SURFACE-TO-CORE ROTATION IN THE MAIN SEQUENCE STAR KIC 11145123

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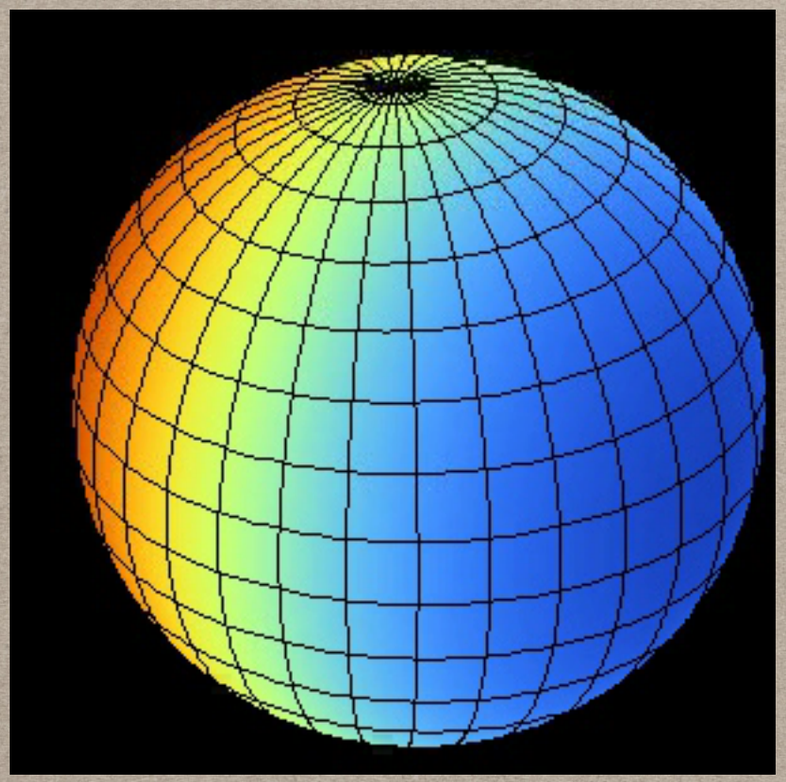
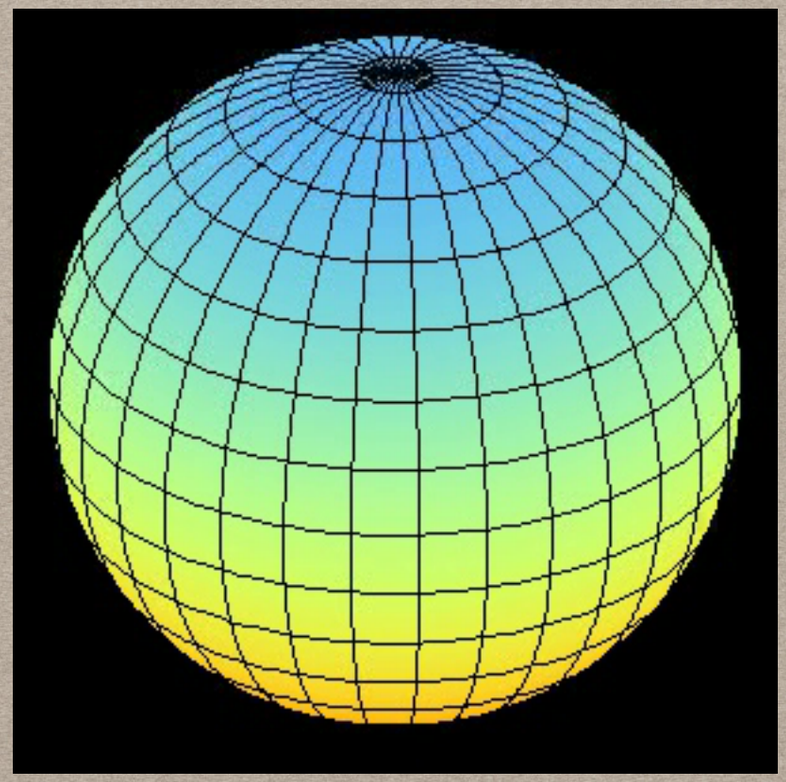
ROTATIONAL SPLITTING

