INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

EXOPLANETARY ATMOSPHERES

Atmosfere di esopianeti

Francesco Borsa

INAF - Osservatorio Astronomico di Brera

On behalf of EXO-Atm team

EXOPLANETARY ATMOSPHERES

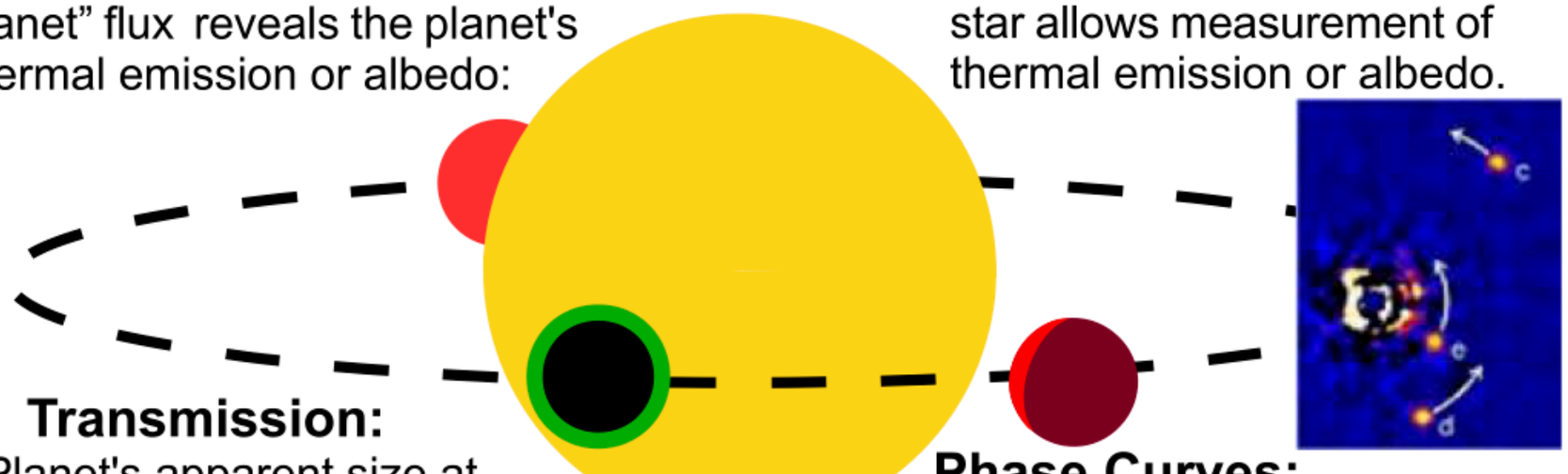
- Exoplanets: from discoveries to characterization
- Young science case: first detection claimed in 2002 (high resolution in 2015)
- Hot and big planets orbiting bright stars, moving to colder, smaller and fainter…
- Distant planets vs. close-in planets
- Multi-wavelength: from UV to far-IR

SCIENCE & TECHNIQUES

Credits: Crossfield+15

Eclipse:
Removing “star” from “star plus planet” flux reveals the planet's thermal emission or albedo:

Direct Imaging:
Spatially resolving planet from star allows measurement of thermal emission or albedo.



Transmission:
Planet's apparent size at different wavelengths reveals atmospheric opacity and composition.

Phase Curves:
Total system light throughout an orbit constrains atmospheric circulation and/or composition.

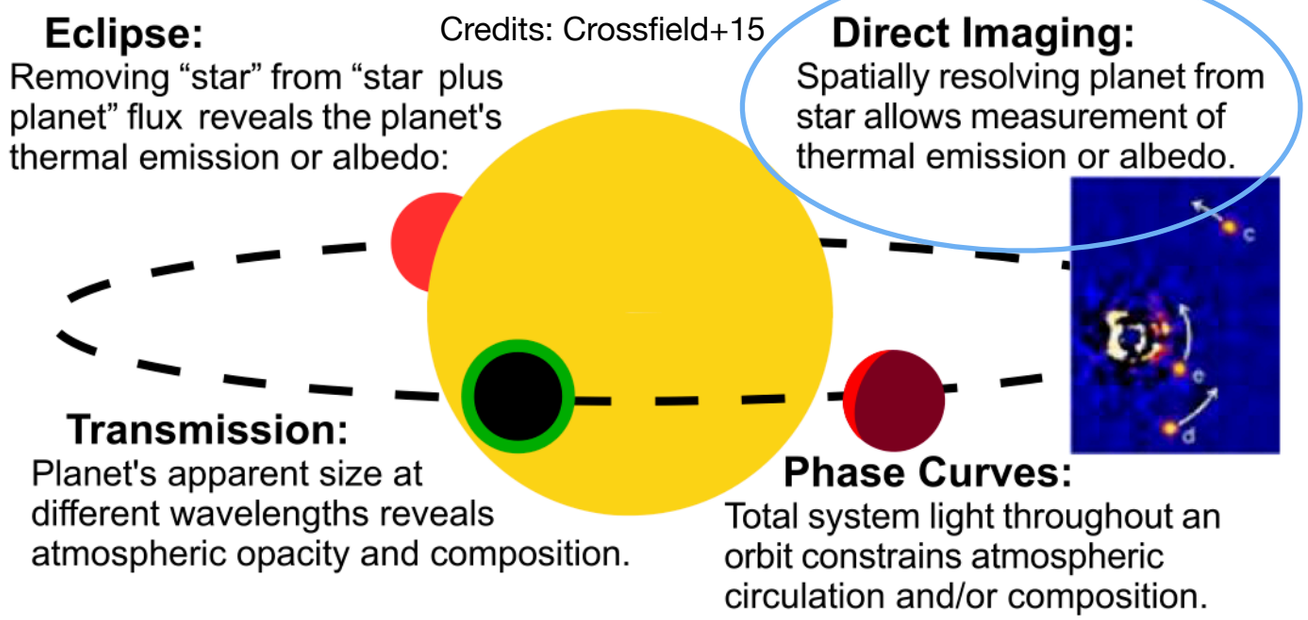
What do we find?

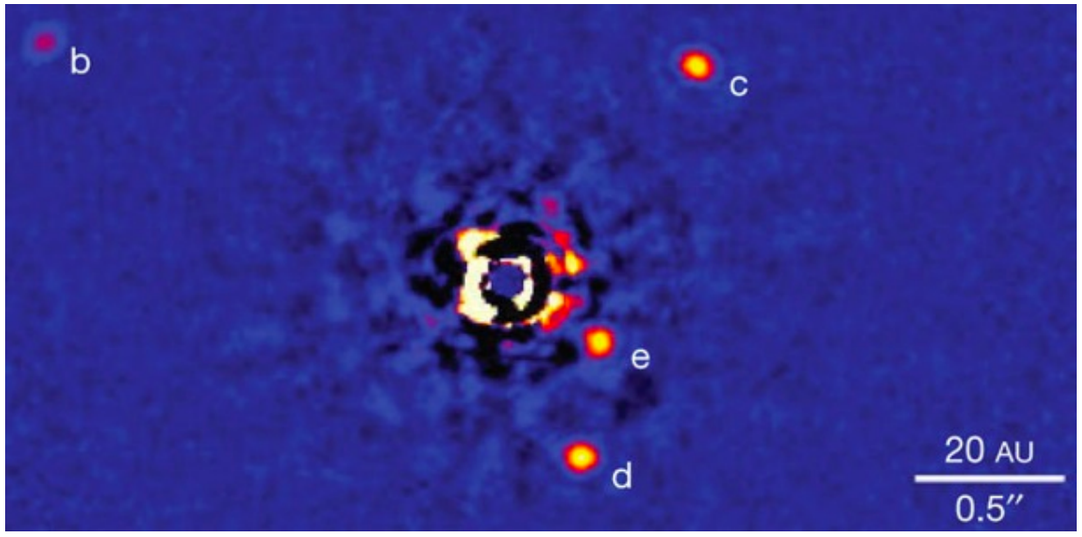
Molecules, atoms, winds, clouds, hazes, dynamics, thermal map, albedo, abundances, planetary mass, dust, accretion, evaporation, T-P profiles, rotation…

Which techniques?

