Program and abstracts

Program

	Monday	Tuesday	Wednesday	Thursday	Friday
09:00	Registration	Invited talk 2	Invited talk 3	Invited talk 4	Block 12
09:15					
09:30		Break	Break	Break	
09:45		Block 3	Block 6	Block 9	
10:00					Interacting with LIFE
10:15					
10:30		Coffee	Coffee	Coffee	Coffee
10:45					
11:00		Block 4	Block 7	Invited talk 5	Discussion / Feedback / Next steps
11:15					
11:30				Block 10	
11:45					
12:00		Poster Pop-ups	Poster Pop-ups		End of Meeting
12:15					
12:30		Lunch	Lunch	Lunch	
12:45					
13:00					
13:15					
13:30					
13:45					
14:00	Welcome	Block 5	Block 8	Block 11	
14:15					
14:30	Invited talk 1	Posters + Coffee	Posters + Coffee	Splinters 2 + Coffee	
14:45					
15:00	Block 1				
15:15					
15:30	Coffee				
15:45					
16:00	Block 2	ECR Mixer / Splinters 1	Free time for museum etc.	Splinters 3	
16:15					
16:30					
16:45					
17:00	End of Day	End of Day		End of Day	
17:15					
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18:00					
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18:30					
18:45					
19:00		Public Talk Laura Kreidberg	Conference Reception		

	Monday	Abstract #	First Name	Name	Title
09:00	Registration				
09:15					
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13:45					
14:00	Welcome				
14:15					
14:30	Invited talk 1		Adrian	**Glauser**	The LIFE Mission - status update
14:45					
15:00	Block 1	28	Eleonora	**Alei**	HWO and LIFE: future space telescopes to look for life in the universe
15:12		88	Óscar	**Carrión-González**	Exploring the synergies of LIFE with upcoming direct imaging facilities on the ground and in space
15:24	Coffee				
15:45					
16:00	Block 2	70	Komal	**Bali**	Can Water-Rich Magma Oceans Create Oxygen-Rich Atmospheres Without Life?
16:12		35	John Lee	**Grenfell**	Responses of Climate and Atmospheric Biosignatures onEarth-like Planets and Detectability with LIFE
16:24		76	Sean	**Jordan**	Using Sulfur Chemistry to Trace the Inner Edge of the Habitable Zone with LIFE
16:36		41	Thea	**Kozakis**	Exploring ozone as a replacement for molecular oxygen in mid-IR biosignature searches
16:48		69	Michele	**Maris**	The Oxygenic Photosyntetic Habitability of M stars acquaplanets
17:00	End of Day				

	Tuesday	Abstract #	First Name	Name	Title
09:00 09:15	Invited talk 2		Rafael	**Luque**	The rocky exoplanet census from RV and transits - today and tomorrow
09:30	Break				
09:45	Block 3	11	Danial	**Almasian**	Investigating the exoplanet HD88986 b by using TESS & CHEOPSspace telescope data.
09:52		87	James	**Jenkins**	Searching for Nearby Solar Systems by Joint RV+Astrometric Measurements
10:04		10	Rafael	**Luque**	K2-18b, a cautionary tale of biosignature identification in the era of JWST
10:30 10:45	Coffee				
11:00	Block 4	71	Rachael	**Roettenbacher**	A Ground-Based, Long-Baseline Optical Interferometric Survey of Potential Targets for Space-Based Studies of Exoplanet Atmospheres
11:12		54	Germain	**Garreau**	Asgard/NOTT: design, assembling, and nulling optimization
11:24		78	Jonah	**Hansen**	An overview and update on the Nulling Interferometer Cryogenic Experiment (NICE)
11:36		56	Guillermo	**Martin**	Recent developments on mid-IR active beam combiners and spectrometers based on Ti:diffusion lithium niobate waveguides
11:48		32	Ahmed	**Sanny**	A 4-telescope integrated optics beam combiner for nulling interferometry with NOTT at the VLTI
12:00 12:15	Poster Pop-ups				
12:30 12:45 13:00 13:15 13:30 13:45	Lunch				
14:00	Block 5	51	Valentin	**Fleury**	Carbon for 4Life: A non nulling space based mid-IR spectro interferometer for investigating the solid-carbon particle abundance as part of the first building blocks in the telluric forming planet region.
14:12		24	Damien	**Galano**	Proba-3: a preliminary assessment of the formation flying performance
14:24		73	Kiwamu	**Izumi**	Overview of SILVIA
14:45 15:00 15:15 15:30 15:45	Posters + Coffee				
16:00 16:15 16:30 16:45	ECR Mixer / Splinters 1				
17:00	End of Day				
17:15 17:30 17:45 18:00 18:15 18:30 18:45					
19:00	Public Talk Laura Kreidberg				

	Wednesday	Abstract #	First Name	Name	Title
09:00 09:15	Invited talk 3		Zita	**Martins**	Search for life in the Solar System
09:30	Break				
09:45	Block 6	62	Marrick	**Braam**	Observing 4D effects in the atmospheric chemistry of rocky exoplanets with LIFE
09:52		60	Janina	**Hansen**	Work-LIFE-Balance: Constraining modern Earth chemical disequilibrium biosignatures using mid-infrared spectroscopy
10:04		13	Natasha	**Latouf**	Exploring New Worlds with BARBIE and KEN
10:30 10:45	Coffee				
11:00	Block 7	53	Sarah	**Rugheimer**	Assessing LIFE's Capability to Detect Liquid Water Oceans on Exoplanets
11:12		31	Salma	**Salhi**	Progress on a machine learning for a data-driven method of correlated noise correction in the JWST NIRISS instrument: a potential method of data processing for LIFE
11:24		25	Benjamin	**Taysum**	Oxygen bistability and triple signature false positives in emission spectra of terrestrial exoplanet atmospheres
11:36		14	Robert	**Washington**	Modeling Sulfur Dioxide Outgassing Across the Habitable Zone using Steady-State Analysis of Influx-Yielding Atmospheric Networks (SAIYAN)
11:48		46	Philipp	**Huber**	Correlated Instrumental Errors or the Next Frontier in the Design of LIFE
12:00 12:15	Poster Pop-ups				
12:30 12:45 13:00 13:15 13:30 13:45	Lunch				
14:00	Block 8	96	Ethan	**Foss**	Distributed Spacecraft Mission Design for the Starlight Acquisition and Reflection toward Interferometry Mission
14:12		33	Jeff	**Kuhn**	Why we are looking for evidence of life or advanced life from the ground: The ExoLife Finder (ELF) project
14:24		90	Romain	**Laugier**	Asgard NOTT Decisive steps for nulling interferometry from the ground at VLTI
14:45 15:00 15:15 15:30 15:45	Posters + Coffee				
16:00 16:15 16:30 16:45 17:00 17:15 17:30 17:45 18:00 18:15 18:30 18:45	Free time for museum etc.				
19:00	Conference Reception				

	Thursday	Abstract #	First Name	Name	Title
09:00 09:15	Invited talk 4		Corinna	**Kufner**	Origin of life
09:30	Break				
09:45	Block 9	80	Anika	**Chan**	The Pyxis Interferometer Inter-spacecraft Metrology System
09:52		29	Vincent	**Foriel**	Tunable Kernel-Nulling interferometry for direct exoplanet detection
10:04		89	Michael	**Ireland**	Spatial filtering at the heart of LIFE's nuller
10:30 10:45	Coffee				
11:00 11:15	Invited talk 5		Caroline	**Piaulet-Ghorayeb**	Current constraints on rocky exoplanet atmospheres and and future prospects
11:30	Block 10	49	Jerome	**Loicq**	A single spacecraft nulling interferometer
11:42		20	Fabien	**Malbet**	Unveiling Habitable Worlds with high precision astrometry for Next-Generation Direct Imaging Missions like LIFE
11:54		74	Taro	**Matsuo**	SEIRIOS: the first demonstration of formation flying interferometry toward LIFE
12:06		23	Enric	**Palle**	ANDES at the ELT: A ground-based pathfinder for LIFE through detailed atmospheric characterization of terrestrial worlds
12:18		38	Stephanie	**Rossini-Bryson**	GLINT: A Photonic Nulling Interferometer for High-Contrast Imaging of Stellar Companions
12:30 12:45 13:00 13:15 13:30 13:45	Lunch				
14:00	Block 11	82	Kevin	**Kouwenhoven**	KIDs: Superconducting Single Photon Counting Detectors for LIFE
14:15		43	Pierre	**Labeye**	Design, fabrication and photometric characterization of Silicon Germanium waveguides and devices for mid-infrared nulling interferometry
14:30		36	Manon	**Lallement**	Towards integrated mid-infrared spectro-interferometry: characterization of SiGe-on-Si Arrayed Waveguide Gratings
14:45 15:00 15:15 15:30 15:45	Splinters 2 + Coffee				
16:00 16:15 16:30 16:45	Splinters 3				
17:00	End of Day				

	Friday	Abstract #	First Name	Name	Title
09:00	Block 12	6	Wei	**Wang**	The Tianlin Mission: a 6+ meter UV-OPT-NIR Space Telescope for Habitable Worlds
09:12		94	Thomas	**Schwarze**	Exoplanets meet Gravity: How LIFE could benefit from LISA and GRACE-FO laser interferometry
09:24		39	Takahiro	**Ito**	Iterative and Incremental Approach towards Future Formation-Flying Optical Interferometry
09:36		27	Marc-Antoine	**Martinod**	Compact high-contrast imaging in high spectral resolution with nulling interferometry and photonics
09:48		15	영석	**정**	Silicon Carbide Mirrors Fabricated by Binder Jetting Additive Manufacturing for Space Optical Systems
10:00	Interacting with LIFE				
10:15					
10:30	Coffee				
10:45					
11:00	Discussion / Feedback / Next steps				
11:15					
11:30					
11:45					
12:00	End of Meeting				

Talk abstracts

6

The Tianlin Mission: a 6+ meter UV-OPT-NIR Space Telescope for Habitable Worlds

Wei Wang
National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China

Abstract

The ongoing and upcoming space-based planet survey missions, such as TESS, PLATO, and ET, are expected to discover thousands of small to medium-sized planets via the transit method, including over a hundred potentially habitable rocky planets. To further study these terrestrial planets, especially those with lower temperatures and wider orbits, the exoplanetary science community has proposed various follow-up missions. However, none of these missions will possess the capability to characterize the atmospheres of Earth-like planets in habitable zones comprehensively or to detect potential biosignatures. China is funding a concept study for **Tianlin**, a 6+ meter class UV to NIR space telescope, projected to begin operations around 2035+ with a mission lifespan exceeding 10 years. Tianlin's primary goal will be the characterization of rocky planets in the habitable zones of nearby stars, with a focus on identifying possible biosignatures. Additionally, this mission aims to significantly enhance our understanding of exoplanet populations, nearby galaxies, and the early universe. In this talk, we will present an overview of the Tianlin mission concept and outline the baseline requirements for the telescope and instruments, informed by our preliminary simulations. We invite international collaborations across hardware, software, and scientific research to contribute to this groundbreaking endeavor. Synergies between LIFE and Tianlin should be considered.

Permission to publish

yes

Categories

6 Instruments / Missions

10

K2-18b, a cautionary tale of biosignature identification in the era of JWST

Rafael Luque
Instituto de Astrofisica de Andalucia, Granada, Spain. University of Chicago, Chicago, United States

Abstract

K2-18 b is undoubtedly one of the most promising planets for interior, atmosphere, and habitability studies of a sub-Neptune in the JWST era. Methane and carbon dioxide have been found in its hydrogen-rich atmosphere, but the presence of additional species is still under debate. Signatures of dimethyl sulfide (DMS) and dimethyl disulfide (DMDS) have been claimed in the near-infrared (using the NIRISS and NIRSpec instruments) and mid-infrared (using MIRI) separately. In this talk, I will summarize the latest work on K2-18b and present the first joint analysis of the panchromatic transmission spectrum of the planet between 0.6 and 12 microns (Luque et al. 2025, A&A, under review). We find insufficient evidence for DMS and/or DMDS in the atmosphere. In addition, other molecules containing methyl functional groups (e.g., ethane) with absorption bands similar to DMS/DMDS provide an equally good fit to the data. This work highlights the shortcomings of biosignature detection in the era of JWST, which will be important to plan for and prepare against when next-generation facilities like LIFE and HWO are ready.

Permission to publish

yes

Categories

1 Observations

11

Investigating the exoplanet HD88986 b by using TESS & CHEOPSspace telescope data.

Danial Almasian
Shahid Beheshti University, Tehran, Iran

Abstract

The discovery of transiting planets with orbital periods exceeding 40 days has been exceptionally rare among the 5000+ planets identified to date. This dearth of findings poses a significant challenge to studying planetary demographics, formation, and evolution. In this study, we report detecting and characterizing HD88986 b, a potentially transiting sub-Neptune with the longest orbital period of any known transiting small planet. Our analysis drew on a combination of two sectors of TESS data and a 7-day observation from CHEOPS. Additionally, TLS was utilized for the analysis of HD88986 data. Our findings indicate that HD88986 b, exhibiting two likely single transits on sector 21 and sector 48, both consistent with the predicted transit time from the RV model, is a likely transit candidate. The wide orbit of HD88986 b suggests that the planet did not experience significant mass loss due to XUV radiation from its host star, likely retaining its original composition and offering insights into its formation. Furthermore, the cold nature of HD88986 b, owing to its extended orbital period, presents exciting prospects for future studies on the characterization of its cold atmosphere composition.

Permission to publish

yes

Categories

1 Observations

13

Exploring New Worlds with BARBIE and KEN

Natasha Latouf, Avi Mandell, Michael Himes, Geronimo Villanueva, Vincent Kofman, Michael Moore, Chris Stark
NASA Goddard Space Flight Center, Greenbelt, United States

Abstract

We have seen the discovery and confirmation of thousands of exoplanets in the last 20 years, and we are now on the verge of entering an exciting new era of planetary exploration: detection and characterization of terrestrial exoplanet atmospheres. Detecting biosignatures in exoplanet atmospheres is the first step on the path to determining planet habitability, and efficiency is key to maximizing the science output from limited observation time, especially in next-generation instrument design such as the upcoming Habitable Worlds Observatory (HWO). Knowing this, the optimal wavelength for the spectral bandpass used for observations is a crucial factor to consider.

Coronagraphic design currently limits the observing strategy used to detect biosignatures such as H2O, O_2, O_3, or CH_4, requiring the choice of specific bandpasses to optimize abundance constraints. We use 4 pre-constructed grids of geometric albedo spectra across a range of abundance and pressure, hereby the KEN gridset, and interpolate to produce forward models for an efficient nested sampling routine, PSGnest, thus enabling wide ranges of parametric retrievals. We have also developed a new grid-building scheme, Gridder, that allows us to unlock simulations of multiple new molecules and parameters over a much wider wavelength space.

By understanding the SNR requirements for detecting molecules of interest and varying planetary archetypes, and properly prioritizing the spectral bandpasses to optimize detectability of different atmospheric constituents, we can provide quantitative relationships between science output and instrument designs and observing procedure as we look to starting the decision-making process for the HWO.

Permission to publish

yes

Categories

2 Simulations

14

Modeling Sulfur Dioxide Outgassing Across the Habitable Zone using Steady-State Analysis of Influx-Yielding Atmospheric Networks (SAIYAN)

Robert Washington
NASA Goddard Space Flight Center, Greenbelt, United States

Abstract

With the growing diversity of detected terrestrial exoplanets, understanding their evolutionary pathways is essential for characterizing and categorizing these worlds. Sulfur dioxide (SO_2), a gas commonly produced by volcanic and biological activity on Earth, has significant implications for the atmospheric and surface conditions of terrestrial exoplanets. In this study, we present three vertical mixing ratio grids for SO_2, each representing different planetary scenarios within the middle and outer habitable zones. For each case, we explore the relationship between atmospheric SO_2 abundance and water liquid or vapor content. We further vary the SO_2 outgassing rate to examine its dependence on water availability and stellar type, providing insight into potential observables for upcoming missions such as JWST and HWO. Finally, we discuss how these grids can inform sensitivity requirements for future UV spectroscopy instruments aimed at characterizing exoplanet atmospheres.

Permission to publish

yes

Categories

2 Simulations

15

Silicon Carbide Mirrors Fabricated by Binder Jetting Additive Manufacturing for Space Optical Systems

Youngsuk Jung, Ji-Won Oh, Shinhu Cho
MADDE, Seoul, Korea, Republic of

Abstract

Silicon carbide (SiC) has become a material of choice for space-based optical systems due to its superior specific stiffness, thermal stability, and low coefficient of thermal expansion. However, its extreme hardness and brittleness make traditional machining and sintering-based manufacturing both costly and restrictive in geometry.

In this study, we present a binder jetting additive manufacturing (BJAM) process tailored for SiC powder to fabricate lightweight, complex-geometry SiC mirrors for space applications. Using a custom-developed printer optimized for non-spherical ceramic powders, we produced porous green bodies with intricate features, which were subsequently densified via reactive melt infiltration. This reaction-bonded SiC (RB-SiC) process eliminates sintering shrinkage and enables production of closed-back and double-sided mirror structures in a single build.

The printed mirrors exhibit surface roughness governed by the initial powder morphology, which is then improved through grinding and polishing to meet optical requirements. The process allows rapid, cost-effective fabrication of dimensionally stable SiC components with integrated lightweighting features.

