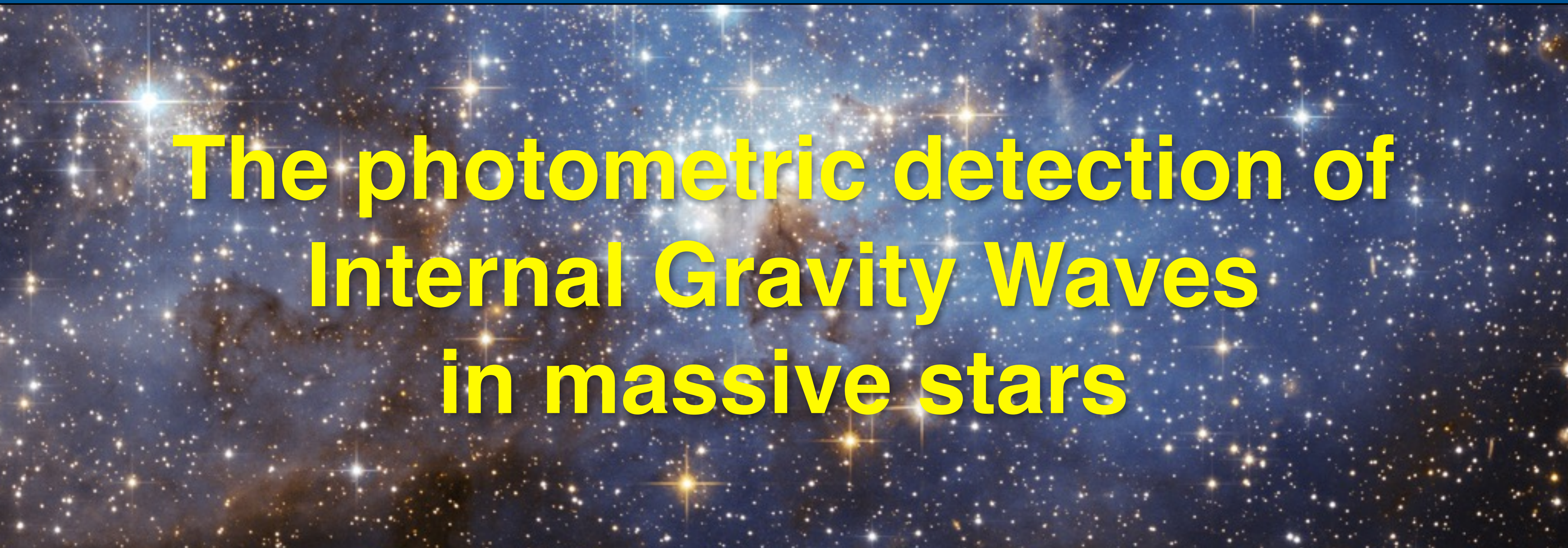
The photometric detection of Internal Gravity Waves in massive stars



Dominic Bowman

C. Aerts, C. Johnston, M. G. Pedersen, T. M. Rogers, P. V. F. Edelmann, S. Simón-Díaz, T. Van Reeth, B. Buysschaert, A. Tkachenko, and S. A. Triana

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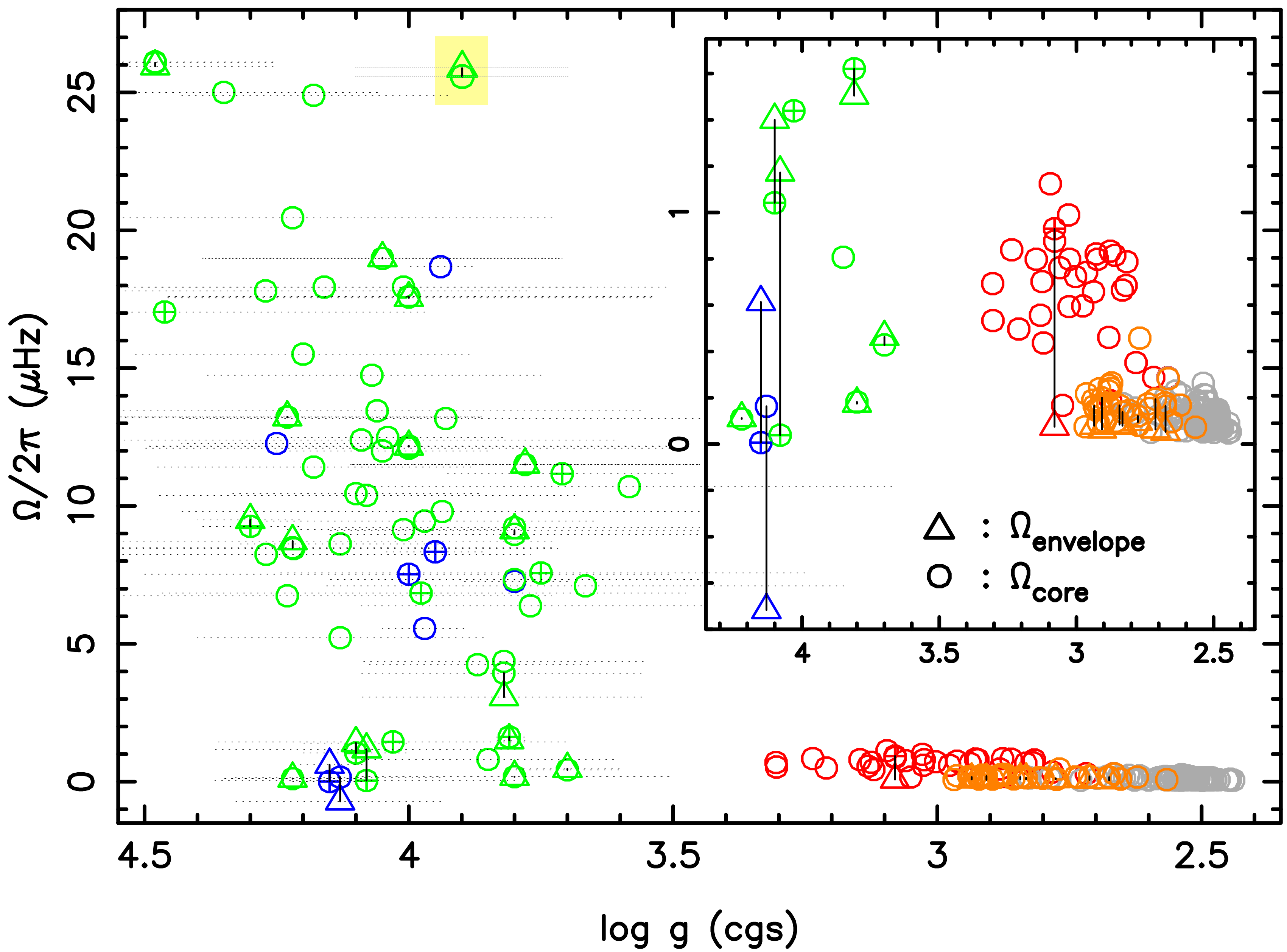
Interior rotation in intermediate-mass stars

The vast majority of BAF stars are approximately rigid rotators.



Main sequence:
gamma Dor (**F**)
SPB (**B**)

