Asteroseismology of Red Giants

Daniel Huber

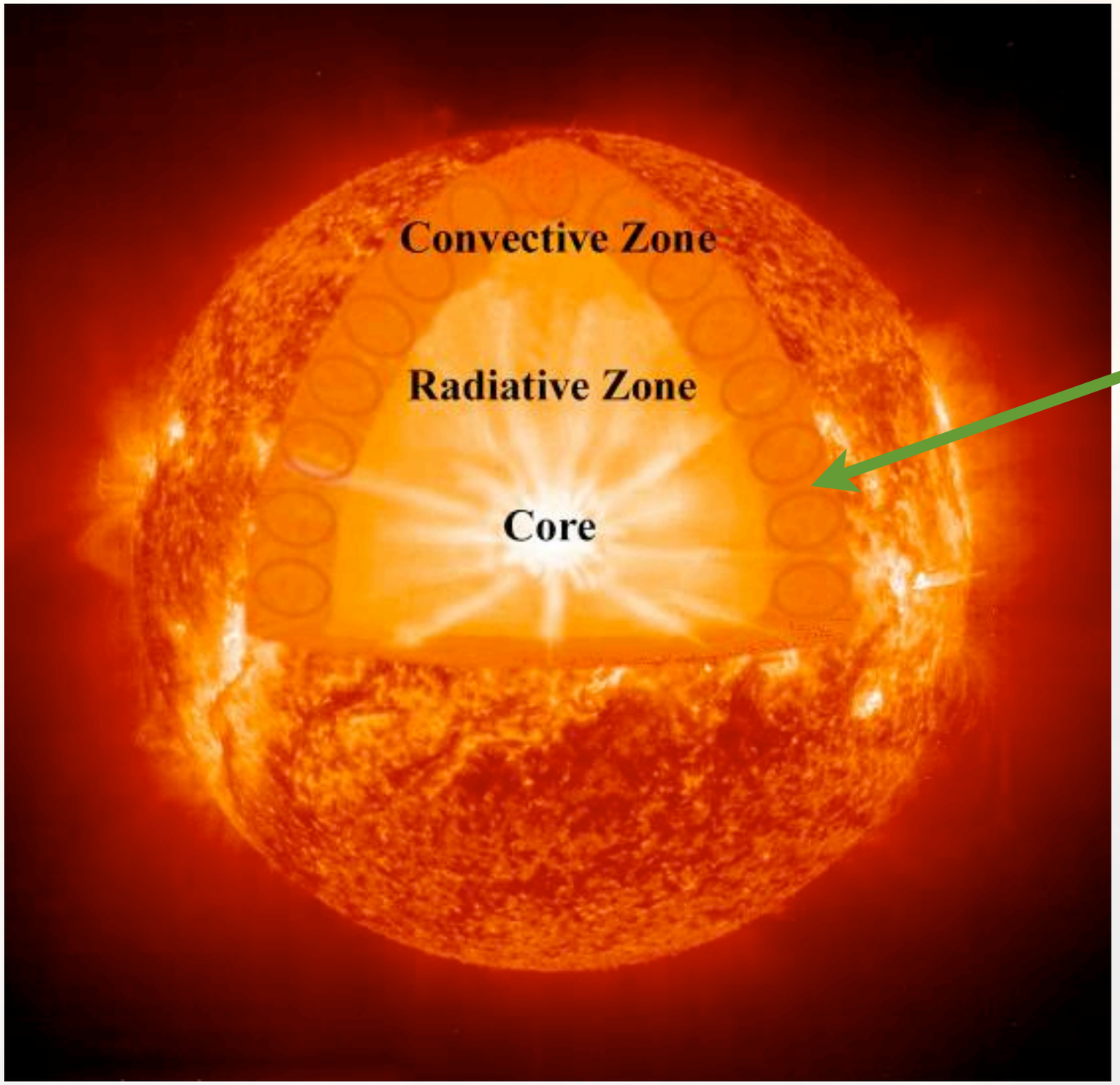
University of Sydney

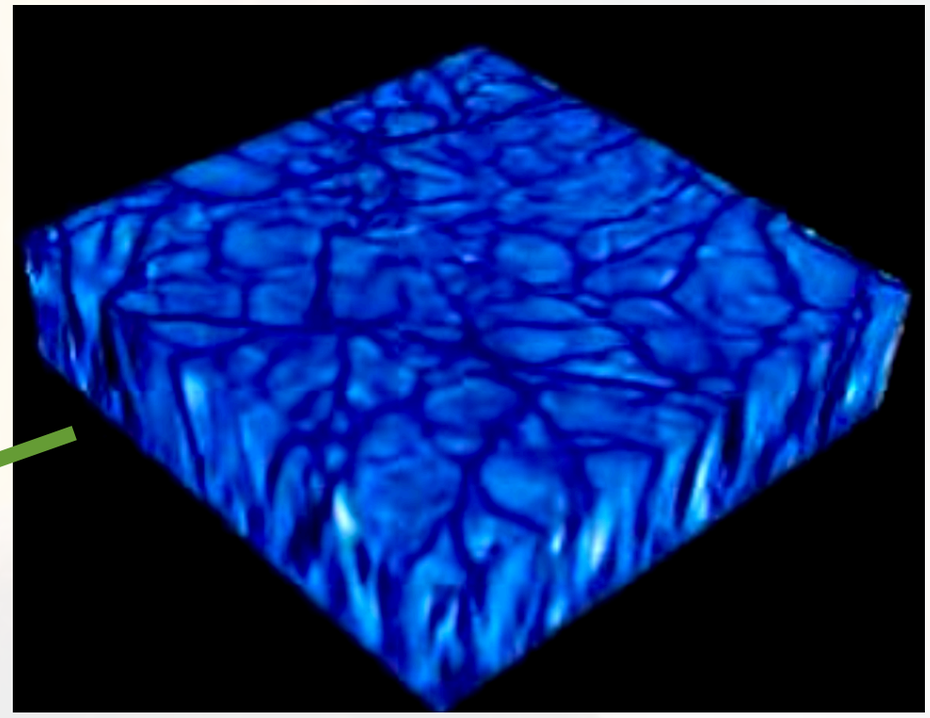
KITP - The Milky Way and its Stars February 2015

Crash Course in Asteroseismology

for more details:
Aerts, Christensen-Dalsgaard & Kurtz (2011, Springer)
Christensen-Dalsgaard (2011, arXiv:1106:5946)

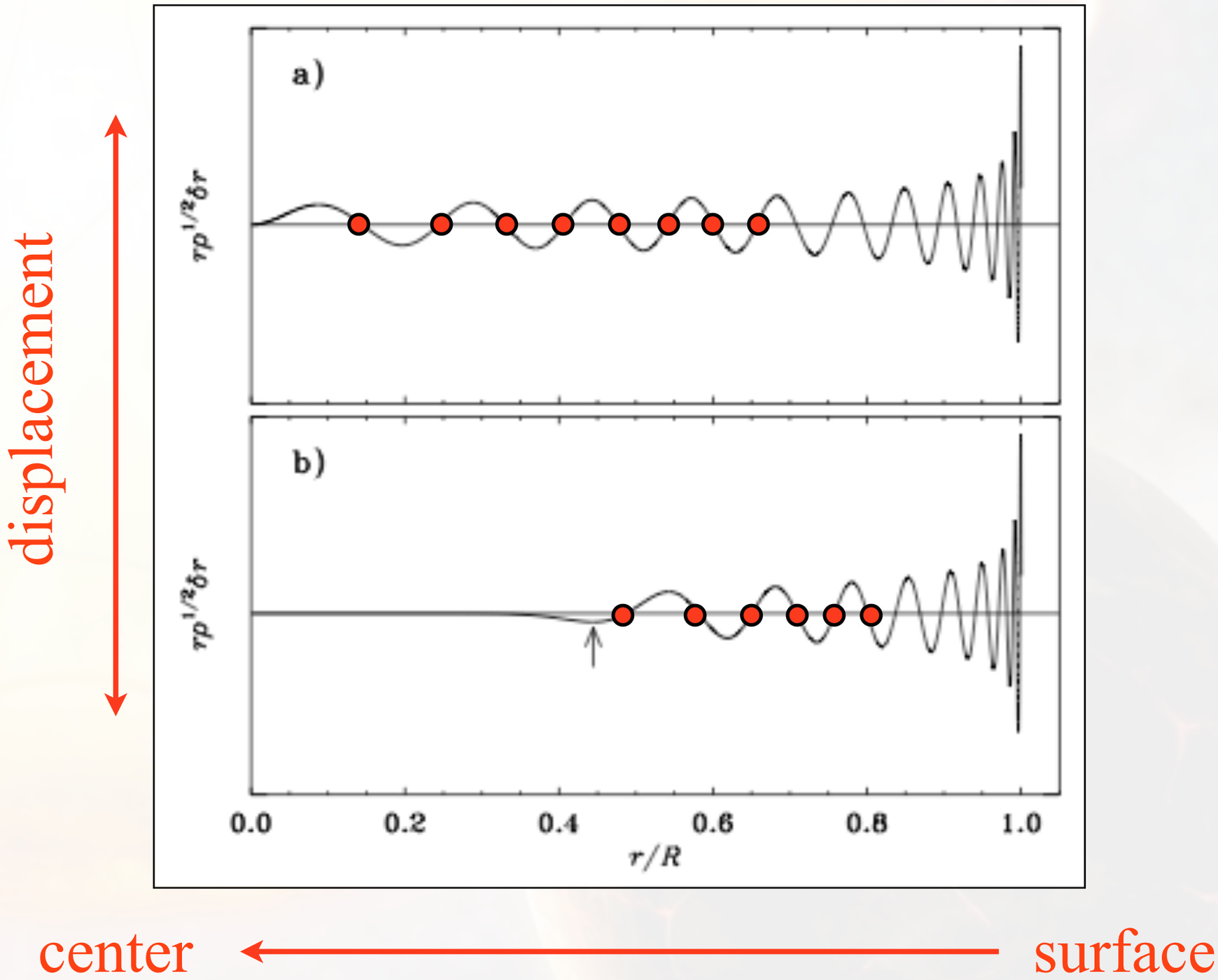
What causes stellar oscillations?





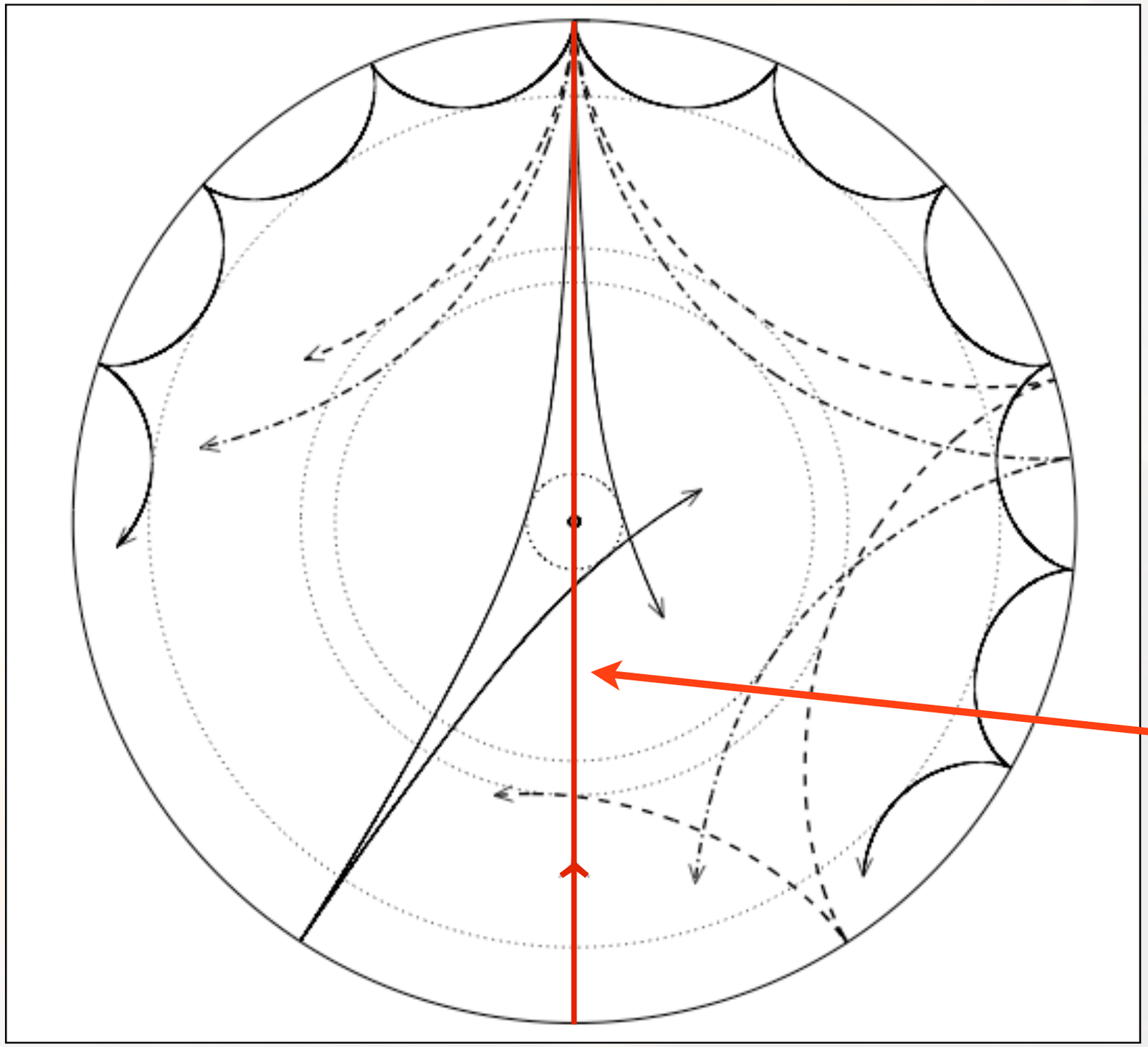
Pressure waves (p modes) are driven by turbulent surface convection

