Dynamo-action in massive stars: from the PMS to the TAMS

A.F. Kholtygin[1], A.S.Medvedev[1],S.Hubrig[2]
[1]Saint-Petersburg University, Russia
[2]AIP, Potsdam, Germany

Stellar and planetary dynamos
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Statistical characteristics of the Magnetic fields

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

We use 3 characteristic of magnetic field weakly depending on the dates of observations

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

RMS magnetic field

Statistical investigation is the key of understanding the nature of the OB stars magnetic field

$$\sigma_B = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(B_l^i\right)^2}$$

Mean error of the magnetic field

$$\chi^2/n = \frac{1}{n}\sum_{i=1}^{n}\left(B_l^i\right)^2 / \left(\sigma_{B^i}\right)^2$$

reduced χ^2 statistics

$|B| > 3\sigma_B$ for at least one measurement => $\begin{cases} \langle B \rangle > 2\sigma_B, \\ \chi^2/n > 1 \end{cases}$

Criteria of real measurements

CPD-28 2561: $\langle B \rangle$ = 239 **Гс**, σ_B=93 **Гс**, $\chi^2/n = 5$

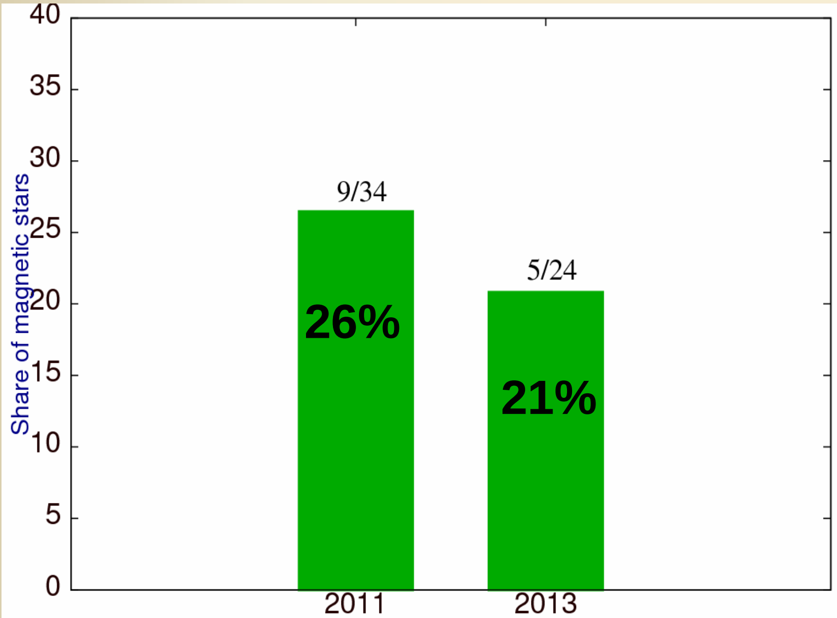
Sources of the magnetic field data

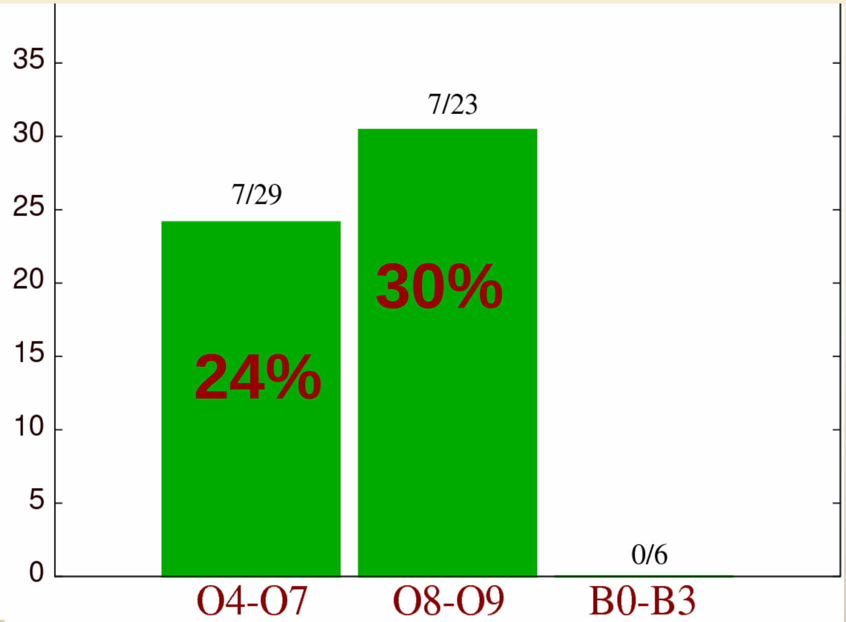
O star observations with FORS and HARPS: MAGORI PROJECT

Aims:
To investigate statistically whether magnetic fields in massive stars are ubiquitous or appear only in stars with a specific spectral classification, certain ages, or in a special environment.

Telescopes and Spectrographs
VLT, 8-m Antu + 3.6 m ESO
FORS2+HARPS, NOT

Results for OB stars:
In 2011 + 2013 65 stars > 100 spectra. Magnetic field at 3 σ level was detected for **14 O stars,** including two Of?p stars.

