The Origins: a new frontier for GIARPS

A.S. Bonomo on behalf of the

GAPS-2 Team

Workshop TNG, Padova, Museo Diocesano

3 March 2017

GAPS-I (2012-2017): exploration of the diversity of the architectures of planetary systems

S. Desidera's talk

We have found an astonishing diversity in the architectures of planetary systems as well as in exoplanet orbital and physical parameters.

Now we are ready for the next step:

What is the origin of this diversity?

GAPS

GAPS-2 (2017-2022): The Origins

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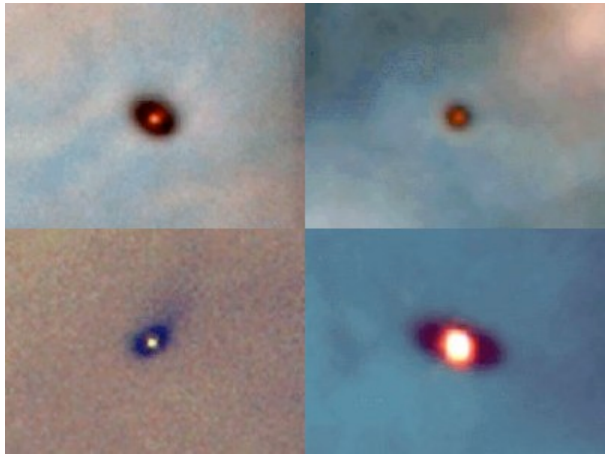
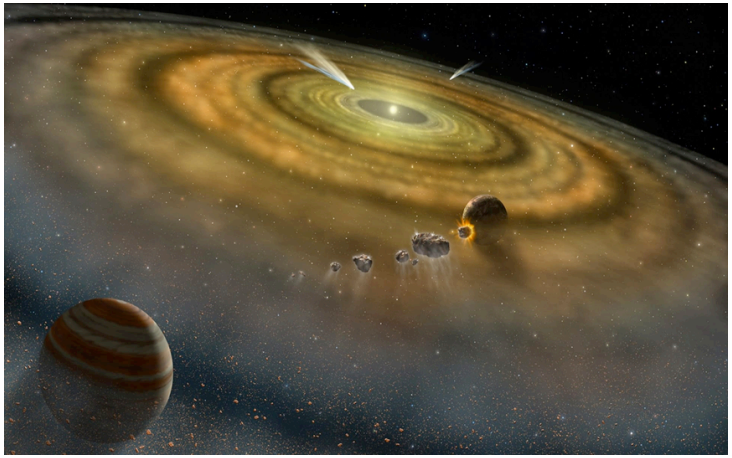


Planet formation in different environments
(discs with different mass and metallicity, stellar multiplicity, crowded or isolated environments, etc.)



Planet migration/evolution
(interactions of planets with the disc and planetesimals, planet-planet dynamical interactions, star-planet tidal interactions)

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GAPS-2 (2017-2022):
The Origins

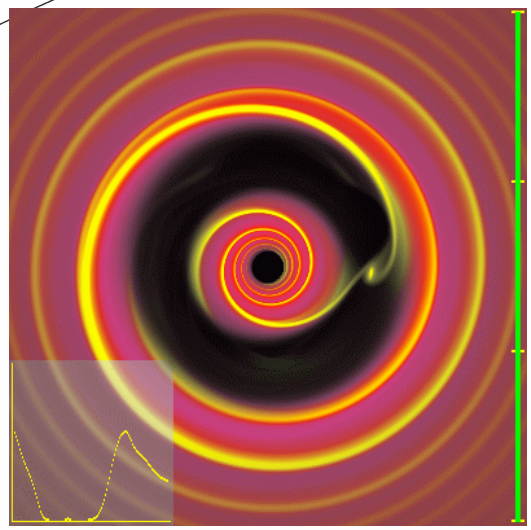
Now we are ready for the next step:

What is the origin of this diversity?

We have identified some crucial issues for the understanding of the origins of planetary systems that we may address with GIARPS with a 5-yr long-term program !

