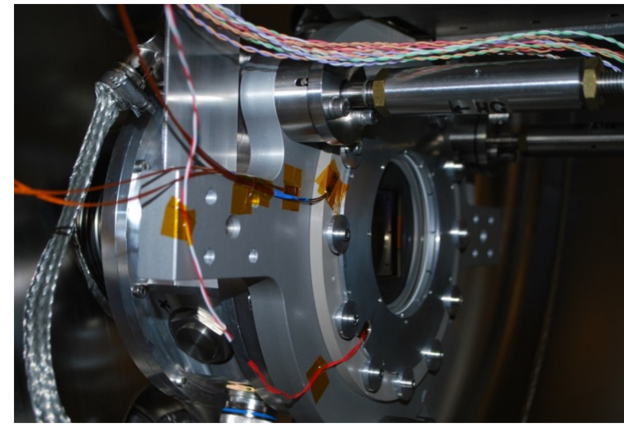
Science with HARPS-N

Giampaolo Piotto
Dipartimento di Fisica e Astronomia Galileo Galilei
Universita’ di Padova

HARPS-N



- Fiber fed, cross-dispersed echelle spectrograph
- Spectral resolution R= 115’000
- Fibre field of view = 1” at TNG f/11 Nasmyth B focus
- Wavelength range 383 nm - 690 nm
- Total efficiency = 8 % @ 550 nm (incl. telescope and atmosphere @ 0.8" seeing)
- ThAr + Simultaneous reference calibration (fed by 2 fibres) (or sky)
- Octagonal fibres for improved scrambling
- Back illuminated CCD 4k4 E2V chips
- Pixel size 15 µm
- Sampling = 3.3 pixel per FWHM
- Vacuum operation - 0.001 K temperature stability
- Global short-term precision 0.3 m/s
- Global long-term precision better than 0.6 m/s
- SNR= 50 per extracted pixel at Mv=8 in 1 minute exposure

Planet	Separation (AU)	RV Amp. (m/s)
Jupiter	1	28.4
Neptune	0.1	4.8
Neptune	1	1.5
SuperEarth	0.1	1.4
SuperEarth	1	0.5
Earth	1	0.1

HARPS-N Consortium

- HARPS-N Consortium

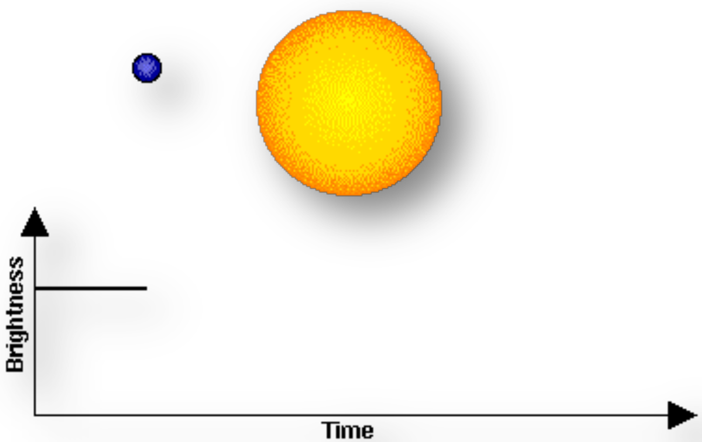
– Geneva Observatory (Head), CfA (Cambridge), Harvard University, INAF-TNG, University of St. Andrews, University of Edinburgh, Queens University Belfast

- HARPS-N Science Team

– Andrew Collier Cameron, David Charbonneau, David Latham, Mercedes Lopez-Morales, Christophe Lovis, Michel Mayor, Giusi Micela, Francesco Pepe, David Phillips, Giampaolo Piotto, Didier Queloz, Ken Rice, Dimitar Sasselov, Damien Ségransan, Alessandro Sozzetti, Andrew Szentgyorgyi, Stéphane Udry, Chris A. Watson and Collaborators ...

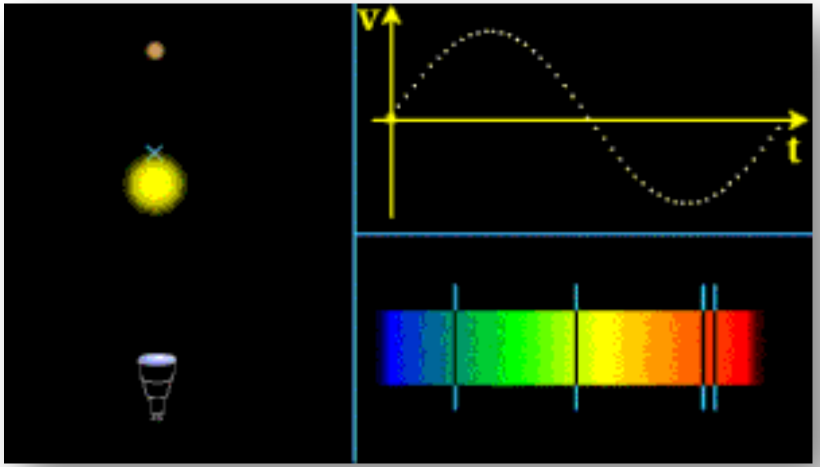
Methods for detection and bulk characterization of planets

