Overveiw of Observational Asterosiesmology

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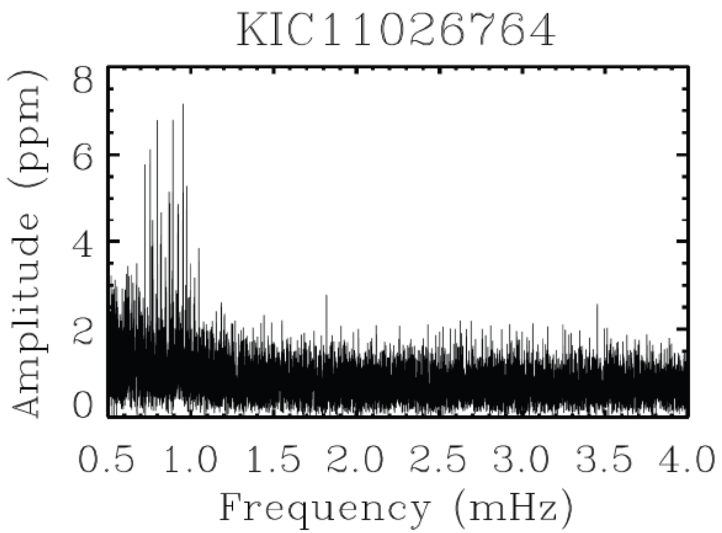
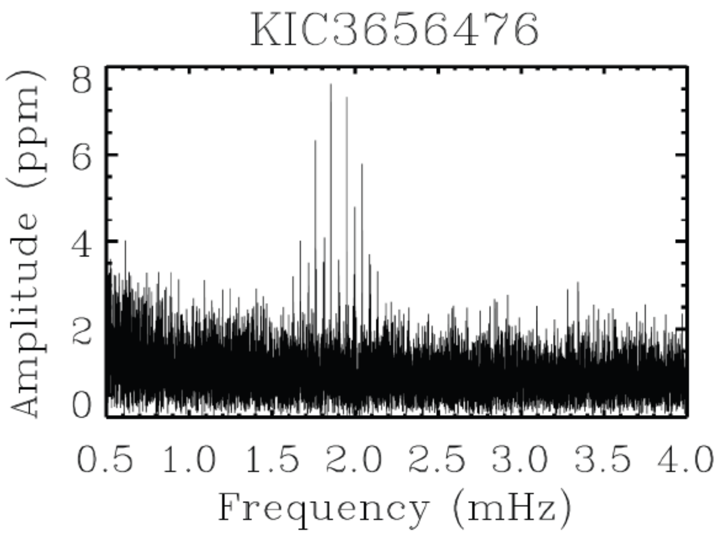
Observational Asteroseismology: Observables

- Oscillation frequencies and frequency differences/ratios/splittings
- Oscillation mode identification (degree, order and mode type; *g*/*p*/*f*, *mixed*)
- Oscillation mode properties (amplitude, amplitude ratios, phase, phase differences, life time, …)
- Changes (short term and long term) in mode parameters (frequencies, amplitudes, …)

Requirements for Observational Asteroseismology:
High-precision time series photometry with high duty cycle





$$data(t) = noise(t) + \sum_{i=1}^{n} a_i \cdot \sin(2\pi \cdot f_i \cdot t - \phi_i)$$

Following Montgomery and D. O'Donoghue, 1999

$$\sigma(a) = \sqrt{\frac{2}{\pi}} \langle A_{Noise}(\nu) \rangle = \sqrt{\frac{\langle P_{Noise}(\nu) \rangle}{2}} \approx 0.80 \cdot \langle A_{Noise}(\nu) \rangle$$

$$\sigma(\phi) = \frac{\sigma(a)}{a}$$

$$\sigma(f) = \sqrt{\frac{3}{\pi^2}} \frac{1}{T} \cdot \sigma(\phi)$$

$$\sigma(f) = \frac{\sqrt{3}}{\pi \cdot T} \frac{\sigma(a)}{a} = \sqrt{\frac{6}{\pi^3}} \frac{\langle A_{Noise}(\nu) \rangle}{a \cdot T} \approx 0.44 \cdot \frac{\langle A_{Noise}(\nu) \rangle}{a \cdot T}$$

$$\langle A_{Noise}(\nu) \rangle = \sqrt{\frac{\pi}{N}} \cdot \sigma_{Noise} \propto T^{-1/2}$$

Following Montgomery and D. O'Donoghue, 1999

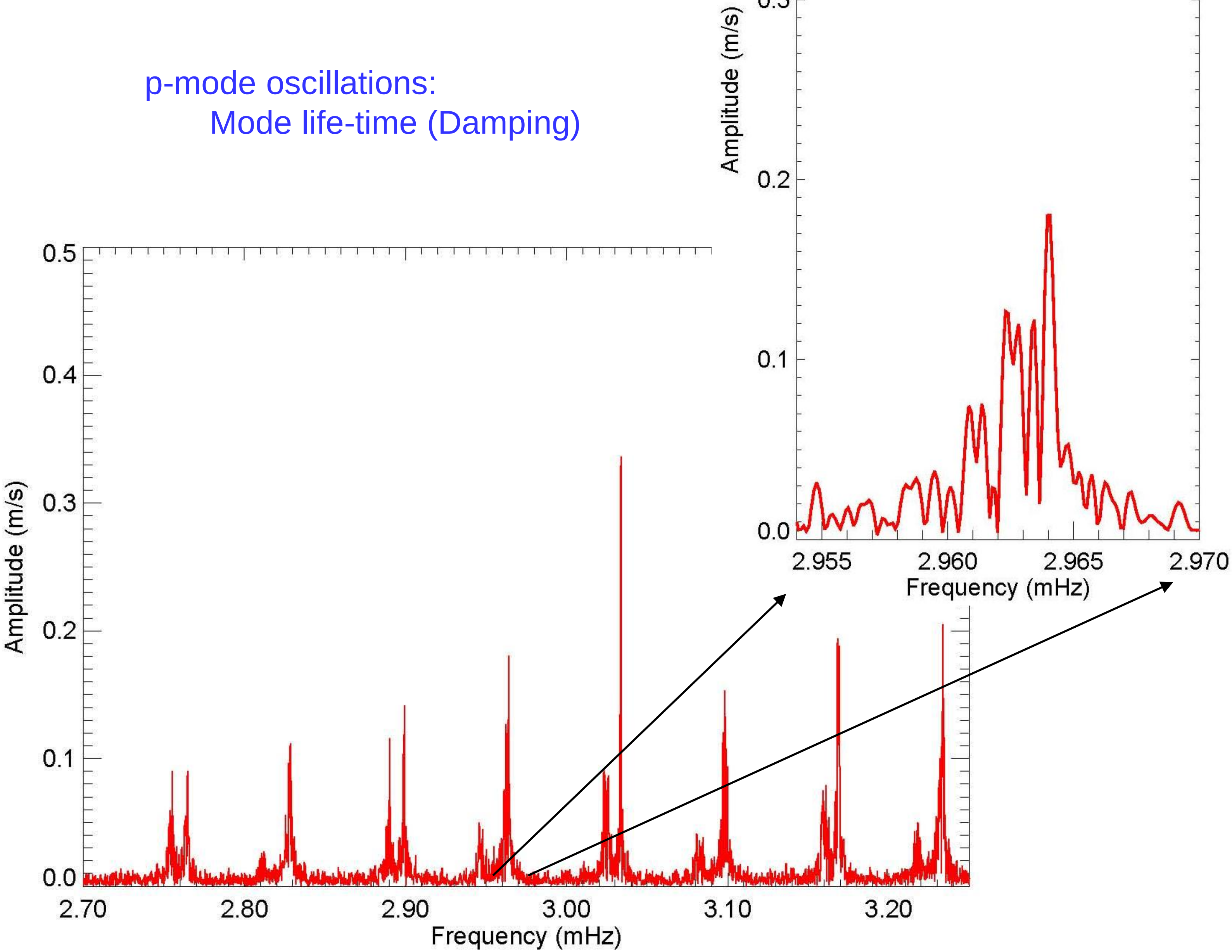
$$\sigma(a) \propto \sigma_{Noise} \cdot T^{-1/2}$$

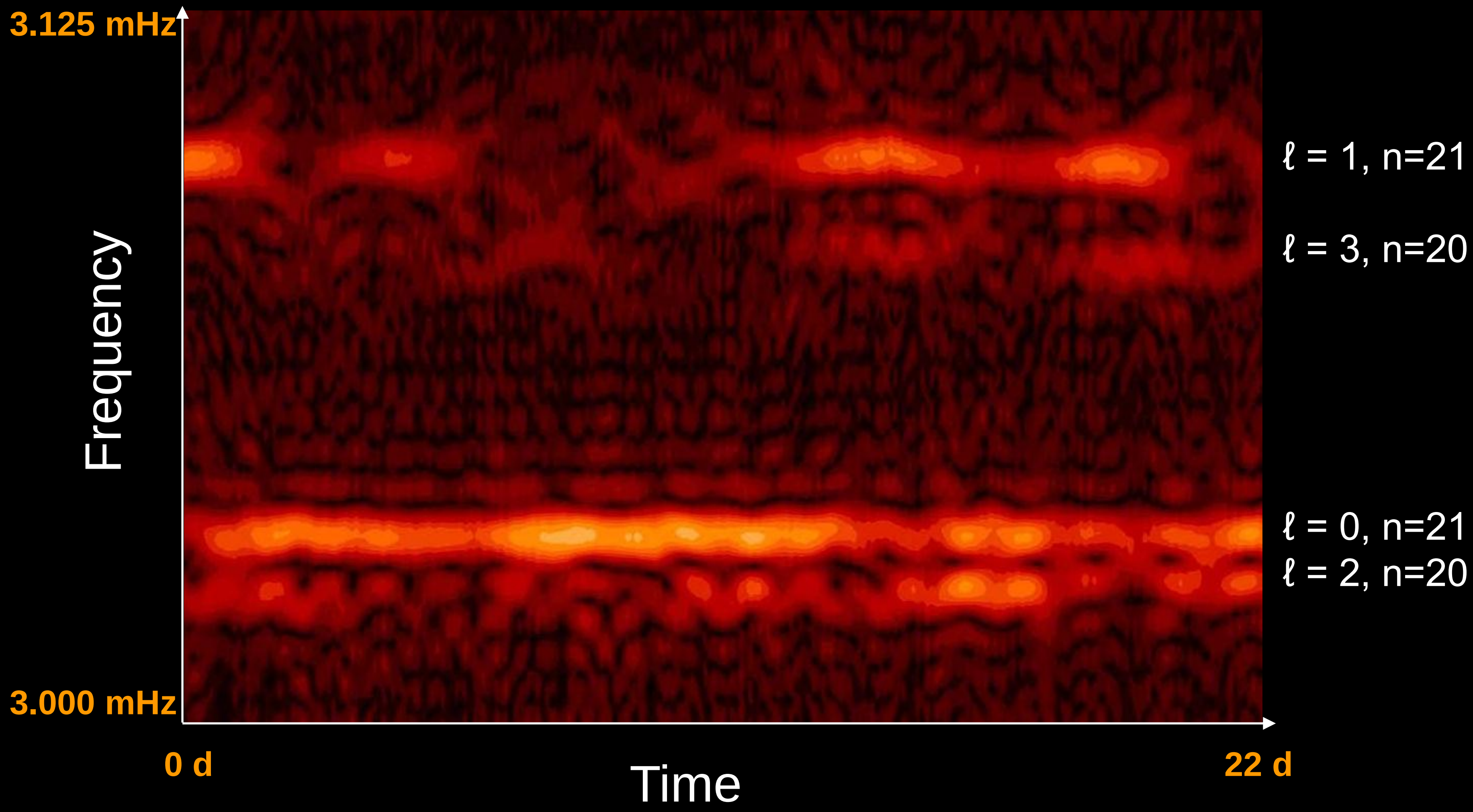
$$\sigma(\phi) \propto \sigma_{Noise} \cdot a^{-1} \cdot T^{-1/2}$$

$$\sigma(f) \propto \sigma_{Noise} \cdot a^{-1} \cdot T^{-3/2}$$

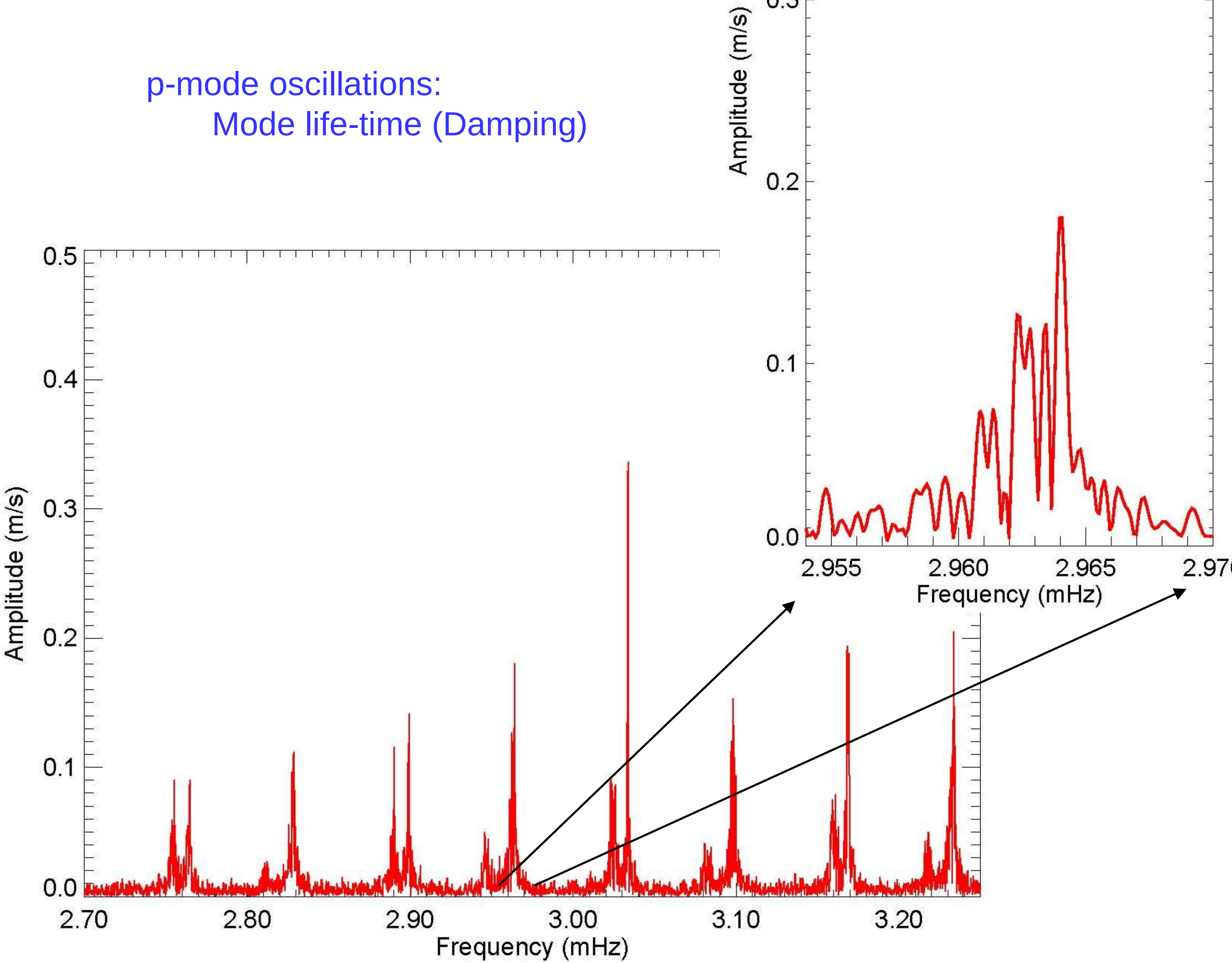
$$\delta f = T^{-1}$$

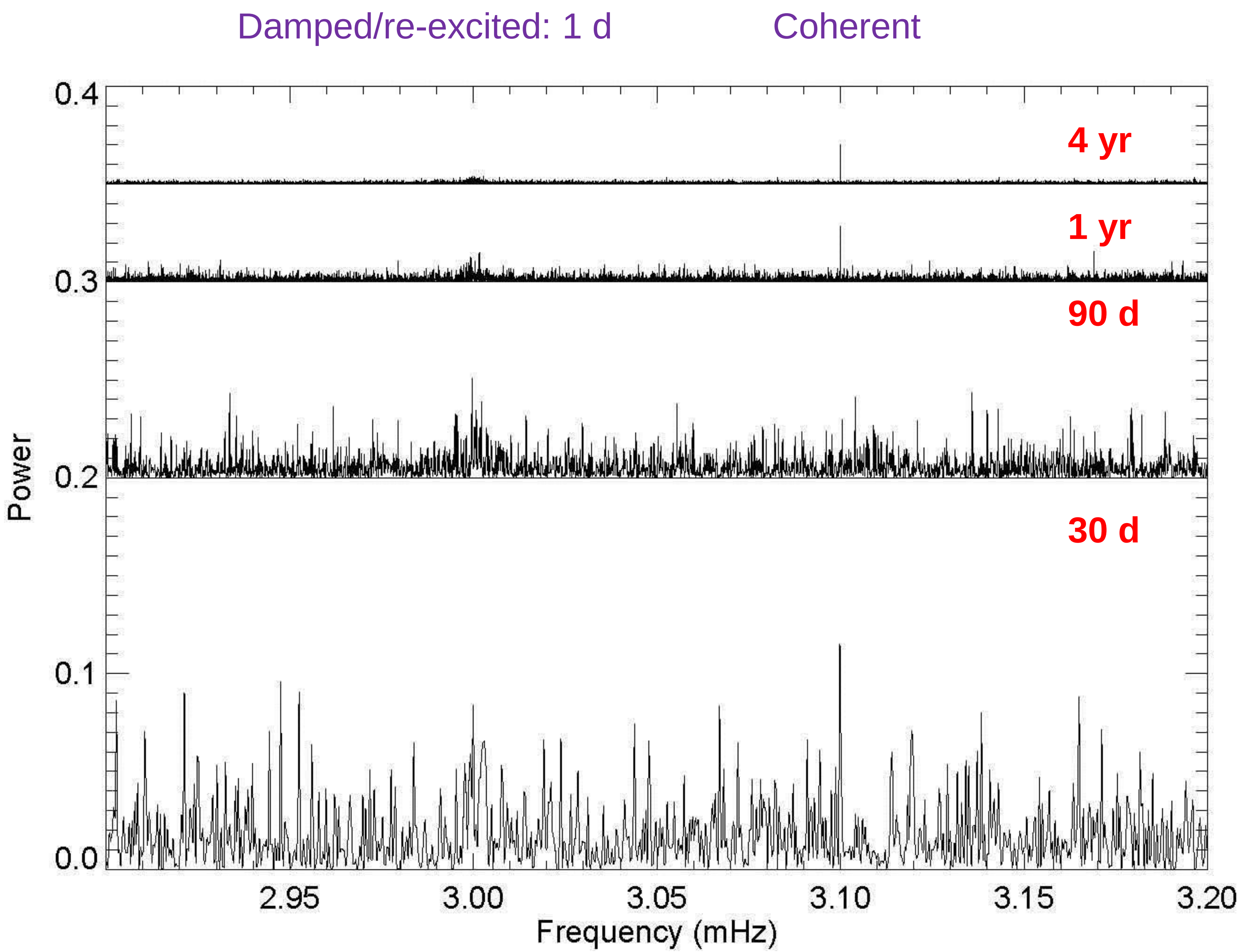
p-mode oscillations:
Mode life-time (Damping)



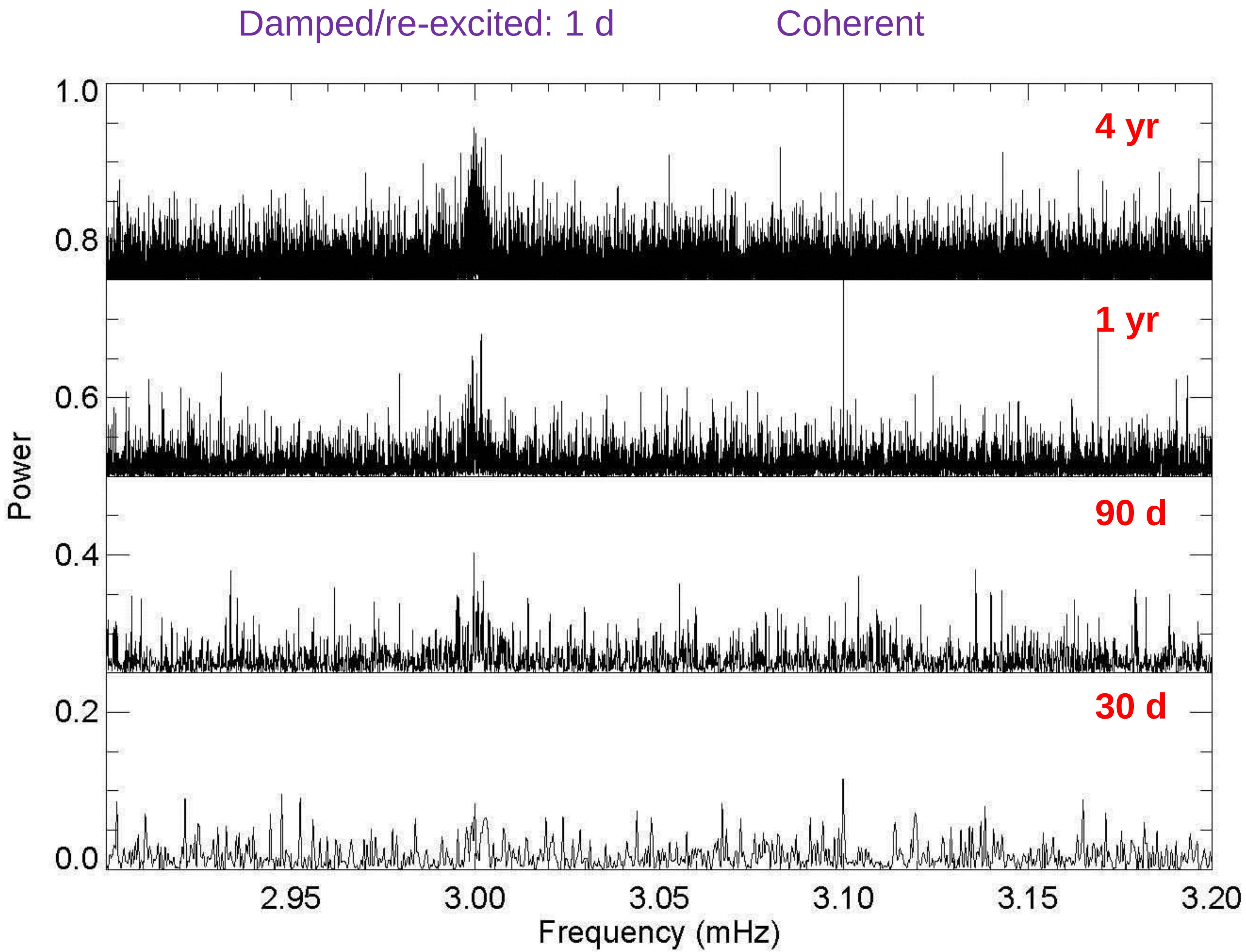

3.125 mHz
3.000 mHz
Frequency
0 d
22 d
Time
ℓ = 1, n=21
ℓ = 3, n=20
ℓ = 0, n=21
ℓ = 2, n=20

p-mode oscillations:
Mode life-time (Damping)

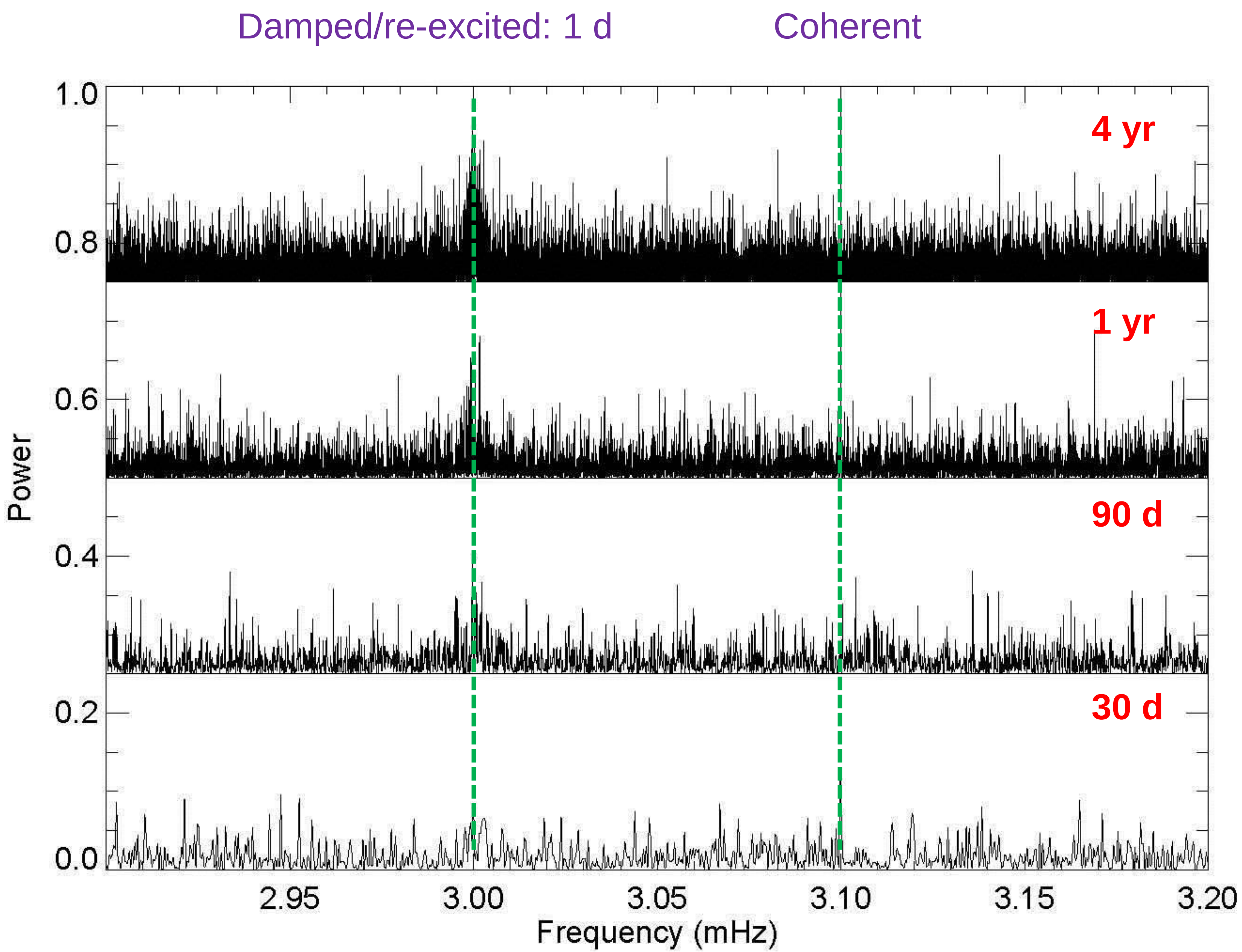


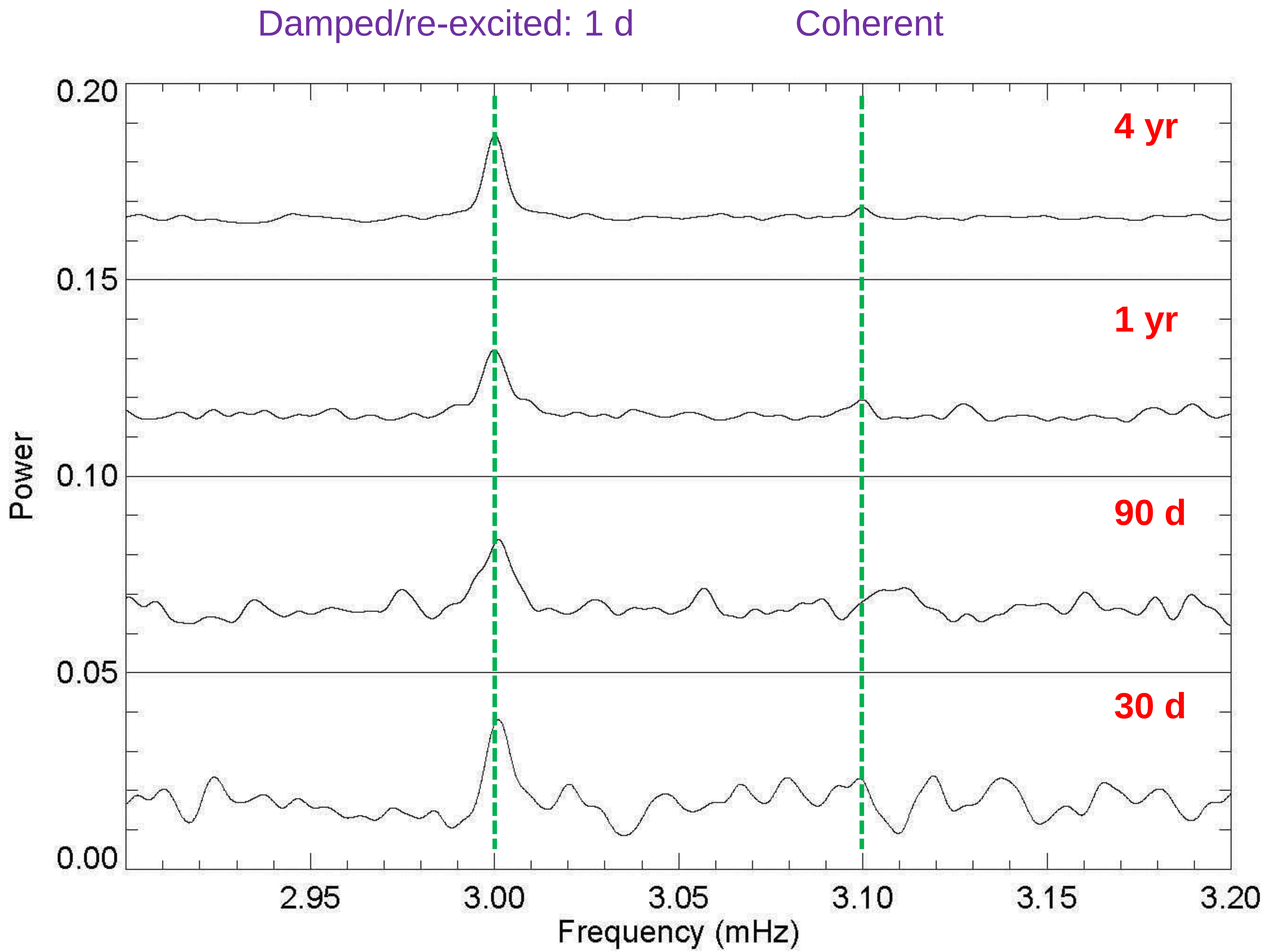


Damped/re-excited: 1 d
Coherent
4 yr
1 yr
90 d
30 d
0.4
0.3
0.2
0.1
0.0
Power
2.95
3.00
3.05
3.10
3.15
3.20
Frequency (mHz)

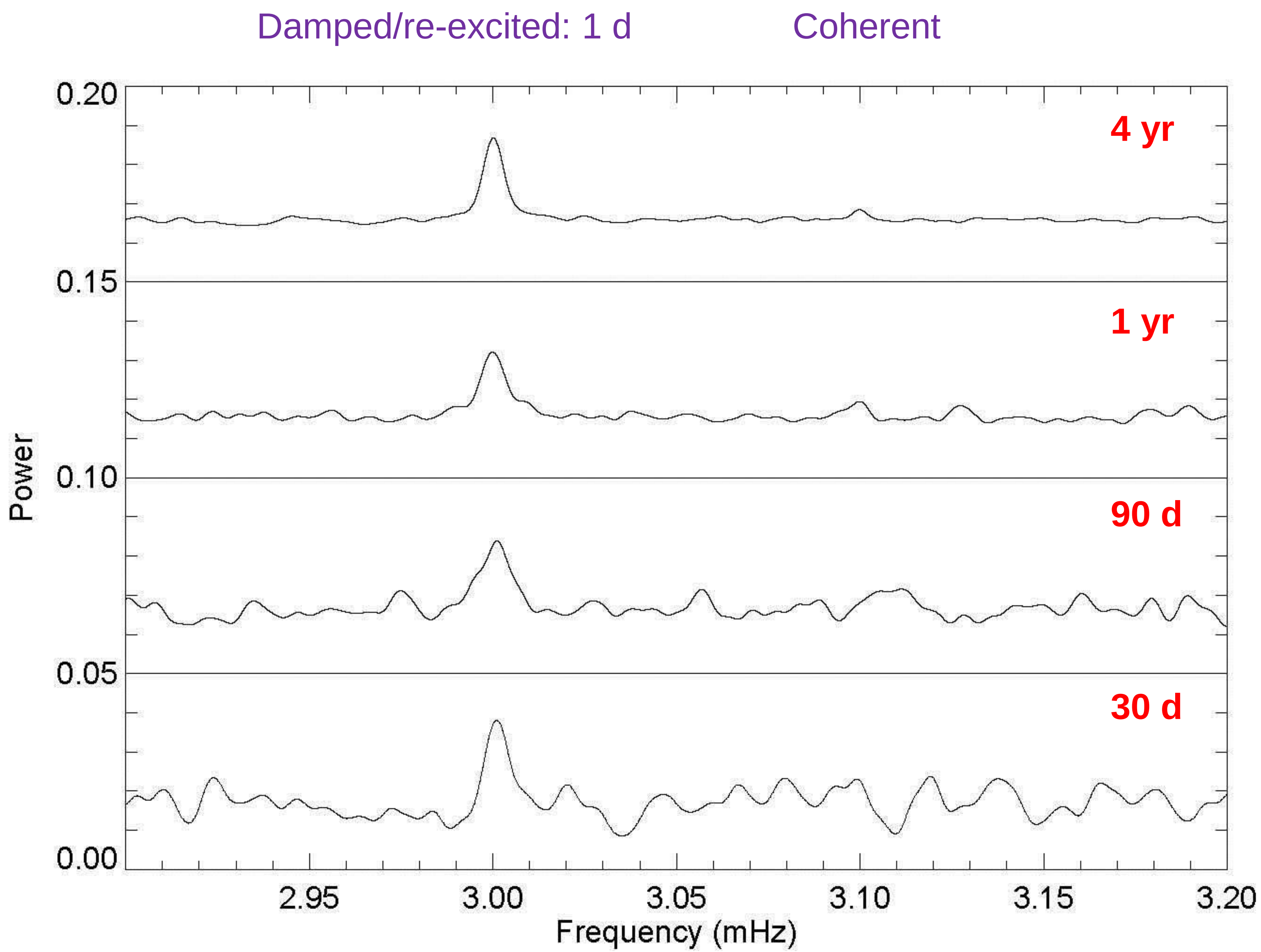


Damped/re-excited: 1 d
Coherent
4 yr
1 yr
90 d
30 d
1.0
0.8
0.6
0.4
0.2
0.0
Power
2.95
3.00
3.05
3.10
3.15
3.20
Frequency (mHz)


Damped/re-excited: 1 d
Coherent
4 yr
1 yr
90 d
30 d
Power
1.0
0.8
0.6
0.4
0.2
0.0
2.95
3.00
3.05
3.10
3.15
3.20
Frequency (mHz)



Damped/re-excited: 1 d
Coherent
4 yr
1 yr
90 d
30 d
Power
0.20
0.15
0.10
0.05
0.00
2.95
3.00
3.05
3.10
3.15
3.20
Frequency (mHz)

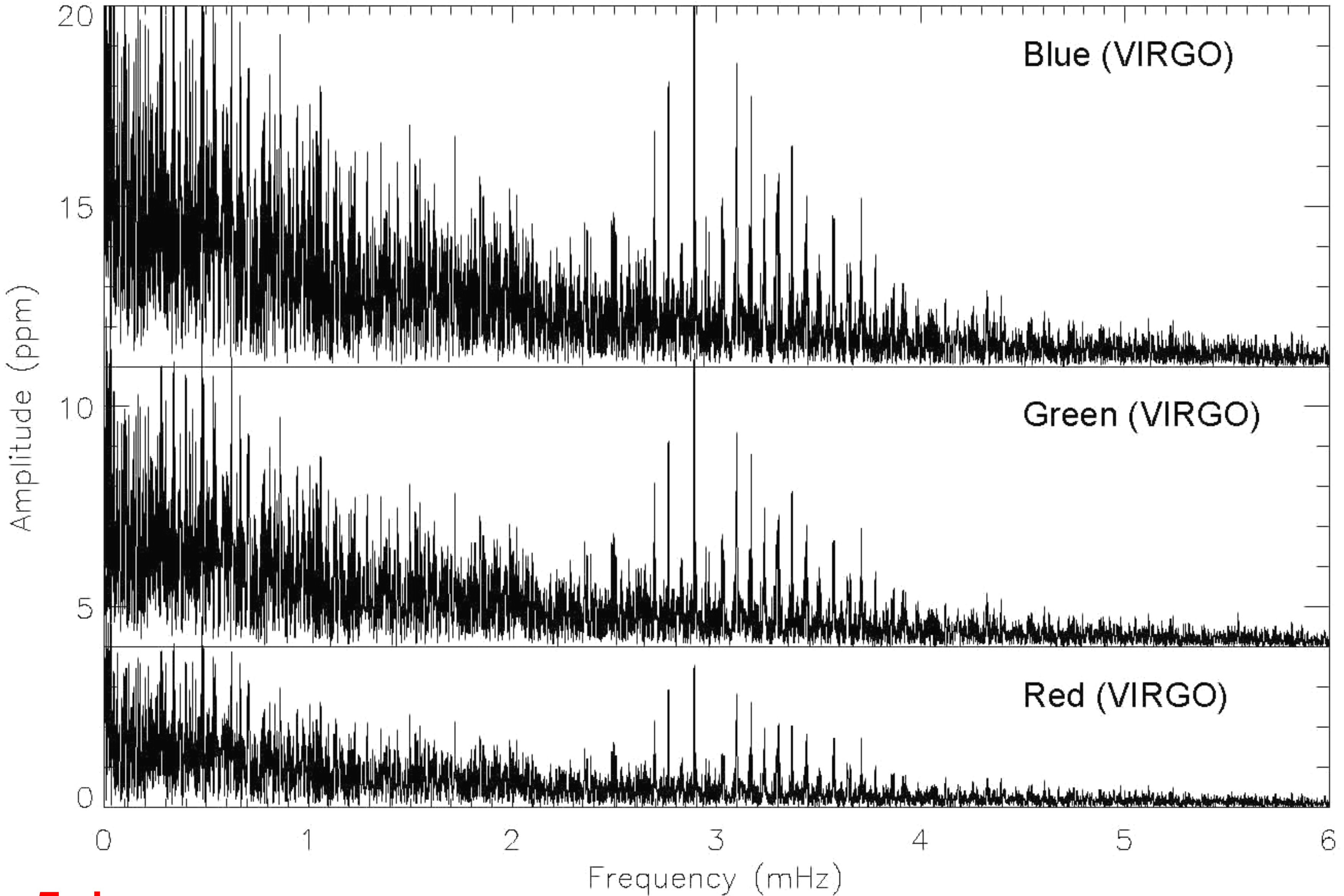


Damped/re-excited: 1 d
Coherent
4 yr
1 yr
90 d
30 d
0.20
0.15
0.10
0.05
0.00
Power
2.95
3.00
3.05
3.10
3.15
3.20
Frequency (mHz)

