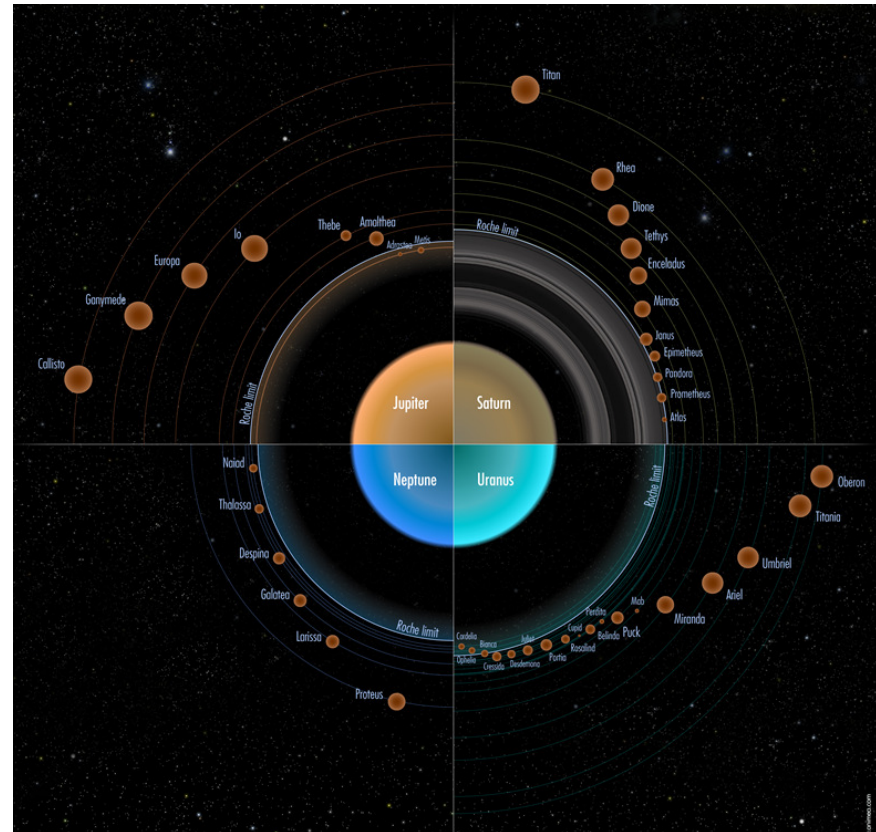


Satellites in the Universe : Formation and Diagnostic tool

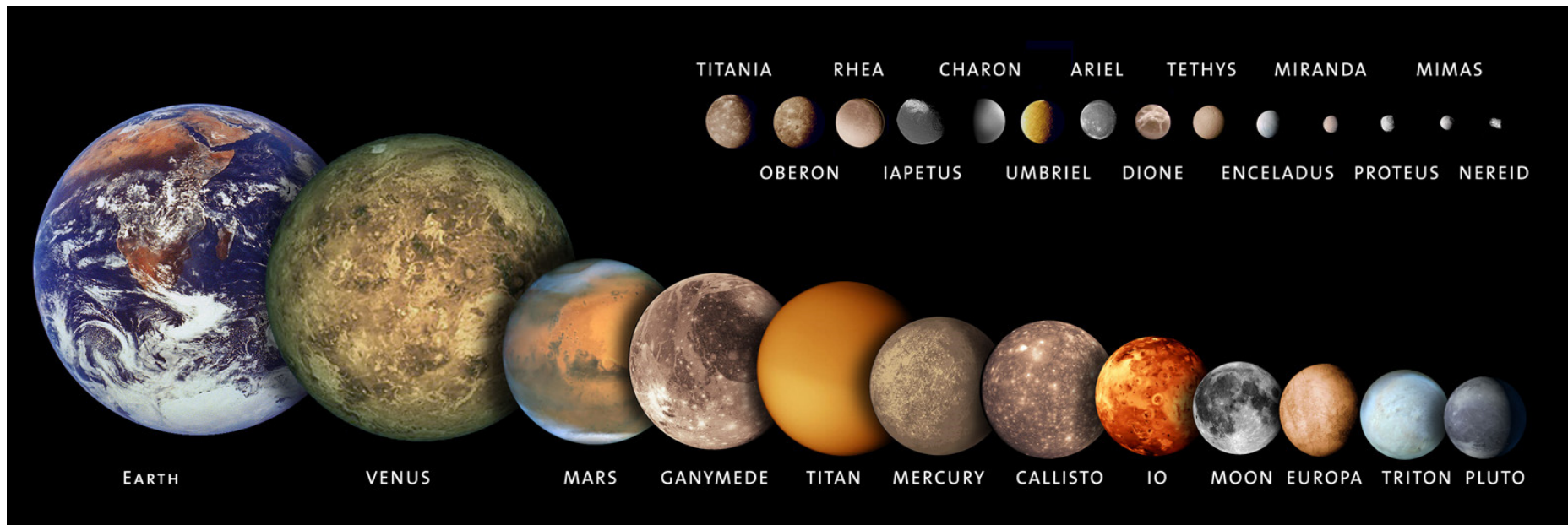


Sébastien CHARNOZ

&

« From dust to planets » UnivEarths exploratory project

Diversity of satellites in the Solar System



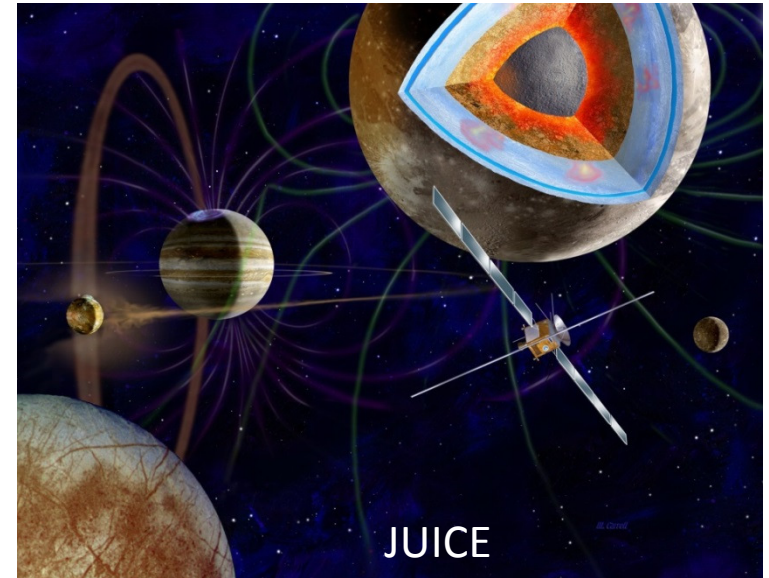
~ 120 satellites in the Solar System (for 9 planets)

**Regular satellites : Orbit in equatorial plane
⇒ formed with the planet**

**Irregular satellites : Orbit in random planes
⇒ Captured (Triton)**

A new and strong interest of the Scientific Community for Moon / Satellites

