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Kepler primary asteroseismic targets – ground-based study

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Abstract. Reported are results of ground-based spectroscopic and photometric observations of Kepler primary asteroseismic targets. We determine $\log T_{\mathrm{eff}}$, $\log g$, [Fe/H], $v \sin i$ and the mean radial velocity, v_r, for all these stars. For new spectroscopic binaries, we provide orbital solutions. Finally, we compute evolutionary models using Monte Carlo simulations.

Key words. Space missions – Kepler: Stars: pulsating – solar-like: Stars: atmospheres – global parameters

1. Introduction

Kepler, the new NASA space mission scheduled for the launch in February 2009, will be the first telescope able to detect Earth-like planets orbiting solar-stars on one-year orbits. With its 1.4-m Schmidt telescope equipped with a 0.95-m correction plate (see Fig. 1), *Kepler* will observe a selected field in the sky in the Cygnus-Lyra region. The observations will be made in one, broad filter and will be continued for the entire life-time of the mission that is planned for 4–6 years.

Kepler's main scientific goal is the detection of planets located in habitable zones where

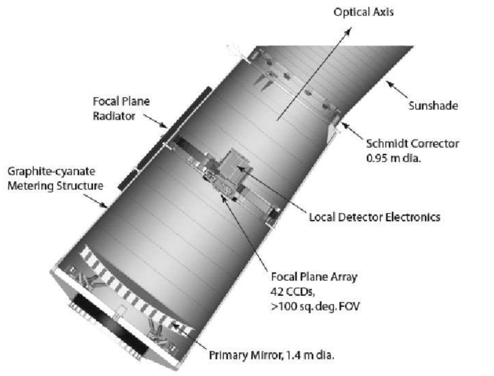

Fig. 1. Kepler photometer cross-section. For a high-resolution, colour version see http://kepler.nasa.gov/sci/design.

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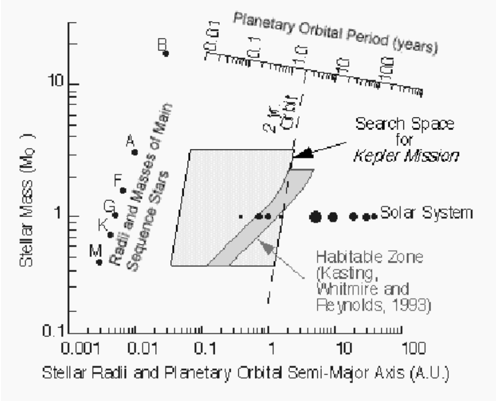

Fig. 2. The habitable zone computed by Kasting et al. (1993) and the search space for the Kepler mission. For the colour version see http://www.solstation.com/stars/4planets.htm.

the conditions are favorable for life as it can be found on Earth, particularly where the liquid water can exist (Huang 1959). In Fig. 2, we show Kepler search space and habitable zones around stars of different spectral type (after Kasting et al. (1993)).

Along with the search for planets, *Kepler* will perform high-cadence measurements with the time-resolution of 1 minute, that will be used for the search for *p*–modes and then for the study of the inner structure of Kepler asteroseismic targets.

Table 1. PATS discussed in this paper.

HIP	SpT	V [mag]	N_{obs}	time-span [days]
91128	K7V	9.91	5	8055
92922	G8IV	9.18	5	1771
93011	F5IV	9.64	4	46
94145	F0III	8.99	8	386
94335	F8V	9.35	14	181
94497	K2V	9.92	5	1772
94565	G0IV	9.35	5	852
94704	sdG0	11.17	4	2031
94734	G2V	9.49	15	852
94743	F2V	9.20	26	856
94898	G8IV	9.50	6	2122
95098	F8III-IV	9.50	5	855
95631	G9IV	9.13	6	1771
95637	F2III	9.18	4	46
95638	G5V	10.58	3	391
95733	G8V	11.02	4	855
95843	F2V	9.26	4	40
96146	F8IV-V	9.09	4	43
96634	K0V	9.15	5	1769
96735	K2V	9.20	5	1299
97168	G0V	10.41	5	1679
97219	K0V	9.03	12	4331
97337	K7V	11.04	1	0
97657	K3V	9.53	7	1996
97974	G0V	10.02	2	47
98381	K4V	9.92	5	1772
98655	G9V	10.46	4	396
98829	G8V	9.70	6	2574
99267	sdF2	10.14	46	8425

