TECHNICAL CHALLENGES IN THE DESIGN OF AN ICE PENETRATING RADAR FOR THE JUPITER ICY MOON

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Overview

- *Radar for Icy Moon Exploration* (RIME) is one of the proposed instrument for the *JUpiter ICy moons Explorer (JUICE)* mission.

- RIME is a radar sounder optimized for the penetration of the Galilean icy moons, Ganymede, Europa and Callisto, up to a depth of 9 km.

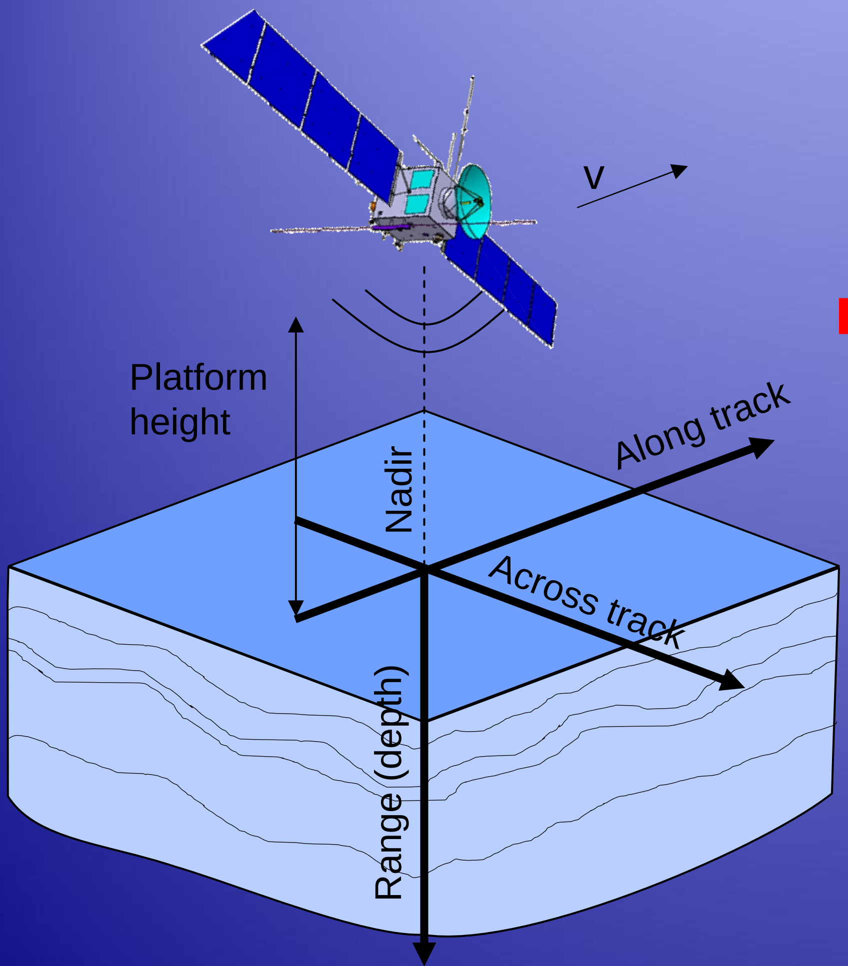
- Recently (Oct. 2012) a proposal to ESA for the development of the instrument has been sent, in response to the AO

- The proposal consortium is lead by the University of Trento (L. Bruzzone, PI)

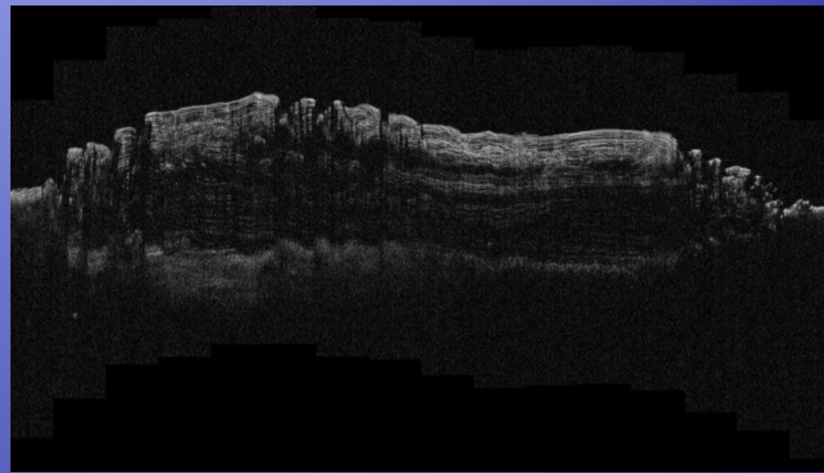
Overview

- The RIME Lead Funding Agency (LFA) is the Italian Space Agency (ASI).
- The RIME Consortium includes the important institutes involved in the development, operation and data analysis of planetary radar sounders of the last decade, from both the European and the US side.
- From the technical point of view, the instrument will be developed by two main partners: a Prime Italian Industry selected by ASI and the Jet Propulsion Laboratory (JPL) of the US National Aeronautics and Space Administration (NASA).

Heritage



Example of radargram
(SHARAD, 1069002)



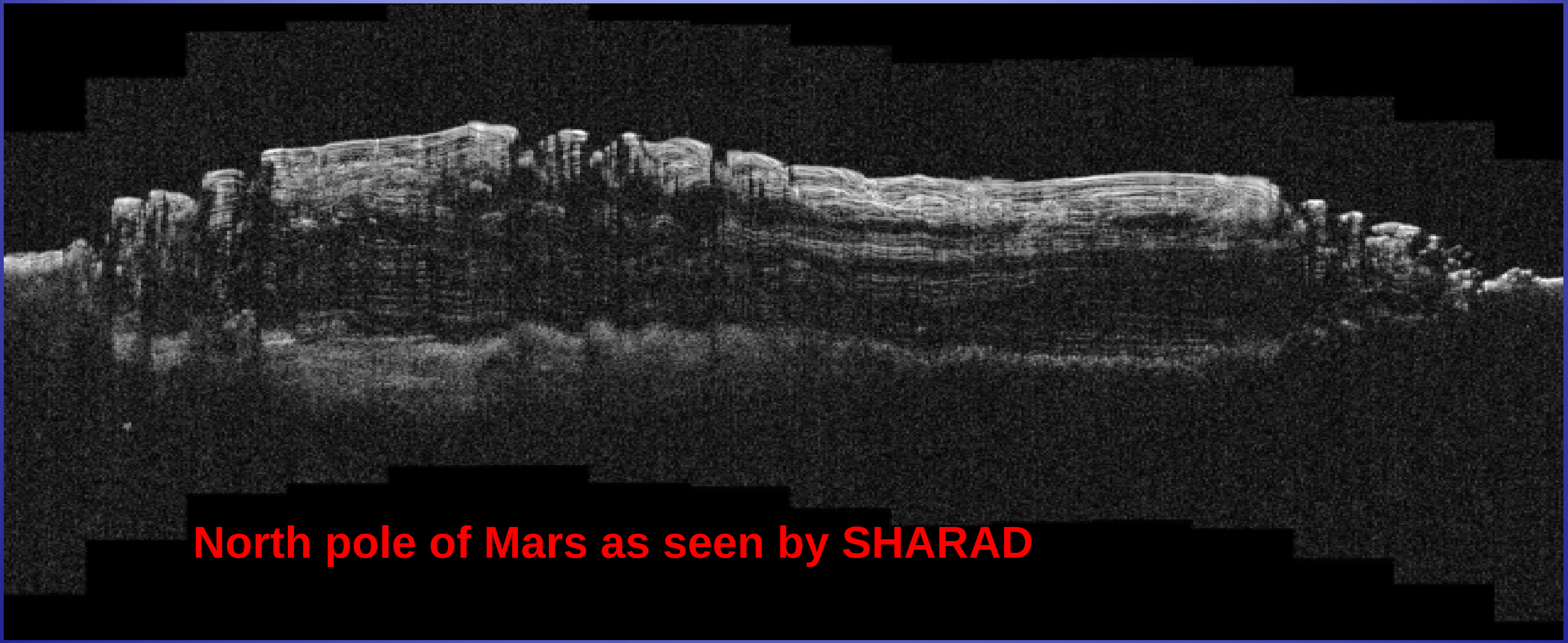
MARSIS (ESA MARS express)