Radial Order *n*

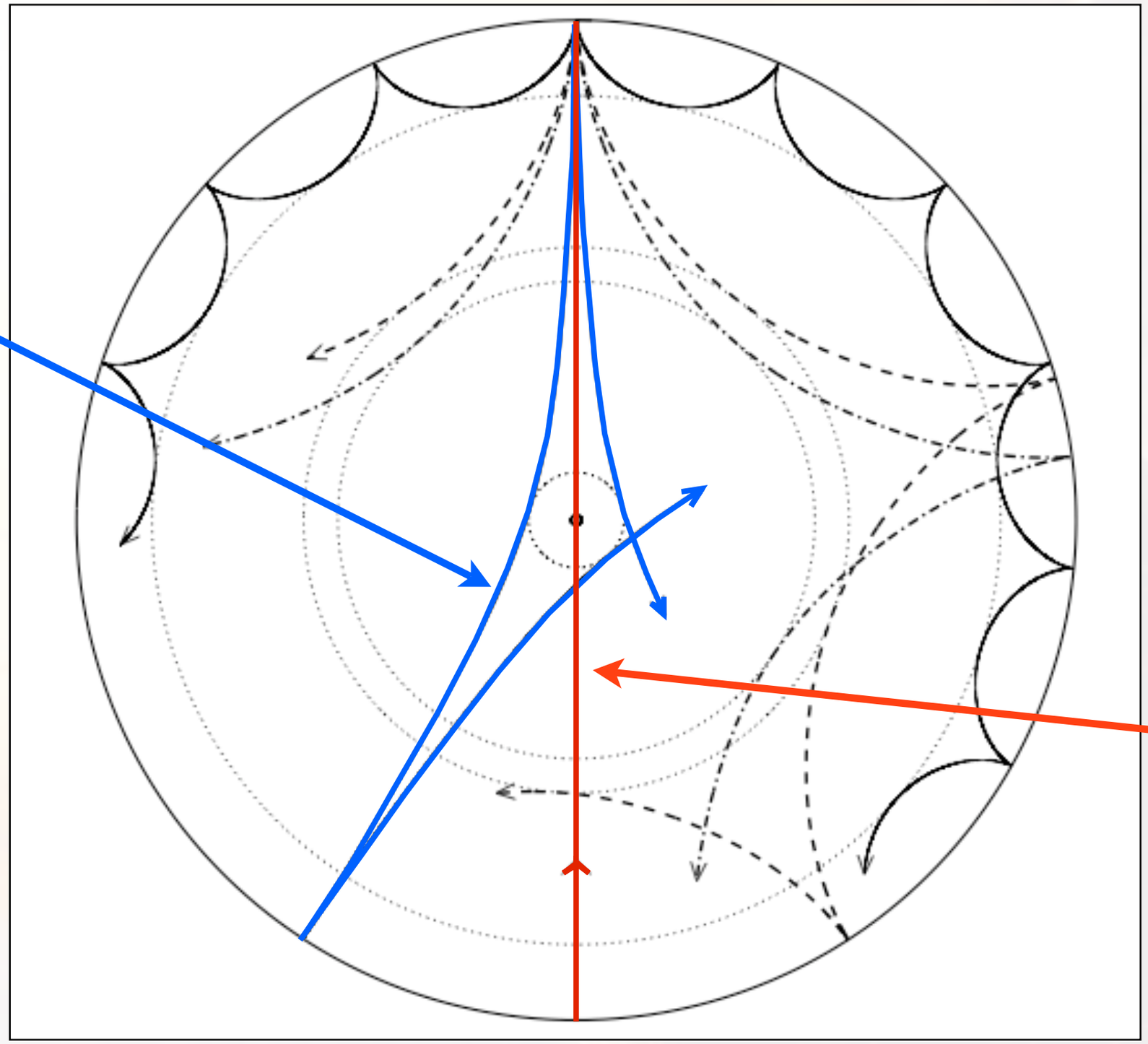


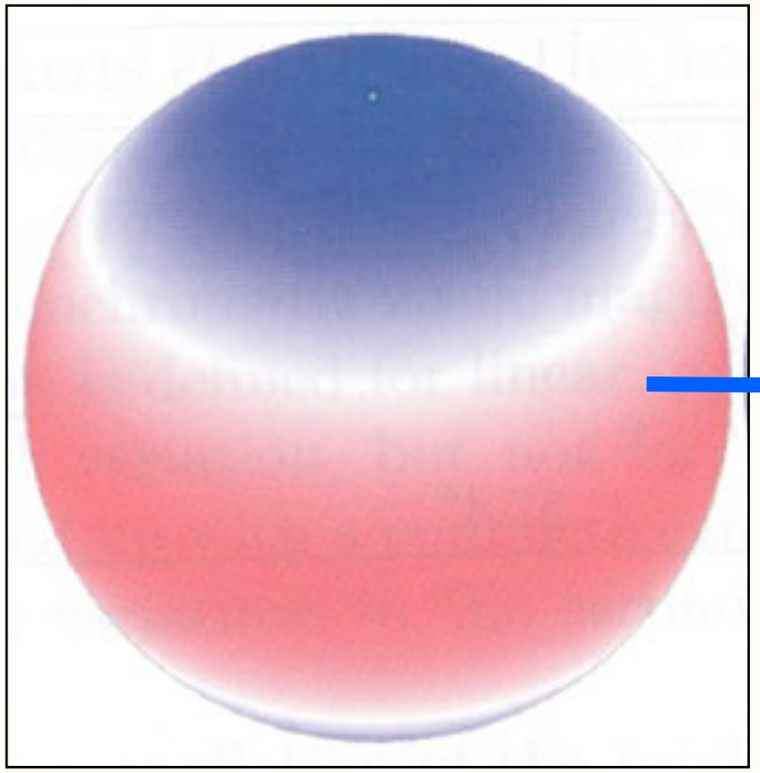
number of nodes from the surface to the center of the star

