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Mode parameters determination in solar-like stars with CoRoT

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On behalf of the DAT team of the Seismology Working Group of COROT

KASC, Orsay, 29 October 2007

The DAT team

- IAS: Appourchaux, Boumier, Baudin
- Nice: Berthomieu, Provost
- Meudon: Michel, Barban, Goupil, Lochard, Mazumdar, Samadi, Neiner, Floquet
- Saclay: Ballot, García, Lambert
- Leuven: De Ridder
- IAA: Garrido
- INAF: Poretti
- Queen Mary: Roxburgh
- Birmingham: Toutain

Contents

- Overview
- The HH exercises (6 of them…)
- Lessons learnt (after each of them)
- Recipes
- Conclusion

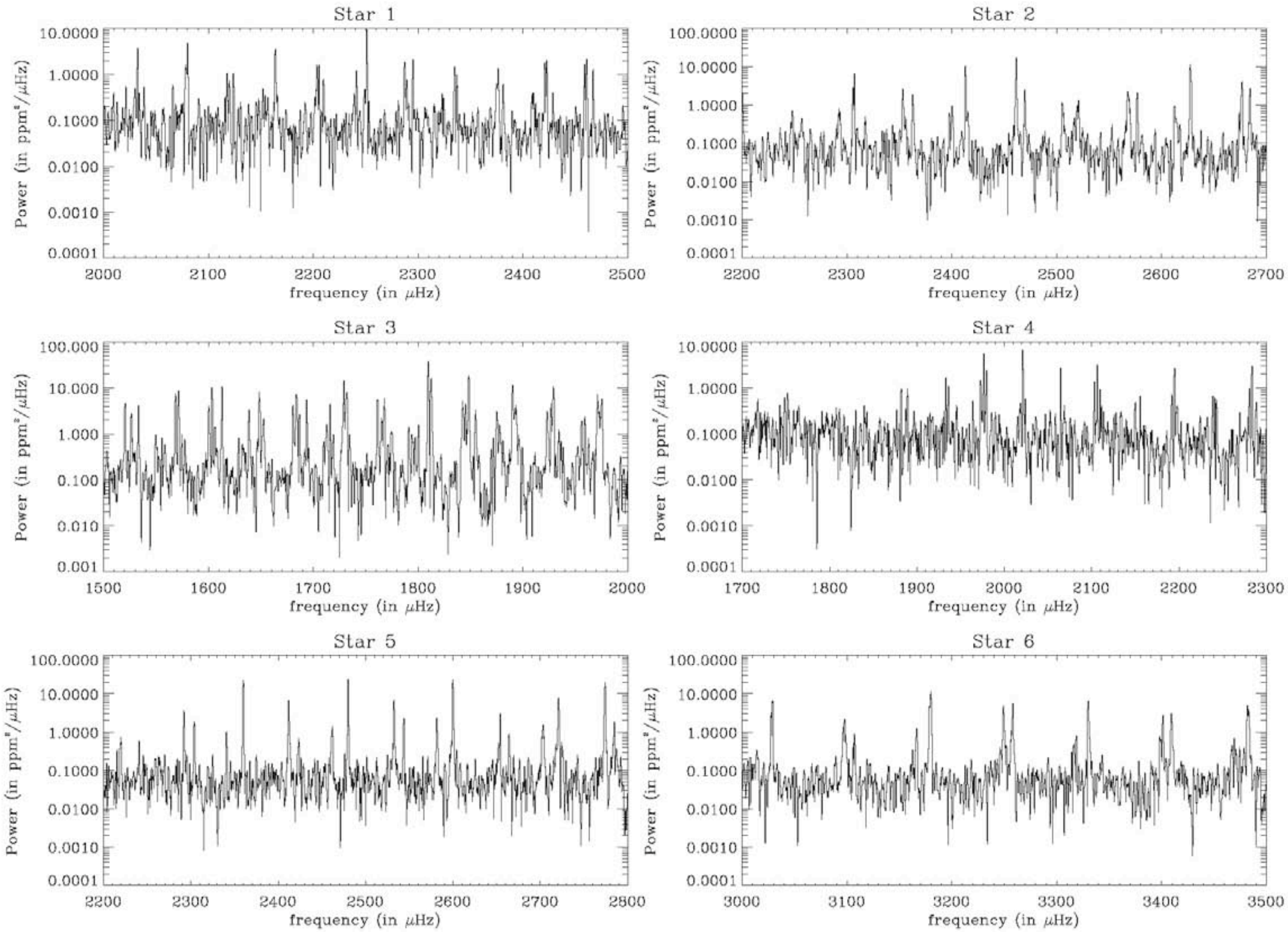
Goals of the HH for CoRoT

- Bring the experience of helioseismologists to asteroseismologists
- Prepare
  - data analysis
  - model comparison
  - derive error bars
  - observing programme

The COROT HH

- HH#1: Basic spectrum generation and data analysis
- HH#2: Comparing input and output model
- HH#3: Choice of COROT targets
- HH#4: Limit of detection
- HH#5: Classical pulsators
- HH#6: Recipe generation

HH#1: Simulations



HH#1: Lessons learnt

- Mode parameters recovered within error bars for solar-like stars
- Needs to implement left out details such as:
  - Inclined rotation axis
  - Differential rotation
  - Theoretical linewidths and amplitudes
  - Realistic stellar noise
  - Surface effects
- Real double blind test

HH#2: Comparing input and output models

- Implementation of the data analysis tools
  - Data reduction
  - Spectrum fitting
  - Debugging
- Assessment of the star model
  - Hands on data (almost as real)
  - Debugging

Team A:

Meudon (freq. prod. and analysis, steps 1 and 4)

T.Appourchaux (power-spectrum prod. and analysis, steps 2 and 3)

Team B:

Nice (freq. prod. and analysis, steps 1 and 4)

T.Toutain (power-spectrum prod. and analysis, steps 2 and 3)

