

The Large Interferometer For Exoplanets (LIFE): a space mission for mid-infrared nulling interferometry

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ABSTRACT

The Large Interferometer For Exoplanets (LIFE) is a proposed space mission dedicated to the spectral characterization of temperate, terrestrial exoplanets in the solar neighborhood. The mission is designed to detect and spectrally characterize the thermal emission of nearby temperate terrestrial exoplanets, and to assess their habitability. LIFE will operate as a space-based formation-flying nulling interferometer in the mid-infrared. The formation would consist of four collectors and a central beam-combiner spacecraft. The envisioned wavelength range will cover 4-18.5μm, requiring cryogenic operations both for the collectors and the combiner spacecrafts. The mission is currently in an early definition phase, and a full concept study is currently underway. In this context, a series of pre-studies are being conducted to help define the mission scope and explore the relevant trade space. We give an overview of the status of the mission concept, discuss key mission requirements, and outline the trade-offs related to the architecture of the mission. We finally present the current LIFE Program roadmap, and the main updates on the different pre-studies

Keywords: Nulling, Interferometry, Space, Mission, LIFE, exoplanets

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Figure 1. Artist impression of the LIFE Space Mission (credit: LIFE Space Mission)

1. INTRODUCTION

The search for life on planets orbiting in systems located in the solar neighborhood (< 30 pc) has become one of the most compelling challenges and a central goal in astrophysics over the past decade. Upcoming major facilities will push forward the search for life, such as the Habitable Worlds Observatory (HWO) which is currently the highest-priority large mission of the 2020 US Decadal Survey, and is now stepping in technology maturation.^{1–4} The first generation of instruments for extremely large telescopes will also contribute to this science goal.^{5–7} The LIFE Space Mission intends to play a complementary but crucial role in this common effort, by focusing on mid-infrared observations of temperate terrestrial planets. The emission of such planets indeed peaks in the mid-infrared wavelength range, thus providing a relaxed contrast with the host star by about three orders of magnitude compared to the reflected light in the visible range. The mid-infrared is also a spectral region rich with molecular features, including molecules considered as potential biosignatures.⁸ To access the mid-infrared regime, the LIFE Space Mission will use the technique of nulling interferometry⁹ in space, and characterize the emission spectrum of dozens of nearby temperate terrestrial planets, to assess their habitability and search for potential biosignatures.¹⁰ Joint observations of planets with LIFE and a reflected-light facility such as HWO would also broaden the range of worlds and wavelengths available to search for biosignatures.¹¹ LIFE is planned to be launched by 2040, which requires a development on a multi-staged program to achieve such timescale, and unlock new funding avenues partnerships across industry and academia.

The LIFE Space Mission builds on the heritage of the twin projects TPF-I/*Darwin* from early 2000s by both NASA (TPF-I^{12,13}) and ESA (*Darwin*^{14–16}). Like these precursors, it proposes to perform nulling interferometry with a formation-flying constellation of four collector spacecrafts and one combiner spacecraft (see Fig. 1), with a spectral range of $4\text{--}18.5\ \mu\text{m}$.¹⁷ Since two decades ago, the substantial improvement of our knowledge concerning the occurrence-rate of temperate rocky planets and their abundance^{18–21} has provided strong motivation and confidence to revive the project of a mid-infrared space nuller. In parallel of LIFE, a concept study for the European Space Agency for a single-spacecraft space nuller *Exoplanet Explorer* has also been carried out.²² Moreover, the programmatic landscape has also shifted: alongside the traditional agency-led route, privately and philanthropically funded initiatives such as the recently announced Eric and Wendy Schmidt Observatory System are pursuing an explicitly fast and risk-embracing model of observatory development. This imposes

markedly different demands on how a mission of this kind is structured and de-risked. Over the past few years, the LIFE initiative has revisited the inherited design reference, the requirements of the precursors, and re-worked individual design choices in light of our current knowledge in an on-going effort.^{8,10,11,23–39}

The LIFE Space Mission concept is therefore still malleable, and must be revisited using scientific, technical and programmatic reality to be allowed to mature into a viable mission. This paper describes the current status and updates on the LIFE Space Mission reference concept, and its general roadmap until its planned launch in 2040. We also give an outlook on the next steps required for the realization of LIFE.

2. THE LIFE SPACE MISSION REFERENCE CONCEPT

Building on the mission reference architecture presented in Glauser et al. (2024),¹⁷ this section outlines the key requirements introduced as the concept advances into the mission definition and technology maturation stage. We begin by reassessing the mission requirements in light of recent developments in both measurement capabilities and exoplanet science, followed by a description of the resulting updates to the mission architecture.

