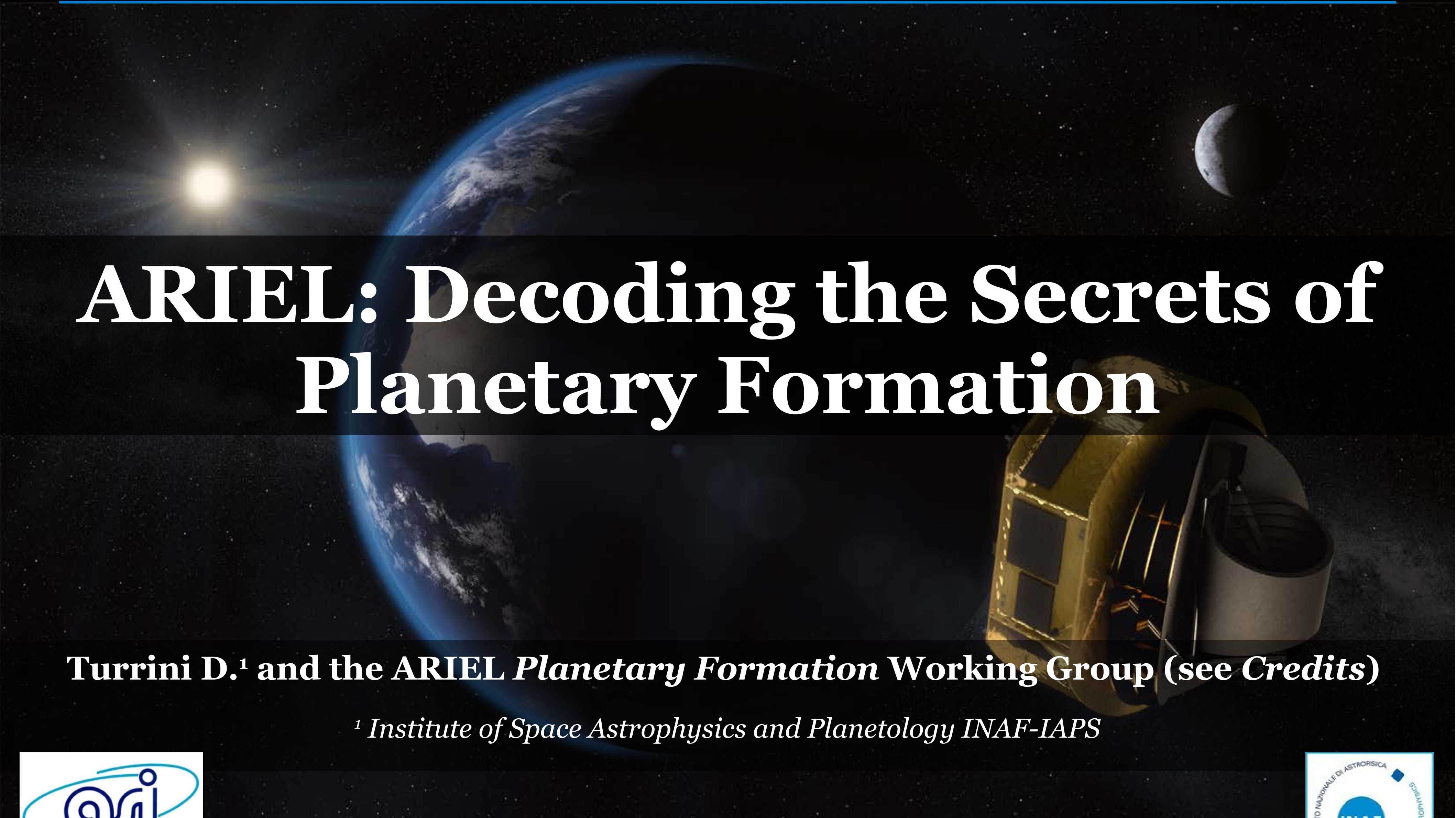
ARIEL Science, Mission and Community 2020 Conference



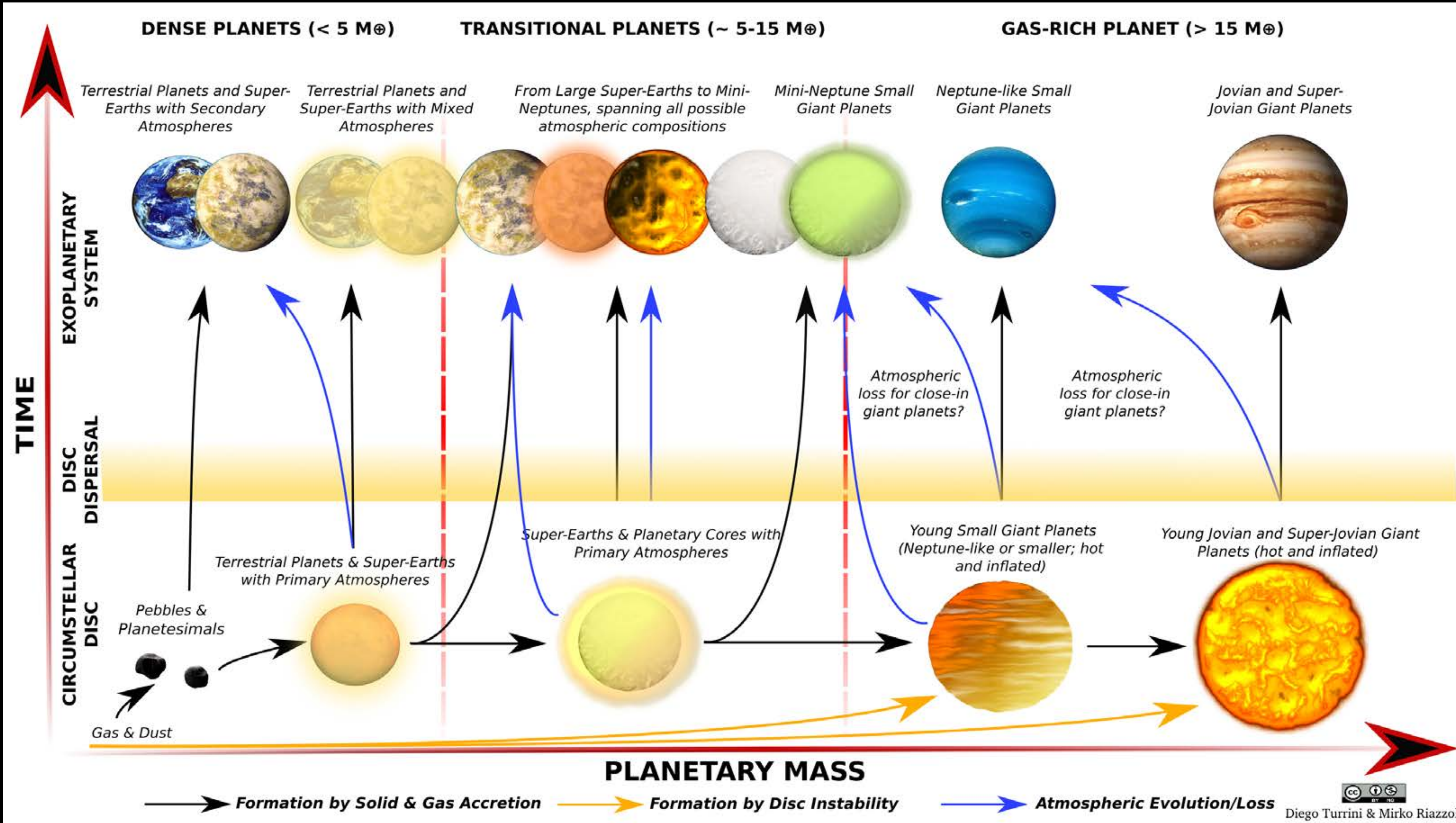
ARIEL: Decoding the Secrets of Planetary Formation

