LIFE SPACE MISSION

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LIFE – Large Interferometer For Exoplanets Rotation-Speed Optimization for Planet Detection in a LIFE-like Nulling Interferometer

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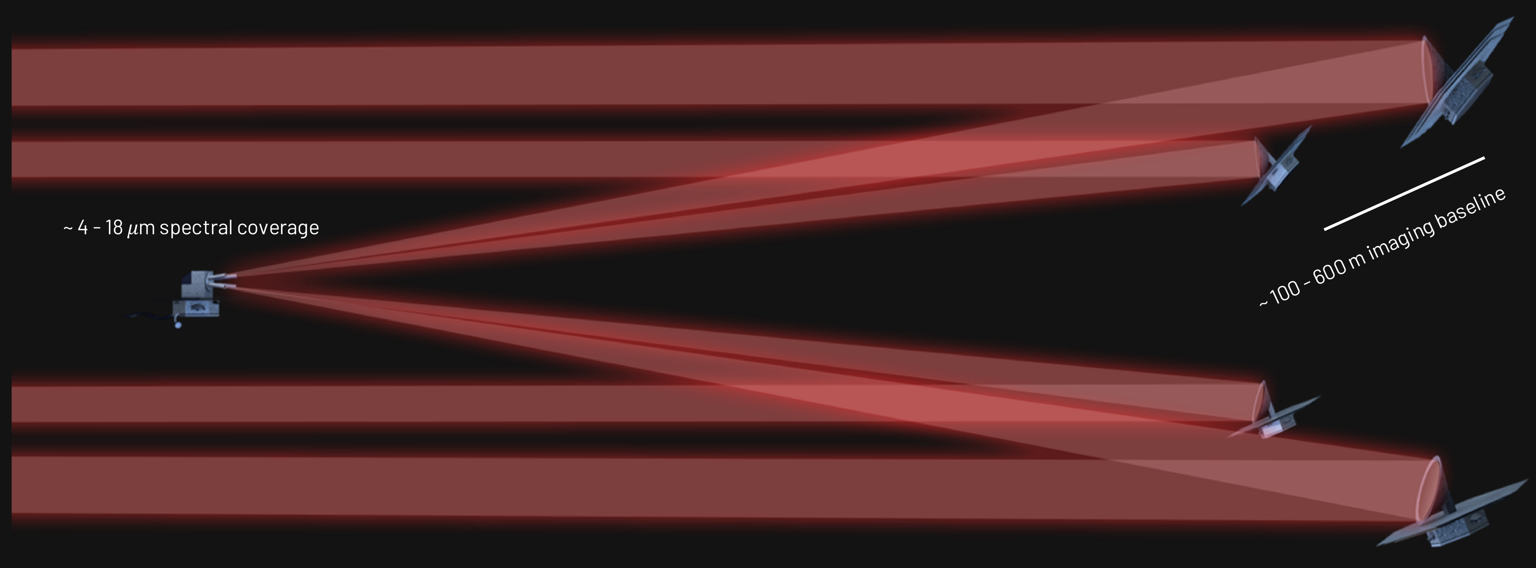


Figure 1: LIFE: Four formation-flying collector spacecraft collecting mid-infrared light from an exoplanetary system, combining it in a central beam combiner spacecraft (www.life-space-mission.com).

LIFE mission concept

LIFE is a proposed space mission designed with the objective of **directly detect and characterize Earth-like exoplanets** beyond our Solar System.
To achieve these goals, observations must be made from space, free from the disturbing effects of Earth's atmosphere. Because potentially habitable planets emit most of their detectable thermal radiation in the mid-infrared, **LIFE is designed as a space-based nulling interferometer operating at wavelengths between 4 and 18.5 micrometers.**

Figure 2: LIFE Mission logo (www.life-space-mission.com).