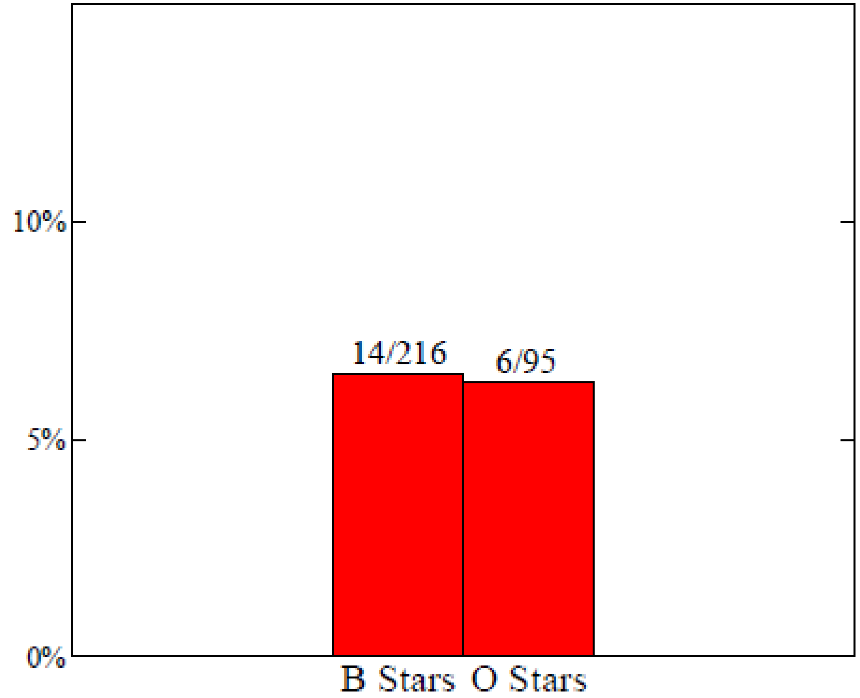


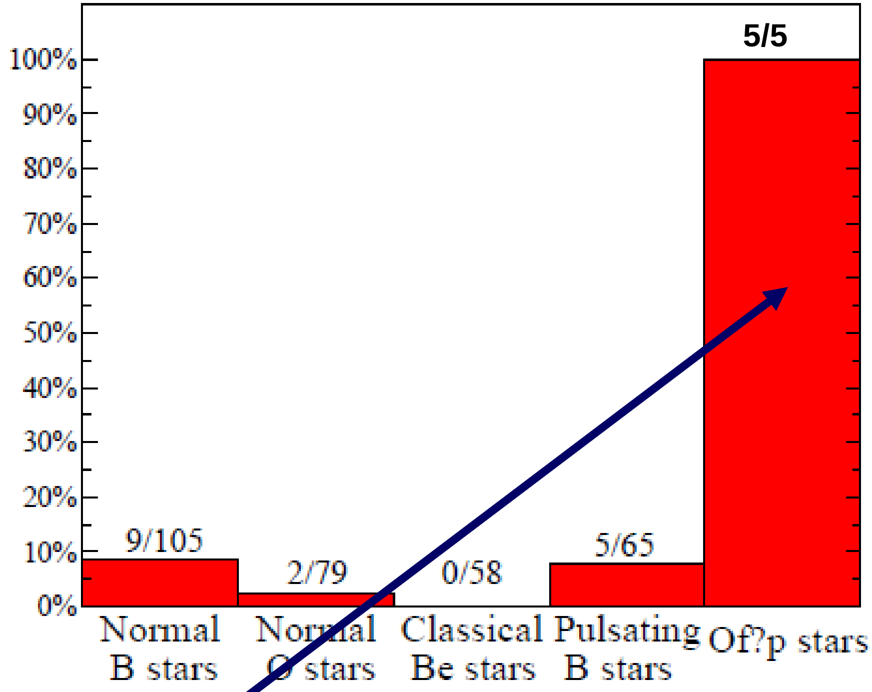


Hubrig et al. (2011, 2013)

Project MIMES:
Magnetism in Massive Stars

Head of the Project: Gregg Wade, Canada

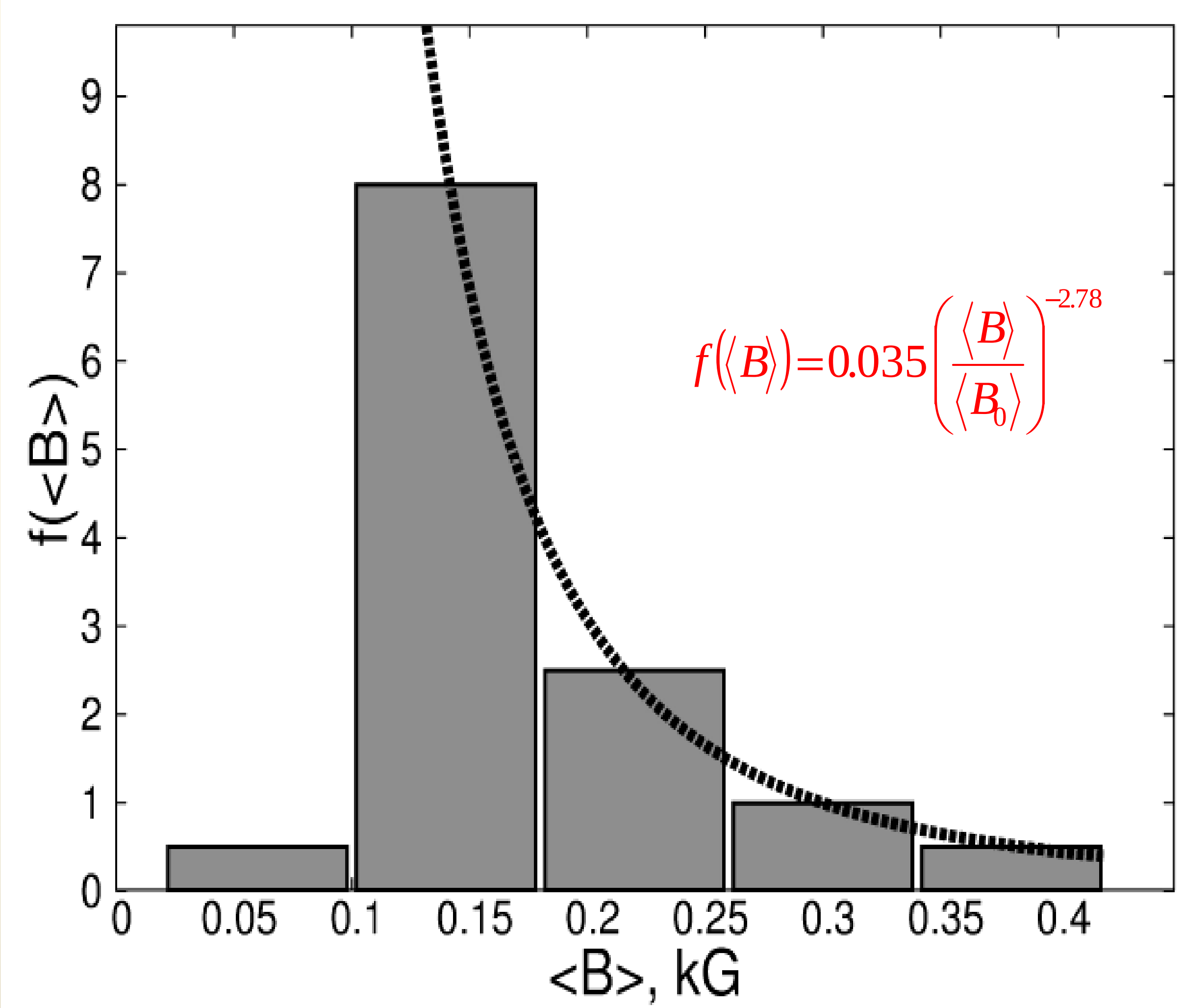




for two Of?p stars (HD 148937 and CPD -28 2561) magnetic fields have been detected by the **MAGORI** group

