TWINKLE: A NEW IDEA FOR COMMERCIAL ASTROPHYSICS MISSIONS

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ABSTRACT

Twinkle is a space mission dedicated to the observation of the atmospheres of extrasolar planets (planets orbiting other stars) through the use of optical and infrared spectroscopy. The mission implementation is based upon a commercial delivery approach that has been successfully applied in other demanding space disciplines.

The study of exoplanets has been incredibly successful over the past 20 years: nearly 2000 planets have been discovered in our galaxy, and along with these discoveries fundamental parameters such as the planetary mass, size and distance to the parent star have been acquired. In the past decade, pioneering results have been obtained using transit spectroscopy with the Hubble and Spitzer Space Telescopes and ground-based facilities, which have enabled the detection of a few of the most abundant chemical species, the presence of clouds, and have also permitted the study of the planetary thermal structure.

The next step is Twinkle: a small dedicated satellite designed to understand these newly found worlds through the measurement of their atmospheric signatures. Twinkle will observe the chemical composition and weather of at least 100 exoplanets in the Milky Way, including super-Earths (rocky planets 1-10 times the mass of Earth), Neptunes, sub-Neptunes and gas giants like Jupiter. It will also be capable of follow-up photometric observations of 1000+ exoplanets in the visible and infrared, as well as observations of Solar system objects, bright stars and disks. Twinkle is a cost-effective space mission taking advantage of lowered costs of access to space. The Twinkle satellite is being built in the UK and will be launched into a low-Earth sun-synchronous polar orbit in 2019, using flight proven spacecraft systems designed by Surrey Satellite Technology Ltd and high Technology Readiness Level science payload built by a consortium of UK institutes. The Twinkle science payload will be composed of a visible-IR spectrograph (between 0.5 and 5µm) with resolving power R~100-300. The funding for Twinkle will be provided through a combination of private and public sources.

This paper gives an overview of the Twinkle mission and provides an update on the business and technical activities in progress for this valuable new class of science mission.

1 VISION AND HIGH LEVEL OBJECTIVES

Twinkle will be the first mission in a wider programme to enable a new generation of dedicated, cost-effective, short timescale scientific missions that respond rapidly to the need of the scientific community worldwide.

This class of mission will:

- Provide capability to do focused, world class science at a fraction of a cost of current astrophysics missions and
- Demonstrate a new business model for space science missions based upon commercial mission delivery

Twinkle has been chosen as the first mission in the programme primarily due to the rapid advances being made in exoplanet research and its wide-reaching impact on science, society and Science, Technology, Engineering, Mathematics (STEM) education activities [1].

Twinkle, has the following high level mission objectives:

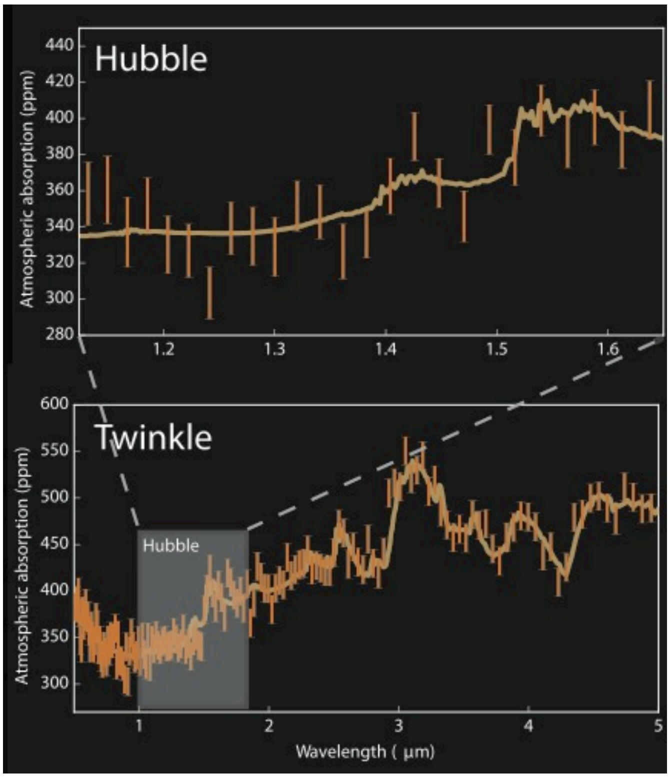
1. Perform space-based spectroscopic observation on at least 100 pre-selected exoplanets in the Milky Way to enable characterisation of their atmospheres
2. Deliver the mission within a 3-4 year timeframe (Kick Off to Flight Readiness Review)
3. Deliver the mission within a cost envelope of £50-60 million
4. Generate revenue from commercial sales of the science service to part fund the next mission

2 RATIONALE

2.1 Rationale - the "Science Bit"

Nearly 2000 exoplanets have been confirmed and several thousand planetary candidates have been detected. Statistical estimates indicate that most stars host planets [2]. Current and upcoming space missions, as well as ground-based surveys, will dramatically increase the planet count over the next 10 years. Many of the exoplanets found so far are very different from those in our solar system: from hot-Jupiters (giant planets that orbit very close to their star) to super-Earths (rocky planets up to ten times the mass of Earth). However, we know very little about these planets beyond their mass, size and distance to their star.

