Asteroseismology of solar-like oscillators: recent results

Saskia Hekker

Max Planck Institute for Solar System Research
Stellar Astrophysics Centre

MPS

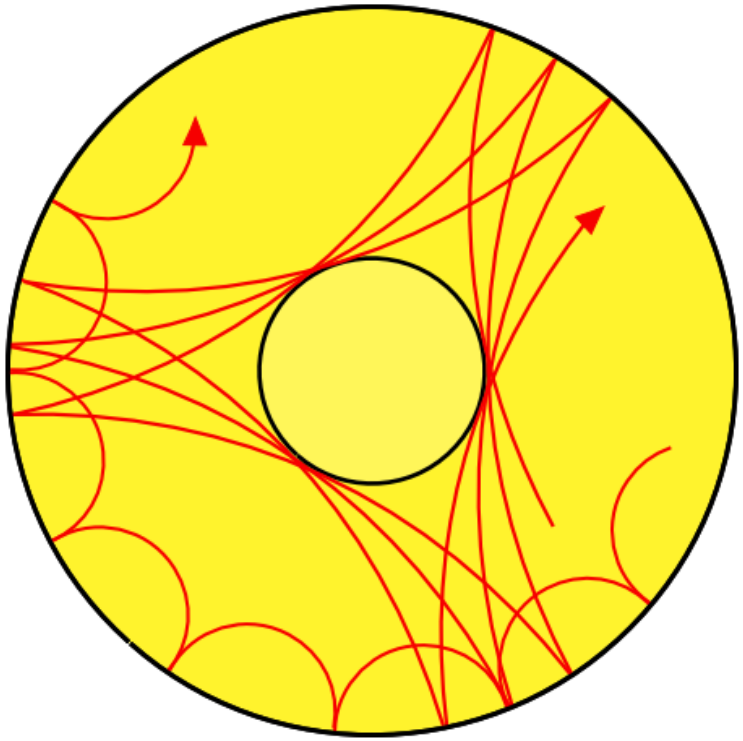
STELLAR ASTROPHYSICS CENTRE

Asteroseismology

aster: star

seismo: oscillations

logos: reasoning

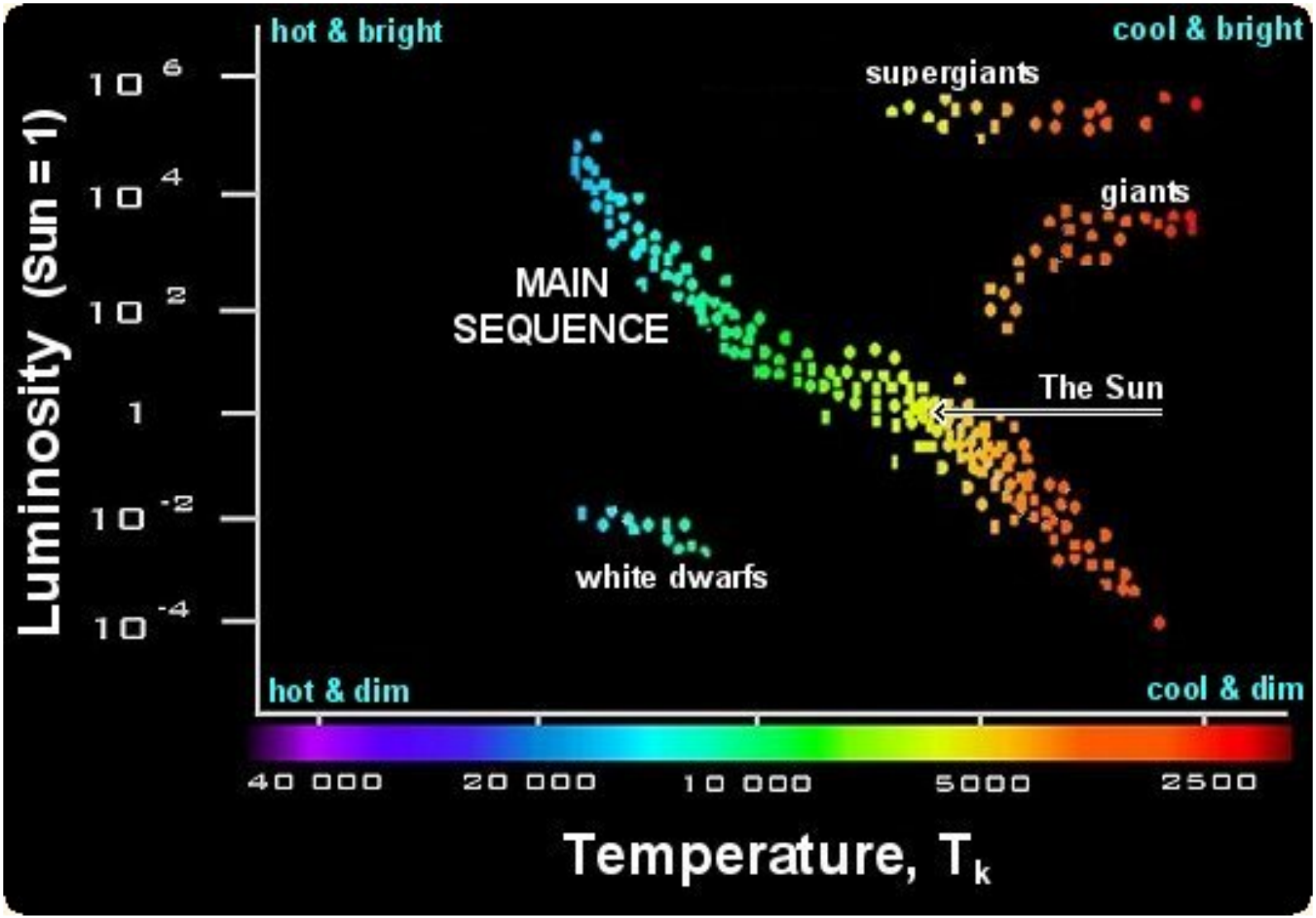


Study of stellar interiors through the analysis of stellar oscillations

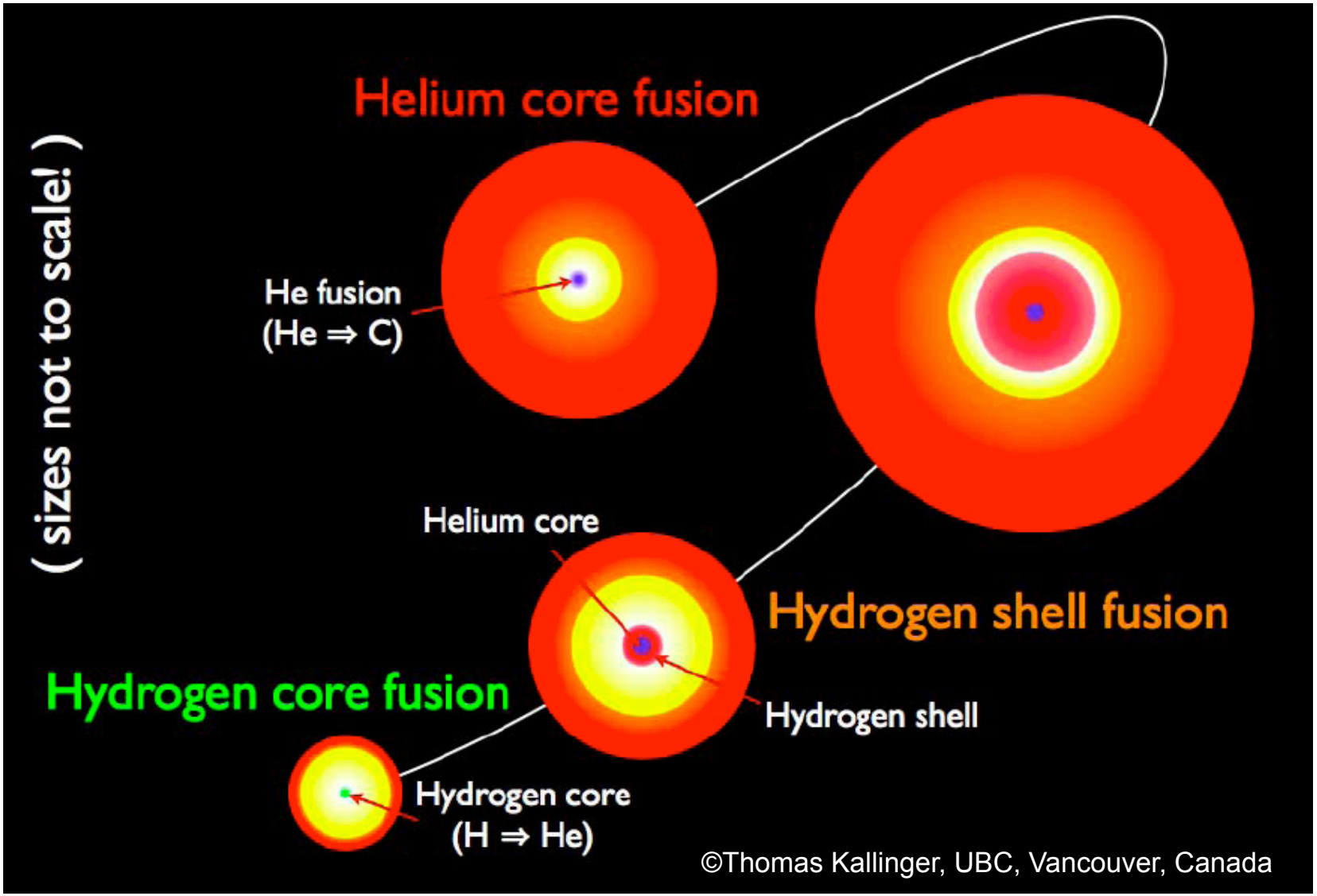
Driving mechanisms

- convective outer layers in which stochastic excitation of oscillations takes place
- some outer layers act as a heat engine:
  partial ionisation zones absorb and accumulate energy generated in the stellar interior (opacity mechanism)
- forced oscillations may occur due to tidal effects in close binaries

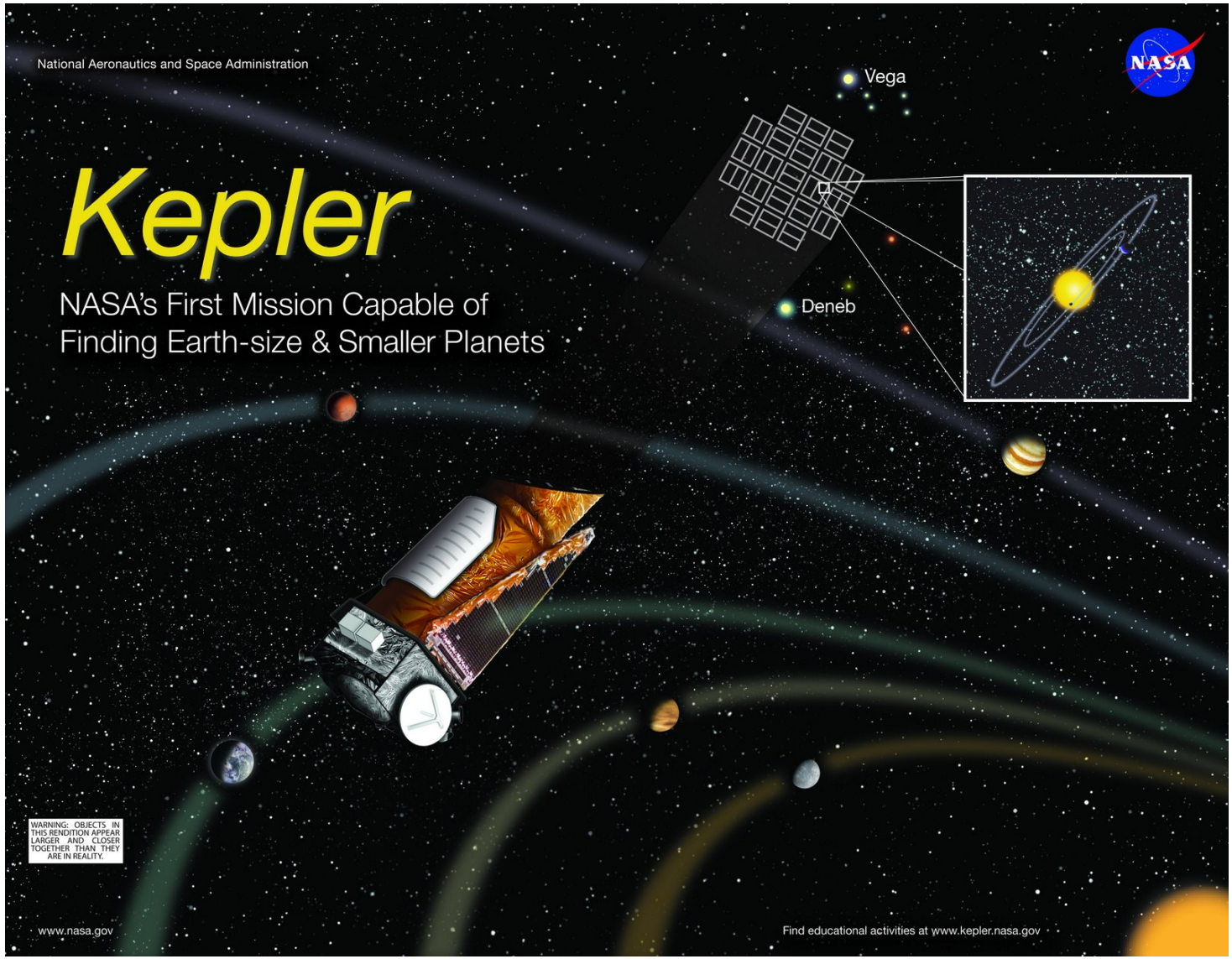
Stars


hot & bright
cool & bright
supergiants
giants
MAIN
SEQUENCE
The Sun
white dwarfs
hot & dim
cool & dim
Luminosity (Sun = 1)
10 6
10 4
10 2
1
10 -2
10 -4
40 000
20 000
10 000
5000
2500
Temperature, T k

