An enigma of the Herbig Ae/Be magnetic stars evolution

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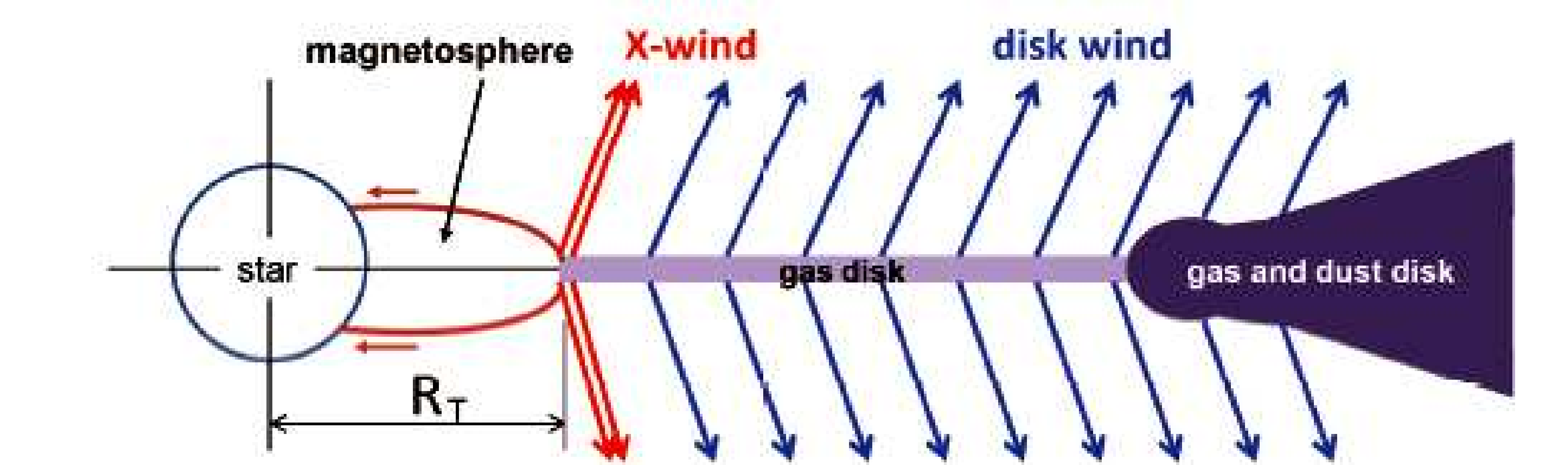
Models

Grinin (2014)



