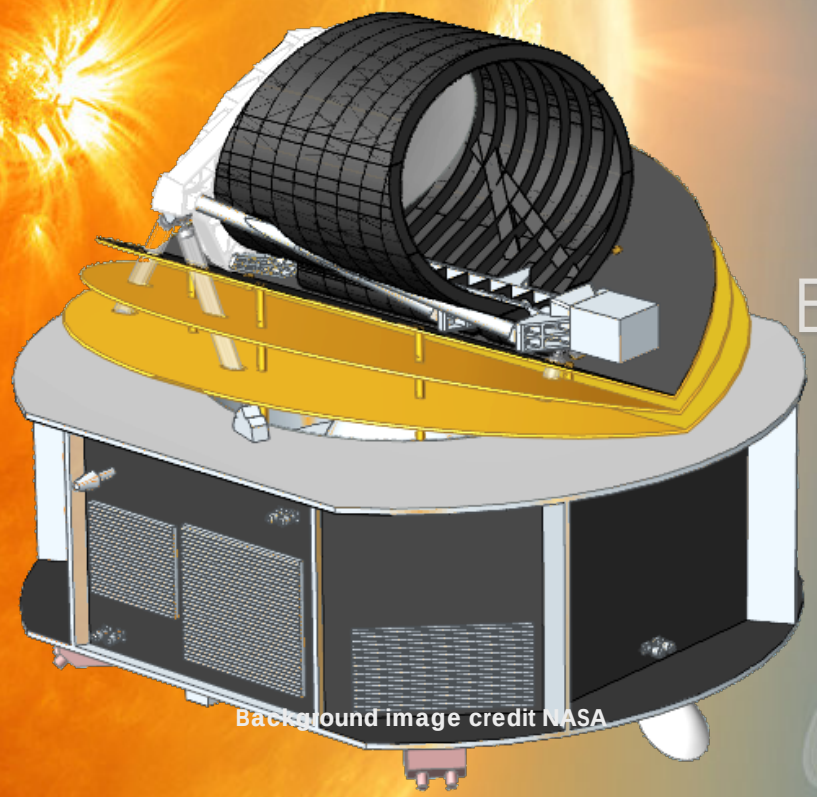
ARIEL

Enabling planetary science across light-years



Background image credit NASA

PLANETS ARE UBIQUITOUS

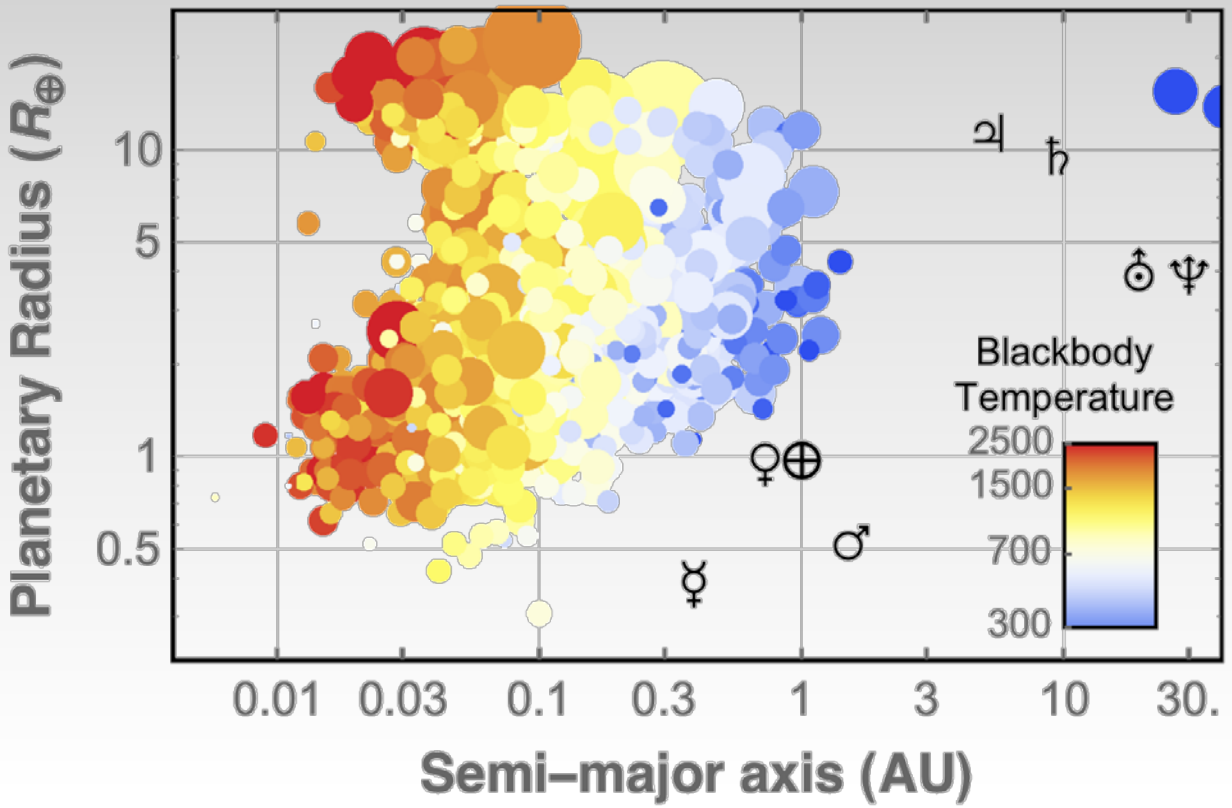
Our Galaxy is made of gas, stars & planets

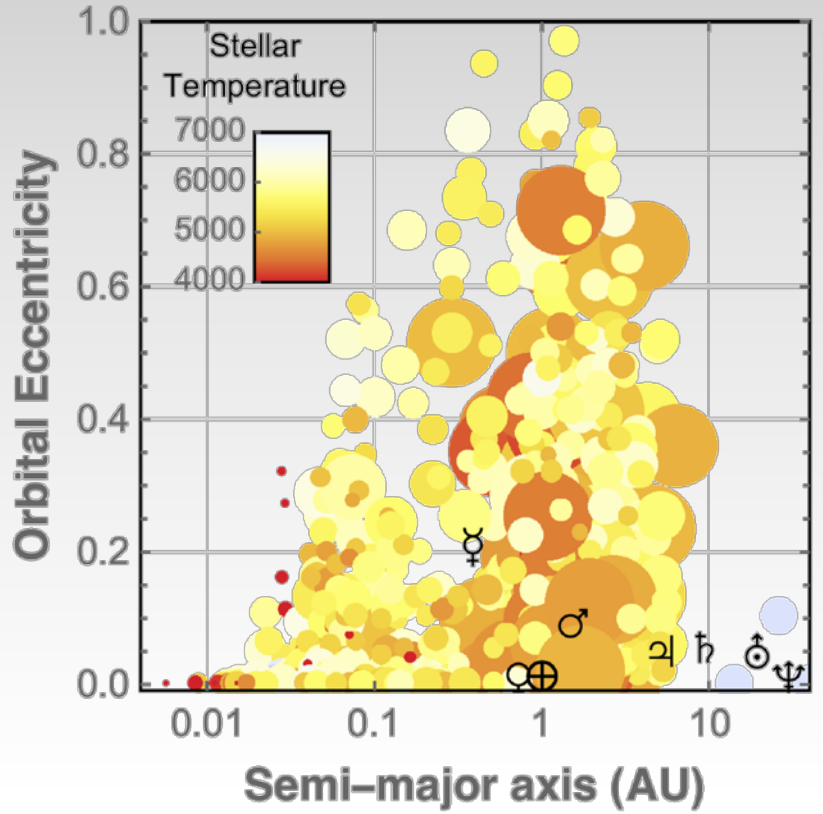
There are at least as many planets as stars

Cassan et al, 2012; Batalha et al., 2015;

EXOPLANETS TODAY: HUGE DIVERSITY

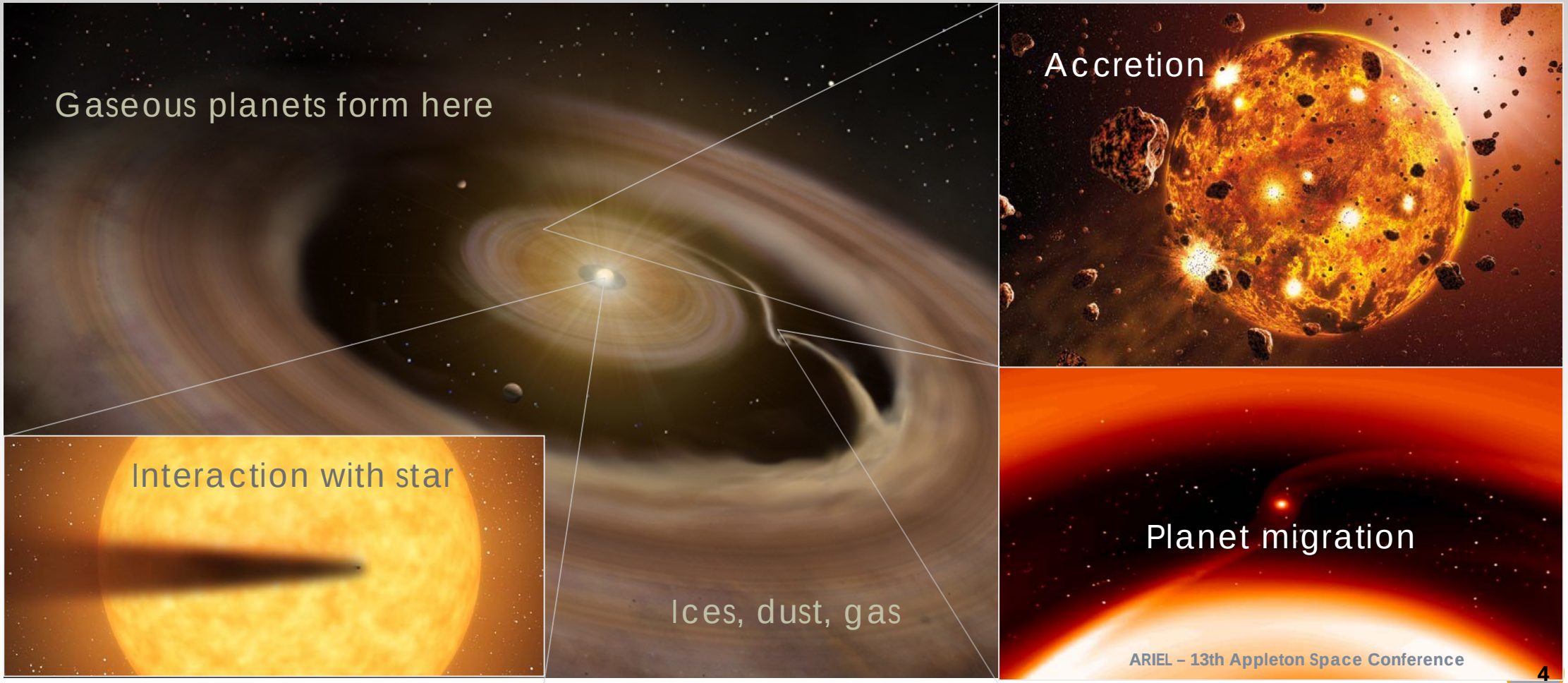
3700+ PLANETS, 2700 PLANETARY SYSTEMS KNOWN IN OUR GALAXY





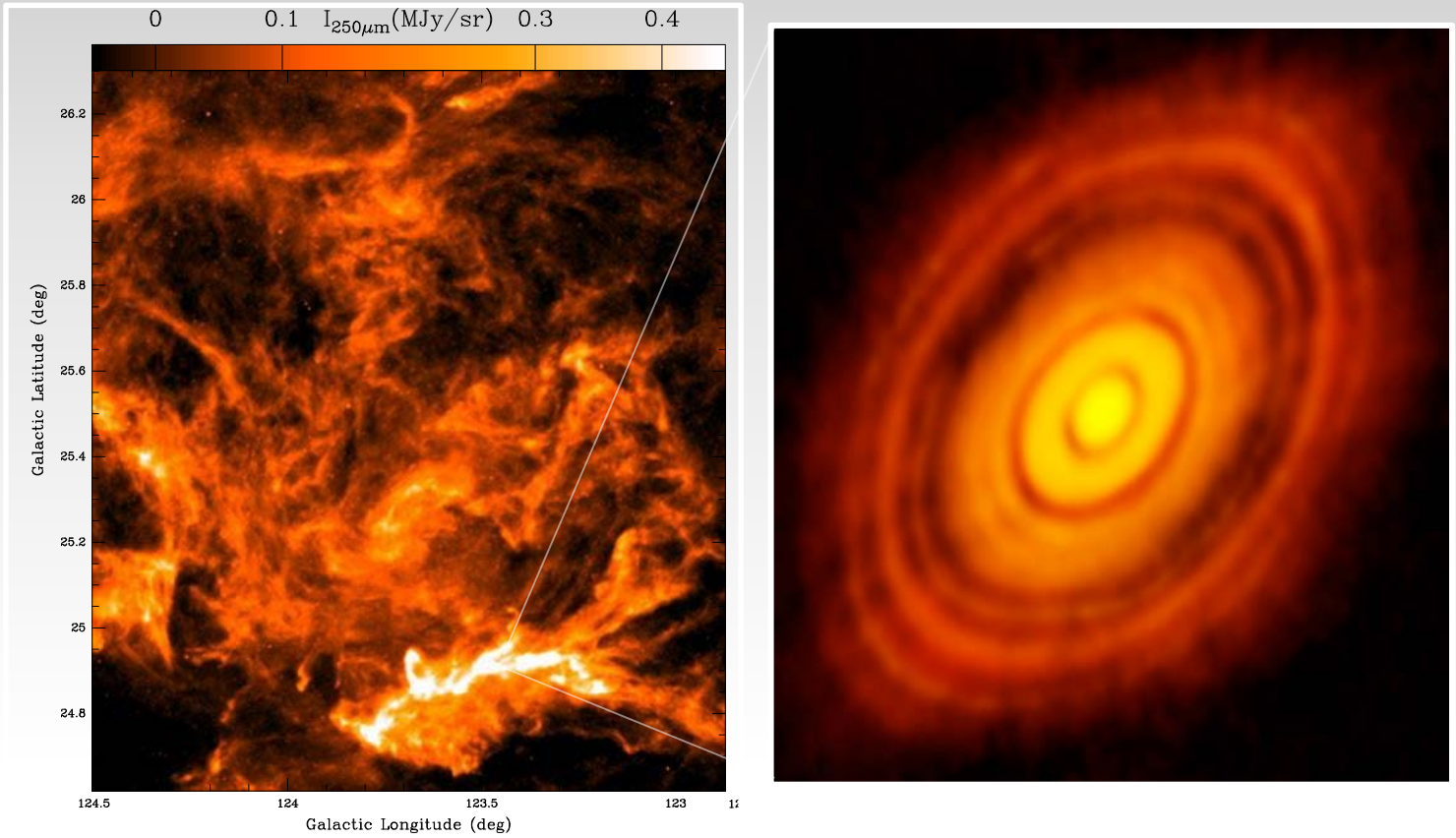
HUGE DIVERSITY: WHY?

FORMATION & EVOLUTION PROCESSES? MIGRATION? INTERACTION WITH STAR?



STAR & PLANET FORMATION/EVOLUTION

WHAT WE KNOW: CONSTRAINTS FROM OBSERVATIONS – HERSCHEL, ALMA, SOLAR SYSTEM



?

Measured elements in Solar system

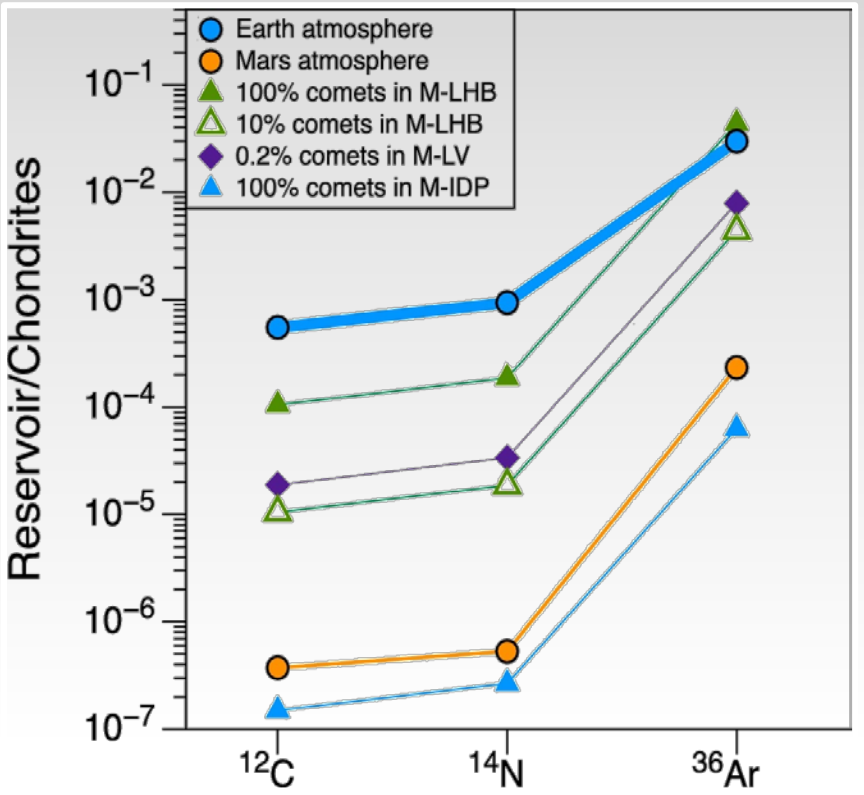
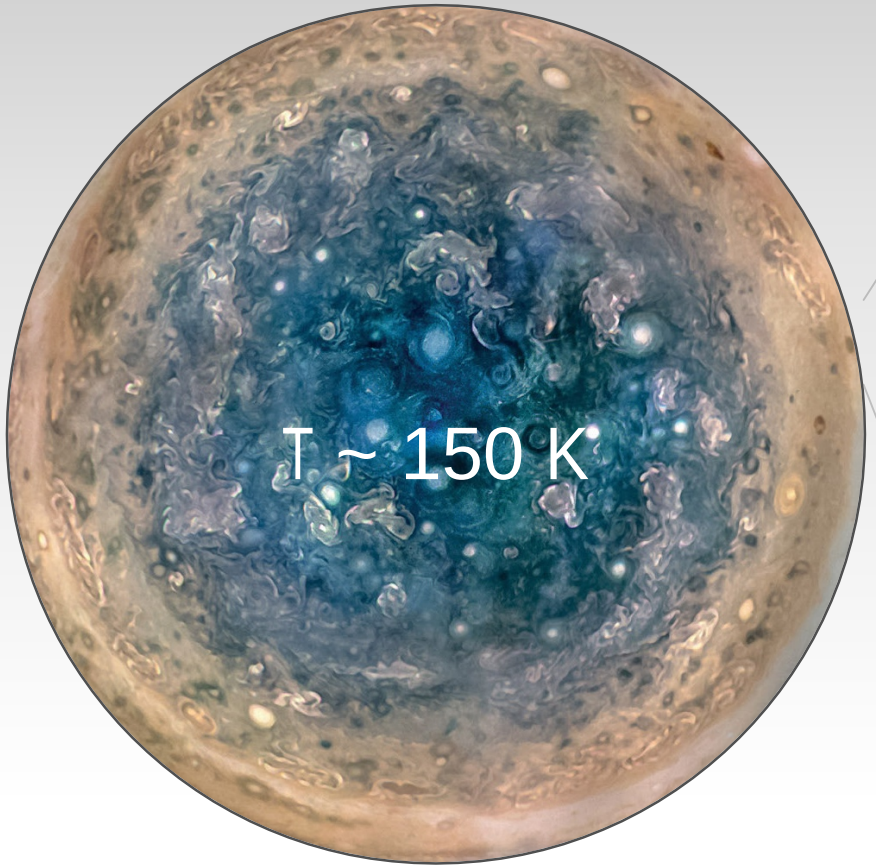


Image credit ESA-Herschel, ALMA (ESO/NAOJ/NRAO), Marty et al, 2016; André, 2012;

