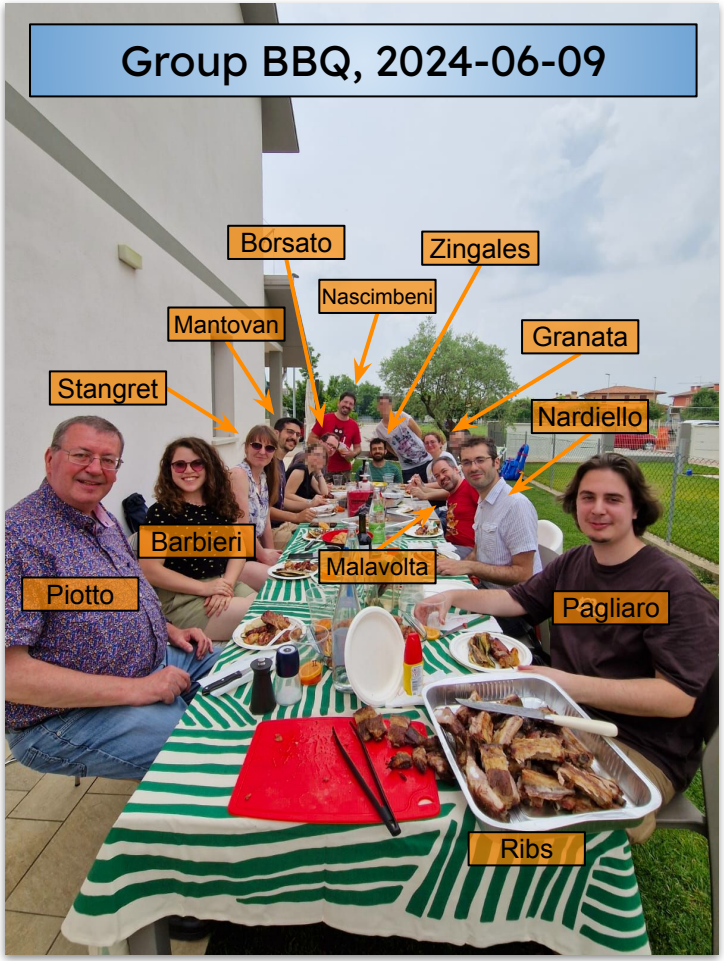
Transiting exoplanets with space- and ground-based facilities: architecture, dynamics, composition, habitability

V. Nascimbeni, A. Barbieri, L. Borsato, R. Claudi, S. Desidera, V. D'Orazi, V. Granata, P. Leonardi, L. Malavolta, G. Mantovan, D. Nardiello, L. Pagliaro, S. Ortolani, G. Piotto, M. Stangret, T. Zingales

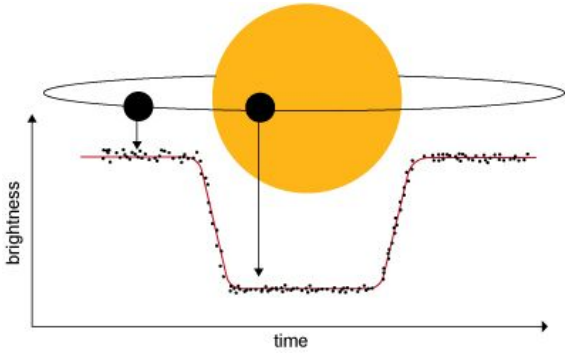
The research group

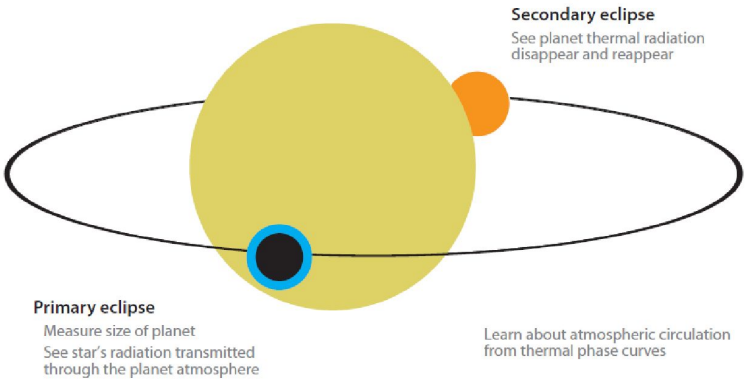
- A. Barbieri★, L. Borsato, R. Claudi, S. Desidera, V. D'Orazi, V. Granata★, P. Leonardi★, L. Malavolta★, G. Mantovan★, D. Nardiello★, V. Nascimbeni, L. Pagliaro★, S. Ortolani★, G. Piotto★, M. Stangret, T. Zingales★ (*counting only people involved in transiting exoplanet science*)
- ~16 people (10 affiliated with ★UNIPD), including PhD students, post-docs, non-permanent and permanent staff
- I will give just a very quick outline of some of the most representative projects we are involved in
- I will focus mostly on the **scientific** contributions, but also the **technological** contributions from OAPD are crucial (e.g., PLATO, CHEOPS)



