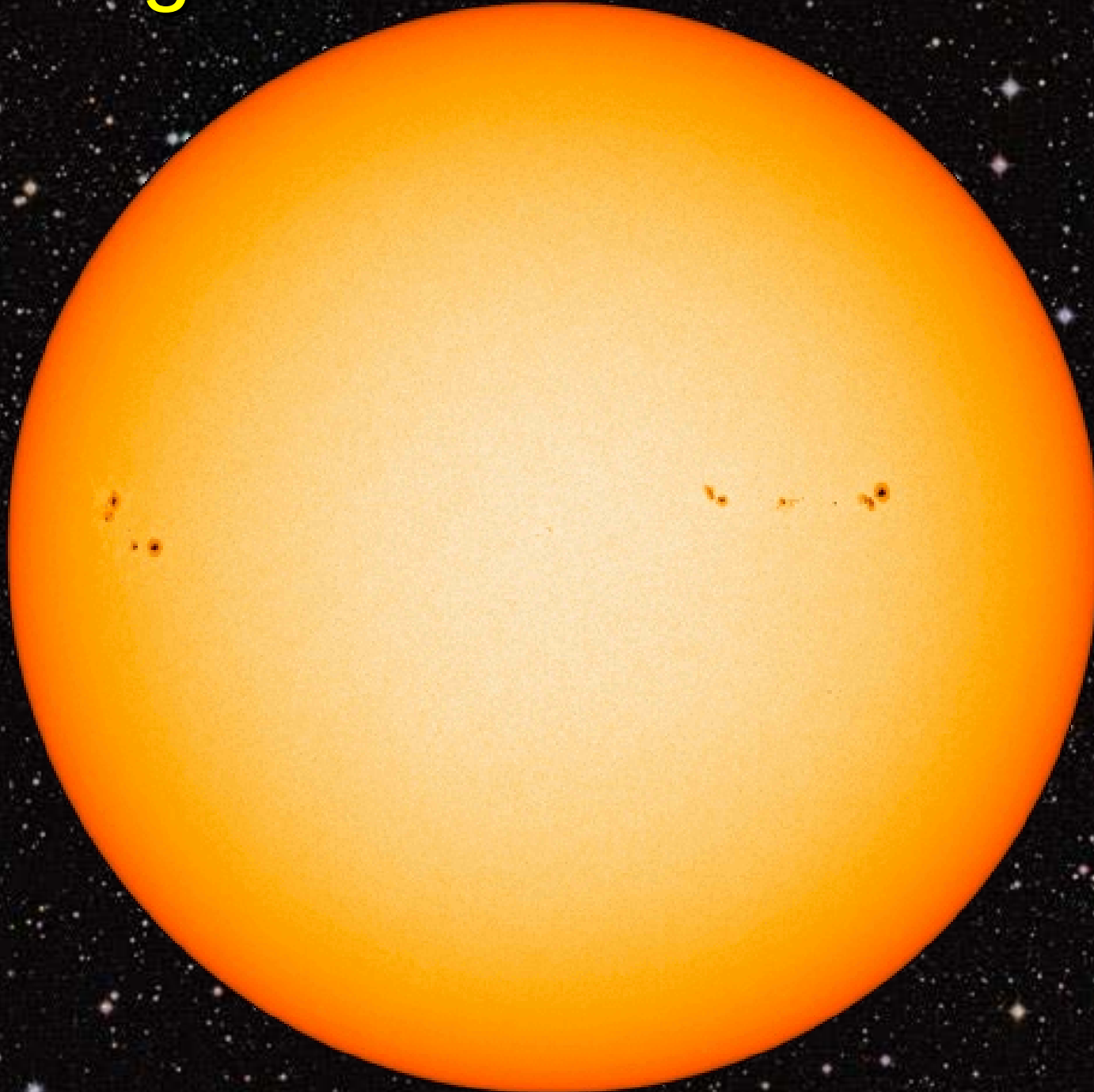
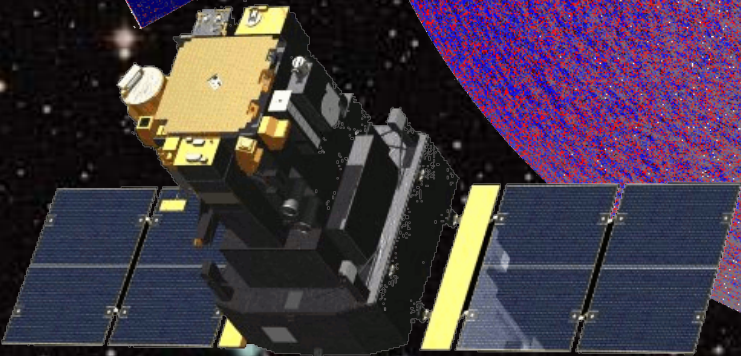


Looking Inside the Sun and Stars



Helioseismology

1996-now



Regner Trampedach

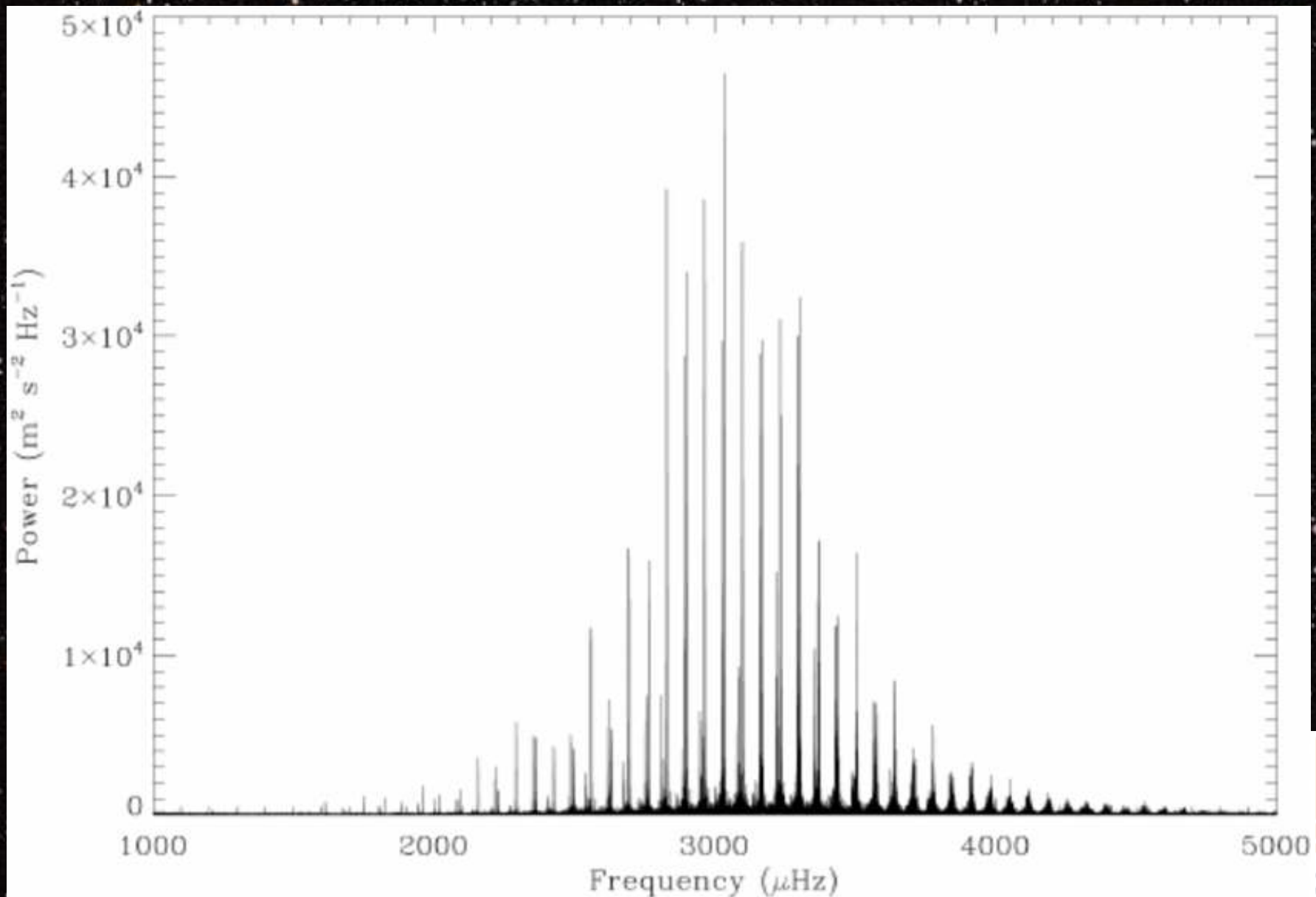


2010-now

Dutch Amateur Astron. visit, SSI, Boulder, 23.08.2017



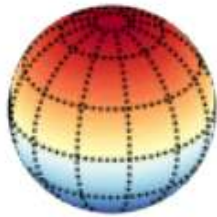
Spectrum of solar sound-waves = p modes



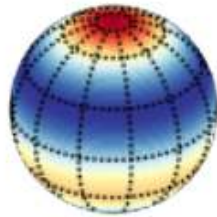
SPACE
SCIENCE
INSTITUTE

Spherical Harmonics

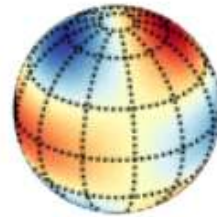
As you know them from atomic physics ;-)



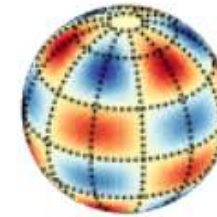
$m = 0, n = 1$



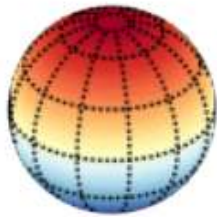
$m = 1, n = 1$



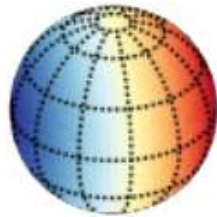
$m = 2, n = 2$



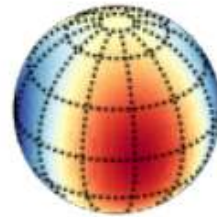
$m = 4, n = 5$



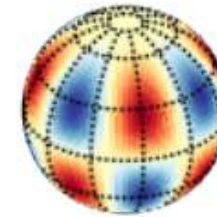
$m = 0, n = 2$



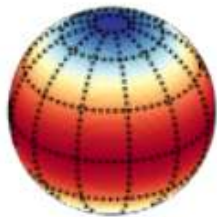
$m = 1, n = 2$



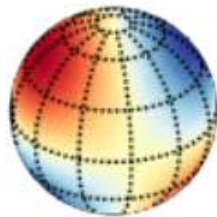
$m = 2, n = 3$



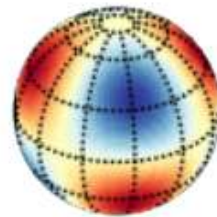
$m = 5, n = 7$



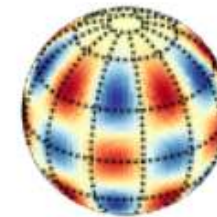
$m = 0, n = 3$



$m = 1, n = 3$



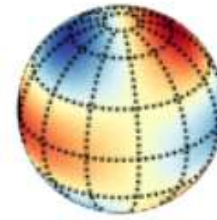
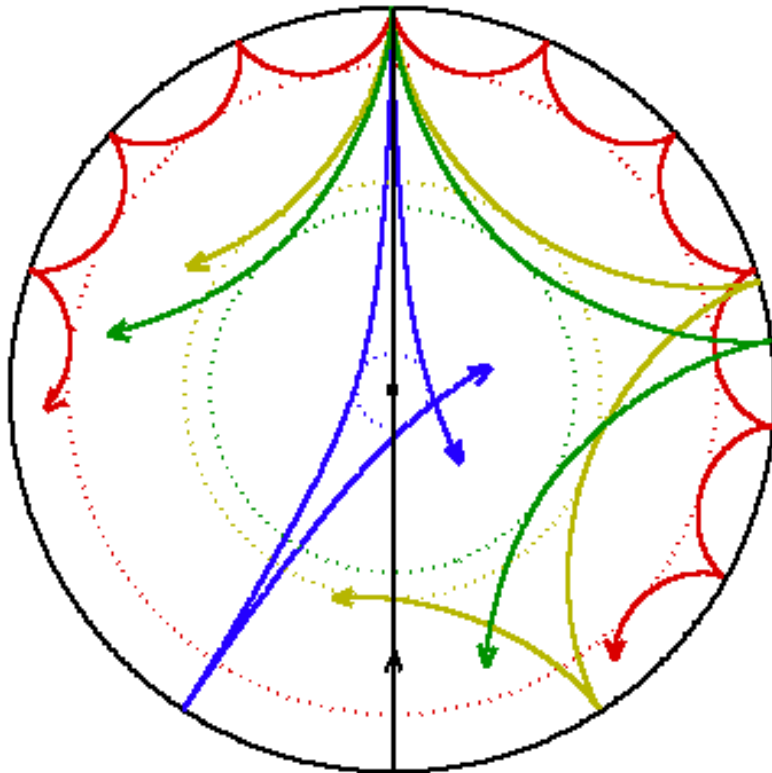
$m = 3, n = 6$



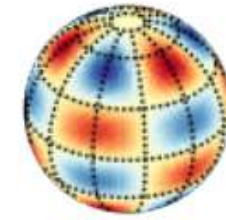
$m = 6, n = 10$

Spherical Harmonics

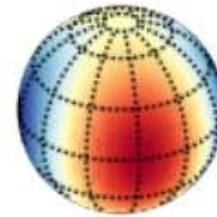
As you know them from atomic physics ;-)