Transit Method



- → Orbit parameters
- → Orbital inclination, ***i***
- → Planet radius

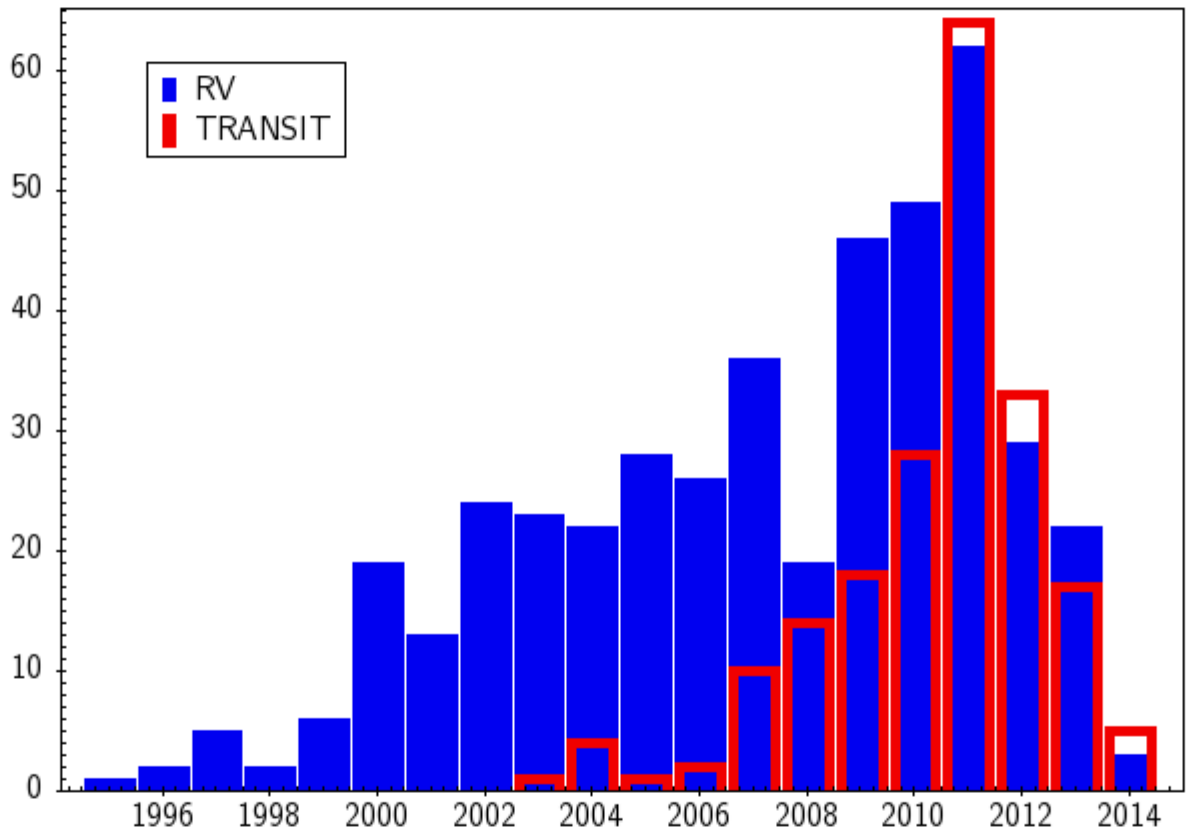
Radial velocity method

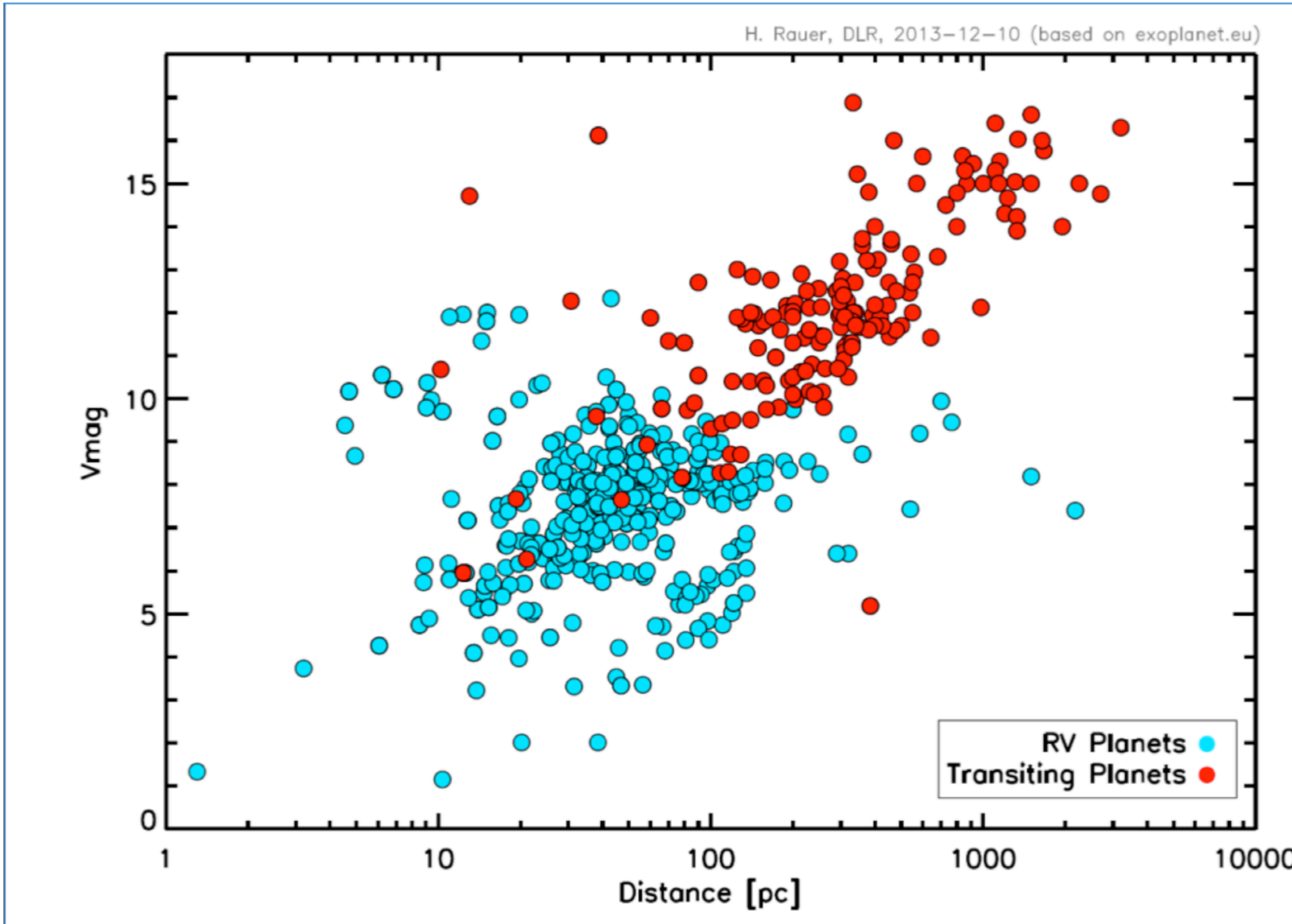


- → Orbital parameters
- → Minimum planet mass, ***m* sin *i***

True planet mass and mean density

Planets identified with the RV and transit methods. Updated 14/5/2014





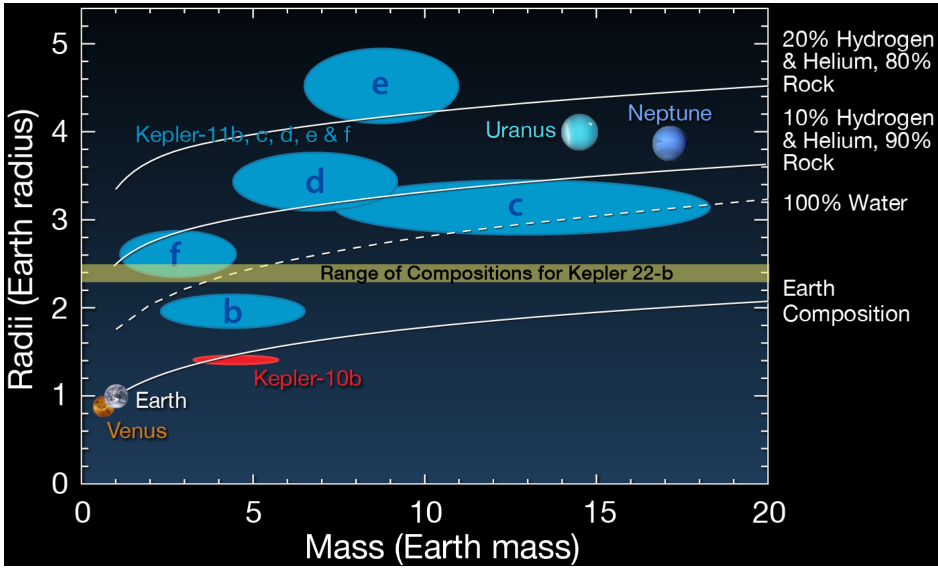
H. Rauer, DLR, 2013-12-10 (based on exoplanet.eu)
Vmag
0
5
10
15
1
10
100
1000
10000
Distance [pc]
RV Planets
Transiting Planets

HARPS-N/Kepler Primary Science Goals

HARPS-N White Paper

HARPS-N@TNG   GTO: 80N/year for 5 years

1. Confirm Earth-twin planet in the habitable zone of a G5V (or later) star, with 30% precision in mass.
   2 planets: 160h over 3 years => 16 N/yr

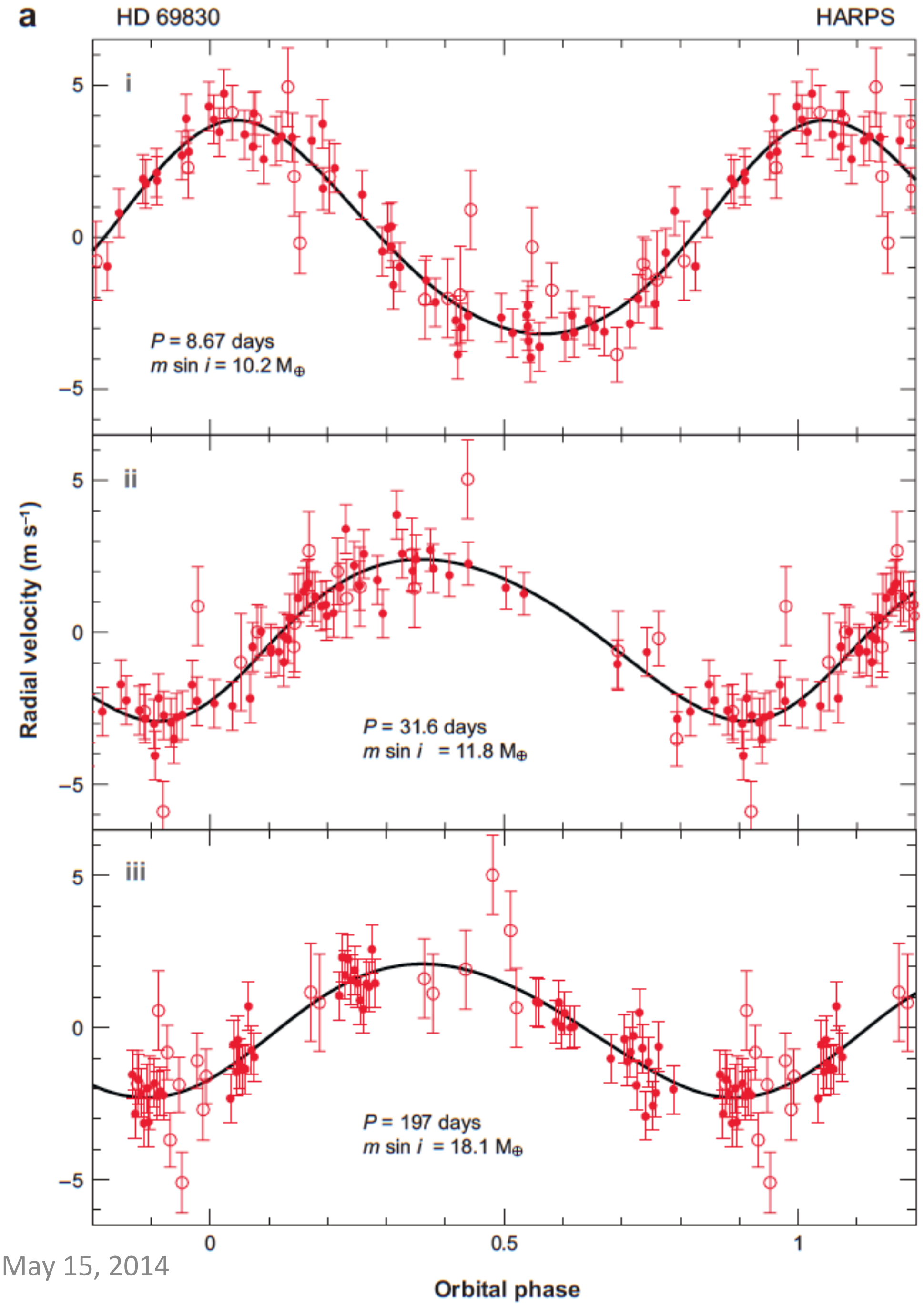


2. Distinguish between water-rich and rocky *super-Earths* in 2-5 Earth-mass range.
20 planets in various orbits: 250h over 3 years => 25 N/year