http://www.physics.queensu.ca/~wade/mimes/MiMeS__Magnetism_in_Massive_Stars.html

Magnetic field distribution for O stars

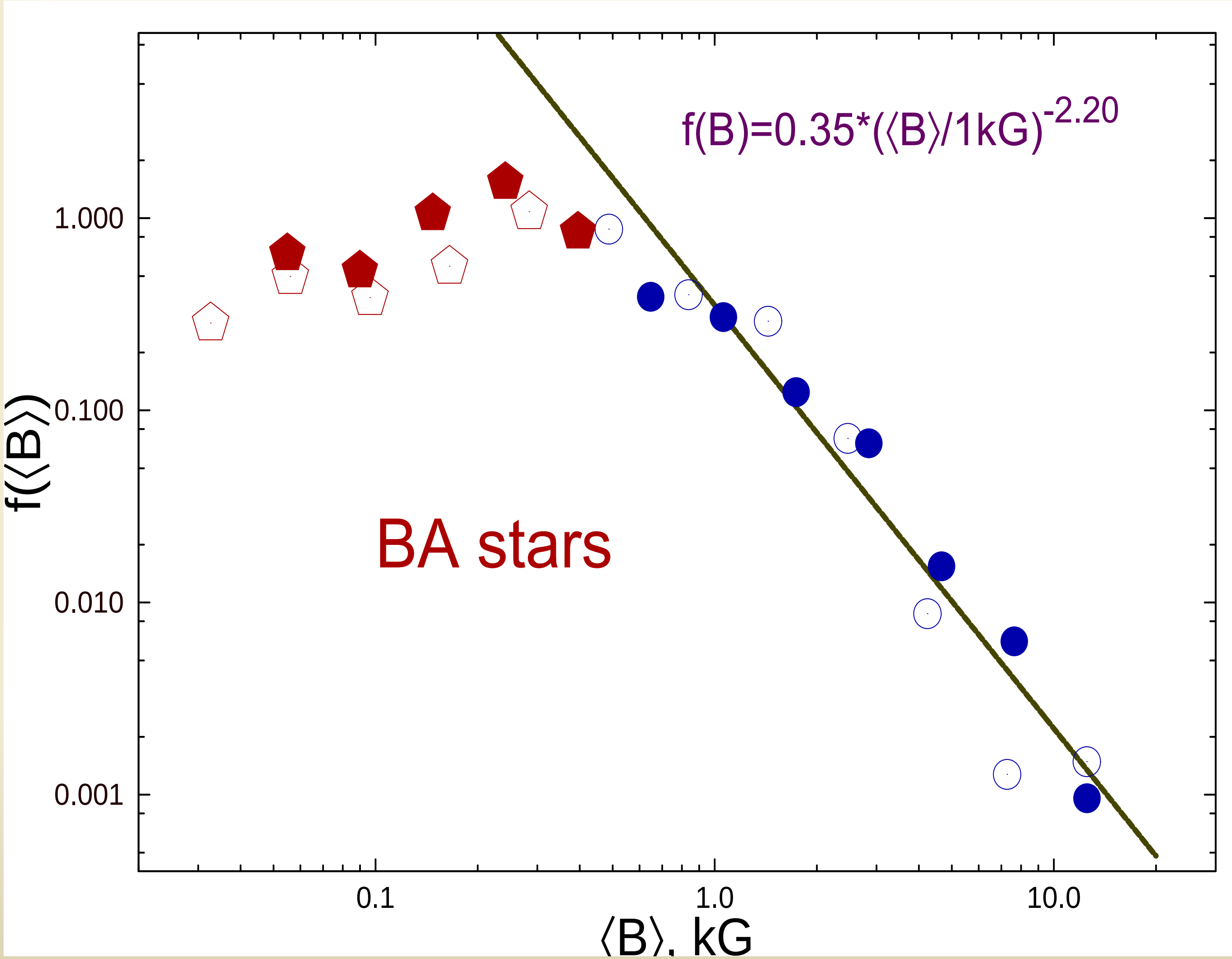


$$f^{obs}(B)=\frac{N(\mathbf{B},\mathbf{B}+\Delta\mathbf{B})}{N_0\Delta\mathbf{B}}$$

$$f(\langle B\rangle)=A_0\left(\frac{\langle B\rangle}{\langle B_0\rangle}\right)^{-\gamma}$$

The number of data is small ~ 10-20 stars

Magnetic field distribution for BA stars: first glance

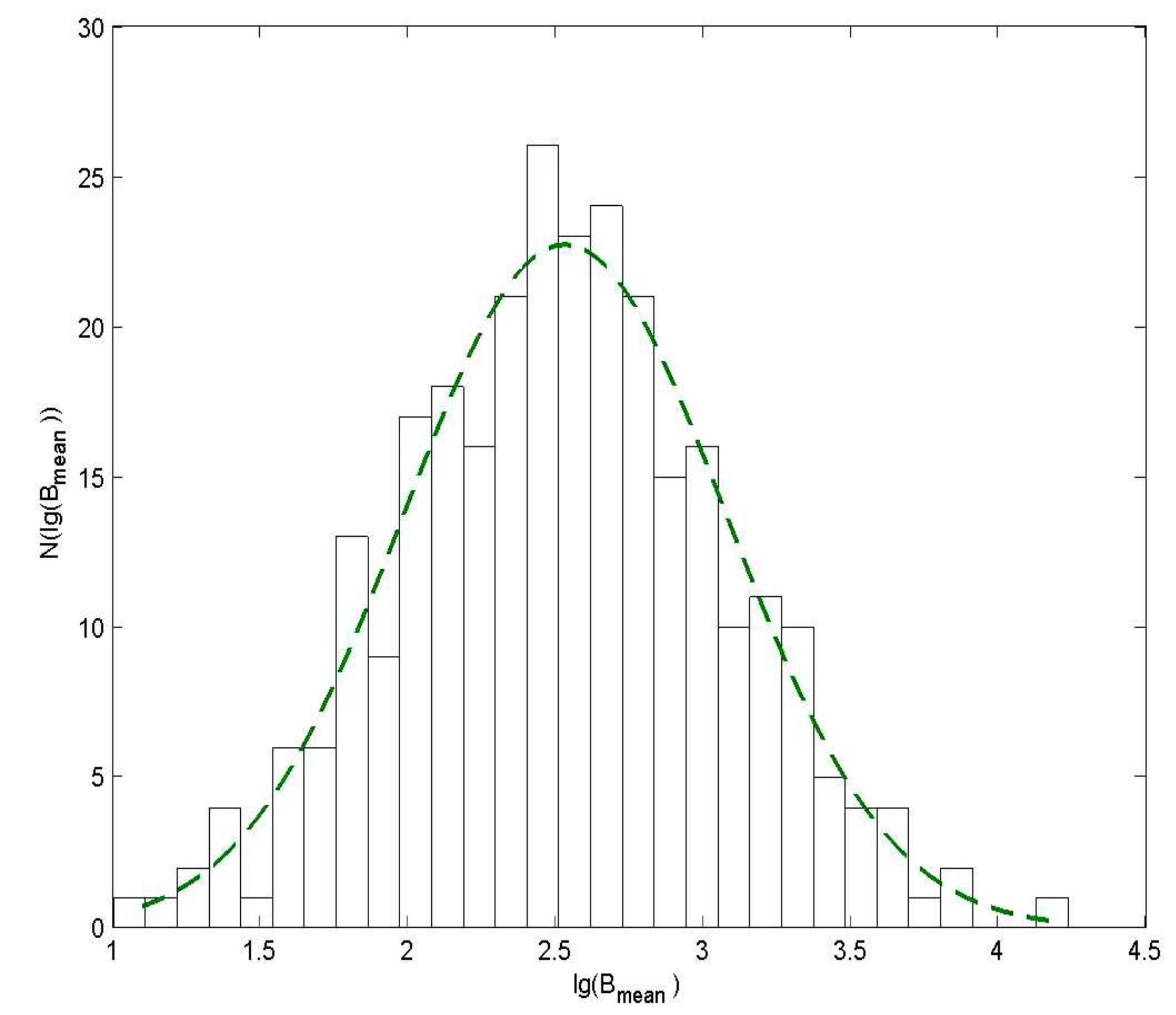


Magnetic field distribution for B (empty) and A (filled) symbols accordingly.

Power approximation is shown with a dashed line. Pentagons mark data in the region ⟨B⟩ < 300 G.

Is the gap at ⟨B⟩ < 0.3 kG (magnetic desert) real?
Probably not!