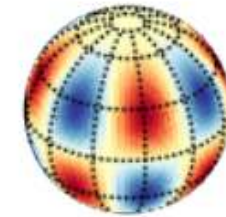
$m = 2, n = 2$



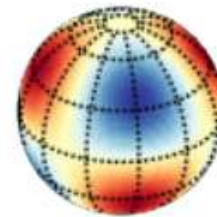
$m = 4, n = 5$



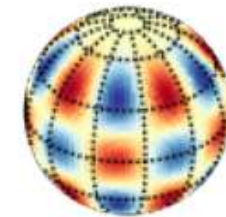
$m = 2, n = 3$



$m = 5, n = 7$

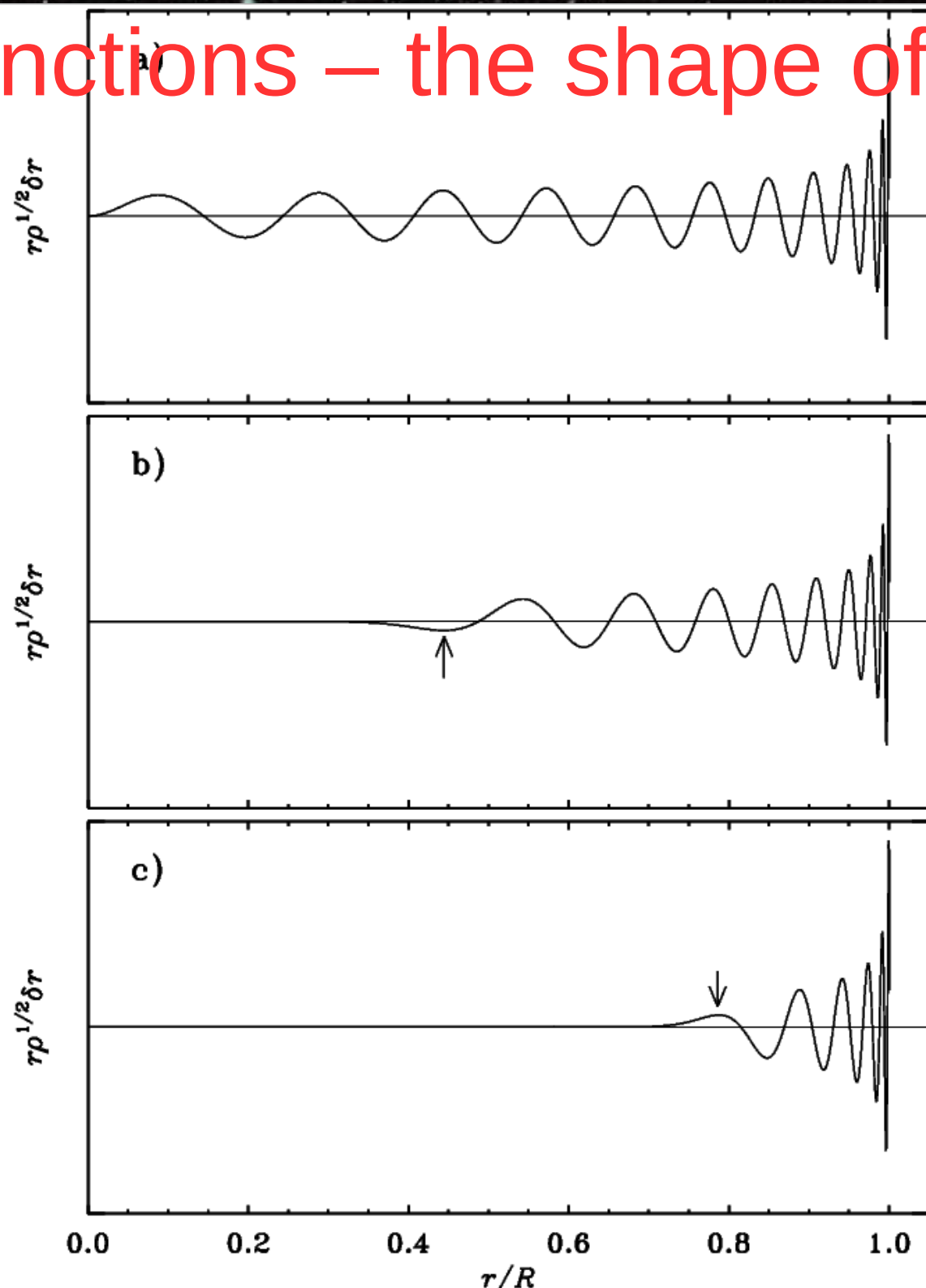


$m = 3, n = 6$



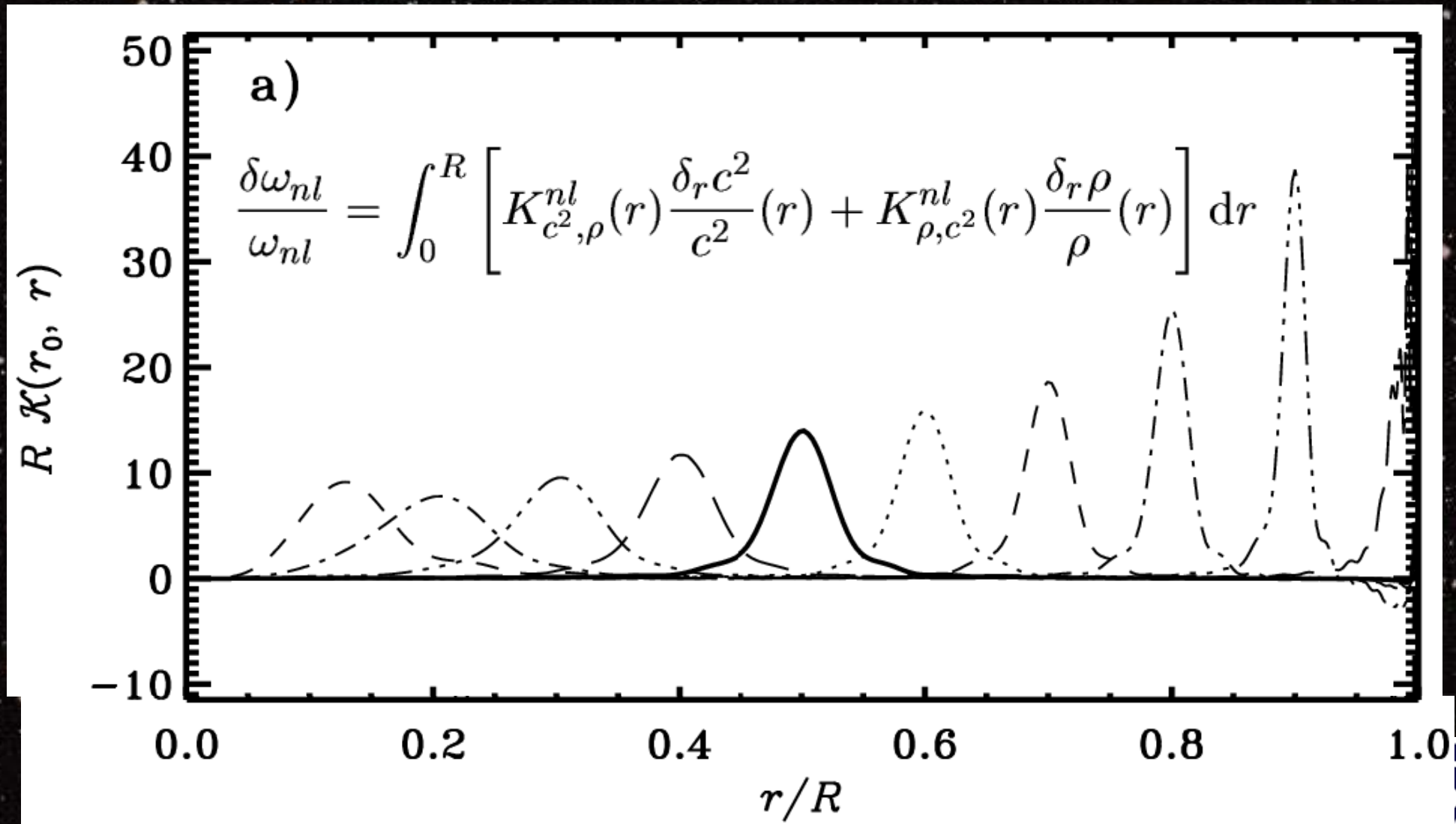
$m = 6, n = 10$

Eigenfunctions – the shape of waves

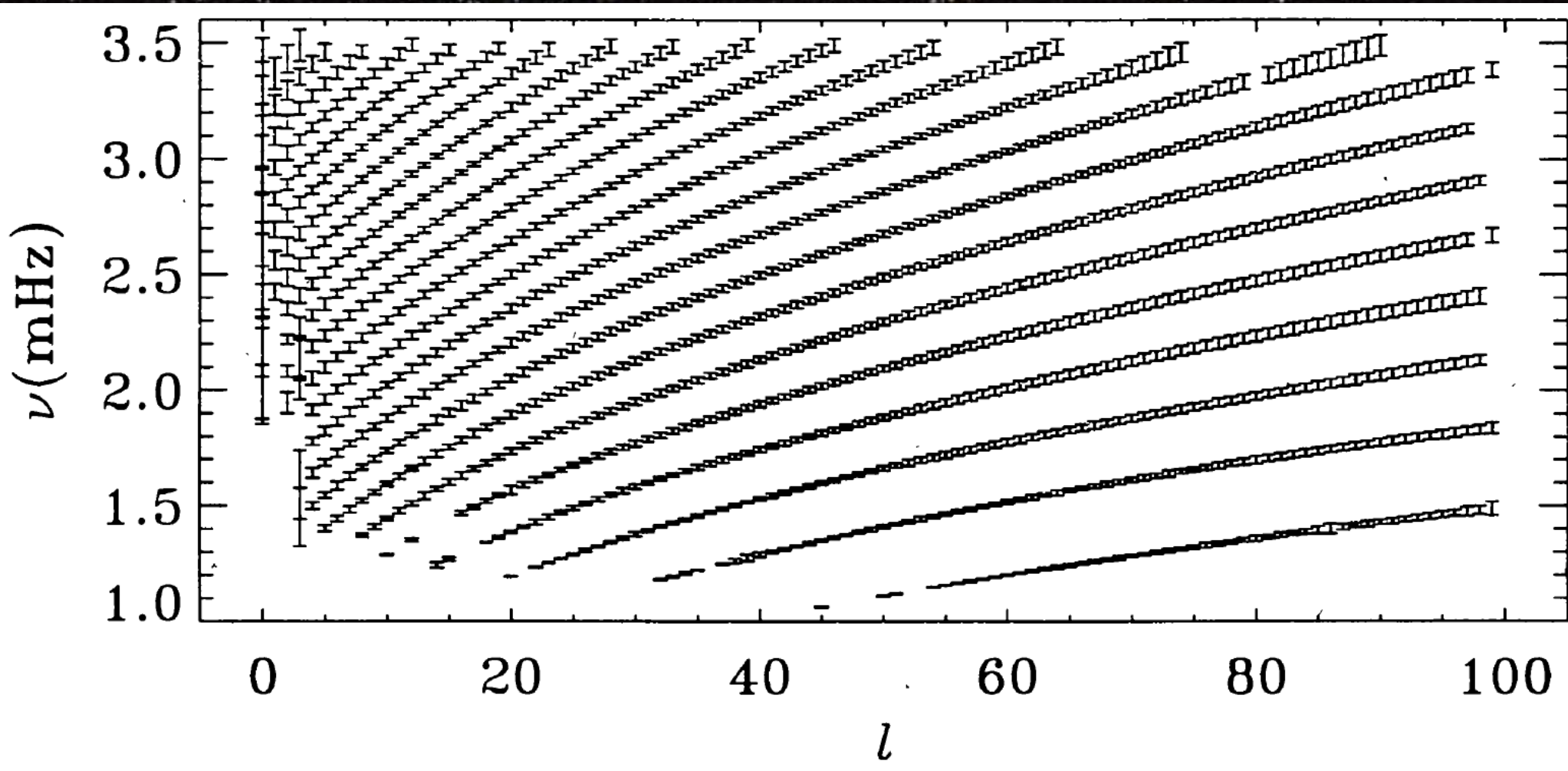


Kernels

the sensitivity to the structure of a star

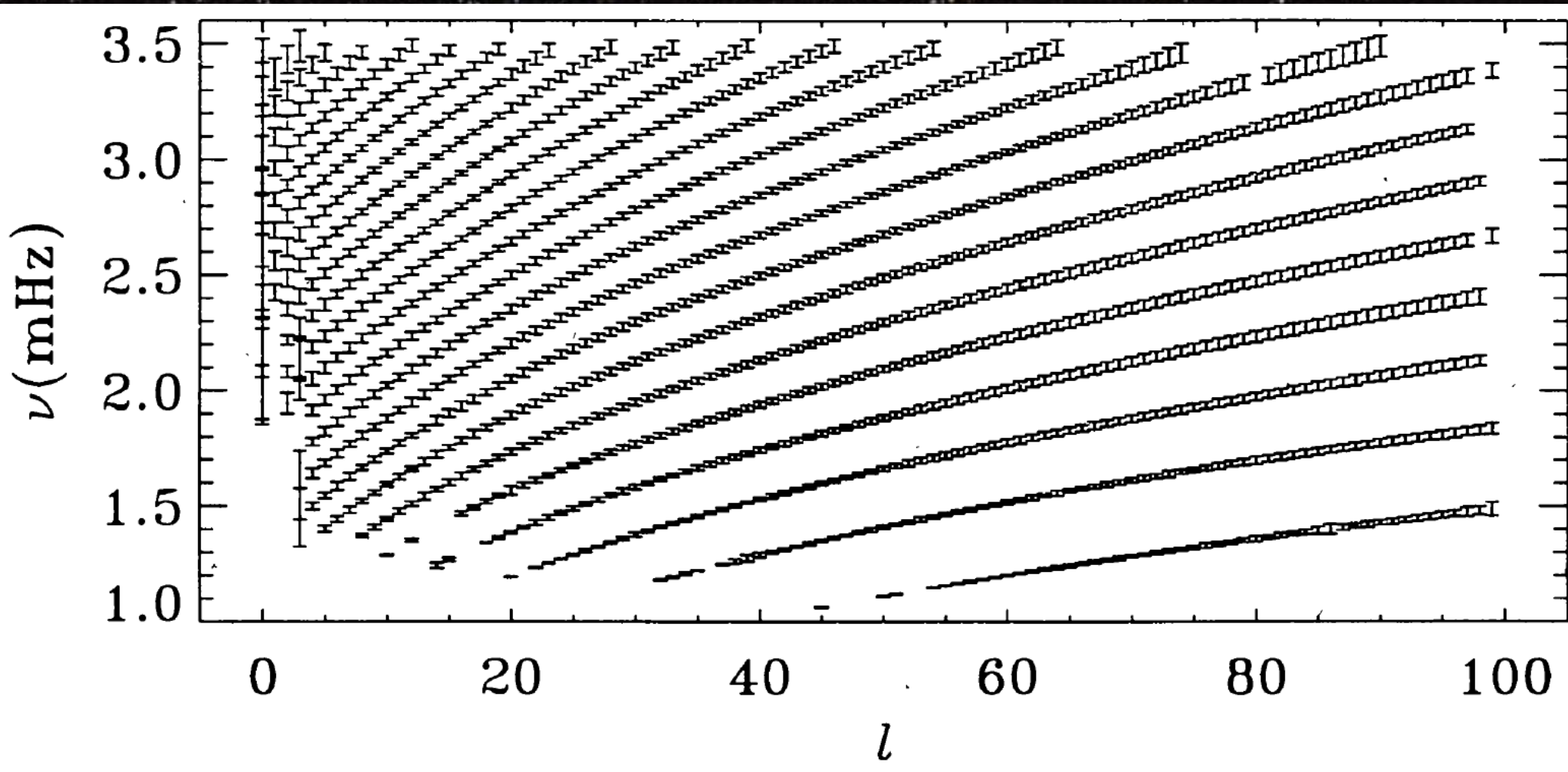


