ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

RADIO SCIENCE AND PLANETARY EXPLORATION
- LABORATORY -

Combining JUICE and Europa Clipper Range, Range-Rate and VLBI Observation to Improve the Galilean Moons Ephemerides.

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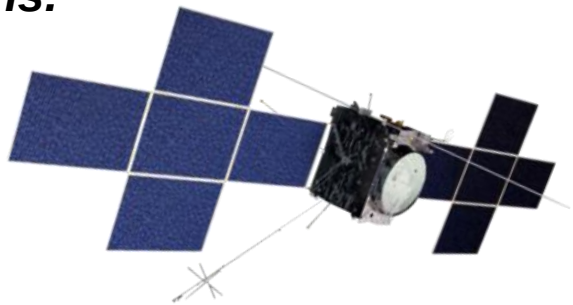
The combined analysis of radio tracking data of JUICE and Europa Clipper could improve the reconstruction of the gravity fields and ephemerides of the Galilean moons.

The objective of this work is to highlight the contribution of VLBI tracking data, in addition to ranging and Doppler, to the estimation of the ephemerides of the Galileian moons.



JUICE

Tracking Link Setup: triple radio link configuration (X/X, X/Ka and Ka/Ka).

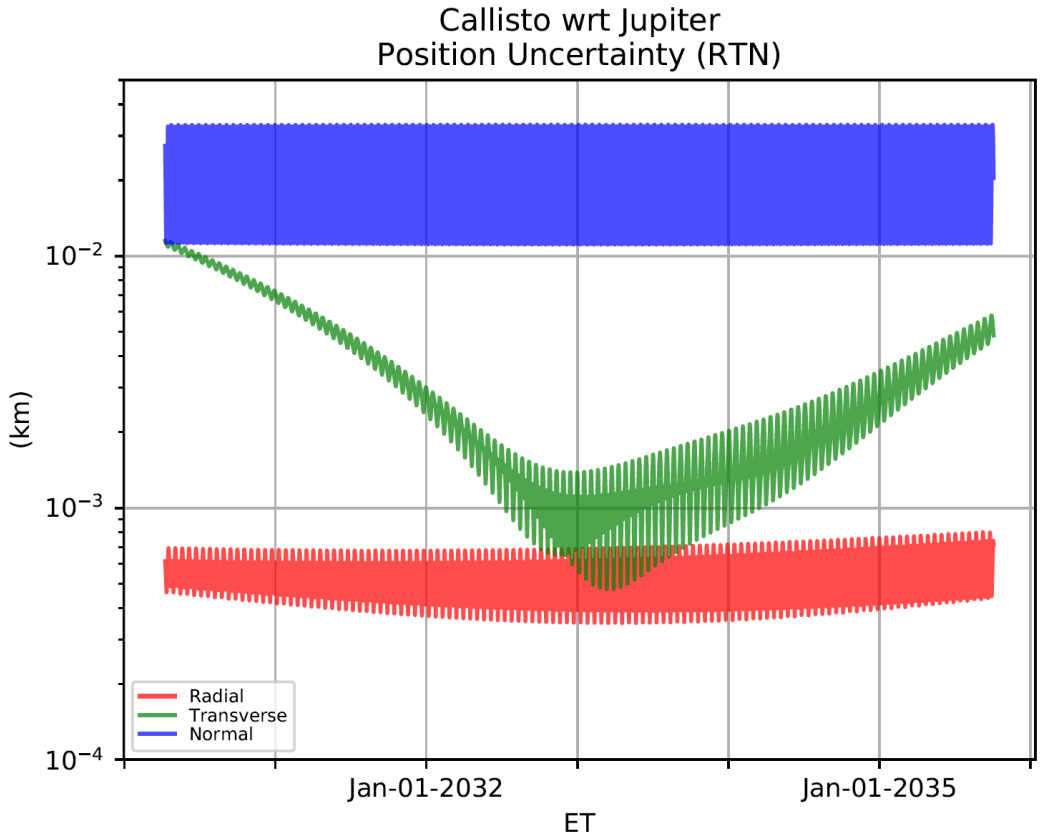
- Range + Doppler (two-way).
- *VLBI (PRIDE): 1 observation every 120 seconds (during PRIDE observing sessions); two noises assumption: 0.22 nrad and 0.6 nrad.*
  - *Flyby phase: full coverage.*
  - *GCO phase: 1 arc/week.*

