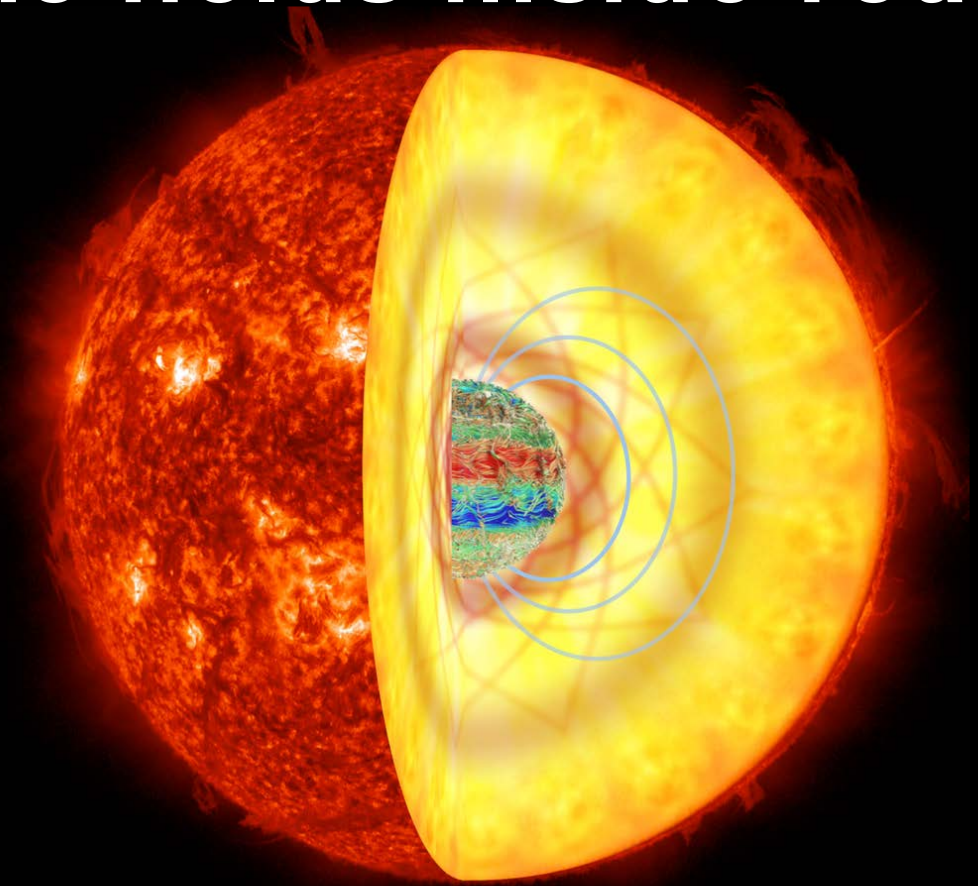
The University of Sydney

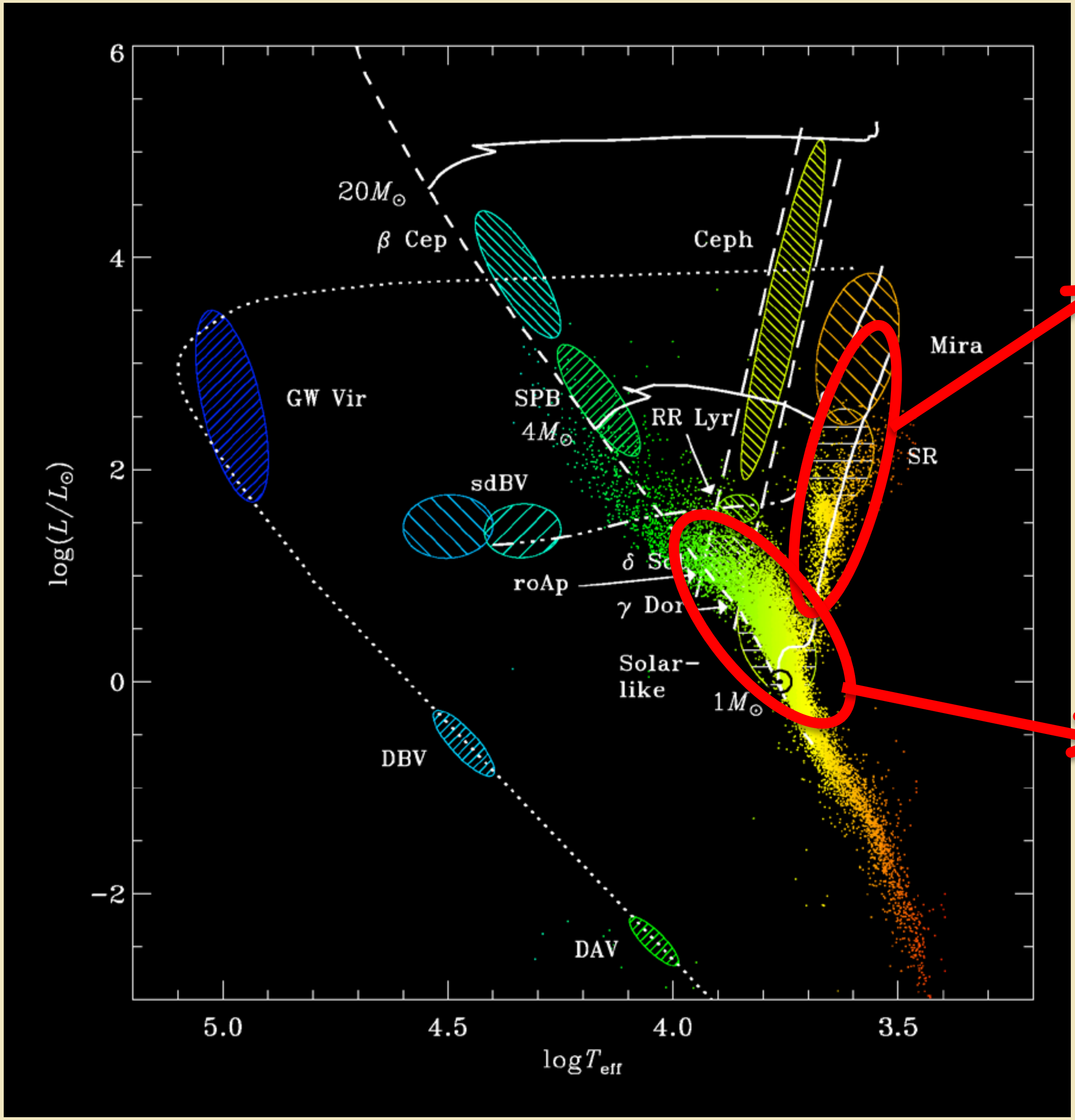
Magnetic fields inside red giants



Dennis Stello

STELLAR ASTROPHYSICS CENTRE

The Must Show Diagram



Red giants:

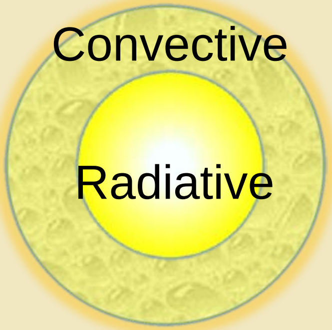
(1) Hydrogen-shell burning (along red giant branch)

(2) Helium-core burning (red clump, secondary clump, horizontal branch)