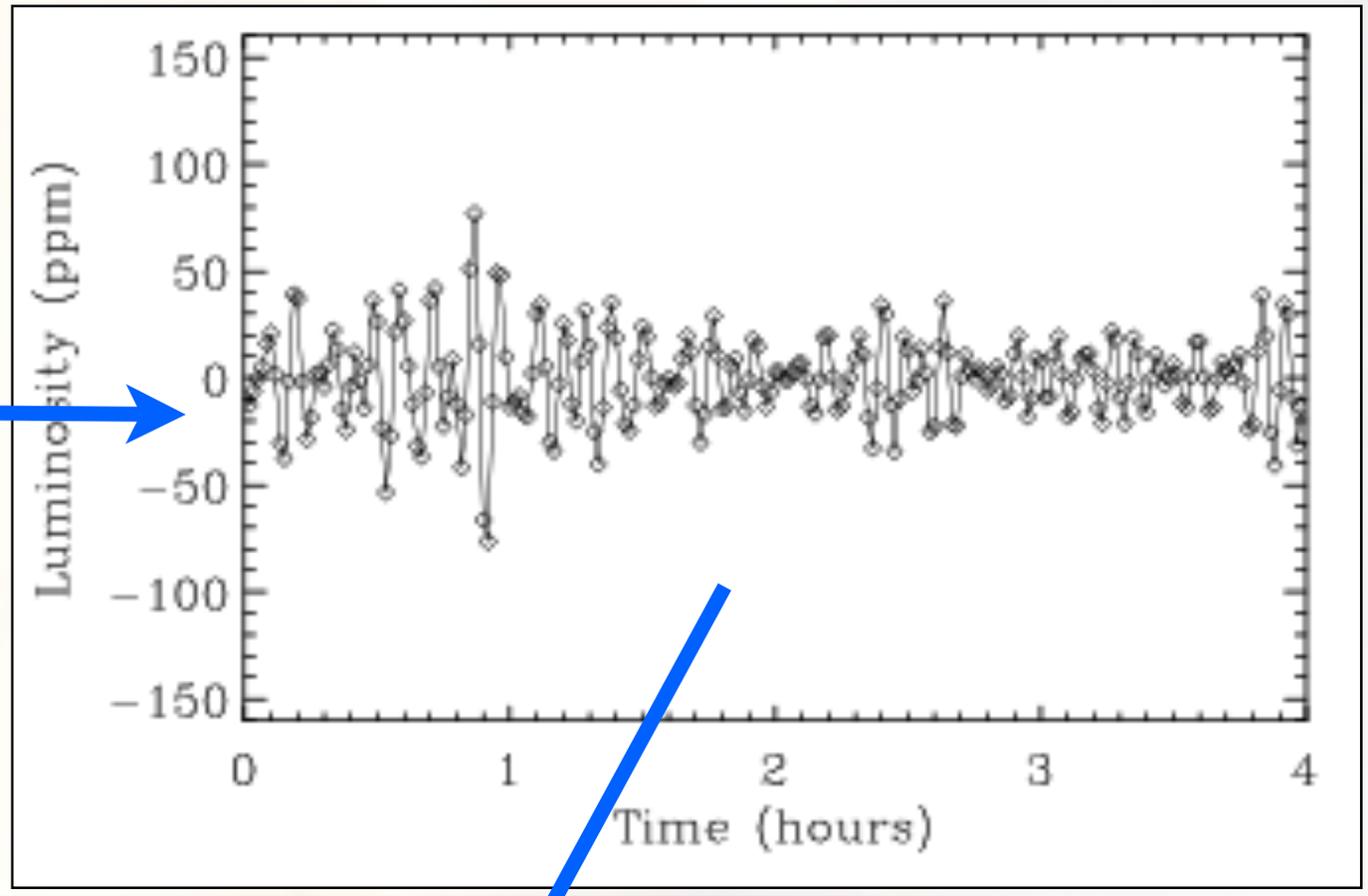
Spherical Degree l

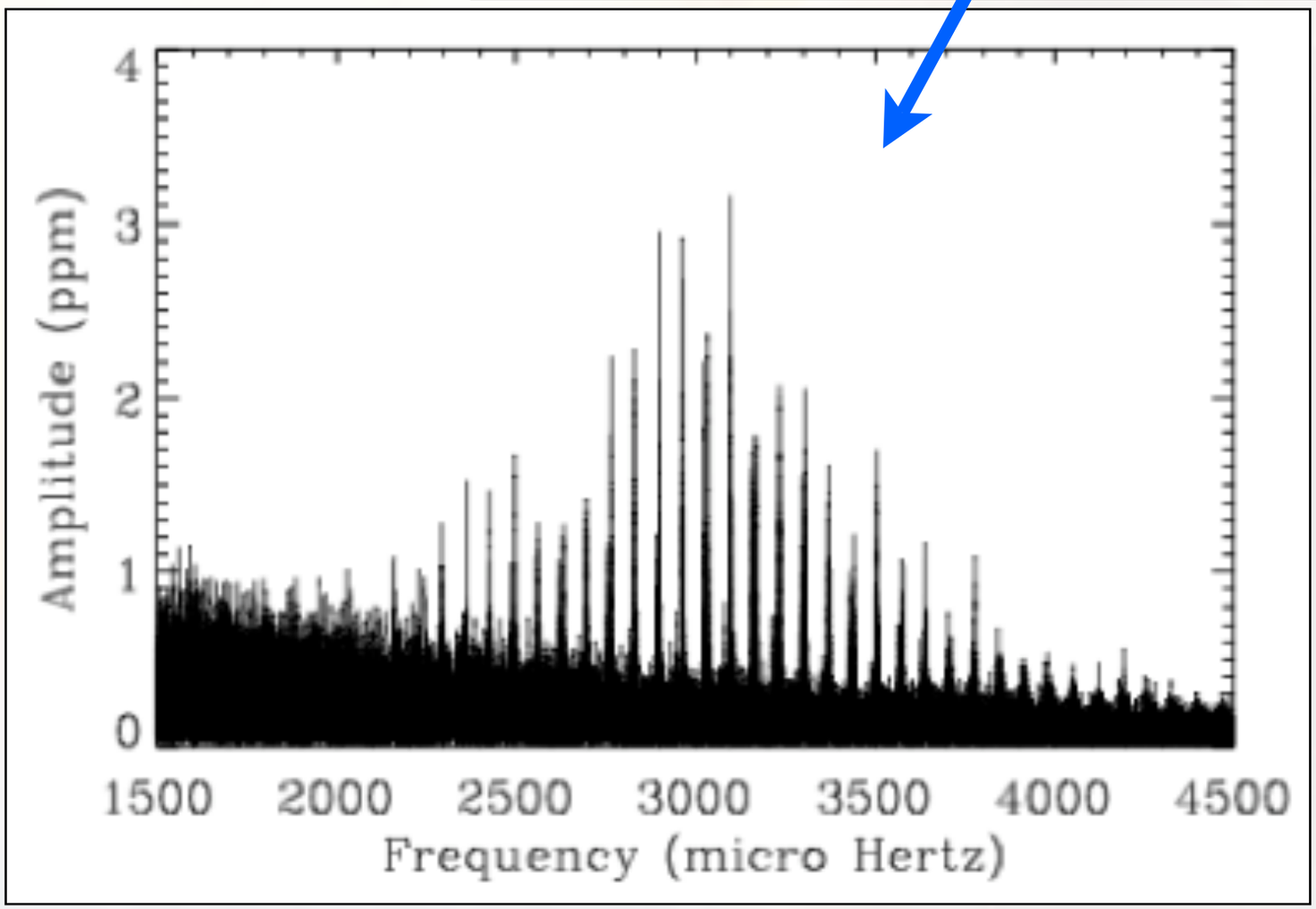


Spherical Degree l

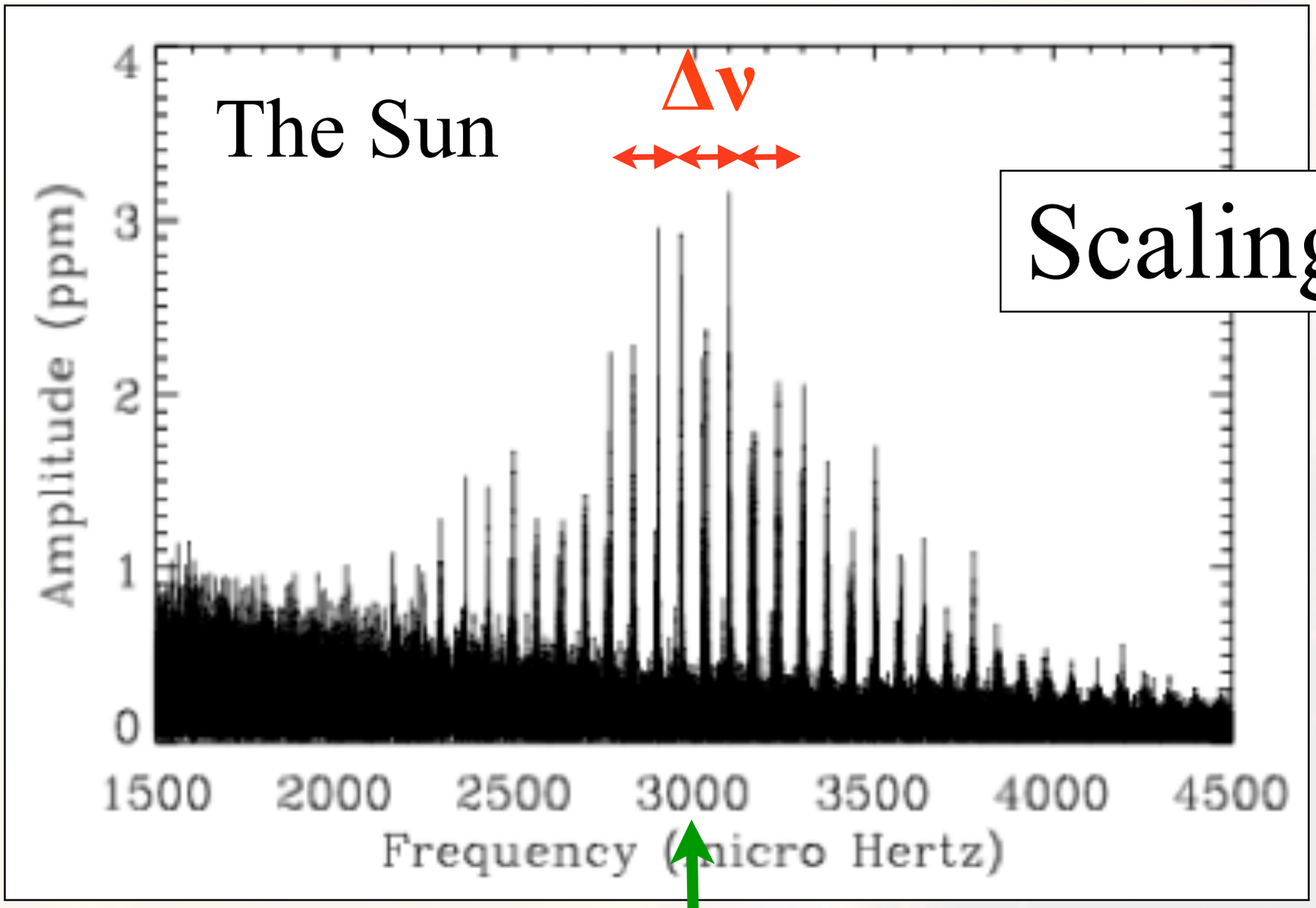





150
100
50
0
−50
−100
−150
Luminosity (ppm)
0
1
2
3
4
Time (hours)


4
3
2
1
0
Amplitude (ppm)
1500
2000
2500
3000
3500
4000
4500
Frequency (micro Hertz)

$$\Delta\nu = (2\int dr/c_s)^{-1} \propto (M/R^3)^{1/2}\,(\text{density})$$



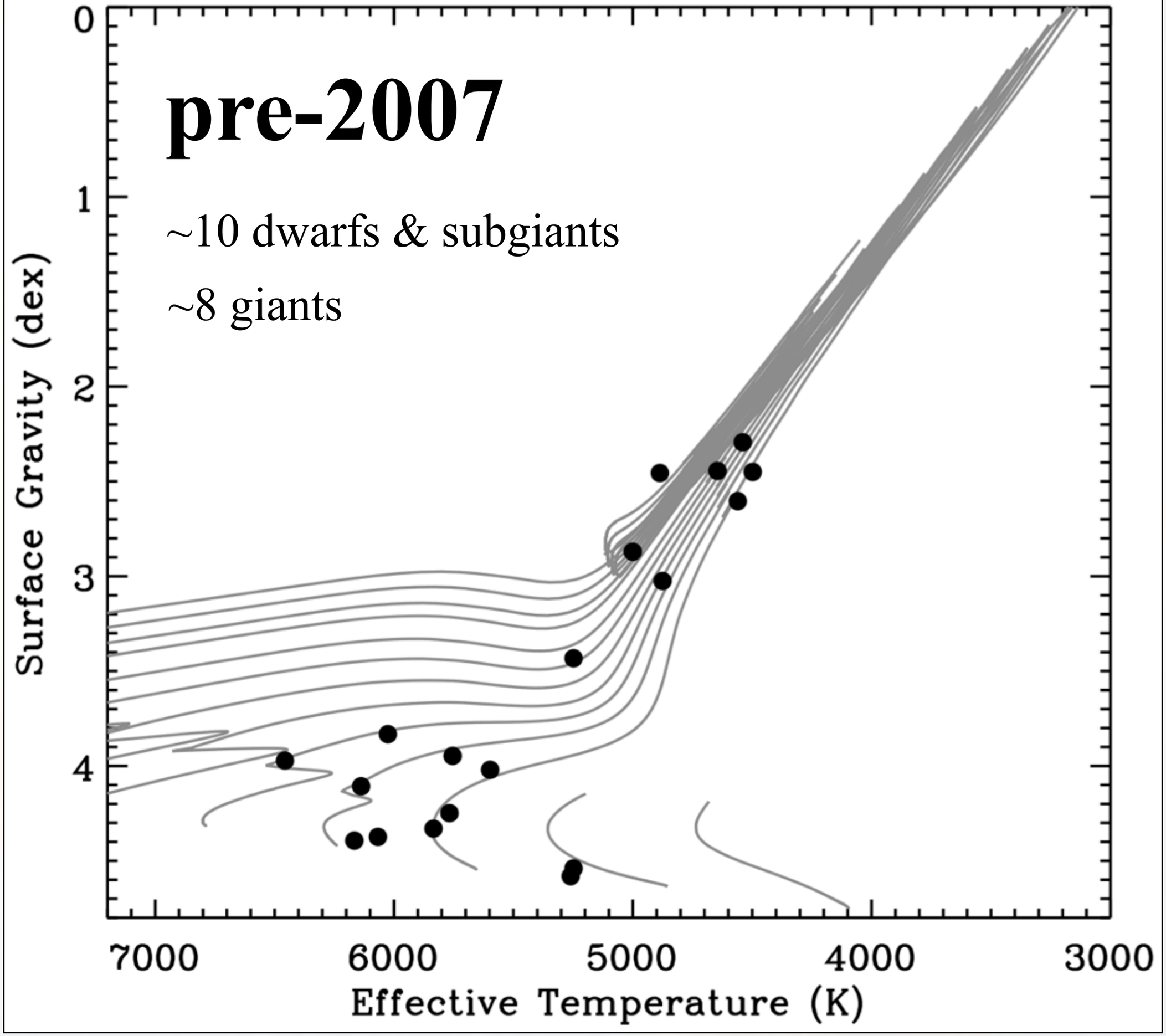
Scaling Relations

$$\nu_{max} \propto \nu_{ac} \propto M\,R^{-2}\,T_{eff}^{0.5}\,(\text{gravity})$$

pre-2007

~10 dwarfs & subgiants

~8 giants

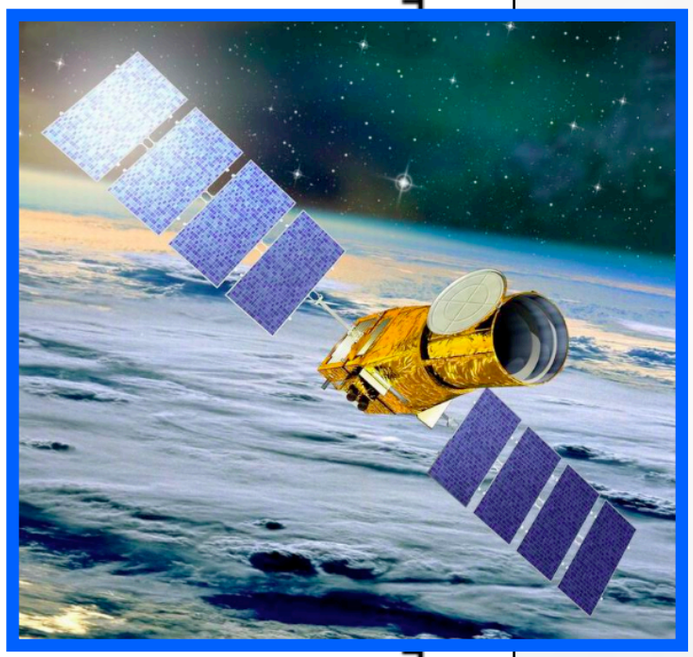


CoRoT

~10 dwarfs & subgiants

~2000 evolved stars

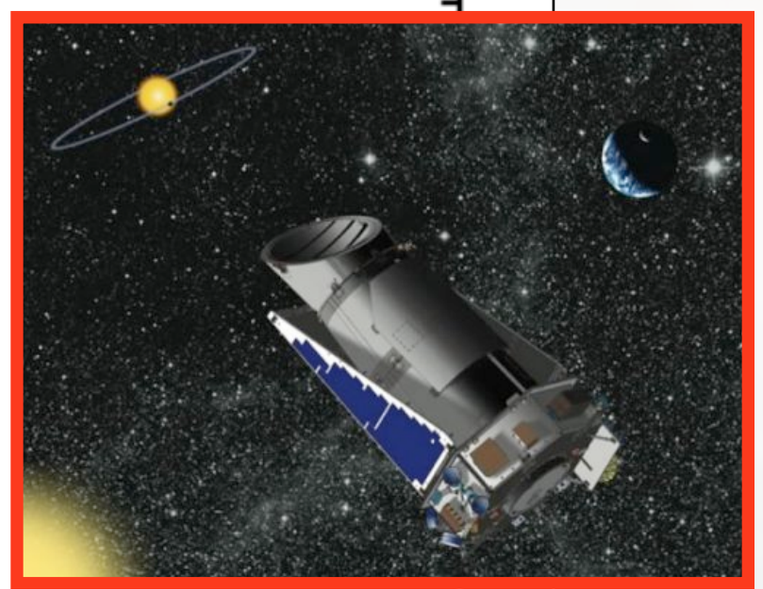
[incomplete]



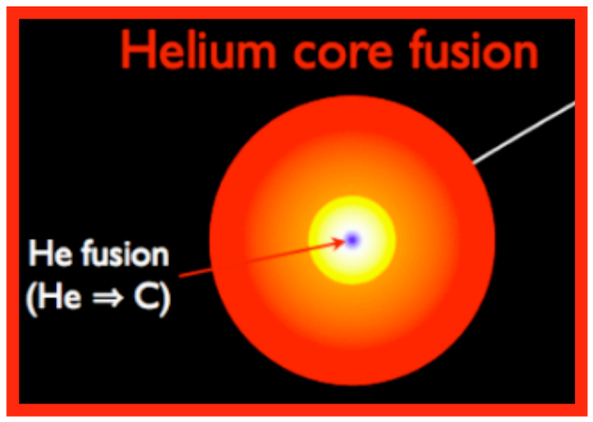
Kepler

~ 600 dwarfs & subgiants

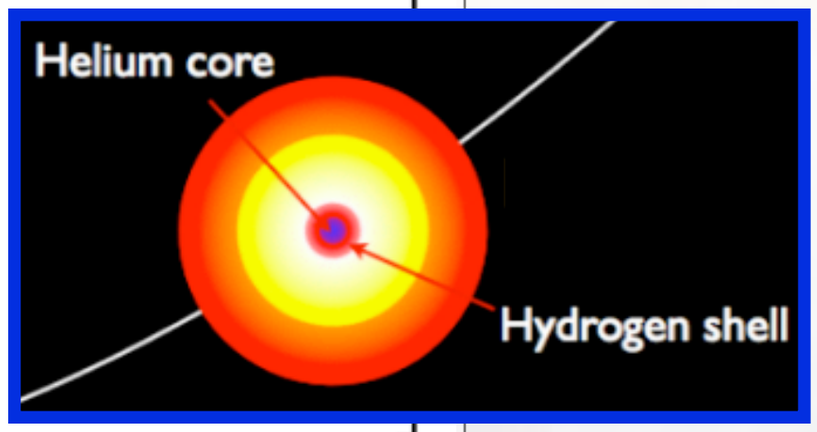
~ 16000 giants



Red Clump
(He-core burning)



RGB
(non He-core
burning)



?