The unique opportunity of transiting exoplanets

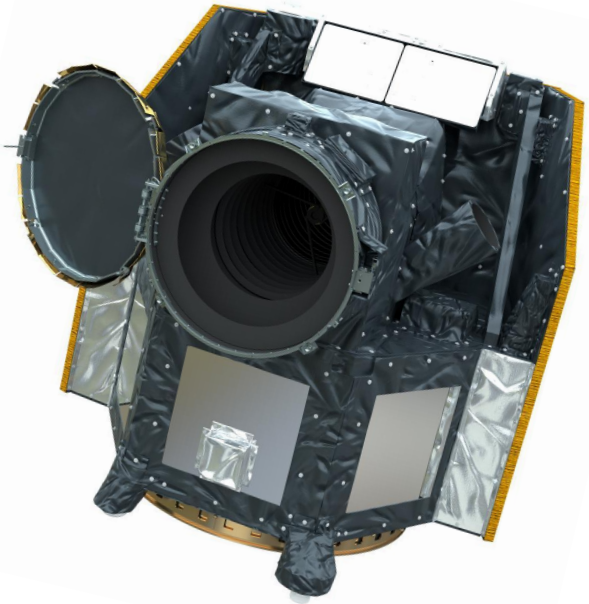
- So far **5671 exoplanets known** –and counting
- **Transit**: a lucky alignment where the planetary orbit is seen edge-on, and we measure a tiny decrease of brightness ~$(Rp/R^*)^2$ due to the dark planet crossing the stellar disk
- Mostly (~75%) detected with the transit technique from ground- or space-based surveys (Kepler, TESS…) and later confirmed/characterized by high-precision radial velocities (HARPS, HARPS-N, Espresso…)
- Mass (RV) & radius (transit) ➜ density ➜ **bulk composition**, but also transits can probe the **planetary atmosphere** and constrain the **dynamical architecture** of the system (through TTVs)!





