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Asteroseismology
Oscillations in solar-type stars

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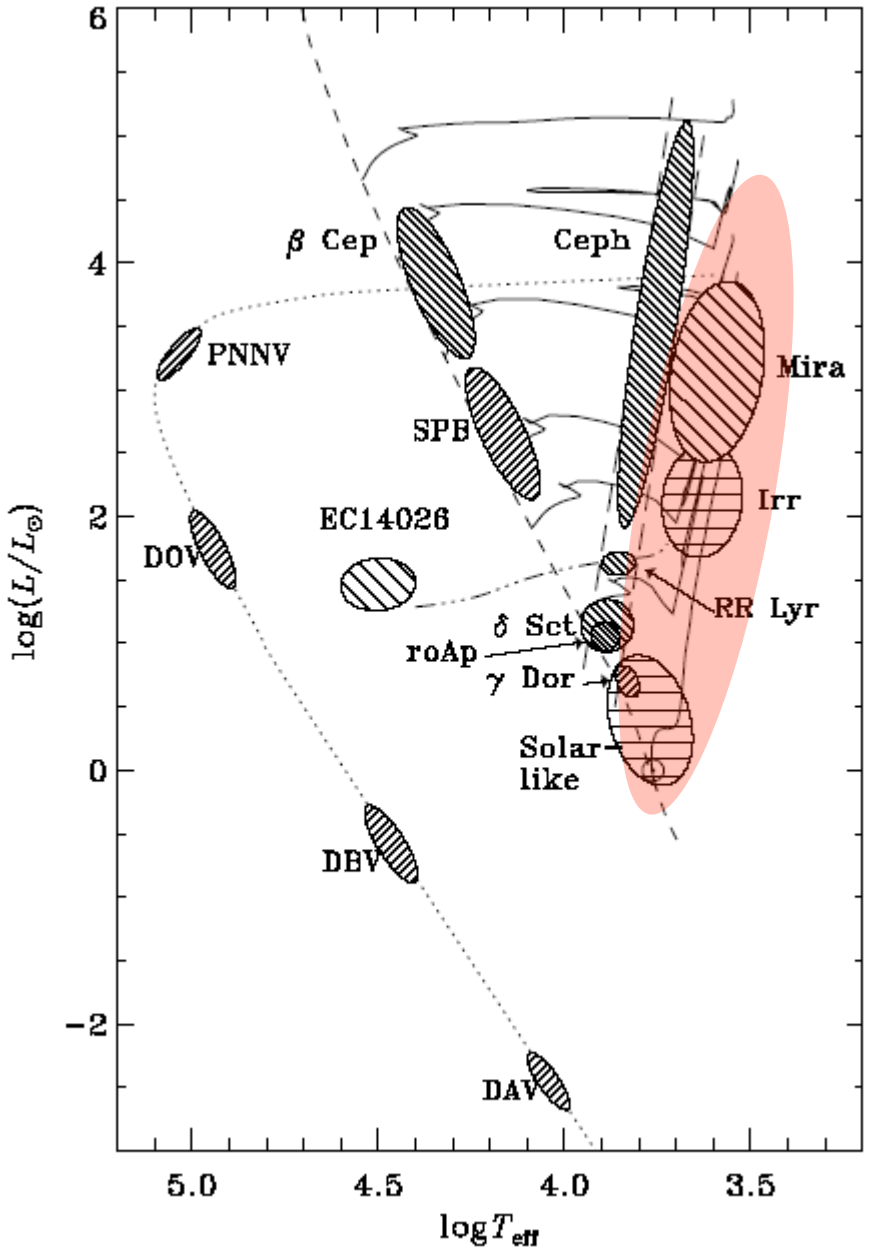
University of Birmingham, UK

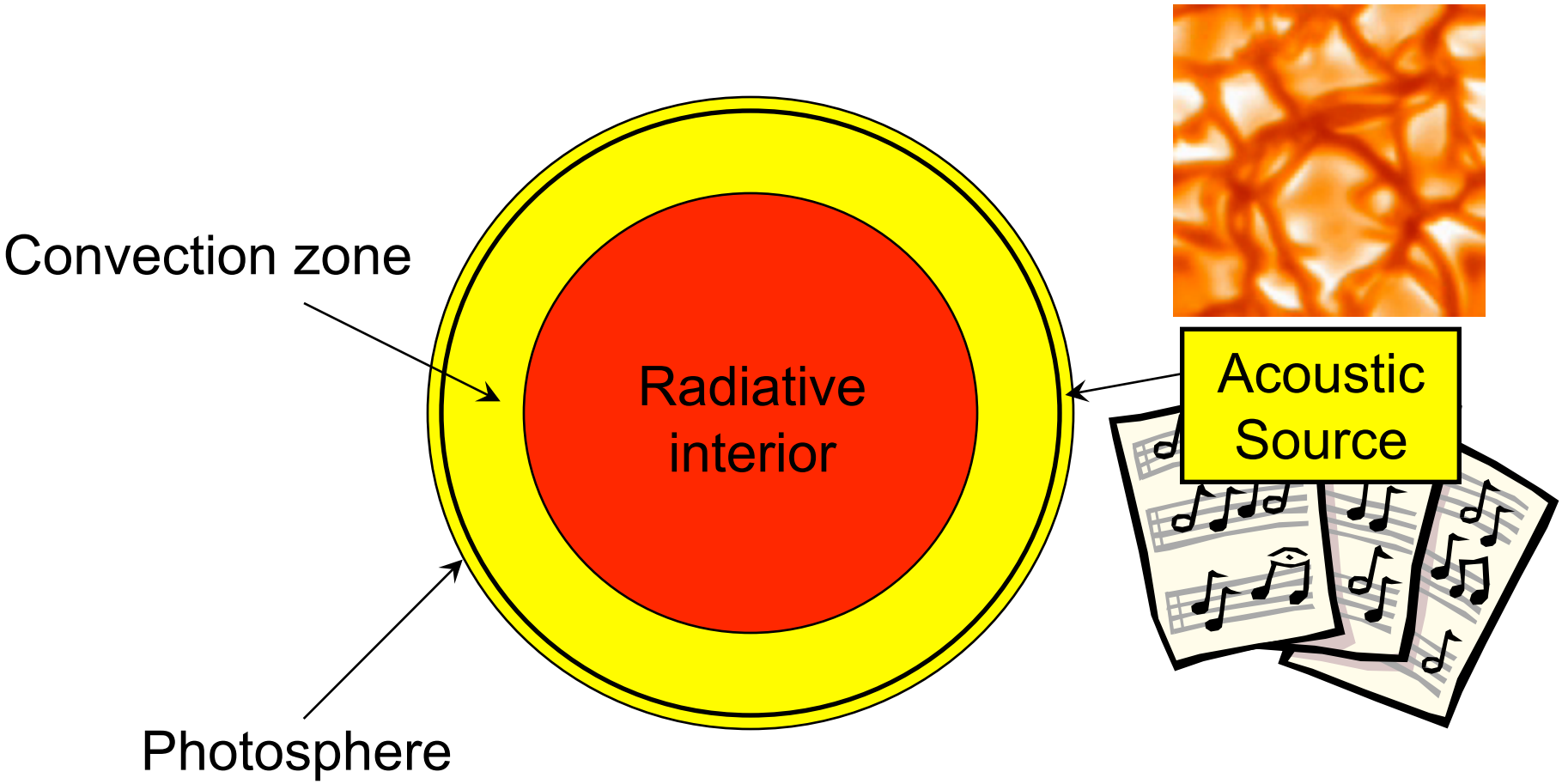
2010 Sagan Summer Workshop, July 28

Pulsations in the HR diagram

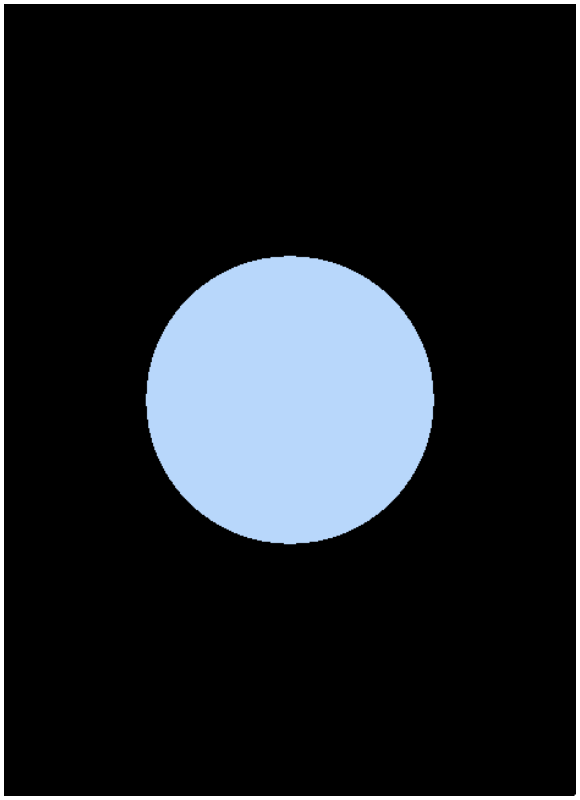
I will focus on "solar-type" stars



Sound generated in convective envelopes…



Timescale for pulsation



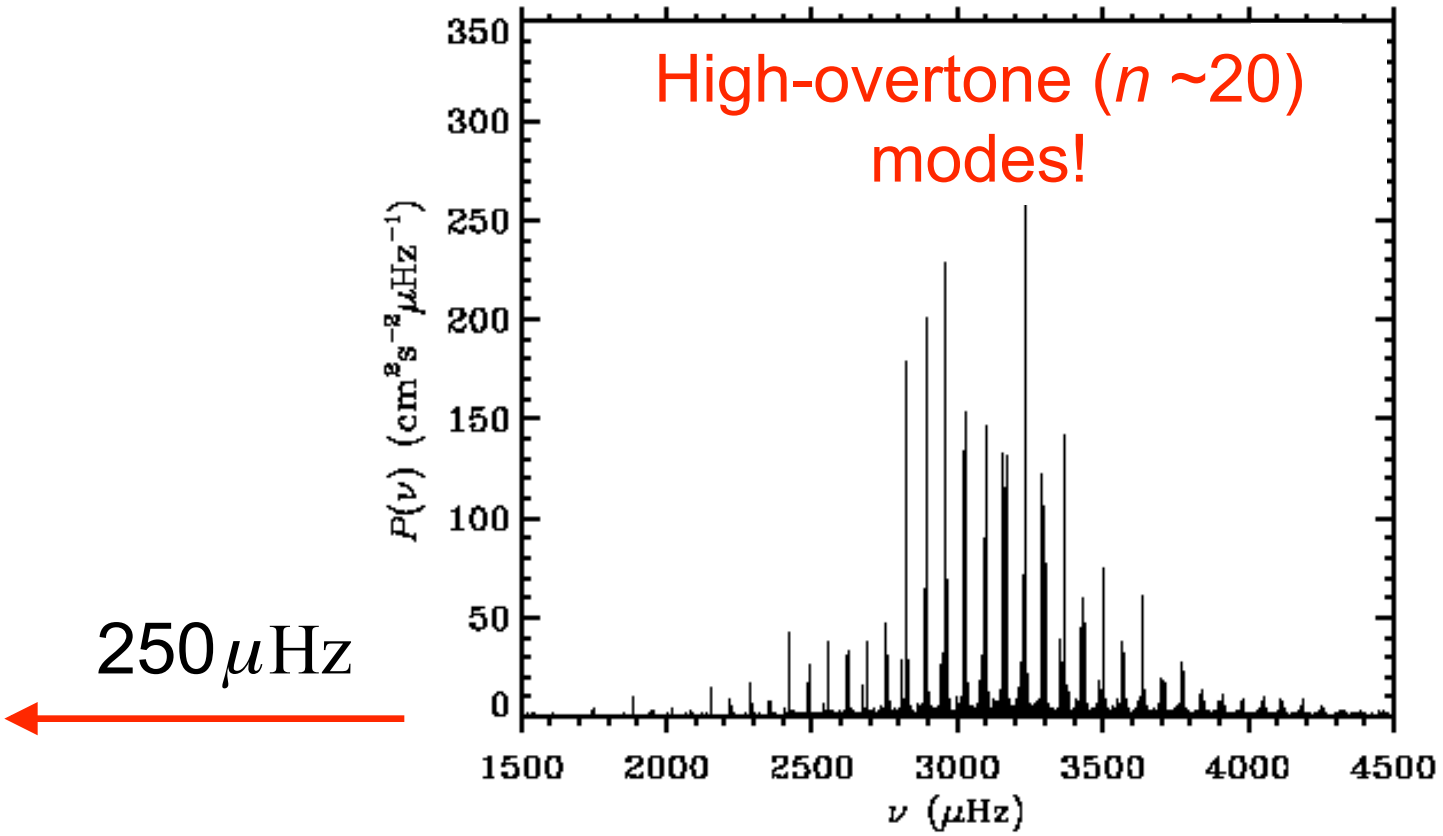
- Fundamental period of radial pulsation:

$$\Pi \propto \langle \rho \rangle^{-1/2}$$

Ritter 1880; Shapley, 1914

- Sun: period~1 hour (~250μHz)

Frequency spectrum of low-degree (low-l) modes (contains overtones of $0 \leq l \leq 3$)