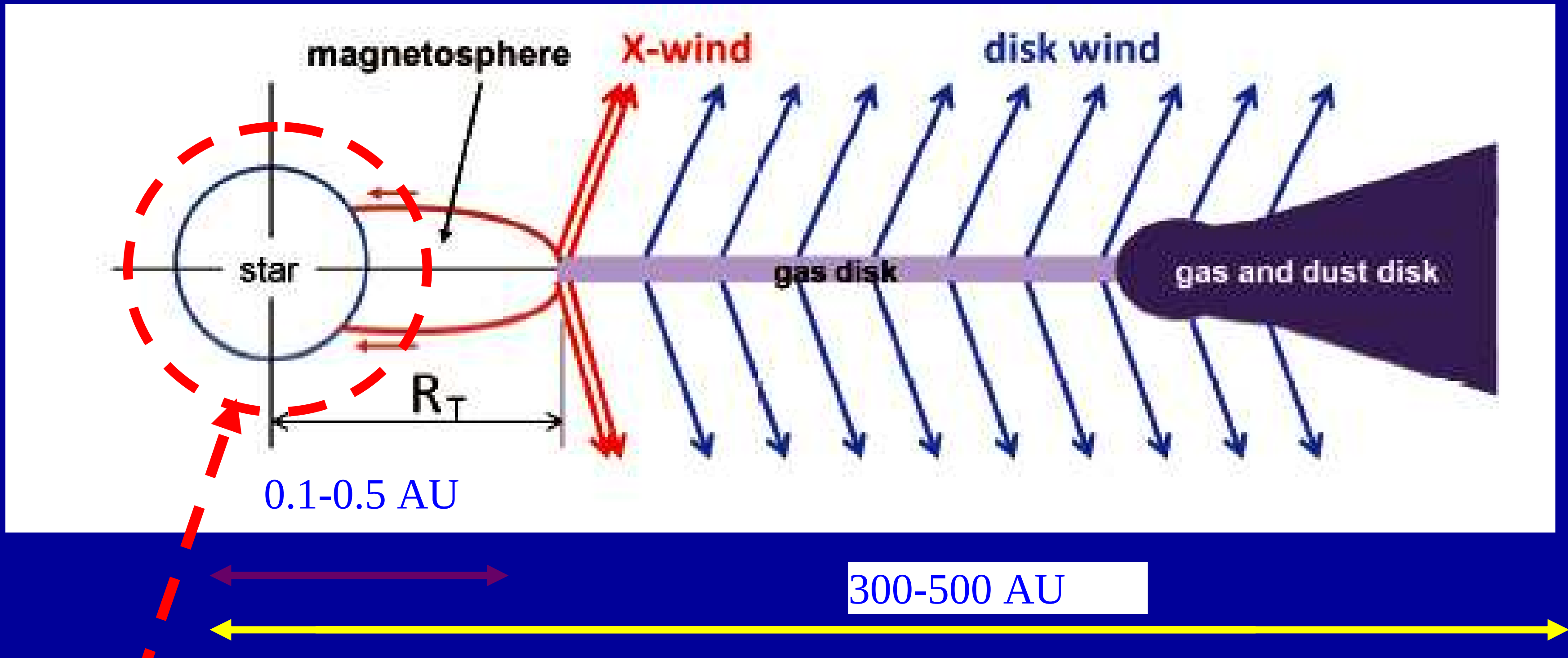
0.1-0.5 AU

300-500 AU

$$\dot{M}_a = 10^{-8} - 10^{-7} M_\odot \text{ yr}^{-1}$$

M_{disk} ~ 0.01 – 0.1 M_{sun}

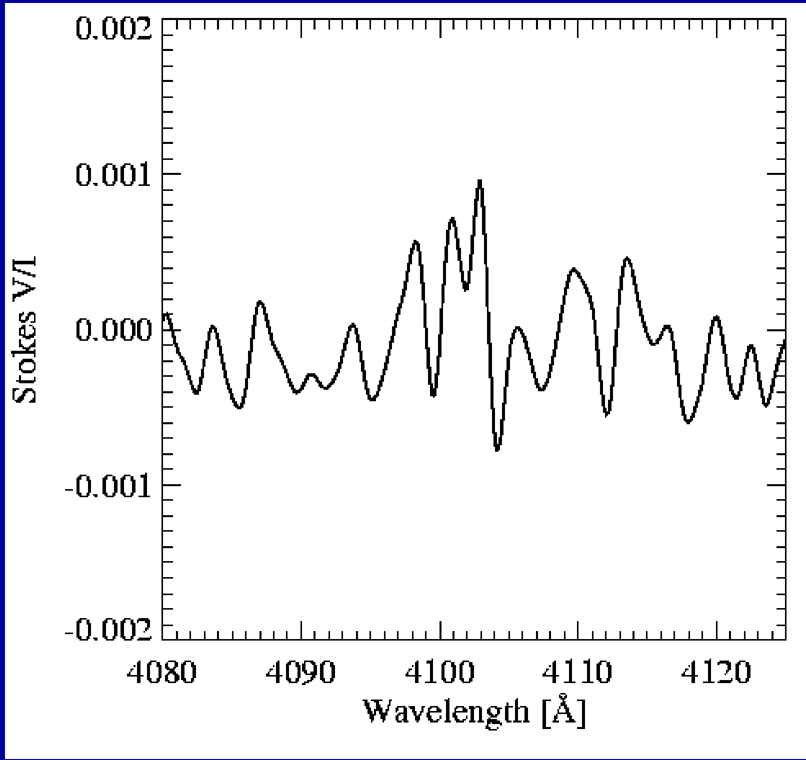
Models – stellar magnetic field



We study the magnetic field of the star only

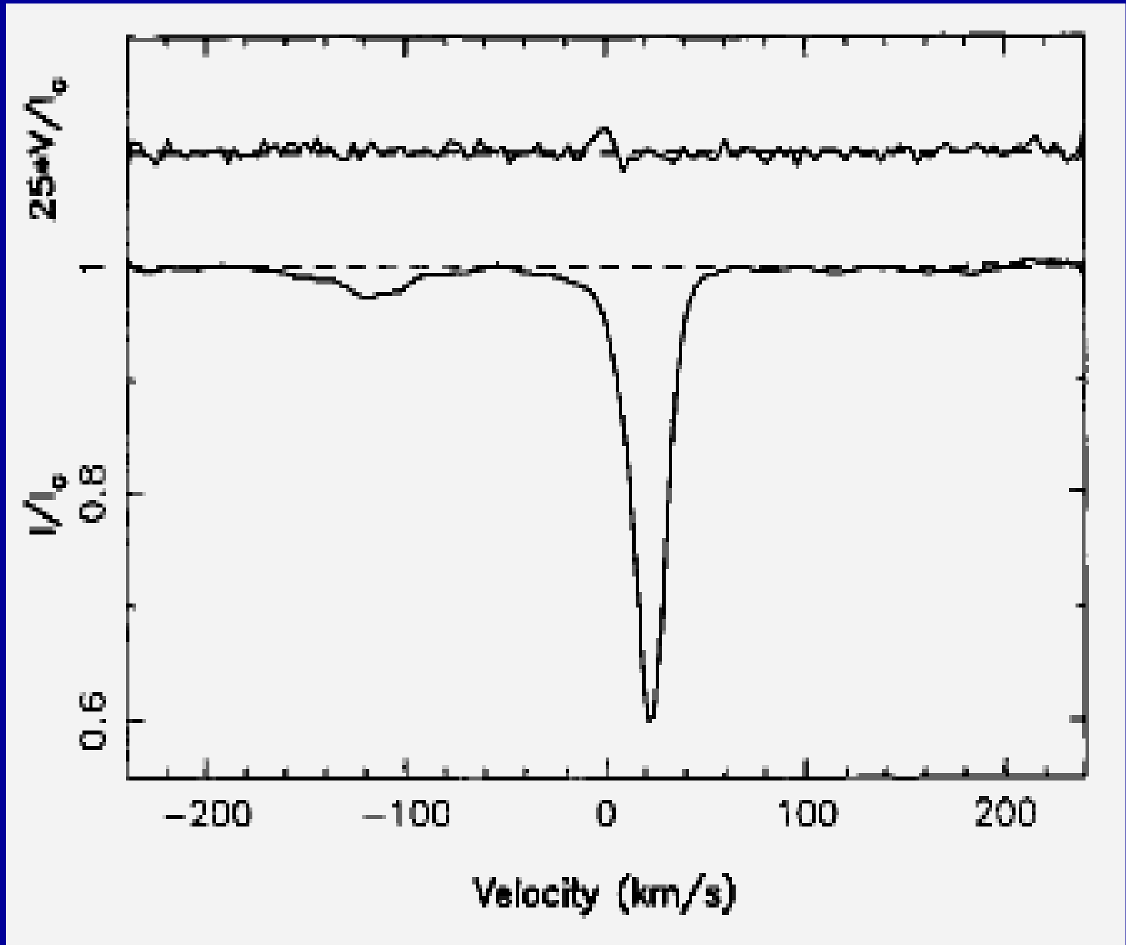
Magnetic fields measuring

$$\frac{V}{I} = \frac{1}{2}\left\{\left(\frac{f^{o}-f^{e}}{f^{o}+f^{e}}\right)_{\alpha=-45^\circ} - \left(\frac{f^{o}-f^{e}}{f^{o}+f^{e}}\right)_{\alpha=+45^\circ}\right\}$$



The longitudinal magnetic field average over the stellar disk is determined by the value of the Stokes parameter V