2.1 Mission Requirements

Table 1 summarizes the most relevant requirements and parameters, and provides the rationales for the numbers listed. We also provide some additional comments on the following parameters or requirements:

Baselines The collector array will have a rectangular architecture, with a small “nulling” baseline and a long “imaging” baseline, with values that will vary in flight to maximize the planetary signal depending on the science target. The nulling baseline is updated from the previously adopted range 10–100 m to 25–80 m. The lower limit is particularly significant, as the minimum separation between collector spacecraft sets the complexity of collision avoidance strategies. A dedicated analysis by Hansen et al. (2026)³⁹ shows that relaxing the short baseline requirement does not increase the required mission time significantly. The upper end of the nulling baseline range can also be reduced without degrading mission performance. Applying the adopted 6:1 ratio between the imaging and nulling baselines, the imaging baseline range is correspondingly revised to 150–480 m.

Combiner spacecraft The combiner spacecraft will collect light from the four collector spacecrafts and recombine it to generate interferences. The combiner spacecraft is located in an orthogonal position with the plane formed by the collectors (see Fig. 1). The angle between the line of sight and the direction of the beams propagating from the collectors to the combiners is held fixed. This revised combiner reference concept is presented in Sect. 2.2. Because the array scales with the nulling baseline, this fixed angle results in a combiner position ranging from 300 m to 960 m above the plane of the collectors.

Contrast – Null depth The planet-star contrast requirement (or “null depth”) was previously set to 10^{-5} at $10\,\mu\text{m}$ wavelength. These requirements have been refined on the basis of a study centered on the Nulling Interferometry Cryogenic Experiment (NICE; Birbacher & Hansen et al. 2026),⁴¹ where they correspond to a loss of less than 10% % in signal-to-noise ratio for an Earth-twin observation located at 10 pc. These requirements are now defined at $8\,\mu\text{m}$ wavelength instead of $10\,\mu\text{m}$, where the contrast requirement is the most stringent.

Null stability In recent years, considerable effort has been put in improving our understanding of the response of nulling interferometers to instrumental instabilities and their impact on instrumental performance.^{35,36,42,44} Instrumental instabilities can arise from vibrations, thermal deformations, control residuals, or the precision of formation flying. They generate amplitude, phase, and polarization errors during beam combination. Two complementary performance simulators have been developed to estimate the impact of instrumental instabilities: INLIFESIM*, a software based on a statistical description of instrumental noise, which relies on temporal correlations in the data, and LIFESIMMC†, which generates Monte-Carlo realizations of the data and studies

*github.com/fdannert/InLIFESim

†github.com/pahuber/LIFESimMC

Table 1. Key mission parameters and requirements for the LIFE Space Mission. Parameters that have changed with respect to Glauser et al. (2024)¹⁷ are discussed in the text. Adapted from Glauser et al. (2026).⁴³

Item	Value	Rationale or comment
Array		
# collector spacecraft	4	Minimum number with which robustness against instrumental noise is achievable with the baseline beam combiner
Nulling baseline	25–80 m	Range reduced following Hansen et al. (2026) ³⁹ (see text)
Imaging baseline	150–480 m	Follows from the 6:1 imaging-to-nulling ratio
Combiner spacecraft	300–960 m above the collector plane	Height range follows from holding the line-of-sight-to-combiner angle constant under the revised combiner concept (see text). Enables full sky coverage over one year, and reduces complexity in combiner spacecraft
Modulation	Rotation & Phase chopping	Rotation for localization of planets and fuel efficiency, phase chopping for detector and incoherent light calibration
Collector Temperature	≤ 45 K	Suppression of the thermal radiation from the collector mirror
Instrument		
Beam combiner	Double Bracewell	Realizable with high technology readiness level (TRL) bulk optics; noise properties for instability noise
Wavelength coverage	Requirement: 6–16 μm Goal: 4–18.5 μm	To include H ₂ O absorption features at 13–17 μm and access H ₂ O and CH ₄ features at 7.7 μm in Earth-like atmosphere ⁸
Resolving power	≥ 100	CH ₄ detection in Earth-like atmosphere ⁴⁰
Effective aperture diameter	3–4 m	Required to detect and characterize the rocky-planet sample within the mission lifetime, now including the characterization phase as a driver (see text)
Optical system throughput	$\geq 15\%$	
Detector quantum efficiency	$\geq 60\%$	
Contrast*	Null depth 7×10^{-6}	Required to keep the signal-to-noise ratio loss below 10% for an Earth-twin observation ⁴¹
	Null stability rms 3×10^{-7}	Based on Dannert (2025) ⁴²
Temperature	≤ 15 K	Suppression of the thermal radiation from the collector internal structure and optics
Mission		
Lifetime	≥ 5 years	Required to detect and characterize the rocky-planet sample within the mission lifetime (see text)

