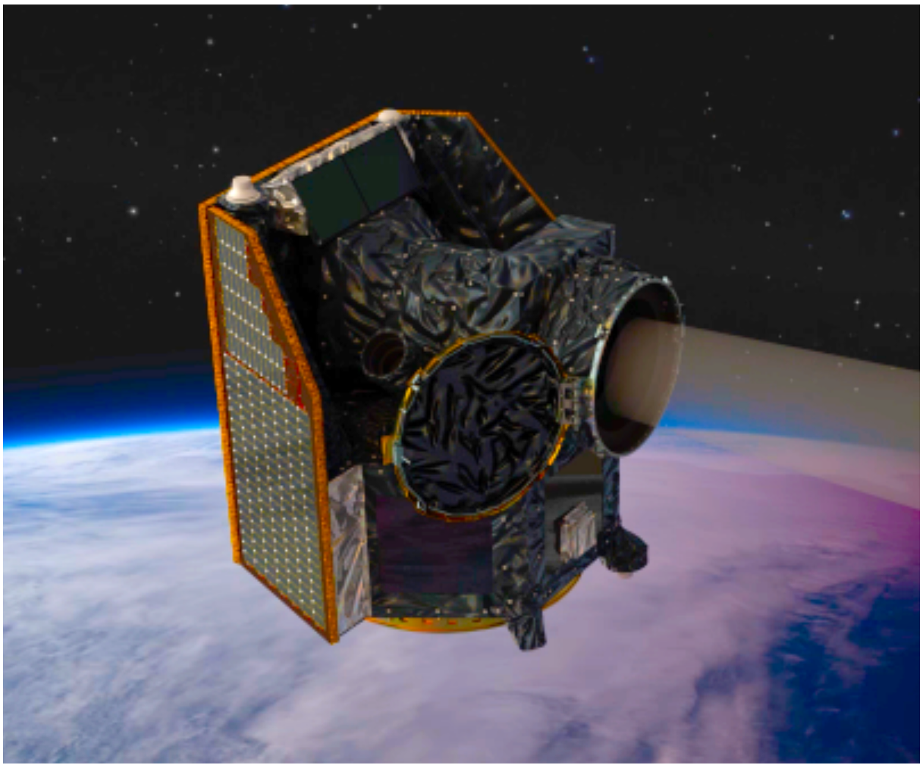

Characterising Exoplanets Satellite (CHEOPS) Guaranteed Time Observation Programme v2.2 (for public release)

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Contents

Introduction

The Characterising Exoplanets Satellite (CHEOPS; Benz et al., 2021) addresses a variety of science topics, much more diverse than originally planned. The follow-up of planetary systems – mostly those newly discovered by the Transiting Exoplanet Survey Satellite (TESS; Ricker et al., 2015) has shown that revisiting systems with a higher photometric precision not only improves planet properties (e.g. more precise radii or masses) but also frequently leads to major changes in of the whole system architecture. One spectacular example of this was the exploration of the TOI-178 system. Originally, TESS discovered three planets in transit (Leleu et al., 2019) while subsequent CHEOPS observations uncovered three more Earth-sized planets. This led to a thorough re-assessment of the entire system architecture, revealing a rare chain of Laplace resonances (Leleu et al., 2021). Such a resonant multi-planet system being dynamically fragile provides invaluable constraints on planet formation theory. Revisiting long-period transiting subneptunes is another bountiful scientific niche for CHEOPS: in the ν^2 Lupi system, originally discovered by radial velocity and for which TESS detected the transit of the two inner planets, CHEOPS uncovered the transit of the third outer planet. Revealing the transit of this volatile-rich super-earth with an outstandingly long orbital period of 107 days (Delrez et al., 2021) provides future access to the atmosphere of a mildly irradiated object, not eroded by stellar radiation. CHEOPS also observed the reflected and emitted light from the burning daysides of ultra-hot super-earths and gas giants by measuring occultations and phase curves with a precision of only a few parts-per-million (Lendl et al., 2020; Morris et al., 2021; Deline et al., 2022). This exquisite precision also made possible the first measurement of the tidal deformation of a giant planet induced by the proximity of its host star (Barros et al., 2022), which opens a new window to probe the internal structure of giant exoplanets. CHEOPS is also allowing monitoring campaigns dedicated at particularly interesting systems, such as that of the young and active red dwarf AU Mic, not only confirming the transit of two young planets, but also measuring their mutual gravitational interactions through the observation of large-amplitude transit time variations throughout strong signs of stellar activity (Szabó et al., 2021, 2022).

These accomplishments are just a few examples of the science enabled by CHEOPS, which establishes it as a reference for precision space photometry. To this date, over 75 articles have been published and many are in preparation by the CHEOPS Consortium. The major scientific impact of CHEOPS emerges primarily along 3 axes: the architecture of systems and structure of planets (chapter 1), the atmospheres and climates of giant planets (chapter 2), and the deep characterisation of planets and their environments at the frontier of exoplanet science (chapter 3).

During the first extended mission (2024-2026), we proposed to focus CHEOPS Guaranteed Time Observations along these three axes of maximum scientific return. In addition, a significant share of CHEOPS observation time is available for community synergies through the Guest Observers (GO) Programme run by ESA and the 'Synergy with other Missions' (SoM) programme run by the consortium (chapter 4), which data are immediately public.

The abstracts and descriptions of observation of the scientific programmes are presented hereafter. These programmes have been designed, reviewed and selected by the CHEOPS Science Team. They tackle the overall GTO science case of the extended mission. The corresponding list of targets, among which the GTO reserved targets, the amount of time requested and the different target priorities, are dynamic information that are available online at URL `https://cheops.unige.ch/pht2/search-reserved-targets/`.

Summary of the Guaranteed Time Observations

Table 1: The GTO programmes selected by the CHEOPS Science Team to tackle the science goals of the Extended Mission.

ID	Shortname	Axis	Programme title	p.
CH_PR140061	Diva	2	A Deep search for hot JupIter VAriability	23
CH_PR140062	Capegg	2	Constraining atmospheric properties of an eccentric gas giant	23
CH_PR140063	Tides	3	Measuring tides that shape planetary systems	32
CH_PR140064	AlphaCen	1	Is there a transiting planet around α Centauri?	9
CH_PR140065	Ygal	1	Solidifying Planet-Star Composition Links by Studying Why the Internal Structures of Planets Across the Galaxy Vary	17
CH_PR140066	Maverick	1	Uncovering a maverick population: CHEOPS observations of hot Jupiter systems with inner small companions	16
CH_PR140067	ArchiChess	1	Probing the architecture-composition-metallicity link	11
CH_PR140068	HotWaterMelon	1	Constraining the abundance of water in hot planets	15
CH_PR140069	Dusty	3	Photometric Transients in Dusty Debris Disks	31
CH_PR140071	AuMic	1	Opening the treasure chest of the young golden system AU Mic with CHEOPS	11
CH_PR140070	ExoComet	3	Photometric transits of exocomets	31
CH_PR140072	ExoMoons	3	Where are the exomoons?	30
CH_PR140073	Gclmp	1	Gas content of low-mass planets	14
CH_PR140075	Evos	1	Giant planets around EVOlved Stars	14

Axis 1

Architecture and structure of planetary systems

1.1 Introduction

The architecture of planetary systems – the orbital properties of planets within one system – and its relation to both stellar metallicity and planetary internal structure and composition, provides unique and novel clues with which to understand the formation, migration and evolution of multi-planet systems (Winn and Fabrycky, 2015). For instance, the chain of planets in Laplace resonances unveiled by CHEOPS around TOI-178 provides strong constraints on how the planets migrated to their current orbits (Delisle, 2017; Leleu et al., 2021).

Planet formation models predict such composition-architecture correlations. Indeed, the internal composition of planets depends on the available solids in the protoplanetary discs, whereas the orbital architecture results from migration driven by the gas content over time. The host star metallicity provides a relation between both components. Additional evidence for such correlations has been demonstrated in a small sample of ∼20 transiting systems, where stars with sub-solar metal content tend to harbour water-poor rocky planets in compact ($a < 0.3$ au) multi-planet systems (Adibekyan et al., 2021).

The scientific objective of Axis 1 is to investigate these correlations further by increasing the handful of well characterised compact multi-planet systems known today. Given their scarcity, any additional well-characterised system will represent a major addition. Achieving this objective requires: 1) identifying suitable multi-planet system candidates; 2) measuring precise and accurate radii and masses for all planets in the system to infer planetary internal compositions; 3) linking planetary architectures and compositions observed today to the ones at the end of the formation phase accounting for atmospheric escape through the study of the evolution of planetary atmospheres (Bonfanti et al., 2021; Wilson et al., 2022).

It is anticipated that the planets discovered by TESS, especially those with longer periods likely to be detected during TESS extension, will provide most of the new systems to be studied by CHEOPS. We will reveal the architecture of these new systems by 1) confirming new planets discovered at low SNR, 2) discovering new planets using transit-timing variations (TTVs), 3) determining the orbital periods of transiting planets on wide orbits. With the CHEOPS-determined TTVs or follow-up radial velocity (RV) measurements obtained in collaboration with RV consortia, we will derive the planetary masses. With their masses and radii known, their internal structure and composition will be determined as a function of stellar metallicity. These systems will become Rosetta stones for planetary formation and evolutionary theory.

