Synergies between Ariel and the Habitable Worlds Observatory

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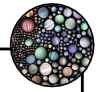
Ariel (*Atmospheric Remote-sensing Infrared Exoplanet Large-survey*)

- M4 ESA mission (adopted in Nov 2020, launch in L2 2029) for a nominal duration of 4 years (with possible extension)
- 1-m telescope, spectroscopy from VIS to IR - Simultaneous coverage 0.5-7.8 μ (R =1 to 300)
- Payload consortium: 16 ESA countries+ USA, JAPAN, CANADA
- Atmospheres of ~1000 exoplanets (rocky + gaseous), mainly transits and eclipse but also phase curves

Individual planet

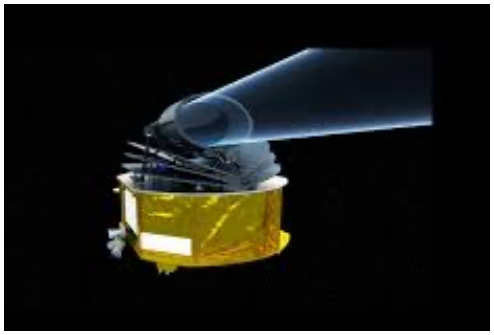
Chemical composition
Atmospheric circulation + cloud pattern
Equilibrium or non-equilibrium chemistry?
Impact with stellar environment
Coupling interior-atmosphere
Impact of stellar environment & system history

Large population of diverse planets



Chemical diversity
Correlation clouds–temperature-stellar-type
How fast atmospheres change through time?
Correlation elemental composition planet provenance
Coupling atmosphere-interior through time
Transition between terrestrial planets and sub-Neptunes

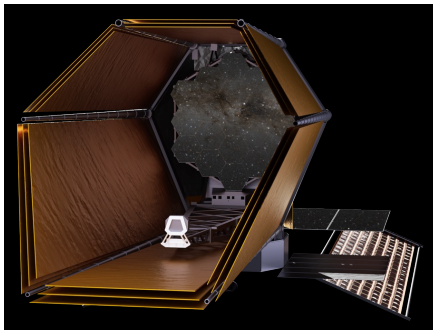
Timeline



Ariel – data in early ‘30s

vs

HWO – data > ’40



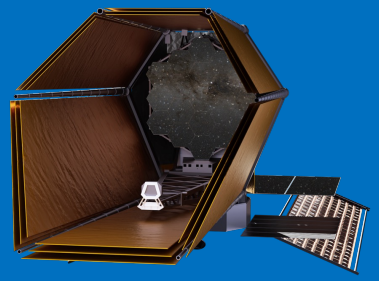
How can Ariel pave the way for HWO to take the next leap—toward detecting signs of life beyond our Solar System?

Similarities, Differences, Synergies, Complementarities

Preliminary specs & candidate instruments

Telescope

Diameter	≳6.0 m
Bandpass	~100–2500 nm
Diff. Limit @	~500 nm



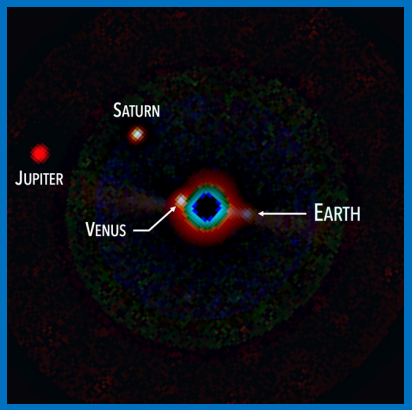
Fourth Instrument

To be defined

Candidates include NUV Coronagraph, FUV IFS, UV Spectropolarimeter

Coronagraph

High-contrast imaging and imaging spectroscopy	
Bandpass	~350–1700 nm
Contrast	$\lesssim 1 \times 10^{-10}$
R ($\lambda/\Delta\lambda$)	Vis: ~140 NIR: ~70, 200



High-Resolution Imager

UV/Vis and NIR imaging	
Bandpass	~200–2500 nm
Field-of-View	~3′× 2′
60+ science filters & grism	
High-precision astrometry?	

UV Multi-Object Spectrograph

UV/Vis multi-object spectroscopy and FUV imaging	
Bandpass	~100–1000 nm
Field-of-View	~2′× 2′
Apertures	~840 × 420
R ($\lambda/\Delta\lambda$)	~500–50,000

Ariel: The Pioneer

Mission Overview:

- Primary objective: Characterize atmospheres of a large, diverse sample of exoplanets (hundreds).
- Key instrumentation: Photometer/ Spectrometer covering visible to mid-infrared wavelengths. (0.5-7.8 μ)

Focus: Bulk atmospheric composition, thermal structures, cloud properties, diversity, and population trends

HWO: The Deep Dive

Mission Overview:

- Primary objective: Search for and characterize potentially habitable exoplanets, including direct imaging.
- Key instrumentation: Large segmented mirror, coronagraphs, spectrometer covering UV, visible to near-infrared wavelengths. (0.2/0.35-2 μ)

Focus: Direct detection of Earth-like exoplanets, search for biosignatures, detailed atmospheric characterization.

