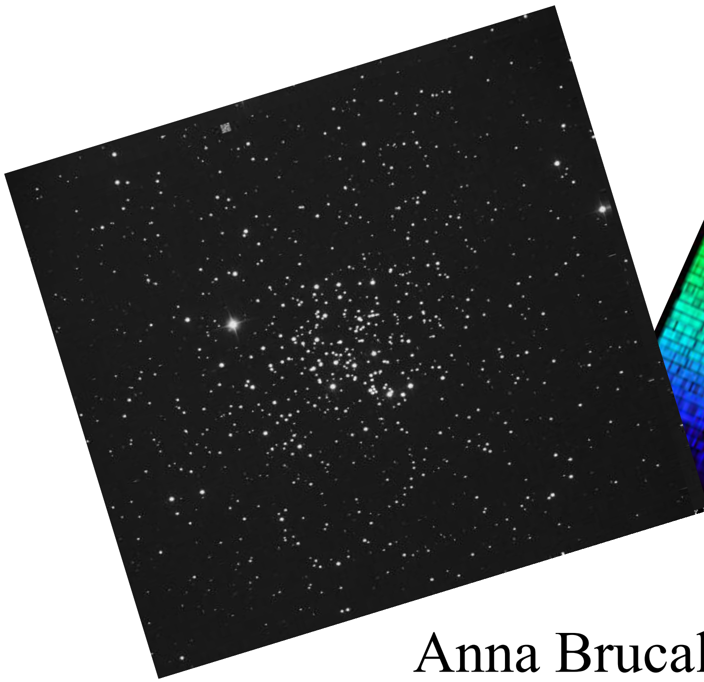
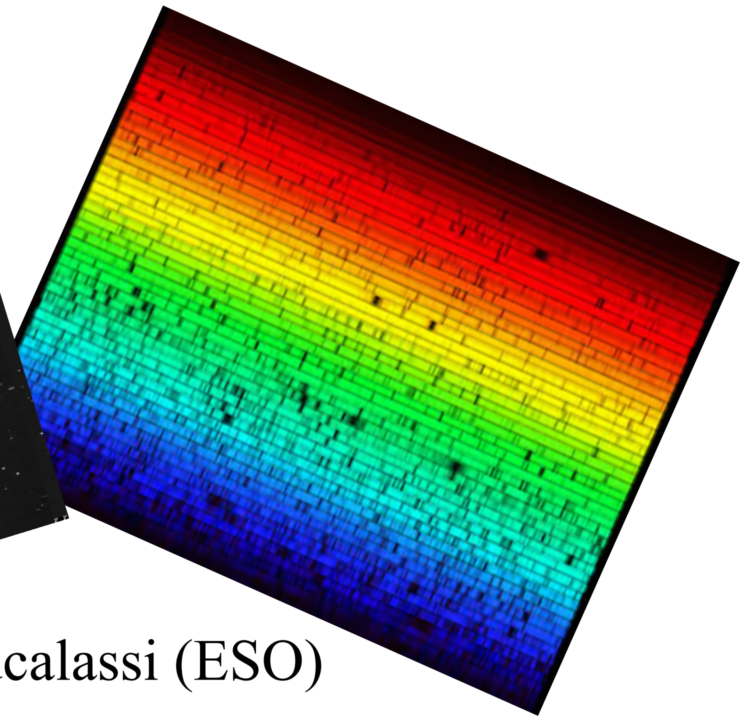
Search for giant planets in M67: Excess of Hot Jupiters





Anna Brucalassi (ESO)

L. Pasquini (ESO), R. Saglia (MPE), J. Koppenhoefer (MPE/USM), M.T. Ruiz (Un.de Chile), P. Bonifacio (GEPI), L. R. Bedin, M. Libralato, K. Biazzo (INAF), C. Lovis (Geneve Obs.), S. Randich (INAF)

Motivations

Context: **Presence of planets and properties of the host stars**

Aims of the project:

- Study the dependence of planet formation on stellar mass and metallicity.
- Compare in details the chemical composition of stars with and without planets.
- Study how the planet formation process depends on the star environment

Several studies with controversial results

Intrinsic difficult research:
High quality data
Field stars with different nature

Planets in the Stars Clusters

Why?