1.2 Axis 1 programmes

1.2.1 AlphaCen

Is there a transiting planet around α Centauri?

Abstract

Alpha Centauri is the third brightest star in the night sky and the closest stellar system to us. It is composed of two stars similar to the Sun, Alpha Cen A and B, and a more distant but gravitationally bound red dwarf, Proxima (the actual closest star to the Sun). Alpha Cen exerts a profound fascination on mankind, from science fiction stories to actual science, and it is also the case for exoplanetology. In 2012, Dumusque et al. (Nature, 491, 207) announced from RV measurements a planet orbiting Alpha Cen B, but its existence is still under debate. In 2015, Demory et al. (MNRAS, 450, 2043) found in highly-saturated Hubble Space Telescope observations of Alpha Cen B a single transit-like event $\sim$95 ppm deep and $\sim$3.6 h long. A likely explanation is an Earth-sized planet with an orbital period shorter than 20 days (the median of the likely orbits is 12.4 d). As envisioned by the authors in their conclusion, it was not possible to confirm this transit event in years that followed, because of the lack of ability of all space-based telescopes to employ successful observing strategies for ultra-bright stars, by mitigating saturation problems.

With this program we aim to observe Alpha Cen with CHEOPS, in order to try to recover the transit seen by Demory et al. (2015). Discovery of transiting planets is a very compelling gain, and confirming a transiting planet around our closest stellar neighbor would have tremendous implications, beyond the exoplanet and even the scientific communities. More generally, CHEOPS observations will allow us to place strong constraints on the presence of close-in transiting planets around Alpha Cen, which is a very valuable objective on its own, and complementary to the current efforts for direct imaging of farther planets around Alpha Cen (Kasper et al. 2019, The Messenger, 178, 5).

Description of the observations

A single 20-day long visit (300 orbits), in order to cover all the possibilities of the transit seen by Demory et al. (2015). The visibility of Alpha Cen by CHEOPS is only 3 months long: early April to early July (with lower efficiency in June compared to April and May).

1.2.2 Arc

Architecture of Resonant Chains

Abstract

Resonant chains are gold mines for fueling our understanding of planetary systems. The minute details of their architectures encode the history of their formation: the order of the capture of the planets in the chain (Delisle 2017), the local shape of the proto-planetary disc and its dispersal (e.g. Nesvorny et al 2022) and the long-term evolution of the system through tidal dissipation (e.g. Papaloizou et al 2018). The high multiplicity of these systems also makes them especially valuable to constrain our models of the formation of planetary systems (See Emsenhuber et al 2022 and other papers of the NGPPS series) since all the planets have to form in the same environment, and the relative fragility of the configuration ensures that no violent evolution (e.g. close encounters/impacts) occurred after the dissipation of the proto-planetary disc (Leleu et al 2021). In addition, the transit timing variations induced by the compactness of the systems allow for precise mass determination, down to a few per cent in the case of Trappist-1 (Agol et al 2021). This allows an in-depth characterization of moderately insolated rocky planets and mini-Neptune, with a precision which is rarely reachable through radial velocities, enabling studies of their interiors and atmospheres. The brightness of the current targets of the program (Gaia band mag 11 for TOI178, 12 for K2-138, 8.4 for TOI1835) allows to combine RVs and photometric measurements. The two methods have a great synergy, as TTVs allow for in-depth characterization of the resonant configuration, while RVs can constrain the mass of non-resonant planets and characterize the non-transiting part of the system. For all these reasons, these systems are also golden targets for the James Webb Space Telescope.

The program aims to complete, understand and constrain the resonant architecture and planetary masses of key multi-planetary systems, as well as discovering new chains of resonances. This will be achieved by predicting and confirming missing planets in a resonant chain based on the known architecture, and a long-term TTV follow-up of the systems. This is an iterative process: the prediction and confirmation of planets increase the interest for a given system for an in-depth TTV characterization, while a better characterization of the system can point toward missing planets and lead to new detections.

Description of the observations

700 CHEOPS orbits are required, to constrain the architecture of the systems using transit timing variation and confirm the existence and orbits of new planets in known chain, or new chains. The confirmation of the predictions of new planet orbits should be conducted as soon as possible to reduce the cost of ephemerides drifts. For such observation, several visits can be necessary if several orbits are possible. These visits are typically of the order of 20 CHEOPS orbits. The long-term TTV follow-up typically requires to observe at least 2 transits per planets per year to constrain the instantaneous orbital period. Less can be required in the event of no variations on timescale shorter than a year, or if the target is re-observed by TESS that year. More can be needed if the transit is low SNR, or if the planet shows short-term TTVs (chopping). With a typical visit of about 5 to 10 CHEOPS orbit.

1.2.3 ArchiChess

Probing the architecture-composition-metallicity link

Abstract

Planet formation models predict the existence of a link between the orbital architecture of a planetary system, the composition of its planets, and the metallicity of the central star. This correlation results from the following two processes: On one hand, the temporal evolution of the gas content of the protoplanetary disk causes migration of the planets and therefore determines the orbital architecture of the system. On the other hand, the composition of the planets depends on the structure and composition of the disk of solids, itself related to the gas content of the disk and the solid-to-gas ratio in the disk. This latter quantity is finally correlated with the stellar metallicity. The goal of ArchiCHESS is to observe multi-planetary systems to constrain their architecture (using architecture coefficients of Mishra et al., 2023) and relate this to the water fractions of the planets, as well as to the metallicity of the central star.

Description of the observations

We will observe transits of planets in multi-planetary systems to improve their radius precision. We consider two samples of planetary systems: systems with at least three known transiting planets (sample 1) and systems with two known transiting planets (sample 2), with 5 systems in sample 1 and 9 systems in sample 2. For both samples, our goal is to refine the radius ratios of the planets down to an uncertainty of 1.5%. The number of transits that is needed to reach this precision was estimated using the ETC and lies between 1 and 20 for each of the planets in the selected systems.

1.2.4 AuMic

Opening the treasure chest of the young golden system AU Mic with CHEOPS

Abstract

AU Mic is a young (∼22 Myr) active M1 star known to host two transiting warm Neptunes close to the 9:4 mean-motion resonance. CHEOPS observations have unveiled transit timing variations (TTVs), which are too large to be due to the weak resonance of AU Mic b and c, suggesting that an additional resonant planet is likely present in the system. We discovered that the rotation period of the star and the orbital period of AU Mic b are in a 7:4 spin-orbit commensurability. We also found systematic variations in the transit depth that correlate with the star's brightness, strongly hampering the accuracy on the planetary radii. We finally discovered that AU Mic displays differential rotation, making it the youngest "red" star known to feature equator-to-pole spot migration.

AU Mic is a "young goldmine" for planetary and stellar physics, a treasure chest just waiting to be opened. Thanks to its short-cadence space-born photometry, CHEOPS is uniquely well suited to seize this opportunity. We propose to carry out an intensive CHEOPS observing campaign of AU Mic to:

- Constrain the TTV signals of AU Mic b and c, and measure their masses.
- Unveil the inner architecture of AU Mic via TTVs, confirming the presence of a third planet in the system, and getting new insights into its inner architecture, young resonant dynamics, and (still on-going?) planet migration.
- Measure the TTV super period to inform future transit observations with JWST.
- Derive accurate planetary radii by combining CHEOPS transit photometry and ground-based follow-up observations.
- Study, for the first time, the equator-to-pole differential rotation, magnetic cycle, and spot evolution of a 22-Myr-old M star.

Description of the observations

Observations covering 8 and 9 orbits are planned to cover transits of AU Mic b and c, respectively. During the visits, continuous observations are planned with an exposure time of 5 sec to resolve the fine structures in flares.

1.2.5 ChOIs reloaded

ChOIs 2.0: new *CHEOPS* Objects of Interest within the Mission Extension

Abstract

While the TESS mission is monitoring the sky for planetary transits, its photometric precision is lower than that of CHEOPS. This means that signals detected at low signal-to-noise by TESS can be confirmed with CHEOPS. We will observe such low SNR candidates from TESS, with a three-fold objective:

1) we will follow-up tentative signals in multi-planet systems, as these are less likely to be false positives than systems with a single planet; 2) we will prioritize the confirmation of candidates that can be confirmed by ongoing and future radial-velocity campaigns; 3) we will collect sufficient transits to measure radii with a precision of at least 6%. Such precision, coupled with a 10% precision on the planetary mass, is necessary for a detailed analysis of both the internal structure of the exoplanet and the formation/evolution process of the system.

Description of the observations

We will observe targets with potential planetary candidates orbiting TESS stars and which were missed-out by the TESS detection pipeline for various reasons. Each target will be observed by CHEOPS once, in order to certify the presence of the planet and later re-observed if the signal appears to be real.

