
INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

# **GAPS2** (to GAPS3 **?**)

**G**lobal
**A**rchitecture of
**P**lanetary
**S**ystems

a common effort to study the diversity of **planetary systems**

born thanks to the opportunity to have **HARPS-N** at the TNG

# GAPS 1-2

- **1st step - The exploration of the diversity of the architectures of planetary systems**
  **GAPS 2012 - 2017**

Planets in open clusters, binary systems, M-dwarf stars, RML orbit alignment, high eccentricity system, SPI

- **2nd step – The origin of the diversity of the architectures of planetary systems**
  **GAPS2 2017 – 2023**

https://theglobalarchitectureofplanetarysystems.wordpress.com

# targets of **GAPS2**

- Search for planets around **young** stars
- Chemistry of planetary **atmospheres**
- Transiting **Neptunes** in the zone between larger gaseous planets and smaller rocky planets

# Young Objects (YO): Objectives

- Monitoring of young (<20 Myr) and intermediate age (<700 Myr) stars to search for **hot Jupiters in formation** or at the **early stage** of their evolution within the timescales of migration
- Confirm/Retract the **apparent high frequency** of hot Jupiters around very young stars (Donati+2016, Yu+2017)
- Target sample:
  - Known planet candidates from RV surveys
  - Blind search
  - Transiting candidates (TESS, K2)

**After ~4 yr of GAPS-YO observations + TESS contribution**

- **no evidence of high frequency of hot Jupiters around young stars** (e.g.: rejection of V830 Tau, Damasso+2020)
- RV-based discovery is heavily hampered by **stellar activity** (up to tens of time larger than the planet signal)

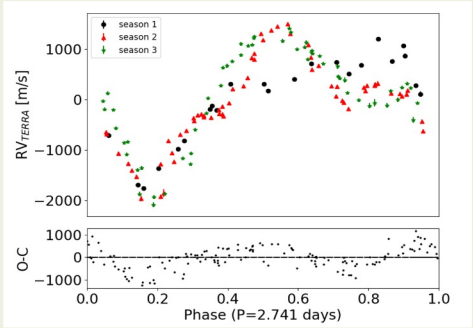
# Young Objects (YO): Strategy and analysis

- Priority to **young transiting planets** with ***high cadence sampling***, mandatory to provide suitable constraints to our modelling tools (GPs) to ***mitigate activity*** in the RV time series
- Optimization of **RV extraction methods** (e.g. Di Maio+in preparation)
- **Simulations** to improve the robustness of our results (e.g. Damasso+2020)
- Dedicated studies on the **stellar properties**:
  - ***Age*** estimation (e.g. Carleo+2020)
  - Stellar parameters and ***abundance*** determination (e.g. Baratella+2020)
  - Stellar ***activity*** (e.g. Maldonado+2022)
  - Star-planet ***interaction*** (e.g. Maggio+2022)

# Young Objects (YO): Results

## Is V830 Tau b really there?

Three different RV extractions and modelling **failed** to recover the claimed HJ. RVs dominated by the rotation.

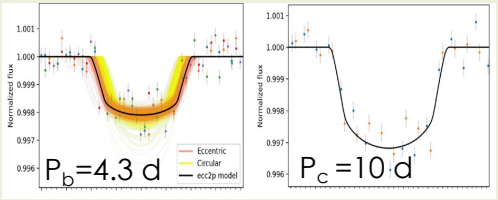



(Damasso et al. 2020)

## Hot Neptunes around TOI-942

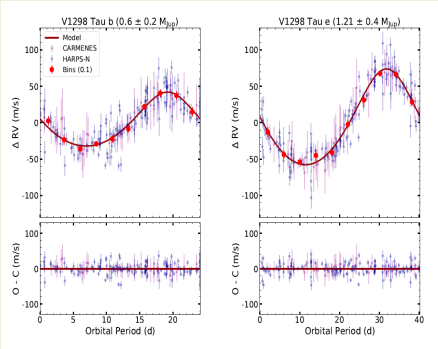
50 Myr old K star hosting 2 transiting **hot Neptunes** from TESS. Mass upper limits provided.

A quick evaporation is expected for planet b.




(Carleo et al. 2020)

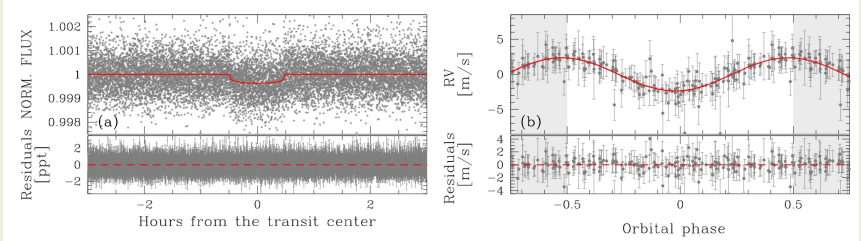
## The benckmark system V1298 Tau




11 Myr old K star with 4 transiting planets. Joint **RV+LC model** Mass detection for planets b & e. Unexpected high density

(Suarez-Mascareño et al. 2022)

## The youngest USP rocky planet

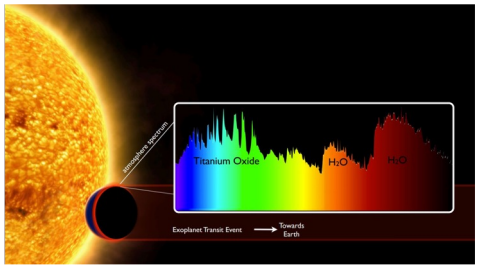


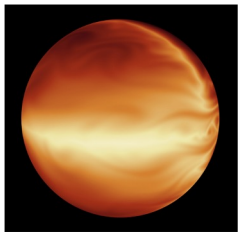

(Nardiello et al 2022)

