CASE/ARIEL & FINESSE Briefing

Presentation to NRC Committee for Exoplanet Science Strategy

including material from the ARIEL consortium

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Background

- FINESSE is a proposed mission concept that was in step 2 competition in the 2016 Explorer program proposal cycle. Per HQ direction, the FINESSE step 2 study has been terminated as of 12 April 2018.
- ARIEL is the recently selected ESA M4 mission for a statistical survey of exoplanet atmospheres.
- CASE is a mission of opportunity concept in the 2016 Explorer program proposal cycle. CASE involves a hardware contribution to ARIEL (2 guider detectors and readout electronics) and a US science data center for handling science processing of photometric guide channels.

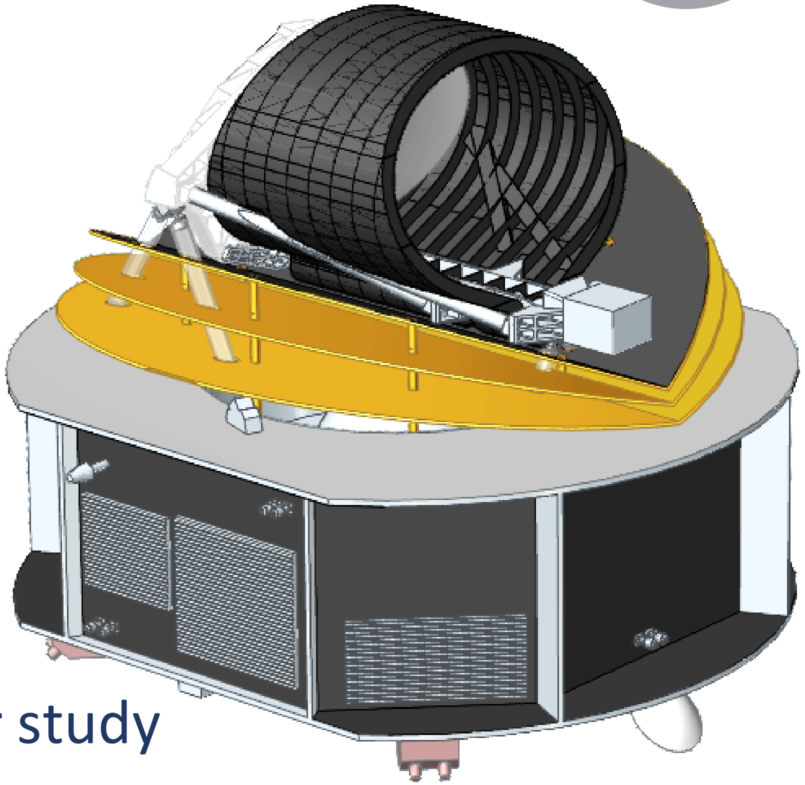
ARIEL: Key Questions and Science Objectives

- What are exoplanets made of?
- How do planets and planetary systems form?
- How do planets and their atmospheres evolve over time?

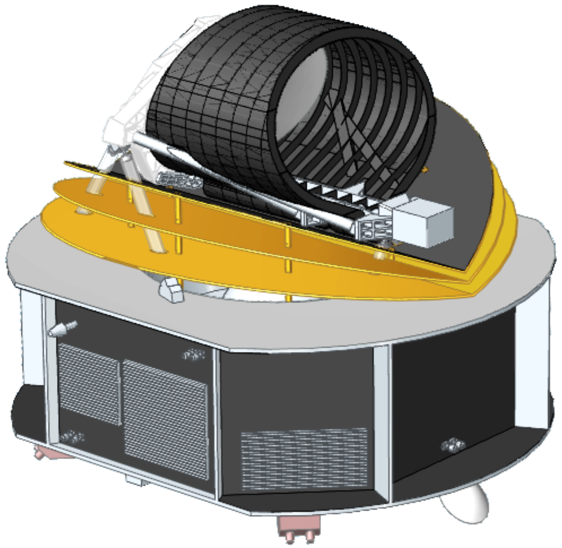
- Detect and determine the composition and structure of a large number of planetary atmospheres
- Constrain planetary interiors by removing degeneracies in the interpretation of mass-radius diagrams
- Constrain planetary formation and evolution models through measurements of the elemental composition (evidence for migration)
- Determine the energy budget of planetary atmospheres (albedo, vertical and horizontal temperature structure, weather/temporal variations)
- Identify and constrain chemical processes at work (thermochemistry, photochemistry, transport, quenching, etc.)
- Constrain the properties of clouds (cloud type, particle size, distribution, patchiness, etc.)
- Investigate the impact of stellar and planetary environment on exoplanet properties
- Identification of different populations of planets and atmospheres (for example, through color-color diagrams)
- Capacity to do a population study AND go into a detailed study of select planets