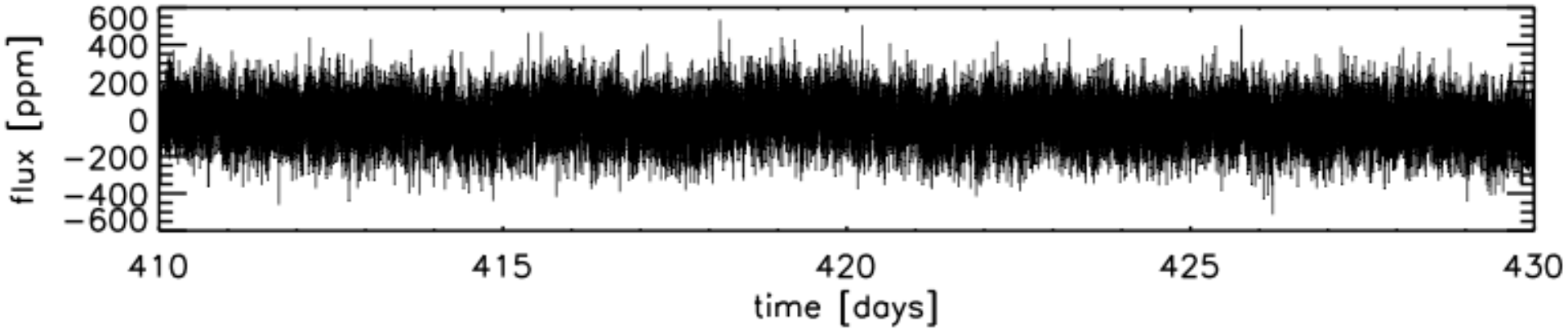
Stellar evolution



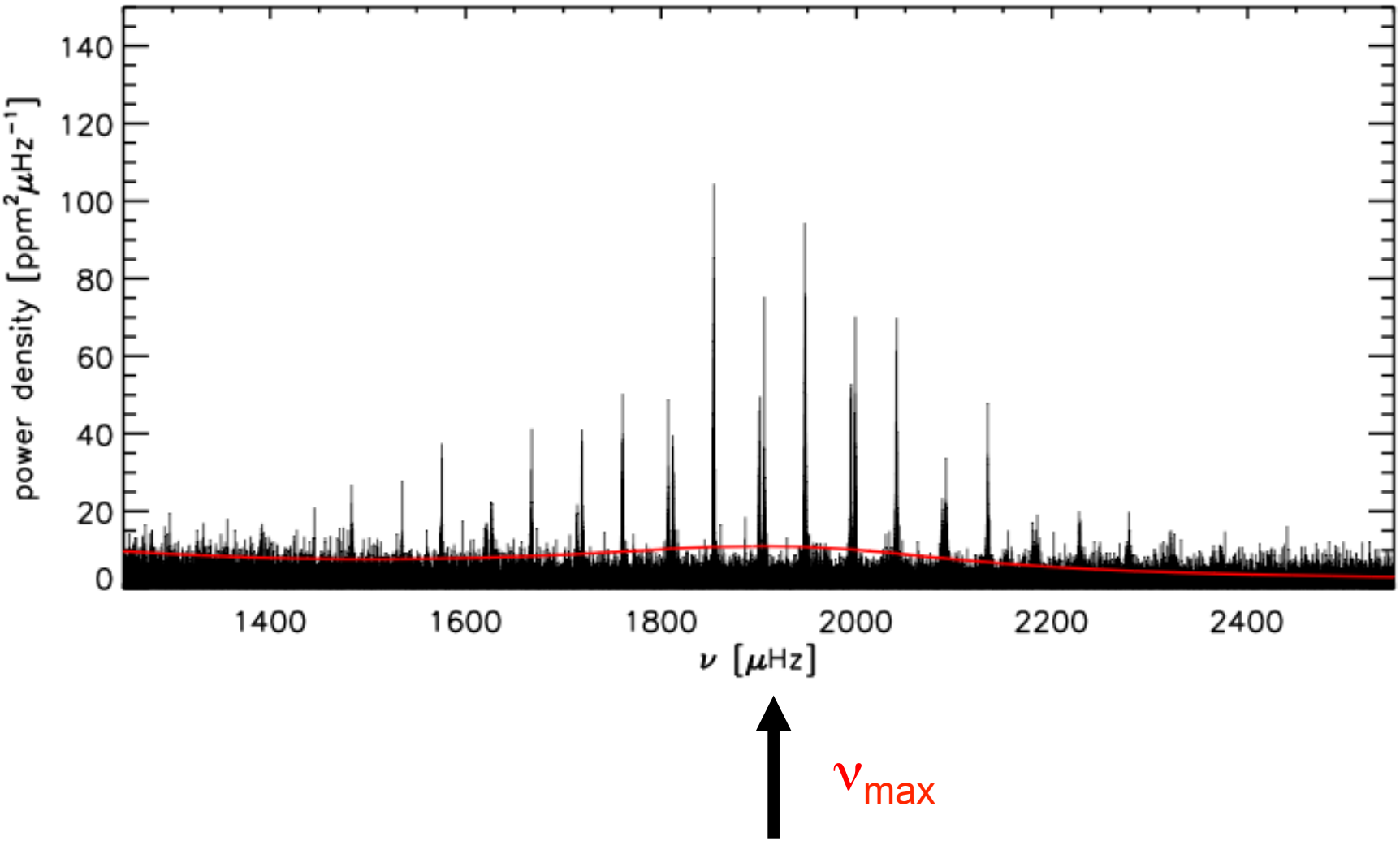
Photometry: Kepler



Time series



Fourier transform

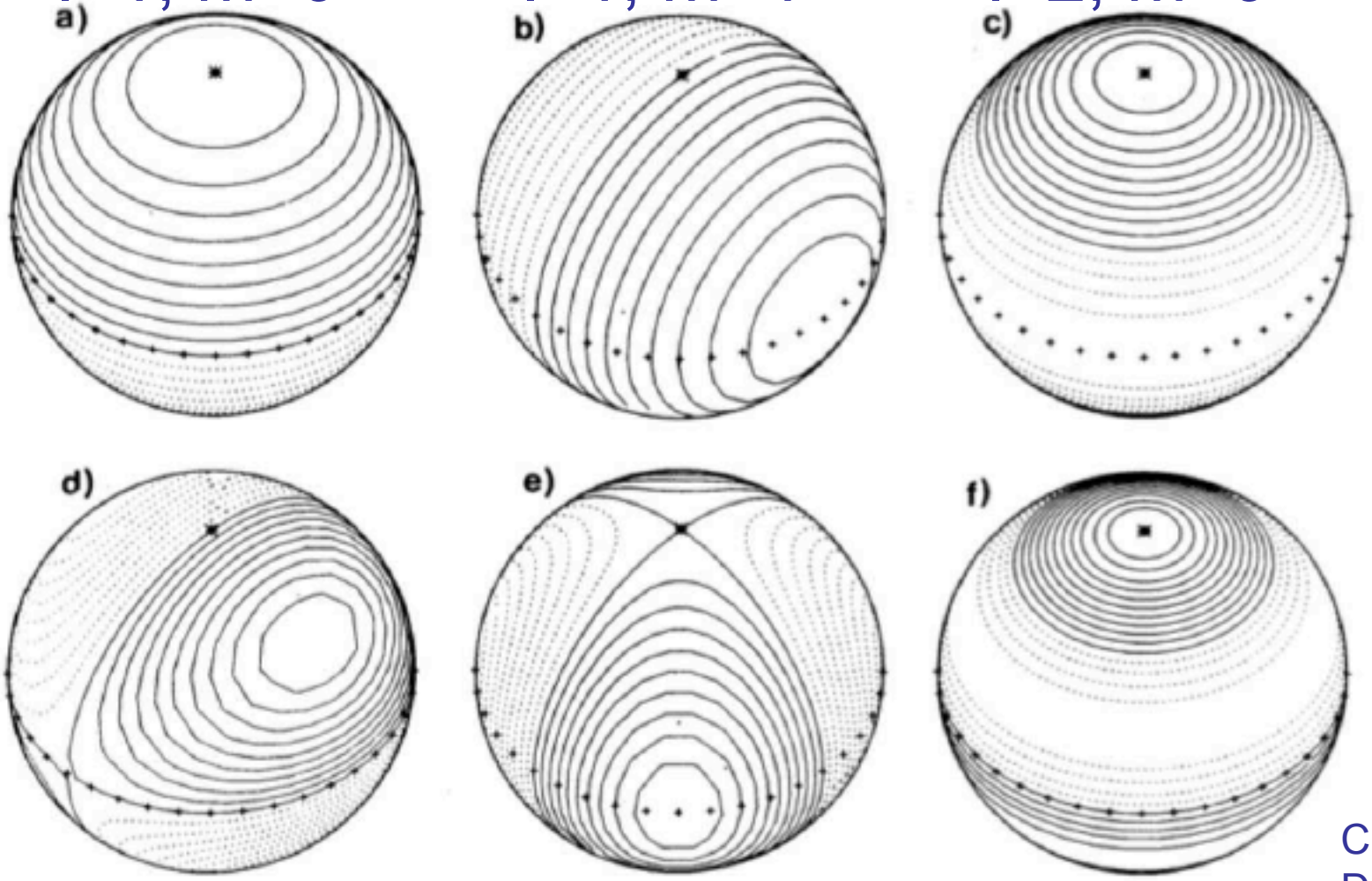


Spherical harmonics

l=1, m=0

l=1, m=1

l=2, m=0



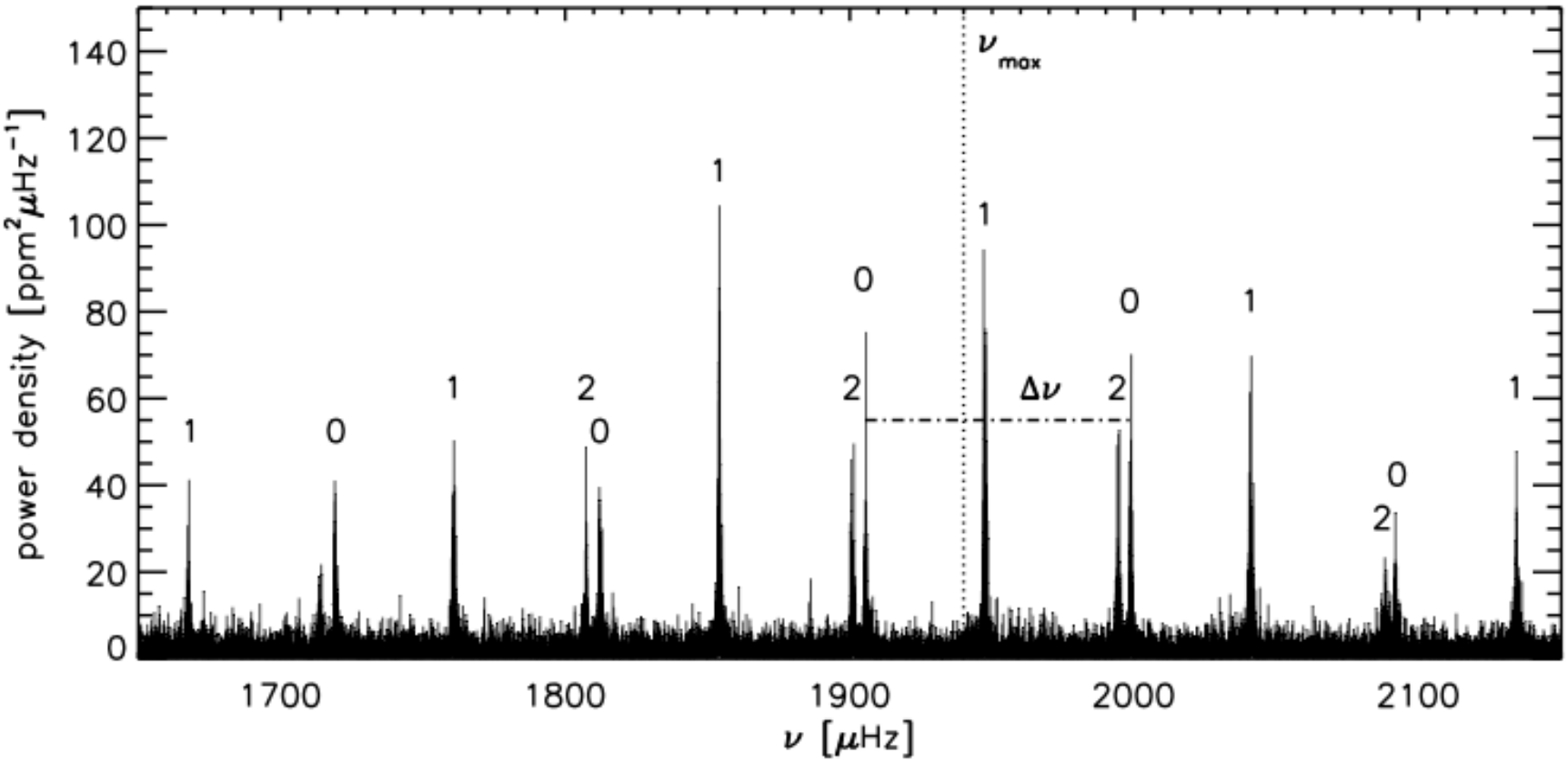
l=2, m=1

l=2, m=2

l=3, m=0

Christensen-Dalsgaard 2003

Oscillations



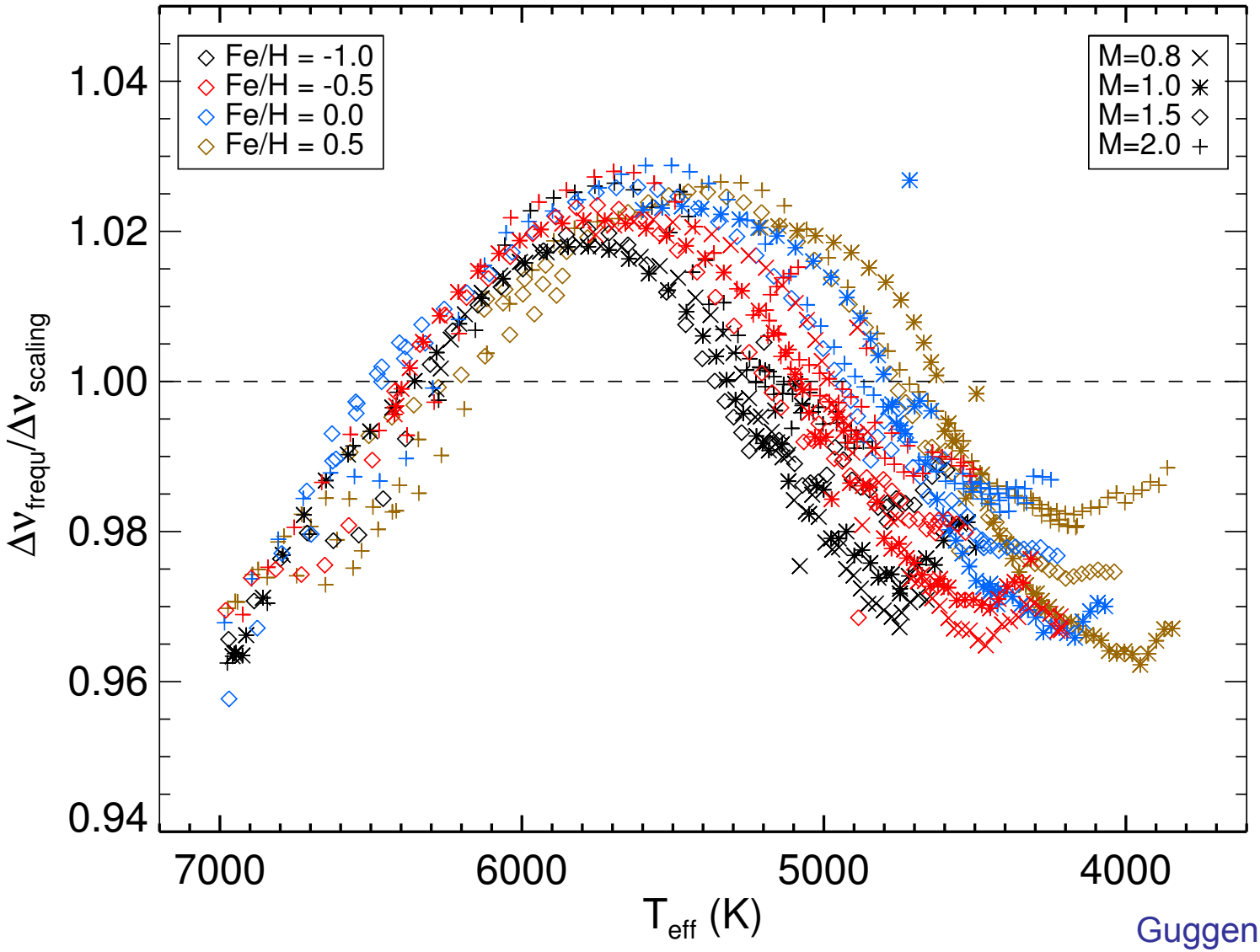
Hekker & Mazumdar 2014

Scaling relations

$$\Delta\nu \propto \sqrt{\frac{M}{R^3}} \propto \sqrt{\bar{\rho}}$$

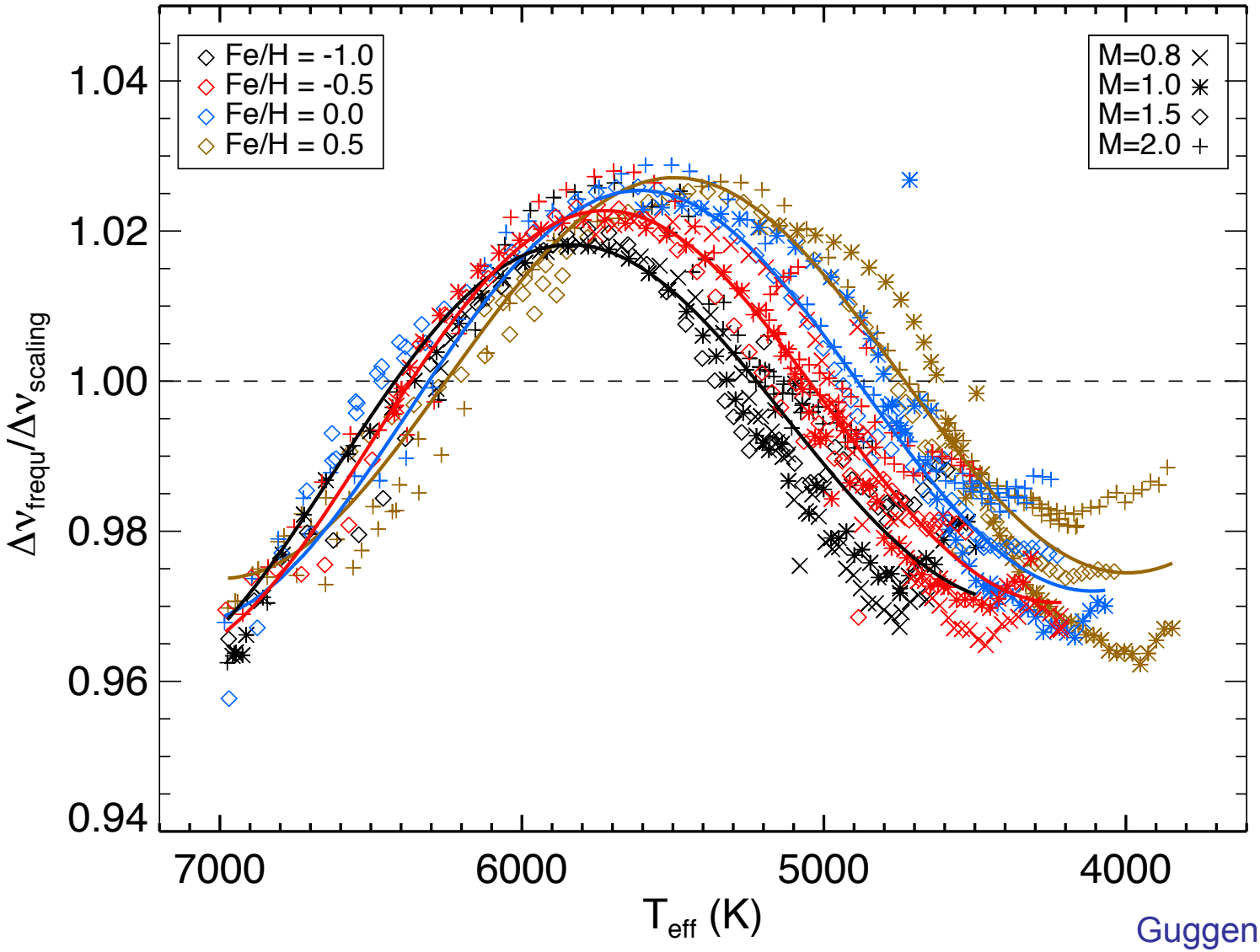
$$\nu_{\max} \propto \frac{g}{\sqrt{T_{eff}}} \propto \frac{M}{R^2\sqrt{T_{eff}}}$$

