LARGE INTERFEROMETER FOR EXOPLANETS





HWO and LIFE

Authors:

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Outline

 \rightarrow No breaking news but making sure we all share common information

- Missions general architecture
- Science ambition
- On-going development organization
- Technical challenges

Space missions enabling the characterization of exosystems, down to a diversity of temperate rocky planets

- Dozens of systems to be deeply observed:
 - Taking benefit from all prior knowledge on exoplanets and host stars characterization
 - With a strong sorting preference towards nearby stars
- High contrast: Inner Working Angle and Sensitivity as primary drivers of the concept
- Importance of probing various spectral signatures, and both reflected light / thermal emission
- Motivates large-scale space missions (>> L mission), for a wide community,
- Planned on a (short !) 2-decade timescale, and on a world-wide framework
- Expertise legacy from past (space and ground-based !) projects





Mission architectures and instrument concepts

Next generation telescopes and flagship missions are needed

Synergies between different missions and ground-based telescopes for the direct detection of terrestrial exoplanets



...consists of 4 collector spacecraft separated by tens to hundreds of meters and a

...covers the mid-infrared wavelength range between ~4-18.5 µm with a spectral resolution of R ~ 100 (tbc)

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The LIFE mission initial concept

LIFE = Large Interferometer

formation-flying mid-infrared

For Exoplanets

beam combiner

... is a space-based

(nulling) interferometer



Defrere et al. (2018); Dannert et al. (2022)

Nulling Interferometry in a nutshell

Example: Earth-Sun system seen from 10 pc at 10 micron wavelength





b

- In one branch, a $\pi/2$ phase shift ٠ is introduced to enable the difference map
- Phase chopping between • Outputs 3 & 4 makes instrument less susceptible to perturbation

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NASA's decades-long investments in developing large space telescopes pay off with aweinspiring science results



Hubble Space Telescope UV-Vis-NIR Flagship Serviceability JWST Scalable Segmented Observatory L2 Operations Nancy Grace Roman Space Telescope High-Contrast Imaging Vis-NIR Detectors

Focus on new challenges, not inventing new ways to do things we know how to

NOTIONAL EXPLORATORY ANALYTIC CASES

EAC1	Assumption	Comments	EAC2	Assumptio n	Comments	EAC3	Assumptio n	Comments
Launch Vehicle	New Glenn	7m diameter Fairing	Launch Vehicle	New Glenn or Starship	9m diameter Fairing	Launch Vehicle	New Glenn or Starship	9m diameter Fairing
Mass	Bottoms up estimate		Mass	Bottoms up		Mass	Bottoms up estimate	
#of Mirrors	19 Hex Segments	1.65m point to point	#of Mirrors	6+1	3m central mirror, 6	#of Mirrors	34 Keystone	
Teelscope Diam + Config	Off-Axis, 6M ID/7.2m OD		Telescope Diam+Config	Off-Axis, 6m Circ.	Reystone	Telescope Diam+Config	On-Axis, 8m Circ.	Large FOV Hybrid OOFS Guider
Deployment	JWST-like Wings, Hinged tower		Deployment	SM hinged, Barrel only		Deployment	JWST-like Wing, SM	

HWO PRELIMINARY SPECS & CANDIDATE INSTRUMENTS

Telescope				
Diameter	6+ meters			
Bandpasst	100 nm (TBR)- 2500nm			
Diffr. Lim. Wavelength, Line of Sight	.5um, .4mas LOS			



Integral Field Unit: Ultraviolet, Optical TBD

GSFC-5500)

Coro	nagraph*	High		
High-contr	High-contrast imaging and			
imaging	spectroscopy	UV/Vis		
Bandpass	.35um-1.7um	Bandpass		
Contrast	$\lesssim 1 \times 10^{-10}$	Field-of- View		
$R(\lambda/\Delta\lambda)$	Vis: ~140	~67 scienc		
	NIR: ~70, 200	High-precis		
Si Aurte	nus			

