

HALO - HAbitability & Life on Other worlds

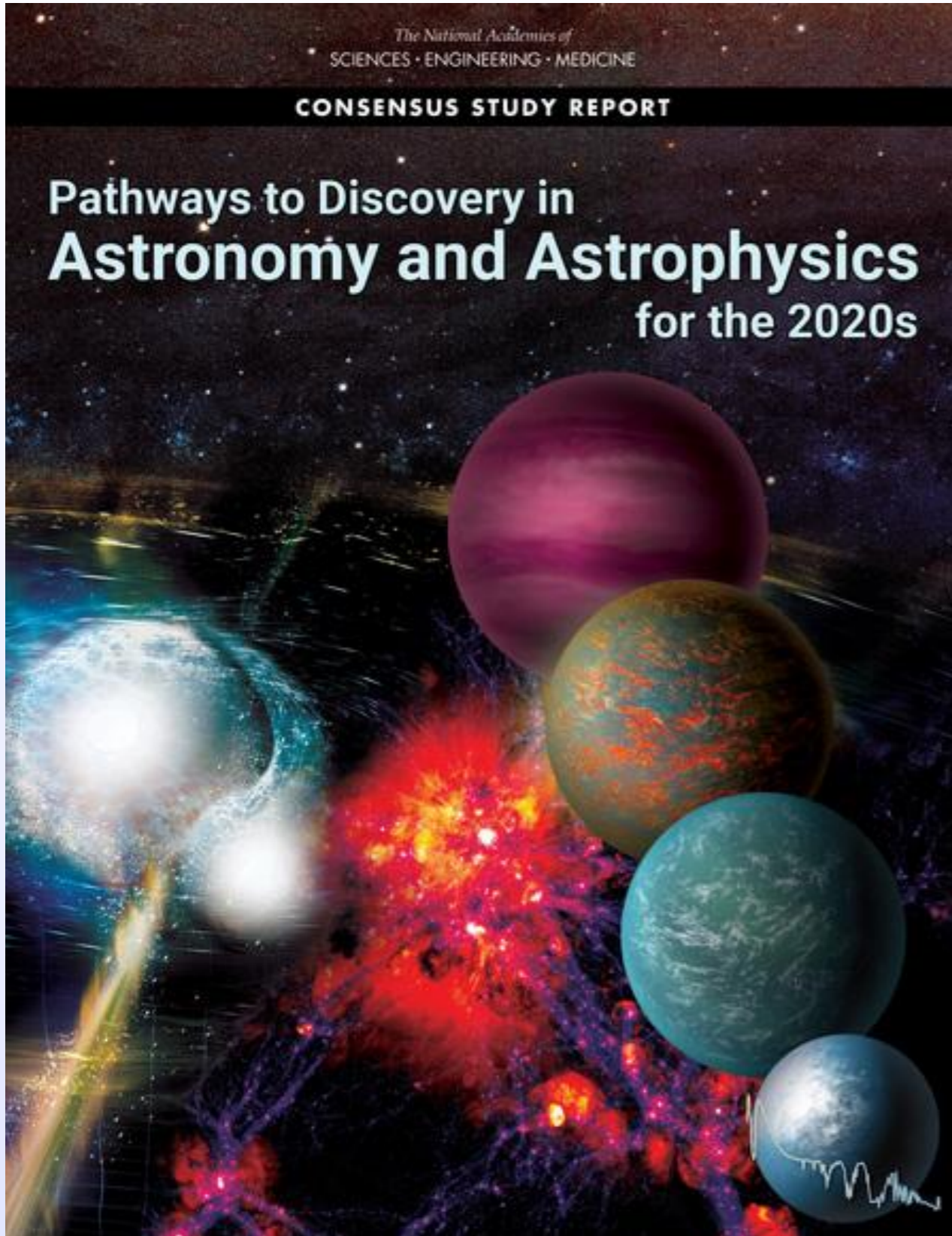
Fréjus, 4-6 December 2024

INSU-PNP/ASHRA/CNES/FOCUS

Scientific & technological roadmap towards the
HWO & LIFE space missions



Context



Priority Area: Pathways to Habitable Worlds

Over the past two decades, thousands of extrasolar planets have been discovered, almost all of them extremely different from any world in our own solar system. This decadal survey's science theme of *Worlds and Suns in Context* encompasses the interlinked studies of stars, planetary systems, and the solar system. Within this broader science theme, the survey has identified the priority science area of Pathways to Habitable Worlds with the goal of trying to discover worlds that could resemble Earth and answer the fundamental question: "Are we alone?" Such planets will be found in the "habitable zone" of their parent stars—not too close and hot and not too distant and cold. Measurements indicate that around 30 percent of stars possess such a planet. The task for the next decades will be finding the easiest of such planets to characterize, and then studying them in detail, searching for signatures of life.