Evolved stars:
RGB
Red Clump
Secondary Red Clump

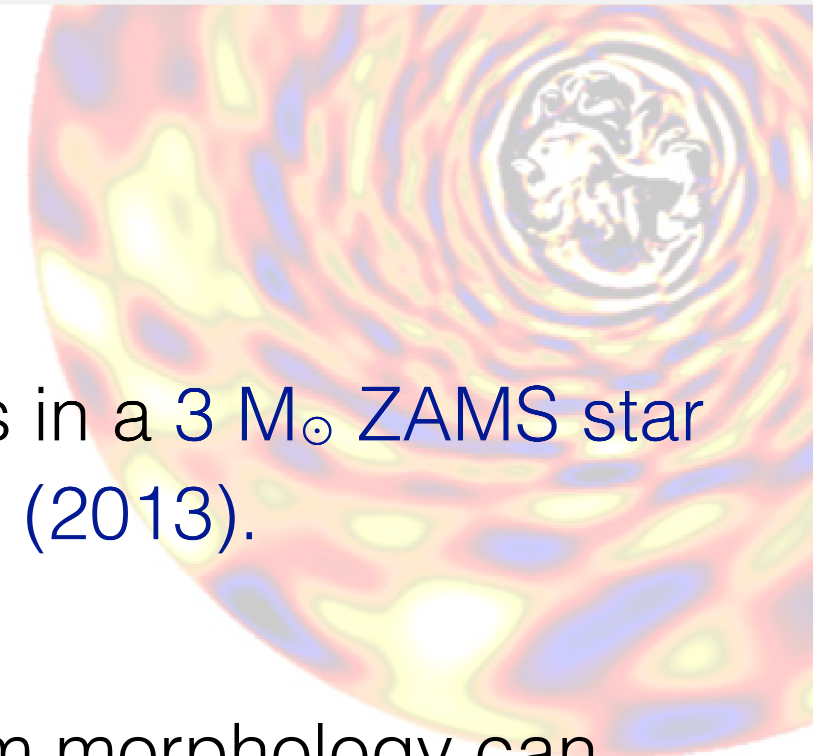
Angular momentum transport mechanism

...Internal Gravity Waves

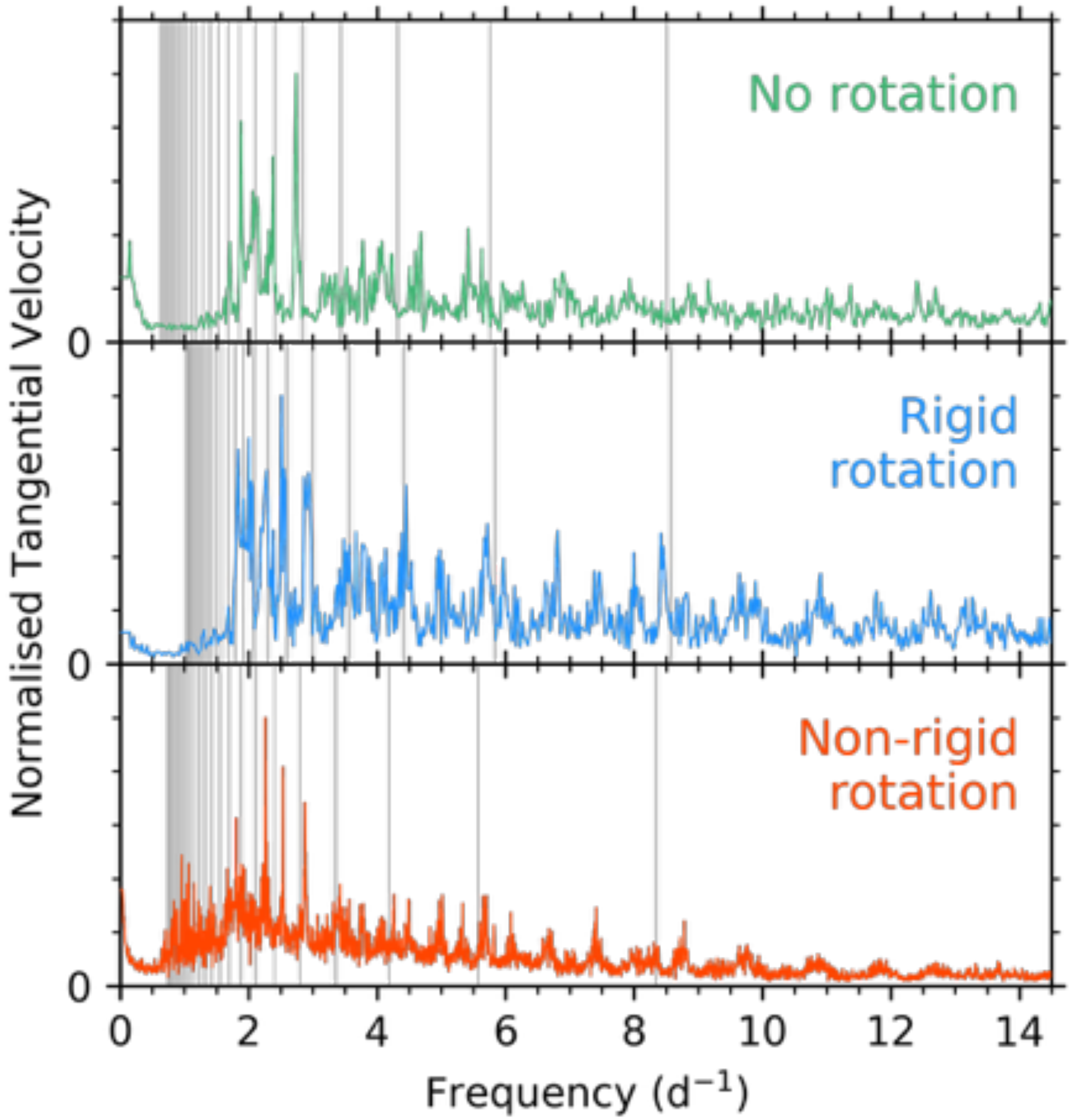
(Aerts et al. 2017)

(c.f. talk by G. Buldgen)

2D simulations of IGWs



Convectively-driven IGWs are effective at transporting angular momentum and chemical elements.



Case study: IGWs in a 3 $M_\odot$ ZAMS star from Rogers et al. (2013).

The IGW spectrum morphology can be characterised as a low-frequency power excess: red noise.

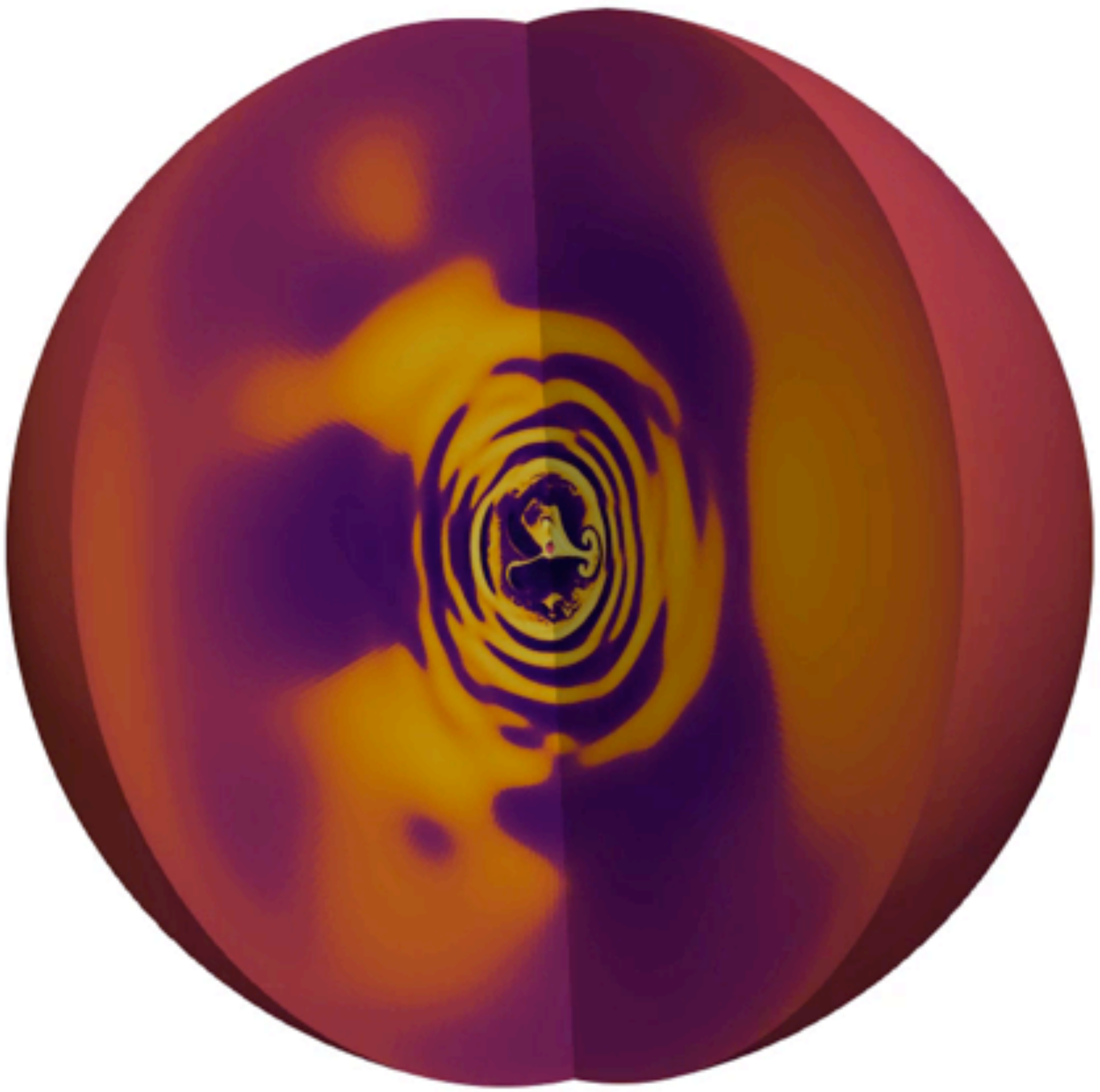
Scaling to other masses:

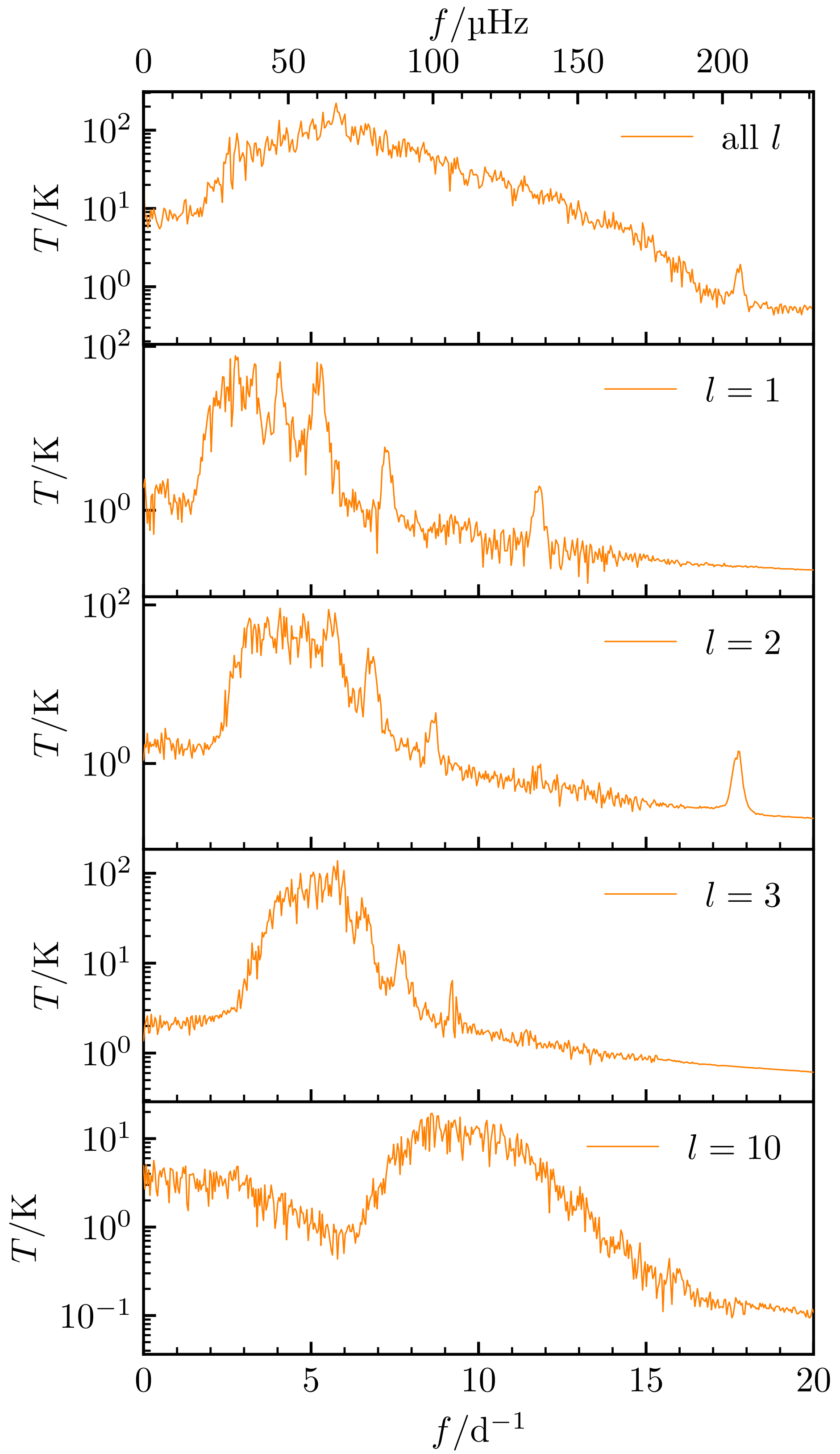
$$\uparrow M \;=\; \uparrow A$$

(Zahn et al. 1997; Talon & Charbonnel 2005-2008; Cantiello et al. 2009; Shiode et al. 2013; Fuller et al. 2014; Lecoanet & Quataert 2013; Rogers 2015; Rogers & McElwaine 2017)

3D simulations of IGWs

IGW excitation through plume penetration, producing low-frequency power excess in temperature and velocity spectra.

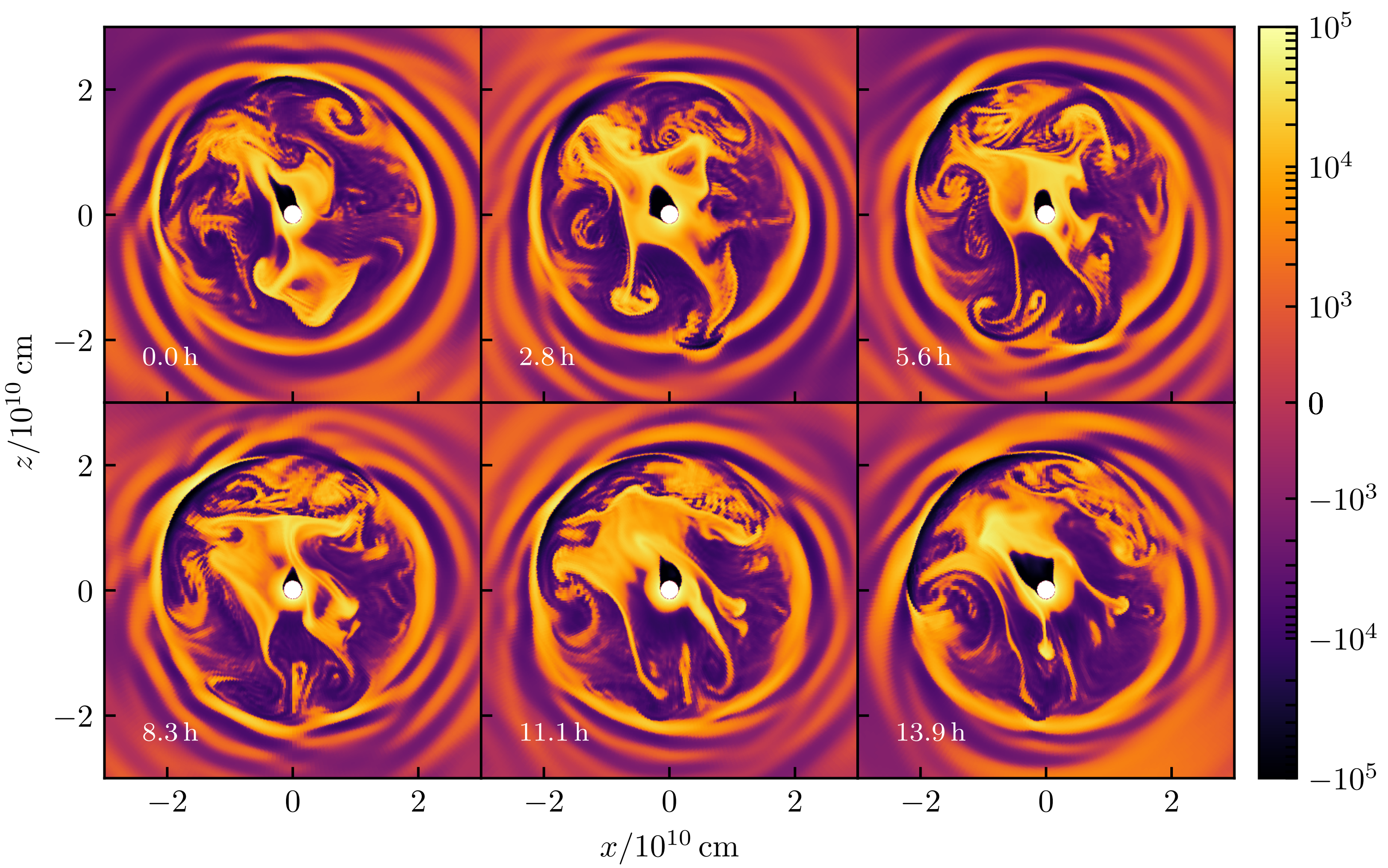


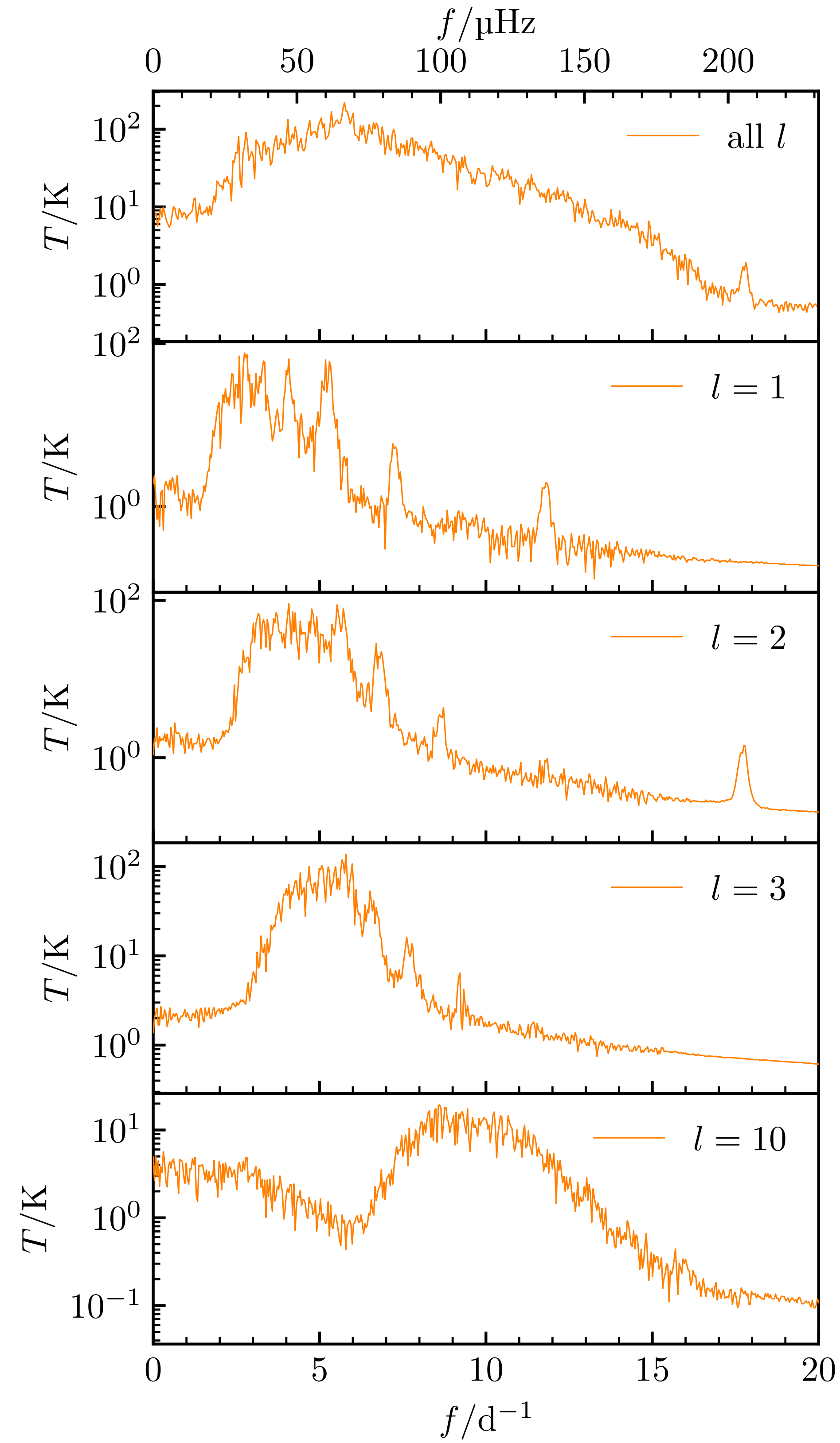


(Edelmann et al. 2018)

3D simulations of IGWs

IGW excitation through plume penetration, producing low-frequency power excess in temperature and velocity spectra.





