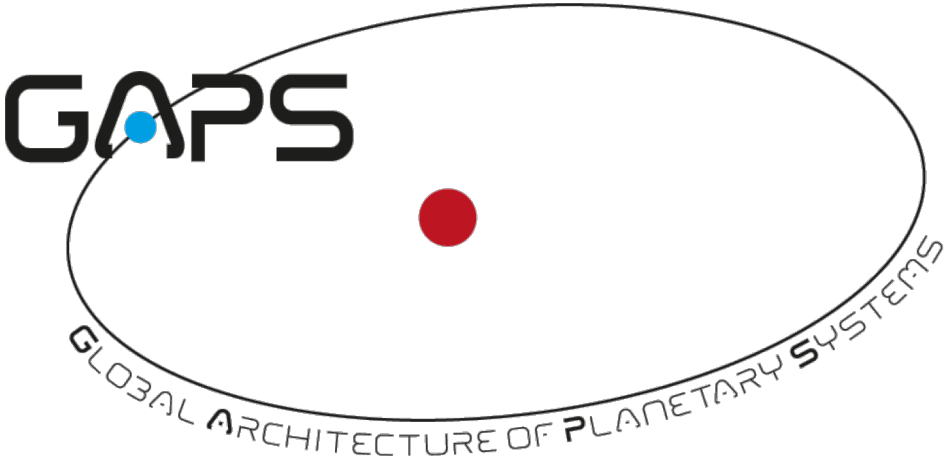


The GAPS Large Program at TNG

The Global Architectures of Planetary Systems

G. Micela, & the GAPS community

The GAPS project (and the GAPS community) was born as a response to the opportunity given by the installation of the HARPS-N@TNG

- **27/06/2010** "*HARPS-N at TNG: A Science Opportunity for the Italian Astronomical Community*", White paper of national community (ed. R. Gratton, +45 contributors)
- Roma, **July 2011**, census of interests
- Padova, **28-29/11/2011**, brainstorming (after a INAF *open call sent to "ricercatori" mailing list*
- Roma, **2/02/2012,** National meeting

How can we take the maximum advantage of the HARPS-N opportunity and play a leading role in the search for exoplanets?

Identification of a broad unifying theme

The theme: **the diversity of the architectures of planetary systems**

1st step - The exploration of the diversity of the architectures of planetary systems

GAPS 2012 - 2017

2nd step – The origin of the diversity of the architectures of planetary systems

GAPS2 2017 – 2023

1st step: The exploration

GAPS - The exploration of the diversity of the architectures of planetary systems