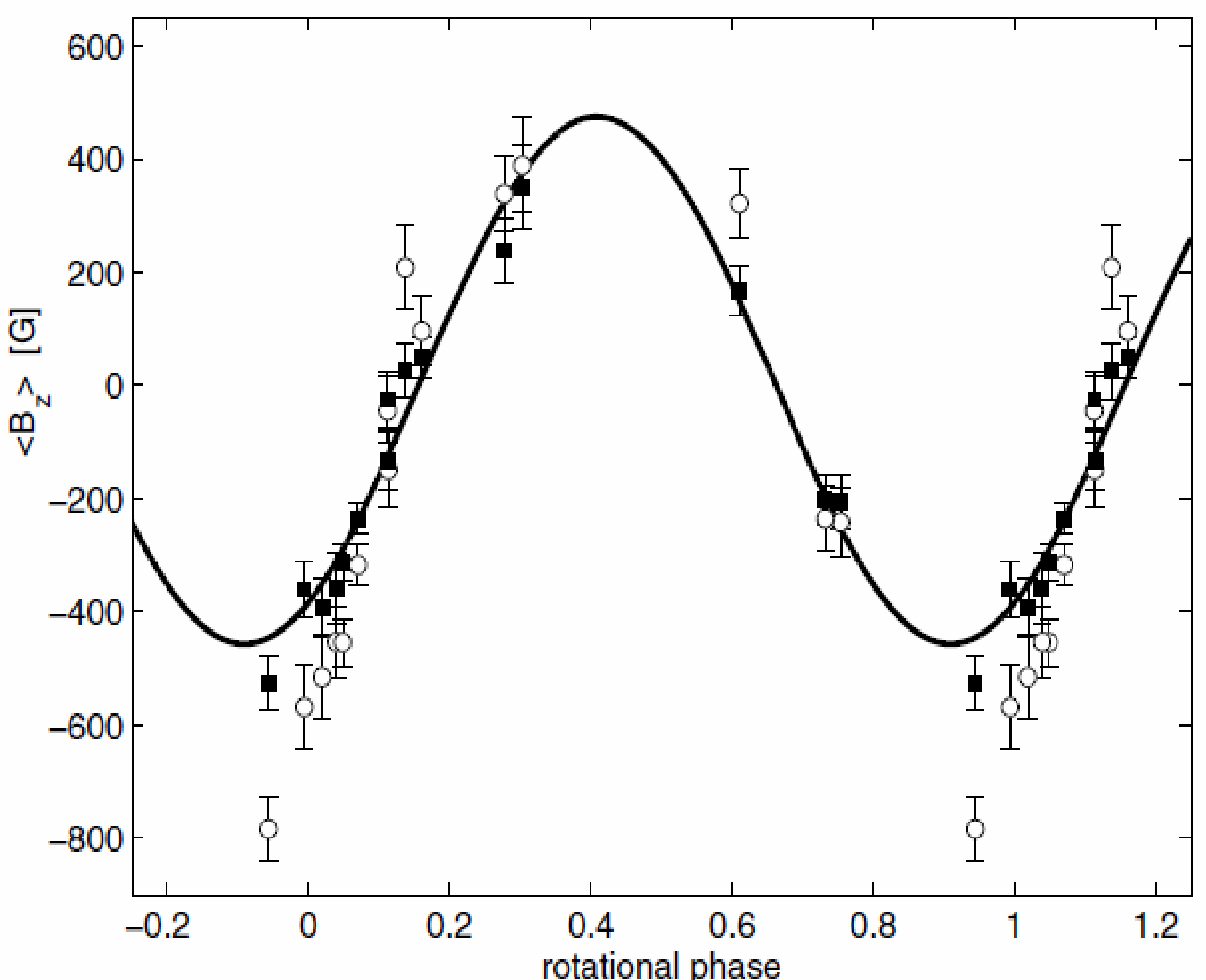
History of magnetic field searches

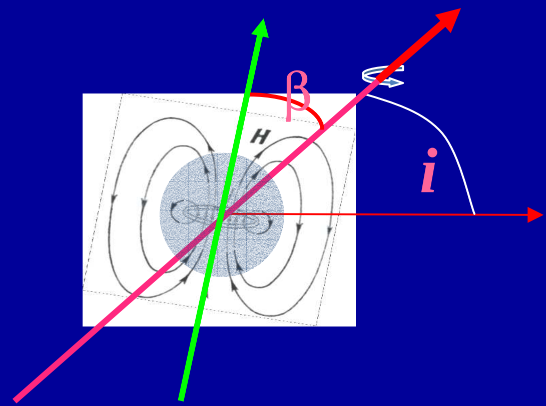


LSD unpolarized (lower curve) line profile and Stokes parameter V for HD 104237 Herbig Ae / Be star (A0)

V ~ 100 Гс (do not confirmed, Donati et al. (1997)

HD 101412 (B9/A0V)





B_p =1.7 кГс
i=80±7º
β=80±7º
P_{rot} = 42.076 ± 0.017^d

d=411 пк
T_{eff}=9750 K
R=2.16 R_{sun}
L=38 L_{sun}
M=2.10 M_{sun}
V=9.24

Phase diagram and its approximation for longitudinal magnetic field measurements using all lines (B_{all}, filled squares) and using only hydrogen lines (B_H, empty circles) according to Hubrig et al. (2011)

Data Sources: Magnetic Fields

1. Hubrig S. et al. A&A, 428, L1-L4 (2004)
2. Hubrig S. et al. A&A, 446, 1089 (2006)
3. Hubrig S. et al. A&A, 463, 1039 (2007)
4. Wade G. et al, A&A 442, L31–L34 (2005)
5. Wade G. et al, MNRAS, 376, 1145 (2007)
6. Catala C. et al, A&A 462, 293 (2007)
7. Alecian E. et al. A&A, 481, L99 (2008)
8. Hubrig S. et al. A&A 502, 283 (2009)
9. Hubrig S. et al. A&A, 536, A45 (2010)
10. Szeifert T. et al. A&A 509, L7 (2010)
11. Hubrig S. et al. A&A, 536, A45 (2011)
12. Hubrig S. et al. AN, 332, 1022 (2011)
13. Hubrig S. et al. AN, 334, 1093 (2013)
14. Alecian E. et al. MNRAS, 429, 1001 (2013)
15. Reiter M. et al. AJ, 852, 5 (2018)
16. Järvinen, S. P. et al. AJ, 858 L18 (2018)

Data Sources: L, R, T_{eff}, M

1. Gaia DR2 study of Herbig Ae/Be stars (Vioque M. et all, A&A 620, A128, 2018)
2. On the Mass Accretion Rate and Infrared Excess in Herbig Ae/Be Stars (AJ 157, 159, 2019)

Statistical characteristic of magnetic fields

Polarimetric observations give only values of B_l. These values strongly depends on the rotational phase and can not be used for the statistical analysis.