Red giant progenitors 0.7-2.5Msun

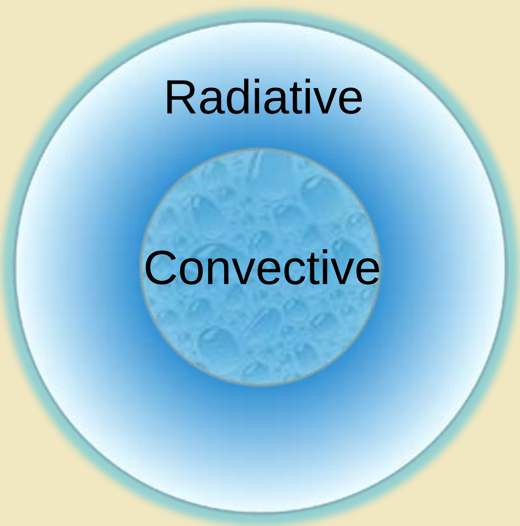
Interior structure

Low-mass Star

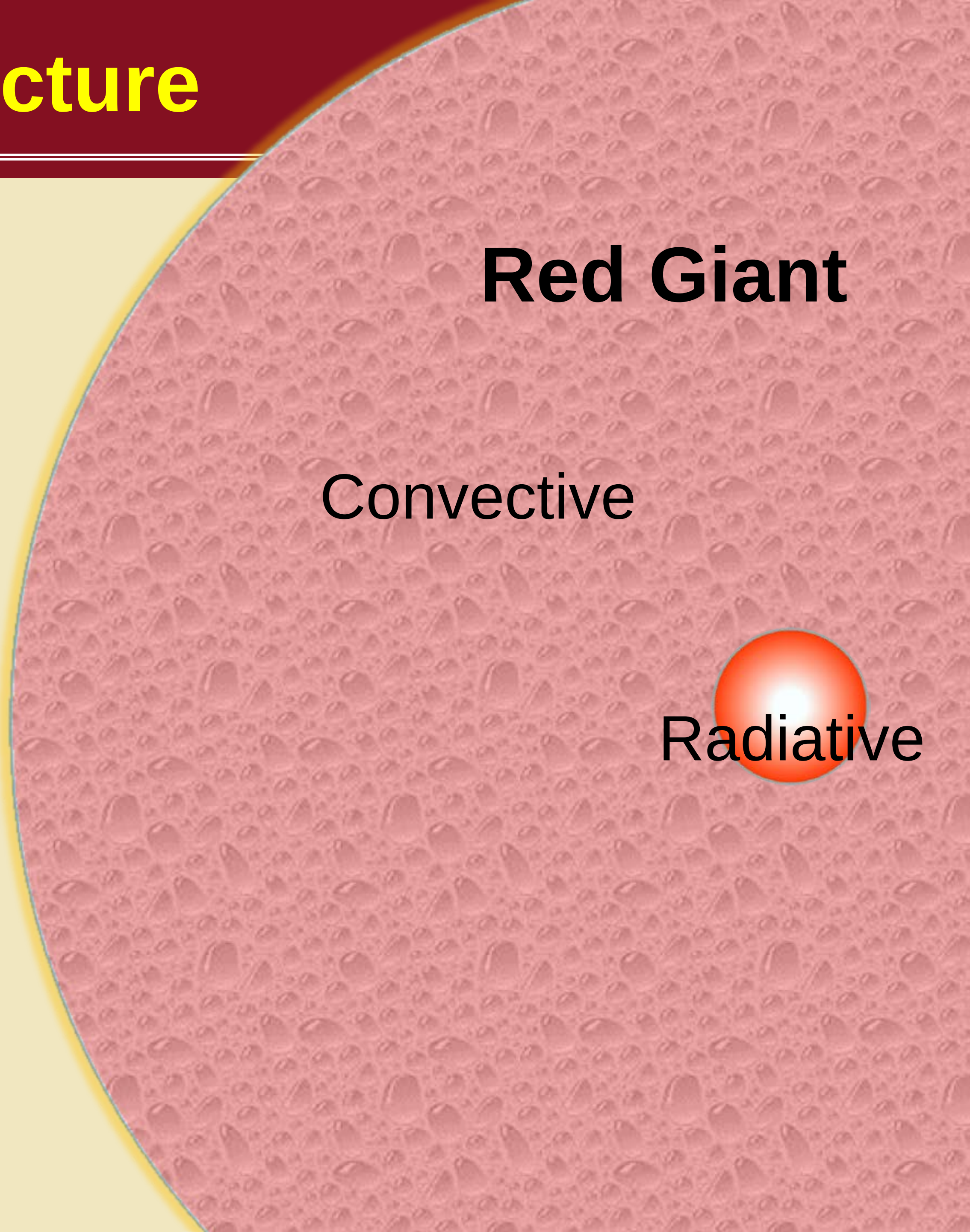


M < 1.2 Msun

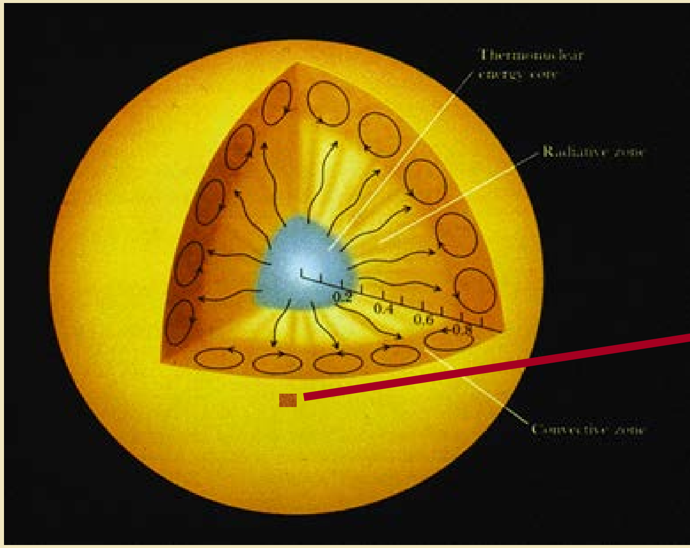
Intermediate-mass Star

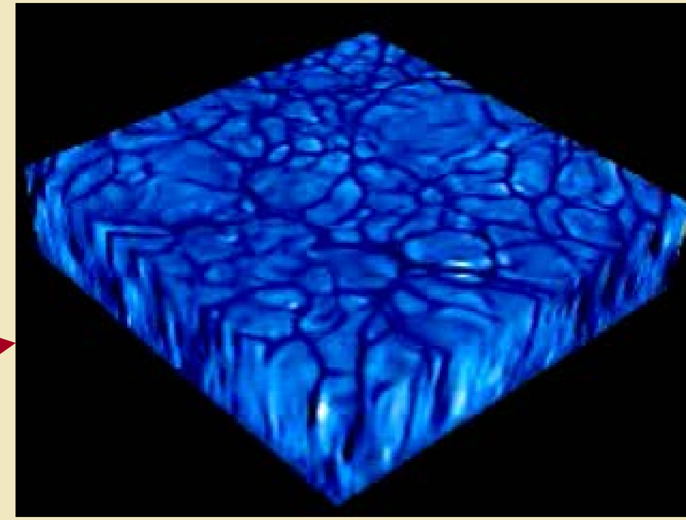


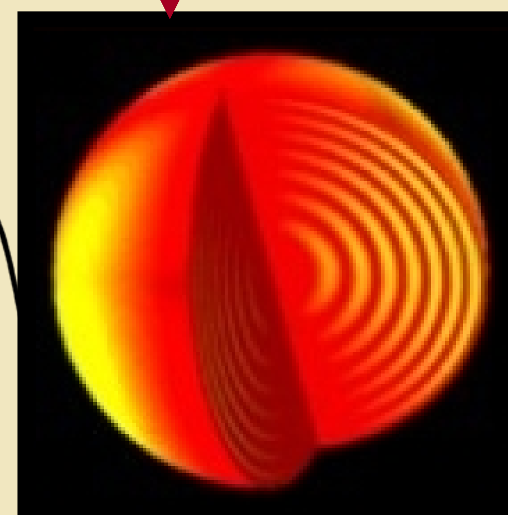
M > 1.2 Msun



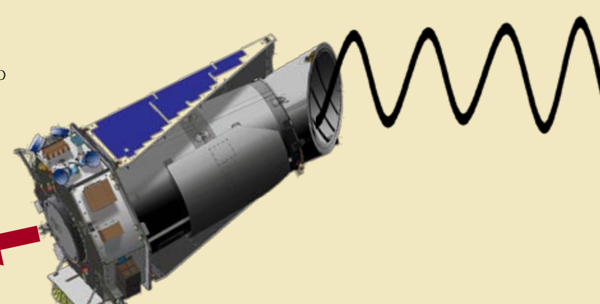
Excitation of solar-like oscillations

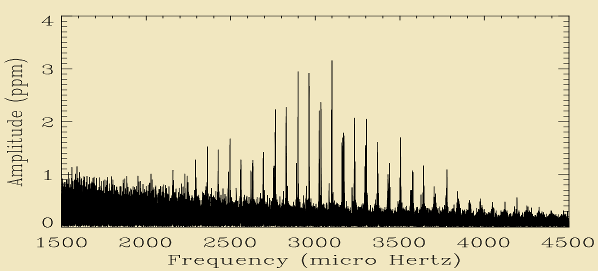


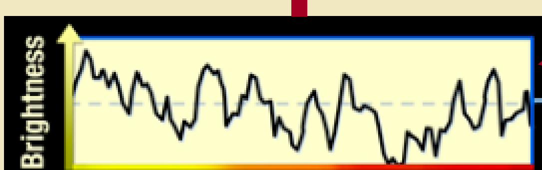




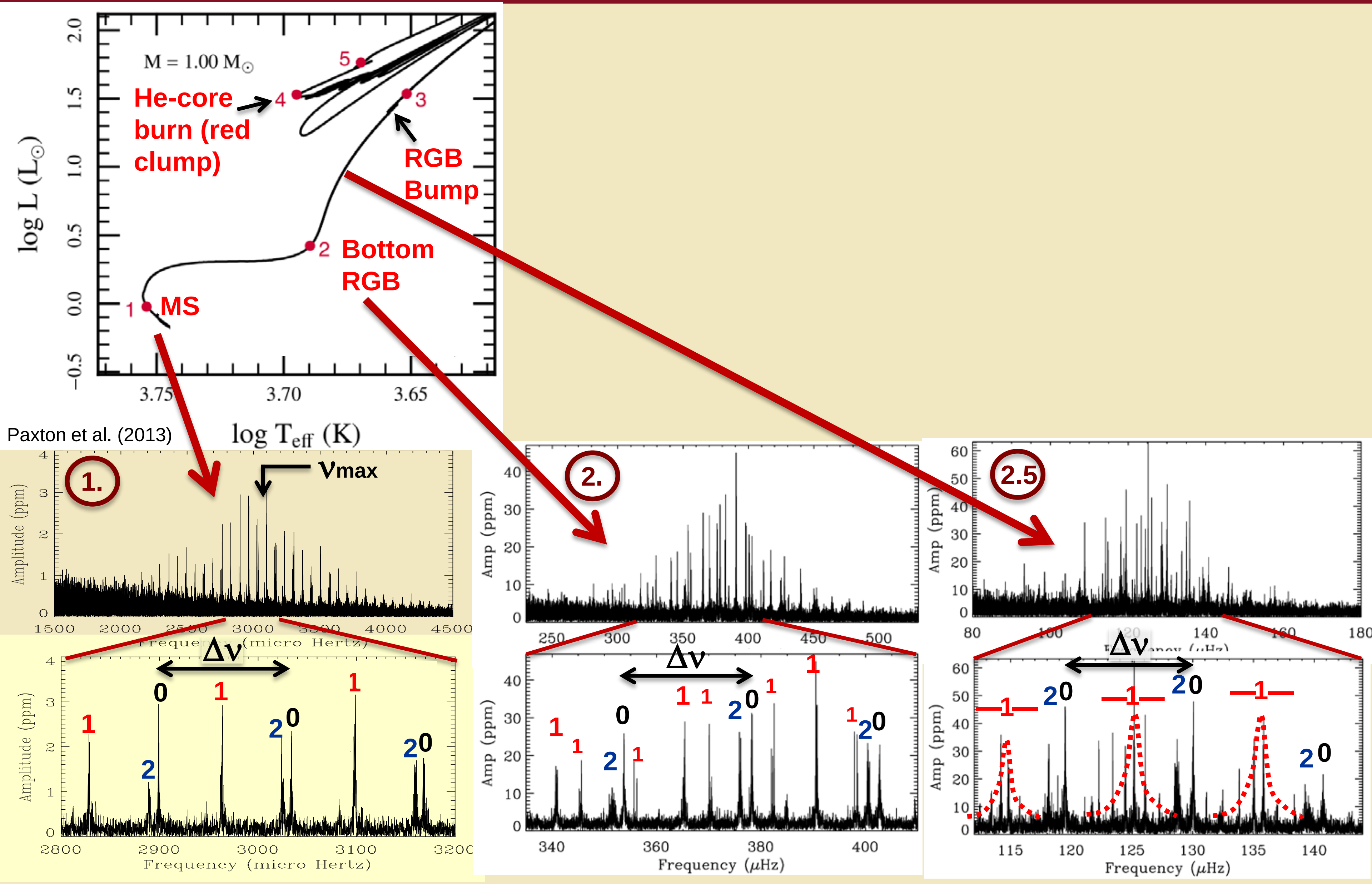
Standing sound waves (p modes)



