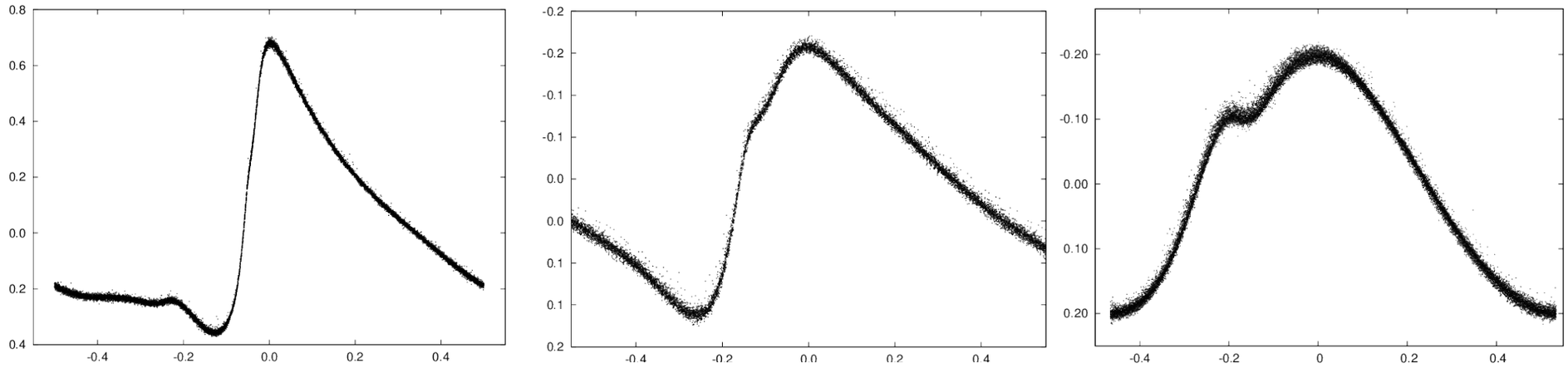
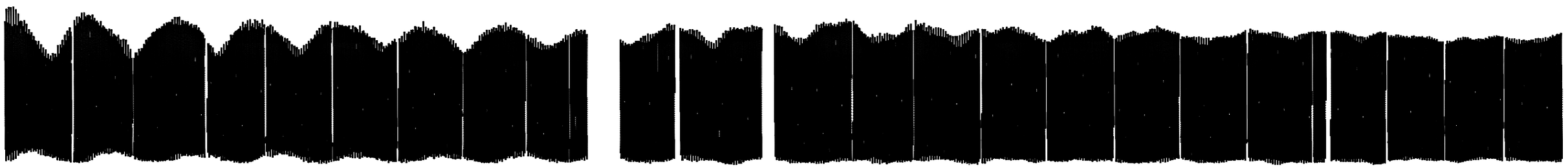
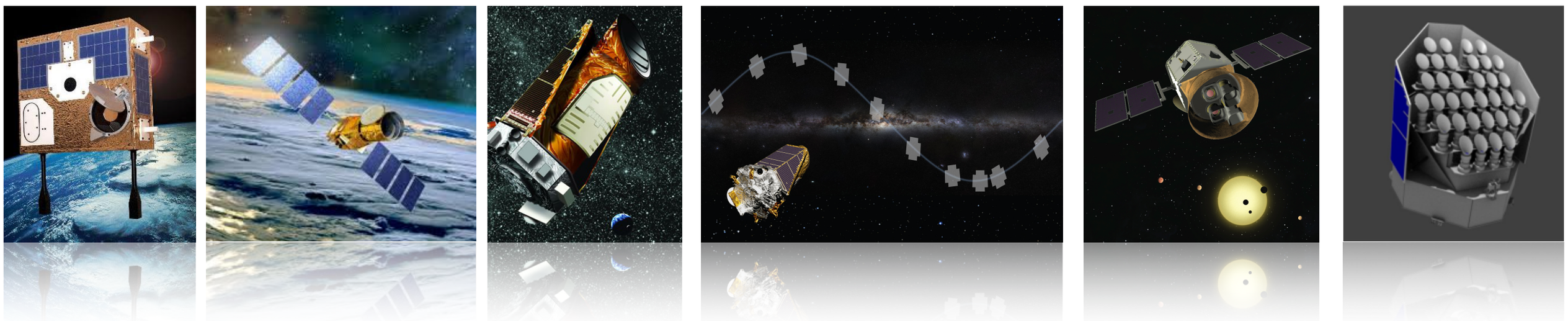


The space photometry revolution and our understanding of RR Lyrae stars

Róbert Szabó
Konkoly Observatory, MTA CSFK
Budapest, Hungary





Collaborators

- **J. M. Benkő** Konkoly Observatory, MTA CSFK, Budapest, Hungary
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- **J.-F. Le Borgne** Université de Toulouse, UPS-OMP, IRAP & CNRS, IRAP, Toulouse, France
- **A. Baglin** LESIA, Université Pierre et Marie Curie, Université Denis Diderot, Observatoire de Paris, Meudon, France
- **W. W. Weiss** Institute of Astronomy, University of Vienna, Vienna, Austria
- **KASC RR Lyrae + Cepheid Working Group**

Introduction

In 2006, a colleague of mine asked:

‘*What are you going to do with RR Lyrae light curves observed from space?*

Those stars are sooooooooooo ‘

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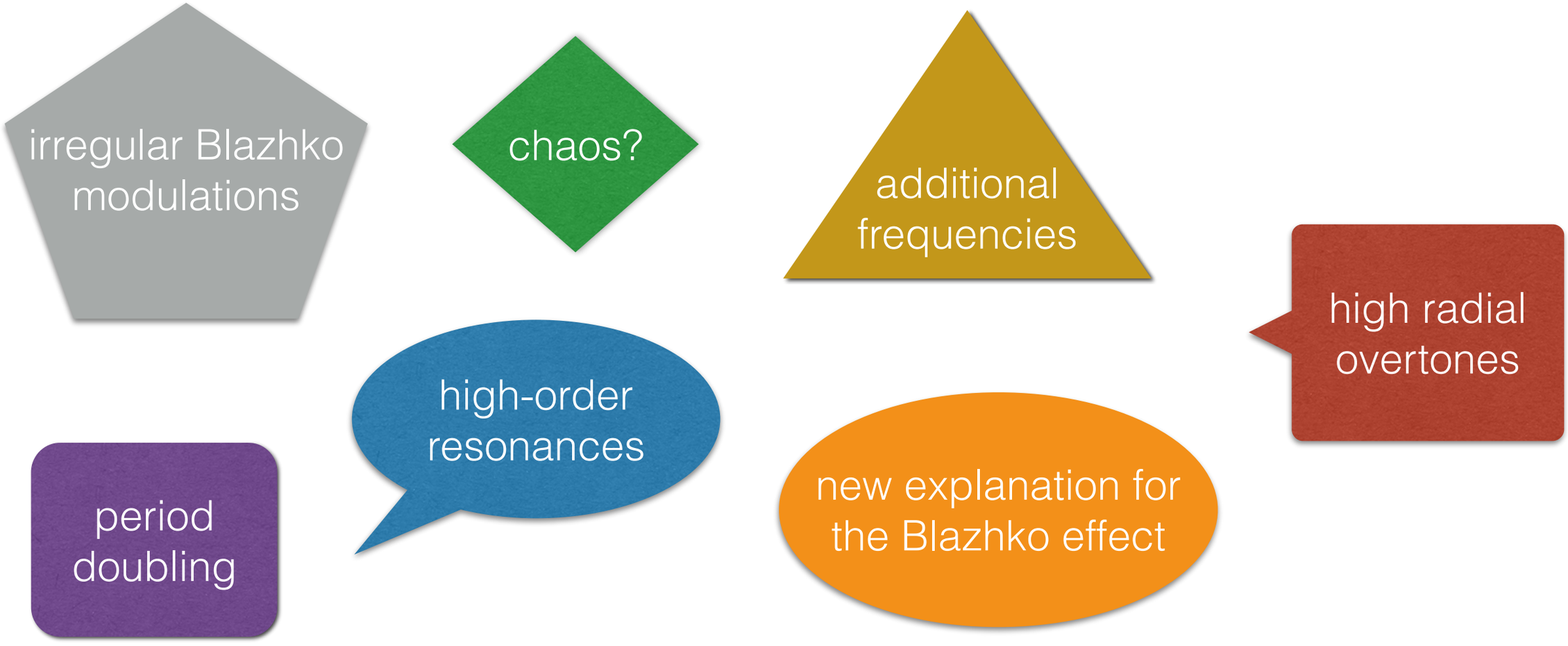

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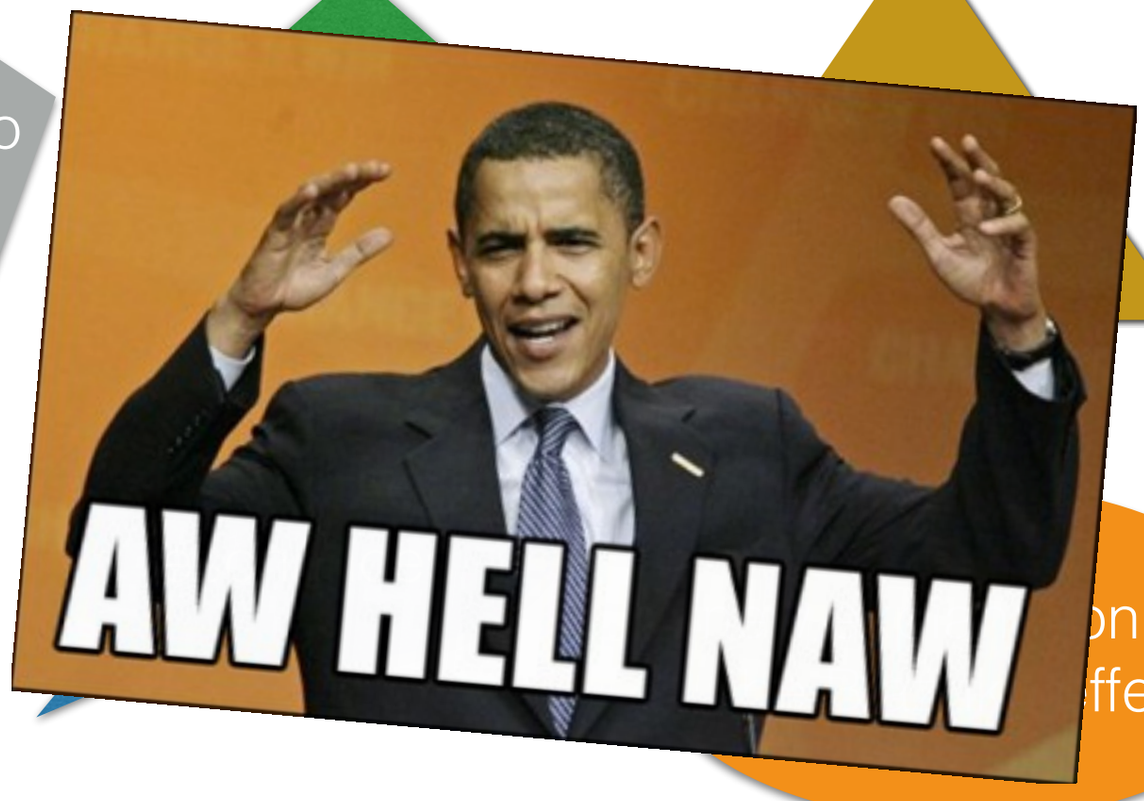
irregular Blazhko modulations



high radial overtones

period doubling

on for
ffect

Period doubling

- Alternating maxima/cycles
- Half-integer frequencies (HIF)
- PD bifurcations - route to chaos

- Only in Blazhko RR Lyrae, no PD in non-modulated RRab stars

- PD is caused by a 9:2 resonance between the F and the 9th radial overtone (Szabó et al. 2010, Kolláth et al. 2011)

- Resonance paradigm: the same resonance is able to cause the Blazhko effect itself (Buchler & Kolláth 2011)

- PD occurrence statistics:
  Kepler: 10/16 (Benkő et al. 2014, accepted)
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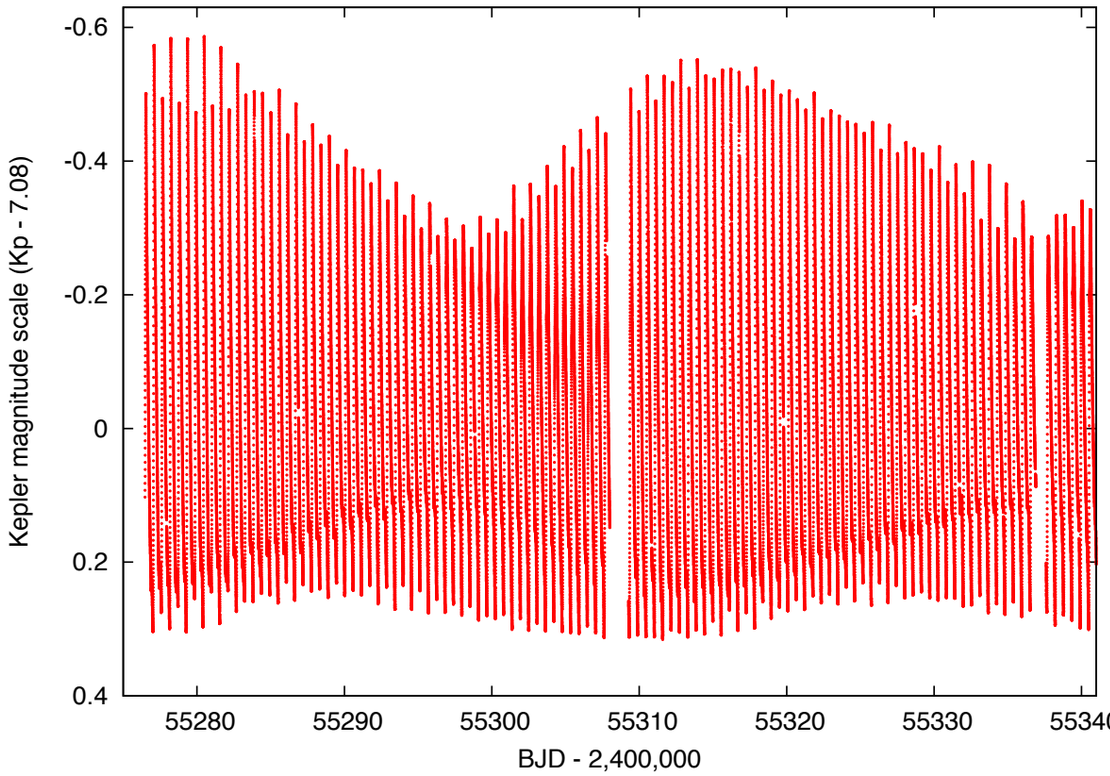

