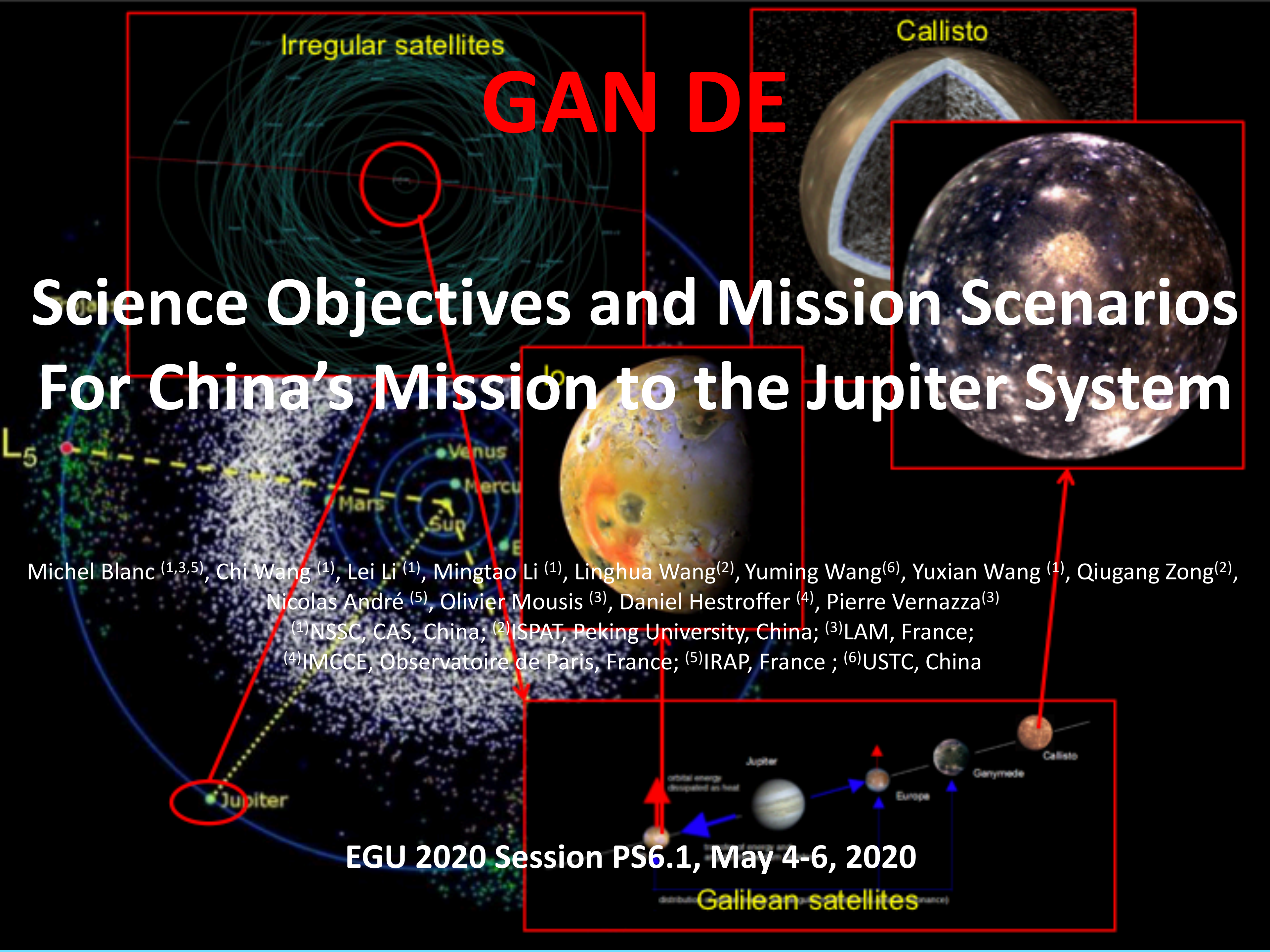

GAN DE

Science Objectives and Mission Scenarios For China's Mission to the Jupiter System

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ABSTRACT

To answer key scientific questions about Planetary Systems, it is particularly fruitful to study the Jupiter System, the most complex "secondary" planetary system in the solar system, using the power of in situ exploration. Two key questions should be addressed by future missions:

A-How did the Jupiter System form? Answers can be found in the most primitive objects of the system: Callisto seems to have been only partly differentiated; its bulk composition, interior and surface terrains keep records of its early eons; the 77 or so irregular satellites, wandering far out beyond the region occupied by the Galilean satellites, are unique and precious remnants of the populations of planetesimals which orbited the outer Solar System at the time of Jupiter's formation.

B-How does it work? One can address this question by studying and understanding the chain of energy transfer operating today in the Jupiter System: how is gravitational energy from Jupiter transferred to Io's interior via tidal heat dissipation to power its volcanic activity? How does this activity in turn store energy into the Io plasma torus to drive the whole magnetosphere into motion? How does the interplay between the Io torus and the solar wind dump energy into heating of Jupiter's upper atmosphere, or release it into the tail and interplanetary space?

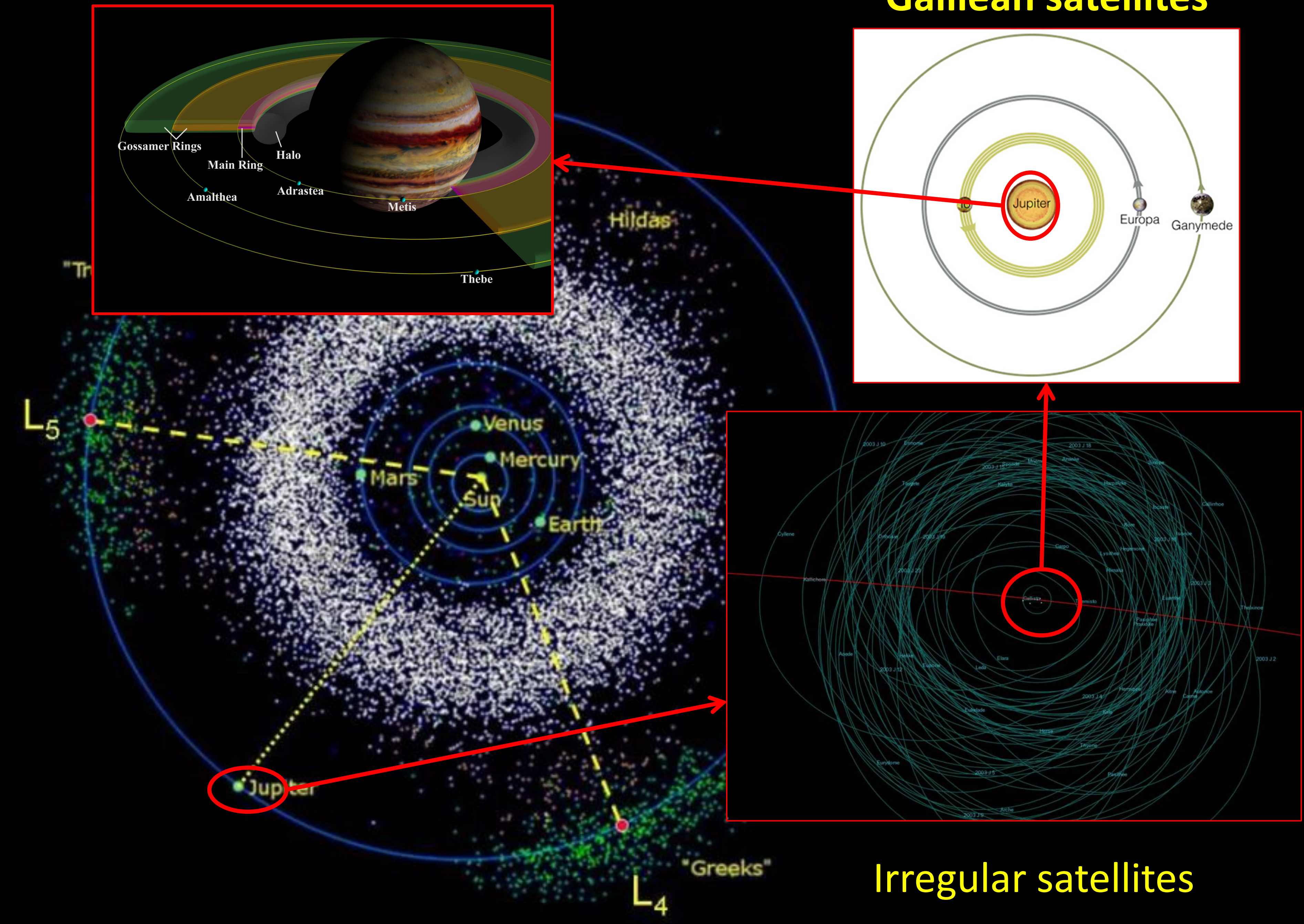
Starting from the measurement requirements derived from these two objectives, we propose two ambitious mission scenarios, named JCO and JSO, to meet these requirements. Both use the combination of a main spacecraft and one or several specialized small platforms.