ARIEL – ESA M4 mission

- 1-m telescope, spectroscopy from VIS to IR
- Satellite in orbit around L2
- ~1000 exoplanets observed (rocky + gaseous)
- Simultaneous coverage 0.5-7.8 micron
- Payload consortium: 15 ESA countries + NASA under study



ARIEL – key Requirements

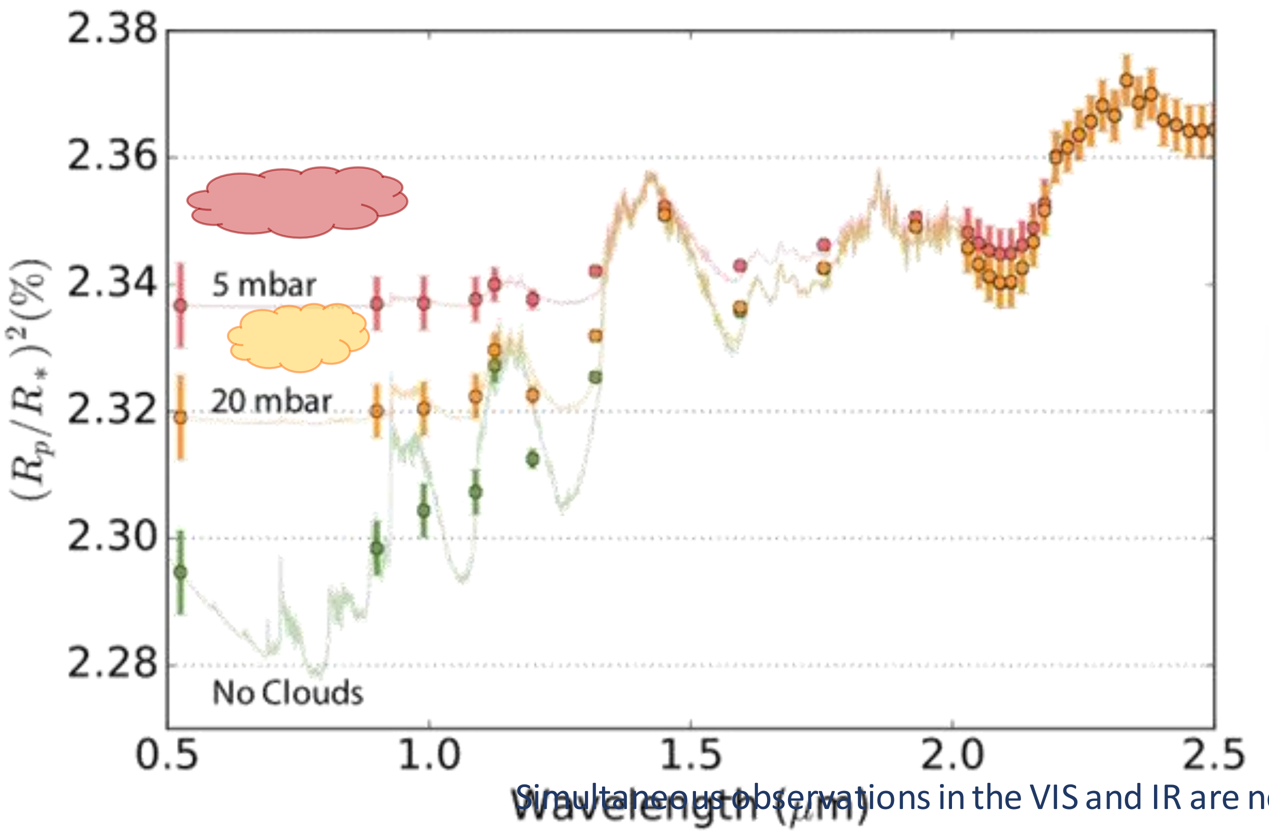


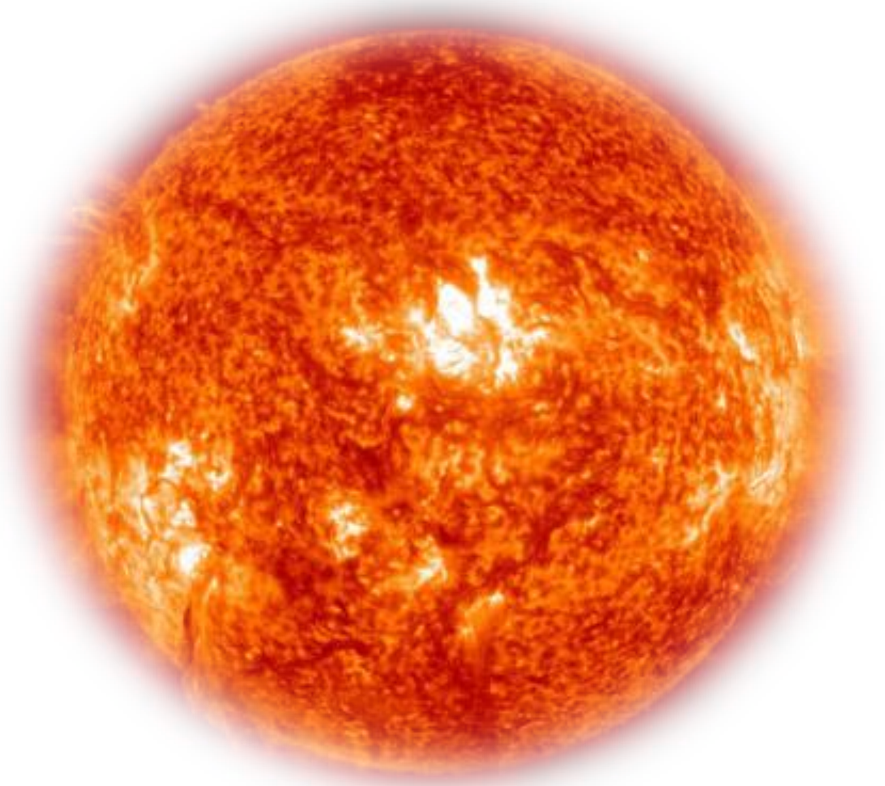
- > 0.6m^2 collecting area telescope, high throughput
- Diffraction limited performance beyond 3 microns; minimal FoV required
- Observing efficiency of > 85%
- Brightest Target: K_{mag} = 3.25 (HD219134);
- Faintest target: K_{mag} = 8.8 (GJ1214)
- Photon noise dominated
- Temporal resolution of 90 seconds (goal 1s for phot. channels)
- Average observation time = 7.7 hours, separated by 70° on sky from next target
- Continuous spectral coverage between spectral bands.

Channel Name	Wavelength (μm)	Spectral Resolution Reqt / Design
VisPhot	0.5 – 0.55	Photometer
FGS-1	0.8 – 1.0	Photometer
FGS-2	1.05 – 1.2	Photometer
NIRSpec	1.25 – 1.95	R = 20 – 25
AIRS-Ch0	1.95 – 3.9	R = 102 – 180
AIRS-Ch1	3.9 – 7.8	R = 30 – 64

