Rotational properties of magnetic chemically peculiar stars

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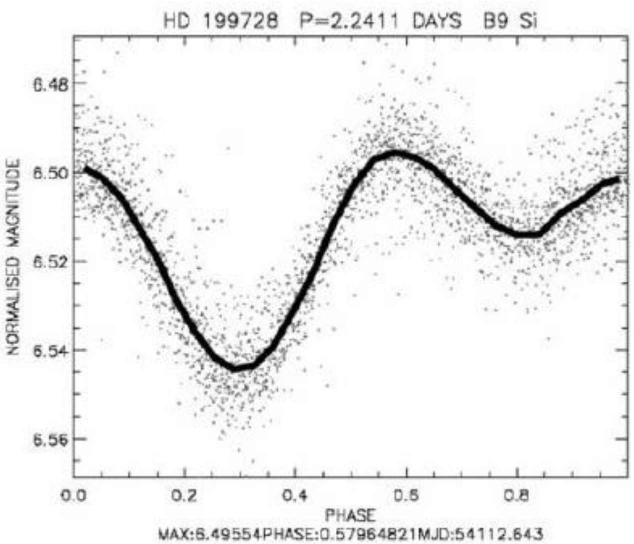
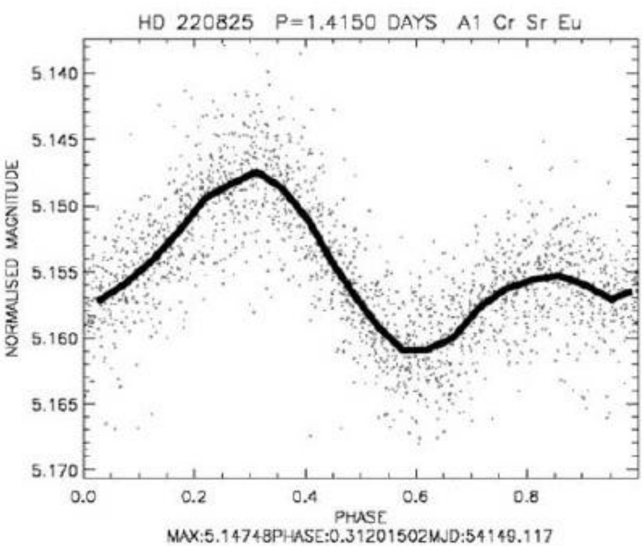
Magnetic chemically peculiar stars

- also known as Ap/Bp, CP2/4 (or mCP) stars
- B- to F-type main-sequence stars, slow rotators
- incidence of about 5-10%
- magnetic fields range from 300G – 30kG
- show photometric variability due to spots (rotation period!)
- useful to investigate rotation in the presence of magnetic fields





characteristic α^2 Can. Vel. (ACV) lightcurves can serve as detection or confirmation tool of the mCP nature.

e.g. Wraight et al. (2012) – STEREO data

Photometric variability of mCP stars

remind talk by *J. Krtička* in the morning about the origin …

latest period compilation was by *Renson & Catalano (2001)*

since then many works made use of photom. survey data:

- STEREO - *Wraight et al. (2012)*
- ASAS – (*Bernhard et al. 2015, Hümmerich et al. 2016*)
- SuperWASP – *Bernhard et al. 2015* …

to derive rotational periods

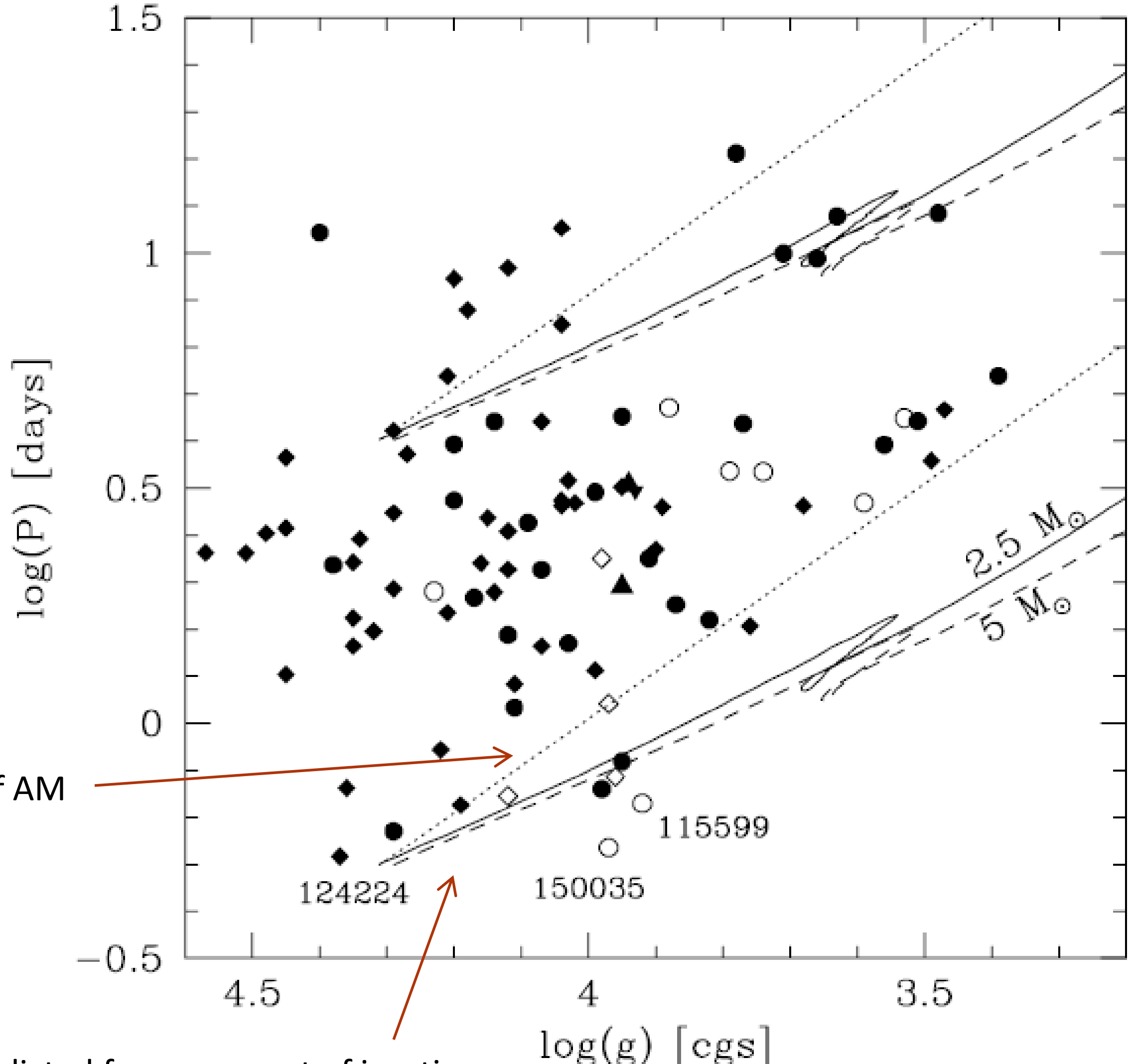
see also talk by *Z. Mikulášek* and poster by *Hümmerich et al.*