Surface Gravity (dex)

2

3

4

7000

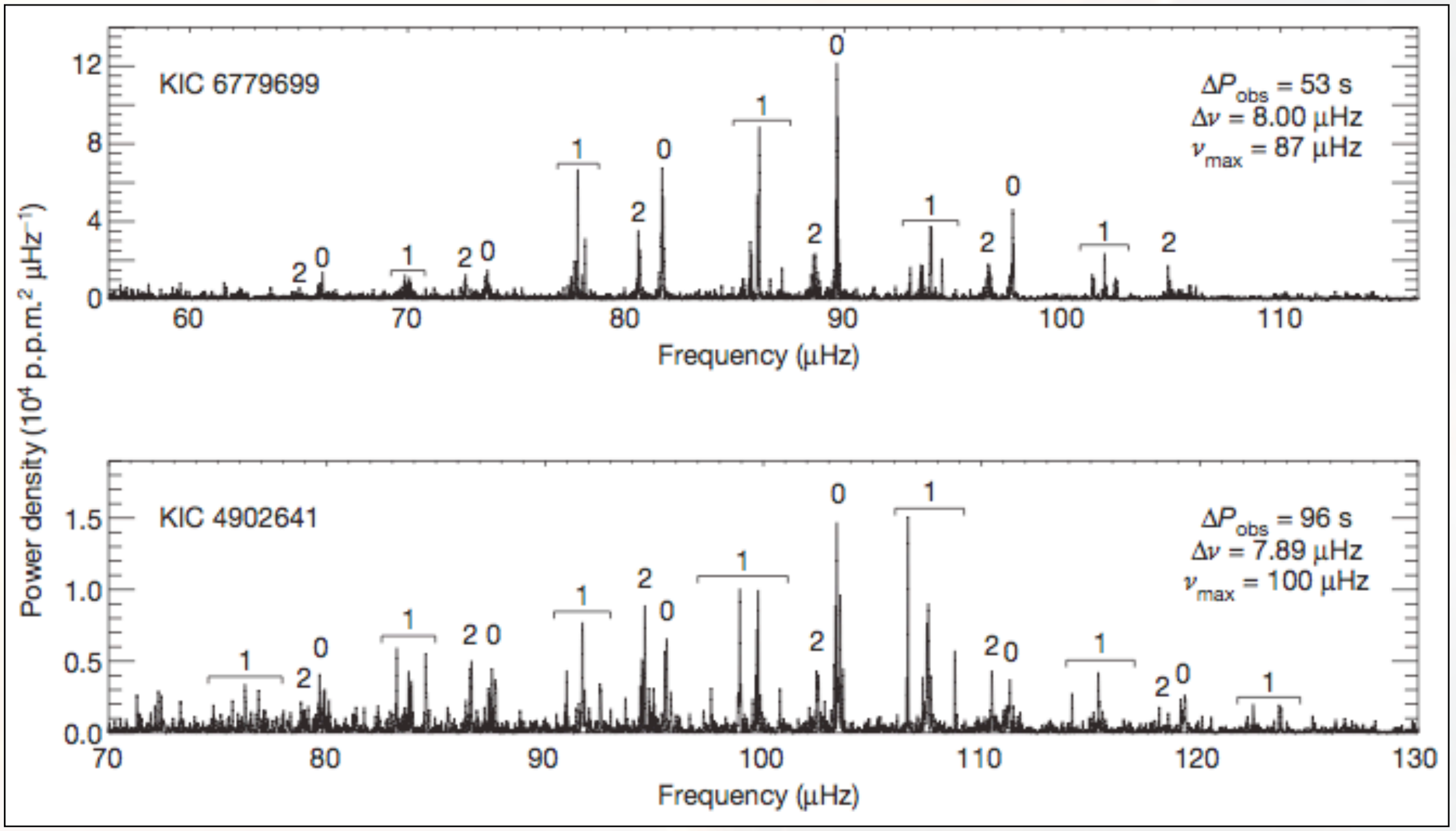
6000

5000

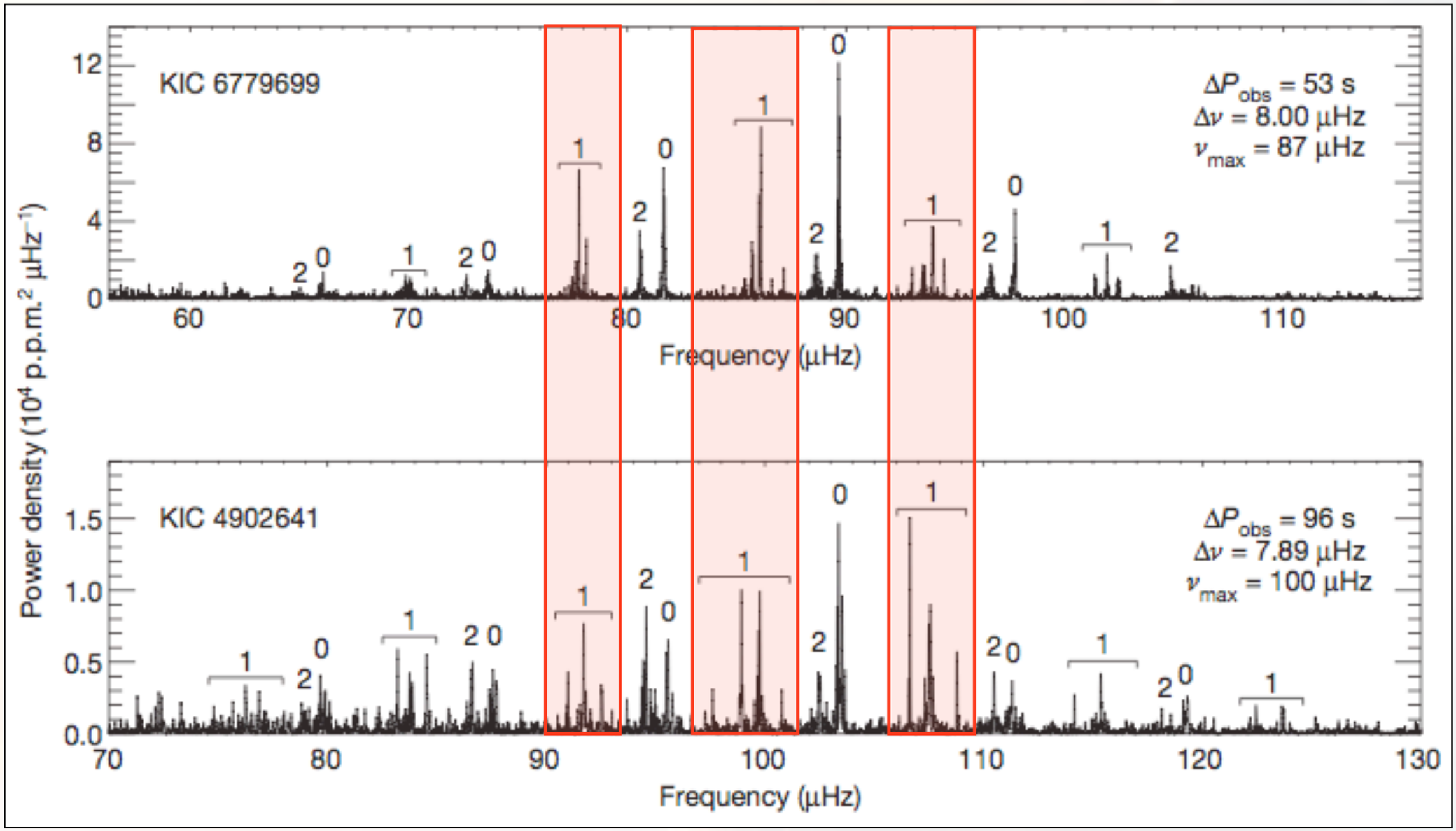
4000

Effective Temperature (K)

The cores of Red Giants: Mixed Modes



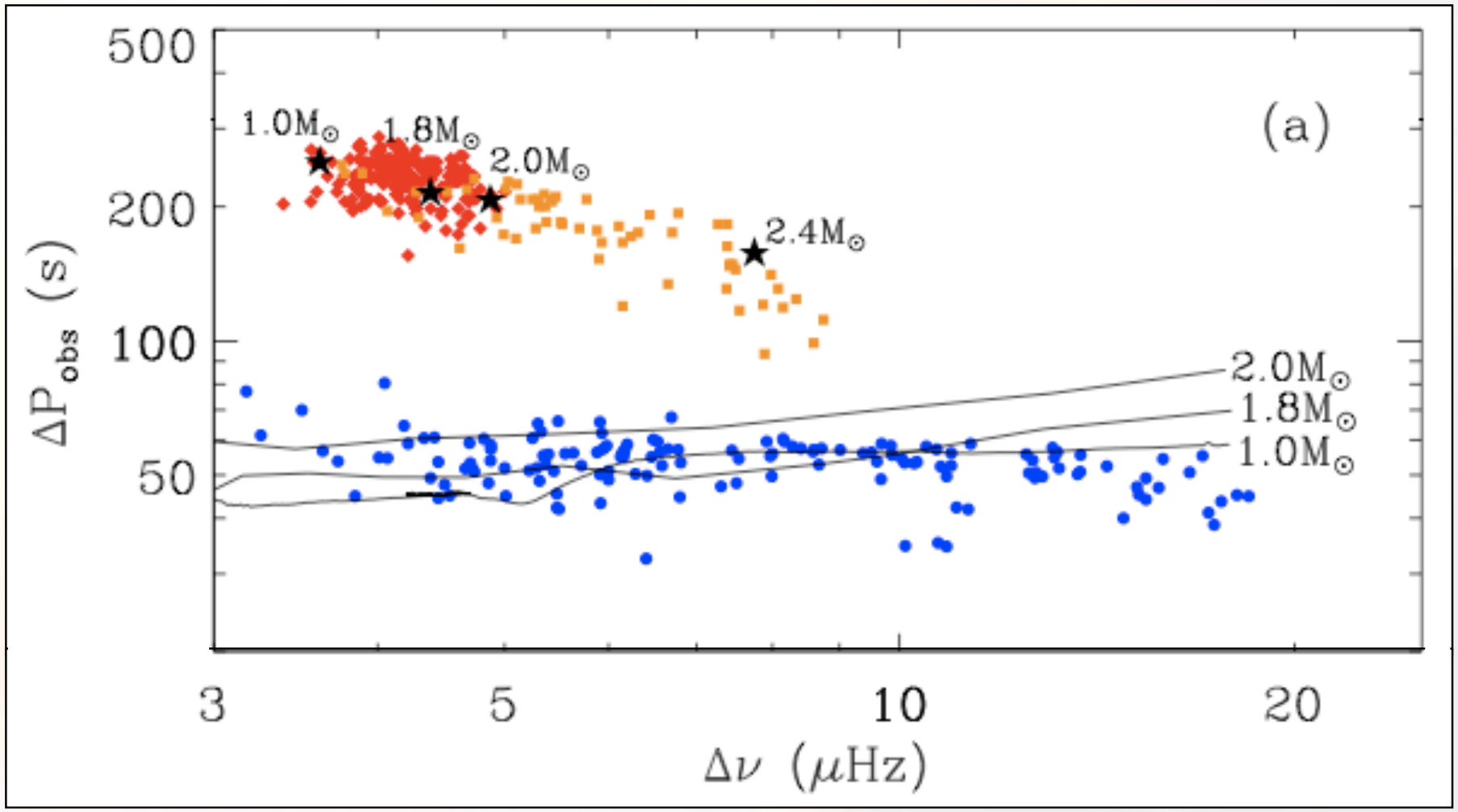
The cores of Red Giants: Mixed Modes



Multiple l=1 modes per order due to coupling of p modes with gravity modes trapped in the core ("mixed modes")

Gravity modes as a way to distinguish between hydrogen- and helium-burning red giant stars