A chemical survey of a large population

SCIENCE REQUIREMENTS: EXOPLANET RADIATION, MOLECULAR & **CLOUD SIGNATURES, STAR ACTIVITY**



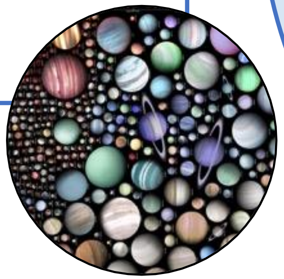


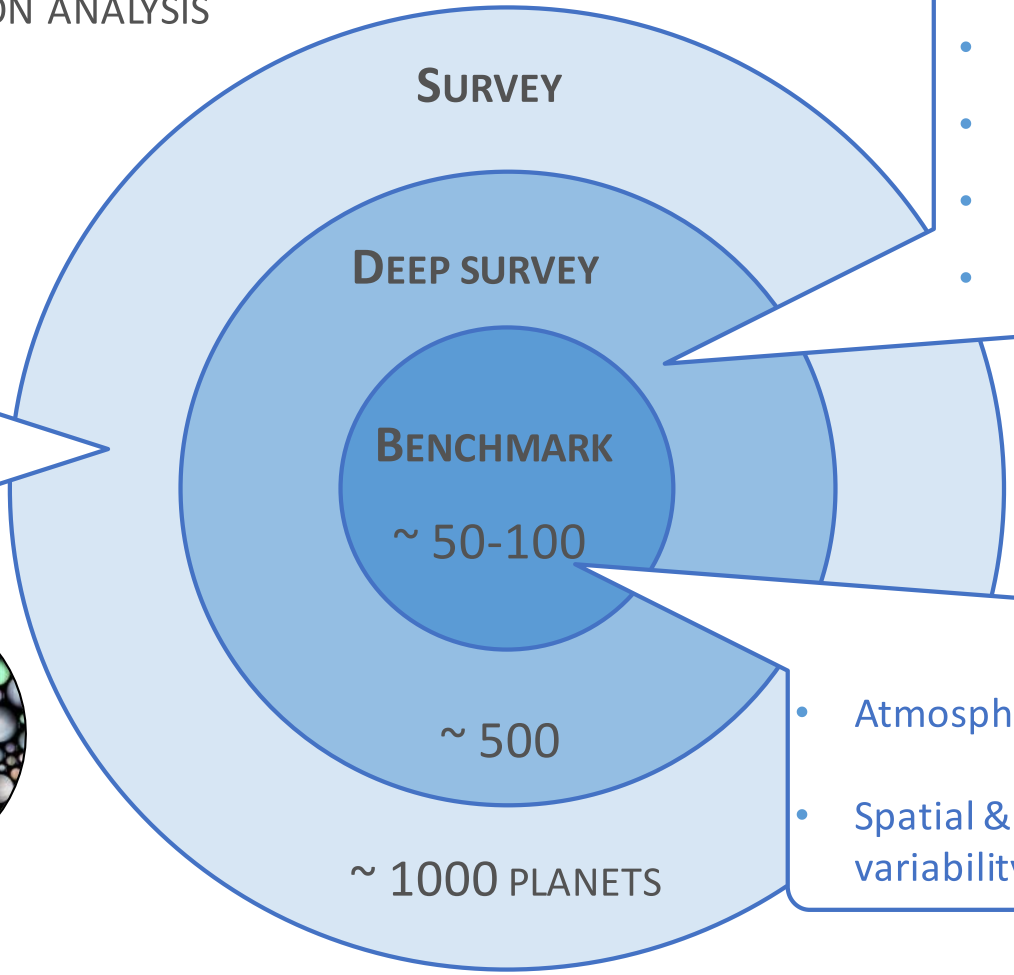
Simultaneous observations in the VIS and IR are needed

Ariel 3-tier approach

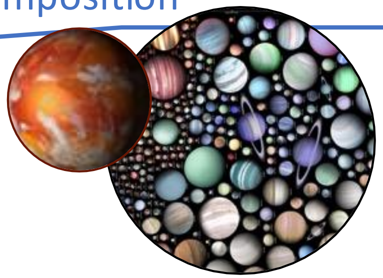
INDIVIDUAL PLANETS & POPULATION ANALYSIS

- What fraction of planets have clouds?
- Have small planets still retained H/He?
- Colour-colour diagrams
- Refinement of orbital/planet parameters in IR