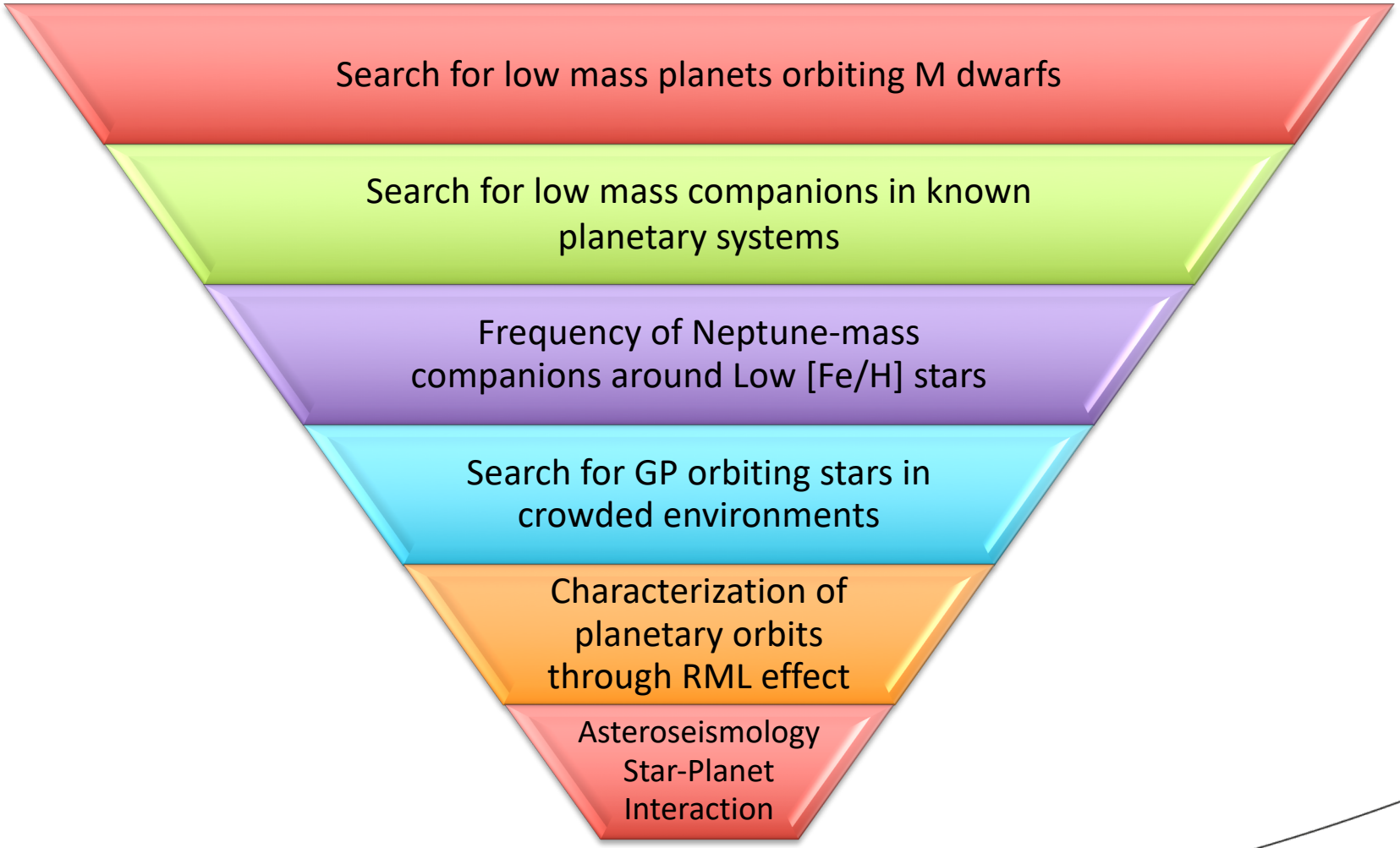
- How the architectures are linked to the environments?
  - Radiations and stellar properties (age, mass, metallicity, activity,..)
  - Environment (presence of additional planets, crowded environments)

Explored both by **searching for new planets** and better **characterization of known systems**

1st step: The exploration

- Frequency and properties of exoplanets around early M dwarfs
- Frequency and properties of exoplanets around metal poor stars
- Impact of the presence of giant planets in wide orbits on the presence of low mass planets in close orbits (scaled Solar System-like)
- How frequently are hot Jupiters accompanied by planets in wide orbits
- Spin-orbit alignement in planetary systems
- Impact of open-cluster environment on frequency and architectures of planetary systems
- How tides shape the orbital properties of hot Jupiters and how they interact with their host stars

How do planetary architectures depend on environments?



2nd step: The origins

GAPS 2 - The origins of the diversity of the architectures of planetary systems

- Planet formation in different environments
  - discs with different mass and metallicity
  - stellar multiplicity
  - crowded or isolated environments
- Planet migration/evolution
  - interactions of planets with the disc and planetesimals,
  - planet-planet dynamical interactions,
  - star-planet tidal interactions