Previous studies of rotational properties

North (1998) made use of Hipparcos data to place mCP stars in the HRD (about 60 objects)

conclusion: compatible with conservation of angular momentum (AM)

later, also concluded e.g. by *Kochukhov & Bagnulo (2006)*

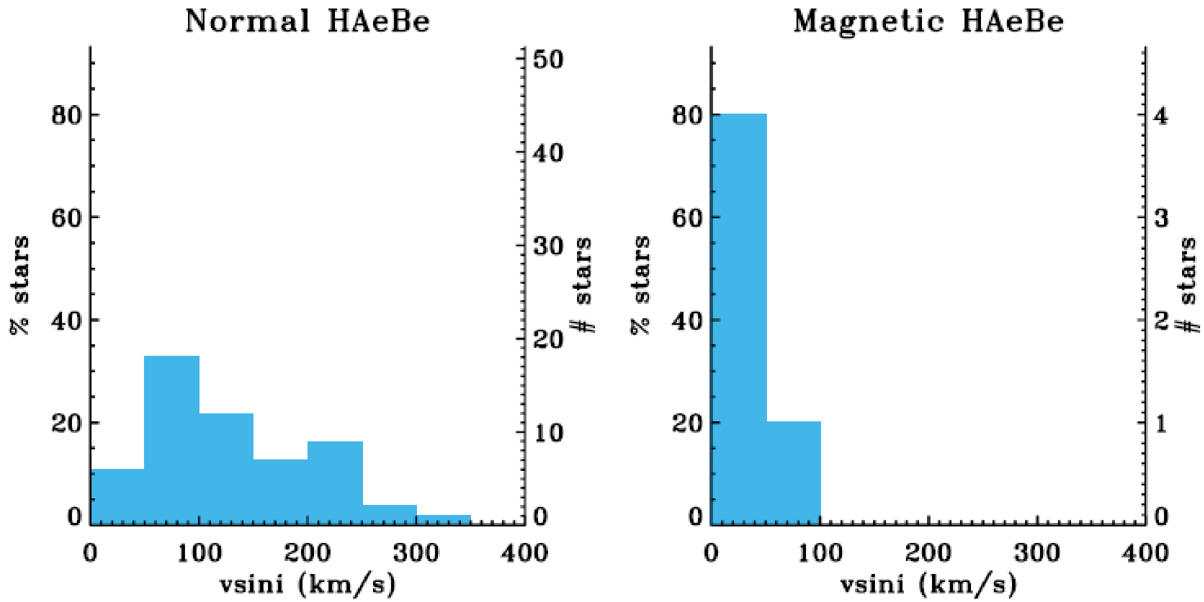


conservation of AM in independent spherical shells

predicted from moment of inertia + rigid body rotation

Previous studies of rotational properties

No evidences for a signicant AM loss on the main sequence. It is thus concluded that mCP stars must lose a large fraction of their AM in the PMS phase of evolution (*Stepien & Landstreet 2002*)

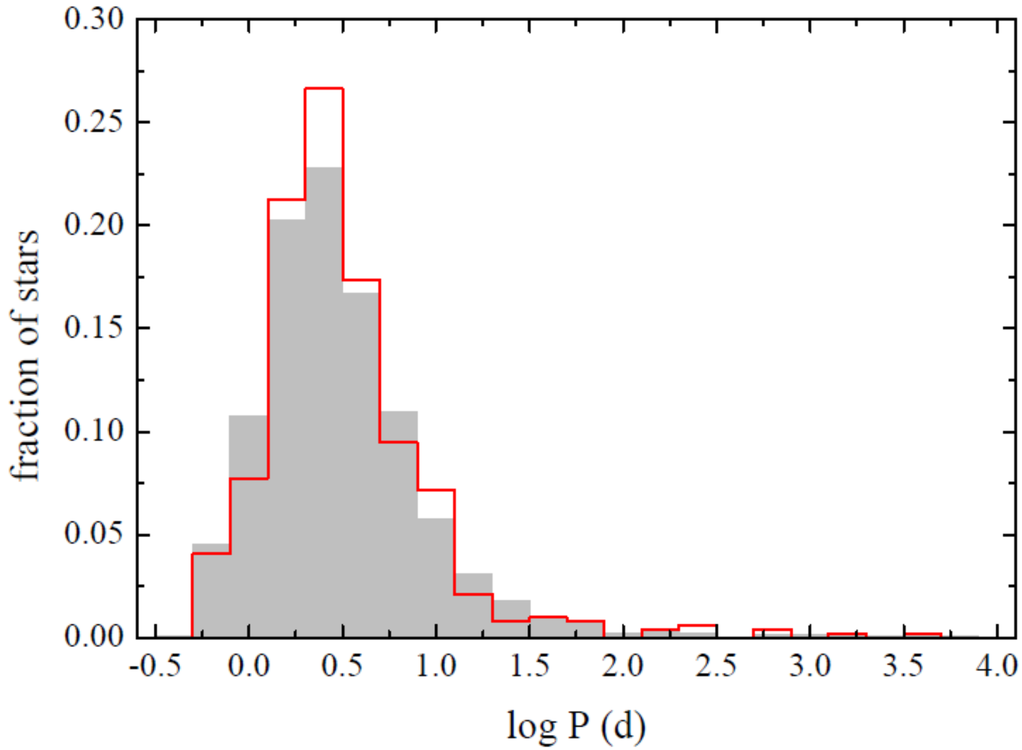


Alecian et al. (2013): magnetic HAeBe more efficiently braked than the normal stars; small sample but confident conclusion