BiSON Sun-as-a-star data

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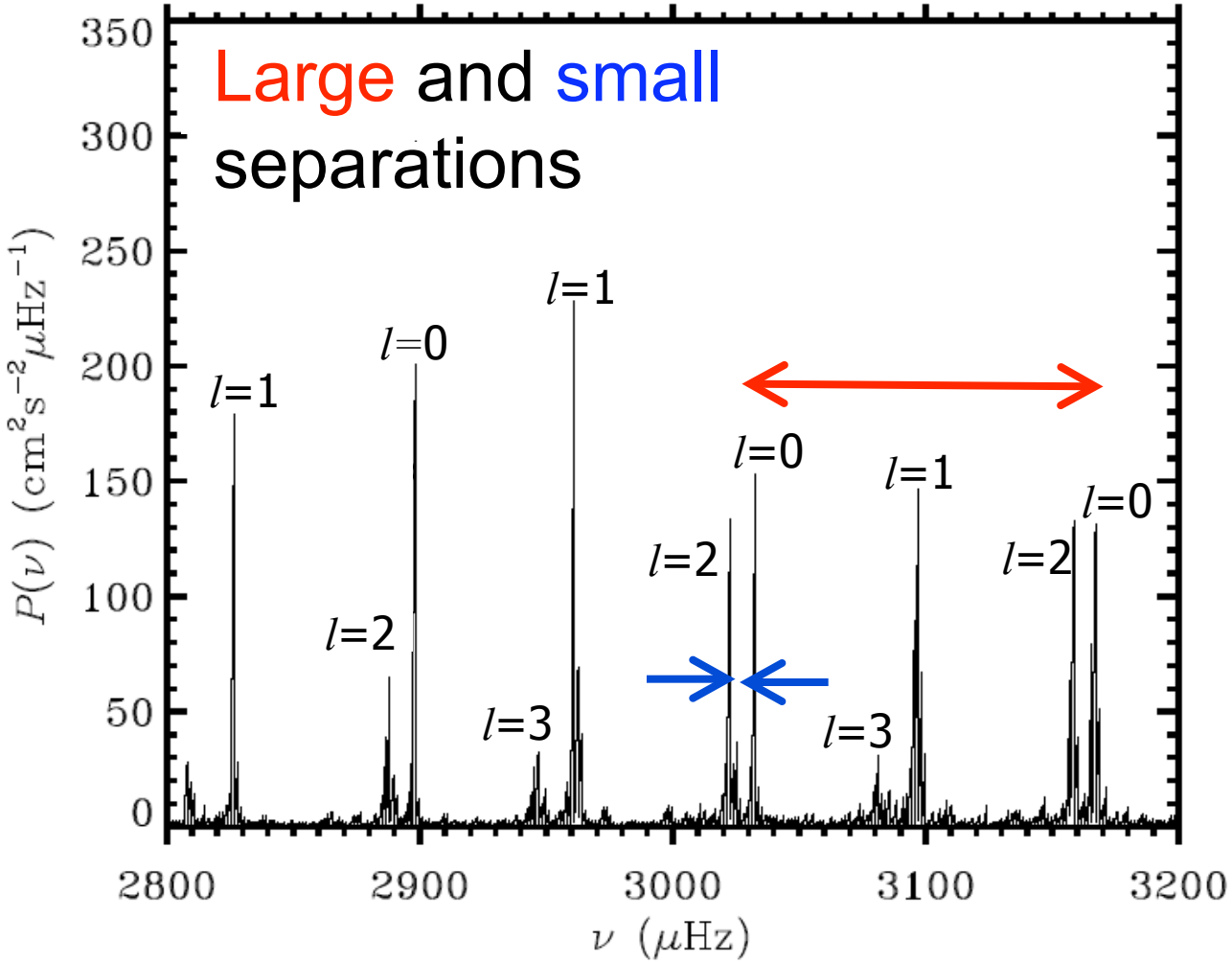
How are overtones of different degree, l, arranged in frequency?



BiSON Sun-as-a-star data

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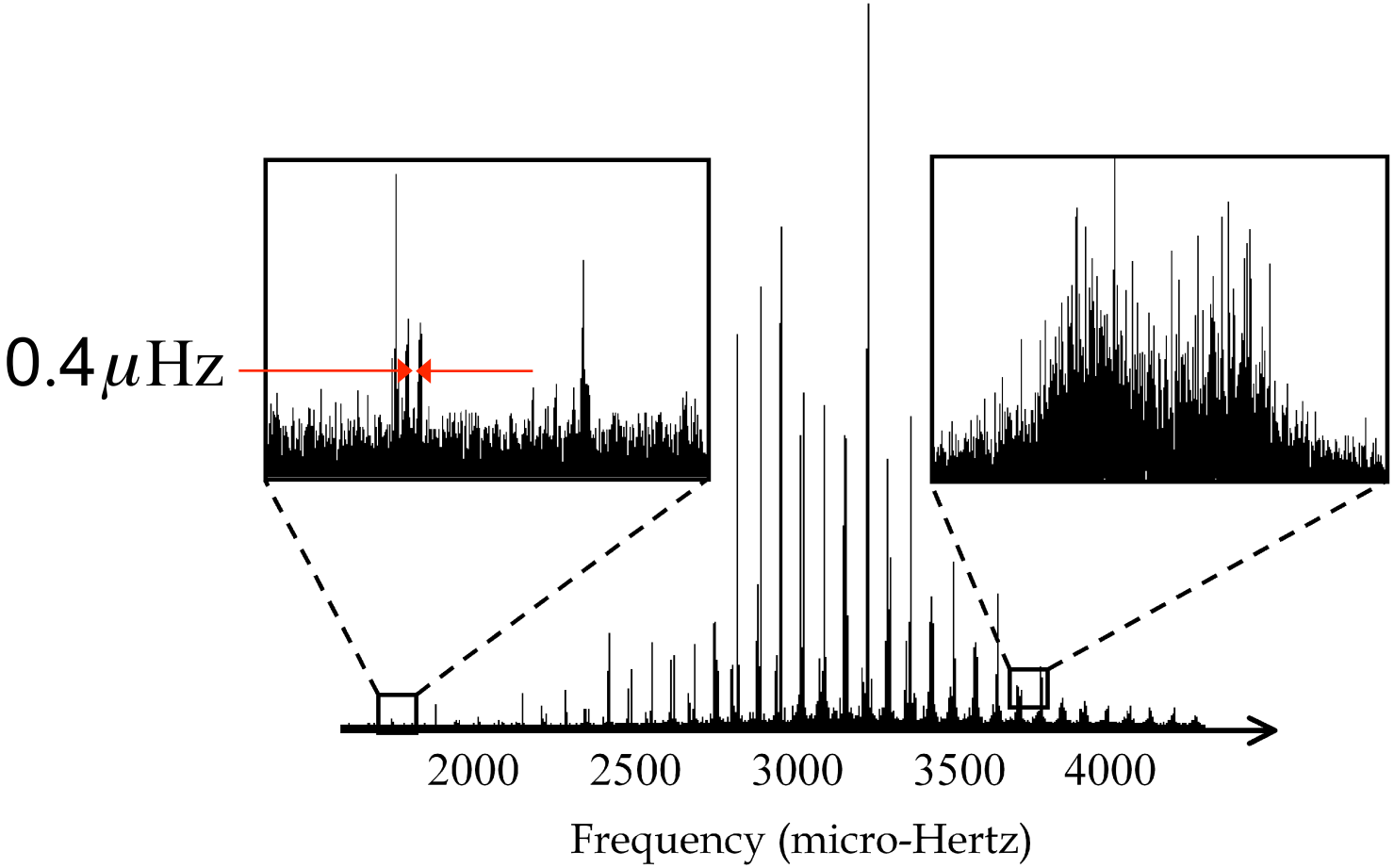
Appearance of the resonant peaks

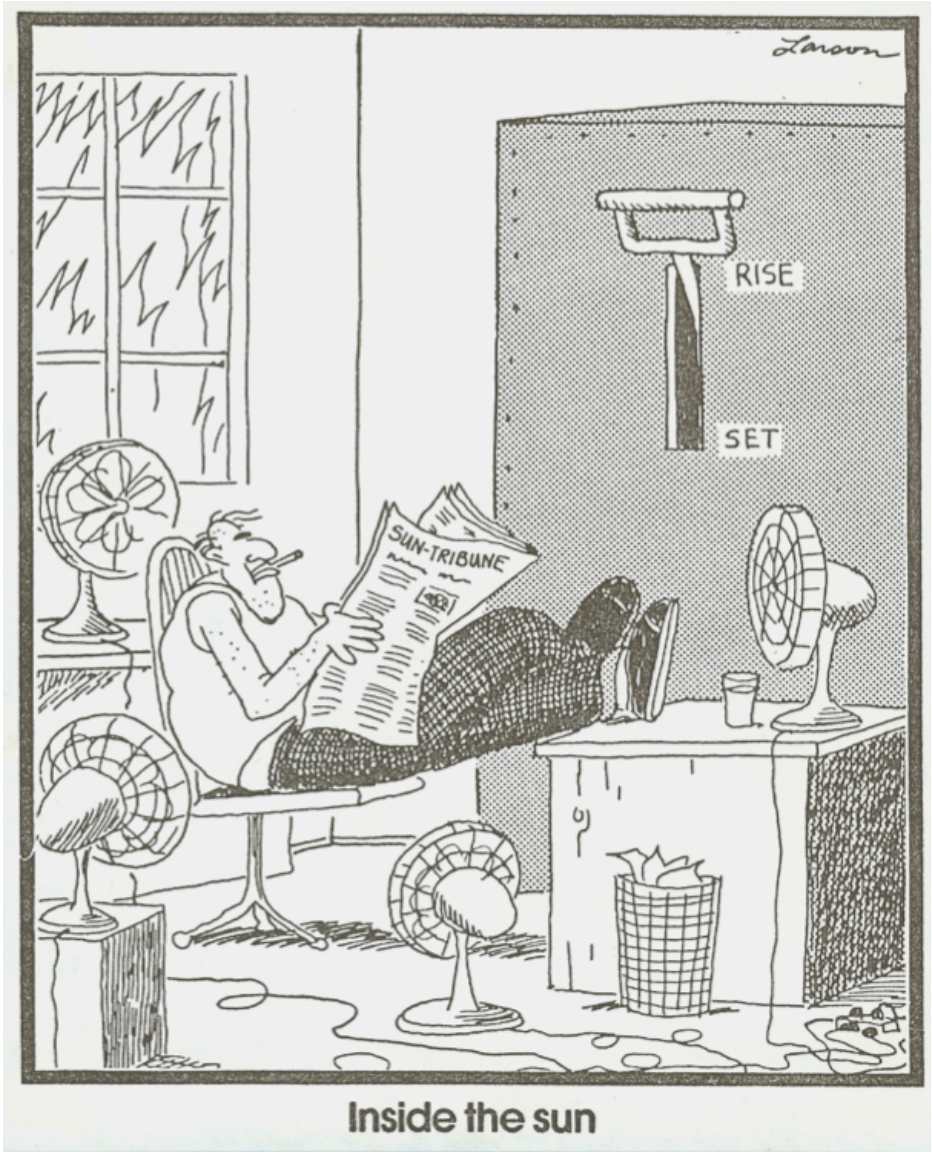
Inferences on rotation and convection



BiSON Sun-as-a-star data

Asteroseismology

Opening windows on the unseen interiors of solar-type stars



Inside the sun

Gary Larson

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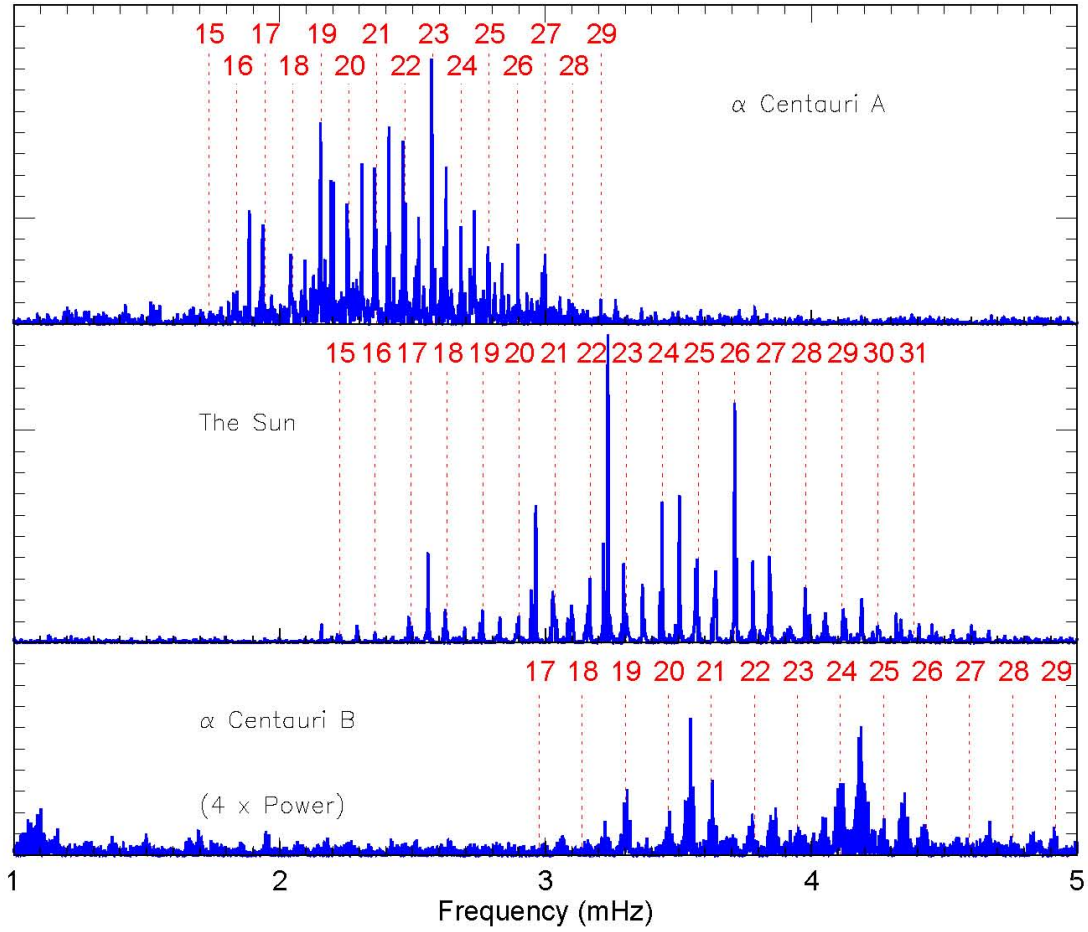
Oscillation spectra of solar-type stars