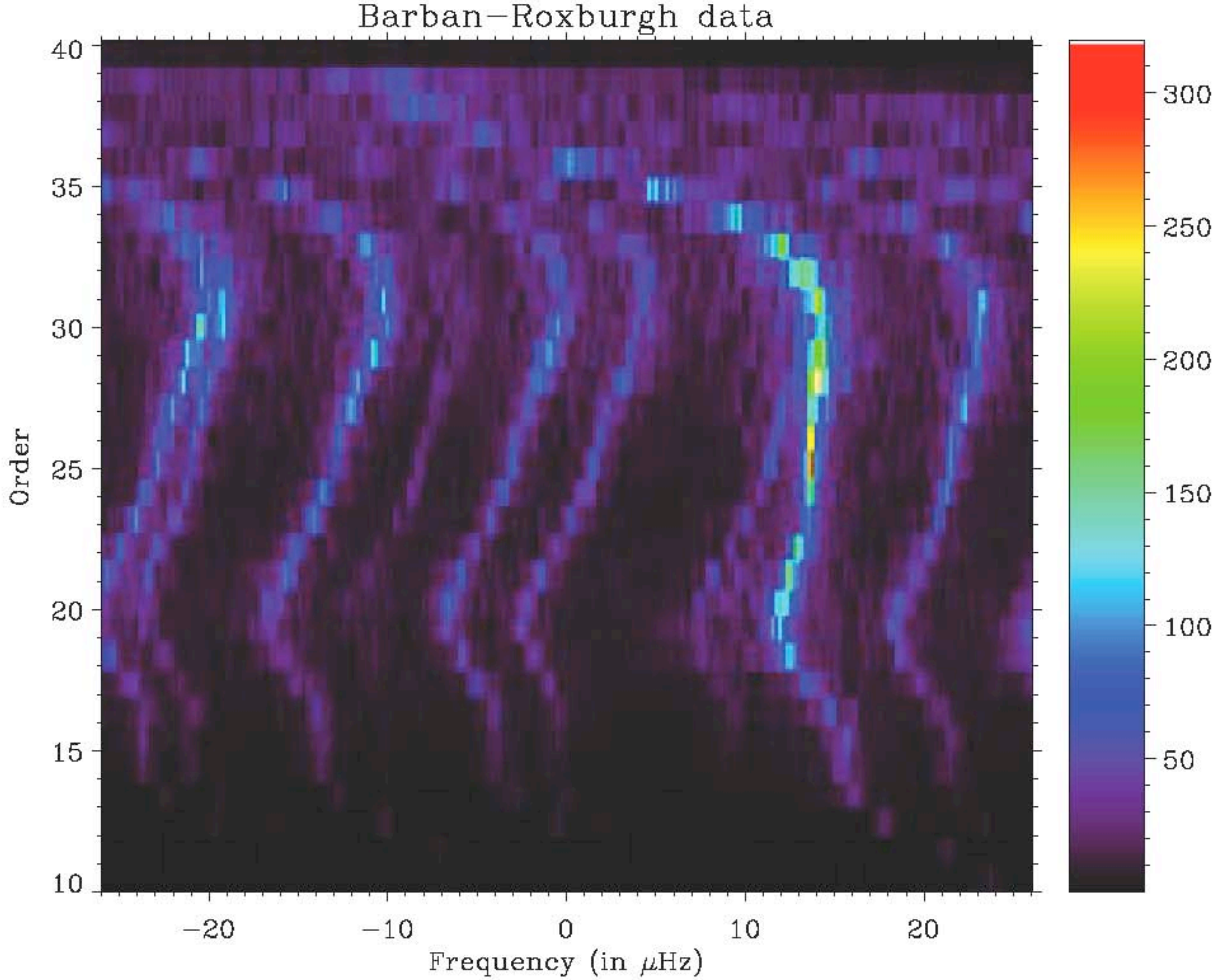
IAS (power spectrum analysis, step 3)

Team C:

Queen Mary (freq. prod. and freq. analysis, steps 1 and 4)

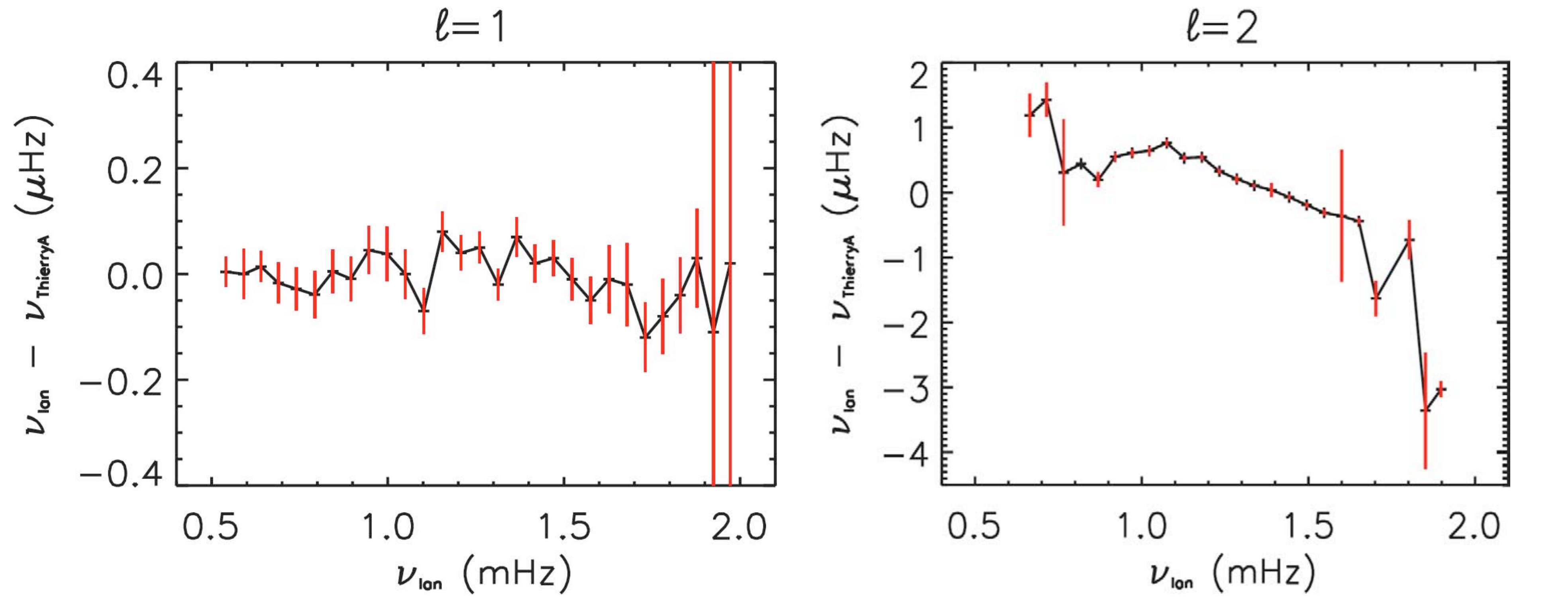
C.Barban (power-spectrum production, steps 2 and 3)

