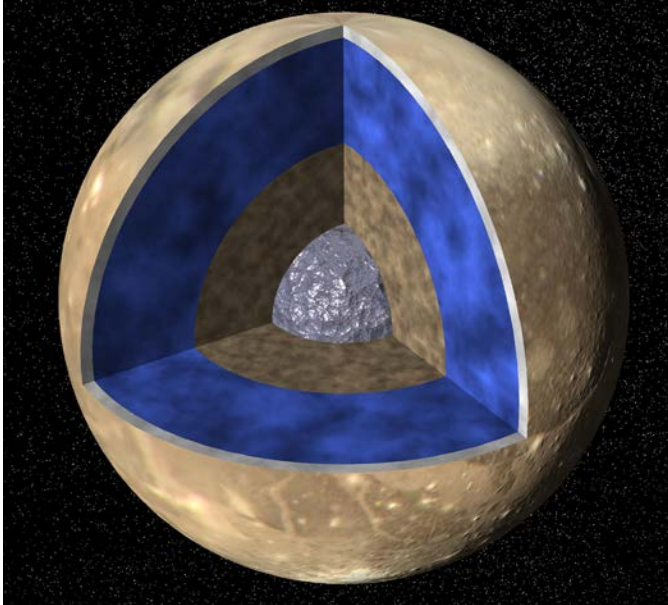


# THE DETERMINATION OF GANYMEDE'S ROTATIONAL STATE AND TIDES FROM RADIO TRACKING OF A LANDER

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# Ganymede Internal Structure



- Doppler data from Galileo mission indicate a ***strongly differentiated interior***:
  - ✓ Liquid (or partially liquid) ***inner core of iron*** or iron sulphide
  - ✓ Outer ***silicate core***
  - ✓ External thick ***shell of ice***
- JUICE mission (2032-2033) will provide accurate radio metric measurements
- The spacecraft will be orbiting the moon for about 9 months
- Stronger constrains on the physical state and thickness of the different layers will be put

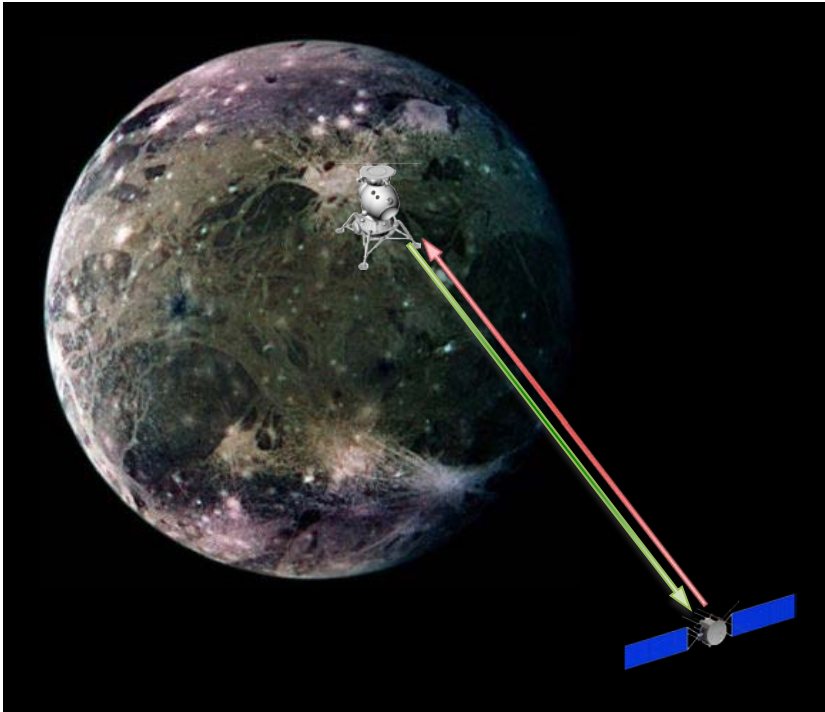
# Scientific Goals

- Radio metric data collected from **two-way radio link** would provide a good determination of **tides** and **rotation**:
  - ✓ **Ranging from JUICE to a lander** would complement the estimate of  $h_2$  **Love number** from the onboard laser altimeter
    - ↳ **Elastic properties** of Ganymede against depth
  - ✓ **Tracking from ground** would enable accurate measurements of Ganymede **physical librations**
    - ↳ Corroborate the hypothesis of a **sub-surface ocean** beneath the external ice shell and provide the **ice thickness**
  - ✓ **Precise ranging from ground**
    - ↳ Update of the **Jovian system's ephemerides**
  - ✓ **Simultaneous tracking of a lander and a spacecraft** to Ganymede would enable to collect **interferometric measurements through Same Beam Interferometry (SBI)** with accuracies of the order of **1 mm at Ka band**
    - ↳ Improvement in the determination of **tidal parameters** and **physical librations**