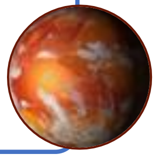




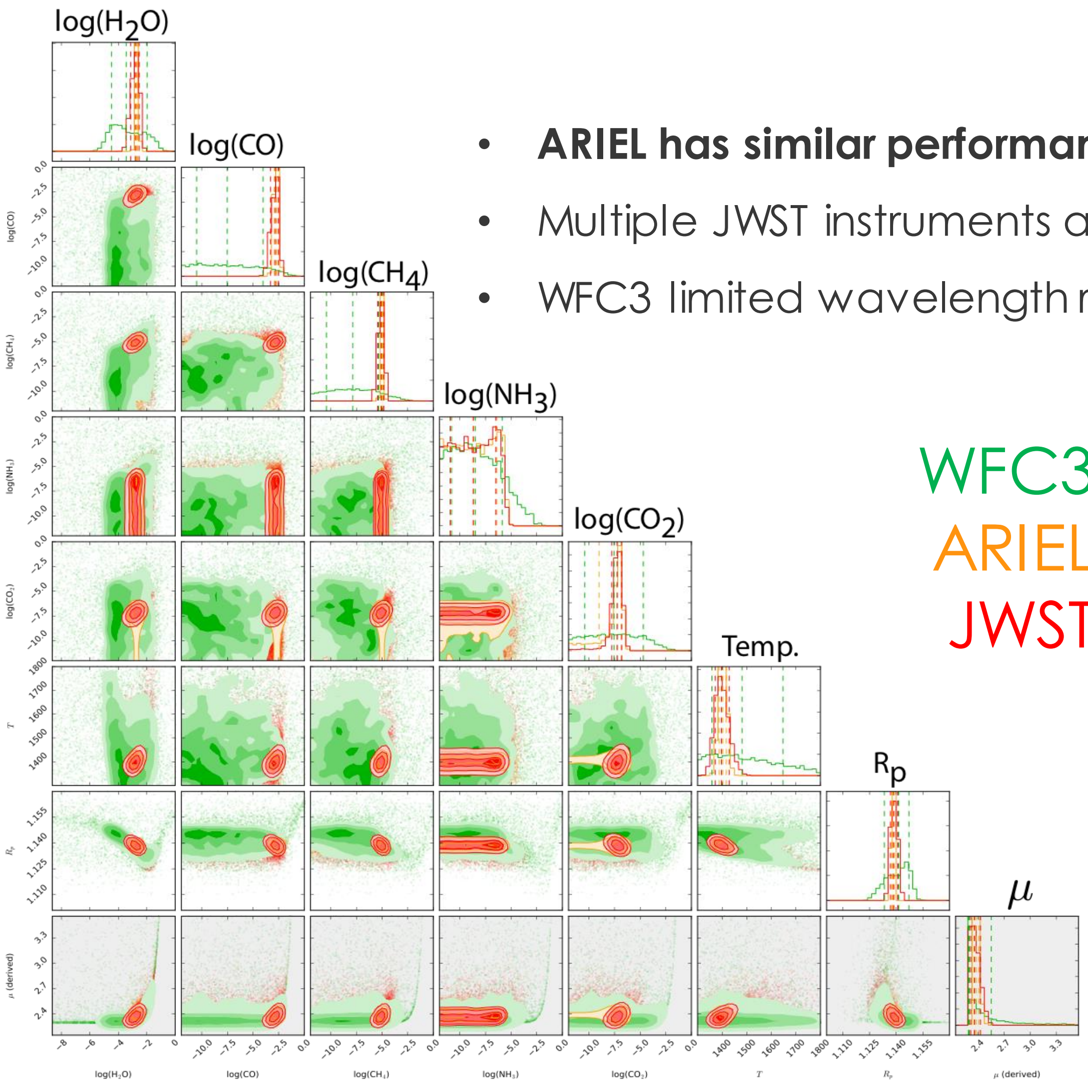
- Main atmospheric component
- Trace gases
- Thermal structure
- Cloud characterization
- Elemental composition



