Asteroseismology with WFIRST

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Sagan Workshop

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Crash Course in Asteroseismology

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?

CORRESPONDENCE

To the Editors of 'The Observatory'

Astereoasteroseismology

Astēr is the more common form used in Attic Greek to denote a star[2]; the less common form is *astron* (ἄστρον), which I address later. *Astēr* was used not only to denote either a fixed star in the heavens[3], particularly the brightest star (*Seirios astēr*)[4], or a shooting star[5–8], but also a starfish[9–10] and other star-like objects such as certain flowers[11]. Indeed, the Greek form survives unaltered in

The Greek word *astron* was used mainly in the plural to mean 'the stars'[25,26]. In the singular, like *astēr*, it was frequently used of Sirius[27–29] (in full, *sērion astron*), although seldom of 'any common star'[30,31]. There were fewer compounds than with *astēr*, although *astronomia* = astronomy[32–34] and related words are notable: *astronomos*[35] and *astrologos*[36] appear to be the more common

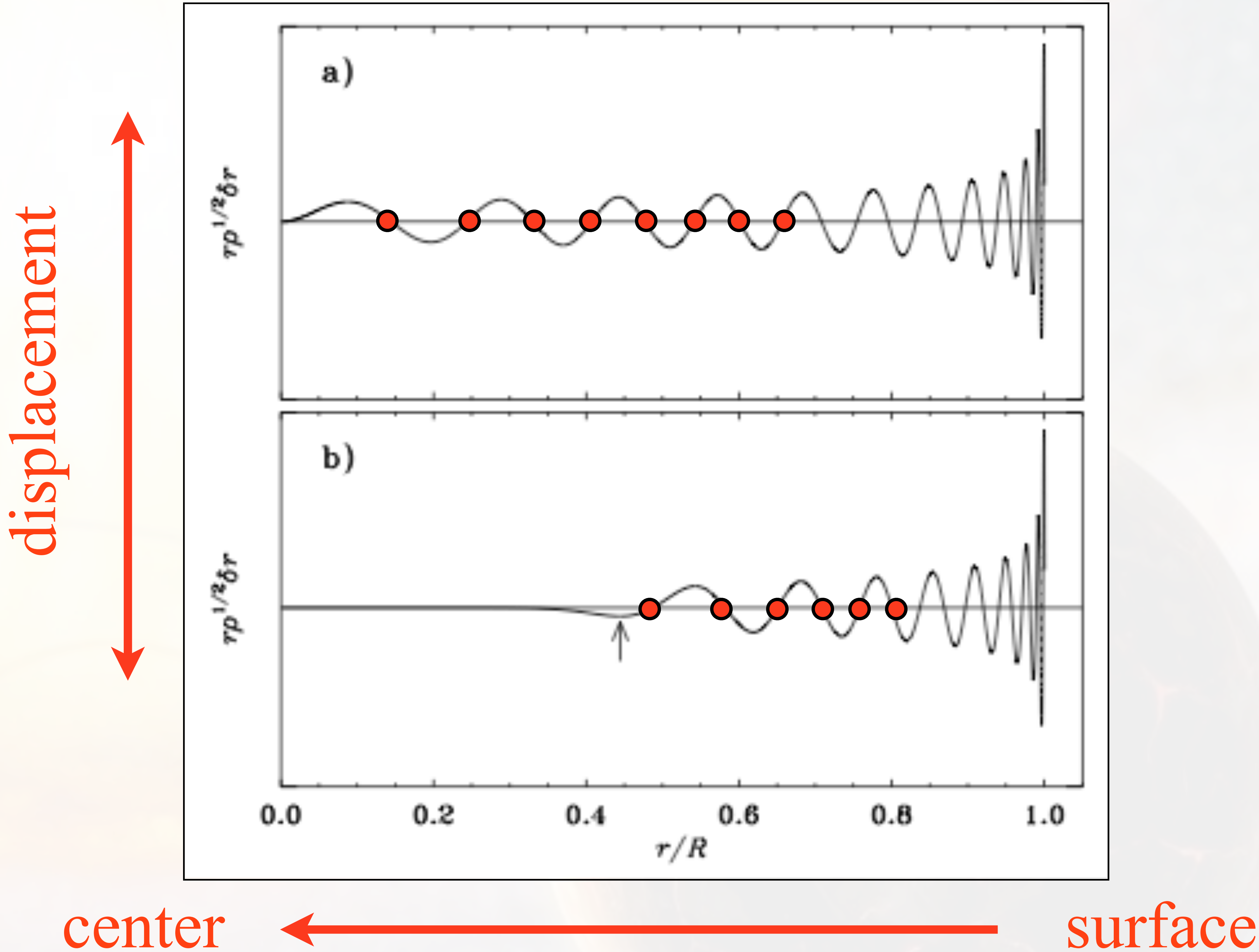
Since asteroseismology pertains specifically to stars, and particularly to individual stars, the appellation is etymologically preferable. Indeed, that is why it was so chosen. Nonetheless, to have originally chosen Trimble's alternative

I hope this discussion will dissuade idiosyncratic reviewers of the field from mispronouncing further on our subject in a manner that detracts from its legitimate etymological origins.

Yours faithfully,

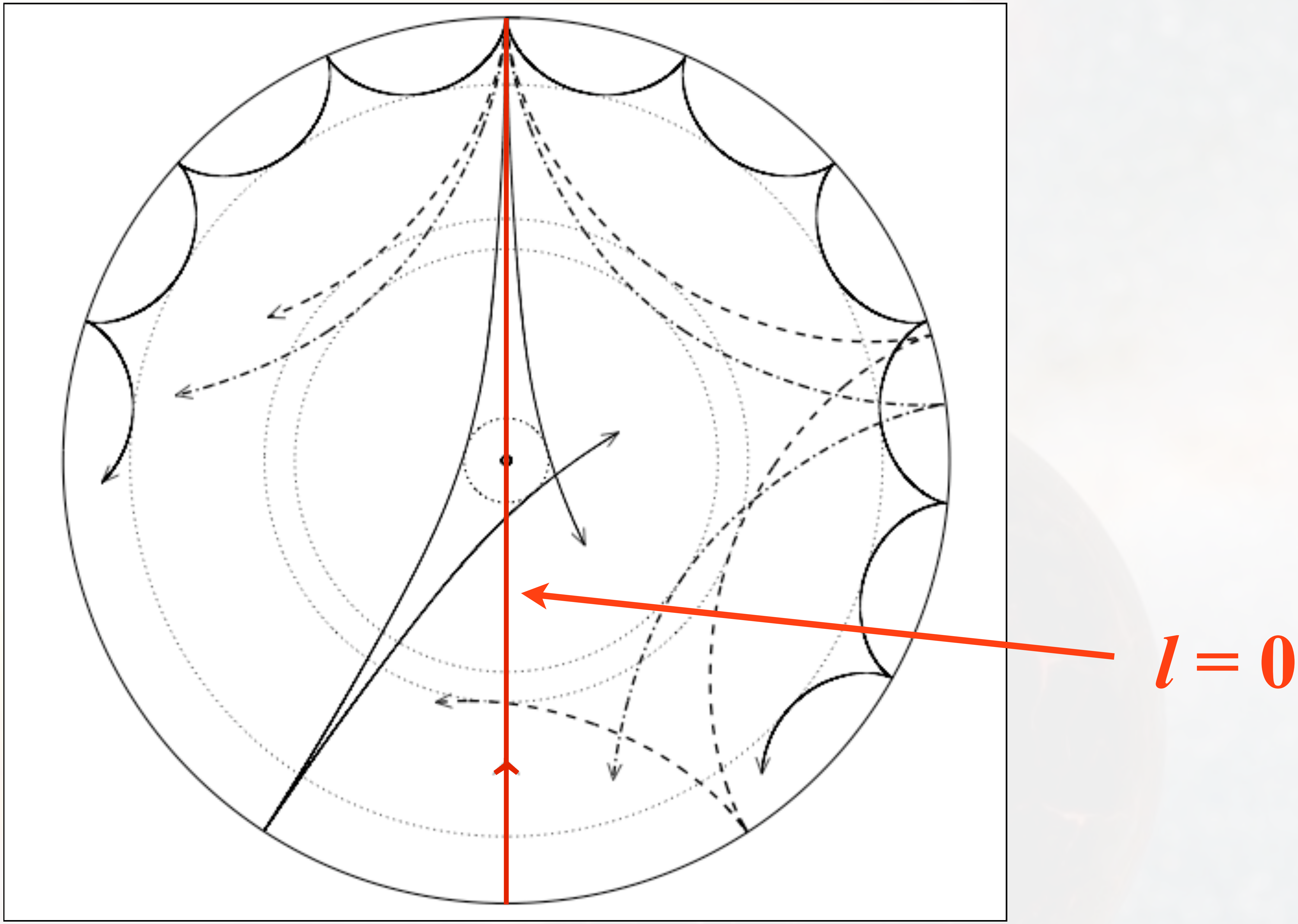
DOUGLAS GOUGH

Radial Order *n*



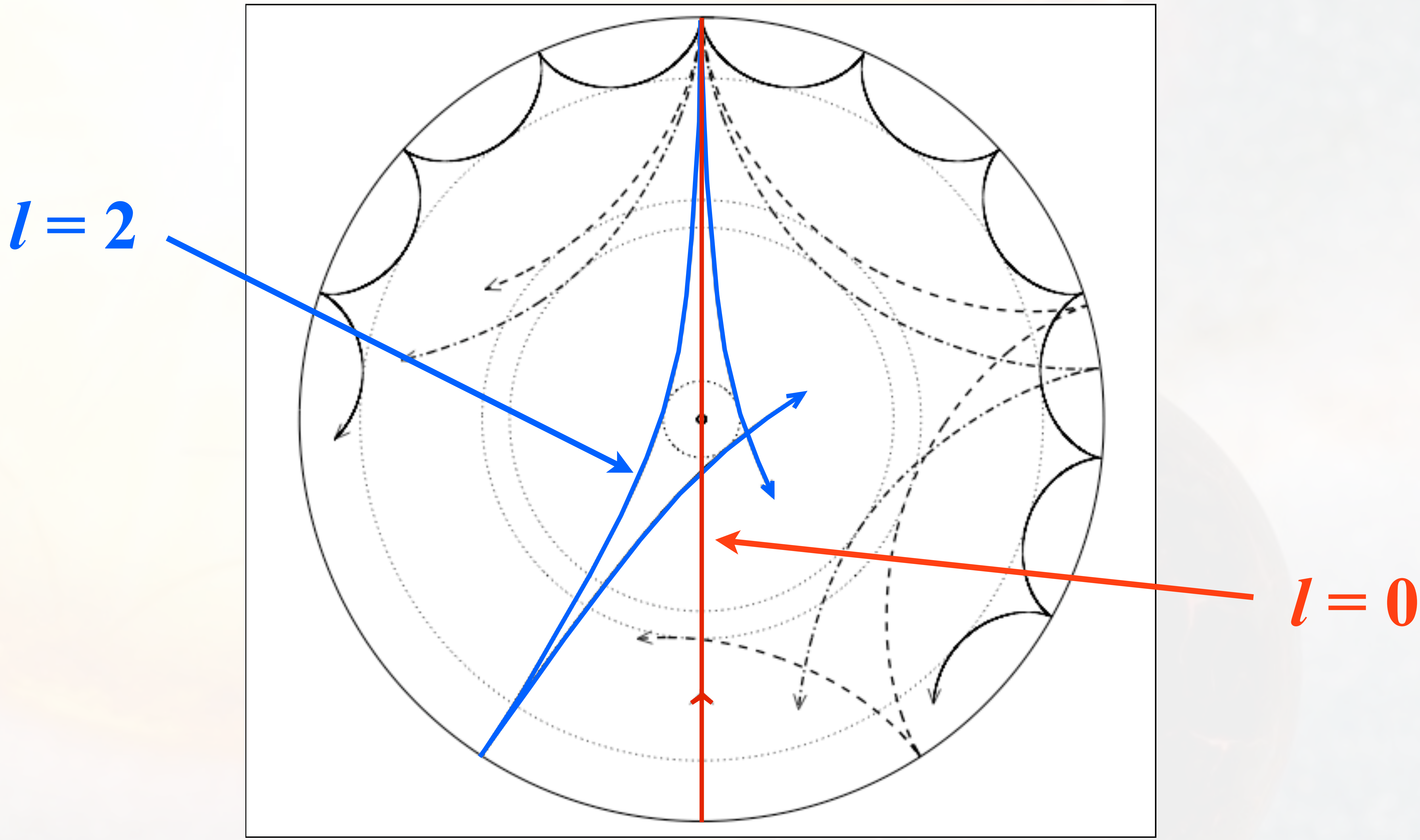
number of nodes from the surface to the center of the star

Spherical Degree *l*



total number of nodes on surface of the star

Spherical Degree *l*



total number of nodes on surface of the star

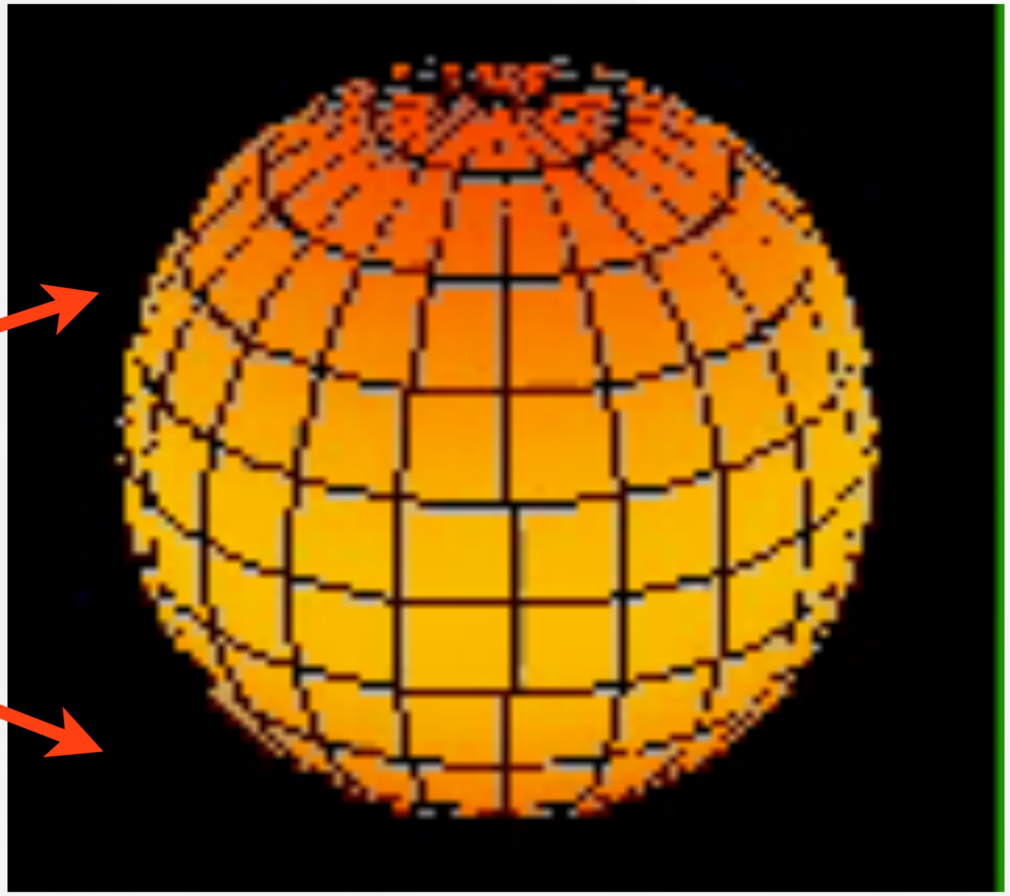
Spherical Harmonics Y_l^m

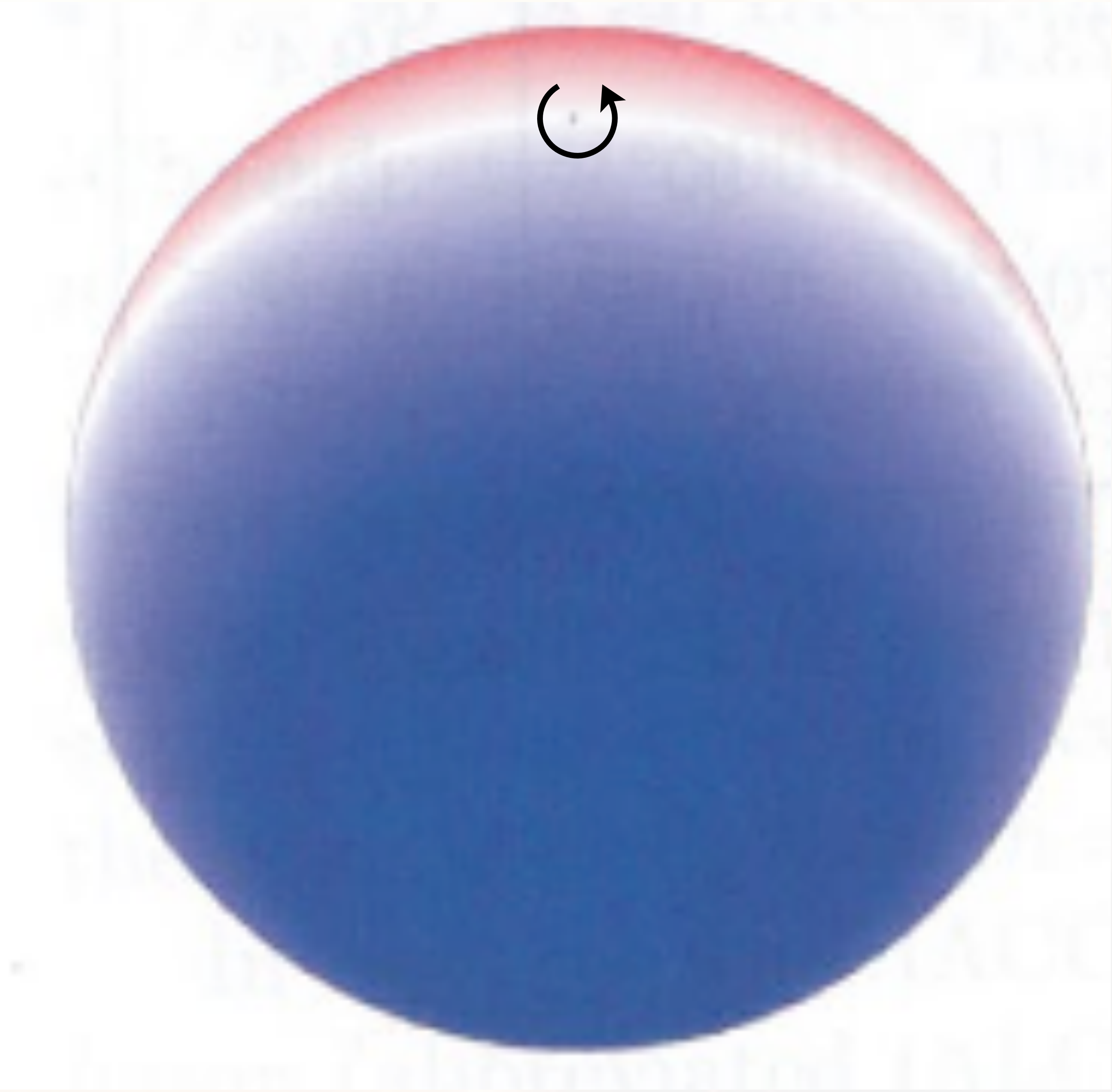
l = spherical degree (total number of surface nodes)

m = azimuthal order (number of nodes through the rotation axis)

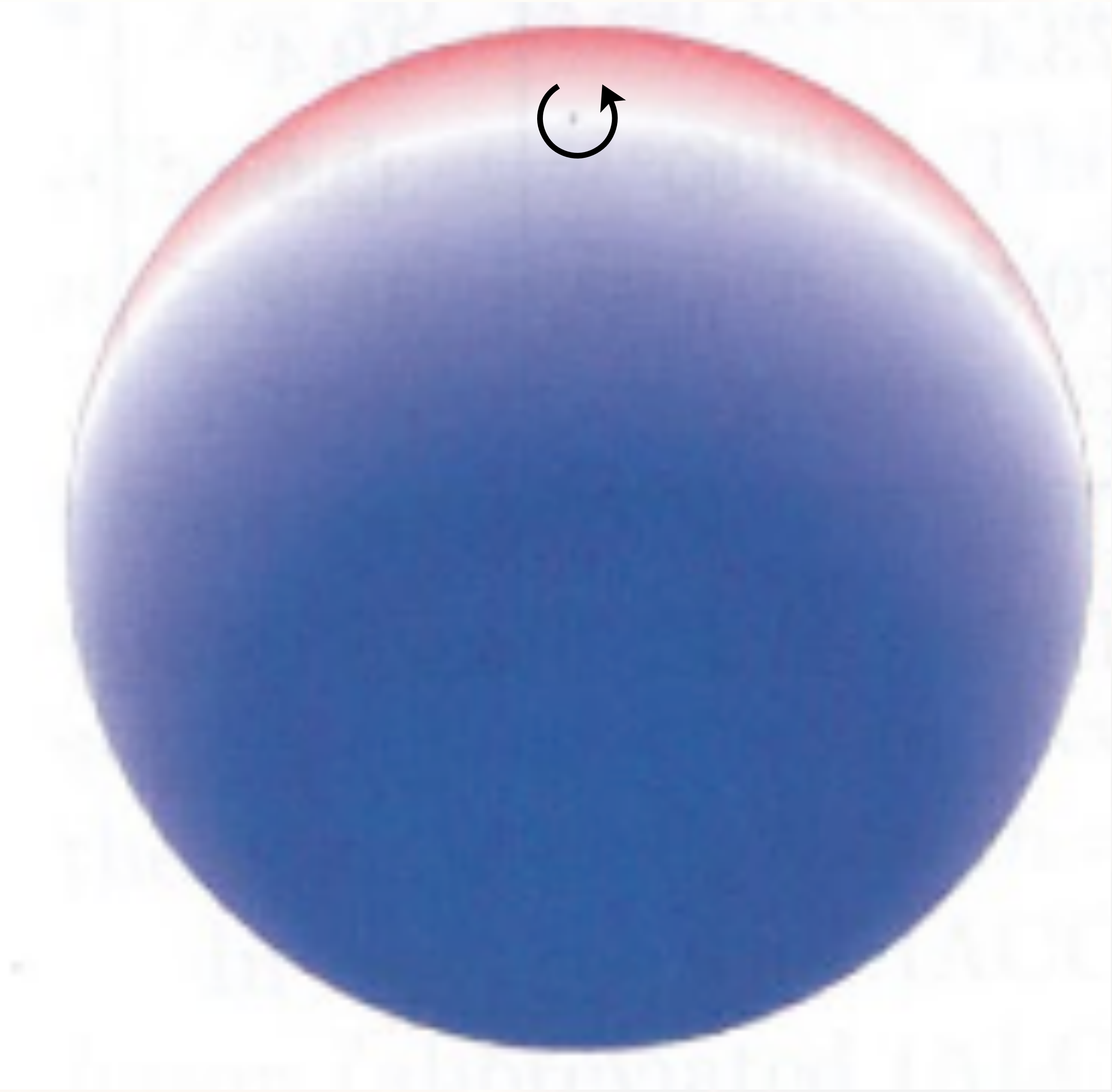
|m| < l

l = 2
|m| = 0

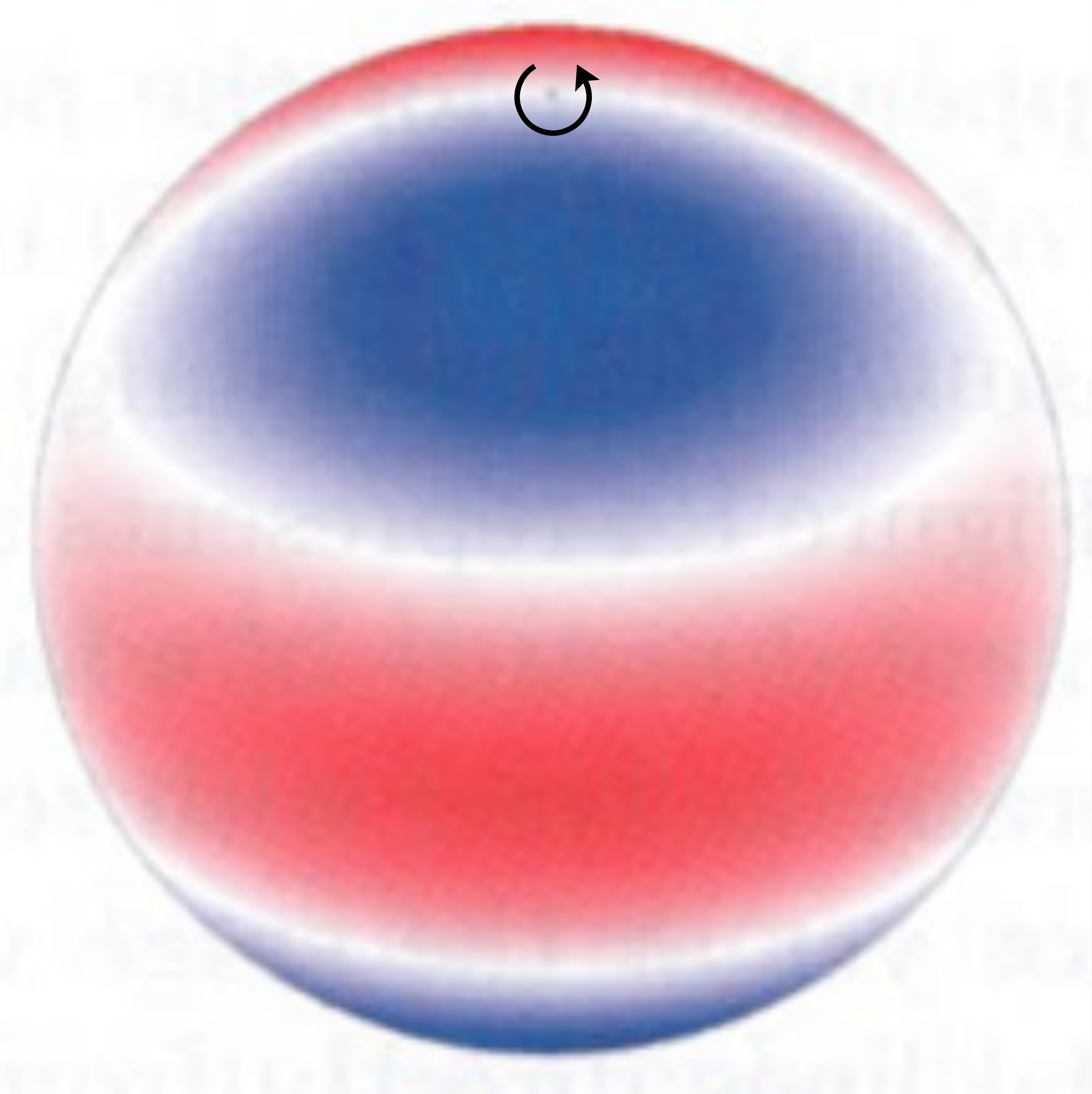




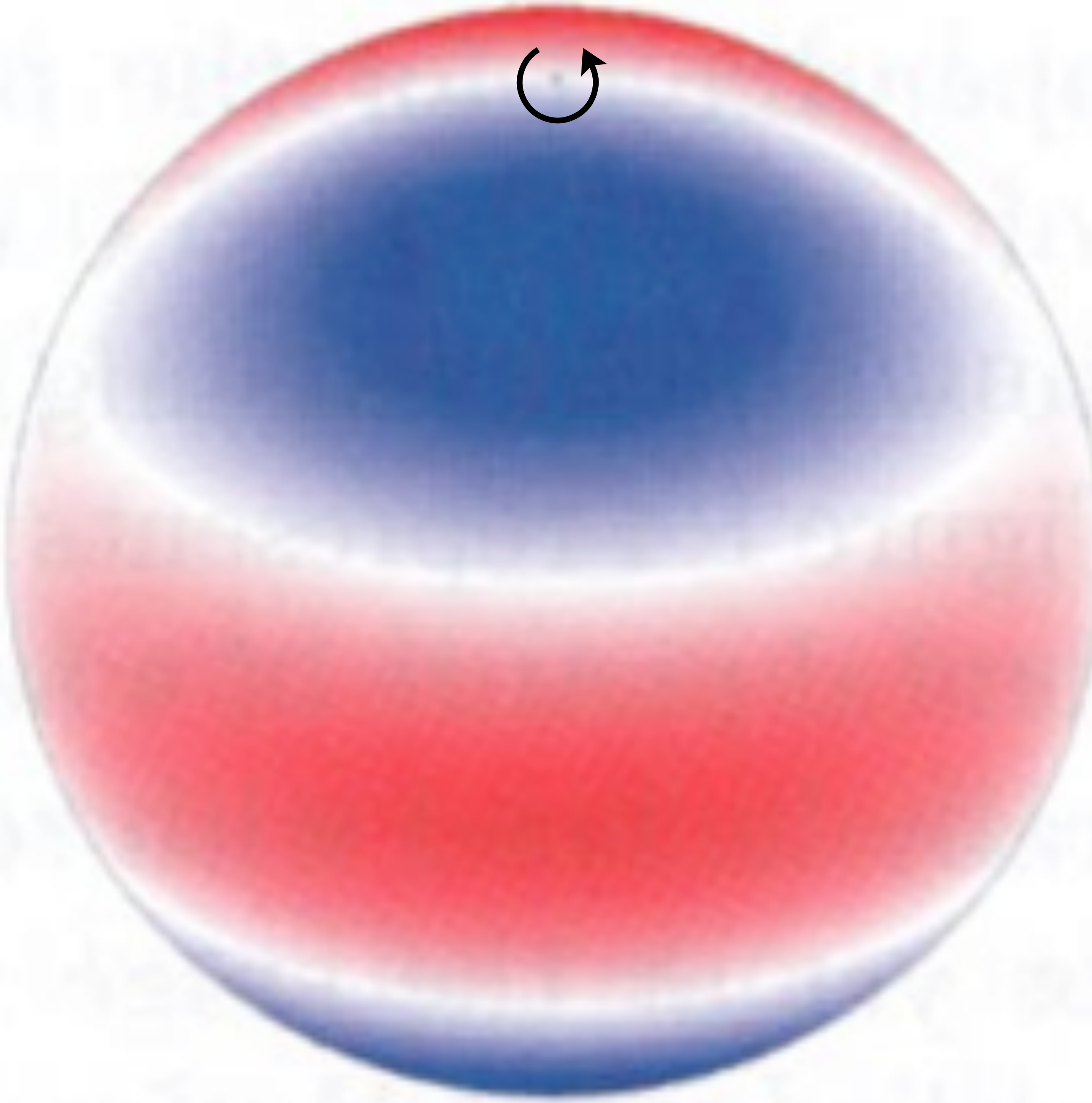
l=?, |m|=?