For damped and re-excited oscillations

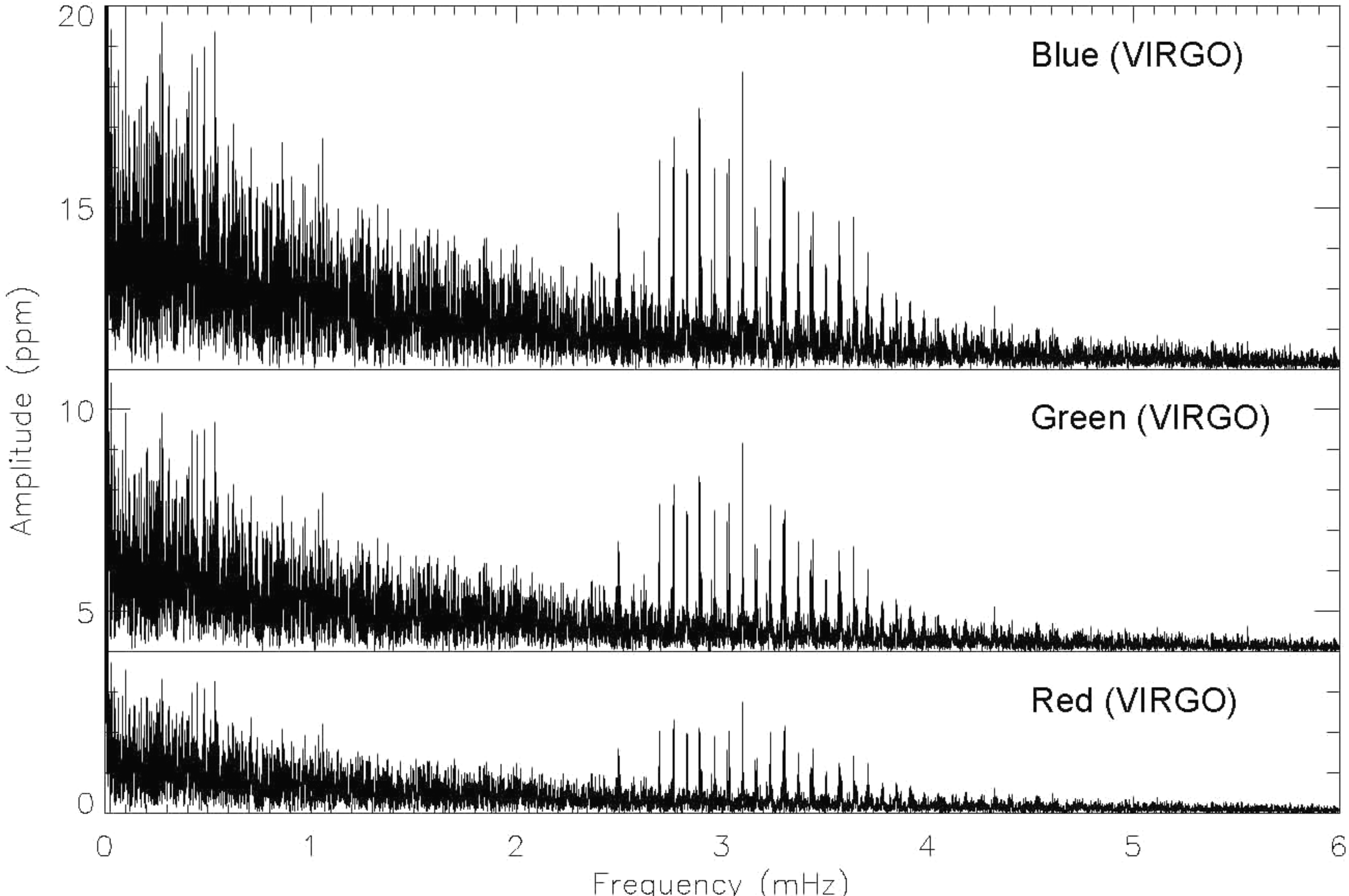
$$\sigma(a) \propto \sigma_{Noise} \cdot T^{-1/2}$$

$$\sigma(f) \propto \sigma_{Noise} \cdot a^{-1} \cdot T^{-1/2}$$



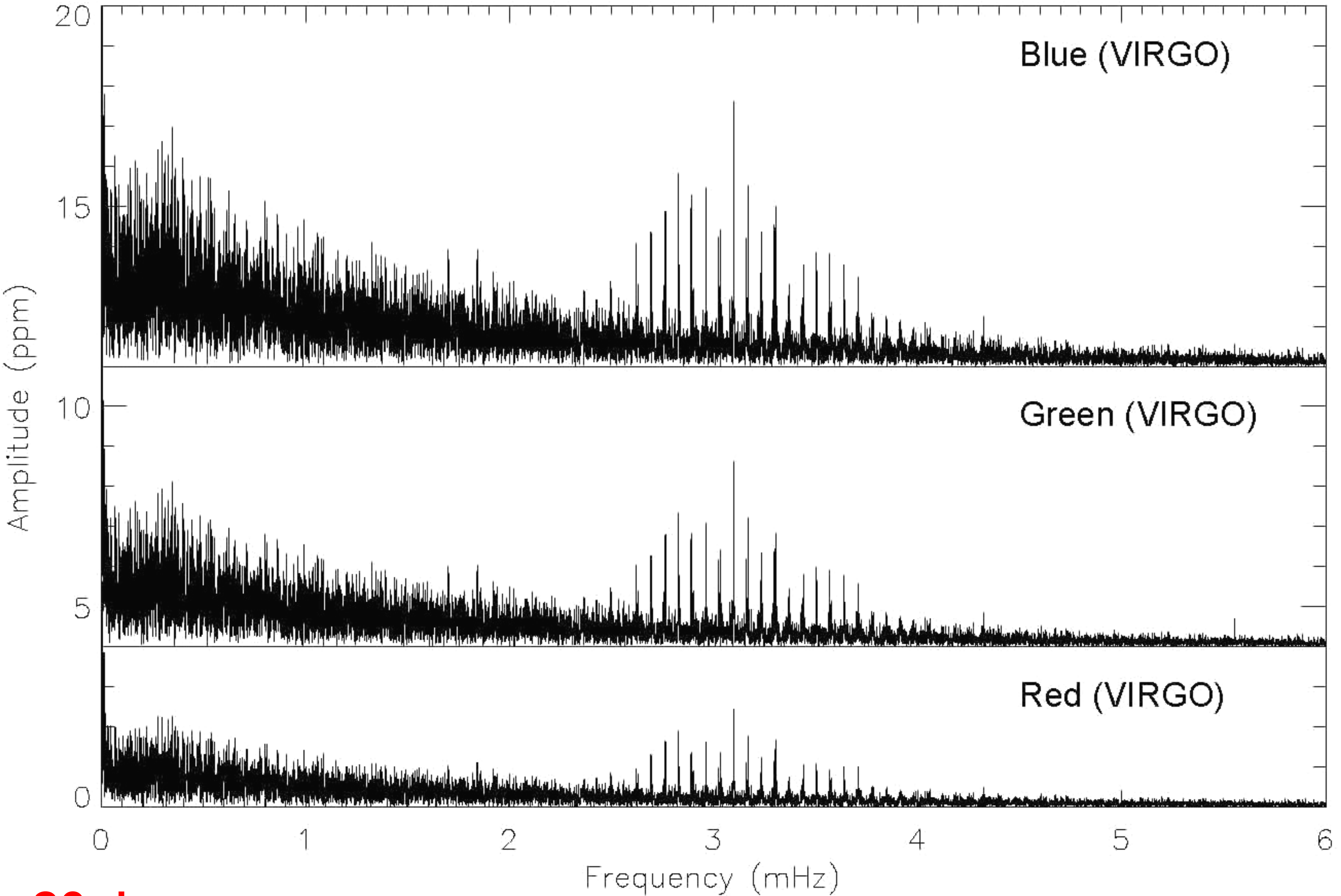
Blue (VIRGO)
Green (VIRGO)
Red (VIRGO)
20
15
10
5
0
Amplitude (ppm)
0
1
2
3
4
5
6
Frequency (mHz)

5 d

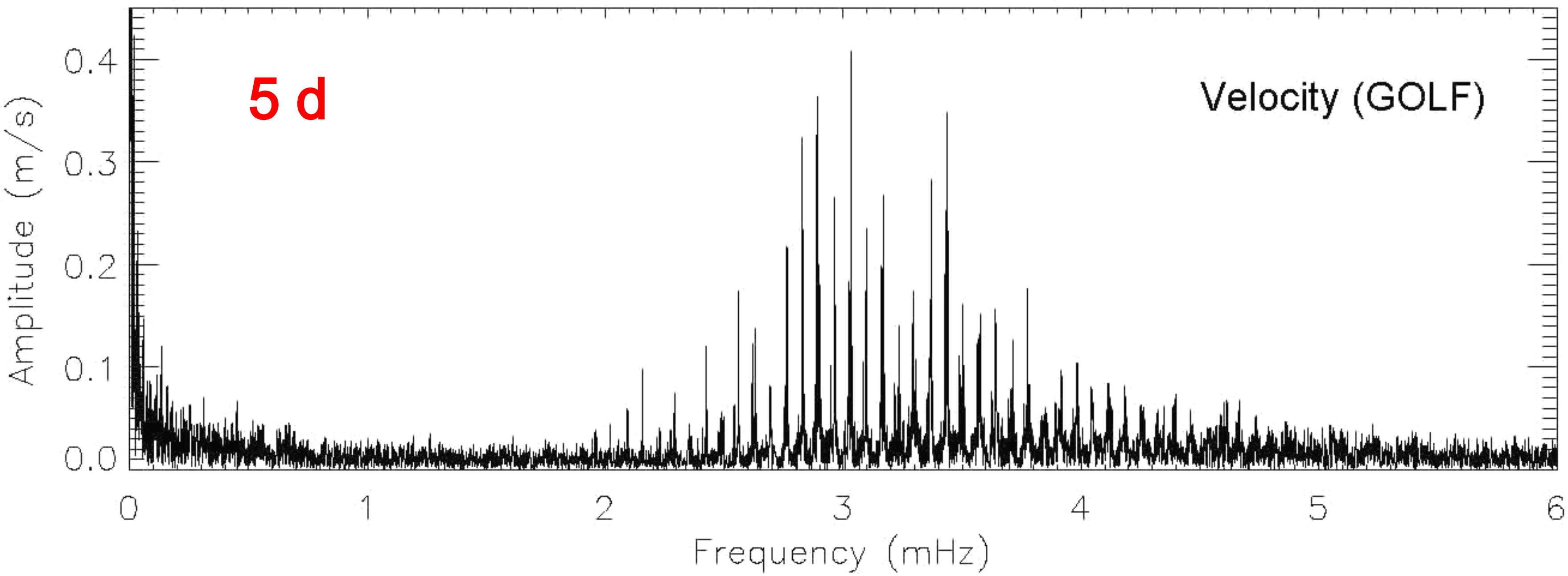


20
15
10
5
0
Amplitude (ppm)
Blue (VIRGO)
Green (VIRGO)
Red (VIRGO)
0
1
2
3
4
5
6
Frequency (mHz)

10 d

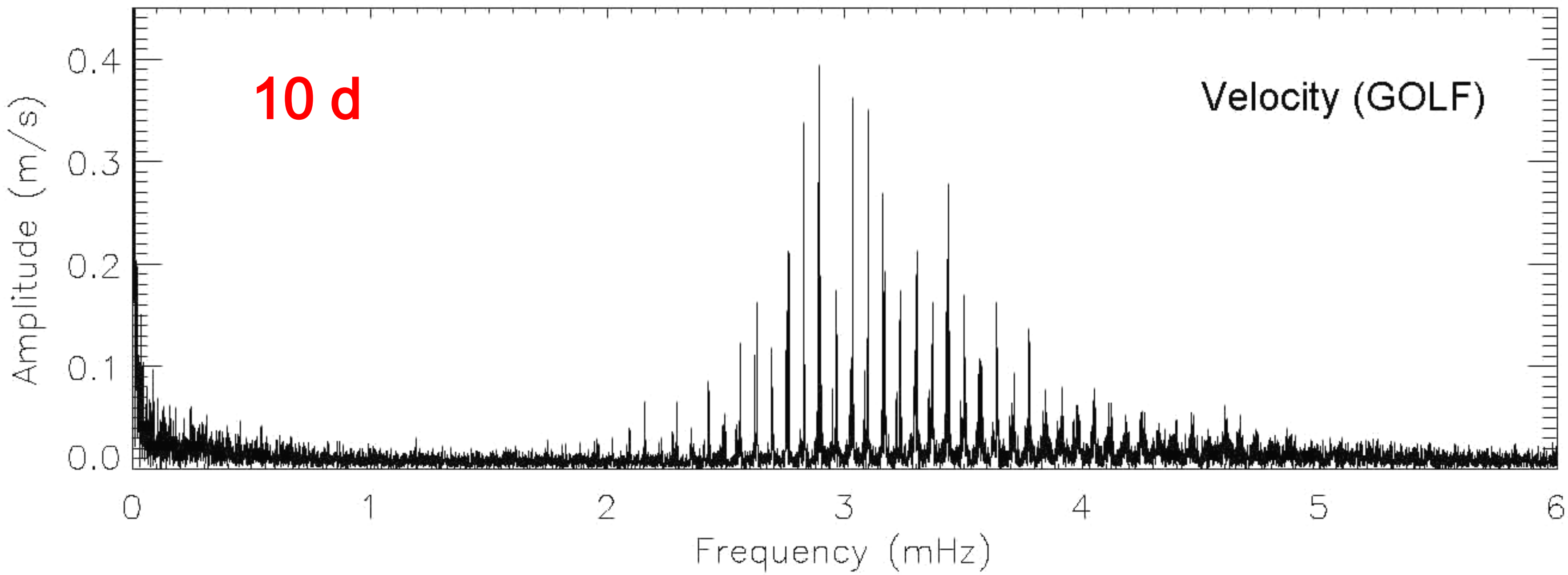

Blue (VIRGO)
Green (VIRGO)
Red (VIRGO)
Amplitude (ppm)
Frequency (mHz)
20
15
10
5
0
0
1
2
3
4
5
6

20 d



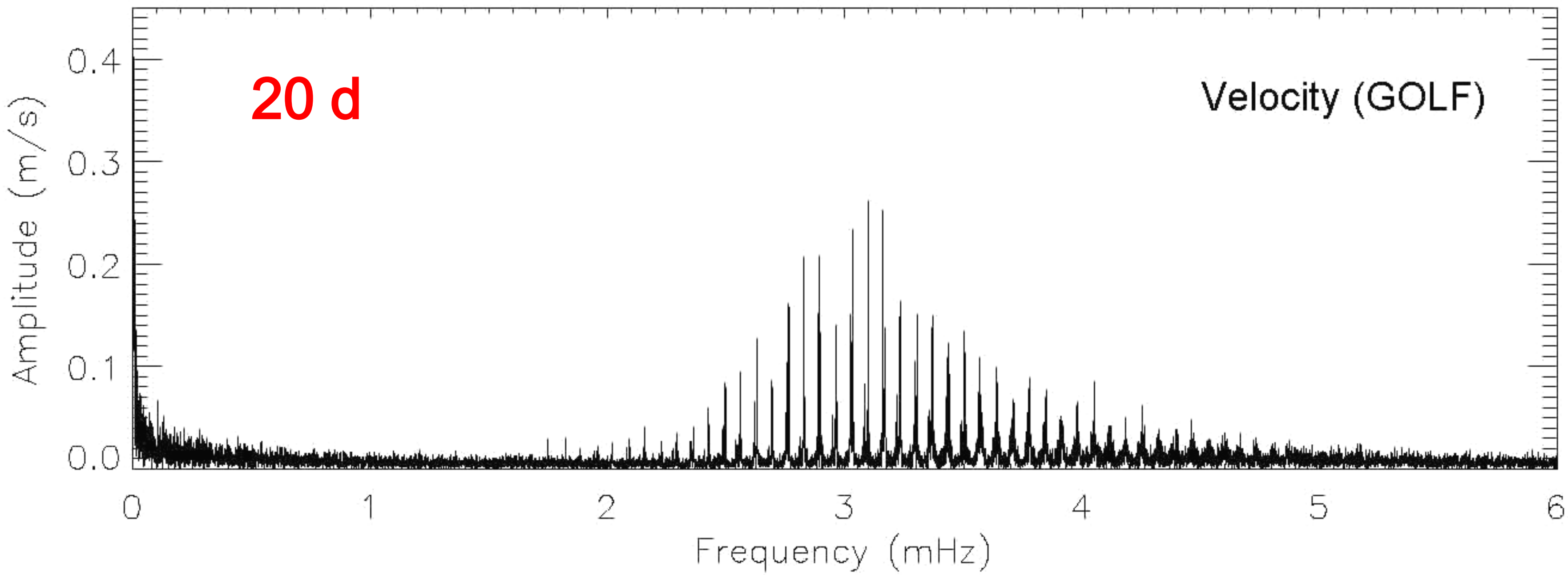
$$\sigma(a) \propto \sigma_{Noise} \cdot T^{-1/2}$$

$$\sigma(f) \propto \sigma_{Noise} \cdot a^{-1} \cdot T^{-1/2}$$



$$\sigma(a) \propto \sigma_{Noise} \cdot T^{-1/2}$$

$$\sigma(f) \propto \sigma_{Noise} \cdot a^{-1} \cdot T^{-1/2}$$



Reaching same accuracy for damped and re-excited oscillations:

OBT.T (intensity) / OBS-T (velocity) ≈ 12-15

… for coherent oscillations:

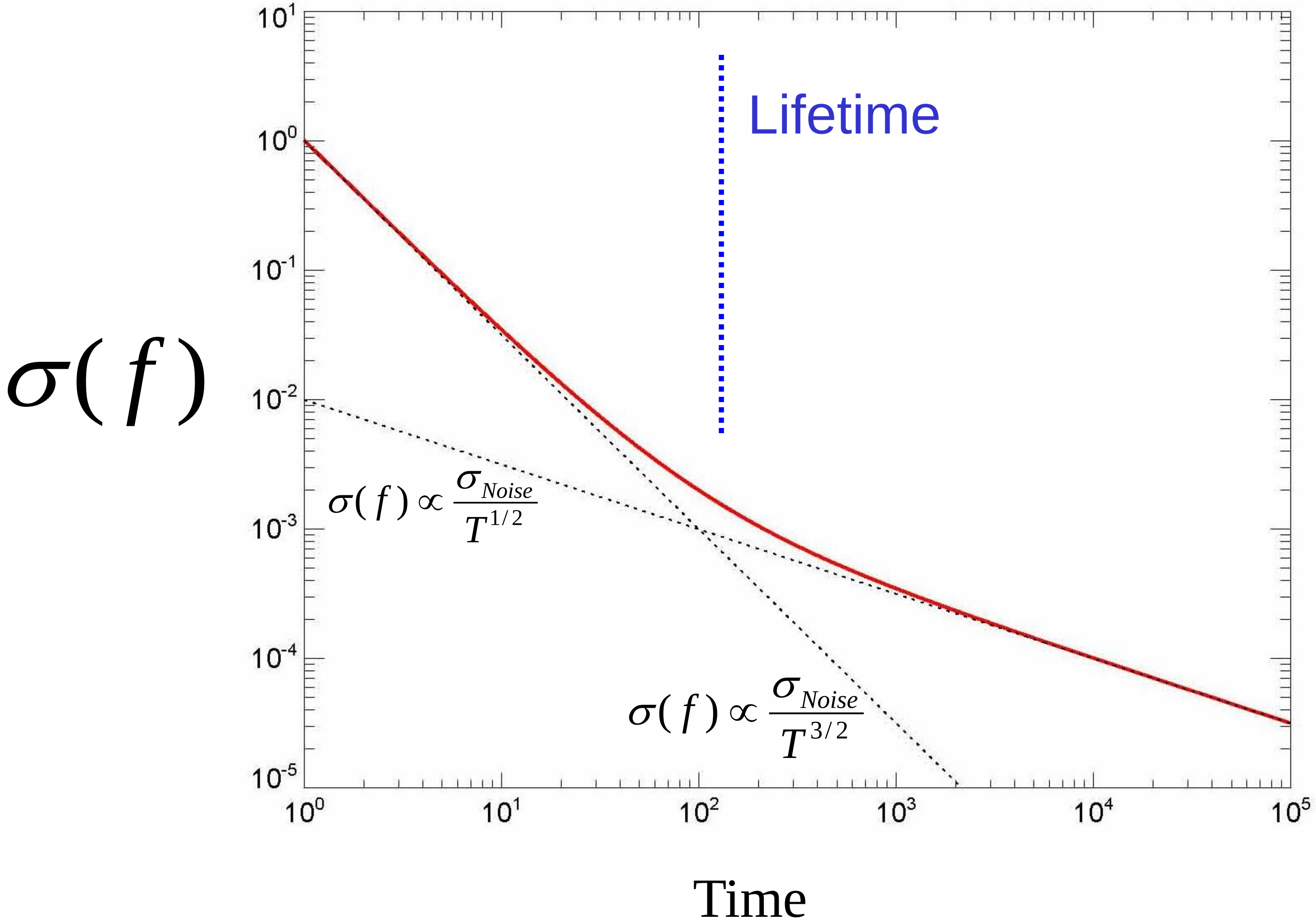
OBT.T (intensity) / OBS-T (velocity) ≈ 2-3

Coherent modes

$$\sigma(f) \propto \frac{\sigma_{Noise}}{T^{3/2}}$$

Damped and re-excited modes

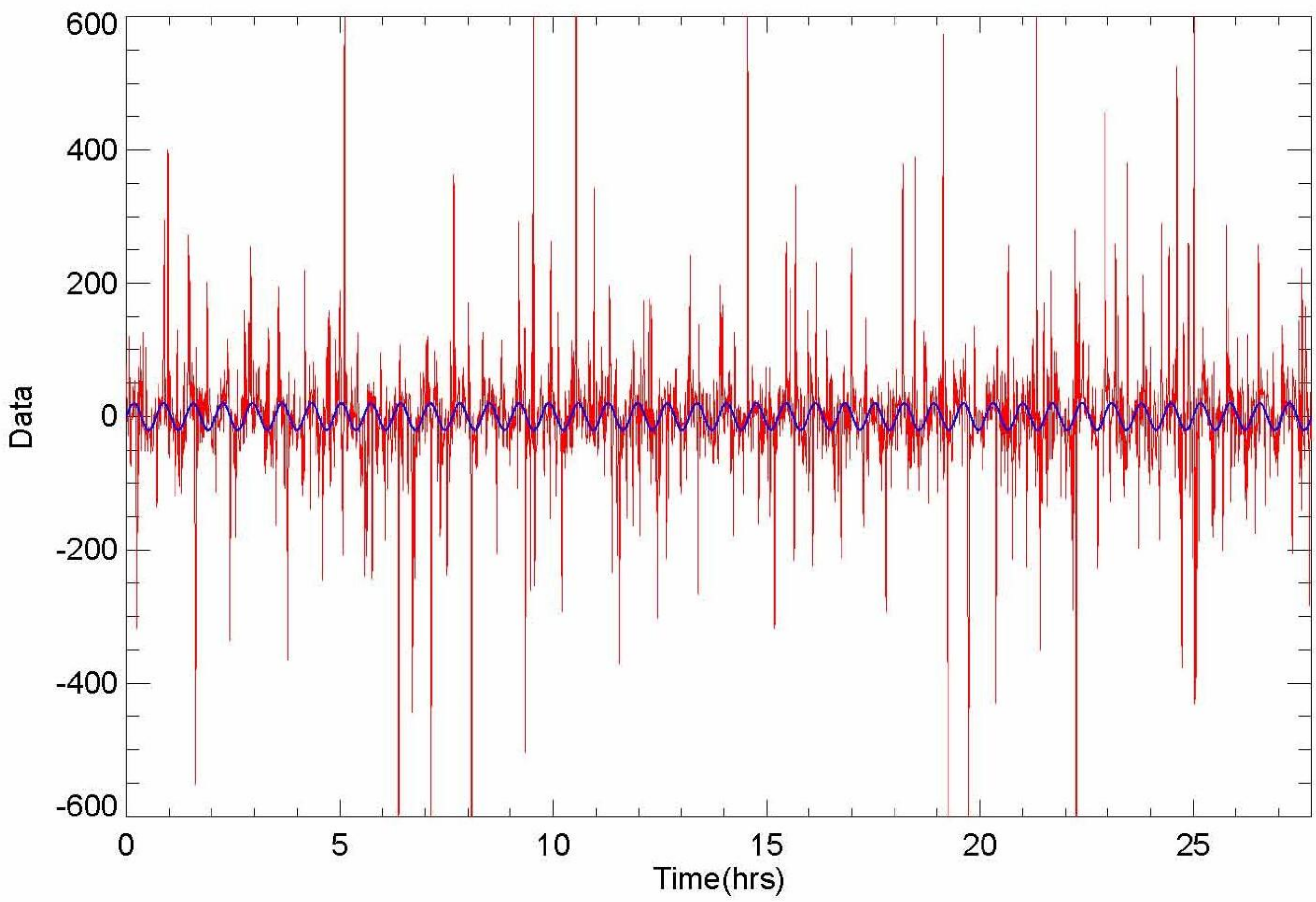
$$\sigma(f) \propto \frac{\sigma_{Noise}}{T^{1/2}}$$



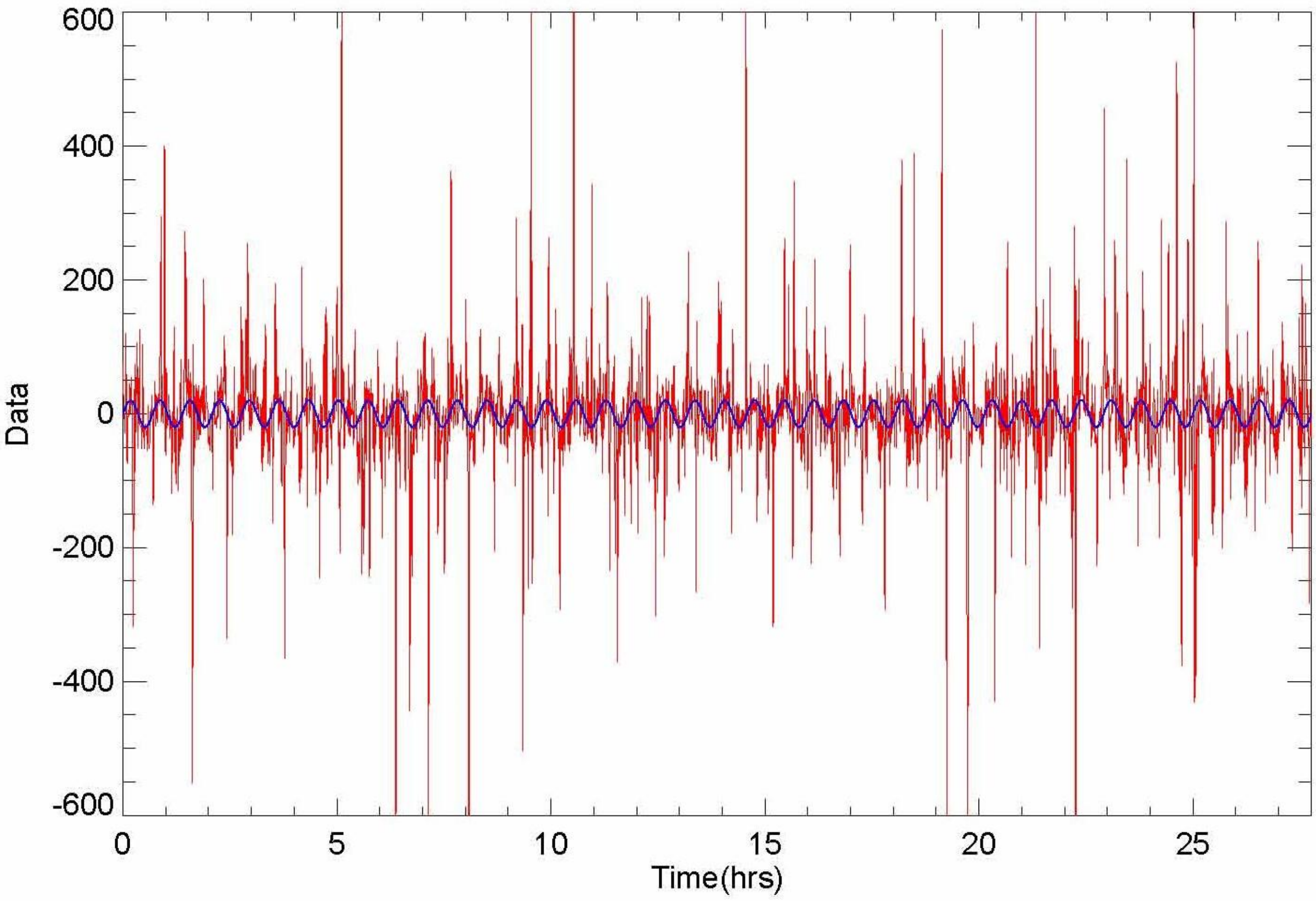
$\sigma(f)$
Lifetime
$\sigma(f) \propto \frac{\sigma_{Noise}}{T^{1/2}}$
$\sigma(f) \propto \frac{\sigma_{Noise}}{T^{3/2}}$
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
Time

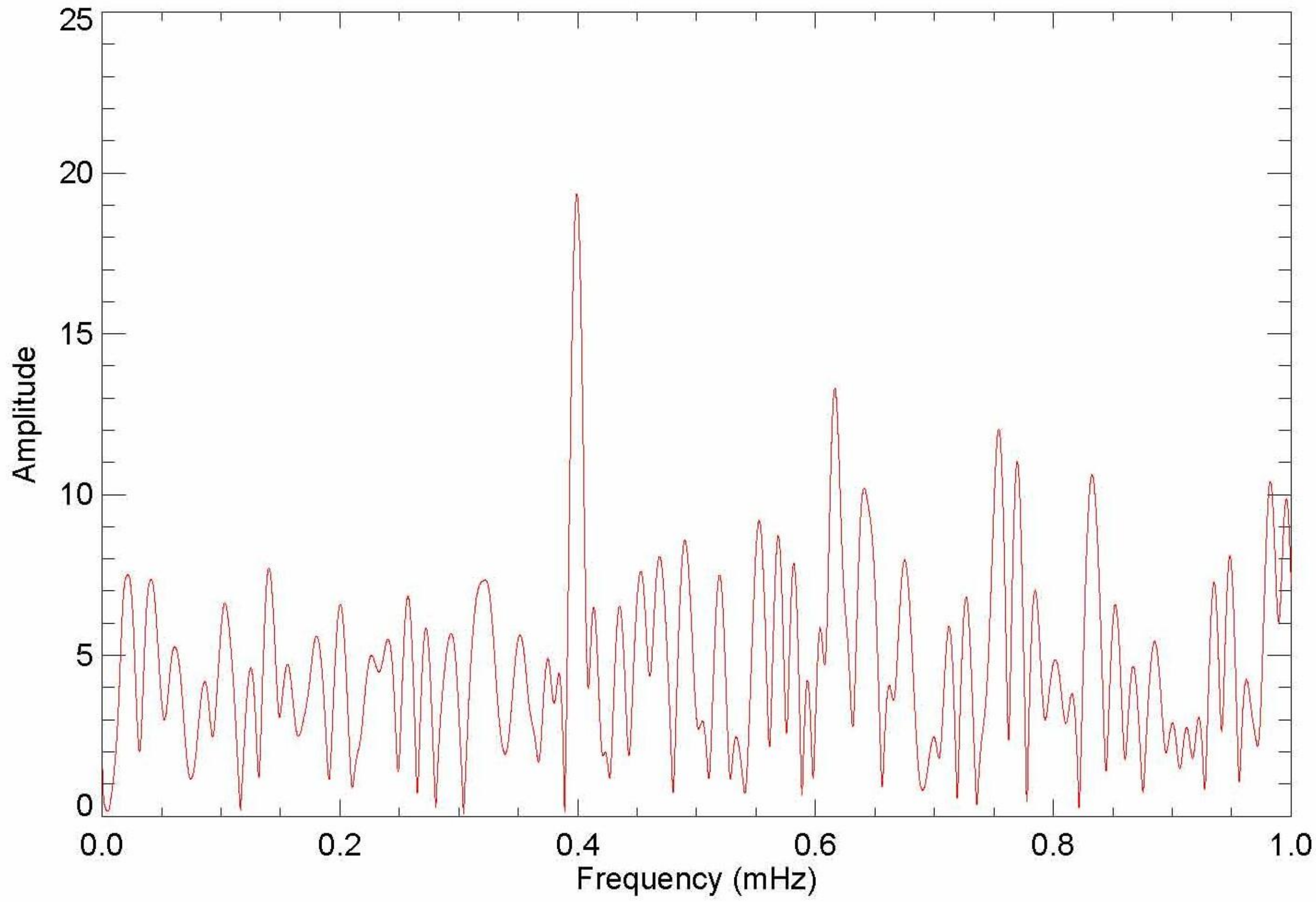
Variable noise level in the data series

Variable SNR

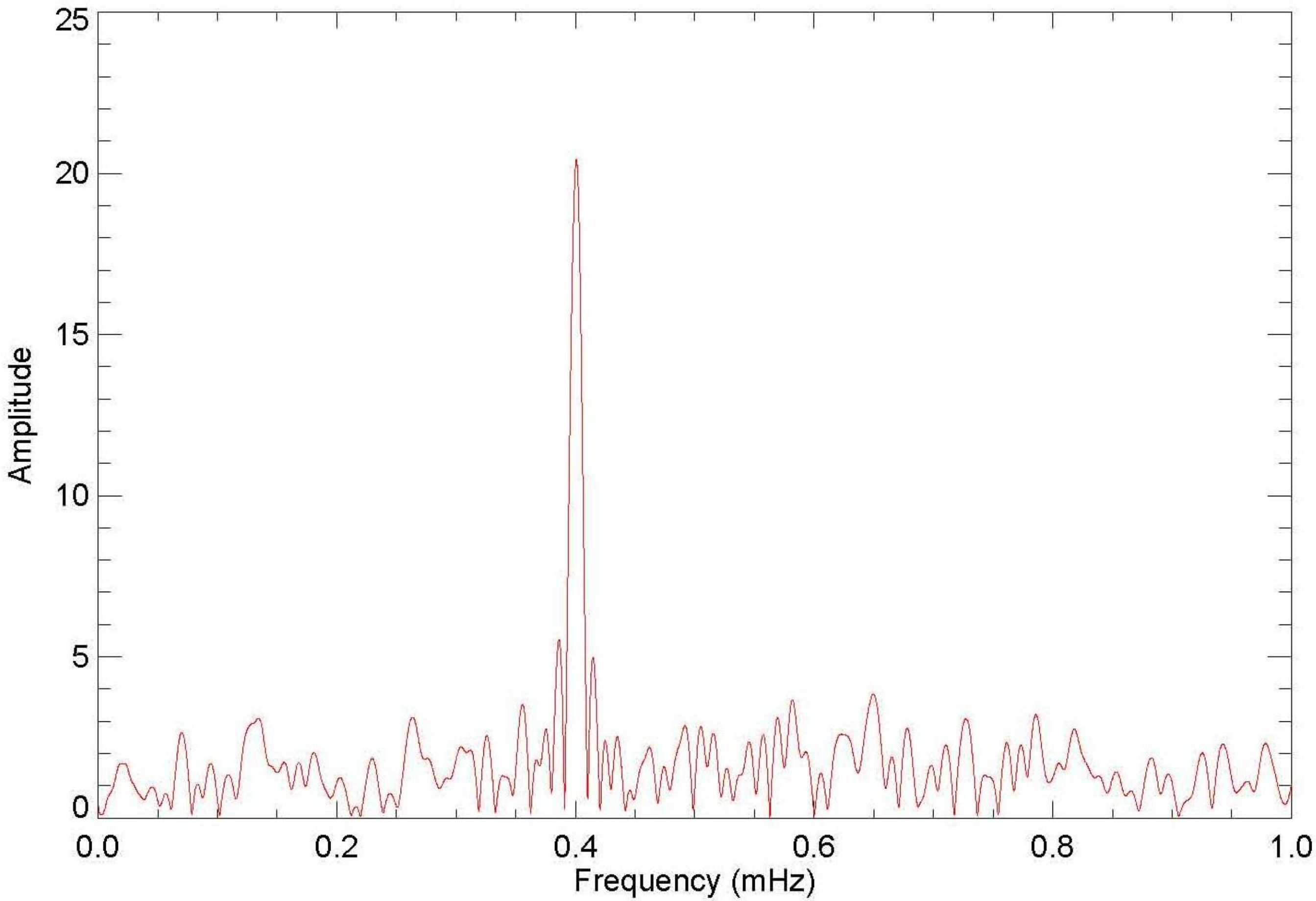


$$w_i = \sigma_i^{-2}$$

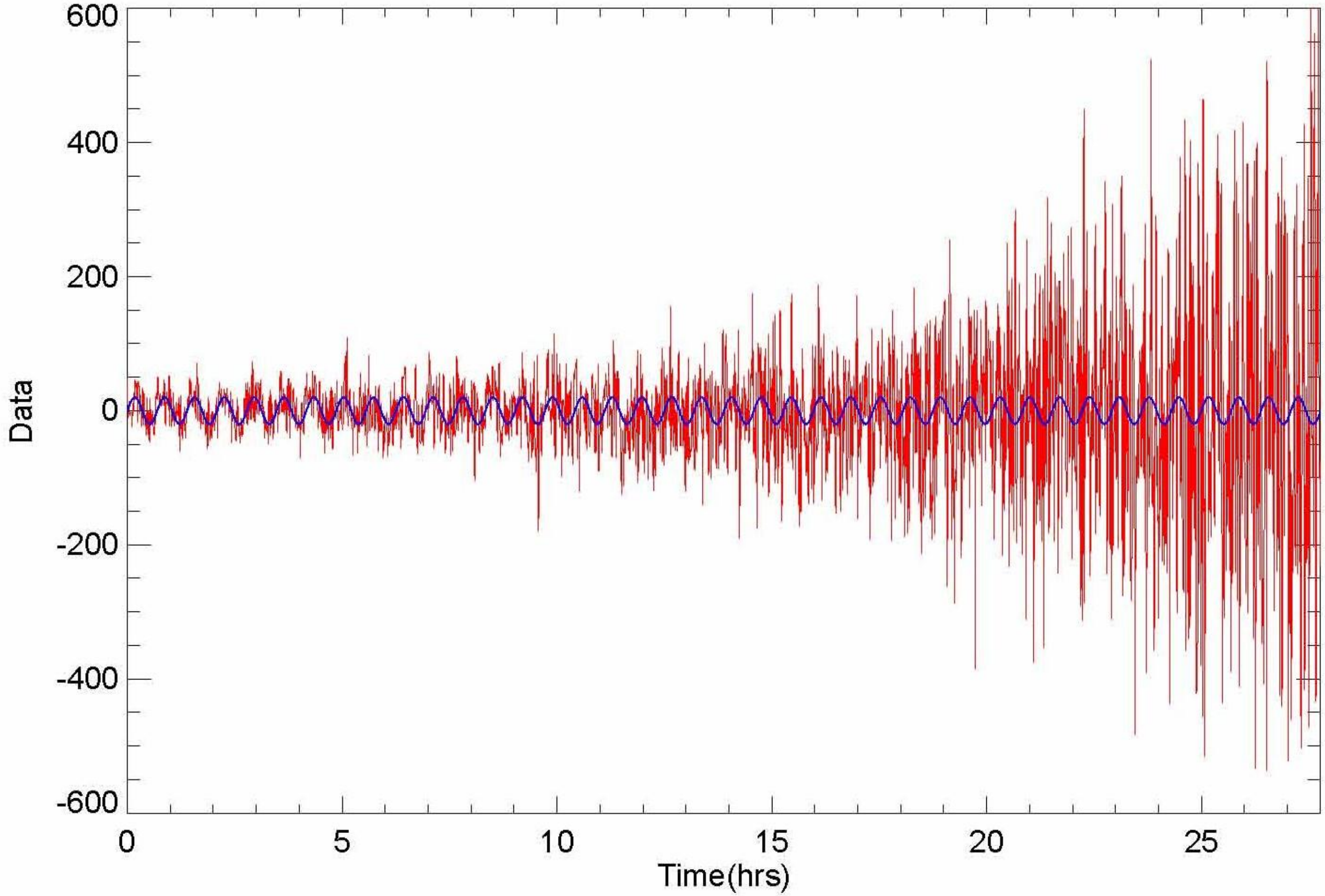




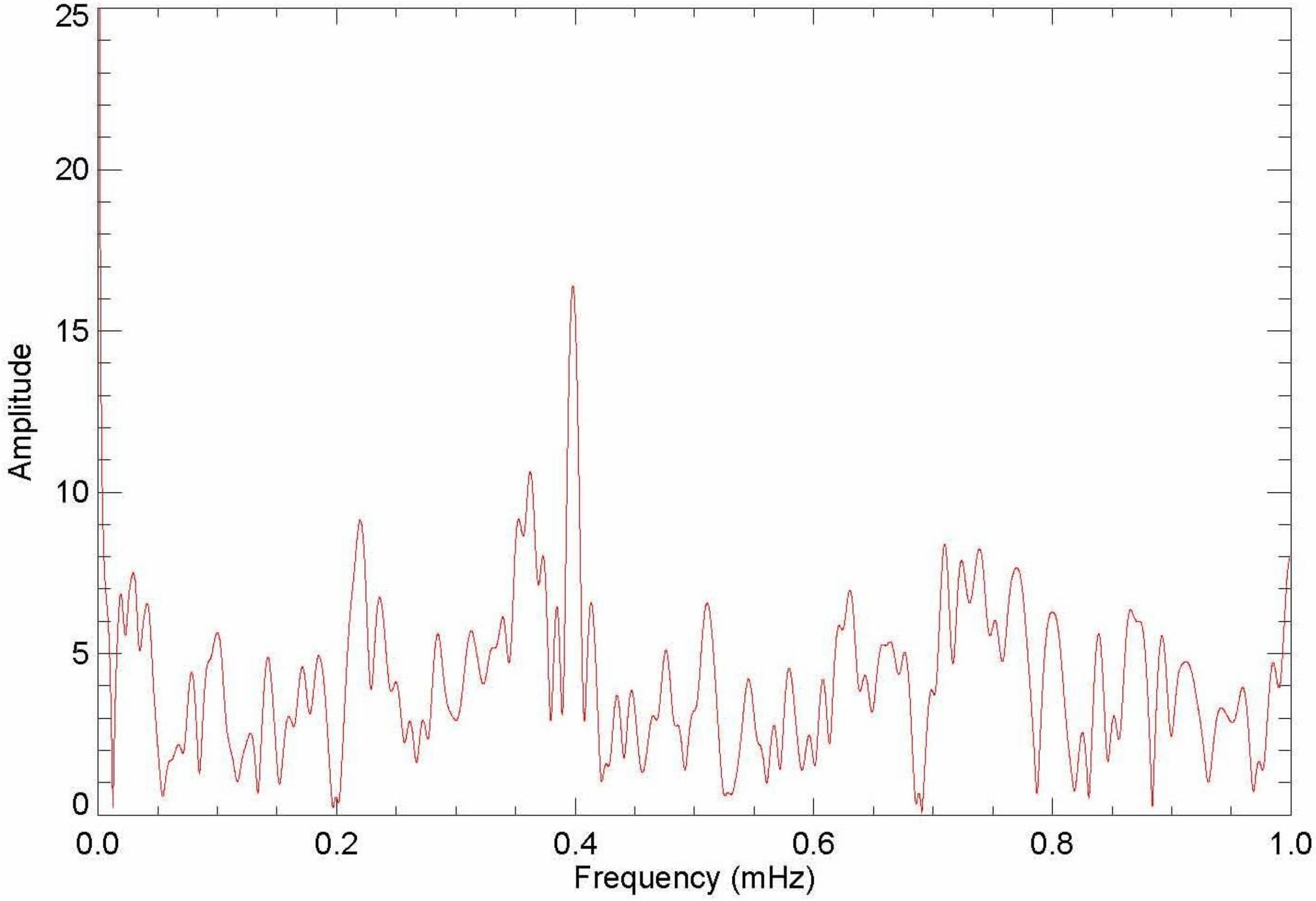
25
20
15
10
5
0
Amplitude
0.0
0.2
0.4
0.6
0.8
1.0
Frequency (mHz)