M.Bossi (time series analysis, step 3)



Appourchaux et al, 2002

HH#2: frequency comparison

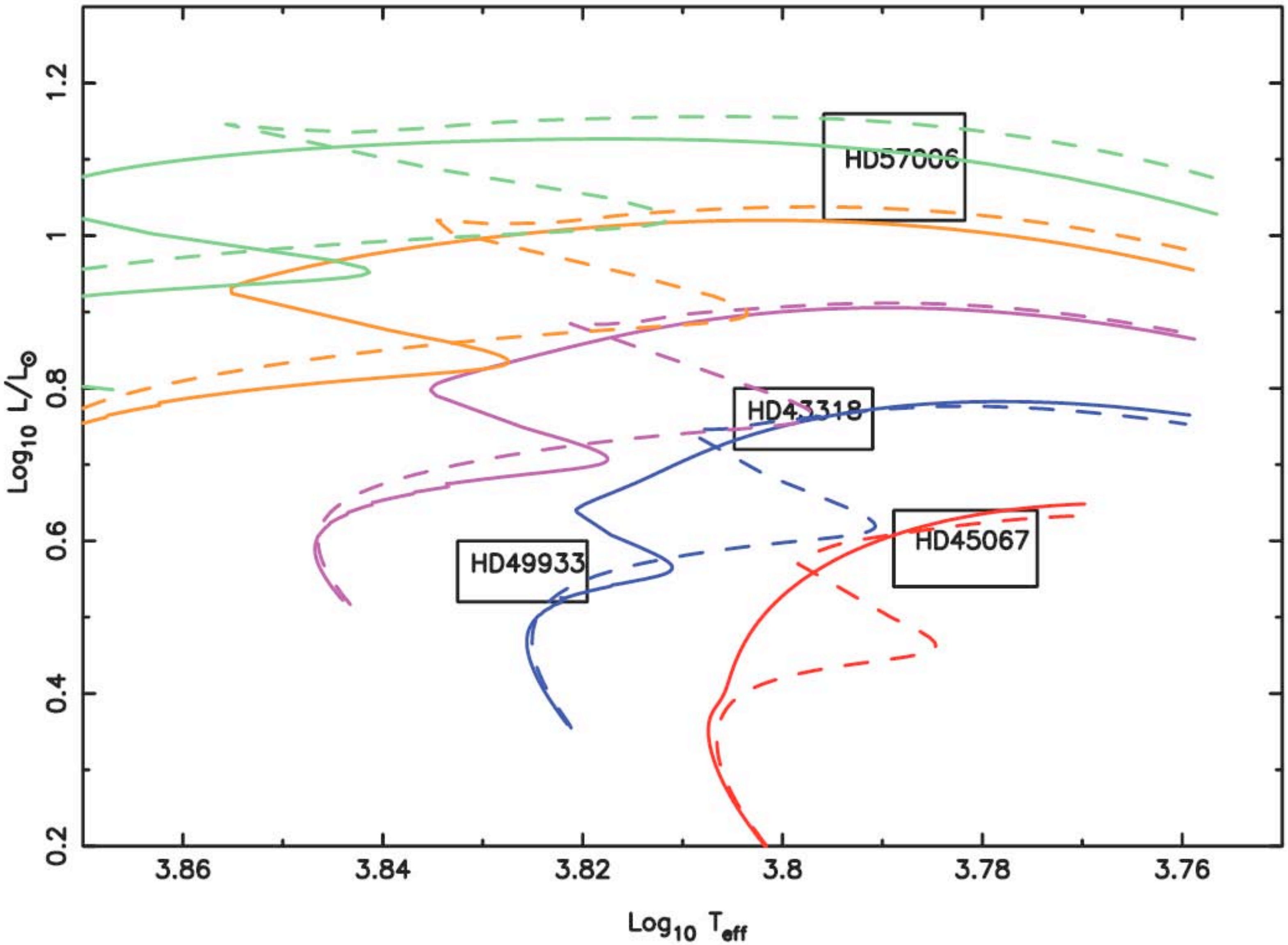


Appourchaux et al, 2002

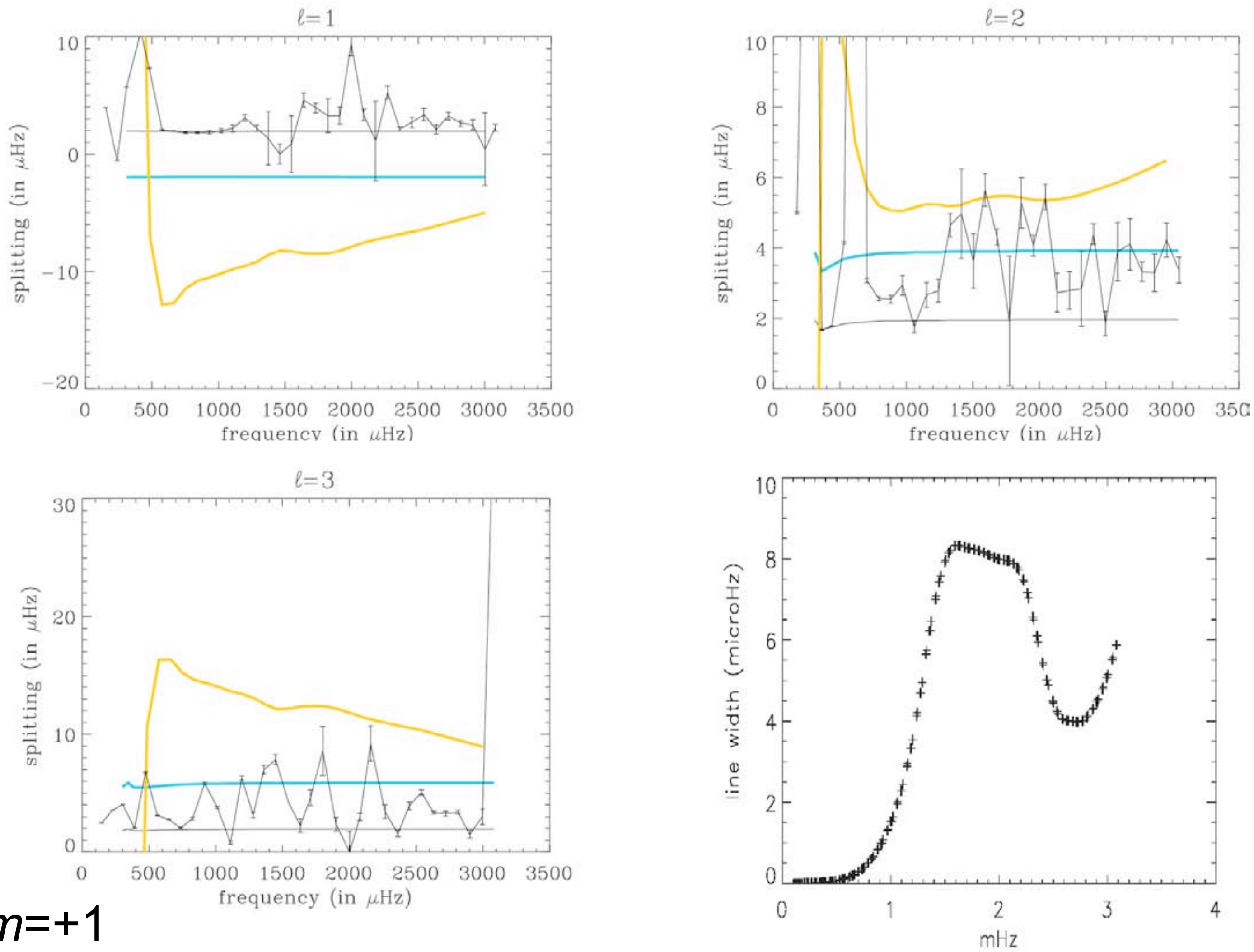
HH#2: lessons learnt

- Stellar models recovered (evolution codes based upon the CESAM code)
- Mode identification relies upon what we model
- Mode identification is key to the recovering
- Very fast rotators are difficult ($\Omega \sim \delta\nu_{01}, \delta\nu_{02}$)

