The R&D community for space-based HCI in France and Europe

Iva Laginja

HALO workshop

6 Dec 2024, Fréjus

LESIA Observatoire de Paris | PSL
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

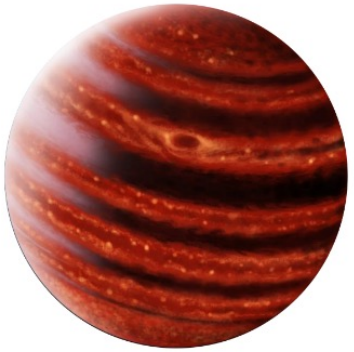
Direct imaging timeline

First detection:
Chauvin + (2004)

Roman
(NASA-led + ESA)

Ground-based
HWO
LIFE

Currently



Young giants very far out observed in **emitted light**

mid-2020s

Jupiter analogs + some super-Earths/ mini-Neptunes

2040s

Earth-like planets around Sun-like stars

Slide by Oscar Carrión-González

Direct imaging timeline

Astro2020 Decadal Survey (Nov. 2021)

The decadal survey recommends a large (~6m diameter) Infrared/Optical/Ultraviolet space telescope with high-contrast imaging and spectroscopy (…). This is an ambitious mission with the goal of searching for biosignatures from habitable zone exoplanets and providing a powerful new facility for general astrophysics.

ESA Voyage 2050 (June 2021)

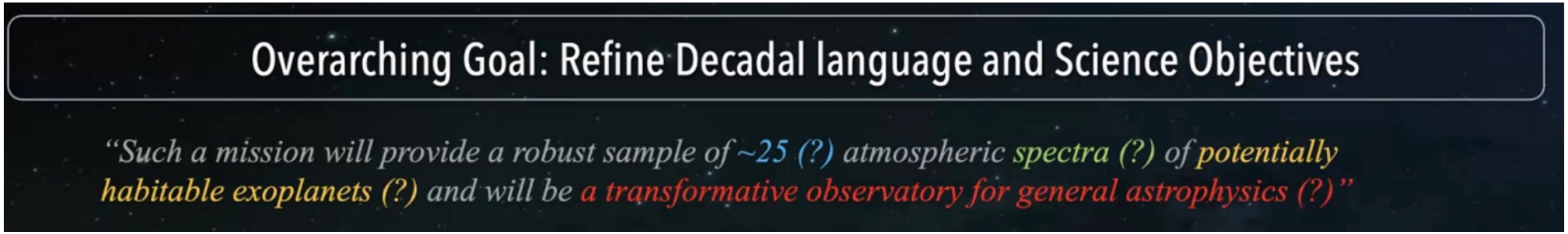
A contribution to LUVOIR will offer a unique opportunity for the community to have access to the UV, a crucial wavelength range that will not be accessible after HST is decommissioned. (…) In the visible, mid and far-IR, a contribution to Origins and HabEx would provide access to a large space facility to study the formation of galaxies, stars and planetary systems as well as the characterisation of exoplanet atmospheres.

The "Characterisation of Temperate Exoplanets" [in thermal emission] is considered as having the highest scientific priority (…). The committee recommends that ESA launch a detailed study involving the scientific community for the exoplanet theme to assess its likelihood of success of feasibility within the Large mission cost-cap. (…) If it is found that at least 10 temperate exoplanets (within some reasonable bound of uncertainty) can be characterised and thus a scientific breakthrough can be achieved in a feasible and affordable mission, then the committee recommends such a theme to be selected for the third Large mission in the Voyage 2050 timeframe.

(…) we thus need to observe a sample of temperate planets with varying size and insolation, including planets that are bigger and receive more insolation that what we think is theoretically possible [to develop a habitable climate]