mCP star investigation in the Gaia era

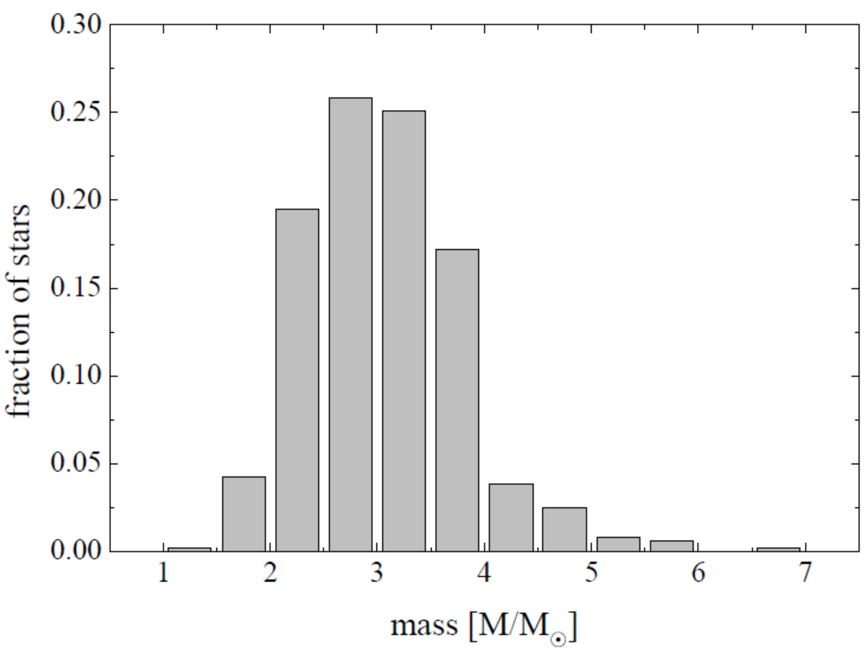
Netopil et al. (2017): compiled periods for ~1300 stars from previous catalogues and recent surveys.

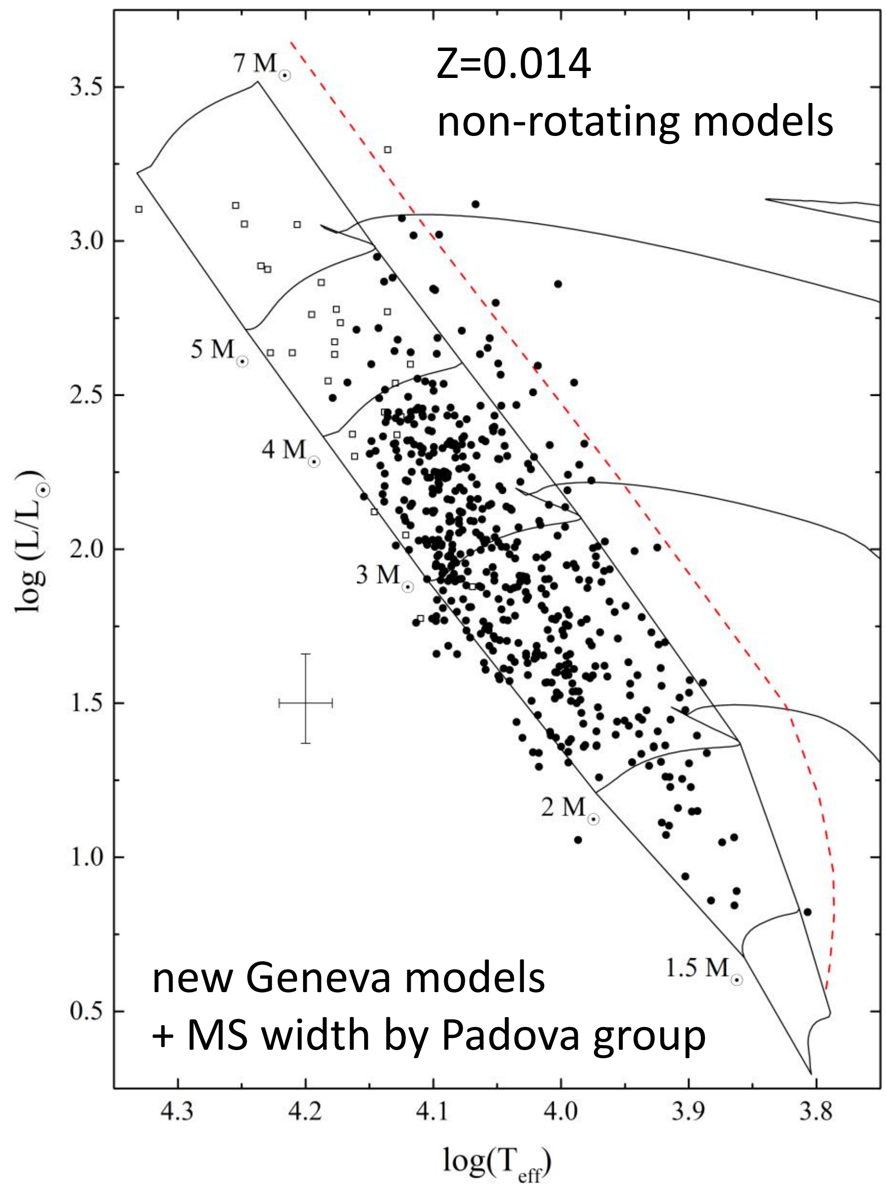
- match with Hipparcos / Gaia
- photometric effective temperatures
- check of CP nature
- final sample: 520 stars



mCP stars in the HRD

- sample excludes known SBs
- some HRD / model issues
- sample size allows smaller bins
- mass distribution similar to previous studies

