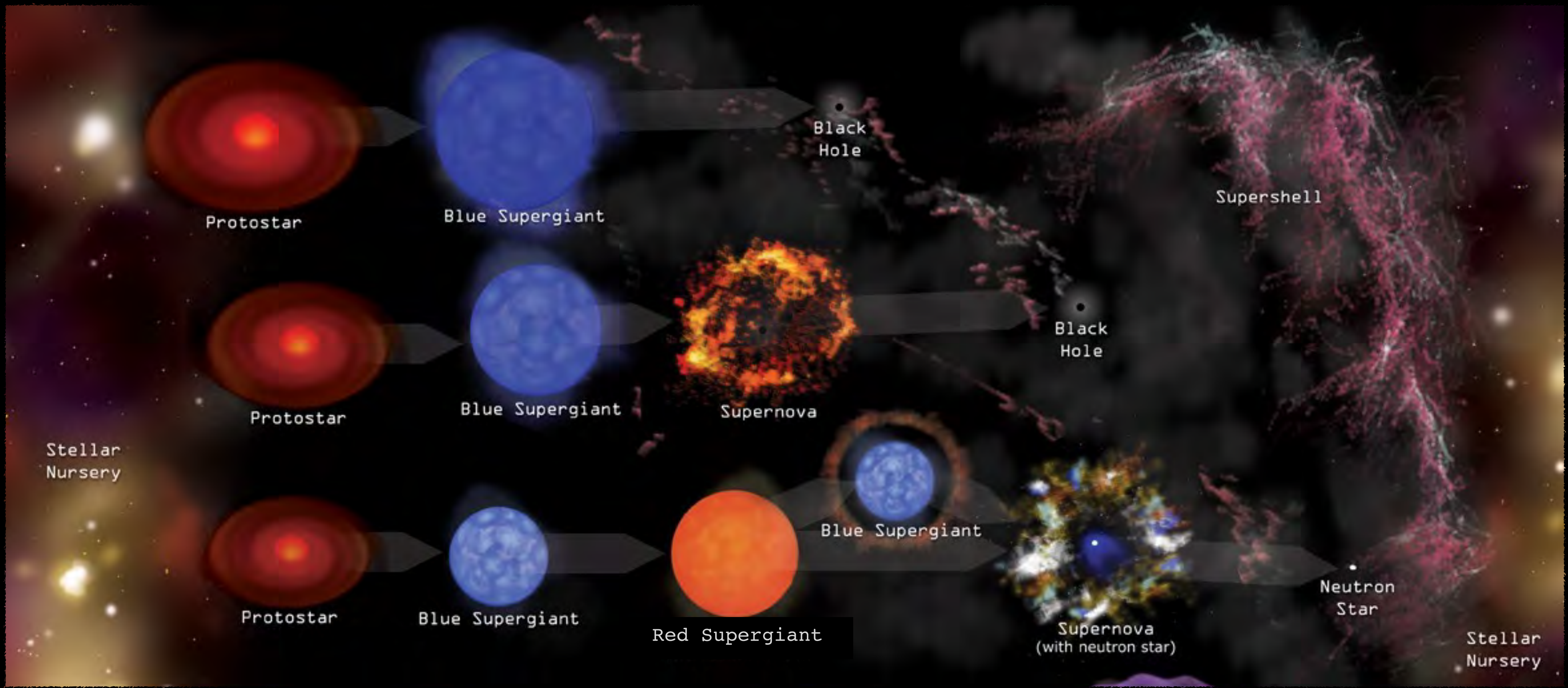


Low-frequency gravity waves in massive stars revealed by high-precision K2 and TESS photometry

