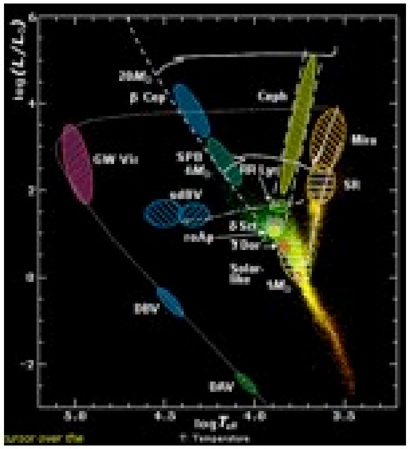
ASTEROSEISMOLOGY AND HELIOSEISMOLOGY

Dr. Reed L. Riddle

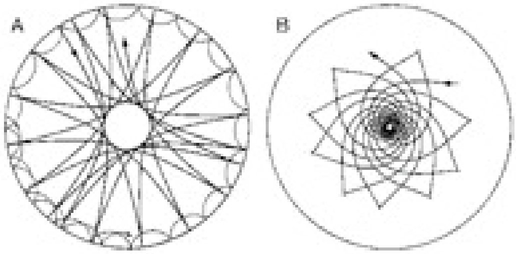


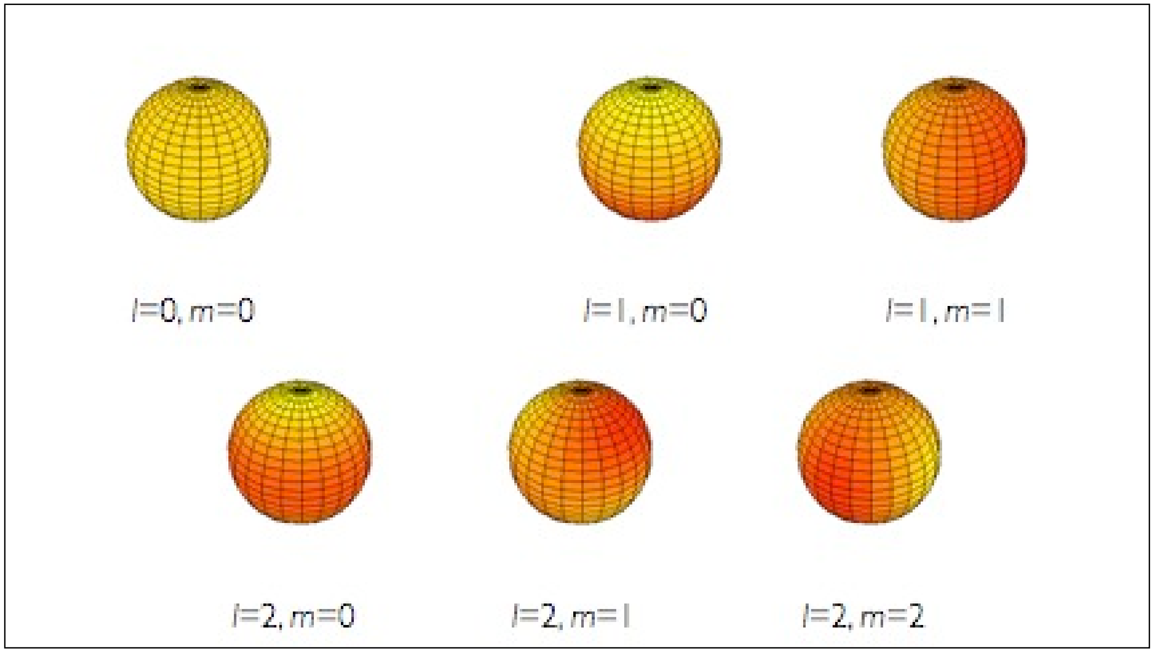
Spherical Harmonics
- Stars are (almost) spherical
- Constructive/destructive waves

Waves travel through star
- p-modes, g-modes

Measurement of waves
- Can be very small amplitude
- Sensitive equipment
- Long period of observations