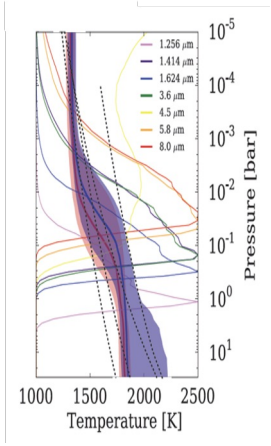
TOI-1807:
Age = 300 Myr
P = 0.55 d, R = 1.37 R⊕, M = 2.72 M⊕

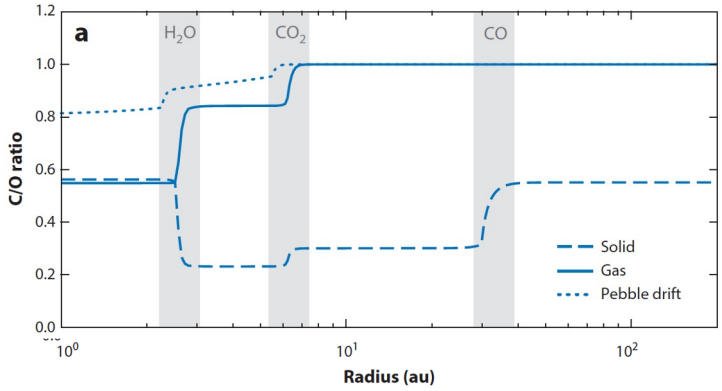
# atmospheres: science cases

- investigate the **chemico-physical properties of hot giant planet's atmospheres**: composition, clouds, P/T profiles, dynamics, effects of disequilibrium chemistry (experience for future atmospheric characterization of smaller and cooler planets with ELT)

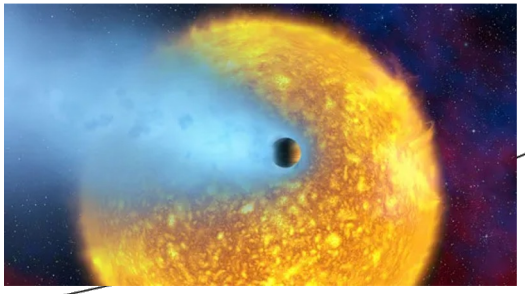




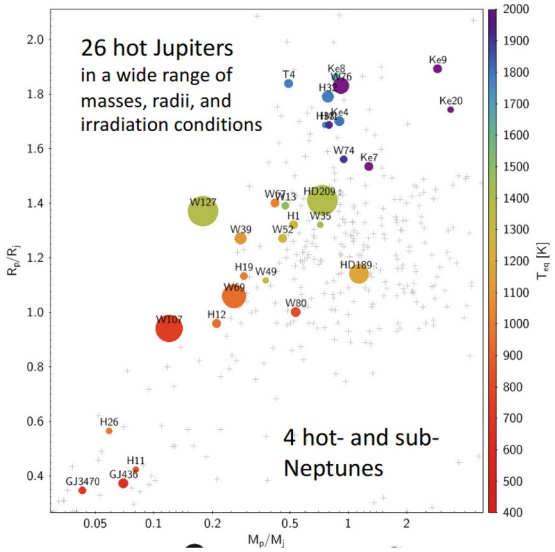

- put constraints on models of giant planet formation and migration from **atmospheric metallicities** and elemental abundances (e.g., C/O ratio)

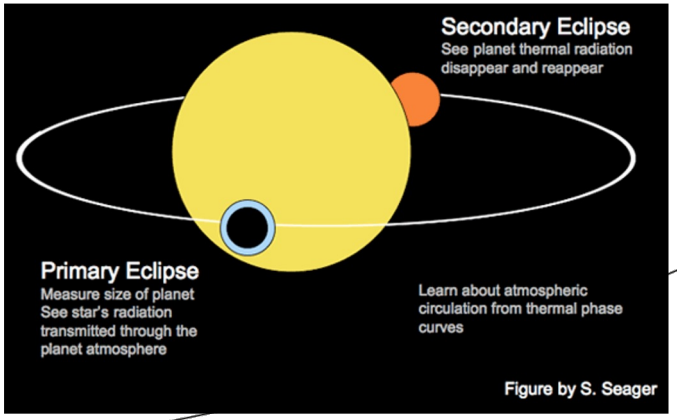


- probe atmospheric **escape / photoevaporation** (hence planet evolution due to atmospheric mass loss and star-planet interactions)

# atmospheres: methods

- **Observables**: chemical species such as $H_2O$, CO, $CH_4$, $NH_3$, HCN in **the NIR** and Na, Fe, TiO in **the VIS** channel
- **Data:** Multiple observations (>=3) of a sample of 26 hot Jupiters and 4 hot Neptunes through GIARPS transmission spectroscopy; +7 HJs through emission spectroscopy
- **Techniques**: cross-correlation of the observed spectra with theoretical atmospheric models; sophisticated tools (PCA, MolecFit, etc.) to remove instrumental, stellar and telluric effects



