CP stars – Introduction II

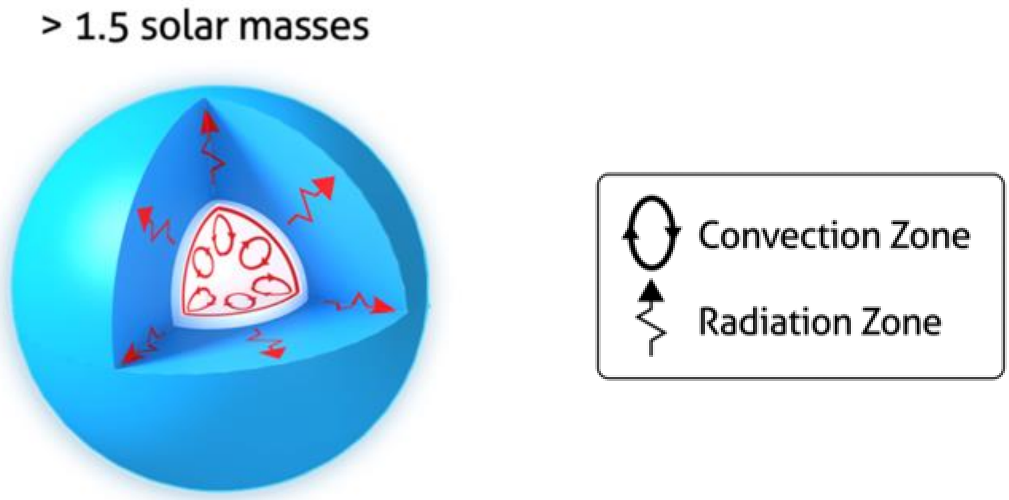
CP subgroups

Classical name	Prestons’s group	Discovery criteria	Spectral types	Magnetic Field
Am – Fm	CP1	weak Ca II and/or Sc II; enhanced metals	A0 – F4	N
Bp – Ap	CP2	enhanced Sr, Cr, Eu, and/or Si	B6 – F4	Y
HgMn	CP3	enhanced Hg II and/or Mn II	B6 – A0	N
He – weak	CP4	weak He I compared with colours	B2 – B8	Y
He – strong		enhanced He I compared with colours	B0 – B2	Y

Preston (1974, ARA&A, 12, 257), Pedersen & Thomsen (1977, A&AS, 30, 11)

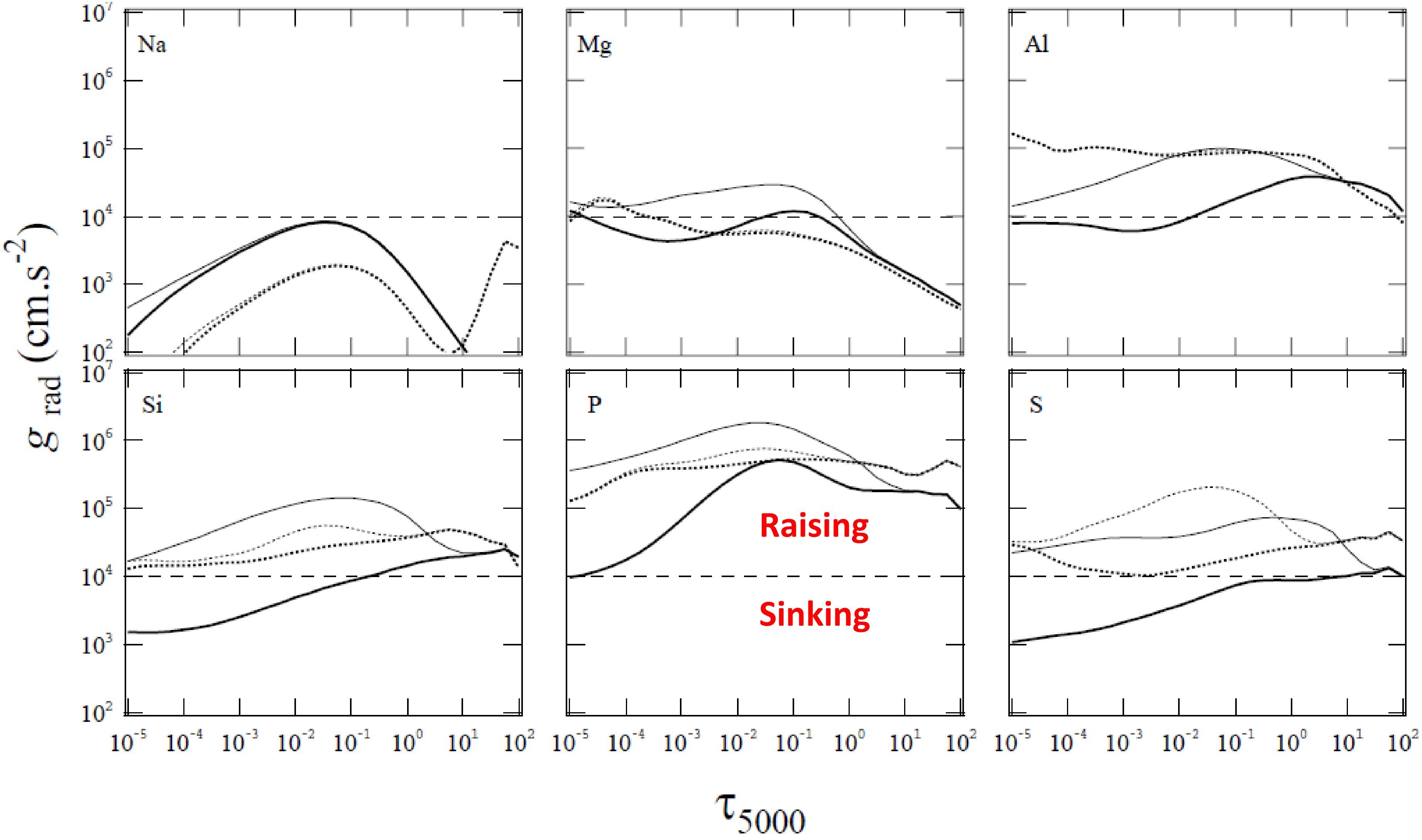
Diffusion in stellar atmospheres

- Standard book: Michaud et al., 2015, ***Atomic Diffusion in Stars***, Astronomy and Astrophysics Library, ISBN 978-3-319-19853-8. Springer International Publishing Switzerland
- Here, we look at the upper main sequence