Gives insight into interior of stars!
- Only way to directly confirm models

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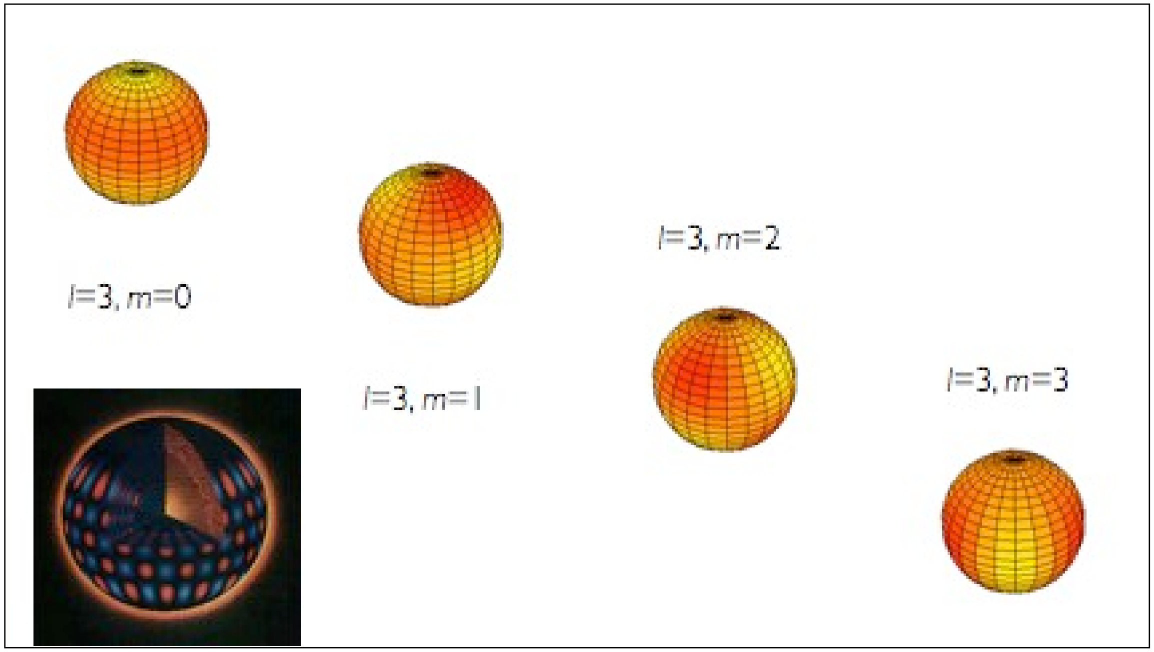
l=1, m=1
l=2, m=0
l=2, m=1
l=2, m=2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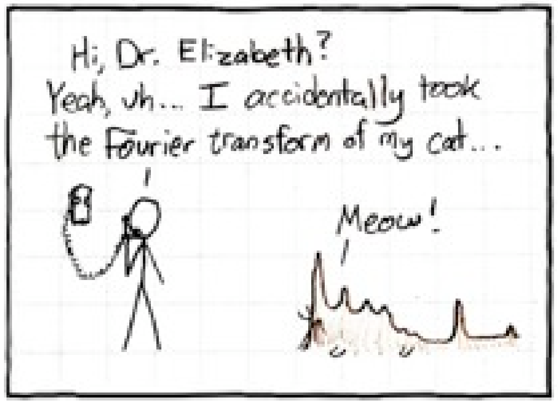
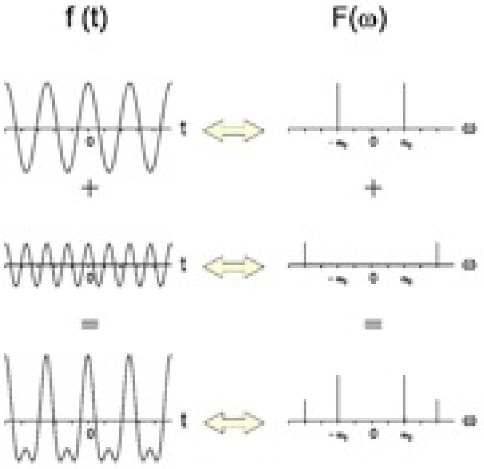
l=3, m=2
l=3, m=3



THE FOURIER TRANSFORM

Your friend, really!

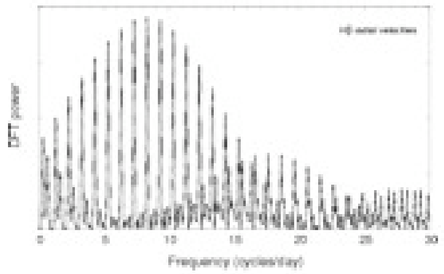
- Fourier Transform
  - Decomposition of a function into a sum of sinusoidal functions that can be recombined to obtain the original function
- Function of
  - Amplitude
  - Frequency
- Perfect for measurement of periodic signals