- Recent selection of the JUICE mission to visit GANYMEDE and EUROPA
- Several US propositions to go to EUROPA
- Recent missions to our Moon (GRAIL 2011, LCROSS 2009 etc..)
- Several proposition of missions proposed to PHOBOS (JETEMME)
- Program: sampling return from PHOBOS (post exomars, Phobos Grunt)
- PLATO and CHEOPS : both have Exomoon detection program => 1 M_{\oplus} moon orbiting 1MJ Planet
- A LOT OF PUBLICATIONS in NATURE and SCIENCE in the ast 2 years



Moons are new target for :

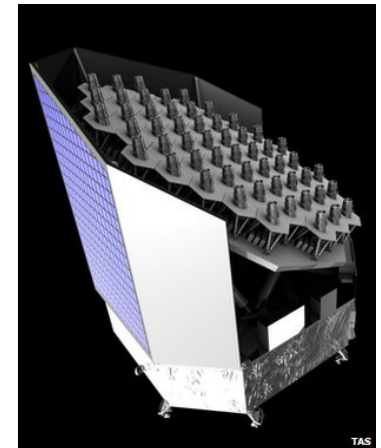
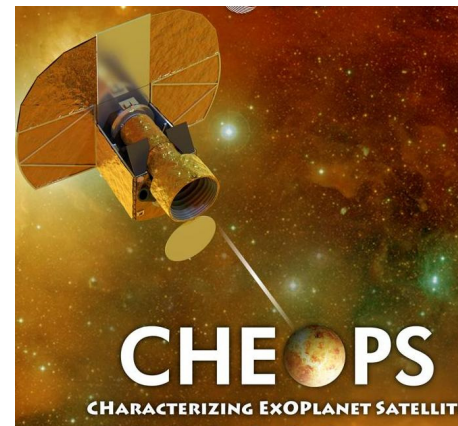
- Understanding planet formation (exoplanet analog