Reference of scaling relation



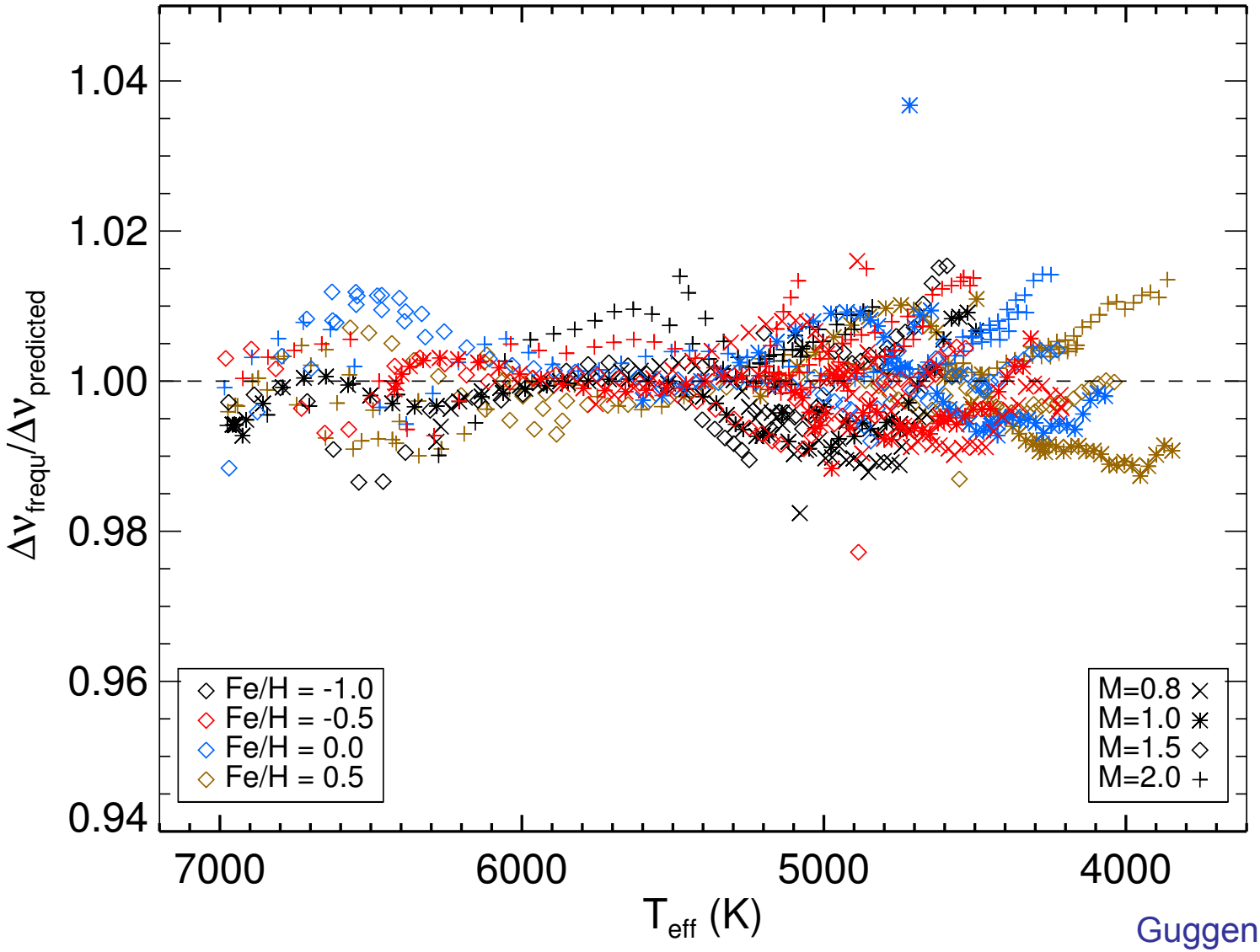
Guggenberger et al. 2016

Reference of scaling relation



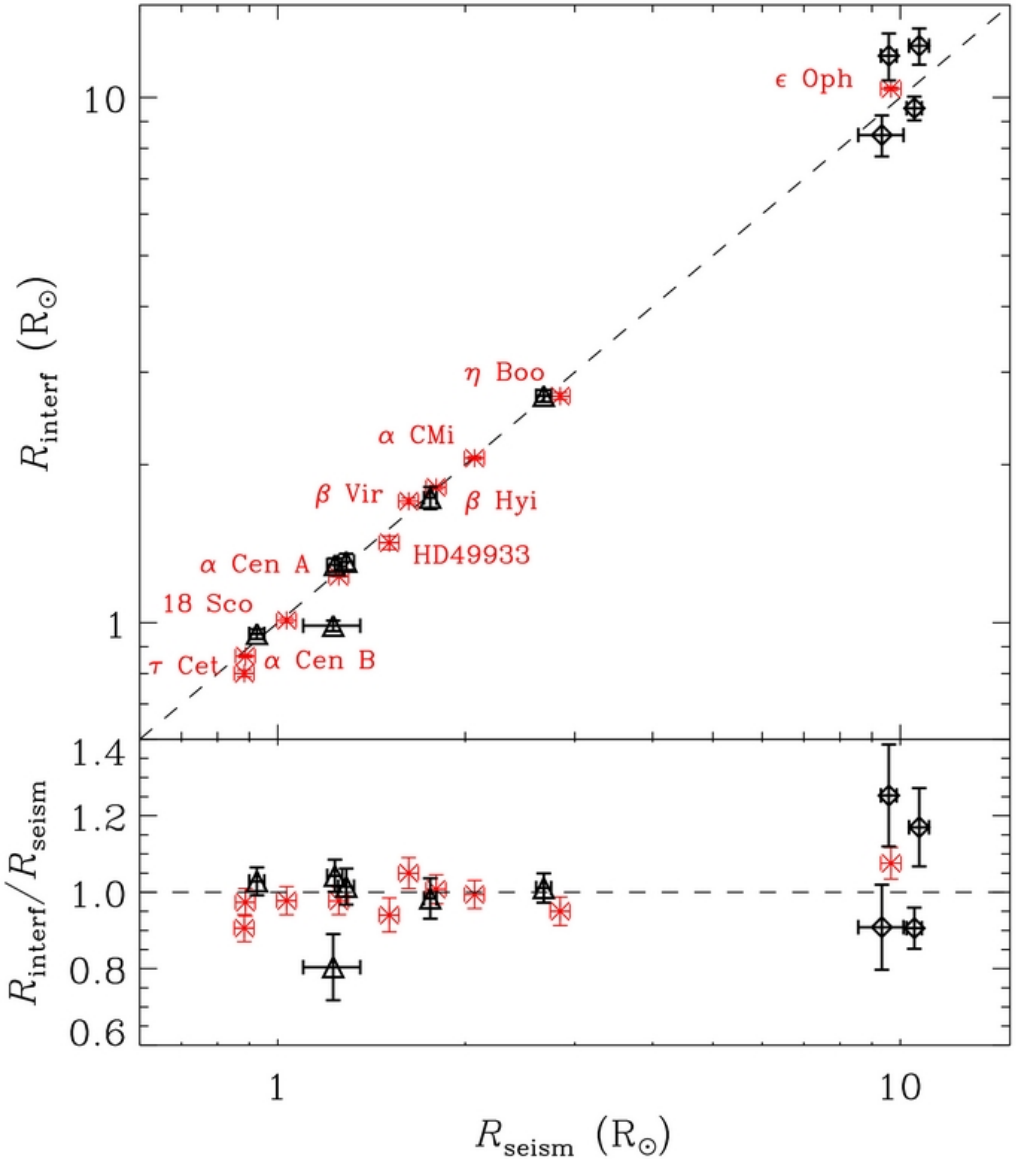
Guggenberger et al. 2016

Reference of scaling relation



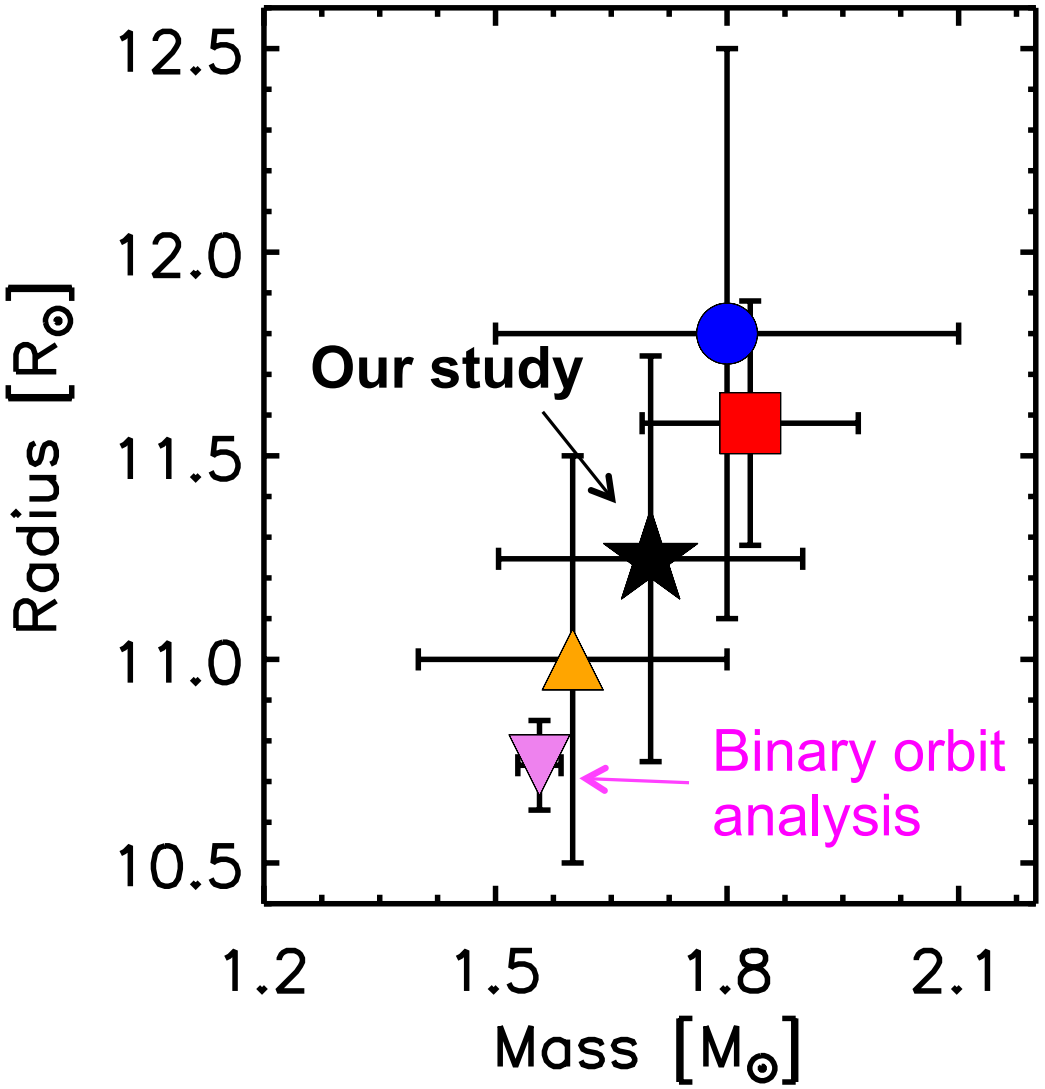
Guggenberger et al. 2016

Testing scaling relations



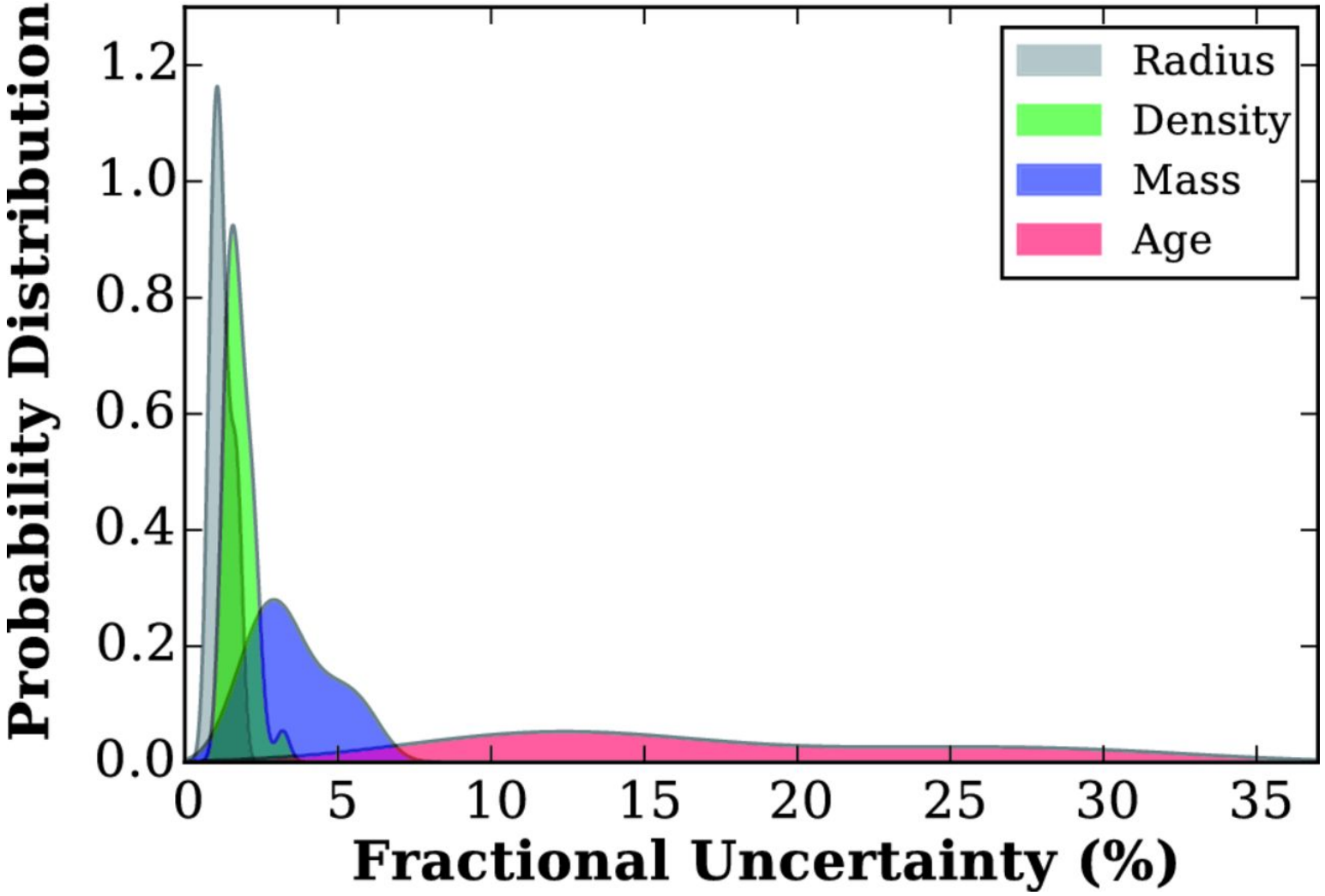
Huber et al. 2012

Testing scaling relations



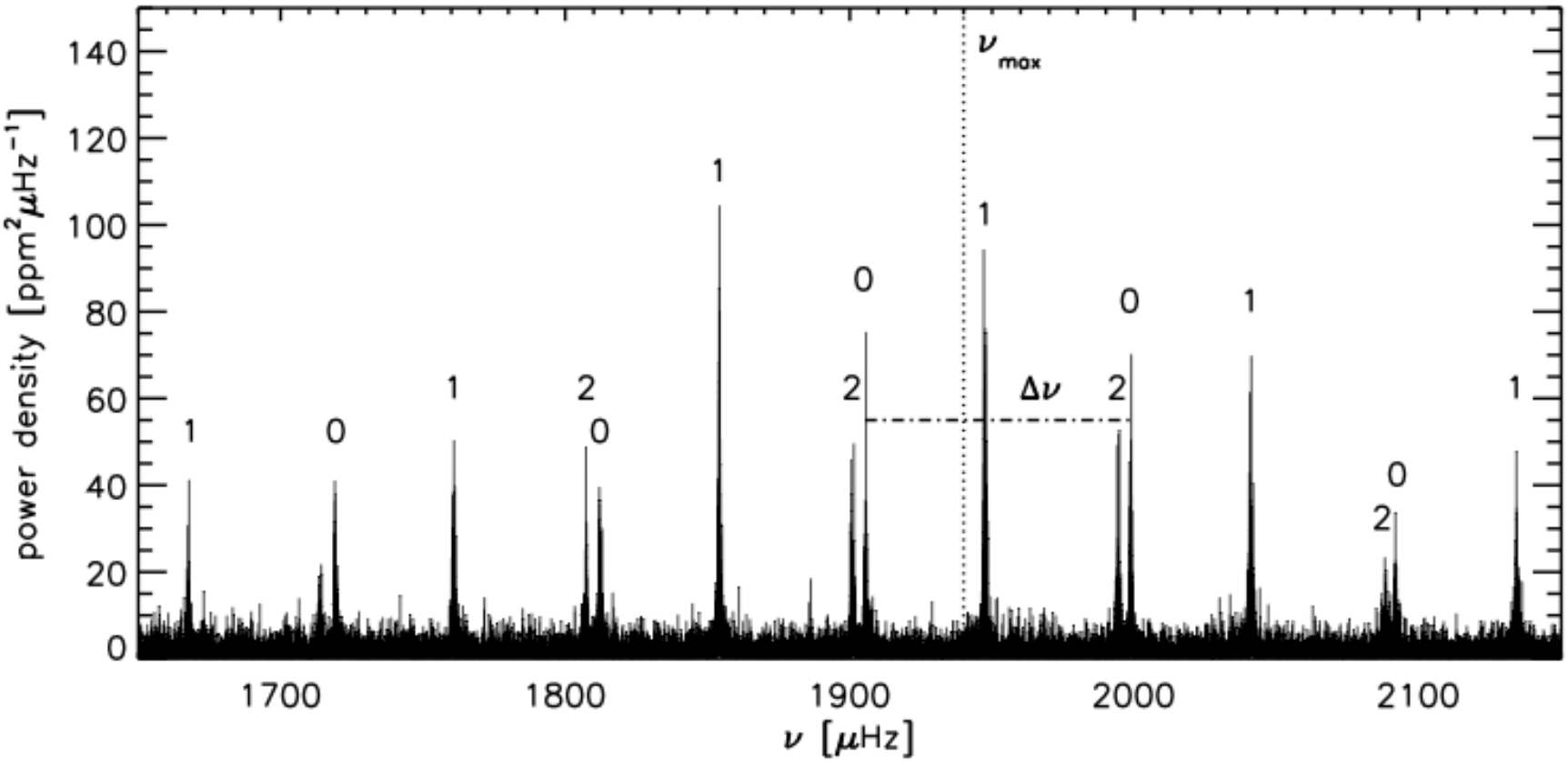
Themeßl et al. in prep.