* Evaluated at 8 μm and $R = 100$, where the impact of stellar leakage on the measurement is strongest; the required null depth is a function of wavelength (see text).

spectrally correlated errors and the impact of post-processing. The two softwares can be used as forward models to estimate the stability requirements⁴² Huber et al. (submitted)⁴⁵ and Rutten et al. (submitted)⁴⁶ also used LIFESIMMC to estimate the trade-offs between different nulling architectures and to support preparatory studies. Using the requirements obtained from these softwares, Birbacher & Hansen et al. (2026)⁴¹ could infer the requirements for phase, amplitude, and polarization stability into a requirement for null stability. The required null stability is 3×10^{-7} at 8 μm .

Sensitivity The sensitivity requirement for the LIFE Space Mission is defined by the science goal and is expressed by the requirements on the effective aperture diameter, the optical system throughput, and the detector quantum efficiency. The science case has recently been updated and is now distributed across three distinct experiments, yielding a larger total number of characterized planets than previously assumed. The LIFE Space Mission now targets the detection and characterization of at least 30 exoplanets located in the habitable zone (HZ) of F0V–K5V stars, at least 15 in the HZ of K6V–M2V stars, and at least 10 in the HZ of M3VM9V stars. A second update incorporates the characterization phase directly into the budget of the mission’s time.⁴² Whereas previous estimates were driven primarily by the blind search, characterization is now found to account for a significant fraction of the total mission time and becomes therefore also a driver of the mission’s requirements. We approximate the time required for characterization by demanding a band-integrated signal-to-noise ratio of 45, the value needed to characterize an Earth-twin around a Sun-like star.⁸ When taken together, these updates correspond to an increase in the sensitivity requirement and translates to an effective aperture diameter of 3 m to 4 m, an optical system throughput of at least 15%, and a detector quantum efficiency of at least 60% (see Table 1).

2.2 Mission Architecture

Figure 2 shows the updated optical concept, with changes primarily concerning the collector spacecraft and the receiving optics within the beam combiner. Glauser et al. (2024)¹⁷ presented a design inherited from the final versions of the *Darwin*¹⁶ and TPF-I^{13,47} missions with some additional adaptations. In this subsection, we comment some of the main updates to the mission architecture.

Collectors The design of the collectors has been updated, now using a three-mirror anastigmat (TMA) collimator design instead of a single spherical mirror. This increases the optical complexity and mass of the collector, but reduces the amount of aberration and the changes in the pupil shape across the different baselines. This simplifies the combiner spacecraft by removing the need for large cryogenic deformable mirrors (DM) and complex optical systems to reshape the incoming beams.

The collector spacecrafts would now consist of an afocal, off-axis telescope with a third flat mirror for beam-steering that will direct the light to the combiner spacecraft. The beam is compressed by a ratio of $\sim 1/10$ by the afocal telescope, minimizing propagation losses during beam transport. Another steering mirror located at the combiner can then stabilize the incoming beam and compensate for any residual relative lateral and attitude movements of the spacecrafts. The two steering mirrors are in close loop, using the target star as a guide to correct for pointing and shear errors. By maintaining a fixed optical angle regardless of the baseline, we minimize system complexity and the stroke requirement on the steering mirror.

Polarization compensation Following the steering mirror, the polarization compensators will provide a passive correction of the relative polarization rotation. Since the effect is expected to remain invariant with the baseline, these compensators would not need to be actuated. However, this assumption should be verified.

Beam compression Beams should be further constrained when propagating inside the combiner spacecraft to minimize instrument volume and optics size. For an estimated optical distance of 1 m to 2 m inside the combiner, a beam size of about 15 mm, corresponding to a compression ratio of 1/20, should keep the beam divergence minimal. The beams then encounter the cold stops and placeholders for potential DMs. These DMs could be used to correct for possible variations of wavefront errors when the collector spacecrafts rotate, causing a deformation of their mirrors.