Differential abundances of planet-host and not planet-host stars

Stars in clusters share the same abundances

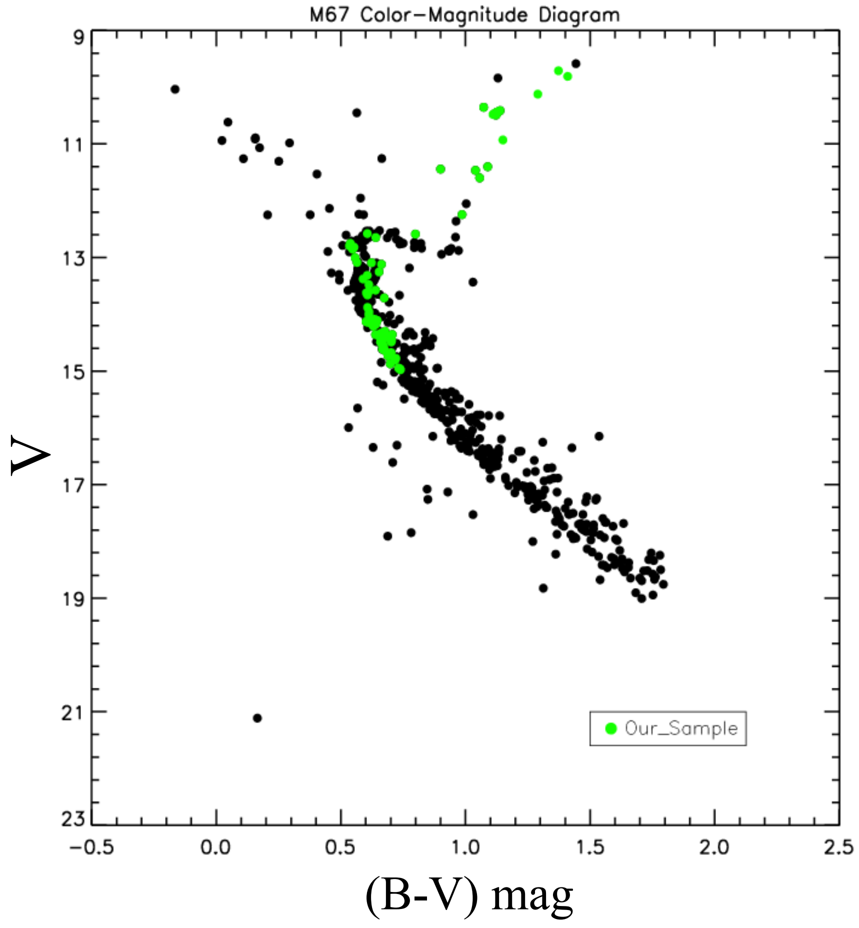
Determine mass-dependence of planet frequency directly

Stellar mass is well constrained in clusters

Compare the planet frequency in field and clusters

M67

Method: **Precise stellar radial velocities to search for massive (Jupiter or higher) exo-planets around stars of M67**



Why M67:

-one of the best studied OC
-CMD well populated
-chemical composition and age close to the sun
- very good candidates for Solar Twins (Onehag+ 2011,2013)

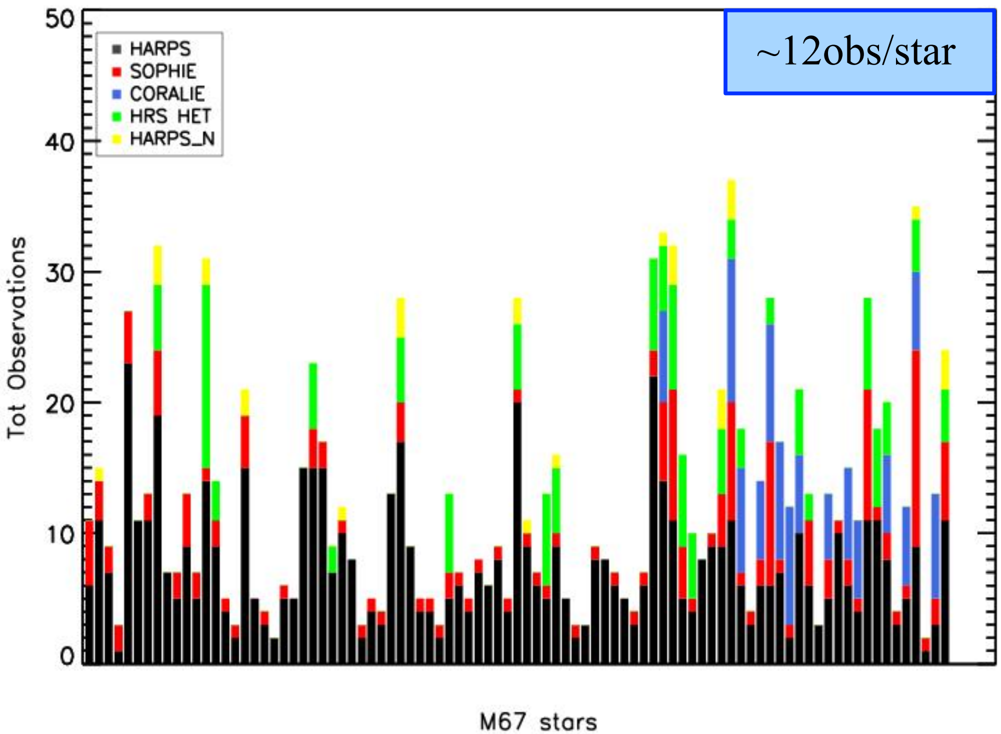
Sample: 88 stars (58 MS + 30 giants and TO) including 10 solar analogs (Pasquini et al. 2008).

proper motion membership probability > 60% (Yadav et al. 2008)

8.9< Vmag< 15

Statistics of observations

Limitation: **Sparse sampling frequency of the observations: few nights/year in the period January-April → Need to use several telescopes/instruments**