HH#3: choice of the targets



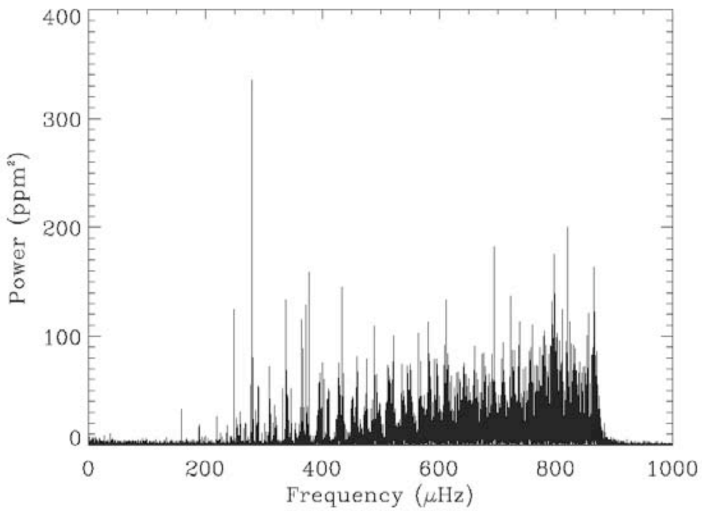
HD49333: splittings

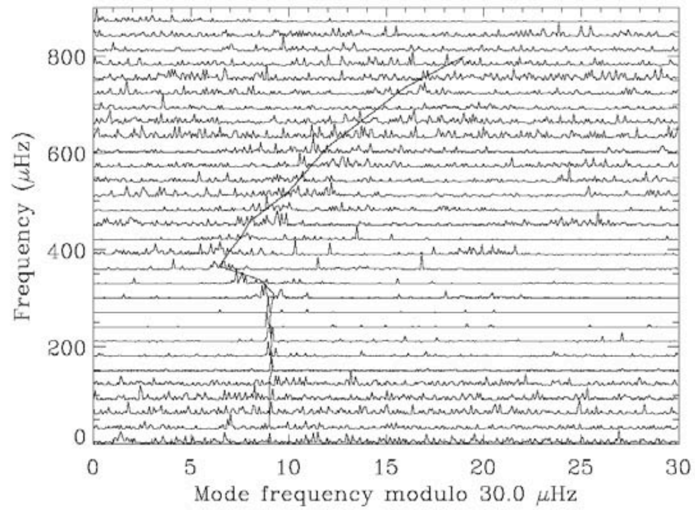


Solid black line: *m*=+1
Turquoise line: *m*=*l*
Yellow line: |*l*'-*l*|=2

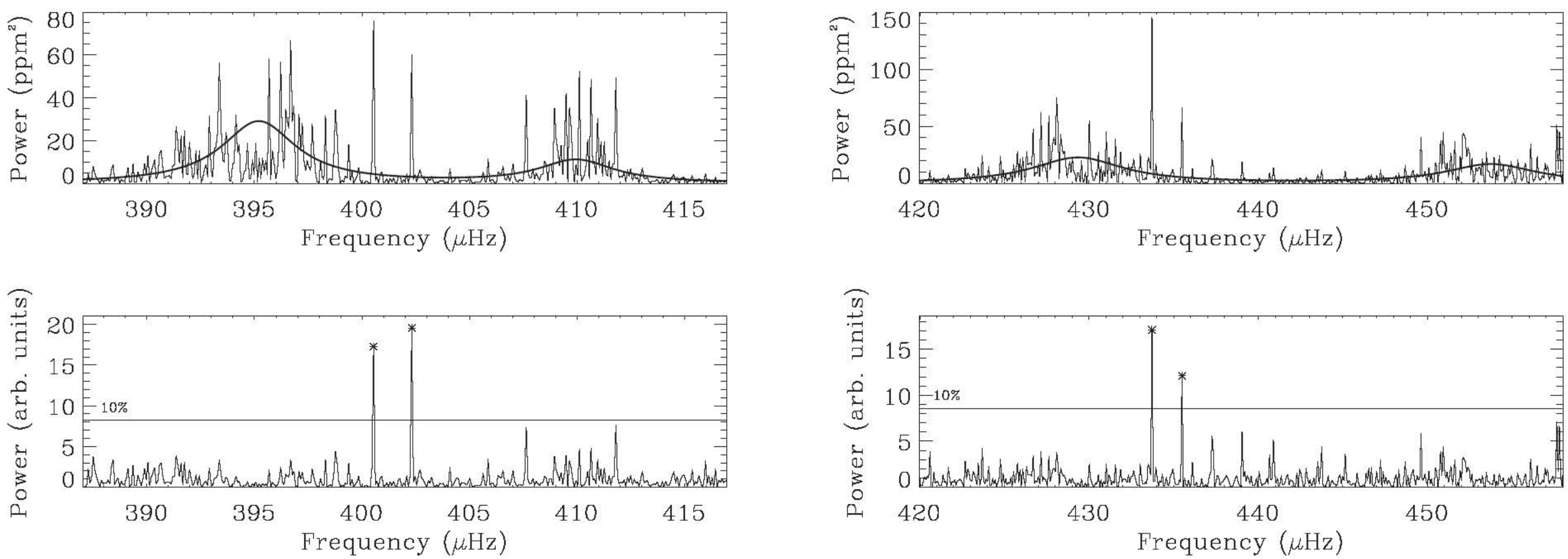
Appourchaux et al, 2006

HD57006





Moreira et al, 2005



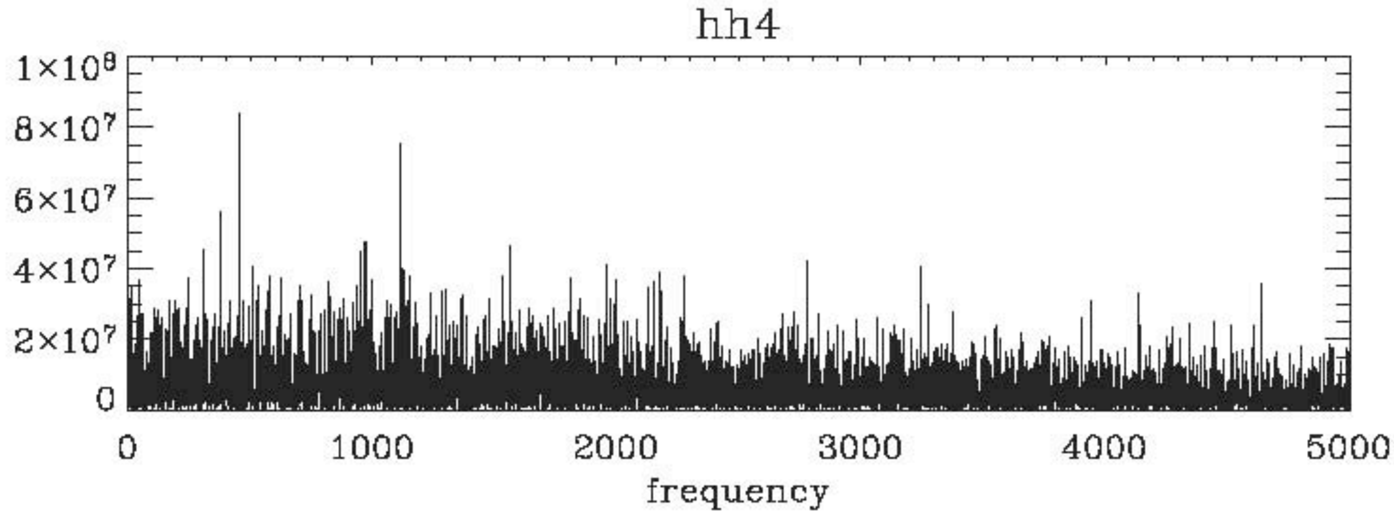
HH#3: Lessons learnt

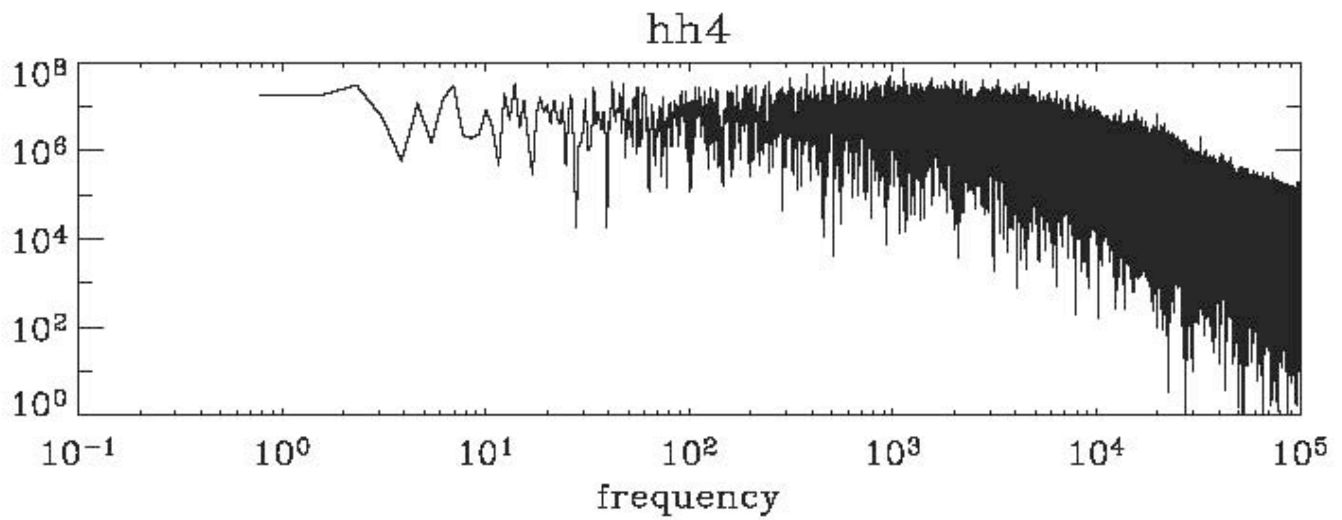
- Recover:
  - Evolutionary stage
  - depth of convection and second Helium ionization zones
- Evolved stars:
  - Desirable but not yet
  - Detection of g modes embedded in p modes
- Splittings:
  - Rotation fast but slow compared to small separation