This approach provides a scalable pathway for producing next-generation ceramic optics for space platforms, especially in free-space laser communication and imaging payloads where structural rigidity and thermal performance are critical.

Permission to publish

yes

Categories

5 Technologies

20

Unveiling Habitable Worlds with high precision astrometry for Next-Generation Direct Imaging Missions like LIFE

Fabien Malbet
Univ. Grenoble Alpes / CNRS / IPAG, Grenoble, France

Abstract

The future space mission Large Interferometer For Exoplanets (LIFE) has been designed to characterize the atmospheres of temperate terrestrial exoplanets and search for potential bio-signatures. To reach this ambitious objective, a precise pre-characterization of target planets is essential—particularly their masses and orbital parameters.

This is where Theia, a high-precision astrometric mission, plays a critical complementary role. Theia aims to detect Earth-mass planets within the Habitable Zones of nearby F, G, and K-type stars, providing exact measurements of their true masses and full 3D orbital architectures—data currently beyond the reach of any existing or planned observatory. This information will be crucial for optimizing the target selection for LIFE, eliminating uncertainties and maximizing the scientific return of direct imaging and atmospheric spectroscopy.

This presentation will give an overview of Theia's recent technical developments. Notable innovations include its compact diffraction-limited 0.8-meter Korsch Three-Mirror Anastigmat (TMA) telescope, large-format CMOS detectors, and a simplified in-flight calibration approach using Gaia reference stars, eliminating the need for laser metrology. Operating from the Lagrange Point L2, Theia is designed to deliver sub-microarcsecond astrometric precision over a 4-year mission.

By providing a robust and efficient target list, Theia would lay the groundwork for LIFE’s future search for life beyond Earth, illustrating the scientific synergy between astrometric and direct imaging missions.

Permission to publish

yes

Categories

6 Instruments / Missions

23

ANDES at the ELT: A ground-based pathfinder for LIFE through detailed atmospheric characterization of terrestrial worlds

Enric Palle
Instituto de Astrofisica de Canarias, La Laguna, Spain

Abstract

The LIFE mission aims to characterize the atmospheres of dozens of terrestrial exoplanets. Ground-based facilities like the ANDES spectrograph on the ELT are crucial pathfinders, developing the techniques and setting the scientific priorities for this future endeavor. ANDES, with its unique combination of high spectral resolution (R > 100,000) and high-contrast capabilities via adaptive optics, aims to conduct the first detailed atmospheric studies of Earth-sized planets in the habitable zones of nearby M-dwarfs.

This talk will present the transformative potential of ANDES for atmospheric science, focusing on its two primary methods: high-dispersion transmission spectroscopy and high-contrast, high-resolution (HCHR) spectroscopy in reflected light. We will show that ANDES can detect molecular features in the atmospheres of dozens of transiting rocky planets. More importantly, its HCHR mode will for the first time unlock the study of non-transiting planets in reflected light, targeting a "golden sample" of nearby habitable-zone worlds. We will present new, advanced end-to-end simulations of ANDES performance that move beyond simple cross-correlation and provide invaluable insights into atmospheric dynamics, chemistry, and the potential for biosignatures—key science drivers for LIFE. Furthermore, ANDES will operate in synergy with other flagship missions (JWST, ARIEL, and PLATO), providing complementary high-resolution data to break degeneracies in JWST and ARIEL retrievals. By pioneering the methods to disentangle stellar activity from planetary signals and to model complex atmospheric scenarios, ANDES will directly inform the observation strategies for LIFE, serving as a vital ground-based precursor in the roadmap to characterizing habitable worlds.

Permission to publish

yes

Categories

6 Instruments / Missions

24

Proba-3: a preliminary assessment of the formation flying performance

Damien Galano, Frederic Teston, Raphael Rougeot, Jorg Versluys, Teodor Bozhanov, Esther Bastida Pertegaz
ESA, Noordwijk, Netherlands

Abstract

ESA Proba-3 mission was launched on 5th December 2025. This demonstration mission aims to advance and demonstrate precise formation flying techniques and concepts. It comprises two spacecraft that replicate the principle of a total solar eclipse, with a telescope positioned 150 meters away within the shadow cast by the occulting spacecraft. This requires millimetric accuracy and stability in the formation geometry. The in-orbit commissioning phase has been completed in June 2025 marked by the first successful acquisition of Sun Corona images. The Proba-3 performance is beyond expectations with respect to the mission requirements. This paper briefly presents the mission concept, and provide a preliminary assessment of the obtained formation flying performance and its technical drivers, and discuss what could be extrapolated for future missions

Permission to publish

yes

Categories

6 Instruments / Missions

25

Oxygen bistability and triple signature false positives in emission spectra of terrestrial exoplanet atmospheres

Benjamin Taysum[1], Sarah Rugheimer[2], John Lee Grenfell[1], Franz Schreier[3], Juan Cabrera[1], Heike Rauer[4]
[1]German Aerospace Center (Institute of Space Research), Berlin, Germany. [2]University of Edinburgh, Edinburgh, United Kingdom. [3]German Aerospace Center (Remote Sensing Technology Institute), Oberpfaffenhofen, Germany. [4]Freie Universität Berlin (FUB), Berlin, Germany

Abstract

The detection of life on a rocky exoplanet currently hinges upon identifying the planet's atmospheric composition. Photochemical modelling studies routinely show that it is challenging, if not impossible, to attribute the detection of any singular molecular species exclusively to biological production. The simultaneous detection of CO_2, O_3, and H_2O ('Triple Signature') is however regarded as a robust indicator of oxygenic photosynthetic processes on the surface of an Earth-like exoplanet. In this study, we use a 1D climate-chemistry coupled atmospheric model to investigate the Triple Signature in emission spectra across 4.0-18.5 µm. The study focuses on abiotic planets throughout the habitable zone [0.95 au, 1.70 au] of a Sun-like (G2). Results suggest that a critical orbital distance exists that is dependent on pCO2 and the total H2O column which dictates the atmospheric O_2 content and the ability of the Triple Signature to be produced abiotically. Positioned at this critical distance, an increase of stellar flux of less than 1% is sufficient to cause the abiotic O2 columns of the planet to collapse from 1000 ppmv to below 1 ppmv and remove the O_3 detection from the Triple Signature. A total of 5000 abiotic atmospheres initialised with a randomly sampled range of CO_2 partial pressures [1 mbar, 50 mbar], H_2O columns [100 ppmv, 10000 ppmv], and orbital distances [0.95 au, 1.70 au] are studied with LIFEsim to identify the integration time required for CO_2, H_2O, and O_3 to produce 3-σ significant absorption features in the planet emission spectra for the LIFE interferometer.

Permission to publish

yes

Categories

2 Simulations

27

Compact high-contrast imaging in high spectral resolution with nulling interferometry and photonics

Marc-Antoine Martinod, Vincent Foriel, Nick Cvetojevic, Frantz Martinache, David Mary, Jeronimo Calderon-Gomez, Roxanne Ligi
Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France

Abstract

Characterisation of exoplanets and finding biosignatures are among the hottest topics in astronomy. This quest is challenged by the brightness contrast between the faint planet and the overwhelming glare of the host star, their angular separation and the observing conditions degraded by optical aberrations (from the atmosphere or the observatory). Nulling interferometry is a promising technique for this goal by fulfilling both high contrast and high angular resolution requirements. However, it requires a highly stable wavefront to suppress the starlight by destructive interference. Such a combination is often performed by deformable mirrors and mechanical delay lines. Aiming for a spectral broadband extinction is even more challenging as we need to phase wavefronts in every spectral channel. Photonic-Integrated Circuits is a flexible and powerful platform to tackle all these challenges: it provides the flexibility and the compactness in the design to address each of these issues and provide scalable and space-compatible solutions. With the PHOTONICS project, we aim to create novel coherent combination architectures, based on a multimode interferometer coupler, on-chip active phase control with no moving parts to unlock an efficient and broadband starlight suppression. We are also developing an arrayed waveguide grating to perform high-resolution spectroscopy on the planet signal. In this presentation, we present the concept of the combination, how we process the light to obtain a spectrally-dispersed signal robust against stochastic noise and how we manage to make achromatic destructive interference.

Permission to publish

yes

Categories

5 Technologies

28

HWO and LIFE: future space telescopes to look for life in the universe

Eleonora Alei
NASA Goddard Space Flight Center, Greenbelt, United States

Abstract

One of the primary goals of the astronomical community in the next few decades is to characterize temperate terrestrial exoplanets to search for life. To address this challenge, the US Astro2020 Decadal survey recommended the pursuit of a technical and scientific study for the Habitable Worlds Observatory (HWO), an ultraviolet/visible/near-infrared (UV/VIS/NIR) "high-contrast direct imaging mission with a target off-axis inscribed diameter of approximately 6 meters" which shares design and technology heritage with the previous concept studies HabEx (Habitable Exoplanet Observatory) and LUVOIR (Large UV/Optical/IR Surveyor). Similarly, European scientists focus on the development of the MIR space-based nulling interferometer LIFE (Large Interferometer For Exoplanets).

These observatories would focus on complementary regions of the electromagnetic spectrum: HWO will explore the reflected light spectrum regime in the UV/VIS/NIR, while LIFE would capture the planetary thermal emission in the MIR. Both wavelength ranges provide us with their specific set of preferred information and come with specific drawbacks. Yet, the scientific yield of synergistic observations in the UV/VIS/NIR+MIR range has the potential of being greater than the sum of its parts: having access to multiple spectral windows into the atmosphere of a potentially habitable planet could be transformative for the search of life in the universe.

In this talk, I will discuss the potential of LIFE and HWO in characterizing a cloud-free Earth twin at 10-parsec distance both as separate missions and in synergy with each other.

Permission to publish

yes

Categories

6 Instruments / Missions

29

Tunable Kernel-Nulling interferometry for direct exoplanet detection

Vincent FORIEL[1], David Mary[1], Frantz Martinache[1], Marc-Antoine Martinod[1], Nick Cvetojevic[1], Romain Laugier[2]
[1]Observatoire de la Côte d'Azur, Nice, France. [2]KU Leuven, Leuven, Belgium

Abstract

Nulling interferometry is a promising technique for direct detection of exoplanets. However, the performance of current devices is limited by the sensitivity to phase aberrations. This project attempts to improve this technique by using an active photonic technology with no moving parts instead of classic bulk optics. The studied component allows to build tunable Kernel-Nulls with 14 electro-optic phase shifters, used to compensate optical path differences that would be induced by manufacturing defects. The first part of the study consists in the development of an algorithm providing the delays to be injected into the component to optimize the performance of that device. This technique is first evaluated via numerical simulations, then in lab. It is then envisaged to leverage the Nuller mode, soon to be installed on the VLTI as part of the ASGARD project, to test this architecture under real conditions of observation. The next step of this study deals with the analysis of the intensity distributions produced at the output of the Kernel-Nuller through a series of observations, against which statistical tests and machine learning techniques will be applied to detect the presence of exoplanets. The preliminary results of this study are presented in this presentation.

Permission to publish

yes

Categories

5 Technologies

31

Progress on a machine learning for a data-driven method of correlated noise correction in the JWST NIRISS instrument: a potential method of data processing for LIFE

Salma Salhi[1,2,3,4], Alexandre Adam[1,3,4], Loïc Albert[1,2], René Doyon[1,2], Laurence Perreault Levasseur[1,3,4,5,6,7]
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Abstract

Currently, all near-infrared instruments aboard the JWST, especially NIRISS, suffer from non-Gaussian (correlated 1/f) noise along with other additive sources of astrophysical and instrumental noise. Even the best correction schemes can leave error bars in transmission spectra that are twice as large as they should be. When dealing with atmospheric signals that are on the order of only a few tens of ppm, as is the case for habitable world candidates, it becomes increasingly important to find a way to improve noise correction such that we can achieve photon-limited precision. This could be especially pertinent for the LIFE mission, as we expect low photon rates from distant observations with LIFE, and thus low SNR. To address this noise problem in the NIRISS SOSS mode, we developed a data-driven, machine learning approach to noise correction that can achieve photon-limited precision on simulated data. We do this by training a score-based generative diffusion model to learn the structure of the noise in real dark images, including bad pixels, hot pixels, cosmic rays, readout noise, and 1/f noise. We then use this noise model as the data likelihood to analyze mock spectral trace observations in a Bayesian framework, allowing us to produce noise-free posterior samples of the pixel values of the underlying signal. This method provides a robust statistical framework for noise correction and uncertainty quantification. Given our success so far with simulated data, this approach could be a fruitful avenue to explore for the development of processing pipelines for the LIFE mission.

Permission to publish

yes

Categories

2 Simulations

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A 4-telescope integrated optics beam combiner for nulling interferometry with NOTT at the VLTI

Ahmed Sanny[1,2,3], Germain Garreau[4], Lucas Labadie[2], Simon Gross[3], Kévin Barjot[2], Romain Laugier[4], Marc-Antoine Martinod[4], Denis Defrère[4], Michael Withford[3]
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Abstract

The NOTT visitor instrument exploits mid-infrared L'-band nulling interferometry to study hot exozodiacal dust and young Jupiter-like planets close to the water snowline. It achieves this by combining the four VLTI beams using a dedicated integrated optics (IO) beam combiner. Based on the double-Bracewell architecture, we manufactured the mid-IR IO beam combiner in Gallium Lanthanum Sulfide glass using Ultrafast Laser Inscription and performed a detailed laboratory characterization in the L′-band. We employ a setup that simulates the four VLTI telescopes and perform nulling using broadband coherent beams at room temperature. We examine the modal, chromatic, and polarization characteristics of the integrated optics beam combiner and quantify its total throughput.

The directional couplers forming the four-telescope beam combiner (4T-nuller) show an achromatic splitting ratio across the wavelength band 3.65 to 3.85 µm, with a splitting ratio of 40/60 for the side couplers and 50/50 for the central coupler. We measure a total throughput of 37%, including Fresnel losses, which will be improved thanks to anti-reflection coatings. We find a low level of differential birefringence. Operating at ambient temperature without polarization control, we record an average broadband raw null of $8.13\pm0.03\times10^{-3}$ and a self-calibrated null of $1.14\pm0.01\times10^{-3}$ over a duration of 20s. This should represent the first measurement of a deep null in the L′-band using a four-telescope integrated optics beam combiner and is also a step forward in the technological readiness of small-scale interferometric beam combiners for future space missions such as LIFE.

Permission to publish

yes

Categories

4 Experiments

33

Why we are looking for evidence of life or advanced life from the ground: The ExoLife Finder (ELF) project

Jeff Kuhn[1], Nicolas Lodieu[1], Rafa Rebolo[1], Natalia Arteaga-Marrero[1], Auxiliadora Padron-Brito[1], Diego Tamayo-Guzman[1], Aleksei Grawe[1], Victor Quintero[1], Max Dobat[2], Adrian Sanchez-Chaves[1], Raquel Conde-Viera[1]
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Abstract

The possibility of detecting life or even advanced life on the nearest exoplanets grows with our increasing understanding of their properties. While we don't yet have much technical capability to see biomarkers, or technomarkers on nearby habitable water-bearing (HW) planets, this is arguably within reach. The problem is worth some investment as the consequences for humanity of exolife detection could be as dramatic as the implications of Galileo's telescopic proof of our place in the physical universe. Empirical evidence of a cosmic ecology, that some scientists have argued about for decades, could not only diminish dangerous human exceptionalism but in the short term it could redirect resources to scientific problems that many of us care deeply about. Furthermore this effort could have enormous long-term societal payoffs. This talk describes our vision of a ground-based "fixed pupil Fizeau Interferometer" as an optical system optimized to find exolife. We'll explain why we want to do this from the ground and how a Small "ExoLifeFinder" or SELF is progressing

Permission to publish

yes

Categories

6 Instruments / Missions

35

Responses of Climate and Atmospheric Biosignatures onEarth-like Planets and Detectability with the Large Interferometer for Exoplanets (LIFE)

John Lee Grenfell[1,2], Benjamin Taysum[1], Franz Schreier[1,3], Hamish Innes[1,2], Alexis M. S. Smith[1], Szilard Csizmadia[1], Nicolas Iro[1], Sarah Rugheimer[4,5], Thea Kozakis[6], Eleonora Alei[7,8], Lena Noack[2], Tim Lichtenberg[9], Sascha P. Quanz[10,11], Konstantin Herbst[12,1], Miriam Sinnhuber[13], Andreas Bartenschlager[13], Juan Cabrera[1], Heike Rauer[14,2]

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Abstract

We investigate the detectability of atmospheric biosignatures with the LIFE mission. Starting with the modern Earth we model the climate, photochemistry and spectra of Earth-like planets over a range of insolation, gravity, humidity, albedo, atmospheric mass and carbon dioxide abundances and investigate detectability of key atmospheric species by LIFE for Earth-like planets assumed to lie at 10pc for the LIFE (20-day viewing) baseline case. We find that atmospheric ozone (O_3) abundances are maintained over a range of conditions. The O_3 fundamental band is visible for most scenarios studied but is weakened for exoplanets with cooler central stars. Additional potential biosignatures such as methane (CH_4), nitrous oxide (N_2O) and chloromethane (CH_3Cl) are favored for low UV conditions e.g. exoplanets orbiting cooler central stars or having strong atmospheric shielding. Regarding spectral signatures, CH_4 and water (H_2O) signals from 6-8 microns are evident in most scenarios, as is the carbon dioxide (CO_2) 15 micron band, which strengthens for low-O_2 scenarios associated with upper atmosphere cooling. Considering the LIFE baseline case with 20-day viewing, H_2O is retrievable with a confidence level (CL) of up to 3-sigma for the high (90%, 0.9 vmr) CO_2 scenario, and with ~2-sigma or less for the other scenarios. N_2O is not be observable with a CL sigma mostly in the range 1-2-sigma. CH_4 features a CL sigma detectability range of 2.3-4.4. O_3 is detectable with a CL (>3-sigma) in most scenarios (including the low-ozone Proterozoic) except for the extremely low O_3 Archaean scenario and the thin atmosphere scenario.