JCO, the Jupiter Callisto Orbiter, first flies by and characterizes several irregular satellites during its Jovian orbital tour. It is then injected into Callisto orbit to characterize its surface and interior, investigate its degree of differentiation and search for the possible existence of an internal ocean. As an option, JCO could release a lander to Callisto's surface to perform key measurements of chemical composition, clues to understanding the formation scenario of the Galilean moons.

JSO, the Jupiter System Observer, performs several fly-bys of Io and visits several irregular satellites during its Jovian orbital tour. As an option, JSO could release one or several small satellites to perform multi-point studies of the dynamics of the Jovian magnetosphere. At the end of its tour it could be injected into a halo orbit around the L1 Lagrangian point of the Sun-Jupiter system to monitor the solar wind upstream of the Jovian magnetosphere, measure Jovian seismic oscillations, and perform a comprehensive survey of the irregular satellites.

Led by China under the name of GAN De, the first astronomer to have claimed an observation of a moon of Jupiter four centuries BC, and broadly open to international collaboration, a mission flying to Jupiter in the 2030's according to either one of these scenarios will be able to capitalize on the legacy of previous missions to Jupiter (Juno, JUICE, Europa Clipper) and to trigger a very exciting international collaboration to unravel the mysteries of the origins and workings of the Jupiter system.

Jupiter and the small regular satellites



Two Key scientific questions

For the GAN De mission

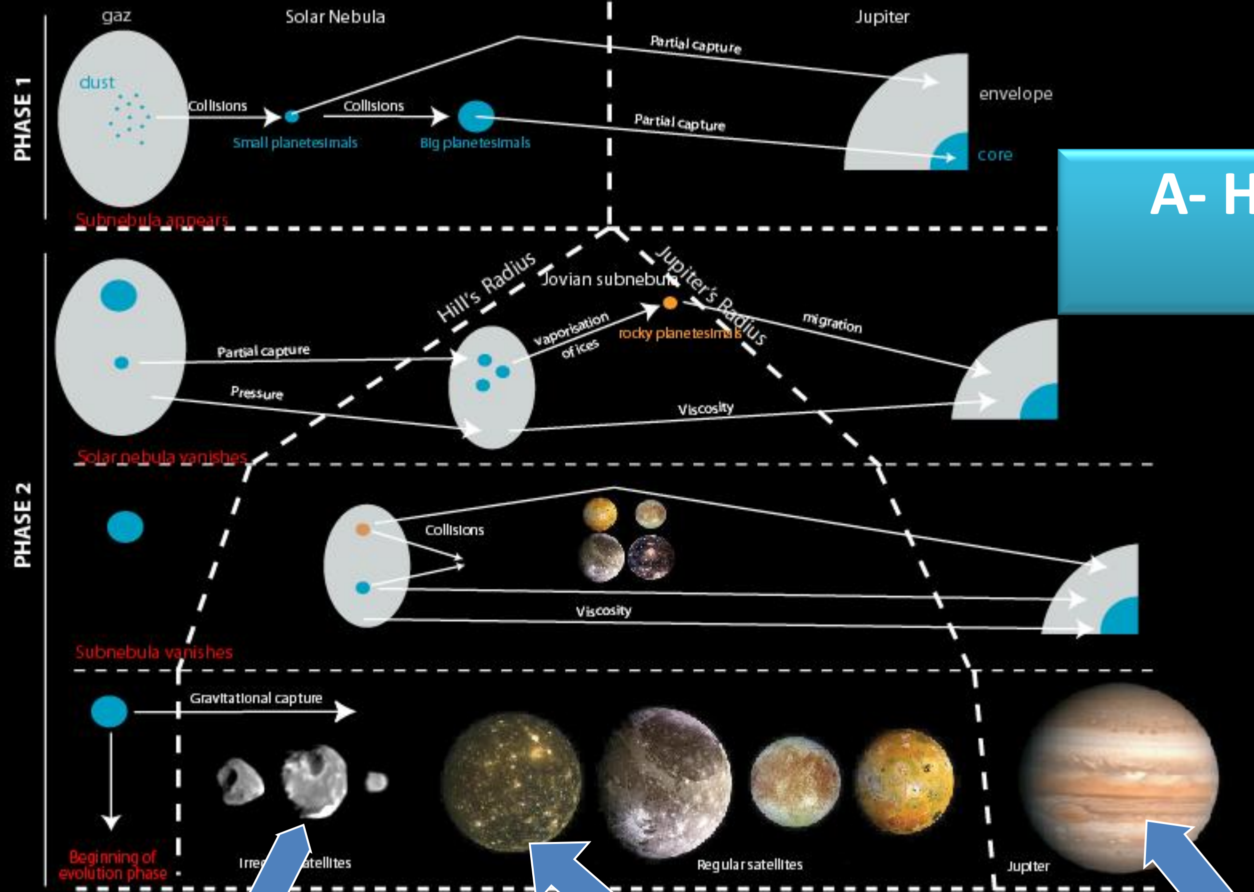
a. How did the Jupiter Satellite System form?

Understand the formation of the regular and irregular satellites and their link to Jupiter formation

d. How does the Jupiter System work?

Build an integrative view of coupling processes among its components

A- HOW DID THE JUPITER SYSTEM FORM?



1- Constraints on internal structure and core size

(JUNO + Jupiter seismology)