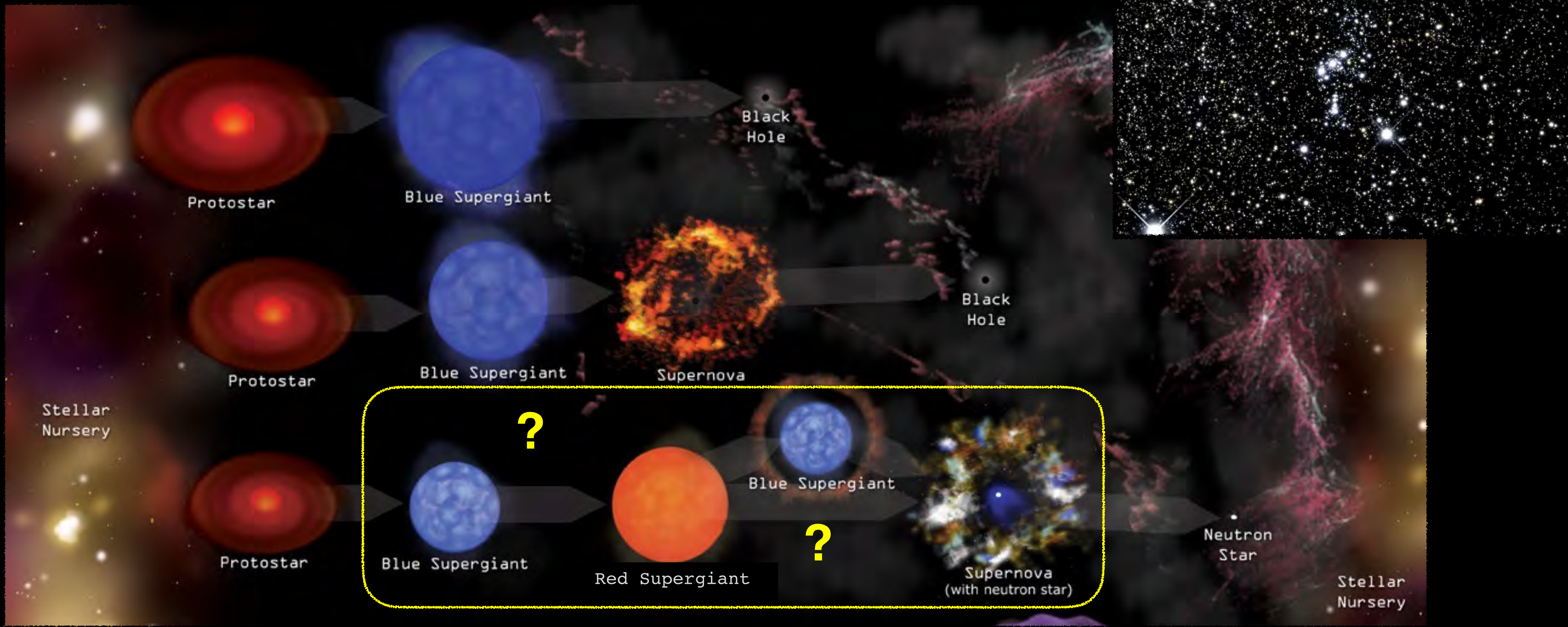
Dominic Bowman



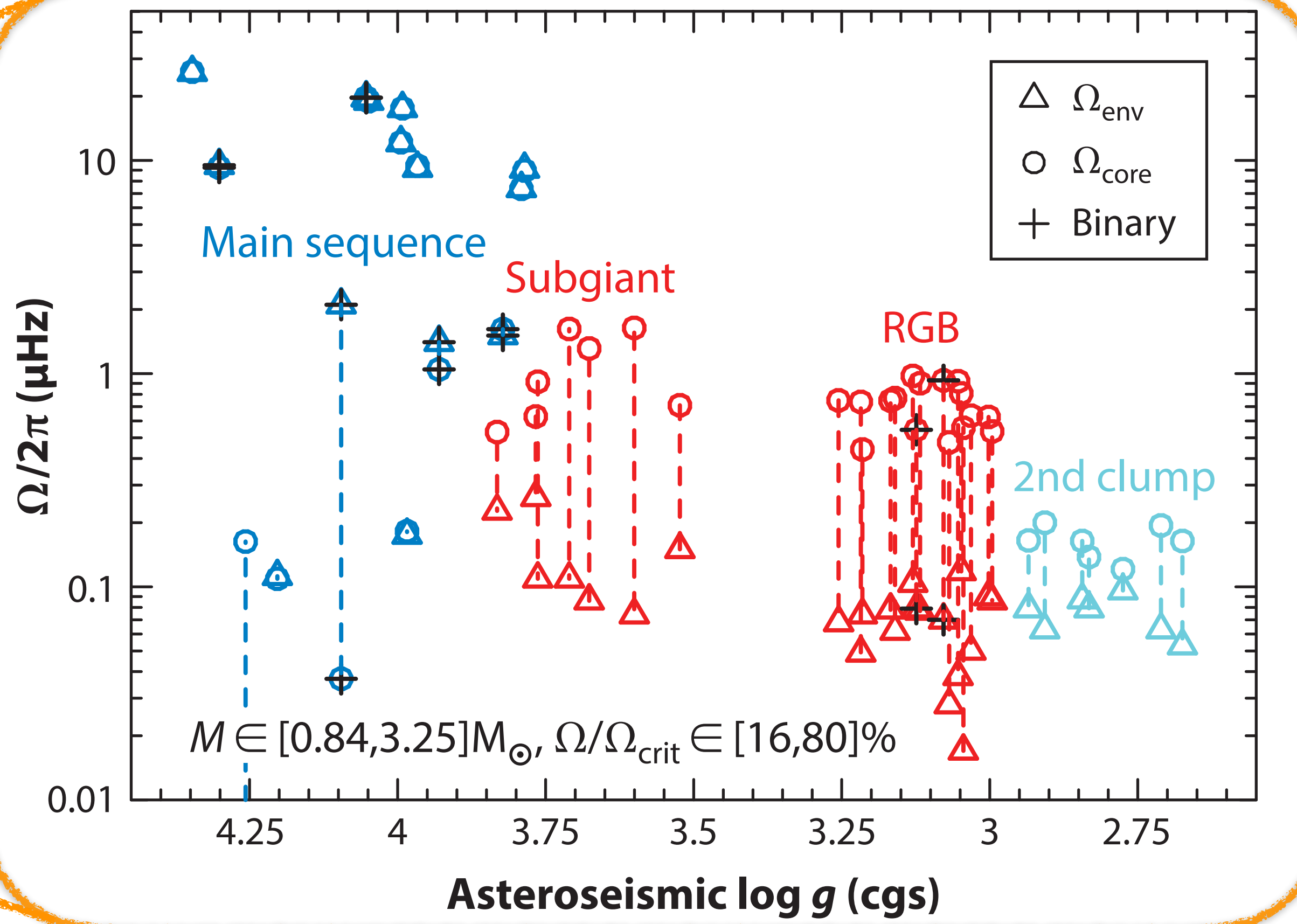
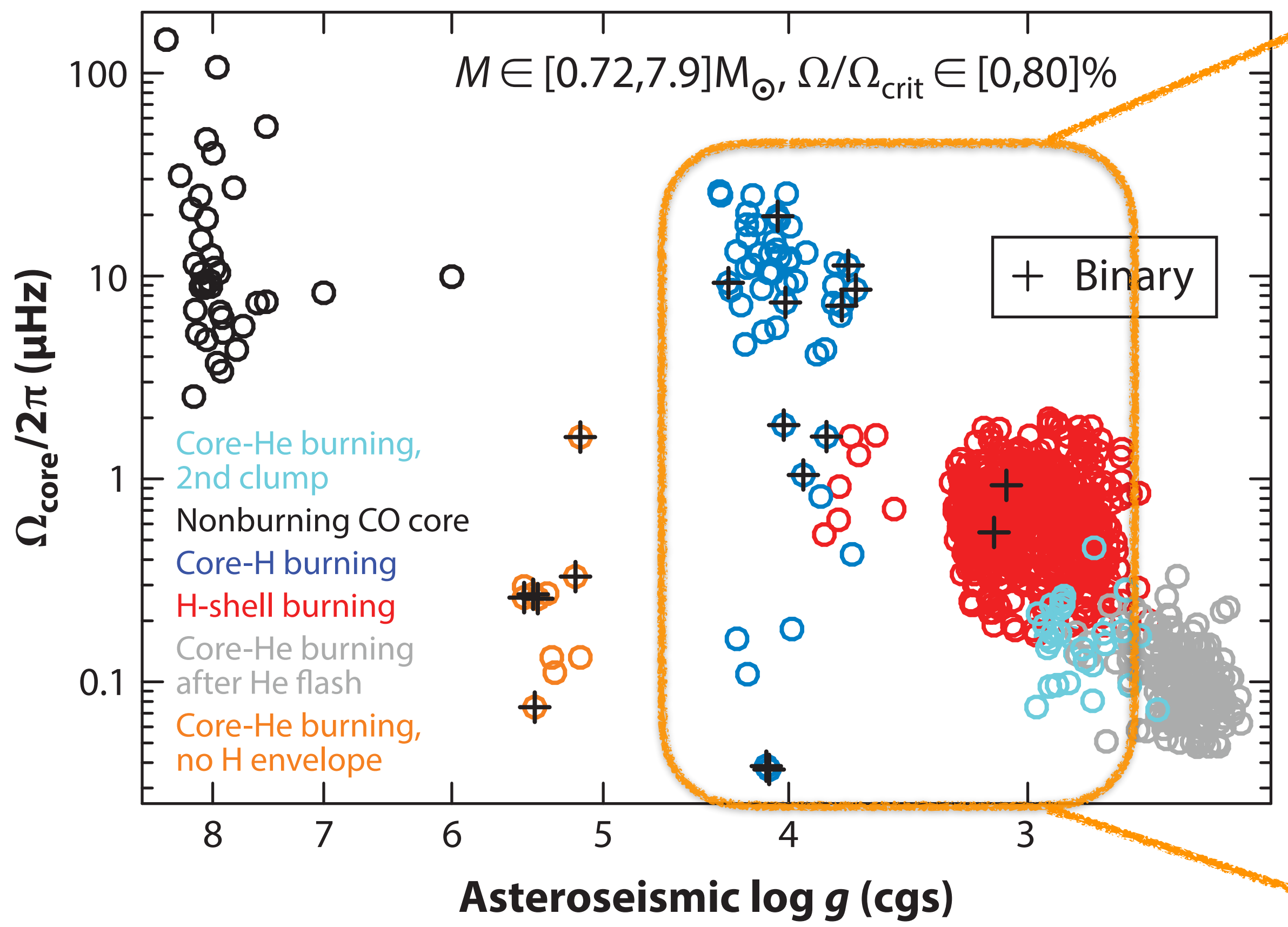
Massive star evolution



