LIFE =
Large Interferometer For Exoplanets

The LIFE Mission – Characterizing other worlds and searching for life

Shaping the Italian contribution to HWO

July 11, 2025

Authors:

Sascha P. Quanz (PI)

for the

LIFE project

CENTRE FOR ORIGIN & PREVALENCE OF LIFE

LIFE is unique among future facilities to directly detect terrestrial exoplanets and search for indications of life

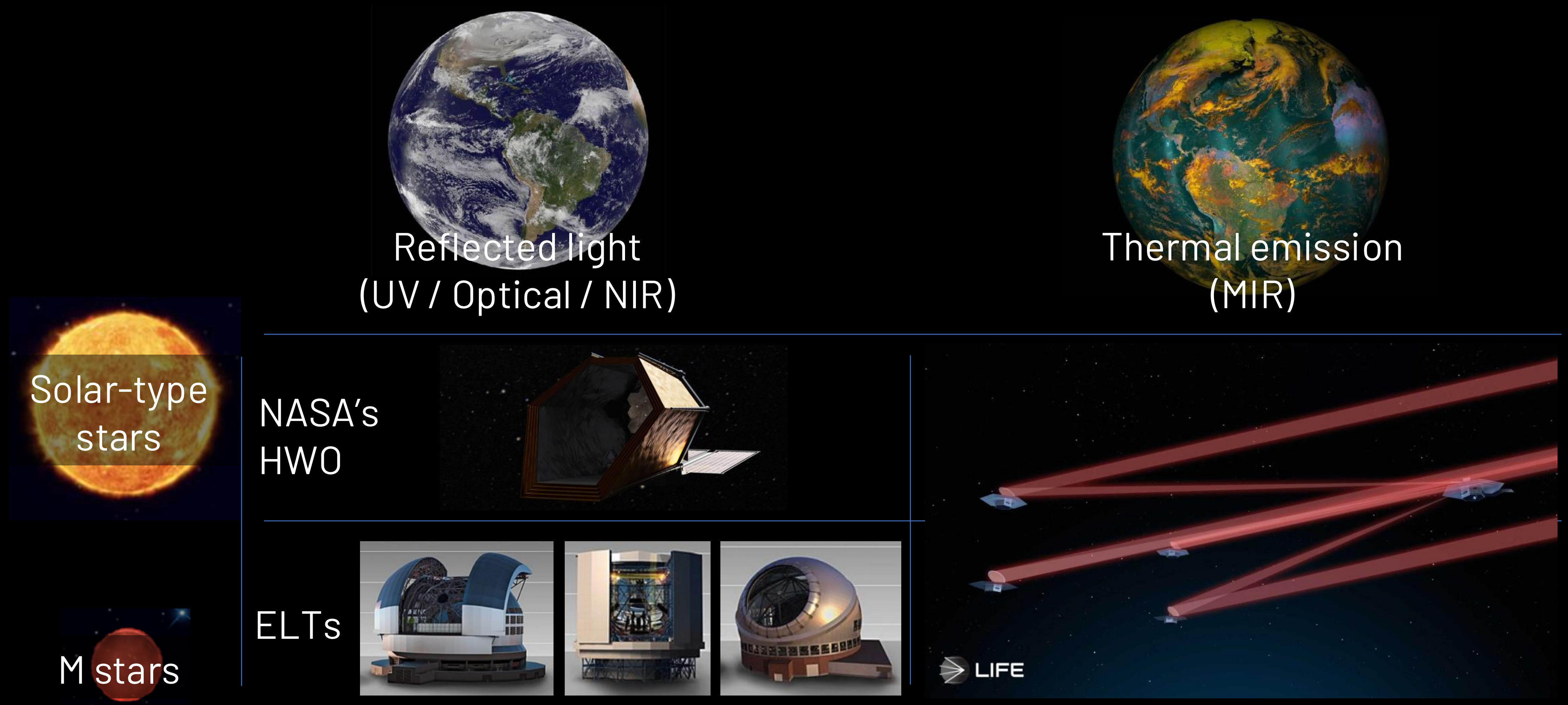
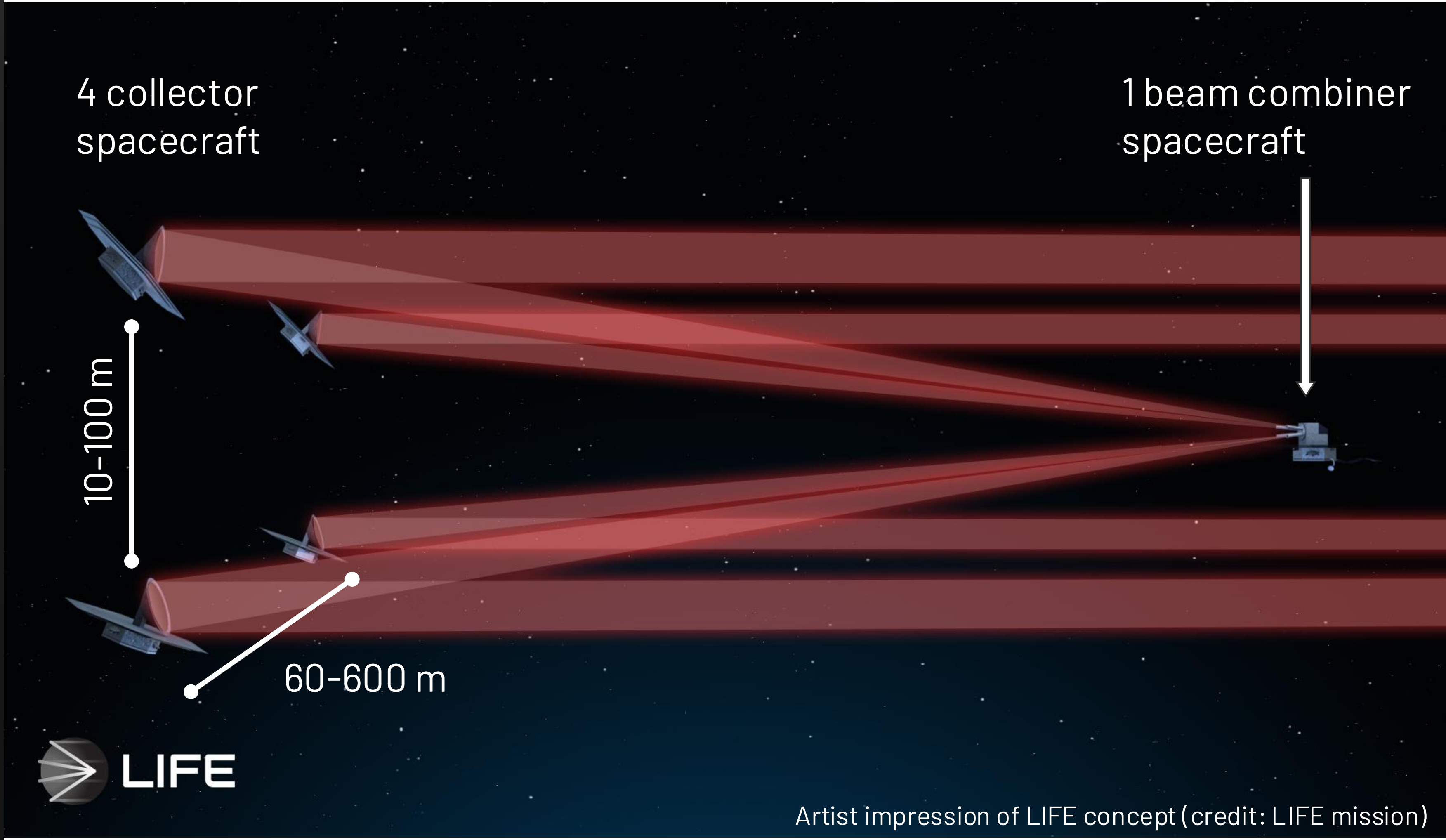


Image credit: NASA's Goddard Space Flight Center Conceptual Image Lab, LIFE Project, ESO, TMT, GMT

The LIFE mission

- LIFE is a space-based formation-flying nulling interferometer
- It consists of 4 collector spacecraft in a rectangular array and a central beam combiner spacecraft above the array
- The separation between the collectors can be freely adjusted to optimize the performance for each nearby star
- Like the James Webb Space Telescope, LIFE will orbit around Lagrange Point 2
- The nominal mission lifetime will be 5-6 years
- LIFE covers the mid-infrared wavelength range between ~6-16 μm (requirement) /~4-18.5 μm (goal) with a spectral resolution of $R = \lambda/\delta\lambda \sim 100$