Magnetic field distribution for BA stars: the second view



Changing paradigm:

Log-normal distribution instead of power law

We use only data from

Bychkov (2009) catalog

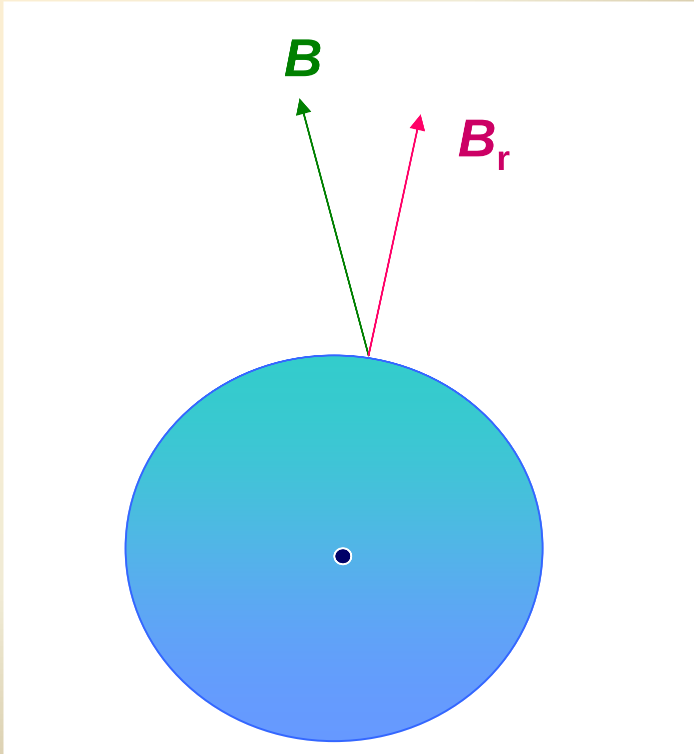
There is NO of the magnetic desert

From Magnetic Fields to Magnetic fluxes

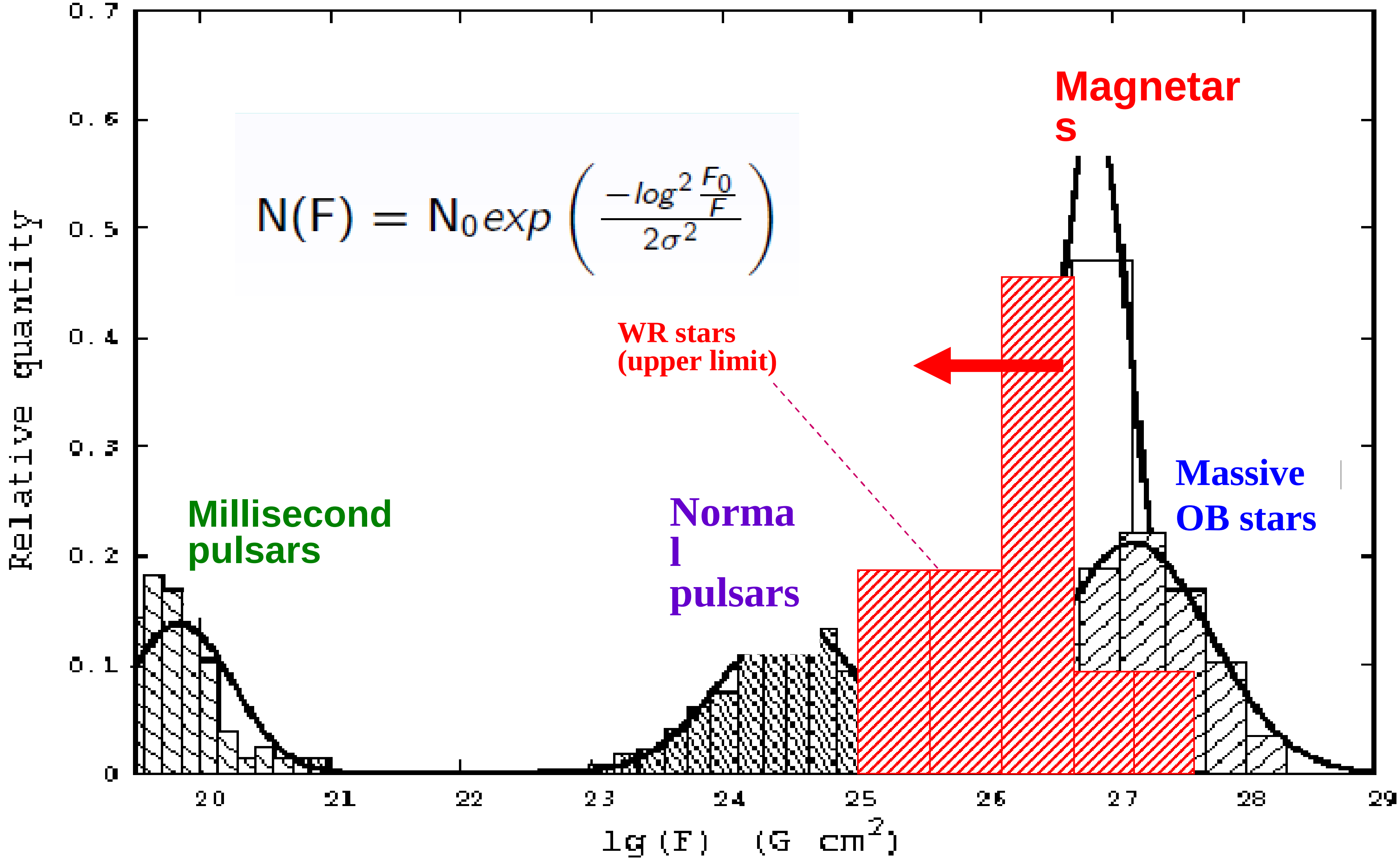
Magnetic pseudo-fluxes of massive stars

$$F = R_*^2 \int_{-\pi}^{\pi} \int_{0}^{2\pi} |B_r| \sin\theta \, d\theta \, d\varphi$$

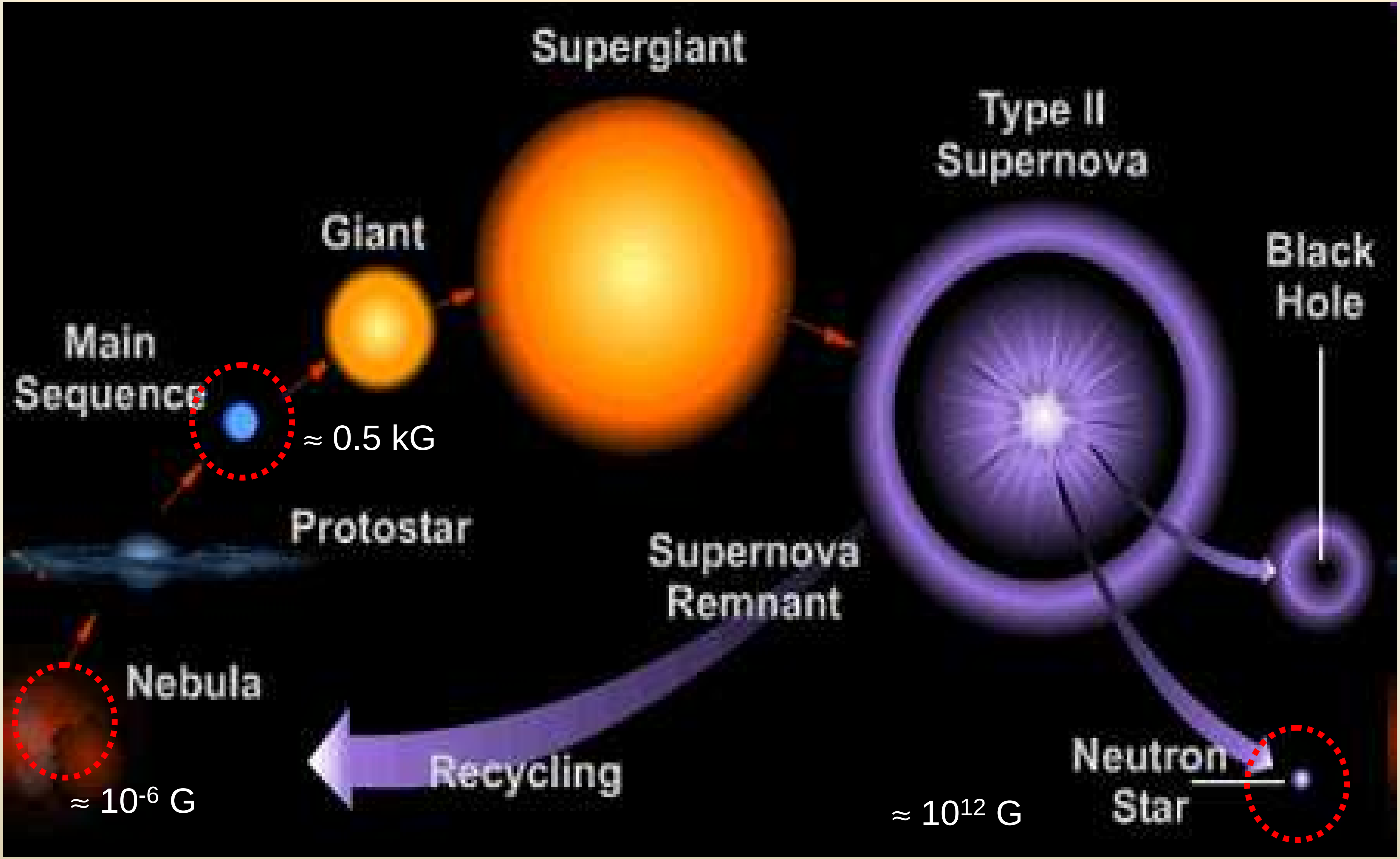
$$F \approx 4\pi \langle B \rangle R_*^2$$