Diffusion in stellar atmospheres

Hui-Bon-Hoa et al., 2002, A&A, 381, 197



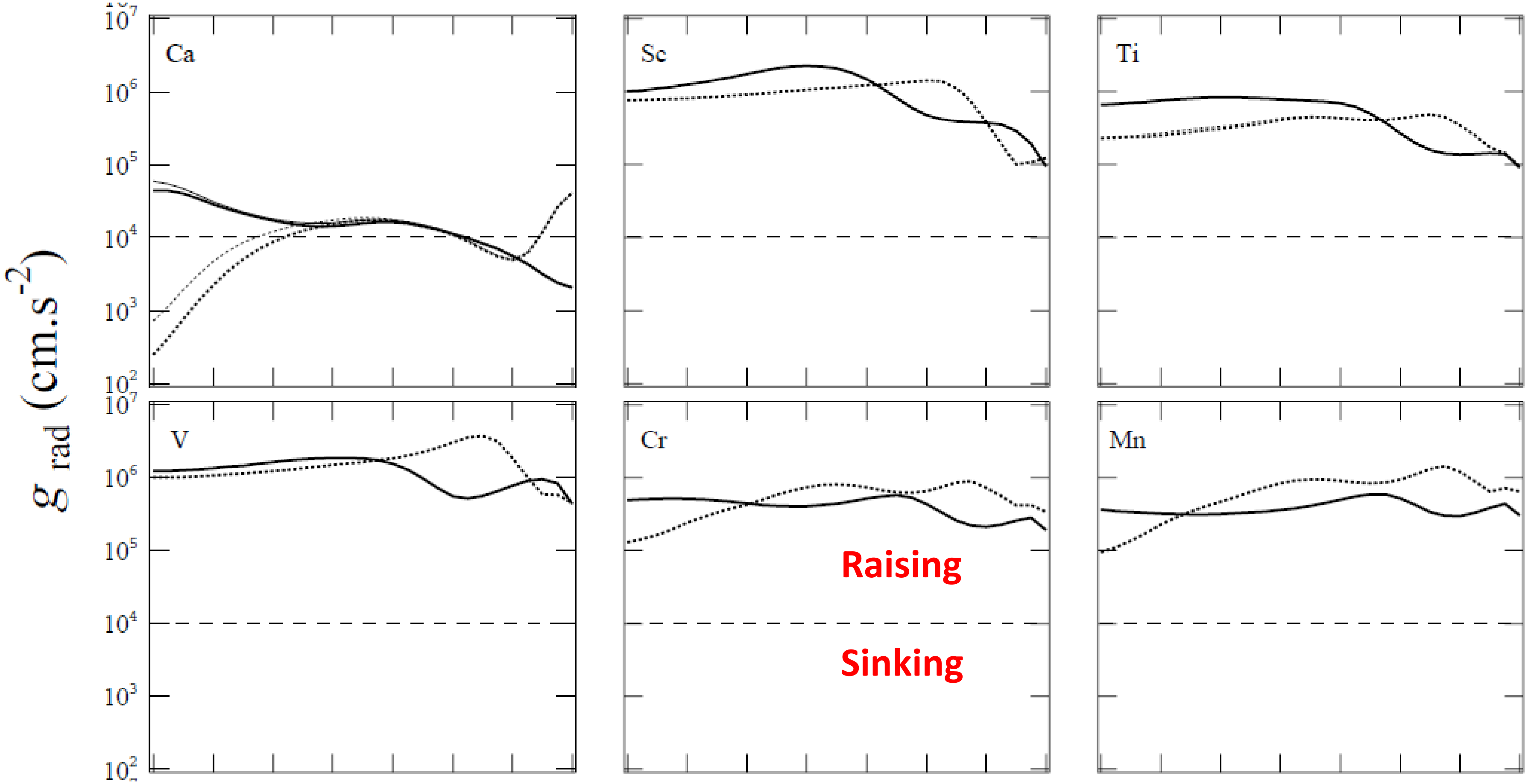
Raising

Sinking

LTE radiative accelerations for the 12 000 K and 18 000 K models with log $g = 4$.

Diffusion in stellar atmospheres

Hui-Bon-Hoa et al., 2002, A&A, 381, 197



Raising

Sinking

LTE radiative accelerations for the 12 000 K and 18 000 K models with log $g = 4$.