Europa Clipper (EC)

Tracking Link Setup:

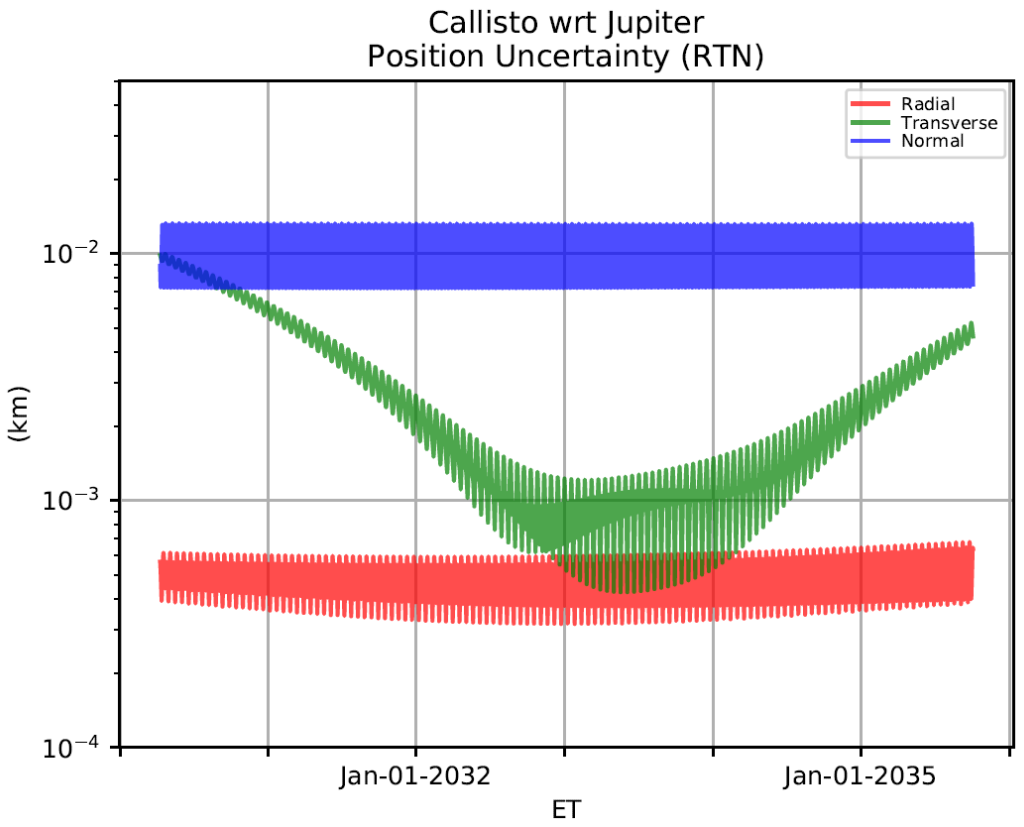
- Range + Doppler (two way)
- *VLBI (DDOR) during navigation passes ~24 h before/after C/A: 1 observation every 15 minutes; two noises assumption: 1.5 nrad and 2.5 nrad.*