Permission to publish

yes

Categories

3 Theory / Models

36

Towards integrated mid-infrared spectro-interferometry: characterization of SiGe-on-Si Arrayed Waveguide Gratings

Manon Lallement[1], Pierre Labeye[2], Louis Gemmerlé[1], Jean-Philippe Berger[1], Rémi Armand[2], Guillermo Martin[1], Stéphane Curaba[1]

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Abstract

Spectrograph volume no longer scales with telescope aperture for a given resolving power owing to guided optics. When implemented with integrated photonics, highly customizable functionalities become accessible. In this context, Arrayed Waveguide Gratings (AWGs) have emerged as promising devices that spatially separate light into discrete spectral channels via optical interference within integrated waveguides.

AWGs' inherent compactness, thermo-mechanical stability and compatibility with interferometric and nulling photonic integrated circuits (PICs) make them attractive for space-based instrumentation. However, astronomical spectroscopy poses stringent requirements on throughput, spectral resolution, and broadband operation. Moreover, while most AWG development has focused on the near-infrared, extending their operation into the mid-infrared is particularly challenging yet highly desirable as this region covers the molecular fingerprint domain, where potential biosignatures (CO_2, H_2O, CH_4, O_3) leave distinct absorption features.

In this framework, we present mid-infrared AWGs characterization conducted at Institut de Planétologie et d'Astrophysique de Grenoble (IPAG). The devices, fabricated by CEA-LETI using silicon-germanium on silicon technology, are optimized for operation between 3.3 and 3.5 microns but offer possibilities to operate up to 9 microns. Two phase-shifted beams from a Michelson interferometer are injected into the AWG. At the output, eight spectrally filtered interferograms are recorded, each corresponding to a narrow wavelength band defined by the device. Applying Fourier Transform Spectroscopy to these interferograms enables retrieval of the AWG dispersion properties. Finally, we discuss key experimental challenges in mid-infrared, including efficient light coupling into high-NA waveguides, thermal background mitigation, and throughput assessment, discussing implications for future astronomical applications.

Permission to publish

yes

Categories

5 Technologies

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GLINT: A Photonic Nulling Interferometer for High-Contrast Imaging of Stellar Companions

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Abstract

Direct imaging and spectroscopy of Earth-like exoplanets requires extreme starlight suppression and precise wavefront control at small angular separations. Nulling interferometry offers a solution by destructively interfering on-axis starlight while transmitting planetary light. The Guided Light Interferometric Nulling Technology (GLINT) instrument on the SCExAO system at the 8.2-meter Subaru Telescope performs nulling photonically, using waveguides and couplers in a photonic chip to achieve compact, stable, and scalable interferometry. GLINT has demonstrated on-sky nulling, photonic fringe tracking, and angular resolution beyond the telescope's classical diffraction limit. Coronagraphs remain limited by quasi-static speckle noise, diffraction leakage, and inner working angles that restrict access to habitable zones around nearby stars; GLINT offers a complementary approach by spatially filtering starlight at small angular separations through destructive interference. Its architecture is highly synergistic with the goals of future ELT-class instruments and space missions such as HWO, serving as a pathfinder for scaling nulling technologies in the next generation of high-contrast observatories. Here, we present an overview of the GLINT instrument, recent developments in its real-time control architecture, including active fringe tracking, and current on-sky performance.

Permission to publish

yes

Categories

6 Instruments / Missions

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Iterative and Incremental Approach towards Future Formation-Flying Optical Interferometry

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Abstract

Spacecraft formation flying is an astronomical instrumentation method to construct large virtual structures in space. Represented by the Large Interferometer For Exoplanets (LIFE) mission, there has been attention to formation-flying astronomical missions by using optical interferometric techniques. They typically require the very high control accuracy of less than 1 µm between science instruments and 1 mm between satellites. However, there is still a lack of such experiences in orbit. To bridge a gap between the current and future technologies, this talk introduces iterative and incremental approach towards future formation-flying optical interferometry. Based on speaker's own experience, two approaches before comprehensive missions will be essential: ground-based demonstration by using hardware-in-the-loop testbed and space-based demonstration. In this context, this talk will show some examples Japan's recent activities on formation-flying optical interferometry, and how the similar approaches might be adopted to the LIFE mission. This talk can support the LIFE community to build a technological roadmap towards its goal.

Permission to publish

yes

Categories

5 Technologies

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Exploring ozone as a replacement for molecular oxygen in mid-IR biosignature searches

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Abstract

Molecular oxygen (O_2) with a reducing gas (i.e., methane) is regarded as a promising sign of life in the atmospheres of terrestrial exoplanets. In circumstances when O_2 may not be detectable in a planetary atmosphere (e.g., in the mid-IR) it has been suggested that ozone (O_3), the photochemical product of O_2, could be used as a proxy to infer the presence of O_2. While O_3 is not directly produced by life, it plays an important role in habitability as the ozone layer is the primary source of UV shielding for surface life on Earth. However, O_3 production has a nonlinear dependence on O_2, along with being strongly influenced by the UV spectrum of the planet's host star. To evaluate O_3 as a proxy for O_2 modeled Earth-like atmospheres of habitable zone planets around a variety of stellar hosts (from G0V-M5V), along with modeling emission spectra of these model atmospheres with the radiative transfer code PICASO. Our models explore the O_2-O_3 relationship under a range of O_2 abundances, along with varying amounts of biologically produced gases (N_2O, CH_4) that contribute to the destruction of O_3. We find that the O_2-O_3 relationship varies significantly around different stellar hosts, with planets orbiting hotter stars (G0V-K2V) reaching peak O_3 levels at O_2 abundances of 25-55% present atmospheric levels, while planets orbiting cooler stars have O_3 levels that decrease consistently along with O_2 levels. Understanding both the context of the planetary atmosphere will be key for interpreting emission spectral features of biosignature gases.

Permission to publish

yes

Categories

3 Theory / Models

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Design, fabrication and photometric characterization of Silicon Germanium waveguides and devices for mid-infrared nulling interferometry

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Abstract

During the past decades, integrated photonics, with originally simple components at both ends of optical fiber links, showed a tremendous increase in performance and complexity, with the emergence of silicon-based devices fabricated using microelectronics technologies. Optical chips now integrate hundreds and even thousands of passive and active elementary functions on a single chip. Examples include AWG multiplexers/demultiplexers or Mach-Zehnder Interferometers which are coupled to laser sources, detectors, phase modulators, and of course grating couplers to couple light between these chips and optical fibers. However, these developments, driven by telecommunications applications, are usually restricted to the near infrared.

Recently, CEA-LETI has extended its technological platform to fabricate devices in the mid-infrared for various environmental sensing and biomedical applications. It is nowadays able to fabricate low loss waveguides operating at wavelengths up to 10µm. Building on its former expertise in integrated recombiners for stellar interferometry and this new Silicon Germanium on Silicon platform, and in collaboration with IPAG, we have designed and realized a first batch of passive waveguides and devices operating in the L spectral band for nulling interferometry.

In this paper, we will present the design, fabrication and preliminary photometric characterization of these devices at 3.35µm. We will discuss the results obtained and the potential application of these devices for nulling interferometry and outline the future developments we intend to implement on these technologies.

Permission to publish

yes

Categories

5 Technologies

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Correlated Instrumental Errors or the Next Frontier in the Design of LIFE

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Abstract

Performance analyses of LIFE and the derivation of specific technical requirements typically require the use of specialized simulations. A major aspect that has largely been ignored in this context until recently are correlated errors arising from instrumental perturbations. If not treated carefully, these errors can significantly reduce the performance of LIFE. Here we present our efforts of modeling those perturbations together with our work on new simulation tools for the LIFE community that allow us to accurately depict their effect on synthetic measurements. We show how so-called data whitening based on the covariance of said errors successfully recovers a large part of the original performance, constituting a means to link instrument stability to performance. Finally, we highlight that future atmospheric retrieval frameworks may benefit from the new-gained knowledge of the covariance between the spectral channels and discuss the implications of our methodology for future developments in the context of requirement derivations and architecture trades.

Permission to publish

yes

Categories

2 Simulations

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A single spacecraft nulling interferometer

Jerome Loicq[1,2], Denis Defrère[3], Romain Laugier[3], Rudolf Saathof[1], Jasper Bouwmester[1], Pierre Piron[1], Colin DANDUMONT[2], alexandra Mazzoli[2], Guilhem Terrasa[2], Ida Sigush[1], Antonin Besse[1], Vincent Moreau[4], Pascal Hallibert[5], David Alaluf[5], Theresa Lueftinger[5]
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Abstract

In this paper, we present the advancements of the single-spacecraft nulling interferometer concept with multiple apertures, aimed at detecting and characterizing exoplanets. TU Delft, in partnership with KU Leuven, CSL/ULiège, AMOS, and supported by the European Space Agency, is currently leading a study on a payload specifically engineered to operate within a single spacecraft compatible with the Ariane 6 launch. As this concept leverages core technologies required for an infrared nulling interferometer, it stands as a likely precursor for future multi-spacecraft missions such as LIFE.

Our design integrates several deployable telescopes on one platform, enabling high-contrast infrared observations across the 3–18 µm range without formation flying, as stated as a requirement from ESA. Parametric simulations show that a four-aperture configuration (including In-line, X-array, and Kernel designs) with diameters ranging from 2 to 3.5 meters and baselines between 15 and 30 meters can effectively suppress stellar light, providing the performance necessary to detect rocky exoplanets. Furthermore, our yield estimates indicate that this payload could potentially survey around 500 habitable zones within 20 parsecs.

This investigation covers various aspects, including optical and mechanical design, deployment strategies, thermal management, scientific yield analysis, and a detailed roadmap for technology maturation. By demonstrating strong performance, we show that single-spacecraft nulling interferometry can provide promising scientific results, despite significant engineering challenges. Our findings emphasise its potential as a pathfinder, a technologically viable and scientifically promising approach for future infrared exoplanet missions based on multi-spacecraft.

Permission to publish

yes

Categories

6 Instruments / Missions

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Carbon for 4Life: A non nulling space based mid-IR spectro interferometer for investigating the solid-carbon particle abundance as part of the first building blocks in the telluric forming planet region.

Valentin FLEURY[1], Bruno LOPEZ[1], Alexis MATTER[2], Eric Pantin[3]

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Abstract

The inner Solar System displays a pronounced carbon deficit, nearly three orders of magnitude lower than the abundance measured in the interstellar medium. This depletion has played a decisive role in shaping conditions essential for Earth's habitability. However, it remains uncertain whether such a deficit is a universal property of planetary systems, raising a fundamental question for assessing planetary habitability across the Galaxy.

Addressing this issue requires direct observations of the innermost regions of protoplanetary disks around young stars. In particular, the Mid-IR range provides access to carbon–carbon vibrational resonances associated with small carbonaceous particles. These grains are expected to influence disk evolution and morphology, yet high-resolution imaging is crucial to constrain structures such as gaps, cavities, and disk inclinations.

We propose the development of a space-based spectro-interferometer designed to characterize the carbon reservoir in the regions of protoplanetary disks where terrestrial planets are expected to form. The instrument will be optimized at 6.2 µm, a critical wavelength for carbon diagnostics, while extending coverage from 3 to 9 µm. This capability will allow us to probe disk regions down to ~2 astronomical units, thereby directly investigating the material available to planet-forming embryos.

Operating in synergy with ongoing and upcoming facilities (JWST, VLTI, ELT), this mission will enable a comprehensive survey of 200–300 young stellar systems. The proposed **Carbon for Life** mission, submitted to ESA, aims to advance our understanding of carbon chemistry in planet formation and shed light on the conditions that govern the emergence of habitable worlds.

Permission to publish

yes

Categories

6 Instruments / Missions

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Assessing LIFE's Capability to Detect Liquid Water Oceans on Exoplanets

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Abstract

We investigate how well the Large Interferometer for Exoplanets (LIFE) mission concept can detect habitable conditions through the presence of liquid water oceans. We model the atmosphere of a pre-biotic early Earth analogue planet across a range of water concentrations, corresponding to very water poor, Earth-like, and water rich cases, with surface partial pressures from 10^{-7} bar to 1 bar of H_2O. We simulate LIFE-like observations of these spectra at spectral resolutions of R = 50 and R = 100 using LIFESIM and then perform Bayesian retrievals to determine the technical requirements for LIFE to confirm habitability. We model three vertical water distributions: an isoprofile, a Manabe–Wetherald based profile, and a diffusion–photochemistry profile, to test how the assumed vertical structure influences the retrieved abundances. For most modeled cases, LIFE detects water vapor at or above Martian levels assuming a mission resolution of R = 100. For the highest water abundances, the absorption features saturate and reduce sensitivity to precise H_2O levels.

Permission to publish

yes

Categories

2 Simulations

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Asgard/NOTT: design, assembling, and nulling optimization

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Abstract

Asgard/NOTT is an upcoming visitor instrument for the Very Large Telescope Interferometer (VLTI), with its first light planned in 2026. It will be the first instrument to perform long-baseline nulling interferometry in the southern hemisphere, and the first nuller with the potential to image exoplanets. The long VLTI baselines will allow for high-contrast imaging of the snowline region around nearby main-sequence stars. The goal of Asgard/NOTT is to characterize young giant planets and warm/hot exozodiacal dust using spectroscopy in the L'-band (3.5-4.0µm). To achieve this, a raw null depth of ~10^{-3} is necessary to obtain a contrast of ~10^{-5} after post-processing. To reach such a level of null depth, the instrument makes use of a photonic chip in Gallium Lanthanum Sulfide (GLS) glass optimized for the L'-band.

We present the design of the instrument and its test bench, with its expected performance in terms of null depth and throughput at the VLTI. NOTT should be able to reach a broadband raw null depth of 0.2%. We also describe the assembly of the test bench, and the on-going efforts to perform, optimize, and automatize the double Bracewell recombination. The first broadband null measurements using a pair of beams show a null depth of 1.4%. A broadband characterization of the photonic chip at cryo-temperature is also performed using a test cryostat down to 140K. They are the first cryogenic measurements obtained with a GLS glass chip. We present the results of these measurements and detail future optimization tasks.

Permission to publish

yes

Categories

4 Experiments

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Recent developments on mid-IR active beam combiners and spectrometers based on Ti:diffusion lithium niobate waveguides

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Abstract

We present our latest developments on mid IR beam combiners and focus on essential basic functions (splitting, directional couplers, phase modulators) using Ti:diffusion lithium niobate waveguides. The samples have been designed to be single mode in the L-band (3.4-4.1um), and guide TE & TM polarizations. In particular, a 4 telescopes beam combiner has been developed. The performances in terms of transmission, polarization behavior, and efficiency of active phase modulation, thanks to the electro-optic effect, will be presented. We will also focus on some basic building blocks such as 1x4 beam splitting and directional couplers. Finally, preliminary results on integrated-optics spectrometers fabricated on the same lithium niobate waveguides, based on Fourier transform spectrometry, will be presented. This late approach, based on sampling an interferogram directly on the top surface of the waveguide, allows to develop monolithic high resolution spectrometers, where no relay optics is needed between the interferogram and the detector, and is therefore well adapted to airborne applications

Permission to publish

yes

Categories

4 Experiments

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Work-LIFE-Balance: Constraining modern Earth chemical disequilibrium biosignatures using mid-infrared spectroscopy

Janina Hansen[1], Sascha P. Quanz[1], Dan J. Bower[1], Amber V. Young[2], Thea Kozakis[3]
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Abstract

The coexistence of CH_4 and O_2 in Earth's atmosphere reflects a chemical disequilibrium sustained by biology. Quantifying such disequilibrium provides a promising framework for identifying potential biosignatures on temperate terrestrial exoplanets, especially when considered in their planetary context. We assess the potential of the Large Interferometer For Exoplanets (LIFE) to constrain the degree of disequilibrium in Earth-like atmospheres using mid-infrared (MIR) spectroscopy. By performing atmospheric retrievals on empirical Earth spectra and coupling them to thermodynamic models, we quantify the available Gibbs free energy (Φ), which measures the extractable chemical work of an atmosphere out of equilibrium, as a potential tracer of biological processes. Preliminary results suggest that Φ constraints are dominated by the precision of retrieved CH_4 abundances and show limited sensitivity to modern Earth–like O_2 levels, with O_3 serving as a sufficient proxy for distinguishing trace- and high-O_2 regimes. Reliable disequilibrium estimates appear achievable at a spectral resolution of R = 100 under moderate signal-to-noise levels (S/N = 10). These findings indicate that LIFE can detect Earth-like chemical disequilibrium biosignatures without requiring direct O_2 constraints, thereby strengthening the case for MIR observations in future life-detection strategies.