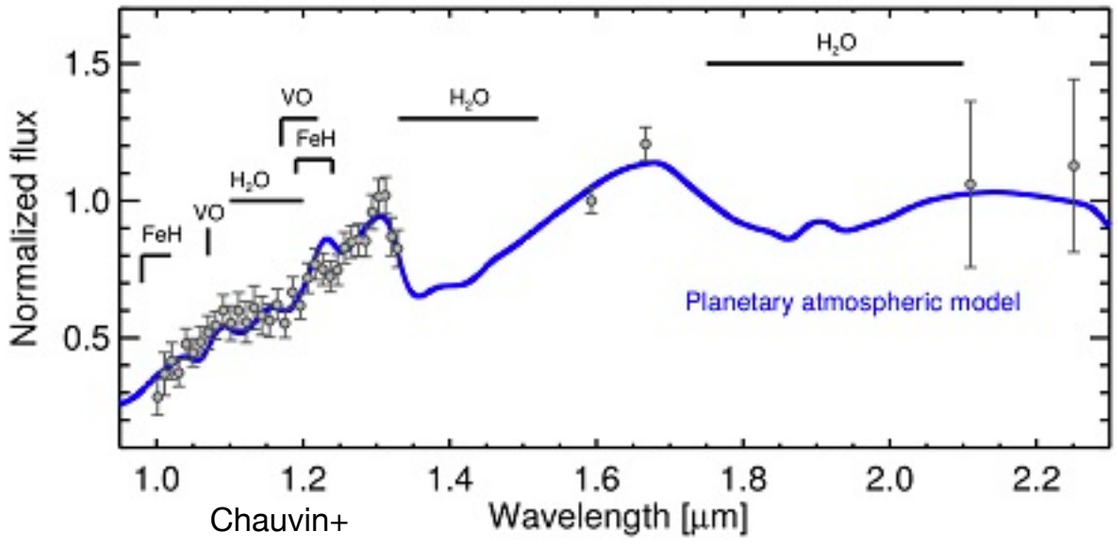
Photometry, spectro-photometry, high-contrast imaging, HR and LR spectroscopy