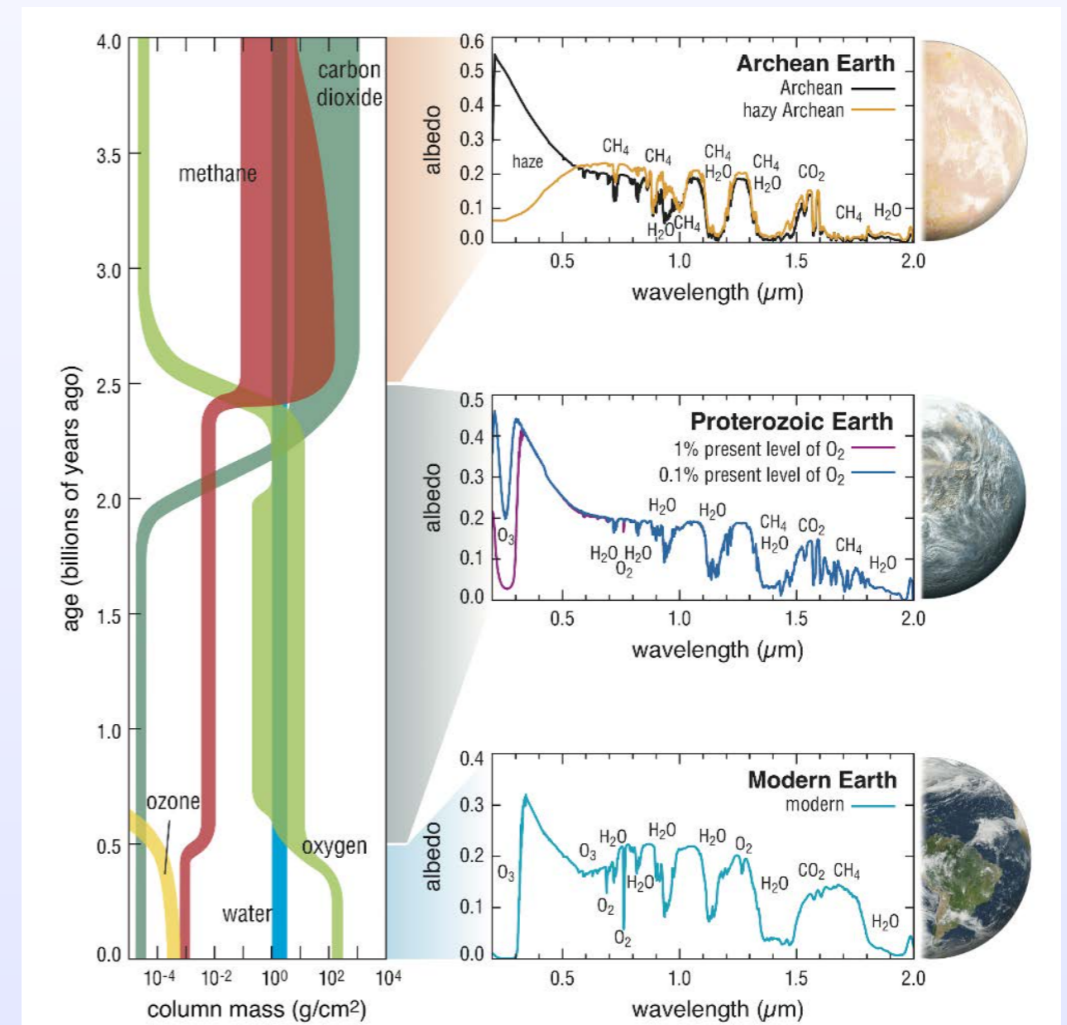
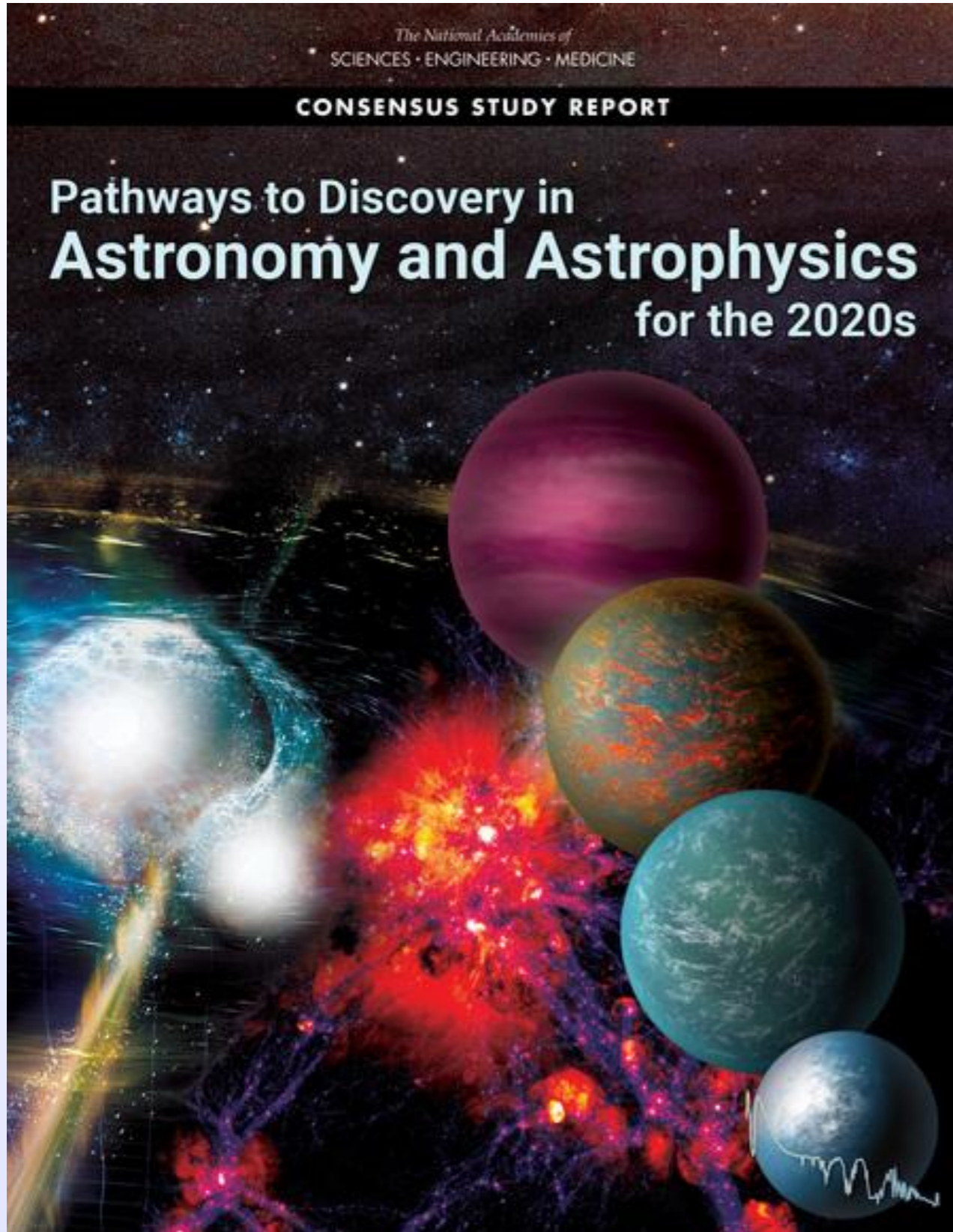