Criteria of the reality of the magnetic field measurements : at least one value $|B_l|>3\sigma_B$)

$$\langle B \rangle = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(B_l^i\right)^2}$$

RMS magnetic field

Magnetic flux

$$\Phi=4\pi R^2\langle B\rangle$$

We use the rms magnetic field as statistical characteristic of stellar magnetic field. This value weakly depending on the dates of observations

Data Sources for stellar radii: Gaia DR2 study of Herbig Ae/Be stars (Vioque M. et all, A&A 620, A128, 2018)

Magnetic field and magnetic flux distributions

$$f(\langle B \rangle) = \frac{N(\langle B \rangle, \langle B \rangle + \Delta B)}{N \cdot \Delta B}$$

N(⟨B⟩, ⟨B⟩+Δ ⟨B⟩) is a number of stars with magnetic field in an interval [⟨B⟩+Δ ⟨B⟩]

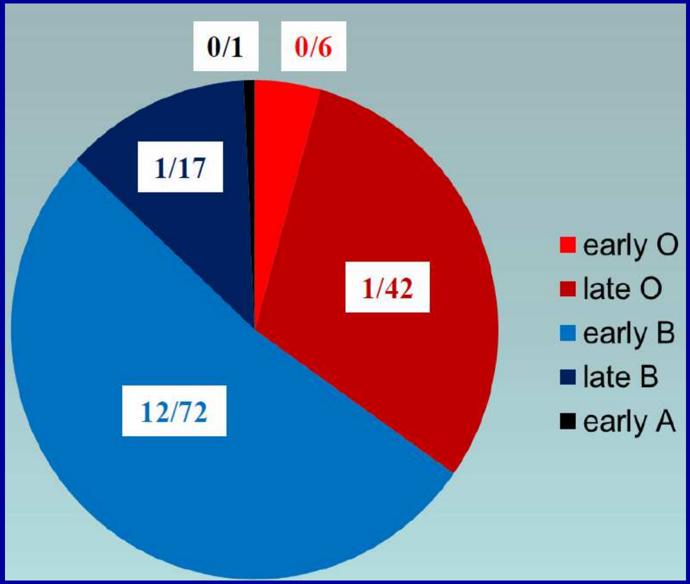
The similar relation holds for the magnetic fluxes

$$f(\Phi) = \frac{N(\Phi, \Phi + \Delta\Phi)}{N \cdot \Delta\Phi}$$

Magnetic fields of OBA stars

The B fields in OB stars (BOB) проект

35.5 nights were allocated for three years (2013-2016) of the large ESO program. Tools FORS2 (R ~ 2000) and HARPSpol (~ 115 000 R). For both FORS2 and HARPS, data reduction and analysis are carried out absolutely independently by two groups (Bonn and Potsdam). Field detection is considered real only if it is of high significance for both groups.