Turrini D.[1] **and the ARIEL *Planetary Formation* Working Group (see *Credits*)**

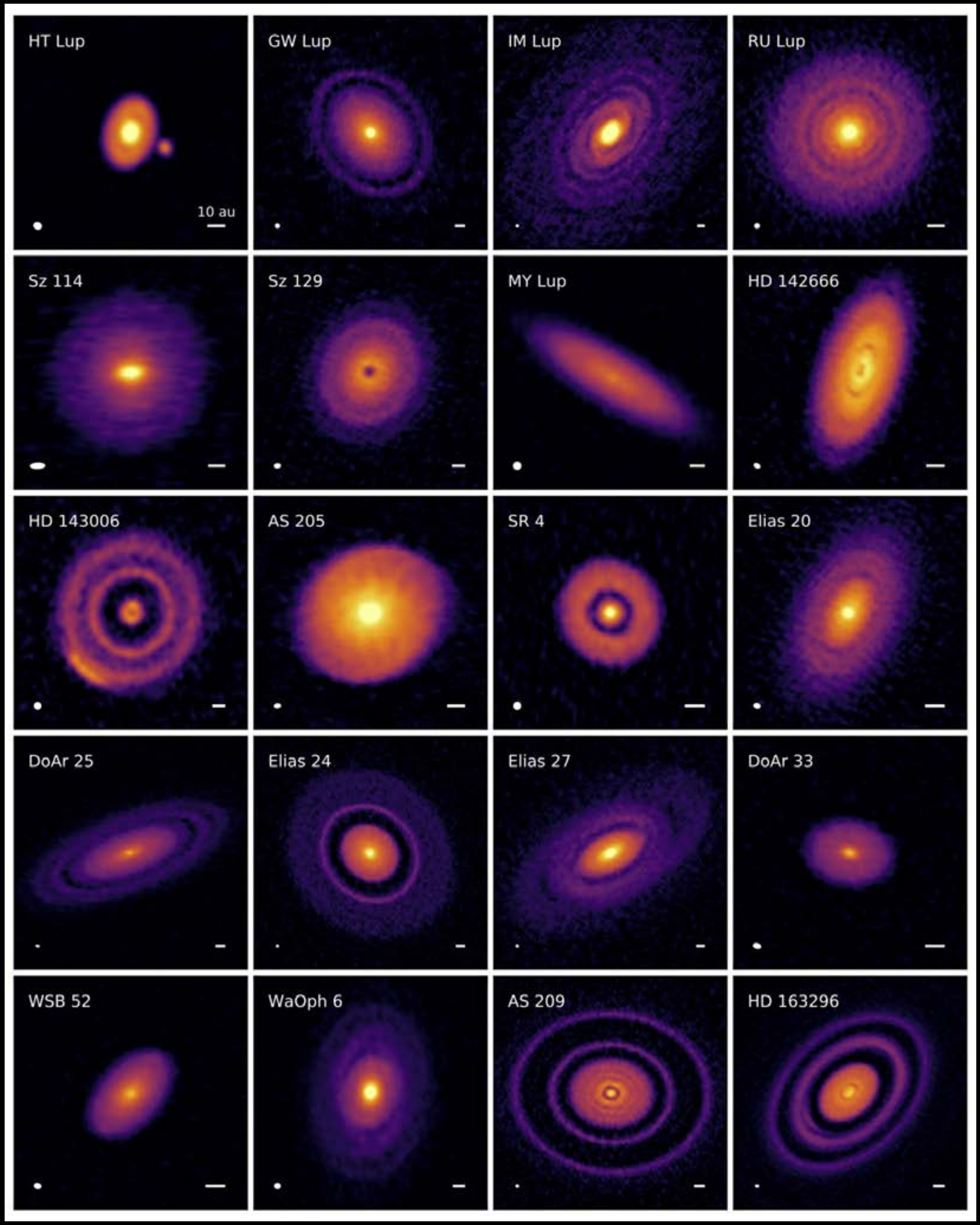
[1] *Institute of Space Astrophysics and Planetology INAF-IAPS*

