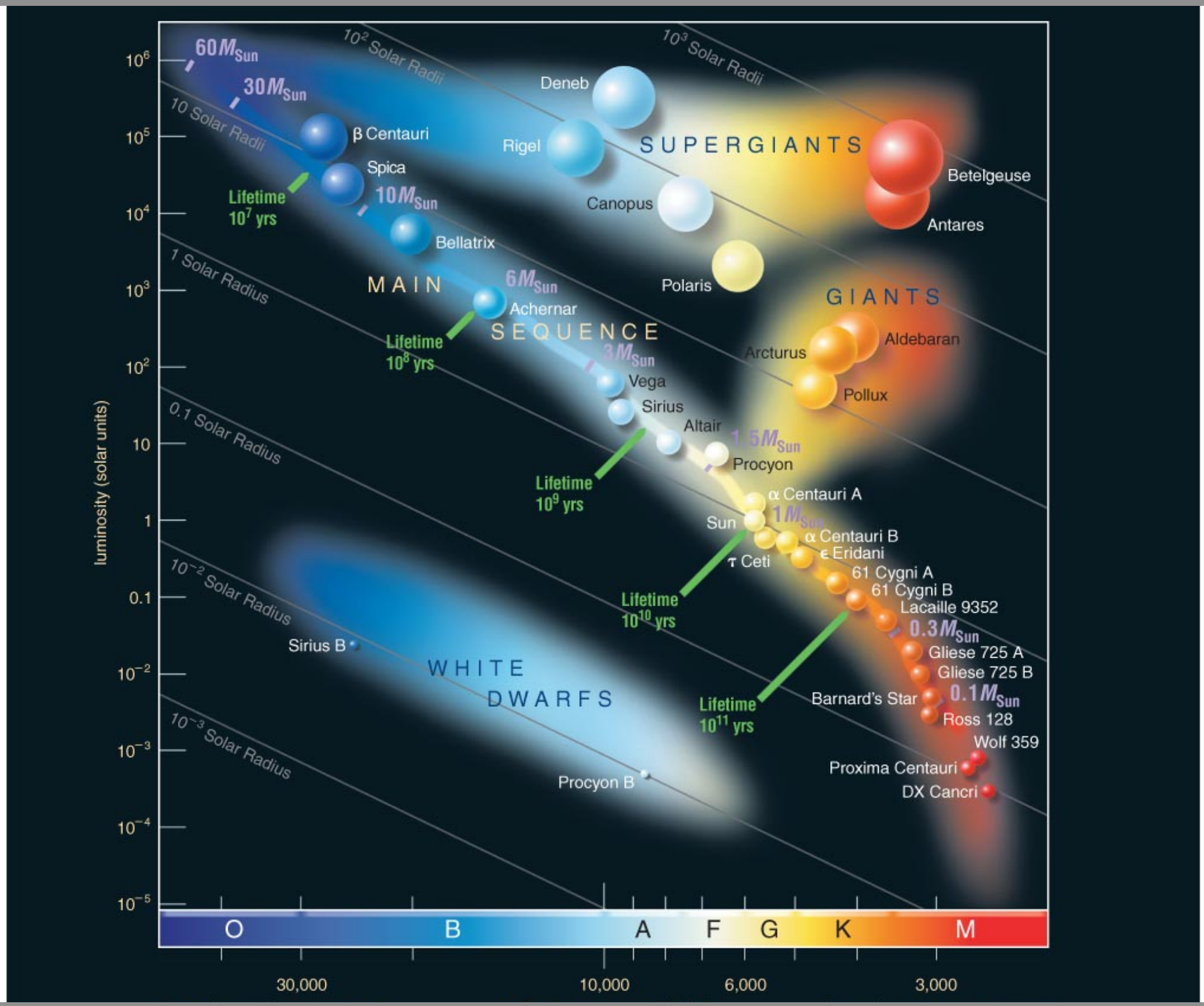
Near-Surface Convection in Massive Stars

What's going on at the surface of hot, massive stars?

Matteo Cantiello, KITP (UCSB)

(N.Langer, A.de Koter, J.S.Vink, A.Voegler, S.N.Shore, I.Brott, S.-C.Yoon,
D. Lennon, F. del Sordo, P. Käpylä, A. Brandenburg, J.Braithwaite,
M.Firnstein, F.Schiller, N.Przybilla)

Which stars is this talk about?



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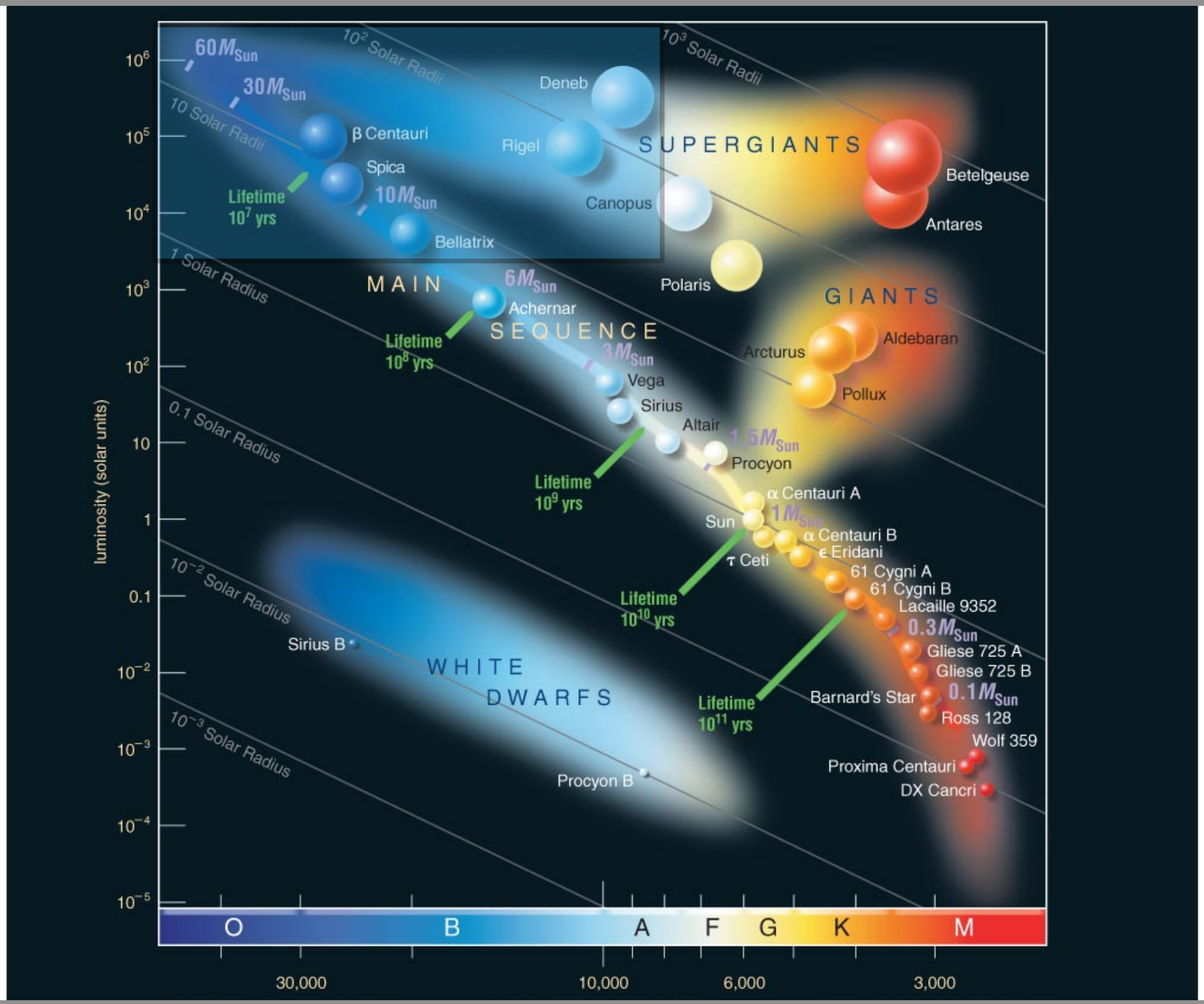


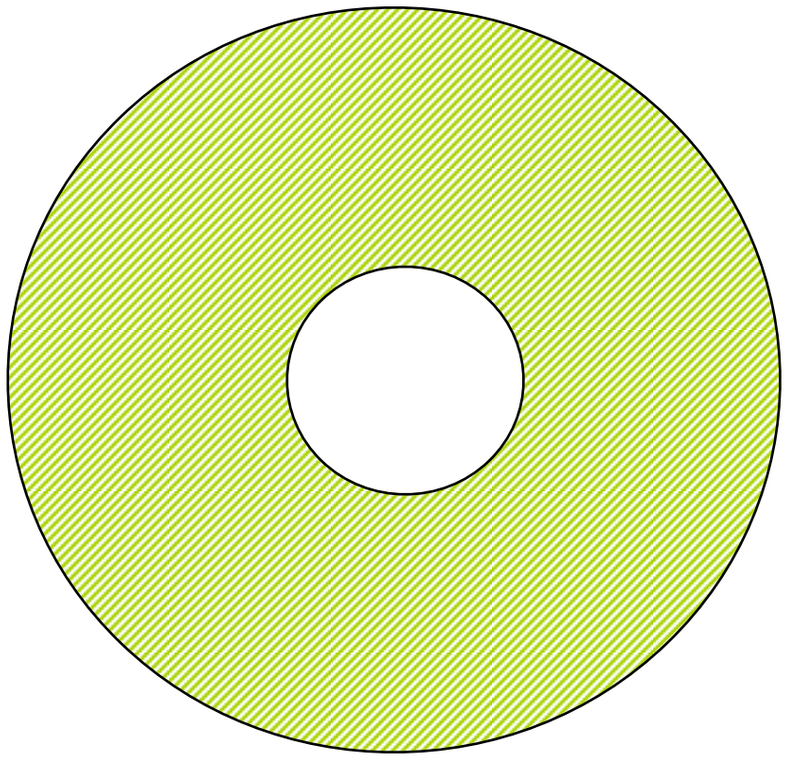
Outline of the talk

- Convection in hot, massive stars
  - Near-Surface convection (FeCZ)
- Observable consequences and implications for Asteroseismology
  - **Surface Turbulence**
  - **Solar-Like Oscillations**
  - **Surface Magnetic Fields / Spots**
- Conclusions

Convection in hot stars

Stellar structure

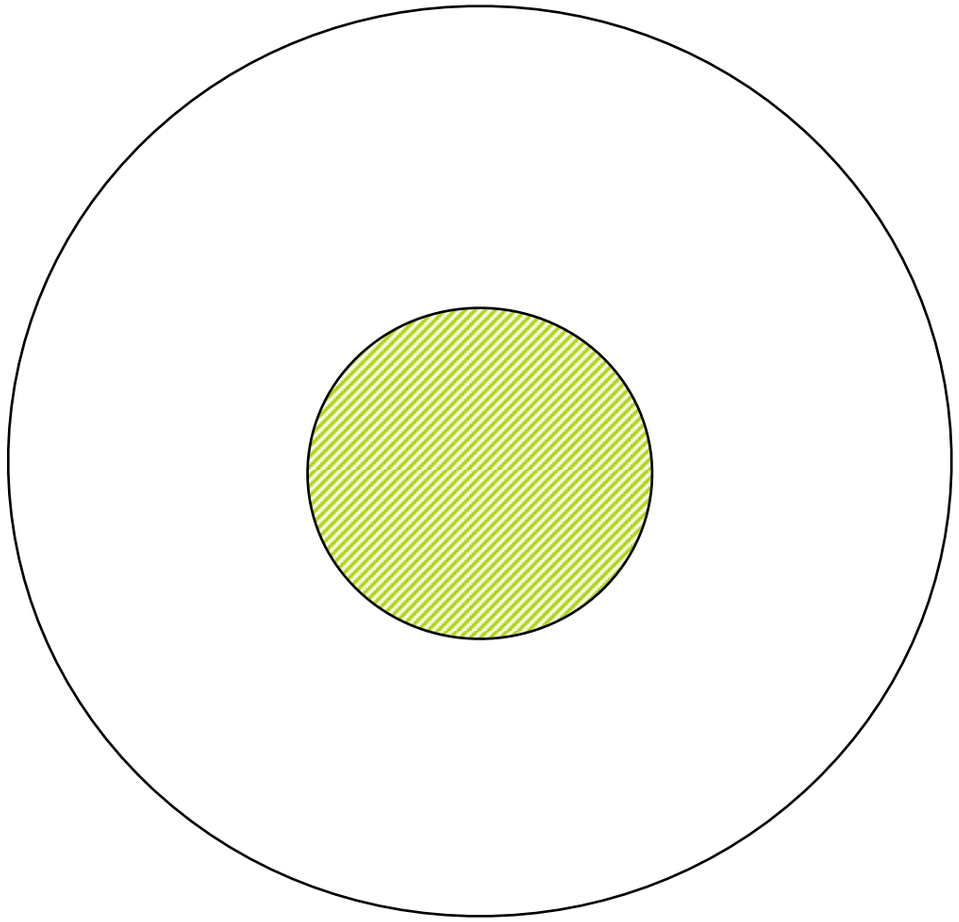
Low Mass stars



e.g $1M_{Sun}$

Radiative core
Convective envelope

Massive stars



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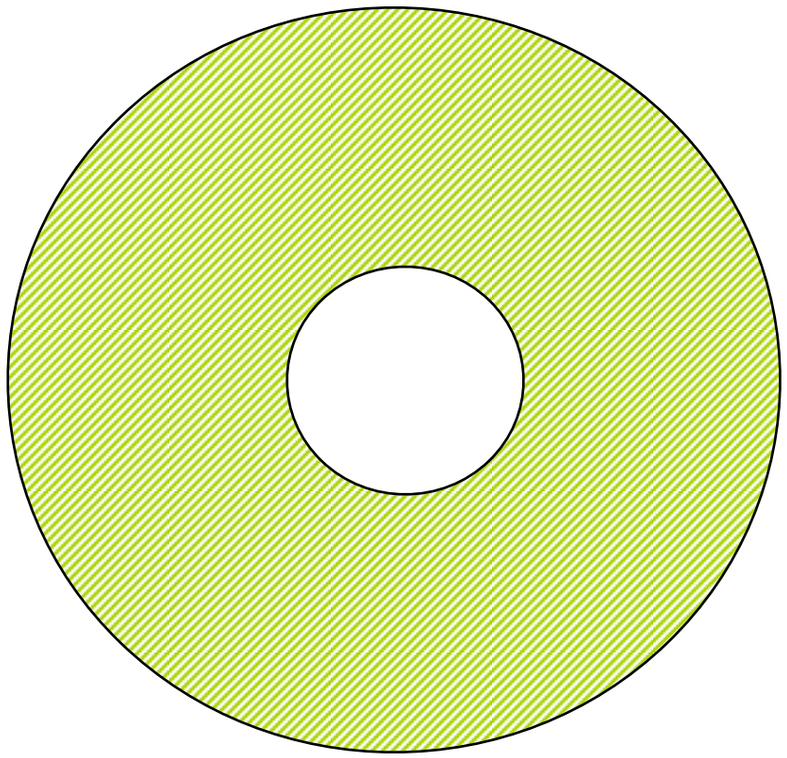

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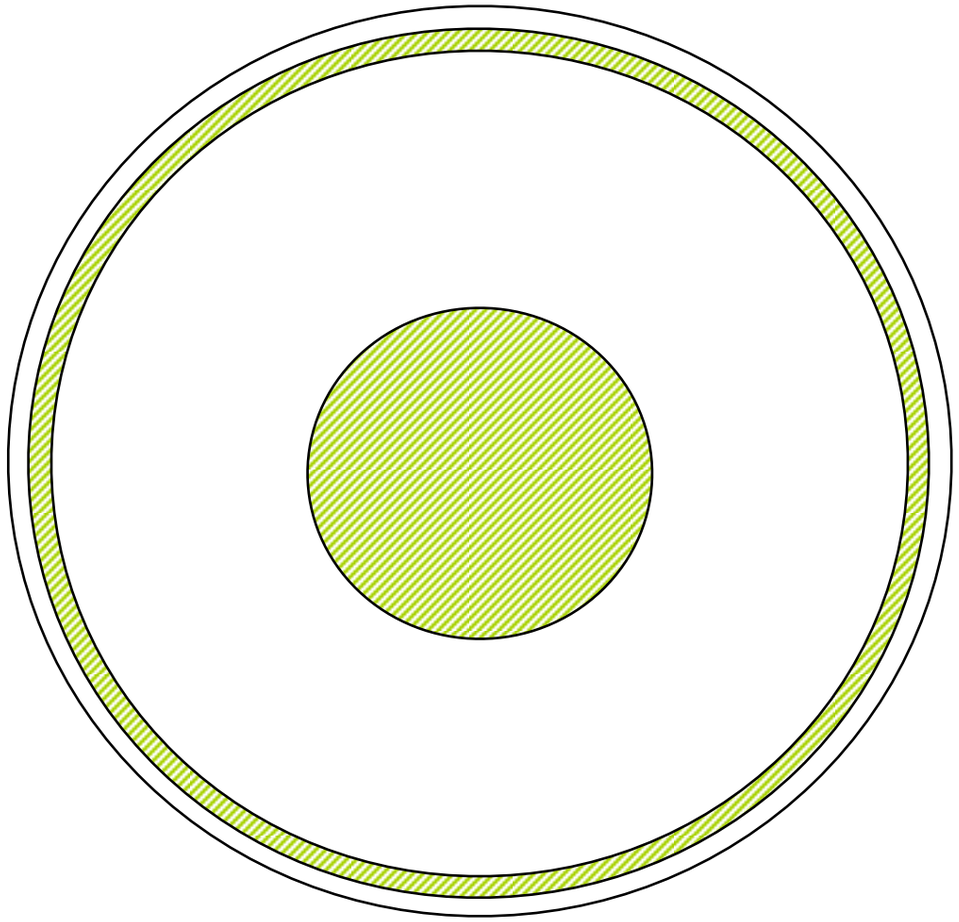

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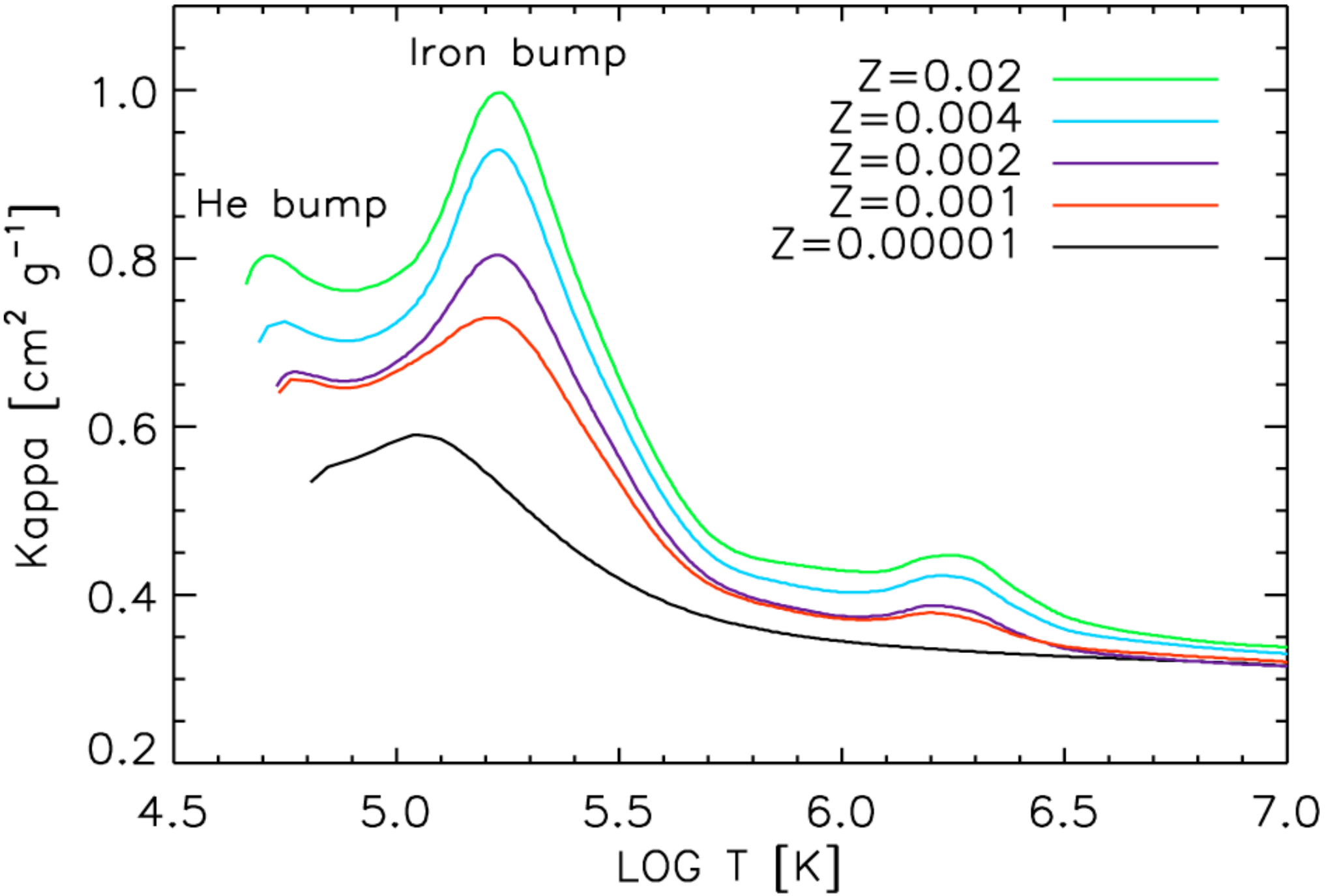
Convective core
Radiative envelope