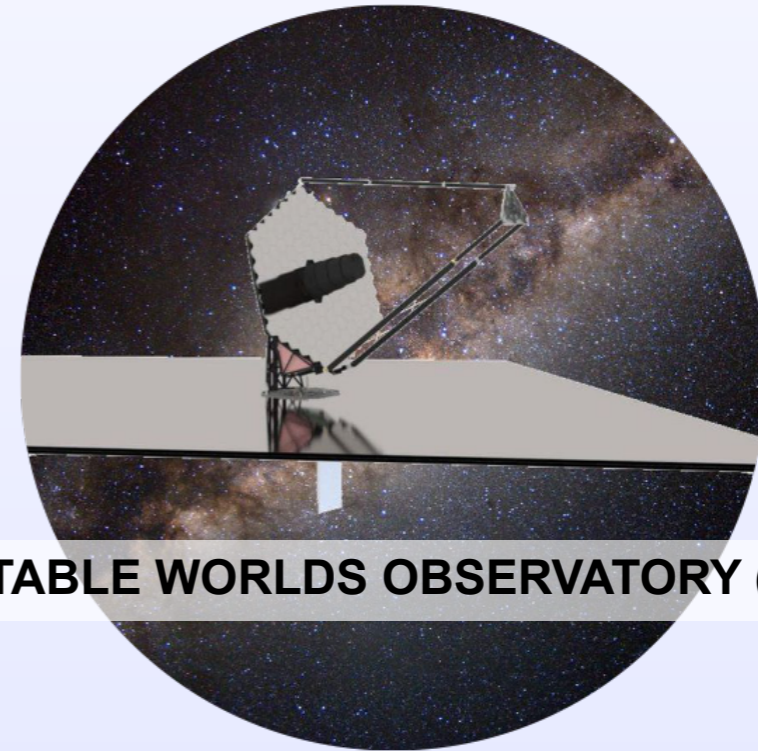
FIGURE 1.1 Evolution of the reflectivity spectrum of Earth. Simulated spectra of Earth before life had significantly altered its atmosphere (top, Archean era 2.5 to 5 Gyr ago), before the development of complex life (middle, Proterozoic era from 0.54 to 2.5 Gyr ago), and the modern oxygen-bearing Earth (bottom). SOURCE: LUVUOIR Report; G. Arney, S. Domagal-Goldman, T. B. Griswold (NASA GSFC).



A Future Large Infrared/Optical/Ultraviolet Telescope Optimized for Observing Habitable Exoplanets and General Astrophysics (Highest Priority for Space Frontier Missions)

Inspired by the vision of searching for signatures of life on planets outside of our solar system, and by the transformative capability such a telescope would have for a wide range of astrophysics, the priority recommendation in the frontier category for space is a large (~6 m diameter) IR/O/UV telescope with high-contrast (10^{-10}) imaging and spectroscopy. This is an ambitious mission, of a scale comparable to the HST and JWST space telescopes. It is also one that will be revolutionary, and that worldwide only NASA is positioned to lead. A period of mission and technology maturation is required, however with sufficient investment this could be completed before the end of the decade, and the mission could commence formulation prior to 2030. (Section 7.5.2)

Decision Rules: Prior to commencing mission formulation, a successful Great Observatories Mission and Technology Maturation program must be completed, and a review held to assess plans in light of mission budgetary needs and fiscal realities.



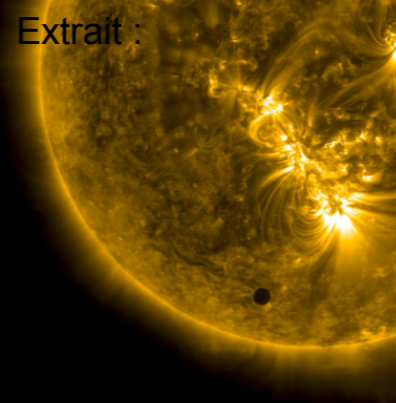
HABITABLE WORLDS OBSERVATORY (HWO) ?