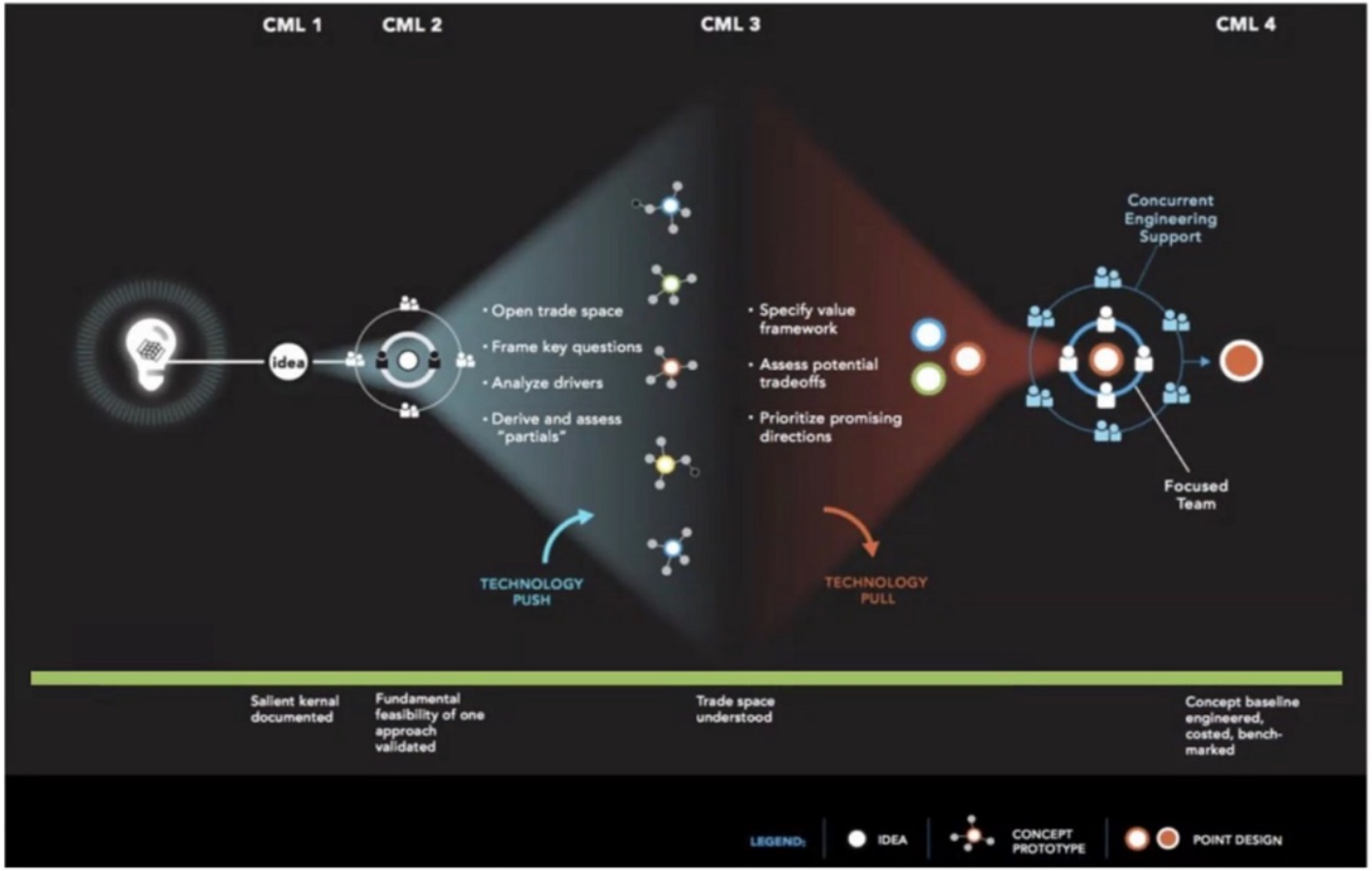
Slide by Oscar Carrión-González

Current HWO WG activities:
Define parameter space before positioning HWO in it



Slide by Bertrand Menneson

Change in paradigm: develop tech first (GOMAP)



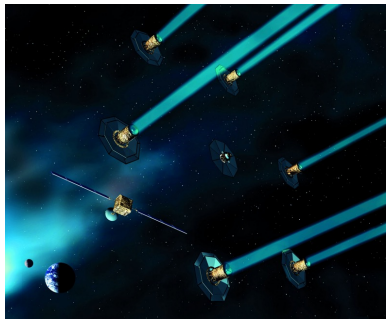
Exploring the Trade Space through Concept Maturity Levels (CMLs)