4. Characterise the transition between ice giants and super-Earths at around 10 Earth masses, with 5% precision.
20 planets in various orbits: 210h over 3 years => 21 N/year

Rocky planet search

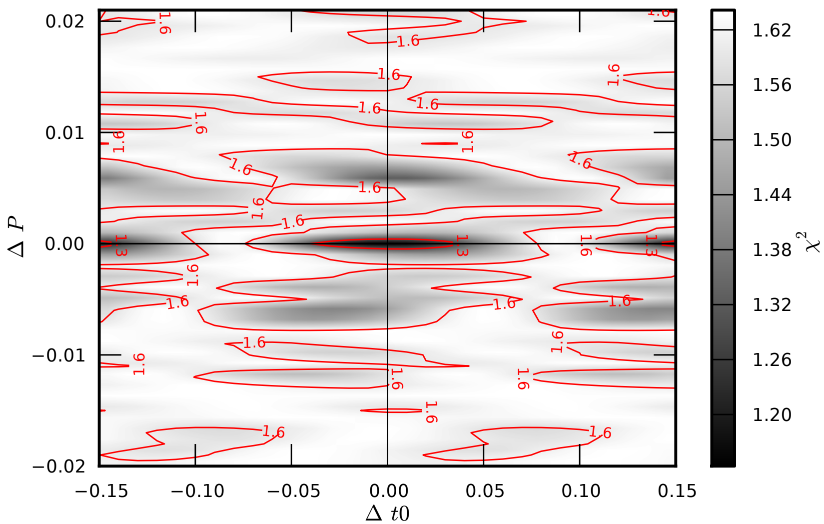
- Kepler field is accessible from April-October (7 months, 61N GTO).
- Remaining 19N GTO are outside this window.
- HARPS-N capable of maybe 20 cm/s precision for stars that are
  - bright
  - magnetically inactive
  - slowly-rotating.
- Search for Earth-mass and multiple planetary systems.
- For long-term precision below ~50 cm/s will devote additional observing time to characterize
  - stellar p-mode oscillations
  - granulation noise power
  - rotation-induced variability.

