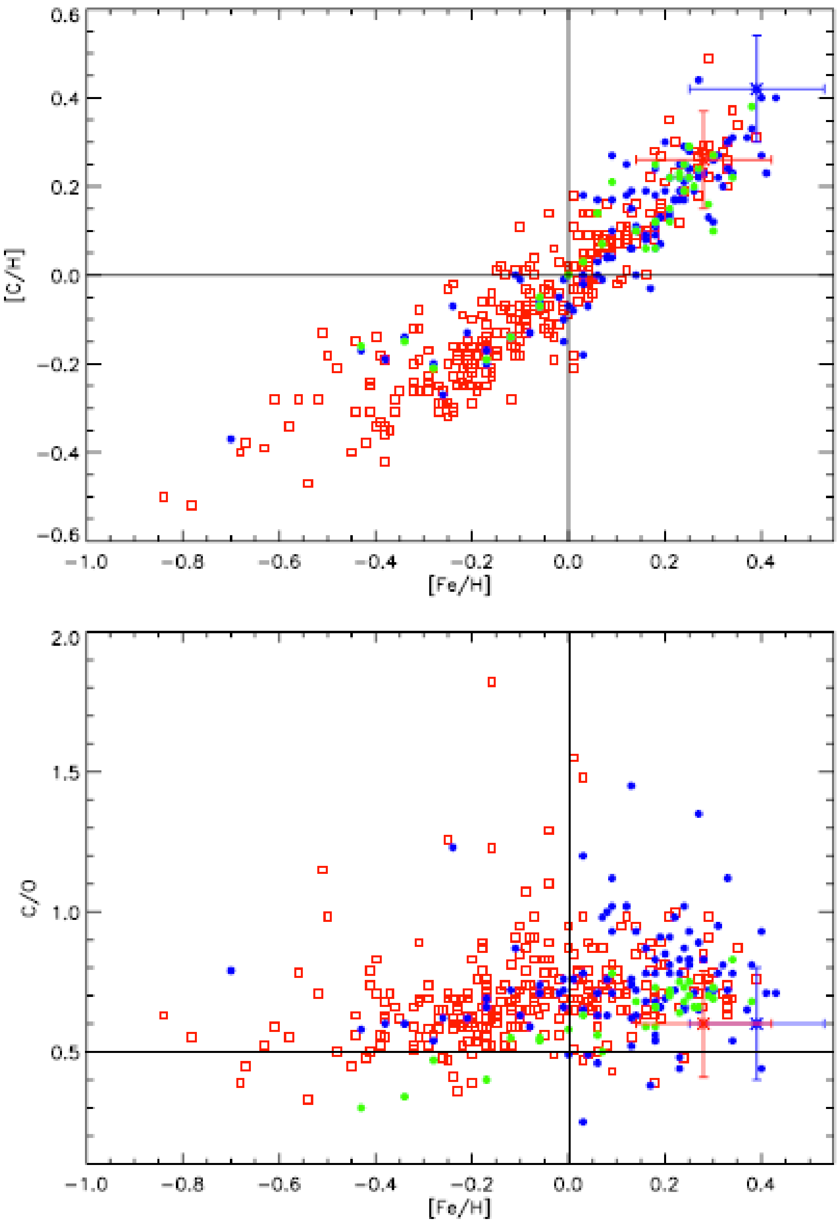


Ghezzi et al. ApJ December 2010

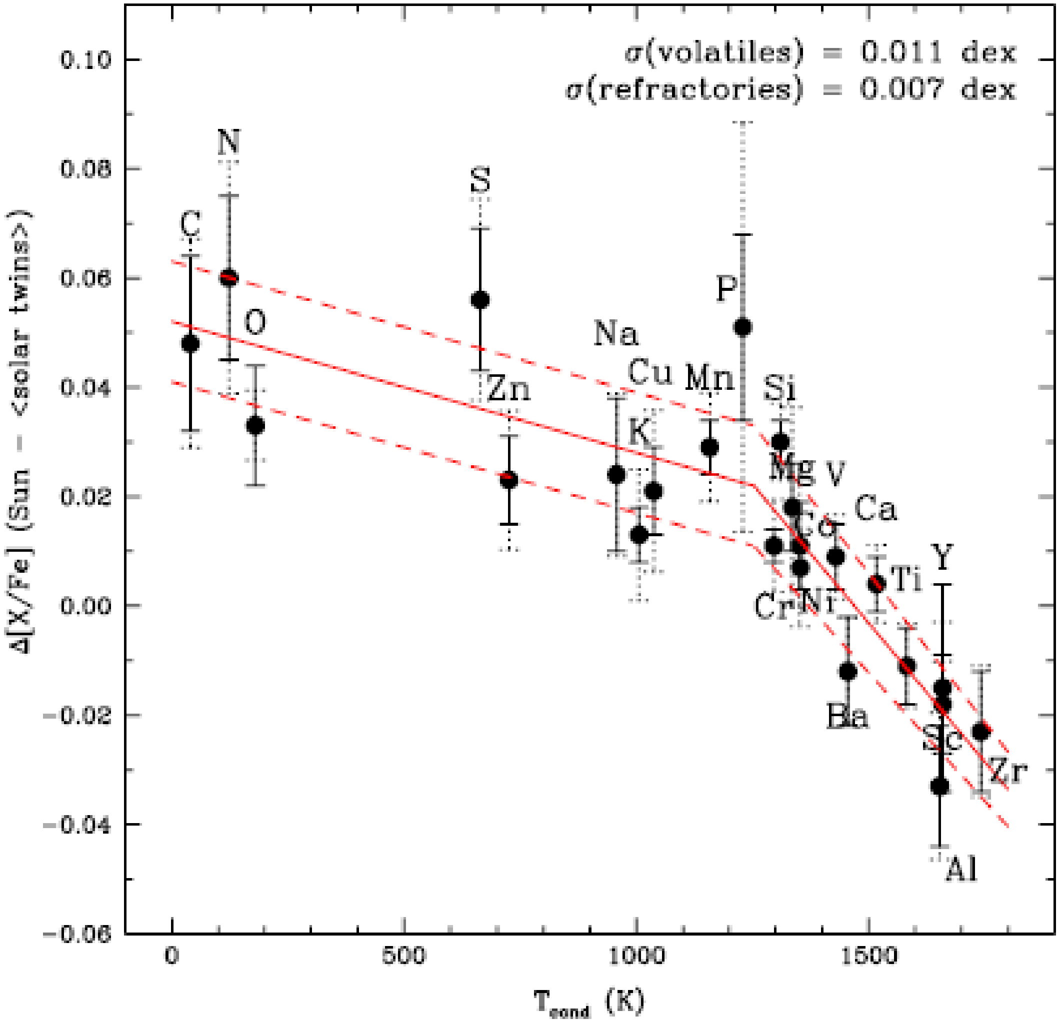


Ghezzi et al. ApJ September 2010

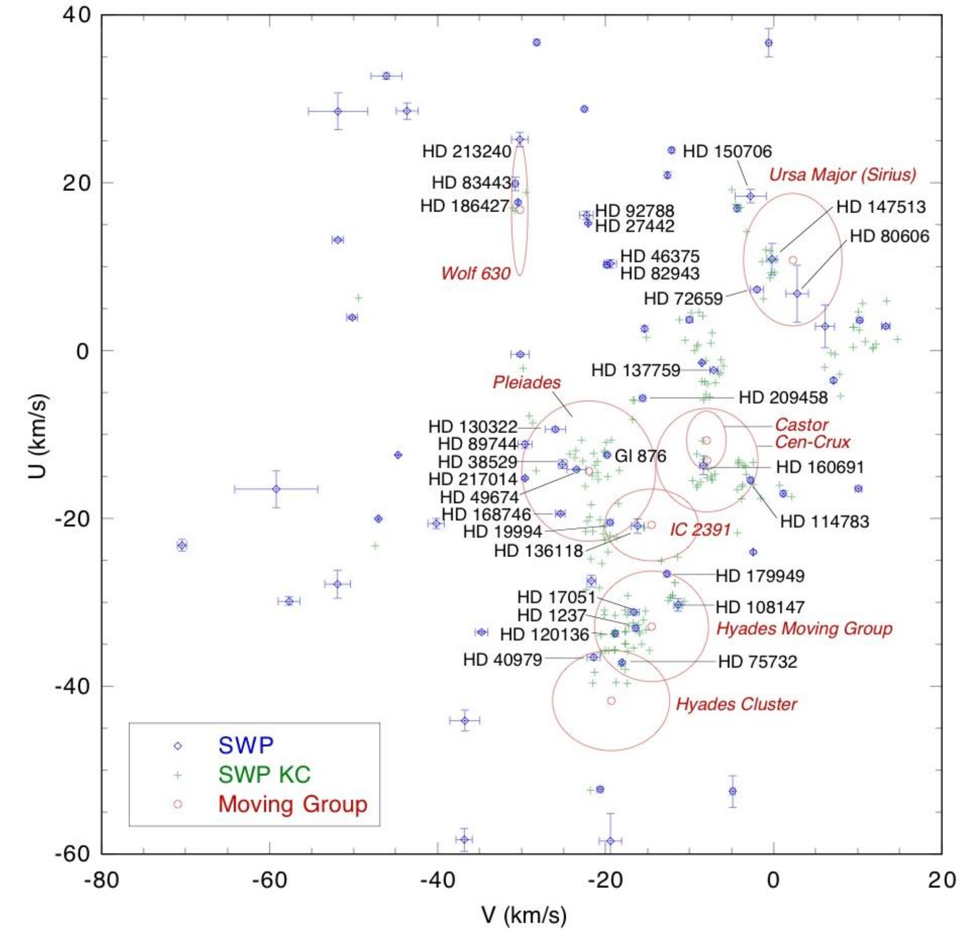
Buchhave et al 2012 : planets with $R_p < 4\ R_\Theta$ at all metallicities