Slide by Bertrand Menneson

Europe's HCI legacy

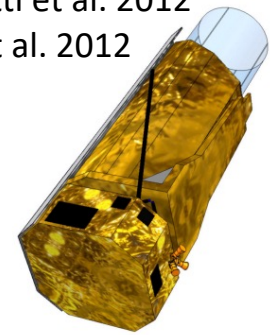
Lyot 1937

(Solar) Lyot coronagraph ~1930s



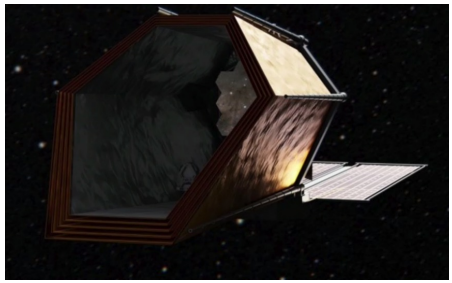
Darwin (cancelled 2005/6)

Boccaletti et al. 2012
Maire et al. 2012



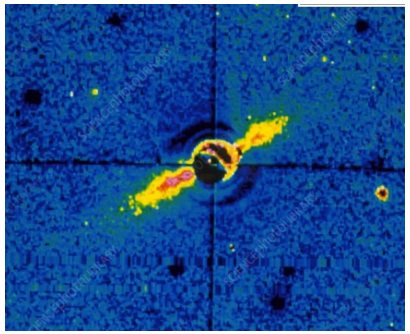
SPICES (cancelled 2014)

HWO (launch ~2040)



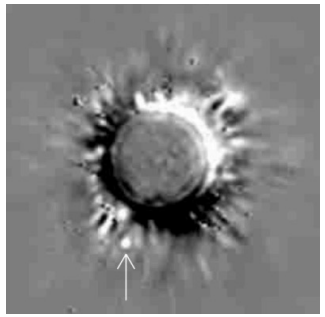
Stellar Lyot coronagraph ~1980s

Circumstellar disks



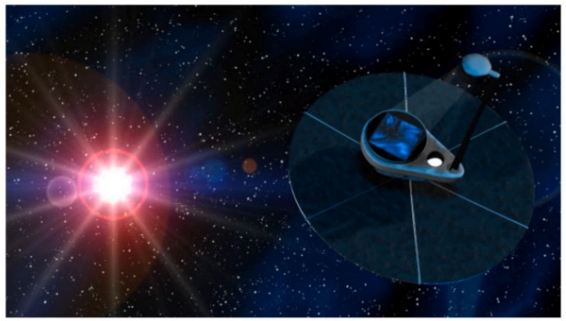
Smit & Terrile 1984
Vilas & Smith 1987

Companions with HST



Boccaletti et al. 2003

TPF-C, TPF-I (cancelled 2006/7)



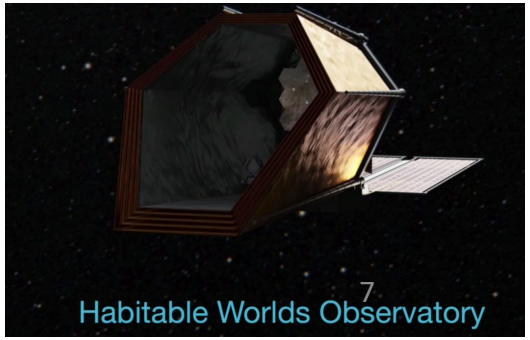
JWST (launched 2021)

Roman (launch 2027)

European current HCI involvement

- JWST:
  - ESA provided MIRI with coronagraphs (FQPM, Lyot), enabling JWST's first exoplanet direct imaging discovery (ϵ Indi Ab, Matthews et al. 2024)
  - European scientists secured ~30% of JWST Cycle 1 GO time

- RST:
  - Off-axis super-polished mirrors for CGI by LAM (France)
  - Precision Alignment Mechanisms by MPIA (Germany)
  - EMCCDs, star trackers, batteries, and a new 35-meter ground antenna (ESA)
  - ESA-appointed scientists (B. Biller, G. Chauvin) represent European interests in Roman's Coronagraph Community Participation Program (CCPP)
- HWO:
  - ESA representatives (D. Mouillet, M. Min, A. Gomez) involved in GOMAP START & TAG groups
  - Involvement decided, but concrete contribution outstanding

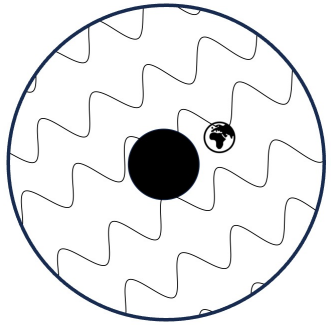


Europe in HWO! Europe in HCI for HWO?