HH#4: limit of detection

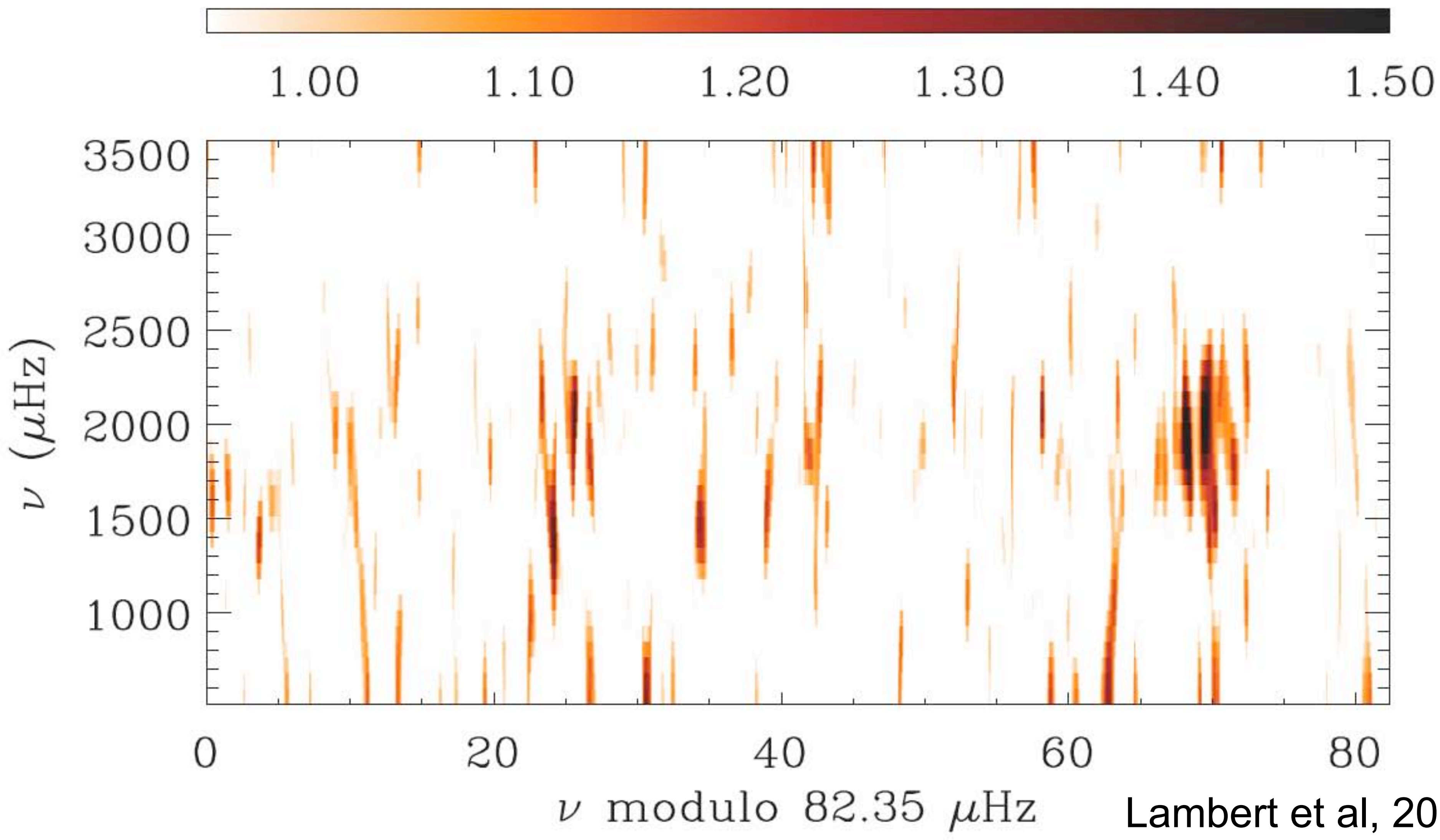
- Procyon syndrome
- Need to say more?