We know solar frequencies pretty well



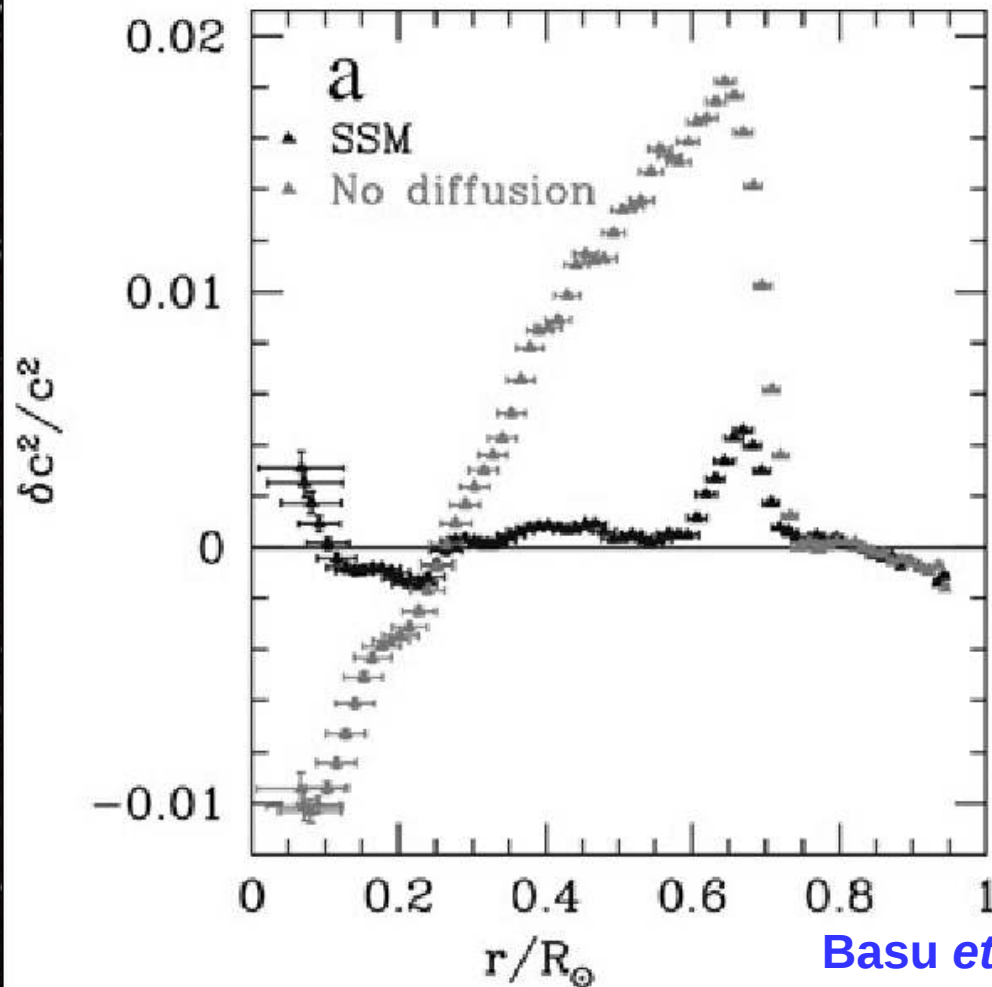
Solar frequencies with error-bars
from Schou, Tomczyk & Thompson (1996)

We know solar frequencies pretty well

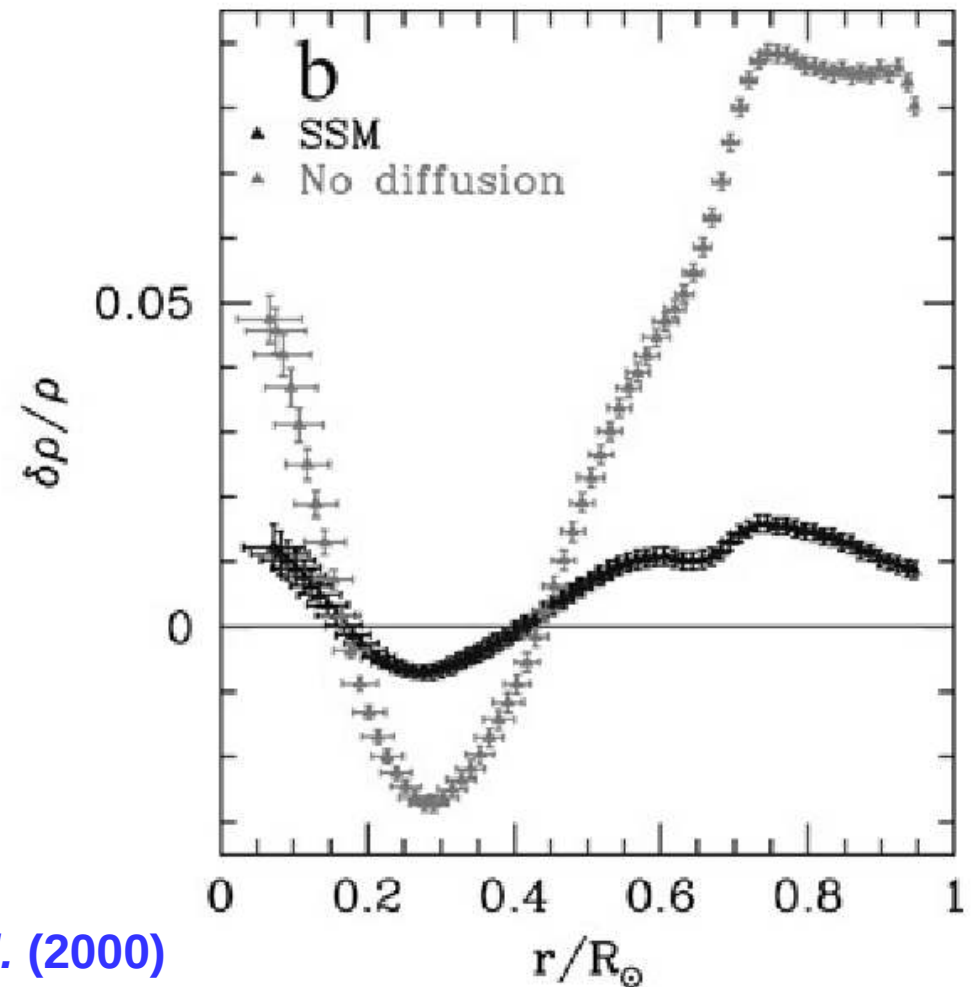


Solar frequencies with 1000σ error-bars!
from Schou, Tomczyk & Thompson (1996)

Converging Models and Good agreement with Sun

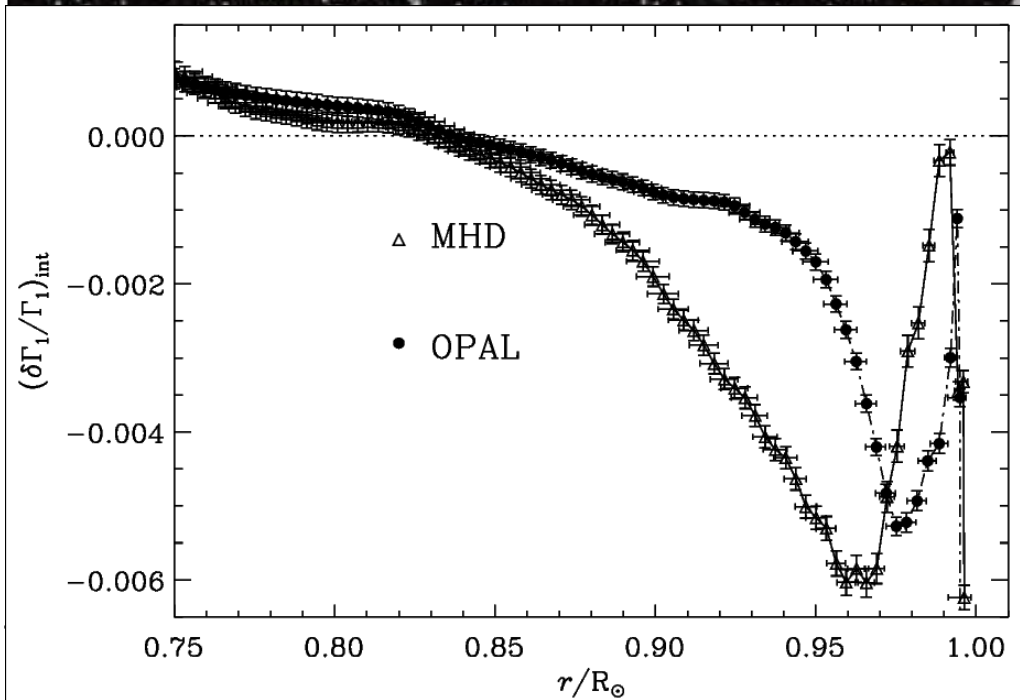
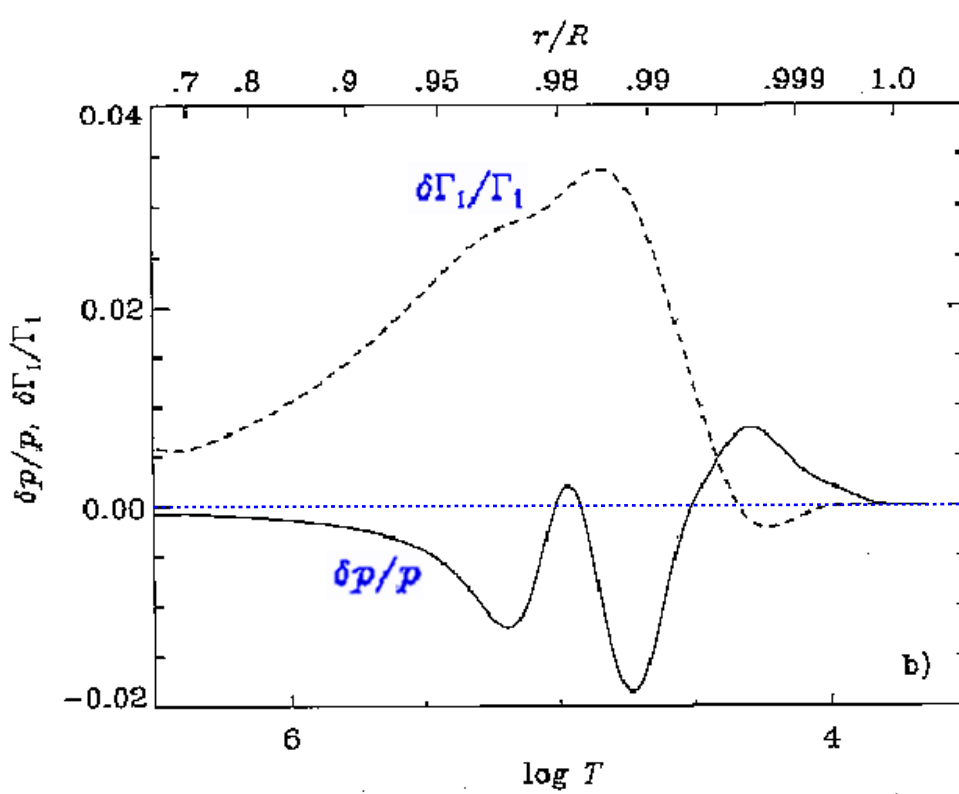
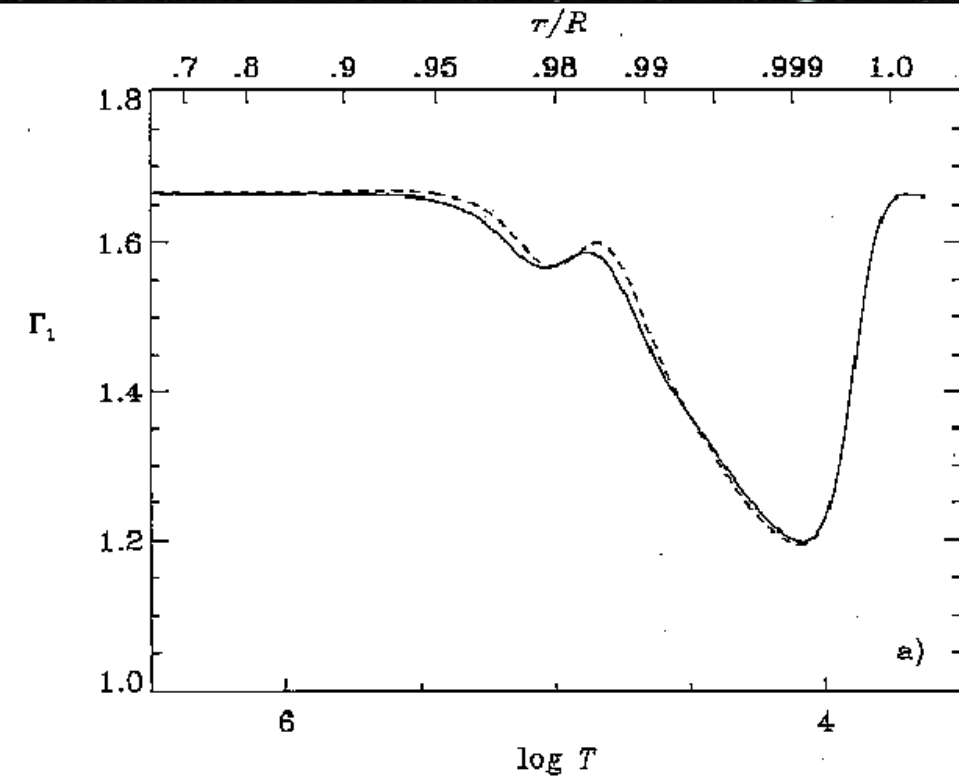


Basu et al. (2000)