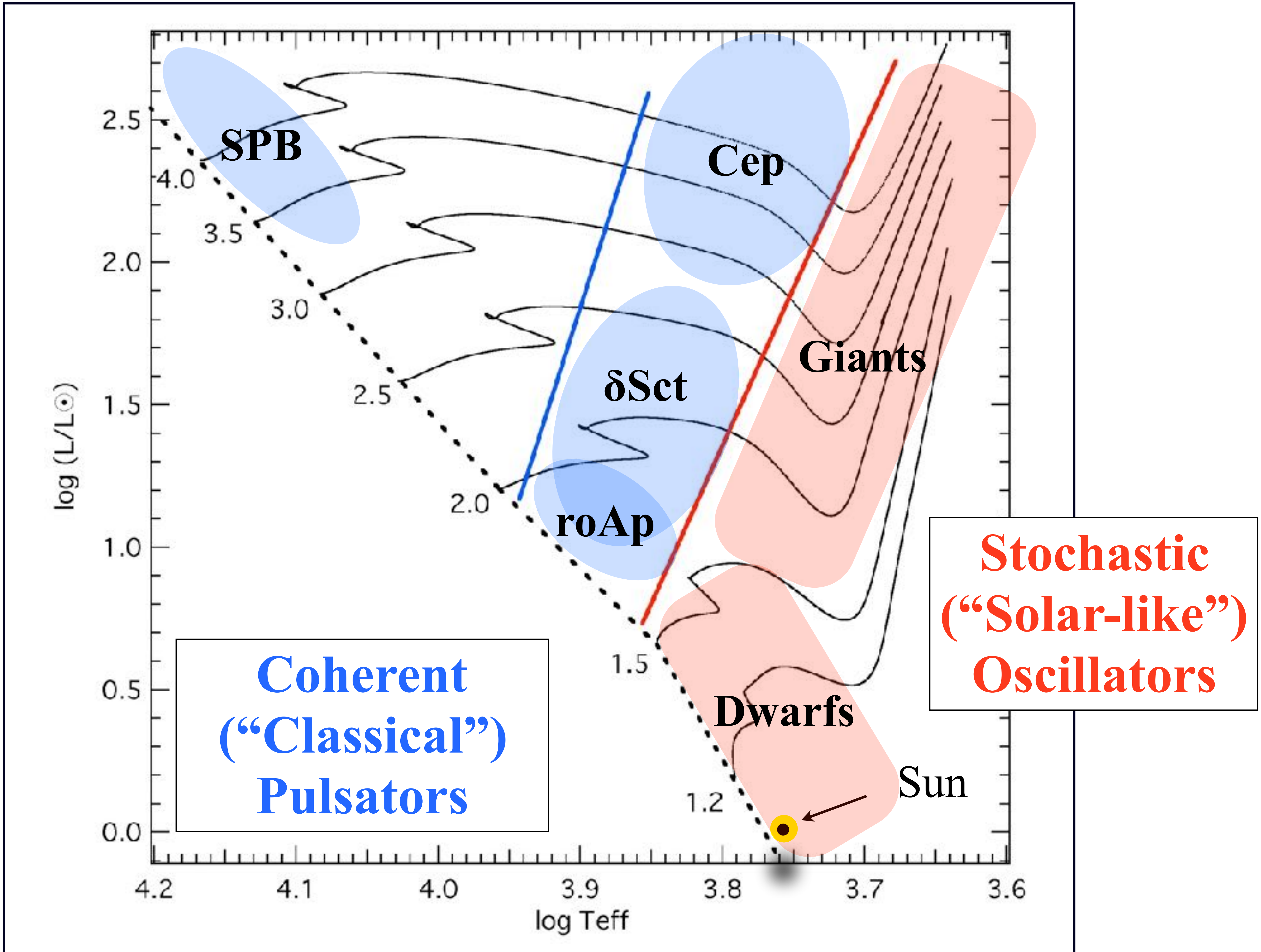
l=1, |m|=1



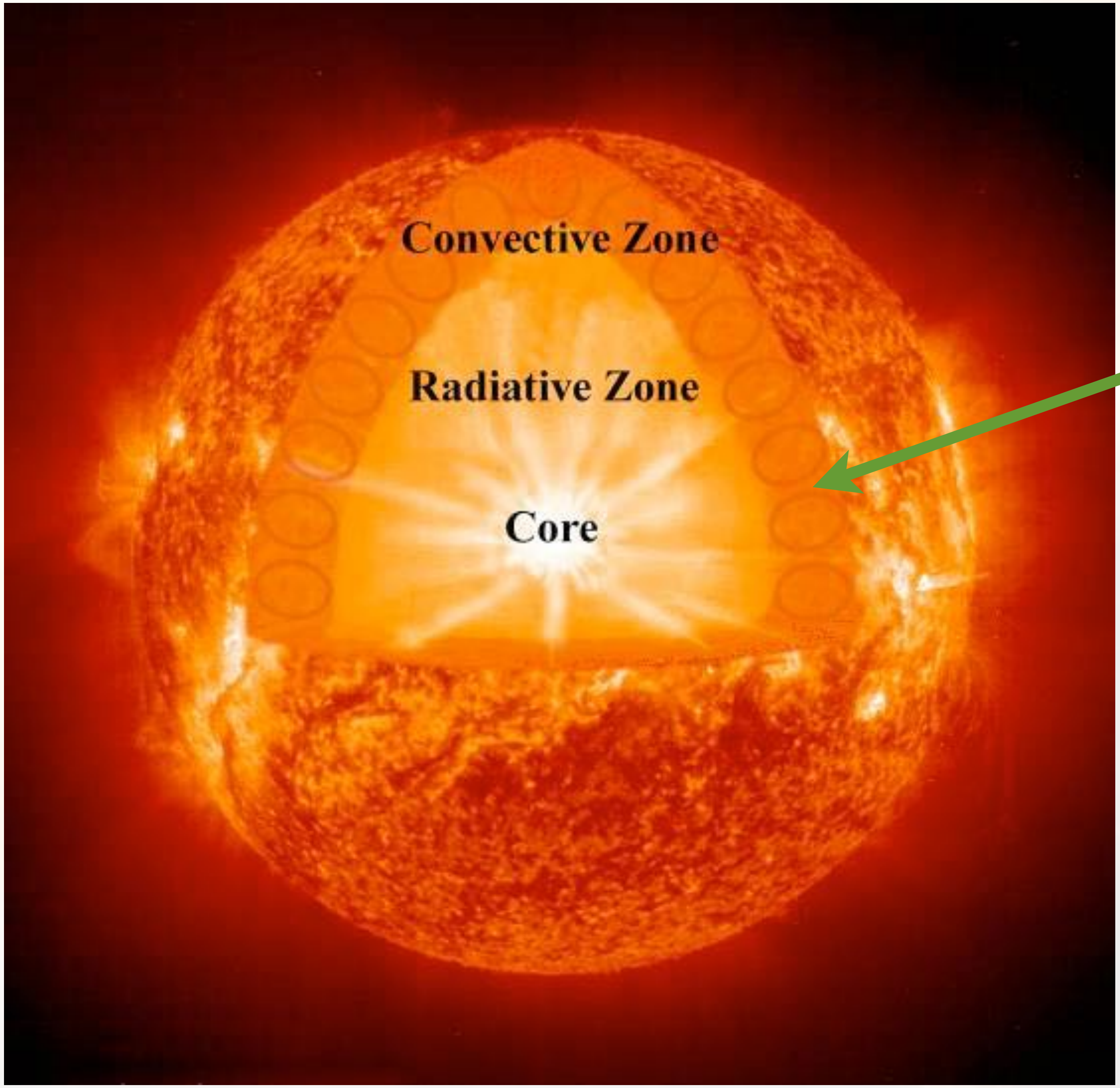
$l=?$, $|m|=?$

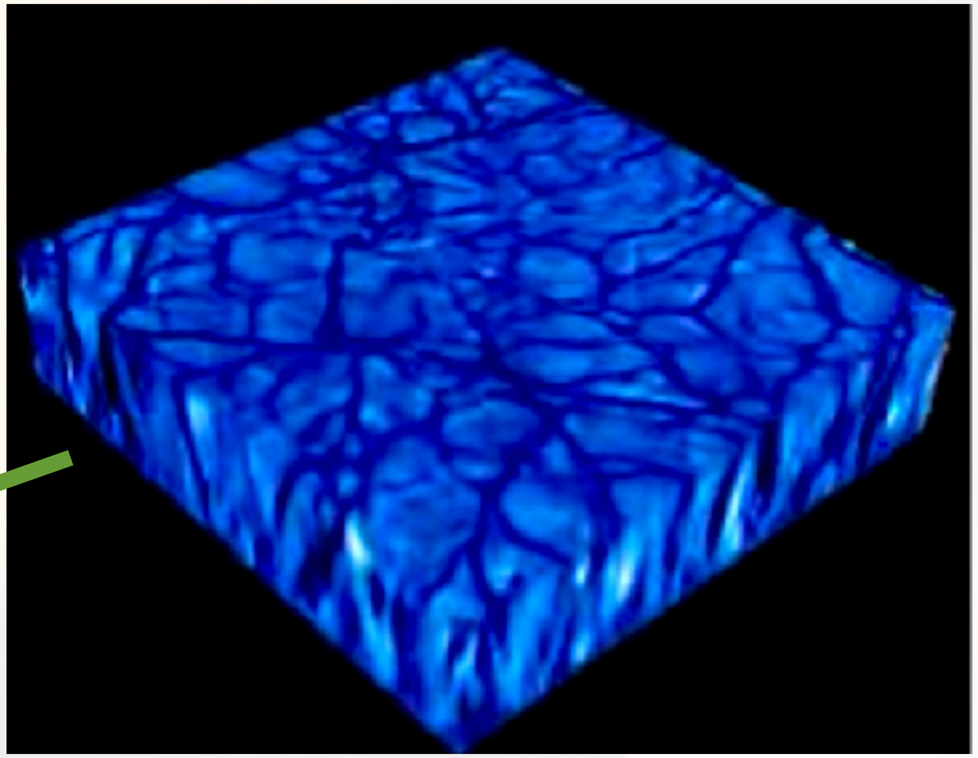


l=3, |m|=1

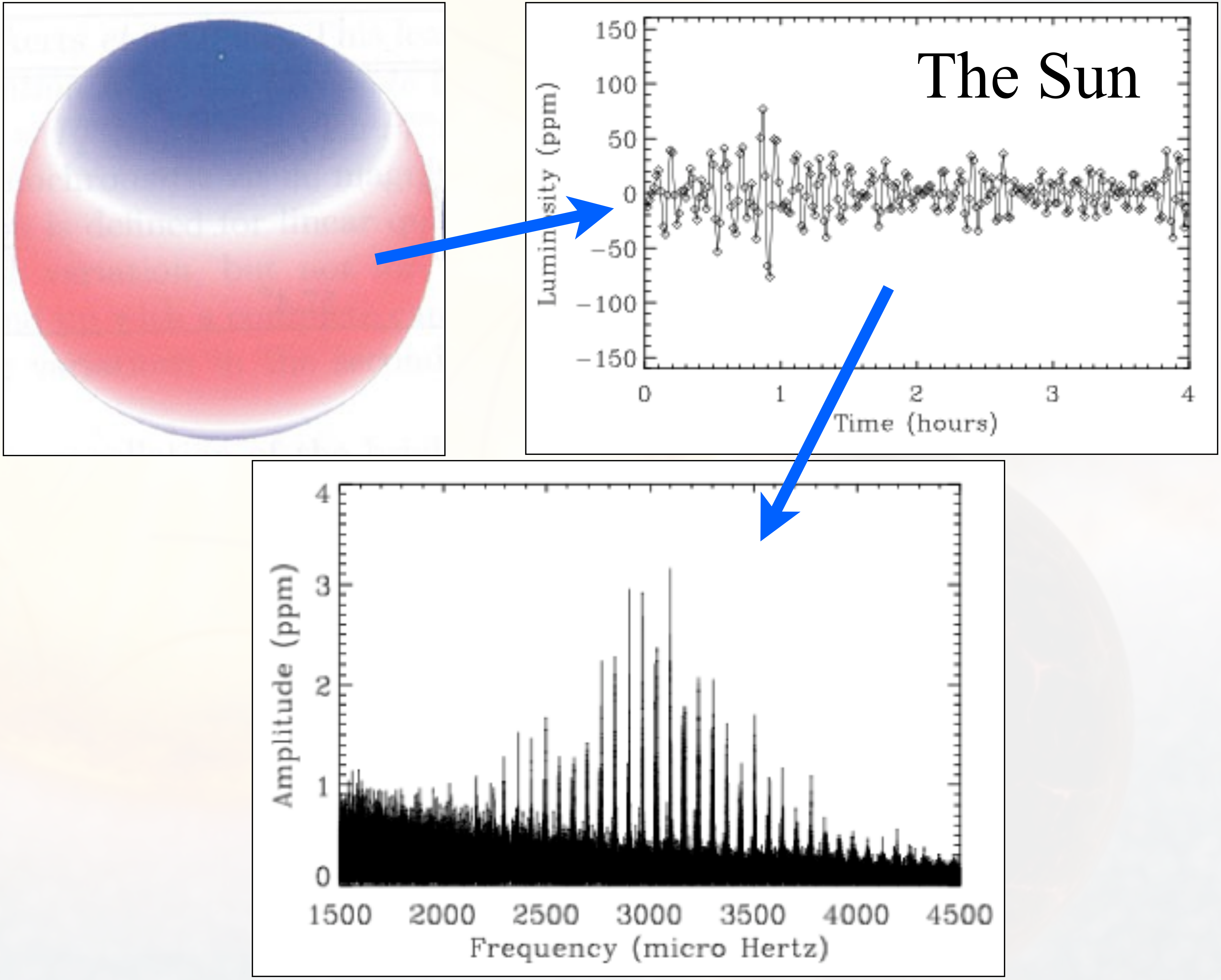

SPB
Cep
δSct
roAp
Giants
Dwarfs
Sun
Coherent
("Classical")
Pulsators
Stochastic
("Solar-like")
Oscillators
4.0
3.5
3.0
2.5
2.0
1.5
1.2
log (L/L☉)
2.5
2.0
1.5
1.0
0.5
0.0
4.2
4.1
4.0
3.9
3.8
3.7
3.6
log Teff

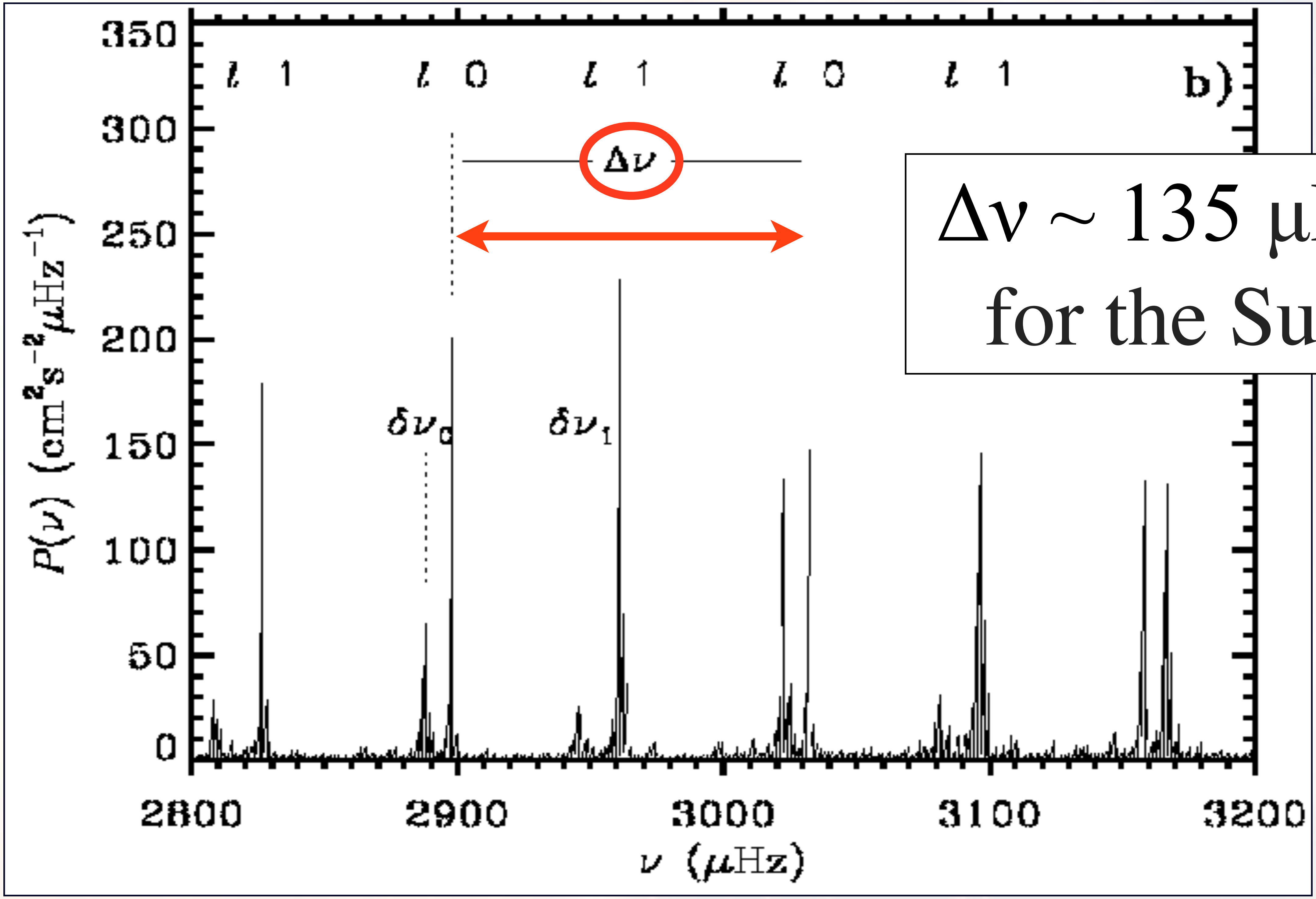
Mode excitation: stochastic oscillations





Oscillations in cool stars are driven by turbulent surface convection


The Sun
Luminosity (ppm)
150
100
50
0
−50
−100
−150
0
1
2
3
4
Time (hours)
Amplitude (ppm)
4
3
2
1
0
1500
2000
2500
3000
3500
4000
4500
Frequency (micro Hertz)



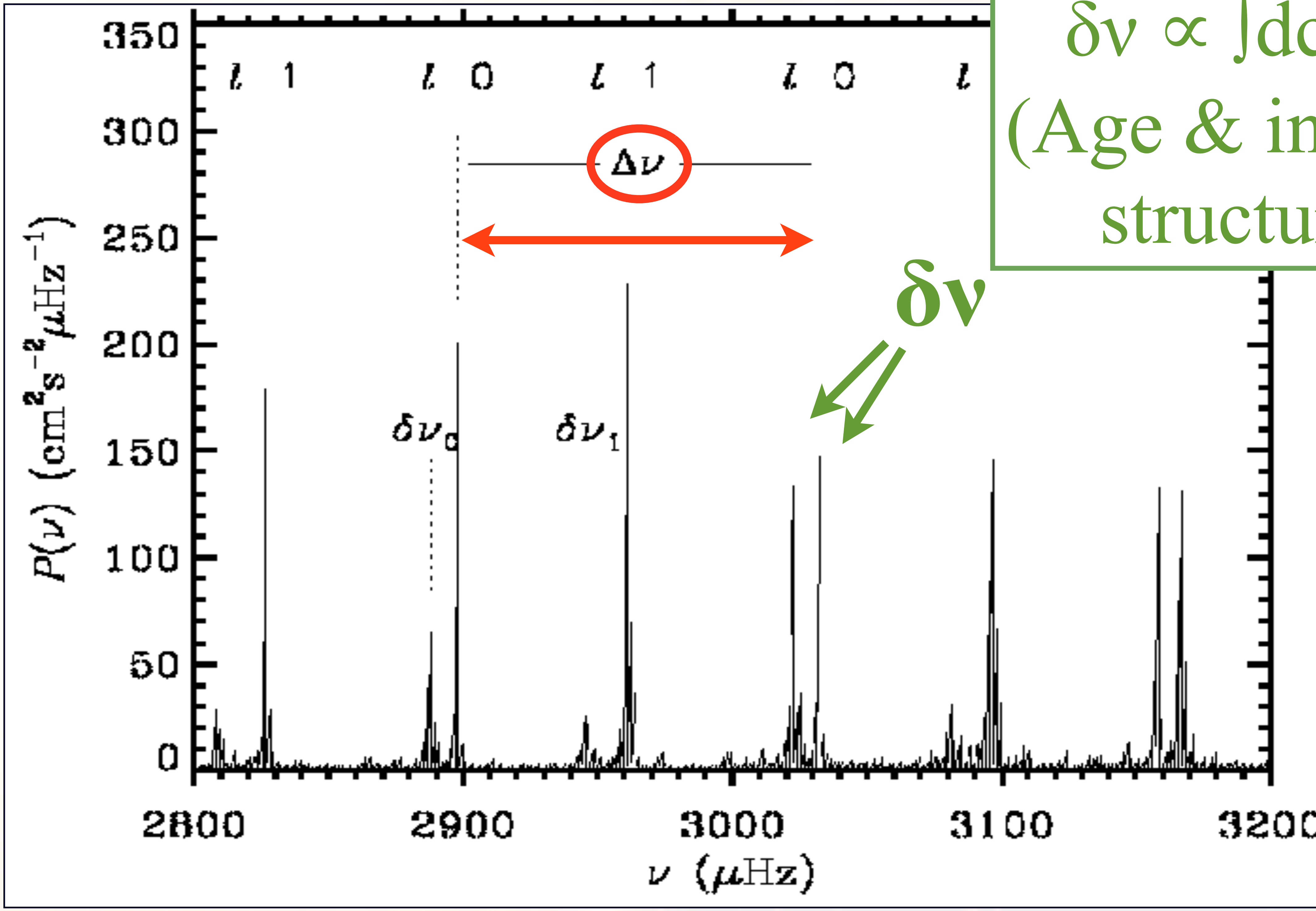
$\Delta\nu \sim 135\ \mu Hz$ for the Sun

sound speed c_s

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

$(\omega = n\,\pi\,c\,/\,L!)$

$\delta\nu \propto \int dc_s/dr$
(Age & interior structure)

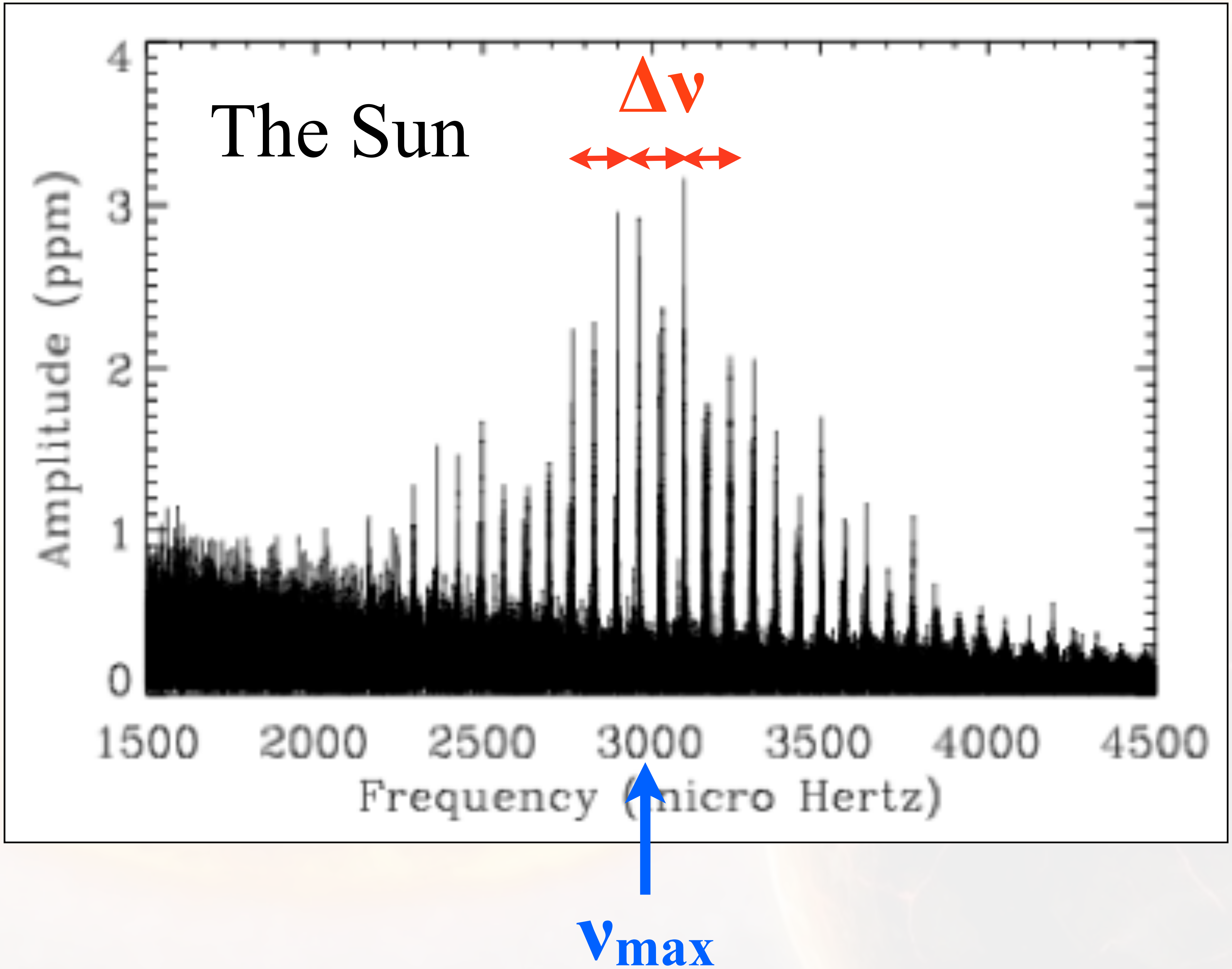


sound speed c_s

$\Delta\mathbf{v} = (2 \int dr/c_s)^{-1} \propto (\mathbf{M/R^3})^{1/2}$

Ulrich (1986)