THE SUN'S PLANETS ARE COLD

SOME KEY O, C, N, S MOLECULES ARE **NOT** IN GAS FORM



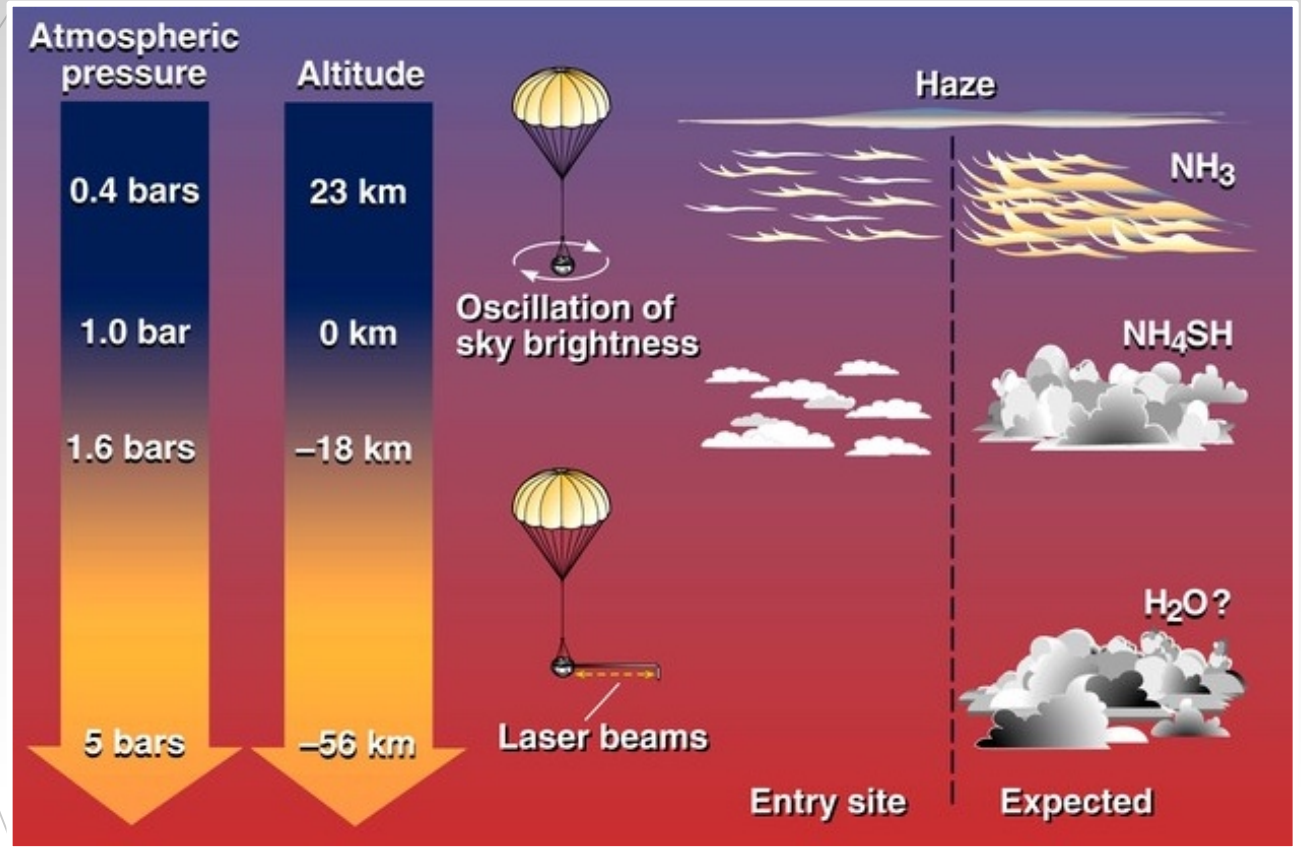
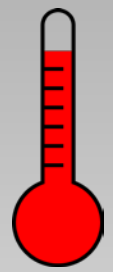
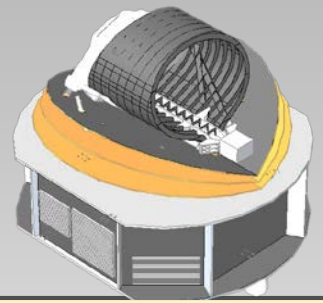


Image credit NASA Juno mission, NASA Galileo

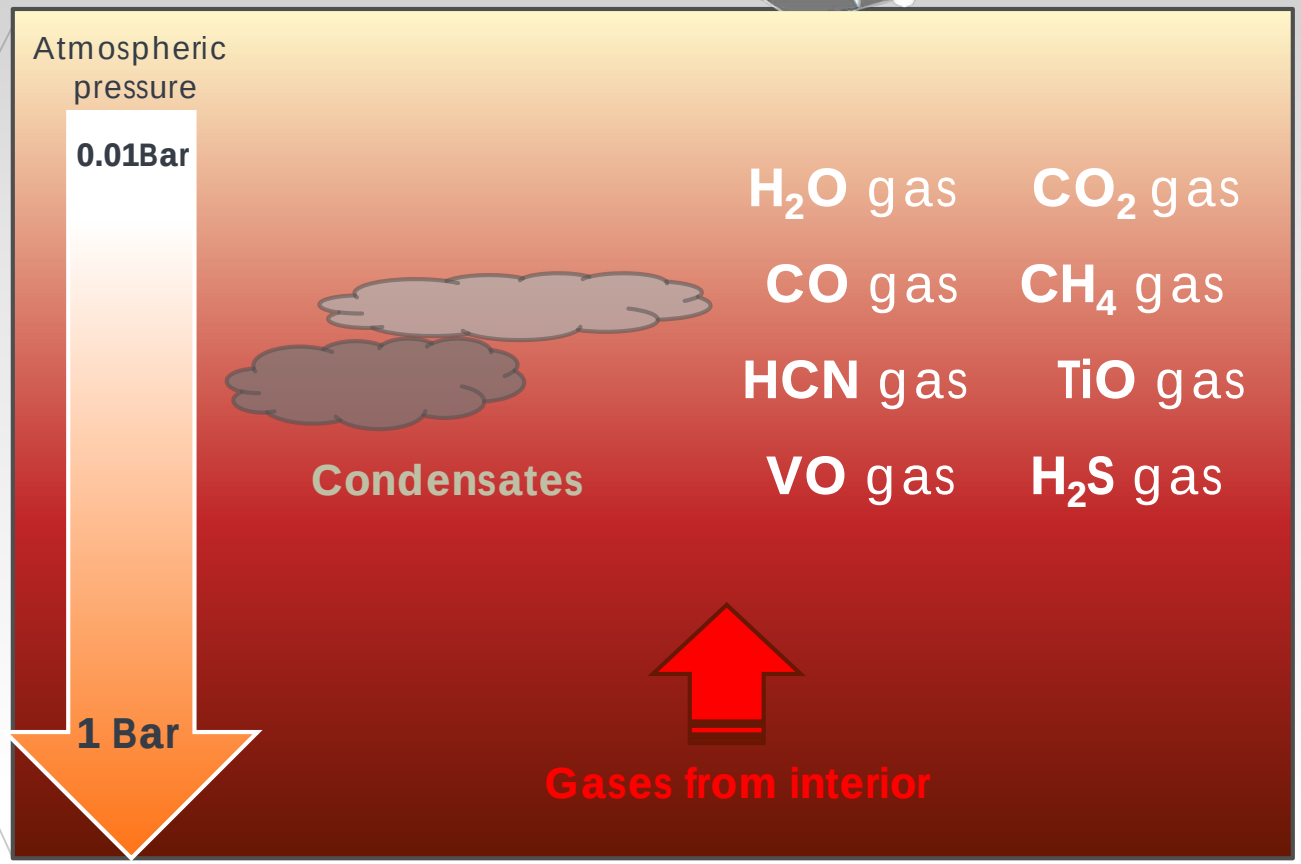
WARM/HOT EXOPLANETS

O, C, N, S (Ti, VO, Si) MOLECULES ARE IN GAS FORM



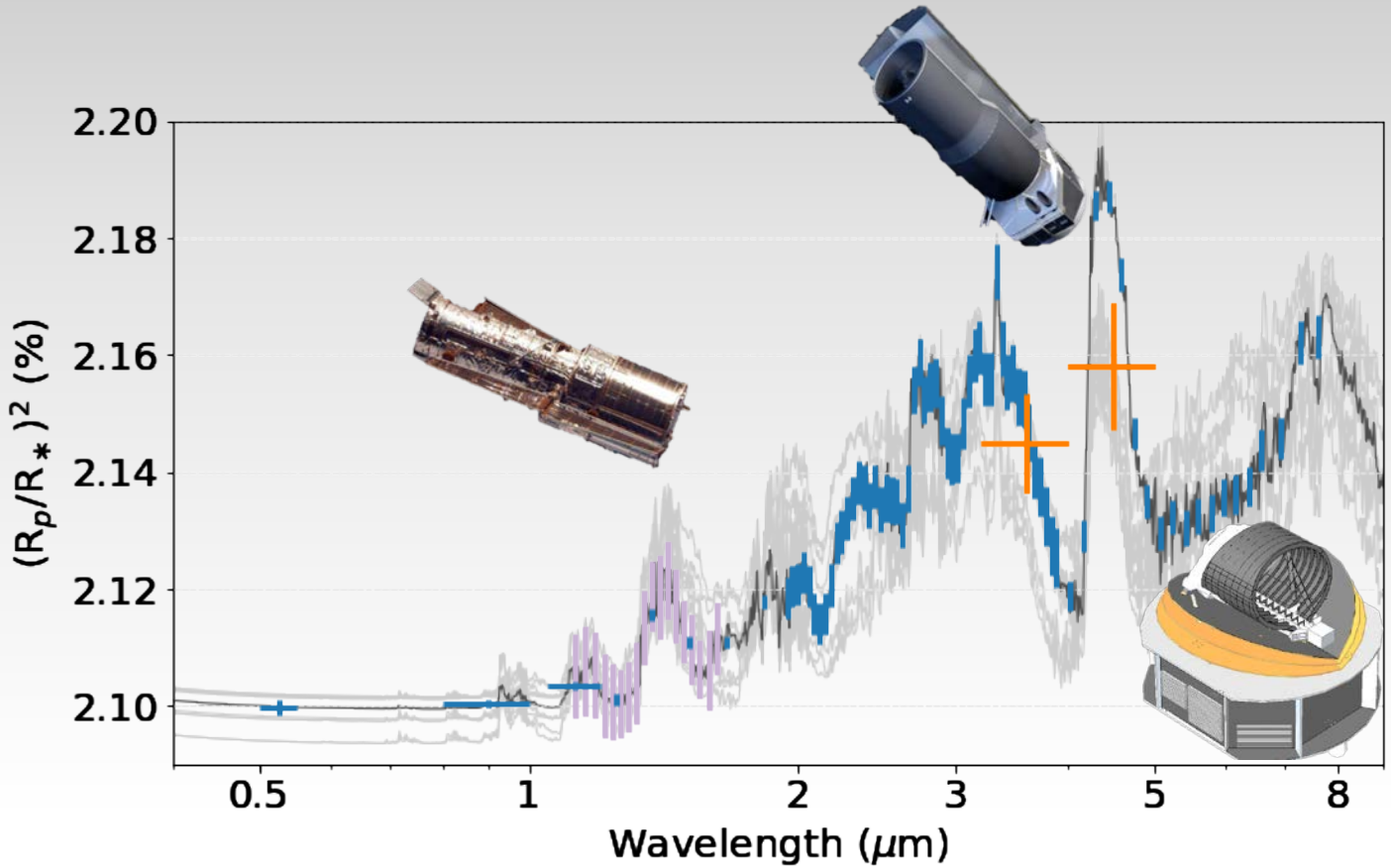


T ~ 500-2500 K



CHEMICAL MEASUREMENTS TODAY

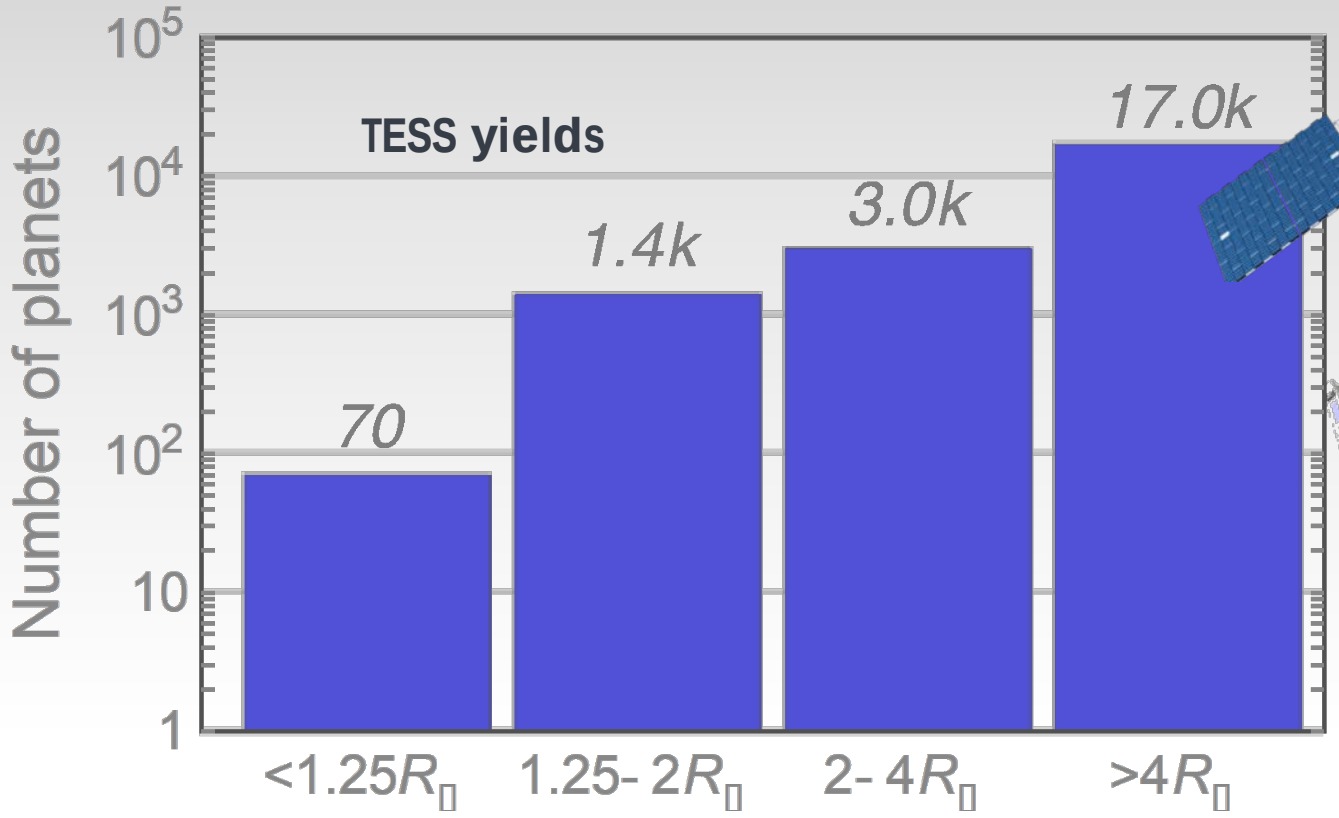
SPECTROSCOPIC OBSERVATIONS WITH CURRENT INSTRUMENTS (HUBBLE, SPITZER,SPHERE,GPI)



- Precision of 20 ppm can be reached today by Hubble-WFC3
- Current data are sparse, instruments not absolutely calibrated
- ~ 40 planets analysed
- Degeneracy of interpretation

LARGE POPULATION OF WARM/HOT PLANETS

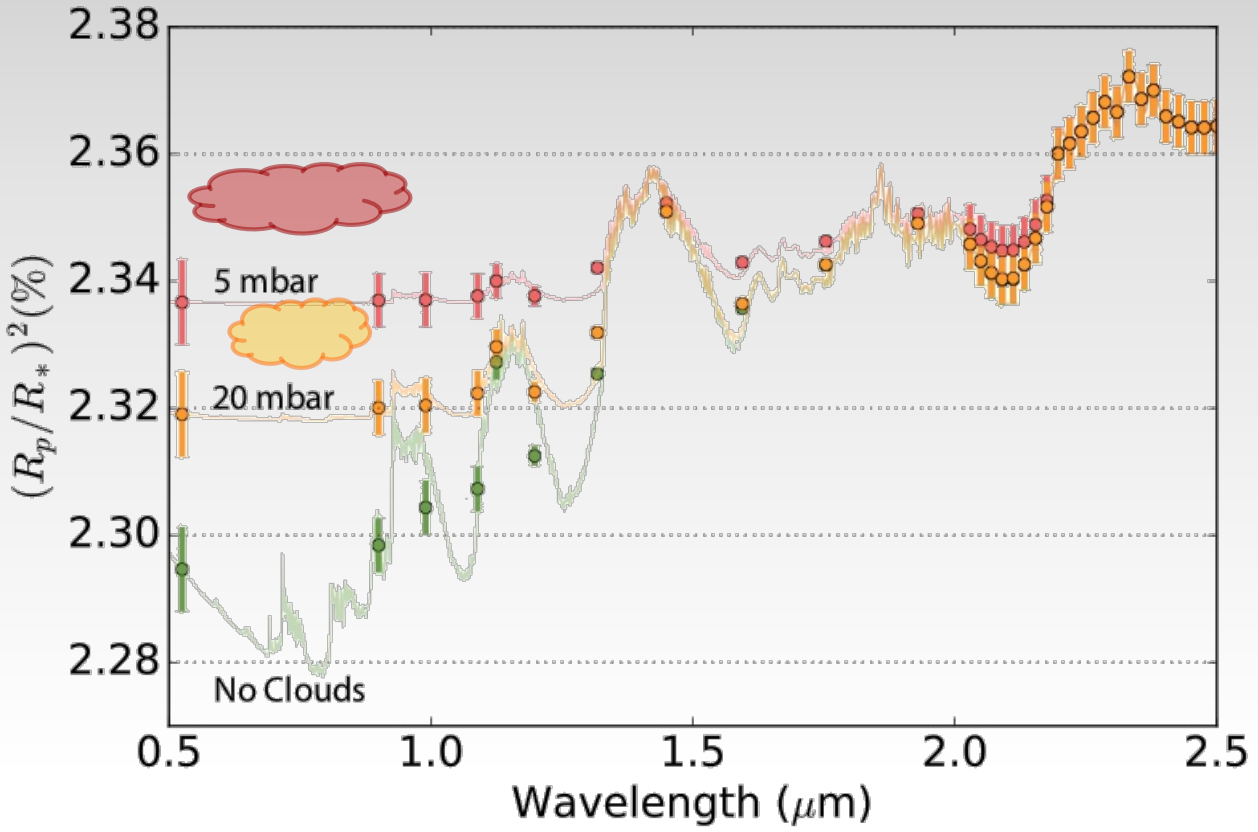
TODAY AND IN THE NEXT DECADE

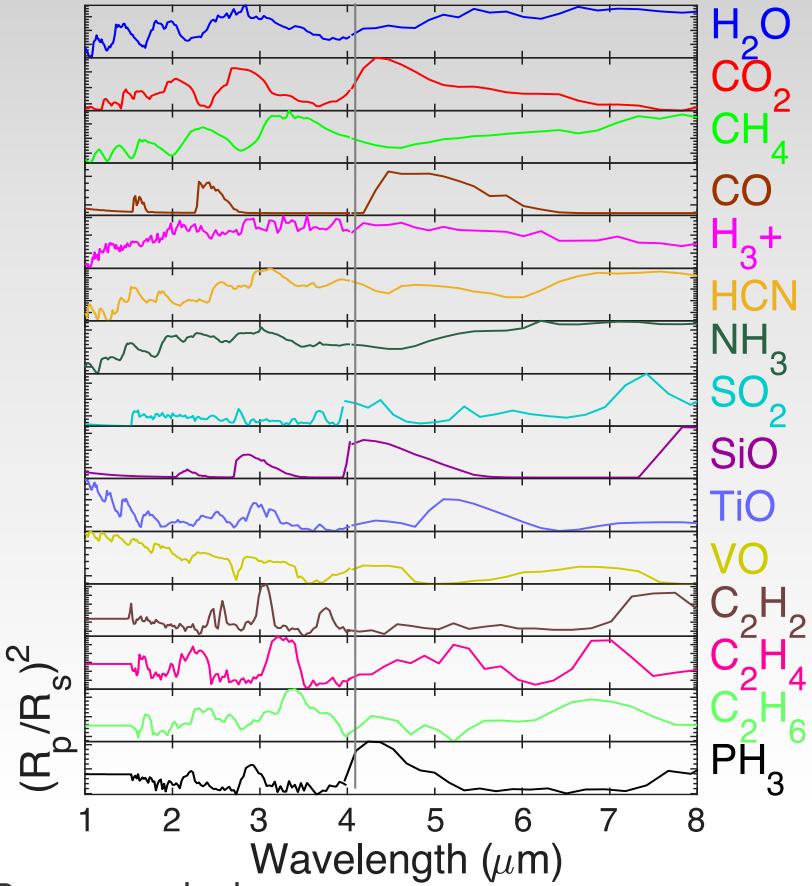


Sullivan et al., 2015

A CHEMICAL SURVEY OF A LARGE POPULATION

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

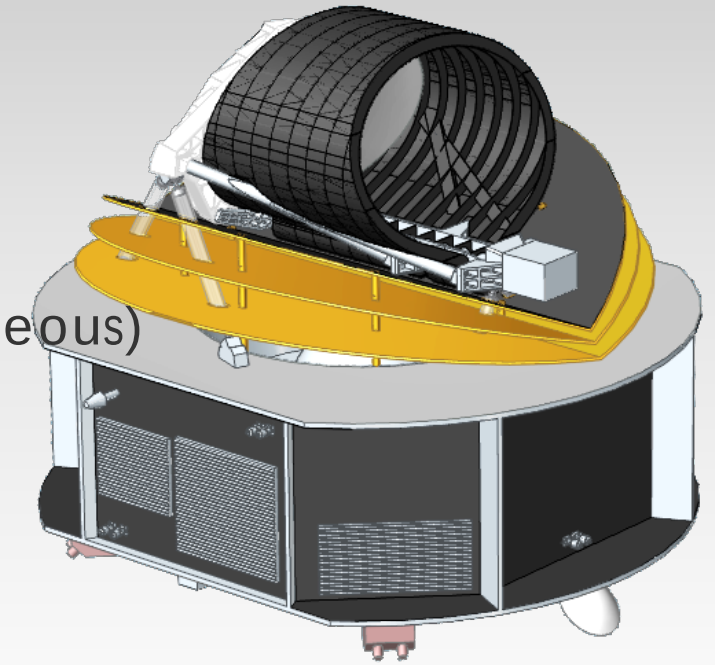




Simultaneous observations in the VIS and IR are needed

ARIEL – KEY FACTS

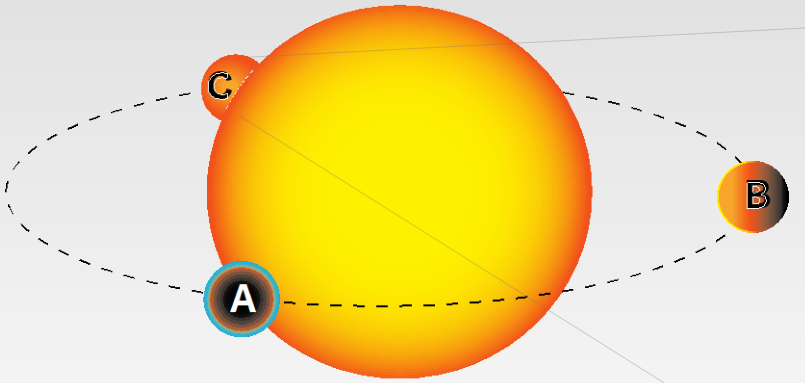
- 1-m telescope, spectroscopy from VIS to IR
- Satellite in orbit around L2
- ~1000 exoplanet atmospheres observed (rocky + gaseous)
- Simultaneous coverage 0.5-7.8 micron
- **UK-led** payload consortium: 11 ESA countries

