SE4 in the GCDS
&
Variable stars and metallicity

N. Mowlavi, L. Eyer, S. Ekstrom
Geneva Observatory

SE4 within SE1&2 and SE3

- **SE4: chemical tagging for the study of stellar physics**
  Not many proposals for SE4 during the GCDE preparation

- **Within SE1-2:**
  Fraction of targets devoted to SE4 candidates

- **Within SE3:**
  Obvious link with the study of Open Clusters

Metallicity and variable stars

- Stellar variability
  - ➙ physics of stars
  - ➙ evolution of stars

- Populations of variable stars
  - ➙ properties of underlying population

Metallicity and variable stars

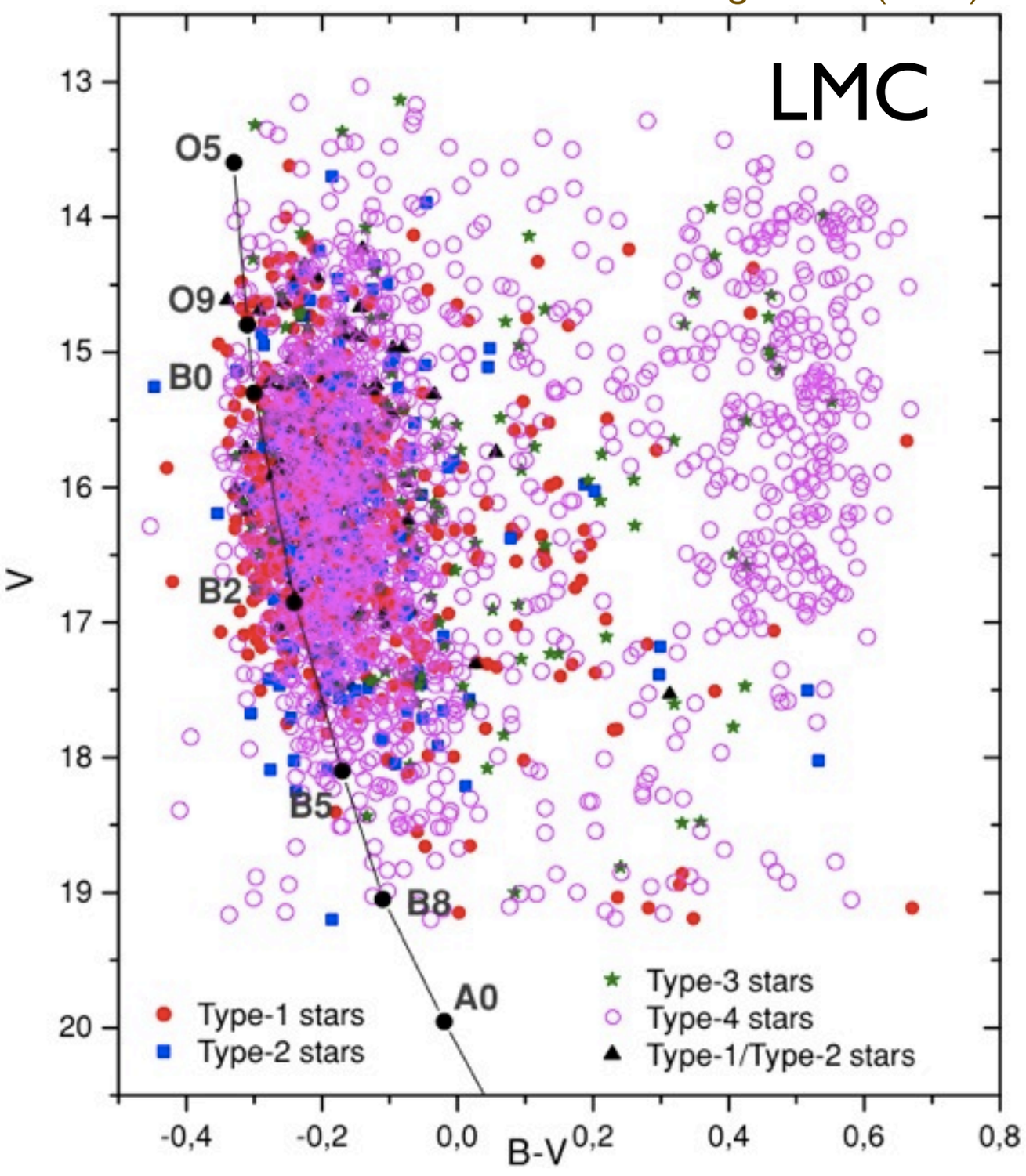
- Stellar variability
  - ➙ physics of stars
  - ➙ evolution of stars

- Populations of variable stars
  - ➙ properties of underlying population

- **Illustrate with a few examples**
  - **Be stars**
  - **Pulsating B stars**
  - **Cepheids**
  - **Active stars**
  - **Long Period Variables**

Be stars

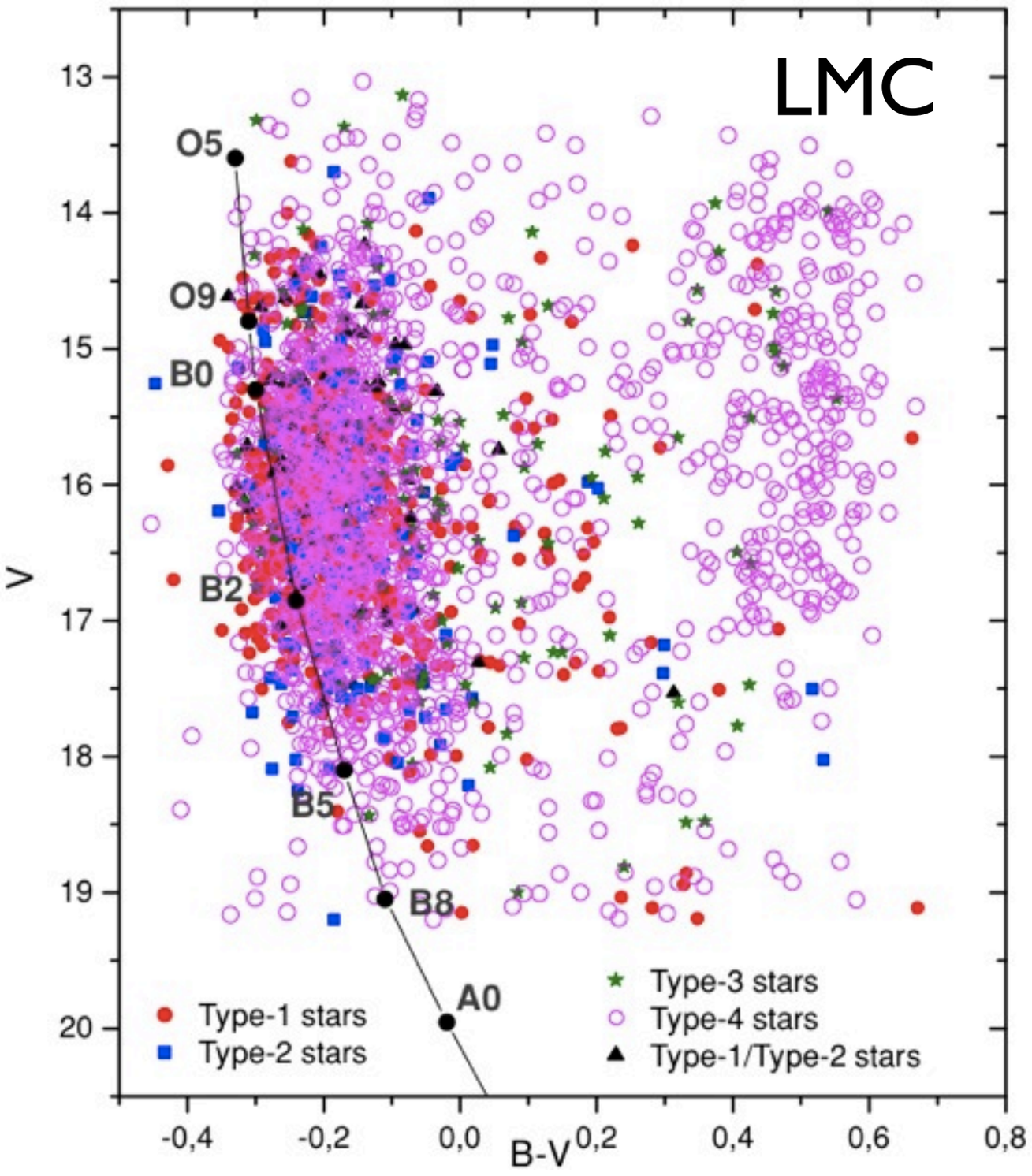
Sabogal et al. (2005)



Are **B stars** that show (or have shown at some point in the past) **emission lines**

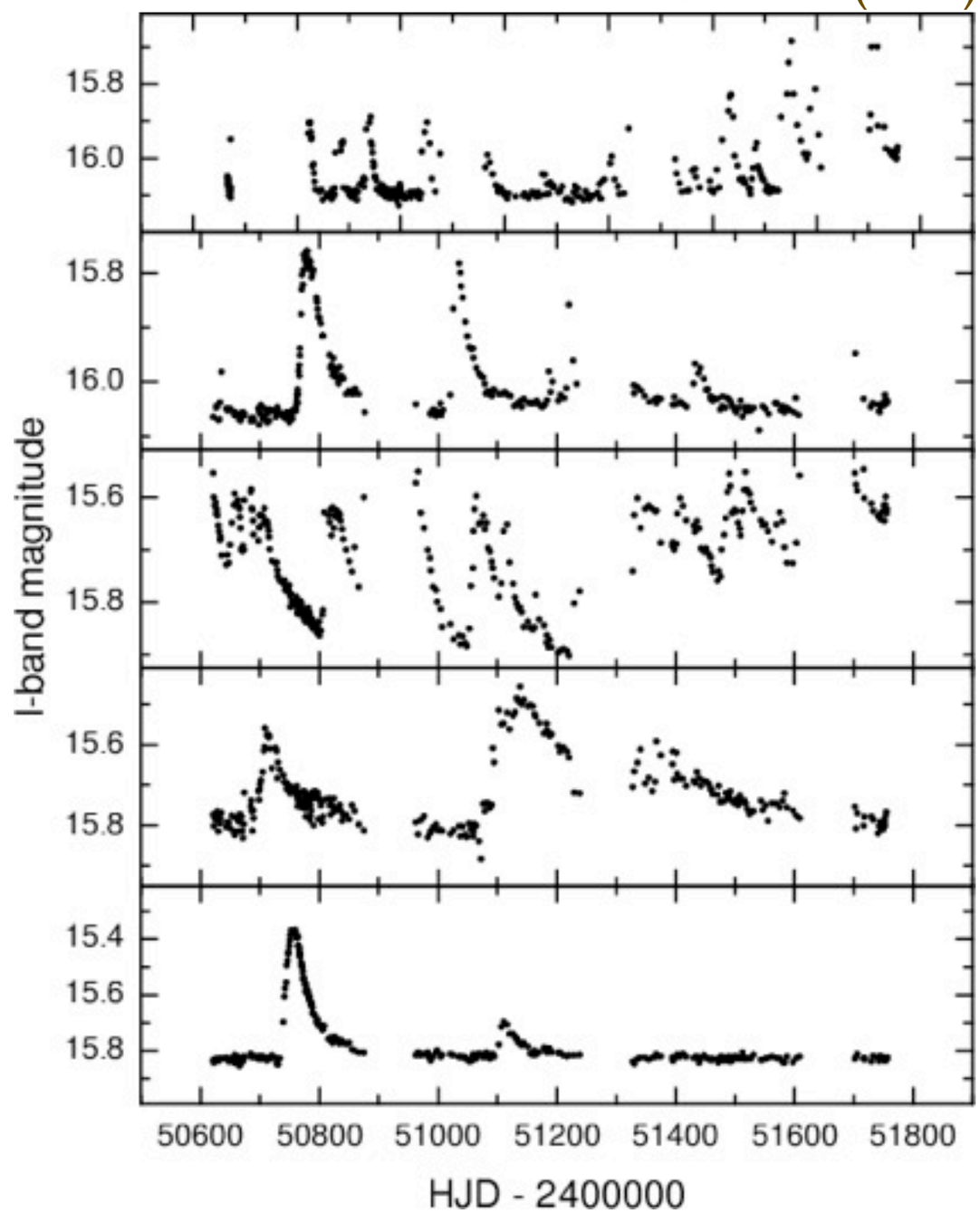
Be stars: light curves

Sabogal et al. (2005)



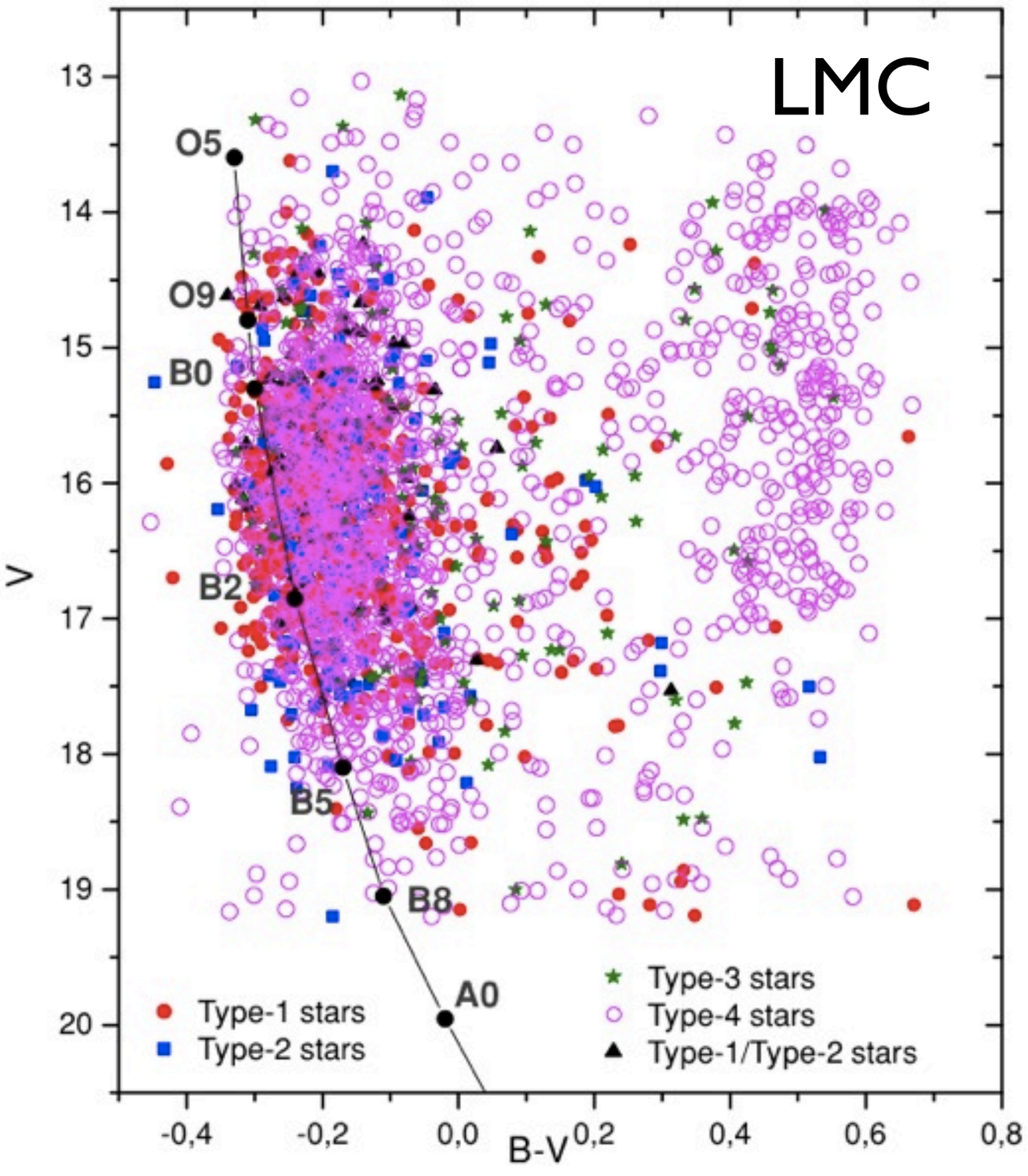
Type I: sharp outbursts

Mennickent et al. (2002)



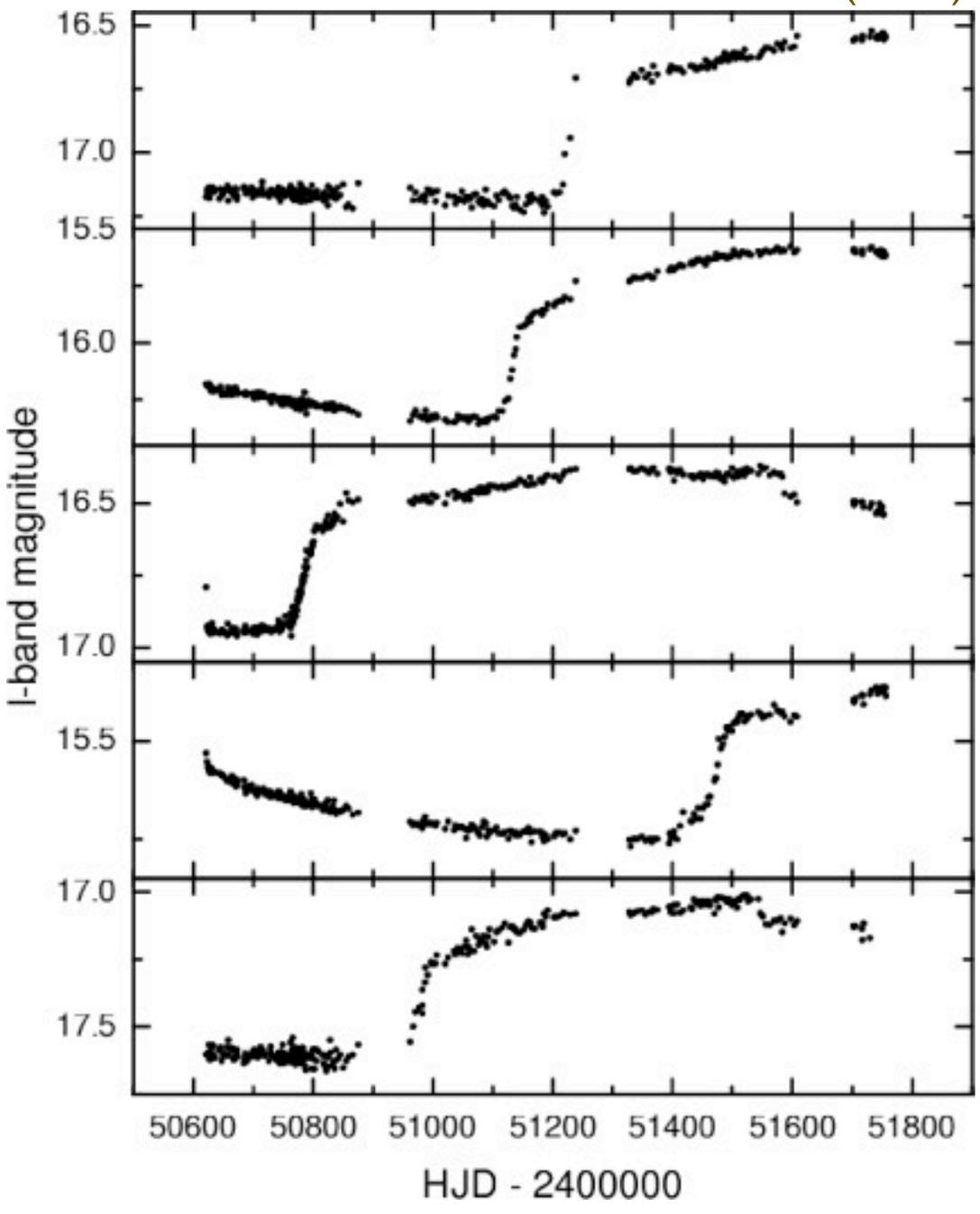
Be stars: light curves

Sabogal et al. (2005)



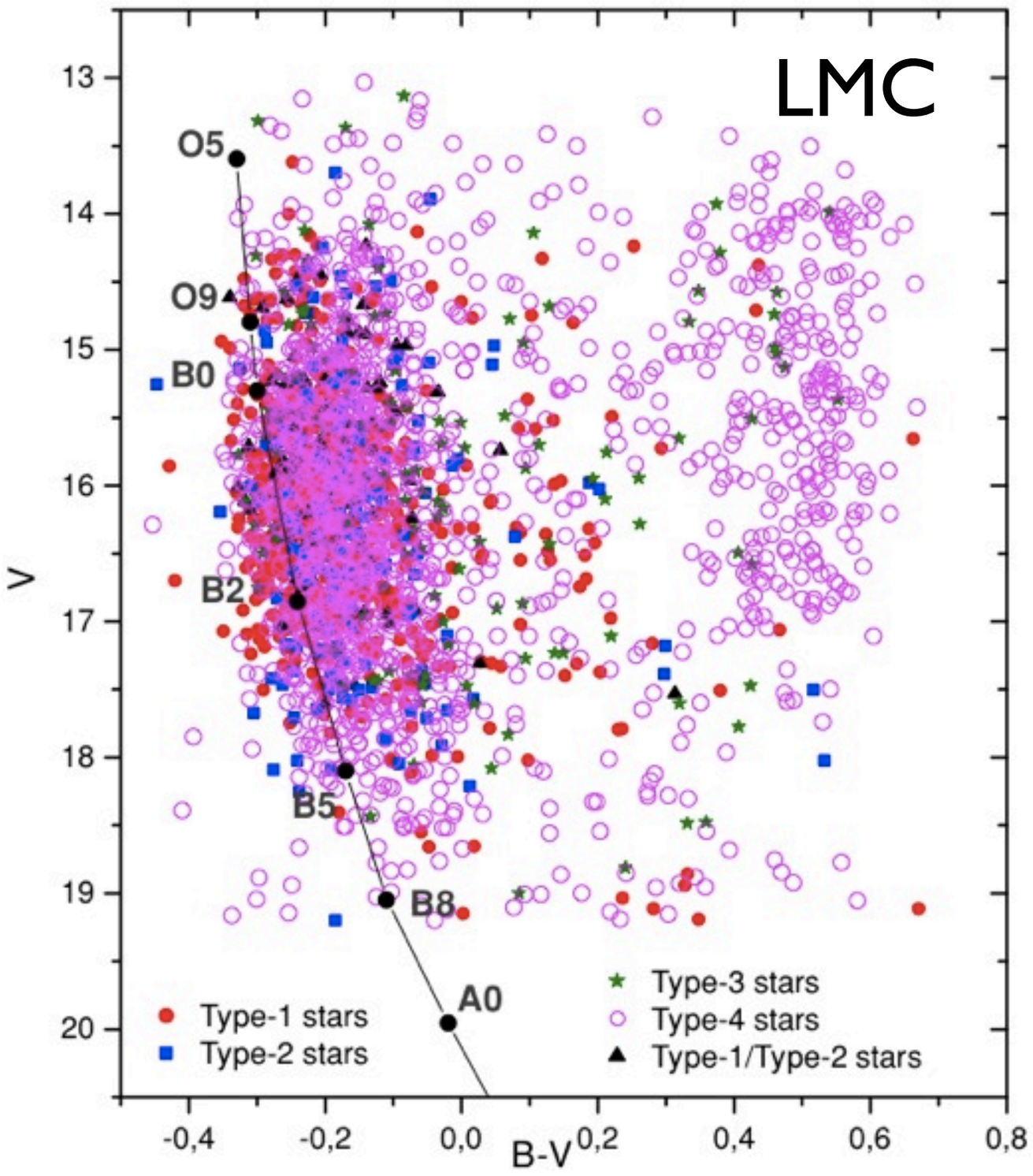
Type II: high and low states

Mennickent et al. (2002)



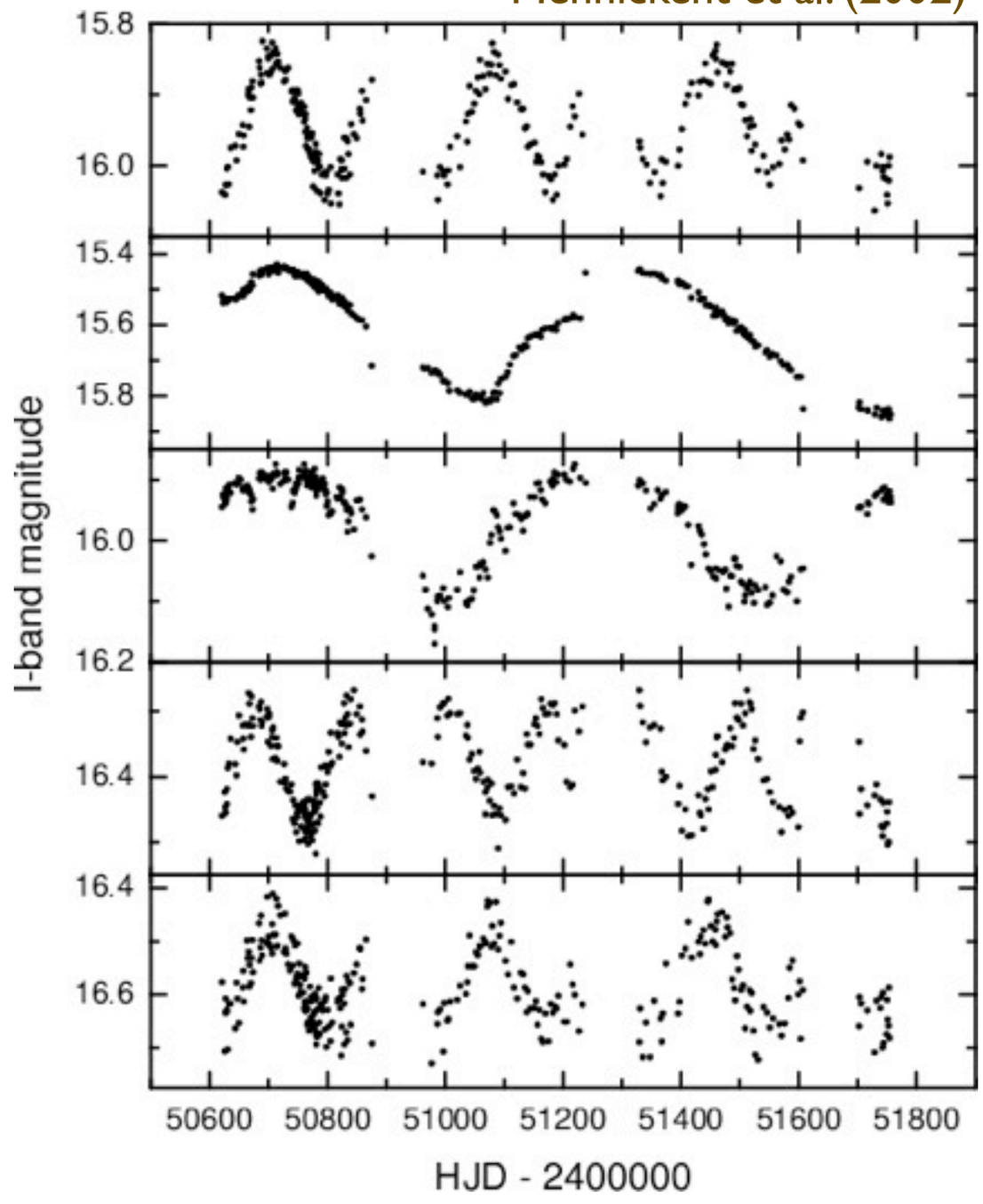
Be stars: light curves

Sabogal et al. (2005)



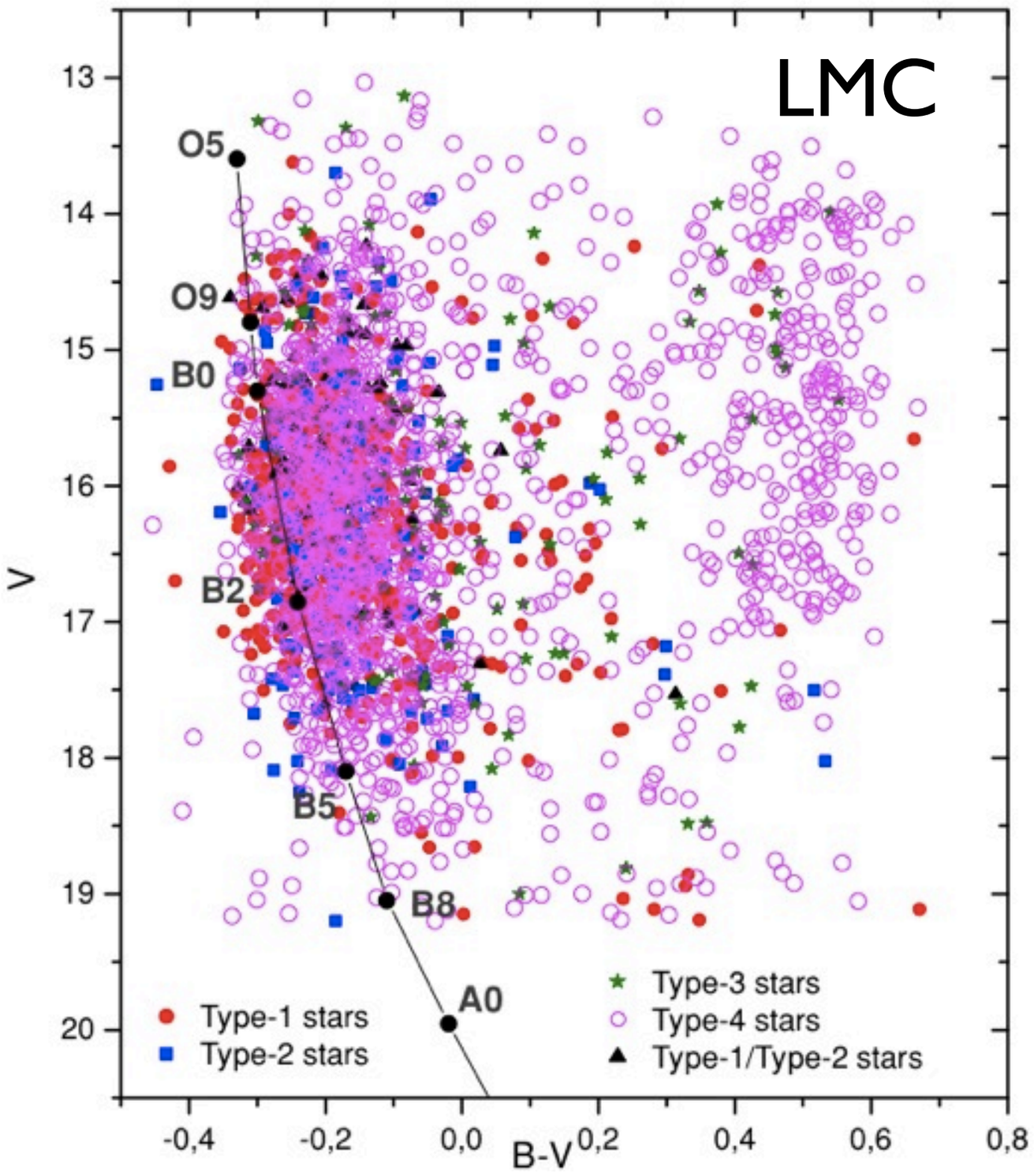
Type III: periodic oscillations

Mennickent et al. (2002)