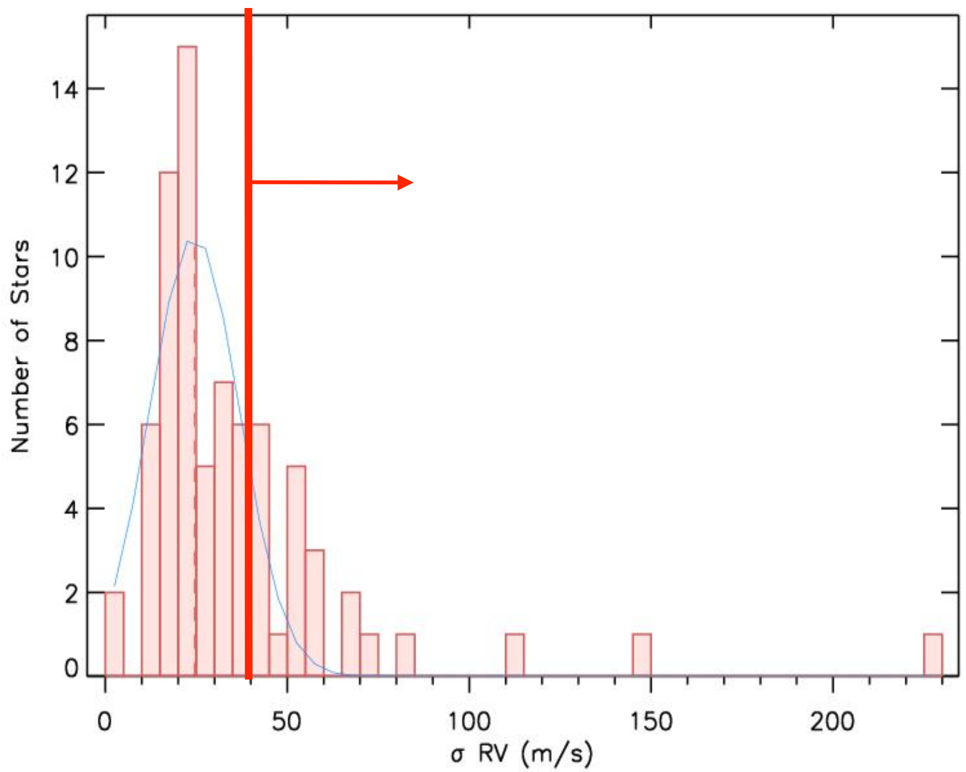
125 obs HRS-HET (2010-2013)
99 obs CORALIE (2003-2005)
168 obs SOPHIE (2008-2015)
23 obs HARPS-N (2013-2014)
734 obs HARPS (2008-2015)

RV precision HRS-HET ~20-25m/s
RV precision CORALIE ~20-25m/s
RV precision SOPHIE ~15m/s
RV precision HARPS-N ~12m/s
RV precision HARPS ~10m/s

Analysis Data: **- Zero Point to HARPS data**
- RV data analyzed together

The RV rms

Analysis Data: **- Best planets host candidates: Evaluation of the RV variability.**
- Lomb Scargle Analysis
- Keplerian Fit (Levenberg-Marquardt/MCMC analysis)



Pasquini et al., 2012

RmsRV centered at 25 m/s with σ=12 m/s

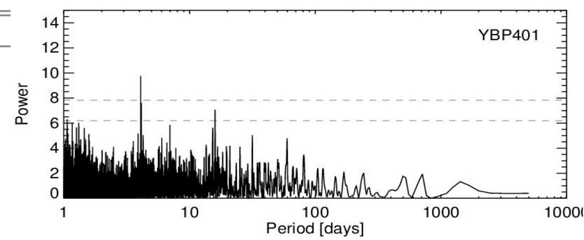
Best candidates:

- stars rmsRV>50 m/s
- stars with 30m/s<rmsRV<50m/s

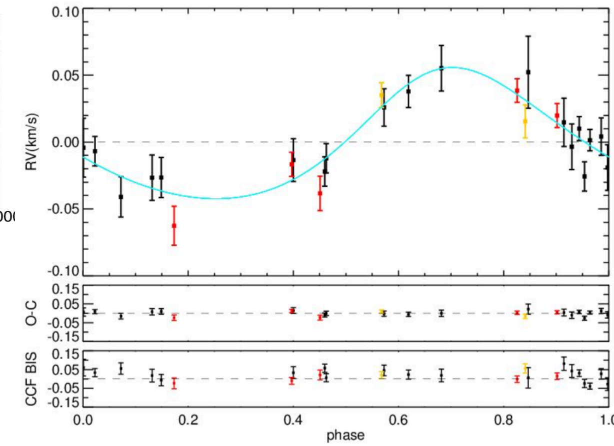
Excess of rmsRV may indicate more candidates among lower variability stars