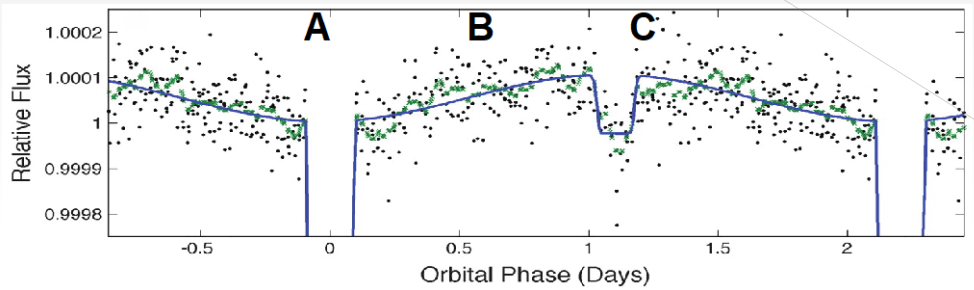


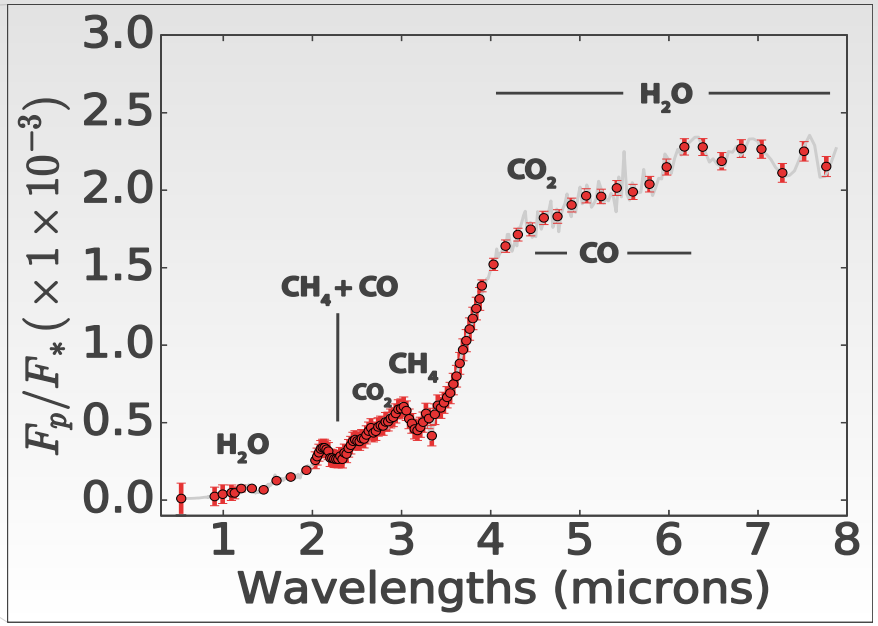
TRANSIT, ECLIPSE, PHASE-CURVE SPECTROSCOPY

AIMING AT 10 PPM STELLAR FLUX AT MULTIPLE WAVELENGTHS

Through stable instrument, external calibration & proven postprocessing analysis

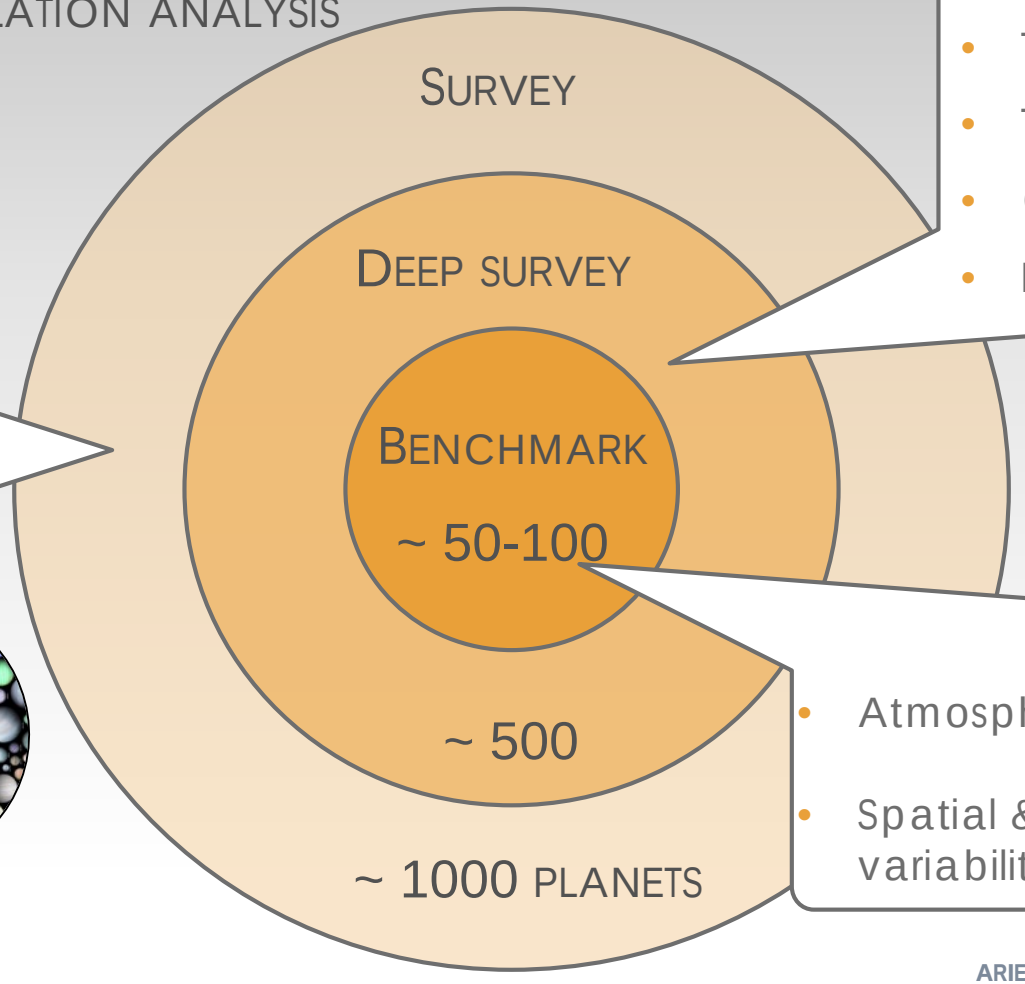




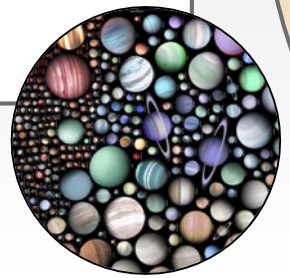


ARIEL 3-TIER APPROACH

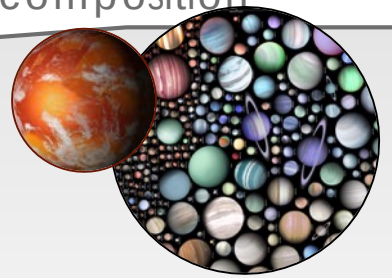
INDIVIDUAL PLANETS & POPULATION ANALYSIS



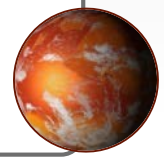
- What fraction of planets have clouds?
- Have small planets still retained H/He?
- Colour-colour diagrams
- Refinement of orbital/planet parameters in IR



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



- Atmospheric circulation
- Spatial & temporal variability

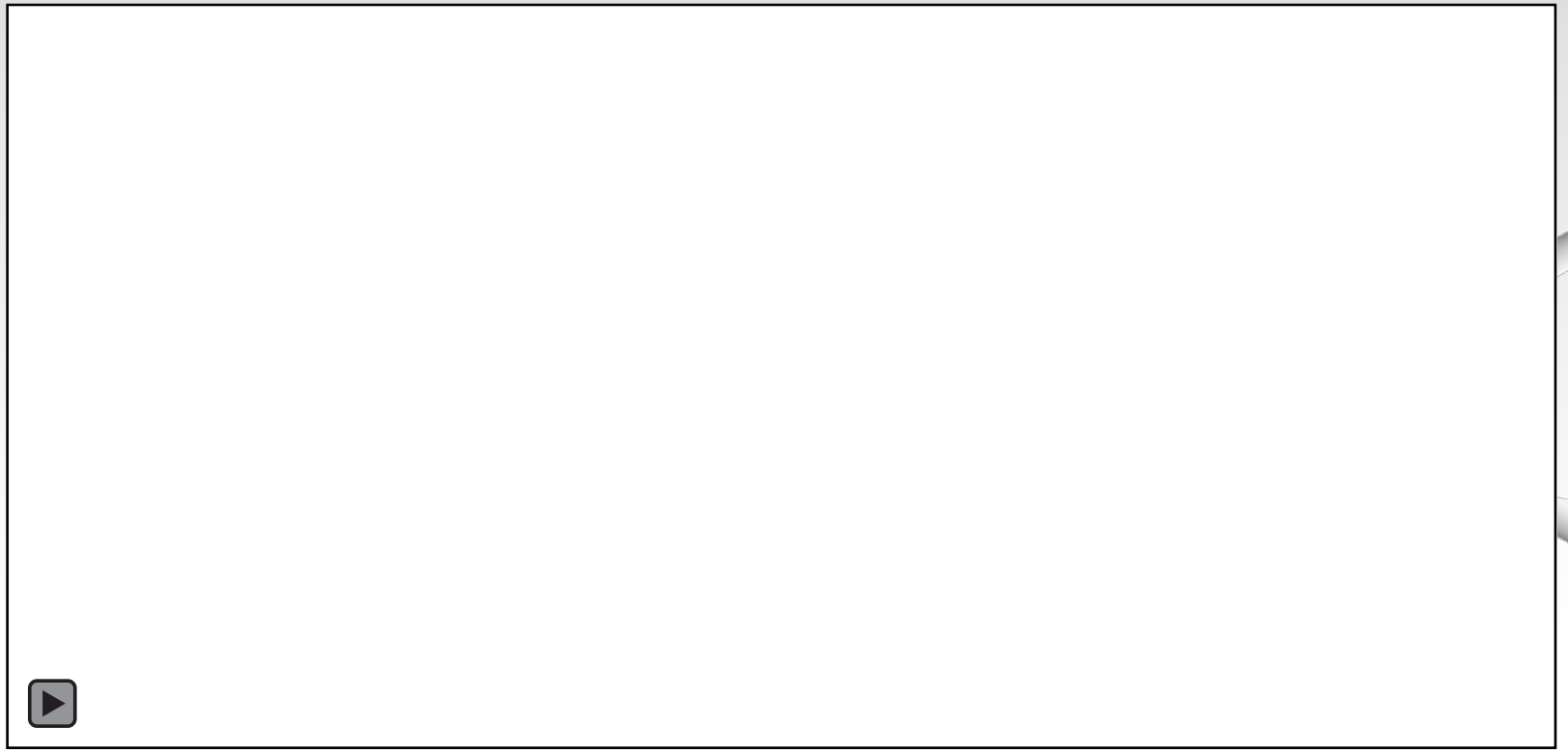


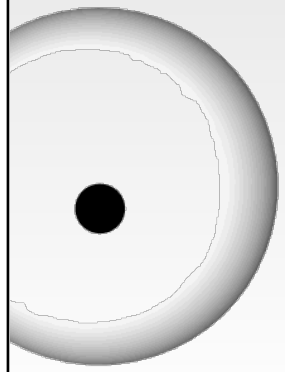
INSTANT & SHORT-TERM VARIABILITY

SIMULATIONS OF ARIEL PERFORMANCES FOR A HOT SUPER-EARTH (55 CNC E)

ARIEL phase-curve spectra, chemical composition & thermal profile

Planet orbiting around the star

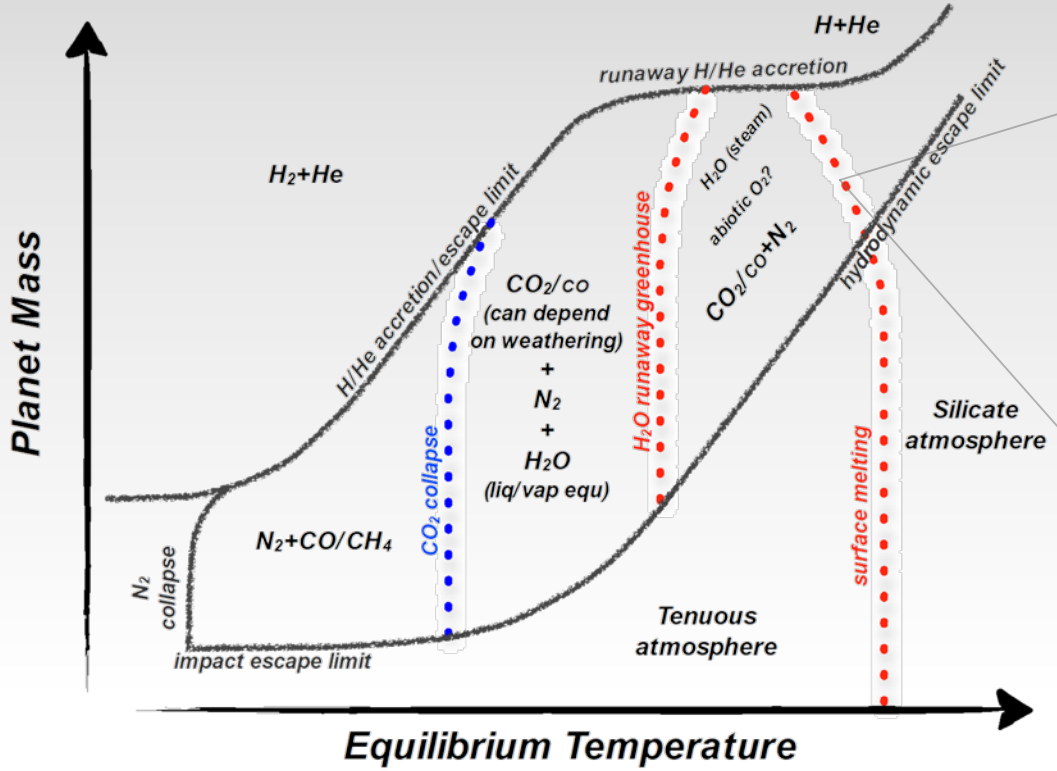




CHEMICAL DIVERSITY

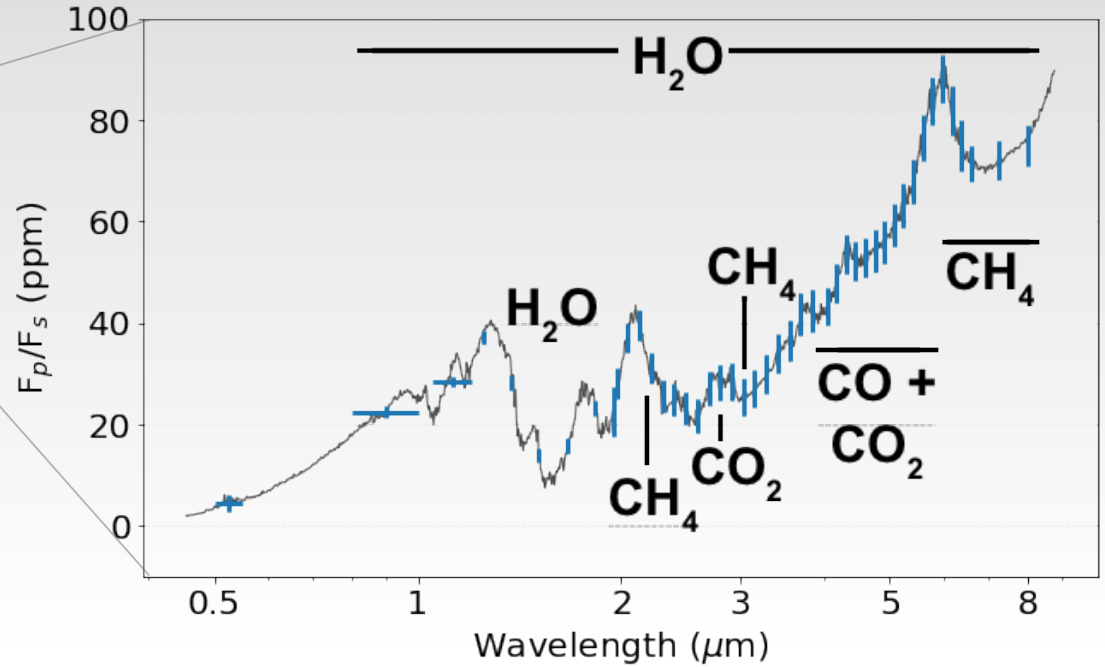
CORRELATION WITH ANY OTHER KEY PARAMETERS?

Is this plot true? Where are the transitions?



Forget & Leconte, 2013

ARIEL observations x 1000 planets

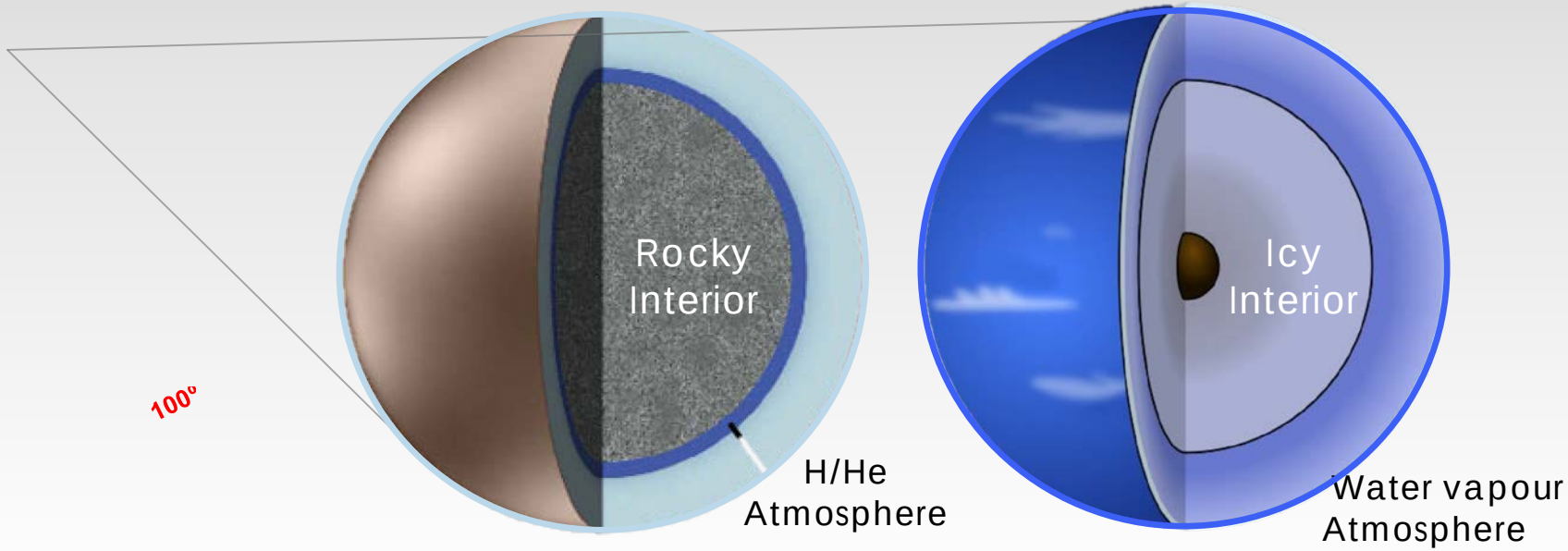


CHEMICAL DIVERSITY

ARIEL WILL CLARIFY CORRELATION WITH THE DENSITY

Density observations

Atmospheric composition through ARIEL will clarify the degeneracy



<u>Same</u> mean density – <u>Different</u> atmospheric signatures

Lopez Morales et al. 2016; Valencia et al., 2013

TERRESTRIAL-SUBNEPTUNES TRANSITION

ARE SUPER-EARTHS BIG TERRESTRIAL PLANETS, SMALL NEPTUNES? IS H/HE STILL THERE?