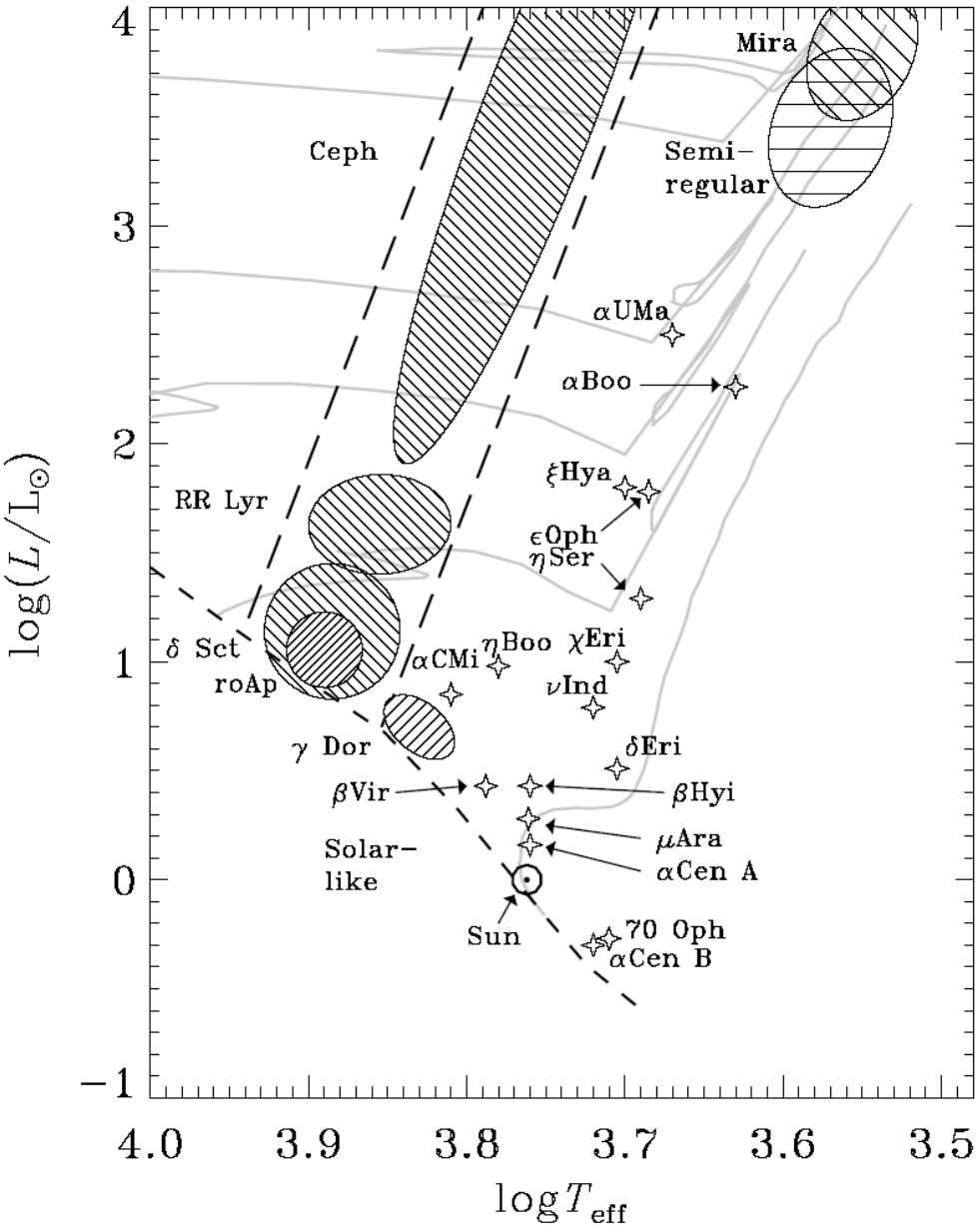
α Cen A

Sun

α Cen B



Courtesy H. Kjeldsen



State of play: pre-CoRoT & pre-Kepler

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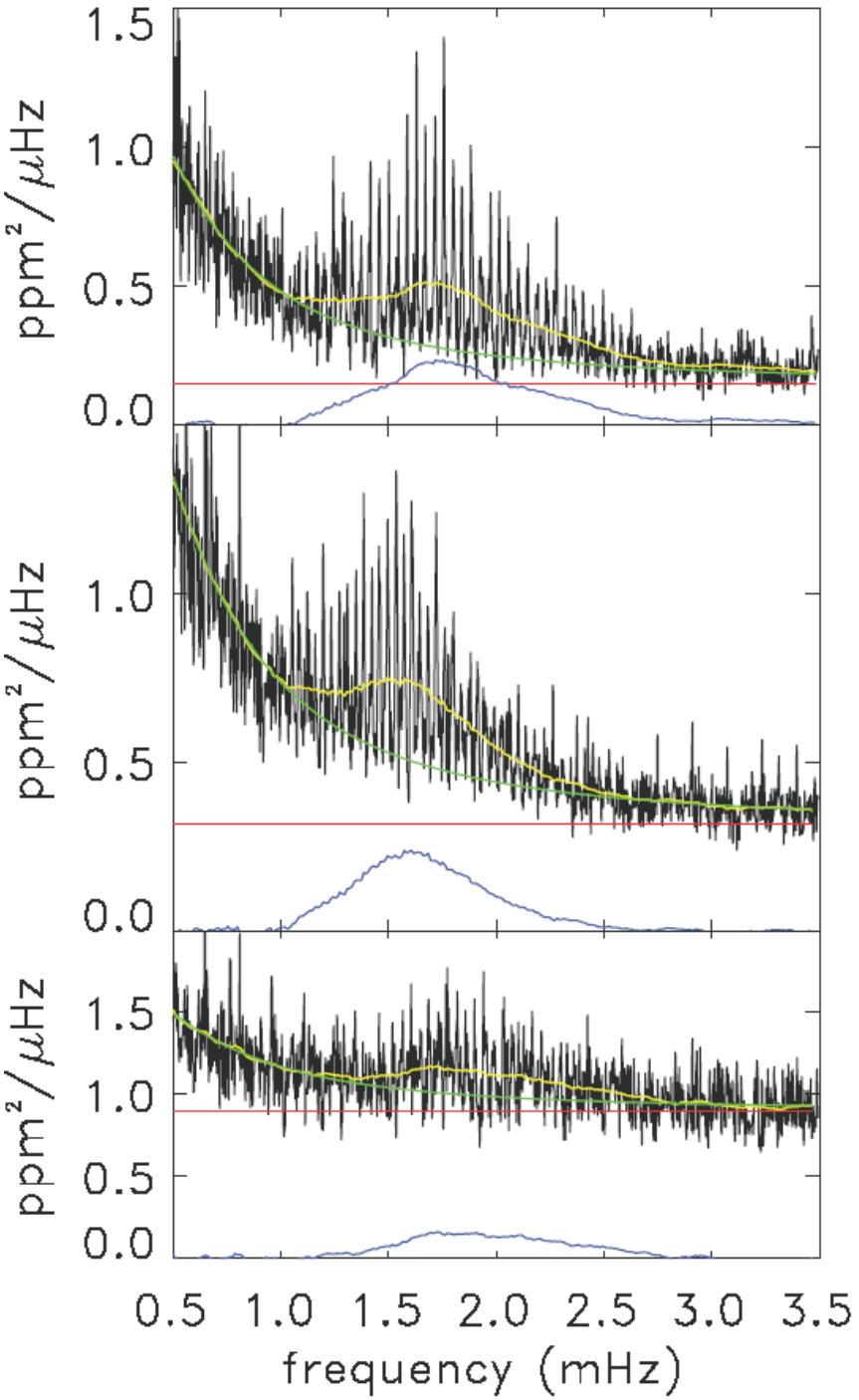
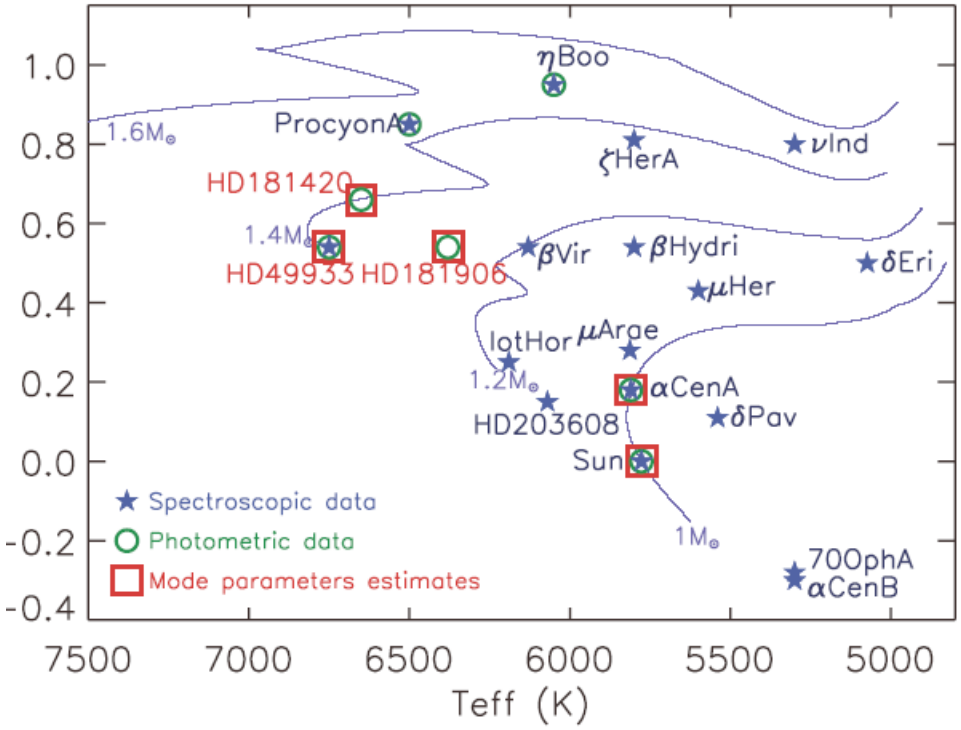
CoRoT sounds F-type stars