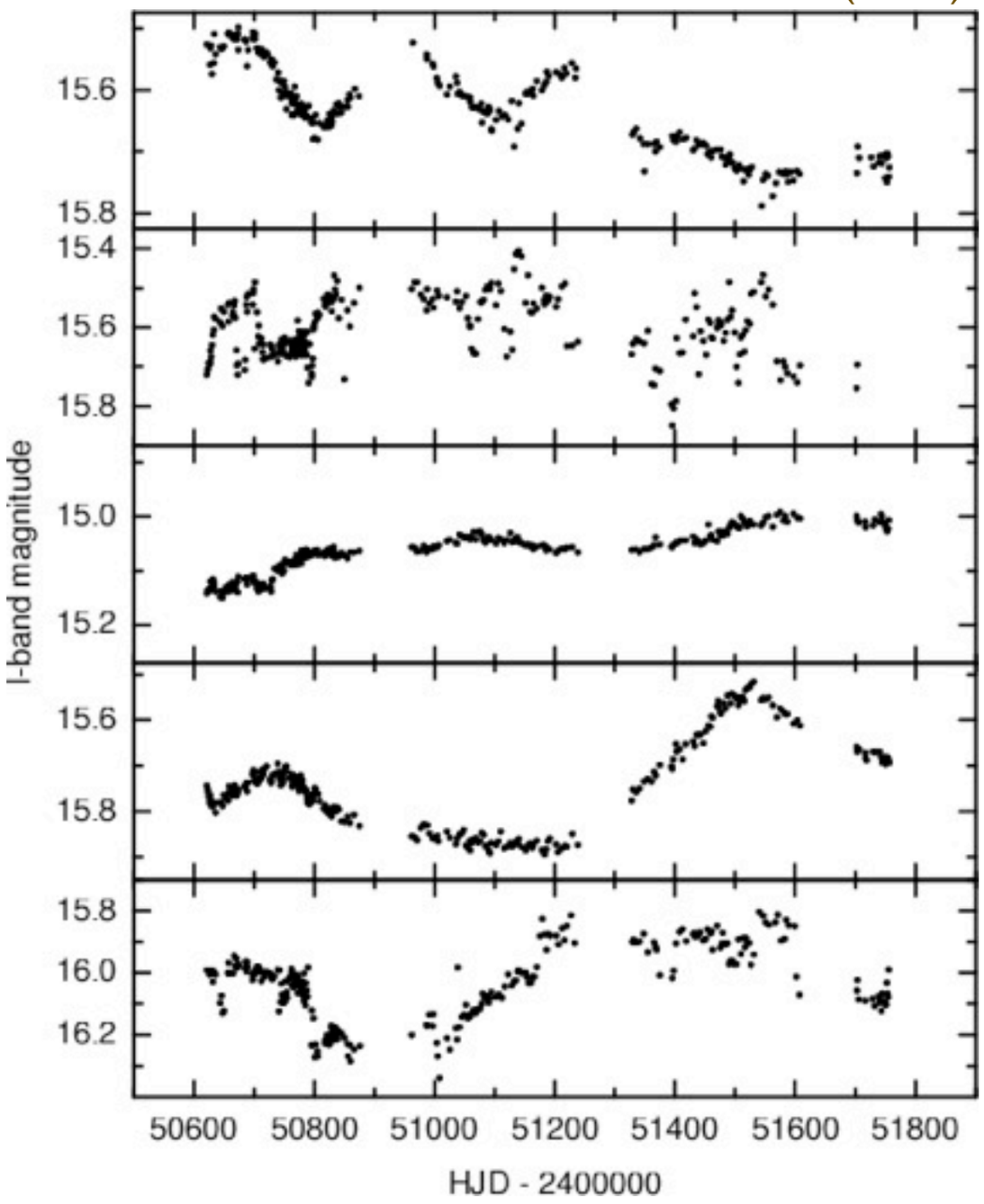
Be stars: light curves

Sabogal et al. (2005)



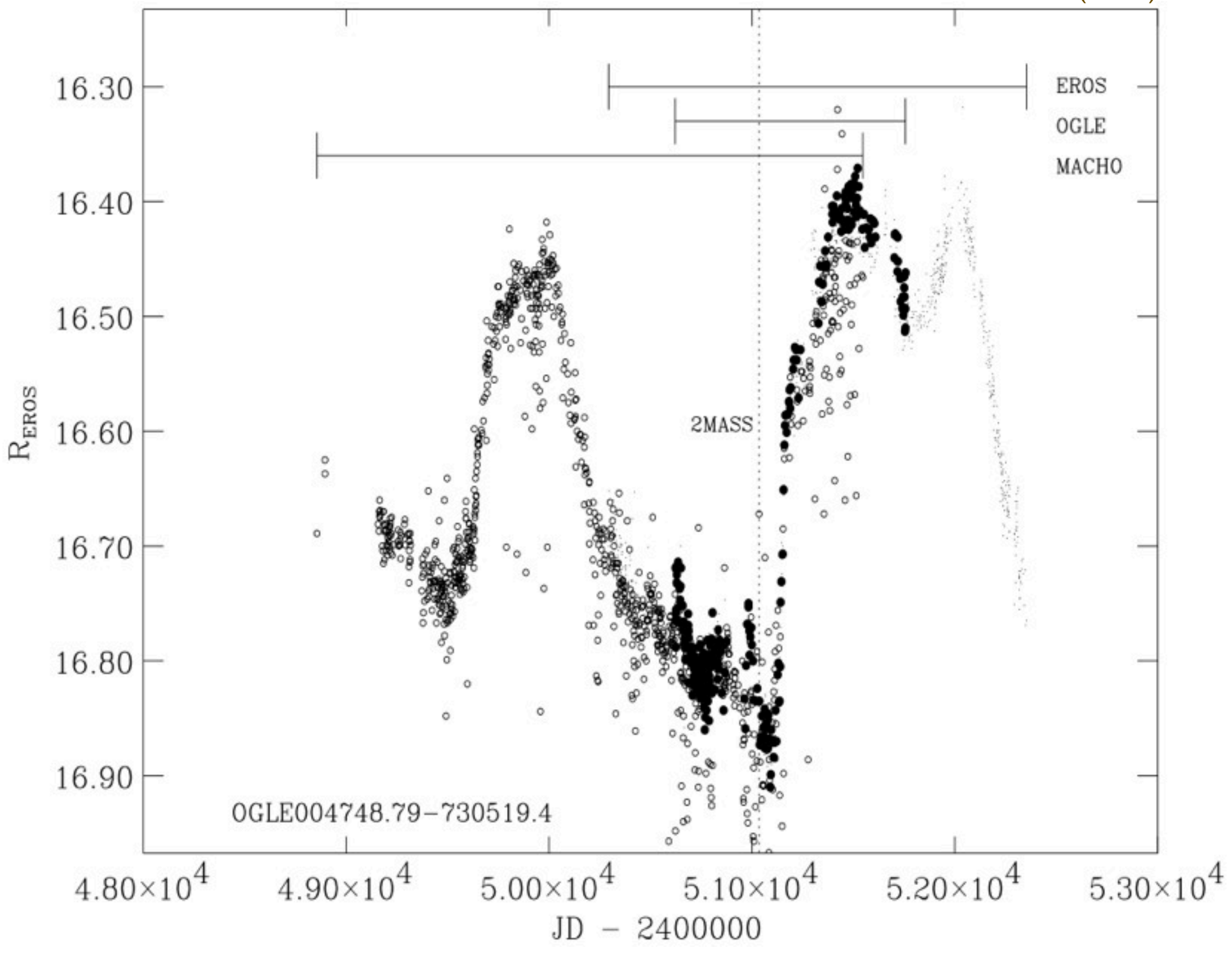
Type IV: random variability

Mennickent et al. (2002)



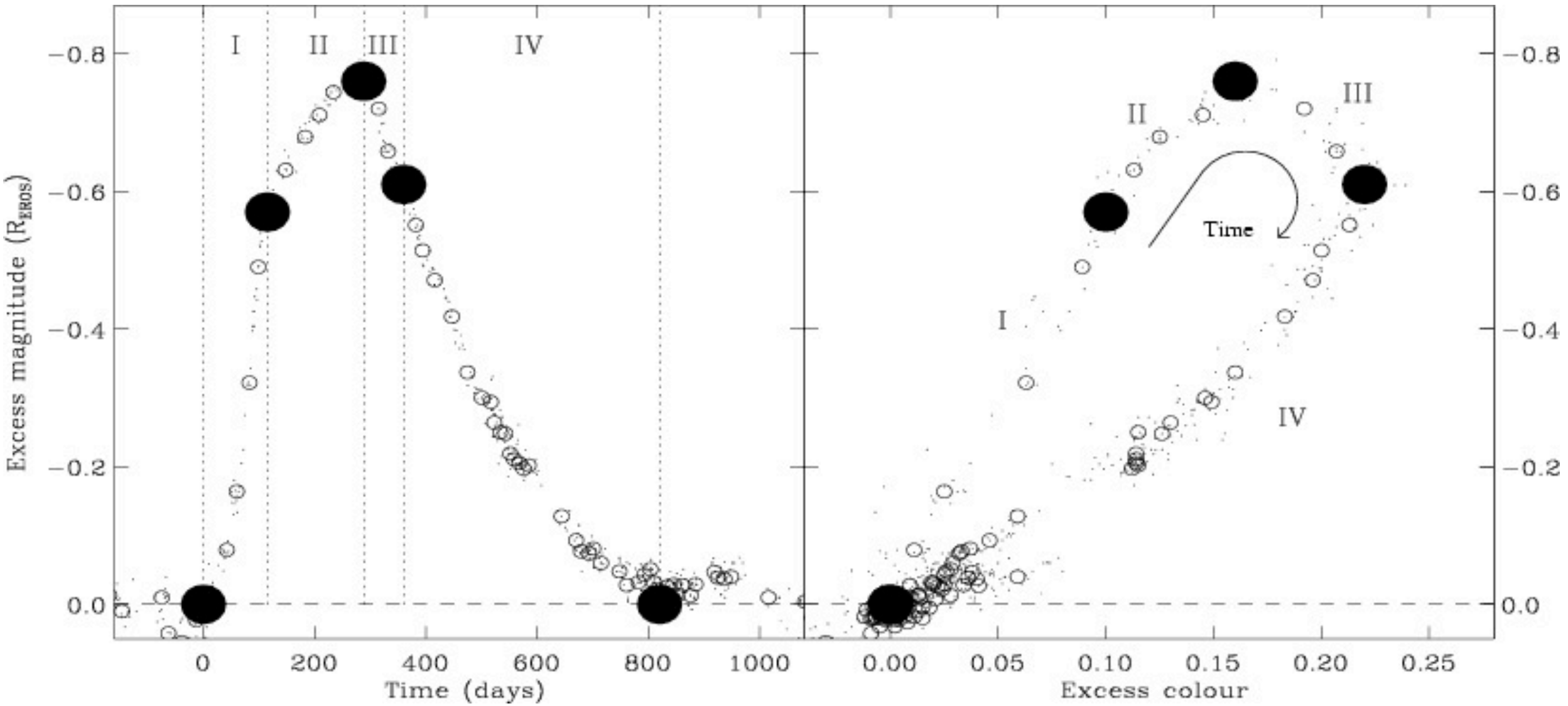
Be stars: star-disk interactions

de Wit et al. (2006)



Be stars: star-disk interactions

de Wit et al. (2006)



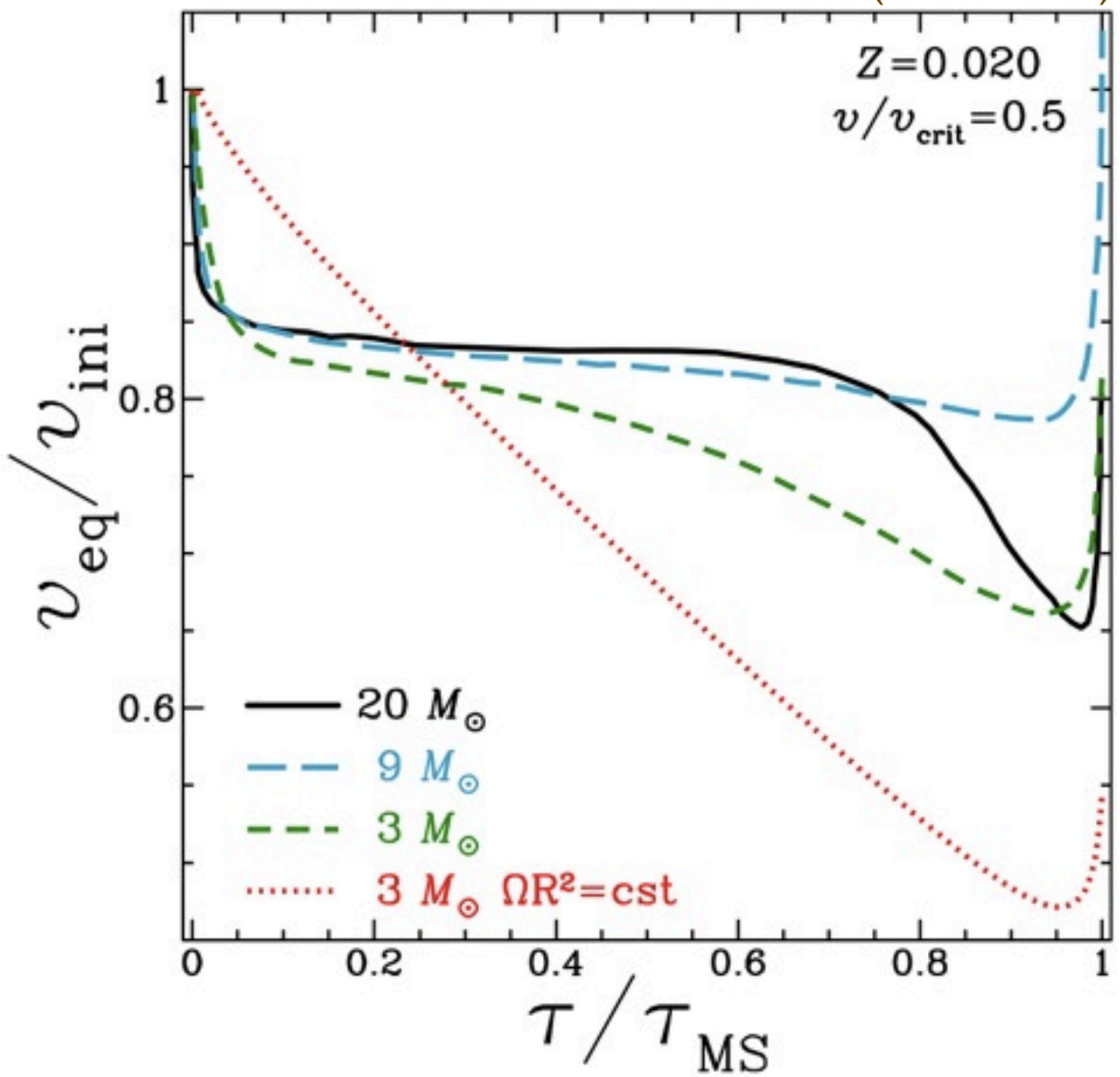
Disk contribution

$$\tau > 1: \quad \frac{F_\lambda}{2\pi R_*^2} = \frac{c_1 T_0 \lambda^{-4}}{-q+2}\left\{x_{\tau=1}^{-q+2} - x_{\text{in}}^{-q+2}\right\}$$

$$\tau < 1: \quad \frac{F_\lambda}{2\pi R_*^2} = \frac{\epsilon_0 h_0 \lambda^{-2}}{0.5q-2p-m-1}\left\{x_{\text{out}}^{0.5q-2p-m-1} - x_{\tau=1}^{0.5q-2p-m-1}\right\}$$

Be stars: stellar model predictions

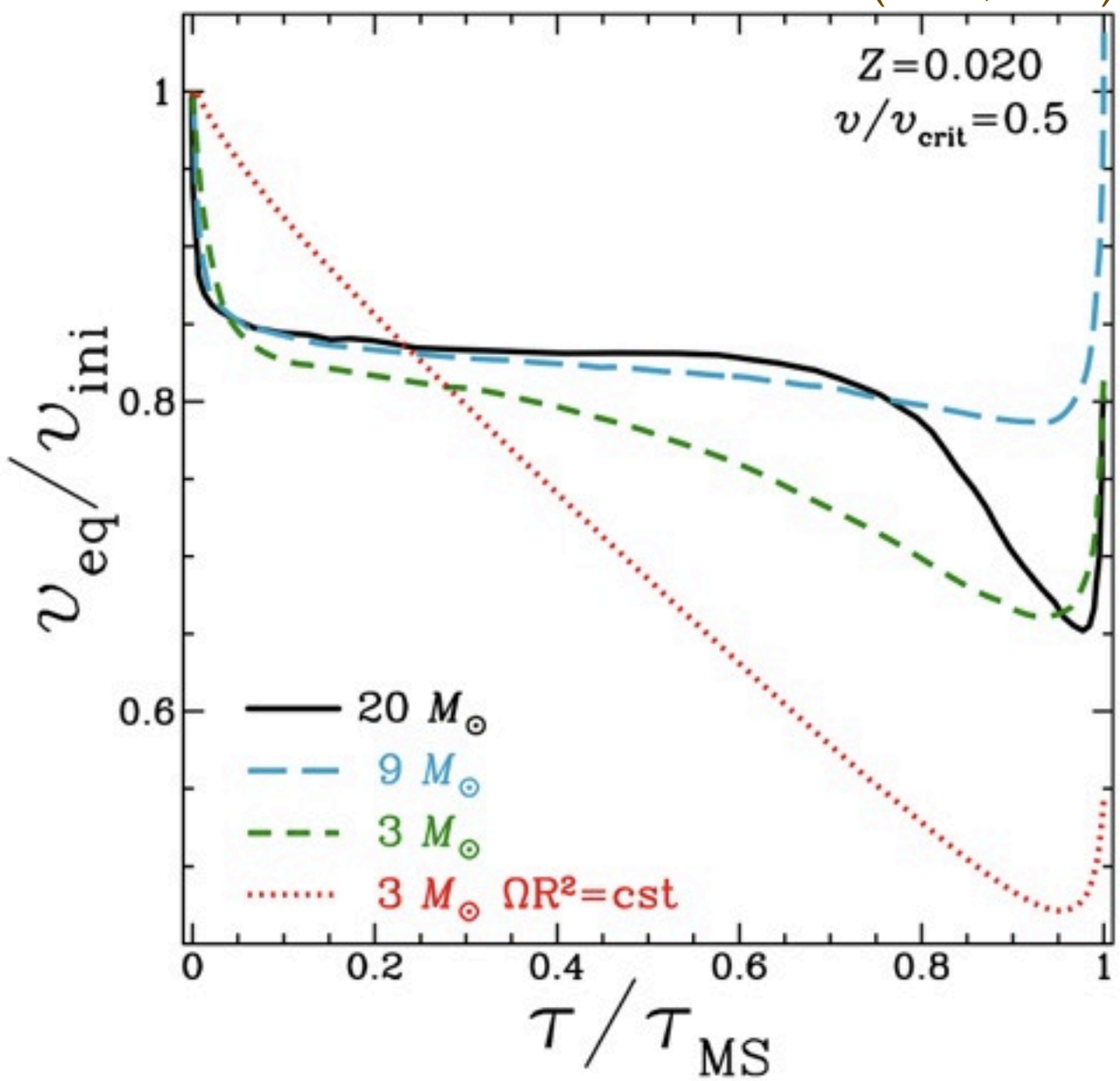
Ekstrom et al. (2008, 2010)



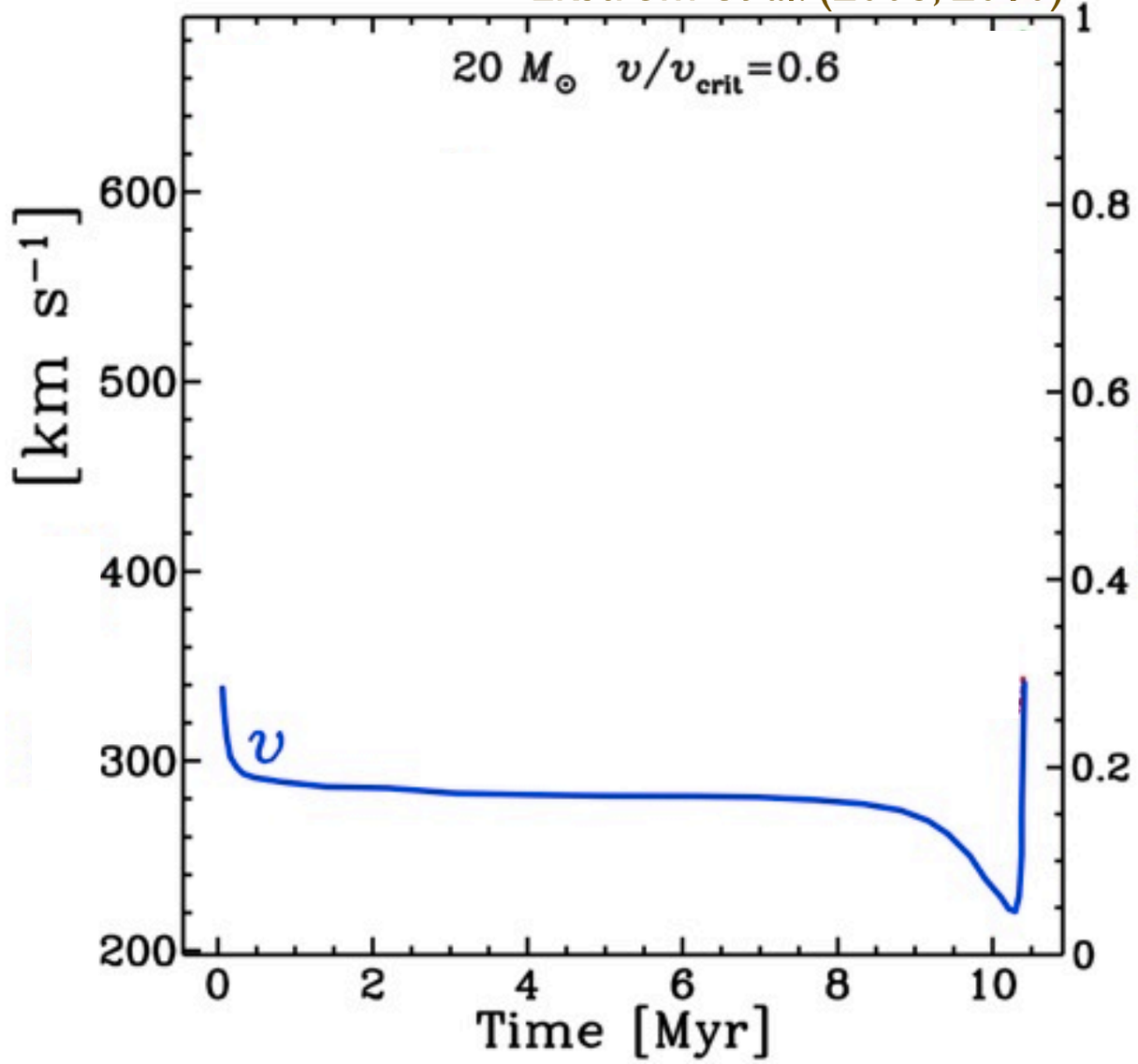
- **Mass loss** removes angular momentum : Ω_{surf} ↘
- **Transport of angular momentum** inside the star (meridional circulation) : Ω_{surf} ↗

Be stars: stellar model predictions

Ekstrom et al. (2008, 2010)



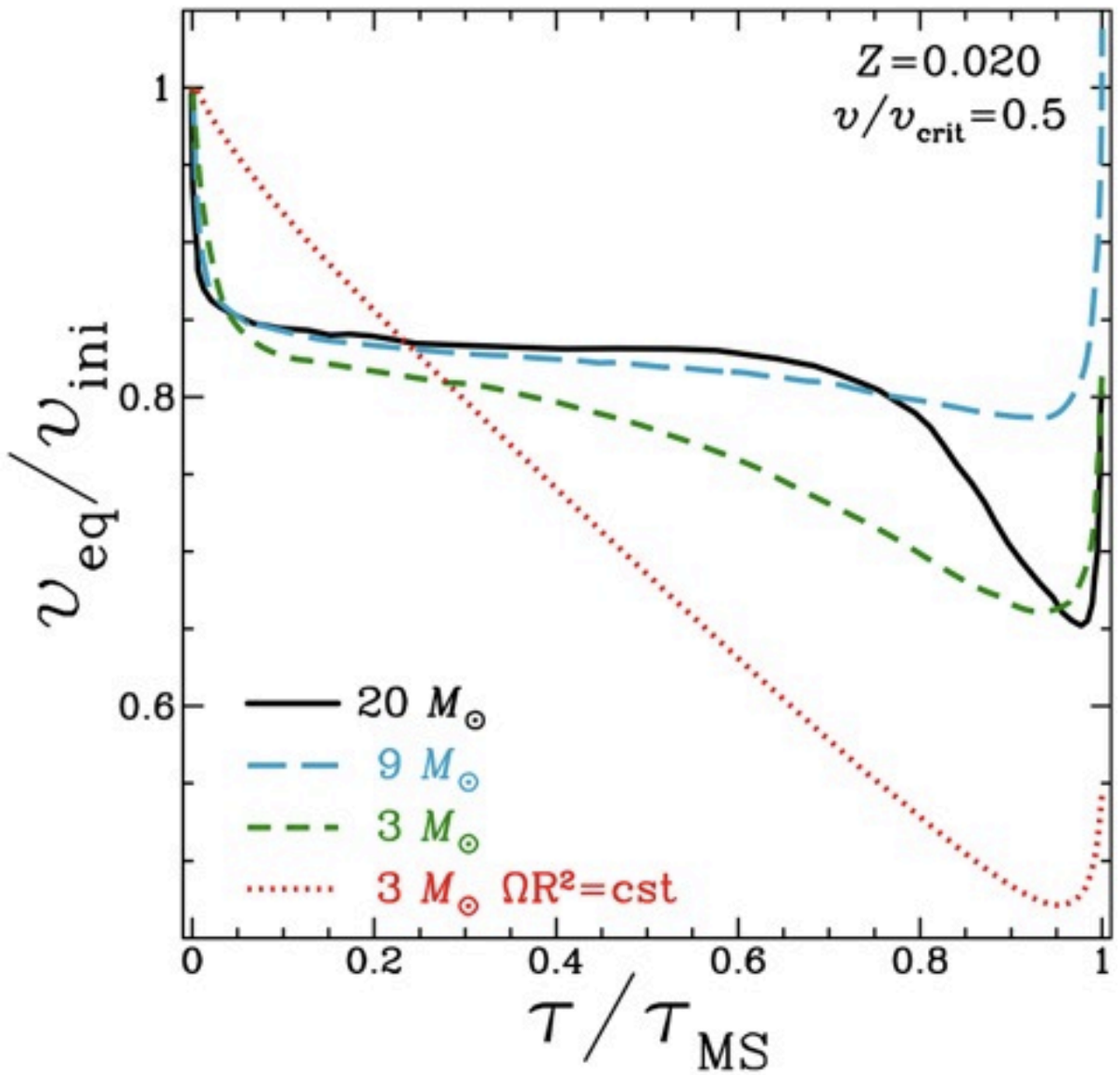
Ekstrom et al. (2008, 2010)