1.2.6 CompoSubNeptu

What are sub-Neptunes made of? A multifaceted approach

Abstract

Sub-Neptunes are the most common type of known planets in the galactic neighborhood. In spite of that, their interior composition, and therefore their origin, has to date not been constrained observationally. The reason is the degeneracy in possible compositions that can explain their observed properties. Two end member compositions are theoretically suggested: dry rocky cores + about 1% of H/He or ocean planets containing about 50% water in mass. The former is suggested by evolutionary evaporation models, the later by formation models. These compositions correspond to fundamentally different in situ formation versus orbital migration pathways. If observationally it should turn out that close-in sub-Neptunian planets are indeed water worlds, this could be seen as one of the largest successes of planet formation theory. The opposite case would mean that one or several elements of our current understanding of the origin of planets is fundamentally flawed. It is therefore of paramount importance to answer the fundamental question "What are sub-Neptunes made of?".

With this program, we propose a three-faceted approach to answer this question, which is not only key for Axis 1 (the study of "planetary structure and system architectures"), but also for the SOM category of the extension. The three facets are: 1) is there a grouping in density? 2) Preparing for the JWST opportunity. 3) Is the ice mass fraction correlated with the stellar composition? We propose to use CHEOPS for the precise radius determination of a carefully chosen sample of TESS planet candidate, whose radii make them susceptible to be either ocean worlds or rocky cores with H/He envelopes.

Description of the observations

We propose to observe with CHEOPS the transits of a sample TESS planet candidates to precisely determine their radii. We selected 20 candidates with a radius between 1.4 and 2.5 Re. The candidates span a broad range of orbital periods and orbit stars brighter than a V magnitude of 11. We require from one to seven visits per target in order to refine the radius precision down to a few percents.

1.2.7 DetectiveCheops

Detective CHEOPS - confirming small transiting planets on long orbital periods

Abstract

Bright transiting planets are key planets for the characterisation of exoplanet atmospheres and internal structures. However the vast majority of such planets have short (P¡20d) orbital periods. This is because long-period transiting planets do not produce consecutive transits in photometric survey data. However, these planets are some of the most interesting as, unlike their interior companions, they are less affected by the gravitational and electromagnetic effects of their host stars. We propose to use CHEOPS to efficiently detect characterisable small transiting planets on long orbital periods. We will do this by leveraging as much external information as possible to constrain orbital periods - from non-consecutive transits (i.e. mono-, duo- or trio-transit candidates) in photometric

survey data such as K2 or TESS, and from radial velocities where available. Such techniques have been shown to be successful in the CHEOPS nominal mission with for example the photometrically-constrained TOI-2076 c & d (Osborn et al 2022), or the monotransit+RV case of TOI-561 d & e (Lacedelli et al 2021 & 2022). We expect to be typically able to detect the transits of such planets in only 40 orbits, and expect more than a dozen such detections during the 2-year extension. These planets, once found by CHEOPS, may also form interesting science targets for other parts of the GTO extended mission science case such as studying the architectural diversity of exoplanetary systems, and even searches for exomoon & rings.

Description of the observations

We will attempt transit searches for 5-8 long-period planet candidates per year. The majority will be planets with only photometric data (i.e. 2 or 3 transits) for which we will calculate the most probable aliases. For these we would schedule visits which cover both the purported transit and reasonable out-of-transit baseline, observing up to 10 period aliases per target. Lower-priority higher-SNR planet candidates can be observed with shorter visit lengths and greater scheduling flexibility. In some rare cases we may require two observing seasons to successfully recover the true period. We expect a small number of candidates from RV detections which may require longer visits.

1.2.8 Evos

Giant planets around EVOlved Stars

Abstract

Despite the large number of detected planets, only a handful of them have been found orbiting evolved stars, and even fewer transiting with short period orbits. Studying giant planets around evolved stars provides useful information on the impact of stellar evolution on planets, their atmospheres, and architecture of planetary systems in general. These planets can also contribute to understanding the mechanism for late-stage planet inflation. It is thus necessary to have a good statistical sample of well-characterised giant planets around evolved stars. We propose a follow-up of TESS planet candidates around evolved stars to populate this parameter space and allow better statistical study. We propose to also refine the radius of such detected planets that have been detected by TESS using long-cadence observations.

Description of the observations

We will observe transits of candidate giant planets around selected evolved stars identified from TESS. Our targets are bright stars with R ¿ 2Rsun, logg¡ 4, Teff¡ 6000K. The number of transits required for radius refinement is determined on a case-by-case basis but for a maximum of seven transits per target.

1.2.9 Gclmp

Gas content of low-mass planets

Abstract

The priority questions for planetary sciences are aimed at understanding the origin of planetary systems and life. Planet formation is a complex process that starts with the condensation of matter in a disc of molecular gas and dust. Planetesimals grow into planets, accrete material, lose volatiles, chemically evolve and outgas, contract as they cool down, and finally are destroyed, or survive, when the star dies, ejecting back material into the interstellar medium and possibly starting again a new cycle. Most of the evidence that we have on these processes comes from the study of our Solar System and astrophysical observations of neighboring stars. The detection and characterization of extrasolar planets revealed a diversity of planetary systems beyond the Solar System but these discoveries challenged existing planet formation theories. Precisely characterized bulk properties of exoplanets help place constraints on the varying formation conditions and evolution processes in order to understand the origin of exoplanets. In this program, we propose the characterization of long-period ($P > 15$ days), low-mass gas-rich planets (defined as planets with radii between 2 and 4 Earth radii) by refining their planetary radii.

Description of the observations

Targets in the program will primarily be selected from TESS detections and they are prioritized based on a range of criteria, such as visibility with CHEOPS, host star properties, characterization from ground (e.g. availability of RVs) and prospects for atmospheric characterization with JWST. We will observe transits of several sub-Neptune planets. Each target will require 2-4 individual transit observations in order to refine the planetary radii to the desired 3% precision.

1.2.10 HotWaterMelon

Constraining the abundance of water in hot planets

Abstract

Planets located close enough to their star experience evaporation, which leads to a dichotomy in the possible gas content of these objects. These planets either contain more than around one percent of gas (in mass), or no gas at all (see Owen and Wu, 2017). This dichotomy, when expressed in term of mass-radius relation, implies the existence of a region in the mass-radius diagram of hot planets, where dry planets cannot exist. We propose to observe planets that could lie in this region with CHEOPS. Combining a precise radius and mass will allow us to identify planets in this forbidden region, hence showing that they have to contain volatiles, most likely water. Our data, combined with future JWST observations, will also constrain the efficiency of evaporation.

Description of the observations

We will observe transits for a sample of 10 planets. These were selected on the basis that they fall in the forbidden region described above, with a radial velocity semi-amplitude of at least 0.5 m/s (based on our internal structure models) and an equilibrium temperature between 900 and 1400 K. We aim to reach a precision of 3% on the radius for all planets in our sample. Using the ETC, we estimate that between 4 and 19 transits will be necessary to achieve this precision, depending on the planet.

1.2.11 Maverick

Uncovering a maverick population: CHEOPS observations of hot Jupiter systems with inner small companions

Abstract

Planetary systems hosting a hot or warm Jupiter (HJ/WJ) plus nearby small companion(s), such as WASP-47 (Nascimbeni et al. 2023, arxiv:2302.01352), are extremely rare and very valuable to constrain formation and migration models. Only five such systems are known so far. Our goal is to increase the sample size by confirming and characterizing five TESS candidates with such an architecture, and improving their orbital/physical parameters including ephemeris, radii, and (when feasible) planetary masses through TTVs. As demonstrated by our work on WASP-47, RVs and TTVs are very synergistic at decoding these complex systems. A dedicated RV follow-up will be coordinated.

Description of the observations

We will observe transits of exoplanets in multiple systems to measure transit timing variations. We selected the sample of targets among the TESS objects of interest (TOIs) systems brighter than V=12, multiplicity ¿=2, at least one planet larger than 6 R_Earth, well visible by CHEOPS: TOI-2350, TOI-2494, TOI-5398, TOI-5143, WASP-132. They are all hosted by solar-type stars and validated at high confidence levels. Based on our experience with TTV follow-up observations with CHEOPS, we expect that at least 5 visits scheduled per year and per planet are needed to gather the needed S/N to detect the TTV signal. All visits will be scheduled at priority 2, except for TOI-5398 (as highest-priority target) and the first visit of the remaining planets.

1.2.12 S-Valley

Towards an S-type radius valley determination

Abstract

The number of planets orbiting binary stars has notably increased in the past three years thanks to follow-up of Tess Objects of Interest by direct imaging and Gaia. The demographic properties of planets in binaries are only starting to be unveiled. An important question to address for planets around binaries is that of the radius valley, a deficit of exoplanets with 1.5 to 2.0 Earth radii found for planets orbiting single stars. A recent study by Sullivan et al. (2023) reports that no radius valley exists for S-type planets (planets in binaries orbiting only one of the stellar components). The study was performed with a sample of Kepler planets, which suffers from large errors in the planetary radii. In addition, the planets were assumed to orbit the primary star, which adds an additional (and large) source of error in case a planet orbits in reality the secondary star.