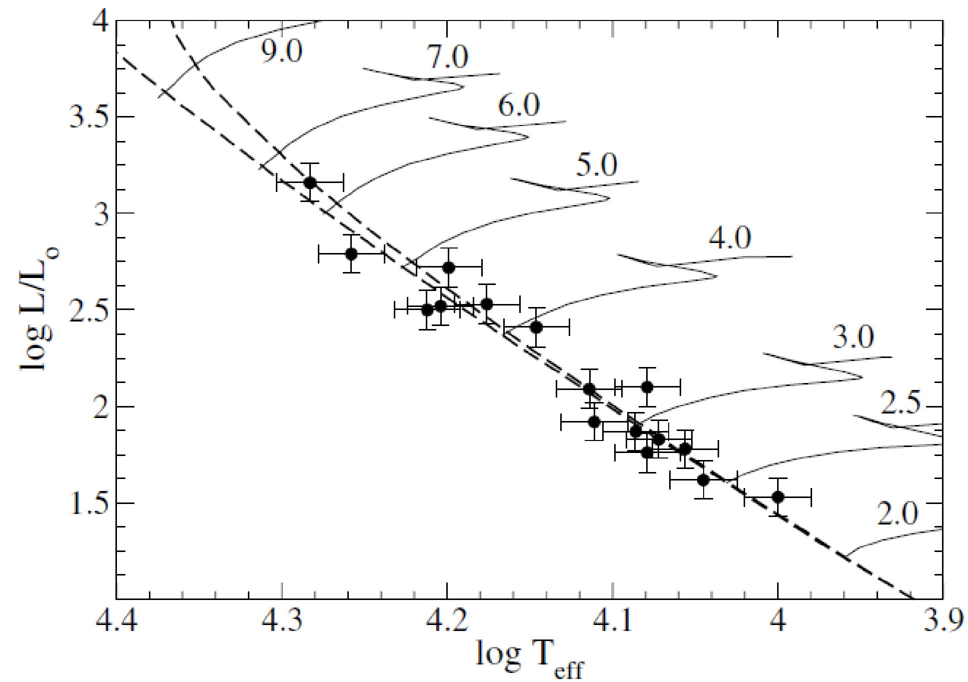




mCP stars in the HRD

apart from model to model differences:

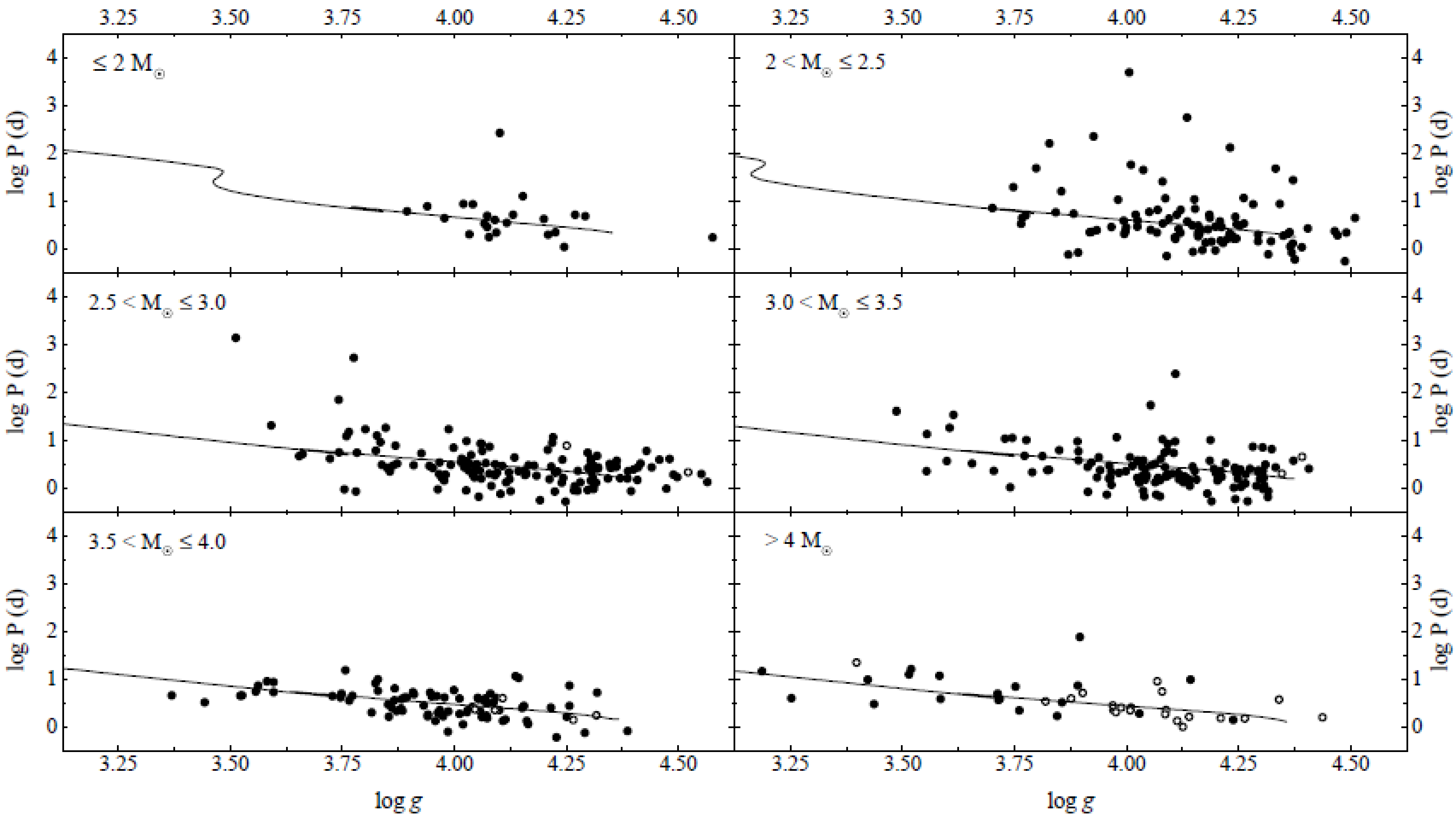
- evolutionary models for Z=0.014 (current solar metallicity) appropriate for mCP stars?
- use of Z=0.020 will place a larger fraction of our programme stars below the ZAMS
- *Nieva & Przybilla (2014)* find reasonable agreement for ‚normal‘ single early B-type stars using Z=0.014
- T_{eff} calibration issues?



appropriate models with the inclusion of magnetic field will be the next important step, though will include another free parameter …

Landstreet et al. (2007): some mCP members in associations, use of Z=0.02 (previous Padova models)