Magnetic pseudo-flux distribution for massive OB stars WR stars, pulsars and magnetars

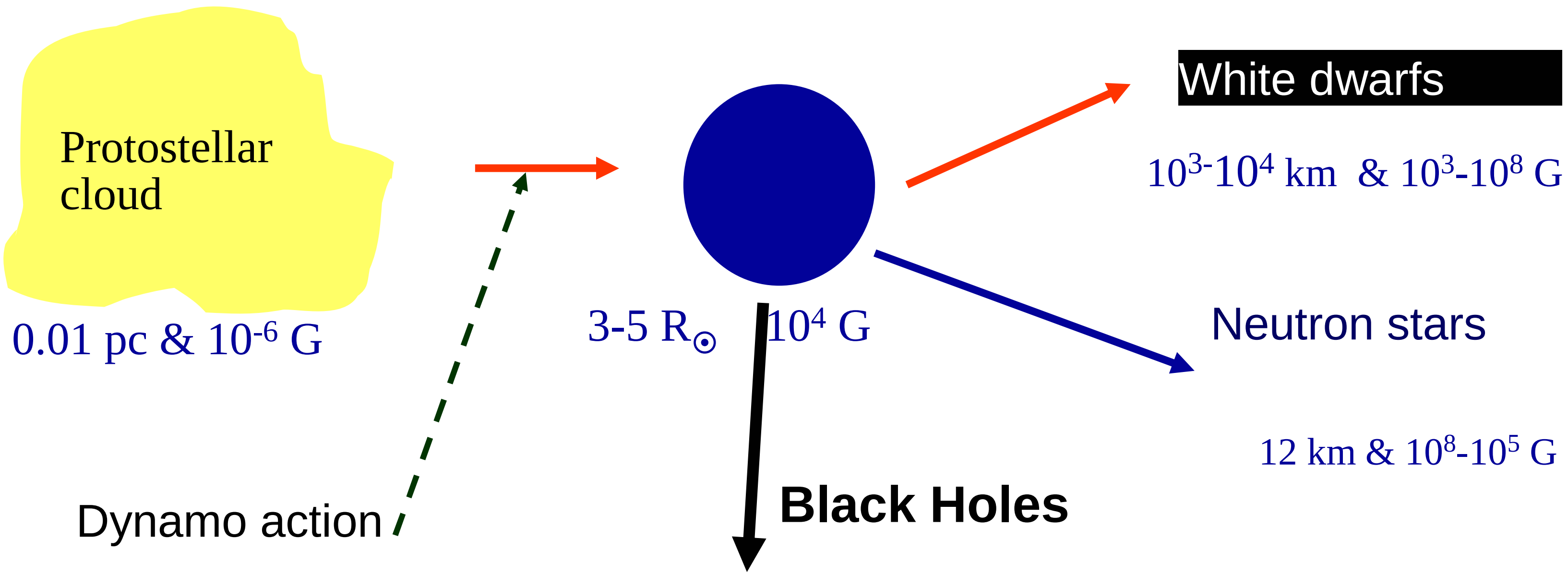


The general scheme of the massive stars and **their magnetic field** evolution



Stages of evolution, about which we know the typical values of the magnetic field **are marked**

The general scheme of the magnetic field generation for massive stars



$$F = 4\pi R^2 \langle B \rangle = const$$

$$\frac{B_1}{B_2} = \frac{R_2^2}{R_1^2}$$

Our new population synthesis code

We create an ensemble of massive stars on the main sequence in order to obtain mass, age, radius distributions of these stars based on the **AMUSE** platform

Initial distribution of magnetic fluxes

$$f(\Phi_0) = \frac{1}{\Phi_0\sqrt{4\pi\sigma^2}} \exp\left\{-\frac{1}{2}\left(\frac{\log\Phi_0 - \langle\log\Phi_0\rangle}{\sigma}\right)^2\right\}$$