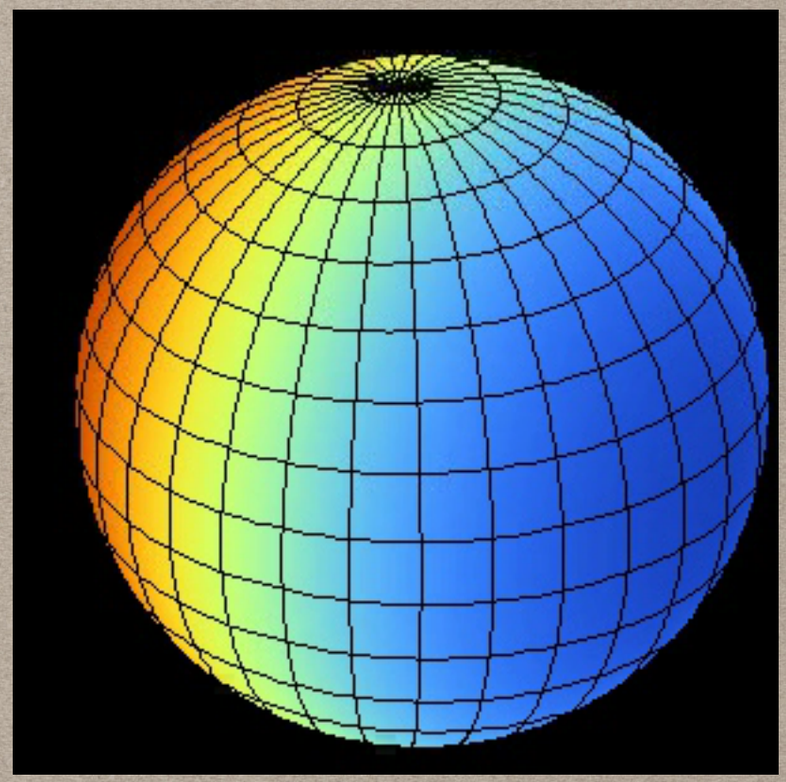
DIPOLE MODE



l = 1, m = -1



l = 1, m = 0

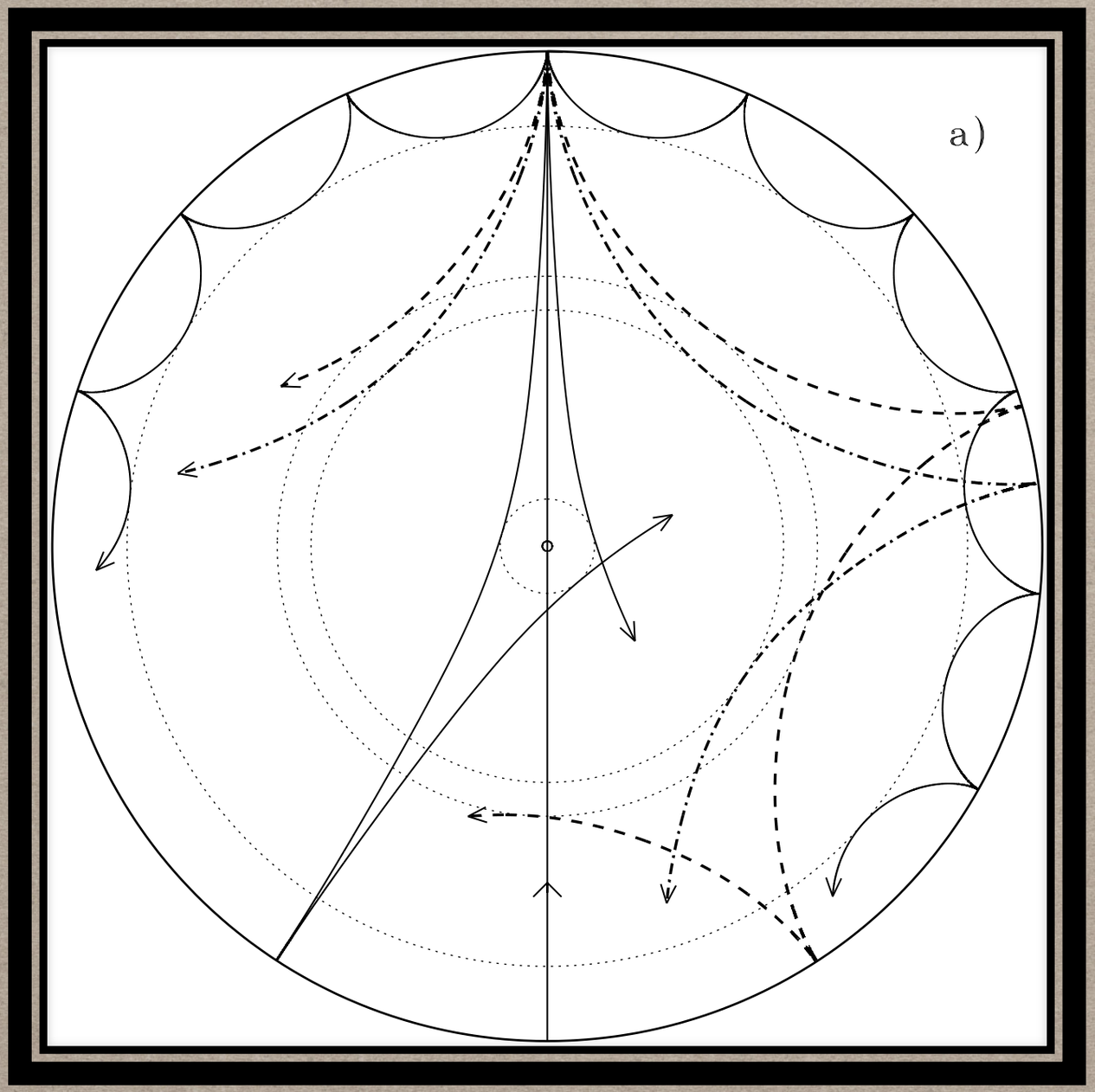


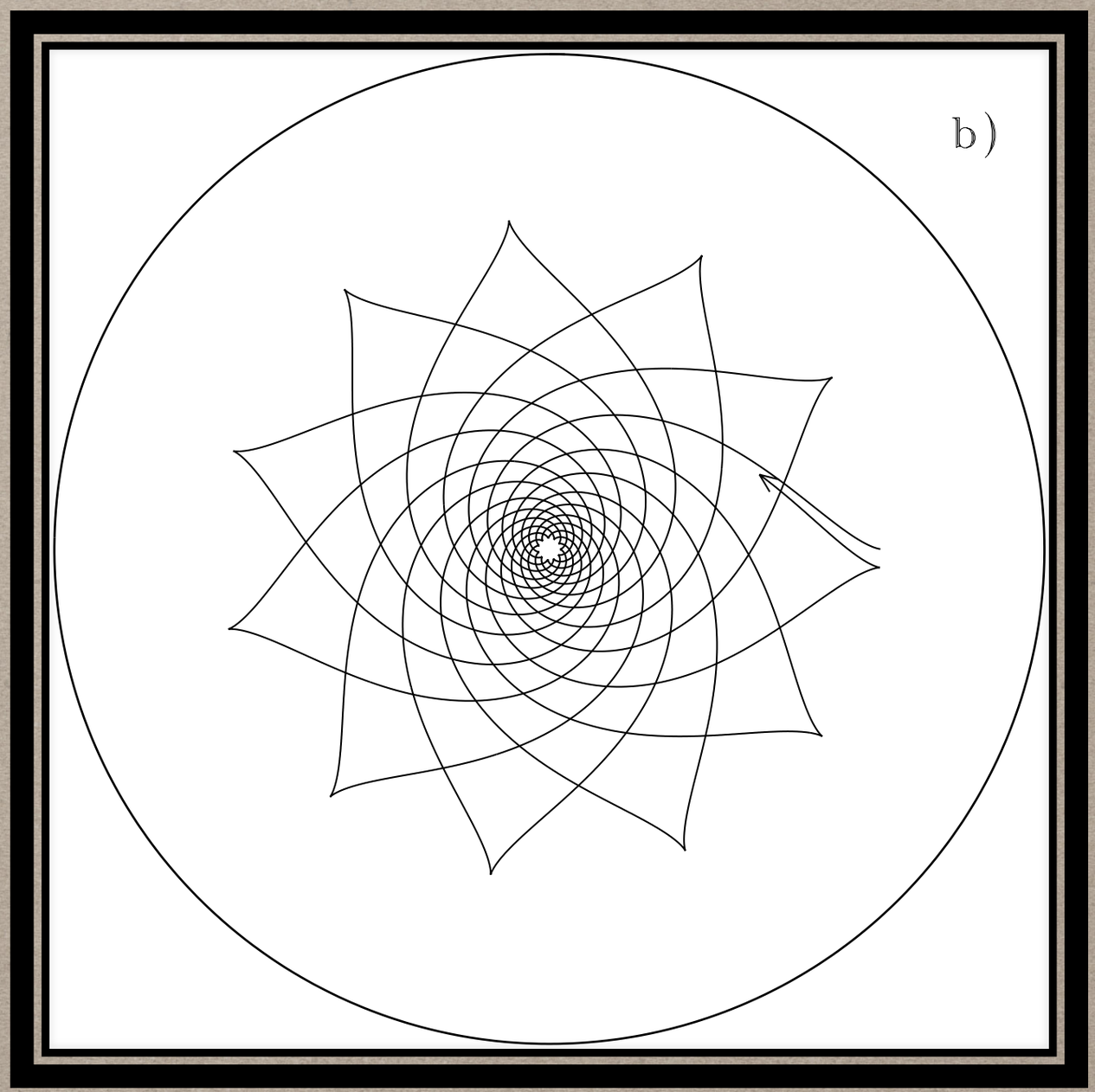
l = 1, m = +1

$$\delta\omega_{n,l,m} = m(1 - C_{n,l}) \int_0^R K_{n,l}(r)\Omega(r)dr,$$