HH#4: Power spectrum



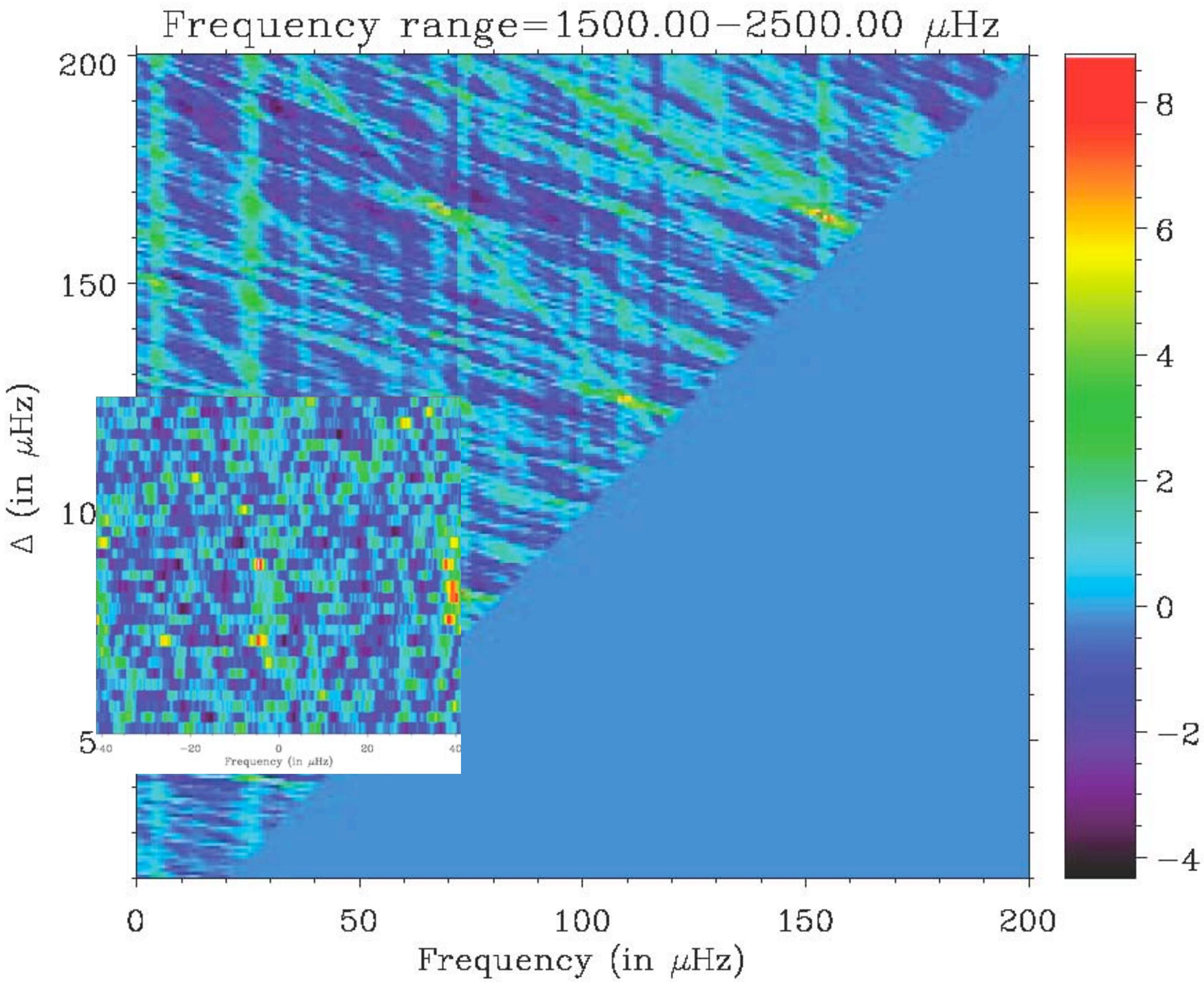


HH#4: echelle diagramme



Lambert et al, 2006

HH#4: Collapsed ED



HH#4: lessons learnt

- 3 different detection techniques
- All 3 detect modes at the signal-to-ratio of 1
- Detection level for the collapsed echelle diagramme (H0 