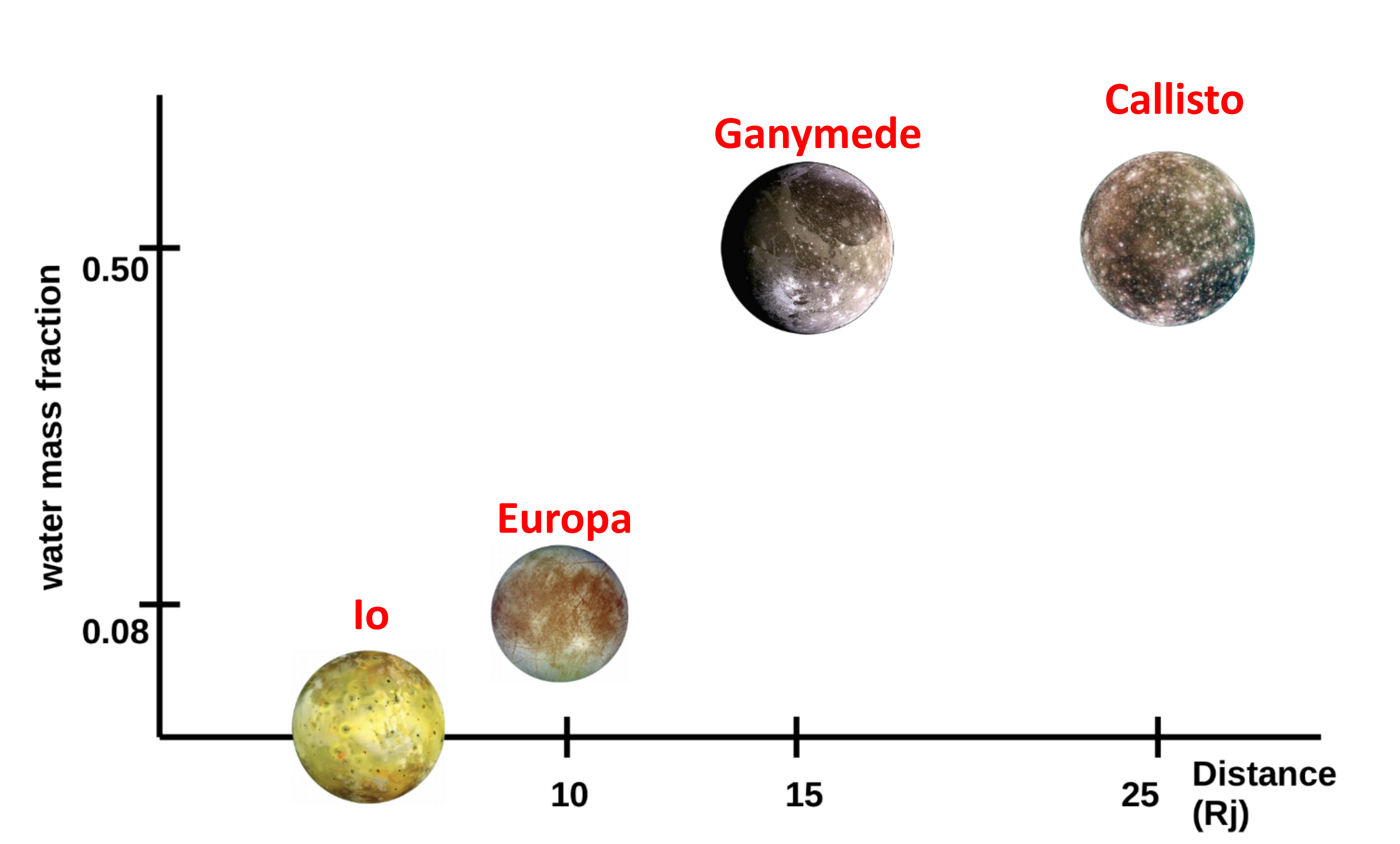
2- Constraints on the proto-jovian nebula from Callisto degree of differentiation + chemical and isotopic composition of ices and refractory components

3- Constraints on formation + early early evolution from irregular satellites mass, density, morphology, dynamics, chemical and isotopic composition of ices and refractory components

(Adapted from Blanc, M. et al., LAPLACE: A mission to Europa and the Jupiter System for ESA's Cosmic Vision Programme, Exp. Astronomy 23, 849-892)

The Galilean moons: a well-ordered system

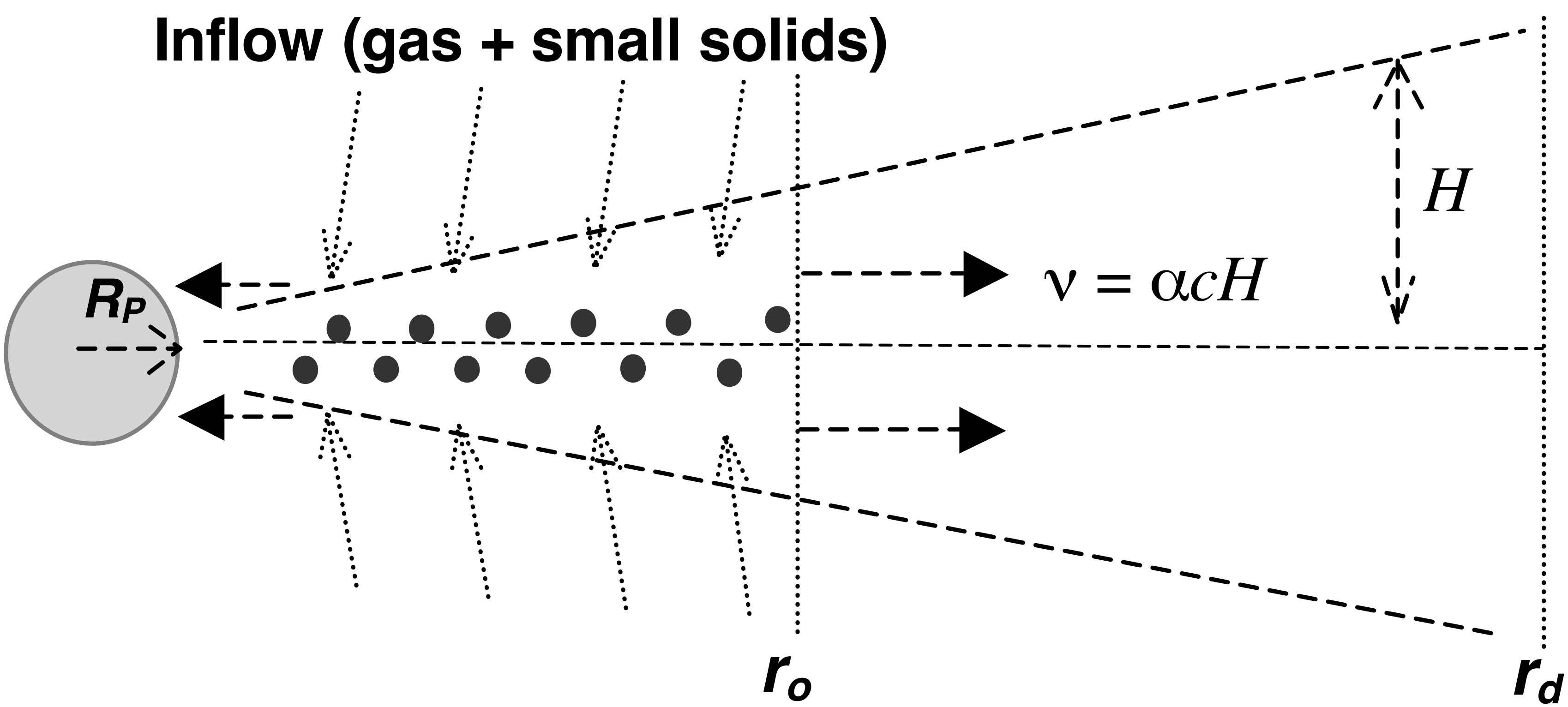
Density of the satellites **decreases** with their **distance to Jupiter**
Generally attributed to **water mass fraction increasing radially outwards in a primordial circumjovian disk!**