Timothy R. Bedding[1], Benoit Mosser[2], Daniel Huber[1], Josefina Montalbán[3], Paul Beck[4], Jørgen Christensen-Dalsgaard[5], Yvonne P. Elsworth[6], Rafael A. García[7], Andrea Miglio[3,6], Dennis Stello[1], Timothy R. White[1], Joris De Ridder[4], Saskia Hekke
Conny Aerts[4,9], Caroline Barban[2], Kevin Belkacem[10], Anne-Marie Broomhall[6], Timothy M. Brown[11], Derek L. Buzasi[12], Fabien Carrier[4], William J. Chaplin[6], Maria Pia Di Mauro[13], Marc-Antoine Dupret[3], Søren Frandsen[5], Ronald L. Gilliland[14], Marie-Jo Goupil[2], Jon M. Jenkins[15], Thomas Kallinger[16], Steven Kawaler[17], Hans Kjeldsen[5], Savita Mathur[18], Arlette Noels[3], Victor Silva Aguirre[19] & Paolo Ventura[20]



Gravity mode period spacing

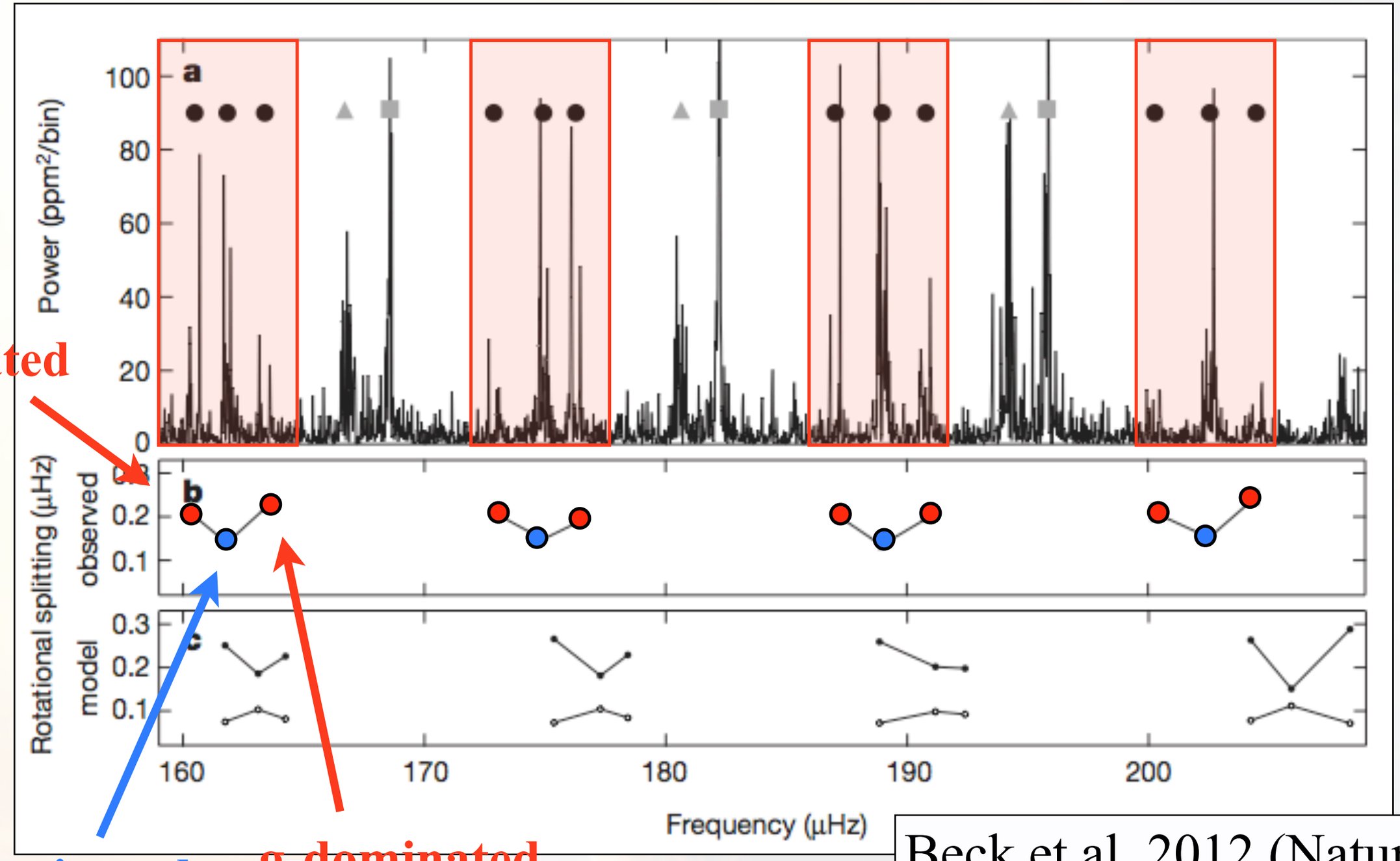
Mean Density

He-core burning

non He-core burning

Bedding et al. 2011, Nature

Radial Differential Rotation



g-dominated

p-dominated

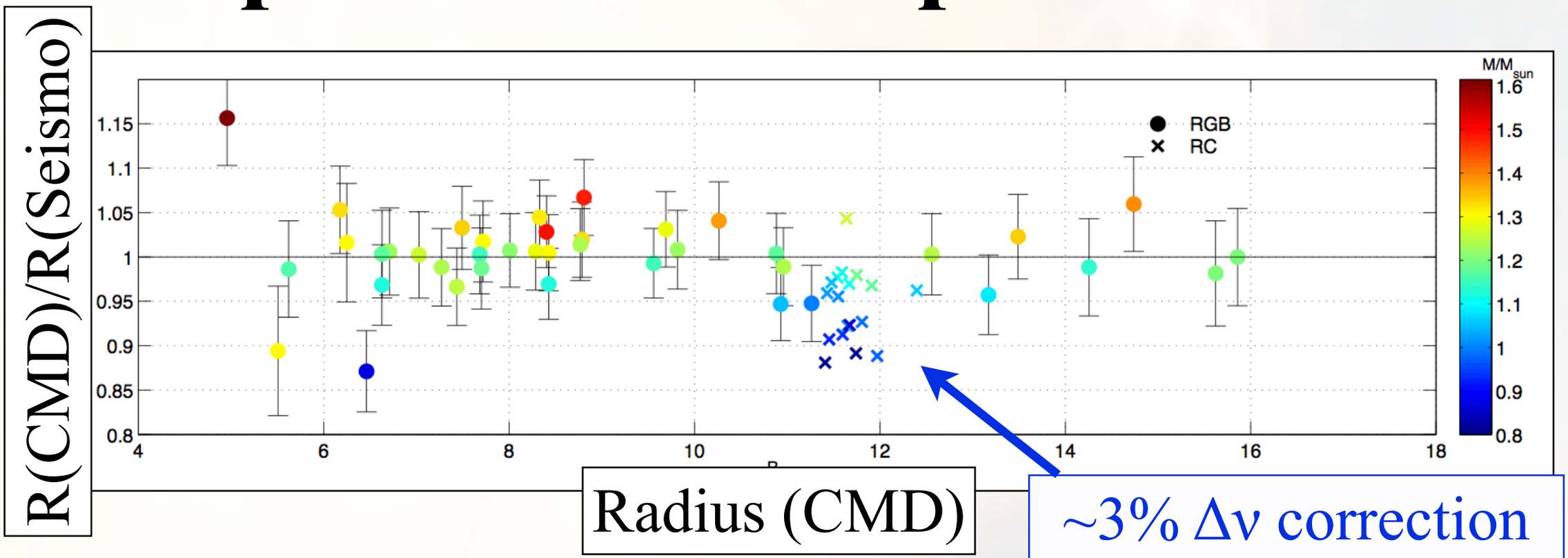
g-dominated

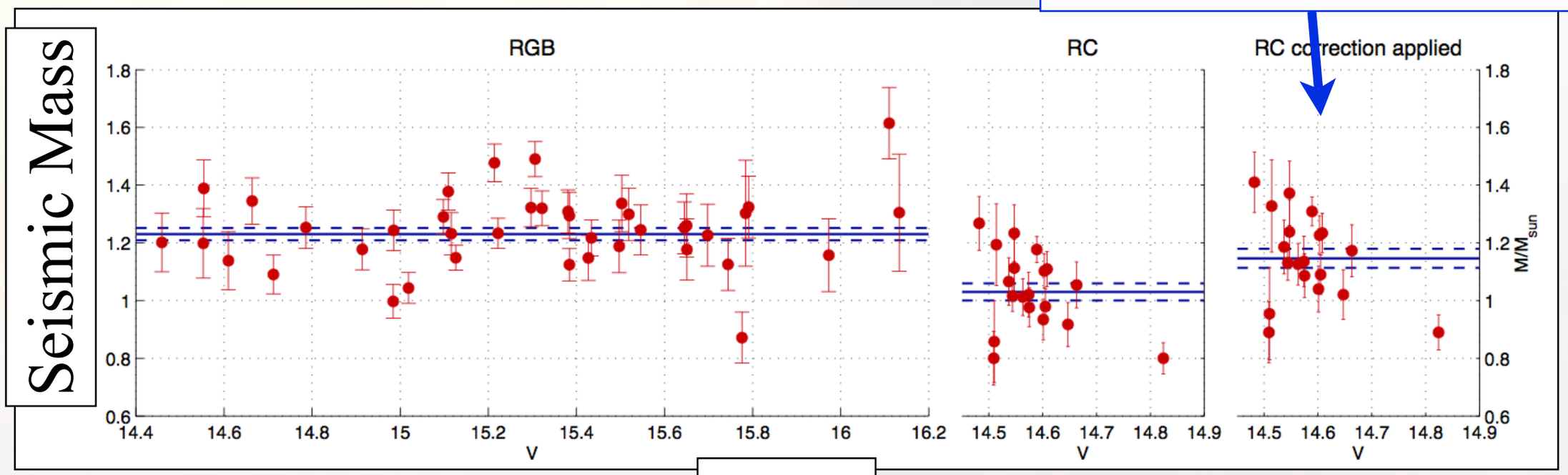
Beck et al. 2012 (Nature)

see also Mosser et al. 2013, Deheuvels et al. 2014 (observations)
Marques et al. 2013, Cantiello et al. 2014, Fuller et al. 2014 (models)

Does Asteroseismology really work?

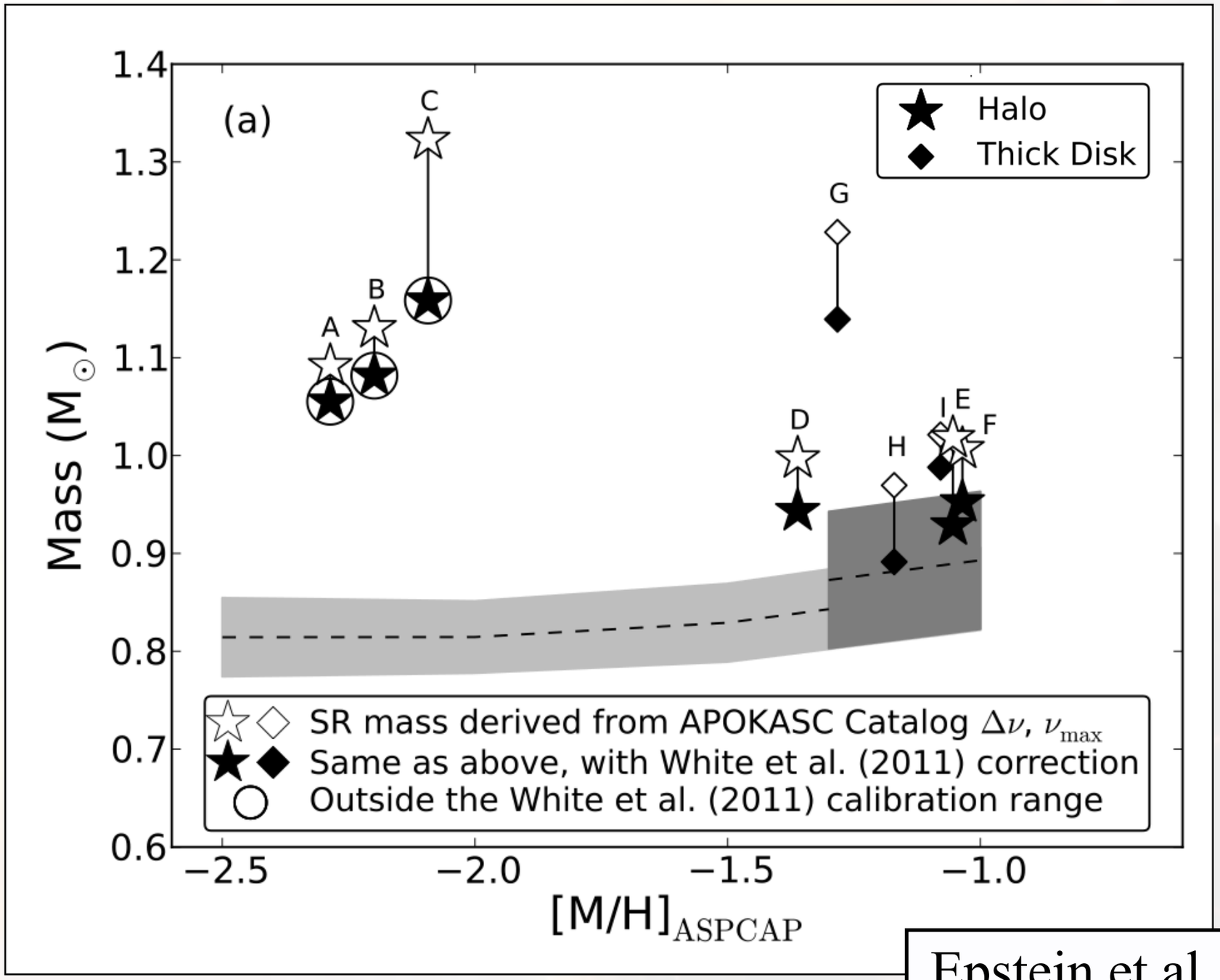
Empirical Tests: Open Clusters





Miglio et al. (2012)