Alecian et al., 2011, MNRAS, 418, 986

Diffusion works on rather short timescales

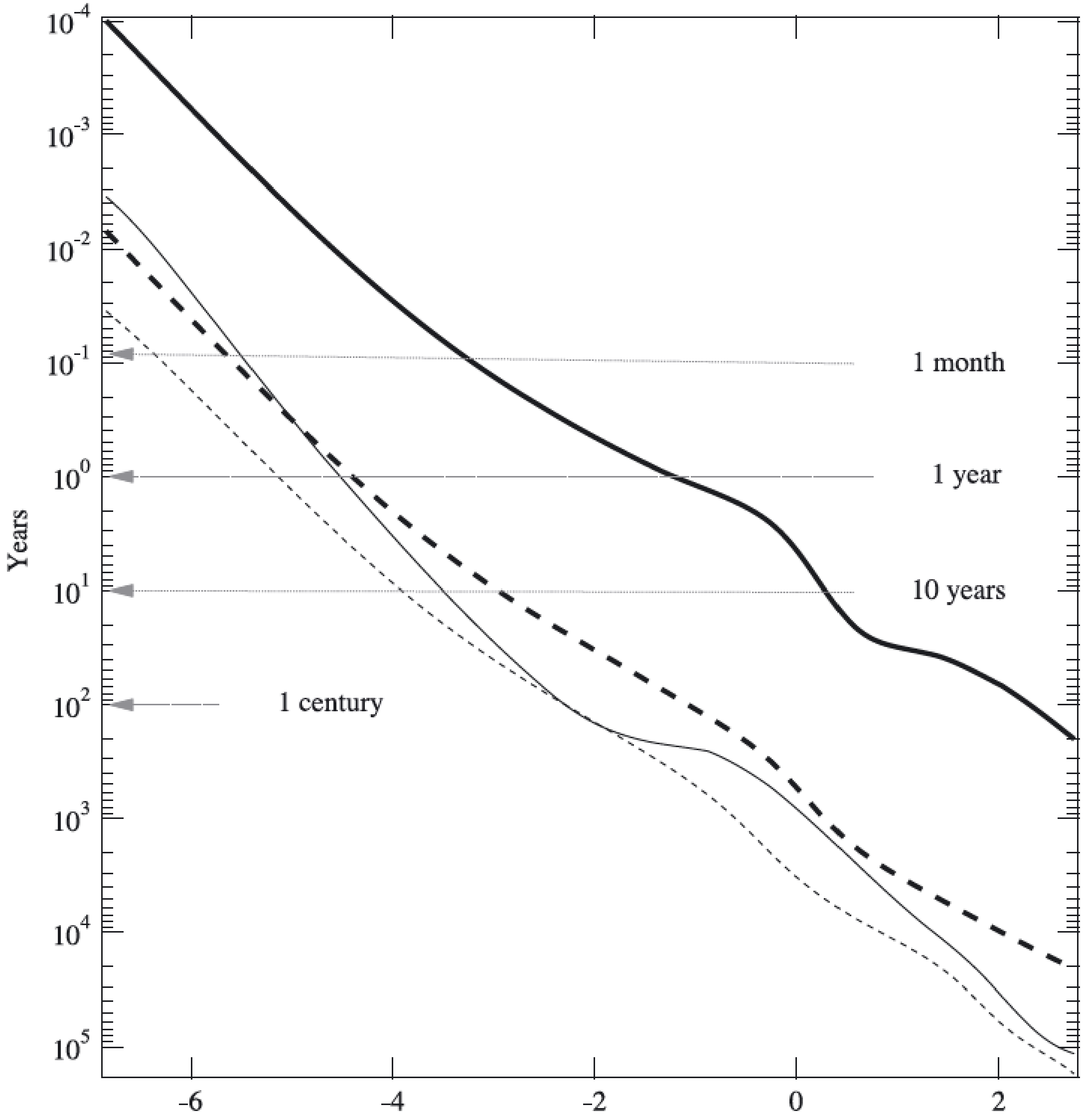


Figure 1. Diffusion time-scales for Fe and Hg [log(years) versus log(optical depth at 5000 Å)] for a non-magnetic atmosphere with $T_{\text{eff}} = 12\,000$ K, $\log g = 4.0$. Note that the time-scale axis (left-hand axis) is reversed. Solid lines correspond to diffusion time-scales, and dashed lines to gravitational settling (diffusion without radiative acceleration). Heavy lines are for Hg, and the others for Fe.

Stratification in the stellar atmosphere

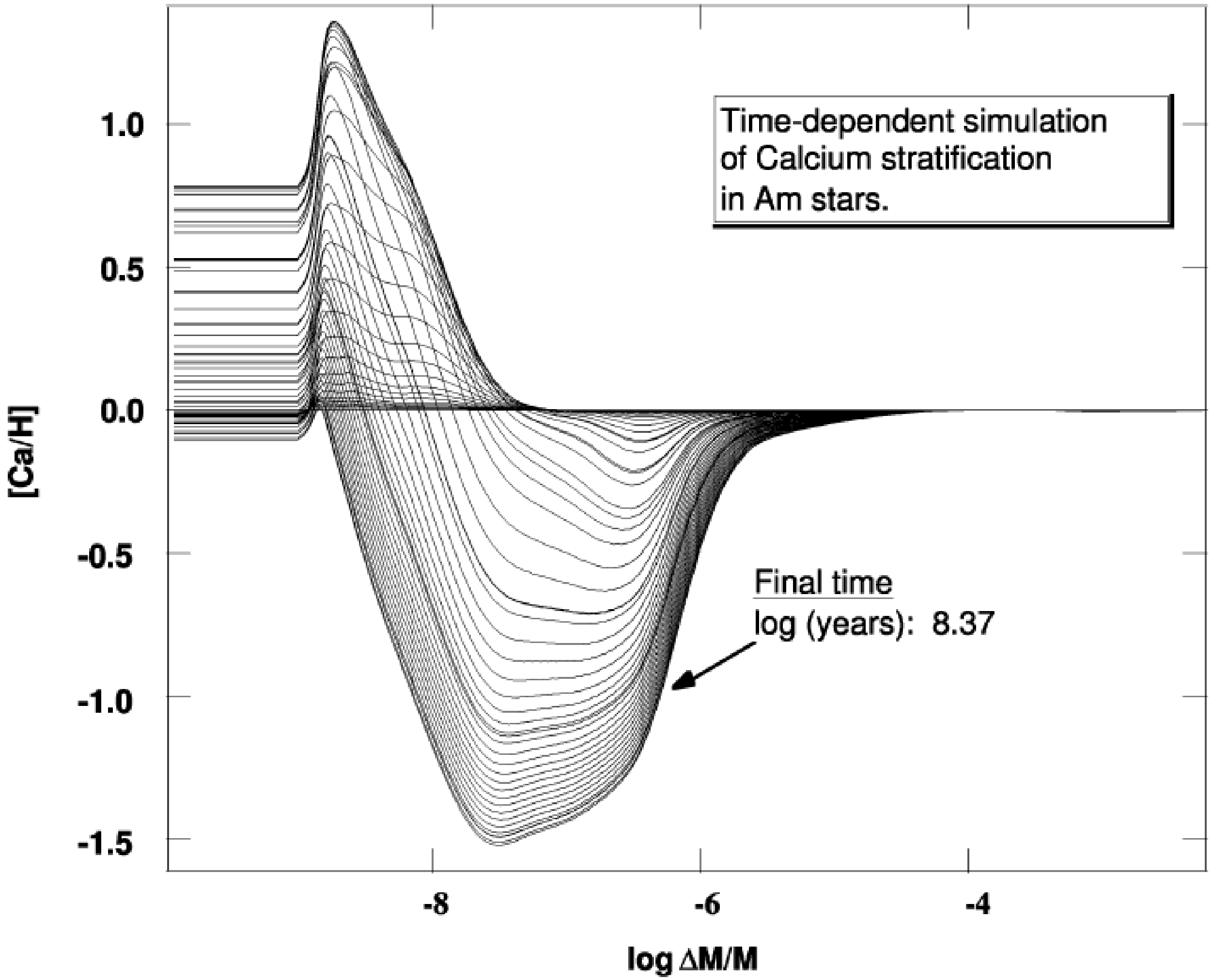
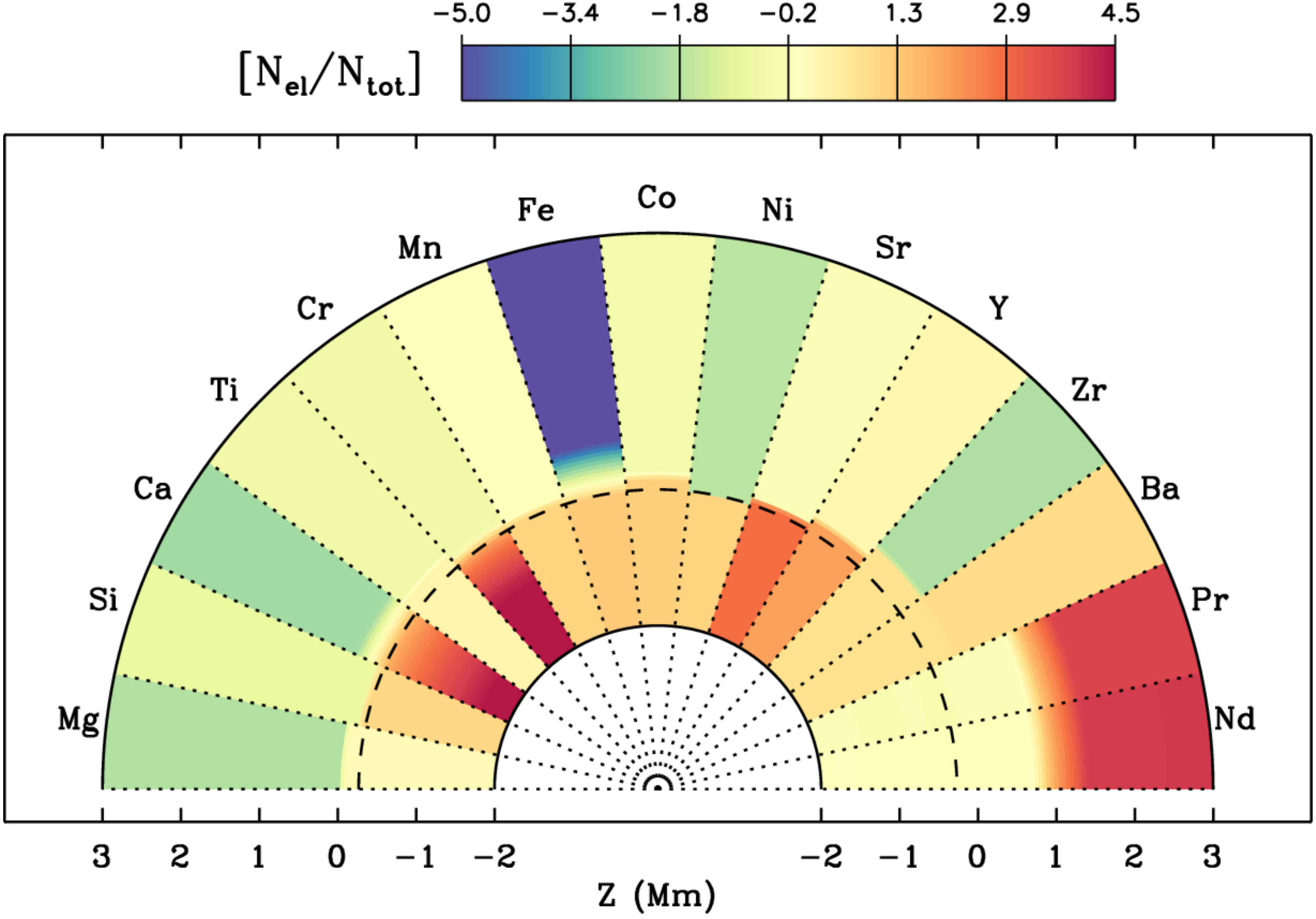