Animations courtesy Rich Townsend

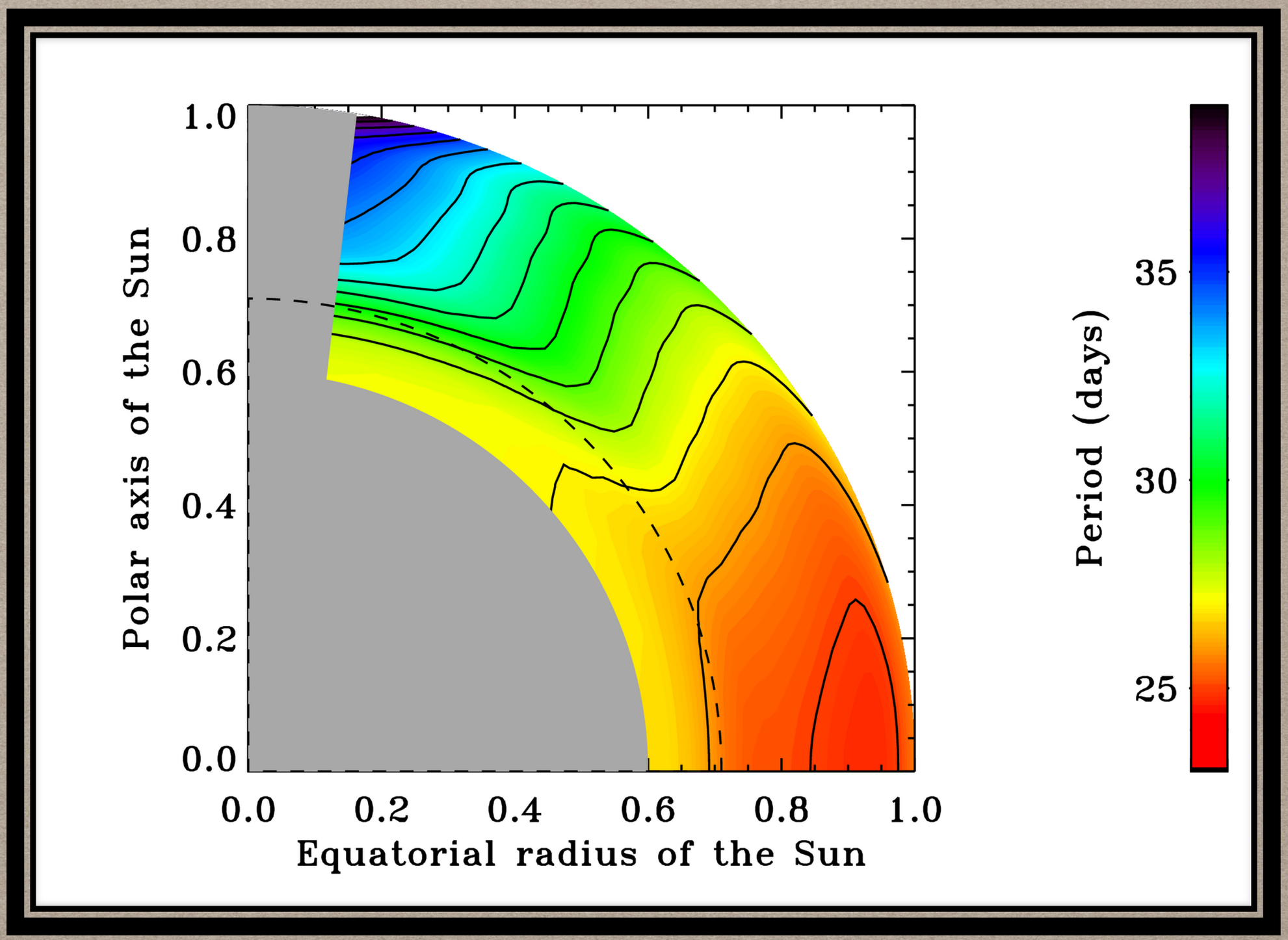
P MODES AND G MODES





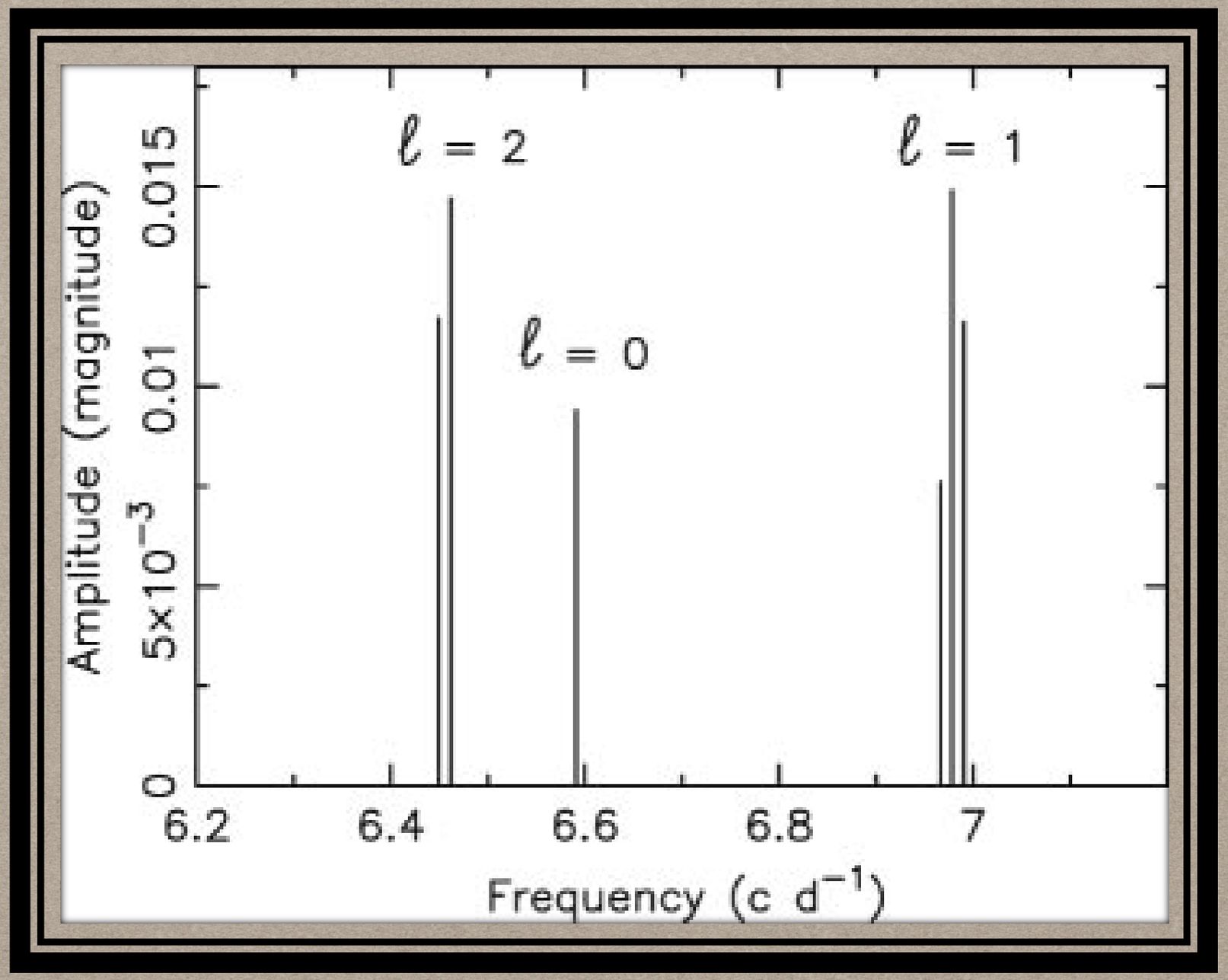
Aerts, Christensen-Dalgaard, Kurtz 2010, Asteroseismology, Springer