SCIENCE & TECHNIQUES



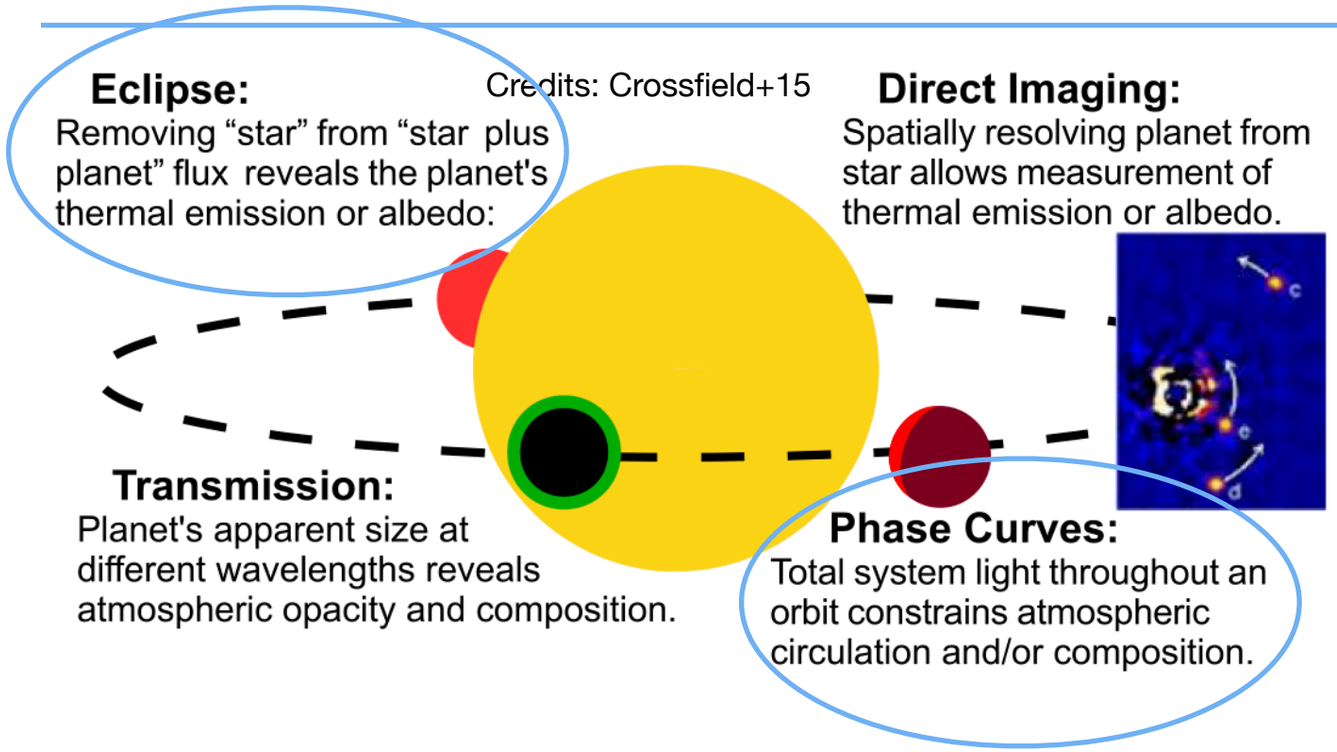


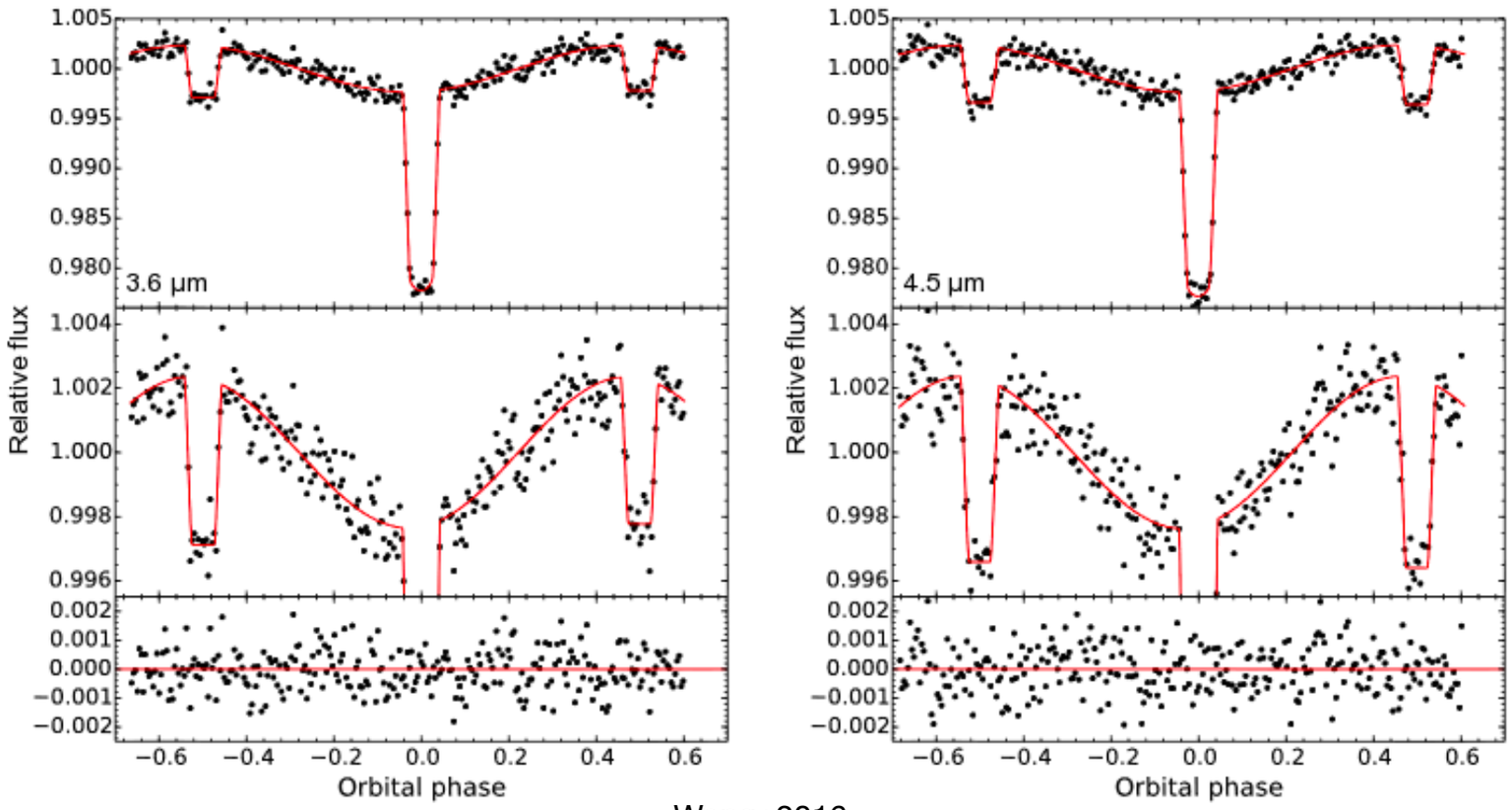
Marois+2010



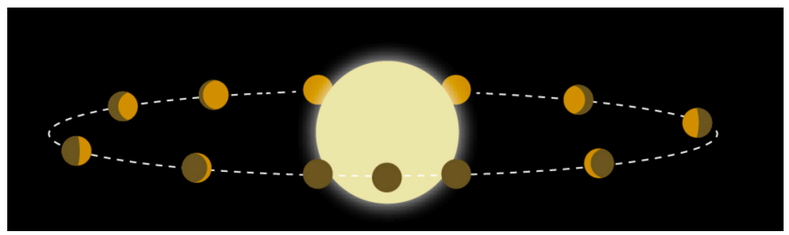
Masking the star, we directly see young planets