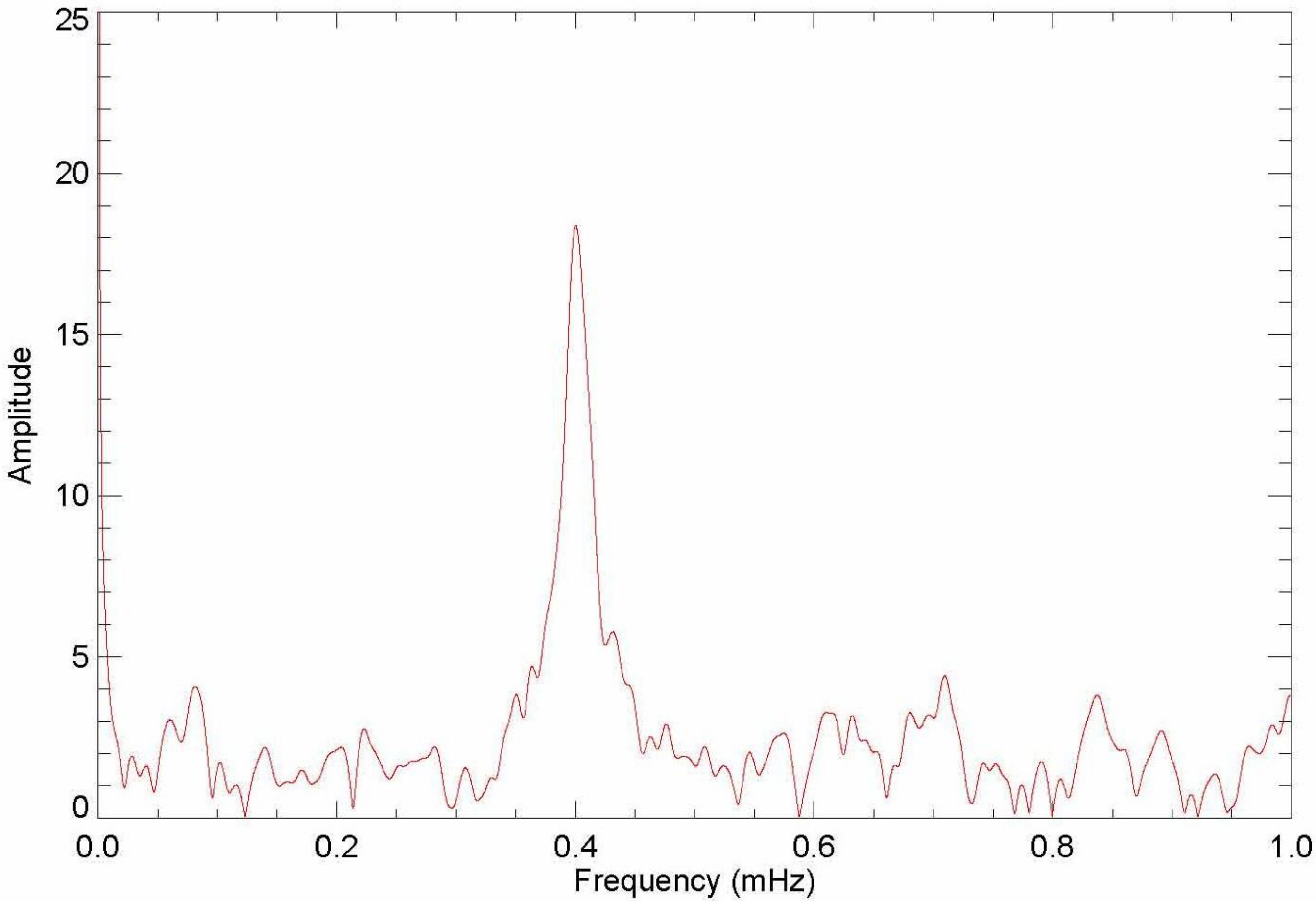
25
20
15
10
5
0
Amplitude
0.0
0.2
0.4
0.6
0.8
1.0
Frequency (mHz)



600
400
200
0
-200
-400
-600
Data
0
5
10
15
20
25
Time(hrs)



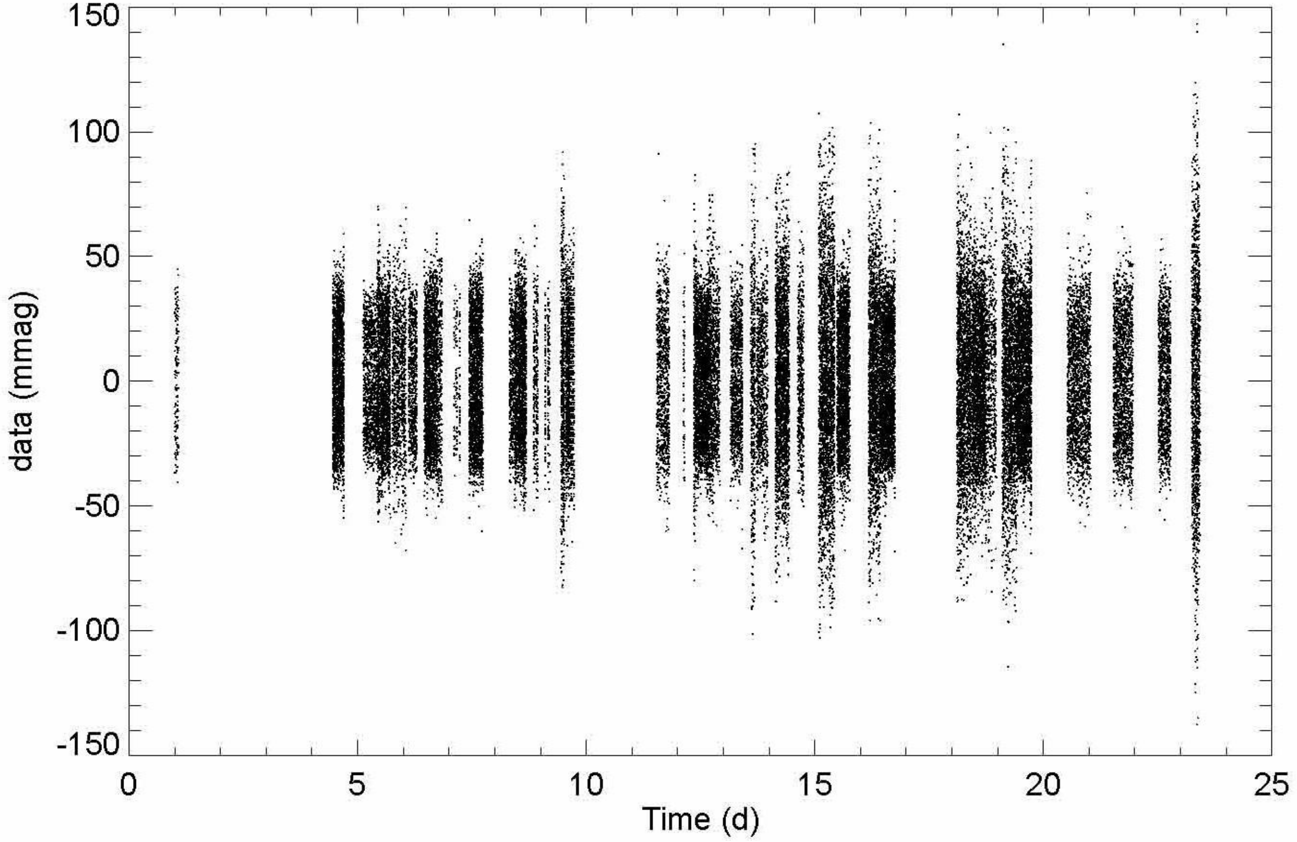
25
20
15
10
5
0
Amplitude
0.0
0.2
0.4
0.6
0.8
1.0
Frequency (mHz)



Amplitude
25
20
15
10
5
0
0.0
0.2
0.4
0.6
0.8
1.0
Frequency (mHz)

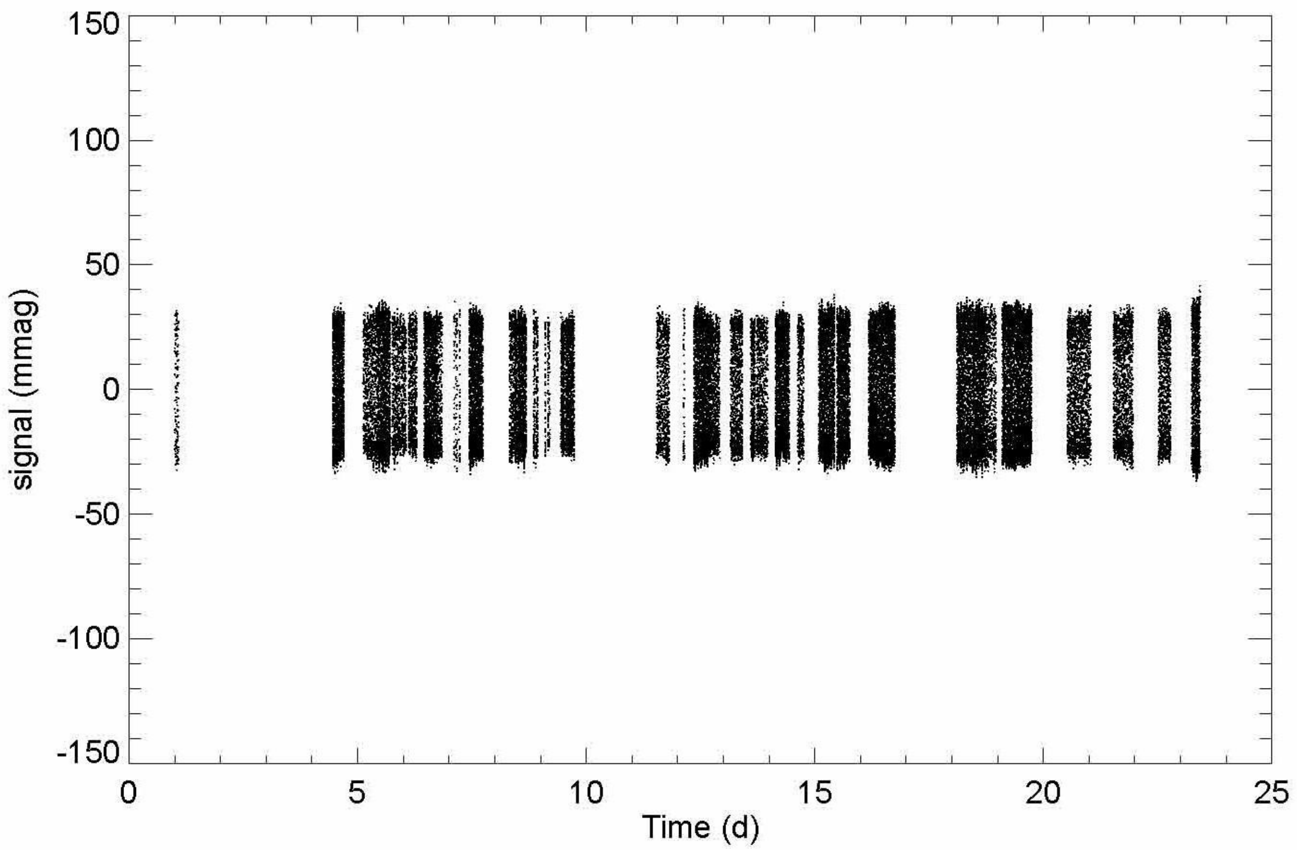
sdB: PG 1325+101

Silvotti et al., 2006 and Charpinet et al., 2006



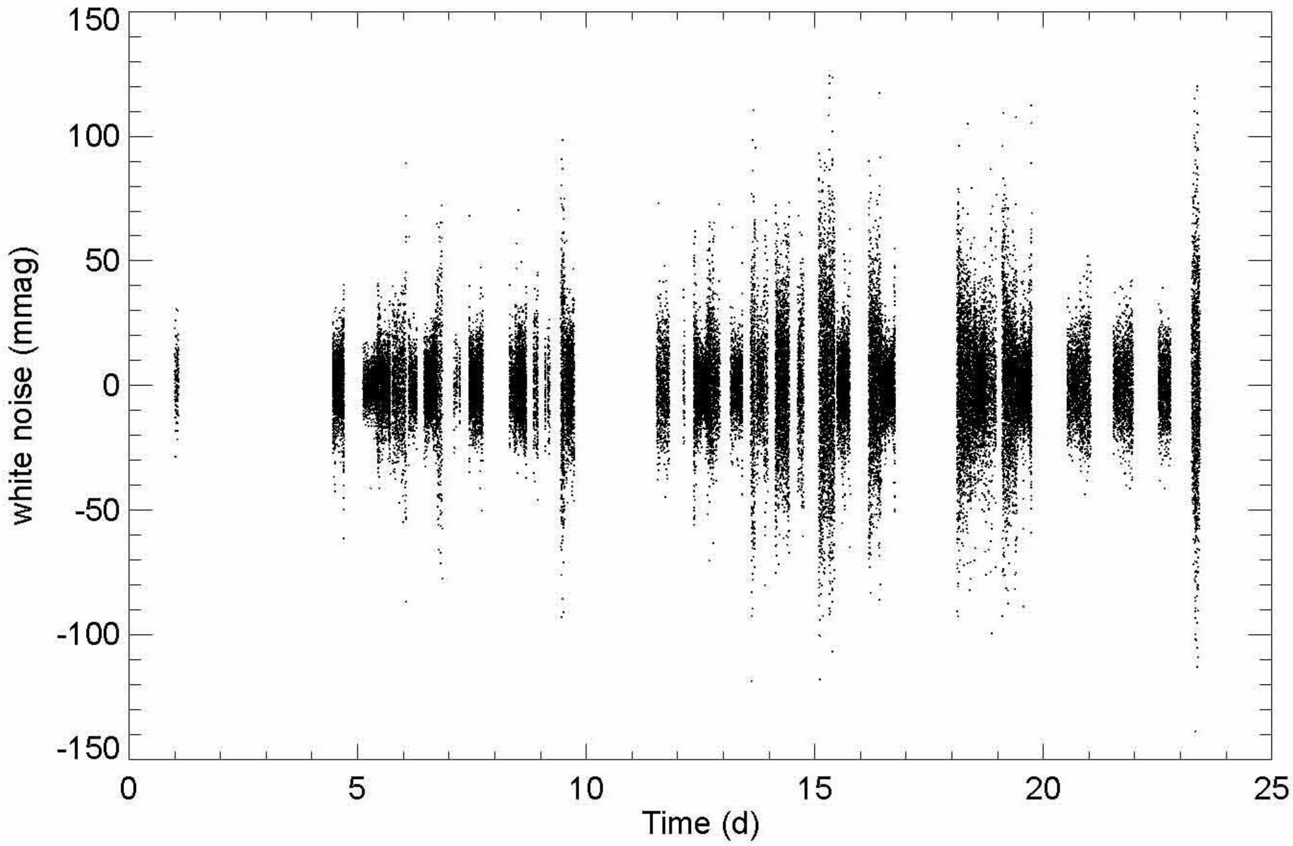
sdB: PG 1325+101

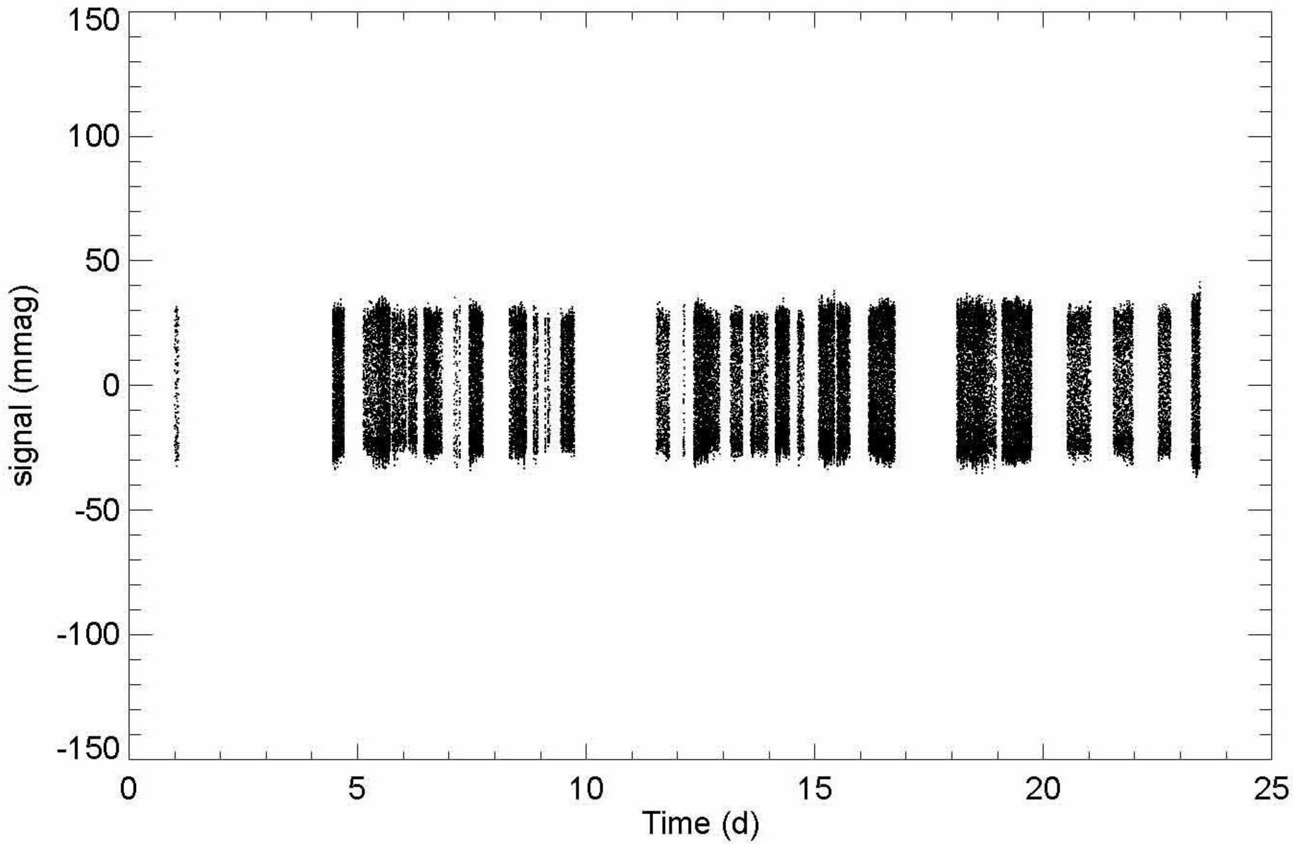
Silvotti et al., 2006 and Charpinet et al., 2006



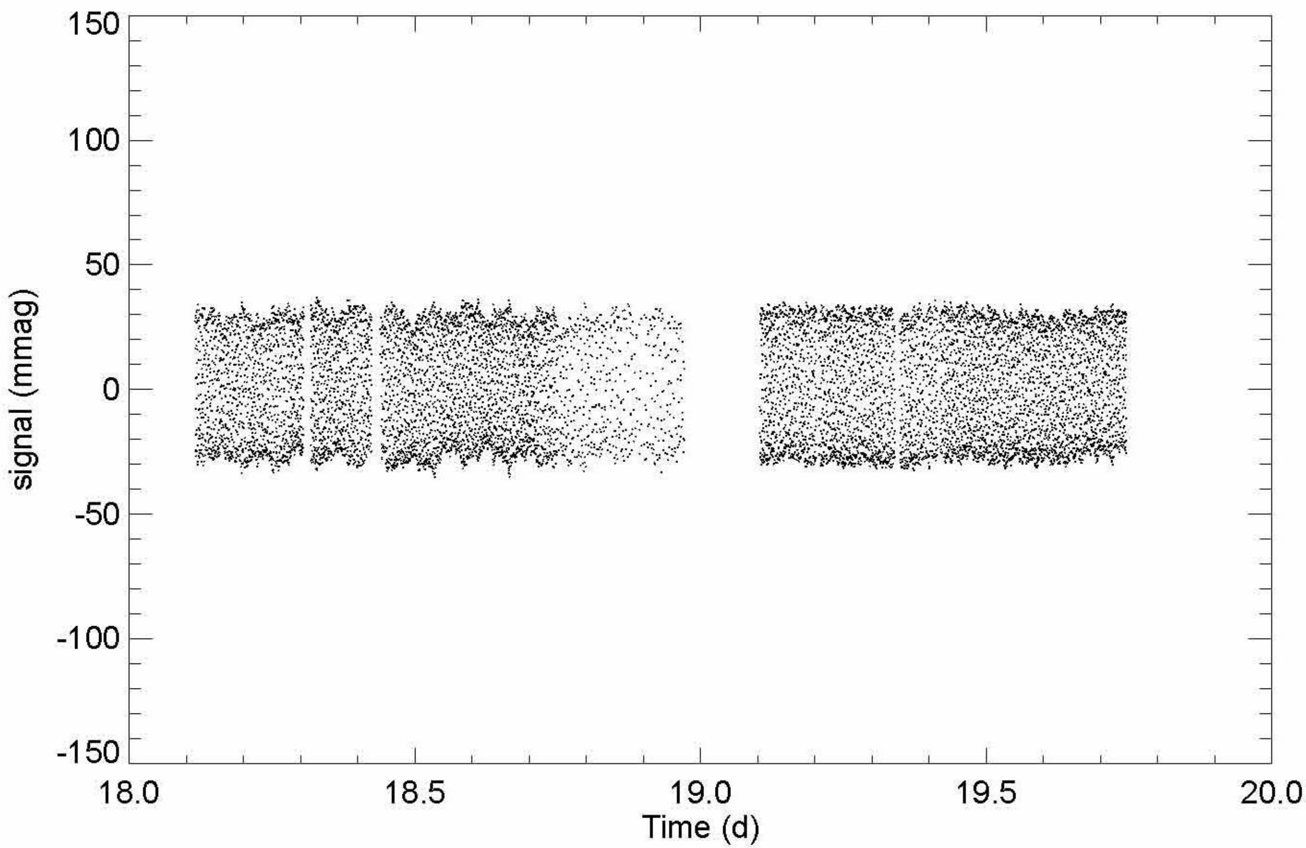
sdB: PG 1325+101

Silvotti et al., 2006 and Charpinet et al., 2006

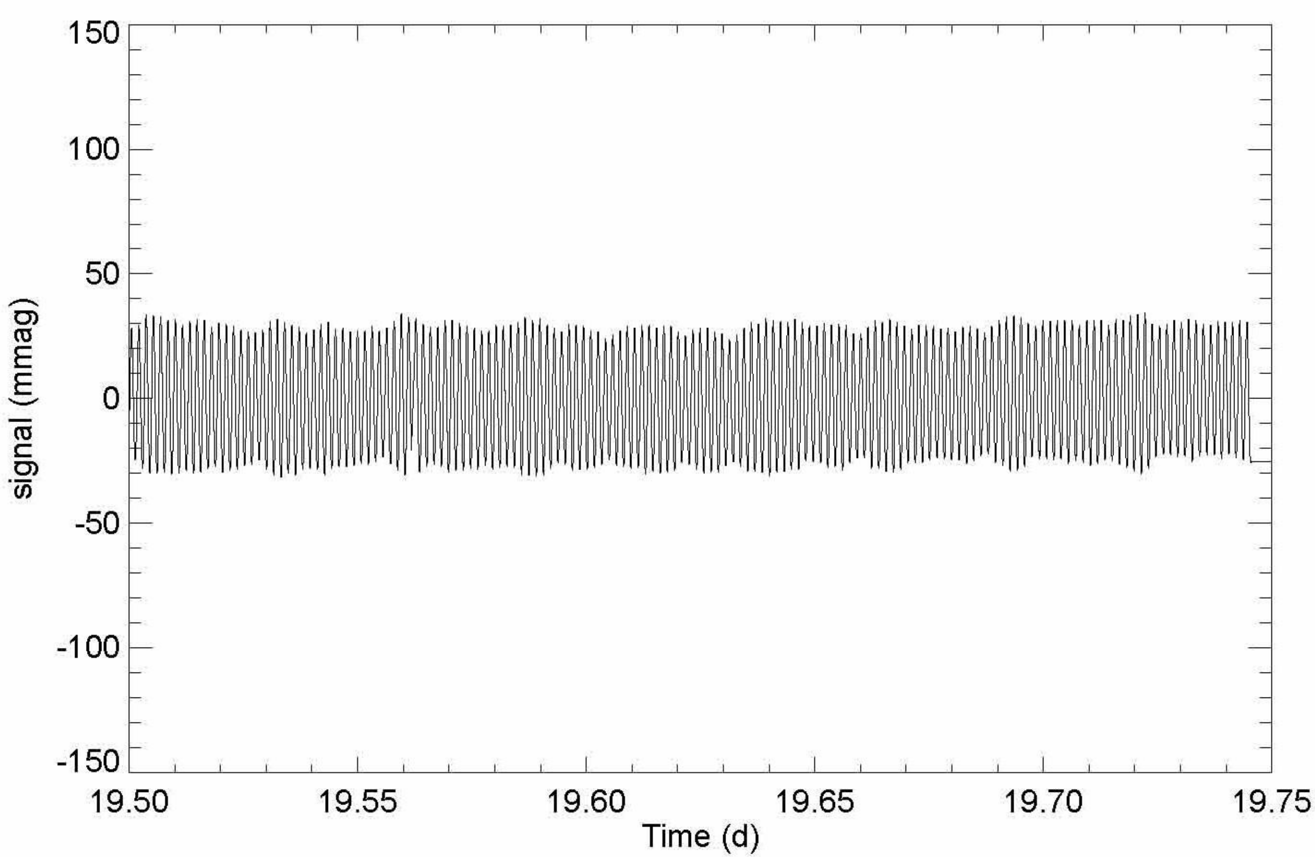


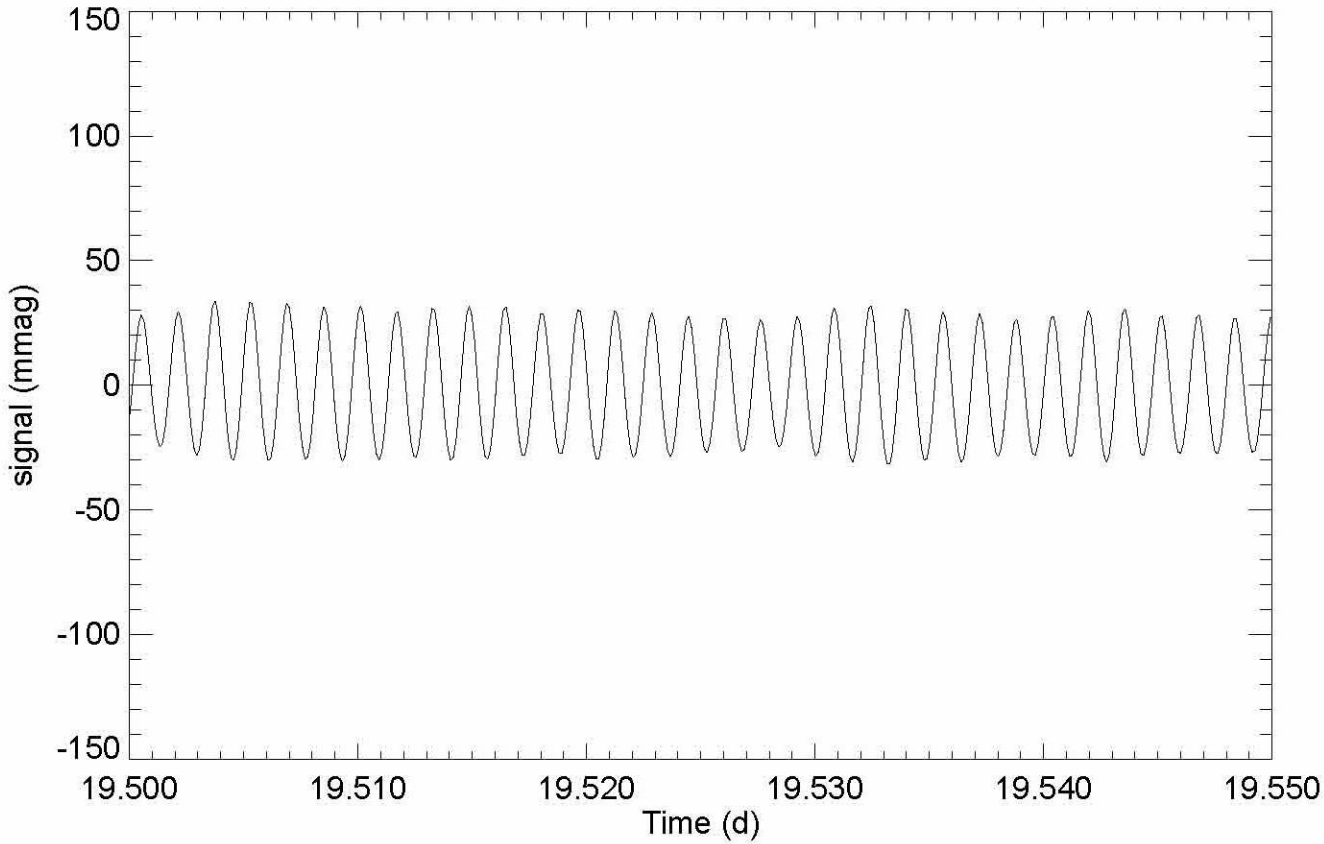


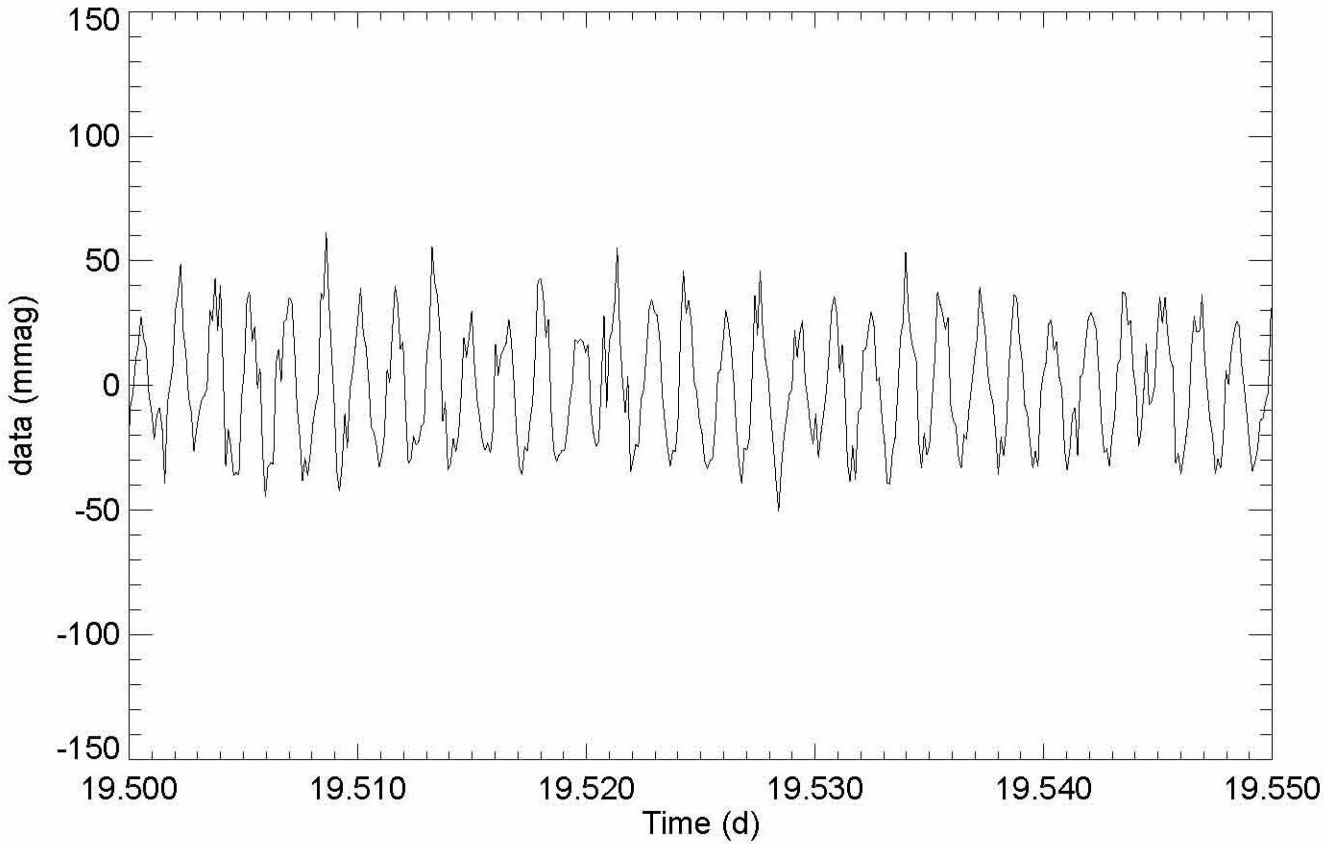
150
100
50
0
-50
-100
-150
signal (mmag)
0
5
10
15
20
25
Time (d)

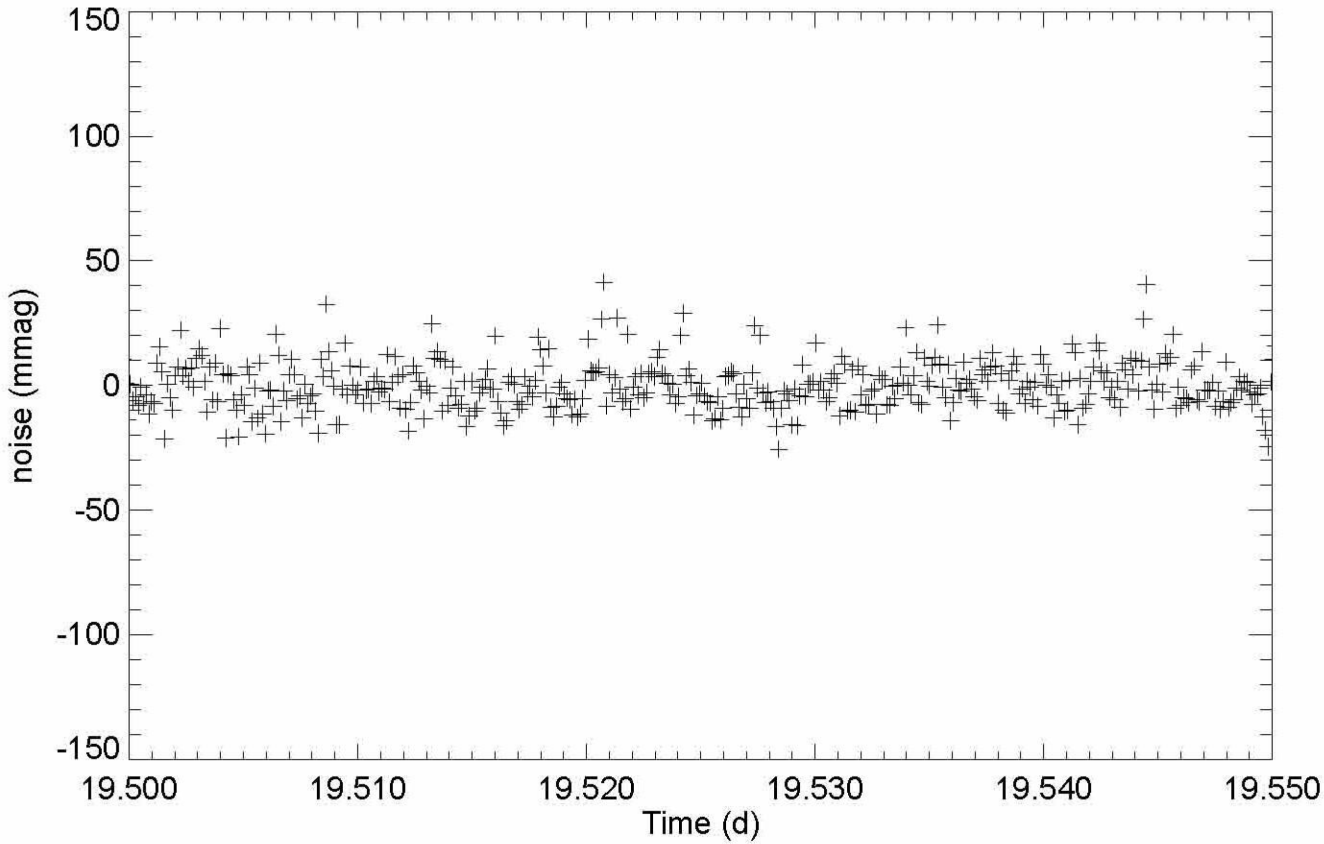


150
100
50
0
-50
-100
-150
signal (mmag)
18.0
18.5
19.0
19.5
20.0
Time (d)


150
100
50
0
-50
-100
-150
signal (mmag)
19.50
19.55
19.60
19.65
19.70
19.75
Time (d)