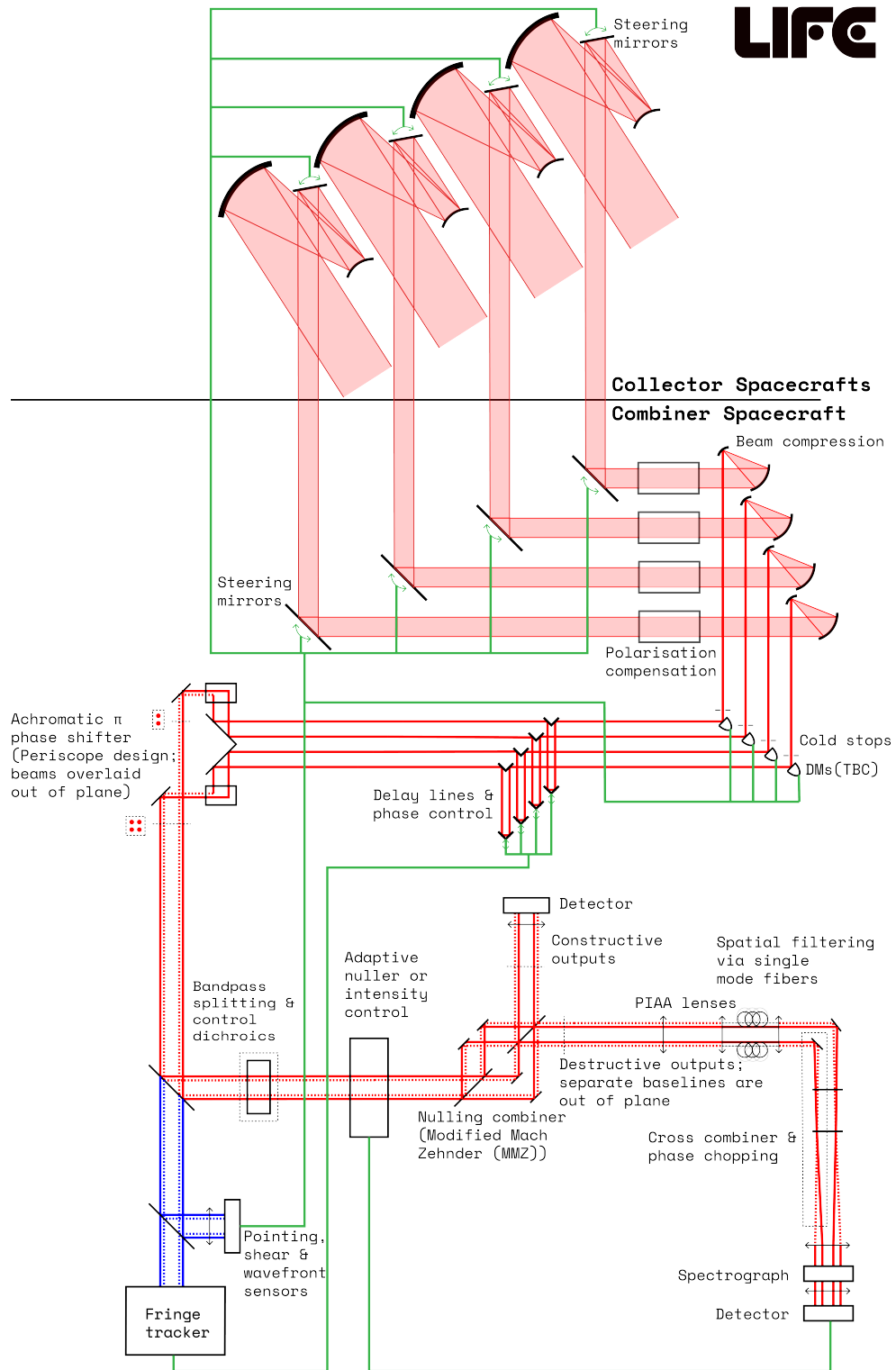


Figure 2. Optical Concept of the LIFE Space Mission. Taken from Glauser et al. (2026).⁴³

Beam combination The remaining components of the optical chain are identical to those described in Glauser et al. (2024).¹⁷ Coarse delay lines first balance the optical path lengths of the beams, and their differences coming from position errors in formation flying. The achromatic phase shifter then generates the broadband π -phase shift required to perform nulling interferences. The dichroics will split the light into different wavelength channels, and separate the K-band from the science light to direct it into the fringe tracker. Finally, the beam combination is performed using a Modified Mach-Zehnder interferometer setup. The destructive output of the interferometer can then be apodized by phase-induced amplitude apodizer (PIAA),⁴⁸ to increase the coupling efficiency into the spatial filter assumed to be step-index single-mode fibers.⁴⁹ After the spatial filter, the beams are dispersed by a low-resolution spectrometer and imaged on the detector. The location of the PIAA system is still under study and could potentially be merged with the upstream beam compression unit. The use of an adaptive nuller⁵⁰ as an alternative to splitting light with dichroics is also under study.

Thermal shielding A new assessment study of the thermal shielding will be needed once the design of the afocal telescope at the collector spacecrafts becomes stable. The goal is to achieve passive cooling of the telescope to a temperature below 45 K, and to know whether this requires deployable collectors. An additional requirement is for the thermal shield of the combiner spacecraft to be centro-symmetric. The combiner indeed needs to co-rotate with the constellation of collectors during observation, which requires the cooling to be rotationally symmetric. A dedicated thermal study will also address this challenge.