Period doubling
RR Lyrae, the eponym
Kepler, Q5 SC

Period doubling

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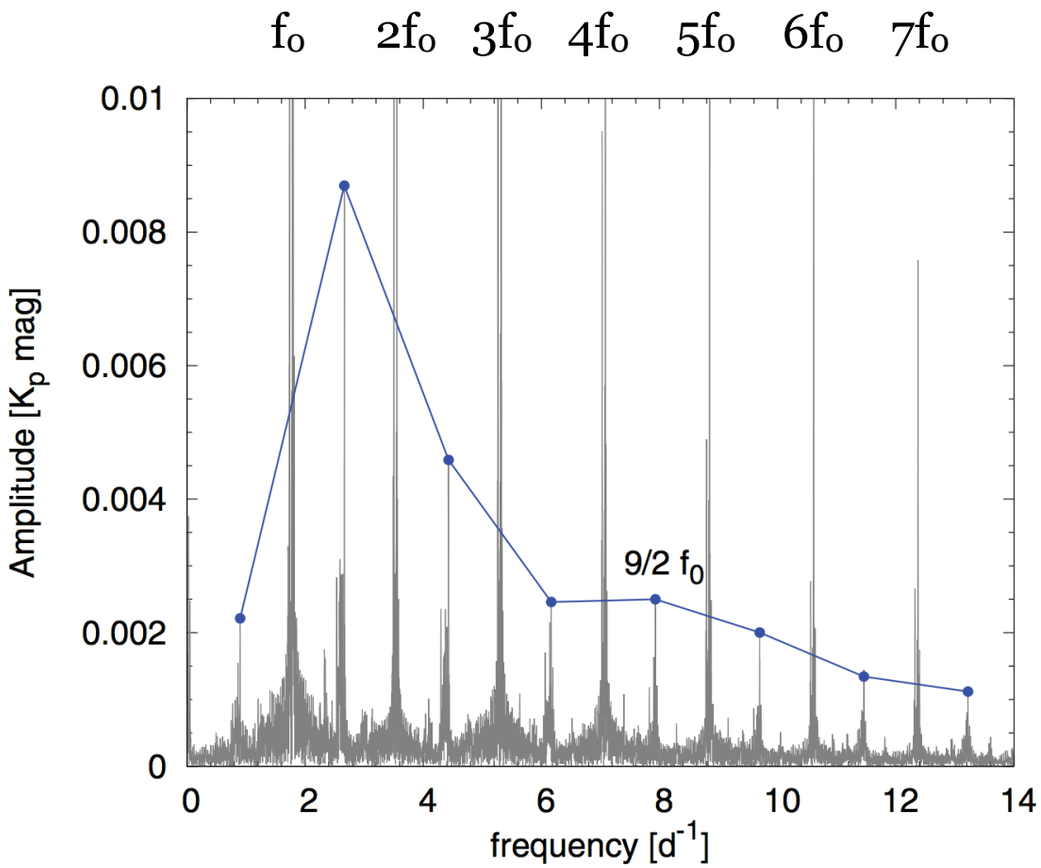

Half-integer frequencies
RR Lyrae, the prototype
Molnár et al. 2012

Period doubling

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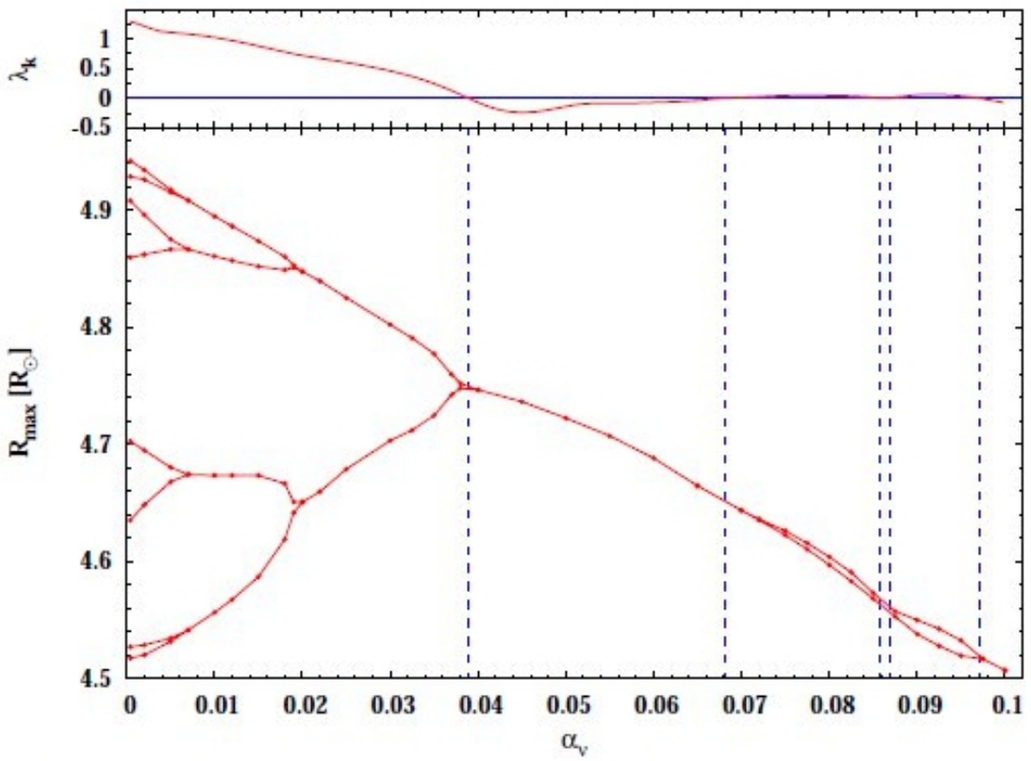
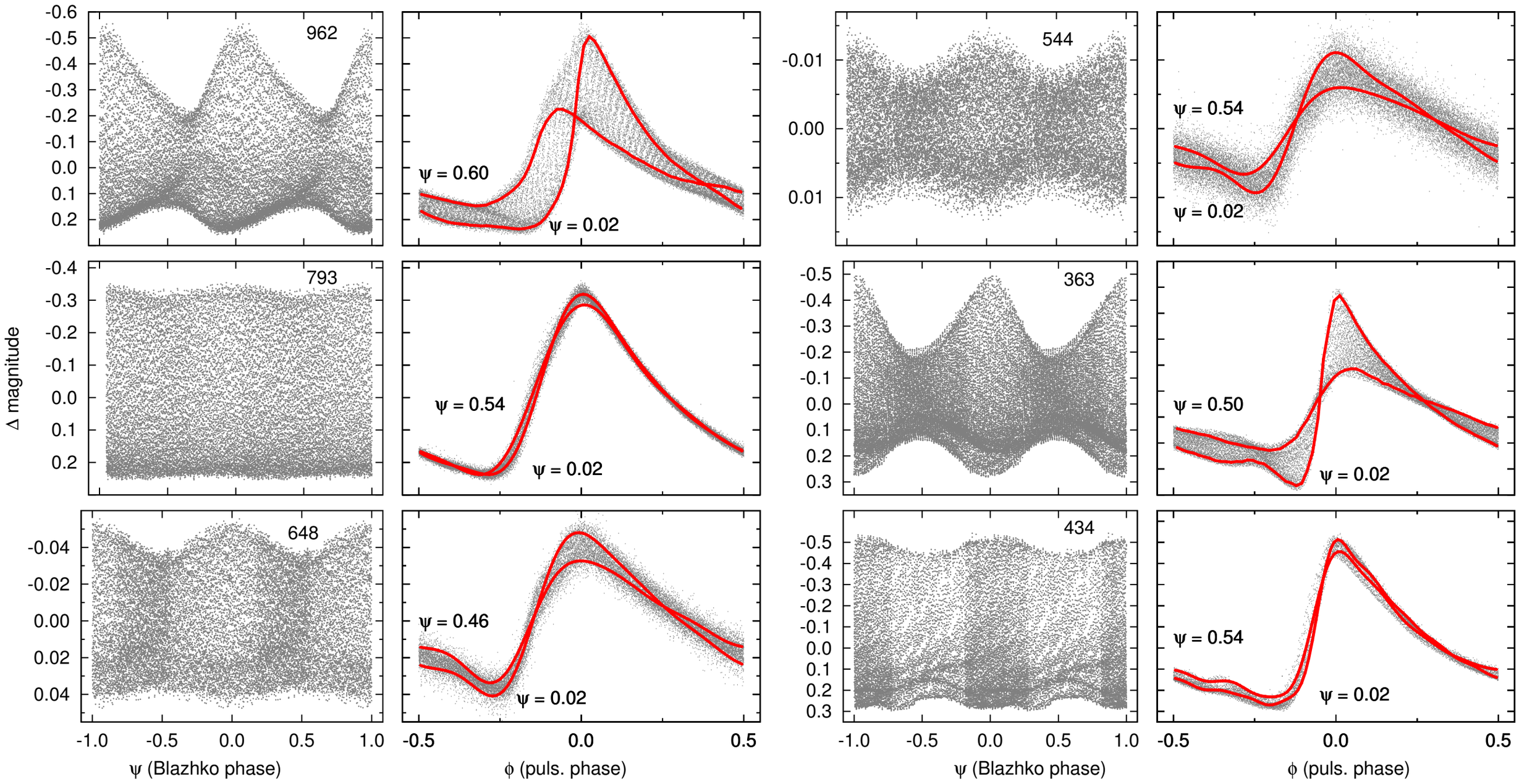


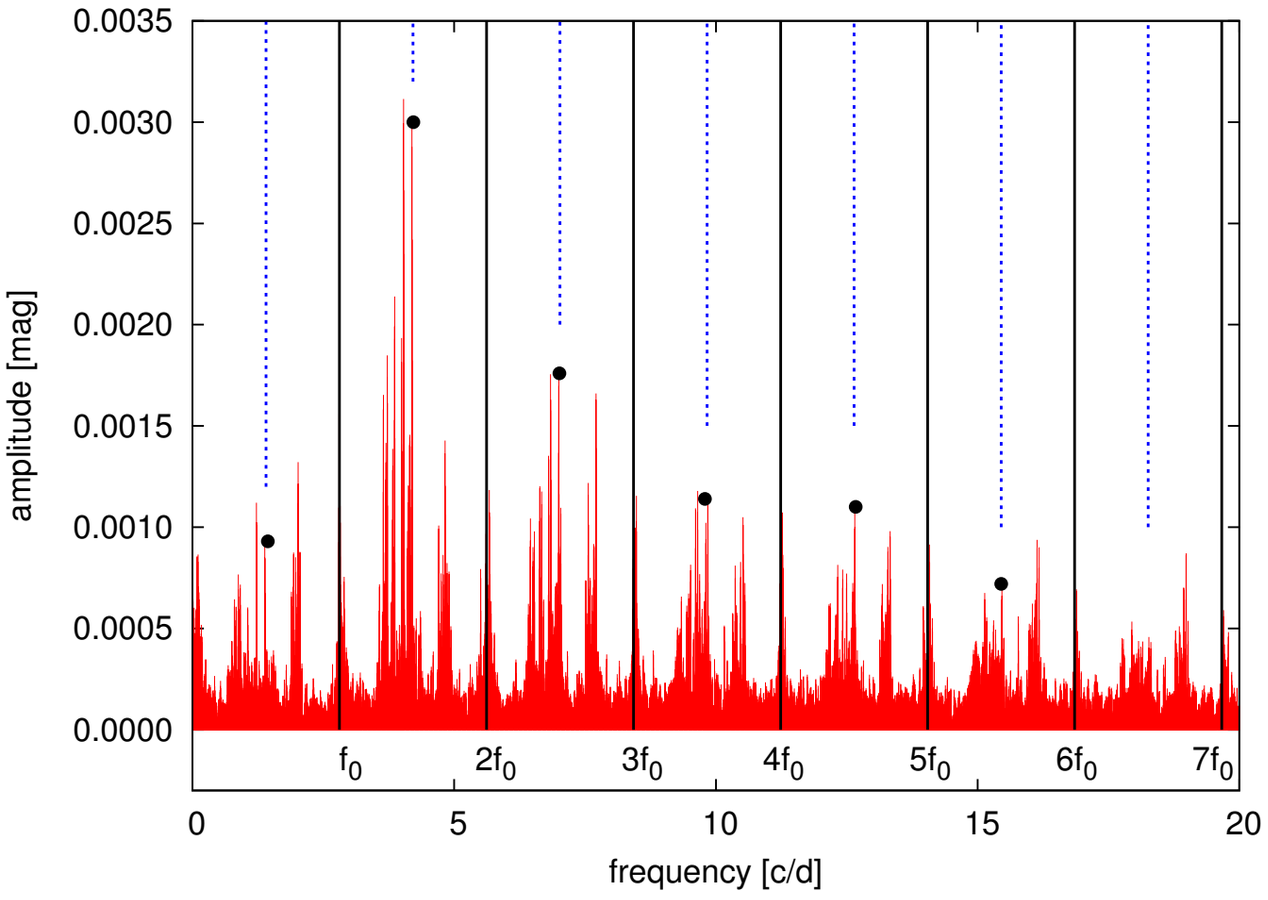
PD bifurcation in
RR Lyrae hydro models
Kolláth et al. 2011