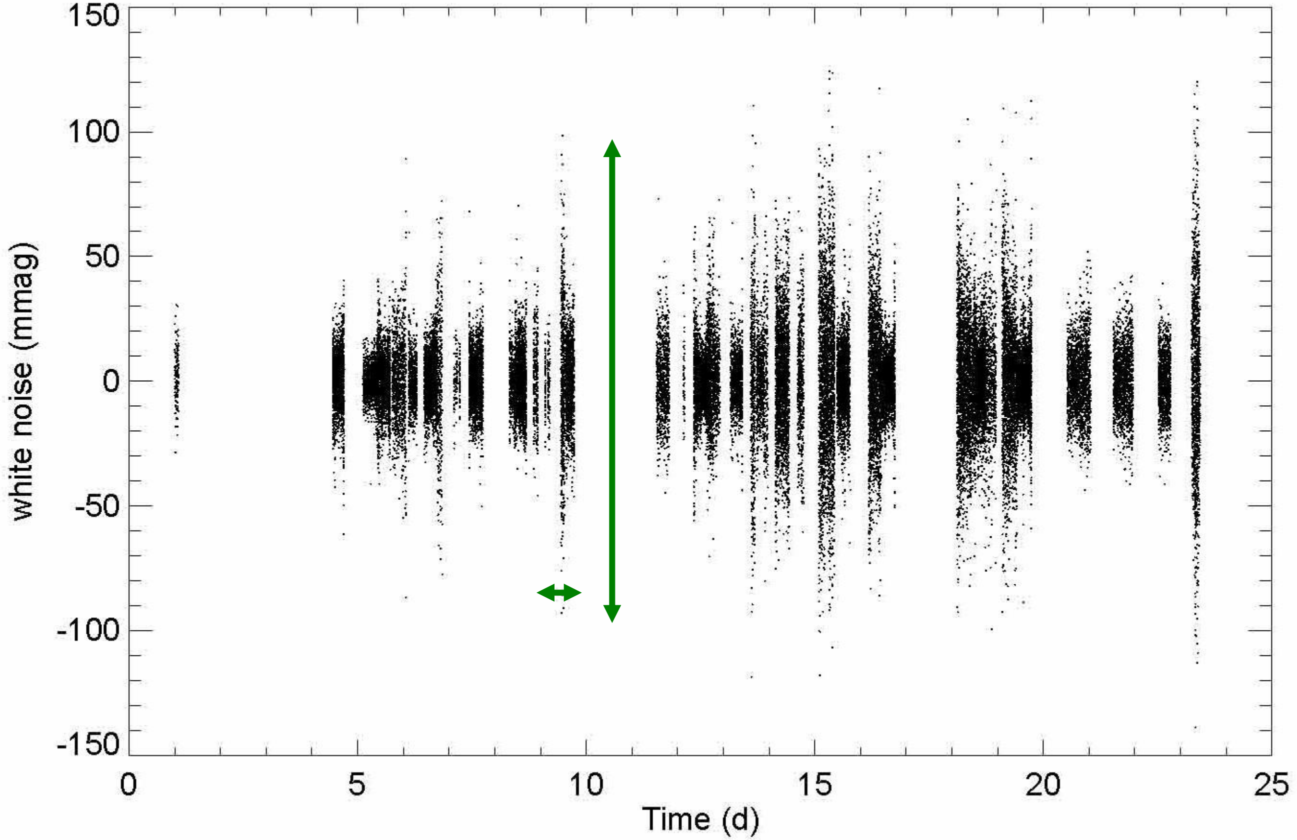

150
100
50
0
-50
-100
-150
signal (mmag)
19.500
19.510
19.520
19.530
19.540
19.550
Time (d)


150
100
50
0
-50
-100
-150
data (mmag)
19.500
19.510
19.520
19.530
19.540
19.550
Time (d)

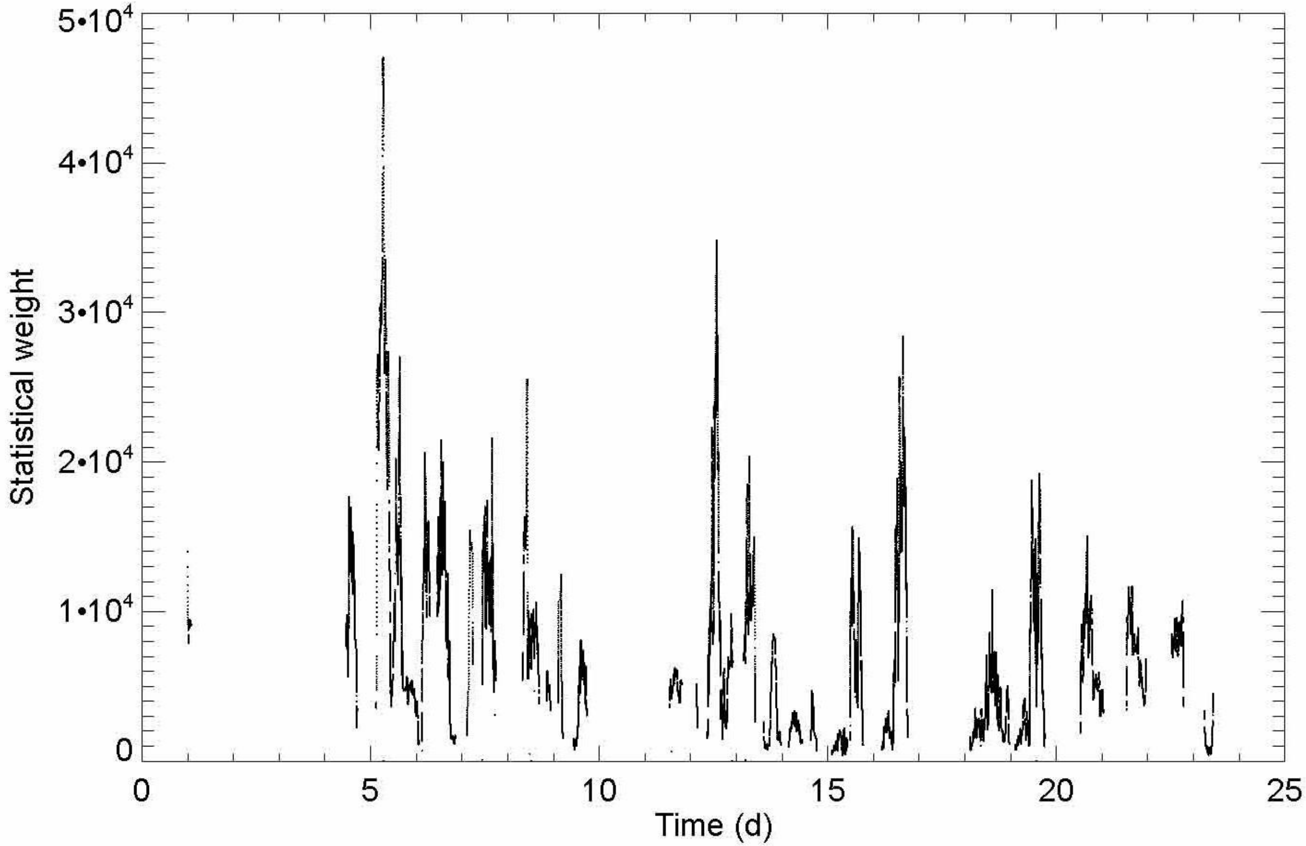


150
100
50
0
-50
-100
-150
noise (mmag)
19.500
19.510
19.520
19.530
19.540
19.550
Time (d)

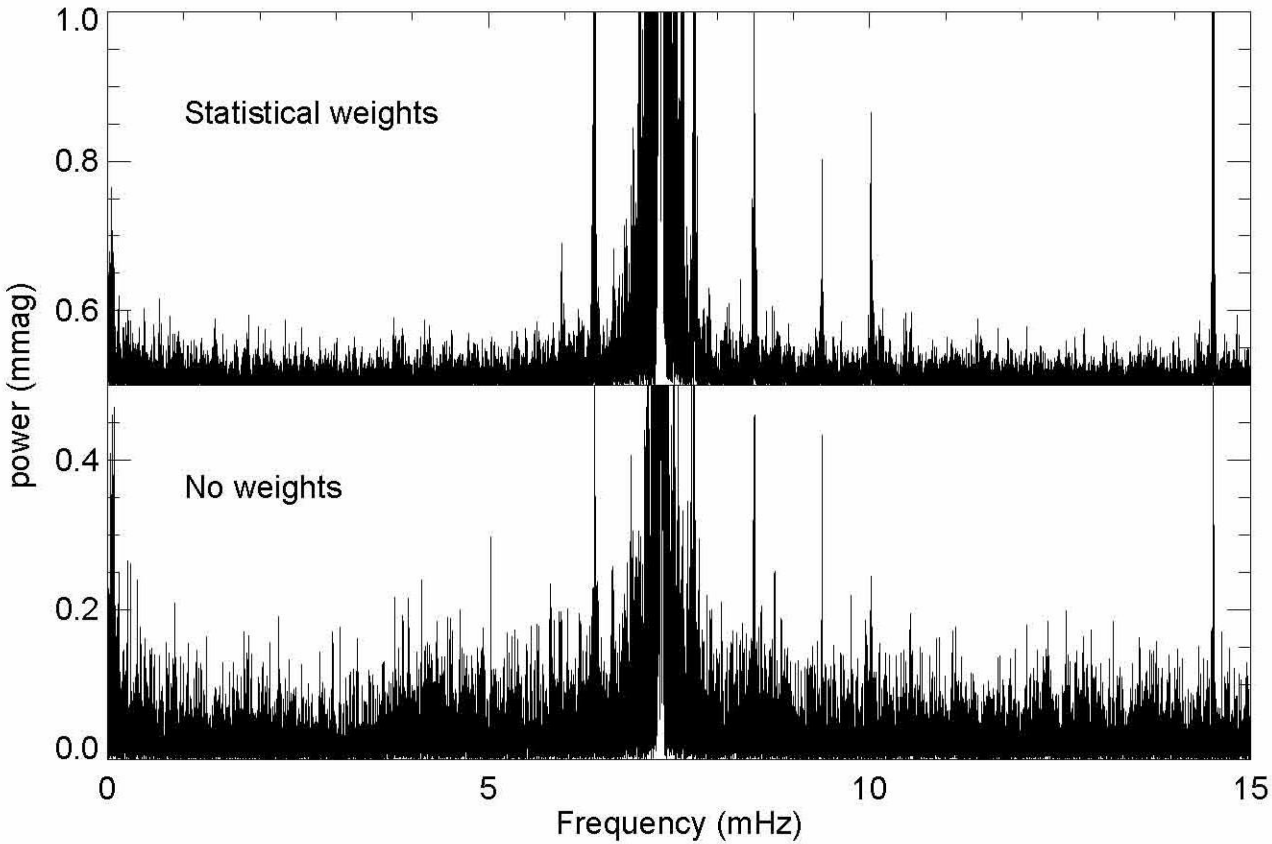
$$w_i = \sigma_i^{-2}$$



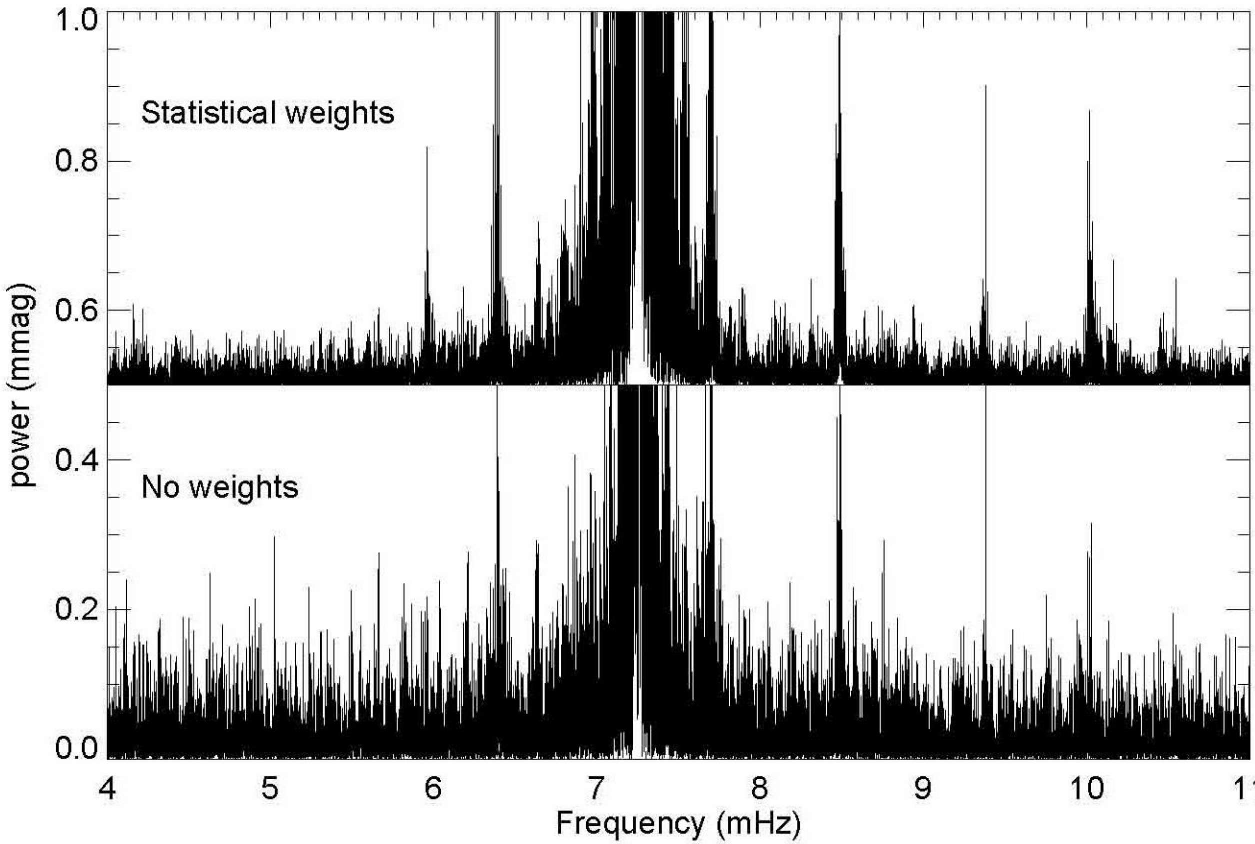
$$w_i = \sigma_i^{-2}$$

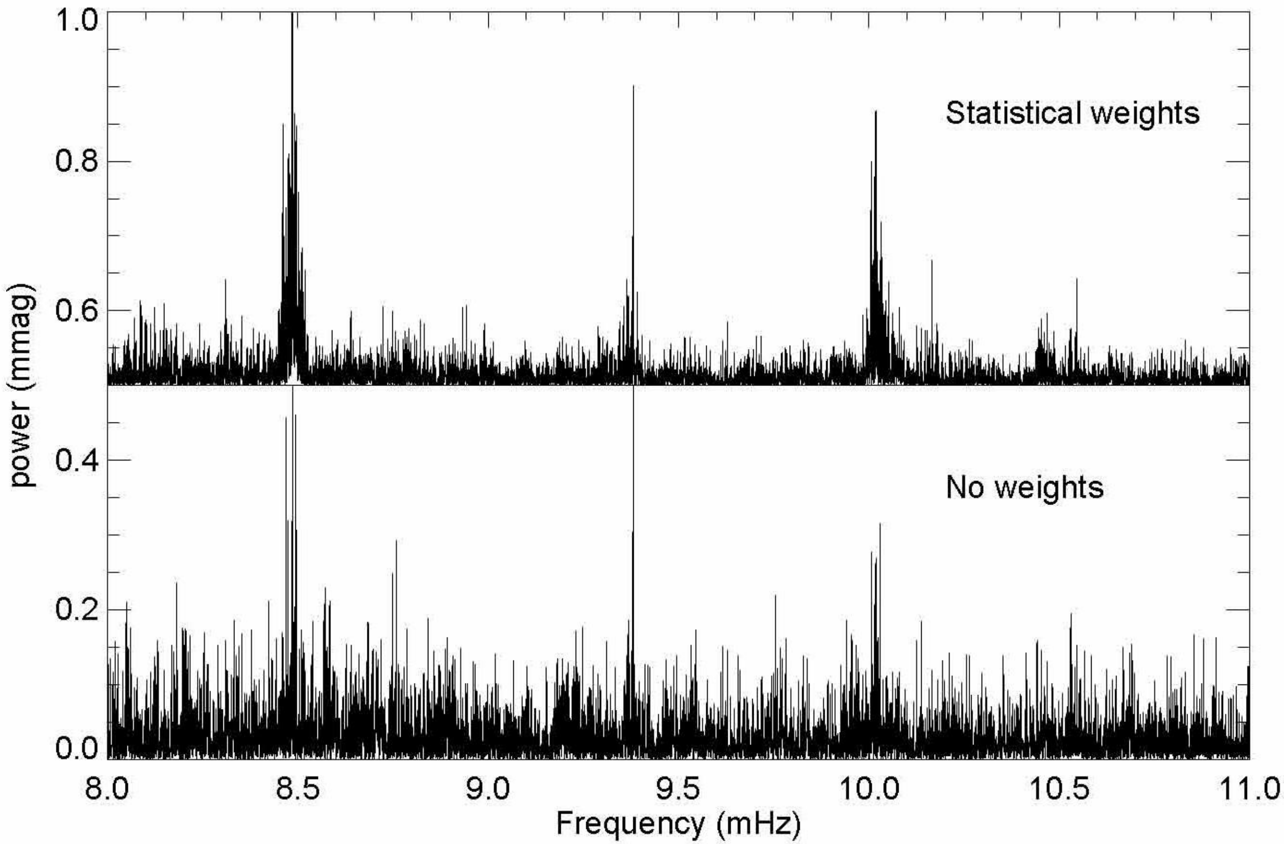


Statistical weight
5•10^4
4•10^4
3•10^4
2•10^4
1•10^4
0
0
5
10
15
20
25
Time (d)

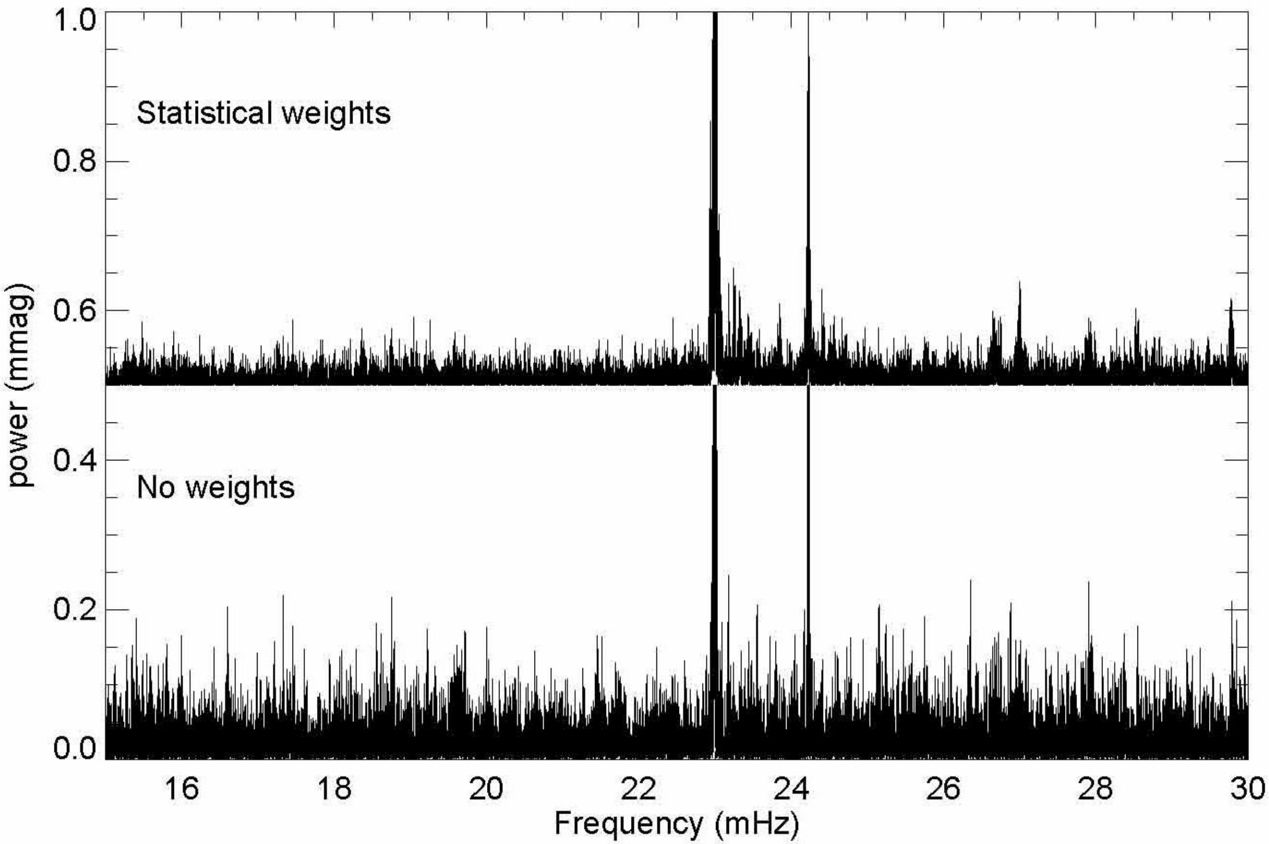


Statistical weights
No weights
power (mmag)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Frequency (mHz)

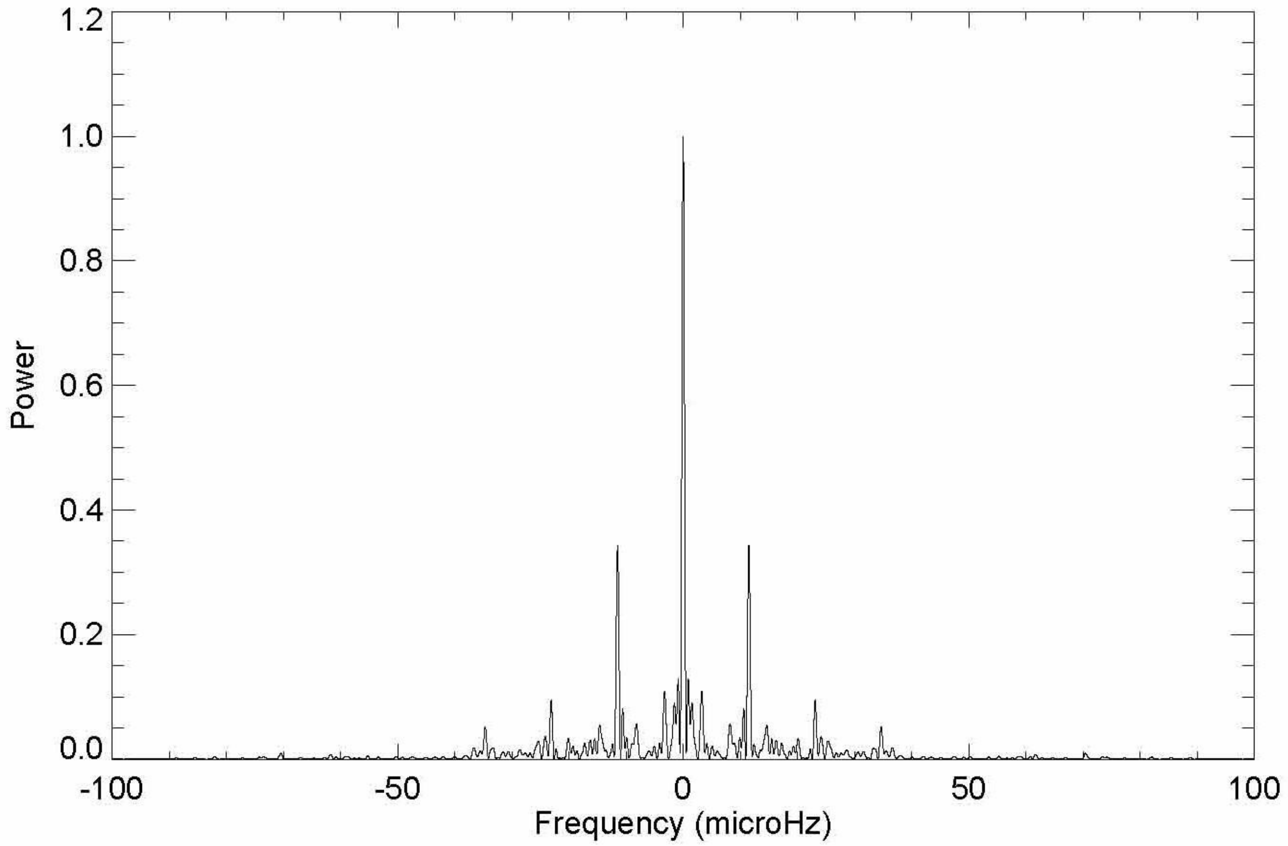

Statistical weights
No weights
power (mmag)
Frequency (mHz)
1.0
0.8
0.6
0.4
0.2
0.0
4
5
6
7
8
9
10
11

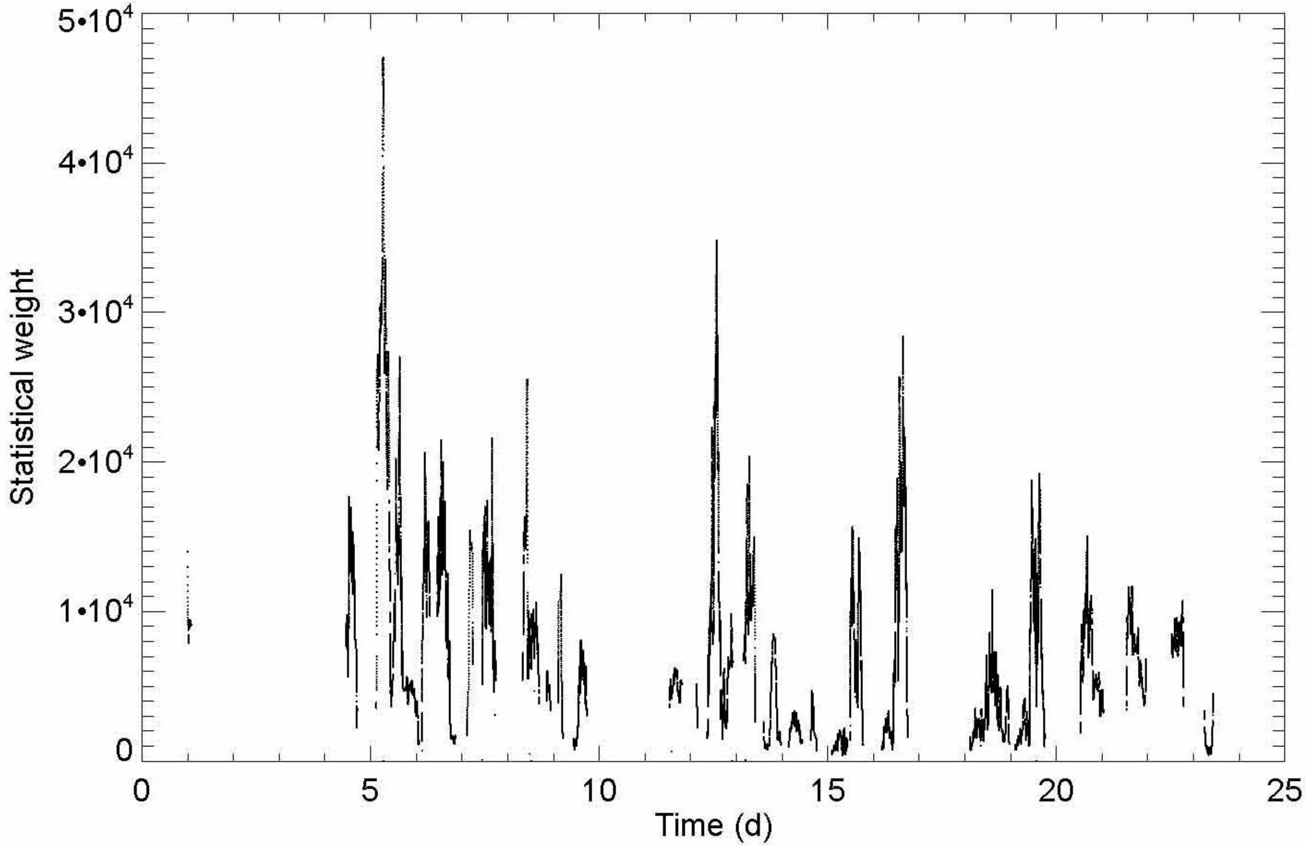


1.0
0.8
0.6
0.4
0.2
0.0
power (mmag)
Statistical weights
No weights
8.0
8.5
9.0
9.5
10.0
10.5
11.0
Frequency (mHz)


1.0
0.8
0.6
0.4
0.2
0.0
power (mmag)
Statistical weights
No weights
16
18
20
22
24
26
28
30
Frequency (mHz)

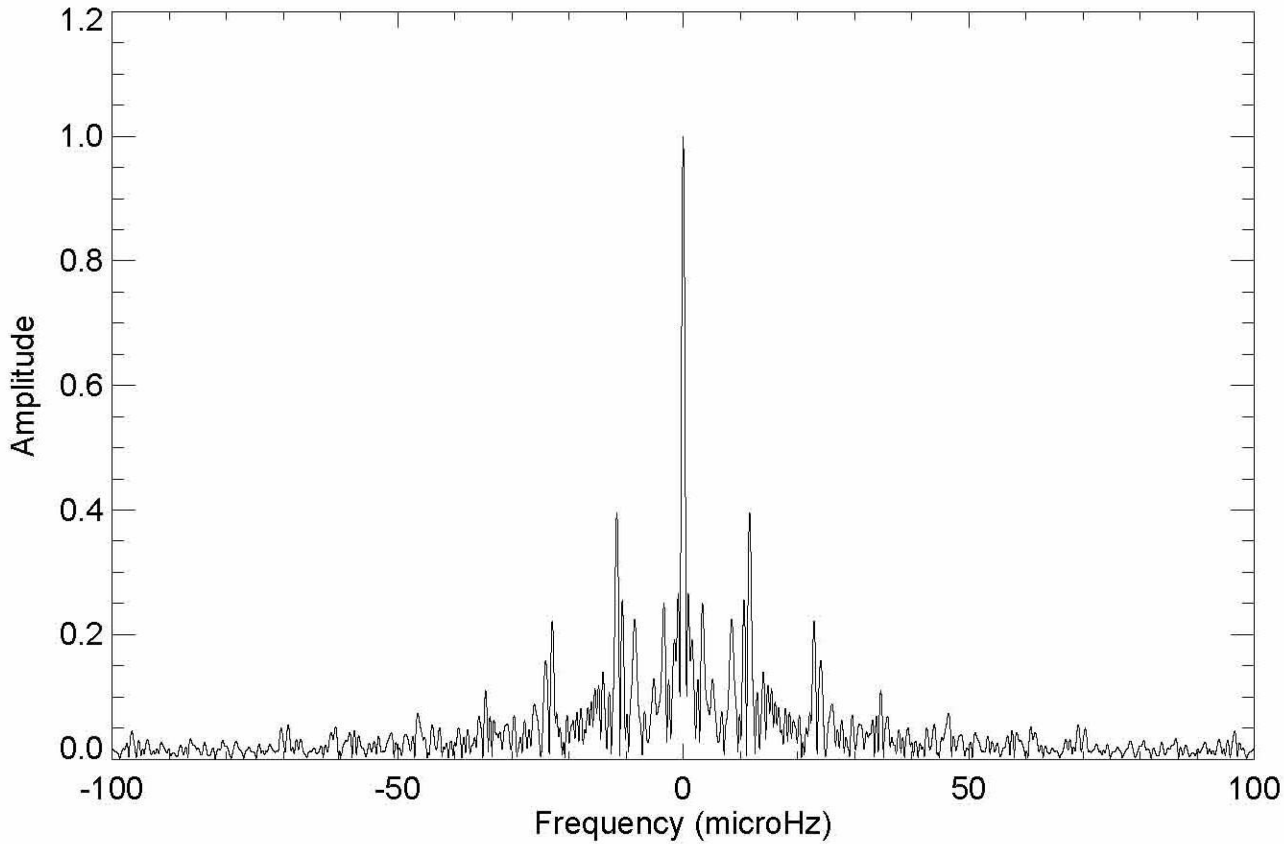
Window $w_i = \sigma_i^{-2}$





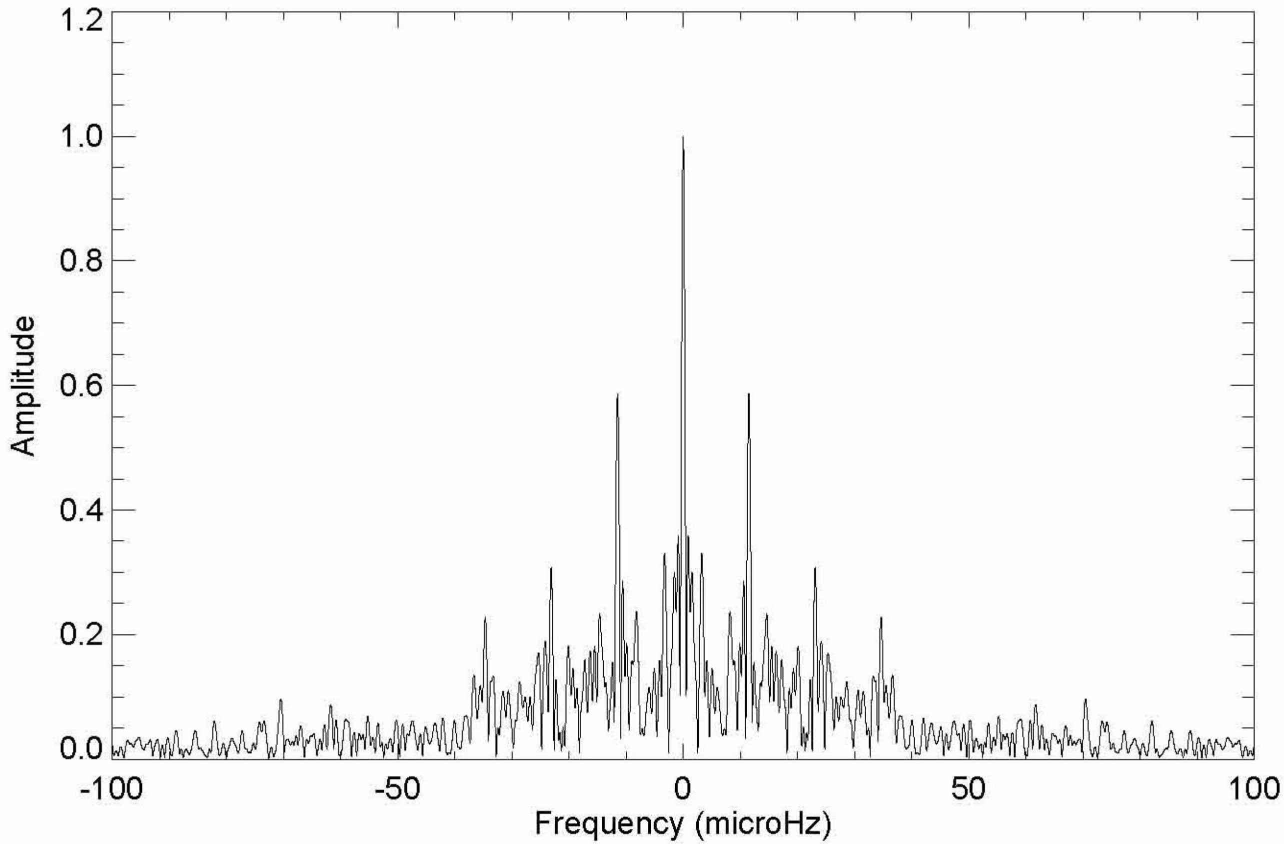
Statistical weight
5•10^4
4•10^4
3•10^4
2•10^4
1•10^4
0
0
5
10
15
20
25
Time (d)

$$w_i = 1$$



1.2
1.0
0.8
0.6
0.4
0.2
0.0
Amplitude
-100
-50
0
50
100
Frequency (microHz)

$$w_i = \sigma_i^{-2}$$


1.2
1.0
0.8
0.6
0.4
0.2
0.0
Amplitude
-100
-50
0
50
100
Frequency (microHz)

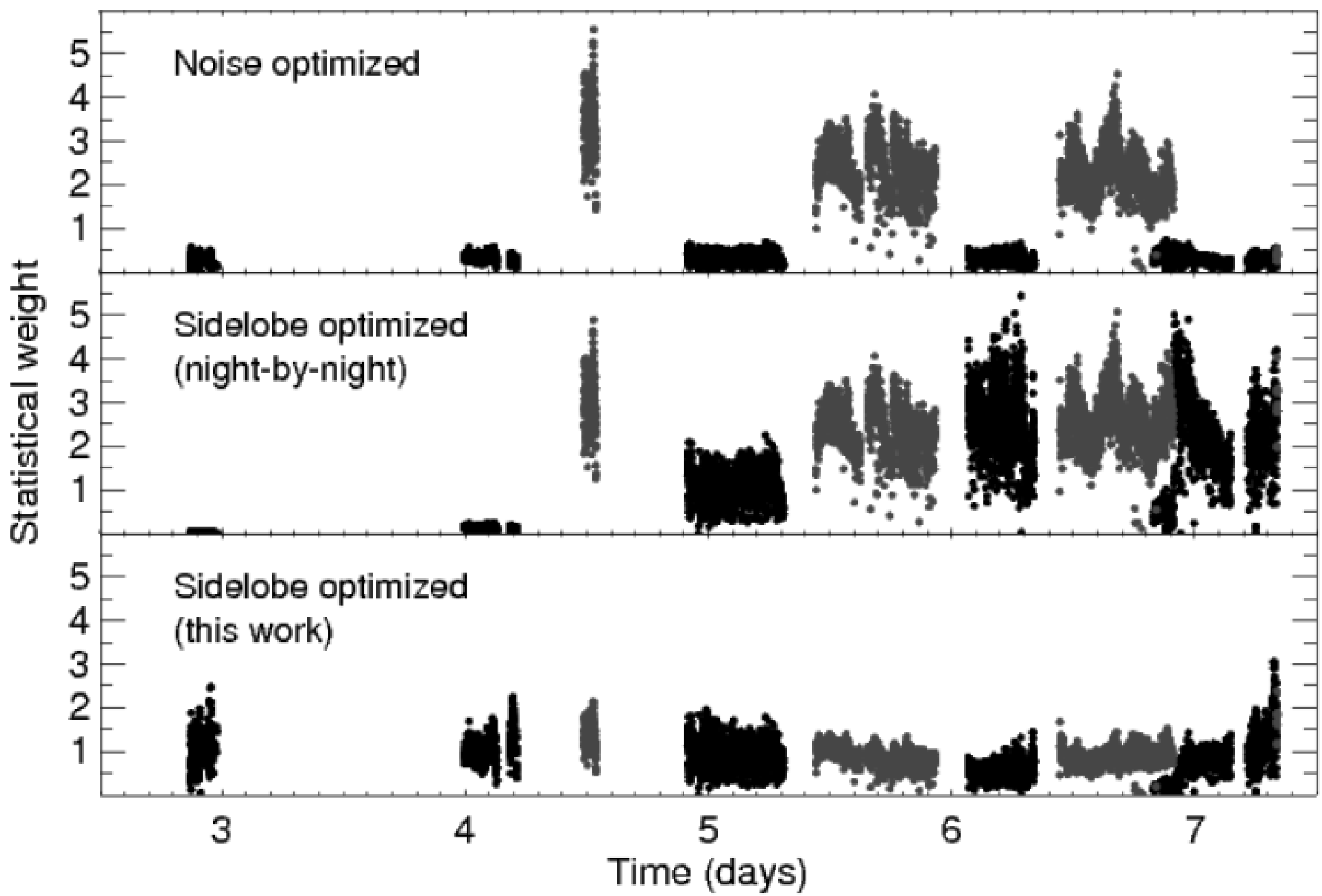
Optimized data weights

- Weight ~ SNR^2
- Signal
- Noise

Solar-Stellar Dynamos as Revealed by Helio- and Asteroseismology
ASP Conference Series, Vol. 000, 2009
M. Dikpati et al.

Optimizing Weights for the Detection of Stellar Oscillations: Application to α Centauri A and B, and β Hydri

Torben Arentoft,[1] Hans Kjeldsen,[1] and Timothy R. Bedding,[2]



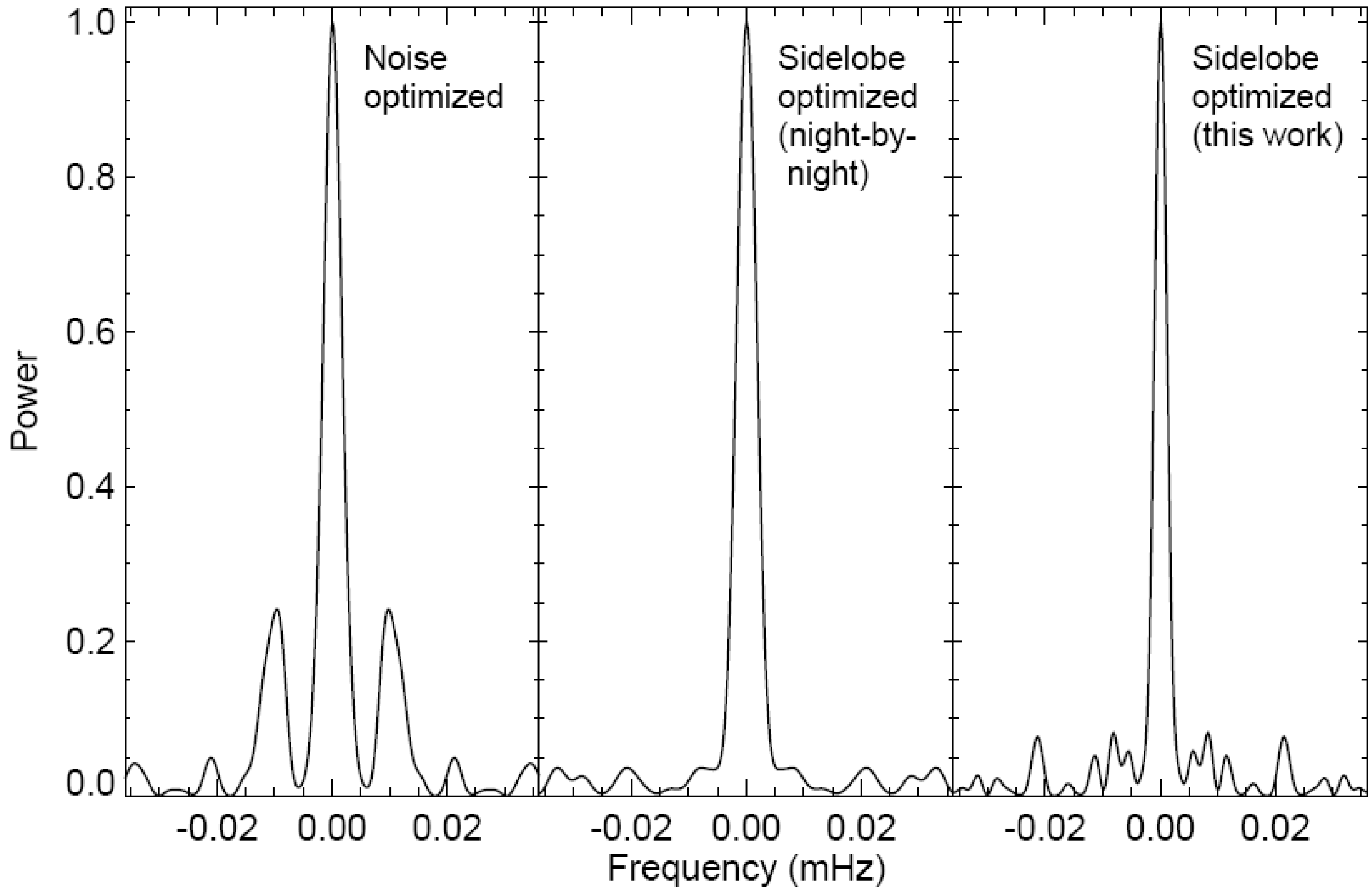


Figure 2. Spectral window for α Cen A for the three different weighting schemes.