Artist impression of LIFE concept (credit: LIFE mission)

Quanz et al. (2022)

Investigating other worlds

- LIFE's wavelength range is chosen to cover the peak of the thermal emission of temperate terrestrial planets
- This wavelength range features absorption bands of major atmospheric constituents including molecules that are only present because biological activity such as ozone (O_3), methane (CH_4) and nitrous oxide (N_2O)

Emission spectra of terrestrial planets in our Solar System

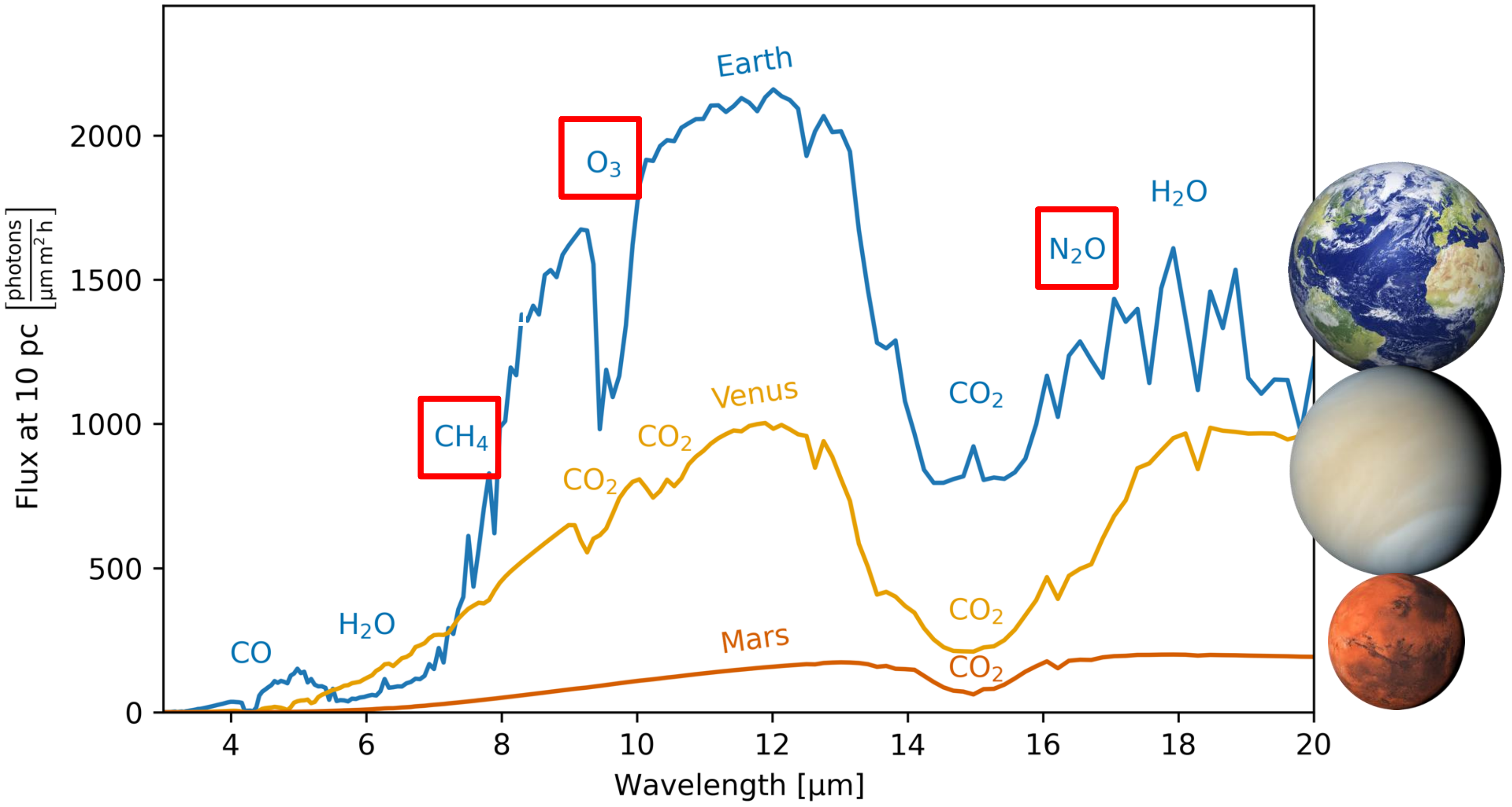


Figure credit: B. Konrad

Investigating other worlds

- LIFE's wavelength range is chosen to cover the peak of the thermal emission of temperate terrestrial planets
- This wavelength range features absorption bands of major atmospheric constituents including molecules that are only present because biological activity such as ozone (O_3), methane (CH_4) and nitrous oxide (N_2O)

Our Solar System as seen with LIFE from 10 pc distance

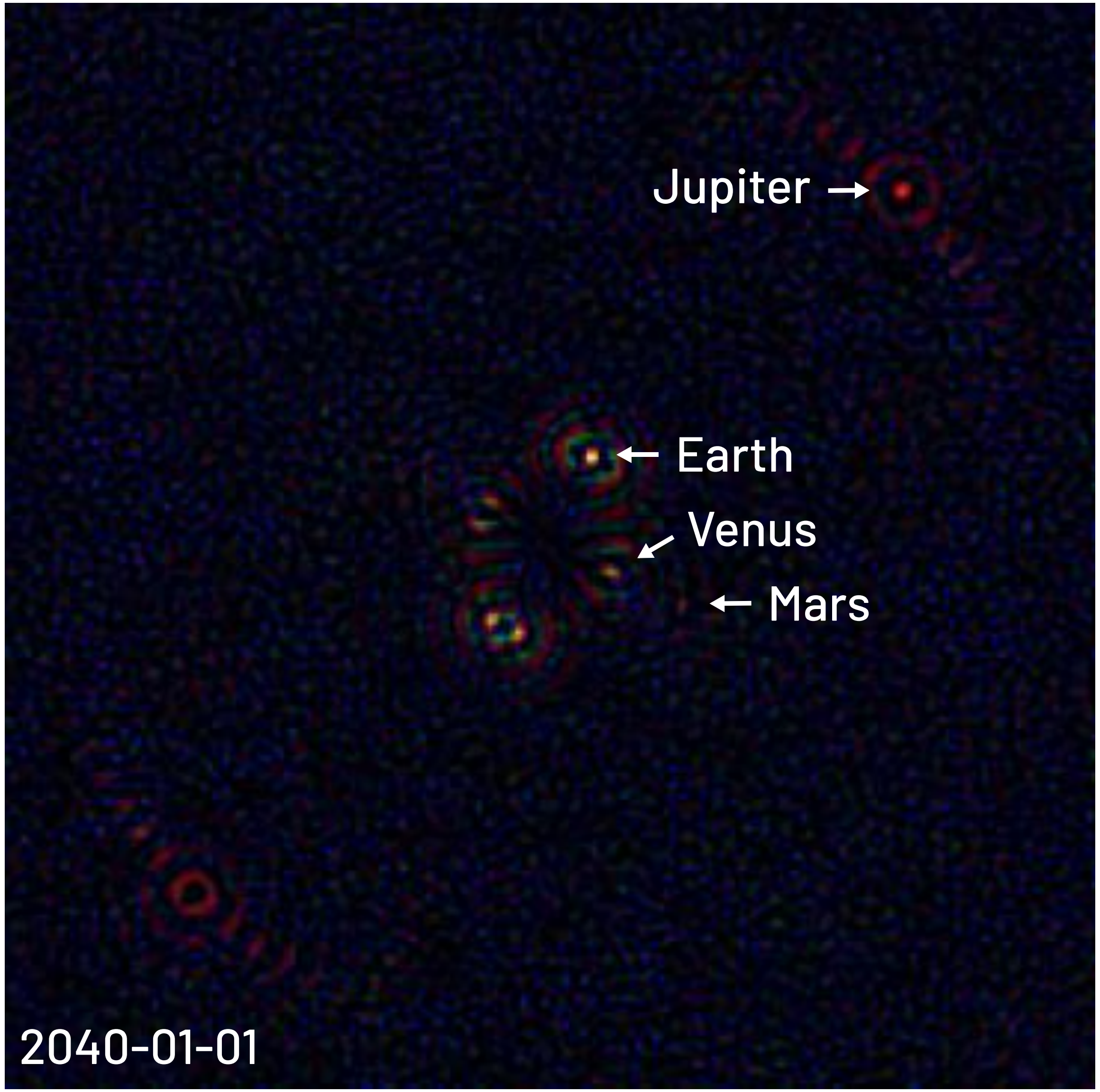


Figure credit: Ph. Huber

Exoplanet characterization: the mid-infrared advantage

In contrast to exoplanet observations in reflected light in the optical/near-infrared, LIFE will...