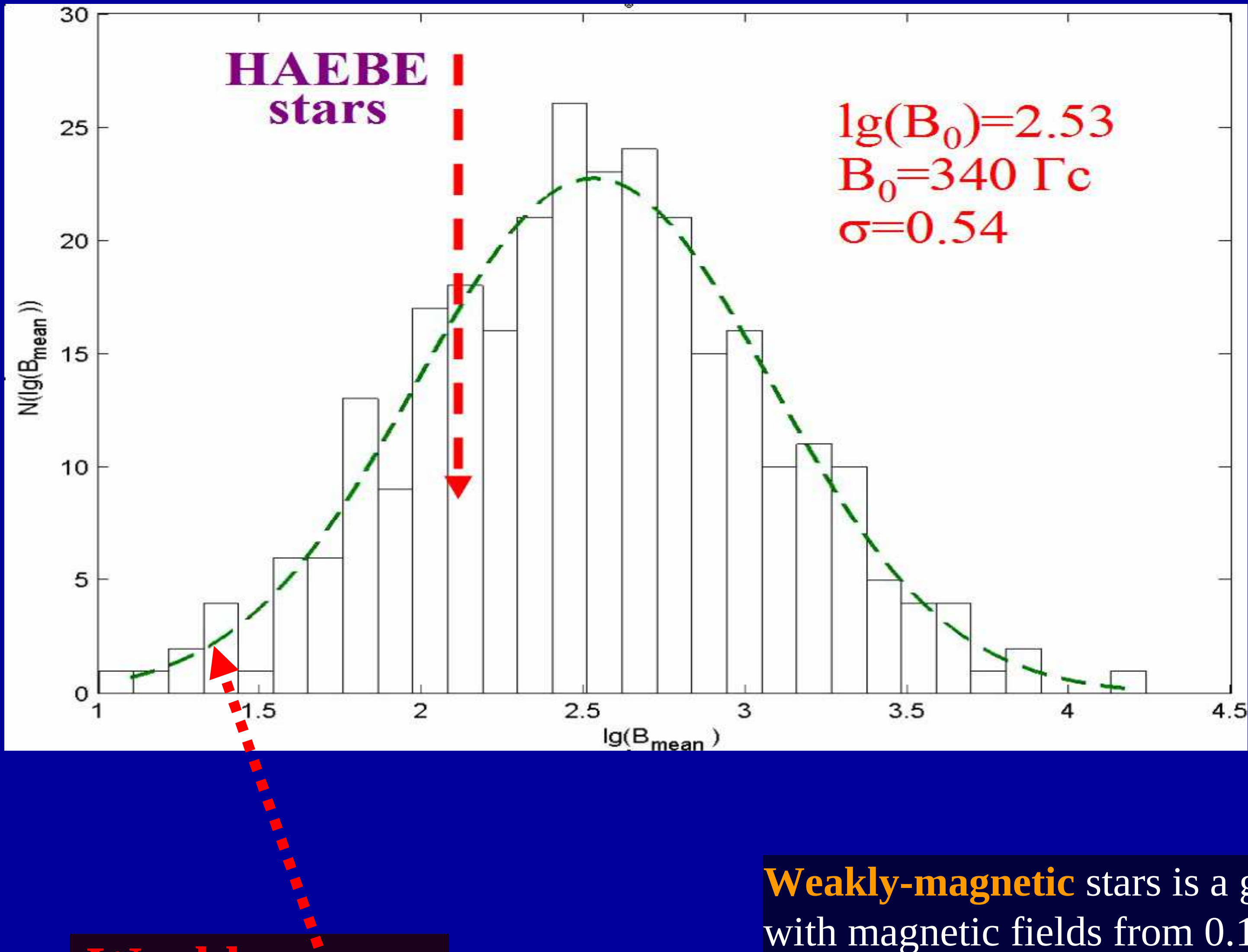


	MiMeS	BOB
Number stars surveyed	~525	138
Number fields detected	~35	14
Detection rate	7±1%	**~10%**

Only 6-10% of OBA stars are magnetic.

And what do we know about magnetic properties of remaining 90-94% of OBA stars?

Mean magnetic fields of AB and HAEBE stars

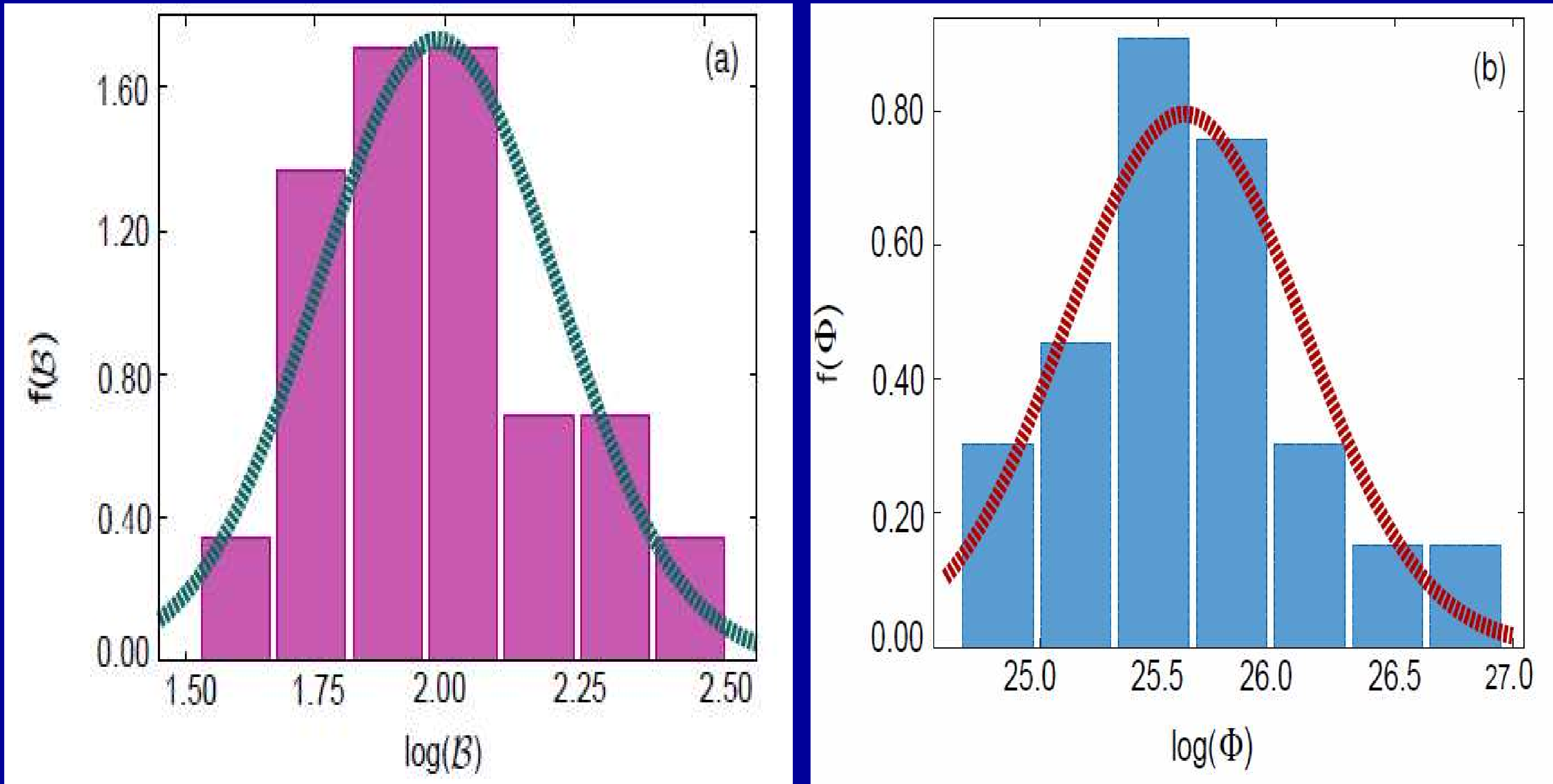


Distribution of magnetic fields of AB stars

Weakly-magnetic stars is a group of stars with magnetic fields from 0.1 to 10 G. This group includes Vega, Sirius B, rho Pup and some other stars.