Figure 2-1 Infrared transmission spectrum of the hot super-Earth 55 Cnc e, as observed by the Hubble Space Telescope [3] (top), and Twinkle expected performance highlighting the significant improvement in wavelength range (below)



In the past decade, pioneering results have been obtained using transit spectroscopy with Hubble, Spitzer and ground-based facilities, which have enabled the detection of a few of the most abundant chemical species, the presence of clouds, and have also permitted the study of the planetary thermal structure. Despite these early successes, currently available data are still too sparse to allow a comprehensive and meaningful understanding of the physical and chemical properties of these planets. Most importantly, with the degraded performance of Spitzer, current data are restricted to wavelengths shorter than 1.7μm. The scientific community is faced with having to wait 5 to 10 years for the next generation of space and ground based facilities with IR capabilities to come online such as the James Webb Space Telescope (JWST) and European Extremely Large Telescope (E-ELT). Even then, the exoplanet community will still not have gained access to a specially designed science payload, and will have to share observation time with other science communities.

Twinkle's highly stable instrument will allow the photometric and spectroscopic observation of a wide range of planetary classes around different types of stars, with a focus on bright sources close to the ecliptic. The planets will be observed through transit and eclipse photometry and spectroscopy, as well as phase curves, eclipse mapping and multiple narrow-band time-series. The targets observed by Twinkle will be composed of known exoplanets mainly discovered by existing and upcoming ground surveys in our galaxy (e.g. WASP, NGTS and radial velocity surveys [4,5]) and will also feature new discoveries by space observatories (GAIA, Cheops, TESS [6,7]).

Follow-up Visible and/or IR photometric observations using Twinkle will improve the orbital ephemerides and other planetary/stellar parameters and properties of a large sample of previously discovered exoplanets. Among those, the brightest targets can be studied in great detail through spectroscopic measurements. The wavelength range adopted covers all the expected key atmospheric gases, e.g. H2O, CO2, CH4, NH3, HCN, H2S, including exotic metallic compounds, such as TiO, VO, SiO [8] and condensed species. It will also permit the simultaneous monitoring of the stellar variability and the presence and distribution of clouds and hazes in the exoplanet atmosphere. Monitoring the weather and thermal properties of these planets, through repeated measurements in the optical and infrared wavelength bands will be a key aspect of this mission.

2.2 Rationale - the "Economic Bit"

Astrophysics is a data-driven research topic. Observations of faint, distant objects often require a satellite-based science payload that can overcome the limitations imposed by our own atmosphere and our day/night cycle. This is particularly true for exoplanets where our own atmosphere provides a real barrier to observations. Exoplanet spectroscopy is one of the fastest growing fields in astronomy [9], but there is an unmet demand in the community for high-quality spectroscopic data for exoplanet atmospheres from a dedicated facility.

More generally, scientists worldwide are challenged by the difficulty in accessing facilities that could provide new data for their research. The two main problems are the oversubscription of existing facilities and the geographical location restrictions imposed on users.

Current oversubscription of facilities

Space facilities for astrophysics are built and launched by national and international space agencies, through a selection of competitive processes and often over long timescales. In the case of exoplanet science, and in particular in the context of observations of exoplanet atmospheres, there is a strong demand for observation time on currently existing space facilities. The Hubble Space Telescope (HST) has been running on a ~640% oversubscription for exoplanet science over the last five years, and the Spitzer telescope reached an oversubscription rate of 1200% for exoplanet spectroscopy by the end of its cold operations phase [10, 11].

Geographical location restrictions

Under the current model applied to satellites designed for astrophysical observations, access to facilities is restricted to researchers located in countries that have participated in the construction of the satellite. This imposes a geographical delimitation on which scientific communities can contribute to a particular field of science. We have investigated the problems faced by worldwide users through several market surveys [12] which indicate this problem is significant, and that there is an opportunity for a new approach to astrophysics missions.

The business plan is to provide a dedicated facility able to deliver the high-quality data needed by the community, regardless of geographical restrictions, in a very short timescale from a spacecraft launched within 3 years of kick-off.

2.3 Twinkle – What is it and what does it offer?

Twinkle is a small satellite designed to understand exoplanets in the Milky Way galaxy through the measurement of their atmospheric signatures. While there are many current and planned missions and programmes designed to discover new planets, there is currently a gap in scientific science payload facilities capable of making the follow up observations needed to characterize and understand these alien worlds. This mission will reveal for the first time the chemical composition, weather and history of hundreds of recently found extrasolar planets in our galaxy. Some of the key offerings and capabilities are outlined below.

Twinkle is a dedicated exoplanet atmosphere characterisation facility which will allow customers to

- Purchase observations of exoplanet targets of interest from the mission catalogue
- Purchase space-based telescope time for solar system observations
- Get exclusive access to the data within days of the observation

Twinkle will deliver:

- The first spectral observations of at least a hundred exoplanets
- The first dataset optimised for characterising exoplanet atmospheres
- The first thermal maps of exoplanets and their cloud cover at multiple wavelengths in the
- optical and infrared parts of the spectrum
- Repeated observations of exoplanets to monitor changes in climate and atmospheric
- composition
- Opportunities for all countries to access space data
- An allocation of public data for citizen scientists, amateurs and students

The benefits of Twinkle will serve both existing and new users in this rapidly expanding field and importantly:

- It can be used by universities, countries and organisations that usually have little or no access to the large international facilities
- It will help to alleviate the oversubscription burden on the existing international multidisciplinary observatories
- It complements the planned hunter and characterisation missions
- Pioneers a programme which can routinely enable answering suitable key science questions with smaller dedicated observatories on a commercial basis and therefore
- Can start to relieve some of the budgetary and complexity trade-offs faced on the larger multidisciplinary observatories
- In general, this wider access to new data will stimulate new research and the resultant discoveries and publishing will encourage increased STEM uptake and public engagement

Success of the commercial model demonstrated on Twinkle will enable a continuing commercial astrophysics / space science programme more generally offering:

- More flight opportunities for more Principle Investigators (PIs).
- Responsivity to emerging opportunities
- Faster turnaround from concept to results
- Regular, strategic opportunities to focus on national goals and capacity building
- De-risking of larger more expensive projects
- Less pressure to accommodate various non-related science payloads
- Less pressure on agency and government budgets
- More opportunities to train next generation of scientists and engineers

3 MISSION DESCRIPTION

3.1 Mission Architecture

The top level mission architecture for Twinkle is shown in Figure 3-1. Balancing the science and programmatic requirements, the proposed baseline is for a single satellite operating in a dawn-dusk (6am to 6pm), 600 to 700km altitude Sun-Synchronous Orbit (SSO).

The space segment is comprised of the single spacecraft (platform and science payload). The platform is from the SSTL range of flight proven platforms [13] and future builds may also benefit from additional cost and schedule savings associated with the ongoing productionisation activities [14]. The science payload is based upon high TRL components and is being delivered by an experienced consortium led by University College London (UCL).

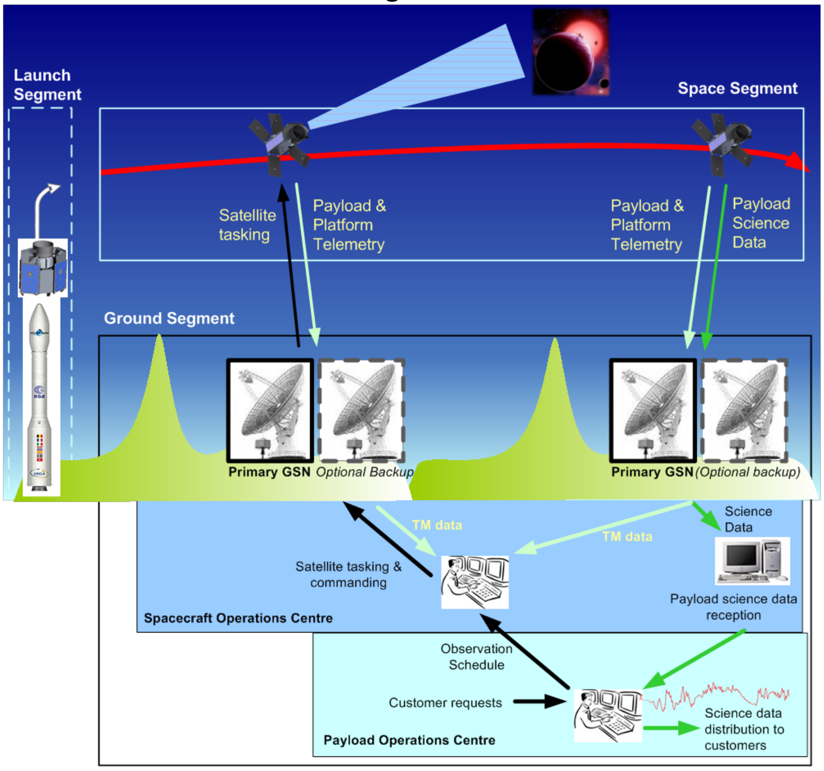


Figure 3-1 Twinkle Mission Architecture

For ground segment, the existing SSTL Spacecraft Operations Centre (SOC) will be used to provide day-to-day operation and maintenance of the spacecraft (Figure 3-2). Science tasking and scheduling will be performed by the Twinkle Mission Operations Centre (MOC) located at **UCL** with direct secure communications links to the SOC. During Assembly, Integration and Test (AIT) of the TWINKLE spacecraft, a dedicated Electrical Ground Support Equipment (EGSE) set will provide ground telecommanding and telemetry. This EGSE set uses the same flight database and mimics the display interfaces used in the SOC, providing a valuable operator training tool. There are some mission specific Payload Operations Centre (POC) developments required, in particular for the Twinkle Mission Planning System (MPS).

There are reasonably regular low cost launch opportunities to this orbit, and the orbit provides good viewing conditions for the payload and good solar illumination for power generation.

Figure 3-2 Spacecraft Operations Centre (SOC) Infrastructure (Left and Middle); Electrical Ground Support Equipment (EGSE) set up in Assembly, Integration & Test mirrors the ground station set up (AIT) Facility (right)

The platform comprises the systems required to support the payload, including power system, attitude and orbit control, communications, thermal control and data handling. Payload and housekeeping data will be stored on board the satellite and will be transmitted to the ground via its downlink antenna to the Space Operations Centre (SOC) ground station located in Guildford, UK. The derived downlink requirements are based on payload data rate and platform telemetry and an average contact period per day and are readily supported by the existing SSTL system in orbit and ground capabilities. Telecommand and Telemetry uplink and downlink are via a low rate S-band system. Launch and Early Operations Phase (LEOP) and emergency communications are also performed using the low rate S-band system.