- ...directly constrain the **pressure-temperature structure** of exoplanet atmospheres
- ...access (multiple) atmospheric absorption bands of **major molecules** such as H_2O and CO_2 as well as collision induced absorption from N_2 and O_2
- ...search for numerous **atmospheric biosignatures** in the context of terrestrial exoplanets and gas dominated sub-Neptunes (e.g., O_3 and CH_4, but also N_2O, PH_3, NH_3, and C_5H_8)
- ...constrain directly **the effective temperature** of exoplanets and provide access to their **radii**
- ...deliver a higher detection yield during search phase as it is **less affected by the orbital phase function** of the exoplanets' emission compared to reflected light missions
- ...immediately **start observing already known small, temperate exoplanets** around nearby M-stars

cf. Line, Quanz et al. (2019; decadal White Paper), Quanz et al. 2022, Dannert et al. 2022, Alei et al. 2022, Konrad et al. 2022

LIFE: today's most transformative mission to search for life beyond the Solar System

LIFE gives access to a broad range of possible biospheres and provides the necessary context for their interpretation

30 – 50 temperate, terrestrial exoplanets around Sun-like stars (F0-K5 stars)
15 – 25 temperate, terrestrial exoplanets around low-luminosity stars (K6-M3)
10-20 temperate, terrestrial exoplanets around very low-luminosity stars (M4-M9)

Earth-like biospheres
LIFE can detect biospheres on planets beyond the Solar System that are like Earth's in their composition and evolution

Non-Earth-like biospheres
LIFE can detect biospheres on exoplanets that differ significantly from Earth's in their stellar environment or their composition

Technological signatures
LIFE can detect imprints of technology in the atmospheres of exoplanets

Planetary diversity as necessary context
LIFE will detect a diverse sample of hundreds of exoplanets providing the large reference sample needed to infer the existence of biospheres

LIFE: today's most transformative mission to search for life beyond the Solar System

NOT EXHAUSTIVE

LIFE gives access to a broad range of possible biospheres and provides the necessary context for their interpretation

Earth-like biospheres

Konrad et al. 2022, 2024
Alei et al. 2022, 2024
Mettler et al. 2023

Non-Earth-like biospheres

Angerhausen et al. 2023, 2024
Leung et al. 2024

Technological signatures

Schwieterman et al. 2024

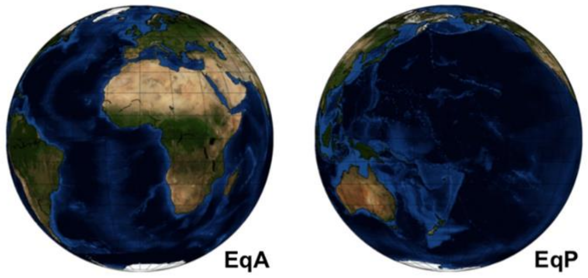
Planetary diversity as necessary context

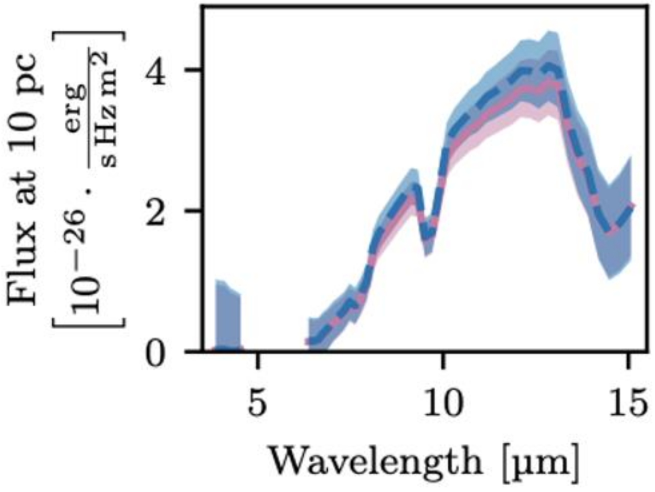
Quanz et al. 2022; Kammerer et al. 2022; Carrión-González et al. 2023; Konrad et al. 2023; Hansen et al. 2025

Atmospheric retrievals: LIFE observes "real" Earth

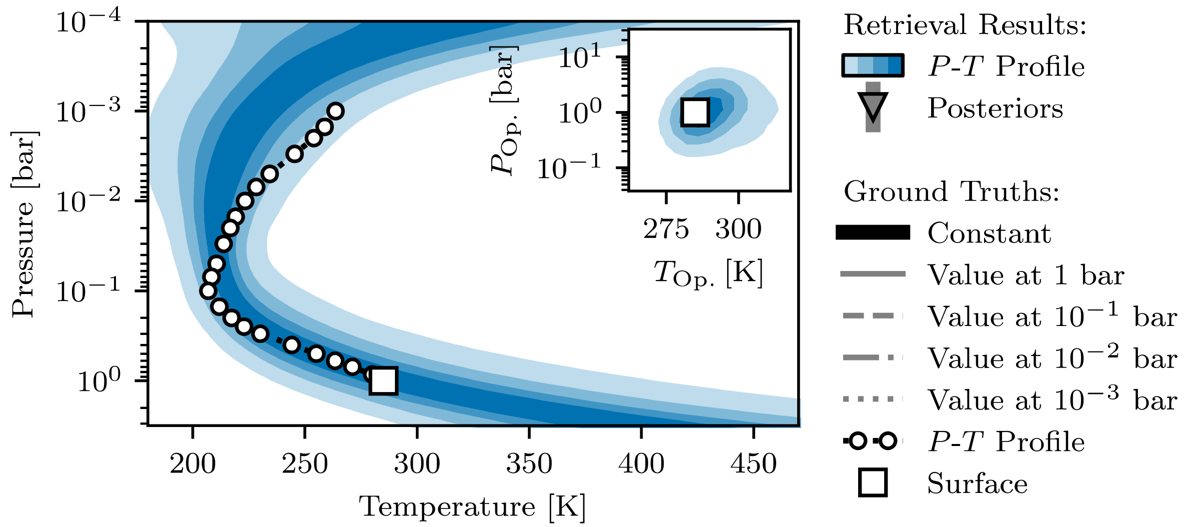
Atmospheric retrieval results based on simulated LIFE observations with SNR=10 and R=100 (~6-16 μm) for July equatorial view

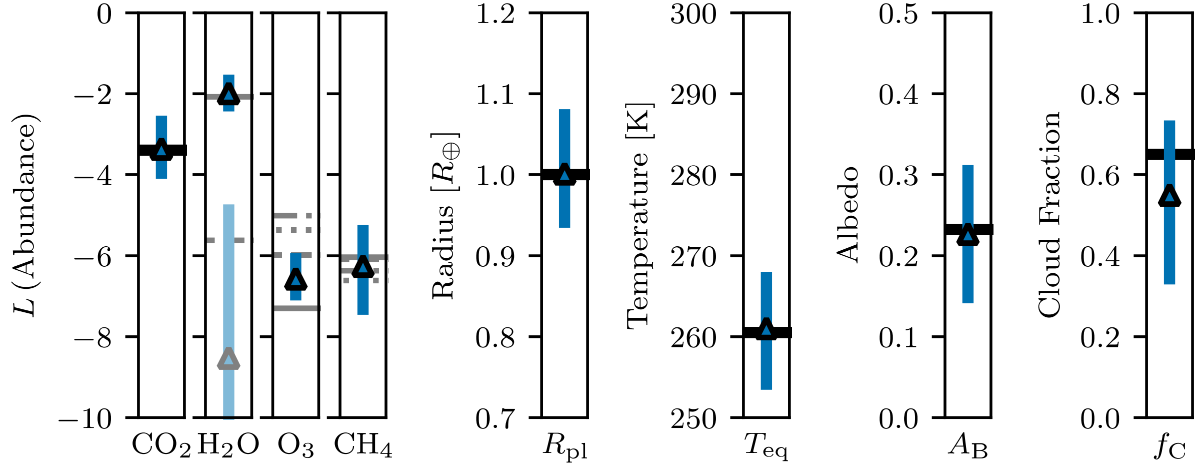
Input data from Earth observing satellite