Teske et al., ApJ letters 2013
See also Teske et al 2014



Melendez et al 2009
(see also Ramirez et al. 2014)



ι Horologii

One planet : 320 days; M = 2.26 M_{Jup}

Paul Kalas 2008

Chereul et al 1999
Chereul and Grenon 2000

i Hor belongs
to the Hyades stream

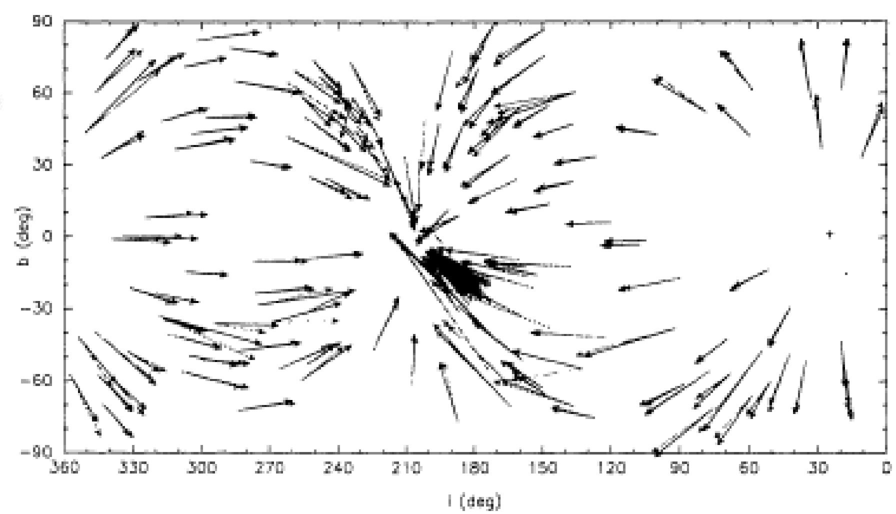


Figure 3. Possible members of the stream including the Hyades open cluster selected by the convergent point method. Full and dotted arrows are respectively the expected and observed proper motions.

Table 3. Chromospheric index, Log R'_{HK}, and age for the EH stars observed at the CASLEO

Name	Log $R'_{HK\ CASLEO}$	<Log $R'_{HK\ without\ CASLEO}$>	<Log $R'_{HK\ with\ CASLEO}$>	D93 Age[Gy]	RPM98 Age[Gy]
GJ 86	−4.67	−4.74	−4.72	2.03	2.94
HD 142	−5.11	−4.92	−5.02	5.93	2.43
HD 1237	−4.31	−4.36	−4.34	0.15	0.25
HD 2039	−5.06	−4.91	−4.98	5.28	1.20
HD 4208	−4.94	−4.94	−4.94	4.47	6.03
HD 6434	−5.23	−4.89	−5.06	6.85	18.51
HD 17051	−4.58	−4.65	−4.63	1.47	0.43
HD 19994	−5.76	−4.83	−5.14	8.91	2.56
HD 23079	−5.23	−4.95	−5.04	6.53	5.92
HD 27442	−5.57		−5.57	24.74	7.15
HD 28185	−4.98	−5.00	−4.99	5.36	1.69

Table 7. Ages derived from isochrone, lithium and [Fe/H] abundances. "L" indicates a lower limit.

Object	Isochr. Age [Gyr]	Isochr. Min. Age [Gyr]	Isochr. Max. Age [Gyr]	Lithium Age [Gyr]	[Fe/H] Max. Age [Gyr]
HD 4208					12.4
HD 6434	13.3	7.0			
HD 8574	8.2	5.7	9.6		5.0
HD 8673	2.8	2.1	3.3		8.7
HD 10647	4.8		7.0		7.9
HD 10697	7.1	6.4	7.9	1.5	1.9
HD 12661				4.4	
HD 16141	11.2	9.7	12.9	4.0	
HD 17051	3.6	1.1	6.7		
HD 19994	4.7	3.1	5.2	1.4	
HD 20367	6.4	3.6	8.9		

Ages given in the literature
(Saffe et al 2008)

ι Horologii

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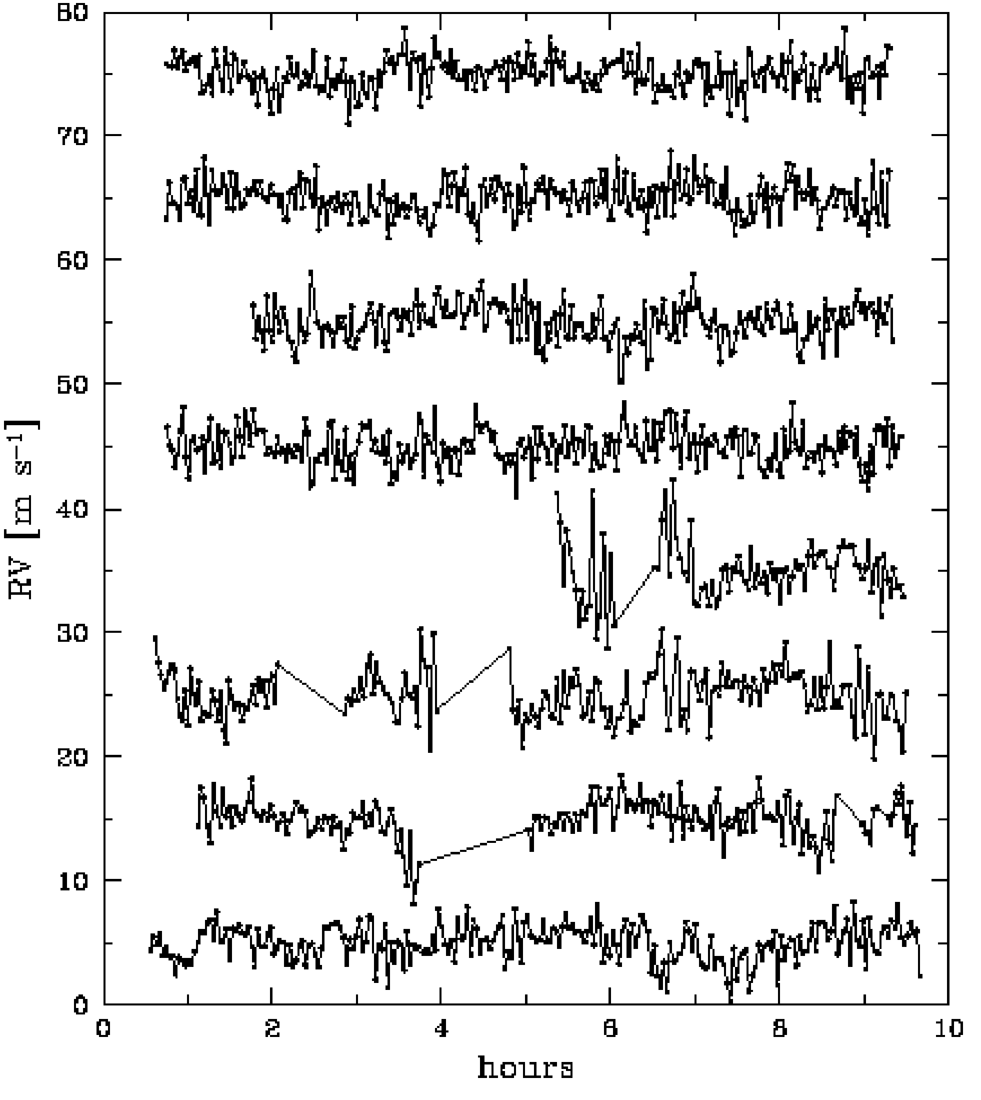
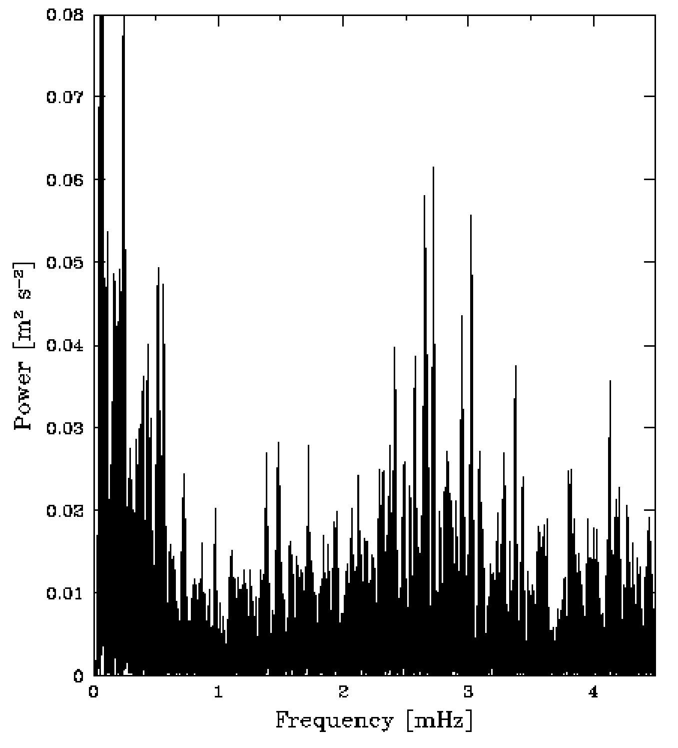
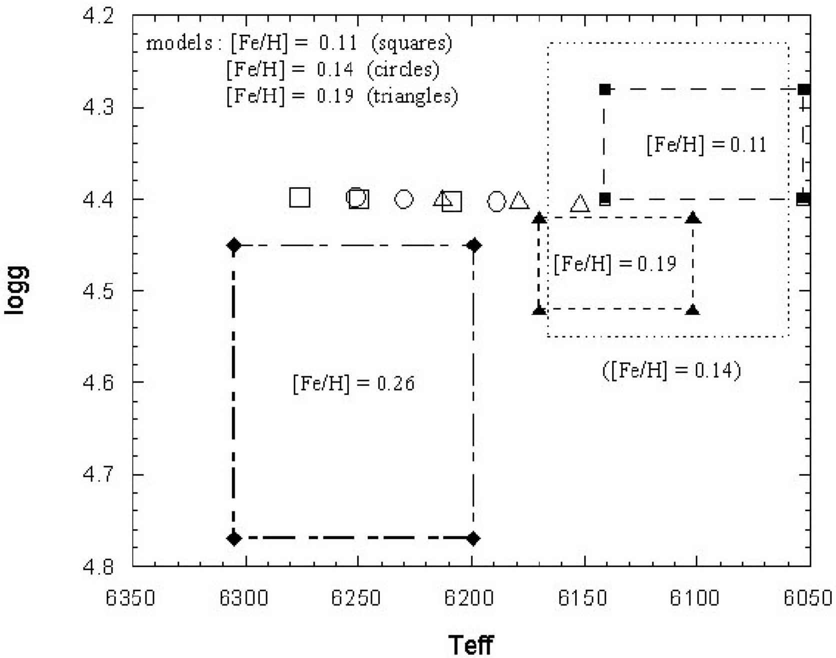