➔ Great Observatory Maturation Program (GOMAP) started. Working groups already at work. Community can join.

Voyage 2050

Final recommendations from the Voyage 2050 Senior Committee

Extrait :



Voyage 2050 Senior Committee: Linda J. Tacconi (*chair*), Christopher S. Arridge (*co-chair*), Alessandra Buonanno, Mike Cruise, Olivier Grasset, Amina Helmi, Luciano Iess, Eiichiro Komatsu, J r my Leconte, Jorrit Leenaarts, Jes s Mart n-Pintado, Rumi Nakamura, Darach Watson.

May 2021

In conclusion, the Senior Committee finds that the science themes focusing on the “Characterisation of Temperate Exoplanets” and the “Galactic Ecosystem with Astrometry in the Near-infrared” are both compelling and offer the potential for a high science return in the 2050 timeframe. The “Characterisation of Temperate Exoplanets” is considered as having the highest scientific priority, but an informed down-selection is currently not possible with the available information.

The committee recommends that ESA launch a detailed study involving the scientific community for the exoplanet theme to assess its likelihood of success and feasibility within the Large mission cost-cap. Specifically, such a study should assess what molecules could be detected, to what precision, and for how many targets. If it is found that at least 10 temperate exoplanets (within some reasonable bound of uncertainty) can be characterised and thus that a scientific breakthrough can be achieved in a feasible and affordable mission, then the committee recommends such a theme be selected for the third Large mission in the Voyage 2050 timeframe. If this is not the case, the committee instead recommends that ESA select the “Galactic Ecosystem with Astrometry in the Near-infrared” for a Large mission. The compelling nature of the astrometry theme is also highlighted by its inclusion in the Medium mission recommendations.

3.2.2 Contributions to the NASA LUVOIR, Origins, HABEX, or Lynx Concepts

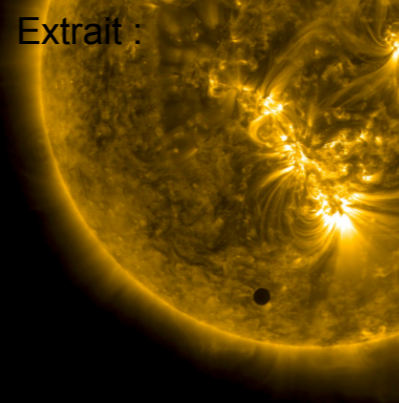
The next generation of large space observatories – all of which are well beyond the financial envelope of an ESA Large mission – will tackle a wide range of very important open problems in astrophysics. This is why contributions at the level of an ESA Medium mission to such a large-size space telescope are of great significance and value to the ESA programme in the time frame of Voyage 2050. Four mission concepts for large space observatories are currently being considered as part of the Astrophysics Decadal Survey in the USA, involving large X-ray, UV, optical or infrared telescopes. A contribution to the observatory concept that will emerge from the decadal survey could follow a similar scheme to the ESA/NASA collaboration in *HST* and *JWST*, and consist of a combination of an ESA contribution and/or nationally funded instruments.

A contribution to *LUVOIR* will offer a unique opportunity for the community to have access to the UV, a crucial wavelength range that will not be accessible after *HST* is decommissioned. Instrumentation in UV provided by the ESA Member States will allow the study of galaxy evolution, interstellar medium, star formation and stellar evolution, exoplanets atmospheres and Solar System objects. In the visible, mid and far-IR, a contribution to *Origins* and *HabEx* would provide access to a large space facility to study the formation of galaxies, stars and planetary systems as well as the characterisation of exoplanet atmospheres. A contribution to *Lynx* would offer access to very high spectral resolution X-ray instrumentation with large effective area and exquisite spatial resolution over a large field of view, offering substantial improvements over what *ESA Athena* will provide in these areas.

Voyage 2050

Final recommendations from the Voyage 2050 Senior Committee

Extrait :