# atmospheres: selected results

**Atomic species in the optical (HARPS-N)**

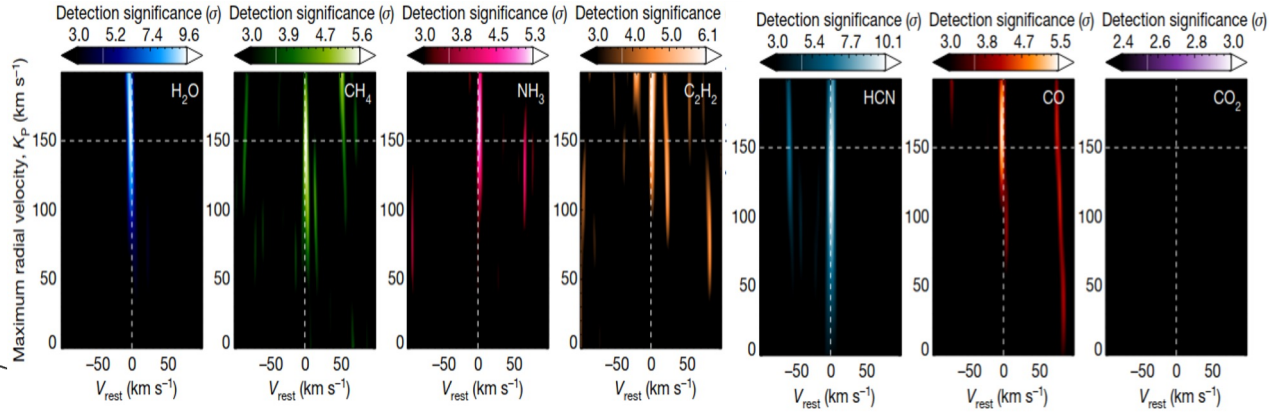
- FeI at the terminator of KELT-9b (Borsa+ 2019, A&A); FeI and inverted P/T profile in the dayside of KELT-9b (Pino+ 2020, ApJL): first observation of the "atmospheric" Rossiter effect + first detection of iron in a planet dayside
- FeI and atmospheric dynamics in the terminator of KELT-20b (Rainer+ 2021, A&A); FeI, FeII, CrI and inverted P/T profile in the dayside of KELT-20b (Borsa+ 2022, A&A)

**Molecular species in the nIR (GIANO-B)**

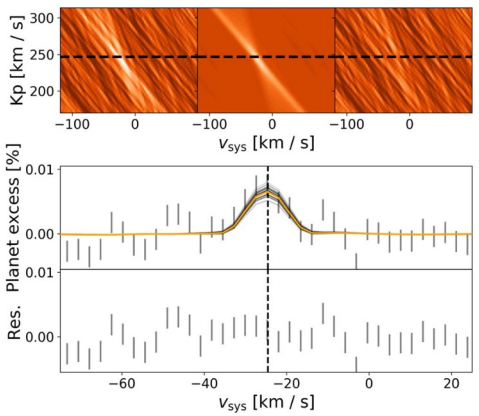
- First simultaneous detection of six molecular species ($H_2O$, CO, HCN, $CH_4$, $NH_3$, $C_2H_2$) and C/O~1 in an exoplanetary atmosphere (HD-209458b, Giacobbe+ 2021, Nature)
- Five and three molecules detected in the atmospheres of WASP-69b (Guilluy+ subm.) and WASP-80b (Carleo+ subm.)

**Atmospheric escape/evaporation (GIARPS)**

- HeI in the atmosphere of HD-189733b (Guilluy+ 2020, A&A) through a novel approach to account for stellar activity
- Hα and Hβ in the atmosphere of WASP-33b (Borsa+ 2021, A&A)
- Unexpected non-detection of HeI in the atmosphere of WASP-80b (Fossati+ 2022, A&A)