8 nights with HARPS, November 2006
25 identified modes

iota Horologii



(Cf triplet Te, Fe/H, log *g*)

For each metallicity,
Teff of best model
decreases for decreasing Y
(ΔYprop to ΔZ, Y = 0.271, 0.255)

	i Hor Vauclair et al.2008	Hyades Lebreton et al. 2001
[Fe/H]	0.165 ± 0.025	0.14 ± 0.05
Y	0.26 ± 0.01	0.255 ± 0.013
Age (Myr)	625 ± 5	625 ± 25
Masse (Msun)	1.25 ± 0.1	
Teff (K)	6160 ± 30	
log g	4.40 ± 0.01	
log L/Lsun	0.243 ± 0.07	

Liu et al 2014

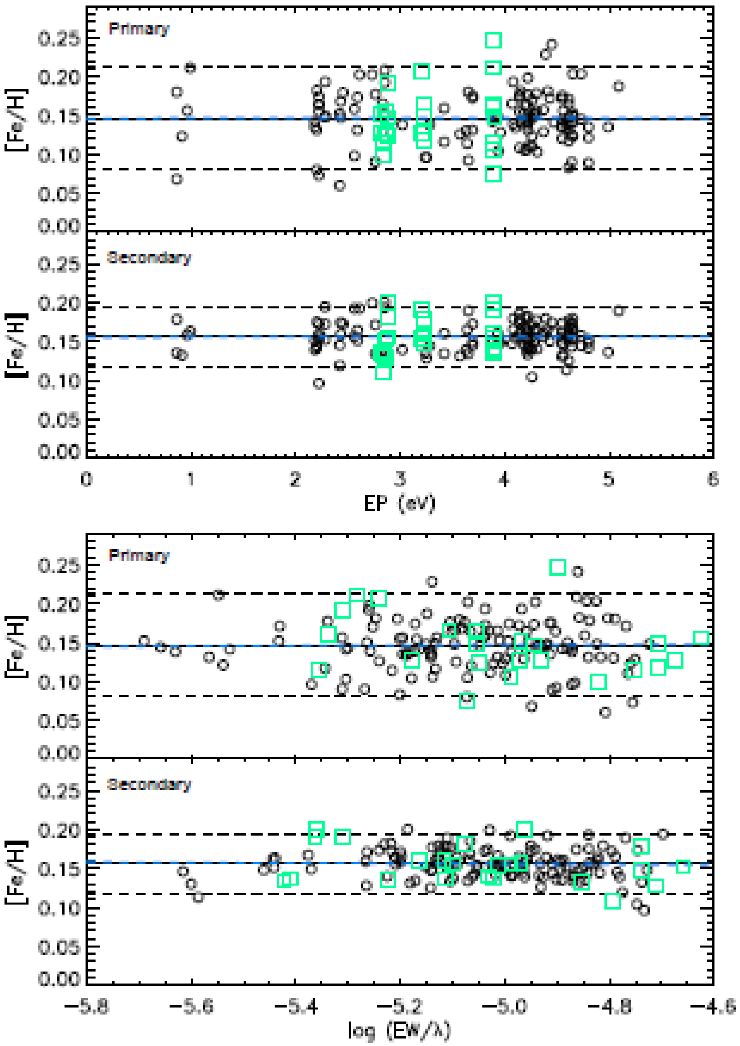


Table 2. Differential elemental abundances for HAT-P-1

Element	Primary[a]	Secondary[a]	Δ[X/Fe][b]
[C I/Fe]	−0.158 ± 0.036	−0.156 ± 0.030	0.002 ± 0.015
[O I/Fe]	−0.063 ± 0.024	−0.067 ± 0.034	−0.004 ± 0.020
[Na I/Fe]	−0.067 ± 0.021	−0.065 ± 0.008	0.002 ± 0.016
[Mg I/Fe]	−0.060 ± 0.020	−0.050 ± 0.008	0.011 ± 0.014
[Al I/Fe]	−0.025 ± 0.018	−0.019 ± 0.011	0.006 ± 0.020
[Si I/Fe]	−0.004 ± 0.012	−0.002 ± 0.007	0.001 ± 0.008
[S I/Fe]	−0.090 ± 0.021	−0.097 ± 0.015	−0.007 ± 0.011
[Ca I/Fe]	0.009 ± 0.011	0.009 ± 0.008	0.000 ± 0.009
[Sc II/Fe]	0.052 ± 0.017	0.042 ± 0.014	−0.010 ± 0.012
[Ti I/Fe]	0.006 ± 0.012	0.006 ± 0.008	0.000 ± 0.009
[Ti II/Fe]	0.031 ± 0.015	0.023 ± 0.010	−0.008 ± 0.012
[V I/Fe]	0.017 ± 0.019	0.014 ± 0.012	−0.003 ± 0.014
[Cr I/Fe]	−0.032 ± 0.011	−0.018 ± 0.008	0.014 ± 0.009
[Cr II/Fe]	−0.032 ± 0.018	−0.022 ± 0.015	0.010 ± 0.013
[Mn I/Fe]	−0.055 ± 0.018	−0.044 ± 0.018	0.011 ± 0.012
[Co I/Fe]	−0.031 ± 0.015	−0.023 ± 0.011	0.008 ± 0.014
[Ni I/Fe]	−0.017 ± 0.011	−0.008 ± 0.006	0.009 ± 0.008
[Cu I/Fe]	−0.094 ± 0.012	−0.102 ± 0.015	−0.008 ± 0.010
[Zn I/Fe]	−0.112 ± 0.027	−0.106 ± 0.021	0.007 ± 0.009
[Sr I/Fe]	0.043 ± 0.019	0.031 ± 0.015	−0.012 ± 0.014
[Sr II/Fe]	−0.016 ± 0.019	−0.018 ± 0.015	−0.002 ± 0.014
[Y II/Fe]	0.019 ± 0.042	0.023 ± 0.029	0.004 ± 0.017
[Zr II/Fe]	0.021 ± 0.013	0.036 ± 0.012	0.015 ± 0.012
[Ba II/Fe]	0.072 ± 0.029	0.056 ± 0.013	−0.016 ± 0.018
[La II/Fe]	0.058 ± 0.017	0.065 ± 0.009	0.008 ± 0.014
[Ce II/Fe]	0.030 ± 0.027	0.028 ± 0.023	−0.002 ± 0.015