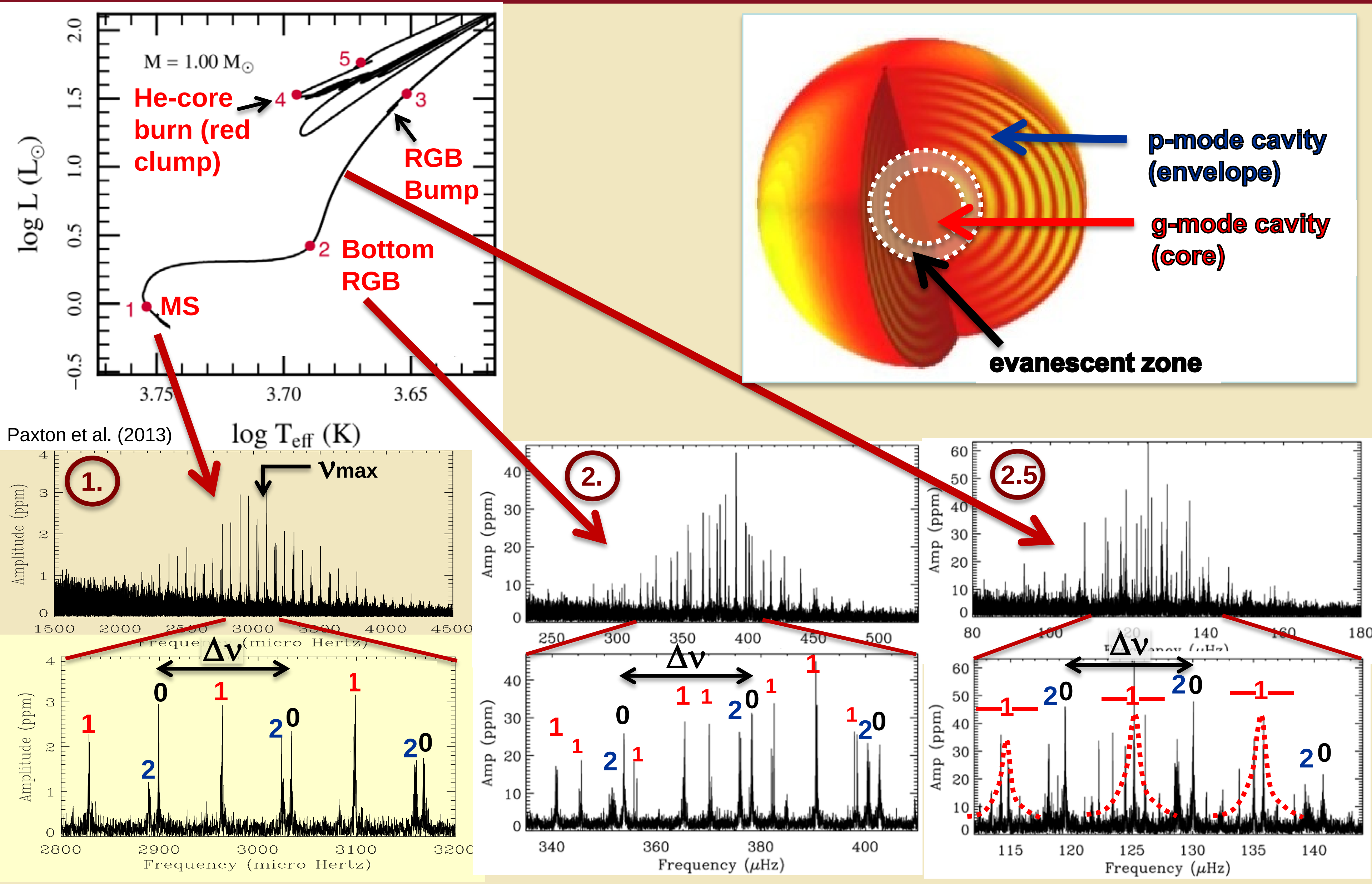




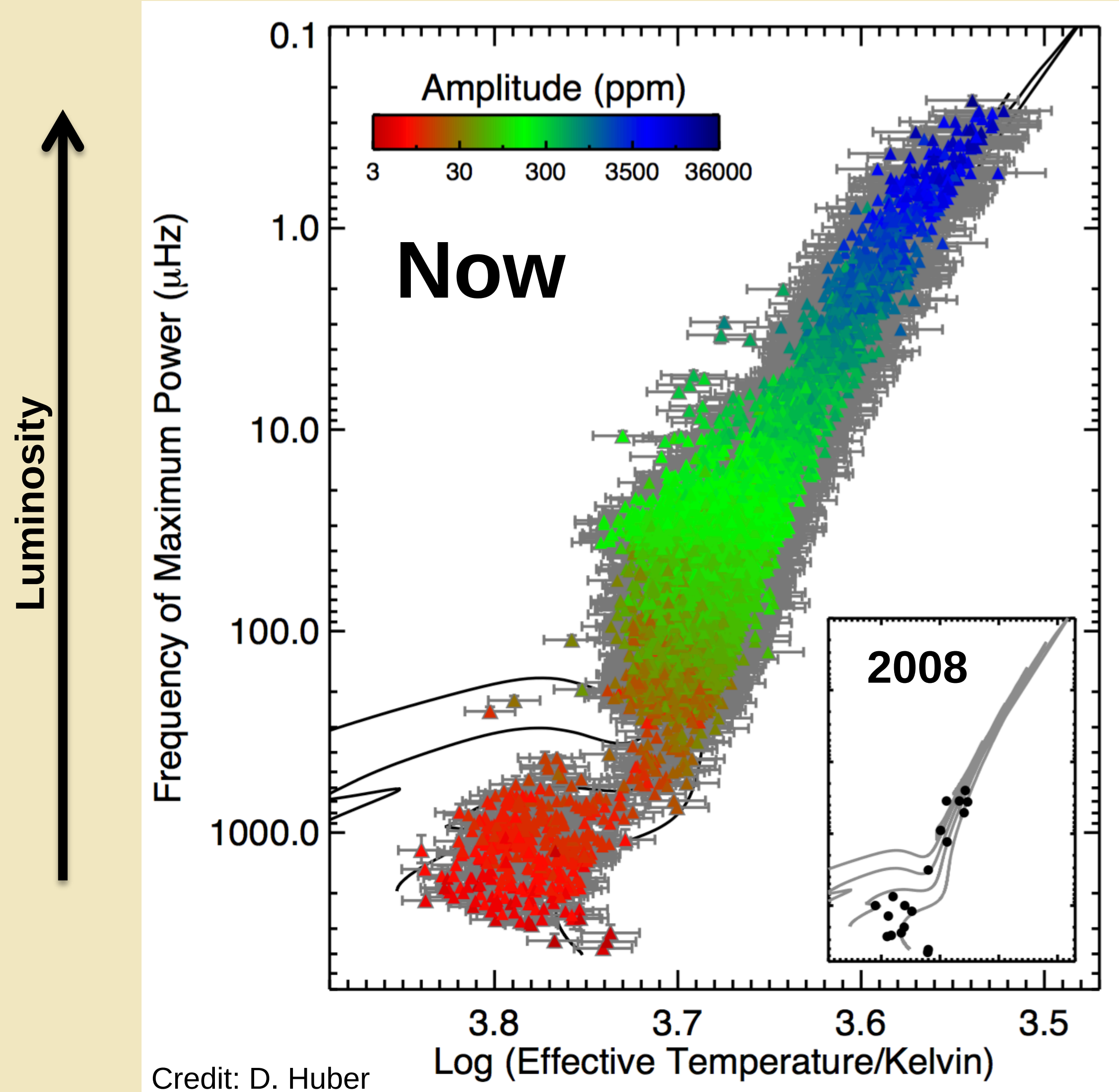
Evolution of frequency spectra



Evolution of frequency spectra



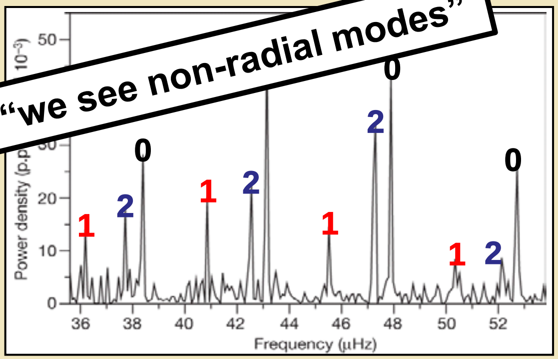
Revolutionising data



Credit: D. Huber

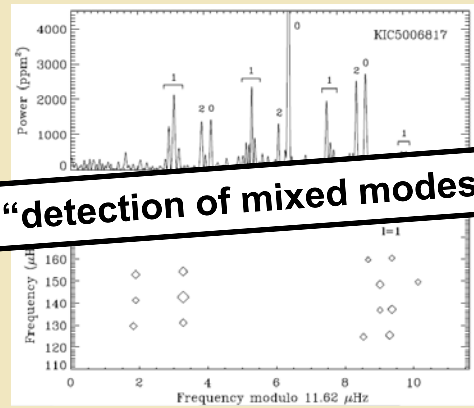
Recent red giant breakthroughs

"we see non-radial modes"



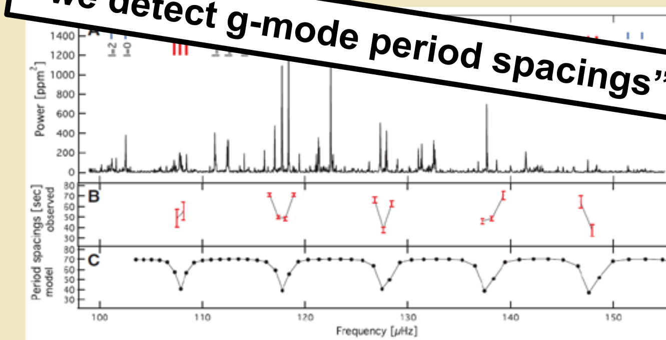
De Ridder et al. (2009)

"detection of mixed modes"



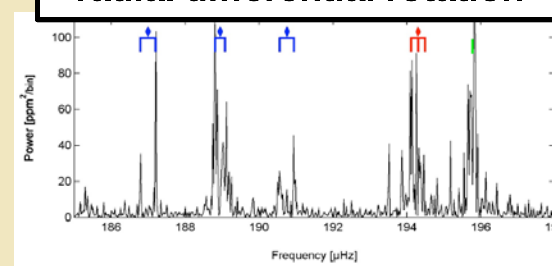
Bedding et al. (2010)

"we detect g-mode period spacings"



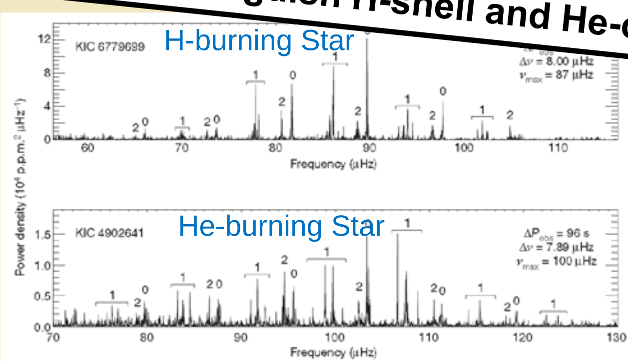
Beck et al. (2011)

"radial differential rotation"

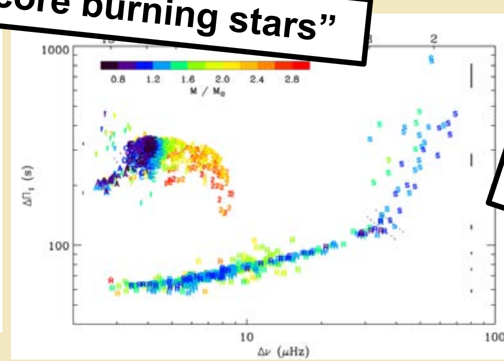


Beck et al. (2012)

"we distinguish H-shell and He-core burning stars"

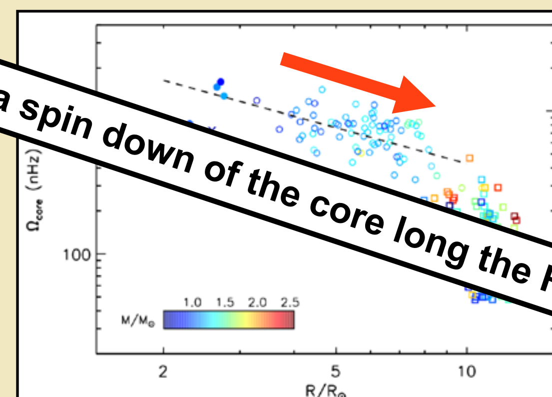


Bedding et al. (2011)



Mosser et al. (2014)

"a spin down of the core long the RGB"



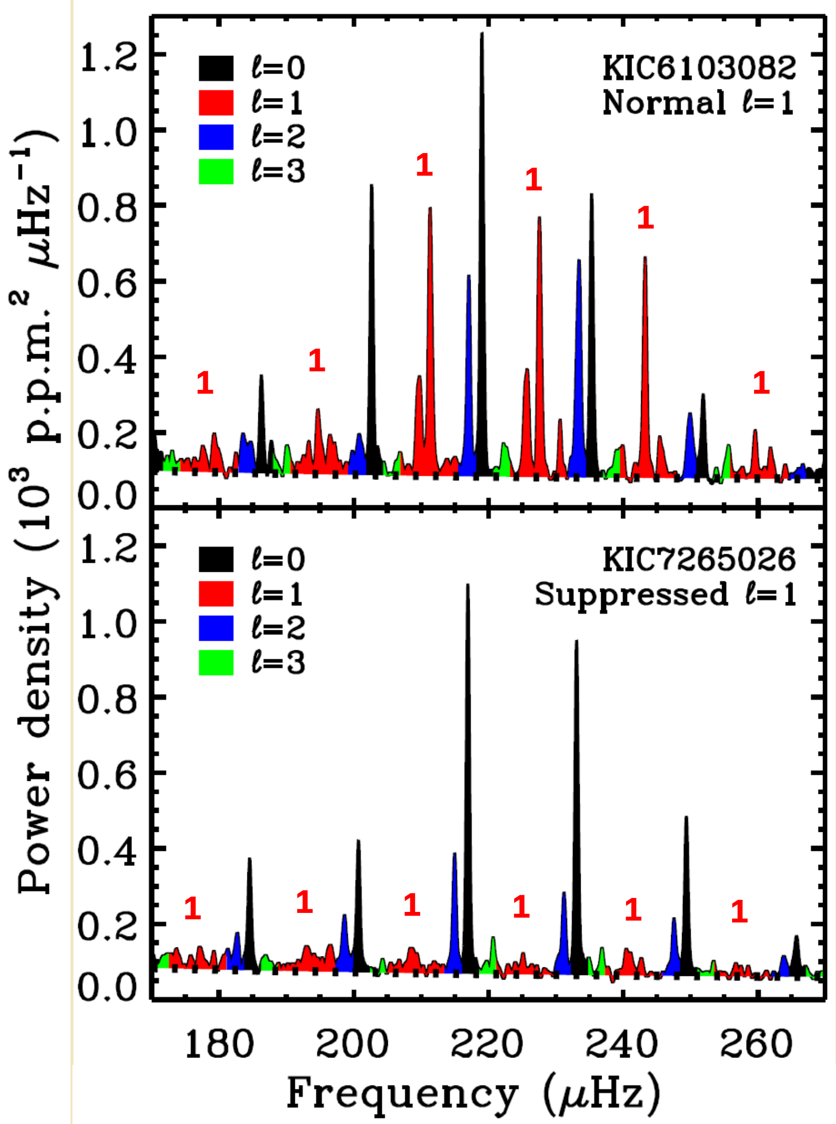
Mosser et al. (2013)

A mystery arises…

"A family of [~40] red giants with very weak [depressed] dipole modes is identified"

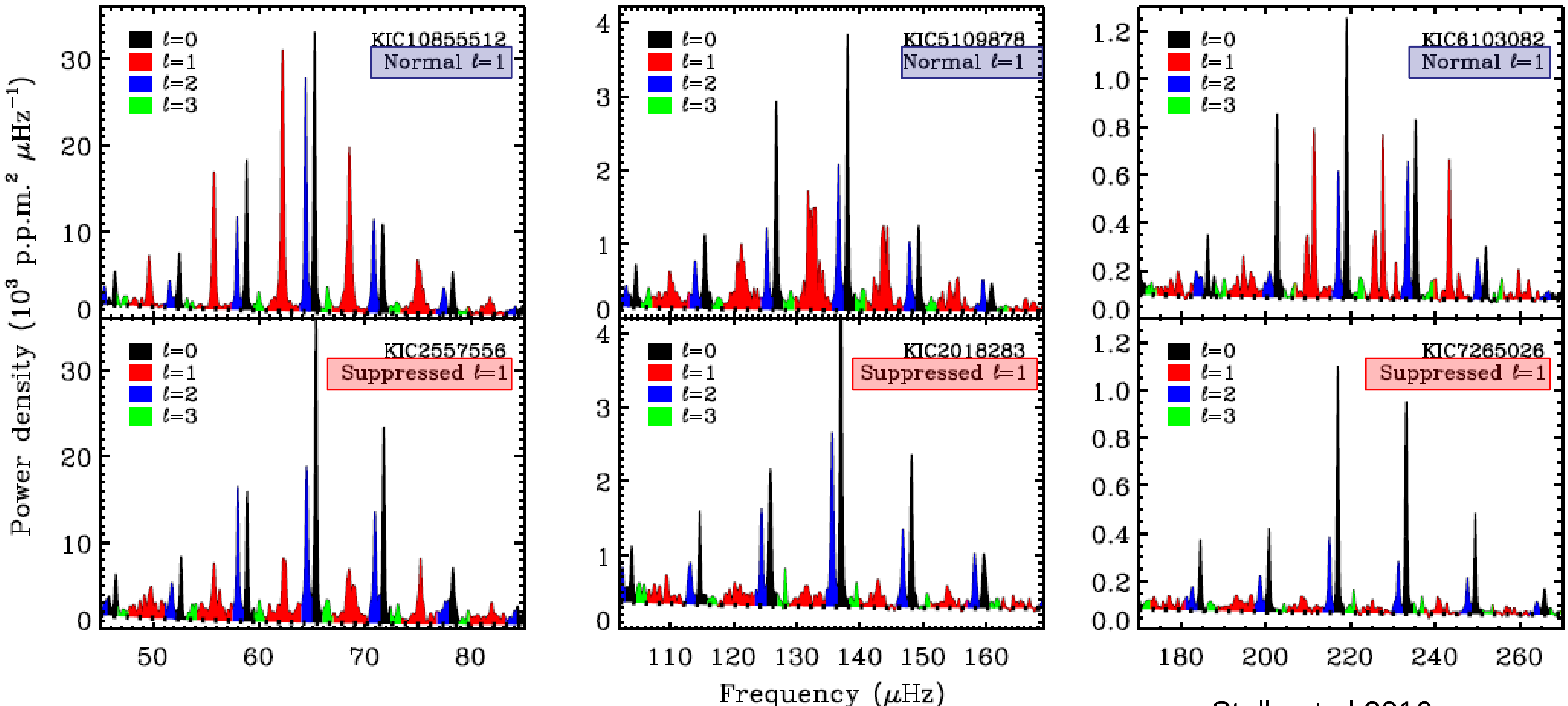
Mosser et al. 2012

[based on < 2yrs of Kepler data]