SCIENCE & TECHNIQUES



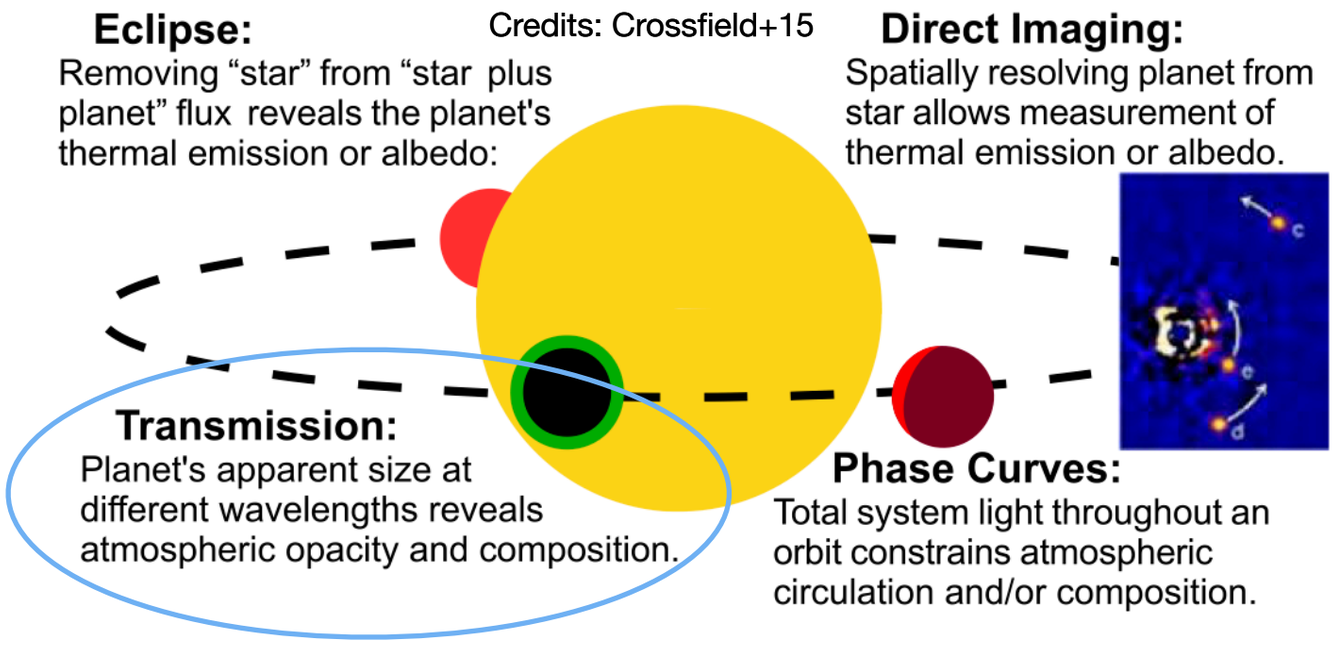


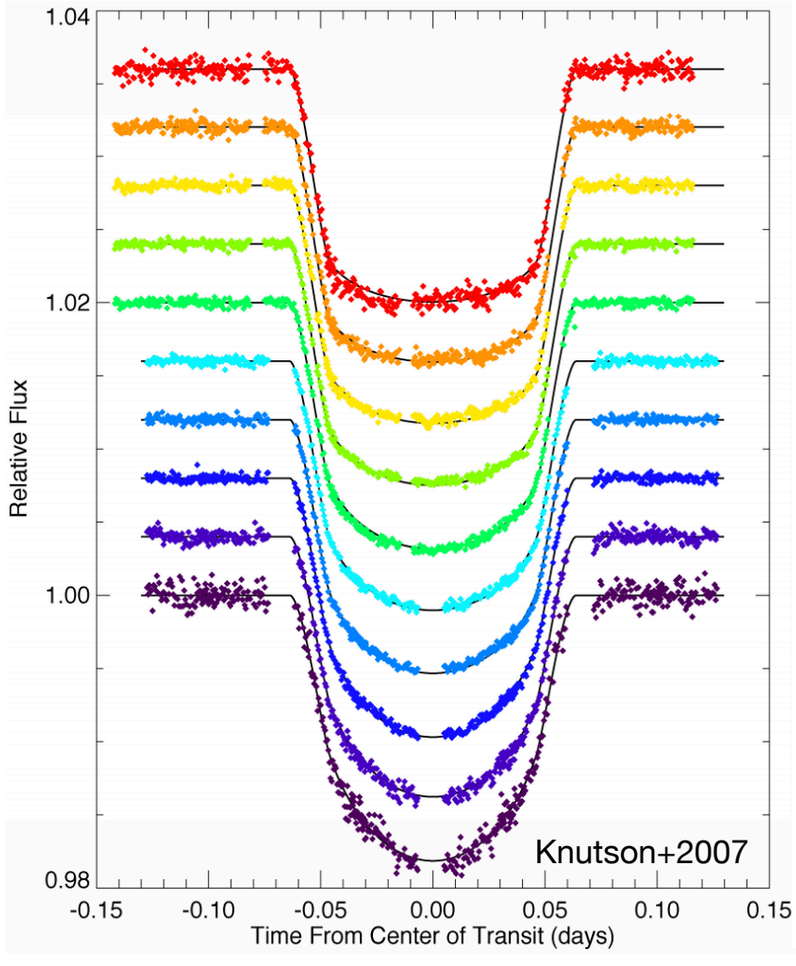
Wong+2016

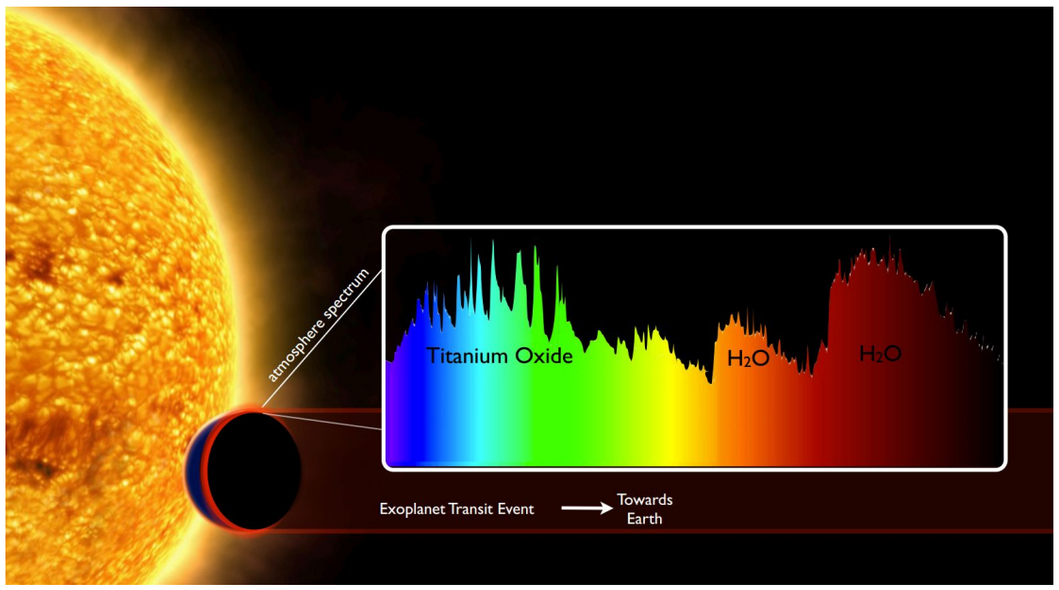


Constraining the energy budget of the planetary atmosphere

SCIENCE & TECHNIQUES

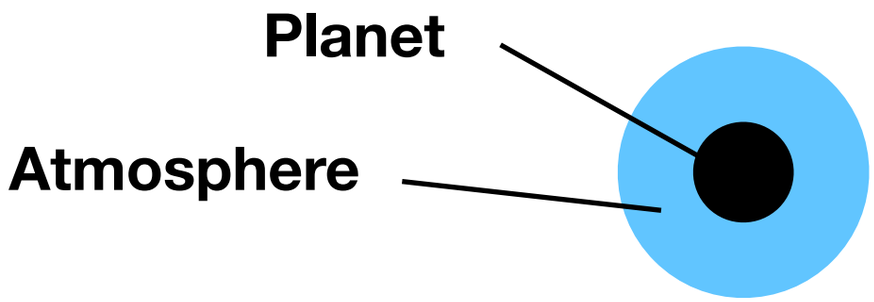






Planetary atmosphere filters the stellar light, leaving an imprint

SCIENCE & TECHNIQUES



Wavelength	UV	VIS	IR
Measure	Lyman alpha, ionized metals	Balmer lines, Na, K, Mg, Li, Cr, V, Ti, Fe, Fe+, Ca+, TiO, VO…	H2O, CO, CH4, CO2, NH3…
What we learn	Info on atmospheric mass loss	Thick/thin clouds, hazes, transparent	Chemistry in equilibrium?