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

GAPS

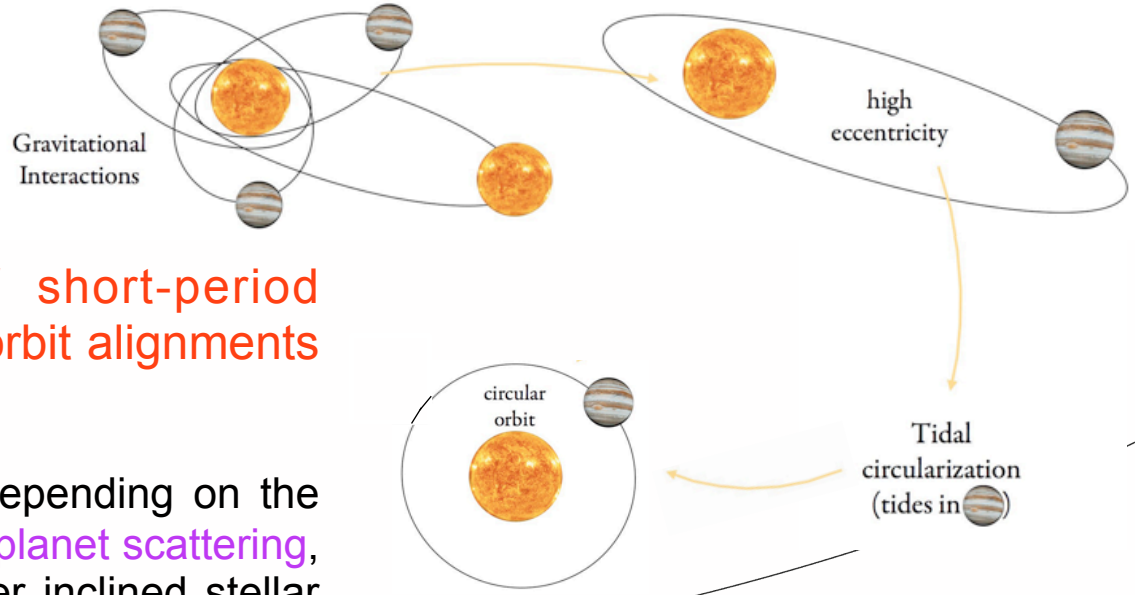


Hot Jupiters (HJs) are generally thought to be formed beyond the water-ice line, where solid material is abundant due to ice condensation, and then migrate towards their stars

Smooth disc migration

small eccentricities (e<0.1) and spin-orbit alignments
(unless the disk was primordially misaligned)

Timescale ~ 1-10 Myr



High-eccentricity migration

circular (eccentric) orbits of short-period (long-period) planets, both spin-orbit alignments and misalignments

Timescales ~ 10 Myr - 1 Gyr, depending on the high-e excitation mechanism (planet-planet scattering, Kozai-Lidov perturbations by an outer inclined stellar or planetary companion, secular chaos)

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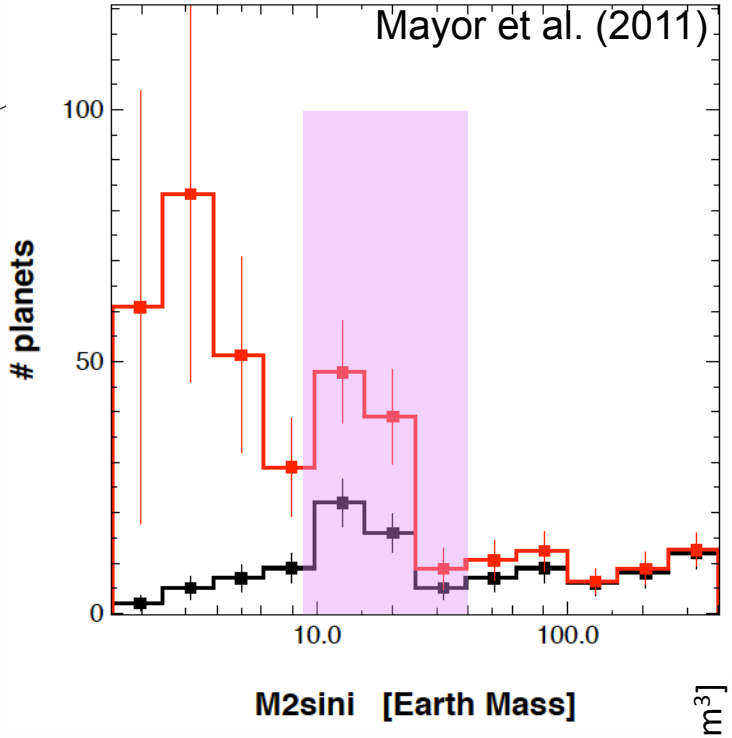
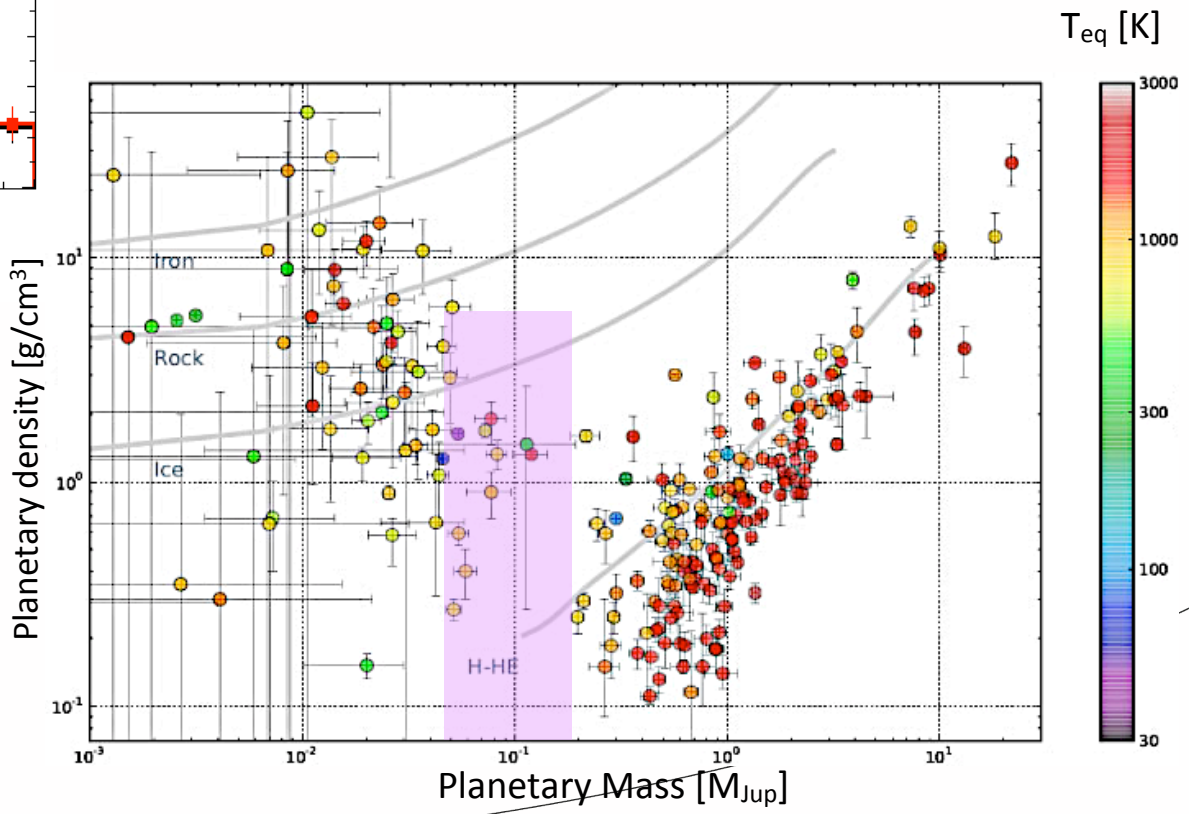
HARPS planet occurrence rate