Atmospheric Retrieval

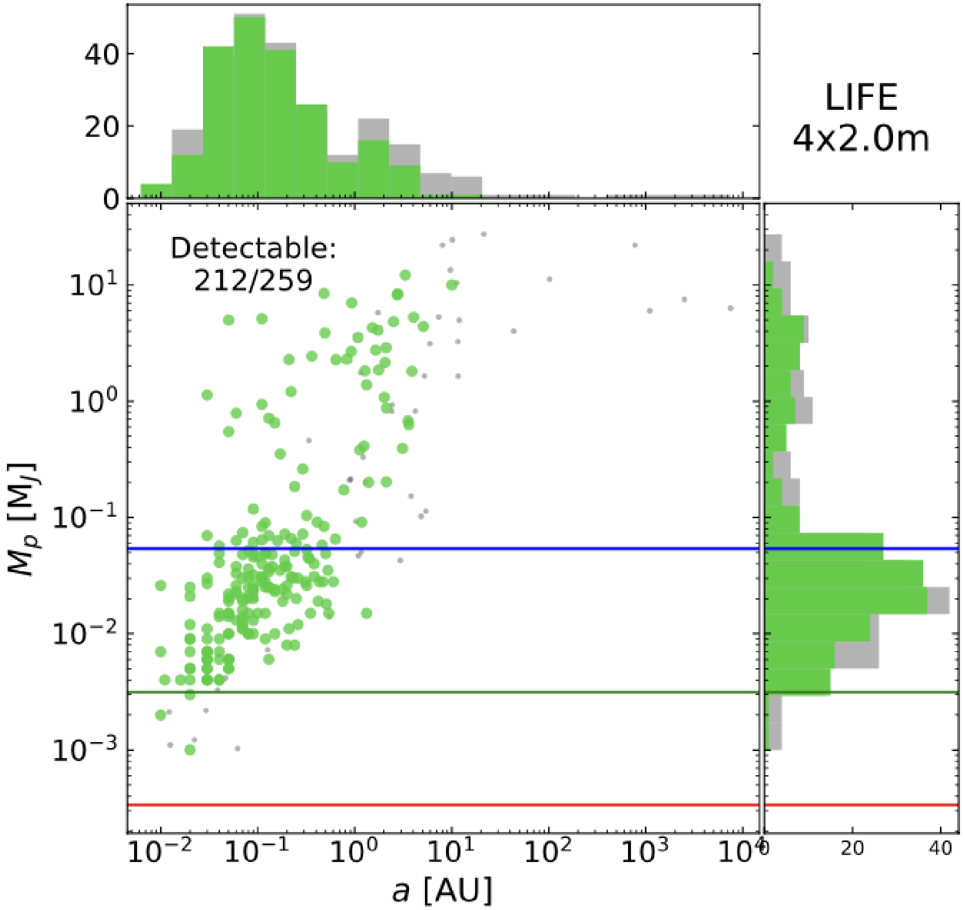


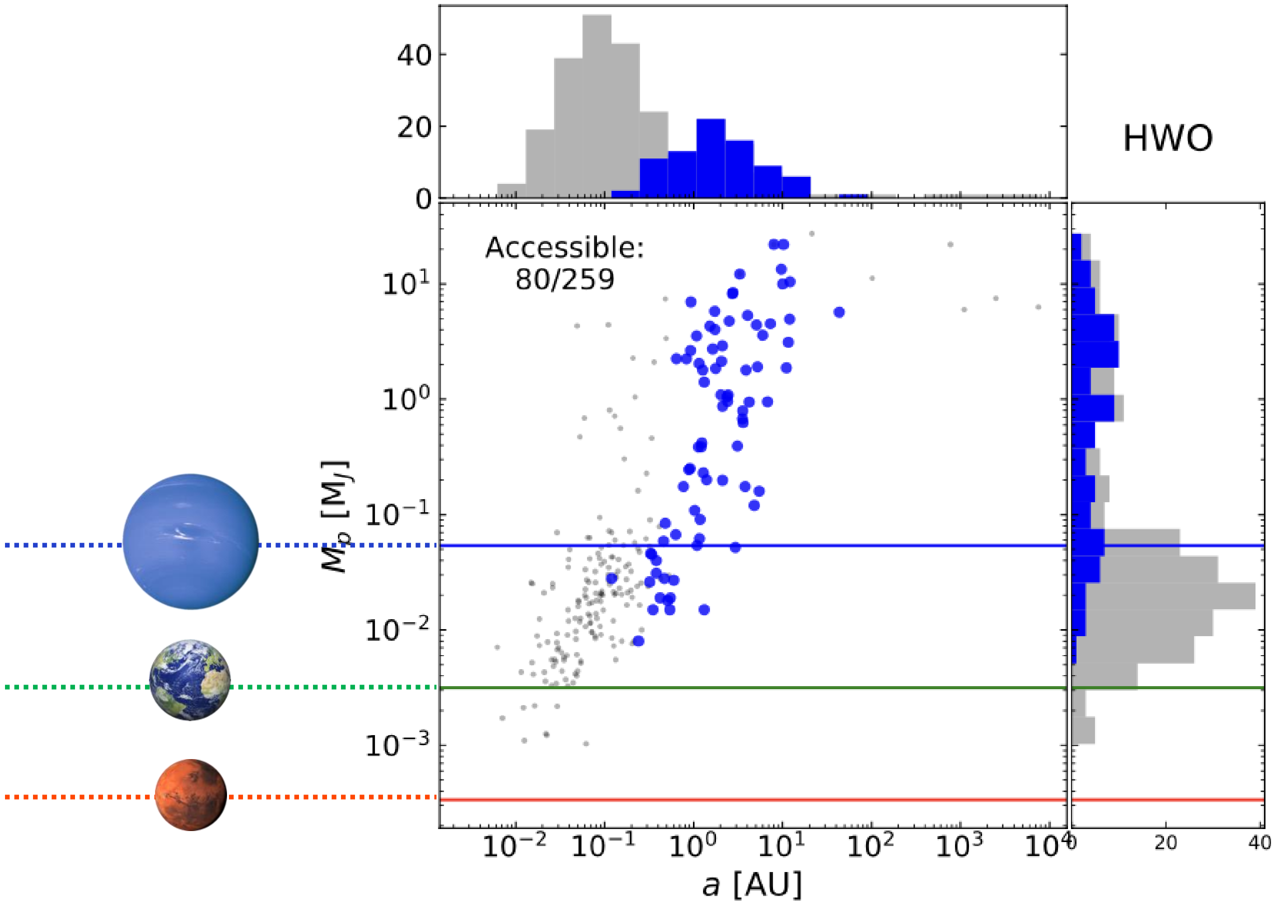


Konrad et al. (2024)

Characterizing known nearby planets from mission day 1

Detectability of known exoplanets within 20 pc





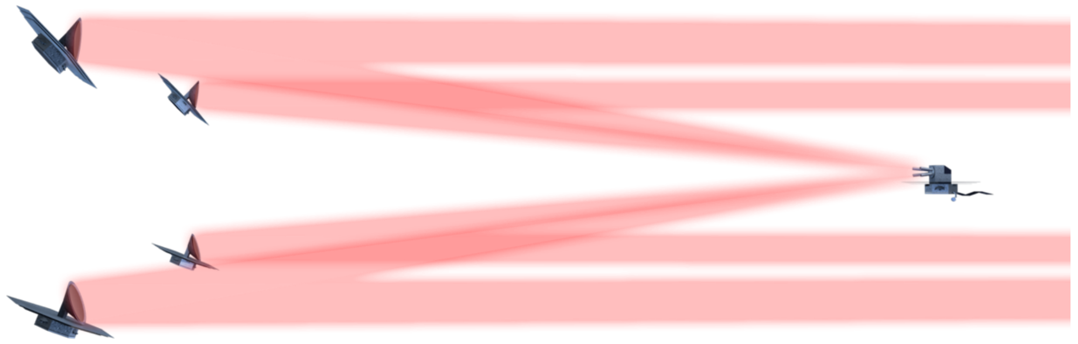
Carrión-González et al. (2023)

LIFE unleashed – beyond standard processes

We embrace scientific and technological challenges, question established mindsets, and pioneer new ways of collaborations

Goal

Implement today's most transformative space mission designed to search for life beyond the Solar System by 2040



Approach

- Seek funding via donors, foundations, and sponsors
- Seek goal-oriented partnerships in industry and academia to

  1) Re-design the development and implementation process

  2) Develop and mature key technologies

  3) Leverage commercialization potential of technologies and processes (e.g., formation flying platforms, photonics, etc.)