- Atmospheric circulation
- Spatial & temporal variability

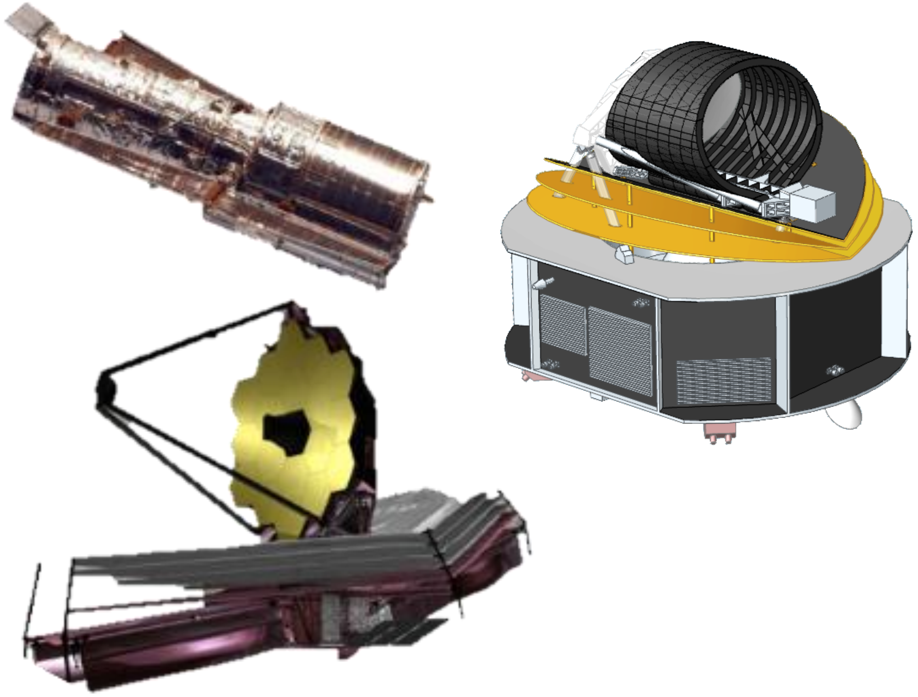


ARIEL optimal design & performances



- **ARIEL has similar performances to JWST for warm/hot planets around bright stars**
- Multiple JWST instruments are combined here
- WFC3 limited wavelength range gives highly degenerate solutions

WFC3
ARIEL
JWST



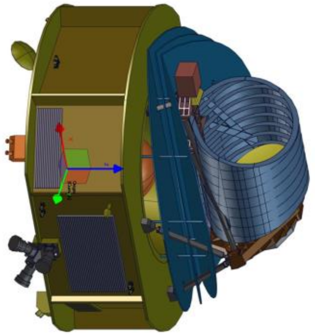

AIV
Coolers
Dichroics
Cold Payload Units
Telescope
Optical Bench
FGS
Common Optics
IR Spectrometer
Thermal Hardware
Cryoharness
Warm Payload Units
FGS Electronics
Instrument Control Unit
Telescope Control Unit
S/C CDMS
% Transmission
% Reflection
Wavenumber (1/cm)
Transmission (%)
Reflection (%)
AIRS Spectrograph
Detector
Camera
Slit
Collimator
Prism
Fold Mirror
Detector
Tip-tilt
FGS Channel
Telescope
V-grooves

Join the ARIEL team!

CASE/ARIEL US Community Access

- ARIEL access model for consortium members does not use specific time allocations
- ARIEL PI welcomes US community input to the consortium discussion for target priorities
- US community makes recommendations to CASE Science Team
- CASE Science Team caries out simulations and studies
- CASE Science Team make recommendations to CASE PI
- CASE PI represents US science community in ARIEL consortium