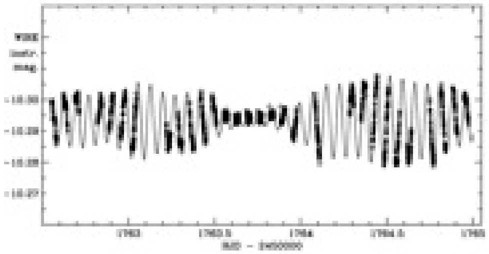


Real oscillations not so simple
- Periodic observations
- Interference between oscillations
- Instrument sensitivity
- Target properties

Periodic gaps in signals
- Single site data
- Large aliasing problem

Continuous data flow
- Breaks aliasing problem
- Increases signal to noise



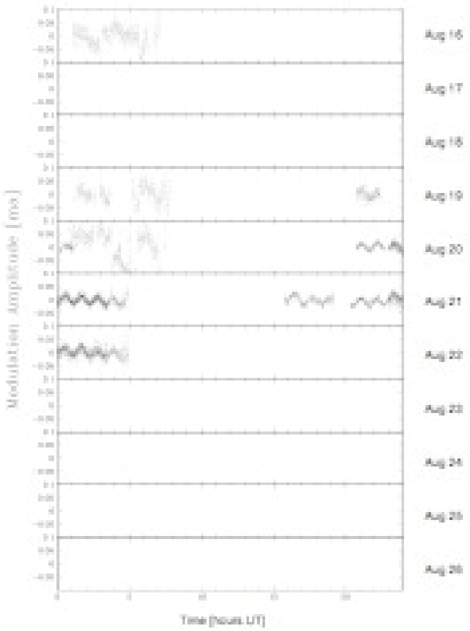


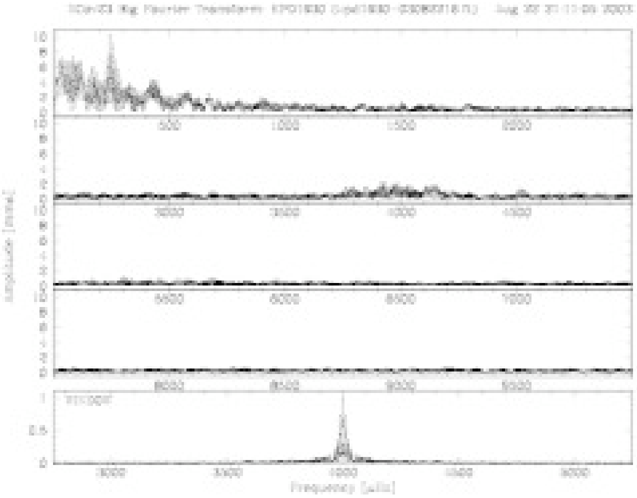
An Observational Problem

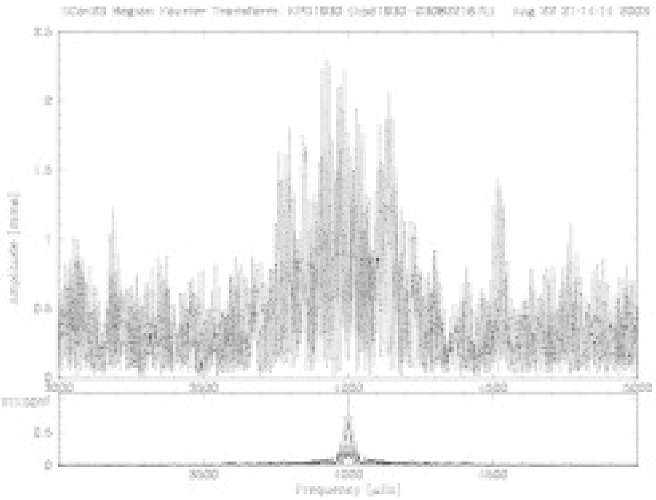
Observations at a single terrestrial site produce periodic time series gaps

The oscillation spectrum is convolved with the temporal window spectrum
- Contaminates oscillation spectrum with spurious peaks

Solutions
- Antarctica
  - max 6 month duration
- Network
  - needs data merging, but maintainable
- Space
  - expensive, difficult


Aug 16
Aug 17
Aug 18
Aug 19
Aug 20
Aug 21
Aug 22
Aug 23
Aug 24
Aug 25
Aug 26
Modulation Amplitude
0
5
10
15
20
Time [hours UT]


Amplitude
Frequency [μHz]
0.5
1



Oscillation networks

Solar Oscillations:

- Global Oscillation Network Group (GONG)
- Birmingham Solar Oscillations Network (BiSON)

Stellar Oscillations:

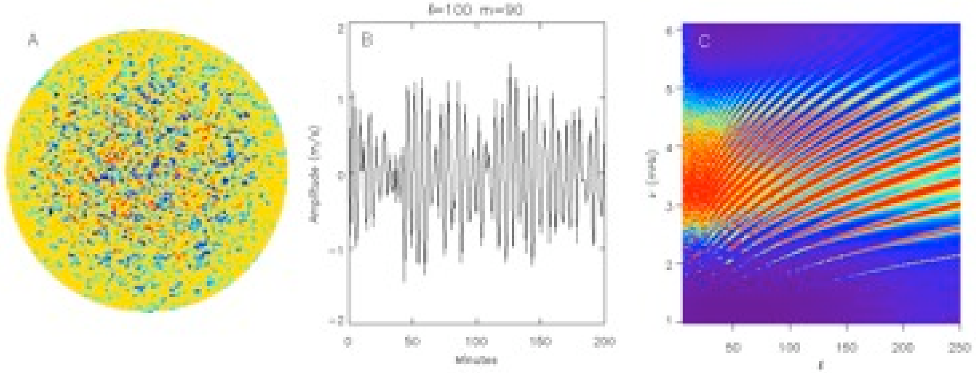
- Stellar Oscillations Network Group (SONG)
- MUSICOS (Multi-SIte COntinuous Spectroscopy)
- Delta Scuti Network - δ Scuti stars
- Whole Earth Telescope (WET) - White Dwarfs

Space Missions:

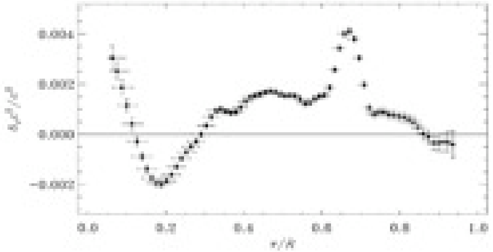
- SOlar and Heliospheric Observatory (SOHO)
- Kepler

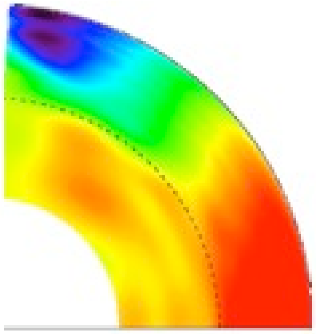
Helioseismology: measuring waves on the surface of the Sun
Discovery of propagating waves on Sun (Leighton et al, 1962)

Doppler Map ==> Time Series ==> Fourier Transform ==> Spherical Harmonics



Confirmation of convection zone boundary





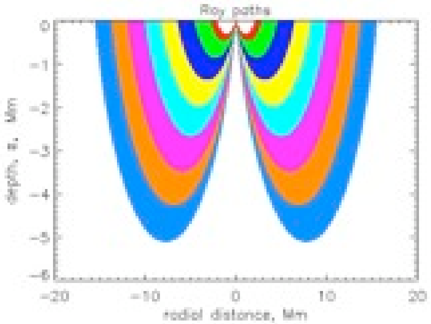
Differential rotation of layers of Sun in convection zone below surface

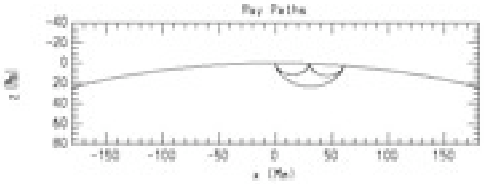
Core and convection rotation different

Modes turn at depth where sound speed = horizontal phase speed = ν/ℓ

All modes with same ν/ℓ must take same time to make one trip between reflections

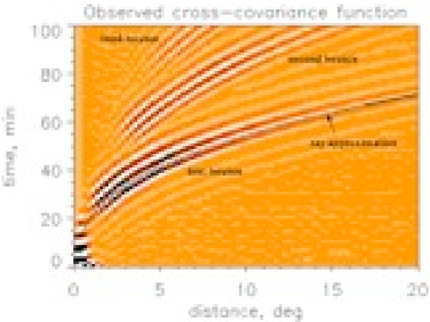
Basis of Time-Distance (or Local) Helioseismology

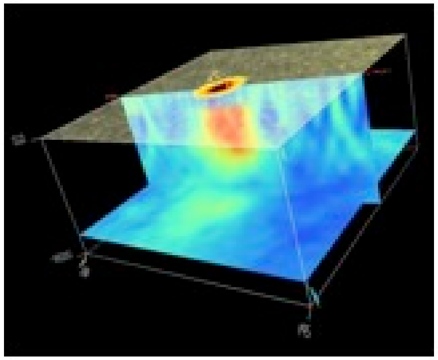




Interesting new results

- Images of activity in the far side of the Sun
- Flare prediction
- Emerging active regions