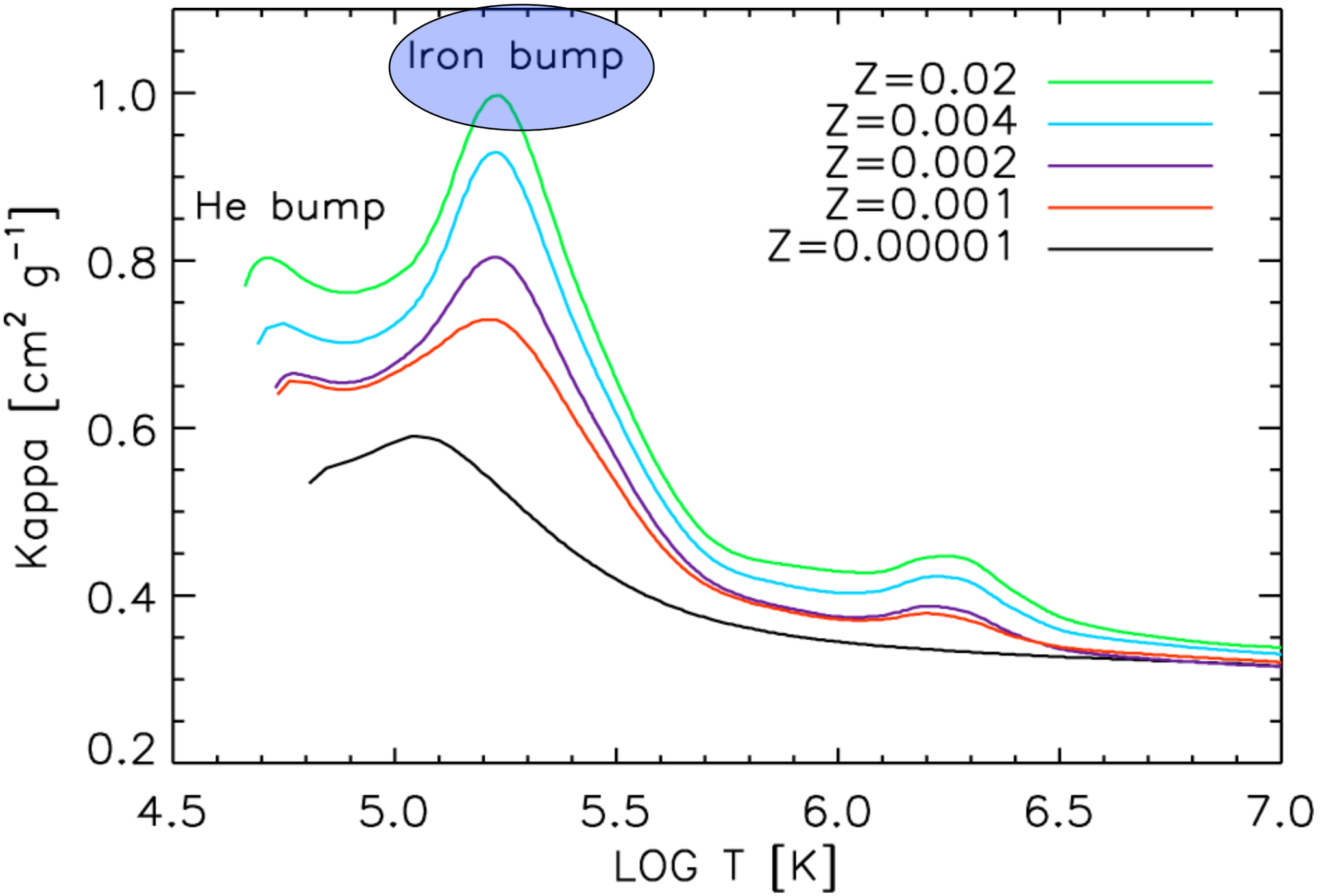
Opacity

Inside a massive star



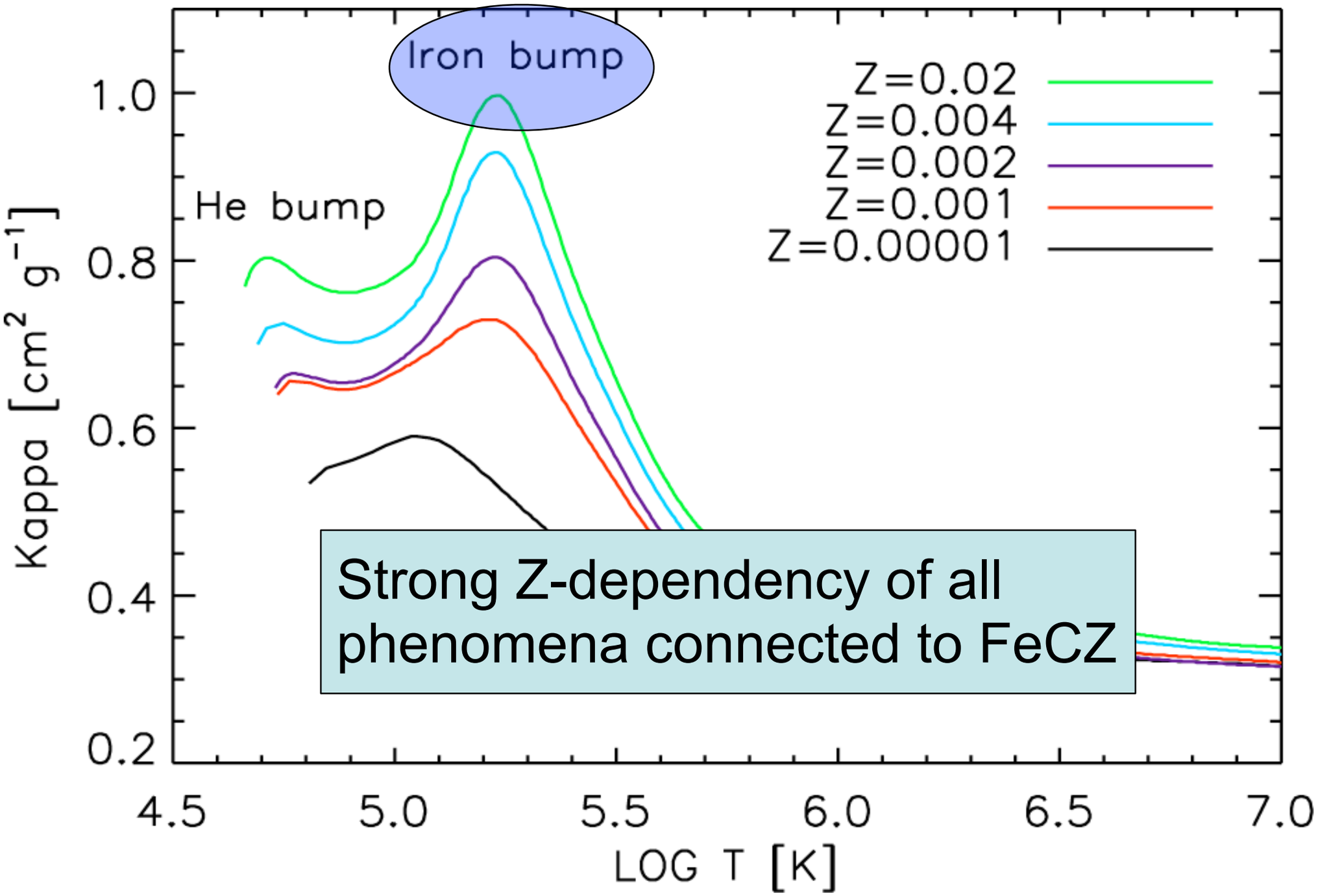
Opacity

Inside a massive star



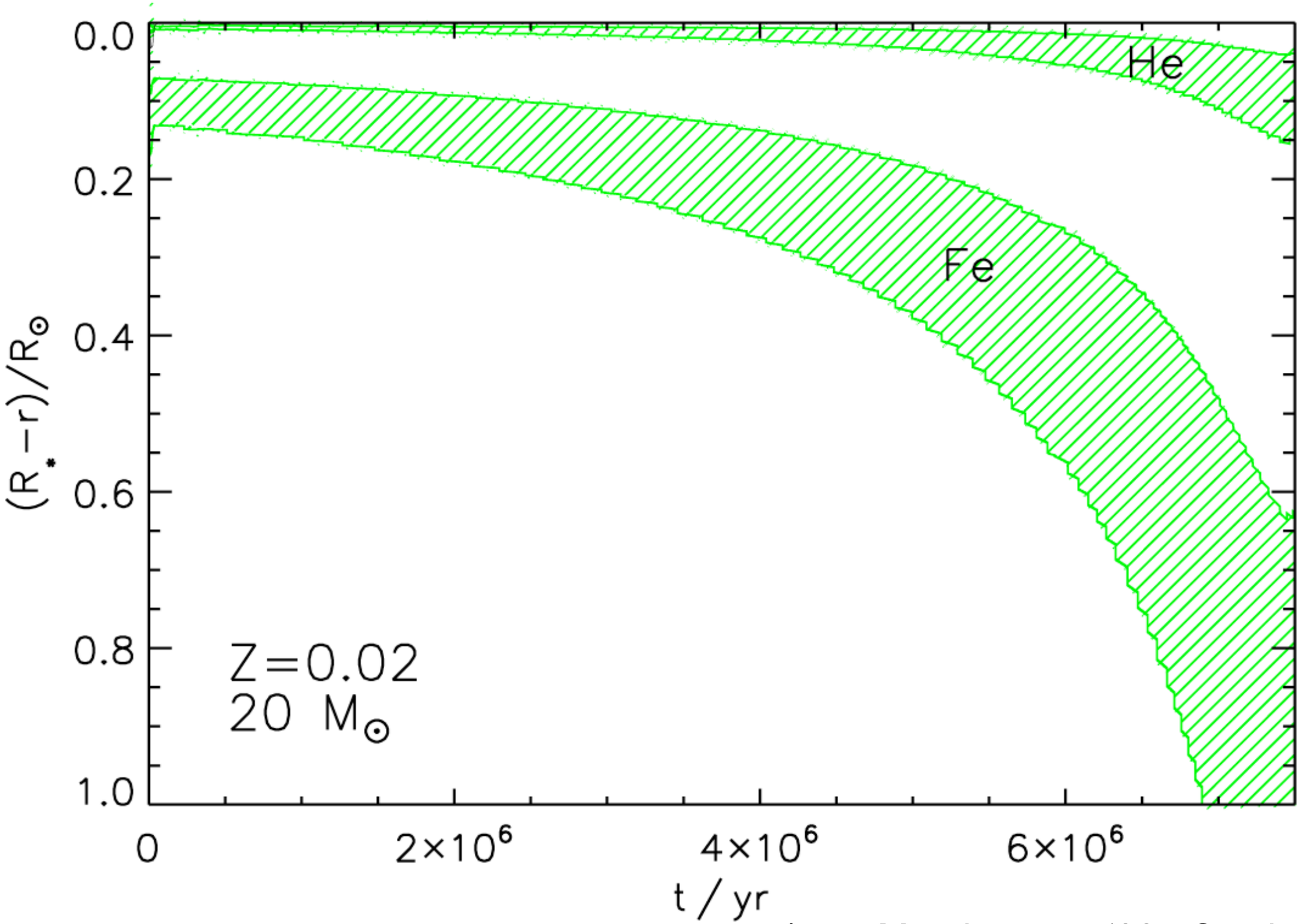
Opacity

Inside a massive star



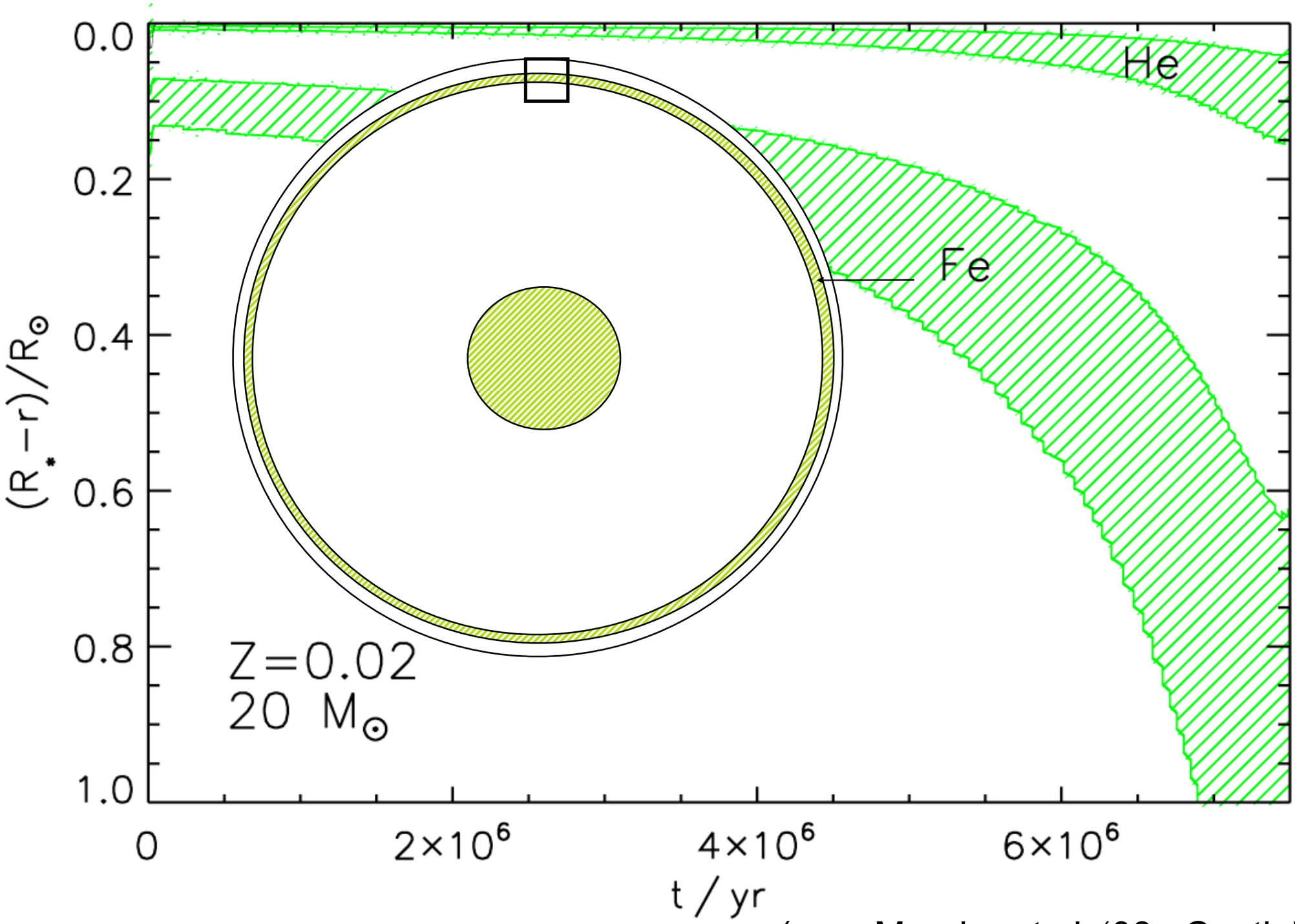
Strong Z-dependency of all phenomena connected to FeCZ

Near-surface convection



(e.g. Maeder et al. ‘08 , Cantiello et al. ’08)

Near-surface convection



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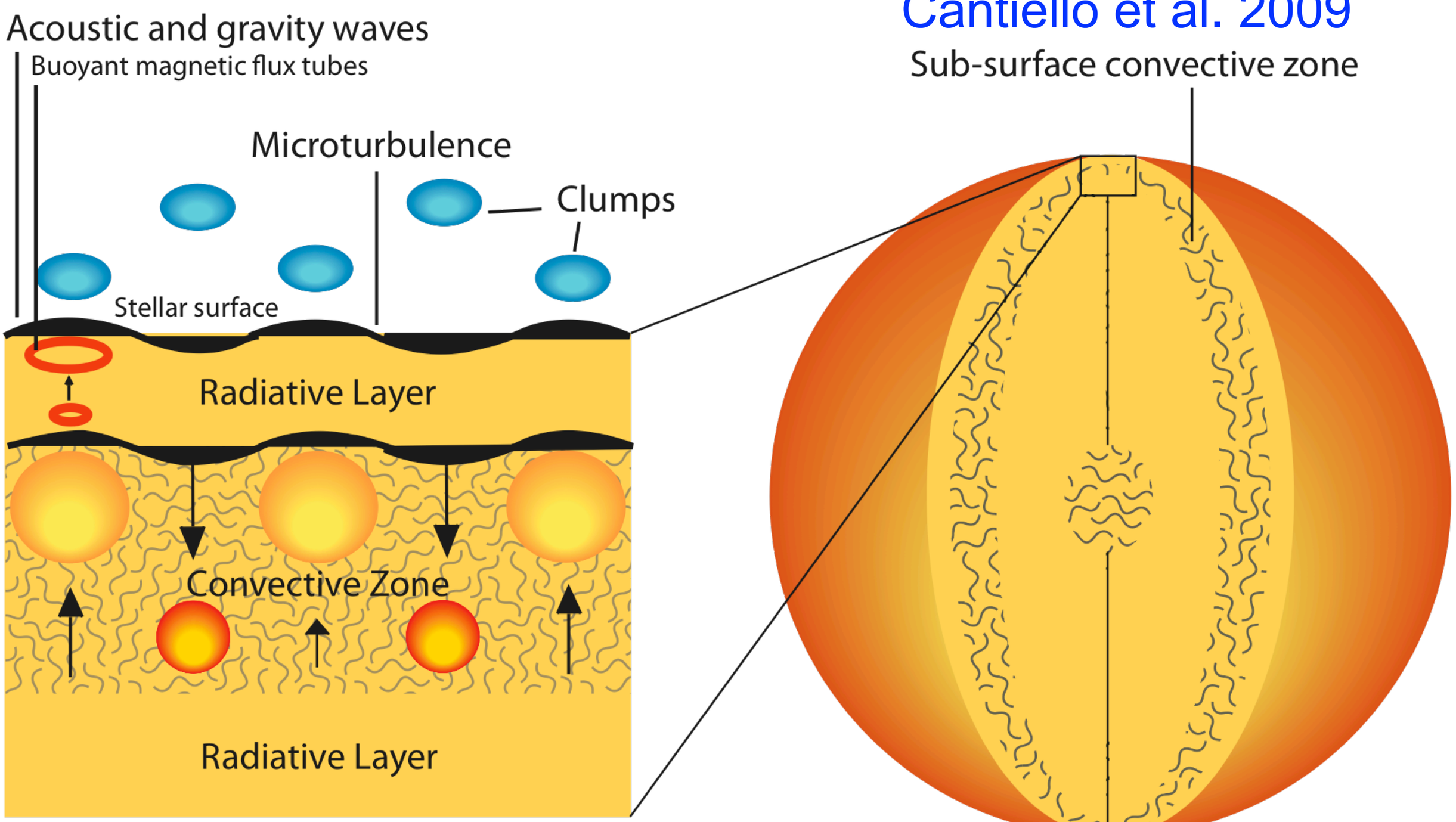
The physical mechanism



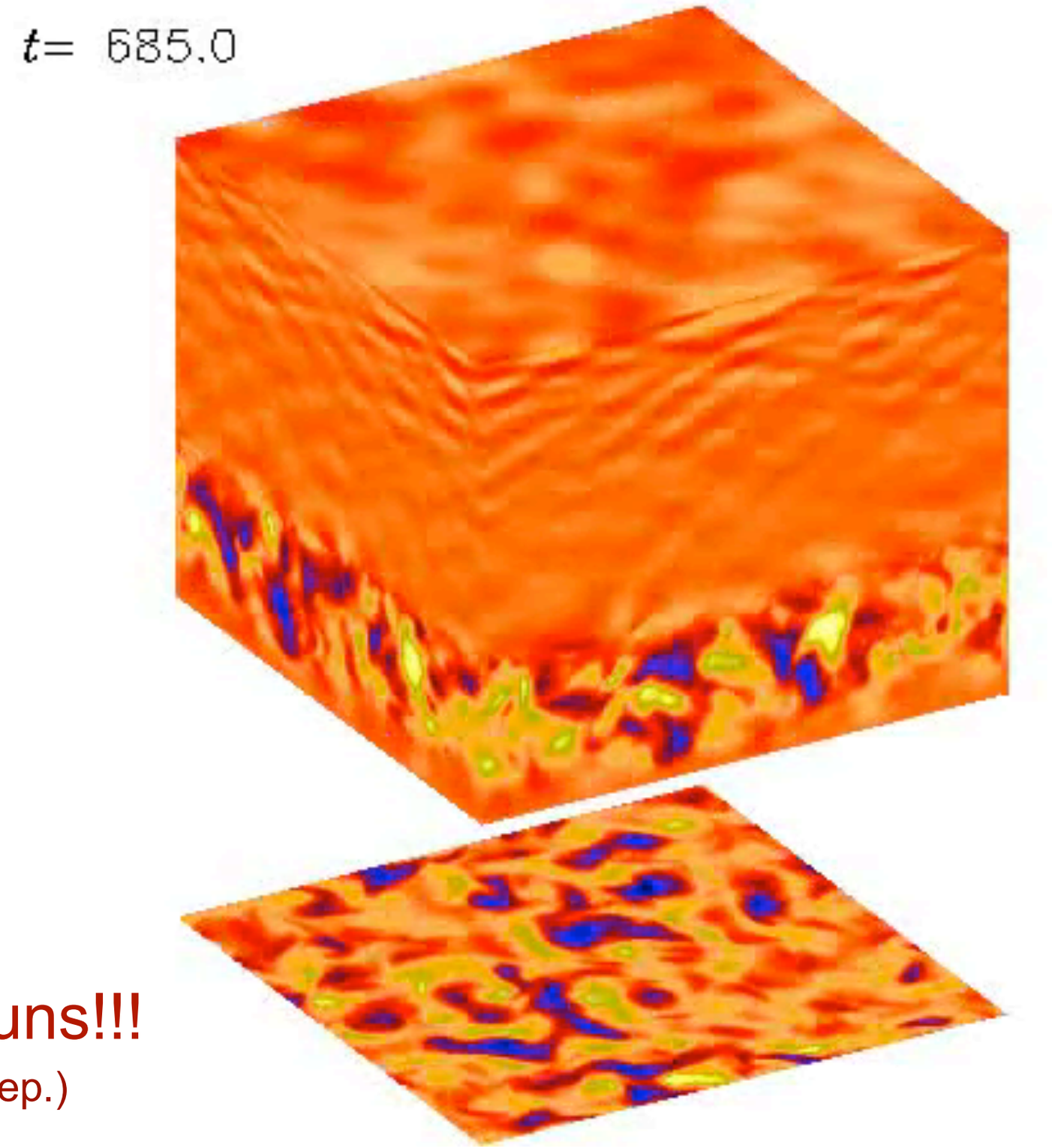
(e.g. Lighthill ‘52, Stein ‘67, Edmunds ’78, Goldreich & Kumar ’90, de Jager et al. ’91)

Surface Turbulence

3D Hydro Simulations

- **Pencil Code**
  (Brandenburg & Dobler 2002)
- Setup: piecewise polytropic (stable-unstable-stable)
- Cartesian grid 128 x 128 x 256
- Fcon/Frad ~ 0.3
- Re ~ 80

- Shown is vertical velocity field

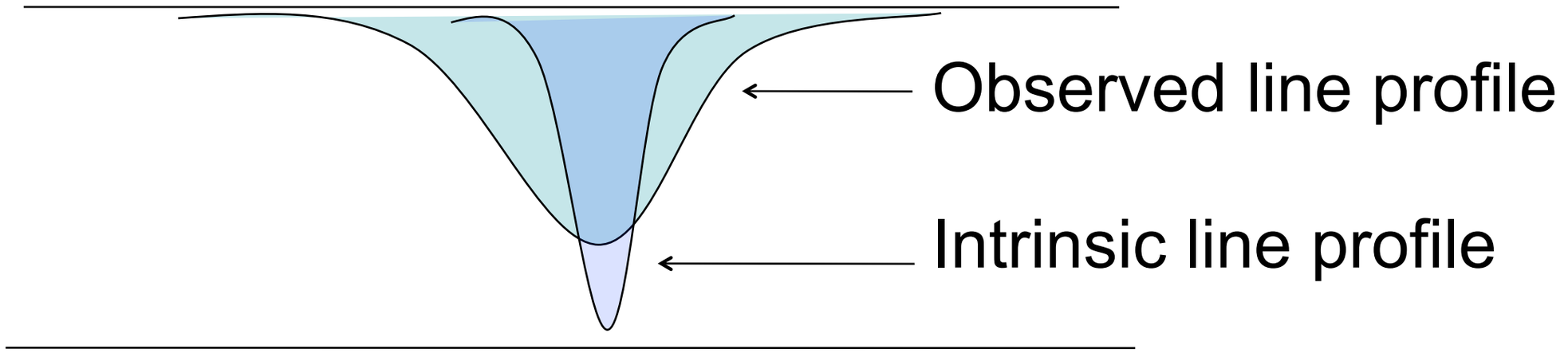


Preliminary, low resolution runs!!!

(Cantiello, Käpylä, Brandenburg et al. In Prep.)