3.2 Design Drivers

To meet the key performance requirements within the key programmatic constraints is on all missions, across all disciplines, a constant trade-off. The mission level trade-space is cluttered with numerous conflicting requirements. A key element to SSTL's achievements has been the focus of projects on identifying and meeting key operational objectives. Secondary 'nice to have' objectives and derived requirements are managed closely to keep the project within timescale and budget. This requirements management approach ensures that the final mission design results in a useful performance whilst concurrently optimising important factors such as system mass, size, manufacturing timescales and cost. Another key feature of the SSTL approach is a successful combination of management, technical and operational elements developed specifically to allow the company to supply low cost space missions rapidly and without sacrificing quality. SSTL is well known for the considered application of advanced Commercial off the Shelf (COTS) technology to its satellites and these are some of the key elements of its success.

The critical area of focus for the present has been in the Science payload definition and the corresponding development and verification plans. It is widely acknowledged that on science missions in particular, that the main cause of schedule delays and cost overruns is often due to the payload and its requisite complexity to meet cutting edge scientific needs. However, there are numerous ways to try to mitigate this.

For Twinkle the high-level mitigation approach against platform and science payload cost and schedule overruns is a combination of the following:

- A carefully selected, well-defined, single primary science objective
- Strict focus on necessary performance to meet the primary science objective, minimisation of secondary objectives and 'nice to haves'
- A small platform and payload consortium working concurrently to simplify and speed up communications and enable a more streamlined approach
- A delivery-focused approach to the overall science payload design and development programme that benefits from the proven approach implemented for the platform
- Use of high TRL equipment, with a preference for those proven in orbit
- Close coordination and direct interaction with the spacecraft prime during all mission phases
    - Critical in the design definition so that any platform or payload developments can be traded off in terms of which offers the best cost, schedule, risk, and performance profile for the overall mission

This combination for Twinkle is based upon the expertise of the science and payload team and their experience as PI's and providers of world class science payloads to missions including Planck, Herschel, JWST-MIRI, ISO [15,16,17,18] as well as the phase-A study of the EChO mission concept [19], combined with the experience of design, delivery and operation of numerous successful high performance commercial missions [20].

Other key design drivers include:

- Science payload safety with respect to sun in the payload boresight field of view in operating and non-operating modes.
- Science payload pointing requirements during observations require the payload boresight to be pointed at a target and to maintain high precision and stability pointing over periods up to tens of minutes per orbit.
- High levels of thermal stability across the science payload to platform interface and accommodation of the payload cryo-coolers with dedicated radiator area to enable cooling of the optical telescope assembly to the required <150K.
- The spacecraft is required to slew between targets and to settle rapidly enough to enable efficient observations of the catalogue of targets set by both the science and the business cases.
- Science payload and science payload radiator constraints with respect to Earth and Sun.
- Meeting international space debris mitigation guidelines with respect to de-orbit and collision risks [21].

In addition to meeting these requirements the spacecraft must be compatible with a range of low cost auxiliary launch options. The launch budget is ~ £16 million, which is roughly a third of the overall mission cost.

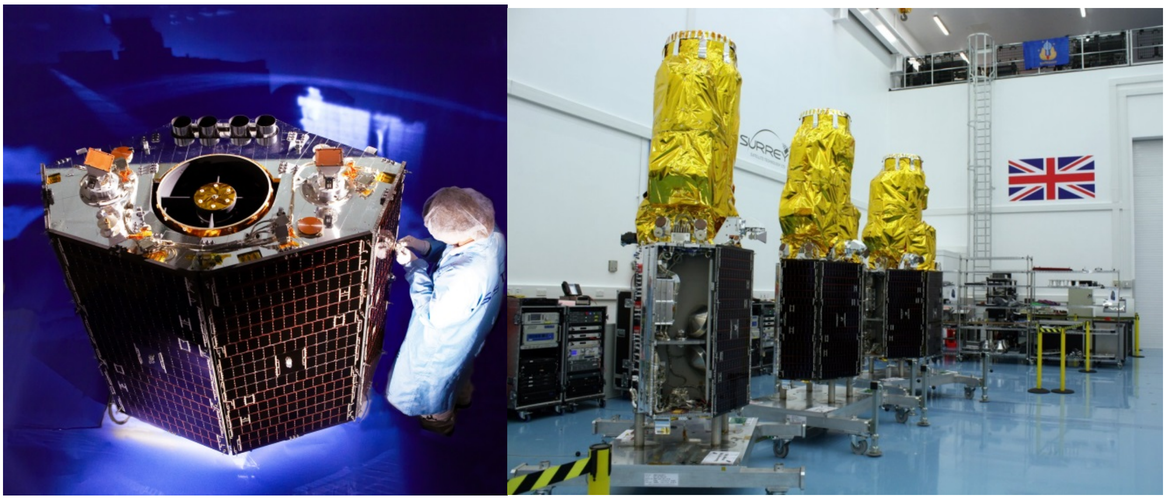


Figure 3-3 Building blocks for Twinkle: SSTL-300-N2 spacecraft (left); SSTL-300-S1 constellation (right)

The total science payload mass with margins is 100kg with a volume of 1200mm x 570mm x 570mm, driven by the minimum aperture size and peripheral equipment required to observe such faint and distant targets. The total spacecraft wet mass and volume is constrained to ensure compatibility with the likely launch options. This is a major consideration and hence the SSTL-300 baseline platform (Figure 3-3) for Twinkle will require some mission specific structural modifications to meet the challenging needs of the science payload pointing constraints, thermoelastic stability, stray light shielding and of course structural support to minimise the impact of the launch loads on sensitive equipment.