From T. Ronnet's PhD thesis, 2018

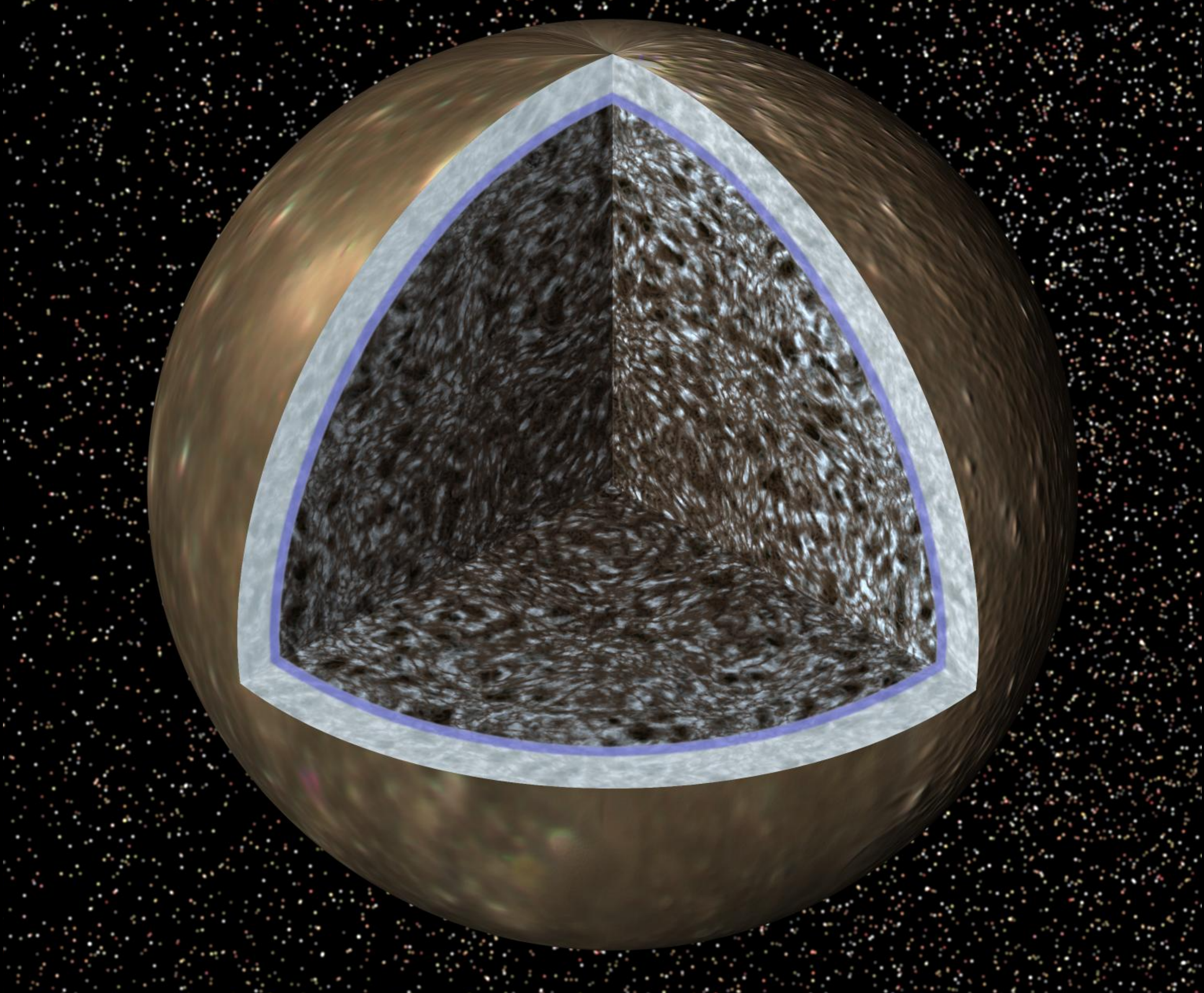
The Galilean moons: a possible formation scenario

Dust accretion model (the « gas-starved nebula »)



From Canup and Ward, Nature, 441, 2006

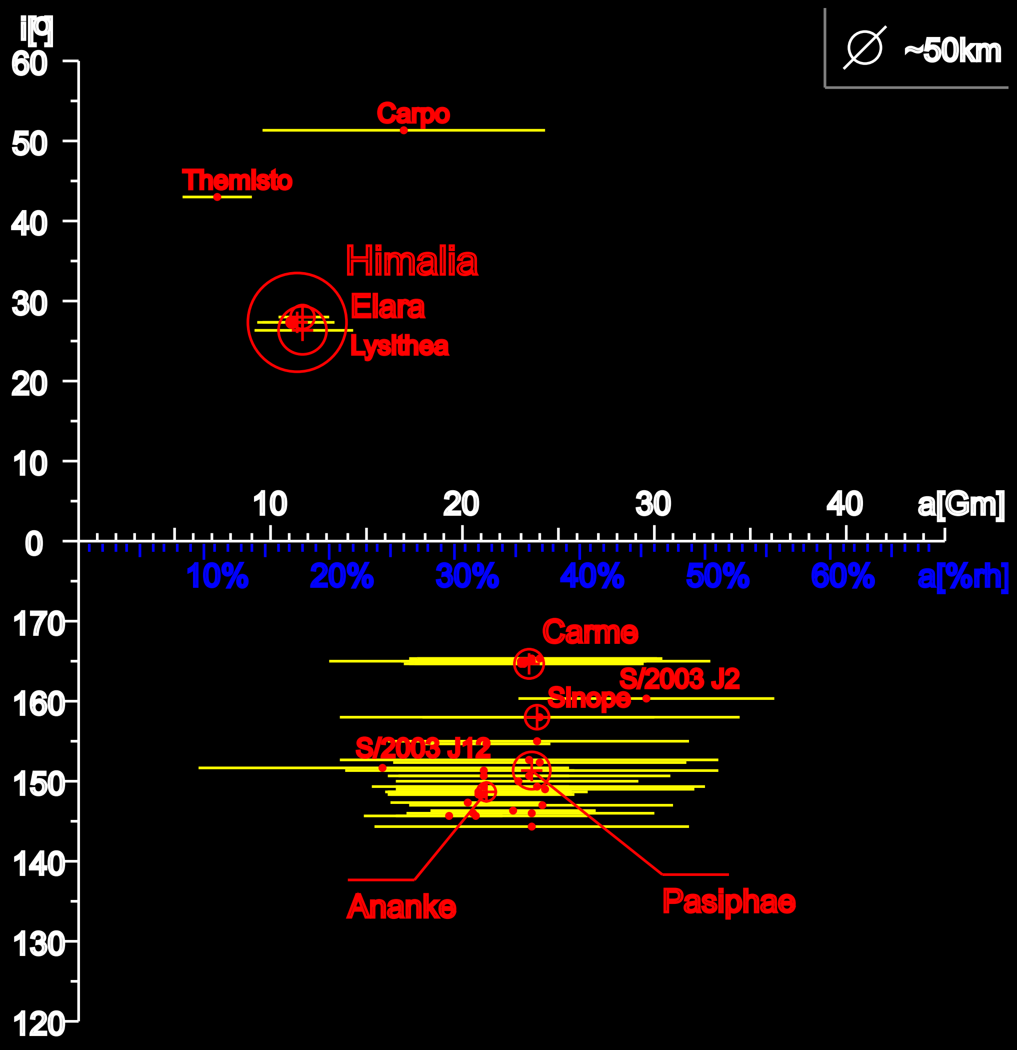
CALLISTO's DEGREE OF DIFFERENTIATION
A test of formation models?



Radius
2410 km

Density
1.834

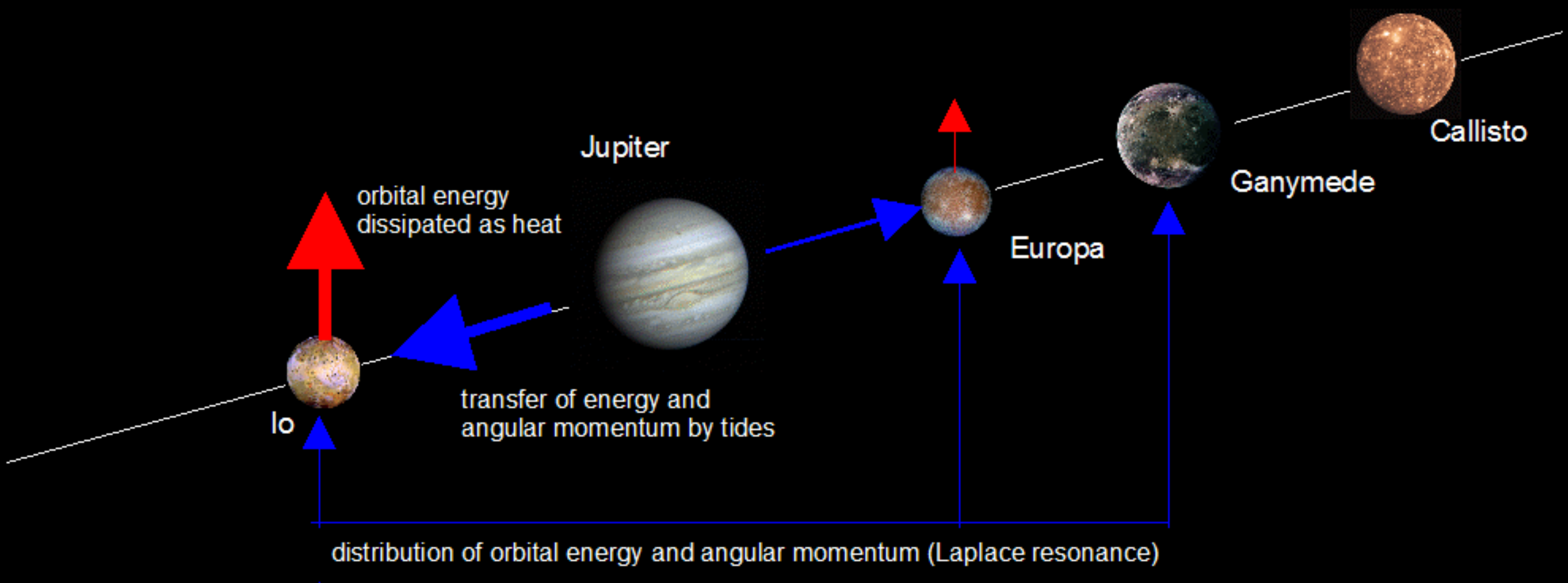
Orbital excentricities and inclinations of the irregular satellites of Jupiter