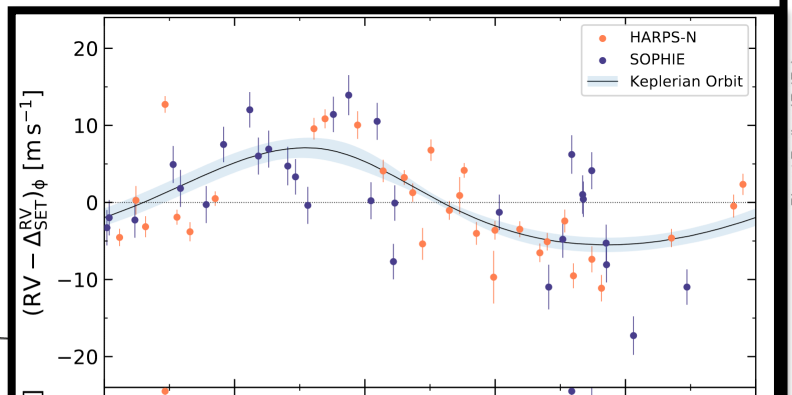

Giacobbe+ 2021

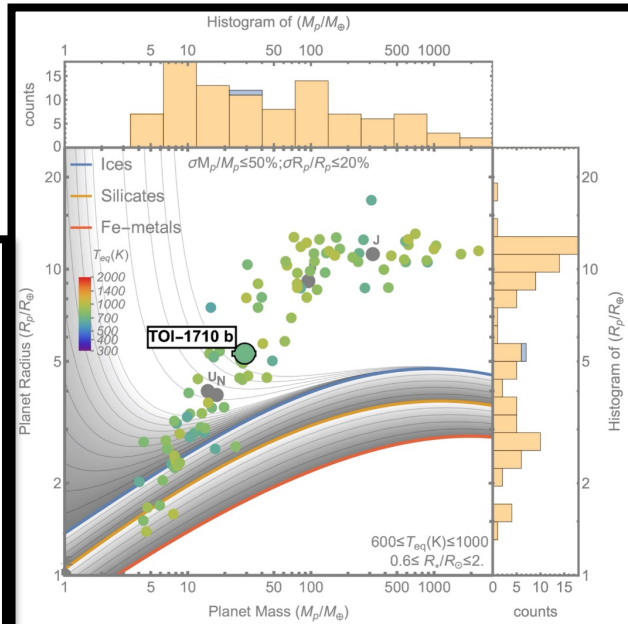



Pino+ 2020

# transiting NEP

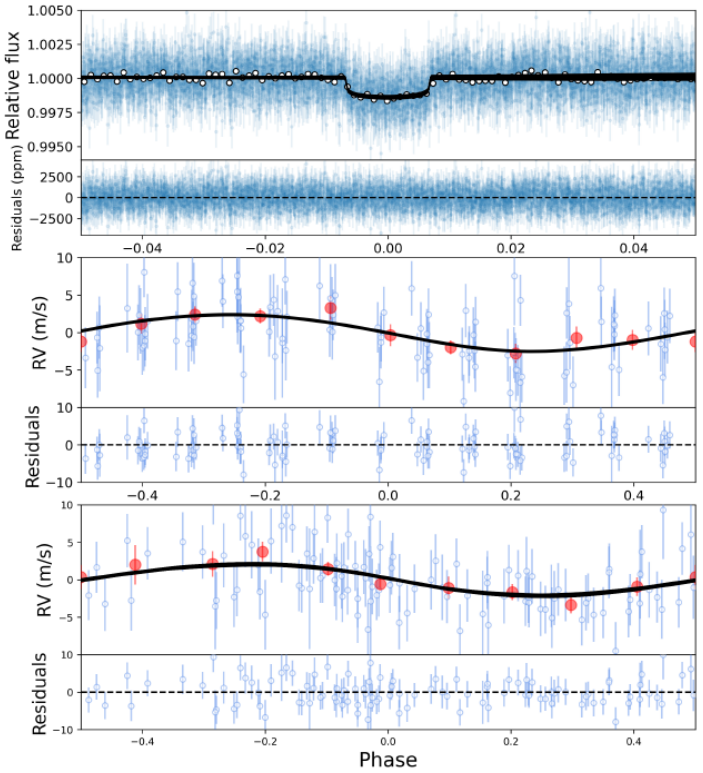
- Hot and warm **Neptunes** formation and migration
- similarity or **difference** from Jovian planets or small-size ones
- different orbit **eccentricity**



# Neptunes found

## TOI-1422b (and c, not transiting)



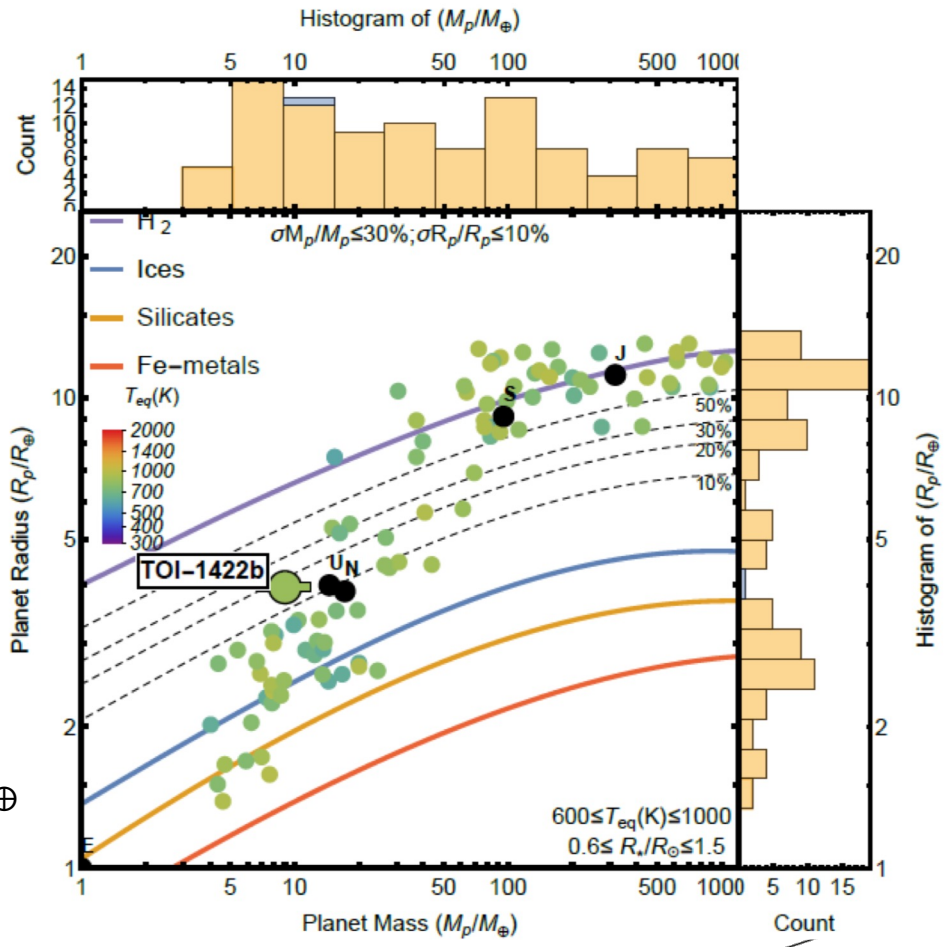

$P_b$= 12.9972(6) d; $R_b$= 3.96 ± 0.11 $R_\oplus$

$K_b$= 2.5 ± 0.5 m/s; $M_b$= 9.0 ± 2.0 $M_\oplus$

$\rho_b$= 0.79 ± 0.11 g/cm$^3$ (like Saturn)

$P_c$= 29.29(2) d; $K_c$= 2.4 ± 0.4 m/s;

$M_c \sin(i)$= 11.1 ± 2.0 $M_\oplus$




Naponiello et al. 2022, A&A subm

# From the start: **TNG** to GAPS

- GAPS is the (*main*) result of the HARPS-N operation at the INAF TNG (2012)
- The GAPS collaboration gathered 99% of the Italian *exo-ficionados* in order to get the most out of this opportunity