M_p~15-60 $M_\oplus$ R_p~2.5-6.0 $R_\oplus$

Possible evolution as rocky planets in ultra-short period orbits for atmospheric mass loss due to high stellar XUV flux



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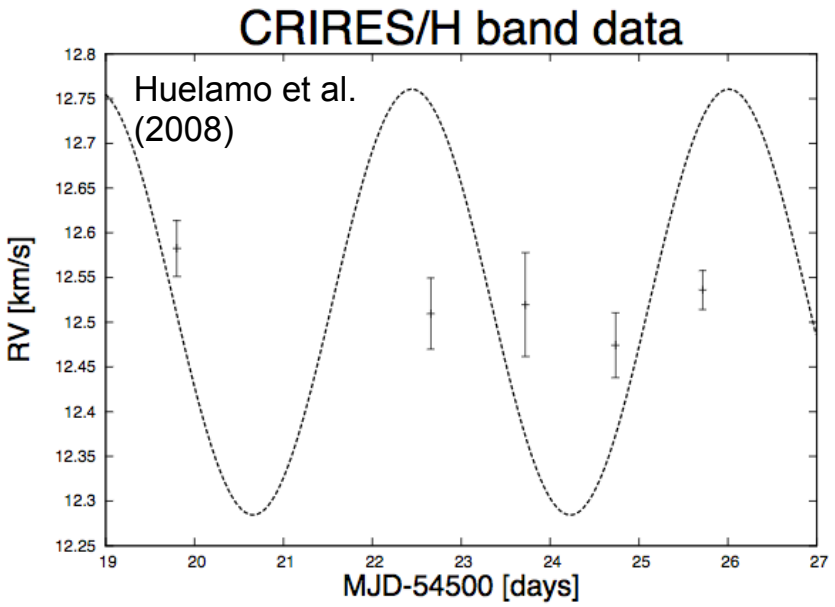
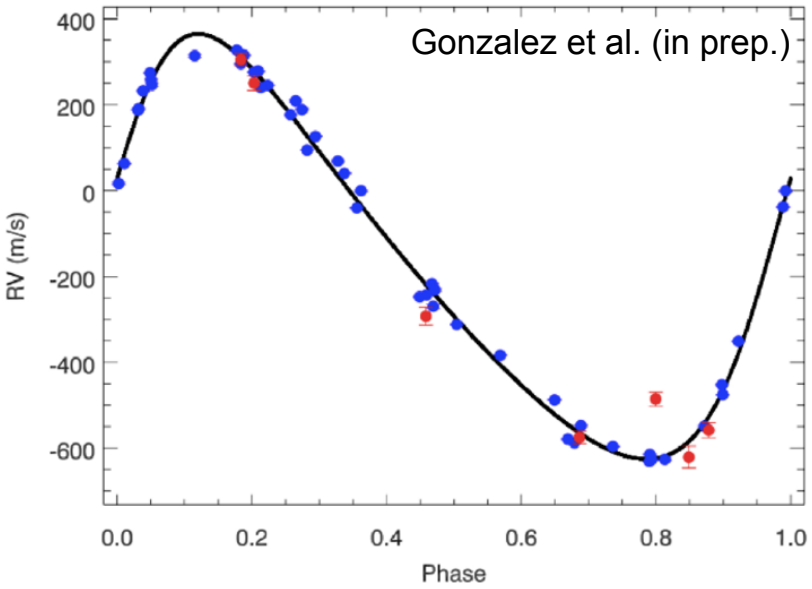
Search for and characterization of young hot/warm planets with GIARPS