Questions	Effects	Observables
Planet migration path: disc-migration and/or high-eccentricity migration?	• Different orbital parameters (eccentricity and/or obliquity) • Different migration timescales	Orbital parameters of hot and warm Jupiters as a function of stellar age
Do hot and warm Neptunes form and migrate as the Jovian planets or as the small-size ones?	• Different orbital parameters (eccentricity and/or obliquity) • Different mass-radius relations	Orbital and physical (mass, radius, density) parameters of hot and warm Neptunes as a function of stellar age
Does the inward migration stop at a given distance or may it continue till the planet is engulfed by its host star?	• Frequency of hot planets may be a function of stellar age (higher for younger stars) • Chemical stellar enrichment	• Frequency of young hot planets • Higher host star metallicity than the average in stellar associations/clusters
Where do planets form and how do they migrate towards their host star?	Atmospheric composition is enriched by the chemical elements at the formation location and those encountered during migration	Atmospheric composition (C/O and O/H ratios)
How does migration of giant planets affect the formation of small planets, especially in the HZ?	Different architectures of planetary systems in the presence or absence of hot planets.	Higher occurrence of small (HZ) planets in the absence of hot/warm Neptunes and Jupiters

2nd step: The origins (still ongoing)

Broad-band observations: HARPS-N + GIANO

- Search for planets around young stars
- Chemistry of planetary atmospheres
- Search for small planets in systems with long-period massive planets

- Targets from literature and from **TESS**
- Active stars: photometry (**TESS** or ground-based instruments)

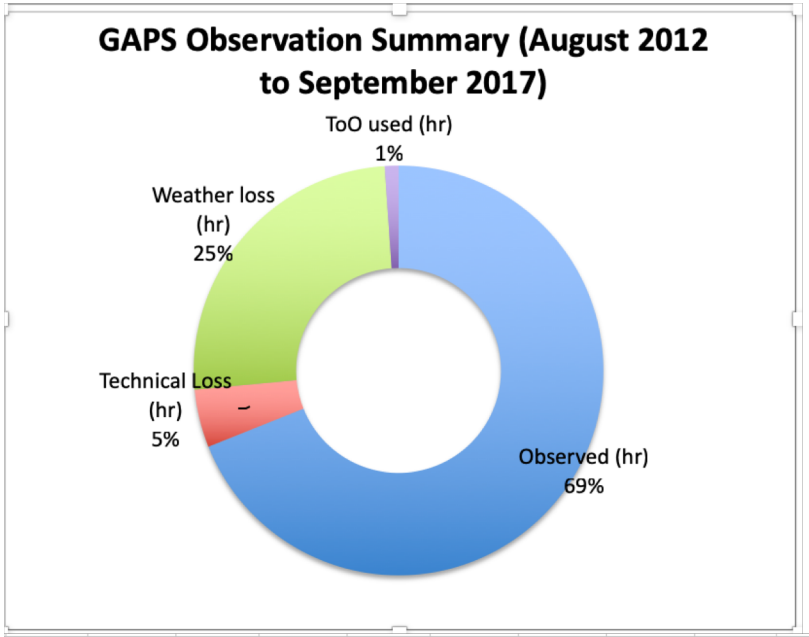
Time allocated to GAPS/GAPS2

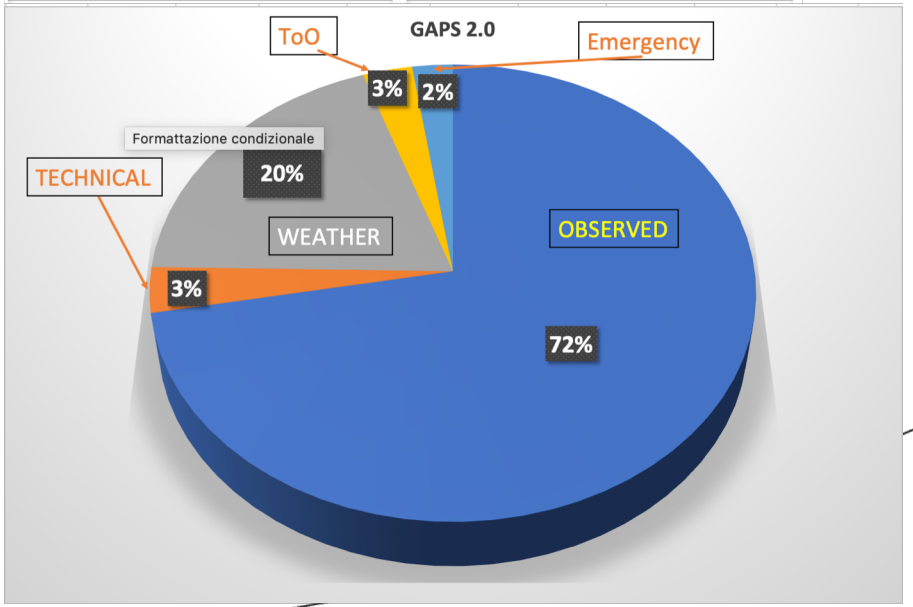
- AOT 26 36n
- AOT 27-35 (4,5yr) 309n (LP status)