(Edelmann et al. 2018)

Can we detect IGWs in photometric observations of massive stars?

IGW amplitudes:

$$\uparrow M \;=\; \uparrow A$$

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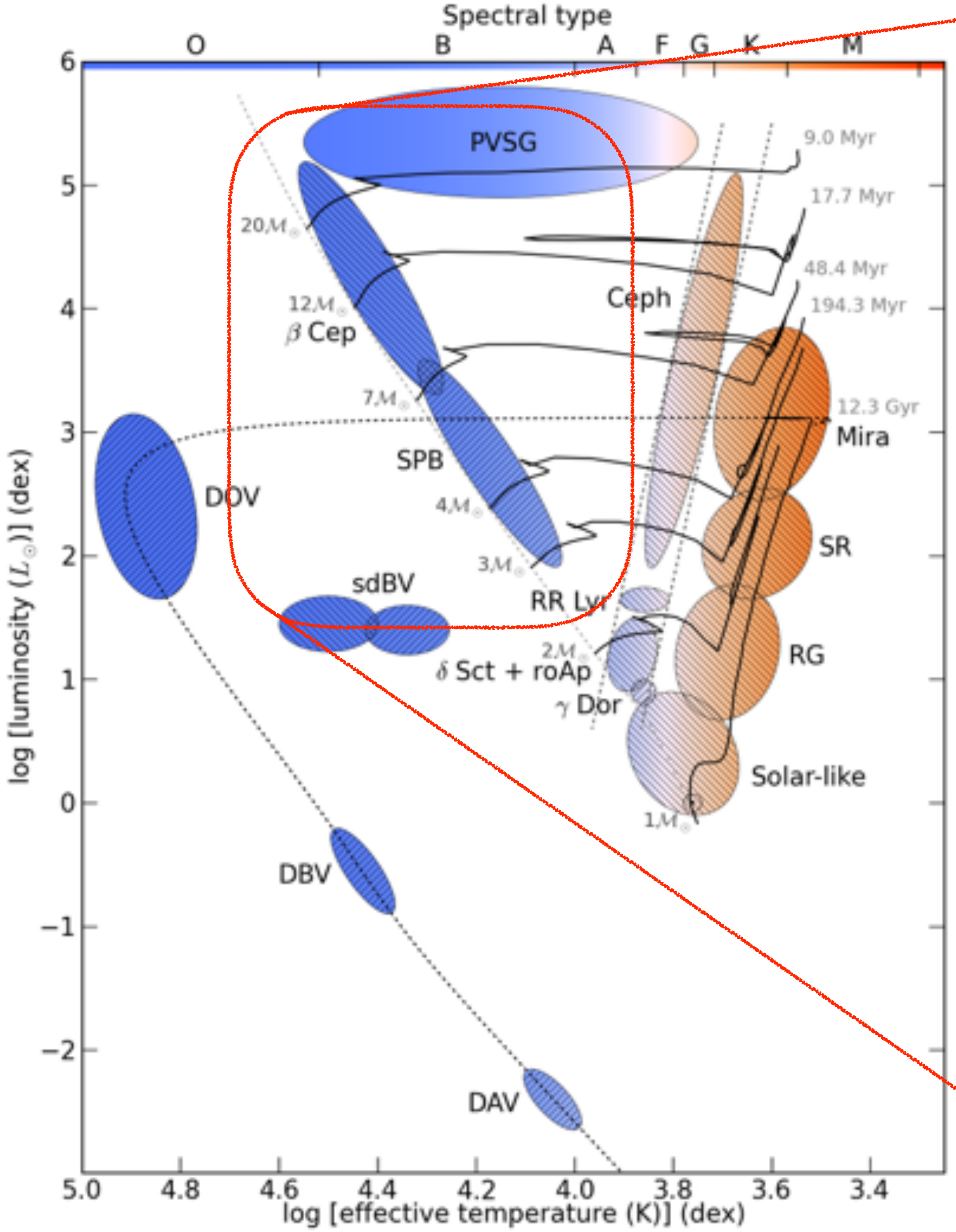
Massive star variability

Widespread and diverse variability in the upper main sequence:



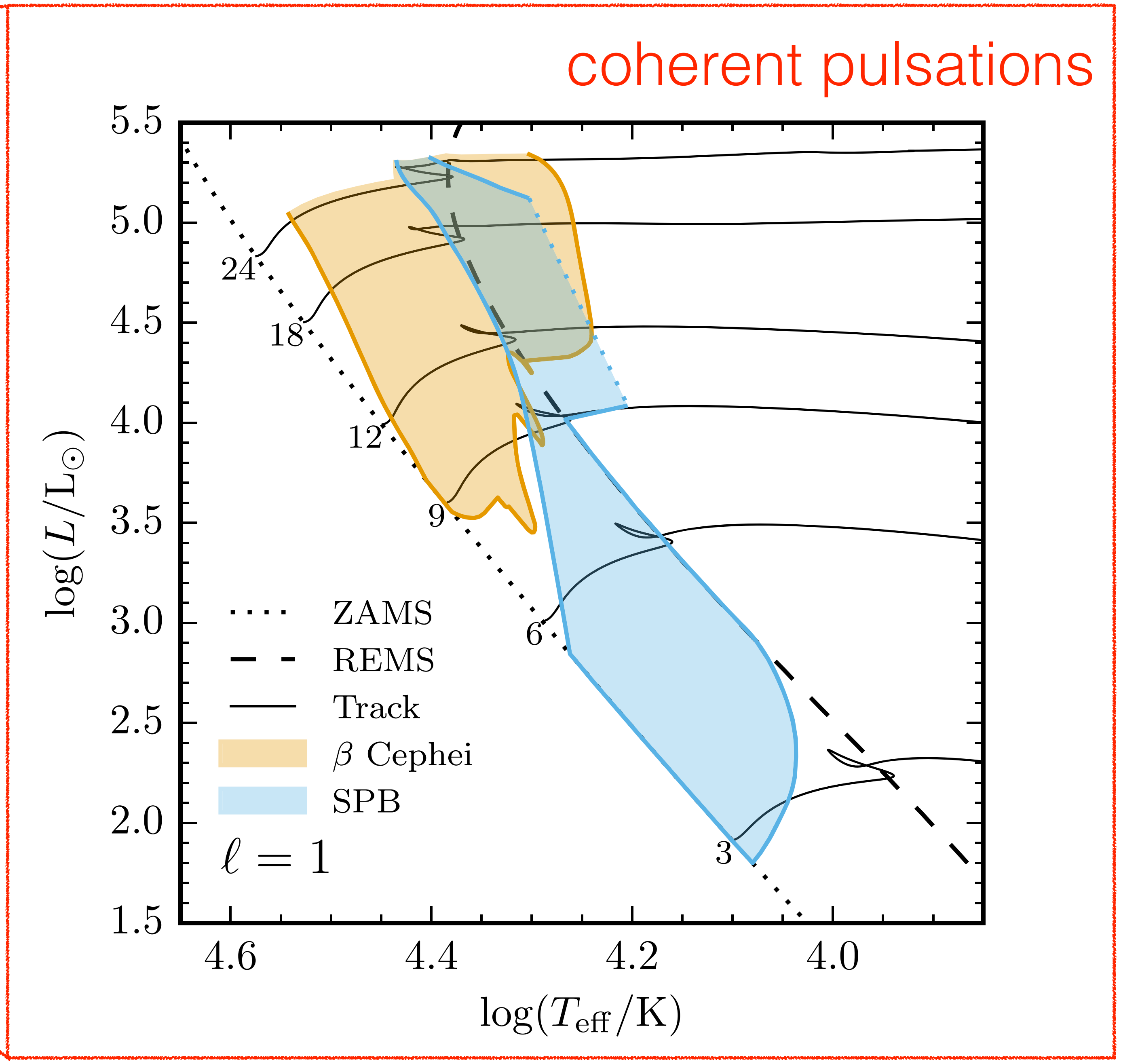
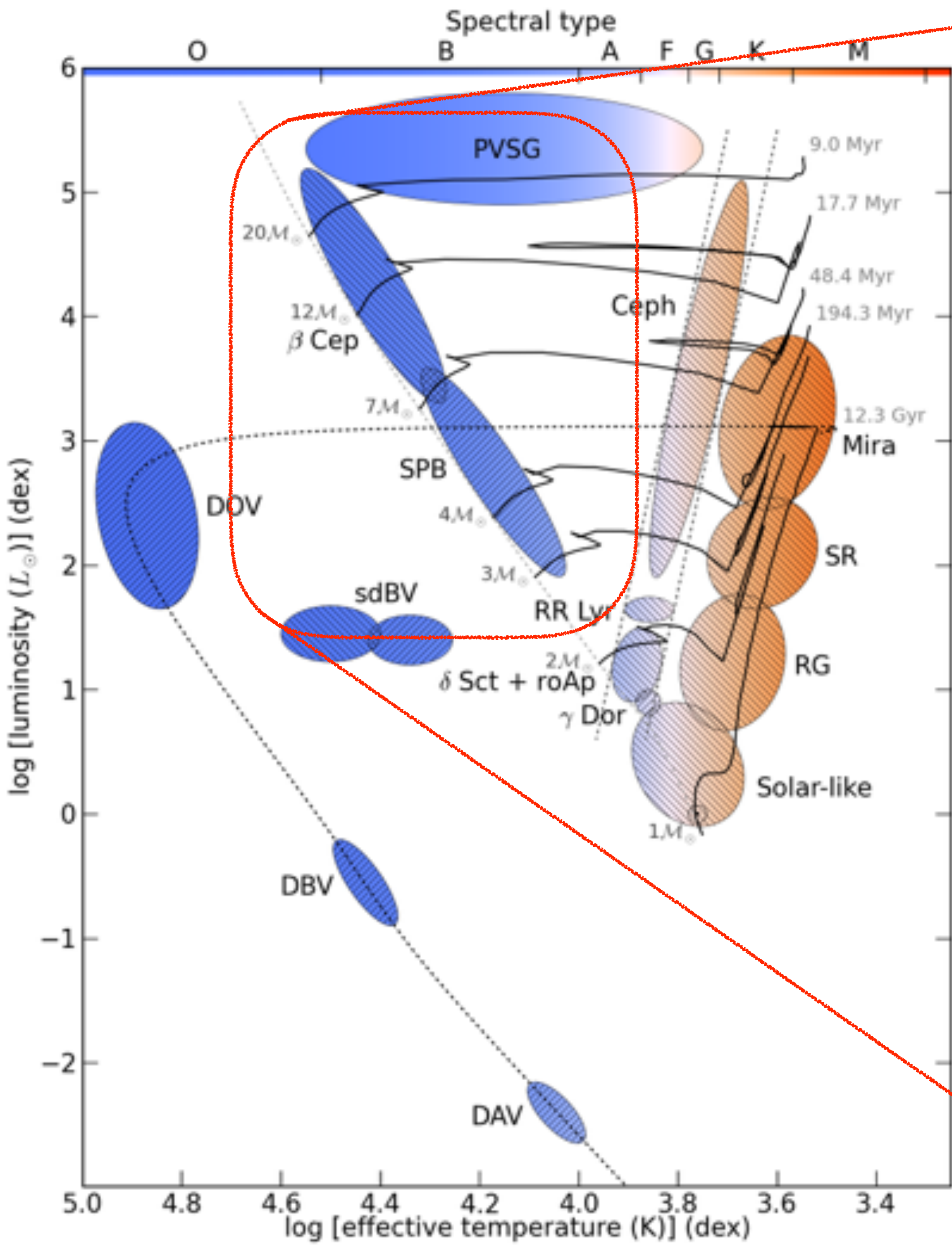