Stello et al.2016a

Missing dipole modes

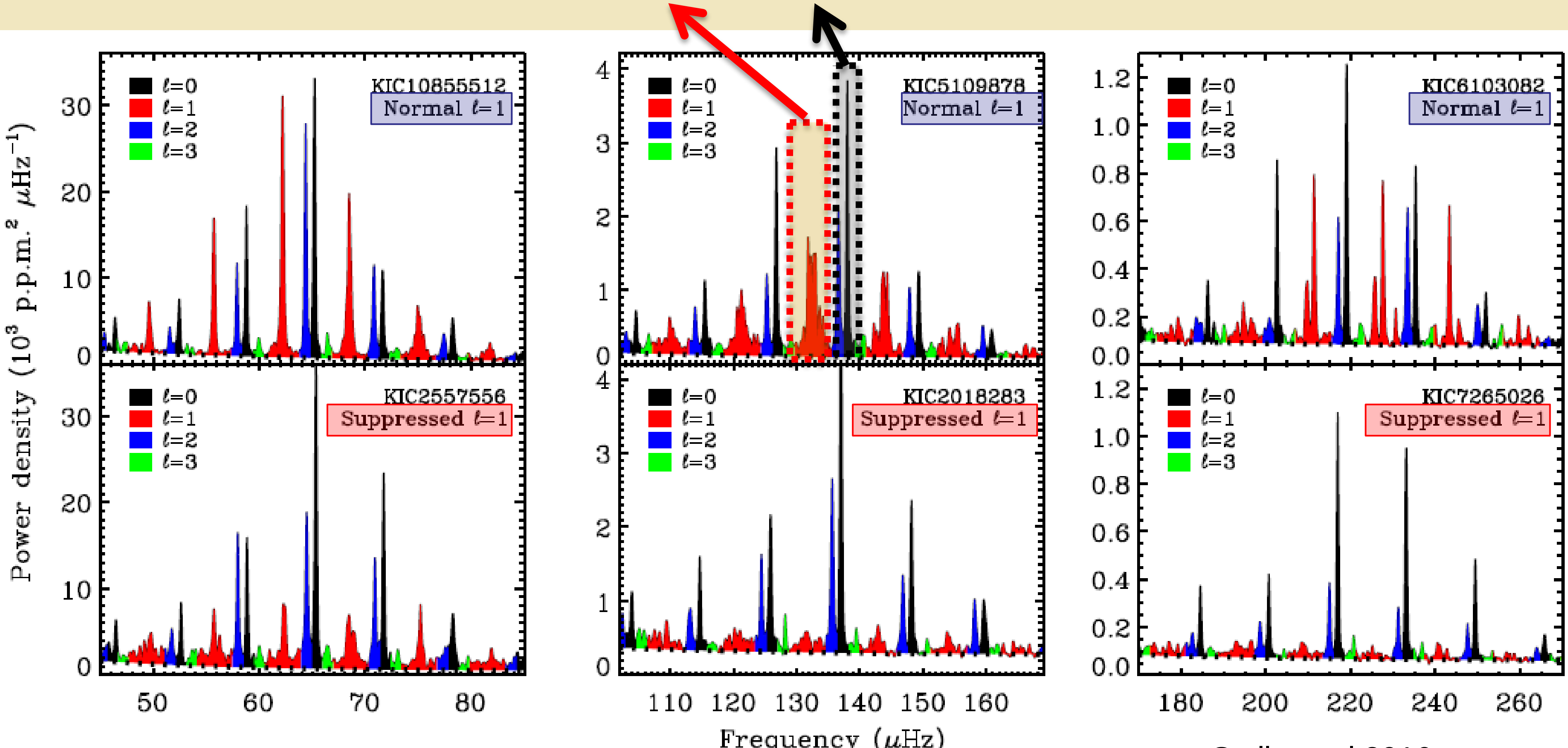


Stello et al.2016a

Stars evolve this way

Missing dipole modes

Dipole mode visibility: V^2=Power(l=1)/Power(l=0)



Stello et al.2016a

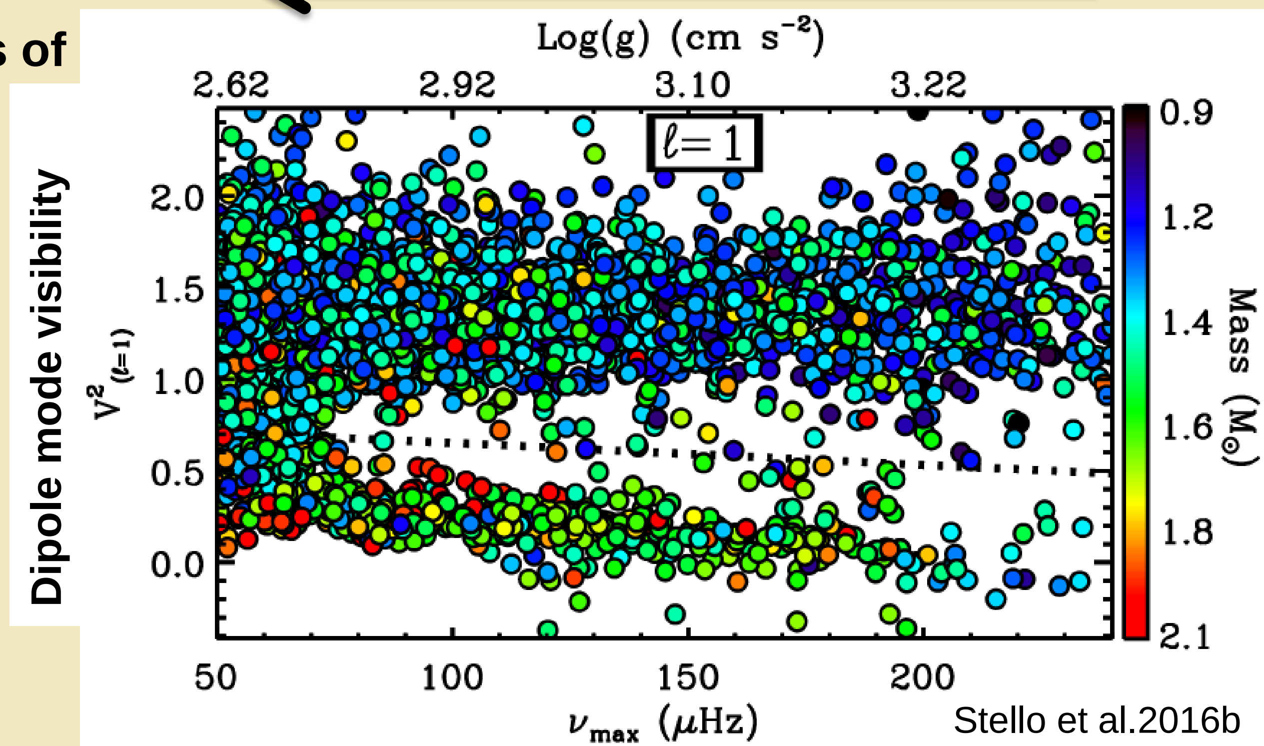
Stars evolve this way

Dipole mode visibility

- The dipole suppressed stars are common, occurring in ~20% (>700) of red giants

Stars evolve this way

Using ~ 4 yrs of Kepler data.



- The visibility of dipole modes depends on the evolutionary state of the star

An idea develops

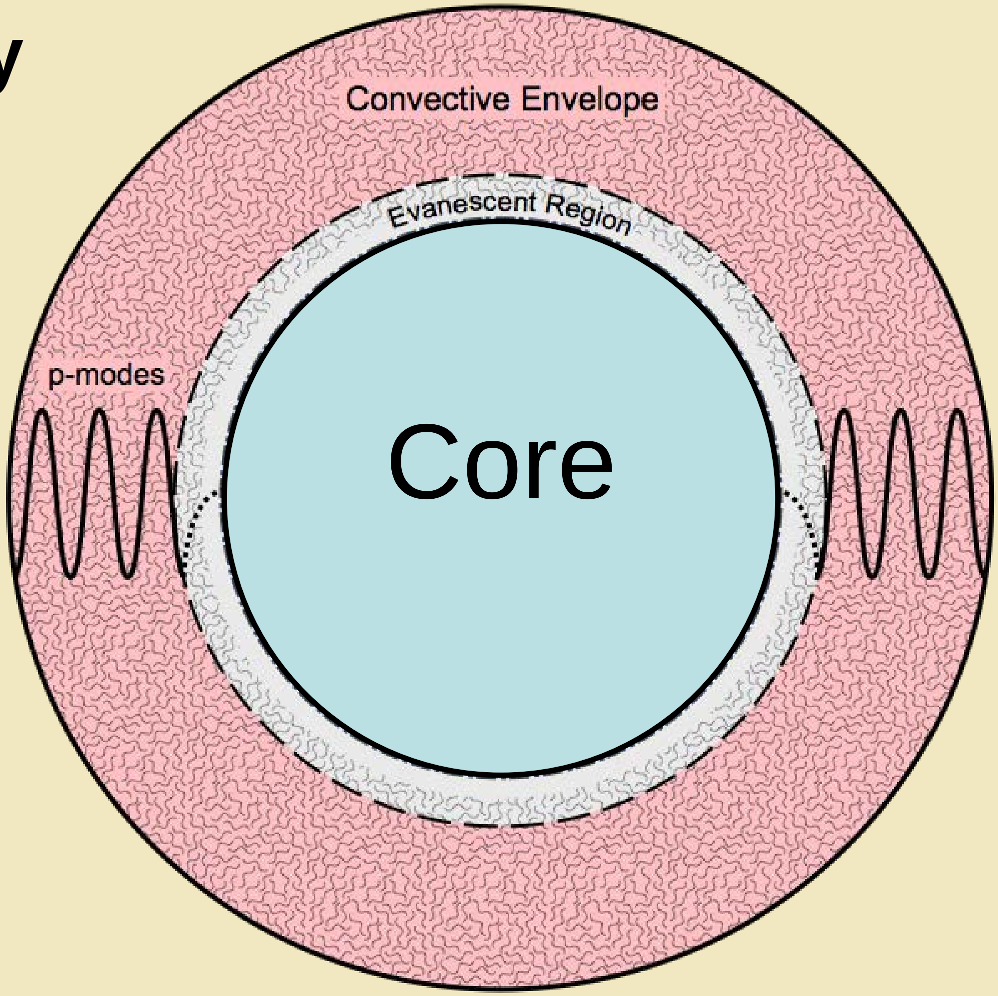
What if all wave energy leaking into the core gets trapped?

Radial-mode lifetime

Mode energy transmission

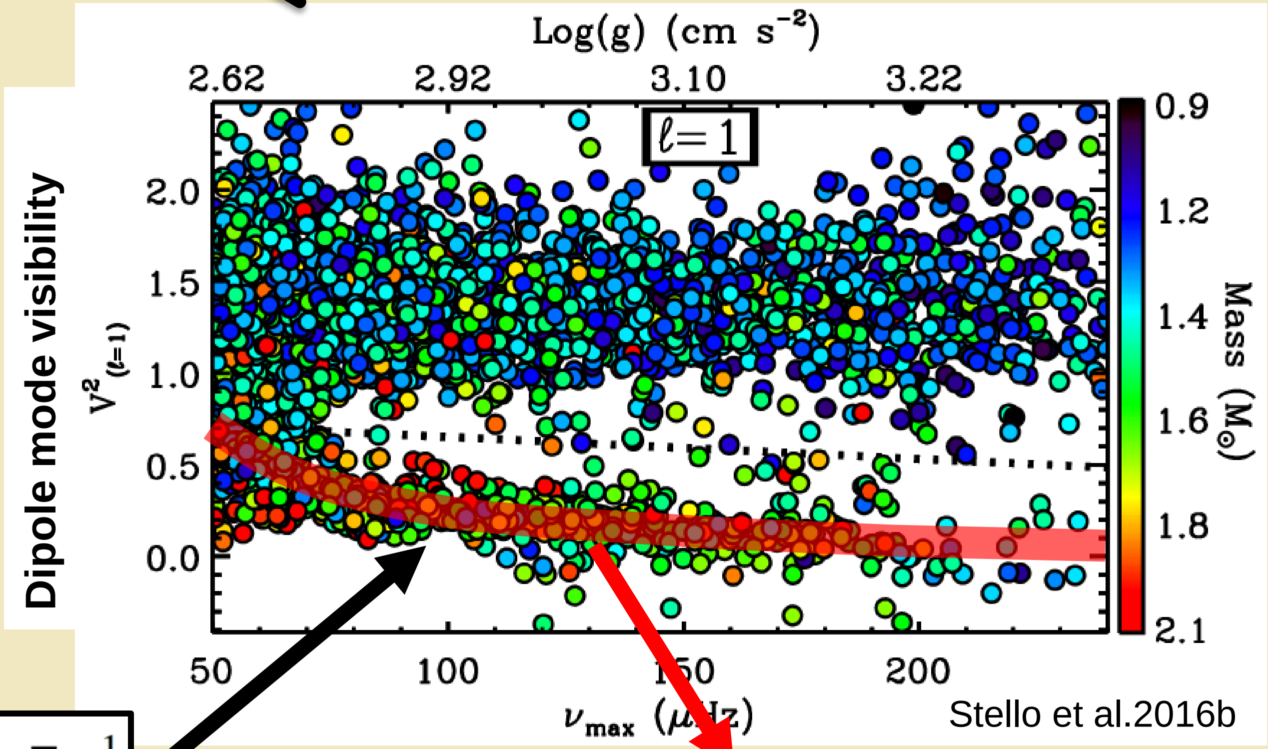
$$\frac{V_{\rm sup}^2}{V_{\rm norm}^2} = \left[1 + \Delta\nu\,\tau\,T^2 \right]^{-1}$$

Fuller et al. (2015)



Dipole mode visibility

Stars evolve this way



$$\frac{V^2_{\rm sup}}{V^2_{\rm norm}} = \left[1 + \Delta\nu\,\tau\,T^2\right]^{-1}$$

Fuller et al. (2015)

Corsaro et al. (2015)

- **Strong support that almost all energy is trapped in the core.**
- **But what physical mechanism is responsible?**