Aiming at a launch in 2040 we consider 3 development and funding stages

INDICATIVE

Stage 1: Preparation
Today - 2028

1. Conclude mission concept study and finalize development plan
2. Demonstrate LIFE measuring principle in the lab (NICE experiment)
3. Mature key technologies and assess commercialization potential

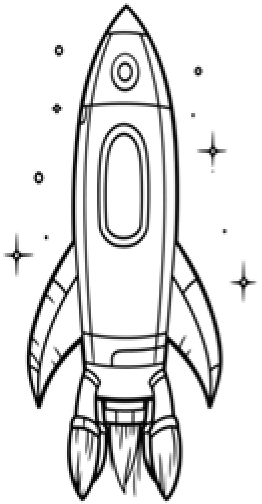
Stage 2: Maturation
2029 - 2033

- Conclude mission design
- Mature and demonstrate sub-system performance, in particular formation flying, interferometric nulling

Stage 3: Implementation
2034-2040

- Integrate flight hardware
- Secure launch opportunity
- Set up ground-segment, mission operations, and data center

Launch



- Establish mission consortium with academic and industry partners
- Develop and execute fundraising strategy
- Develop and execute communication strategy

Stage 1: Preparation Today - end of 2028

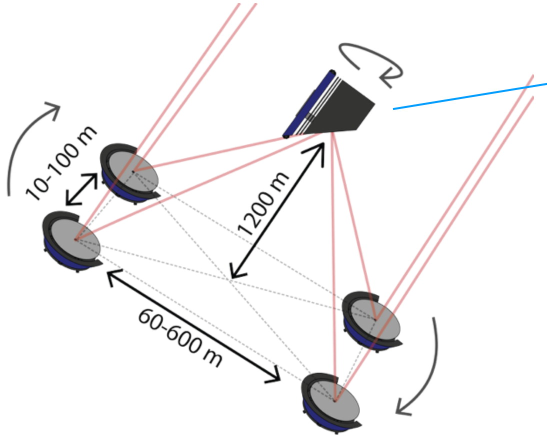
1 **Conclude mission concept study and development plan**

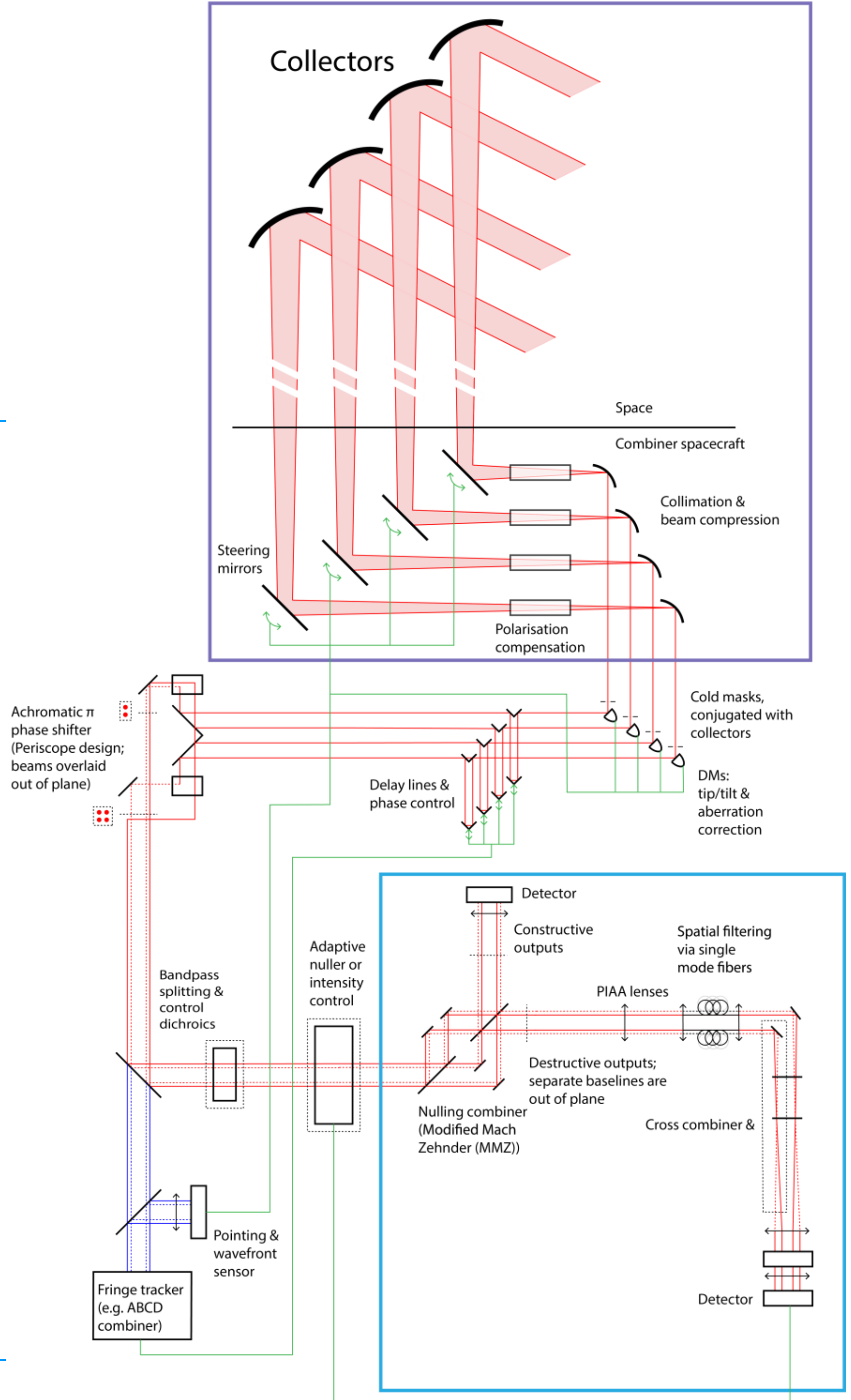
2 Demonstrate LIFE measuring principle in the lab

3 Mature key technologies and investigate commercialization potential

Optical Concept

- Key building blocks identified
- Definition of major architecture trades
- Refinement of Mission Requirements
- Pre-studies launched





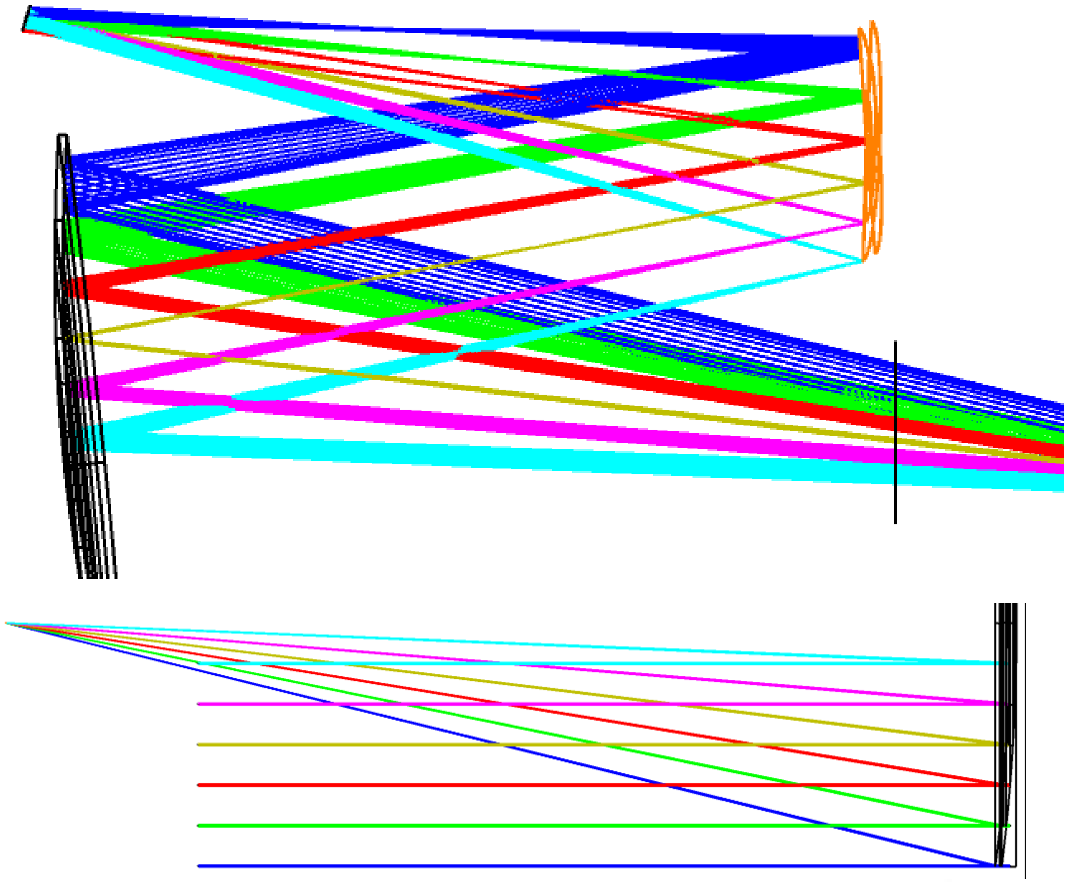
cf. Glauser et al. 2024

Stage 1: Preparation Today - end of 2028

1. **Conclude mission concept study and development plan**
2. Demonstrate LIFE measuring principle in the lab
3. Mature key technologies and investigate commercialization potential