# Radio Science with a Ganymede Lander

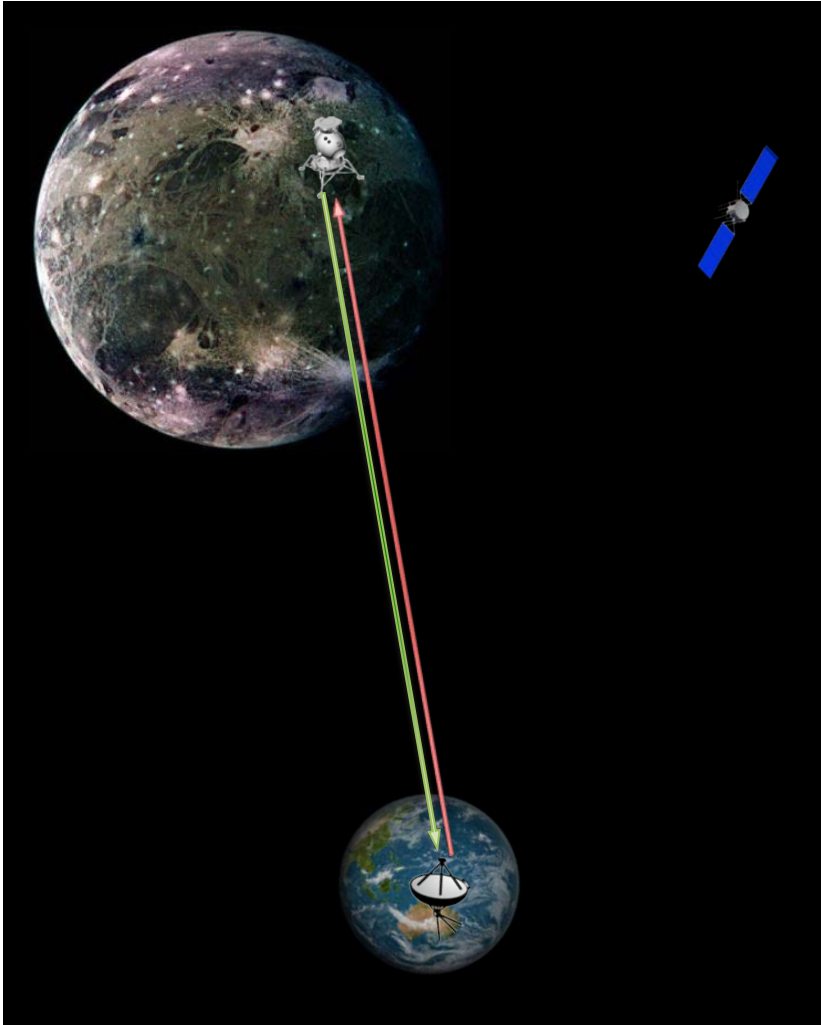
- A lander on Ganymede, equipped with a **digital Ka band transponder (KaT)** and a **steerable medium gain antenna (MGA)**, as proposed for JUICE spacecraft, would enable **several radio science experimental configurations**:
  - ✓ **Lander-JUICE link**
  - ✓ **Lander-Earth link**
  - ✓ **SBI technique**
  - ✓ **Lander-JUICE-Earth link**
- **KaT** could be configured to act also as a **complete TT&C subsystem for the lander**, with dedicated telemetry and telecommand channels, with considerable **benefits for the mission mass and power budget**.

