Asteroseismic analysis of selected High Amplitude Delta Scuti Candidates in the *Kepler* field

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2nd LAMOST-Kepler workshop : LAMOST in the era of large spectroscopic surveys

31 July 2017 to 3 August 2017, Royal Observatory of Belgium

Outline

- HADS Stars
- The Role of LAMOST observations in the *Kepler* Field
- Kepler observations of the selected HADS candidates
- Preliminary analysis of the Kepler light curve of selected HADS candidates
- Discussion and Comments on the results

High Amplitude Delta Scuti Stars (HADS)

- Population I subclass of Delta Scuti type variables.
- peak-to-peak light amplitudes in excess of about 0.3 mag
- Distinction is still arbitrary (Socynski 2008).
- One or two dominant radial modes (they might be called as low mass cepheids ?)
- some of them may have low-amplitude non-radial modes in addition to the main pulsation modes.
- A large number of combination frequencies and harmonics with the modes of highest amplitude

High Amplitude Delta Scuti Stars (HADS)

- Slow rotators *v sin i <30 km/s*. (some exceptions are available e.g. V2367 Cyg *v sin i =100 km/s* , Ulusoy et.al, 2013)
- They are located in the central part of the instability strip (McNamara 2000) in the core or shell hydrogen burning stage of stellar evolution.
- intermediate between normal δ Scuti stars and classical Cepheids (Breger 2007)

High Amplitude Delta Scuti Stars (HADS)

HADS stars are important. Why?

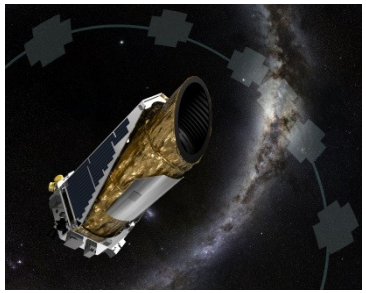
It is an interesting laboratory for investigating mode interaction and pulsat'onal behavior by using the method Asteroseismology!!!

Better Classification of HADS, LADS or Low Mass Cepheids?

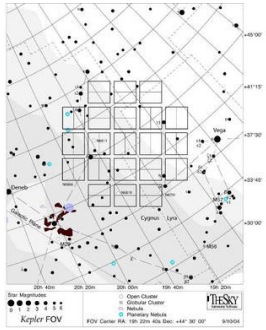
More precise effective temperatures and luminosities are required to test he hyphothesis of HADS If they are really intermediate between Delta Scuti stars and Cepheids.

HADS stars are just below the horizontal branch, and the debate whether the light curves of HADS stars could show similarities with those of RR Lyr stars is still open (Breger 2010).

Better understanding of complex nature of the pulsation and coupled modes as suggested by the models (MODE IDENTIFICATION) for unusual HADS!



Kepler and *K2* Missions
Scientific Objectives



Kepler Mission (2009-2013)

- launched on 2009 March 7
- The *Kepler* mission, designed to detect Earth-like planets using the transit method (Koch et al. 2010)
- Provided unprecendented data set
- New era for astrophysics, especially stellar physics!!
- monitored continously (30 min and 1 min) more than 150,000 stars in the Cygnus-Lyra region over four years
- exceeded its nominal mission operated for an additional year as an extended mission.
- Discovered thousands of transiting planets

K2 Mission (2014-2018)

- Entirely community-driven mission: Guest Observer Program
- a new concept for spacecraft

a list of potential targets:

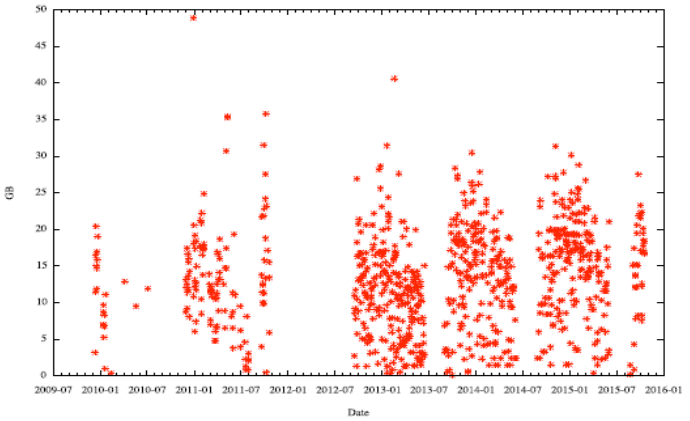
- Possible transiting planet hosts
- Known exoplanet hosts
- Pulsating stars
- Rotationally variable stars
- Flaring stars
- Accreting stars and interacting binaries
- Binary stars
- Open clusters
- Stellar associations
- Galaxies and supernovae
- Active galactic nuclei
- Microlenses
- Solar System planets
- Asteroids
- Comets