Michel et al. 2008





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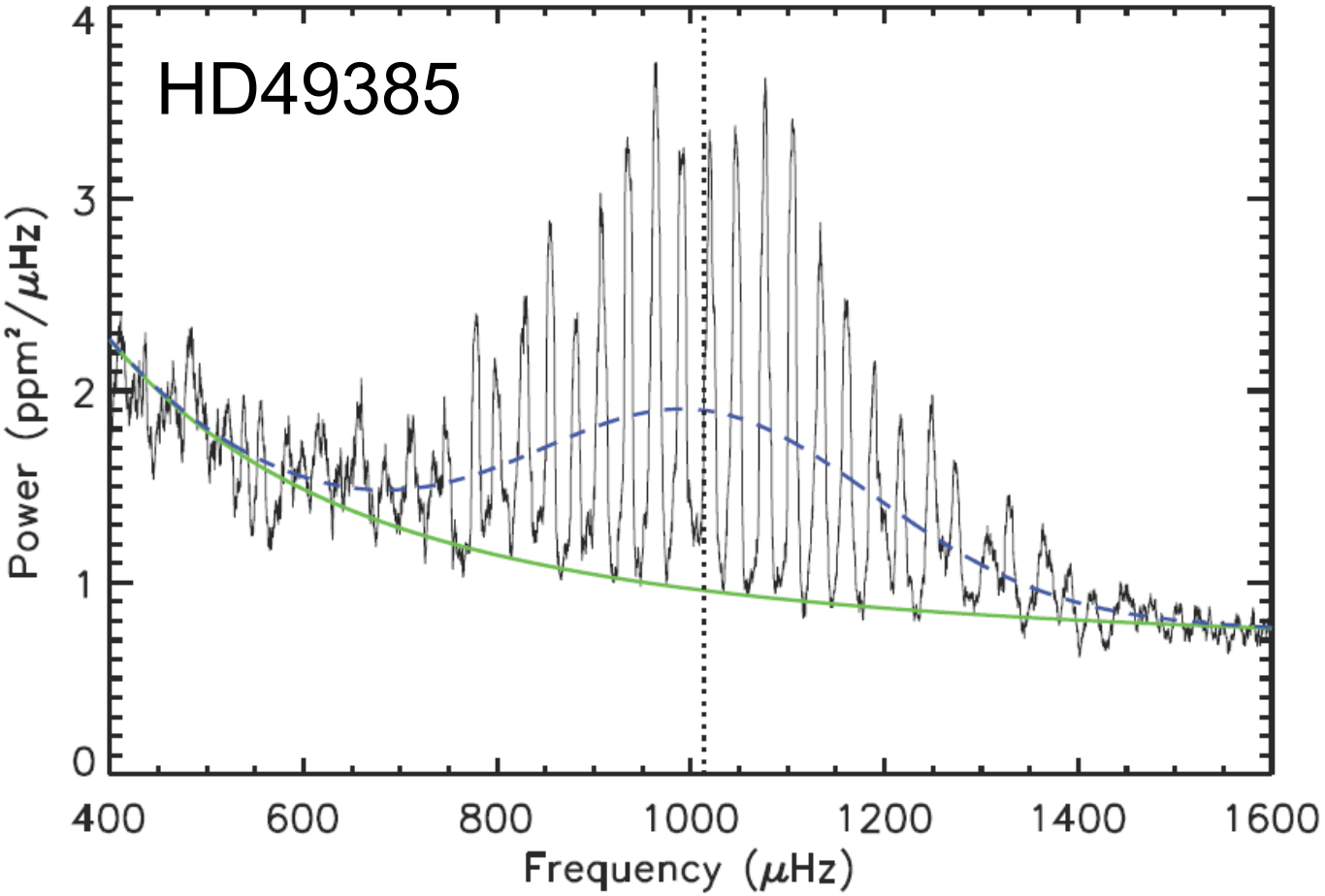
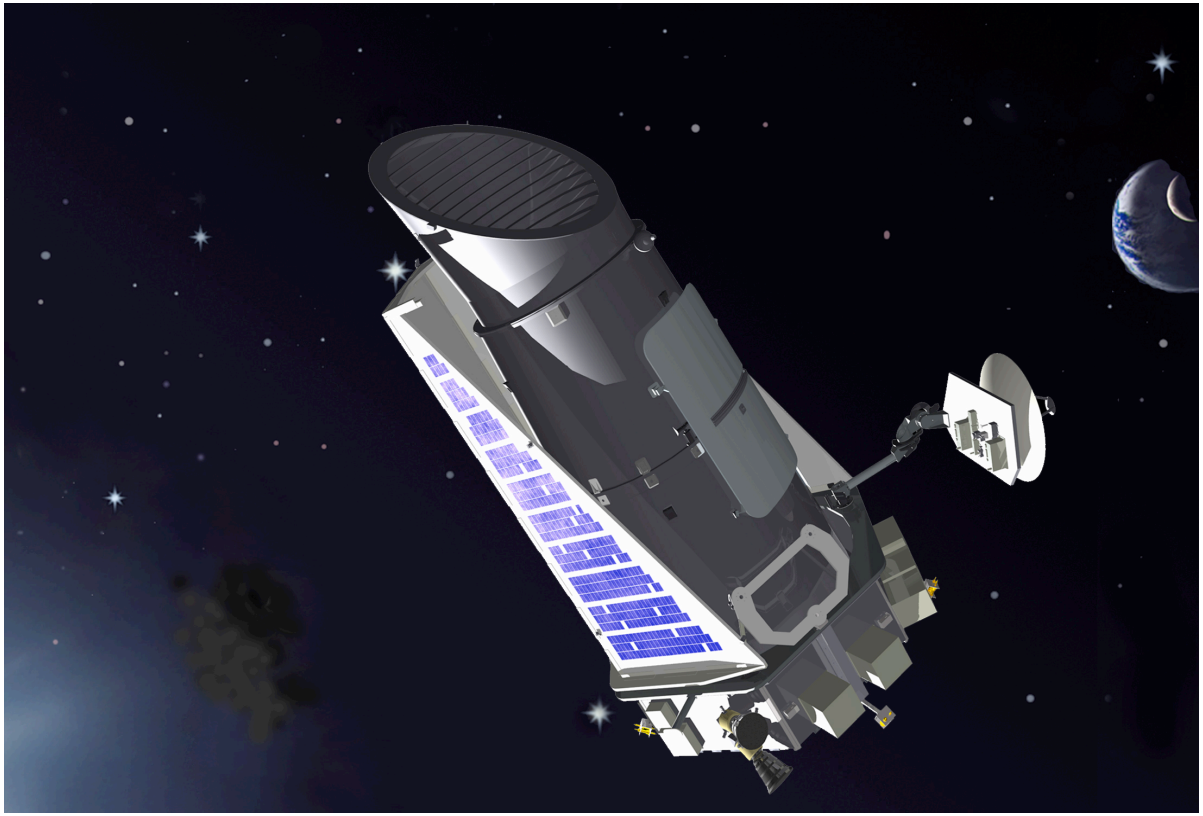
… and G-type stars



Deheuvels et al. 2010

Kepler



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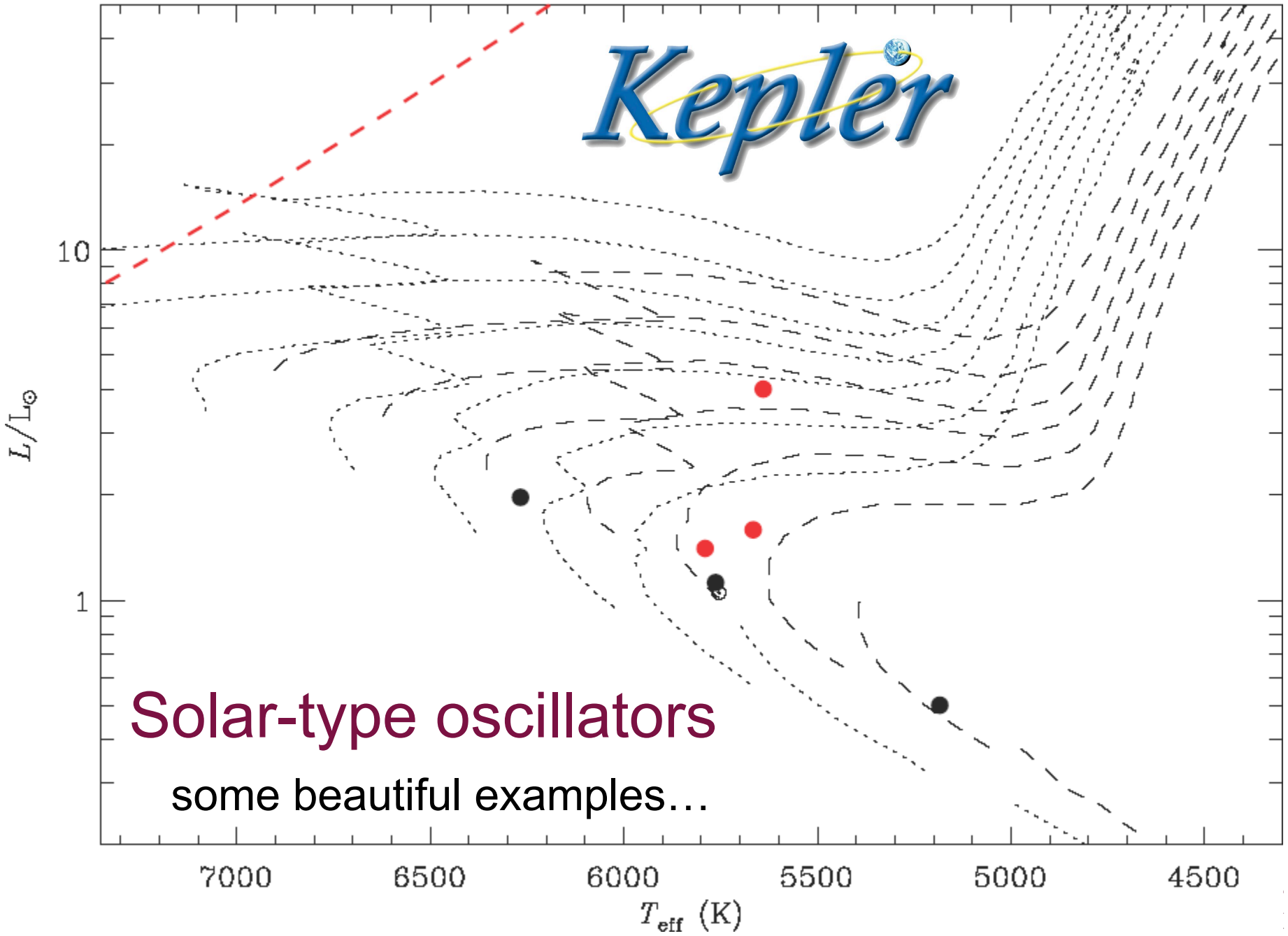
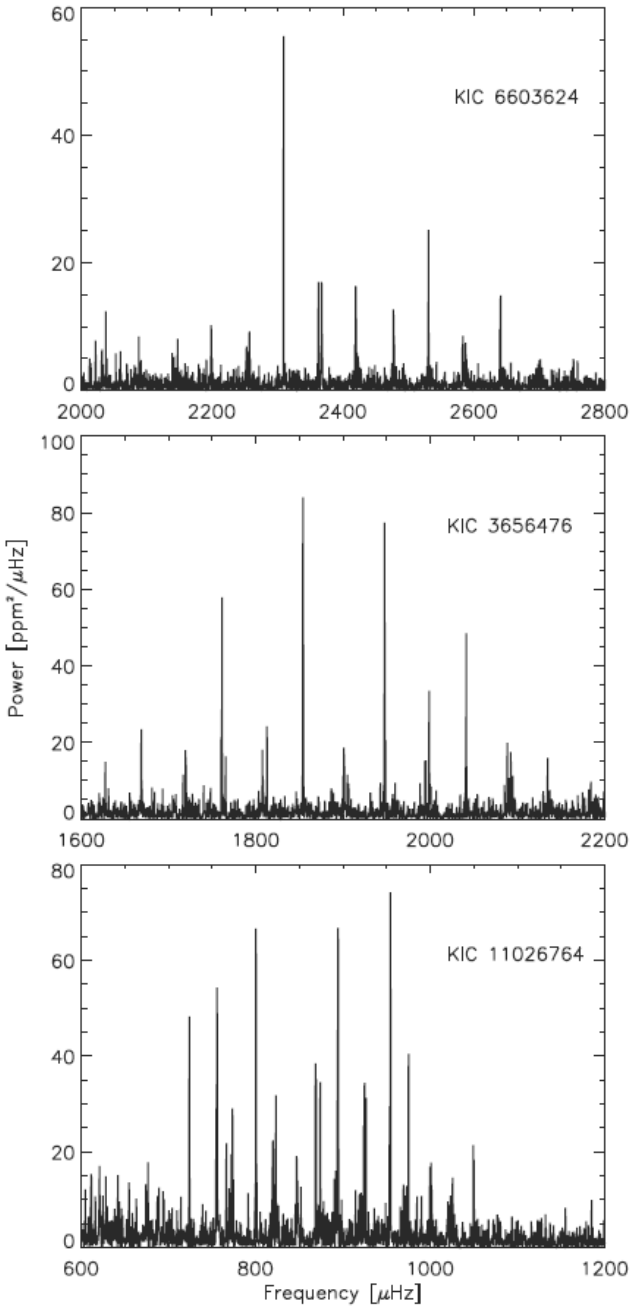


Solar-type oscillators

some beautiful examples…



First results from Kepler on solar-like oscillators

THE ASTROPHYSICAL JOURNAL LETTERS, 713:L169–L175, 2010 April 20 doi:10.1088/2041-8205/713/2/L169

THE ASTEROSEISMIC POTENTIAL OF *KEPLER*: FIRST RESULTS FOR SOLAR-TYPE STARS

W. J. CHAPLIN[1], T. APPOURCHAUX[2], Y. ELSWORTH[1], R. A. GARCÍA[3], G. HOUDEK[4], C. KAROFF[1], T. S. METCALFE[5], J. MOLENDA-ŻAKOWICZ[6], M. J. P. F. G. MONTEIRO[7], M. J. THOMPSON[8], T. M. BROWN[9], J. CHRISTENSEN-DALSGAARD[10], R. L. GILLILAND[11], H. KJELDSEN[10], W. J. BORUCKI[12], D. KOCH[12], J. M. JENKINS[13], J. BALLOT[14], S. BASU[15], M. BAZOT[7], T. R. BEDDING[16], O. BENOMAR[2], A. BONANNO[17], I. M. BRANDÃO[7], H. BRUNTT[18], T. L. CAMPANTE[7,10], O. L. CREEVEY[19,20], M. P. DI MAURO[21], G. DOĞAN[10], S. DREIZLER[22], P. EGGENBERGER[23], L. ESCH[15], S. T. FLETCHER[24], S. FRANDSEN[10], N. GAI[15,25], P. GAULME[2], R. HANDBERG[10], S. HEKKER[1], R. HOWE[26], D. HUBER[16], S. G. KORZENNIK[27], J. C. LEBRUN[28], S. LECCIA[29], M. MARTIC[28], S. MATHUR[30], B. MOSSER[31], R. NEW[24], P.-O. QUIRION[10,32], C. RÉGULO[19,20], I. W. ROXBURGH[33], D. SALABERT[19,20], J. SCHOU[34], S. G. SOUSA[7], D. STELLO[16], G. A. VERNER[33], T. ARENTOFT[10], C. BARBAN[31], K. BELKACEM[35], S. BENATTI[36], K. BIAZZO[37], P. BOUMIER[2], P. A. BRADLEY[38], A.-M. BROOMHALL[1], D. L. BUZASI[39], R. U. CLAUDI[40], M. S. CUNHA[7], F. D'ANTONA[41], S. DEHEUVELS[31], A. DEREKAS[42,16], A. GARCÍA HERNÁNDEZ[43], M. S. GIAMPAPA[26], M. J. GOUPIL[18], M. GRUBERBAUER[44], J. A. GUZIK[38], S. J. HALE[1], M. J. IRELAND[16], L. L. KISS[42,16], I. N. KITIASHVILI[45], K. KOLENBERG[4], H. KORHONEN[46], A. G. KOSOVICHEV[34], F. KUPKA[47], Y. LEBRETON[48], B. LEROY[31], H.-G. LUDWIG[48], S. MATHIS[3], E. MICHEL[31], A. MIGLIO[35], J. MONTALBÁN[35], A. MOYA[49], A. NOELS[35], R. W. NOYES[27], P. L. PALLÉ[20], L. PIAU[3], H. L. PRESTON[39,50], T. ROCA CORTÉS[19,20], M. ROTH[51], K. H. SATO[3], J. SCHMITT[52], A. M. SERENELLI[53], V. SILVA AGUIRRE[53], I. R. STEVENS[1], J. C. SUÁREZ[43], M. D. SURAN[54], R. TRAMPEDACH[55], S. TURCK-CHIÈZE[3], K. UYTTERHOEVEN[3], R. VENTURA[17], AND P. A. WILSON[56,57]