+ some Spanish time (HADES MoU with ICE & IAC for the M dwarfs program)

- *AOT 36 28 n*
- *AOT 37-46 (5yr) 340n (LP status)*

Up to AOT43 →





Team organization

- **Annual rotation of the chair of the board**
- **Inclusive project**
- **Internal review of the results**
- **Communication and outreach**

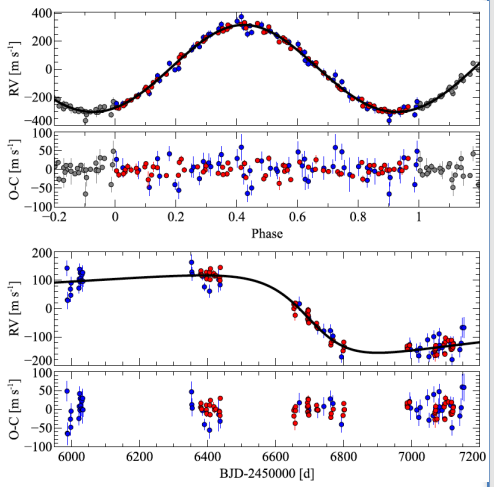
- **Nov/2012**
  53 INAF/associates
- **Feb/2017**
  78 INAF/associates
- **Oct/2021**
  93 INAF/associates

MoM with EXOTEAM Spanish consortium *(observations, analysis, observing time, targets, publications…)*

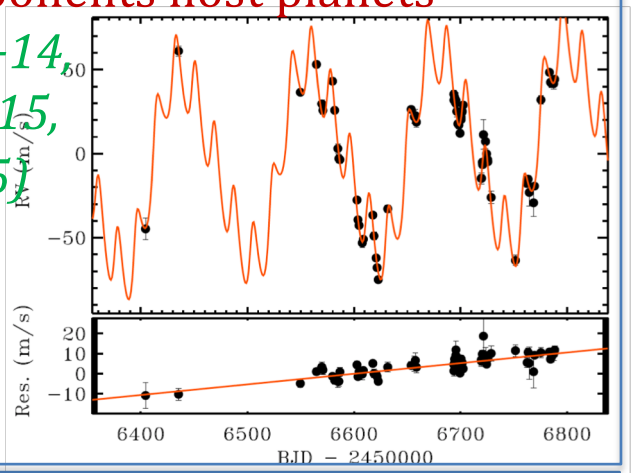
Collaboration with **GTO** (*nights exchanges, specific targets*), share of time with other GO programs

Selected results (GAPS1)

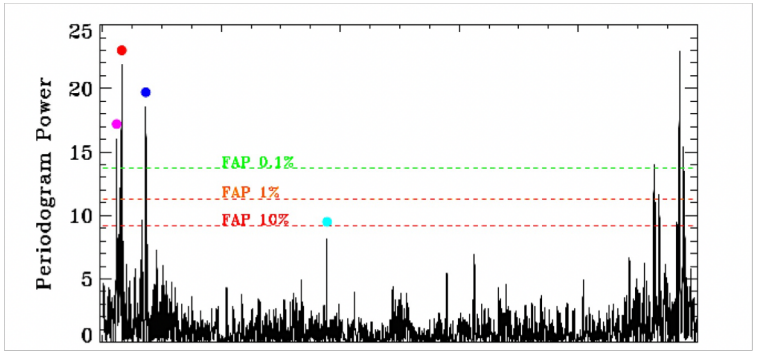
First planetary system in an open cluster *(Malavolta+16)*