Permission to publish

yes

Categories

2 Simulations

62

Observing 4D effects in the atmospheric chemistry of rocky exoplanets with LIFE

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Abstract

The Large Interferometer For Exoplanets (LIFE) enables unprecedented atmospheric characterisation of nearby rocky exoplanets, probing mid-infrared signatures of molecules like CO_2, H_2O, O_3, and CH_4. We investigate whether LIFE can characterise 4D spatial and temporal variability in the atmospheres of tidally locked exoplanets. Whilst 4D spectral variations of Earth as an exoplanet are below detection limits, such variability is strongly planet-specific.

Using LIFESim, we create daily synthetic LIFE observations of Proxima Centauri b in 1:1 and eccentric 3:2 spin-orbit resonance (SOR), based on 3D climate-chemistry model simulations assuming Earth-like composition. Distributions of temperature, clouds, and chemical species determine spectral signatures and variability with phase angle. Such variability dictates the extent to which parameters (e.g., radius, temperature, or chemical abundances) can be reliably inferred from snapshot spectra at arbitrary viewing geometries. In the 1:1 SOR, LIFE spectra vary with viewing geometry and indirectly trace atmospheric circulation. Nightside temperature inversions generate O_3, CO_2, and H_2O emission features below LIFE's detection threshold; instead, O_3 features disappear for certain phase angles. In contrast, the 3:2 SOR yields a more homogeneous atmosphere with weaker variability but higher flux due to eccentric heating. LIFE confidently distinguishes between SORs (5σ at the 9.6 μm O_3 feature, >20σ in the continuum) and captures seasonal O_3 variability for golden targets like Proxima Centauri b, presenting a false positive scenario in case of abiotic O_2/O_3 buildup.

Hence, LIFE can disentangle different SORs and resolve atmospheric variability, providing daily characterization of the 4D physical and chemical state of nearby terrestrial worlds.

Permission to publish

yes

Categories

2 Simulations

69

The Oxygenic Photosyntetic Habitability of M stars acquaplanets

Michele Maris[1,2,3], Nicoletta La Rocca[4], Mariano Battistuzi[5,4], Laura Silva[1,2,3], Erica Bisesi[1,2,6], Giuseppe Murante[1,2,3], Jost Von Hardenberg[7], José A. Caballero[8], Daniela Billi[9]

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Abstract

JWST has recently observed exoplanets such as GJ 486b, GJ 3929, and K2-18b (Moran+ 2023, Sue+ 2025, Madhusudhan+ 2025). At the same time, the ELT (Bowens+ 2021) is progressing, while missions like LIFE (Quanz+ 2022) and HWO are under preparation. Together, these efforts pave the way for the search for gaseous biosignatures in the spectra of habitable exoplanets. The strength of such biosignatures depends on the productivity of a potential biosphere, which in turn is shaped by planetary conditions, chiefly temperature and illumination.

Here we present a study within the Italian Space Agency's ASTERIA collaboration, aimed at assessing the potential for oxygenic photosynthesis on habitable aquaplanets around M dwarfs—i.e., their Oxygenic Photosynthetic Habitability. These planets are expected to be spin-synchronous, with a permanently illuminated hemisphere.

We applied the framework of Hall et al. (2023) to estimate the photosynthetic activity of free-floating cyanobacteria in the ice-free portions of the illuminated oceans. The biological model is based on cyanobacteria such as Microcystis aeruginosa and M. weisembergii (Yang+ 2020, Battistuzi+ 2023), while climate conditions are provided by the PLASIM model (Fraedrich+ 2012), applied to a representative set of potentially habitable M-dwarf exoplanets (Bisesi+ 2025) taken from the Habitable World Catalog (http://phl.upr.edu/hwc,).

Our results suggest that the key limiting factor is ocean temperature: mesophiles or thermophiles would likely be better suited to these environments. In contrast, surface irradiance does not appear so limiting, as underexposed regions are frozen and thus excluded, while cloud coverage provides protection against excessive exposure.

Permission to publish

yes

Categories

3 Theory / Models

70

Can Water-Rich Magma Oceans Create Oxygen-Rich Atmospheres Without Life?

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Abstract

Oxygen is often considered a key biomarker in exoplanetary atmospheres, yet abiotic processes can also produce oxygen. We examine a geochemical pathway for abiotic oxygen production in relevant to water-rich rocky planets, with bulk water contents around 3%. In such planets, reactions between water and mantle iron at higher pressures(>86GPa) can form FeOOH (iron oxyhydroxides) and increase the interior oxidation state. Formation of FeOOH drives the mantle to high oxidation states. Consequently, volcanic gases released from FeOOH-rich mantles at the surface-atmosphere interface are dominated by H_2O (~70% by volume mixing ratio), with CO_2 (~1%) and O_2 (~30%) as significant additional components. We quantify this mechanism using interior-atmosphere coupling models that build on Dorn et al. (2021) and Luo et al. (2024), include updates from Zhang et al. (2025, in review), and integrate Atmodeller, HELIOS, FastChem, and Vulcan. As magma oceans solidify, the resulting volatile-depleted mantles yield mass-radius trends consistent with some of the TRAPPIST-1 planets, highlighting this process as a possible explanation for their bare-rock scenarios. To place this pathway in LIFE's context, we forward-model mid-infrared emission spectra for atmospheres shaped by oxygen release from FeOOH-rich mantles. These spectra show ozone absorption bands arising without biology, especially on more massive, water-rich planets where higher pressures form more FeOOH and enhance oxygen outgassing. Our results highlight a novel abiotic pathway for oxygen accumulation and demonstrate the need to couple planetary interiors with atmospheric models when assessing habitability and interpreting biosignatures in the era of JWST, LIFE, and future missions.

Permission to publish

yes

Categories

3 Theory / Models

71

A Ground-Based, Long-Baseline Optical Interferometric Survey of Potential Targets for Space-Based Studies of Exoplanet Atmospheres

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Abstract

To ensure the success of LIFE for the detection and identification of exoplanetary biosignatures, the target planets' host stars must be well-characterized. For the target selection of LIFE, a census of nearby stars is needed to survey stellar parameters, to search for low-mass stellar companions, and to study their stellar surface activity and its potential impact on the target planets. Ahead of the design for the Habitable Worlds Observatory (HWO), the astronomical community has been asked to vet preliminary targets; these studies have the potential to reveal the best candidates for LIFE, as well. Using ground-based long-baseline optical interferometry from the Center for High Angular Resolution Astronomy (CHARA) Array and the Very Large Telescope Interferometer (VLTI), we are conducting a systematic survey of 42 nearby potential targets for both HWO and LIFE. The interferometric survey consists of a uniform set of stellar parameters, a systematic search for low-mass companions, and images of the stellar surfaces, where possible. Here, we will discuss our methods and early results.

Permission to publish

yes

Categories

1 Observations

73

Overview of SILVIA

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Abstract

SILVIA (Space Interferometer Laboratory Voyaging towards Innovative Applications) is a mission concept aiming at the demonstration of ultra-precision formation flying between three spacecraft apart by 100 meters. SILVIA plans to achieve an unprecedented control precision at a sub-micron level in the relative distances between spacecraft with the use of intersatellite laser interferometer and low-thrust and low-noise micro-propulsion system.

This talk attempts to give an overview of SILVIA with the emphasis on the potential impact on the astronomical observation activities in future.

Permission to publish

yes

Categories

6 Instruments / Missions

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SEIRIOS: the first demonstration of formation flying interferometry toward LIFE

Taro Matsuo[1,2], Michael Ireland[3], Gautam Vasisht[4], Satoshi Ikari[5], Satoshi Itoh[2], Rashied Amini[4], Israel Vaughn[3], Chathura Bandutunga[3], Adrian Glauser[6], Sascha Quanz[6], Motohide Tamura[5], Charles Beichman[4]
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Abstract

SEIRIOS is the first formation-flying space interferometer, consisting of two 6U CubeSats and one 50-kg-class nanosatellite in low Earth orbit to coherently combine light from astronomical targets. The project aims to demonstrate millimeter-level precision in three-satellite formation flying and then stabilize the optical path difference (OPD) to tens of nanometers to obtain visible-light fringes. This is a critical step toward future space interferometry missions for the direct detection of exoplanets.

To manage the large dynamic range and relax the strict requirements on relative satellite positioning, SEIRIOS employs multiple layers of metrology and correction systems. The metrology suite includes an alignment system that measures the angular and positional offsets between the beams, as well as two complementary beam combiners for OPD determination. One beam combiner is based on a pupil-plane interferometer that records spectrally resolved fringes even under degraded alignment conditions, albeit at the cost of reduced signal-to-noise ratio. The other uses a photonic integration circuit coupled with a low-resolution spectrograph (R ~ 50), which improves sensitivity and enables OPD precision of a few tens of nanometers for targets as faint as 6th magnitude in the I band. In addition, a laser interferometer may provide nanometer-level accuracy in measuring offsets perpendicular to the baseline. The correction system consists of a tip-tilt mirror for angular compensation and a delay line for OPD stabilization.

This presentation will introduce the SEIRIOS instrument suite, describe how high-precision fringe measurements can be achieved in orbit, and discuss the pathway toward LIFE.

Permission to publish

yes

Categories

6 Instruments / Missions

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Using Sulfur Chemistry to Trace the Inner Edge of the Habitable Zone with LIFE

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Abstract

The sulfuric-acid cloud layer on Venus obscures its hostile surface from view, leading to an observed emission temperature of 227K, despite a true surface temperature of 735K. The formation of Venus's sulfuric-acid cloud layer is driven by the photochemical destruction of SO2, a molecule which is volcanically outgassed on both the Earth and Venus, but is efficiently removed from the Earth's atmosphere via wet deposition due to the presence of surface liquid water. SO2 may therefore also be commonly outgassed on terrestrial exoplanets, and can usefully be linked to a lack of surface water, provided that it does not lead to the formation of a Venus-like sulfuric-acid cloud layer. The formation of such a cloud-layer on an exoplanet would obscure observations and instead make the planet appear potentially temperate. Whether or not a sulfuric-acid cloud layer will be formed from SO2 in an exoplanet's atmosphere depends on the UV-flux of the host star. We here show that the intrinsically low near-UV flux of M-dwarfs and late-K-dwarfs drives little to no photochemical depletion of SO2, and thus no photochemical cloud formation, in the atmospheres of exoplanets at orbits spanning model estimates of the Habitable Zone inner-edge. Our results demonstrate that a targeted search for SO2 in the atmospheres of exoplanets orbiting M- and K-dwarfs will therefore be possible with the LIFE mission. Further, due to the sensitivity of SO2 to wet deposition, observing an SO2 *trend* with LIFE may provide a population-level test of the location of the Habitable Zone inner-edge.

Permission to publish

yes

Categories

3 Theory / Models

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An overview and update on the Nulling Interferometer Cryogenic Experiment (NICE)

Jonah Hansen, Thomas Birbacher, David Eglin, Adrian Glauser, Ryan Meierhofer, Julio Pino, Eckhart Spalding, Sascha Quanz
ETH Zurich, Zurich, Switzerland

Abstract

The Large Interferometer For Exoplanets (LIFE) aims to be one of the most transformative space missions in recent decades, and in order for it to achieve its scientific goals we must first ensure the measurement strategy is feasible. This is the primary objective of the Nulling Interferometer Cryogenic Experiment (NICE): a mid-infrared laboratory testbed at ETH Zürich which aims to reproduce the deep ($<10^{-5}$) broadband nulls of the earlier nulling testbeds of the early 2000s, but at the required sensitivity levels expected for the LIFE space mission. This sensitivity enforces the experiment to go cryogenic at temperatures around 15K; an ambitious task for an ultra-precise interferometer. As such, NICE will be the first cryogenic nulling testbed, bringing together the requirements of sensitivity, stability and contrast. In this presentation, we aim to share the motivation and design principles behind this experiment, give an update of the progress we have made, and outline the future challenges, opportunities and developments in store to achieve our desired performance.

Permission to publish

yes

Categories

4 Experiments

80

The Pyxis Interferometer Inter-spacecraft Metrology System

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Abstract

The characterisation of Earth-like exoplanets has only been explored via indirect observation. The bright local star, coupled with weak signals from the exoplanet itself means that direct detection can only be achieved with a specific class of observation technique - mid-infrared nulling interferometeric detection. This class of detection requires the development of multi-satellite constellations of mid-infrared telescopes [1]. With stringent absolute positioning requirements for their separation, the development of such multi-aperture telescope systems, the ranging and positioning requirements have been a technological barrier for previous space interferometry missions.

In recent history, with the successful deployment of the GRACE mission laser-ranging instrument, and technical de-risk of the LISA gravitational wave mission, there has been significant progress in space-qualified optical interferometric systems.

In this work, a three stage metrology system is proposed, which combines three different ranging techniques on a single optical beam. This include optical phase, radio-frequency phase and pseudo-code ranging with code phase detection. By leveraging three separate ranging techniques on the one platform, we demonstrate the ability to extend the ambiguity range of detection in a compact architecture.

We will report on development progress towards a system specified to the Pyxis interferometer, a science demonstrator for the Large Interferometer for Exoplanets (LIFE), and outline future development towards adjacent missions including SERIOS and the LIFE mission itself.

1. Monnier, J. D. et al., 2019. A realistic roadmap to formation flying space interferometry. arXiv preprint arXiv:1907.09583, (2019).

Permission to publish

yes

Categories

5 Technologies

82

KIDs: Superconducting Single Photon Counting Detectors for LIFE

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Abstract

Given the low photon rates in the nulled output of the LIFE interferometer, we need a photon-counting, low-noise, high-efficiency, and stable detector that covers the entire LIFE wavelength range (4-20 µm). Kinetic Inductance Detectors (KIDs) are such detectors.

A KID is a superconducting resonator for which the resonance frequency and internal loss strongly depend on the properties of a thin superconducting film. Below the critical temperature, most of the electrons in this film pair up into Cooper pairs, giving rise to a kinetic inductance. Due to the low microwave loss of a superconductor, we can make very high Q-factor resonators that can be easily frequency multiplexed into kilopixel arrays with just a few readout channels.

When an IR photon is absorbed in the superconducting film, it has enough energy to break multiple Cooper pairs, changing the resonance frequency and the microwave loss of the resonator. By continuously monitoring the resonator's resonance frequency, we can identify each photon hit as an individual pulse with a lifetime of around 10 – 500 us, depending on the superconductor's properties. We have measured single photon counting with KIDs at the wavelengths 3.8 µm, 8.5 µm, and 18.5 µm with dark currents of 10 mHz, 30mHz, and 100 mHz, respectively, with a detector design that was not yet optimized for these wavelengths. We show how the detector performance is still limited by the setup. We will sketch how to optimize KIDs for efficiency and sensitivity for LIFE in future work.

Permission to publish

yes

Categories

5 Technologies

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Searching for Nearby Solar Systems by Joint RV+Astrometric Measurements

James Jenkins
Universidad Diego Portales, Santiago, Chile

Abstract

We have been embarking on a search for the nearest planetary systems to the Sun, with a particular focus on the brightest stars within 50pc that will provide the best possibilities for direct studies in the future. As part of this endeavour, we have uncovered a number of candidate Jupiter-analogues orbiting these nearby stars using precision radial-velocity (RV) measurements from multiple instruments. By developing new Bayesian tools, we aim to both confirm these signals as genuine planets and measure their absolute masses by combining our RVs with space-based astrometric measurements from Hipparcos and Gaia. These joint samplings also have the potential to uncover additional planets in these systems, and we aim to further scrutinise the parameter space interior to the orbiting giants in order to search for smaller rocky planets in and around the Habitable Zones of these stars. I will present the recent work done as part of this effort, focusing on our Bayesian tool development and the new planetary systems we have uncovered, finishing by summerising how this work will help focus the future direct characterisation of small and nearby planets by missions like LIFE.

Permission to publish

yes

Categories

1 Observations

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Exploring the synergies of LIFE with upcoming direct imaging facilities on the ground and in space

Óscar Carrión-González[1], Jens Kammerer[2]
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Abstract

In the near future, multiple new direct-imaging facilities will become available, reaching for the first time the sensitivity required to detect and characterize cold and temperate long-period exoplanets. The Nancy Grace Roman Space Telescope –to be launched in 2026 or 2027– will pave the way with its coronagraph instrument, capable of imaging cold exoplanets in reflected starlight. On the ground, the ELT will host METIS, a mid-IR instrument with its first light planned for 2029, and PCS, an optical camera expected for the second half of the 2030s. These two instruments will be able to directly image temperate exoplanets around nearby stars, respectively in thermal emission and in reflected starlight. This will be a great test for the next generation of space-based facilities, where LIFE and the Habitable Worlds Observatory will also cover these two spectral ranges. In this talk, we explore the synergies of LIFE with the direct imaging facilities of the near- and the longer-term future. We will discuss the lessons that will be learnt from ELT observations in the mid-IR and the optical range. We will also discuss the unique potential of LIFE to provide highly complementary thermal-emission observations of the planets observed in reflected light around Sun-like stars by HWO, around M dwarfs by PCS.

Permission to publish

yes

Categories

6 Instruments / Missions

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Spatial filtering at the heart of LIFE's nuller

Michael Ireland, Ludovic Rapp, Stephen Madden, Shan Liu, Esha Garg
Australian National University, Canberra, Australia

Abstract

A deep null of starlight is only possible if nulling performed in a single spatial mode. This typically needs an optical fibre, which is a technology that isn't yet available at the longest wavelengths of LIFE where the deep carbon dioxide band is at 15.5 microns. I will describe why a spatial filter is needed, what the key metric of rejection ratio really means, and how the needed performance of a spatial filter is different under slightly different architectures. I will then describe the current efforts at ANU to both characterise the ability for a spatial filter to create a deep null, and also to create the spatial filter itself through a variety of techniques including laser drilling of photonic crystal waveguides.