WET founded in 1986
    University of Texas at Austin

Worldwide collaboration of astronomers interested in
    observations of oscillating stars

Technological goal:
    To resolve the multi-periodic oscillations observed in white dwarfs (and other objects) into their individual components

Scientific goal:
    To construct accurate theoretical models, constrained by observed behavior, from which fundamental astrophysical parameters could be derived

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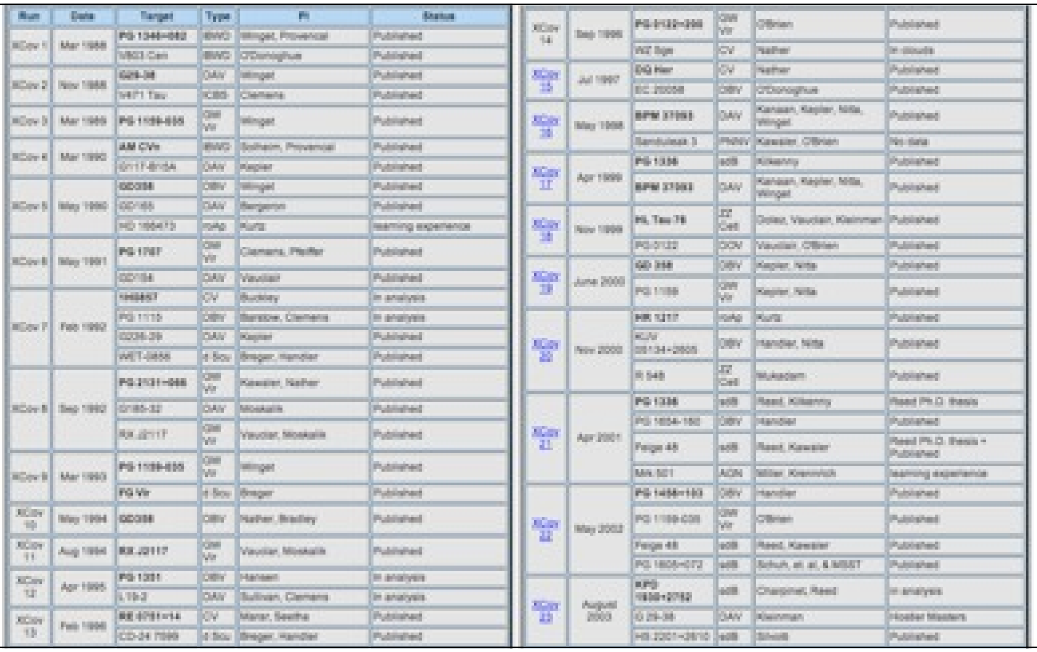
Headquartered at
    UT Austin 1986 - 1996
        Ed Nather, Director

    Iowa State University 1997 - 2006
        Steve Kawaler, Director
        Chris Clemens, Scot Kleinman, Reed Riddle, ADWOs

    Delaware Asteroseismic Research Center (DARC)
        Judi Provencal, Director; Harry Shipman, Financial director
        Mike Montgomery, Science Director; Susan Thompson, Assoc. Dir.

Council of the Wise (CoW)
    Oversees WET
    Charts scientific direction

eXtended Coverage campaigns (XCov)



26 XCov campaigns completed

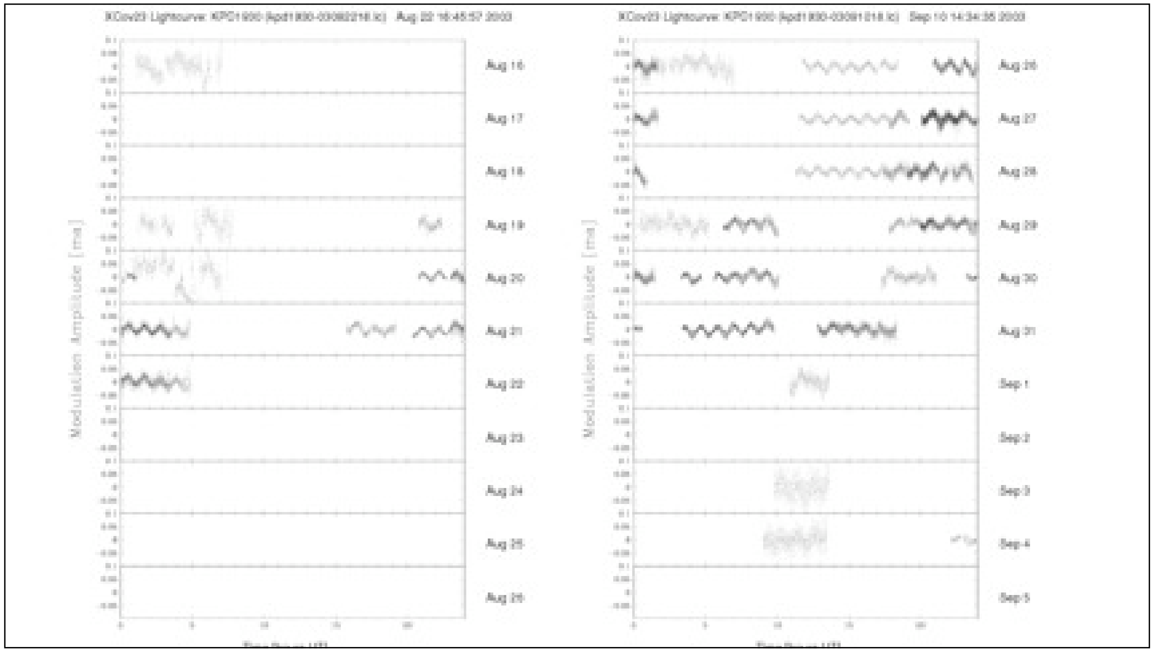
- XCov 27 in May
- http://www.physics.udel.edu/darc/2009_targets/2009_targets.html