THE SUN



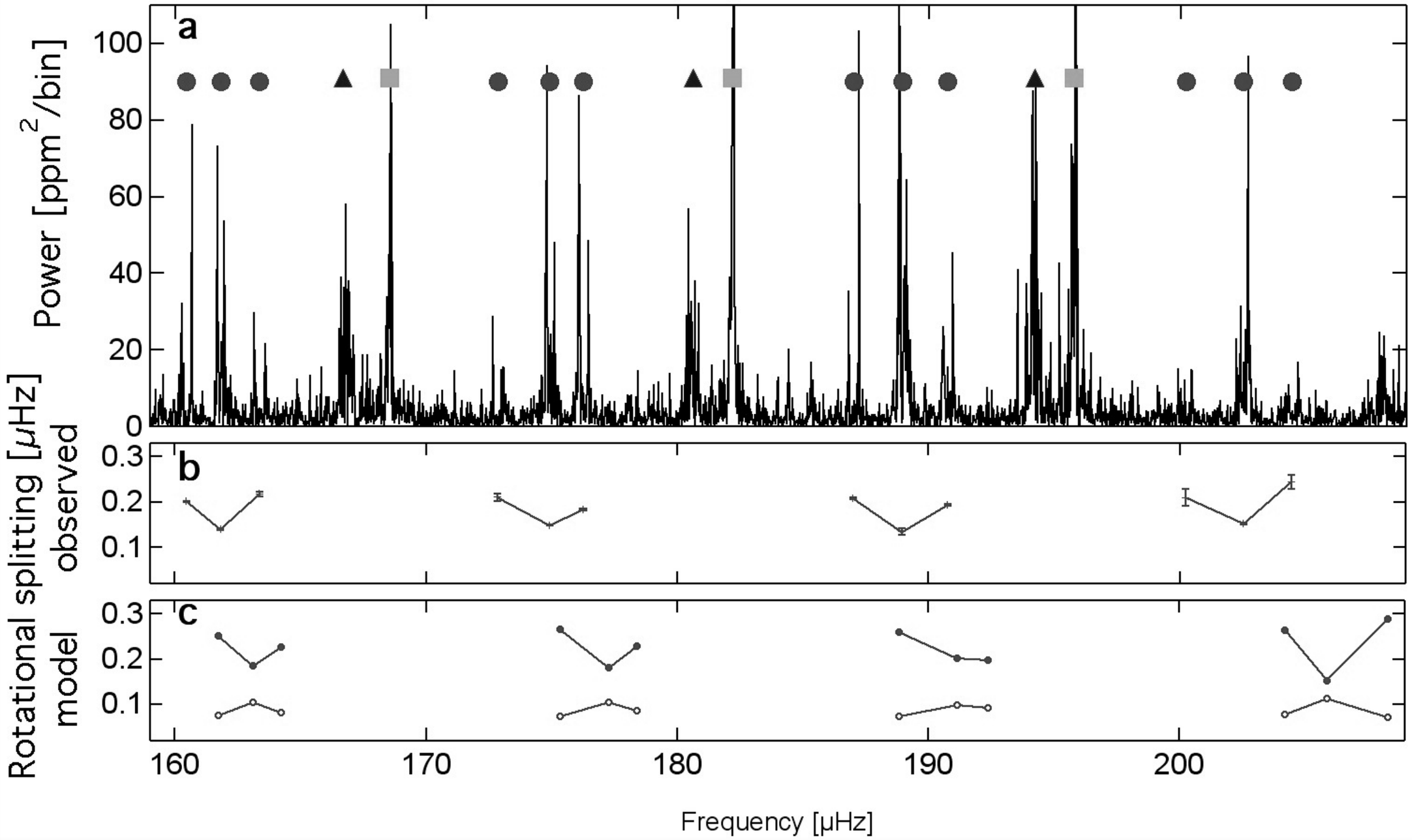
Courtesy Jesper Schou & Rachel Howe

HD 129929 - B3V



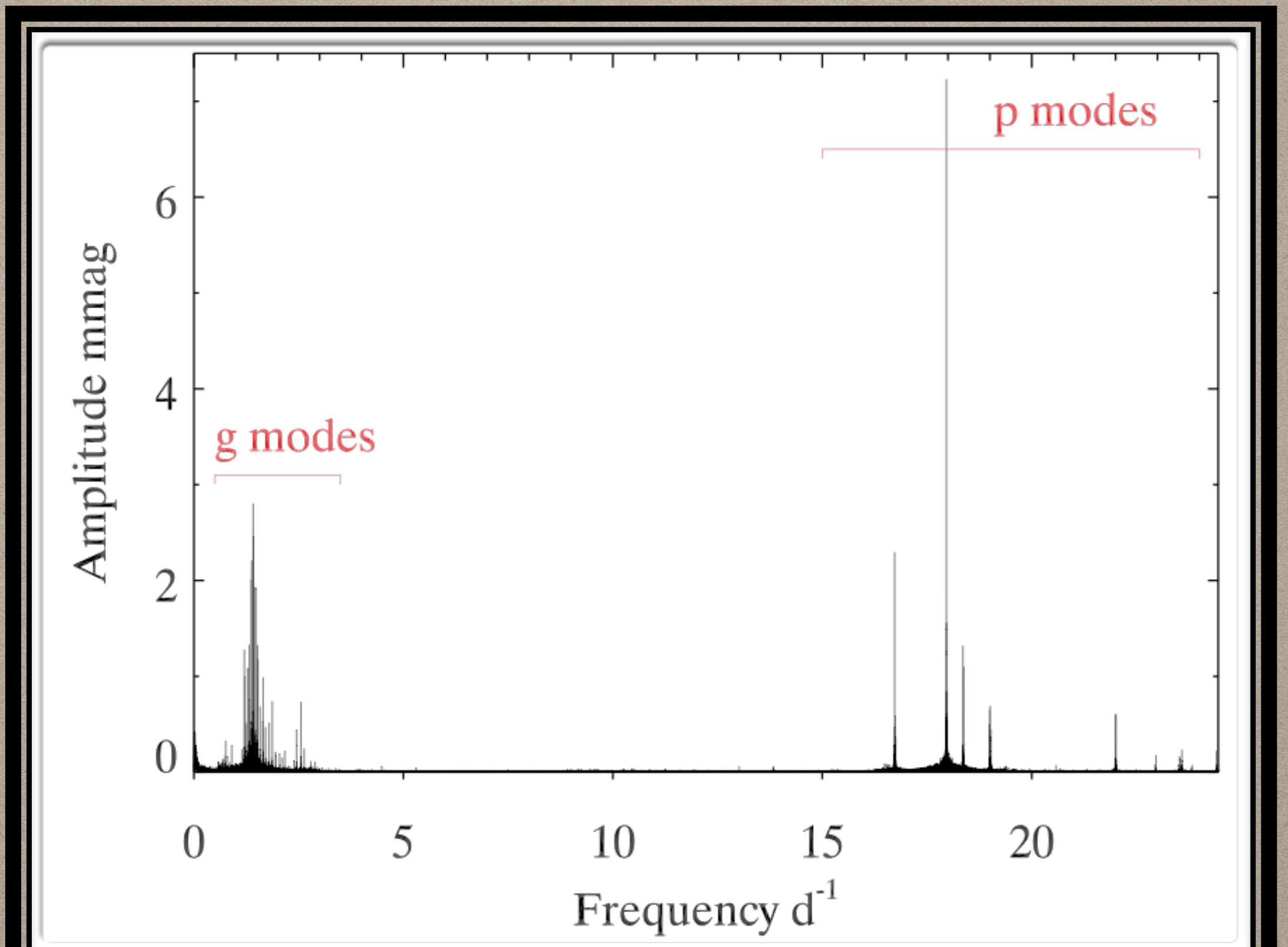
Aerts et al., 2003, Science, 300, 1926

KIC 8366269 - 5000 K RED GIANT

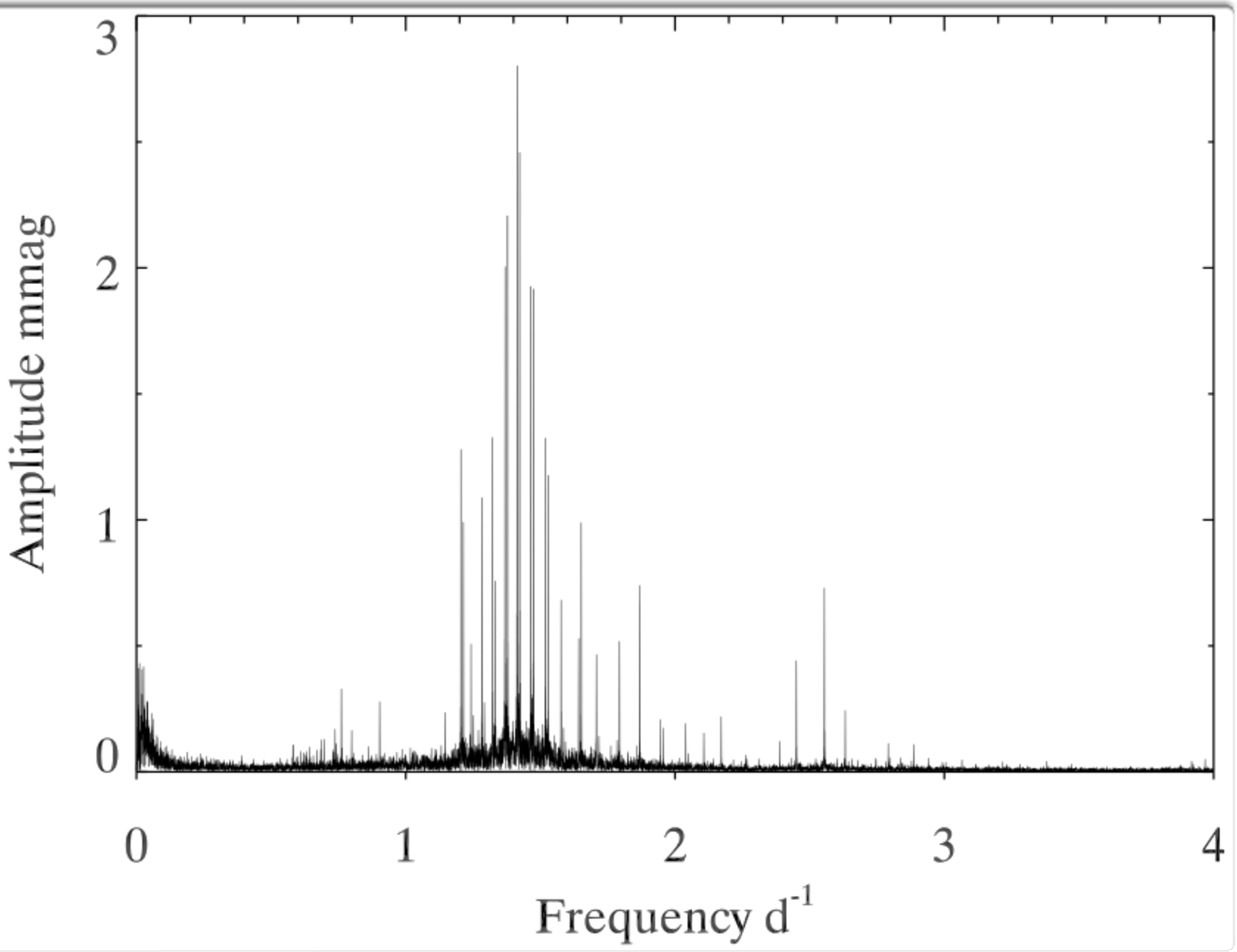


Beck et al., 2012, Nature, 481, 55

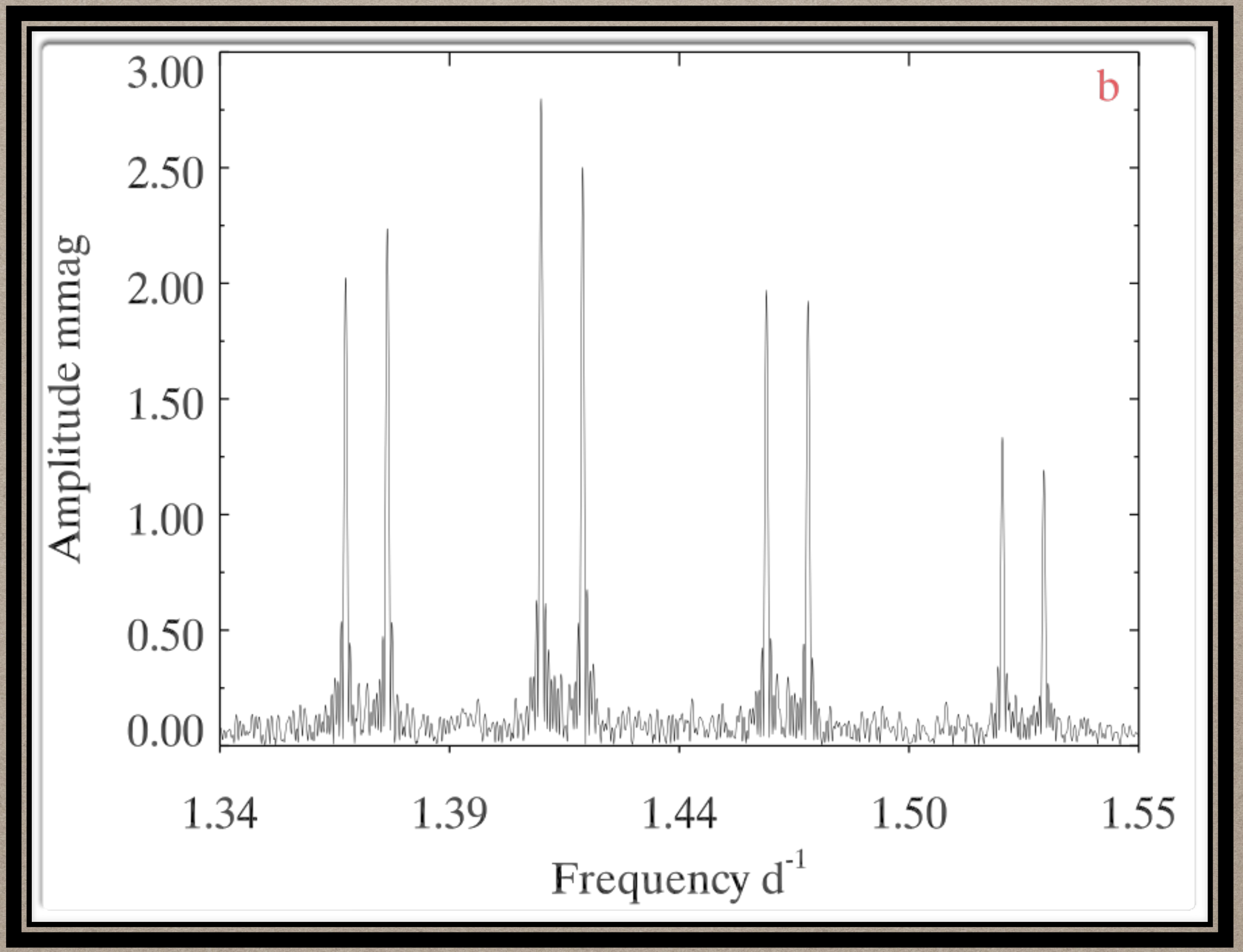
KIC 11145123