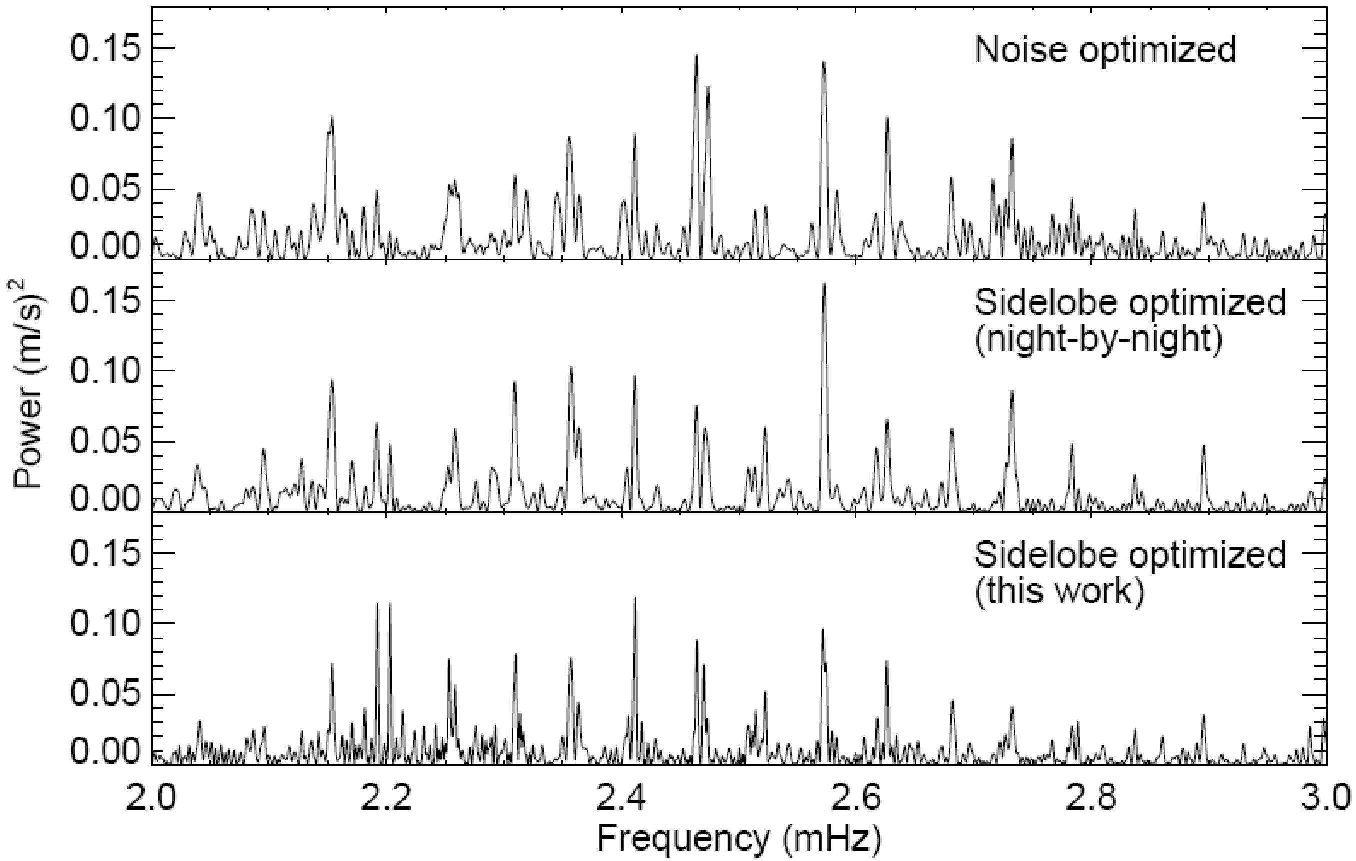


Figure 3. Power spectrum of α Cen A for the three different weighting schemes.

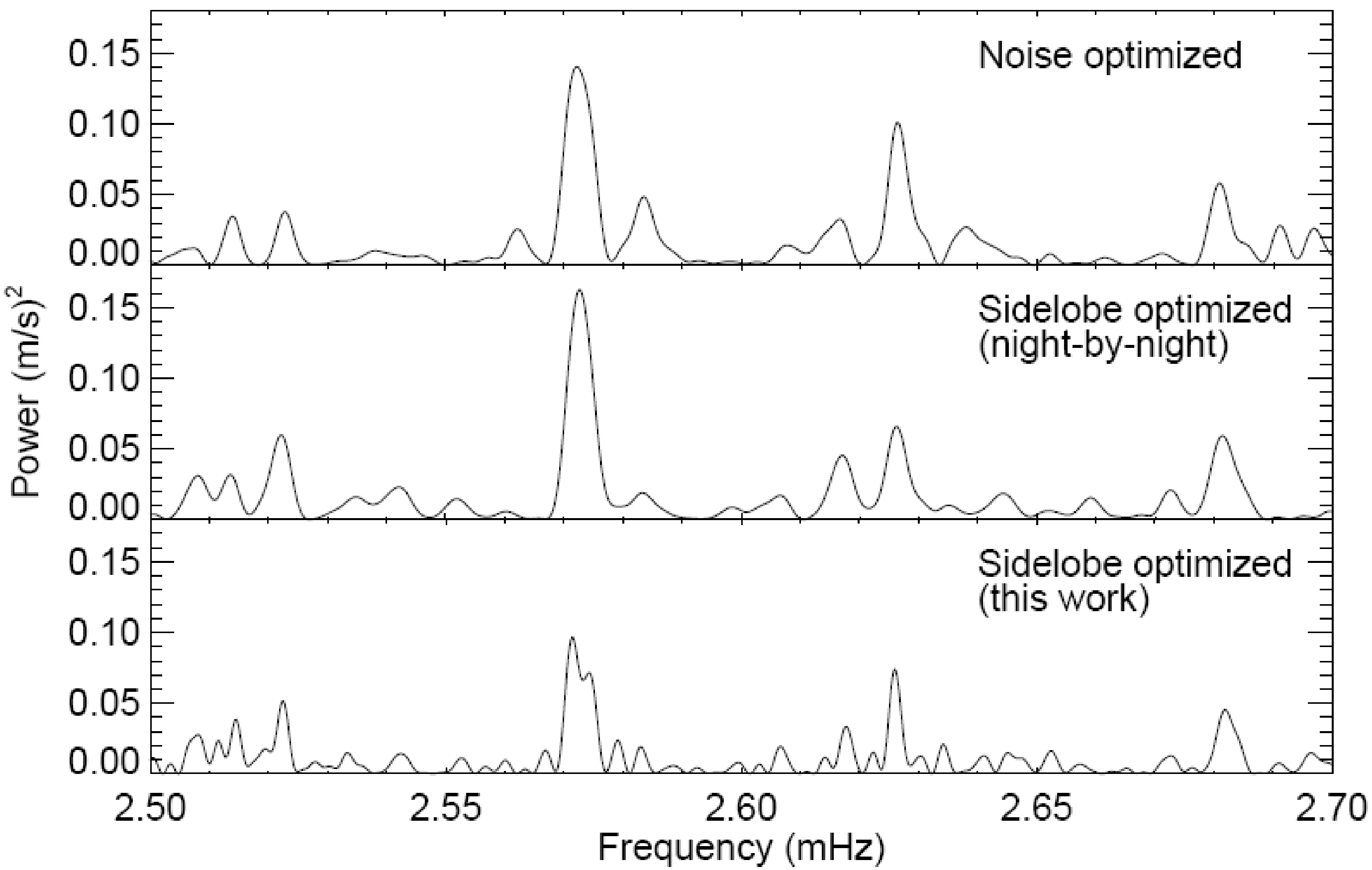


Figure 4. A close-up of the power spectrum of α Cen A shown Fig. 3.

The Astrophysical Journal, 687:1180–1190, 2008 November 10

A MULTISITE CAMPAIGN TO MEASURE SOLAR-LIKE OSCILLATIONS IN PROCYON. I. OBSERVATIONS, DATA REDUCTION, AND SLOW VARIATIONS

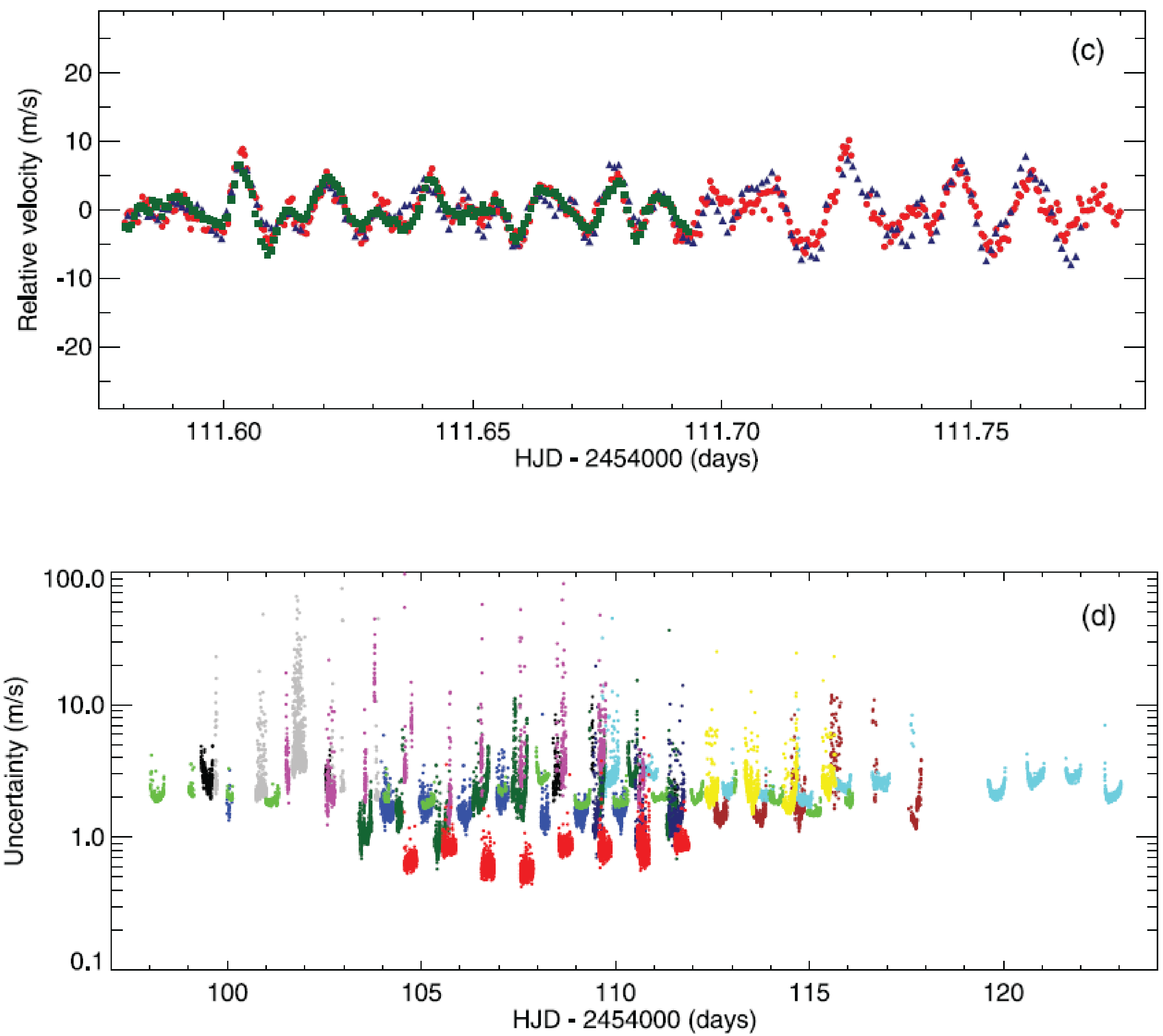
Torben Arentoft,[1] Hans Kjeldsen,[1] Timothy R. Bedding,[2] Michaël Bazot,[1,3] Jørgen Christensen-Dalsgaard,[1] Thomas H. Dall,[4] Christoffer Karoff,[1] Fabien Carrier,[5] Patrick Eggenberger,[6] Danuta Sosnowska,[7] Robert A. Wittenmyer,[8] Michael Endl,[8] Travis S. Metcalfe,[9] Saskia Hekker,[10,11] Sabine Reffert,[12] R. Paul Butler,[13] Hans Bruntt,[2] László L. Kiss,[2] Simon J. O'Toole,[14] Eiji Kambe,[15] Hiroyasu Ando,[16] Hideyuki Izumiura,[15] Bun'ei Sato,[17] Michael Hartmann,[18] Artie Hatzes,[18] Francois Bouchy,[19] Benoit Mosser,[20] Thierry Appourchaux,[21] Caroline Barban,[20] Gabrielle Berthomieu,[22] Rafael A. Garcia,[23] Eric Michel,[20] Janine Provost,[22] Sylvaine Turck-Chièze,[23] Milena Martić,[24] Jean-Claude Lebrun,[24] Jerome Schmitt,[25] Jean-Loup Bertaux,[24] Alfio Bonanno,[26] Serena Benatti,[27] Riccardo U. Claudi,[27] Rosario Cosentino,[26] Silvio Leccia,[28] Søren Frandsen,[1] Karsten Brogaard,[1] Lars Glowienka,[1] Frank Grundahl,[1] and Eric Stempels[29]
Received 2008 June 5; accepted 2008 July 17

TABLE 1
Participating Telescopes

Identifier	Telescope/Spectrograph	Observatory	Technique	Reference
HARPS	3.6 m/HARPS	ESO, La Silla, Chile[1]	ThAr	1
CORALIE	1.2 m Euler Telescope/CORALIE	ESO, La Silla, Chile	ThAr	2
McDonald	2.7 m Harlan J. Smith Tel./coudé échelle	McDonald Obs., Texas USA	Iodine	3
Lick	0.6 m CAT/Hamilton échelle	Lick Obs., California USA	Iodine	4
UCLES	3.9 m AAT/UCLES	Siding Spring Obs., Australia	Iodine	4
Okayama	1.88 m/HIDES	Okayama Obs., Japan	Iodine	5
Tautenburg	2 m/coudé échelle	Karl Schwarzschild Obs., Germany	Iodine	6
SOPHIE	1.93 m/SOPHIE	Obs. de Haute-Provence, France	ThAr	7
EMILIE	1.52 m/EMILIE+AAA	Obs. de Haute-Provence, France	White light with iodine	8
SARG	3.58 m TNG/SARG	ORM, La Palma, Spain	Iodine	9
FIES	2.5 m NOT/FIES	ORM, La Palma, Spain	ThAr	10

[1] Based on observations collected at the European Southern Observatory, La Silla, Chile (ESO Program 078.D-0492 [A]).

References.—(1) Rupprecht et al. 2004; (2) Bouchy & Carrier 2002; (3) Endl et al. 2005; (4) Butler et al. 1996; (5) Kambe et al. 2008; (6) Hatzes et al. 2003; (7) Mosser et al. 2008b; (8) Bouchy et al. 2002, and J. Schmitt 2008, private communication; (9) Claudi et al. 2005; (10) Frandsen & Lindberg 2000.



(c)
Relative velocity (m/s)
20
10
0
-10
-20
111.60
111.65
111.70
111.75
HJD - 2454000 (days)
(d)
Uncertainty (m/s)
100.0
10.0
1.0
0.1
100
105
110
115
120
HJD - 2454000 (days)

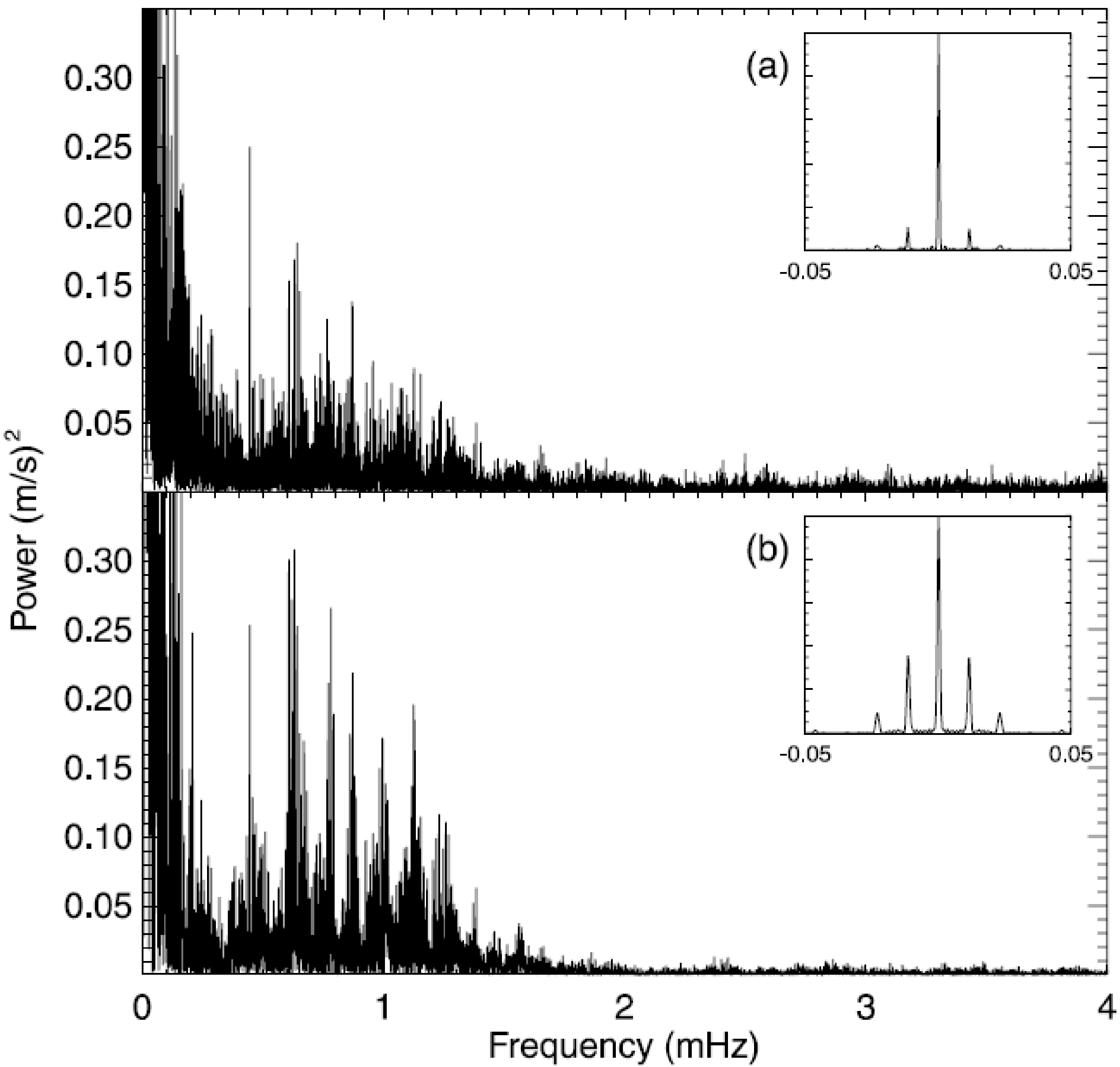


FIG. 6.—Final power spectrum based on the noise-optimized weights (*bottom*), and also without applying the weights (*top*). The inset shows the spectral window.

The Astrophysical Journal, 713:935–949, 2010 April 20 doi:10.1088/0004-637X/713/2/935

A MULTI-SITE CAMPAIGN TO MEASURE SOLAR-LIKE OSCILLATIONS IN PROCYON. II. MODE FREQUENCIES

Timothy R. Bedding[1], Hans Kjeldsen[2], Tiago L. Campante[2,3], Thierry Appourchaux[4], Alfio Bonanno[5], William J. Chaplin[6], Rafael A. Garcia[7], Milena Martić[8], Benoit Mosser[9], R. Paul Butler[10], Hans Bruntt[1,11], László L. Kiss[1,12], Simon J. O'Toole[13], Eiji Kambe[14], Hiroyasu Ando[15], Hideyuki Izumiura[14], Bun'ei Sato[16], Michael Hartmann[17], Artie Hatzes[17], Caroline Barban[11], Gabrielle Berthomieu[18], Eric Michel[11], Janine Provost[18], Sylvaine Turck-Chièze[7], Jean-Claude Lebrun[8], Jerome Schmitt[19], Jean-Loup Bertaux[8], Serena Benatti[20], Riccardo U. Claudi[21], Rosario Cosentino[5], Silvio Leccia[22], Søren Frandsen[2], Karsten Brogaard[2], Lars Glowienka[2], Frank Grundahl[2], Eric Stempels[23], Torben Arentoft[2], Michaël Bazot[2], Jørgen Christensen-Dalsgaard[2], Thomas H. Dall[24], Christoffer Karoff[2], Jens Lundgreen-Nielsen[2], Fabien Carrier[25], Patrick Eggenberger[26], Danuta Sosnowska[27], Robert A. Wittenmyer[28,29], Michael Endl[28], Travis S. Metcalfe[30], Saskia Hekker[6,31], and Sabine Reffert[32]

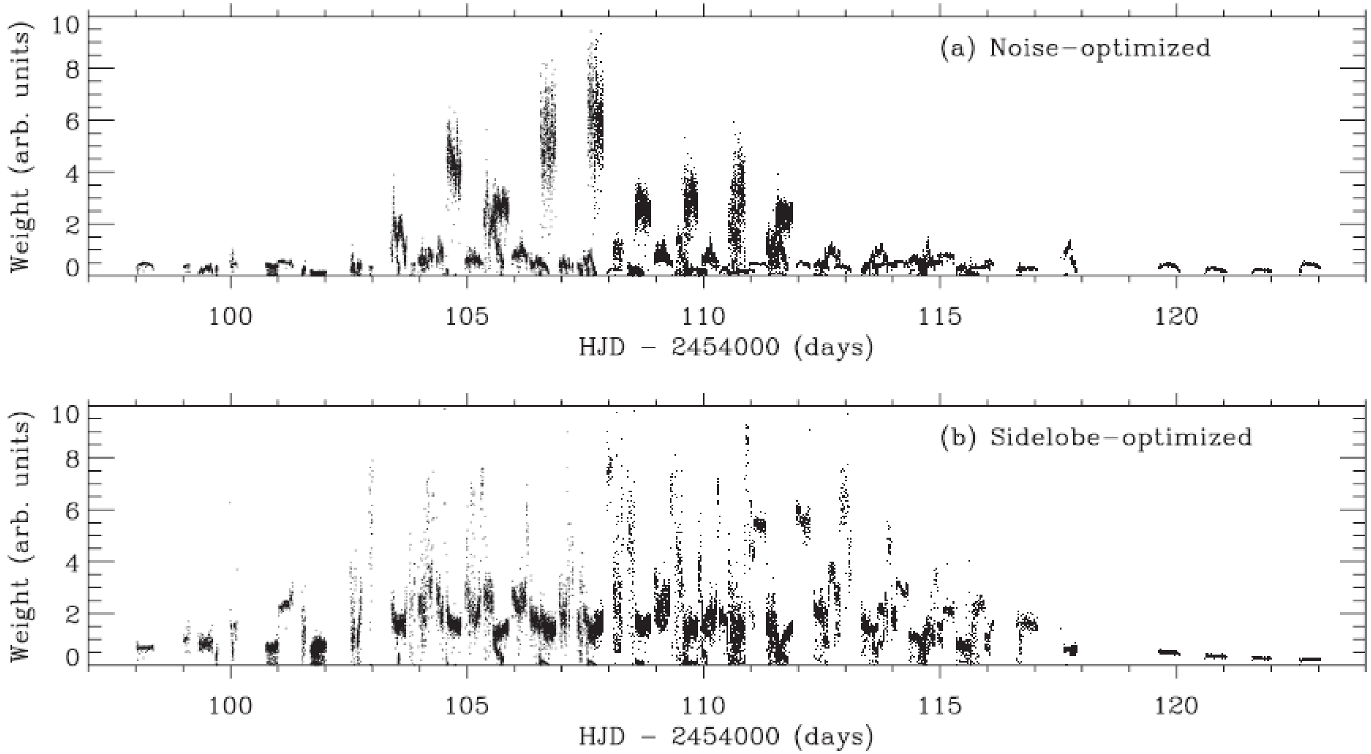


Figure 1. Weights for time series of velocity observations of Procyon, optimized to minimize: (a) the noise level and (b) the height of the sidelobes.

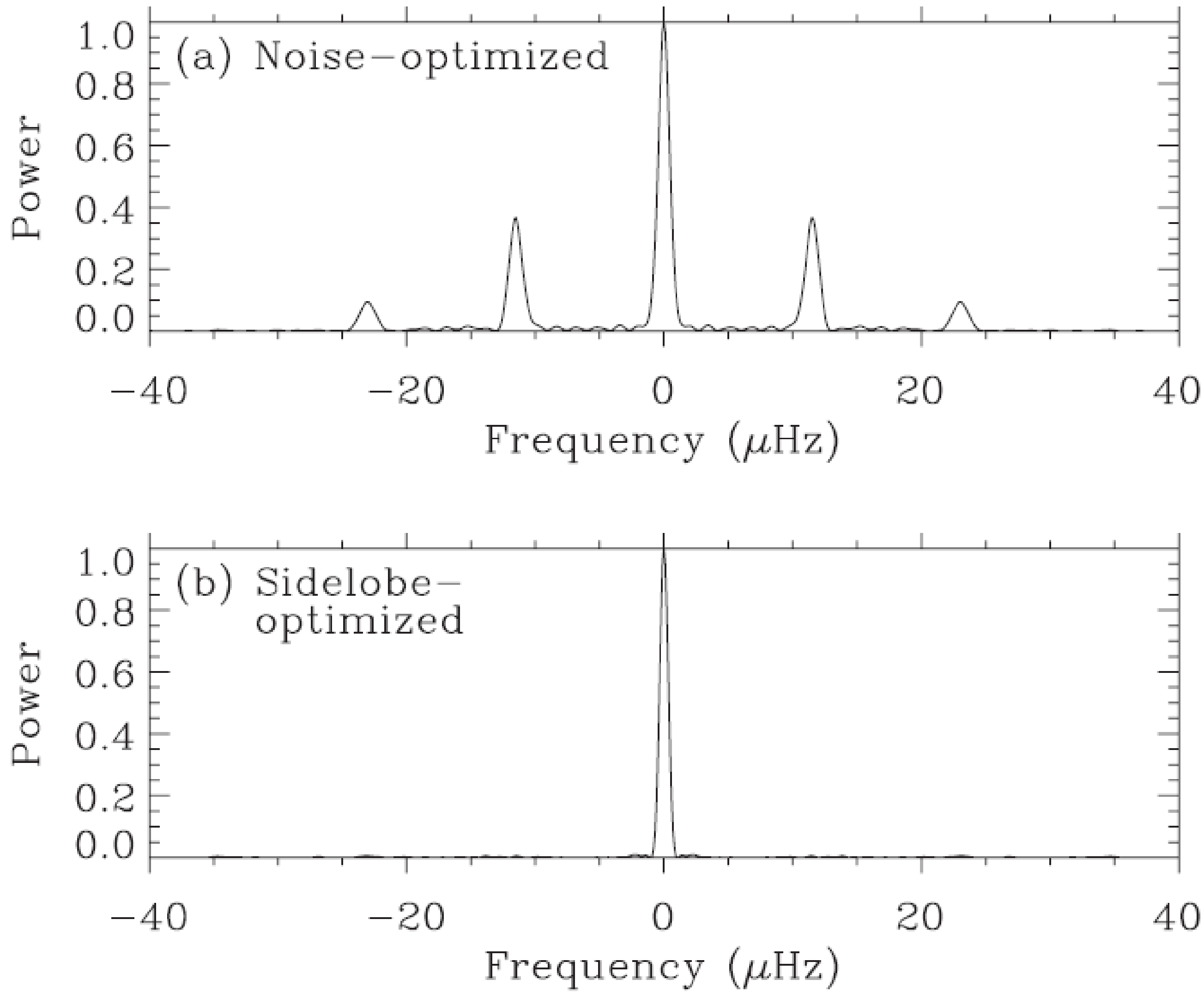
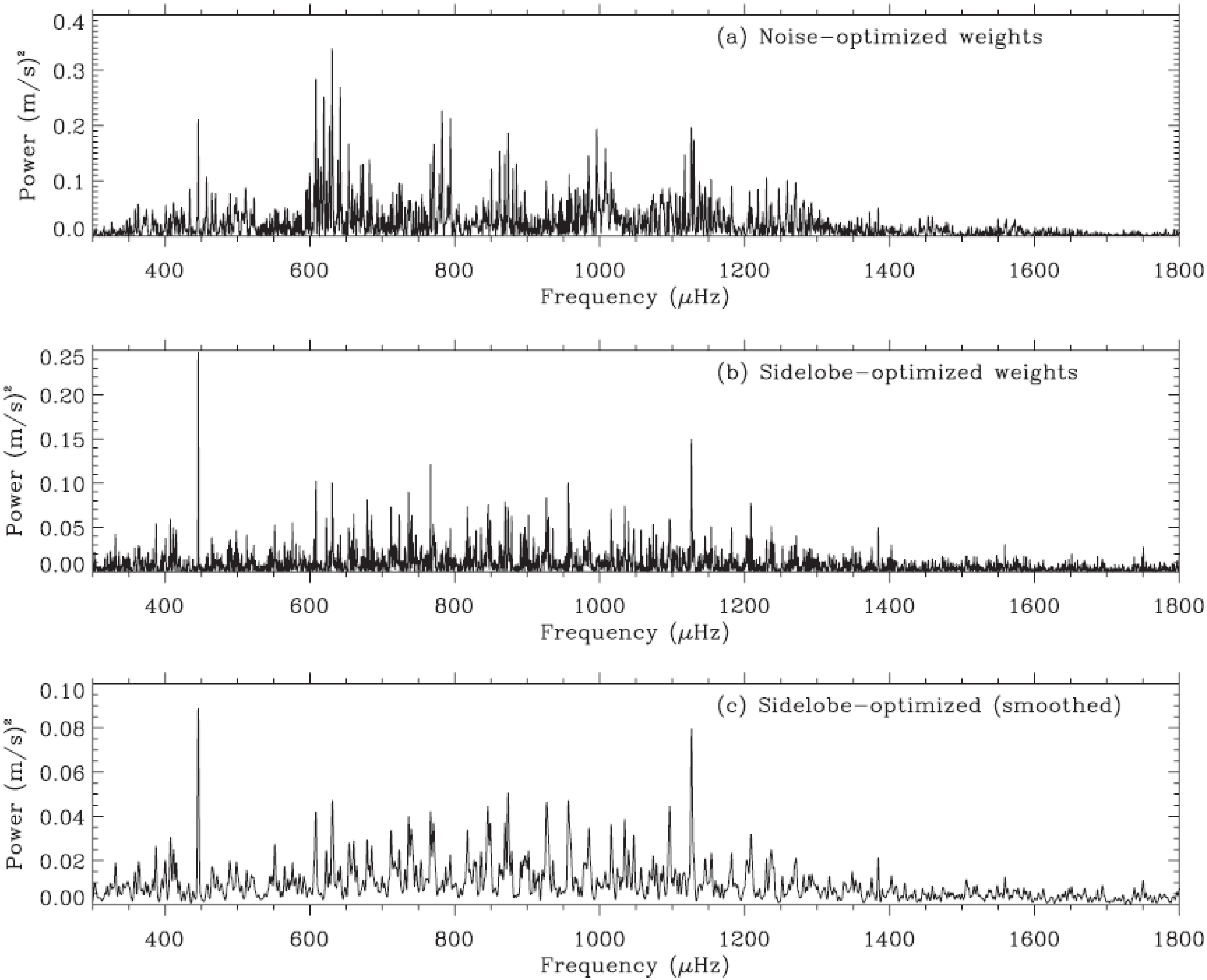


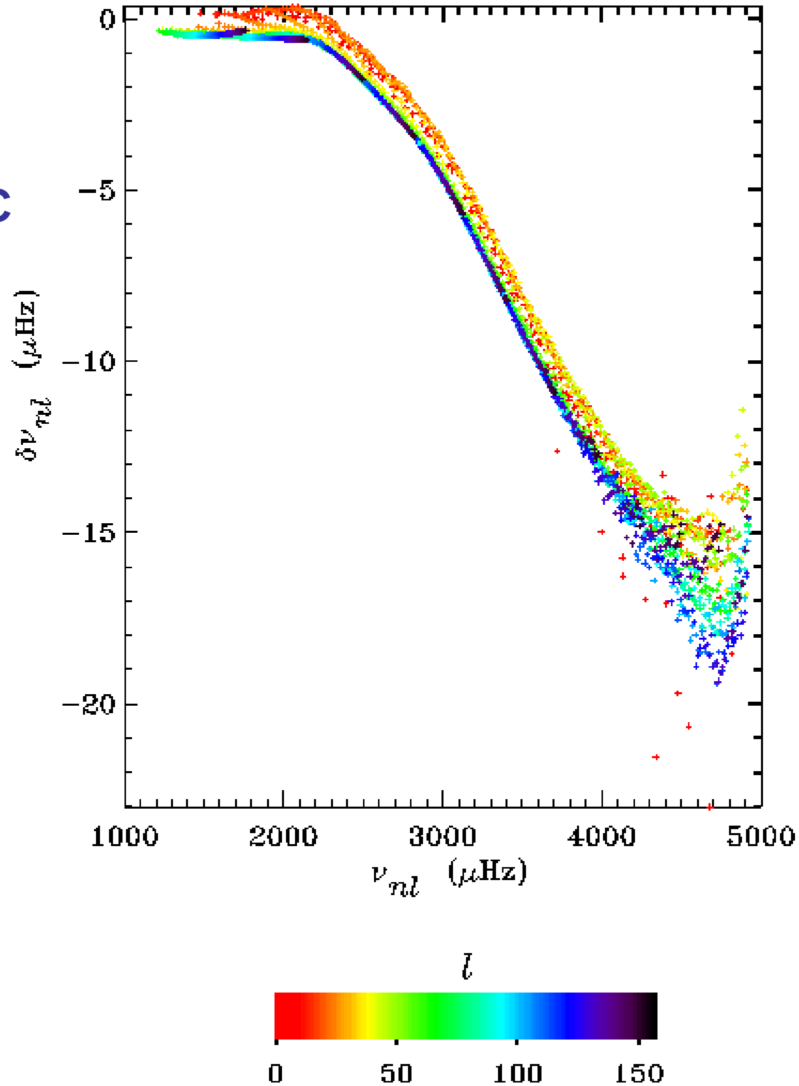
Figure 3. Spectral window for the Procyon observations using (a) noise-optimized weights and (b) sidelobe-optimized weights.



(a) Noise-optimized weights
Power (m/s)²
Frequency (μHz)
(b) Sidelobe-optimized weights
Power (m/s)²
Frequency (μHz)
(c) Sidelobe-optimized (smoothed)
Power (m/s)²
Frequency (μHz)

The Surface Offset

O - C



The Surface Offset

$$\nu_n \propto \sqrt{\rho}$$

$$\Delta\nu_0 \propto \sqrt{\rho}$$

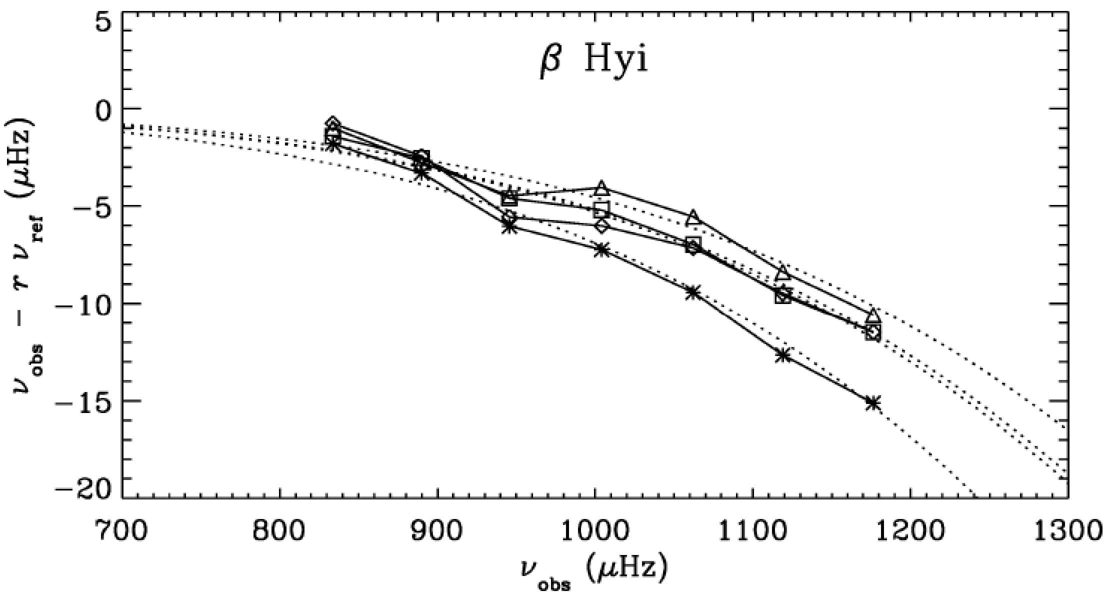
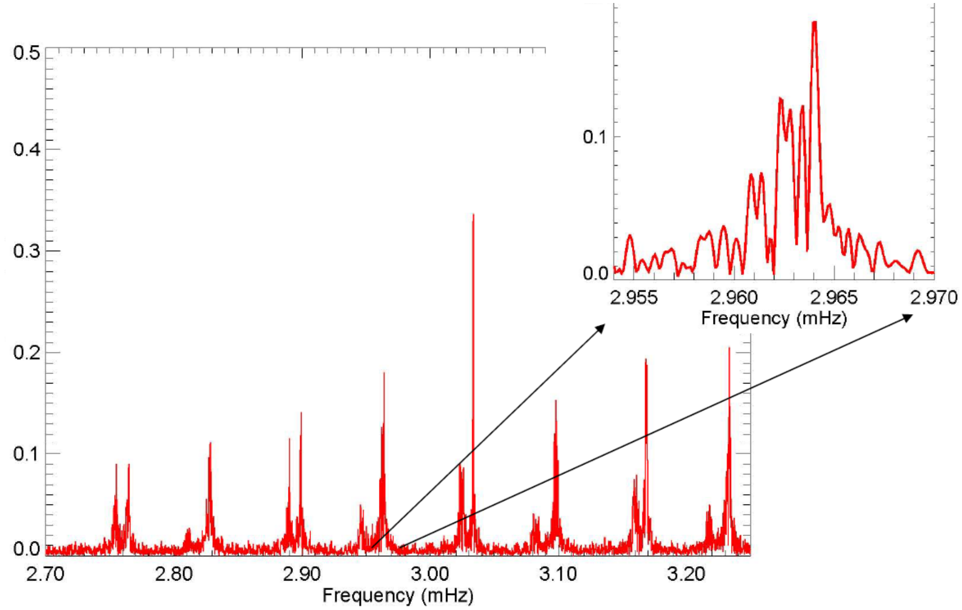


Fig. 2.—Difference between observed and calculated frequencies for radial modes in β Hyi. The models shown are model H (*squares*), model H^- (*triangles*), model H^+ (*diamonds*), and FM2003 (*asterisks*). The dotted curves show the corrections calculated from eq. (4).