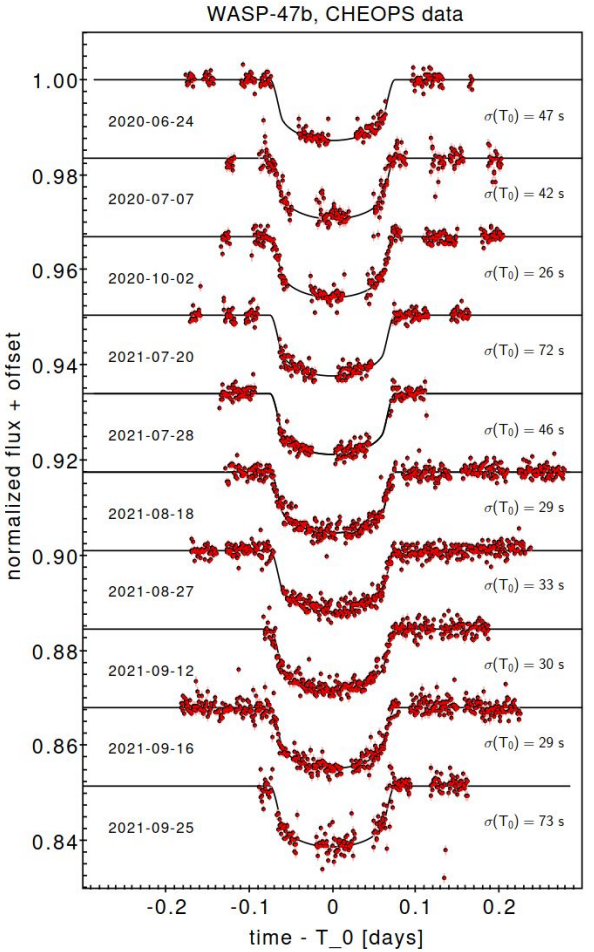
The CHEOPS mission

- ESA S-class satellite, launched in 2019 on LEO; **nominal 3.5-yr mission** ended in 2023, currently running its **1st extension** until 2026 (2nd extension foreseen until 2029)
- Single-target ~30-cm reflecting telescope, designed for ultra high-precision, single-band optical photometry
- **Main goal**: single-target space ~30-cm telescope aimed at the characterization of known transiting planets. *It's (mostly) a follow-up mission*
- 80% of the observing time is managed by a **GTO program** (70% in the extended mission)
- **62 GTO papers** published so far; 26 in preparation



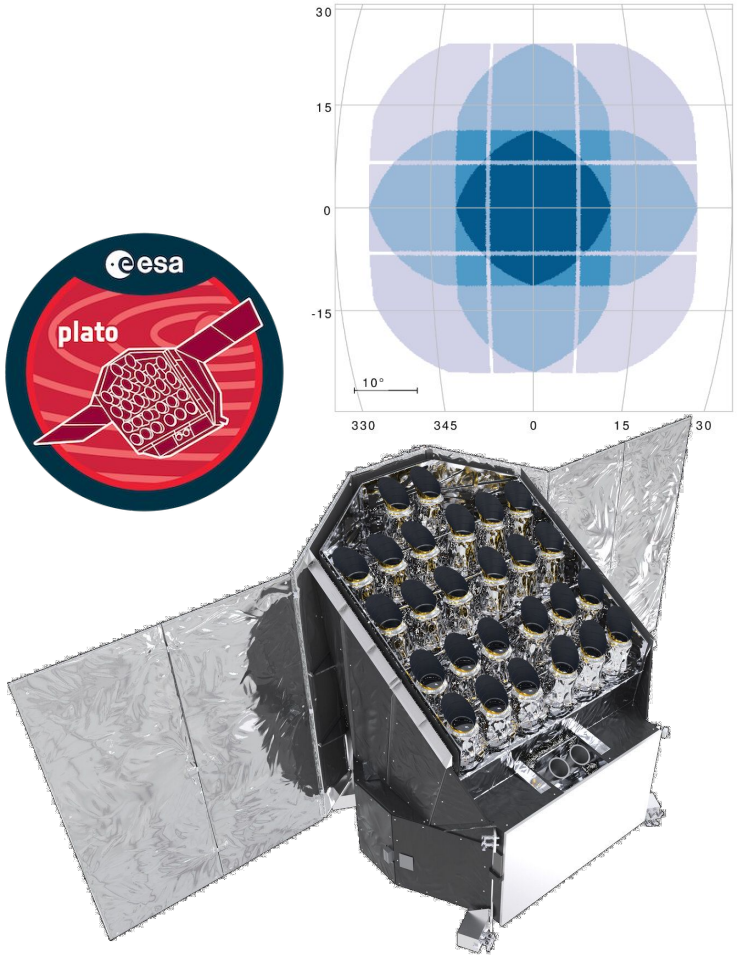
CHEOPS: our contribution

- Borsato, Leonardi, Mantovan, Nascimbeni, Piotto, Zingales.
- Science Team core members/associates, collaborators
- **Responsibility** for the GTO programs **#15** ("*TTVs in warm Jupiters*"; manager: Piotto, Borsato), **#25** ("*Mass-radius relation in planetary systems*"; Nascimbeni), **#66** ("*hot Jupiter system with close companions*", Nascimbeni)
- Contribution to the **dynamical analysis** of multiple systems (TTV modeling, stability…) for many GTO works, through the N-body code TRADES (Borsato+ 2014)
- **Highlights**: TTV analysis of warm Jupiters (Borsato+ 2021), characterization of the WASP-47 system (Nascimbeni+ 2023)