Collector Optical Design

- Pre-study to understand aberration and pupil shape of spherical M1
- Investigation to correct the pupil distortions by using two freeform mirrors in the beam combiner optics
- Spherical aberrations and astigmatism resulting present in each individual baseline
- → Easily corrected with a Deformable Mirror
- Strong variations in pupil shape for each baseline
- → Much harder to correct



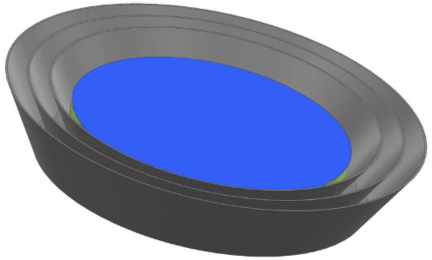
Stage 1: Preparation Today – end of 2028

beyond gravity

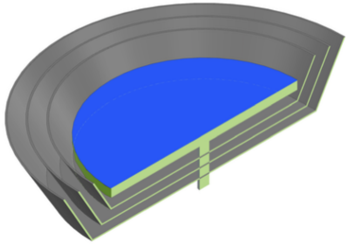
1. **Conclude mission concept study and development plan**
2. Demonstrate LIFE measuring principle in the lab
3. Mature key technologies and investigate commercialization potential

Project Update: Collector Spacecraft Thermal Control Concept

Thermal Concept Design → **Geometric Simplification** → **Thermal Analysis**

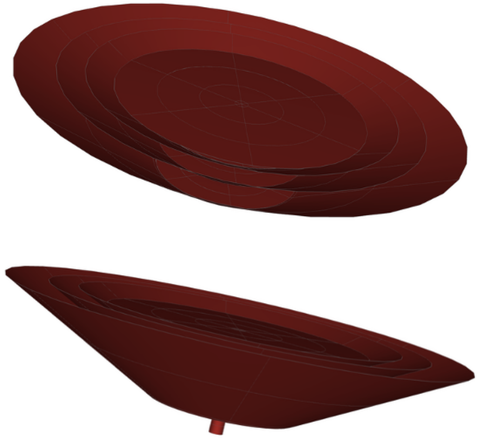


CAD Model

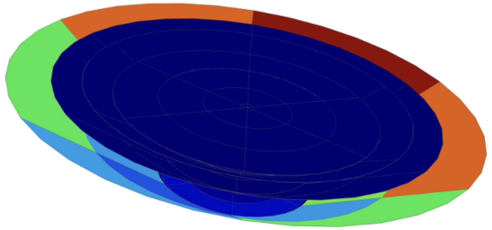


Cross-section view of CAD Model

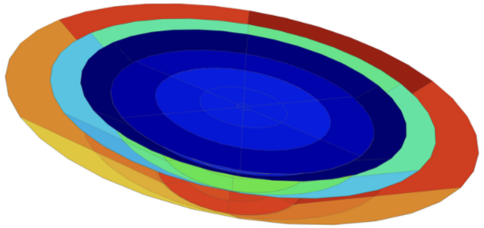
- BG input: V-groove composition, geometry
- BG input: GFRP strut geometry



Simplified Model using Shell Elements



Solar Flux



Temperature Distribution
(! first result → needs to be optimized)

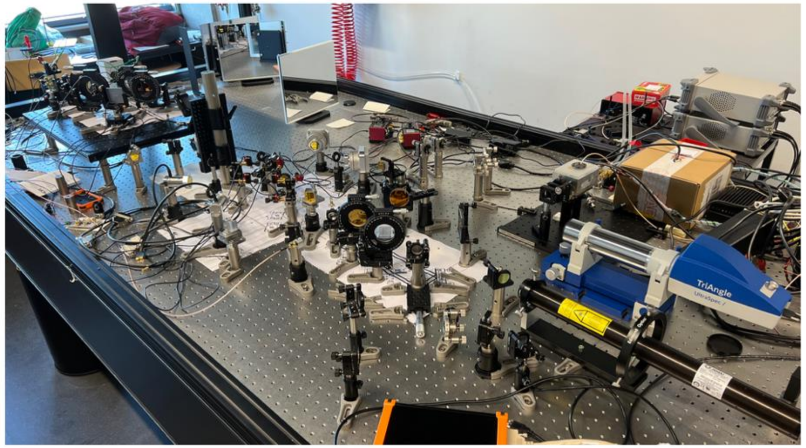
- BG input: material properties (thermal conductivity, emissivity, density, specific heat)

Stage 1: Preparation Today – end of 2028

1. Conclude mission concept study and development plan
2. **Demonstrate LIFE measuring principle in the lab**
3. Mature key technologies and investigate commercialization potential

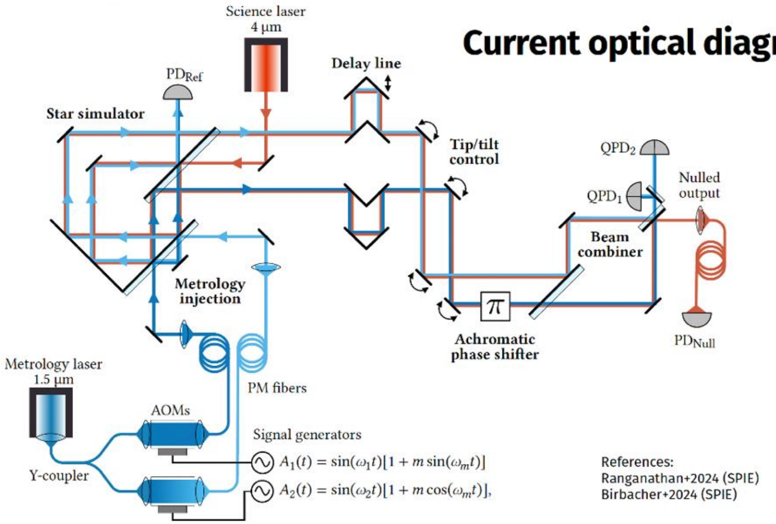
NICE objectives:

Demonstrate a broadband null with a null depth of 10^{-5} and stability of 10^{-8} while maintaining a high system throughput, and consequently a high level of sensitivity



Warm precursor setup of NICE

Current optical diagram



Simplified Layout

References:
Ranganathan+2024 (SPIE)
Birbacher+2024 (SPIE)