- **It has happened**
- **72/80 n/yr (LP)**

# The **People** of GAPS

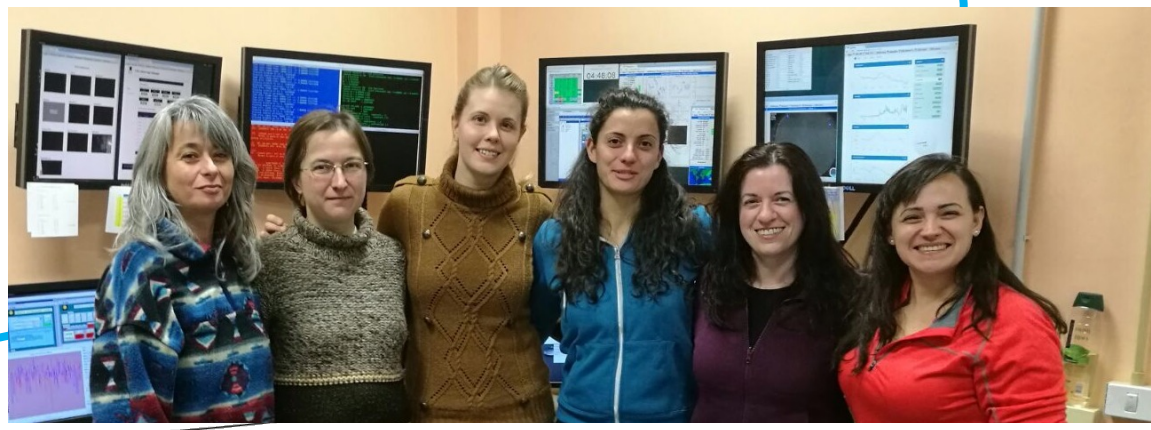
(the *main* result)

- 93 **INAF** personnel / associates (2021)
- 78 in 2017
- 53 in 2012

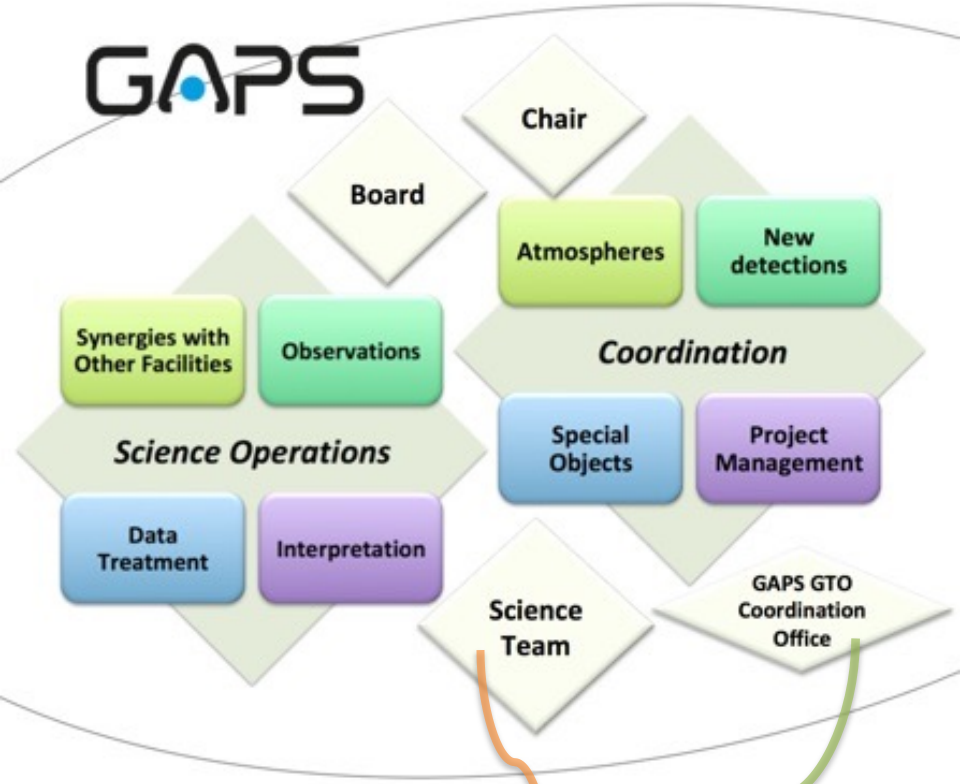
- 11 external institutes (univ, ext)
- 18 PhD Thesis

**Young** people entered and tenured :-)

Know-how
**increased** to
high level



# GAPS2 organization




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

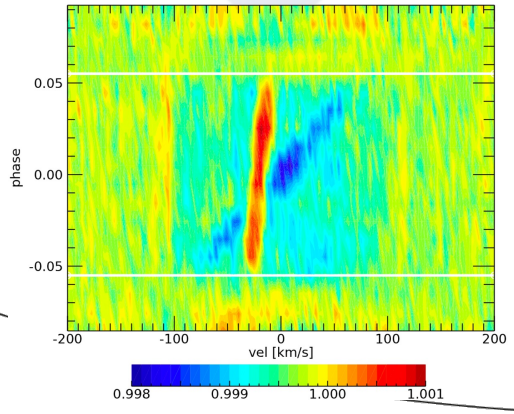
**MoM with EXOTEAM Spanish consortium** *(observations, analysis, observing time, targets, publications...)*
Collaboration with **GTO** (*nights exchanges, specific targets*), share of time with other GO programs