Magnetic flux evolution

$$\Phi_i = \Phi_{0,i} e^{-\tau_i/\tau_d}$$

τ_d is the dissipation parameter. $\tau_i = t/\tau_{MS}$

Magnetic flux and rms magnetic field

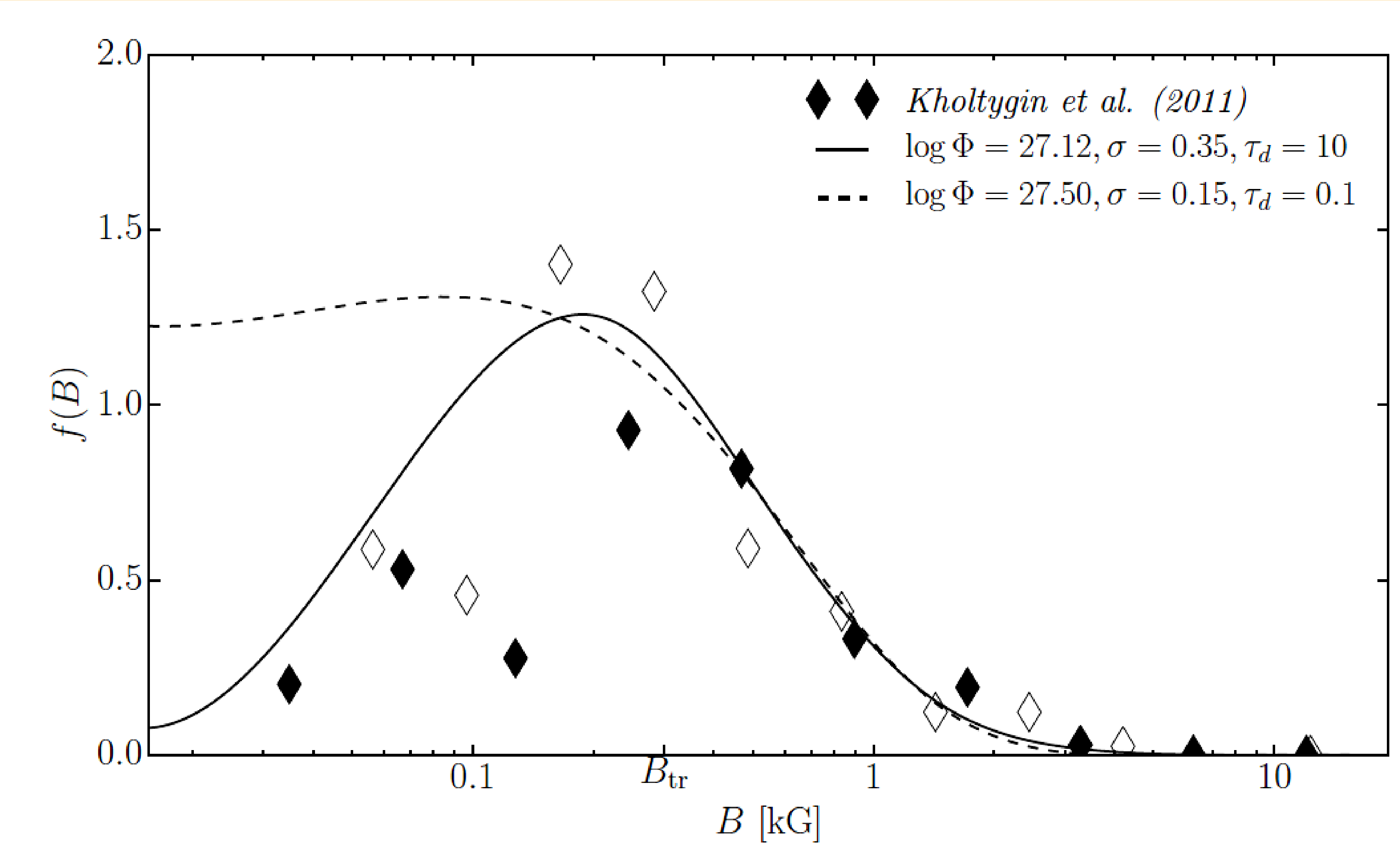
$$B_{\rm rms} = \frac{\Phi_i}{4\pi R_i^2}$$

•Also we introduce a threshold value of the magnetic field B_{min} ~ 300 G (**Auriere et al. 2007**) as an optional parameter.

- Dissipation parameter derived from observations is about 0.1
- In that case a magnetic field distribution would be highly asymmetric.
- Observational data is incomplete, more data is needed

$f_1 = N_{magn}/N_{nomagn}$ (at ZAMS) $f_2 = N_{magn}/N_{nomagn}$ (at the present time)

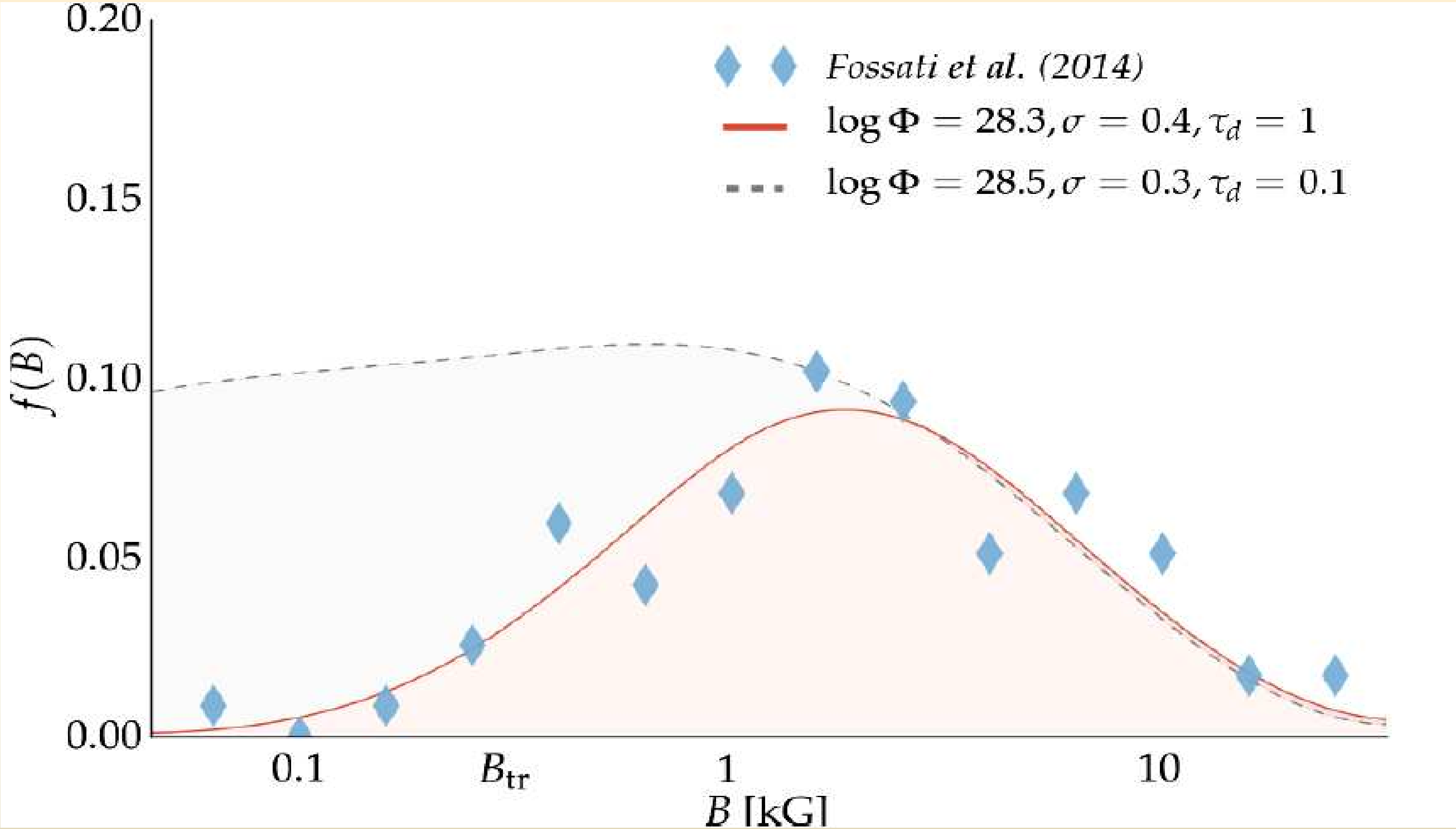
Common distribution function for AB stars