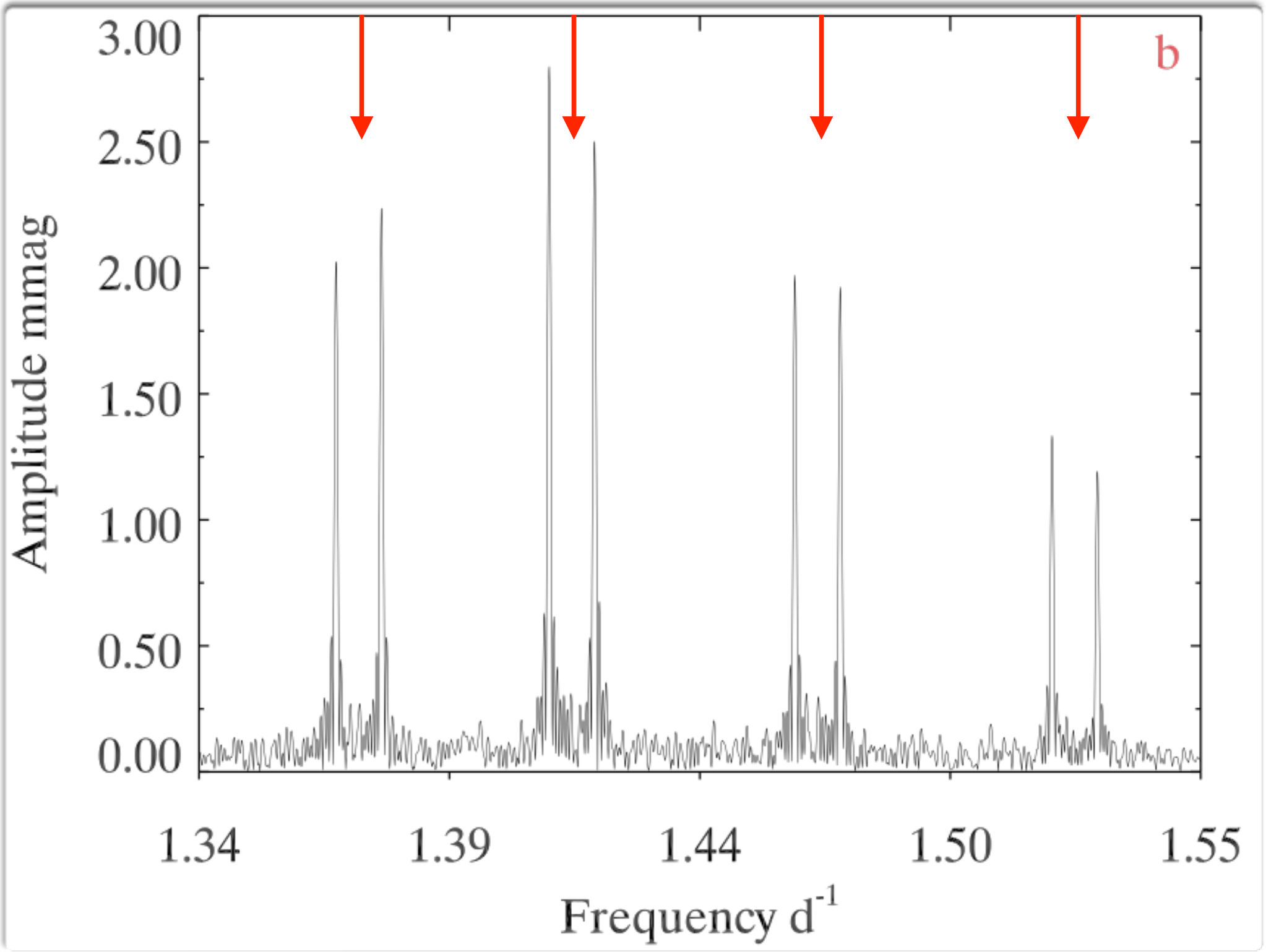
G MODES



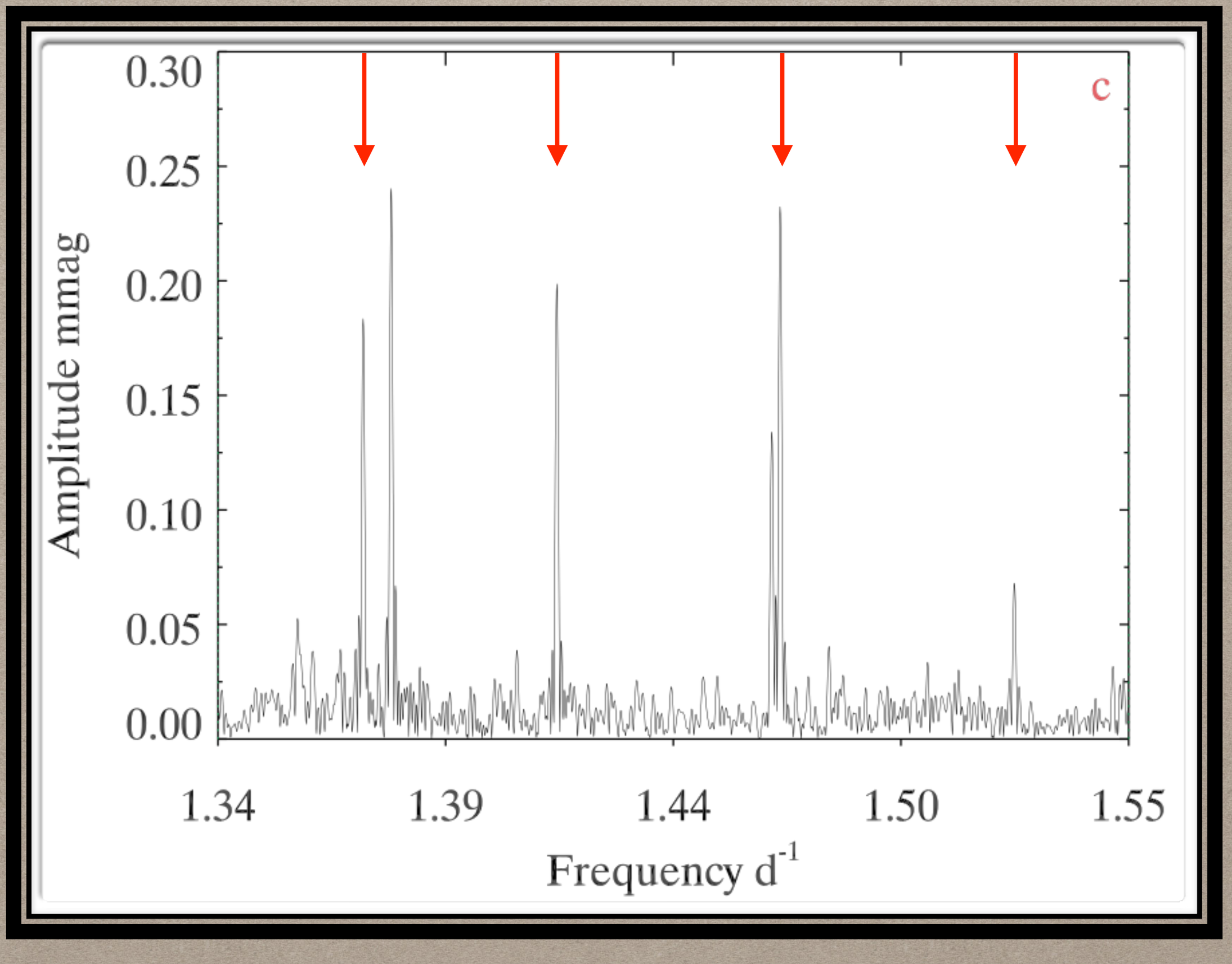
G MODES


b
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Amplitude mmag
1.34
1.39
1.44
1.50
1.55
Frequency d-1

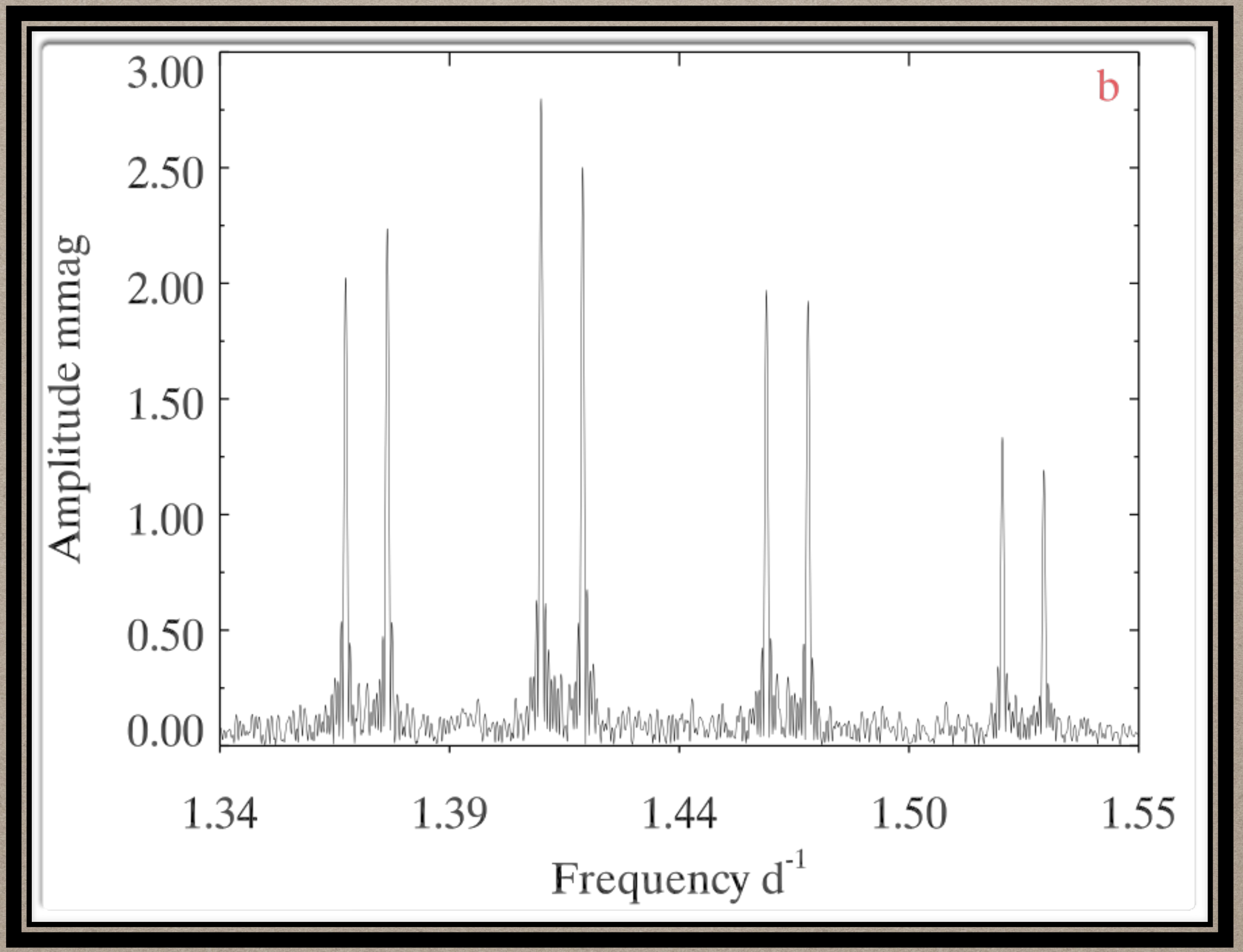
G MODES


b
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Amplitude mmag
1.34
1.39
1.44
1.50
1.55
Frequency d-1

