Gaia, Exoplanets, Atmospheric Characterization: Prospects for the Italian Community

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Meeting ma2 – bologna, 16/06/2016

Frontiers / Breakthroughs

Observationally, two main paths:

1) Determine the global architecture of planetary systems, including those containing terrestrial, potentially habitable planets, as a function of the properties of the parent stars

2) Physical characterization (internal structure, atmospheric chemistry and dynamics) of planetary systems across orders of magnitude in mass, size, and orbital separation

Help make better formation, structural and evolutionary models

Ultimately, putting our Solar System in context!

The Gaia Exoplanet Yield

Starcounts (V<13), $F_p(M_p,P)$ for F-G-K dwarfs, Gaia completeness limit

Δd (pc)	$N_\star$	Δa (AU)	ΔM_p (M_J)	N_d	N_m
0-50	~10 000	1.0 - 4.0	1.0 - 13.0	~ 1400	~ 700
50-100	~51 000	1.0 - 4.0	1.5 - 13.0	~ 2500	~ 1750
100-150	~114 000	1.5 - 3.8	2.0 - 13.0	~ 2600	~ 1300
150-200	~295 000	1.4 - 3.4	3.0 - 13.0	~ 2150	~ 1050

Casertano, Lattanzi, Sozzetti et al. 2008

M dwarf starcounts (G<20) → **2-3x10^3 additional giants (Sozzetti et al. 2014)**

All spectral types (G<17.5) → **2x10^4 new gas giants (Perryman et al. 2014)**

Close binaries within 200 pc → **100s circumbinary giants (Sahlmann et al. 2014**

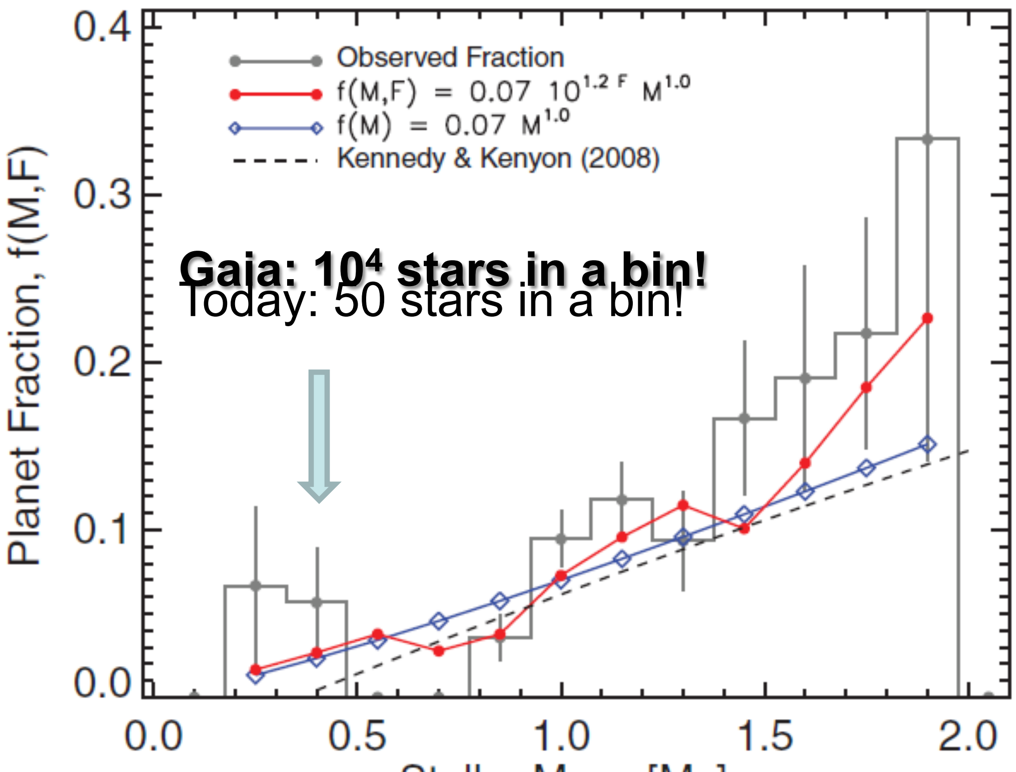
Unbiased, magnitude-limited planet census of possibly millions of stars