[a] Relative to the Sun
[b] Secondary star relative to primary star

The secondary hosts a giant planet

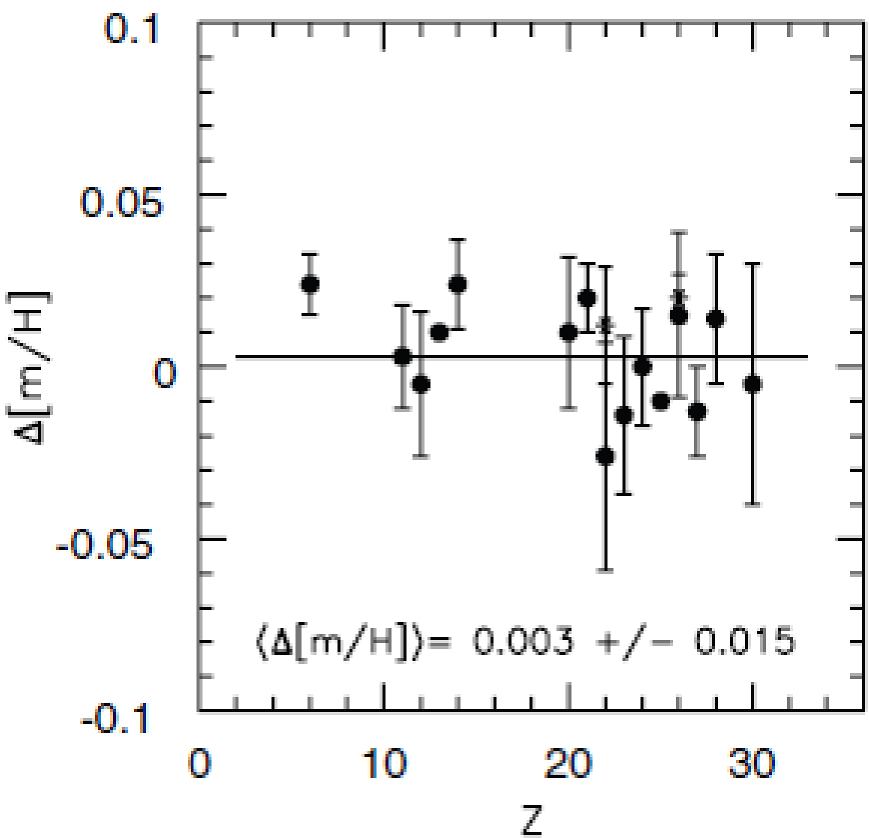
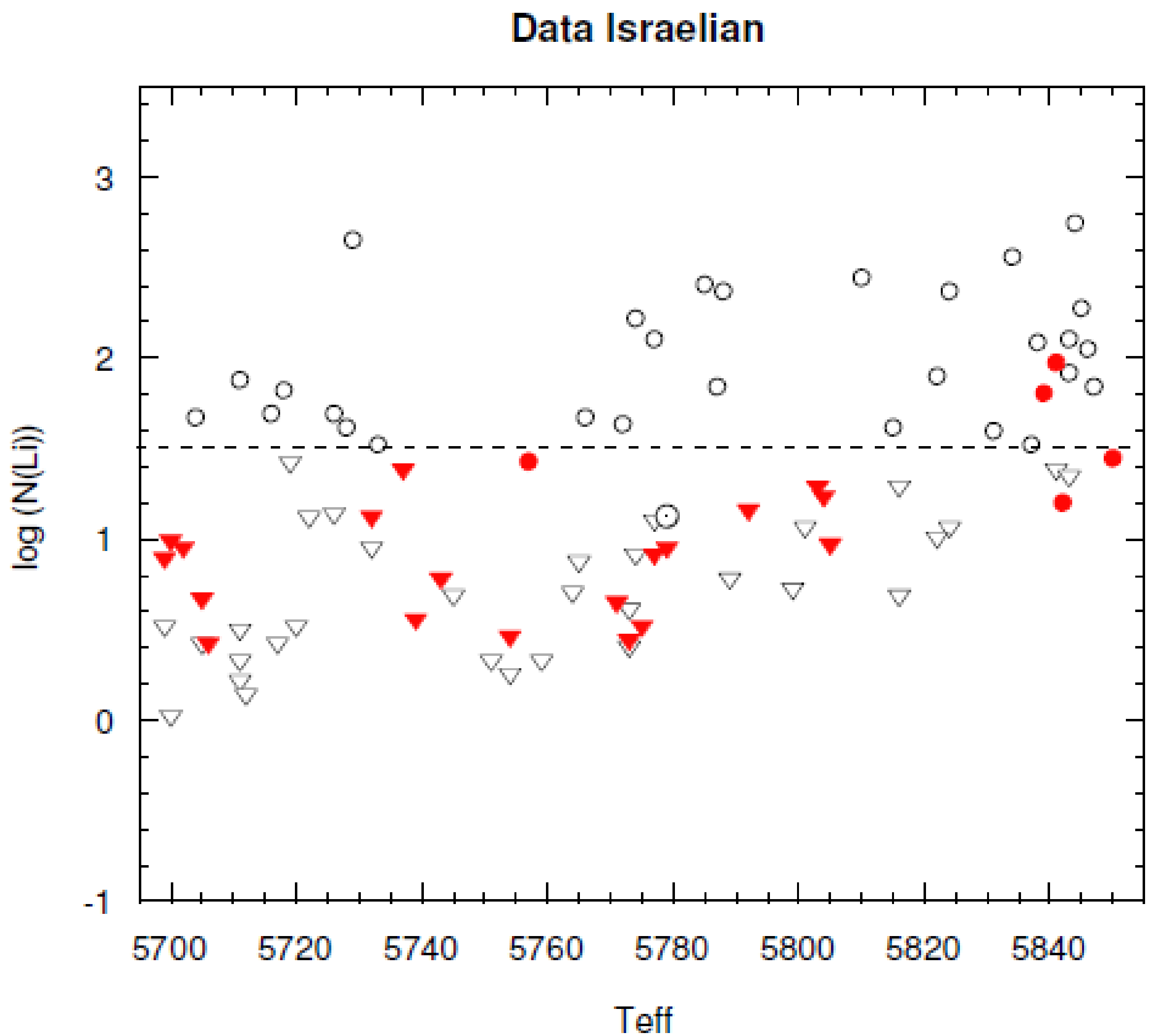


Table 1
Stellar Parameters and Abundances

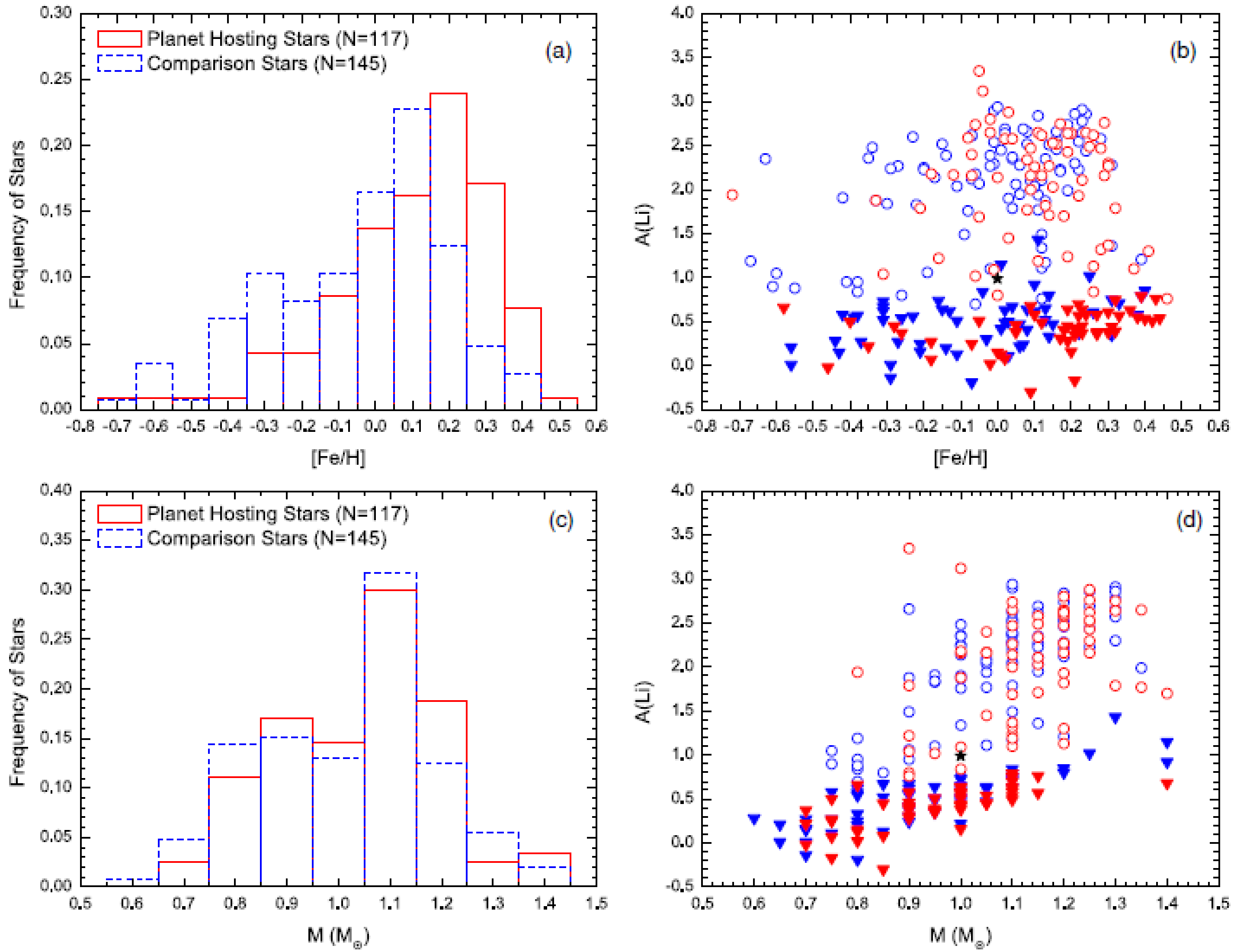
Parameter[a]	16 Cyg A	16 Cyg B
T_{eff} (K)	5796 ± 34	5753 ± 30
log g (cgs)	4.38 ± 0.12	4.40 ± 0.12
ξ (km s^{-1})	1.45 ± 0.07	1.35 ± 0.08
[Fe/H]	$+0.07 \pm 0.01$[b] ± 0.05[c]	$+0.05 \pm 0.01 \pm 0.05$
[C/H]	$+0.10 \pm 0.03 \pm 0.05$	$+0.08 \pm 0.03 \pm 0.05$
[Na/H]	$+0.07 \pm 0.00 \pm 0.03$	$+0.07 \pm 0.00 \pm 0.03$
[Mg/H]	$+0.07 \pm 0.04 \pm 0.05$	$+0.07 \pm 0.04 \pm 0.03$
[Al/H]	$+0.11 \pm 0.02 \pm 0.03$	$+0.10 \pm 0.02 \pm 0.03$
[Si/H]	$+0.09 \pm 0.01 \pm 0.01$	$+0.07 \pm 0.01 \pm 0.01$
[Ca/H]	$+0.08 \pm 0.01 \pm 0.04$	$+0.07 \pm 0.01 \pm 0.04$
[Sc/H]	$+0.12 \pm 0.01 \pm 0.07$	$+0.10 \pm 0.01 \pm 0.07$
[Ti/H]	$+0.10 \pm 0.01 \pm 0.07$	$+0.11 \pm 0.01 \pm 0.07$
[V/H]	$+0.06 \pm 0.02 \pm 0.04$	$+0.07 \pm 0.02 \pm 0.04$
[Cr/H]	$+0.08 \pm 0.02 \pm 0.04$	$+0.08 \pm 0.02 \pm 0.03$
[Mn/H]	$+0.07 \pm 0.03 \pm 0.04$	$+0.08 \pm 0.03 \pm 0.04$
[Co/H]	$+0.08 \pm 0.02 \pm 0.04$	$+0.09 \pm 0.02 \pm 0.03$
[Ni/H]	$+0.09 \pm 0.01 \pm 0.02$	$+0.08 \pm 0.01 \pm 0.02$
[Zn/H]	$+0.10 \pm 0.02 \pm 0.04$	$+0.10 \pm 0.02 \pm 0.03$