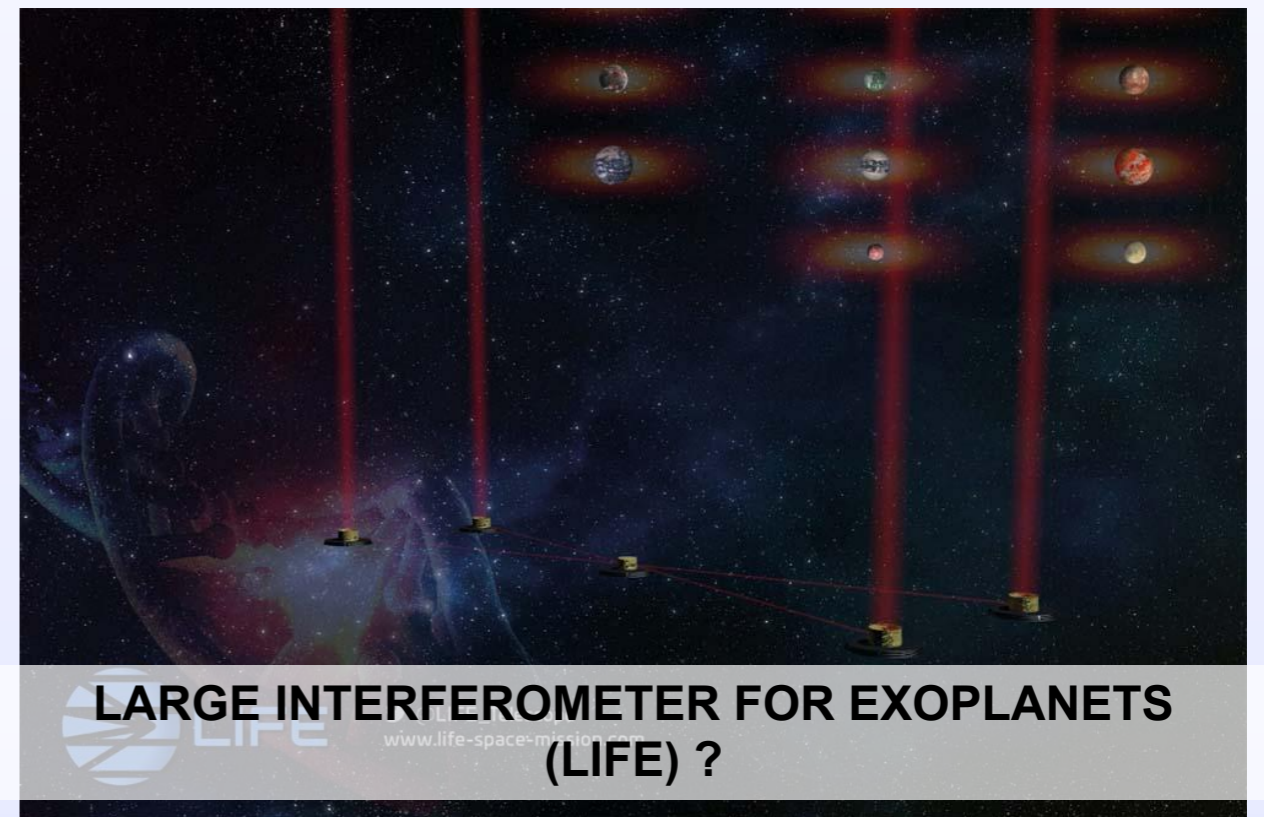


Therefore, launching a Large mission enabling the characterisation of the atmosphere of temperate exoplanets in the mid-infrared should be a top priority for ESA within the Voyage 2050 timeframe. This would give ESA and the European community the opportunity to solidify its leadership in the field of exoplanets, which started with the first detection of an exoplanet from the ground and the first detection of a terrestrial planet from space by the *CoRoT* mission. Being the first to measure a spectrum of the direct thermal emission of a *temperate* exoplanet in the mid infrared would be an outstanding breakthrough that could lead to yet again another paradigm-shifting discovery. Indeed, discovering any hint of life on an alien world and understanding the conditions for its emergence would have a transformative impact not only on the scientific community but also on society as a whole.



Voyage 2050 Senior Committee: Linda J. Tacconi (*chair*), Christopher S. Arridge (*co-chair*), Alessandra Buonanno, Mike Cruise, Olivier Grasset, Amina Helmi, Luciano Iess, Eiichiro Komatsu, Jérémy Leconte, Jorrit Leenaarts, Jesús Martín-Pintado, Rumi Nakamura, Darach Watson.

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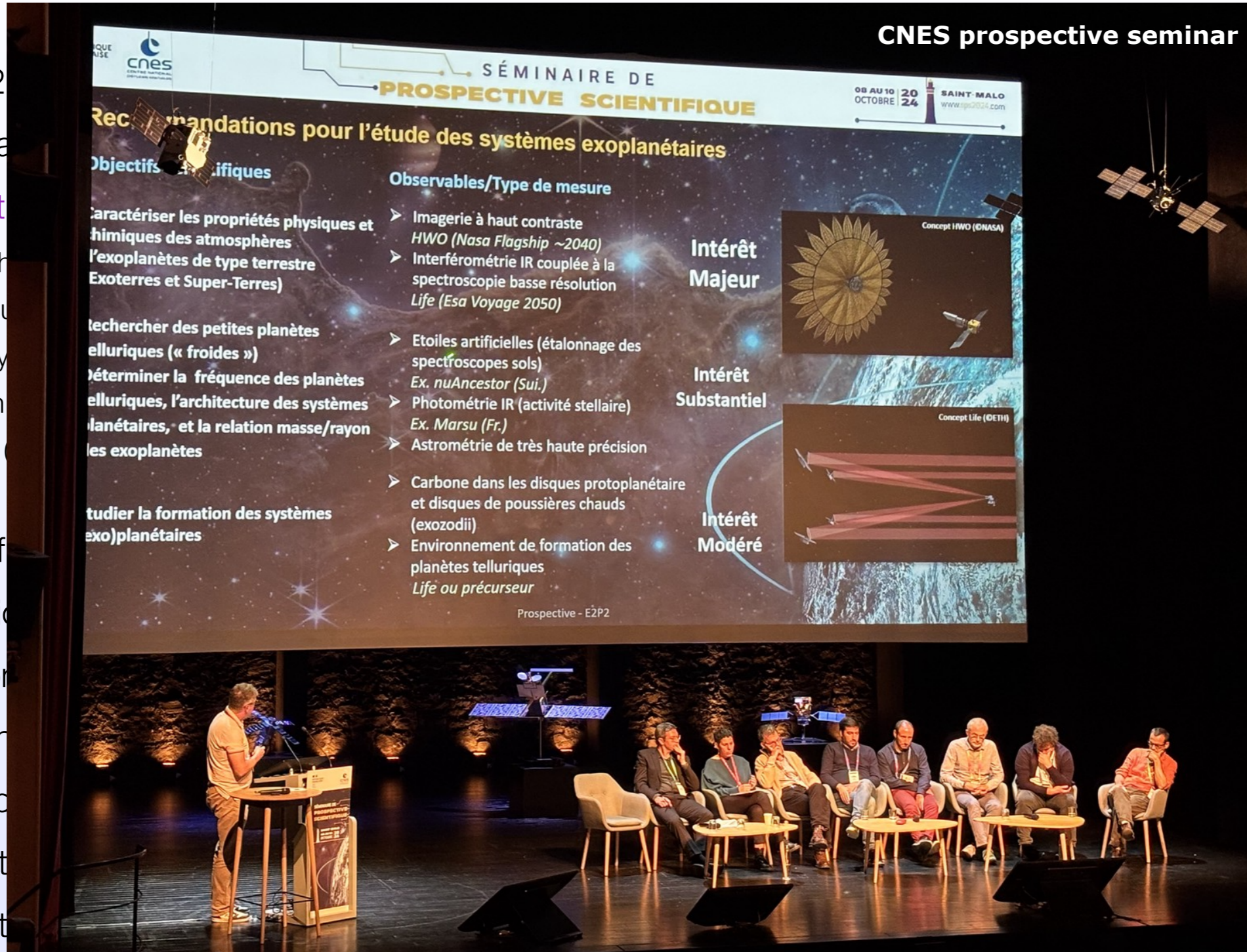
➔ Very active group led by ETH Zürich! Series of LIFE papers (XII). Possibility to join the science team