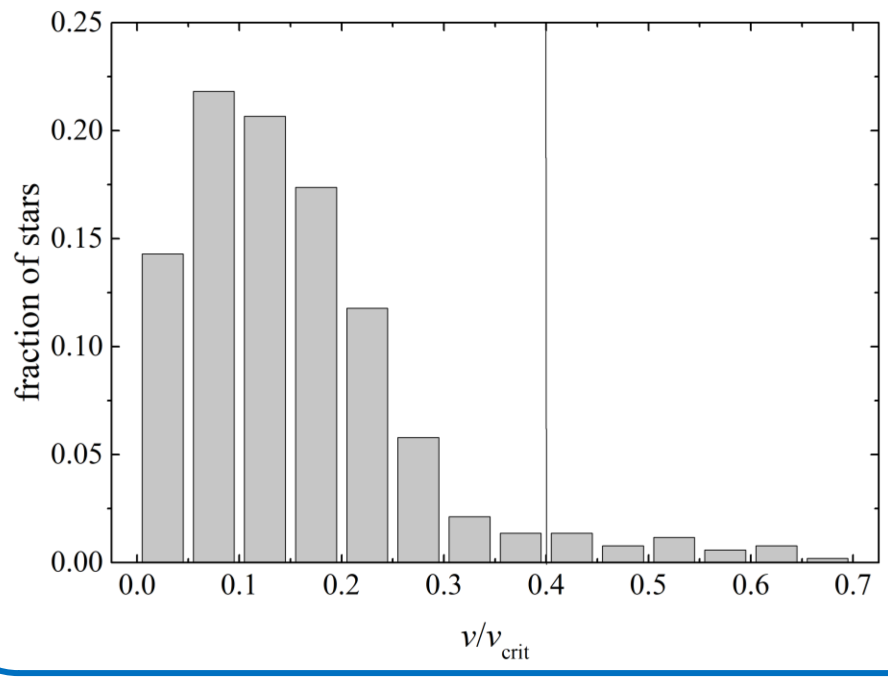
Evolution of rotational periods

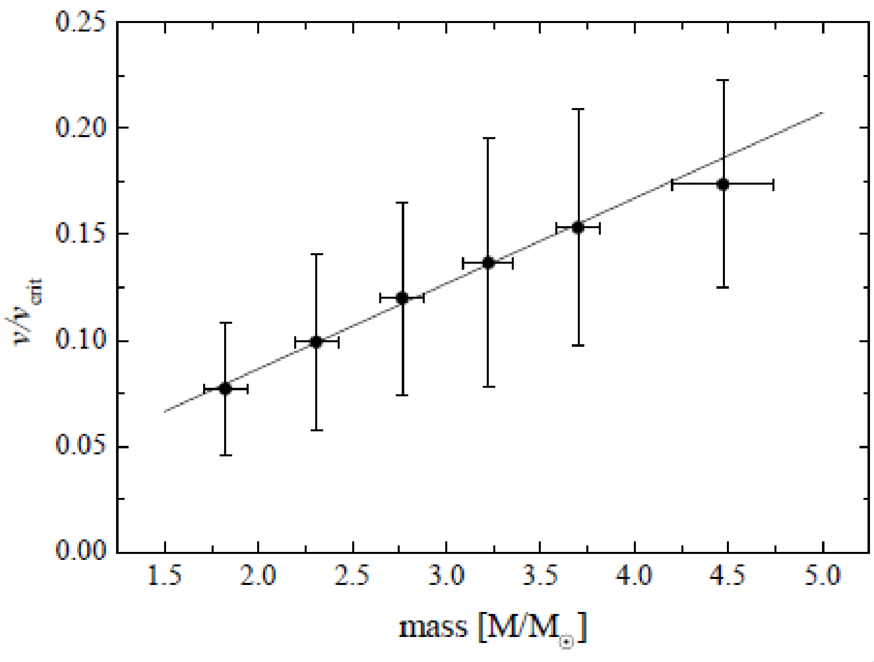


Comparison of observations with rotation models by Georgy et al. (2013).
The new large sample also shows compatibility with conservation of angular momentum.

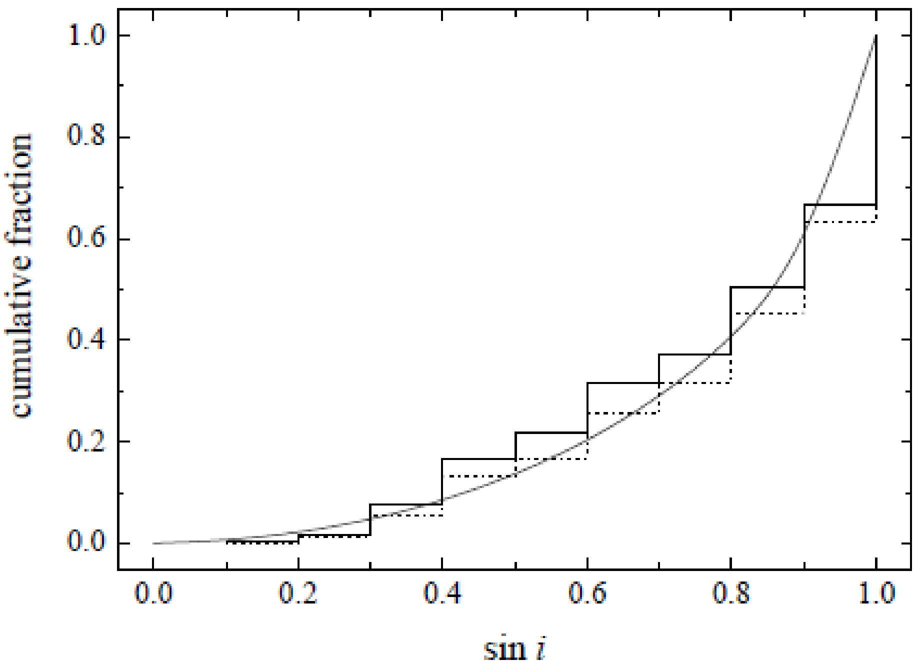
Evolution of rotational periods

- investigation using velocity ratio v/v_{crit}
  - little dependence on evolutionary effects (e.g. *Zorec & Royer 2012*)
- mCP stars few times slower rotating than normal stars
  (also noted already by e.g. *Preston 1970*)
- tail of fast rotators, proper periods?
- clear mass/velocity dependence, but large scatter – influence by magnetic field strength?