For this class of mission, PSLV, Dnepr and Falcon 9 offer good mass-volume-price ratios. Soyuz, Rockot and Vega may also provide suitable options. The SSTL-300 is designed to be launched efficiently on such launch vehicles, and in July 2015 three SSTL-300-S1 spacecraft were successfully launched on a PSLV-XL mission [13]. Surrey launch services are currently performing assessment of launch manifests in the 2019 to 2021 timeframe in order to commence negotiations on the viable options for Twinkle.

3.3 Payload Overview

The Twinkle satellite is conceived to have the agility and stability required (1 part in 10,000 of stellar flux over the duration of exoplanet orbits) to observe the spectra of over 100 already known exoplanets. This unique stability will also provide the capability for observing Solar System objects and stars in our galaxy. The spectrometers within the payload have been designed to maximize the capability of a small, low-Earth orbit spacecraft. The detailed design of the scientific payload has been completed (as part of a Phase A/B1 payload study), and is currently being documented [22]. A brief summary of the scientific payload is provided in Table 3-1.

Orbit	Low Earth Orbit, sun-synchronous, dawn-dusk, 650km
Primary mirror diameter	450mm
Spectral range	
Visible	0.5-1μm
Infrared channel 1	1.3-2.4μm
Infrared channel 2	2.4-4.5μm
Resolving power	R~100-300 across all bands
Photometric stability	1 part in 10,000 of flux of the star
Pointing stability (max RPE)	67 milliarcsec (on Ch-0) (TBC)

Table 3-1 Scientific Payload Overview

The payload consists of a unit which is located in the central bay of the SSTL-300 platform. The forward part of the payload is occupied by the telescope, a Korsch three mirror anastigmat design with a 450mm diameter primary which allows a wide-field Field of View (necessary to allow the Fine-Guidance System (FGS) to relieve part of the requirement on the pointing stability).

The mirror is mounted on the Telescope Optical Bench (TOB) which acts as the overall reference plane for the payload subsystems. On the same side of the TOB and concentric to the telescope an external black baffle provides both a reduction in stray light as well as the thermal emitter for the "top" side of the satellite facing the cold sky (shielded from the Sun), and together with the bulkheads provides the mechanical interface to the platform. The TOB on which the primary is mounted has the same diameter hole as the primary and allows location on its other side of both a folding flat and the curved tertiary (or M4) in order for the telescope powered surfaces to be referenced to the same surface for ease of alignment. Prior to reaching the focal plane, the beam encounters a tip-tilt mirror which provides fine-adjustment to the beam position, followed by a dichroic which separates the optical paths of the visible channel from that of the infra-red instrument (1.3-4.5 μm). The visible light beam is then further split by a beam-splitter which directs a fraction of the light away from the visible spectrometer and into the FGS imaging camera. From the tip-tilt mirror mechanism onwards, all optical elements are mounted inverted on a second plate, the Instrument Optical Bench (IOB) linked to the TOB via low-conductivity supports at sufficient height to locate all optical elements as well as both instruments. The visible instrument is a compact diffraction grating spectrometer with a resolving power of 300 and is a modified design of an existing subsystem (UVIS) on board the NOMAD instrument of the ExoMars mission, adapted to the 0.4 to 0.9 micron range.

The IR instrument is on the other hand a bespoke design by the UK Astronomy Technology Centre, based on COTS components. The instrument entry is via a prism dichroic separating the two IR channels (1.3-2.4 and 2.4-4.5 mm) which then focus on two sets of slits appropriately sized to allow the longer wavelength diffraction limited PSF of the star object of interest as well as a separate slit to for the neighbouring region for background removal. The instrument optics allow for spectral separation (grating and prism) to then refocus on a single cooled SELEX array with dual coating.

The cooling of the detectors and of the IR instrument optics is provided by two small RAL-Space coolers, one linked directly to the detector module to allow the detector to operate at ~70K and the other to the IR instrument base. The hot-end of the coolers are linked to the platform radiators to efficiently remove the heat they generate. Further details about the instrument will be released in the Twinkle Whitebook [22].

3.4 Platform Overview

The platform must physically accommodate a telescope assembly with an aperture of 45 cm and length of 100 cm. The science payload includes cryo-coolers and a dedicated radiator to maintain the telescope to its required operating temperature of 150K. The total mass of the payload is 100 kg with an average power requirement of 100 W, including all margins. The mission will operate in a 600 to 700km sun-synchronous dawn-dusk orbit with the boresight of the telescope pointed within a 40° cone centred around the anti-sun vector.

The core operations and avionics for the platform are from the range used on the majority of SSTL-100, SSTL-150 and SSTL-300 missions. These have the advantage of not only being flight proven in similar operating environments to Twinkle, but they have also been operated together routinely across a range of mission types. This means that platform avionics development effort is limited to the payload interface. Using the SSTL core avionics suite allows Twinkle to leverage the CONOPS (Concept of Operations) and Fault Detection, Isolation and Recovery (FDIR) approach that has been developed and proven over several previous generations of SSTL spacecraft. Twinkle therefore benefits from the streamlined operations approach, a system designed for robustness and safety, plus high levels of availability all of which have been refined over three decades.