Microturbulence

Is the additional broadening coming from nonthermal motions varying on a small scale in the region of line formation.



$$\Delta\lambda_D = \frac{\lambda}{c}\sqrt{V^2_{therm} + \xi^2_{turb}}$$

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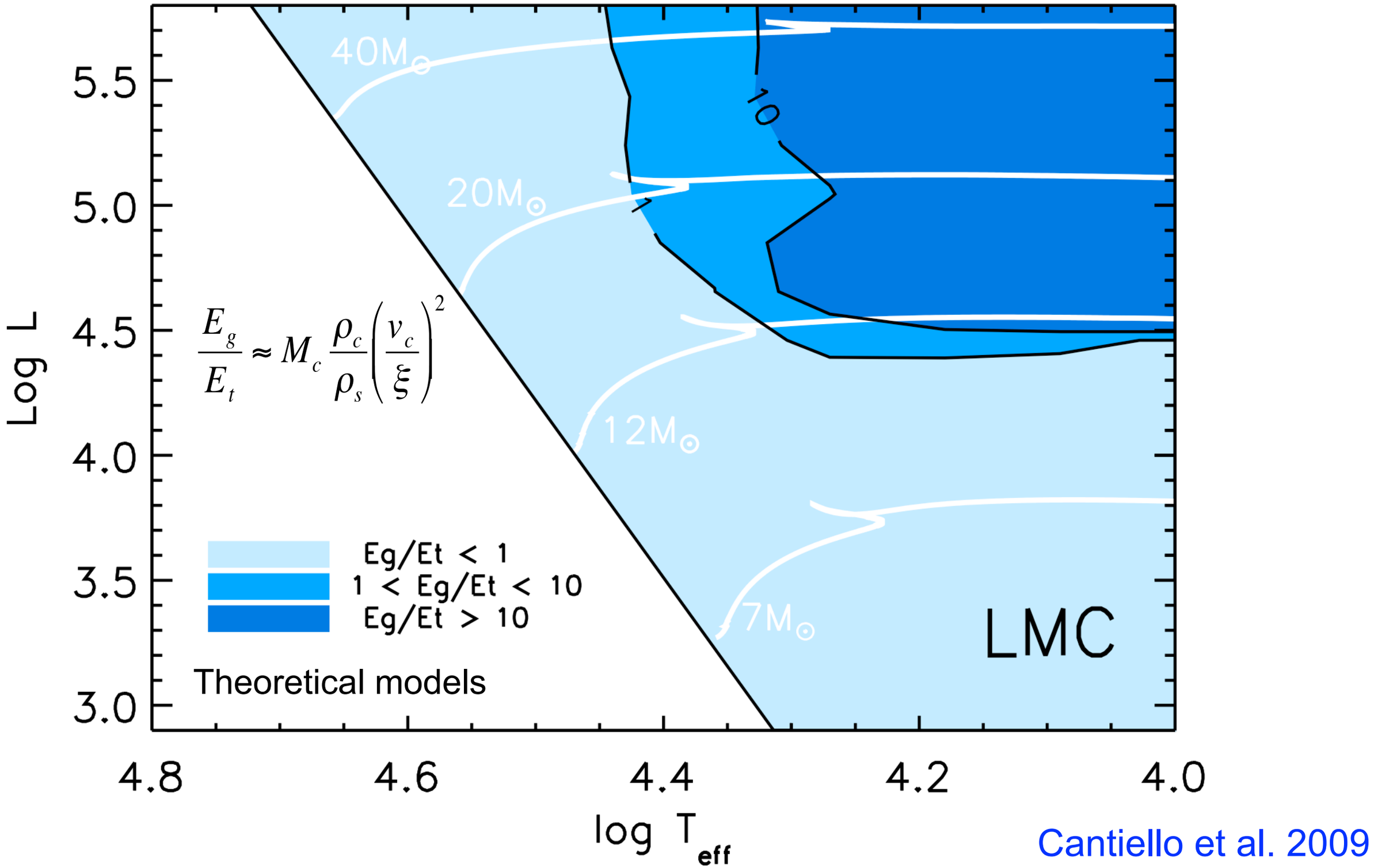
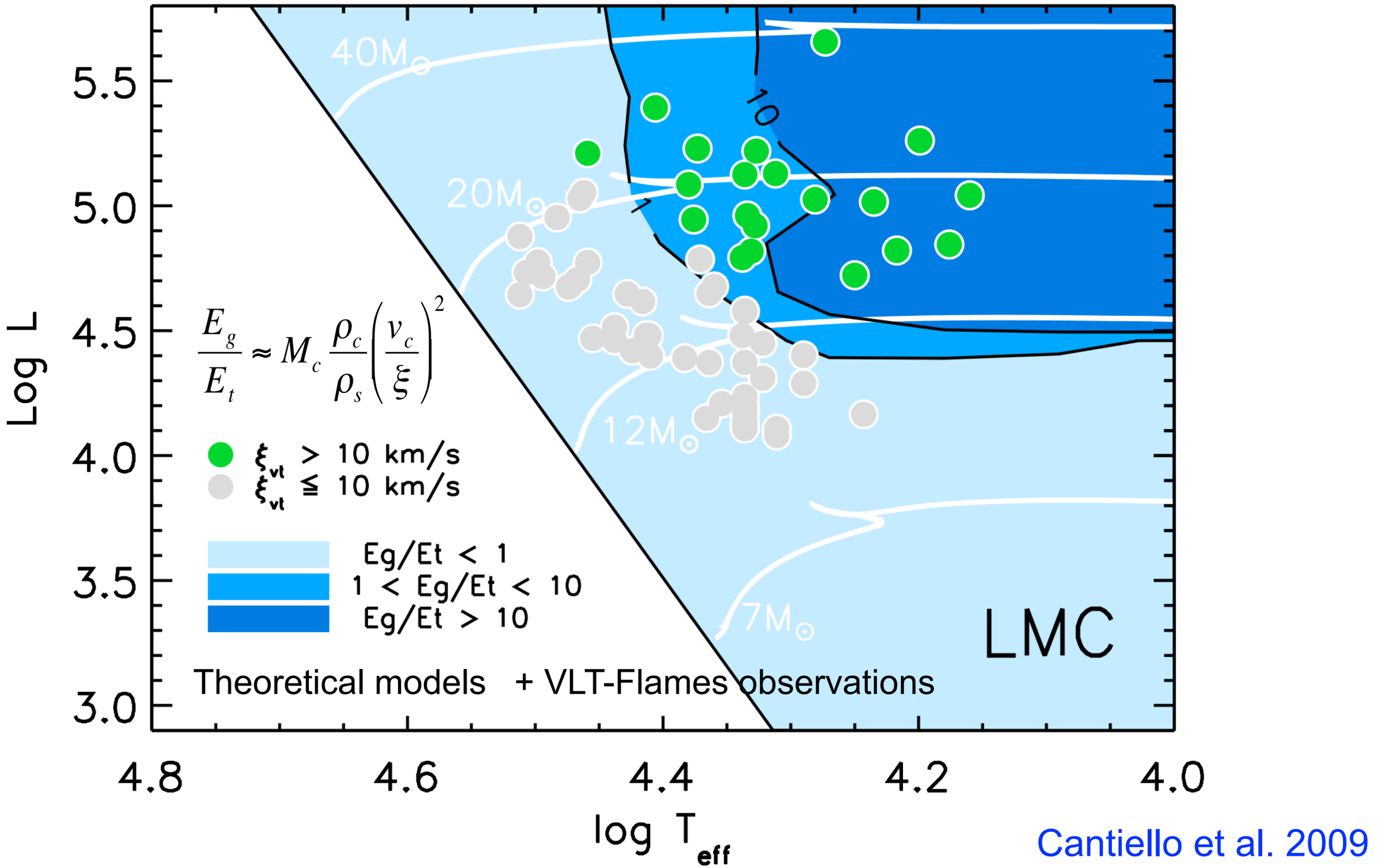
- To fit stellar spectra of hot stars microturbulence (~0-25 km/s) is needed
- Used as a fudge-factor. **Unknown physical origin**
- But recently a correlation between **near-surface convection** and microturbulence has been found!

Energetic considerations



Cantiello et al. 2009

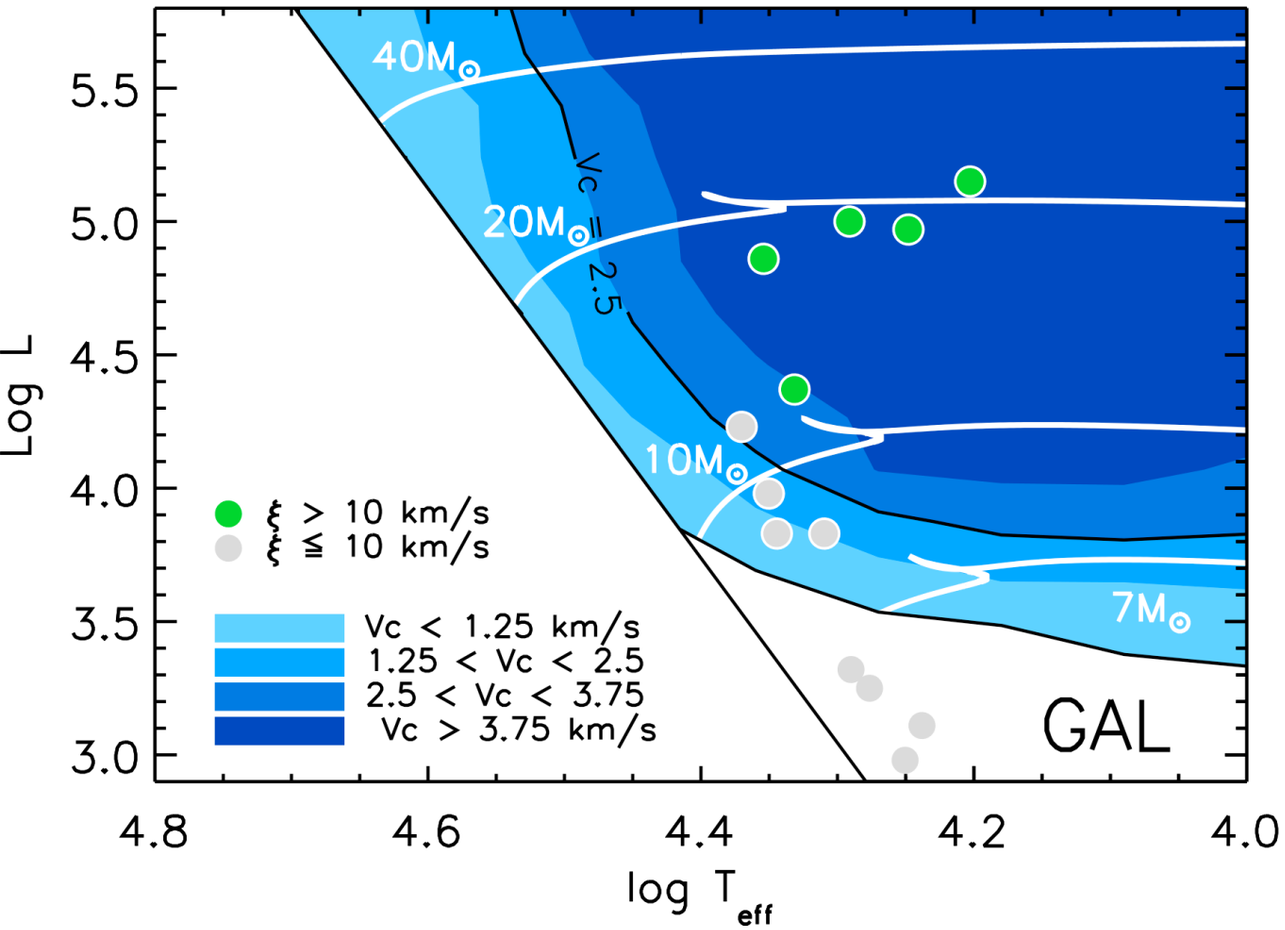
Energetic considerations



Cantiello et al. 2009

Results

$$\xi = f(L, T_{eff}, Z)$$



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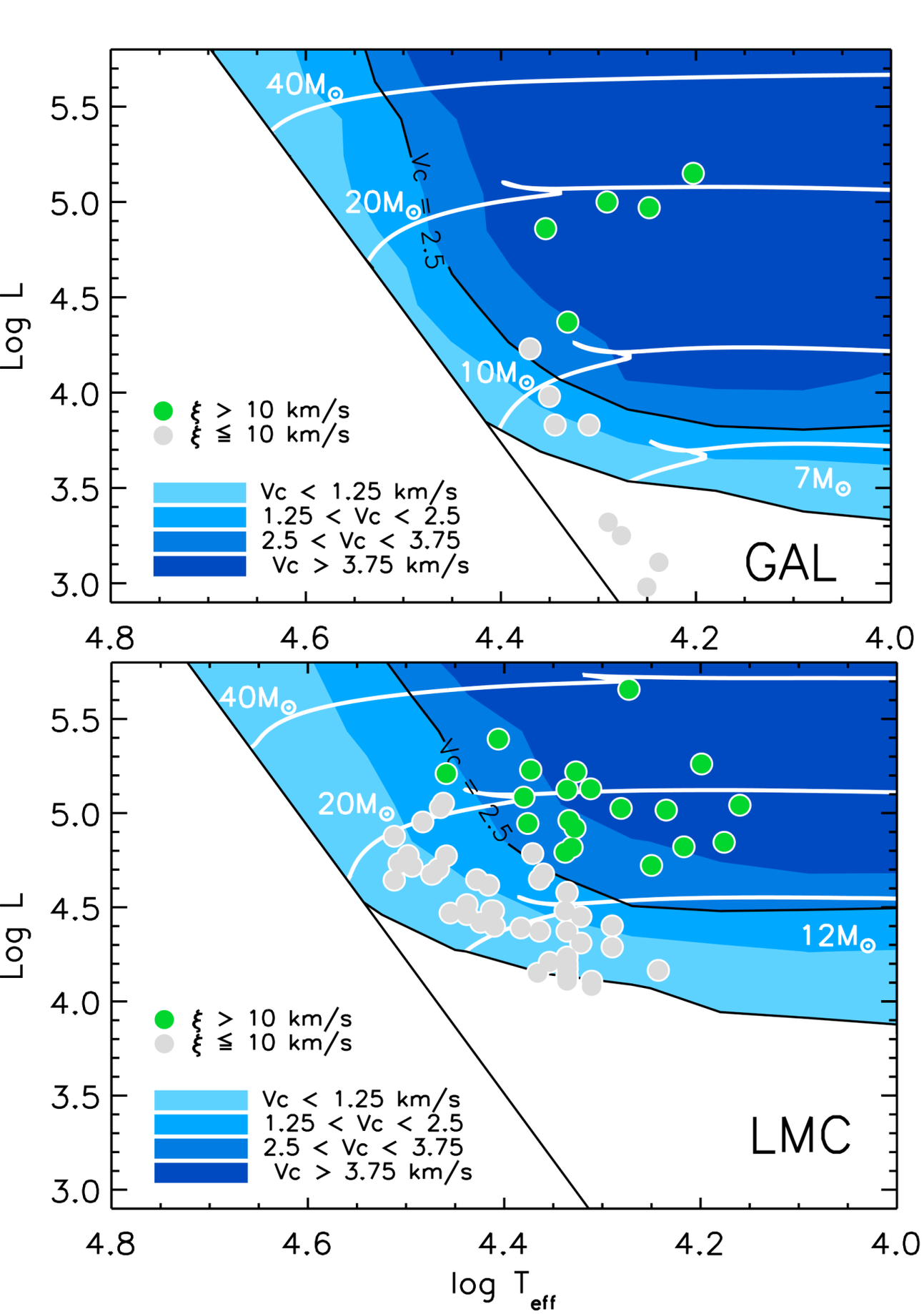

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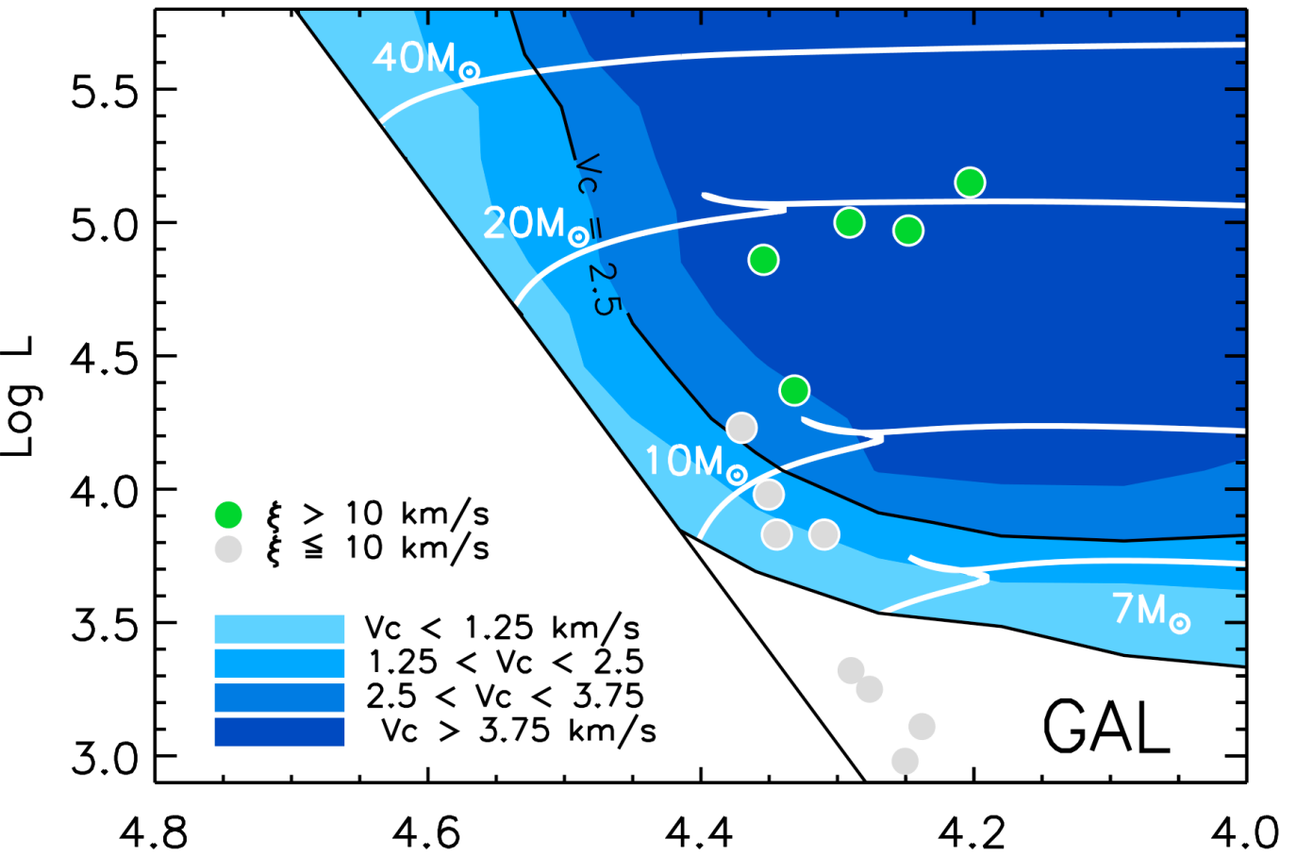