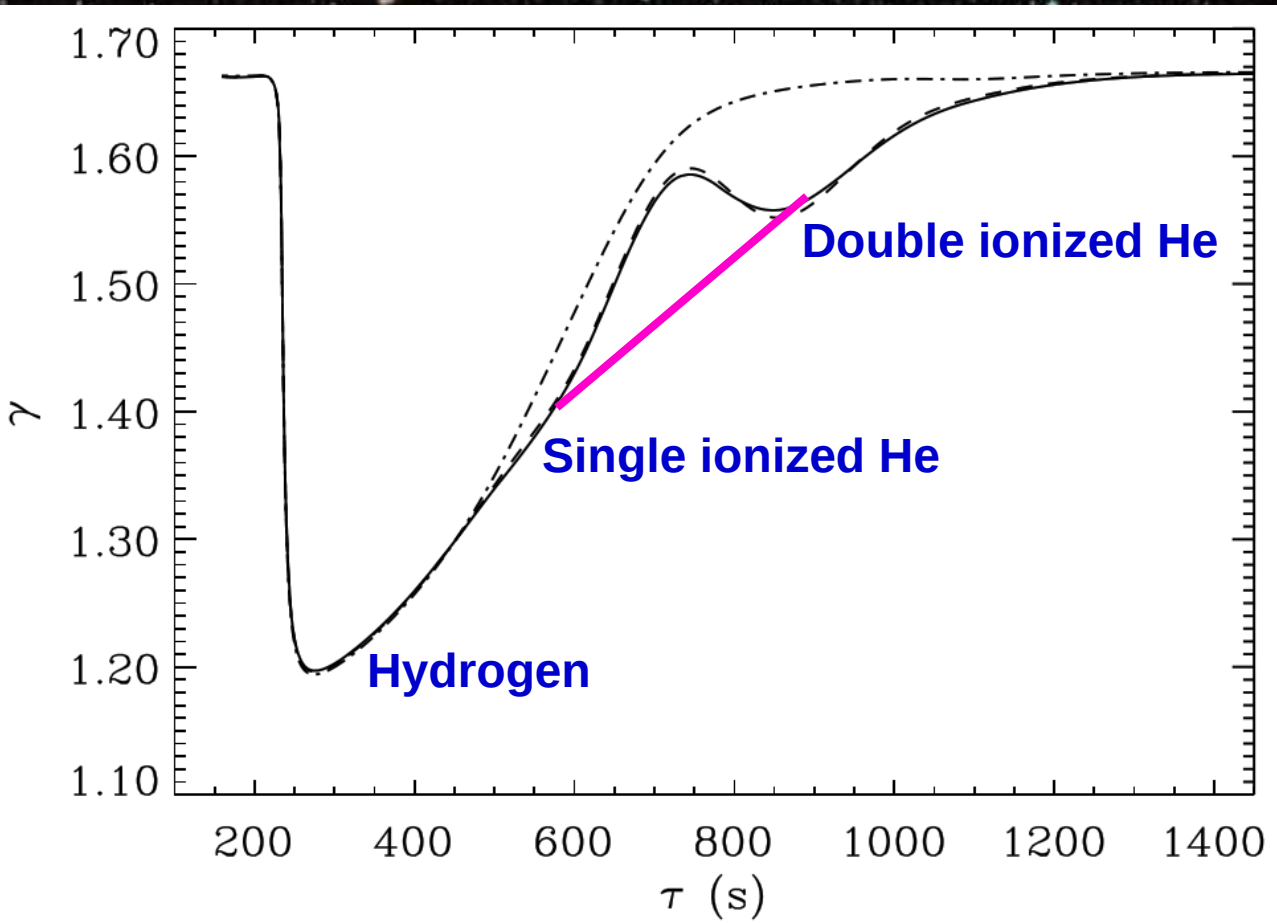
The Sun Teaches us Physics!

Effects of the Sun's plasma not being ideal (Coulomb interactions matter) are obvious on the scale of helioseismology.

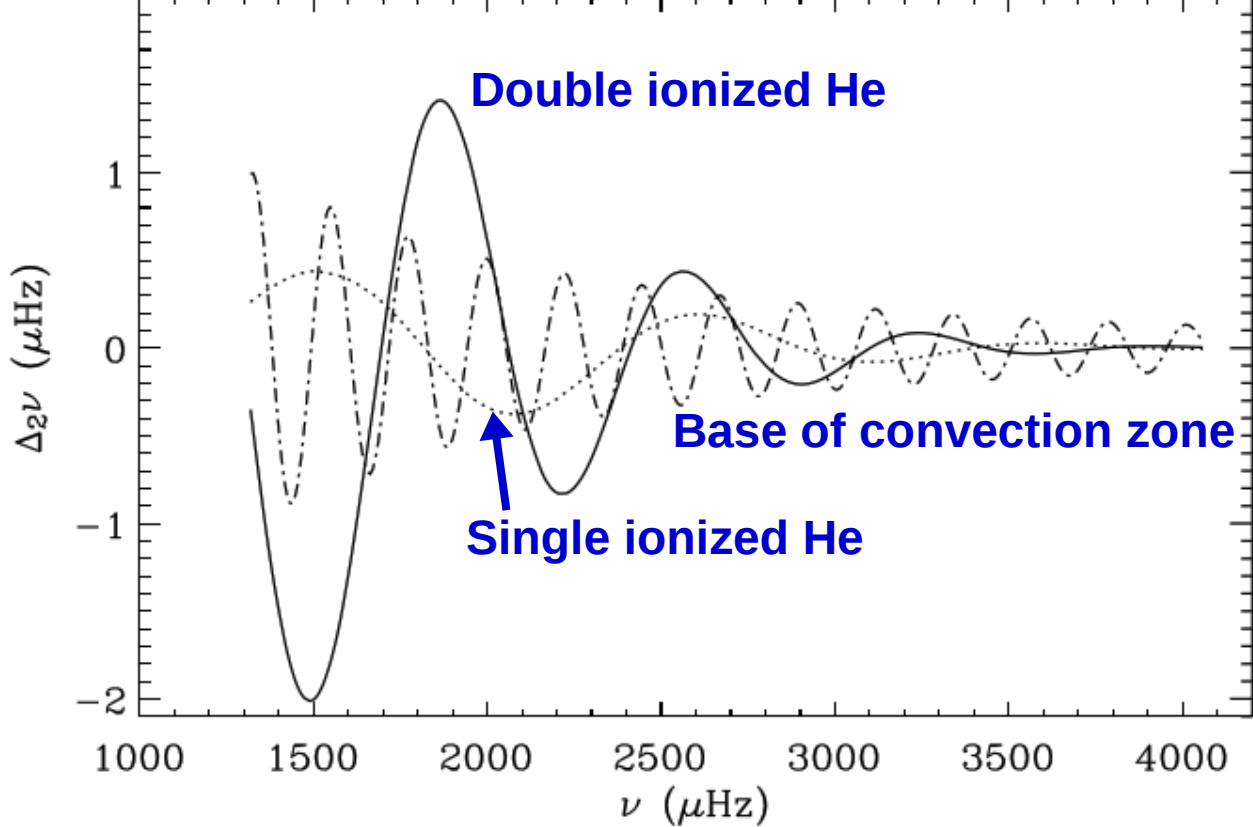
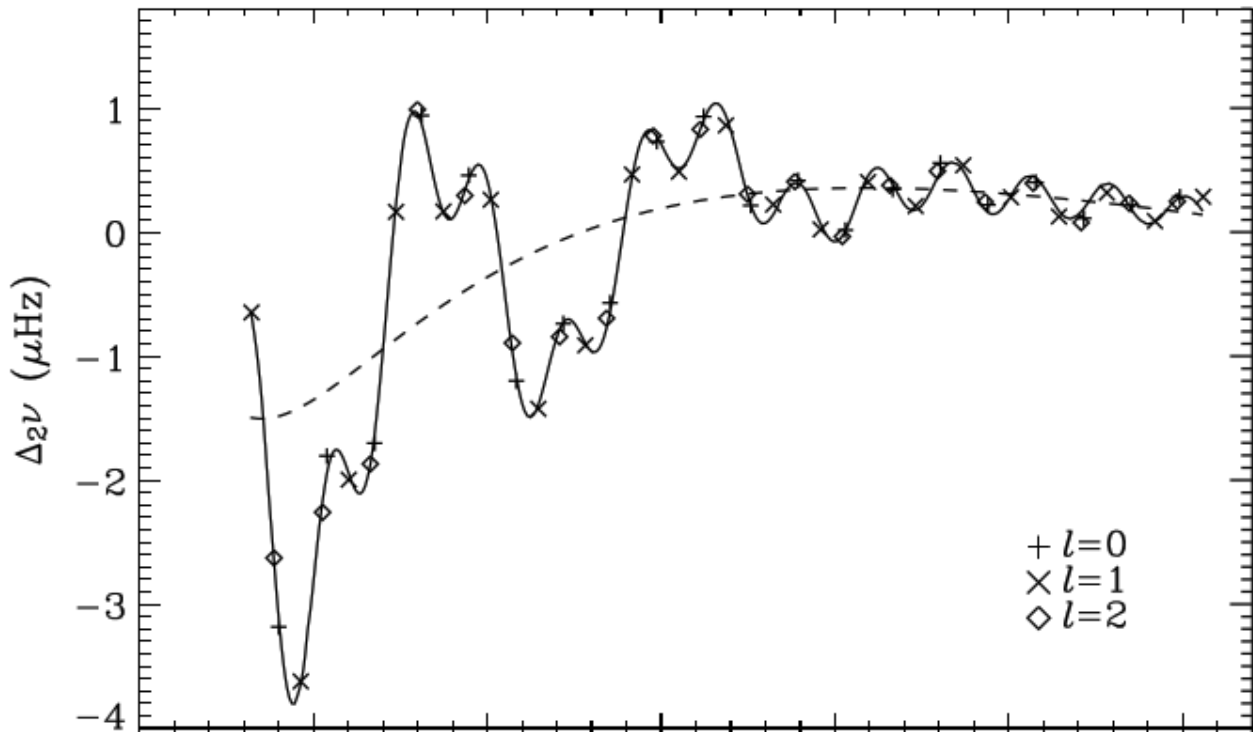
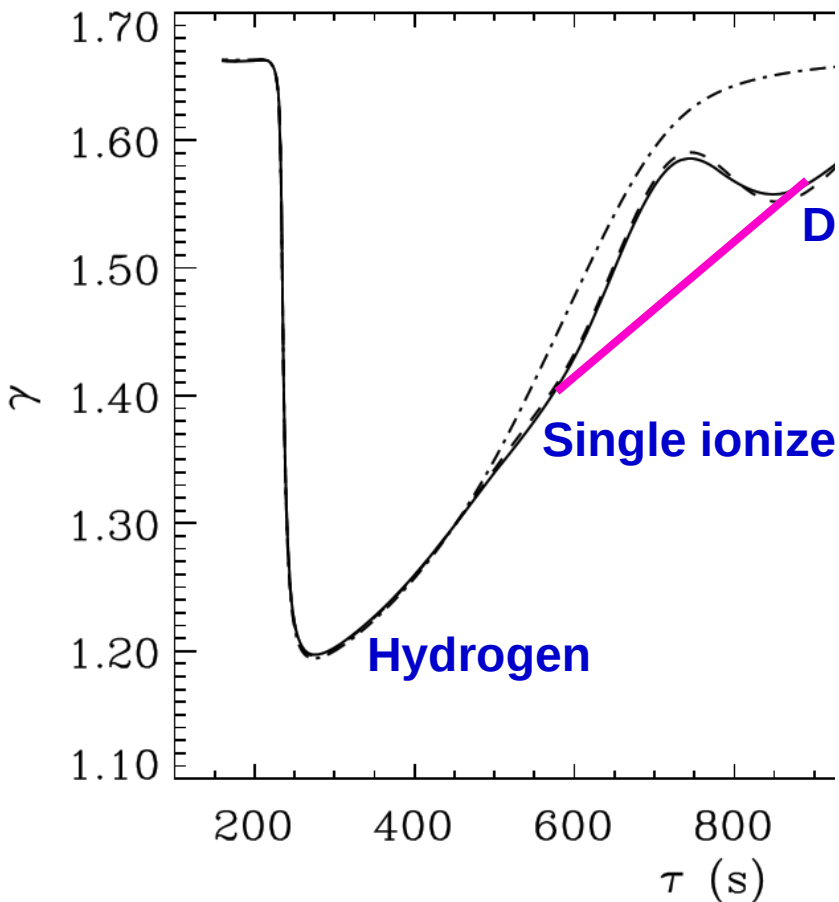