Massive star evolution

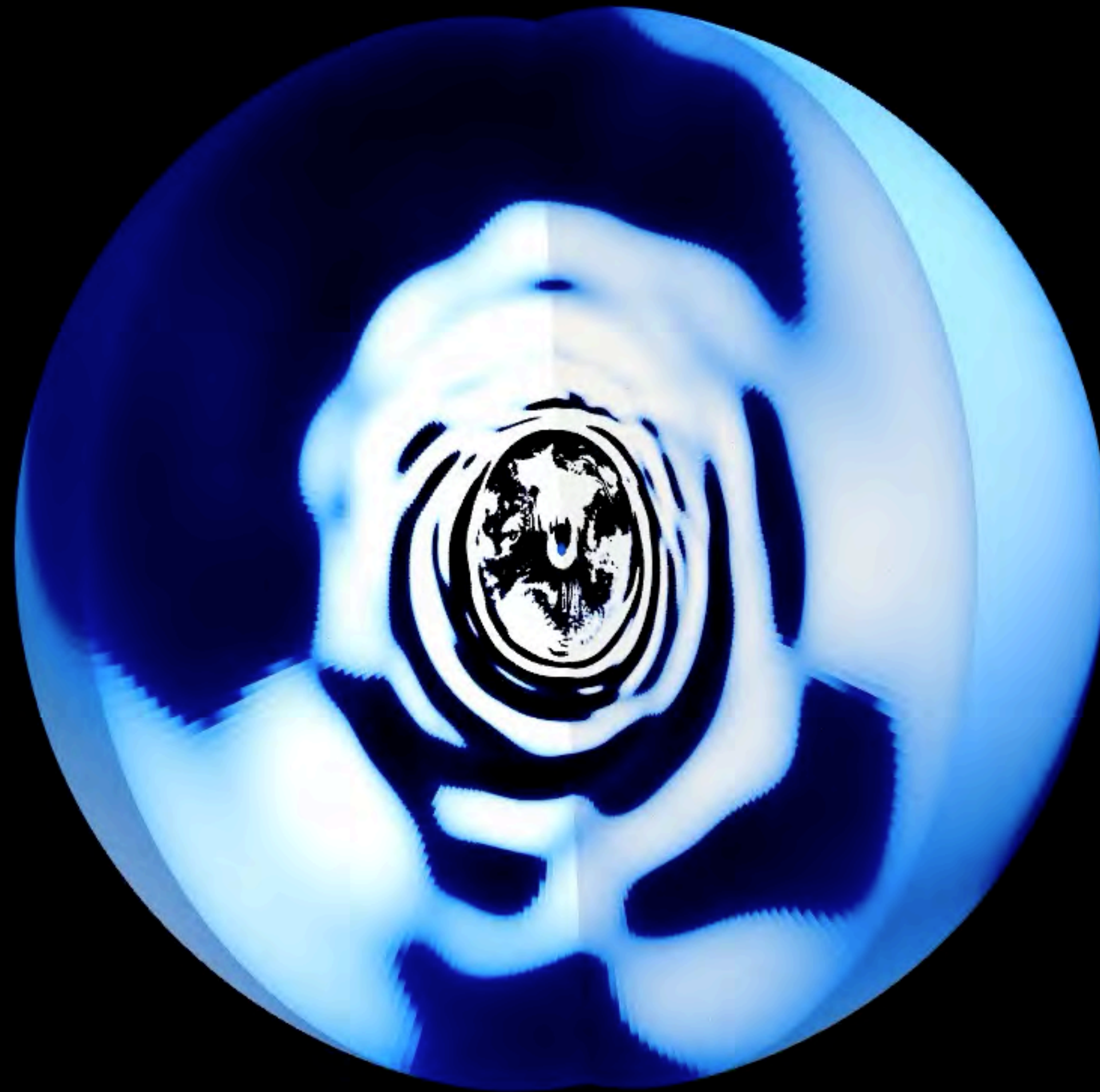


Why are stars rigid-body rotators?