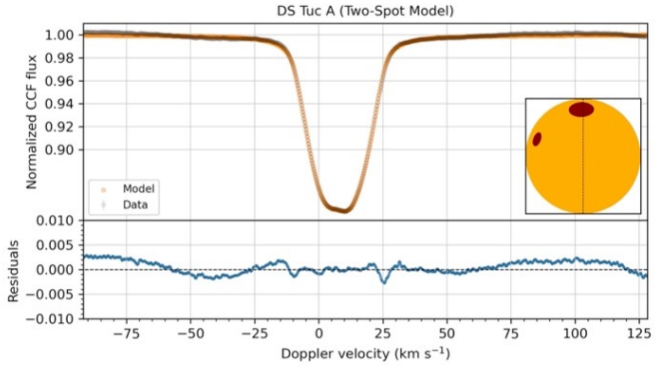
# leadership

- GAPS(2) **is** INAF led

- People from GAPS(2) gained leading roles at **international** level

- **Original** analysis methods developed



# from **GAPS** to TNG (nighttime)

- **GIARPS** (GIAno+haRPS)

simultaneous spectra

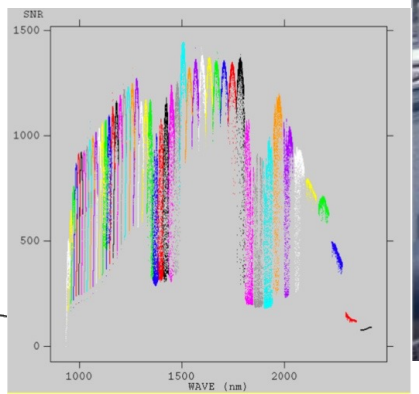
from 0.38 to 2.45 μm

# **from** GAPS to TNG (daytime)

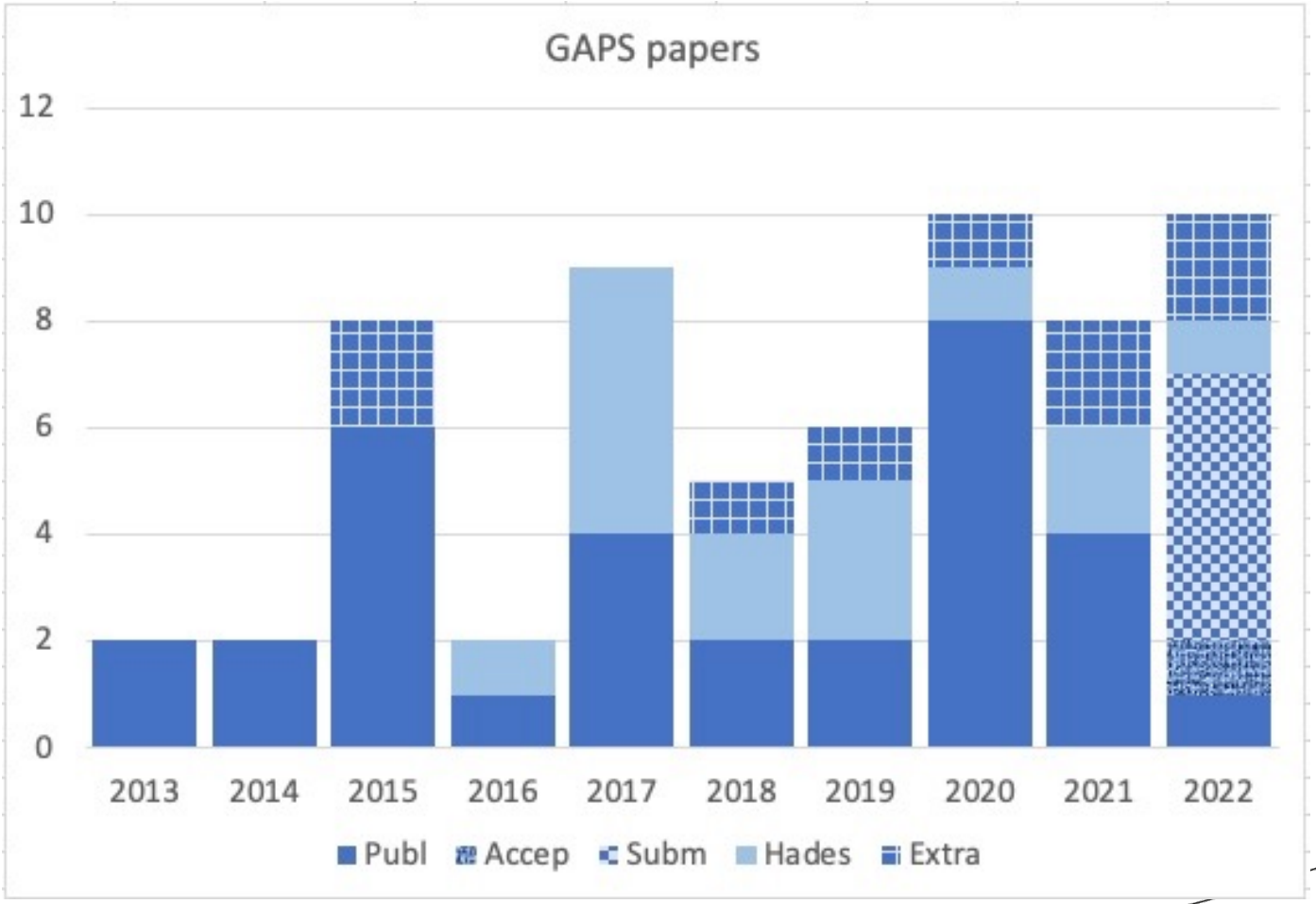
- **LOCNES**

an **infrared** companion to LCST (looking at Sun spectrum since 2015, every sunny day)