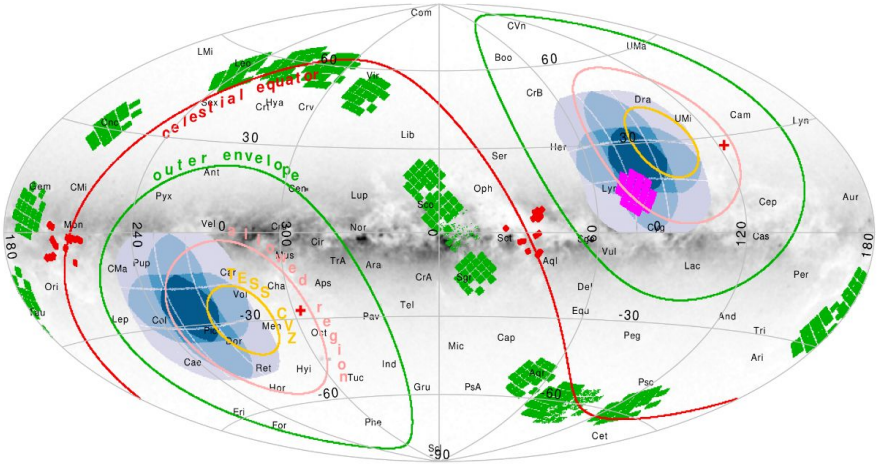
The PLATO mission

- **ESA M-class mission**, to be launched to L2 **end 2026**, currently on schedule. Primary mission 2027-2030 (4 yr), extendable to 6.5 yr (2031.5)
- Array of **24 wide-field cameras** with partly overlapping fields, **~2100 deg²** overall (+2 “fast” cameras with color information). Optimized for ultra-high precision single-band photometry
- **Main goal**: *discovery of transiting planets hosted by bright and nearby stars*, with a particular focus on habitable Earth twins around G stars; accurate characterization of the stellar host including ages through asteroseismology
- **Observing strategy**: combination of Long-duration Observing Phase (LOP), one or two fields for least 2 yr each + A Short-duration Observing Phase (SOP, aka “step & stare”), fields 2-3 months each.

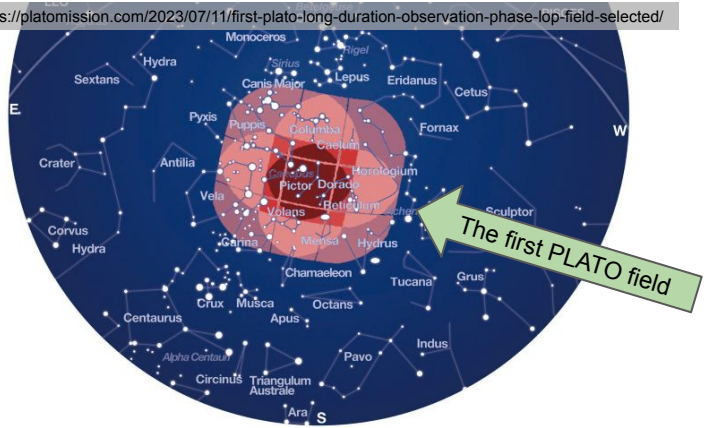


PLATO: our contribution

- Borsato, Desidera, Granata, Malavolta, Nardiello, Nascimbeni, Ortolani, Piotto
- Responsibilities: **WP13 (*Target and field characterization***; top-level: Piotto; WPs: Granata, Malavolta, Nascimbeni, Ortolani), crucial because PLATO will not download full-frame images but rather datafor a pre-selected sample of stars
- First long-duration field (LOPS2) unveiled in 2023. Work ongoing on the other fields
- But also involved in **TTV analysis** (WP11; Nascimbeni, Borsato); **multiple systems** (WP11; Desidera) **light curve filtering** (WP11; Malavolta); **inputs for stellar parameters** (WP12; Nardiello); RV follow-up **hi-res imaging follow-up** (WP14 Desidera; see talk), **RV homogenisation** (WP14 Malavolta)...
- So much work in the next years!