15 January 2020, ESA-ESTEC

Planetary Formation in a Nutshell



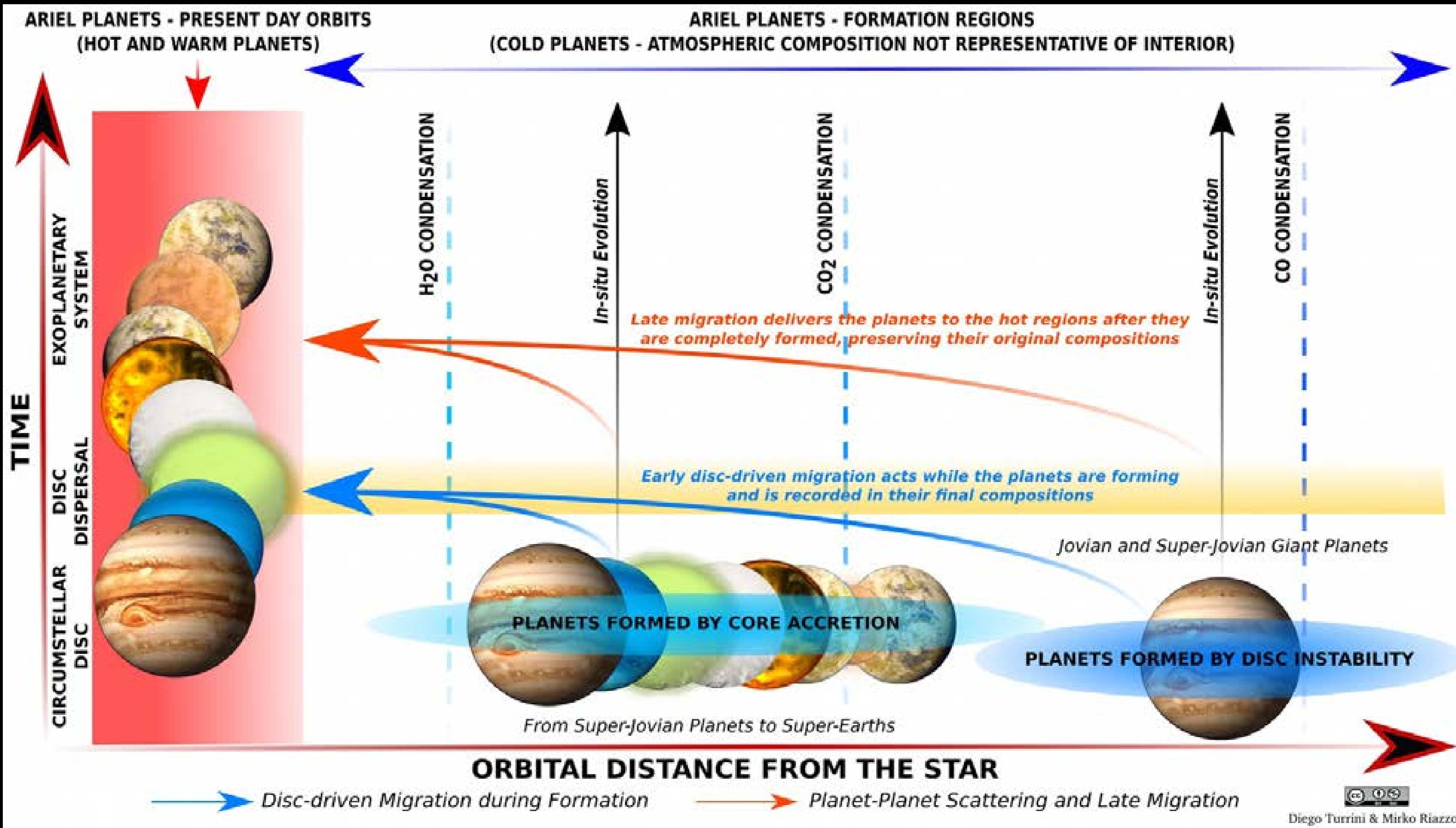
Planetary Formation in the Age of ALMA



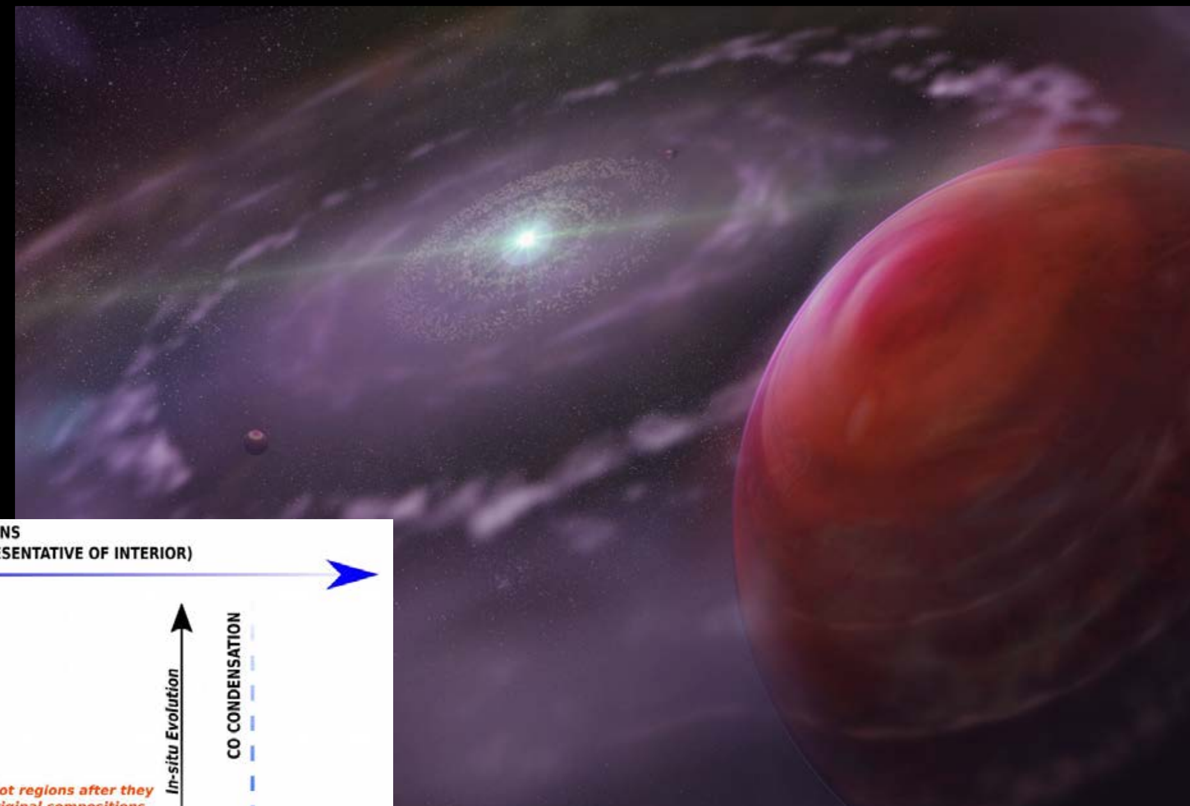
The dust distribution of observed **circumstellar disks older than about 1 Myr** shows the presence of gaps, rings, spirals indicative of the presence of **giant planets** (e.g. Andrews et al, 2018).

Dust morphology in the circumstellar disks observed by the ALMA Large Program DSHARP (Andrews et al. 2018)

Planetary Migration as ARIEL's Best Ally

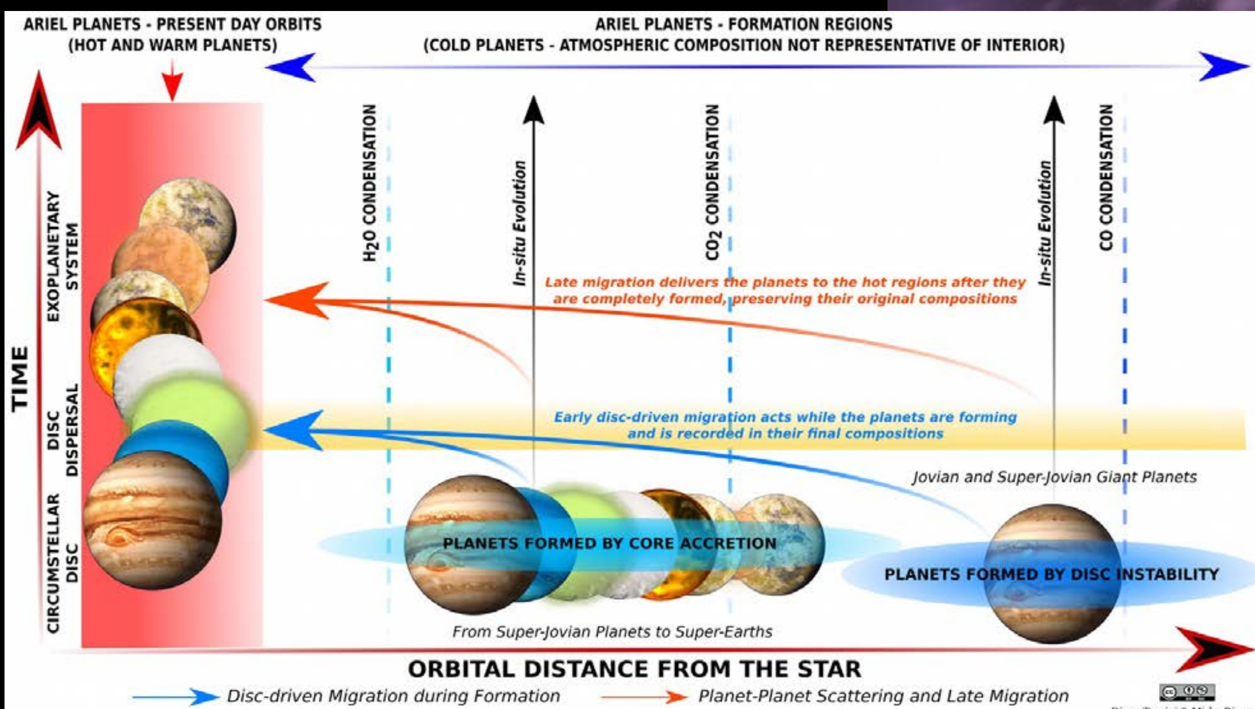


ARIEL and the Birthplace of Hot Jupiters



Where do hot Jupiters come from?