SHARAD (NASA MRO)

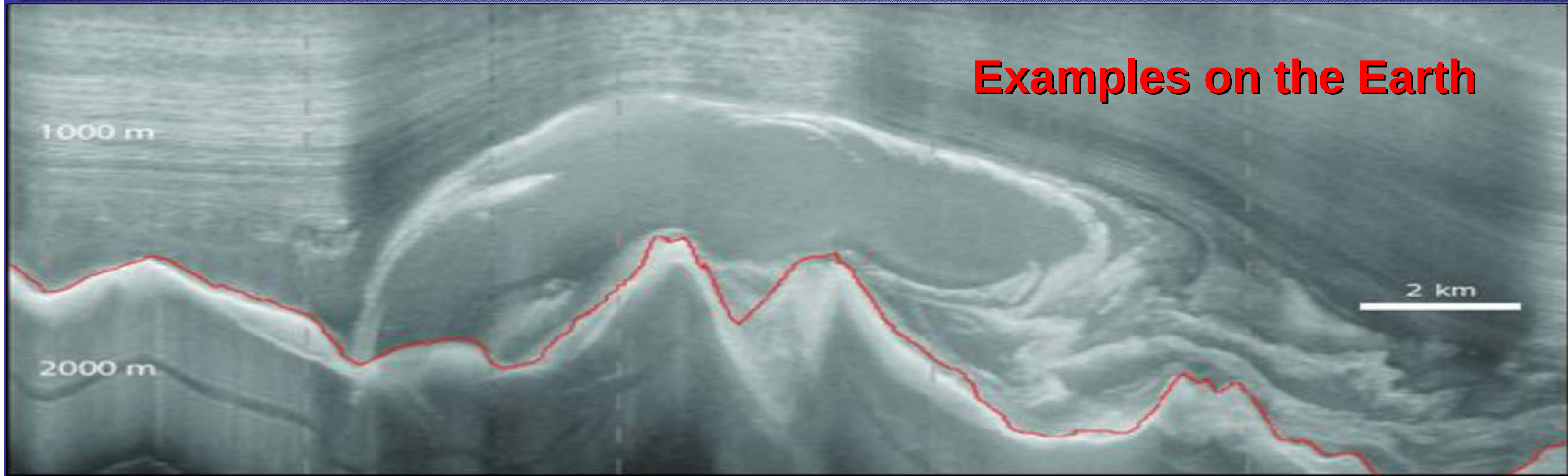
Science objectives

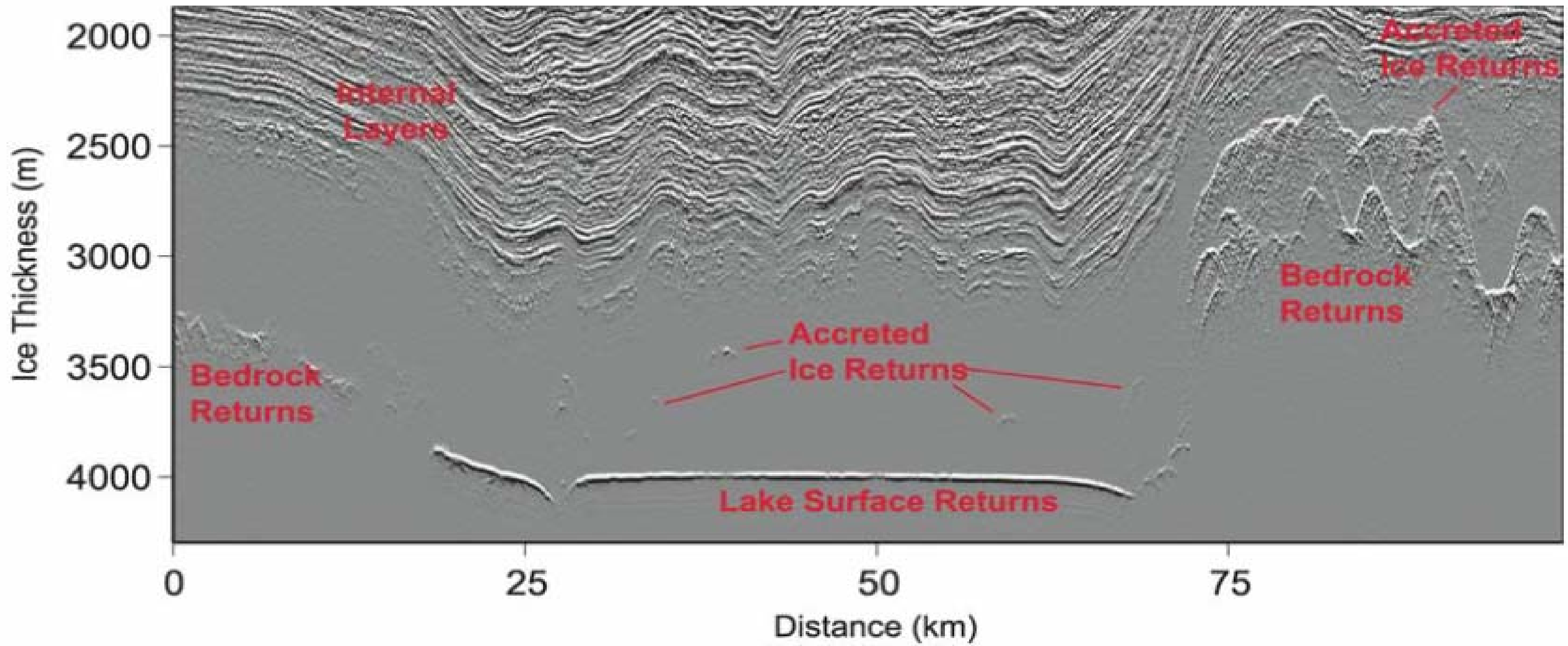
Goals	Science Objectives	
Exploration of the habitable zone: Ganymede, Europa, and Callisto	Characterise Ganymede as a planetary object and possible habitat	Characterise the extent of the ocean and its relation to the deeper interior
		Characterise the ice shell
		Determine global composition, distribution and evolution of surface materials
		Understand the formation of surface features and search for past and present activity
		Characterise the local environment and its interaction with the jovian magnetosphere
	Explore Europa's recently active zones	Determine the composition of the non-ice material, especially as related to habitability
		Look for liquid water under the most active sites
		Study the recently active processes
	Study Callisto as a remnant of the early Jovian system	Characterise the outer shells, including the ocean
		Determine the composition of the non-ice material
		Study the past activity