Slide adapted from H. Knutson

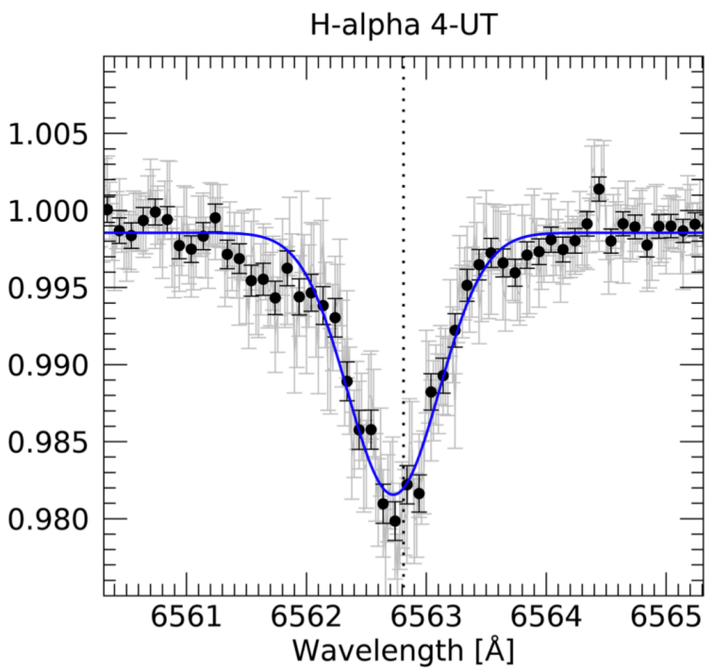
SCIENCE & TECHNIQUES

HR spectroscopy

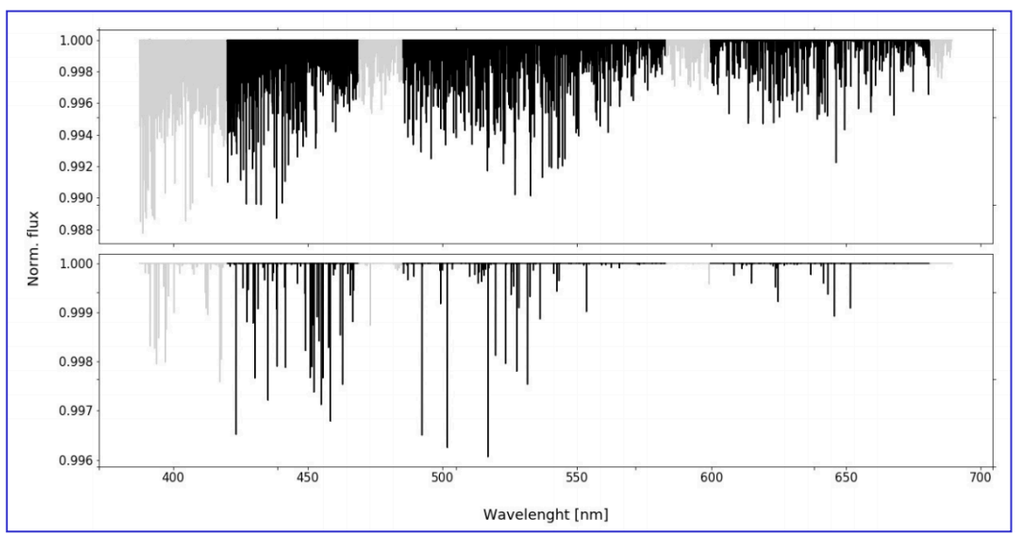
High-resolution unambiguously resolves chemical species in the planetary atmosphere

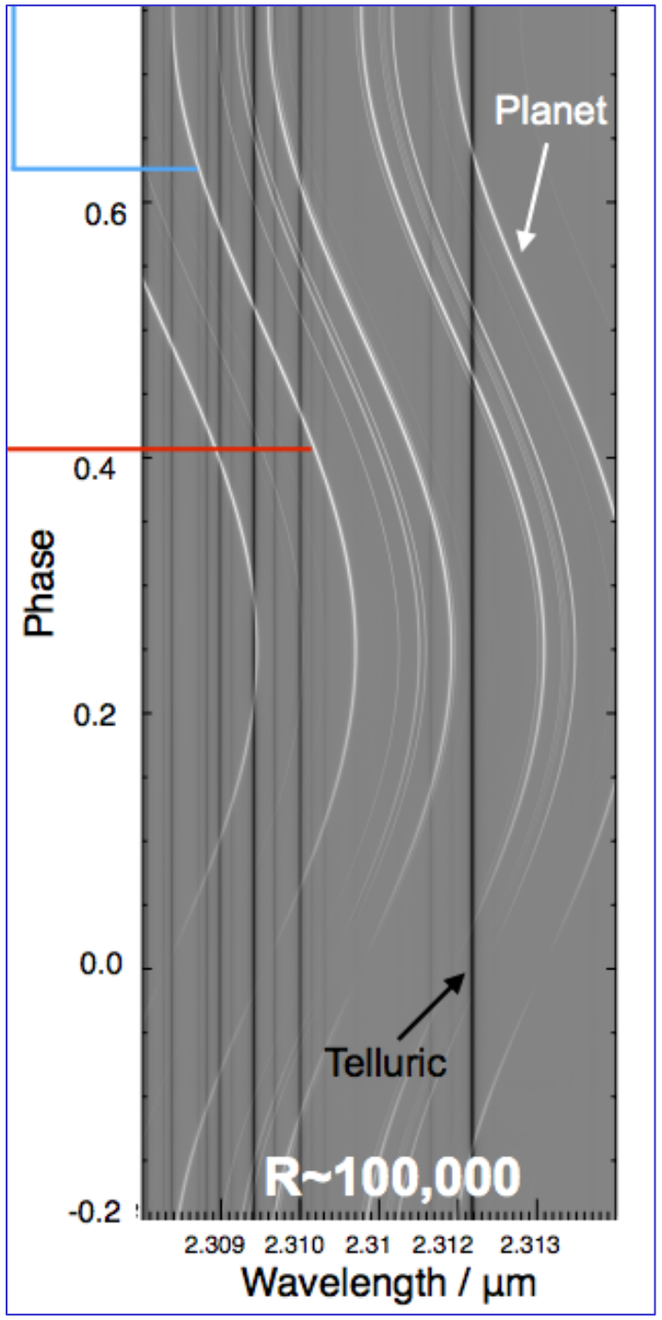
Complementary to LR, investigating different layers of the atmospheres

Species detected by isolating line profiles (H, Na, Mg, Li, K…) or cross-correlating with theoretical templates (Fe, Cr, H2O, CO, CH4…)