3. UPDATES ON THE PROGRAM DEVELOPMENT PLAN

The goal of the LIFE Program is to design, build and operate a system with the capacity to meet the LIFE science case in orbit no later than 2040. To reach this goal, it intends to leverage today's New Space economic and industrial landscape and adopt modern development and funding approaches.

Along the program roadmap, mission performance and system capability will be demonstrated iteratively to strengthen confidence in the LIFE Space Mission, deepen understanding of the mission architecture, and reduce overall program risk. Whenever possible, this technological maturation will be accompanied by scientific results, involving the community early with nulling scientific data. Therefore, the LIFE Program implementation strategy follows a development logic that pushes for direct validation of system performance both on ground testbeds and in orbit (see Fig. 3). In particular, the roadmap is structured around three principal development directions:

1. Instrumental development, from the warm and cryogenic nulling testbed (NICE, see Sect. 3.1) to a first LIFE Prototype (see Sect. 3.2) that will enable first space-based nulling observation of known exoplanets,
2. Development of mid-infrared cryogenic technologies (see Sect. 3.3),
3. High-precision multi-spacecraft formation flying development, allowing close range approach, using ground testbeds, and potential space-based demonstrators (see Sect. 3.4).

Eventually, the three development directions will be combined and converge to a final cryogenic, formation flying mission, the latest from 2032 onward. At this stage of the program, additional mission(s) may be developed to demonstrate the two-spacecraft formation flying and validate the opto-thermal performance before the launch of the final mission no later than 2040.

For the next 5 years, the LIFE Initiative will focus its efforts on the nulling testbed NICE, and thus on the LIFE Prototype, to demonstrate the fundamental measurement principle on a real target in space (see Sect. 3.2). Additional efforts will also be made in the other development directions, i.e., the maturation of mid-infrared cryogenic technologies and formation flying.

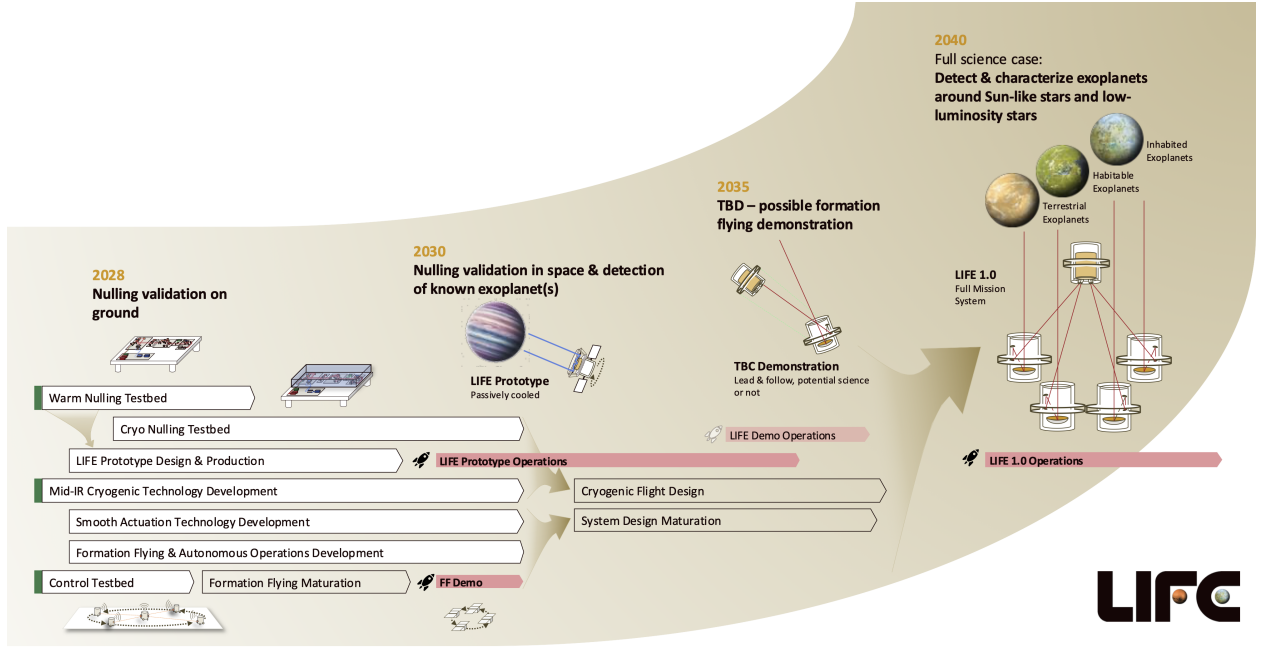


Figure 3. Indicative Roadmap of the LIFE Program. Taken from Glauser et al. (2026)⁴³

