Radar sounding of Ganymede and Callisto: Two-way attenuation and SNR evaluation in diverse dielectric scenarios. F. Di Paolo[1,2], A. Ruggieri[3], B. Cosciotti[4], S. E. Lauro[4], E. Mattei[4], L. Bruzzone[5], R. Claudi[6], E. Pettinelli[4]. [1]Dip. di Scienze e Tecnologie, Università degli Studi di Napoli "Parthenope", CDN, IC4, 80143 Naples, Italy (federico.dipaolo@uniparthenope.it), [2]Istituto di Astrofisica e Planetologia Spaziali, Istituto Nazionale di Astrofisica, Via fosso del cavaliere, 100, 00133 Rome, Italy, [3]Dip. di Fisica e Astronomia, Università degli Studi di Padova, Via F. Marzolo, 8, 35121 Padova, Italy, [4]Mathematics and Physics Dept., Roma Tre University, Via della vasca navale, 84, 00164 Rome, Italy (barbara.cosciotti@uniroma3.it, elisabetta.mattei@uniroma3.it, sebastian.lauro@uniroma3.it, elena.pettinelli@uniroma3.it), [5]Department of Information Engineering and Computer Science, University of Trento, Via Sommarive, 9, 38123 Povo (TN), Italy (lorenzo.bruzzone@unitn.it), [6]Astronomical Observatory of Padova, Istituto Nazionale di Astrofisica, Vicolo Osservatorio, 5, 35122 Padova, Italy (riccardo.claudi@inaf.it).

Introduction: In the next future, the JUpiter ICy moons Explorer (JUICE) of ESA will be launched to explore the icy moons of Jupiter. The mission, after some flybys on Europa and Callisto, will be dedicated to an extensive observation of Ganymede [1]. Since the ice is transparent to the radio waves, the spacecraft will host onboard the 9 MHz Radar for Icy Moons Exploration (RIME), that is expected to sound the icy subsurfaces of Europa, Ganymede and Callisto down to at least 9 km [2]. Here we present an evaluation of two-way radar attenuation and signal-to-noise ratio (SNR) in different dielectric scenarios for the radar sounding of Ganymede and Callisto.

Dielectric scenarios: A 10 km thick crust is considered, having thermal and dust content profiles as described by [3]. For Ganymede, both bright and dark terrains are studied. The brittle-ductile transition is fixed at 2 km depth: in this layer, the absence/presence of fragmented ice is represented by the two extreme values of porosity (ϕ), 0 and 20%. The dielectric properties of ice as a function of temperature are taken from [4]. Regarding the contaminant, we consider five silicates, whose dielectric properties are reported in Table 1. Note that the permittivity of models 3-5 has been extracted from the original values for porous media by using an inverse Bruggeman formula [8].

#	Ref.	Material	Permittivity
1	[5]	Shergottite	$8.8 + 0.017i$
2	[6]	Basalt	$6.2 + 1.5\ 10^{-6}/(\omega\varepsilon_0)i$
3	[7]	LL5 chondrite	$7.2 + 0.033i$
4	[7]	L5 chondrite	$8.8 + 0.040i$
5	[7]	H5 chondrite	$9.0 + 0.204i$

Table 1. Dielectric properties of silicate contaminants in ice.

The permittivity of the three-phase mixture (ice+dust+air) is evaluated using a Bruggeman mixing rule for spherical inclusions.

Two-way attenuation and SNR: The two-way radar attenuation is evaluated following [9]. Being in the far-field case, a simple one-dimensional transmission line model is used, considering a normal incidence and the propagation of a plane wave into a layered structure. The SNR is evaluated following [9], using a 2.7 MHz bandwidth. Since the focus of this work is a study of the effect of the dielectric properties of the subsoil on radar propagation, the simple 1D model implemented is reasonably acceptable; such approximation does not affect significantly the values of two-way attenuation and SNR.

Results: Figs. 1-3 show the two-way attenuation (upper panels) and SNR (lower panels) profiles along the vertical coordinate, for each scenario. Solid and dashed lines represent a 0 and 20% porosity in the first 2 km, respectively. The main evidences are:

- The effect of porosity is minimal;
- Scenarios 3 and 4 provide similar results;
- Scenario 5 provides a severe attenuation.

The SNR values are reported in Figs. 1-3 (lower panels) down to the zero, since negative SNR means no radar penetration. In order to be more conservative, the maximum radar penetration can be fixed at 5 dB SNR threshold. Table 2 shows the maximum depths that are expected to be reached by RIME on Ganymede an Callisto as a function of dielectric scenario and porosity in the brittle layer.

	Ganymede (bright terrains)		Ganymede (dark terrains)		Callisto	
ϕ	0%	20%	0%	20%	0%	20%
1	> 10	> 10	> 10	> 10	> 10	> 10
2	> 10	> 10	> 10	> 10	> 10	> 10
3	> 10	> 10	> 10	> 10	2.7	2.8
4	> 10	> 10	> 10	> 10	2.6	2.8
5	2.0	2.1	1.3	1.4	0.5	0.5

Table 2. Radar penetration (km) at SNR = 5 dB.