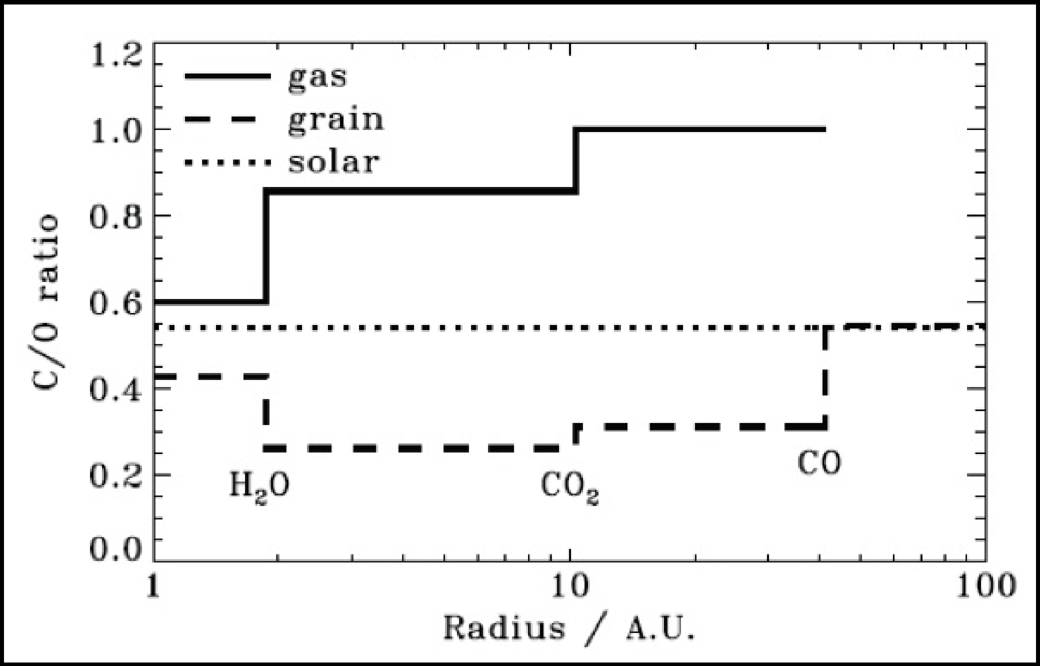
Did they form almost locally, in the inner regions of their disks?



Did they form in the outer regions of disks as revealed by ALMA?

Or anywhere in between?

C/O Ratio as our Window into the Past?

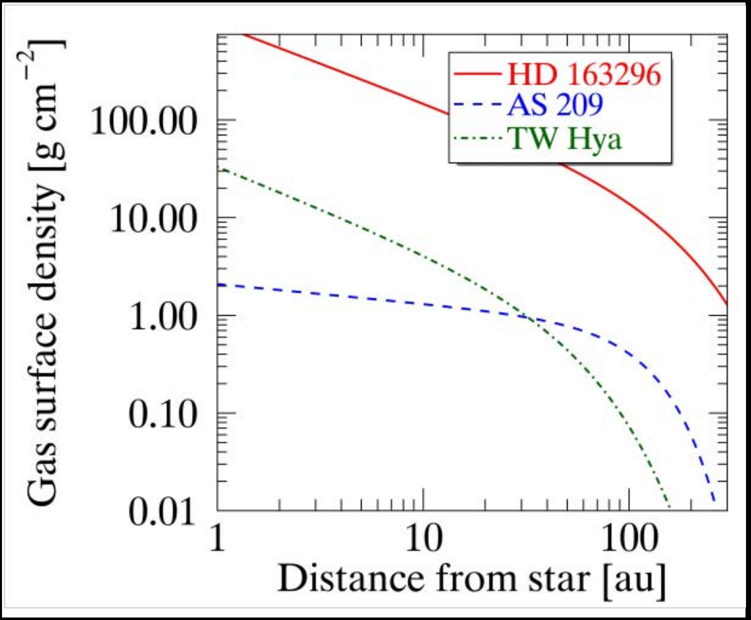


The study of the **C/O elemental ratio** in planetary atmospheres has been suggested to track the formation region of planets (e.g. Oberg+2011, Madhusudhan+2016).

In more detailed scenarios, **additional snow lines** (e.g. CH_4 and CH_3OH) and **rocks and refractory organics** contribute in incorporating C and O.

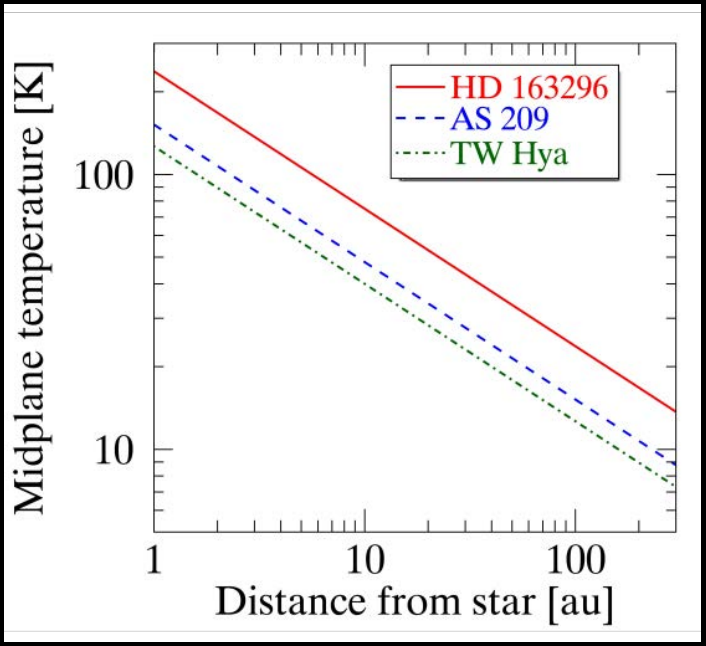
C/O contrasts between regions are **more limited** and migration can dilute them even more.

Looking at Wide & Hot Circumstellar Disks



Observed disks have **more mass in the outer regions** (*right*) than the theoretical Minimum Mass Solar Nebula (MMSN, Weidenschilling 1977).