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



T_{eff}

+

$\Delta\nu$, ν_{max}

↓

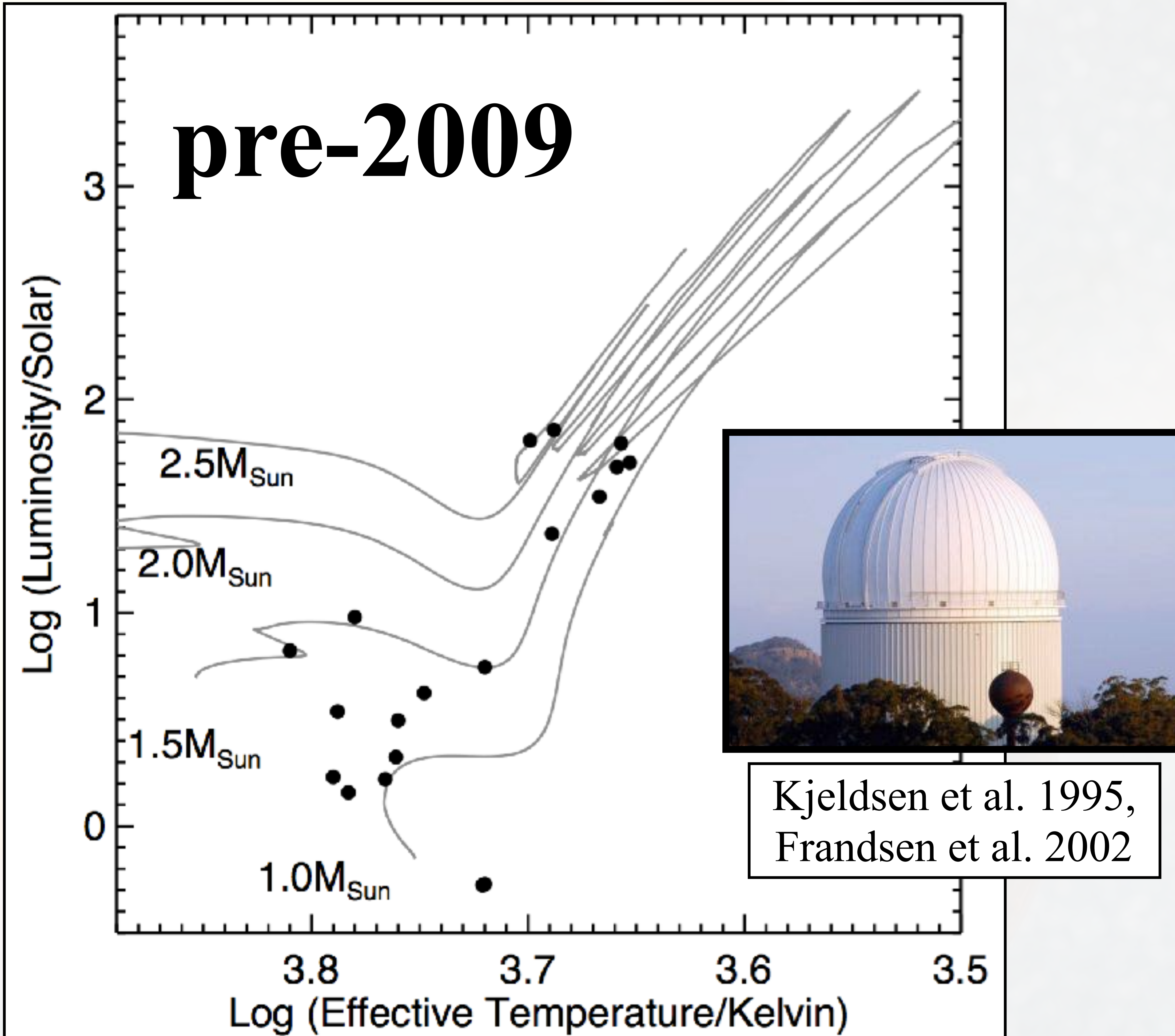
R <~ 5%

M <~ 10%

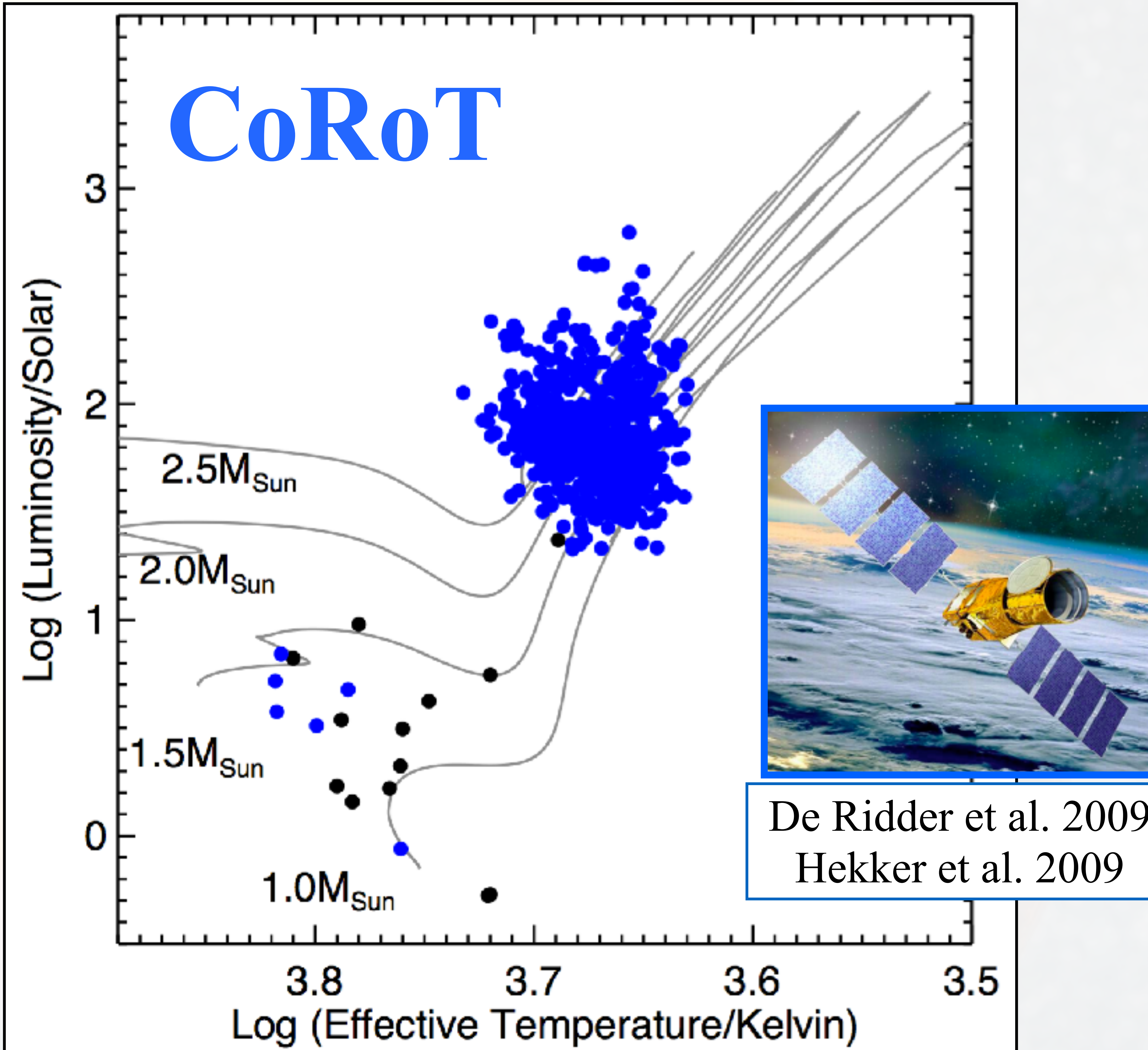
$$\nu_{max} \propto \nu_{ac} \propto M R^{-2} T_{eff}^{0.5} \text{ (gravity)}$$

The Space-Photometry Revolution of Asteroseismology

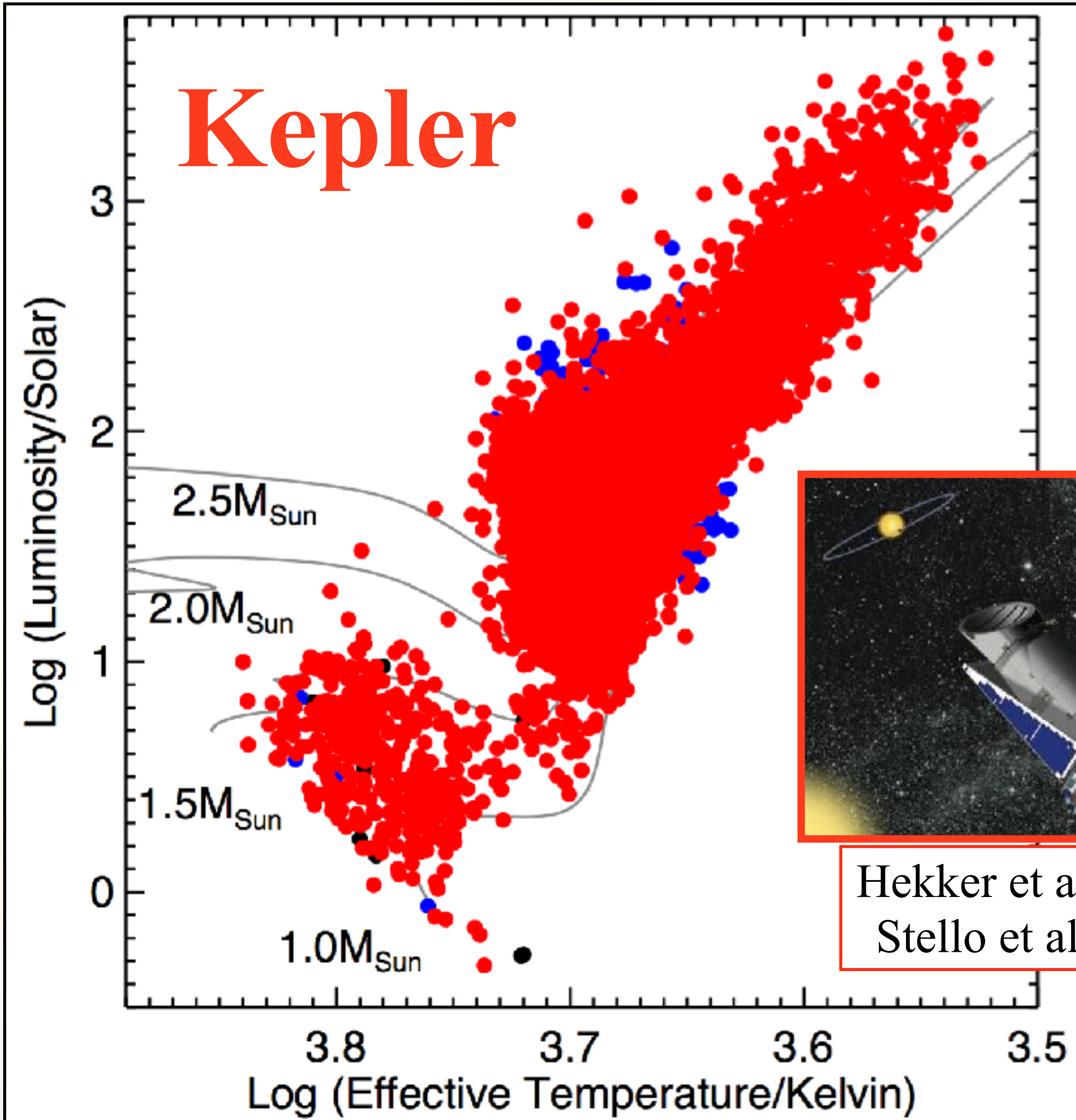
pre-2009



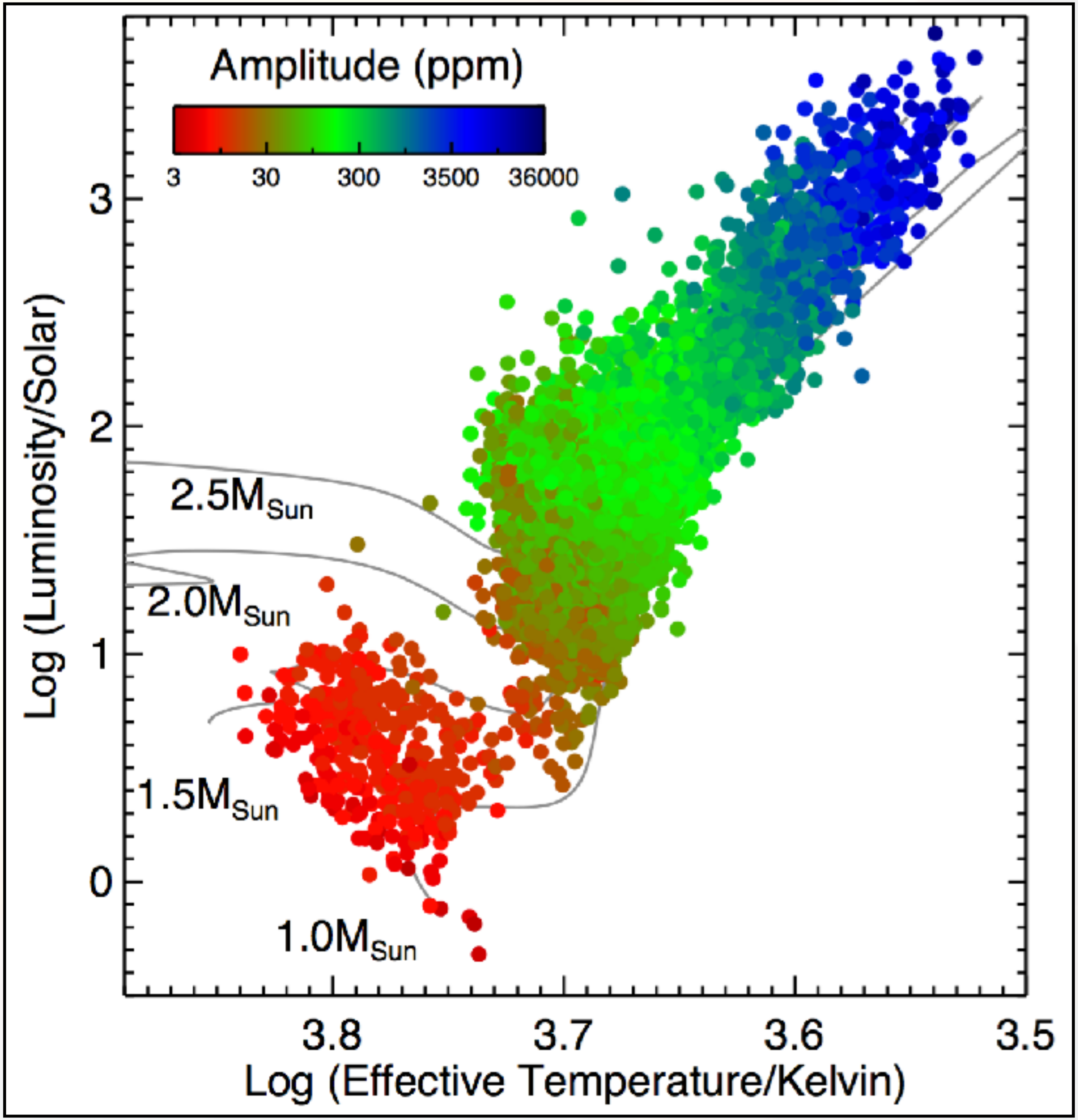
Kjeldsen et al. 1995,
Frandsen et al. 2002



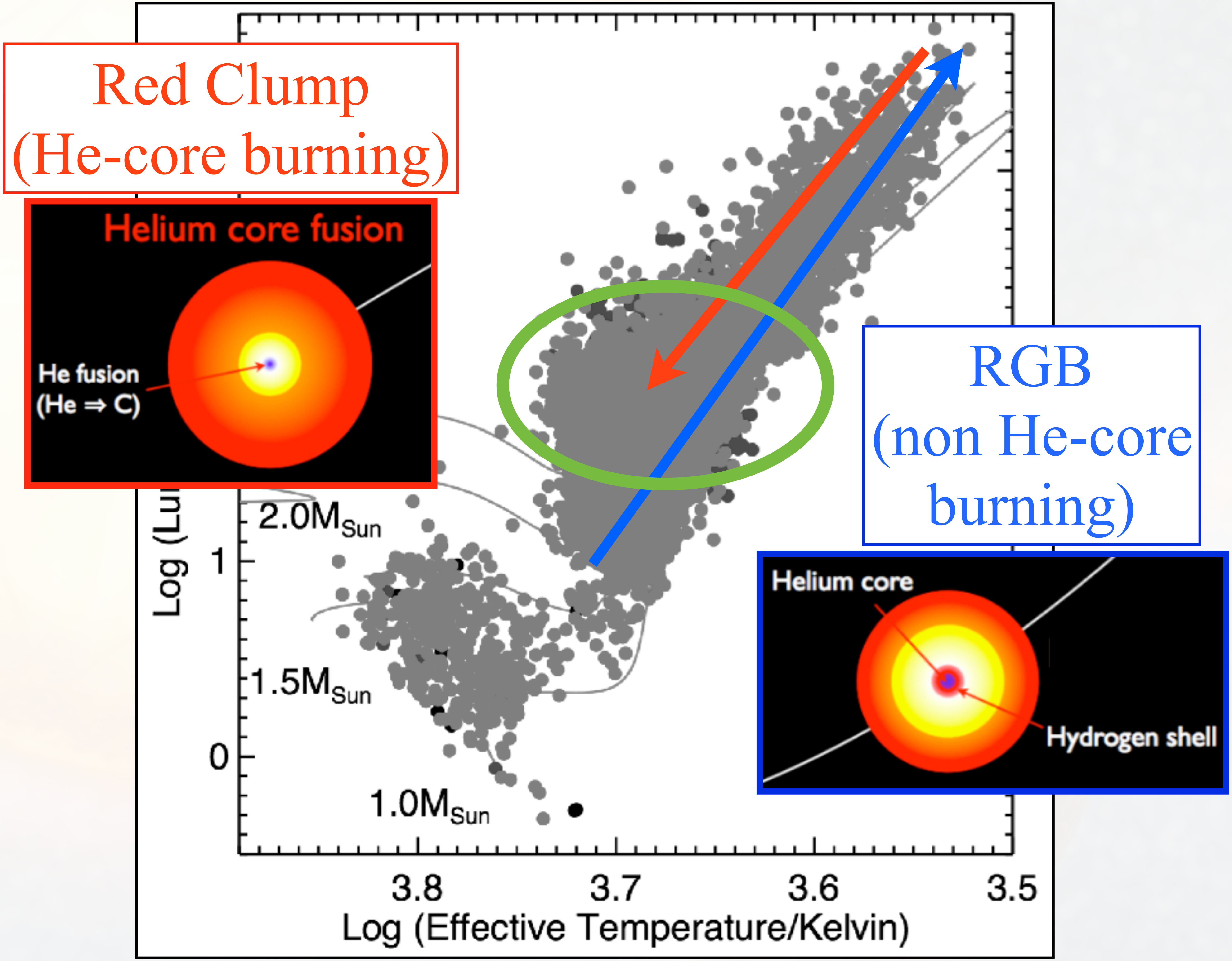
De Ridder et al. 2009,
Hekker et al. 2009



Hekker et al. 2011,
Stello et al. 2013

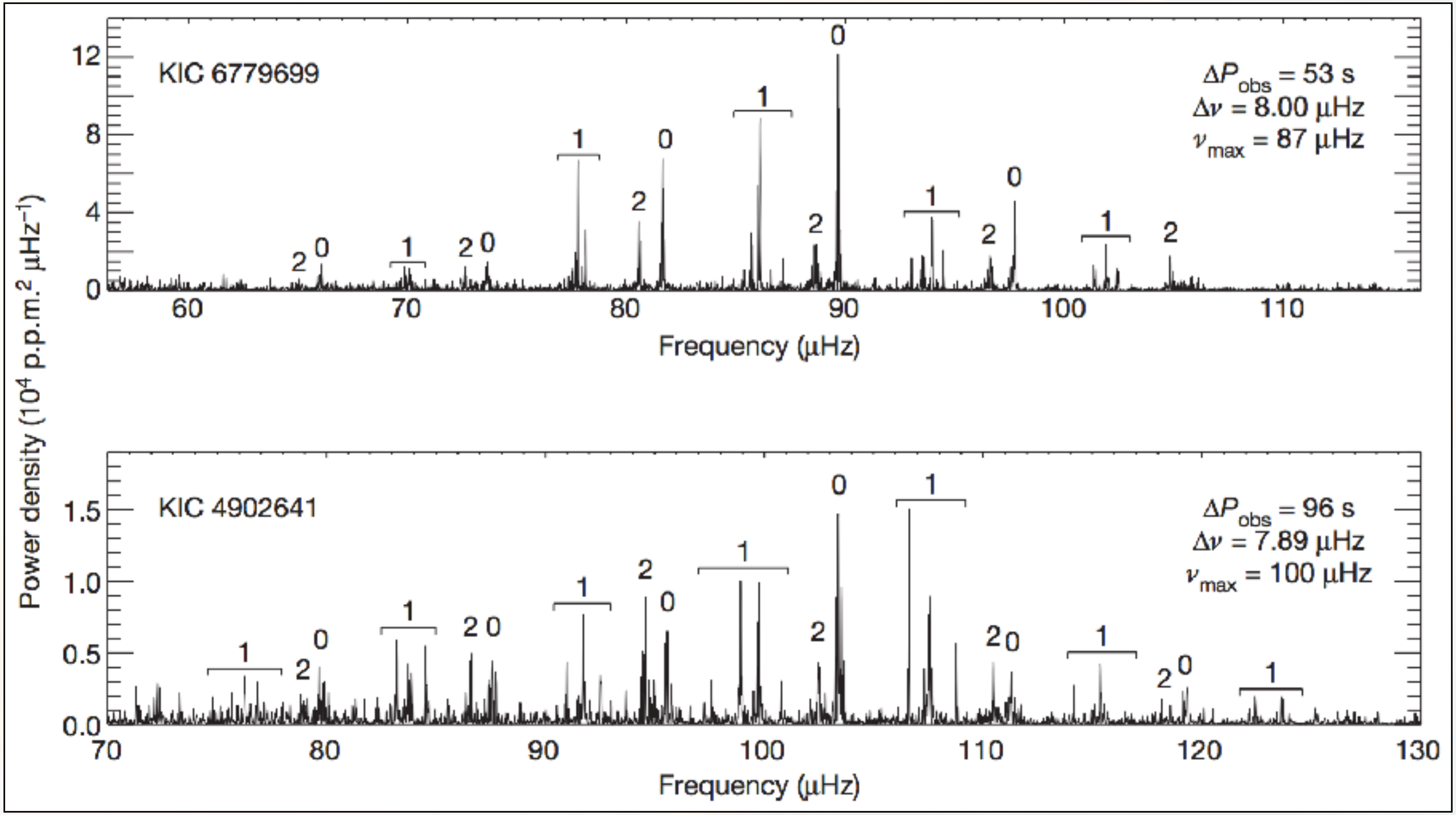


Amplitude (ppm)
3
30
300
3500
36000
3
2
1
0
2.5M_Sun
2.0M_Sun
1.5M_Sun
1.0M_Sun
3.8
3.7
3.6
3.5
Log (Luminosity/Solar)
Log (Effective Temperature/Kelvin)

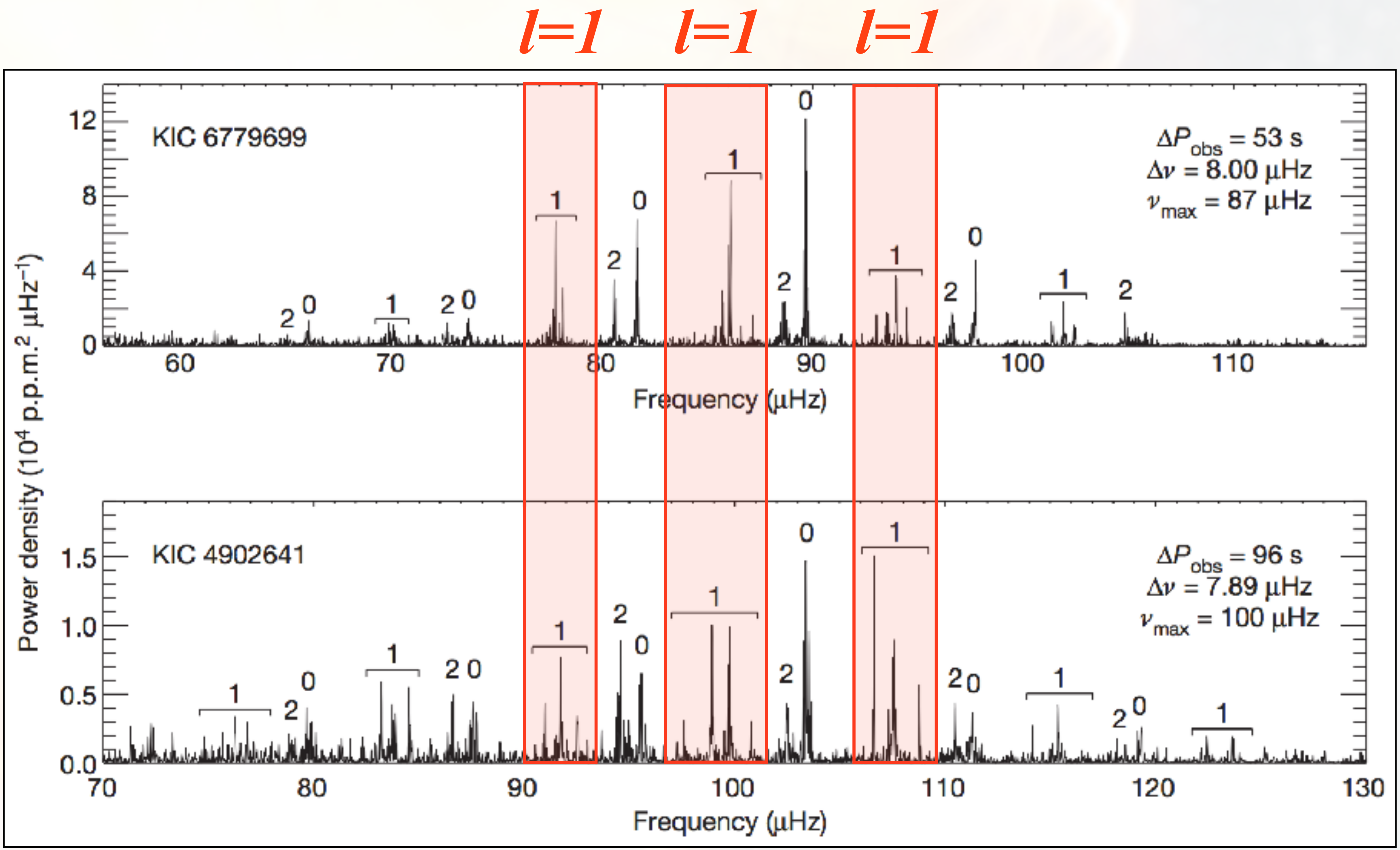


Red Clump
(He-core burning)
Helium core fusion
He fusion
(He ⇒ C)
RGB
(non He-core
burning)
Helium core
Hydrogen shell
2.0MSun
1.5MSun
1.0MSun
Log (Lu
1
0
3.8
3.7
3.6
3.5
Log (Effective Temperature/Kelvin)