Credit: T. Birbacher, M. Ranganathan

Stage 1: Preparation Today - end of 2028

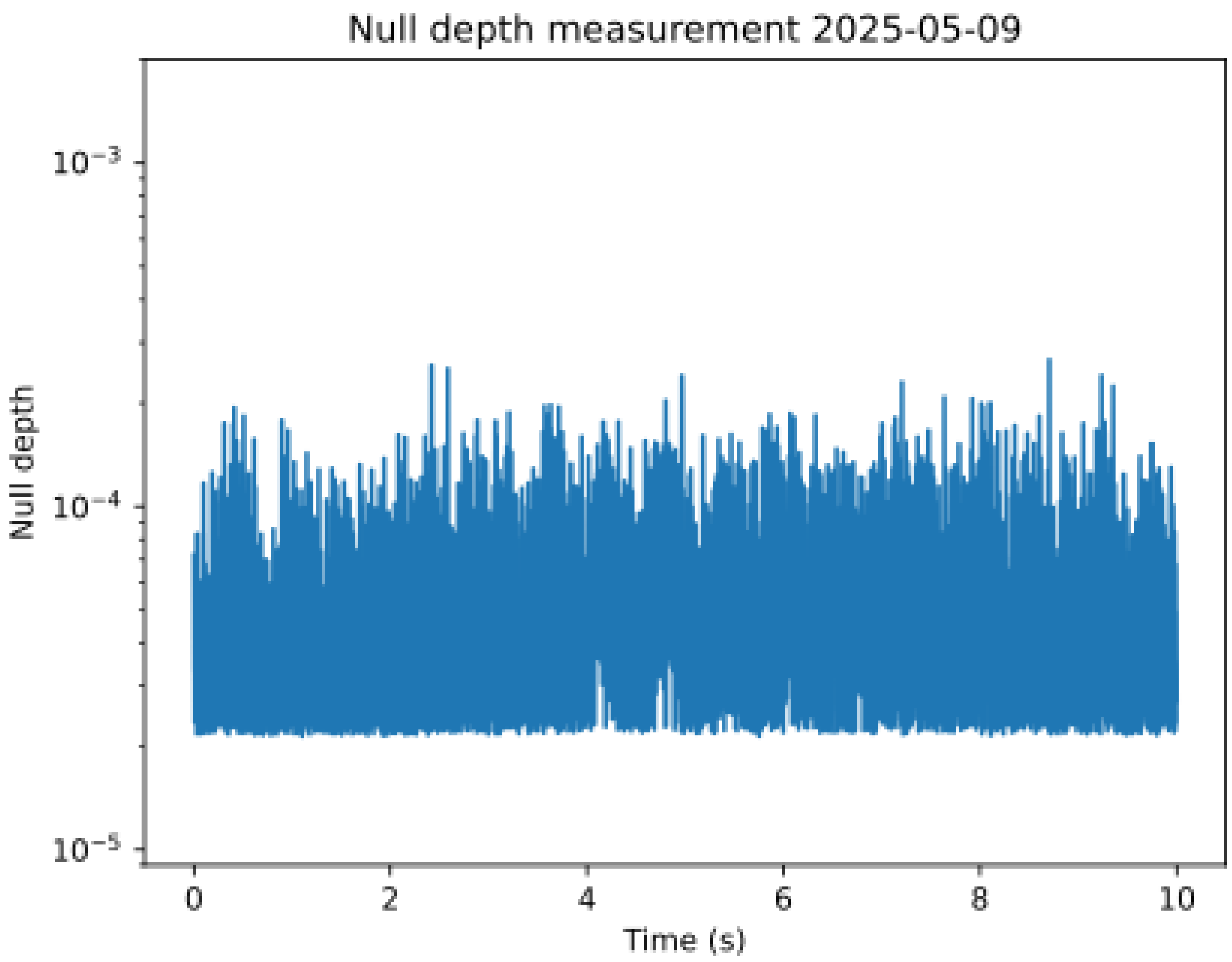
1 Conclude mission concept study and development plan

2 **Demonstrate LIFE measuring principle in the lab**

3 Mature key technologies and investigate commercialization potential

Status:

- Mean recorded null depth of **<5*10^{-5}**, with a minimum around **2*10^{-5}** at 4 micron
- Fast OPD control loop allowing noise to be reduced at the sub nm level up to 1kHz
- Bench upgrade in progress to enhance stability and allow for broadband operation.



Stage 1: Preparation Today - end of 2028

1 Conclude mission concept study and development plan

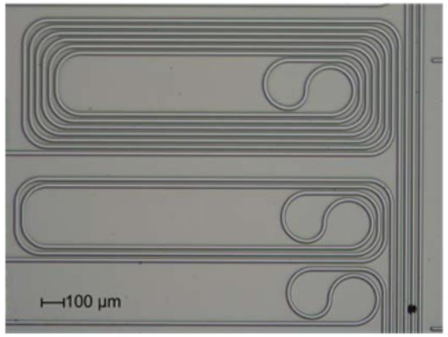
2 Demonstrate LIFE measuring principle in the lab

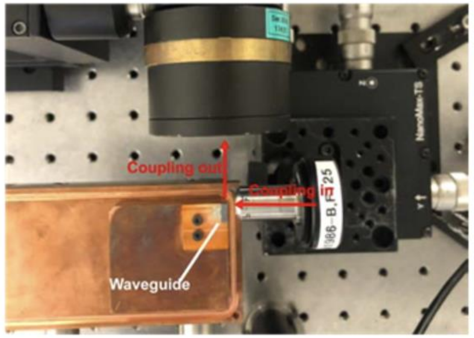
3 **Mature key technologies and investigate commercialization potential**

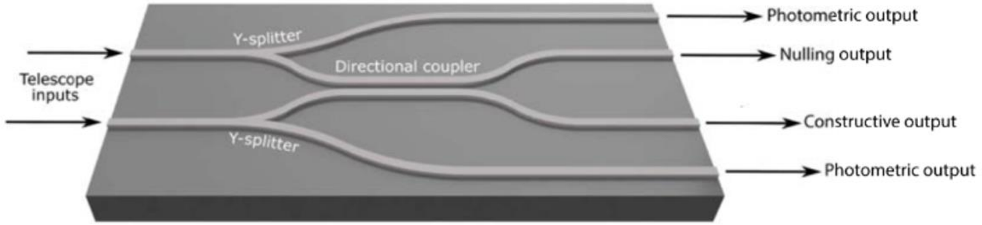
Development of InGaAs waveguides with InP cladding and Fe doping

MPIS4LIFE Collaboration with Institute for Quantum Electronics (Prof. J. Faist, Prof. R. Grange)

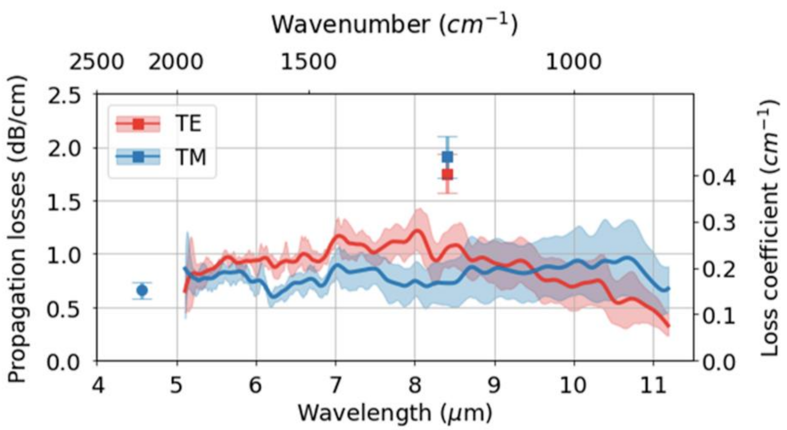
MIR waveguides / integrated optics







Measured transmission losses (Montesinos, 2024)



Montesinos et al. 2024

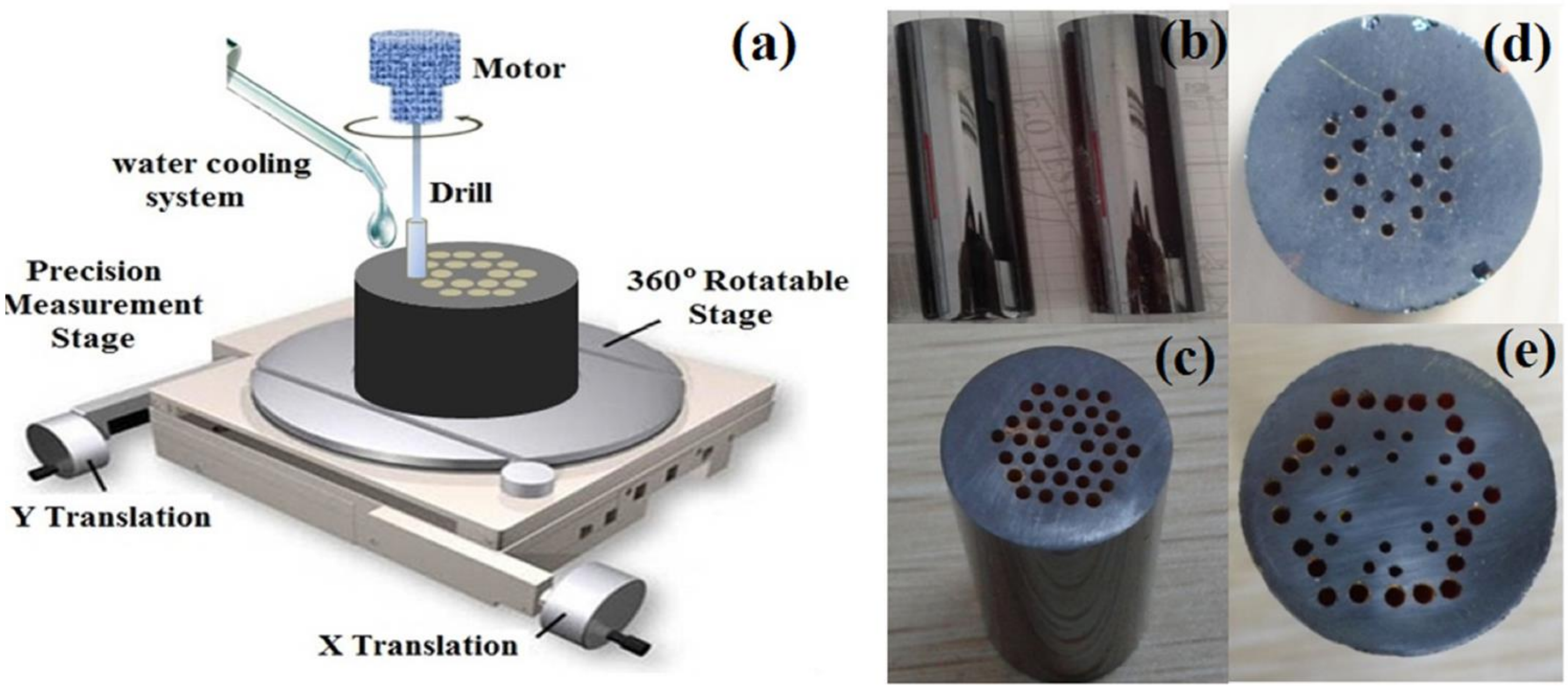
Stage 1: Preparation Today - end of 2028