Magnetic fields

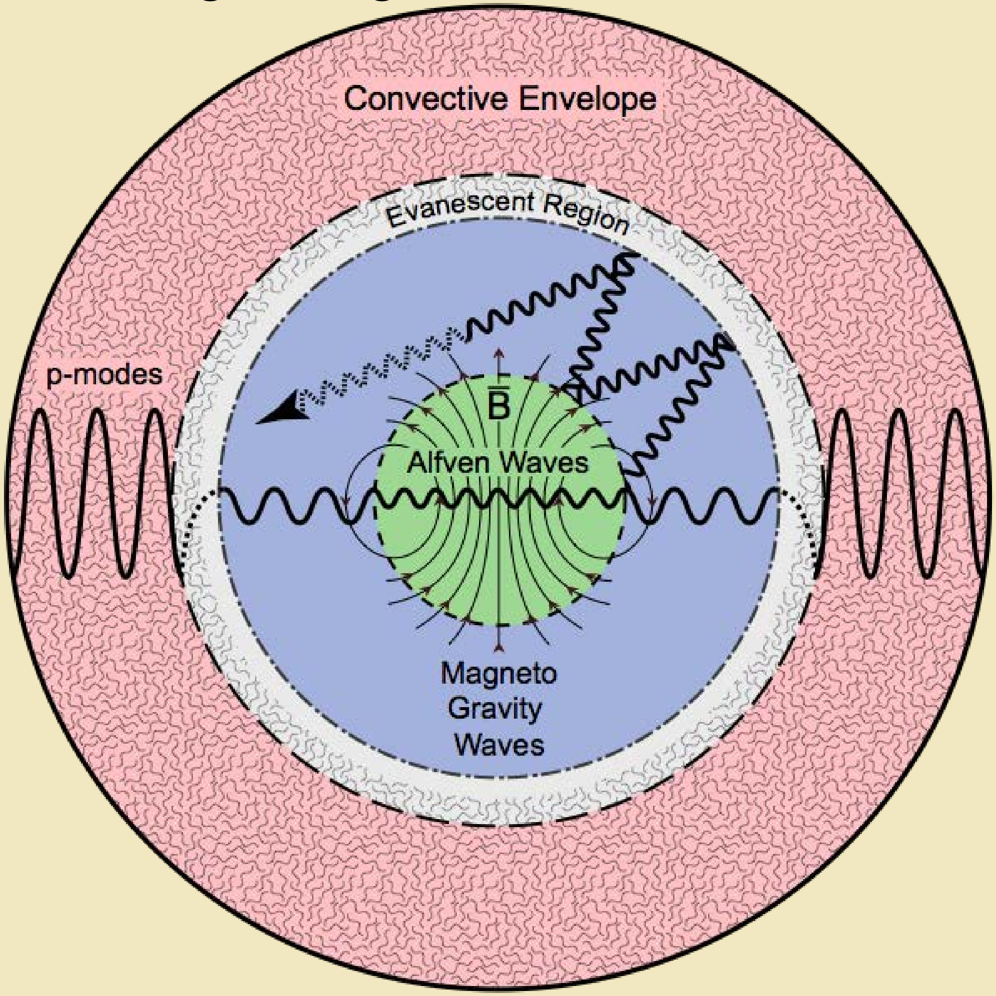
Magnetic green house effect

1. Waves excited by turbulent convection near stellar surface, travel inward, and tunnel into radiative core

2. Ingoing waves reflect off regions of high field strength

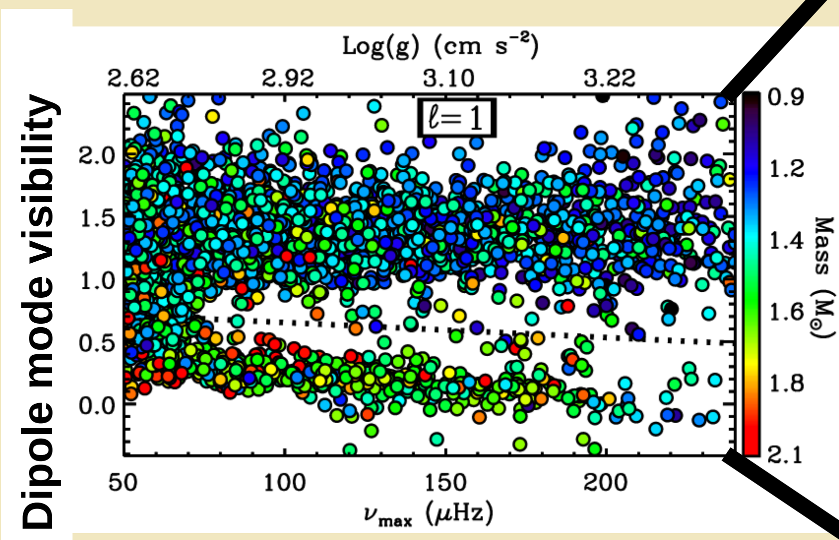
3. Magnetic mirror converts gravity waves into Alfven waves (Lecoanet et al., in prep)

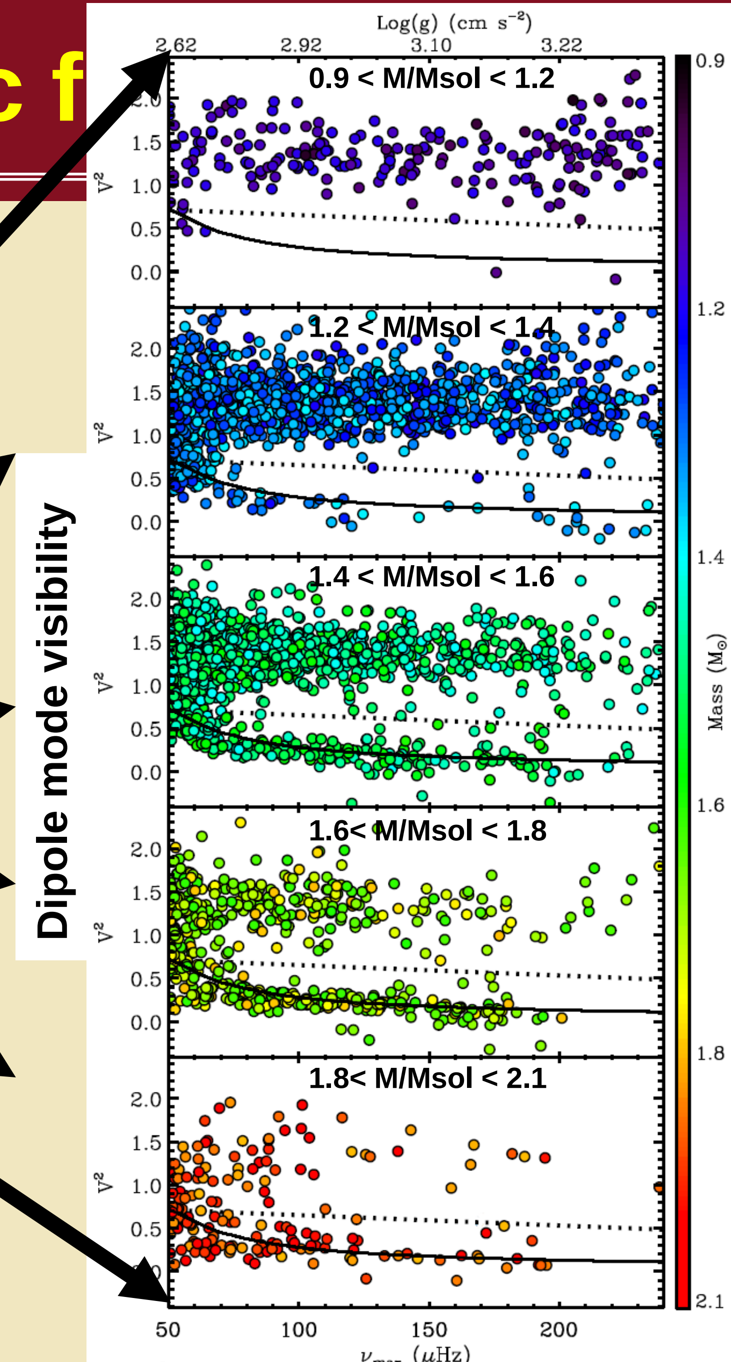
4. Alfven waves dissipate in regions with small magnetic fields



Fuller et al. (2015)

Magnetic f

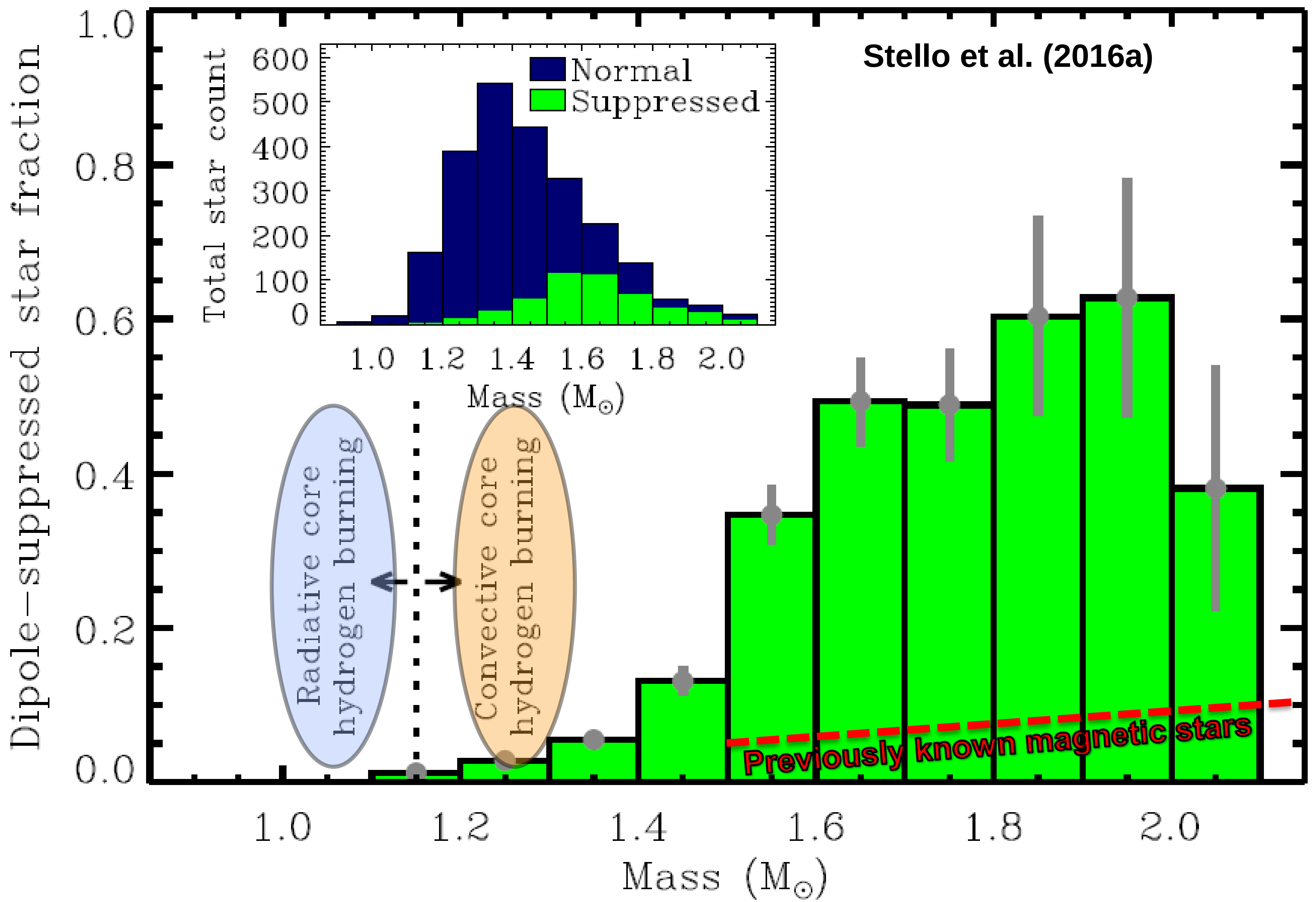




Stars evolve this way

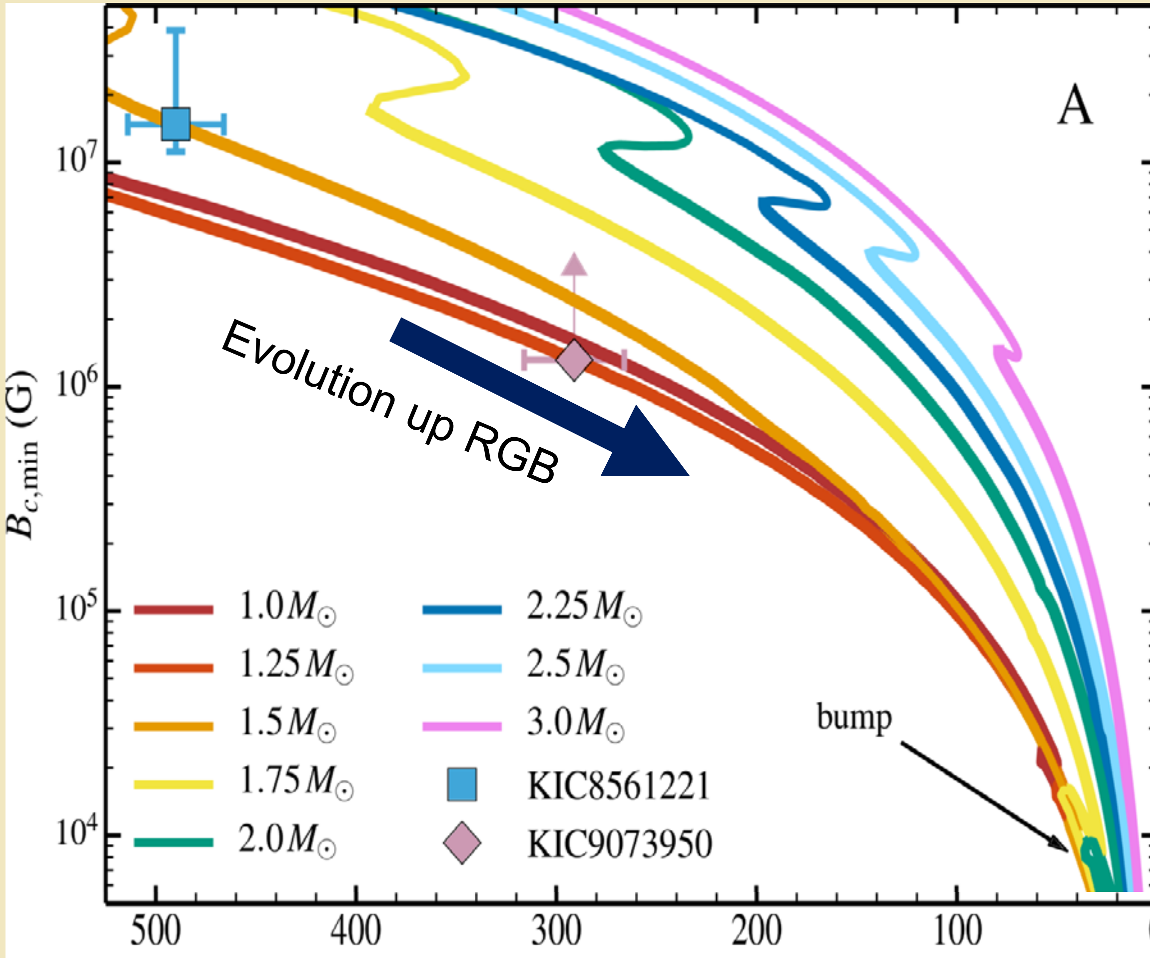
Stello et al. (2016a)