2. Ground-based observations

The spectroscopic observations of Kepler primary asteroseismic targets, PATS, (see Table 1 in Molenda-Żakowicz et al. (2006)) we obtained at the Catania Astrophysical Observatory with the FRESCO spectrograph (74 spectrograms), at the Oak Ridge Observatory, Harvard, Massachusetts (32 spectrograms), and at the F.L. Whipple Observatory, Mount Hopkins, Arizona (119 spectrograms).

The photoelectric *UBV* Johnson and *uvbyβ* Strømgren magnitudes were measured, at the Catania Astrophysical Observatory alone.

In Table 1, we list the PATS with the spectral type assigned by us, photoelectric visual magnitude measured at the Catania Astrophysical Observatory, the total number of spectrograms gathered and the total time-span of spectroscopic observations.

3. Analysis and results

We reduced and analyzed our echelle spectrograms with the IRAF[1] software. For extraction of the spectra we used the apall task in the echelle package. For radial velocity measure-

[1] IRAF (http://iraf.noao.edu/) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

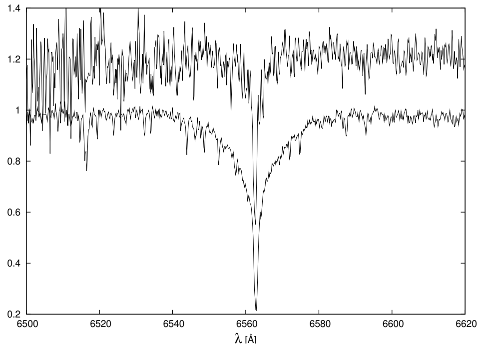

Fig. 3. Hα region of our faintest target, HIP 94704, sdG0, V = 11.17 mag (*top*) and of the brightest one, HIP 95145, F0III, V = 8.99 mag (*bottom*), observed at the Catania Astrophysical Observatory with the FRESCO echelle spectrograph. The spectra are moved to the laboratory rest-frame.

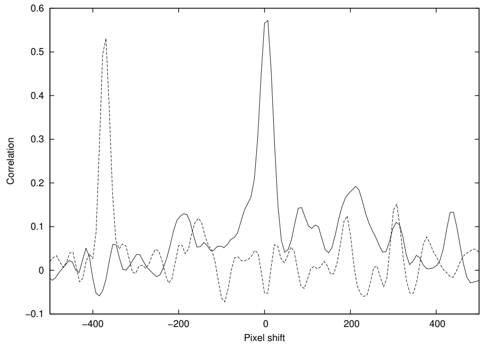

Fig. 4. Fourier cross correlation function for HIP 95145 with the maximum at +2.4 km/s (*solid line*) and for HIP 94704 with the maximum at -347.3 km/s (*dashed line*).

ments, the cross-correlation method and the fxcor task in the rv package.

In Fig. 3, we plot a part of the spectra centered at the Hα line, measured for our brightest and faintest target, i.e., HIP 94145 and HIP 94704, respectively. In Fig. 4, we plot the cross-correlation function computed for these two stars. Both functions show high and sharp maxima that occur at +2.4 and -347.3 km/s for HIP 95145 and HIP 94704, respectively.