Callisto Ephemerides Uncertainties: VLBI contribution



Range and Doppler Only

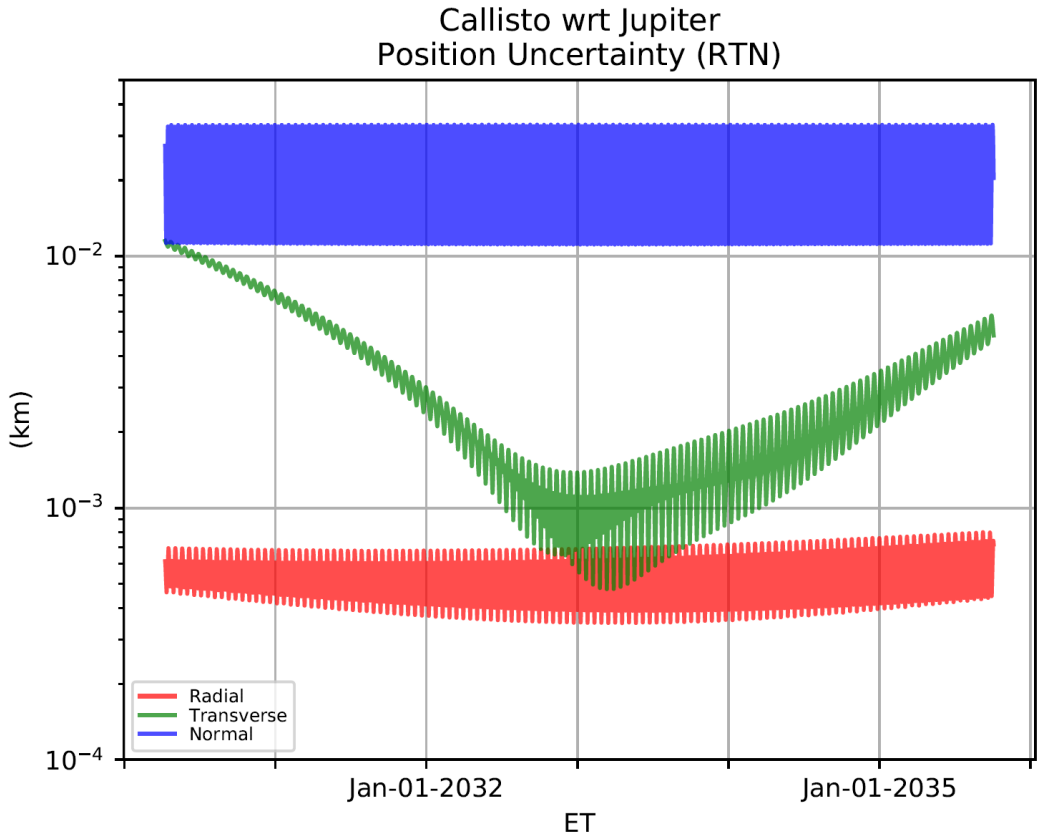
Formal Uncertainty	Radial	Transverse	Normal
Callisto	0.5 m	0.6-10 m	20 m



Range and Doppler + VLBI (0.6 nrad noise)