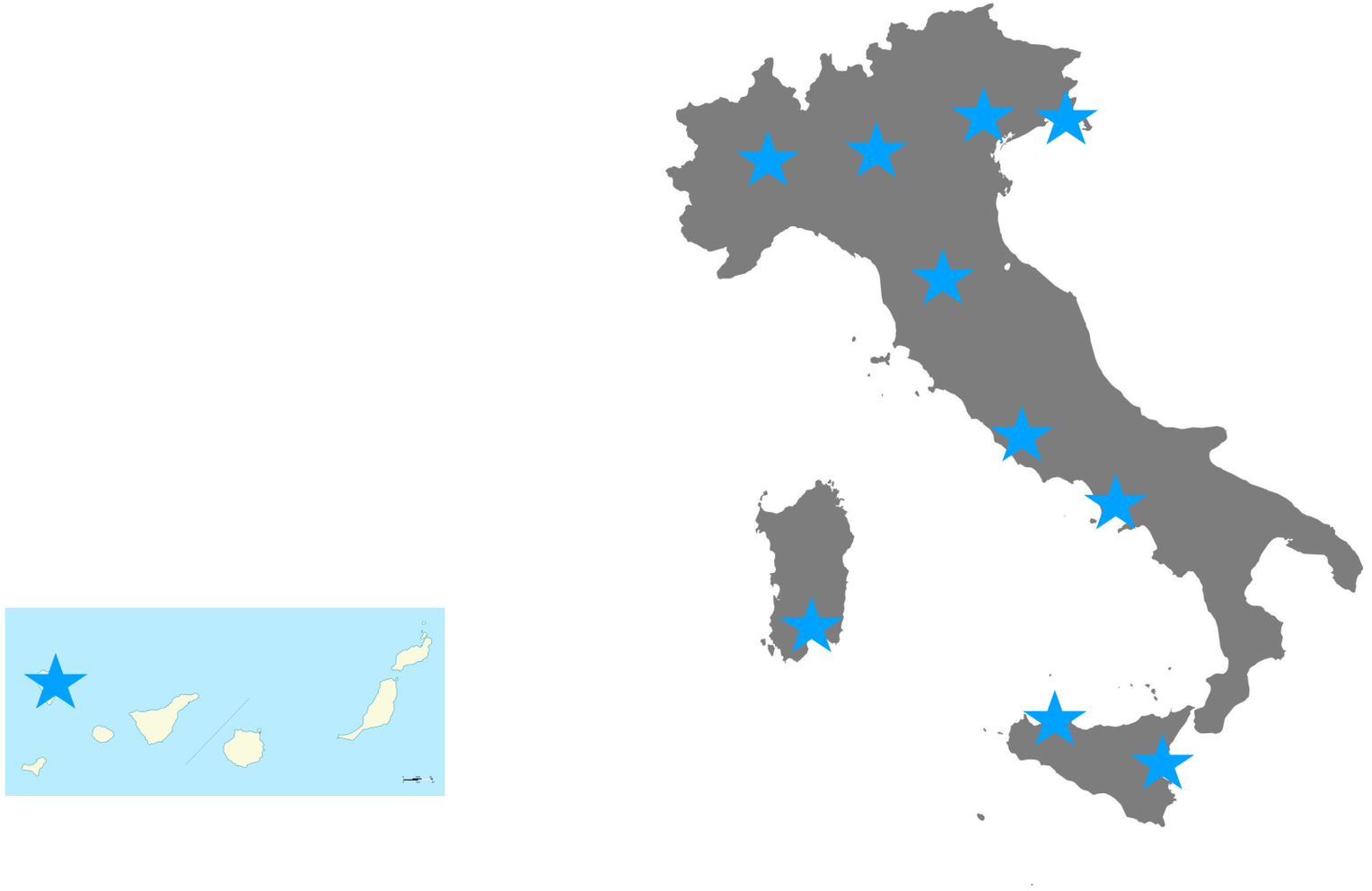
Borsa et al. 2021





Credits: M. Brogi

THE EXO-ATM TEAM



- 10 INAF structures + FGG
- 54 INAF members + 10 associates
- 18 correlated “schede progetto”

CORRELATED PROJECTS

Ongoing projects
Potential projects

	LR/photometry	HR	imaging	INAF funds
AMS	x			
ARIEL	x			x
CHEOPS	x			
Ecube		x		
ESPLORA	x	x		
EXO-FAMILIES			x	
EXOGAL	x			
EXO-SELENE			x	
GAPS2		x		
HARPS-N/GTO		x		
HEXODUS	x	x		
HIRES		x		
HOT-ATMOS		x		x
PETS		x		
SHARK-NIR			x	x
SPHERE-GTO			x	
SPHERE+			x	x
THE StellaR Path		x		x

LEADERSHIP

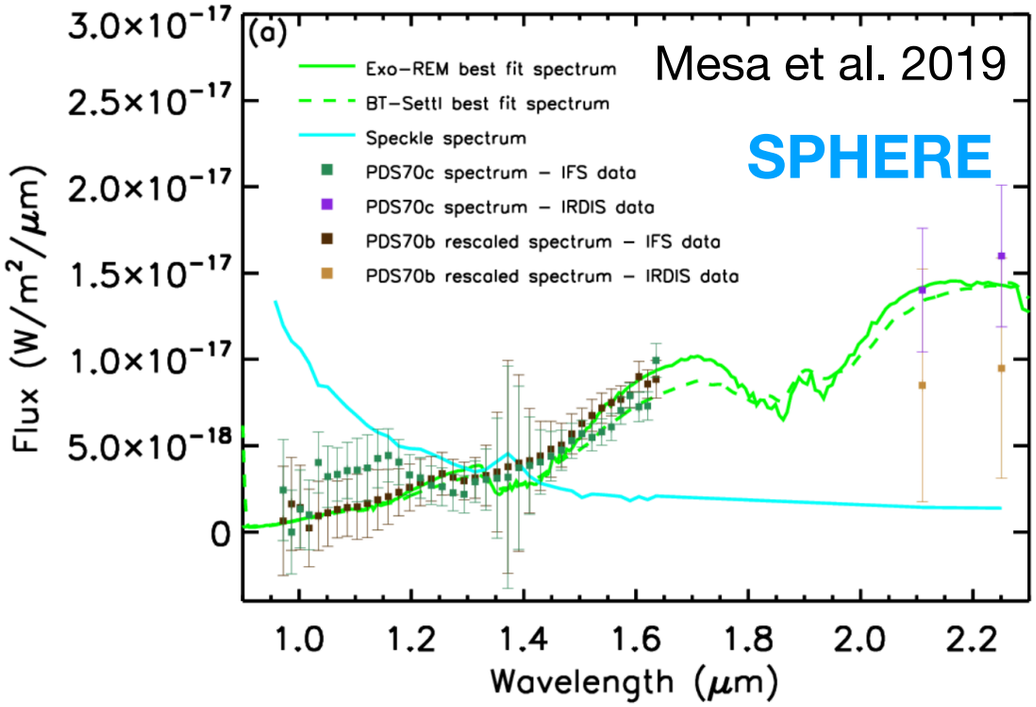
Science

- Leader in the systematic exploiting of HR large wavelength coverage VIS-IR with GIARPS
- Development of different independent pipelines for the analysis of data coming from space-based and ground-based facilities.
- Involved in projects exploiting top-class instrumentation, with conspicuous GTO and competitively approved long-term/large programs. Participating (both as first author and collaborators) in most of the papers within the CHEOPS and ARIEL consortia, the ESPRESSO/GTO, HARPS-N/GTO and SPHERE/GTO programs (soon PETS@LBT), leading all the papers within GAPS2 program

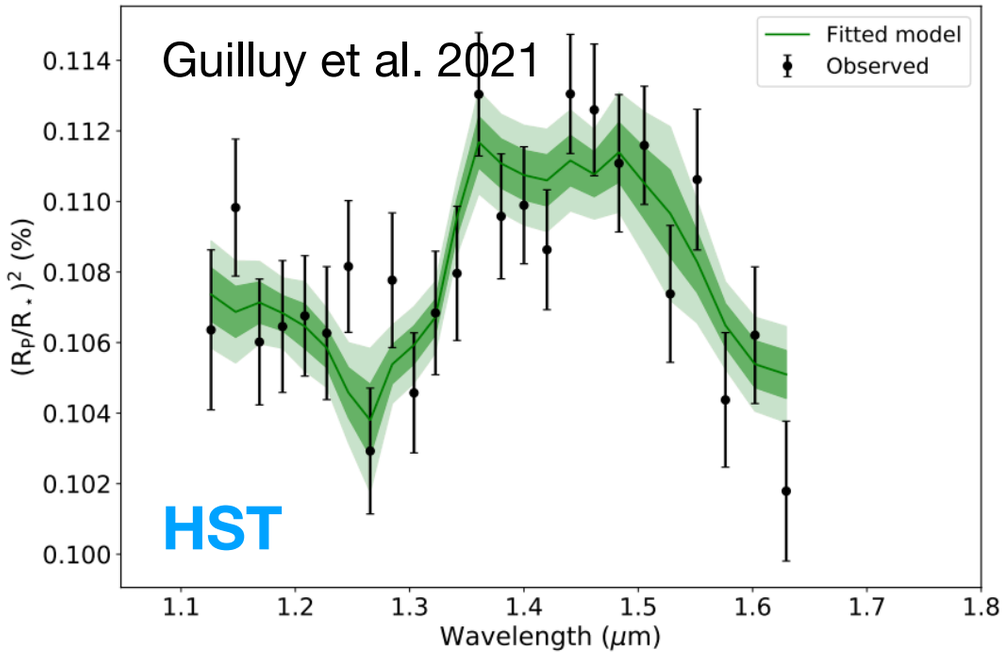
Technology

- Strongly involved in the technological development and realization of breakthrough instrumentation: ESPRESSO@VLT, GIARPS@TNG, SPHERE@VLT, CHEOPS
- Leading role in future instrumentation such as, e.g., SHARK@LBT and HIRES@ELT (+ARIEL)