The limiting factor is the stellar noise: young stars are very active but...
...**stellar magnetic activity** is a colored phenomenon while **Keplerian signals** are achromatic!



nIR RVs of TW Hydrae showing no variations of a HJ announced with optical RVs



blue circles: optical/HARPS RVs
red circles: nIR/GIANO RVs

GIARPS is a unique instrument to obtain high-resolution spectra from optical to nIR thus enabling us to identify the origin of RV signals (stellar or planet-induced variations?)

Search for and characterization of young hot/warm planets with GIARPS

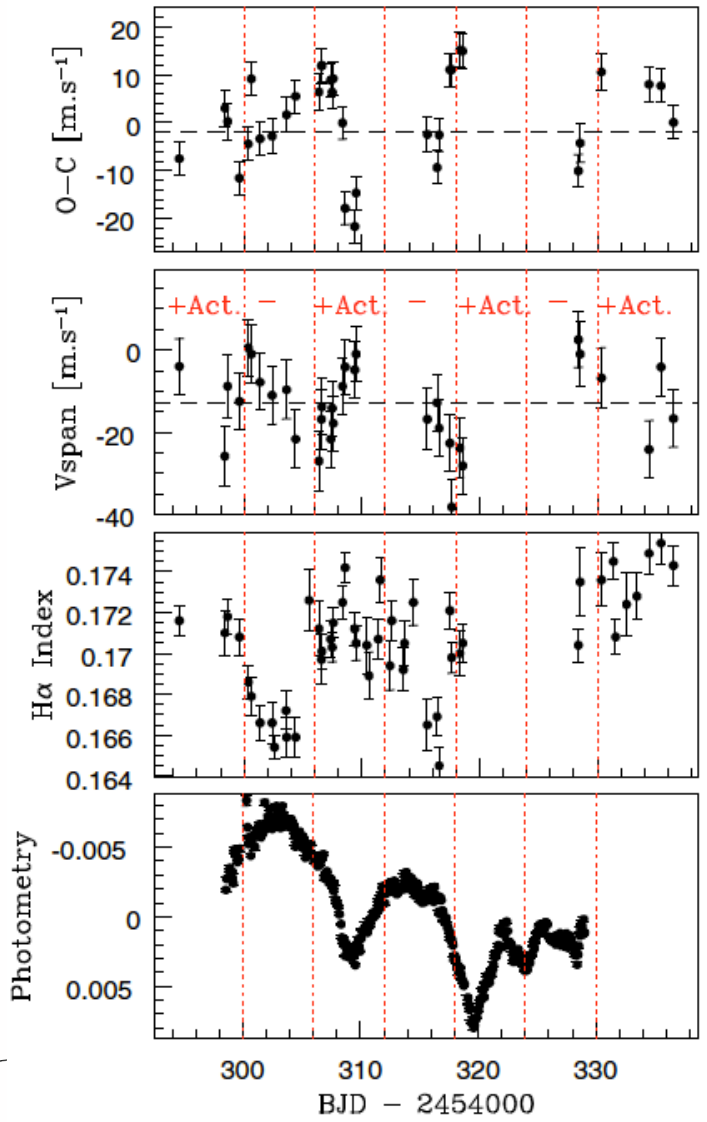
The limiting factor is the **stellar noise**:
young stars are very active but...

► activity indicators (logR'$_{HK}$ and Hα indices, CCF bisector and FWHM, etc.) and ground-based photometry (SLN, APACHE, etc.) further help in disentangling between stellar and planetary signals

► sophisticated techniques such as Gaussian Processes are very efficient to filter out stellar activity variations and allow us to detect planetary signals with amplitudes 5-10x lower than stellar noise

► **GAPS: the 2nd world's best team** in discovering planetary signals embedded in stellar noise for an international blind test competition
(Dumusque, Borsa, Damasso, et al. 2017)

Boisse et al. (2009)