Schuler et al, ApJ letters 2011
16 Cyg A and 16 Cyg B

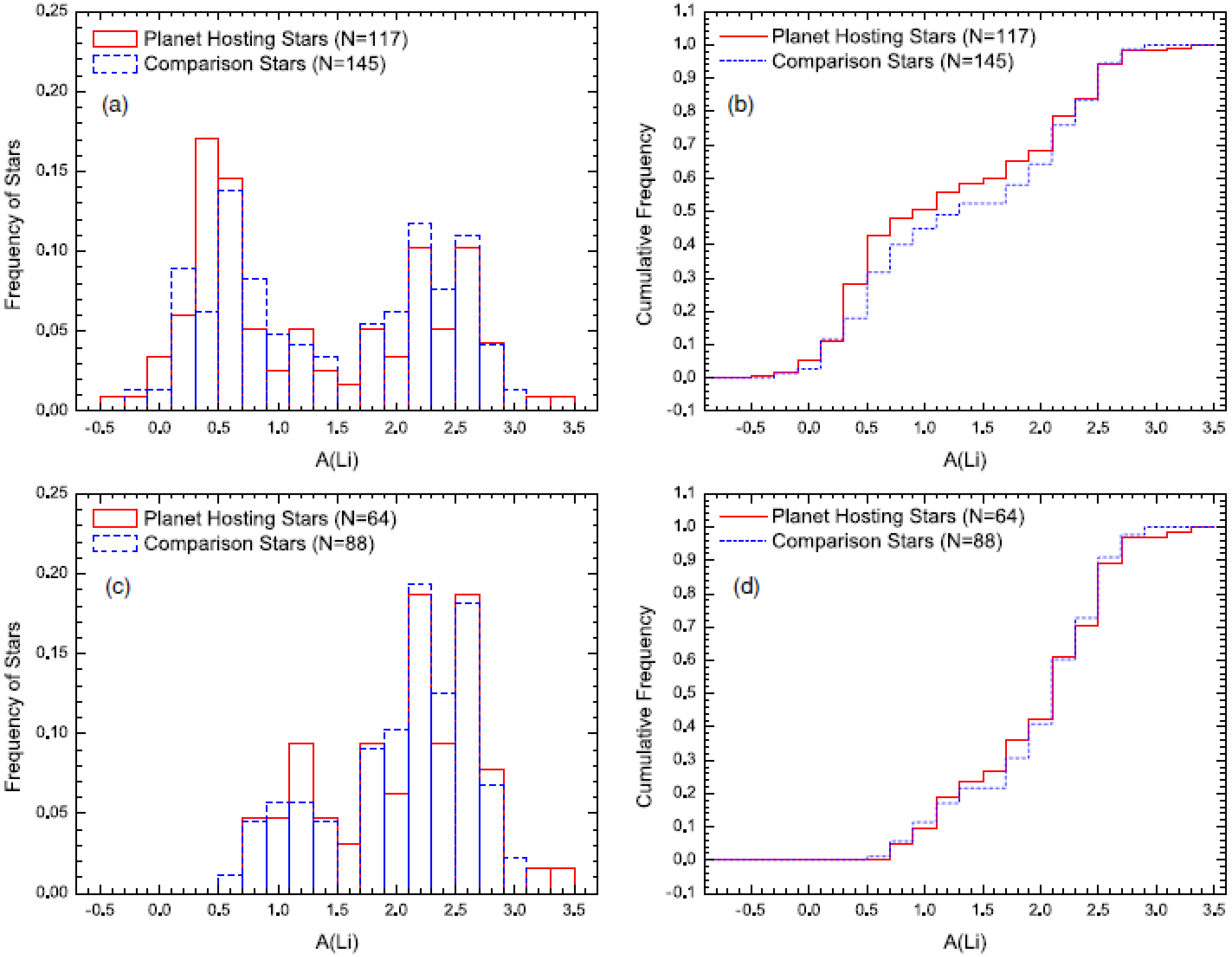
Lithium abundances (Friel et al. 1993, King et al. 1997) :
16 Cyg A : log N(Li) = 1.27 ; 16 Cyg B : log N(Li) < 0.60



Israelian et al, Nature 2010 (contestation: Melendez et al.)



Ghezzi et al. ApJ November 2010



Ghezzi et al. ApJ November 2010

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Sugar solution

Salt solution

Double-diffusion experiment (Pringle et al. 2002) with sugar and salt solutions (κ (salt)/ κ (sugar) $\approx$ 3)

Thermohaline convection: the ocean case

Define the density anomaly ratio as :

$$R_\rho = \alpha\nabla T/\beta\nabla S$$

where :

$$\alpha = (1/\rho)(\partial\rho/\partial T)_{S,P}$$

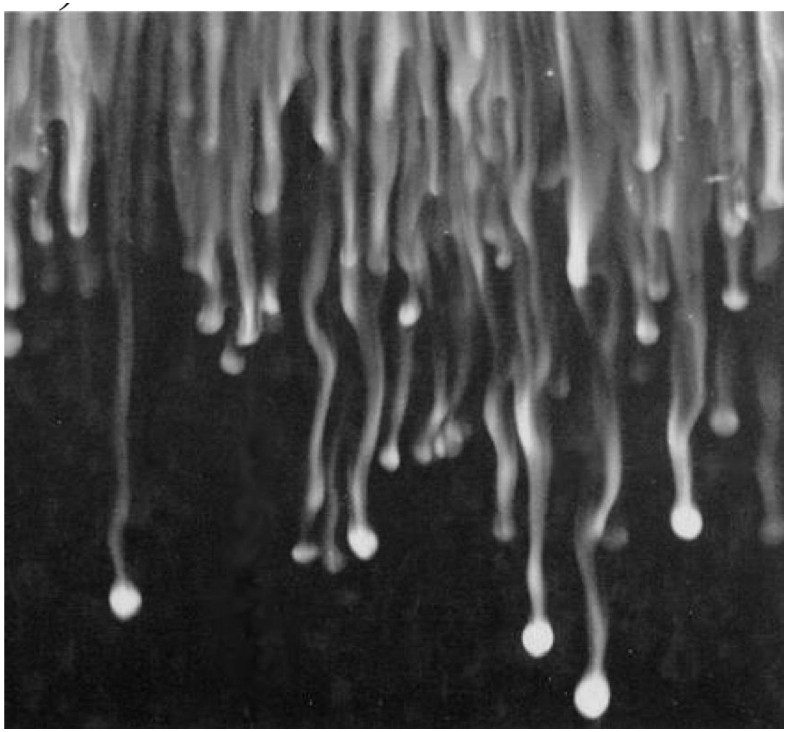
$$\beta = (1/\rho)(\partial\rho/\partial S)_{T,P}$$

and the inverse Lewis number :

$$\tau = \kappa_S/\kappa_T = t_T/t_S$$

salt fingers can grow if :

$$1 \leq R_\rho \leq \tau^{-1}$$



Stern 1960, Kato 1966, Veronis 1965, Turner 1973, Turner and Veronis 2000, Wells 2001, Piacsek and Toomre 1980, Shen and Veronis 1997, Yoshida and Nagashima 2003, Gargett and Ruddick 2003 etc.

The stellar case

∇_μ = dlnμ/dlnP plays the role of the salinity gradient;

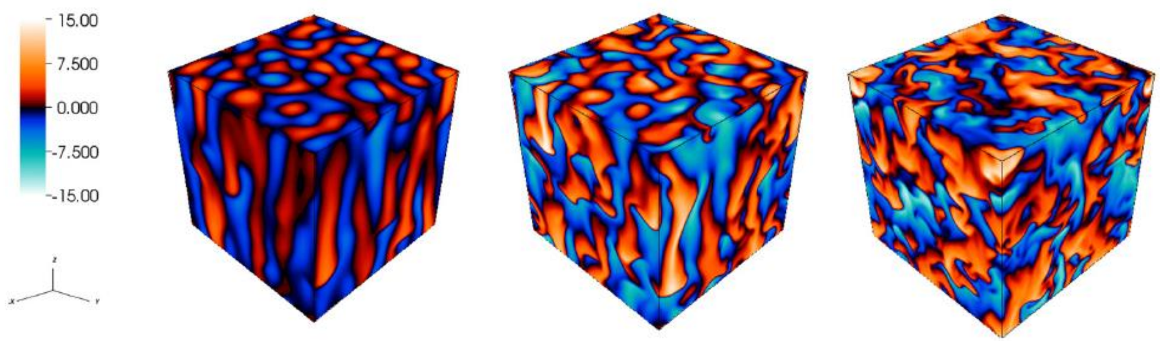
∇_{rad}- ∇ plays the role of the temperature gradient

« fingers » form if :

$$1 < R_0 < \frac{1}{\tau}$$

with: $$R_0 = \frac{\nabla_{ad} - \nabla_{rad}}{\nabla_\mu}$$

and $\tau = \kappa_\mu / \kappa_T = \tau_T / \tau_\mu$



Simulations by Brown et al. 2013
R_0 = 3 ; Pr = 1/10; τ =1/ 30
reduced time: t=100 (prior to saturation)
155 (disrupted modes), 180 (saturated regime)

For R_0<1, dynamical convection
For R_0=1/τ, dissipation

Fingering convection is known to occur in stars in the following cases:

accretion of heavy material onto stars:

- planetary matter on MS stars
- CEMPstars
- debris disks on WDs

metal accumulation induced by atomic diffusion inside stars:

- MS stars
- SdB stars

mu variations induced by nuclear reactions:

- RGB stars ?