Image credit: P. I. Pápics

(Paxton et al. 2015)

Massive star variability

Widespread and diverse variability in the upper main sequence:



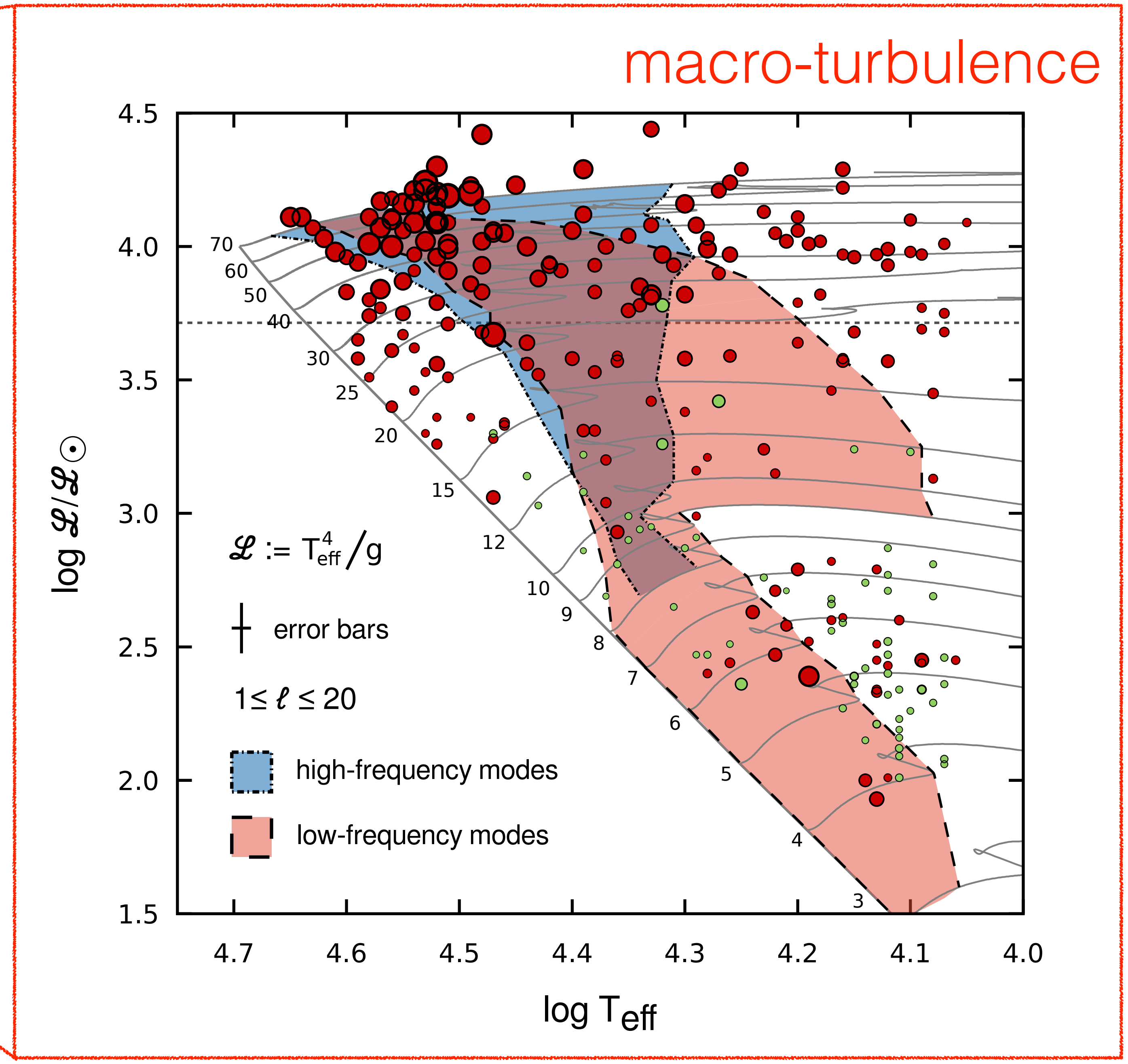


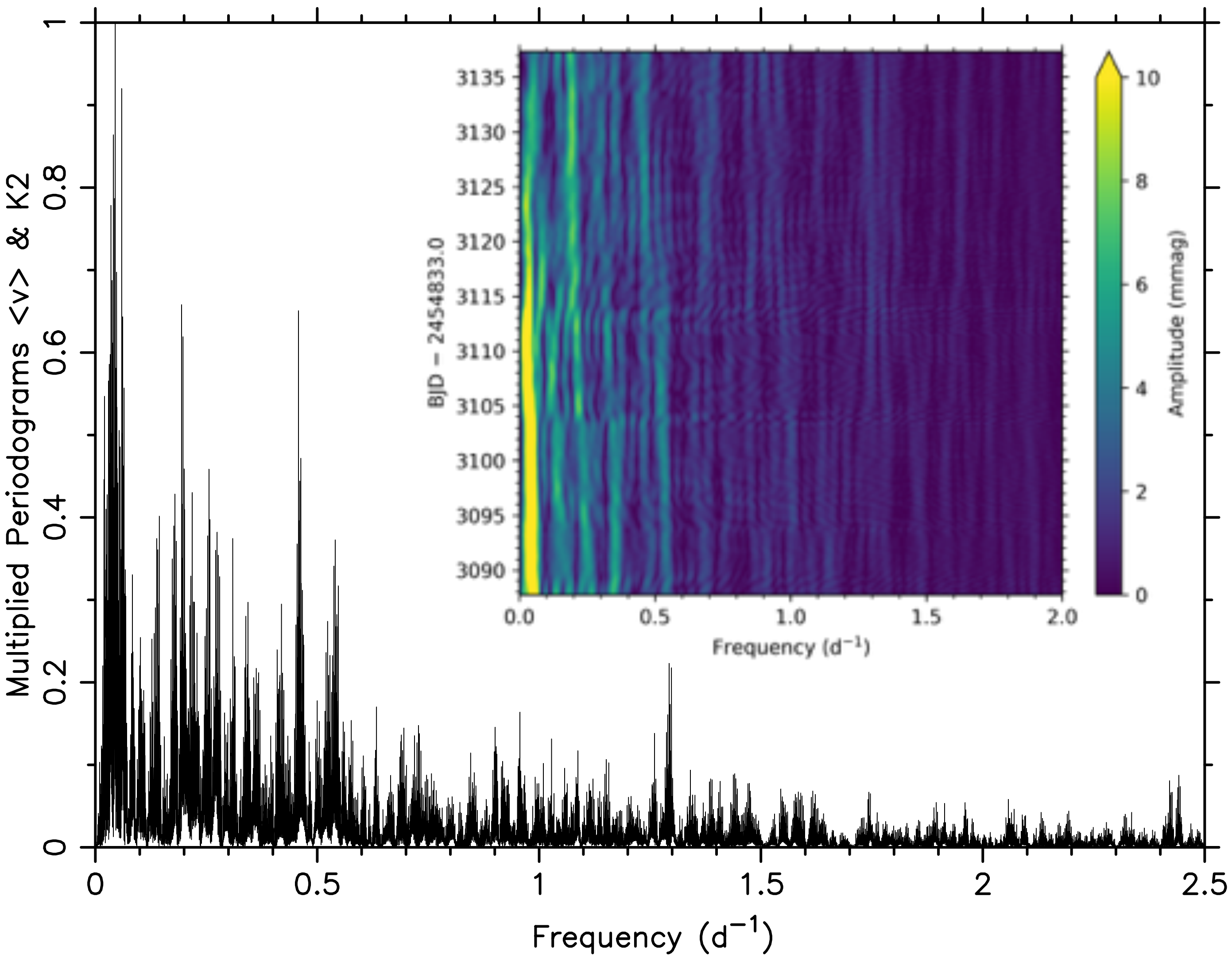
Image credit: P. I. Pápics

(Simón-Díaz et al. 2016, 2017; Godart et al. 2017)

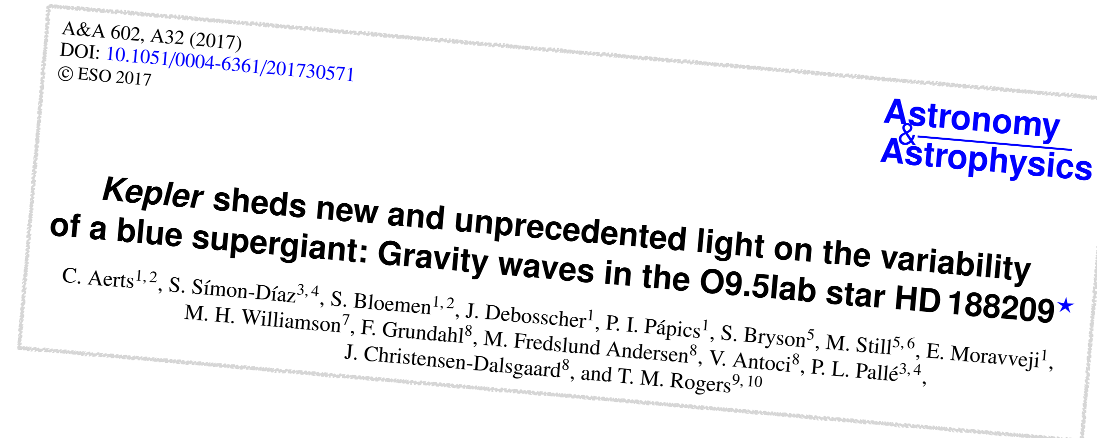
Massive star variability

Physical relationship between macroturbulence and pulsations:

case study: blue supergiant ρ Leo



(Aerts et al. 2018)


A&A 602, A32 (2017)
DOI: 10.1051/0004-6361/201730571
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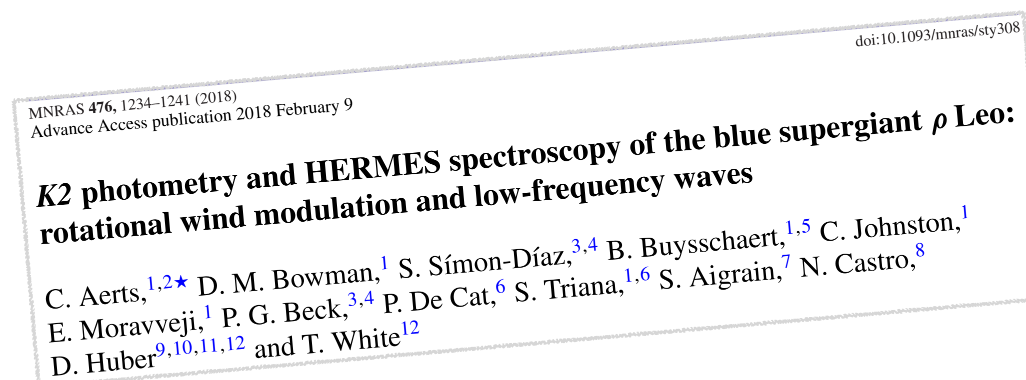
Astronomy & Astrophysics

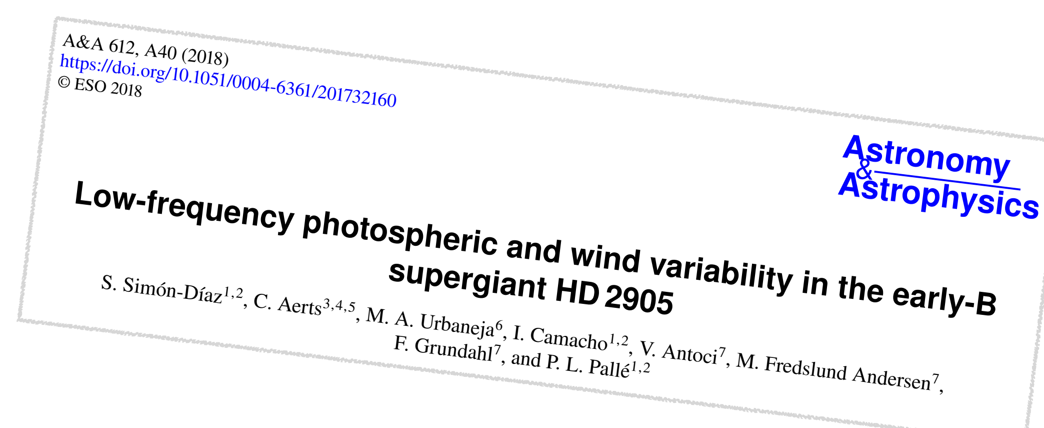
Kepler sheds new and unprecedented light on the variability of a blue supergiant: Gravity waves in the O9.5Iab star HD 188209★

C. Aerts[1,2], S. Símon-Díaz[3,4], S. Bloemen[1,2], J. Debosscher[1], P. I. Pápics[1], S. Bryson[5], M. Still[5,6], E. Moravveji[1], M. H. Williamson[7], F. Grundahl[8], M. Fredslund Andersen[8], V. Antoci[8], P. L. Pallé[3,4], J. Christensen-Dalsgaard[8], and T. M. Rogers[9,10]


MNRAS 476, 1234–1241 (2018)
Advance Access publication 2018 February 9
doi:10.1093/mnras/sty308

***K2* photometry and HERMES spectroscopy of the blue supergiant ρ Leo: rotational wind modulation and low-frequency waves**

C. Aerts,[1,2★] D. M. Bowman,[1] S. Símon-Díaz,[3,4] B. Buysschaert,[1,5] C. Johnston,[1] E. Moravveji,[1] P. G. Beck,[3,4] P. De Cat,[6] S. Triana,[1,6] S. Aigrain,[7] N. Castro,[8] D. Huber[9,10,11,12] and T. White[12]