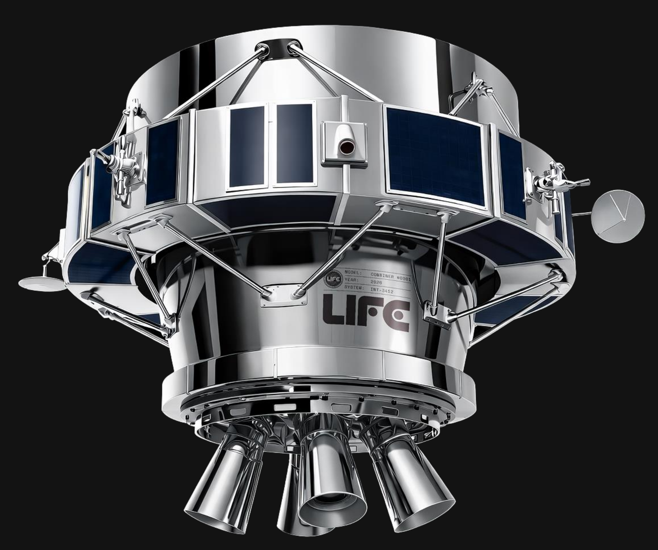


Figure 3: LIFE combiner (www.life-space-mission.com).

Mission concept consists of **four collector spacecraft flying in precise formation**, separated by tens to hundreds of meters, together acting as one large virtual telescope. **A fifth spacecraft — the combiner — sits at the center of the formation and combines the incoming light with extreme precision.**
Using nulling interferometry, LIFE suppresses the overwhelming light from a host star through destructive interference, while preserving the faint signal from orbiting planets. This enables the **direct detection of temperate rocky exoplanets** and allows to analyze their atmospheric spectra for molecules linked to habitability and potentially even biological activity.

Instrumental Noise

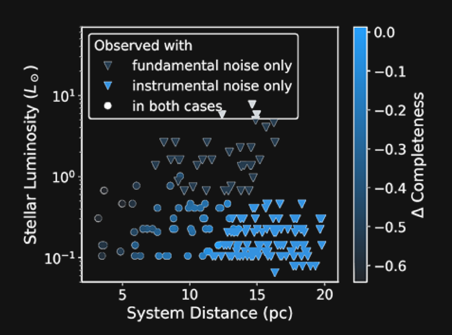
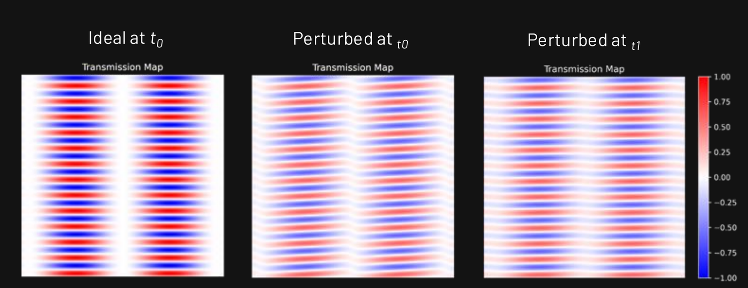


Figure 4:
Top: Yields for Emma-X configuration considering different noise sources (Felix Dannert). Bottom: On-sky transmission map of an ideal instrument in the Emma-X configuration (left) and a perturbed instrument at time step 0 (center) and time step 1 (right, Philipp Huber).



Previous studies have focused on fundamental noise and assumed that instrumental noise is non-dominant. This assumption is revisited and the impact of instrumental noise assessed with two different approaches: **Dannert et al. 2024** use an **analytical approximation** to model instrumental perturbations and estimate the impact thereof on the LIFE mission yields, specifically for the Emma-X configuration (Figure 4, top). **Huber et al. 2024** use a more flexible model and numerically estimate the impact of instrumental perturbations (Figure 4, bottom) by means of **stochastic simulations**. This model can also be used to **compare the performance of different architectures** under the influence of instrumental noise.

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Why rotation speed matter?

In LIFE, array rotation turns the planet signal into a time-modulated signal that can be extracted with matched-filter techniques. This project tests whether faster rotation improves detectability by shifting the planet signal toward higher temporal frequencies, where correlated instrumental noise is expected to be weaker. Because higher rotation speeds also increase spacecraft-control and propellant demands, the goal is to identify a favorable **science-cost operating regime**, not a single universal optimum.