Difference between semi-convection and fingering (thermohaline) convection

Semi-convection :

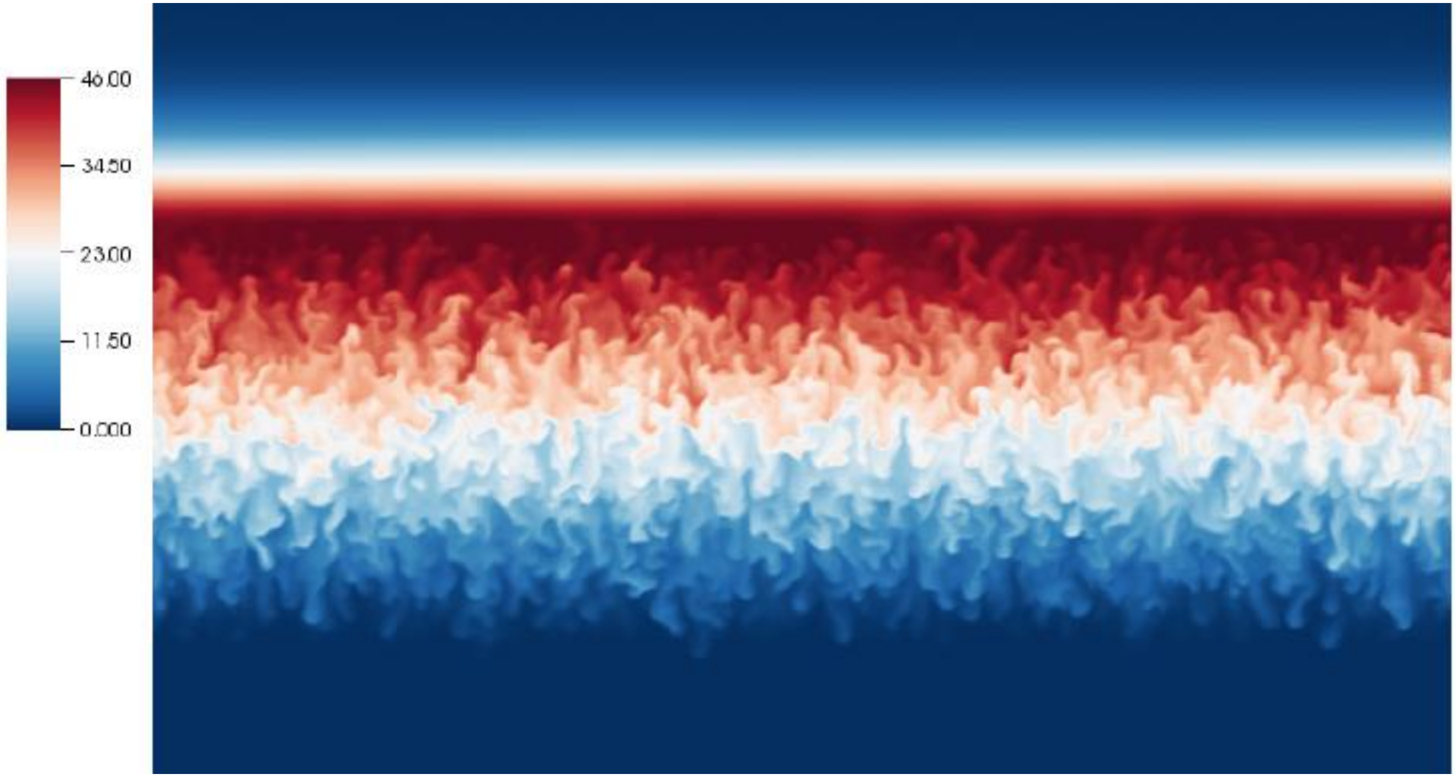
- unstable temperature gradients
- stable mu-gradients

Fingering (thermohaline) convection :

- stable temperature gradients
- unstable mu-gradients

In both cases: environment stable for dynamical convection

Mixing of an iron-rich layer with the gas below
(3D - numerical simulations)



Barbara Zemskova, Pascale Garaud, Morgan Deal, Sylvie Vauclair, 2014, ApJ, 795, 118.

Ap.J., 744, 123, 2012

Metal-rich accretion and thermohaline instabilities in exoplanets-host stars: consequences on the light elements abundances

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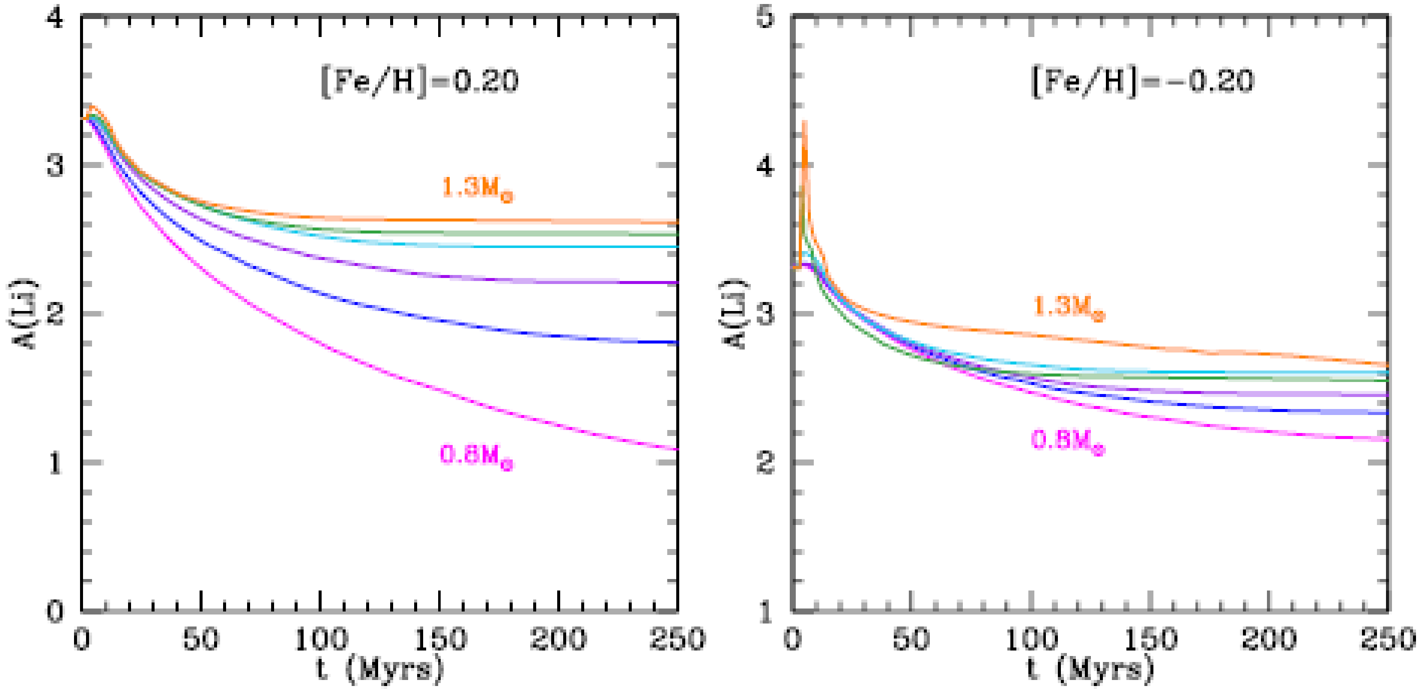

Fig. 6.— Lithium surface abundance over the accretion/mixing period in models experiencing 5 accretion episodes of $0.03M_{Jup}$. The presented models have different masses (0.8, 0.9, 1.0, 1.1, 1.2 and $1.3M_{\odot}$) and initial metallicities. These models have been computed with the KRT coefficient, C_t=12.