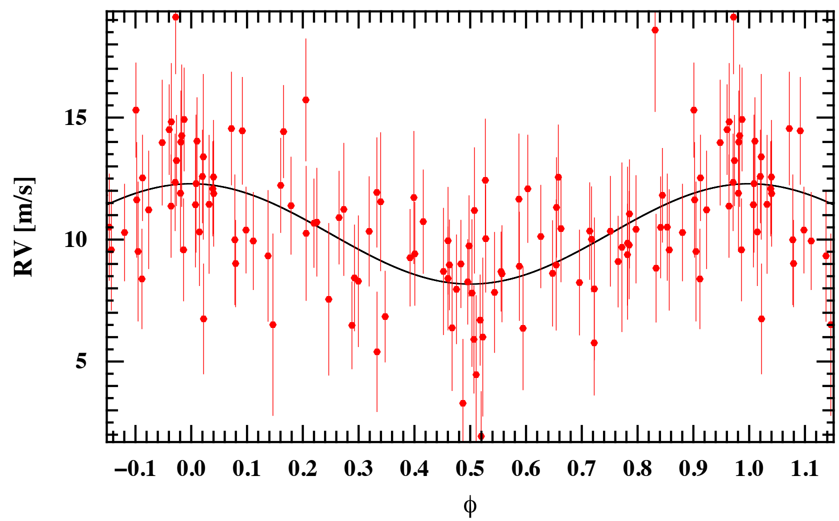


Kepler-78b: An Earth-sized planet with an Earth-like density

Max likelihood solution relative to Kepler transit ephemeris

RV curve phase folded on Kepler transit ephemeris: K=1.86 m/s

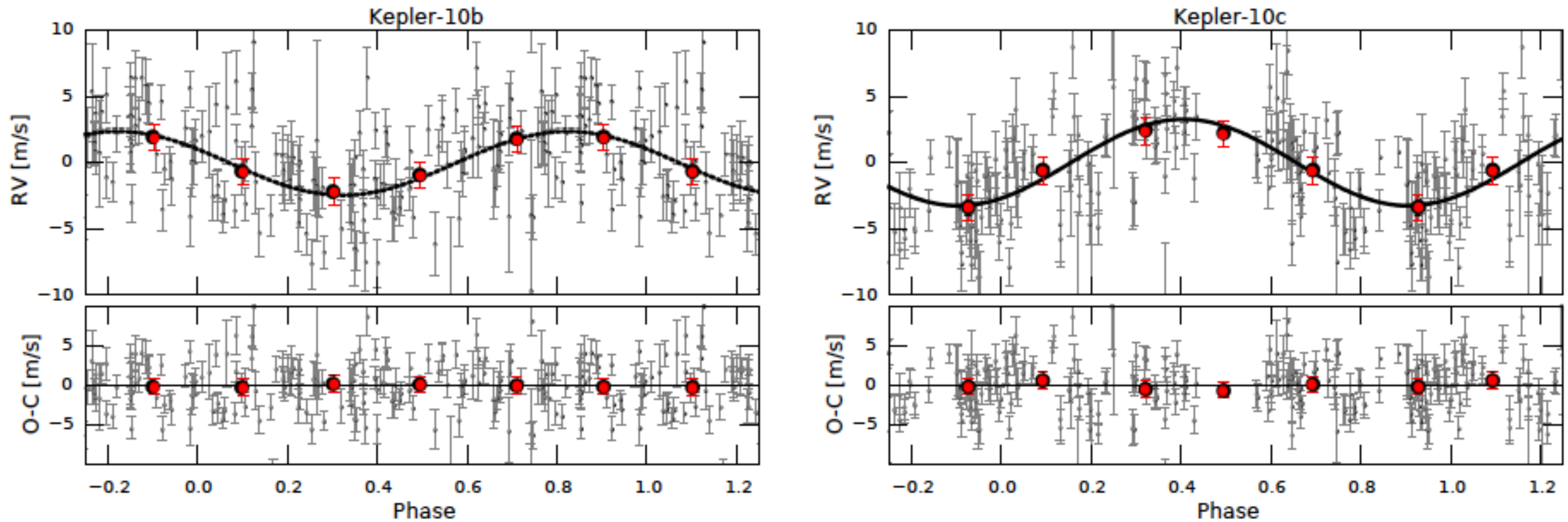




Radius: 1.16 R_{Earth}
Mass: 1.86 M_{Earth}
Density: 5.57 g/cm^{-3}

Pepe, F. et al 2013, *Nature*, 503, 377

Kepler-10 b and c



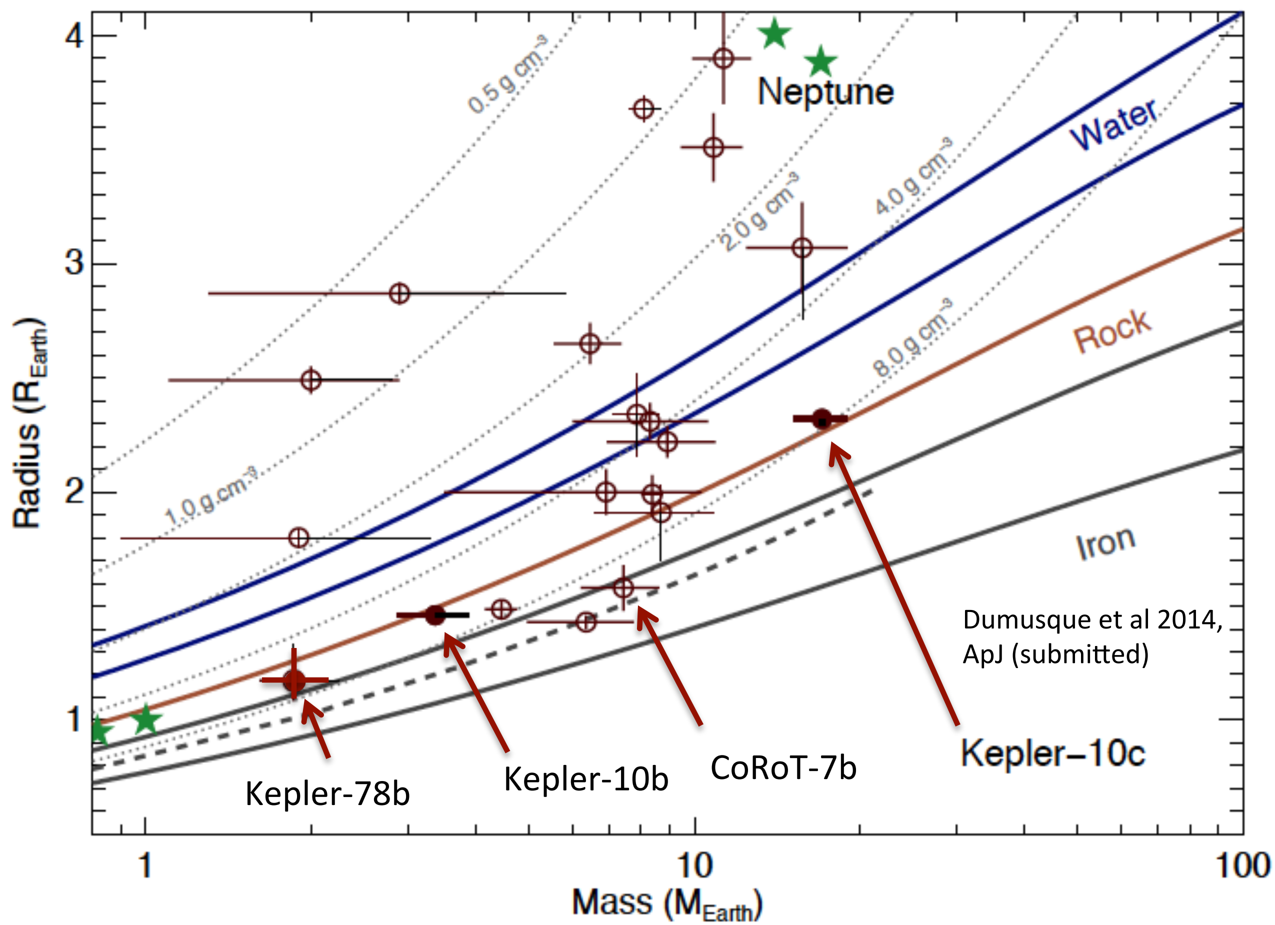
$R_b = 1.47 \pm 0.02\ R_{Earth}$
$M_b = 3.33 \pm 0.41\ M_{Earth}$
density = 5.08 ± 0.80 g/cc

$R_c = 2.32 \pm 0.03\ R_{Earth}$
$M_c\ 14.04 \pm 1.41\ M_{Earth}$
density = 7.01 ± 0.70 g/cc

Dumusque et al 2014, ApJ (submitted)
Fogtmann-Schulz et al 2014, ApJ

Kepler 10c: a Rocky Neptune???

Mass-radius diagram

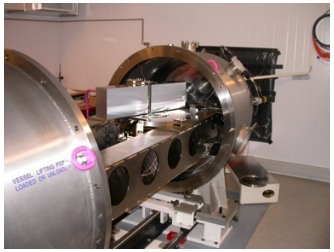


The GAPS Project

- **GAPS**, *Global Architecture of Planetary Systems,* is a long-term programme for the comprehensive characterization of the architectural properties of planetary systems as a function of the hosts' characteristics (mass, metallicity, environment).

- GAPS has been approved by Italian TNG TAC:
  - **AOT 26** (Aug 2012-Jan 2013): 36 nights
  - **AOT 27** (Feb 2013-Jul 2013): 40 nights
    + long-term status ➔ proposal approved for 2 years.
    ➔ till Feb 2015!

INAF Guidelines to TAC: to dedicate ~80 nights/year of TNG to a large coordinated effort of the Italian community willing to study exoplanets with HARPS-N.



The GAPS Team

~ 61 INAF and associated scientists in Italy;

~16 scientists from foreign institutes.

Wide range of expertise

- High resolution spectroscopy
- Stellar rotation and activity
- Crowded stellar environments
- Formation of planetary systems
- Planetary dynamics

GAPS
Global Architecture of Planetary Systems

22 different institutes

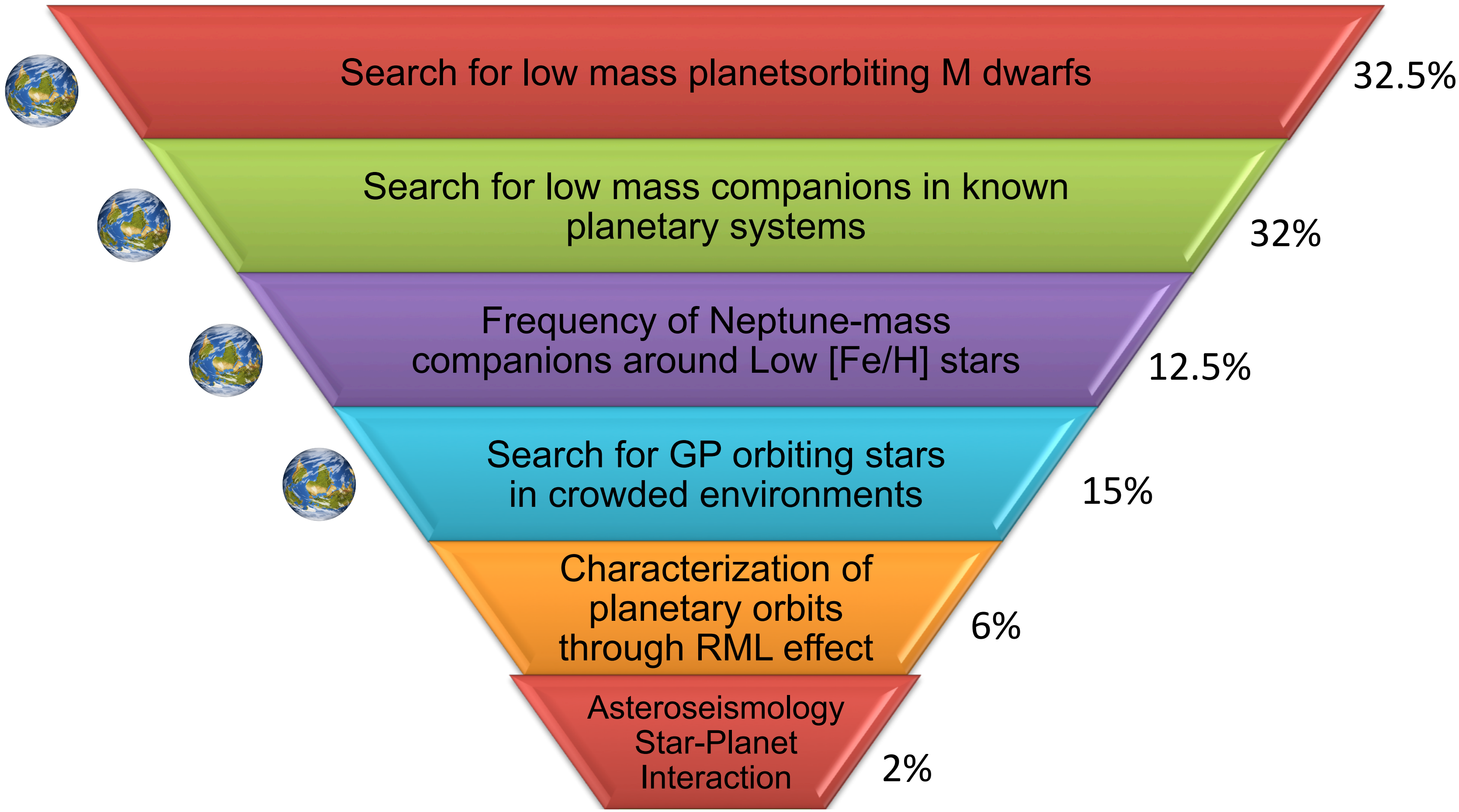
11 in Italy, 11 outside Italy

2/3 senior scientists
1/3 post-docs

6+1 on GAPS funds

Funds secured through Progetti Premiali granted to INAF

GAPS Science Themes



Where we are

- The 6 programs have almost reached the same level of completeness.
- Collaboration with Spanish program on M dwarfs well in progress (MoU ready to be finalized)
- Involvement of amateur astronomers ready to start.

- 3 papers published
- 3 new planets secured
- Some interesting candidates
- A lot of good science ready to be published ➔ several papers in progress.

Coming steps:

- New proposal to be submitted for AOT 31 at beginning of the fall
- NEXT Meeting in Naples 22-24 October 2014: Major review after the first two years of GAPS Project.