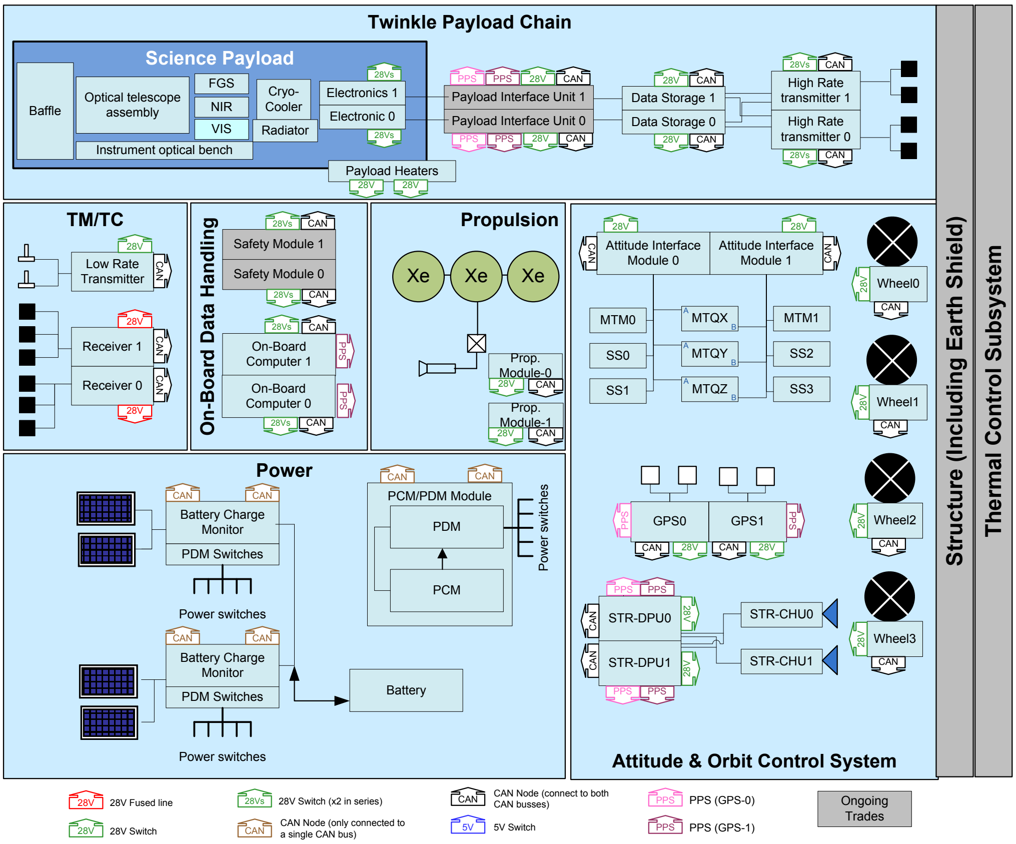


Figure 3-4 Current Twinkle Spacecraft System Functional Block Diagram (trade-offs in progress)

Key features of the CONOPS and FDIR are therefore:

- Robustness and redundancy; simple and robust operational modes that deliver high payload availability performance with multiple back-up functionality and equipment on board to assure mission lifetime and guard against unforeseen and random outages and failures.
- On-board autonomy and simple satellite safe-modes, resulting in the elimination of the need for expensive, constantly manned ground segments.
- Extensive use of proven, off-the-shelf components for both platform and payload and ground segment.
- Modularity; key systems, designed to interface together, that can be arranged in configurations to deliver a wide variety of performance and capacity variations depending on mission requirements.

The current spacecraft system block diagram is shown in Figure 3-4. Ongoing trade-offs relating to the platform to payload interface with respect to balance between cost, risk/complexity and performance/ utility are highlighted in grey.

In addition to use of the core building blocks from previous missions, there are some specific missions from which the on-ground and in-orbit experiences can be directly utilised. For example, SSTL has provided the space segment platform to Prime Contractor MDA for the Canadian Department of National Defence mission, Sapphire [23]. Leveraging from this highly agile resident space object tracking mission for Twinkle for e.g. handling the seasonal variation of the eclipse times during eclipse seasons in this low dawn-dusk SSO is relevant across areas such as operations, attitude and orbit control, thermal control and power subsystem. Additionally, on ground Assembly Integration and Test (AIT) issues such as the management of stringent science payload cleanliness and contamination control requirements are also similar for Twinkle. Contamination is controlled through the use of suitable design techniques, selection of suitable materials, hardware pre-cleaning and maintenance of cleanliness during assembly, testing, transportation, storage, launch and on-orbit operations. Failure to do so can result in reduced mission performance or a reduction of mission lifetime and so a mission-specific contamination and control budget and corresponding contamination control plan is necessary for Twinkle.

The SSTL-300-S1Attitude and Orbit Control System (AOCS) design has been used as a starting baseline for the Twinkle mission. The AOCS has to point the payload towards a target stars and maintain the necessary pointing accuracy (APE of 3 arcminutes, 99.7% confidence) during an observation period. The AOCS will also rotate the satellite about the payload boresight during an observation to ensure that payload radiators observe cold space. Pointing requirements are currently being developed in consultation with the mission scientists and are expected to be further iterated as the mission design progresses.

