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1 INTRODUCTION

Significant parts of the electromagnetic spectrum, including the far infrared (approx. 30 to 300 µm wavelength) and much of the ultraviolet regions (approx. 10 to 320 nm wavelength), are completely absorbed by the atmosphere and therefore inaccessible for ground-based telescopes. Yet, observations at these wavelength ranges are indispensable for answering some of the fundamental questions in modern astronomy and astrophysics. This includes essential questions about the formation and evolution of stars and planetary systems and about the path to complex molecules and the building blocks of life.

Observations in these spectral regions can be addressed by space missions – yet, for the far infrared, the last space telescope was retired in 2013 and no new mission is expected until the end of the 2030s. In the UV, much needed capabilities for surveys are missing. The gaps in both regions need to be closed in order to advance our understanding of our planet's and our own origin – and also in order to maintain the existing expertise in these fields.

ESBO provides a solution to close this gap with a dedicated, regularly flying and community-accessible astronomical observatory based on stratospheric balloons. If successful, it will provide the required space-like observation conditions in the far infrared and in parts of the UV available to a much larger part of the astronomical community than currently possible, at a significantly lower cost and on significantly shorter timeframes than what comparable space missions would require.

With a UV platform prototype already built during the ESBO *Design Study* project, scientific observation flights could start as soon as in 2022. Building on the heritage of this platform, scientific observation flights for far infrared astronomy could start as soon as in 2026.

2 SCIENTIFIC AND TECHNICAL RATIONALE

Next steps in far infrared (FIR) astronomy prominently include investigations within the Solar System, in distant planetary systems, in the Interstellar Medium of our Galaxy and also in nearby galaxies of different types. Such investigations include, but are not limited to, the origins of water on planets in our solar system and also on distant exoplanets, the study of mechanisms leading to the formation of stars and their planetary systems, the chemical evolution of interstellar matter, particularly due to heating and cooling processes, within the Galaxy, and its reactions to the interaction with galaxy dynamics in the local universe. Taking these scientific steps forward requires on the one hand telescopes with better angular resolution in order to overcome fundamental limitations imposed by galactic dust and gas in the foreground as well as by the spatial resolution of observations themselves. On the other hand observational survey telescopes are required offering larger amounts of observation time, large detectors, and, preferably, high spectral resolution, e.g., to distinguish and trace individual molecules and to capture large-scale processes as well as to compare processes in different star- and planet forming regions.

With the last far infrared space mission, the Herschel Space Observatory (carrying a 3.5 m mirror), decommissioned in 2013, the only observational capabilities remaining for the far infrared are the Stratospheric Observatory for Infrared Astronomy (SOFIA, carrying a 2.5 m mirror, providing around 1000 observation hours per year) and sporadically flying balloon experiments (such as the Balloon-borne Large Aperture Submillimeter Telescope, BLAST, or the Polarized Instrument for Long wavelength Observation of the Tenuous interstellar medium, PILOT). The next space telescope under consideration, the Origins Space Telescope, will not fly before the end of the 2030s. This leaves a gap of about a decade between the end of SOFIA's operational life in 2030 and the earliest potential launch of a space telescope[1], in addition to, e.g., survey capacities that SOFIA currently cannot offer.

ESBO can, on the one hand, fill this gap by providing a next generation-observatory with a 5 m telescope from the early 2030s on. On the path towards this goal, ESBO can furthermore complement SOFIA with much-needed survey capacities with a smaller (1 to 1.5 m) telescope providing at least an additional 700 h of observation time per year.

In the UV, two space observatories exist at the moment: NASA's Hubble Space Telescope (HST) with the Wide Field Camera 3 (WFC3) imaging instrument and the Indian ASTROSAT observatory with the Ultraviolet Imaging Telescope (UVIT). The capabilities of both in regard to wide surveys are limited, with the WFC3 only providing a comparably small field of view and the UVIT having only a limited light-collecting area due to its relatively small telescope diameter of 0.3 m. Spectroscopic capabilities in the near UV are even more sparse, with only Hubble offering the Cosmic Origins Spectrograph and the Space Telescope Imaging Spectrograph, both with their own limitation, e.g. with regard to inner solar system pointing. In addition, several recent shutdowns of the HST have shown that the duration of its further operation is very uncertain. Several concepts for space-based UV survey telescopes are currently being proposed, although the likelihood of their implementation is unclear. For several years to come, the two existing space-telescopes will thus remain the only non-solar UV telescopes.