Planets orbiting M stars

M stars (mass < 0.6 $M_{\odot}$) opportunity:

– Vast majority of stars

– More favorable contrast with the star → Rocky planet "easily" detectable with present day facilities

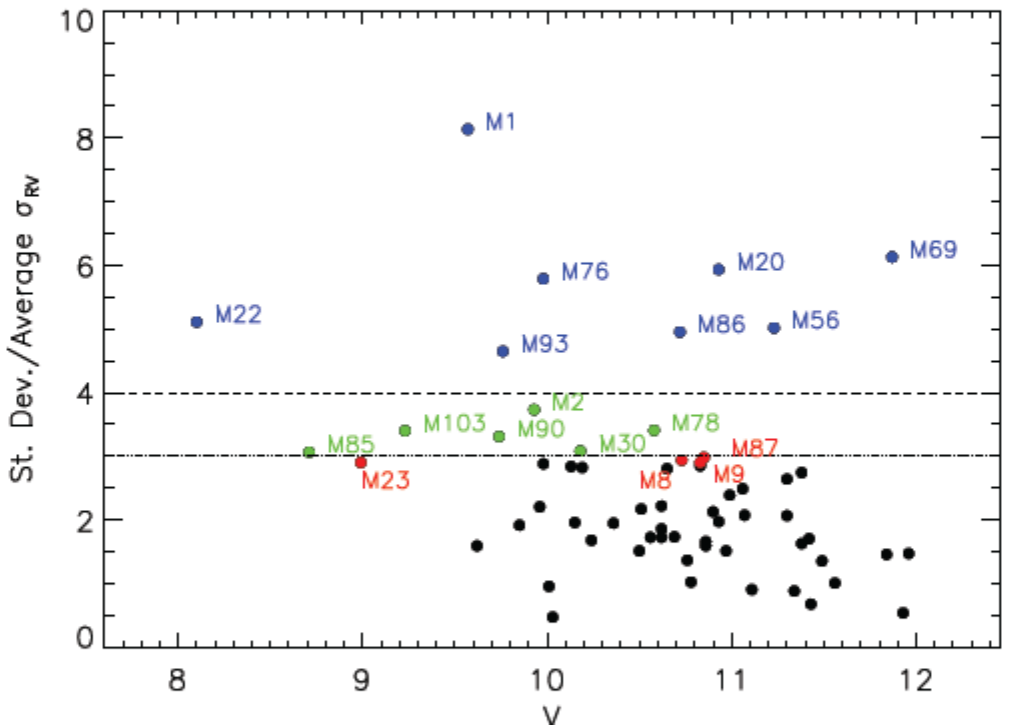
– Closest habitable zone (shorter periods)

- **M stars disadvantages**

– Activity

– Complex spectra

M stars program



- 80 objects monitored
- Synergy with similar program with Spanish group
- E few interesting candidates emerging

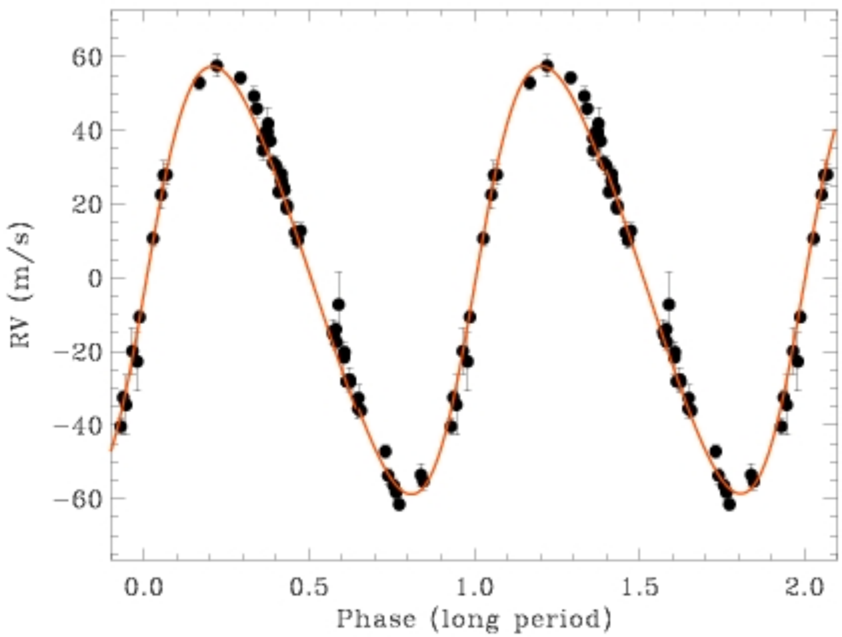
Know Planet program

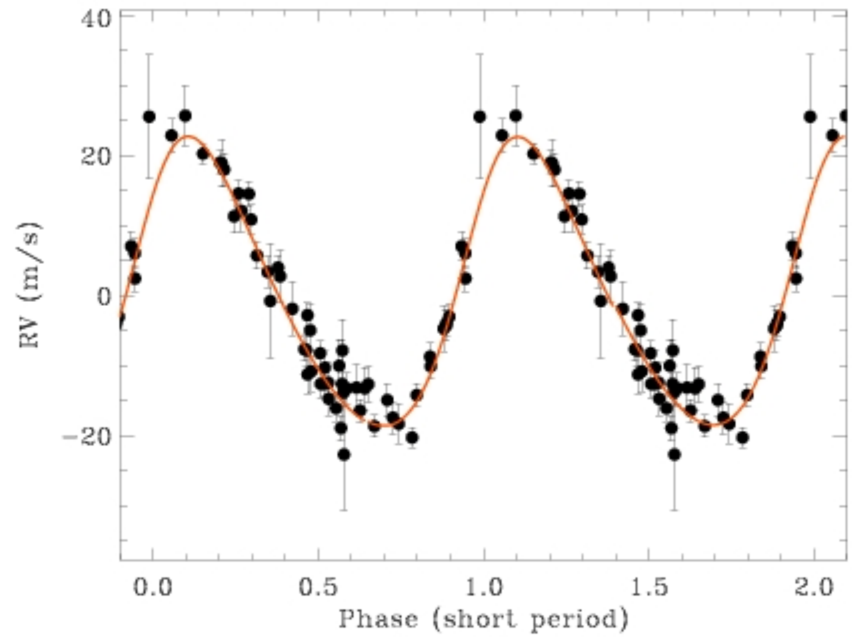
Three components

- Stars with long period giant planets (search for low mass planets in close orbits, i.e. scaled solar system analogs)
- A small sample of stars with known planetary systems for further characterization
- Transiting planets (system characterization, search for additional planets)

A new planetary system (KP Program)

- Discovery of two planets with HARPS-N, a Jupiter-mass planet at 0.5 AU and a Saturn-mass planet at 0.13 AU
- Paper being submitted (Desidera et al.)

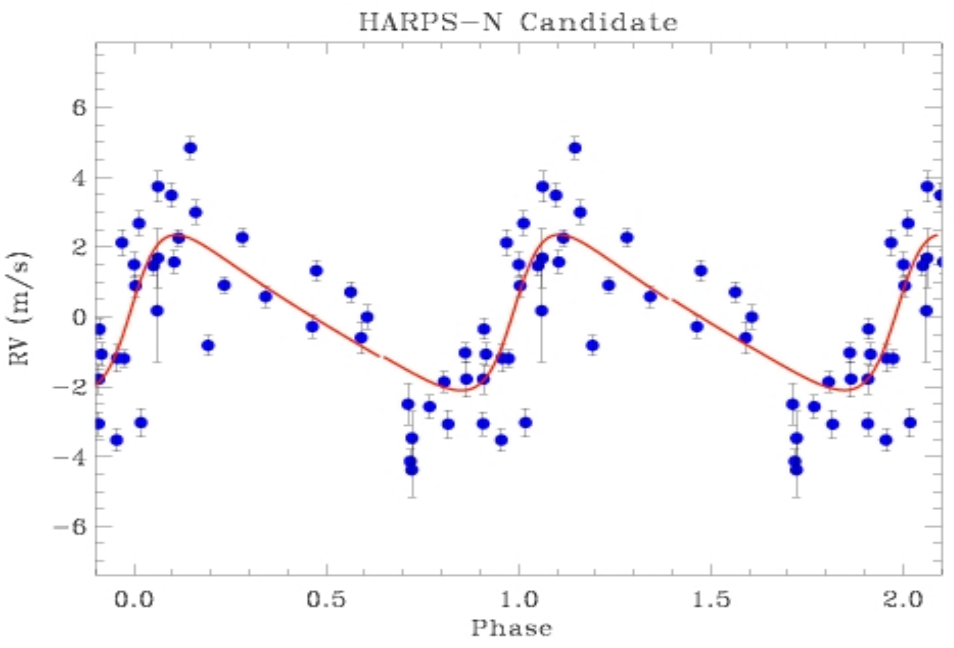




Very interesting case: two distinct planetary systems around the components of a binary