Permission to publish

yes

Categories

5 Technologies

90

Asgard NOTT Decisive steps for nulling interferometry from the ground at VLTI

Romain Laugier[1], Denis Defrère[2], Peter Chingaipe[2], Germain Garreau[2]
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Abstract

Despite the large number of exoplanets discovered, the dominant pathways of planet formation are still uncertain, as they can only be witnessed around young stars, most of which are several tens of parsecs away. In this regime, the 10m-class coronagraphs are strongly limited by the diffraction limit. By leveraging the baselines of hundreds of meters between telescopes of the VLT, a nuller has the potential to be sensitive to young giant planets well within the snow-line, at angular separations ~20x smaller than current coronagraphs.

At this regime, it will also enable the study of hot exozodiacal dust, whose ubiquity, origin and evolution remain elusive. Exozodiacal dust is also a major noise source for the LIFE mission, and it is critical to characterise stars in the Southern hemisphere inaccessible with the Northern ground-based nullers.

Asgard/NOTT is in its last months of integration in Europe before shipping to the VLTI in Paranal, where it will become the first four-telescope nuller on sky, the first nuller in the L band, and the first one to leverage the new data format NIFITS. As such, Asgard/NOTT is both a technical and scientific precursor of the LIFE mission.

This presentation will give an overview NOTT's key characteristics, its multiple observing modes, and some of the lessons learned that will be crucial for the design of the LIFE mission.

Permission to publish

yes

Categories

6 Instruments / Missions

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Exoplanets meet Gravity: How LIFE could benefit from LISA and GRACE-FO laser interferometry

Thomas S. Schwarze, Alexander Koch, Johann Max Rohr, Julia van den Toren, Kevin Grossel, Gerald Bergmann, Stefan Ast, Joshua Reeder
German Aerospace Center (DLR), Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

Abstract

The LIFE mission will apply formation flying between its five spacecraft, requiring advanced sensing of inter-satellite position and orientation. These technology requirements are not entirely unique to LIFE, but are shared with other missions, in particular in the fields of gravitational wave astronomy and earth gravimetry. The gravitational wave observatory LISA (Laser Interferometer Space Antenna) is an ESA-lead mission that just passed Mission Adoption. It will utilize heterodyne inter-satellite laser interferometry to perform relative displacement measurements, targeting picometer precision over spacecraft separations of 2.5 million km. Simultaneously, DWS (Differential Wavefront Sensing) and PRN (Pseudo-Random Noise) ranging will be applied, with the former providing angular tracking and the latter absolute distance measurements. The mission GRACE-FO has been demonstrating the feasibility of these technologies in orbit since its launch in 2018. Its LRI (Laser Ranging Interferometer) performs relative distance and angle measurements in the nm range and nrad range, respectively. The department Laser Interferometric Sensing of the German Aerospace Center's (DLR) Institute for Satellite Geodesy and Inertial Sensing has its roots deep in these missions and intends to transfer the technology to a broader range of applications. Here we will give a short overview of the aforementioned satellite missions and highlight two of our developments to explore potential synergies with the LIFE mission: A CubeSat-compatible version of the LRI miniaturizing laser interferometric ranging for a broader range of applications and MiniCAS (Miniaturized Constellation Acquisition Sensor), a versatile sensor system that can be used to acquire and track a constellation of spacecraft.

Permission to publish

yes

Categories

6 Instruments / Missions

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Distributed Spacecraft Mission Design for the Starlight Acquisition and Reflection toward Interferometry Mission

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[1]Stanford University, Stanford, United States. [2]University of Michigan, Ann Arbor, United States

Abstract

The Starlight Acquisition and Reflection toward Interferometry (STARI) mission is a NASA-funded technology demonstration aimed at advancing critical capabilities for future space-based interferometry. The mission employs two 6U CubeSats flying in close formation in a Sun-synchronous terminator orbit, effectively emulating a single arm of a linear distributed interferometer. STARI plans to be the first mission to demonstrate both the reflection and transfer of starlight between spacecraft and its subsequent injection into a single-mode optical fiber.

Following basic mission definitions, we present early progress on mission requirements, concept of operations, and trajectory design, along with an initial definition of the GNC architecture and operational modes. Unlike existing interferometry approaches, STARI leverages relative orbital elements to encode observation requirements to provide a clear geometric interpretation of relative orbital states as configuration parameters tied to inertial observation directions. The science orbit is complemented by a passively safe standby orbit used during engineering activities such as momentum management, communications, or replanning. Transitions between these orbits restore passive safety and provide operational flexibility through closed-form impulsive control techniques. A Sun-synchronous orbit design allows gradual coverage of multiple sky regions over the mission lifetime.

Achieving STARI's ambitious science objectives requires unprecedented precision in spacecraft navigation and control, motivating the development of a fully autonomous six-degree-of-freedom GNC system. We outline a preliminary GNC design and identifying key challenges to address in subsequent phases. By validating technologies for distributed interferometry, STARI will progress systematic and affordable exoplanet detection with multi-spacecraft observation, while also advancing capabilities for proximity operations.

Permission to publish

yes

Categories

6 Instruments / Missions

Poster abstracts

7

Detectablity of Water Vapor on Terrestrial Exoplanets around GK stars with Tianlin

Meng Zhai, Wei Wang
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Abstract

China has proposed a space telescope with aperture size of 6 meters named Tianlin, which is dedicated for the characterization of rocky planets in the habitable zones (HZ) around nearby GK stars. It will be equipped with a low to high resolution spectrograph and a high contrast coronagraph that should allow the delivery of high quality transmission and reflected spectrum of exoplanets. We conduct a preliminary simulation of transmission and reflected spectra for Earth-like planets around G, K type stars and perform retrieval analysis of the detectablity of H2O, a key bio-indicating molecule. Our results show that Tianlin has the ability to constrain H2O abundances in the atmosphere of Earth-like planets in most cases, except for dry large-size rocky planets around G2 or hotter stars for a 5-yr time span. Importantly, we point out that higher spectral resolution can largely improve the detection capability and the significance of the water vapor abundance assessment.

Permission to publish

yes

Categories

6 Instruments / Missions

8

The architecture of planetary systems: from physical models to AI

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Abstract

Near future facilities like LIFE aim at detecting and characterizing Earth twins. In this context, understanding the correlations between properties of planets in the same system, also called the architecture of planetary systems, can provide valuable guidance to optimize observational campaigns. In this talk, we will present models of planetary system formation, the so-called ‘Bern model’, and how they can be used to train generative AI models. We will demonstrate how the combination of end-to-end planetary system formation models and generative AI models can be used to optimise future search of potentially habitable planets.

Permission to publish

yes

Categories

3 Theory / Models

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Deciphering the Properties of Polluted White Dwarfs with Machine Learning

Mariona Badenas-Agusti[1], Andrew Vanderburg[2], Javier Viaña[2], Simon Blouin[3], Patrick Dufour[4], Siyi Xu[5], Amy Bonsor[1], Laura Rogers[5]

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Abstract

Between 25% to 50% of white dwarfs exhibit traces of heavy elements in their atmospheres, likely from the accretion of tidally disrupted exoplanetary debris from a planetary system that survived the post-main-sequence evolutionary stages of its host star. These so-called "polluted" white dwarfs (PWDs) provide a unique and direct window into geology and chemistry of extrasolar material. Despite their potential, however, the limited number of well-characterised PWDs, combined with the manual, time-intensive nature of conventional white dwarf data analysis techniques, has prevented the field from acquiring a statistical understanding of extrasolar geochemistry. To overcome these challenges, we have developed"cecilia," the first Bayesian and Machine Learning (ML)-based interpolation and modelling framework capable of accurately measuring the abundances of PWDs from their spectra (R≤50,000) within a reasonable timeframe, using a modest training set and minimal human supervision. Here, I will summarise the ML architecture of "cecilia", discuss its predictive accuracy with both synthetic and real data of PWDs, and share new findings from several heavily polluted systems. As we venture into the era of Big Data, "cecilia" offers a scalable solution to exploit massive databases from upcoming spectroscopic surveys, therefore paving the way for large-scale studies of extrasolar compositions.

Permission to publish

yes

Categories

1 Observations

12

Direct imaging of exoplanets with Coronography

salma Makhtich
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Abstract

The direct imaging of exoplanets represents a pivotal method for exploring planetary systems beyond our solar system. This technique faces significant challenges, primarily due to the extreme brightness contrast and small angular separation between exoplanets and their host stars. Coronagraphy has emerged as a powerful optical approach to suppress starlight and enhance the detection of faint planetary signals. This work provides an in-depth review of coronagraphic techniques, including phase masks, Lyot coronagraphs, vortex coronagraphs, and their integration with adaptive optics systems. Recent advancements in these methods are analyzed, alongside their application in state-of-the-art instruments such as the James Webb Space Telescope (JWST) and future observatories like the Extremely Large Telescope (ELT). The study also highlights the current limitations and technical challenges in advancing the field of exoplanet imaging.

Permission to publish

yes

Categories

3 Theory / Models

16

The Small ExoLife Finder (SELF): A technology demonstrator for the future 30-50m ELF to detect life outside of our solar system

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Abstract

We are designing the ExoLife Finder (ELF), a next-generation ground-based telescope with an aperture of 30 to 50m, designed to detect signs of life and signatures from advanced civilisations on planets orbiting nearby stars. The project is led by the Laboratory for Innovation in Opto-Mechanics (LIOM) and funded by the European Union through the ERA Chair programme, integrating cutting-edge advances in optics, photonics, and artificial intelligence (AI). Our goal is to achieve operational readiness within this decade.

We are building a technological pathfinder for the future ExoLife Finder (ELF): the Small ExoLife Finder (SELF). In this talk, we will present recent progress on SELF and outline its scientific objectives. Commissioning is planned for 2026-2027 at the Teide Observatory in Tenerife. The mechanical structure is scheduled for delivery in December to IACTEC (La Laguna), enabling first on-sky tests of nulling interferometry. The dome is expected to be installed at Teide Observatory by the end of 2025. The primary mirrors are being fabricated in collaboration with CIOMP, a leading optics institute in China, while LIOM is advancing the development of multi-mode fibres and machine learning tools for active wavefront sensing. SELF will target bright exoplanets well separated from their host stars, as well as brown dwarf companions. This prototype represents a pivotal step toward realising ELF's ultimate goal: addressing one of humanity's most enduring and profound questions - Are we alone?

Permission to publish

yes

Categories

6 Instruments / Missions

17

Probing Extreme-UV Environments of Exoplanets through X-ray Analysis of AD Leo

Iva Vilović, Katja Poppenhäger
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Abstract

The high-energy radiation environment of exoplanet host stars drives atmospheric escape and shapes planetary habitability. A central obstacle is that the stellar radiation most critical for atmospheric escape—the extreme-UV (EUV)—remains largely unobservable, as it is absorbed by interstellar gas before reaching Earth. To overcome this limitation, we focus on the active M dwarf star AD Leo, using its X-ray spectra to infer high-energy output and extend our understanding from the observable X-ray regime into the elusive EUV domain.

Here we analyze both high- and low-resolution spectral data from XMM-Newton, which provides a comprehensive view of AD Leo's coronal properties and high-energy output. Through spectral fitting, we determine coronal elemental abundances and temperature distributions, which are essential for characterizing the star's high-energy emission. The availability of extensive high-resolution X-ray observations for this star allows us to test and validate approaches for inferring the high-energy stellar environment not only from high-resolution data but also from low-resolution spectra. This is a critical step for characterizing fainter or more distant host stars where only low-resolution data are accessible.

Our results demonstrate the value of AD Leo as a reference for assessing atmospheric escape in exoplanets across a broad range of stellar types and distances, which advances our observational and theoretical insights into which planets are likely to retain secondary atmospheres and remain habitable over long timescales.

Permission to publish

yes

Categories

1 Observations

18

Coronal Abundances: Their Role in Atmospheric Evaporation of Exoplanets

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Abstract

The extreme ultraviolet (EUV) and X-ray radiation of the stellar host can cause an exoplanet's atmosphere to expand and be lost to outer space (the so-called "photoevaporation" process). Some absorption lines in the transmission spectrum of this expanded atmosphere, such as the He(I) triplet at 10830 angstroms, make the study of this phenomenon possible. Since it is a spectral feature emerging from EUV-photoionized He(I) recombination, its absorption depth and equivalent width come determined by the host's EUV luminosity. However, EUV suffers severe extinction through the interstellar medium, and that, together with the lack of specific instrumentation, hinders the obtention of this EUV luminosity—and as consequence, the prediction of the presence of the He(I) triplet in a given exoplanet atmosphere. Such a prediction can be undertaken by scaling the EUV luminosity with the X-ray one, but it has been recently suggested that the scaling would be affected by the coronal abundances of low first ionization potential (low FIP) elements; this could explain some unexpected non-detections of the spectral feature in particular sub-Neptunes. In our work, by feeding a code designed to simulate photoevaporation (ATES) with synthetic stellar spectra created from different coronal models, we address the connection between the presence of the He(I) triplet in exoplanetary atmospheres and the distribution of low FIP elements in stellar coronae.

Permission to publish

yes

Categories

2 Simulations

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Distinguishing the oxidation state of rocky exoplanets with LIFE

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Abstract

The geochemical composition of rocky exoplanets influences the composition of their secondary atmospheres. The presence and abundance of volatile species, such as CO_2, H_2O, and CH_4, are affected by the oxidation state of the rocky planetary mantle through volcanic outgassing and thus set the background atmosphere of rocky planets – the abiotic baseline in which we will have to interpret any atmospheric features with statistical biosignature surveys. In this project we aim to assess the necessary instrumental design of the LIFE mission concept to distinguish the oxidation state of individual Earth-like exoplanets. In this contribution I will present results based on simulated observations of Earth-sized exoplanets with a range of volcanic outgassing composition at 10 pc distance from the Sun, orbiting a Solar-type star.
Their synthetic spectra are simulated with the ARCiS radiative transfer code and observational noise is estimated with LIFEsim. I will discuss how atmospheric retrievals based on this pipeline recover key redox-sensitive molecules with varying accuracy, depending on the planet's redox state. Reduced planets exhibit flatter spectra and are harder to constrain, while oxidised cases show stronger features and are thus better retrieved. I then quantify the distinction between redox states using statistical comparisons of molecular posteriors, finding that CO_2, NH_3, and CH_4 act as effective tracers when jointly considered. Our results establish a proof-of-concept framework for redox state distinction of Earth-like exoplanets through the LIFE mission, which – in its baseline architecture – will be capable of assessing the principal oxidation state of an observed Earth-like exoplanet.

Permission to publish

yes

Categories

2 Simulations

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Characterization of rocky exoplanets in habitable zones: Anastrobiological approach

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Abstract

Rocky exoplanets, defined by their predominantly silicate and metal composition, represent a fascinating frontier in contemporary astrobiology, as their study allows us to explore conditions that could sustain life forms beyond our solar system. Complementary to this, those rocky planets that orbit in the habitable zone, which refers to the region around a star where the temperature allows for the existence of liquid water on the surface, becomes an essential criterion for selecting targets in the search for life outside planet Earth.
The identification of exoplanets in the habitable zone, especially those that share characteristics with Earth, gives us a perspective on the diversity of planetary environments that could exist in the universe. . Research on the interaction between exoplanets and their host stars also provides us with information about how initial conditions in a planetary system can influence the evolution of its atmosphere and its impact on habitability. With the advancement of tools like the James Webb telescope, we will be able to detect biomarkers such as methane and oxygen, reinforcing the importance of a multidisciplinary approach in the exploration of life in the cosmos.
This work focuses on the characterization of rocky planets located in habitable zones, with the aim of finding possible candidates for future astrobiological research. For this purpose, habitable zones will be identified based on the spectral type of host stars. Subsequently, the physical and orbital properties of these confirmed exoplanets in these planetary systems will be studied. Finally, prioritization criteria will be established for those planets with the highest probability of harboring conditions conducive to life.

Permission to publish

yes

Categories

1 Observations

22

Broadband focal-plane wavefront sensor based on a short multimode fiber.

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Abstract

The Exo-Life Finder (ELF) will be a ground-based, Fizeau-type hybrid interferometric telescope with a 30-50-meter baseline, designed to image exoplanets and search for biosignatures. A major milestone toward this goal is the Small ELF (SELF), a prototype under construction at the Instituto de Astrofísica de Canarias (IAC) to validate key technologies.

SELF's pupil consists of a circular array of 15 identical apertures. Achieving diffraction-limited performance requires co-phasing these apertures to a fraction of the wavelength, while also correcting for dynamic atmospheric distortions. This places stringent demands on the wavefront sensing system.

We present a novel focal-plane wavefront sensor based on a short multimode fiber (MMF), operable with broadband light. Light propagating through a MMF excites a complex superposition of guided modes. Their interference produces a speckle pattern at the fiber output that encodes information about the input electric field's phase. Although the mapping from input phase to output intensity is highly nonlinear, we show that a convolutional neural network (CNN) can be trained to decode this information.

Initial simulations validate the feasibility of this approach for accurate phase reconstruction. In particular, we show that the short MMF can distinguish even phase distributions at the pupil, and that the CNN can reconstruct pupil-phase profiles with a root-mean-square error (RMSE) as low as 30 mrad from the MMF output.