Ariel's Preparatory Role

- **Statistical Foundation:** Provides the first large-scale survey of exoplanet atmospheres, identifying trends and outliers. Ariel provides a broader context for HWO's targeted, high-resolution observations
- **Target Identification for HWO:** Helps pinpoint the most promising targets for detailed follow-up by HWO, especially those with interesting atmospheric signatures or potential biosignatures.
- **Technology Maturation:** Develops and refines techniques for exoplanet atmospheric modeling and retrieval that HWO can build upon.
- **Early Science Return:** Delivers ground breaking science years before HWO is operational, keeping the field dynamic.

HWO's Complementary Role

Deeper Insights: HWO can perform detailed, spectroscopy on Ariel's most interesting discoveries, confirming and expanding upon initial findings.

Direct Imaging: HWO's unique direct imaging capabilities allow for characterization of planets inaccessible to Ariel's transit method.

Biosignature Confirmation: HWO can investigate potential biosignatures with high sensitivity and precision.

Maximizing Scientific Return: This sequential approach ensures efficient use of both observatories' resources, leading to a more comprehensive understanding of exoplanet diversity and habitability.

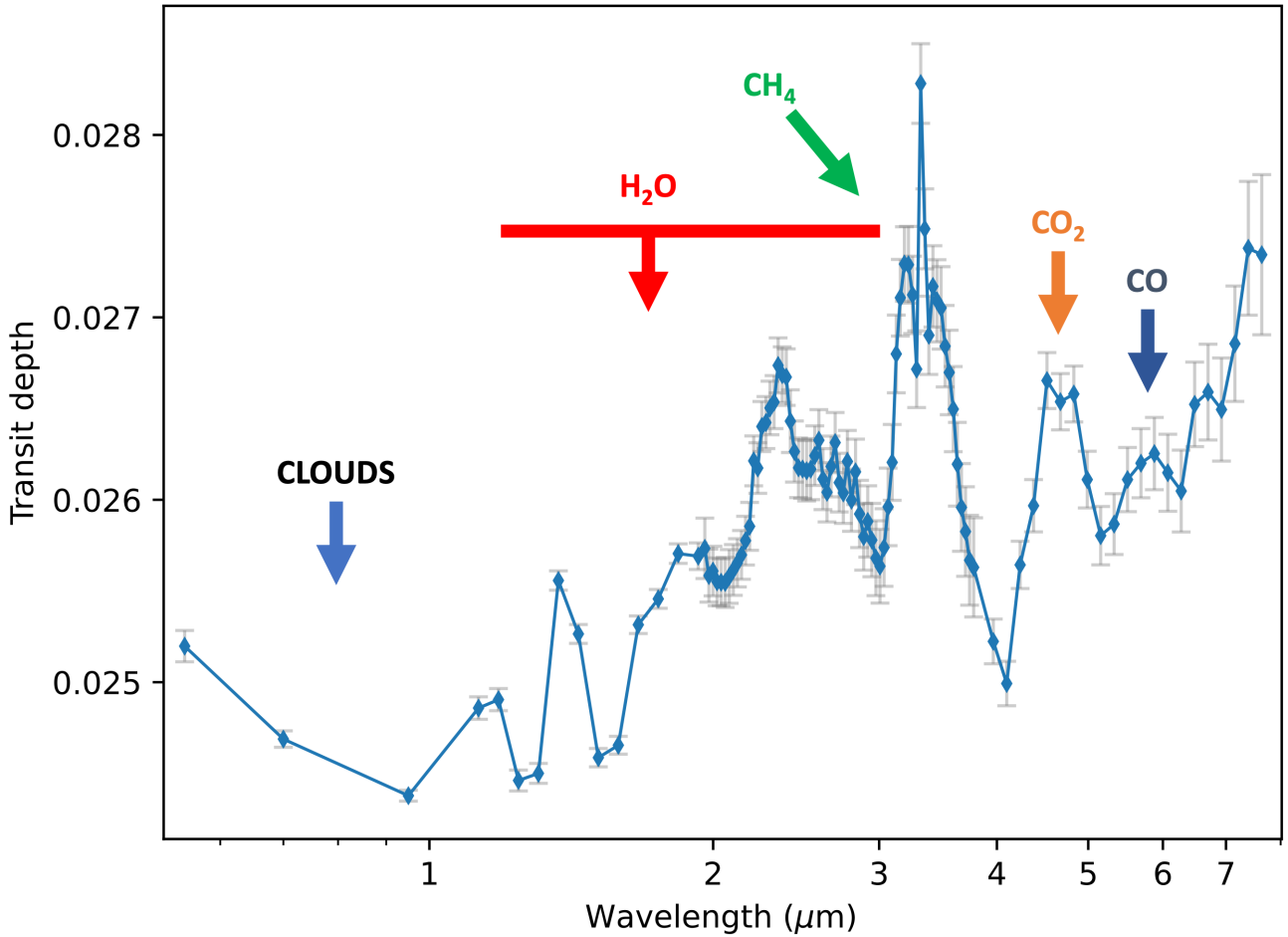
ARIEL: bulk composition & clouds

TOI-277, Teff = 4031

$R_p = 3.1\ R_E$
$M_p = 9.8\ M_E$
$T_{eq} = 711$ K
a = 0.0269 au

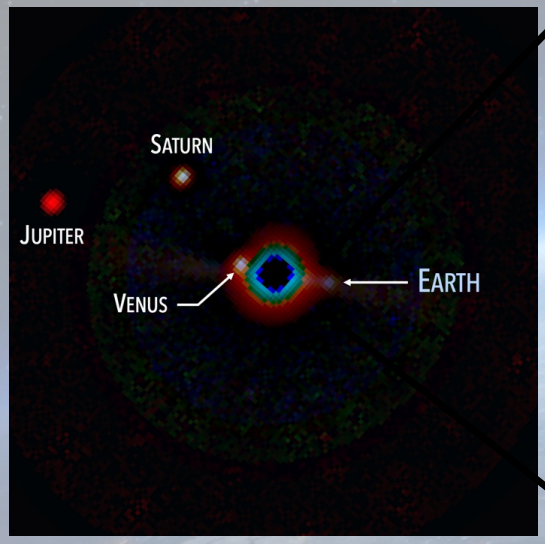
Primary atmosphere

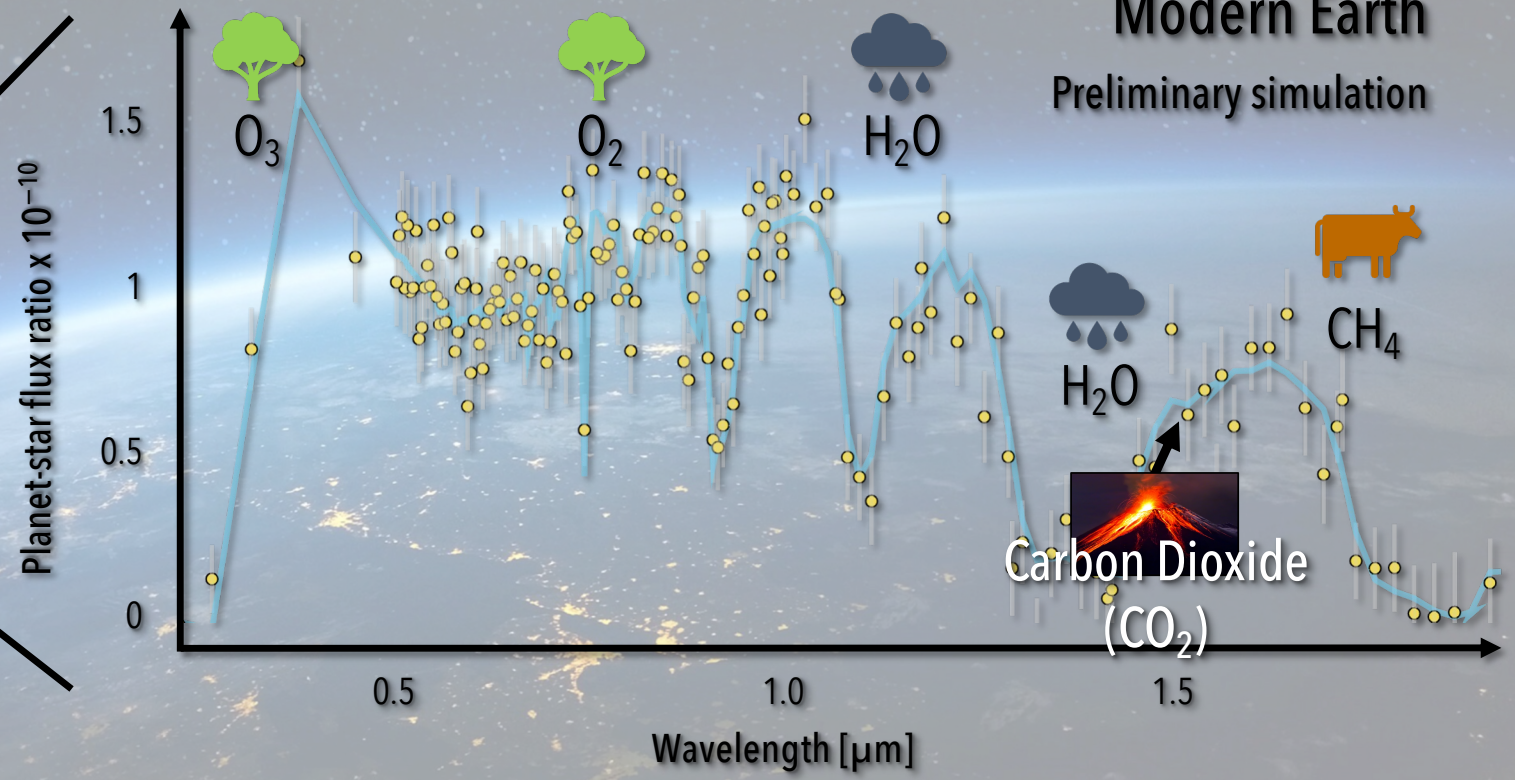
$H_2O = 1e^{-5}$
$CH_4 = 5.e^{-6}$
CO $= 1e^{-4}$
$CO_2 = 1e^{-8}$