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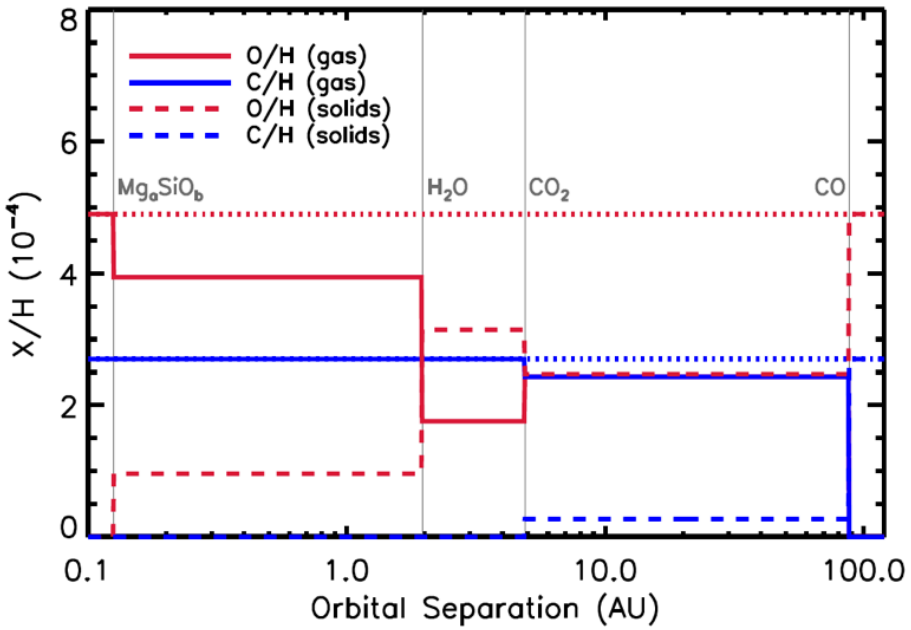
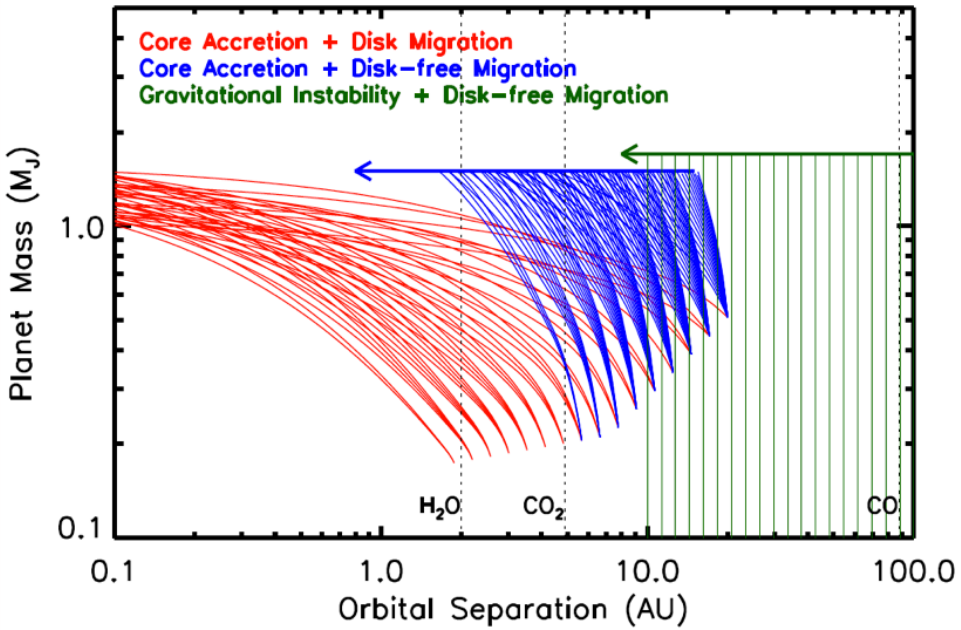
Where do planets form and how do they migrate towards their host star?	Atmospheric composition is enriched by the chemical elements at the formation location and those encountered during migration	Atmospheric composition (C/O and O/H ratios)

Atmospheric composition as an imprint of planet formation location and migration

Madhusudhan et al. (2014)





$[C/O]_{planet} > [C/O]_{star}$ ➪ the planet was born beyond the water-ice line

$[C/O]_{planet} > [C/O]_{star}$ AND $[O/H]_{planet} < [O/H]_{star}$ ➪ disk-free (i.e. high-e) migration