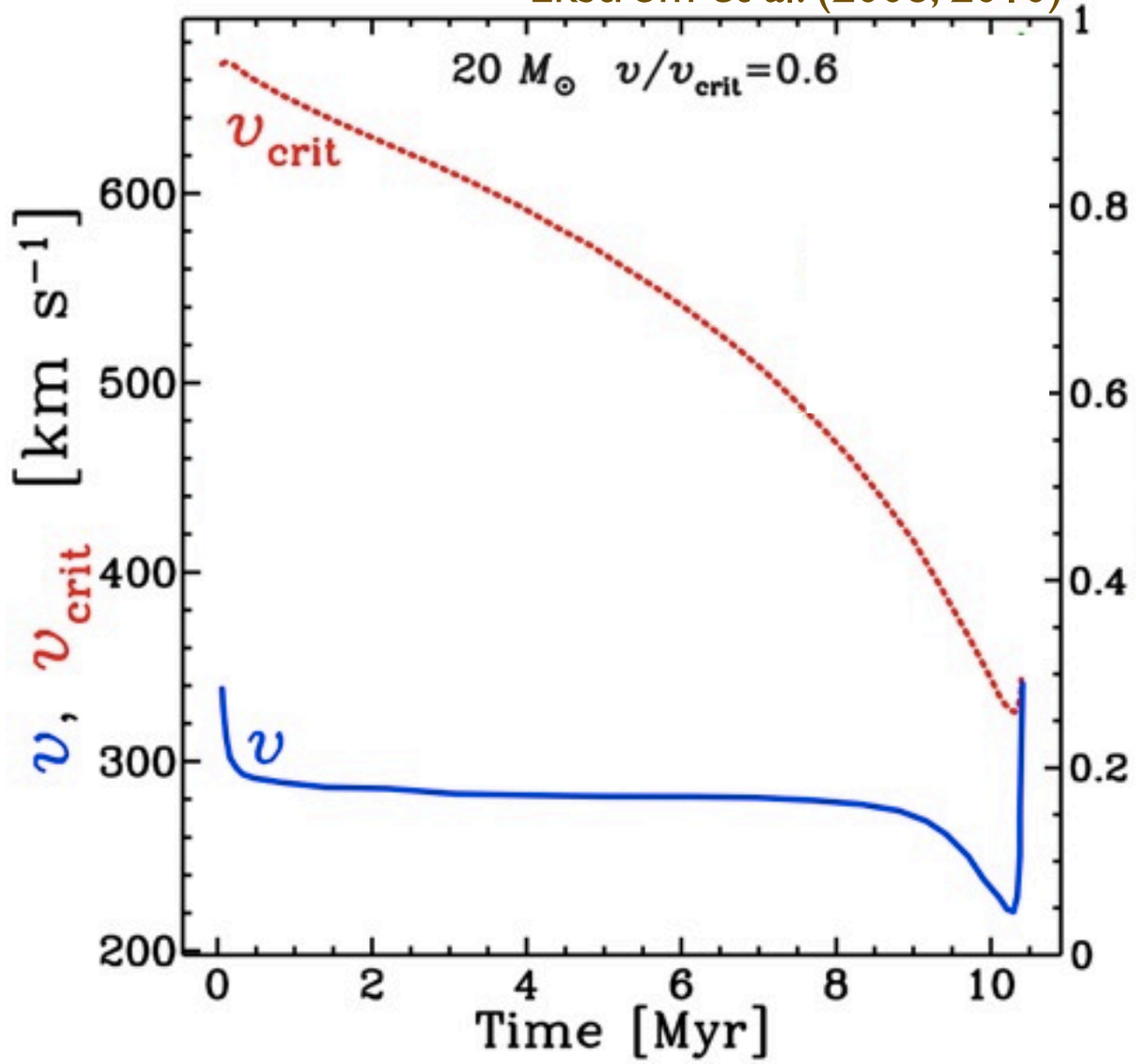
- **Mass loss** removes angular momentum : Ω_{surf} ↘
- **Transport of angular momentum** inside the star (meridional circulation) : Ω_{surf} ↗

Be stars: stellar model predictions

Ekstrom et al. (2008, 2010)



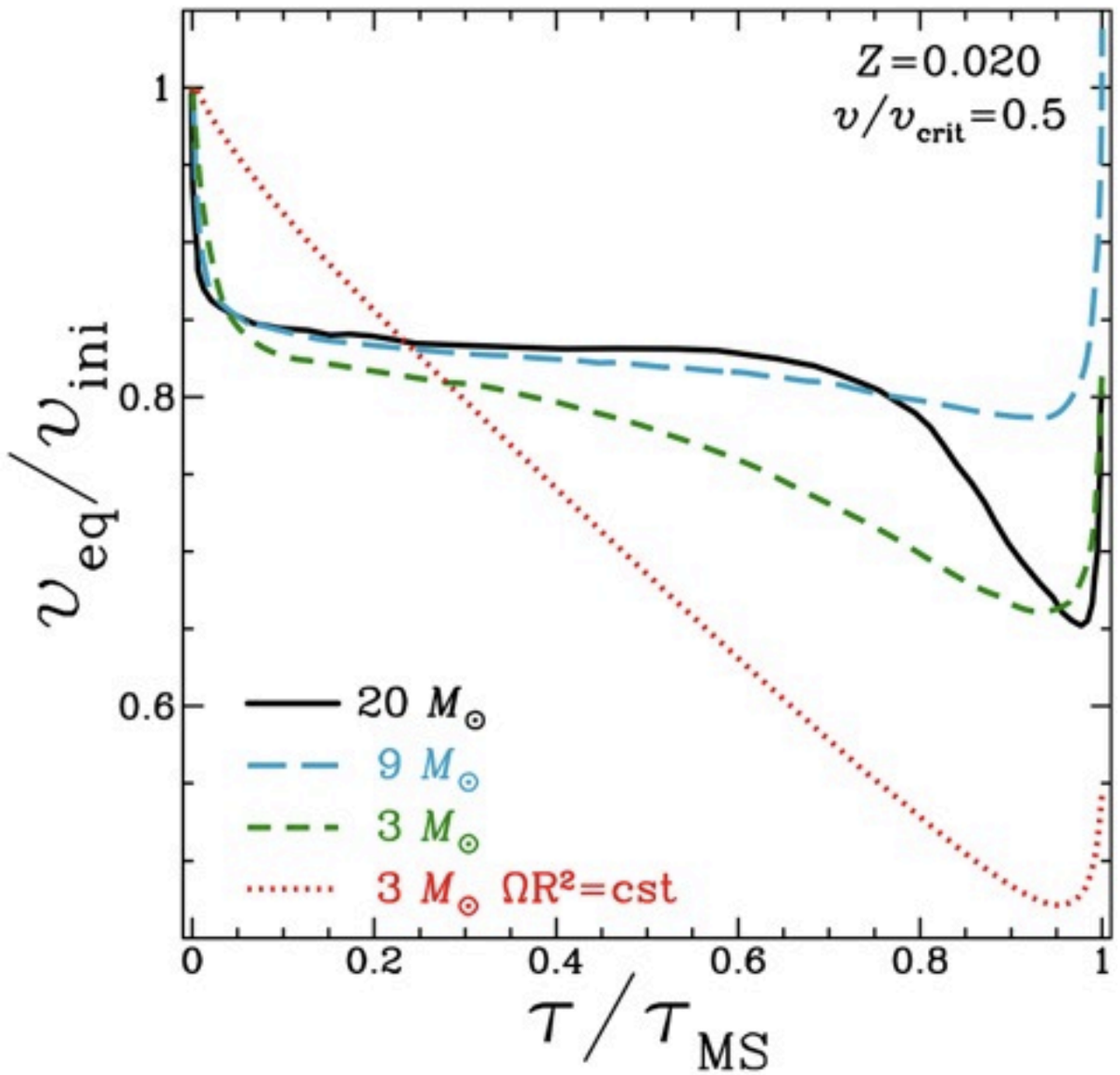
Ekstrom et al. (2008, 2010)



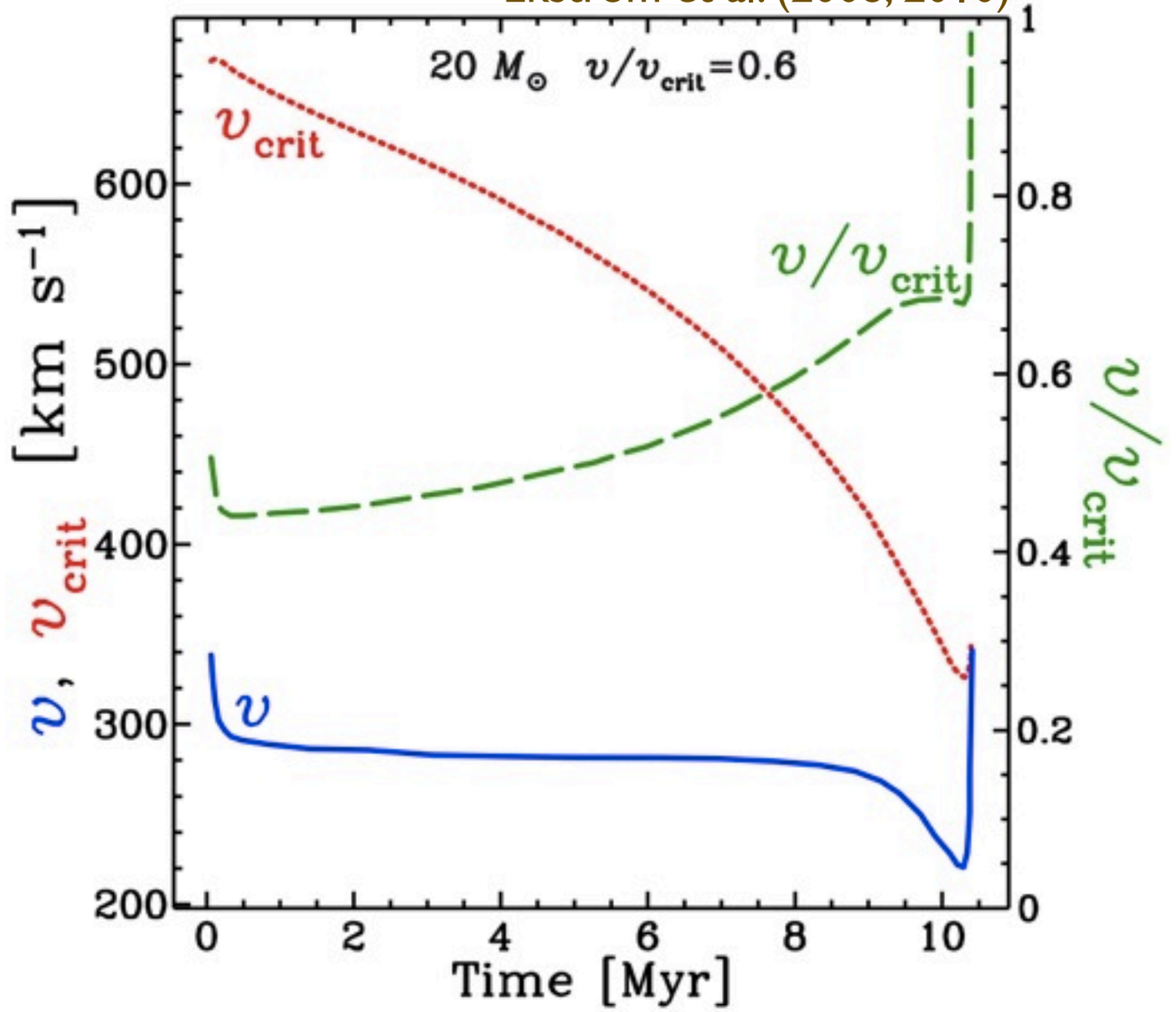
- **Mass loss** removes angular momentum : Ω_{surf} ↘
- **Transport of angular momentum** inside the star (meridional circulation) : Ω_{surf} ↗
- $\mathrm{v}_{crit} = \sqrt{\frac{2}{3}\frac{G\ M}{R_{pol}}}$

Be stars: stellar model predictions

Ekstrom et al. (2008, 2010)



Ekstrom et al. (2008, 2010)

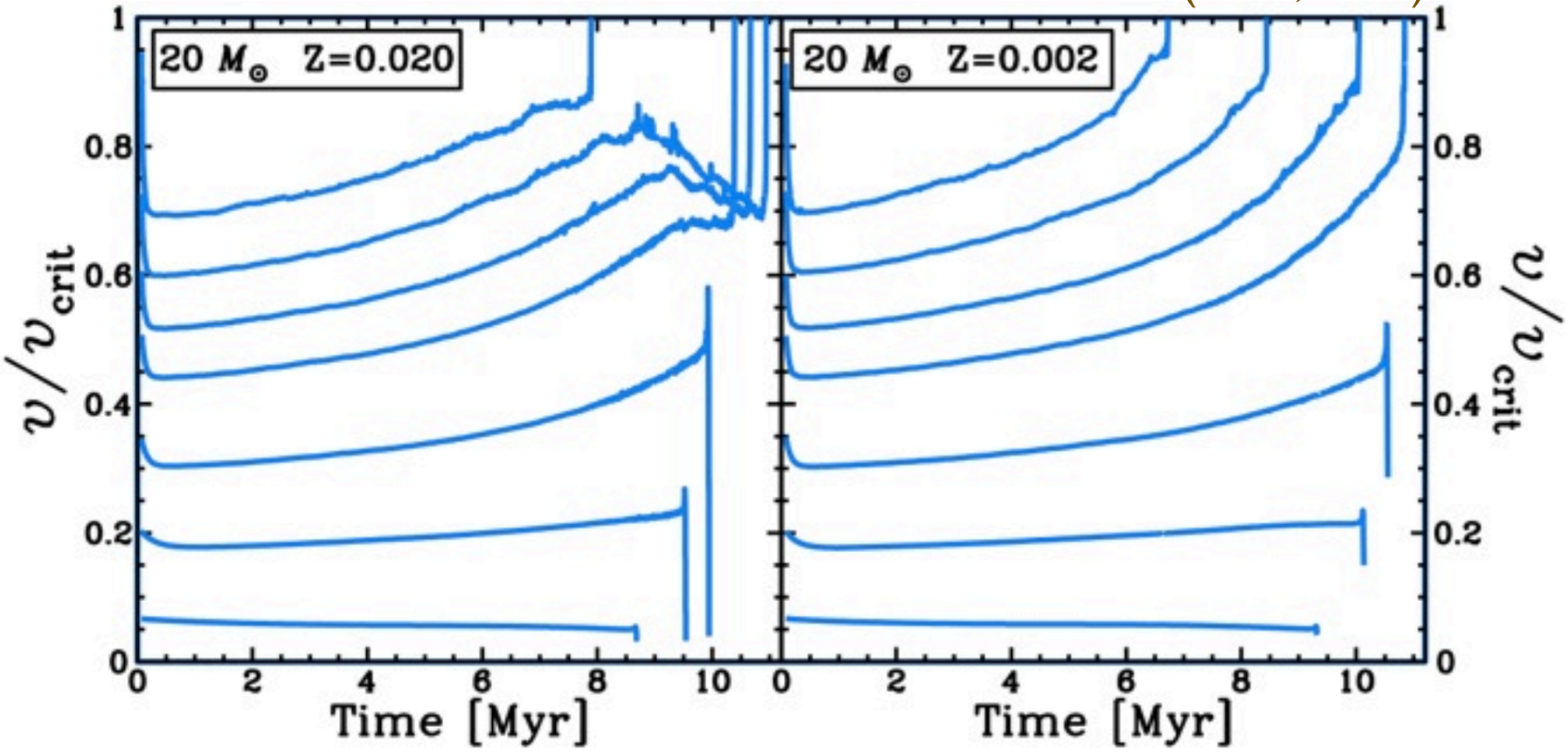


- **Mass loss** removes angular momentum : Ω_{surf} ↘
- **Transport of angular momentum** inside the star (meridional circulation) : Ω_{surf} ↗
- $\mathrm{v}_{crit} = \sqrt{\frac{2}{3}\frac{G\ M}{R_{pol}}}$

-> Be = fast rotators, close to break-up velocity -> bursts of mass loss (appear for age =10-25 My).

Be stars: stellar model predictions

Ekstrom et al. (2008, 2010)

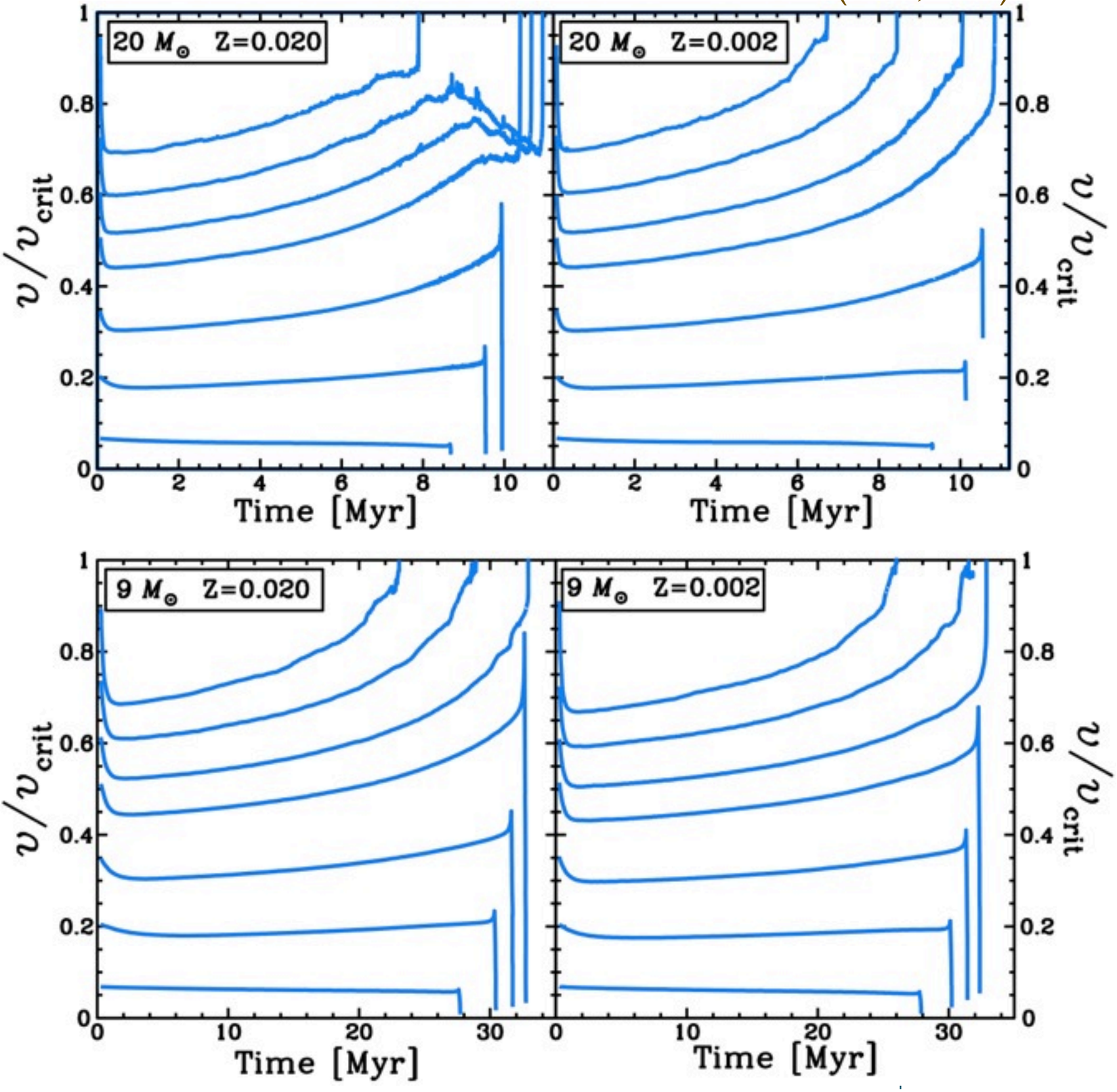


For large masses :

Be phenomenon favored at low Z

Be stars: stellar model predictions

Ekstrom et al. (2008, 2010)



For large masses :

Be phenomenon favored at low Z

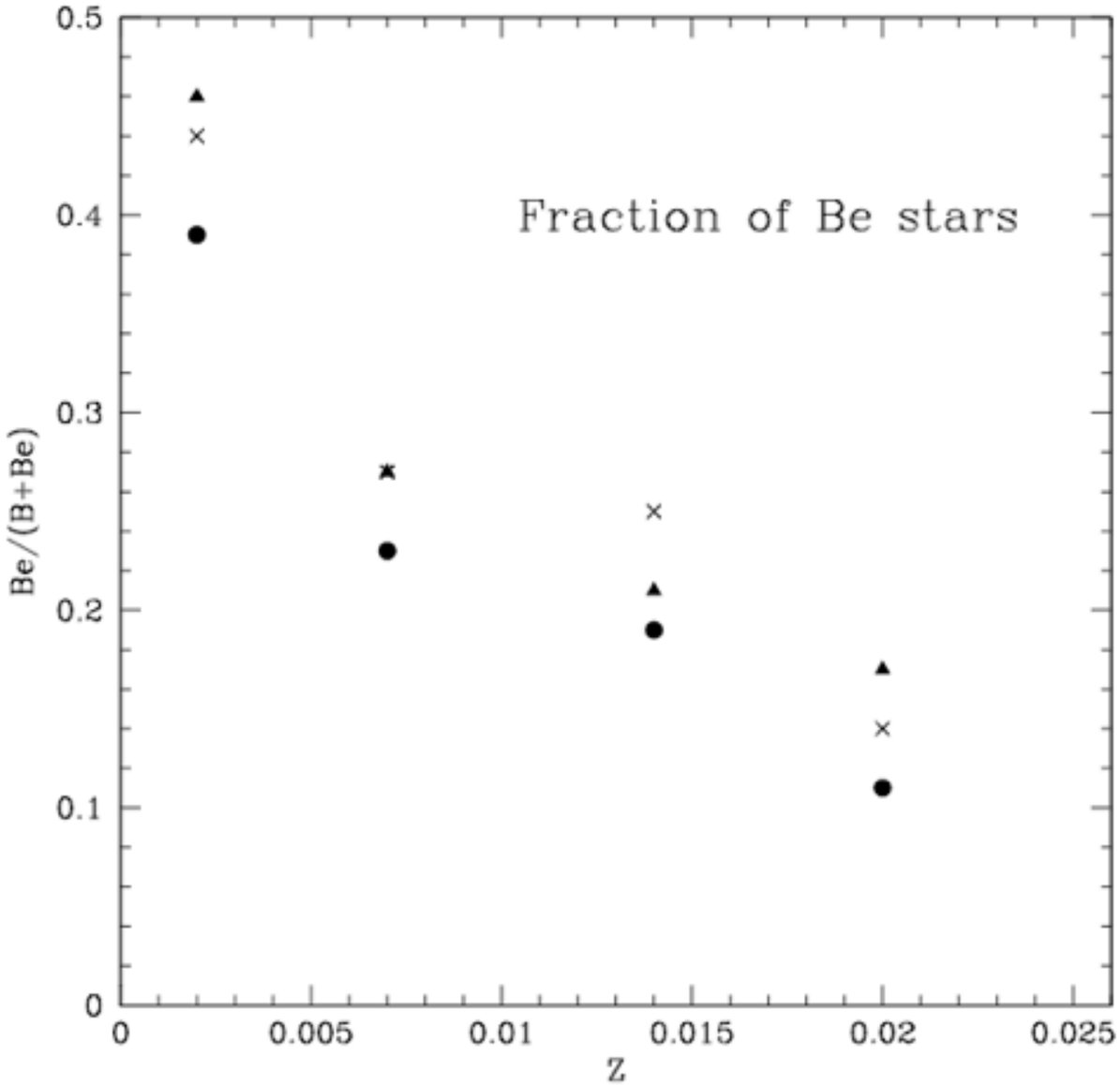
But for M<9Mo (where most Be stars are) :

Be phenomenon NOT favored at low Z

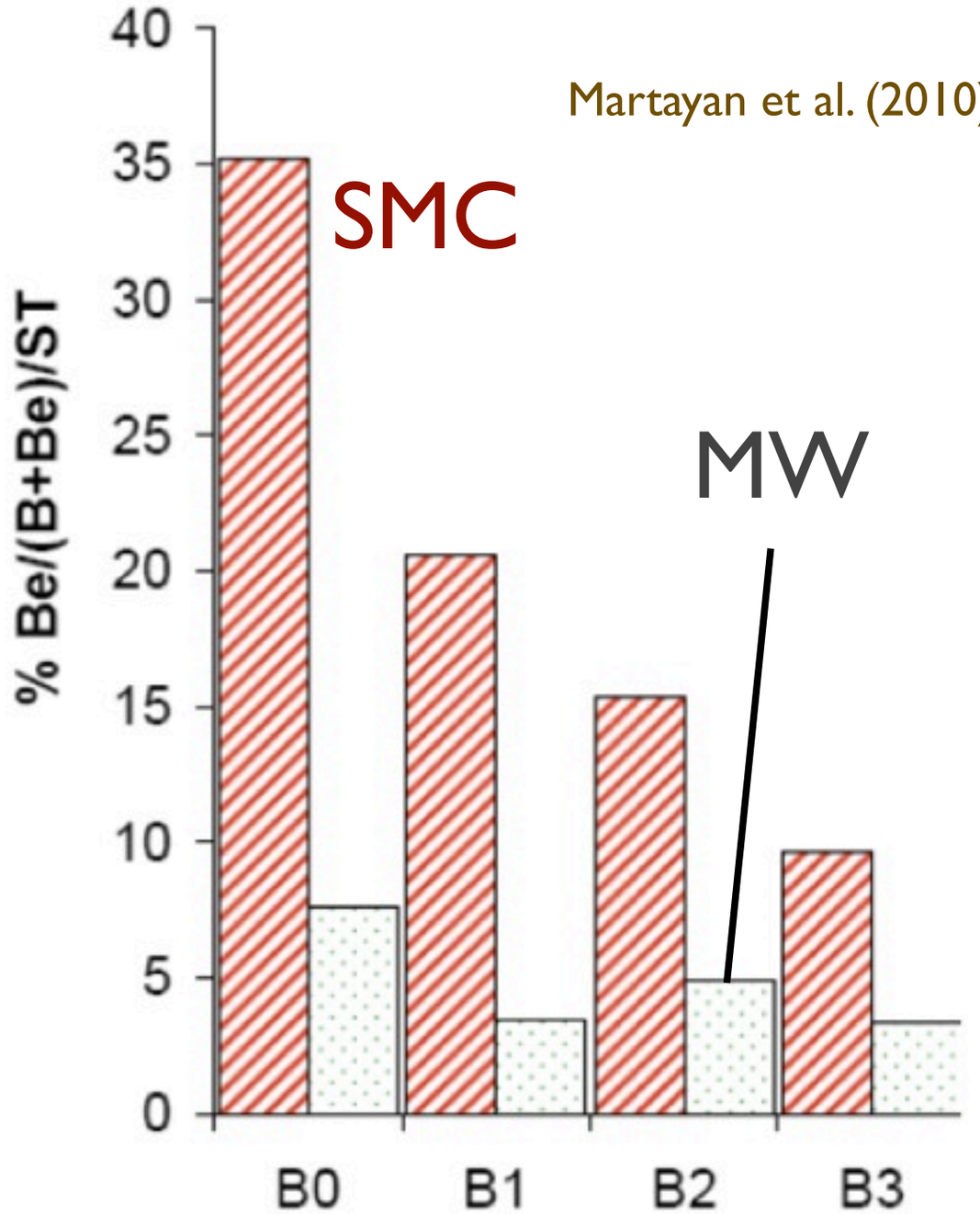
Be stars: observations vs metallicity

Observation of B and Be stars in Open Clusters

Maeder et al. (1999)

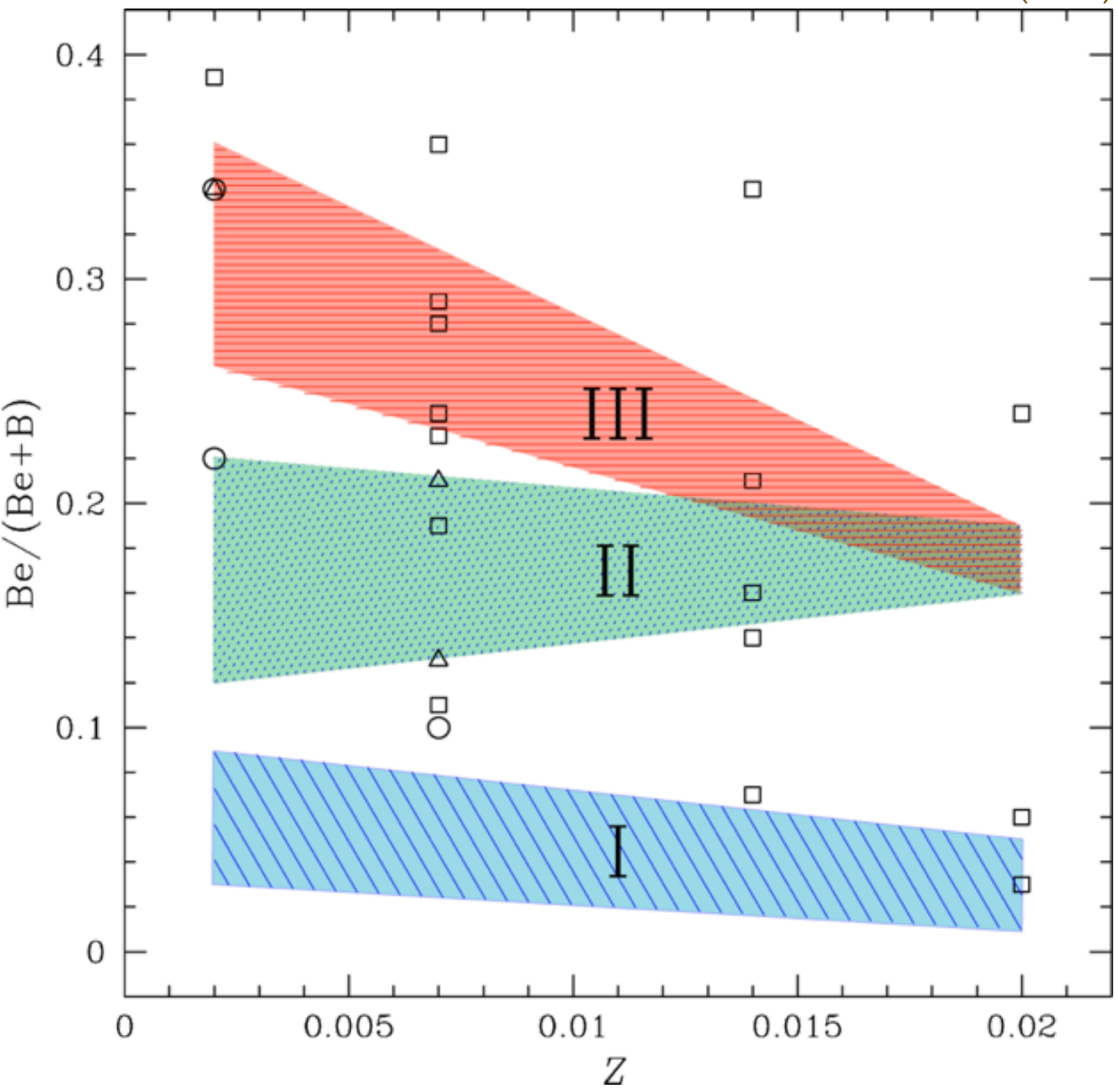


Martayan et al. (2010)