On the order of 10^4 NEW giant (< 15 M_{JUP}) planets

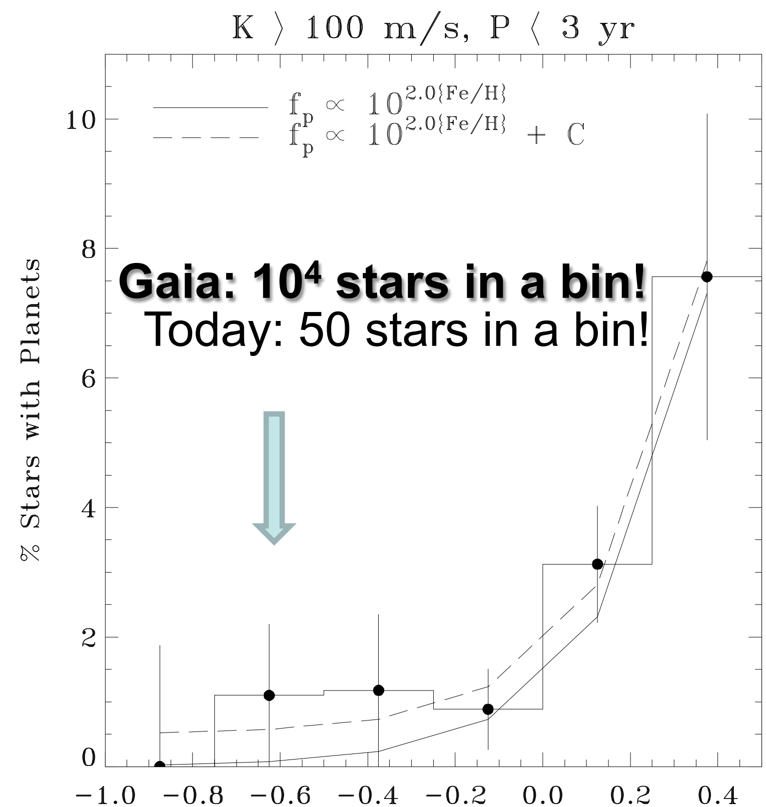
Final catalogue: around 2022, pending extension

The Gaia Legacy

How do giant planets properties (mass, orbit) depend on those of the host stars?



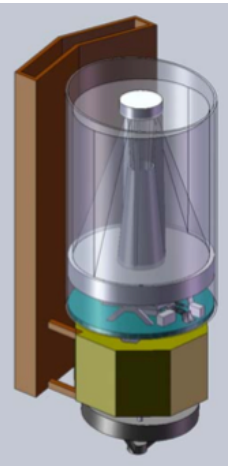
Johnson et al. 2010

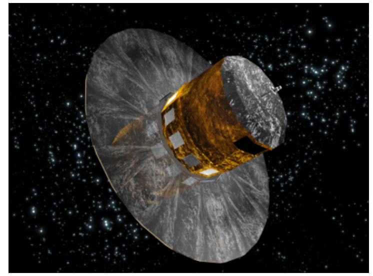


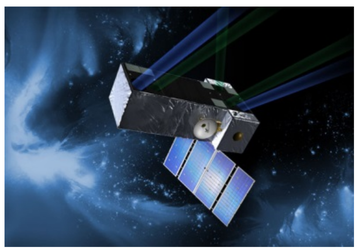
Sozzetti et al. 2009

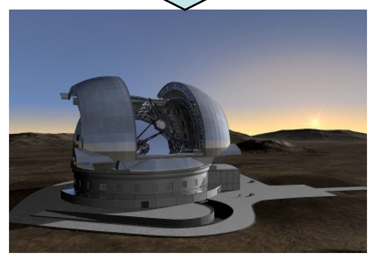
Gaia will test the fine structure of GP parameters distributions and frequencies (including the GP/BD transition), and investigate their changes as a function of stellar mass, metallicity, and age with unprecedented resolution

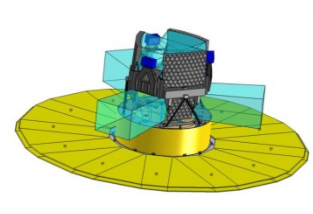
Gaia - Synergies

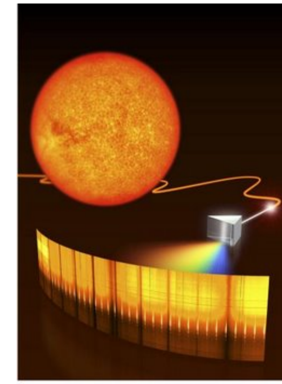












- Gaia & spectroscopic characterization observatories (e.g., JWST, E-ELT)
- Gaia & transit surveys from the ground (e.g., WASP, HAT, APACHE, NGTS) and in space (CoRoT, Kepler, K2, TESS, PLATO)
- Gaia & direct imaging observatories (e.g., SPHERE/VLT, PCS/E-ELT, WFIRST)
- Gaia & RV programs (e.g., HARPS(-N), ESPRESSO, CARMENES, and the likes)
- Gaia & ground-based and space-borne astrometry