With this program, we re-address the radius valley question by combining past observational data with new measurements from CHEOPS.

Description of the observations

We propose to observe the transit of 9 planet candidates with CHEOPS. We constructed our sample by filtering for several criteria which are relevant for our science case and for being able to know the stellar radii and masses of the two stellar components of the binaries.

1.2.13 Ygal

Solidifying Planet-Star Composition Links by Studying Why the Internal Structures of Planets Across the Galaxy Vary

Abstract

Terrestrial planets form through the accretion of building blocks from dust grains to proto-planets. Heavier components sink and form metallic cores, whilst pebbles from beyond snow lines deliver volatiles influencing atmospheres or water on Earth-like planets. Understanding the composition of planetary ingredients is vital. Planetary refractory elemental abundances mirror stellar values; the Earth is a devolatised piece of the Sun. If this is universal we would expect a diversity in internal structures and atmospheres of planets orbiting metal-diverse stars. This is currently not well investigated, however in recent years tantalising evidence has emerged for metallicity-driven trends in the physical characteristics of super-Earth and sub-Neptune exoplanets. These first pieces of evidence might be pointing towards chemically-diverse formation scenarios impacting the internal structures of planets, however this is currently unclear as there are very few well-characterised small planets around metal-poor stars. Therefore, we propose a program to refine the radii of a handful of key planets around Galactic thick-disk, metal-poor host stars to an unprecedented level in order to solve the current mysteries that we are just starting to unravel.

Description of the observations

From our sample of exoplanet candidates around thick-disk, metal-poor stars, we propose the following observing strategy. If needed, an initial CHEOPS visit of a transit to secure the ephmerides as well as aid our radii refinement goal, followed by multiple shorter visits of transits to achieve the radius precision needed for our science case. The need for an initial longer visit will be assessed on a planet-by-planet basis by conducting a pre-CHEOPS transit fit of all available photometry. From our experience, these visits typically last 7-10 CHEOPS orbits depending on orbital period, whereas the shorter visits are expected to last 4-8 CHEOPS orbits depending on transit width and out-of-transit baseline. Within the nominal mission we have found that 5 visits per target are needed to obtain a precise planet radius.

1.2.14 Youngster

Monitoring of YOUNG STars for Exoplanet Recovery

Abstract

Young exoplanetary systems offer unique opportunities to study planetary systems which are still evolving to their mature distributions and compositions. However, the characterisation of young exoplanets is severely complicated by the stellar activity of their host stars. In order to precisely characterise young exoplanets, it is crucially important that we understand the behaviour of their host stars when measurements are taken. This programme represents a new CHEOPS filler program to photometrically monitor the stellar activity of several young exoplanet candidates from TESS while they are being actively followed up by the HARPS and NIRPS spectrographs to measure these planet candidates' masses. These planet candidates are key targets to constrain early planet evolution, given their ages of < 50 Myr and position in the dynamic hot-Neptune desert/savanna.

Description of the observations

We aim to use a series of 1-2 orbit fillers to track the stellar variability of several young exoplanet candidate-hosting stars which are undergoing spectrographic follow-up for mass measurement with HARPS or NIRPS.

1.2.15 Duke

Do you like Kepler-9?

Abstract

The focus of this CHEOPS GTO proposal is a warm giant planet ($P_{\rm orb} > 10$d, $R_p > 8\ R_\oplus$) that exhibits a strong TTV signal, indicating the presence of a low-order resonant companion. All the information we currently have suggests an architecture similar to Kepler-9 and to other systems with a warm giant and one or more companions with periods ¡ 100 days. Moreover, this warm giant is well-suited for JWST atmospheric characterisation, and the proposed CHEOPS observations are crucial to enable such future studies.

Description of the observations

We will observe 11 transits of TOI-5552. The average visit duration for our target is 15 hours 9 CHEOPS orbits. We add 4 orbits to the first visit to take into account the ephemeris drift. The observations are time critical, as we need to observe the warm gas giant planet during its transits.

1.2.16 Outer

Observing Unseen Transits of External Relatives

Abstract

Using single-orbit filler observations, we will observe the potential transit windows of known long-period ($P > 1$ year) planets which have transiting companions. If these systems are geometrically 'flat' (i.e. the mutual inclinations between orbital planes is low), such planets will have greatly enhanced transit probabilities. The planets are massive, and hence will produce deep transit signals that can be detected by differences in the mean flux level of each visit. The expected transit durations are long (> 12 hours), and so a cadence of $\sim$2 visits per day is sufficient to cover the 2-sigma transit window, which is typically 1-5 weeks long. CHEOPS data will be combined with TESS and ground-based data where applicable, to cover as much of the transit windows as is possible. Detecting long-period transiting planets is valuable for a range of open questions in exoplanetology, including the atmospheres of temperate gas giants, the search for exomoons, and understanding the architecture of systems beyond 1 au, which is a valuable input for formation and evolution models. Specifically, these observations may help determine whether the 'flat' architecture observed in tightly-packed multi-planetary systems extends to sparser systems containing planets with longer orbital periods.

Description of the observations

Filler observations during the predicted windows of transit for known (RV) planets, which are not known to transit.

1.2.17 Host-S

HOST star identification in S-type binaries

Abstract

Around half of Sun-like stars in our galaxy are in binary systems, yet fewer than 10% of validated/confirmed exoplanets are found orbiting one of the stellar components of the binary (S-type configuration). Nevertheless, follow-up campaigns are revealing blended stellar companions to known planet-hosting stars, putting into question which of the two stars is the real planet host. Furthermore, without properly accounting for dilution effect on the transit depth, the planet radius will be underestimated. Our HOST-S program aims to identify the planet-host star of TOI candidates in blended S-type binaries, using the same observing and analysis strategy as in the successful S-Valley program. This program also aims to reduce the error in planet radius to less than 3% and to foster radial velocity programs. This will allow to obtain accurate mean density and construct a increasingly filled Mass-Radius diagram for S-type planets, particularly in the Neptune desert and savanna. Furthermore, once the host is identified, we also aim to refine the ephemerides, which is essential for future planet characterization, and to search for potential transit timing variations (TTVs) that may indicate additional planetary companions.

Description of the observations

We observe the transit of 5 TOIs in blended S-type binaries. To get accurate estimates of the stellar densities from the transit parameters, we impose an higher efficiency in the regions corresponding to the transit ingress/egress.

1.2.18 Chromatic

Validation of young exoplanets using multi-colour photometry

Abstract

Young exoplanets represent some of the most interesting yet challenging exoplanets to characterise, existing in one of the most dynamic eras of exoplanet evolution. However, due to the combination of the increased stellar activity of their young hosts and the pressure on existing high-precision radial velocity instruments, many smaller (sub-Jupiter) young exoplanet candidates will not be confirmed through spectroscopic measurement of their masses, and hence require other means to validate them as planets. Here we propose to use CHEOPS in combination with a suite of ground-based instruments to measure simultaneous multi-colour transits of eight promising young exoplanet candidates, with the aim of validating them as planets. The design of this program also gives the opportunity to explore the effects of stellar activity of the transits of these young exoplanets, and to search for any signs of transit timing variations (TTVs). While the former provides opportunities to look at mapping the stellar surface of these young stars, any TTVs could point help to put an upper mass on these challenging young systems and also hint towards other planets in the systems. In total we request five visits of each target, for a total of 220 orbits.

Description of the observations

Two to five observations of the following young exoplanet candidates, in order to validate them using multi-colour photometry and search for additional TTVs. Candidates: TOI-612, TOI-2519, TOI-4596, TOI-6555, TOI-6557 Observations will be carried out in two stages:

- Stage 1: Priority 1 transit observations of a transit of each target concurrent with at least one ground-based instrument (2 transits).
- Stage 2: Additional Priority 2 transits with CHEOPS only for any promising validated candidates to map the surface of their host stars and search for any transit timing variations (three transits).

1.2.19 Syzygy

Planet-planet eclipses during transit

Abstract

A rare geometric phenomenon in celestial mechanics is when multiple bodies line up on a straight line, a so-called syzygy. For transiting multiplanetary systems, a syzygy would result in a planet fully or partially eclipsing another planet while both are transiting the star, called an overlapping double transit. These events can be used to strongly constrain relative orbital parameters between the planets. This programme is designed to use the strengths of CHEOPS to try observe such planet-planet eclipse events.

Description of the observations

Double-transits are rare and typically not periodic, so each OR is for a single double-transit event, with the hope of detecting a planet-planet eclipse. Some targets are shared with other programmes.