The Role of LAMOST observations in the *Kepler* Field

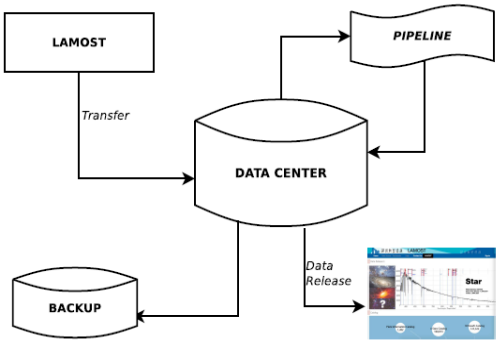
LAMOST

(The Large sky Area Multi-Object Fiber Spectroscopic Telescope, Guo Shou Jing telescope)

- The largest (the size of its main mirror is 6.67 meters with 4 meters effective aperture) optical telescope in China
- Effective spectra telescope
- first light in 2008
- the pilot sky survey from 2010 to 2012
- the regular sky survey is in progressing from 2012 to 2017
- In the last four years, operated about 900 night.
- The wavelength range of LAMOST is
- from 3700 to 9000°A



The average size of raw data is about 20GB per night



The data cycle management system architecture

Boliang He et al., 2016 2016arXiv160102334H

The Role of LAMOST observations in the *Kepler* Field

- LAMOST is the most powerful optical spectroscopic survey instrument in the Northern hemisphere at present.

- The Kepler Input Catalogue (KIC, Latham et al. 2005) is useful only for the solar-type stars.
- As for stars which are hotter, cooler, or chemically peculiar, the precision of the KIC drops significantly and for many stars in the KIC the atmospheric parameters are lacking. (Brown et al. 2011)
- Asteroseismic modelling also needs more accuracy of atmospheric parameters !

- **As a Result , the ground-based follow-up observations are a key element for ensuring a complete and exhaustive exploitation of the Kepler data.**

The Role of LAMOST observations in the *Kepler* Field

- Lamost-Kepler (LK) project (De Cat et al. 2014 and) is helpful for many studies of stars in the *Kepler* field How?

  - Homogeneously obtain
  - Accurate spectral classification
  - Availability of stellar parameters

- Lamost observations are also promising for K2 mission fields !!

Kepler observations of the selected HADS candidates

Morphological Classification of Variable Star Types

Category	Sub-category	number
γ Dor	Asymmetric (ASYM)	33
(207 stars)	Symmetric (SYM)	88
	multiple periods (MULT)	86
δ Sct	High amplitude (HADS)	47
(84 stars)	multiple periods (MULT)	33
	"other"	4
Hybrid	γ Dor dominant	5
(32 stars)	δ Sct dominant	8
	roughly equal	19
Binary	EA (detached)	17
(76 stars)	EB (contact)	52
	"transit"	4
	"heartbeat"	3
Rotation	SPOTV (dominant period)	75
(1132 stars)	SPOTM (traveling wave)	109
	ROT (dominant low frequency	844
	VAR (low amplitude, type unknown)	103

(Bradley et al., 2015)

We present preliminary results on the analysis of the *Kepler* light curve of selected HADS candidates listed by Bradley et al., (2015).

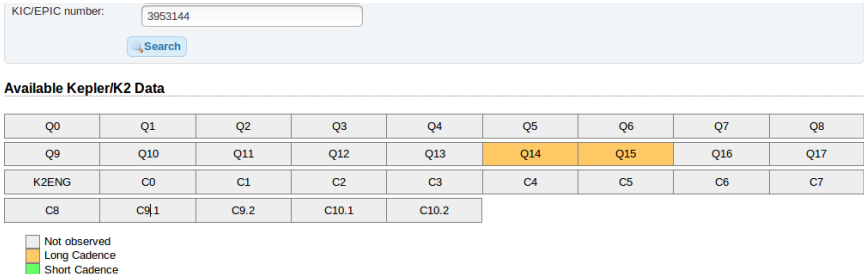
In order to detect more stars showing the similar physical properties with HADS, Bradley et al., 2015 define the criteria for the HADS candidates with the amplitudes between 10^4 ppm (0.01 mag) and 10^5 ppm (0.1 mag).