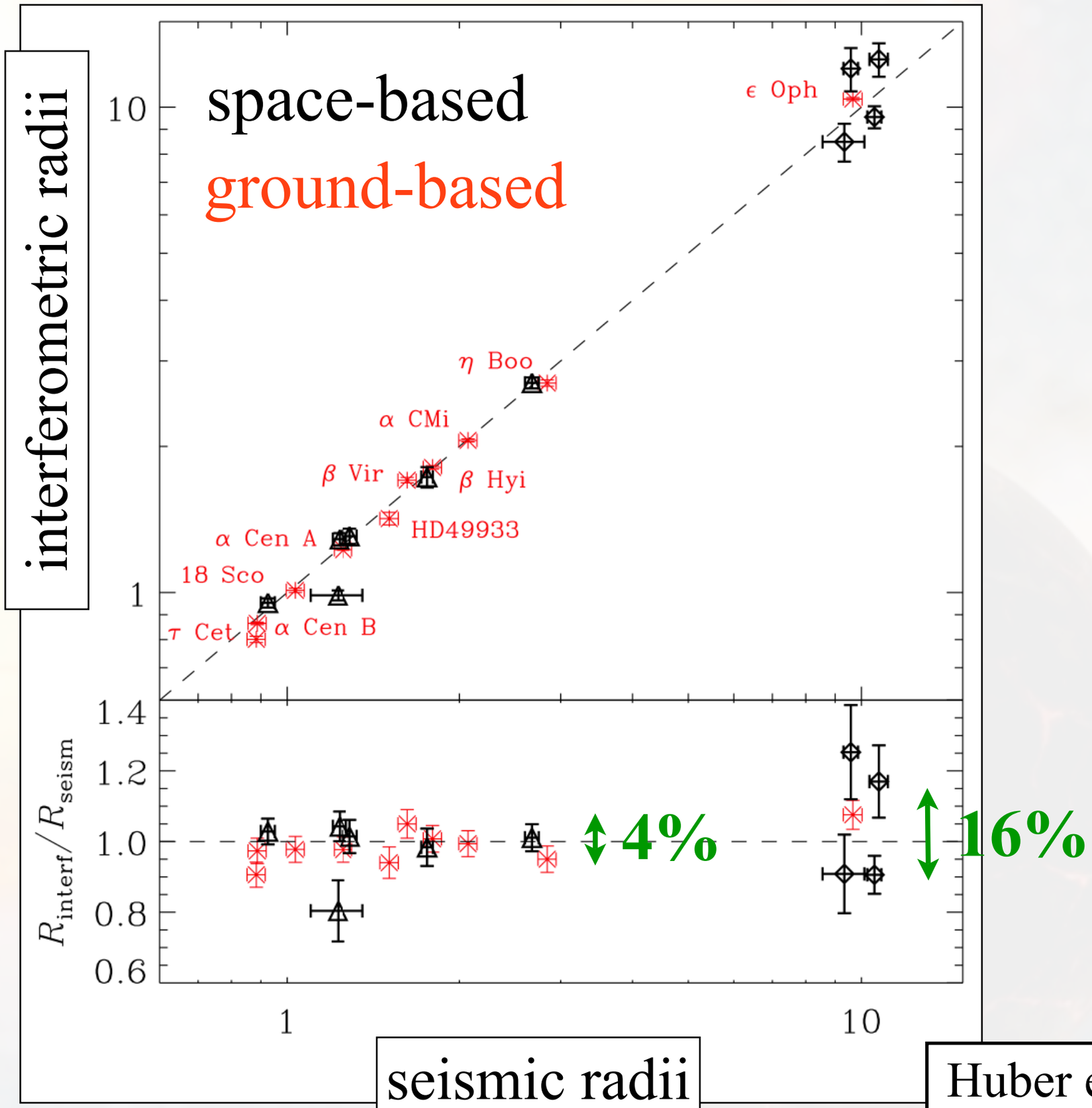
Semi-Empirical Tests: Halo Stars



Epstein et al. (2014)

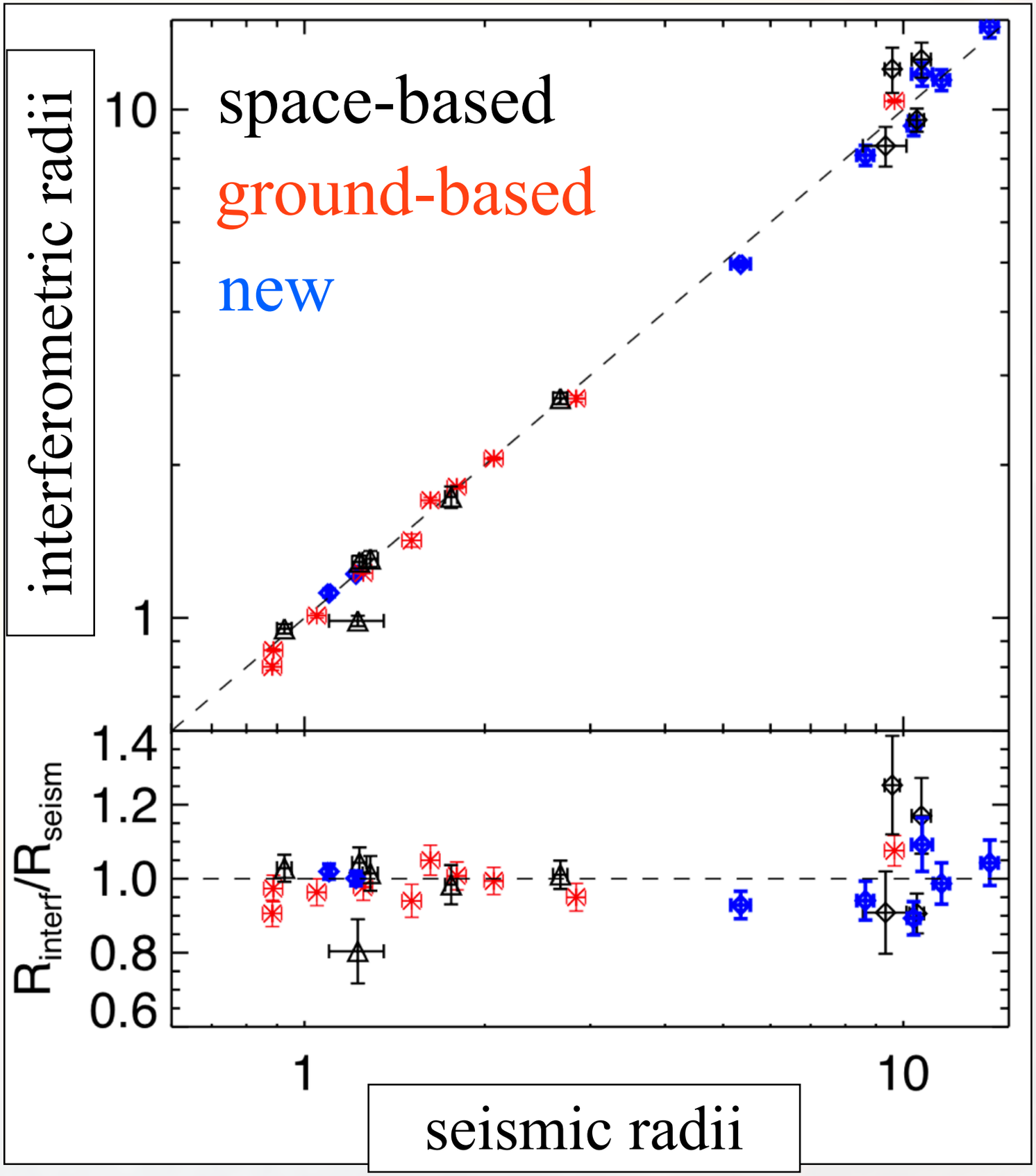
Mass-scale problematic for metal-poor stars

Empirical Tests: Interferometry



Huber et al. (2012)

Empirical Tests: Interferometry



Tim White et al., in prep

Red Giant Asteroseismology & Galactic Archeology

Asteroseismology

$$\Delta\nu \propto M^{1/2} R^{-3/2}$$

$$\nu_{max} \propto M R^{-2} T_{eff}^{-1/2}$$

$$\Delta P = \text{RGB/RC/2ndRC}$$

+

Spectroscopy/Photometry

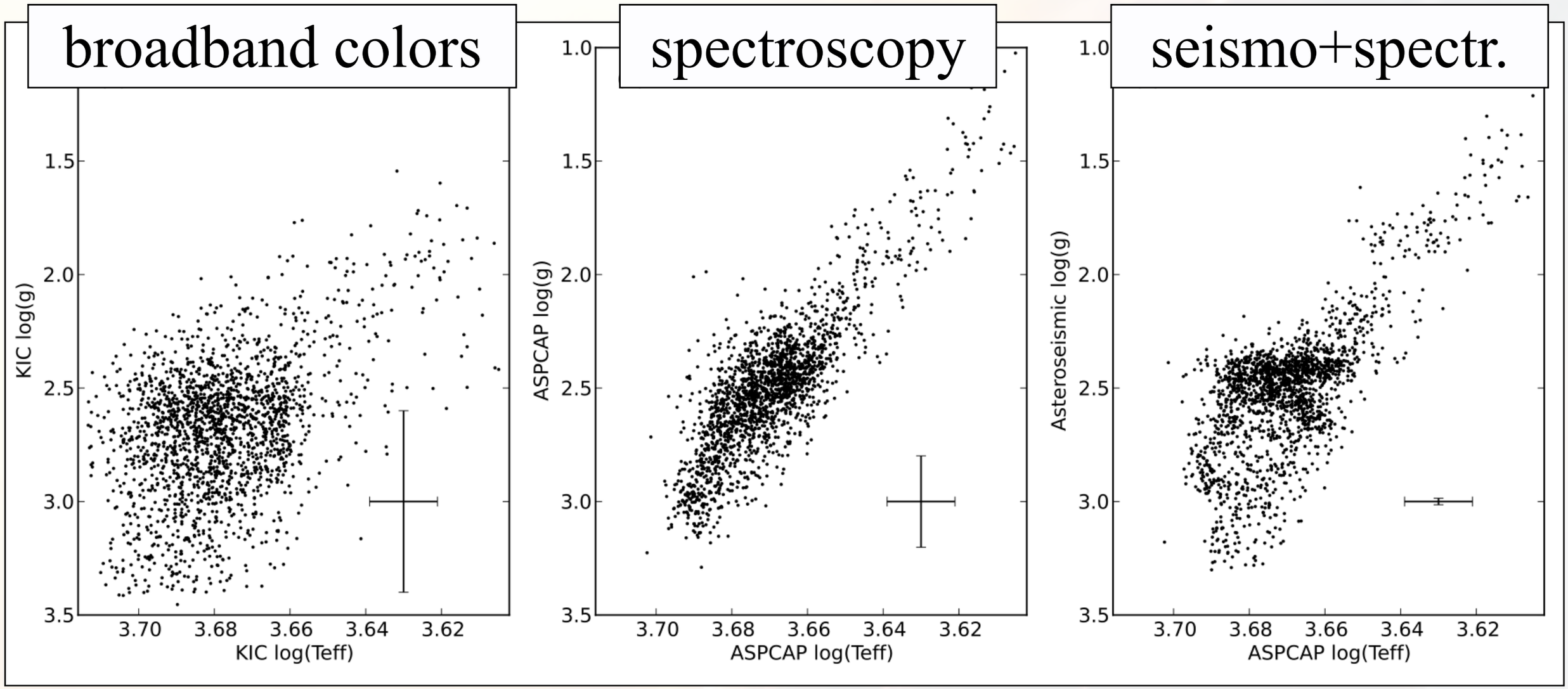
T_{eff}, [Fe/H], [α/Fe], ...