High- lı	U U	
UV/Vis a	and NIR imaging	
Bandpass	~200-2500 nm	sp
Field-of- View	~3' × 2'	Bandp
~67 science	Field-o	
High-precisio	View	
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		R (λ/

JV High Contrast Instrument from 250nm Ozone: TBD

Note: Expect instrument suite to iterate, some may be 2nd generation

UV Multi-Object Spectrograph					
UV/Vis spectros	s multi-object copy and FUV imaging				
Bandpass	~100–1000 nm				
Field-of- View	~2' × 2'				
Apertures	~840 × 420				
$R(\lambda/\Delta\lambda)$	500-50,000				



LARGE INTERFEROMETER FOR EXOPLANETS





Exoplanet science ambitions

HWO: a wide-community observatory

Main Science case working groups:

- Galaxy growth (IGM, AGN, ionizing, dark sector)
- Evolution of elements

(stars pop & formation, explosions)

• Solar system in context

(solar system, exosystems: demographics, characterization, formation-evolution)

• Living worlds

(biosignatures possibilities / interpretation, target stars)



HWO driven by the most demanding exoplanetary driver



Characterizing known planets from day 1



Carrión-González et al. (2023)

Synergy in atmospheric retrieval

HWO

LIFE



Synergy in atmospheric retrieval

HWO + LIFE



Alei et al. (2024)



Alei et al. (2024)



Alei et al. (2024)







Alei et al. (2024)

Synergy in atmospheric retrieval



Alei et al. (2024)



Probability Density





Development organization

Long-awaited ESA follow-through

The community strongly pushes for the complementary **need for both** reflected light and thermal emission

ESA Senior Committee Report; June 2021

"Therefore, launching a Large mission enabling the characterisation of the **atmosphere of temperate exoplanets** <u>*in the mid-infrared*</u> **should be a top priority for ESA** within the Voyage 2050 timeframe."

"[...] 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."

"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" A mission specifically focusing on the Characterisation of Temperate Exoplanets would be transformational and of great interest to scientists and to the public alike. The Senior Committee considers a mission on the **Characterisation of Temperate Exoplanets to have a higher scientific priority**. However, since an informed down-selection is not currently possible with the available information, the committee specifically recommends that a **study be carried out before selection**.

"Soutien **majeur à la définition et au développement** de **HWO** (Nasa/2040) et **Life** (Esa/2045) en valorisant l'expertise française pour PLATO, Ariel et Roman-ST"

"Soutien modéré à des missions précurseur de Life"

<u>CNES SPS 2024</u> Exobiologie, exoplanètes, protection planétaire. 2024

(+ voir aussi soutien autre groupe thématique)

Aiming at a launch in 2040 we consider 3 development stages



Stage 1: Preparation Today - 2028

- Conclusion of **mission concept study** and development plan with **academic and industry partners**
- Successful demonstration of LIFE measuring principle in the lab
- Significant maturation of key technologies, in particular mid-infrared photonics, cryogenic optics and detectors

Stage 2: Maturation 2029 - 2033

- Conclusion of **mission design**
- Maturation and demonstration

of sub-system performance, e.g., formation flying, interferometric nulling Stage 3: Implementation 2034-2040

Manufacturing / Integration of spacecraft

- Securing of launch opportunity
- Setting up of ground-segment, mission operations, and data center



We keep pushing forward

Cannot wait for the involvement of ESA

- **Team 1 Project office** : Coordination and support (contact Daniel Angerhausen)
- **Team 2 "Science"** : Continues to explore science cases; everybody is invited to participate in these activities.
- **Team 3 Instrument science** : Refining yield and performance vs design relationship for requirement
- **Team 4 Technology** : Identification and maturation of technical concepts