# Lander-JUICE Link



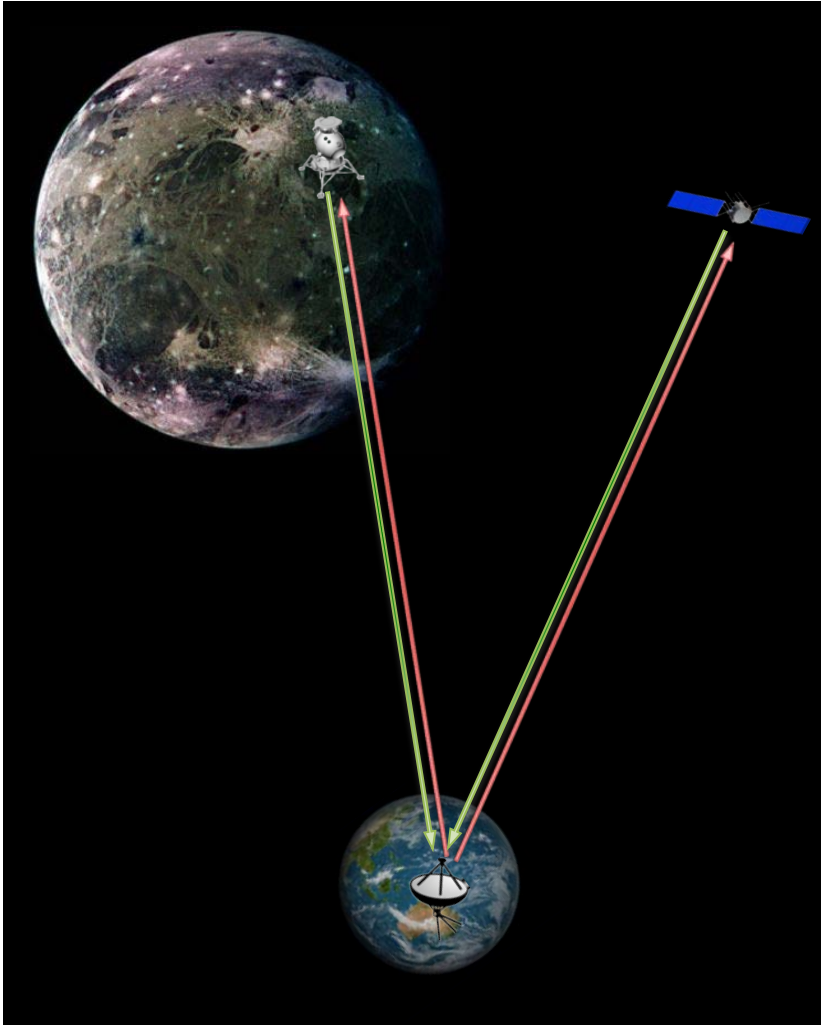
- ***Types of measurement:***  
two-way range and range rate
- ***Frequency reference:***  
JUICE ultra-stable oscillator (USO)
- ***Requirements for the lander:***
  - ✓ Steerable horn antenna
- ***Improvements wrt JUICE:***
  - ✓ Solid tides
  - ✓ Obliquity
  - ✓ Physical librations

# Lander-Earth Link



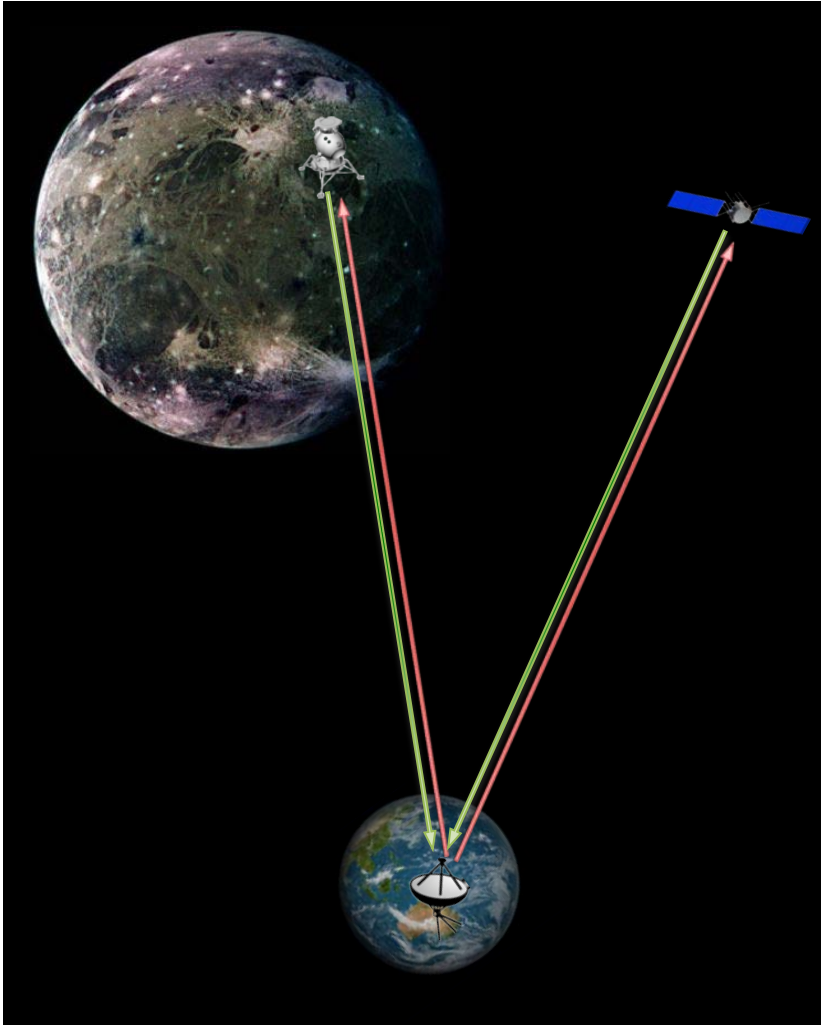
- ***Types of measurement:***  
two-way range and range rate at Ka-band
- ***Frequency reference:***  
ground station clock
- ***Requirements for the lander:***
  - ✓ JUICE-like MGA
  - ✓ KaT transponder
- ***Improvements wrt JUICE:***
  - ✓ Solid tides
  - ✓ Obliquity
  - ✓ Physical librations
  - ✓ Update Ganymede's ephemerides