1. Conclude mission concept study and development plan
2. Demonstrate LIFE measuring principle in the lab
3. **Mature key technologies and investigate commercialization potential**

Spatial Filters - Phase Induced Amplitude Apodization in combination with Photonic Crystal Fibres

Australian National University

M. Ireland, ANU, Australia

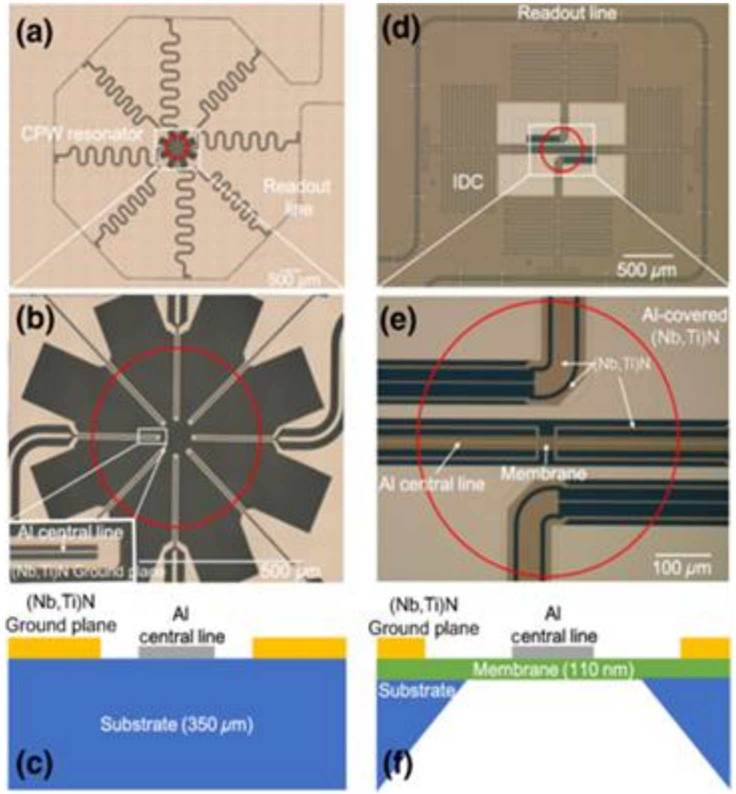


Stage 1: Preparation Today – end of 2028

1. Conclude mission concept study and development plan
2. Demonstrate LIFE measuring principle in the lab
3. **Mature key technologies and investigate commercialization potential**

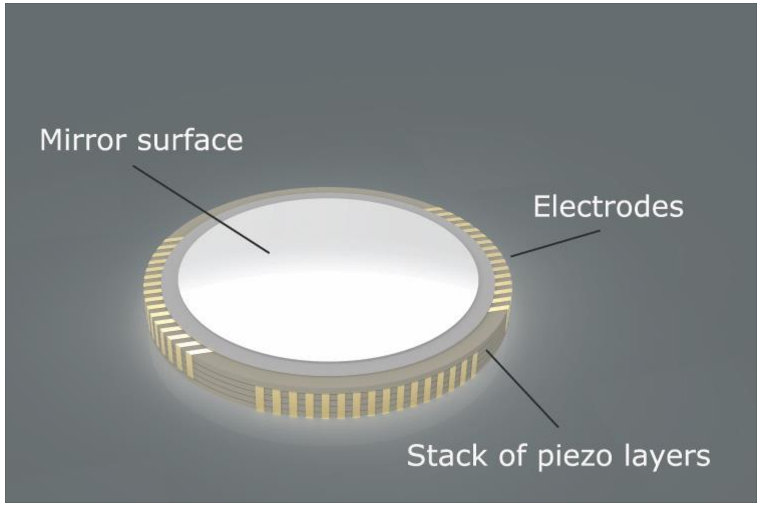
MKID detectors

P. de Visser (SRON)



Cryogenic DMs

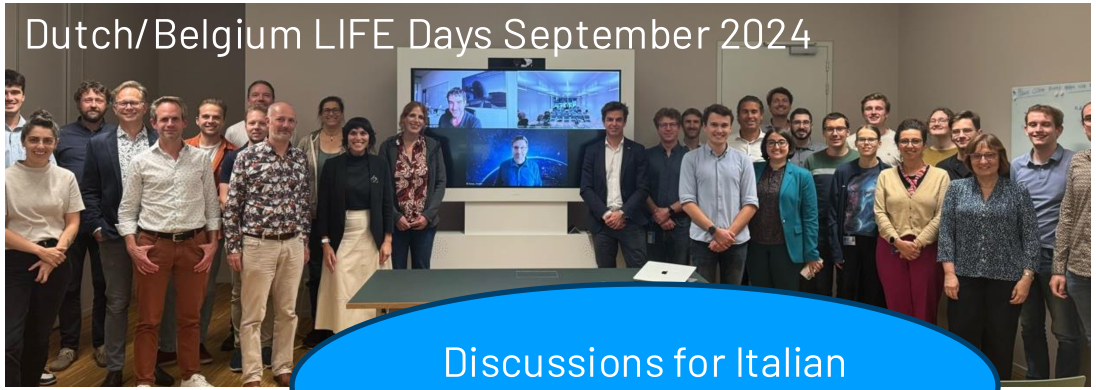
Robert Huisman (SRON)



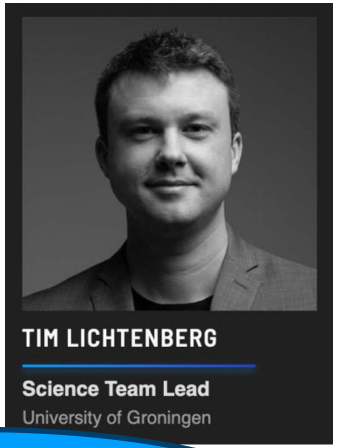
SRON

Join and engage in LIFE-related activities

Bottom-up engagement in LIFE Science community



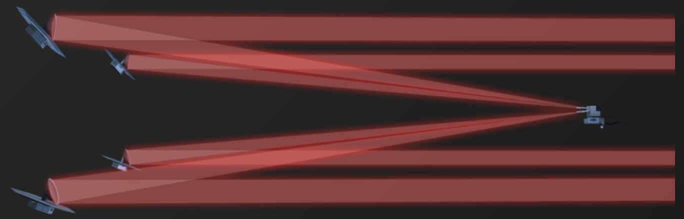
Discussions for Italian LIFE Days are ongoing



Monthly LIFE Science community calls

Abstract submission open!
Deadline: August 31

Information / contact:
www.life-space-mission.com



The LIFE mission

We inspire and unite humankind in the way we perceive ourselves and our home planet Earth. We encourage current and future generations to pursue bold visions.

We embrace scientific and technological challenges, question established mindsets, and pioneer new ways of collaborations.

We develop and implement today's most transformative space mission to search for life beyond the Solar System and investigate the diversity of other worlds.

Backup