A&A 612, A40 (2018)
https://doi.org/10.1051/0004-6361/201732160
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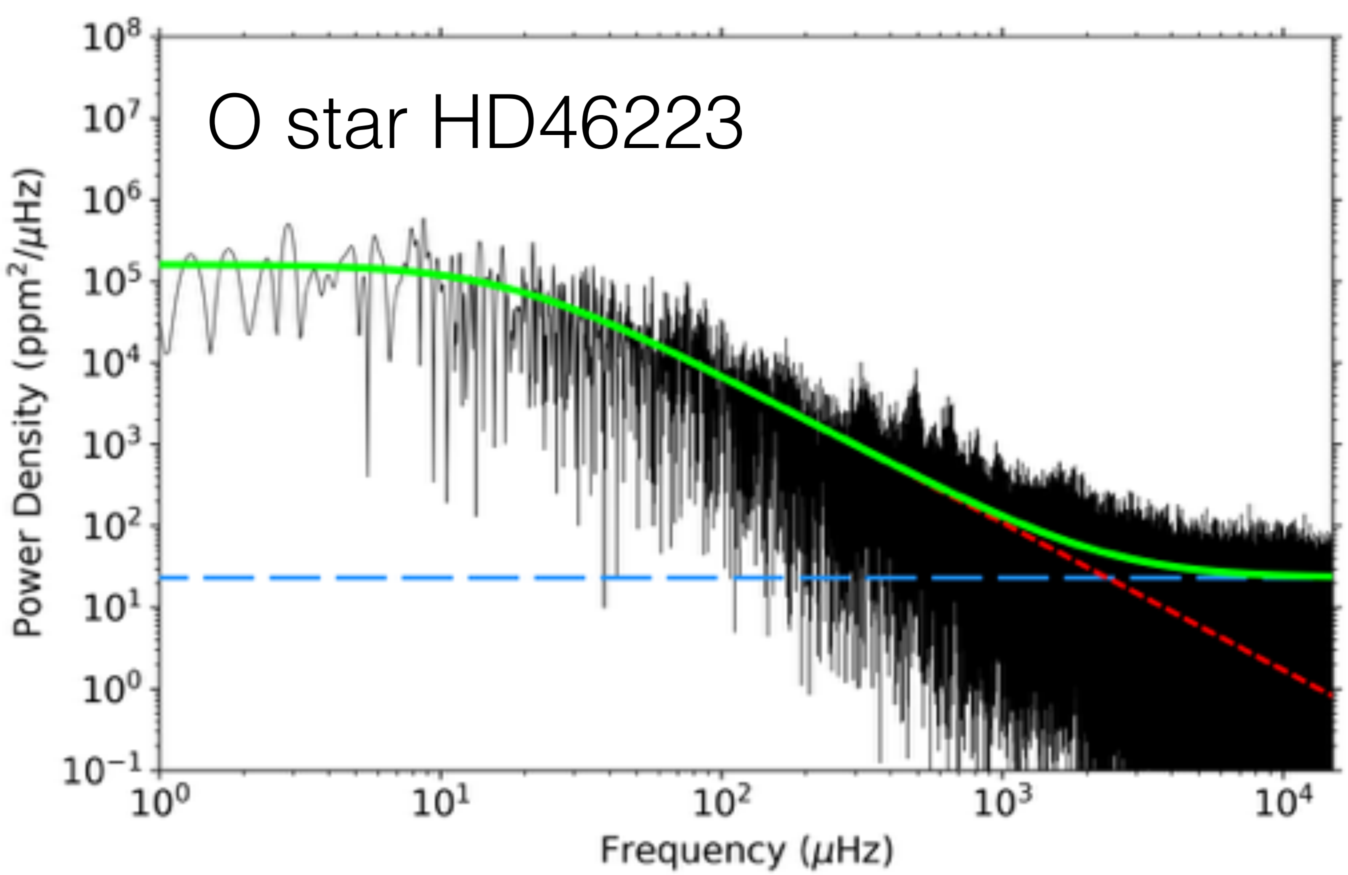
Astronomy & Astrophysics

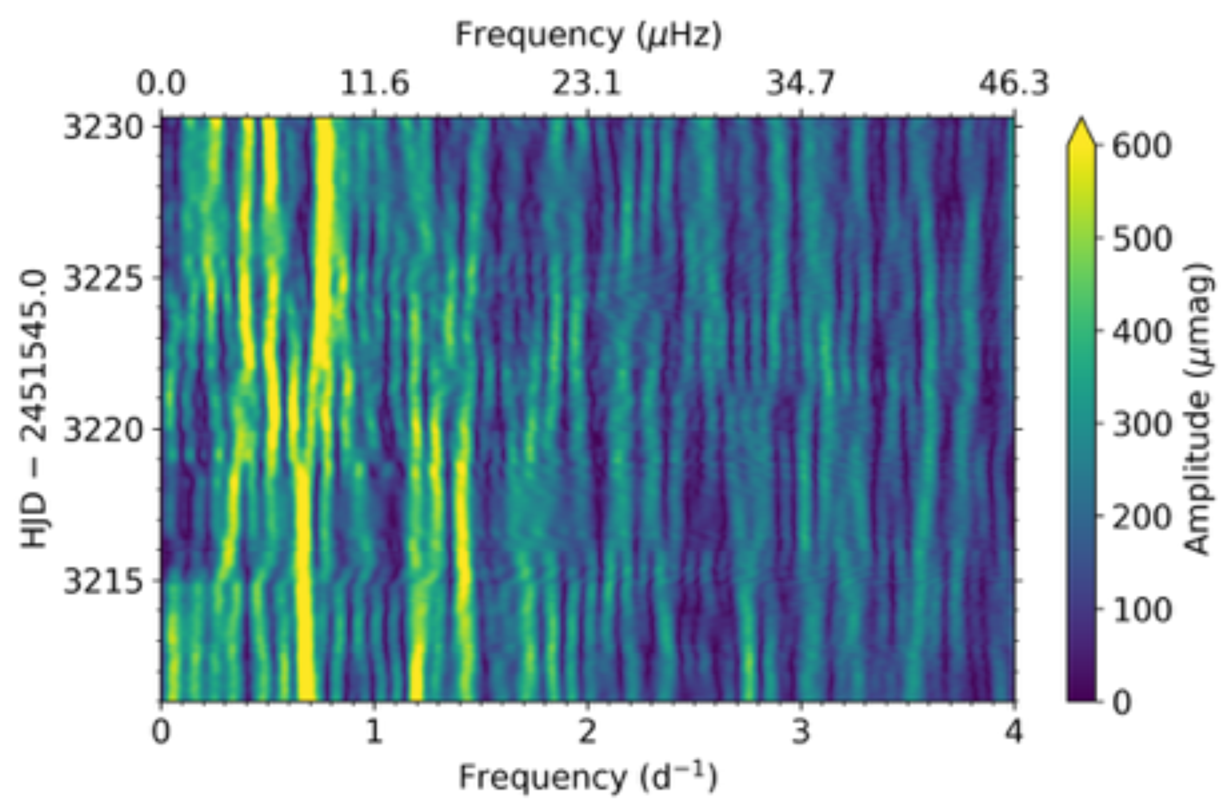
Low-frequency photospheric and wind variability in the early-B supergiant HD 2905

S. Simón-Díaz[1,2], C. Aerts[3,4,5], M. A. Urbaneja[6], I. Camacho[1,2], V. Antoci[7], M. Fredslund Andersen[7], F. Grundahl[7], and P. L. Pallé[1,2]

Searching for IGWs in CoRoT photometry

- Compile a sample of OBAF stars between 1.5 to 40 $M_\odot$ with spectroscopic parameters and CoRoT photometry.
- Remove high-S/N coherent pulsation modes by pre-whitening.
- Fit the background morphology using: $\alpha = \dfrac{\alpha_0}{1 + (2\pi\tau\nu)^\gamma} + C$