Seismic Glitches

Helium content and Convection Zone

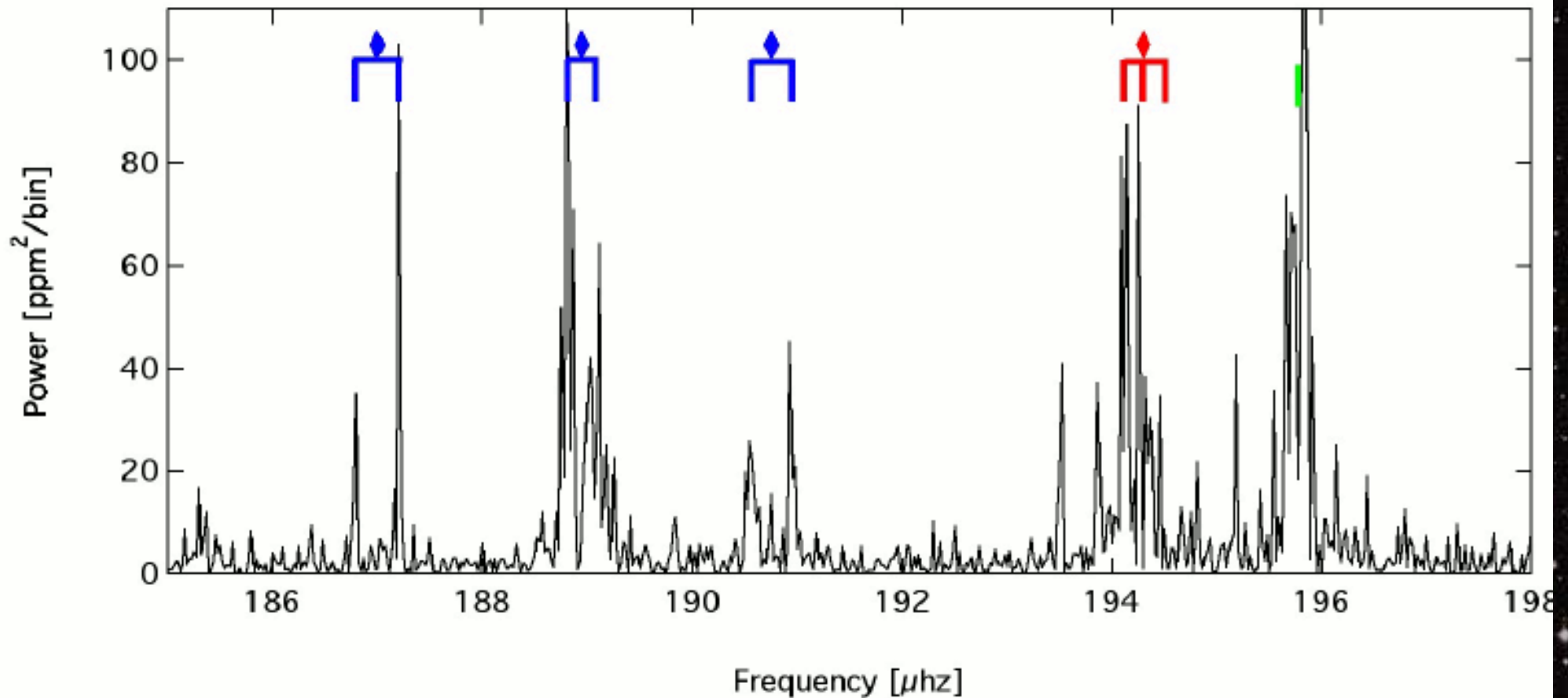


Seis Helium conte

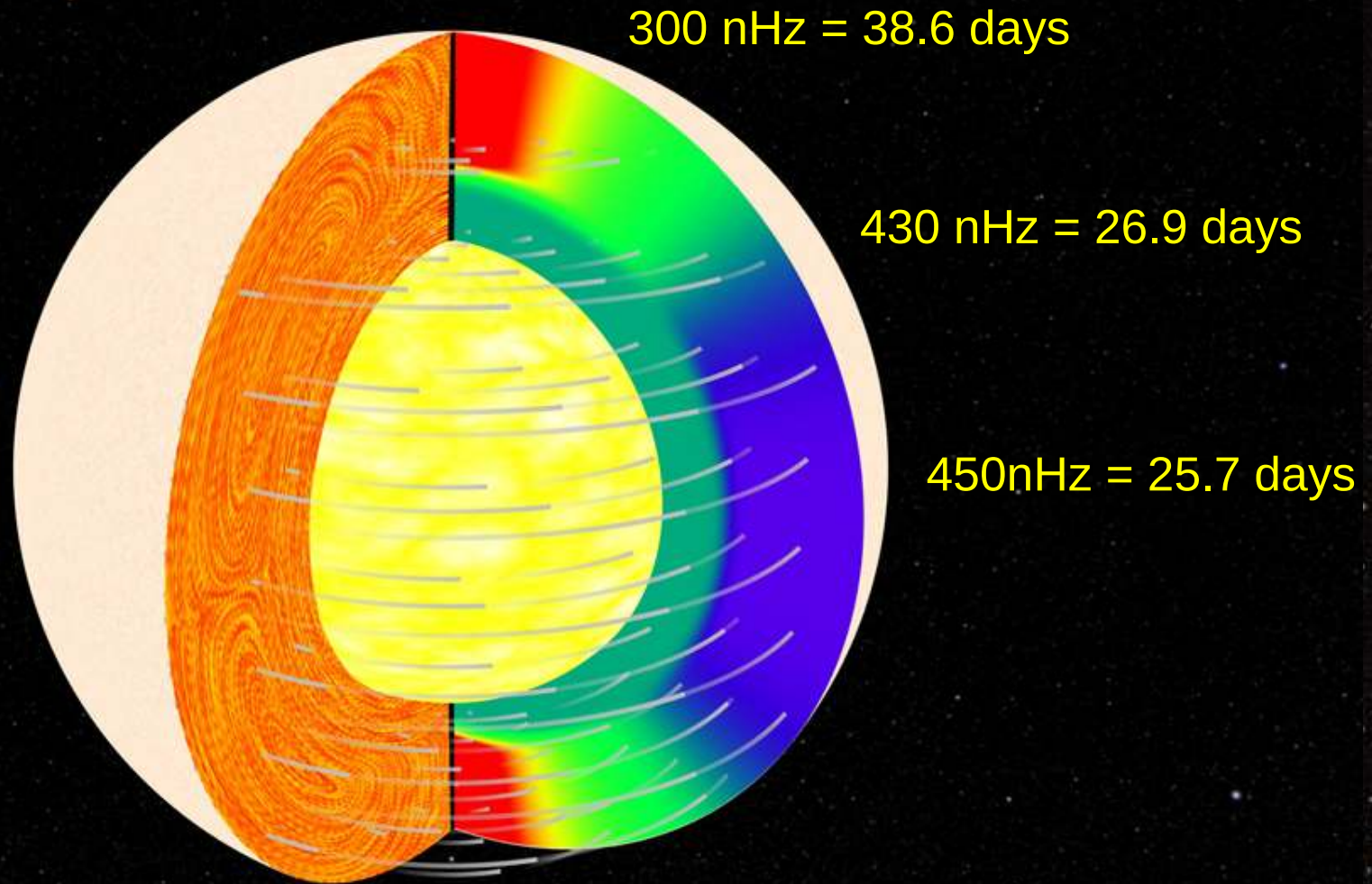


Solar Rotation

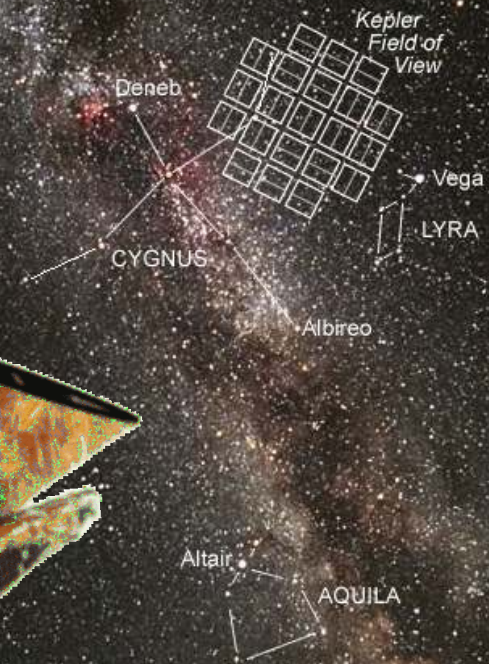
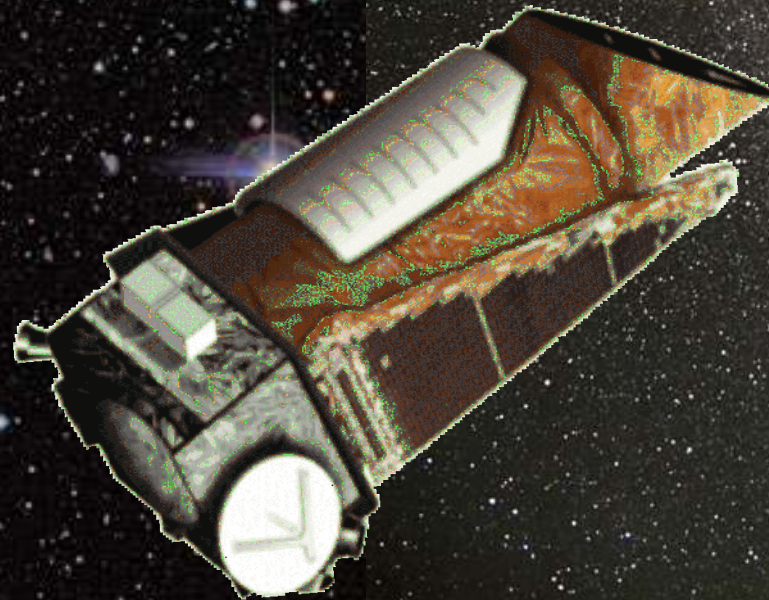
Splitting of resonant modes by rotation



Solar Rotation



Kepler the Planet Hunter 2009-2014



Kepler Planet Hunter 2009-2014

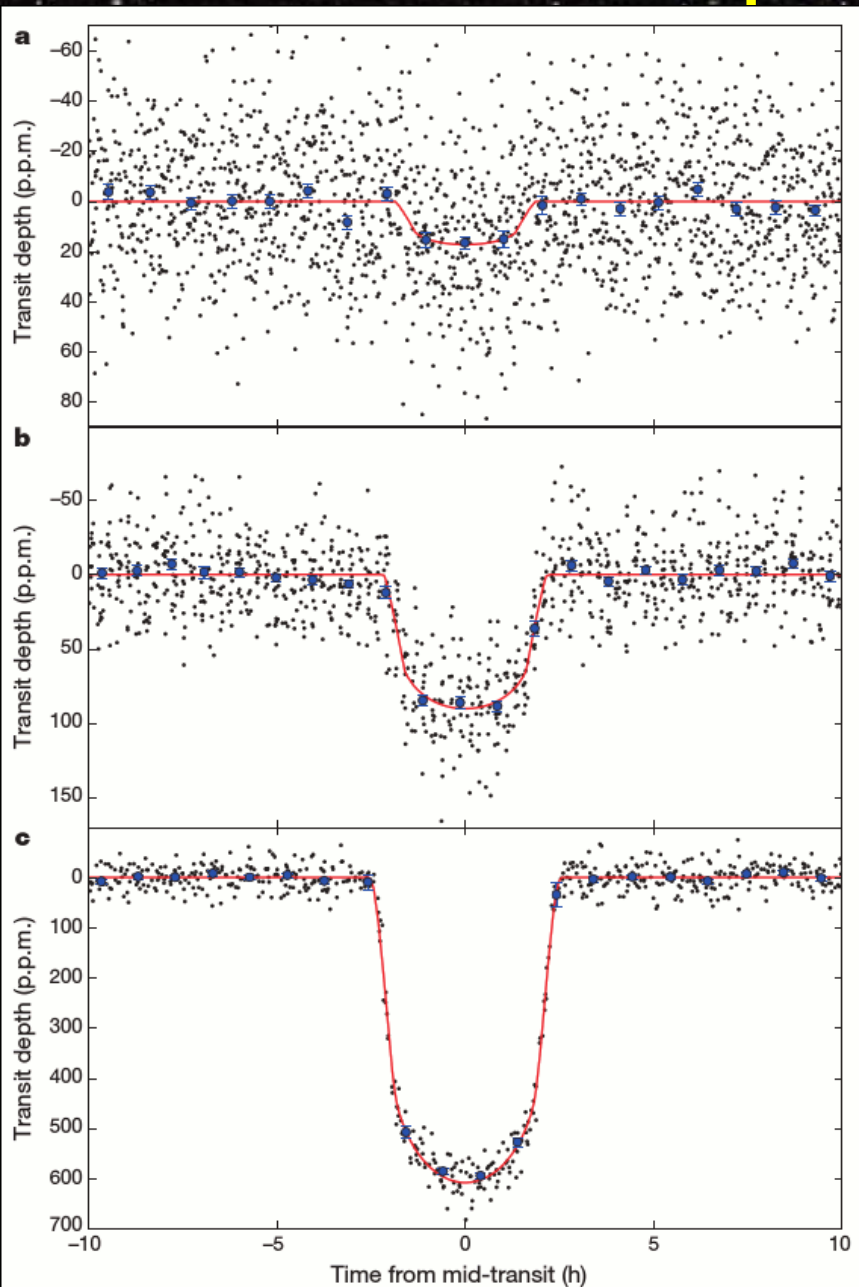
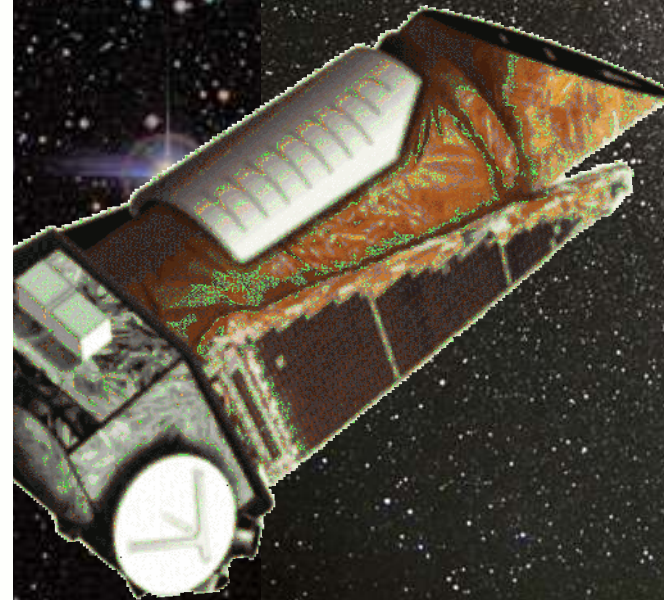
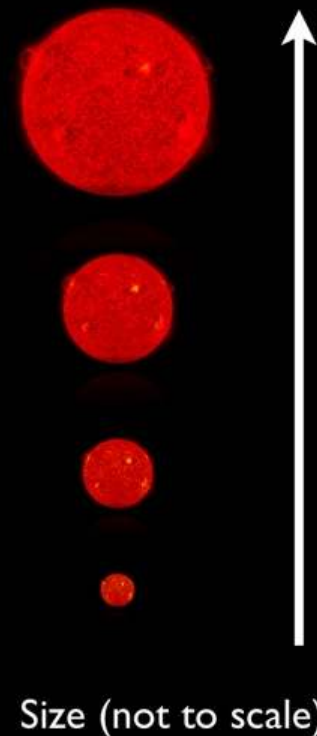
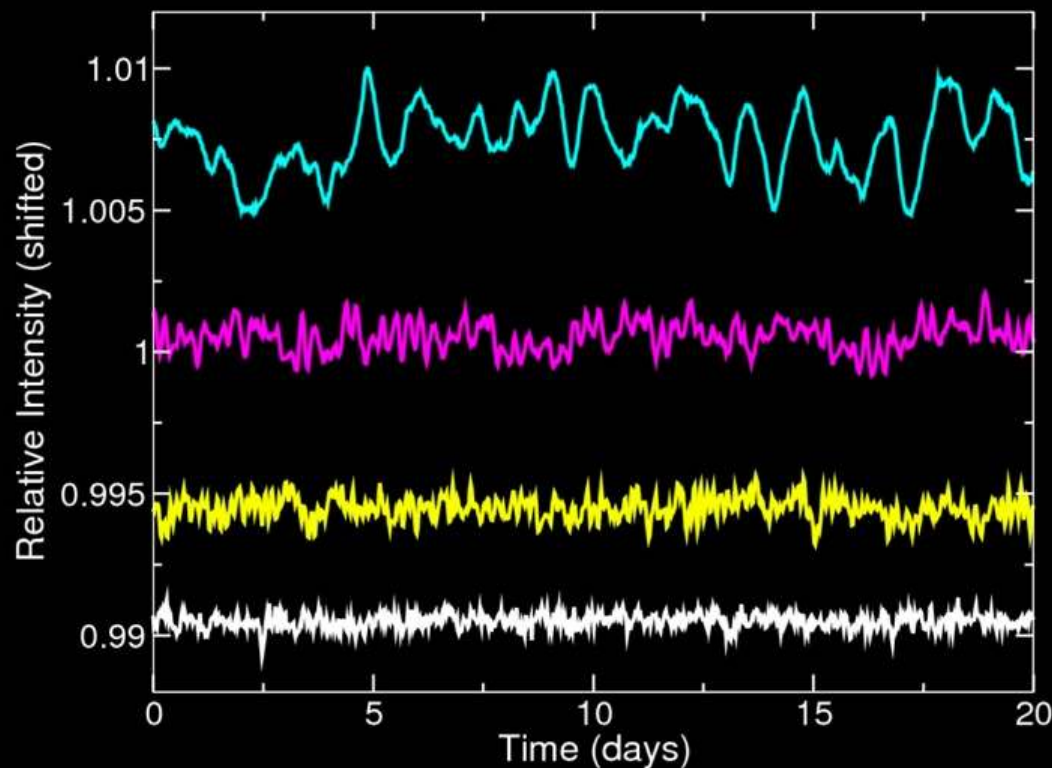


Figure 1 | The transit light curves for the planets orbiting Kepler-37.



Kepler the Asteroseismologist!