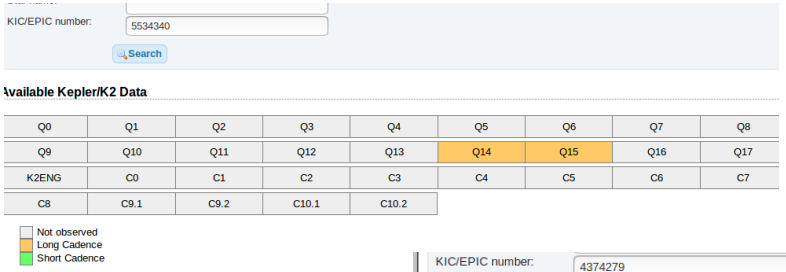
2768 stars were observed with Kepler as part of the GO program.

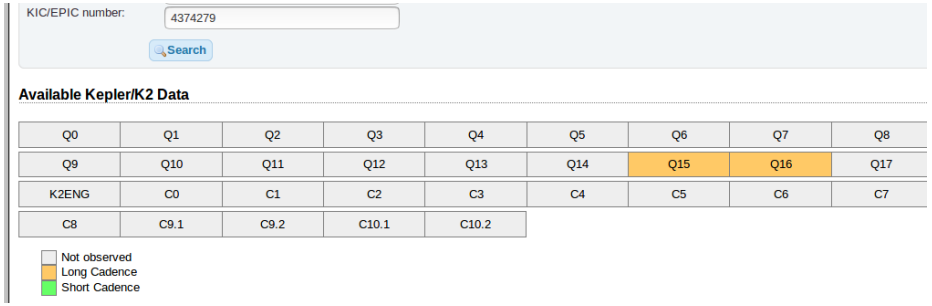
Kepler observations of the selected HADS candidates

Data availability of the targets

- *Kepler* photometry (LC mode Q14-Q16 only available data) is used to derive frequency content of the variability of the stars.







Kepler observations of the selected HADS candidates

Data availability of the targets

- *Kepler* photometry (LC mode Q14-Q16 only available data) is used to derive frequency content of the variability of the stars.

Data Preparation method of the available data

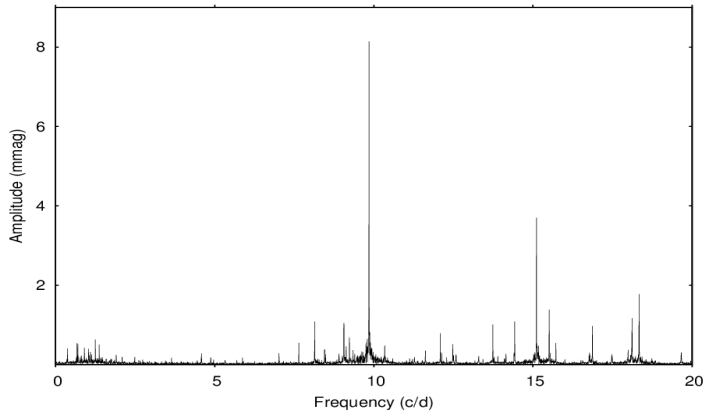
- The data were prepared for analysis using cotrending basis vector (CBV) files (Christiansen et al., 2012) and **Kepcotrend** task of **PyKE** package (Still and Barclay, 2012).

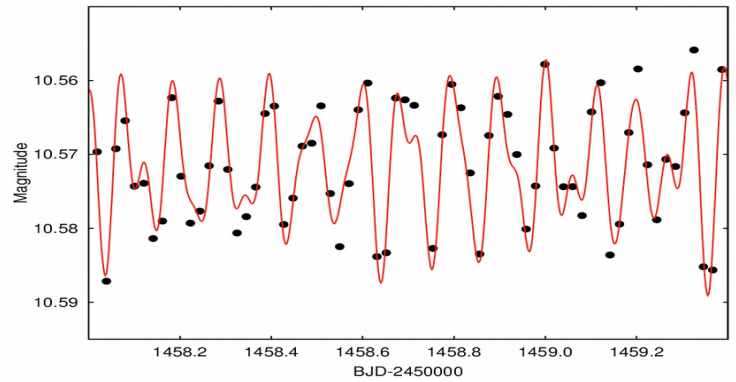
Data Analysis

- Then, the frequency analysis has been performed for each star using the software package SigSpeC (Reegen, 2007).