Sun activity observed **as-a-star**



# from GAPS to **PAPERS**



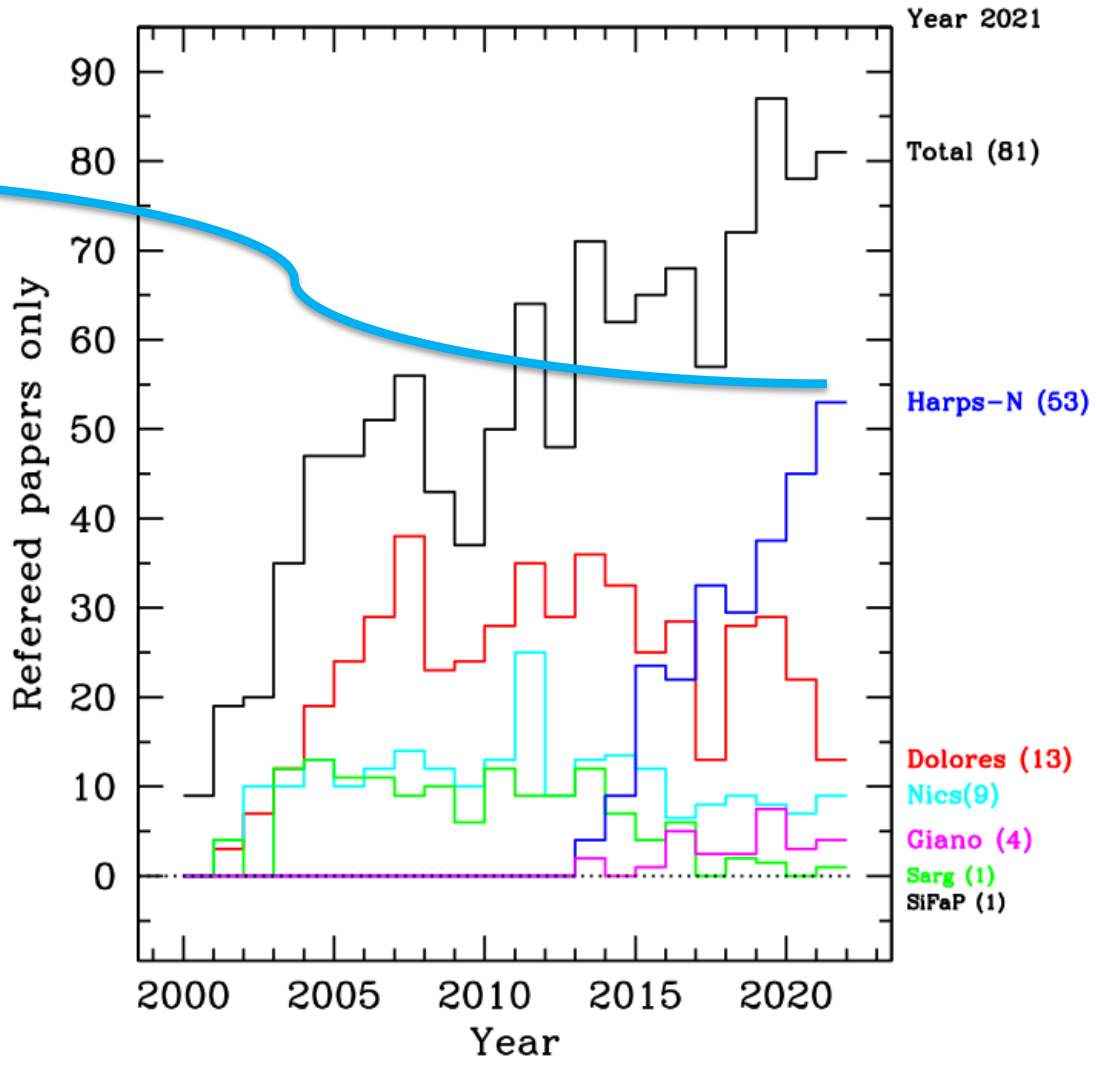
# from TNG to JOURNAL

HARPS-N: not only GAPS

**GTO ***

(but also others)

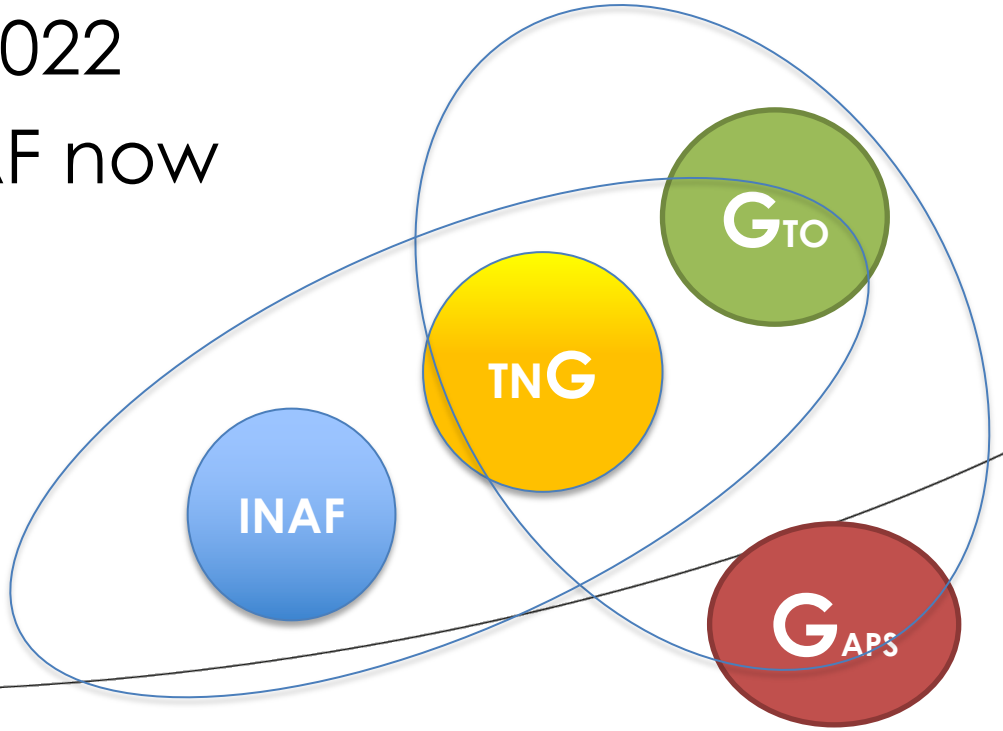
* CH+US+IT+UK (80 n/yr)