Be stars: observations & predictions

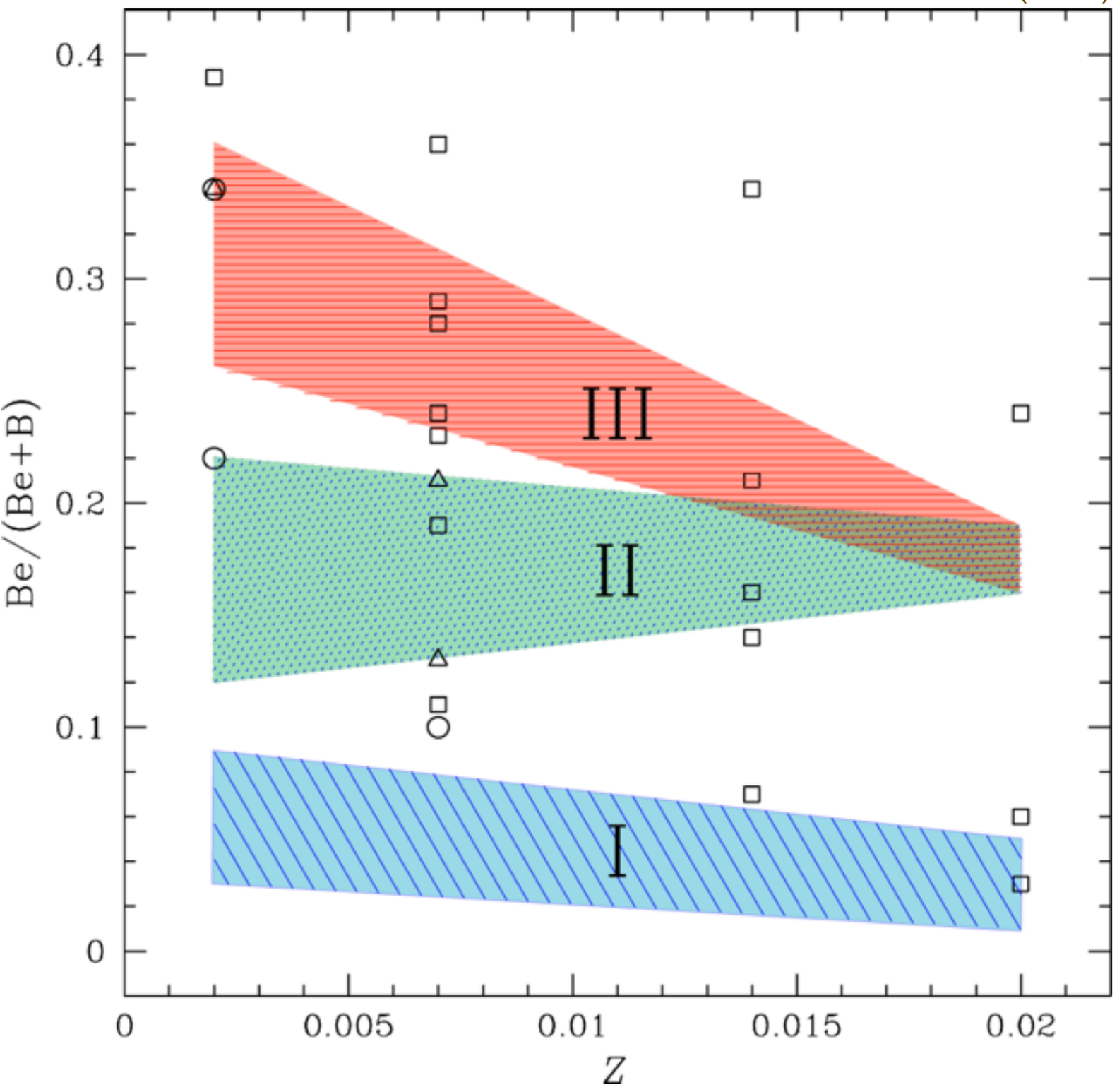
Ekstrom et al. (2008)



1. Be with $v > v_{crit}$:
   → ***not enough Be***

Be stars: observations & predictions

Ekstrom et al. (2008)

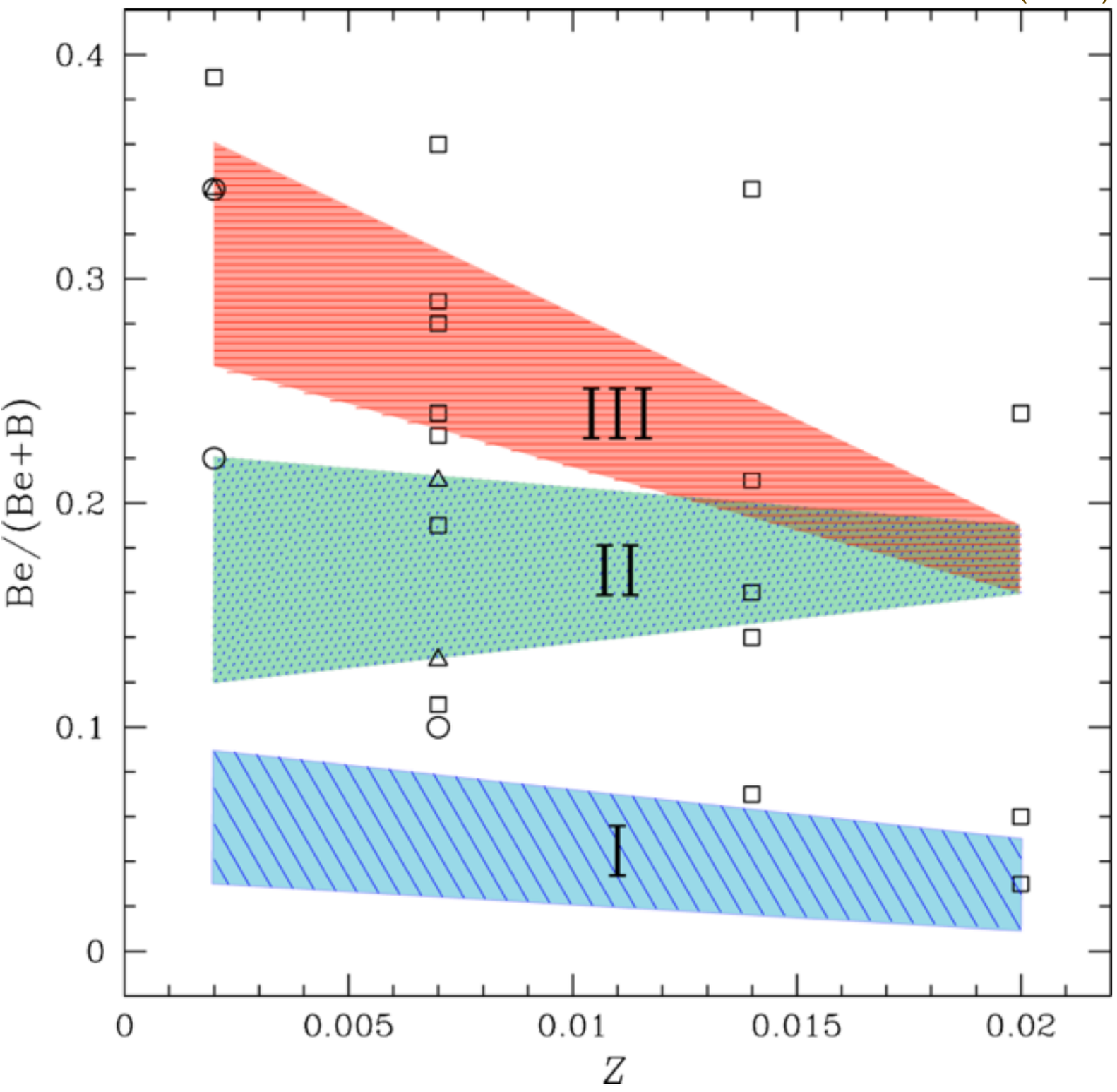


II. Be with $v > 0.7\ v_{crit}$:
→ ***no Z dependence***

I. Be wih $v > v_{crit}$:
→ ***not enough Be***

Be stars: observations & predictions

Ekstrom et al. (2008)



III. Be with $v > 0.7\ v_{crit}$
+ modified v_{init} distribution
→ ***ok***

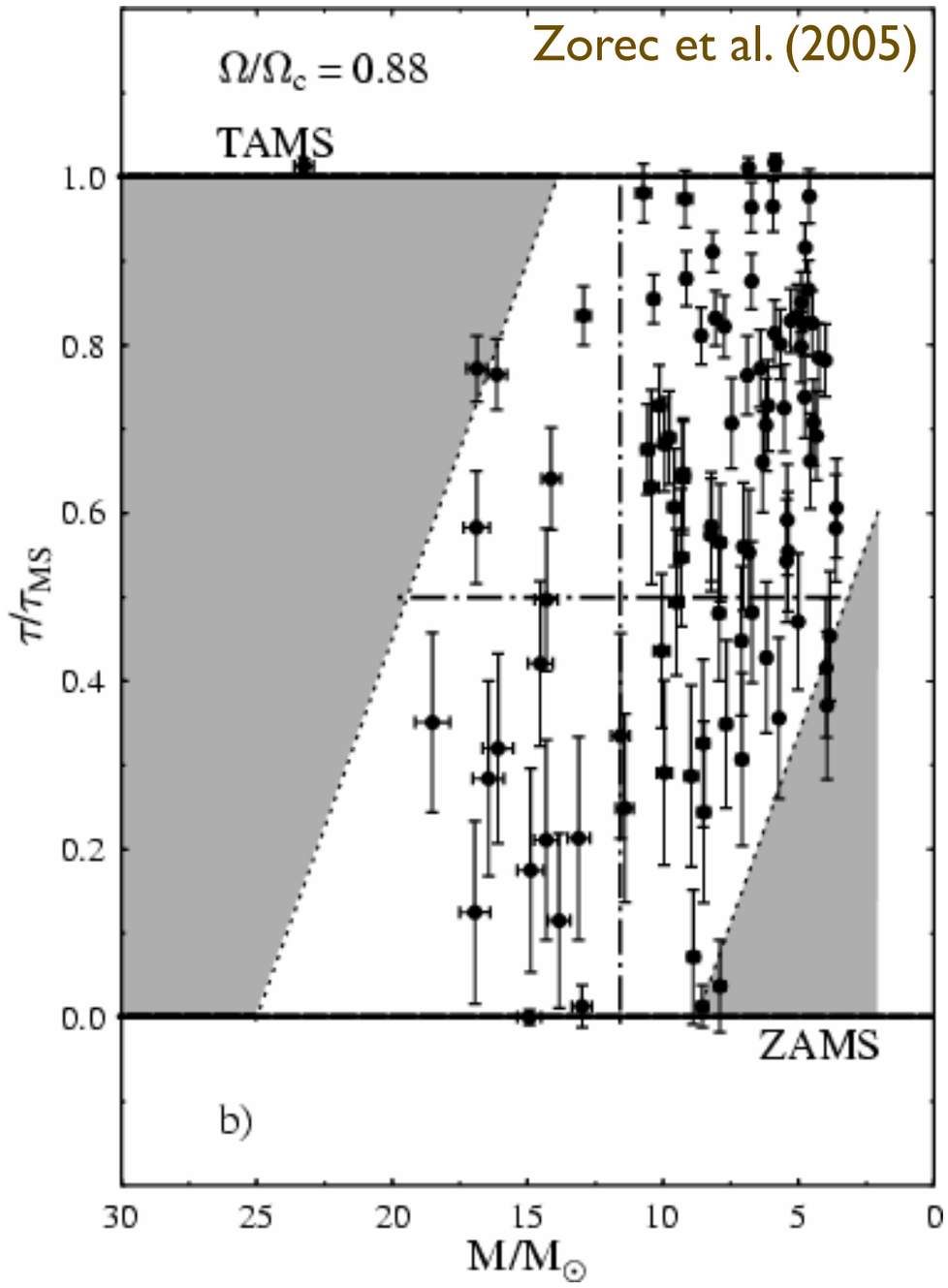
II. Be with $v > 0.7\ v_{crit}$:
→ ***no Z dependence***

I. Be with $v > v_{crit}$:
→ ***not enough Be***

Be stars: observations & predictions

Evolutionary state of Be stars

97 field Be stars near the Sun

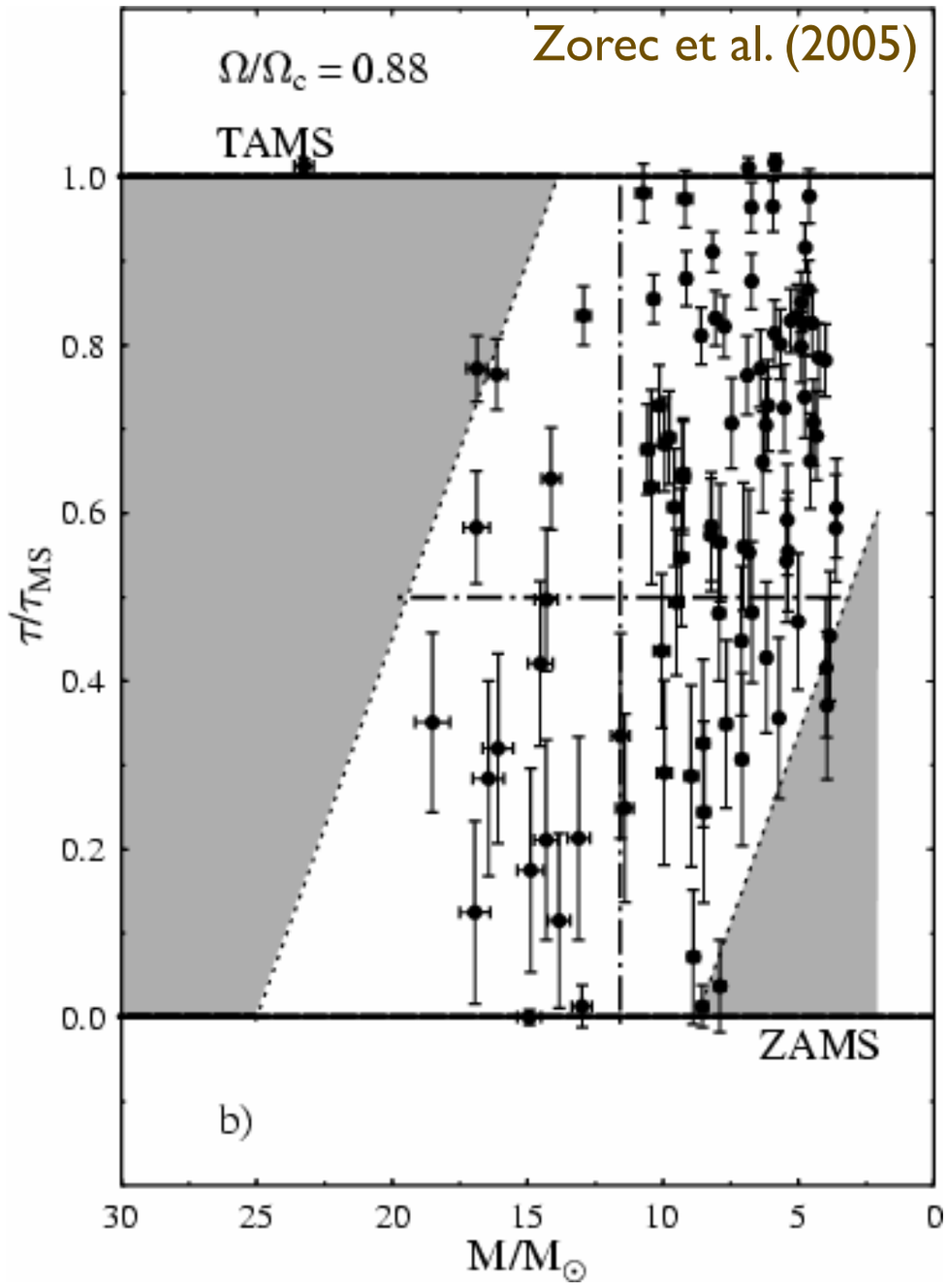


→ mass distribution: **many Be have M<12M$_\odot$**

Be stars: observations & predictions

Evolutionary state of Be stars

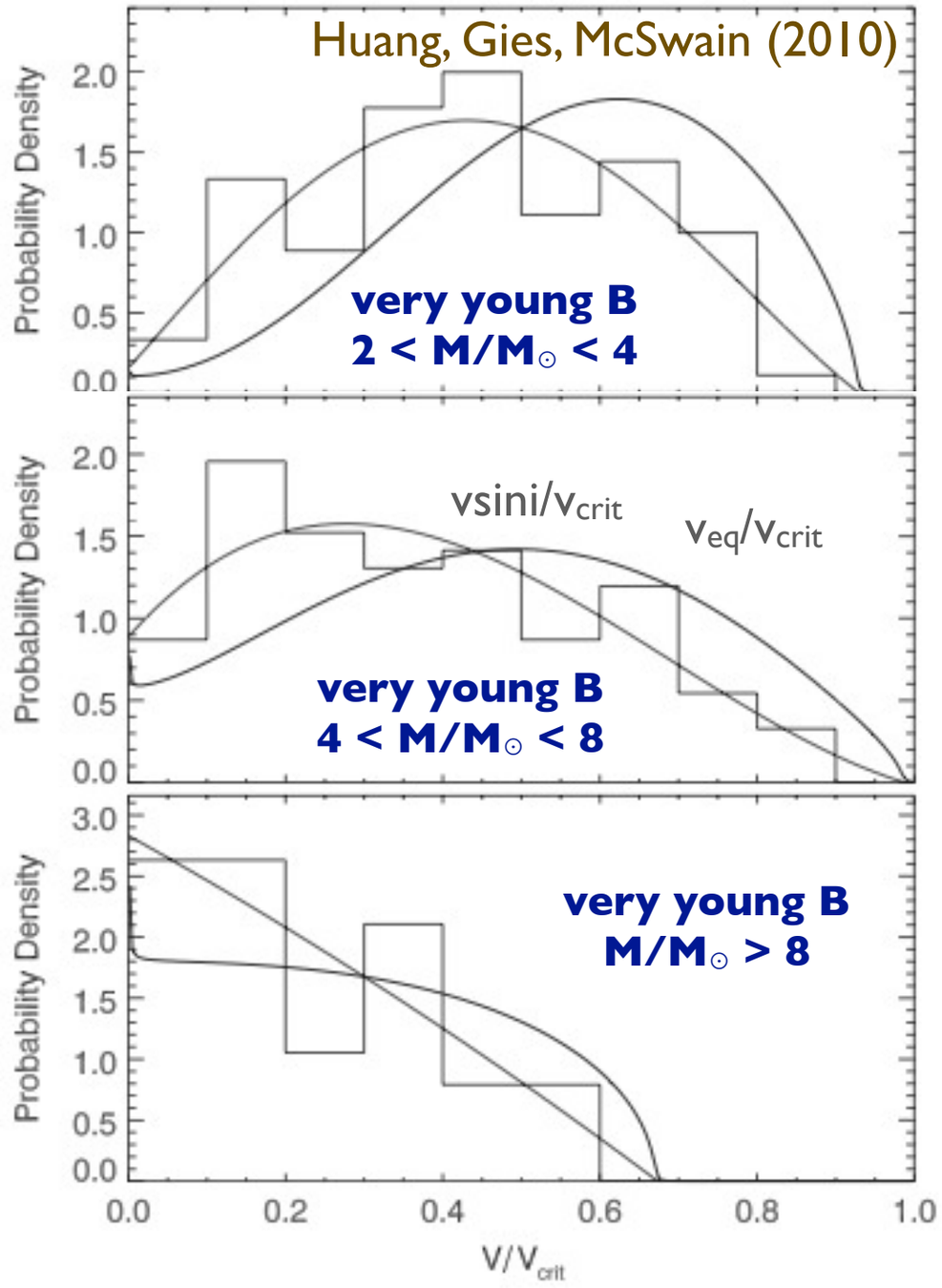
97 field Be stars near the Sun



→ mass distribution: **many Be have M<12M$_\odot$**

Initial rotational velocities of B stars

600 targets from cluster and field B stars

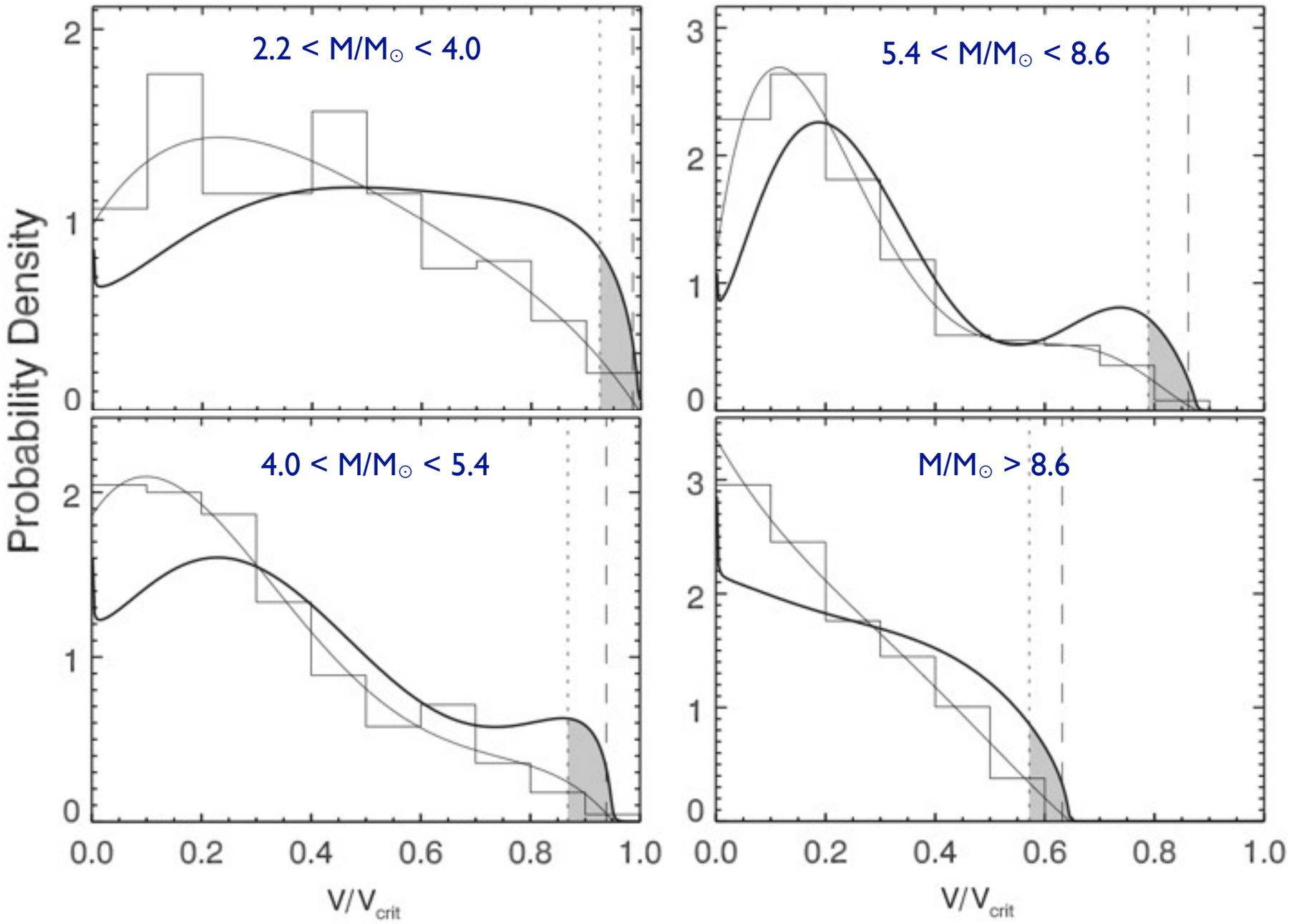


→ **lower-mass B stars are faster rotators**

Be stars: observations & predictions

Rotational velocities of B stars that are not Be

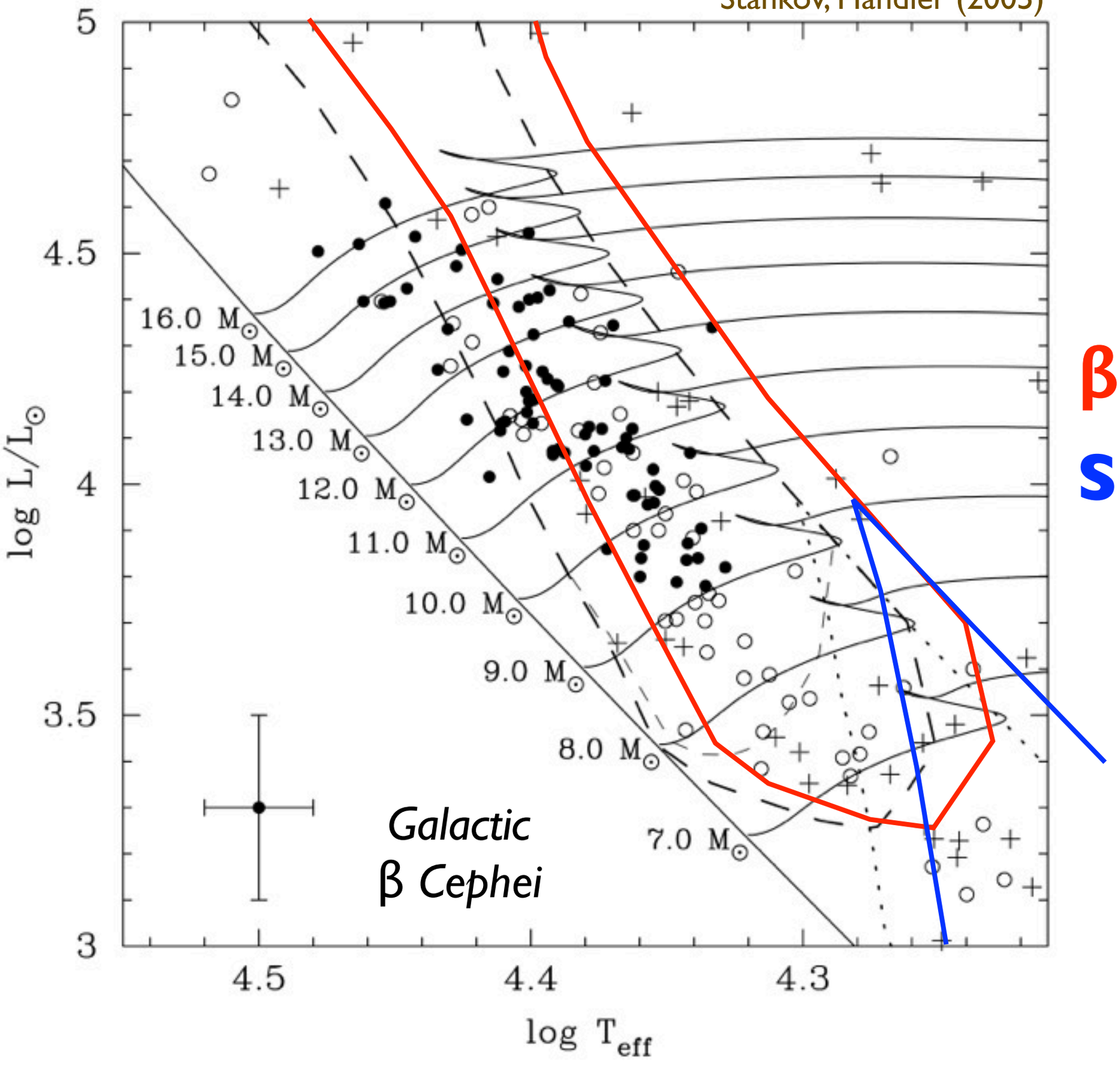
Huang, Gies, McSwain (2010)



→ **Higher v/v_{crit} needed at lower masses to trigger Be phenomenon**

Pulsating B stars

Stankov, Handler (2005)