3.1 Nulling Interferometry Cryogenic Experiment (NICE)

NICE is a mid-infrared nulling testbed developed at ETH Zurich, which aims at maturing the optical and mechanical measurement concept that drives the design of the LIFE Space Mission.^{41, 51} Its objective is to achieve nulls with depth and bandwidth similar to those obtained by previous testbeds in the late 2000s,^{50, 52} but with a high-enough sensitivity to allow the detection of terrestrial exoplanets. This high sensitivity in the mid-infrared can only be obtained by operating the testbed at cryogenic temperatures (i.e., 15 K for NICE). The bench currently recombines two beams in a single Bracewell configuration at ambient temperatures (see Fig. 4). It currently serves as a precursor to the LIFE Mission, which will ultimately need a four-beam double Bracewell combination with phase chopping at cryogenic temperatures.

With the current ambient bench, NICE has demonstrated a repeatable null of 7.2×10^{-6} at $4.7 \mu\text{m}$ and polarized light, confirming that the chosen architecture can achieve the required contrast at a single wavelength with linear polarization.⁴¹ On-going efforts are extending this result to broadband, polarization-agnostic, repeatable, and stable nulling, with the support of an end-to-end optical model that estimates the required opto-mechanical tolerances.⁵¹ Efforts are also carried out in parallel to transition from warm to cryogenic operation with the commissioning of the modular “Ice Cube” cryostat.⁵³ The cryostat will be used to characterize the thermal deformation of optical components and subsystem assemblies when cooled down to 15 K. It will also inform the design of the final NICE cryostat under study. The instrument concept of the LIFE Prototype (see Sect. 3.2) benefits from the direct feedback given by NICE and will closely follow its design. Birbacher & Hansen et al. (2026)⁴¹ and Hansen et al. (2026)⁵¹ provide an exhaustive description of the progress of NICE.

3.2 LIFE Prototype

As shown in the roadmap in Fig. 3, the LIFE Prototype is planned to be the first iteration of space mission used as a build-up toward the full LIFE Space Mission. It will be the first nulling interferometer in space with the goal of observing a few known exoplanets to demonstrate the key aspects of the LIFE architecture and its technology, build a data reduction pipeline, and engage with the scientific community. The LIFE Prototype will only use passively cooled optics and detectors to avoid the cost and complexity of active cooling. The detectors will also use mature technology for the same reasons. It will also operate as a single spacecraft, recombining

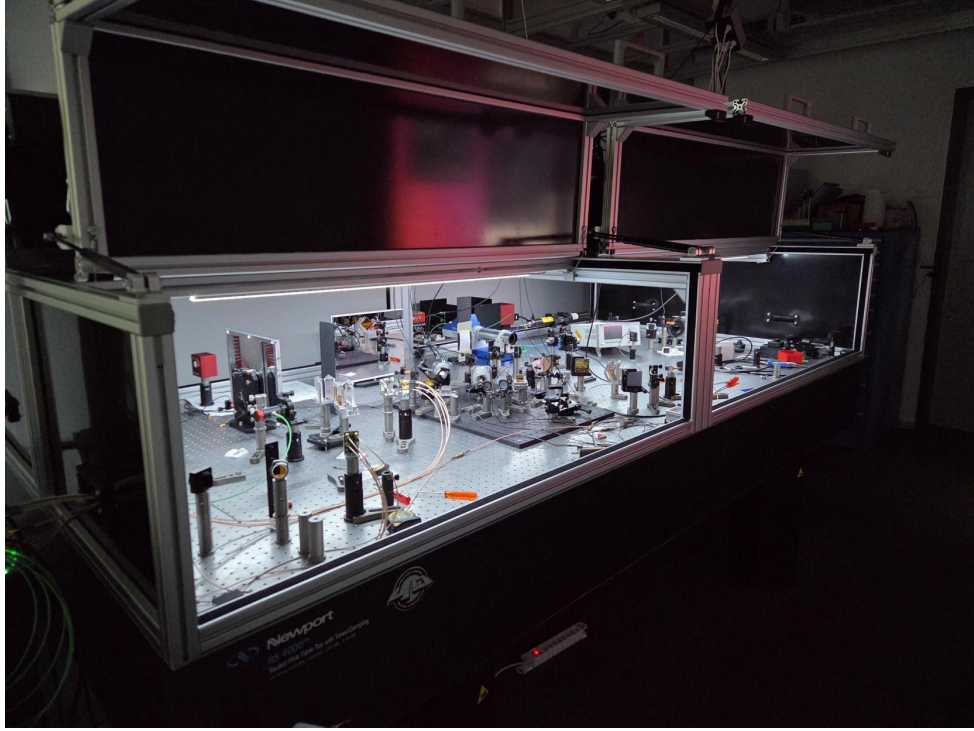


Figure 4. Picture of the NICE ambient optical table.