Formation scenarios for small planets

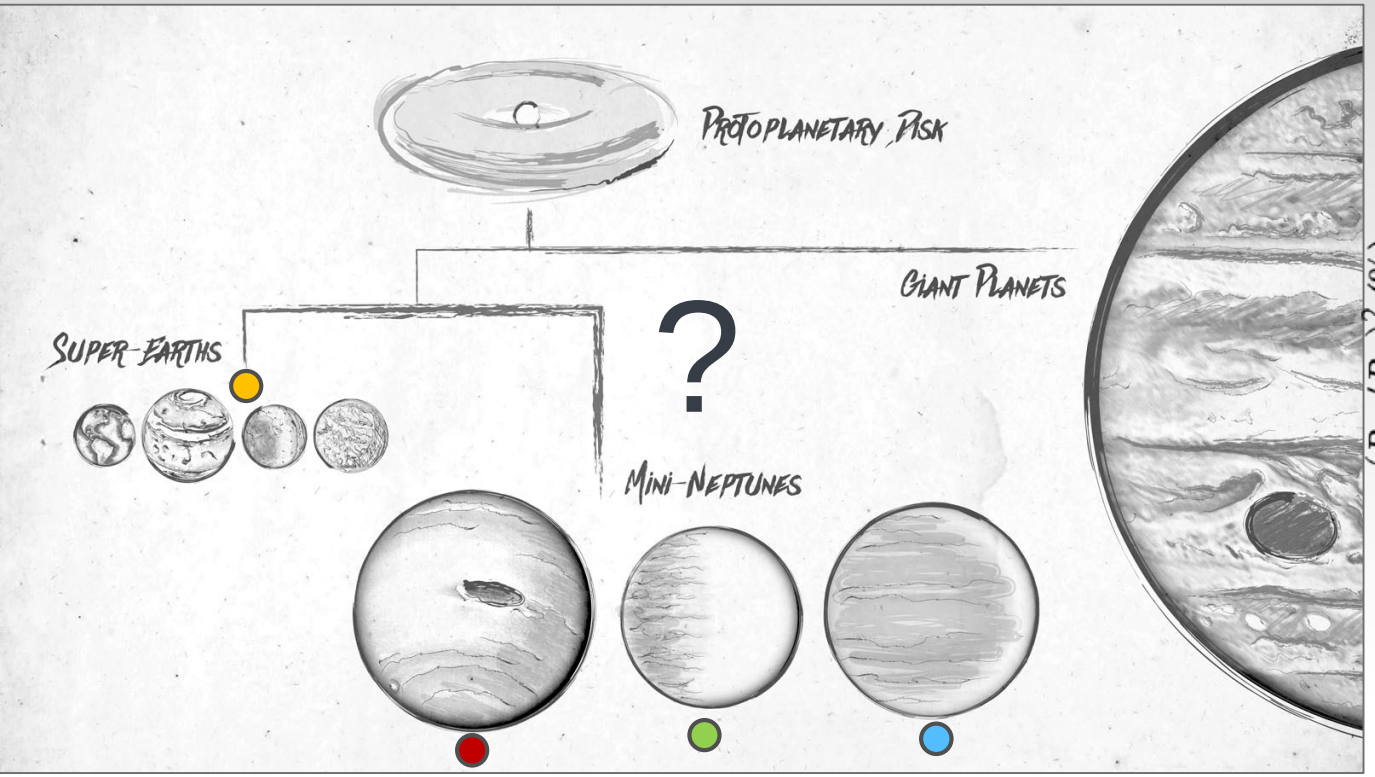
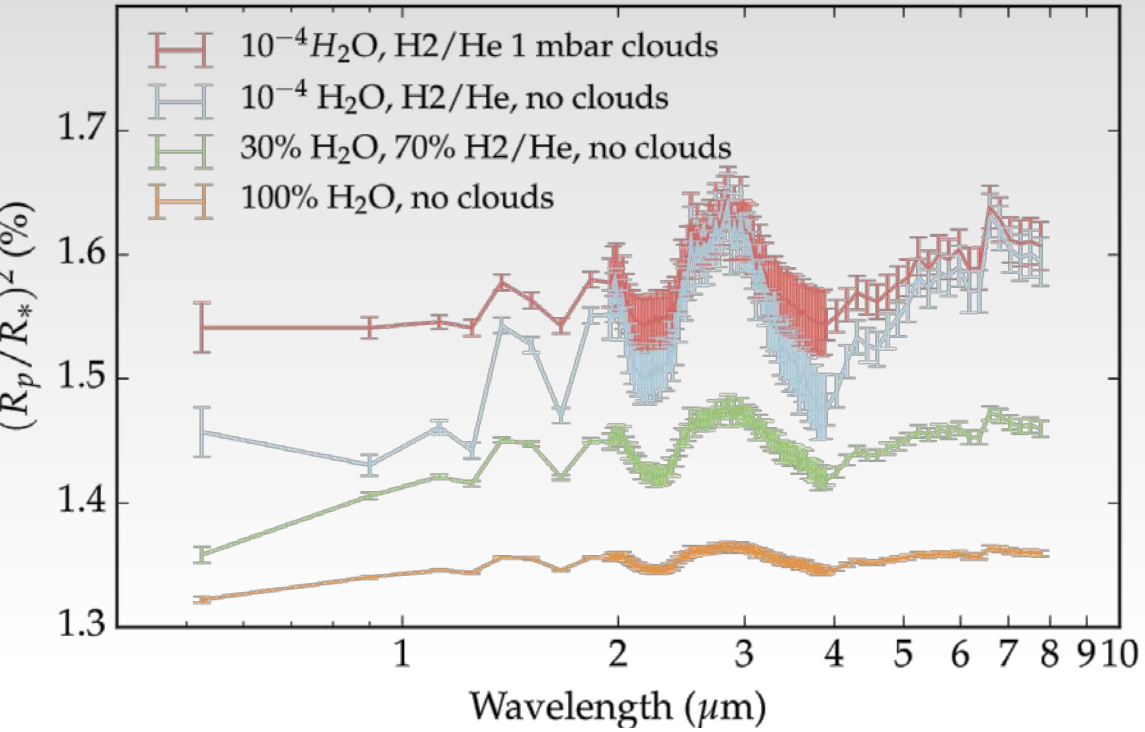


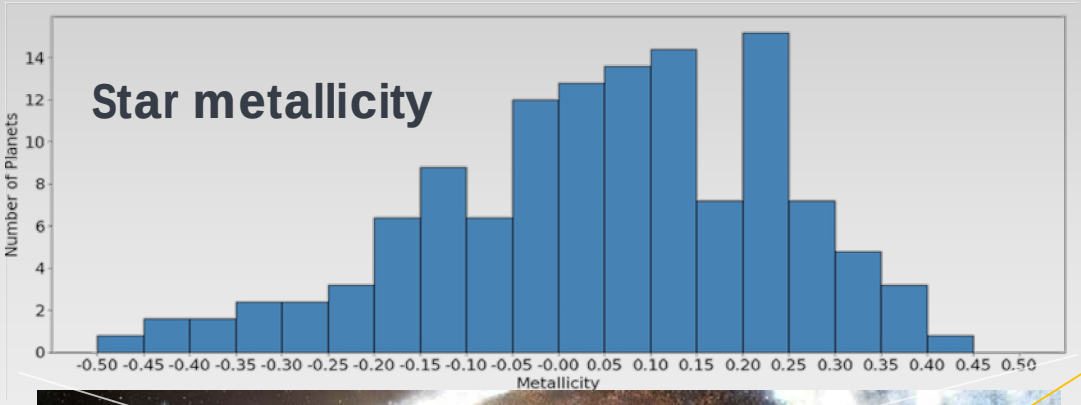
Image credit NASA/Kepler/Caltech (T Pyle). Simulations using Tau-Rex and ExoSim

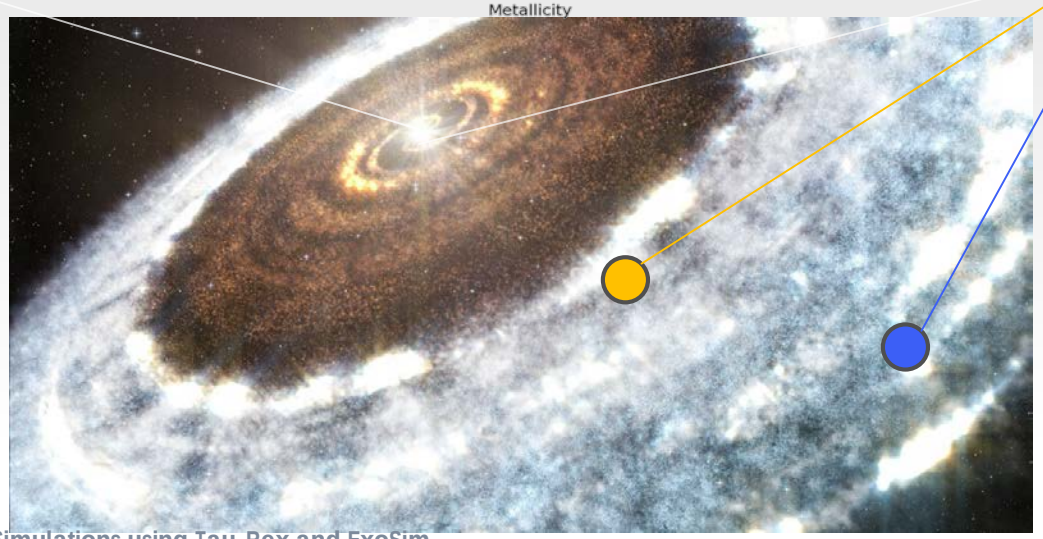
ARIEL observations for small planets



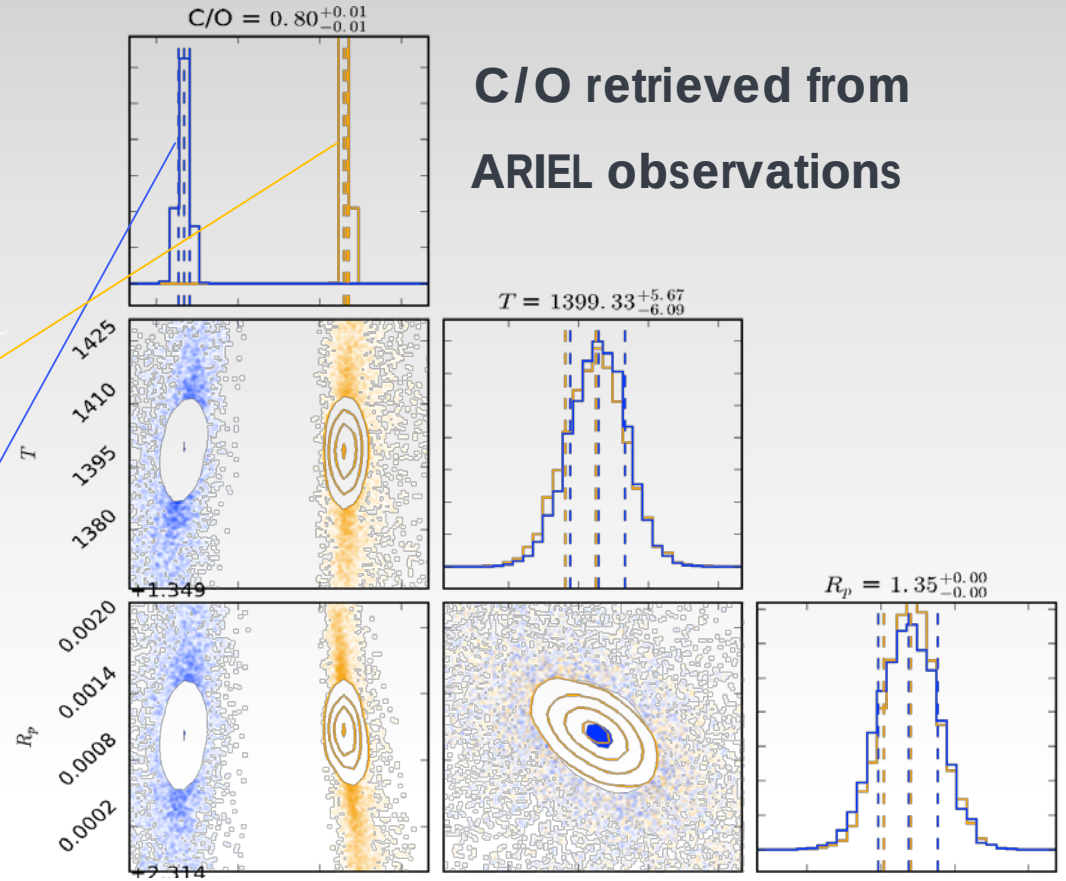
IS ELEMENTAL COMPOSITION CORRELATED …

…TO EXOPLANET PROVENANCE OR STELLAR METALLICITY?





Simulations using Tau-Rex and ExoSim

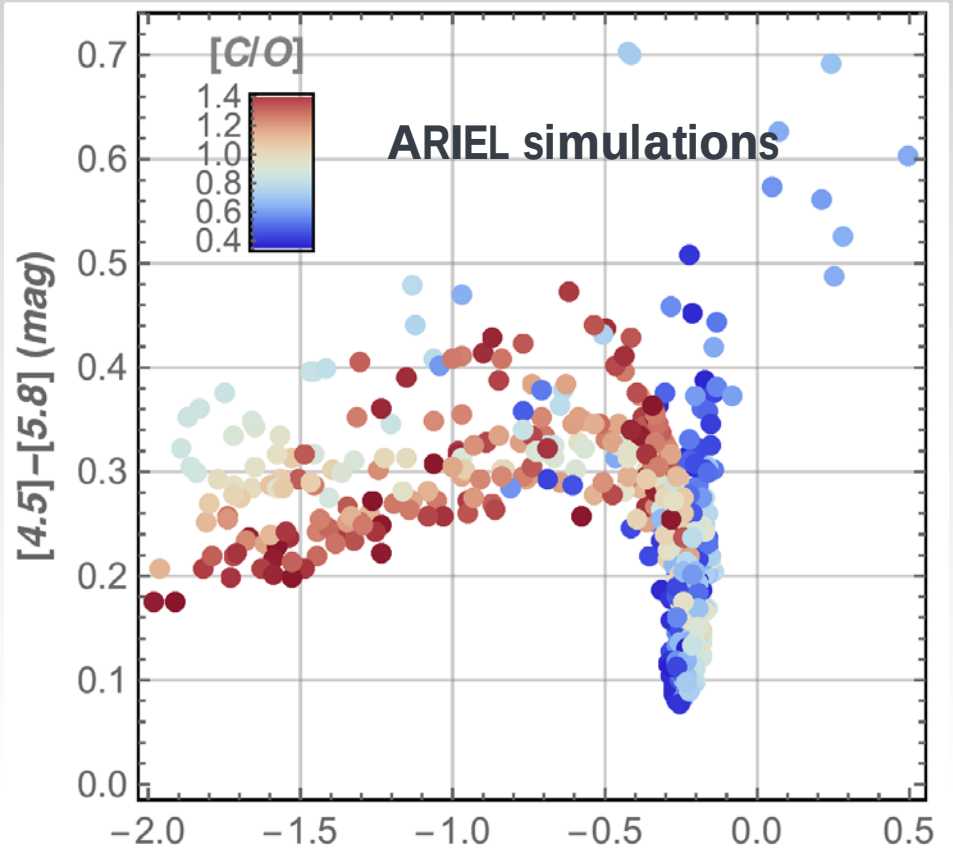


C/O retrieved from ARIEL observations

POPULATION ANALYSIS

COLOUR-MAGNITUDE DIAGRAMS, CLOUD-CHARACTERISATION

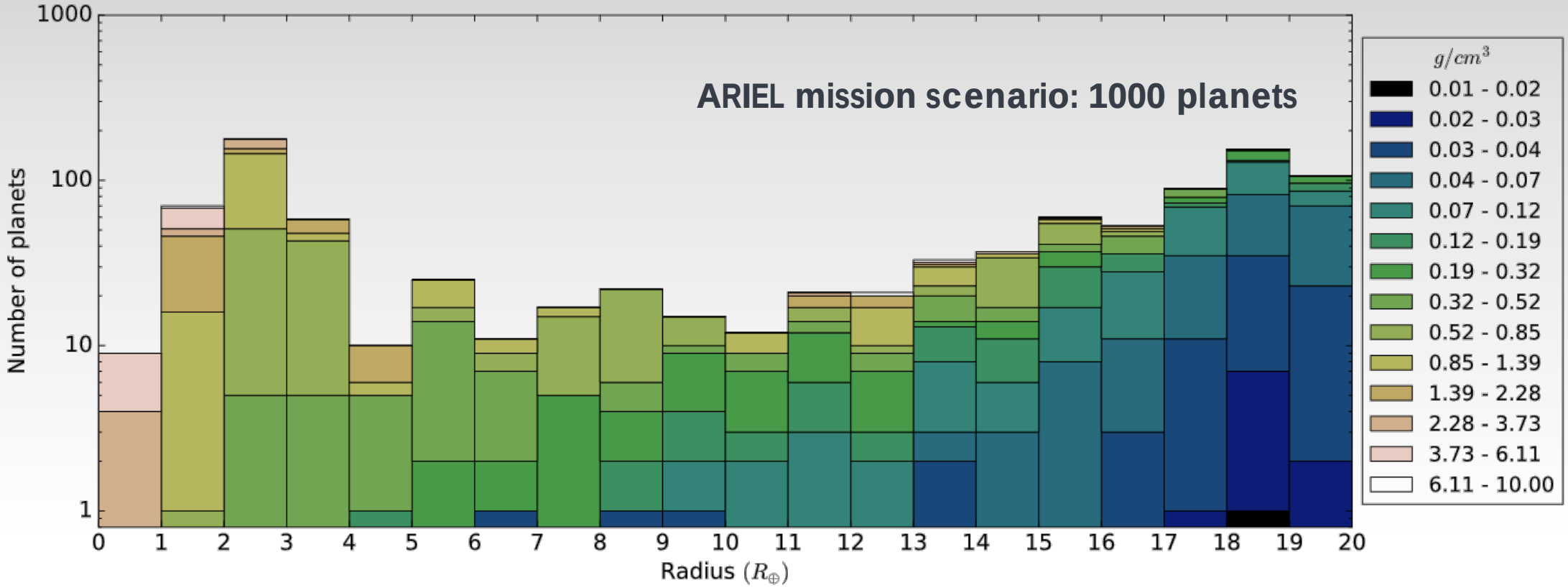
- Colour-colour diagrams and colour-magnitude diagrams in the IR and VIS will allow to identify **families of planets**



Simulations using approach and data from: Triaud 2015; Moliere et al., 2016

DIVERSITY PROBED IN ARIEL CORE SAMPLE

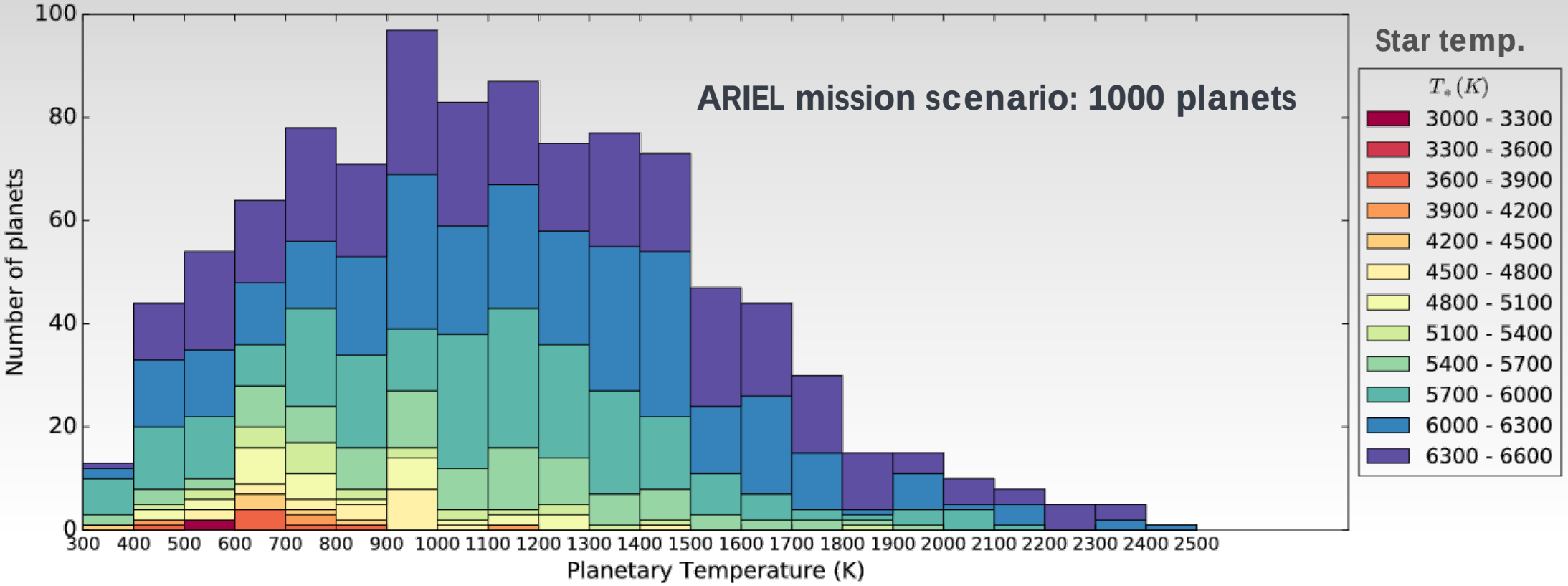
PLANET SIZE, DENSITY, TEMPERATURE, STAR TYPE, METALLICITY



Zingales et al., 2017

DIVERSITY PROBED IN ARIEL CORE SAMPLE

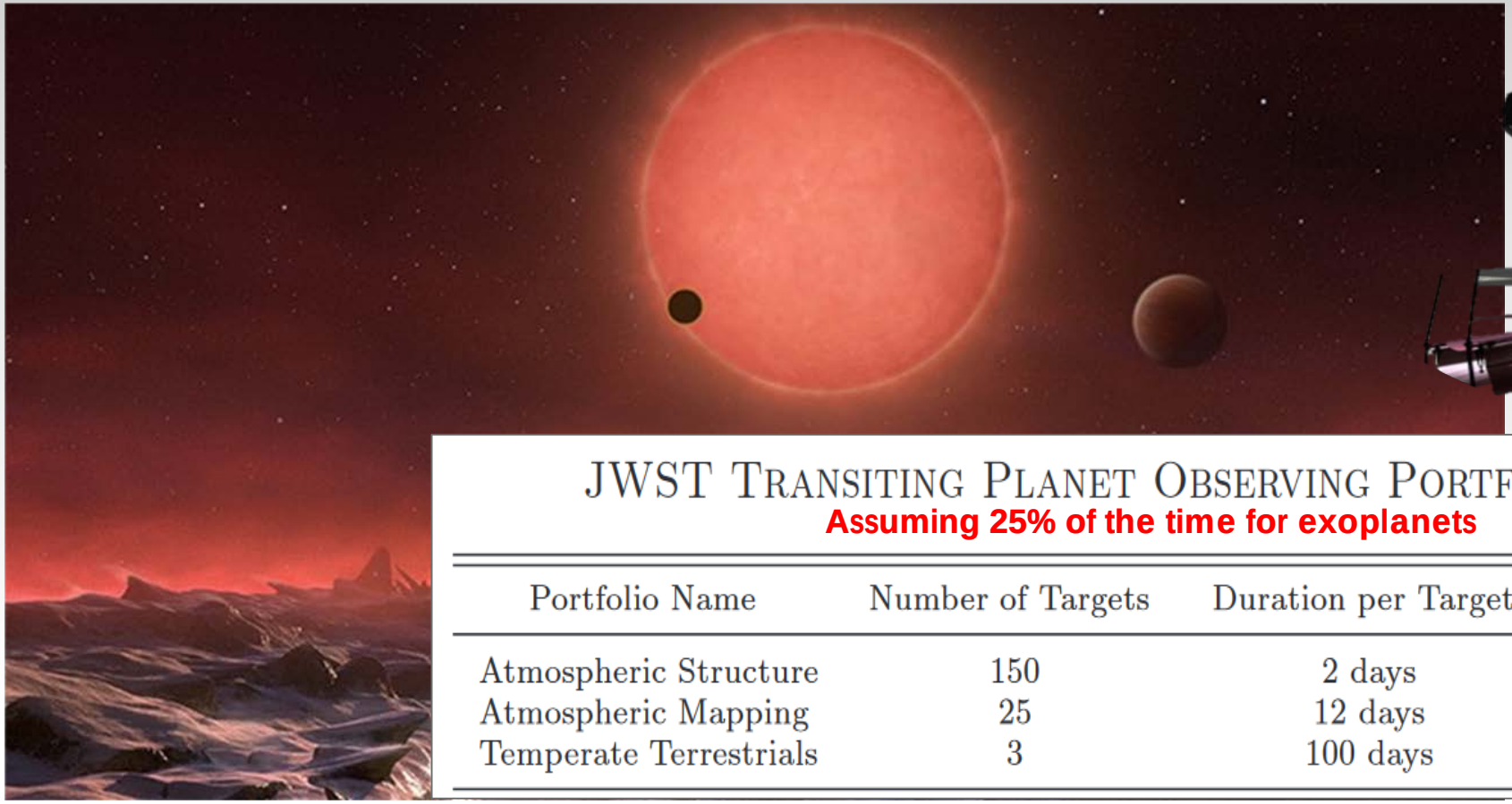
PLANET SIZE, DENSITY, **TEMPERATURE, STAR TYPE**, METALLICITY