Synergy with RVs

- Complete characterization of systems architectures across (some) orders of magnitude in mass and orbital separation
- Refinement of known orbits (both ways)
- Complete dynamical stability studies in multiple systems
- Very important synergy with present (e.g., HARPS@ESO, HARPS-N@TNG), and upcoming (ESPRESSO@VLT, IR instruments) RV surveys

Combined analyses can profit from large time baseline, particularly when Gaia intermediate astrometry data will become available (> 2022)

Astrometry + Direct Imaging

- Direct imagers to-date sensitive to young giants at wide separations

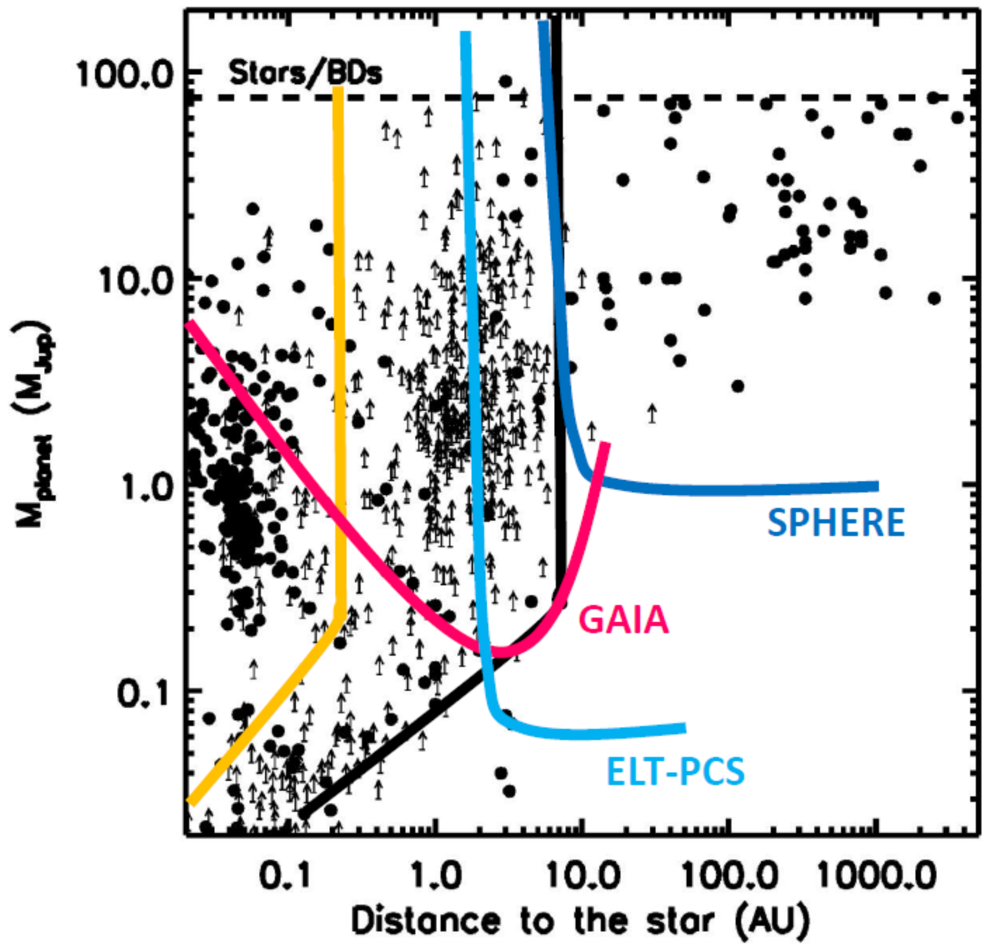
- Mass estimates rely on models, ages have big uncertainties