Gan De mission Science Traceability Matrix (Goal A)

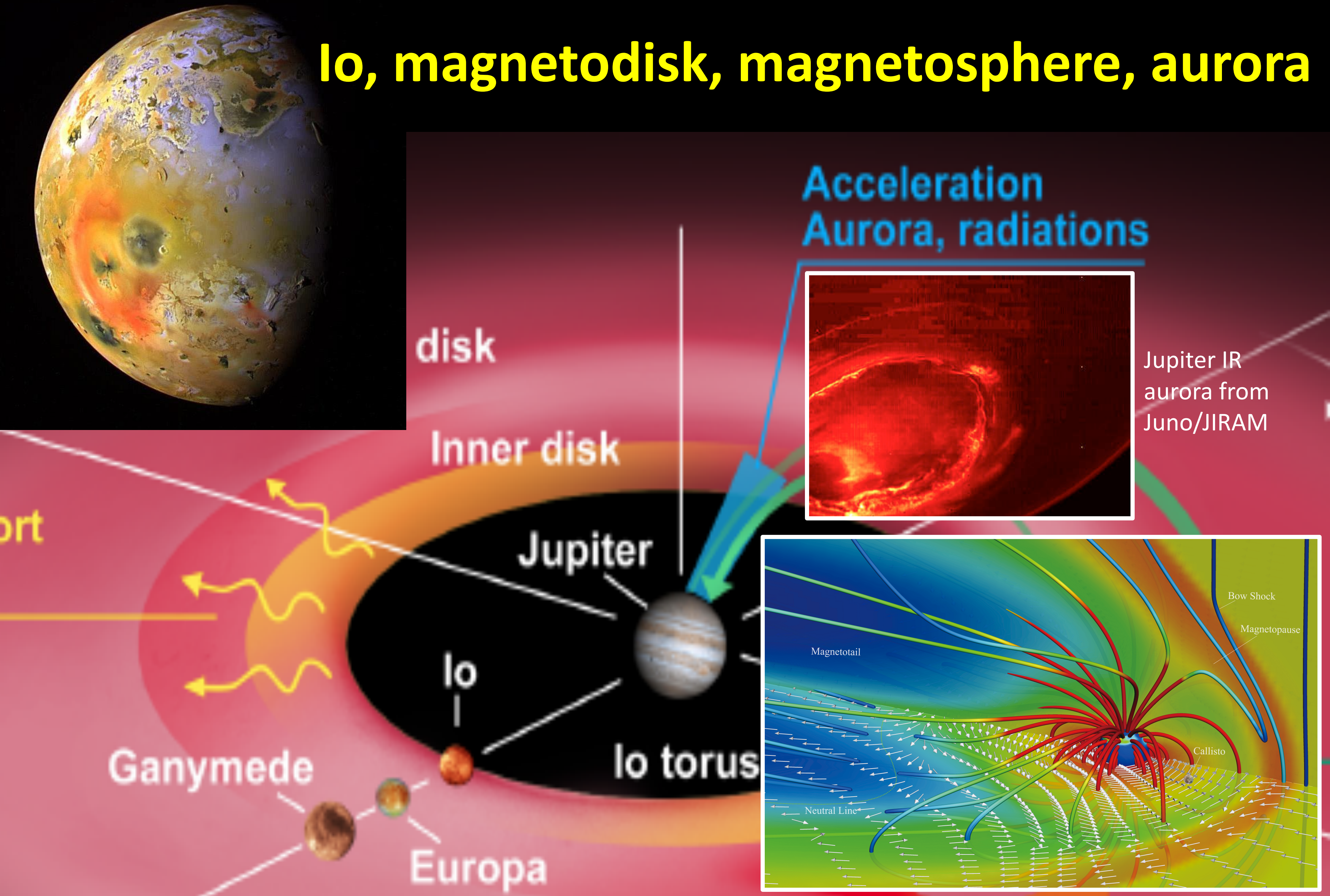
GOAL A: How did the Jupiter System form?				
Specific Science Question	**Required measurements**	**Instrumentation**	**Targets/ Platforms**	**Synergies with international program**
A-1. How did Jupiter itself form?	Determination of the proper modes of mechanical oscillation of Jupiter by remote-sensing seismology.	Long-duration high-accuracy photometry or doppler imaging of the full Jovian disk	Jupiter/JSO	Key complement to the gravimetry and magnetic field measurements performed by NASA's Juno.
A-2. Determine the formation History, internal structure and exosphere of Callisto and provide key constraints on the formation scenario of the Galilean satellites	Internal structure, degree of differentiation, putative presence of an ocean, exosphere-ionosphere, internal and external electric currents, full visible imaging, NIR reflectance spectra, dust population and composition. D/H ratios of ices, elemental and isotopic abundance ratios of main heavy elements and noble gases	Radio Science w. USO, magnetometer, plasma and dust detectors, NIR imaging spectrometer, visible imaging camera High-resolution Mass Spectrometer fed by sample collection of surface ices and refractory component (with pyrolysis capacity?)	Callisto/JCO In Callisto orbit Callisto/CL	Synergistic science with JUICE and Europa Clipper by comparison of the Galilean satellites Collaboration with JUICE on Callisto science using the the 12 JUICE flybys to prepare lander mission
A-3. What is the origin of the small irregular satellites and their relationship to other families of small bodies in the solar system?	Mass, size and shape, density as a function of orbital parameter class and groups. Resolved NIR reflectance spectra and visible imaging for mineralogy and collision history. D/H ratios of ices, elemental and isotopic abundance ratios of main heavy elements and noble gases	Radio science w. USO; vis. Imaging; NIR imaging/spectroscopy High-resolution Mass Spectrometer fed by sample collection of surface ices and refractory component	Irr. Sat. /JSO + JCO One Irr. Sat. /SE (option)	Complements to international and JUICE + Europa Clipper astrometry observations. Synergy with NASA's LUCY mission to the Jupiter Trojans.

B- HOW DOES THE JUPITER SYSTEM WORK?