Results scaling relation



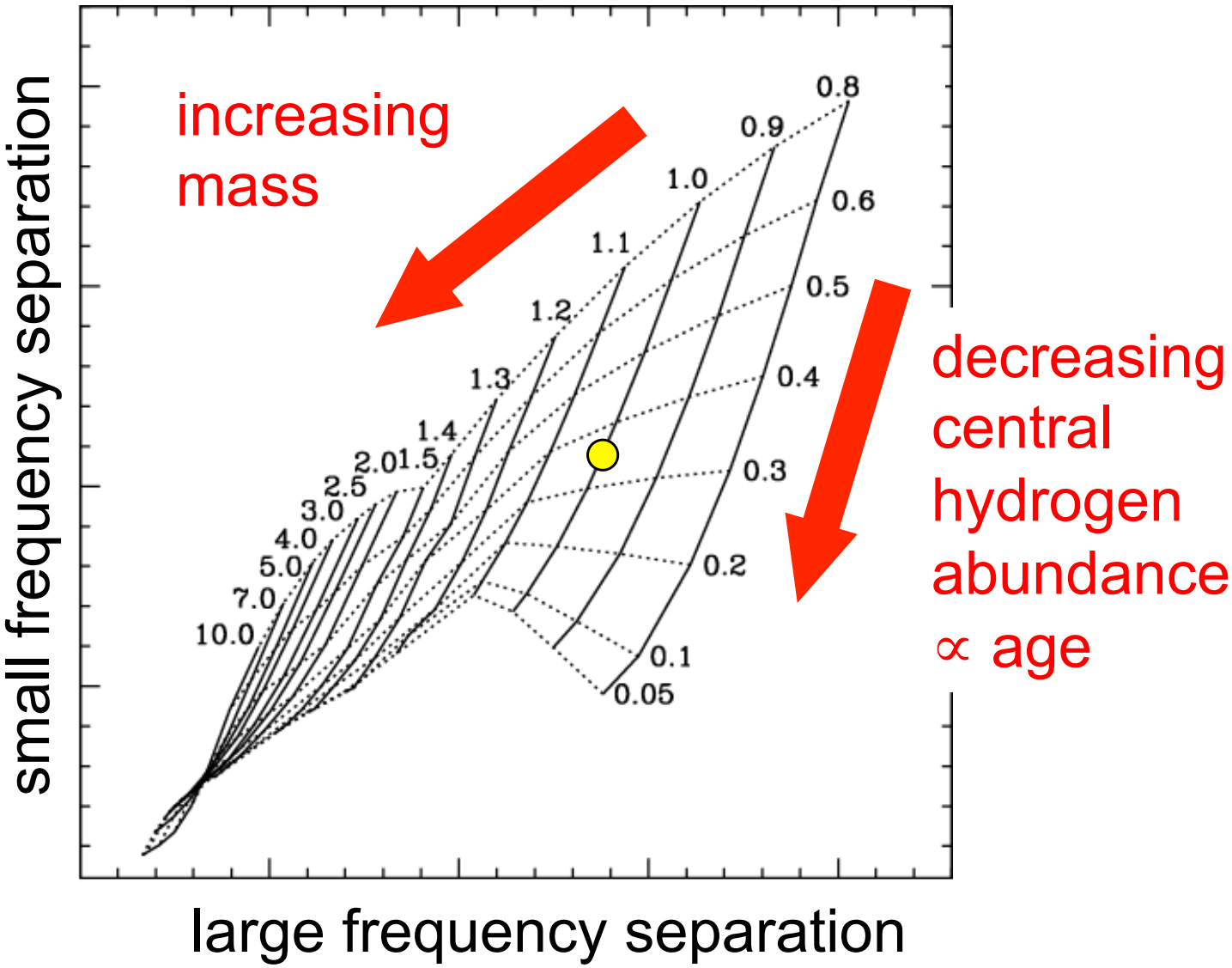
Silva Aguirre et al. 2015

Oscillations



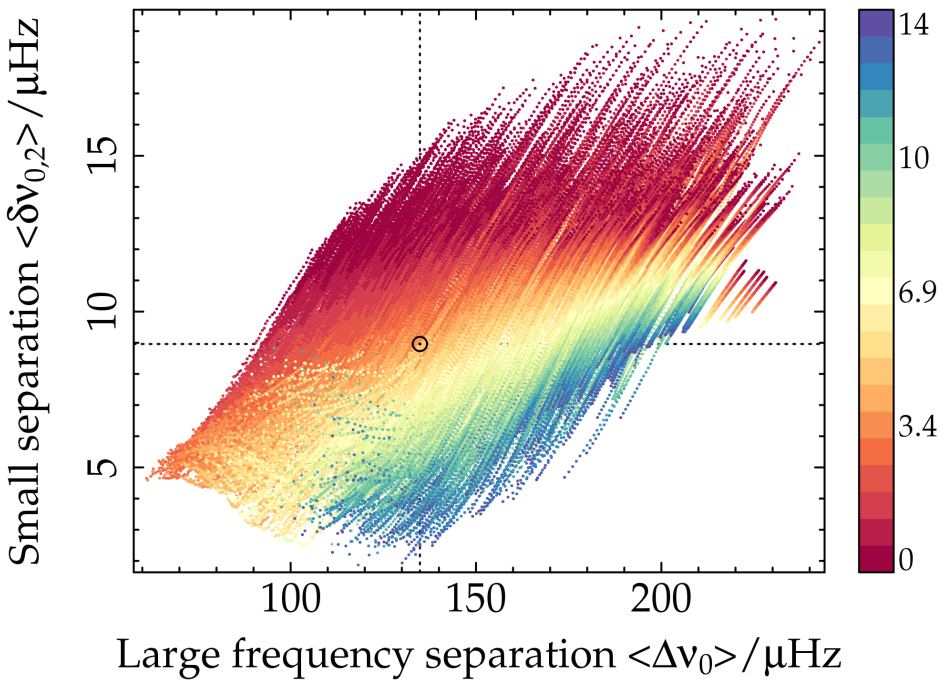
Hekker & Mazumdar 2014

Christensen-Dalsgaard Diagram

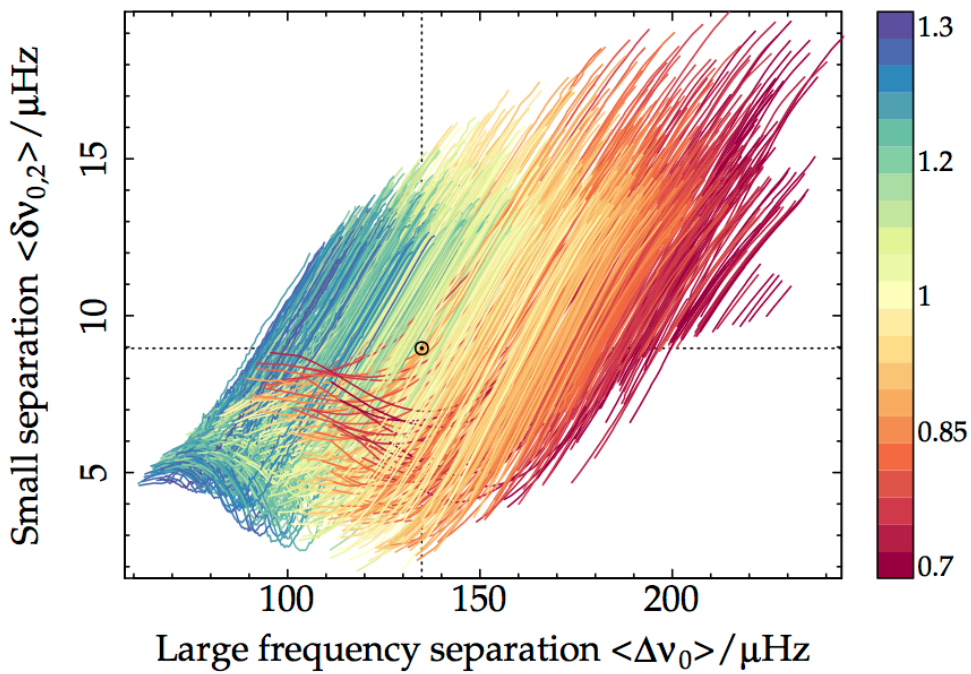


Christensen-Dalsgaard Diagram

age

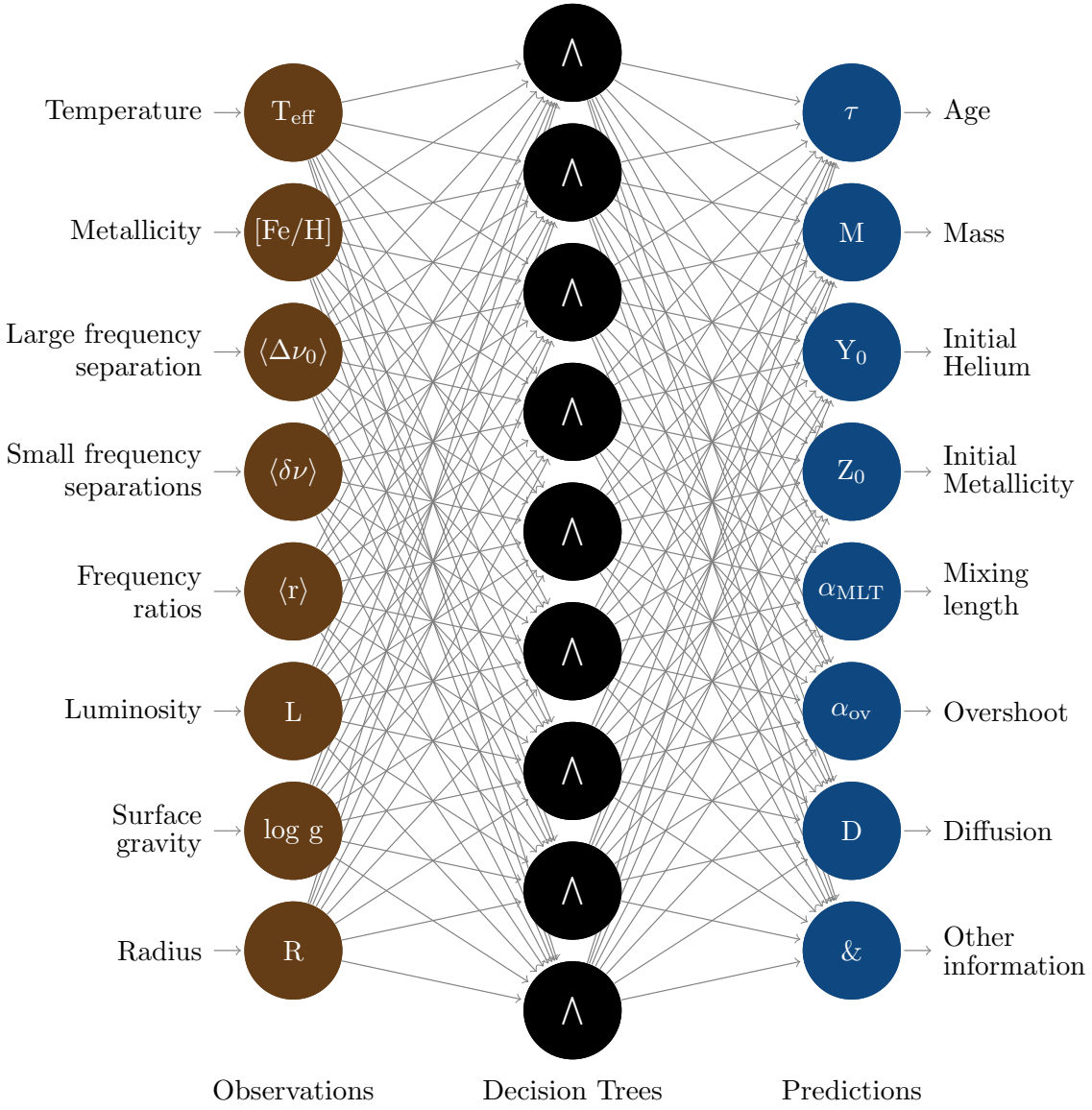


mass



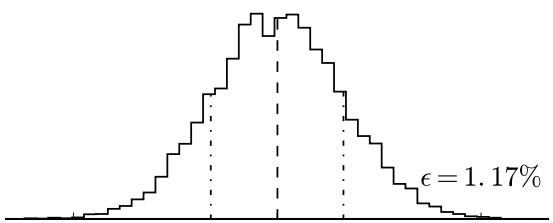
Bellinger et al. submitted

Random forest

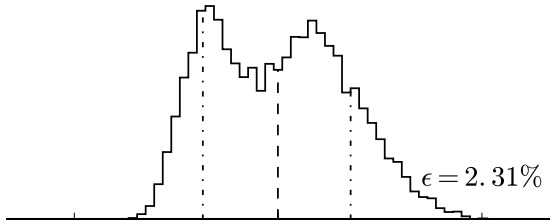


Bellinger et al. submitted

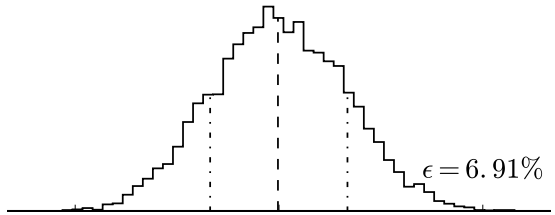
Result “Kepler” data Sun



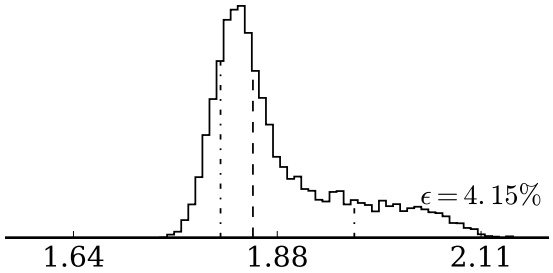
Mass $M/M_\odot = 1^{+0.0114}_{-0.0115}$



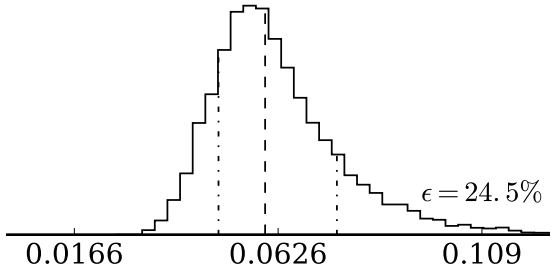
Initial helium $Y_0 = 0.27^{+0.00667}_{-0.00689}$



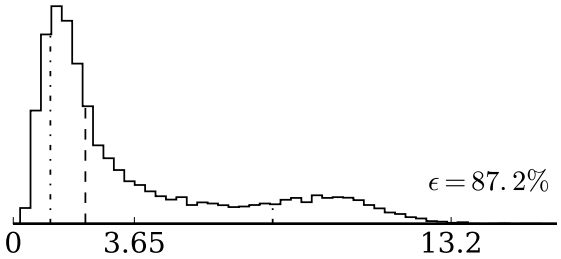
Initial metallicity $Z_0 = 0.0197^{+0.00139}_{-0.00136}$



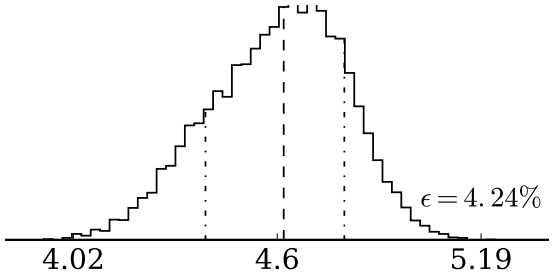
Mixing length $\alpha_{\rm MLT} = 1.85^{+0.116}_{-0.0371}$



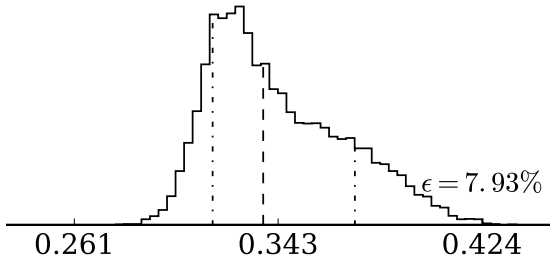
Overshoot $\alpha_{\rm ov} = 0.0596^{+0.0162}_{-0.0105}$



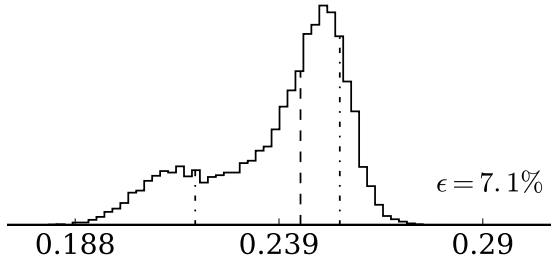
Diffusion factor $D = 2.17^{+5.64}_{-1.06}$



Age τ/Gyr $= 4.62^{+0.174}_{-0.225}$



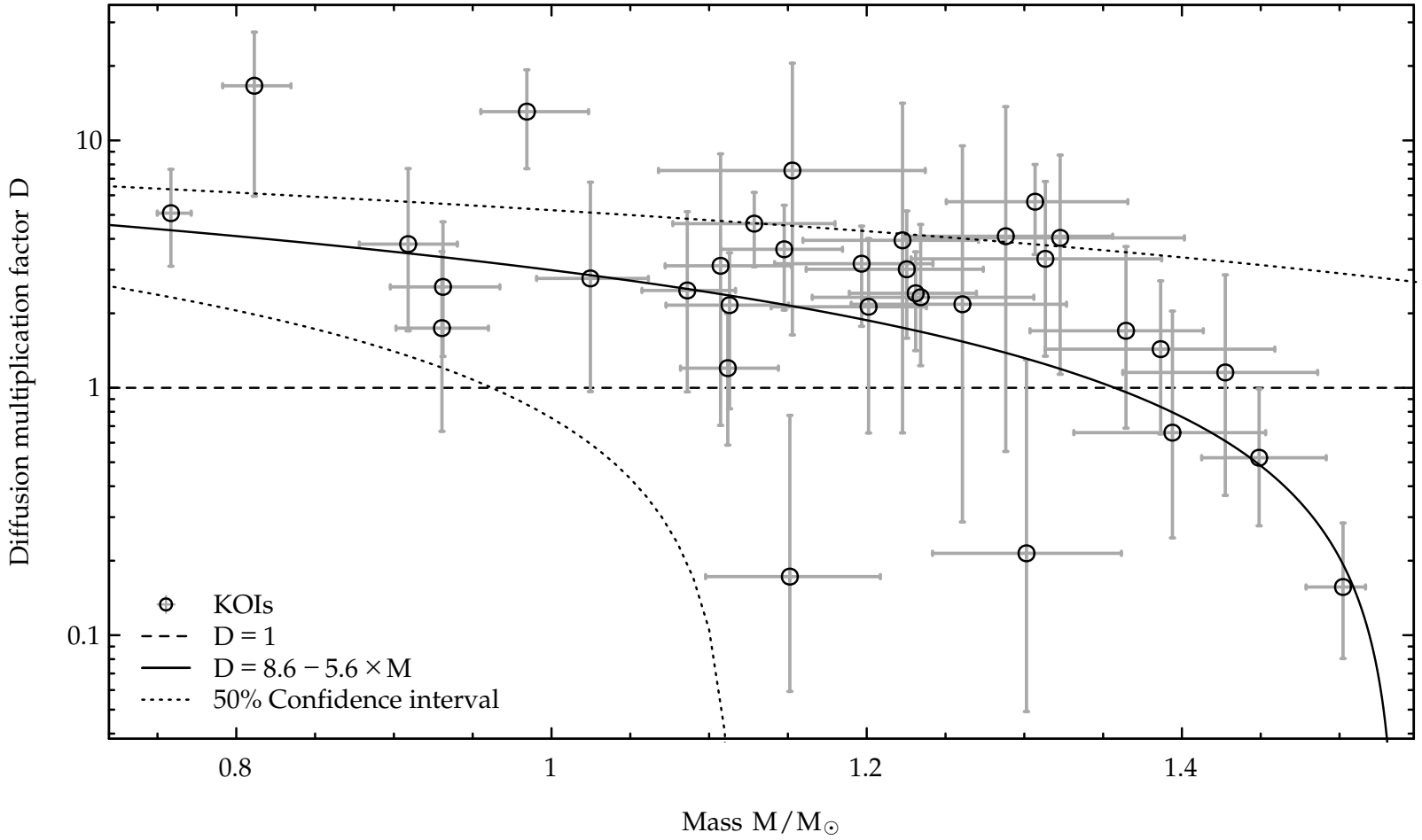
Core-hydrogen $X_c = 0.337^{+0.0367}_{-0.0202}$