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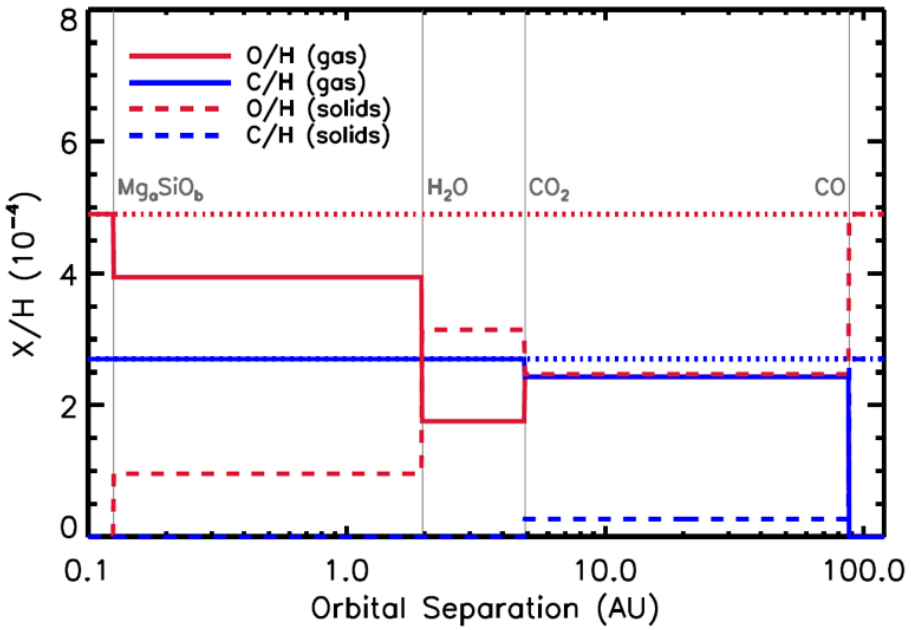
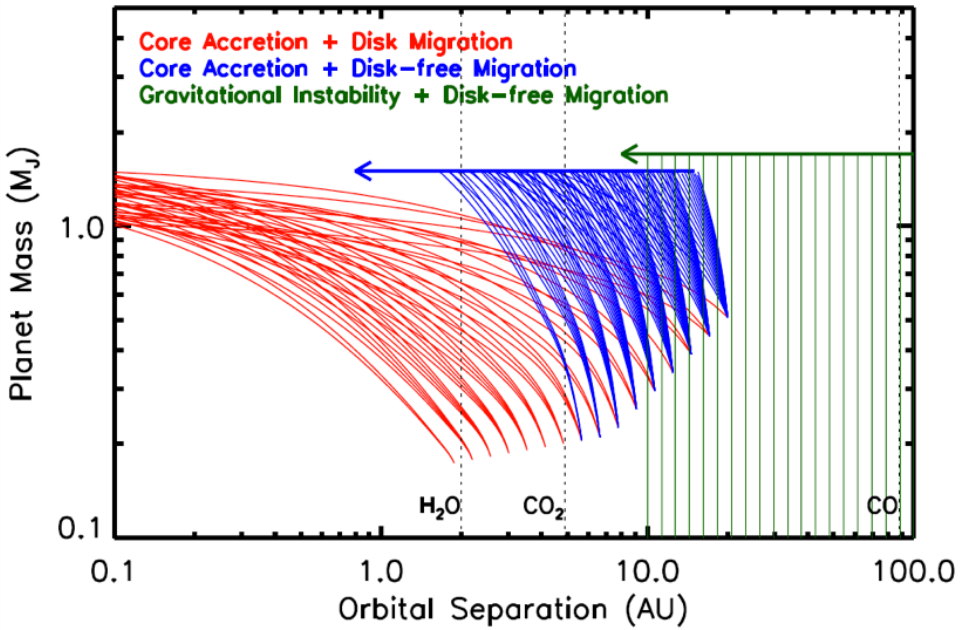
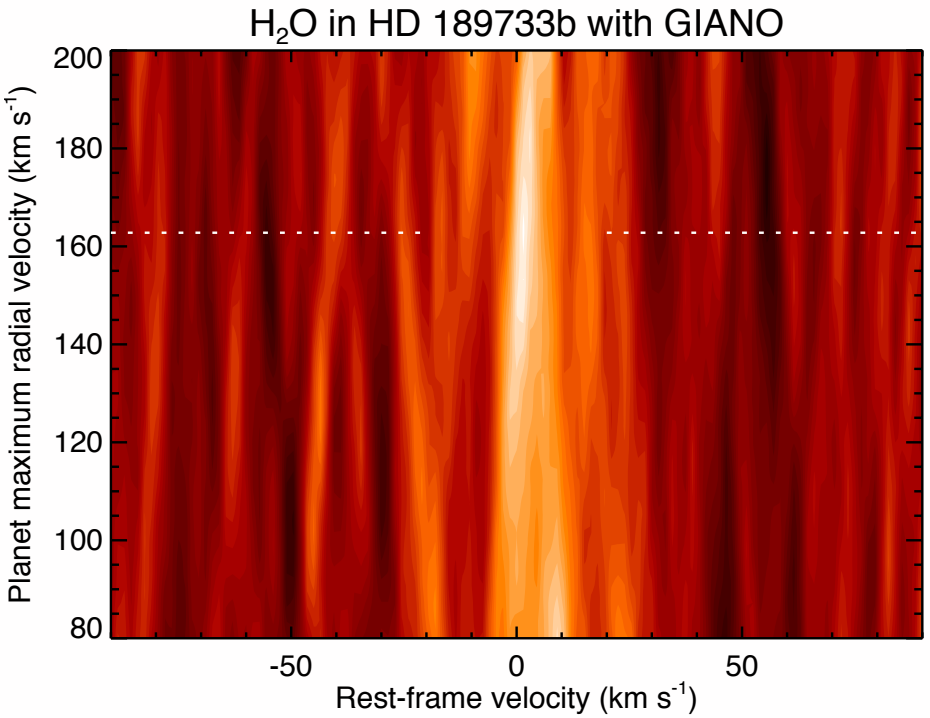