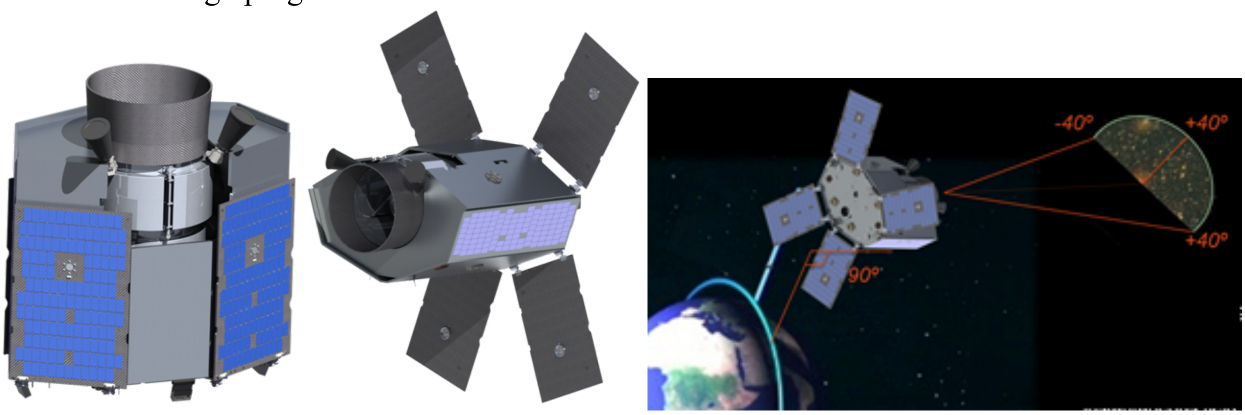


Figure 3-5 Current Platform Configuration (left and middle); Depiction of the operational set up (right)

The payload contains a fine guidance sensor (FGS) and a focal plane steering mechanism (FSM). The FGS measures the position of the target star within the science payload and may be used as both an attitude sensor and for adjusting the FSM to correct errors in the attitude control system to the level required for science observations. The FGS has a 1 Hz update rate and an accuracy of 0.05” (1 sigma).

The measurement errors of the FGS are nearly two orders of magnitude less than the Star Trackers, however the FGS is only able to measure pointing errors in the across Line of Sight (LOS) directions. Requirements on pointing accuracy and stability in the Around LOS direction can be relaxed due to the narrow field-of-view of the imager however in the Across LOS direction the pointing and stability requirements are tight and it is natural to consider the use of the FGS as an attitude control sensor to achieve the performance required for Twinkle science.

The currently proposed Twinkle AOCS Science Mode (SM) will be required to

- Slew between target attitudes.
- Settle to an attitude error within the FGS field-of-view and attitude rates compatible with Fine Guidance Sensor (FGS) operation.
- Switch from STR in-the-loop to FGS-in-the-loop operation on the across LOS directions (the STR will be used for Around LOS control)

Re-targeting of the platform is required twice an orbit to prevent the Earth limb getting too close to the science payload field-of-view. Twinkle reuses the existing SSTL-300-S1 slew mode design. Large (0.2 Nm, 12 Nms) reaction wheels are used to perform an open-loop slew between two target attitudes and then fine control is re-enabled using smaller reaction wheels to settle onto the target and maintain fine control.

Pointing accuracies better than 1’ are achievable using the star trackers. Simulations show that these can be reduced significantly with the use of the FGS as an attitude sensor. Although the FGS-in-the-loop operation offers much improved pointing stability in the across LOS directions, the initial assessment of the AOCS performance suggests that it may be possible to achieve the required performance using only STR-in-the-loop control and further work on the AOCS will look at this option

The structure is an evolution of the SSTL-300 heritage design, optimised for the new payload size (Figure 3-5). It comprises of composite honeycomb aluminium panels to reduce mass whilst retaining strength. A central core of these panels surrounds the science payload and provides the primary load paths, as well as accommodating the majority of the platform equipment. (zA set of more lightweight panels close the structure, several of which are used for as fixed solar arrays or the holding points for deployable arrays.

3.5 Mission Timeline

The Twinkle mission timeline and key activities for each phase are outlined in Figure 3-6 and Table 3-2