- Dynamical constraints on mass are difficult, but highly desirable

- Full astrometric orbits improve phase function and light-curve modeling

- RV amplitudes are small at large separations, and young stars are trouble

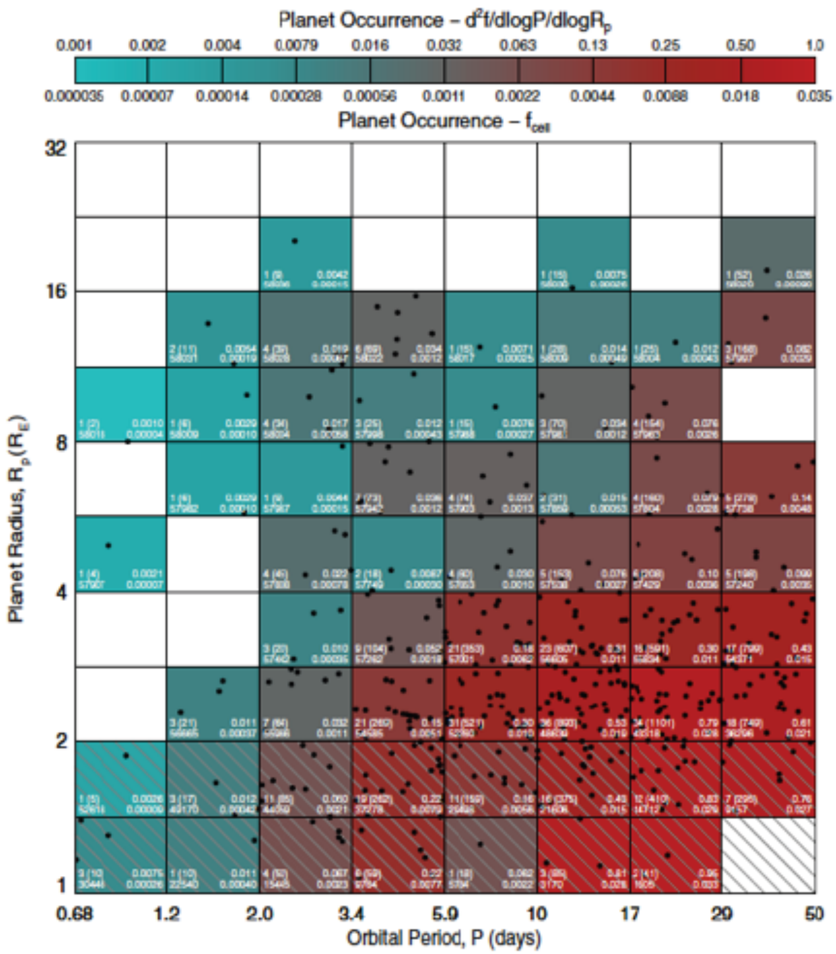
- Youth not an issue for astrometry, signal amplitudes increase at large a



Gaia astrometry + direct imaging: an ideal synergy!

Gaia – Kepler - HARPS-N

Howard et al. 2012



*** ALL parallaxes of stars in the Kepler field released formally around mid-2017**

*** For a typical target with V<15 at <0.5 kpc, expect σ(π)/π<2-3% from Gaia**

*** Re-calibrate absolute luminosities**

*** Re-determine the stellar radii to <5% -> re-assess the planets' structural properties**

A global statistical re-analysis of planetary properties and frequencies (including $\eta_\oplus$) in the Kepler field as a function of e.g. M_*, [Fe/H]

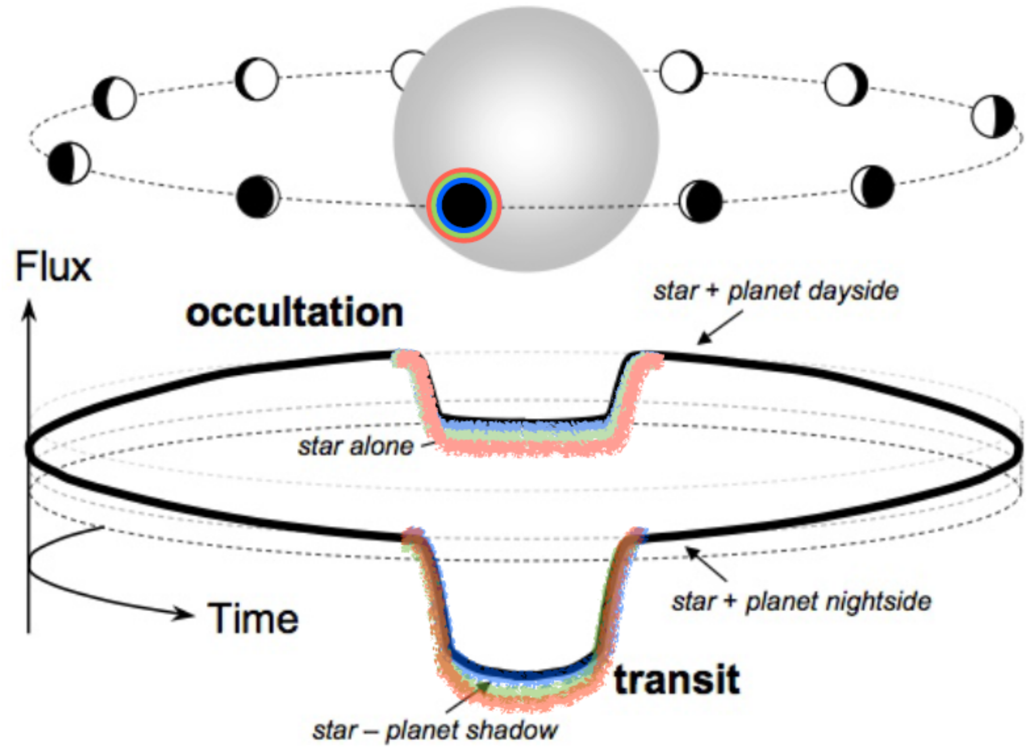
$$f_{\rm cell} = \sum_{j=1}^{n_{pl,cell}} \frac{1/p_j}{n_{\star,j}}, \qquad p_j = (R_\star/a)_j$$