Science objectives



Science objectives



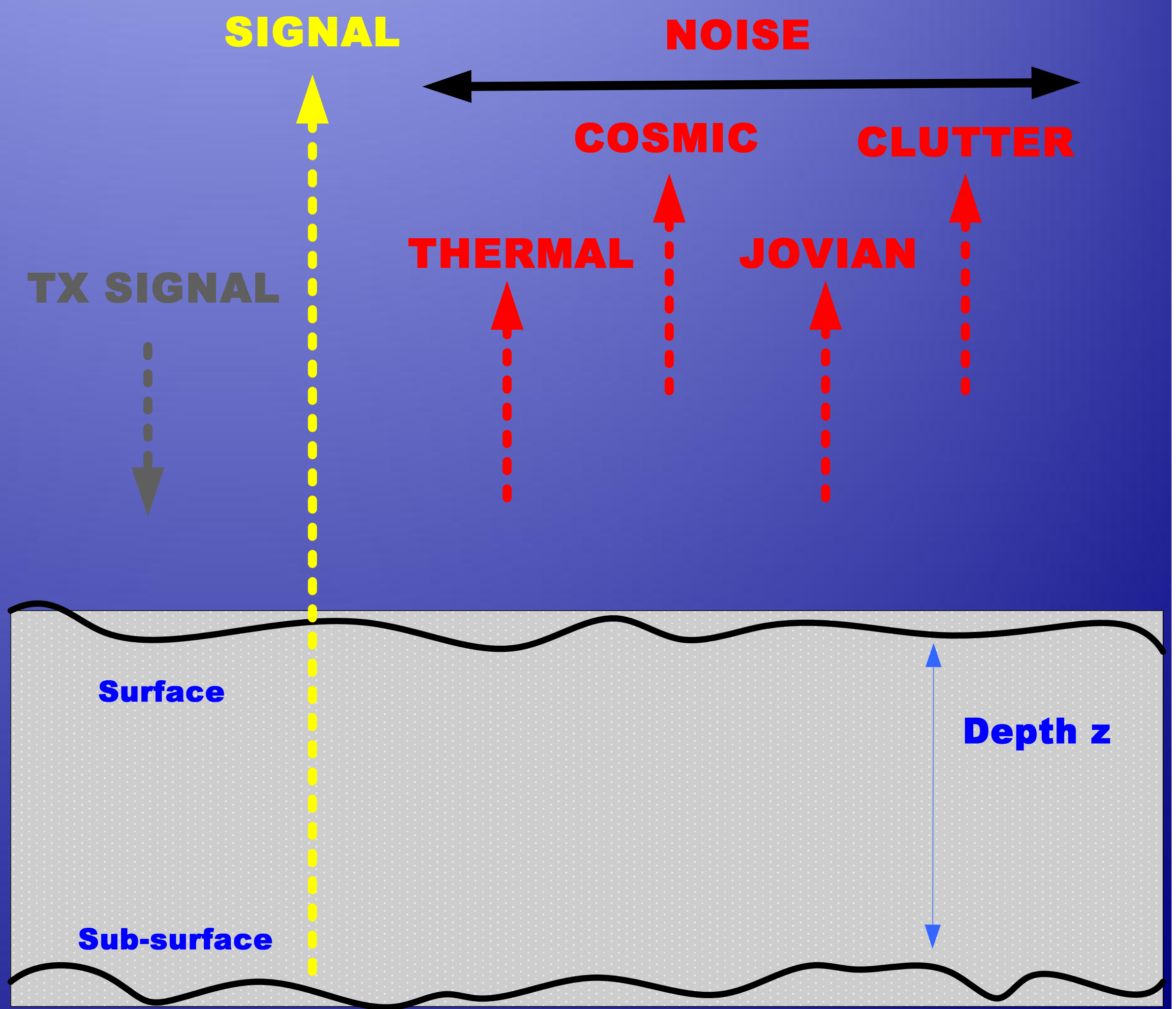


Instrument main characteristics

Specification	JUICE RIME	MARSIS	SHARAD
Operating altitude (km)	200-1000	300-800	300
Antenna length (m)	16 desired (other lengths possible)	40	10
Central frequency (MHz)	9	1-5	20
Bandwidth (MHz)	1, 3	1	10
PRF (Hz)	200-500	130	700
Chirp length (μs)	50-100	250	85
Peak radiated power (W)	10	1	10
ADC bits	8	8	8
ADC speed (MHz)	12	2.8	26.7
Sampling scheme	Direct	Down conversion	Direct
On-board process	Pre-summing Closed-loop tracking	Doppler filtering Closed-loop tracking	Pre-summing Closed-loop tracking
Spatial resolution (km)	0.3-1 (ground processing)	3 (on-board process)	0.3 (ground process)
Data rate (kbps) in Ganymede orbital phase	216-250	10-30	2200
Data rate (kbps) in flyby phases (special operation)	2400	N.A.	N.A.
Profiling depth (km)	9	4	3
Flat surface SNR (dB)	55 @ 200 km	50 @ 300 km	46@ 300 km

Instrument performance

The penetration capability of a radar sounder depends on the power ratio between the signal coming from a generic sub-surface interface (a change in the dielectric constant) and, generally speaking, noise that is related to disturbing and unwanted signal sources