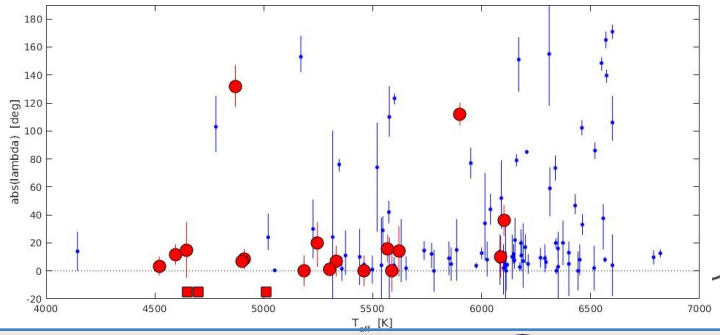
First case of binary system on which both components host planets *(Desidera+14, Damasso+15, Biazzo+15)*



A planetary system around an early M star *(Affer+16)*

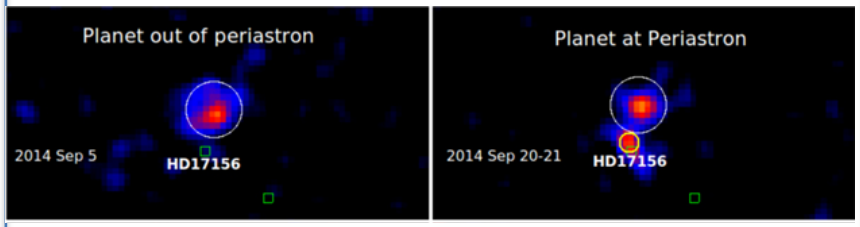


System spin-orbit alignment through Rossiter effect *(Covino+13, Esposito+14,17 Mancini+16)*

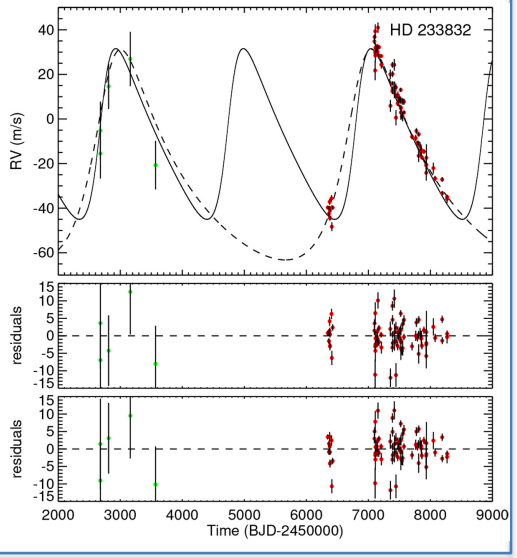


Selected results (GAPS1)

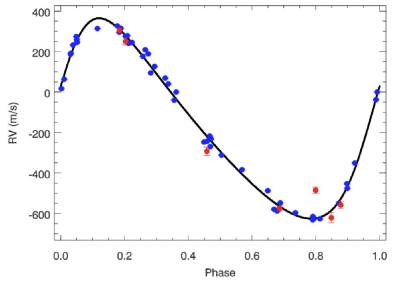
Star-planet interaction in a highly eccentric planetary system *(Maggio+15)*



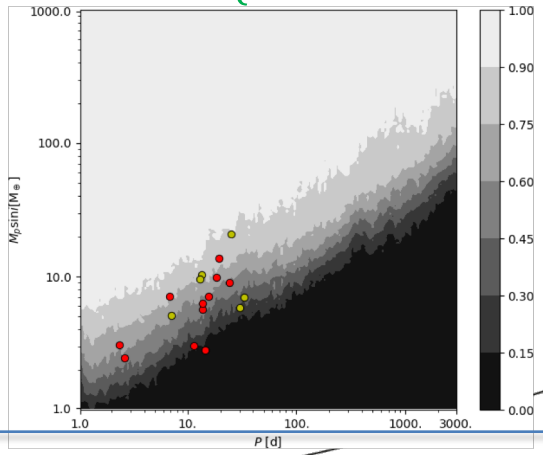
A hot jupiter around a metal-poor star *(Barbato+19)*