Capability Comparison

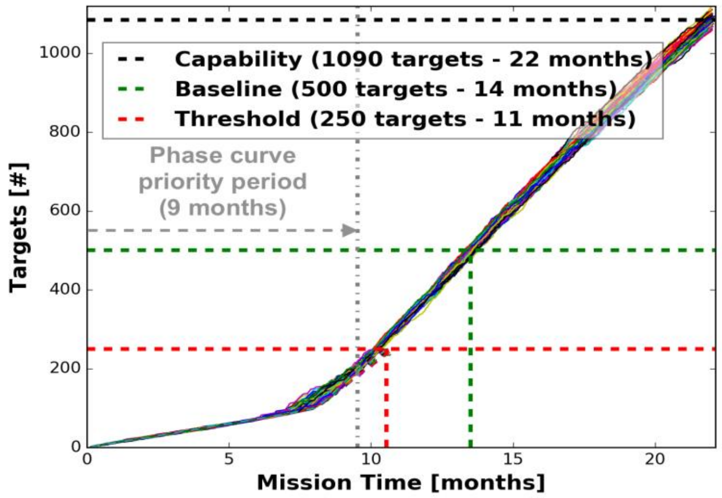


	FINESSE	ARIEL
Launch date	2023	2028
Orbit/cooling	L2/passive + heaters	L2/passive + active cooler
Mission duration	2 y + (2 y extd.)	4 y + (2 y extd.)
Mirror Size	0.75 m	1.1 x 0.7 m
Spectral Resolution	R= 150 @ 0.7 µm R= 70 @ 1.2 µm R= 200 @ 3 µm	R~0.5 0.5-1.2 µm R=20 1.2-1.95 µm R=150 1.95-5.0 µm R=30 5.0-7.8 µm
instrument	Prism, 1 detector	3 filters, prism, 2 gratings, 4 detectors
Observing strategy	500 transits (5 mo.) 100 phase curves (9 mo.) New targets/revisit (8 mo.)	1000 targets Tier 1 (1 yr.) ~500 <10 visits each Tier 2 ~50-100 Tier 3 targets
Data products	Light curves, spectra, retrievals public <90 days	Periodic public releases (no specific timeline)

FINESSE: Key Questions and Science Objectives

- Is our solar system formation scenario typical or exceptional?
- How does the planet formation process influence planetary composition?
- What are the atmospheric factors that influence planetary climate?