This method provides a compact, robust, and inherently broadband solution for FPWFS, offering advantages for future space- and ground-based exoplanet imaging missions.

Permission to publish

yes

Categories

5 Technologies

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Revealing Habitable Planet Formation via High-Resolution Infrared Observation

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Abstract

Observations of planet formation events around temperatures of $\approx 300\,$K is necessary to reveal the origin of Earth-like habitable planets, which is allowed by mid-infrared observations with milliarcsecond-scale spacial resolution. In the late stage of terrestrial planet formation, Earth-like planets are believed to be formed from collisions among Mars sized protoplanets due to a long-term orbital instability in several 10 million years, which are induced by the depletion of protoplanetary disks. This formation scenario is consistent with the formation ages of Earth and Mars inferred from the Hf-W chronometer (e.g., Kobayashi and Dauphas 2013). Such collisions between protoplanets produce a large amount of fragments, whose thermal emission is bright enough for observation (Genda et al. 2015). Giant impact fragment clouds form characteristic small structures in short timescales after giant impact invents. Such rare structured derbris disks tends to include fragments smaller than particles blowout by radiation pressure, which may show strong silicate features in spectral energy distributions. Analysis of silicate features in debris disks indicate good candidate systems with planets and giant-impact structures. Therefore, 0.1\,au-scale observations of the candidates reveal collisional events in habitable planet formation by future IR-interferometers, such as Large Interferometer for Exoplanets (LIFE).

Permission to publish

yes

Categories

3 Theory / Models

30

A NICE set of tolerances: an optomechanical study into chromatic and polarisation effects for a nulling interferometer

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Abstract

The Large Interferometer for Exoplanets (LIFE) is a proposed space mission that aims to characterize the thermal emission of terrestrial exoplanets in the mid-infrared through space-based nulling interferometry. Achieving the required contrast levels and sensitivity demands stringent control of optomechanical tolerances. In this work, I present the current status of tolerancing studies for LIFE and its laboratory precursor, the Nulling Interferometer Cryogenic Experiment (NICE). The work is focused on the study of broadband and polarization effects on null depth, and evaluates the impact in mechanical alignment tolerances of the optical elements. The goal is, through optical models and simulations, to quantify how misalignment affects the system throughput performance; a critical study for the upcoming translation from ambient to cryogenic conditions. These results will guide the design and error budget for both NICE and LIFE, and highlight the optomechanical stability required to maintain deep and stable nulls across a broad spectral range.

Permission to publish

yes

Categories

4 Experiments

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Resolving exoplanet surfaces from unresolved light curves with the ExoLife Finder (ELF)

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Abstract

The ExoLife Finder (ELF) is a 30–50 m ground-based, hybrid Fizeau-interferometric telescope currently under development at the Laboratory for Innovation in Opto-Mechanics (LIOM). As a step toward ELF, the Small ELF (SELF), a 3.5 m prototype, is being built at the Instituto de Astrofísica de Canarias (IAC) and is scheduled to become operational at the Teide Observatory by 2027. SELF and ELF use novel, unconventional designs and employ advanced optics and photonics, including lightweight mirrors and an innovative approach to starlight suppression through destructive interference.

SELF is a dedicated telescope for directly imaging exoplanet and brown dwarf companions. Although even the world's largest telescopes cannot resolve exoplanet surfaces directly, dedicated instruments like SELF and ELF can reconstruct surface features from unresolved light curves by solving an inverse problem. This will enable the creation of the first resolved maps of exoplanets. SELF will target Jovian planets and substellar companions to bright nearby stars, while ELF will be capable of observing Earth-like worlds.

Deep neural networks (DNNs) offer significant potential to improve raw reconstructions, even at moderate signal-to-noise ratios (SNRs). Applied to Earth, this approach can distinguish continents from oceans and differentiate between biomes—an important step toward identifying biosignatures.

Here, preliminary results from testing the performance of SELF- and ELF-class telescopes in mapping exoplanet surfaces using DNNs are presented. This capability is a key asset for future exoplanet characterization and may guide the search for life beyond Earth—all contributing to one of the most profound questions: are we alone?

Permission to publish

yes

Categories

2 Simulations

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How unique is our rocky planet as a cradle of life in the universe?

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Abstract

Hydrogen cyanide (HCN) is crucial for the RNA World hypothesis, forming biomolecules essential for early life. Life likely emerged around 4 billion years ago during the early Archean Eon, a period on Earth with a fainter sun, frequent impacts, and a weakly reducing atmosphere. Warm little pond (WLP) are hypothetical protective aqueous environments that help explain the emergence and evolution of fragile prebiotic chemistry in such a hostile environment. WLPs undergo cycles of evaporation and rehydration, concentrating prebiotic molecules that increase the likelihood of (de-)polymerisation and forming early RNA molecules. We use a 1-D model of atmospheric chemistry to compare atmospheric HCN delivery to WLPs with exogenous sources. Using early Archean Earth as our baseline, we examine the sensitivity of atmospheric HCN delivery to the atmospheric C:O ratio, the orbit semi-major axis, and assume stellar host type, exploring conditions across rocky exoplanets. We find atmospheric HCN delivery is sensitive to these parameters but is generally more important than meteoritic delivery and for our baseline Archean Earth. Planetary atmospheres with higher C:O ratios within the habitable zone of G stars and those closely orbiting M-dwarfs deliver the most atmospheric HCN. Because atmospheric HCN delivery is remarkably robust, this molecule is likely not the rate limiting step for the emergence of prebiotic chemistry on rocky exoplanets. This finding, with important caveats, potentially increases the probability of life emerging on other worlds.

Permission to publish

yes

Categories

2 Simulations

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Earth as an Exoplanet: Investigating the effects of cloud variability on the direct-imaging of atmospheres

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Abstract

A planet’s spectrum is dynamic and only represents a time-dependent snapshot of its properties. Changing atmospheric conditions due to climate and weather patterns, particularly variation in cloud cover, can significantly affect the spectrum in ways that complicate the understanding of a planet's baseline atmospheric properties. Variable cloud cover and cloud properties affect the detectability of atmospheric constituents, and also greatly influence the radiative transfer that determines a planet's spectrum. This has considerable implications for direct imaging observations of potentially habitable exoplanets and thus it is critical to study and characterize the effects of clouds on their spectra. Clouds have been extensively modeled before and their effects have been incorporated across climate frameworks spanning a spectrum of complexity. Given the challenges associated with modeling clouds, we adopt a novel approach in this work to study the effects of clouds by using real-time cloud data from Earth observations. Treating Earth as an exoplanet and using detailed observations from the MERRA-2 data collection, we quantify the effects of cloud variability on the spectrum as well as on the detectability of atmospheric constituents, specifically biomarkers like O_2, O_3 and H_2O. The coverage and vertical position of clouds significantly affects the SNRs of these gases and subsequently their detectability in exo-Earth atmospheres. Moreover, variations in the amount of cloud cover will potentially confound efforts to retrieve a stable baseline atmosphere for a planet. This work has important applications to future exoplanet missions like the Habitable Worlds Observatory (HWO) and LIFE.

Permission to publish

yes

Categories

2 Simulations

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Curved Space Telescope: E-sail concept to the solar gravitationallens focal point

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Abstract

The solar gravitational lens focal point (SGLFP), as predicted by the general relativity theory, provides up to 10^{11} light amplification and about 10^{-10} arcsec angular resolution for one observable, even though that specific point is far-away (roughly 550 au from the Sun) and beyond the reaching capabilities of conventional, both chemical and electric, propulsion systems. In fact, in a typical preliminary mission design, classical (photonic) solar sails are used as primary thrusters to obtain the hyperbolic excess velocity required to reach the SGLFP in few decades. In this context, a recent NIAC study “Direct Multipixel Imaging and Spectroscopy of an Exoplanet with a Solar Gravity Lens Mission” has thoroughly analysed the science case and proposed a viable TRL3 solar sail-based mission concept. Based on the NIAC study, and bearing in mind the results of the recent literature, this paper presents the preliminary design of a scientific mission to the SGLFP, by considering a spacecraft equipped with two propulsion systems, that is, a classical electric thruster and an electric solar wind sail (E-sail), which is an advanced propellantless propulsion concept that converts the momentum of the solar wind into deep space propulsive acceleration. This paper shows that the combined use of the two methods could allow to reach the SGLFP with a telescope capable of imaging exoplanets in a reasonable timeframe.

Permission to publish

yes

Categories

6 Instruments / Missions

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Robust Retrieval Statistics for LIFE

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Abstract

Atmospheric retrievals are a cornerstone of exoplanetary science and will underpin the science return of the LIFE mission. However, common statistical shortcuts can distort the robustness of detections. Here, we present three statistical nuances particularly relevant for retrieval studies and how they can affect the outcome of exoplanetary atmosphere analyses:

1. Likelihood Functions: Many studies assume Gaussian likelihood functions to calculate the Bayesian evidence and compare model performances. Nevertheless, recently published datasets imply more complex probability distribution functions, which are often neglected in atmospheric retrievals.
2. Bayesian Complexity: While the Bayes factor is widely used for model comparison, it is not the only useful metric. The Bayesian complexity provides complementary insights and can be directly estimated from retrieval results, offering a valuable addition to the exoplanetary toolkit.
3. Detection Significance σ: Molecular detections are commonly expressed by converting Bayes factors into frequentist σ-values. Regardless of its usefulness, however, this conversion is regularly performed incorrectly, leading to an overestimation of the detection significance.

We elaborate on how these choices propagate into false positives, target selection and detection robustness. By raising awareness of these issues, we aim to help the community converge on statistical practices that maximize LIFE’s scientific success while remaining transparent and reproducible across instruments and teams.

Permission to publish

yes

Categories

3 Theory / Models

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Challenging the Emma-X Design

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Abstract

The Emma-X design consisting of five formation-flying, corotating spacecraft -- four collectors and one central beam combiner -- has been the reference concept for LIFE ever since the initiative started in 2018. Originating in the Darwin and TPF-I performance studies, its properties such as intensity response and modulation of the planetary signal resulting from the circular motion are well studied and form the basis of almost all LIFE-related publications. However, in the context of architecture trade studies, new ideas challenge this status quo. For instance, different motion (modulation) patterns or structurally connecting pairs of collectors could lead to a reduced amount of fuel that is required or open up new options for a gradual deployment of the mission. Yet, all architecture choices are closely linked to signal extraction procedures and influence instrumental errors that arise in measurements. We investigate this complex interaction with our new end-to-end simulator \textsc{LIFEsimMC} and showcase several promising configurations. This work serves as the basis for more in-depth architecture trade studies in the near future by exploring the trade space and pre-selecting suitable candidates.

Permission to publish

yes

Categories

2 Simulations

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Exoplanet explorer: Optical design of a single spacecraft nulling interferometer

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Abstract

The optical design layout of a single spacecraft nulling interferometer is presented. This development is part of a new study initiated by the European Space Agency to explore the design parameters and performance of an interferometric concept based on a single spacecraft with multiple sub-apertures. Launch constraints—specifically, that the spacecraft must fit within the Ariane 6 fairing—drive the ray-traced model to cover the entire optical chain, from the telescope entrance to the null output after the recombination scheme. A trade-off among several telescope architectures (siderostat, two-mirror, and three-mirror off-axis configurations) led to the choice of a compact two-mirror solution. The final concept consists of four 2.5-meter-diameter telescopes arranged in a linear configuration with a 16-meter baseline. The optical design guarantees pupil transfer and equal optical paths. Dedicated delay lines and retro-reflective cat’s eye assemblies are used to reimage the pupils and reduce beam size while maintaining alignment and stability. The beam combination stage utilizes two modified Mach-Zehnder interferometers, which recombine telescope pairs into dark and bright outputs. Dark outputs are routed to the spectrometer via fiber injection, and bright outputs are used for fringe tracking. Optical performance at the null output is evaluated, confirming compatibility with starlight suppression targets and establishing the key figures of merit for the interferometer. This work represents the first integrated optical design of the mission concept, laying the groundwork for future iterations that include mechanical, thermal, and control aspects.

Permission to publish

yes

Categories

5 Technologies

50

Exoplanet explorer: Mechanical and thermal design of a single spacecraft nulling interferometer

Guilhem Terrasa[1], Jasper Bouwmeester[2], Félix Wilting[2], Antonin Besse[2], Benoit Borguet[3], Denis Defrère[4], Colin Dandumont[1], Imran Khan[2], Jérôme Loicq[2], Alexandra Mazzoli[1], Vincent Moreau[3], Pierre Piron[2], Rudolf Saathof[2], Ida Sigusch[2], Romain Laugier[4]

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Abstract

The mechanical and thermal design of a single spacecraft nulling interferometer is presented. This development is part of a new study initiated by the European Space Agency to explore the design parameters and performance of an interferometric concept based on a single spacecraft with multiple sub-apertures. Launch constraints—specifically, the requirement that the spacecraft fit within the Ariane 6 fairing—result in strict mass and volume limitations. Mass estimates derived from JWST heritage indicate that 3-meter primary mirrors would exceed launch capabilities, while 2.5-meter mirrors remain compatible. To reduce stowed volume, the secondary mirrors are designed as deployable components. Deployment concepts were evaluated through comparison and modal analysis. The interferometer architecture can accommodate four telescopes arranged in either a linear (baseline option) or X-array configuration. In both configurations, telescopic booms are needed to extend the baseline from 8 meters in stowed form to up to 32 meters in orbit. Due to thermal considerations—specifically, the low operating temperature of the detectors (~40 K) and the required stability —a preliminary thermal model was developed, including the payload, deployable structures, and sunshield. Results emphasize the necessity for a multi-layer sunshield and highly reflective materials to achieve the required temperature range. Temperature gradients across the payload and their effects on thermo-elastic deformations have been identified as key factors for future investigation. This study provides the first integrated mechanical and thermal concept for the interferometer, laying the groundwork for more detailed analysis and trade-off studies in subsequent phases.

Permission to publish

yes

Categories

5 Technologies

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Decoding Planetary Diversity: A Unified Four-Parameter Code for Exoplanet Classification

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Abstract

We present a concise exoplanet classification expressed through a four-parameter code that integrates mass, orbital temperature (Mean Dyson Temperature, MDT), eccentricity, and bulk density. Mass (M, E, S, N, J, D) and temperature (F, W, G, R, P) classes are linked to Solar System analogs and thermal regimes, while surface attributes (g, w, t, i, s) reflect density structure. Eccentricity is rounded to one decimal for simplicity. This compact notation allows rapid comparison of planetary properties, distinguishing for example Venus (EG0t) from Earth (EW0t). Applied to the NASA Exoplanet Archive (June 2025), the scheme classified over 90% of known planets, exposing natural divides such as the Super-Earth/Sub-Neptune gap and identifying borderline cases. The classification provides a scalable taxonomy and a common language to support comparative exoplanetology, habitability assessment, and mission planning.

Permission to publish

yes

Categories

3 Theory / Models

Laboratory testbed and digital simulation tools for space-based far-infrared double Fourier interferometry

Christopher Benson[1], Will Grainger[2], David Leisawitz[3], Lee Mundy[4], Ettore Pedretti[2], Berke Ricketti[2], Giorgio Savini[5], Jeremy Scott[6], Locke Spencer[7], Gerard van Belle[8], David Wilner[9]

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Abstract

Many fundamental questions leading current astrophysics research require both imaging at high spatial resolution as well as spectroscopic resolution, i.e., hyper-spectral imaging, observations in the Far-Infrared (Far-IR). Topics include: the origin of the universe, the requisite conditions for star and planet formation, and, ultimately, the conditions for the emergence of life. Over half of the energy emitted by the Universe appears in the relatively unexplored Far-IR spectral region, most of which is opaque from ground-based sites necessitating space-borne instrumentation.

We discuss laboratory testbed instrumentation development and digital simulation tools supporting the advancement of Far-IR Double Fourier Interferometry instrumentation, requisite components, and associated technology. Far- IR astronomical observations with sub-arcsecond angular resolution and high spectral resolution require a space-based interferometer observatory with baselines of at least tens of meters in length. The laboratory testbed instrument and software tools presented in this work provide a framework with which to study double Fourier interferometry in the far-IR and allow the astronomical community further exploration of the unique capabilities of such instrumentation with a long-term goal of the deployment of a Far-IR astronomy space mission.

Permission to publish

yes

Categories

4 Experiments

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Recent developments on mid-IR waveguides, directional couplers and Fourier Transform spectrometers using ultrafast laser writing

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Abstract

We present our latest developments on laser written waveguides using ultrafast laser writing on different mid IR optical materials (GLS, YAG, Lithium Niobate) and more complex functions such as beam combiners, or fabrication of nano-scale antenna in order to sample the signal on the waveguide and use it to extract the spectrum.

In a first part, we will present the results on the single mode waveguides obtained by ultrafast laser writing on GLS, YAG and Lithium niobate materials. We will show that depending on the technique used, we can fabricate surface or buried waveguides, and will compare their performances in terms of TE/TM confinement and transmission.

In a second part, we will present the results on the performances of simple directional couplers devoted to beam combination or beam splitting, ideally aiming at 50/50 flux balance. Besides, we will present the fabrication on nano-antenna gratings close to the waveguides, in order to periodically sample the optical signal. If the signal consists on a static interferogram obtained by beam combination, the Fourier transform of the interferogram allows to recover the spectrum of the source. We will discuss the performances of the sampling centers, in order to achieve high resolution spectrometry in the mid IR.