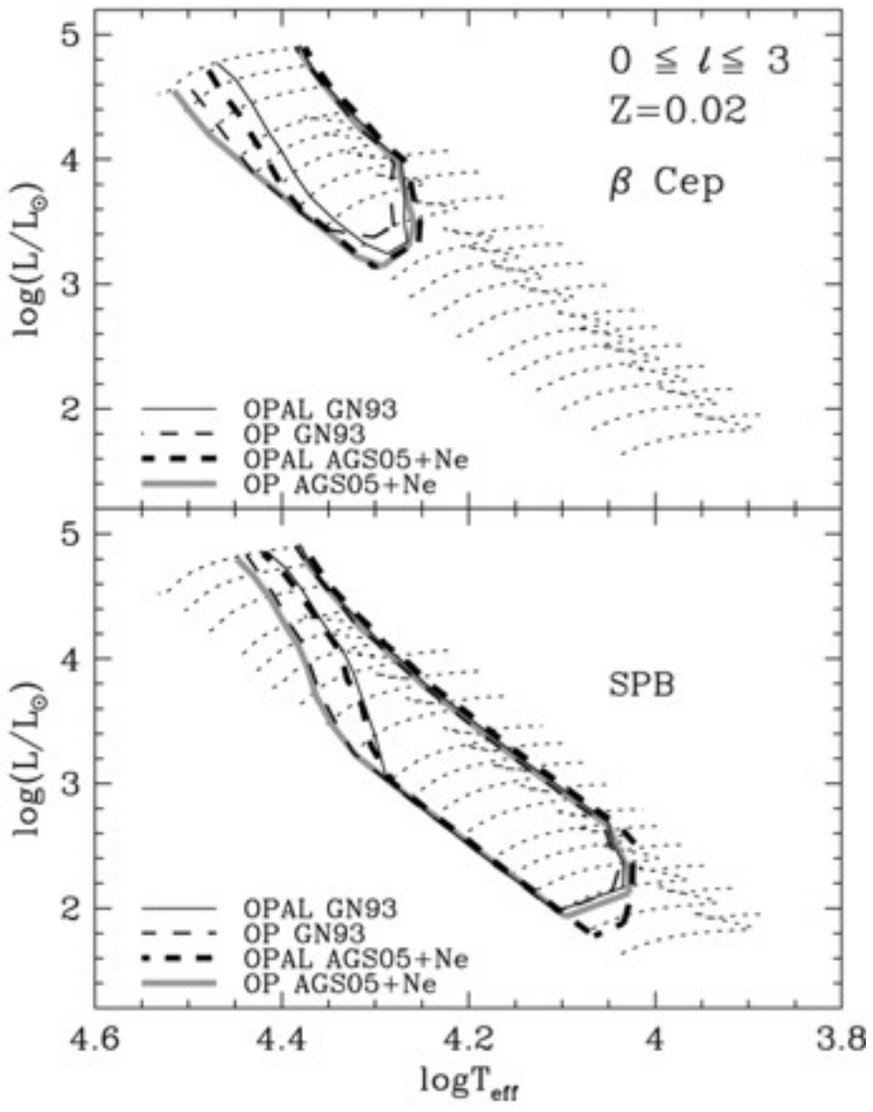
β Cephei stars

Slowly **P**ulsating **B** stars

Pulsating B stars: stellar model predictions

κ mechanism on iron-peak elements

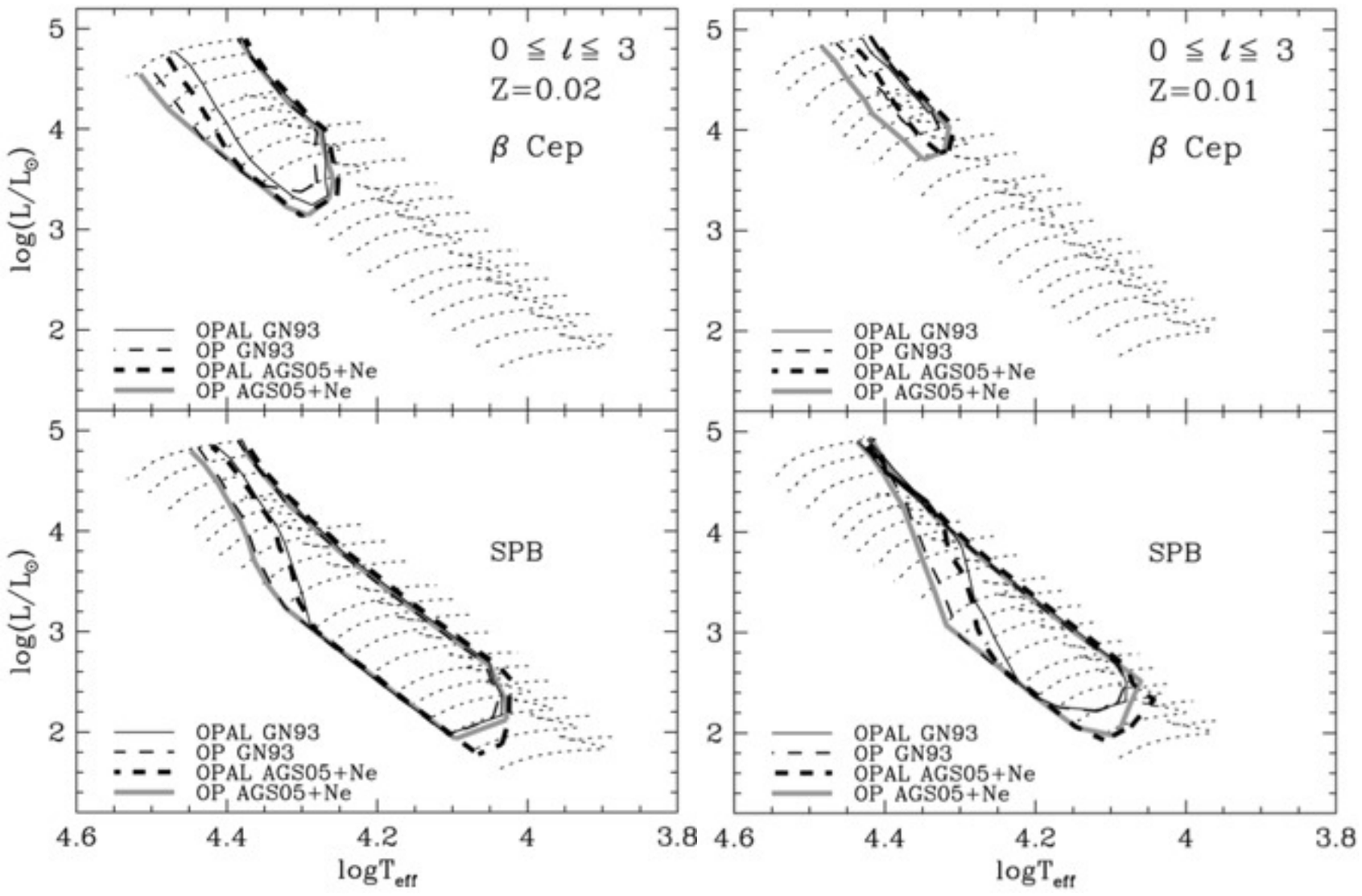
Miglio, Montalban, Dupret (2007)



Pulsating B stars: stellar model predictions

κ mechanism on iron-peak elements

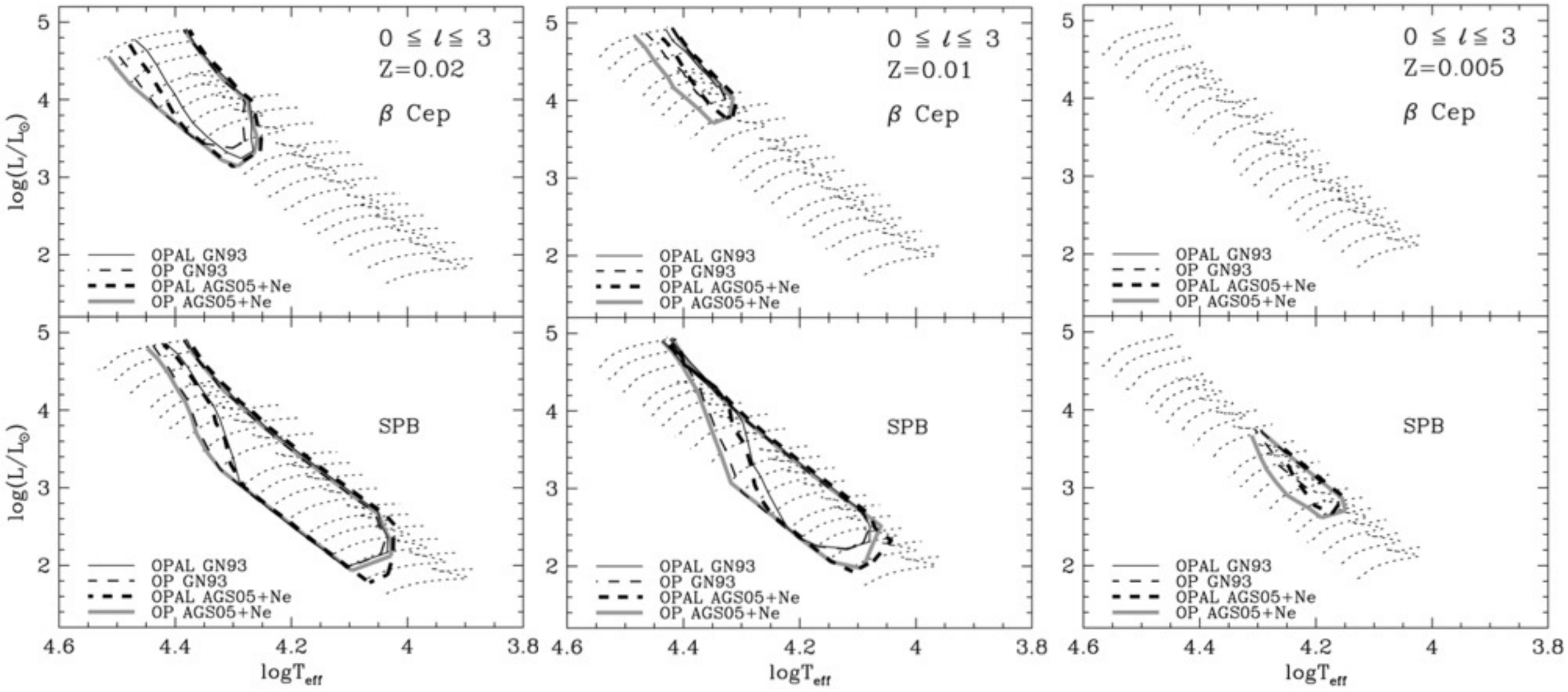
Miglio, Montalban, Dupret (2007)



Pulsating B stars: stellar model predictions

κ mechanism on iron-peak elements

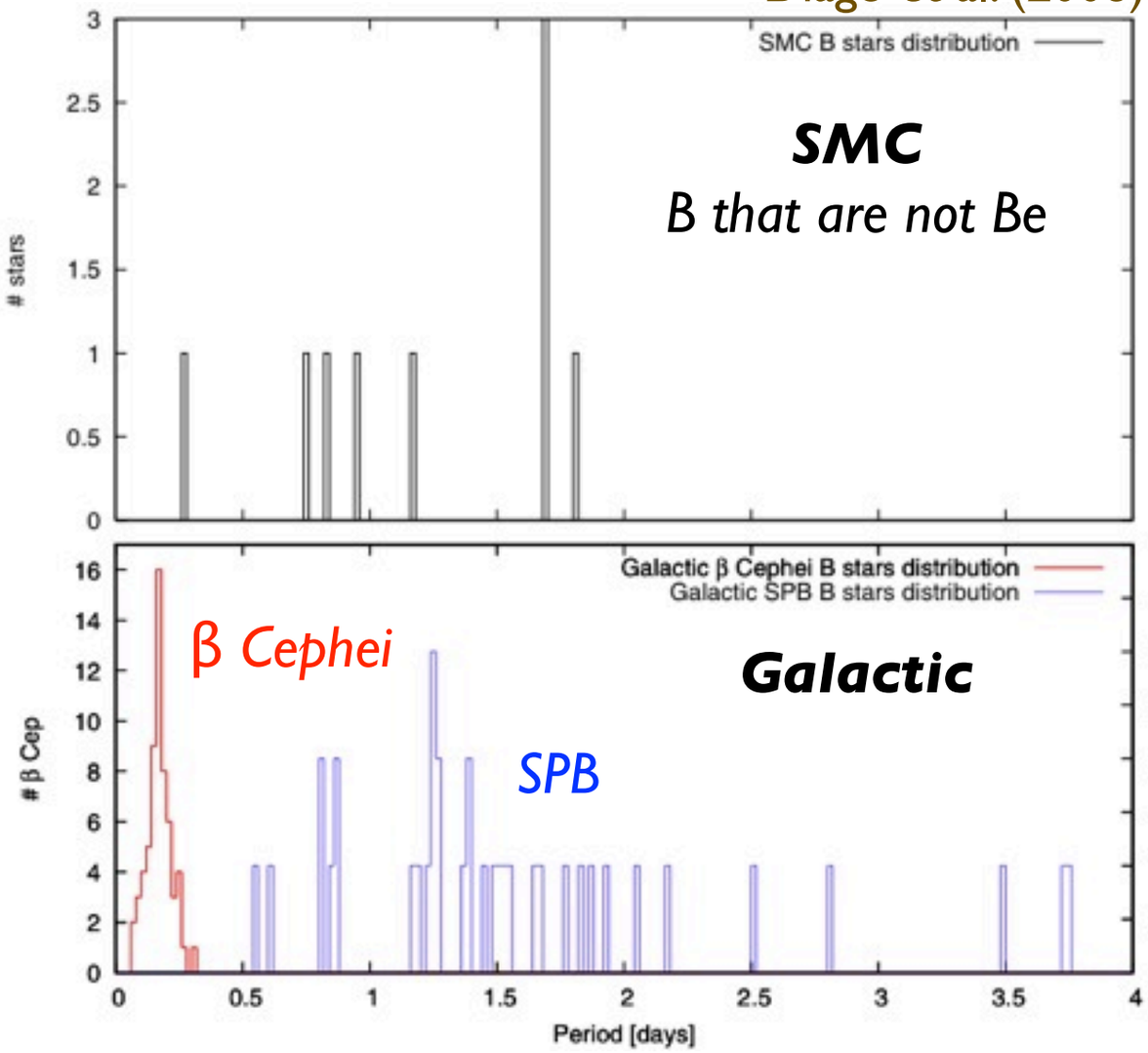
Miglio, Montalban, Dupret (2007)



Pulsating B stars: observations at low Z

From MACHO survey of the SMC

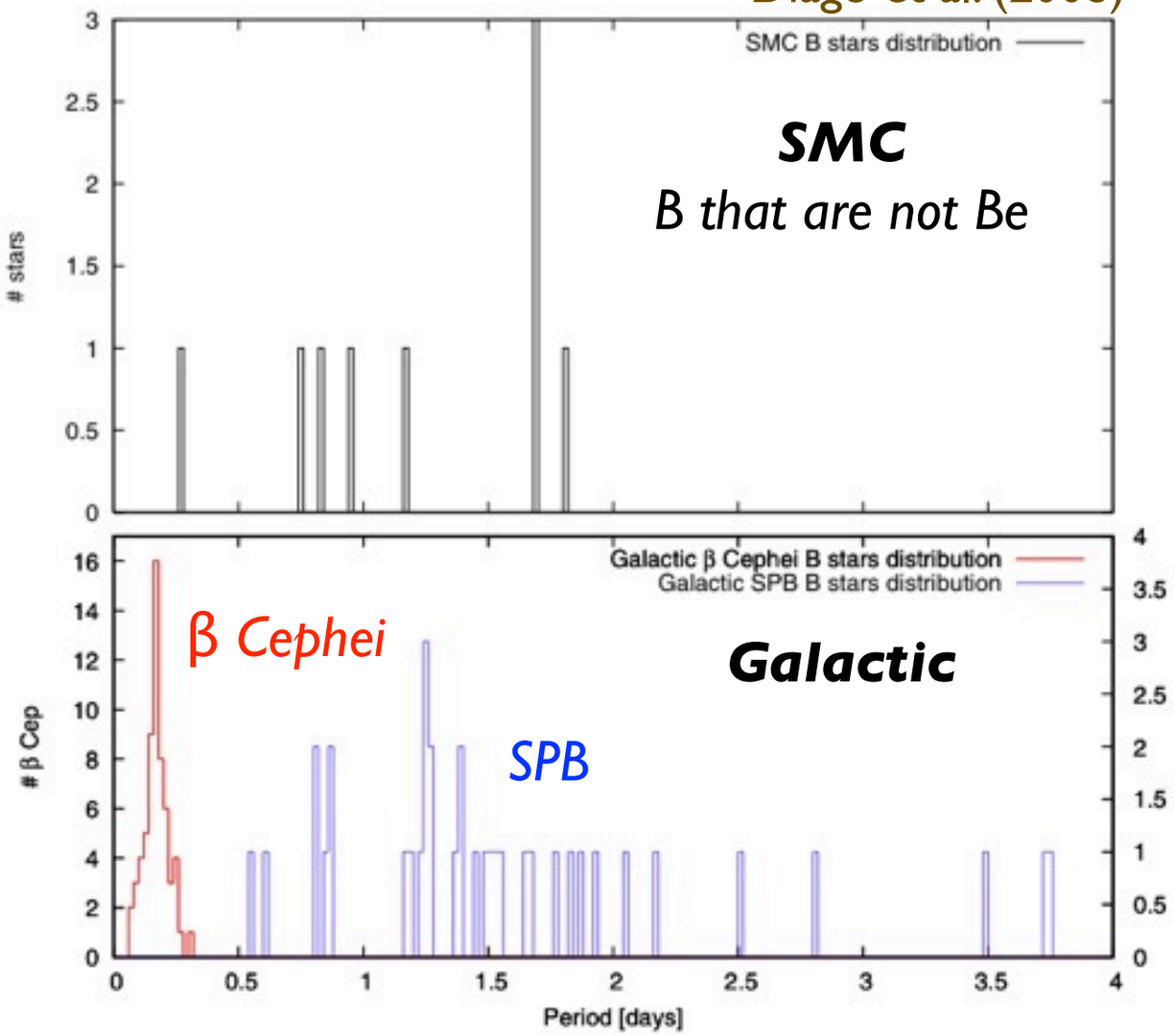
Diago et al. (2008)



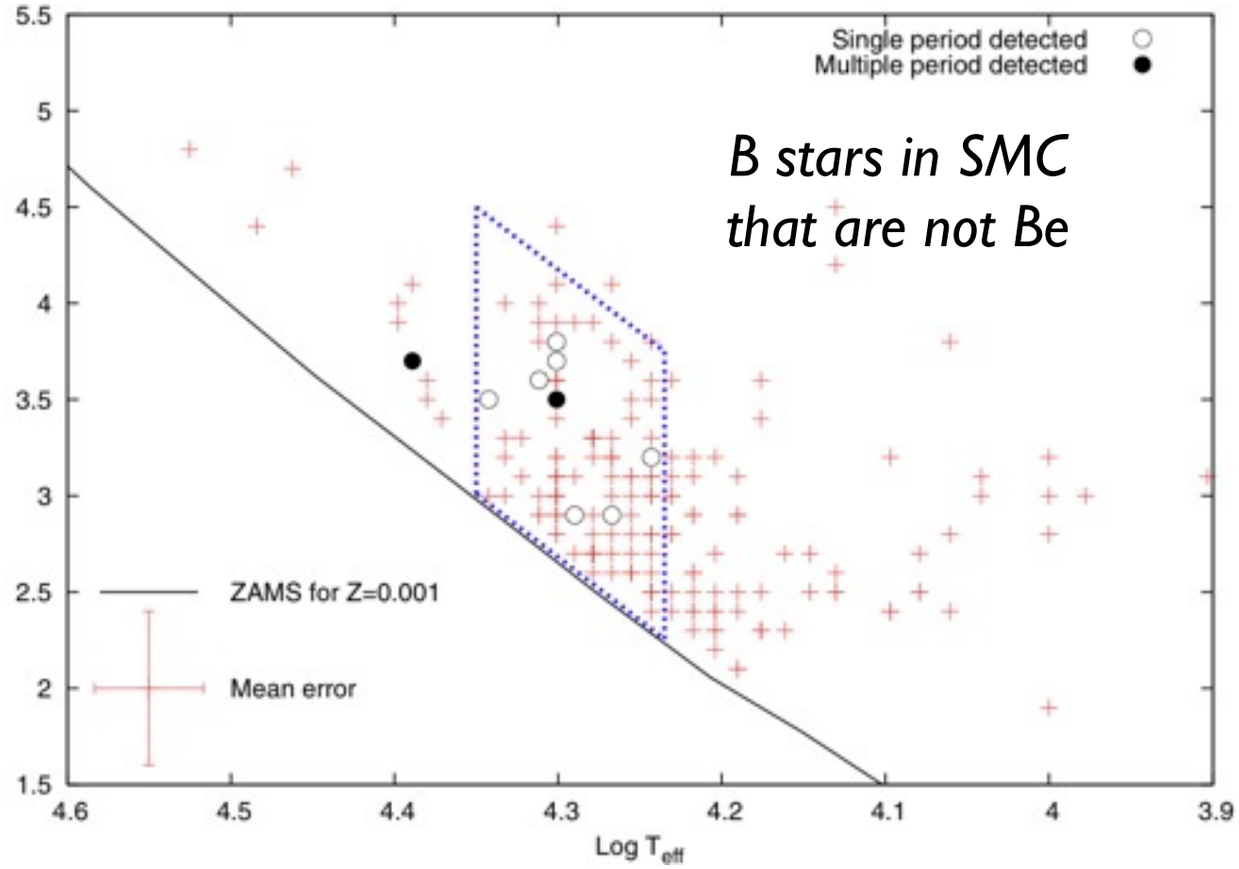
Pulsating B stars: observations at low Z

From MACHO survey of the SMC

Diago et al. (2008)



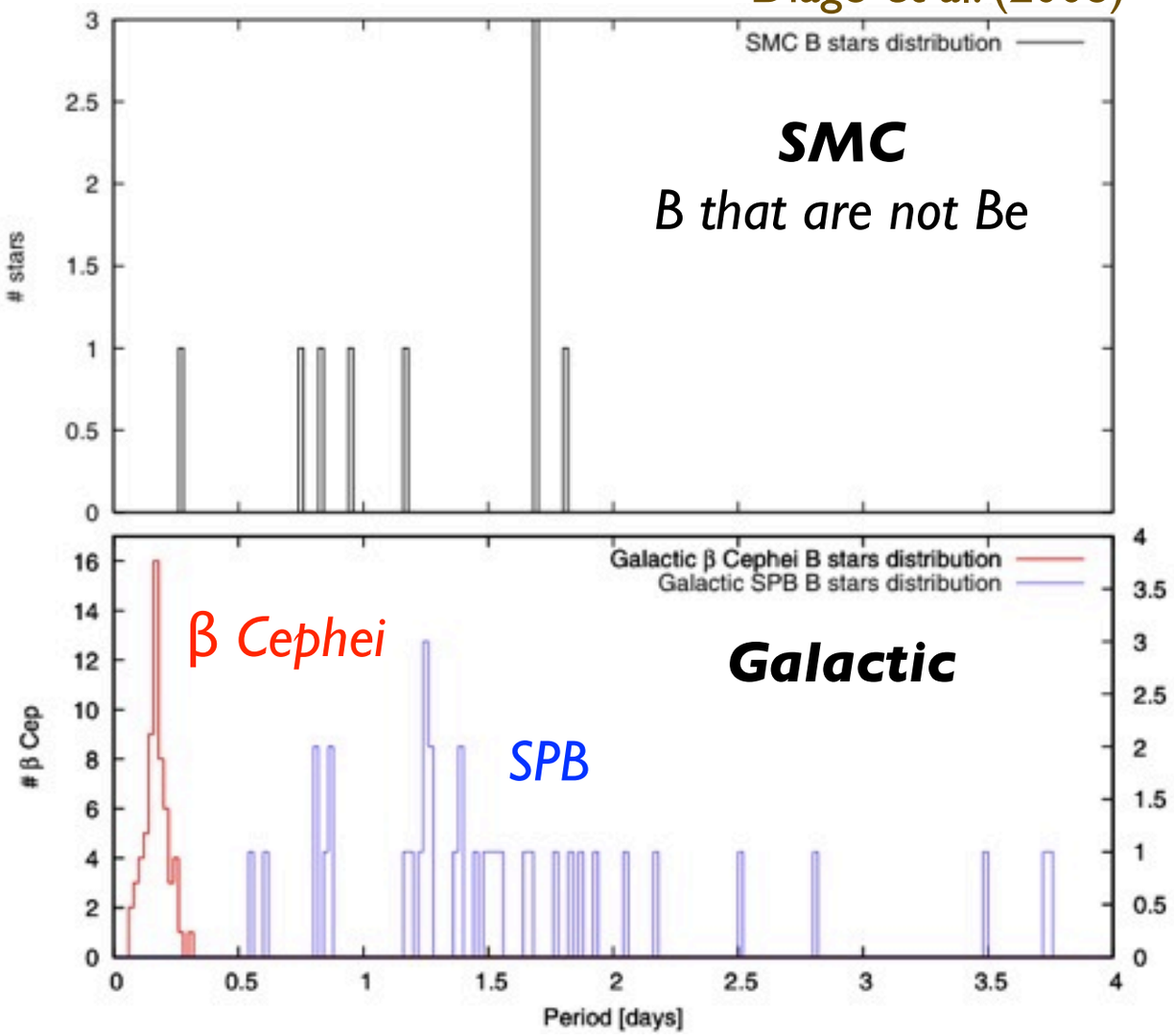
Diago et al. (2008)



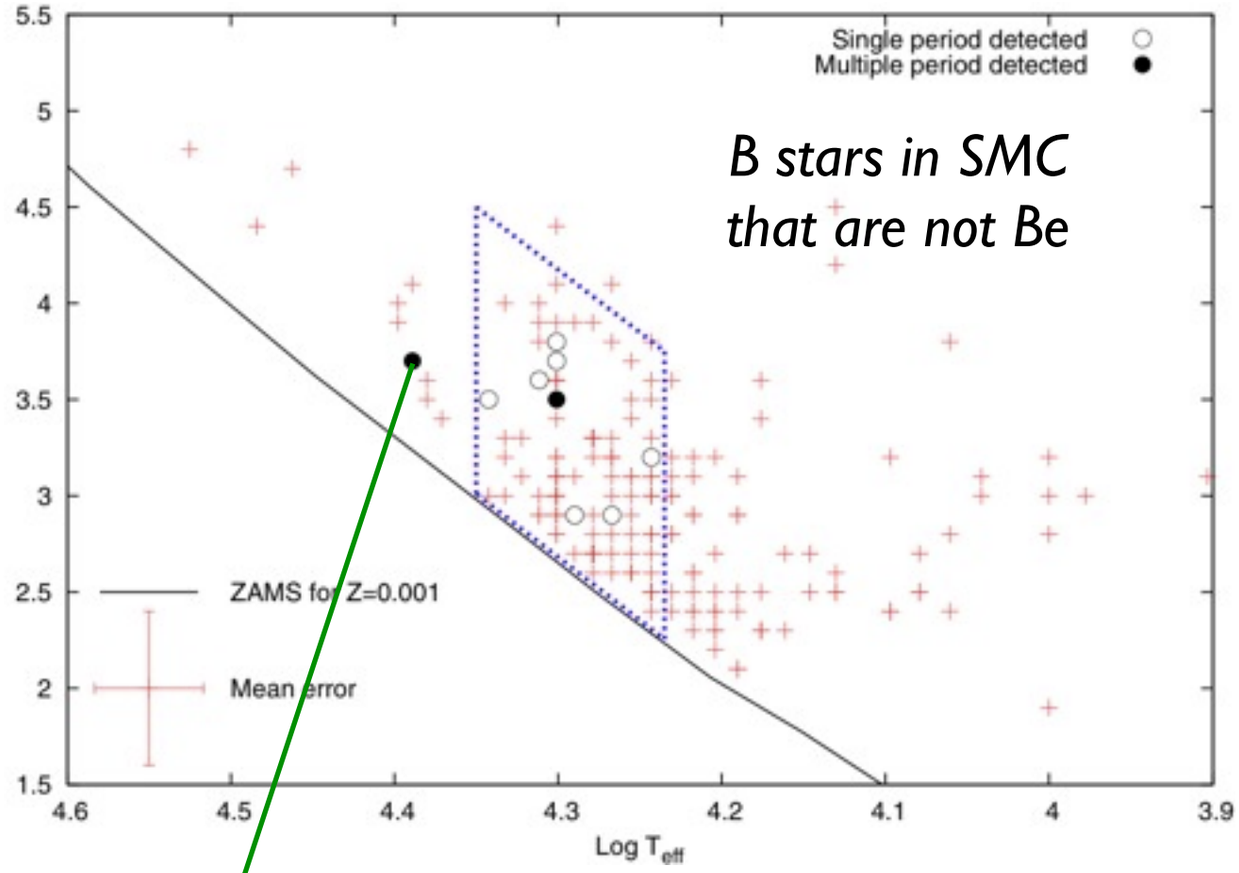
Pulsating B stars: observations at low Z

From MACHO survey of the SMC

Diago et al. (2008)



Diago et al. (2008)

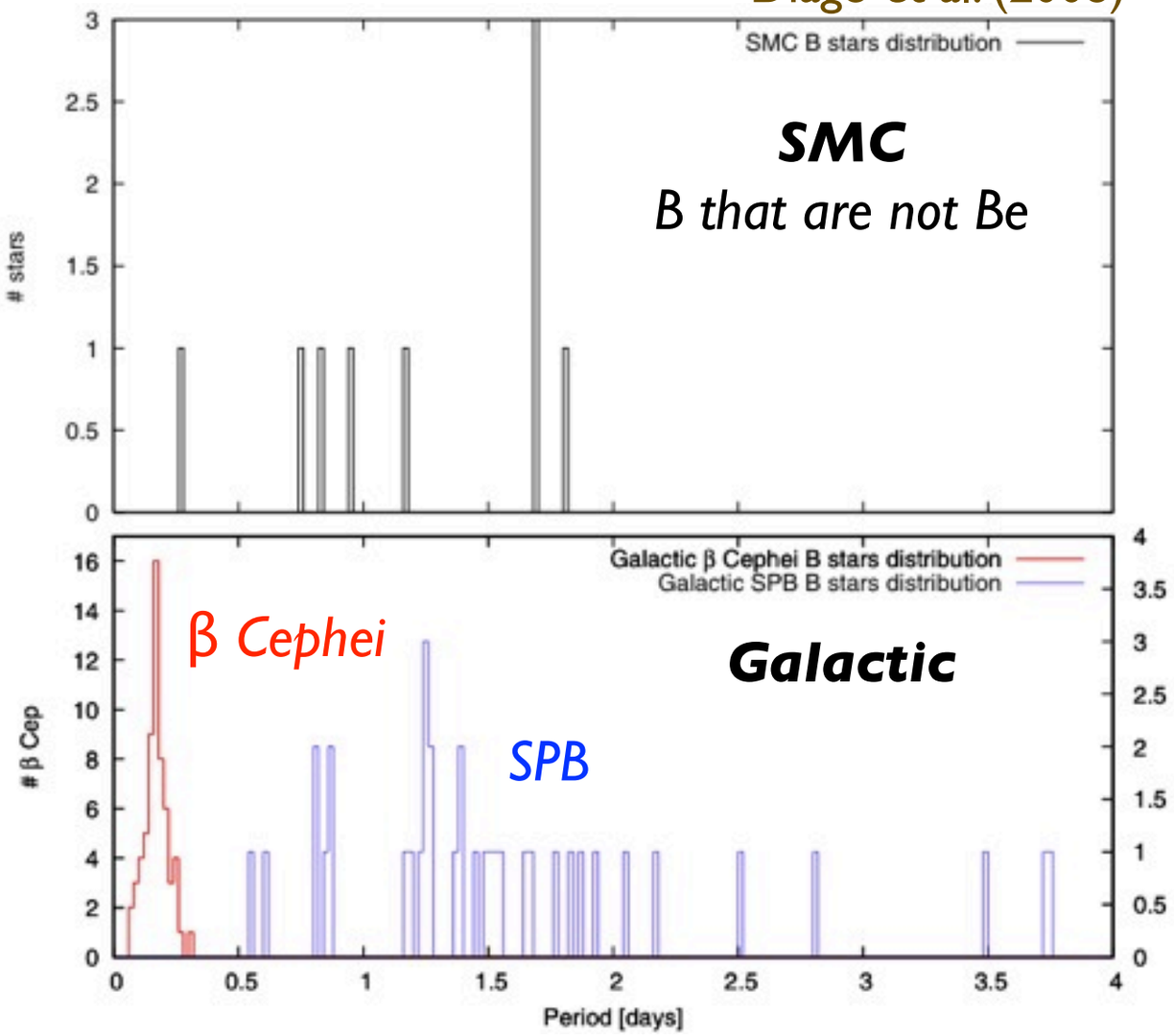


higher Z ?