Surface helium $Y_{\rm surf} = 0.244^{+0.0098}_{-0.0263}$

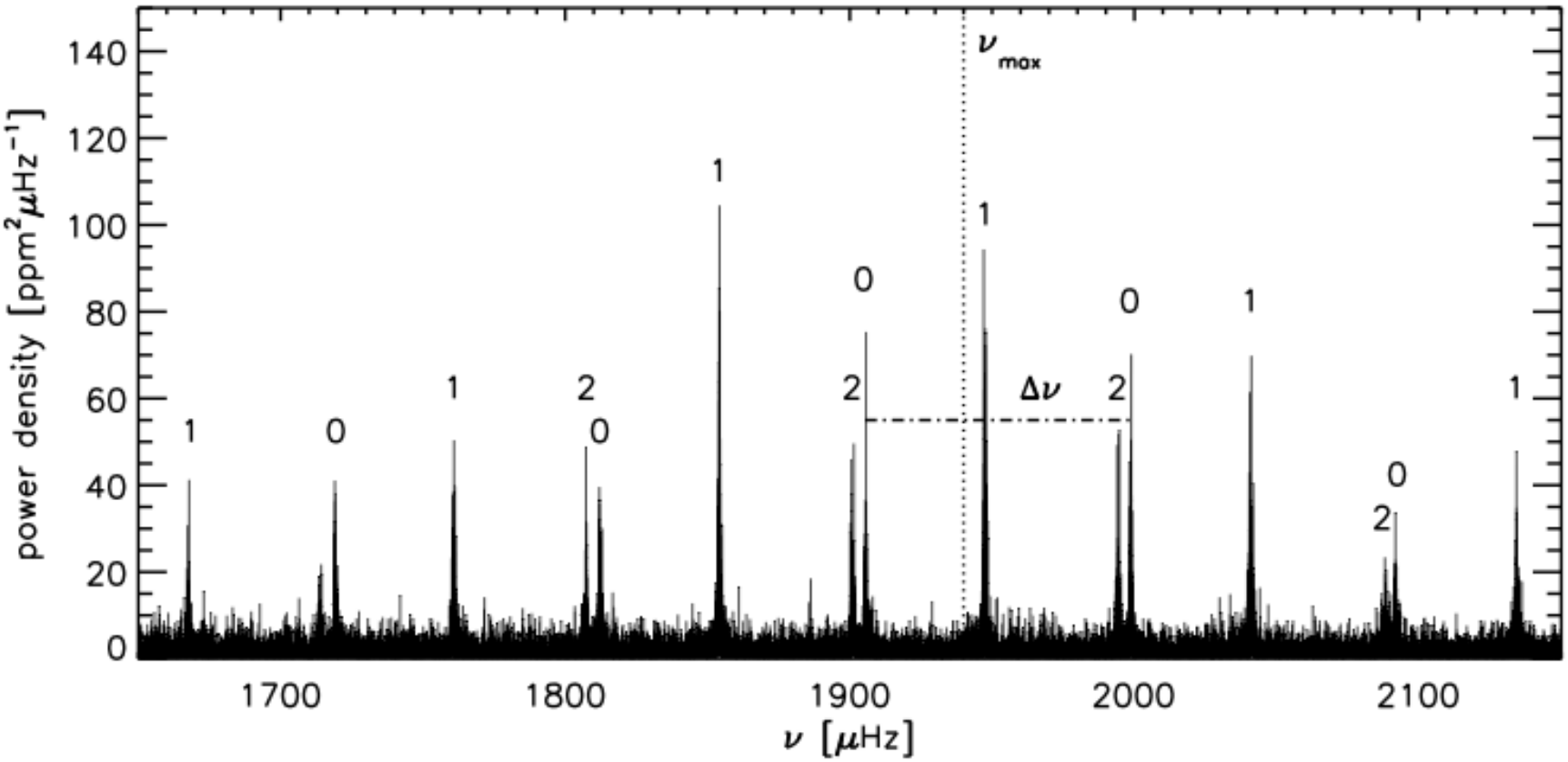
Bellinger et al. submitted

Diffusion



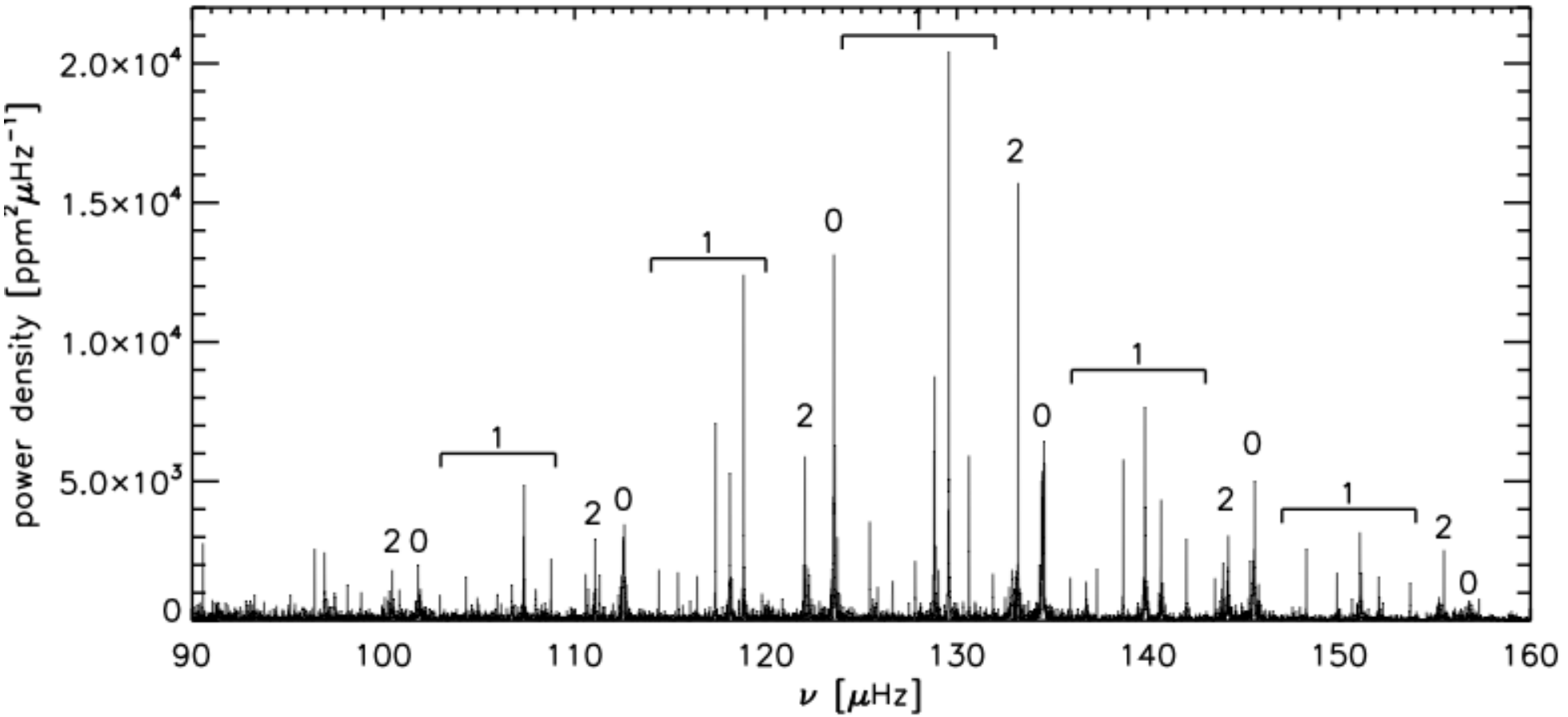
Bellinger et al. submitted

Main-sequence star

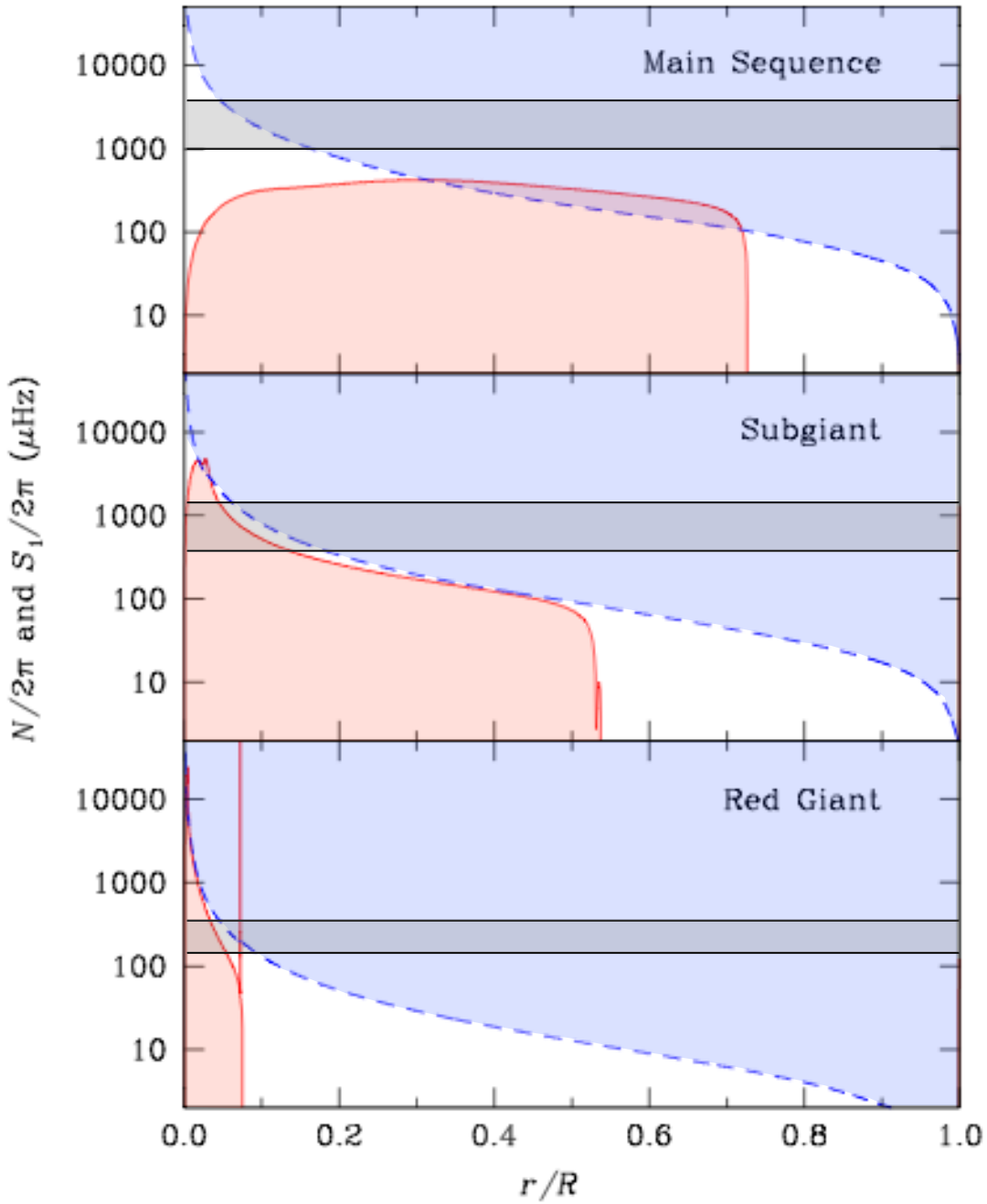


Hekker & Mazumdar 2014

Red giant



Hekker & Mazumdar 2014