SOLAR SYSTEM MOONS AS ANALOGS FOR COMPACT EXOPLANETARY SYSTEMS

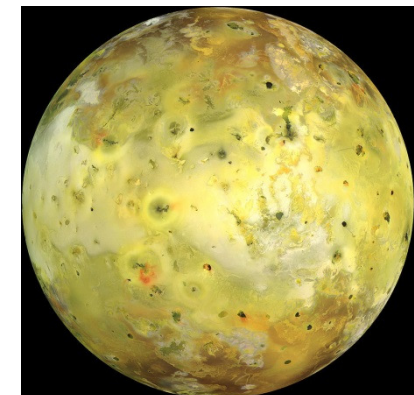
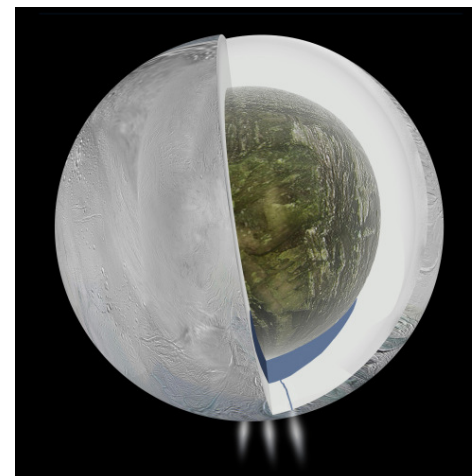
STEPHEN R. KANE^{1,2}, NATALIE R. HINKEL^{1,2}, SEAN N. RAYMOND^{3,4}

Submitted for publication in the Astronomical Journal

- Exoplanets observatories :



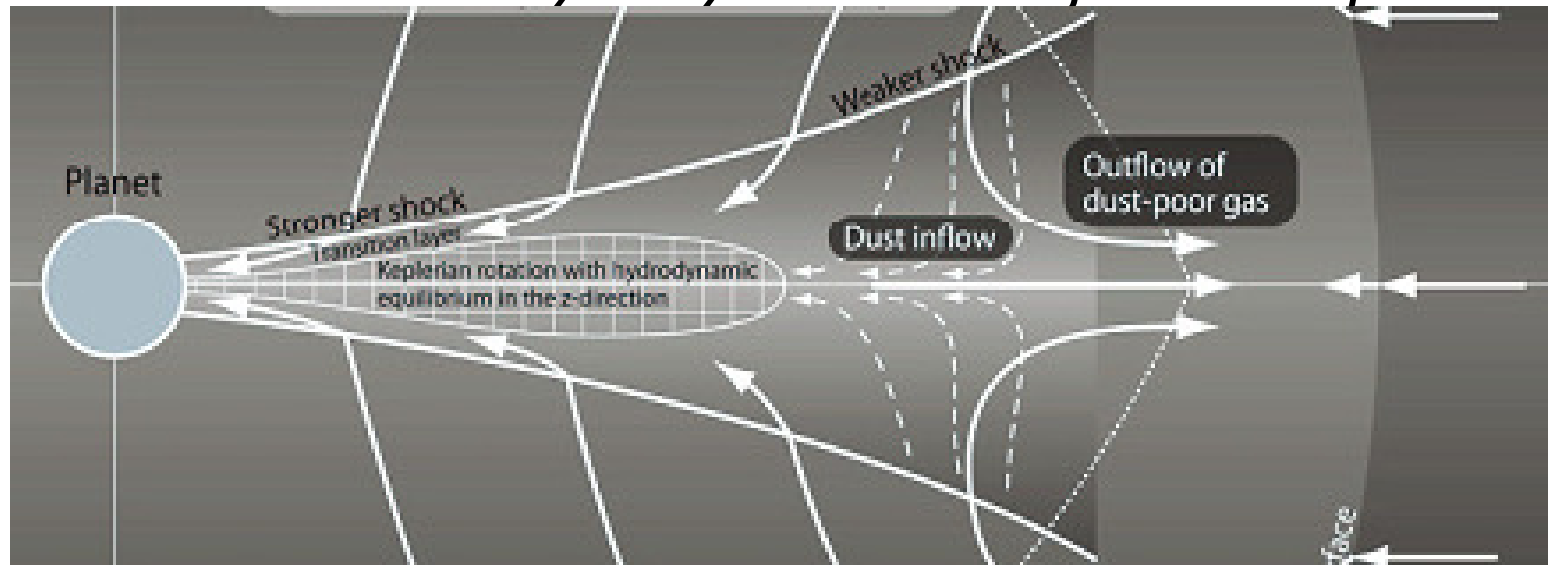
- Habitability / Comparative planetology