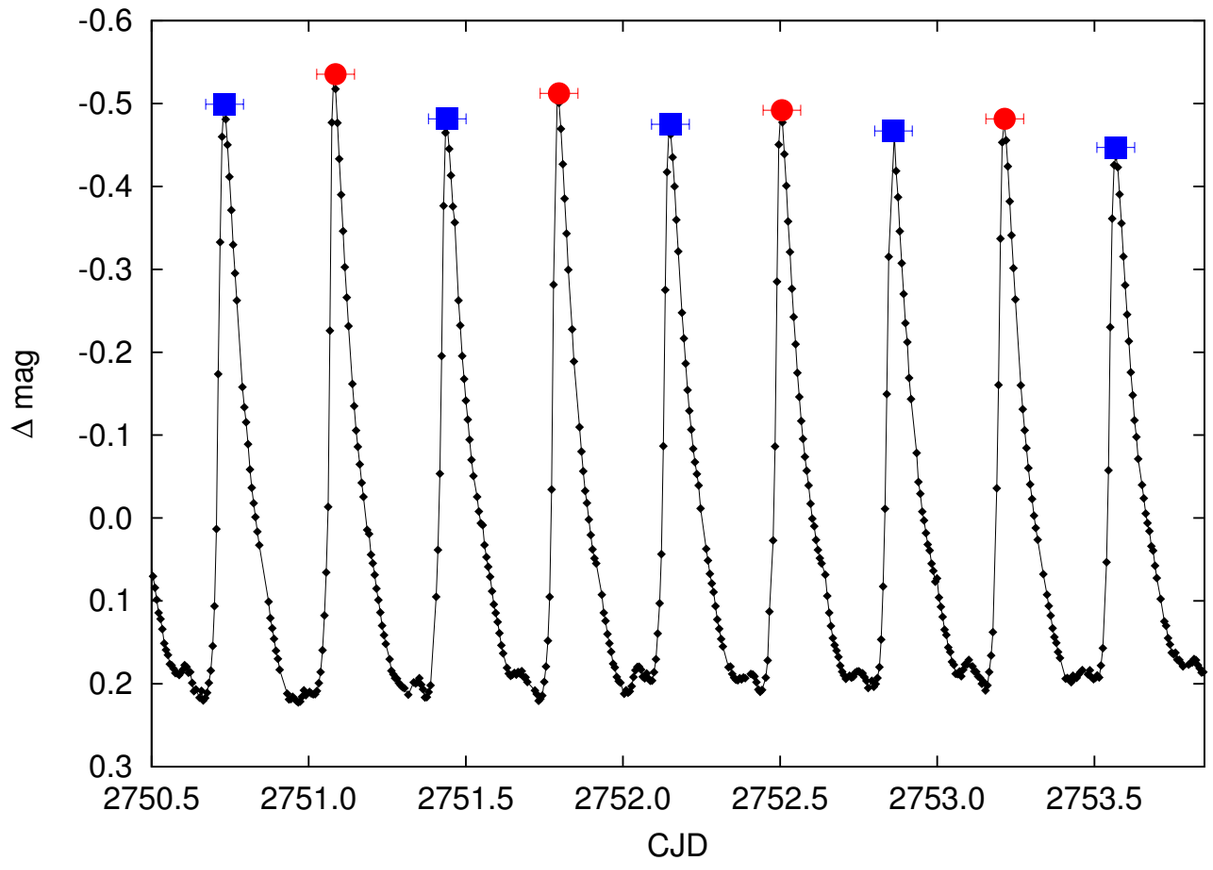
Period doubling



CoRoT Blazhko zoo
Szabó et al. 2014, submitted

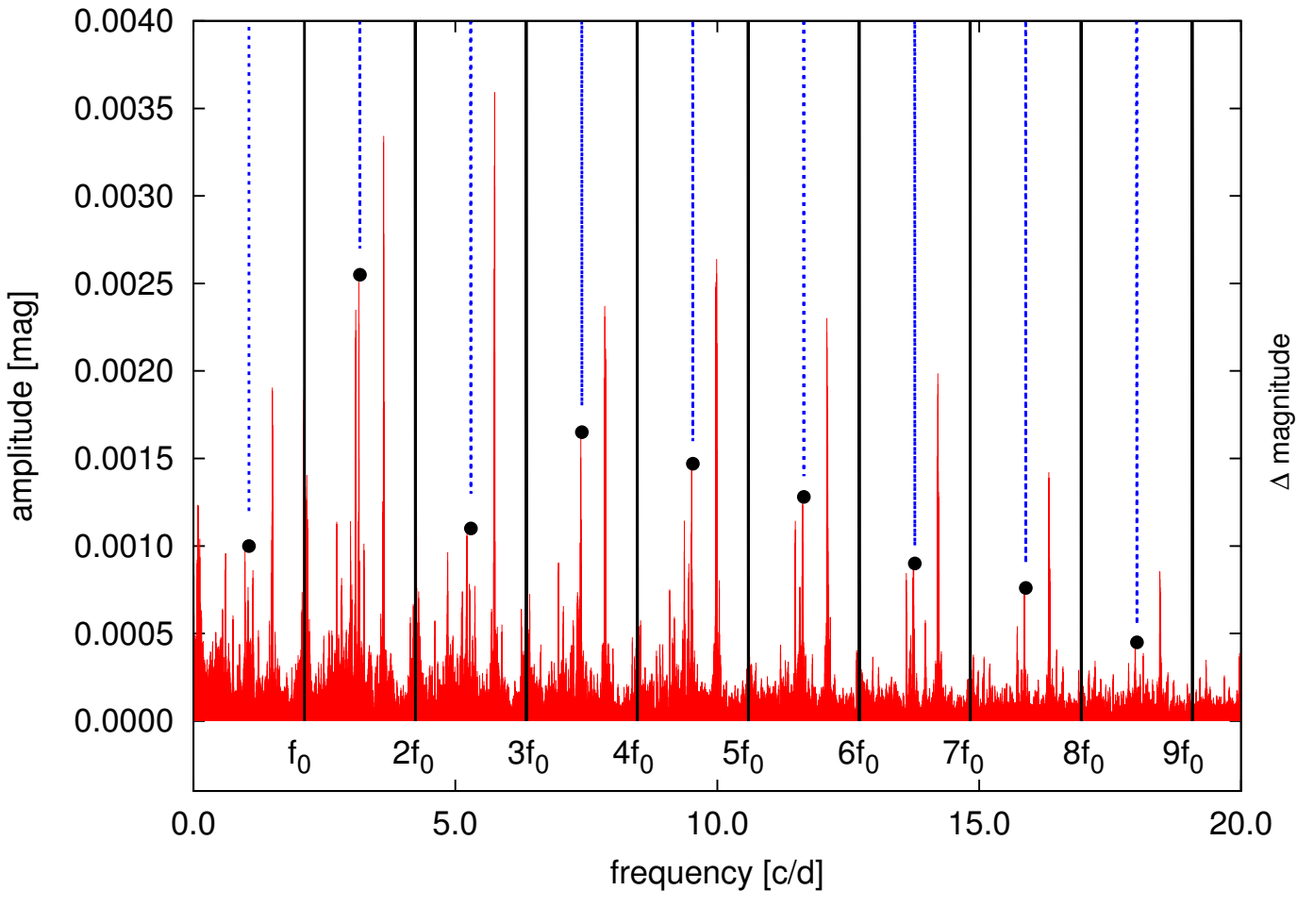
Period doubling

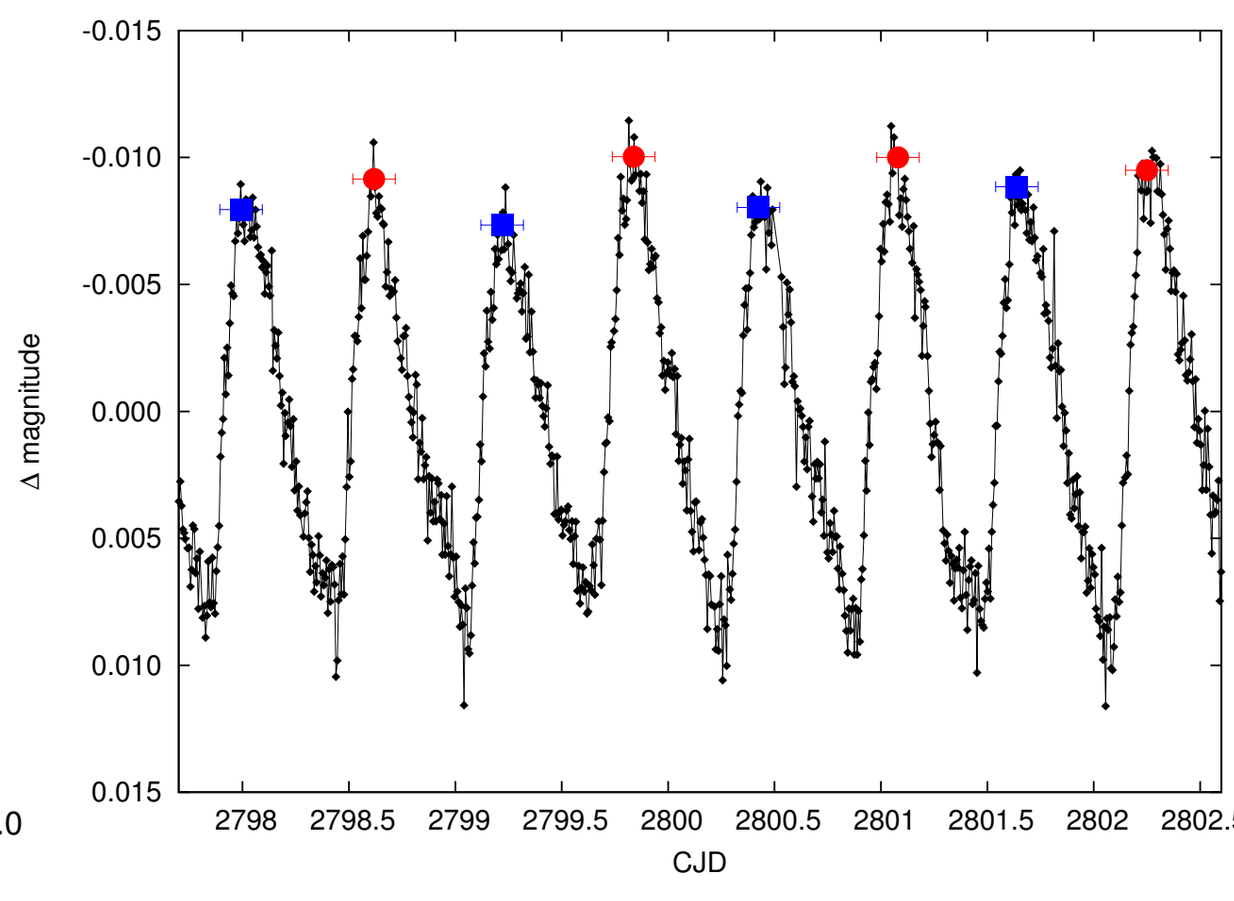




CoRoT 0100689**962** - V1127 Aql
Szabó et al. 2014, submitted

Period doubling



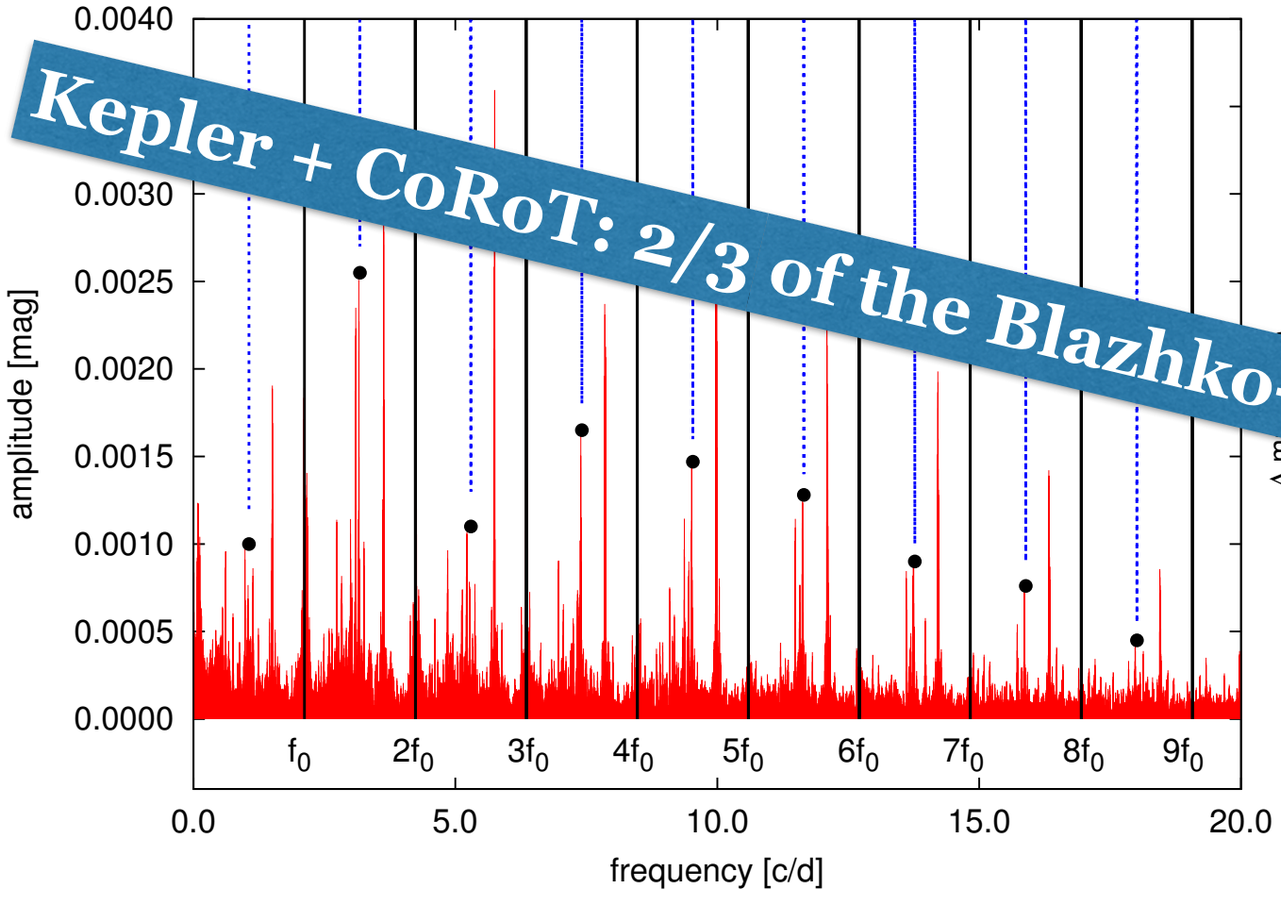


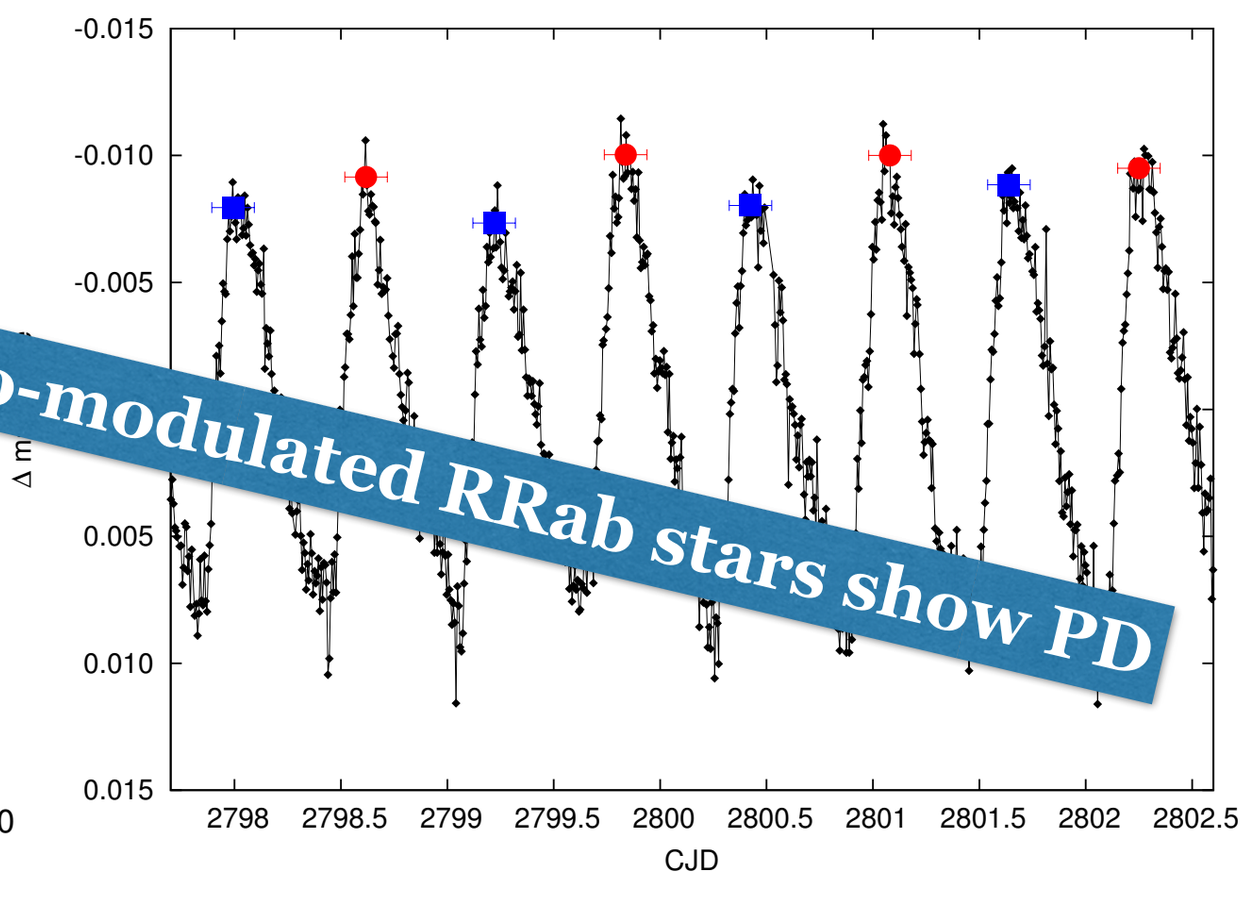
CoRoT 0101128979**3**

CoRoT 0101503**544**

Szabó et al. 2014, submitted

Period doubling





Kepler + CoRoT: 2/3 of the Blazhko-modulated RRab stars show PD

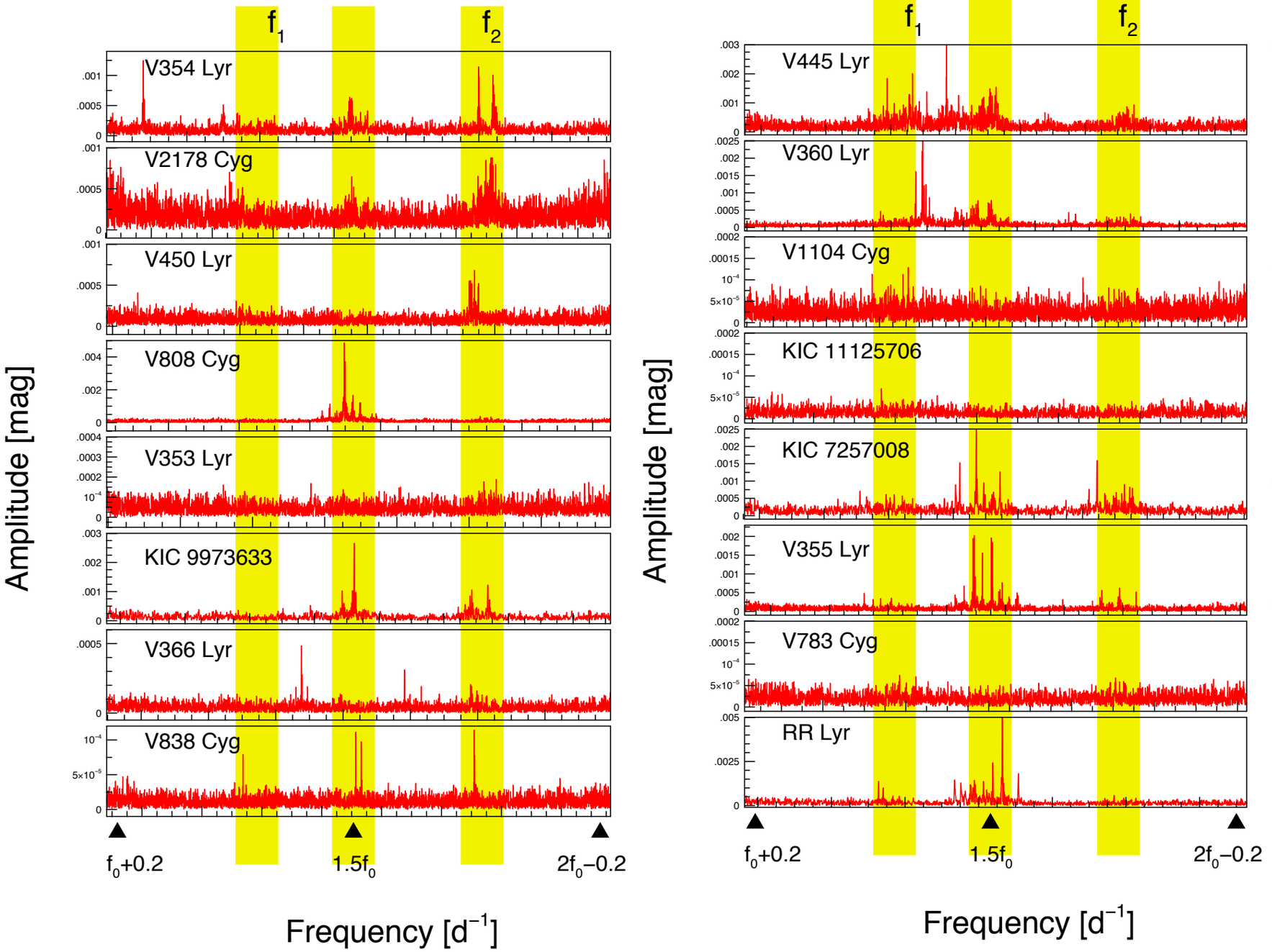
CoRoT 0101128979**3**

CoRoT 0101503**544**

Szabó et al. 2014, submitted

Additional modes

Radial modes



- Frequencies around the radial O1, O2 are common