# SBI Technique



- ***Types of measurement:***  
two-way range, range rate, and differential phase at Ka-band
- ***Frequency reference:***  
ground station clock
- ***Requirements for the lander:***
  - ✓ JUICE-like MGA
  - ✓ KaT transponder
- ***Improvements wrt JUICE:***
  - ✓ Solid tides
  - ✓ Obliquity
  - ✓ Physical librations
  - ✓ Update Ganymede's ephemerides

# SBI Technique



- **Link performances:**

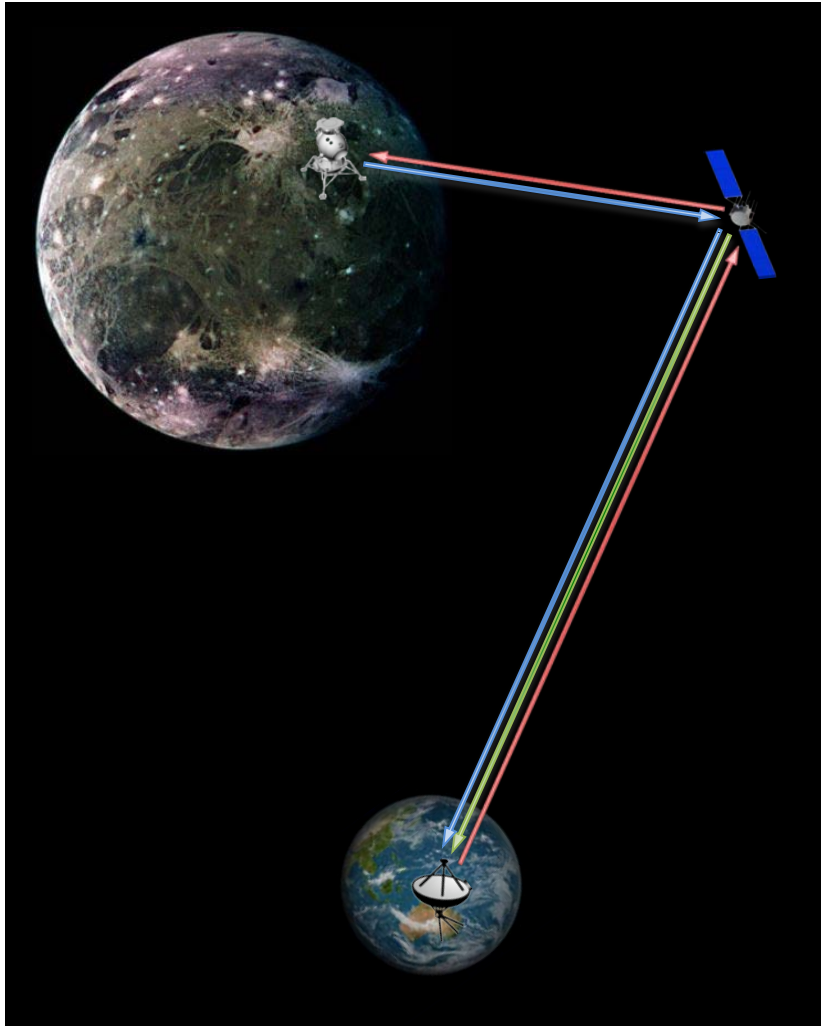
- ✓ Lander transmitting power  $< 2$  W
- ✓ Phase delay due to thermal noise  $< 0.2^\circ$  (two-way), with an integration time of 100 s