KEY QUESTIONS / ASPECTS
THAT CAN BE ADDRESSED
BY MOONS STUDIES

1) Constraining planet formation processes

No consensus => Finally they MAY NOT form like planets



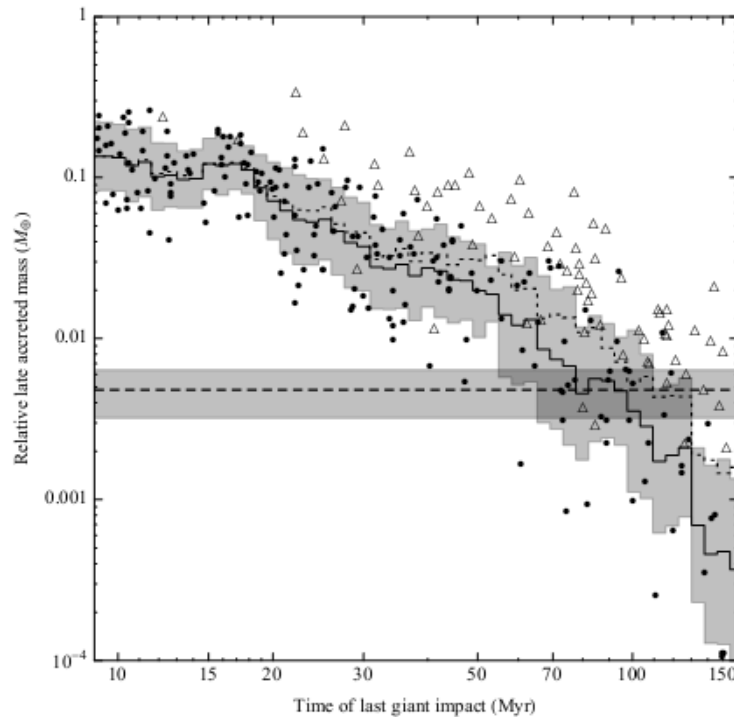
Giant impacts

Reconsideration ?

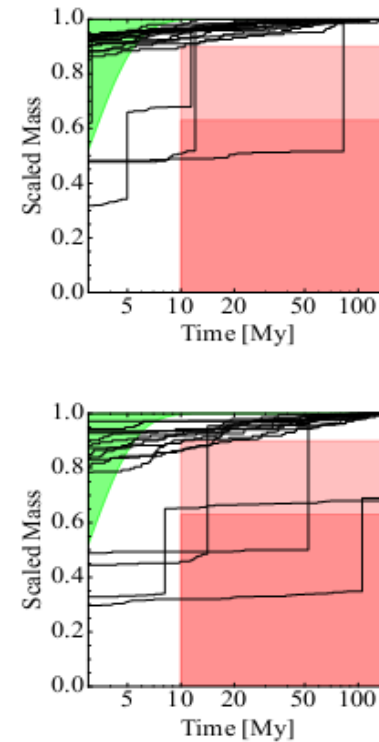


Moon forming in rings (Murray et al., 2014 => Charnoz 2011)

2) Moons as a diagnostic of the last stages of Solar System Formation => Link with Isotopic Data