Preliminary Analysis of some Selected HADS Candidates

KIC 3953144





No	Frequency (c/d)	Amplitude (mag)	Phase (rad)	S/N
f_1	9.8471(2)	0.0085(25)	2.93(1)	58
f_2	15.1110(2)	0.0041(17)	2.16(2)	42
f_3	15.5117(4)	0.0016(12)	1.25(4)	22
f_4	8.1411(5)	0.0012(11)	3.88(4)	19
f_5	9.0587(3)	0.0015(10)	2.29(3)	26

Kepler Input Catalog (KIC)

Kp	14.673
Right Ascension:	+19:24:46.20
Declination:	+39:02:58.2
$T_{\rm eff}$ (K)	7950
$\log(g)$	4.074
[Fe/H]	-0.128
$R/R_\odot$	1.846
$E(B-V)$	0.242
$A(V)$	0.749
Contamination	0.056

Preliminary Analysis of some selected HADS Candidates

KIC 3953144

No	Frequency (c/d)	Amplitude (mag)	Phase (rad)	S/N
f_1	9.8471(2)	0.0085(25)	2.93(1)	58
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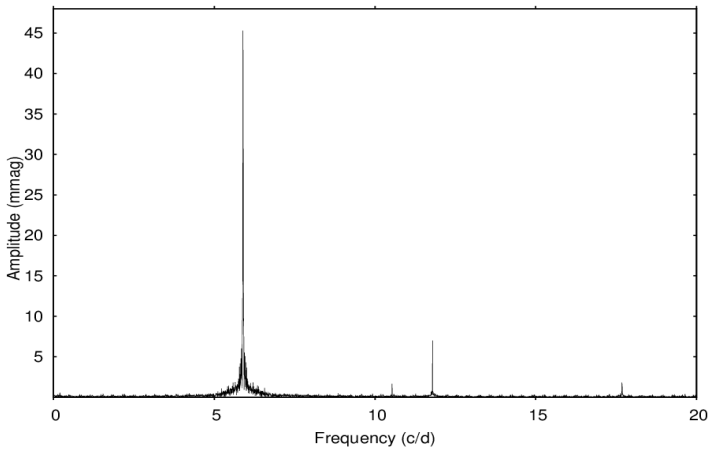
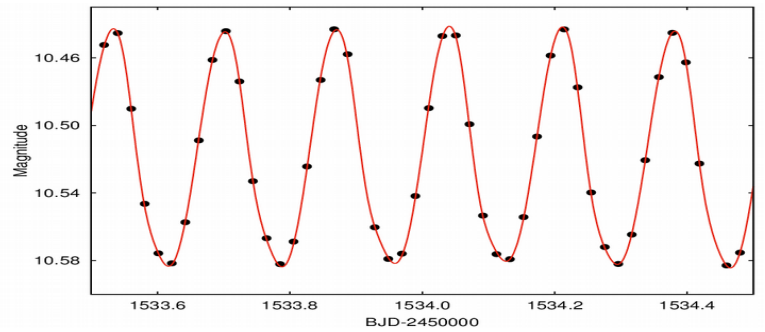
f_5	9.0587(3)	0.0015(10)	2.29(3)	26

- Five independent frequencies
- 134 combination terms
- No harmonics detected
- The lowest frequency peak detected as 0.675756 c/d

Preliminary Analysis of some selected HADS Candidates

KIC 4374279





No	Frequency (c/d)	Amplitude (mag)	Phase (rad)	S/N
f_1	5.8951(1)	0.06819(165)	4.68(1)	71
f_2	11.7901(3)	0.00186(9)	1.11(2)	35
f_3	5.8886(5)	0.00053(5)	4.05(4)	19
f_4	0.1983(4)	0.00069(5)	2.40(4)	22
$2f_4$	0.3967(11)	0.00016(3)	1.15(9)	9
$2f_1$	11.7852(12)	0.00016(3)	0.16(10)	8
$3f_1$	17.6810(16)	0.00010(3)	4.06(14)	6

Kepler Input Catalog (KIC)

Kp	14.583
Right Ascension:	+19:35:52.64
Declination:	+39:26:09.9
$T_{\rm eff}$ (K)	6856
$\log(g)$	4.212
[Fe/H]	-0.106
$R/R_\odot$	1.439
$E(B-V)$	0.218
$A(V)$	0.677