HIGHLIGHTS

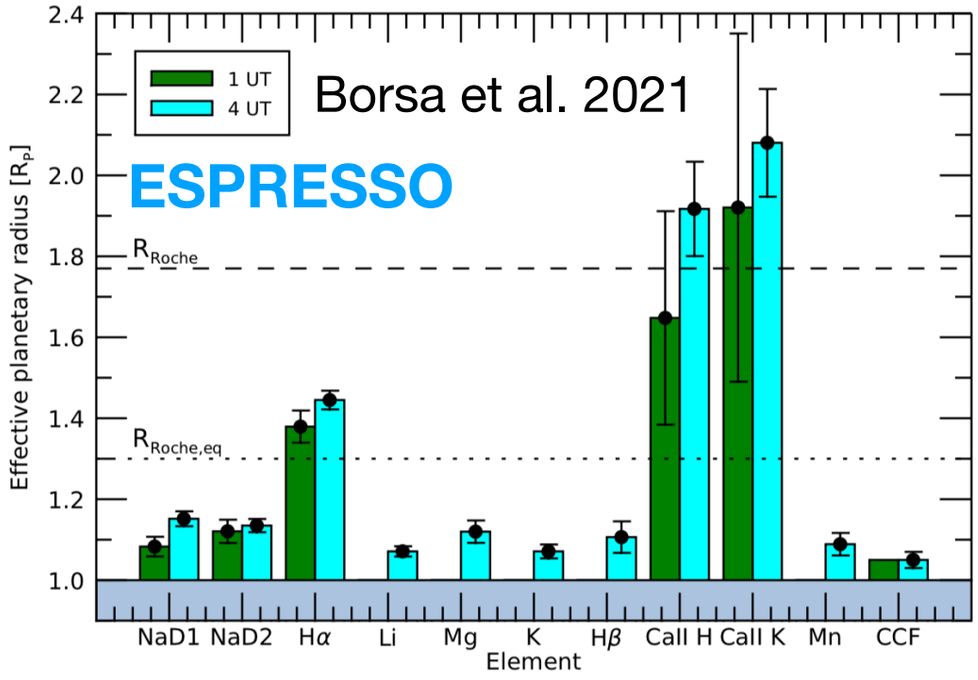


Spectrum of two imaged exoplanets in the same system, dust in the atmosphere

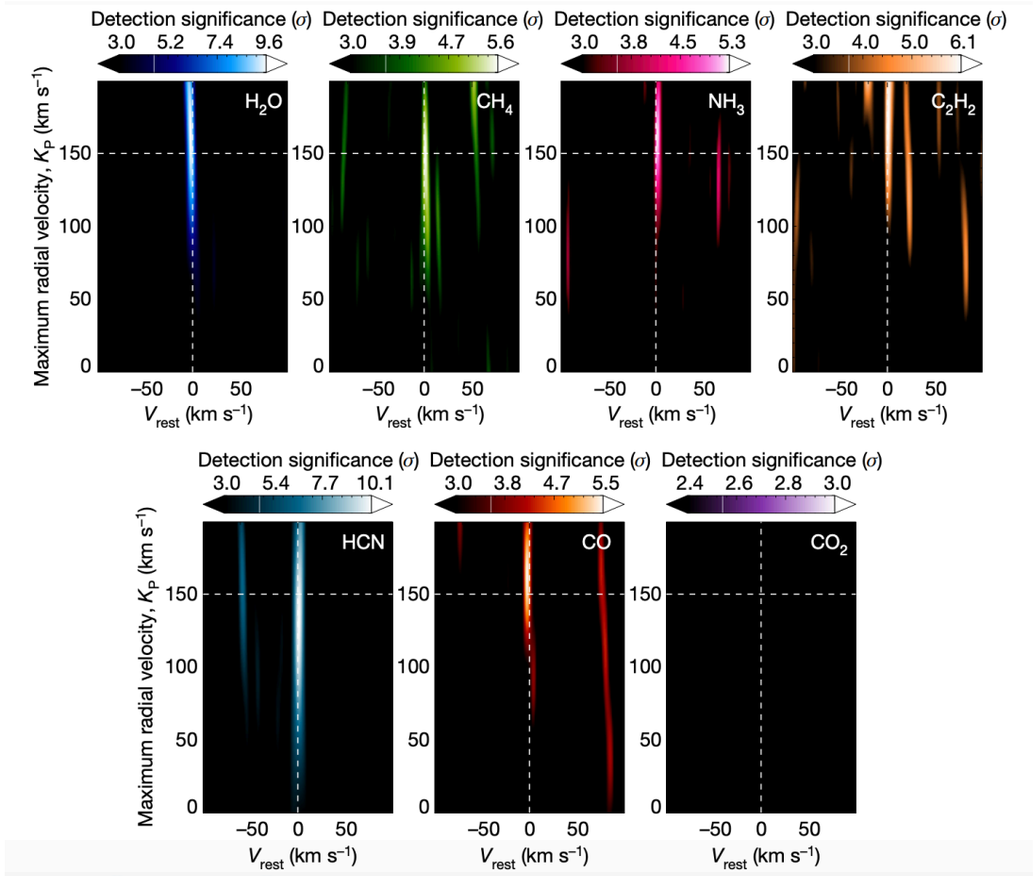


H2O in a hot-Neptune

First transmission spectrum with the 4-UT of VLT

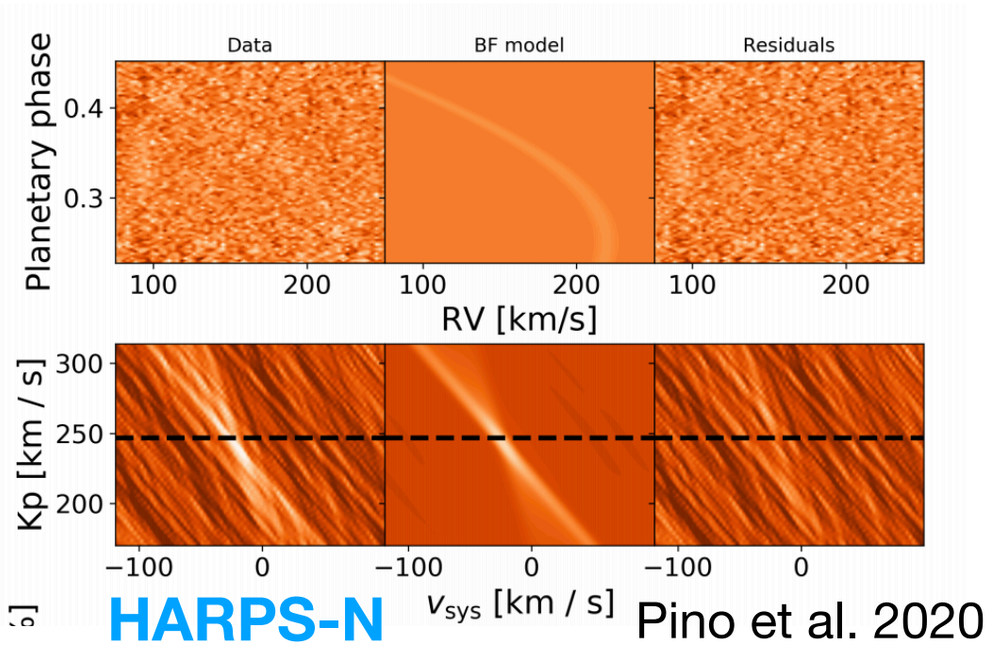


HIGHLIGHTS



GIANO-B Giacobbe et al. 2021

Six molecules in the atmosphere of an exoplanet

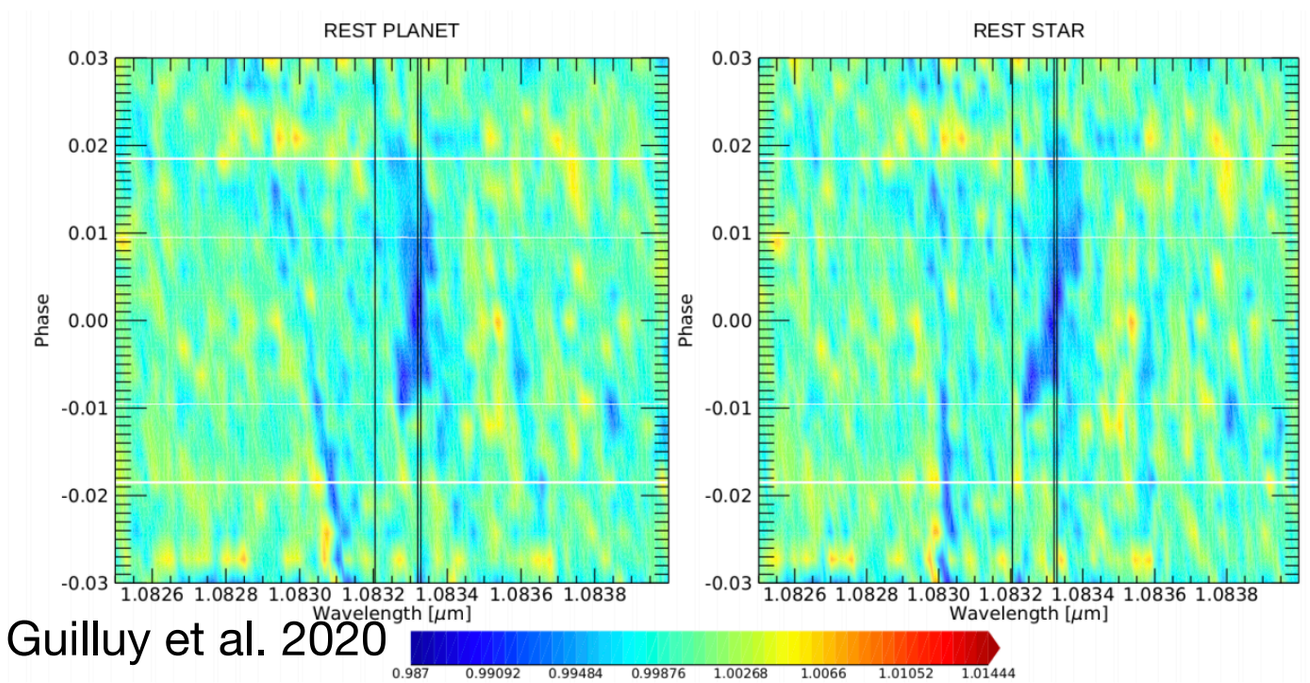


HARPS-N Pino et al. 2020

First detection of iron emission from an exoplanet

GIARPS

Helium in the planetary velocity rest frame

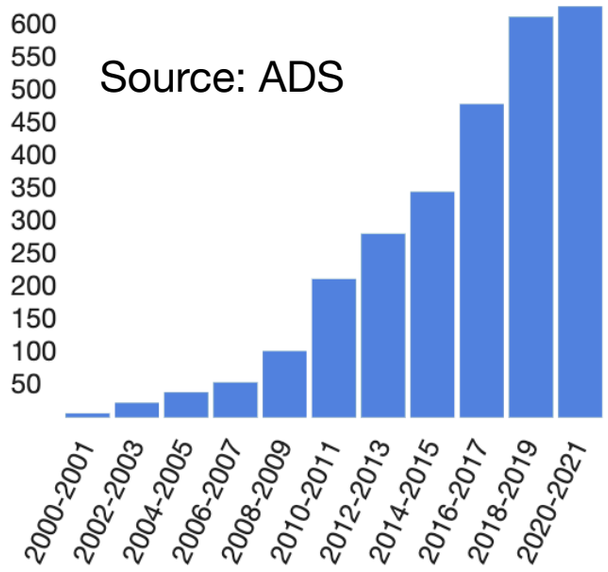


Guilluy et al. 2020

CRITICAL POINTS

- Atmospheric retrieval
  - → Complex and computationally expensive for HR
  - → Merging LR and HR results
- Improve pipelines/analysis tools to go toward smaller and colder planets
- Stellar activity and contamination in the planetary atmospheric spectrum
- Merging different scientific communities (e.g., Solar System and stellar expertise)