G MODES


c
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Amplitude mmag
1.34
1.39
1.44
1.50
1.55
Frequency d-1

G MODES

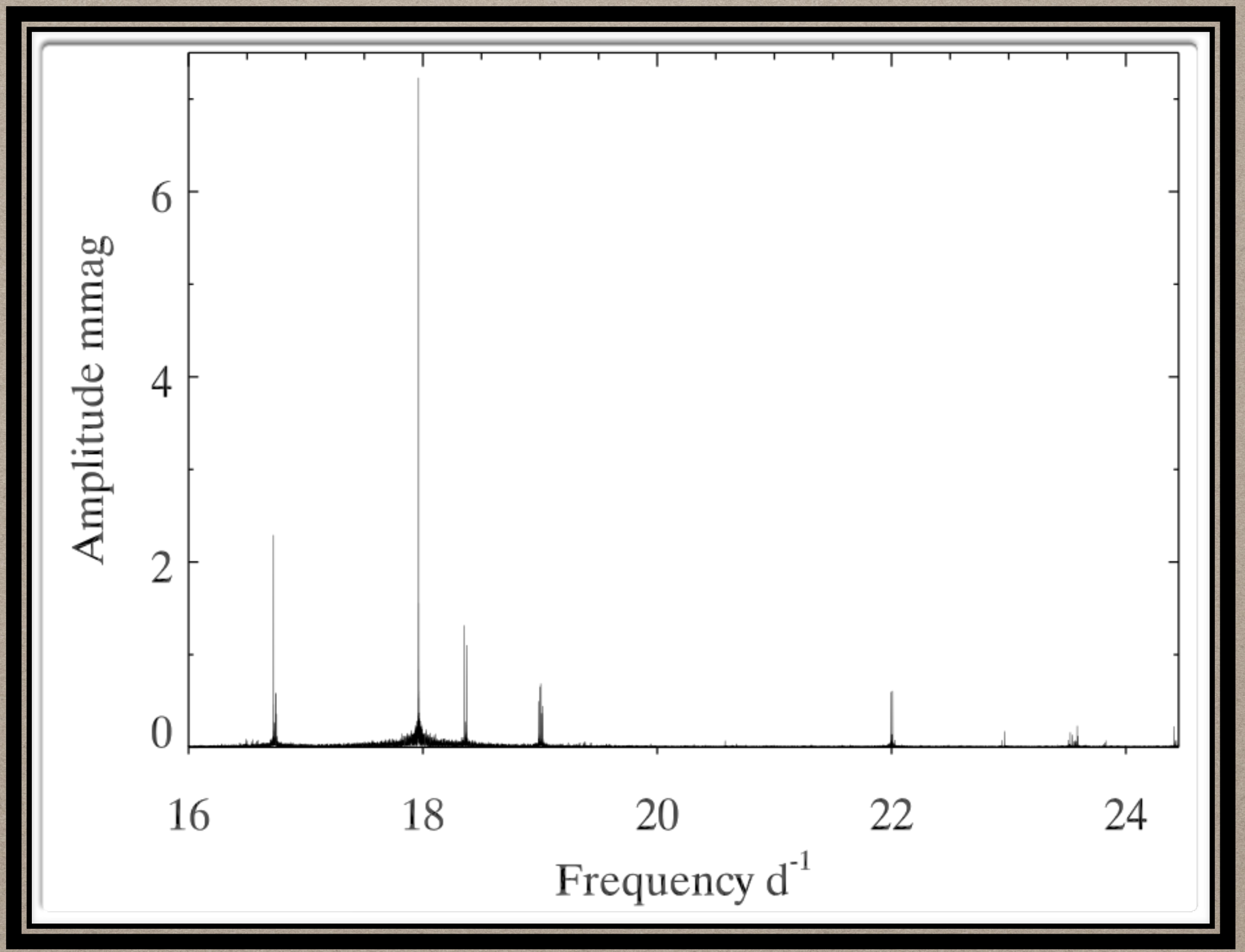

b
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Amplitude mmag
1.34
1.39
1.44
1.50
1.55
Frequency d-1

G MODE SPLITTING

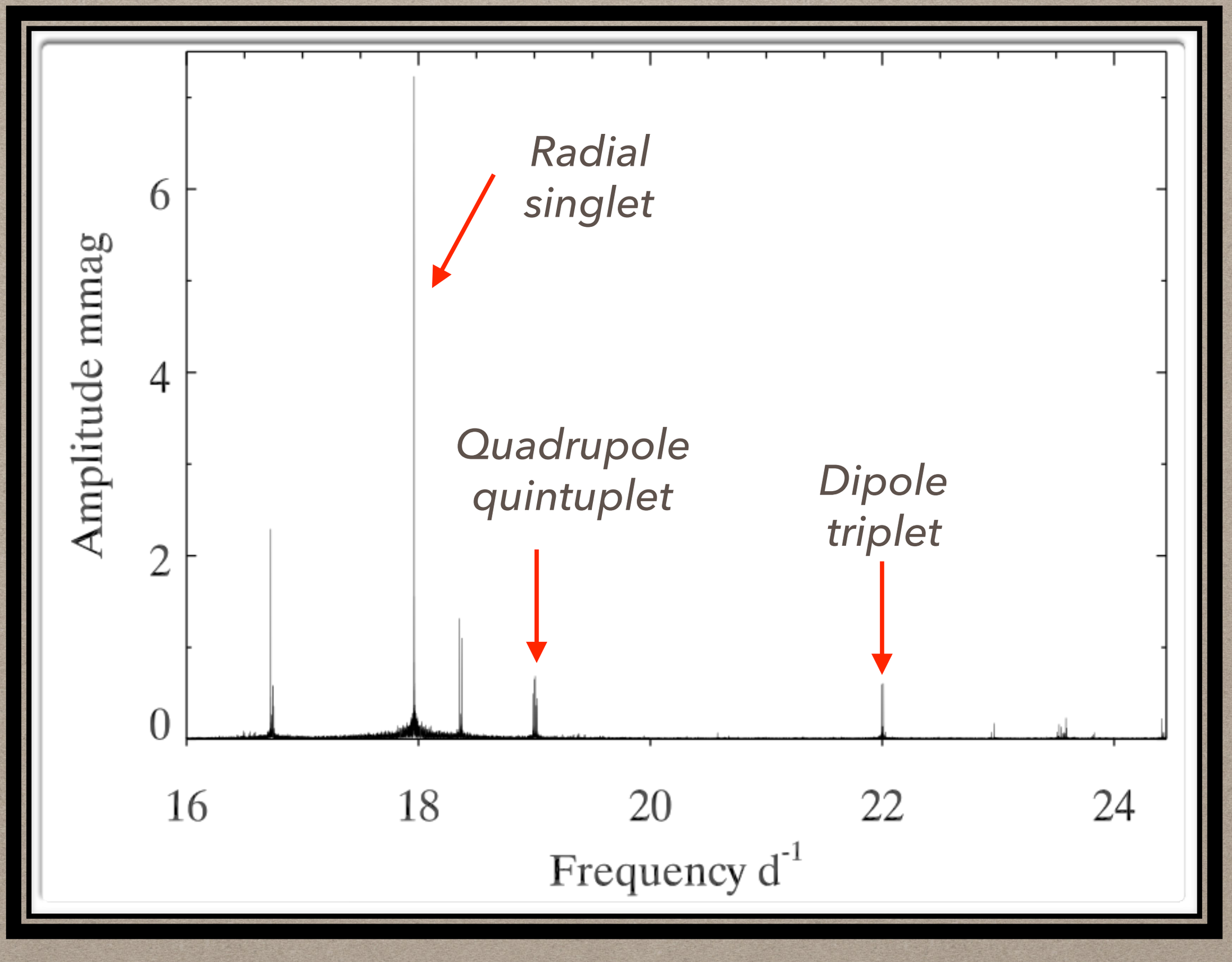
$$\delta\omega_{n,l,m} = m(1 - C_{n,l}) \int_0^R K_{n,l}(r)\Omega(r)dr,$$

- **For high overtone g modes $C_{n,l}$ asymptotically approaches 0.5**
  - **$C_{n,l} \approx l/(l+1) = 0.5$ for KIC 11145123 g modes**
    - **This is model independent**
- **The splitting between the g mode sectoral m = +1 and -1 frequencies measures the "average" rotation rate in the core.**
  - **$P_{core} \geq 105.13 \pm 0.02$ days**
- **All mode splittings are equal within the precision of 4 years of data**
  - **There are no second-order effects**
  - **The star is nearly spherical**