A low-mass planet candidate

- A low-mass planet candidate around a stars hosting a long-period giant planet

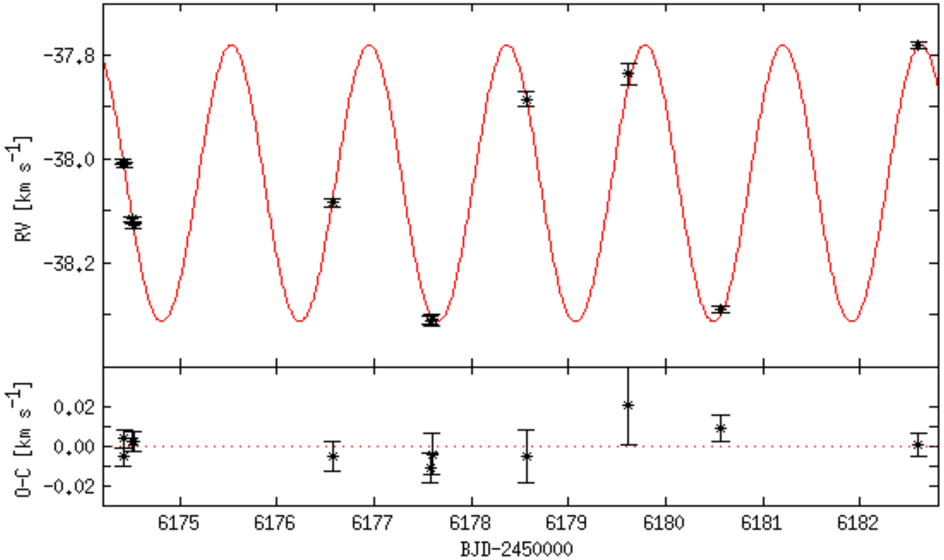


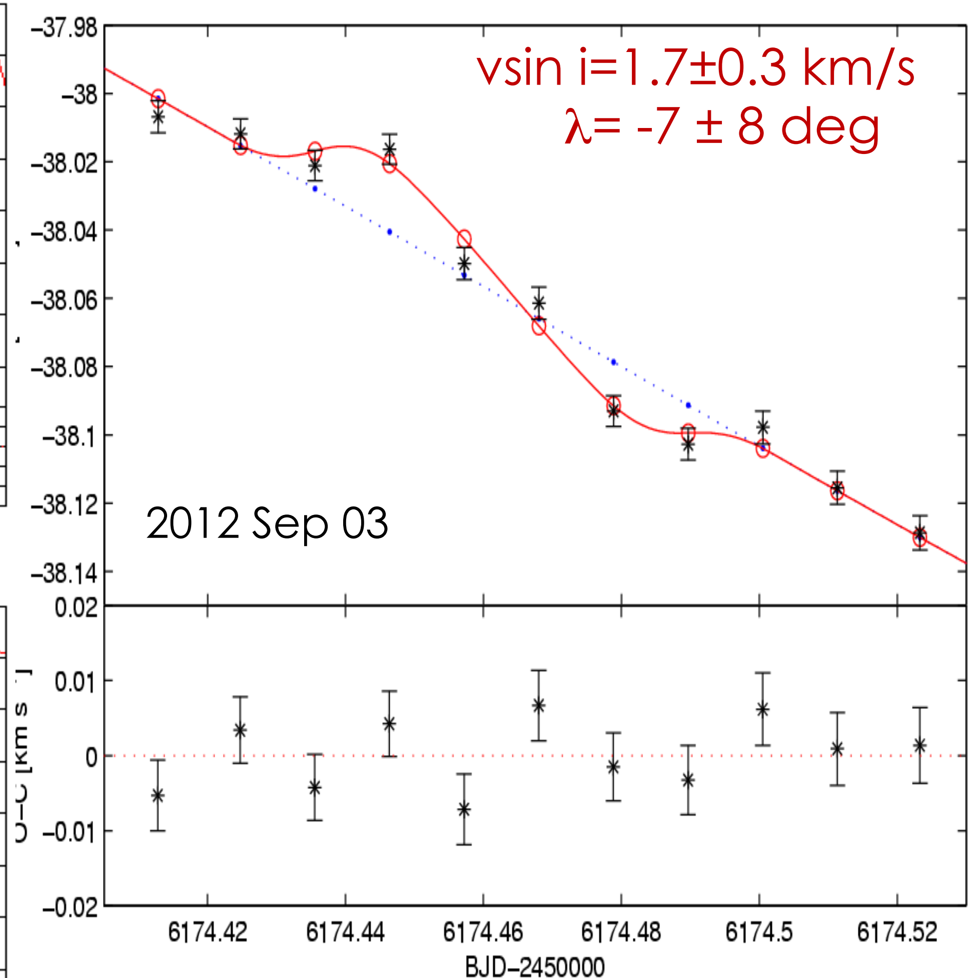
Rossiter-McLaughlin effect program

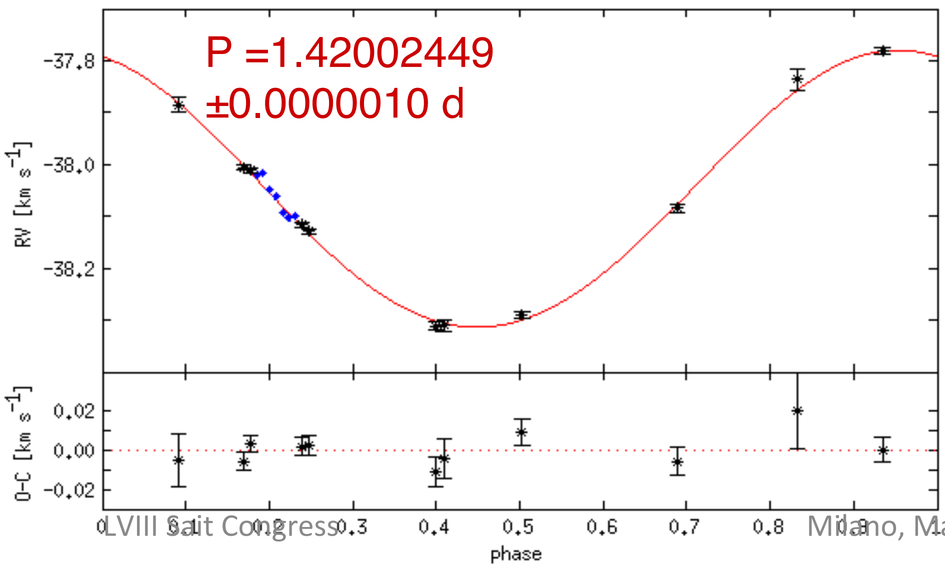
- Aims:
- **derive the orbital obliquity** for a range of planet and host properties (*i.e.* P_{orb}, M_p, M_*, age)
- **characterize orbits and physical properties** of transiting systems containing hot GPs (thanks to synergy with KP program)
- **address planetary orbit evolution issues**, and find clues to migration mechanisms and star-planet tidal interactions

