#### Characterization of Kepler asteroseismic targets through ground-based observations

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# Kepler science

- goals:
  - detection of the Earth-size and larger planets with the method of photometric transits
  - study of stellar interiors with asteroseismic methods
- asteroseismology of Solar-like stars
  - frequent and expected to show solar like oscillaitons
  - very promising objects for the study of stellar structure
  - tiny amplitudes very difficult to observe from the Earth
  - Kepler precision and lenght of observations: a new epoch of the study of solar-like oscillations
  - observations + model = understanding of stellar structure
  - precise models require appropriate input parametres: need for ground-based observations



Acoustic Waves in a Solar-like Star

ESO PR Photo 23a/01 (28 June 2001)

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Acoustic waves in a solar-like star.

# Kepler asteroseismic targets

- 104 stars with different priority
- *Primary targets* 29 Hipparcos stars fainter than 9 mag and with the ratio  $\sigma_{\pi}/\pi$ < 0.175
  - FGK stars expected to show solar-like (and other) pulsations
- *Secondary targets* 74 other Hipparcos stars with less precise parallaxes
  - FGK but also A and B-type stars
- around 60 brightest stars from NGC6811 and NGC6866 open clusters



### Ground-based observations

- aims
  - determination of global parameters:  $T_{eff}$ , log g, [Fe/H], v sin i,  $v_r$  from spectroscopy and photometry
  - measurements of standard *UBV*,  $uvby\beta$  photoelectric magnitudes: reddening
  - time-series photometry of open clusters: study of variable stars
- observations: spectroscopy and photometry
- started in 2005 and now realized in seven observatories

#### Ground-based observations

- Catania Astrophysical Observatory in Serra la Nave (Mt. Etna), Italy
  - $T_{eff}$ , log g, [Fe/H], v sin i and  $v_r$  for stars brighter than V = 11 mag
  - standard *UBV* and *uvby* $\beta$  magnitudes for all targets
- Oak Ridge Observatory, Harvard Massachusetts and -
- Fred Lawrence Whipple Observatory, Mount Hopkins, Arizona
  - $v \sin i$  and  $v_r$  for all targets and  $T_{eff}$  and  $\log g$  with [Fe/H] assumed
- Nordic Optical Telescope, La Palma, Canarian Islands, Spain
  - $T_{eff}$ , log g, [Fe/H], v sin i and  $v_r$  for Hipparcos stars fainter than V = 11 mag and for open clusters
- Czech Academy of Sciences, Ondrejov, Czech
  - $v_r$  for stars brighter than V = 11 mag: spectroscopic binaries
- Wrocław University, Białków, Poland and -
- Slovak Academy of Sciences, Stara Lesna, Slovakia
  - time series multicolour CCD photometry of NGC6811 and NGC6866 open clusters

# Observations in Catania - instruments

- altiude: 1750 m.a.s.l
- fiber-fed FRESCO (Fiber-optic Reosc Echelle Spectrograph of Catania Observatory) spectrograph with a CCD camera based on a thinned back-illuminated SITe chip (SI033B) of 1024x1024 pixels (24x24 micron) as the detector
- single channel photometer with the EMI 9893QA/350, spectral response S20 photomultiplier, which cooled to -15° C has a dark current of 1 count/sec with UBV and *uvbyβ* filters
- a thinned back-illuminated CCD of 1Kx1K, pixel size 24x24 micron with UBVRI and three neutral filters



- 0.91m Cassegrain telescope
- german mount
- went into operation by the end of 1965
- mirrors made and polished by Tinsley (Berkeley, USA)

# Observations in Catania - FRESCO

- gratings:
  - echelle grating: reflection grating of 128x254 mm, with 79 l/mm blazed at 63.433 deg.
  - echellette grating (cross-disperser): reflection grating of 160x106 mm, with 300 l/mm blazed at 4.3 deg, maximum efficiency 80% at 5000 Å
- dispersion modes:
  - single dispersion: only the echellette grating of 300
    l/mm is used, the echelle grating being replaced by
    a flat mirror. This configuration yields a linear
    dispersion of about 90 Å/mm (R=1000) and a 2500
    Å spectral range recorded
  - crossed dispersion: both gratings are employed; the linear dispersion varies from 3.5 Å/mm at H-gamma to 6.8 Å/mm at Hα (R=21,000). The spectral range covered in one exposure is about 2500 Å in 19 orders



# Observations in Catania - CCD

- mounted and tested between 28 June 1 July 2007
- field of view: 13 x 13 arc min
- below left: M57 (Ring) planetary nebula obtained by combining three images in R, V, and B filters taken with exposure times of 80, 100, and 180 sec, respectively.
- below right: the Point Spread Function, PSF, on an R raw image