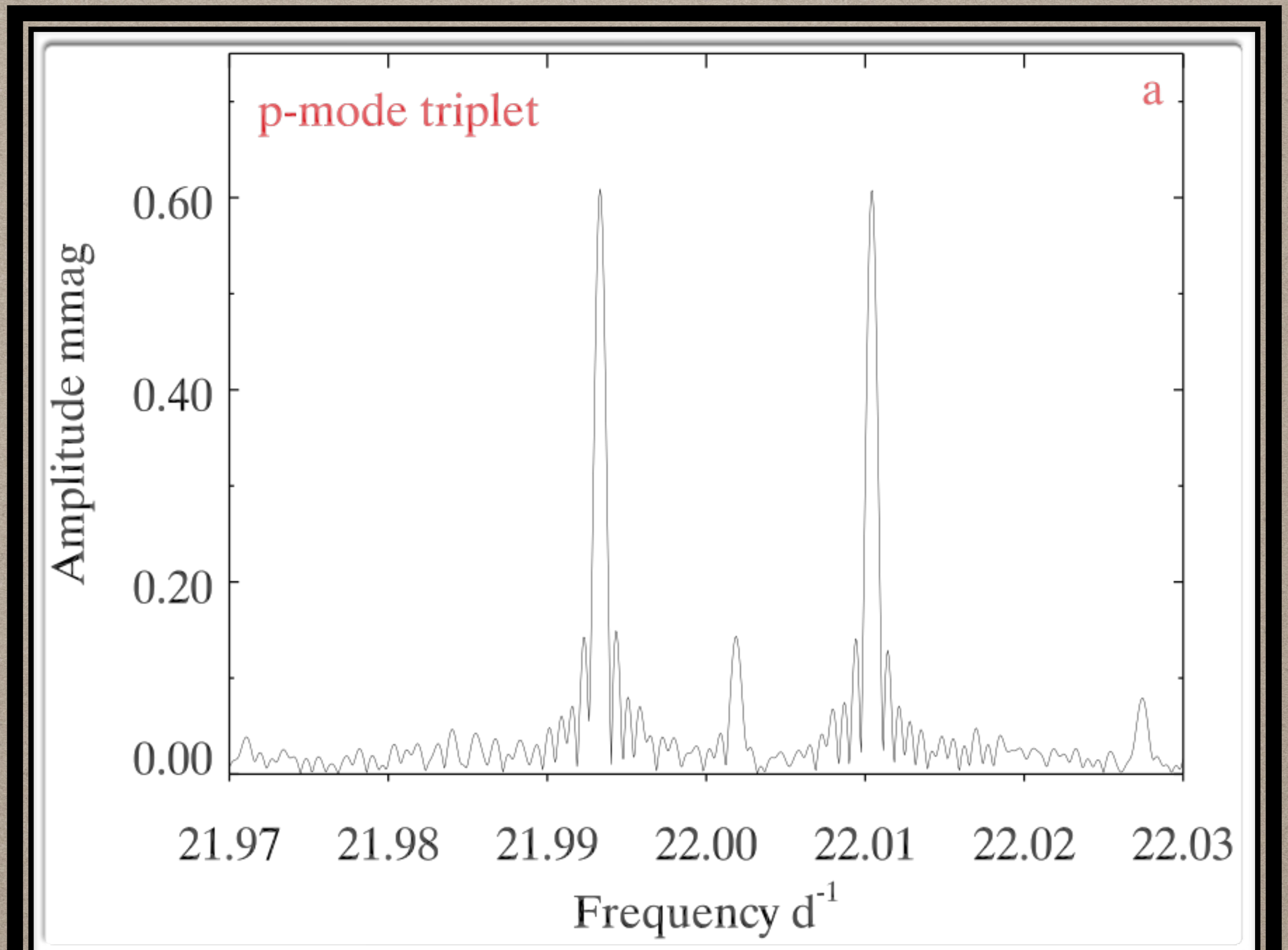
P MODES



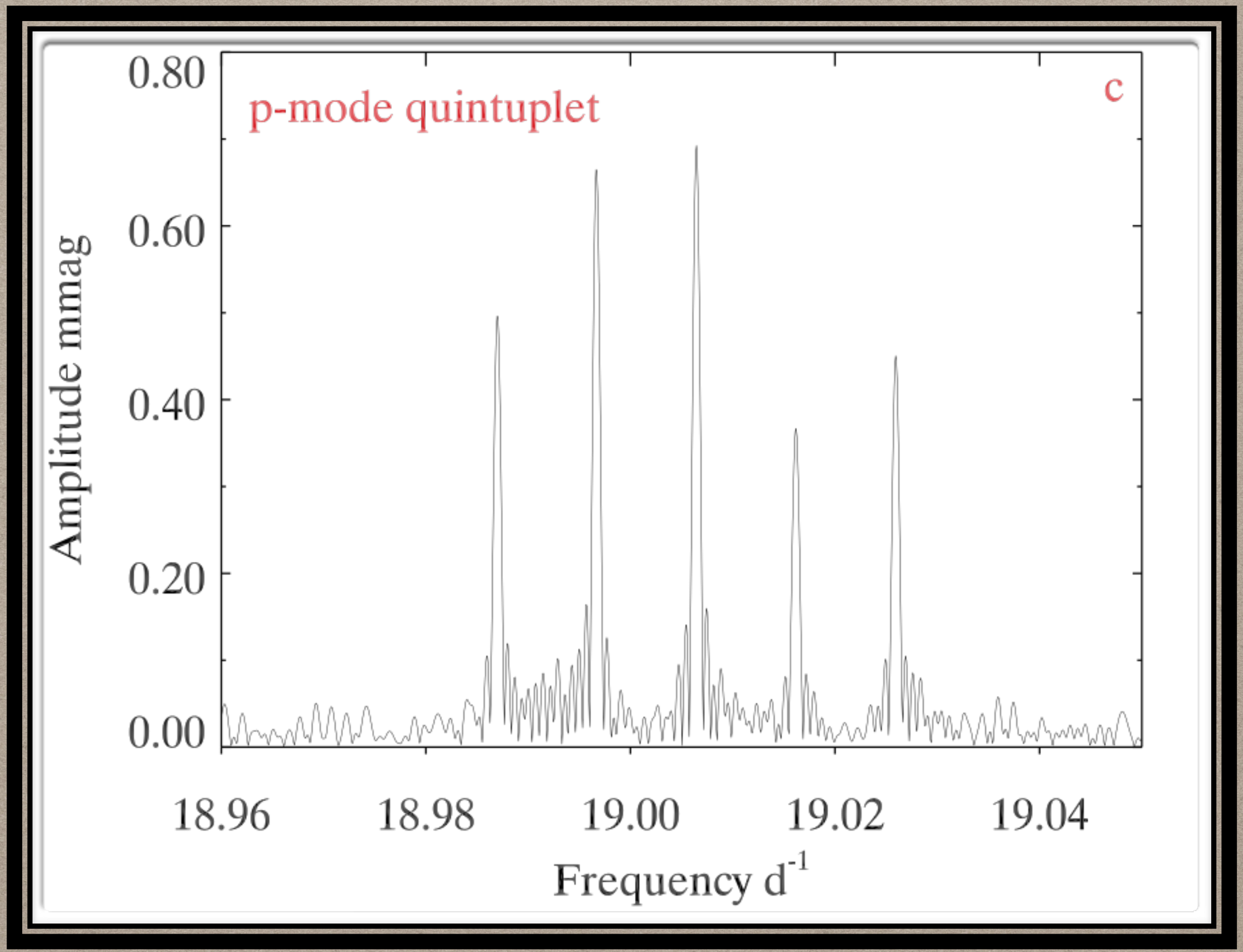
P MODES


Radial
singlet
Quadrupole
quintuplet
Dipole
triplet
Amplitude mmag
0
2
4
6
16
18
20
22
24
Frequency d-1