Three new HJs around MS stars

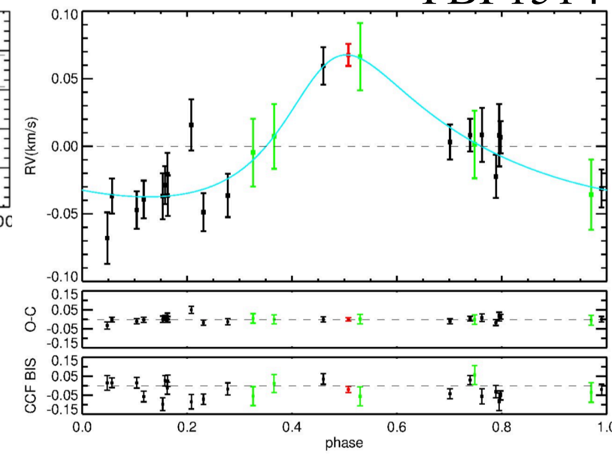
Parameters	YBP401	YBP1194	YBP1514
α (J2000)	08:51:19.05	08:51:00.81	08:51:00.77
δ (J2000)	+11:40:15.80	+11:48:52.76	+11:53:11.51
Spec.type	F9V	G5V	G5V
m_V [mag]	13.70^a	14.6^a	14.77^a
$B-V$ [mag]	0.607^a	0.626^a	0.680^a
$M\star$ [$M_\odot$]	1.14 ± 0.02^d	1.01 ± 0.02^d	0.96 ± 0.01^d
log g [cgs]	4.30 ± 0.035^f	4.44 ± 0.05^e	4.57 ± 0.06^g
$T_{\rm eff}$ [K]	6165 ± 64^f	5780 ± 27^e	5725 ± 45^g
P [days]	4.087 ± 0.003	6.960 ± 0.001	5.118 ± 0.001
T [JD]	2 456 072.4 ± 0.6	2 455 679.9 ± 0.4	2 455 986.3 ± 0.3
e	0.16 ± 0.08	0.31 ± 0.08	0.27 ± 0.09
ω [deg]	343.33 ± 62.12	109.16 ± 20.16	328.58 ± 17.78
K [m s^{-1}]	49.29 ± 5.50	37.35 ± 4.55	50.47 ± 3.90
$m \sin i$ [$M_{\rm Jup}$]	0.42 ± 0.05	0.33 ± 0.03	0.40 ± 0.35
γ [km s^{-1}]	33.179 ± 0.004	34.184 ± 0.003	34.058 ± 0.004
χ^2_{red}	0.97	0.95	0.93
σ(O-C) [m s^{-1}]	12.31	11.51	14.24