OBJECTIVE OF THE INAF-LED FP7-SPACE ETAEARTH PROJECT

Exoplanet Atmospheres

KEY QUESTIONS

1. What are planets made of?
2. How did they form?
3. How do they evolve?



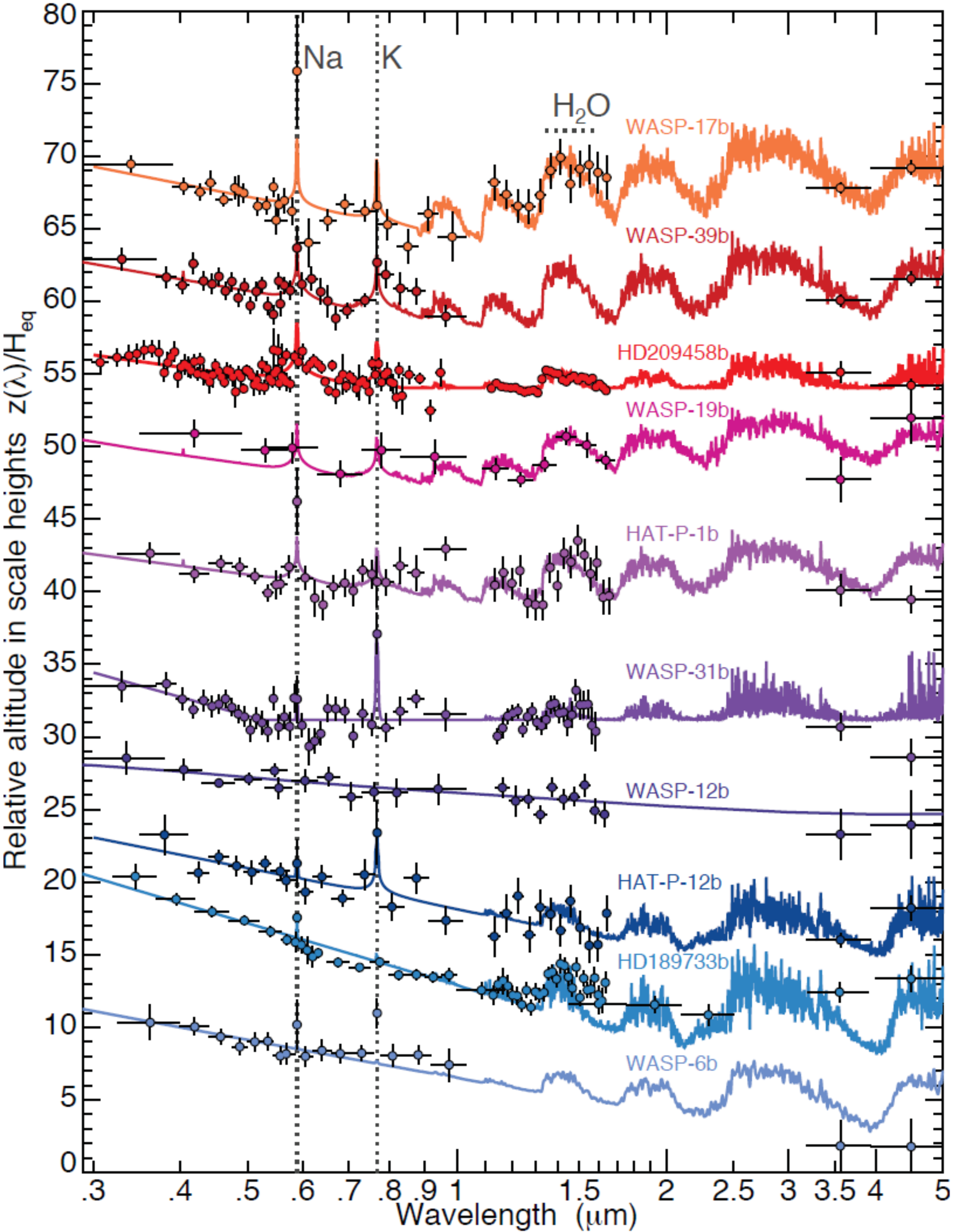
USE:

* multi-band differential photometry (broad or narrow band), imaging
* high-res spectroscopy, multi-object spectroscopy, low-res spectroscopy

GET:

* Albedo, T-p profile, molecular chemistry (dayside)
* Upper atmosphere (clouds, hazes), chemistry, dynamics (nightside)

Hot Jupiters' Atmospheres:



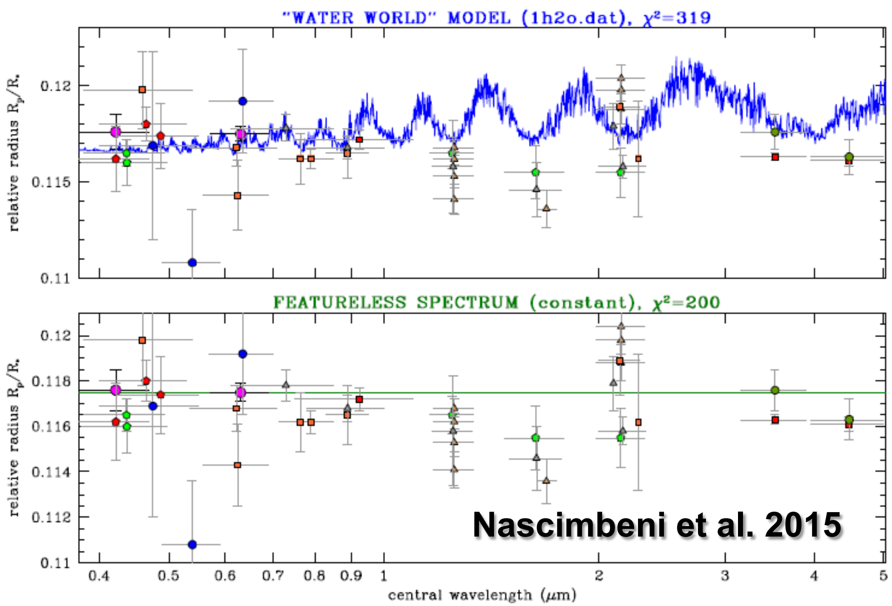
Sing et al. 2015

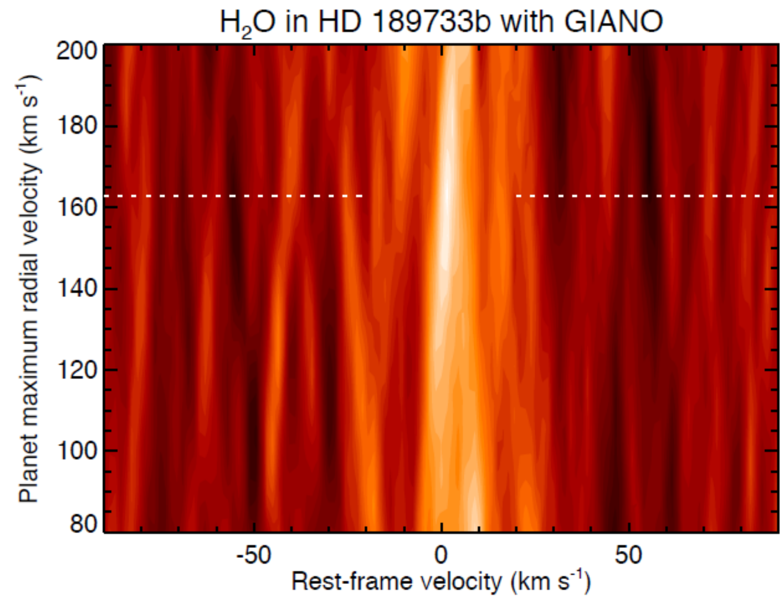
A continuum:
from clear to cloudy atmospheres