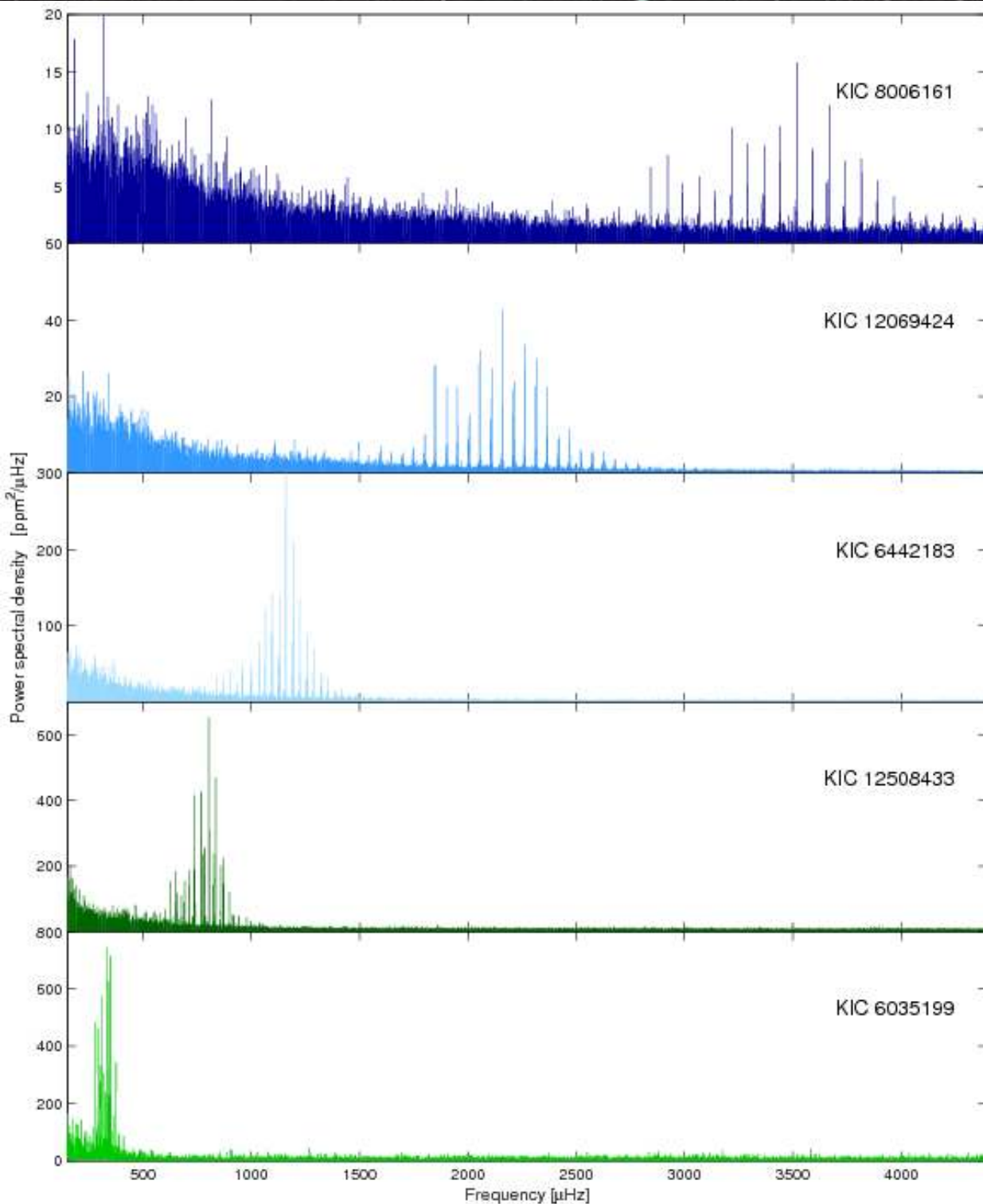
A Kepler “concert” of Red Giant Stars



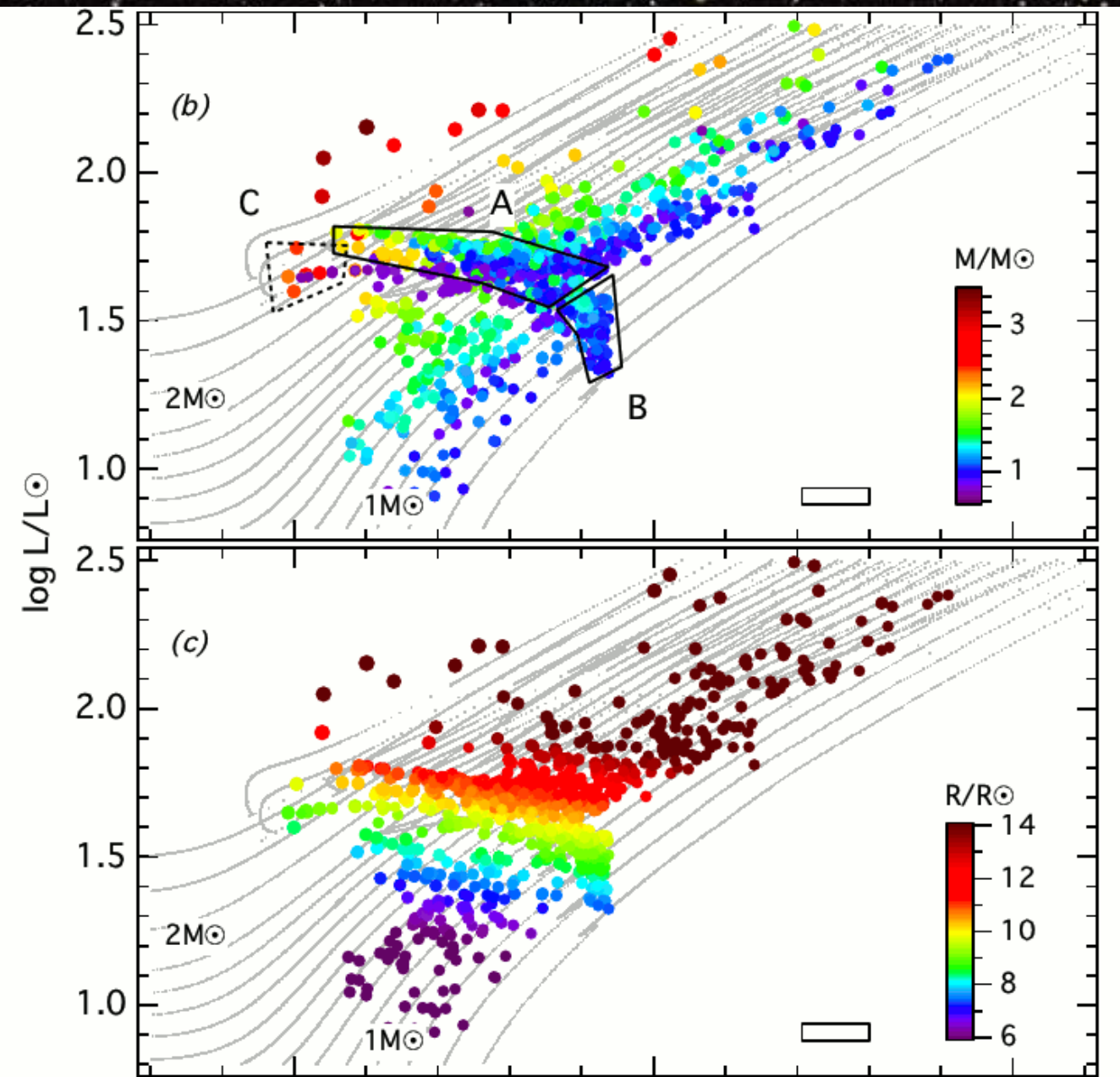
Monitored 150,000 stars! For 4.5 years!

These 5 stars have
solar mass, but vary
in surface gravity.

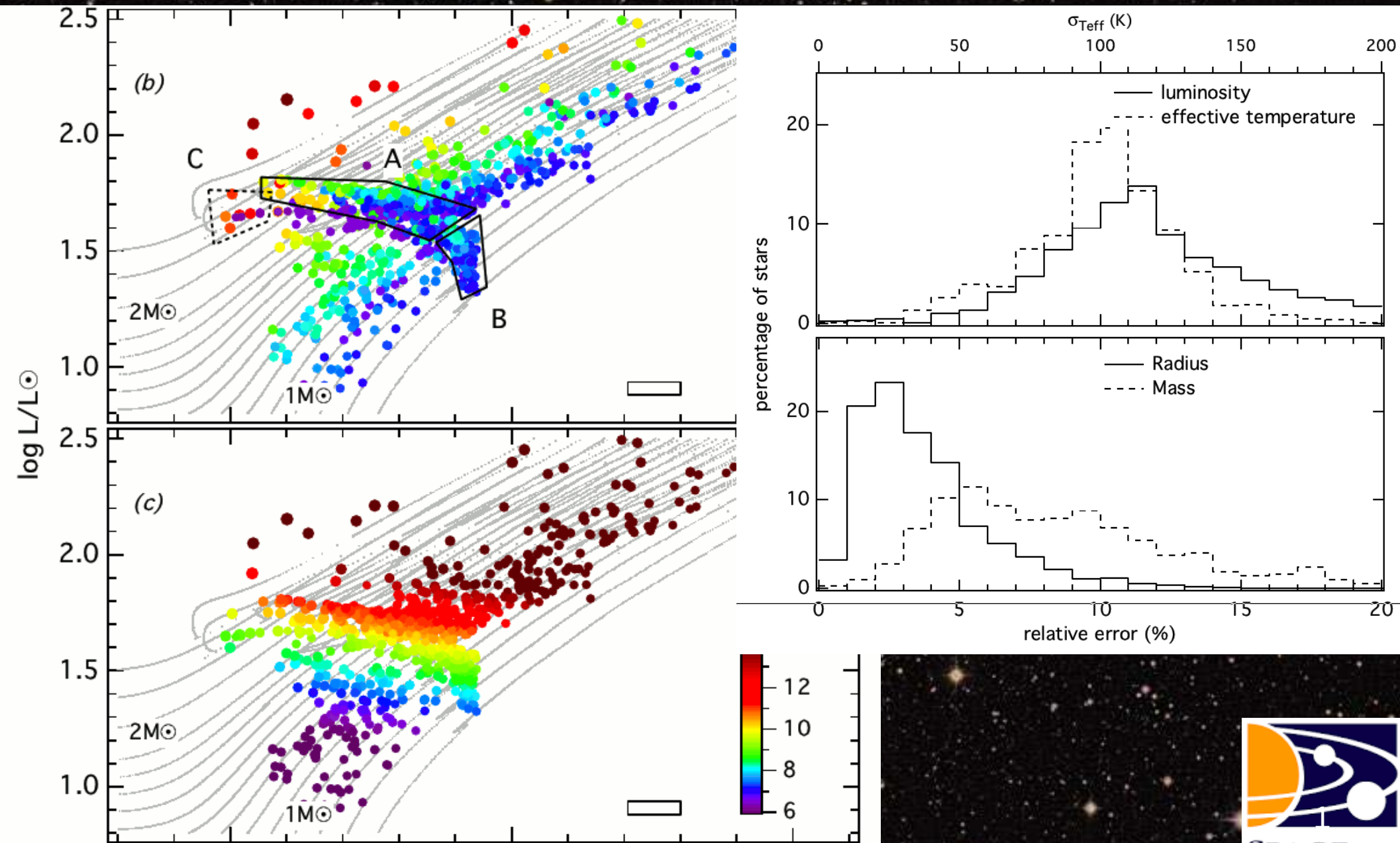
Which has the higher
surface gravity?