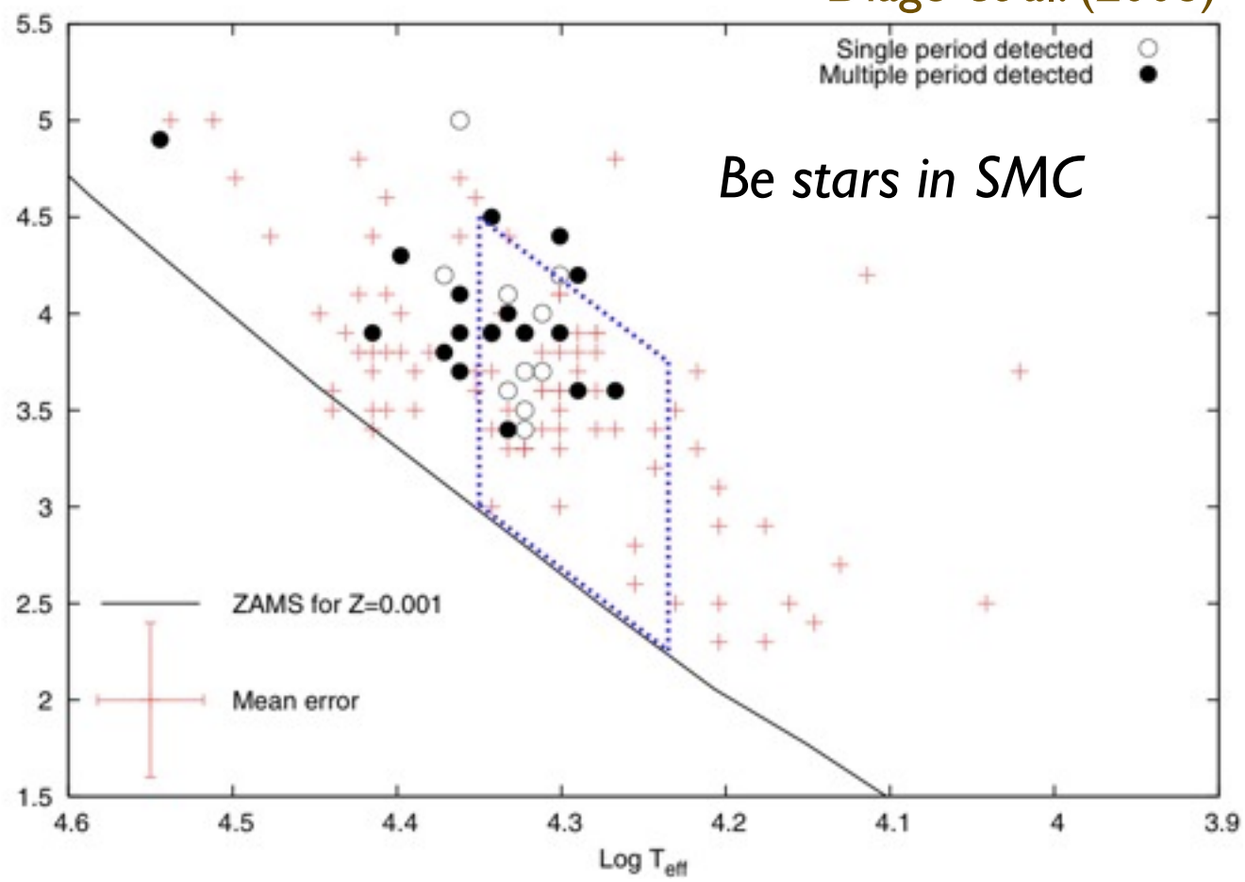
Pulsating B stars: observations at low Z

From MACHO survey of the SMC

Diago et al. (2008)



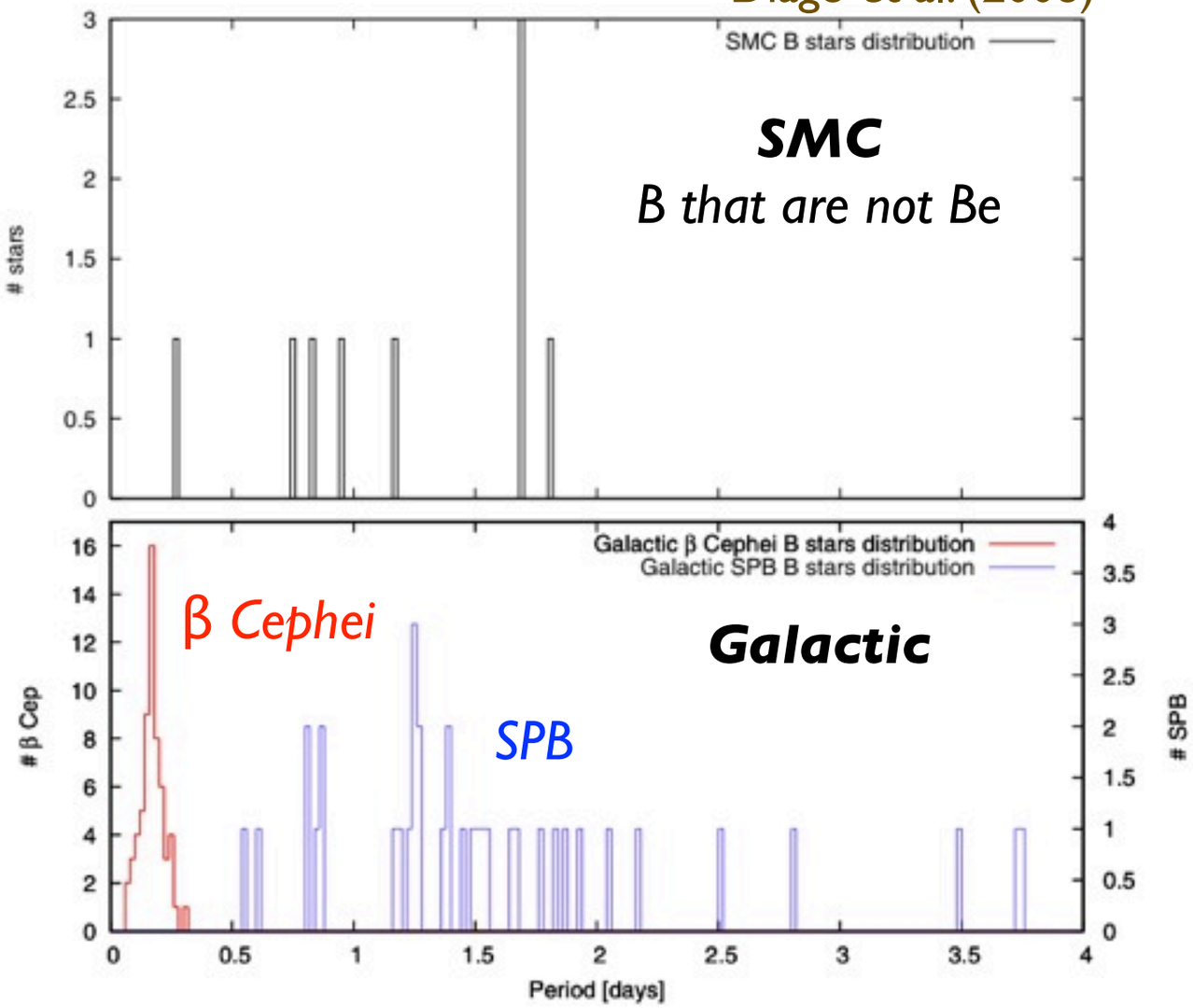
Diago et al. (2008)



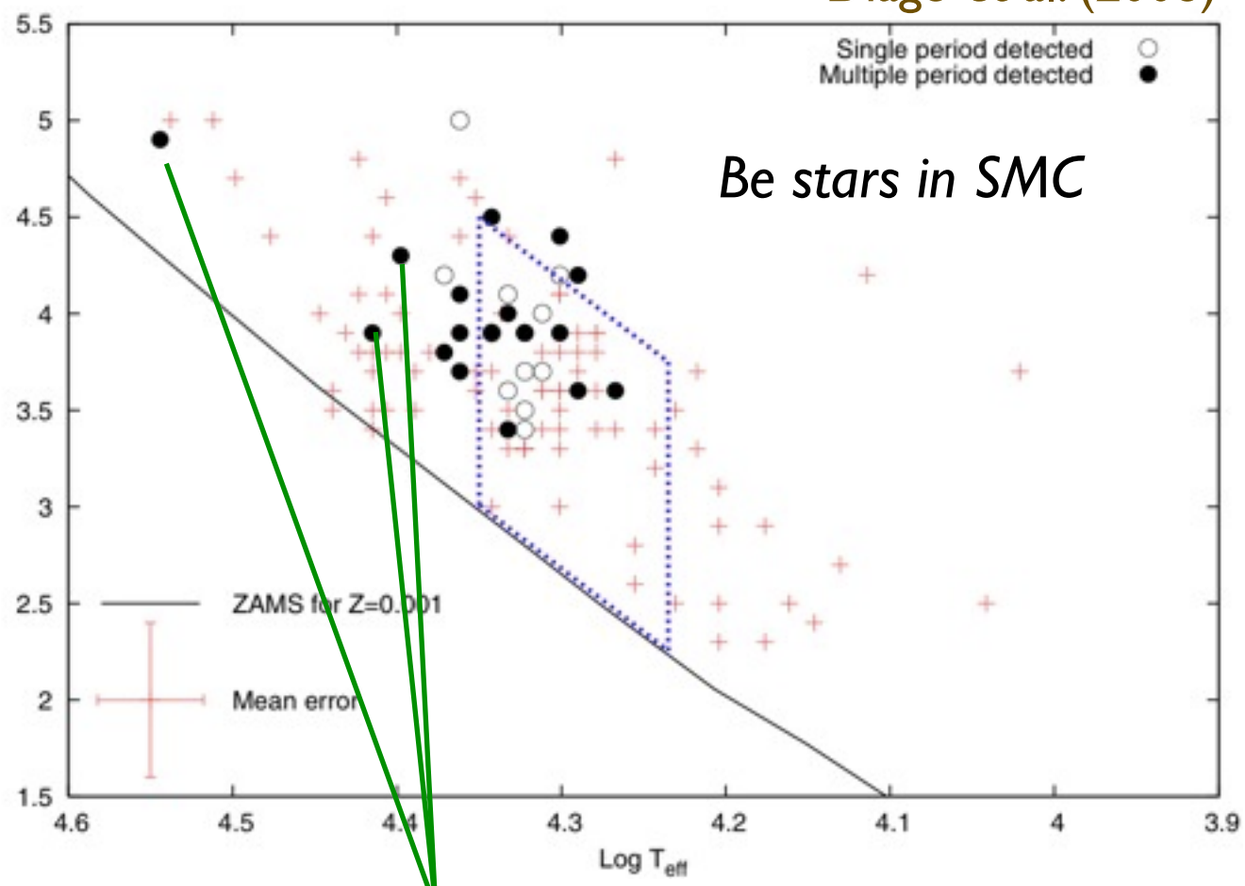
Pulsating B stars: observations at low Z

From MACHO survey of the SMC

Diago et al. (2008)



Diago et al. (2008)

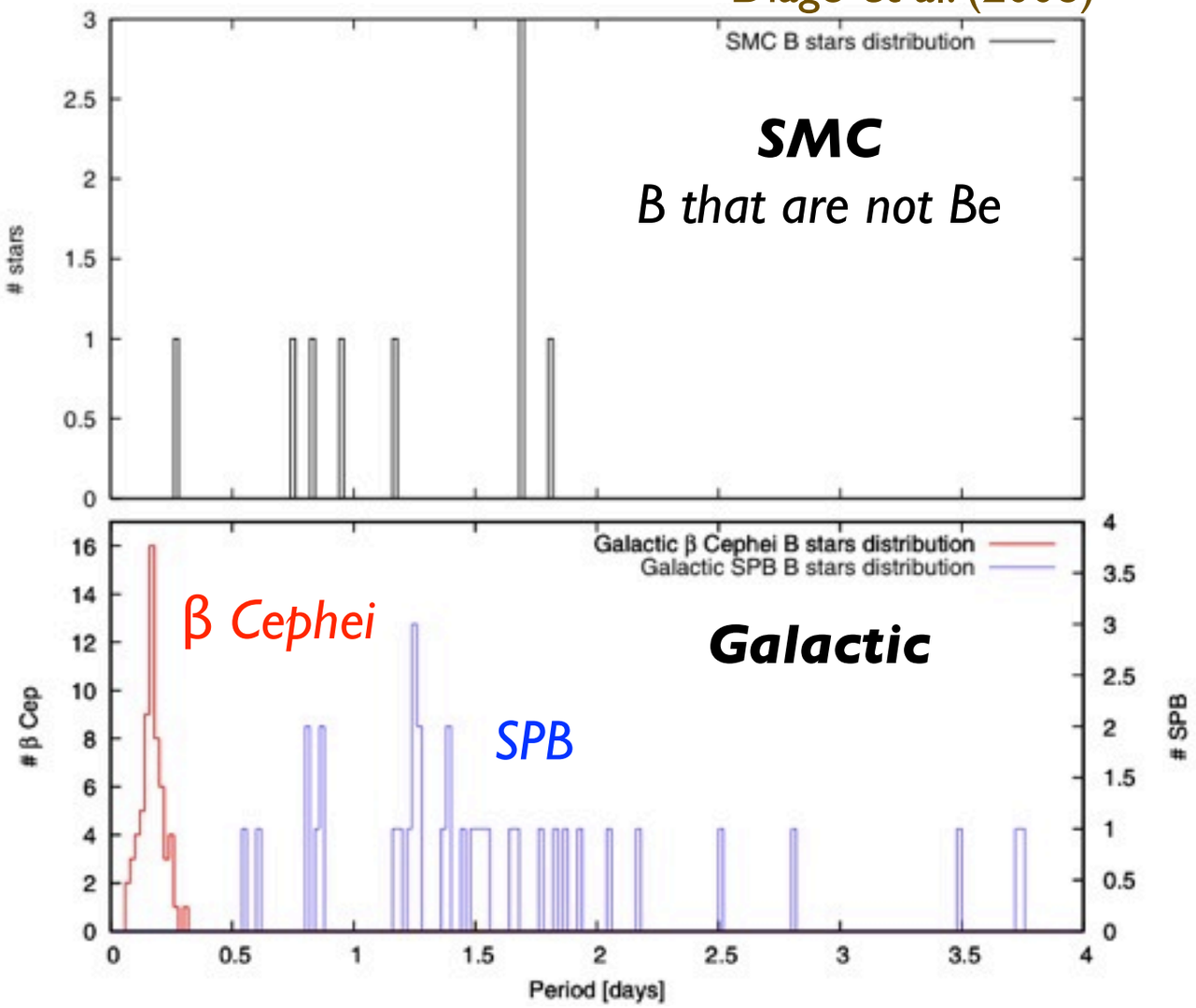


most likely β Cephei have P < 0.3 d

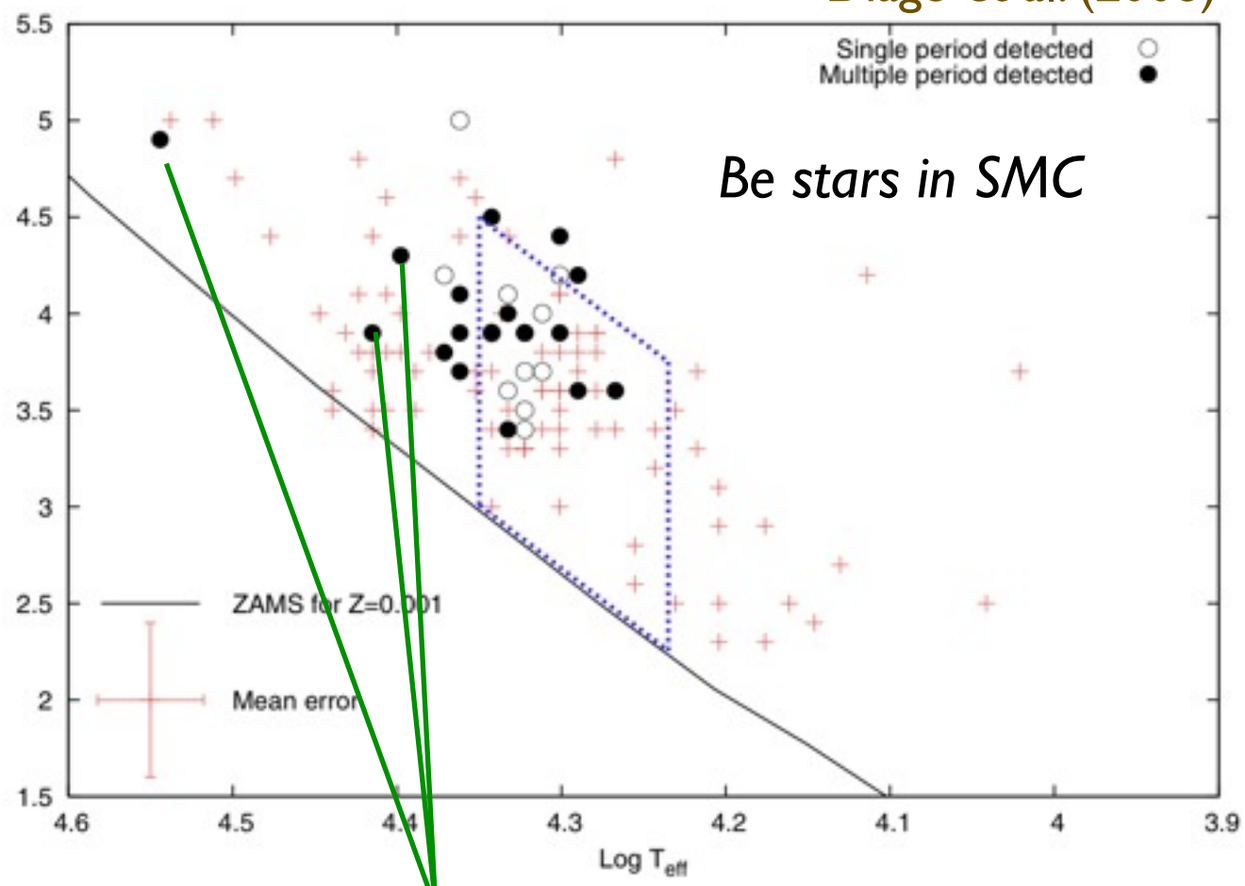
Pulsating B stars: observations at low Z

From MACHO survey of the SMC

Diago et al. (2008)



Diago et al. (2008)



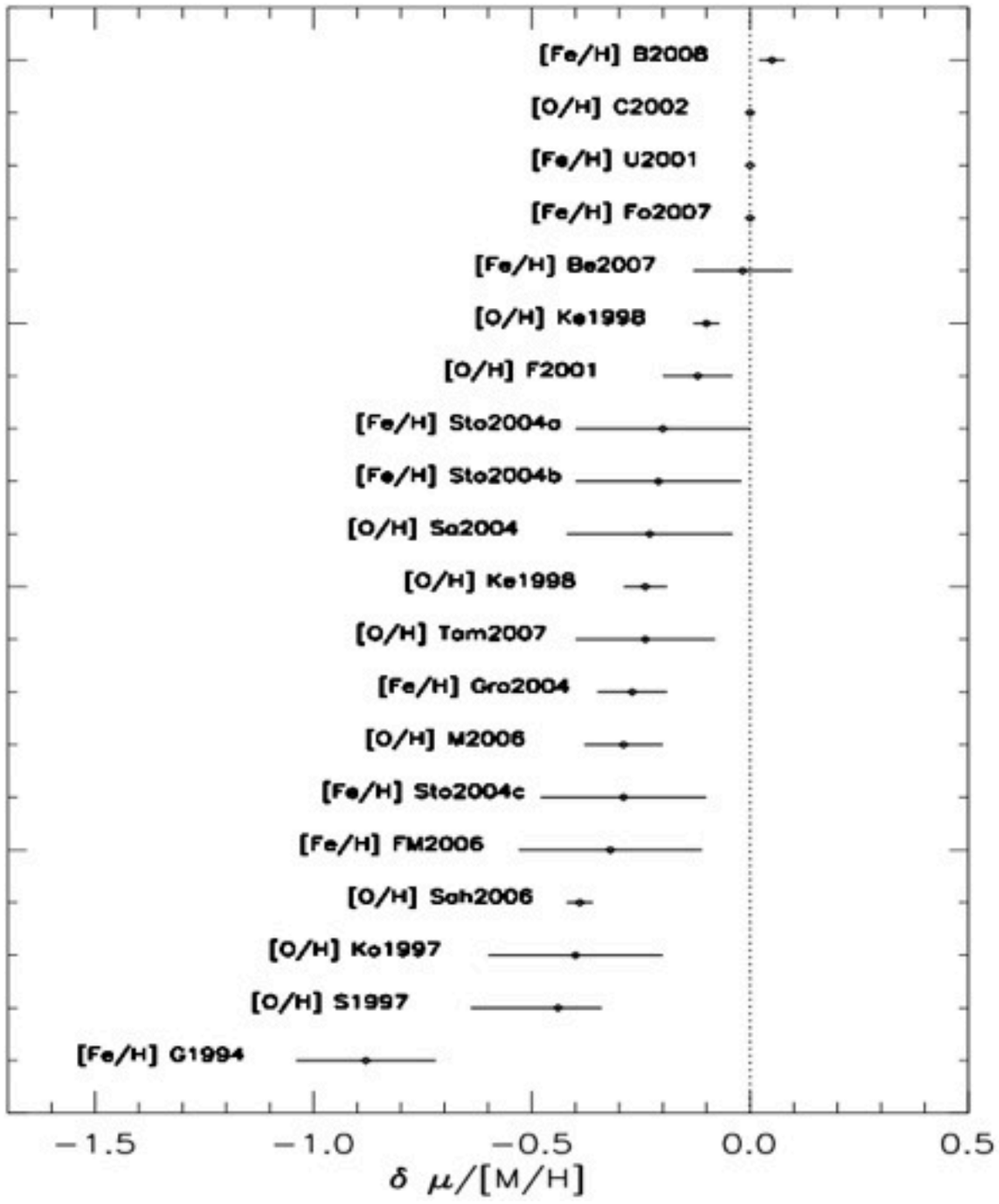
most likely β Cephei have P < 0.3 d

Diago et al. (2010)

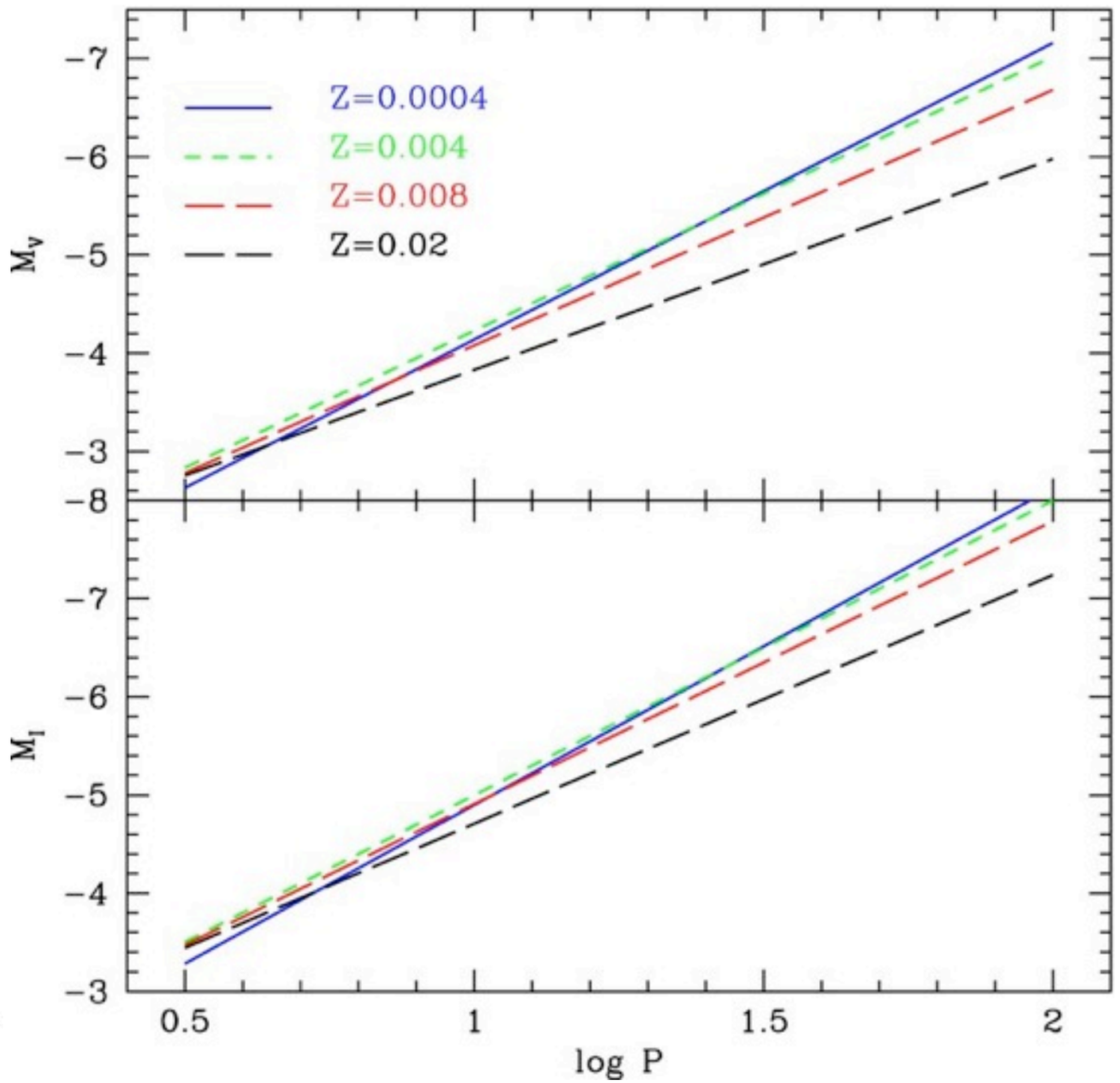
	MW	*LMC*	*SMC*
Pulsating B	16 %	6.9 %	4.9 %
Pulsating Be	74 %	14.8 %	24.6 %

Stellar pulsations : Cepheids

Romaniello et al. (2008)



Marconi et al. (2010)