Weakly-magnetic stars

I. Magnetic fields and fluxes of HAEBE stars



Distribution of magnetic fields (left panel) and magnetic fluxes (right panel) for HAEBE stars (Kholtygin et al. 2019)

Average magnetic fields and fluxes of HAEBE stars

Star group	Log(B)	σ_B (dex)	log(Φ)	σ_Φ (dex)
Weakly-magnetic stars	**1.5**	**0.5**	**23.8**	**0.6**
HAEBE (single)	**2.0**	**0.3**	**25.53**	**0.4**
HAEBE (in binary systems)	**2.1**	**0.4**	**25.78**	**0.7**
AM (MS)	**2.53**	**0.5**	**26.42**	**0.7**
AB (Pop Synt, no dissipation)	**-**	**-**	**26.42**	**0.5**
AB (Pop Synt, with dissipation)	**-**	**-**	**26.83**	**0.4**

Magnetic fields of AB stars before MS and at ZAMS

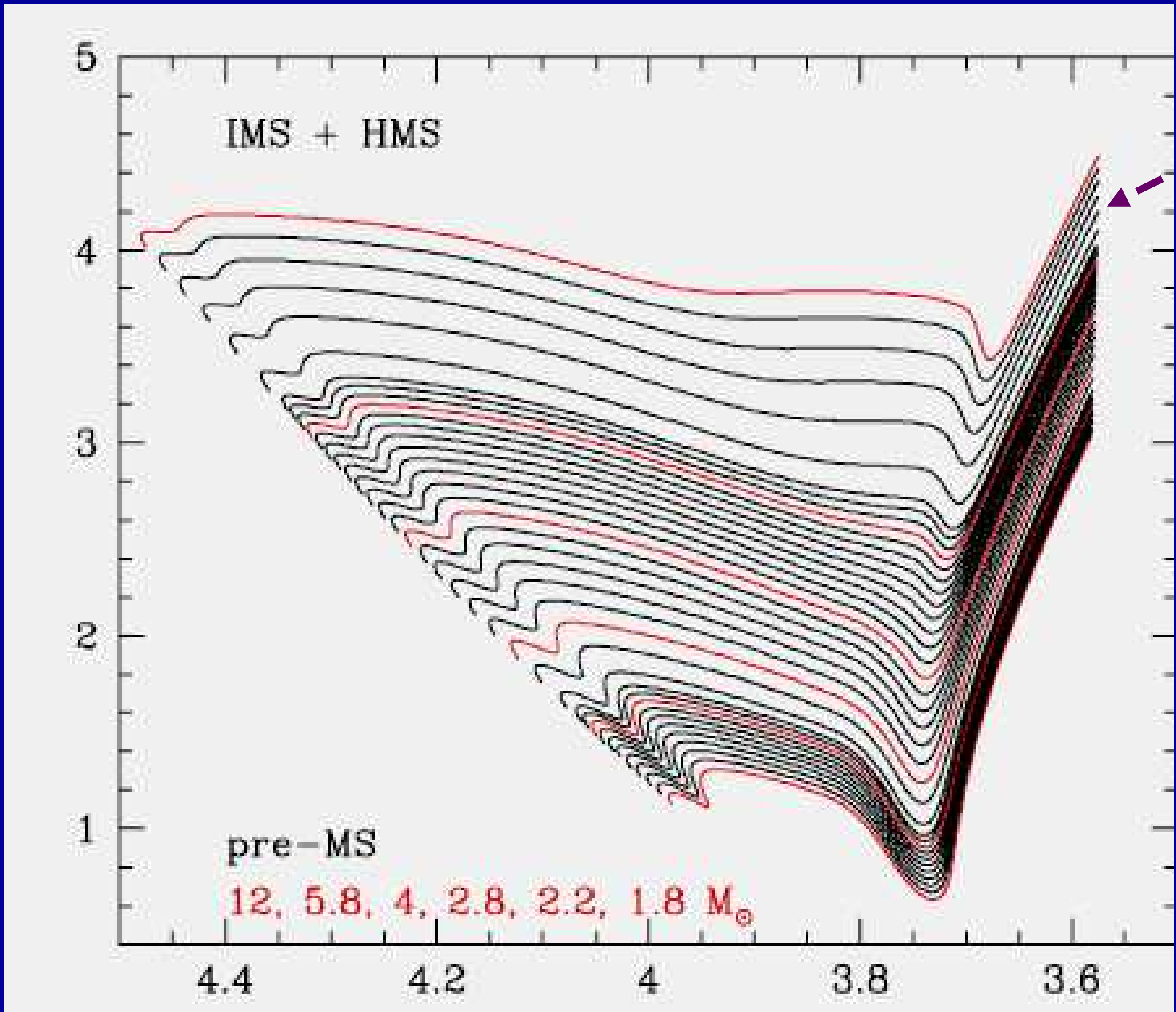
The fraction of magnetic stars among all Ae/Be Herbig stars with measured magnetic field is ~20% (3 times larger than for AB stars at MS)

BUT! The average magnetic flux of HAEBE stars is 5-10 times less than that for AB MS stars

How could this happens?

1. Such a large difference in the magnetic fluxes before MS and on the ZAMS can be explained in the framework of the idea of Ferrario (2009) that the merging of protostars can play an important role in the formation of the magnetic field of massive stars. That is, it can be considered that magnetic BA stars are those that merged before MS. After merging the magnetic field increased significantly..
2. Maybe the magnetic field structure is very different for BA stars before MS and at MS
3. The sample size (~ 20 Herbig stars with measured magnetic field) is still too small for the reliable statistics