On Ganymede, only Scenario 5 could prevent a deep penetration of the radar signal. Nevertheless, such a composition is not expected because, as reported by [10], a significative presence of iron in the crust has been observed only on Callisto. Conversely, on

Callisto, the penetration depths are strictly dependent on the dielectric model.

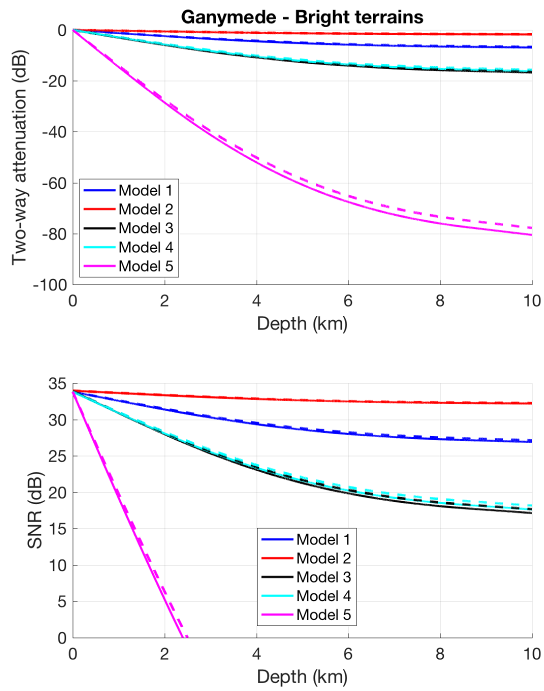

Fig. 1. Two-way attenuation (upper panel) and SNR (lower panel) for bright terrains on Ganymede.

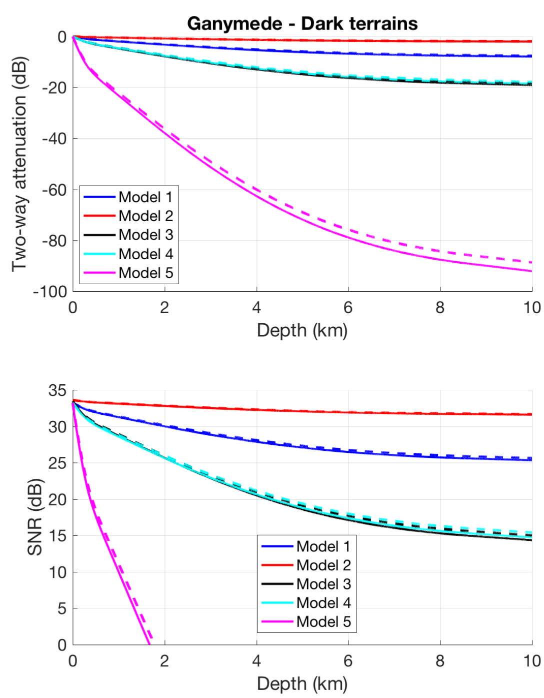

Fig. 2. Two-way attenuation (upper panel) and SNR (lower panel) for dark terrains on Ganymede.

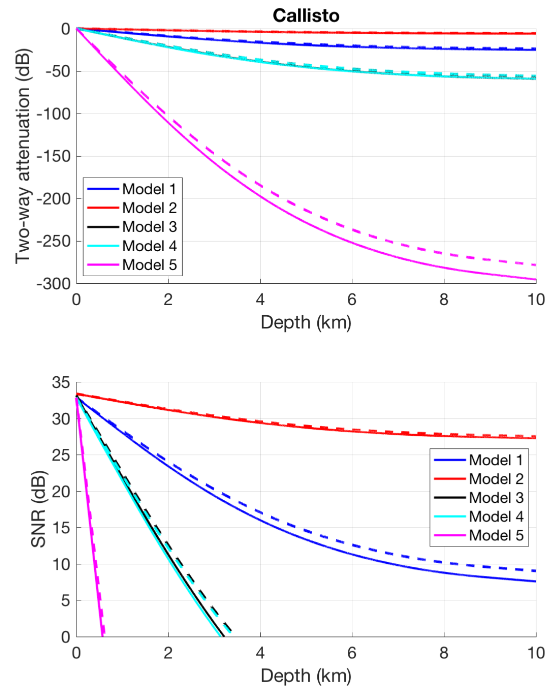

Fig. 3. Two-way attenuation (upper panel) and SNR (lower panel) for Callisto.

Summary: In the considered space of parameters, radar sounding of Ganymede and Callisto is expected to reach a significative depth in the majority of the cases studied. In particular, considering the 9 km value as the requirement of the instrument, for Ganymede, no significative issues are expected. Conversely, for Callisto, a low penetration depth results in Scenarios 3-5. Nevertheless, even under such conditions, RIME could reach a depth sufficient to detect the most interesting geologic features, that are expected to be located in the first kilometers of its subsurface.

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