We used our data to measure the mean radial velocities for all the PATS and for computing orbital solutions for, HIP 94734

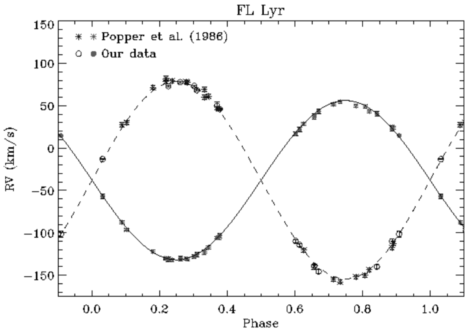

Fig. 5. Radial velocity curve for both components of FL Lyr. Asterisks - measurements of Popper et al. (1986), circles - our data.

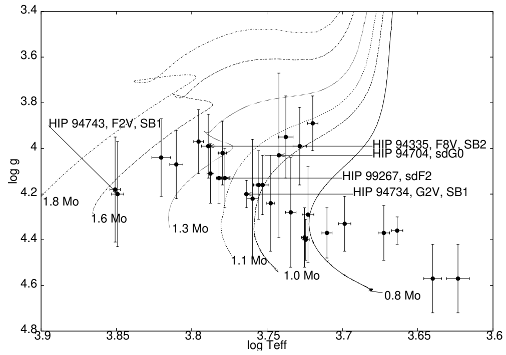

Fig. 6. $\log T_{\rm eff}$ - $\log g$ diagram for Kepler primary asteroseismic targets. The evolutionary tracks computed for Z = 0.02 are adopted from Claret (2004).

and HIP 94743, two single-lined spectroscopic binaries discovered in our observations (Molenda-Żakowicz et al. 2007). For HIP 94335 (=FL Lyr), a well known double-lined spectroscopic and Algol-type eclipsing binary, our orbital solution is in a full agreement with the observations obtained by Popper et al. (1986) (see Fig. 5).

Then, we computed $\log T_{\rm eff}$, $\log g$, [Fe/H] and $v \sin i$ for all the targets using the ROTFIT code (see Frasca et al. (2003) and Frasca et al. (2006)) with a method similar to that of Katz et al. (1998) and Soubiran et al. (1998)). This method is based on comparing the spectrum of the program star with a library of spectra of reference stars. The aim is to find several reference stars with spectra most similar