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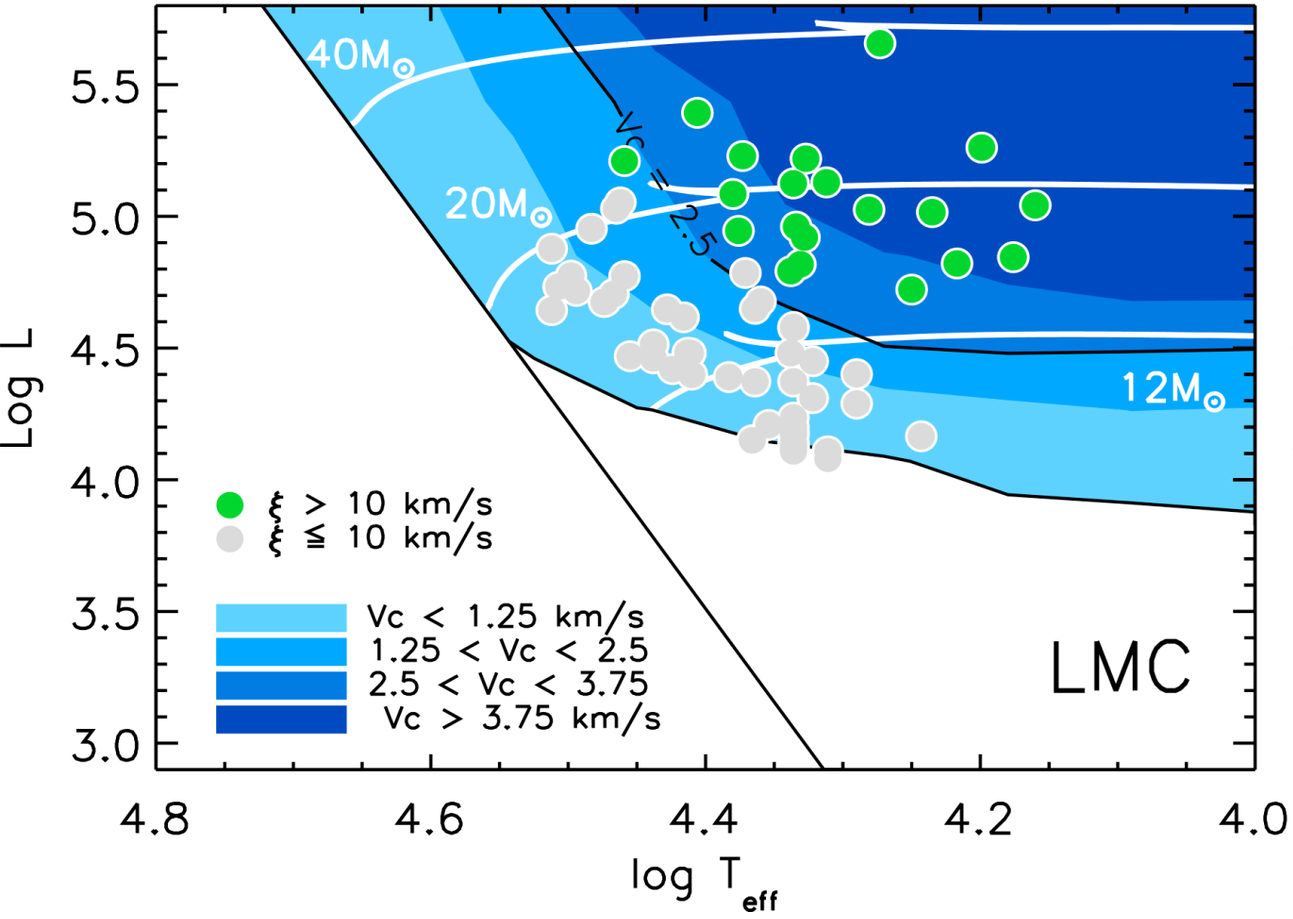
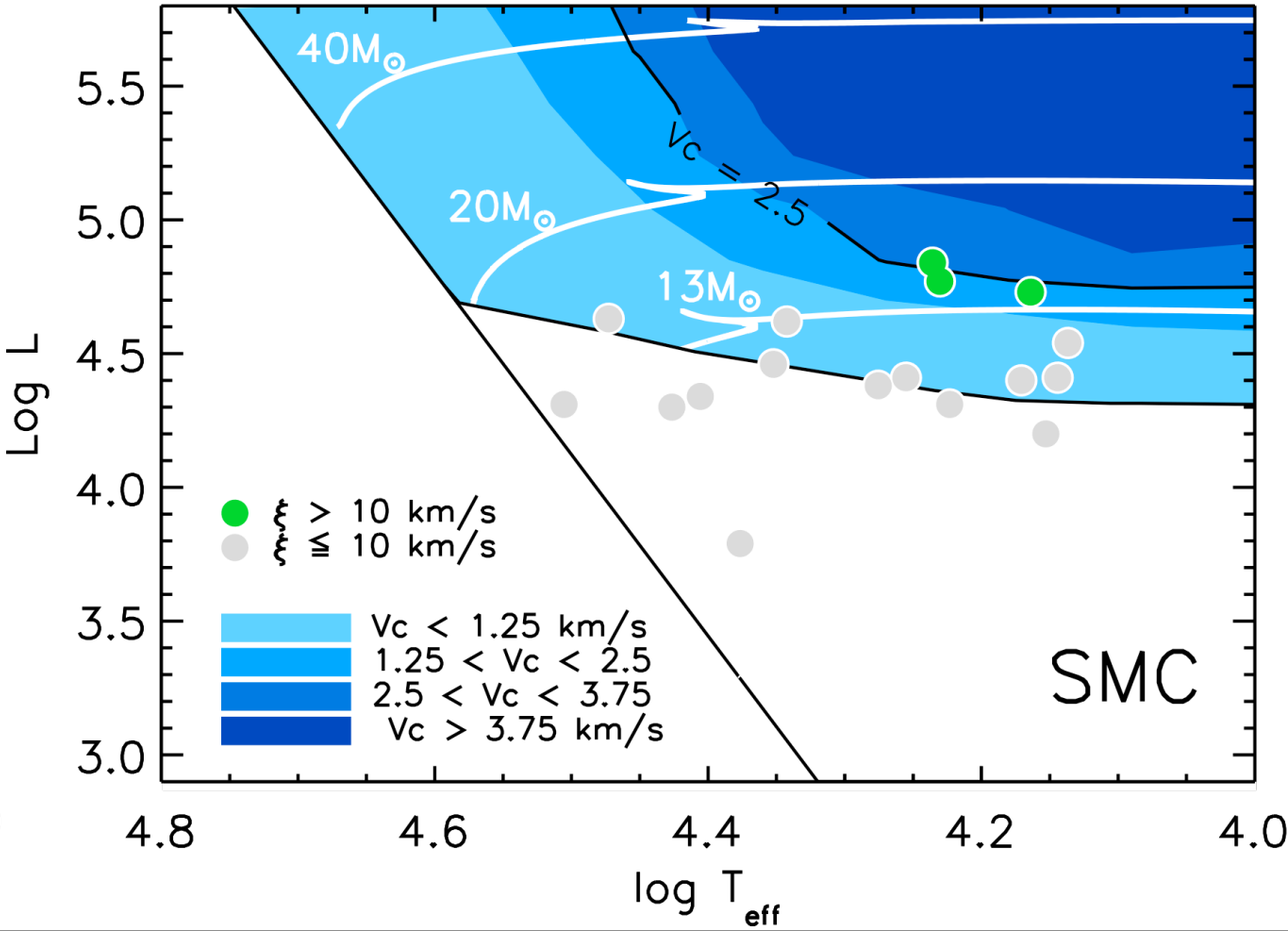
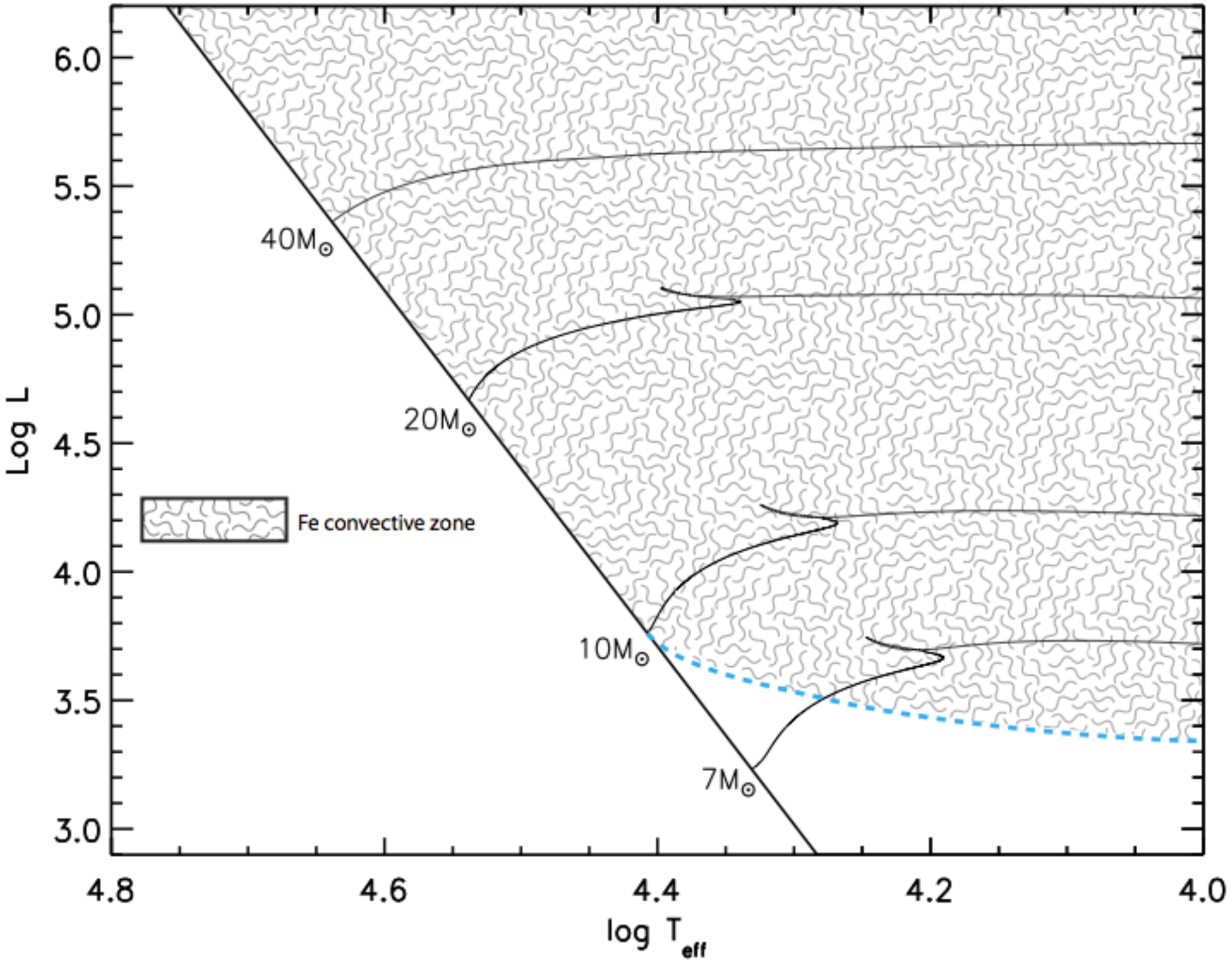




Solar-like oscillations

Near-Surface Convection (Solar Z)



Solar-like oscillations in massive stars

Cantiello et al. 2009
Suggest that near-surface convection in hot, massive stars could cause stochastically excited pulsations

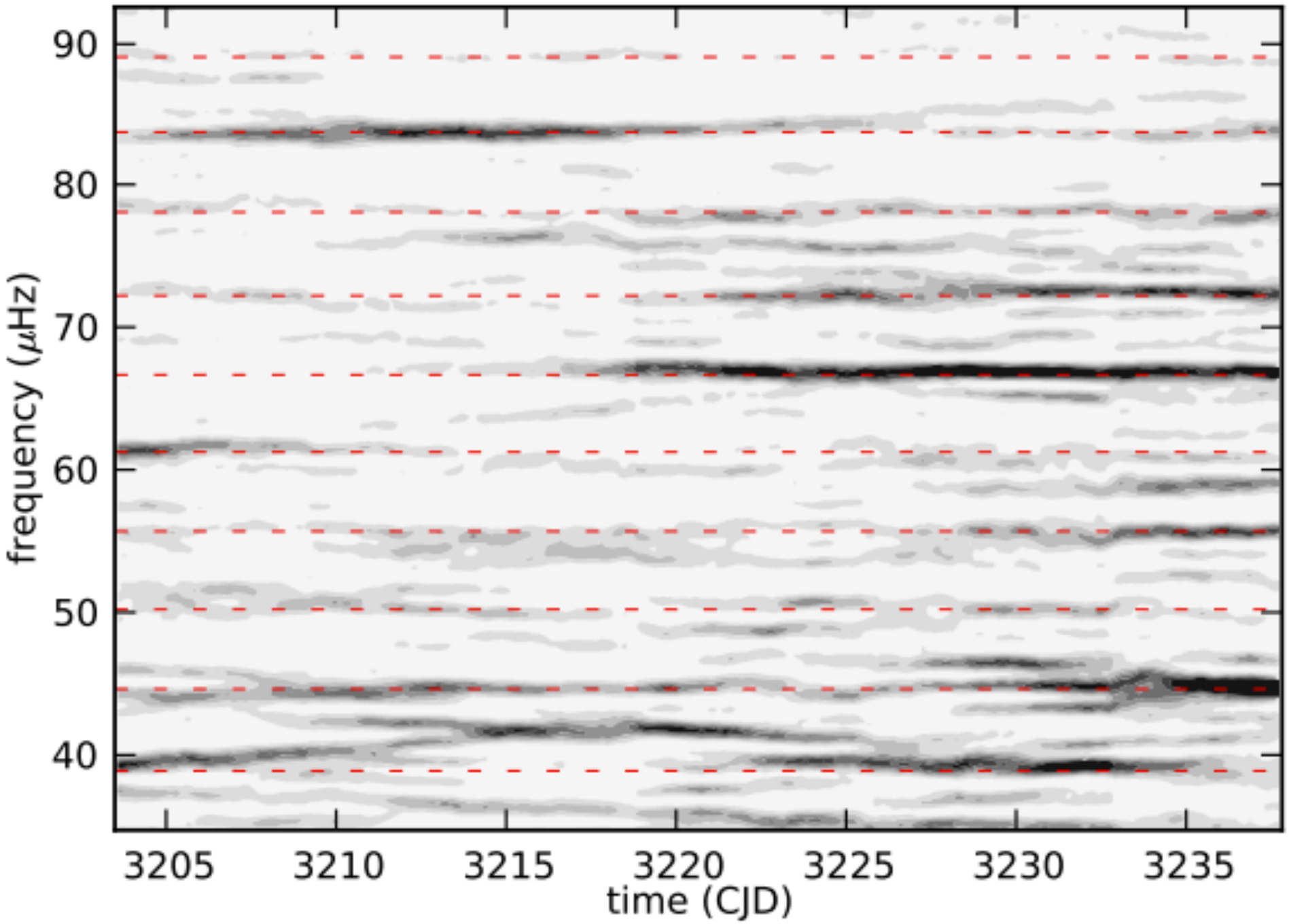
Belkacem et al. 2009
Corot detection of solar-like oscillations in the massive star V1449 Aql (B type Star) [However, see Aerts et al. 2011]

Belkacem et al. 2010
Theoretical calculations of stochastically excited modes from sub-surface convection.

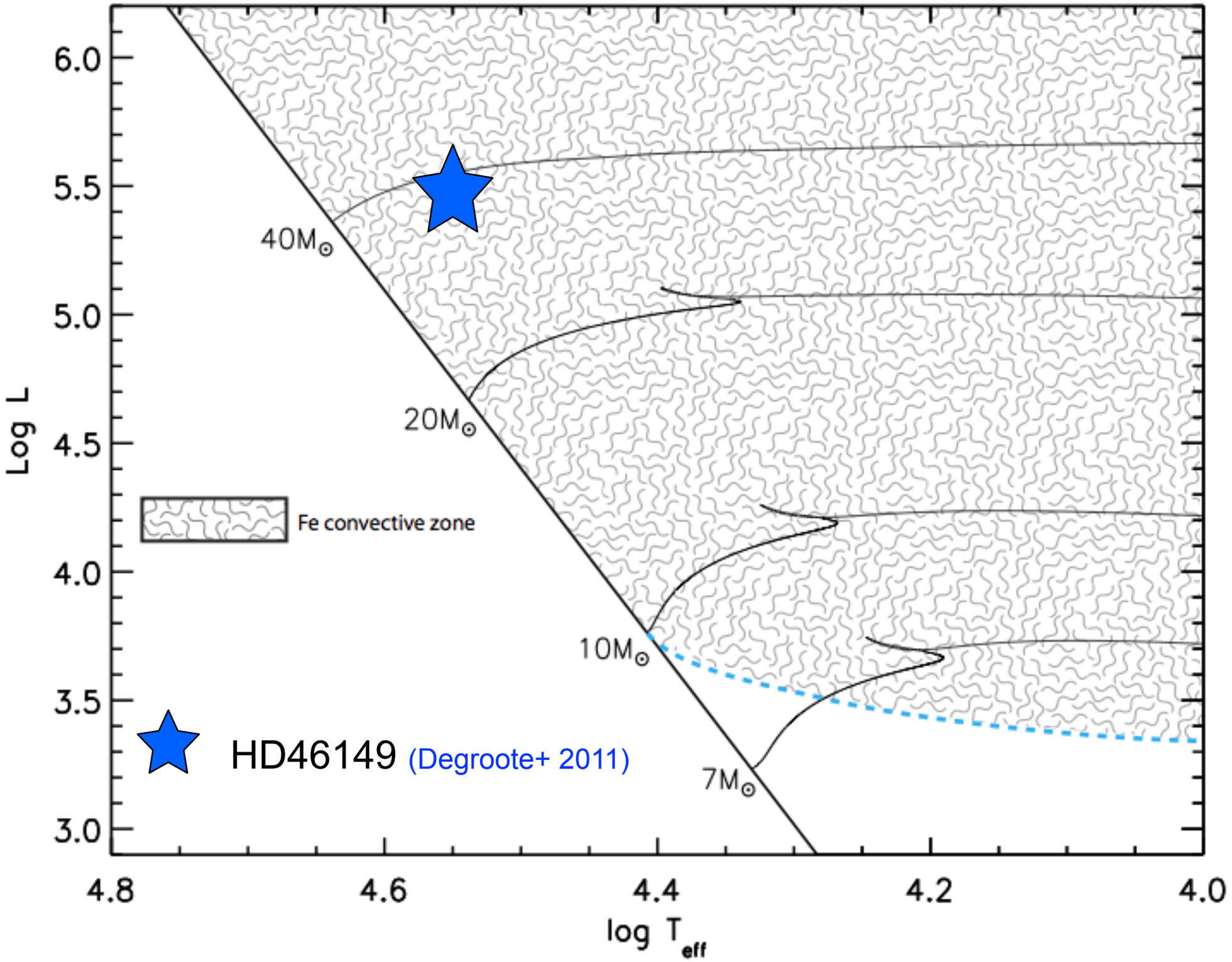
Degroote et al. 2010
Corot detection of solar-like oscillations in an O-type star

Solar-like oscillations in O star

HD 46149 (Degroote et al. 2010)

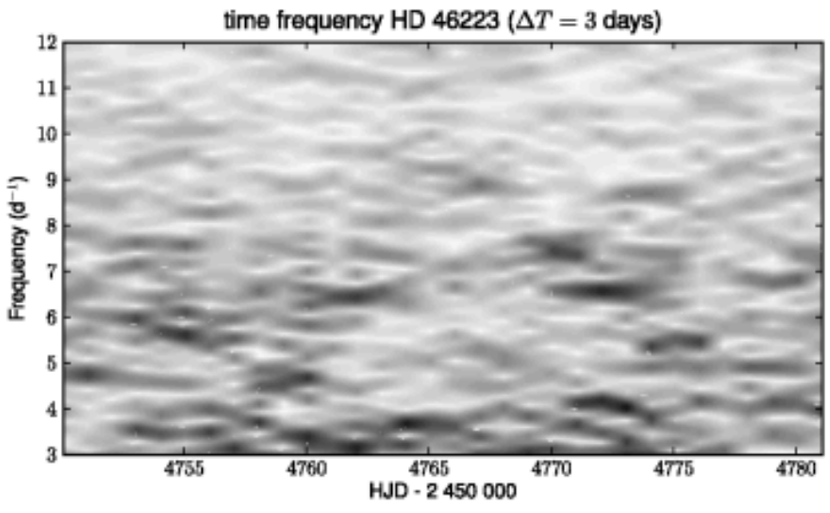


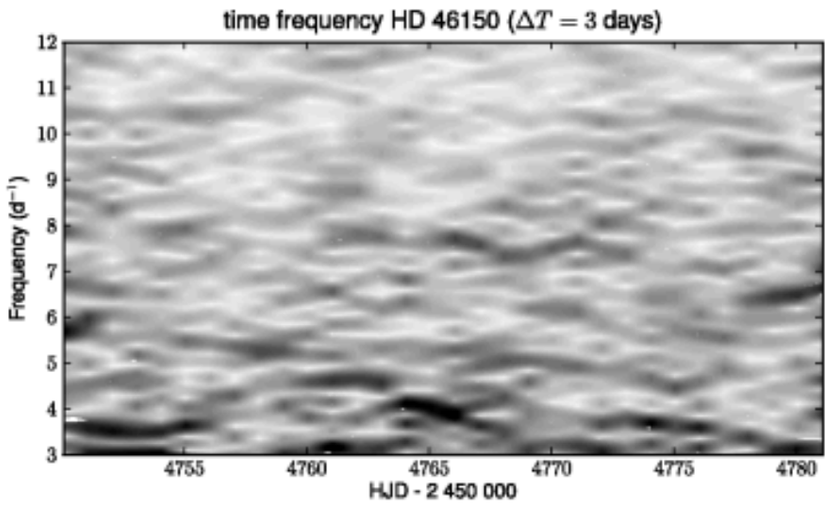
Photometric variability: HRD location

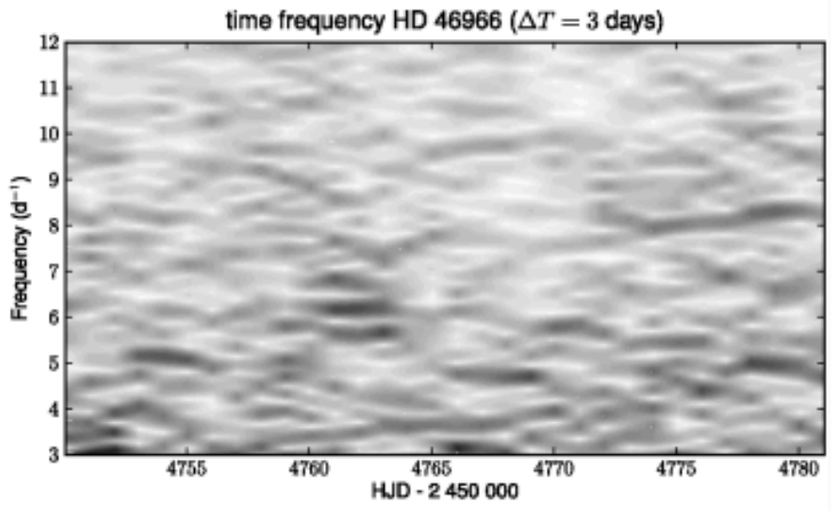


Red Noise

“Red Noise” in O stars







- Variability in the CoRoT photometry of 3 hot O-type stars

(Blomme et al. 2011)

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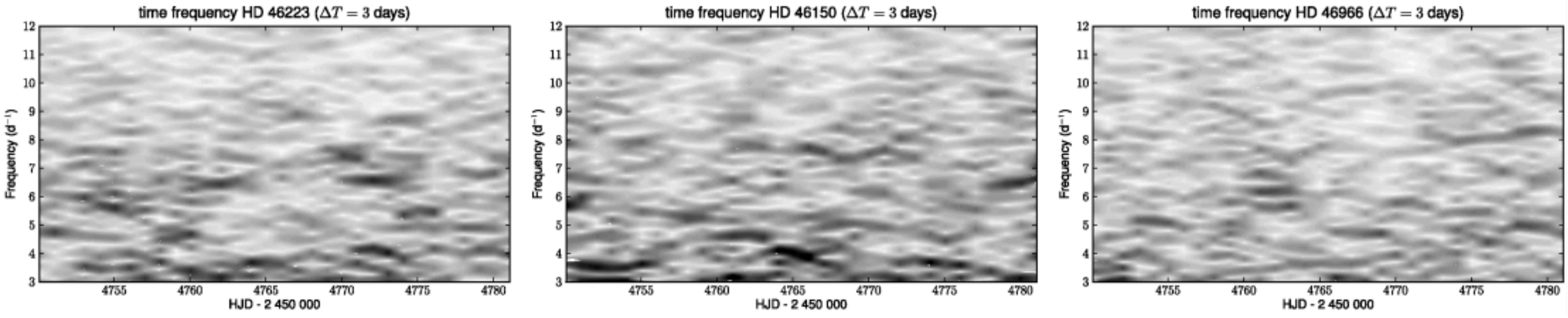

- Variability in the CoRoT photometry of 3 hot O-type stars
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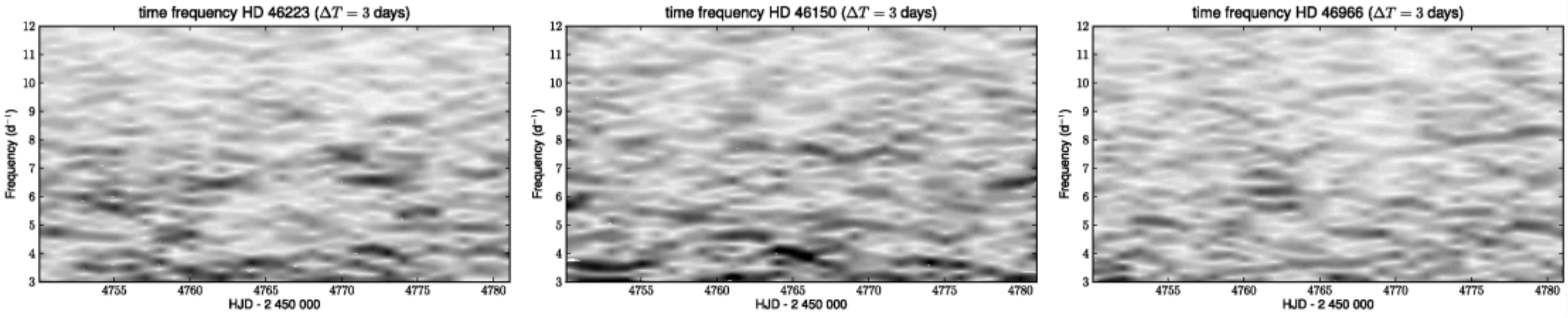