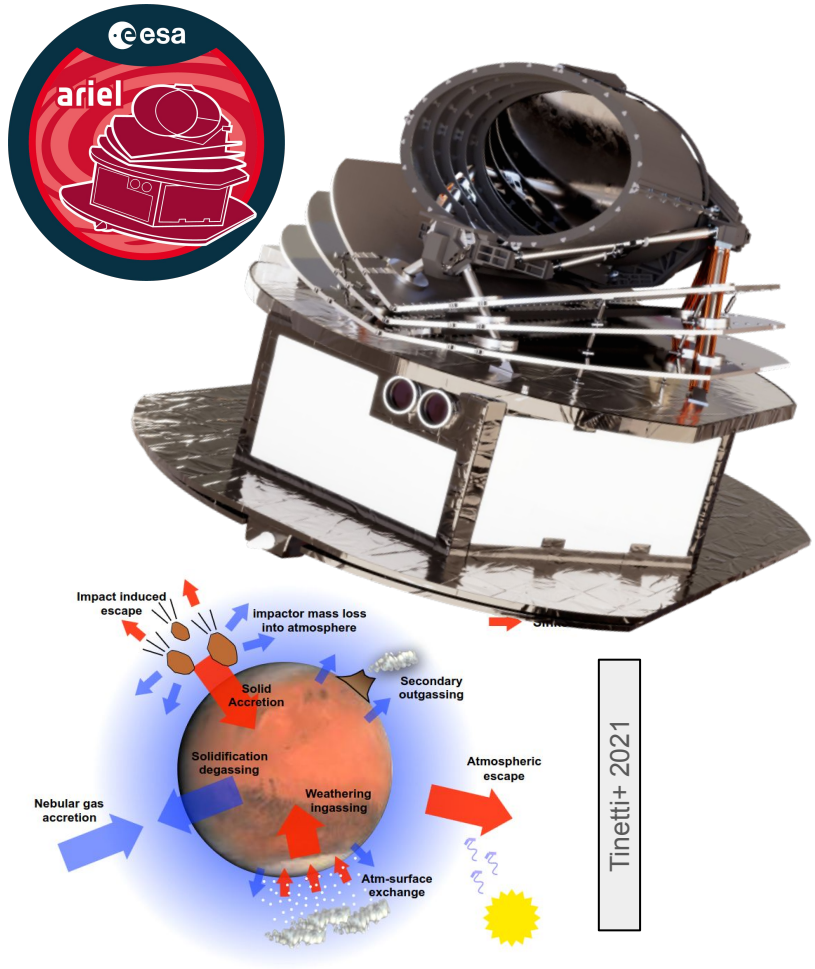


https://platomission.com/2023/07/11/first-plato-long-duration-observation-phase-lop-field-selected/



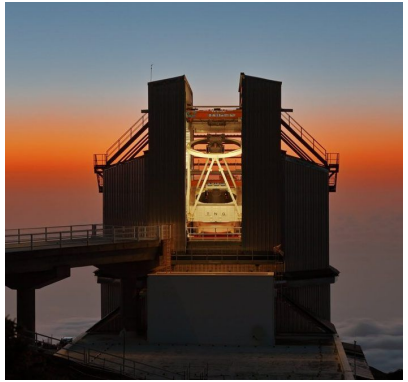
The Ariel mission

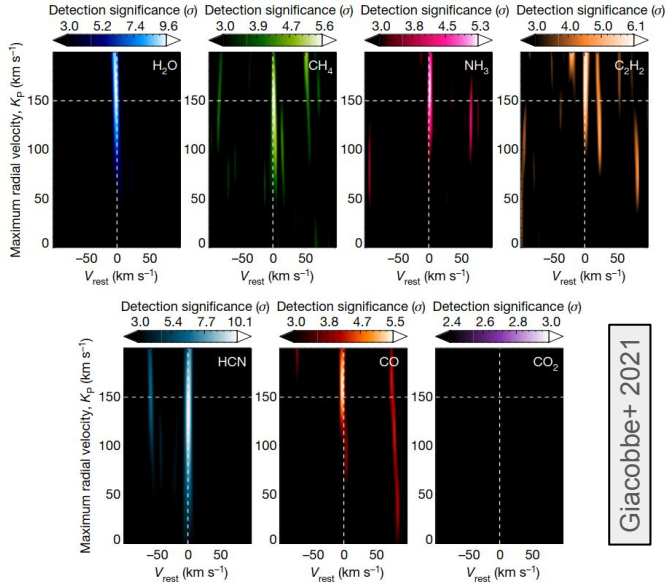
- ESA M-class mission, in construction, to be launched in ~2029 to L2
- ~1-m class telescope equipped with an optical-to-NIR (0.5-8 μm) low-resolution single-target spectrograph + FGS
- **Main goal**: *large scale* (4 yr, ~1000 targets) survey of known transiting planets through transmission/emission spectroscopy to perform a **comparative study of exoplanetary atmospheres** (rocky, icy, gaseous planets)
- Borsato, Nascimbeni, Piotto, Zingales involved, for instance in the *exploitation of the TTV technique on the FGS light curves* (responsible: Borsato; Borsato+ 2022) to the *target selection* task and the *retrieval of atmospheric chemical chemistry* through ML techniques (Zingales+ 2018)