Ongoing fundraising for the Concept Study and technology development program

From Sascha Quanz, 2024-11-21

HWO: involving a very wide community

Starting with a very open world-wide contribution to mission working groups

SCIENCE					
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iving Worlds.	Biosignature Possibilities	SG Co-Chair	Schwieterman	Eddie	UC Riverside
iving Worlds	Biosignature Possibilities	SG Co-Chair	Sara	Walker	Arizona State Univ.
iving Worlds	Biosignature Interpretation	SG Co-Chair	Olson	Stephanie	Purdue Univ.
iving Worlds	Biosignature Interpretation	SG Co-Chair	Krissansen-Totton	Josh	Univ. Washington
iving Worlds	Target Stars & Systems	SG Co-Chair	Mamajek	Eric	ExEP / JPL
iving Worlds	Target Stars & Systems	SG Co-Chair	Hinkel	Natalie	Louisiana State Univ.
Evolution of Elements	*	WG Co-Chair	Lee	Janice	STScI
Evolution of Elements		WG Co-Chair	Scowen	Paul	NASA GSFC
volution of Elements	Stars & Stellar Populations	SG Co-Chair	Senchyna	Peter	Carnegie Observatories
volution of Elements	Stars & Stellar Populations	SG Co-Chair	Barstow	Martin	Leicester
volution of Elements	Star Formation	SG Co-Chair	Salim	Samir	Indiana U
volution of Elements	Star Formation	SG Co-Chair	Paladini	Roberta	IPAC-Caltech
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Galaxy Growth	IGM & ICM	SG Co-Chair	Burchett	Joe	New Mexico State Univ
Salaxy Growth	AGN	SG Co-Chair	Packham	Chris	UTSA
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Salaxy Growth	Dark Sector	SG Co-Chair	Rhodes	Jason	JPL
Salaxy Growth	Dark Sector	SG Co-Chair	Massey	Richard	Durham Univ.
Solar System in Context		WG Co-Chair	Robinson	Tyler	Univ. Arizona
Solar System in Context		WG Co-Chair	Shkolnik	Evgenya	Arizona State Univ.
Solar System in Context	Characterizing Exoplanets	SG Co-Chair	Hu	Renyu	JPL
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Solar System in Context	Demographics & Architectures	SG Co-Chair	Christiansen	Jessie	Caltech/IPAC-NExSci
Solar System in Context	Demographics & Architectures	SG Co-Chair	Rice	Malena	Yale Univ.
Solar System in Context	Birth & Evolution	SG Co-Chair	MacGregor	Meredith	Johns Hopkins Univ.
Solar System in Context	Birth & Evolution	SG Co-Chair	Hasegawa	Yasuhiro	JPL

And formal representatives from Canada, Japan, ESA

Science Case Simulation Science Case Simulation Science Case Simulation Science Case Simulation	Merging with Science Data Simul Merging with Science Data Simul Astrometry	:WG Co-Chair :WG Co-Chair	Batalha Osten	Natasha Rachel	NASA ARC STSci
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Science Data Simulation	High-Contrast	SG Co-Chair	Krist	John	JPL
Science Data Simulation	High-Contrast	SG Co-Chair	Macintosh	Bruce	UC Observatories
Science Data Simulation	UV	SG Co-Chair	France	Kevin	CU Boulder
Science Data Simulation	UV	SG Co-Chair	Tuttle	Sarah	Univ. Washington
Science Data Simulation	Wide-Field Imaging	SG Co-Chair	Malhotra	Sangeeta	NASA GSFC
Science Data Simulation	Wide-Field Imaging	SG Co-Chair	Pierre-Olivier	Lagage	Commissariat à l'Energie A
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Sci-Eng Interface		WG Co-Chair	Sitarski	Breann	NASA GSFC
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AI/ML		WG Co-Chair	Dean	Bruce	NASA GSFC
COMMUNIT	Y				
Inclusion-Mentoring	2	WG Co-Chair	Scannapieco	Evan	Arizona State Univ
Inclusion-Mentoring		WG Co-Chair	Beaton	Rachael	STSel
Inclusion-Mentoring	Inclusion	WG Co-Chair	Mahadevan	Suvrath	Pennsylvania State Univ
Inclusion-Mentoring	Inclusion	WG Co-Chair	Miles	Drew	CalTech
Inclusion-Mentoring	Inclusion	Emercing Leader	Washington	Robert	Howard Univ.
Inclusion Mentoring	Mentoring	WG Co Chair	Tran	Kim3br	Center for Astrophysics
Inclusion-Mentoring	Mentoring	WG Co-Chair	Repaud	loa	NASA CSEC
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HWO: involving a very wide community