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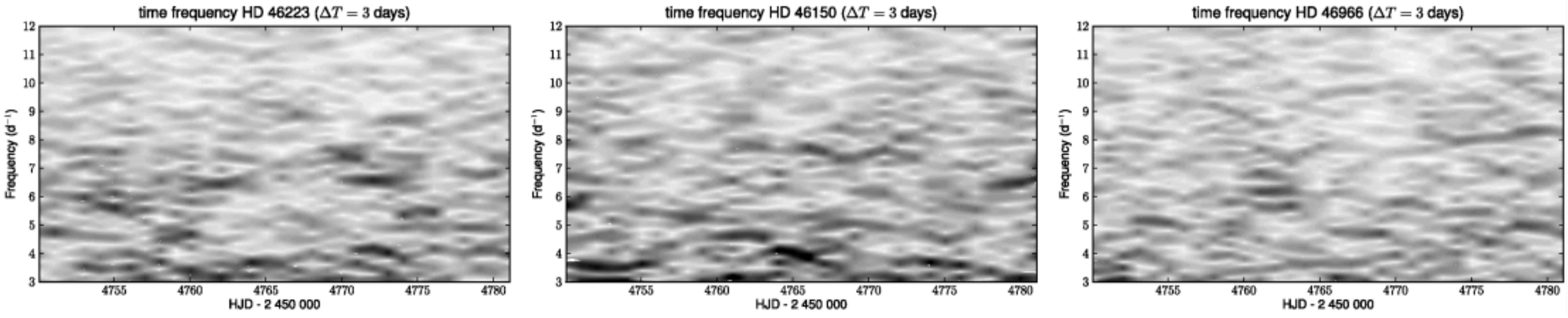
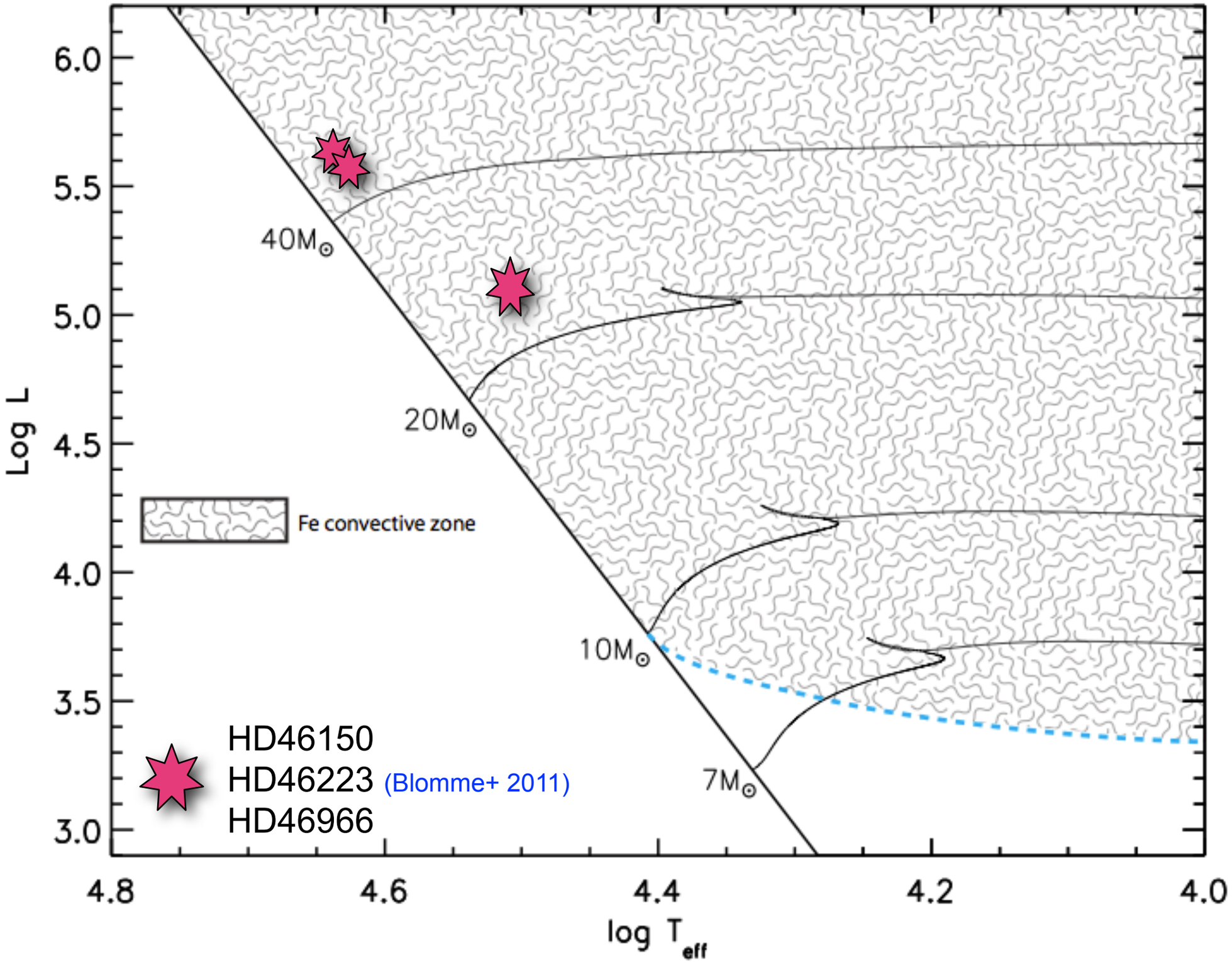


- Variability in the CoRoT photometry of 3 hot O-type stars
- No clear pulsations detected
- Variability of stochastic nature
- Near-surface convection, granulation or wind inhomogeneities

(Blomme et al. 2011)

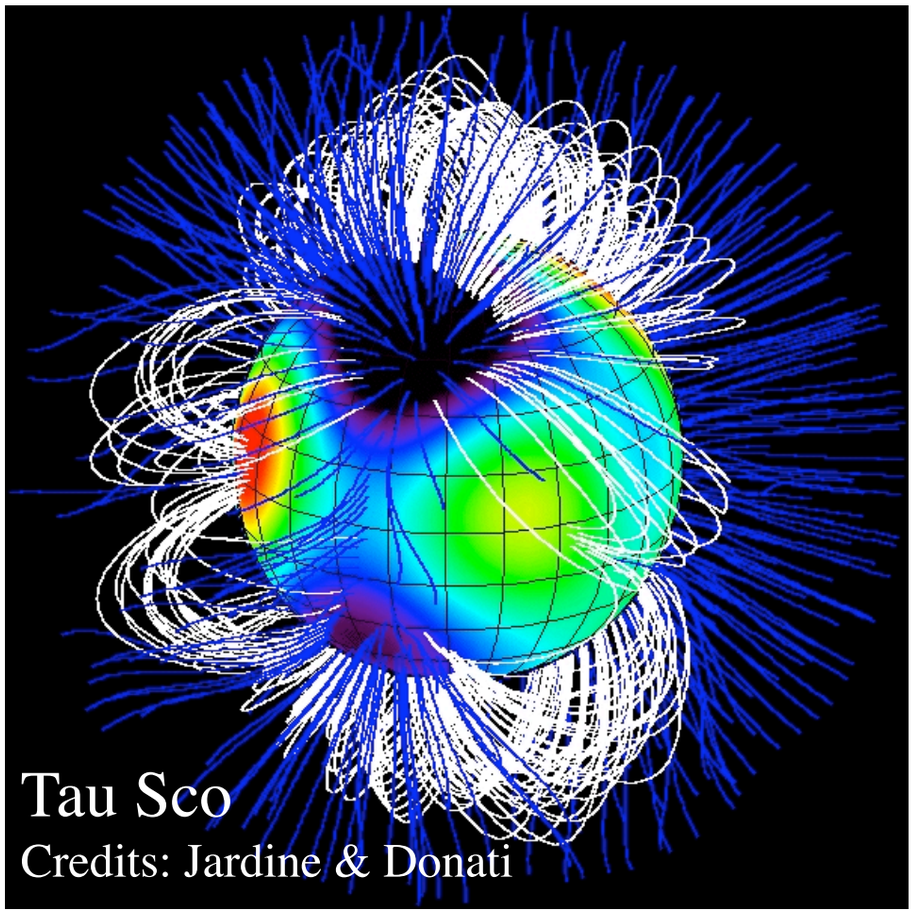
Photometric variability: HRD location



Magnetic fields / Spots

B fields in massive stars (direct evidence)

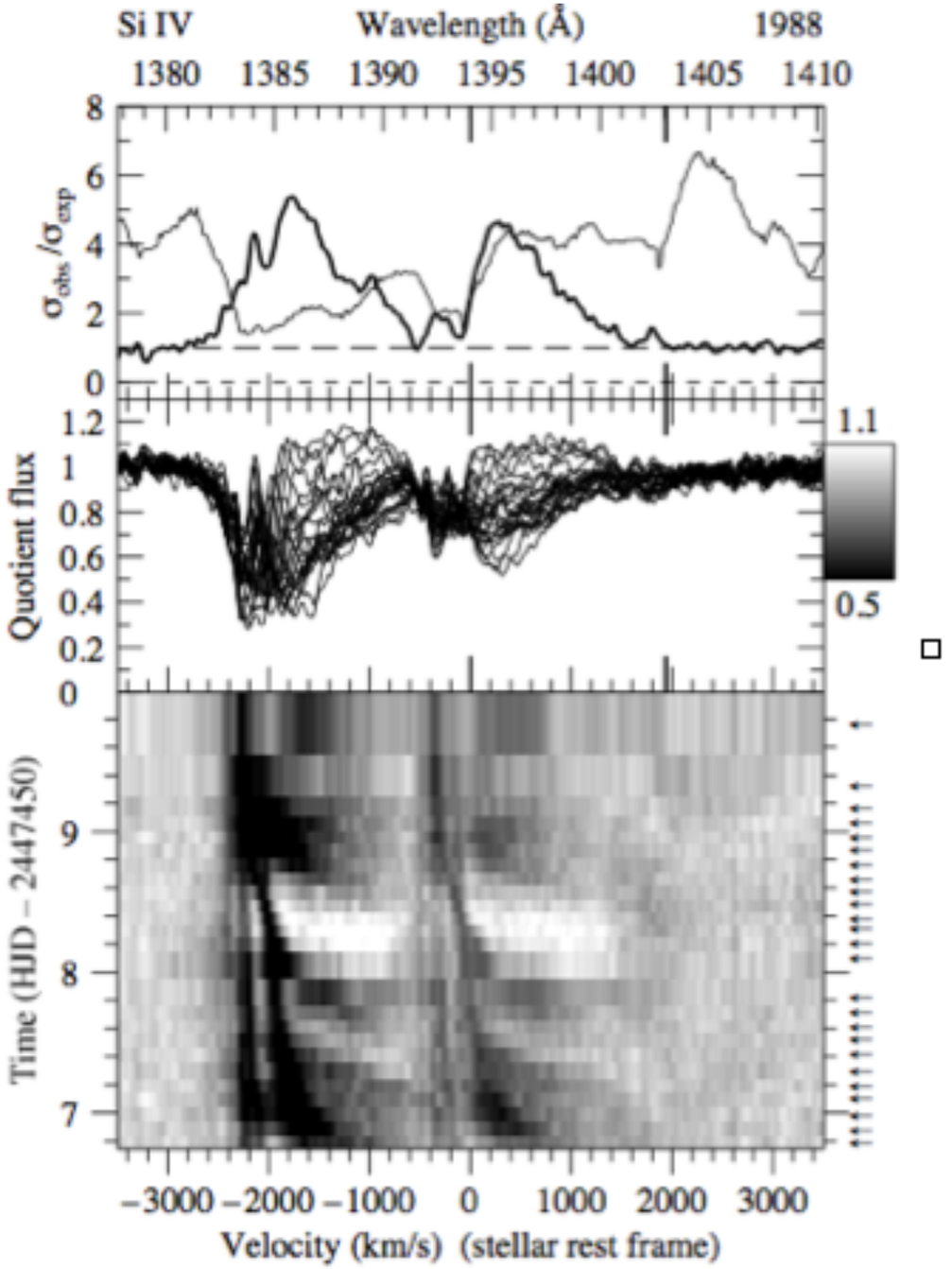
- About 3 dozen magnetic OB stars found (e.g. Donati, Hubrig, Neiner, Petit)
- Detection through Zeeman spectral signature
- **Bias** toward strong, large scale fields
- Origin unclear. Likely **Fossil** (Wade et al. 2010)



- Important evolutionary consequences (e.g. ud-doula & Owocki 02, Meynet et al. 2010)

B fields in massive stars (indirect evidence)

- OB stars show puzzling surface phenomena
  (e.g. DACs, LPV, Wind Clumping, Solar-Like Oscillations, Red Noise, Photometric variability, X-ray emission...)
- Some of these phenomena are **ubiquitous**. Therefore can not be explained by large scale fields! (e.g. Schnerr+08)
- Small scale / small amplitude fields? (e.g. Cranmer & Owocki 96, Fullerton+96, Kaper+97, Henrichs+05)



(DACs: Kaper, Henrichs et al. 1999)

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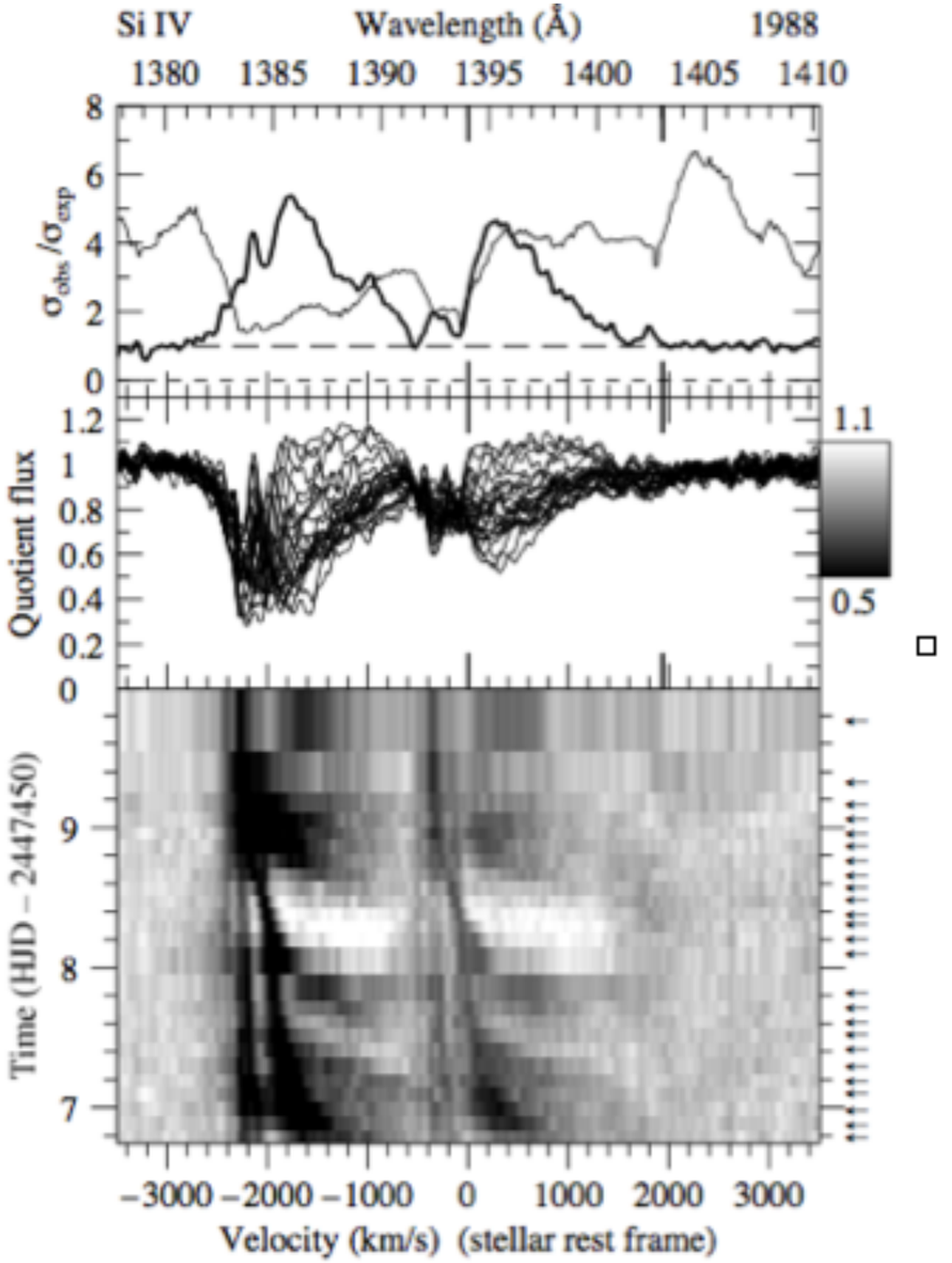
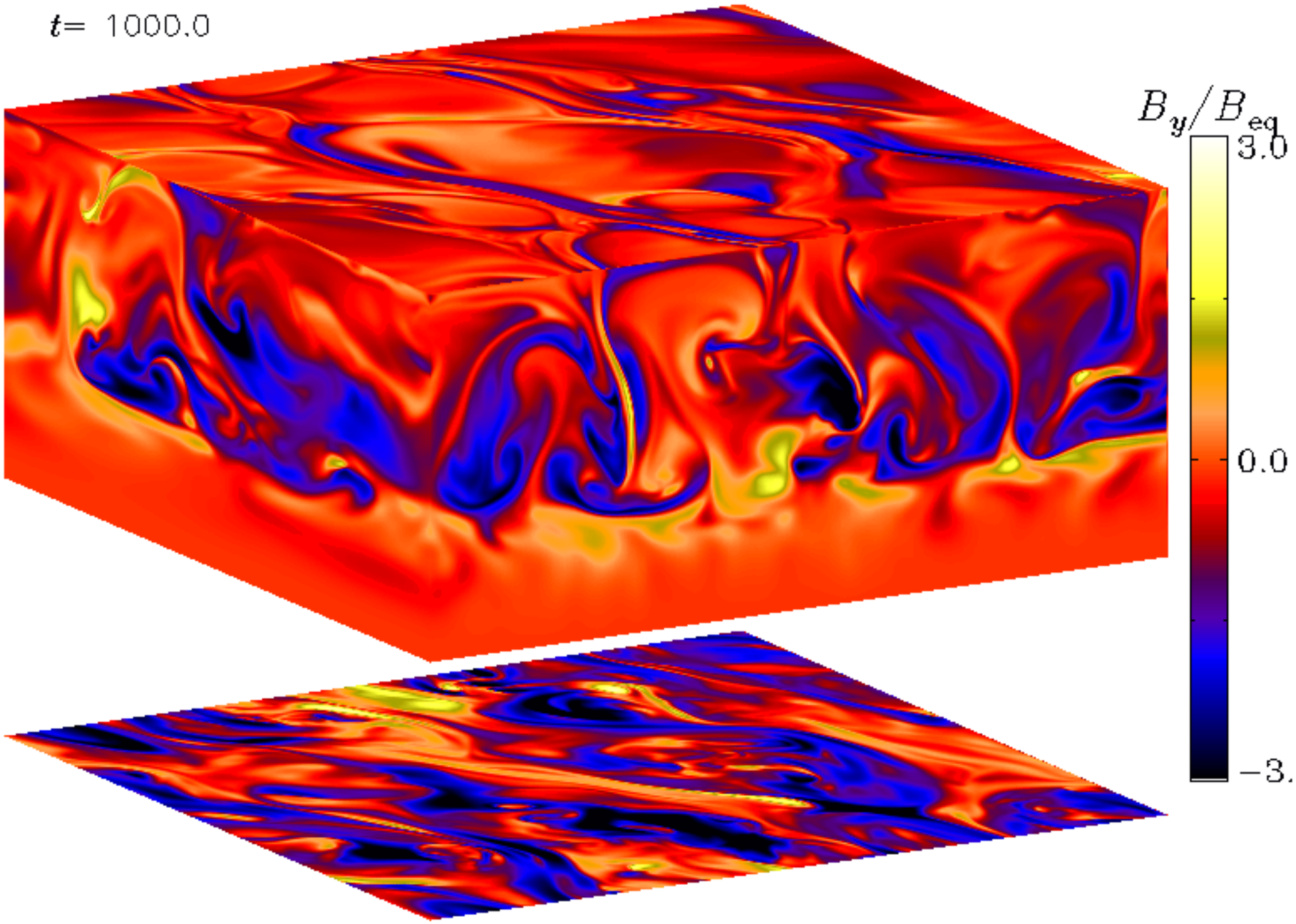
Where these fields could come from?



(DACs: Kaper, Henrichs et al. 1999)