- **Radial modes**
  RR Lyrae: O1
  Molnár et al. 2012

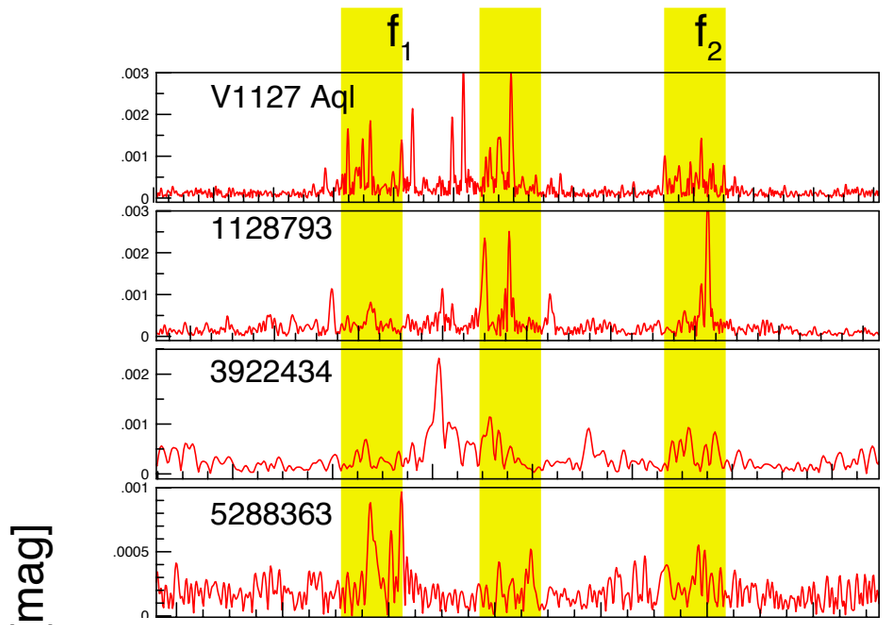
or

- **Nonradial modes**
  in 1:1 resonance with the radial mode
  Dziembowski & Mizerski 2004
  van Hoolst et al. 1998

Kepler Blazhko RRab sample Benkő et al. 2014, ApJS accepted

Additional modes

Radial modes



Blazhko RRab

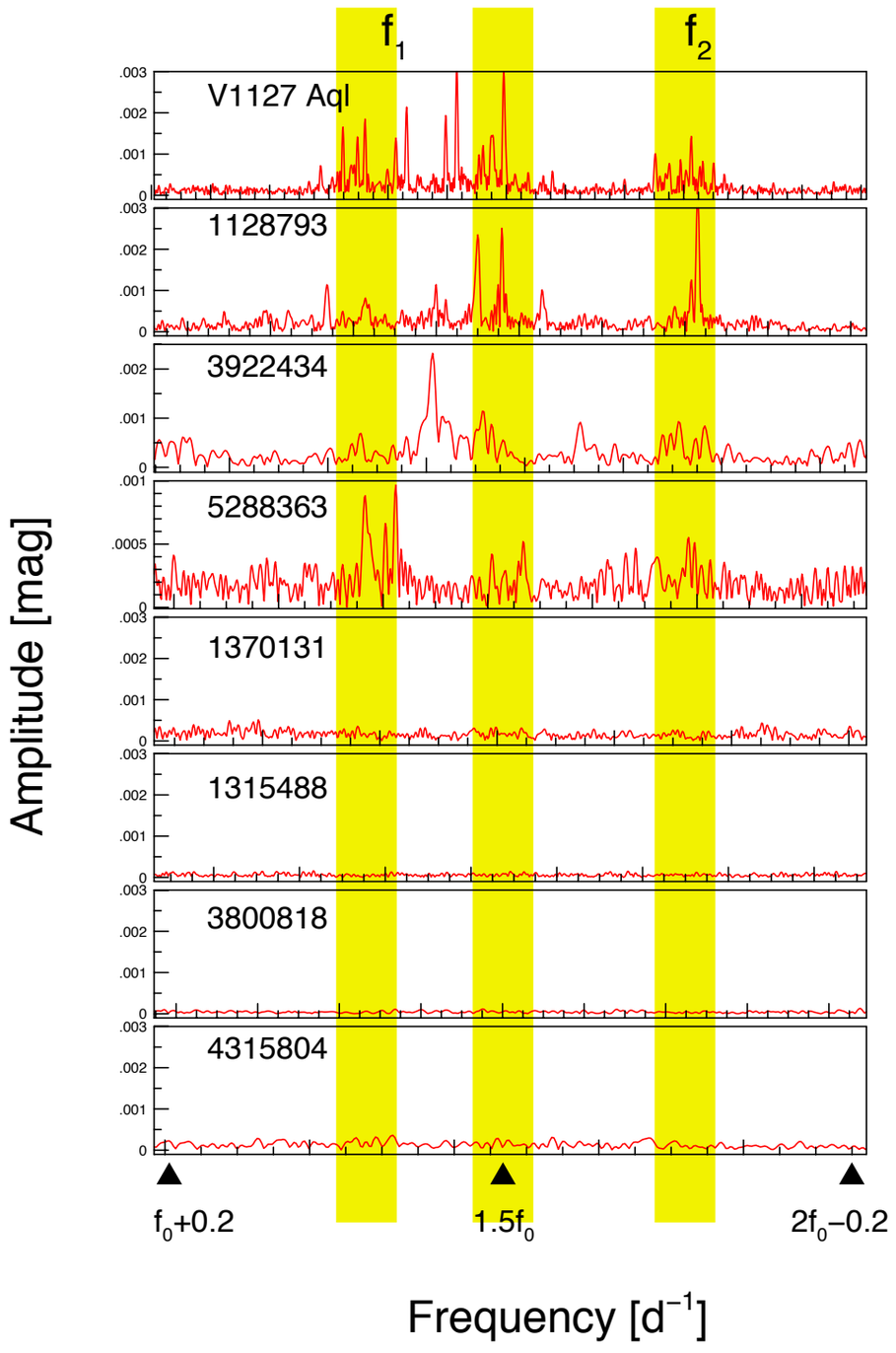
Modulated stars: frequencies around the radial O1, O2 are common.

Radial modes or Nonradial modes in 1:1 resonance with the radial mode

CoRoT RRab sample Szabó et al. 2014, A&A submitted

Additional modes

Radial modes



Blazhko RRab

non-Blazhko RRab

Modulated stars: frequencies around the radial O1, O2 are common.