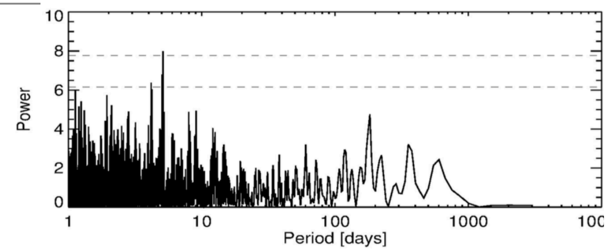


YBP401

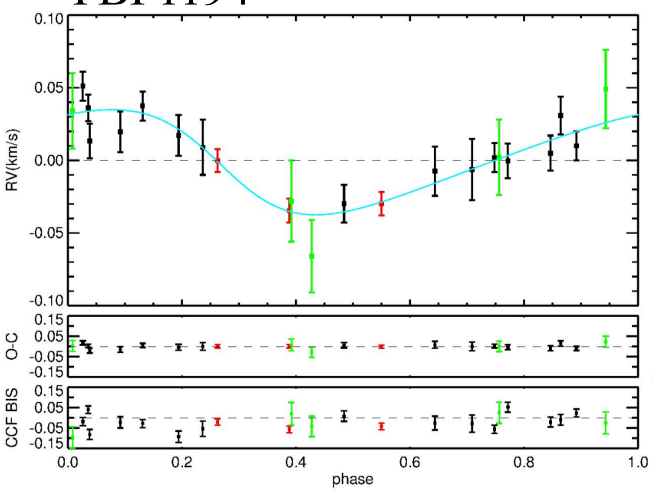


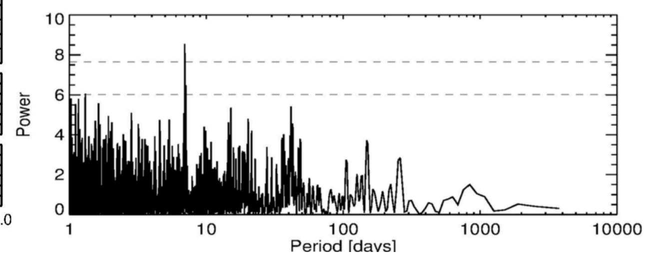
YBP1514





YBP1194



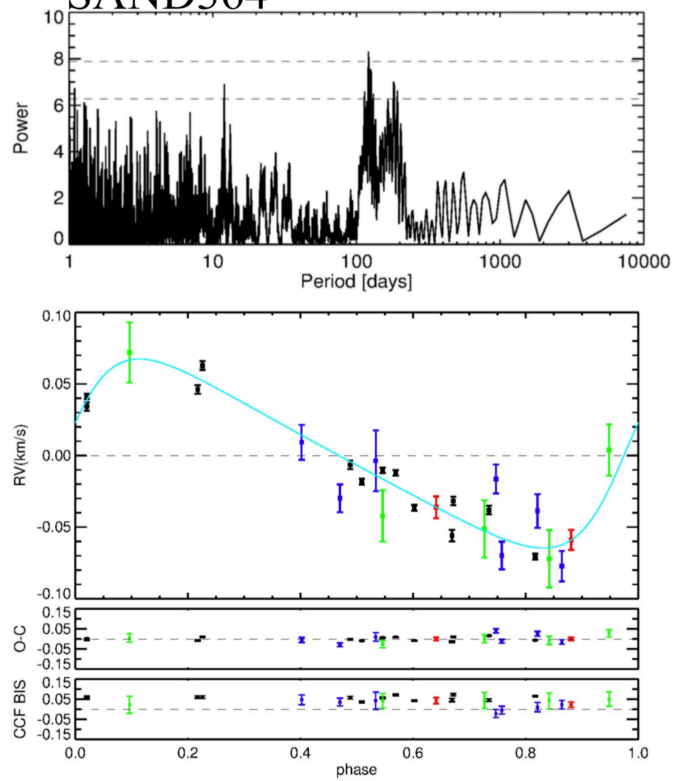


Brucalassi+ 2014, 2016

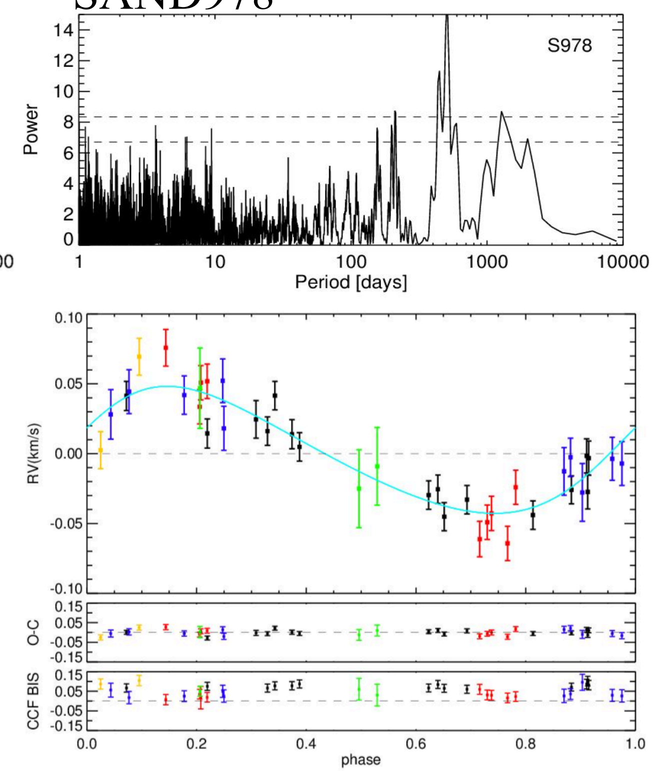
Two new planetary companions around giant stars

	SAND364	SAND978
	08:49:56.82	08:51:17.48
	+11:41:33.00	+11:45:22.69
	K3III	K4III
	9.8[b]	9.71[c]
	1.360[b]	1.370[c]
	1.35 ± 0.05[d]	1.37 ± 0.02[d]
	2.20 ± 0.06[h]	1.80 ± 0.09[i]
	4284 ± 9[h]	4200 ± 21[i]
P	120.951 ± 0.453	511.21 ± 2.04
	2 456 231.22 ± 4.26	2 456 135.92 ± 21.23
e	0.35 ± 0.10	0.16 ± 0.07
	254.62 ± 15.91	291.68 ± 35.85
K	56.94 ± 4.26	45.48 ± 3.65
msin*i*	1.57 ± 0.11	2.18 ± 0.17
	33.188 ± 0.019	34.567 ± 0.008
	1.08	1.57
	15.93	12.90