The GAPS programme with HARPS-N at TNG★

I. Observations of the Rossiter-McLaughlin effect and characterisation of the transiting system Qatar-1★★,★★★



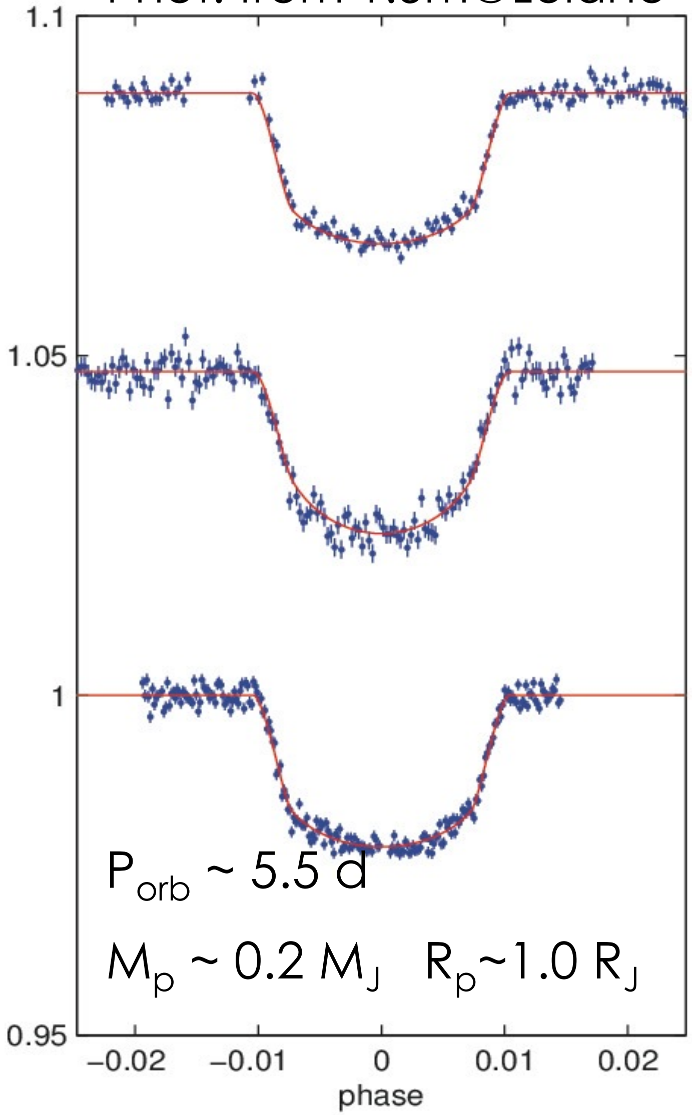




Covino et al. (2013) A&A 554, 28

GAPS III. HAT-P-18b retrograde orbit

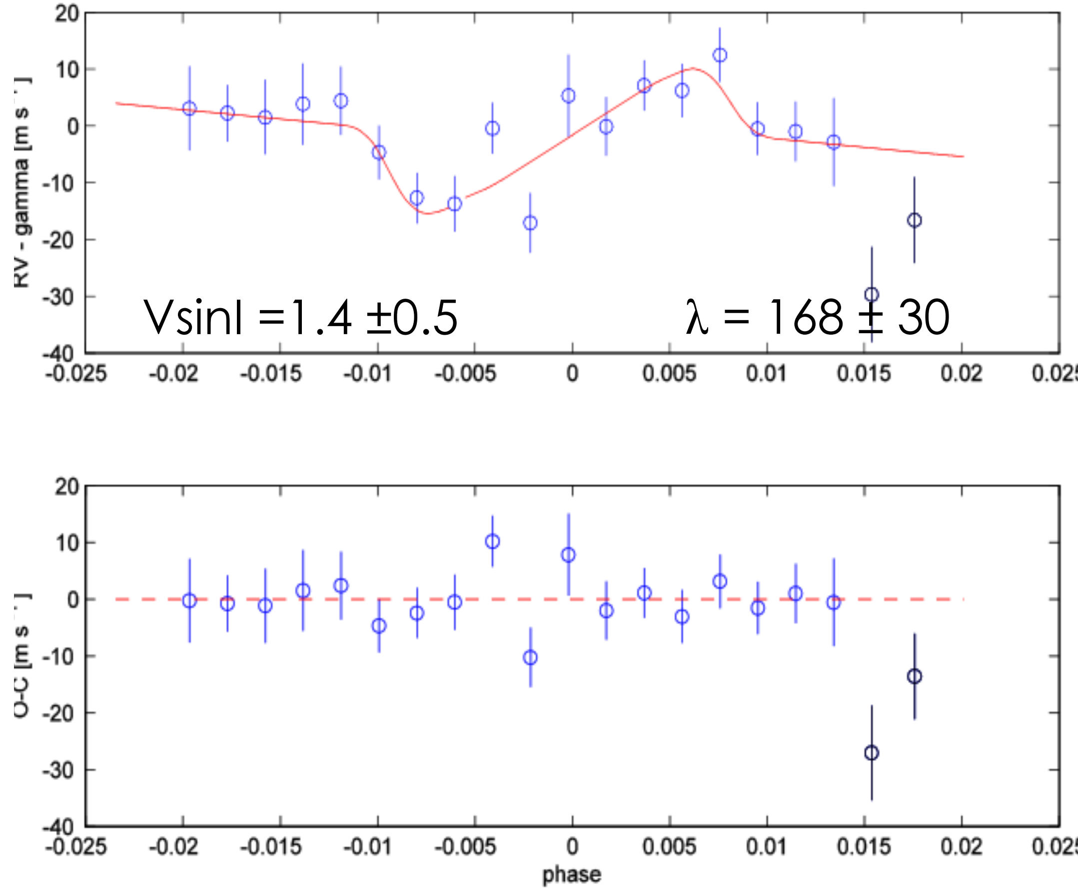
Phot. from 1.5m@Loiano



P_{orb} ~ 5.5 d

M_p ~ 0.2 M_J R_p~1.0 R_J

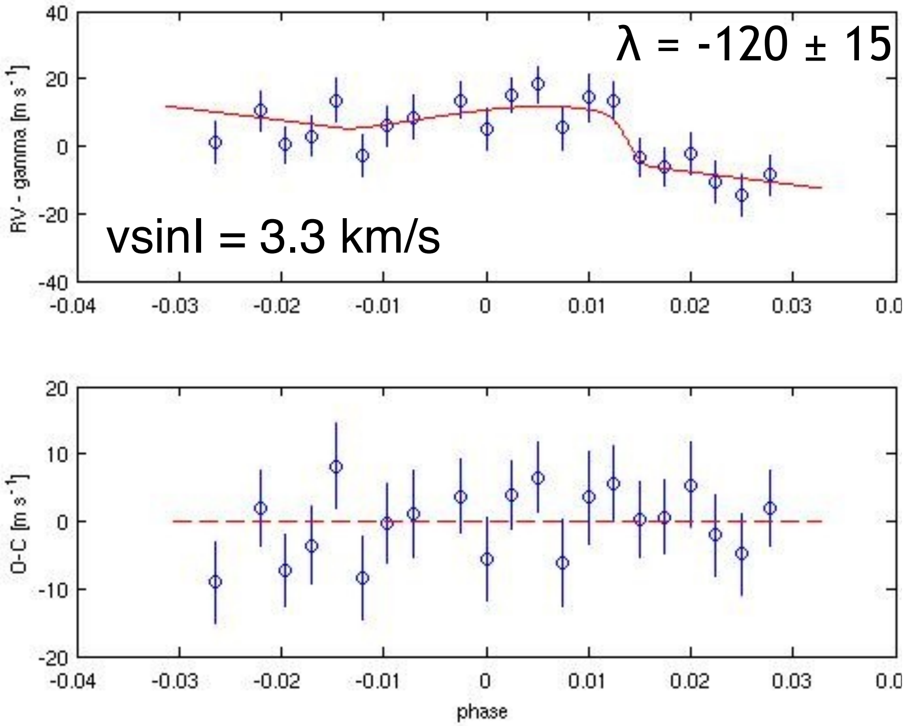
HARPS-N RM-effect data

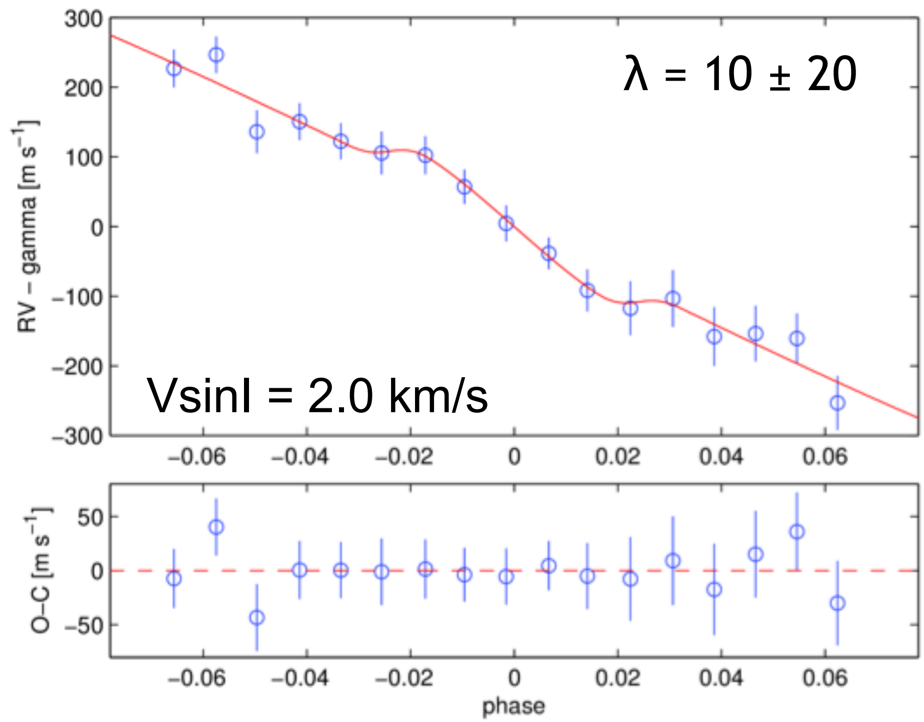


Host: V~12.8 K7V T_{eff}=4860±70K log*g* =4.5±0.1 [Fe/H]= 0.11 ±0.09

Esposito et al. 2014 A&A 465 L13

Latest RM-effect observations



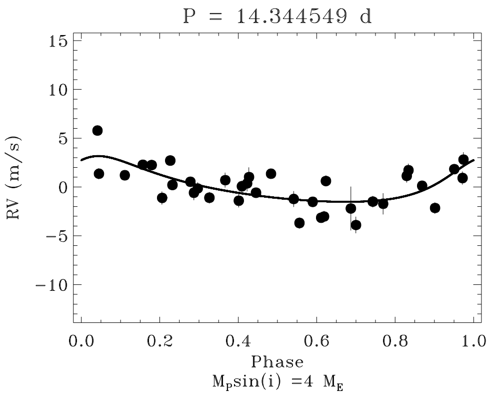


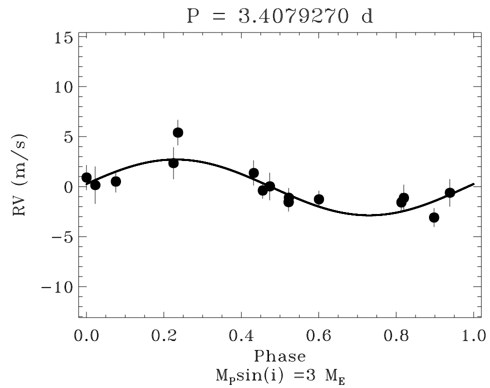
- Retrograde system with a half-Jupiter mass planet transiting a solar-mass star on 4.3d orbit
- Aligned system with a Jupiter-mass planet transiting a low-mass star on 1.3d orbit

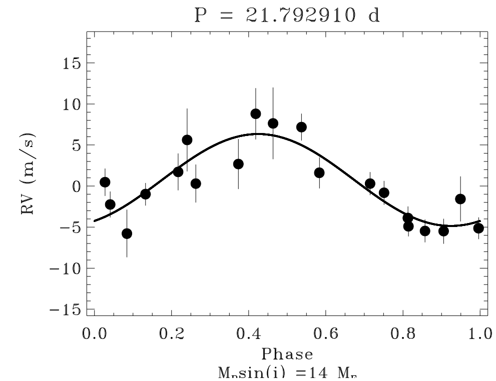
Metal poor Planet Search

- A HARPS-N search for Neptunes and Super-Earths ($M < 20\ M_{\oplus}$) around a sample of moderately ($-1.0 <$ [Fe/H] < -0.5 approximately) metal-poor stars.
- To derive the frequency of Neptunes and Super-Earths ($P <$ 100 d) in the metal-poor regime
- To compare it to published results for solar metallicity stars.
- To characterize the architecture of planetary systems as a function of stellar metallicity for useful comparison with theoretical model predictions.
- 60 stars selected from the Keck/HIRES metal-poor sample.