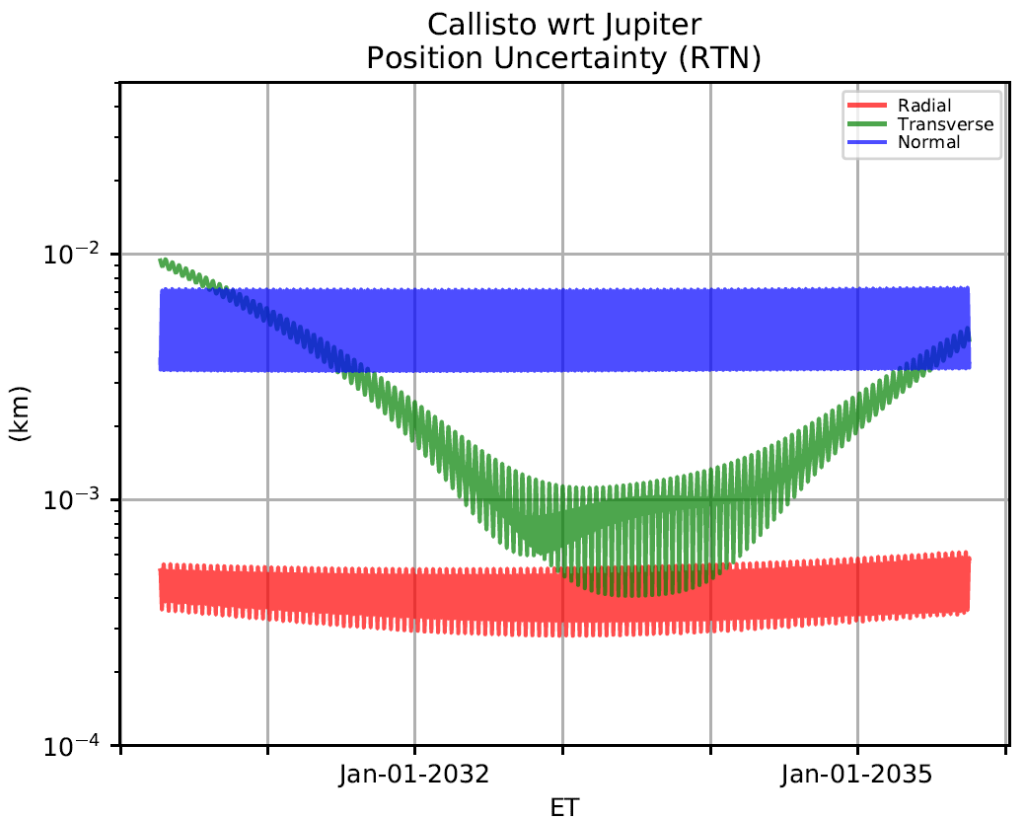
Formal Uncertainty	Radial	Transverse	Normal
Callisto	0.5 m	0.6-10 m	10 m

Callisto Ephemerides Uncertainties: VLBI contribution



Range and Doppler Only

Formal Uncertainty	Radial	Transverse	Normal
Callisto	0.5 m	0.6-10 m	20 m



Range and Doppler + VLBI (0.22 nrad noise)

Formal Uncertainty	Radial	Transverse	Normal
Callisto	0.4 m	0.5-10 m	5 m

Ephemerides Uncertainties improvements adding VLBI

	JUICE & EC VLBI NOISES SCENARIOS			
σ_{R+D} / $\sigma_{R+D+VLBI}$ in NORMAL Direction*	0.22 nrad only JUICE	0.6 nrad only JUICE	1.5 nrad only EC	2.5 nrad only EC
Io	1.12	1.05	negligible	negligible
Europa	1.33	1.17	1.05	1.03
Ganymede	1.14	1.07	negligible	negligible
Callisto	**4.0**	**2.0**	negligible	negligible
Jupiter Im(k_2) (Io)	1.12	1.07	negligible	negligible

** With respect solution considering Range and Doppler tracking data only.*

- Almost all the VLBI improvement comes from PRIDE VLBA data.
- EC VLBI DDOR considering 1.5 nrad noise, improve the uncertaninty on Europa N direction about 5%.
- The largest improvement is for Callisto, the smallest is for Io.
- The uncertainty on Jupiter Im($\boldsymbol{k_2}$) at the frequency of Io improve by ≈7-12%, depending on the noise assumptions.

Additional considerations:

- Considering different schedule for the GCO: 1 arc every 2 weeks or 1 arc every 1 month the results were weakly affected (maximum 5% for Ganymede).
- Considering 1 every 2 flybys the results changes to a maximum of ≈ 30% for Callisto.

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THANK YOU FOR ATTENTION!