# Observations at ORO and FLWO

- Oak Ridge Observatory (*ORO*), Harvard Massachusetts
  - 1.5-m Wyeth reflector
- Fred Lawrence Whipple Observatory (*FLWO*), Mount Hopkins, Arizona
  - 1.5-m Tillinghast reflector
  - Multiple Mirror Telescope (before its conversion to the monolithic 6.5-m mirror)
- equipment at ORO and FLWO
  - echelle spectrograph with resolving power R=35 000
  - photon-counting Reticon for the detector
  - 45Å spectrogram centred at around 5187Å recorded in one exposure



# Observations at the NOT

- altitude: 2382 m.a.s.l.
- 2.5-m telescope
- FIES instrument a cross-dispersed high-resolution echelle spectrograph with a maximum spectral resolution of  $R = 65\ 000$  and the entire spectral range of 370-740 nm
- faintest Kepler asteroseismic targets and open clusters





*Photos: Michael J.D. Linden-Vørnle and Bob Tubbs* 

#### Observations at the NOT



#### Observations at the NOT



# Observations in Ondrejov

- altitude: 500 m.a.s.l.
- 2-m telescope used for high-dispersion coude spectroscopy
- CCD for the detector
- spectroscopy of selected binaries from the list of Kepler asteroseismic targets





Photos: Josef Havelka and Aleš Kolář

## Observations in Białków

- altitute: 120 m.a.s.l.
- 0.6-m Cassegrain telescope
- CCD with *UBVRI*, *uvby* $\beta$  and H $\alpha$  filters
- time-series of NGC6811 and NGC6866 open clusters





# Observations in Stara Lesna

- altitude: 785 m.a.s.l.
- 0.6-m Cassegrain telescope
- CCD and a photoelectric photometer with *UBV* filters
- time-series of NGC6811 and NGC6866 open clusters





# Atmospheric parameters - method

- T<sub>eff</sub>, log g and [Fe/H] determined simultaneously with a method similar to that of Katz et al. (1998) and Soubiran et al. (1998)
- adopted are respective means of  $T_{eff}$ , log g and [*Fe/H*] of several templates that have spectra most similar to the spectrum of the program star
- allows simultaneous and fast determination of logT<sub>eff</sub>, log g and [Fe/H] as well as v sin i even for stars which spectra have low signal-to-noise ratio or limited resolution



# Atmospheric parameters - grid

- dense grid of template spectra with precisely determined atmospheric parameters is required
- 240 stars from the ELODIE library of spectra (Prugniel & Soubiran 2001)
- 82 templates from the library of FRESCO spectra
- consistent results from both grids

ELODIE templates (red) and program stars (green) in the Teff-log g-[Fe/H] plane



## Atmospheric parameters - results



# radial velocities - new SB1 stars

- HIP 94734
  - G2V, [Fe/H] = 0.10,  $T_{eff} = 5800$ , log g = 4.2
  - SB1, not known to show eclipses
  - $P_{orb} \sim 100 \text{ days}$
- HIP 94743
  - F2V, [Fe/H] = -0.23,  $T_{eff} = 7060$ , log g = 4.2
  - classified as E: in the Hipparcos
    Catalogue
  - $P_{orb} \sim 6 \ days$



# radial velocities - HIP 94335 SB2

- known Algol-type SB2 eclipsing binary FL Lyr
- $P_{orb} \sim 2.2 \text{ days}$
- very good agreement with the results of Popper et al. (1986)



# rotational velocities

- measured with the use of dense grid Kurucz model spectra
  - targets' spectra measured at the Oak Ridge Observatory and Fred Lawrence Whipple Observatory
- and with the Full Width Half Maximum, FWHM, method
  - targets' spectra measured at the Catania Astrophysical Observatory
- consistent results obtained form these two different methods applied to two separate sets of targets' spectra

Determination of  $v \sin i$  for both components of FL Lyr with the use of model spectra.

# photometry

- measured at the Catania Astrophysical Observatory
  - UBV Johnson photoelectric magnitudes
  - *uvby* $\beta$  Strömgren photoelectric magnitudes
- Kepler primary targets already completed
- Kepler secondary targets and open clusters started



## Future work

- Spectroscopic (almost completed) and photometric (started) observations of Kepler secondary targets
  - atmospheric parameters
  - standard *UBV*, *uvby*  $\beta$  magnitudes
- Spectro-polarimetric observations of selected Kepler asteroseismic targets with the aim of the study of their activity and magnetic fields
- Evolutionary and asteroseismic models for all the targets (started)
- Variable stars in NGC 6811 and NGC 6866 (started, see the poster of Pigulski et al.)
- Further spectroscopic and photometric observations of selected Kepler asteroseismic targets

# Evolutionary models

- model of HIP 94734
- computed with the use of Monte Carlo Markov Chains method
- M = 1.114±0.023 M<sub>sol</sub>
- age = 7.07±0.79 Gyr
- see also the poster of Bazot et al.