f_1 = 30% f_2=10%

It means that 2/3 of AB are non-magnetic at ZAMS

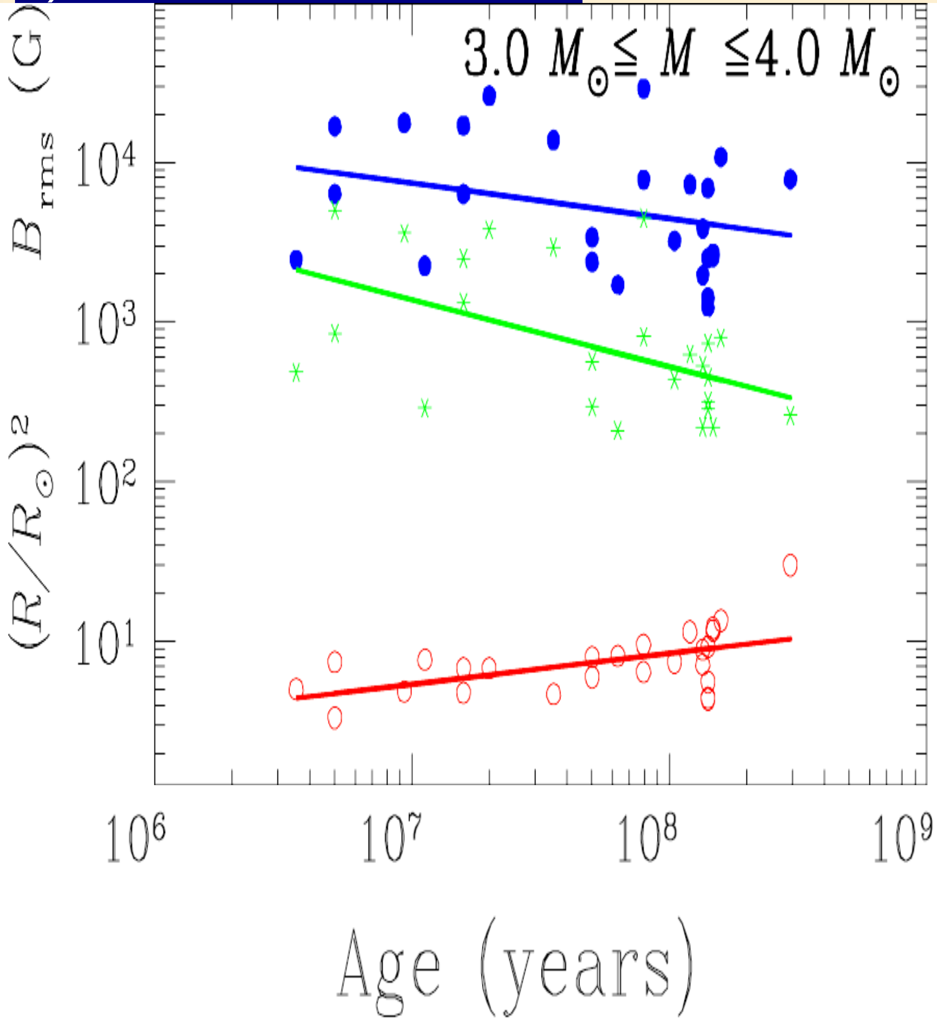
Distribution function for OB stars



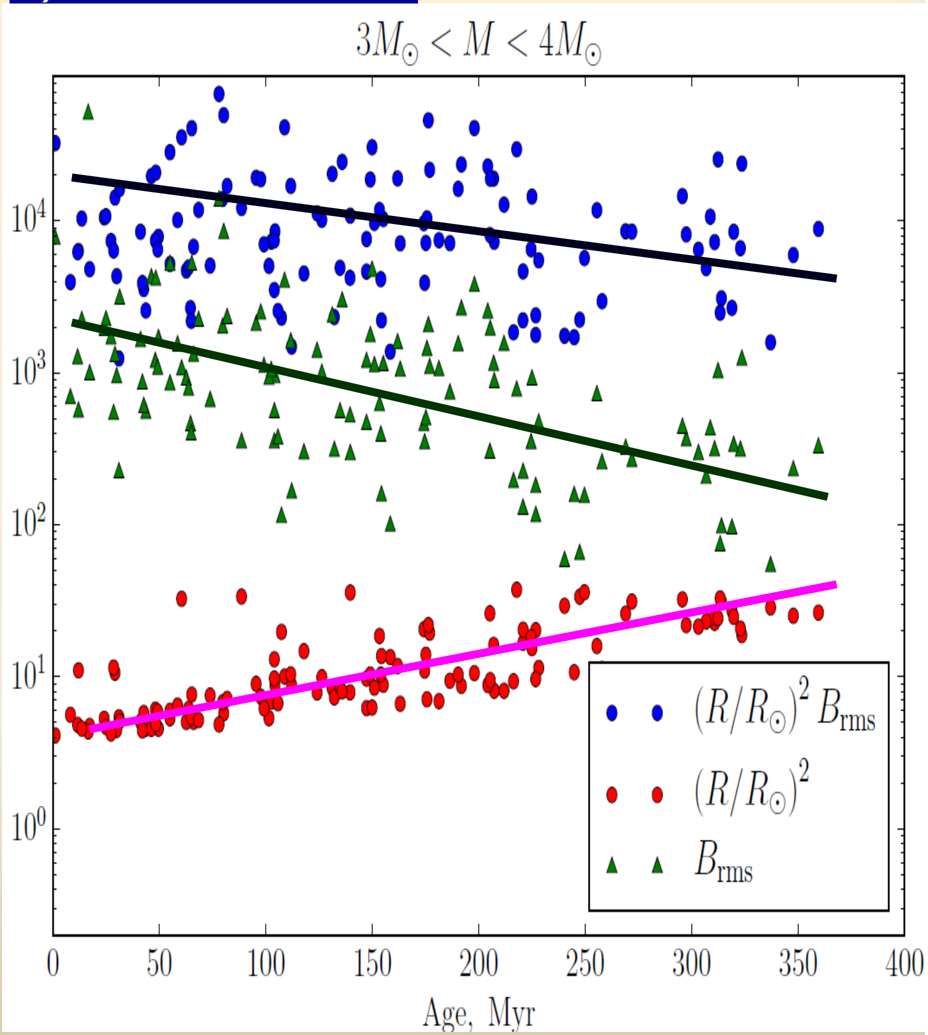
Fraction of magnetic stars is significantly higher if we assume that Bth = 300 G. Then if f_1= 90% => f_2=30%

Evolution of the magnetic fields and magnetic fluxes for stars with masses in the interval [3,4] solar masses