P MODE TRIPLET



P MODE QUINTUPLET



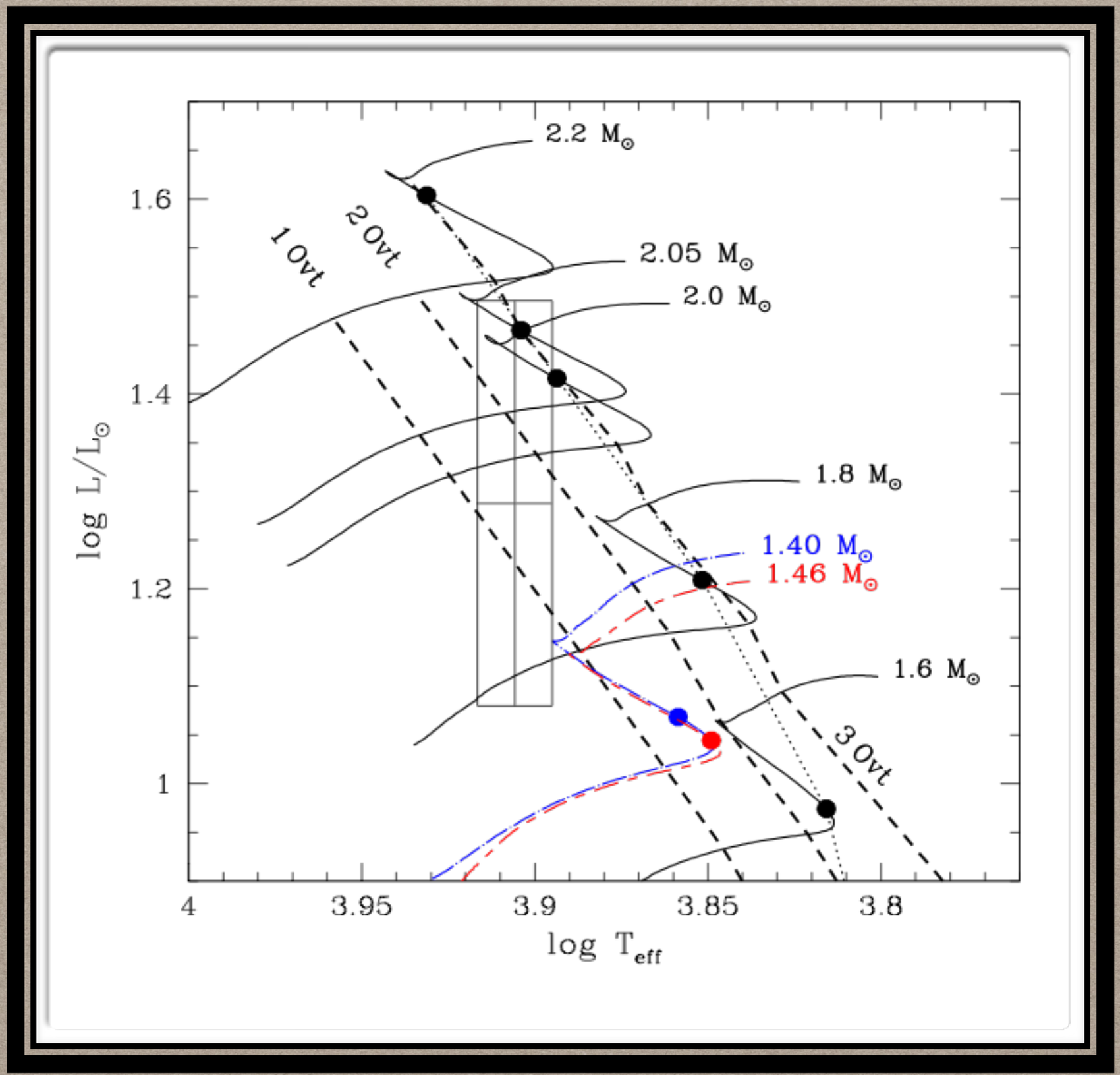
P MODE SPLITTING

$$\delta\omega_{n,l,m} = m(1 - C_{n,l}) \int_0^R K_{n,l}(r)\Omega(r)dr,$$

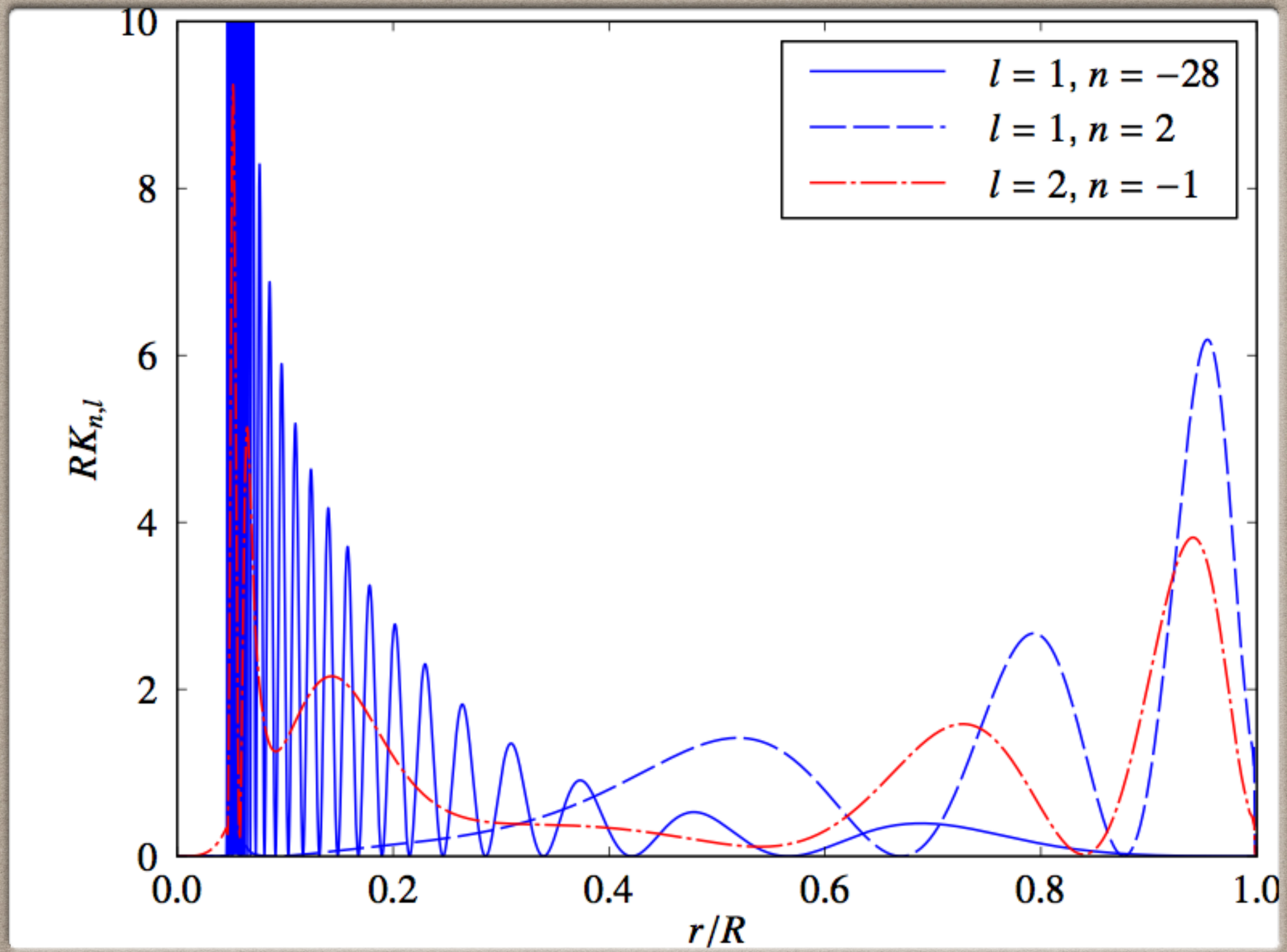
- **For the p modes $C_{n,l} < 0.03 \approx 0$**
  - **This is model independent**

- **The splitting between the p mode frequencies measures the "average" rotation rate near the surface.**
  - **$P_{surface} \leq$ 98.57 ± 0.02 days**
- **All mode splittings are equal within the precision of 4 years of data**
  - **There are no second-order effects**
  - **The surface rotates more quickly than the core**

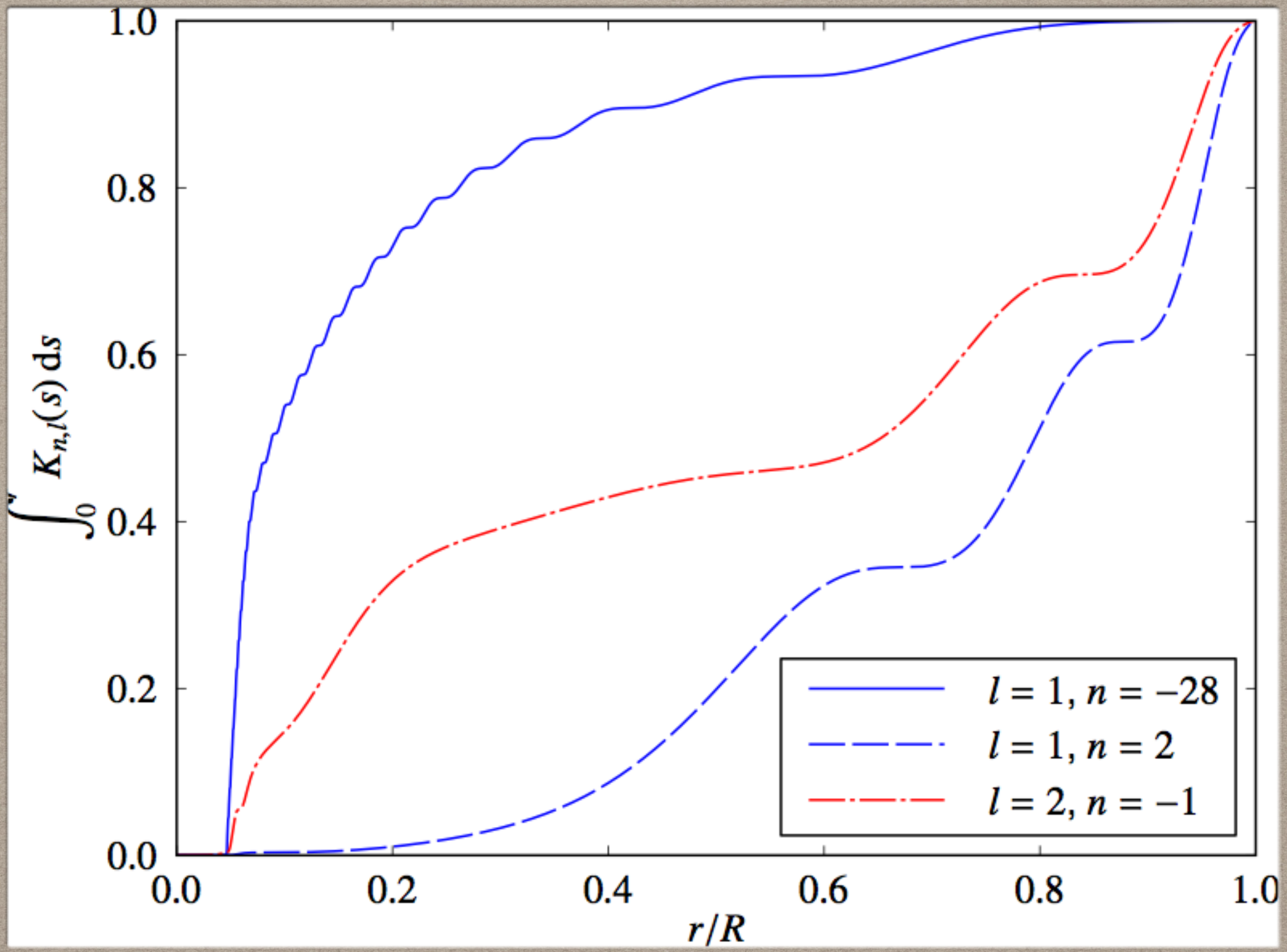
HR DIAGRAM AND MODEL TRACKS



ROTATION KERNELS



ROTATION KERNELS



KIC 11145123 - CONCLUSIONS

- **We see surface-to-core rotation clearly in a main sequence star for the first time**
- **KIC 11145123 is nearly a rigid rotator with $P_{rot} \approx 100$ d**
- **The surface rotates faster than the core**
  - **$P_{surface} \leq 98.57 \pm 0.02$ days**
  - **$P_{core} \geq 105.13 \pm 0.02$ days**
- **A strong angular momentum transport mechanism other than viscosity must be operating**
- **Angular momentum transport in stars over their entire lifetimes is now an observational science**

THE P MODES AND G MODES ARE COUPLED