1.2.20 SnowLeopards

Snow Line Exoplanetary Origins from Precise Attributes in Resonant Dynamical Systems

Abstract

We propose to investigate the formation and evolution of planetary systems by focusing on near-resonant planet pairs using the CHEOPS space telescope. These systems, where two planets orbit in near-integer period ratios, offer valuable insights into planetary migration, particularly from regions beyond the snow line where planets may form with substantial water mass fractions and H2 envelopes. Recent studies suggest sub-Neptune planets in resonant configurations are less dense than their non-resonant counterparts, indicating unique formation histories influenced by migration. Testing this hypothesis is critical for understanding planetary system evolution. Our primary objective is to confirm the presence of transit timing variations (TTVs) for our 56 selected planets and refine their planetary radii. TTVs are a hallmark of gravitational interactions in multi-planet systems and provide a means to validate dynamical interactions and improve orbital parameters. By obtaining precise transit timing measurements, we will confirm TTVs in near-resonant configurations, advancing our understanding of planetary dynamics. In the mission extension, we aim to derive precise planetary masses for systems with confirmed TTVs. By combining these with refined radii, we will determine the planets' bulk densities, providing insights into their interior structures and atmospheric compositions. Our work will contribute to theories of planetary migration and evolution, with broad implications for exoplanetary science, while also identifying prime candidates for follow-up atmospheric studies with JWST.

Description of the observations

Photometric observations of targets that might show transit timing variations in 24 systems with multiple planets. We want to observe at least 2 transits until the end of 2026 to detect transit timing variations.

Axis 2

Atmospheres of exoplanets

2.1 Introduction

One of the main impediments to our quest for a better understanding of planet formation and the emergence of life is the scarcity of constraints on the chemistry, energy budget and overall conditions in exoplanet atmospheres. Atmospheric science is therefore a focal point for current and future observatories (JWST, ELTs, ARIEL). The first 2 years of the CHEOPS mission have demonstrated that the combination of high photometric precision, sufficient observing time, visible light sensitivity and the capacity to repeat observations over several years, ensures a unique role for CHEOPS in an otherwise rather crowded landscape, especially regarding the atmospheric properties of gas giants (Lendl et al., 2020; Hooton et al., 2022; Deline et al., 2022).

Scattering processes in exoplanet atmospheres are poorly understood. The challenge is to measure optical phase curves for objects with temperatures low enough that thermal infrared emission does not contaminate the reflected light signal and confuses their interpretation (Heng and Demory, 2013). To date, the cleanest measurement of this kind has been retrieved for the hot Jupiter Kepler-7b (Demory et al., 2013). This single reflected light phase curve has served as a legacy of the Kepler mission and has inspired numerous follow-up studies. Thanks to its precision and sensitivity in the blue, CHEOPS is in a unique position to establish new benchmarks. The occultation measurement of the hot Jupiter HD 209458b (Brandeker et al., 2022) demonstrates that the required precision to obtain an optical phase curve on this and new targets is within reach, provided the use of an extended time baseline during the extension.

Our understanding of observations of exoplanet atmospheres relies on the assumption of time-invariant properties. However, rare phase-curve observations obtained with Kepler (Armstrong et al., 2016; Jackson et al., 2019) have shown significant variability: fluctuations of wind structure (Rogers, 2017) or aerosol formation & disappearance (Armstrong et al., 2016); the origin of this variability is difficult to identify given the small number of cases detected and the lack of complementary data. The additional measurement opportunities provided by a mission extension, combined with the precision and pointing flexibility of CHEOPS, will address this issue and probe the different time scales of exoplanet climates.

Given the complementarity in terms of temporal coverage with TESS (and PLATO later) and in terms of bandpass with JWST, the CHEOPS mission extension will offer unique opportunities for contemporaneous observations. These could reveal, e.g., the origin of the phase curve of 55 Cnc e (Morris et al., 2021), the meteorology of long period and highly eccentric planet like HD 80606b (Lewis et al., 2017), and the thermal profile of ultra-hot Jupiters like WASP-76 b (May et al., 2021).

2.2 Axis 2 programmes

2.2.1 Diva

A Deep search for hot JupIter VAriability

Abstract

The temporal stability of hot Jupiter atmospheres remains an open question. While there are several tentative detections of changes in the observed planetary occultation depths, phase curve shapes, or transmission spectra, no indisputable evidence exists to date. This program will perform a deep search for variability in the dayside brightness of several hot Jupiters.

Description of the observations

We will repeatedly observe occultations of three hot Jupiters to search for variations in the observed planetary dayside brightness. The observations will be time-constrained such that timescales of 1 - 100 days are well-sampled, as well as achieveing a season-to-season measurement. For each target, we plane to observe 20-30 individual occultations.

2.2.2 CapEgg

Constraining atmospheric properties of an eccentric gas giant

Abstract

HD 80606 is a unique planetary system with a Sun-like star hosting a highly-eccentric ($e > 0.9$) Jupiter-size planet with an orbital period 111.4 days. The orientation of the system with respect to the Earth is such that we are able to see both the transit and the occultation of HD 80606 b. The occultation occurs a few hours only before the periastron passage allowing us to observe the planet dayside at its highest temperature. Laughlin et al. (2009) could determine that the atmospheric temperature undergoes a rapid heating of more than 500 K (from 725 K to 1250 K) when approaching the star. The planet spends most of its time far from its star, where the received irradiation is hundreds of times smaller than the one at periastron allowing for reflective clouds to form in the atmosphere. The program aims at observing the occultations of HD 80606 b to constrain its reflectivity (geometric albedo) and infer the presence of reflective clouds, their composition and/or possible on-going evaporation processes.

Description of the observations

The observing strategy is to cover the occultations of HD 80606 b with an out-of-eclipse baseline to capture the rapid planetary flux increase-decrease around periastron. The baseline will also serve for the correction of instrumental systematics. The observations will start 20 hours before the occultation to mitigate the possible thermo-mechanical ramp effect at the beginning of the visit and to capture the flux increase as the planet approaches periastron. The observations will end 20 hours after the occultation to properly cover the predicted flux peak (after the occultation and just before periastron) and the following flux drop. Finally, given that HD 80606 has a binary companion, we will request the target to be observed without the automated on-board guiding, or PITL for "Payload In The Loop", preventing the spacecraft to point to the barycenter of the two PSFs and having both stars rotating around the image center.

2.2.3 Terminators

Constraining morning and evening terminators of exoplanets

Abstract

Exoplanetary atmospheres are 3D objects and various physical processes make them inhomogeneous over different parts of the planet. In particular, several studies have demonstrated that different thermal structures and wind patterns over the morning and evening terminator can produce an inhomogeneous cloud coverage over the atmosphere. However, a common assumption made while performing transmission spectroscopy of exoplanets is of a homogeneous atmosphere. Considering such an inhomogeneous atmosphere as a homogeneous one can lead to biases in retrieved atmospheric properties. Inhomogeneities in the atmosphere also leave an impact on broadband photometry. In this program, we aim to detect this effect directly on the transit lightcurve of three planets. The magnitude of this effect could be as large as 1000 ppm for suitable targets, which CHEOPS should be able to detect comfortably. While inhomogeneity can be in chemical structure or aerosol properties, we mainly aim to put constraints on asymmetric cloud coverage with CHEOPS observations. We have identified WASP-54 b, HAT-P-30 b and WASP-131 b, as being the best candidates for detection due to their atmospheric transmission signal, transit duration and temperature. Our observations would pave a way for future observations with spectroscopic capabilities to constrain the inhomogeneous atmospheres of these planets.

Description of the observations

We plan to observe multiple transits of our planets to achieve enough signal-to-noise ratio to detect the asymmetry in the lightcurve. The sample of planets itself was selected from all known exoplanets to have the highest probability to detect this effect, i.e., the planets that have a higher atmospheric transmission signal, a larger transit duration and a proper temperature range. Since the signal is maximum during the ingress/egress period, we plan to observe the transits such that ingress/egress is observed with the highest efficiency. This is to ensure that we do not miss data from this range.

2.2.4 Albedos

Constraining geometric albedo and day-side temperature of ultrahot Jupiters

Abstract

CHEOPS has observed the occultations of several hot-Jupiters during the nominal mission and successfully characterised their atmospheres. Building onto the success stories like WASP-189b, MASCARA-1b, WASP-12b, WASP-76b, KELT-9b, KELT-20b etc., we propose a program to study the newly discovered Ultra Hot-Jupiters of TESS to further explore their reflective and thermal properties with CHEOPS. Under this program, we aim to observe the newly validated TESS UHJs and provide precise observational constraints on the planetary gray-sky geometric albedo and the dayside brightness temperature within the CHEOPS-TESS passband.

Description of the observations

This program aims to provide high-precision constraints on the geometric albedo of UHJs. The observational strategy is to observe occultations of the target with a sufficient baseline to cover the instrumental systematics and known phase curve trends. The exact number of visits will be set depending on the depth and precision measured by TESS, accounting for realistic CHEOPS noise and the expected depth in the CHEOPS passband.