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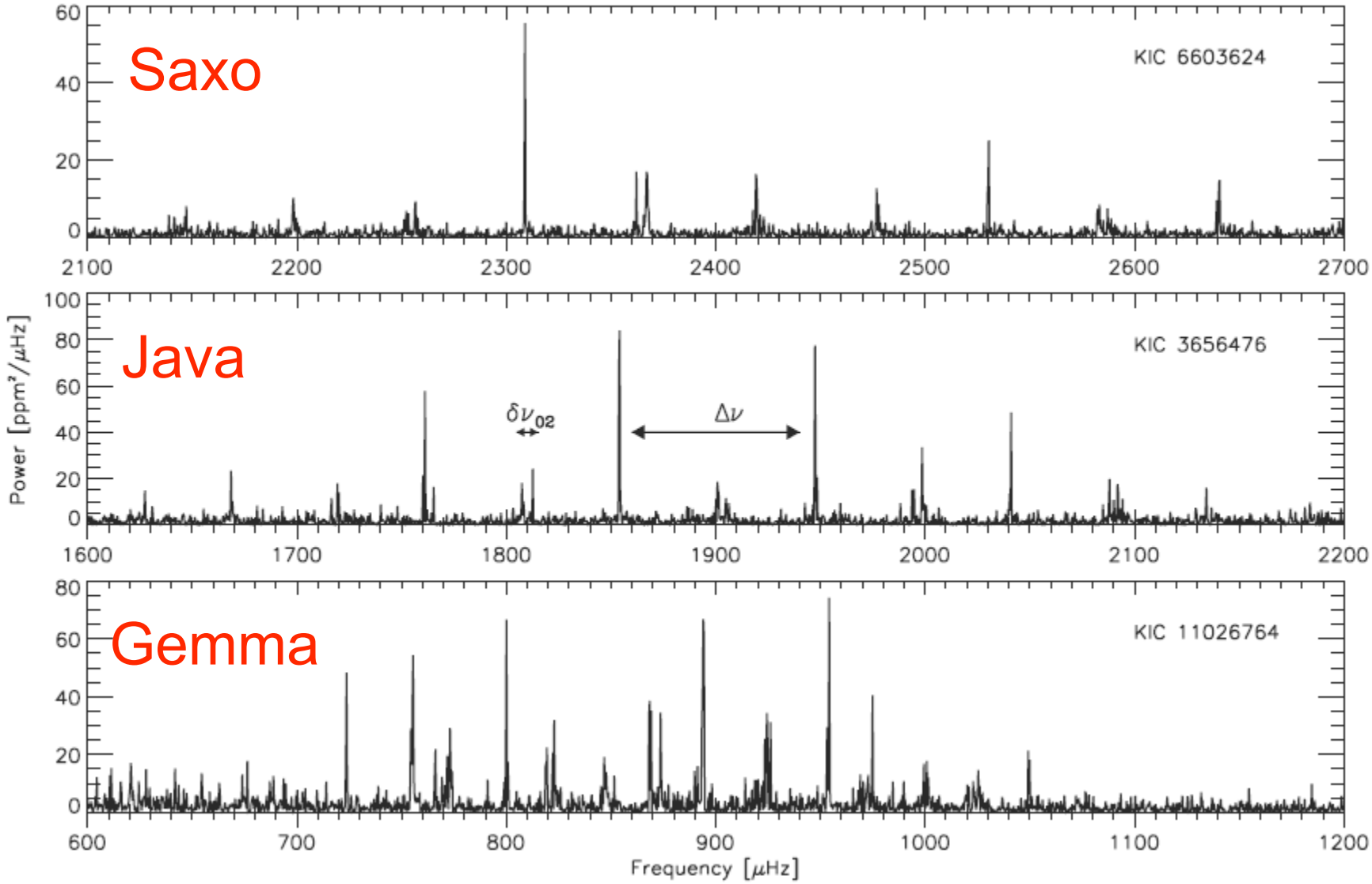

With unofficial names!

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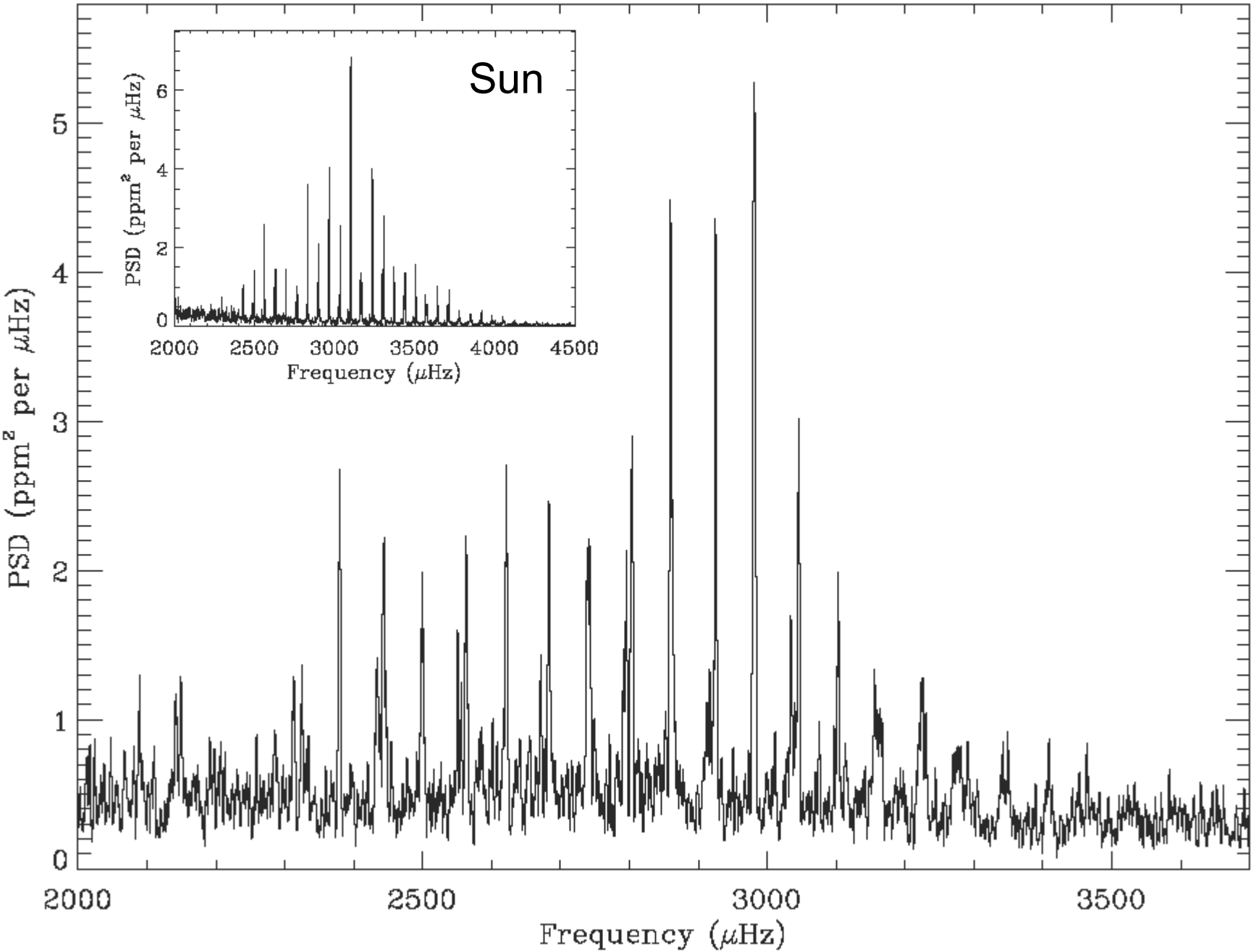
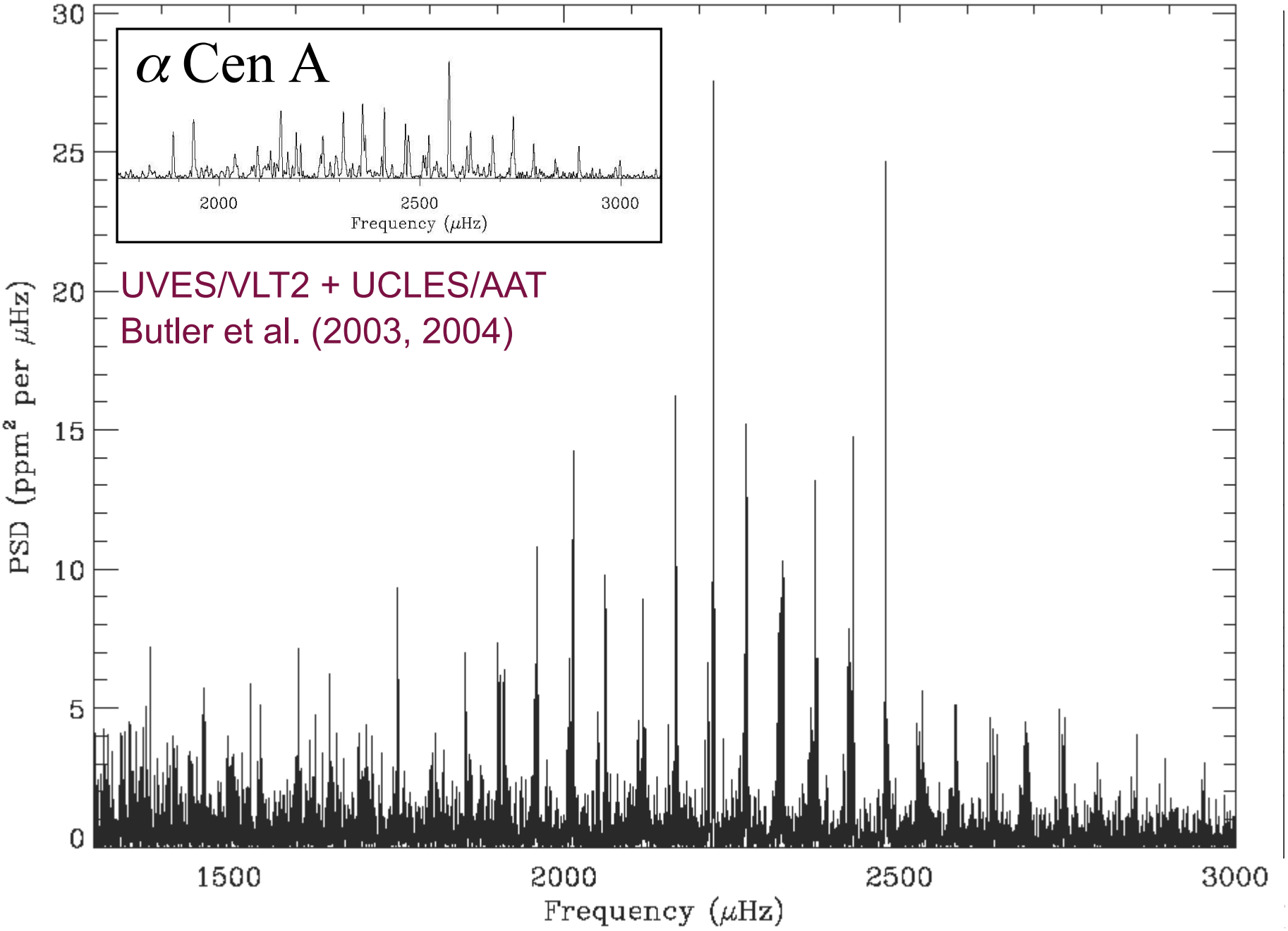
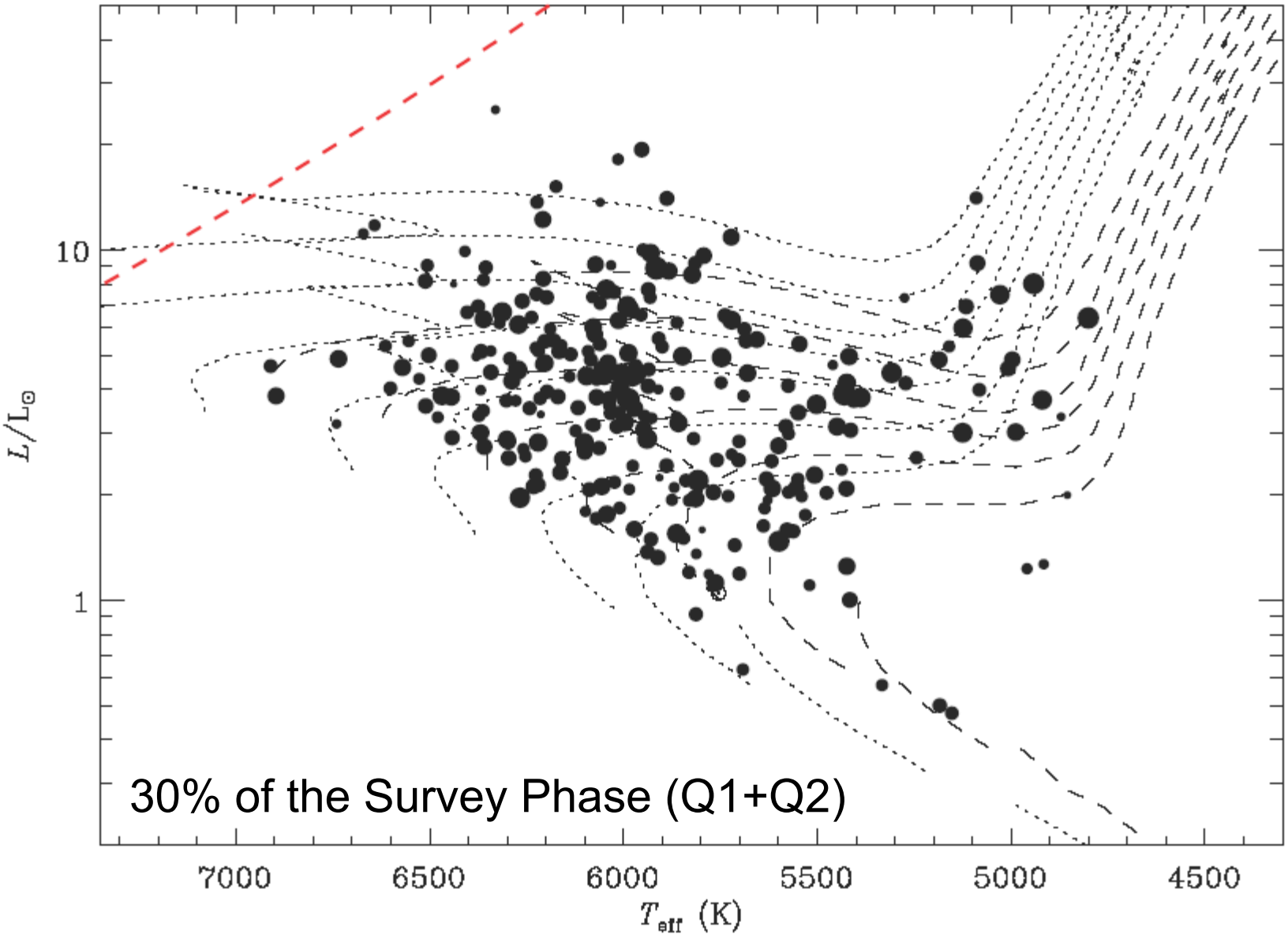