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BACK UP SLIDES

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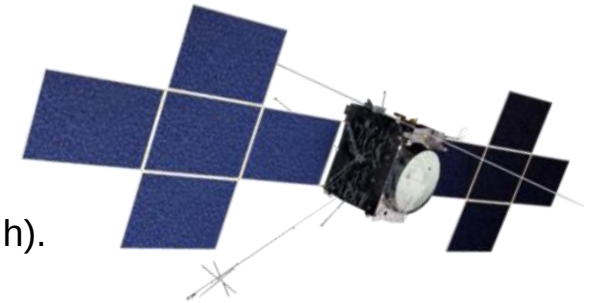
The combined analysis of radio tracking data of JUICE and Europa Clipper could improve the reconstruction of the gravity fields and ephemerides of the Galilean moons.

The objective of this work is to highlight the <u>contribution of VLBI tracking data</u>, in addition to ranging and Doppler, to the estimation of the ephemerides of the Galileian moons.



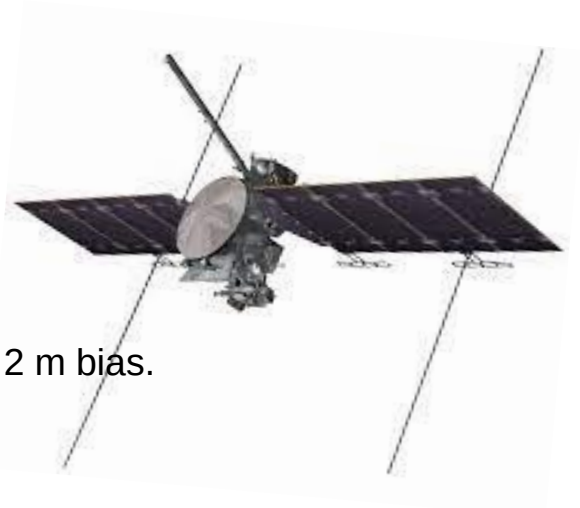
<u>JUICE</u>

Arcs Setup: *from latest planned trajectory (CReMa 5.0)*

- Jupiter tour flybys: Callisto (21), Ganymede (4), Europa (2), 48 h around C/A.
- Ganymede eccentric orbital phase: 3 arcs of 24 h (altitude <1000 km).
- Ganymede circular orbital phase, altitude 500 km (GCO500): 5 months, 135 arcs of 24 h (orbital period: ~3.5 h).

Tracking Link Setup: triple radio link configuration with full calibration of dispersive noise sources (X/X, X/Ka and Ka/Ka)

- Doppler noise (two-way): 12 μm/s at 60 s integration time.
- Range noise (two-way): 20 cm; Range Bias: 1 m.
- *<u>VLBI (PRIDE): 1 observation every 120 seconds; two noises assumption: 0.22 nrad and 0.6 nrad.</u>*
  - *<u>Flyby phase: full coverage.</u>*
  - *<u>GCO phase: 1 arc/week.</u>*



<u>Europa Clipper (EC)</u>

Arcs Setup: *proposed tour 21F31_v3.*

- Flybys: Europa (53), 56 hours around C/A.

Tracking Link Setup:

- Europa C/A (4 h): LGA-FBs, X/X only. Doppler avg. noise 0.1 mm/s. No range.
- Navigation passes ~24 h before/after C/A: HGA, X/X+X/Ka. Doppler avg. noise: 0.05 mm/s. Range: 1 m jitter, 2 m bias.
- *<u>VLBI (DDOR): 1 observation every 15 minutes; two noises assumption: 1.5 nrad and 2.5 nrad.</u>*

Conclusions

- *PRIDE data introduce the main improvement to JUICE+EC Doppler & Range solution.*
- *As predicted in Dirkx et al., 2017, VLBI data improve the ephemerides reconstruction mainly in normal direction.*
- *The larger improvement in normal direction is obtained for Callisto, by a factor 2-4, depending on the noise assumptions.*
- *Regarding JUICE PRIDE data, considering every flyby data is more important than considering every arc of the GCO.*
- *Adding VLBI data the estimation uncertainty of the dissipation in Jupiter improve by ≈7-12%, depending on the noise assumptions.*