SAND364



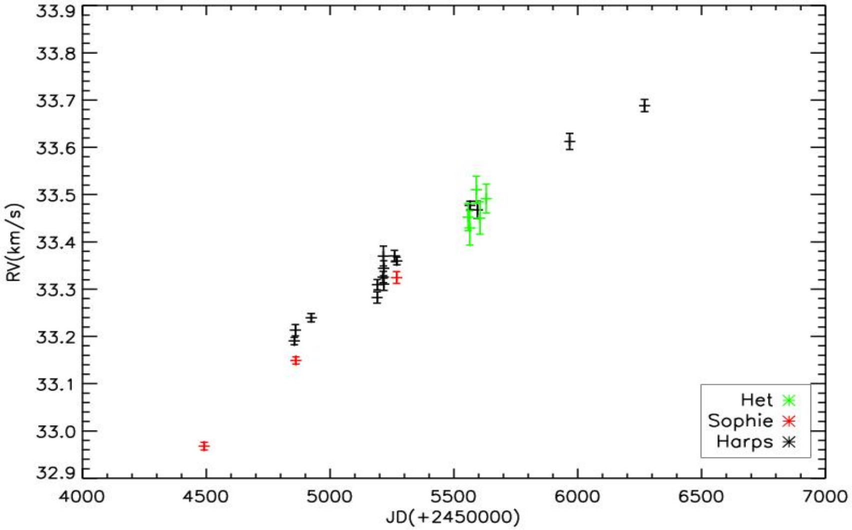
SAND978

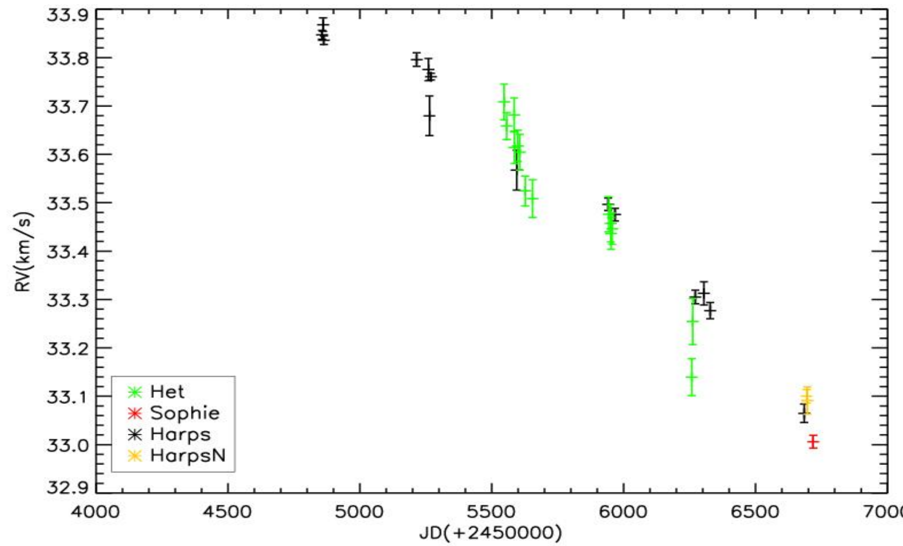


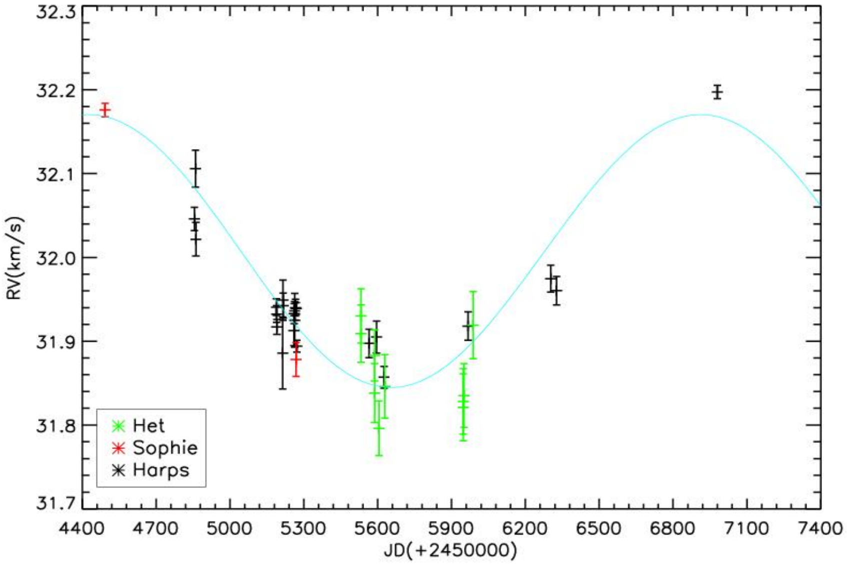
For each case we verified that the RVs did not correlate with the bisector span of the CCF or other stellar activity indicators.

Brucalassi+ 2014, 2017

Binaries and Long Term Variability







Binary candidates:

- 12 stars out the original sample of 88 (Pasquini+2012)
- 2 new stars show significant trend: peak to peak RV amplitude ~1.0km/s
- 2 stars show RV variations ~400m/s Tentative of Keplerian solution: ~11Mjup and P~2487.0 days

Detection efficiency and Planet Frequency

Monte Carlo Simulations to:
Determine the detection efficiency
and the occurrence rate of giant planets