Sun
PSD (ppm² per μHz)
Frequency (μHz)
0
1
2
3
4
5
2000
2500
3000
3500
PSD (ppm² per μHz)
0
2
4
6
2000
2500
3000
3500
4000
4500
Frequency (μHz)


α Cen A
2000
2500
3000
Frequency (μHz)
UVES/VLT2 + UCLES/AAT
Butler et al. (2003, 2004)
PSD (ppm² per μHz)
0
5
10
15
20
25
30
1500
2000
2500
3000
Frequency (μHz)



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Solar-like oscillations with Kepler
Asteroseismic observing strategy

- Seismic survey:
  - First 10 months of science operations
  - 1-month datasets on ~2500 solar-like targets
- Long-term observations:
  - From month 10 onwards…
  - Choose best targets for observations lasting up to several years!

Asteroseismology provides…

- Extremely precise and accurate fundamental properties:
  - Potential to provide accurate age calibrations for stars with convective cores
  - Internal rotation, angular momentum evolution
  - Tests of gyrochronology
  - Mixing, diffusion etc.

Asteroseismology provides…

- Inferences on stellar populations:
  - Large Kepler ensemble of solar-like stars
  - “Differential” or “comparative” asteroseismology
- Signatures of regions of abrupt structural change:
  - He abundances in solar-type stars

Asteroseismology provides…

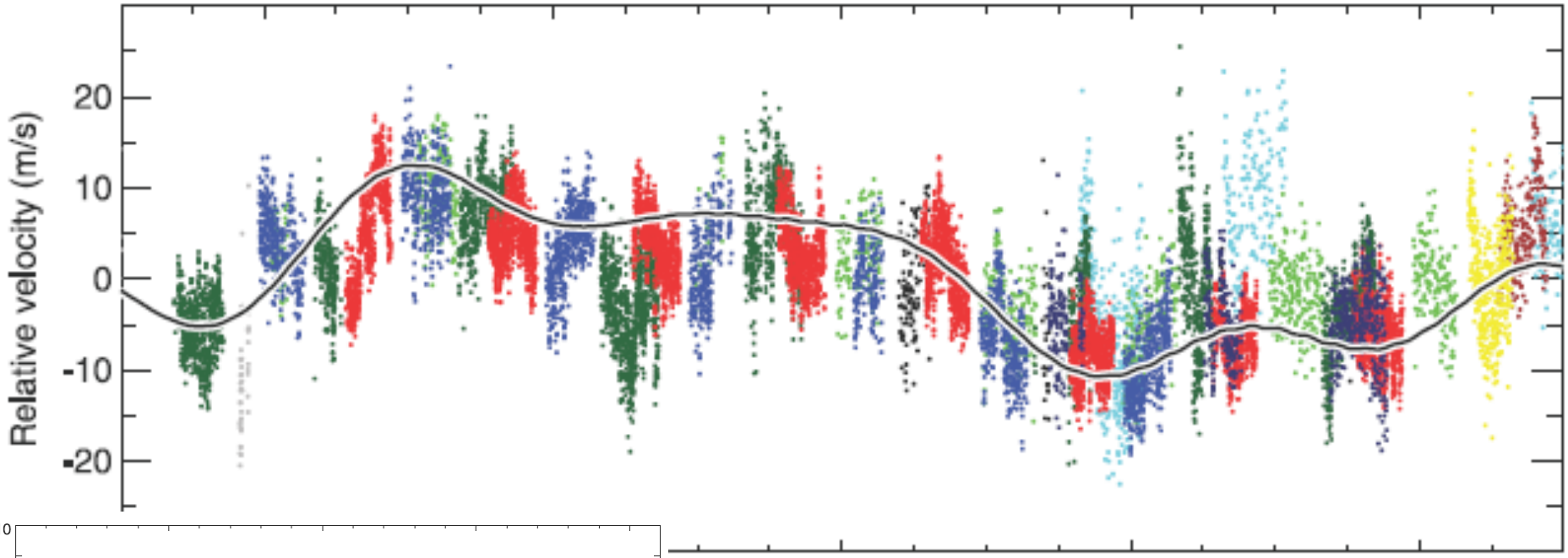
- Inferences on stellar activity, dynamo theories:
  - "Sound" stellar cycles
  - Constrain surface distribution of active regions (acoustic asphericity…)
- Signatures of regions of abrupt structural change…
  - Accurate inference on depths of convective envelopes

Synergies with exoplanet searches

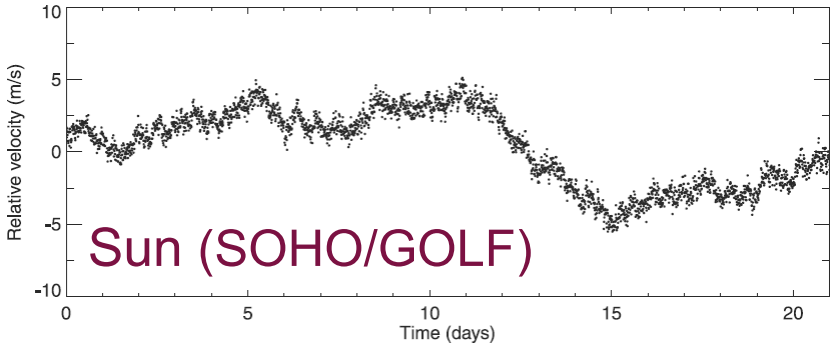
- Precise, accurate stellar radii constrain planetary radii
- Ages of host stars constrain ages of stellar systems
- Intrinsic activity, variability of host stars:
  - implications for exoplanet detectability
  - habitability of exoplanets

Signatures of stellar activity

Multisite campaign on Procyon A



Arentoft et al. 2008



Sun (SOHO/GOLF)