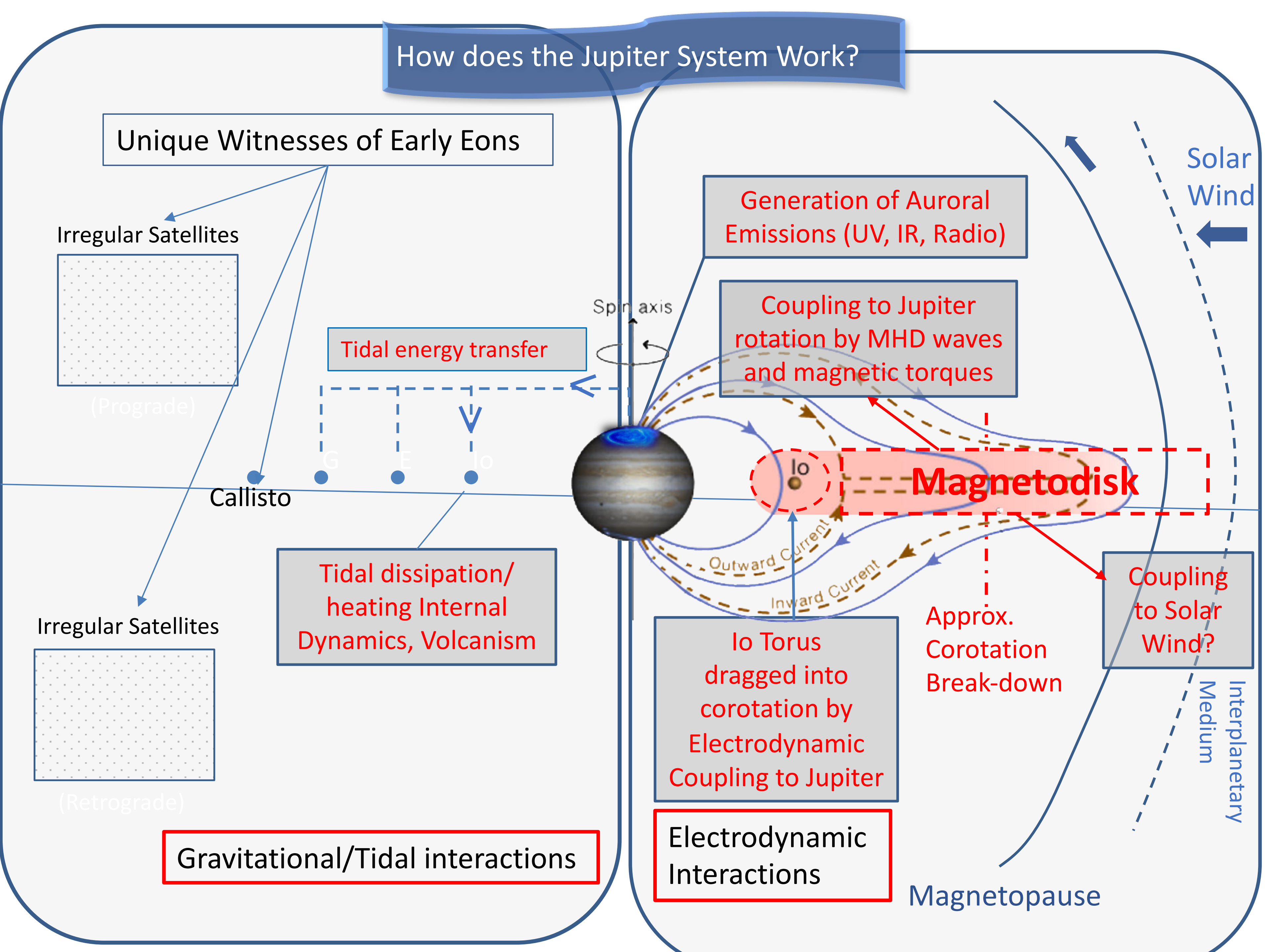
THE GALILEAN MOONS
and the Laplace resonance

Io, magnetodisk, magnetosphere, aurora



Jupiter IR aurora from Juno/JIRAM

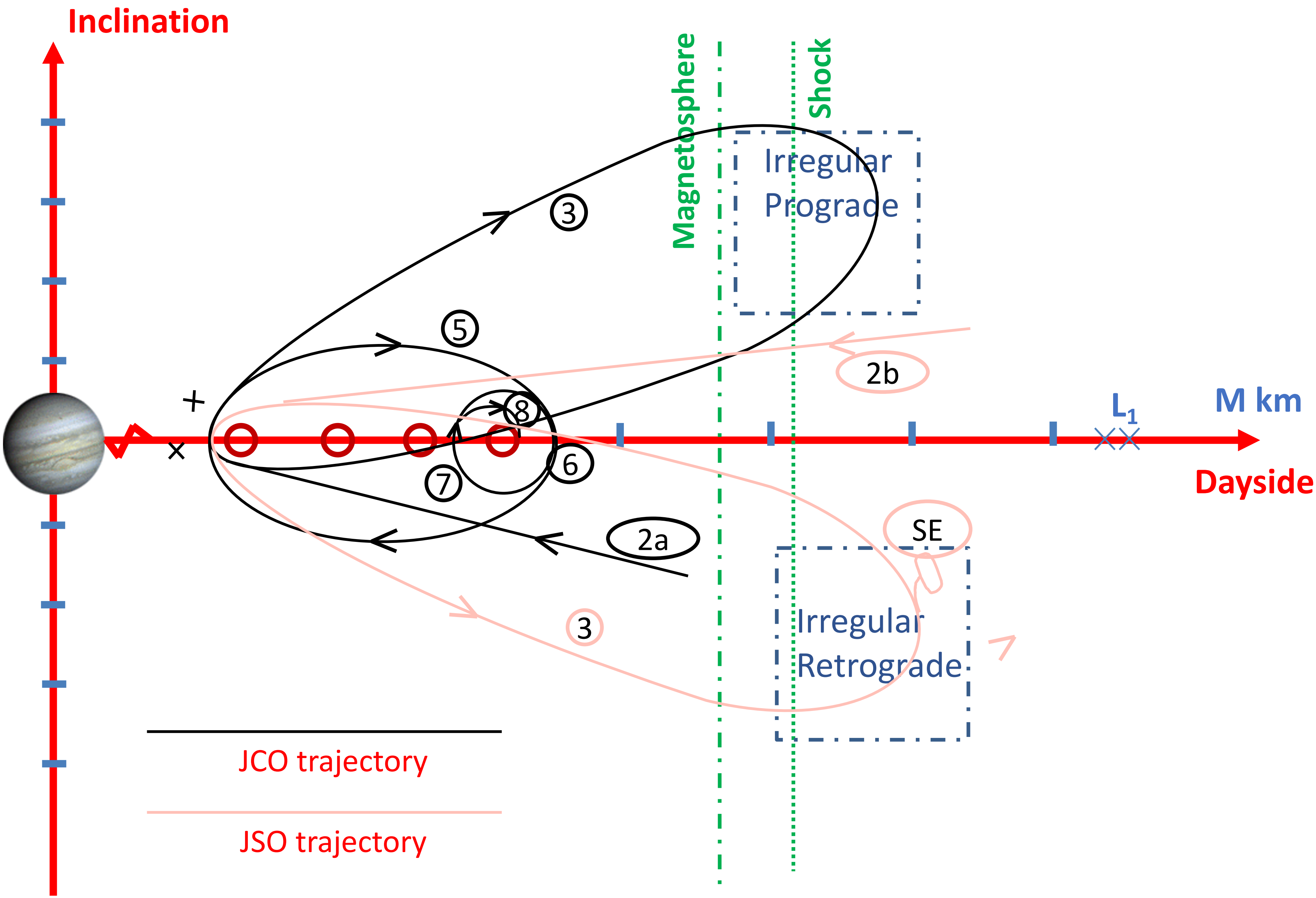
From **Wang Y. X.**, Guo X. C., Tang B. B., Li W. Y., and Wang C. (2018). Earth Planet. Phys., 2(4), 303–309. http://doi.org/10.26464/epp2018028



How does the Jupiter System Work?
Unique Witnesses of Early Eons
Irregular Satellites
(Prograde)
Tidal energy transfer
G
E
Io
Callisto
Irregular Satellites
(Retrograde)
Tidal dissipation/ heating Internal Dynamics, Volcanism
Gravitational/Tidal interactions
Spin axis
Generation of Auroral Emissions (UV, IR, Radio)
Coupling to Jupiter rotation by MHD waves and magnetic torques
Solar Wind
Io
Magnetodisk
Outward Current
Inward Current
Io Torus dragged into corotation by Electrodynamic Coupling to Jupiter
Approx. Corotation Break-down
Coupling to Solar Wind?
Interplanetary Medium
Electrodynamic Interactions
Magnetopause

Gan De mission Science Traceability Matrix (Goal B)