Core dynamo-generated fields



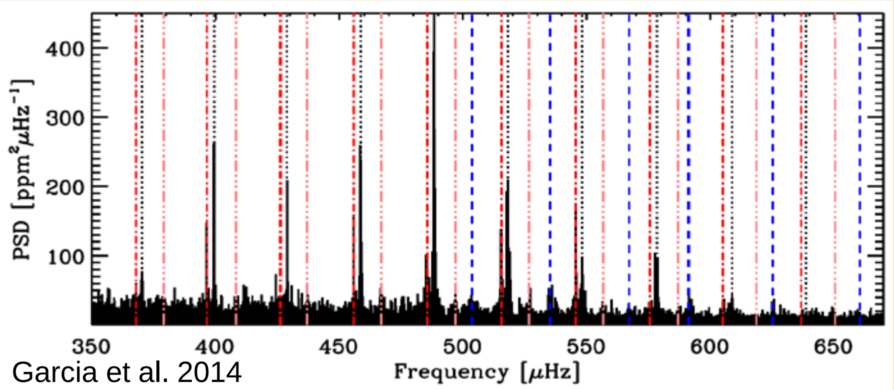
Minimum magnetic field for magnetic greenhouse effect to operate

$$B_c = \sqrt{\frac{\pi\rho}{2}\,\frac{\omega^2 r}{N}}$$

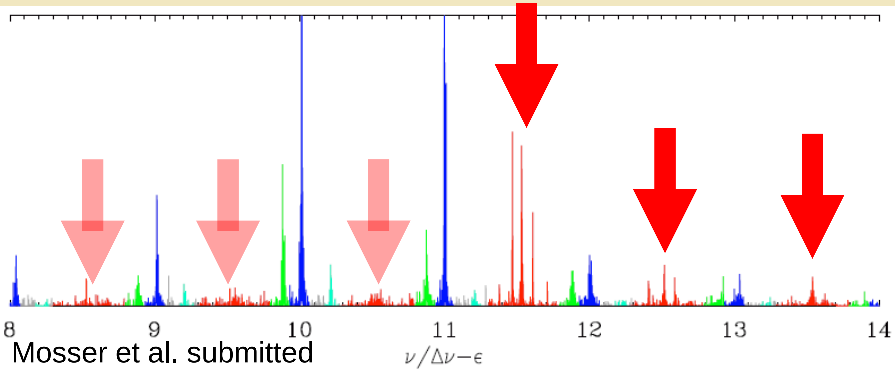


Fuller et al. 2015

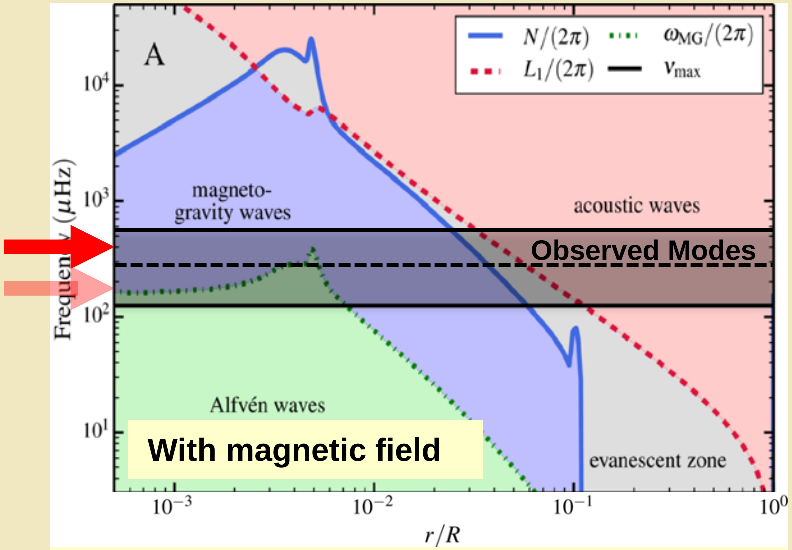
Measurement of magnetic field in Droopy-like stars

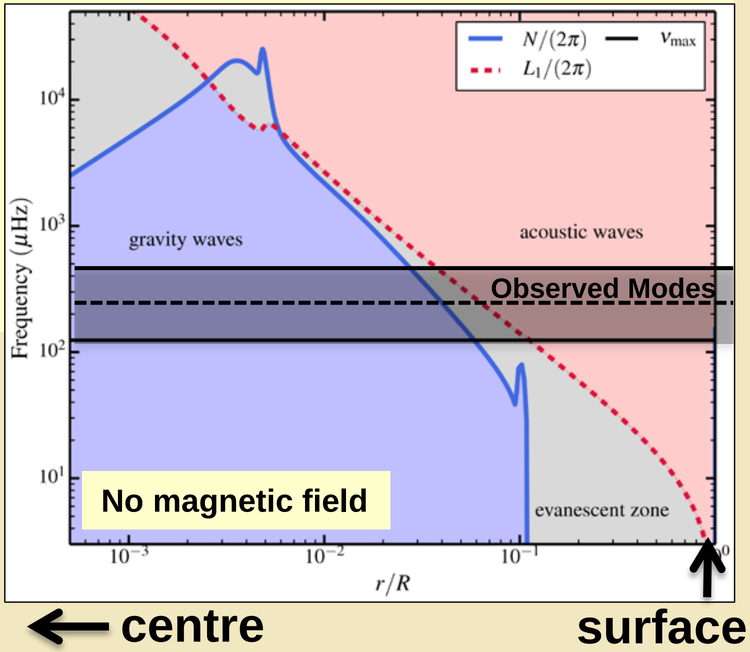


Garcia et al. 2014



Mosser et al. submitted





- **Modes above cutoff frequency not suppressed.**
- **Measurement of cutoff frequency yields B-field at H-burning shell: ≈10^7 G**

Further tests of the theory

"...we have to conclude that only l=1 are affected"

Mosser et al. 2012

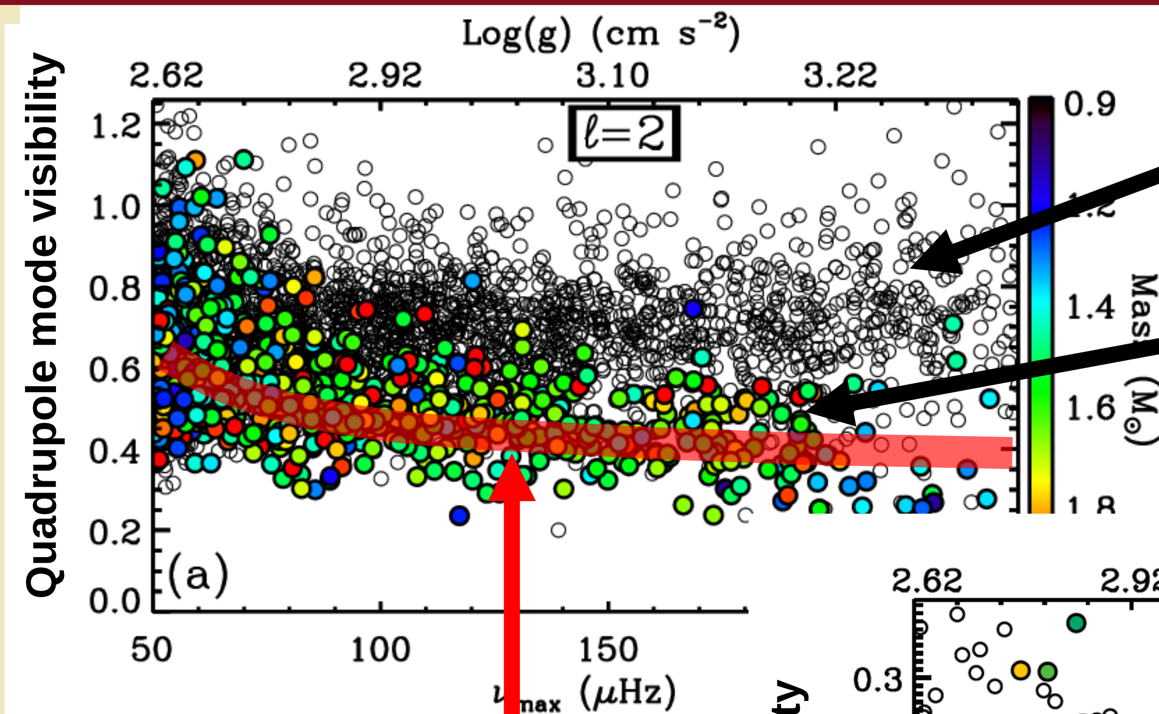
$$\frac{V_{\rm sup}^2}{V_{\rm norm}^2} = \left[1 + \Delta\nu\,\tau\,T^2\right]^{-1}$$

Can we test that now with 4yrs of Kepler data?

Strong dependence on mode degree

$$T \sim \left(\frac{r_1}{r_2}\right)^{\sqrt{\ell(\ell+1)}}$$

What about l=2 and l=3?

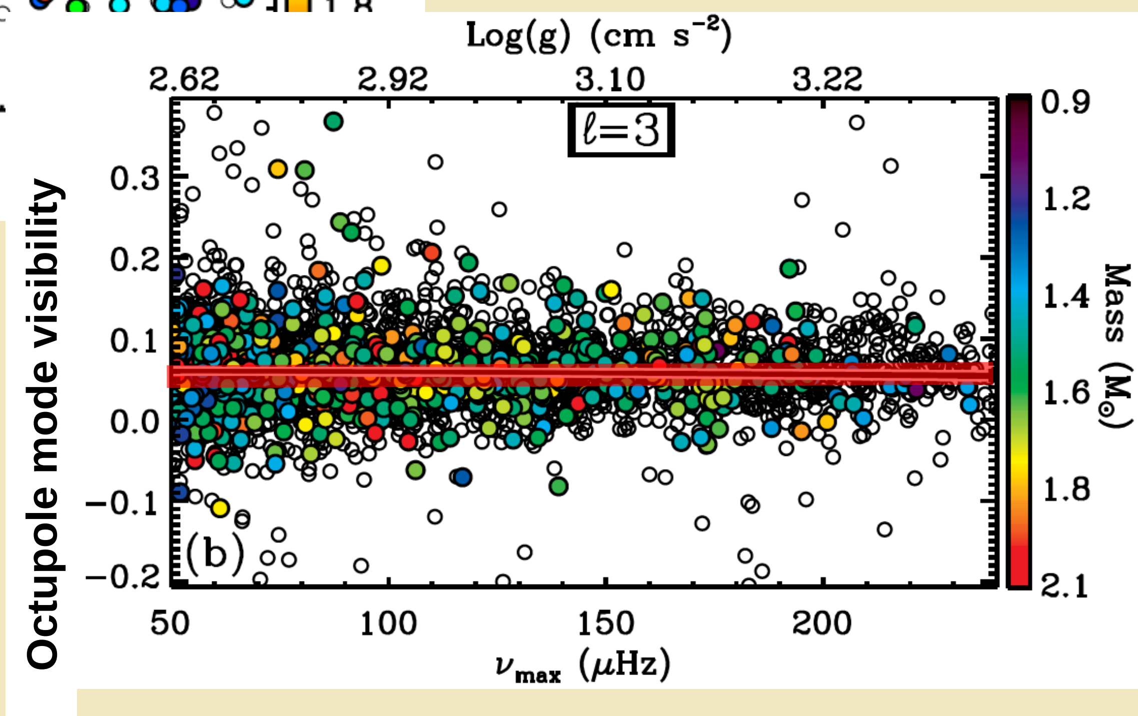


Empty symbols = Normal stars

Filled coloured symbols = Dipole-suppressed stars

Stello et al. (2016b)