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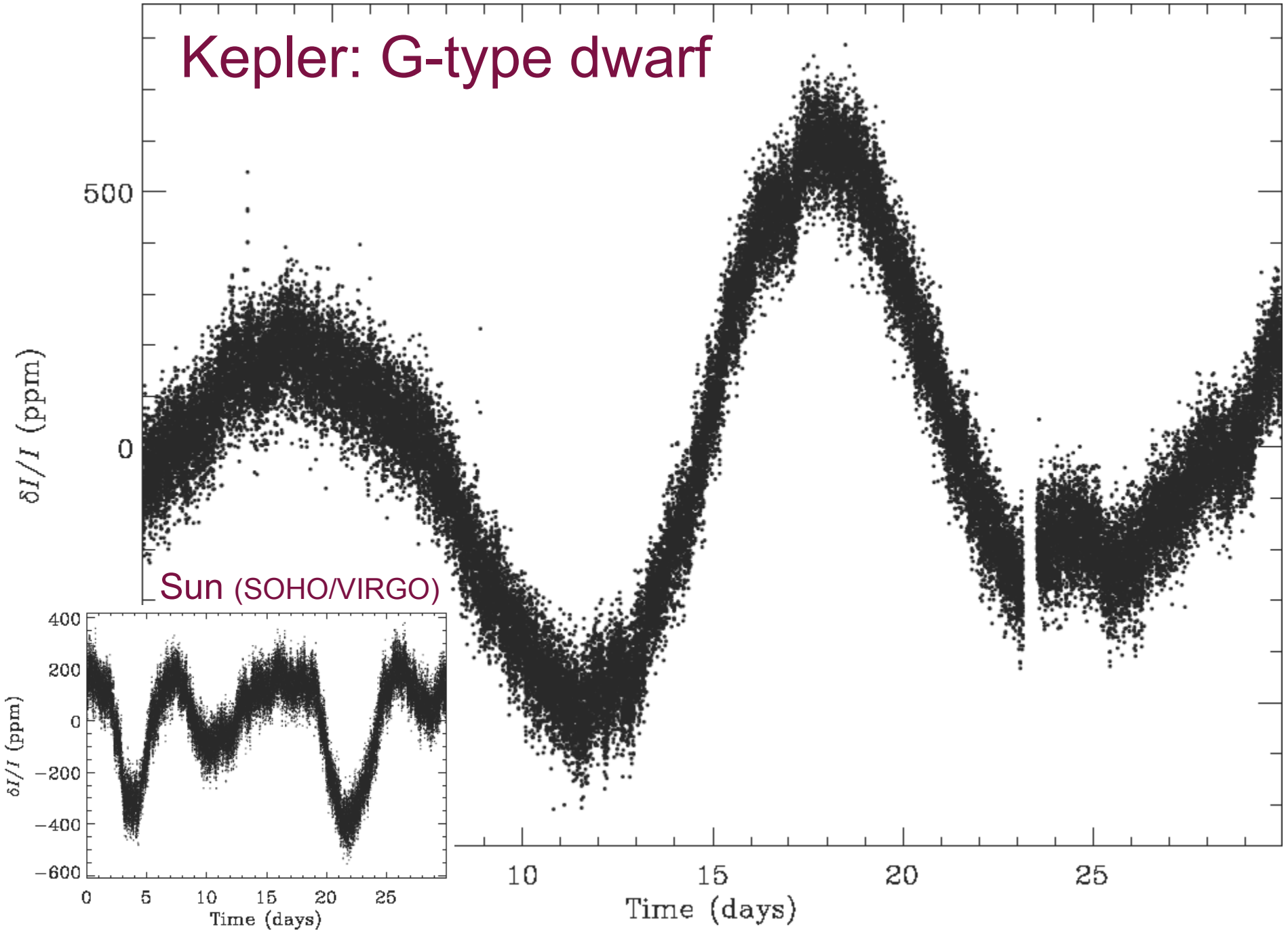
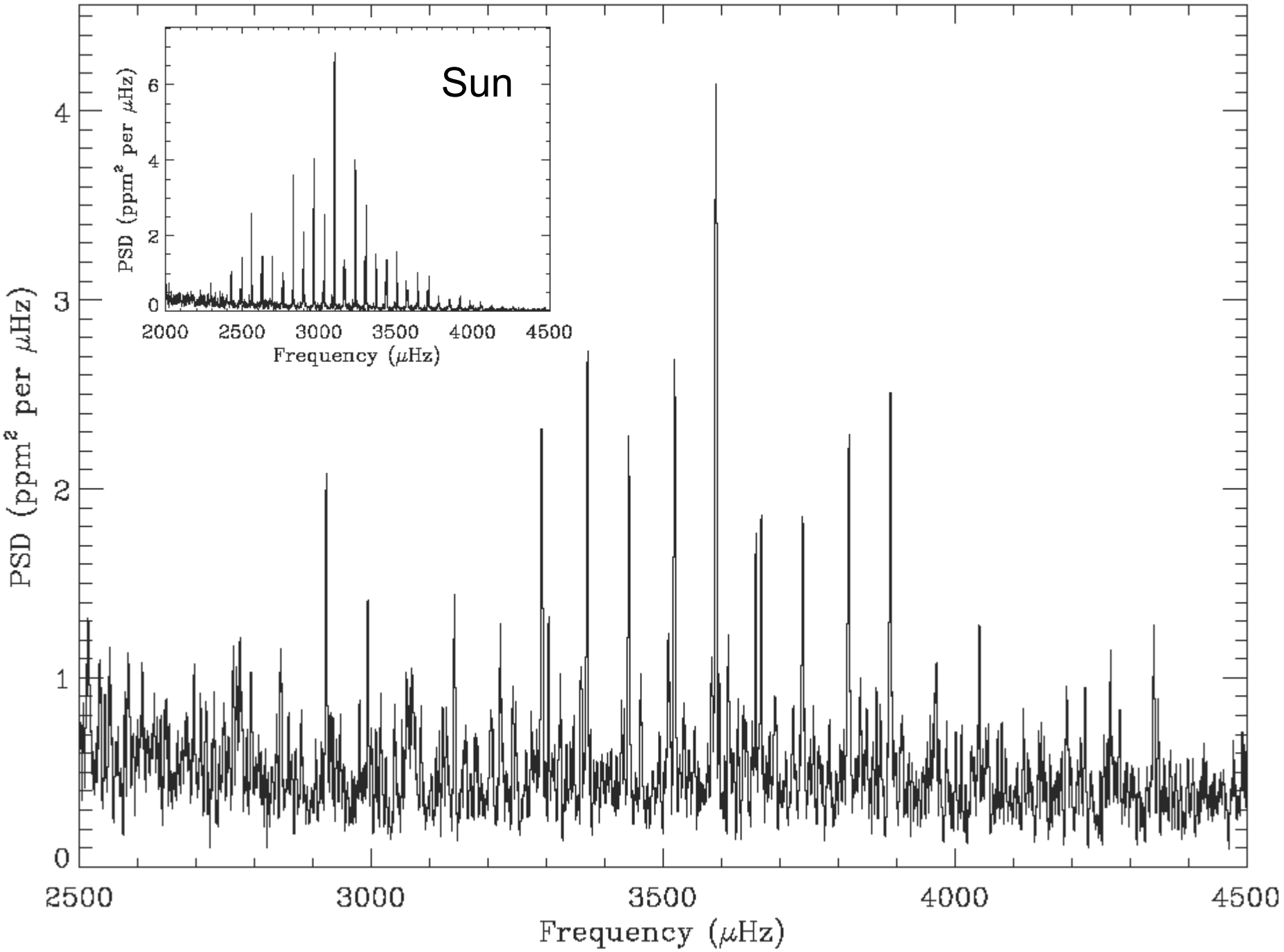
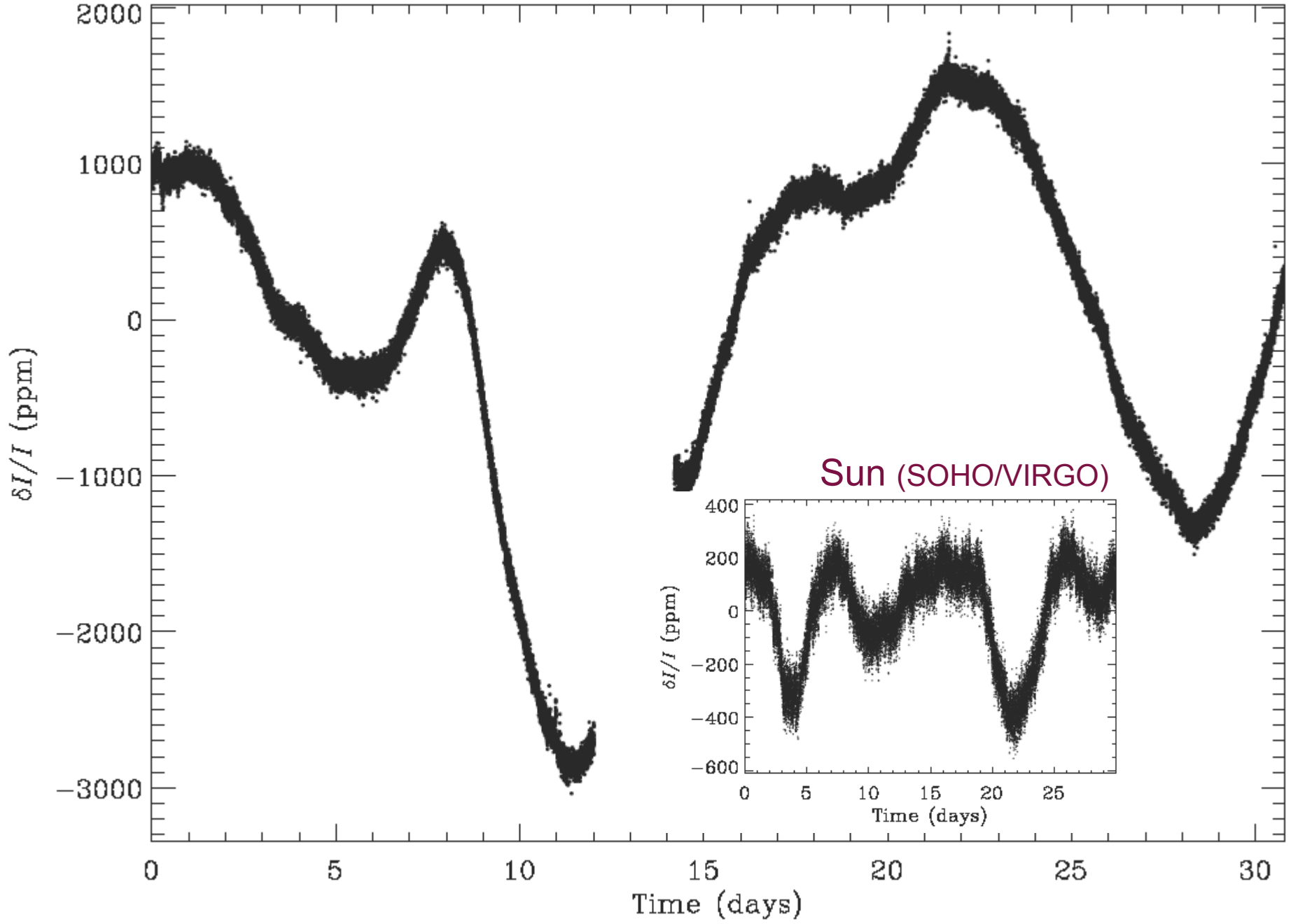
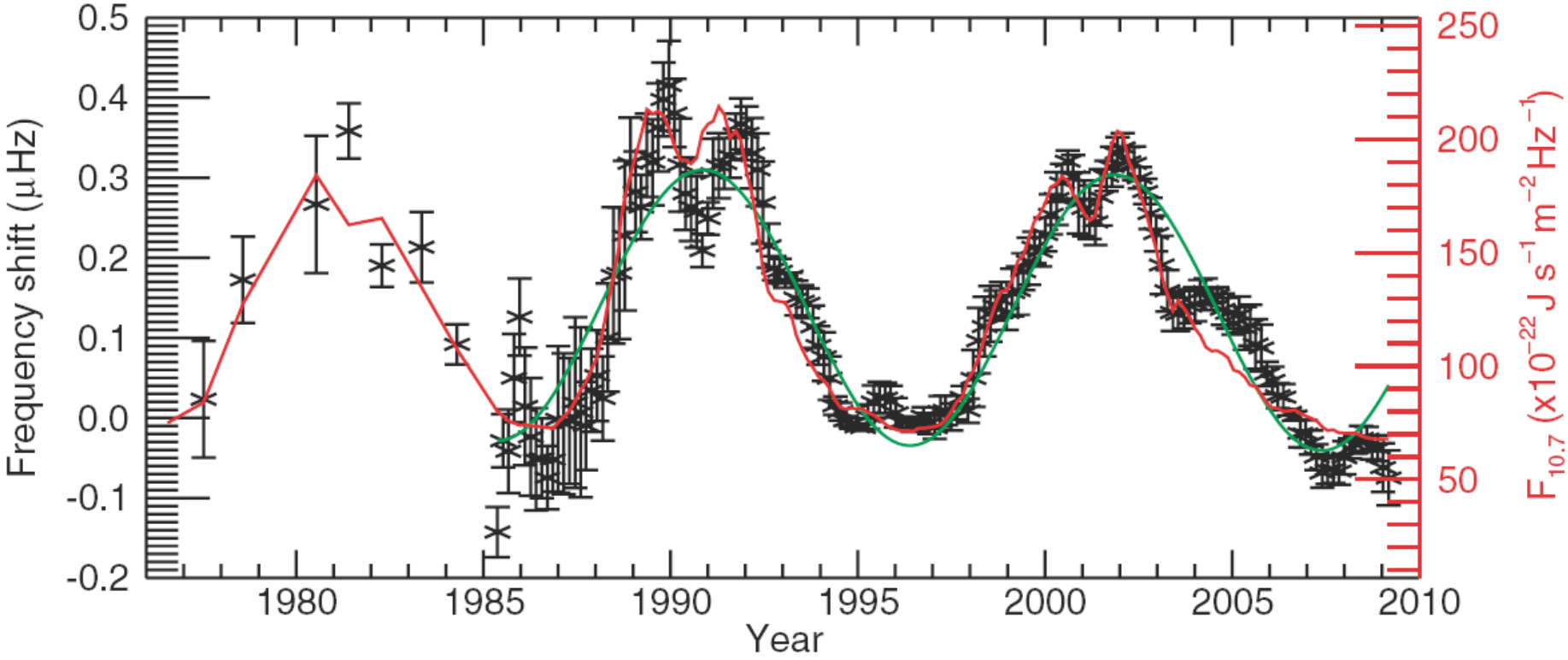

Kepler: G-type dwarf
500
0
δI/I (ppm)
10
15
20
25
Time (days)
Sun (SOHO/VIRGO)
400
200
0
−200
−400
−600
δI/I (ppm)
0
5
10
15
20
25
Time (days)


Sun
PSD (ppm² per μHz)
Frequency (μHz)
0
1
2
3
4
2500
3000
3500
4000
4500
0
2
4
6
2000
2500
3000
3500
4000
4500


2000
1000
0
−1000
−2000
−3000
δI/I (ppm)
0
5
10
15
20
25
30
Time (days)
Sun (SOHO/VIRGO)
400
200
0
−200
−400
−600
δI/I (ppm)
0
5
10
15
20
25
Time (days)

“Sounding” stellar activity cycles: Sun



Broomhall et al., 2009, ApJ, 700, L162

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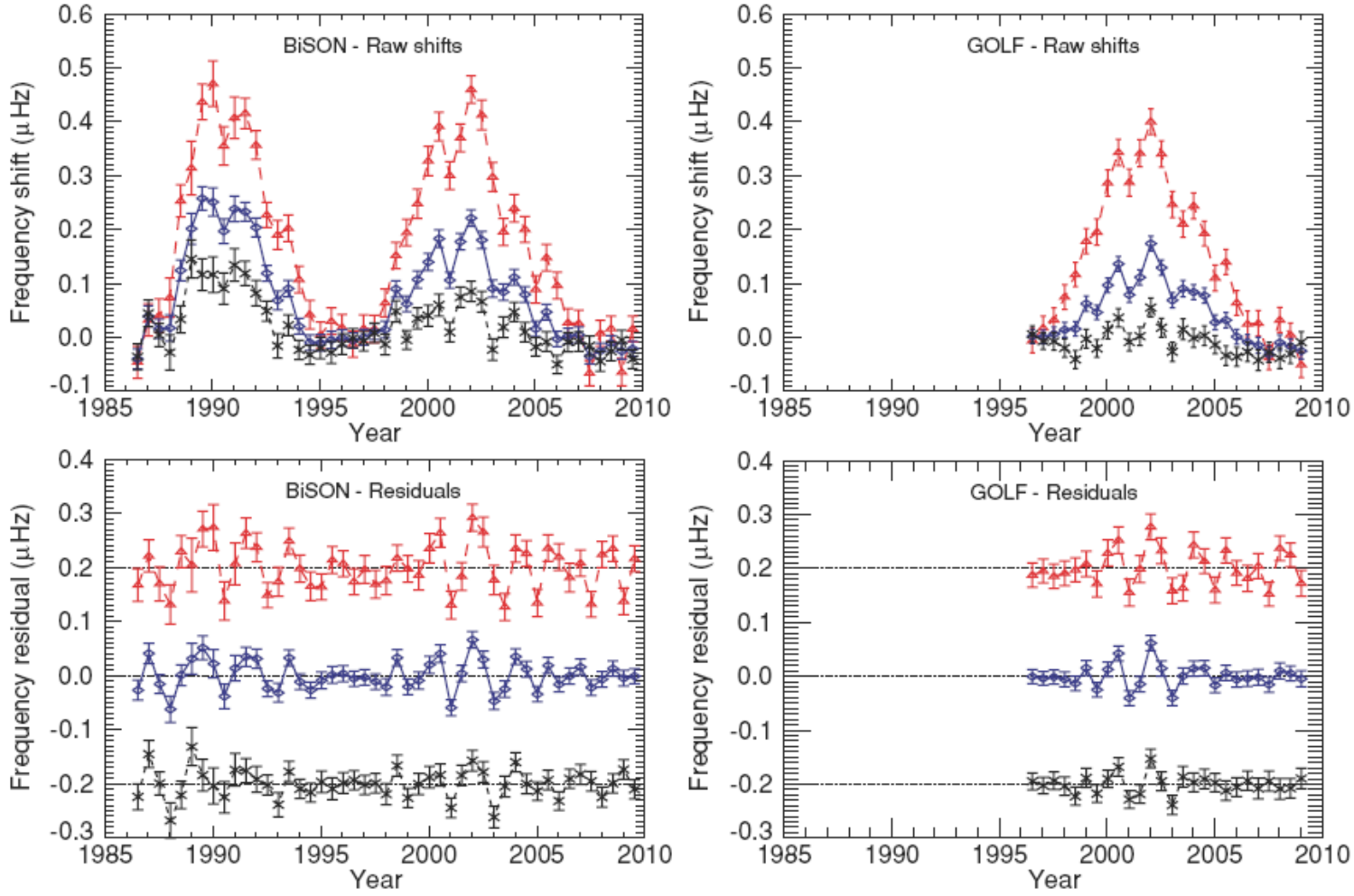
“Sounding” stellar activity cycles: Sun