HWO-LIFE national working group

- May/June 2022 : visit of Sascha Quanz (PI LIFE) @ LAM, Lagrange, and IPAG
- Start of a national working group **Contact Arthur Vigan if you want to join!**
 - **Current members** : Arthur Vigan (LAM), David Mouillet (IPAG), Elodie Choquet (LAM), Elsa Huby (LESIA), Frantz Martinache (Lagrange), Gael Chauvin (Lagrange), Isabelle Boisse (LAM), Jean-Philippe Berger (IPAG), Lucie Leboulleux (IPAG), Mamadou N'Diaye (Lagrange), Marc Ferrari (LAM), Pierre Baudoz (LESIA), Maud Langlois (CRAL), Alexis Matter (Lagrange), Sean Raymond (LAB), Olivia Venot (LISA), Sylvestre Lacour (LESIA), Vassilissa Vinogradoff (AMU), Xavier Delfosse (IPAG), Benjamin Charnay (LESIA), Jeremy Leconte (LAB), Martin Turbet (LMD), Bruno Lopez (Lagrange), Iva Laginja (LESIA), Johan Mazoyer (LESIA), Raphael Galicher (LESIA), Alexandre Santerne (LAM), Alexis Carlotti (IPAG), Anthony Boccaletti (LESIA) & Adrienne Kish (MNHN)
- Definition of objectives
 - **Stay informed** on the evolution of the HWO and LIFE projects, in coordination with international teams leading these projects (NASA, JPL, STScI, ETH-Z ...)
 - **Participate to the structuration and animation of the French community** around these projects and the related astrophysical questions
 - **Propose a coordinated answer to solicitations** for participation in the HWO and LIFE missions
 - **Be able to answer to various calls in a coordinated manner** (CNES, ESA, INSU...) and **feed the scientific perspectives of national agencies** (CNES, INSU)
 - Finally, **provide a feedback of on-going action to the national community**

HWO-LIFE national working group

- May/June 2023
- Start of a national working group
 - Current members:
 - Martinach
 - Mamadou
 - Sean Ray
 - Benjamin
 - Mazoyer
 - Adrienne
- Definition of HALO
- Several activities
 - Creation of HALO
 - First funding proposal
 - First workshop
 - Presentation of HALO
 - Presentation of HALO
 - Second funding proposal CNES-APR HALO (September 2024)
 - **CNES and INSU** perspectives
 - **HALO workshop!** (Fréjus, December 2024)



CNES prospective seminar

SÉMINAIRE DE PROSPECTIVE SCIENTIFIQUE
 08 AU 10 OCTOBRE 2024 SAINT-MALO www.esa.int

Recommandations pour l'étude des systèmes exoplanétaires

Objectifs Scientifiques

- Caractériser les propriétés physiques et chimiques des atmosphères d'exoplanètes de type terrestre (Exoterres et Super-Terres)
- Rechercher des petites planètes telluriques (« froides »)
- Déterminer la fréquence des planètes telluriques, l'architecture des systèmes planétaires, et la relation masse/rayon des exoplanètes
- Étudier la formation des systèmes (exo)planétaires

Observables/Type de mesure

- Imagerie à haut contraste
HWO (Nasa Flagship ~2040)
- Interférométrie IR couplée à la spectroscopie basse résolution
Life (Esa Voyage 2050)
- Étoiles artificielles (étalonnage des spectroscopes sols)
Ex. nuAncestor (Sui.)
- Photométrie IR (activité stellaire)
Ex. Marsu (Fr.)
- Astrométrie de très haute précision
- Carbone dans les disques protoplanétaires et disques de poussières chauds (exozodii)
- Environnement de formation des planètes telluriques
Life ou précurseur

Intérêt Majeur

Intérêt Substantiel

Intérêt Modéré

Concept HWO (ONASA)