ESBO will be able to offer:

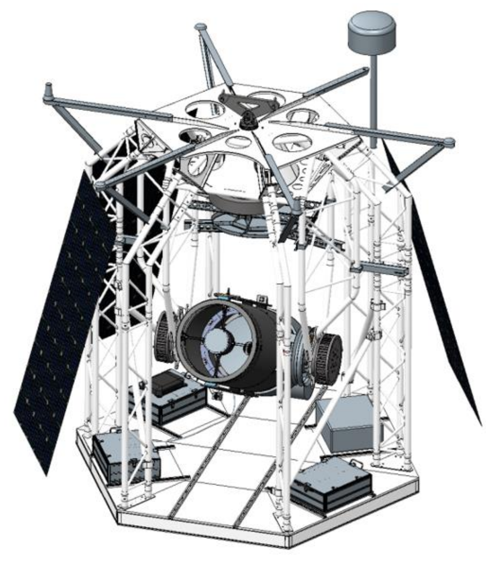
- Photometric imaging / survey capabilities with the microchannel plate detector built during the ESBO *DS* project on the STUDIO platform, limited to night time operation;
- Filter imaging of inner solar system planets e.g. for atmospheric studies with a minor upgrade of the STUDIO attitude control system to daylight capabilities;
- Potentially spectroscopic capabilities for both solar system and galactic observations with a new instrument on the STUDIO platform.

3 INFRASTRUCTURE CONCEPT

In order to provide reliable access to observations, ESBO aims at establishing a full infrastructure for developing and operating balloon-borne telescopes. The clear goal is to make observation time and instrument flight opportunities on ESBO-maintained telescopes/balloon gondolas easily and freely available to the scientific community via regular open calls for proposals.

On the hardware side, this includes three foreseen flight systems with different telescopes to be developed and deployed in a step-by-step approach:

Step 1 is the "STUDIO" gondola with a 0.5 m aperture UV telescope and instrument that was already developed during the ESBO *DS* project and is being prepared for its first test flight. It is primarily foreseen for short- to



STUDIO balloon gondola with UV telescope built under ESBO DS.

[1] The upcoming James Webb Space Telescope only covers the near and mid-infrared spectral regions up to approx. 28 µm, but does not offer any observational capabilities in the far infrared.

medium duration balloon flights, i.e. either flying during the semi-annual turnaround conditions over Kiruna, Sweden (2 days), or during Northern summer on transatlantic flights from Sweden to Canada (7 days per flight). Depending on the successful maturation of Super Pressure Balloons (SPBs) required to fly ultra long duration flights in the Southern hemisphere, starting from New Zealand, these flights would be a medium-term up-scoping option for STUDIO.

Performance of flight platforms

	Wavelength range	Observation time/year
Step 1	0.2 – 0.32 µm (UV)[2]	130 h[3]
Step 1 pot. upscoping	0.2 – 0.32 µm (UV)[2]	1000 – 2000 h[3]
Step 2	28 – 230 µm (FIR)	> 700 h
Step 3	28 – 230 µm (FIR)	> 1400 h[4]

Step 2 is a gondola with a 1/1.5 m class FIR telescope and a very high spectral resolution heterodyne instrument as a baseline first light instrument. It is primarily foreseen for long-duration flights on the polar flight routes, with a focus on flights in the Arctic during Northern Summer, providing around 700 h observation time per year.

Step 3 is a gondola with a 5 m class FIR telescope and a large array, very high spectral resolution instrument baselined as first light instrument. This platform is equally foreseen for long-duration flights on polar flight routes, providing at least another 700 h observation time per year.

For all three steps, building more than one gondola would furthermore be advisable in order to increase the available observation time and observatory reliability, thereby decreasing the cost per observation hour.

Beyond the flight systems with telescopes, some infrastructure development for the efficient operation of ground systems will need to be undertaken, a suitable administration and support infrastructure will need to be established (preferably connected to an existing organization or observatory), and observer tools and data processing / provision pipelines and tools will be provided.

4 REQUIRED DEVELOPMENT / ROADMAP

Technical development of the ESBO gondolas will go hand-in-hand with a community-supported selection of instruments and the development thereof by research groups external to ESBO as “PI instruments”.