$[C/O]_{planet}$ and $[O/H]_{planet}$ can be derived from the abundance of **molecular species** in exoplanetary atmospheres **detectable in the nIR**:
CO, H_2O, CH_4, CO_2, NH_3, C_2H_2

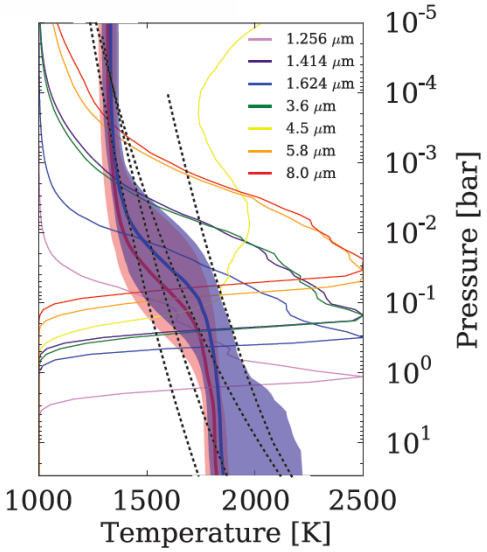
High-resolution spectroscopy with GIARPS

Study of exoplanetary atmospheres through **high-resolution spectroscopy**: individual molecular lines are resolved and can be robustly identified through cross correlations with theoretic templates at the expected RV of the planet (which allows to disentangle the planetary signal from telluric and stellar contribution); see R. Gratton's talk



Detection of H_2O at S/N=5.3 with GIANO_A with 4 hr observations (just one transit!). Significant improvement expected with GIARPS (higher efficiency, no modal noise in the K band, see R. Claudi's talk)

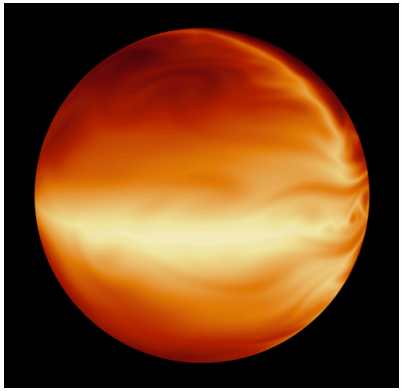
Properties of exoplanetary atmospheres at different ages

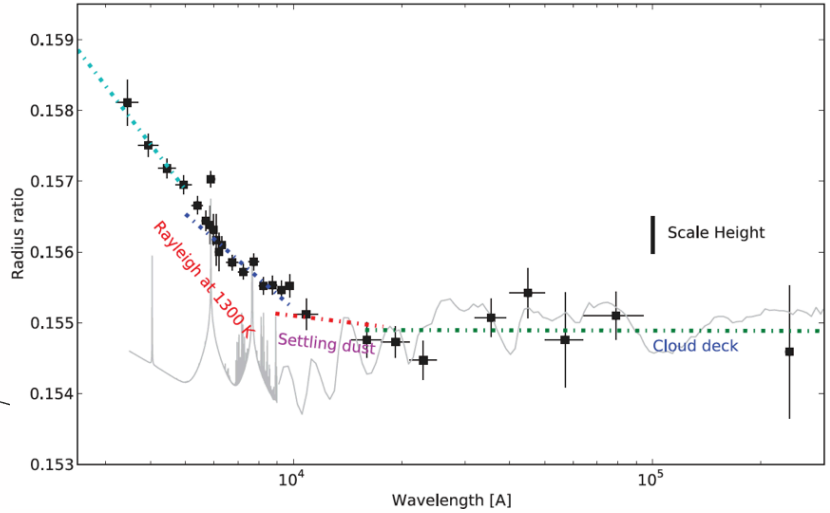


atmospheric composition:
CO, H_2O, CH_4, CO_2, NH_3, C_2H_2 in the nIR
Na, TiO in the optical

temperature inversions, possible connection with the presence of TiO and stellar magnetic activity level

atmospheric dynamics:
rotation, super-rotation, and winds





detection of hazes/clouds that may flatten transmission spectra

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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

Impact of giant planet migration on habitable terrestrial planets

Simulations show that dynamical instabilities among giant planets in most cases lead to merger with the star or ejection of potentially habitable terrestrial planets.

Higher frequency of small (R_p=1-2 $R_\oplus$) planets in the HZ around M dwarfs (30-50%) than GK dwarfs (5-15%) from Kepler:

less giant planets form around M dwarfs ➪ less dynamical instabilities ➪ ➪ less hot giant planets ➪ higher frequency of HZ planets ?

We will search for super-Earths in the HZ of young low-mass stars that don't have hot/warm Neptunes or Jupiters ➪ need for the highest achievable RV precision (laser comb) and very efficient suppression of activity variations (GIARPS, and very useful also for ESPRESSO!)