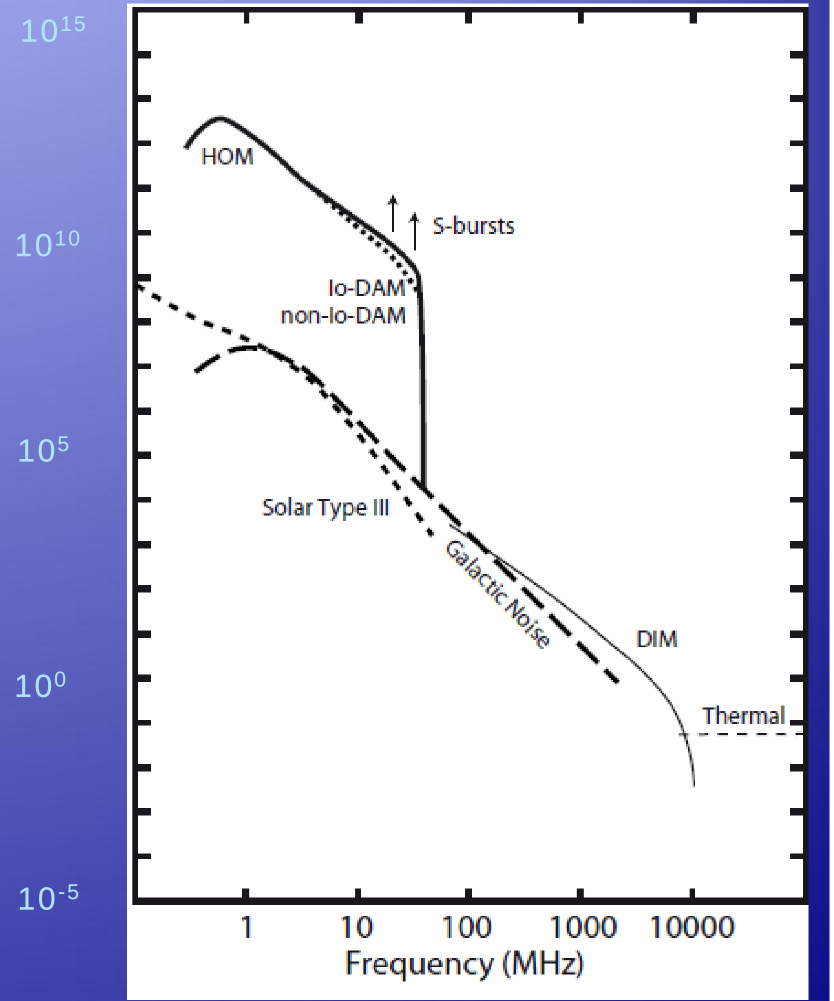
Jovian radio noise

***Four radio components**:*

- Non thermal Jovian radio emissions emitted on high latitude magnetic fields line (Io-DAM, non-Io-DAM, and S-burst)
- Synchrotron radiation from the Jovian radiation belts (DIM)
- Solar radio emission (Solar type III burts)
- Galactic noise background emission

Natural Jovian radio emission:

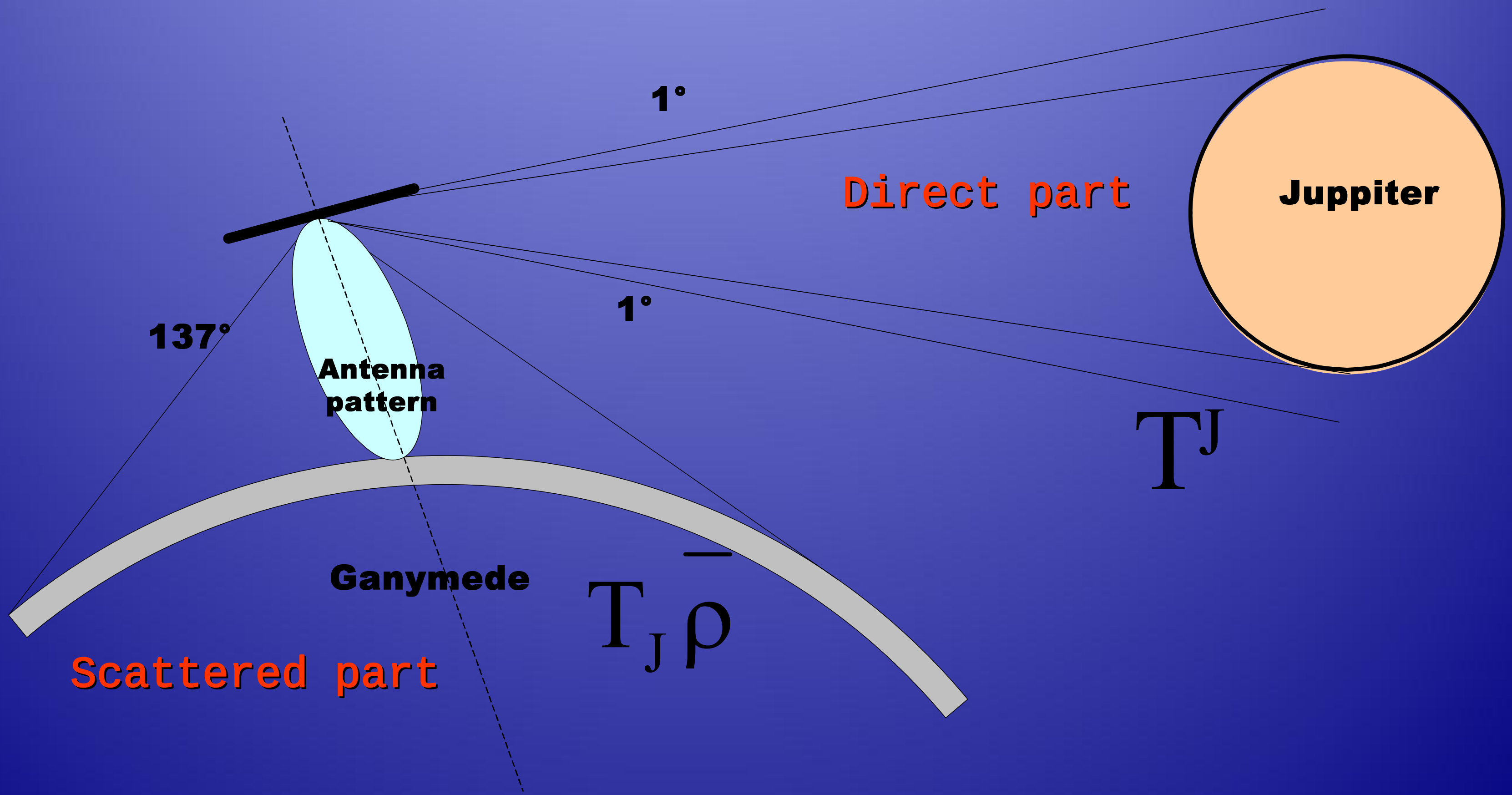
- Cutoff frequency at 40 MHz
- Sporadic
- Beamed (beaming pattern is a thin conical sheet)



Antenna temperature of the radio emissions at Jupiter observed at Ganymede in K (Cecconi et al 2010)

Jovian radio noise

The radio background coming from Jupiter and Ganymede is localised and it should be weighted by antenna pattern considering its angular extension