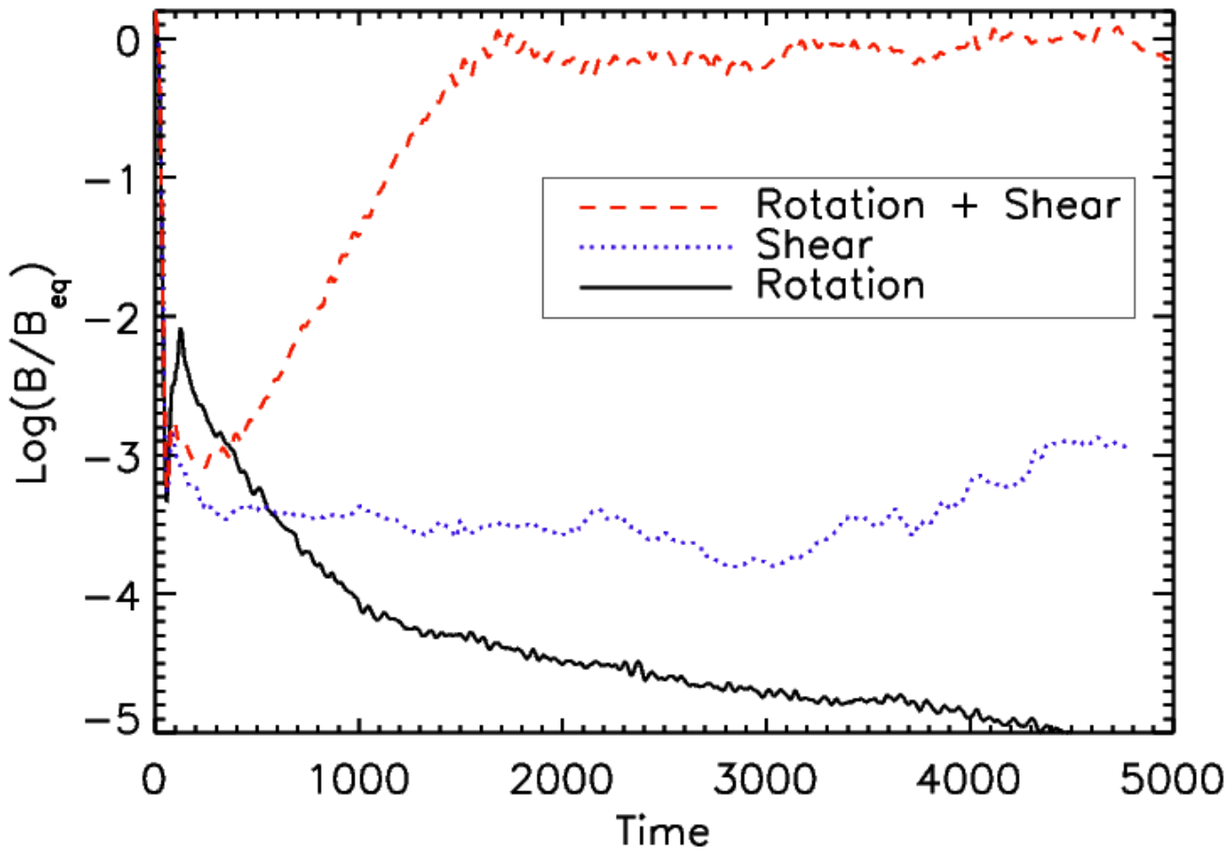
Dynamo Action in turbulent convection

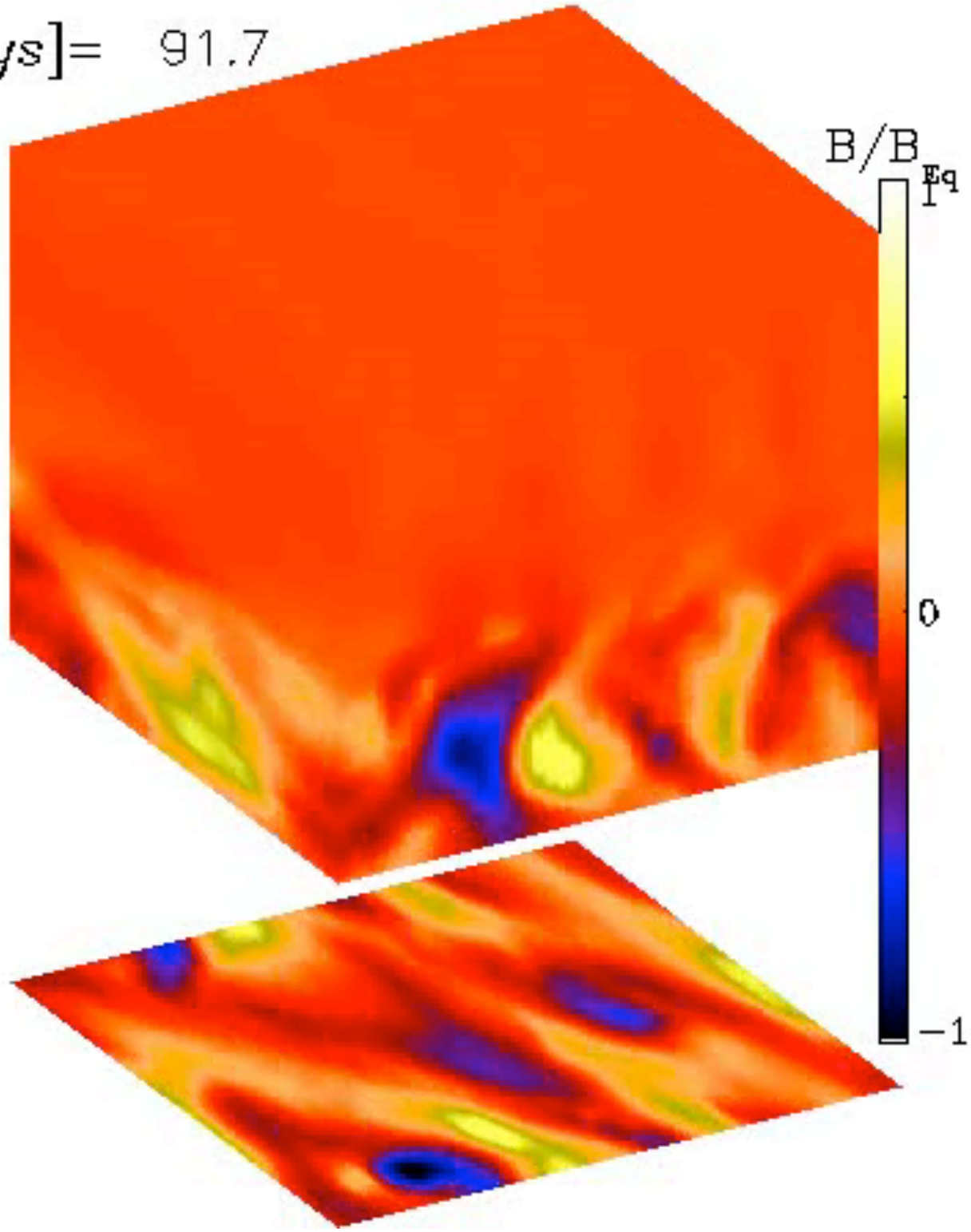


Käpylä et al. 2008,2010; Hughes & Proctor 2008

Dynamo Action in FeCZ

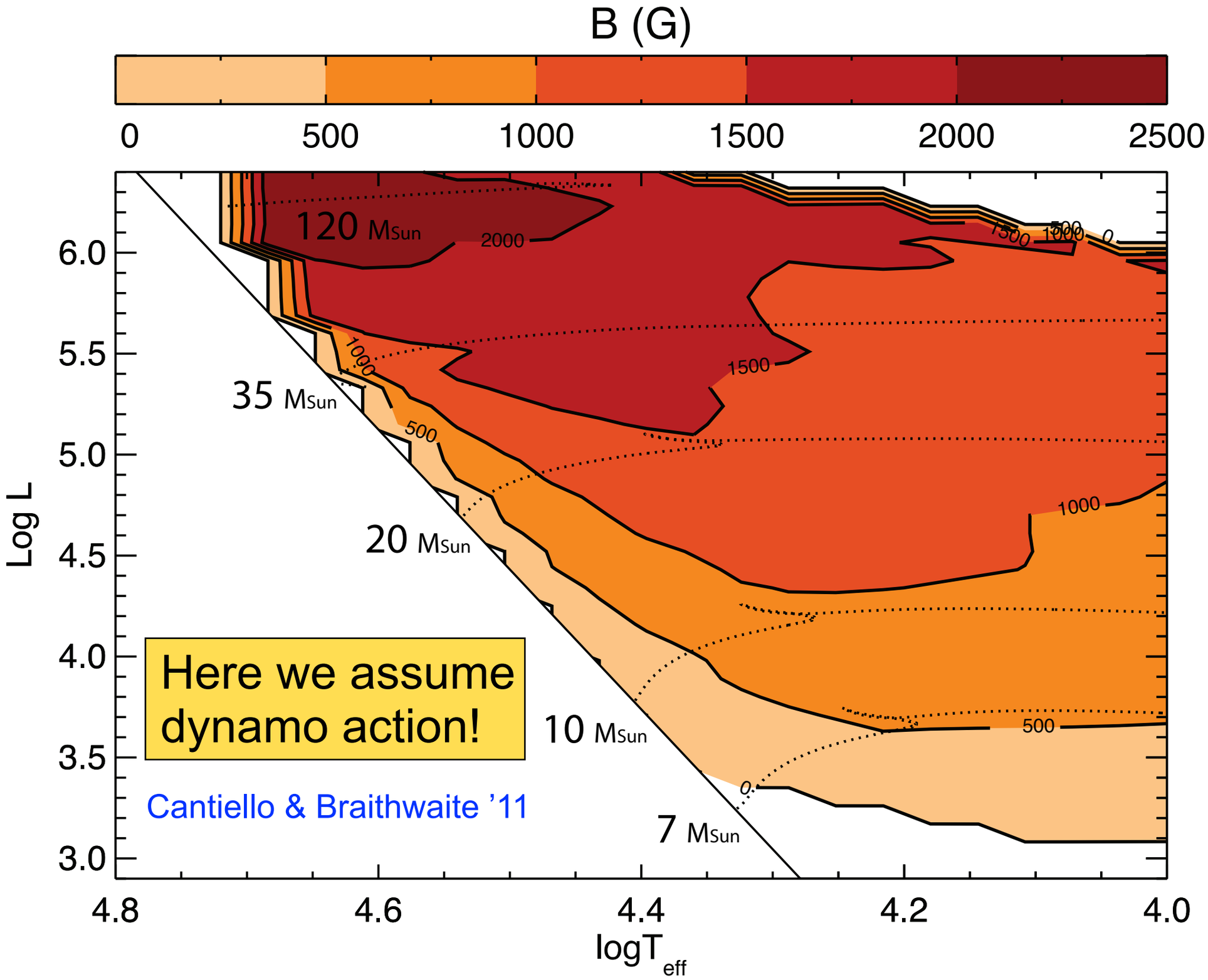
Subsurface convection
Rotation + Shear



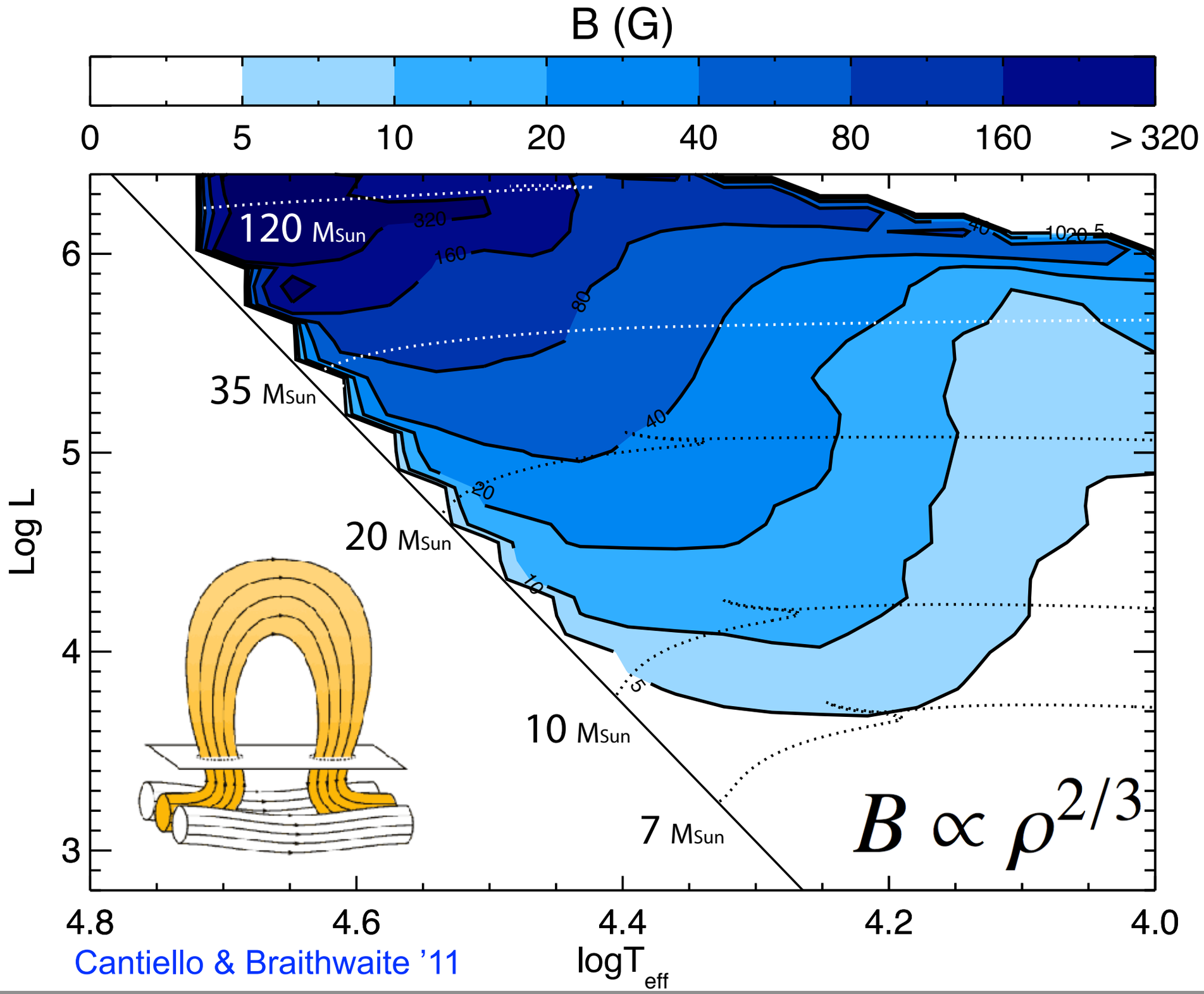


(Cantiello, Brandenburg et al. In prep)

Equipartition B Field in FeCZ

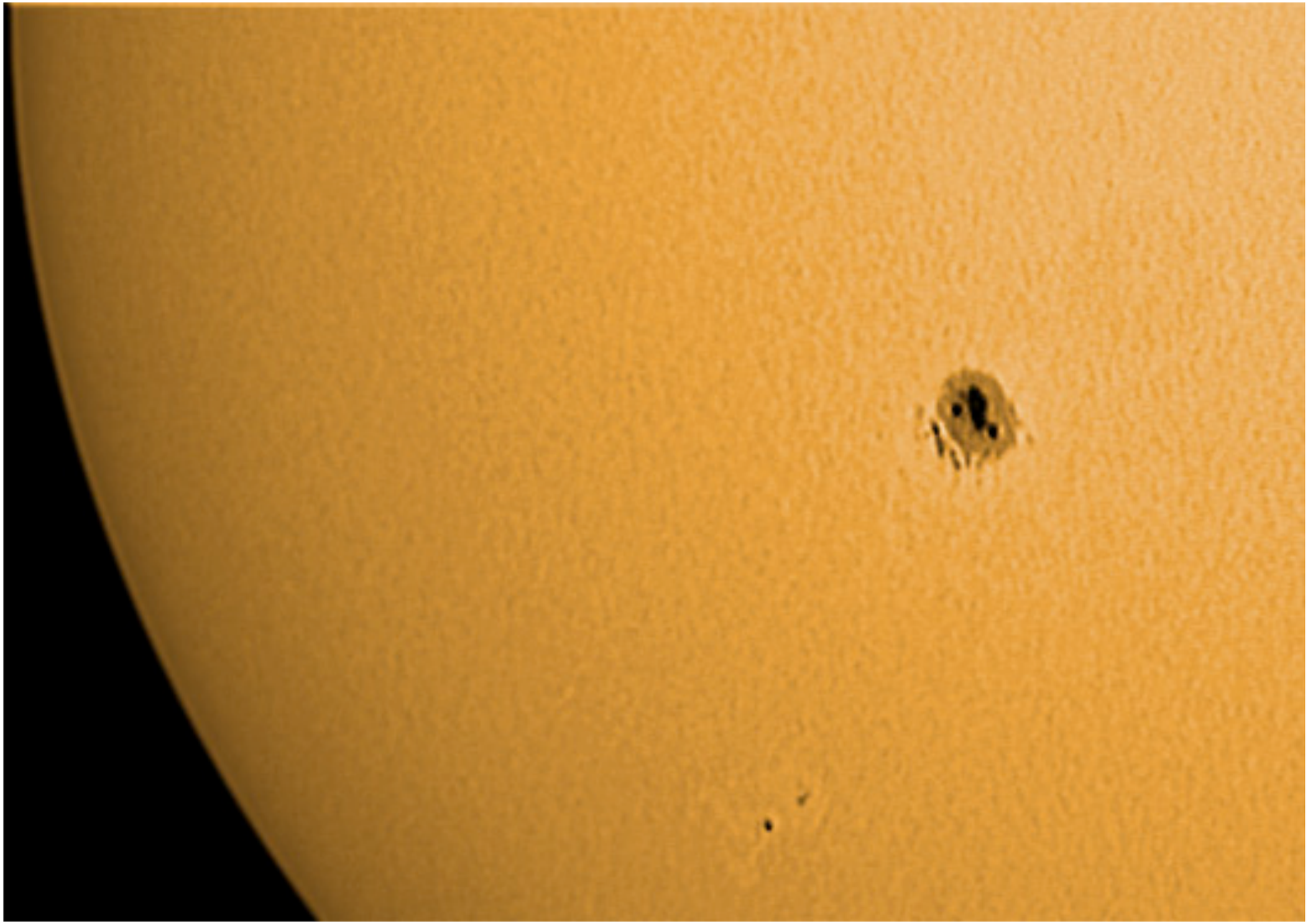


Surface B Field from FeCZ



Cantiello & Braithwaite ’11

Magnetic Spot in the Sun



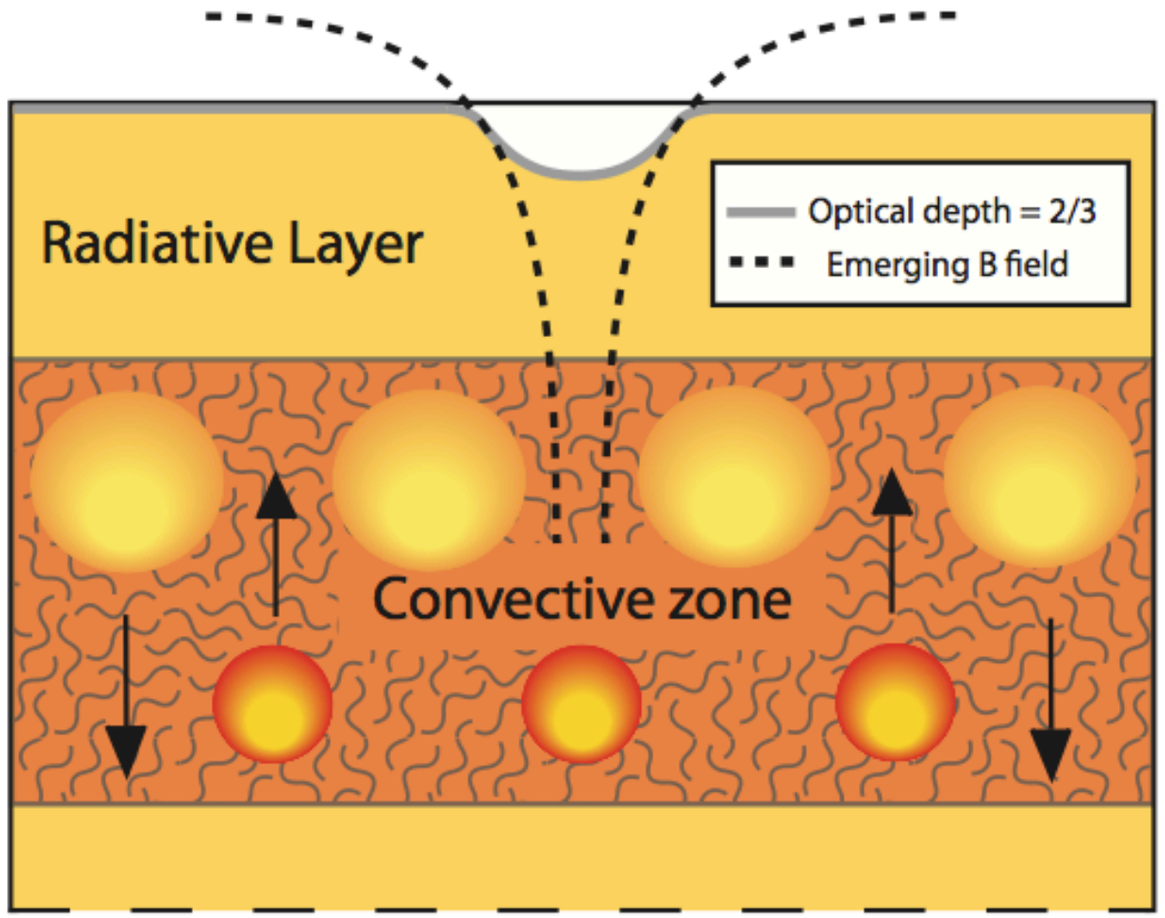
How they would look like?

A **very** simple model:

1) Assume hydrostatic equilibrium
2) Assume thermal equilibrium
3) Assume beta >> 1

$$P_e = P_i = \rho_i k T + B^2/8\pi$$

e.g. Parker (1955)



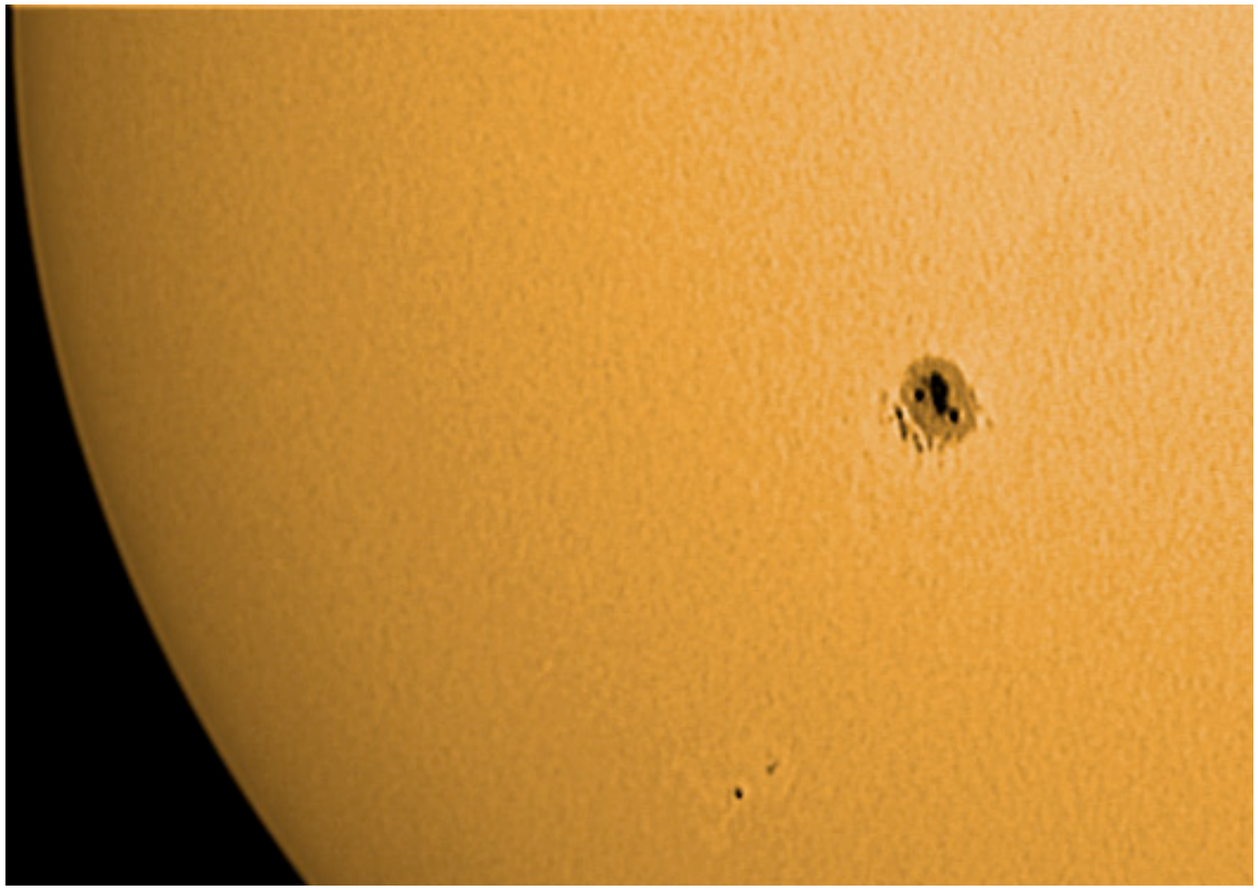
$$\frac{\Delta \ln T}{\Delta \ln P} = \nabla_{\rm rad} \qquad \beta = \frac{\rho k T}{B^2/8\pi}$$

$$\boxed{\frac{\Delta T}{T} = \frac{\nabla_{\rm rad}}{\beta}}$$

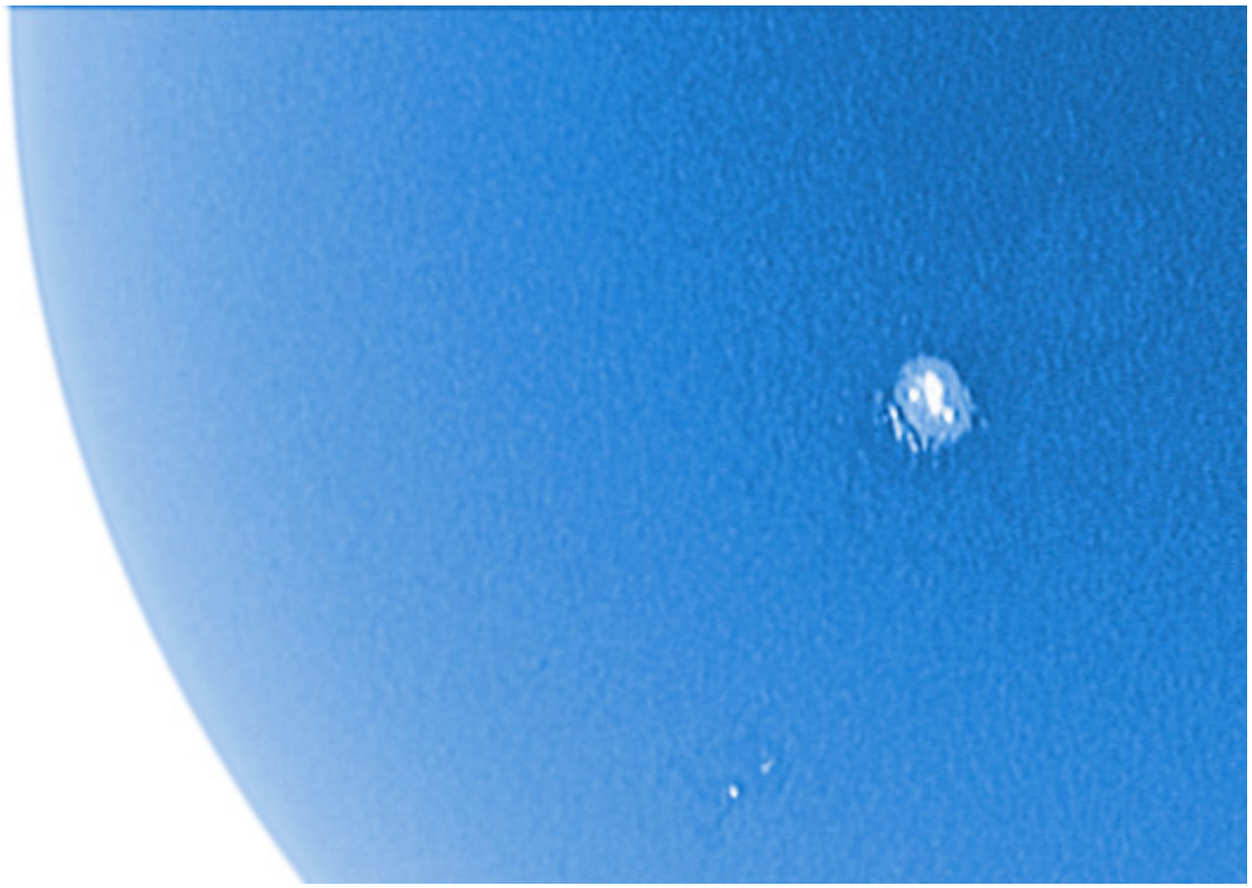
For fields of ~ 100 G emerging at the surface this leads to a temperature increase of ~ 300 K. A **hot, bright spot**

Cantiello & Braithwaite (2011)

How they would look like?