Fletcher et al., 2010, ApJ, 718, L19

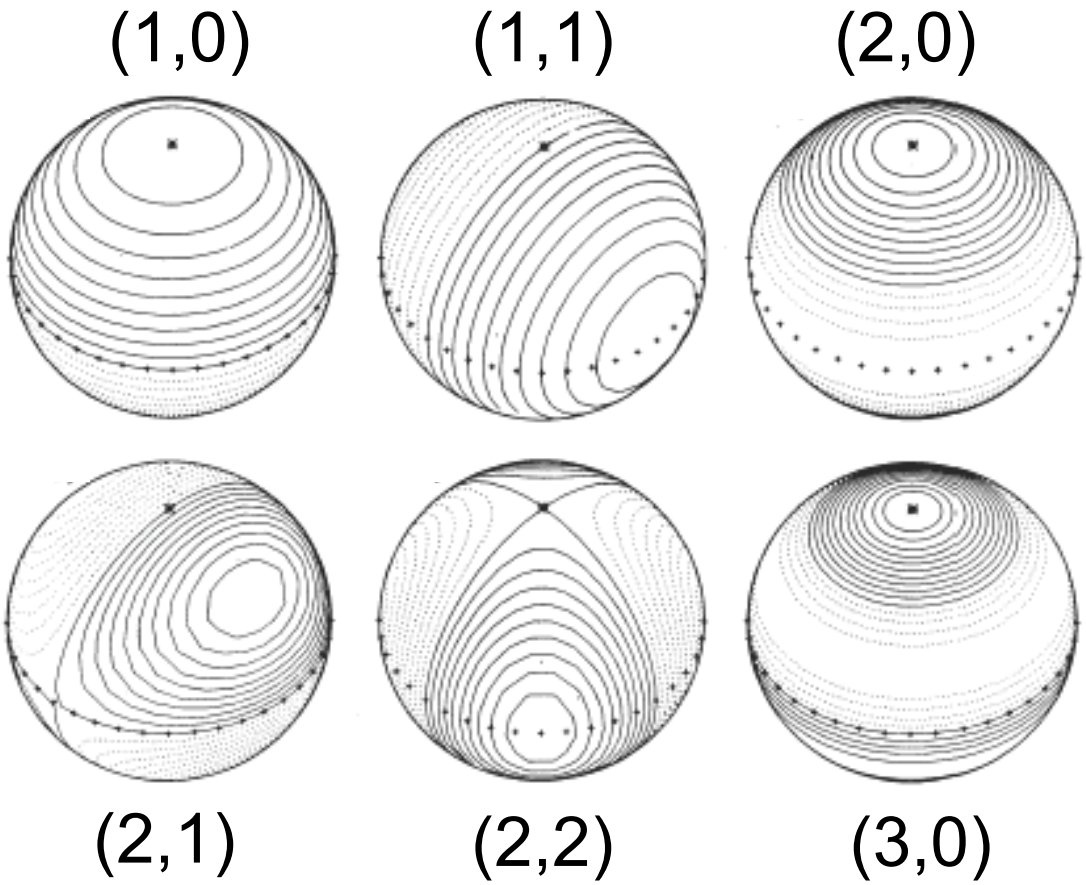
Inference: surface distribution of activity

sizes and phases of frequency shifts depend on (l, m)

- Activity distribution: non homogeneous, preferred bands of latitude
- Response of modes: depends on (l, m)

Inference: surface distribution of activity

sizes and phases of frequency shifts depend on (l, m)



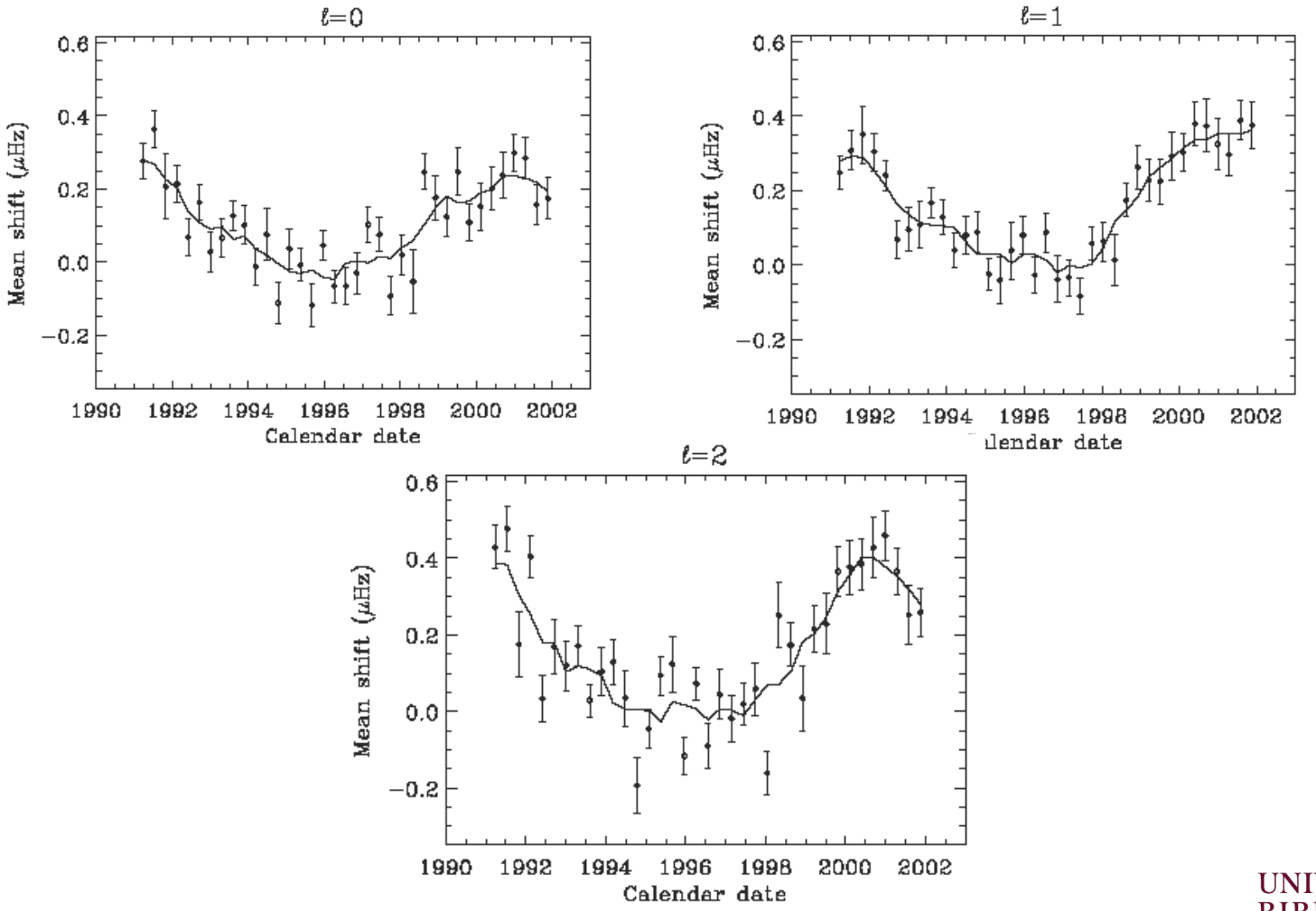
Inference: surface distribution of activity

sizes and phases of frequency shifts depend on (l, m)

- Inference on distribution:
  - From frequency shifts of different modes
  - From frequency asymmetry of components of non-radial modes

Inference: surface distribution of activity

sizes and phases of frequency shifts depend on (l, m)



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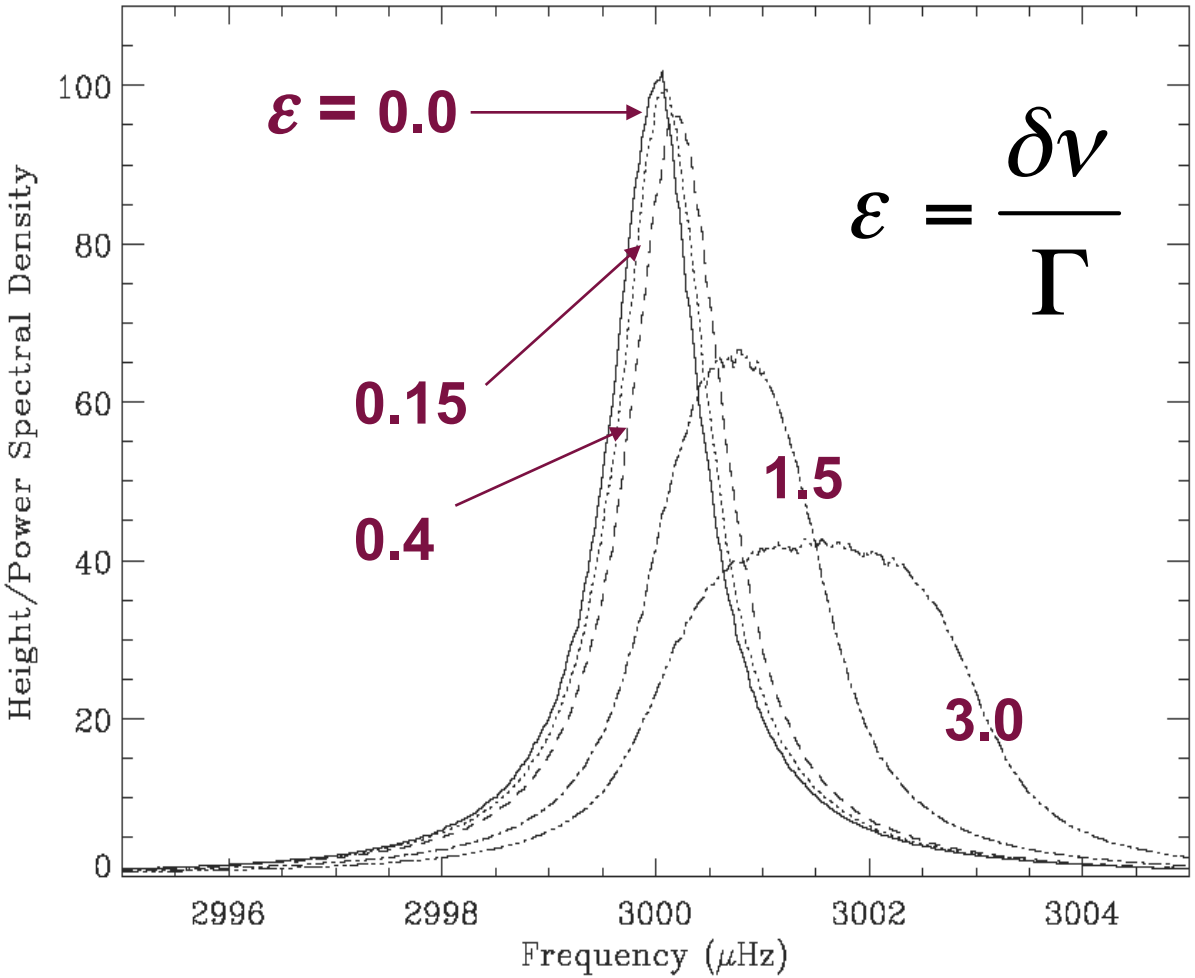
Stellar activity squashes mode peaks!



See Chaplin et al., 2008, MNRAS, 384, 1668

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Testing the boundaries

- Ensure robust inference:
  - Demands on analysis and theory
  - What information can we extract reliably from our data?
  - What diagnostics are possible, when are they reliable, and how can they be optimized?

Testing the boundaries

- Hare and hounds exercises
  - AsteroFLAG group
- Or should it be “cat and mouse”?

Kepler Asteroseismic Science Consortium (KASC)

WG #1: 160 members and counting…

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