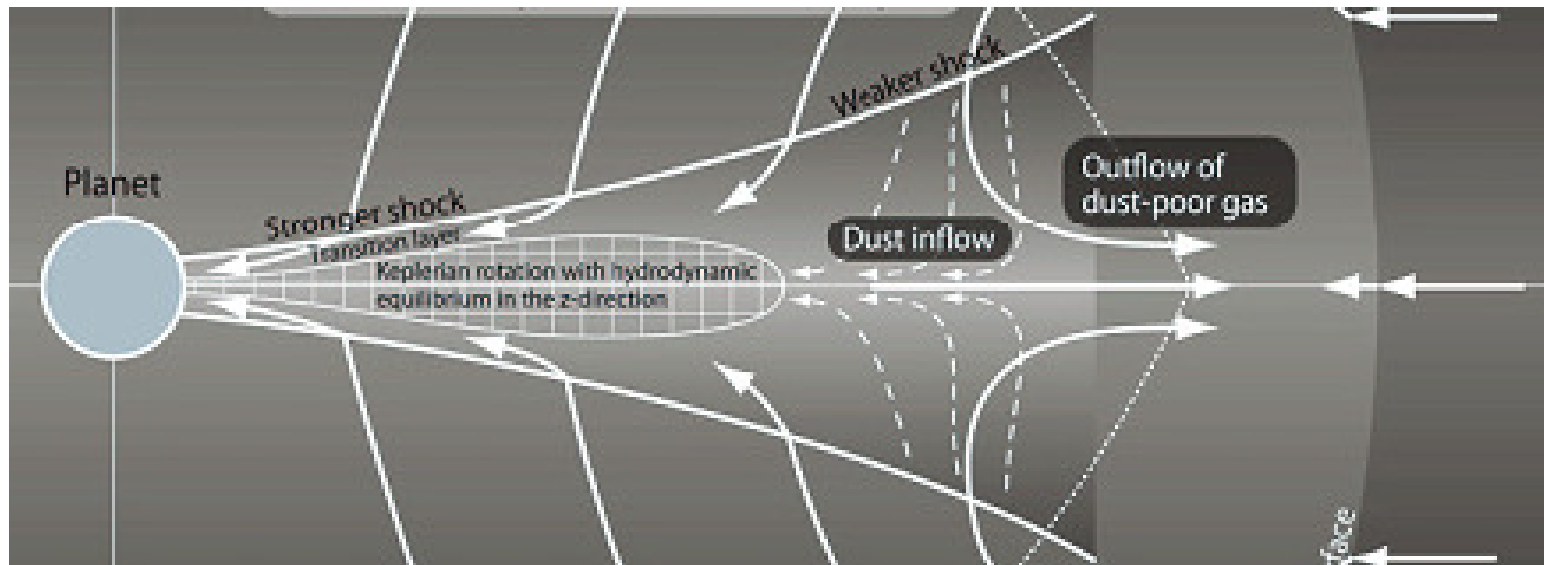
Jacobson et al., 2014 (Nature)



- Uranus's tilted axis => origin in a giant collisions => formation of the current satellite system

Formation of Moons in circumplanetary disks :