↓

Distances, Masses, Ages

Not trivial! ➔ *Andrea Miglio (Wed), Aldo Serenelli (Fri)*

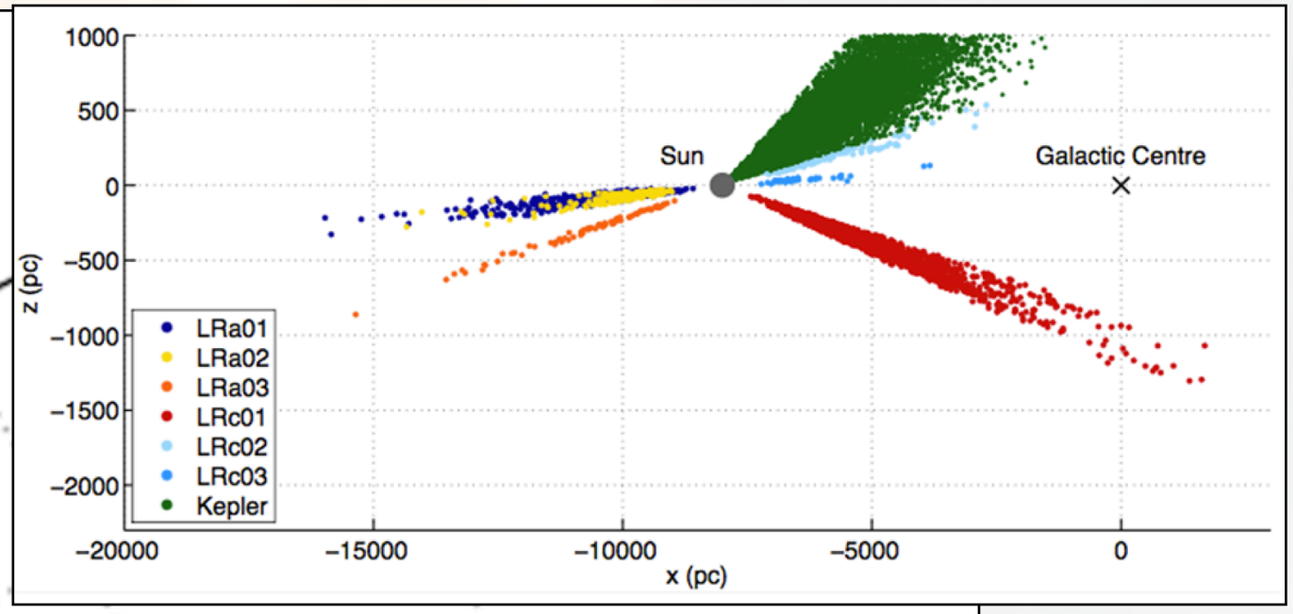
Chasing Asteroseismic Giants



Pinsonneault et al. (2014) (see also Bovy et al. 2014)

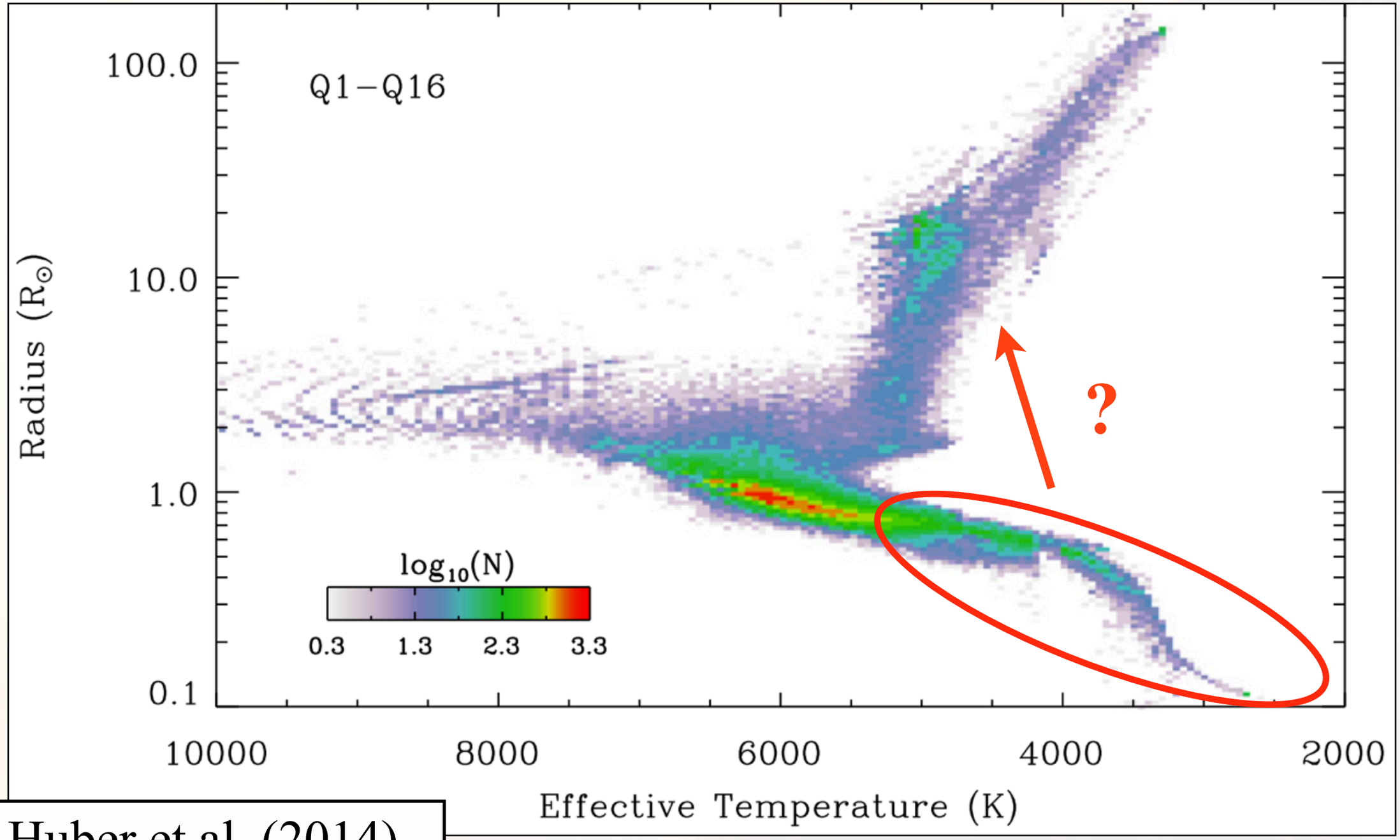
➔ *APOGEE, SAGA, GALAH, LAMOST, Gaia-ESO, ...*

Asteroseismic View of the Milky Way



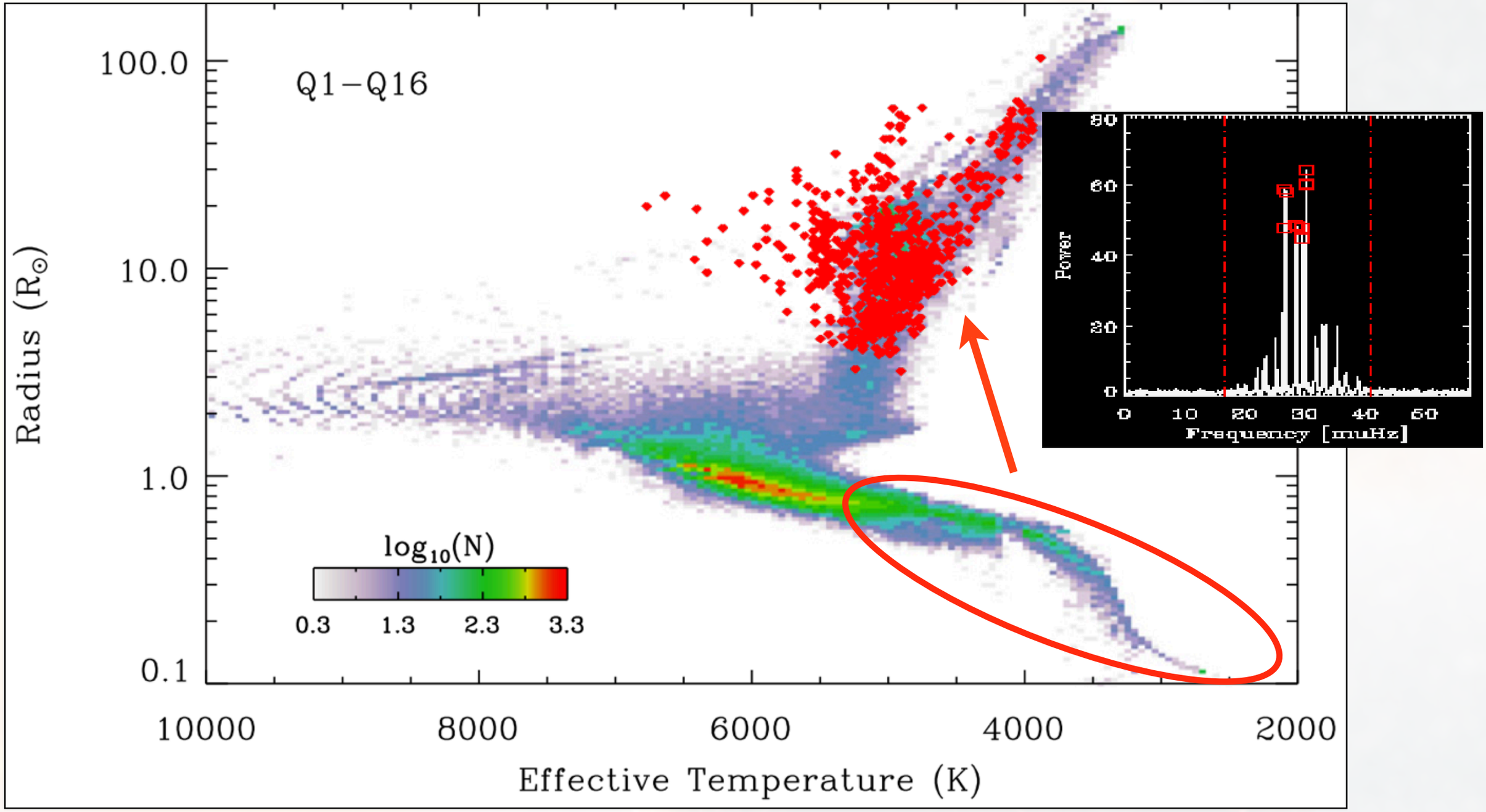
Andrea Miglio

Kepler Target Sample



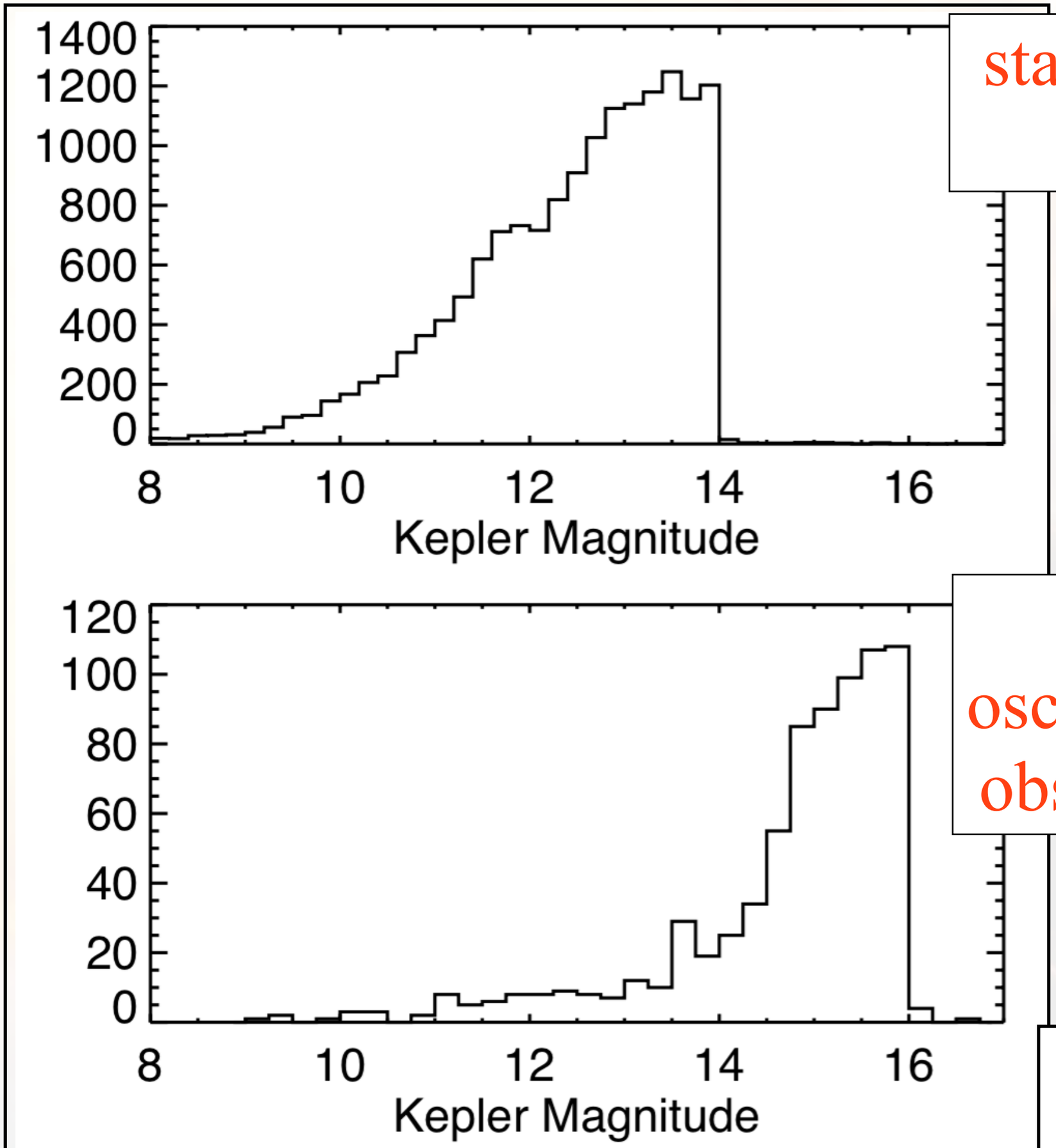
Huber et al. (2014)

Kepler Target Sample



~900 Kepler "dwarfs" are oscillating giants!