Finally, we will present more complex beam combiners achievements, although in the visible range, in order to show the interest of ultrafast laser writing in order to achieve 3D beam combination, avoiding in plane crossings, and therefore avoiding any crosstalk between optical channels

Permission to publish

yes

Categories

5 Technologies

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A Cool Earth-sized Planet Candidate Transiting a Bright K-dwarf: A Beacon for LIFE?

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Abstract

As we progress towards future missions designed for imaging of extrasolar Earth analogues, there is growing need for precursor observations. Perhaps the most valuable precursor science of all are detections of potential imaging targets – that is, candidate Earth-like exoplanets. However, detecting these planets in the solar neighbourhood is extremely challenging with current instruments. Here we report the discovery of the hitherto unnoticed single transit of a candidate cool Earth-sized planet in K2 photometry of a bright (V = 10) and nearby (45 parsec) K-dwarf. Though this candidate cannot yet be confirmed with existing observations, a combination of new and archival data allows us to rule out the main false positive scenarios, indicating a high likelihood it is a real planet. With only one transit the orbital period cannot be directly constrained, but from the long transit duration we estimate it is near to 1 year; this implies an incident flux around 30% of the Earth value, placing the planet candidate near to the outer edge of the habitable zone. This is the first potentially habitable Earth-sized exoplanet candidate with a host star sufficiently bright and nearby to enable follow-up observations; in particular, it is a unique example of a transiting Earth-sized planet potentially amenable to imaging with LIFE. Future observations of this target will therefore offer potential for unparalleled insights into the nature of a cool Earth-sized exoplanet.

Permission to publish

yes

Categories

1 Observations

59

Machine Learning-driven autonomous control for the Small ExoLife Finder (SELF)

Natalia Arteaga-Marrero[1,2], Auxiliadora Padrón-Brito[1,2], Adrián Sánchez-Chaves[1,2], Diego Tamayo-Guzmán[1,2], Jeff Kuhn[3,1,2]

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Abstract

The Small ExoLife Finder (SELF) is a 3.5-meter ground-based prototype envisioned as a testbed for the ExoLife Finder (ELF), a next-generation 30-50meter-class hybrid Fizeau interferometric telescope aimed at direct exoplanet imaging and the detection of potential bio- and technosignatures. Currently under development at the Instituto de Astrofísica de Canarias, SELF advances several key technologies, including astrophotonics, lightweight mirrors, a tensegrity-based structure, and machine learning–driven control systems.

A central challenge in SELF's design is determining the number and nature of the degrees of freedom required to co-phase its sub-apertures. SELF's architecture comprises a sparse interferometric array of 15 independently controlled primary mirrors, each paired with a corresponding secondary mirror in a one-to-one configuration. This configuration requires real-time stabilization of optical path differences to within a fraction of a wavelength, at high-cadence, even under dynamic disturbances.

An innovative approach is proposed in which a detailed optical model of the telescope is combined with machine learning to extract the nonlinear mappings between focal plane images and the control parameters of each sub-aperture. Several convolutional neural network (CNN) architectures were implemented within a supervised learning framework for both classification and regression tasks. These networks process focal-plane wavefront sensing data to identify applied perturbations and generate control signals required to maintain stable, high-contrast imaging.

Preliminary results demonstrate that the trained CNNs can effectively maintain co-phasing and achieve diffraction-limited performance. These findings underscore the potential of data-driven, autonomous control strategies to address the unique challenges posed by next-generation interferometric telescopes.

Permission to publish

yes

Categories

5 Technologies

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Optical bench to explore mid infrared integrated circuits technologies for four beams nullers

Louis Gemmerlé[1], Jean-Philippe Berger[1], Manon Lallement[1], Guillermo Martin[1], Stéphane Curaba[1], Pierre Labeye[2]

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Abstract

Nulling interferometry allows us to benefit from the high angular resolution provided by current ground-based (or future spatial) interferometric facilities, as well as the capability to observe exoplanets with higher planet-to-star flux ratio through coherent cancellation of the flux from the star. Using photonic integrated circuits (PIC) for the aperture recombination function has the potential to considerably improve the instrument performance : it allows the instrument to gain in compactness and thermo-mechanical stability compared to bulk optics as well as providing intrinsic self-alignment, positively impacting the nulling performance. We are currently exploring several mid-infrared technologies among which the Si/SiGe offers a great potential for the 3-9 µm domain. For that purpose we have built a dedicated four beam interferometric bench. The chosen design of this characterisation bench is composed of an association of Michelson's interferometers, dividing the flux of a unique source into four beams. The coaxial aspect of this architecture provides identical pupils for all the beams, so a more uniform injection efficiency among the inputs of the nulling PIC. Moreover, in order to achieve deep null values, a stringent precision in controlling the phase, intensity and polarisation of each individual beam is required. We present the error budget established to evaluate these constraints and the characterisation of various control elements used on the bench. Monochromatic interferograms (at 3.39 µm) acquired using a preliminary version of the optical bench are presented. We analyse several sources of degradation of the experimental null value and discuss ways to mitigate them.

Permission to publish

yes

Categories

4 Experiments

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A Multiwavelength Four Beam Scene Simulator for Experimental Nulling Interferometry

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Abstract

The rising interest of the astronomical community in observing and characterizing earth-like exoplanets led to the revival of a space-based, mid-infrared (2-20µm) nulling interferometric mission concept. A four-telescope based array was identified by the community to be the most promising architecture in terms of characterization yield. Instrumental simulation tools have been developed to aid answering questions concerning the beam combination and detection strategies. In addition to the theoretical effort, experimental work is needed to validate those concepts in preparation of a LIFE-like mission. Following the legacy of ground-based stellar interferometers, testbenches dedicated to different aspects of nulling interferometry are under development.

The Space Instrumentation Group at TU Delft aims to develop a testbench dedicated to aspects concerning the multiwavelength and four beam combination in nulling interferometry. The focus of the experiments will be on different beam combination strategies as well as the effects and applications of polarization in a nulling interferometer.

In this communication, we will report on the development of our multiwavelength (4µm, 8µm, 10µm) four beam testbench. At the moment our focus was placed on two aspects of the beam preparation: the spectral coalignment and generation of the four coherent beams. They will later feed our experiments dedicated to beam combination and polarization. The optical characteristics of different spectral coalignment and four beam generation strategies will be summarized and complemented by our results from numerical simulations to justify the design choices for our beam preparation. Finally, the transposition of our concepts into an optical breadboard will be presented.

Permission to publish

yes

Categories

4 Experiments

64

Polarization in Nulling Interferometry: Errors and Impacts

Antonin Besse[1], Ida Sigusch[1], Alexandra Mazzoli[2], Imran Khan[1], Pierre Piron[1], Karl Fleury-Frenette[2], Nandini Bhattacharya[1], Jérôme Loicq[1,2]
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Abstract

In nulling interferometry, the extreme contrast and the minuscule angular separation between the planets and their host star, respectively about 10^{-6} at 10 microns and 100 mas, impose stringent instrumental requirements. One such requirement is the control and manipulation of the polarization of light. Any phase mismatch between the arms or inhomogeneity across the pupils will lead to a degradation of the null depth.

Within the framework of the single spacecraft nulling interferometry study, our team investigates the polarization effects introduced by the different optical subsystems, including the telescopes, the fold mirrors, the cat's eyes, and the interferometers. We evaluate the crosstalk, i.e. the mixing of the polarization states, the spectral response of that crosstalk, and the reflection and transmission losses due to the optical components. Mirrors and beam splitters are the main contributors to these effects, which introduce differential phase shifts between the beams, thus degrading the null depth and limiting the instrument's scientific capabilities. Therefore, we use Code V and Python tools to model the polarization associated with the different optical surfaces in the 3-20 microns bandwidth.

Our work provide insights into the necessary polarization considerations for the optical design, the coatings, and the beam recombination of a nulling interferometer. Understanding these instrumental effects is necessary to build a nulling interferometry mission that would characterize terrestrial exoplanets.

Permission to publish

yes

Categories

6 Instruments / Missions

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Earth Through Time: Assessing Biases in Atmospheric Retrievals of Terrestrial Worlds with LIFE

Dibya Bharati Pradhan, Lia Sartori, Zach Burr, Janina Hansen, Philipp A. Huber, Felix Dannert, Sascha P. Quanz
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Abstract

LIFE will deliver mid-infrared spectra to constrain the climates and habitability of terrestrial exoplanets, making it crucial to understand the limitations of current atmospheric retrieval methods that are used to analyze and interpret the data. The standard approaches often rely on simplified models that neglect the realistic vertical structure of atmospheric constituents and either ignore clouds entirely or treat them with very simplified prescriptions, such as fully covering grey cloud decks. These assumptions can bias the results, including the detectability of atmospheric biosignature gases. Our goal is to quantify potential biases in the pressure-temperature profile, gas abundances, and cloud properties, and assess when simplified models break down.

For this, we combine physically motivated retrieval models including a vertically variable water vapor profile and cloud coverage with thermal emission spectra of Earth. These spectra cover four geological epochs, from the prebiotic era to the modern Earth, modeled using a 1D climate–photochemistry model. We systematically apply three retrieval setups of increasing complexity: (i) constant water vapor profile with no clouds, (ii) a variable water profile derived from condensation physics with no clouds, and (iii) a variable water profile with partial cloud coverage. We explore how the retrieval results depend on the quality of the assumed input spectrum and on the applied retrieval setup. As such, this work will shed new light on both the ability of LIFE to characterize Earth-analogs and remaining biases in state-of-the-art atmospheric retrieval frameworks.

Permission to publish

yes

Categories

2 Simulations

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Habitability of Rapidly Rotating and Tidally Locked Planets: Biological Feedbacks and Climate Dynamics

Laura Silva[1,2], Erica Bisesi[1,3], Michele Maris[1,2,4], Giuseppe Murante[1,2,3], Jost von Hardenberg[5,6], Mariano Battistuzzi[7], Daniela Billi[8], José A. Caballero[9], Nicoletta La Rocca[10], Antonello Provenzale[3]
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Abstract

We present recent results focussed on exoplanet habitability studies in two contrasting rotational regimes, tidally locked and rapidly rotating planets, drawing on different types of climate simulations of observed exoplanets and deep-time Earth analogs.

Using a modified version of the intermediate-complexity 3D climate model PLASIM, we modeled 22 tidally locked M-dwarf planets from the Habitable Worlds Catalog under varying surface pressures and compositions. Our results reveal three distinct climate states: Snowball (globally frozen), Eyeball (liquid water confined to a substellar hotspot with localized hydrological cycles), and Hot (globally ice-free) regimes, all driven by 3D atmospheric dynamics.

In complementary studies with the pRT-ESTM (petitRADTRANS - Earth-like planet Surface Temperature Model) energy balance model, suitable for rapidly rotating planets and wide parameter sweeps, we have investigated albedo-driven climate feedbacks. Simulations of the late Proterozoic Earth show that vegetation significantly stabilizes climate, suppressing Snowball transitions even with equatorial continents and reduced solar luminosity. Conversely, laboratory-based reflectance measurements of cyanobacteria incorporated into Archean scenarios indicate that microbial colonization of ocean surfaces could directly increase albedo, promoting glaciation and amplifying oxygenation-driven cooling.

These studies are performed within the Italian Space Agency's ASTERIA collaboration, which aims to assess the potential for oxygenic photosynthesis on habitable exoplanets. From this modeling framework, we are working to compute observability and retrieval prospects for these climates with future instruments.

Permission to publish

yes

Categories

3 Theory / Models

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From Galaxy Formation to statistics of Habitable Planets: Linking Cosmic Chemical Evolution to Planetary Interiors

Gian Luigi Granato[1], Laura Silva[1], Valeria Grisoni[1], Giuseppe Murante[1], Cinthia Ragone[2]
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Abstract

We quantify the potential occurrence of habitable planets by bridging cosmic structure formation with geochemical and geophysical conditions that shape planetary interiors.

I will present a suite of cosmological zoom-in simulations of a Milky Way–like galaxy, tracing its baryonic assembly from high redshift to the present. By following the detailed chemical enrichment of individual star particles, we reconstruct the evolving distribution of elements critical for rocky planet formation. These abundances are then coupled to a planetary interior and mineralogy code (ExoInt, Wang+2019), which translates stellar chemistry into predictions for key planetary properties such as mantle composition, iron core fraction, and volatile delivery potential.
A further distinctive aspect of our approach is the inclusion also of long-lived radioactive isotopes (e.g. U235, U238, Th232, K40), which govern a planet's internal heat budget. These isotopes sustain mantle convection, geological activity, and plate tectonics, processes considered essential for long-term habitability.

This multi-scale framework connects galaxy formation physics to planetary geophysics.
The results may inform the LIFE mission by providing a physically grounded basis for habitable planet statistics, and by contributing to prioritize stellar targets most likely to host geologically active, habitable planets.
More broadly, this approach illustrates how the interplay between cosmology, stellar evolution, and planetary mineralogy can illuminate the pathways from galaxy formation to life-friendly environments.

Permission to publish

yes

Categories

3 Theory / Models

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Interrelationships of Topology, Mission, and System Architectures in Designing Formation-Flying Space Telescopes

Alireza Vafa, Alireza Basohbat Novinzadeh
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Abstract

Modern satellite missions are increasingly empowered by distributed architectures involving multiple spacecraft working together. Exploring the universe and characterizing Earth-like exoplanets with unprecedented resolution is among the most anticipated applications of such systems, exemplified by the Large Interferometer For Exoplanets (LIFE). For distributed observatories, three architectural domains are central in the design phase: **mission architecture**, defining what scientific objectives must be achieved; **topology architecture**, specifying how spacecraft are arranged and connected; and **system architecture**, determining how the mission is realized through subsystems, autonomy, and operations. The synergistic consideration of these domains is now recognized as a cornerstone of advanced space mission design.

This paper first investigates the definitions, relationships, and contrasts of these architectural layers. We then propose a **conceptual design loop** specifically tailored for distributed, formation-flying observatories. The loop illustrates how mission requirements (e.g., resolution, coverage, and duration) drive topology choices (number, geometry, and separation of spacecraft), which in turn cascade into system requirements (propulsion, communication, metrology, and control). Crucially, innovations or limitations at the system level feedback to reshape both mission goals and topology options.

Two case studies—LISA, a gravitational-wave observatory in matured phase of design and development, and LIFE, an exoplanet interferometer in early design—demonstrate the framework's utility. Together they highlight how co-designing mission, topology, and system architectures in unison is essential for feasibility, resilience, and science optimization. We conclude by emphasizing this integrated approach as key to realizing ambitious distributed telescopes like LIFE.

Permission to publish

yes

Categories

6 Instruments / Missions

Asymmetric Dust Distributions in Debris Disks and Their Impact on the Direct Imaging of Earth-Mass Exoplanets

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Abstract

Planetary systems often host debris disks. If circumplanetary dust is dense and uniform, its thermal emission can obscure planetary signals. In contrast, asymmetric structures shaped by planetary gravity may indicate a planet's presence. We investigate the dust distribution around an Earth-mass planet on a circular orbit at 1 au in a system like the solar system. Dust grains are supplied from a planetesimal belt at 2–3 au and drift inward by the Poynting-Robertson (P-R) effect. We computed orbital evolution under stellar radiation pressure, the P-R effect, and planetary gravity. By dividing the disk into radial and azimuthal meshes and summing particle residence times, we reconstructed the steady-state dust density distribution. We find large dust grains form characteristic structures around planets, while small dust forms smooth and structureless disks.

Using the results of dust structures, we evaluate the infrared flux of the debris disk relative to the star. We estimate the size distribution of drifting dust grains, which is determined by comparing collisional and drift timescales in planetesimal belts. We obtain disk structures from the integration of five representative sizes. Faint disks are dominated by large grains and have strong asymmetric features that may enhance exoplanet detectability. On the other hand, brighter disks are dominated by smaller grains and obscure planets, but retain weak detectable structures from small-population large grains. Therefore, debris disks may assist the detection of Earth-like planets via direct imaging.

Permission to publish

yes

Categories

2 Simulations

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Constraining the Background Gas in an Earth-like Atmosphere with LIFE

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ETH Zurich, Zurich, Switzerland

Abstract

Proper determination of the background gas of a planet is crucial for understanding its physical and chemical state and assessing habitability. Many potential background gases (e.g. H_2, He, N_2, O_2) have no strong absorption features in the mid-infrared. However, collision induced absorptions (CIA) can impart detectable spectral features in this wavelength range. In an Earth-like atmosphere, N_2–N_2 CIA produces a characteristic feature near 4.3µm. Detecting this feature could prove challenging for LIFE: in the 4–5µm range the planet flux is expected to be comparatively low, while stellar leakage—a critical noise source—becomes more prominent at these shorter wavelengths, resulting in an overall low SNR. Thus far retrieval studies have largely ignored N_2, accepting that the posteriors are unconstrained. An assessment of the observational requirements for detecting Earth-like levels of N_2 is therefore needed.

We will present an analysis of the detectability of N_2 with LIFE. We quantify the SNR and spectral resolution required for unambiguous identification of an N_2 dominated atmosphere, and assess the feasibility of these requirements. Furthermore, we will outline a framework for delineating between other potential background gases based on planetary parameters such as mass, radius, and temperature. These results provide a way to constrain the background gas of Earth-like planets with LIFE, a crucial ingredient to fully characterize the atmospheres of other worlds.