Inclination of rotational axes



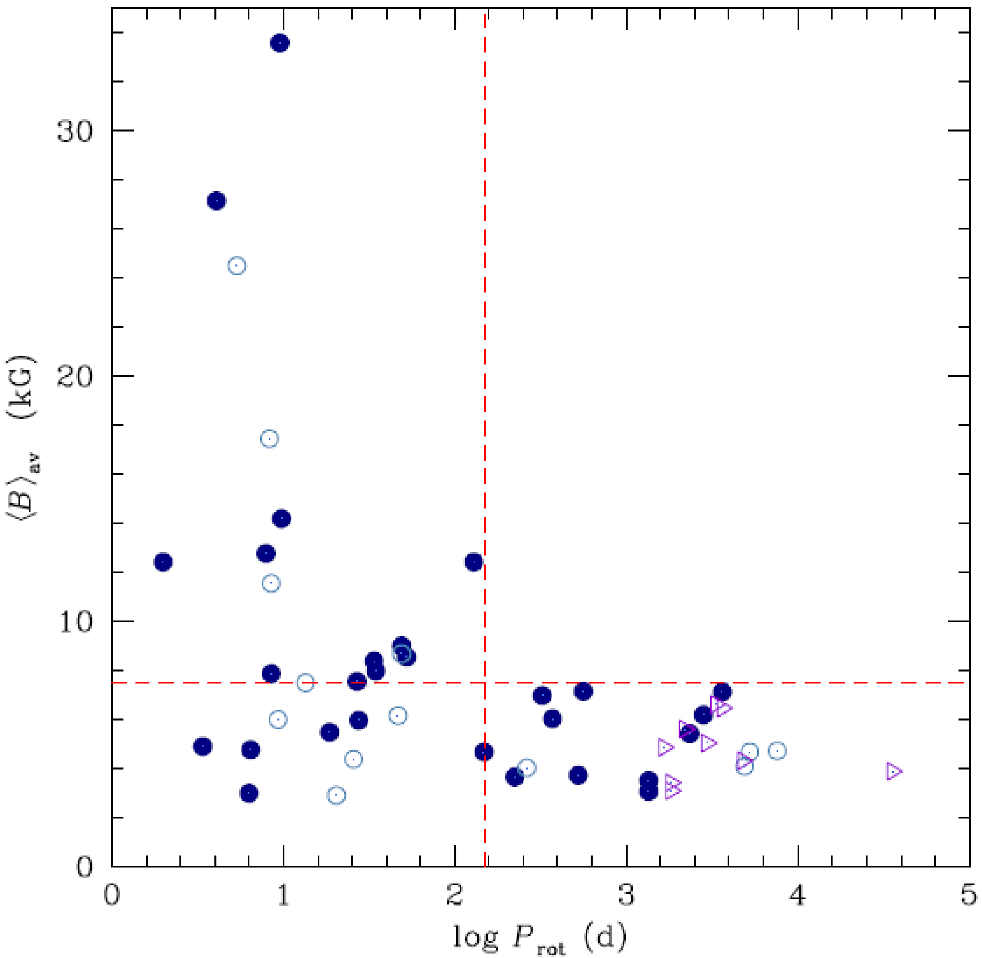
*v*sin*i* measurements available for ~180 stars
=> allows to retrace the distribution of rotational axes

rotational axes randomly distributed as expected; confirms previous conclusions, such as *Abt (2001)*

Though, excess around sin*i* ~ 0.4 – 0.7 noticeable; probably caused by the fast rotator tail (> 0.35 v/v_{crit})

So far, confirmation of mCP star properties we already know for long (mass distribution, conservation of AM, inclination angles, …)

Magnetic field vs. rotation



Mathys (2017) increased the sample of stars with a measured mean magnetic field modulus.

Magnetically resolved lines are observable at about ≥ 2.7kG.

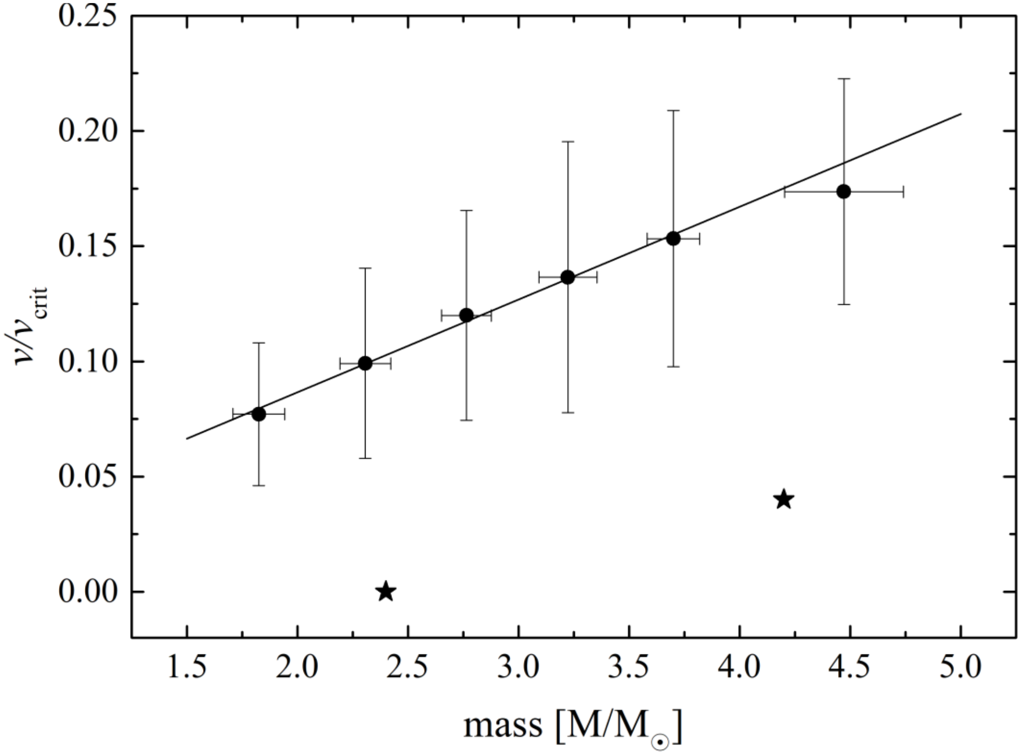
Obviously, the strongest magnetic stars are not the slowest rotators.

- Babcock‘s star and few others: atypical representatives?
- Representation misleading?
- Mass and evolutionary effects?

Magnetic field vs. rotation

	HD 110066	HD 215441
Period	4900 d	9.5 d
$\langle B \rangle_{av}$	4.1 kG	33.6 kG
$M/M_\odot$	2.4 ± 0.1	4.2 ± 0.3
R/R_Z	1.5 ± 0.2	1.3 ± 0.3
υ/υ_{crit}	0.00 ± 0.00	0.04 ± 0.01

Comparison of parameters for the strongest magnetic star and the slowest rotating one in our sample.



Magnetic field vs. rotation

Mass and evolutionary effects on rotation?

- already shown in previous slides

Evolution of magnetic field strength?