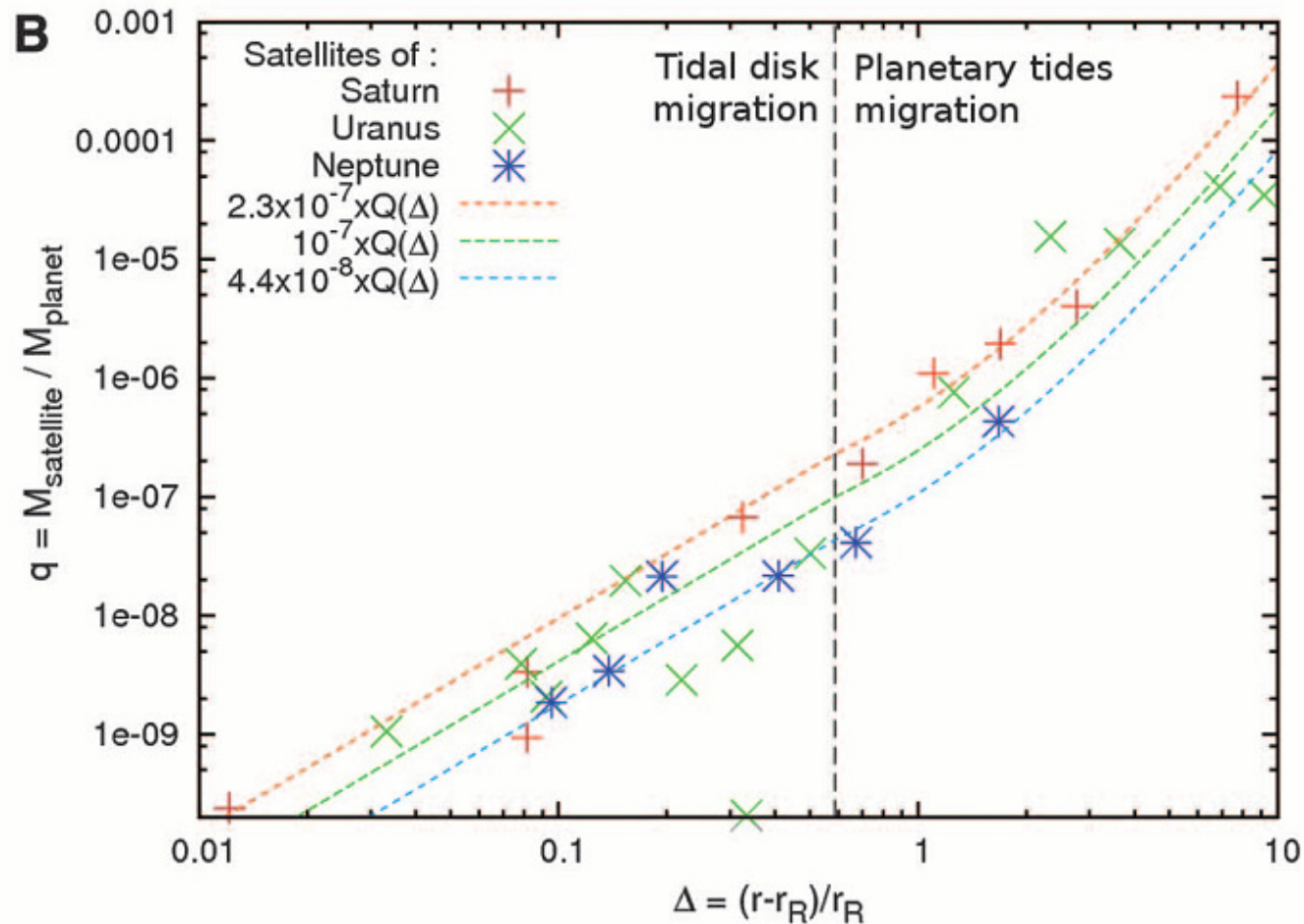
Very end of planet formation



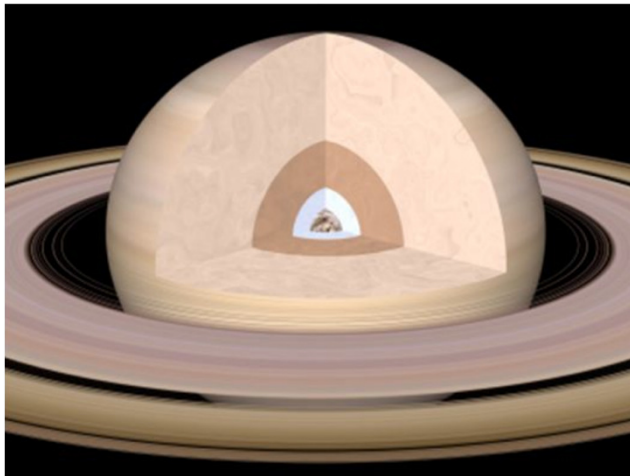
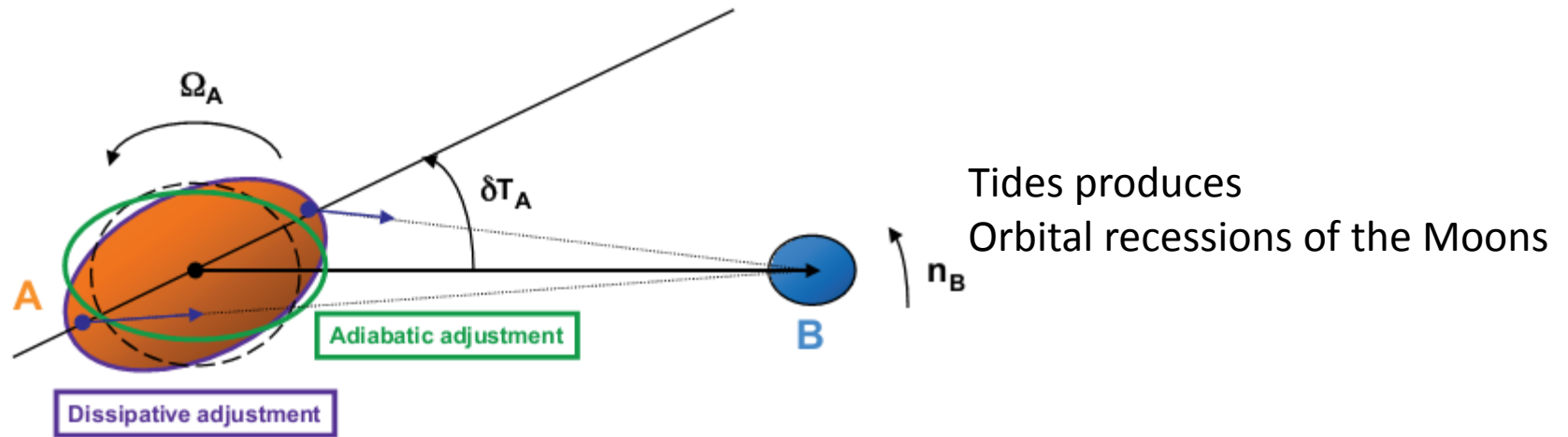
The disk's temperature leaves imprints in the moons chemical composition =>