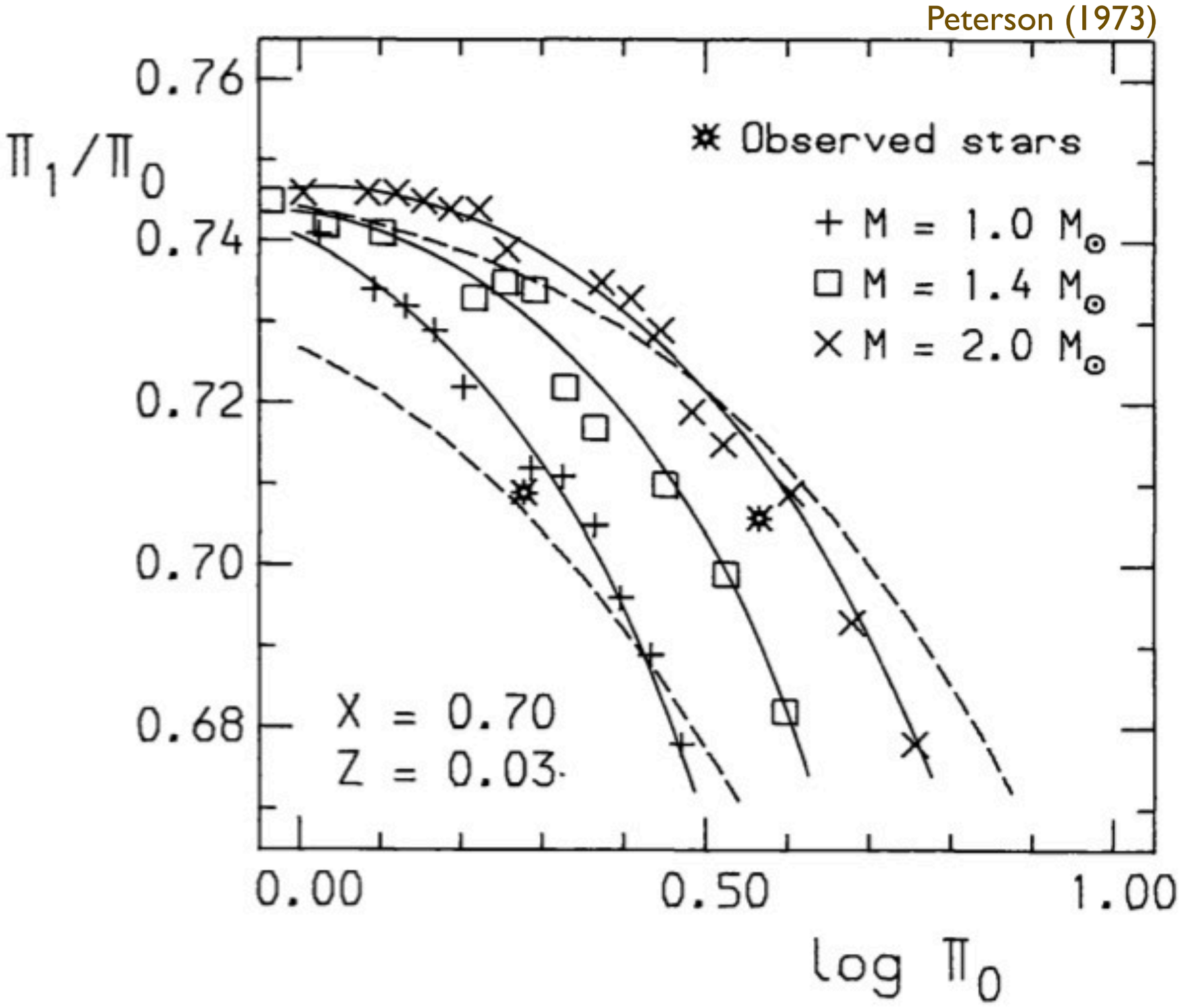
Metal-rich Cepheids brighter than metal-poor ones

See Lemasle's talk

Beat Cepheids

Cepheids pulsating in two modes: F/O1 or O1/O2

Peterson (1973)

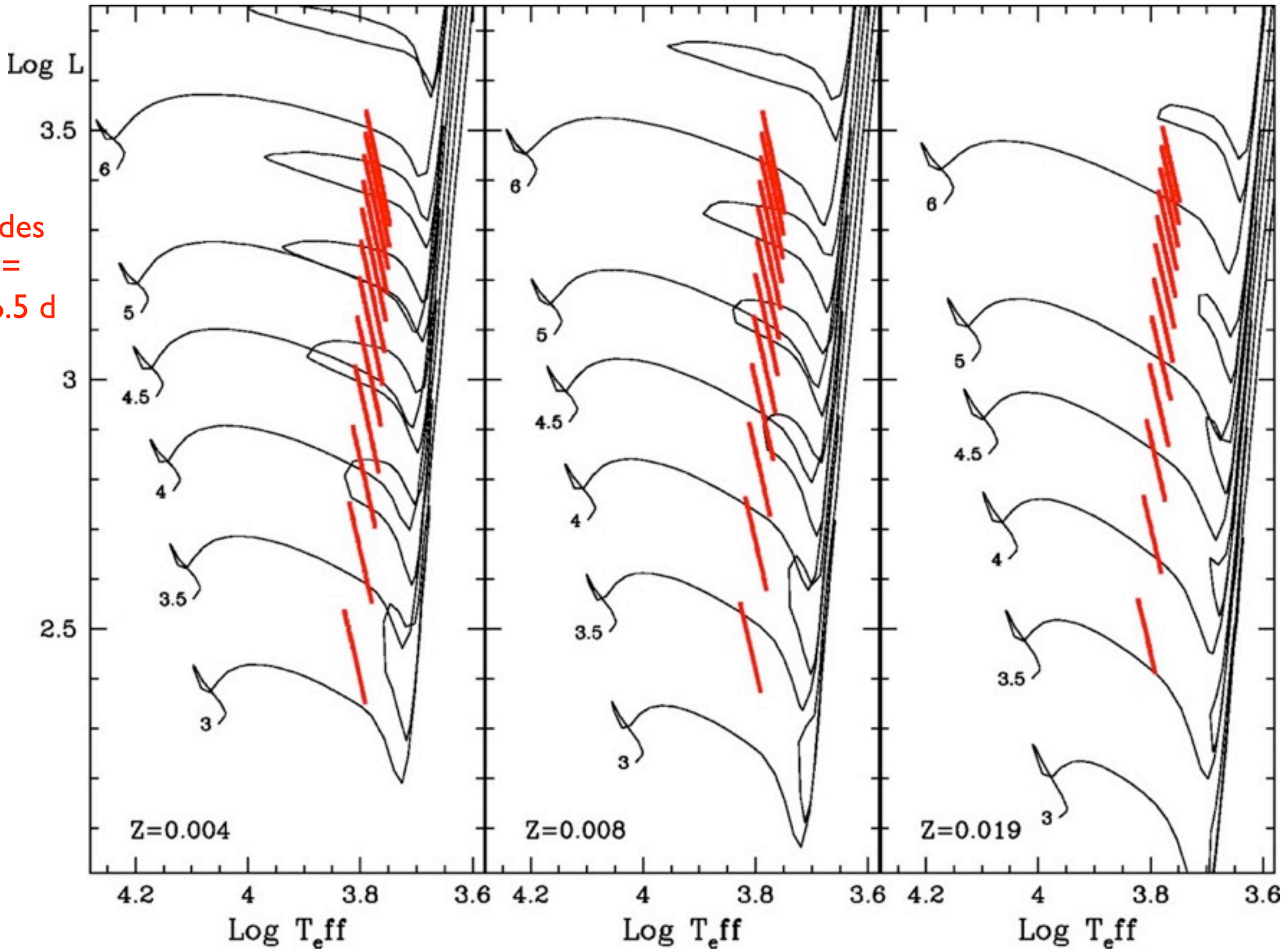


Peterson diagrams

Beat Cepheids

Buchler, Szabo (2007)

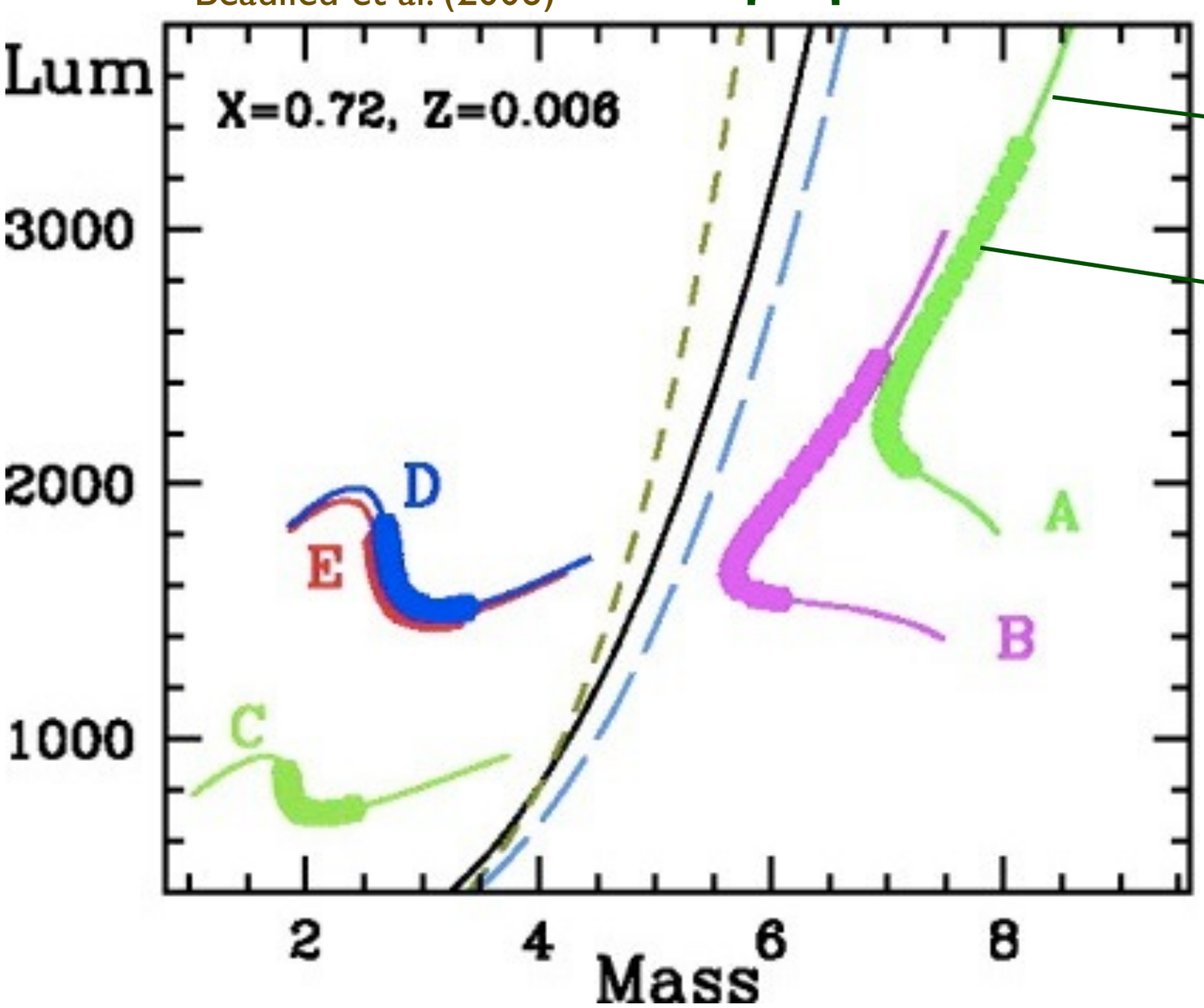
F/O1 modes with P_0 = 1...[0.5]...6.5 d



Beat Cepheids

5 beat cepheids in M33 → P_0, P_1

Locii from evolutionary tracks

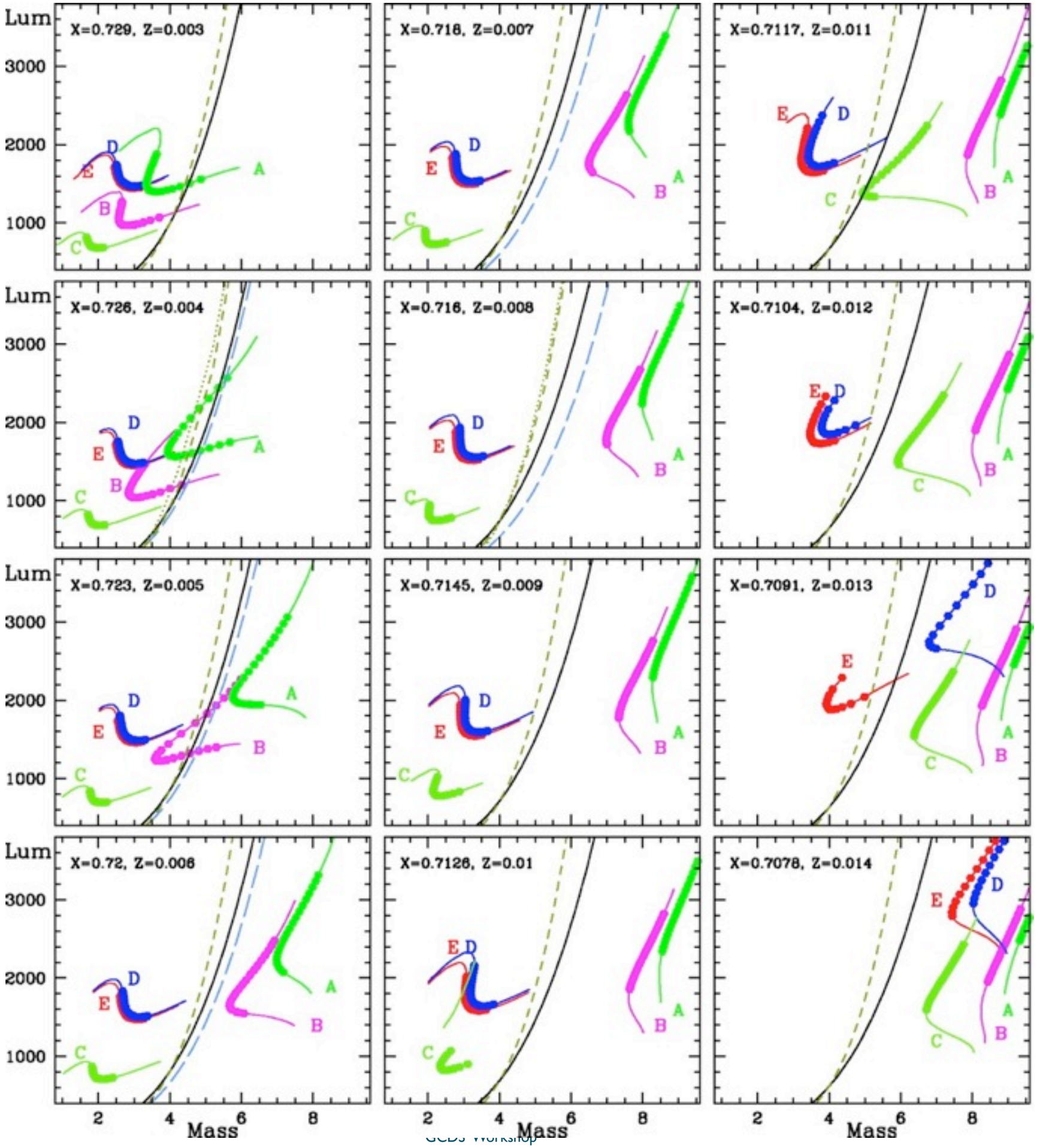


Models with P_0 and P_1 at different T_{eff}

Those that are unstable in both P_0, P_1

Very sensitive to Z

Beat Cepheids

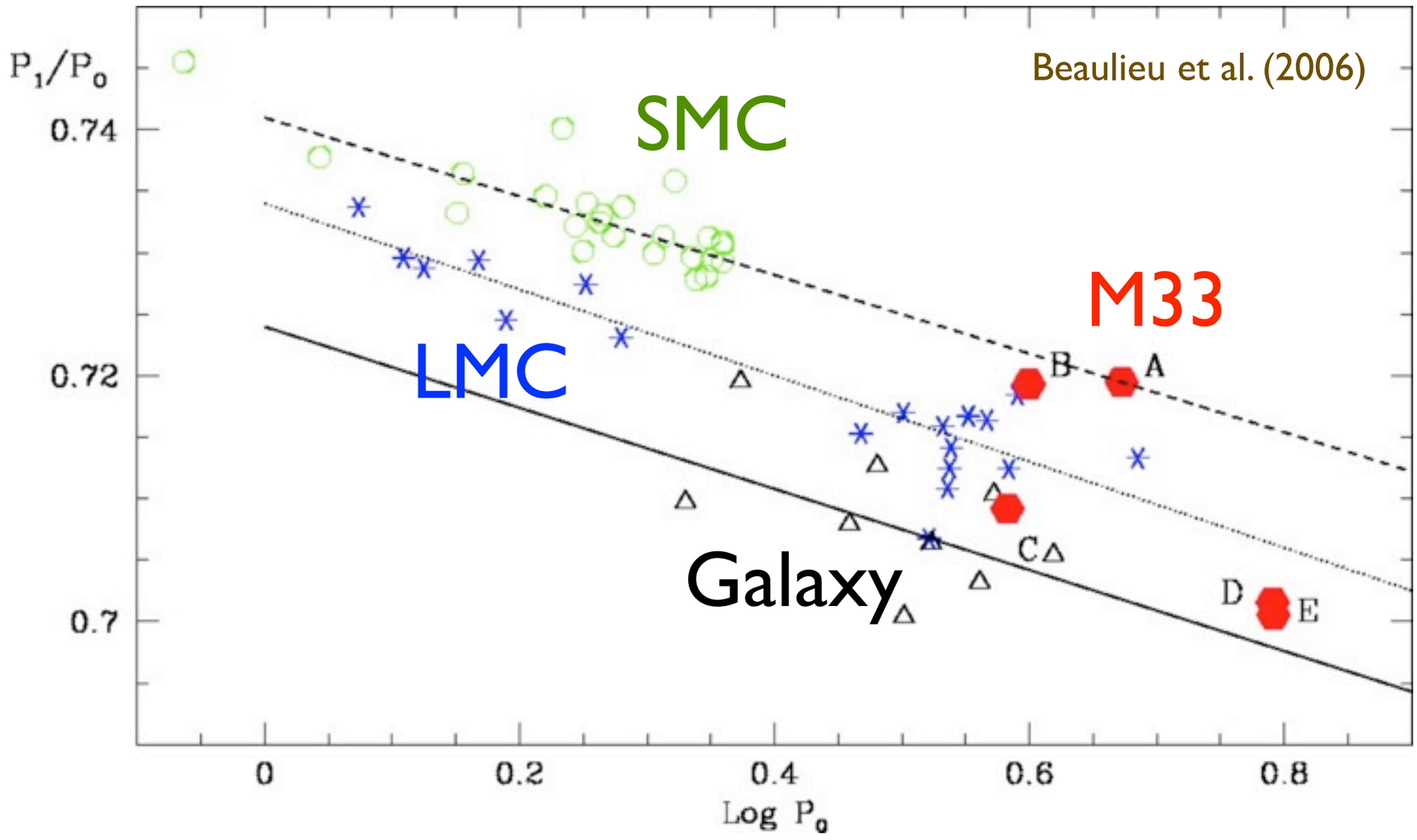


Beaulieu et al. (2006)

METALLICITIES OF M33 BEAT CEPHEIDS

ID	P_{10}	Distance (kpc)	[O/H] (G97)	Z (G97)	[O/H] (C06)	Z (C06)	Z from BCs
A	0.7195	3.5	−0.355	0.005	−0.492	0.003	0.004
B	0.7190	3.1	−0.311	0.006	−0.487	0.003	0.005
C	0.7091	2.3	−0.223	0.008	−0.478	0.004	0.011
D	0.7015	1	−0.080	0.013	−0.462	0.004	0.0125
E	0.7005	1	−0.080	0.013	−0.462	0.004	0.0135

NOTES.—Shown are the period ratio (P_{10}), deprojected galactocentric distance, [O/H] and Z metallicities from Garnett et al. (1997) and Crockett et al. (2006), and Z from the BCs.

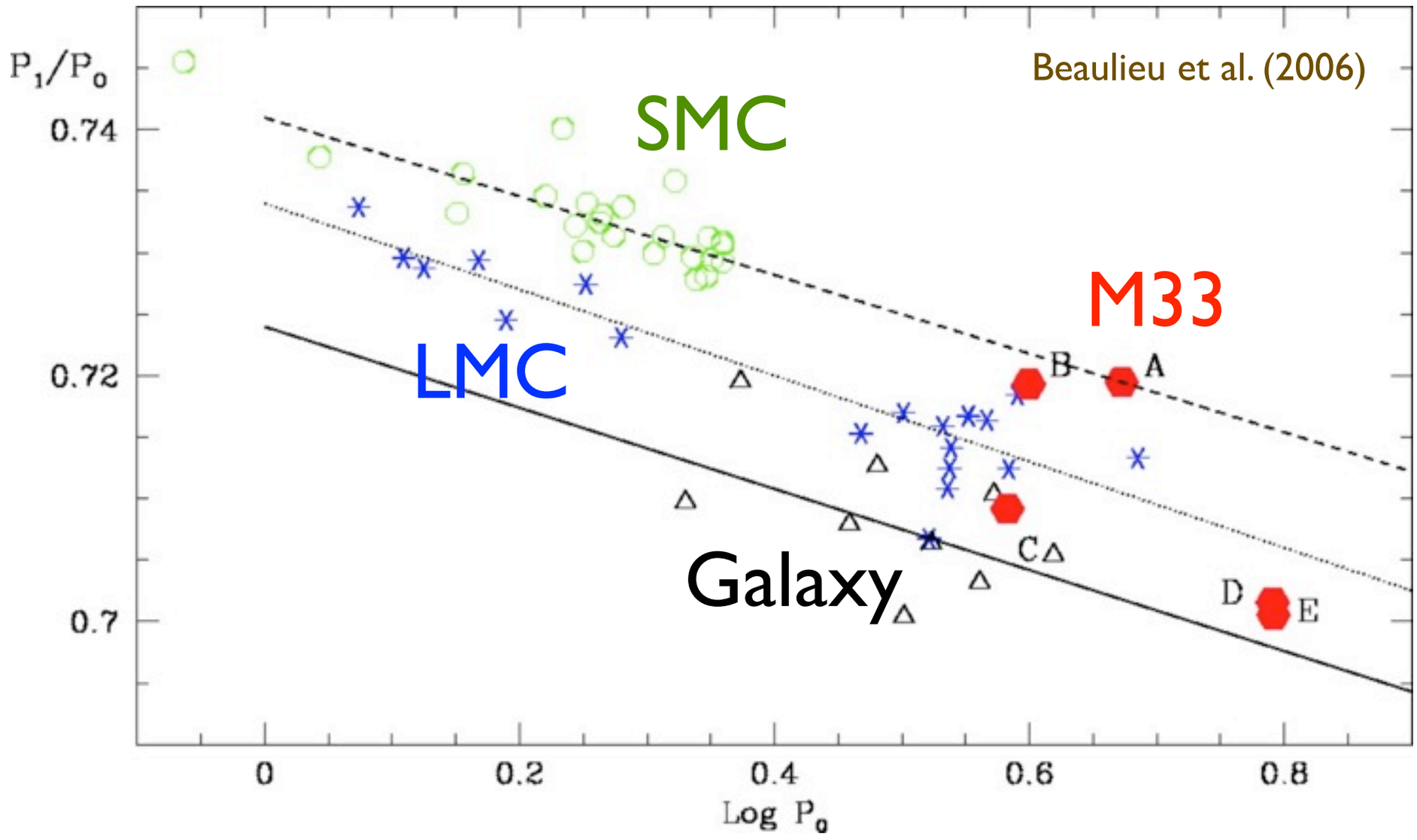


METALLICITIES OF M33 BEAT CEPHEIDS

ID	P_{10}	Distance (kpc)	[O/H] (G97)	Z (G97)	[O/H] (C06)	Z (C06)	Z from BCs
A	0.7195	3.5	−0.355	0.005	−0.492	0.003	0.004
B	0.7190	3.1	−0.311	0.006	−0.487	0.003	0.005
C	0.7091	2.3	−0.223	0.008	−0.478	0.004	0.011
D	0.7015	1	−0.080	0.013	−0.462	0.004	0.0125
E	0.7005	1	−0.080	0.013	−0.462	0.004	0.0135

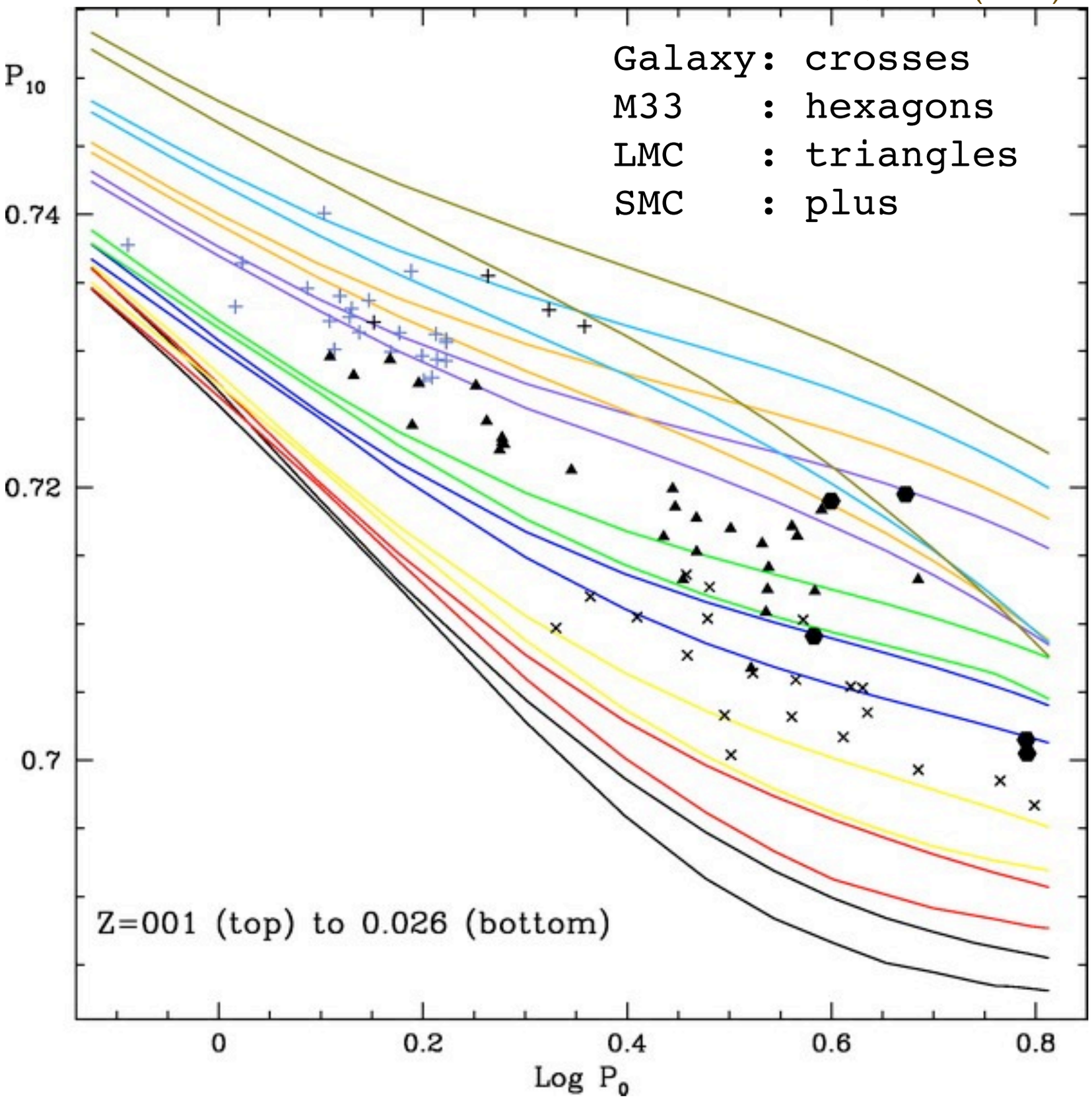
NOTES.—Shown are the period ratio (P_{10}), deprojected galactocentric distance, [O/H] and Z metallicities from Garnett et al. (1997) and Crockett et al. (2006), and Z from the BCs.

galactic gradient



Beat Cepheids: dependence on metallicity

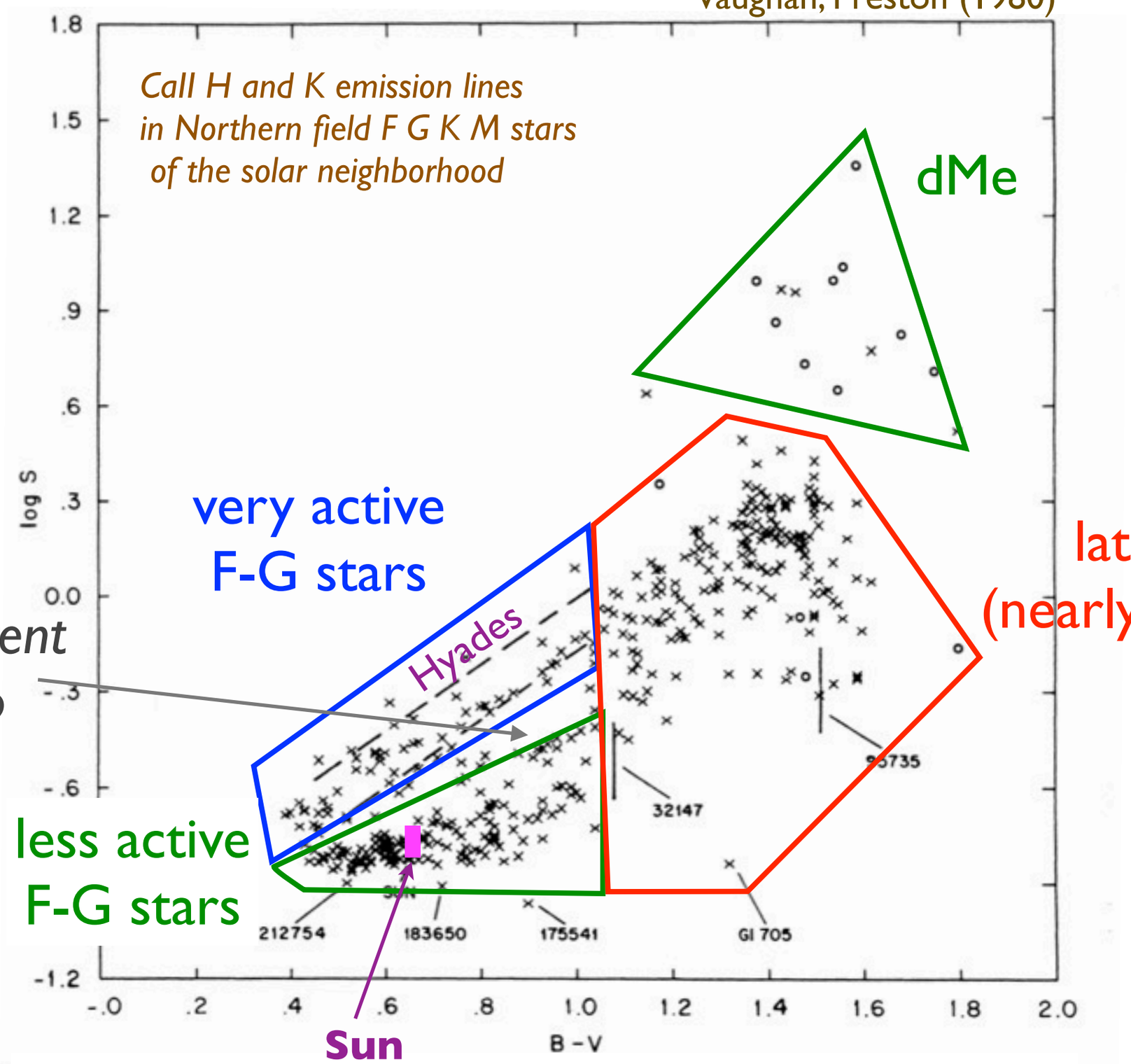
Buchler, Szabo (2007)