GOAL B: How does the Jupiter System work?				
B-1. Constrain the energy balance of Io between tidal heating, driving of its volcanic activity and transfer of mass, momentum and energy to its torus	Contributions to improved determinations of Galilean satellites orbital drifts (gravitational energy exchange with Jupiter). Phase and amplitude of tides. Thermal radiation; long-term volcanic activity monitoring; structure and chemical composition of neutral and plasma components of torus.	Astrometry Investigations by Radio Science w. USO and VLBI tracking (PRIDE-like) Metric-decametric accuracy altimeter; FIR-Submm spectrometer; vis. imaging of volcanic activity; plasma instrument and INMS measurements of torus.	Io / JCO+JSO	Complements to international and JUICE + Europa Clipper astrometry observations.
B-2. Understand how mass, momentum and energy initially stored in the Io torus are transferred to the Jovian magnetodisk and partly lost to interplanetary space	Characterization of the different modes of plasma and flux tubes radial transport in magnetosphere/disk by in-situ plasma + energetic particles measurements + ENA, radio and plasma waves monitoring (1) at a broad range of radial distances, heights above disk equator and with comprehensive local time coverage; (2) in solar wind; (3) with a multi-point resolution capacity (MC option)	Plasma detector High-energy detector/ENA imager Radio and plasma waves spectrometer INMS On the two platforms w. solar wind monitoring by JSO On magnetospheric cubesats (option)	Io torus and magnetosphere/disk JCO + JSO + MC (option)	Synergies with Juno Synergies and potential collaborations with JUICE and Europa Clipper Determination of upstream solar wind for these missions if relative timing adequate
B-3. Understand the interplay of internal and solar wind sources in the control of the dynamics of the Jovian magnetosphere, generation of auroral emissions and heating of the Jovian upper atmosphere.	Synergistic studies of (1) Io torus (2) magnetosphere/disk radial, latitudinal and local time distributions/variations (3) solar wind conditions (4) Jovian radio and auroral emissions using comprehensive coupled models of Jovian magnetosphere and upper atmosphere	Same as above + assimilation of data into models	Magnetosphere/disk; Jovian upper atmosphere and radio/auroral emissions JCO+JSO +MC (option)	Synergies with Juno; synergies and potential collaborations with JUICE on magnetosphere, auroral studies and aeronomy of Jovian upper atmosphere and Io torus



Inclination
Magnetosphere
Shock
Irregular Prograde
3
5
2b
+
8
L1
M km
×
6
Dayside
7
2a
SE
3
Irregular Retrograde
JCO trajectory
JSO trajectory

Possible/optional flight elements

#	Flight element	Orbital spin	Heritage	Instrument packages	
JCO	Jupiter/Callisto carrier/orbiter	Prograde	Moon and Mars orbiters	1 + 2	
CL	Callisto Lander	“	Chang’e Moon landers	3	
JSO	Jupiter System Observer/ Relay Satellite	Retrograde	Chang’e 4 Relay Satellite	1 + 2	4
MC	Magnetospheric cubesats	Either		1	
SE	Irregular satellite surface element	t.b.d.	Asteroid mission surface elements	3	

Possible science payload

A Plasma + dust

Thermal plasma spectrometer (100 ev-100 kev), I &e
High-energy charged particle detector + ENA imager
Ion and Neutral Mass Spectrometer
Magnetometer
Radio and plasma waves spectrometer
Cosmic dust detector w. mass spectrometer

B Multi-lambda imaging/spectroscopy

VIS imaging camera
NIR imager/spectrometer
FIR/Submm radiometer/spectrometer
UV imager/spectrometer

C Geology/glaciology/geochemistry

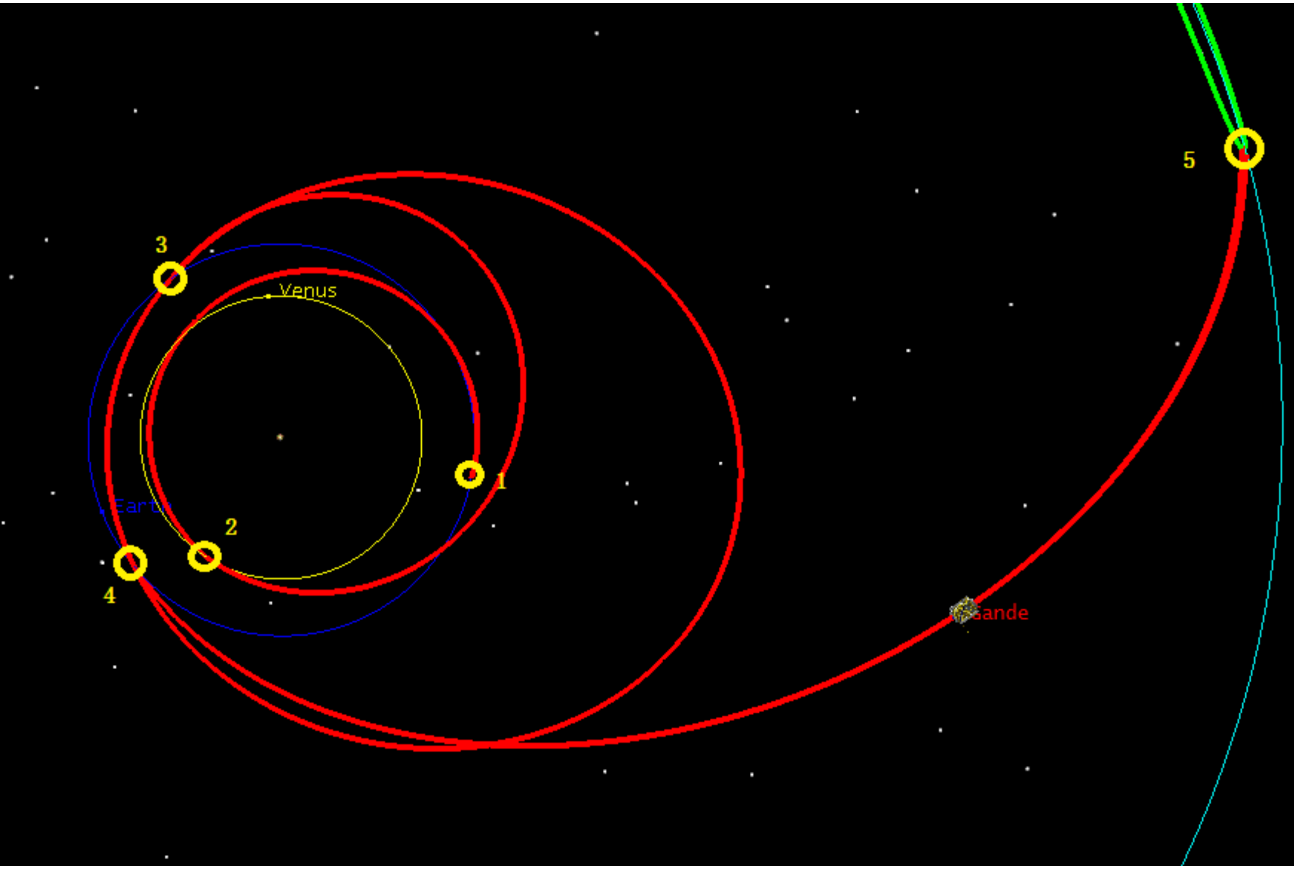
High-mass resolution - large mass range mass spectrometer
Fed by:

- Sampling system for ice surface
- Pyrolyser (for refractory component)