Figure 1. The logarithm of calcium abundance is plotted versus the logarithm of the mass fraction above the point of interest. At time t = 0, calcium is homogeneous and solar, the curves represent the abundance at successive time steps. The final time corresponds to log (years) = 8.37.

Alecian, 1998, Contributions of the Astronomical Observatory Skalnate Pleso, 27, 290

Stratification in the stellar atmosphere

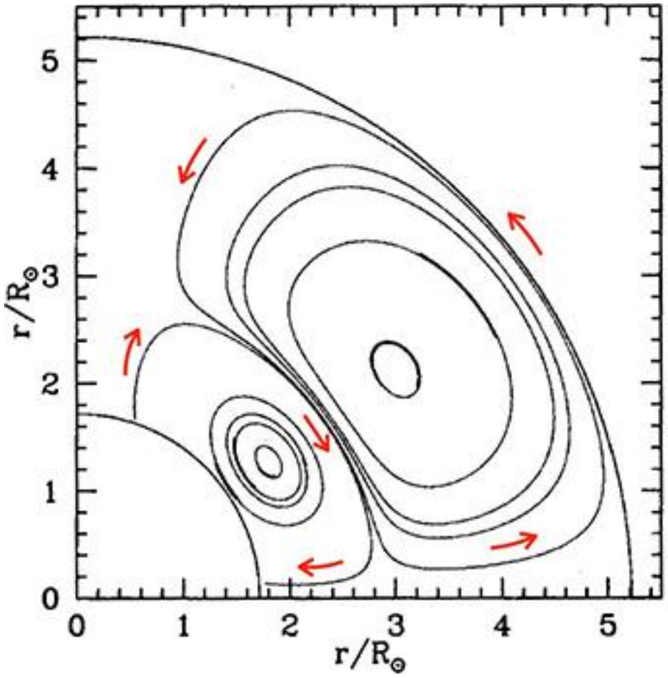


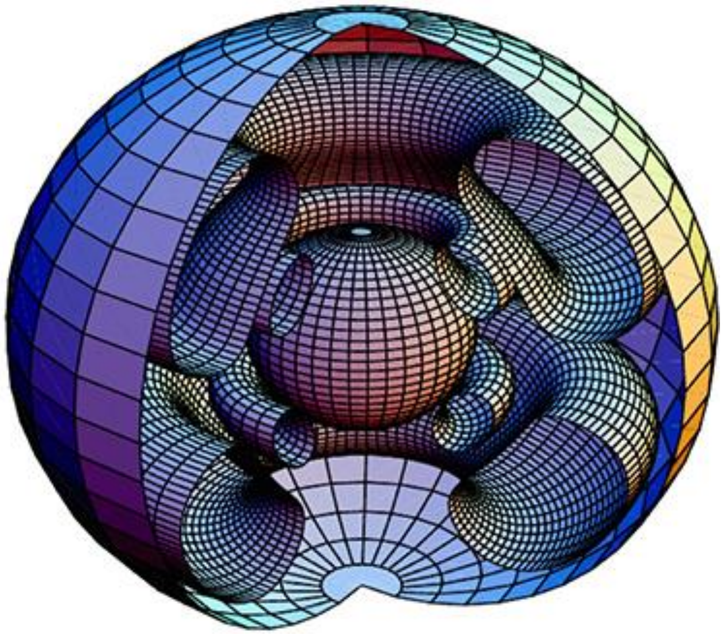
O. Kochukhov: HD 24712

Diffusion in stellar atmospheres

- What can destroy the pattern from diffusion?