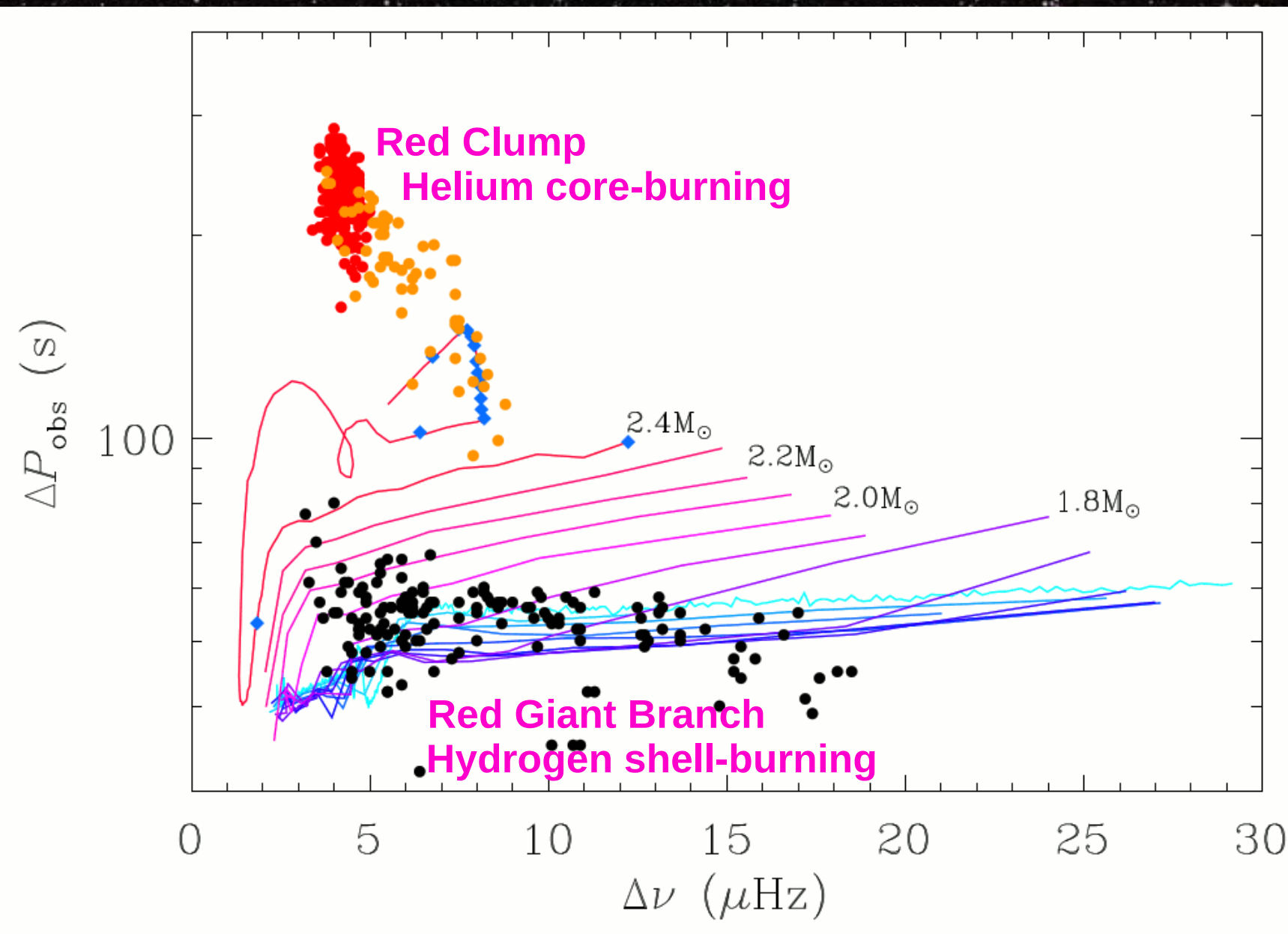
Fundamental Parameters



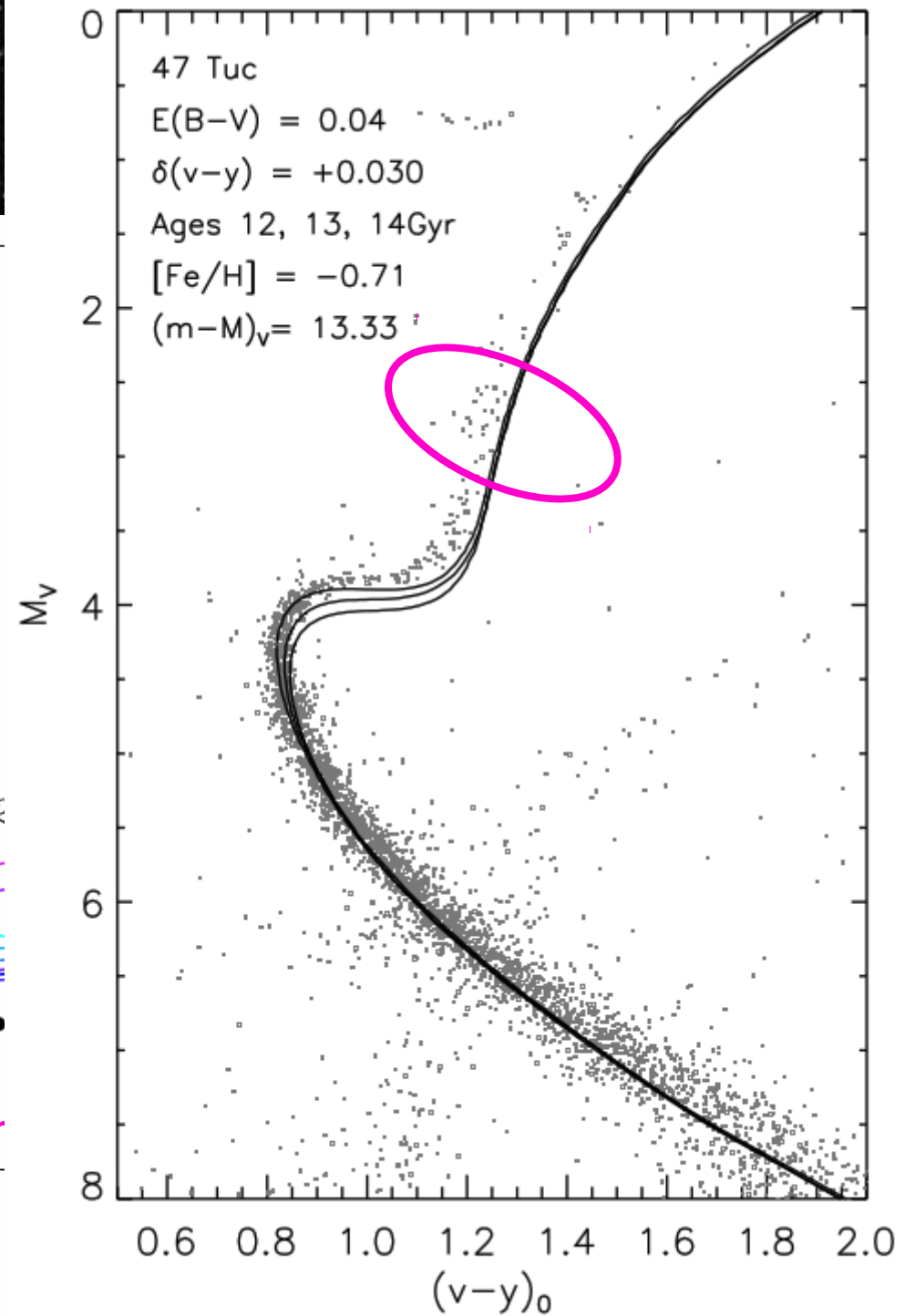
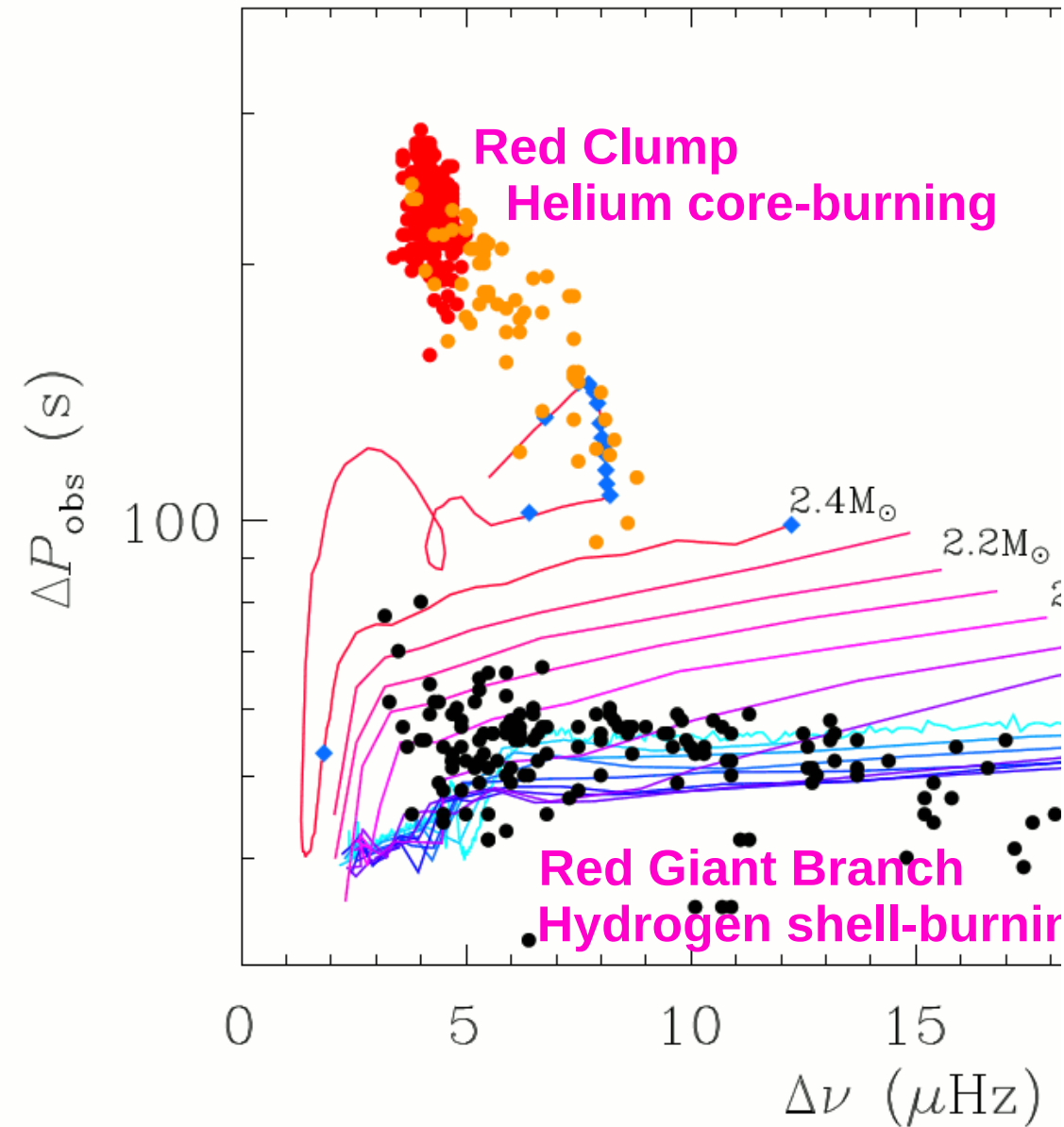
Fundamental Parameters