- NASA is turning to ESA, ESA refers to national agencies
- ESA does have representatives to START
- Other contributions, apart from full instrument, very much on the table
- HCI will not be an instrument contribution by ESA to HWO
    1. ESA doesn't know much about HCI (Presentation at ESA/ESTEC May 2023)
    2. NASA wants to keep HCI instrument in their hands
    3. -> But still loads to contribute in collaborations and R&D!
- Funding from tech/optics department (e.g. SUPPPPRESS)
- Strong heritage in Europe, huge European community working on HCI in the US

R&D for Space-Based HCI in Europe workshop

21-22 Mar 2024 Paris (France)



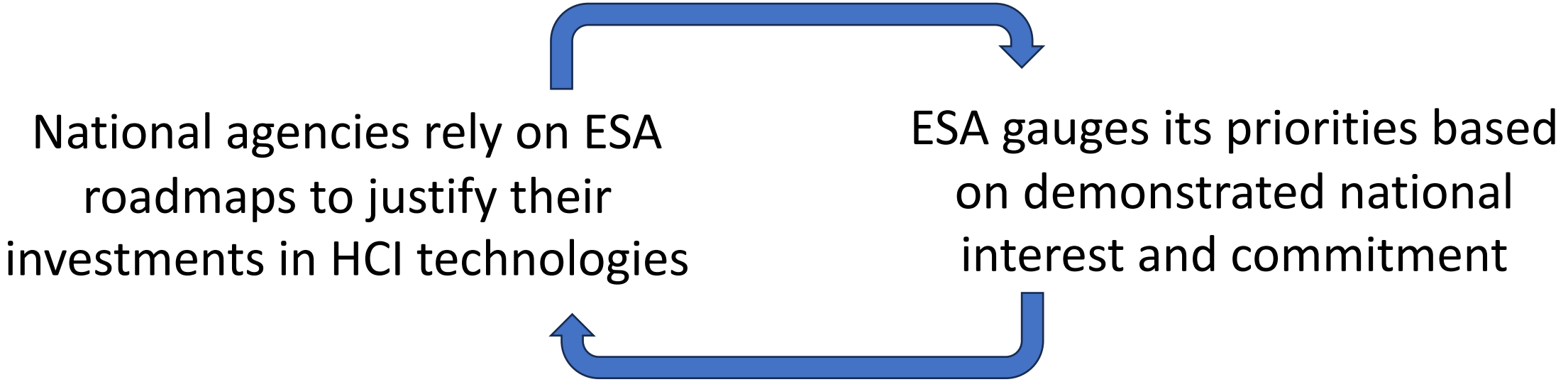
- Workshop in March 2024 in Paris, 2 days, 37 attendants from 9 countries
- 2 out of 3 ESA reps to START attended (Mouillet, Min)
- ESA + French Roman reps and European Roman partners attended
- Tighten European community for engagement and exchange with US community
- Workshop focused on aligning European R&D with international HCI missions like HWO and explore synergies with LIFE