The cores of Red Giants: Mixed Modes



The cores of Red Giants: Mixed Modes

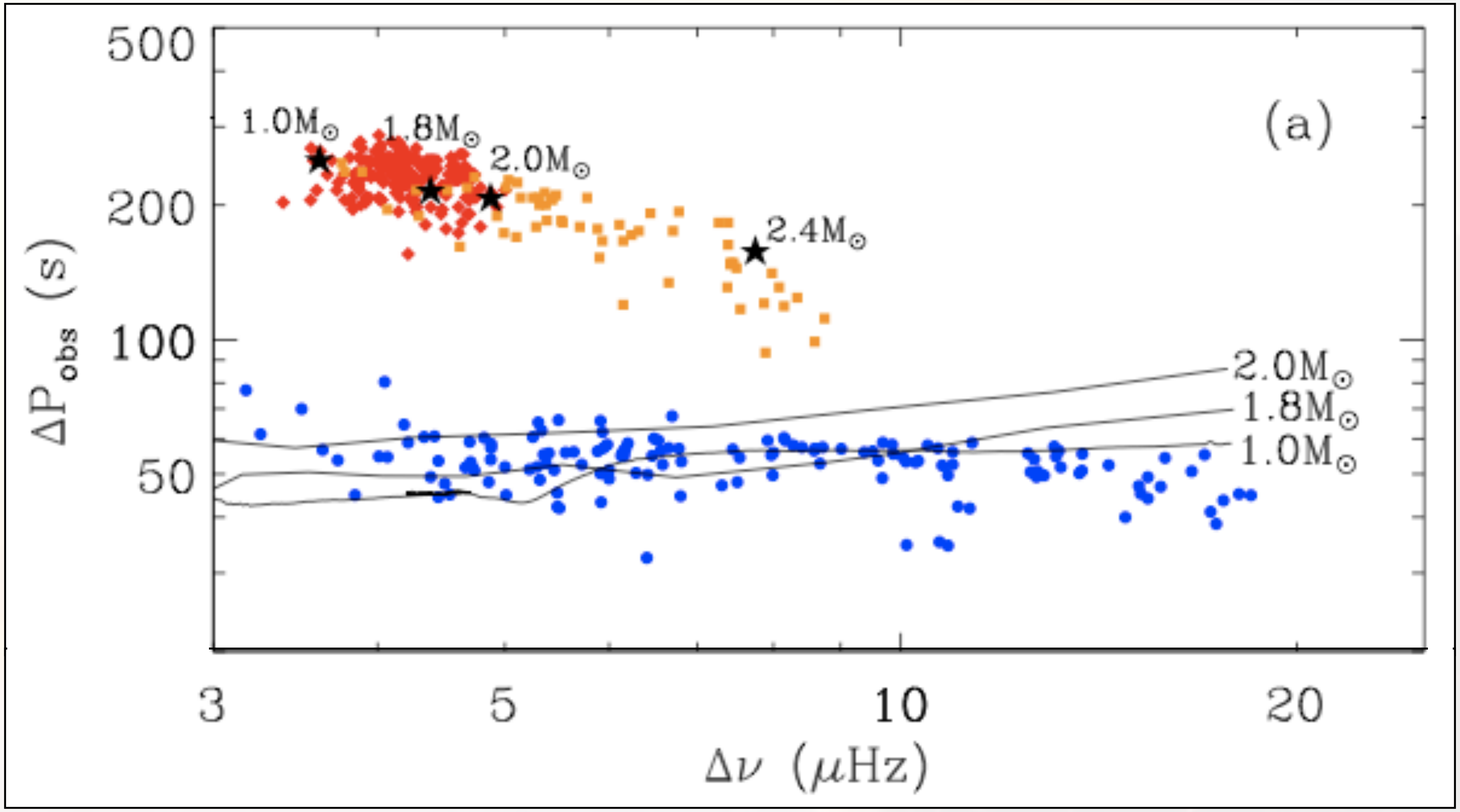


Multiple *l*=1 modes per order due to coupling with gravity modes trapped in the stellar interior ("mixed modes")

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 Hekker[6,8], 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]

Mixed mode spacing



He-core burning

non He-core burning

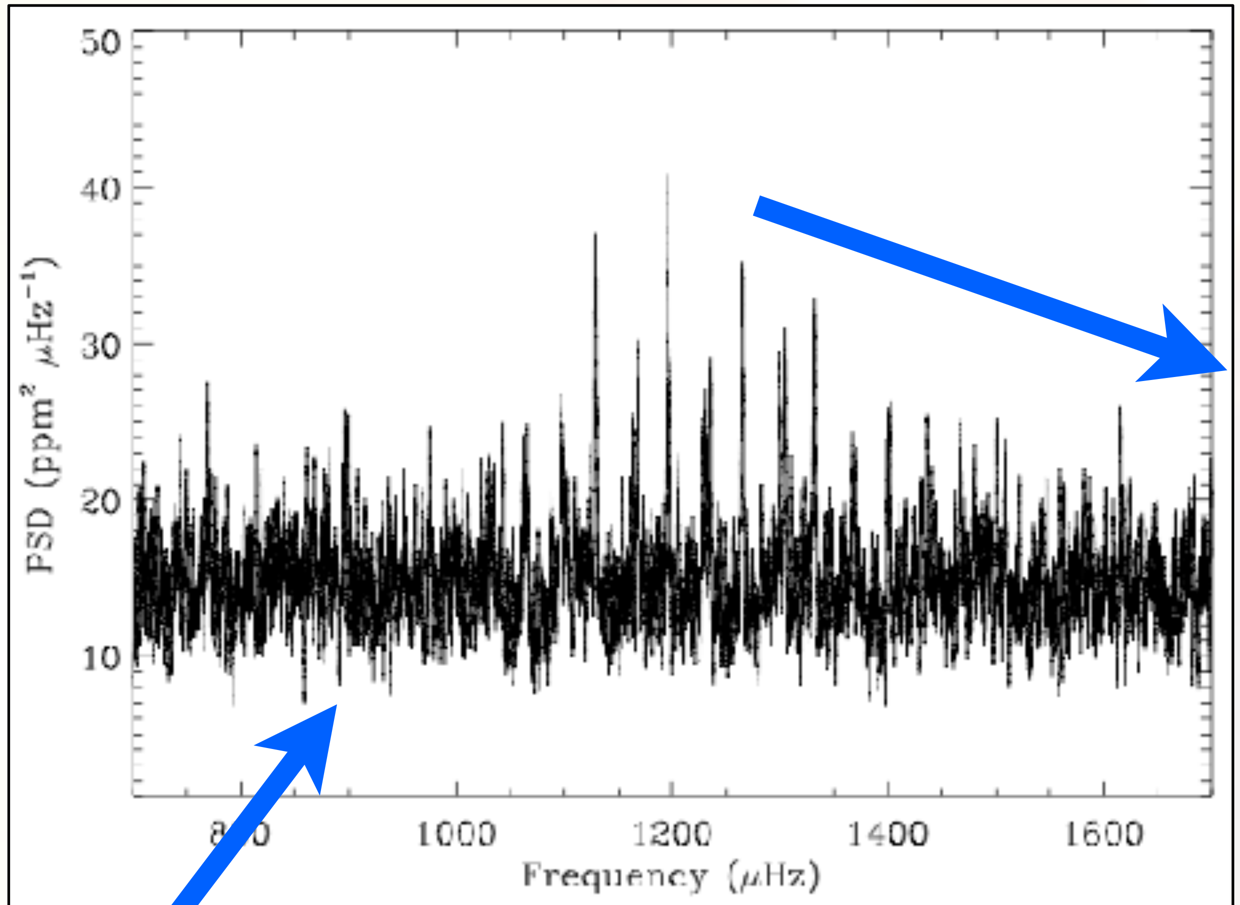
Mean Density

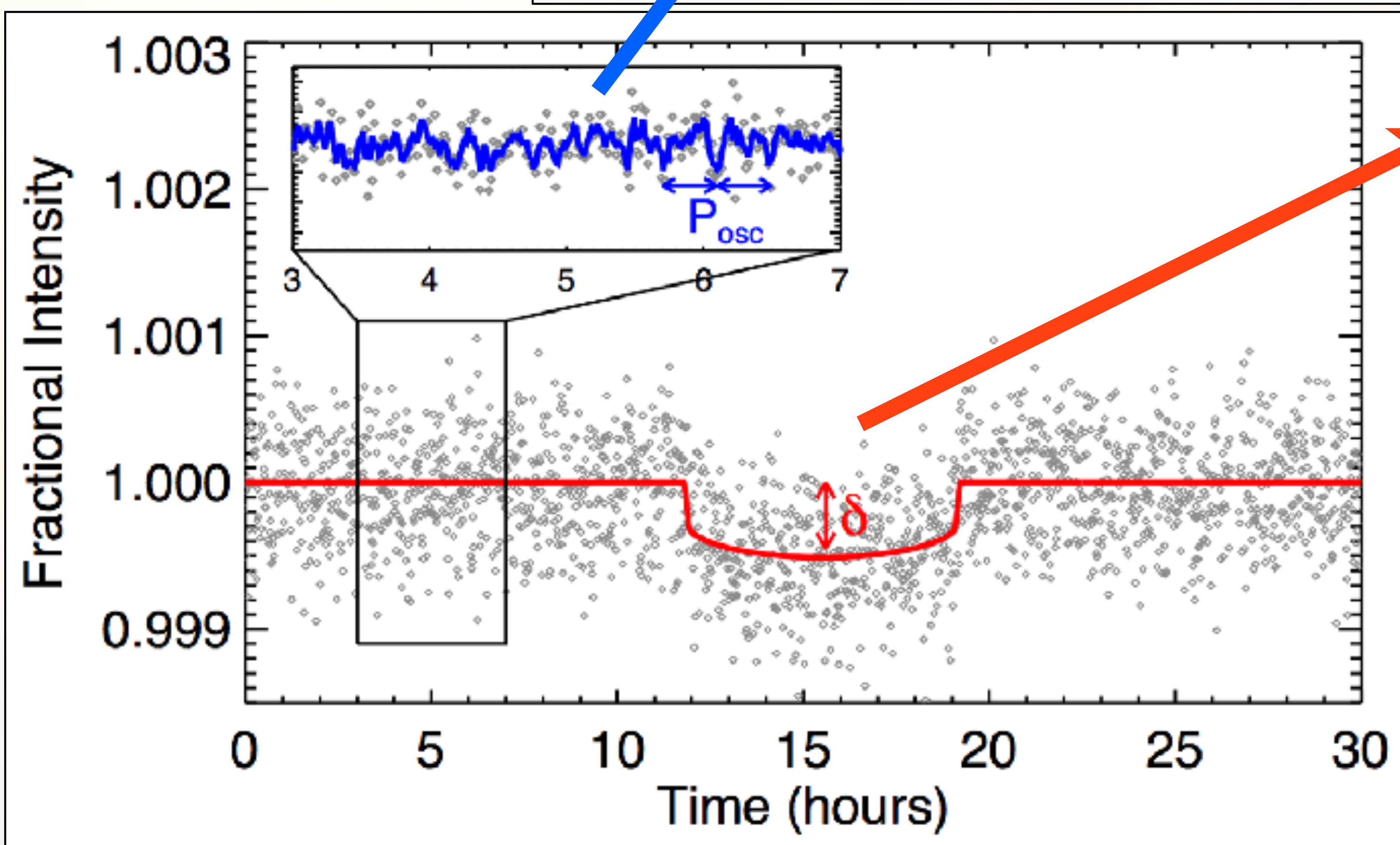
Bedding et al. 2011, Nature

The Exoplanet - Asteroseismology Synergy

Kepler-36

Carter et al. 2012





$M_\star$ & $R_\star$

+

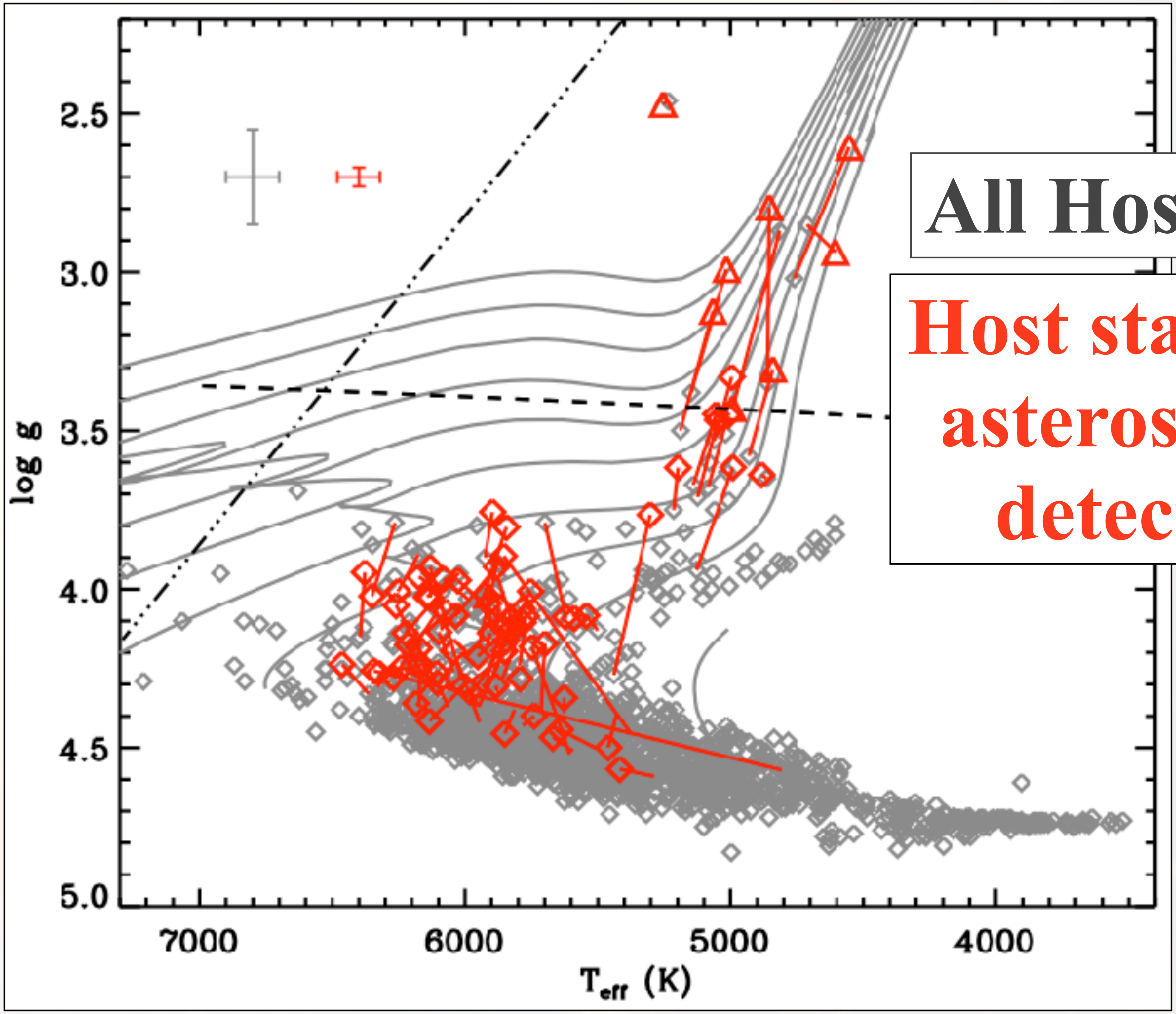
$(R_P/R_\star)^2$

↓

R_P

(<5% uncertainty!)

The Kepler Host Star Sample

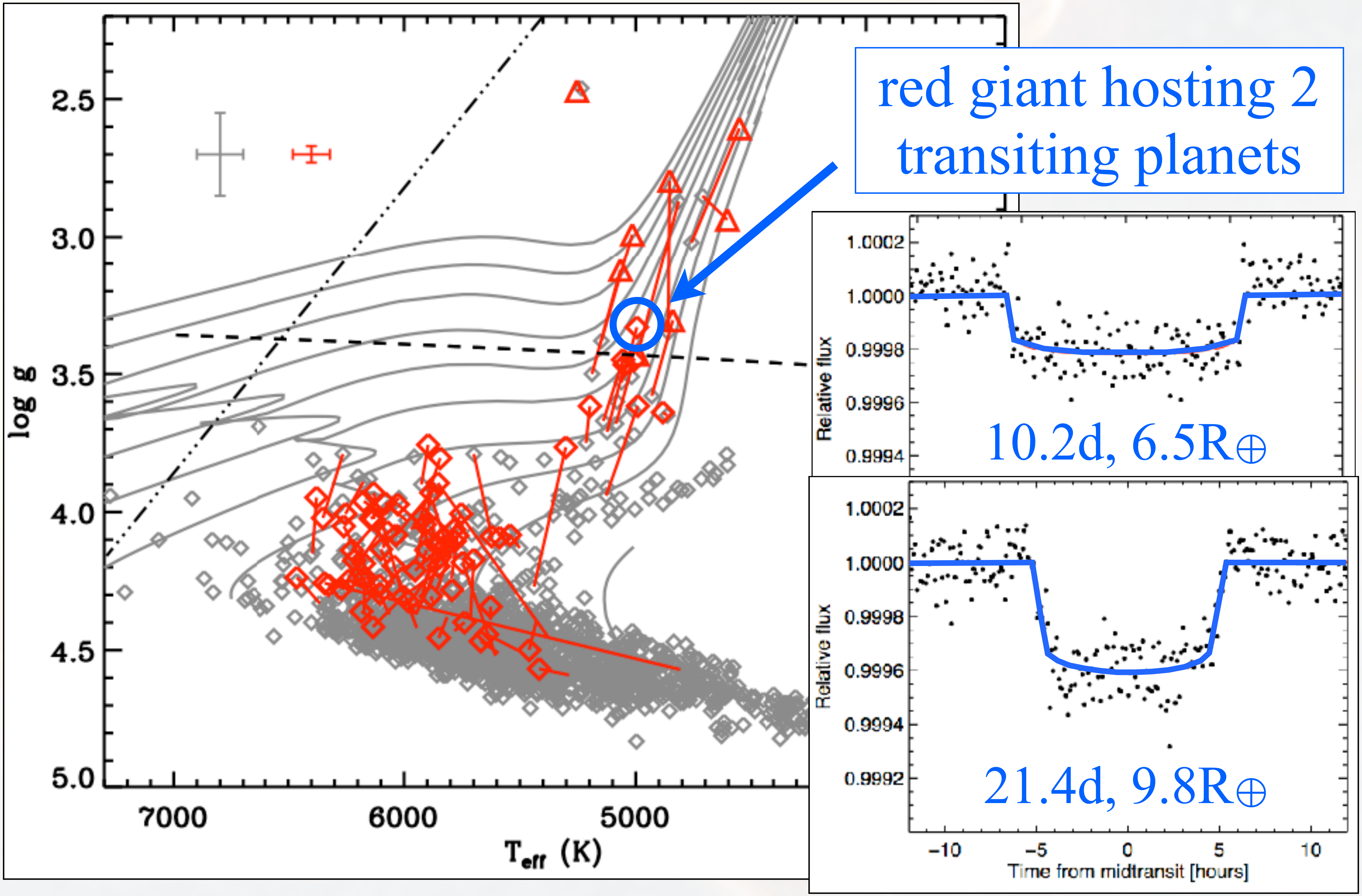


All Host Stars

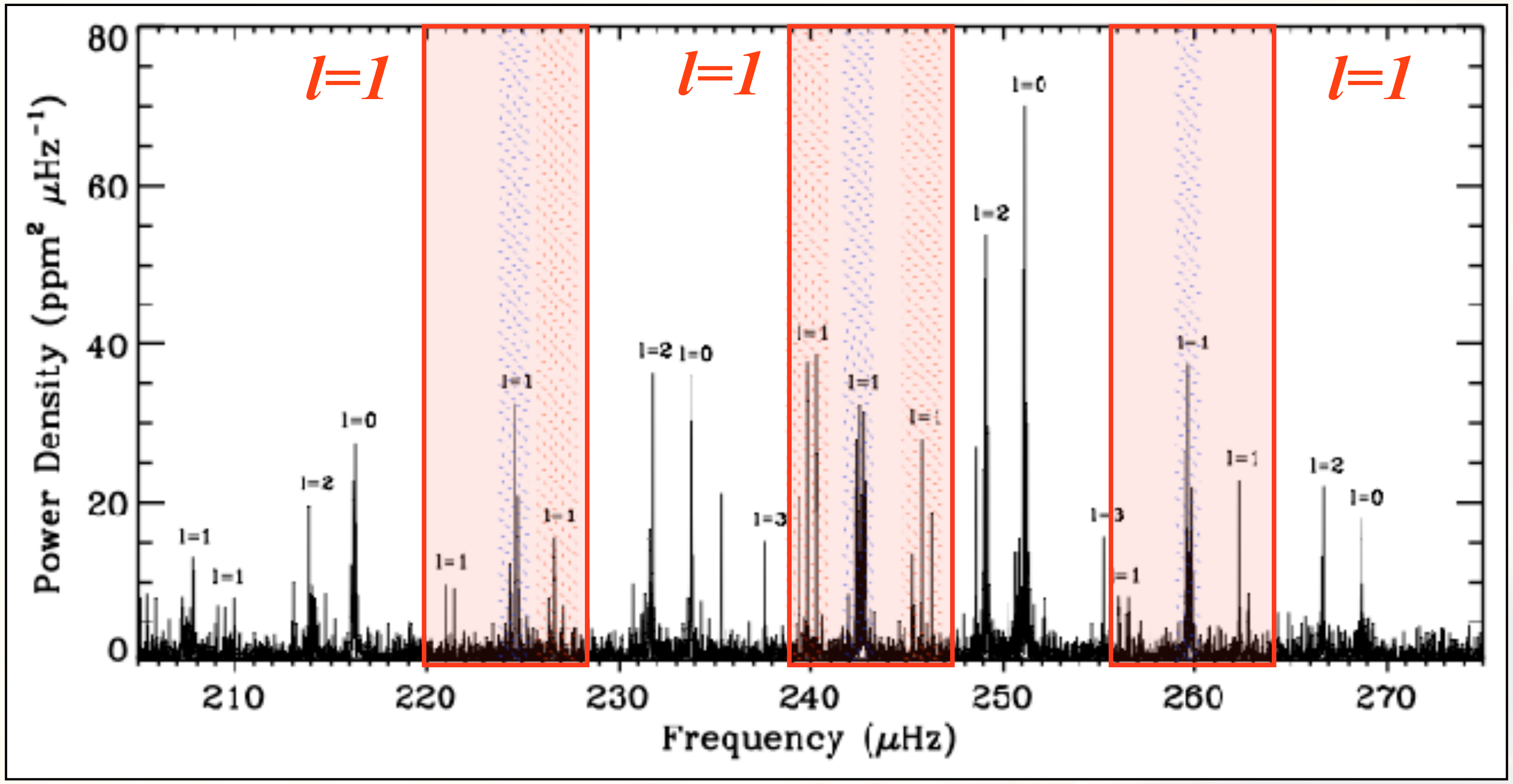
Host stars with asteroseismic detections

Huber et al. (2013a)