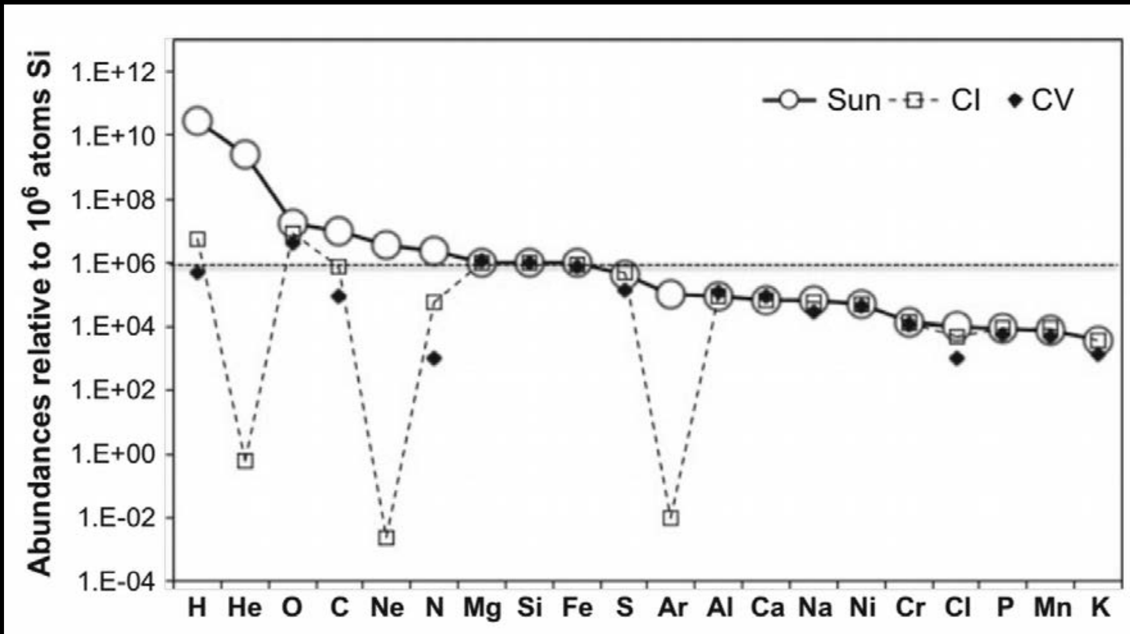
As a consequence, their **planet-forming regions extend outward** (*right*) and are characterized by **different compositions** w.r.t. the MMSN.



The **gas temperature profile** in the disk midplane (left) appear **similar** between real disks and the MMSN.

Species	T_{cond} [K]
H_2O	130 - 150
HCN	100 - 120
CH_3OH	95 - 110
NH_3	75 - 85
CO_2	60 - 70
H_2S	45 - 50
CH_4	26 - 32
CO	22 - 28
N_2	12 - 15

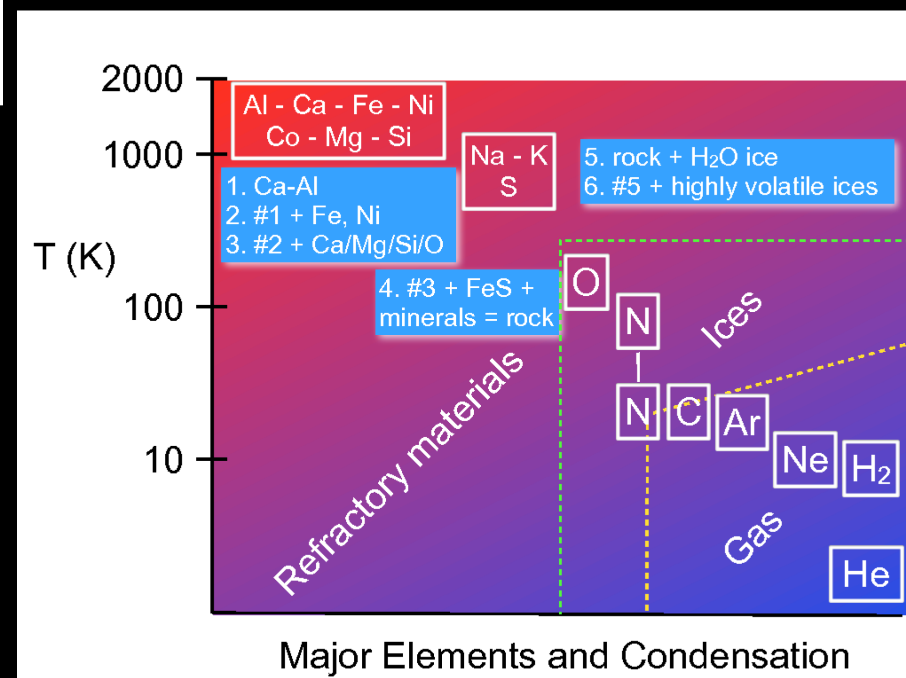
ARIEL's Planetary Compositional Model



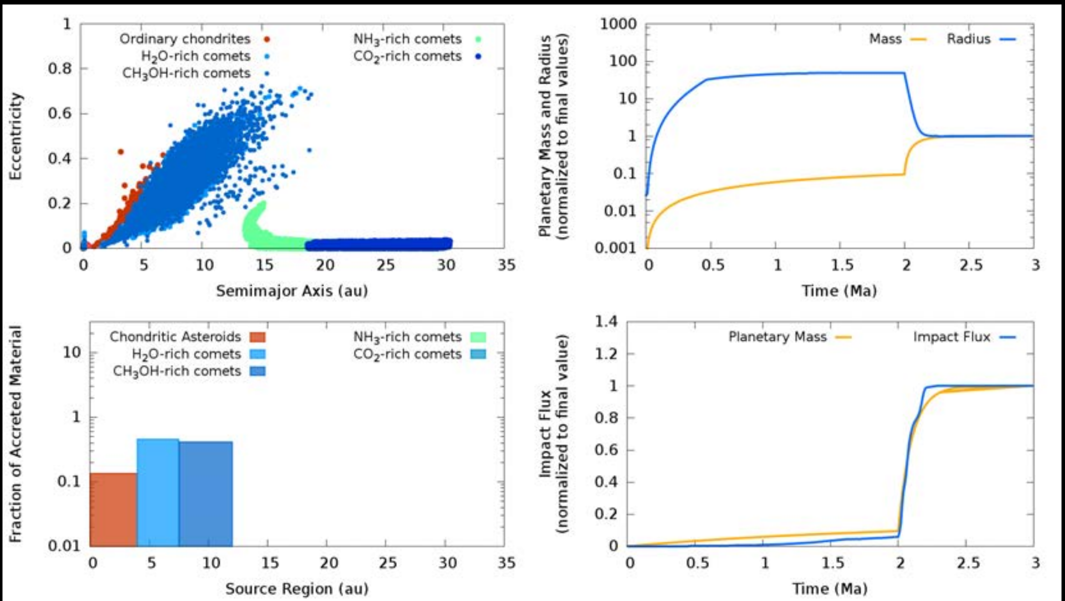
We built a **reference compositional framework for planetary materials** combining information from:

- *meteorites*
- *comets*
- *solar elemental abundances*
- *astrochemical models*
- *astronomical observations*

Combining it with the temperature profiles of our template disk, we built a **compositional model** of the different disk compositional regions, cross-calibrated on **solar & extrasolar materials.**



Different Tracks, Different Mixtures, All Non-Solar



Total accreted mass of heavy elements changes among the migration scenarios:

12 au: ~4.5 Earth mass

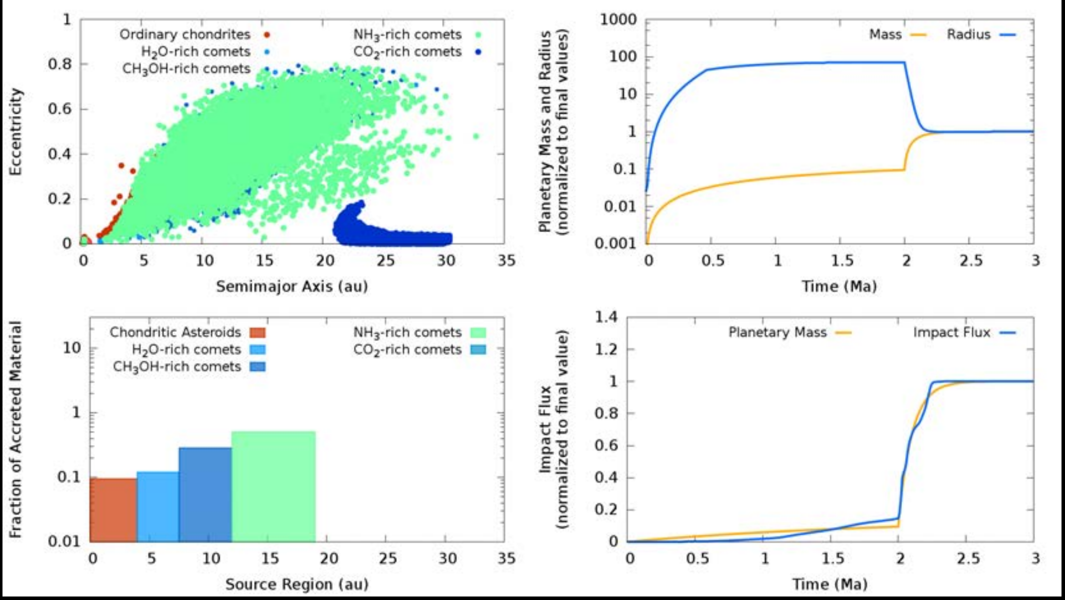
19 au: ~6 Earth masses

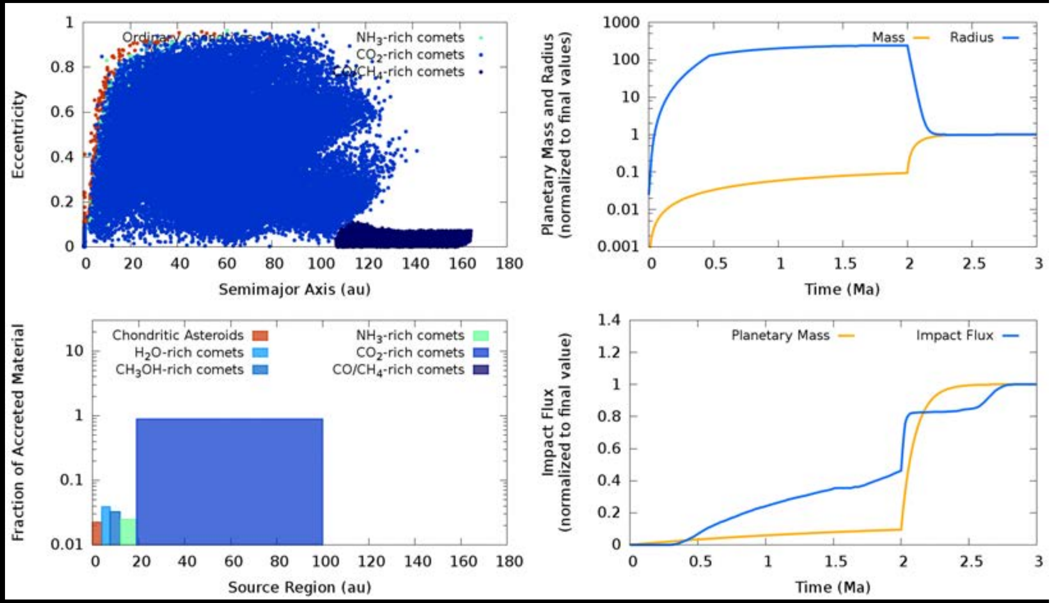
50 au: ~14 Earth masses

100 au: ~20 Earth masses

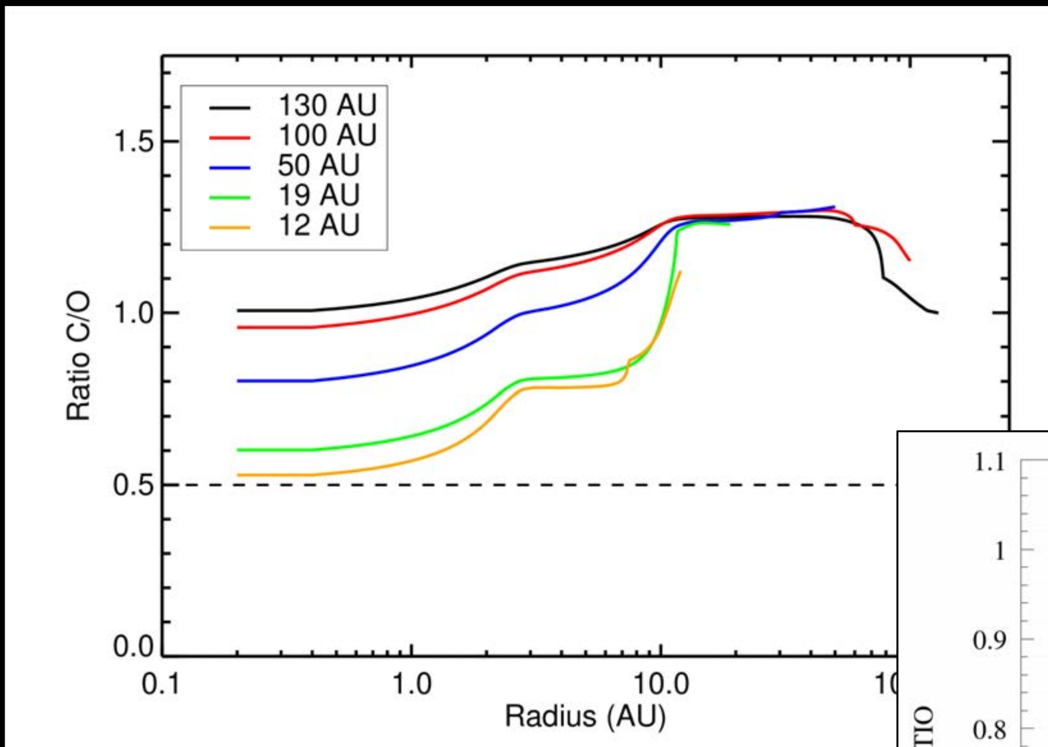
130 au: ~33 Earth masses

Gas and solids are accreted with different efficiencies, the **resulting mix is non-solar**.