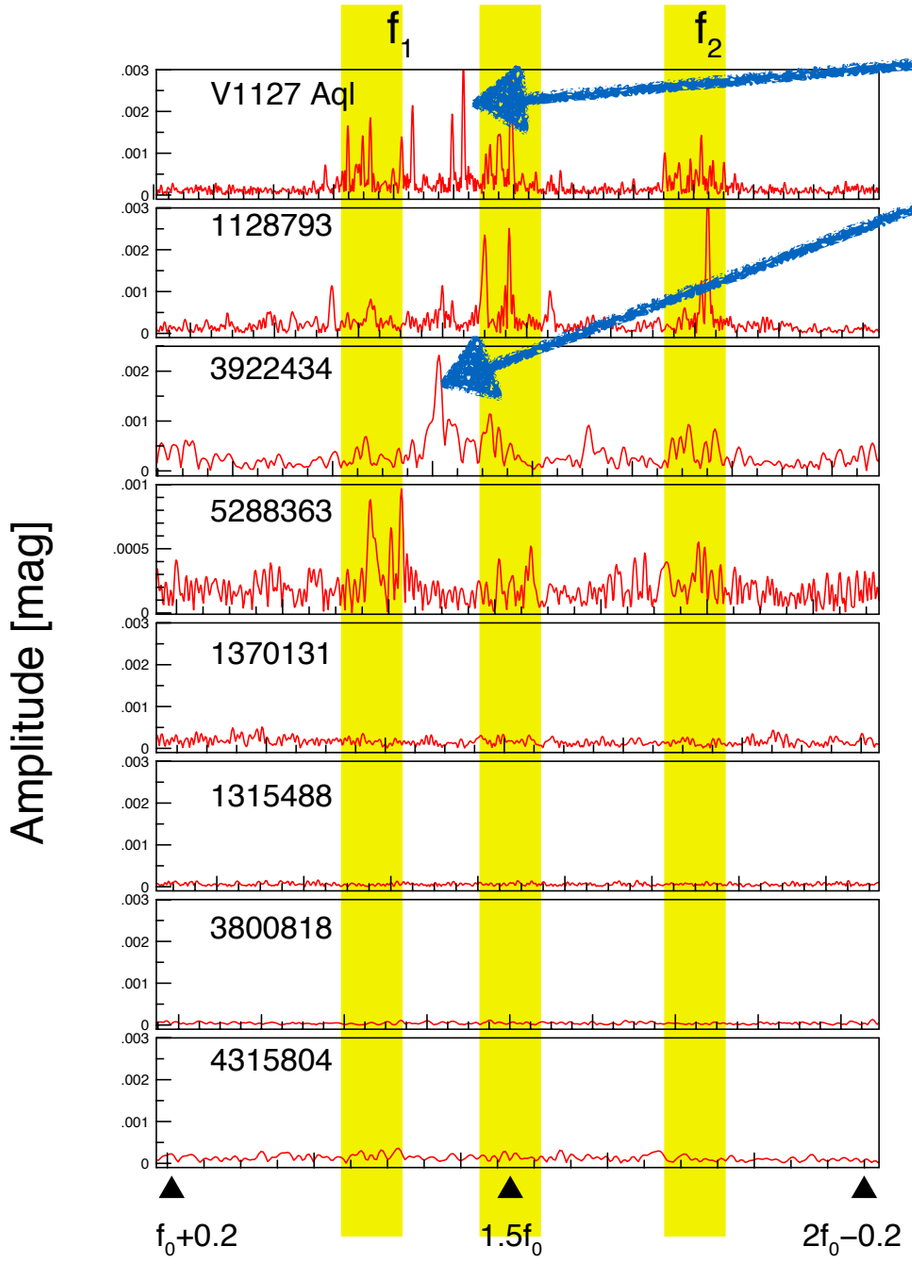
Radial modes or Nonradial modes in 1:1 resonance with the radial mode

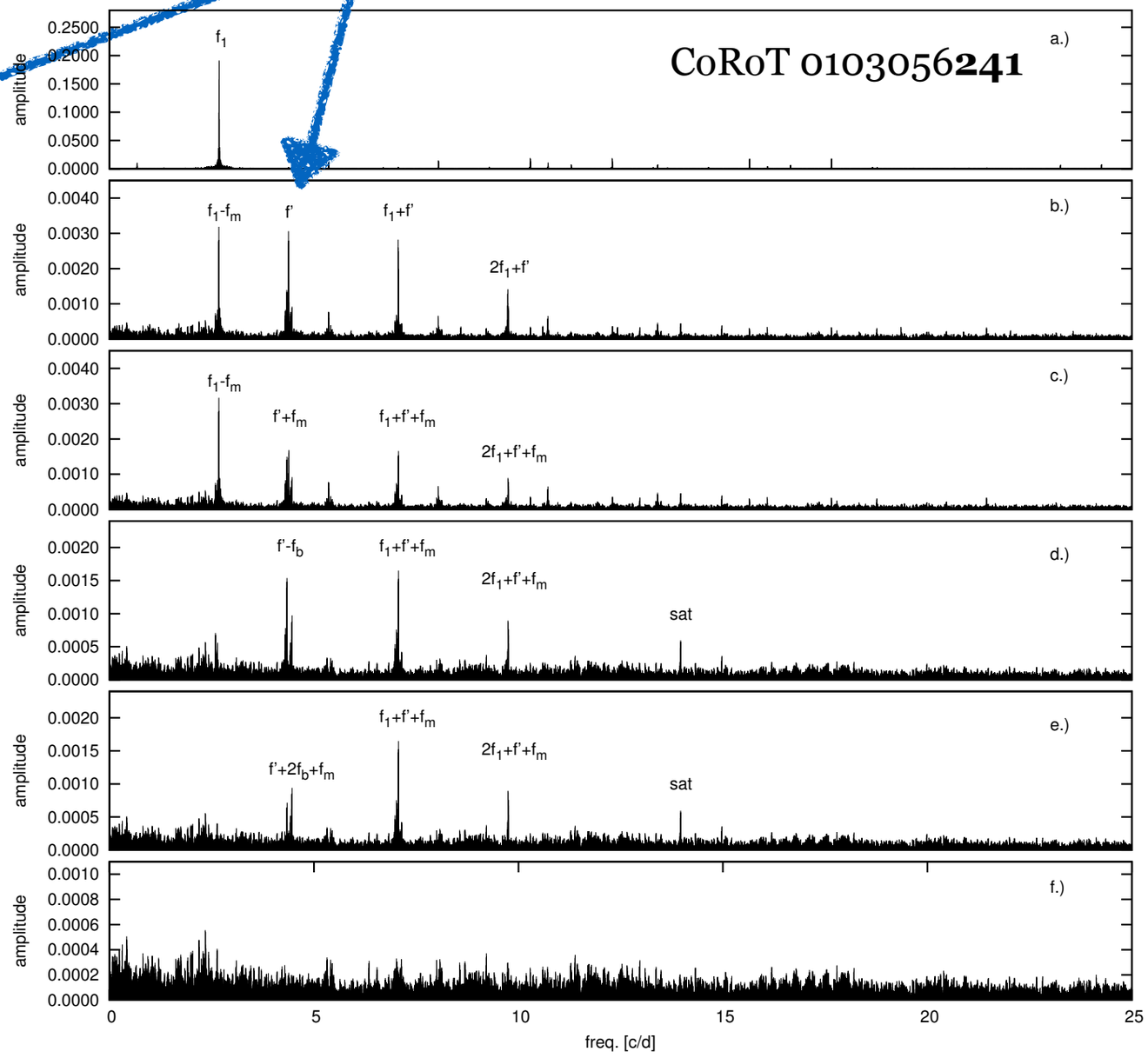
Non-modulated stars: no additional frequencies in the spectra down to the Kepler & CoRoT limits.
Nemec et al. 2011 - Kepler
Szabó et al. 2014 - CoRoT

CoRoT RRab sample Szabó et al. 2014, A&A submitted

Additional modes

Nonradial modes

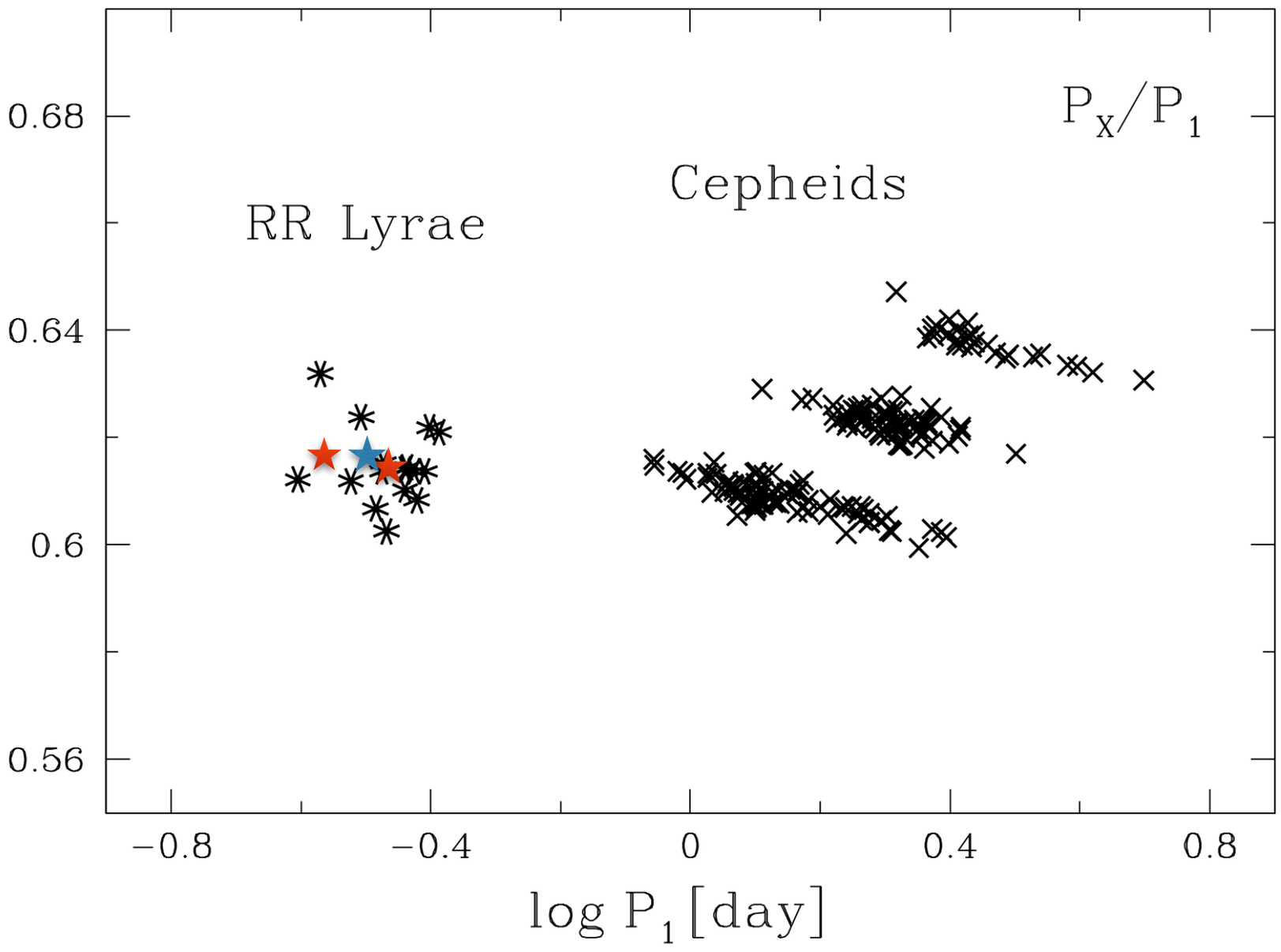




CoRoT sample Szabó et al. 2014, A&A submitted

Non-radial modes

Moskalik, 2014



- RRc and RRd stars: period ratio of P_X/P_1 ~ 0.61 is frequent
- 15 RRc (4 Kepler) + 1 RRd
- CoRoT:
  0105036**241** RRc
  0105735**652** RRc
  0101368**812** RRd
  (Szabó et al. 2014)

Additional modes

Additional frequencies in space photometry targets

- Blazhko-modulated RRab stars : all 
- non-modulated RRab stars: none 
- RRc (first overtone pulsators O1): all 
- RRd (fundamental mode + O1): all 

Additional modes

Additional frequencies in space photometry targets

- Blazhko modulated RRab stars : all

- non-modulated RRab stars:

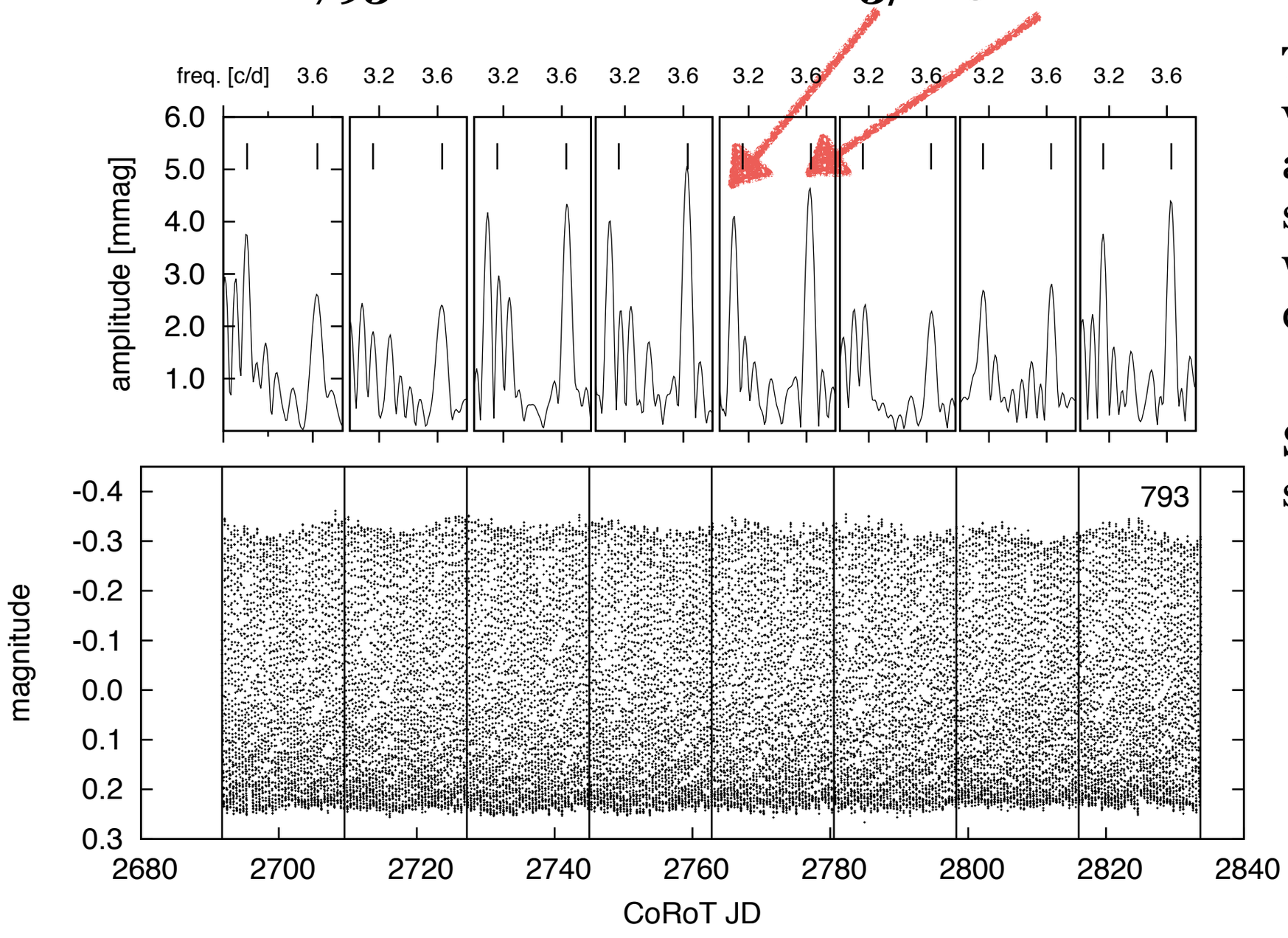
- RRc (first overtone pulsators O1): all

- RRd (fundamental mode + O1): all

Kepler + CoRoT: additional modes are universal !