hypothesis) and the smoothed spectrum (H0, H1 hypotheses)

HH#5: classical pulsators

- HD180642 (β Cephei)
- HD181555 (δ Scuti)
- Principal targets of a Long Run

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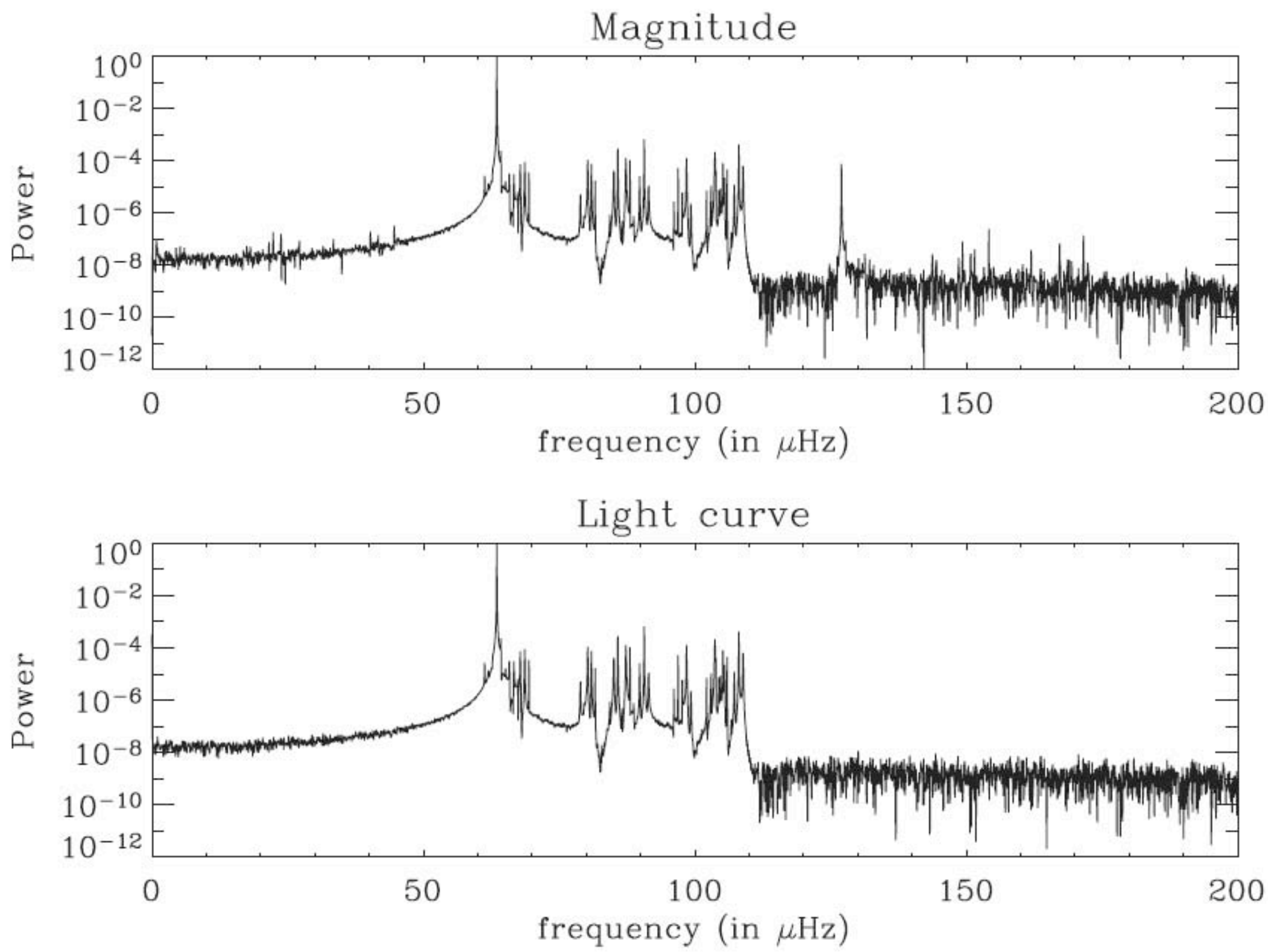
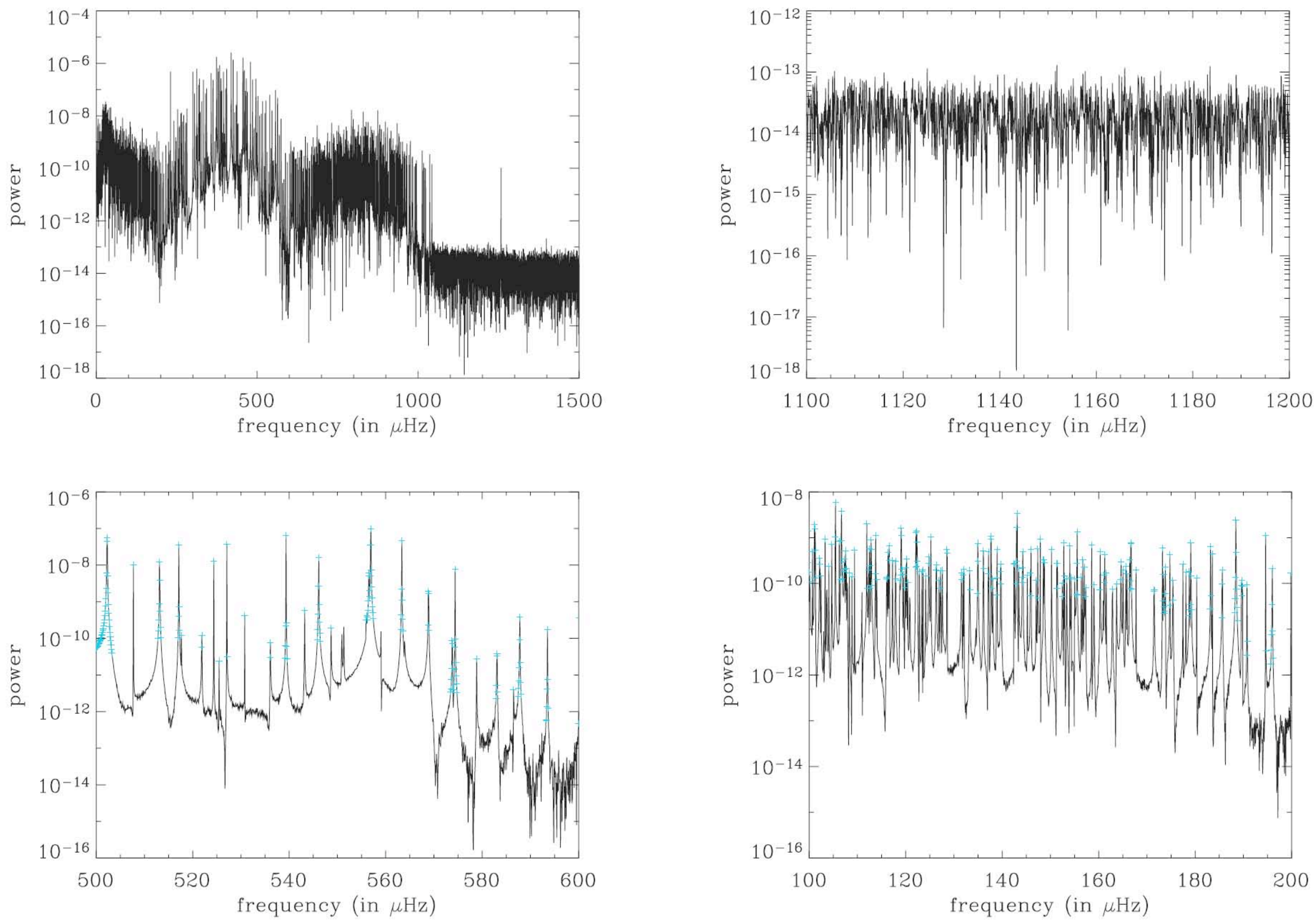
HH#5: HD180642