Synergy I: Exoplanet Architectures

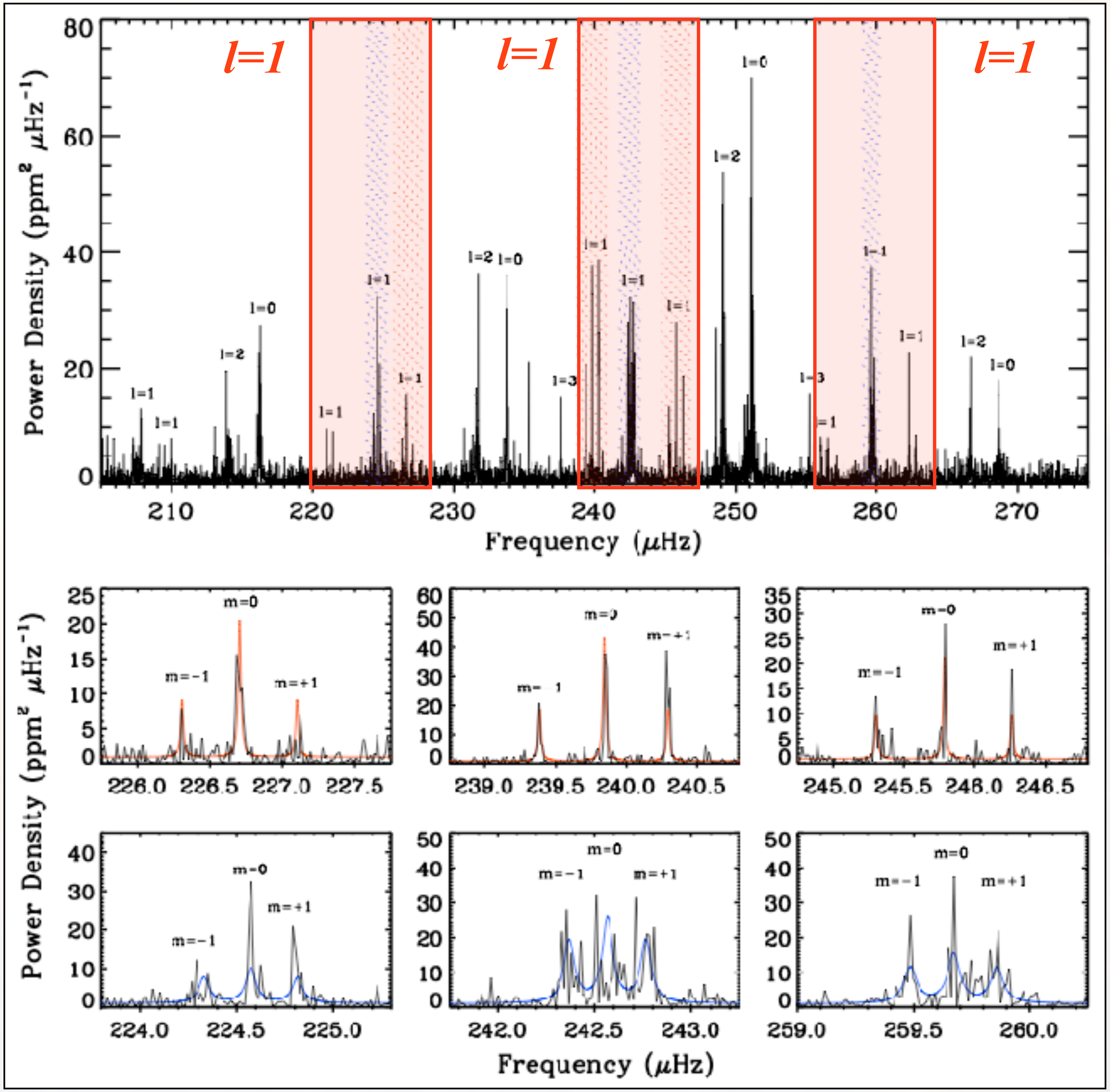


Kepler-56 Asteroseismology



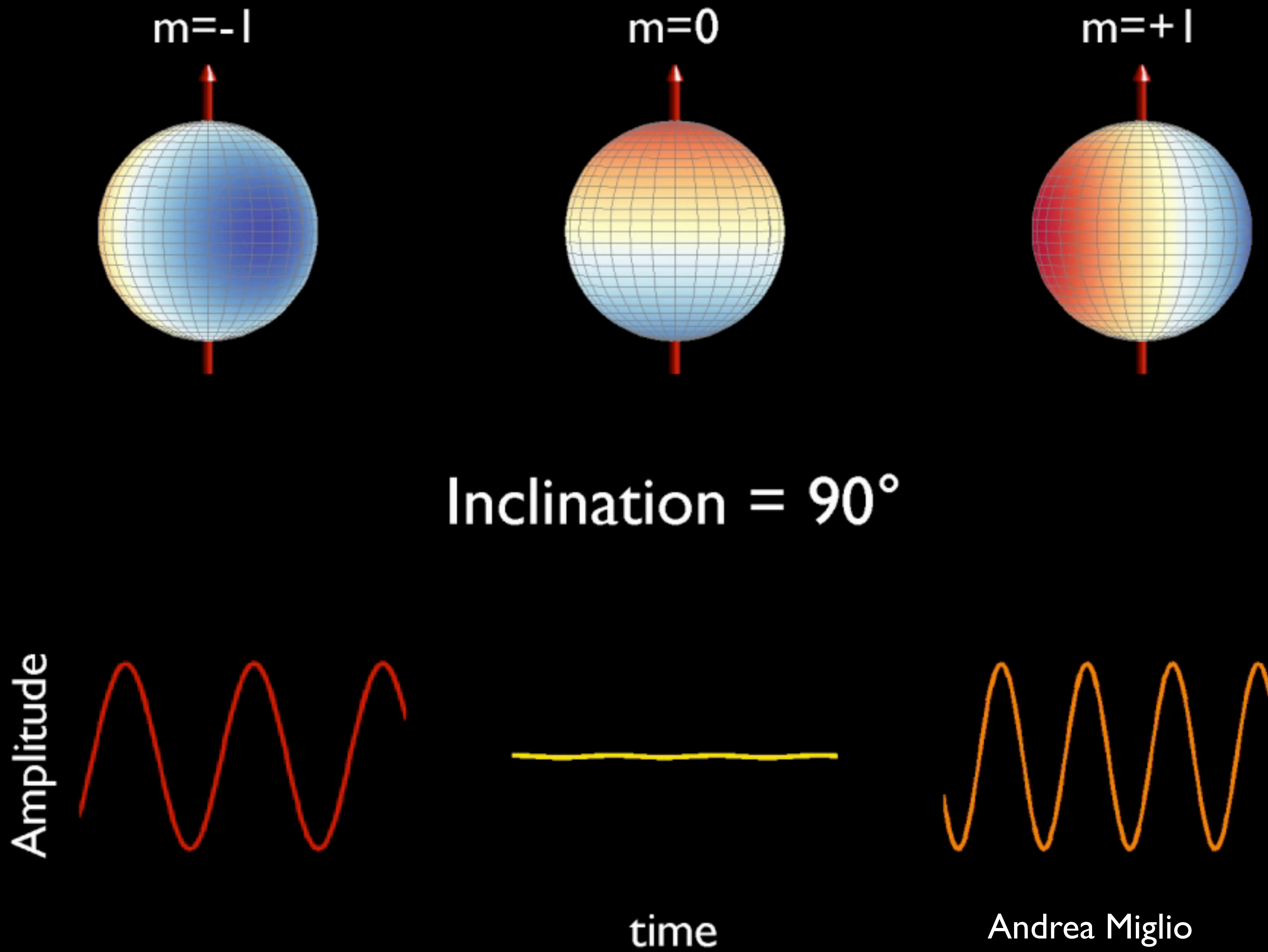
~50 individual frequencies detected

Kepler-56 Asteroseismology



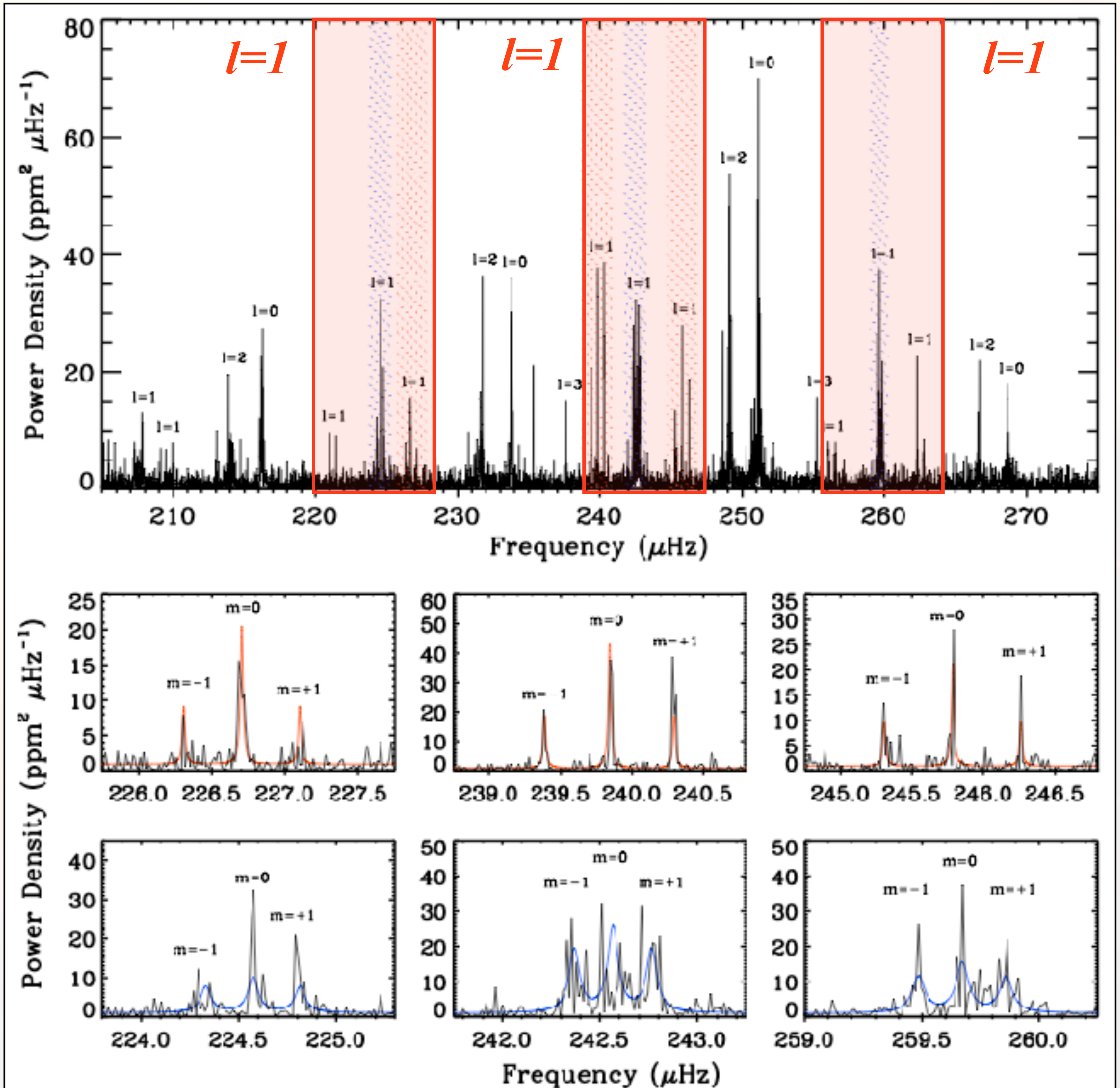
~50 individual frequencies detected

mixed *l=1* modes are split into triplets by rotation



Andrea Miglio
University of Birmingham, UK

Kepler-56 Asteroseismology

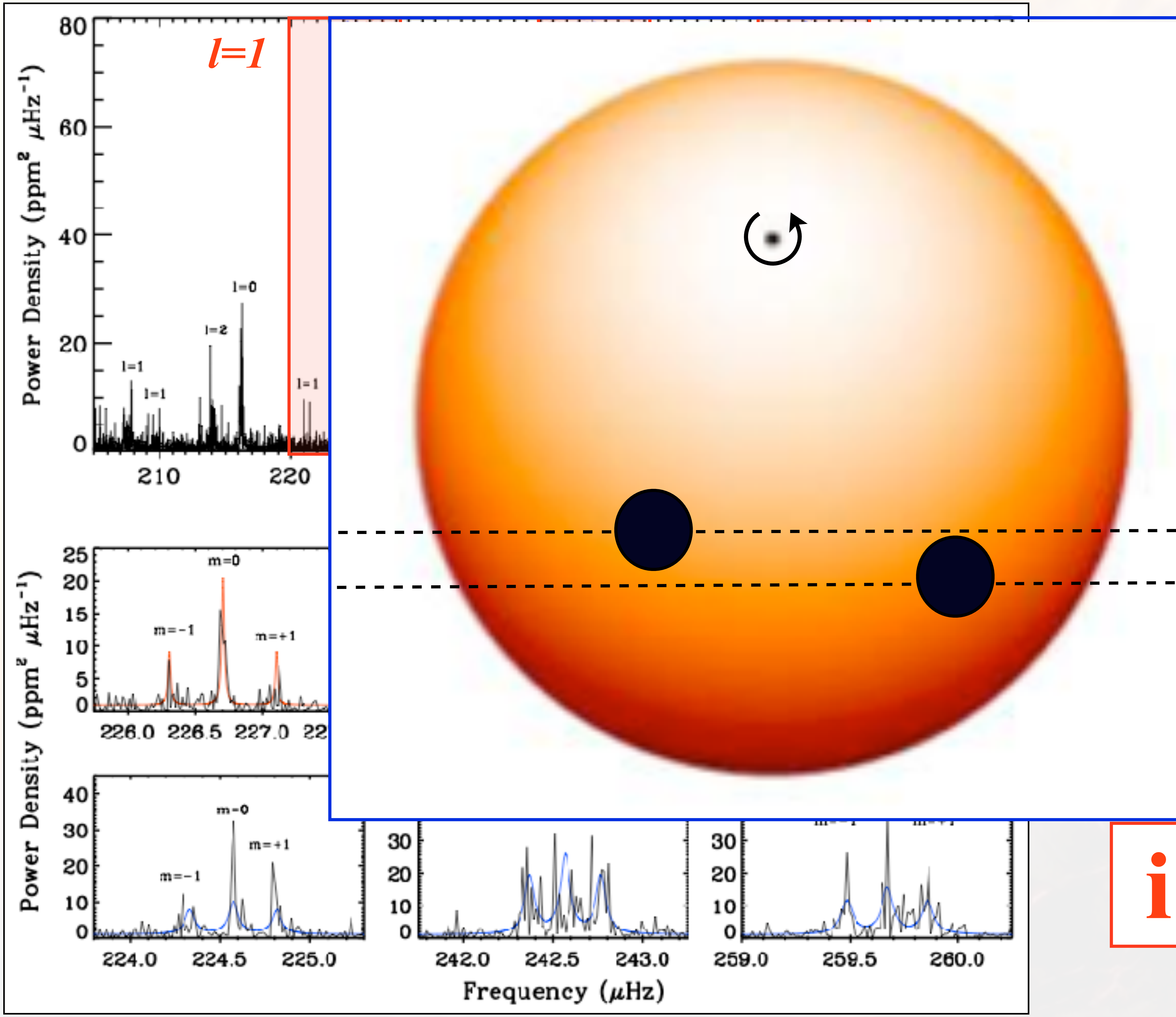


~50 individual frequencies detected

mixed *l=1* modes are split into triplets by rotation

i ~ 45°!

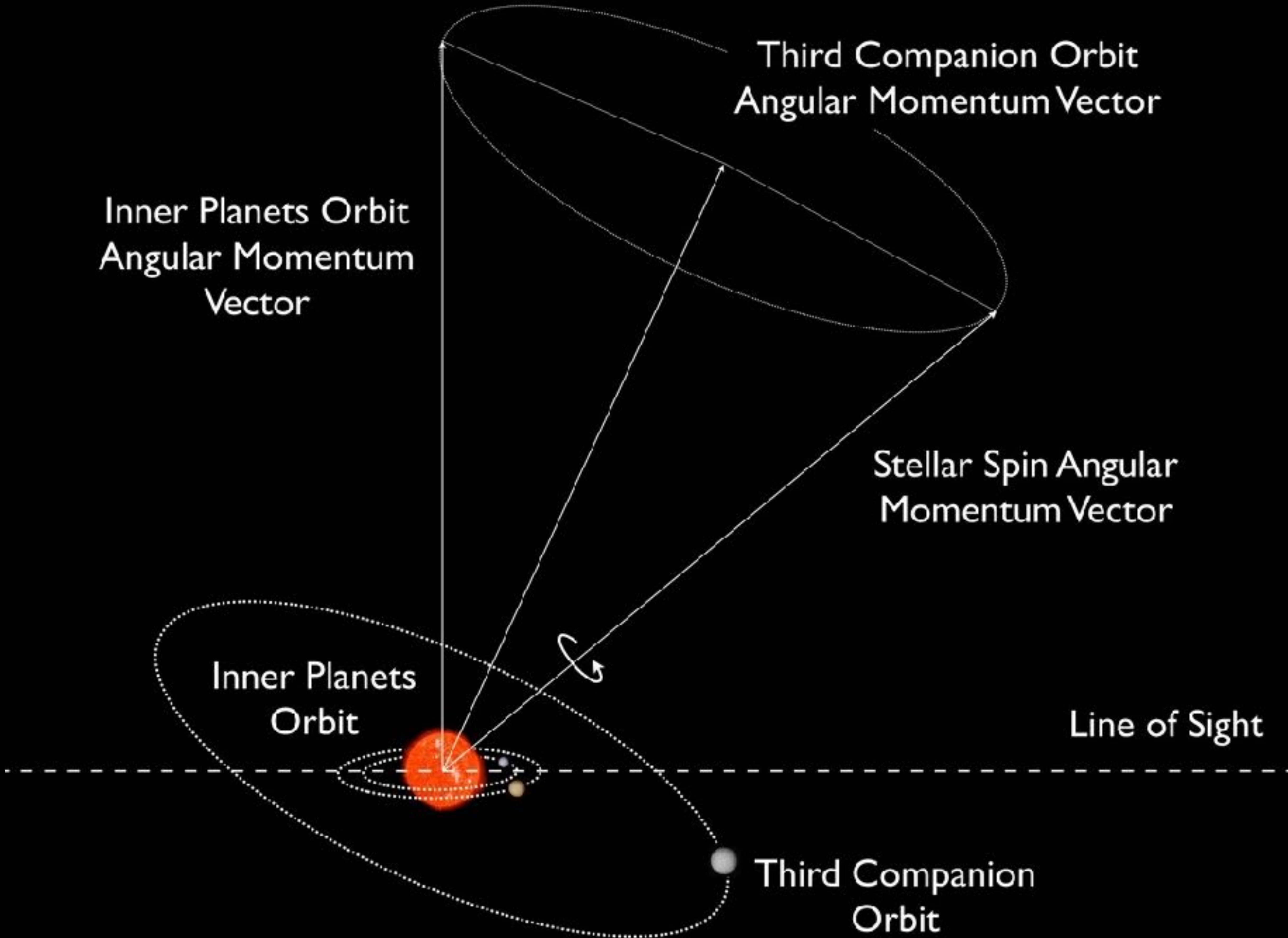
Kepler-56 Asteroseismology



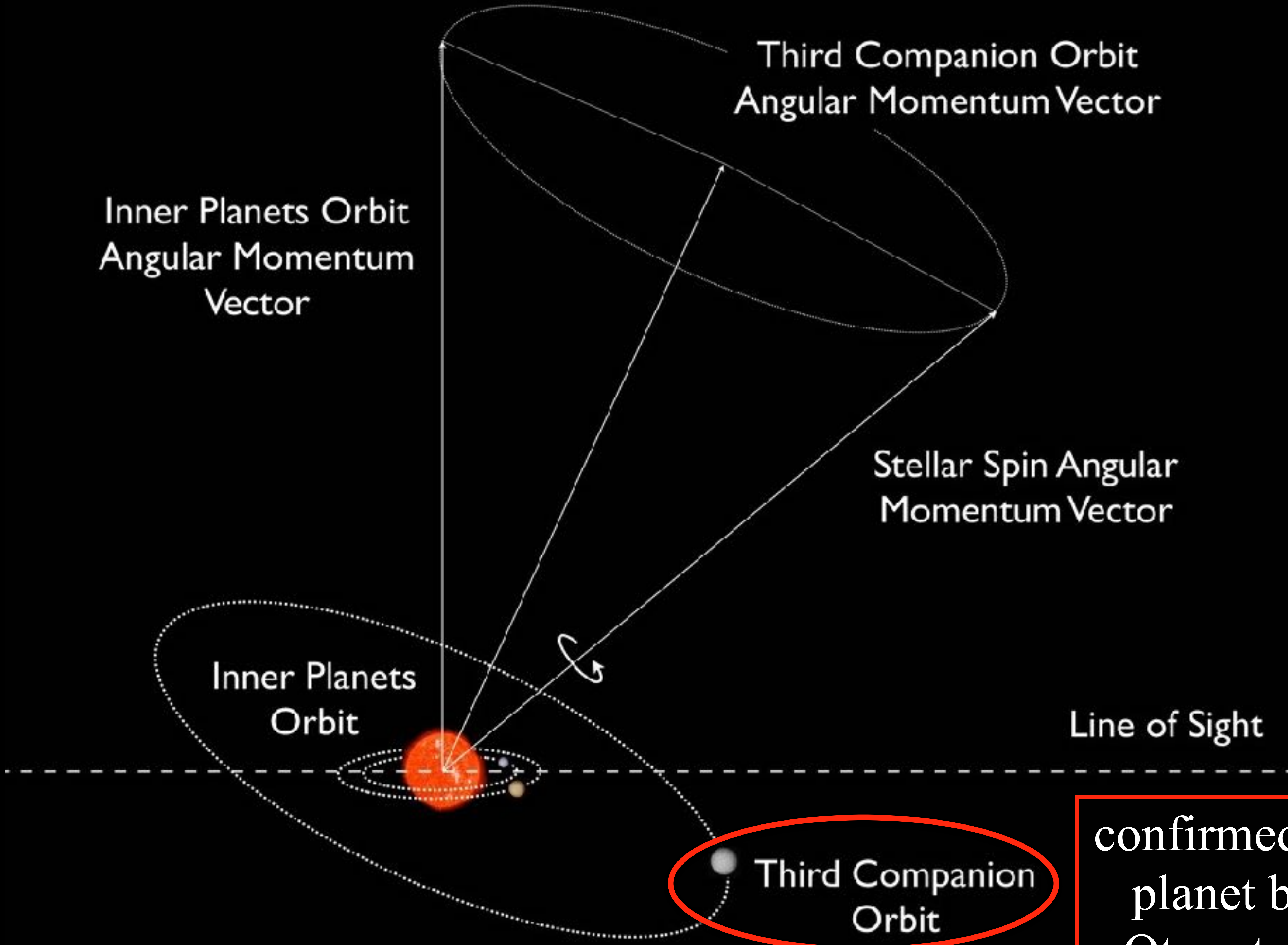
individual
equencies
detected

ixed *l=1*
les are split
triplets by
rotation

i ~ 45°!



Huber et al. 2013b

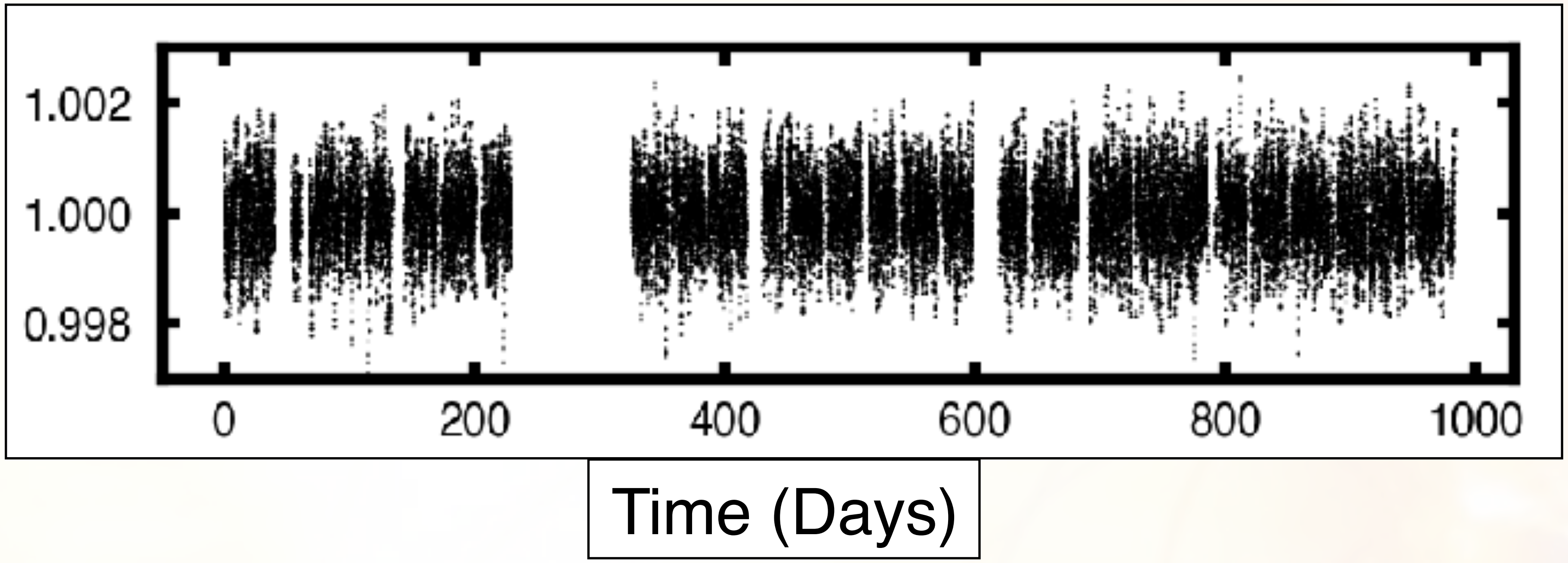


Huber et al. 2013b

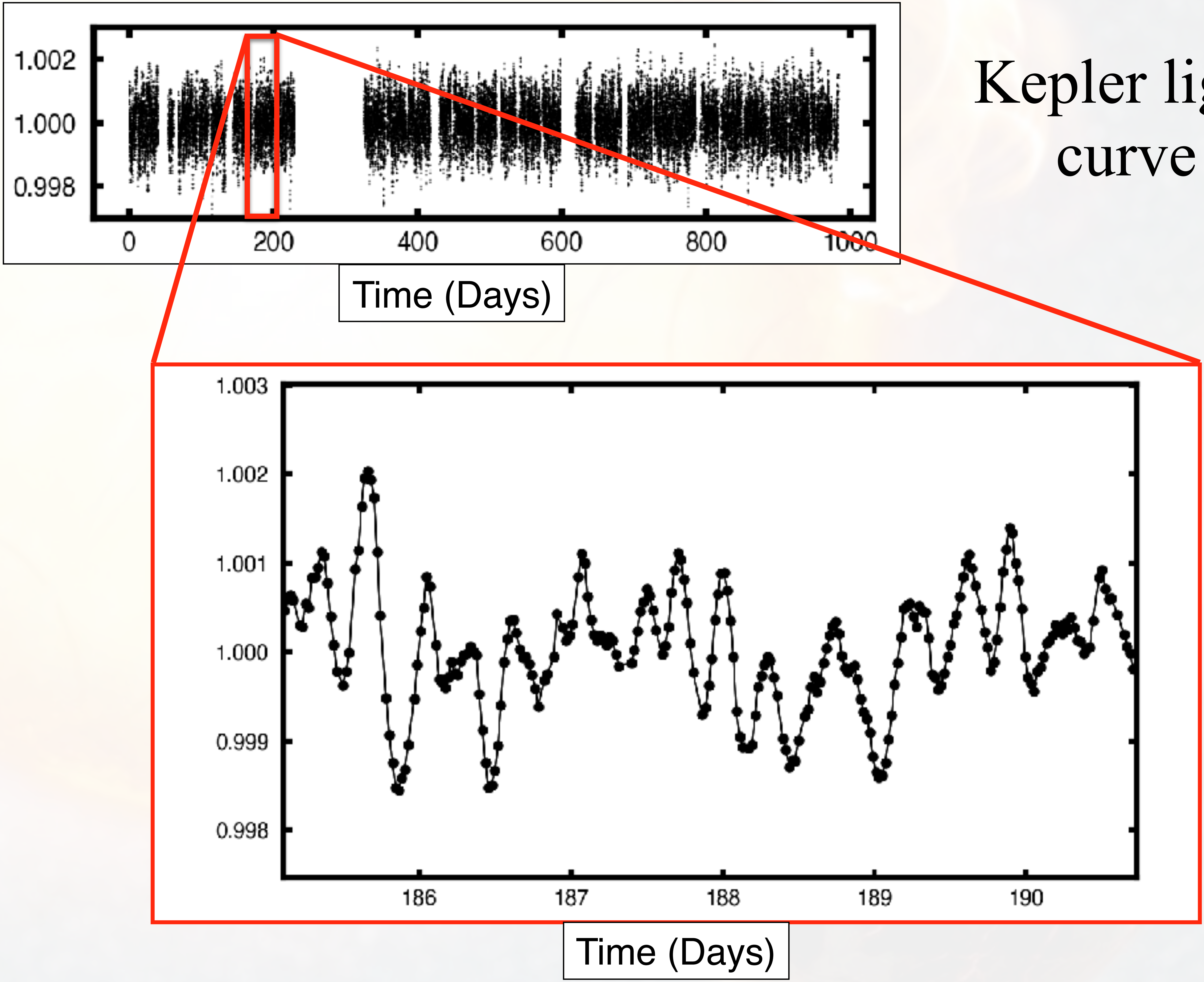
confirmed as planet by Otor et al. 2016!