the light from two apertures in a single Bracewell configuration and using its rotation to detect the signal modulation generated by the known exoplanet. The development of the LIFE Prototype is meant to overlap in functionality and technologies with the final LIFE combiner spacecraft. Preliminary studies constrain the diameter of the apertures to 0.25 m, with a baseline of 1.5 m and a wave-range covering 3.5–5 μm . This wave-range is compatible with passive cooling, and corresponds to the shortest wavelengths of LIFE that are the most sensitive to instrumental noise. They are therefore the most critical wavelengths to demonstrate the feasibility of space nulling.

To continue the development of the architecture of the LIFE Prototype, a 9-month study is conducted with several potential collaborators to specify the reference mission concept, its key elements, its cost and its schedule. At the end of the study, an end-to-end reference concept will be delivered with draft top-level requirements and a preliminary design.

3.3 Progress on Critical Technologies

3.3.1 Mid-IR photonics

NICE is currently performing nulling interferometry using conventional bulk optics, which represent a challenge in size and complexity for cryogenic operation and space deployment. Integrated optics has been developed in the past decades as an alternative to bulk optics, to the point that it is now the core of several astronomical interferometers such as GRAVITY,⁵⁴ GLINT,⁵⁵ and NOTT.⁵⁶ The photonic chips used in these instruments ensure a more compact, robust, and stable beam combination than bulk optics.

The LIFE Space Mission supports the maturation of integrated optics optimized for the mid-infrared, using substrates made of lithium niobate (LiNbO_3 ; with high transmission up to $\sim 5 \mu\text{m}$) and indium gallium arsenide (InGaAs ; with high transmission from ~ 2 to $19 \mu\text{m}$). Photonic chips made of LiNbO_3 are currently being developed to test fringe tracking around $2.2 \mu\text{m}$ and test single Bracewell nulling around $4 \mu\text{m}$. Photonic chips made of InGaAs are also investigated as an alternative to bulk optics over the full LIFE wave-range of 4 to $18.5 \mu\text{m}$.

Depending on their performance, these chips could be used as spatial filters, beam combiners, or even as double-Bracewell nullers. More details about the development carried out at ETH Zurich is described in Glauser et al. (2026).⁴³

3.3.2 Detectors

The sensitivity requirement of the LIFE Space Mission imposes strict requirements on the photon-to-voltage conversion and readout of the detectors. The dark current – corresponding to the thermal emission of electrons from the detector – and the quantum efficiency are the main metrics considered. We developed a simulation framework which models astrophysical and instrumental noise from observations and infers the requirements for the dark current and quantum efficiency. Several types of detectors have materials that cover parts of the passband of LIFE: HgCdTe, Ge:Cu, GaAs, and Si:As. This section comments on each of these possibilities.

HgCdTe Although typically reaching cutoff points of around $5\ \mu\text{m}$, HgCdTe arrays can, in principle, reach cutoff points of $\gtrsim 15\ \mu\text{m}$,^{57,58} and work with low-dark current. GeoSnap arrays have the benefit of covering a significant part of the LIFE Space Mission wave-range, while having deep full-well capacities with fast readout. However, their low dark currents remain prohibitively high for the LIFE Space Mission.⁵⁹

Si:As Si:As arrays offer large bandpasses and high quantum efficiency, and are advantageous in a space environment with their low power dissipation and their high radiation hardness.⁶⁰ These detectors are suitable for astronomical observations as demonstrated in space on the James Webb Space Telescope (JWST) and on the ground on the Large Binocular Telescope Interferometer (LBTI). However, they are difficult to replicate as the ones currently used were manufactured two decades ago.

MKIDs An alternative technology to the ones presented above would be the Microwave kinetic inductance detectors (MKIDs), currently in development. These detectors can count single photons with no effective dark current⁶¹ using a superconducting surface where light perturbs a microwave probe signal within resonator circuits, which is then multiplexed into large arrays. Efforts are on-going to develop these detectors for the mid-infrared range to make it suitable for the LIFE Space Mission.^{62–65}

SNSPDs Superconducting nanowire single photon detectors (SNSPDs) can count single photons in a similar way to MKIDs. Each photon creates a localized hotspot of excited electrons, which disrupt superconductivity and create a resistive barrier. This translates into a voltage that can be measured.⁶⁶ They have low dark-count rates, can support multiplexing, and recently demonstrated detection capabilities up to $29\ \mu\text{m}$.^{67–69}