WET campaigns

- 2 to 4 weeks long
- 10 to 20 observatories per campaign
  - Different sets of telescopes each time
  - Overlap with special guests (HST)
- Manned headquarters to manage campaign

Only use WET for specific targets

- Single site observations not good enough
- Oscillation periods of "20 seconds to 20 minutes"


XCov23 Lightcurve: KPD1930 (kpd1930-03082216.lc)   Aug 22 16:45:57 2003
XCov23 Lightcurve: KPD1930 (kpd1930-03091018.lc)   Sep 10 14:34:35 2003
Modulation Amplitude [ma]
0.1
0.05
0
-0.05
0
5
10
15
20
Aug 16
Aug 17
Aug 18
Aug 19
Aug 20
Aug 21
Aug 22
Aug 23
Aug 24
Aug 25
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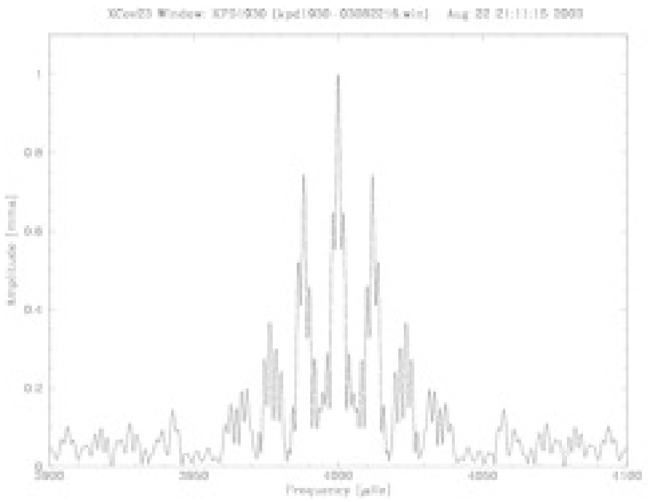
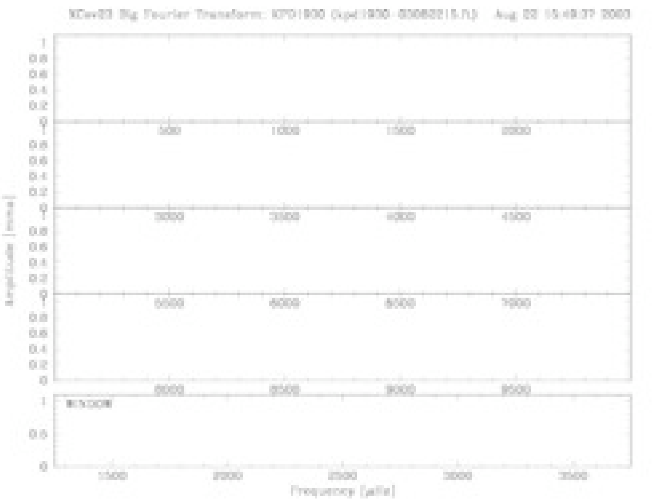
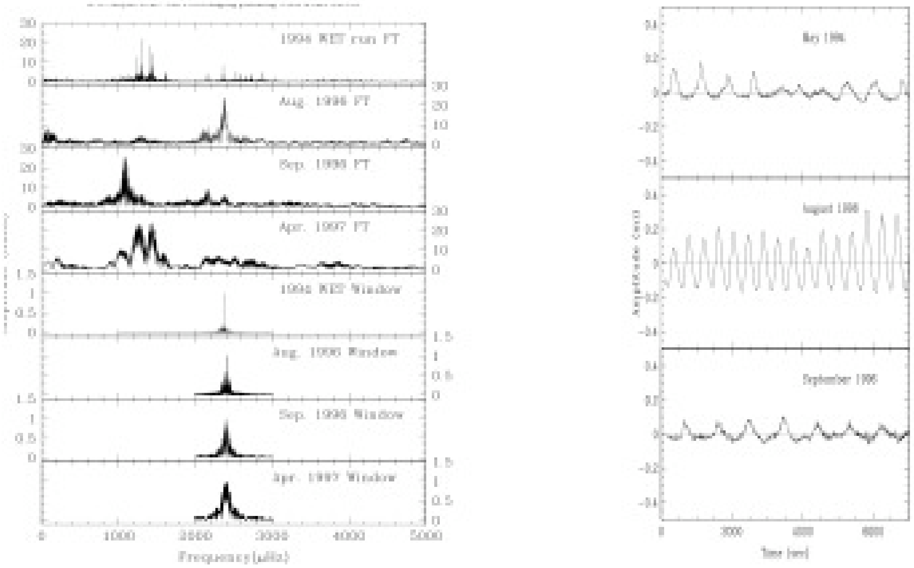
Sep 1
Sep 2
Sep 3
Sep 4
Sep 5