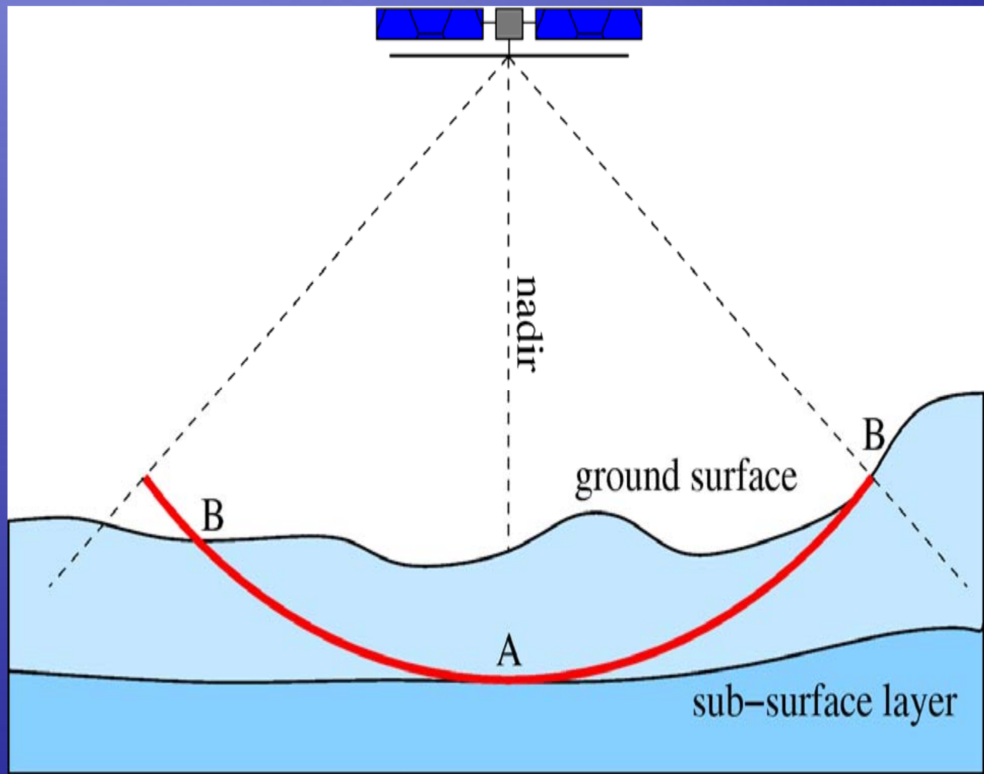


Surface clutter

Surface clutter is generated by off-nadir echoes (B) recorded at the same time of subsurface returns coming from the nadir direction (A).

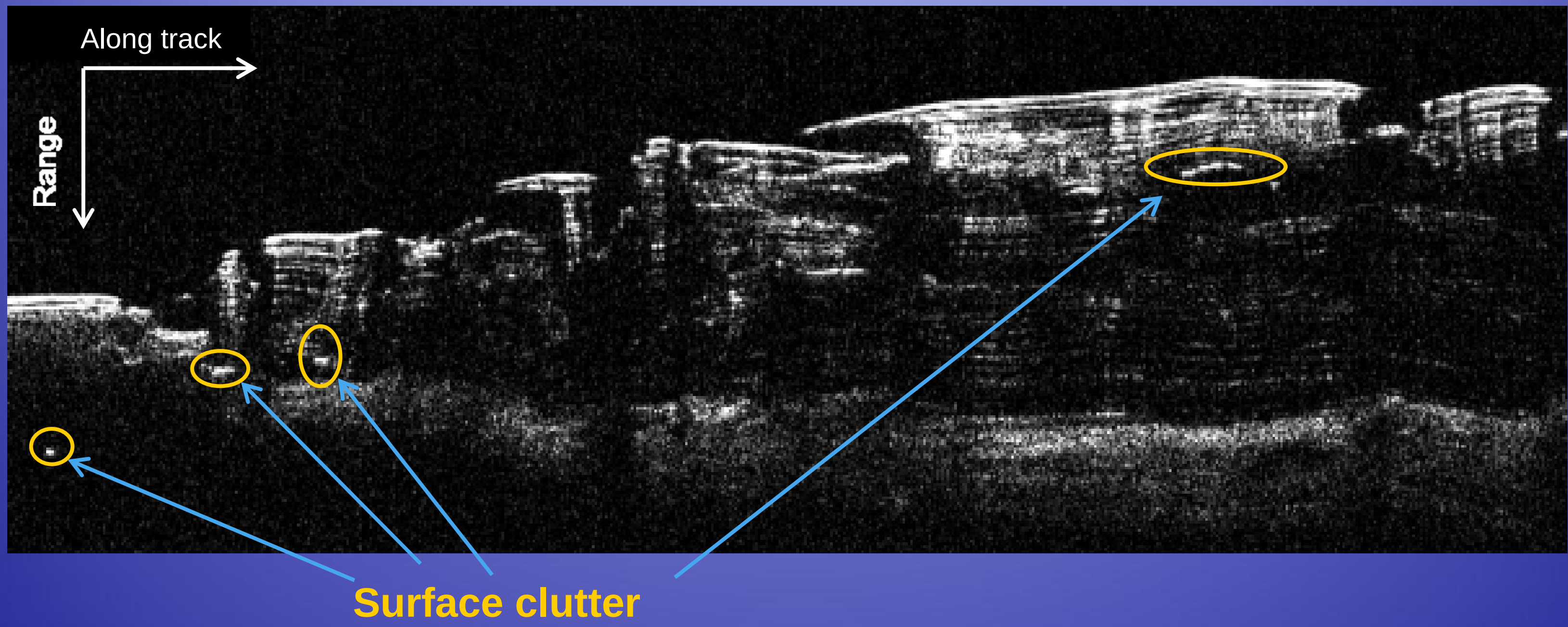
Off-nadir returns are caused by surface topography and roughness.

The discrimination between clutter and sub-surface echoes can be done on the basis of the knowledge of the surface topography.



Surface clutter

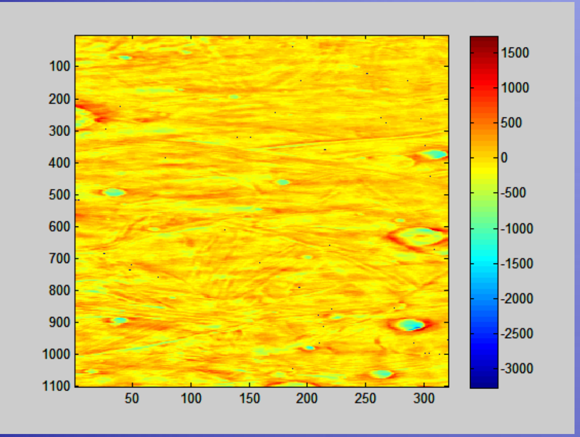
Example of SHARAD radargram of the North Pole of Mars

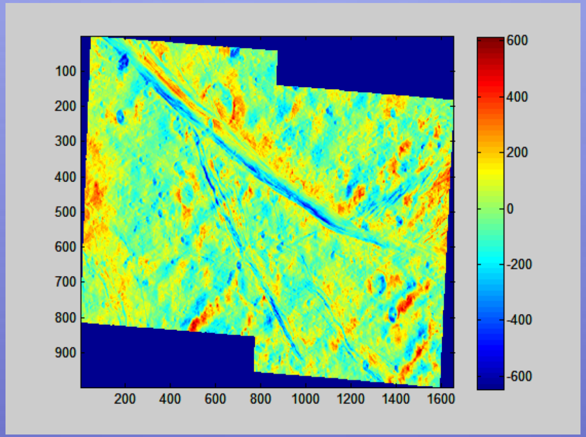


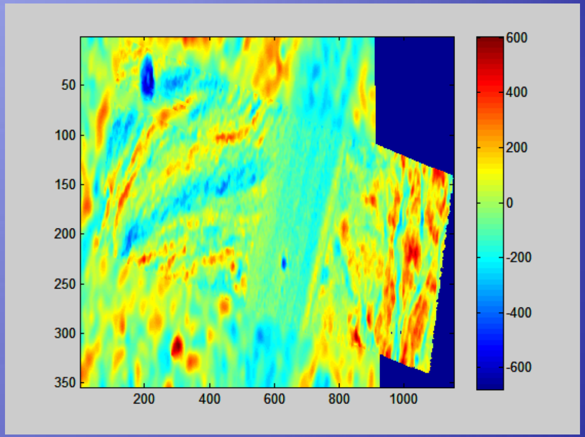
Clutter can be:

- reduced by "reducing" the surface roughness, i.e. decreasing the central frequency of the radar.
- predicted by exploiting Digital Elevation Models of the surface.