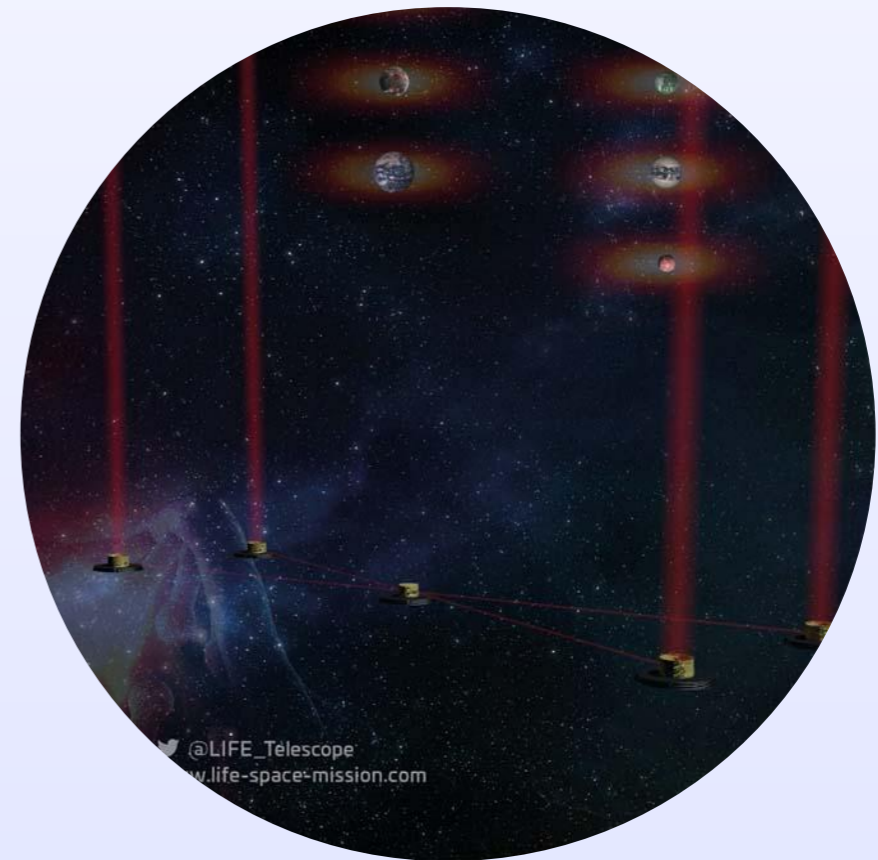
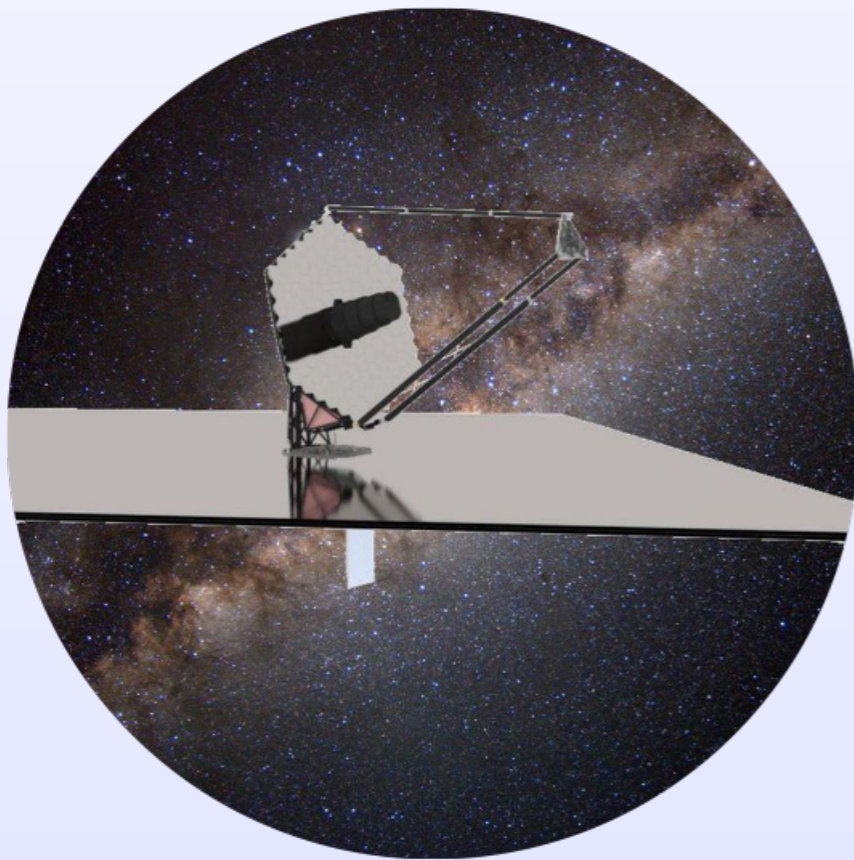
Concept Life (OETH)