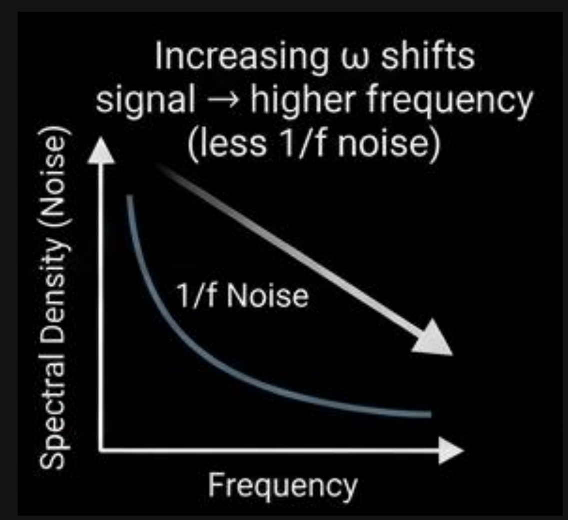


Figure 5: Faster rotation shifts the planet signal toward higher frequencies, where $1/f$ noise is lower

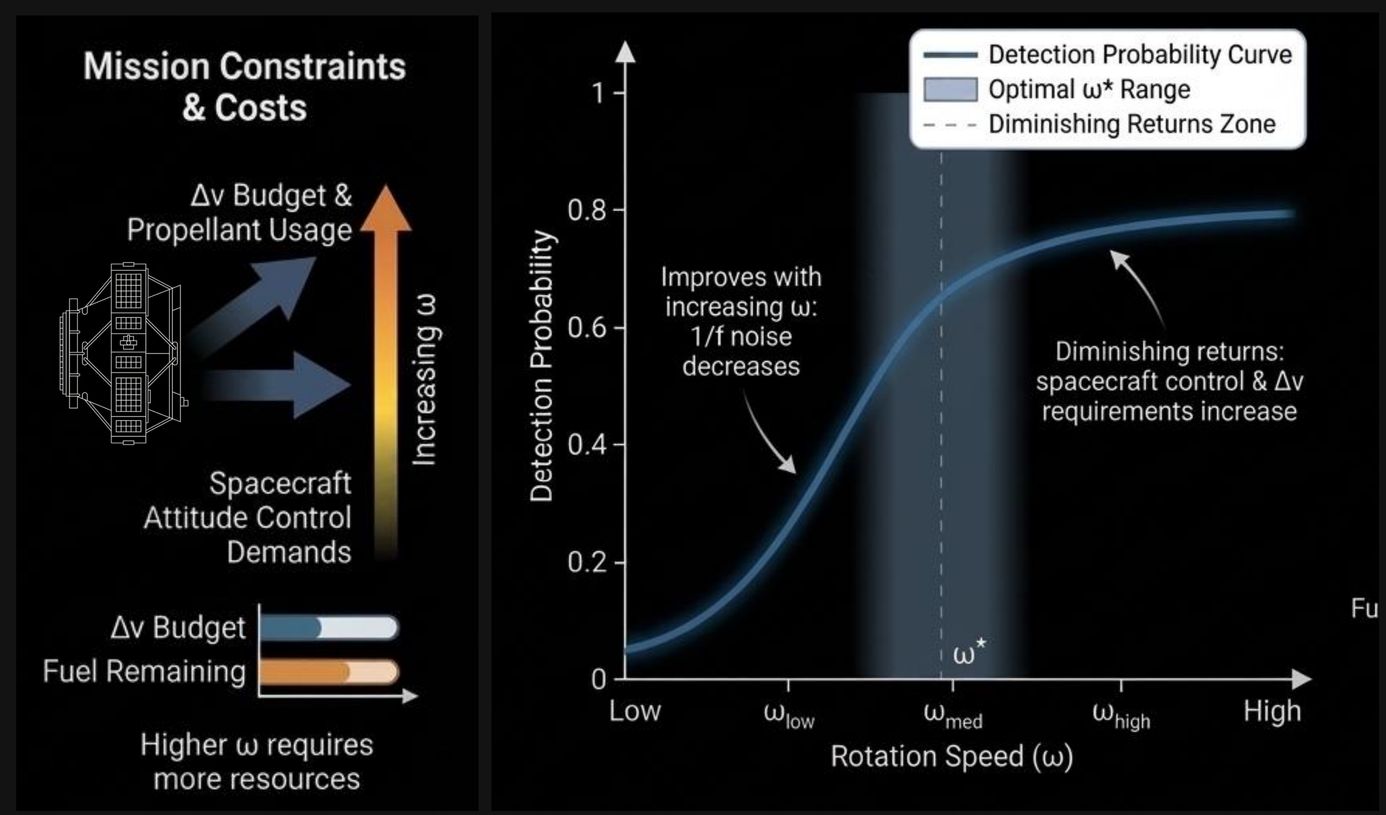
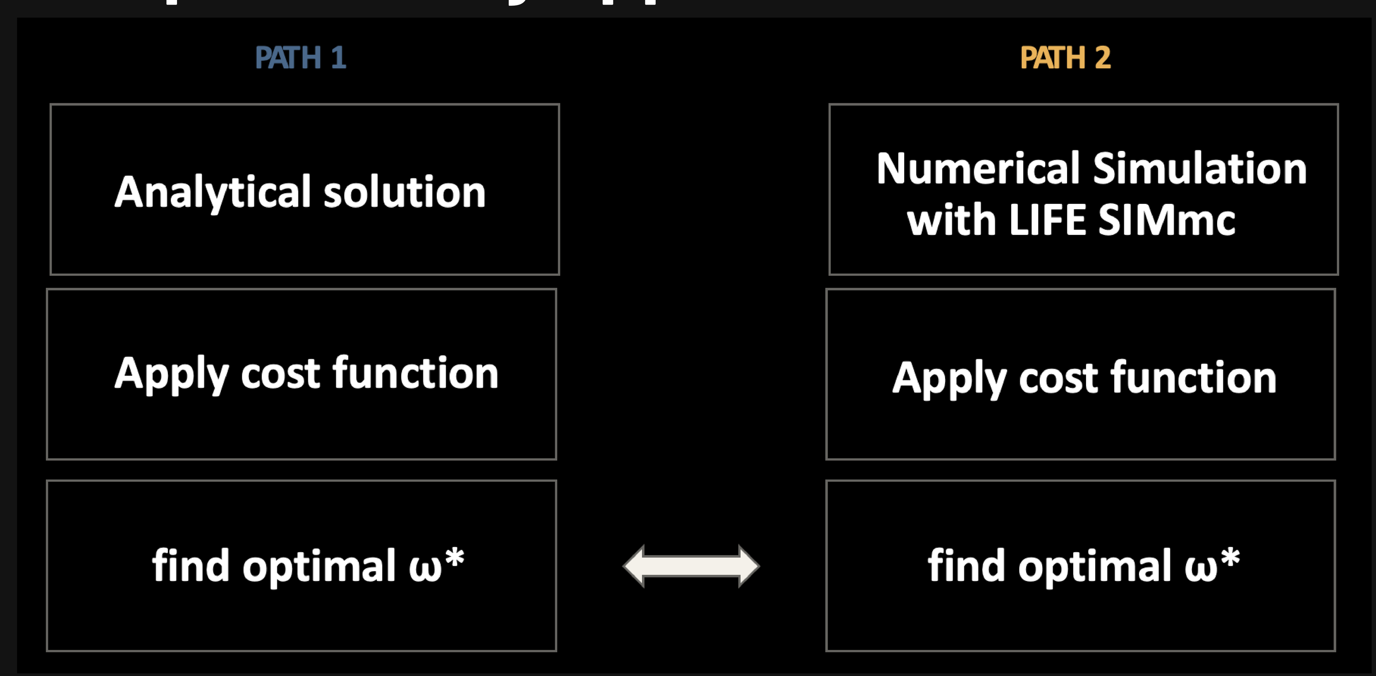