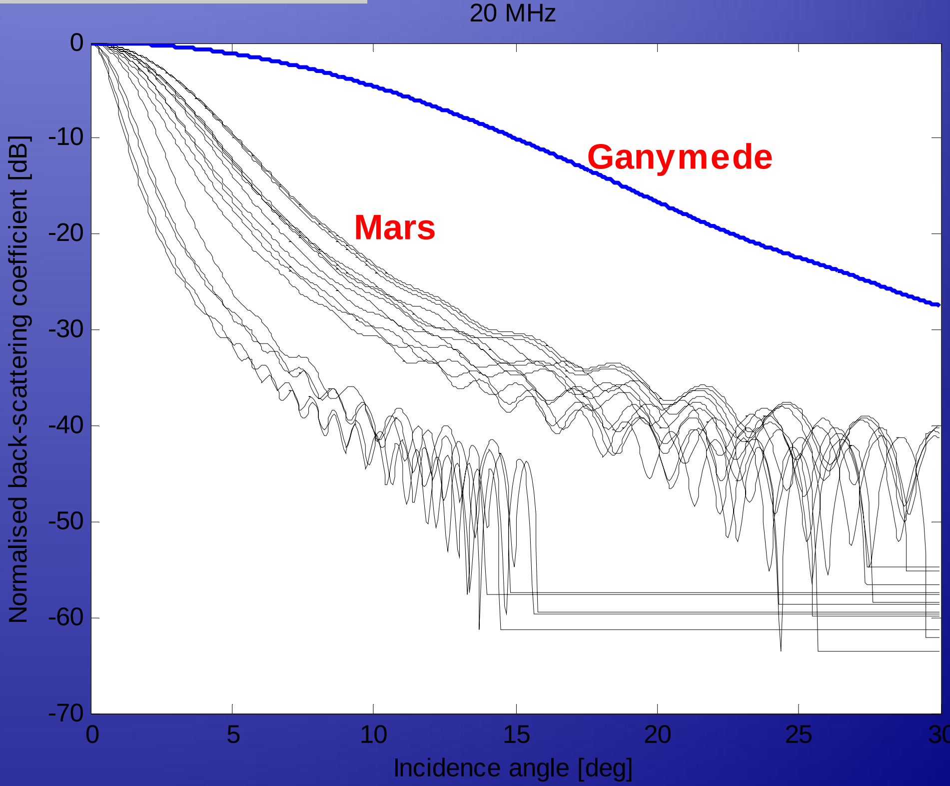
Surface clutter





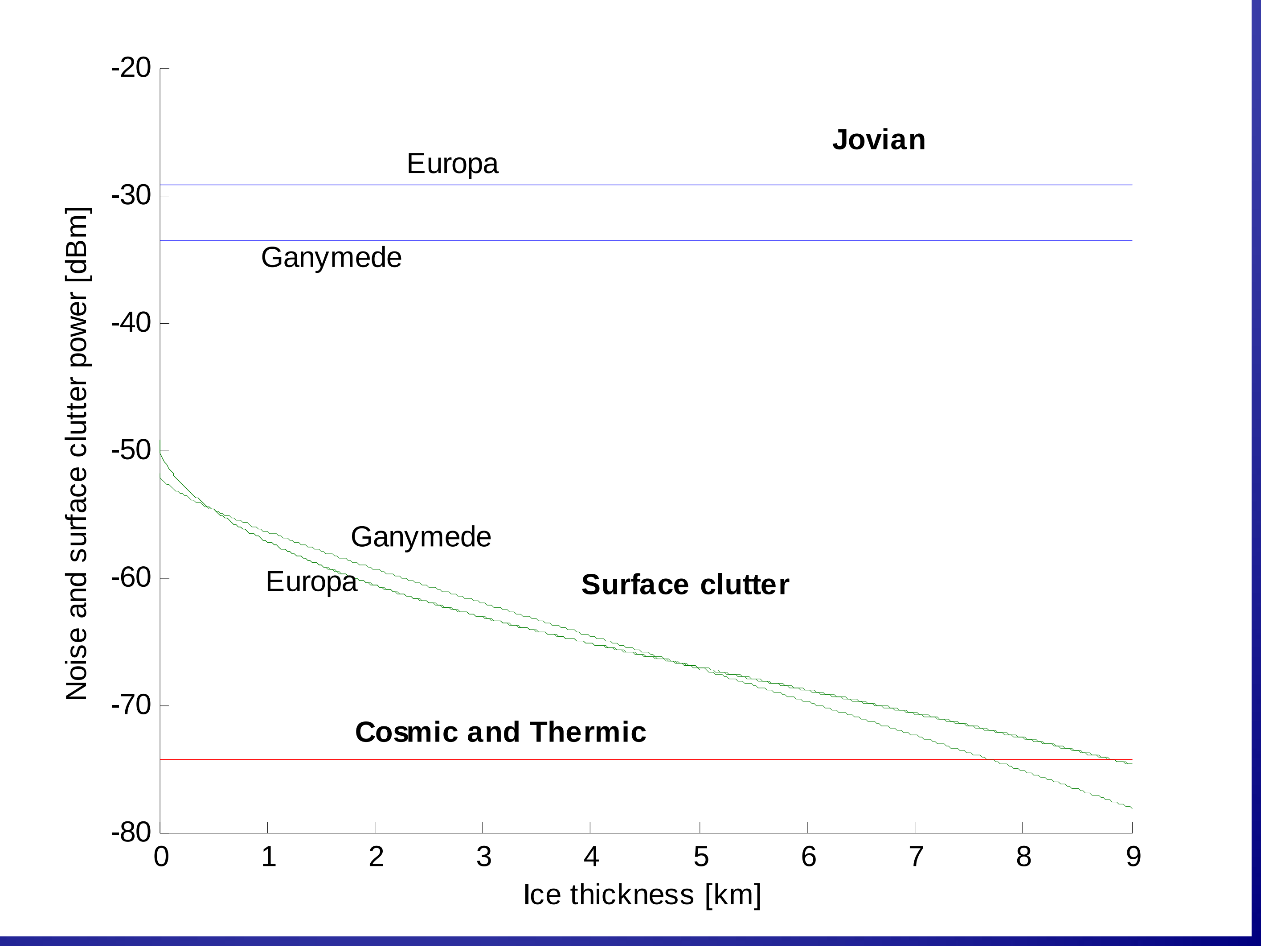


Evaluation of clutter is based on expected terrain backscattering, that can be calculated by estimating the statistical parameters of the surface (either classical or fractal)



Noise & clutter effects

Radio noise and clutter issues mainly driven the choice of a low transmitted frequency and the radar operation in the anti-Jovian part of the orbit



Signal attenuation in ice

C.F. Chyba, S.J. Ostro, B.C. Edwards, *Radar Detectability of a Subsurface Ocean on Europa*, Icarus 134, 292-302 (1998).