Aerts et al. 2019, ARAA, 57

3D simulations of gravity waves

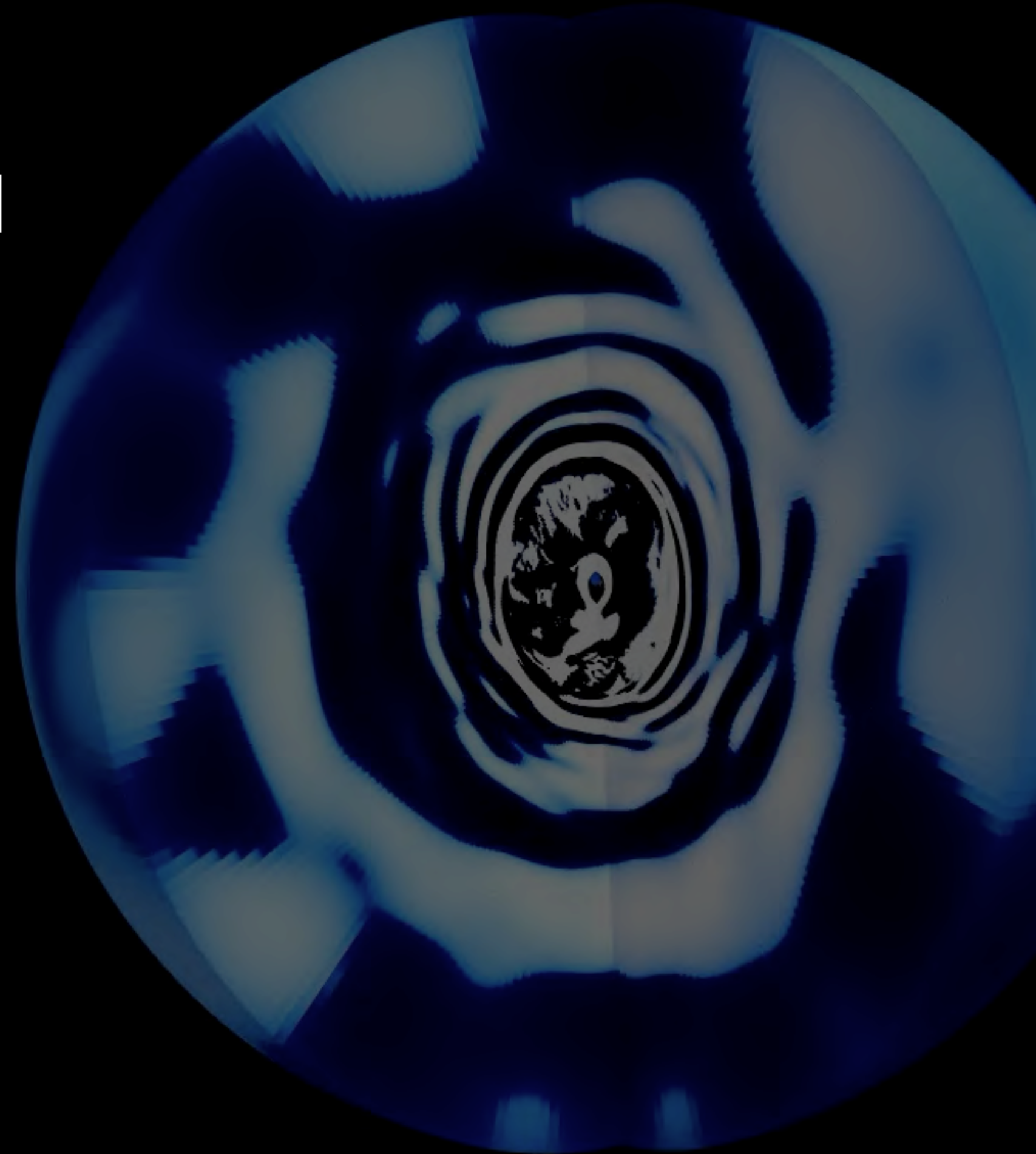


Rogers et al. 2013, ApJ 772, 21

Edelmann et al. 2019, ApJ 876, 4

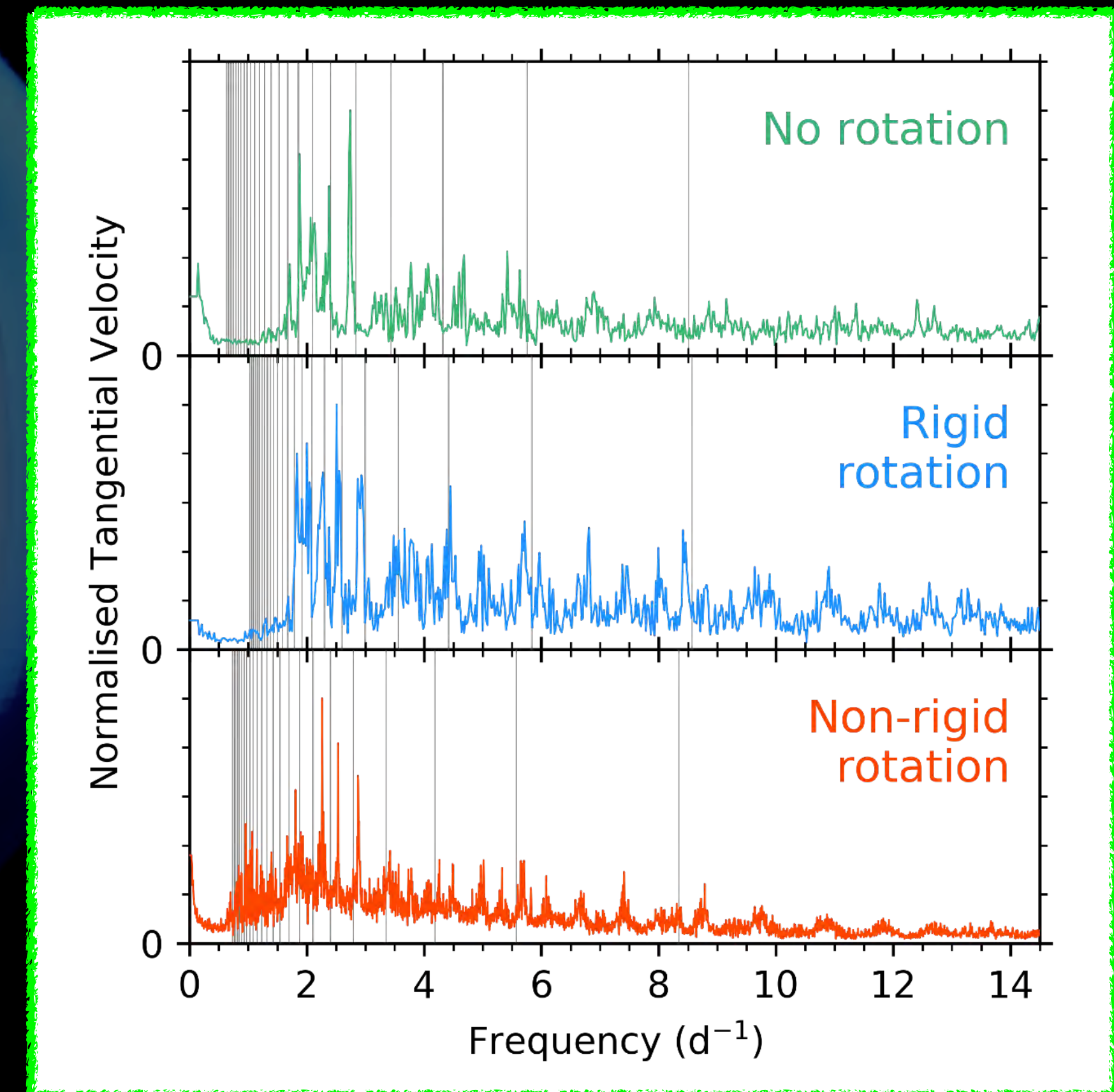
3D simulations of gravity waves

Gravity waves are very efficient at **chemical** and **angular momentum** transport



Gravity wave model:

$$\alpha(\nu) = \frac{\alpha_0}{1 + \left(\frac{\nu}{\nu_c}\right)^\gamma} + C$$



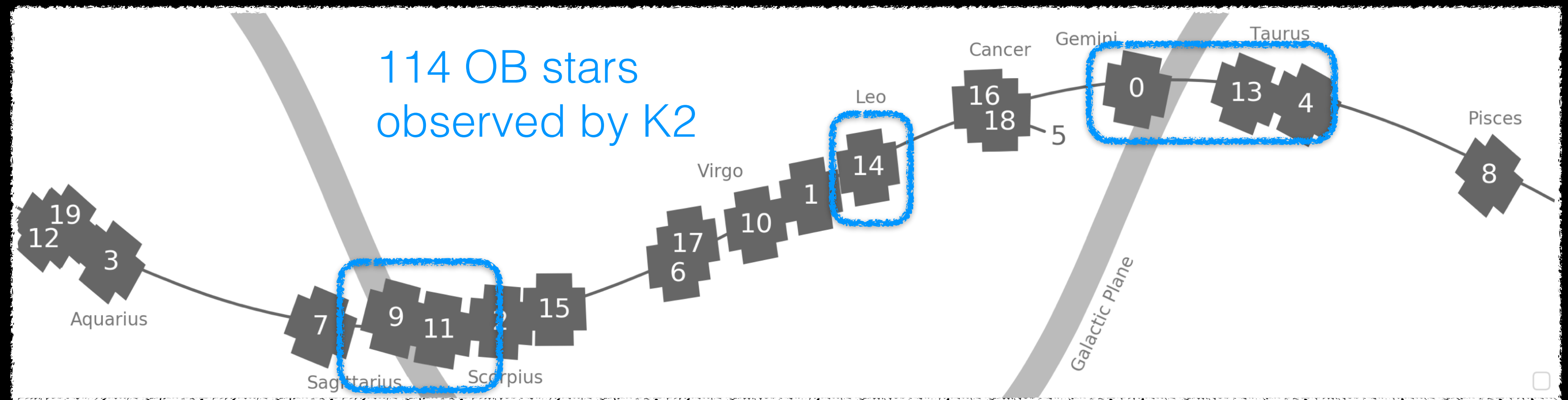
Rogers et al. 2013, ApJ 772, 21

Edelmann et al. 2019, ApJ 876, 4

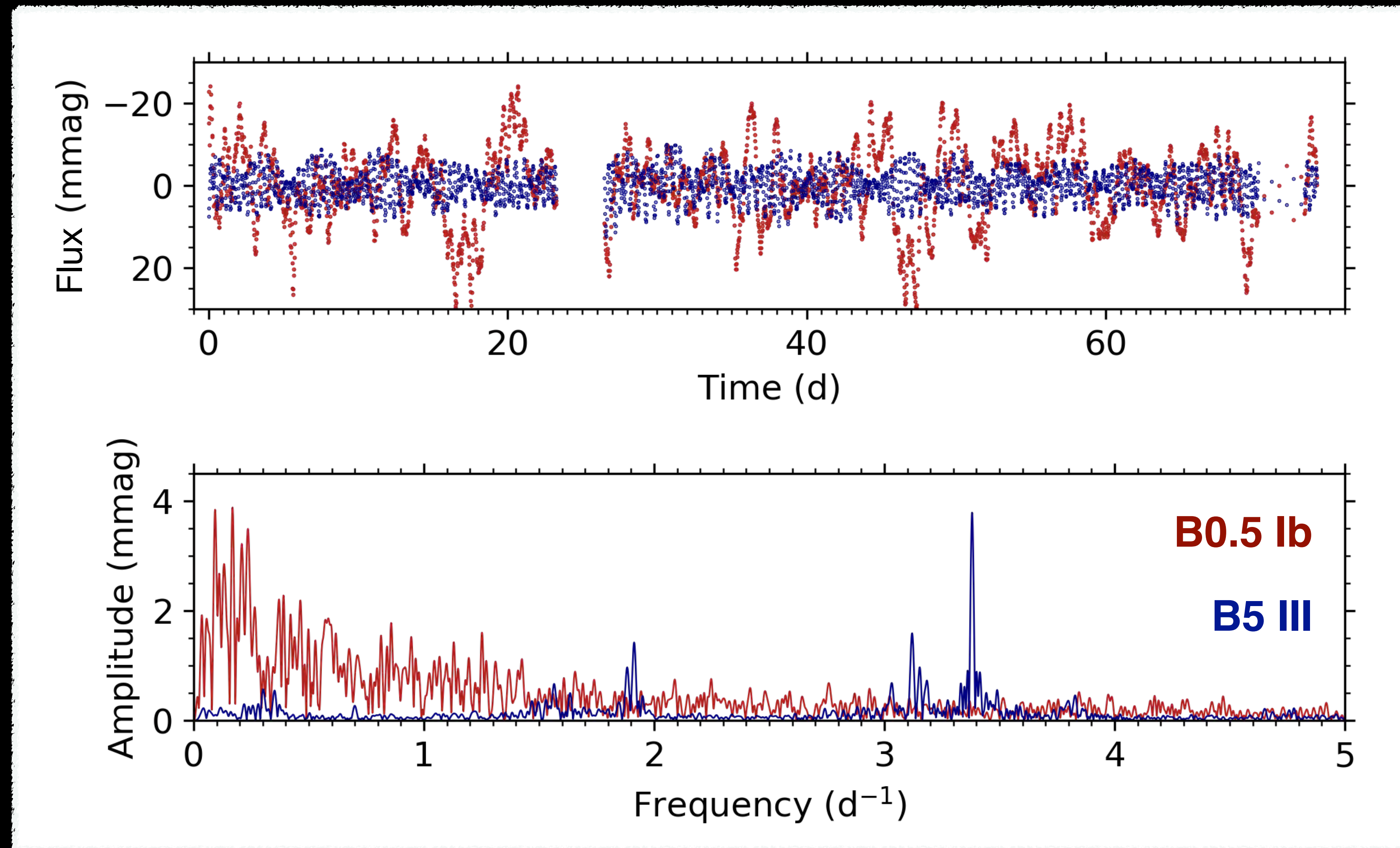
53 blue supergiants
observed by TESS
in the LMC

K2 and TESS observations of massive stars

*Thank you to K2/TESS
guest observer/investigator
office members and
science teams!*