1. Rotation as meridional circulation: limit 100 km/s





2. Convection: not significant, ***low mass boundary***
3. Mass-loss: ***high mass boundary***

The Rotation of BAF stars

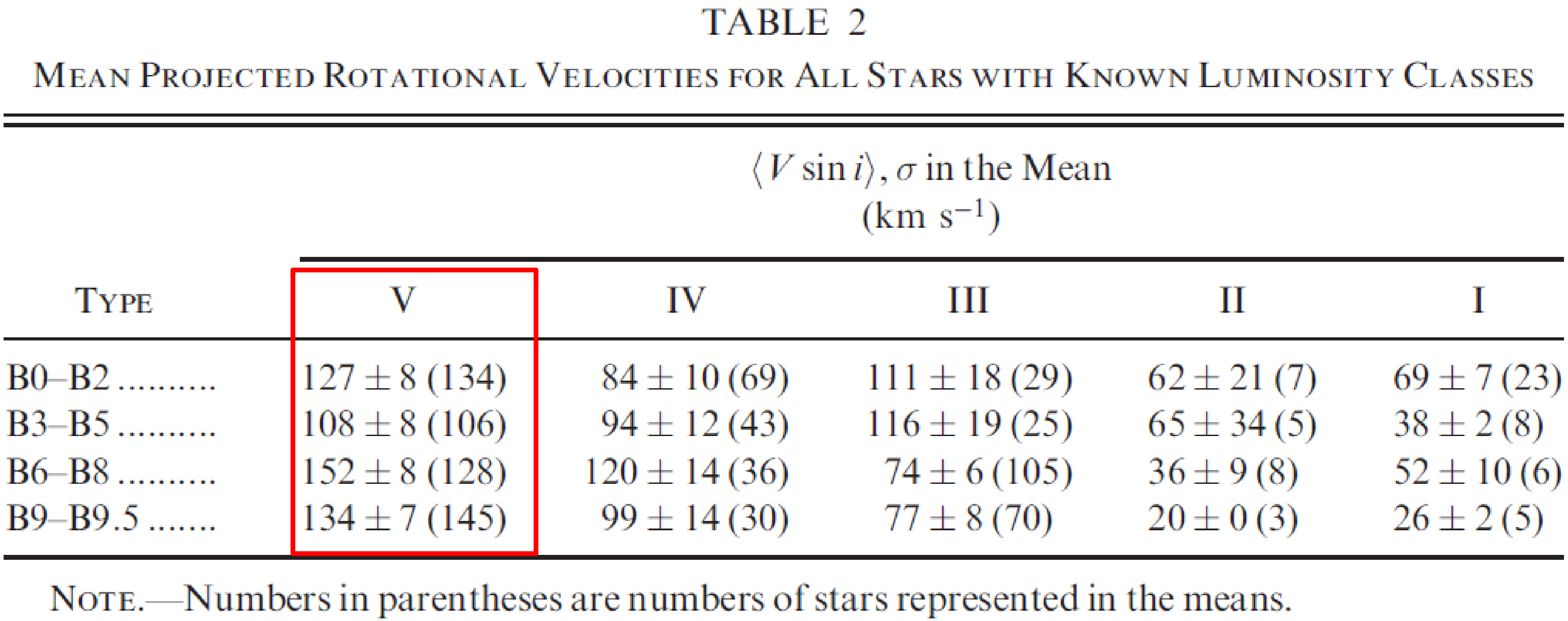


TABLE 2

MEAN PROJECTED ROTATIONAL VELOCITIES FOR ALL STARS WITH KNOWN LUMINOSITY CLASSES

	⟨$V \sin i$⟩, σ in the Mean (km s^{-1})				
TYPE	V	IV	III	II	I
B0–B2	127 ± 8 (134)	84 ± 10 (69)	111 ± 18 (29)	62 ± 21 (7)	69 ± 7 (23)
B3–B5	108 ± 8 (106)	94 ± 12 (43)	116 ± 19 (25)	65 ± 34 (5)	38 ± 2 (8)
B6–B8	152 ± 8 (128)	120 ± 14 (36)	74 ± 6 (105)	36 ± 9 (8)	52 ± 10 (6)
B9–B9.5	134 ± 7 (145)	99 ± 14 (30)	77 ± 8 (70)	20 ± 0 (3)	26 ± 2 (5)

NOTE.—Numbers in parentheses are numbers of stars represented in the means.