HH#5: HD181555



HH#5: lessons learnt

- Do not use magnitude for the time series
- Classical pulsators do not know anout noise…
- Parameters derived in the spectrum but preferrably in time (See HH#6)
- The number of modes (>300) is a problem for the interpretation

HH#6: Recipe generation

- COROT frequencies to be used as reference and properly referenced to
- Data reduction group provides generic recipe for:
  - Solar-like stars, heavier stars
  - Classical pulsators (Cepheids, β cepheids, etc…)
- Frequencies are produced using this recipe by one fitter
- Various cases:
  - Generic recipe works: OK!
  - Generic recipe fails:
    - no COROT frequencies
    - needs for more elaborate techniques

HH#6: Recipe for solar-like stars

- General agreement:
  - S1: Normalisation such that the power in [0,Nyquist/2] is half the square of the rms of the time series (σ^2)
  - S2: Inclination angle must be determined beforehand
  - S3: Total power in a multiplet is one (angle compensation)
- Steps of the recipe:
  - Compute power spectra (or Lomb Scargle)
  - Normalize according to S1
  - Perform degree tagging (echelle diagramme) and guess parameters
  - Estimate best possible inclination angle (S2) and use it as a fix parameter
  - Fit a symmetrical profile over a window of $\Delta\nu_0/3$, assuming a white noise, the same linewidth for pair of modes (l=0-2 or l=1-3) and different splitting for each degree (Multiplet as per S3)

HH#6: Recipe for classical pulsators

- General agreement:
  - C1: Detection level set to 1% for the [0 μHz ,5000 μHz] window (taking into account the number of bins in the window)
  - C2: The mean noise level in a 10-μHz window will be determined using the median or other methods
  - C3: After detection, frequencies, amplitudes and phases will be obtained by fitting the time series by the hundred (requiring frequency filtering)
- Steps of the recipe:
  - Compute power spectra (or Lomb Scargle)
  - Normalize according to S1
  - Detection level computation according to C1
  - Mean noise level computation according to C2 in the 10-μHz wide windows over the range [0 μHz ,5000 μHz]
  - Detection by getting all peaks above the product of the mean noise level x detection level
  - Fit of set of 100 sine wave in the time series after filtering in the frequency domain

Conclusion

- The experience gained in CoRoT will benefit to AsteroFlag, Kepler
- What remains to be done:
  - Angle determination
  - Asymmetry
  - Rotation and star structure (interference)
  - Surface activity (removal)
  - Global spectrum fitting (in progress…)
  - Cluster (binary) spectrum fitting

Bibliography of the DAT

- Appourchaux et al, 2006, ‘HH exercises’, ESA SP 1306 and references therein
- Appourchaux et al, 2006, ‘Recipes’, ESA SP 1306 and references therein
- Baudin et al, 2006, ‘Light curve simulator’, ESA SP 1306
- www.ias.u-psud.fr/virgo/html/corot/datagroup/hh.html
- HH compilation (available above)
- HH6 minutes (available on request)
- Angle fit strategy document (available on request)

HH#4: Collapsogramme

- Compute power spectrum
- Whiten power spectrum
- Select a window for detection (1000 μHz or so) and a central frequency
- Compute echelle diagramme (ED) over that window with various spacing
- Collapse ED
- Normalize collapsed ED by mean value
- Subtract mean value and normalize by number of degrees of freedom

Idea courtesy of Korzennik

HH#6: strategy for the angle

- Use 3 quadruplets (*l*=0,1,2,3) for deriving the angle *i* and the projected splitting ($\nu_s \sin i$)
- for applying the recipe:
  - if the ratio of splitting to linewidth is greater than 60% use the angle fitted as a fixed parameter
  - if the ratio of splitting to linewidth is smaller than 60% use 45 degrees as a fixed parameter