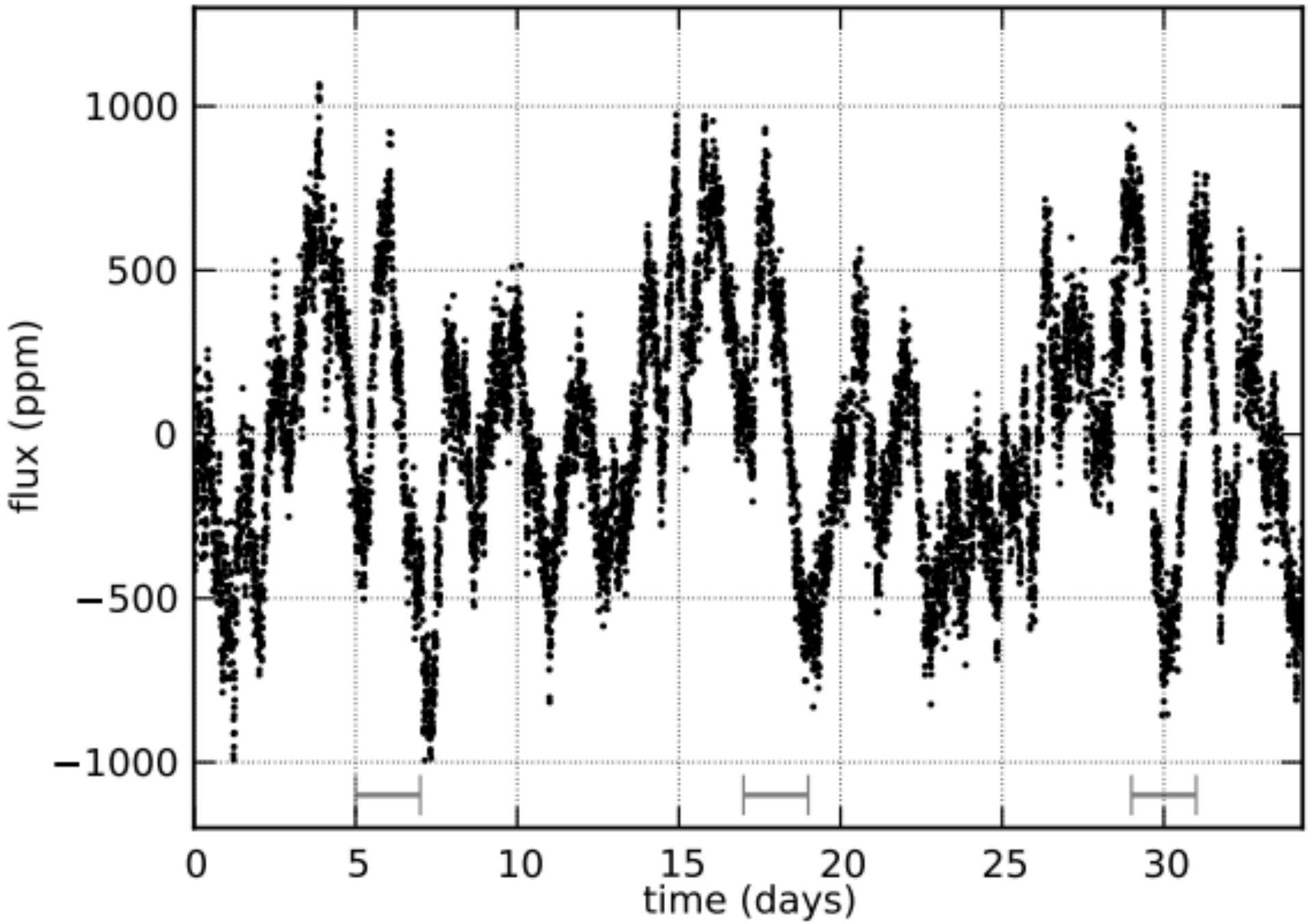
Spot in a convective star



Spot in a radiative star (?)

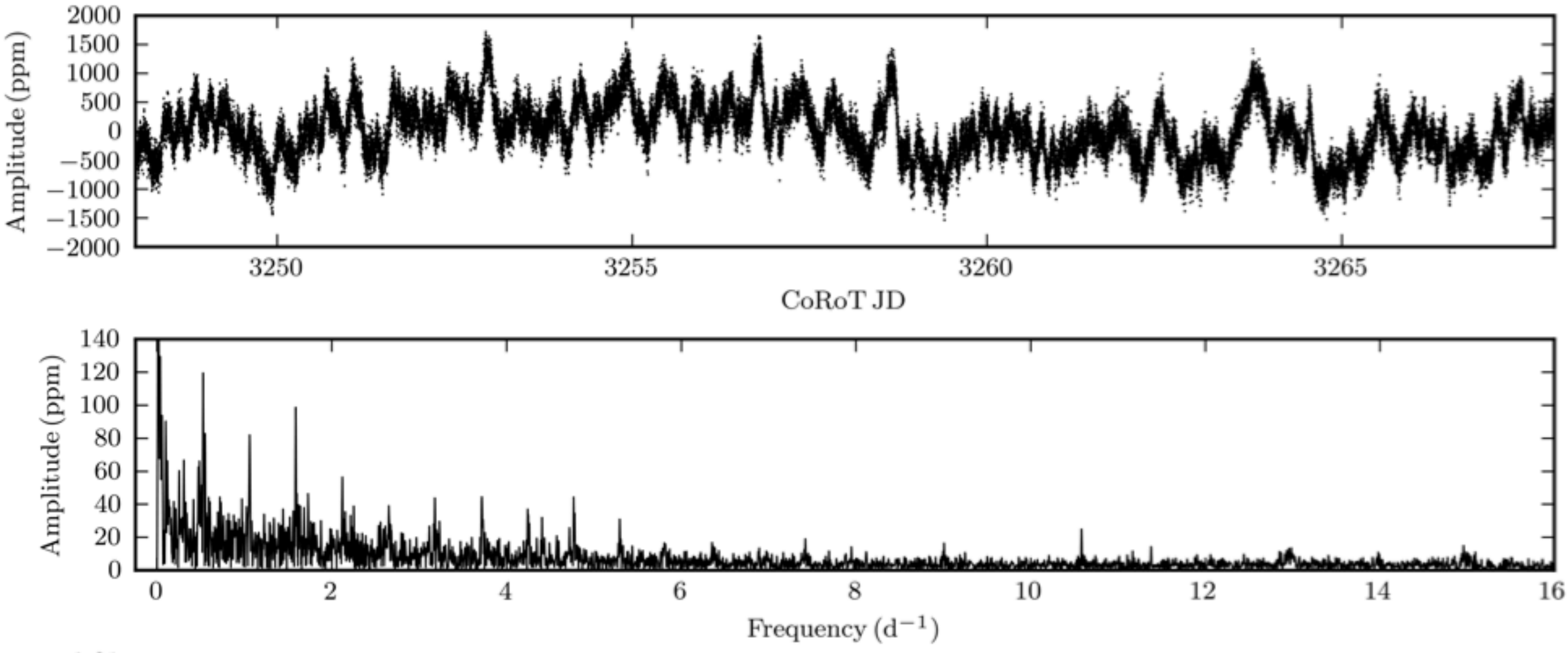
Spots in a O8V star?

HD 46149 (Degroote et al. 2010)

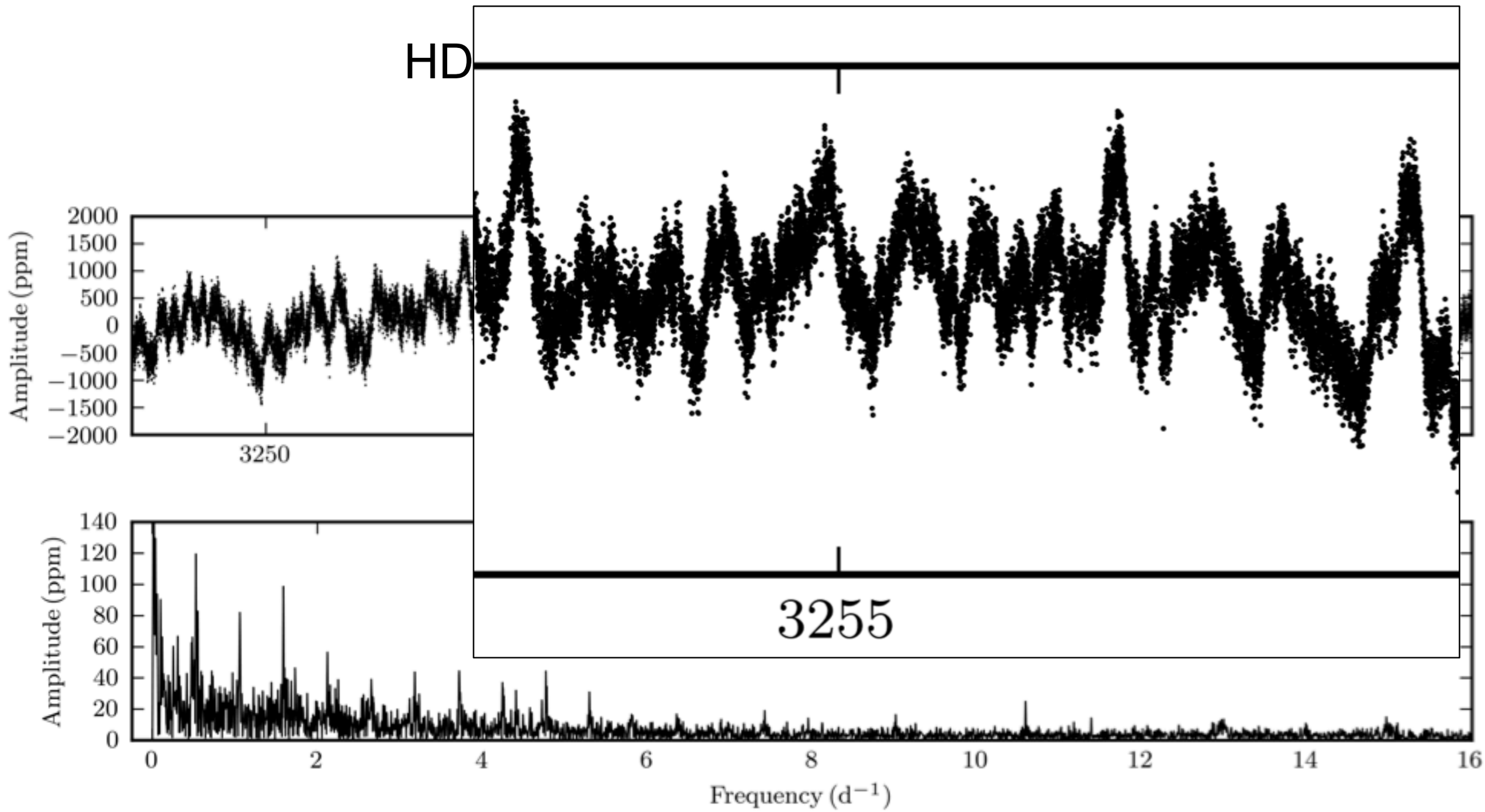


Spots in a B0.5IV star?

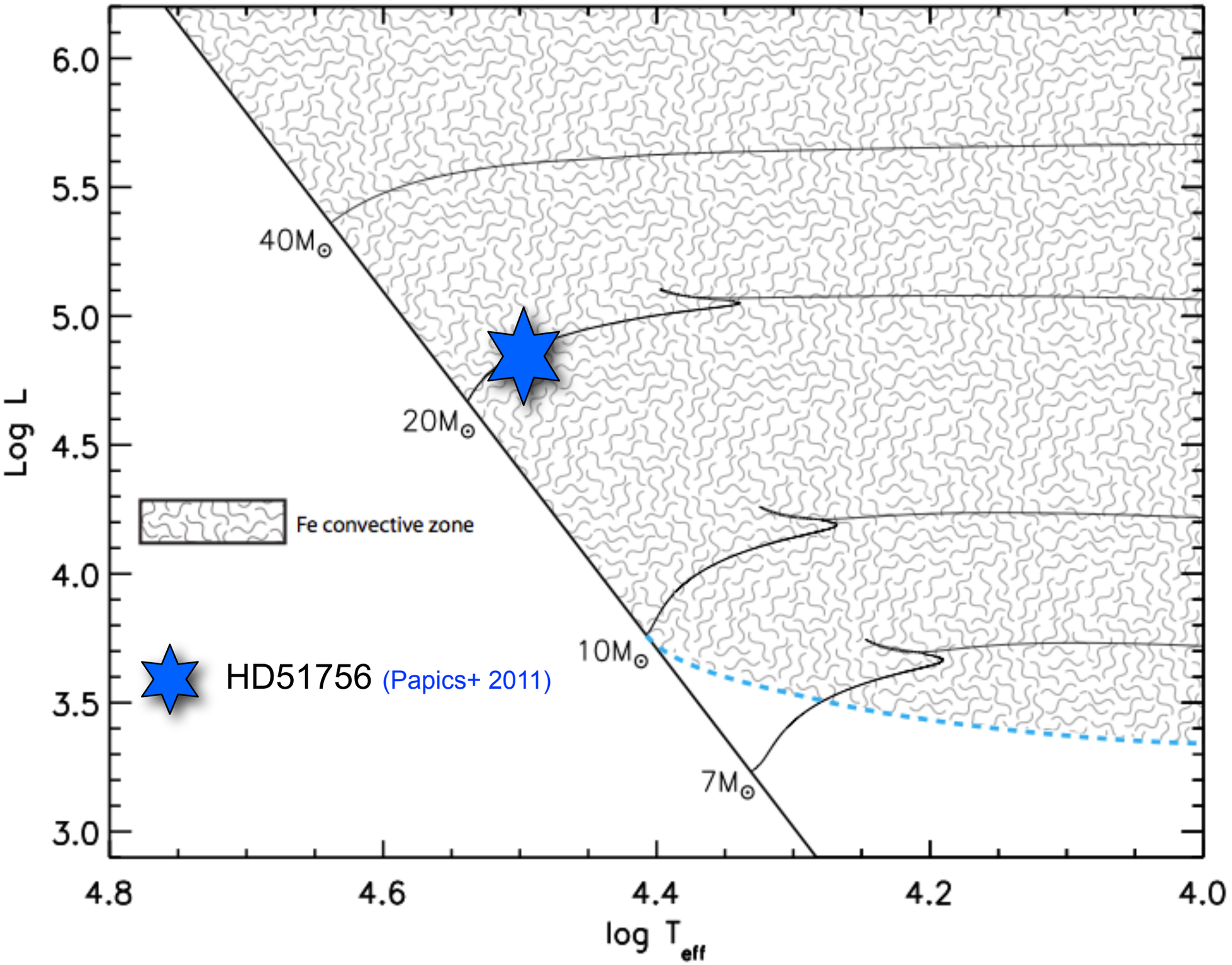
HD51756 (Papics et al. 2011)



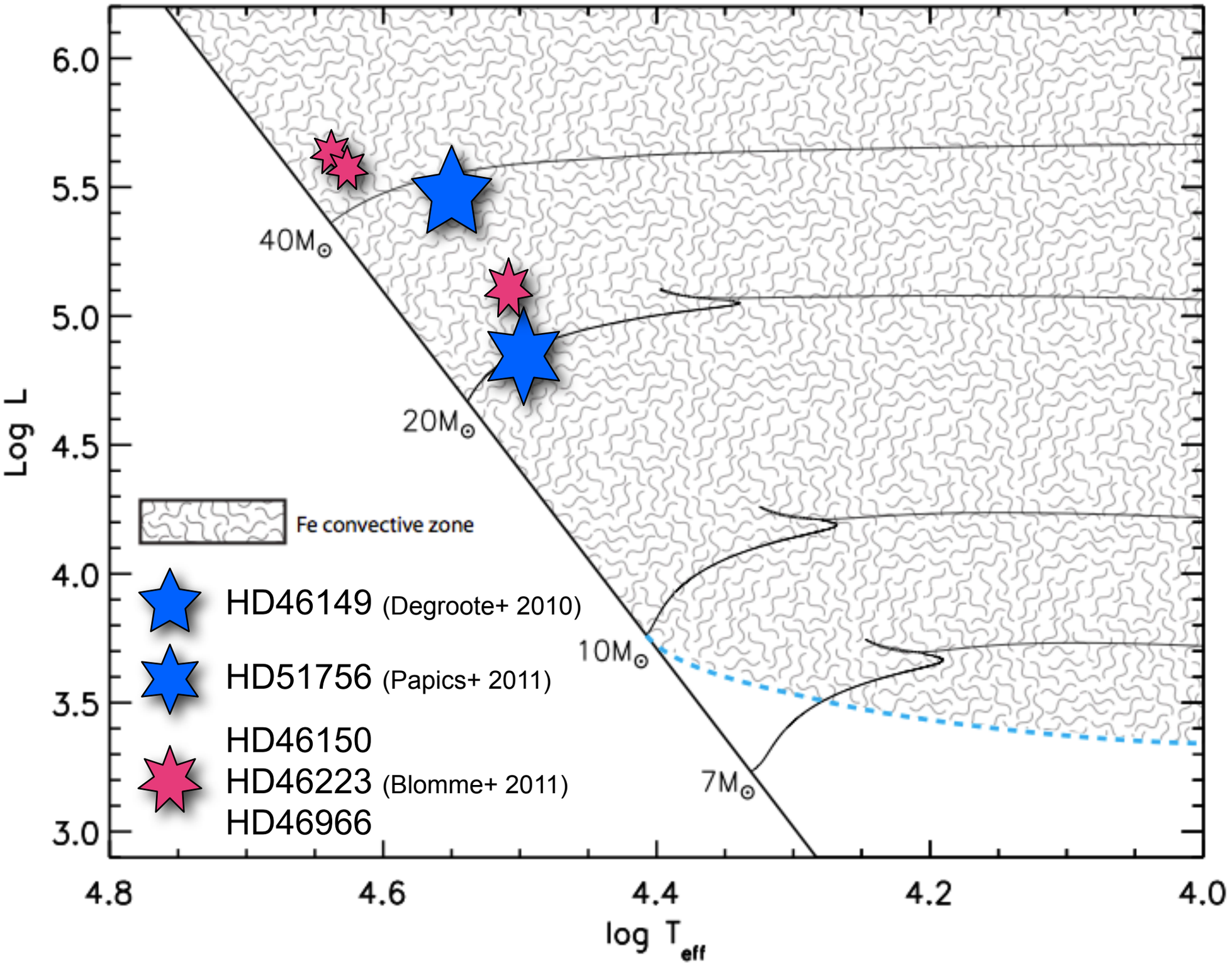
Spots in a B0.5IV star?