Prospective - E2P2

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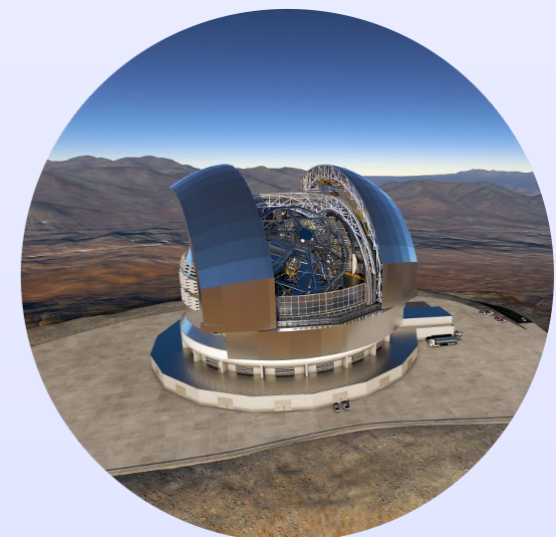
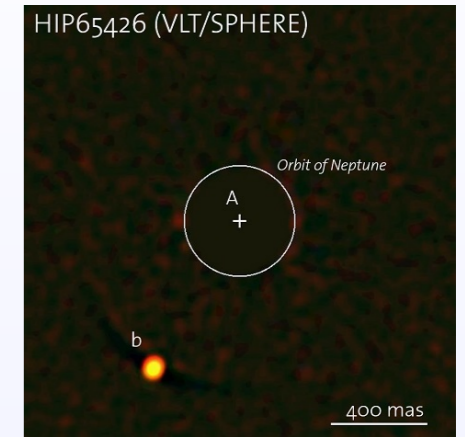
Roadmap and perspectives

- What now? Where do we go **as a community**?
- **Positioning and timing:**
 - Strategic challenge for future large instruments
 - Very active and federative context: GOMAP, HWO, LIFE
 - Major interest at the national level: PEPR *Origines* programme started in 2023



Roadmap and perspectives

- What now? Where do we go **as a community**?
- **Positioning and timing:**
- Recognised **national expertise**
 - Exoplanetology:
 - Large and transverse community
 - Variety of observational techniques
 - From telluric planets to gas giants
 - Implications in future large facilities (ground and space) with VLT/I, ELT, PLATO, Gaia, Ariel, Roman, ...
 - Theory and modelling (formation, atmospheres, evolution)
 - Instrumentation:
 - >100 researchers in 12 laboratories
 - ASHRA for national coordination
 - Interferometry, high-contrast imaging, components, testbeds, R&D, signal extraction and processing



Roadmap and perspectives

- What now? Where do we go **as a community**?
- **Positioning and timing:**
- Recognised **national expertise**
- Need for **long-term coordination** and **programmatic vision**
 - Necessary for our research community
 - But also for our funding and supporting agencies (INSU, CNES, ESA)

HALO workshop

- Status of our **current knowledge**
- Structure our community
- Start thinking about long-term actions



What do we know about Life and habitability?



What do we need to know about exosystems?



What are the technological challenges?

Programme

Thursday 5 December

09:00 / Introduction

Atmospheric measurements : planetary knowledge, knowledge of life

- 09:15 - 10:15 / Review talk by Elsa Ducrot & Franck Selsis [45 min] + discussion [15 min]
- 10:15 - 10:35 / Julia Seidel [10 min] + discussion [10 min]
- 10:35 - 11:00 / Coffee break
- 11:00 - 11:20 / Benjamin Charnay [10 min] + discussion [10 min]
- 11:20 - 11:40 / Arnaud Salvador [10 min] + discussion [10 min]
- 11:40 - 12:10 / Post-it session, general brainstorming: identification of research directions, future collective actions

12:15 - 13:30 / Lunch

Upstream knowledge : planetary detections, stellar physics

- 13:30 - 14:30 / Review talk by Nathan Hara & Andrea Chiavassa [45 min] + discussion [15 min]
- 14:30 - 14:50 / Lucile Mignon [10 min] + discussion [30 min]
- 14:50 - 15:30 / Post-it session, general brainstorming: identification of research directions, future collective actions

15:30 - 16:00 / Coffee break

16:00 - 17:30 / Discussion on the identified research directions and collective actions

Friday 6 December

HWO and LIFE missions : technical definition, technological obstacles

- 08:30 - 09:30 / Review talk by Romain Laugier & David Mouillet [45 min] + discussion [15 min]
- 09:30 - 09:50 / Iva Laginja [10 min] + discussion [10 min]
- 09:50 - 10:15 / Coffee break
- 10:15 - 10:35 / Marc Ferrari [10 min] + discussion [10 min]
- 10:35 - 10:55 / Elsa Huby [10 min] + discussion [10 min]
- 10:55 - 11:15 / Post-it session, general brainstorming: identification of research directions, future collective actions
- 11:15 - 11:45 / Discussion on the identified research directions and collective actions

11:45 - 13:00 / Time for open discussions on conclusions, perspectives, how to structure our community, messages to be sent to agencies (CNRS-INSU, CNES, ESA)

13:00 - 14:30 / Lunch

SOC, LOC, admin, zoom

- SOC
 - Isabelle Boisse
 - Gaël Chauvin
 - Xavier Delfosse
 - Adrienne Kish
 - Iva Laginja
 - Lucie Leboulleux
 - Alexis Matter
 - David Mouillet
 - Martin Turbet
 - Olivia Venot
 - Arthur Vigan
- LOC and admin support
 - Gaël Chauvin
 - Alexis Matter
 - Paulina Palma Bifani
 - Mamadou N'Diaye
 - Adrien Simonnin
 - Christine Delobelle
 - Julie Frisetti
 - Sophie Rousset

- Zoom connection for remote participants:

<https://univ-amu-fr.zoom.us/j/81808977461>

Presenters: please use your own laptop and connect to the zoom for screen sharing