The Surface Offset

$$\nu_n \propto \sqrt{\rho}$$

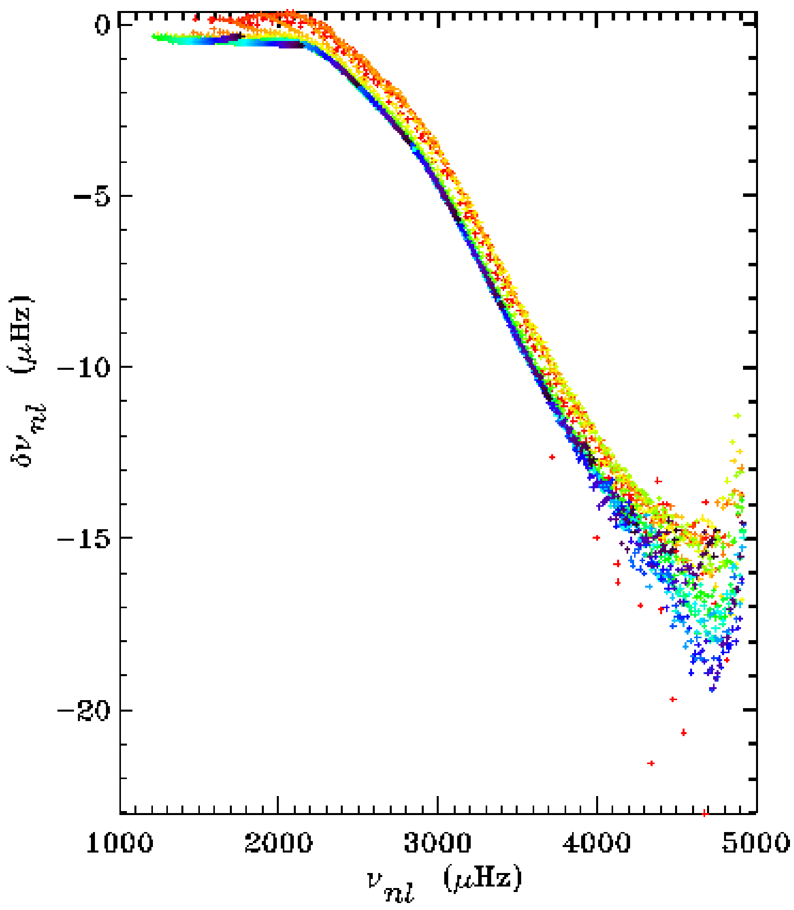
$$\Delta\nu_0 \propto \sqrt{\rho}$$



	MODEL S	GOLF	radial order, *n*
1. Frequency (*f*)	3038.95	3034.15	17-25 (21)
2. Large separation	135.855	134.810	17-25 (21)
3. f(n=17)	2497.35	2496.04	17
4. f(n=13)	1957.46	1957.45	13

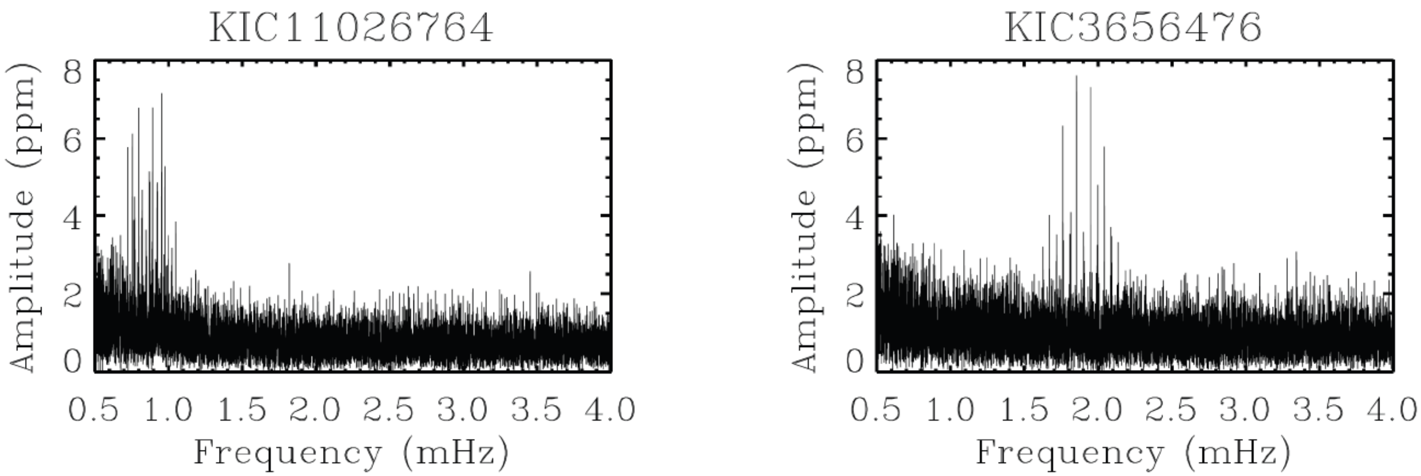
$$\nu_n \propto \sqrt{\rho}$$

$$\Delta\nu_0 \propto \sqrt{\rho}$$



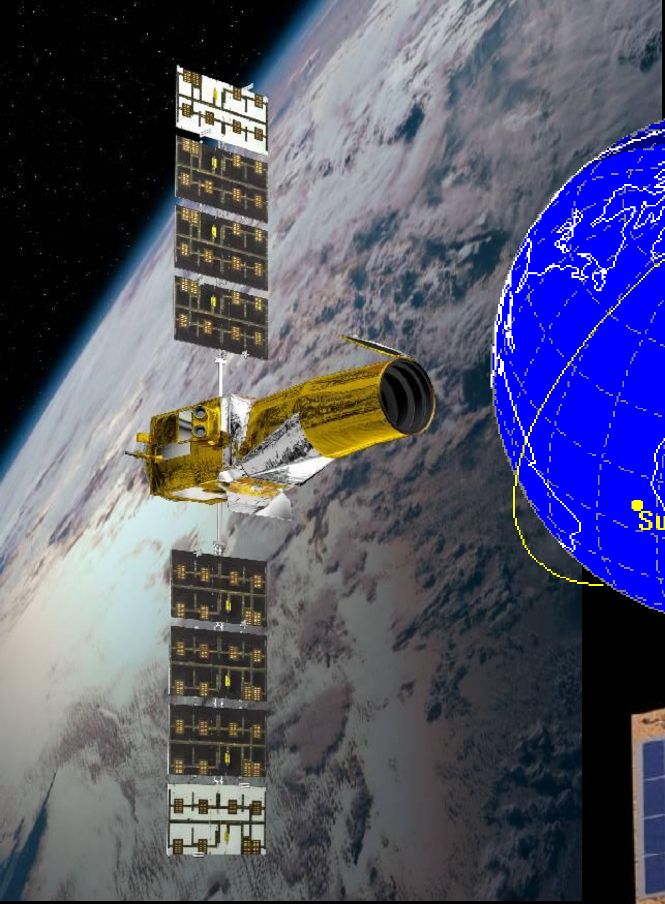
	MODEL S	GOLF	
1. Frequency (*f*)	3038.95	3034.15	**0.16 %**
2. Large separation	135.855	134.810	**0.78 %**
3. f(n=17)	2497.35	2496.04	**0.05 %**
4. f(n=13)	1957.46	1957.45	**0.0005 %**

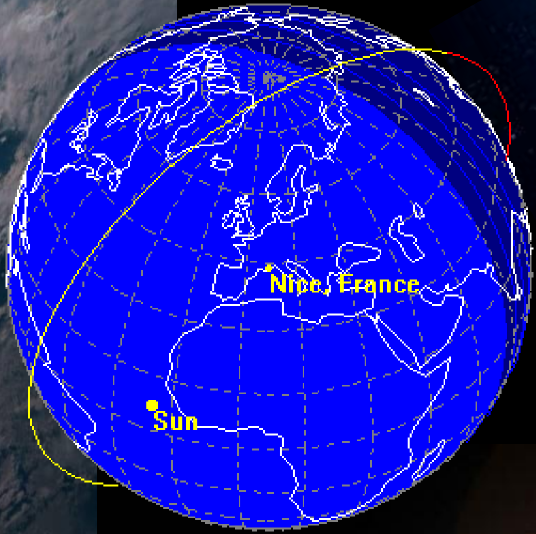
Requirements:
High-precision time series photometry with high duty cycle

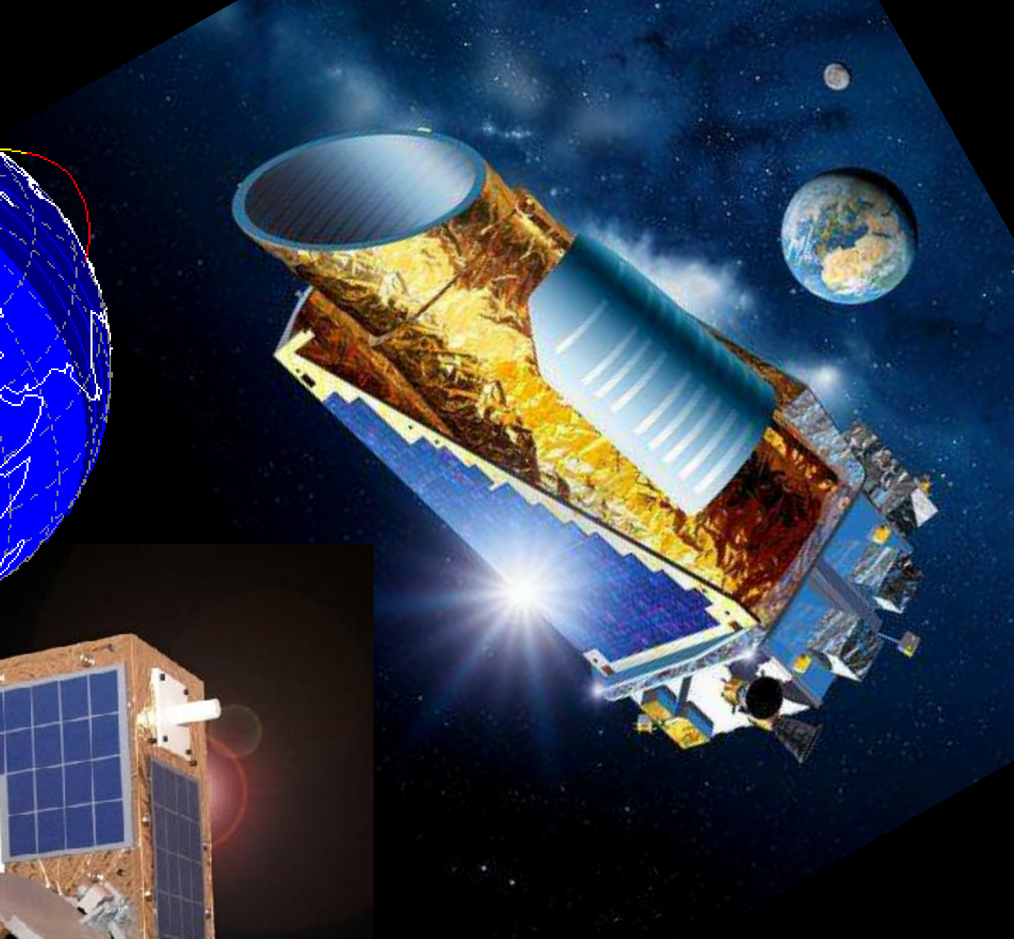


Space:

- High Photometric Precision due to no atmospheric effects (scintillation)
- Long uninterrupted time series (high duty cycle, extended observation)
- Large number of targets observed (large FOV, high density of stars)







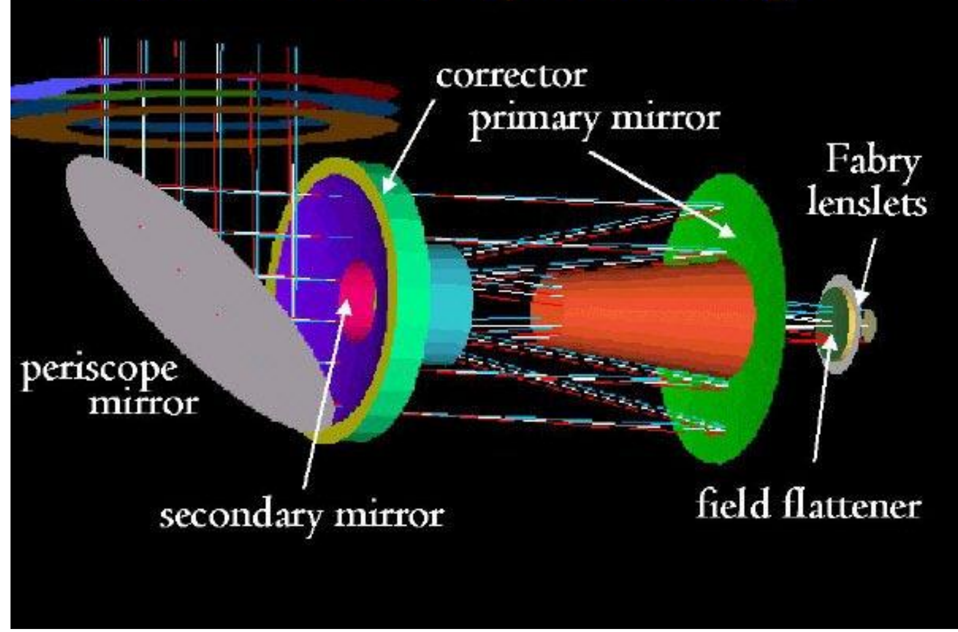
CoRoT and MOST
Low Earth Orbit (LEO)

Several pointings

Kepler Orbit
Earth trailing Heliocentric

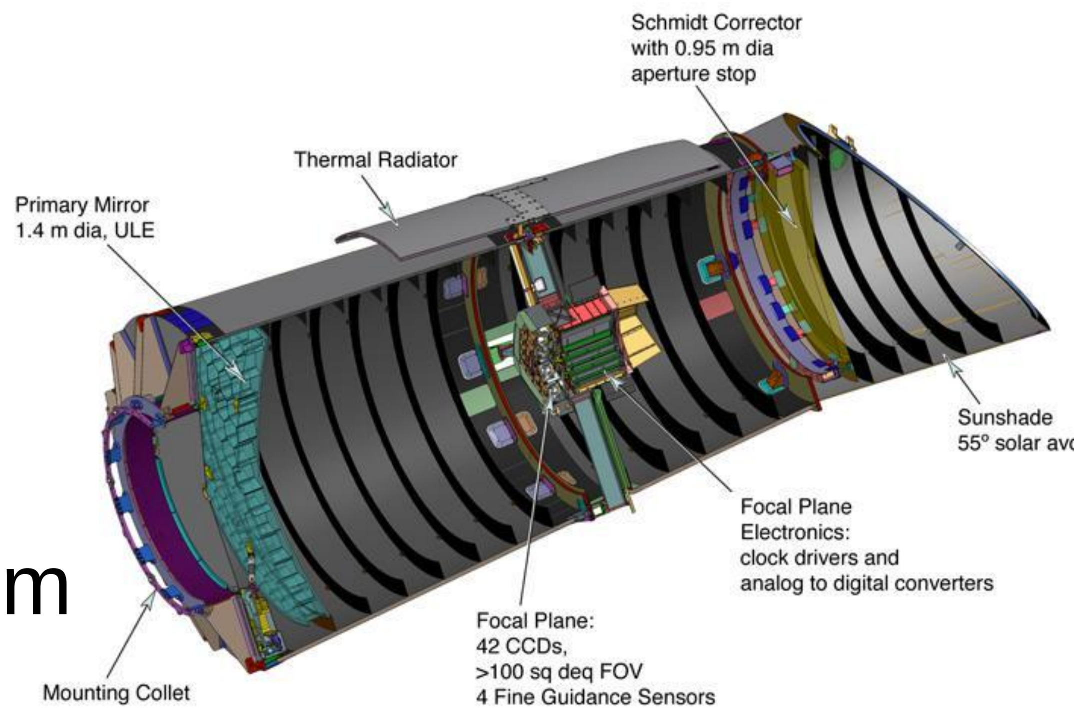
One FOV for whole mission

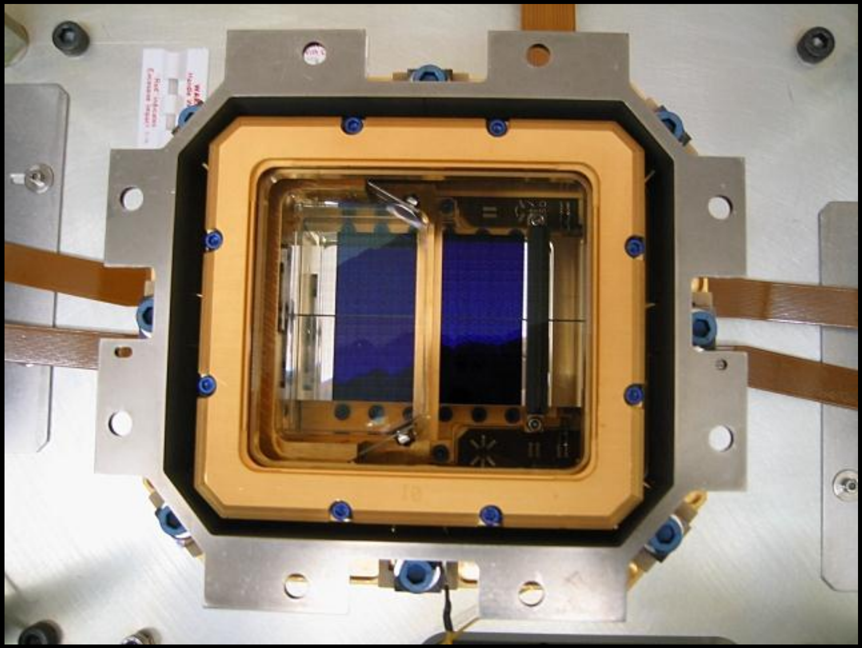
MOST (CSA): 15 cm



CoRoT (CNES): 27 cm

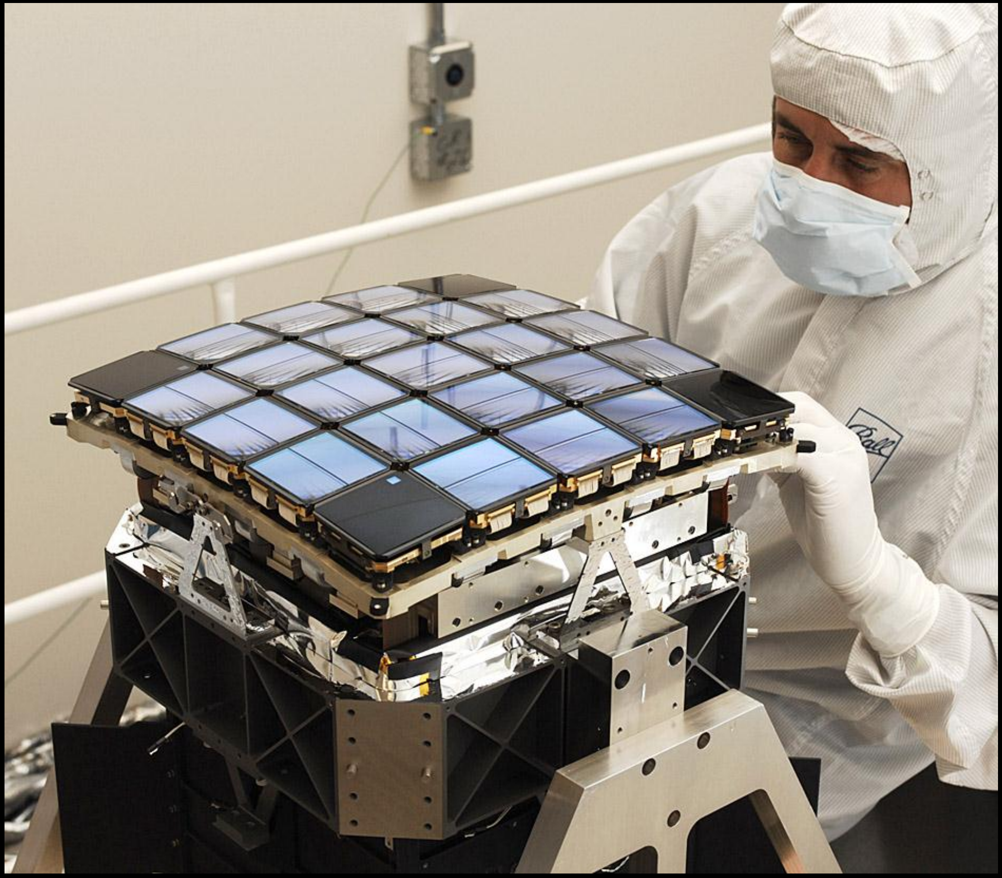
Kepler (NASA): 95 cm



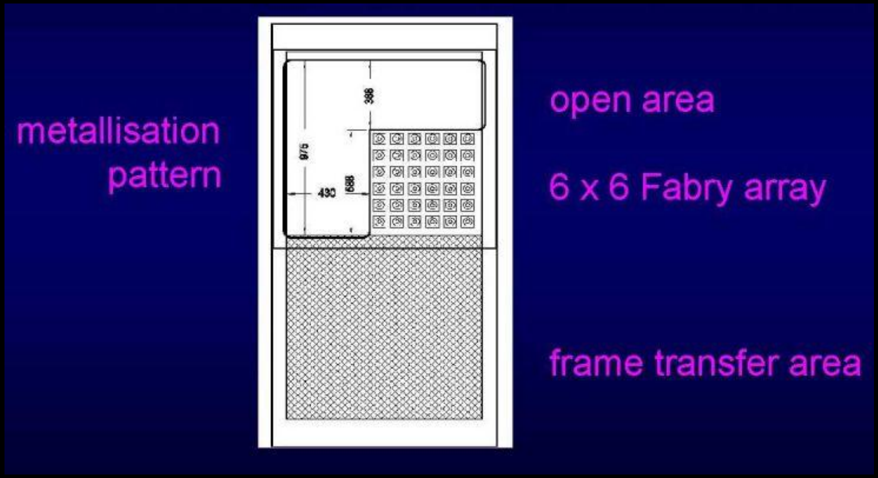


CoRoT: 4 CCD's

Kepler: 42 CCD's



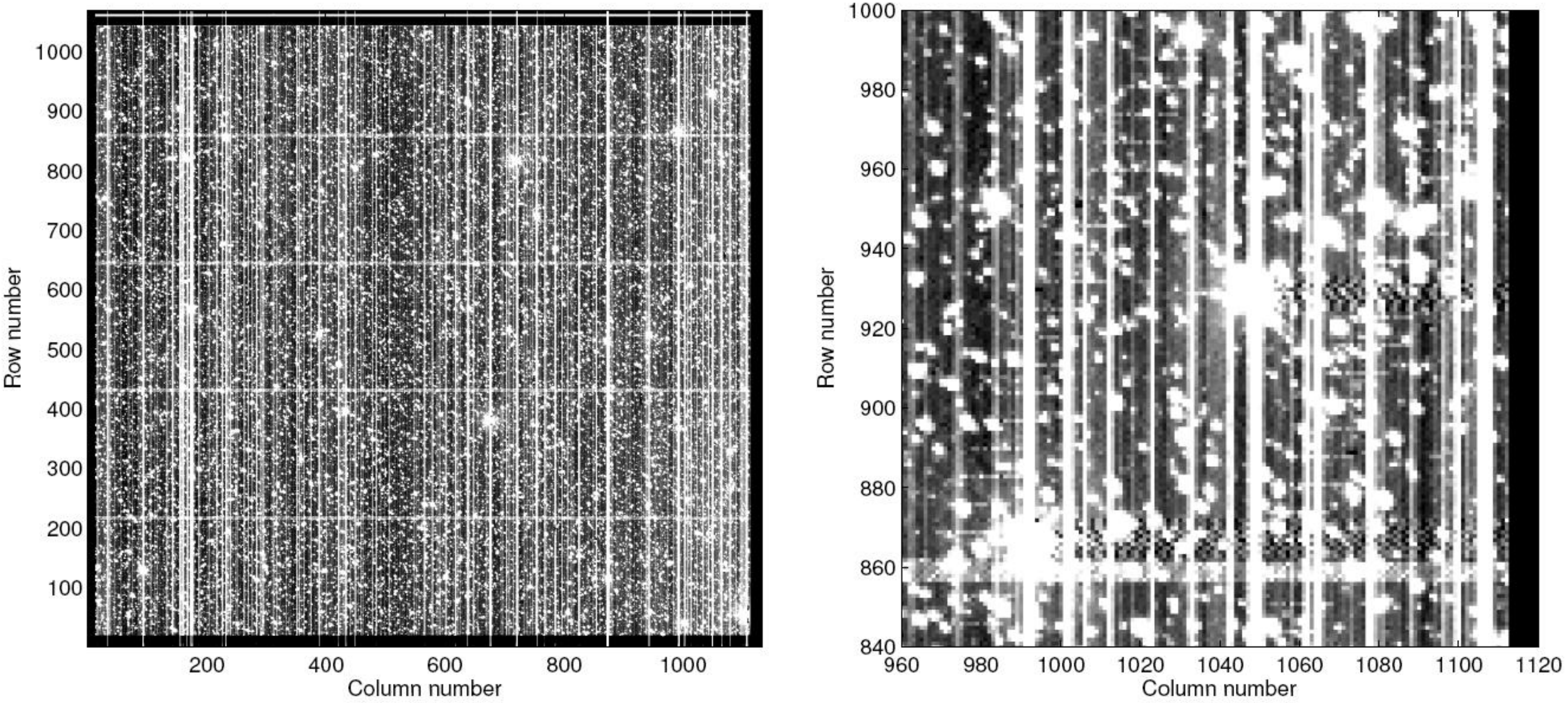
MOST: 1 CCD



The three Space Missions

- **MOST**: Precursor for dedicated time series missions. Focus is on bright stars.
- **CoRoT**: More than 100,000 targets for exoplanet studies (T(obs) < 180d). Few hundred stars observed for asteroseismology.
- **Kepler**: Very extended time series data (years). Relatively low crowding effects. High dynamical range (V: 7-16)

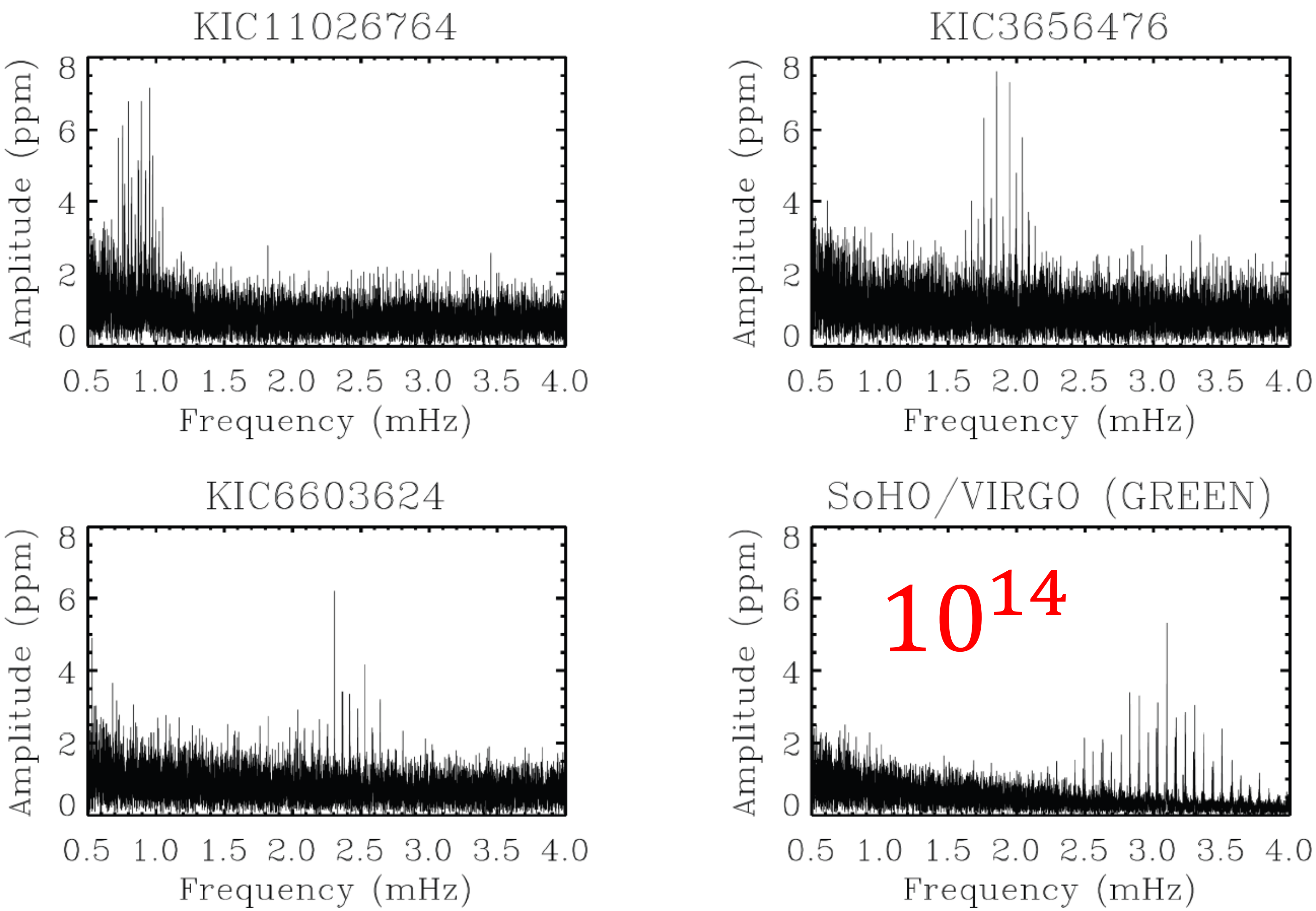
The data …



Jenkins et al. 2010

Kepler

Can the data meet the challenges?
…. a series of examples …

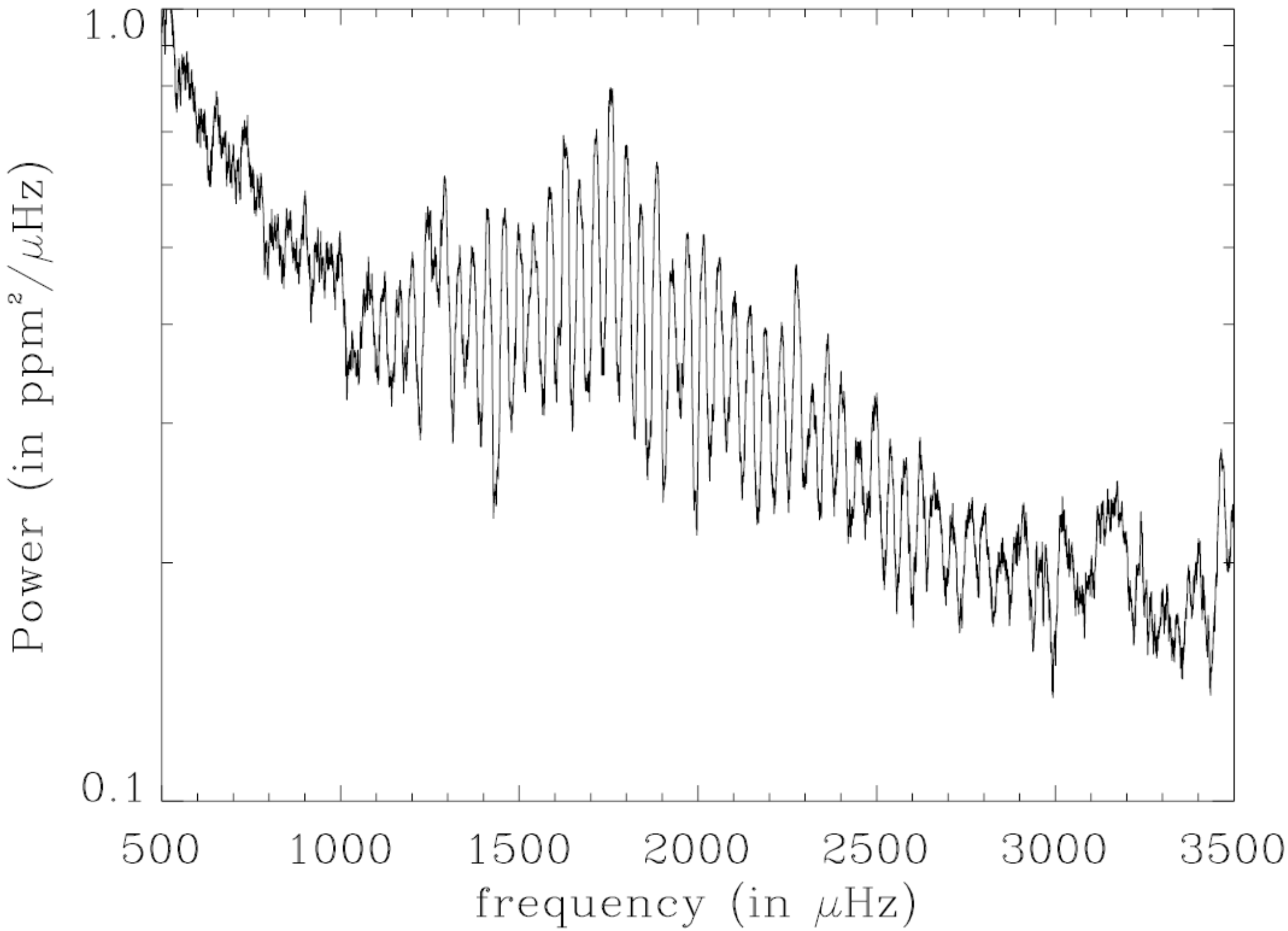


Kepler

A&A 2008

CoRoT sounds the stars: p-mode parameters of Sun-like oscillations on HD49933*

T. Appourchaux[1], E. Michel[2], M. Auvergne[2], A. Baglin[2], T. Toutain[3], O. Benomar[1], W. J. Chaplin[3], S. Deheuvels[2], G. A. Verner[4], R. A. García[5], F. Baudin[1], P. Boumier[1], R. Samadi[2], B. Mosser[2], J. Ballot[6], C. Barban[2], Y. Elsworth[3], S. J. Jiménez-Reyes[8], H. Kjeldsen[7], C. Régulo[8], and I. W. Roxburgh[4,2]

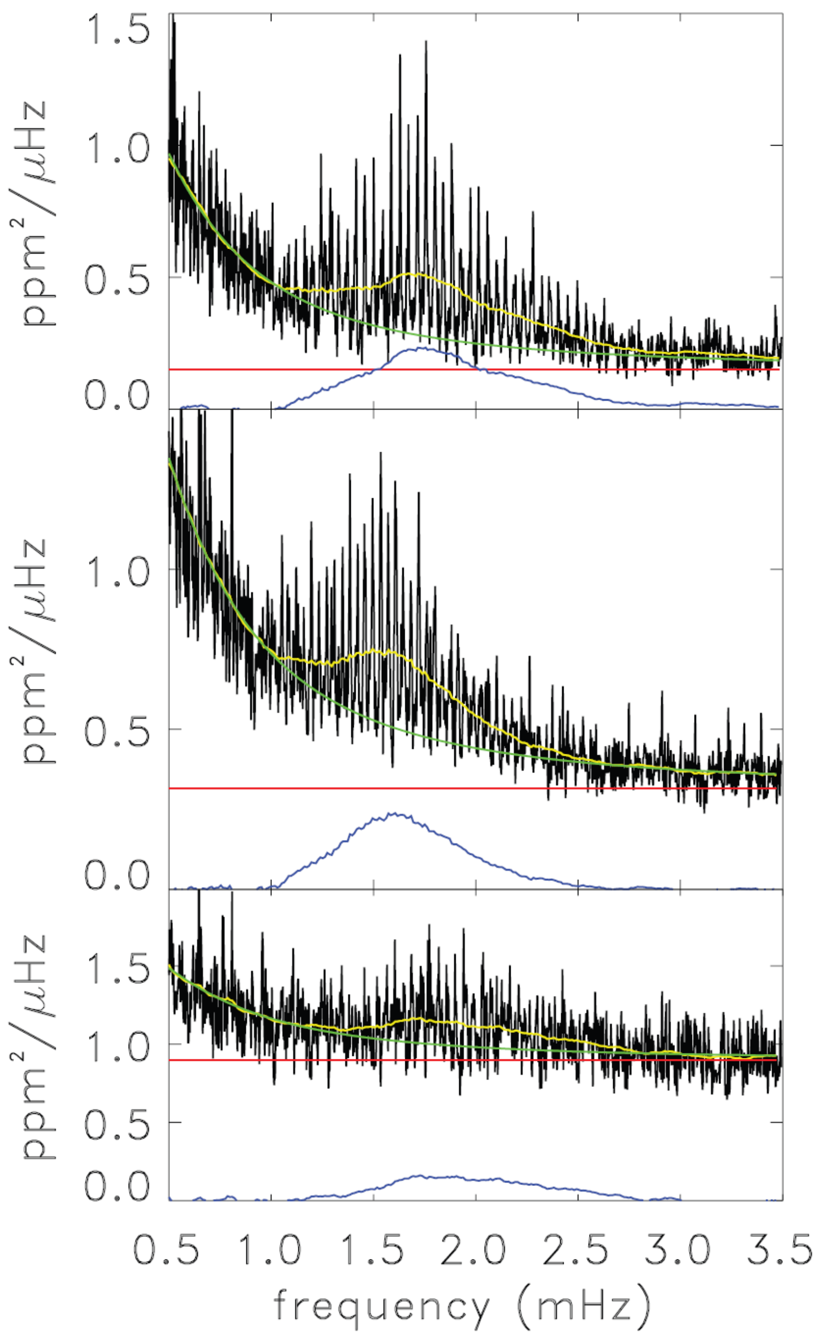


CoRoT

Michel et al. 2008

CoRoT Measures Solar-Like Oscillations and Granulation in Stars Hotter Than the Sun

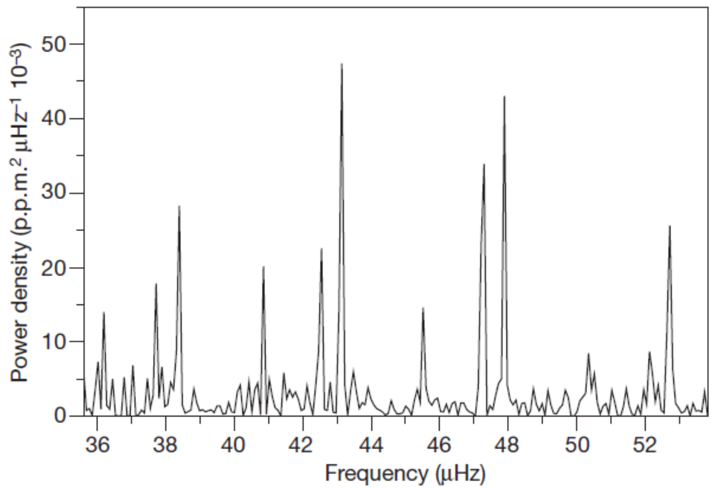
Eric Michel,[1*] Annie Baglin,[1] Michel Auvergne,[1] Claude Catala,[1] Reza Samadi,[1] Frédéric Baudin,[2] Thierry Appourchaux,[2] Caroline Barban,[1] Werner W. Weiss,[3] Gabrielle Berthomieu,[4] Patrick Boumier,[2] Marc-Antoine Dupret,[1] Rafael A. Garcia,[5] Malcolm Fridlund,[6] Rafael Garrido,[7] Marie-Jo Goupil,[1] Hans Kjeldsen,[8] Yveline Lebreton,[9] Benoît Mosser,[1] Arlette Grotsch-Noels,[10] Eduardo Janot-Pacheco,[11] Janine Provost,[4] Ian W. Roxburgh,[12,1] Anne Thoul,[10] Thierry Toutain,[13] Didier Tiphène,[1] Sylvaine Turck-Chieze,[5] Sylvie D. Vauclair,[14] Gérard P. Vauclair,[14] Conny Aerts,[15] Georges Alecian,[16] Jérôme Ballot,[17] Stéphane Charpinet,[14] Anne-Marie Hubert,[9] François Lignières,[14] Philippe Mathias,[18] Mario J. P. F. G. Monteiro,[19] Coralie Neiner,[9] Ennio Poretti,[20] José Renan de Medeiros,[21] Ignasi Ribas,[22] Michel L. Rieutord,[14] Teodoro Roca Cortés,[23] Konstanze Zwintz[3]