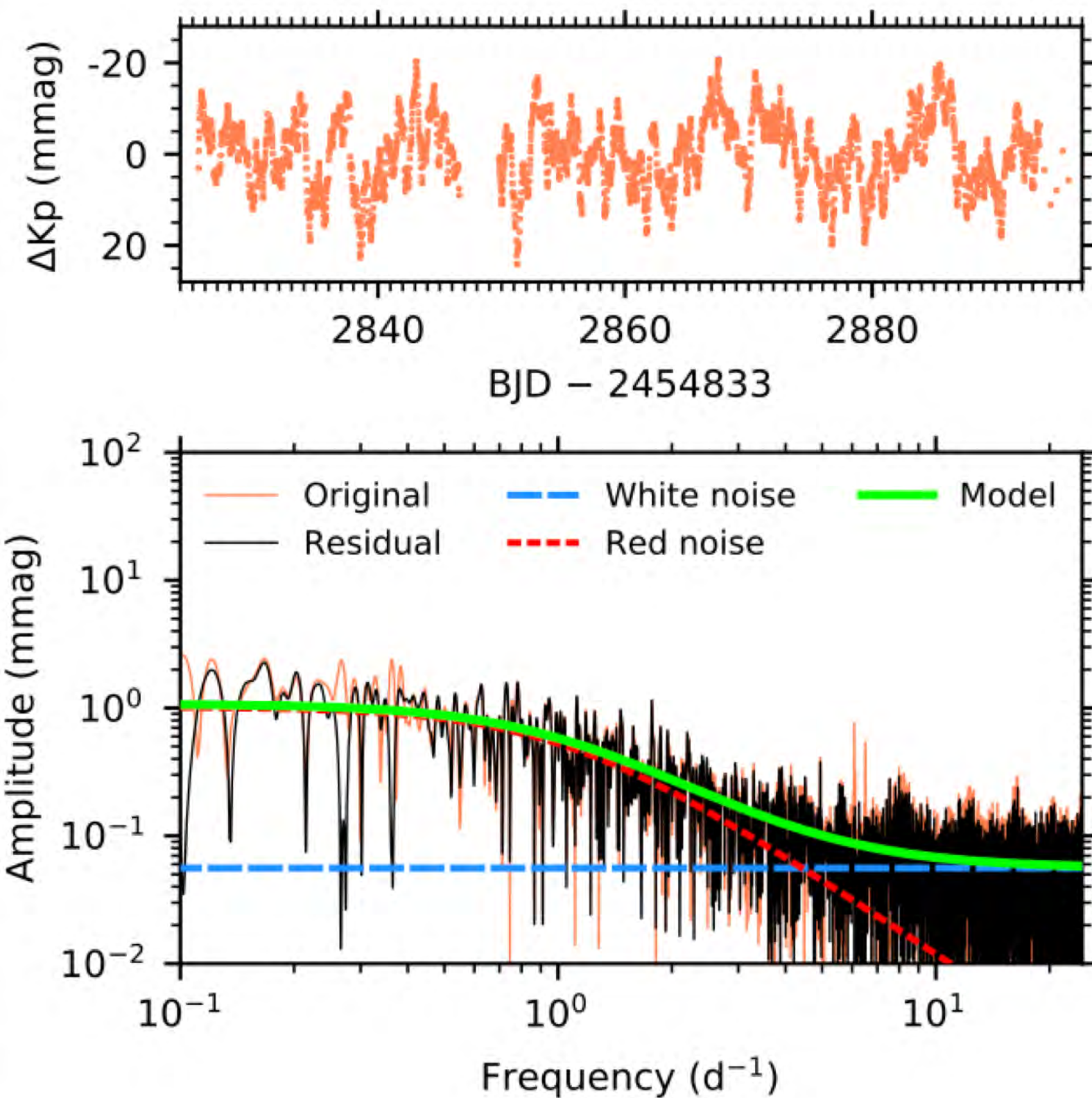


Pulsation modes and waves

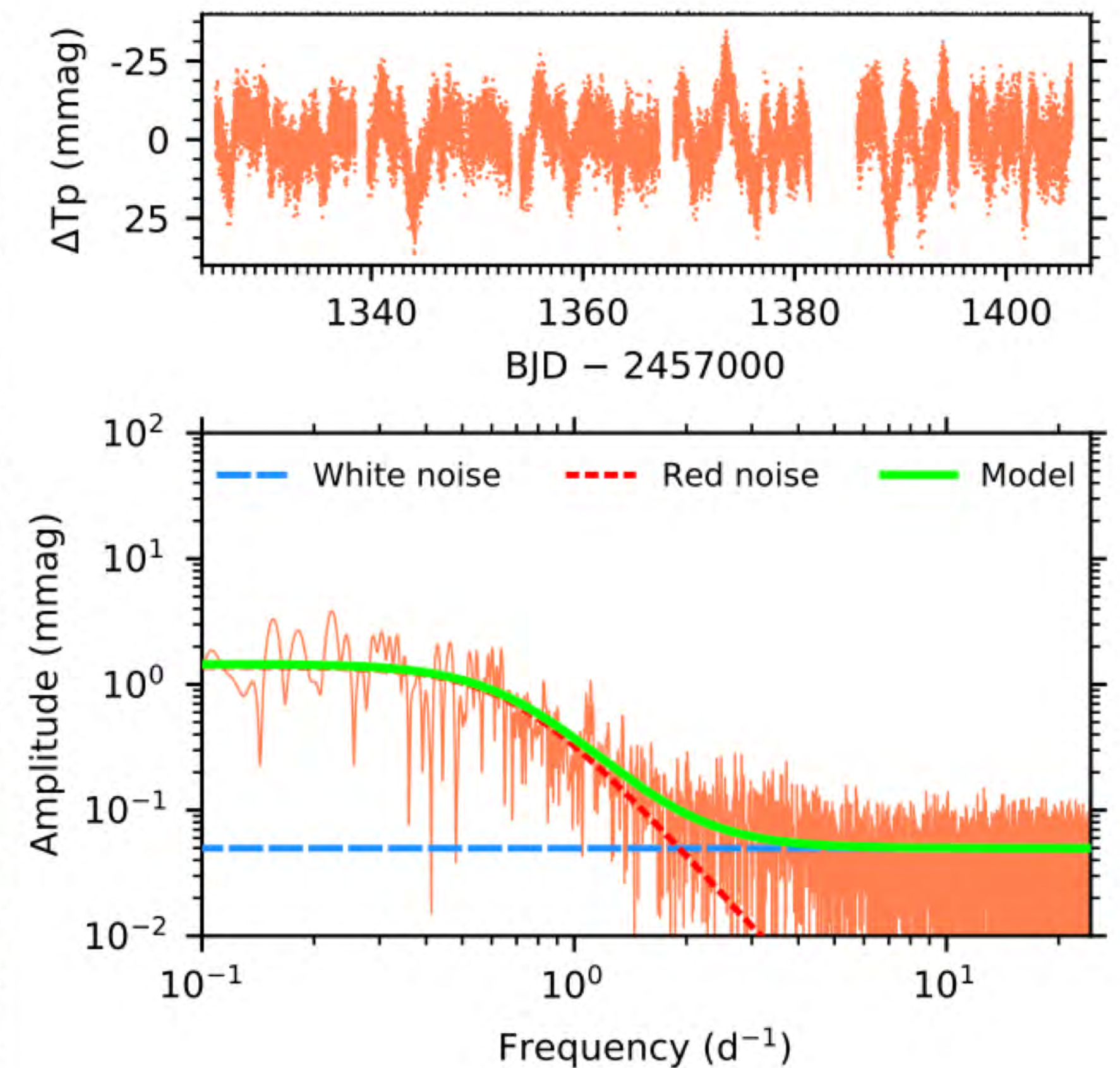


Stochastic low-frequency gravity waves

K2 blue supergiant: B0 Ia



TESS blue supergiant: B1 Ia

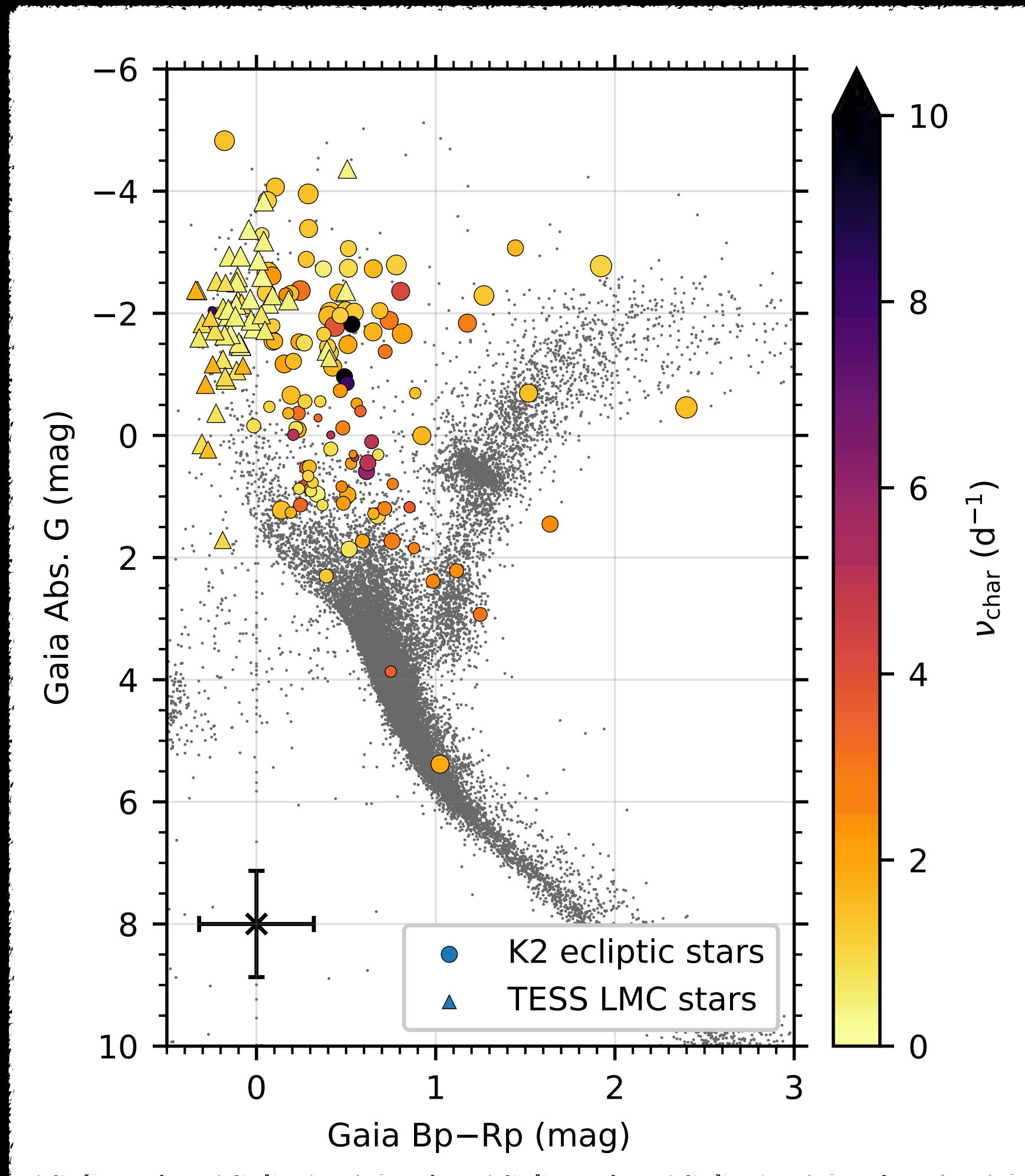


Gravity wave model:

$$\alpha(\nu) = \frac{\alpha_0}{1 + \left(\frac{\nu}{\nu_c}\right)^\gamma} + C$$

Bowman et al. 2019, NatAst

Stochastic low-frequency gravity waves



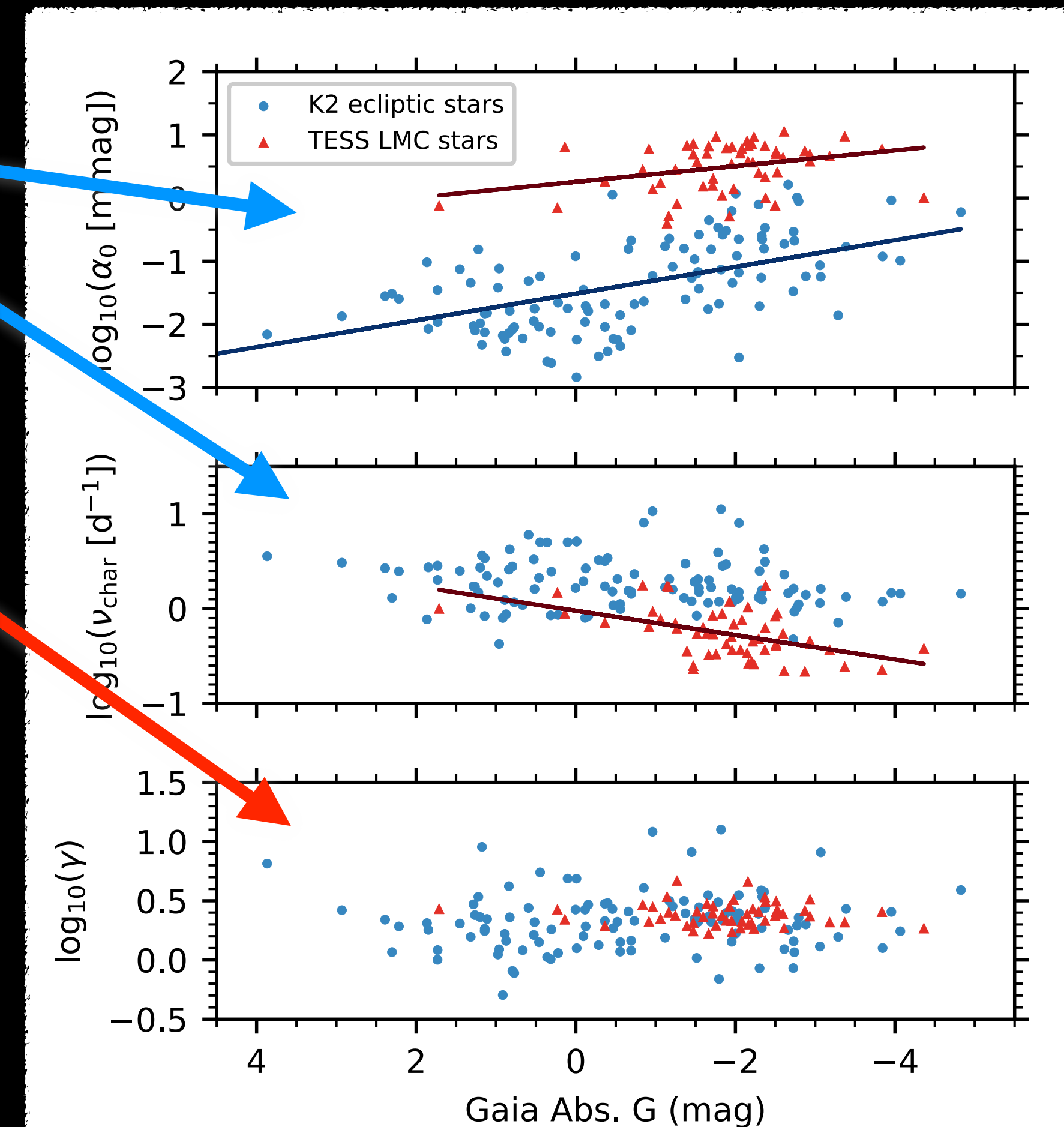
Brighter and more massive stars have **larger wave amplitudes** and **lower frequencies**

Gravity wave morphology is **insensitive to metallicity**

Gravity wave model:

$$\alpha(\nu) = \frac{\alpha_0}{1 + \left(\frac{\nu}{\nu_c}\right)^\gamma} + C$$

Bowman et al. 2019, NatAst





nature
astronomy

Take Away Messages...

- K2 and TESS show **near-ubiquitous** detection of gravity waves in massive stars
- Strong mandate to include **angular momentum transport** caused by gravity waves in stellar evolution codes

nature
astronomy

to appear in print:
7 August 2019

ARTICLES

<https://doi.org/10.1038/s41550-019-0768-1>

Low-frequency gravity waves in blue supergiants revealed by high-precision space photometry