Abt et al., 2002, ApJ, 573, 359

v (Sun) = 2 km/s; v (Jupiter) = 12,7 km/s

v (Earth) = 0,465 km/s

The Rotation of BAF stars

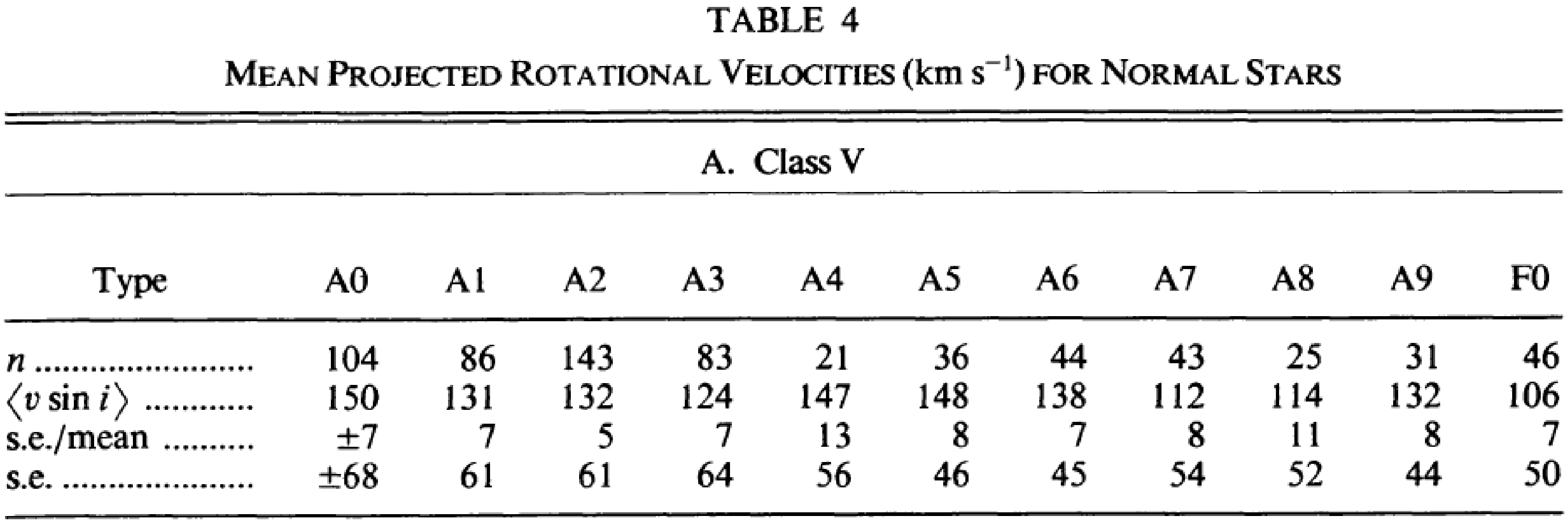


TABLE 4

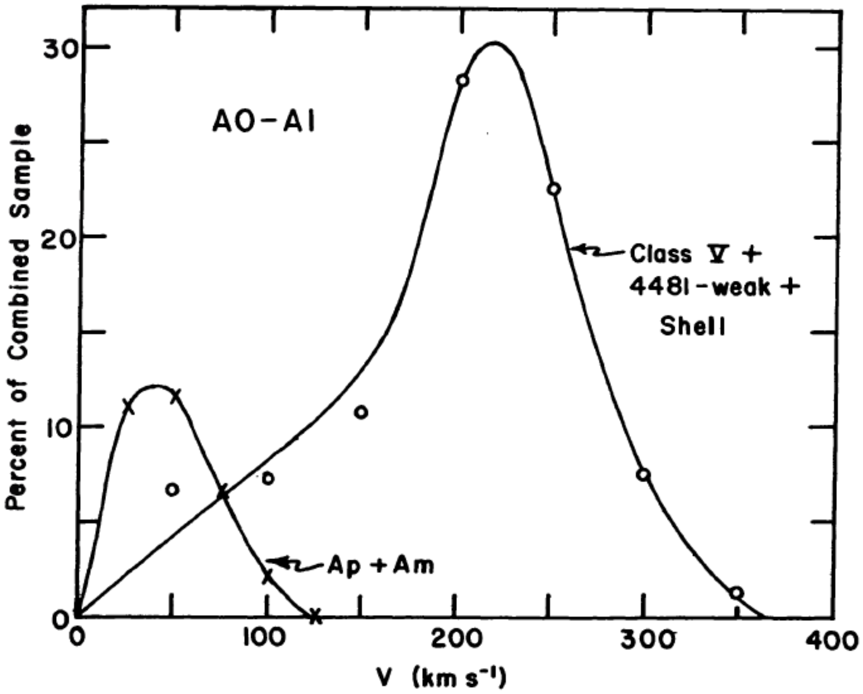
MEAN PROJECTED ROTATIONAL VELOCITIES (km s^{-1}) FOR NORMAL STARS

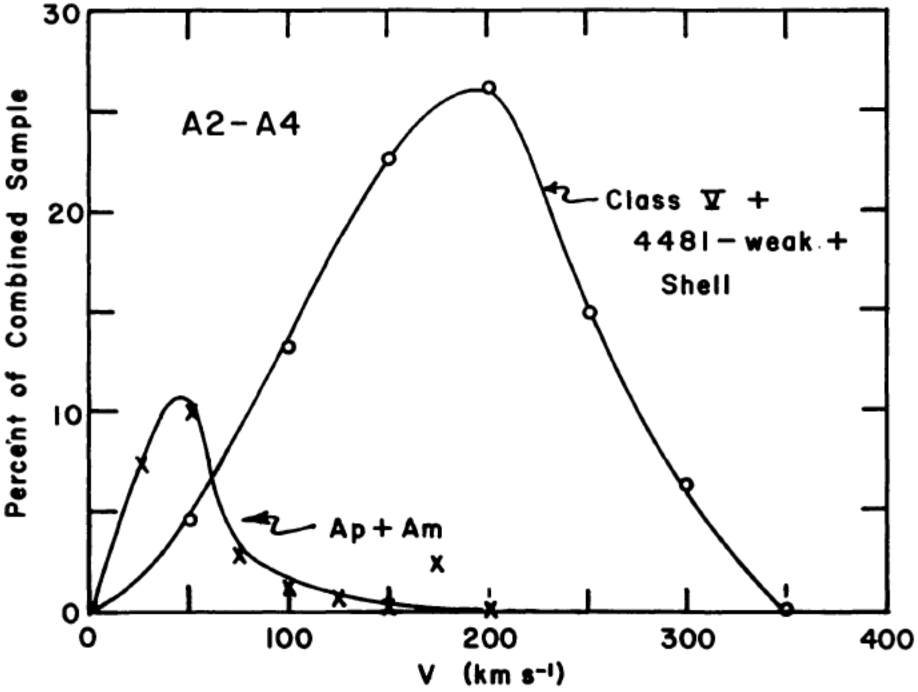
A. Class V

Type	A0	A1	A2	A3	A4	A5	A6	A7	A8	A9	F0
n	104	86	143	83	21	36	44	43	25	31	46
$\langle v \sin i \rangle$	150	131	132	124	147	148	138	112	114	132	106
s.e./mean	±7	7	5	7	13	8	7	8	11	8	7
s.e.	±68	61	61	64	56	46	45	54	52	44	50