- conservation of magnetic flux a reasonable assumption

Thus, a comparison of different stars requires some ‚normalization'

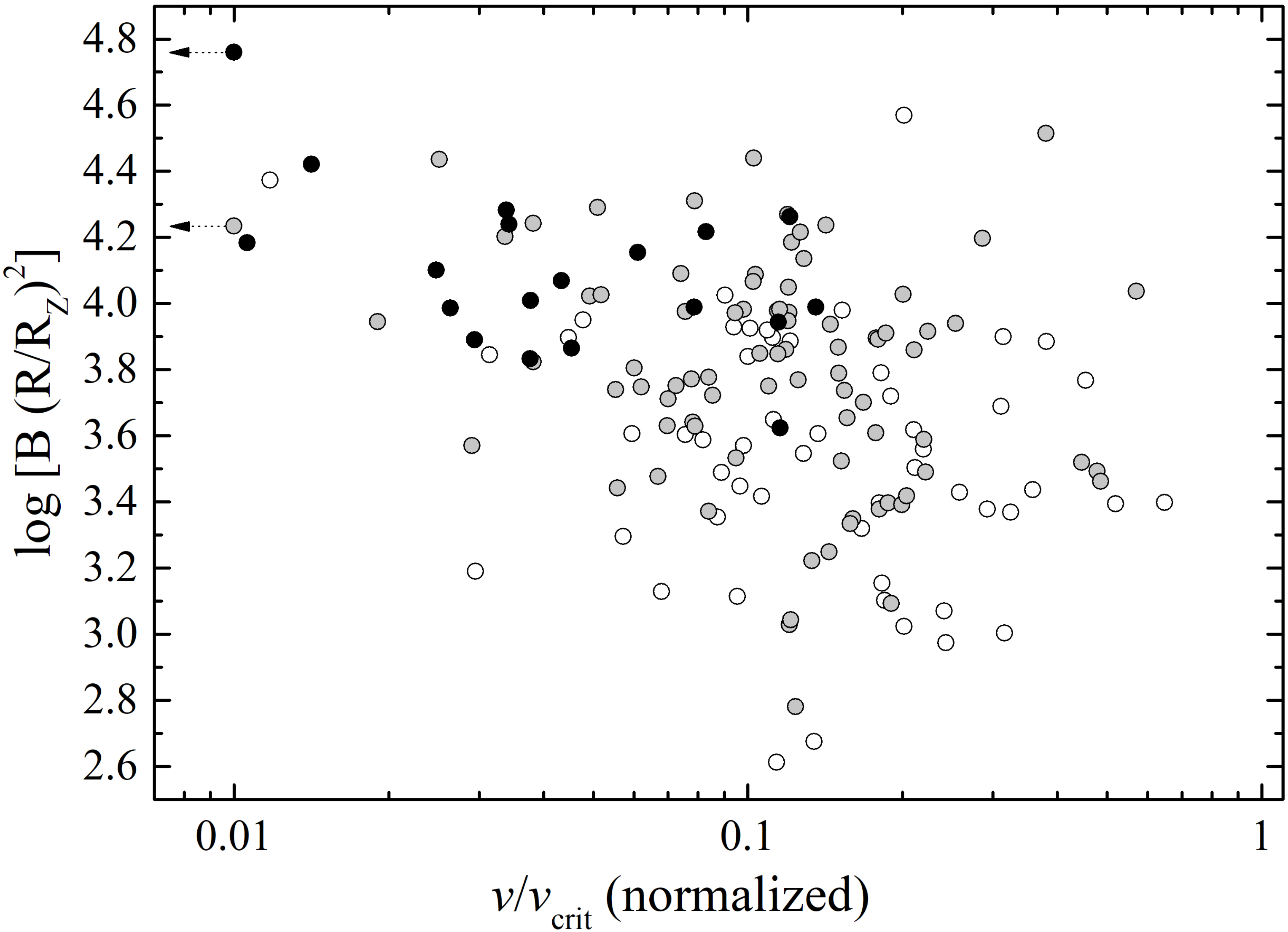
- *mass/rotation: linear relation, rotation rate normalised to e.g.* $3M_{\odot}$
- *magnetic field strength:* $B\,(R/R_Z)^2$

measurements of magnetic field strength:

- mean magnetic field modulus (most reliable actual field strength)
- phase covered longitudinal field measurements
- B_{rms} of longitudinal field measurements (least reliable)

➢ compiling such data for our programme stars

Magnetic field vs. rotation



Magnetic field vs. rotation

limitations of the current sample:

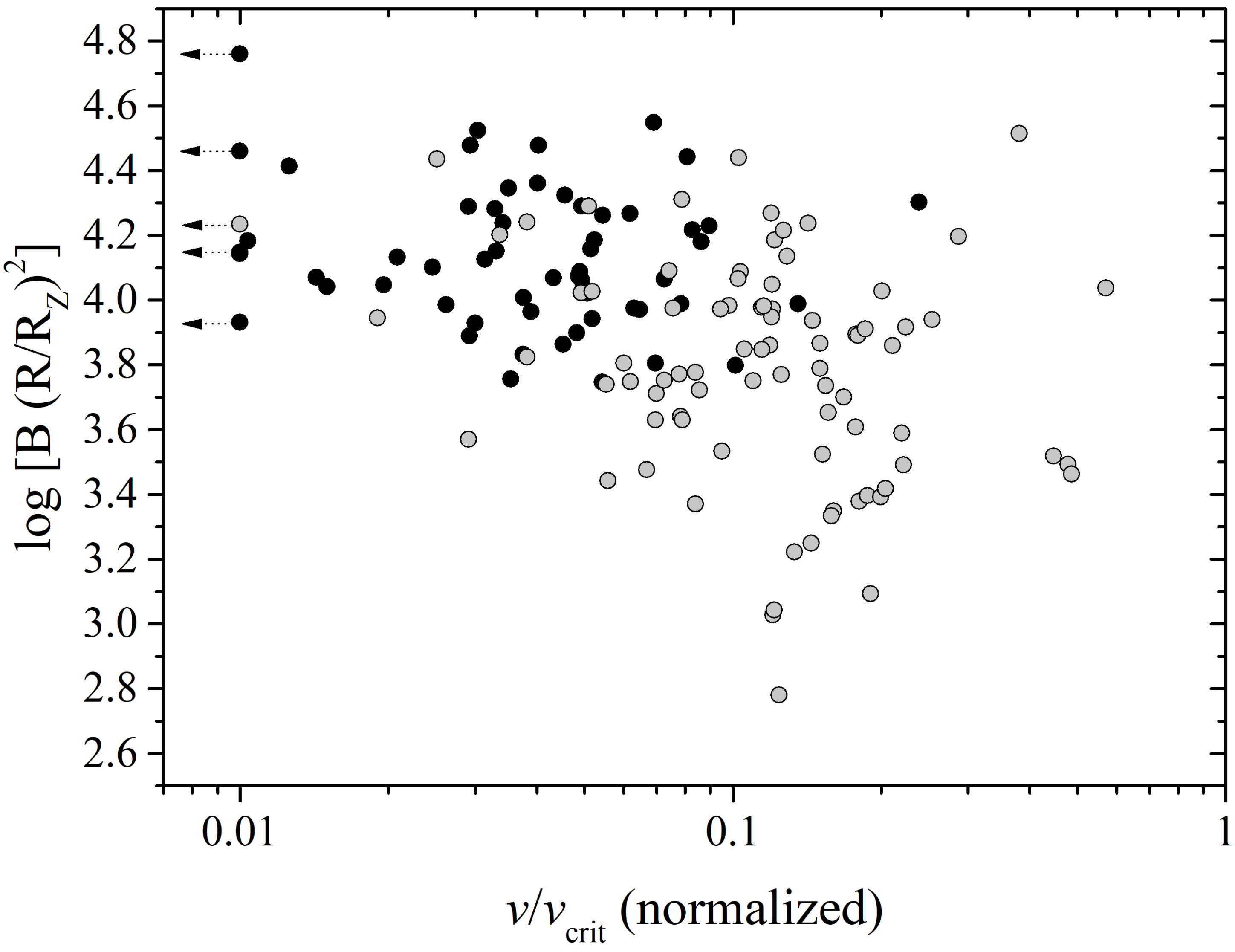
- excludes SBs
- probably somewhat biased towards shorter periods
- most known longer period estimates did not make it into used catalogues