Starting with a very open world-wide contribution to mission working groups

SCIENCE



~	Solar System in Context		wis co-chair	Shkolnik	Evgenya	Anzona State Univ.
l	Solar System in Context	Characterizing Exoplanets	SG Co-Chair	Hu	Renyu	JPL
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WG Co-Cha	ir Dean	Megan	NASA HQ
WG Co-Cha		Bruce	NASA GSFC
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WG Co-Cha	ir Tran	Kim-Vy	Center for Astrophysics
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WG Co-Cha	ir Miyazaki	Satoshi	AXAL
WG Co-Cha	ir Lopez-Mor	ales Mercedes	Center for Astrophysics
WG Co-Cha	ir Petre	Rob	NASA GSFC
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HWO: involving a very wide community

Starting with a very open world-wide contribution to mission working groups

Contributions welcome and encouraged

• Discussions directly at **agencies** level (ESA), and/or for bilateral collaboration (eg **countries**)

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- Some instrument lead, or significant part of instrument
- Knowledge of **industrial** specific expertise (complementary to US)
- Collaboration of teams/institutes on specific field of expertise: team-to-team collaborations
- Individual contributions

Explicit request from L. Feinberg for a panorama of European field of expertise/interest, potential collaboration or investment.

HWO: a schedule-driven organization







Technical challenges and preparation of a roadmap

HWO techno overview



Funded efforts and experiments



Most visible / integrated

- 🔁 Zurich:
 - Project office
 - NICE bench (15 funding)
- 🔁 Leiden SRON
 - Mid-infrared MKID detectors (**Z** fundings)
 - Instrument architecture design and deformable mirrors (fundings)
- 🛛 🔁 📕 Delft Leuven Liège
 - Single spacecraft mission concept pre-study (Single small ESA funding)
- 🕅 Canberra
 - Moving interferometer demonstrator
- Nagoya
 - Discussions with JAXA
- 🗾 JPL
 - Formation flying simulations
- - PEPR Photonics (Nice Grenoble Paris)
 - Why not more ? :-)

Key technologies to mature: wavefront control

Wavefront sensing and control	HWO	LIFE
Space-compatible WFS and DMs	High order	Low to medium order
Non-common path errors -> tuning from the science detector	Electric field conjugation (EFC, iEFC)	Discrete electric field conjugation (iEFC)
High dimensional stability	Down to ~10 ⁻¹¹ m	Down to ~10⁻⁰m
Laser metrology system	×	\checkmark

Key technologies to mature Starlight suppression

Deep starlight suppression	HWO	LIFE
Achromatic phase shifter/masks	High precision High resolution masks Broadband	Broadband High precision
Polarization control	\checkmark	\checkmark
Broadband spatial filtering	×	Broadband infrared single-mode waveguide(s), possibly PIAA
Balanced beamsplitters or waveguide couplers	×	Broadband highly uniform
Photonics beam-combiner	For possibly for 1-2µm	~2µm for fringe-tracking

Key technologies to mature

Data reduction

Data reduction	HWO	LIFE
Accounting for correlated instrumental noise		\checkmark
Accounting for non-Gaussian statistics	\checkmark	\checkmark
Covariance Shrinkage	\checkmark	\checkmark
Atmospheric retrieval	✓,+ polarization, + glint, + Rayleigh	\checkmark

Key technologies to mature

Others

Miscellaneous	HWO	LIFE
Beam transportation / pupil matching / stray light	\checkmark	\checkmark
Sensor technology	UV, Vis, NIR	Mid IR (6-18.5µm)
Formation flyingPrecision position control	For external occulters For remote servicing	For u-v coverage Efficient slewing transfers