Chromospherically active stars

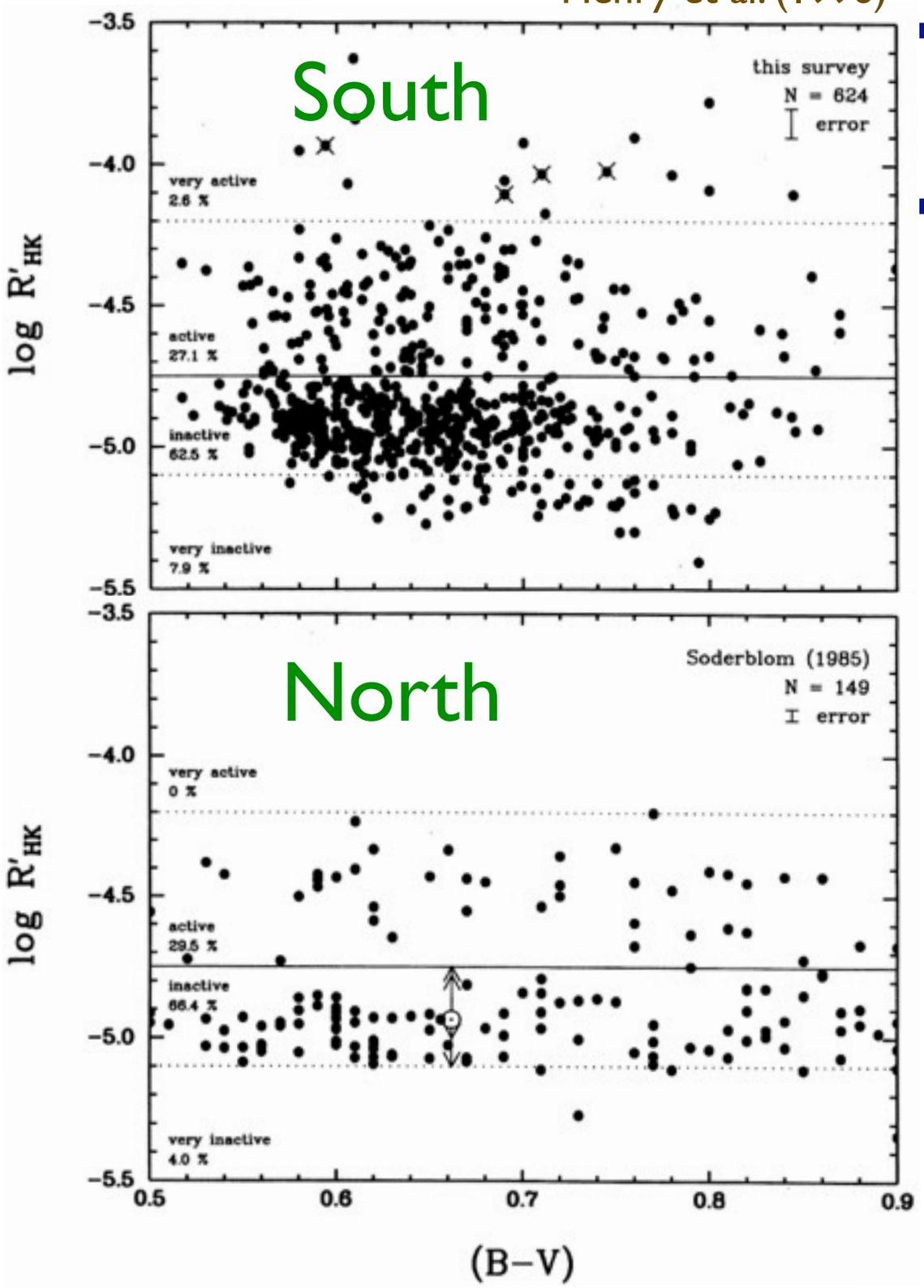
Activity closely related to **stellar rotation**
through the **stellar dynamo** generating the surface **magnetic fields**

Vaughan, Preston (1980)



Active solar-type stars

Henry et al. (1996)



Very active : 2.6%

Crosses: binaries

Others : very young?

Active : 27.1%

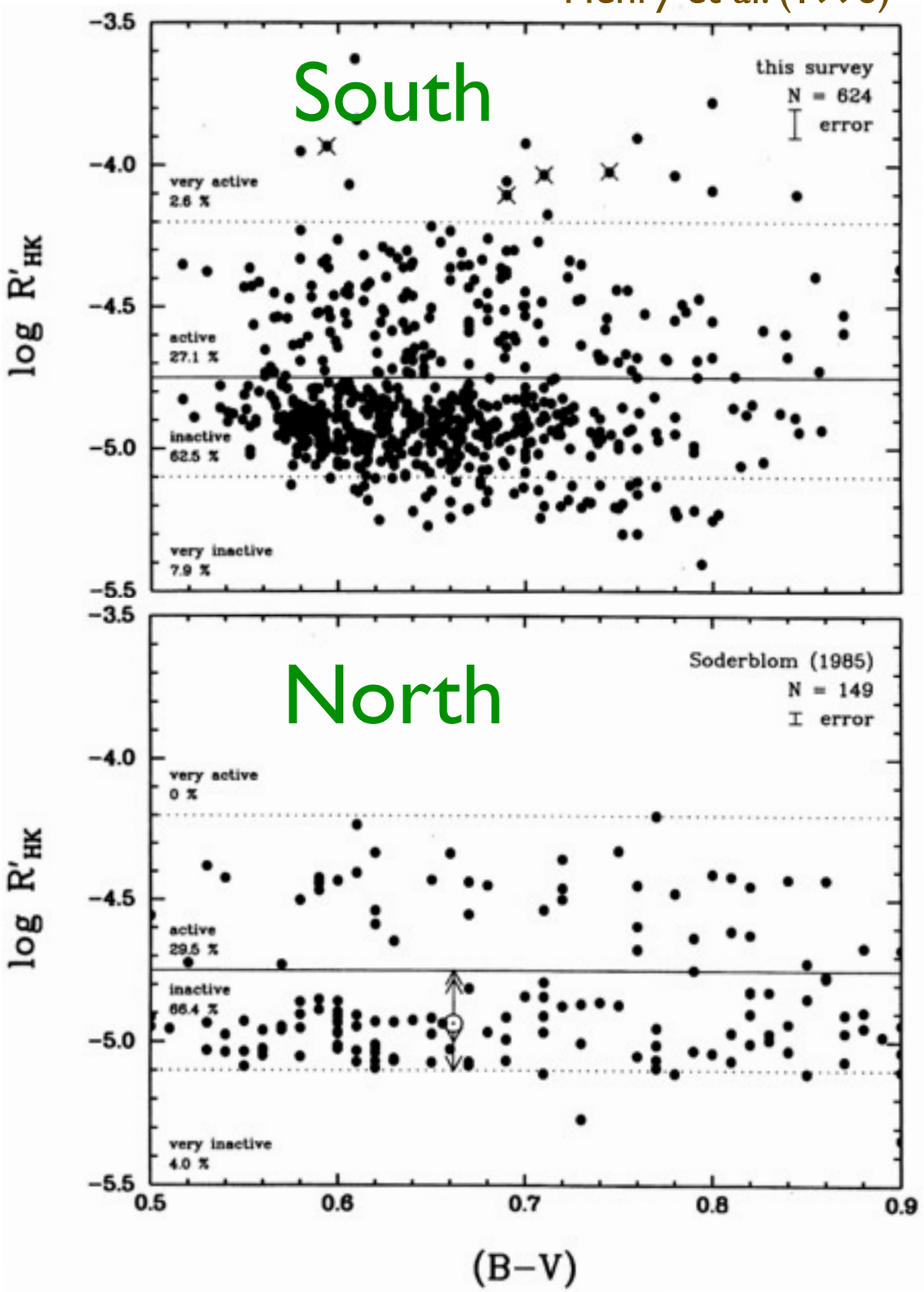
Inactive : 62.5%

Very inactive : 7.9%

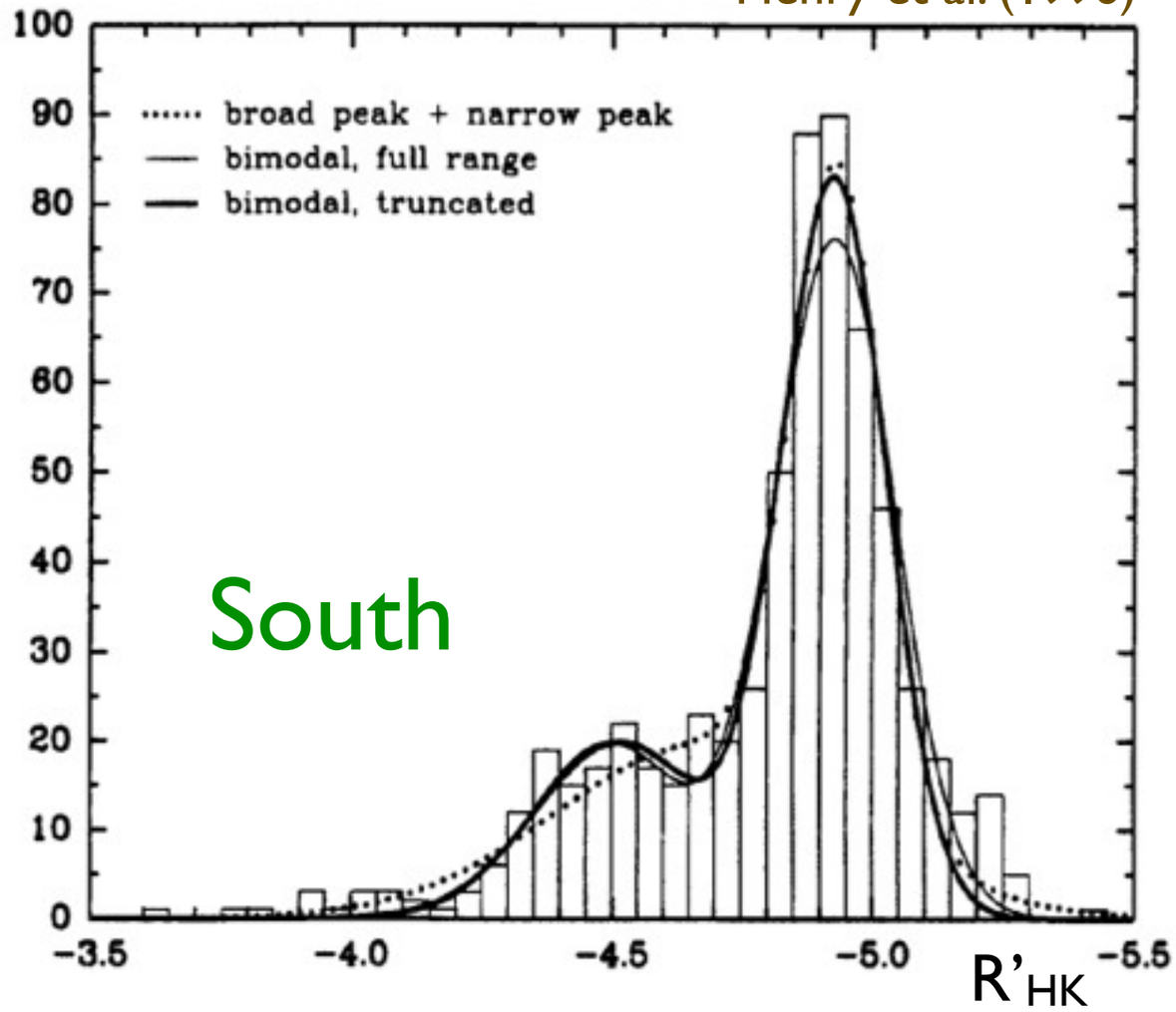
In a Maunder Minimum type phase?

Active solar-type stars

Henry et al. (1996)



Henry et al. (1996)



Vaughan-Preston gap confirmed, but partially filled.

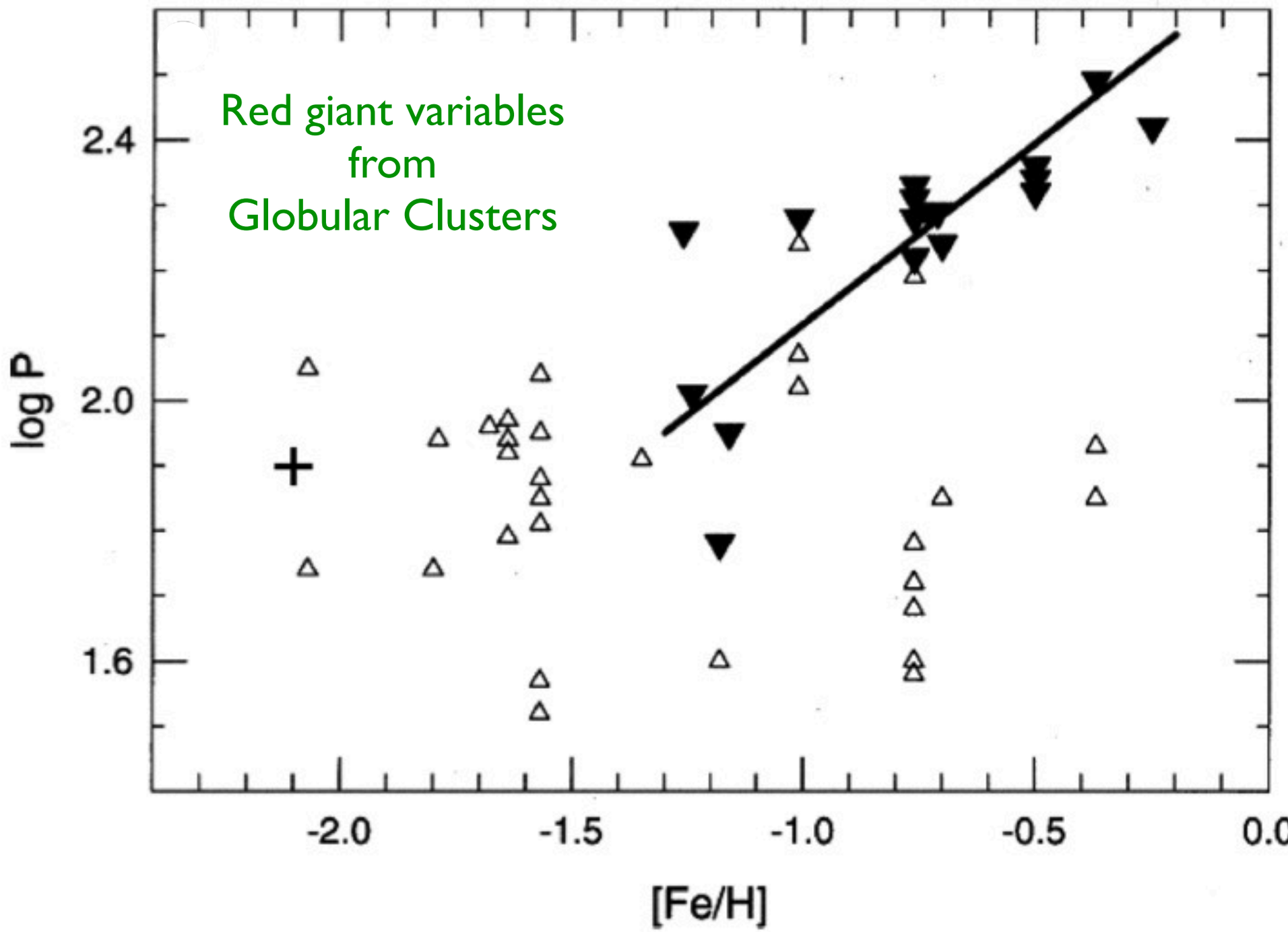
Origin of the gap under debate

- **Spotted stars**
  - ➙ tests of loss of angular momentum
- **Study in Open Clusters**
  - ➙ known ages
- **Metallicity dependence?**

Long period variables

Metallicity dependence?

Frogel & Whitelock (1998)

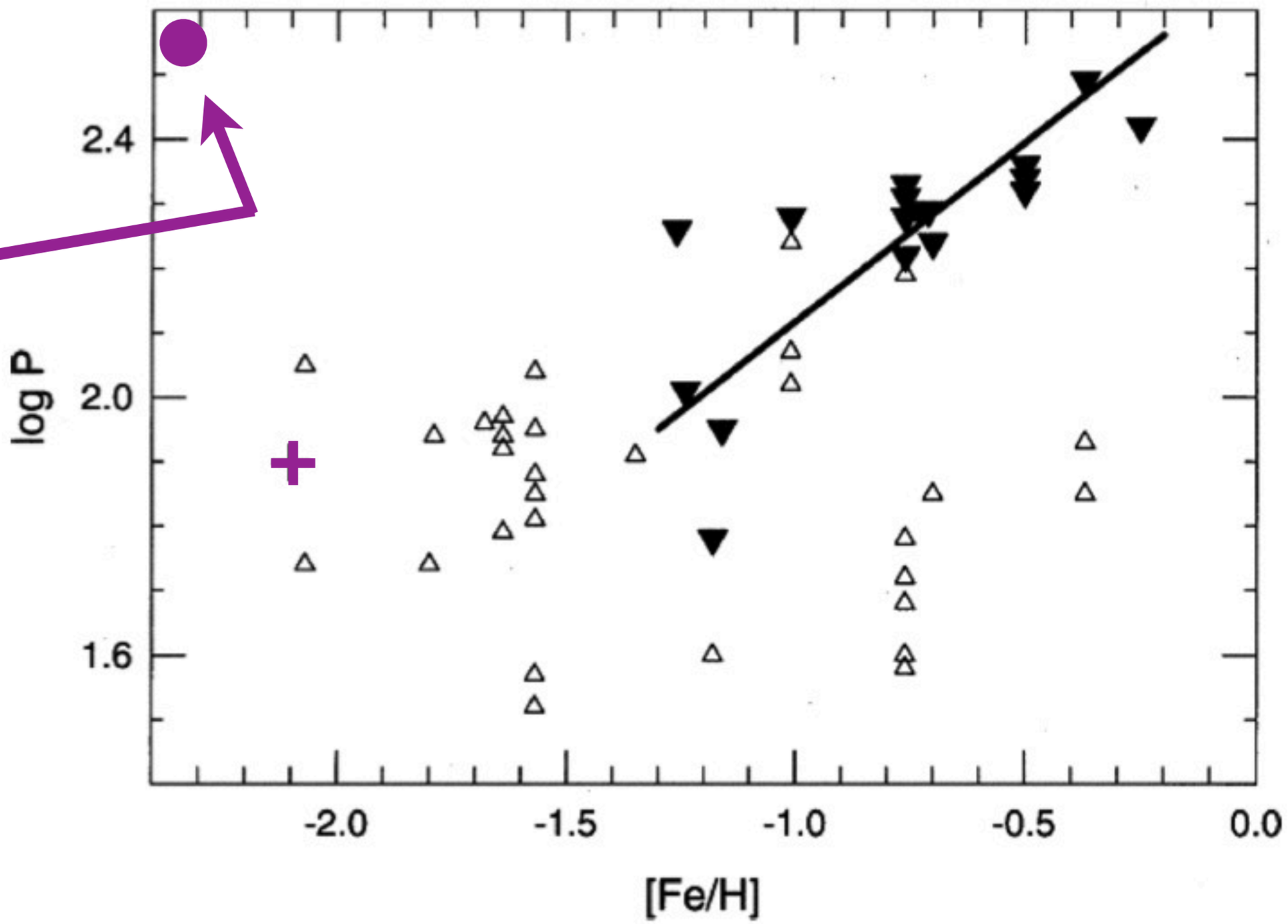


No LPV in metal-poor globular clusters [Fe/H]<-1.5 ...

Long period variables

... until a study by McDonald et al. (2010)

McDonald et al. (2010)



in M15

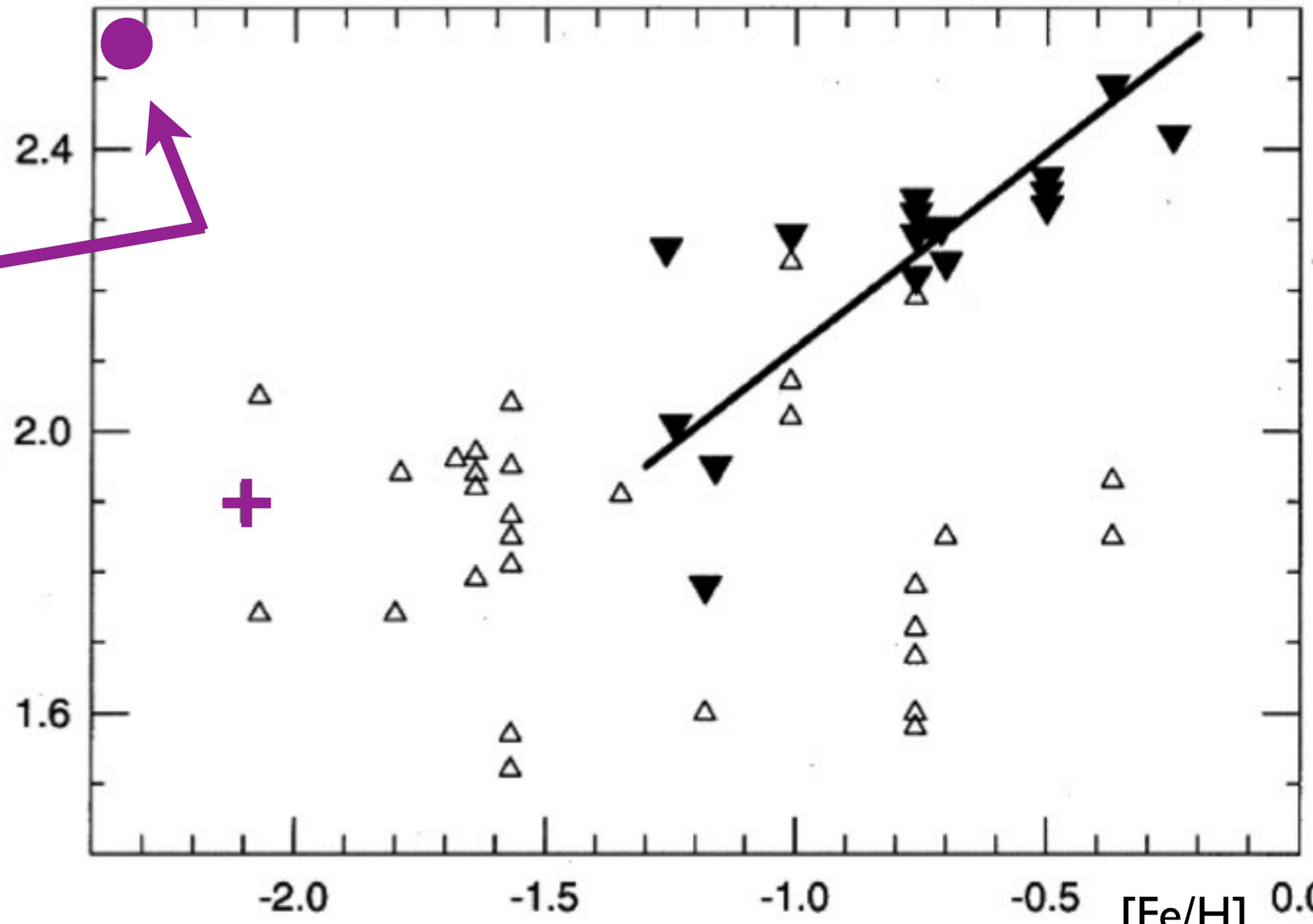
at [Fe/H]~-2.3

Long period variables

McDonald et al. (2010)

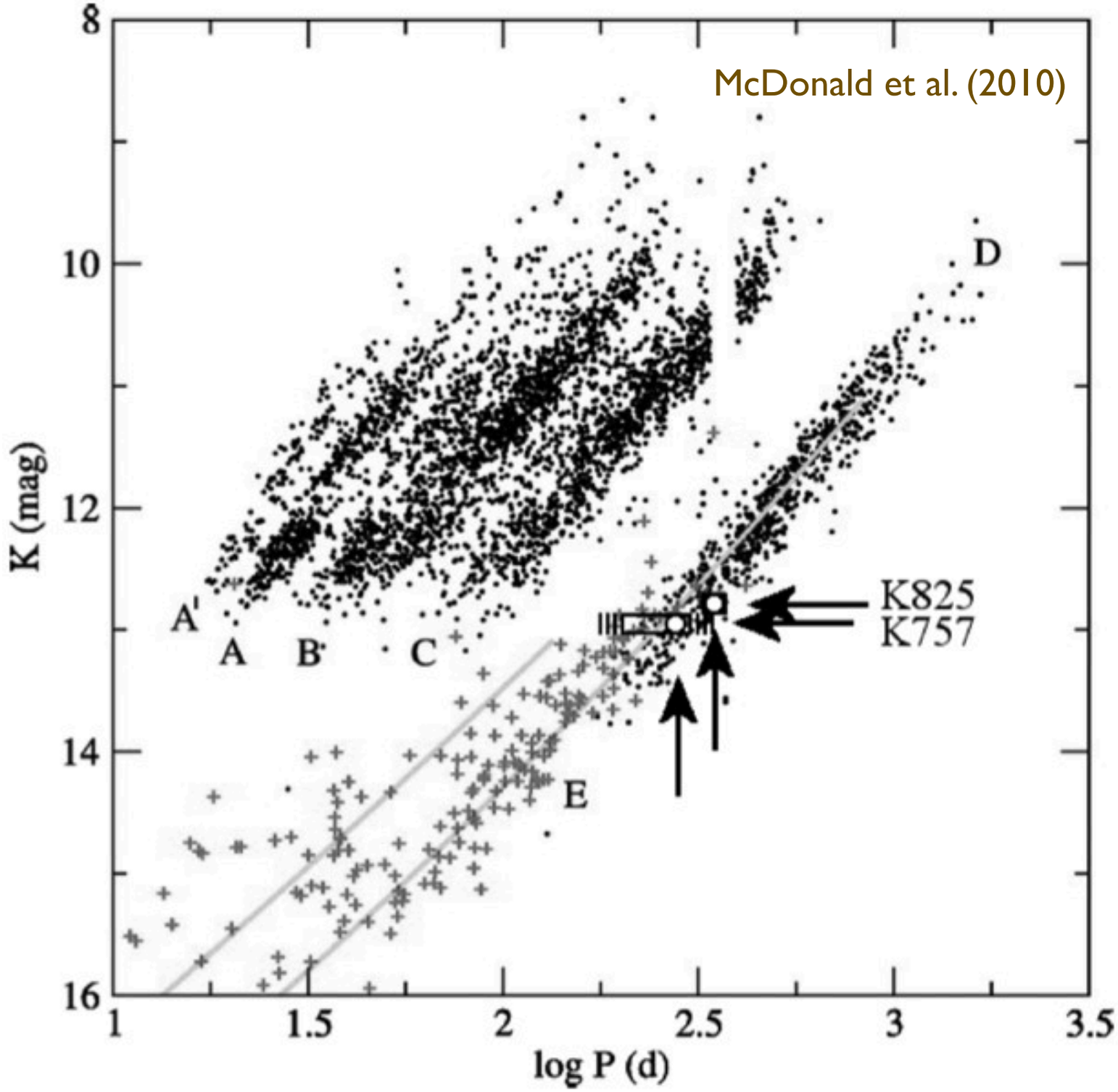
in M15

at [Fe/H]~-2.3



- Have **smaller amplitudes** than the metal-rich LPVs
- Are both ***"Long Secondary Periods"*** but the ***only*** period found.

Why ?



- Have **smaller amplitudes** than the metal-rich LPVs
- Are both ***"Long Secondary Periods"*** but the ***only*** period found.

Why ?

Conclusions

- Study of variable stars
  - Stellar physics
  - Stellar populations
  - Distances

- Need of multi-epoch photometry for identification
  - MACHO, OGLE, EROS, ...
  - Gaia: dedicated coordination unit (CU7) for the processing of variable stars to populate the Gaia catalogues

Predictions for Gaia

beta Cephei	3000
SPBs	15000
Cepheids	2000-8000
Miras	140,000-150,000

Eyer & Cuypers (2000)

- GCDS
  - stellar characterization

- **Remember:** *input of SE4 cases to SE1+2 and SE3 ...*
  ... if you are interested !