2.2.5 Bengal

Beyond Geometrical Albedo: A deeper understanding of the reflective behavior of exoplanet atmospheres

Abstract

Our knowledge of the reflective properties of exoplanet atmospheres is extremely limited outside of the Solar System planets. The geometric and Bond albedo measurements constitute the majority of the subject's observational constraints. Reflected light phase curves hold the key to gaining a better understanding of the fundamental scattering properties: single scattering albedo and asymmetry, as well as determining the degree of inhomogeneity in the spatial distribution of clouds, hazes, and aerosols. However, due to observational biases, the vast majority of existing datasets that show a clear phase curve signal in the visible are aimed at hot gas giants. As a result, they are plagued by the degeneracy between reflected and thermal light. Only Kepler-7 b was cool enough and Kepler sensitive enough to deliver a high precision phase curve that is dominated by reflected light. Kepler-7 b is thus the only exoplanet for which we have direct measurements of cloud distribution inhomogeneity and fundamental scattering properties.

With this program, we will leverage CHEOPS' photometric precision, bandpass and pointing flexibility to perform repeated phase curves observations of a few key targets. These canonical datasets will provide precise reflected light

phase curves and will offer long-awaited counterparts to Kepler-7 b. We will investigate atmospheric inhomogeneity and measure fundamental scattering properties. We will begin to explore the diversity of exoplanet atmospheres by focusing on planets with different properties than Kepler-7 b.

Description of the observations

We will rely on repeated phase curve observations. The main target selection criterion is to achieve a signal-to-noise ratio of 5 to 10 at the peak of the reflected light phase curve. According to our simulation, a signal-to-noise ratio of 5 is required to constrain the single scattering albedo and asymmetry meaningfully. To determine whether a given target meets this criterion, we require an existing measurement of Ag with a signal-to-noise ratio of at least 5 at visible wavelength. We do not limit ourselves to planets cold enough for the contribution of thermal light to the CHEOPS bandpass to be negligible (below 15%), as JWST could provide a strong enough constraint of thermal light to robustly decontaminate the CHEOPS phase curve. Furthermore, probing a planet with different equilibrium temperatures would allow us to begin investigating the diversity of the exoplanet population, which is a compelling argument for including another target in this program.

2.2.6 55CncE

A Panchromatic probe in 55 Cancri e's remaining questions

Abstract

In the past two years, CHEOPS observations of the hot super-Earth 55 Cancri e have provided key insights on the origin of the optical short time-scale phase-curve variations. In particular, the data at hand enable to constrain the size distribution and composition of possible dust particles that would be ejected by the planet. Alternately, we cannot firmly discard the possibility that star-planet interactions are at play and cause the observed modulations. During the mission extension, we will be able to grasp several opportunities to nail the origin of the CHEOPS photometric variations through parallel observations with other facilities, monitoring 55 Cnc at different wavelengths (e.g. JWST) or by using different observing techniques (e.g. spectro-polarimetry). The coordinated observations will provide a robust means for disambiguation to firmly capture the process at play in the atmosphere of this iconic world.

Description of the observations

We ask for two CHEOPS visits to cover the already scheduled and proposed JWST parallel observations as well as two CHEOPS visits for the Neo-NARVAL observations. One 55 Cnc e CHEOPS visit encompasses 22 orbits (36h). As our previous experience with CHEOPS 55 Cnc observations showed us, a longer baseline enables a more accurate assessment of the stellar variability during the parallel observations with the paired facility. We thus ask for 88 CHEOPS orbits in the frame of this programme. NB: The proposed observations will not be triggered in case they are not scheduled on these facilities.

2.2.7 Vulcan

Observing the dayside emission from lava planets

Abstract

Ultra-short-period (USP) rocky planets are a unique class of planets that orbit their host stars in less than a day. Because of their proximity to their host stars, they experience intense stellar irradiation resulting in extreme temperatures on their permanent dayside. Indeed, it is believed that the dayside temperature on many USP planets could reach as high as 2000 K. Such a high temperature can melt the surface of the planet resulting in the creation of magma ocean on its dayside. The high temperature on the planet's dayside starts the surface evaporation that can generate a secondary rock vapour atmosphere on the planet. We aim to detect the emission from a possible rock vapour atmosphere on one USP TOI-1807 b using CHEOPS. TOI-1807 b, with an orbital period of 13 hr and a dayside temperature ¿1700 K, is an excellent candidate for hosting a secondary silicate atmosphere. Theoretical models for a rock vapour atmosphere on TOI-1807 b suggest that the emission from the planet should be high enough to be detected in the optical CHEOPS bandpass. Our extensive observing program will try to detect this signal by observing many occultations of the planet. The detection of the planet's occultation with CHEOPS would provide a strong indication of the silicate atmosphere on the planet's dayside.

Description of the observations

We plan to observe high precision occultation observations of TOI-1807 b using CHEOPS in order to constrain the dayside emission from the planet.

2.2.8 Bengalii

Beyond Geometrical Albedo II: A deeper understanding of the reflective behaviour of exoplanet atmospheres

Abstract

Our knowledge of the reflective properties of exoplanet atmospheres is extremely limited outside of the Solar System. The geometric and Bond albedo measurements constitute the majority of the observational constraints. The current BENGAL program of CHEOPS aims to drastically improve the current state of the art by providing high signal-to-noise reflected light phase curves to constrain fundamental scattering properties: single scattering albedo and asymmetry, as well as determining the degree of inhomogeneity in the spatial distribution of clouds, hazes, and aerosols. BENGAL has focused on hot and ultra-hot Jupiter-sized planets. In this extension, we aim to observe a smaller and unique target: the ultra-hot sub-Neptune LTT 9779 b. LTT 9779 b is a singular sub-Neptune which retained its gaseous atmosphere despite its high dayside brightness temperature (2300K). Crucially for the program, it is also known to be highly reflective.

Description of the observations

We will rely on repeated (currently 12 visits are foreseen) phase-curve observations to reach a signal-to-noise of 5 on the phase curve. We want to cover 1.2 orbital period at each visit, starting with an occultation and ending with the next one. We aim to intentionally spread the visits over the visibility window, to address potential time variabilities of the atmosphere

2.2.9 GoldenPC

Golden Phase-Curve

Abstract

WASP-121b is a cornerstone Ultra-Hot Jupiter orbiting a bright F6-type star and one of the most-studied exoplanets with several phase curve observations in the infra-red from HST and Spitzer. It is also the hot Jupiter with the most compelling evidence for variability known. We propose to observe WASP-121 through two seasons with CHEOPS, obtaining in each season a high-precision optical phase curve. These data will allow us to anchor emission spectra at different longitudes of the object in the optical, constrain the composition, isolate inhomogeneous scattered light and finally probe the presence of variability.

Description of the observations

We will observe phase curves of WASP-121b, starting between 1 and 3 orbits before occultation and ending 1-3 orbits after the successive occultation.

Axis 3

New frontiers in exoplanetary science

3.1 Introduction

The unique precision of CHEOPS has pushed space-borne photometry of exoplanets into new territories. This is best demonstrated by the measured optical phase curve of a super-Earth (Morris et al., 2021) or the measurement of a gas giant Love number (Barros et al., 2022). Combined with the longer observational baseline provided by the mission extension, CHEOPS can further push the limits and achieve additional ground-breaking results defining new frontiers in exoplanetary science. Tidal forces acting over long timescales have the power to sculpt planetary systems through the transfer of angular momentum. Orbital decay due to tidal interaction was detected unambiguously for the first time (Yee et al., 2020) by TTV measurements carried out over several years. The CHEOPS mission extension will allow the precision measurements needed to detect tidal decay in other systems, offering key insights into the timescales of the various tidal processes shaping planetary systems.

CHEOPS can observe the transits of long-period planets (≥ 100 days) without restriction, provided the transit time is known. The extended mission, offering the possibility to stack several transits of such long-period planets and therefore to increase the precision further, will lead to new science: only long-period planets can host moons and rings on stable orbits (Dobos et al., 2021); none have been conclusively detected so far even though a few candidates exist (Teachey and Kipping, 2018; Kipping et al., 2022). By observing enough out-of-transit baseline for planets such as ν^2 Lupi d, CHEOPS can explore their Hill spheres and potentially provide a first exomoon detection. Ring systems could be detected as for example in HIP 41378 f, whose anomalously low apparent bulk density might be caused by an extensive ring system mimicking a large planetary radius (Akinsanmi et al., 2020). Long-period planets are not tidally locked and therefore might be rotating fast enough for CHEOPS to measure their oblateness and derive their rotation velocity. Finally, young stars with ongoing planetary formation or in a late-heavy-bombardment stage host debris discs, which exhibit transient and shallow transits when viewed edge-on. CHEOPS monitoring of these 'exocomets' will allow to better understand these systems. Any unambiguous detection of one of the above would represent a 'first' in exoplanet systems and a significant step towards putting our solar system in an astronomical context.

3.2 Axis 3 programmes

3.2.1 HD31221

Photometric confirmation of planet candidate HD 31221 b

Abstract

HD 31221 is one of only a handful of δ Scuti type stars hosting close-in, substellar companions. Such systems are excellent testbeds for understanding how planetary mass objects can influence the stellar oscillations, while also being well-suited for atmospheric investigations. Based on the TESS light curve, HD 31221 b has a radius of 1.32 ± 0.14 R_J and a mass of 11.5 ± 10.3 M_J. It's phase curve is dominated by the reflection effect, owing to the high geometric albedo. The host star, HD 31221 is a rapid rotator ($v \sin i = 175.31 \pm 1.74$ km s^{-1}), which means that radial velocity measurements are not feasible. Because of the rapid rotation however, the spin-orbit misalignment can also be derived. Combining the CHEOPS data with the existing TESS observations, we will be able to narrow down the possible mass ranges of HD 31221 b, while the two different bandpasses will let us carry out a detailed atmospheric investigation as well.