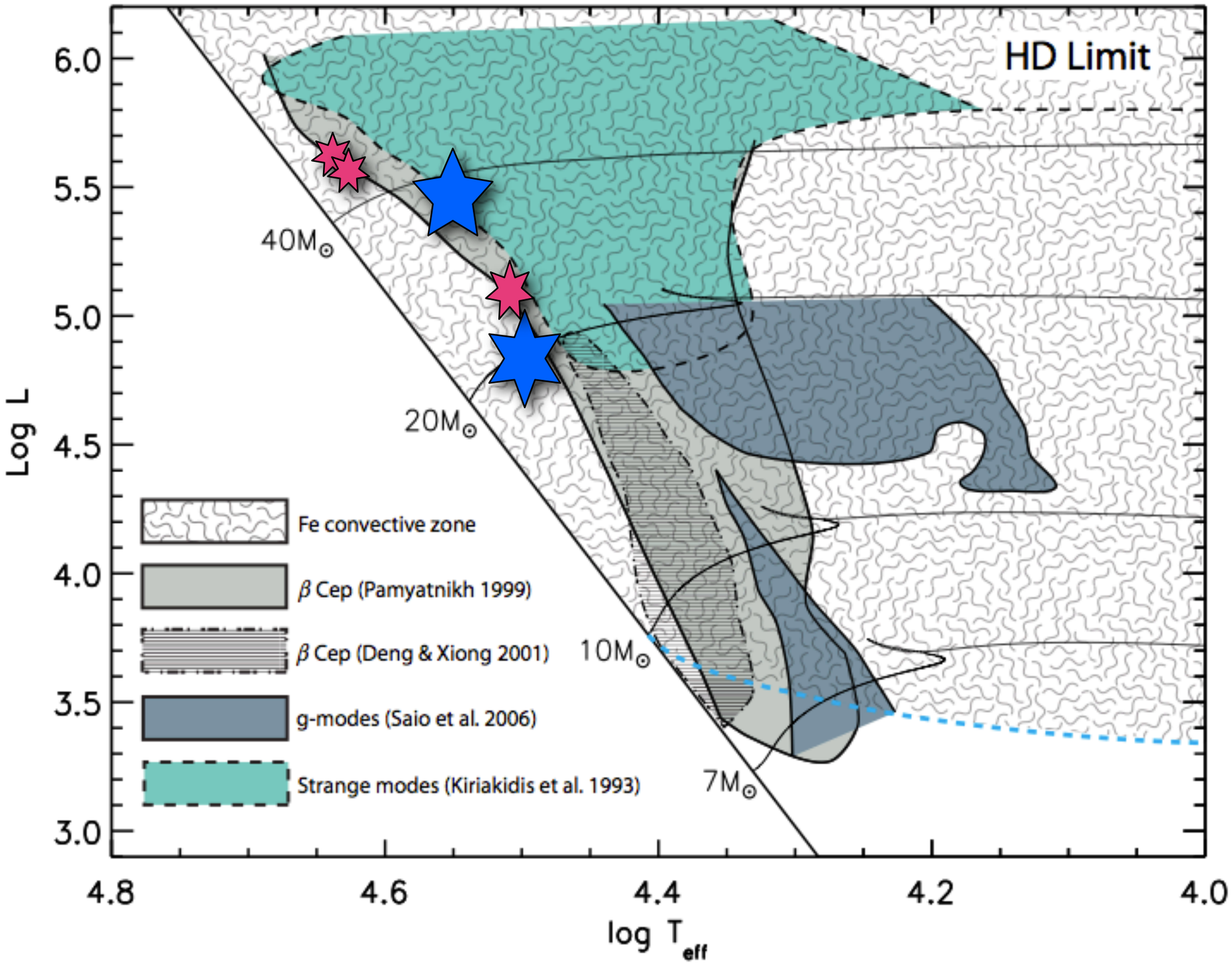
Photometric variability: HRD location



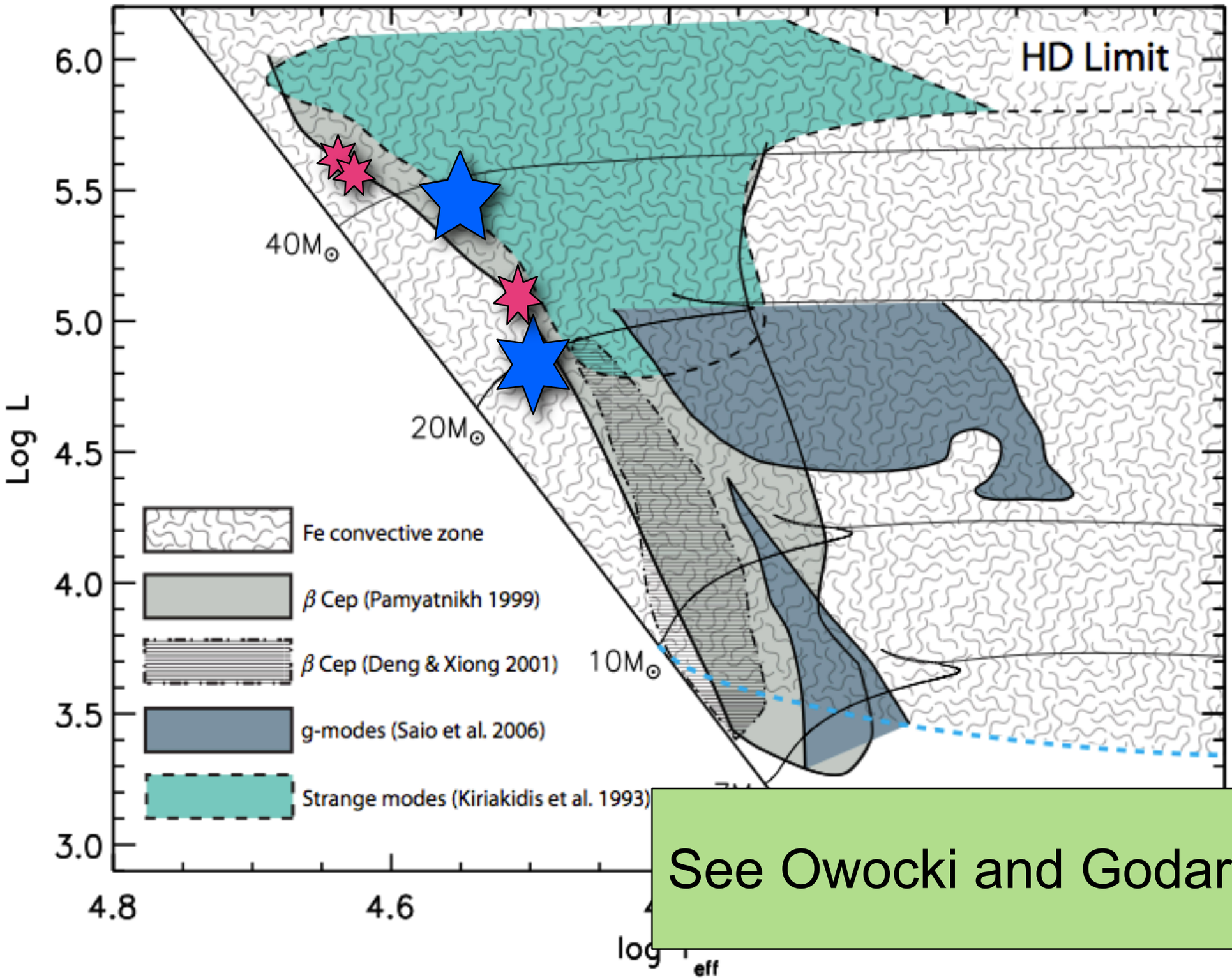
Photometric variability: HRD location



Photometric variability: HRD location

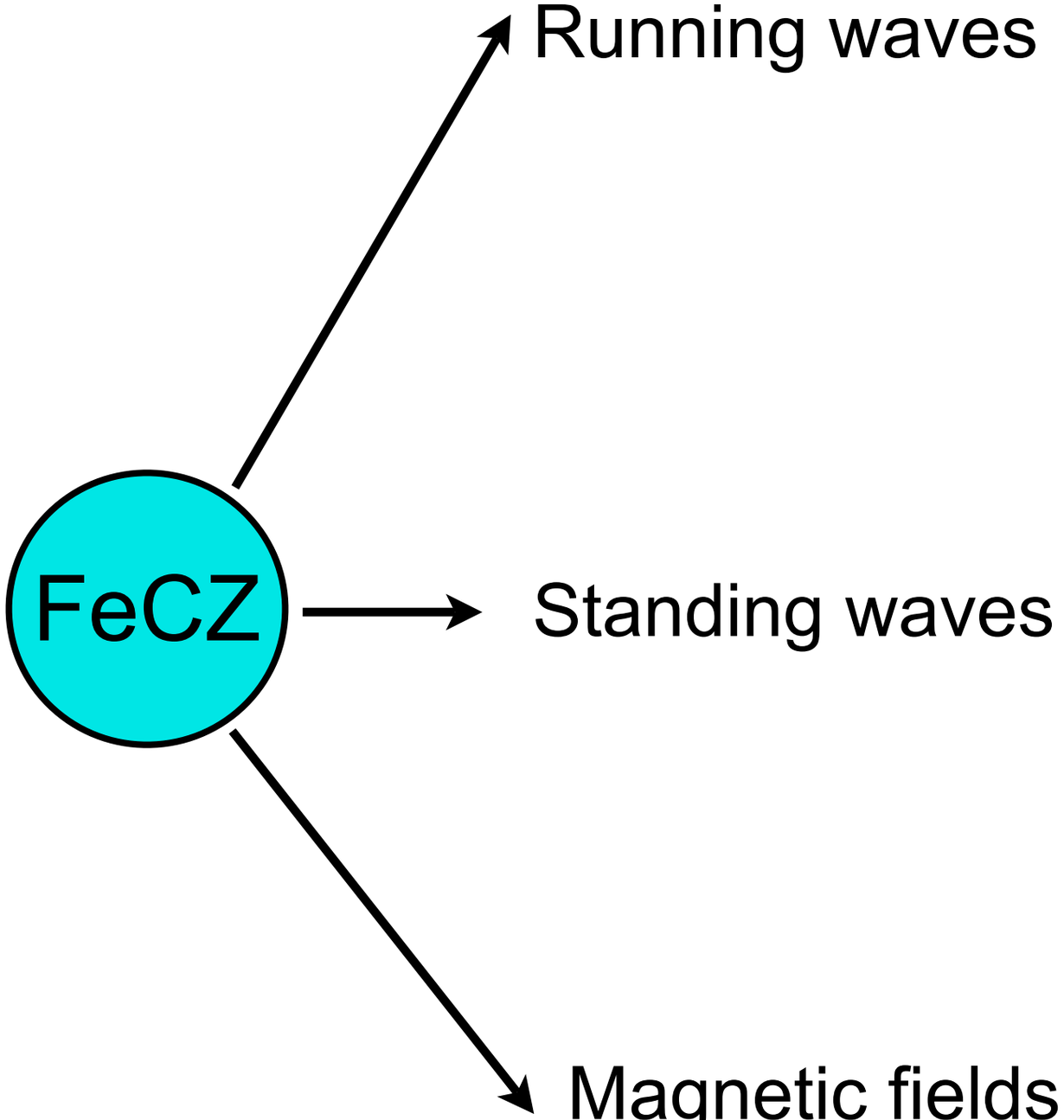


Photometric variability: HRD location

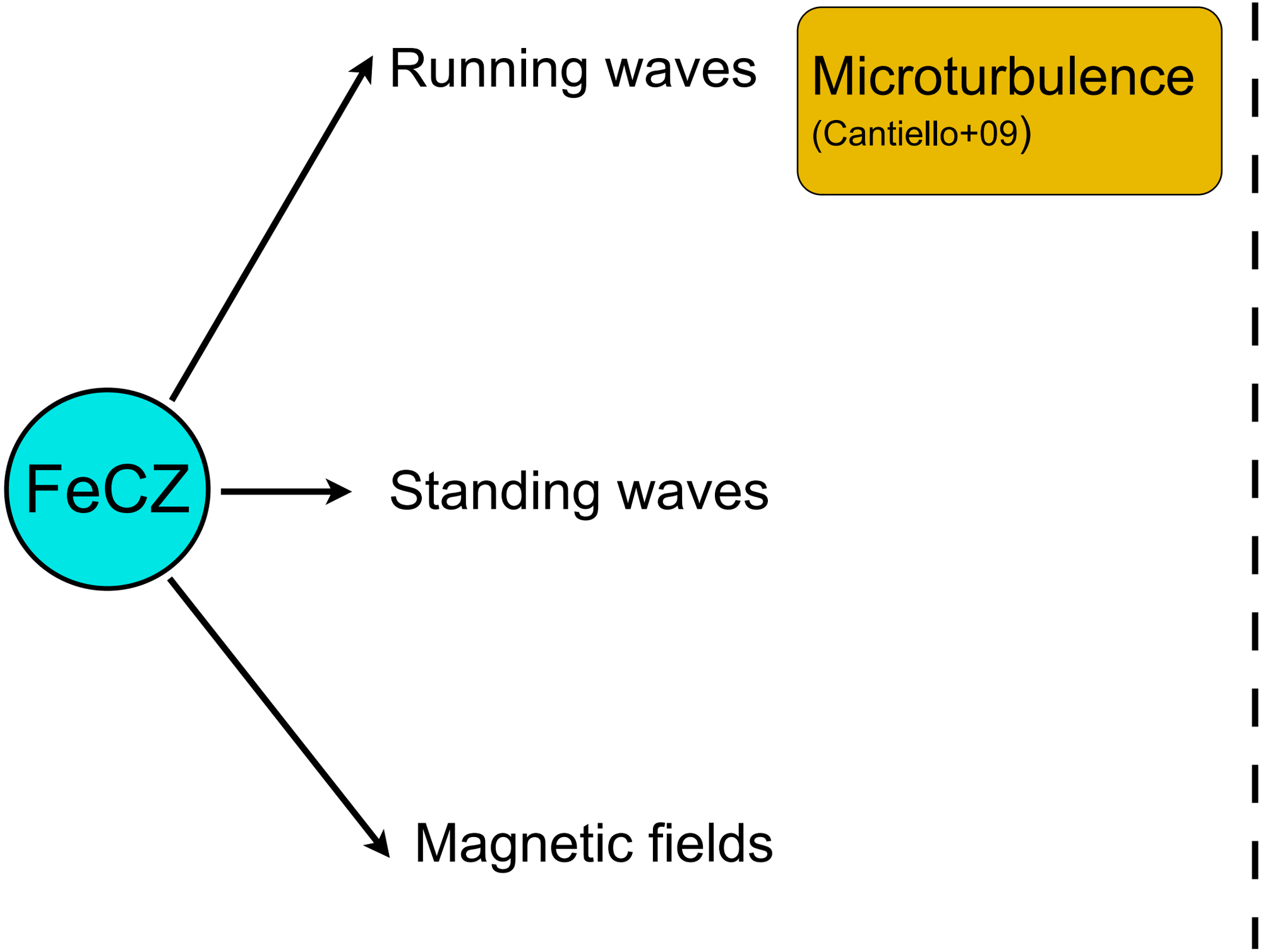


See Owocki and Godart's talks

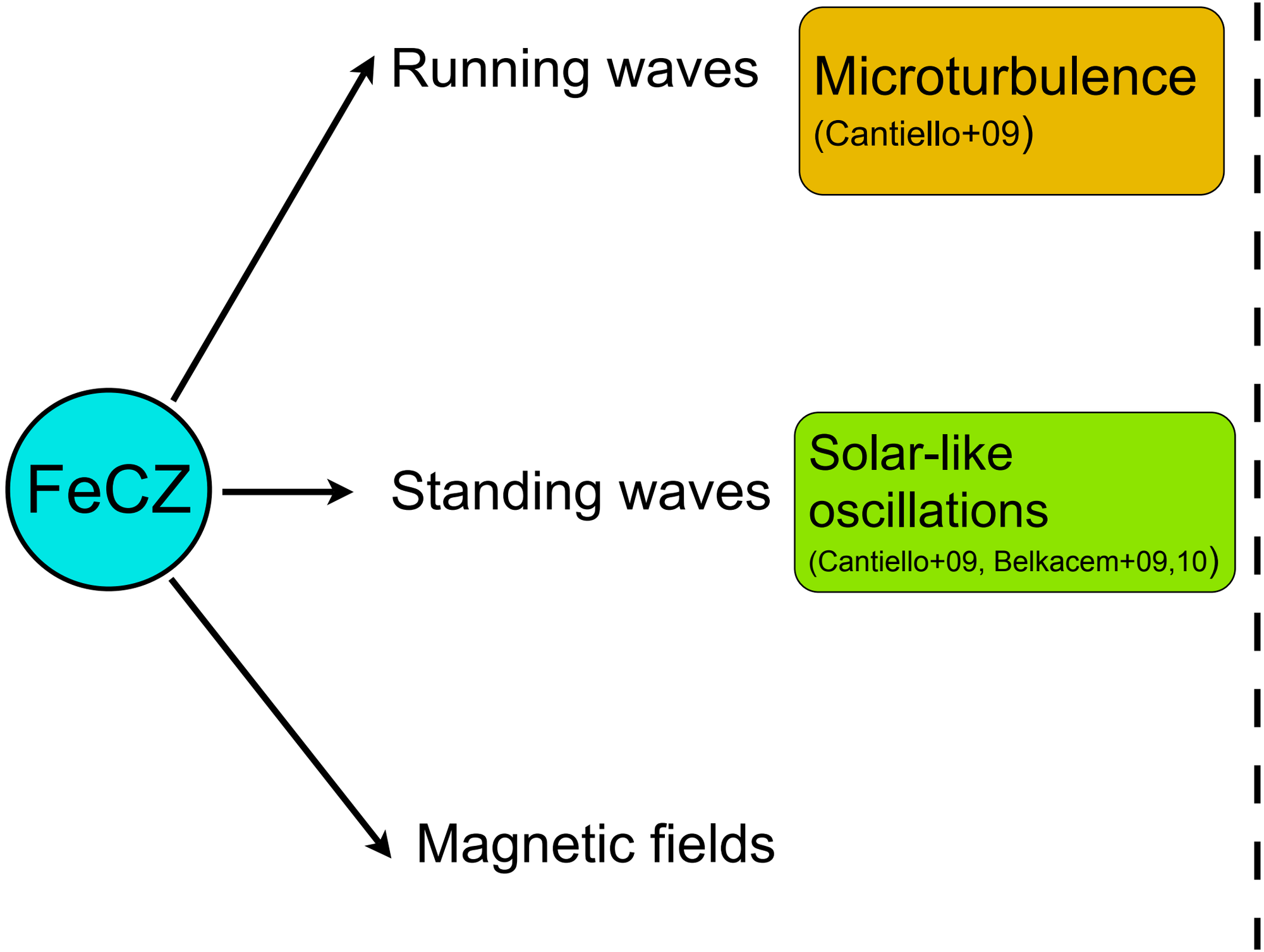
Effects from turbulent convection



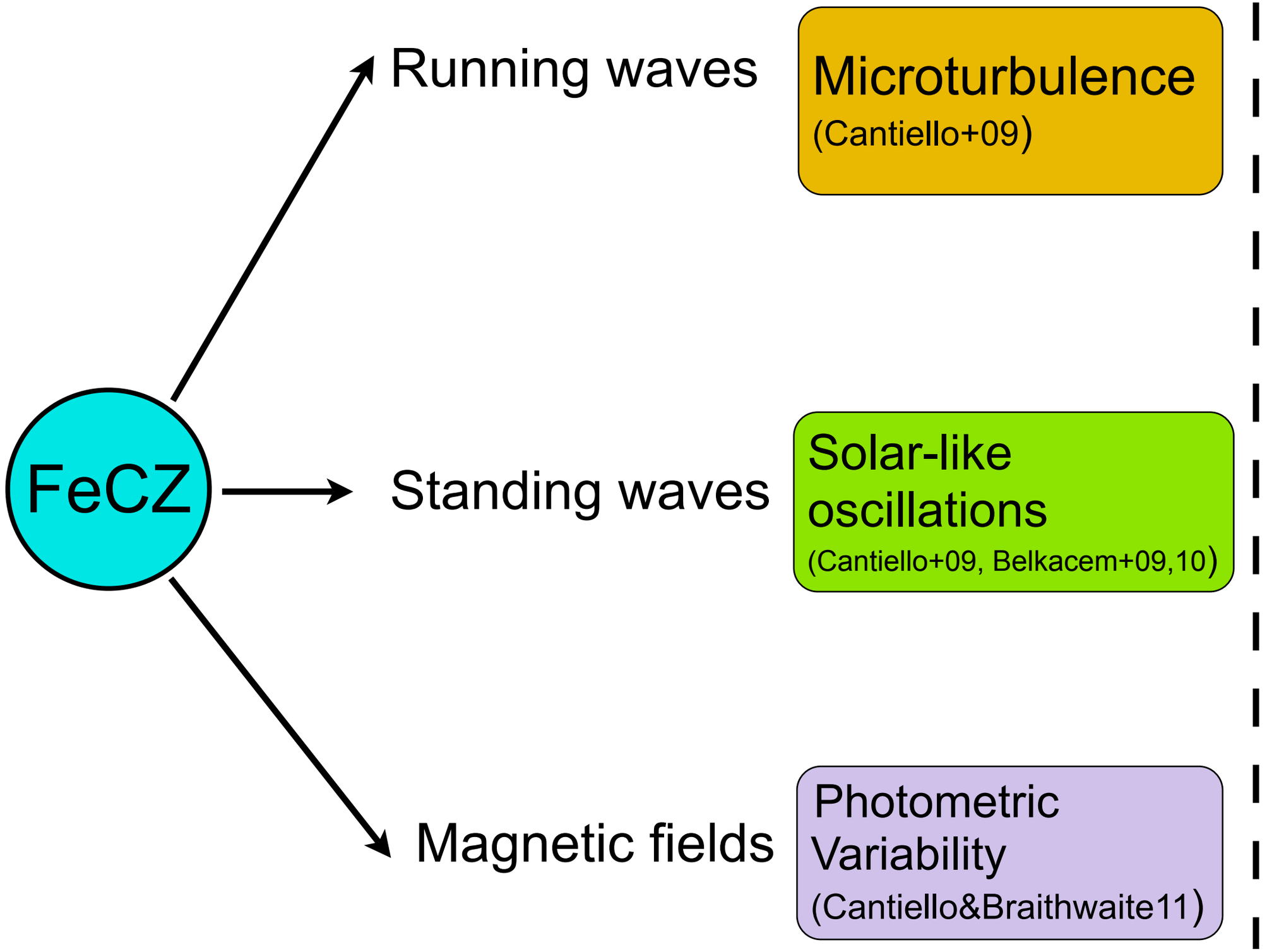
Effects from turbulent convection



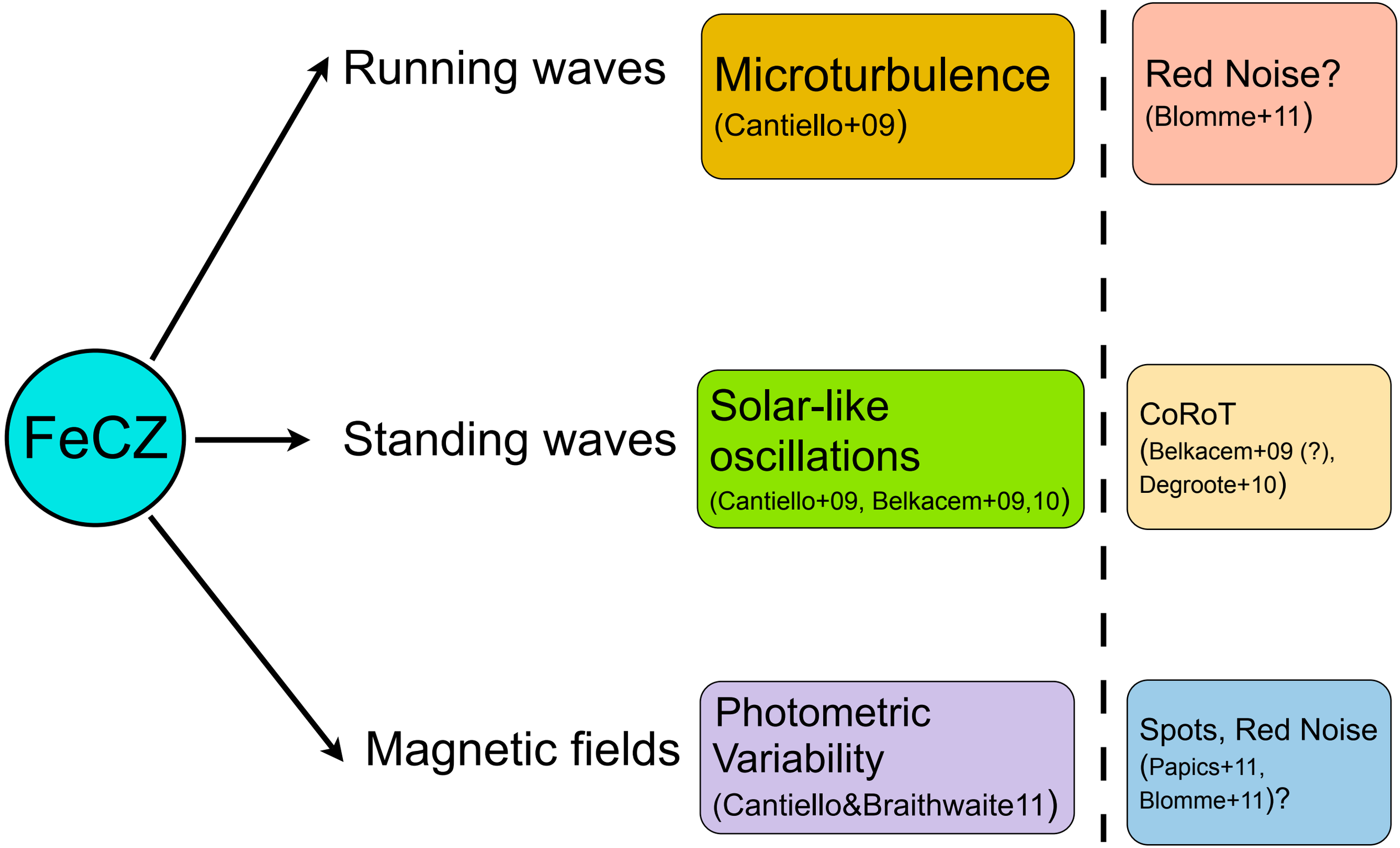
Effects from turbulent convection



Effects from turbulent convection



Effects from turbulent convection



Take-Home Messages

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- The envelope of early type stars is not fully radiative
- Surface turbulence induced by near-surface convection
- Photometric variability in hot massive stars compatible with effects from FeCZ
- Massive stars might have **bright magnetic spots** at their surface

The End

Thanks!