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Sample / Targets

Orbital parameters of hot and warm Jupiters as a function of stellar age

Orbital and physical (mass, radius, density) parameters of hot and warm Neptunes as a function of stellar age

~100 young stars (age < 500 Myr, H≤9) in stellar clusters/associations/moving groups

~40 K2/TESS transiting candidates with R_p=2.5-6.0 $R_\oplus$ around bright stars (V<11.5)

~35 (~5) hot Jupiters (Neptunes) orbiting bright stars (K<10)

• Frequency of young hot planets
• Higher host star metallicity than the average in stellar associations/clusters

Higher occurrence of small (HZ) planets in the absence of hot/warm Neptunes and Jupiters

Atmospheric composition (C/O and O/H ratios)

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5-yr long-term program
40 nights/semester
80 nights/year

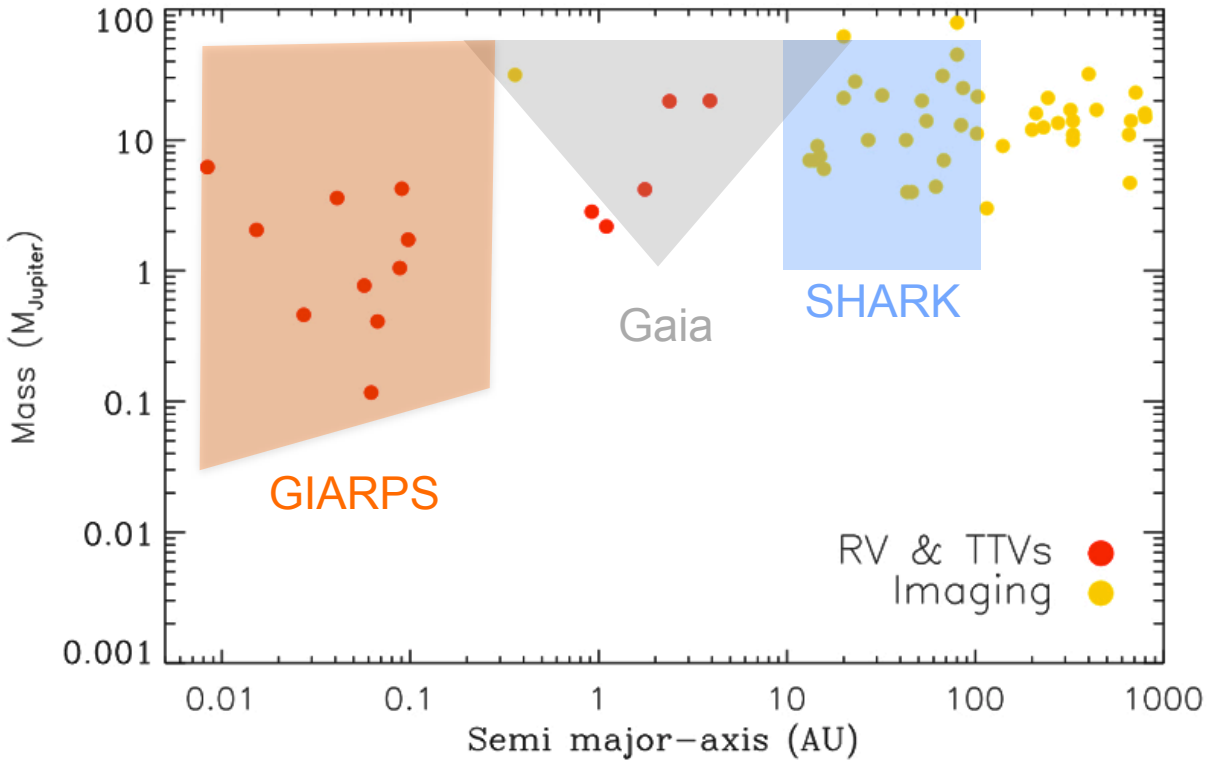
Perspectives: synergies with other instruments

- **Gaia/SPHERE/SHARK** to search for additional outer planets around young stars with hot planets (survived giant planets that were scattered to wide orbits because of the dynamical instability)

G2V

age < 500 Myr

d ~ 50 pc



- **HST/JWST** for atmospheric characterization with low-resolution spectroscopy (complementary to high-resolution spectroscopy);

- **K2, TESS, and CHEOPS** providing transiting planetary candidates in the transition region between low-mass and gaseous giant planets;

Perspectives: atmospheric characterization of potentially habitable planets

We will be ready to search for **biomarkers** (O_2, CO_2, H_2O, CH_4) in the atmospheres of potentially habitable terrestrial planets with the high-resolution HIRES and METIS spectrographs at E-ELT...

... by using exactly the same techniques of data reduction and analysis we have been developing to search for molecular species in the HJs' atmospheres with GIARPS!! See, e.g., Snellen et al. (2013, 2015) and R. Gratton's talk

An ever increasing number of small planets in the HZ will be discovered by high-precision RV (HARPS-like, HIRES@KECK, ESPRESSO spectrographs) and space-based photometric (TESS, CHEOPS, PLATO) surveys.