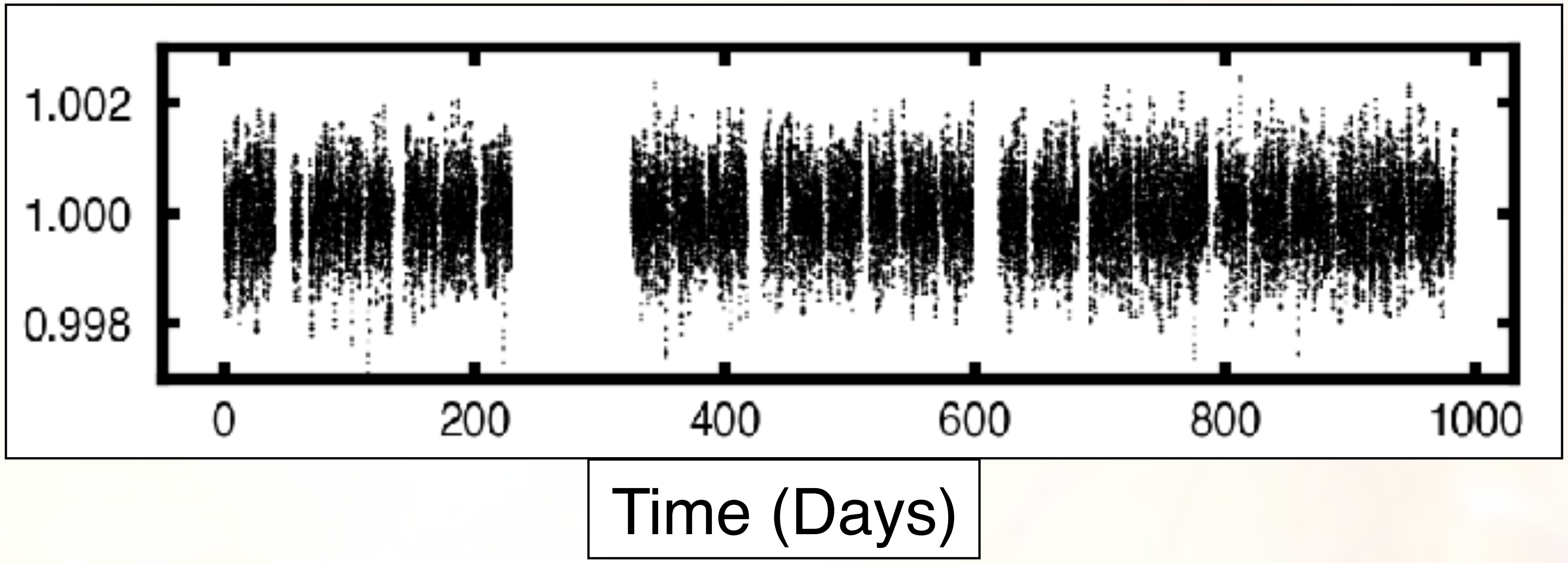
WFIRST Asteroseismology

Kepler light curve

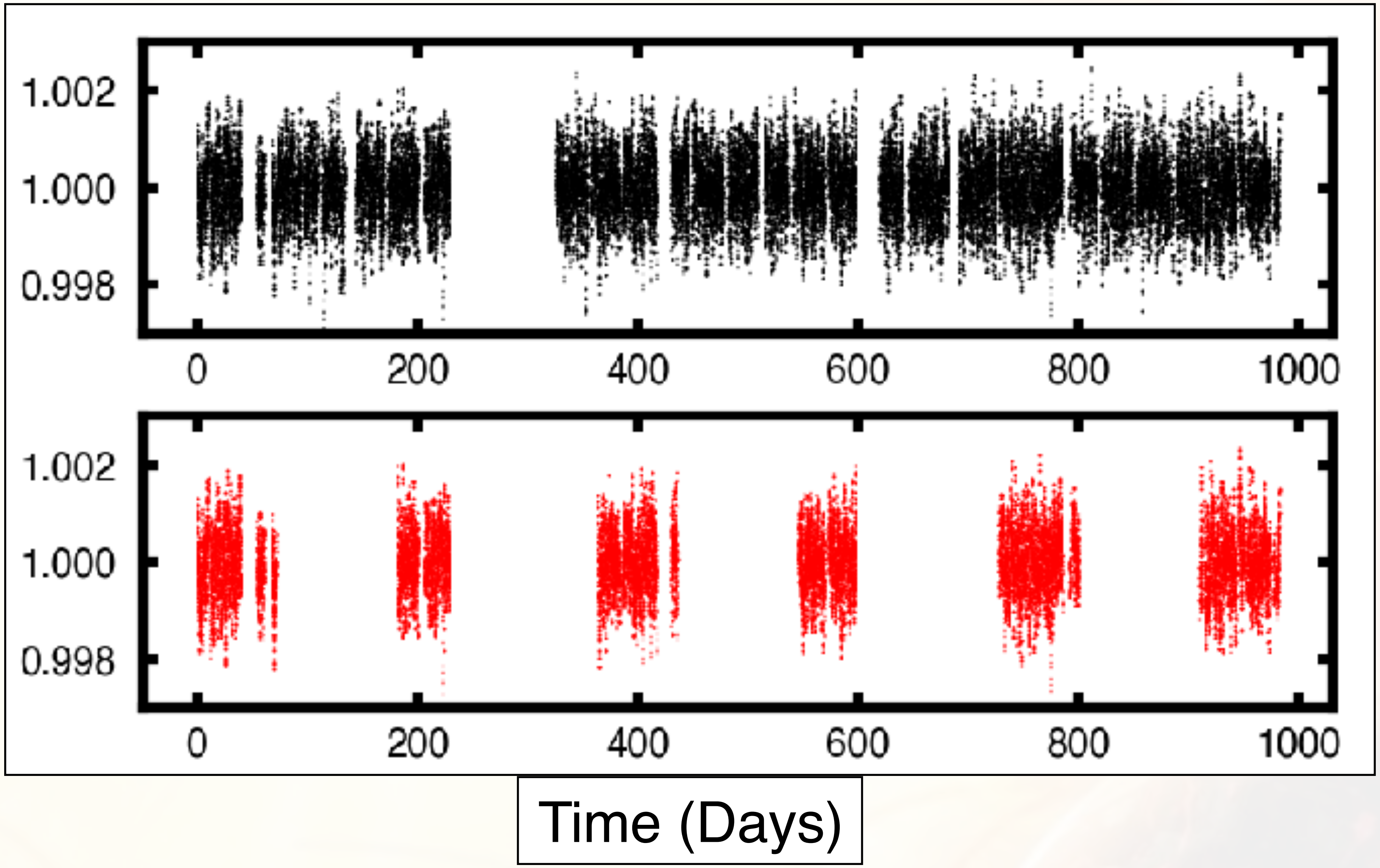


Kepler light curve



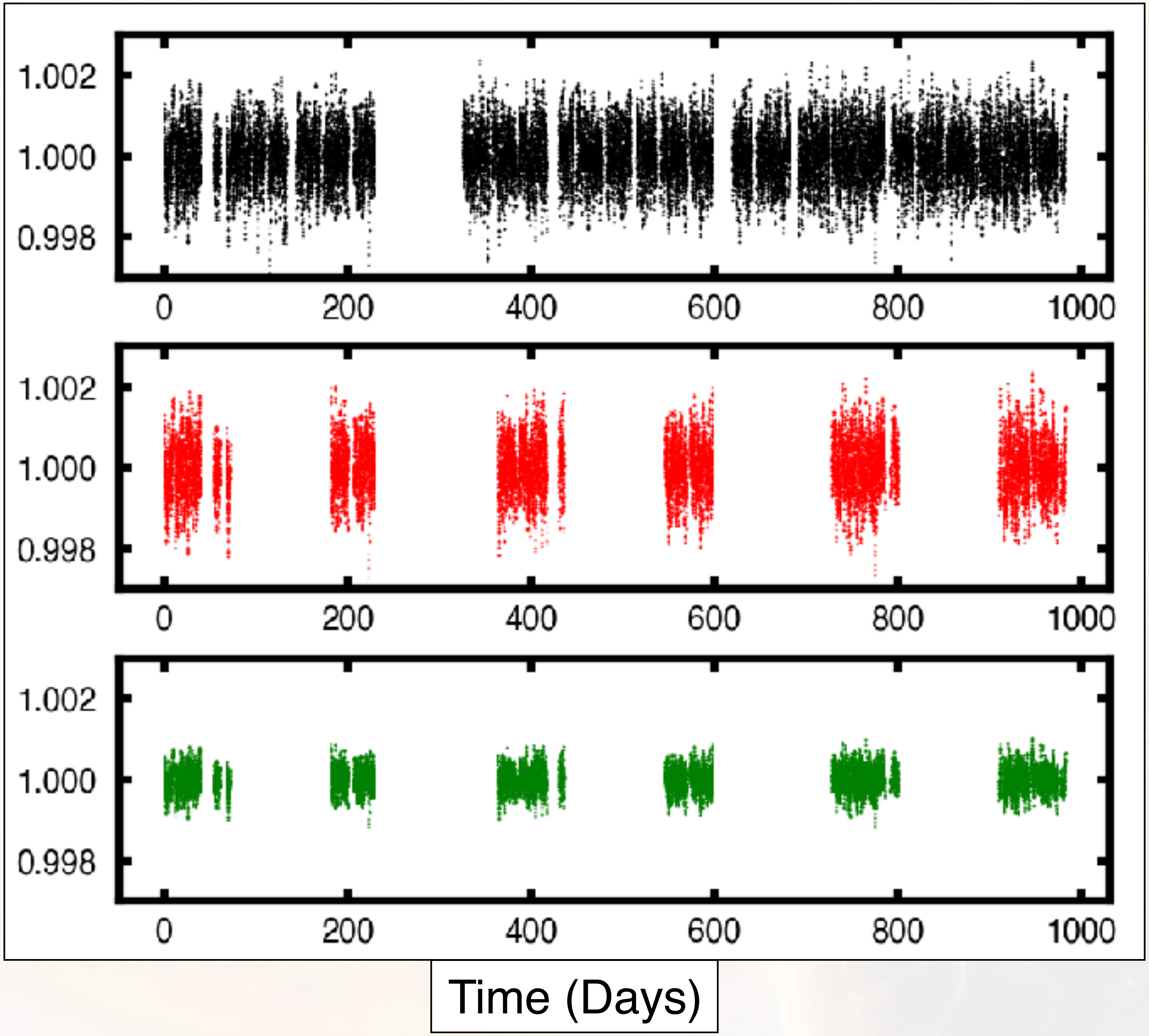


Kepler light curve



Kepler light curve

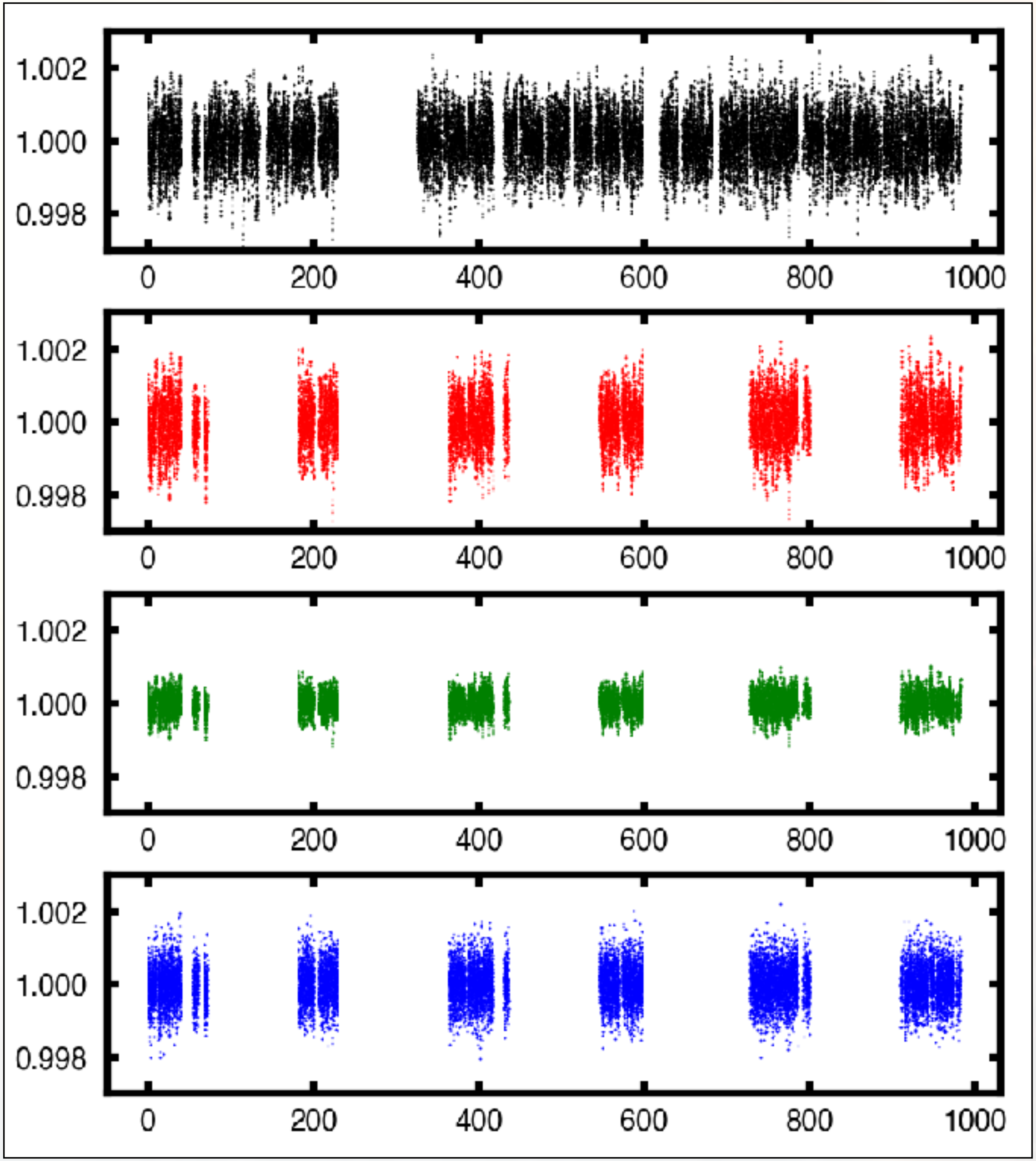
WFIRST Duty Cycle



Kepler light curve

WFIRST Duty Cycle

Amplitude (H/Kp) ~ 0.5

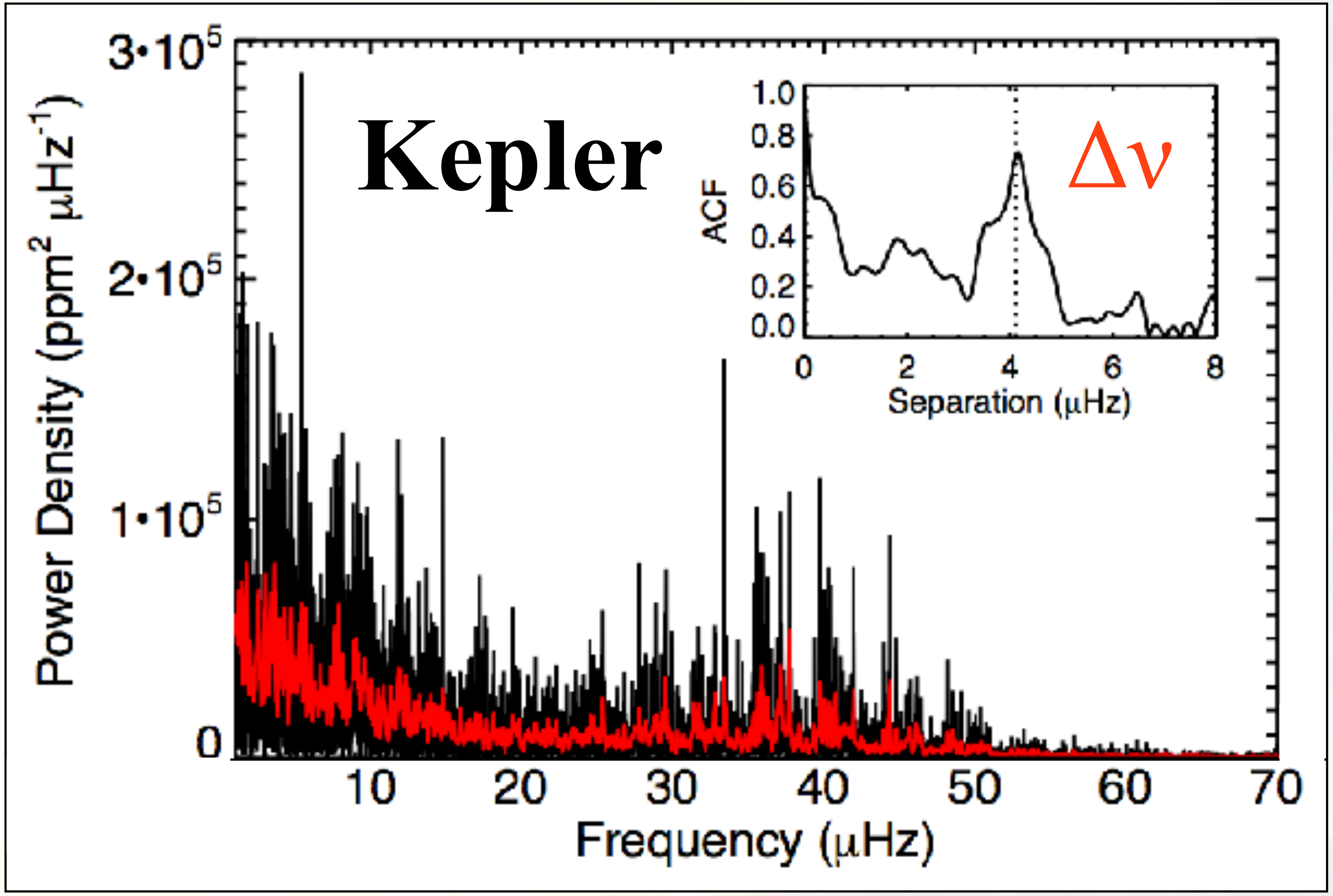


Kepler light curve

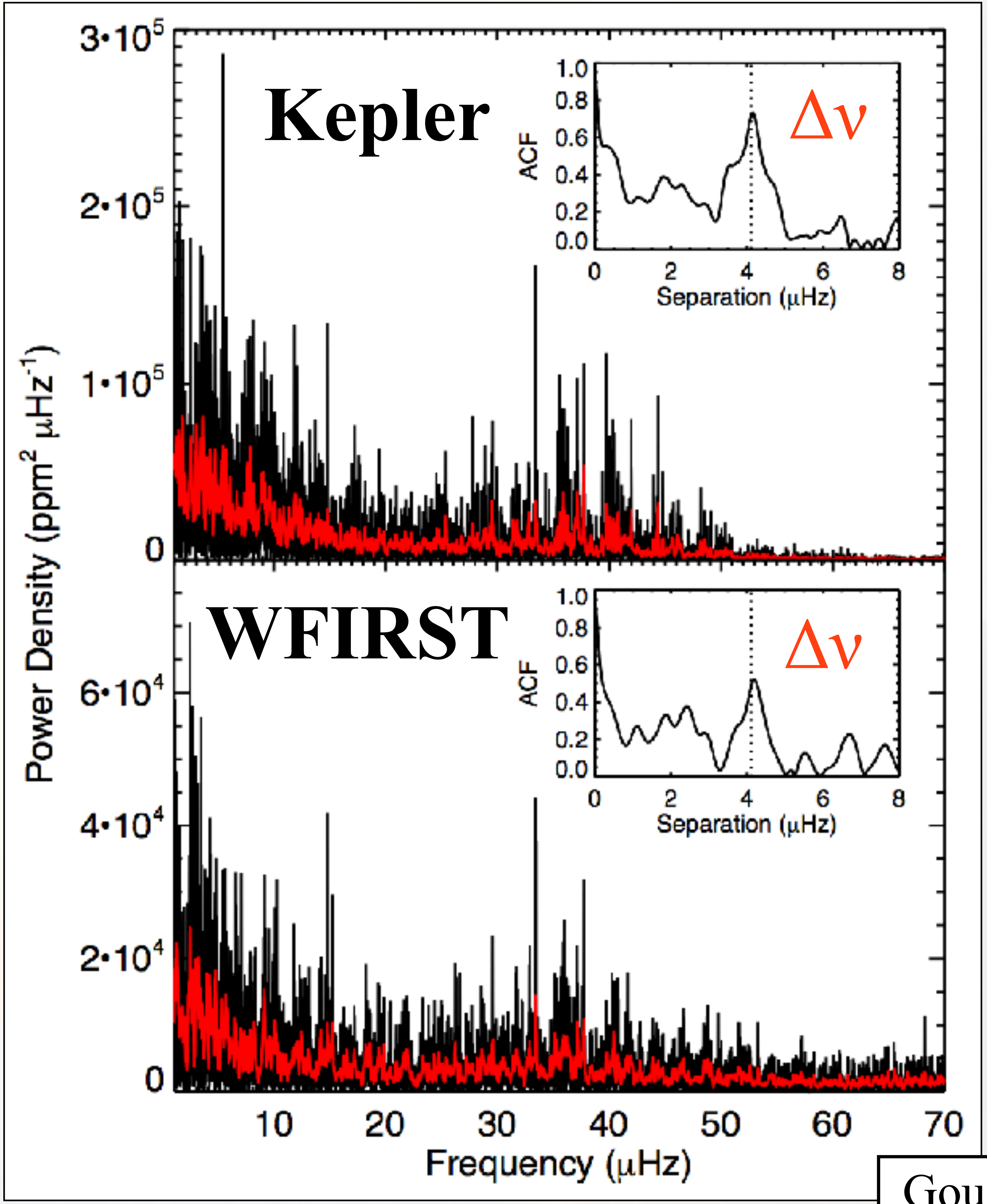
WFIRST Duty Cycle

Amplitude (H/Kp) ~ 0.5

WFIRST photometry noise

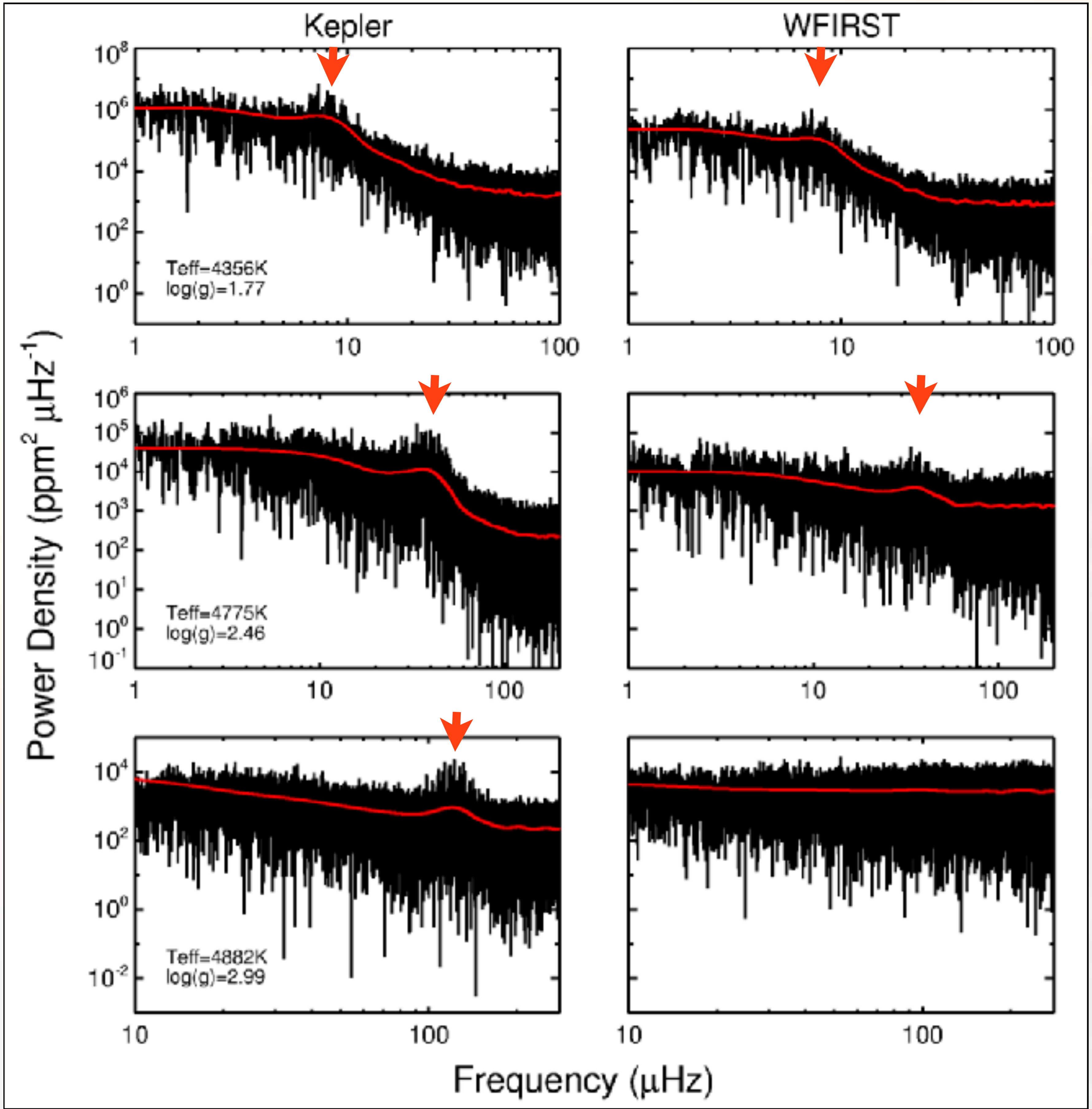


Kepler
Δν
Power Density (ppm² μHz⁻¹)
Frequency (μHz)
ACF
Separation (μHz)



Gould et al. (2014)

Simulated Bulge Giants

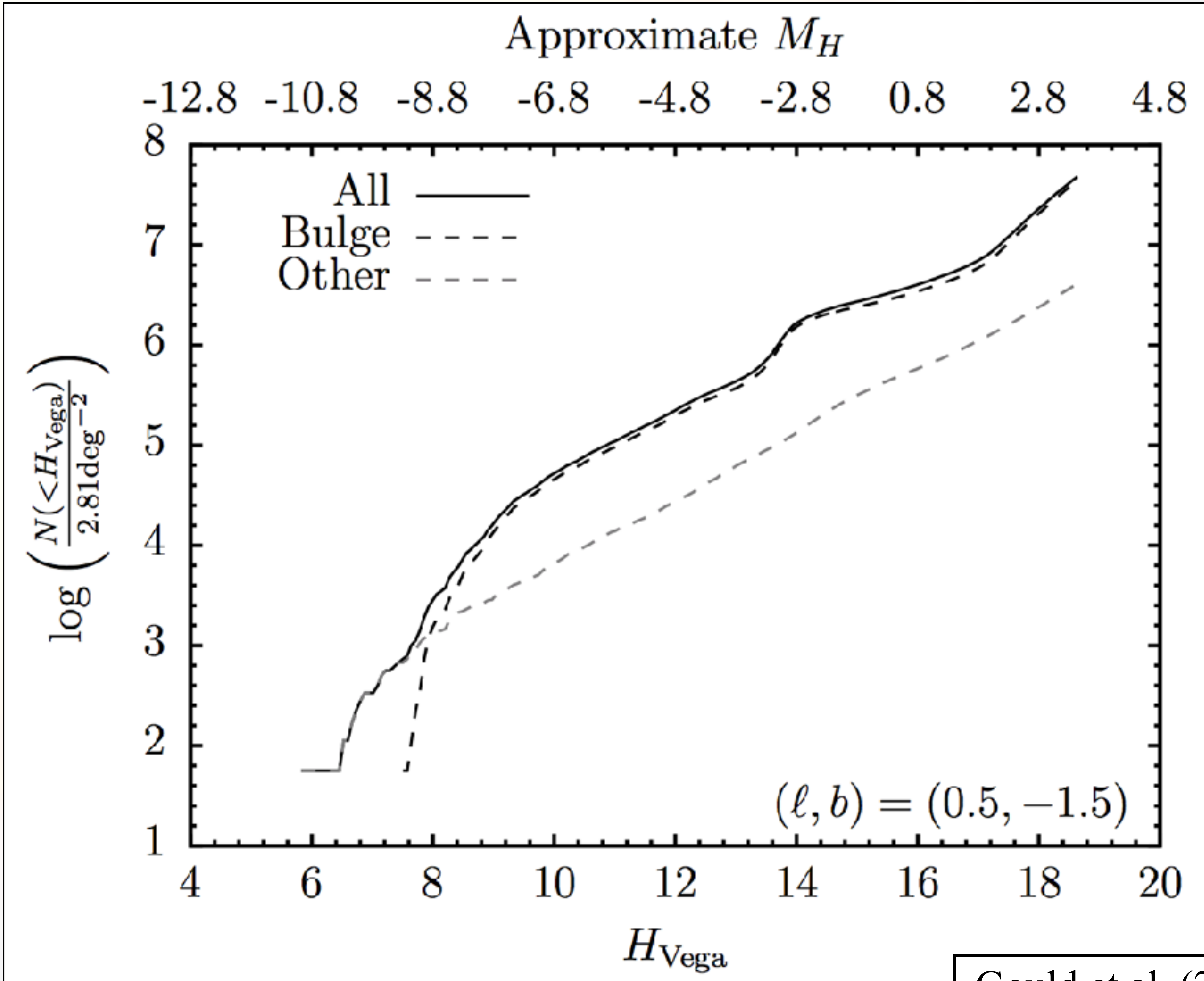


H ~ 14.8 mag
log(g) ~ 1.8
R ~ 25 R☉

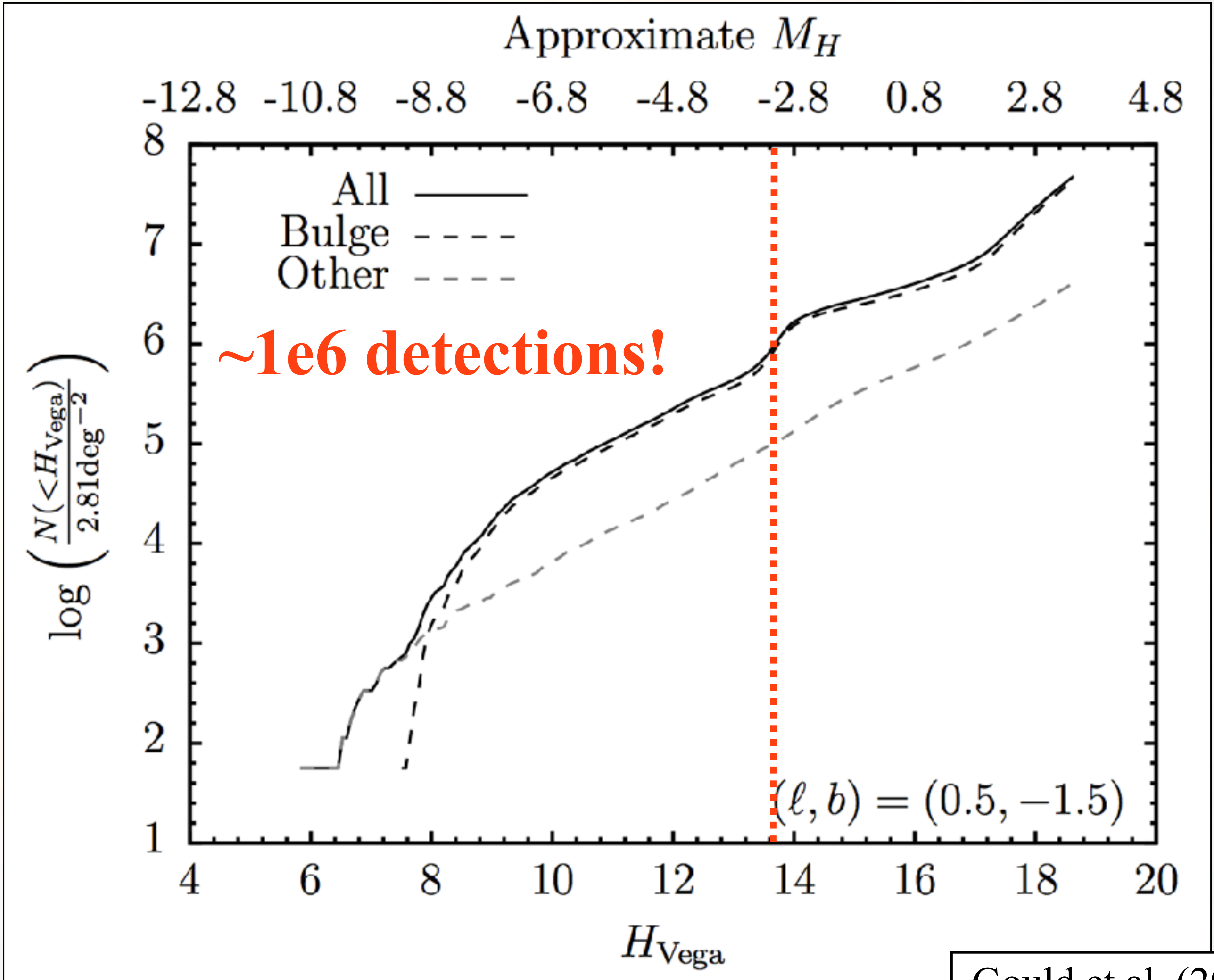
H ~ 13.6 mag
log(g) ~ 2.5
R ~ 11 R☉

H ~ 12.1 mag
log(g) ~ 3.0
R ~ 7 R☉

Gould et al. (2014)



Gould et al. (2014)



Gould et al. (2014)

Galactic Archeology

How old are the galactic bulge & halo?