➢ in particular sample by *Mathys (2017)* little covered

reinvestigation in preparation, starting with the list by Mathys and an updated catalogue of magnetic phase curves by *Bychkov et al.*

Magnetic field vs. rotation

about 2/3 of list by Mathys + previous magnetic phase curve results



Magnetic field vs. rotation

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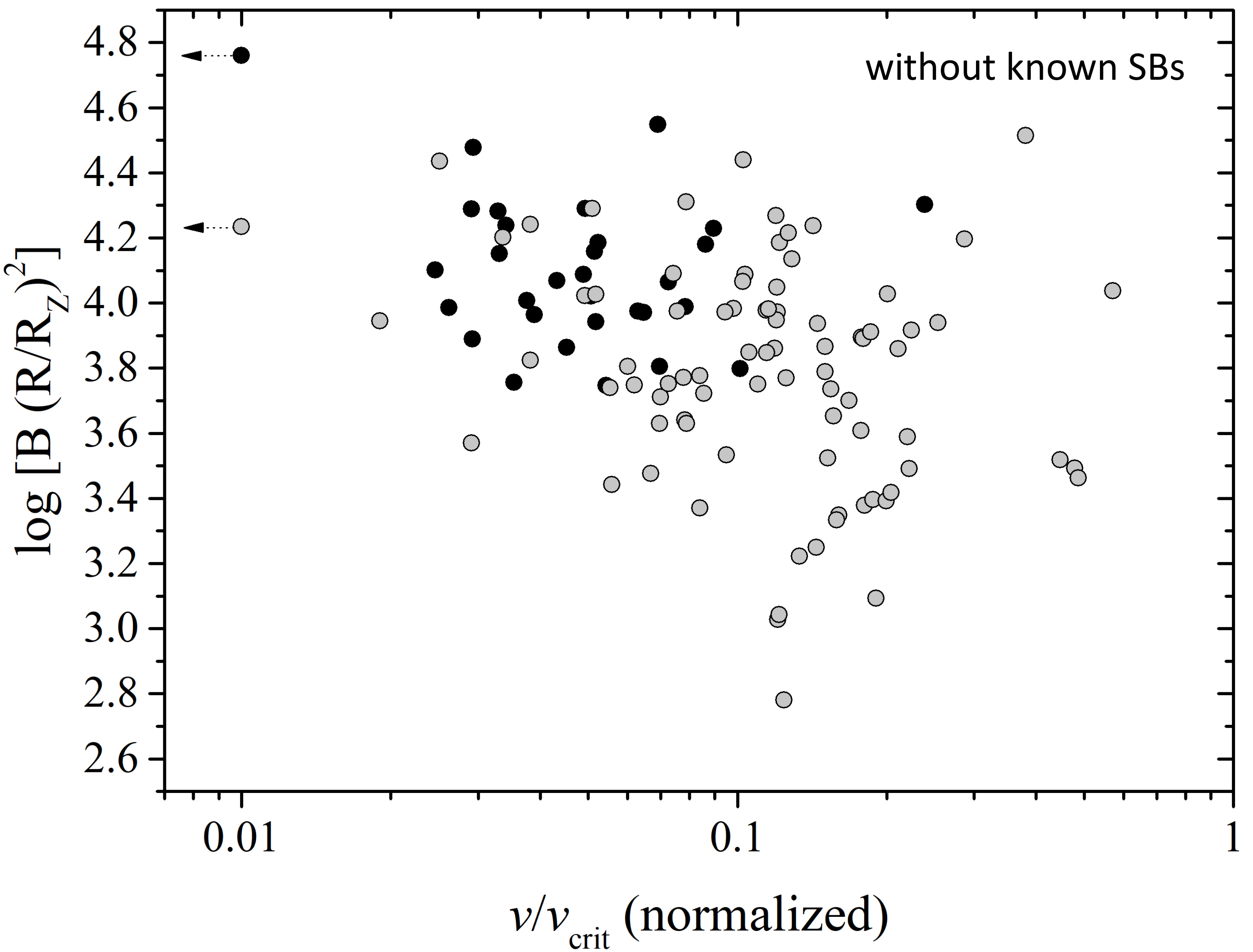

Conclusions 1

‚easy‘ ones:

- mCP stars follow conservation of magnetic flux; good agreement with models
- inclination angles randomly distributed
- we have derived the relation between mass and rotation

the difficult one:

relation between magnetic field strength and rotation

- after normalization, the strongest magnetic stars also the slowest rotating ones
- Babcock‘s star not atypical (at least in this respect)
- but SBs clearly alter the conclusion

Conclusions 2

limitations:

- the use of available evolutionary models (metallicity …)
- better knowledge of SB nature needed
- reliability of period values (e.g. fast rotator tail)
- period aliasing certainly still present
- very long periods difficult to detect
- alignment of rotation and magnetic axes not considered yet

2007, Vienna

2017, Brno