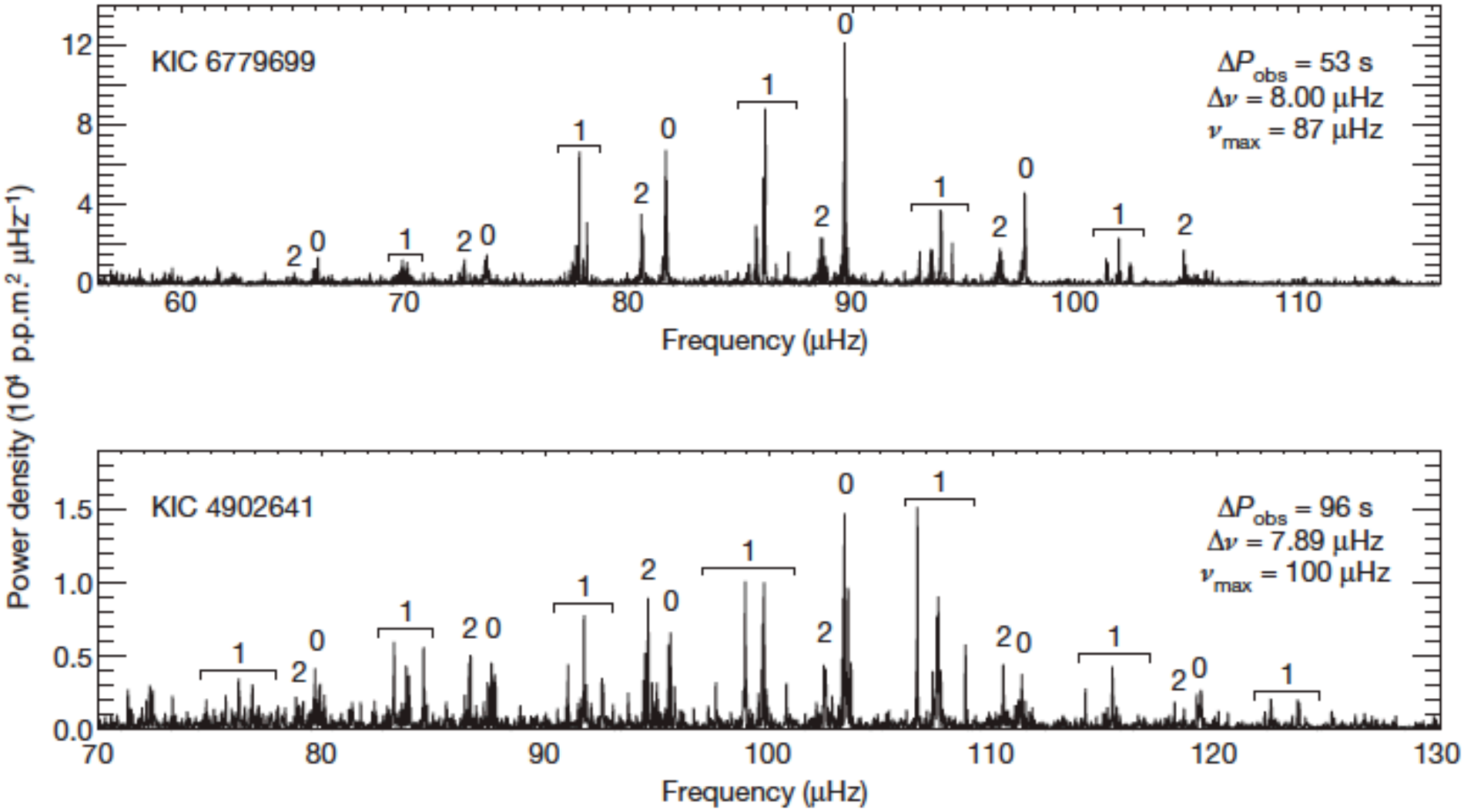


-Brunt-Väisälä frequency buoyancy cavity

- Lamb frequency acoustic cavity

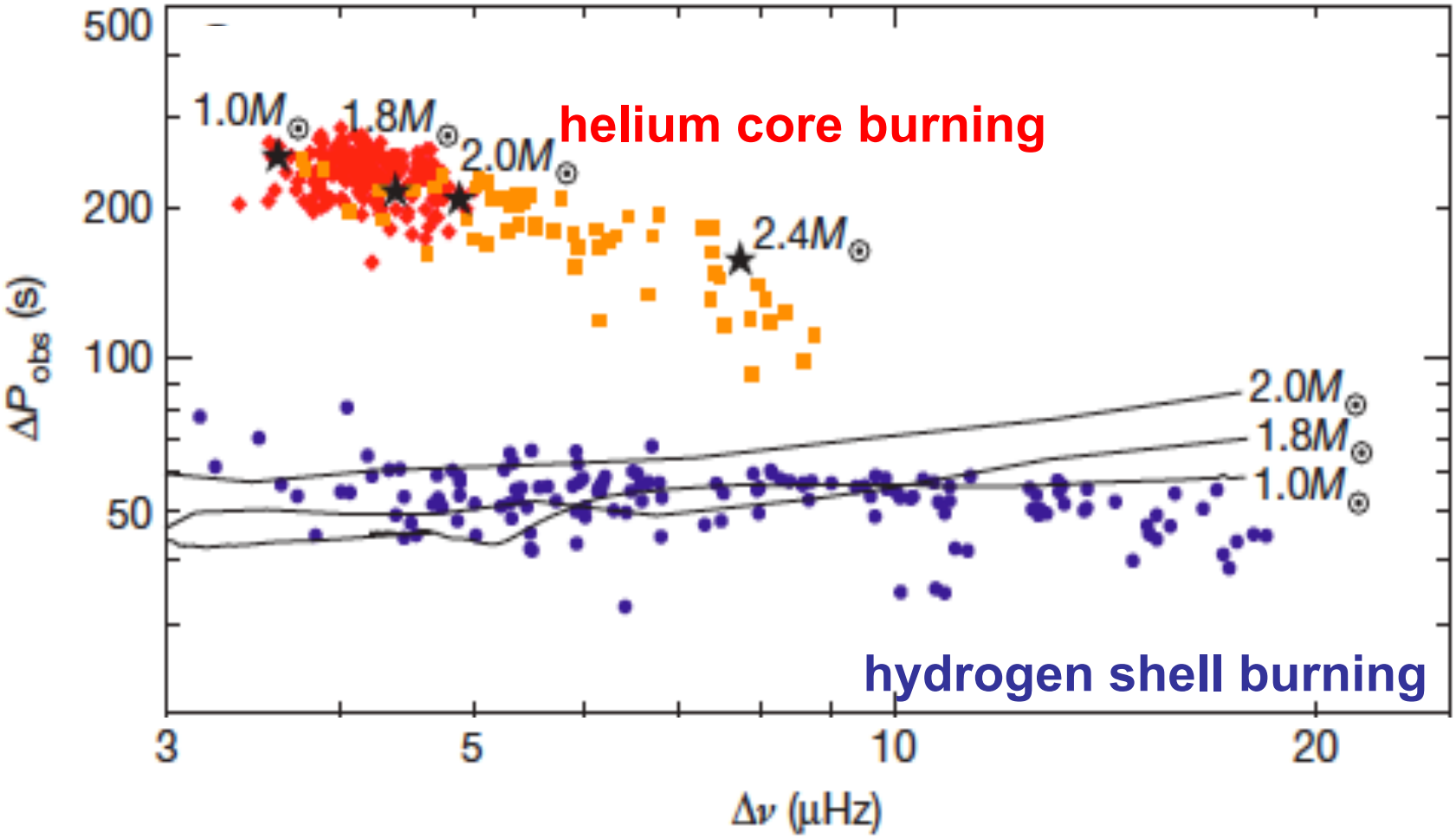
Hekker & Mazumdar 2014

Mixed modes



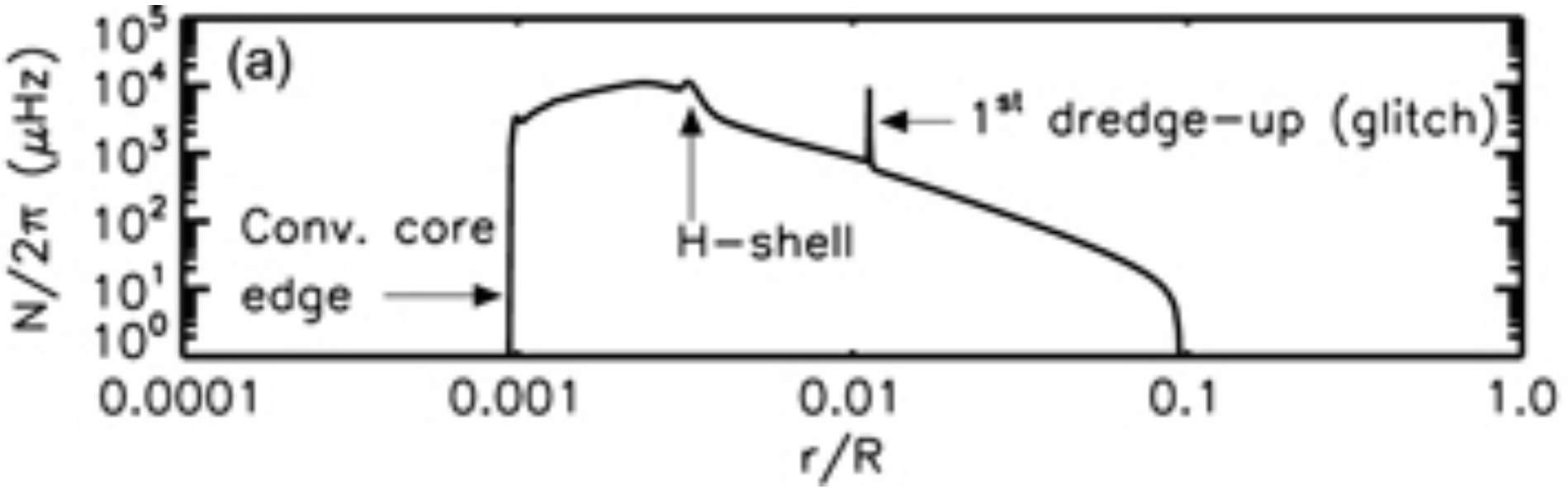
Beck et al. 2011, Science / Bedding et al. 2011, Nature / Mosser et al. 2014