R&D for Space-Based HCI in Europe

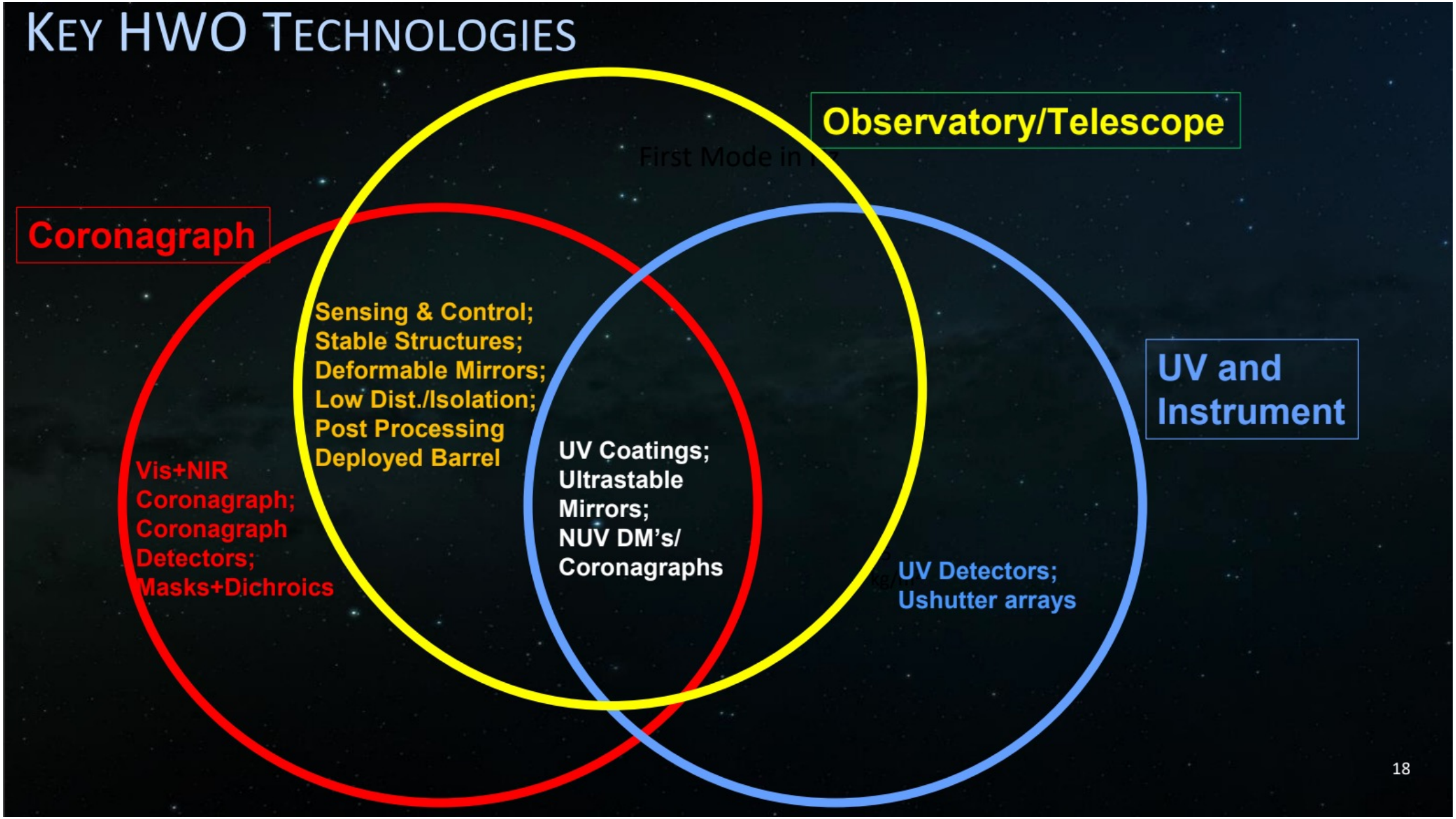
- Discuss R&D avenues for high-contrast imaging (HCI) at European institutions, focusing on space-based visible and near-IR direct imaging.
- Foster synergetic discussions, bridging expertise from science, space-based, and ground-based technologies.
- Recap NASA's technology development program for HWO and its implications for European research.
- Identify concrete research and development pathways, timelines, and investment priorities -> independently from NASA missions

https://hcieurope.sciencesconf.org/

“Chicken and egg” dynamic with ESA



- No clear endorsements from ESA for HWO → smaller national agencies find it difficult to justify early-stage funding for HCI-related technologies (since not tied to concrete missions) .
- This feedback loop creates barriers to securing funding for exploratory R&D.