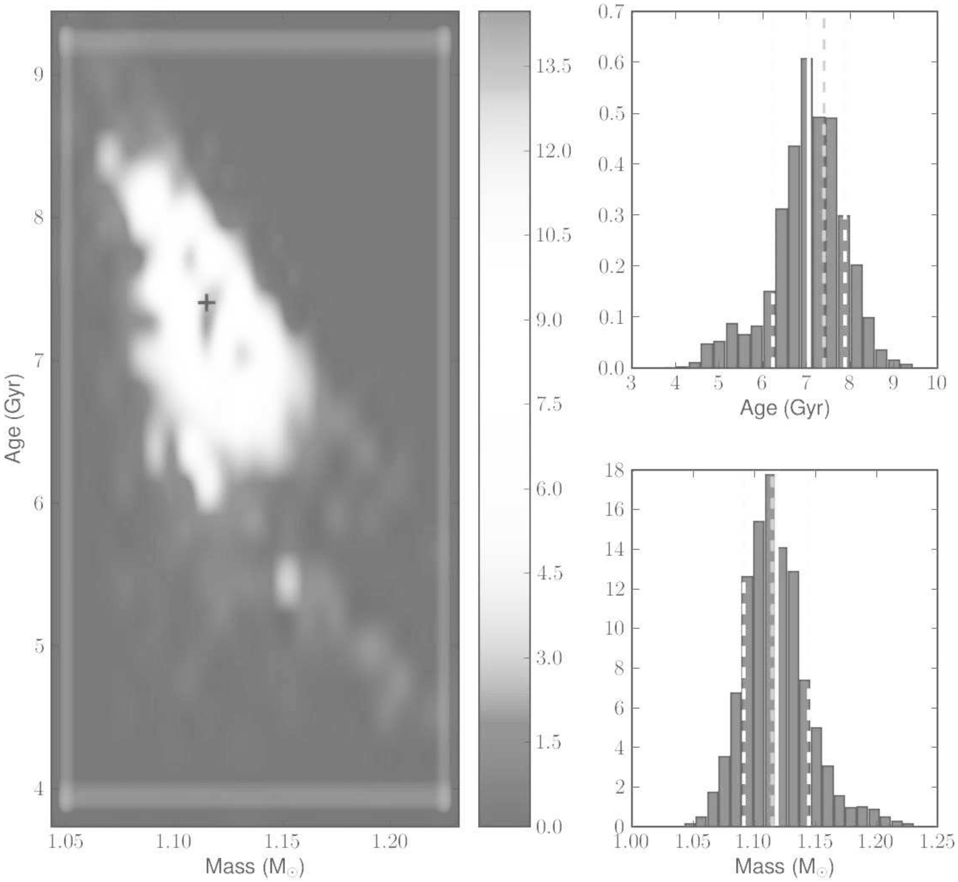

Fig. 7. Evolutionary model of HIP 94734. The maximum of the posterior probability function computed the use of Monte Carlo Markov Chains method occurs at the mass of 1.114±0.023 $M_\odot$ and age of 7.070±0.79 Gyr. *Right:* marginal distributions of the model parameters: the age and the mass.

to the target's one. After selecting these stars, respective means of their $\log T_{\rm eff}$, $\log g$ and [Fe/H] are computed and adopted as estimates of the astrophysical parameters of the target. We applied this method to spectrograms measured with the FRESCO instrument. For the reference stars, we used 240 slowly rotating stars which spectrograms are available from the ELODIE[2] archive (Moultaka et al. 2004). In a separate run of computations, for the reference stars we used 82 slowly rotating stars observed with FRESCO. We conclude that the atmospheric parameters determined with these two different sets of reference stars are fully consistent (see Molenda-Żakowicz et al. (2007)). In Fig. 6, we plot the Kepler primary asteroseismic targets in the $\log T_{\rm eff} - \log g$ diagram using the $\log T_{\rm eff}$ and $\log g$ values computed with the method described above. In the next step, we measured rotational velocities of

[2] http://atlas.obs-hp.fr/elodie/

all our targets. For each star, we used two separate approaches, namely, the comparison with the grid of Kurucz model spectra and the Full Width at Half Maximum (FWHM) method. In the first method, we compared each observed spectrum with a library of synthetic spectra using correlation techniques and we computed the $v \sin i$ for each observation by a quadratic interpolation for three templates centered on the template that gives the highest value for the peak correlation coefficient. We used this method for spectrograms measured at the Oak Ridge and the F.L. Whipple Observatories. For stars observed with FRESCO, we determined $v \sin i$ using the FWHM method for each order of the echelle spectrum. For the templates, we used a grid of rotationally broadened spectra of non-rotating stars. We found the results obtained from these two different methods applied to two separate sets of observations to be in a full agreement. Finally, we commenced computations of the mass and age of our targets with the method of parametric estimation that applies Monte Carlo simulations and the Markov Chains. This method consists in obtaining the posterior density function of stellar parameters, conditional to the observations available for the target, having the model of the stellar physics specified in advance (see Bazot et al. (2007)). Since this procedure requires thousands of simulations, its usage is very time-consuming and our computations require more time for completion. We started from low-mass stars and will end up with the most massive, that have convective cores and are more difficult to model. In Fig. 7, we show the first results of our computations and the posterior probability function computed for HIP 94734. The maximum of this function occurs at the mass of 1.114±0.023 $M_{\odot}$ and the age of 7.070±0.79 Gyr, locating HIP 94734 slightly off the main sequence. The secondary, much lower, maximum occurs at a lower age and higher mass, pointing to a main-sequence star with a convective core.

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