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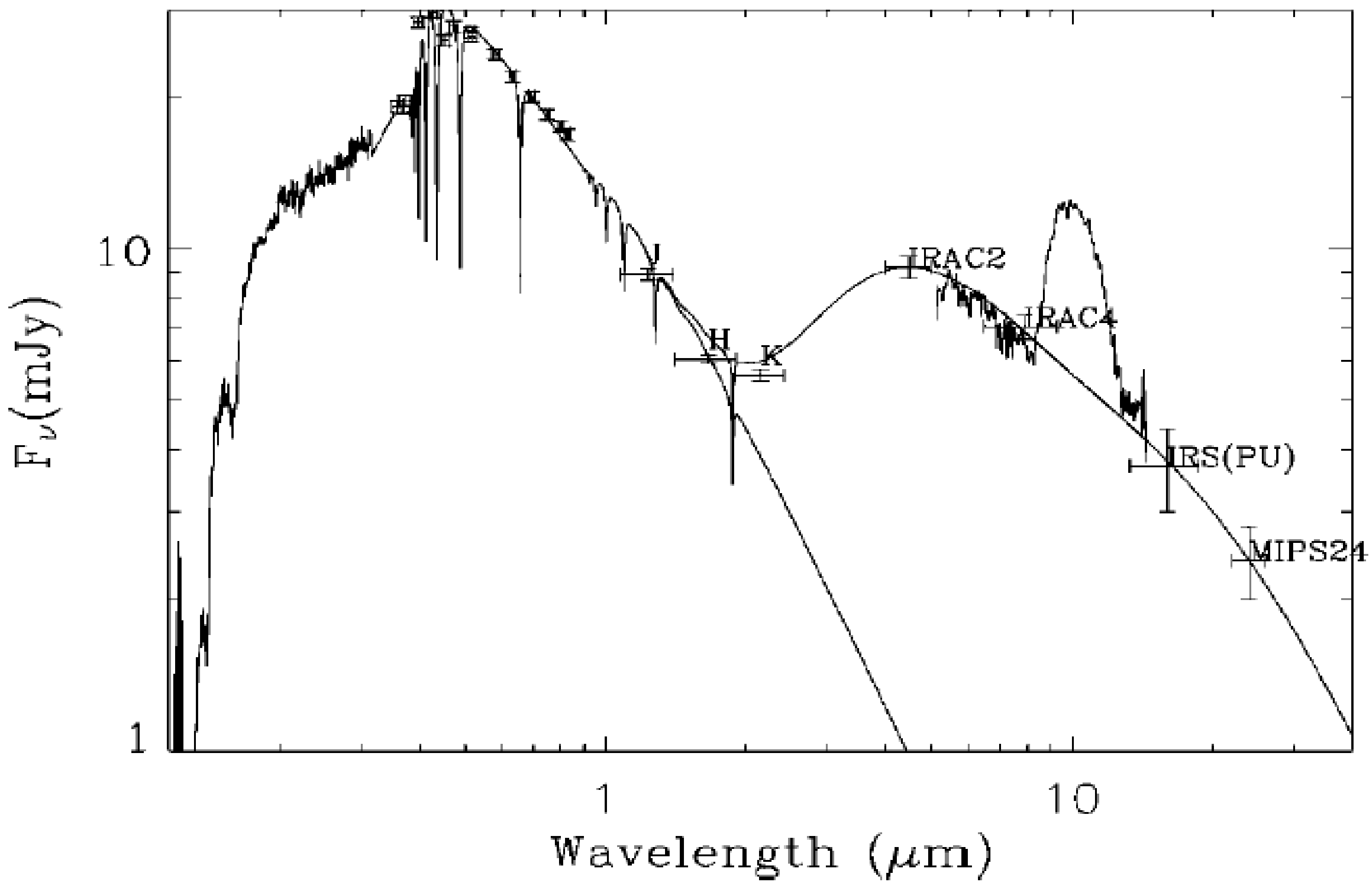
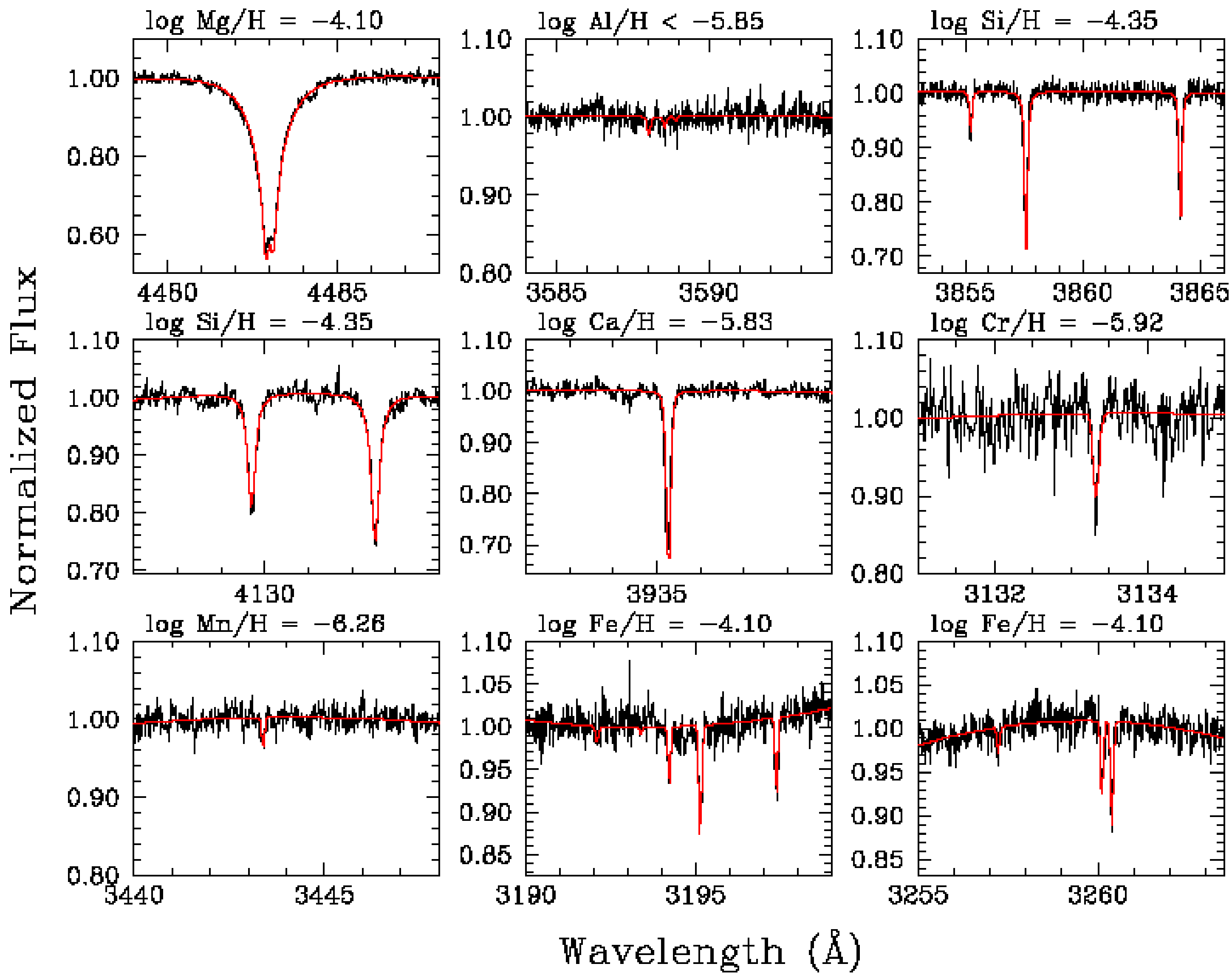
(col. G. Vauclair, M.Deal)

Helix Nebula (Spitzer)



ZZ Ceti pulsator with a debris disk (Reach et al. 2005, ApJ 635, L161)



Heavy elements in the DA GALEX J193156.8+011745 (Melis et al. 2011, ApJ 732, 90)
Spectra from KECK HIRES

An important fraction of observed white dwarfs (DAZ and DBZ) suffer accretion from debris disks (at least 30%, from KGF14)

- lines of heavy elements are observed :

  in DAZ with T_{eff} between 6000 K and 27000 K

  in DBZ with T_{eff} between 13500 K and 21000 K

- which corresponds to cooling ages $7.3 < \log t_{cool\,(yr)} < 9.9$

(e.g. Desharnais et al. 2008, Zuckerman et al. 2010 and 2011, Koester et al. 2014....)

- The heavy elements abundances have ratios similar to terrestrial planets (e.g. for C, Si, O, Mg, S, Ti, Cr, Mn, Fe).

- The calcium abundances lie between:

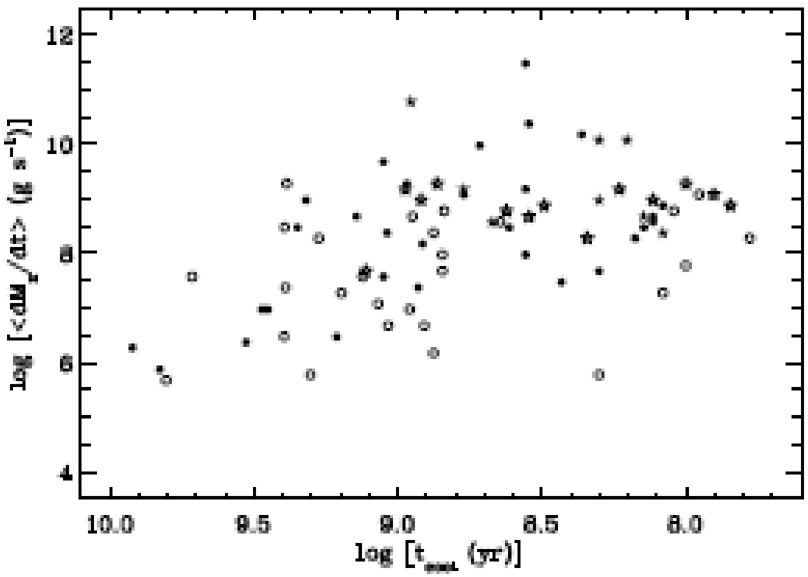
  $-12.0 < \log [Ca/H] < -6.0$ for DAZ

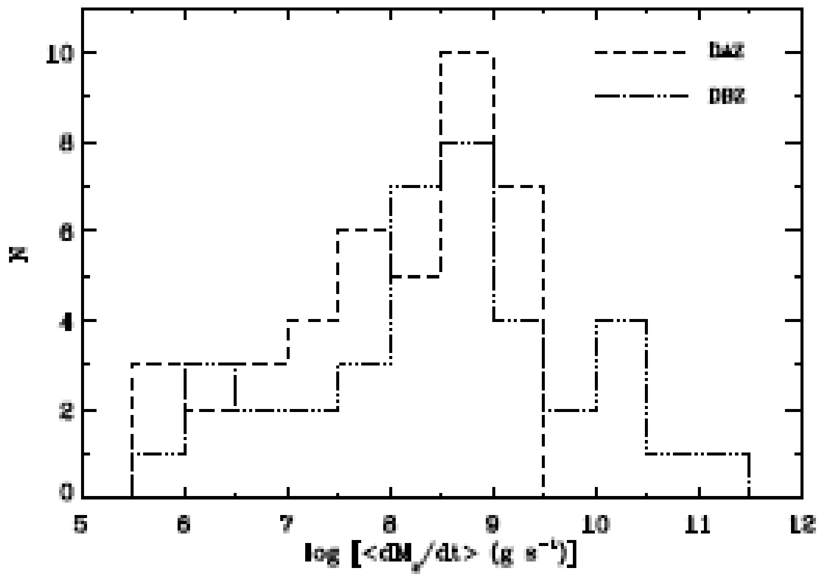
  $-12.4 < \log [Ca/He] < -6.9$ for DBZ

(e.g. Melis et al. 2011, Dufour et al. 2012, Gänsicke et al. 2011, Xu et al. 2014, Koester et al. 2014)