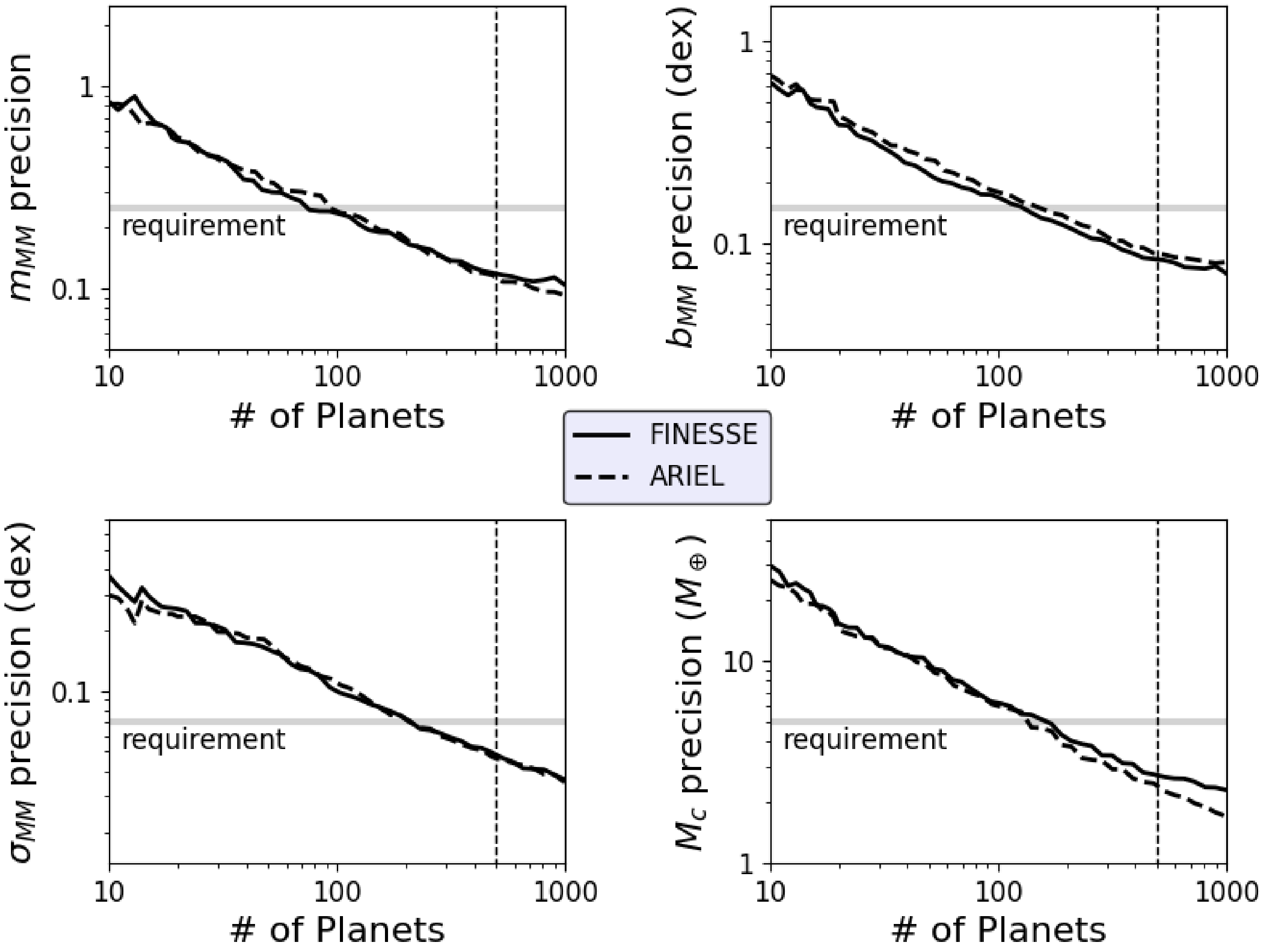
Science Goals	Science Objectives	Science Measurement Requirements: Observables	Science Measurement Requirements: Physical Parameters
"What are the characteristics of planetary systems orbiting other stars?" 2010 Decadal Survey	**Formation 1:** Determine if our solar system formation scenario is exceptional or typical by comparing the relationship between planet mass and metallicity slope, m_{MM}, for the solar system and for a statistically representative sample[1] of exoplanets from 5 M_E Super Earths to 8 M_E sub-Neptunes and 1000 M_E Gas Giants (hereafter termed F1 sample).	**Transmission spectrum** **250 planets** •Measured when planet transits the star	m_{MM} ±0.25
	Formation 2: Determine the characteristic properties of atmospheric metal-enrichment and the carbon to oxygen ratio (diagnostics of the accretion process and location) by measuring the dispersion, σ_{MM}, and intercept, b_{MM}, of the mass-metallicity relation and by determining the average carbon to oxygen ratio, <C/O>, for the F1 sample.	Captures features of key molecules H_2O, CH_4, CO_2, CO *(mass from RV measurements)*	σ_{MM} ±0.07 dex b_{MM} ±0.15 dex <C/O> ±0.1 dex
"Discover [illegible] study planets around other stars" 2014 NASA Science Plan	**Formation 3:** Test a key prediction of the core accretion model for planet formation, that lower mass planets have a different mass-metallicity relation, by determining if there is characteristic mass, M_c, of the "break point" in the mass-metallicity relation in the sub-Neptune mass regime. **This science objective is descoped in the threshold mission.**	**Transmission spectrum** **500 planets** •Currently known +TESS/K2 discoveries[2]	M_c ±5 M_{Earth}