KIC 4374279

No	Frequency (c/d)	Amplitude (mag)	Phase (rad)	S/N
f_1	5.8951(1)	0.06819(165)	4.68(1)	71
f_2	11.7901(3)	0.00186(9)	1.11(2)	35
f_3	5.8886(5)	0.00053(5)	4.05(4)	19
f_4	0.1983(4)	0.00069(5)	2.40(4)	22
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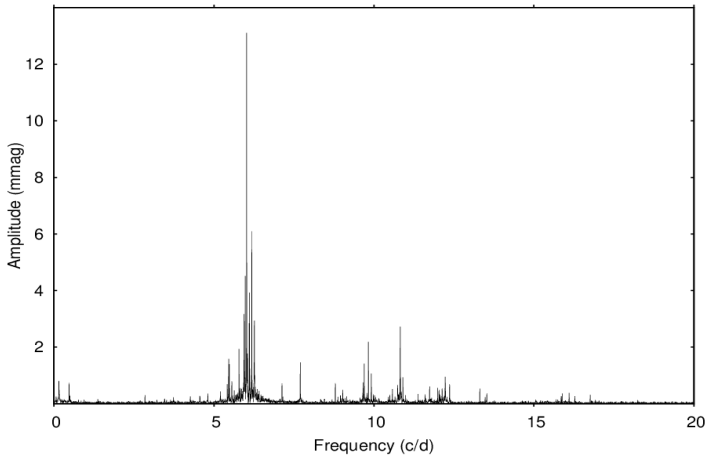
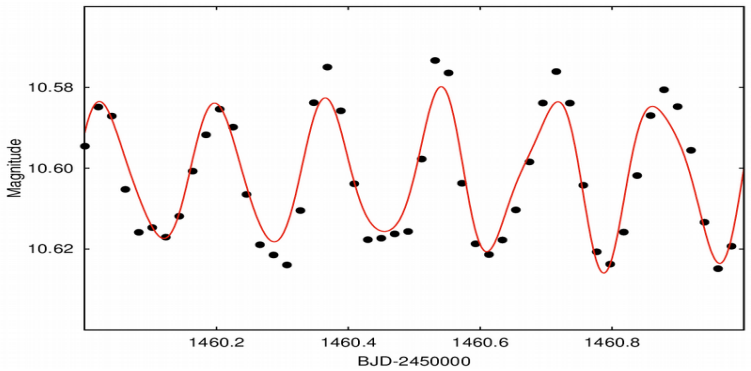
$2f_1$	11.7852(12)	0.00016(3)	0.16(10)	8
$3f_1$	17.6810(16)	0.00010(3)	4.06(14)	6

- Four independent frequencies
- 50 combination terms
- Harmonics detected
- The lowest frequency peak detected as 0.014926 c/d

Preliminary Analysis of some selected HADS Candidates

KIC 5534340





No	Frequency (c/d)	Amplitude (mag)	Phase (rad)	S/N
f_1	6.0199(2)	0.01296(41)	4.87(1)	54
f_2	6.1820(2)	0.00613(29)	4.98(2)	36
f_3	5.9755(3)	0.00461(25)	4.14(3)	31
f_4	6.2616(2)	0.00433(21)	1.63(2)	35
$2f_2$	12.3640(5)	0.00079(8)	3.52(5)	16
$2f_1$	12.0398(7)	0.00052(7)	2.37(6)	12
$2f_3$	11.9543(18)	0.00012(4)	4.27(16)	5

Kepler Input Catalog (KIC)

Kp	14.645
Right Ascension:	+19:28:17.08
Declination:	+40:42:54.0
$T_{\rm eff}$ (K)	7052
$\log(g)$	4.083
[Fe/H]	-0.084
$R/R_\odot$	1.713
$E(B-V)$	0.219
$A(V)$	0.678