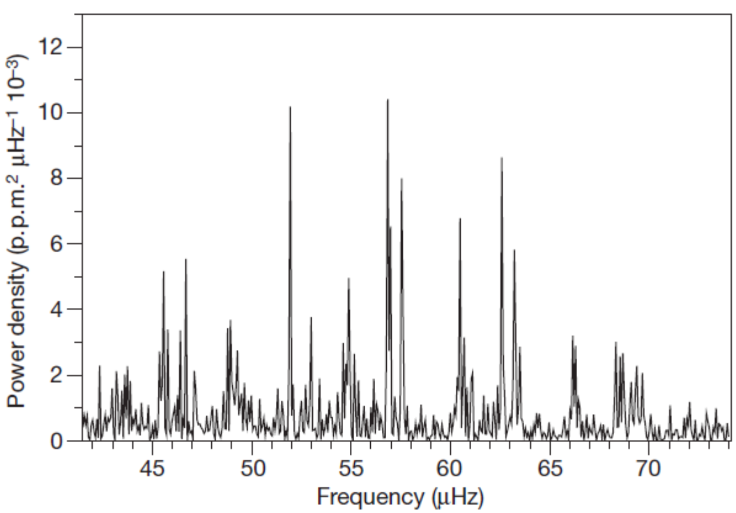


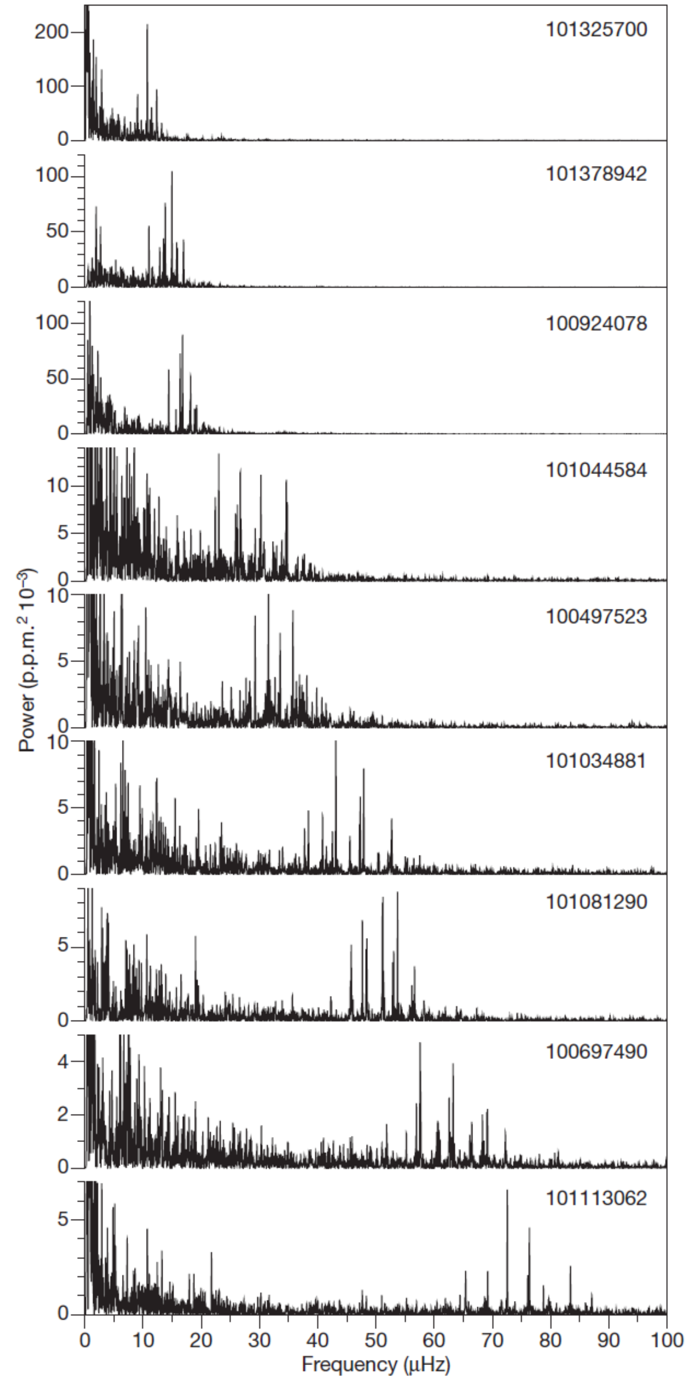
De Ridder et al. 2009

Non-radial oscillation modes with long lifetimes in giant stars

Joris De Ridder[1], Caroline Barban[2], Frédéric Baudin[3], Fabien Carrier[1], Artie P. Hatzes[4], Saskia Hekker[5,1], Thomas Kallinger[6], Werner W. Weiss[6], Annie Baglin[2], Michel Auvergne[2], Réza Samadi[2], Pierre Barge[7] & Magali Deleuil[7]

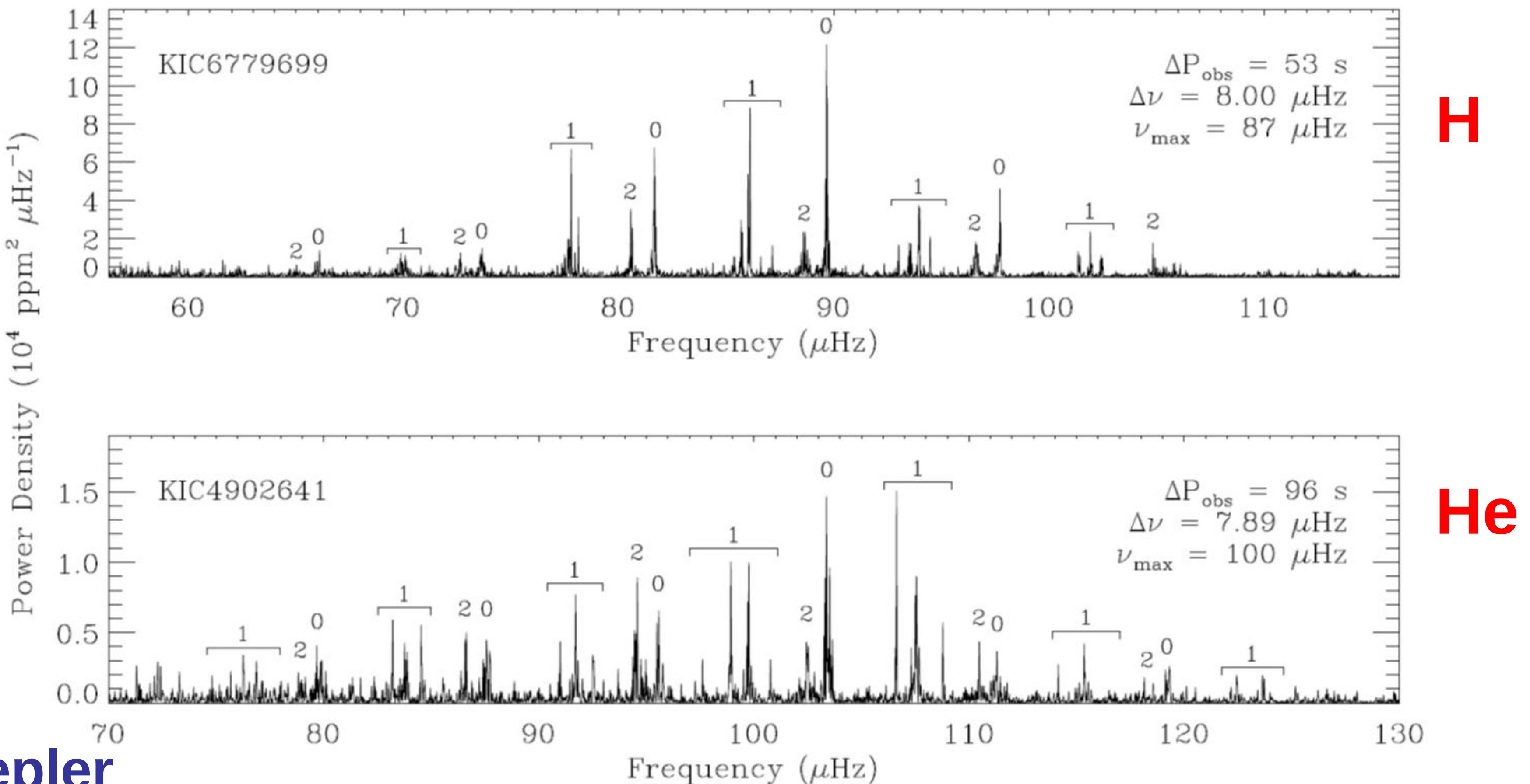






Gravity modes as a way to distinguish between hydrogen- and helium-burning red giant stars

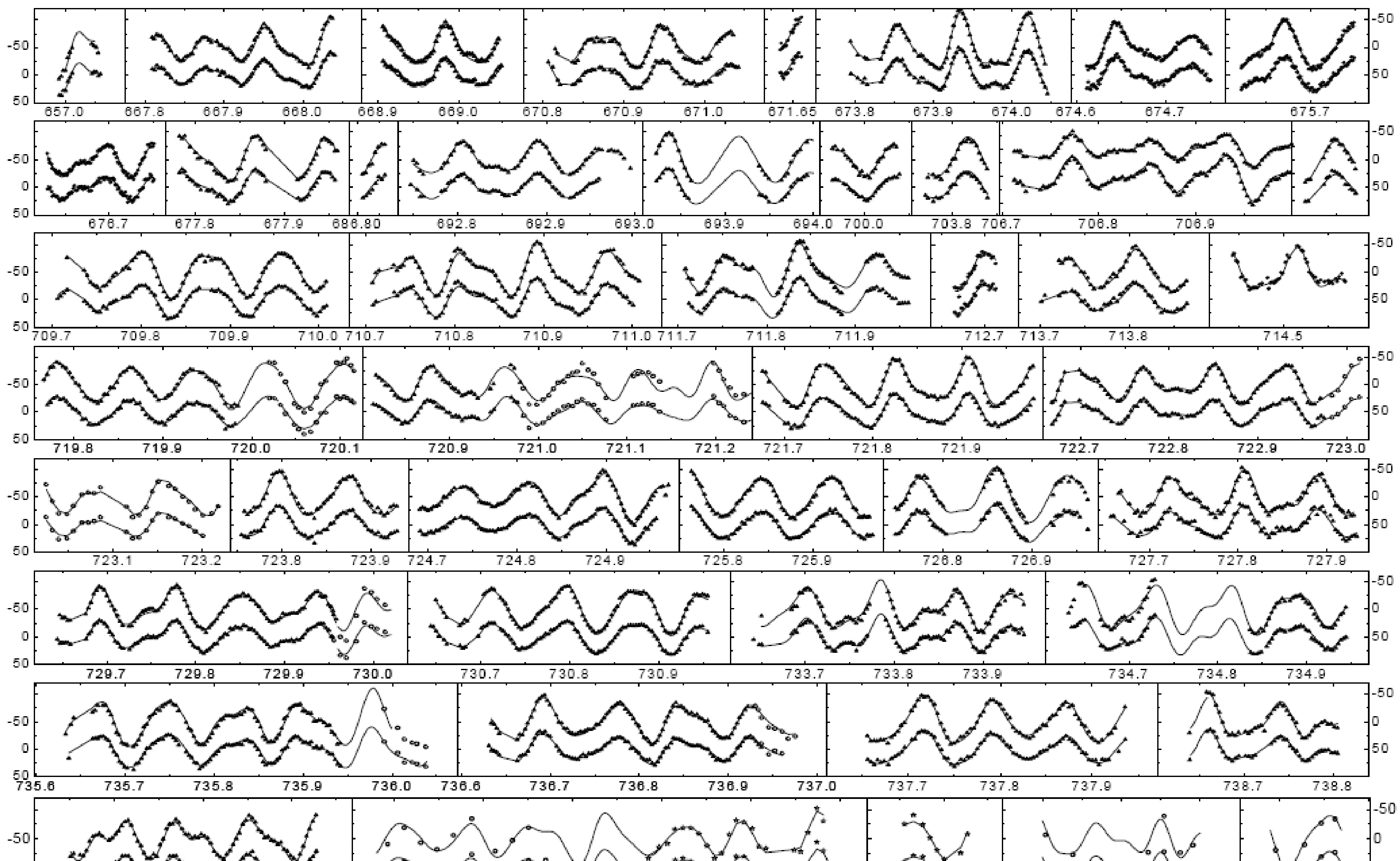
Timothy R. Bedding[1], Benoit Mosser[2], Daniel Huber[1], Josefina Montalbán[3], Paul Beck[4], Jørgen Christensen-Dalsgaard[5], Yvonne P. Elsworth[6], Rafael A. García[7], Andrea Miglio[3,6], Dennis Stello[1], Timothy R. White[1], Joris De Ridder[4], Saskia Hekker[6,8], Conny Aerts[4,9], Caroline Barban[2], 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]

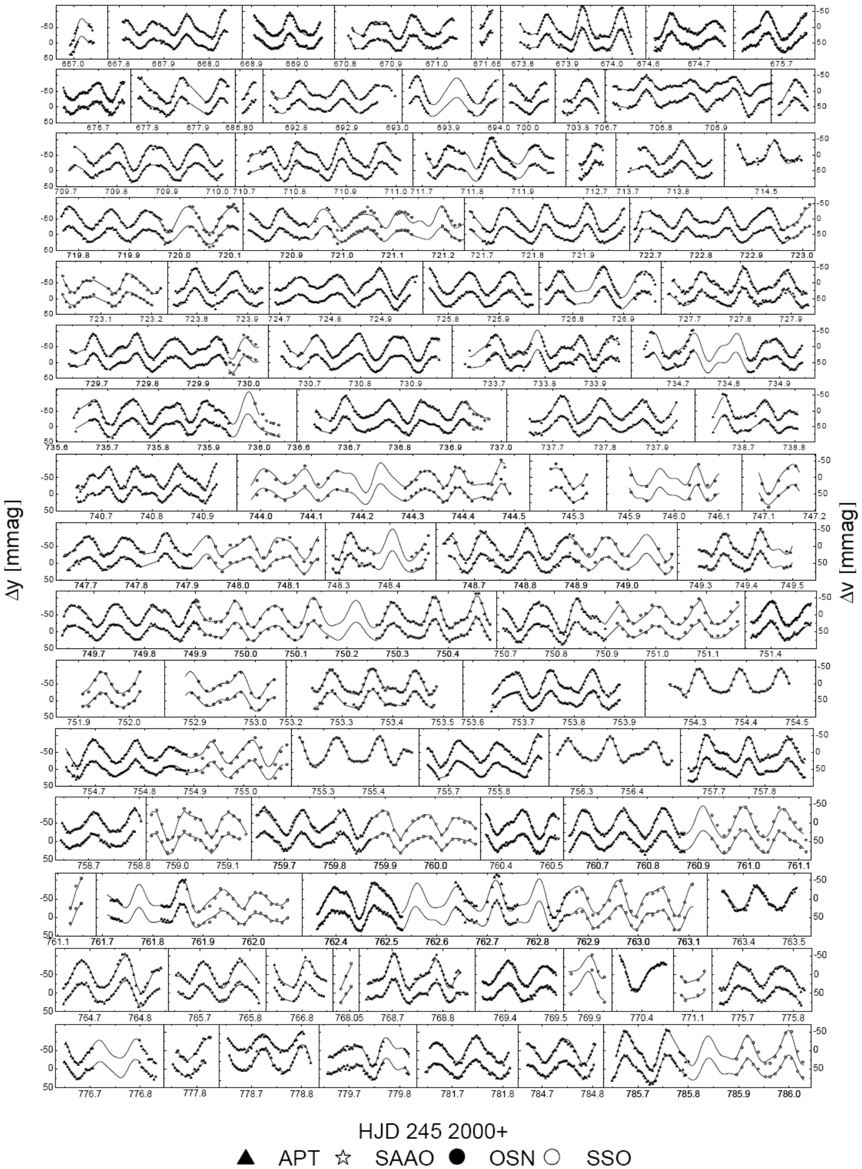


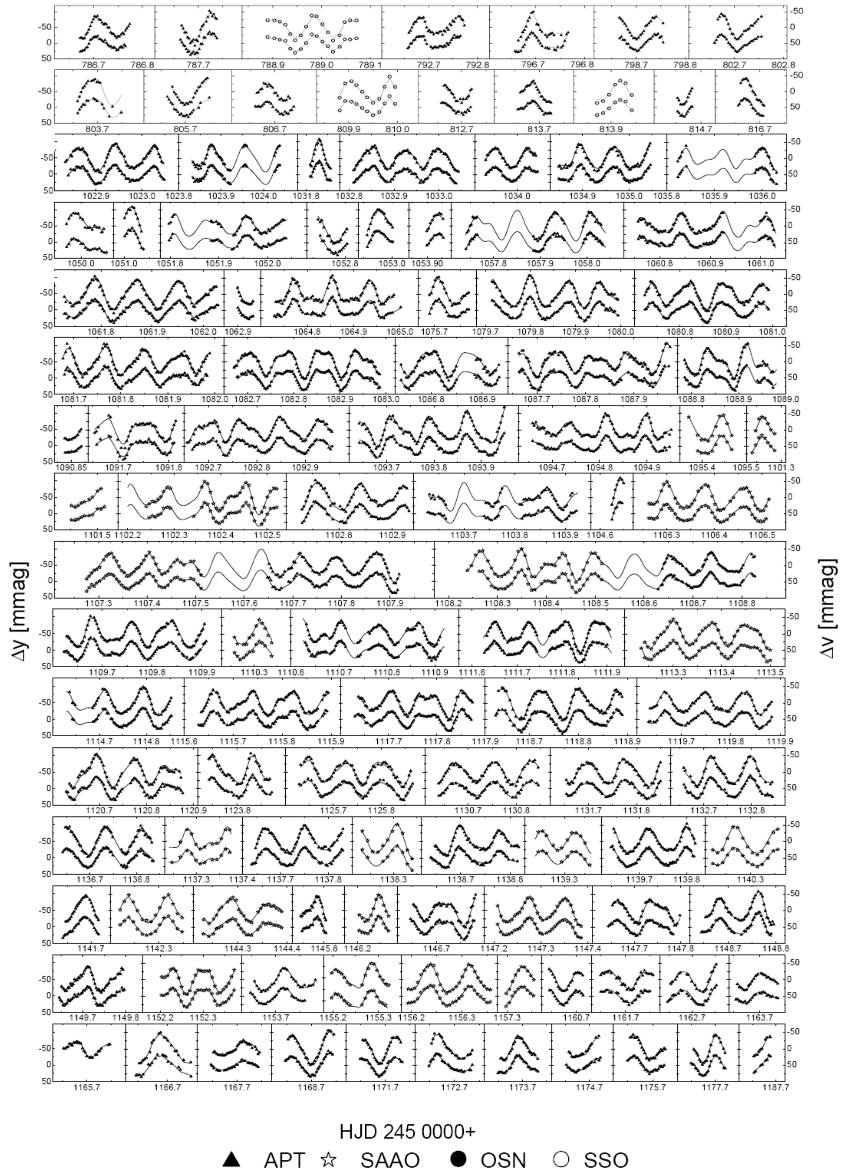
Kepler

Detection of 75+ pulsation frequencies in the δ Scuti star FG Vir

M. Breger[1], P. Lenz[1], V. Antoci[1], E. Guggenberger[1], R. R. Shobbrook[2], G. Handler[1], B. Ngwato[3], F. Rodler[1], E. Rodriguez[4], P. López de Coca[4], A. Rolland[4], and V. Costa[4]




Δy [mmag]
Δv [mmag]
HJD 245 2000+
APT SAAO OSN SSO


Δy [mmag]
Δv [mmag]
HJD 245 0000+
APT SAAO OSN SSO

Mode Identification?

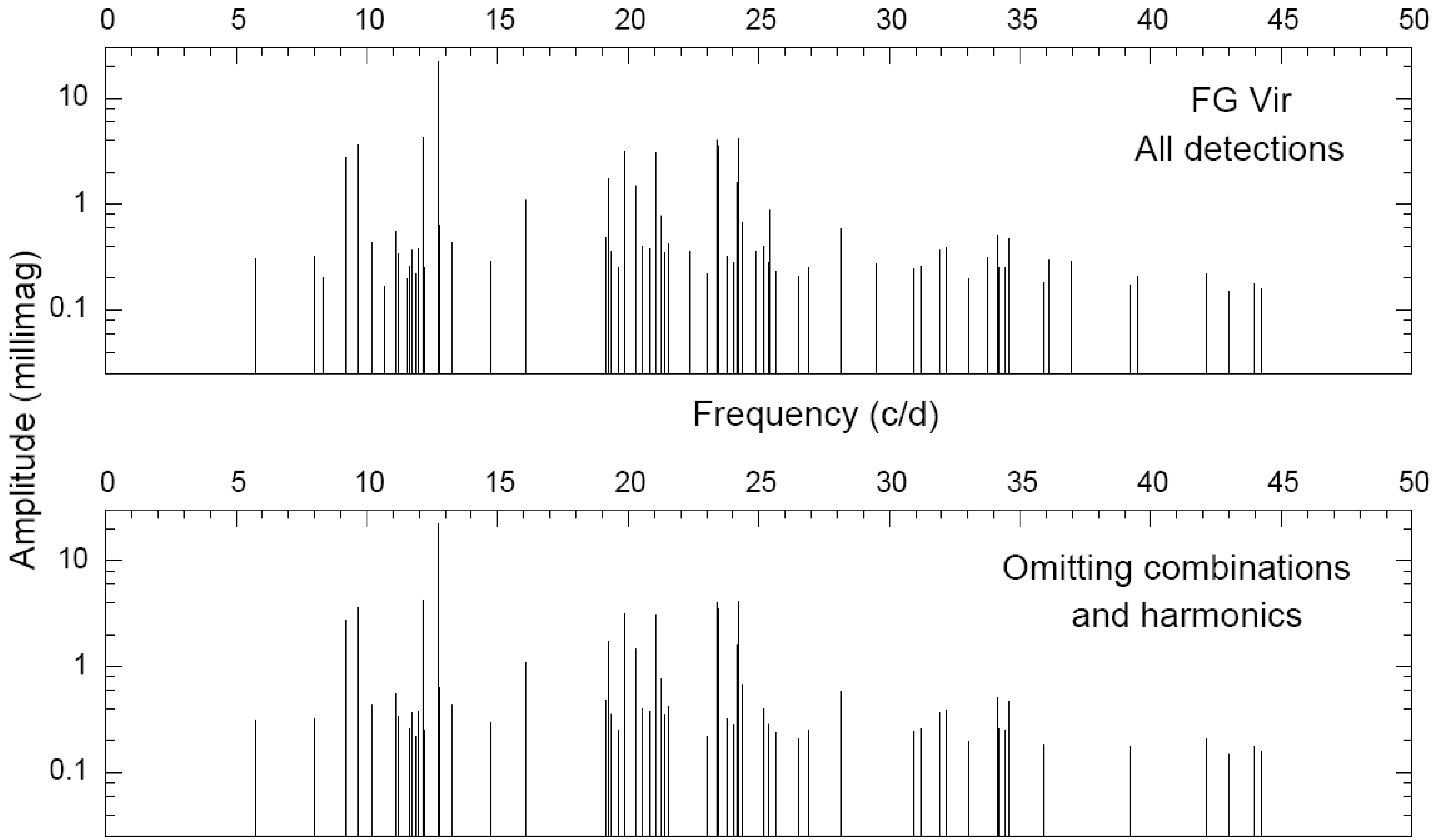


Fig. 4. Distribution of the frequencies of the detected modes. The diagram suggests that the excited pulsation modes are not equally distributed in frequency.

HD 50844: a new look at $^{\delta}$ Scuti stars from CoRoT space photometry

E. Poretti[1] - E. Michel[2] - R. Garrido[3] - L. Lefèvre[2] - L. Mantegazza[1] - M. Rainer[1] - E. Rodríguez[3] - K. Uytterhoeven[1] - P. J. Amado[3] - S. Martín-Ruiz[3] - A. Moya[3] - E. Niemczura[4] - J. C. Suárez[3] - W. Zima[5] - A. Baglin[2] - M. Auvergne[2] - F. Baudin[6] - C. Catala[2] - R. Samadi[2] - M. Alvarez[7] - P. Mathias[8] - M. Paparò[9] - P. Pápics[9] - E. Plachy[9]

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2 - LESIA, Observatoire de Paris, CNRS (UMR 8109), Université Paris 6, Université Paris Diderot, 5 place J. Janssen, 92195 Meudon, France
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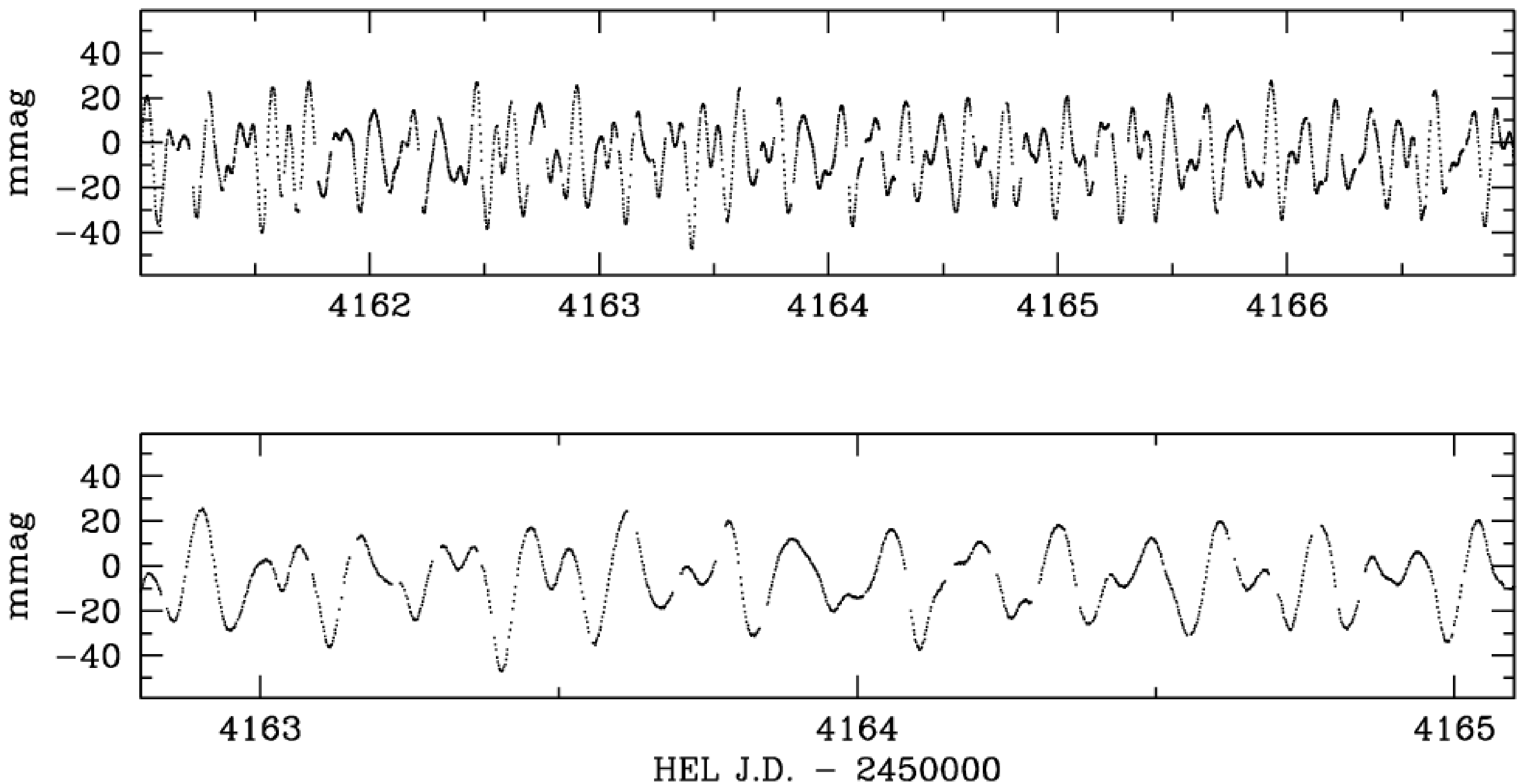
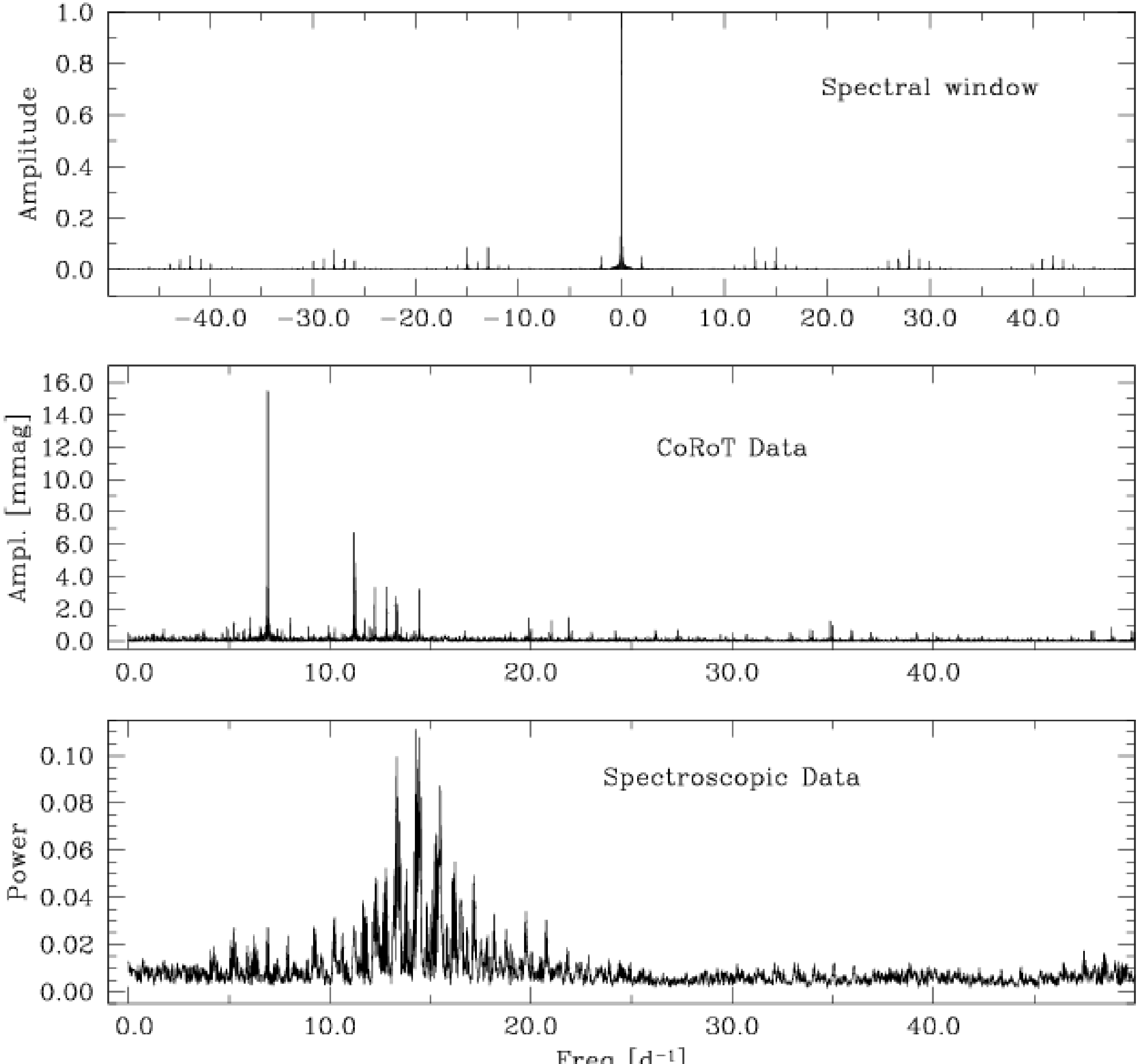
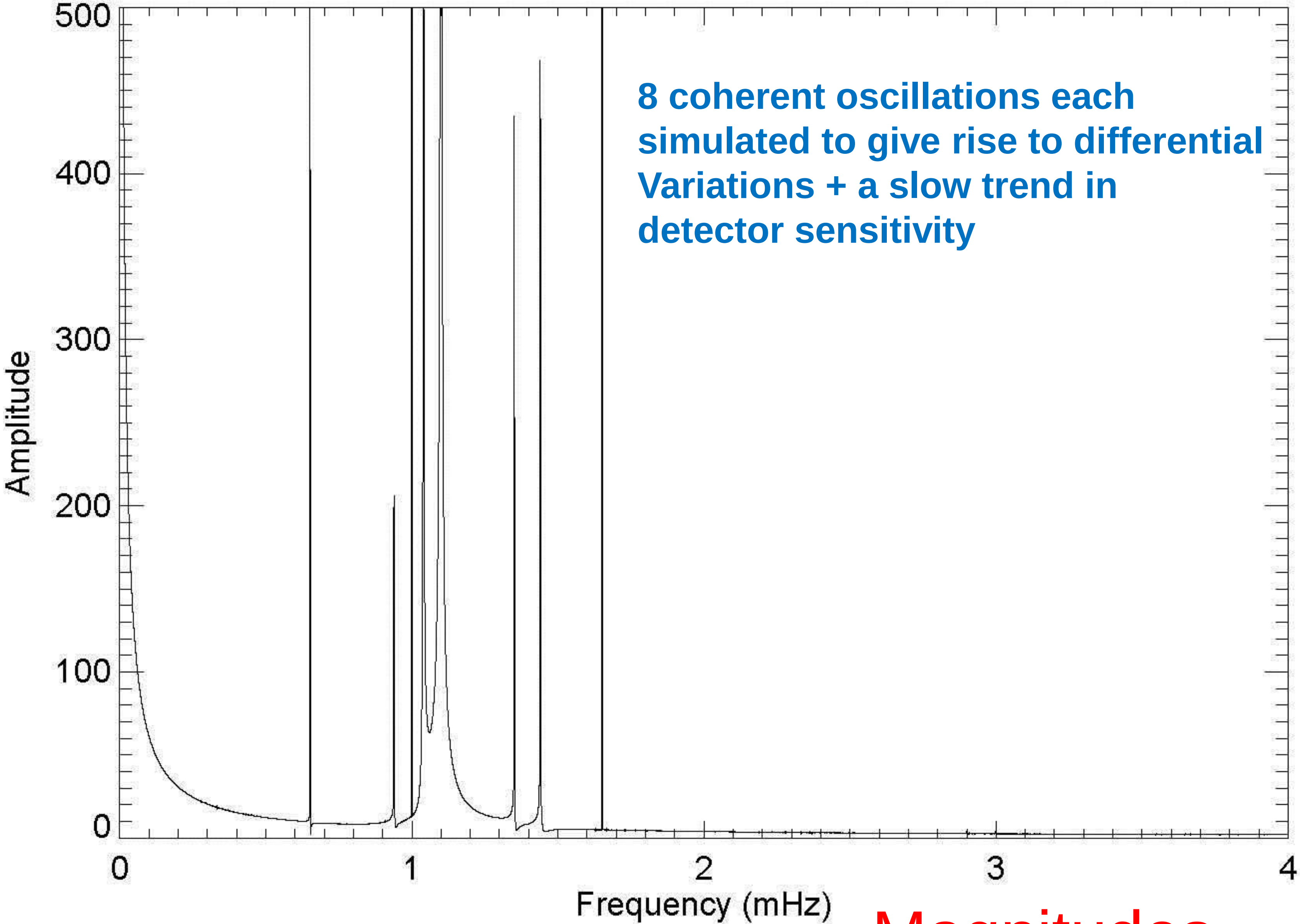
4 - Astronomical Institute of the Wroclaw University, ul. Kopenika 11, 51-622 Wroclaw, Poland
5 - Instituut voor Sterrenkunde, K.U. Leuven, Celestijnenlaan 200 D, 3001 Leuven, Belgium
6 - Institut d'Astrophysique Spatiale, CNRS, UMR 8617, Université Paris XI, 91405 Orsay, France
7 - Observatorio Astronómico Nacional, Instituto de Astronomia, UNAM, Apto Postal 877, Ensenada, BC 22860, Mexico
8 - UMR 6525 H. Fizeau, UNS, CNRS, OCA, Campus Valrose, 06108 Nice Cedex 2, France
9 - Konkoly Observatory, PO Box 67, 1525 Budapest, Hungary

Received 11 March 2009 / Accepted 10 May 2009

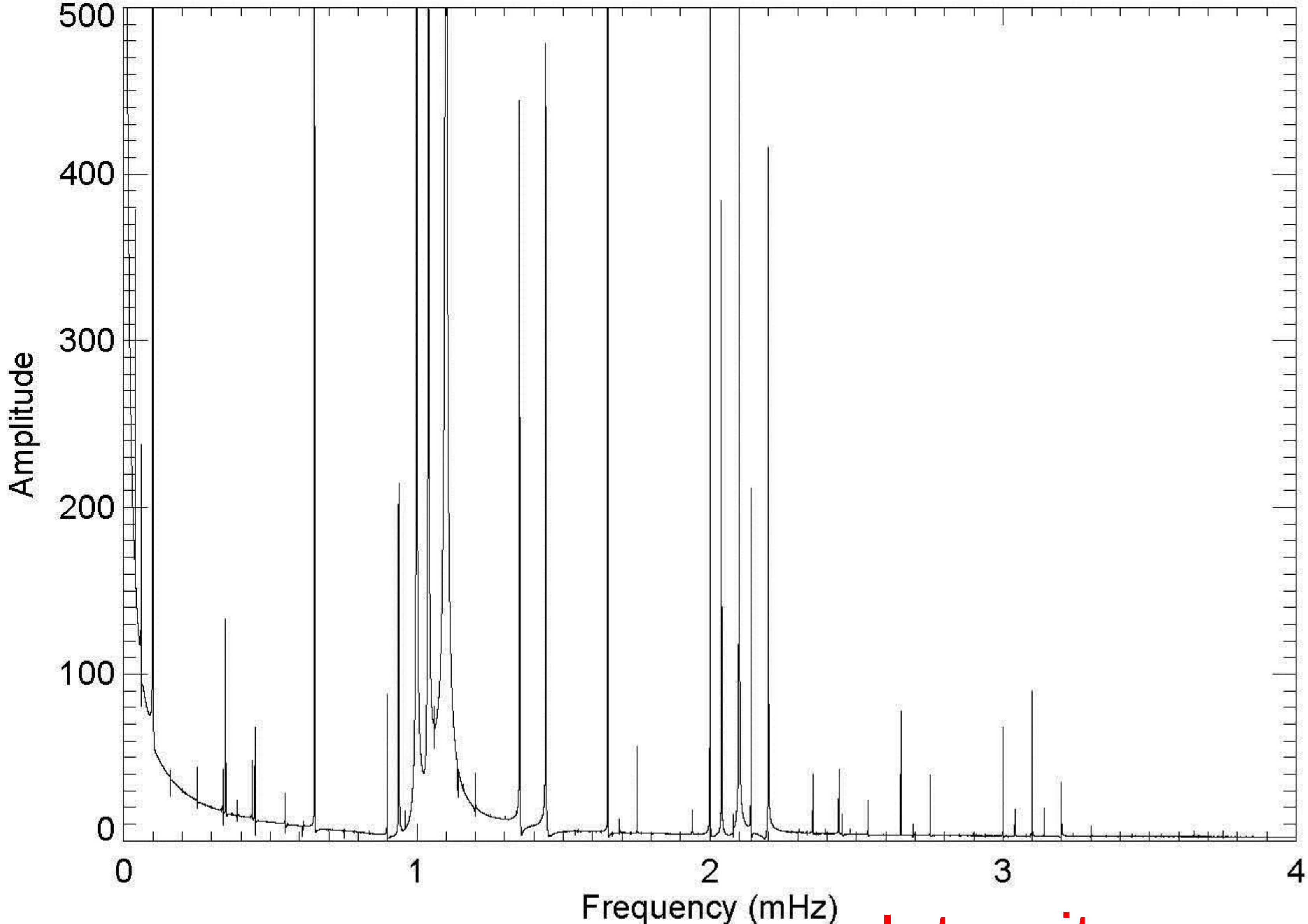


Mode Identification?