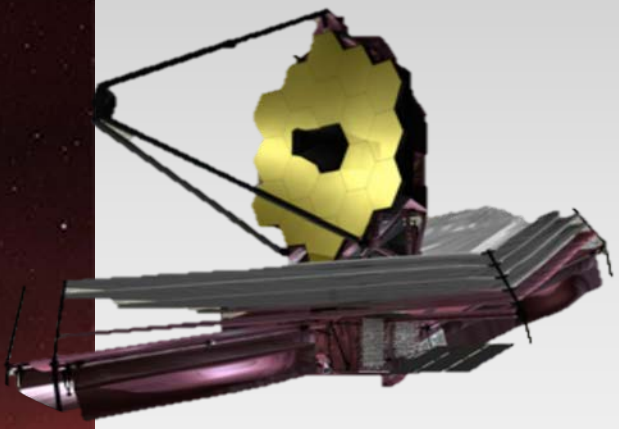


Zingales et al., 2017

SYNERGIES/COMPLEMENTARITIES WITH JWST

JWST CANNOT OBSERVE 1000 PLANETS





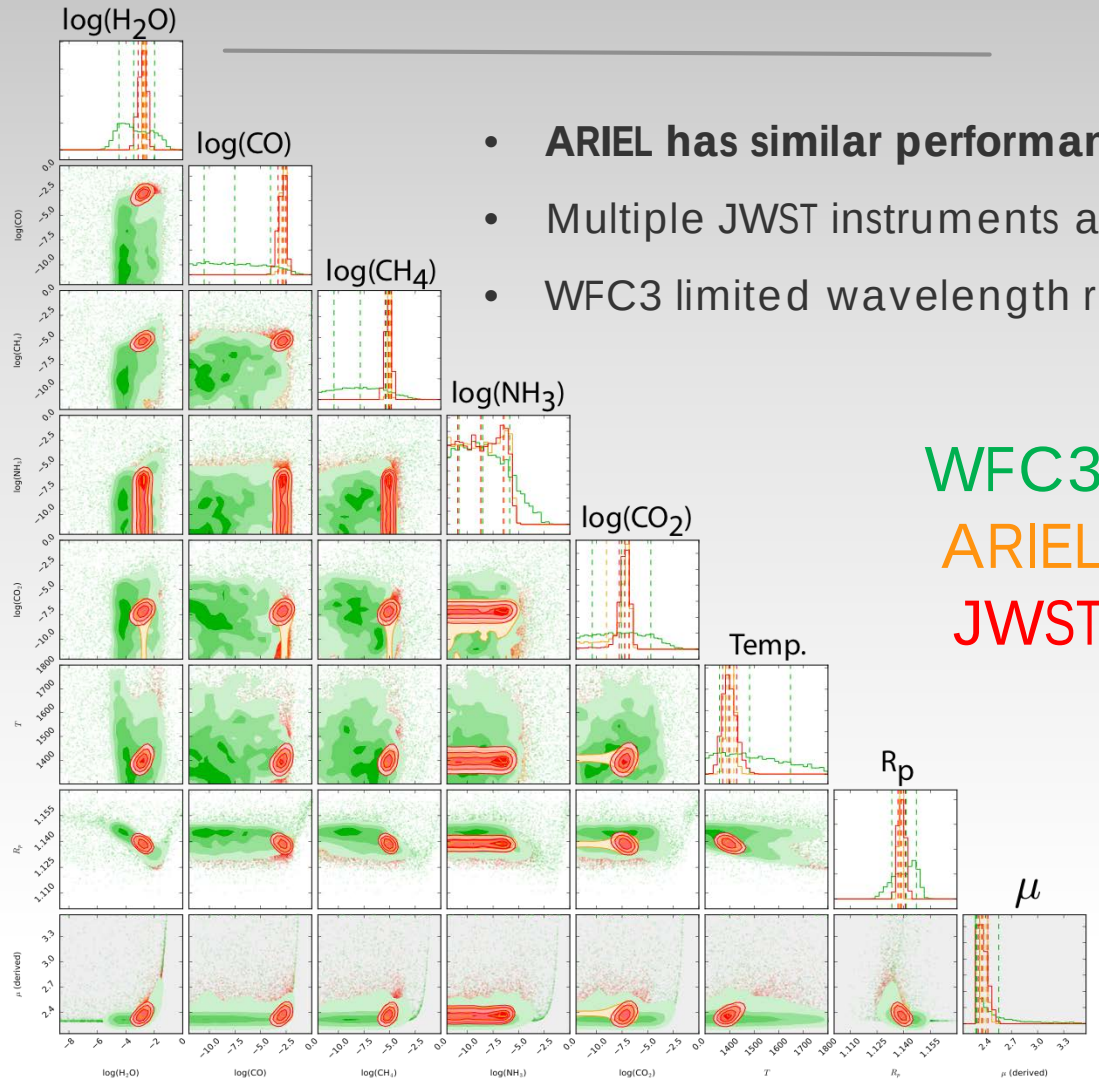
JWST TRANSITING PLANET OBSERVING PORTFOLIOS

Assuming 25% of the time for exoplanets

Portfolio Name	Number of Targets	Duration per Target	Total Time
Atmospheric Structure	150	2 days	300 days
Atmospheric Mapping	25	12 days	300 days
Temperate Terrestrials	3	100 days	300 days

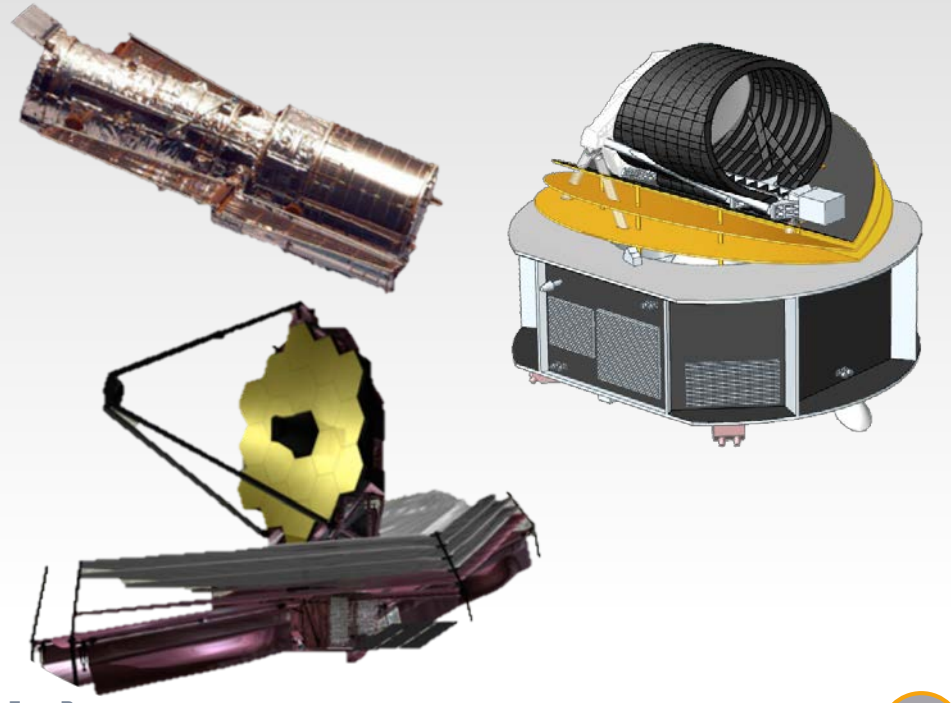
Cowan et al. 2015

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

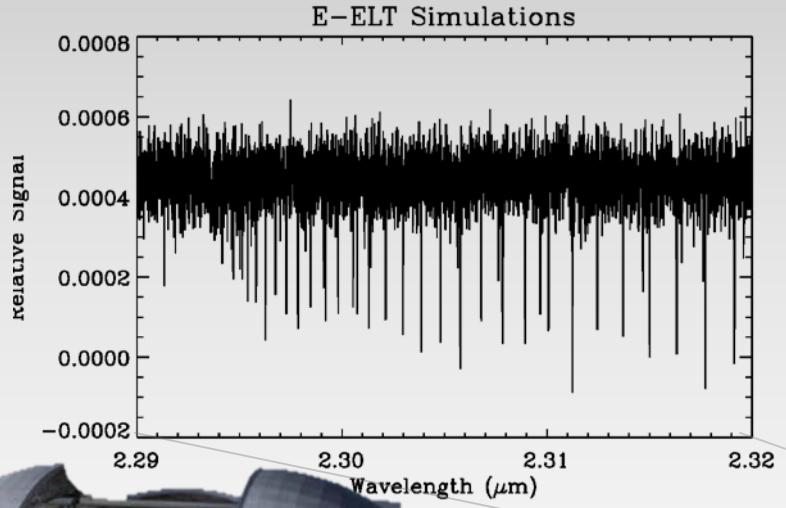
WFC3
ARIEL
JWST

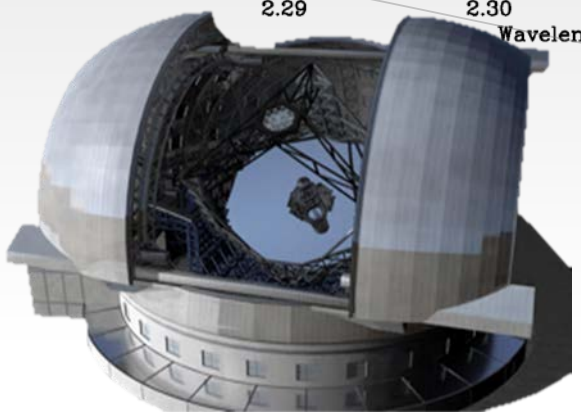


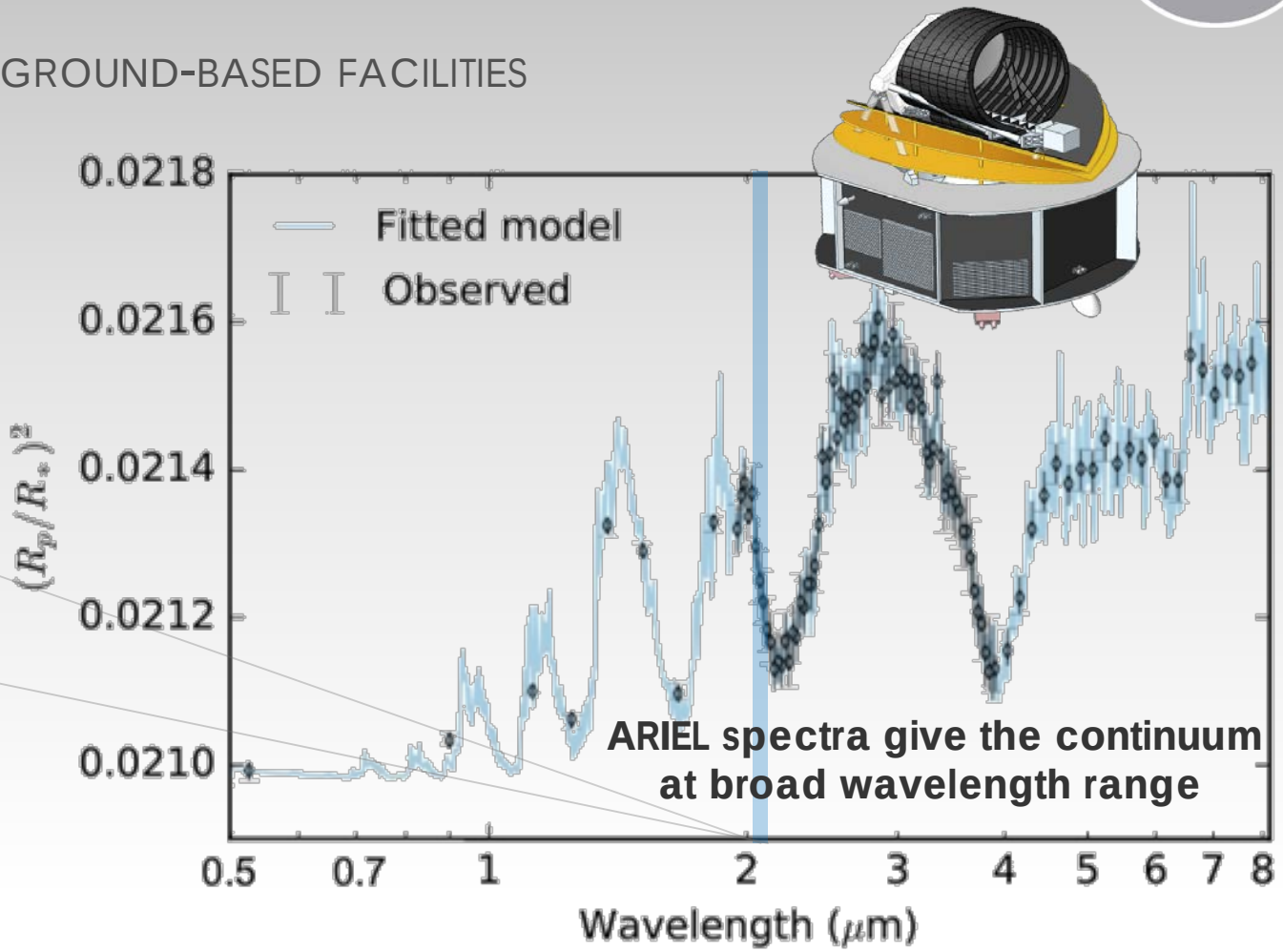
Simulations using Tau-Rex

SYNERGIES/COMPLEMENTARITIES WITH ELT

HIGHLY COMPLEMENTARY TO LARGE, GROUND-BASED FACILITIES

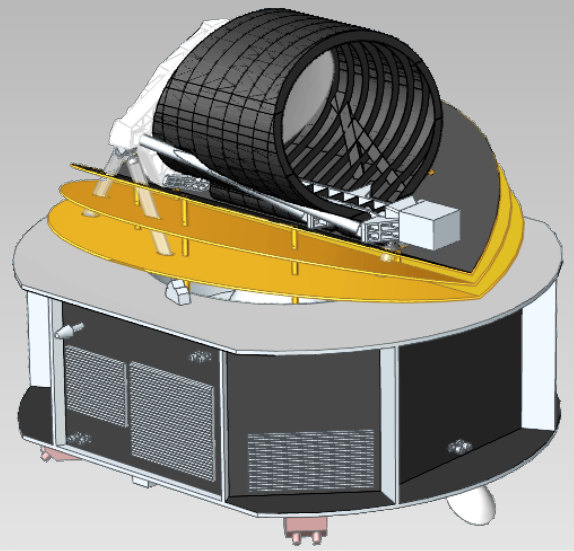






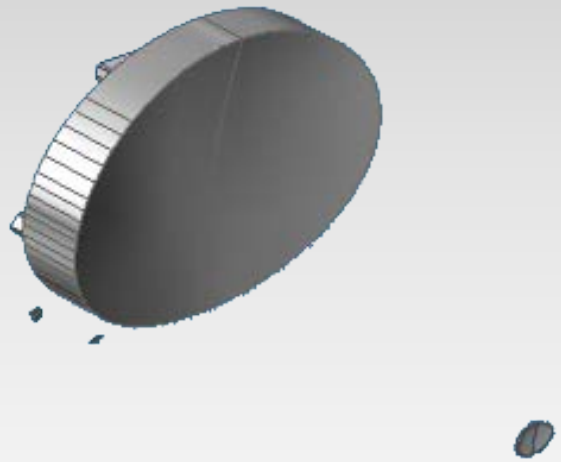
ARIEL – KEY REQUIREMENTS

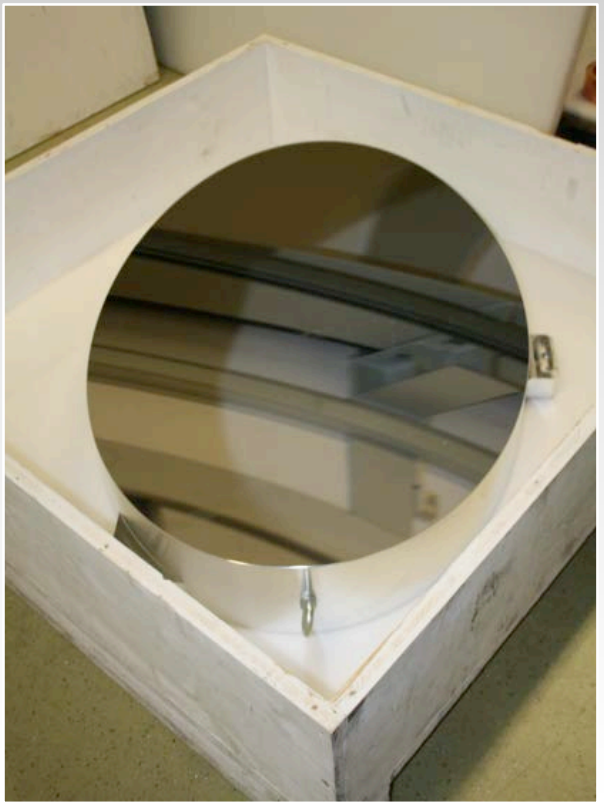
- > 0.6m^2 collecting area telescope, high throughput
- Diffraction limited performance beyond 3 microns; minimal FoV required
- Observing efficiency of > 85%
- Brightest Target: K_{mag} = 3.25 (HD219134);
- Faintest target: K_{mag} = 8.8 (GJ1214)
- Photon noise dominated
- Temporal resolution of 90 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.



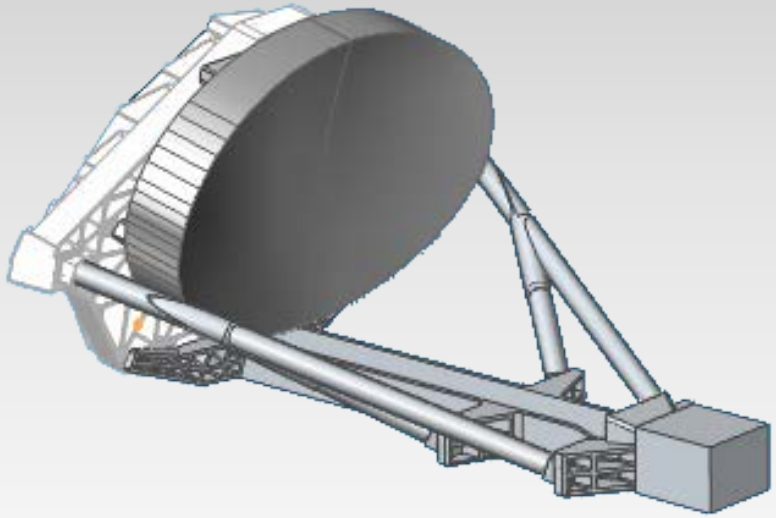
Channel Name	Wavelength (μm)	Spectral Resolution Reqt / Design
VisPhot	0.5 – 0.55	Photometer
FGS-1	0.8 – 1.0	Photometer
FGS-2	1.05 – 1.2	Photometer
NIRSpec	1.25 – 1.95	R≥10 / 20 – 25
AIRS-Ch0	1.95 – 3.9	R≥100 / 102 – 180
AIRS-Ch1	3.9 – 7.8	R≥30 / 30 – 64