- **Advantages:**

- ✓ Very effective common mode rejection of error sources
- ✓ Expected accuracy of about 1 mm

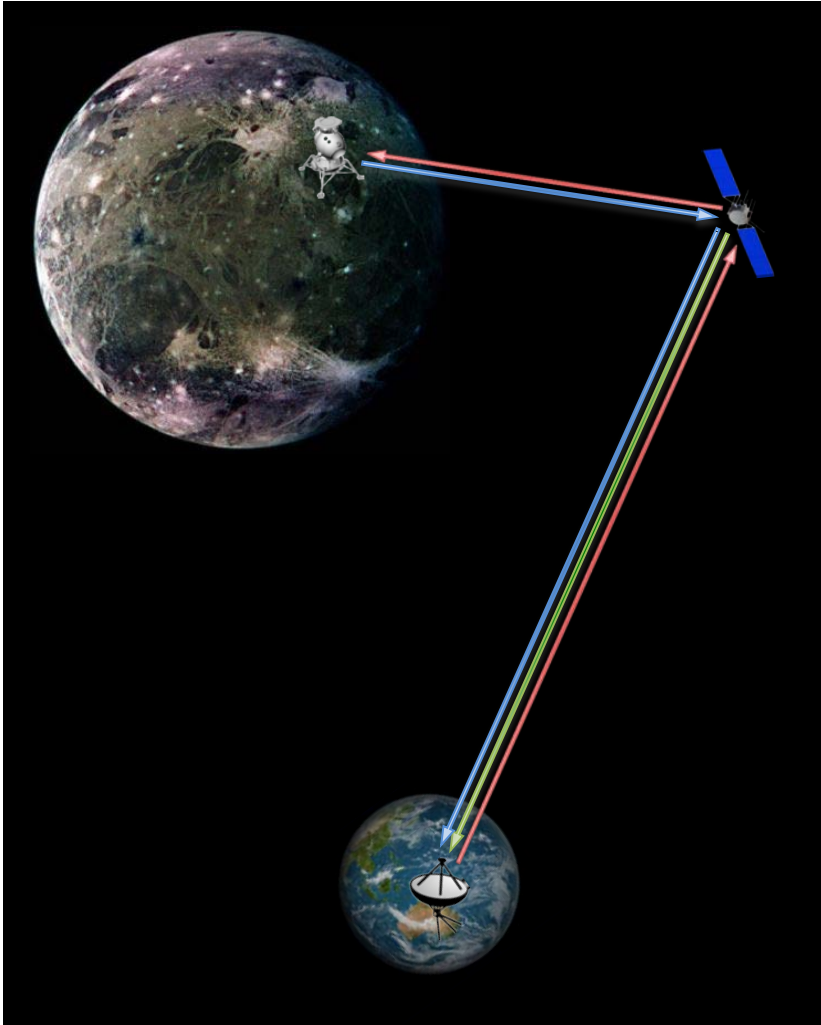


# Lander-JUICE-Earth Link



- ***Types of measurement:***  
two-way range, range rate, and differential phase at Ka-band
- ***Frequency reference:***  
ground station clock
- ***Requirements for the lander:***
  - ✓ Steerable horn antenna
- ***Improvements wrt JUICE:***
  - ✓ Solid tides
  - ✓ Obliquity
  - ✓ Physical librations

# Lander-JUICE-Earth Link



- **Link performances:**
  - ✓ Lander transmitting power  $< 2$  W
  - ✓ Phase delay due to thermal noise  $< 0.2^\circ$  (two-way), with an integration time of 100 s
- **Advantages:**
  - ✓ Common mode rejection of error sources better than SBI
- **Constraints:**
  - ✓ Measurements can be done only when JUICE is pointing the high gain antenna towards Earth (keeping the MGA pointed to the lander)

# Conclusions

- **Location** of the lander should be **optimized** for the determination of the **rotational state** (tidal information will come from JUICE laser altimeter, too)
- **Medium latitude landing site** is a good trade-off between **mutual visibility time** with JUICE and the **amplitude of physical librations**.
- **SBI measurements** do not require mutual visibility with JUICE, but they are sensitive enough to physical librations, thanks to unprecedented quality wrt standard tracking
- Adoption of **KaT as TT&C subsystem of a Ganymede lander**, together with the use of a **40 cm dish antenna** (both technologies with **very high TRL**) would enable the measurement of **solid tides** and **rotational state** of Ganymede with an excellent accuracy
- A simpler **single radio link** (direct to ground or a proximity link to the orbiter) would also give **improvements** over what is planned with the **JUICE orbiter alone**

# Questions