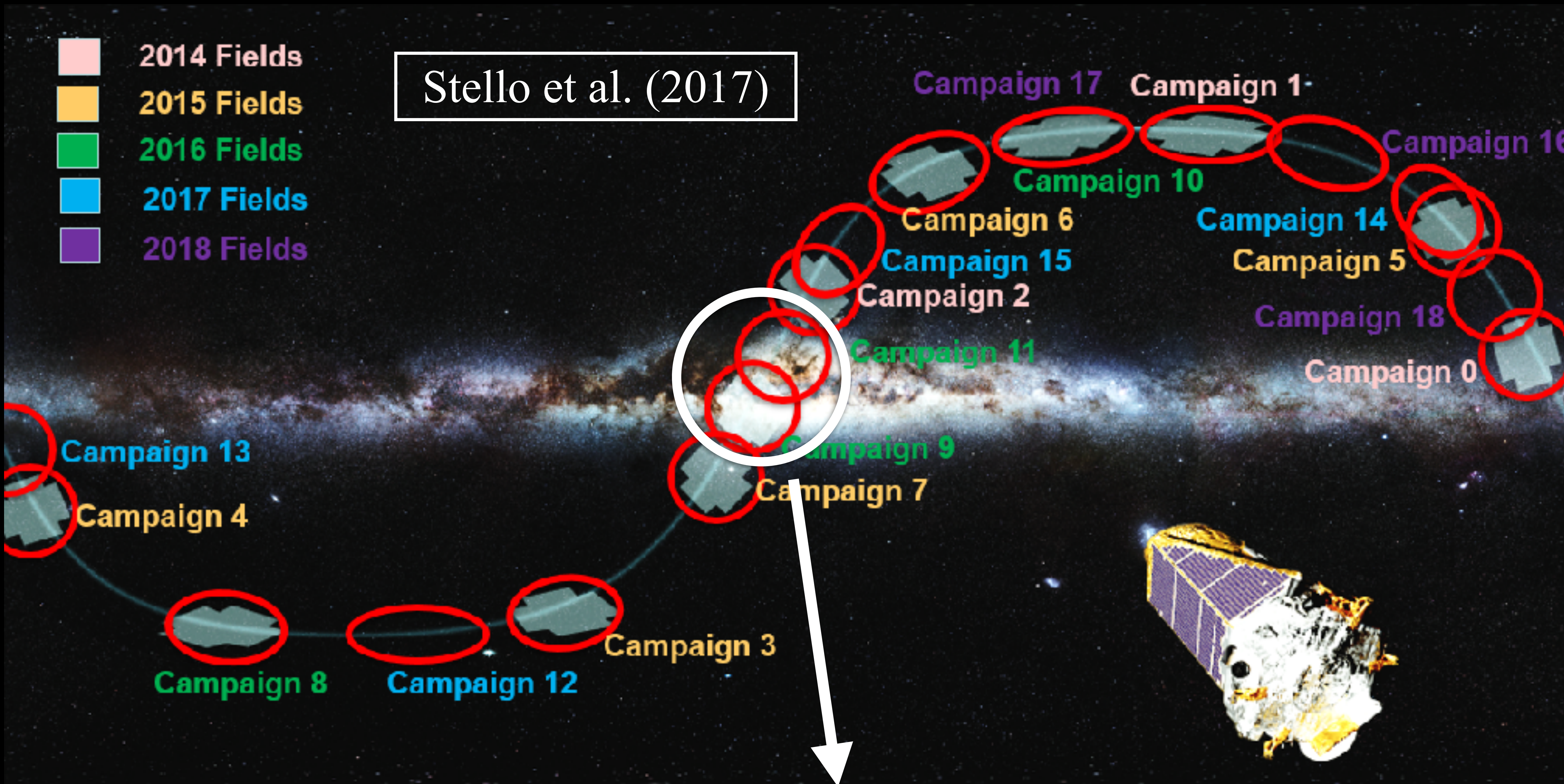
How did the thin & thick disc form?

How important is radial migration?

Galactic Archeology

K2 Galactic Archeology Program

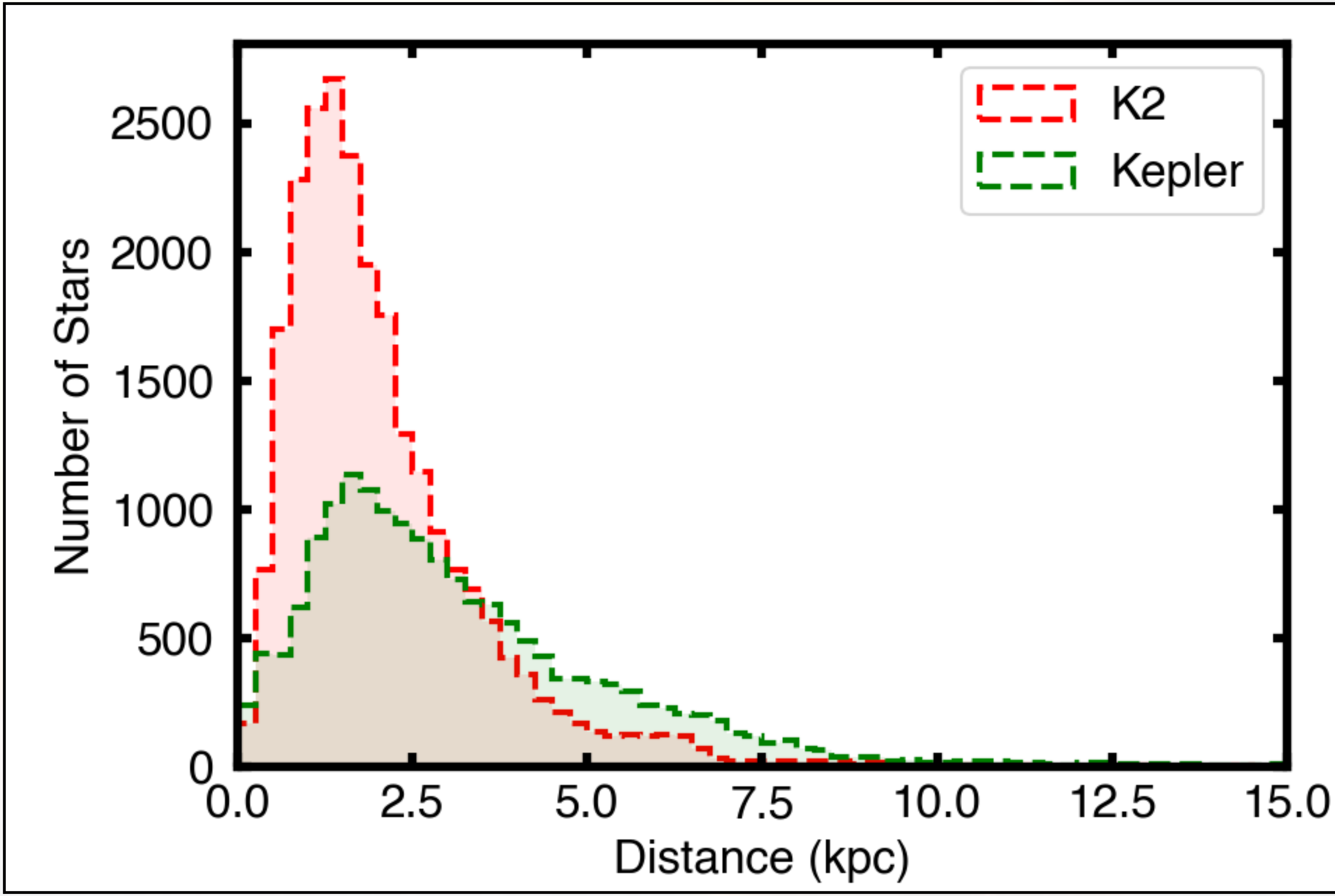
K2 Galactic Archeology Program



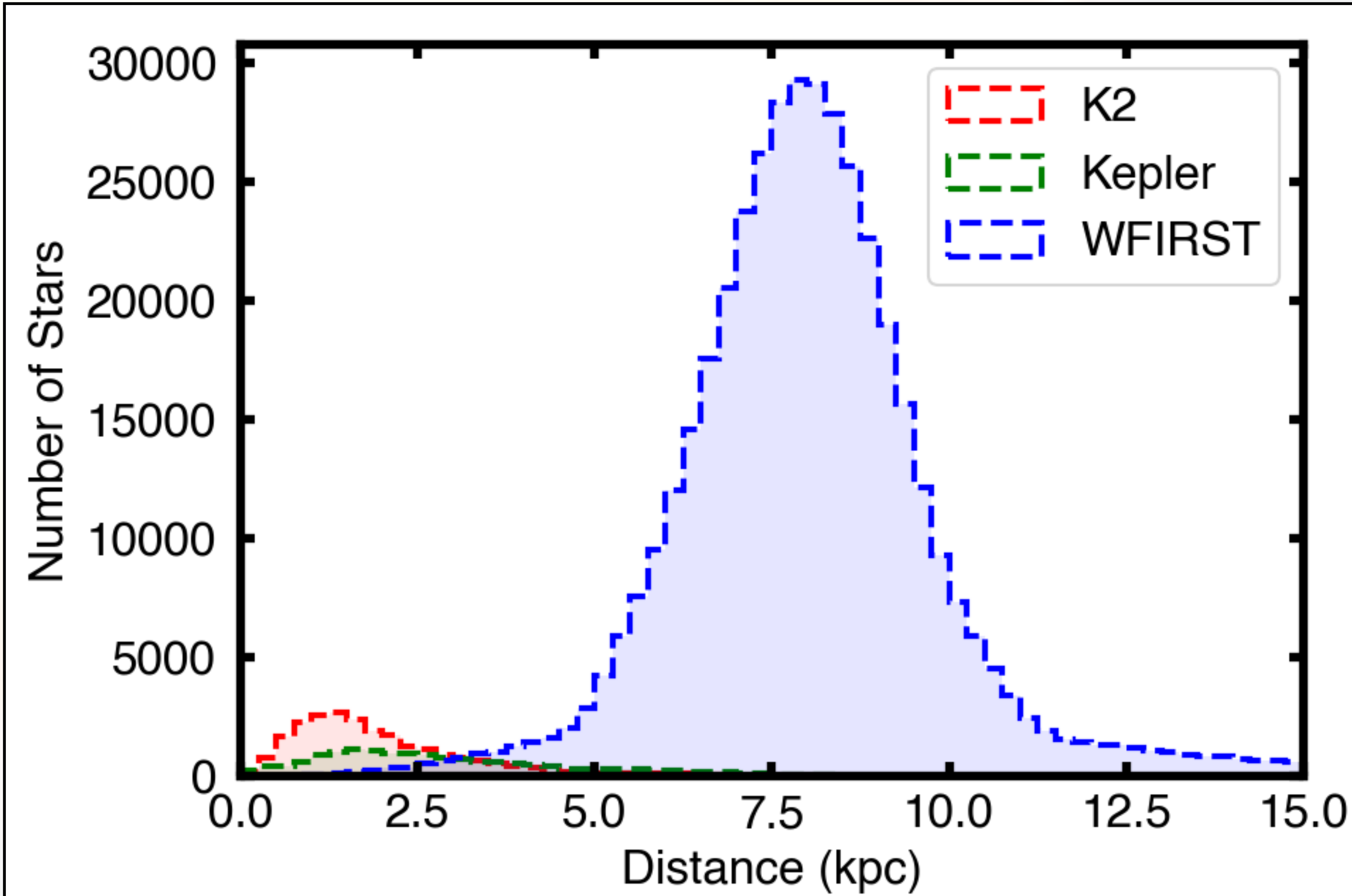
Challenges:

- Crowded Field Photometry (4" pixels!)
- 70 day campaigns limit distance reach

Asteroseismic Distance Reach

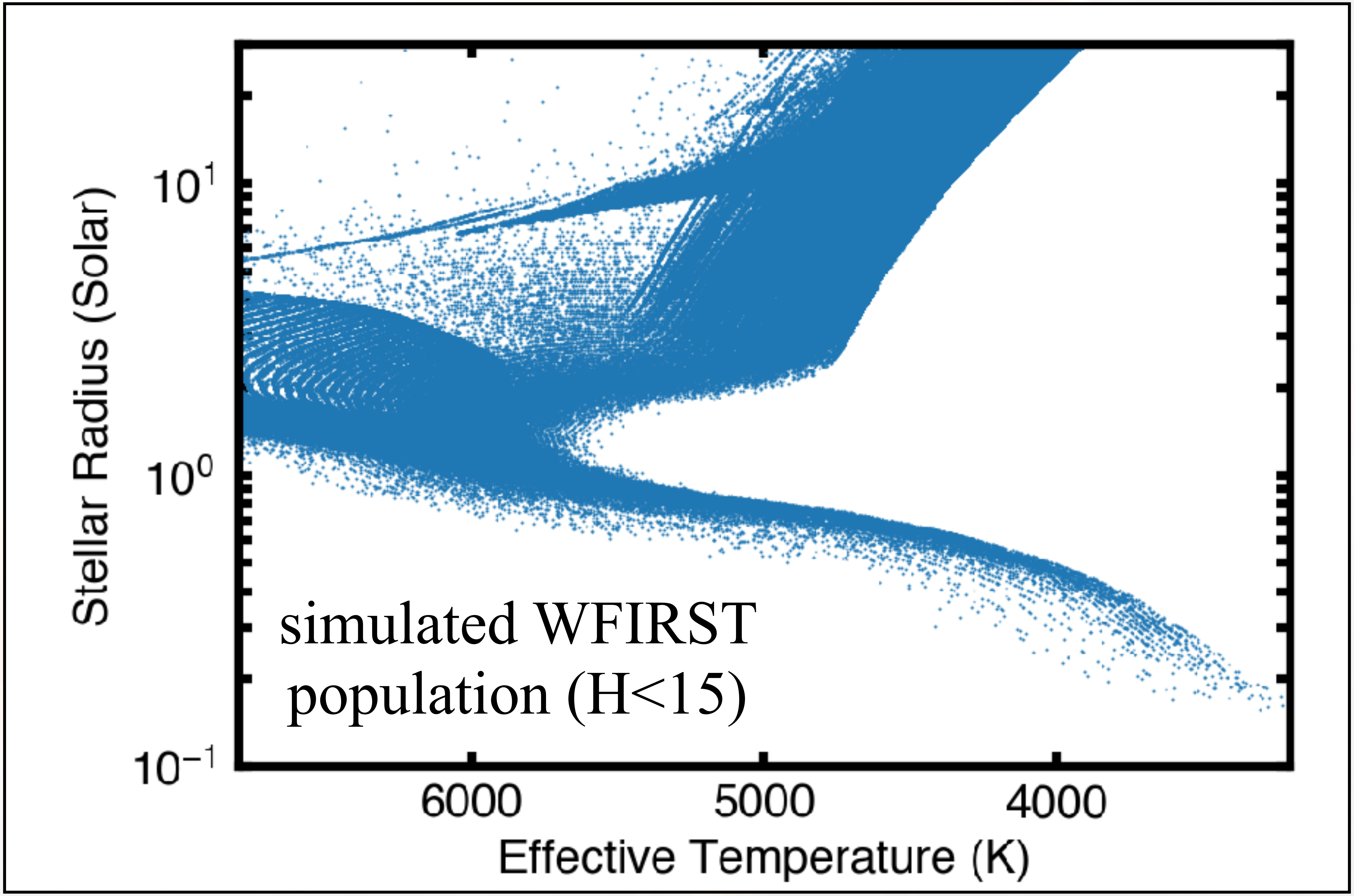


Asteroseismic Distance Reach

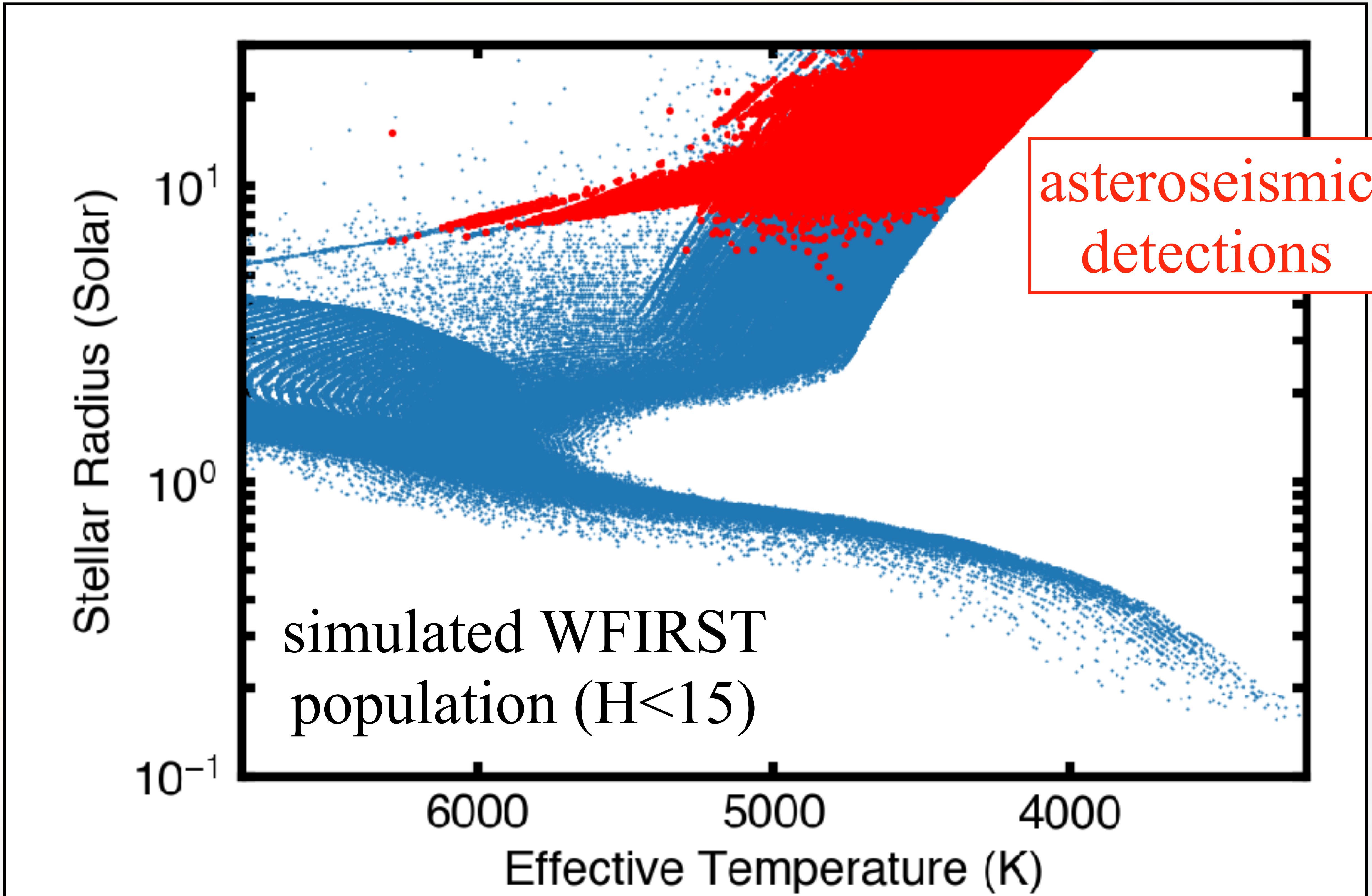


What can WFIRST Asteroseismology do for Exoplanets?