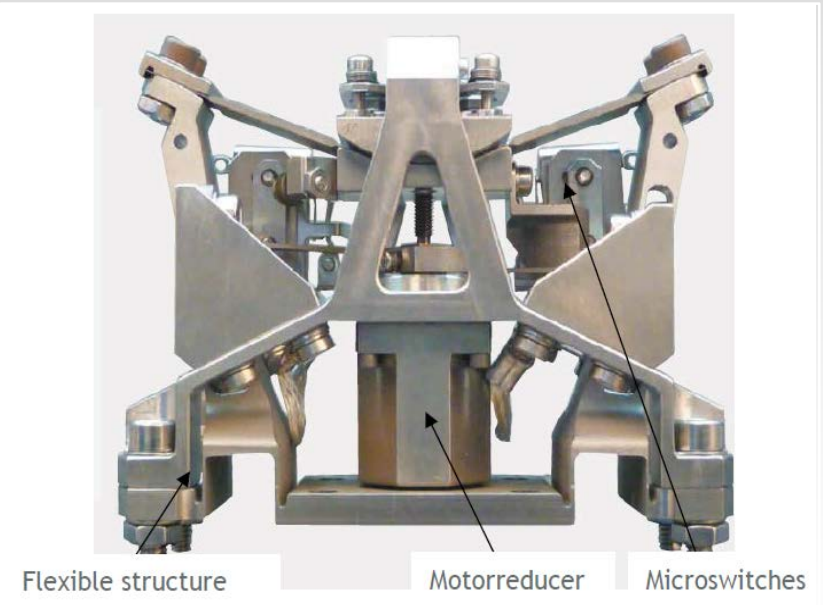
ARIEL – PAYLOAD & S/C CONFIGURATION



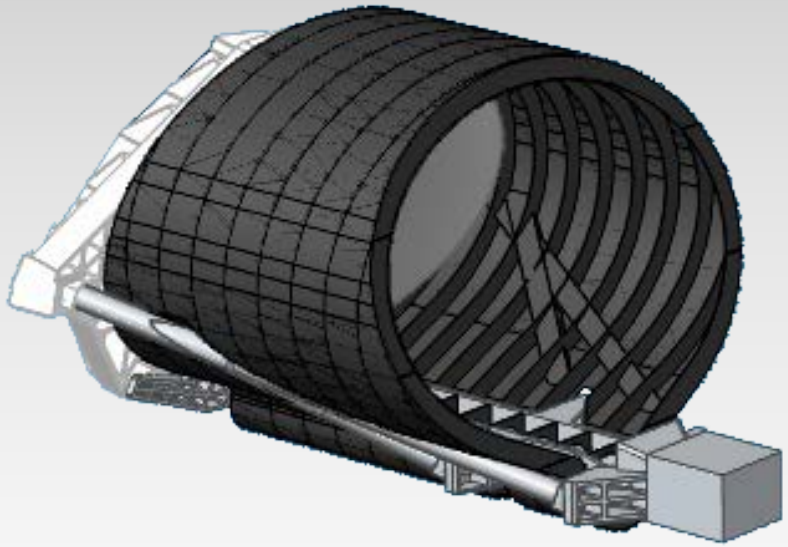


ARIEL – PAYLOAD & S/C CONFIGURATION





ARIEL – PAYLOAD & S/C CONFIGURATION



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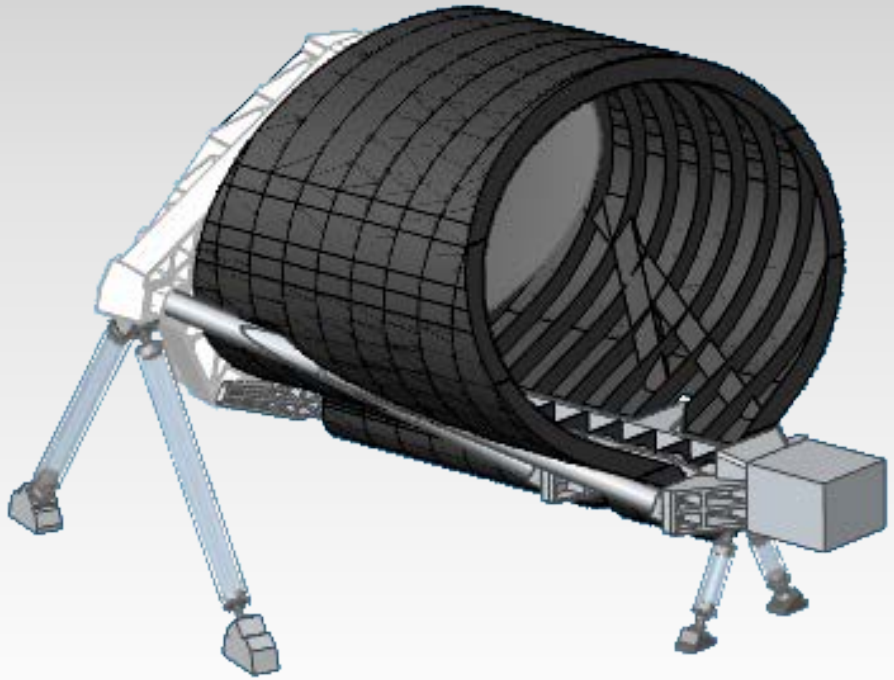

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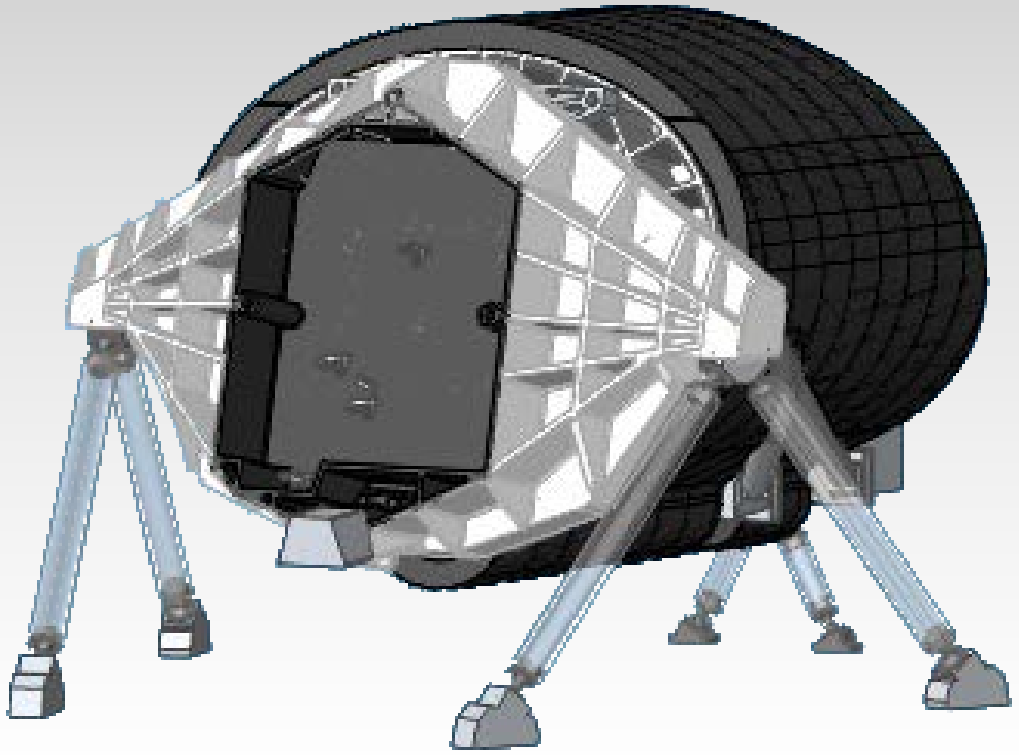

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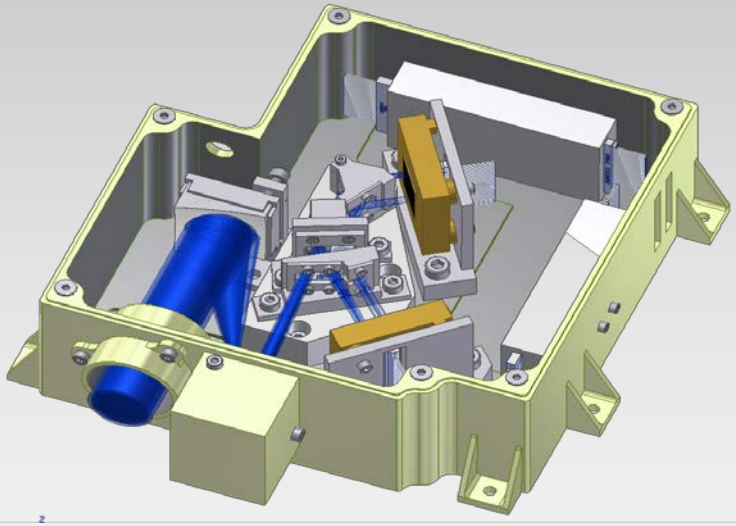

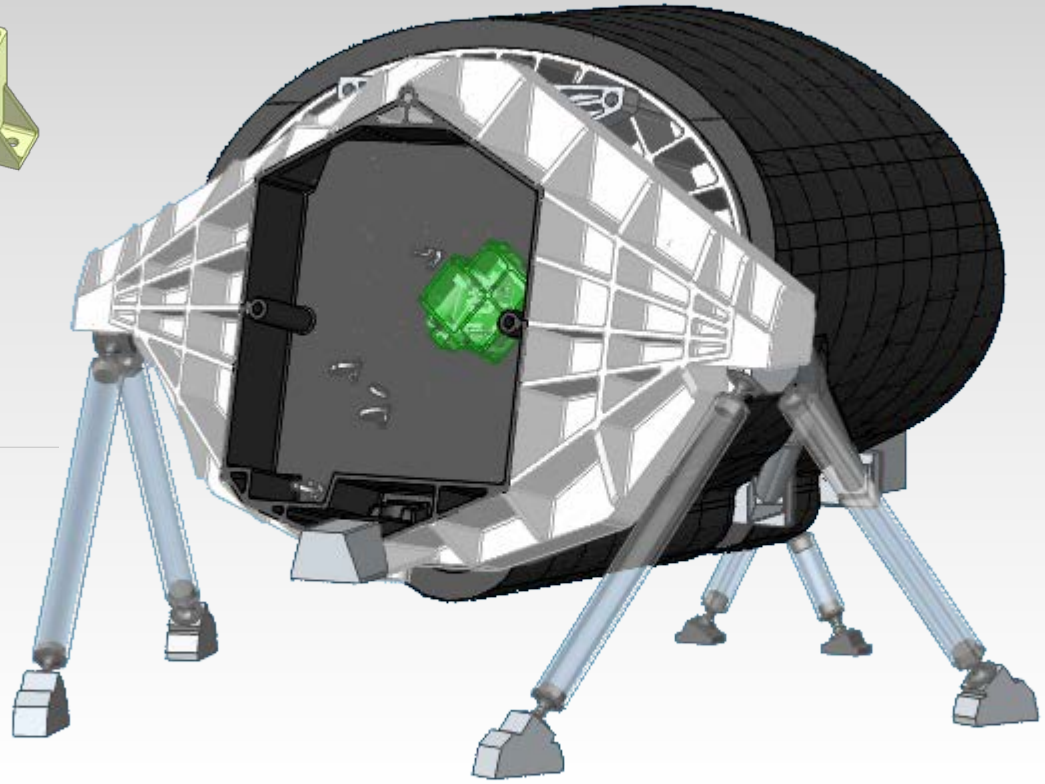

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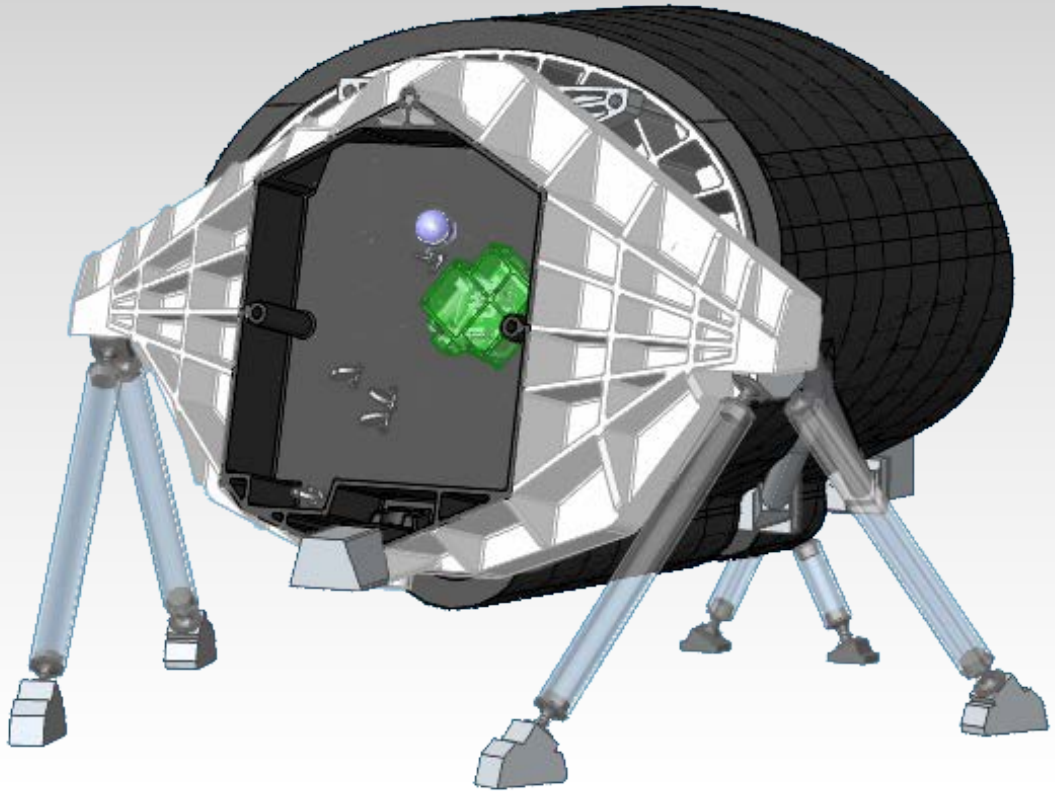

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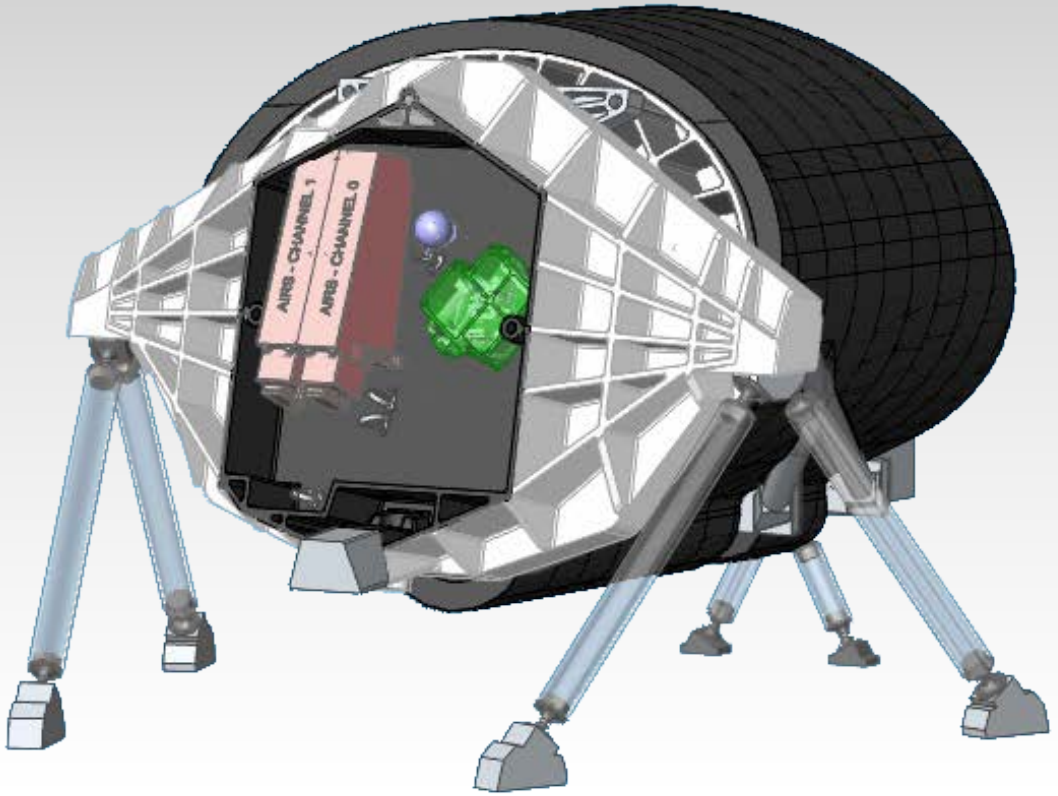

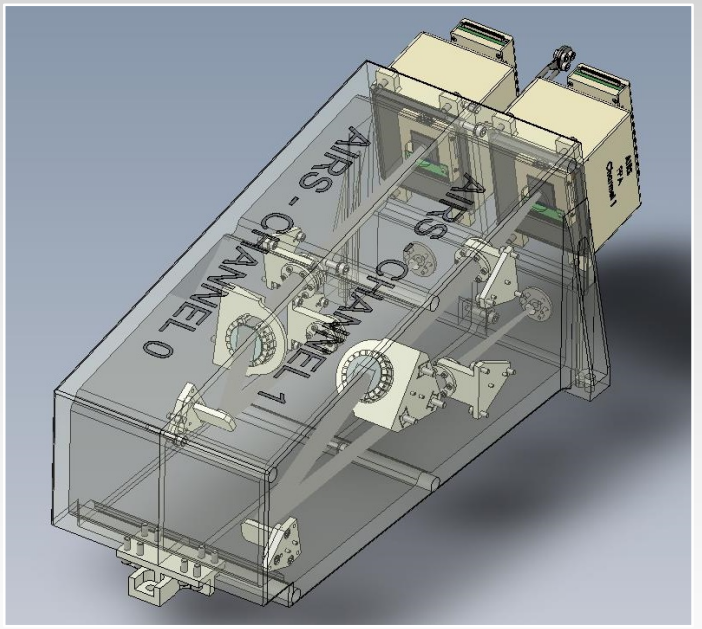

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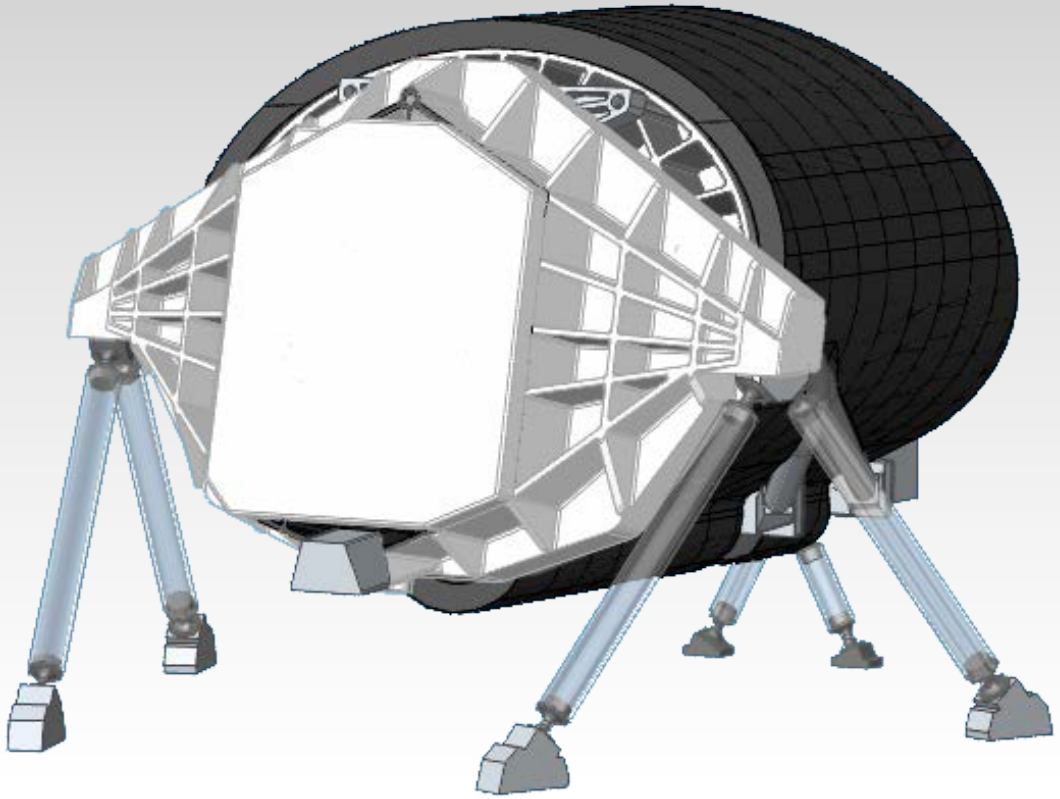

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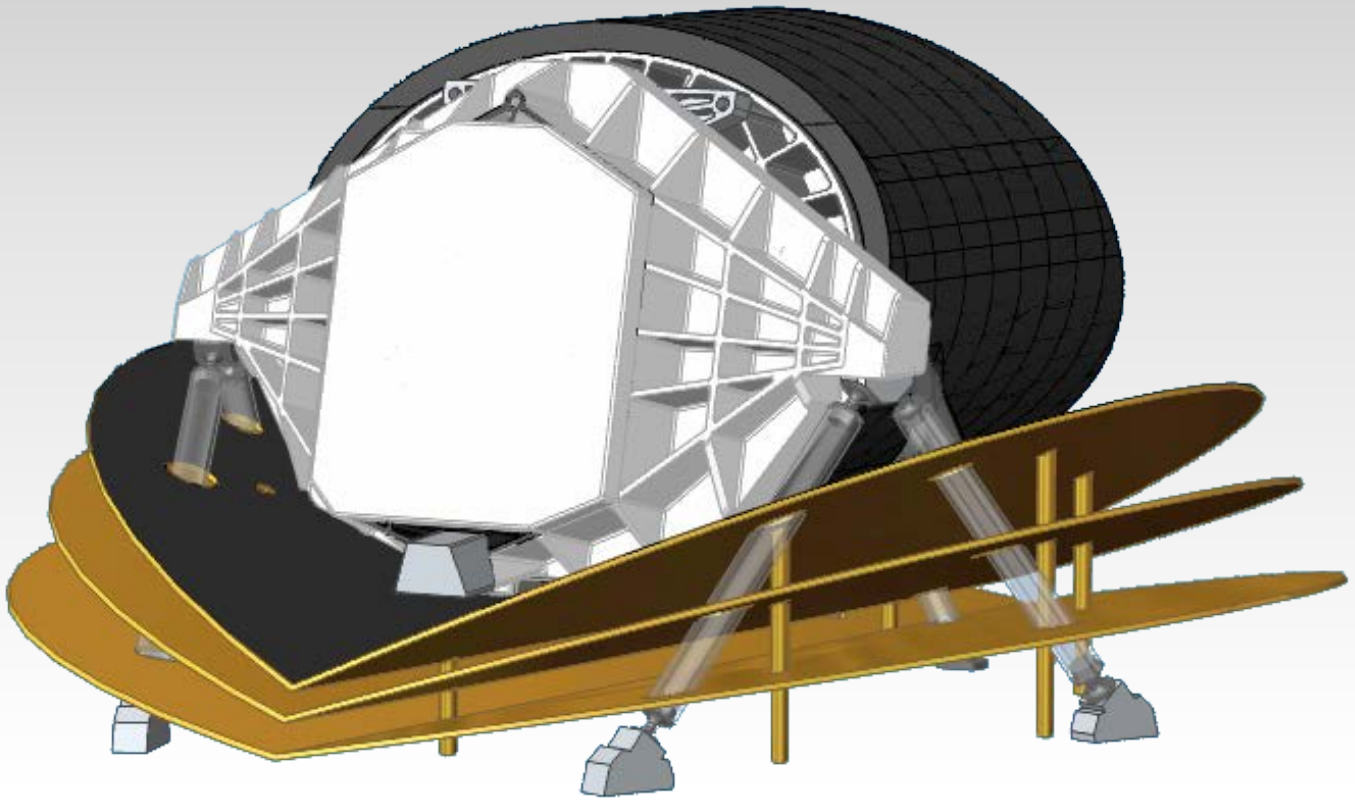