- Rapidly growing and highly demanding scientific subject: very competitive science! Need to increase critical mass…

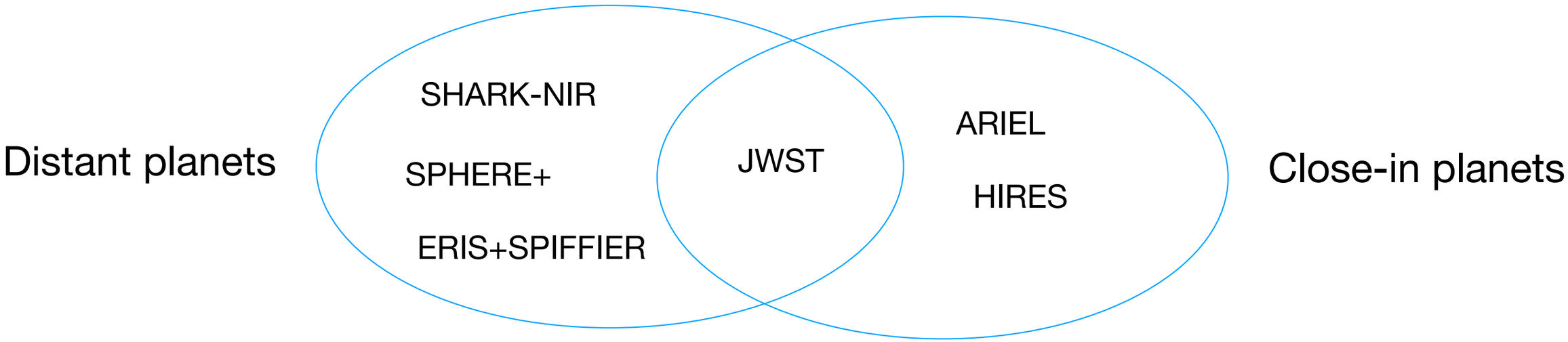
FUTURE PLANNING



Refereed publications with “exoplanet atmosphere” in the abstract

The international scientific context is going to prioritise this science case in the next decade

Many new space missions and scientific projects completely/strongly devoted to study exoplanetary atmospheres, and coupling techniques (spatial+spectral HR)



Toward the characterization of “terrestrial planets” orbiting the “Habitable Zone”

FUTURE PLANNING

Important instruments with Italian PI-ship are being realized/developed

For HIRES priority science case driver #1 is exoplanetary atmospheres

The detection of a biosignature in an exoplanetary atmosphere is definitely conceivable over the next decade

→ **enormous cultural impact beyond the scientific one!**

INAF should capitalize the strong efforts that are being made

INAF-led first detection of a biosignature on an exoplanet is not an utopia