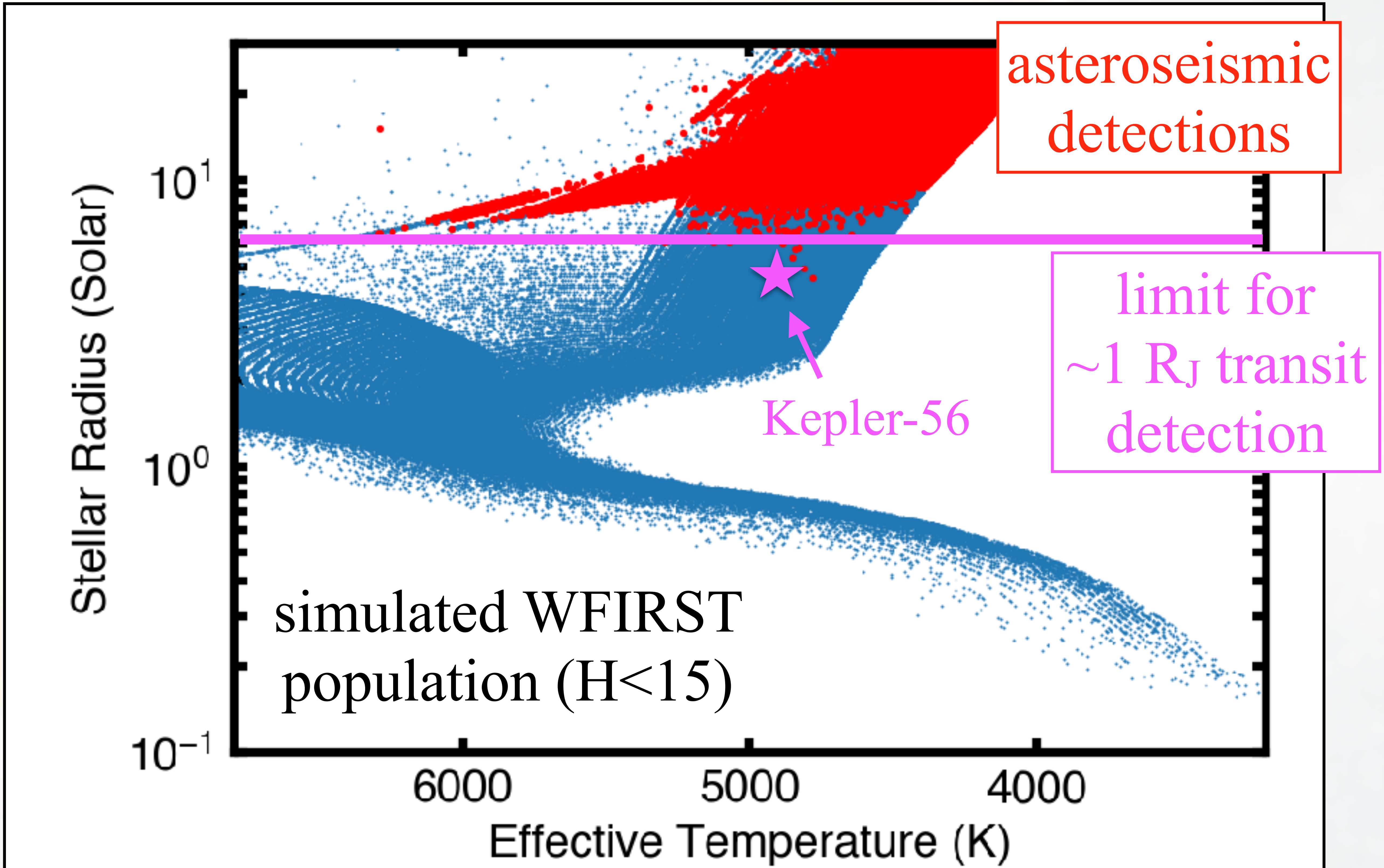
Transiting Exoplanet Hosts

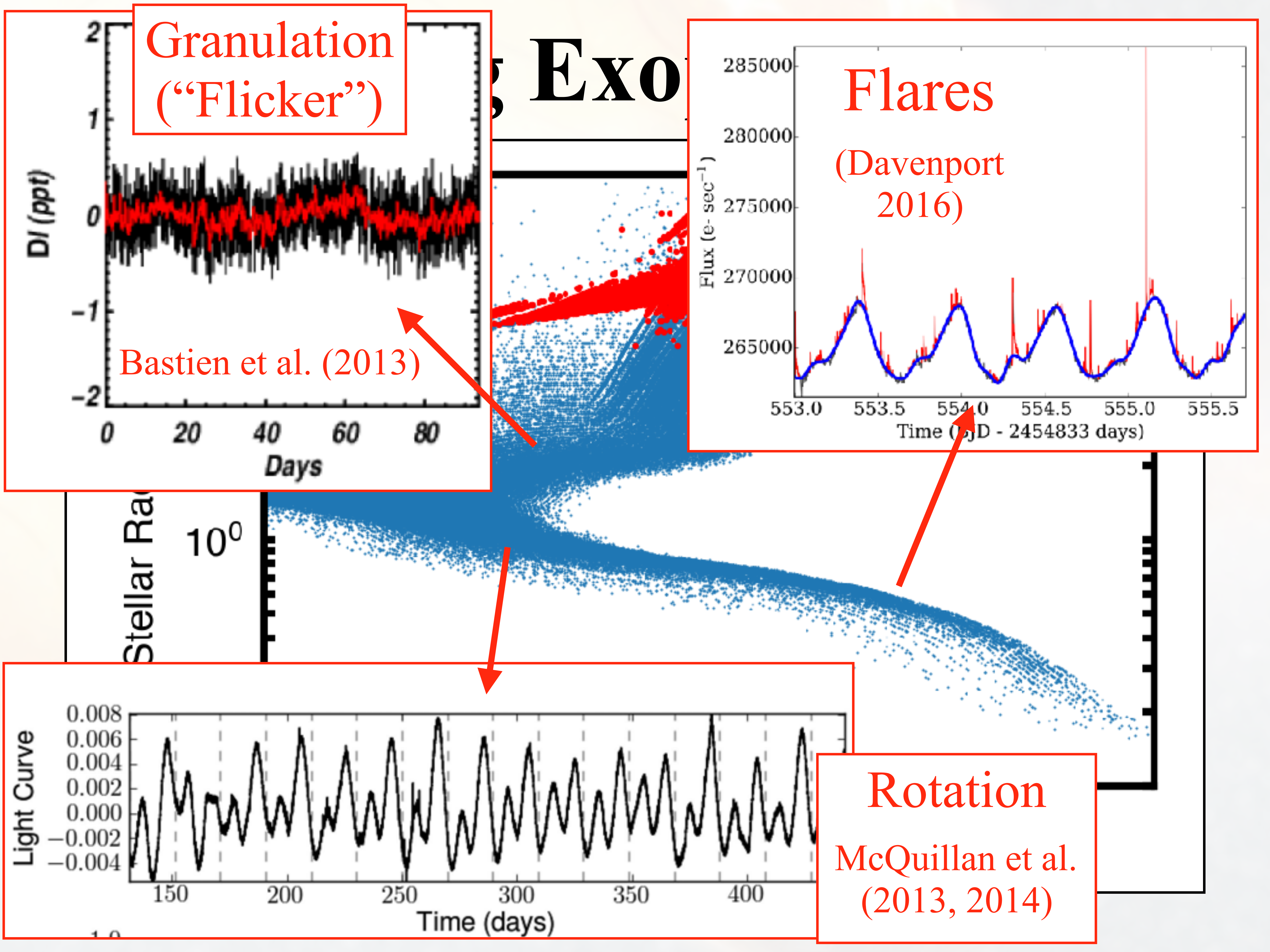


Transiting Exoplanet Hosts



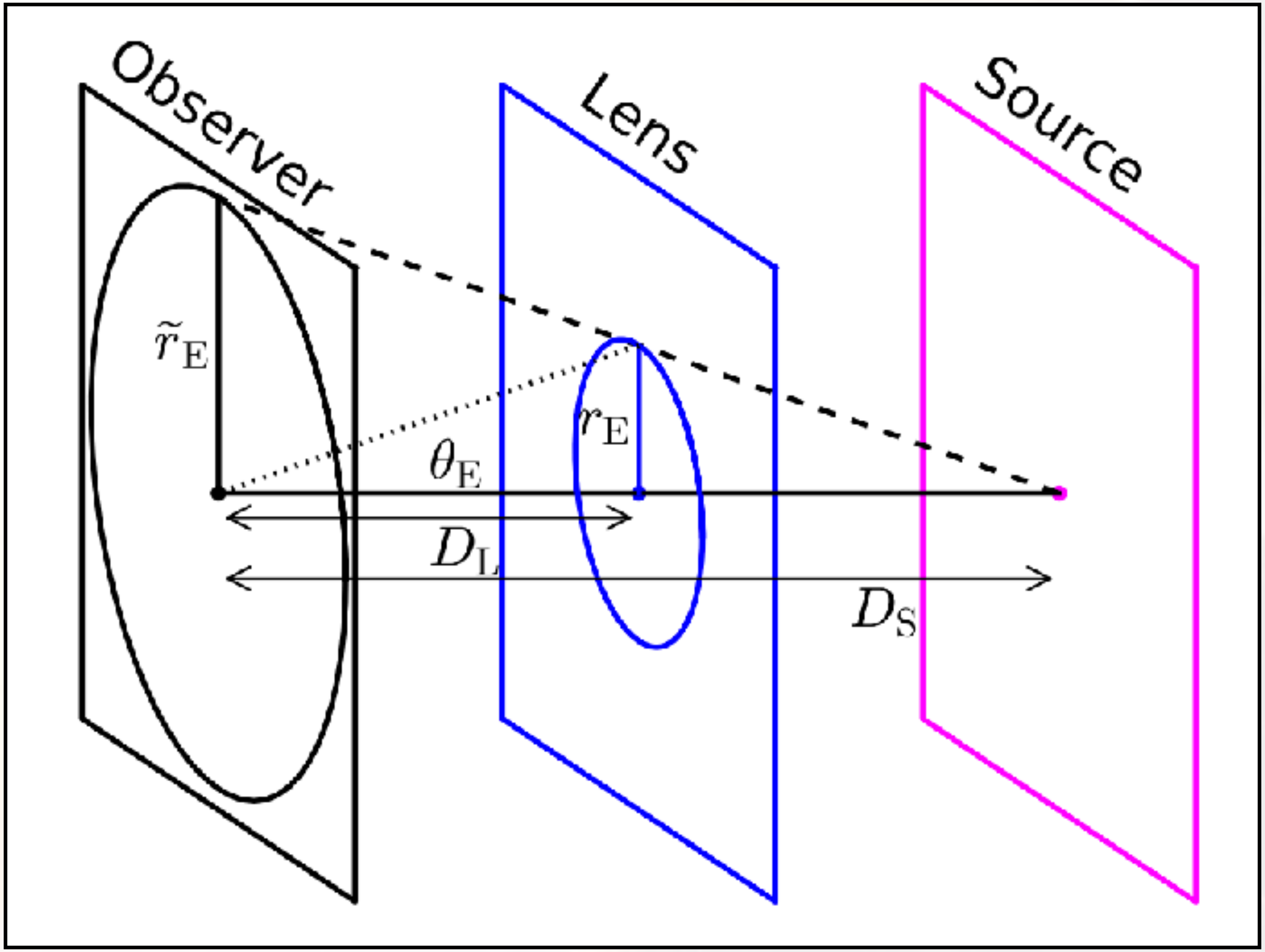
Transiting Exoplanet Hosts



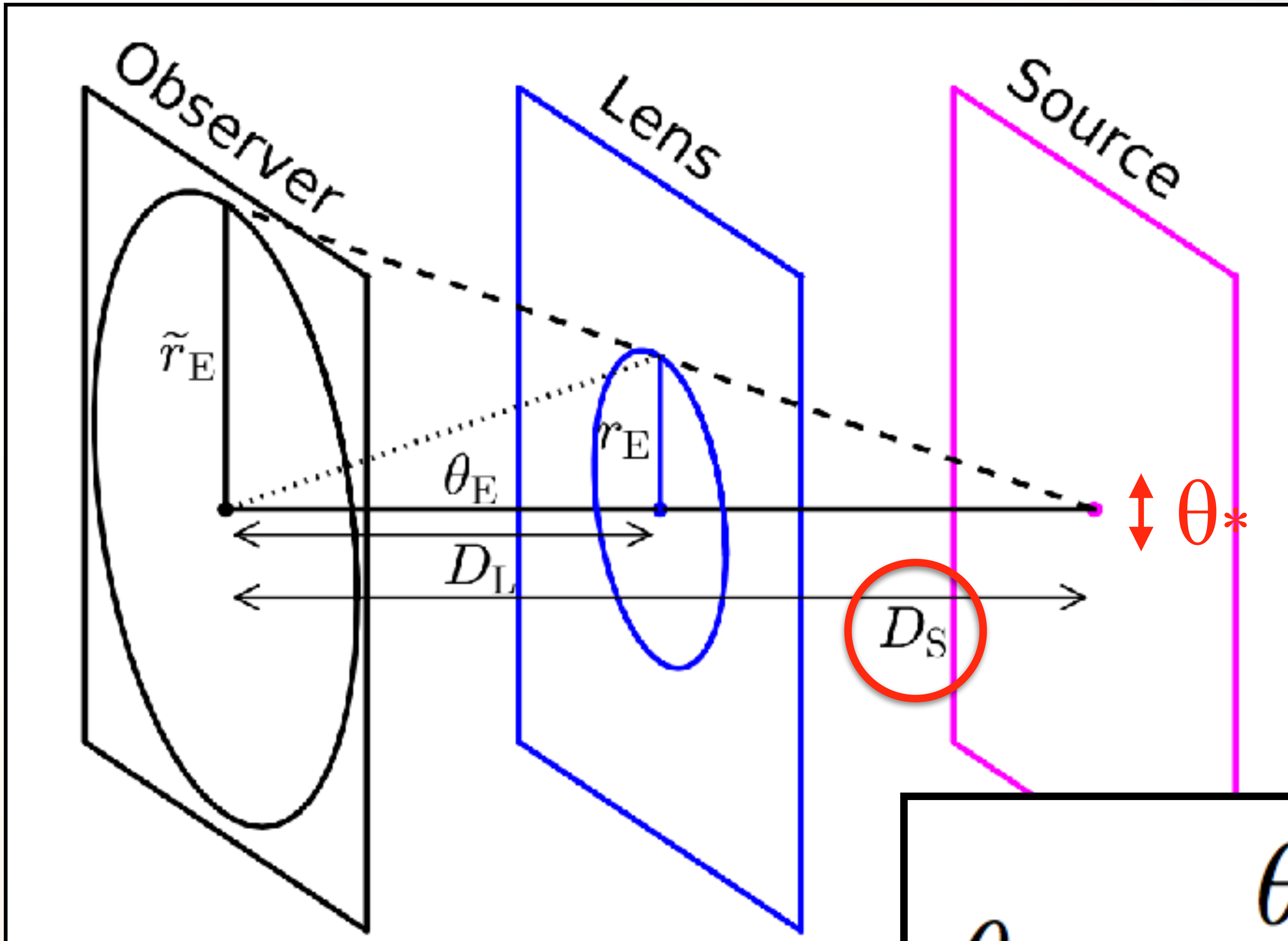


g Exo
Granulation
("Flicker")
Bastien et al. (2013)
DI (ppt)
Days
Flares
(Davenport
2016)
Flux (e- sec^{-1})
Stellar Ra
10^0
Light Curve
Time (days)
Rotation
McQuillan et al.
(2013, 2014)

Asteroseismology & Microlensing



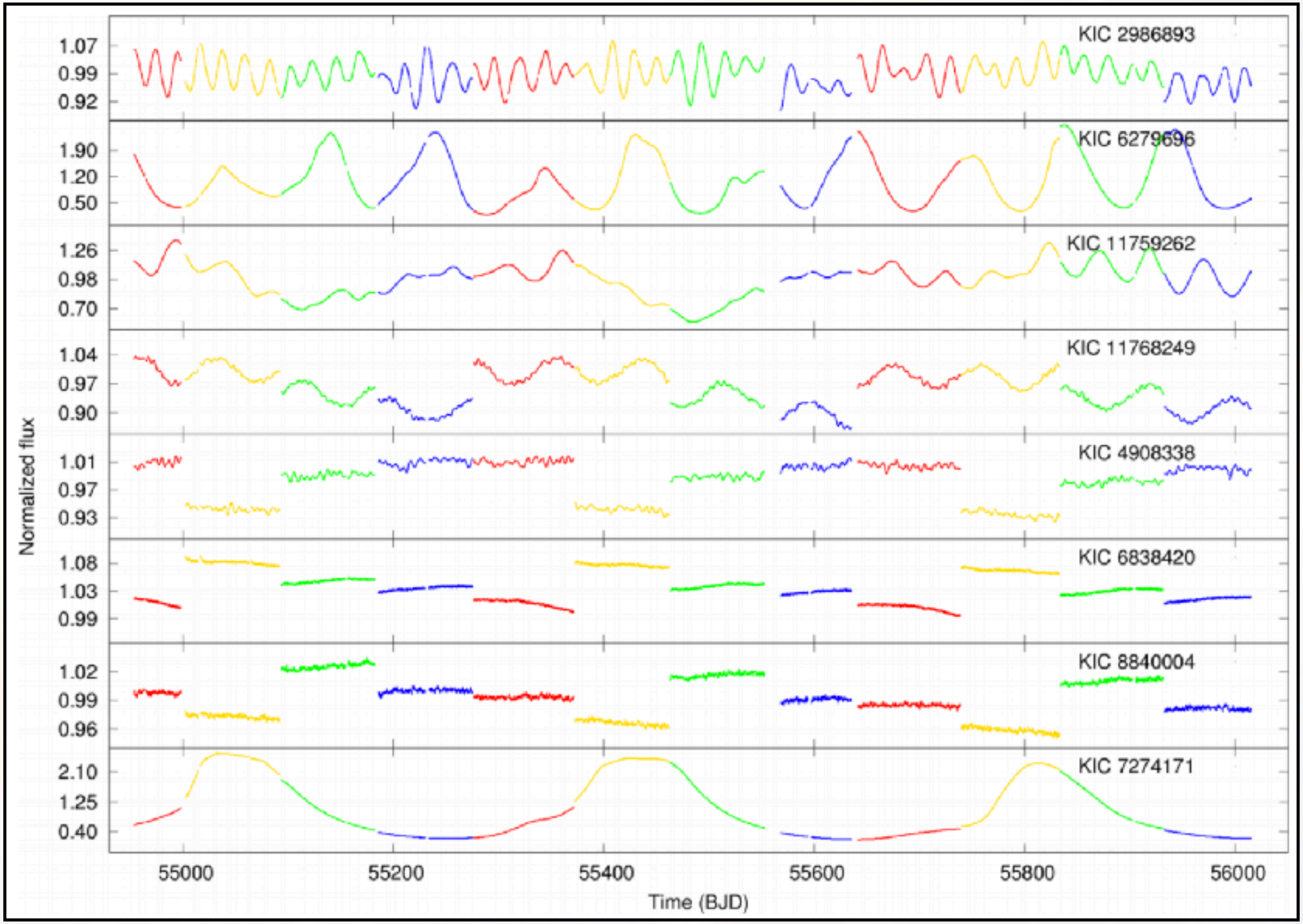
Asteroseismology & Microlensing



$$\frac{R}{R_\odot} = \left(\frac{\nu_{max}}{\nu_{max,\odot}}\right)\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2}\left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{1/2}.$$

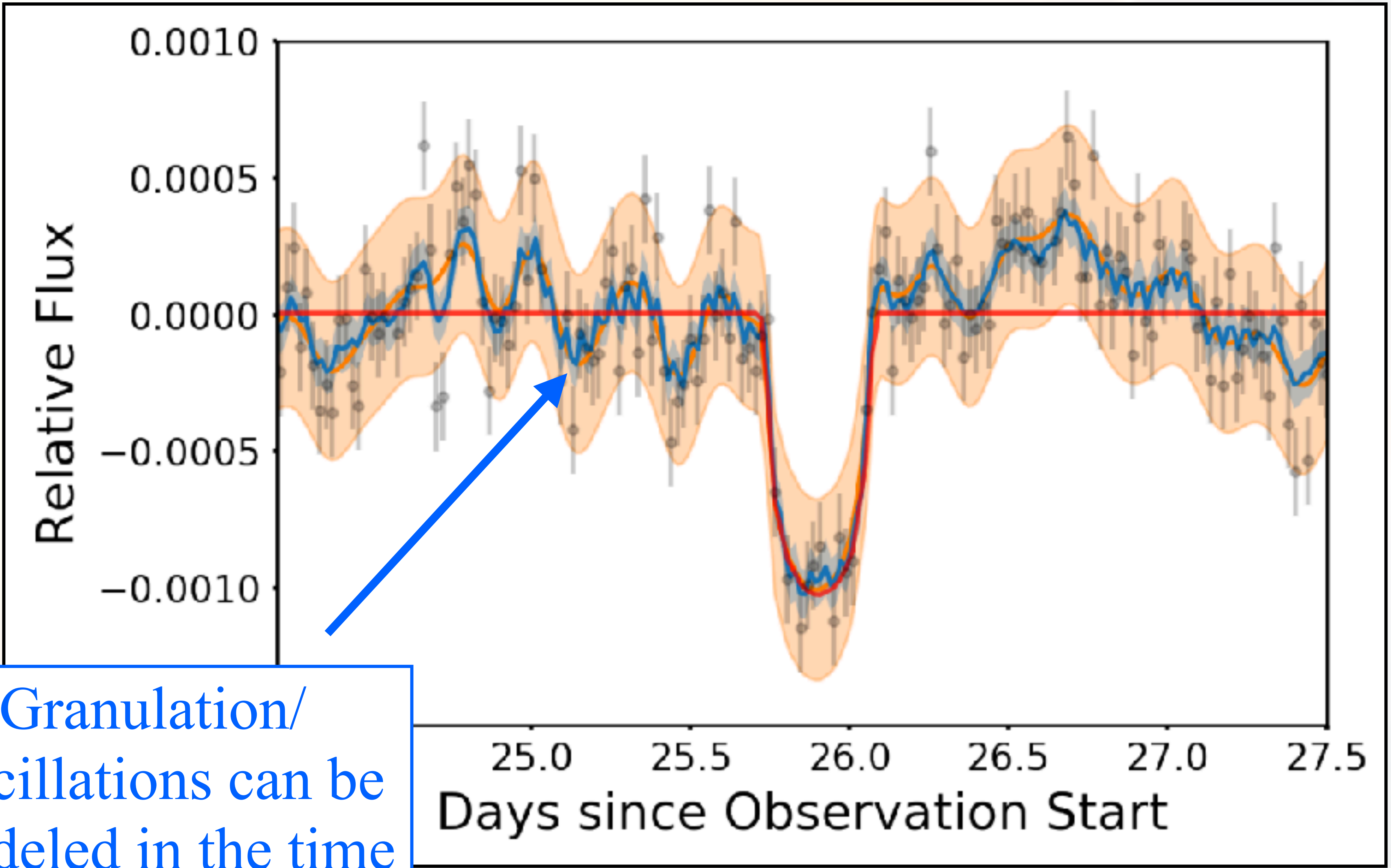
$$\theta_E = \frac{\theta_* t_E}{t_*}.$$

Source Star Variability



Banyai et al. (2013)

Source Star Variability



Granulation/ Oscillations can be modeled in the time domain!

Grunblatt et al. (2017)

Summary

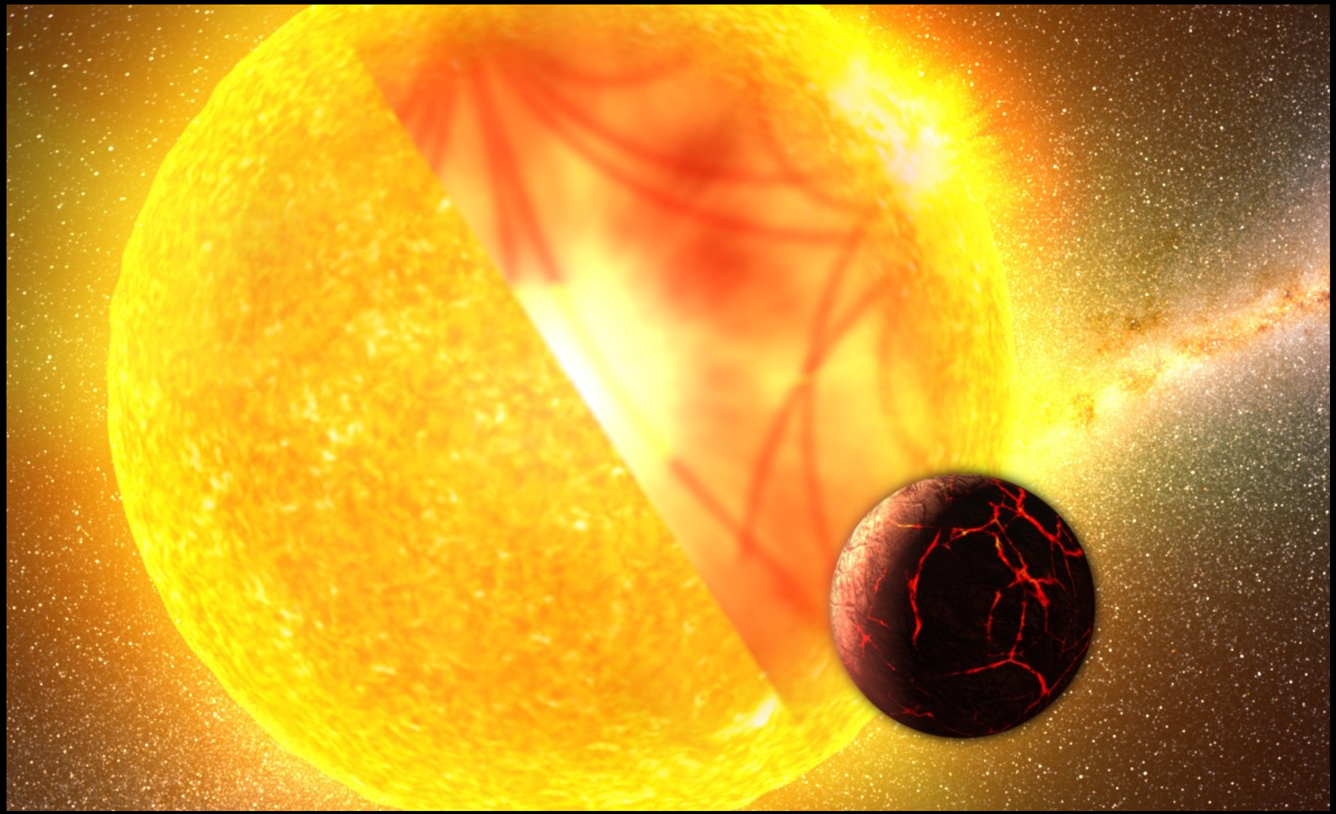
• ***Asteroseismology is a rapidly growing field in stellar astrophysics:*** highlights include interior properties of stars and characterization of transiting exoplanets

• ***WFIRST will detect oscillations in ~1e6 giants:*** strong potential for galactic archeology of the bulge

• ***What can WFIRST asteroseismology do for exoplanets?***

- Transits: not much overlap; however, powerful for general astrophysics (e.g. rotation, granulation, flares, …)
- Microlensing: strong constraints on red-giant source distance, size and variability!

Better Stars, Better Planets: Exploiting the Stellar - Exoplanet Synergy (exostar19)

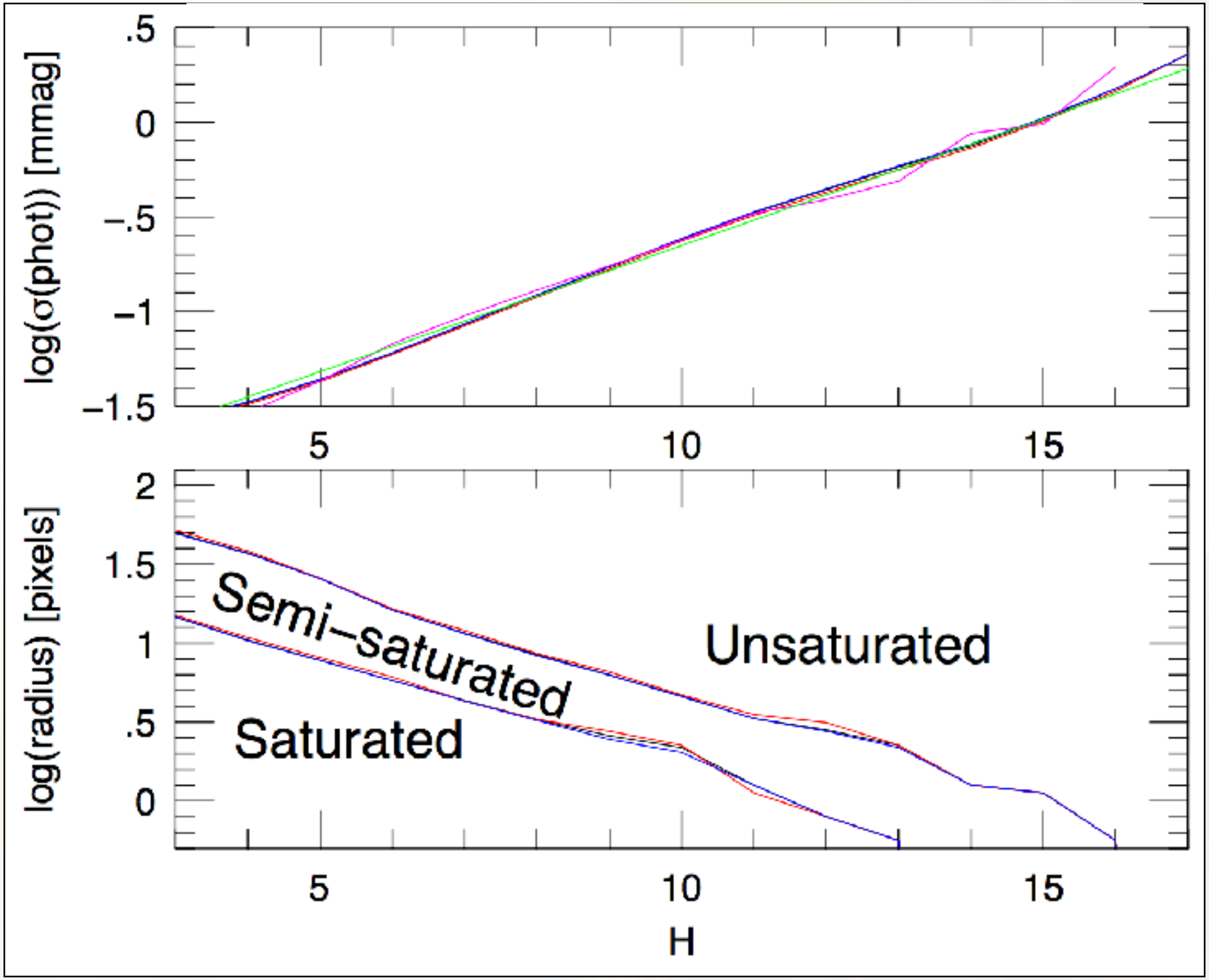


April - June 2019, KITP Santa Barbara

Coordinators: Victor Silva Aguirre, Rebekah Dawson, Jim Fuller, Daniel Huber, Katja Poppenhaeger

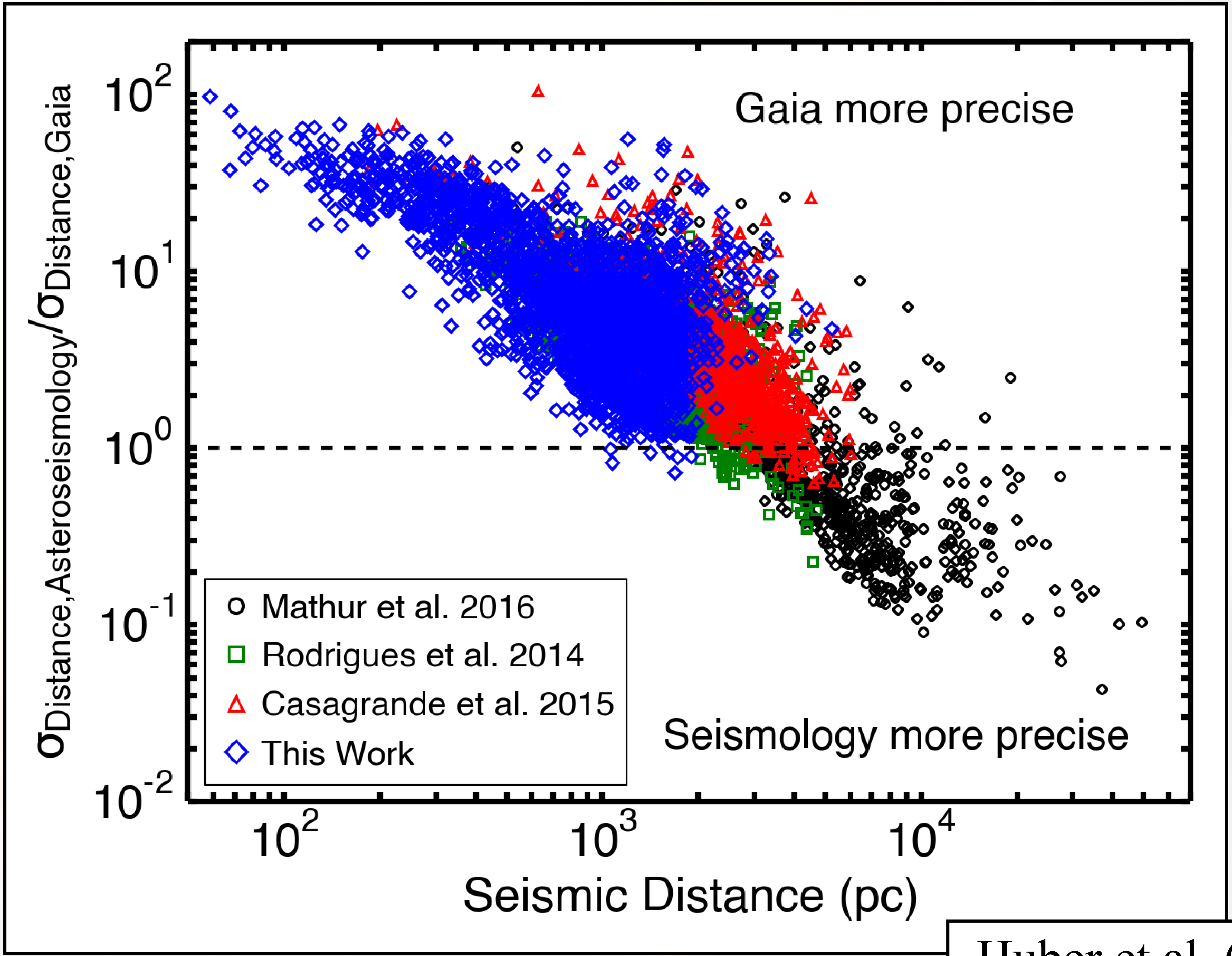
Science Advisors: Josh Winn & Eric Agol

WFIRST Photometric Precision

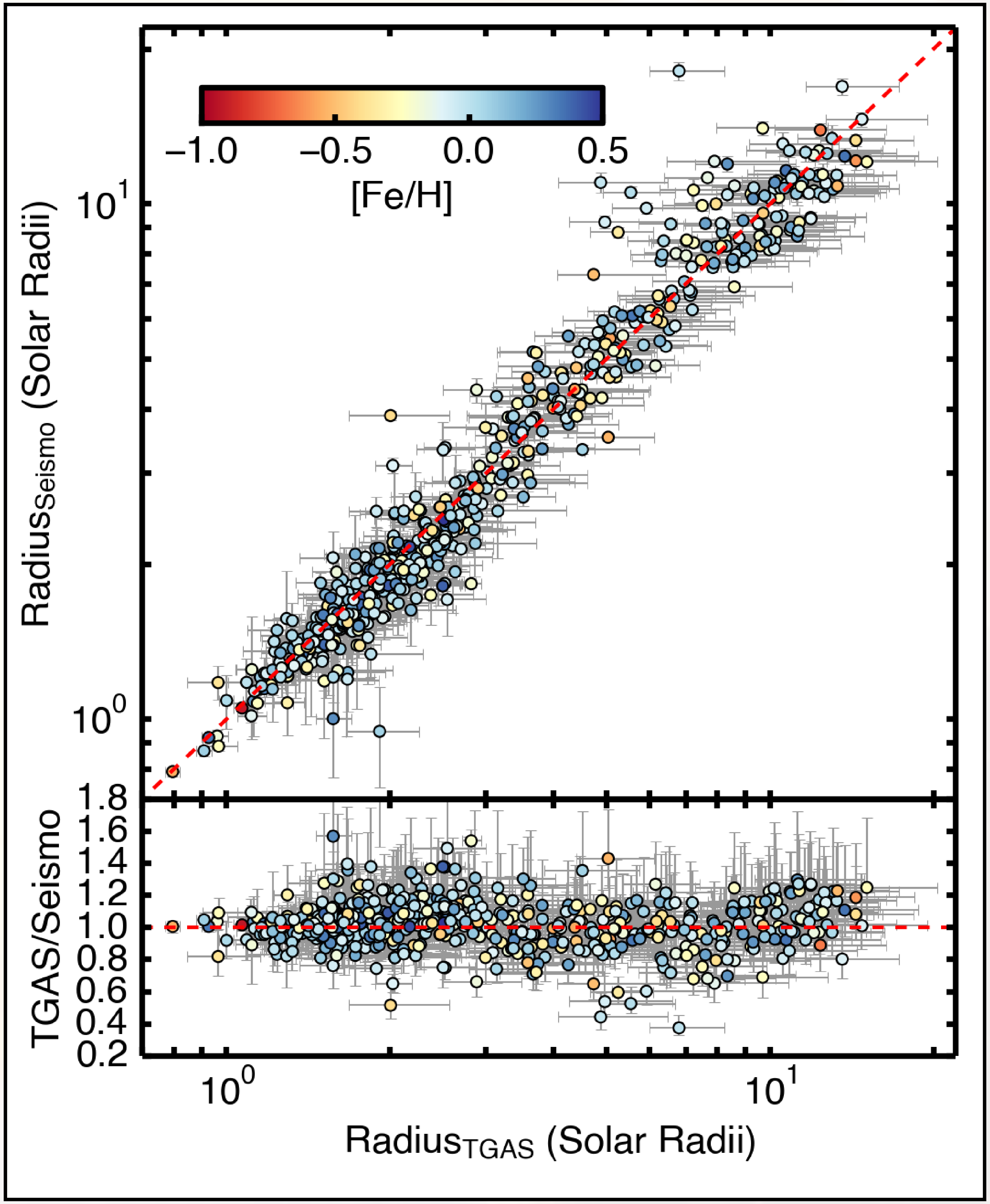


Gould et al. (2014)

Asteroseismic Distances



Huber et al. (2017)



Huber et al. (2017)