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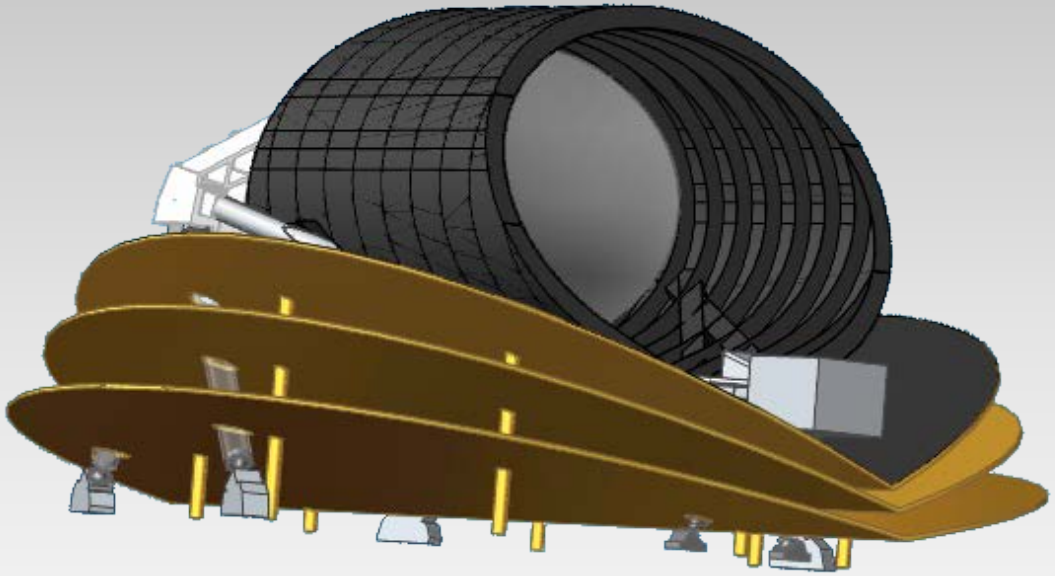

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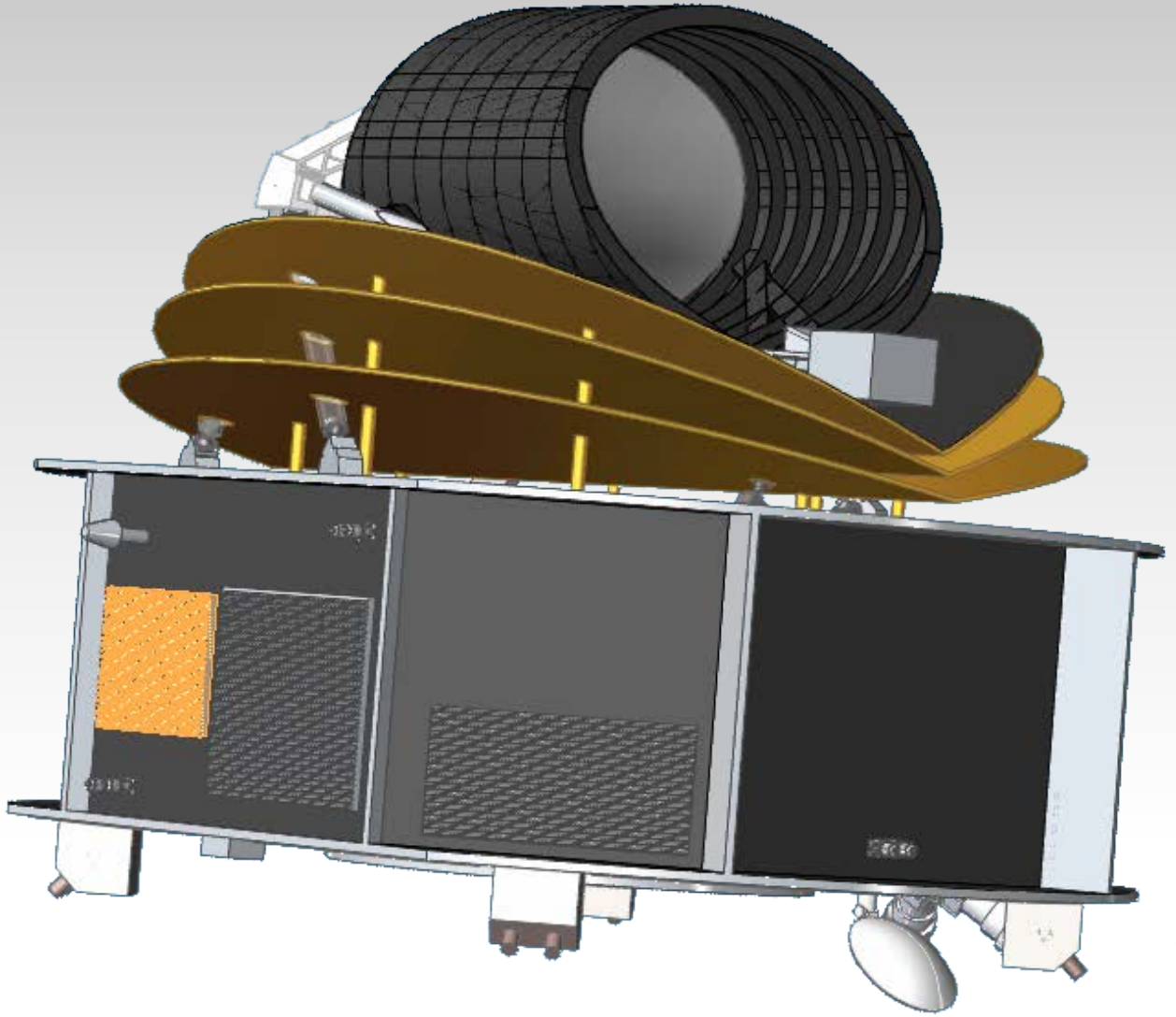
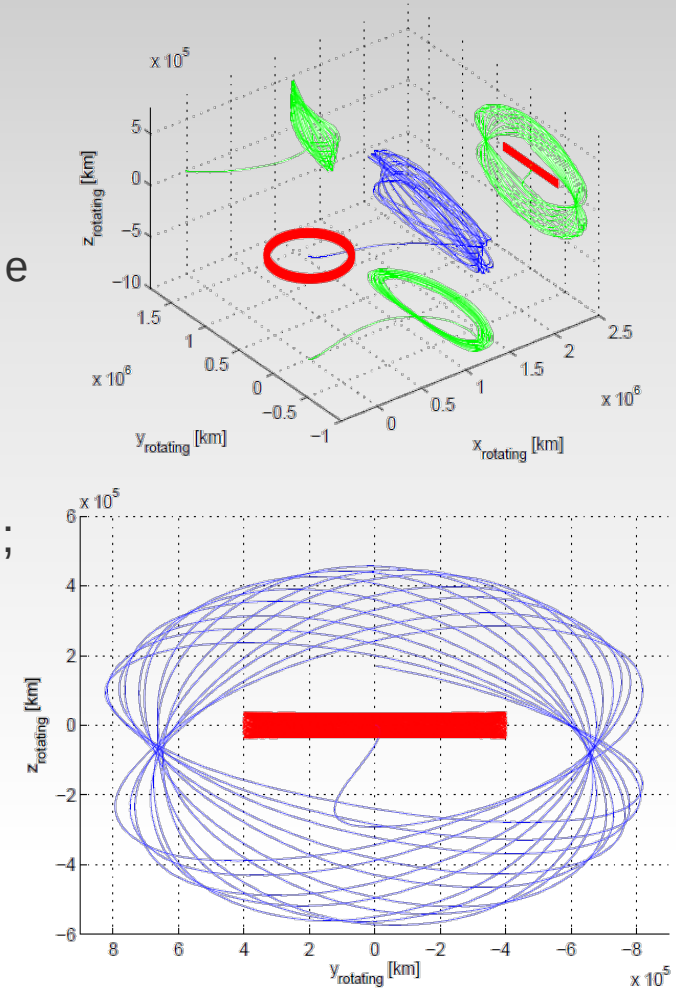
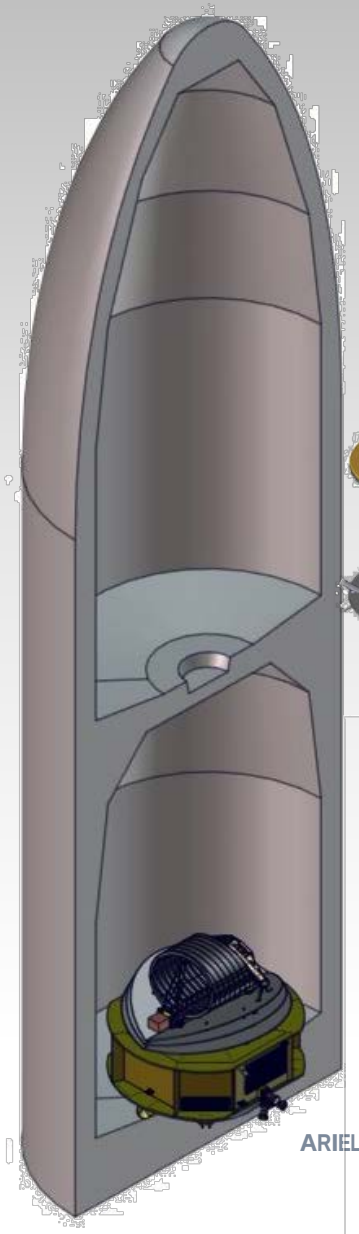
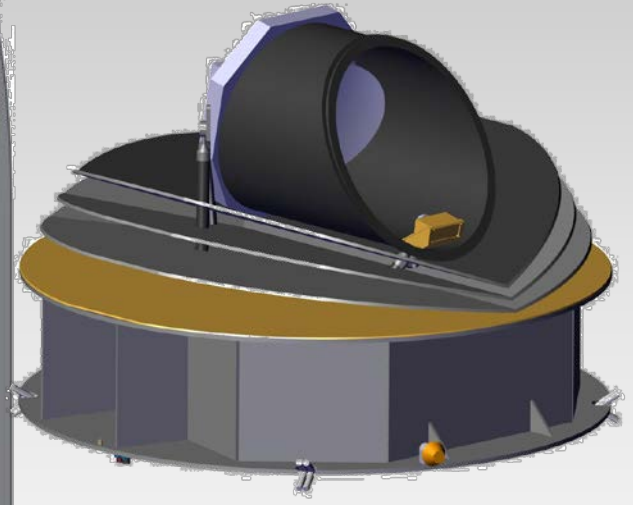


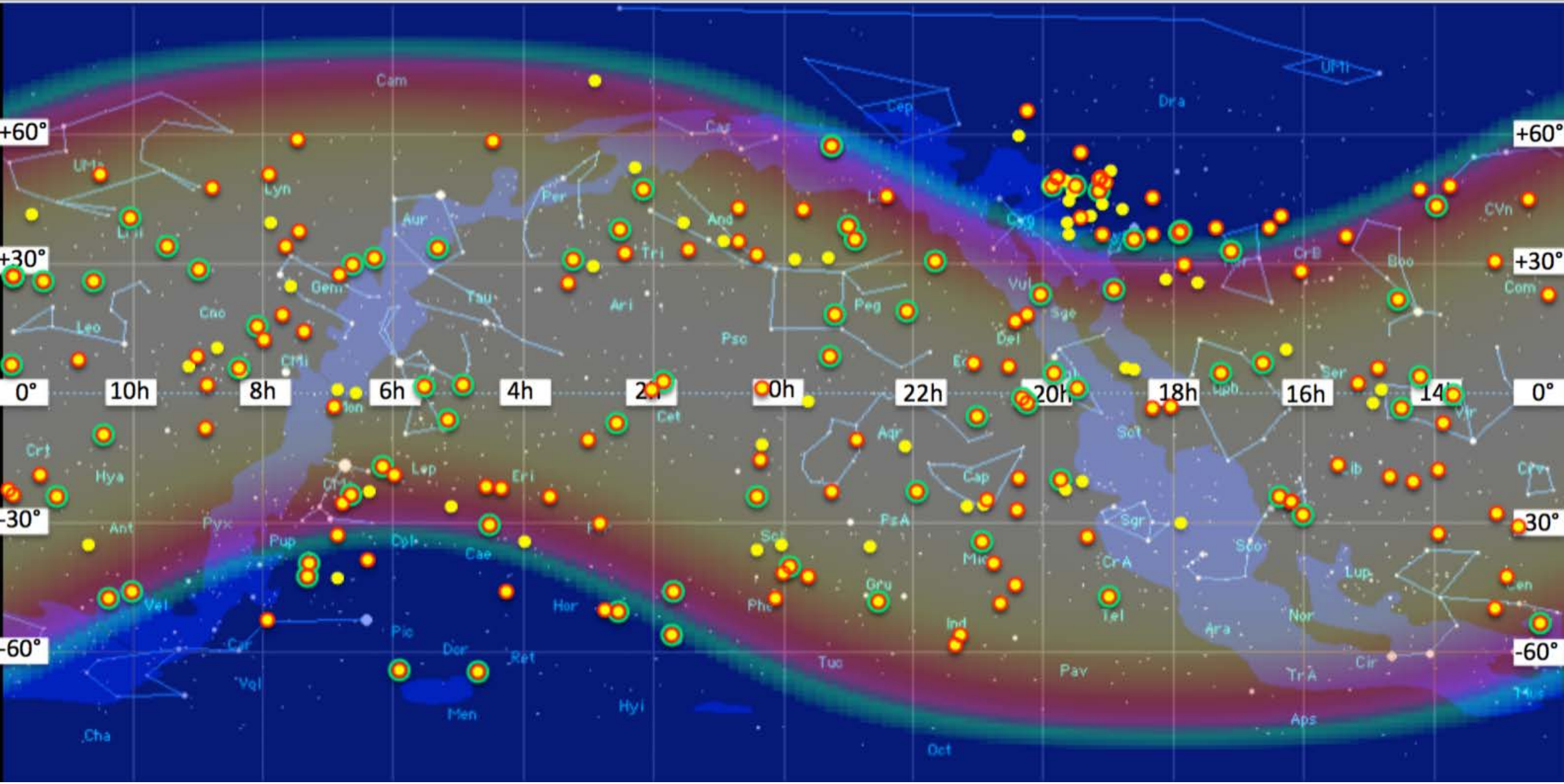
ARIEL – MISSION DESIGN

- Launch direct to large amplitude orbit around L2 by Ariane 6-2
  - Alternative flight profiles possible including shared launch
- Six months: transfer to L2, cooldown, commissioning and performance verification phase; followed by 3.5 years of routine science operations
- Wet Mass: < 1300kg
- Power: < 957 W
- Data Rate: 25 Gbits / day









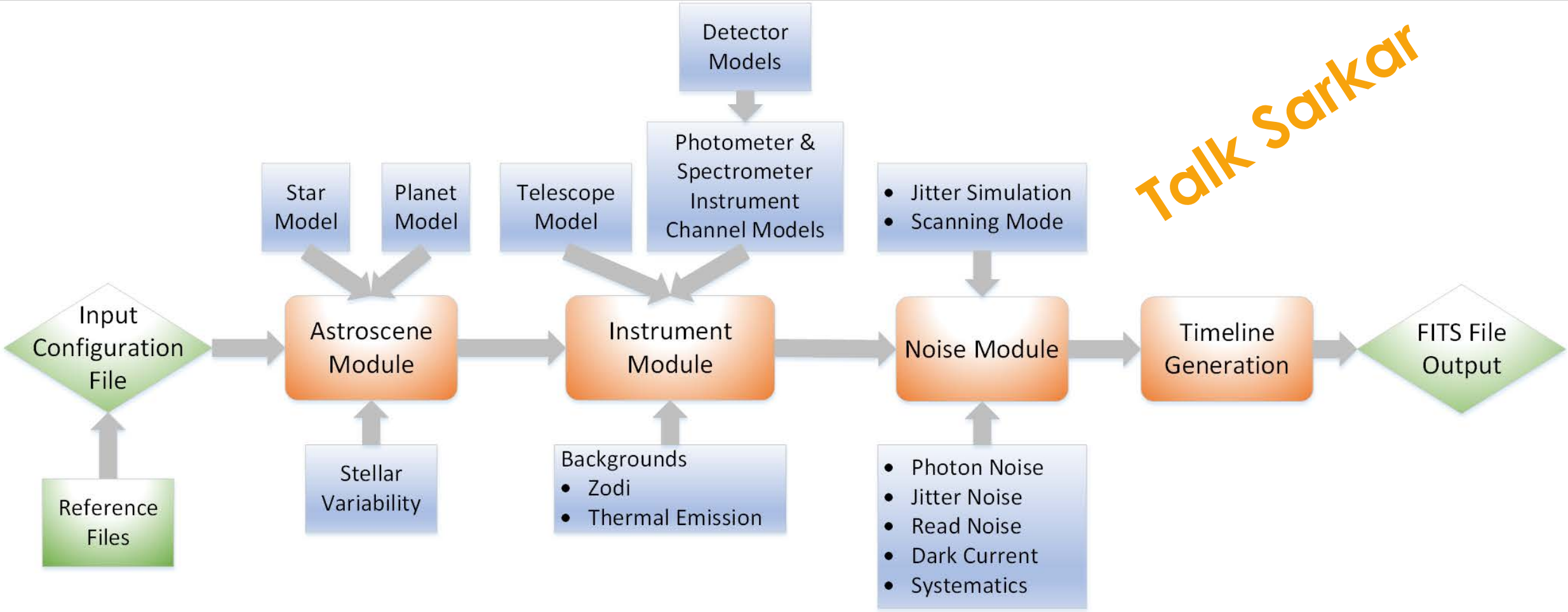
Instantaneous Sky Visibility

100% 80% 60% 40%

ARIEL

- Survey
- Deep
- Benchmark

PERFORMANCE MODELLING: EXOSIM



Talk Sarkar

Sarkar et al, 2016; Pascale et al, 2014, Puig et al, 2014

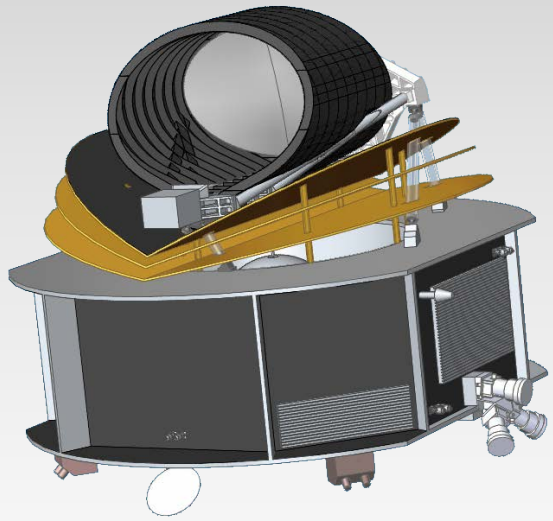
GROUND SEGMENT & DATA POLICY

- **Science community extensively engaged prior to launch and during operation in definition of target list through ARIEL ESA Science Team and whitepapers**
- **Open Data Policy: All data released quarterly once required SNR reached**

Data Level	Description	Comments
Level 0	Raw Telemetry	As sent from MOC to SOC
Level 1	Raw Spectral cubes of frames	Formatted cubes of raw detector images
Level 2	Extracted target spectra (star + planet)	In physical units as f(time) with instrument signatures removed
Level 3	Individual spectra of planets	Stacking of multiple revisits & extraction of planet spectra