The GAPS/AT collaboration

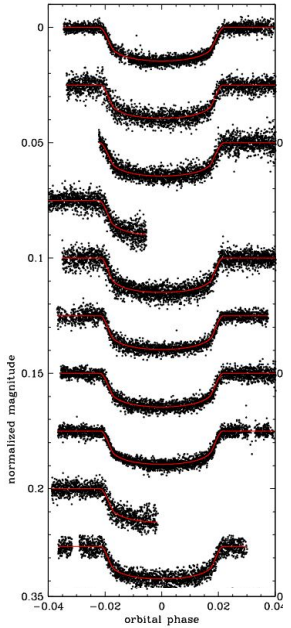
- GAPS (*Global Architecture of Planetary Systems*), a large Italian collaboration for the exploitment of HARPS-N at TNG (and now GIARPS: HARPS-N + GIANO-B) active since 2012; 13 institutes, ~100 researchers
- **GAPS/AT** (2017-; project manager: Nascimbeni) is the program focused on the study of exoplanetary atmospheres through high-resolution transmission and emission VIS+NIR spectroscopy (0.38-2.45 μm). *Little competition in the northern hemisphere*!
- Desidera, Malavolta, Nascimbeni, Stangret, Zingales
- ~12 TNG transits/semester since 2017: large effort at scheduling, observing, analyzing, interpreting the data.
- Also Nascimbeni (2013-2019), Malavolta, Piotto also part of the **HARPS-N GTO consortium** (2012-ongoing)



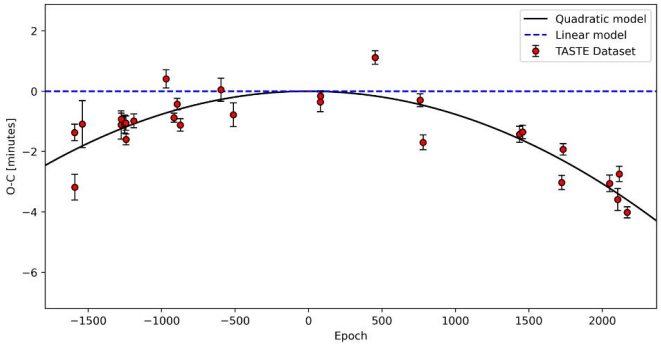


The TASTE project

- **TASTE**: ***T**he **A**siago **S**earch for **T**ransit time variation of **E**xoplanets* (Nascimbeni+ 2011a) is a multi-site, long-term campaign to monitor transiting exoplanets
- Borsato, Granata, Nascimbeni (PI), Piotto
- Ongoing with the **Asiago** telescopes since 2010 (LP 2012-15 PI: Piotto; LP 2016-2024 PI: Nascimbeni). Mostly AFOSC@1.82m, but also 1.22m and Schmidt and also external facilities
- **Science goal**: long-term monitoring of transiting exoplanets (mostly HJs) to search for **TTVs** and **tidal decay** effects, and for a more general characterization (ephemeris/radius refinement, support of GAPS/AT observations, etc)
- **Advantages** of Asiago: 1) *easy access* 2) *scheduling flexibility* 3) *fast reaction* time, 4) perfect as *training* on data analysis
- 18 papers, 4 in prep.



Nascimbeni+ 2013a



Leonardi+ 2024

Some other projects

- *Photometric extraction and detrending of TESS light curves*: Nardiello
- *Astrometric detection of exoplanets*: Barbieri, Nascimbeni, Piotto
- *Machine learning and quantum computing applied to exoplanet detection and characterization*: Pagliaro, Zingales
- Development/maintenance of data analysis software such as TRADES (Borsato), PyORBIT (Malavolta), SLOPpy (Malavolta), STARSKY (Nascimbeni)
- *Pulsation timing to detect planets around Delta Scuti stars*: Nascimbeni, Piotto
- *Characterization of exoplanetary atmospheres through ground-based spectrophotometry*: Mantovan, Nascimbeni, Piotto

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