Pre-MS evolution of intermediate masses stars

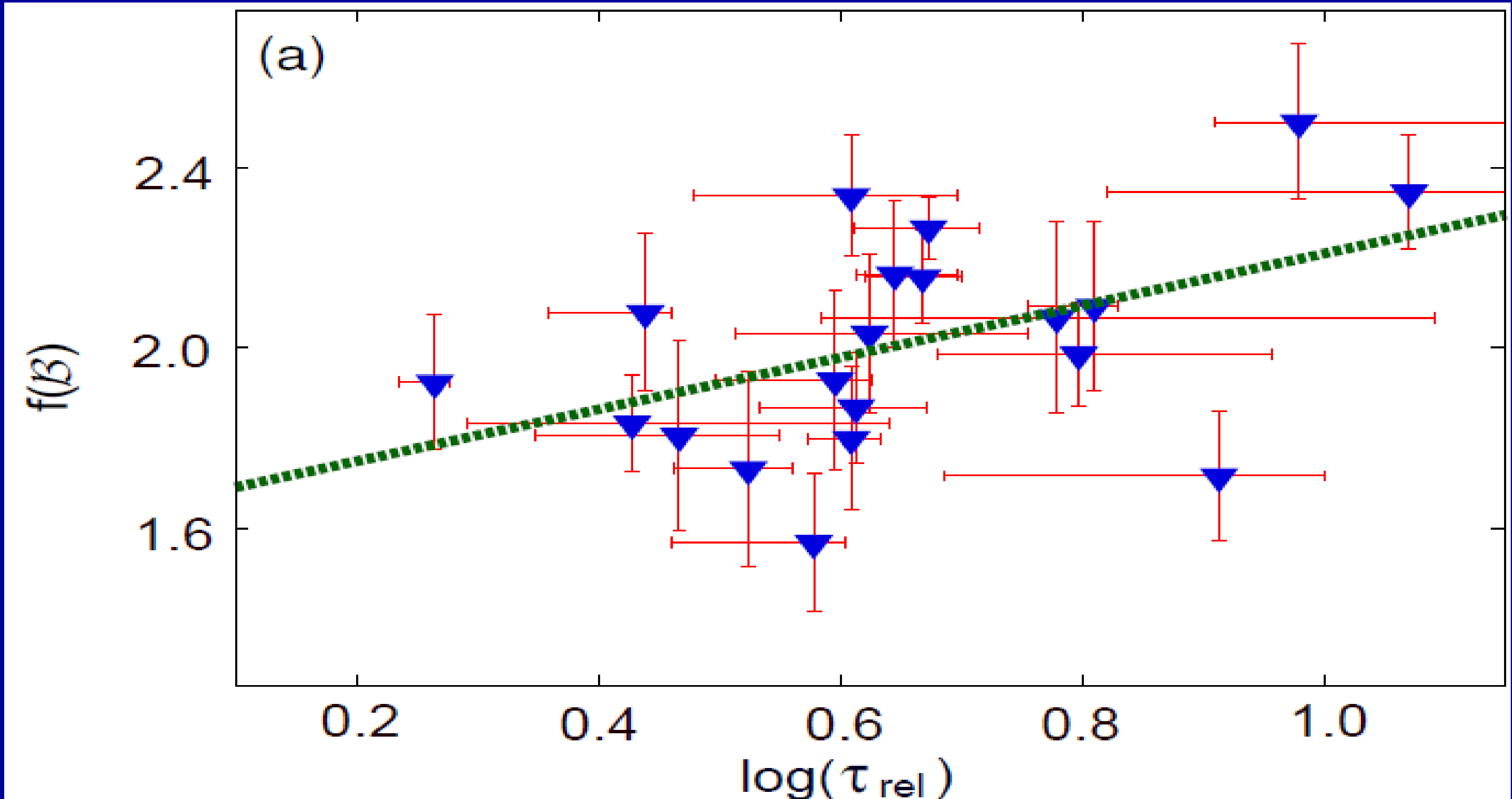


$T_c = 10^5$ K

Evolutionary tracks of stars with masses of 1.8 -12 M_{sun} before MS (Z = 0.008, Y = 0.263) Bressan et al. (2012)

The zero-point of the model corresponds to the position of the star on the Hayashi track with a central star temperature T_c = 500 K

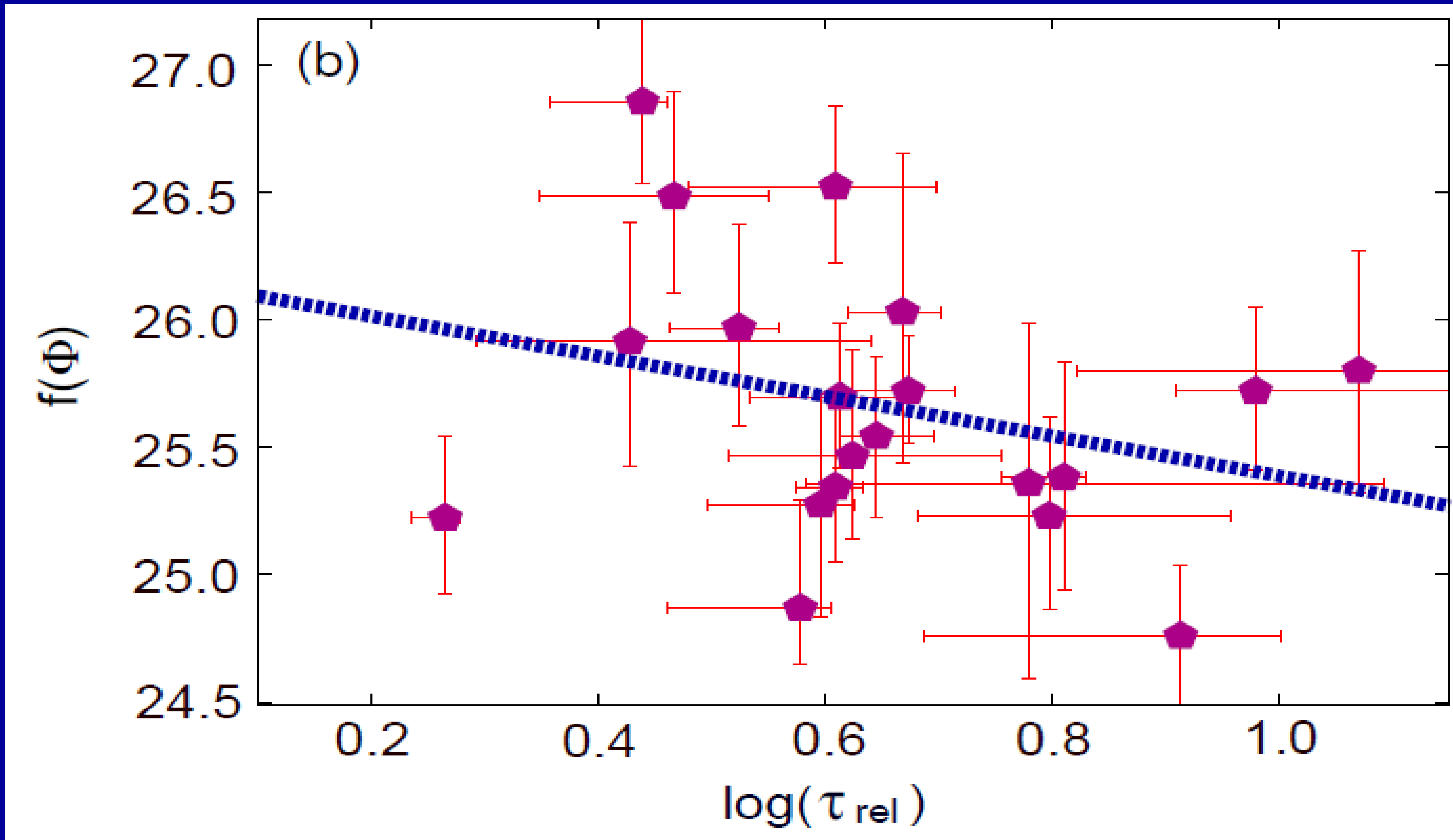
Magnetic fields of HAEBE stars: evolution