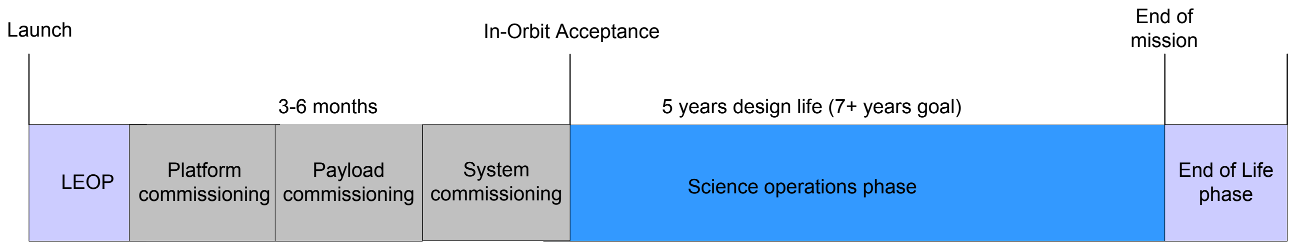


Figure 3-6 Twinkle Mission Timeline

Mission Phase	Key Activities
Launch and Early Operations, (LEOP)	• Launch and separation of spacecraft from launcher • Initial signal acquisition and platform testing • Attitude acquisition and stabilisation and placement of the spacecraft into a controlled attitude
Commissioning Phase	• Completion of platform testing including redundant systems as appropriate • Launcher Error Injection Corrections (TBC) • In-orbit payload checkout, characterisation, and calibration, end-to-end operations testing [supported by POC]
Science Operations Phase	• Routine mission operations • Periodic platform maintenance • Periodic payload calibration [supported by POC] • Collision avoidance manoeuvres (as required)
End of Life (EOL) Phase	• Platform passivation • De-orbit activities (as required)

Table 3-2 Overview of Mission Phase Activities

The timings for LEOP and the overall system commissioning will be refined in the next phases, in line with the definition of the detailed requirements for activities such as payload safety, commissioning and calibration.

4 PROJECT STATUS

4.1 The Team

Twinkle is led by University College London (UCL) and SSTL, and involves a consortium of UK research institutes and companies with a strong heritage in infrared (IR) instrumentation (JWST-MIRI, Herschel, Planck, ISO) and experience in development of both large and small missions, as well as ground-breaking science. The Twinkle science payload design benefits from the scientific and technical expertise developed at UK institutions over the phase-A study of the EChO mission concept.
The science payload consortium includes: Cardiff University, Mullard Space Science Laboratory, Open University, Selex ES, Rutherford Appleton Laboratory (RAL Space), UCL, UK Astronomy Technology Centre (UKATC).

Surrey Satellite Technology Ltd (SSTL): Over the last 30 years, SSTL has established itself as a world leader in small satellite development, operations and services. The company has more than 500 satellite-years operations experience.

4.2 Education and Outreach

Our team is committed to using the Twinkle mission to engage and inspire students and young people with STEM (Science, Technology, Engineering and Maths) subjects. Since early 2015, we have been piloting activities for our educational programme, EduTwinkle, to engage students with real, cutting-edge exoplanet research. To date, workshops, teaching resources and teacher training activities have been developed for elementary schools and the final years of high school (as a first step in England). By the time Twinkle launches, we aim to have developed resources aimed at the direct inclusion in the school curriculum. For more details please visit http://www.twinkle-spacemission.co.uk/edutwinkle/

4.3 Opportunities to Get Involved

We will deliver the Twinkle spacecraft on time by 2019/2020 by using existing technologies and with limited research and development. Our payload design (see "Payload overview") will ensure Twinkle has the performance to observe a large sample of bright exoplanets.
Our mission scenario can accommodate allocation of time to multiple science cases:

- Spectroscopy of bright exoplanets (100+), down to super-Earth-sized objects
- Infrared and/or visible photometric follow-up of 1000+ exoplanets
- Dedicated telescope time for Solar system objects, bright stars and disks.

Tyipcal users include:

- Individual scientists worldwide
- Research institutes / universities
- Consortia

With a rapid development schedule and the use of off-the-shelf components for Twinkle, we are able to offer very competitive pricing. There are a number of ways to engage with the mission, contact us to discuss the possibilities for your scientific community.

A key driver for the mission funding is the use of a commercial model to offer access to worldwide users. In parallel to this route, we are also pursuing parallel funding opportunities through philanthropy and public sector support.

5 SUMMARY

This paper has provided an overview of the Twinkle mission and an insight into the business and technical activities in progress.

Market research activities have demonstrated the demand for the mission through oversubscription of current facilities, limited or no access to large sections of the community. This is underlined through the continuing engagement with the first sets of customers.

To meet this demand, Twinkle is the first in the programme of a series of commercial astrophysics missions and it will generate

- Transformative exoplanetary science with insights into how planets form and evolve
- A major step in the direction of probing the habitability of exoplanets
- Weather and temperature information on a range of planet types
- Unique access to an infrared space instrument for spectroscopic and photometric observations.

Success of the business model demonstrated on Twinkle will enable a continuing commercial astrophysics / space science programme resulting in:

- A new approach for space science missions based upon commercial mission delivery and sale of a science service.
    - Less pressure on agency and government budgets, alongside increasing economic

    growth directly attributable to science.

- Regular capability to do focused, world class science at a fraction of a cost of current astrophysics missions.
    - More flight opportunities for more PI's.
- Regular, strategic opportunities to focus on national goals and capacity building
- Increased responsivity to emerging opportunities
- More opportunities to train next generation of scientists, engineers and students
- Wider reaching impact on science, education and society

The delivery team for the Twinkle mission comprises an expert science and payload team lead by UCL and an experienced small satellite prime contractor, SSTL. The experience of the PI's and suppliers of world class science payloads to flagship missions combined with maximum re-use of the systems, delivery methods and operational techniques employed on numerous successful cost constrained commercial missions from SSTL is ideally suited to the providing maximum mission utility required for Twinkle with the required 3-4 year timeframe and budget of £50-60 million.

Twinkle and its successors will provide us with a means to answer fundamental questions like "What are exoplanets made of?" and "Are they habitable?" alongside an opportunity to inspire the next generation, to contribute to economic growth and essentially to play a part in the democratisation of space science.

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