D Radio + optical links + radio science

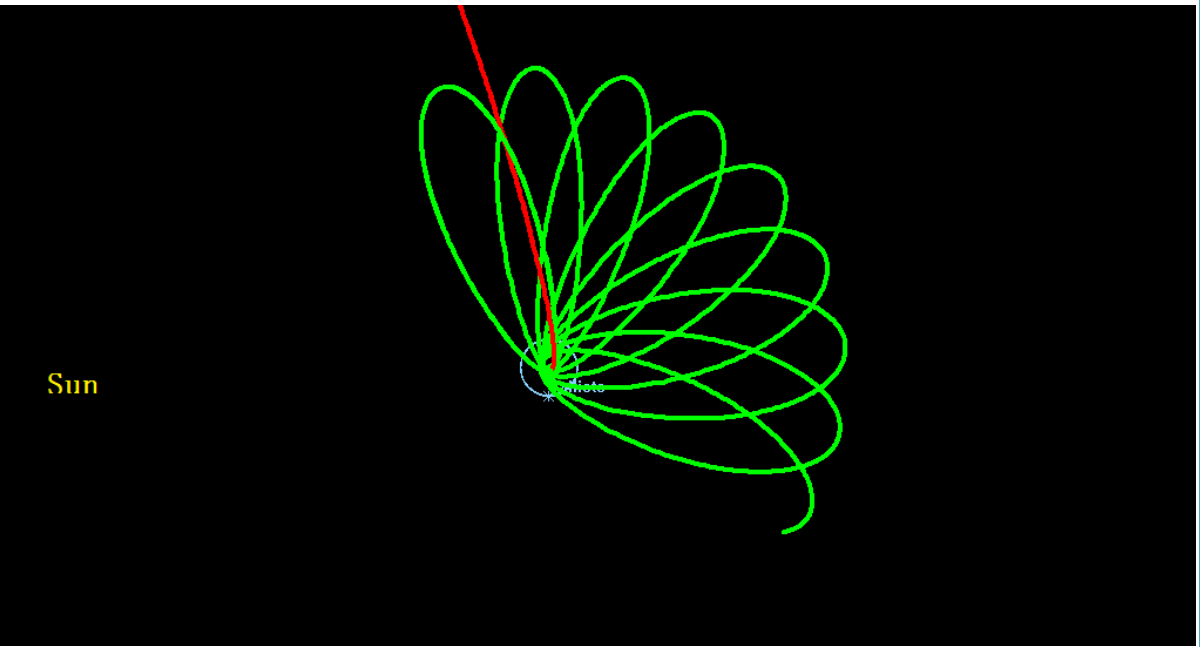
T/R Radio link to Earth with USO for Doppler tracking and occultations
Inter-platform radio links for additional doppler tracking and occultation measurements
PRIDE astrometry experiment (VLBI tracking of each flight element
Altimeter (with meter accuracy)

Gan De Earth-Jupiter Transfer Trajectory



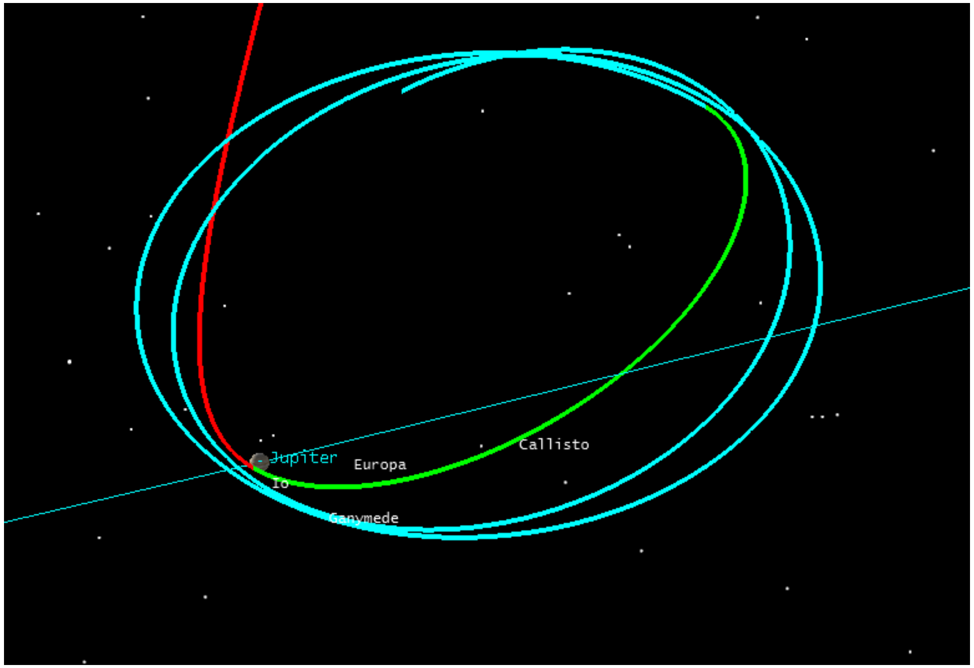
1	Launch	2029-10-02
	Launch C3	14.84 km2/s2
2	Venus Flyby	2030-04-11
	altitude	12716 km
3	Earth 1st Flyby	2031-02-15
	altitude	5246 km
4	Earth 2nd Flyby	2033-05-23
	altitude	2151km
5	Jupiter Arrival	2035-08-15
	Transfer Time	5.87 yr
	Arrival C3	35.96 km2/s2

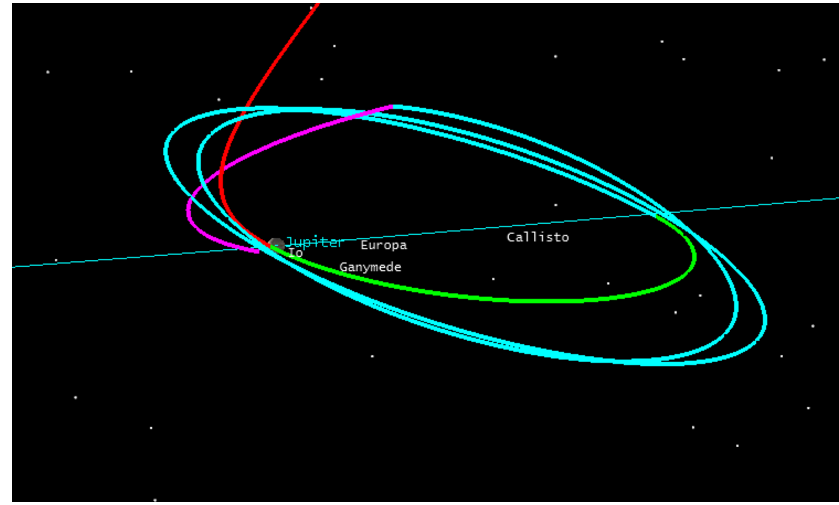
Jupiter System Orbiter



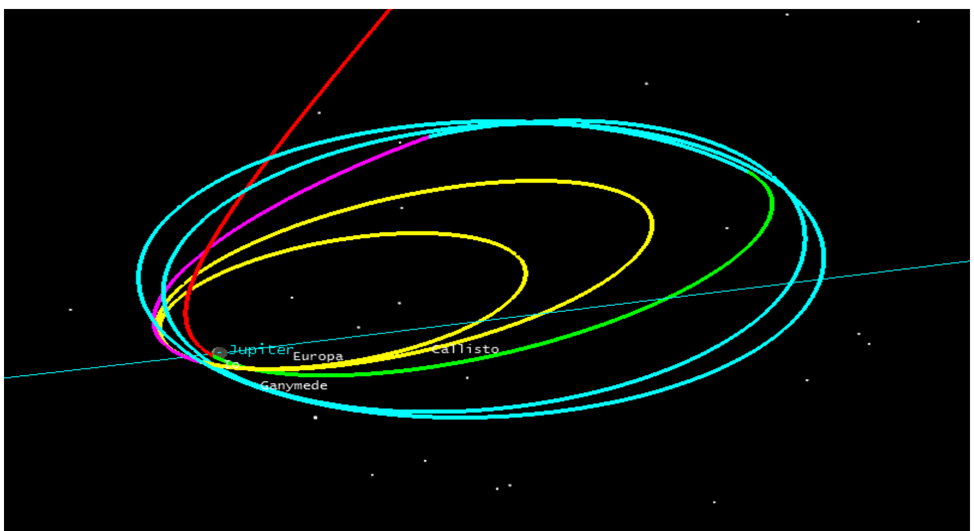
Jupiter Insertion altitude	142861 km (2 Rj)
Jupiter Insertion Delta-V	0.696 km/s
Apojove altitude	20 Mkm
Period	211 days
Inclination	144° -155°

Jupiter Callisto Orbiter





2) JCO is then transferred into a 0 degree orbit to flyby Jovian moons



3) Apojove alititude is lowered by flybys of jovian moons

4) JCO is insertion into a Callisto polar orbit

PRELIMINARY CONCLUSIONS

- **GAN DE will address key science questions about the Jupiter System!**
- **Work in progress! Much more to do!**
- **GAN DE will be a great contribution to an international plan for an in-depth study of the Jupiter system**
- **Can gain a lot from synergies with previous missions and collaborations with their teams! Especially JUICE!**

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