A dependence of the mean magnetic fields of Herbig Ae/Be stars) on their relative age (stellar tracks from Bressan et al.2012, zero point (ZP) corresponds to T=50 000 K in Hayashi tracks).

τ_{rel}=t(ZP to present time)/t(ZP to ZAMS)

Evolution of magnetic fluxes of HAEBE stars



A dependence of the mean magnetic fluxes of Herbig Ae/Be stars on their relative age

But where are the UXORs?

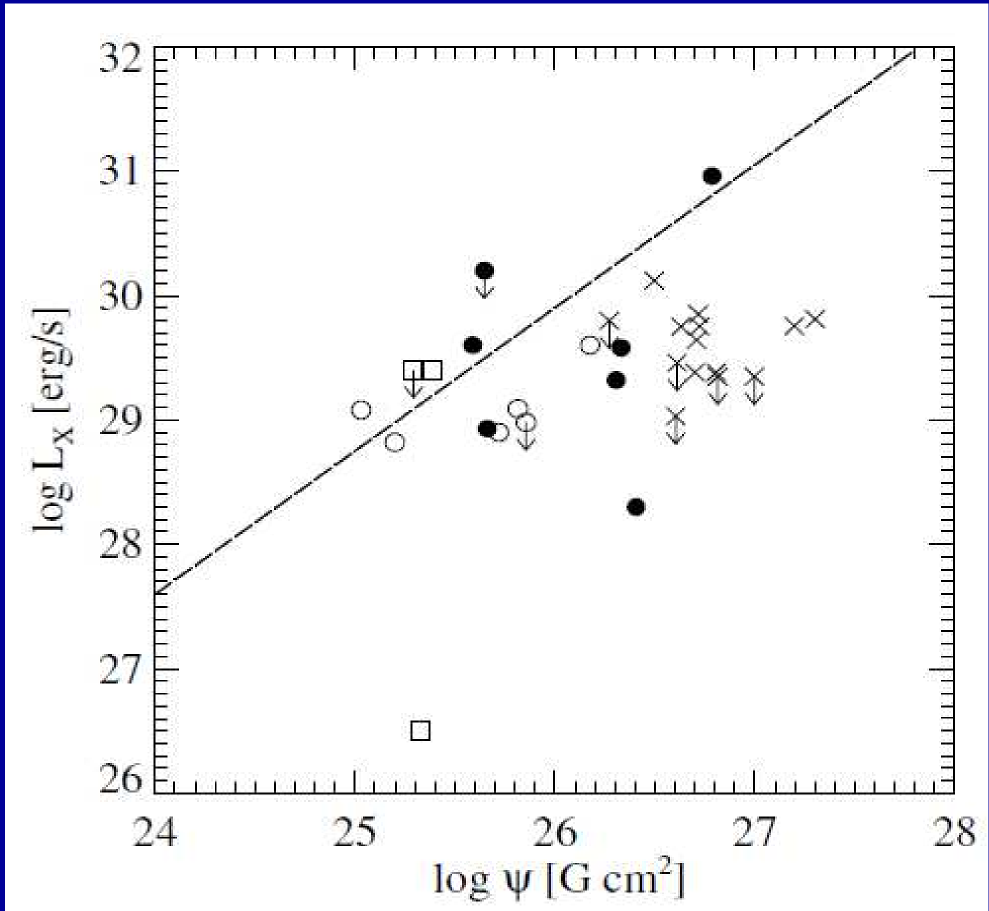
OBA stars: $f_{magnetic}$ = 6-7%

HAEBE all:
N(HAEBE) with MF measurements ~100
$f_{magnetic}$ = 20%

UXORS:
$f_{magnetic}$ = 17%
$f_{magnetic}$ (V<12) = 20%

It means that there is no significant differences between the magnetic properties of UXORS and all sample of HAEBE stars with measured magnetic fields

X-ray fluxes of Ae/Be Herbig stars



Dependence of the X-ray luminosity of Herbig stars on their magnetic flux for Herbig Ae stars and T Tau stars (crosses,), compared with the power-law dependence obtained for the Sun and active field stars (Pevtsov et al. 2003) .

Shaded circles indicate magnetic Herbig stars . The filled circles are Herbig stars with an undetected magnetic field. The squares denote stars with debris discs (none of which have a magnetic field detection of 3σ).

Conclusions and prospects

1)The average magnetic fluxes of Ae / Be Herbig stars are 5-10 times less than that of AB stars in GP

2) Need to be explained decreasing magnetic fluxes for Herbig stars with the age.

3) Why percentage of magnetic among HAEBE stars is large than for OBA ones?

4) New observations including the looking for weakly magnetic Herbig stars are needed.