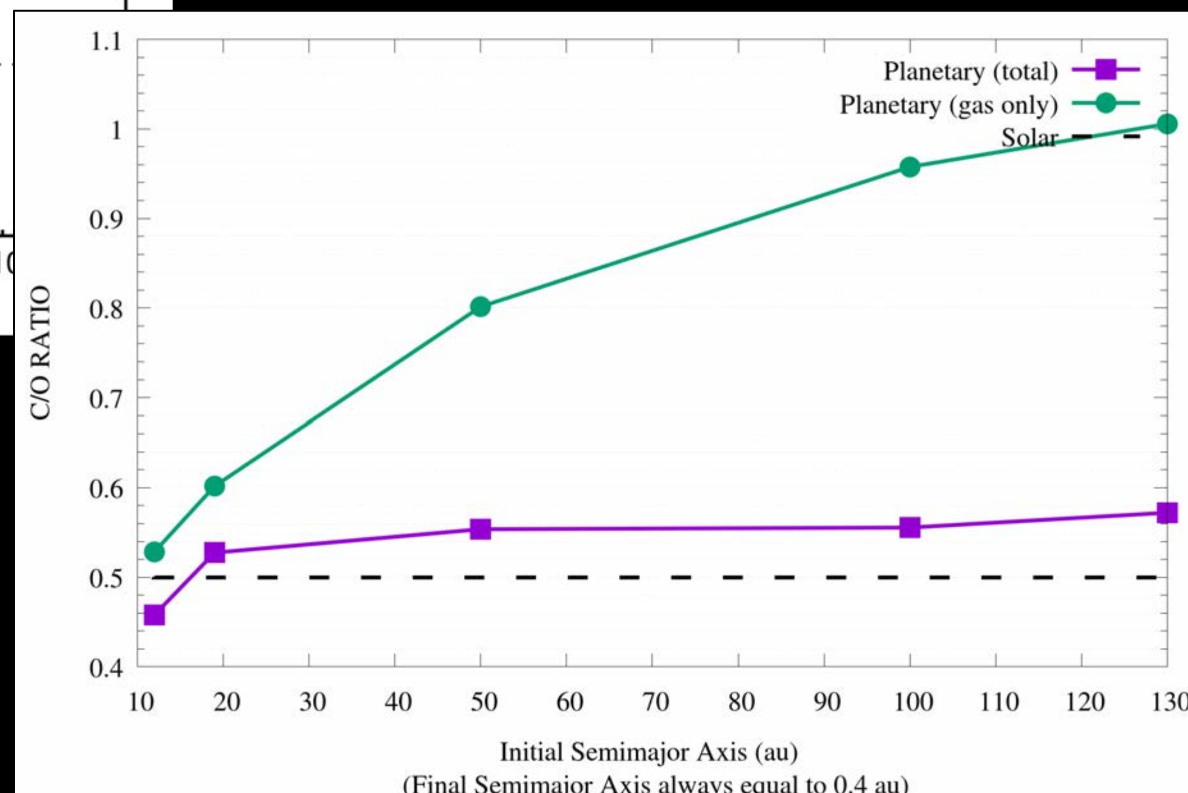




C/O – Gas-dominated vs Solid-Dominated



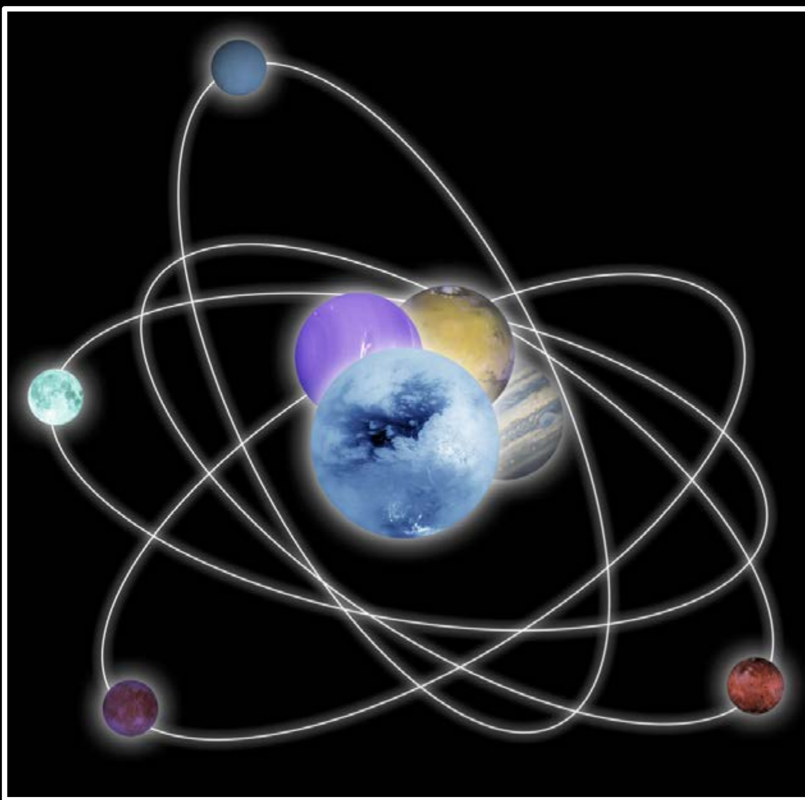
As expected, the C/O ratio in case of gas-dominated hot Jupiter is super-solar (though in some cases the values can be close to the solar one).



In the case of solids-dominated giant planets migrating from beyond the CO_2, the C/O ratio flattens toward the solar-one.

ARIEL – Elements & Tracers

The *Planetary Formation* WG is working to expand the list of **compositional tracers** (Turrini+2018) and increase ARIEL's cosmochemical coverage among **refractory and moderately volatile elements**. Their proper use as tracers requires the knowledge of the **stellar abundances** (synergy with the *Stellar Characterization* WG, see talk by *C. Danielski*).



Lithogenous & Refractory Elements:

SiO*, AlO, CaO, TiO*, VO*, MgH, TiH

Moderately & Highly Volatile elements:

HF, H_2S, SO, SO_2*, NaH, HCl, HBr, KCl, PH_3*

Atmophile elements:

H_2O*, CO*, CO_2*, CH_4*, NH_3*, HCN*, C_2H_2*, C_2H_4*, C_2H_6*

** indicates elements from the ARIEL M4 proposal (Tinetti et al. 2015)*

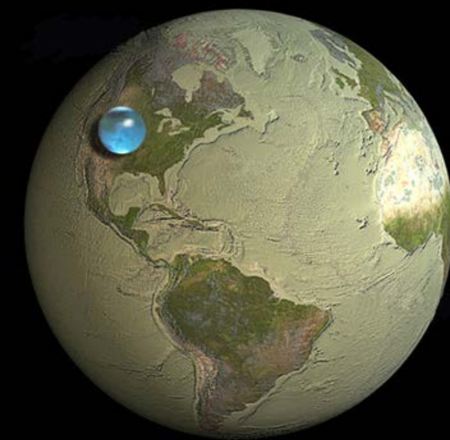
ARIEL – From Super-Earths to Giants

Terrestrial Planets vs. Giant Planets

We currently don’t have direct observational constraints on where and how the **transition between giant planets and terrestrial planets** occurs in the mass spectrum.

ARIEL will be able to assess the **mean molecular weight** of exoplanetary atmospheres for planetary masses between super-Earths and Neptune-like planets to constrain their abundance of H and He (Turrini+2018; Edwards+2019).

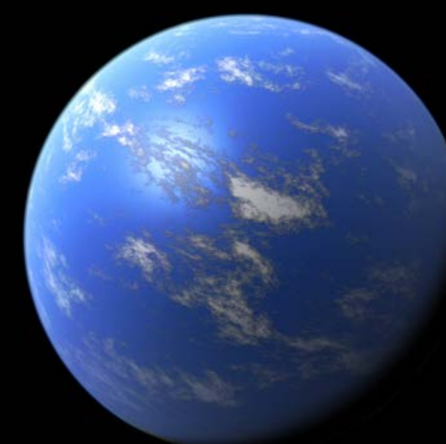
ARIEL – Water and Super-Earths



Water: Rare or Abundant?