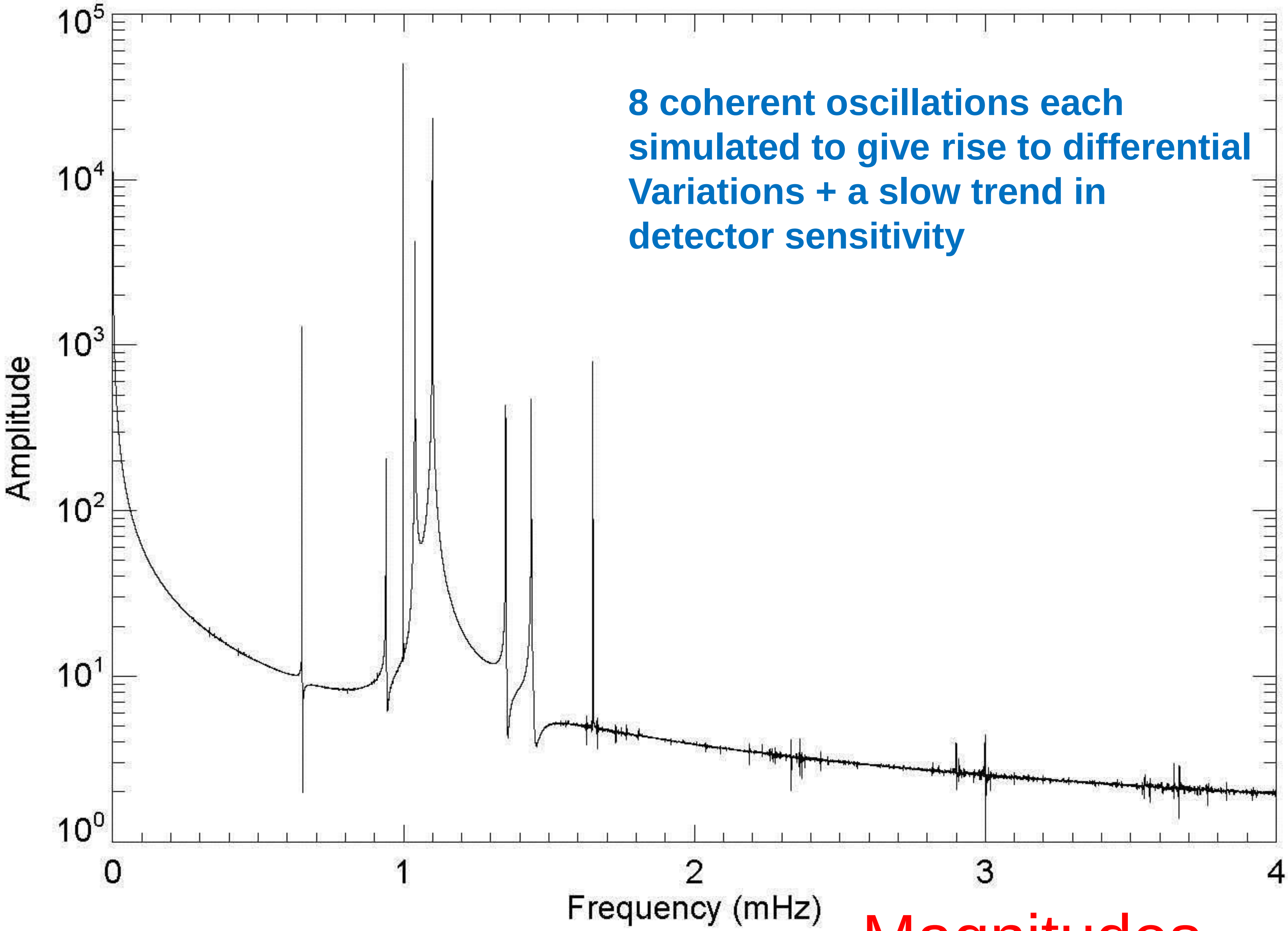



8 coherent oscillations each
simulated to give rise to differential
Variations + a slow trend in
detector sensitivity
500
400
300
200
100
0
Amplitude
0
1
2
3
4
Frequency (mHz)

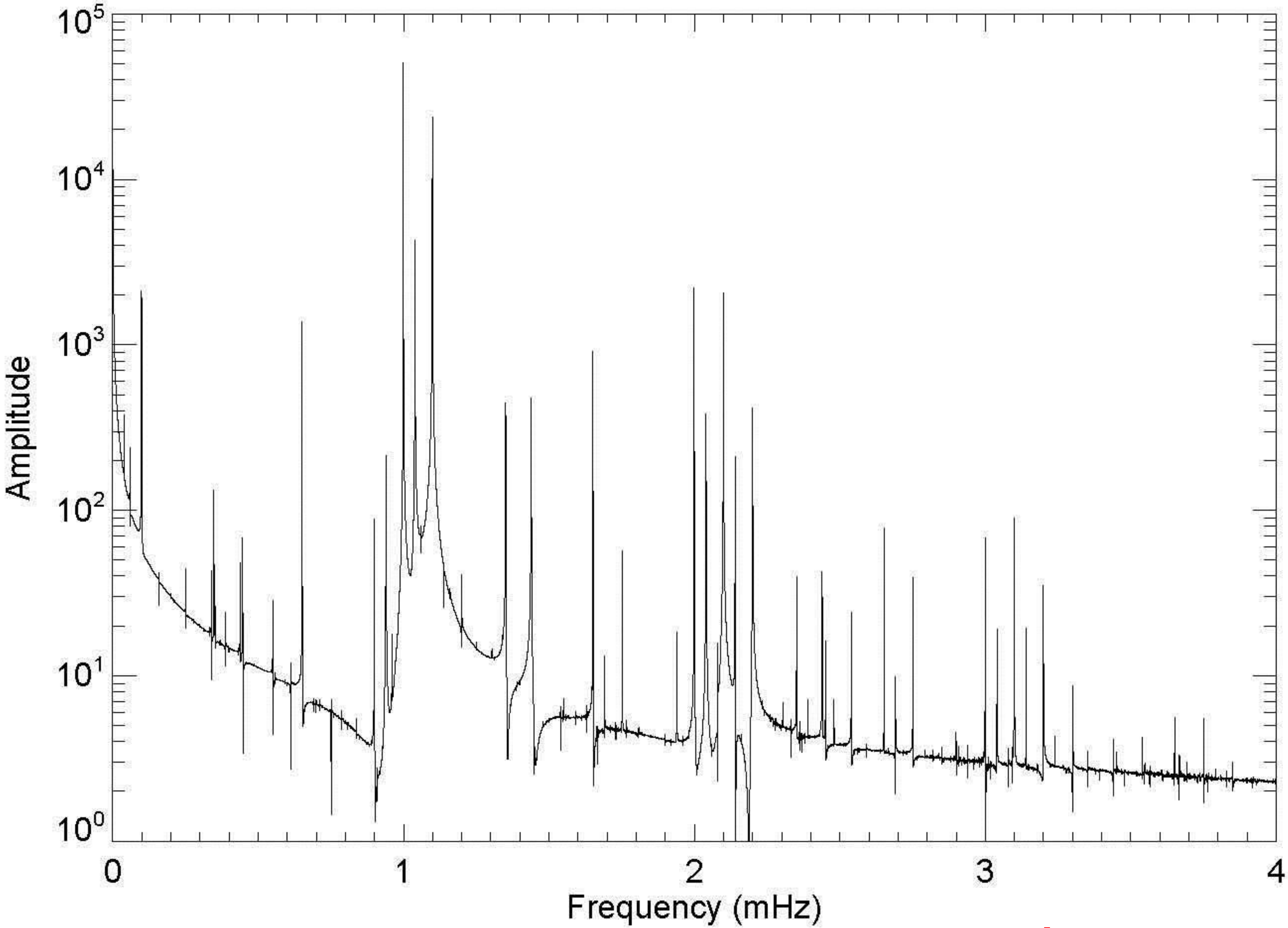
Magnitudes



Intensity


8 coherent oscillations each simulated to give rise to differential Variations + a slow trend in detector sensitivity
Amplitude
Frequency (mHz)
10^5
10^4
10^3
10^2
10^1
10^0
0
1
2
3
4

Magnitudes



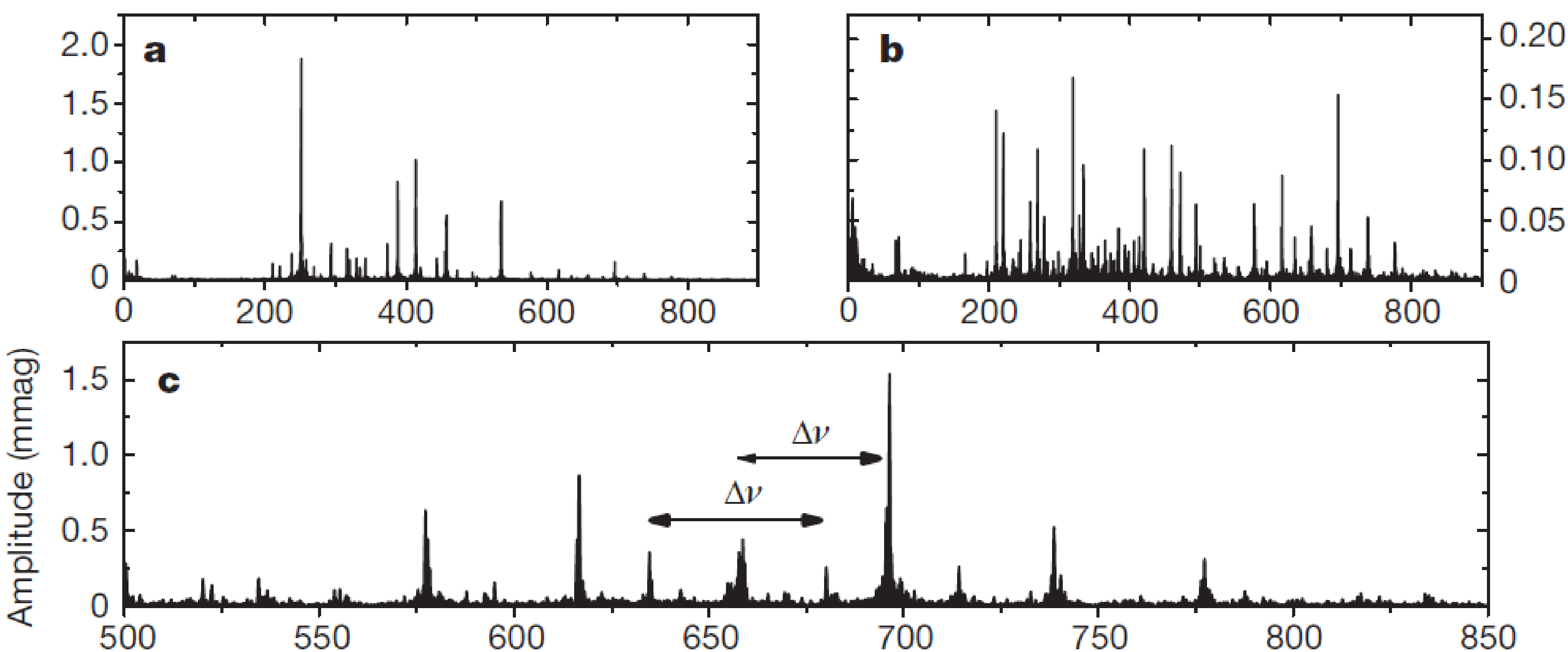
Intensity

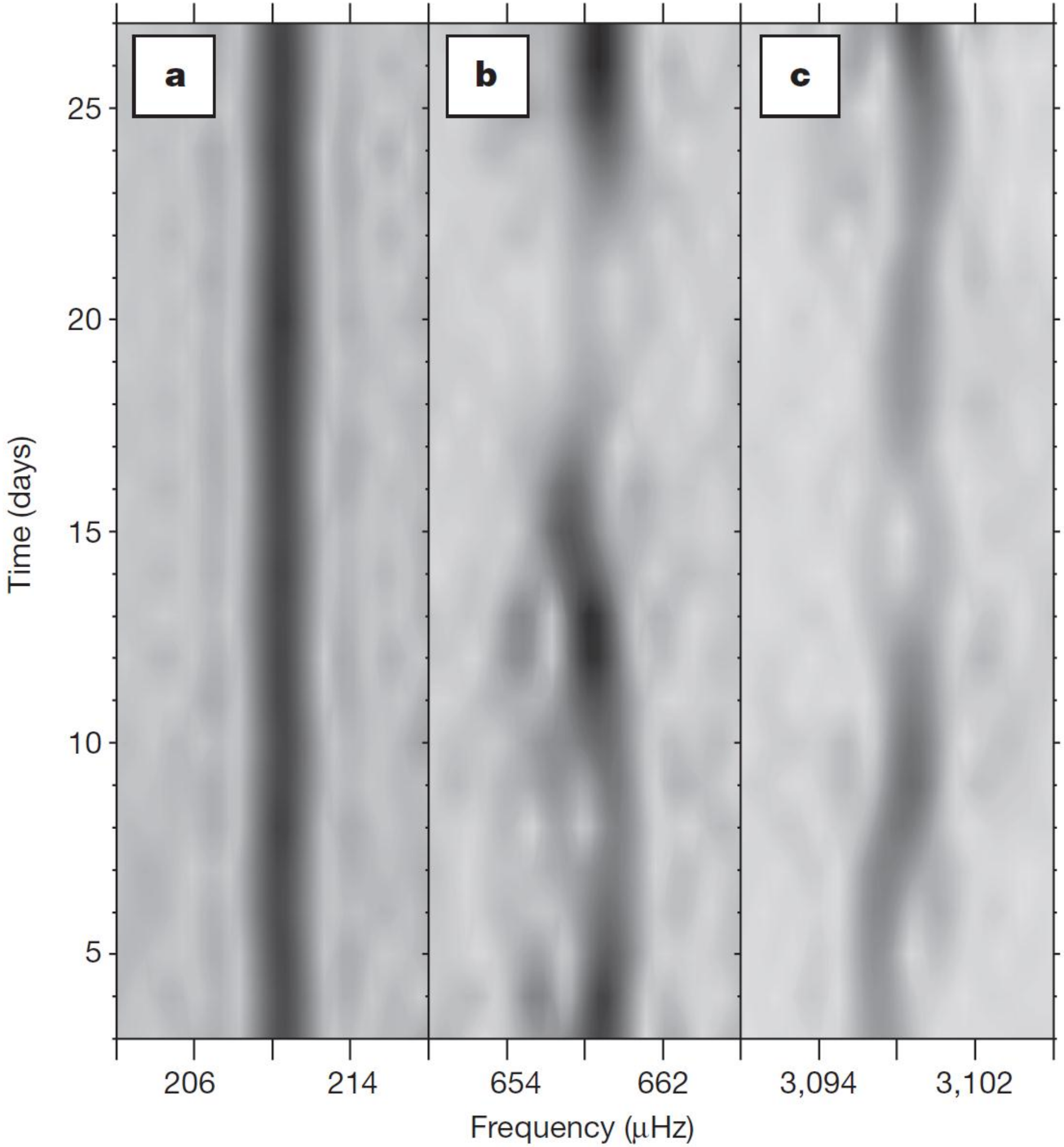
LETTER

doi:10.1038/nature10389

The excitation of solar-like oscillations in a δ Sct star by efficient envelope convection

V. Antoci[1], G. Handler[1,2], T. L. Campante[3,4], A. O. Thygesen[4,5], A. Moya[6], T. Kallinger[1,7,8], D. Stello[9], A. Grigahcéne[3], H. Kjeldsen[4], T. R. Bedding[9], T. Lüftinger[1], J. Christensen-Dalsgaard[4], G. Catanzaro[10], A. Frasca[10], P. De Cat[11], K. Uytterhoeven[12,13,14,15], H. Bruntt[4], G. Houdek[1], D. W. Kurtz[16], P. Lenz[2], A. Kaiser[1], J. Van Cleve[17], C. Allen[18] & B. D. Clarke[17]

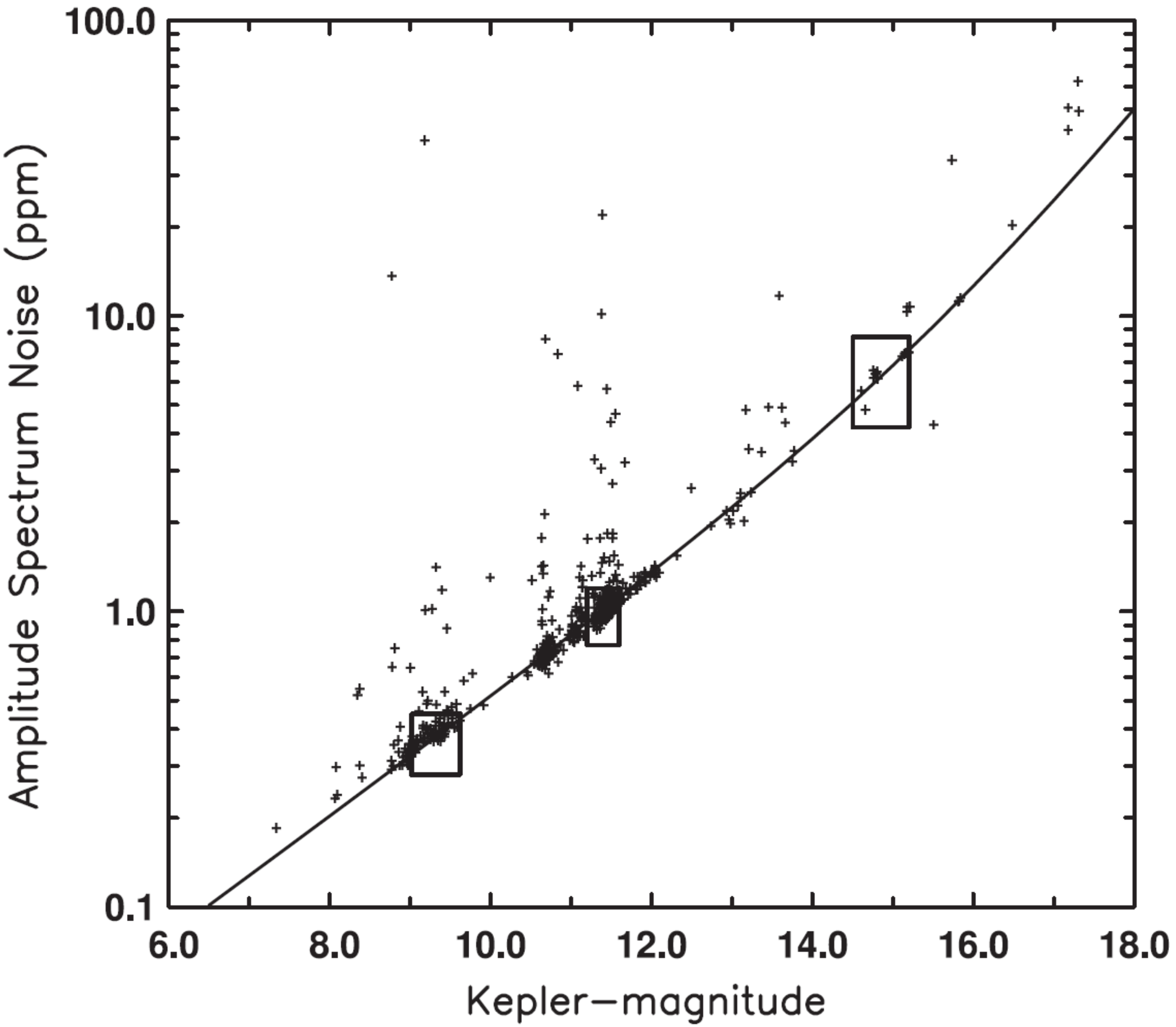




HD187547
KIC7548479

Space data: Kepler

Gilliland et al. 2010



Noise levels

- Magnitude 13: 260 ppm / min
  50 ppm / 30-min
  7 ppm / day
  0.7 ppm / Q (90-d)

Amplitude Spectrum Noise (90-d):
1.3 ppm

Noise levels

- Magnitude 7: 15 ppm / min

  2.8 ppm / 30-min

  0.40 ppm / day

  0.04 ppm / Q (90-d)

Amplitude Spectrum Noise (90-d):

0.08 ppm

Following Montgomery and D. O'Donoghue, 1999

$$\sigma(f) \approx 0.44 \cdot \frac{\langle A_{Noise}(\nu) \rangle}{a \cdot T}$$

a = 0.001, COHERET (magnitude: 10) Kepler

Amplitude Spectrum Noise (30-d):	0.55 ppm
Amplitude Spectrum Noise (90-d):	0.32 ppm
Amplitude Spectrum Noise (365-d):	0.158 ppm
Amplitude Spectrum Noise (1460-d):	0.079 ppm

Frequency accuracy:

30 d: $\sigma(f) \approx 9.3 \cdot 10^{-5}\ \mu\mathrm{Hz}$

90 d: $\sigma(f) \approx 1.8 \cdot 10^{-5}\ \mu\mathrm{Hz}$

365 d: $\sigma(f) \approx 2.2 \cdot 10^{-6}\ \mu\mathrm{Hz}$

1460 d: $\sigma(f) \approx 2.8 \cdot 10^{-7}\ \mu\mathrm{Hz}$

Following Montgomery and D. O'Donoghue, 1999

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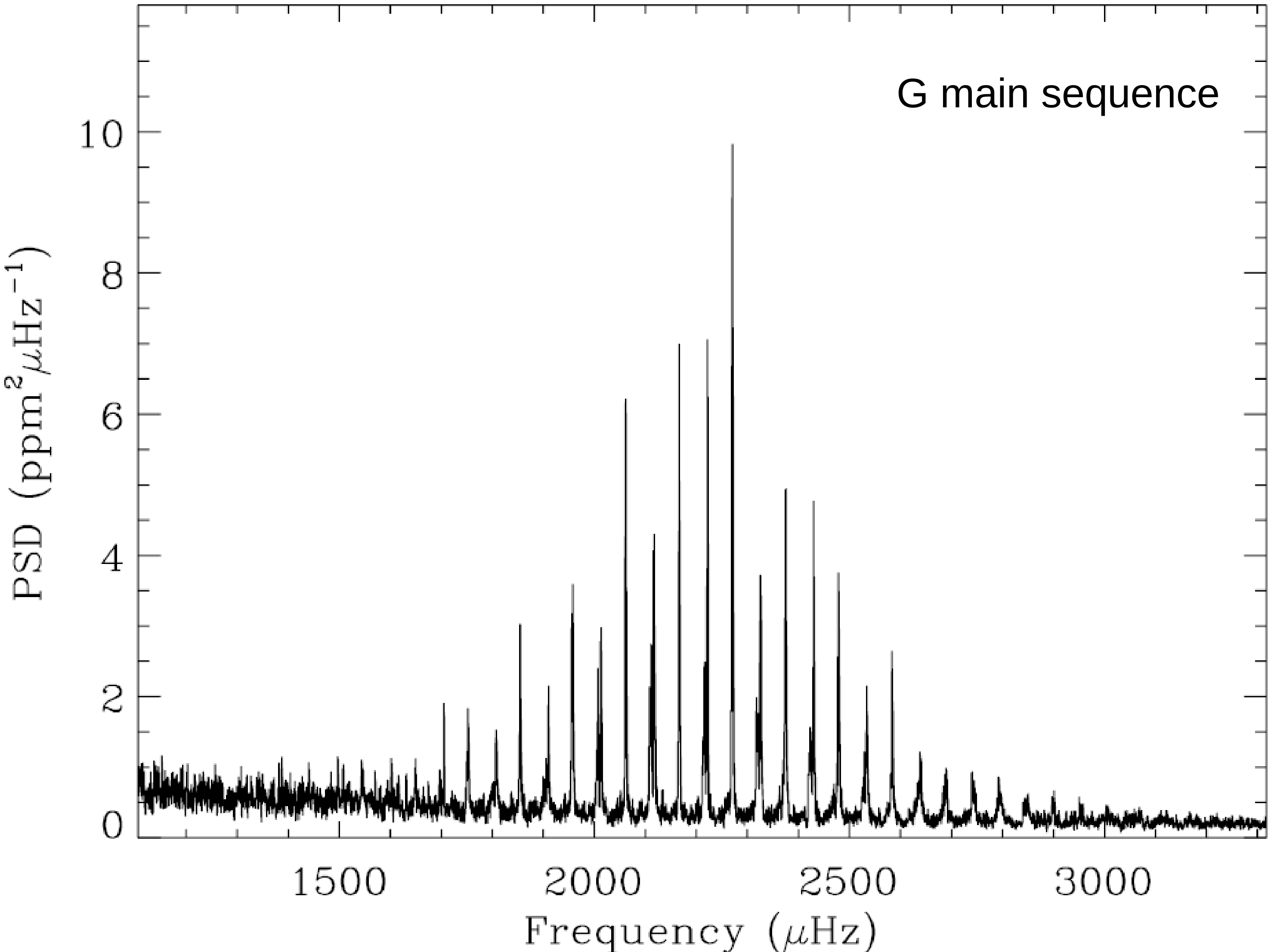
1460 d: $\sigma(f) \approx 2.8 \cdot 10^{-7}\ \mu\mathrm{Hz}$

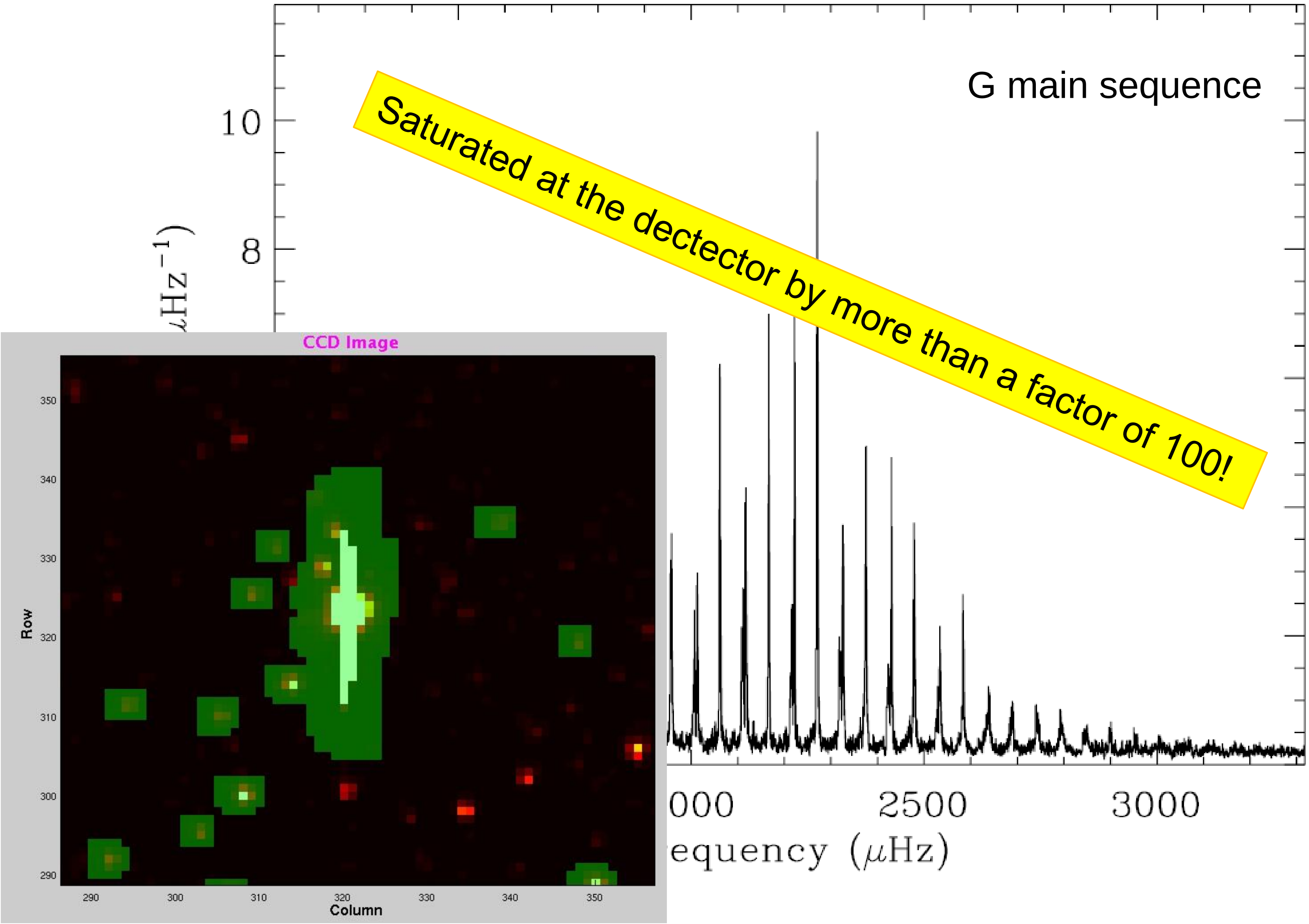
$$\sigma\left(\frac{1}{P}\frac{dP}{dt}\right) < 10^{-9}\, yr^{-1}$$

450 d, mag: 7.18

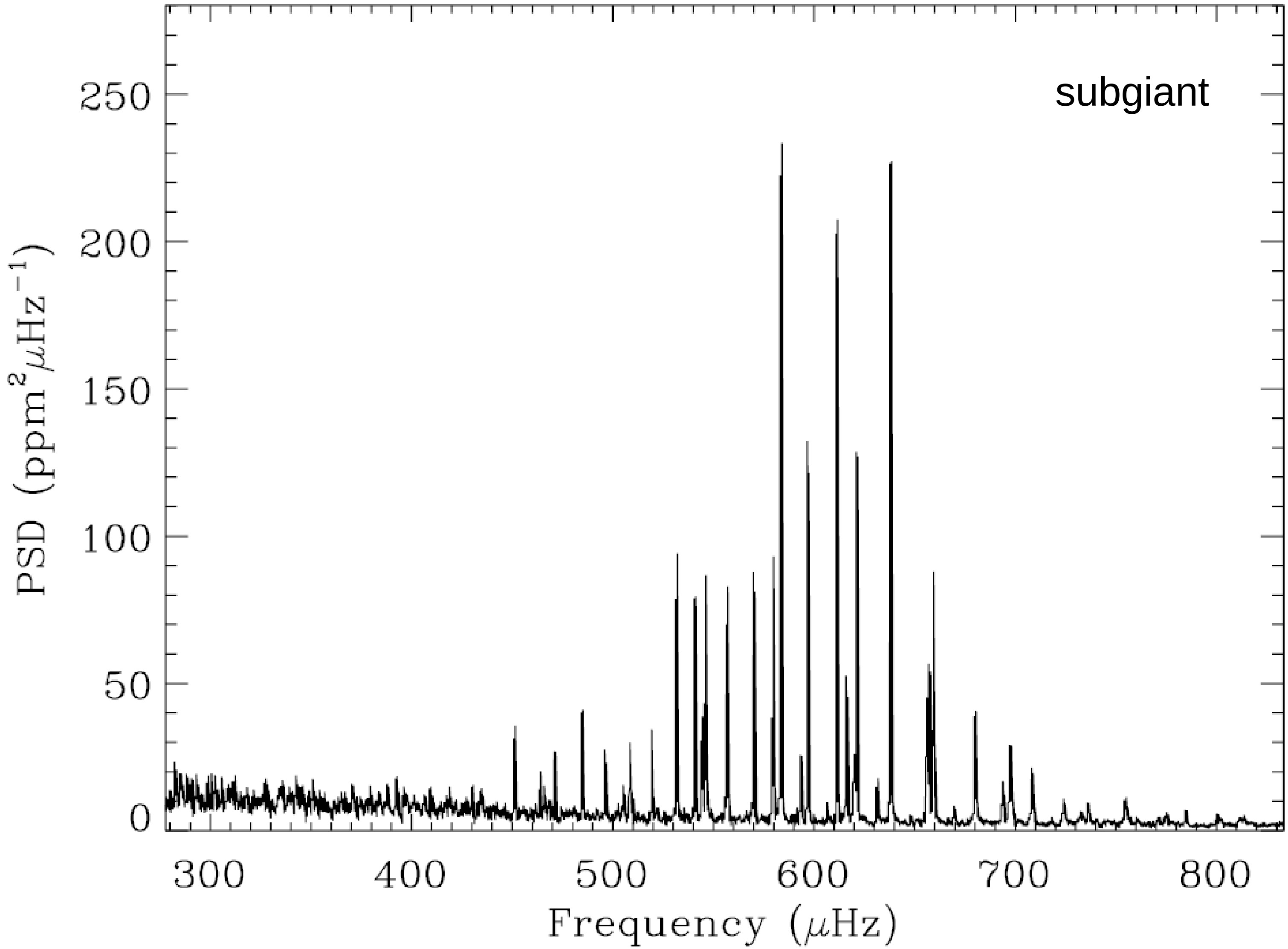


Kepler

450 d, mag: 7.18

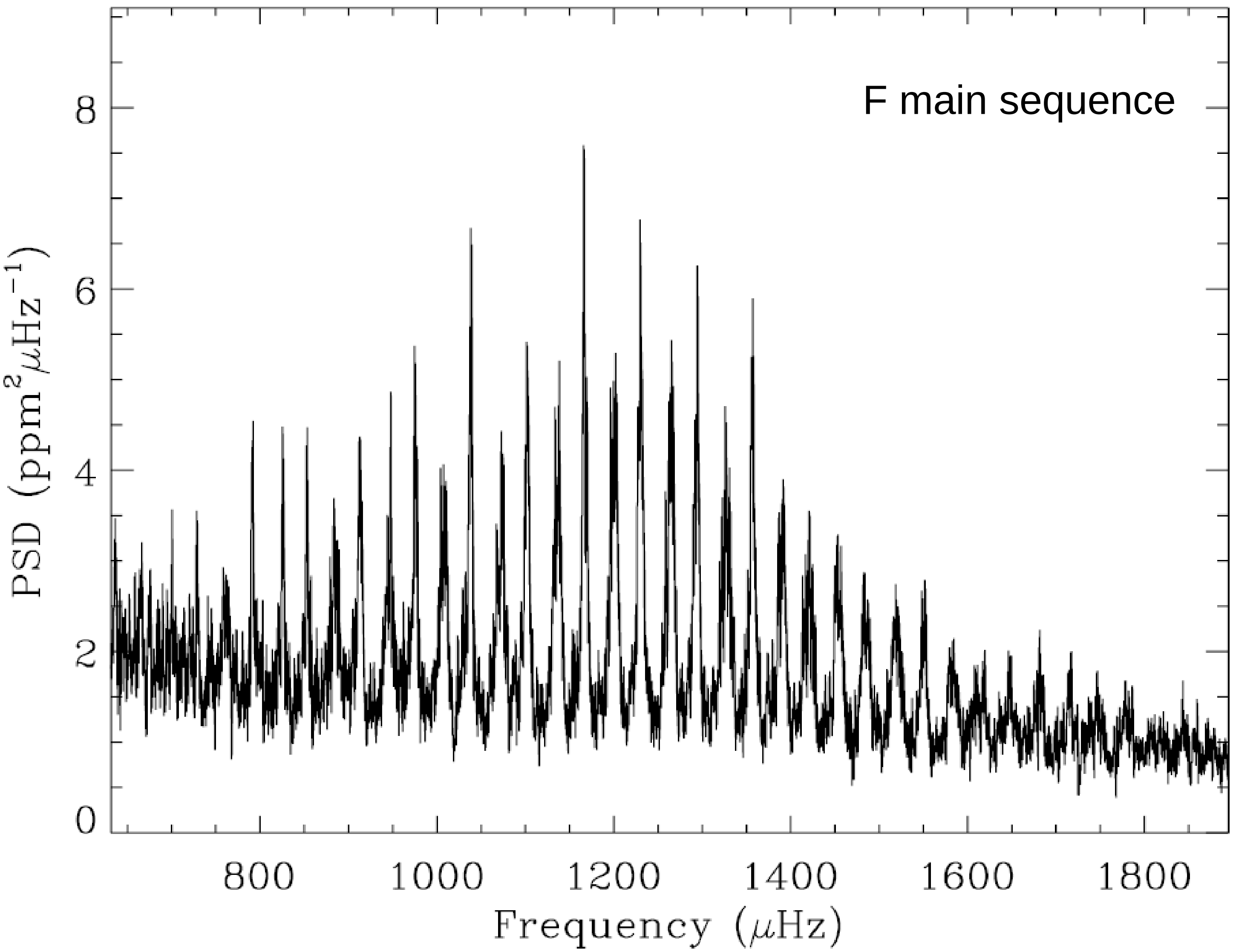

G main sequence
Saturated at the dectector by more than a factor of 100!
10
8
Hz^{-1})
000
2500
3000
equency (μHz)
CCD Image
Row
350
340
330
320
310
300
290
290
300
310
320
330
340
350
Column

540 d, mag: 9.27



Kepler

540 d, mag: 8.74



Kepler

Observables

- Oscillation frequencies and frequency differences/ratios/splittings
- Oscillation mode identification (degree, order and mode type; *g*/*p*/*f*, *mixed*)
- Oscillation mode properties (amplitude, amplitude ratios, phase, phase differences, life time, …)
- Changes (short term and long term) in mode parameters (frequencies, amplitudes, …)

Observables

- Oscillation frequencies and frequenc
  differences/ratio
- Osci
  and r)
- Oscill mode properties (amplitude, amplitude ratios, phase, phase differences, life time, …)
- Changes (short term and long term) in mode parameters (frequencies, amplitudes, …)

High quality un-interrupted time series data for many types of pulsating stars
Optimizing the SNR

Observables

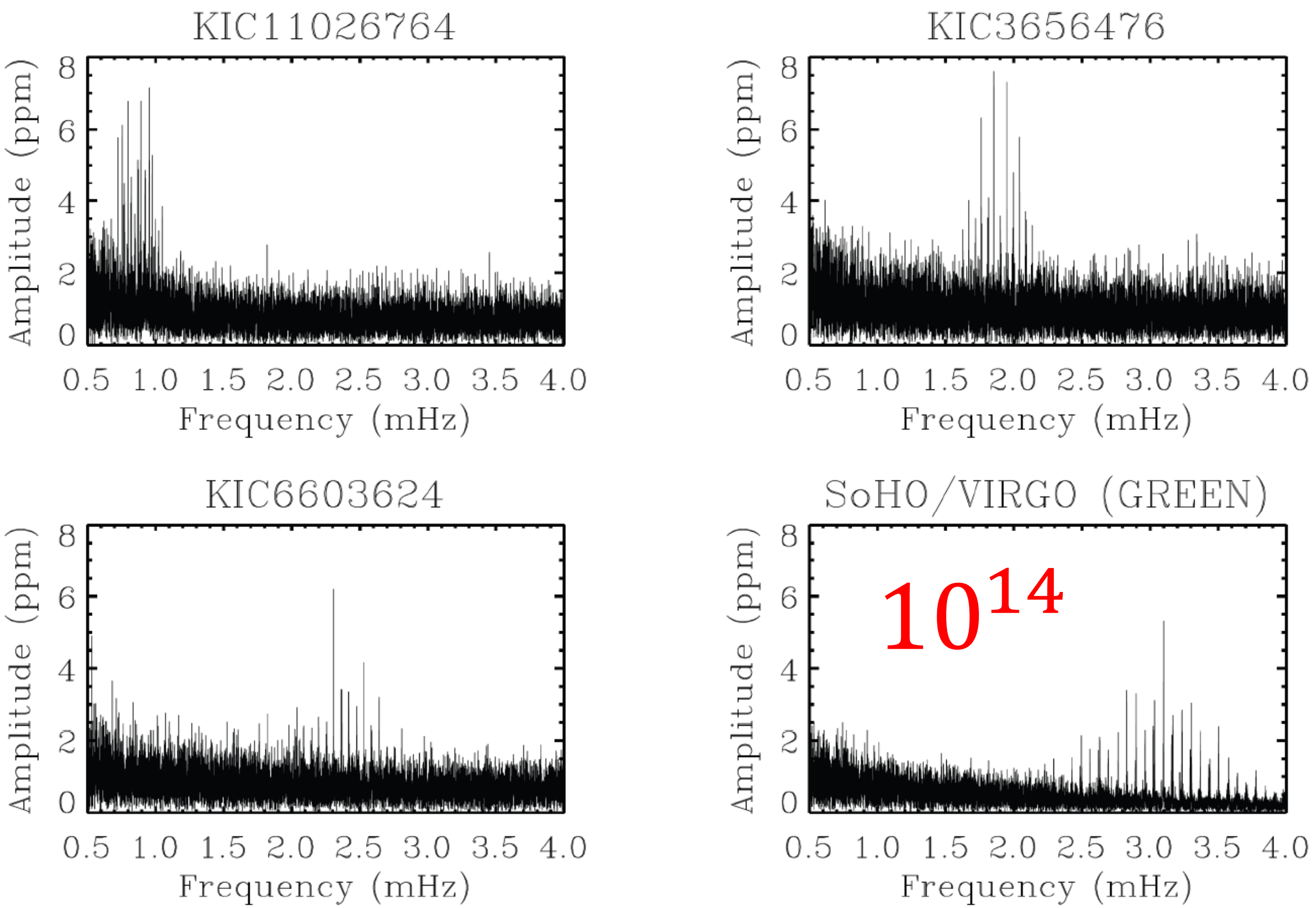
- Oscillation frequencies and frequenc... differences/ratios/...
- Osci... and ...)
- Oscill... mode properties (amplitude, amplitude ratios, phase, phase differences, life time, …)
- Changes (short... n mode parameters (fr... …)

High quality un-interrupted time series data for many types of pulsating stars
Optimizing the SNR

$$\sigma\left(\frac{1}{P}\frac{dP}{dt}\right) < 10^{-9}\, yr^{-1}$$

Can the data meet the challenges?

….. YES!



Kepler