$$V_r(t) = a\cos\nu(t) + b\sin\nu(t) + c,$$

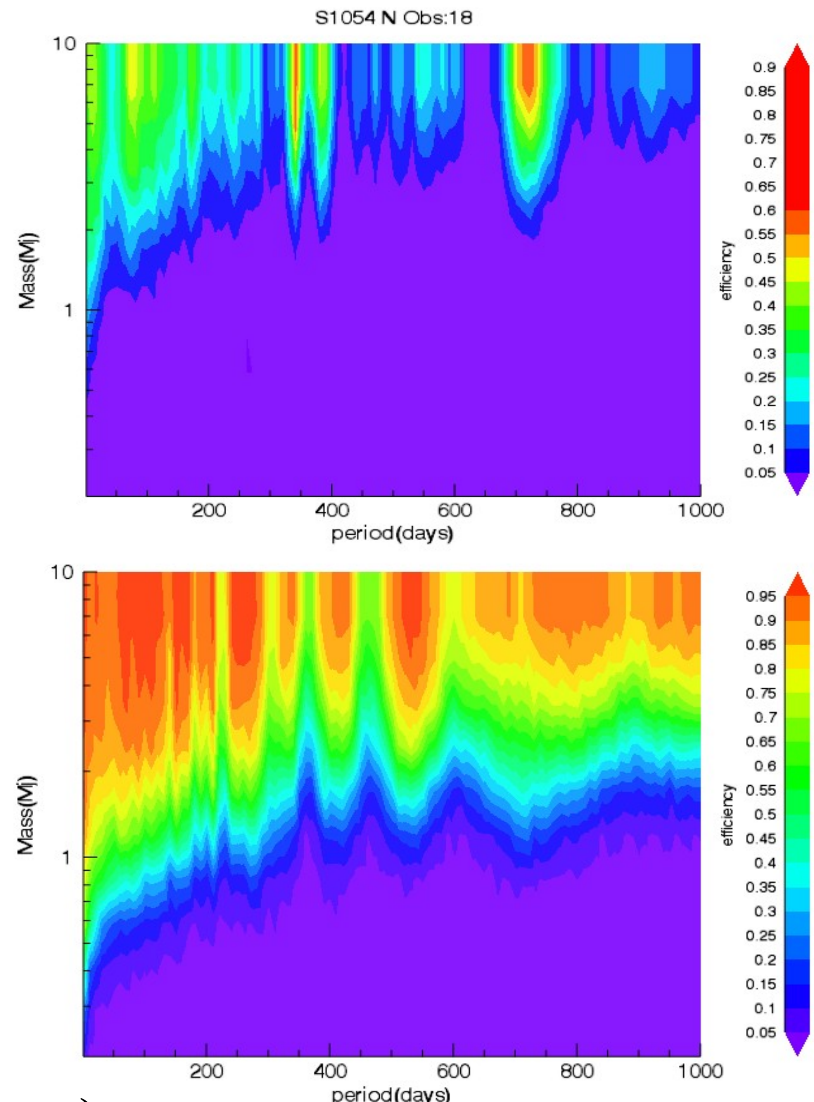
where $a = K\cos\omega$, $b = -K\sin\omega$ and $c = Ke\cos\omega + \gamma$.

$$K = \left(\frac{2\pi G}{P}\right)^{1/3}\left(\frac{m_{\rm p}\sin(i)}{M_{\rm Jup}}\right)\left(\frac{M_\star}{M_\odot}\right)^{-2/3}\left(\frac{1}{\sqrt{1-e^2}}\right)$$

- Virtual series of planets mass and period pairs
- RV values derived for Keplerian orbit
- Periodogram or RMS analysis
- Fraction of detected planets over the total simulated
- Estimation of Planet Occurrence Rate

Giant planets occurrence rate: ~16.3%
HJ Planets occurrence rate: ~5.1%

(In the field with RV surveys: ~1.2%, Wright+ 2012**)**



Brucalassi+ 2017

Other Open Clusters

HJs in OCs for RV surveys for FGK stars:

- Praesepe Cluster (Quinn et al. 2012)→ **2 HJs**
- Hyades (Quinn et al. 2014, Malavolta et al. 2014)→**1 HJs + 1 Long Period giant planet**

6HJs/240 stars → to compare in the field: **10HJs/836 stars** (Wright et al. 2012)

Possible explanation:

Recent numerical simulations show relevance of fly-by and encounters in dense environments for triggering migrations and formations of HJs (Bancelin+ 2017, Xu Cai+ 2017, Shara+ 2014, Davies+2014, Malberg+ 2011)**:**

- Stellar density
- Binary fraction
- Timescale of exposition to perturbations

Qualitatively: M67 is evolved, mass segregation occurred. HJ occurrence might result from high HJ formation **and** preferential retention of the HJ host stars

Conclusions

- **Planets are common in Clusters!**

- Recent RV discoveries and new Kepler (K2) detections in OCs changed paradigm.
- Study of planets in clusters are essential to understand the dependence of planets formation on the host stars properties and environment.

- **Our survey shows 5 new planetary companions**
- **Hot Jupiter frequency in our sample ~5.1%** in excess with the field studies.
- **Overall massive planet frequency: ~16.3%**

  also in agreement with the field studies (Mayor et al. 2011).