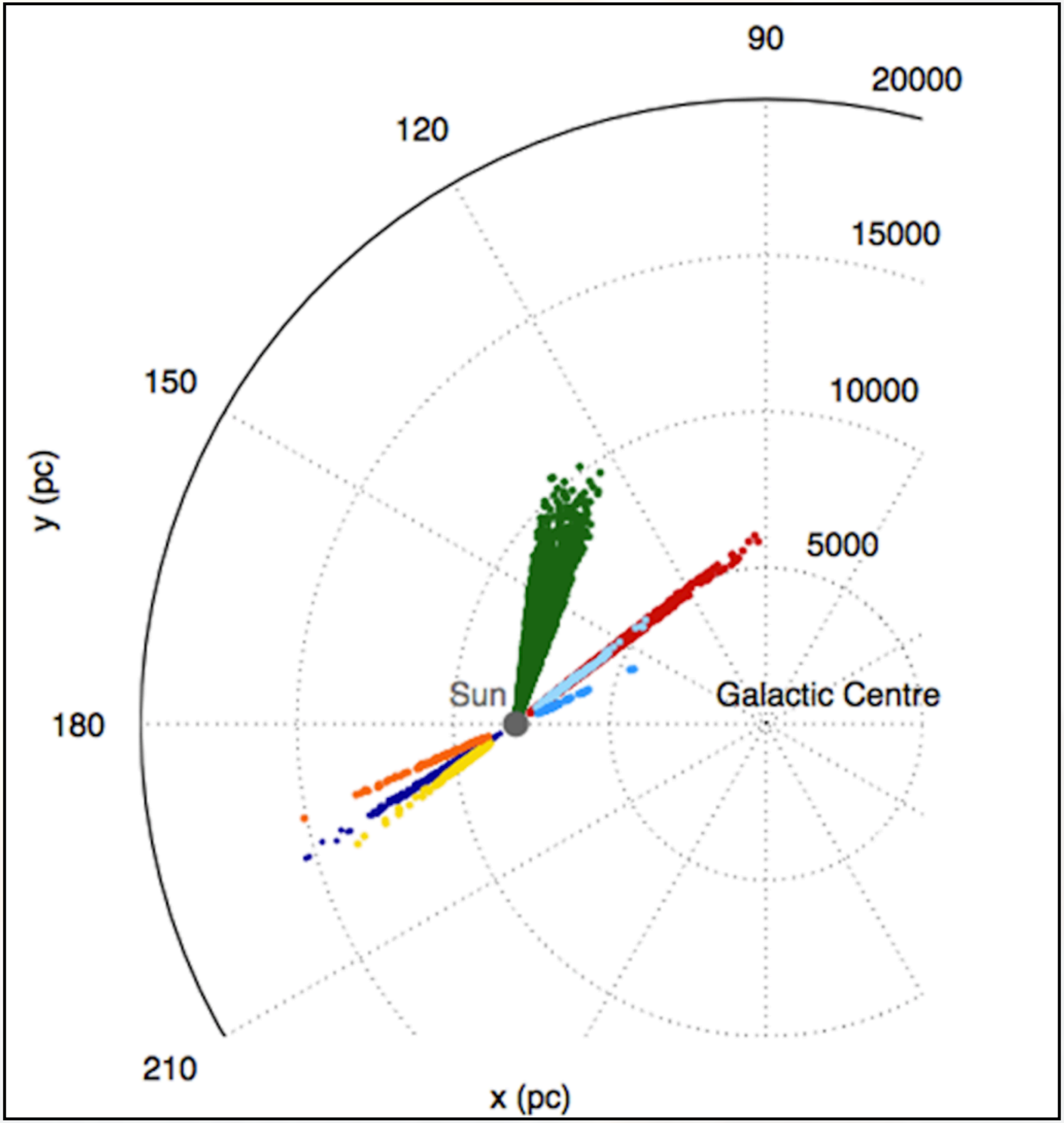
Savita Mathur et al., in prep



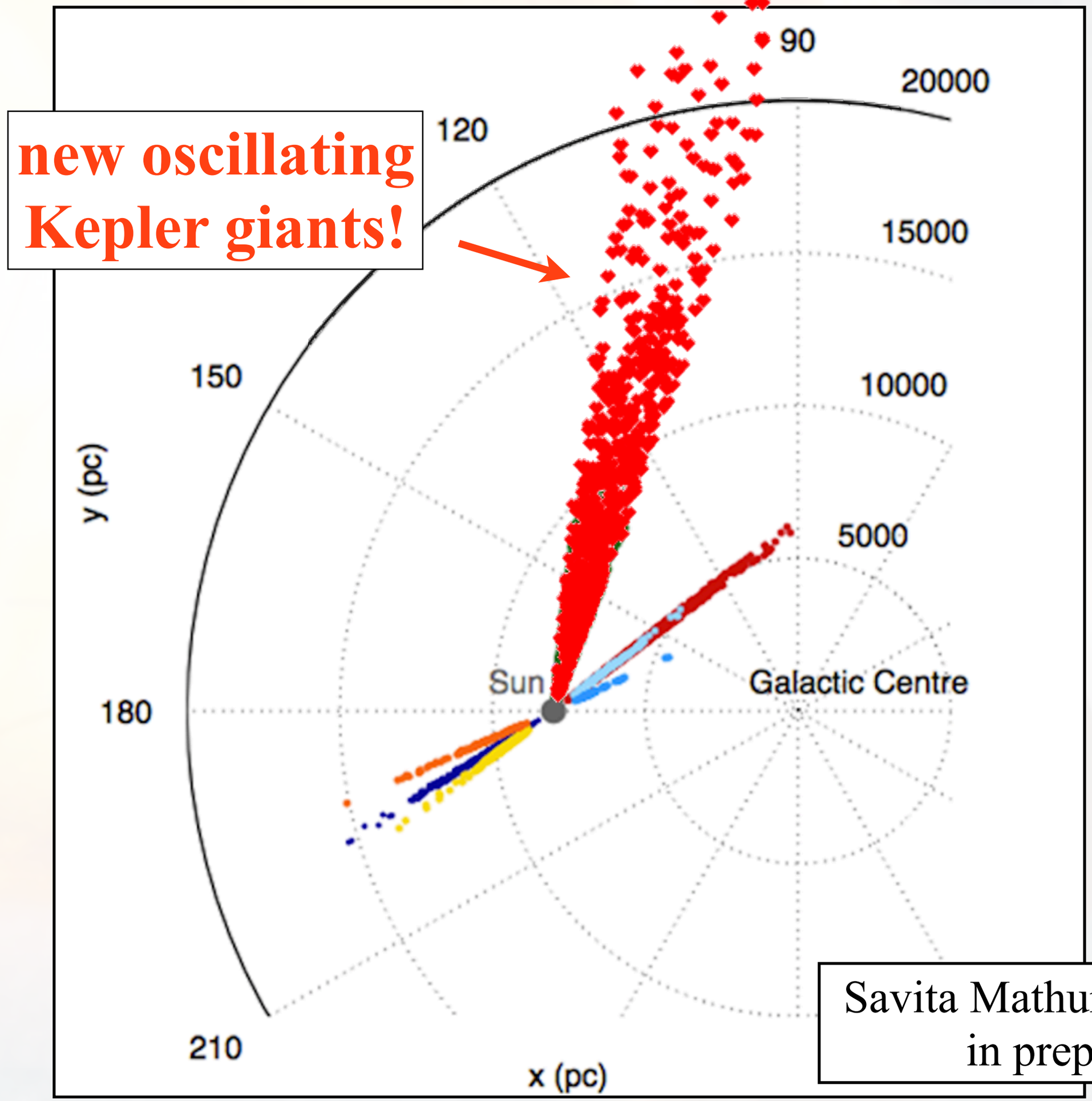
standard Kepler sample

faintest oscillating giants observed so far!

Savita Mathur et al., in prep


90
120
150
180
210
20000
15000
10000
5000
Sun
Galactic Centre
y (pc)
x (pc)

new oscillating Kepler giants!



Savita Mathur et al., in prep

Outlook & Conclusions

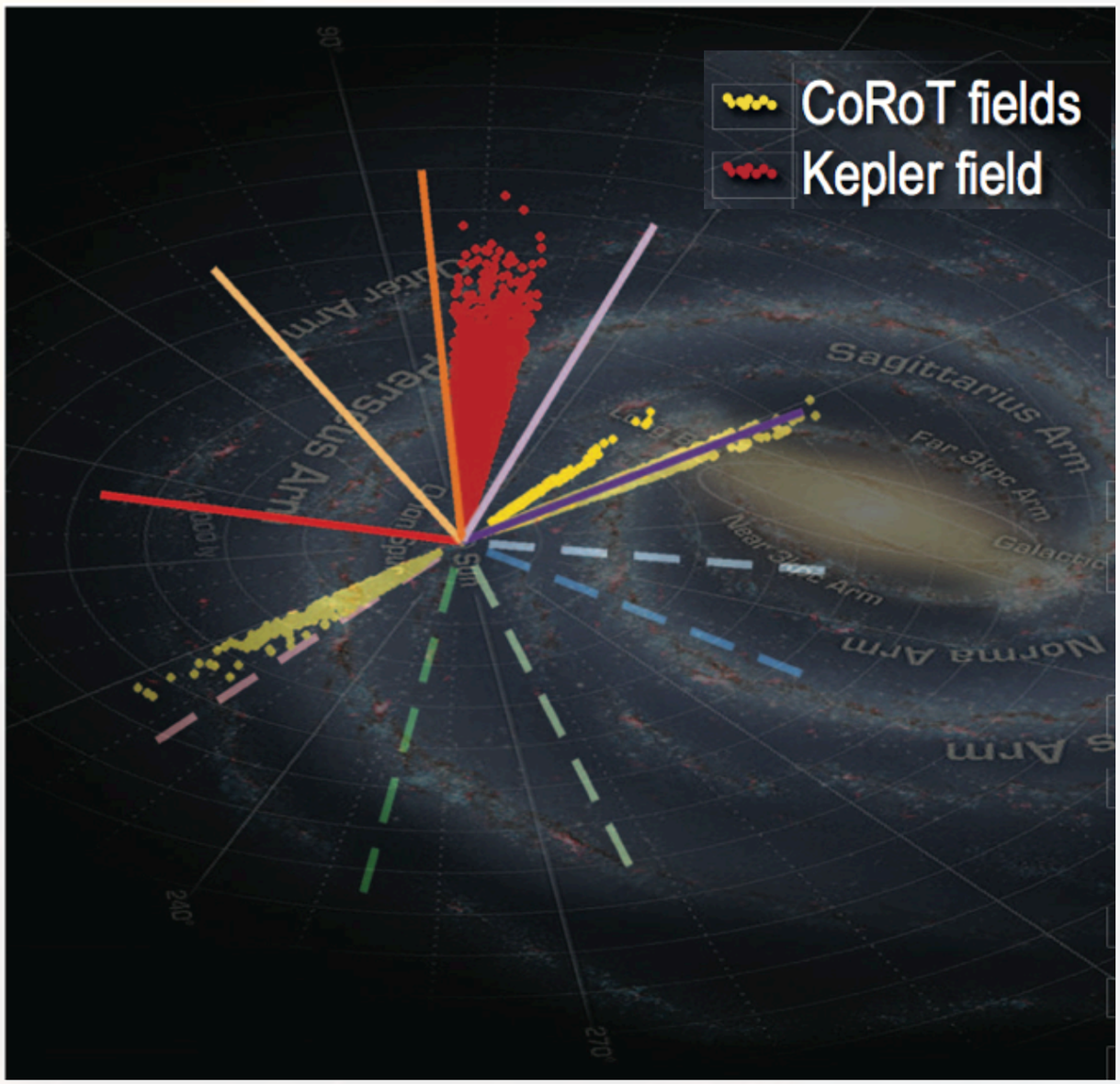
Bright Future!

K2 (ongoing): Ecliptic, ~10,000 giants, 70 days
(➔ Dennis Stello)

TESS (2017): all-sky, 30+ days (Ricker et al. 2014)

WFIRST (~2024): Bulge, ~430 days, ~1e6 giants (Gould et al. 2014)

PLATO (~2024): fields tbd, ~2-3 years



Conclusions

• Asteroseismology (in combination with ground-based surveys!) is a powerful tool to determine the interior structure, masses, and ages of stars (and populations)

• Empirical tests generally validate seismic radii and masses, but some problems remain (RGB-RC, metal-poor stars)

• Upcoming space-based surveys will increase seismic detections by ~ order of magnitude throughout the galaxy (over the next ~10 years)