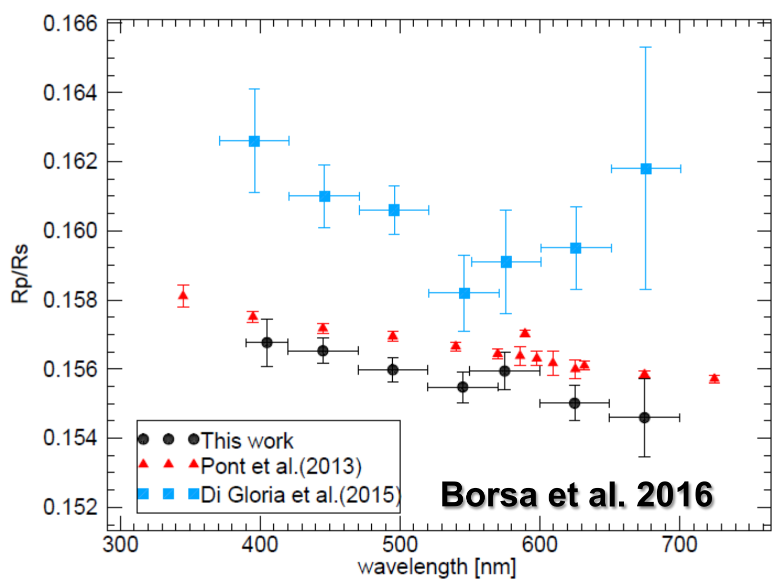
- **Clear**: strong Alkali and H_20 absorption, larger radii in the NIR
- **Hazy, cloudy**: strong Rayleigh scattering slope, narrow Alkali lines, H_20 absorption more or less obscured

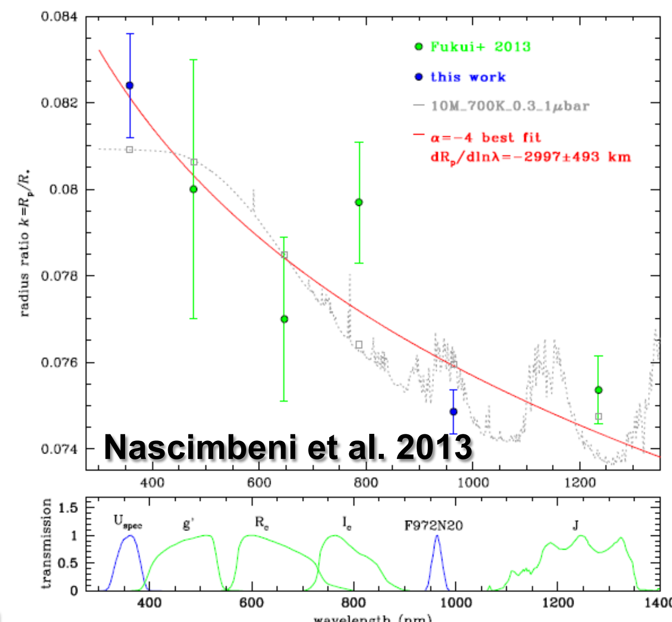
The field is still in its infancy, nonetheless !

Italy Today? Growin' up!