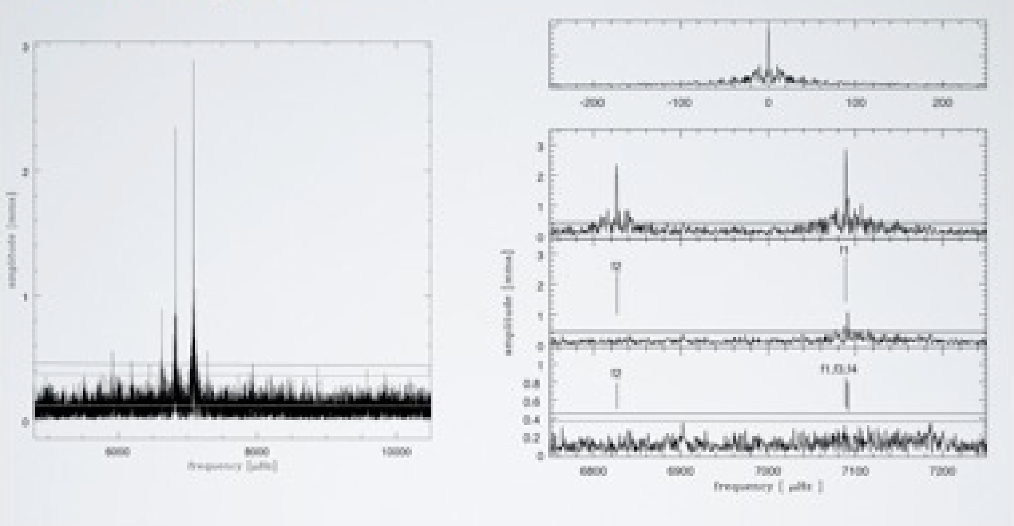

XCov23 Window: KPD1930 [kpd1930-030822l6.win]   Aug 22 21:11:15 2003
Amplitude [mma]
0
0.2
0.4
0.6
0.8
1
3900
3950
4000
4050
4100
Frequency [μHz]


XCov23 Big Fourier Transform: KPD1930 (kpd1930-030822l5.ft)   Aug 22 15:49:37 2003
Amplitude [mma]
0
0.2
0.4
0.6
0.8
1
500
1000
1500
2000
3000
3500
4000
4500
5500
6000
6500
7000
8000
8500
9000
9500
WINDOW
0
0.5
1
1500
2000
2500
3000
3500
Frequency [μHz]