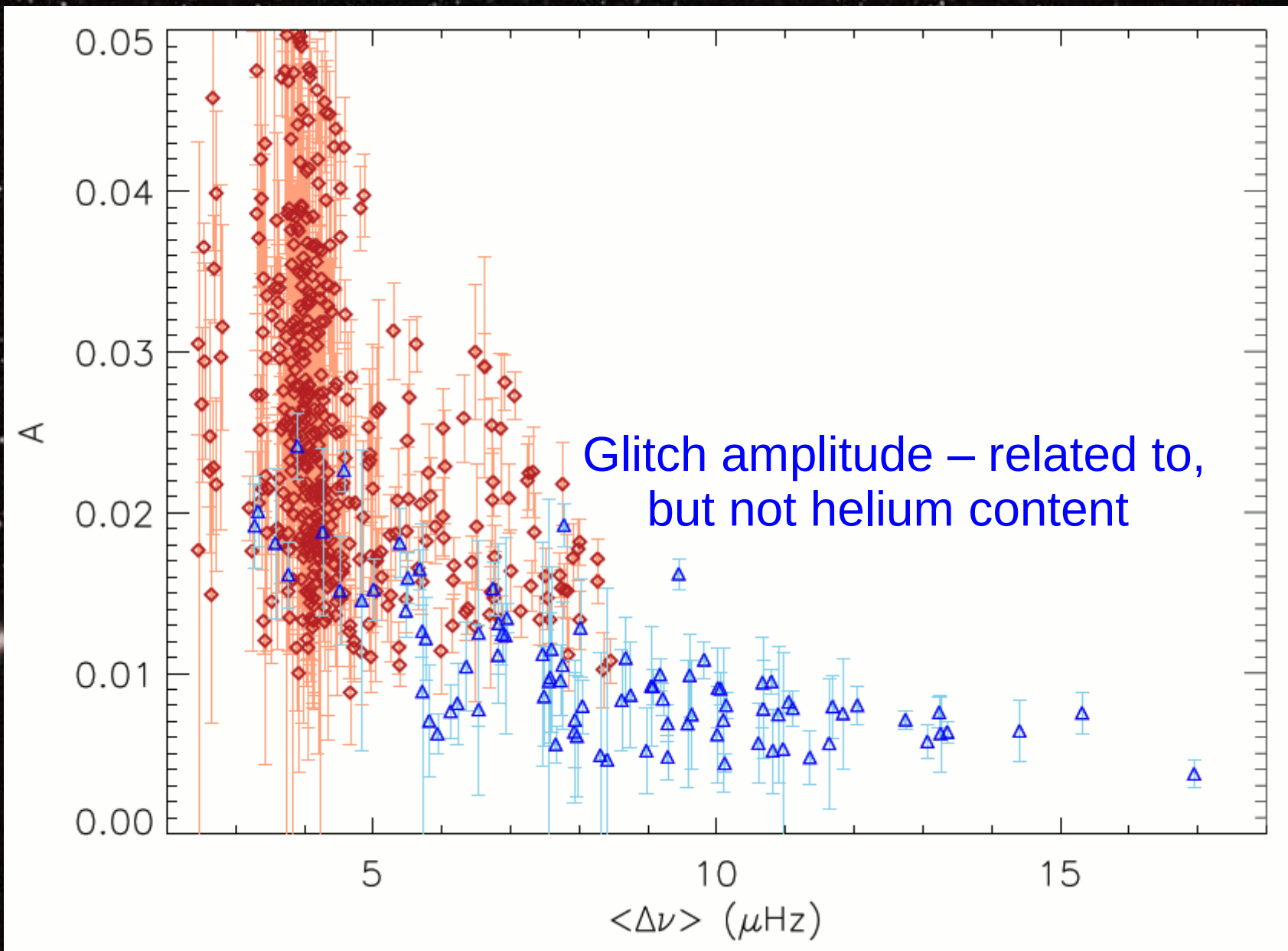
Evolutionary stage



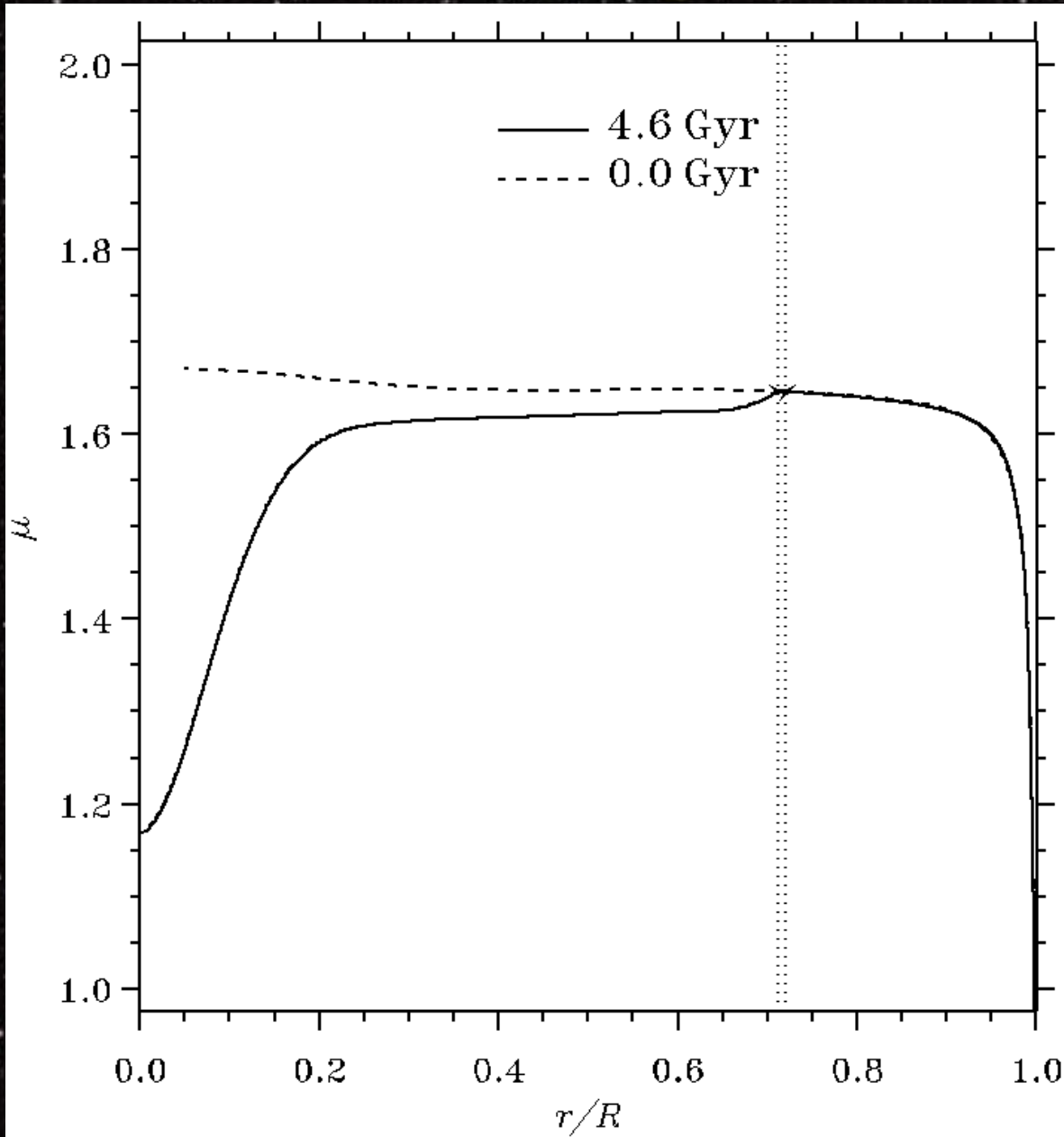
Evolutionary stage



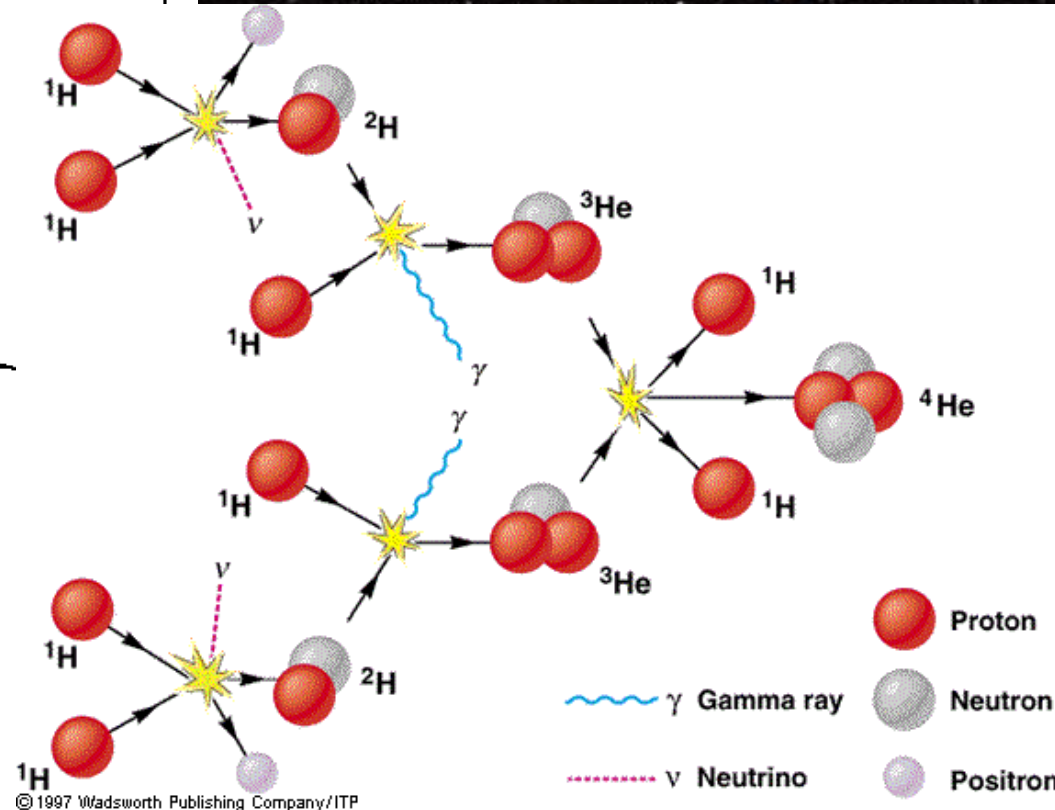
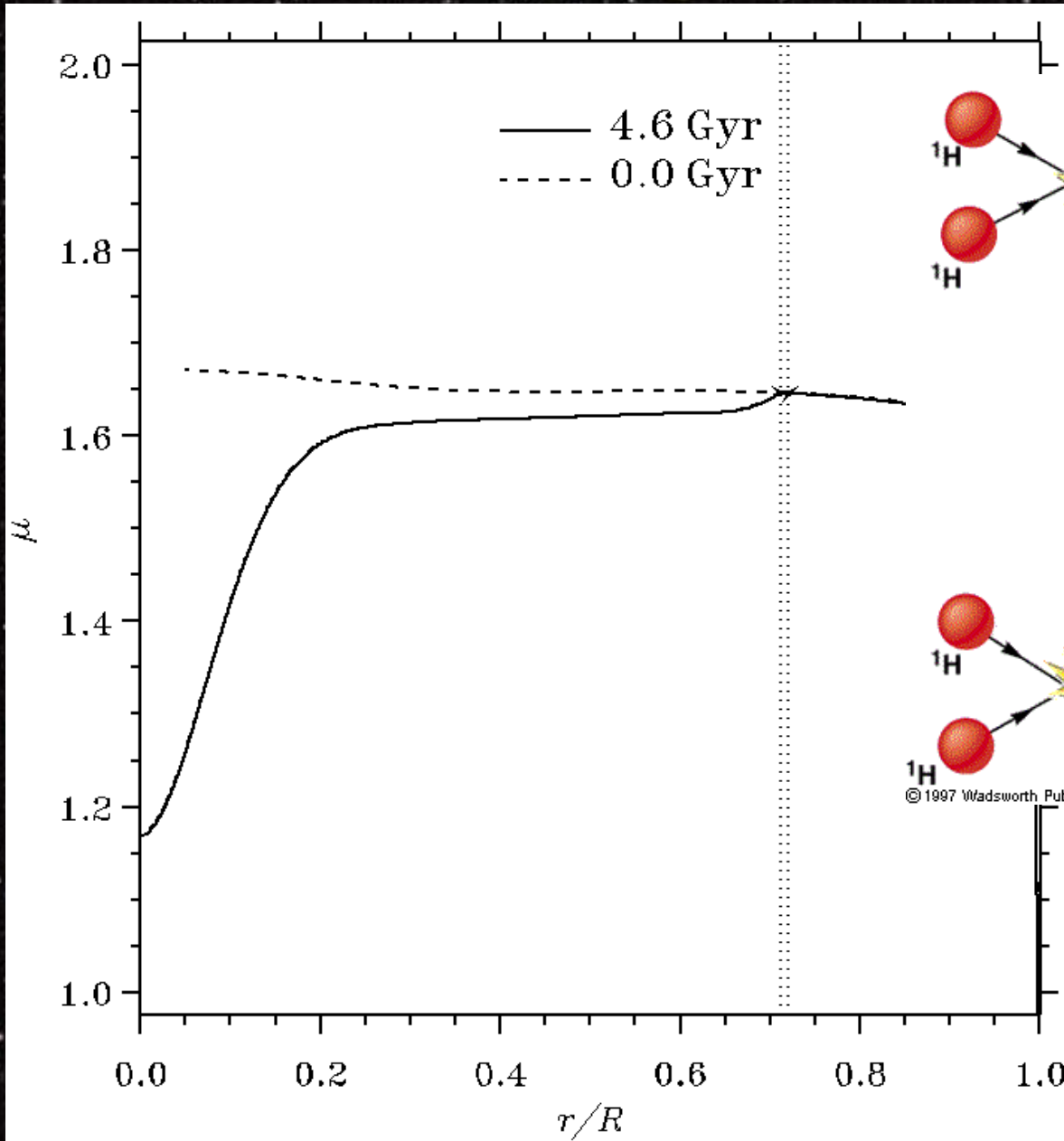
Helium Content



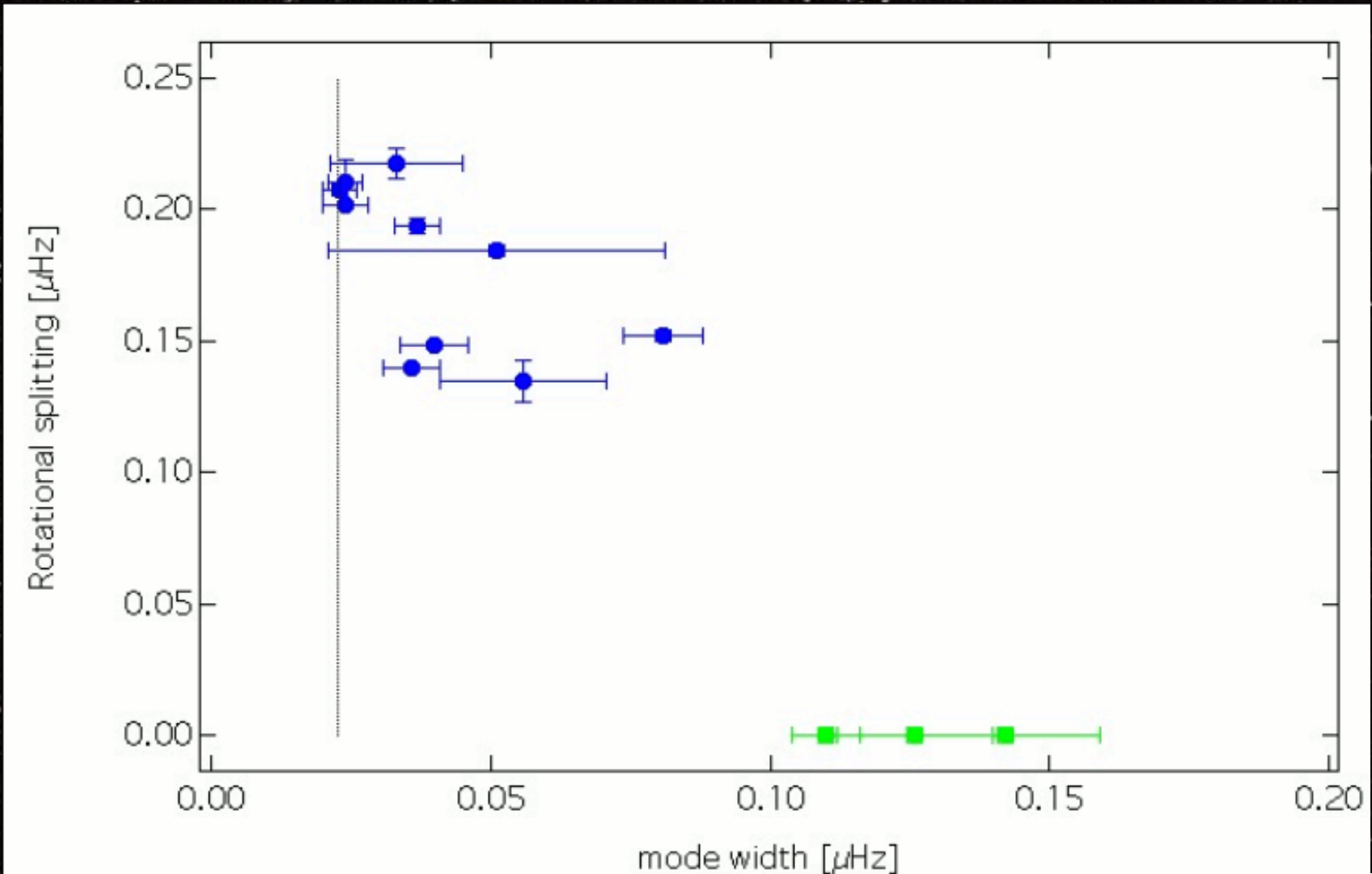
Stellar Ages



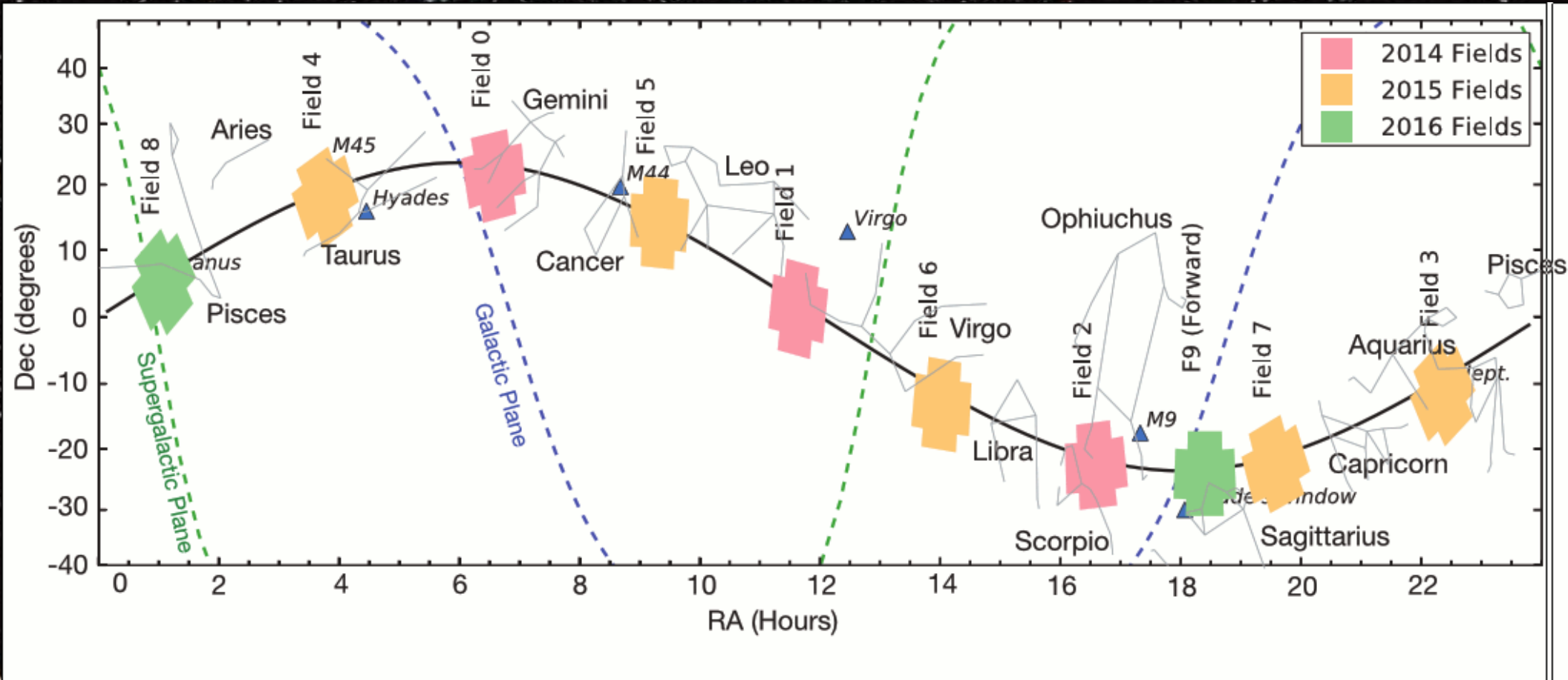
Stellar Ages



Rotation Rate



K2 – Scanning the Ecliptic



Some Conclusions

- With helio- and astero-seismology we can see inside the stars!
- We can measure:
 - Their masses, radii and ages! – for individual stars!
 - Their helium content
 - Location of convection zone boundaries
 - Internal rotation
- The stars teach about atomic + plasma physics
- The new TESS and Plato missions => bright future
- Great tool for Galactic Archeology.