Prédiction for JUICE

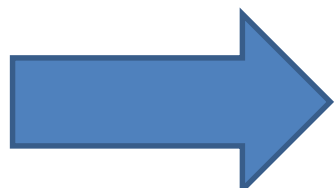
2) Moons orbital architecture as diagnostic of the interior of the host planet



Crida & Charnoz
SCIENCE
2012



The recession speed of satellites
=> signature of a planet's core



Discovery of exo-moons can be used as a tool to probe
planet interior

What we DO NOT know and that has fundamental consequences

- Is there a **UNIQUE** moon formation process or **SEVERAL** ?

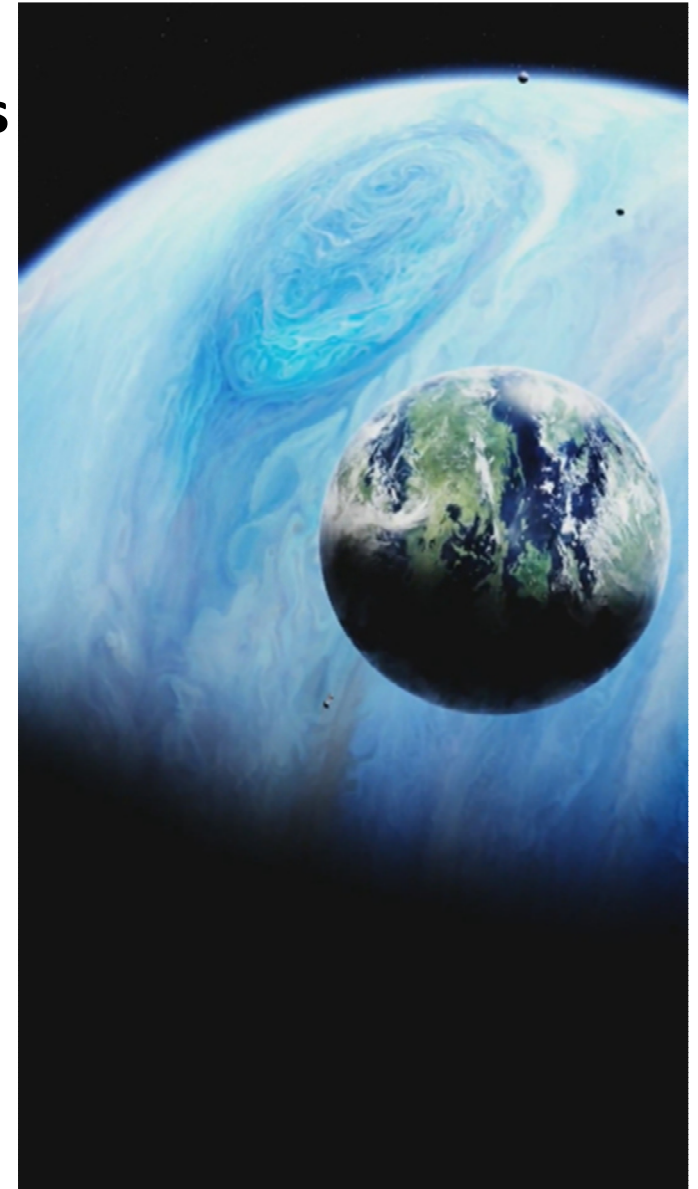
- Are giant planet's moons different from terrestrial planets' ?