- *It permits to evaluate ice attenuation as a function of ice temperature and for different concentration of impurities*
- *It gives suitable ice temperature profile for Europa and Ganymede*

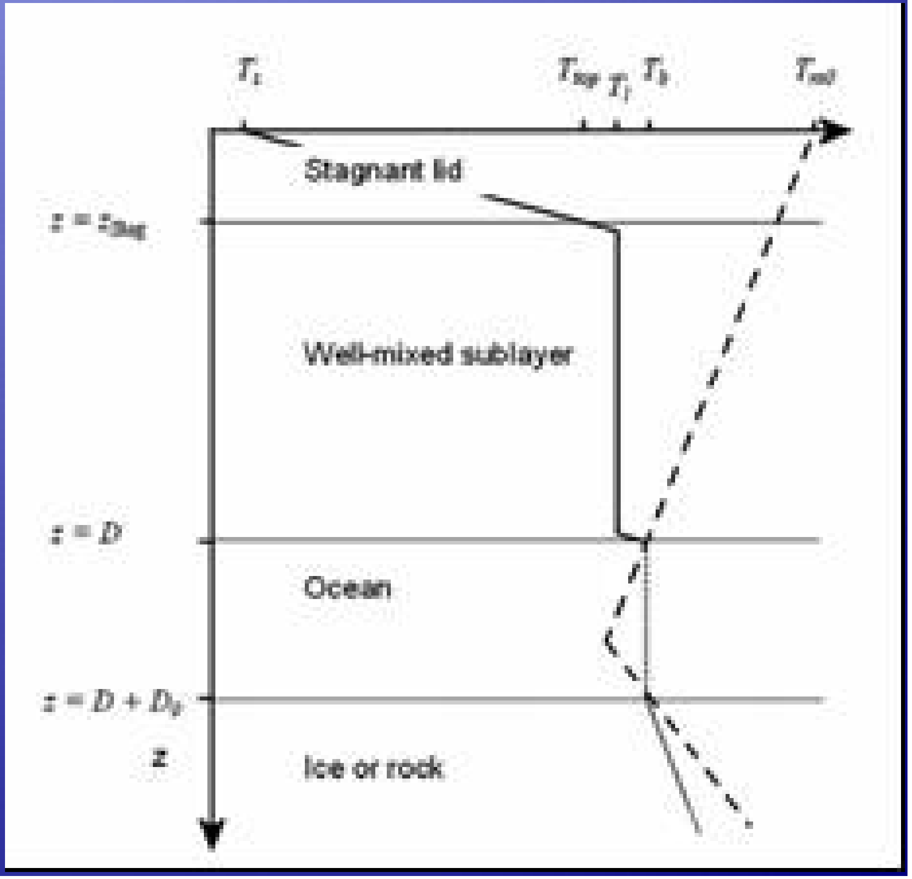
T. Spohna and G. Schubertb, *Oceans in the icy Galilean satellites of Jupiter?* Icarus 161 (2003) 456–467

- *It gives suitable ice temperature profile for Europa and Ganymede*

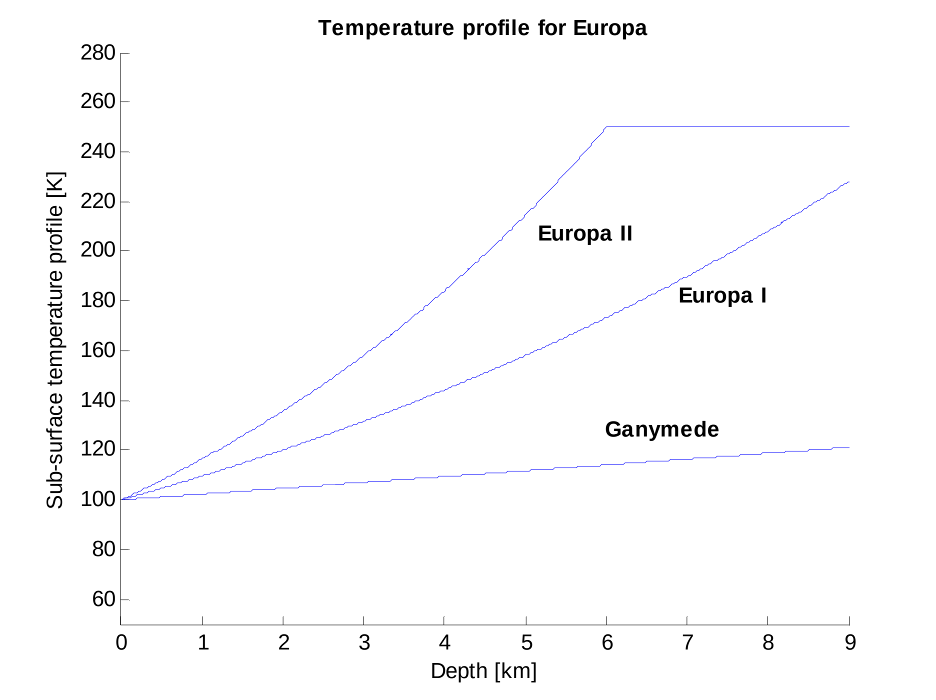
Signal attenuation in ice

- *Both the references supposed that the top ice shell is divided in a conductive stagnant lid and a convective layer*

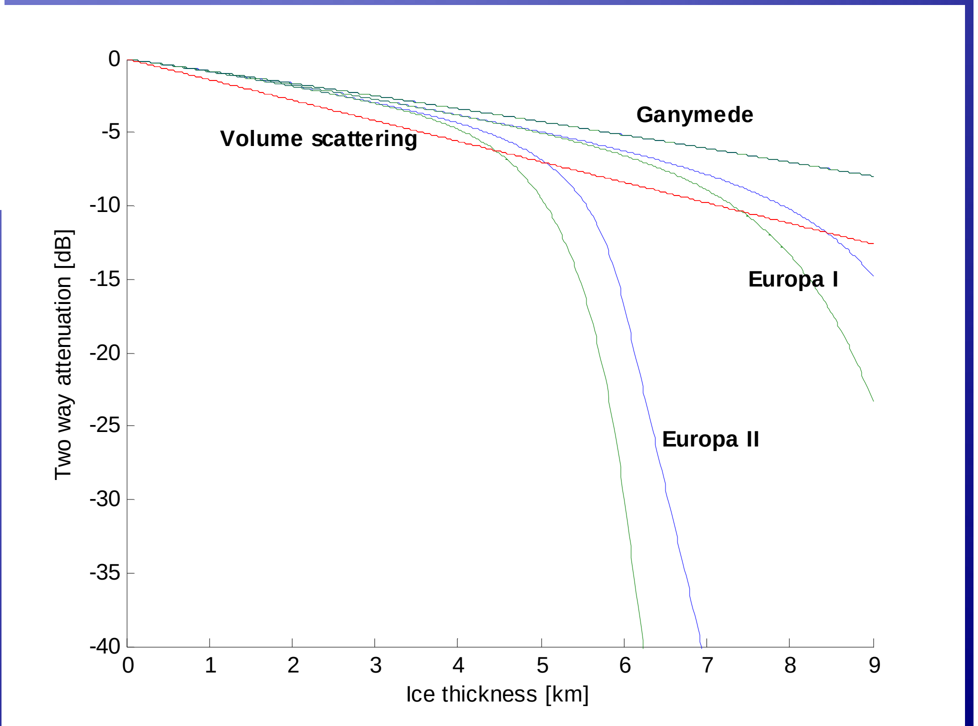
- *In the conductive layer, the temperature follows the heat diffusion law (including possible tidal heating).*
  The convective layer is expected to be well-mixed, and its temperature profile follows the adiabatic transformation of water ice, where the temperature is almost constant for the expected pressure range