Planetary formation scenarios for the Solar System favour a central role of **giant planets** in shaping the delivery of **water to the Earth**. Yet, giant planets are not as abundant as super-Earths among exoplanets (e.g. Fressin+2013).

ARIEL will be capable of **searching for the atmospheric presence of water in exoplanetary systems with different architectures** and both with and without giant planets (Turrini+2018).



Small Planets and Molecular Weight

Number of Planets	Observation Requirement	Required Science Time (hr)
1000	Achieve Tier 1 resolutions	~10,600
400	Increase resolution from Tier 1 to Tier 2	~3100
500		~6000
600		~10,500
200	Achieve Tier 1 resolutions in the second method	~1400
300		~2500
400		~4200
50	Tier 3 (five repeated observations per planet)	~1700
…	Tier 4 (additional science time)	~2300

Science time over 4 yr of mission is quantified in 24800 hr (Edwards+2019).

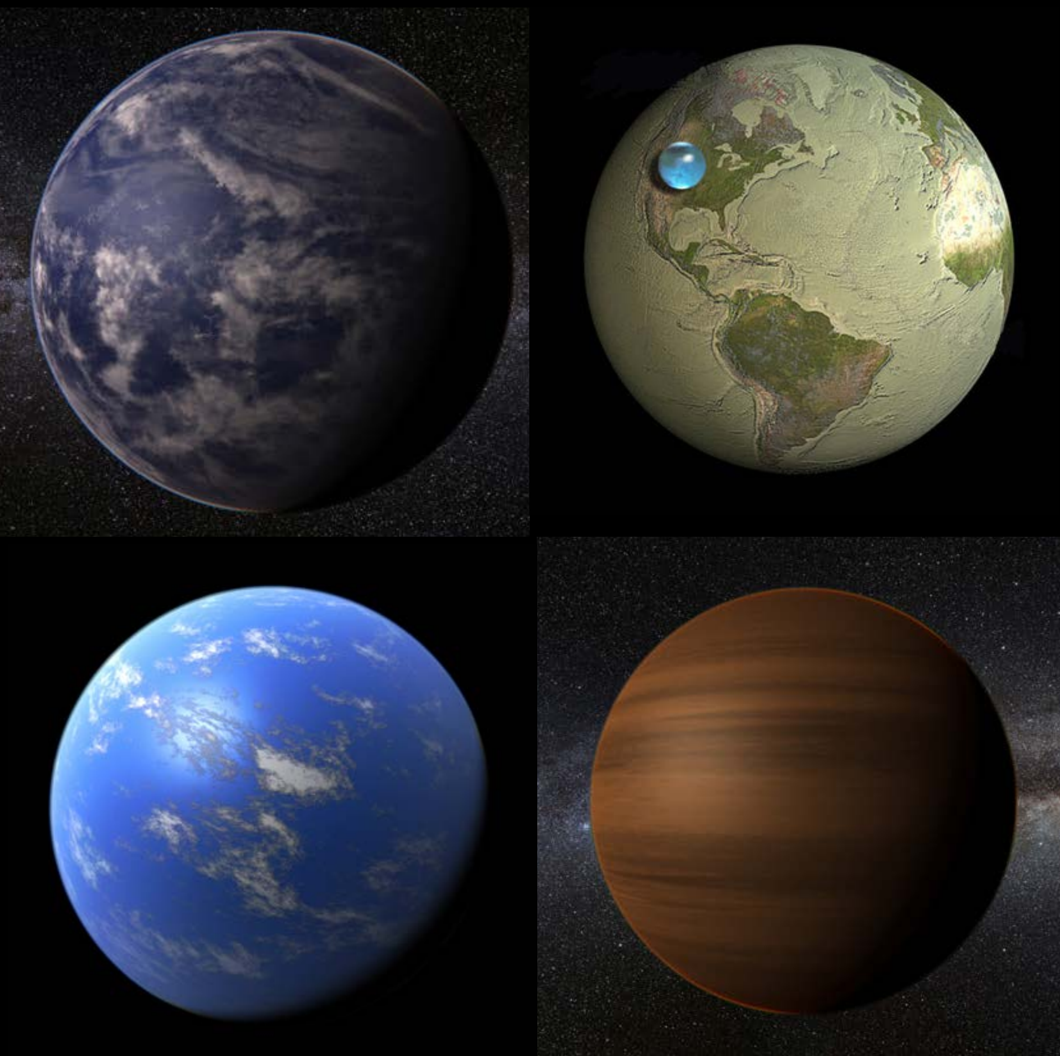
Tier 1 on 1000 planets + Tier 2 on 500 planets + Tier 3 on 50 planets + Tier 4: 20600 hr (Edwards+2019).

Atmospheric Mean Molecular Weight	Number of Planets	Required Science Time (hr)
2.3	All	~1000 (t_0)
5	50	t_0 + ~360
	All	t_0 + ~3000
8	50	t_0 + ~1100
	All	t_0 + ~9200
10	50	t_0 + ~1900
15	50	t_0 + ~4400
18	25	t_0 + ~1700
	50	t_0 + ~6400
28	25	t_0 + ~4300
	50	t_0 + ~15,600

Mixture 50/50 of Earth atmosphere and H_2 has m.w. ~15

Mixture 60/40 of Venus atmosphere and H_2 has m.w. ~28

Exploring a *Small Planets Tier*



The feasibility of a **dedicated Tier** for **small planets** with intermediate resolution between Tier 1 and 2, is under investigation (see also talk by *L. Mugnai*).

The Tier would combine the measure of the **atmospheric molecular weight** with the detection of the **main heavy molecules**, for more insight on the nature of these planets.

Additional Activities

The outcomes of the planetary formation modelling activities are being used to further improve the assessment of ARIEL's retrieval capabilities in collaboration with the *Spectral Retrieval* and *Atmospheric Chemistry* Working Groups.

A collaboration with the *Stellar Characterization* Working Group is ongoing to further assess the impact of the uncertainties and variability in the stellar composition on the elemental ratios and abundances retrieved by ARIEL.

Future efforts will also focus on understanding how the star formation and galactic environments affect the initial conditions and compositional setup of the planetary formation process and how this reflect on the final planetary composition.

Credits

(in alphabetical order)

INAF-IAPS ARIEL Team

Sergio Fonte, Alessandra Migliorini, Sergio Molinari, Fabrizio Oliva, Romolo Politi, Eugenio Schisano, Paulina Wolkenberg

ARIEL Planetary Formation Working Group

Claudio Codella, Camilla Danielski, Davide Fedele, Andrea Garufi, Mario Guarcello, Masahiro Ikoma, Mikhel Kama, Diederik Kruijssen, Jesus Maldonado, Yamila Miguel, Lorenzo Mugnai, Athanasia Nikolaou, Olja Panic, Enzo Pascale, Marco Pignatari, Linda Podio, Hans Rickman, Allona Vazan... and anyone I might have unwittingly forgotten...

With Additional Thanks to: Marco Fulle & Cecilia Ceccarelli

The activities of the working group are supported by the **INAF *Main Stream* Project** *ARIEL and the astrochemical link between disks and planets* (PI: D. Turrini)