Period spacing



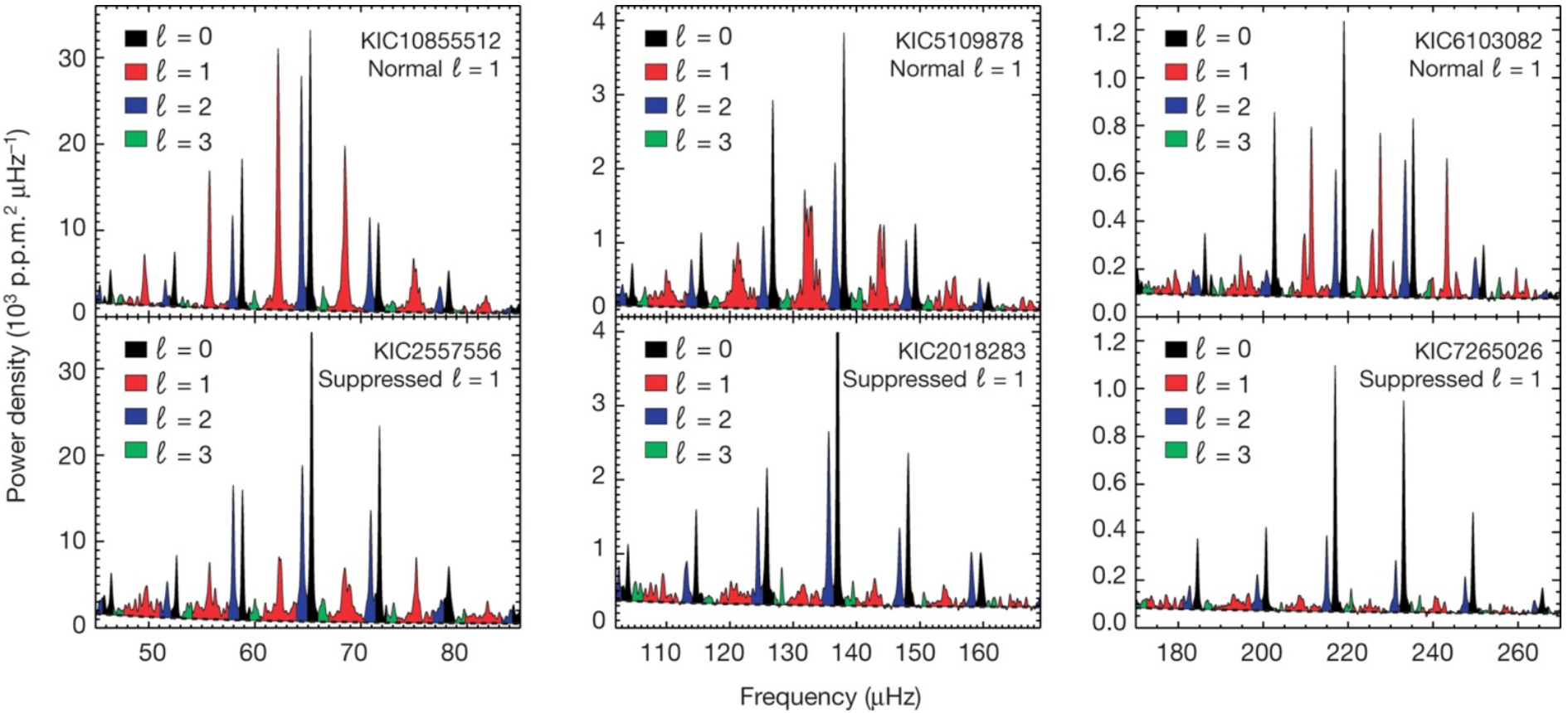
Bedding et al. 2011; Mosser et al. 2014

Stellar structure features



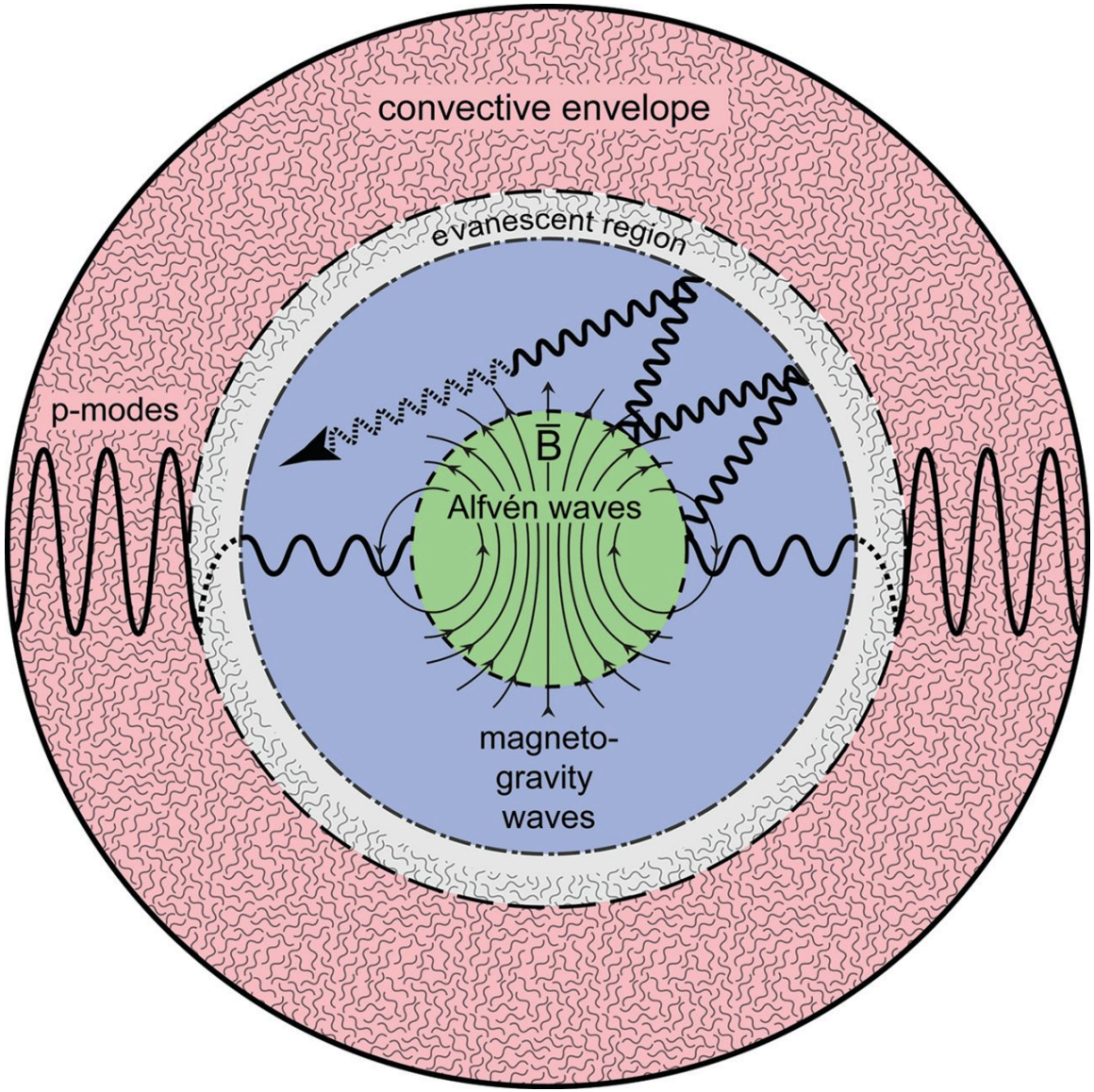
Cunha et al. 2015

Suppressed dipole modes

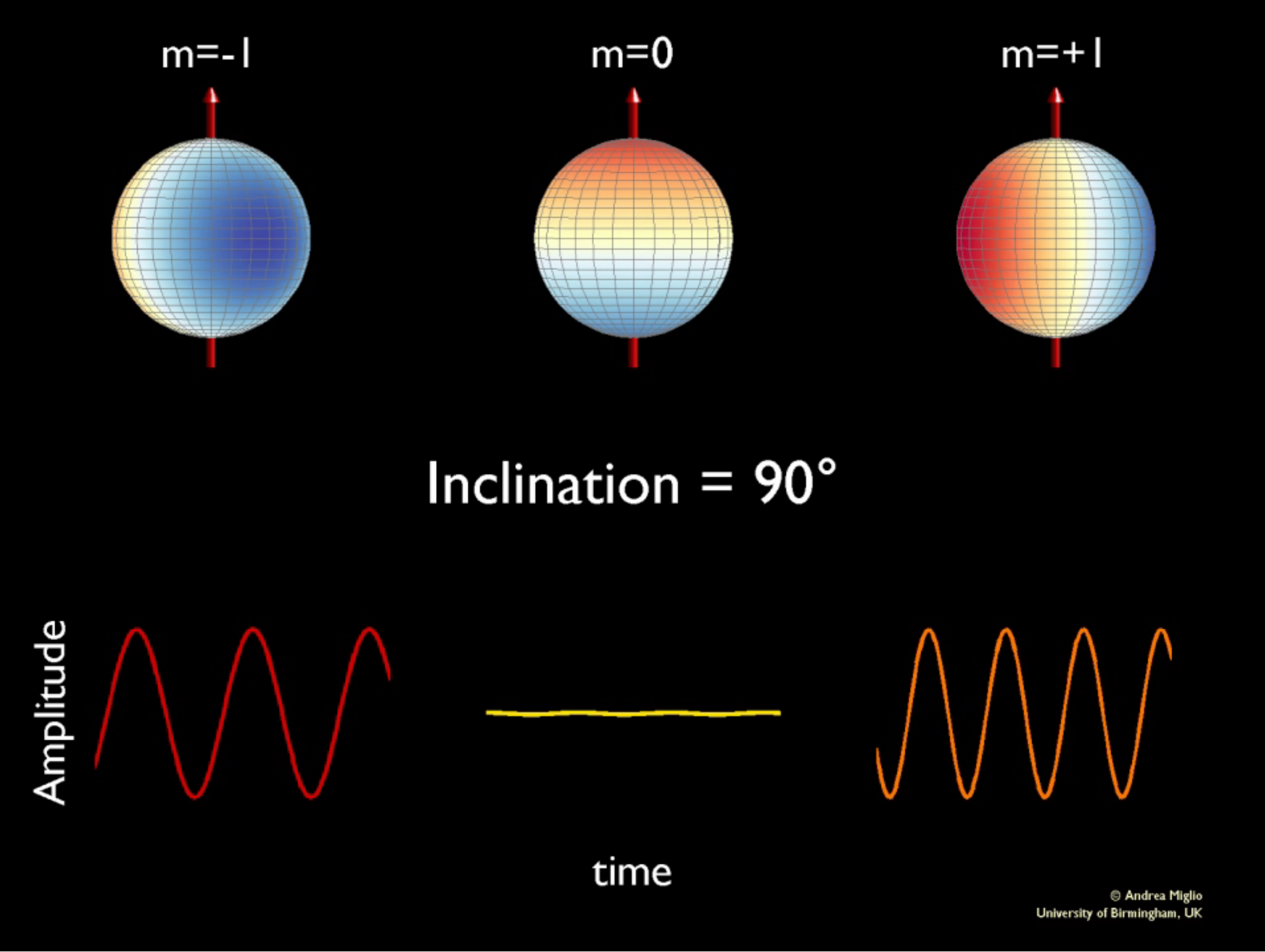


Stello et al. 2016

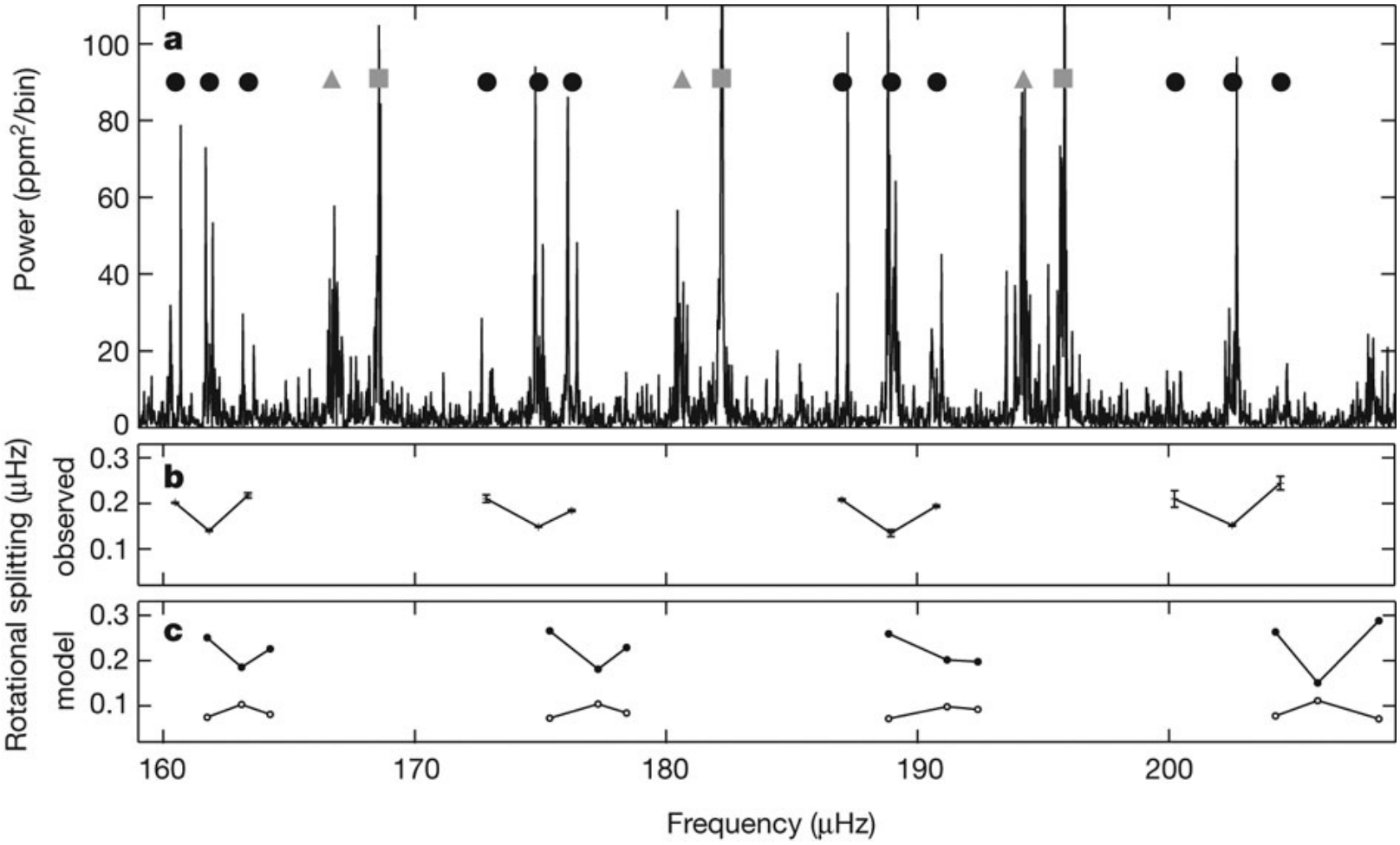
Suppressed modes: magnetic greenhouse



Fuller et al. 2015


m=-1
m=0
m=+1
Inclination = 90°
Amplitude
time
© Andrea Miglio
University of Birmingham, UK

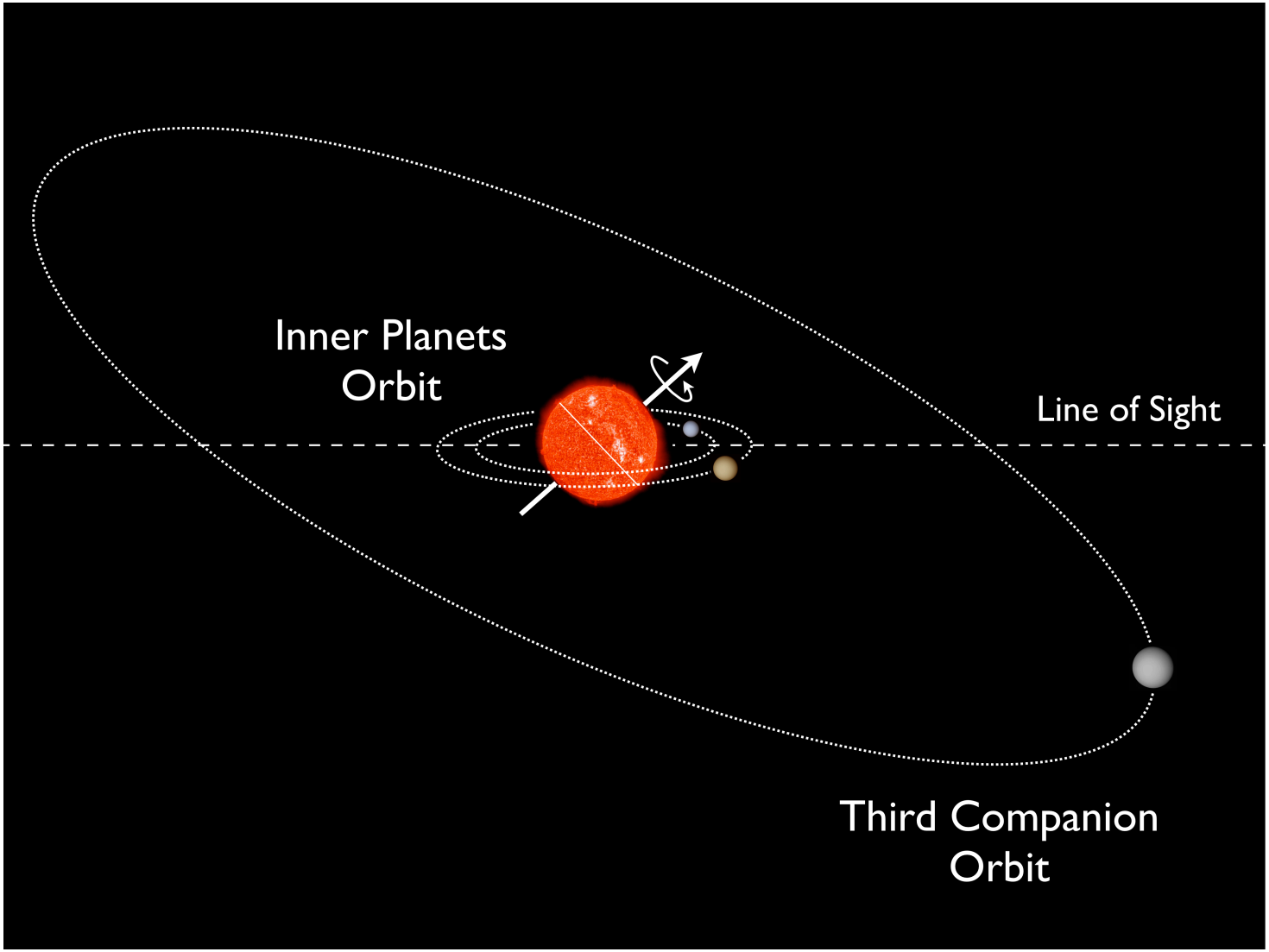
Rotational splitting of non-radial modes



fast core