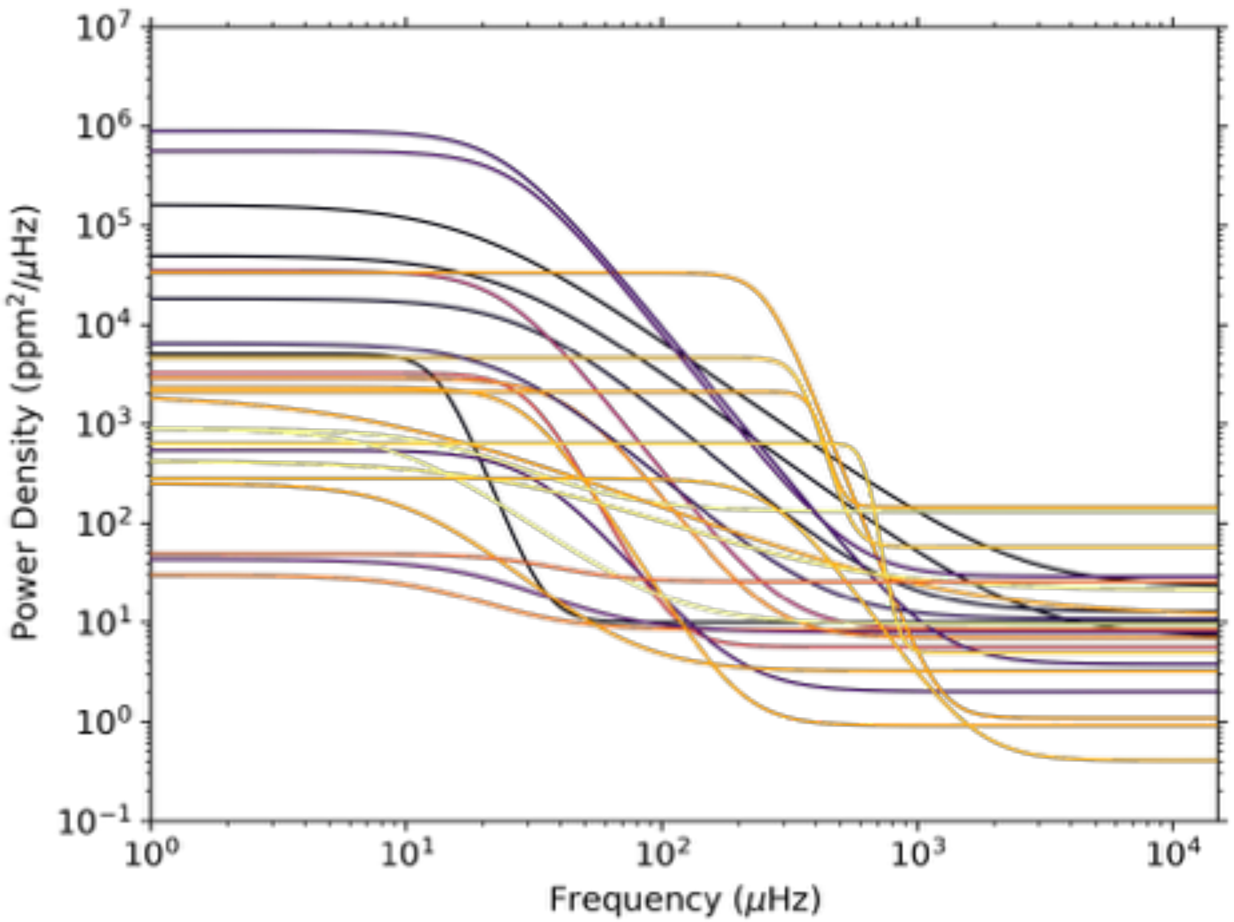


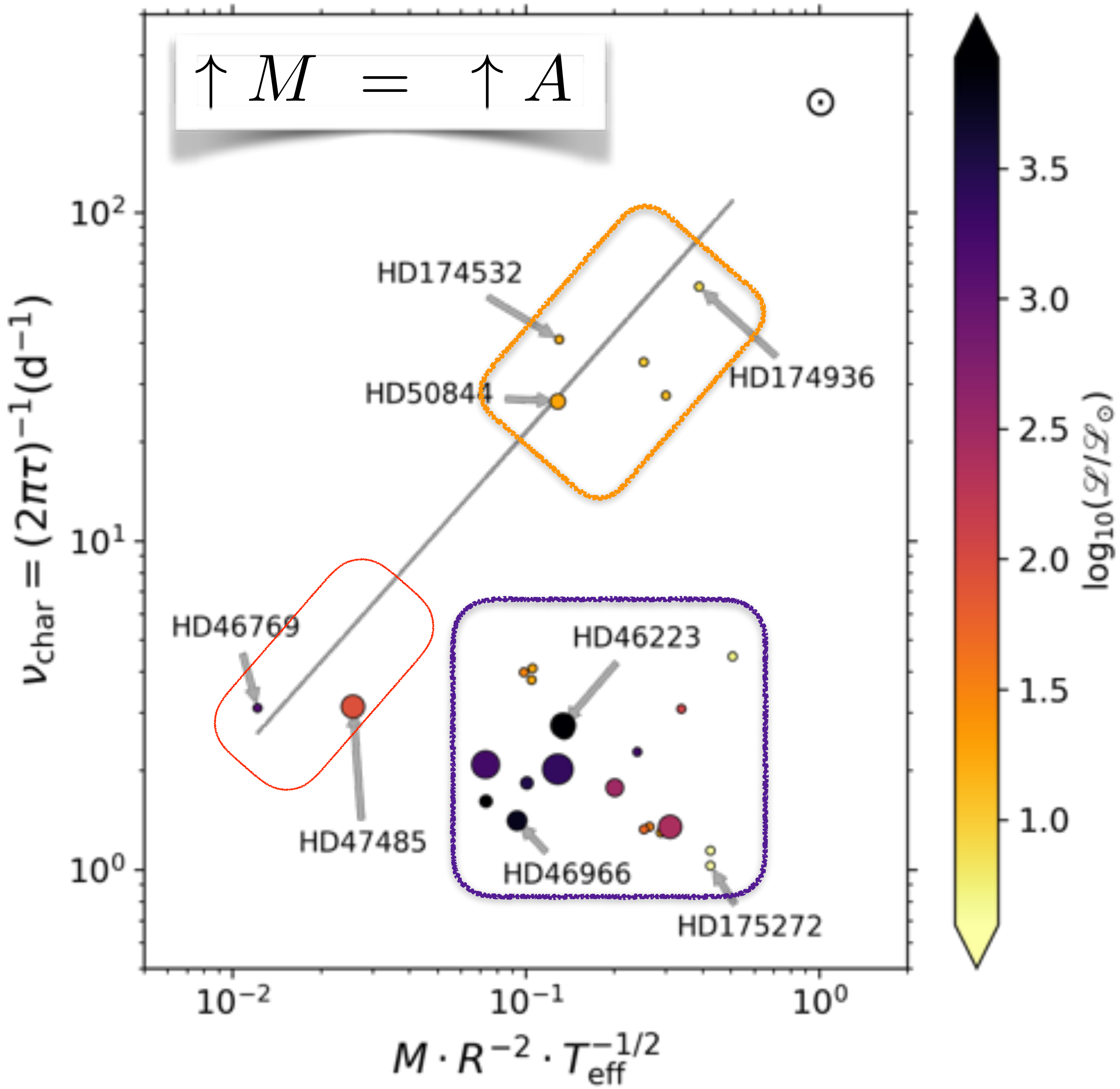
(Bowman et al. 2018)

Searching for IGWs in CoRoT photometry

Low-frequency power excess is not (systematically) correlated with stellar parameters:

- granulation in AF stars?
  (e.g. Kallinger & Matthews 2010)
- wind variability in OB stars?
  (e.g. Blomme et al. 2011;
  Krtička & Feldmeier 2018)

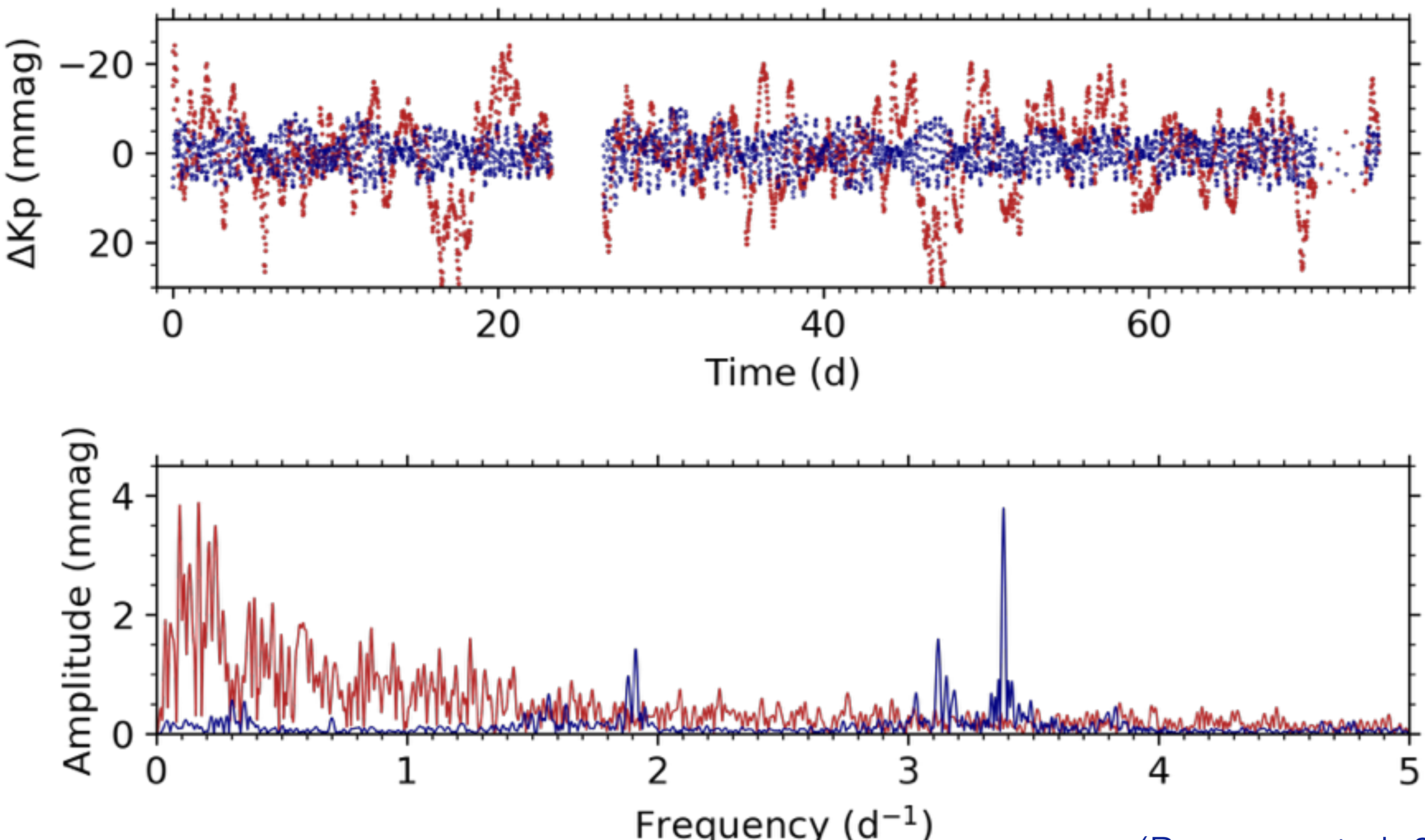




(Bowman et al. 2018)

K2 photometry of OB supergiants

Variability from **coherent** and/or **damped** pulsation modes in many stars!



(Bowman et al. 2018)

Conclusions

Can we detect IGWs in photometric observations of massive stars? ... **YES**

Constraints on IGW surface amplitudes:

- Of order a few μmag for AF stars and 0.5 mmag for late-O stars
- Common morphology in photometry that cannot systematically be explained by granulation
- Link between photometry and macroturbulence... damped modes

Variability in massive stars:

- A significant fraction of K2 OB supergiants are pulsating in coherent and damped pulsation modes...
- TESS observations of many OB stars are underway...

...to be continued!

The photometric detection of Internal Gravity Waves in massive stars

Dominic Bowman

Thank you for your attention!