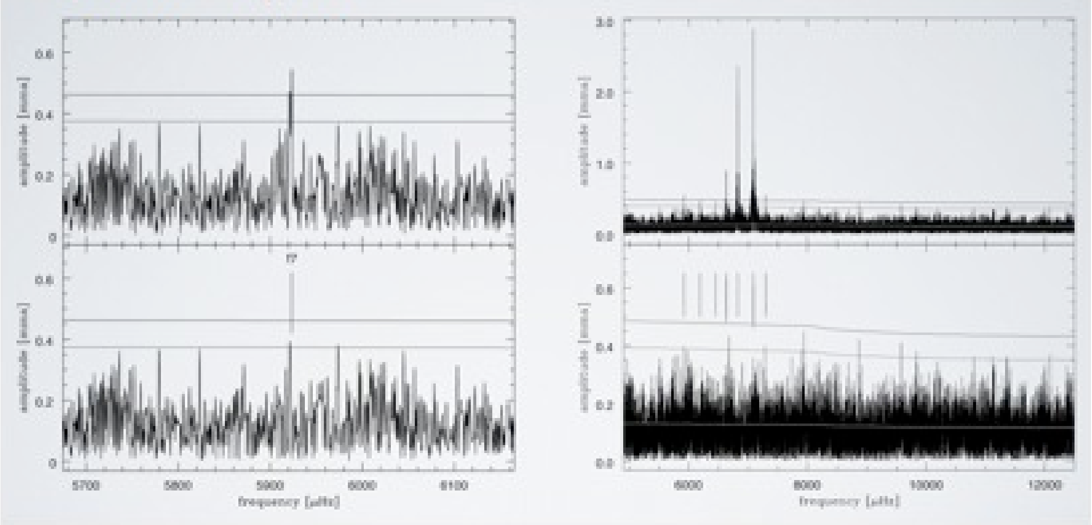


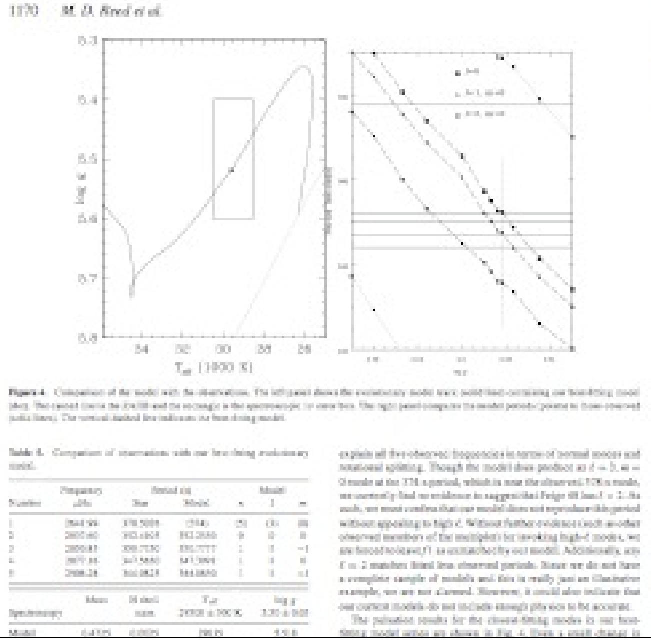
Kepler et al, A&A 401, 639–654 (2003)

M.Vuckovic et al, ApJ, 2006



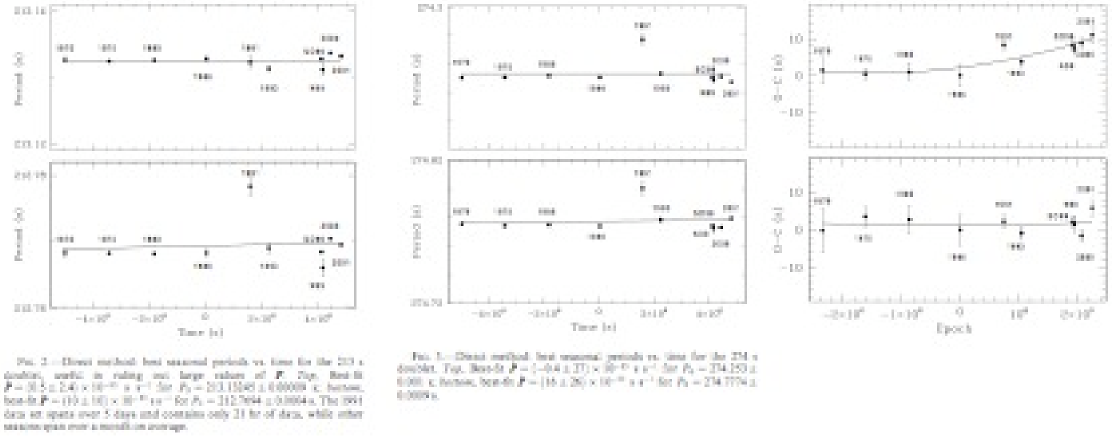
M.Vuckovic et al, ApJ, 2006




1170 M. D. Reed et al.

Reed et al, MNRAS, 348, 1164–1174 (2004)

Mukadam et al, ApJ, 594: 961–970, 2003



Silvotti et al, Nature, 449, 2007