Description of the observations

In order to be able to effectively subtract the stellar pulsations from the light curve of HD 31221, we need observations on a relatively long baseline. We will achieve this by observing HD 31221 between two occultations of its companion, during two separate visits. As HD 31221b has an orbital period of 4.67 days, each of the visits will be made up of 70 orbits. As a result, we will be able to handle the stellar pulsations, and we shall be able to analyze the phase curve of HD 31221b.

3.2.2 ExoMoons

Where are the exomoons?

Abstract

During the past thirty years, astronomers have discovered many extrasolar planets (e.g., Batalha et al. (2013)) which has sparked an excitement in the community whether these exoplanets may host a detectable and/or a habitable satellite, so called extrasolar moon or exomoon. The technological and theoretical methods now allow the detection of sub-Earth-sized extrasolar planets and the first detection of an extrasolar moon appears feasible (Heller et al., 2014), but so far there is not a single case where the existence of an exomoon could have been demonstrated. Detecting the first exomoon would be a major discovery because

moons can be new places for habitability Awiphan and Kerins, 2013; Heller and Barnes, 2013; Heller, 2012, can play a significant role in the evolution of the host planets and can play a key role in stabilising rotation axis (as Moon does for Earth, Laskar et al. (1993)). Even though the mechanisms of moon formation are not fully understood, moons seem to be an outcome of planet formation and a presence of exomoons would provide invaluable information on the planet's interior and formation process (Crida and Charnoz, 2012). To answer the question "Where are the exomoons?" we would like to continue the search for them in the extended phase of the CHEOPS mission.

Description of the observations

In order to detect moons as small as 0.75 Earth-sized, we will select Sun-sized stars that have a brightness of 9 magnitude or greater. To increase the stability of potential exomoons, we will observe planets with periods longer than 50 days. Shorter-period systems are more likely to be unstable. We will limit ourselves to planets at and above the size of Neptune. We will allocate sufficient out-of-transit time to capture possible exomoon transits within the planetary Hill sphere.

3.2.3 Dusty

Photometric Transients in Dusty Debris Disks

Abstract

Here, we propose to extend the previous CHEOPS survey to systems with warm dust disks, regardless to the orientation of the disk, but with positive detections of photometric transients from the disk with TESS. The targets will be selected from the results of Ansdell et al. (2020) and Gaidos et al. (2022); Gaidos (2022), in respect to the expected efficiency of CHEOPS observations, and if possible, simultaneously to TESS observations. The simultaneous CHEOPS+TESS multiband data will give us the first two-band space photometry of scattering dust in distant solar systems.

Description of the observations

Continuous observations are planned with an exposure that maximises the S/N ratio. We propose the observation window of 60 orbits (4 days) per target. The targets are planned to be observed by CHEOPS simultaneuously with TESS revisits. All stars have been previously observed by TESS. This will help refine priors of the stellar signal, which makes the removal more reliable.

3.2.4 ExoComet

Photometric transits of exocomets

Abstract

We propose to observe the spectroscopically proven exocomet-hosting systems with CHEOPS. This will be a continuation of the similar program during the

nominal mission, but during the extended mission, emphasis will be on the two-band TESS+CHEOPS photometry and the synchronous spectroscopic observation to observe the same transit in spectroscopy and photometry for the first time. Photometric observations will give us an insight to the structure and the total scattering cross section of the comet in transit, while spectroscopy shows us the total amount of refractory elements in the line of sight. Combining these two, we will be able to observe the parameters of the dust, such as the content of refractory elements in the dust, and we can infer to the size distribution index of the dust grains.

Description of the observations

Continuous observations are planned with an exposure that maximises the S/N ratio. We propose the observation window of 60 orbits (∼4 days) per target. The targets are planned to be observed by CHEOPS simultaneuously with TESS revisits. All stars have been previously observed by TESS. This will help refine priors of the stellar signal, which makes the removal more reliable.

3.2.5 More

Measuring the Oblateness and rapid Rotation of Exoplanets

Abstract

Planets can attain non-spherical shapes as a result of the forces acting upon them. Centrifugal forces due to rapid planetary rotation lead to an equatorial bulge referred to as oblateness. Saturn has the largest oblateness within the Solar system owing to its fast rotation and low density. Therefore, measuring the oblateness can provide information about the rotation rate of a planet and its interior structure which can in turn provide insight into the dynamical history of the planet. The oblateness signal amplitude depends on the extent of oblateness/rotation of the planet. We propose to leverage the precision of CHEOPS to probe for large oblateness indicative of super-rapid rotation rate in selected planets around bright stars.

Description of the observations

We will observe multiple transits of selected long-period planets in order to measure their rotation-induced oblateness. The number of transits per target is determined on a case-by-case basis depending on the brightness of the star and the expected amplitude of the oblateness signal.

3.2.6 Tides

Measuring tides that shape planetary systems

Abstract

Ultra-short orbital period planets suffer from intense tidal forces which lead to a deformation of the planet's shape (Correia, 2014; Barros et al., 2022) and shrinkage of the planet's orbit. Measuring the tidal deformation of the planet allows us to estimate the second-degree fluid Love number and gain insight into the planet's internal structure. Moreover, measuring the tidal decay timescale allows us to estimate the stellar tidal quality factor, which is key to constraining stellar physics. Therefore, studying tidal effects in ultra-short orbital period planets gives us a wealth of information on planet-to-star tidal interactions that shape planetary systems. We also propose to estimate the tidal decay of a few hot-Jupiters for which we expect a measurable orbital period decrease within the next 3 years. The longer baseline allowed by the CHEOPS extension will be crucial for our ability to measure the tidal decay of some systems. During the CHEOPS nominal mission, we achieved a breakthrough on the direct detection of the tidal deformation of exoplanets. Building on these results we also propose to better constrain the tidal deformation of WASP-103b and WASP-12b directly from the transit deformation signature (similar to Barros et al. 2022) and also from the signature in the phase curve (similar to Akinsanmi et al in prep.).

Description of the observations

Our ability to measure the tidal decay increases linearly with the increase in the time span of the observations. Therefore, our strategy is to spread the observations of each target during the 2 years of the mission extension. Since $Q'_\star$ is uncertain by orders of magnitude we can not predict when we will be able to significantly measure the orbital period variation of the planet. Hence, the best strategy is to keep obtaining measurements every year and continuously adapt the planning of the observations and which targets to focus on. If we get a hint of a detection, we can increase the number of observations in the following year to increase our ability of detection. We selected targets which have a large predicted tidal decay signal, excluding those with faint or otherwise difficult to observe (e.g. pulsating) host stars. This leaves us with 5 good targets already previously observed with CHEOPS and three possible new targets which are also observable with CHEOPS, prioritised by stellar magnitude and predicted signal amplitude. As for the nominal mission we only observe the targets in the years where TESS does not observe the targets to optimise the observing time and spread of observations. WASP-12b and WASP-103b are the only targets for which we can measure the tidal deformation with CHEOPS. Our current precision on the Love number is not enough to have a good constraint on the internal structure of these planets. However, a large number of transit observations would be required to improve the current precision, it would require 70 CHEOPS transits to reach 5-sigma. This number could be highly reduced if other observations are available. Therefore, depending on observations by other facilities, we would like to have the possibility to obtain some transits 10 for each planet in the last year of the extension to combine with other datasets.

3.2.7 OrbitalWaltz

Looking for precession in eccentric hot Jupiters

Abstract

We propose to conduct photometric follow-ups for six eccentric hot Jupiters with CHEOPS to extend their observational baseline. Our aim is to improve

constraints on their orbital parameters and investigate long-term transit timing variations (TTVs) indicative of apsidal precession. These measurements will not only enhance our understanding of the dynamical evolution of these systems but also provide valuable insights into the interior structures of eccentric hot Jupiters, by computing the planet Love number k2,p .

Description of the observations

We will observe several transits of five eccentric HJs with CHEOPS. (Gaia-2b, XO-3b, GJ-436b, TOI-778b and WASP-186b) For each target we considered between 7 and 8 orbits, covering each time the transit window plus a baseline of 2.5 orbits.

3.2.8 Chewd

CHEOPS Hunt for Exoplanets and debris around White Dwarfs

Abstract

We will use the CHEOPS space telescope to search for planetary material orbiting close to white dwarfs (WDs). White dwarfs are the dense remnants of stars like our Sun, which, during their evolution, expand into red giants that can engulf nearby planets and asteroids. Despite this, observations show that many WDs continue to accrete planetary or asteroidal material, indicating that remnants survive or are delivered close to the WD over time. Our primary goal is to discover new transiting systems by utilizing CHEOPS's capabilities for high-precision, high-cadence photometry to search for short-term variability caused by the transits of planets, asteroids, or debris disc structures. A key aspect of this project is determining the magnitude limit achievable with the new PIPE data reduction pipeline, which will enable the detection of transits of fainter targets. Given the small number and diversity of known transiting systems, any new detection will be significant and will improve our understanding of their frequency and characteristics.