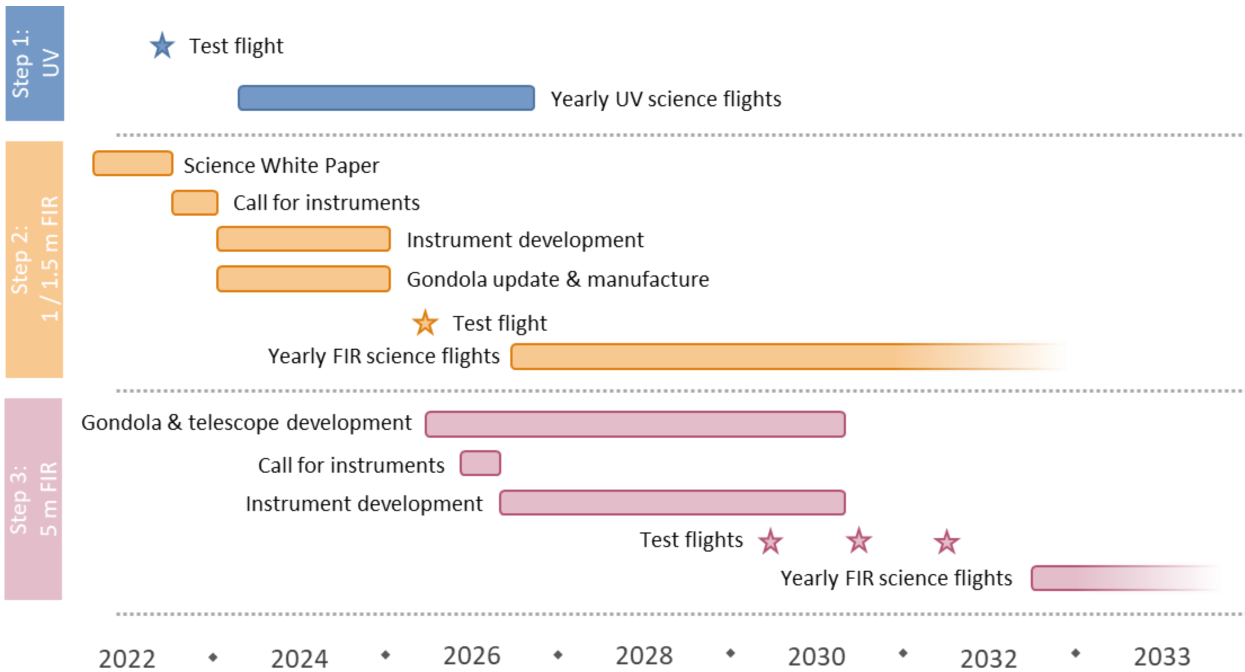
The development furthermore follows a step-wise approach, with each platform building upon technologies and subsystems developed for the earlier ones. A rough order of magnitude cost estimate for the individual development phases has been carried out and is available in the more detailed ESBO Development Roadmap document[5].

[2] Platform also includes limited science capabilities in the visible and near infrared band from 0.32 to 1.1. µm.

[3] Stratospheric day + night conditions

[4] With both the small and the large FIR platform or two large platforms flying.

[5] Accessible at http://esbo-ds.irs.uni-stuttgart.de/development-roadmap



Main development milestones and scalable technologies

- Design of highly accurate Image Stabilization System in the optical system (already developed for UV platform, useable for all platforms);
- Development of highly accurate, gondola pointing system (already developed for UV platform);
- Development of robust and automated mission control system (already under development for UV platform);
- Development of highly accurate, daytime compatible gondola pointing system for daytime FIR flights (extension of already developed UV platform pointing system with a daytime-optimized sensor);
- 1/1.5 m FIR platform: gondola design and subsystems (re-use and scaling of UV platform gondola and subsystems);
- Demonstration of controlled, steered parafoil landing (during 1/1.5 m FIR platform development, to be used for all platforms);
- Development and demonstration of high bandwidth communication for science data downlink;
- Development of 5 m aperture CFRP FIR mirror for 5 m platform;
- Optimization of existing balloons for higher lift at lower altitude (~ 30 km);
- Demonstration of highly efficient power systems for stratospheric balloon gondolas.