ARIEL – CONCLUSIONS

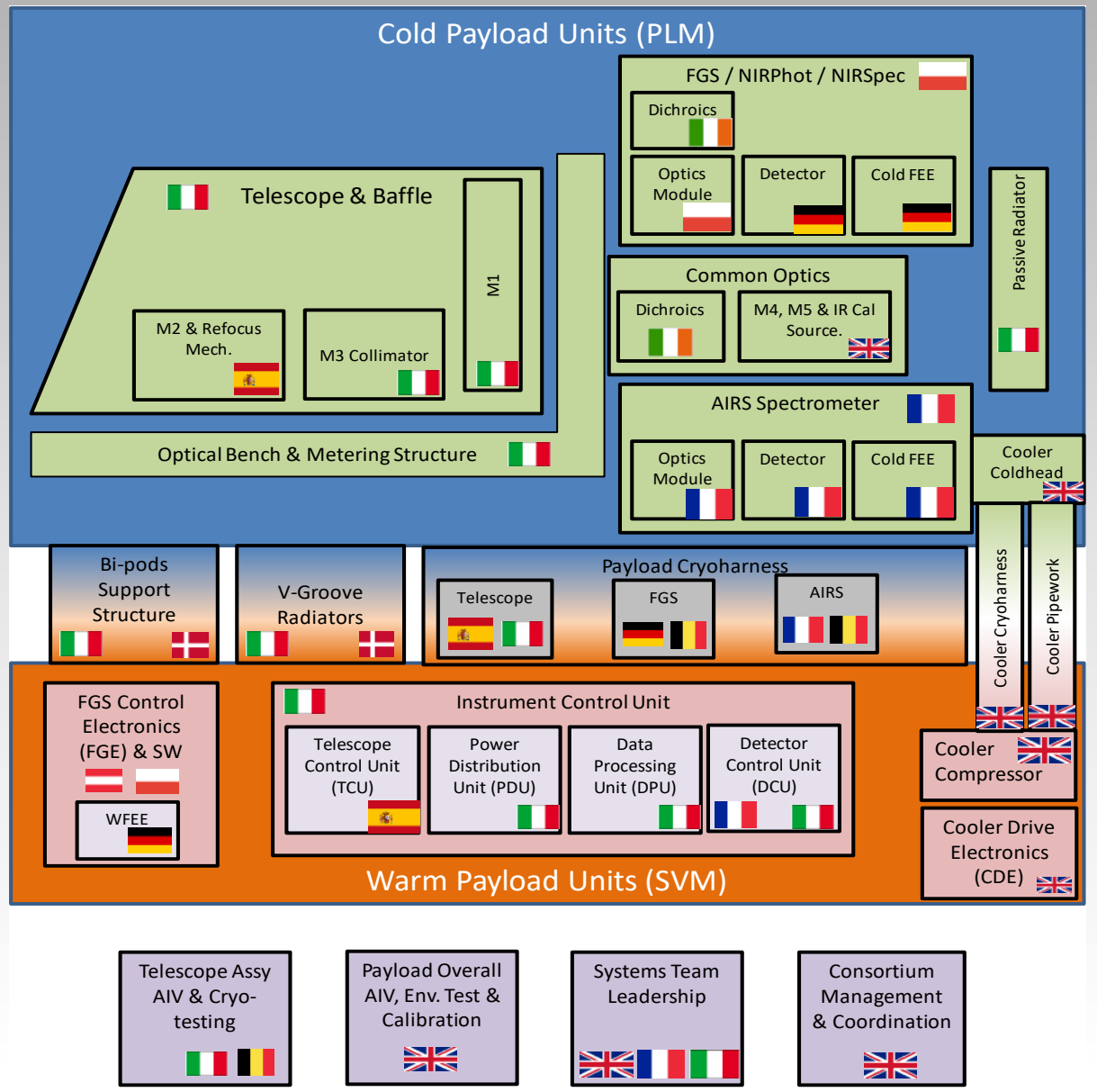
- ARIEL will enable us to understand why planets in our galaxy are so diverse and how they evolve
- ARIEL will do so by delivering the first chemical survey of ~ 1000 exoplanets, probing uniformly the gamut of planet and stellar parameters
- ARIEL will do for exoplanets what Herschel did for star formation and what ALMA is doing for disk evolution
- ARIEL science will provide a galactic perspective to the history and nature of our Solar System



Time is ripe for this endeavour and we are ready for it

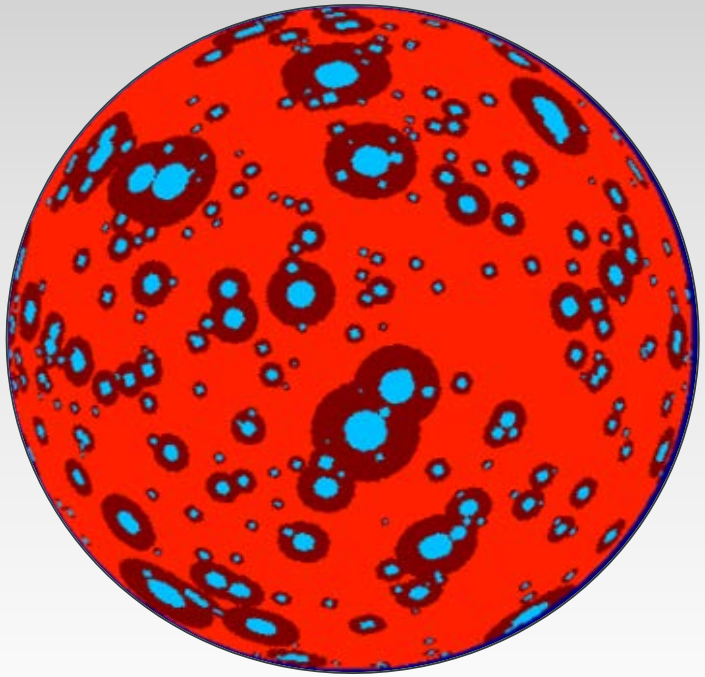
MISSION RESPONSIBILITIES

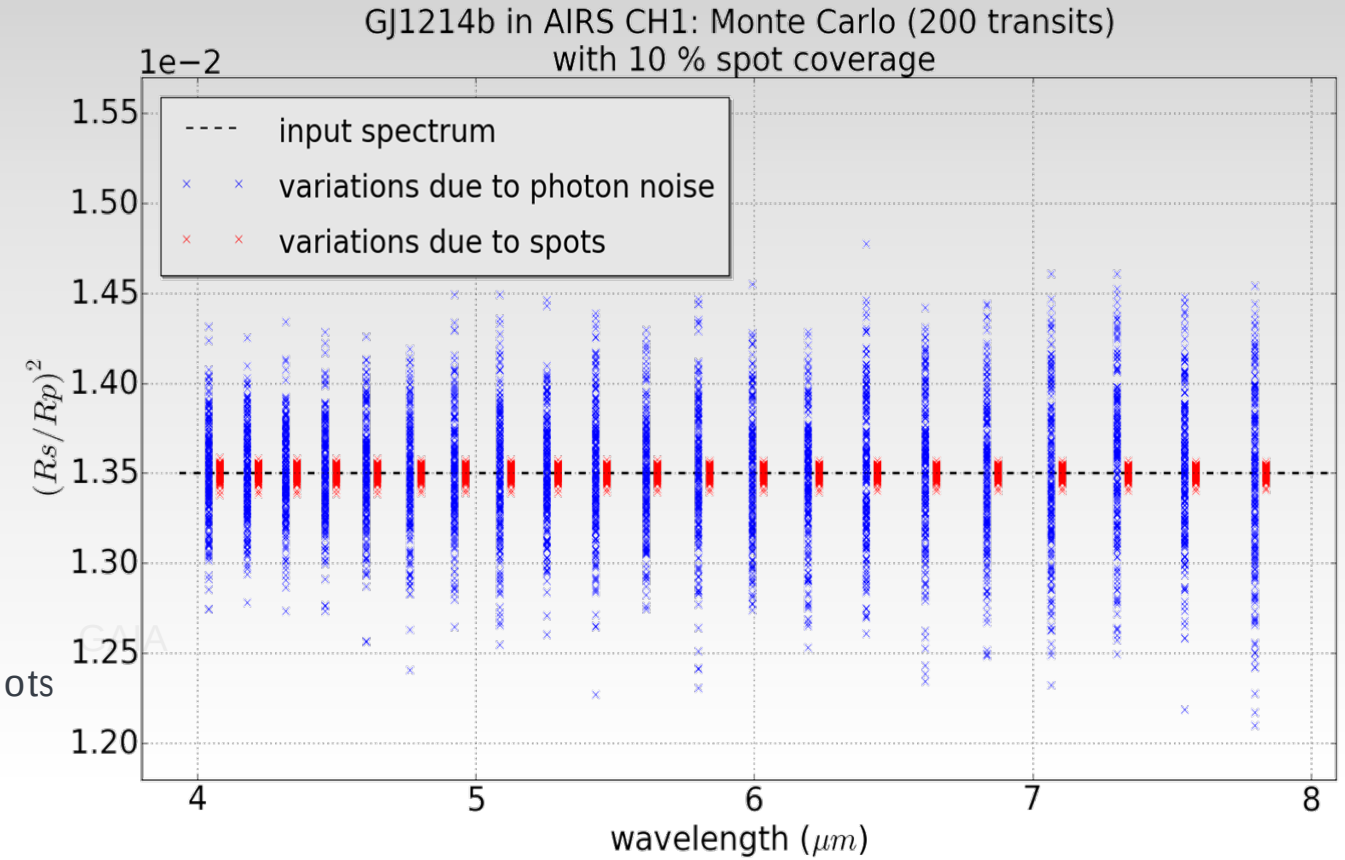
- Clear division between ESA / Prime & single Payload Consortium
- Responsibilities within payload are clearly defined
  - Based on modular design and test approach to simplify interfaces and management
- Ground Segment responsibility share between ESA and Consortium also well defined and mature (MOC / SOC / IOSDC)



EXOSIM: STELLAR SPOTS

STELLAR VARIABILITY: CORRECTING THE EFFECTS OF SPOTS





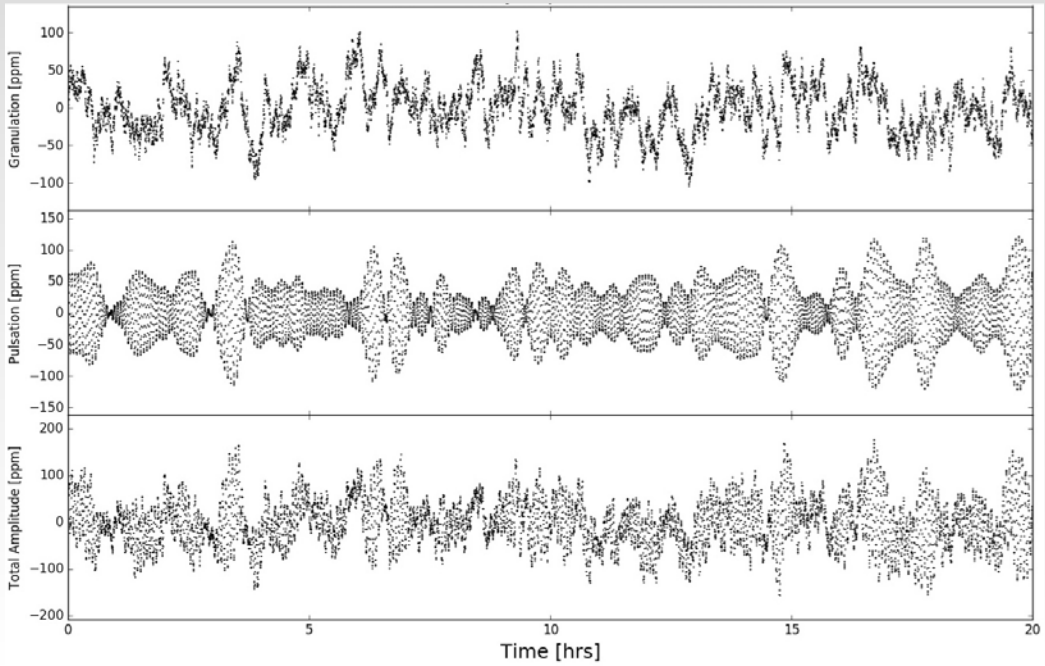
The example shows an extreme case: a star with 10% spots (the Sun is < 1%).
Cold spots are shown in light blue.
Hot faculae are in brown surrounding each spot.

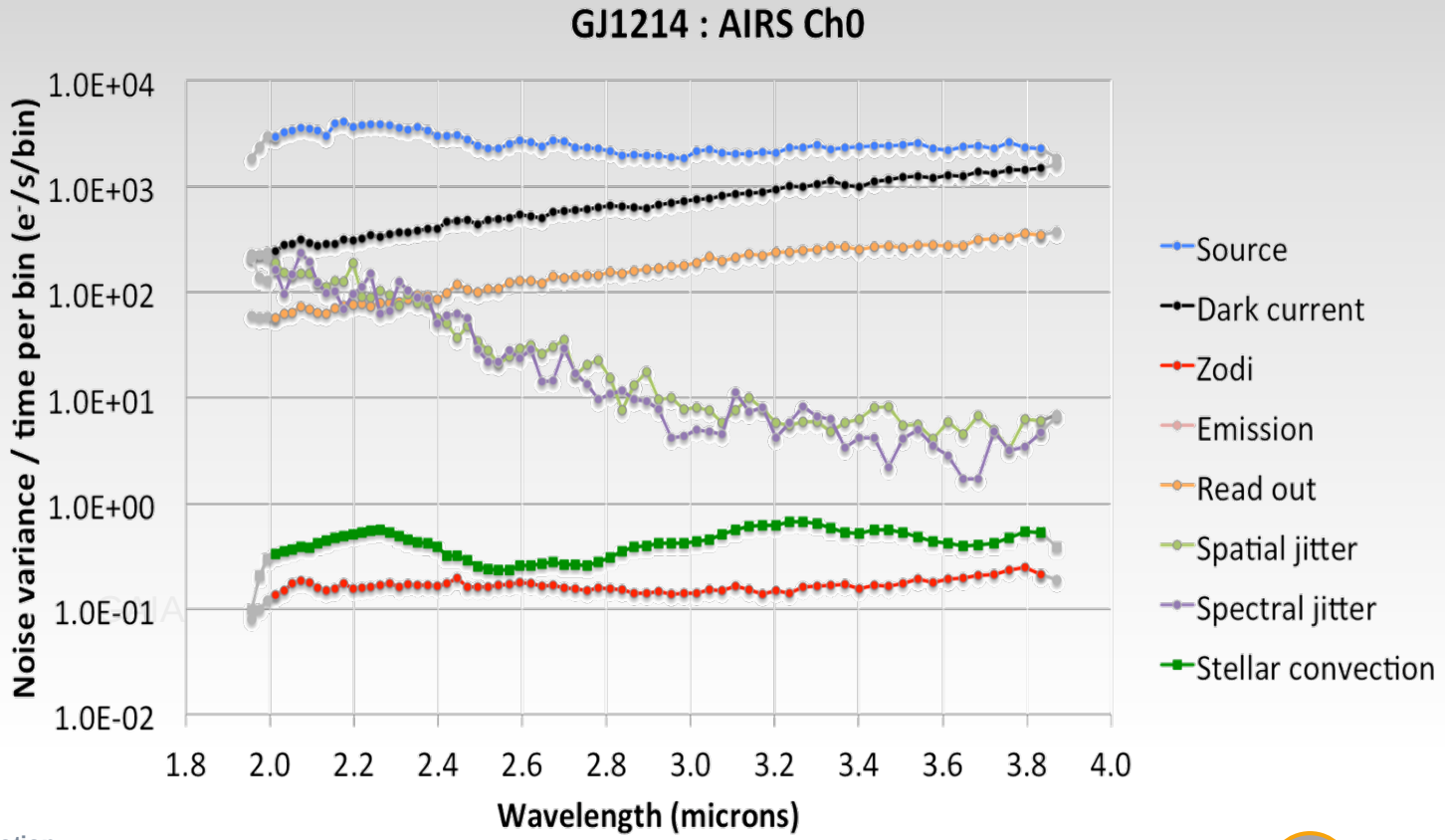
Sarkar et al, 2016; Herrero et al., 2015; Micela, 2015; Scandariato et al., 2015

EXOSIM: PULSATION AND GRANULATION

STELLAR VARIABILITY: CORRECTING THE EFFECTS OF PULSATION & GRANULATION

Simulated pulsations & granulations for M2V star

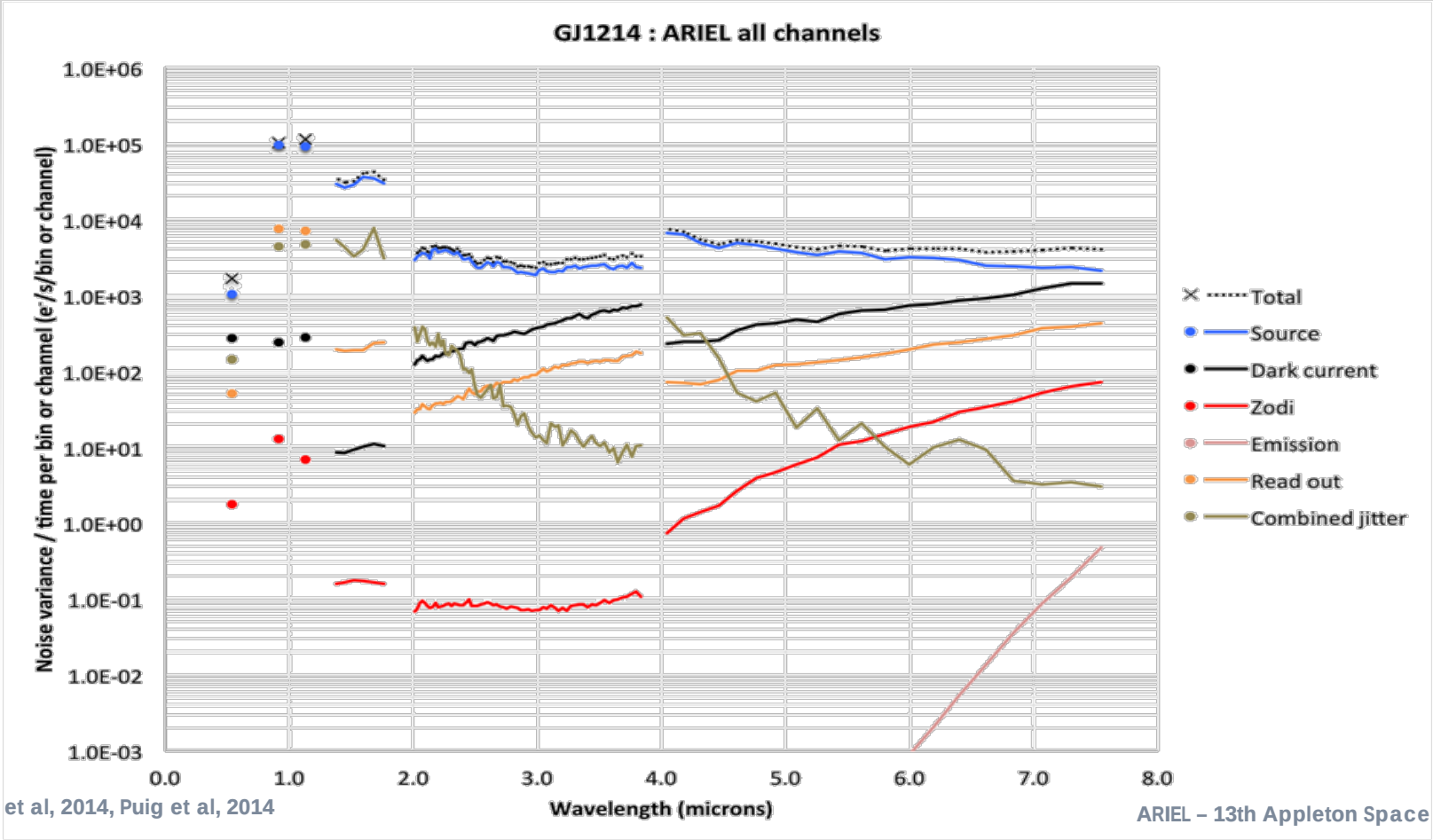




Sarkar et al, 2016; University of Leuven's simulations for pulsation & granulation

NOISE BUDGET – FAINTEST TARGET

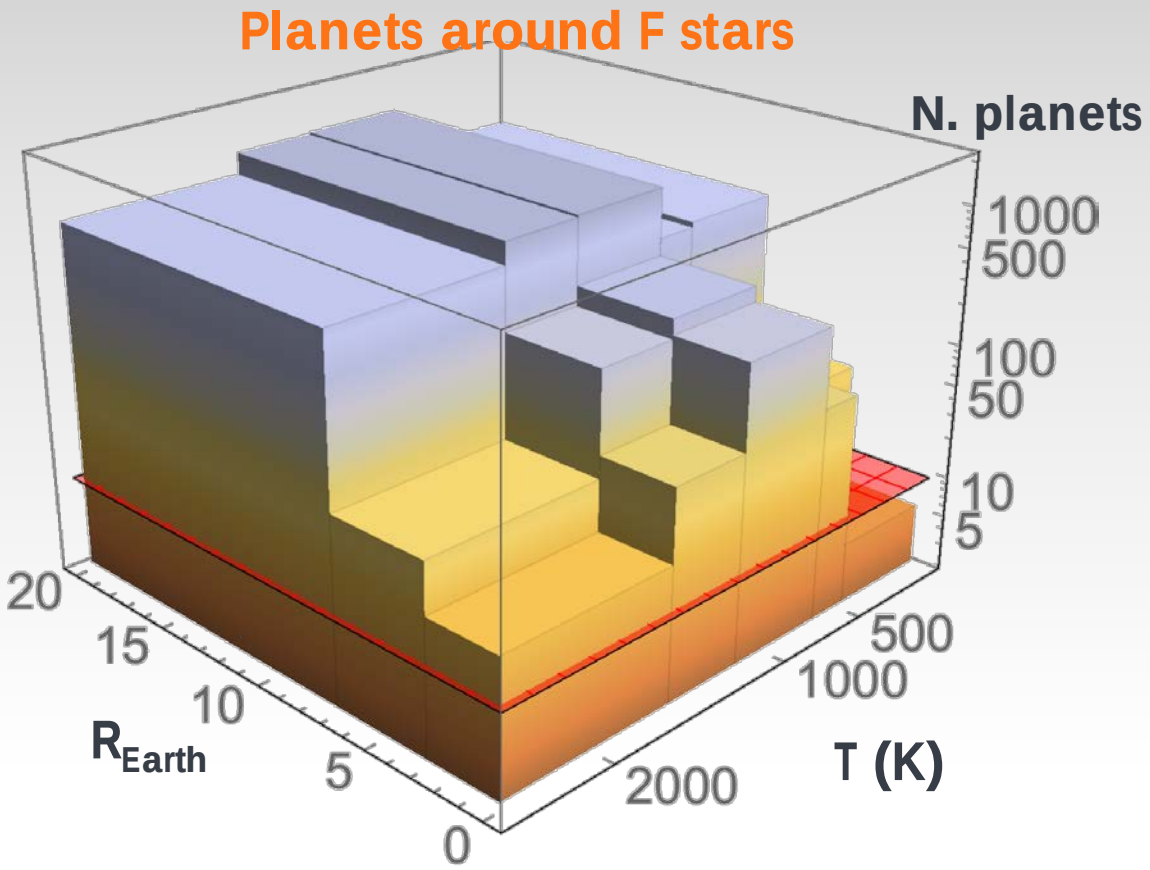
ARIEL IS PHOTON NOISE LIMITED FOR ALL TARGETS



Sarkar et al, 2016; Pascale et al, 2014, Puig et al, 2014

LARGE POPULATION OF WARM/HOT PLANETS

SELECTED OUT OF 10,000 PLANETS OPTIMAL FOR CHEMICAL OBSERVATIONS



Parameter space to be sampled:

- Planet size (density)
- Temperature
- Stellar type
- Metallicity

The sample should have ~ 1000 planets