# GAPS3, it is time.

- GAPS-2 ends Apr 2023
- GAPS3 ready by Summer/Fall 2022

- GTO-2 ends Aug 2022
- negotiation w/INAF now



# theNEXT**G** objectives

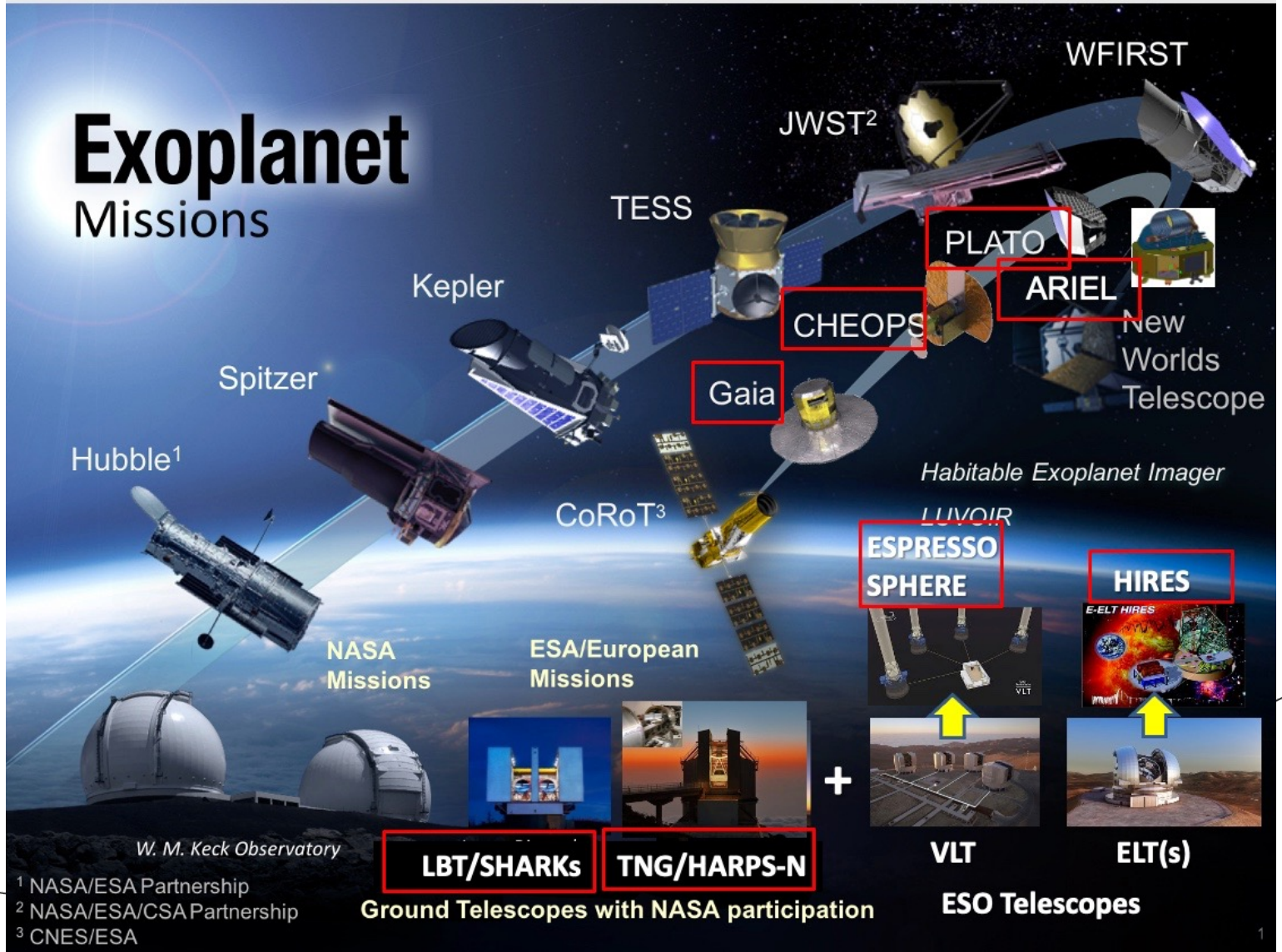
- **atmospheres**, a success for GAPS2
- small planet mass for **TESS** and **CHEOPS**
- mass determination for **JWST** and **Ariel**
- synergies with **Gaia DR3**, planets in close orbits to complete systems architecture, BDs from DR3 (~Solar System with DR4 )
- **young** planets, possibly multiplanet
- **PLATO** follow up (2026+)

- still at a ***brain storming*** level …

# theNEXTG fellows

- **ground based**
- [HARPS-N, SHARKS, ESPRESSO, SPHERE+, ANDES]

- **spacecrafts**
- [ARIEL, CHEOPS, GAIA, PLATO, TESS]



# theNEXT**G** *critical* points (**risks**)

1) NEED for large **number** of yearly nights for many years (science driver)

2) NEED **NEW AGREEMENT** with HARSP-N with closer collaborations **Gaps+Gto** (organization driver)

3) NEED for **funds** (life driver)

4) efforts with **dissemination**, more effort

# theNEXT**G** ***mitigation** of risks*

1) large **number** of nights → INAF **vision** /LLP

2) collaborations **G+G** → we're **working** on this, also a mitigation for 1)

3) funds → wait for GTO/GO/LG/MG grants (Micela/Sozzetti/Damasso/..)

GAPS

# thank you

rintaH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