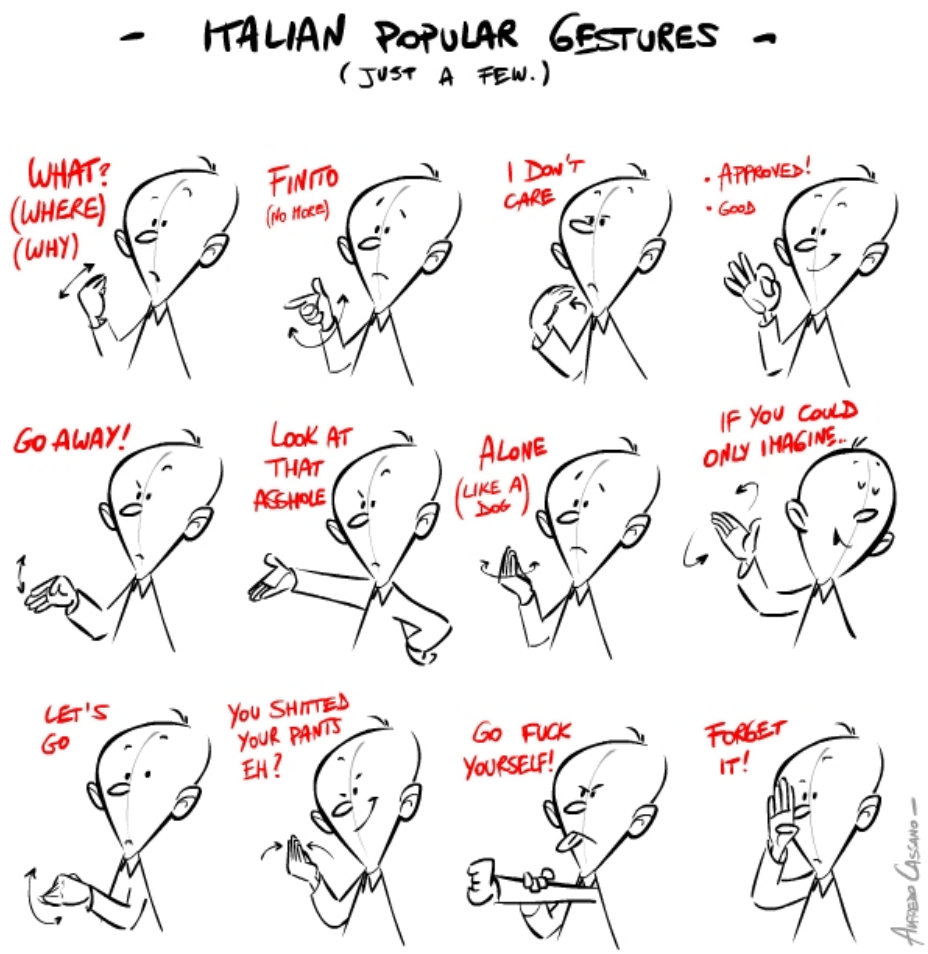
- **Normal chemical composition for planet hosts:**

  - No evidence of Li under-abundance in planet host stars
  - YBP1194 abundance pattern fully compatible with other M67 stars even in the refractory elements

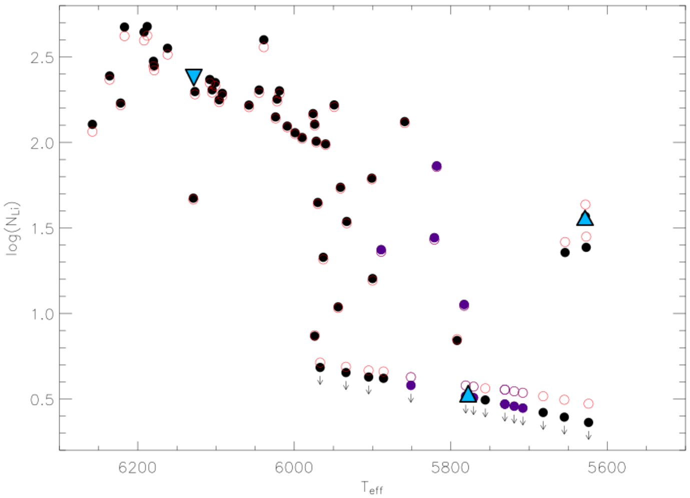
- **Next steps:**

  - Use the spectra to search for possible chemical differences between stars with and without planets.
  - Extend the search of planets in other dense Open Clusters

Thanks for your attention!



Chemical composition



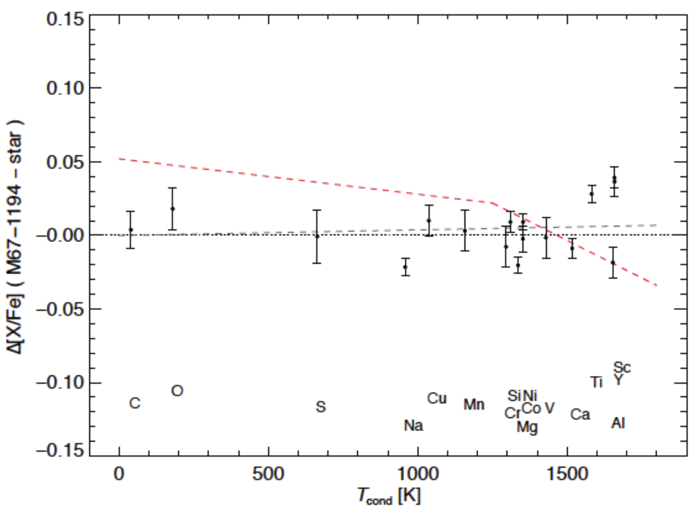


Fig. 6. The differences in logarithmic abundances between M67-1194 and the means for the other 13 programme stars of the present study, plotted vs the condensation temperature of the elements (Lodders 2003). The red dashed line indicates the rough mean locus of the solar-solar twin abundances, according to Meléndez et al. (2009). The grey dashed line is a regression line to the data. Error bars represent the RMS errors in the means for the entire sample ($\sigma/\sqrt{N}$).

Detailed differential analysis of the sample is on going

Planet Hosts:
NO obvious preference for Li-Poor Stars

YBP1194 (solar Twin):
analyzed independently (Oneahag et 2013):
No difference for volatiles with respect to other M67 stars.