Temporal variability of the additional modes

CoRoT 0101128793 **Blazhko RRab**



Temporal and structural variability of the additional frequencies seems to be **ubiquitous** whether be HIFs, O2, f_X or other nonradial

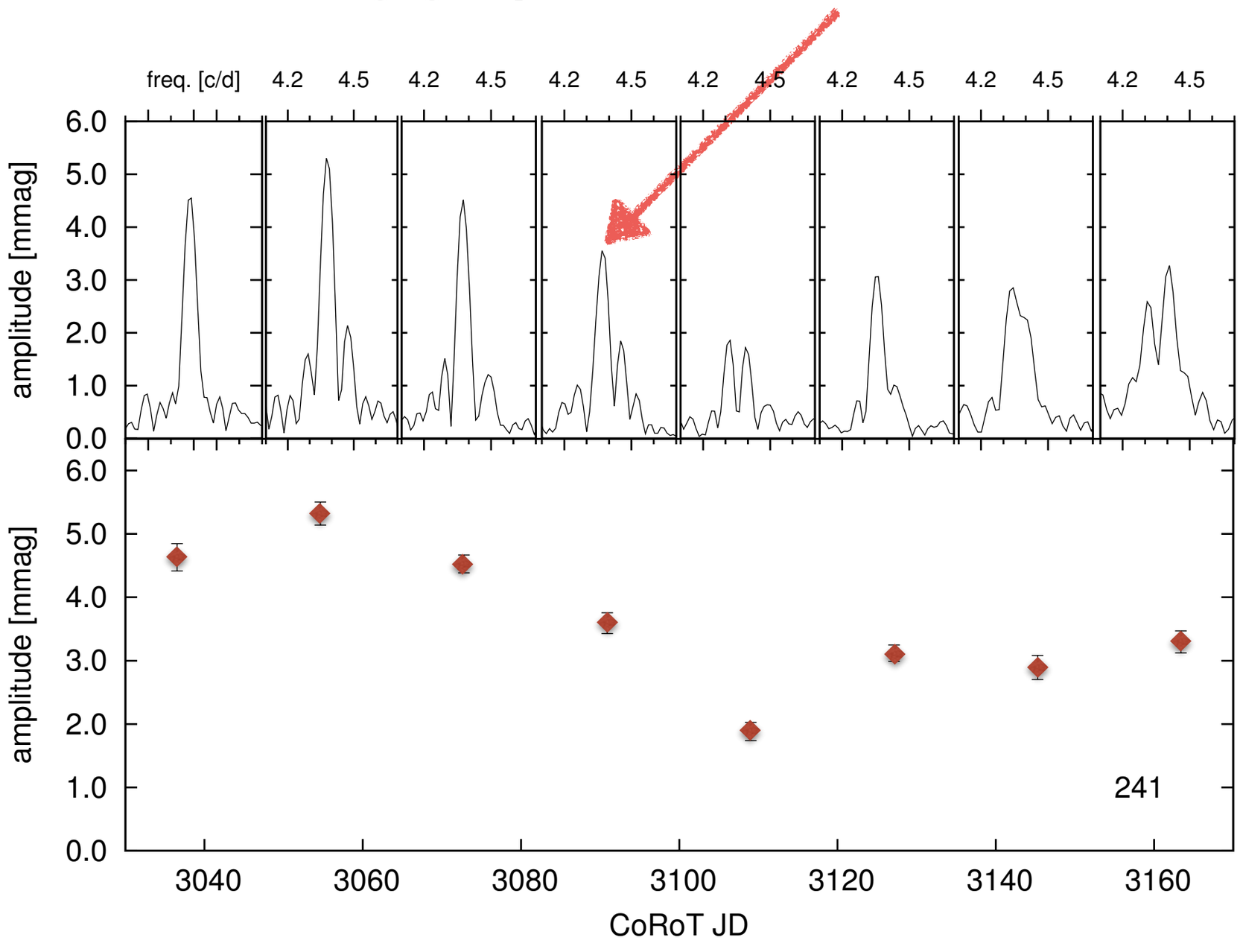
Szabó et al. 2014 submitted

CoRoT Blazhko sample Szabó et al. 2014, A&A submitted

Temporal variability of the additional modes

CoRoT 0105036**241** **RRc**

f_X



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Szabó et al. 2014 submitted

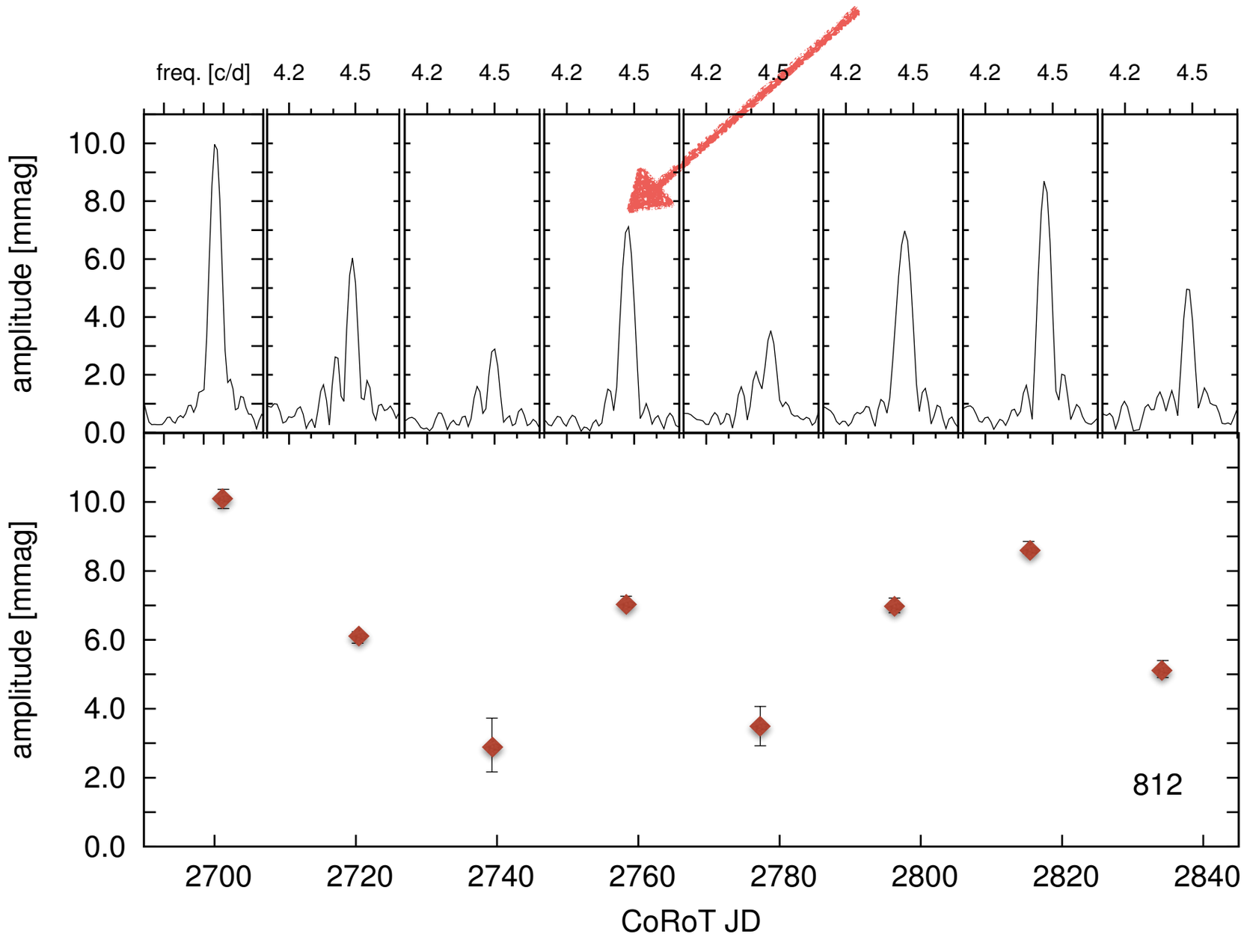
amplitude change
or
close-by unresolved frequencies?

CoRoT Blazhko sample Szabó et al. 2014, A&A submitted

Temporal variability of the additional modes

CoRoT 0101368**812** **RRd**

f_X



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Temporal variability of the additional modes

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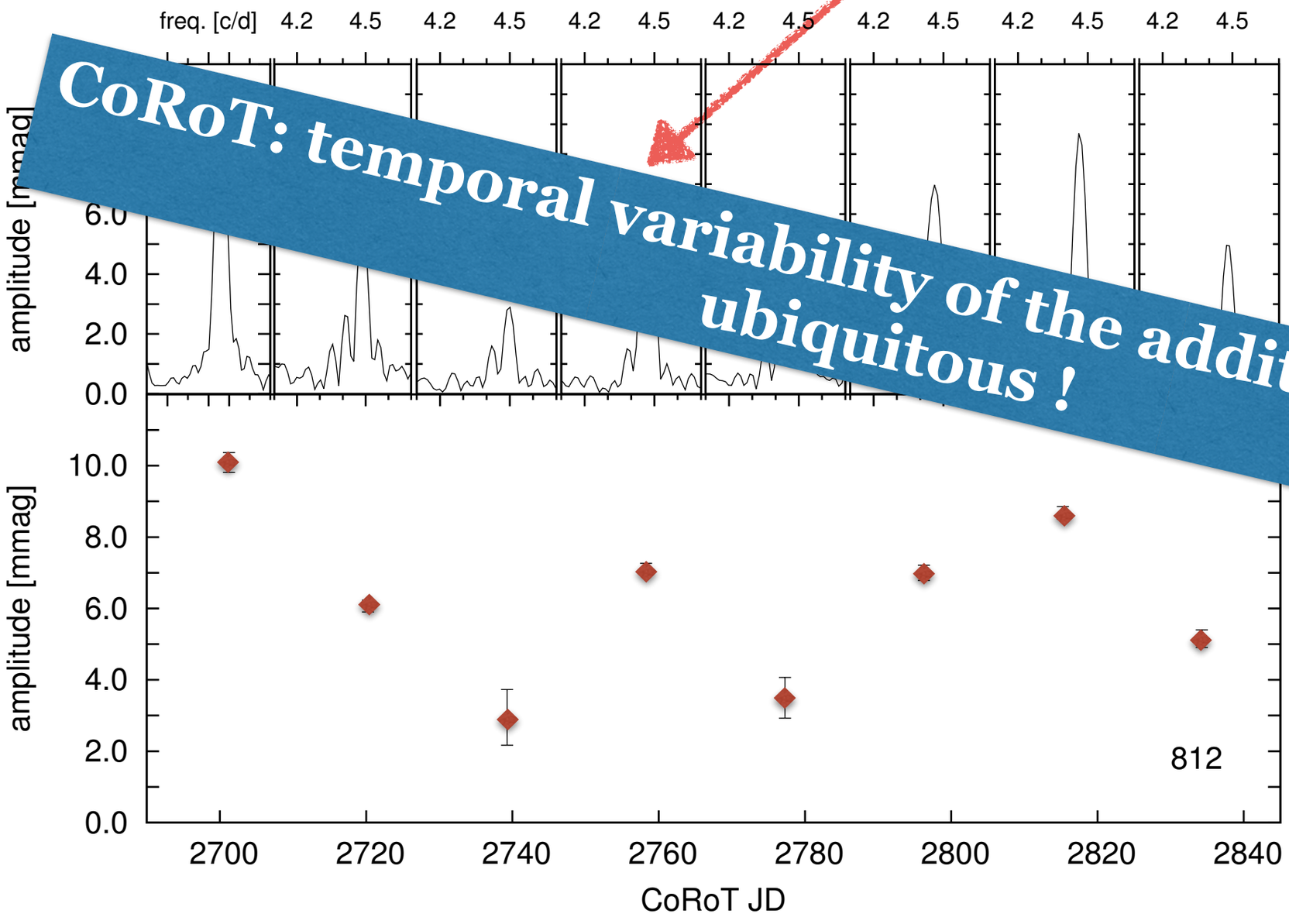

CoRoT: temporal variability of the additional modes is ubiquitous !