Abt & Morrell, 1995, ApJS, 99, 135

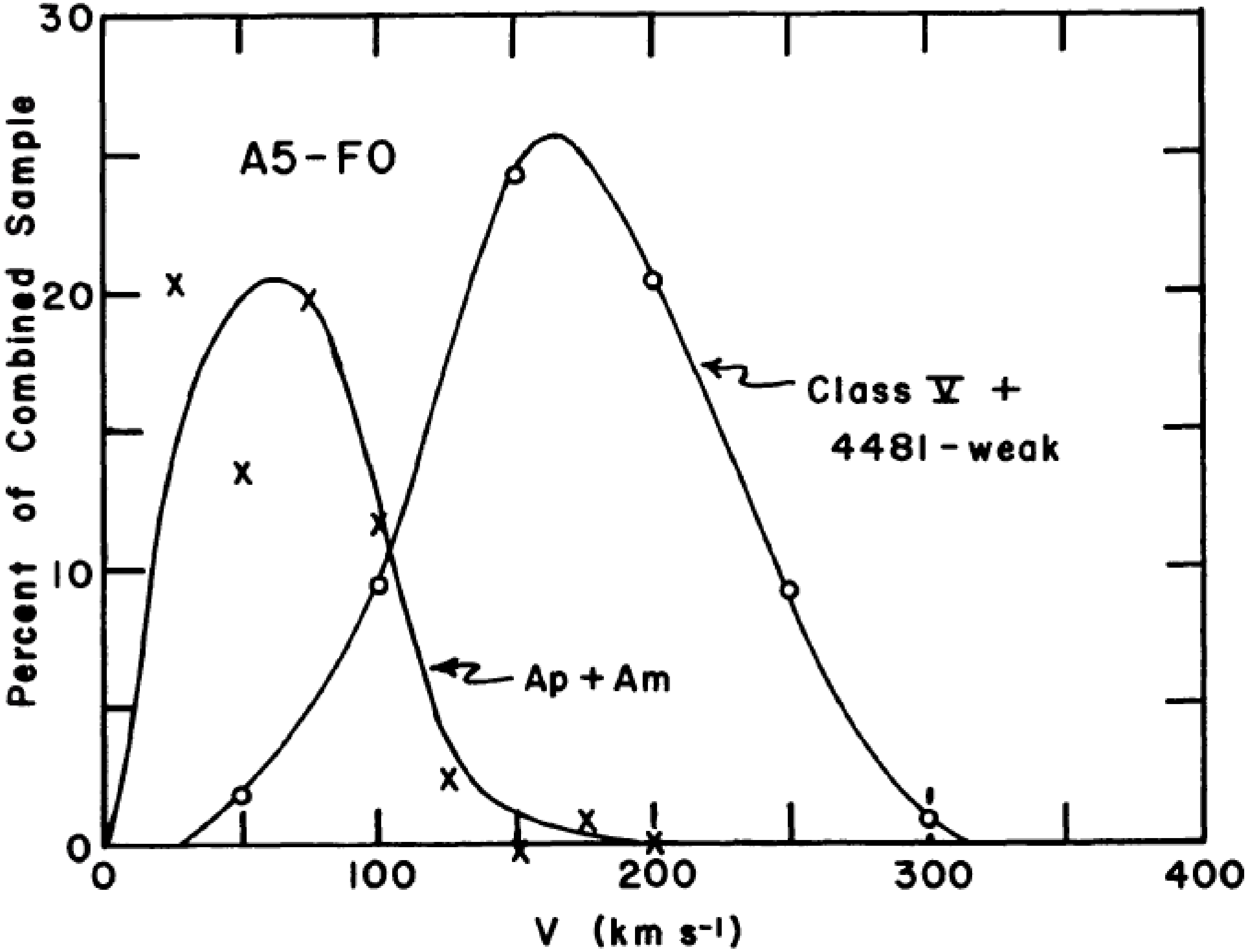
The Rotation of A-type stars





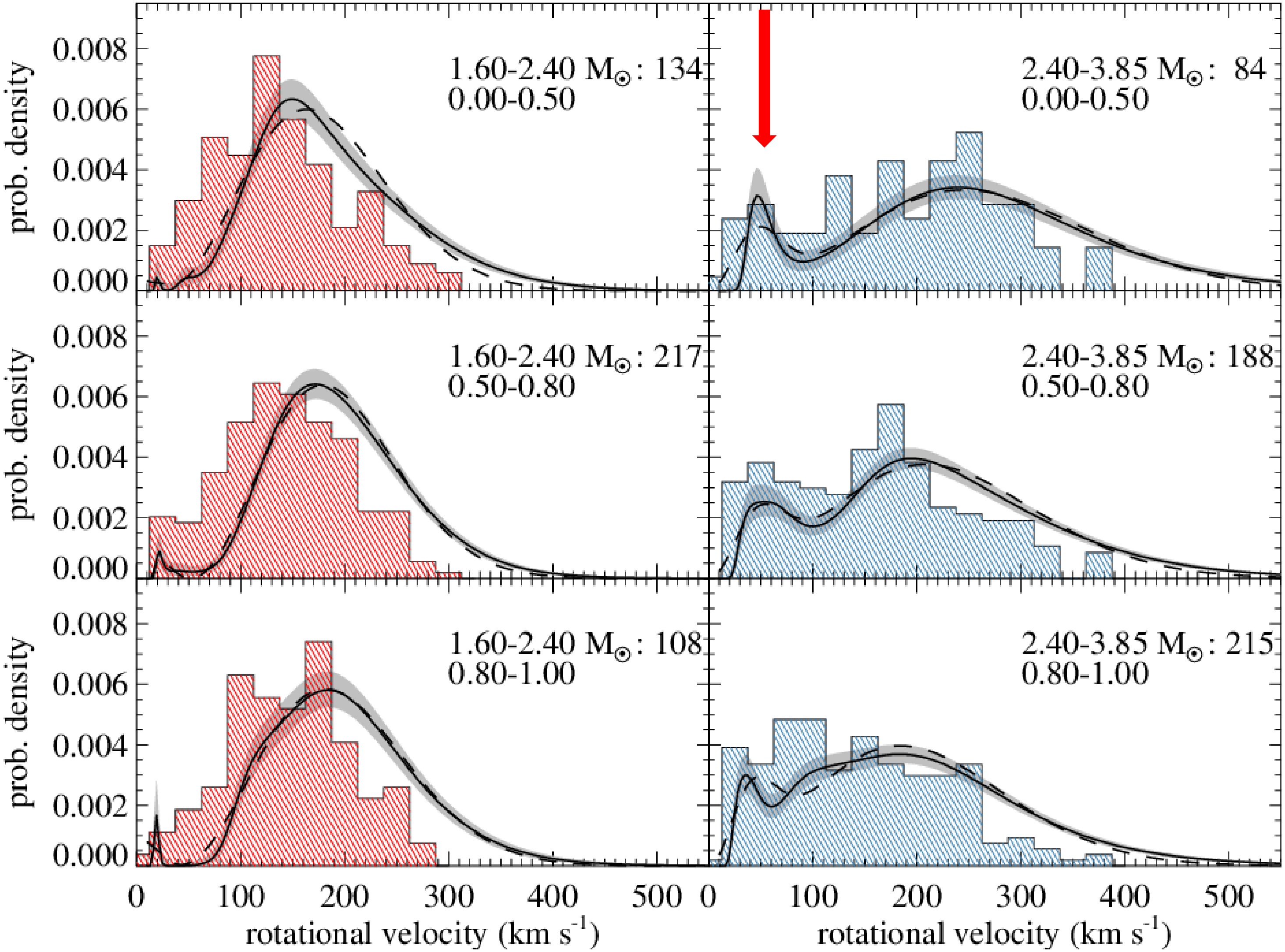
Abt & Morrell, 1995, ApJS, 99, 135

The Rotation of A-type stars



Abt & Morrell, 1995, ApJS, 99, 135

The Rotation of BAF stars



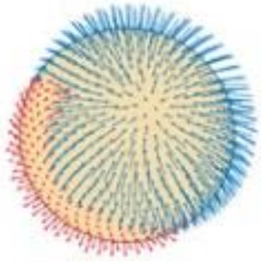
Zorec & Royer, 2012, A&A, 537, A120

- Mixing wins over diffusion for *v* > 100 km/s

The origin of the magnetic field

Fossil Field

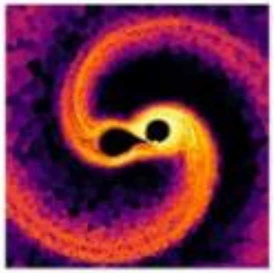
Star formation / pre-main sequence convection. Reaches stable equilibria



Alecian et al., 2019, EAS Publications Series, 82, 345

Stellar Merger

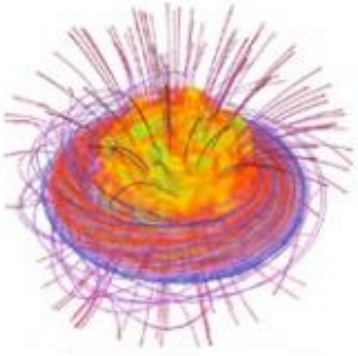
Differential rotation activates dynamo. Relaxes in stable equilibrium



Schneider et al., 2019, Nature, 574, 211

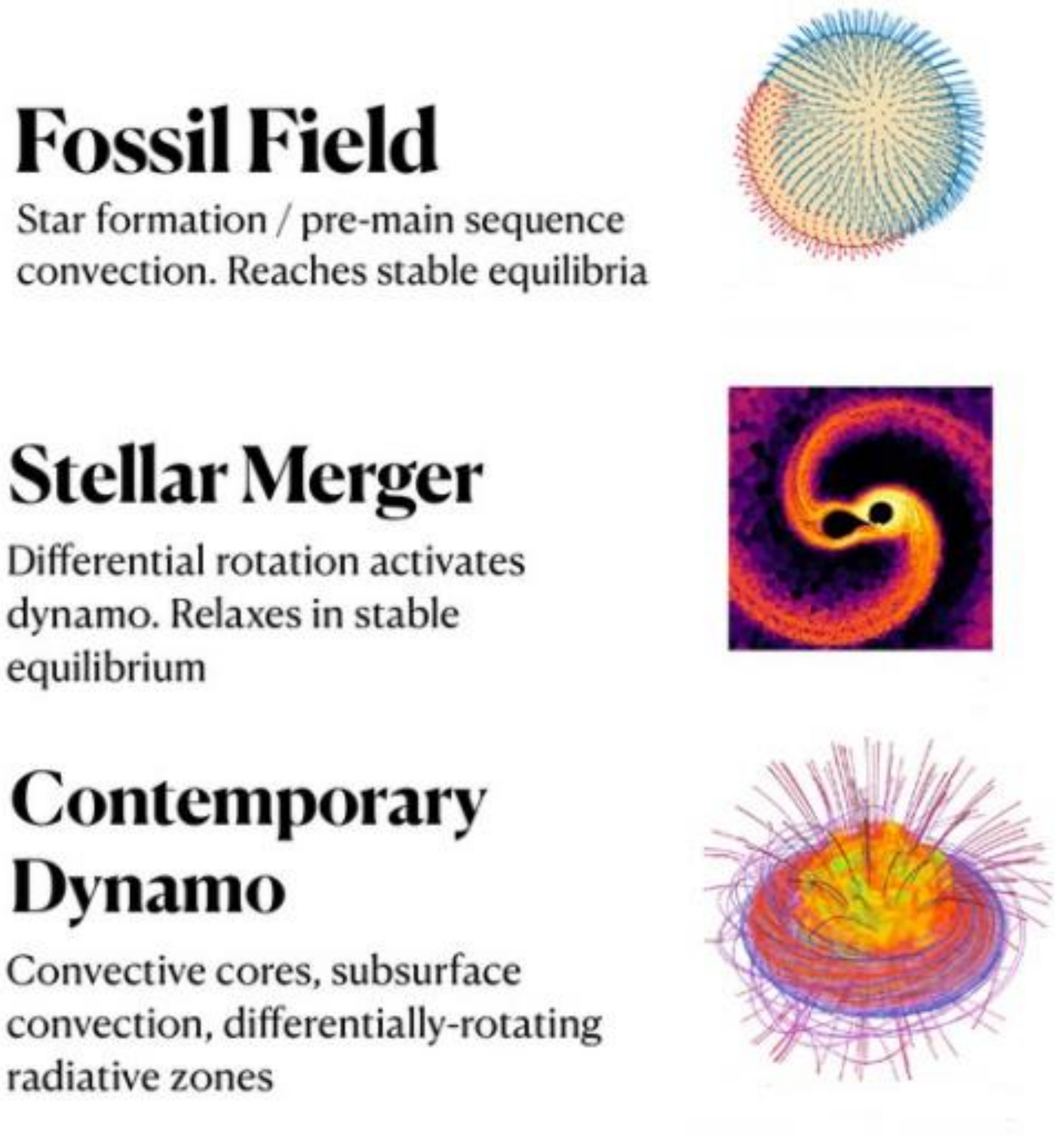
Contemporary Dynamo

Convective cores, subsurface convection, differentially-rotating radiative zones



Featherstone et al., 2009, ApJ, 705, 1000

The origin of the magnetic field



Fossil Field

Star formation / pre-main sequence convection. Reaches stable equilibria

Only for low rotational velocities

Stellar Merger

Differential rotation activates dynamo. Relaxes in stable equilibrium

Many known binary CP stars known

Contemporary Dynamo

Convective cores, subsurface convection, differentially-rotating radiative zones

No differential rotation detected
Takes several hundred Myrs

Some open questions

- Are CP stars just the slow rotating “normal stars”?
- Are all slow rotating stars also CP stars?
- Are there also “fast rotating” CP stars?
- Is there a dynamo working in magnetic CP stars?
- On which time scales work the dynamo?
- Is there a magnetic breaking?