A substellar companion around a K giant star with quasi-simultaneous HARPS-N and GIANO measurements* *(Gonzalez-Alvarez+17)*

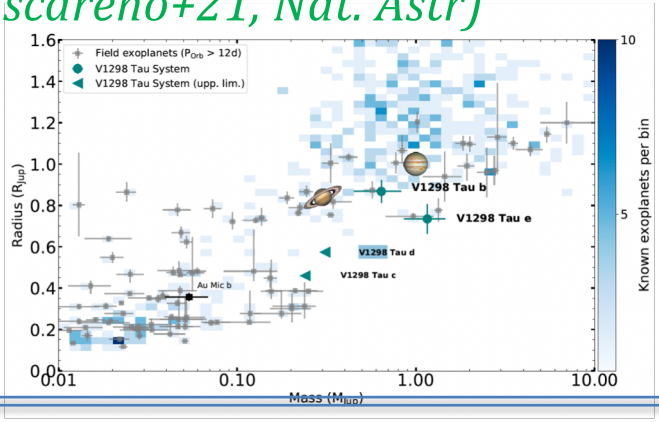


Planetary occurrence rates around early-M dwarfs *(Pinamonti+21)*

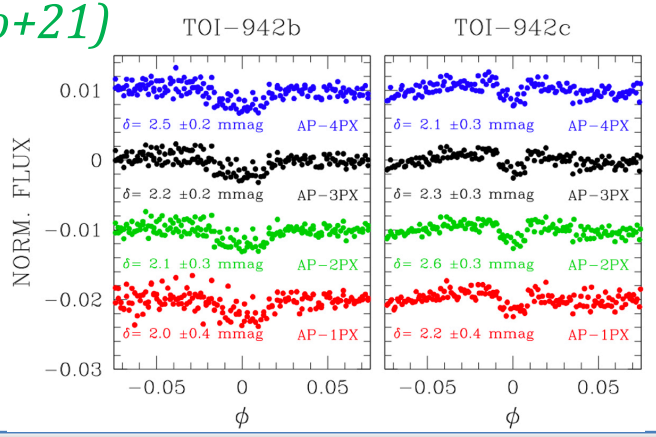


Selected results (GAPS2)

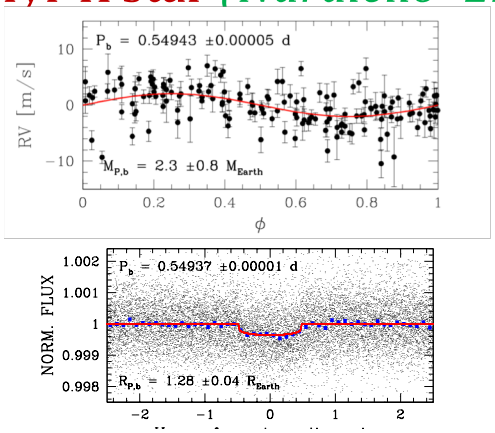
A planetary system around the 20Myr starV1298 Tau *(Suarez Mascareno+21, Nat. Astr)*



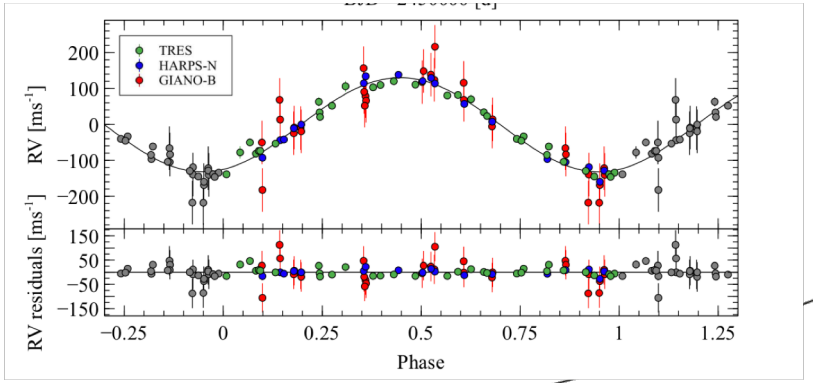
A pair of hot-Neptunes orbiting the young star TOI-942 (50My) *(Carleo+21)*