A) MF measurements



B) Model



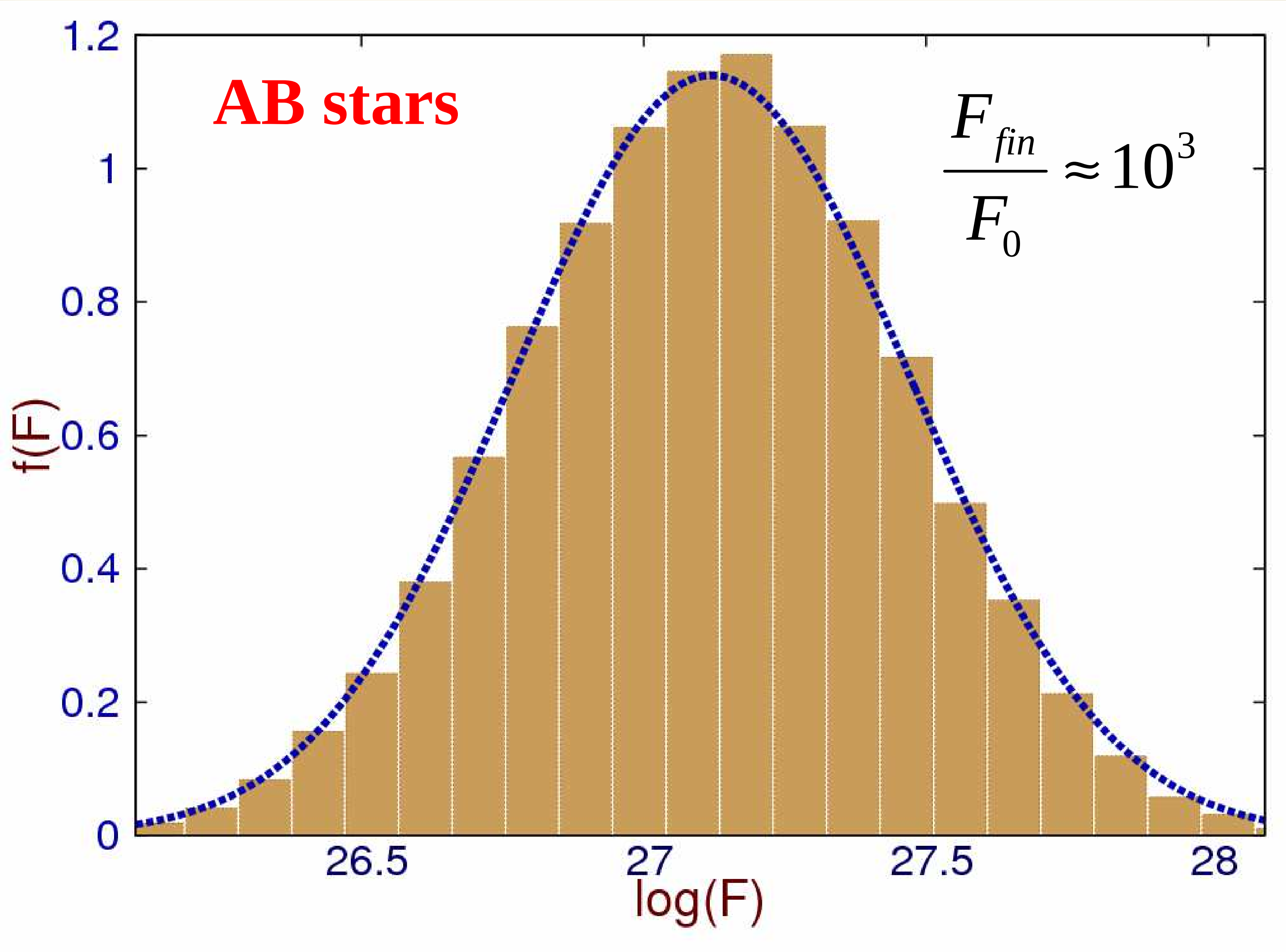
Landstreet et al. (2007)

What happens before ZAMS

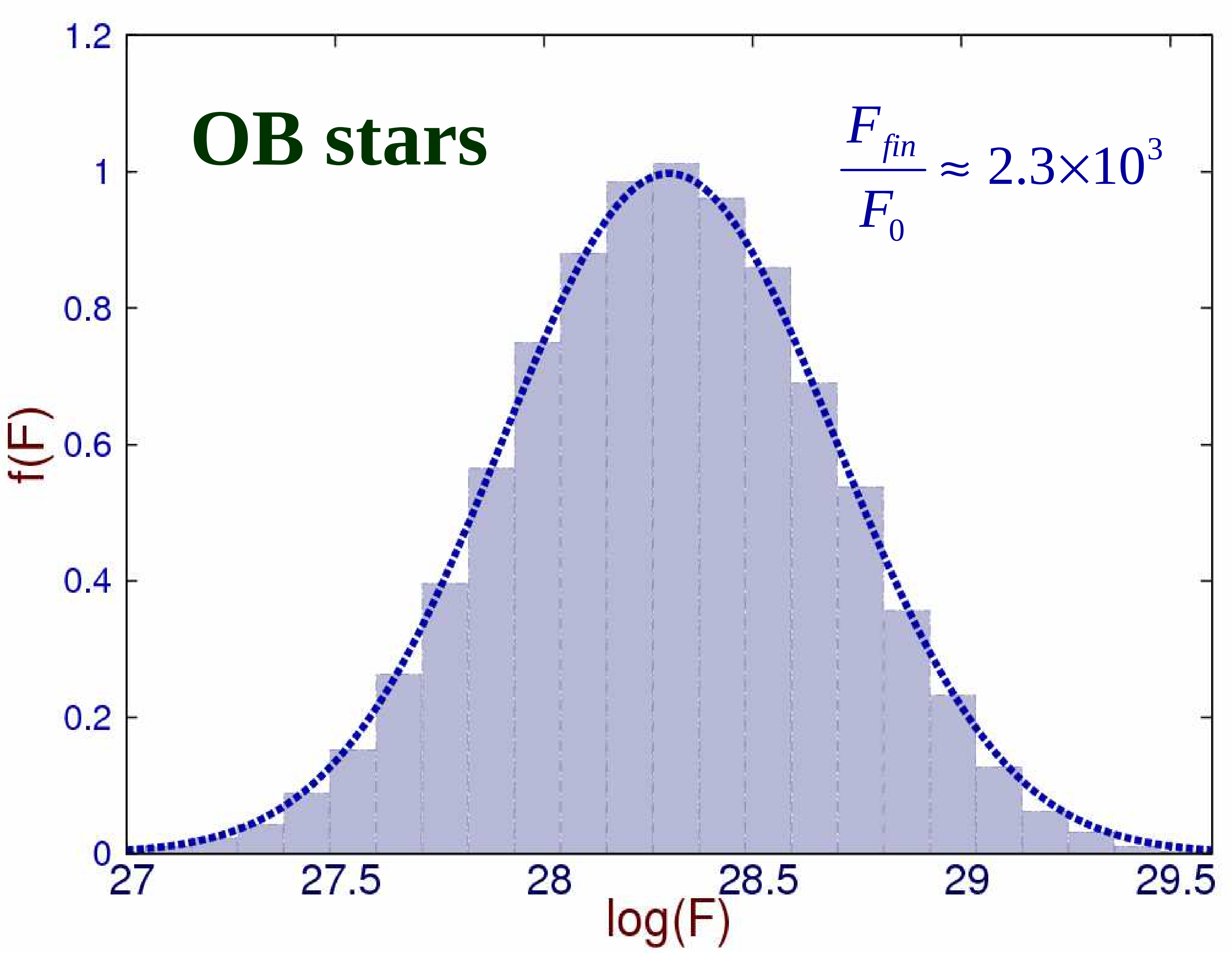
Toy model of the magnetic field and magnetic flux generation by dynamo-action

- All stars have the equal initial magnetic flux F_0
- **Magnetic field** is generated during the N cycles
- $B_{fin} = B_0 * \alpha_1 * \alpha_2 * \dots \alpha_N$
- α_i – is the uniformly distributed random variable in an interval [a,b]
- **Magnetic flux** $F_i = 4\pi R_i^2 B_i$, R_i is the stellar radius at the cycle i,
- $F_{fin} = F_0 * \beta_1 * \beta_2 * \dots \beta_N$, where $\beta_{i+1} = \beta i * (\alpha_{i+1} / \alpha_i) * (R_{i+1}/R_i)^2$
- $F_0 = B_0 * 4\pi R_0^2$

Parameters of the model: B_0 (or F_0), R_0, a, b, N



Parameters of the model: $\log F_0 = 1.5 * 10^{24}$ G*cm^2, a=1.0, b=1.85, N=20



Parameters of the model: $\log F_0 = 8.8*10^{24}$ G*cm^2, a=1.0, b=2.00, N=20

Conclusions

1. The magnetic desert for **OBA** does not exist.
2. We create a model which can describe the real distribution of massive star magnetic fields
3. Initial fraction (at ZAMS) of magnetic OB stars can be in the range from 30% to 90%
4. **The question remains why only a small fraction of OB stars are magnetic remains unanswered**