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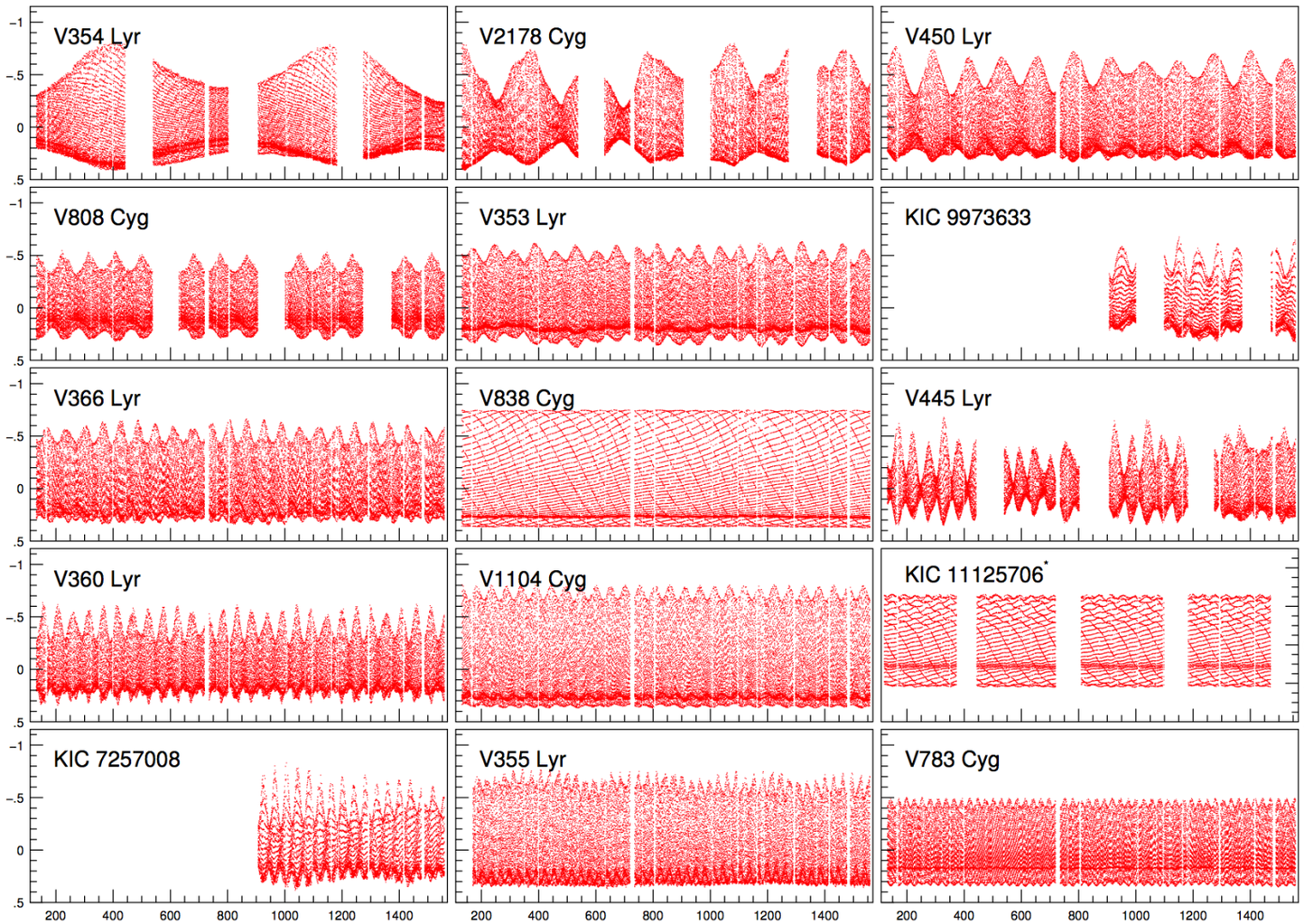
CoRoT Blazhko sample Szabó et al. 2014, A&A submitted

Multiple modulations in Blazhko RR Lyrae stars



Kepler Blazhko sample Benkő et al. 2014

- Is the Blazhko modulation simple and monoperiodic? in general: **NO**

- **2 modulation periods**

XZ Cyg	LaCluyzé et al.	2004
UZ UMa	Sódor et al.	2006
SU Col	Szczygiel & Fabrycky	2007
LS Her	Wils et al.	2008
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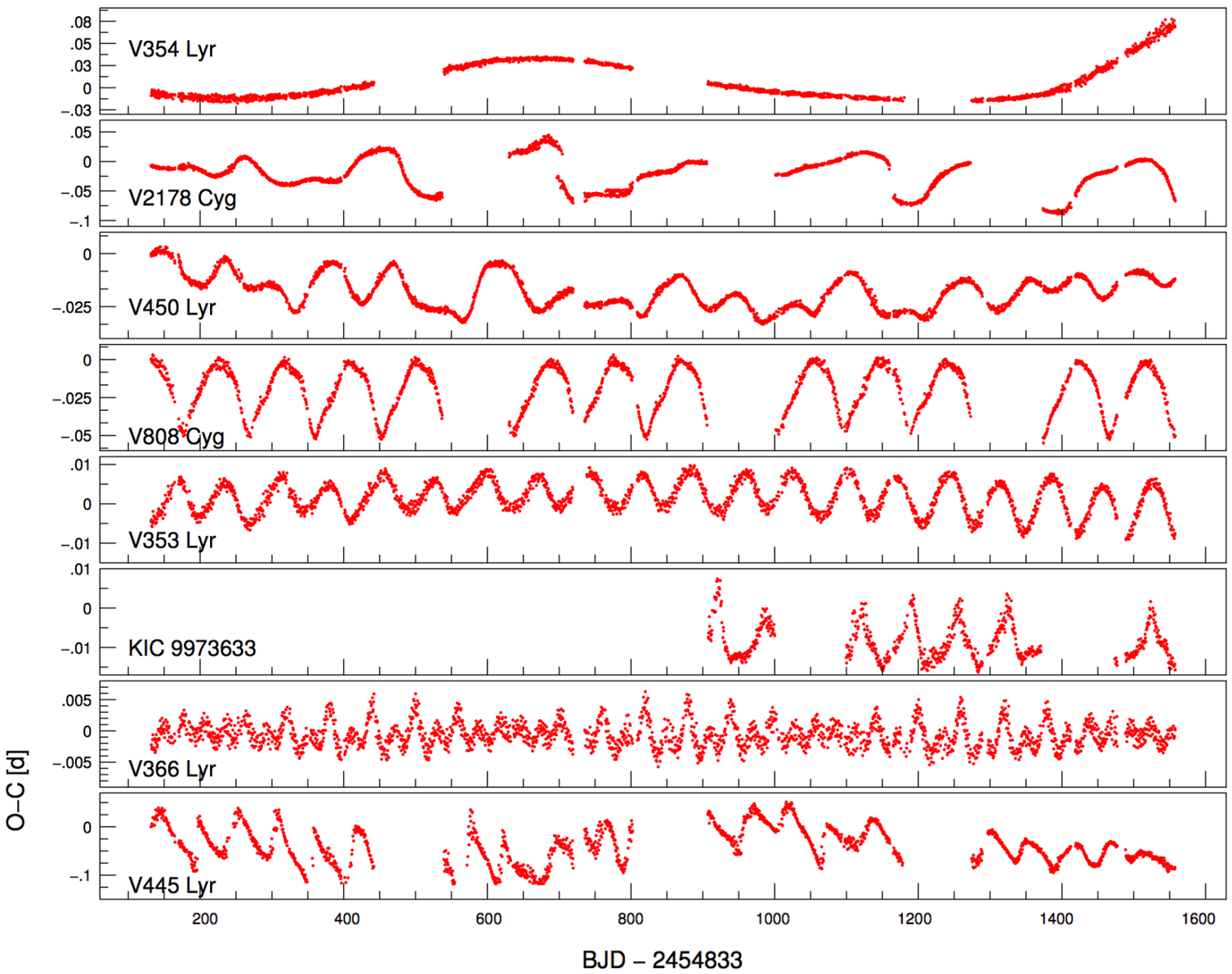
- Large sample
  Multiperiodic and irregularly modulated: **12%**
  Skarka 2014, A&A 562, A90

- Kepler sample
  Multiple modulations: **80%**
  Benkő et al. 2014, ApJS, accepted, arXiv: 1406.5864

Final, rectified, normalized, stitched, 4-year-long Kepler Blazhko light curves with tailor-made apertures are available: http://www.konkoly.hu/KIK/data.html

Multiple modulations in Blazhko RR Lyrae stars



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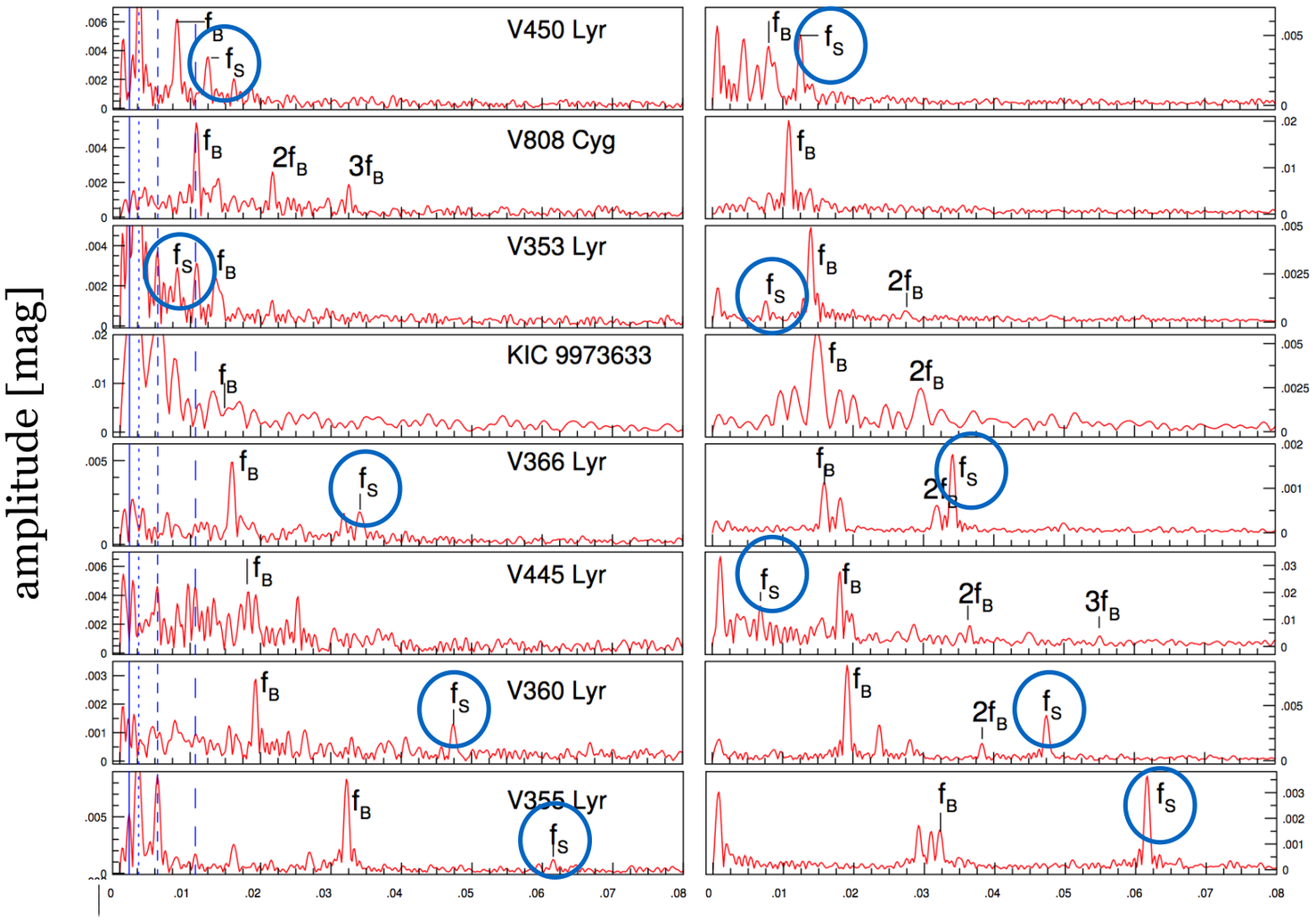
Multiple modulations in Blazhko RR Lyrae stars

Light curve O-C diagram



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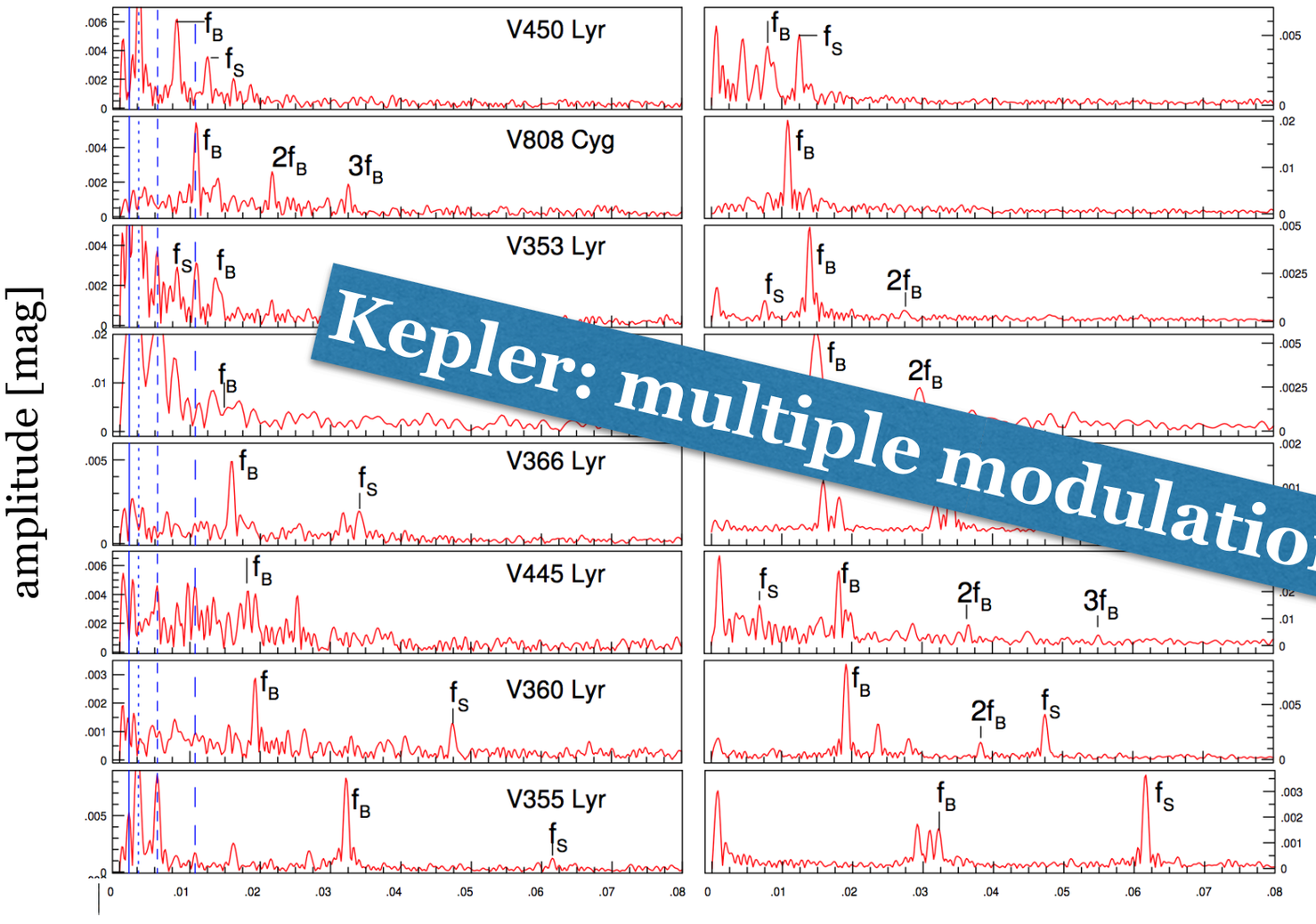

Kepler: multiple modulation is frequent !