Description of the observations

Photometric time series with durations of 2 CHEOPS orbits to be scheduled flexibly.

3.2.9 Grinch

GRanulation IN teCHnicolor

Abstract

We propose to observe the chromatic signature of stellar granulation, in one of the first studies of this kind. The wavelength dependence of granulation was observed for the Sun, but constraints are lacking for other stars, especially those on the main sequence. We can take advantage of the complementarity of the CHEOPS bandpass compared to TESS's to probe "colored granulation" in a sample of bright stars, recently published for the study of their oscillations with

TESS. We selected those objects for which we expect the highest S/N detections with CHEOPS: as they span a significant part of the F and G exoplanet host star parameter space, our results will be an asset for exoplanet atmospheric characterization.

Description of the observations

The targets were extracted from the sample studied by Corsaro et al. (2024), and chosen among those that maximize the potential efficiency of CHEOPS observations (found by limits in DEC and dedicated simulations). Moreover, we rejected the stars with Gaia magnitude ¿6, in order to minimize the white noise level. We request the efficiency of our observations to be at least 70%. Following simulations. we request enough visits to reach a granulation signal detection of S/N = 4 for each target. We initially set each visit duration to 5 CHEOPS orbits, but might adjust this parameter to optimise visit scheduling.

Axis 4

Synergies with other missions

4.1 Introduction

4.2 SoM programmes

4.2.1 ArielExoClock

Ephemeris Refinement of Key Ariel Targets

Abstract

To uncover the demographics of exoplanet atmospheres, ARIEL will require a large, diverse list of potential targets. Luckily, ground-based and space-based surveys have detected hundreds of transiting planets around bright stars. However, simply knowing of the planet's existence is not enough and preliminary characterisation efforts must be undertaken to ensure the suitability of the target for study. A key piece of information is an accurate knowledge of the predicted transit time of a planet. In this programme, CHEOPS observations will be used to support the Ariel mission by maintaining the ephemeris of critical targets.

Description of the observations

We will take transit observations of exoplanets which will be suitable for study with ARIEL but currently have poor constraints on their predicted transit time.

4.2.2 ArielGranulation

Characterising granulation in the ARIEL Reference Sample

Abstract

This is a pilot study to characterise stellar granulation in a representative subset of the Ariel Reference Sample. Sulis et al. (2023) showed that granulation has a strong chromatic effect and is able to significantly contaminate observations

in the visible channels of the Ariel telescope. Results from CHEOPS photometry will be combined with the spectroscopic information collected by the Ariel Stellar Characterisation working group, in order to provide a more detailed picture of stellar granulation in the observed targets, constraints to optimise Ariel observing time, and input for the development of modelling and data analysis techniques.

Description of the observations

We selected a short list of bright mid-F to mid-G type targets for which we expect a significant granulation signal, and which can be observed by CHEOPS with high efficiency. CHEOPS high-precision photometric time series will allow us to derive the characteristic granulation amplitude and frequency for these stars. Observations can be carried out any time. The number of needed visits was assessed using SNR estimates based on Kallinger et al. (2014) results for similar stars and the CHEOPS ETC. The duration of the visits was motivated by experience with CHEOPS data detrending from instrumental effects. We will need $> 70\%$ (ideally, $> 80\%$) observation efficiency in order to reduce gaps in the time series to a minimum, as they are known to degrade the granulation signal.

4.2.3 Chateaux

CHeops And TEss vAlidate Unconfirmed eXoplanets

Abstract

The science goals of both TESS and CHEOPS require confirmed and characterised small planets around bright stars. While many TESS candidates (or TOIs) exist, only a small fraction have so far been validated as true planets - this is in part due to limited follow-up resources. We propose a synergy programme between CHEOPS and TESS which would use unconfirmed TOIs as filler targets during the CHEOPS extended mission. These observations would improve TOI ephemerides & radius precision, as well as constraining parameters which could assist in the validation of these candidates as bona fide planets such as chromaticity & transit centroid. We plan to observe select TOIs where CHEOPS observations can uniquely aid their validation by performing strict cuts on brightness, transit depth, period, etc. Despite these cuts, hundreds of TOIs fit these criteria and many are near- or in-transit at any one time, allowing great flexibility in scheduling despite the time-critical nature of these transit observations. This has been demonstrated by a successful pilot programme during the nominal mission. We plan to work closely with TESS teams to prioritise the most interesting candidates, and share CHEOPS-derived information directly with the community to assist and potentially speed-up planetary confirmation. We expect a handful of TOIs to be scheduled as 3-orbit fillers per month, potentially allowing 100-150 such candidates to be observed during the extended mission.

Description of the observations

We will filter and rank candidates for various metrics to ensure that the candidates are very likely not false positives, and that the CHEOPS data which may be acquired is useful. The pilot will test the following four aspects: - Are the ORs successfully scheduled? - What should our thresholds be for filtering (e.g. on the minimum Cheops SNR expected)? - Can we successfully detrend data using only 3 orbits? - Do we obtain scientifically useful transit photometry?

4.2.4 JWST

Simultaneous exoplanet observations with JWST

Abstract

JWST observations of exoplanet transits, occultations, and phase curves, can strongly benefit from simultaneous high-precision photometry in the optical. Advantages range from disentangling even minute stellar variability from the planetary signal to help characterise the exoplanet atmosphere, from e.g. the strong wavelength dependence of potentially time variable aerosol hazes. Since approved JWST programmes are scheduled well in advance, this synergy programme is designed to attempt simultaneous exoplanet observations with CHEOPS whenever possible. The total number of requested orbits is expected to be around 100 per year.

Description of the observations

The observations are set to be time constrained to already scheduled JWST observations. The duration of each visit depends on the planned JWST visit, but typically lasts for 5 orbits for transit and occultation observations, and longer (10-20 orbits) for phase curves. Since simultaneous observations with JWST requires time constraind to a specific date, the period of the planet is irrelevant and quoted as 10 days to simplify the start phase slack calculation.

4.2.5 Pre-PlatoTTVigil

Transit Timing Variation observations to fill In Gaps In Long-baseline data

Abstract

Important current questions of exoplanet science require an underlying precise determination of planet internal structures that can be done by studying their mass and/or orbital evolution. Transit timing variations (TTVs) can bypass stellar activity issues that can hinder RVs observations to achieve accurate mass determination, and transit timing monitoring may reveal tidal decay that can inform the orbital evolution history of planets. The accuracy of these methods is mainly driven by 1) the knowledge of individual transit centre times and 2) the number of transits obtained, and their baseline and sampling. PLATO will launch at the end of 2026 and focus on the detection of new exoplanets around bright stars. A supplementary scientific outcome will be the continuous observation of known exoplanets that will provide TTV/tidal decay monitoring. However, to constrain planetary masses and orbit evolution we need to fill in gaps in the long-baseline data between the discovery transits and those that PLATO will observe. To do this we will observe transits of known exoplanets in the PLATO long- stare fields that are visible by CHEOPS.

Description of the observations

We will obtain at least one transit per planet per season for a given target to reach the goal of the program. Where possible we will aim to obtain transits of a planet near the beginning and end of its visibility period to further enhance the TTV baseline coverage.

4.2.6 Trace

Measuring the TRansit light sourCe Effect with CHEOPS

Abstract

The TRACE (Measuring the TRansit light sourCe Effect with CHEOPS) program aims to use the CHEOPS telescope to characterize the transit light source effect (TLSE) for exoplanet targets scheduled for observation with the JWST. This effort addresses a critical challenge in exoplanet atmosphere analysis: contamination from stellar activity, such as star spots and faculae, which can skew measurements of planetary atmospheres by introducing variability in observed spectra. The program will conduct high-precision photometric observations in the optical band, an essential range that JWST does not cover but is critical to identify and mitigate stellar contamination in transmission spectra. Focusing on two primary targets in a first stage —TOI-1416 and GJ9827— the project plans long-baseline in and out-of-transit observations, spread across a few stellar rotations to model activity-related flux variations. These findings are expected to help the JWST data interpretation of the planet's atmosphere, and support the broader scientific community by making data publicly available immediately. By characterizing activity in CHEOPS-observed systems, TRACE aims to enhance our understanding of exoplanet atmospheres and prepare for future synergy with upcoming missions such as PANDORA.

Description of the observations

We will perfom a long-term photometric follow-up of two targets that will be observed by JWST in 2025, to study their activity levels. This is a non-time critical, filler programme. We hope to get 1-orbit observations spreaded within the CHEOPS observability window of each target. TOI-1416 (G9, Prot: 18 d) will be observed by CHEOPS between March and mid-May, and GJ9827 (K6, Prot: 29 d) between mid-July and mid-November.

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