Preliminary Analysis of some selected HADS Candidates

KIC 5534340

No	Frequency (c/d)	Amplitude (mag)	Phase (rad)	S/N
f_1	6.0199(2)	0.01296(41)	4.87(1)	54
f_2	6.1820(2)	0.00613(29)	4.98(2)	36
f_3	5.9755(3)	0.00461(25)	4.14(3)	31
f_4	6.2616(2)	0.00433(21)	1.63(2)	35
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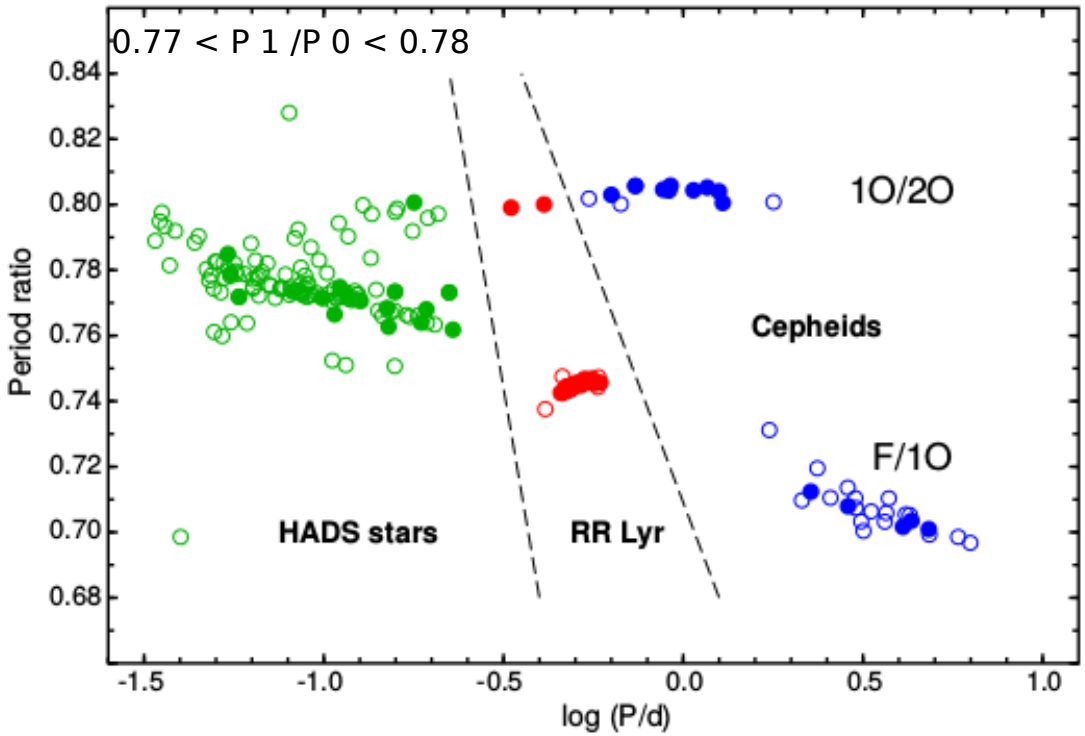
$2f_3$	11.9543(18)	0.00012(4)	4.27(16)	5

- Four independent frequencies
- 191combination terms
- Harmonics detected
- The lowest frequency peak detected as 0.043987 c/d

Petersen Diagram



Petersen diagram for known double-mode Galactic classical pulsators: HADS stars (green), RR Lyrae stars (red), and classical Cepheids (blue on-line).Two clear sequences of the F/1O and 1O/2O pulsators can be seen. Filled symbols denote starsthat were discovered using the ASAS data. (Pigulski, 2014)

Petersen Diagram

In order to explain the Petersen diagram for the HADS stars, Poretti et al. (2005) used appropriate stellar models for different masses and metallicities to calculate theoretical values of P 1 /P 0 .

A similar work has been done earlier by Petersen & Christensen-Dalsgaard (1996).

- both mass and metallicity influences P 1 /P 0 . On the other hand, the metallicity is most important in the short-period range

- The effect of mass is largest for periods longer than ~0.12 d where lower mass leads to the lower value of P 1 /P 0 .

Preliminary Analysis of some selected HADS Candidates

Results and Comments

- More data are needed.
- show a single dominant peak (typically between 4 and 6 c d −1),

along with a small peak at half the frequency of the dominant peak and at least one harmonic peak.

If the small peak (at half the frequency of the dominant peak) is the rotation frequency of a spotted star, then the implied rotation velocities are between 150 and 250 km , which is physically plausible Balona (2011).

rotation frequency.

All candidates should be plotted in the petersen diagram and compare with photometric mode id of the highest amplitude.

- Ground based observations are needed for Mode ID at least for the highest amplitude peaks

Spectroscopic data (v sini, Teff,logg and [Fe/H]) would be very useful for more accurate classification as well as astereoseismic modelling.

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THANK YOU!