3.4 Formation Flying

The LIFE Space Mission employs a five-spacecraft constellation that fly in a precisely coordinated, reconfigurable formation that rotates around the line of sight to the target.^{10,17} Expanding the interferometric array to multiple spacecrafts allows us to reach baselines that would otherwise be too challenging for single-spacecraft architectures, therefore making formation-flying a mission-enabling technology for the LIFE Space Mission. The array is planned to operate near the Sun-Earth L_2 point, which will introduce a communication delay between the spacecrafts and the ground. The formation must be able to acquire, maintain, reconfigure, and rotate in full autonomy. Since the TPF-I and *Darwin* studies, several missions have achieved significant progress in maturing the formation-flying strategy: ESA/PROBA-3⁷⁰ was the first mission to reach millimeter-level position precision between two spacecrafts, while NASA’s Starling/StarFOX⁷¹ demonstrated autonomous relative navigation and maneuver planning in low Earth orbit with a swarm of four CubeSats. The LIFE Space Mission requires the combination of all precision, baseline range, and autonomy for five spacecrafts.

Table 1 lists the requirements for the precision of the formation-flying. The array must maintain centimeter-level line-of-sight ranging, decimeter-level lateral positioning, and arcsecond-level attitude while ensuring the required baseline range. The remaining errors will be corrected by the fine optical control layer inside the combiner. The correction range and dynamics of the fine control will determine whether the requirements on the

formation-flying precision may be relaxed or tightened. The precision is also limited by the propellant consumption of the spacecrafts, which must be limited so as not to affect the mission lifetime. Other operational constraints must be respected: collision avoidance which drives the shortest baseline,³⁹ connectivity (with communication and sensing), sun avoidance, thruster saturation, and avoiding disruptions of the combiner during observation. The main challenge is to meet these requirements safely and robustly against hardware faults and perturbations.

These challenges will be studied with the development of a hardware-in-the-loop (HIL) testbed and algorithms on physical vehicles subjected to realistic space-like conditions. Its preliminary design currently envisions a low-friction planar surface, with several vehicles equipped with sensors, inter-spacecraft metrology, communication links, and external cameras for motion tracking. The vehicles should be able to reproduce the core mission phases, including the formation rotation during observation and the reconfigurable baselines. Such testbeds have been used before, such as the POSEIDYN testbed (Naval Postgraduate School),⁷² to investigate formation control and spacecraft proximity operations. They typically provide three degrees of freedom: two in translation and one in rotation. We are investigating whether it can be extended to five or six degrees of freedom as already demonstrated by the M-STAR (Caltech) and ADAMUS (Rensselaer Polytechnic Institute) testbeds.^{73,74} This would allow for a more realistic reproduction of the formation flying dynamics in space. Additionally, the testbed will allow end-to-end evaluation of guidance/navigation/control (GNC) architectures, bridging simulation efforts and hardware together. This will be an essential step toward the in-orbit formation flying demonstration for the LIFE Program roadmap.

We are also developing LIFECONTROLSIM, a multi-spacecraft simulator to propagate the dynamics of the formation near L_2 with maximum fidelity. It will include the dominant gravitational and solar-radiation pressure perturbations, the modeled thruster and their inertia, and the propellant depletion. This will allow for benchmarking of future candidate control architectures and how well they can meet the requirements in terms of Δv , propellant balance, and constraint satisfaction over full mission cycles.

4. OUTLOOK

The work and pre-studies carried out over the past years and reported here now place the LIFE Space Mission concept on a firmer technical and programmatic footing, and the next steps will have a decisive impact on the final concept of the mission that will be launched. The pre-studies have established physically consistent measurement principle and inferred top-level requirements for the LIFE Space Mission and the LIFE Prototype. The central task is to convert it to a credible implementation path.

The immediate priority on the LIFE Program is to advance both the prototype and the full mission to the next level of engineering maturity. This means creating full development plans for both missions, including end-to-end reference concepts with top-level technical requirements, and estimates for cost and schedule.

Several critical technologies and subsystems will also require focused effort in the near future because they will drive early design choices or are long-lead items. The main ones currently identified with mission-shaping consequences are the continued maturation of NICE (Sect. 3.1) toward broadband and cryogenic operation, a validated control architecture, and the development of mid-IR detectors and integrated optical components (Sect. 3.3).

Taken together, these programmatic and technical steps mark the transition of the LIFE Space Mission from a mission concept into a mission in preparation and bring the prospect of searching the atmospheres of nearby temperate Earth-like worlds for signs of life materially closer.

DISCLOSURES

This paper is an adaptation of the work presented by Glauser et al. (2026).⁴³

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