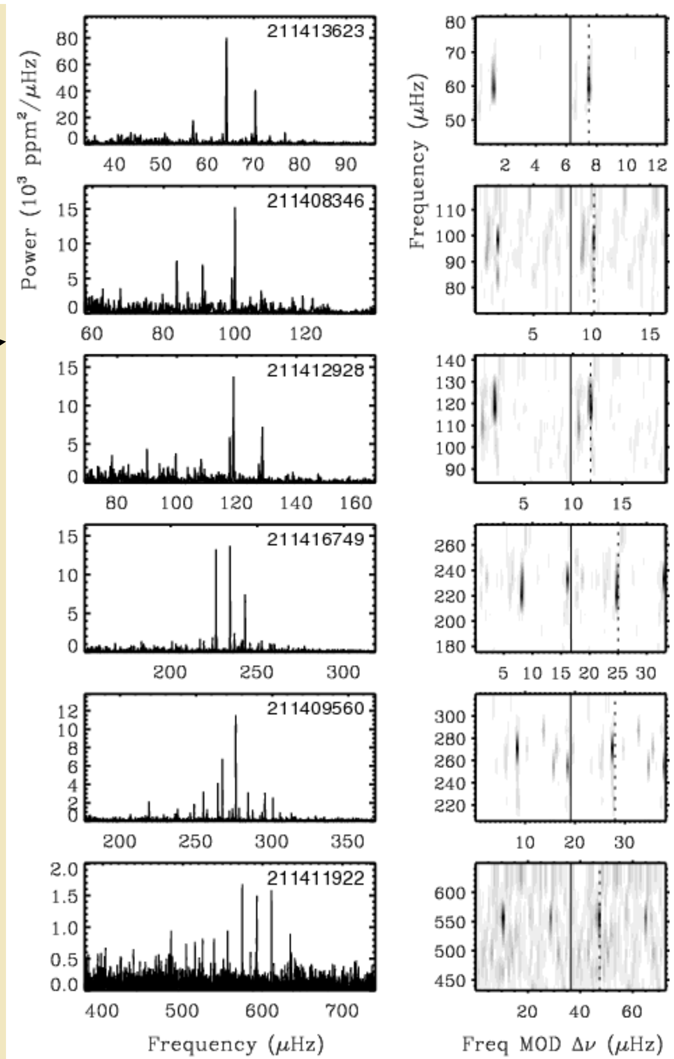
$$\frac{V_{\rm sup}^2}{V_{\rm norm}^2} = \left[1 + \Delta\nu\,\tau\,T^2\right]^{-1}$$



Future work

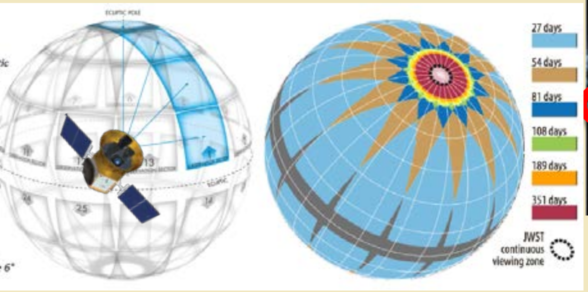
- **Connection to surface rotation (*Ceillier et al. in prep*).**
- **Search for supressed mixed modes (*Mosser et al. submitted KASOC*).**
- **Mode visibility in cluster stars (*Stello et al. in prep*).**
- **We can do this sort of analysis using short time series: including K2 and TESS.**

K2 observes open cluster M67

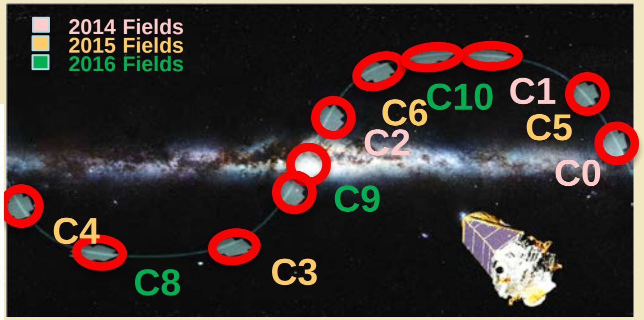


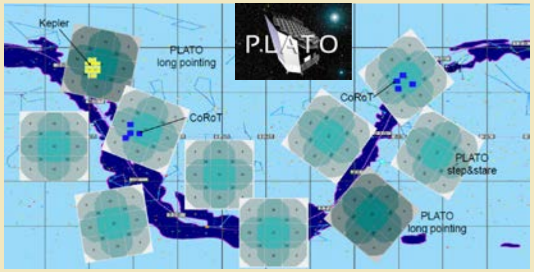
Stello et al. submitted

~0.5M oscillating red giants



Each campaign field: 10K red giant observed for ~80 days

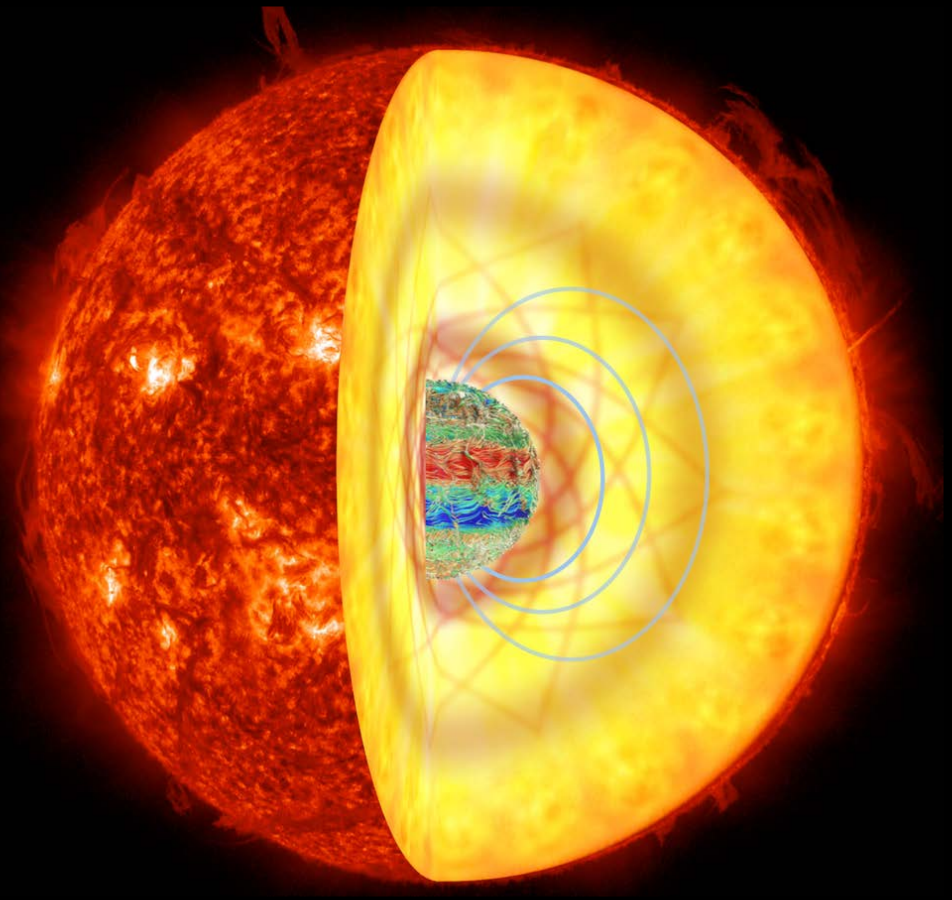




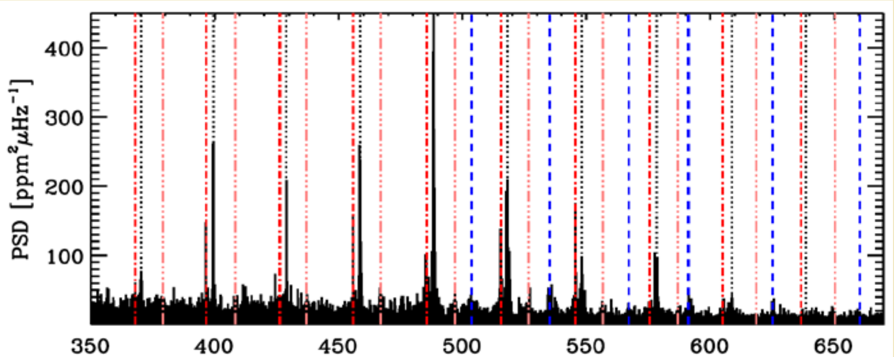

depeche
MODE


Thank you!
depeched
MODES

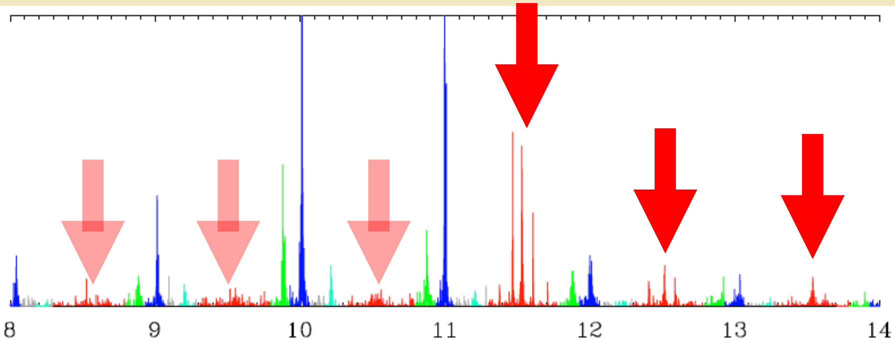
Thank you!



Measurement of magnetic field in Droopy-like stars

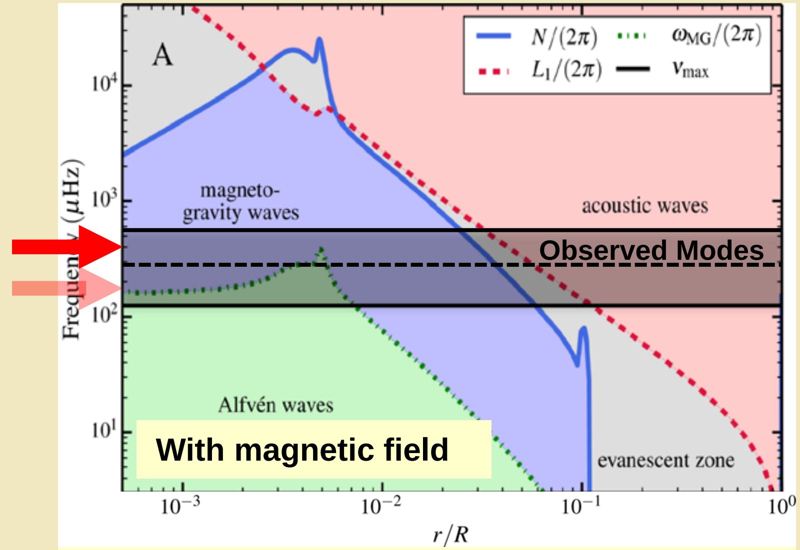


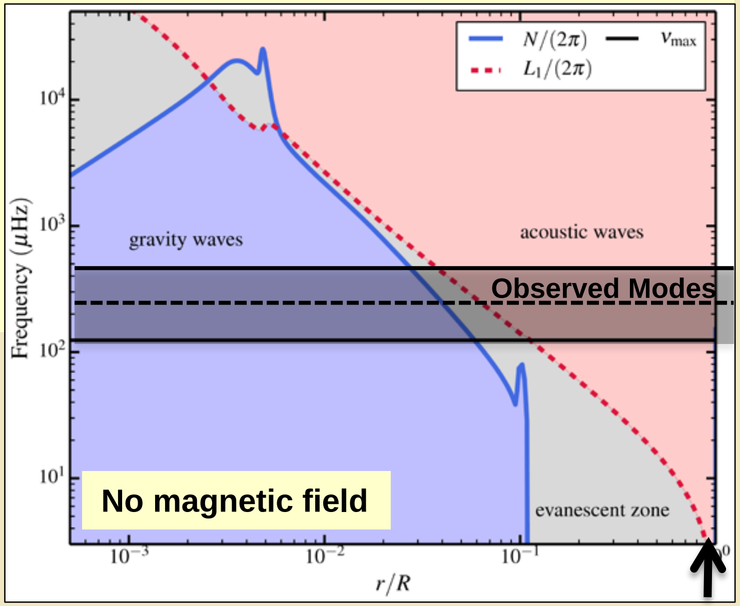
Garcia et al. 2014



Mosser et al. submitted

- Modes above cutoff frequency not suppressed.
- Measurement of cutoff frequency yields B-field at H-burning shell: $\approx 10^7$ G