Scars of Intense Accretion Episodes at Metal-Rich White Dwarfs

J. Farihi, B. T. G¨ansicke, M. C. Wyatt, J. Girven, J. E. Pringle, A. R. King



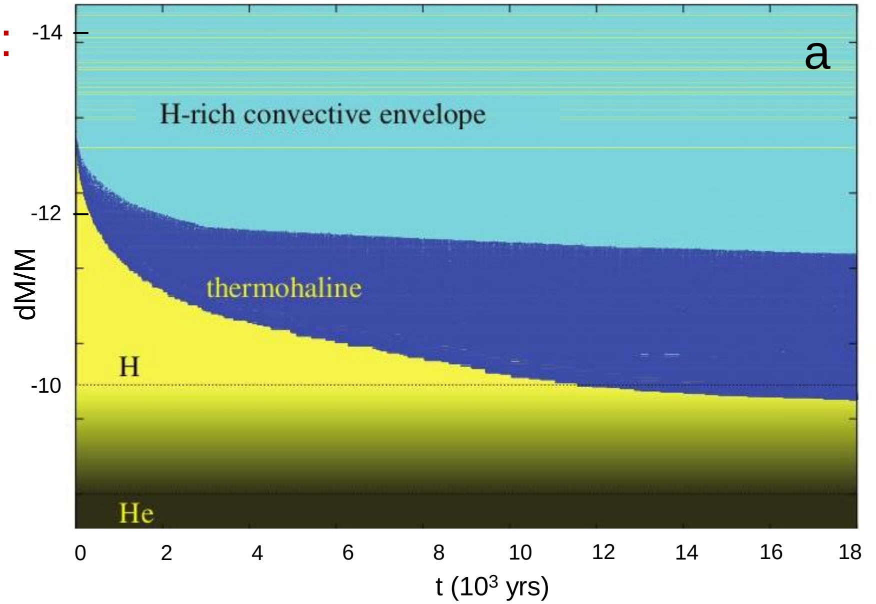


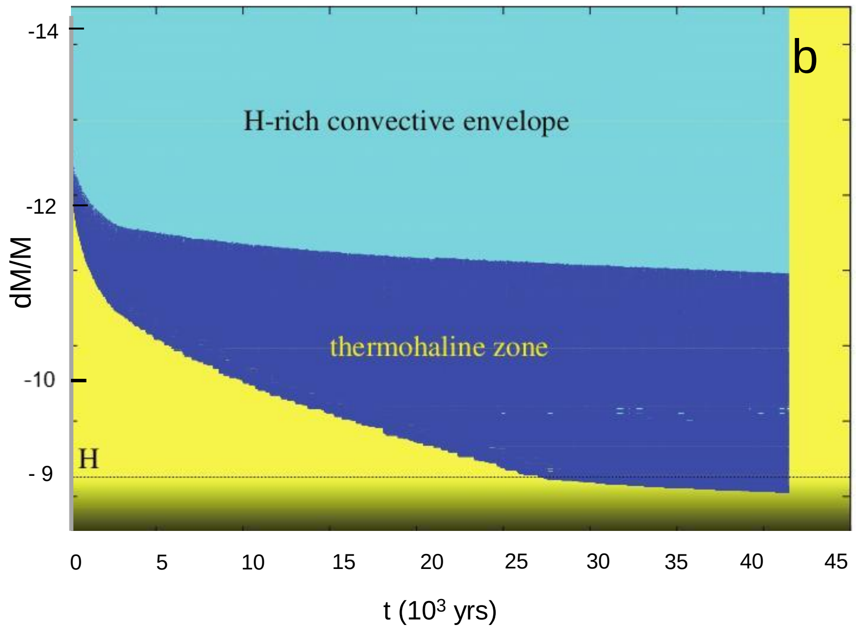
MNRAS 424, 464, 2012

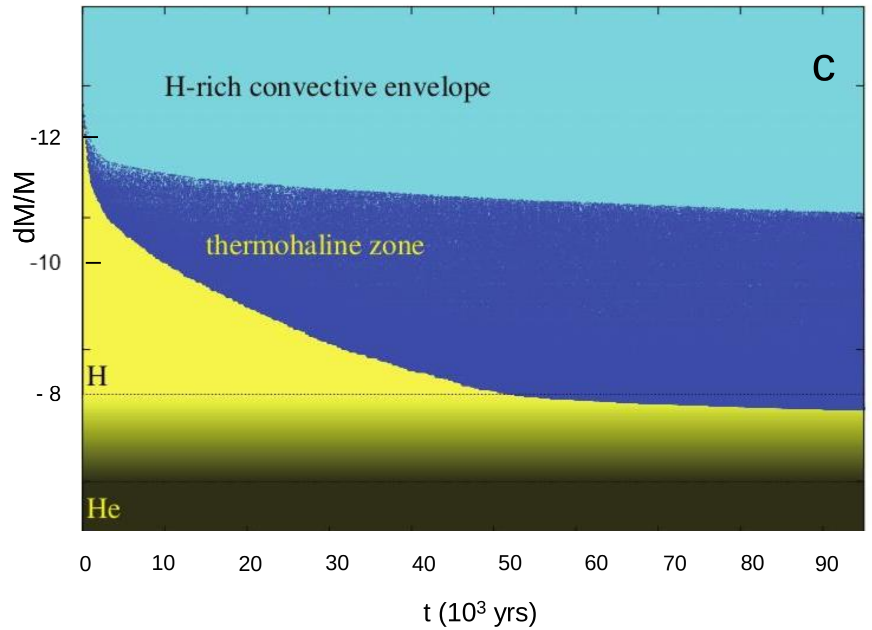
Simulations by Felipe Wachlin (La Plata):
(work in progress)

DA model, 0.6 $M_{\odot}$, Teff = 11000K
accretion rate: log dMz/dt = 9.5 $g.s^{-1}$

Hydrogen mass fraction:
a) 10^{-10}
b) 10^{-9}
c) 10^{-8}





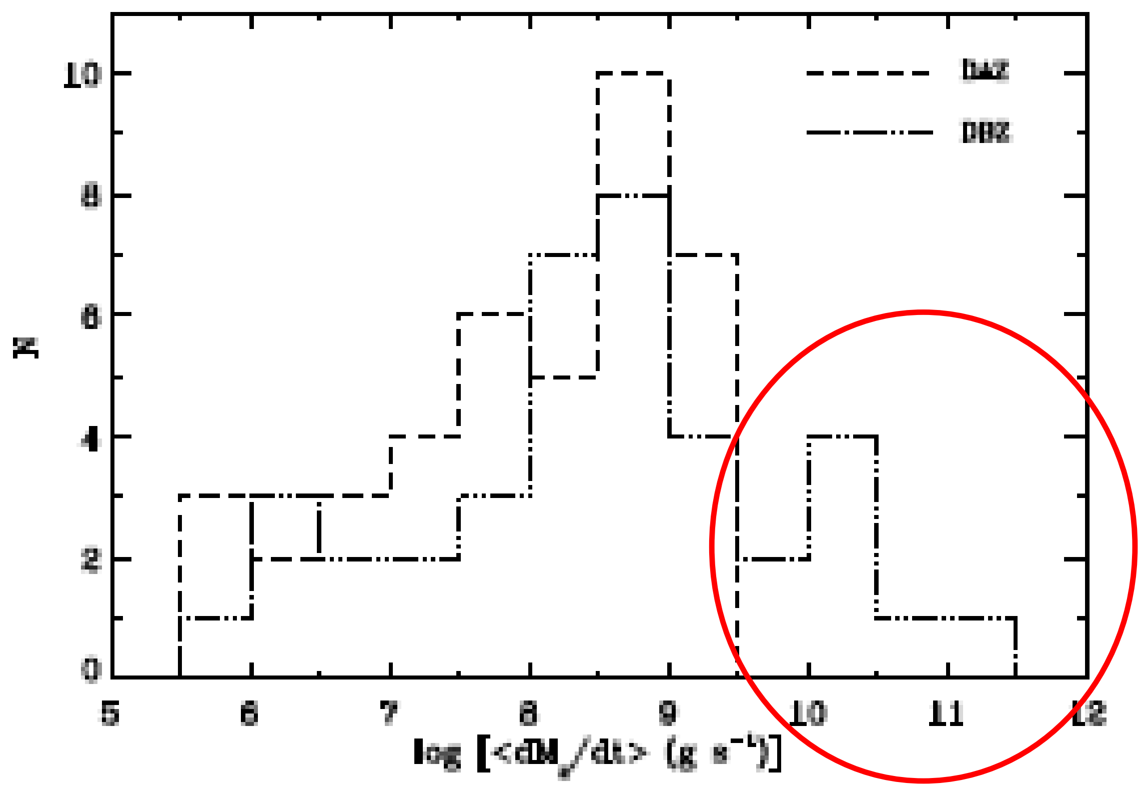


Examples of accretion rates needed to explain the observed abundances without or with fingering convection included (Deal et al. 2013)

Model	Teff	log (dM/dt) (no fingering)	log (dM/dt) (fingering)	log(Ca/H) (DAs) log(Ca/He) (DBs)
DAZ	10600 K	9.23	9.83	-7.2
DAZ	12800 K	7.74	10.01	-7.1
DAZ	16900 K	7.70	9.40	-7.7
DBZ	17100 K	10.08	10.08	-7.5
DBZ	21110 K	10.70	10.80	-8.0

Fingering convection is less efficient in DBs than in DAs because

1) The convection zone is deeper and the Lewis number smaller
2) The initial mu value is larger



N
0
2
4
6
8
10
5
6
7
8
9
10
11
12
log [<dM_z/dt> (g s^-1)]
DAZ
DBZ

Conclusions

1) The internal chemical composition of stars is important for the determination of the habitable zone; in solar type stars, metallicity is observable but not helium; Y does not always vary like Z.

2) If planetary matter is accreted onto main sequence stars, it does not stay in the outer convective zone; the inverse mu-gradient induces a special type of double-diffusive convection(fingering convection) which mixes the heavy matter downwards; for similar accretion rates, the effect is more important when the convective zone is shallower; this extra-mixing may have important consequences on the destruction of light elements in EHS.

3) The study of accreting white dwarfs is important to understand the ultimate fate of planetary systems. Fingering convection must be taken into account in the computations of accretion rates in DAZ and DBZ WD stars.