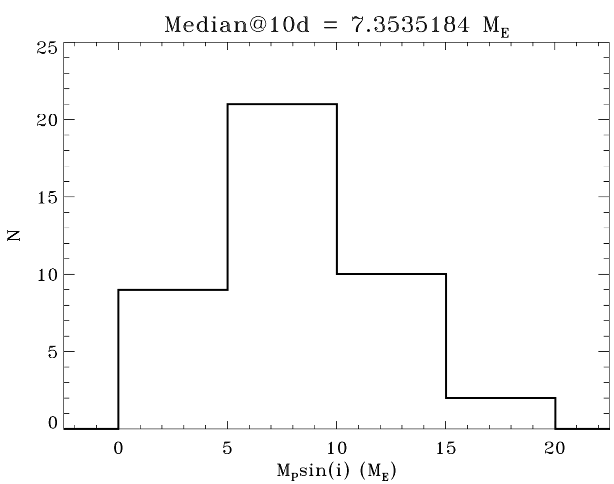
Emerging Results

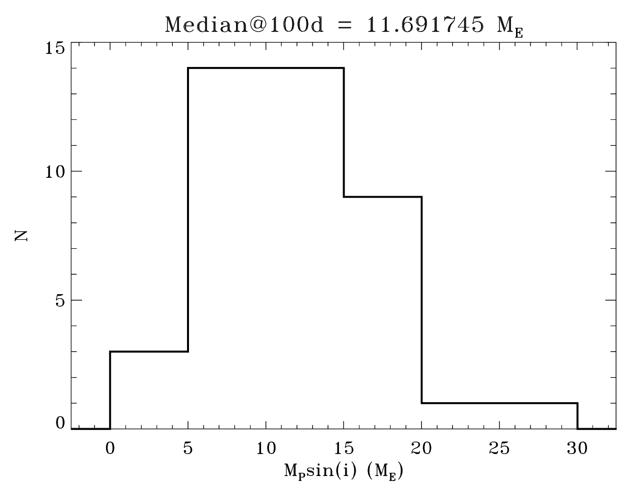






Exoplanet detections: several short-period candidates under follow-up

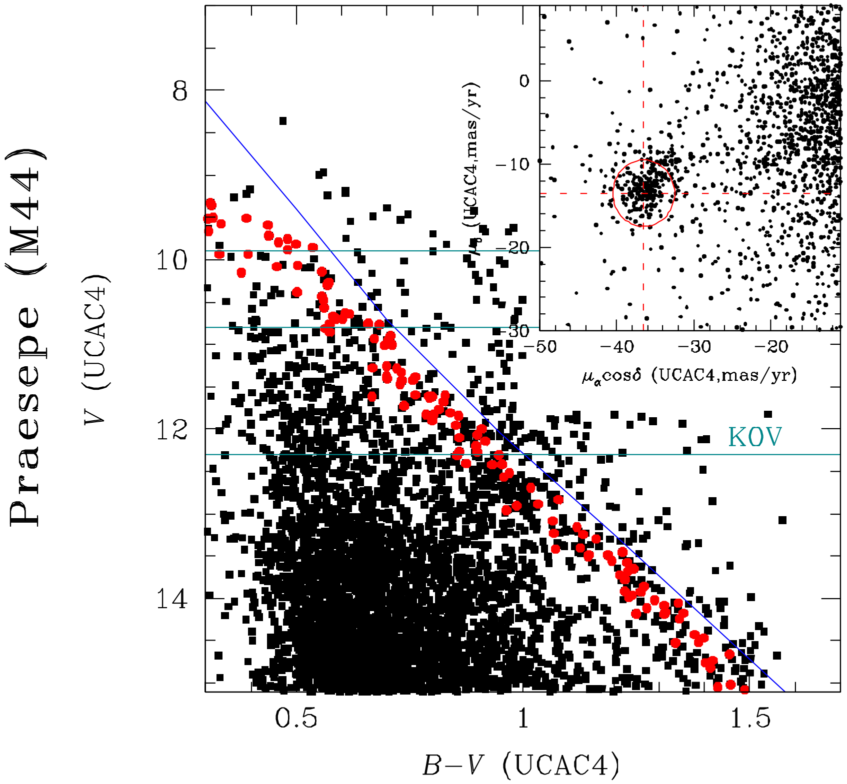




Sensitivity Limits: very well in line with the goals of the program

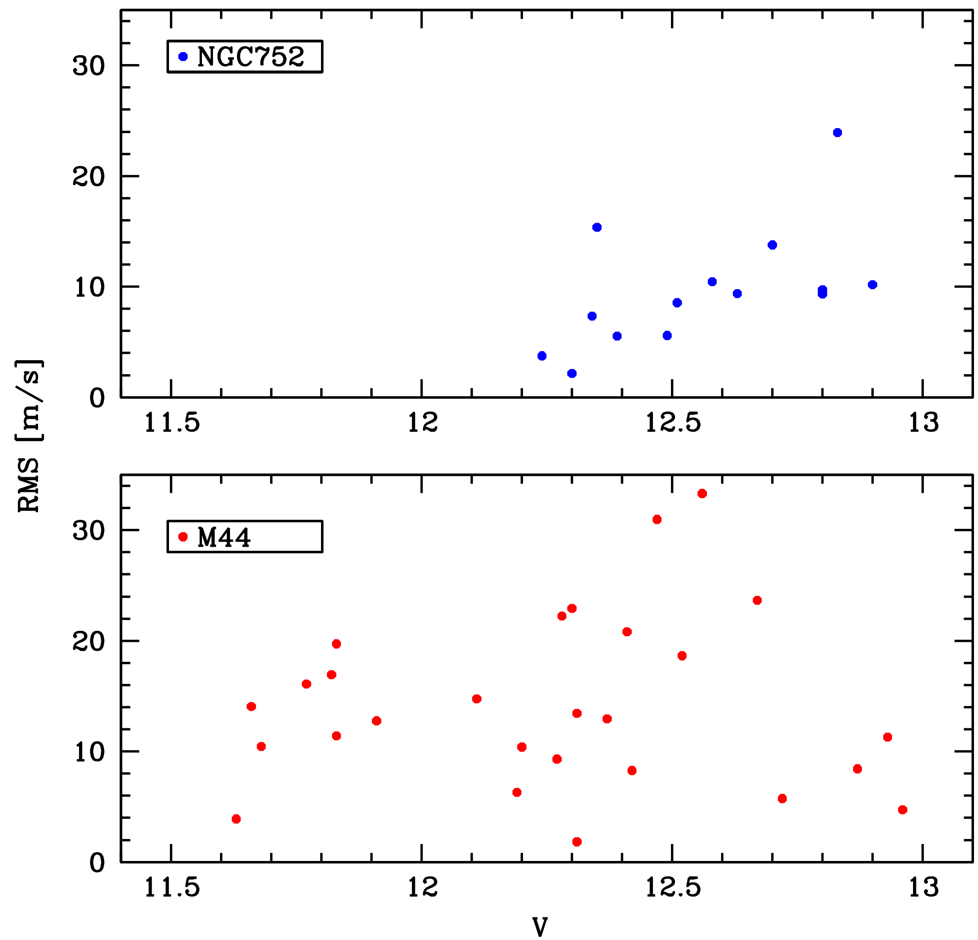
Search of Planets in Open Clusters

- Open Clusters (OCs): ages, metallicites and distances, as well as stellar masses and radii more precise than for field stars
- Role of dynamical and chemical environment on planet formation
- Ultimate goal: direct estimate of frequency of Giant Planets in OCs



Where do we stand?

- More than 120 confirmed members with V<14 at the end of the survey. 1/3 already surveyed.
- Activity of NGC752 stars is below detectability
- M44 stars are more active, but are supported by high-precision photometric time-series
- No GP detected so far, but survey still ongoing



1 M_J planet with 60-days orbit, or 0.35 M_J in a 3-days orbit

Measured RMS 40 m/s (K=50m/s)

Clearly detectable even with an active host star