Credit: Lustig-Yaeger (JHU-APL), Robinson (NAU), Arney (NASA GSFC)

HWO: Searching for global biospheres





Analyze light directly reflected by the planet, with little or no starlight mixed in

Ariel: The Mid-Infrared Surveyor

- **Spectral Range: 0.5 to 7,8 µ**
- **Transit spectroscopy**

- Detects abundant molecules like H_2O, CO_2, CH_4, CO.
- Determines bulk atmospheric composition and thermal structures.
- Characterizes clouds and hazes.

Provides a statistical overview of hundreds of transiting exoplanets, identifying global atmospheric properties.

HWO: UV to NIR for Direct Imaging

- **Spectral Range:** ~0.3 to ~2.5 **µ**
- **Direct imaging**

- Detects crucial biosignatures like O_2 and O_3 in the UV/optical.
- Studies high-altitude chemistry and disequilibrium processes.
- Characterizes Earth-sized planets in habitable zones.

HWO's shorter-wavelength capabilities complement Ariel's mid-infrared data, enabling deep dives into promising targets for the ultimate search for life.

Comparative planetology
Bridging the Inner and Outer Systems

- **Transit spectroscopy**: **inner regions of planetary systems** (shorter orbital periods).
- **High-contrast coronagraphy** for **direct imaging** of exoplanets: **larger orbital distances**, including potentially Earth-like worlds in the habitable zones of Sun-like stars.

- **Wider Context:** This combined approach allows us to study planetary properties across an unprecedented range of orbital distances, stellar fluxes, and environmental conditions

Comparative planetology
Deeper Insights into System Evolution

- **Understanding Formation & Evolution:** By analyzing planets at various orbital radii, we can gain crucial insights into planetary formation processes, migration, and long-term atmospheric evolution.
- **Chemical Gradients:** Investigate how atmospheric composition, volatile content, and habitability potential vary with distance from the central star.
- **Holistic System View:** Build a comprehensive understanding of planetary system architecture and the factors driving the diverse outcomes we observe.

Science developments useful for both missions

- **Stellar Astrophysics Studies:** A deep understanding of host stars (spectral type, activity, age, etc.) is crucial for correctly interpreting planetary atmospheres. Stellar variability can mimic or obscure planetary signals – *complementary science time with Ariel could help*
- **Atmospheric Modeling and Biosignatures:** Continued development of complex models for exoplanet atmospheres and their evolution. This is essential for predicting the spectral signatures of biosignatures and differentiating them from abiotic false positives – *Ariel observations can provide useful feedback*
- **Planetary System Formation and Evolution Studies:** To better understand where and how habitable planets form.

- I have assumed for HWO the “today” instrumentation → spectral resolution = few hundreds ~ Ariel
- → Both access similar layers of the exoplanet atmospheres

- Should a high-resolution instrument (R > 10^{4-5}) become available we could probe lower-pressure layers –> opening up new scientific questions.

Summary

- **Complementary Strengths:** Ariel and HWO offer distinct yet highly complementary capabilities for exoplanet characterization.
- **Enhanced Discovery:** Their combined approach maximizes scientific return by covering a broader range of planetary types and orbital regimes.
- **Future Insights:** This synergy is crucial for achieving a more complete understanding of planetary formation, evolution, and the potential for life beyond Earth.