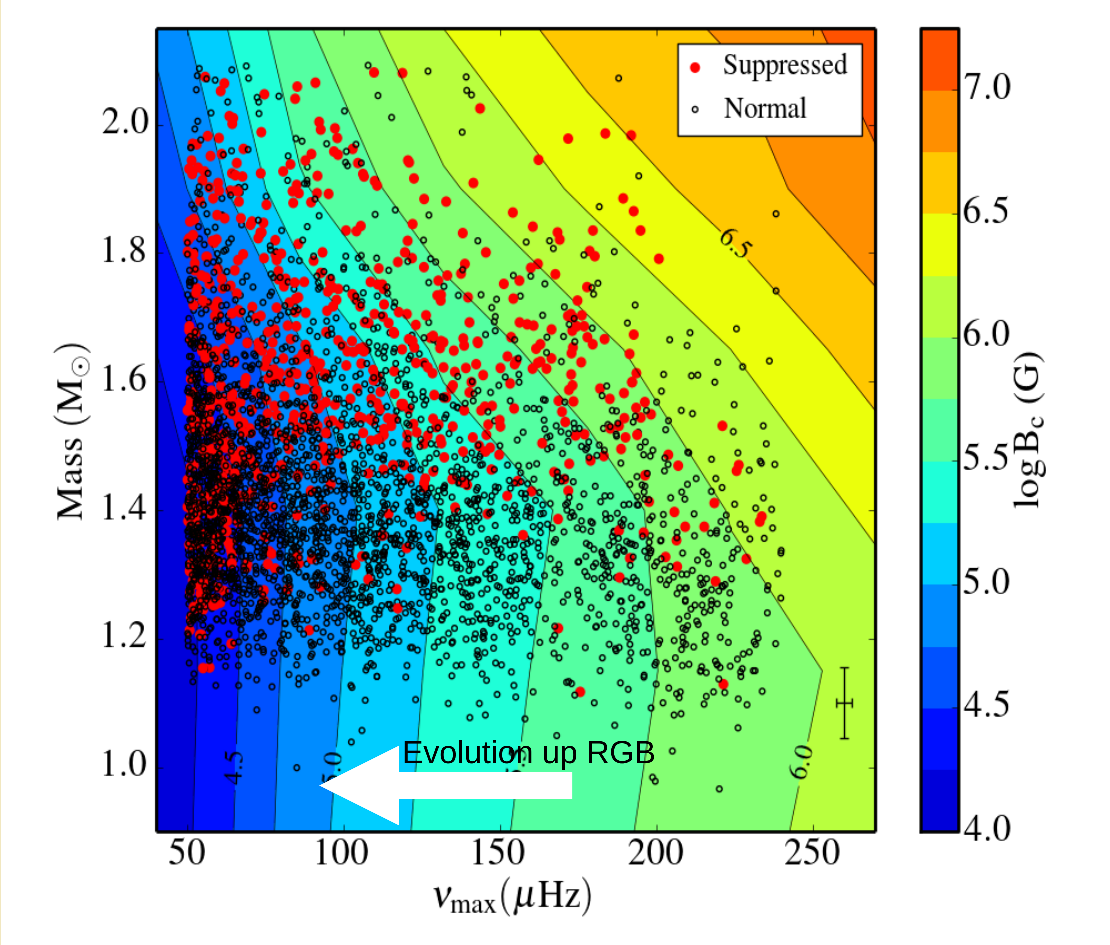
centre

surface

Magnetic fields for the Kepler sample

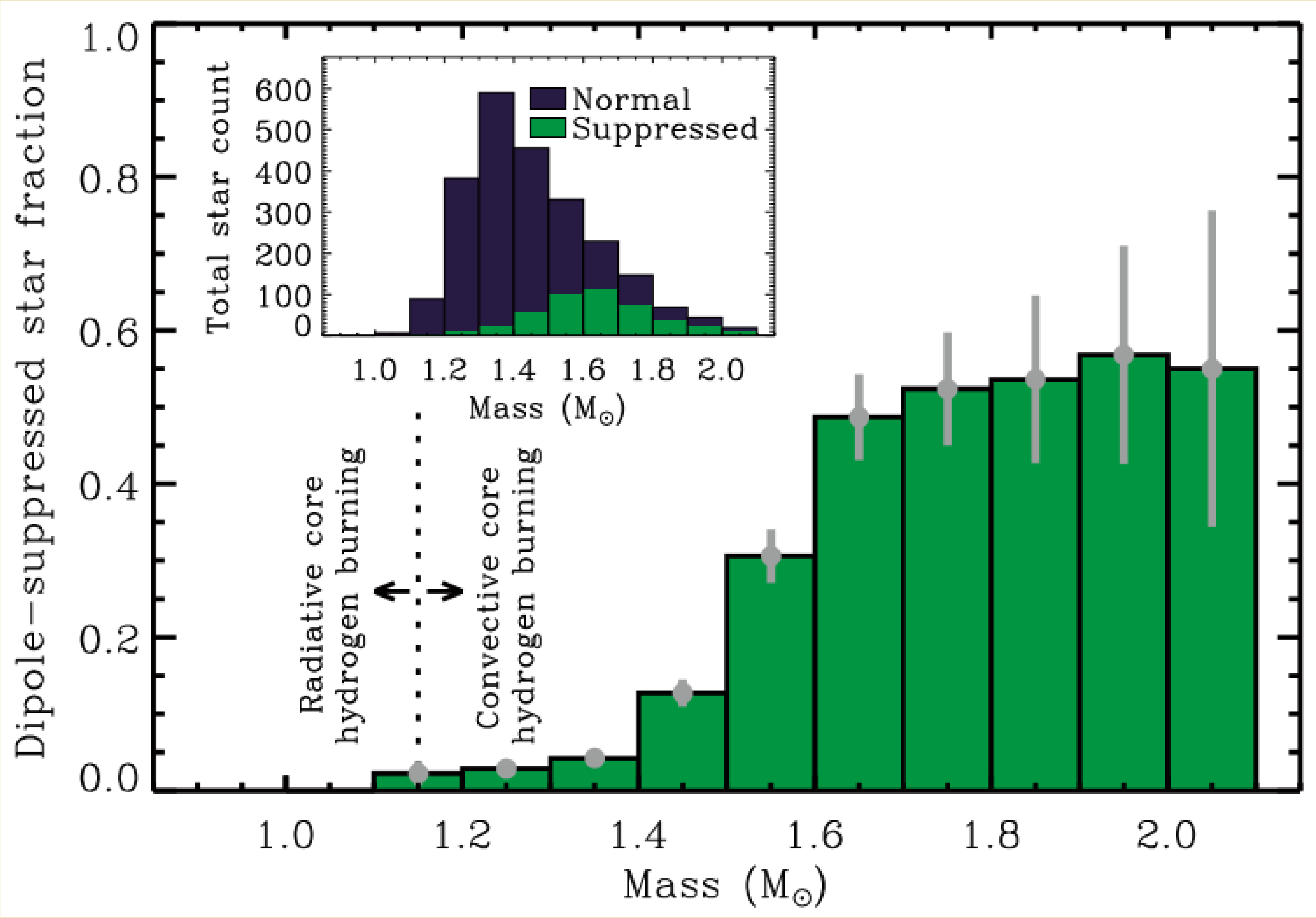
- No evidence of maximum attainable field strength

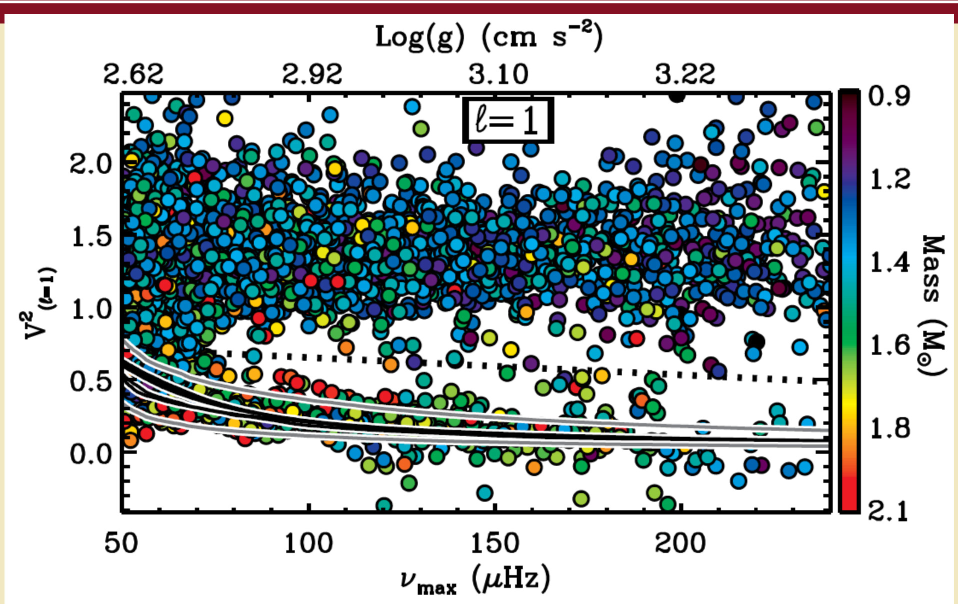
- No evidence of point at which magnetic greenhouse effect “turns on”[GET THIS RIGHT]



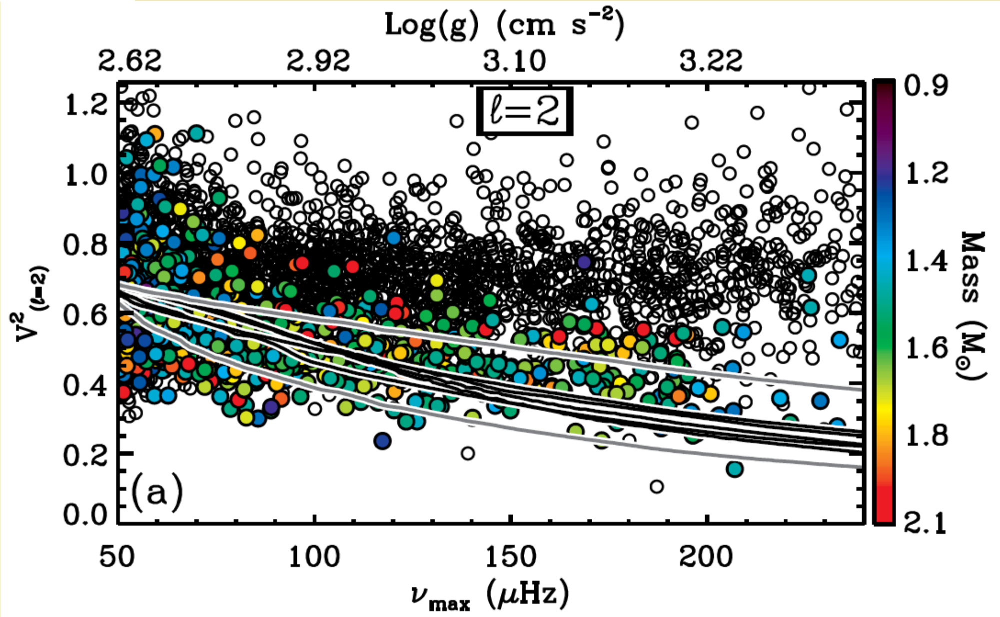
Stello et al 2016a

Δν scaling-corrected mass

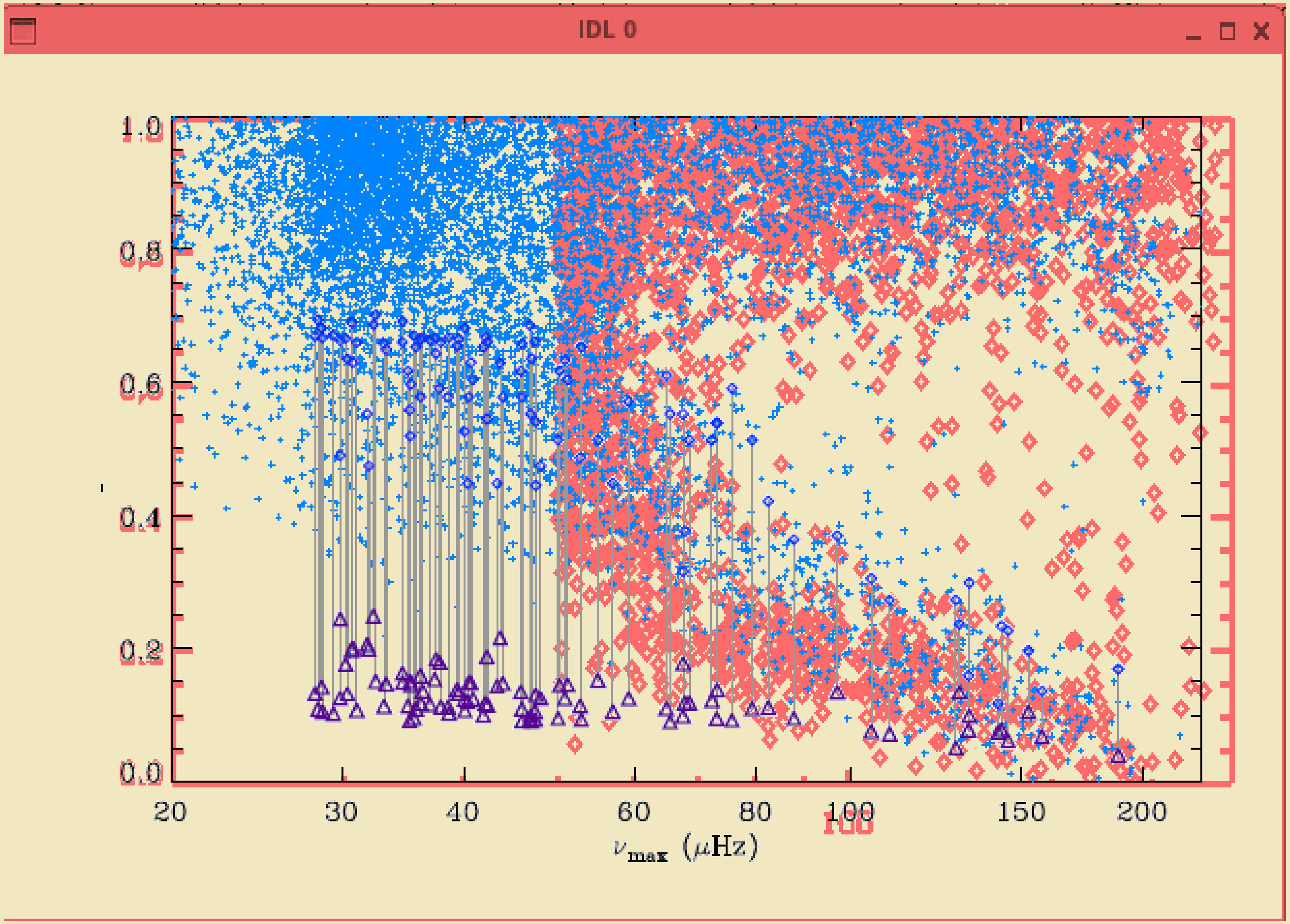




Log(g) (cm s^{-2})
2.62
2.92
3.10
3.22
ℓ=1
$V^2_{(\ell=1)}$
2.0
1.5
1.0
0.5
0.0
50
100
150
200
ν_{max} (μHz)
0.9
1.2
1.4
1.6
1.8
2.1
Mass ($M_\odot$)



Log(g) (cm s^{-2})
2.62
2.92
3.10
3.22
ℓ=2
$V^2_{(\ell=2)}$
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(a)
50
100
150
200
ν_{max} (μHz)
0.9
1.2
1.4
1.6
1.8
2.1
Mass ($M_\odot$)


IDL 0
1.0
0.8
0.6
0.4
0.2
0.0
20
30
40
60
80
100
150
200
ν_{max} (μHz)