Is it possible to have 1 Earth mass sat. around a G.P.

- Are Moons Ubiquitous in the Universe ?

About 9 billions planets in our galaxy (from exoplanets) =>
100 to 1000 billion satellites ?

- What tells the differences/similarities with the
host moon/ planet material ?



Brainstorming ideas

Fund a project dedicated to

1) Understanding of moons origin in the Universe through Numerical simulations AND laboratory study of extraterrestrial material
=> Moon Formation

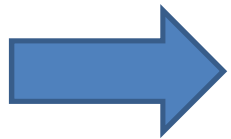
2) Exploration of S.S. Moons

⇒ Laboratory measurements of Moons samples

⇒ Exploration of Moon

⇒ Sample from Phobos?

2) Build analytic tools to interpret future detection of exomoons
(CHEOPS and PLATO missions)



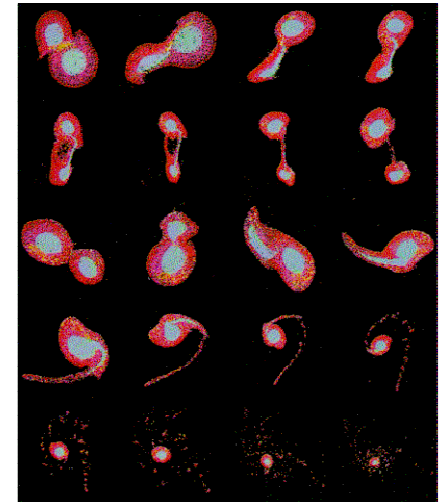
Labex UnivEarths is in a privileged position
We can build an ambitious project with
multidisciplinary approach constrain moon formation
Do predictions for CHEOPS and PLATO

Theoretical side :

**S. Charnoz (AIM/IPGP) => moon formation processes
in impacts and in sub-nebula**

Contribution :

**What satellites system are formed around
Terrestrial and Giant planets**



How the Moon material was processed (interact. Experiments)

S. Mathis (AIMP/ IPGP) => theory of tidal interactions

Key Question : What satellites orbital architecture

Tells us on planet interior and formation

=> Consequences on exoplanets

Moon Experimental and exploration side

Cosmochemistry group at IPGP

(Marc Chaussidon, F. Moinier, M. Moreira)

Contribution :

Volatile content of the Moon (P, Zn, Water) ?

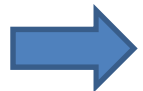
Isotopic identity of Earth and Moon (O, Ti) ?

Presence of peridotites (early magma)?

M. Wieczorek (IPGP) : implied in GRAIL

Contribution :

Moon internal structure, core state



Feedback with theory

Implication into exoplanets

S. Mathis : Leader of PLATO WORKCPACKAGE « star-planet tidal interactions »

S. Charnoz : implied in PLATO workcpakage :

- EXOMOONS (G. Szabo Leader)
- Planet Formation (R. Nelson PI)

Throug G. SZABO : possible implication in CHEOPS mission (2017)

R. GARCIA, S. BRUN : aspects stellaires de PLATO

National / International context / community :

In France :

Good links with NANTES (icy satellites interior)

Good links with NICE (planet /satellite formation)

In Europe:

Links with G. Szabo (Hungaria, exomoon detection)

Links with Cambridge (Mathis => tides)

In US :

Good links with SWRI (Numerical simulation moons, exomoon detection, CANUP,)

In Israel :

O. Ahaaronson : moon formation.

In Japan

Collaboration with O. Genda (Tokyo)