solid body

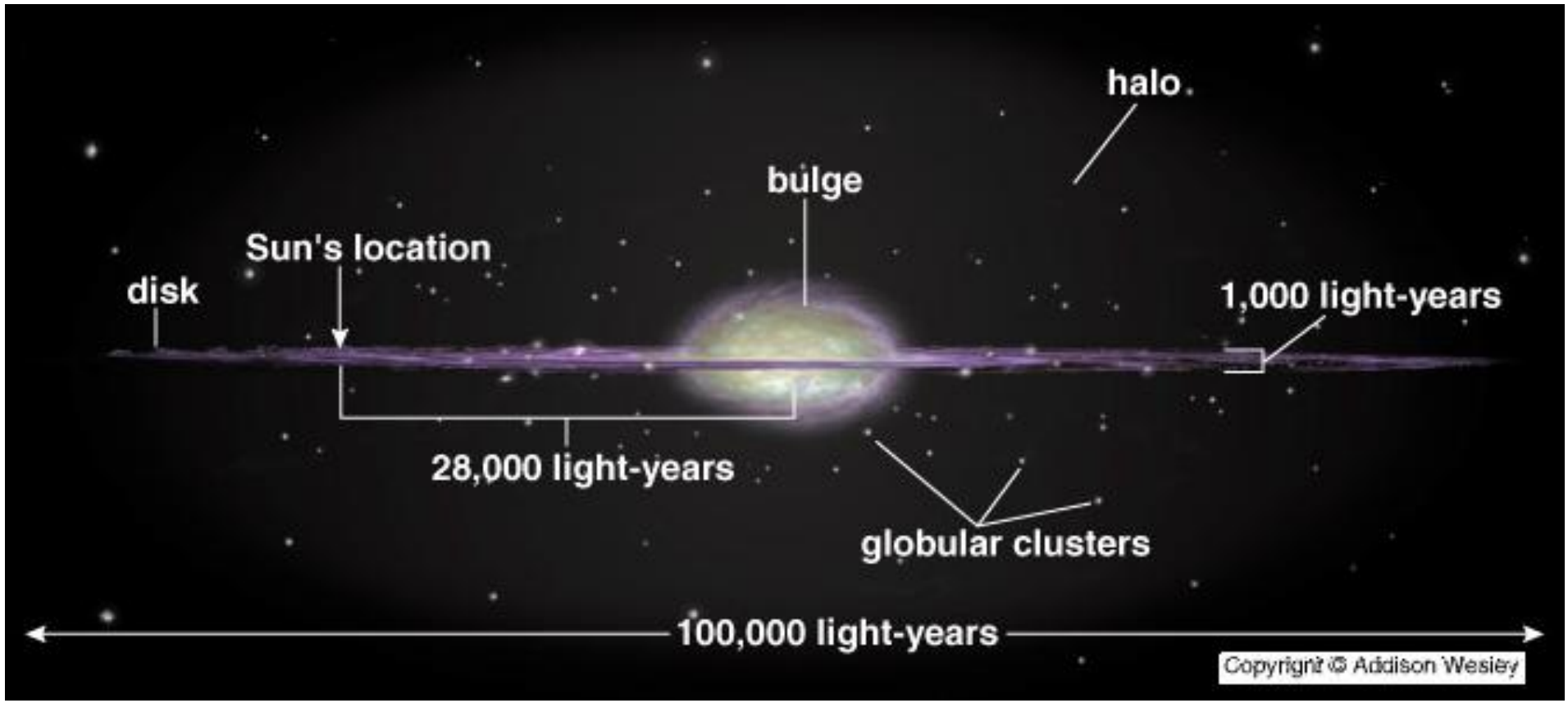
Beck et al. 2012, Nature

Kepler 56

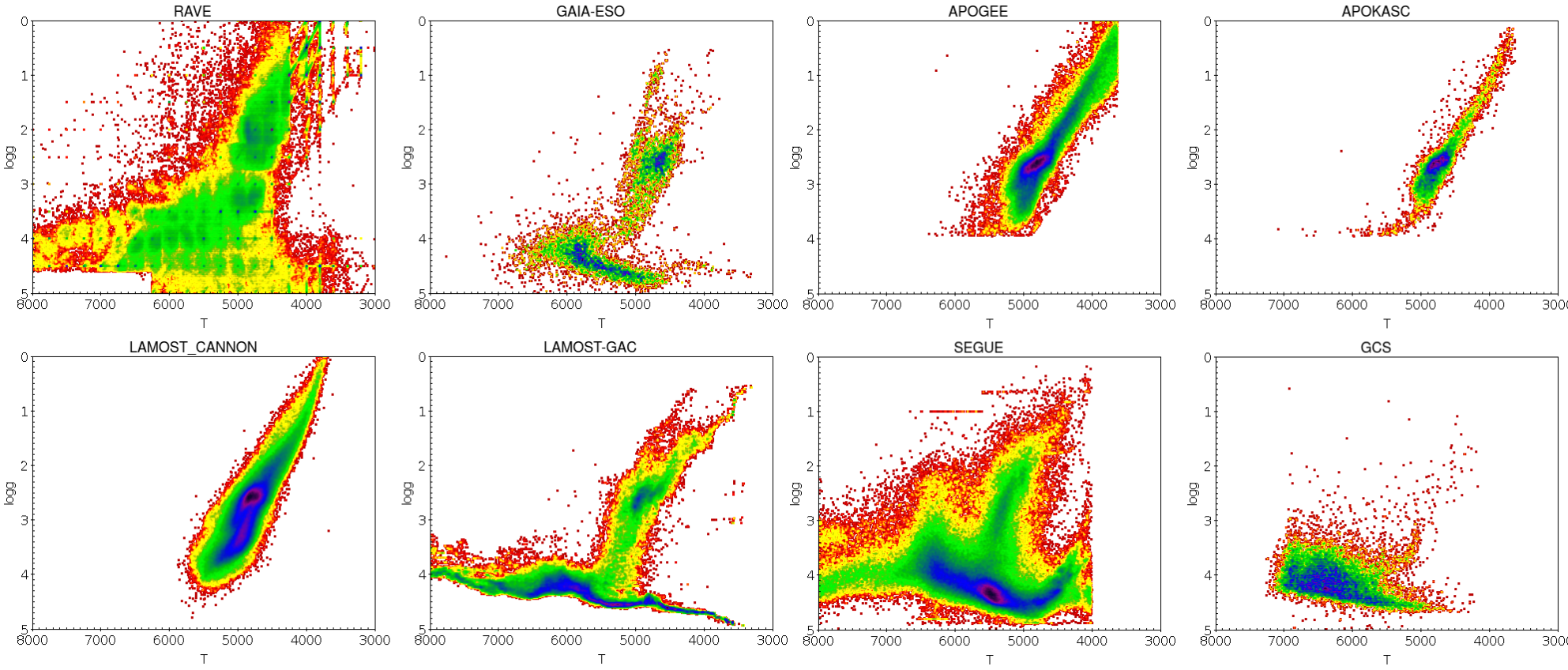


Huber et al. 2013

Milky Way

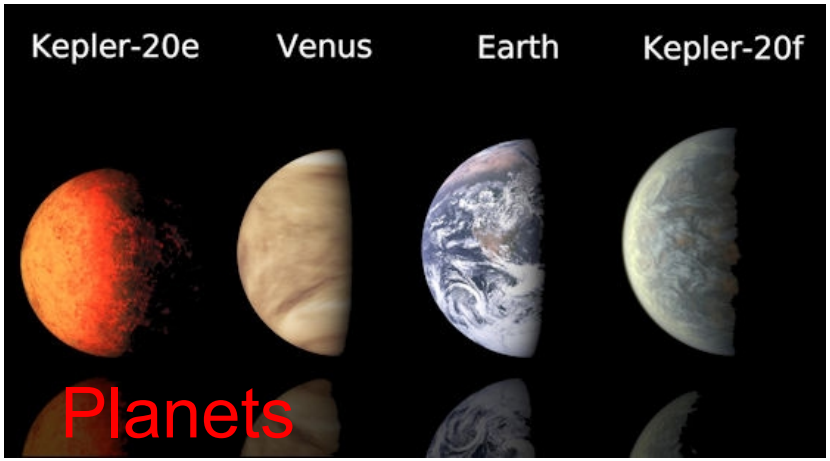

halo
bulge
Sun's location
disk
1,000 light-years
28,000 light-years
globular clusters
100,000 light-years
Copyright © Addison Wesley

Homogeneous parameters across MW



Mints et al. in prep.

Importance of accurate stellar parameters



SAGE group:

Felix Ahlborn
Earl Bellinger
Alexey Mints
Elisabeth Guggenberger
George Angelou
Andrés Garcia S
Nathalie Themeßl