A short-period super-Earth around a 500Myr K star *(Nardiello+22)*

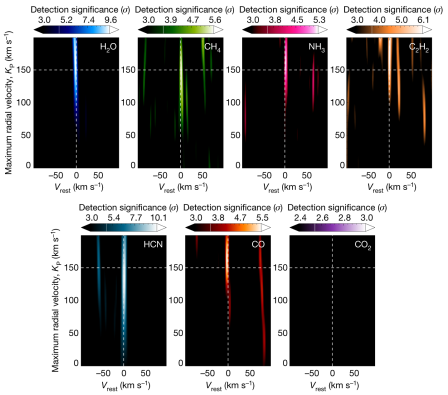


Confirmation of a planet around a Hyades member *(Carleo+20)*

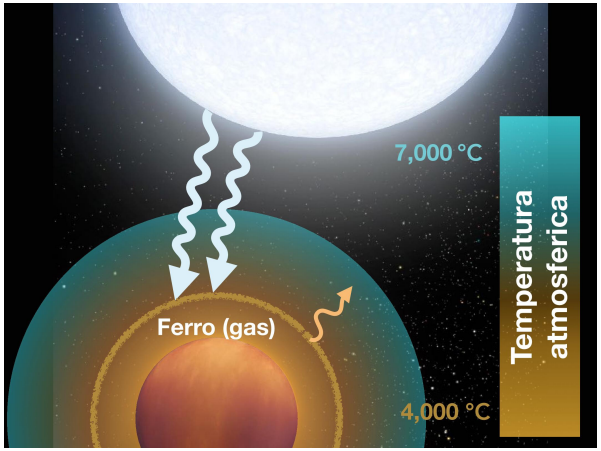


Selected results (GAPS2)

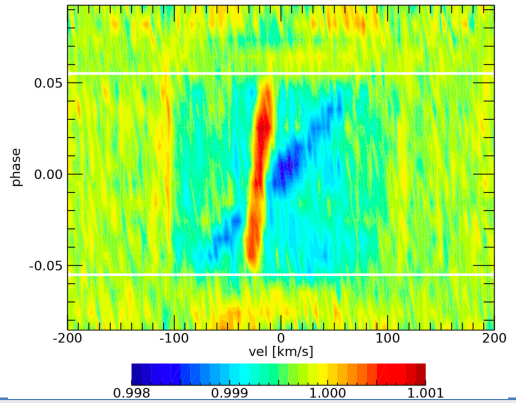
Five carbon and nitrogen bearing species in a hot giant planet atmosphere *(Giacobbe+21)*



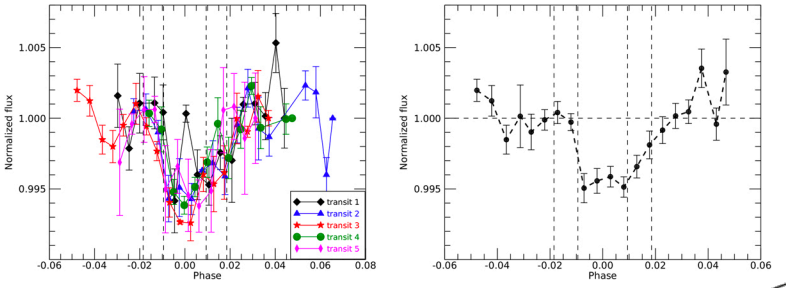
Neutral Emission Lines from the dayside of Kelt9b *(Pino+20)*