Figure 6: Detection performance is expected to improve with rotation speed, but higher ω increases spacecraft-control and propellant demands.

Complementary approach



$$J(\omega) = \int S(f)|\tilde{\eta}_\omega(f)|^2 df$$

Equation 1: $J(\omega)$ quantifies the overlap between the planet-signal template and the instrumental-noise spectrum.

Current results and next steps

The analytical model predicts that faster rotation should reduce the overlap between the planet signal and low-frequency instrumental noise. This should improve detection performance before mission-cost constraints are included. However, the current LIFE SIM MC results do not yet show a robust matching trend.

The first next step is to resolve the analytical–numerical discrepancy by checking whether the perturbation noise spectrum changes when the modulation period is varied. The study will then be extended from rotation speed to the imaging-to-nulling baseline ratio a parameter that modifies the interferometer transmission map, the planet-signal modulation, and possibly the coupling between instrumental leakage and noise.

References:

Dannert, F.A. et al. (2024).
Hansen, J.T., Ireland, M.J., & LIFE Collaboration. (2022). A&A, 664, A52.
Huber, P.A. et al. (2024).
Huber, P.A. «Large Interferometer For Exoplanets (LIFE) Recent Progress & Ongoing Work», Planet S Poster
LIFE mission website (https://life-space-mission.com)