Kepler Blazhko sample Benkő et al. 2014

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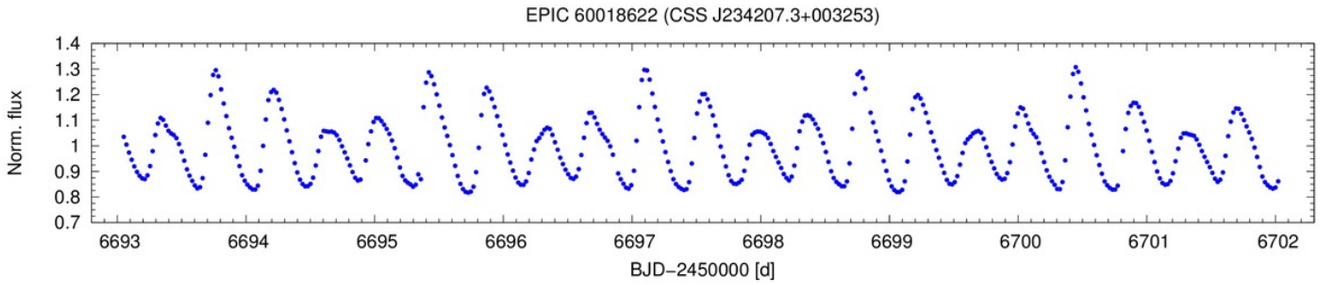
K2, TESS, PLATO

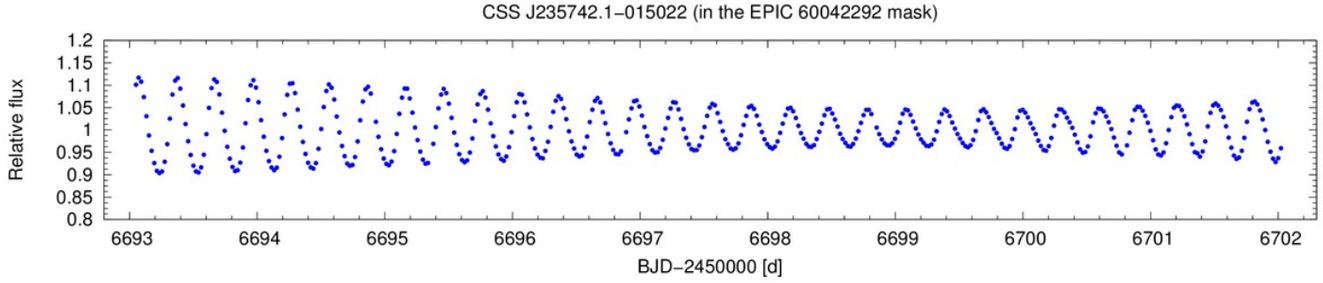
- will see different populations, metallicities
- rare objects (RRd stars, ultra-long period Blazhko modulations, etc.)
- will deliver much better statistics to understand similarities and differences in dynamical phenomena, period doubling, nonradial modes, resonances, … and occurrence rates

K2 preliminary results

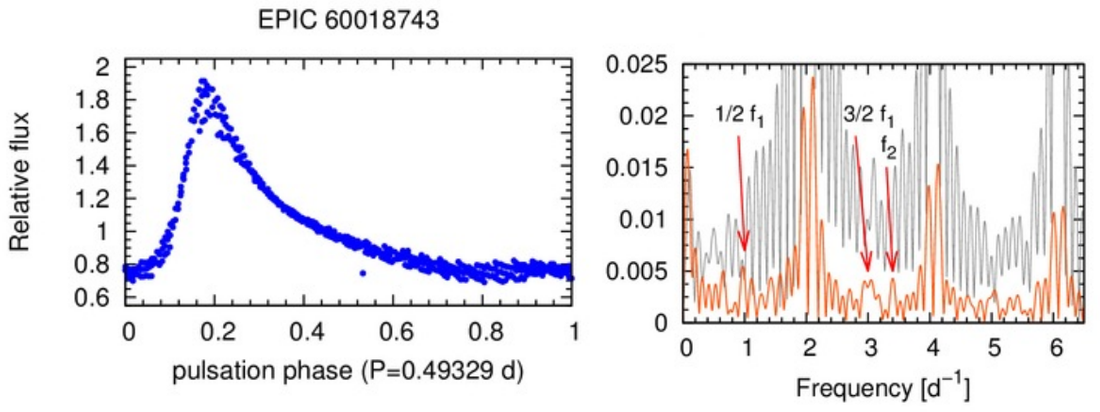
RRd



AM RRc



Blazhko RRab with PD



Molnár et al. 2014, IBVS, 6108
See L. Molnár's poster

Take home messages

- RR Lyrae stars are interesting!
- **Period doubling** is seen in many Blazhko RRab stars
- Additional modes are **ubiquitous**
  - in **Blazhko RRab, RRc** and **RRd** stars
  - missing from **non-modulated RRab stars**
- Additional frequencies show **temporal variability**
- **Multiple Blazhko-modulations** are very common
- K2, TESS, PLATO: **bright future** for space photometry

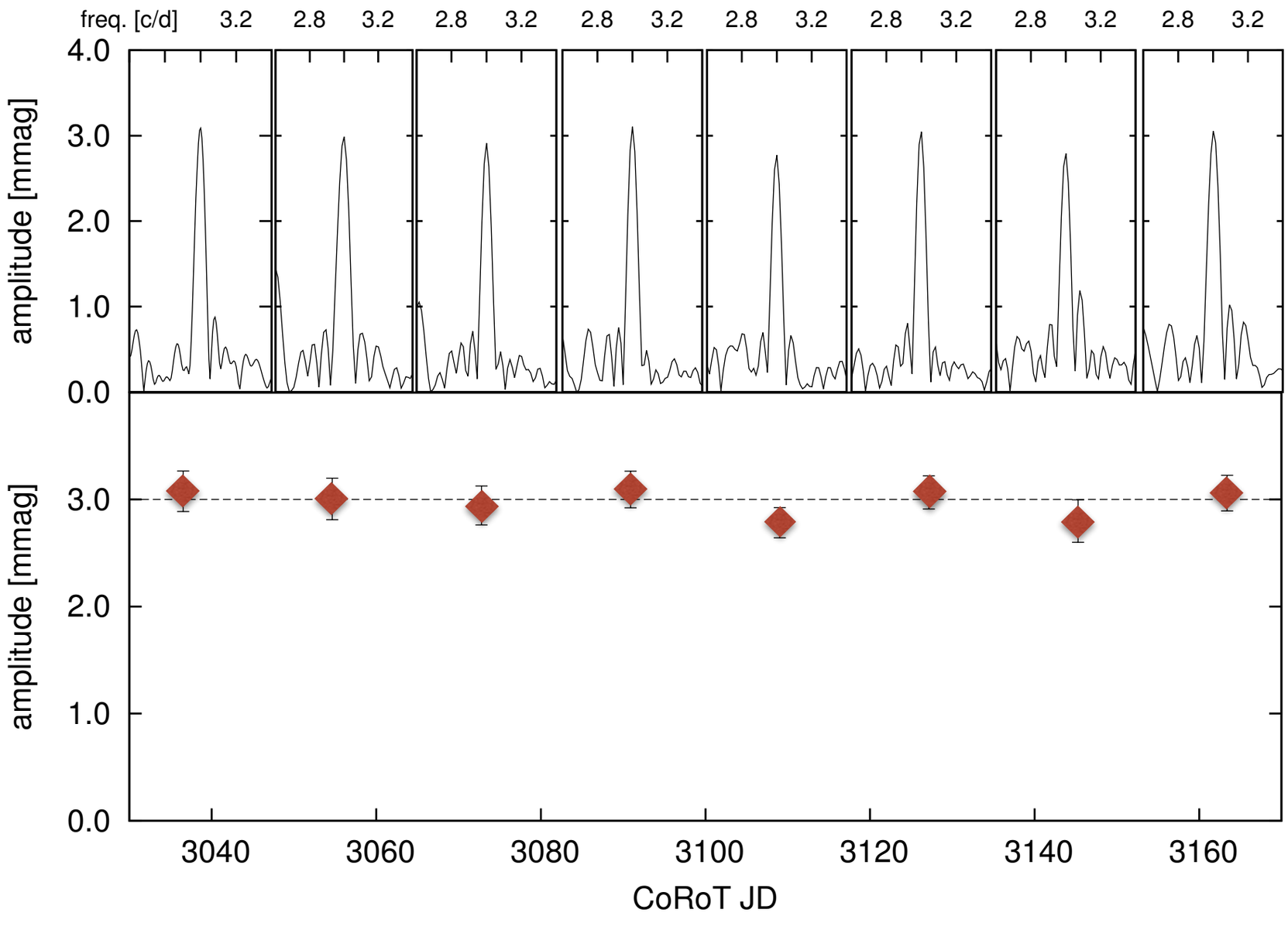
Thank you

Acknowledgements

- ESA PECS project No. 4000103541/11/NL/KML
- Hungarian OTKA grant K83790
- European Community's Seventh Framework Programme (FP7/2007–2013) grants
  - no. 312844 (SPACEINN)
  - no. 269194 (IRSES/ASK)
  - ERC grant agreement no. 338251 (StellarAges)
- János Bolyai Research Scholarship of the Hungarian Acad. of Sciences

Temporal variability of the additional modes

test cases - clean spectrum



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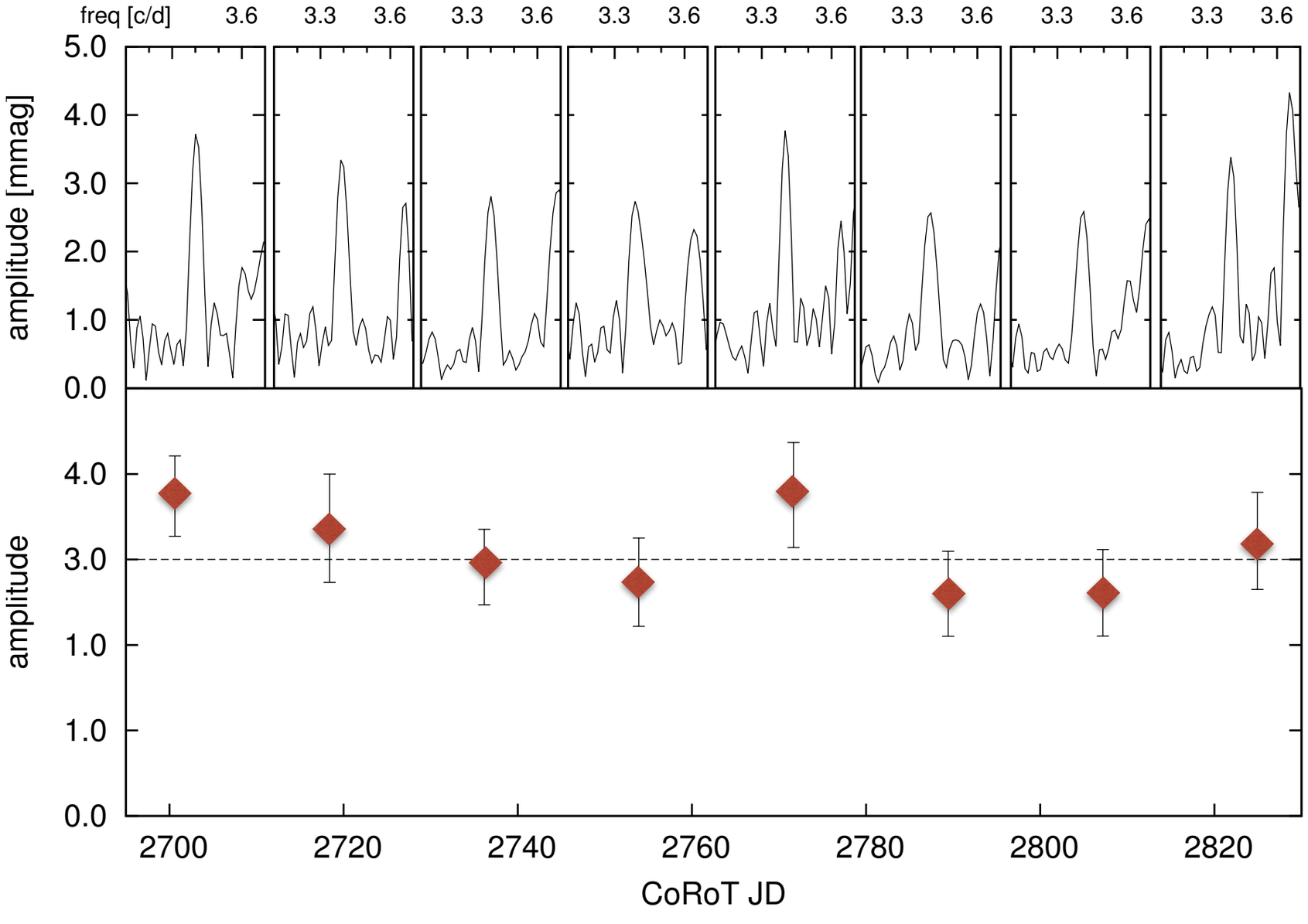
Szabó et al. 2014 submitted

CoRoT Blazhko sample Szabó et al. 2014, A&A submitted

Temporal variability of the additional modes

test cases - cluttered spectrum



Temporal and structural variability of the additional frequencies seems to be **ubiquitous** whether be HIFs, O2, f_X or other nonradial

Szabó et al. 2014 submitted

CoRoT Blazhko sample Szabó et al. 2014, A&A submitted