Atmospheric Rossiter-Mc Laughlin effect of Kelt9b *(Borsa+19)*



The extended helium atmosphere of HD 189733 b *(Guilluy+20)*



GAPS

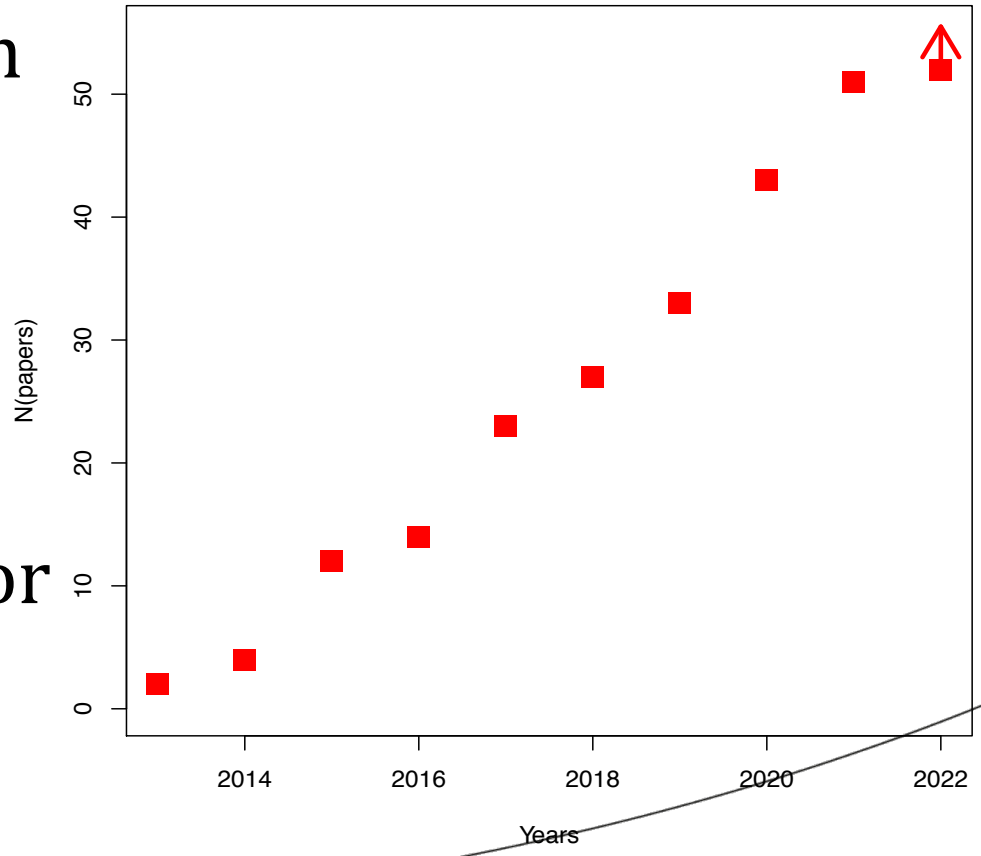
Some answers

- Moderately frequent super-Earth planets at small separation around early M dwarfs. Often multiple systems
- Lack of hot Neptunes and Super-Earths around metal-poor stars, frequency of warm neptunes similar to solar-type stars
- No paucity of planets in open clusters
- Possible signatures of dynamical interactions in the architectures
- Negative impact of the presence of outer giant planets on inner low-mass planets
- Decisive role of tides in shaping the properties of close-in planets revealed by eccentricity +spin-orbit determination
- Erratic nature of SPI, role of planet eccentricity?
- The frequency of giant planet around young stars is comparable with that of older stars

@October 2021

- 51 published refereed papers +1 in press
- 1 submitted
- Several in preparation
- 1101 citations
- 18 PhD Thesis

- 22 new planets
- Other confirmations or refutations



Not only papers!

- **Critical mass,** Capability to assume **leading roles** at an international level
- Sviluppo di **metodi originali** per la ricerca dei pianeti extrasolari
- Cohesive and inclusive **community**
- Investment in **young** people
- **Usage** of other instruments (HARPS, ESPRESSO,…)
- Synergy with **Gaia**, **SPHERE and SHARKs**
- Preparation for **future instrumentation**

The future

GAPS 2 observations will be completed mid-2023 – analysis and papers will last 2-3 years more

We are starting a braimstorming for a possible GAPS 3

- Next INAF-HARPS-N agreement
- On the way to PLATO/Ariel missions and HIRES@ELT
- Where our experience directs us to the study of ever smaller and more temperate planets