Permission to publish

yes

Categories

3 Theory / Models

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LIFE, HWO and TianLin: Worldwide synergies in target lists for exoearth hunting

José A. Caballero[1], Adrián Aranda Oliva[2], Natalie R. Hinkel[3], Franziska Menti[4], Wei Wang[5], Mark Wyatt[6]
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Abstract

Upcoming missions such as LIFE, Habitable Worlds Observatory (HWO) and Tianlin, the Chinese exolife-searching space mission, will observe very similar, complementary targets. Habitability and its detectability require a lot of stellar, planetary, and system-wide conditions to be ideal, which means that the focus of all three missions will be on similar habitable candidates around solar-type stars in the immediate solar neighbourhood. However, this state of affairs will be optimal, as we will independently observe a set of biosignatures at different wavelengths and with different instruments and methodologies. Only then, and with the collaboration of cross-disciplinary researchers from all projects, will we be able to firmly shout "We've discovered life!". But before that, there is a lot of work to do. Some of our tasks include defining the list of the best targets and characterising them all with the utmost care. Here we propose the European, US and Chinese astronomical communities to share ideas and resources on the LIFE, HWO and Tianlin target input catalogues for maximising synergies and minimising overlaps. "From space the Earth has no frontiers". Let's work together!

Permission to publish

yes

Categories

6 Instruments / Missions

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LIFE's baseline strategy: a study into the requirements of an interferometer's most critical parameter

Jonah Hansen[1], Thomas Birbacher[1], Philipp Huber[1], Felix Dannert[1], Andrea Fortier[2], Adrian Glauser[1], Jens Kammerer[3], Maximillian Kirchhoff[1], Romain Laugier[4], Sascha Quanz[1]

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Abstract

Until now, the present reference design of the Large Interferometer For Exoplanets (LIFE) has implemented order-of-magnitude numbers for the array baselines; namely that of a nulling baseline between 10 and 100m. However, these ranges have not been scientifically or technically fully validated, especially for the very ambitious 10m short baseline that may impose challenges regarding satellite collisions and thermal/propulsion contamination. For that reason, we have conducted a performance study focused on this one critical parameter asking the following questions: can we reduce the range of baselines such that the science and fringe tracking is not heavily impacted? Rather than allowing a continuous range of baselines, does it make sense to implement a fixed number of discrete baselines? And what is a more rigorous derivation of the optimal baseline for a given planet/star system? In this presentation, we highlight the results of our work and the impact it has on the LIFE mission concept; primarily that the minimum baseline can be modestly increased without a huge impact on performance.

Permission to publish

yes

Categories

2 Simulations

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Efficient MID-IR Photon Counting: Lens-Absorber Coupled Microwave Kinetic Inductance Detectors

Kevin Kouwenhoven[1,2], Pieter van Zweeden[2], Shahab Odin Dabironezare[2,1], Daan Roos[1,2], Wilbert Ras-Vinke[1,2], Tonny Coppens[1], Daniela Perez Capelo[1], Dimitry Lamers[1], Martijn Veen[2], David Thoen[1], Jochem Baselmans[2,1], Pieter de Visser[1,2]

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Abstract

Kinetic Inductance Detectors (KIDs) can operate as principally noiseless single photon counting detectors in the wavelength range for LIFE (4-20 µm). A KID is a pair-breaking detector, where a single mid-IR photon has enough energy to change the properties of a thin superconducting film. When this film is part of a superconducting resonator, an absorbed photon changes the resonator's resonance frequency and the internal losses of the resonator. If we continuously probe the resonance frequency, we see each photon event as an individual pulse.

The challenge lies in efficiently absorbing mid-IR photons in the basically reflective superconducting film. To efficiently capture the photons, we pattern the superconductor in a set of meandering lines referred to as the absorber, the shape of which is optimized to match the impedance of the surrounding medium. We have verified this design at 18.5 µm through experiments with a black body thermal source, which yield an efficiency that matches the modelled efficiency of the absorber.

An absorber-based design is not angular selective: It accepts radiation from any angle of incidence. This means that the total efficiency of the detector can only be defined in relation to the angular distribution of the source and "background". To get the best performance, the absorber-lens system will need to be designed in concert with the diffractive element used for LIFE.

Permission to publish

yes

Categories

5 Technologies

83

Detector considerations for the LIFE mission

Eckhart Spalding, Thomas Birbacher, Jonah Hansen, Sascha Quanz, Adrian Glauser, Felix Dannert
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Abstract

The LIFE mission is designed to sieve science signals which are many orders of magnitude fainter than competing sources which may only be partially nulled, or, in the case of diffuse zodiacal light, are not localized enough to be nulled away. The science detector itself will contribute potentially highly variable noise terms to the signal-to-noise of a science detection, and thus represents a critical design choice. This poster will present noise budgets to be expected, and a trade study of current detector types vis-à-vis their applicability for the LIFE mission. We will also describe the ongoing commissioning of an MCT detector for the Nulling Interferometer Cryogenic Experiment (NICE) cryogenic test bench experiment, and describe the road ahead.

Permission to publish

yes

Categories

5 Technologies

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AWG characterization for the development of compact, high-resolution spectrographs

Jeronimo Calderon-Gomez, Frantz Martinache, Nick Cvetojevic, Marc-Antoine Martinod, Vincent Foriel, David Mary, Roxanne Ligi, Sylvie Robbe-Dubois
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Abstract

Direct detection and characterization of exoplanets has been one of the fastest growing areas in astrophysics in recent years. New generation high-angular and spectral resolution instruments have revolutionized the volume and quality of the available datasets, leading to ground-breaking discoveries in the field of planetary science. With the increased sizes of telescopes and interferometric arrays in the era of ELTs and Optical/IR Long Baseline Interferometry, comes the challenge of increased size and cost of their instruments. Astrophotonics jumps in as a promising area to provide the technological solutions that allow meeting the needs of next-generation instruments at a small footprint, low cost, and reliable operability. All while being capable of matching the capabilities of their bulk-optics-based counterparts. At the Laboratoire Lagrange - Observatoire de la Côte d’Azur, the Astrophotonics team is working on the characterisation of Arrayed-Waveguide Grating (AWG) chips for a photonics-based approach to high-resolution spectro-interferometry. The AWG chips were acquired from a collaboration with N. Jovanovic and P. Gatkine at Caltech/JPL. Along with the development of another setup to perform on-chip interferometric nulling, the AWG spectrographs will allow us to test the feasibility of photonic spectro-interferometers for exoplanet characterization, another step towards the design and construction of integrated photonic instruments for astronomy, beneficial for both ground-based and space-based observatories. In this presentation, we show the current status of the AWG characterization and our preliminary results on the diagnosis of the chips, besides presenting a comparison against bulk-optics based setups with similar capabilities.

Permission to publish

yes

Categories

5 Technologies

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The age-chromospheric activity relation in solar-type stars.

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Abstract

Chromospheric emissions within deep photospheric lines are useful proxies of stellar magnetism for FGK stars. This emission decays with stellar age and is a potential determinant of this important stellar quantity. We report Hα chromospheric fluxes for hundreds of solar-type stars in a wide range of masses, [Fe/H], ages, and evolution states. The comparison of Hα and Ca II chromospheric fluxes reveals a strong metallicity bias affecting Ca II fluxes, whereby metal-rich stars with deep line profiles mimic low levels of chromospheric flux, and vice versa for metal-poor stars. The Hα age-activity calibration aligns with the theoretical expectation that more massive stars have narrower convective zones and are less active than their less massive counterparts. In contrast, metal-rich stars have deeper convective zones and appear more active than metal-poor stars. We determine chromospheric ages by means of the chromospheric emissions, for the solar-type nearby stars. For low mass K-type stars, this is the only available "deterministic", non-statistical method for deriving ages. We discuss the age distribution of nearby solar-type stars in the context of biosignature detectability in nearby potentially habitable exoplanets.

Permission to publish

yes

Categories

1 Observations

86

The Nulling Interferometry Cryogenic Experiment (NICE): Beam metrology and control systems

Thomas Birbacher, Jonah T. Hansen, Adrian M. Glauser, Ryan Meierhofer, David Eglin, Sascha P. Quanz
ETH Zürich, Zürich, Switzerland

Abstract

The Nulling Interferometry Cryogenic Experiment (NICE) is a testbed for mid-infrared nulling technologies for the Large Interferometer For Exoplanets (LIFE). While cryogenic efforts are under development, we report here on the metrology and control systems of the NICE Warm Bench, a preparatory experiment at ambient conditions.

To achieve the required null depth of 1e-5 at 6 µm, both the cryogenic and the warm setup need metrology and control systems to stabilise the optical path length difference (OPD) between the beams to within 2.2 nm RMS, and shear and pointing to within 170 µm and 20 µrad RMS, respectively. We implemented a heterodyne laser metrology system on the Warm Bench, using modulation techniques to measure OPD, shear, and pointing of all beams, while introducing no additional components in the science beam path.

Using this system, we achieve 7e-6 to 1e-5 mean nulls over periods of up to 60s, with residual OPD sensor noise less than 1.5 nm RMS, corresponding to a level of starlight suppression sufficient for LIFE. Next steps for the Warm Bench include the use of multiple laser sources for a broadband measurement, and the investigation of constructions methods and compensation mechanisms to null at multiple wavelengths and polarisation modes simultaneously.

Permission to publish

yes

Categories

4 Experiments

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NIFITS, the nulling interferometry data standard and its role in instrument science of the LIFE mission

Romain Laugier[1], Philipp Huber[2], Loes, W. Rutten[1], Felix Dannert[2], Jonah Hansen[2], Jens Kammerer[3], Marc-Antoine Martinod[4], Denis Defrère[1]
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Abstract

The direct investigation of planets in the mid-infrared has been identified decades ago as a scientific priority and has come back on the table with ESA's Voyage 2050 programme. Due to the sheer nature of the problem, the situation calls for a nulling interferometer with baselines must reach into the tens of meters at least.

Post processing techniques, often credited for a x10 gain in performance for coronagraphs, face a unique challenge of mitigating the variation of so-called leakage light.

Yet the nature of nulling interferometers has prevented the use of the FITS format used for coronagraphs, or the OIFITS format used for classical beam-combiners, and this lack of an adequate data format has strongly limited the community. The new data format NIFITS, already publicly available to the community, is on track for broad adoption by most nulling teams as shown by the results obtained during this hackathon the recent summer hackathon.

NIFITS empowers the user to deploy the full extent of their reduction and modelling tools even when agnostic of the details of the instrument.

The adoption of NIFITS by the LIFE community is transforming the efforts of the instrument science working group, allowing formalization of instrument concepts and the elimination of throwaway code in favor of longer lasting reduction pipelines that can grow to crystalize the multiple aspects of data reduction under a coherent framework. Soon it will enable the organization of data challenges to consolidate the viability of instrument concepts from end to end, in realistic conditions.

Permission to publish

yes

Categories

2 Simulations

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Integrated InGaAs/InP Waveguides for Low-Loss Astrophotonics between 4-18 µm

David Eglin[1], Miguel Montesinos-Ballester[1], Théa Boussion[1], Lucius Miller[1], Davide Pinto[1], Alexei N. Baranov[2], Roland Teissier[2], Adrian Glauser[1], Sascha P. Quanz[1], Jérôme Faist[1]

[1]ETH Zürich, Zürich, Switzerland. [2]Université de Montpellier, Montpellier, France

Abstract

Photonic technology in the mid-infrared (MIR) remains underdeveloped compared to that in the near-infrared due to challenges in materials and fabrication. Yet the absorption properties of many molecules in the MIR make applications valuable for sensing and spectroscopy. In particular, LIFE would benefit from using photonic chips instead of bulk optics for beam processing to characterise exoplanet atmospheres at wavelengths between 4-18 µm. This step could enable lighter, more compact and robust instruments. However, achieving low losses, broadband operation, and cryogenic compatibility poses challenges in today's technological landscape.

A promising approach uses integrated InGaAs/InP photonic waveguides, where low propagation losses were demonstrated between 4-11 µm. We aim to assess the suitability of this material platform for astrophotonic signal processing by first characterising propagation losses over a broader range. For this, a new setup including five monochromatically emitting quantum cascade lasers is designed allowing measurements at wavelengths between 4-16 µm. Understanding waveguiding behaviour at longer wavelengths demands particular consideration of loss contributions in core and cladding, mode confinement, and waveguide geometry, as well as their wavelength dependence, which are assessed in simulation and experiment. In addition, we prepare for cryogenic measurements to evaluate performance under space-like conditions.

The waveguide represents the fundamental component in photonics, similar to a conductor in an electronic circuit. This work therefore constitutes the beginning of the development of a photonic platform for low-loss and broadband signal processing, enabling advanced circuits for beam splitting, combining, and phase shifting, suitable for LIFE and similar missions.

Permission to publish

yes

Categories

5 Technologies

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Probing thermal gradient of habitable-zone rocky planets with LIFE as anti-indicator of surface ocean

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Abstract

The LIFE mission aims to characterize the thermal emission of potentially habitable planets in the search for life. While previous studies have examined the detectability of atmospheric biosignatures, evidence of "habitability" (i.e., surface liquid water) remains elusive. General circulation model (GCM) studies have shown that oceans tend to reduce horizontal gradients in top-of-atmosphere thermal emission through efficient heat transport and cloud cover. Motivated by this, we investigate the detectability with LIFE of large thermal emission gradients across the planet, which would serve as an anti-indicator of global oceans for certain planets.

Using Teegarden's Star b (zero-albedo equilibrium temperature ~ 280 K) as a benchmark, we compute three-dimensional atmospheric structures with and without a global ocean using the ROCKE-3D GCM and simulate geometry-dependent thermal emission spectra. As expected, we find larger thermal gradients for no-ocean cases, which manifest in both orbital phase variations and the spectral shape of snapshot spectra. Phase variations are more readily detectable: one-day integrations with LIFE at two orbital phases can reveal flux differences in no-ocean atmospheres of 1–10 bar, depending on composition. Clues in snapshot spectra—specifically the running continuum brightness temperature and detailed band shapes—provide complementary constraints, but require $\gtrsim 5$ times longer integrations. These three-dimensional effects, if neglected, can bias interpretations based on one-dimensional models. We also discuss applications to other nearby exoplanets. Our results highlight the importance of incorporating three-dimensional atmospheric structures to constrain surface conditions and to avoid misinterpreting spectral data.

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Categories

3 Theory / Models

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Architecture of systems hosting Earth-like planets detected by LIFE

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Abstract

The LIFE mission aims to detect Earth-like planets located within the habitable zone of their host stars. During its exploratory phase, the mission currently prioritizes a blind search strategy over a targeted approach. In this work, we employ a variety of planetary formation models to investigate the architecture of planetary systems hosting Earth-like planets in their habitable zones. Our objective is to identify the potential signatures that a planetary system may provide regarding the presence of an Earth analog, as well as to characterize the properties of such a planet. To this end, we explore multiple planetary formation models under different assumptions.

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3 Theory / Models

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The CHARA Array - ground-based interferometry technology development

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Abstract

The CHARA Array provides the highest angular resolution currently available in the visible and near-infrared wavebands, achieving resolutions down to ~200 µas in R, J, H, and K bands using its six 1 m telescopes with baselines from 34 to 331 m. Improvements for simultaneous imaging across the R, H, and K wavebands have been funded and we are developing beam transport and control upgrades to improve science performance. Efforts are underway to extend CHARA’s reach by utilizing fiber-based beam transport for kilometer-scale baselines and by incorporating a mobile seventh telescope, further pushing the limits of direct stellar characterization. Optical fibers with lengths of 650m now connect multiple telescopes, including the new mobile telescope, to the lab and have achieved lab fringes. In the context of LIFE, CHARA plays a central role: accurate measurements of host-star properties are essential for interpreting exoplanet atmospheres and demographics. Interferometric determinations of stellar radii, limb darkening, and binarity provide critical input for selecting and prioritizing LIFE targets while also informing the mission’s observing strategies. In parallel, we are pushing for nulling interferometry concepts at the CHARA Array by offering a platform for developing and validating techniques relevant to future high-contrast instruments. A testbed is being iteratively improved to provide a plug-and-play system for testing various integrated optics (IO) technologies in the H and K-bands, with plans for ultimately placing an infrared nuller at the CHARA Array. These initiatives underscore CHARA contribution as ground-based support for LIFE’s success.

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5 Technologies

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Astrophotonic Beam Combination in Thin-Film Lithium Niobate

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Abstract

The use of integrated photonics in astronomical instrumentation allows for the realization of complex beam combiners for stellar interferometry on a small footprint. Thin-film Lithium Niobate offers a platform for realizing space-compatible integrated photonics in the mid-infrared wavelength regime up to ≈ 5 µm. By leveraging a newly developed Lithium Niobate on Sapphire platform, we are designing an integrated broadband beam combination scheme for nulling interferometry in the astronomical L-band. This operates in a single-Bracewell configuration and relies on shape-optimized passive phase shifters and couplers. Additionally, we are developing an integrated fringe-tracker on Lithium Niobate on Insulator in the astronomical K-band, which measures the optical path difference between two beams originating from the same light source, particularly useful for formation-flying spacecraft. We show various designs for an ABCD combinaiton scheme, able to provide fringe characteristics in a single shot measurement.
Low-loss ridge waveguides and couplers are fabricated in the Lithium Niobate thin-film by electron-beam lithography and inductively coupled plasma etching. Beams are injected into polished waveguide facets using lensed flouride fibers. We present the designs and most recent characterization results of the integrated fringe tracker and nulling interferometer.

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