Slide by David Mouillet

Technological opportunities in Europe

- **Advancing TRL levels** in Europe is valuable, no matter what
- E.g. **deformable mirror technology**: European companies like ALPAO are exploring promising solutions tailored to European needs.
- E.g. ultra-stable structures, gap in European R&D activities

Technological opportunities in Europe

High-quality in-air testbeds provide **high-gain opportunity** for direct involvement in HCI R&D activities that the US has no capacity for (anymore)

Technological opportunities in Europe

High-quality in-air testbeds provide **high-gain opportunity** for direct involvement in HCI R&D activities that the US has no capacity for (anymore)

- In-air testbeds seem to have ~1e-9 contrast performance level
- Limitations not fully understood yet
- But even reaching 1e-9 in air is very hard
- → Working on in-air testbeds can still teach us a lot

Technological opportunities in Europe

High-quality in-air testbeds provide **high-gain opportunity** for direct involvement in HCI R&D activities that the US has no capacity for (anymore)

- Existing in-air testbeds remain more than capable to answer vital questions for HWO, but they start being neglected
  - System interactions between components: coronagraph, wavefront sensing and control, post processing…
  - System stability for 1e-10 contrast, control loop tradeoffs
  - Quantification of performance limitations
- US is focused on getting new vacuum testbeds built for HWO work
- → *THD2 testbed in Paris is folds into this context*

Technological opportunities in Europe

- Emphasis on **advancing technical understanding**, prioritize expertise and utility beyond immediate applications
- Some funding opportunities are independent from programmatics, e.g. ERCs, ESA TDEs
- ERC grants offer flexibility and freedom from programmatic constraints, enabling exploratory research without political interference

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- **Objective 2** - Identify technological challenges and current technological developments
  - Pursue research for its own sake
  - Invest in high-quality infrastructure like testbeds

Alignment with HALO objectives

- **Objective 1** - Address the current state of scientific knowledge
- **Objective 2** - Identify technological challenges and current technological developments
  - Pursue research for its own sake
  - Invest in high-quality infrastructure like testbeds
- **Objective 3** - Provide feedback on our work and conclusions to the CNES and INSU working group
  - Work needs to be invested ***now***, don't wait for mission definition
    → the way things are done have fundamentally changed!
  - INSU and CNES mentioned HWO in their perspective seminars

Objective 4 - Raise awareness in astro community

- Most people get stuck up on name: “Habitable Worlds”
- Most people they can wait to start caring towards the end of 2030s
- → Give talks, repeat info, inside and outside exoplanet community
- → Stay up to date yourself: join HWO_Community Slack workspace, follow NASA announcements

https://habitableworldsobservatory.org/

2024 Workshop paper: Laginja et al., in prep for ApSS

Slack workspace for R&D HCI community

- New Slack work space (no ESA affiliation)
- Specifically for ***R&D in HCI***
- Please reach out to one of admins if interested in joining

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Next workshop: 12-14 May in Heidelberg

https://hcieurope-mpia.sciencesconf.org/

R&D for Space-Based High-Contrast Imaging in Europe II

12-14 May 2025 , Haus der Astronomie, Max-Planck Institute for Astronomy, Heidelberg (Germany)

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- Code of conduct

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We now know of more than 5,000 exoplanets, i.e. planets orbiting stars other than our Sun.

Statistical analyses suggest that the frequency of planets with a radius of between typically 0.5 and 1.5 Earth radii and orbital separations that could in principle allow the existence of liquid water on their surface (i.e. the so-called habitable zone) is of the order of 60% for solar-type stars. Consequently, **a systematic atmospheric study of dozens of Earth analogues and a quantitative assessment of their habitability and the possible existence of clues to life**, i.e. atmospheric constituents that would indicate the presence of a biosphere on the planet (Schwieterman et al. 2018), **requires large-scale, highly optimised space missions, in particular with the two HWO and LIFE projects**.

As an initiative of researchers from the High-Contrast Imaging (HCI) community, **the purpose of the workshop is to discuss R&D avenues at European institutions for technology and its applications in HWO-related science**. We want to focus in particular on space-based, visible-light and near-IR direct imaging at high contrast. We recognize that this goal requires expertise from all different angles, including science, and space-base technology even if not explicitly High-Contrast Imaging.