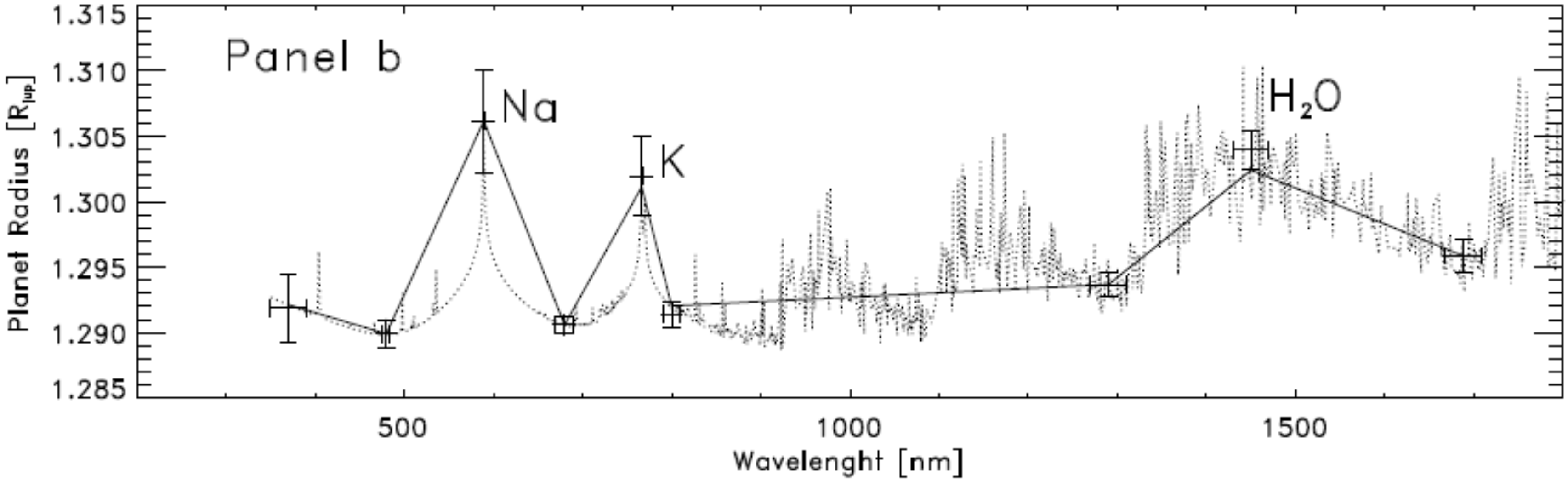


– bologna,

The SIOUX Project

- Systematic survey for atmospheric characterization of hot giant planets
- Measure radii ratios vs. λ and REPEAT the observations!
- Achieve < 1% accuracy on R_p/R_s -> < 1mmag differential photometry
- Simultaneous multi-wavelength, INDEPENDENT measurements
- Ad-hoc (very) narrow-band filters at VIS and NIR wavelengths
- High cadence observations, 2-4 m class telescope

THE SIOUX PROJECT

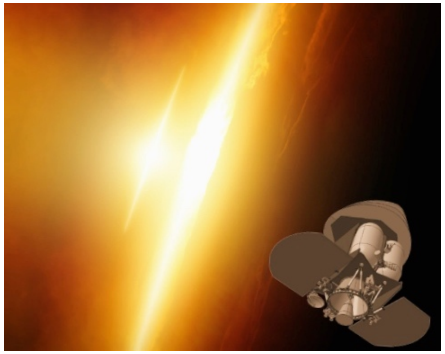


Christille et al. 2016, SPIE

ARIEL

ATMOSPHERIC REMOTE-SENSING INFRARED EXOPLANET LARGE-SURVEY

ESA-M4 mission candidate (launch 2026)
1m class telescope in space (L2)
Highly stable over a few hours, high visibility of sky
Spectral range probed: 0.5-8 micron



ARIEL recipe

Probe exoplanets' atmospheric chemistry & dynamics through VIS+IR transit/eclipse spectroscopy & multiband phase-curves

Ingredients:

- Large sample of (exo)planets

  E.g. ~ 200 Gas giants, ~ 100 Neptunes, ~ 100 Rocky planets & sub-Neptunes

- They transit, they are hotter than ~ 500K, their star is brighter than K=9-9.5

Courtesy G. Micela

ARIEL: Italian Participation

6/16/16

Science

Telescope

Electronics

Thermal Design

Ground Segment

Spectrometer

Courtesy G. Micela

Target Providers

- **K2, TESS**: short-period Super Earths, HZ planets around M dwarfs
- **CHEOPS:** accurate radii of old and new transiting giants and Super Earths
- **Gaia:** MANY intermediate-separation giants (relevant for indirect habitability considerations)
- **PLATO:** identification of transiting Earth-size systems at HZ distance around bright Sun-like stars (not nearby)

RV@1-10 cm/s, Astrometry@1 μas:
HZ terrestrial planetary companions to our nearest neighbors

Atmospheric Characterization

- **Time Domain: transit/eclipse Spectroscopy and Photometry**

SIOUX, JWST, **ARIEL**

- **Spatial Domain: High Contrast Imaging**

SPHERE, GPI, Subaru

JWST; WFIRST

METIS@E-ELT, **PCS@E-ELT**

- **Spectral + Time Domain: High Dispersion Spectroscopy**

GIANO+HARPS -> GIARPS

HARPS+NIRPS

ESPRESSO and CRIRES+

E-ELT: METIS and **HIRES**

- **Spectral + Spatial Domain: HDS + HCI**

CRIRES+

E-ELT: METIS and **HIRES** + **PCS**