	Climate I: Determine the global energy budget encompassing how heat is absorbed and transported in planetary atmospheres by measuring Bond Albedo, A_B, day-night redistribution efficiency, ε, longitude of maximum temperature[3], ϕ_{Tmax}, and vertical temperature contrast, ΔT_z, for planetary equilibrium temperatures of 750-2500 K (specified as median precision for subset of F1 sample).	**Emission Measurement** **100 planets** • Dayside spectrum • Phase curve *(Nightside emission from transit measurements)*	A_B ±0.2 ε ± 0.12 ϕ_{Tmax} ±15° ΔT_z ±250
	Climate 2: Determine the occurrence rate of aerosols (clouds and haze), by providing the capability of measuring the median aerosol amplitude, a_a, for the F1 sample.	**Transmission spectrum** **250 planets**	a_a ± 1.25
	Baseline: 500 planets (current + TESS discoveries) Threshold: 250 planets (currently known)	$(SNR/hr^{1/2})_{max}$ stressing case: (syste Hmag=4.27 (55 Cnc)	



Requirements and survey method optimized to answer these questions and validated with a complete design reference mission simulation

FINESSE and ARIEL have similar performance

- Comparing FINESSE and ARIEL performance using the FINESSE Design Reference Mission simulation tools.
- Same target set and observing model used for both cases
- Simulation of mass-metallicity relation parameters



JWST benefits from ARIEL

- ARIEL allows extrapolation of detailed JWST knowledge to the broader planet population
- Potential opportunity if ARIEL schedule were accelerated
  - TESS target ephemerides maintenance
  - TESS target secondary eclipse timing
  - Identify best TESS targets for detailed JWST study by detecting spectral modulation
  - Large amounts of phase curve science
  - Allows JWST to concentrate the most important exoplanet targets