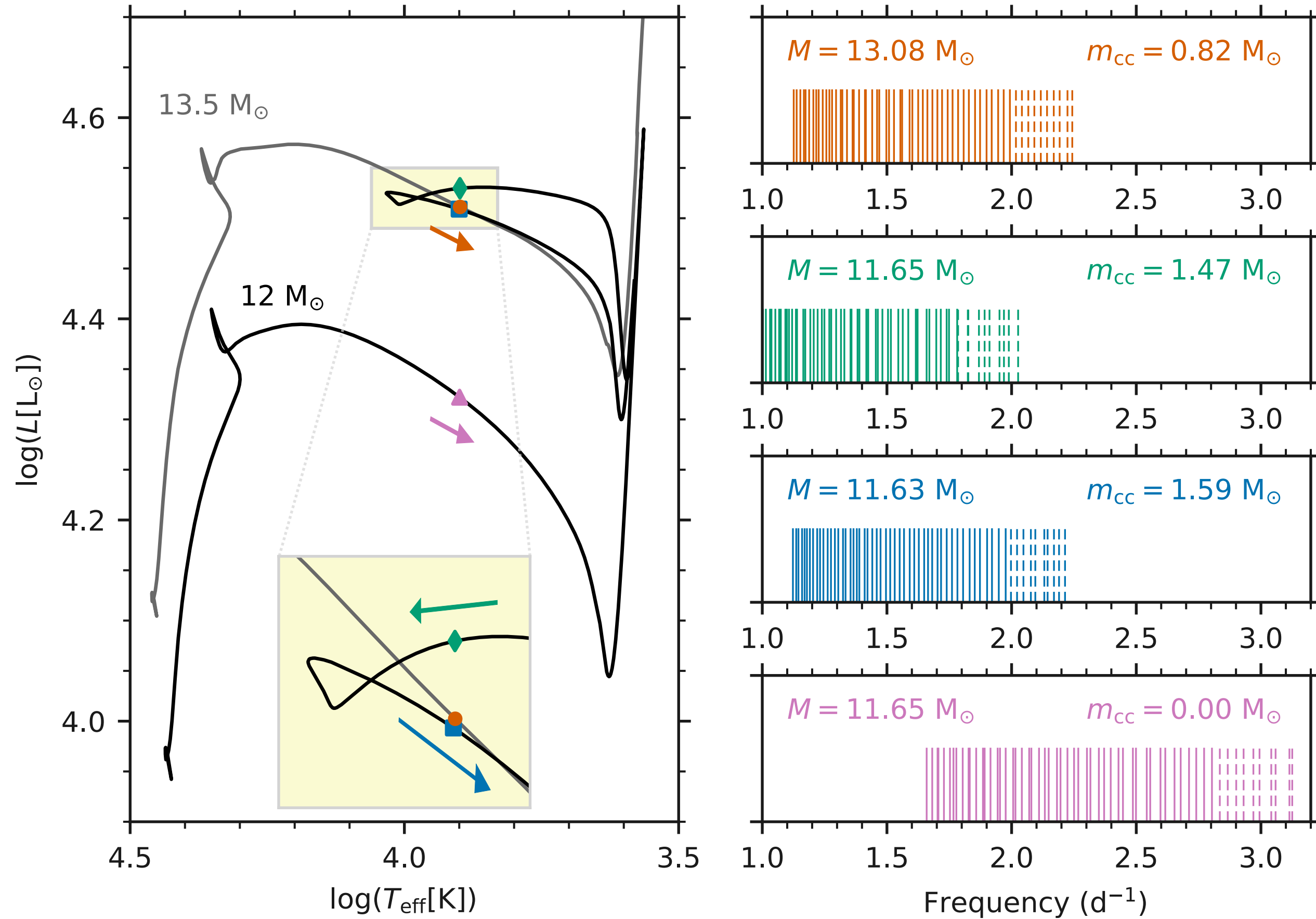
Dominic M. Bowman ^{1*}, Siemen Burssens ¹, May G. Pedersen ¹, Cole Johnston¹, Conny Aerts^{1,2}, Bram Buysschaert^{1,3}, Mathias Michielsen ¹, Andrew Tkachenko¹, Tamara M. Rogers^{4,5}, Philipp V. F. Edelmann ⁴, Rathish P. Ratnasingam ⁴, Sergio Simón-Díaz^{6,7}, Norberto Castro ⁸, Ehsan Moravveji¹, Benjamin J. S. Pope⁹, Timothy R. White¹⁰ and Peter De Cat¹¹

Low-frequency gravity waves in massive stars revealed by high-precision K2 and TESS photometry

Dominic Bowman



Asteroseismology of blue supergiants

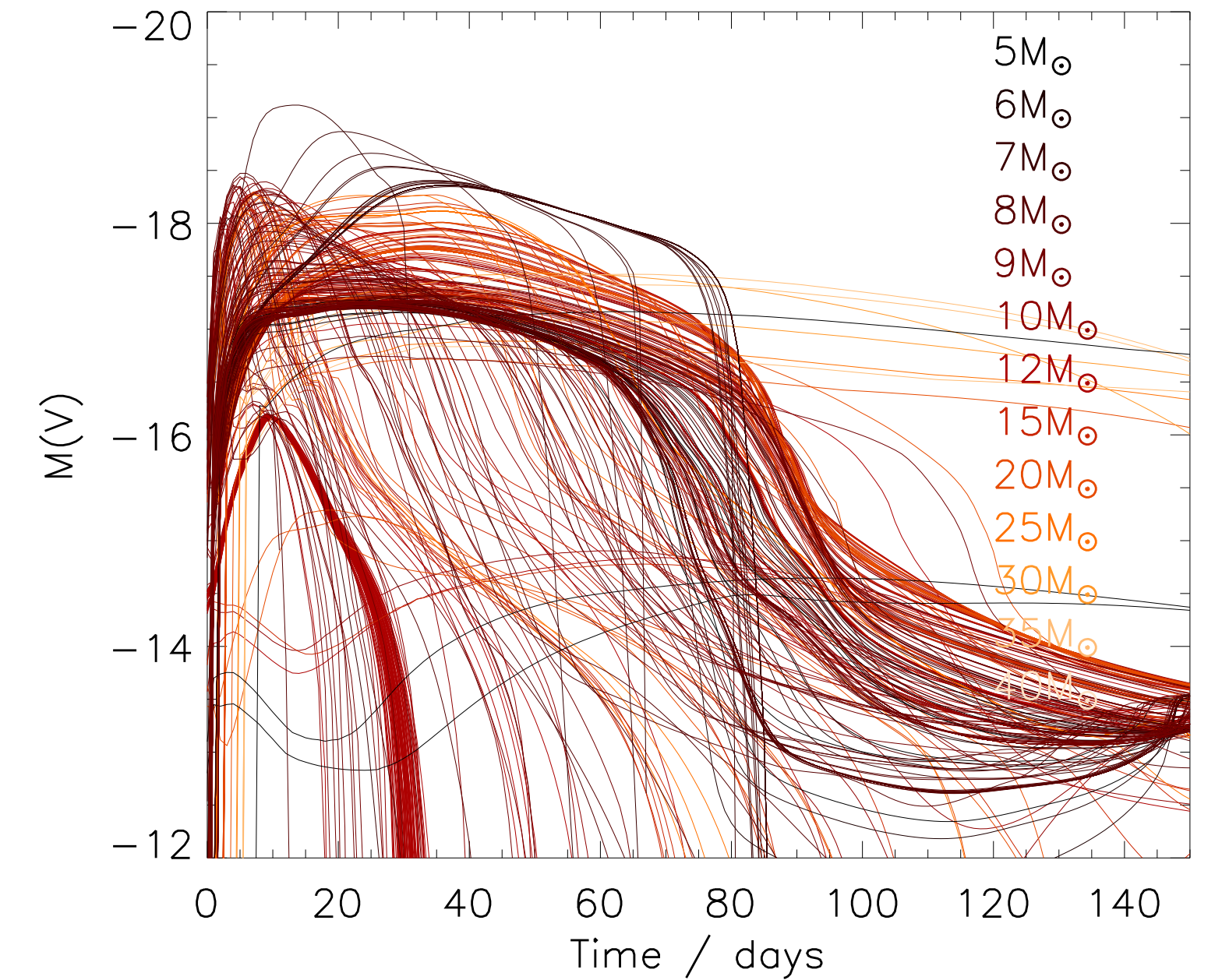


Bowman et al. 2019, NatAst

A&A 622, A70 (2019)
<https://doi.org/10.1051/0004-6361/201833966>
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Astronomy
&
Astrophysics

Supernovae from blue supergiant progenitors: What a mess!
 Luc Dessart¹ and D. John Hillier²



Eldridge et al. 2018, PASA 35