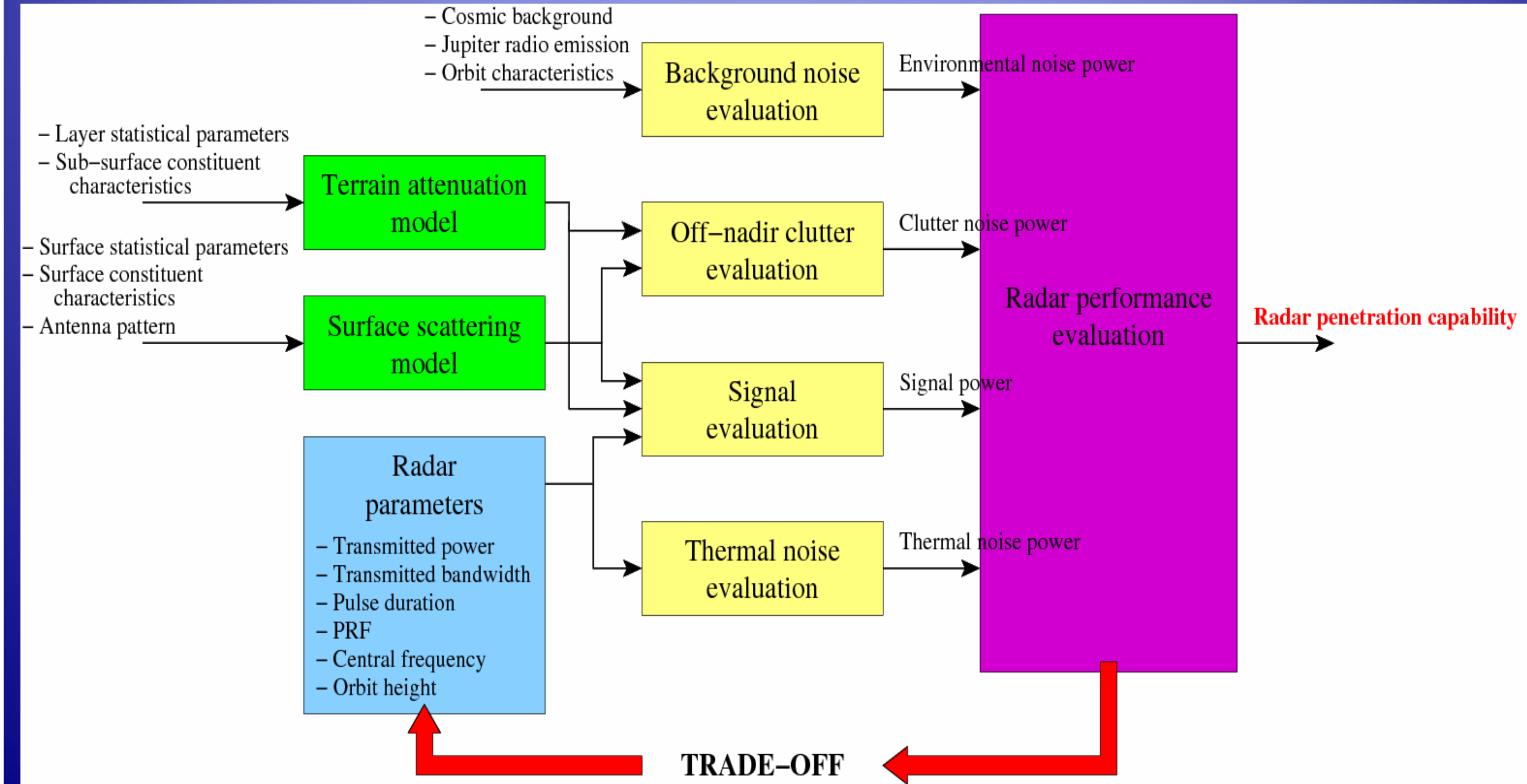
Signal attenuation in ice



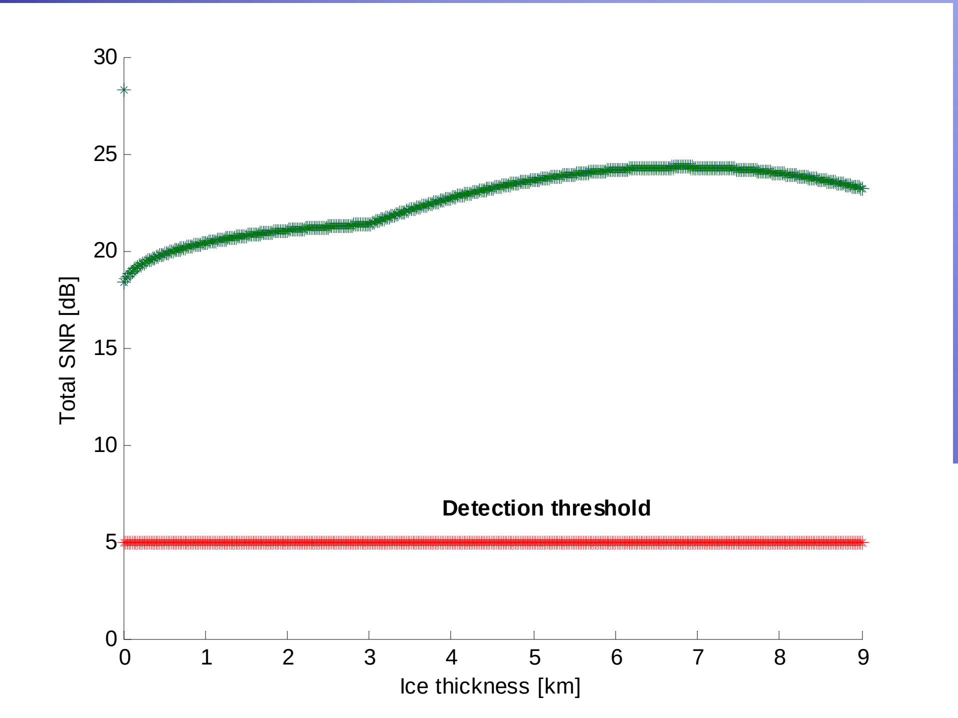
- *For Europa two different scenarios in term of ice temperature profile have been considered*



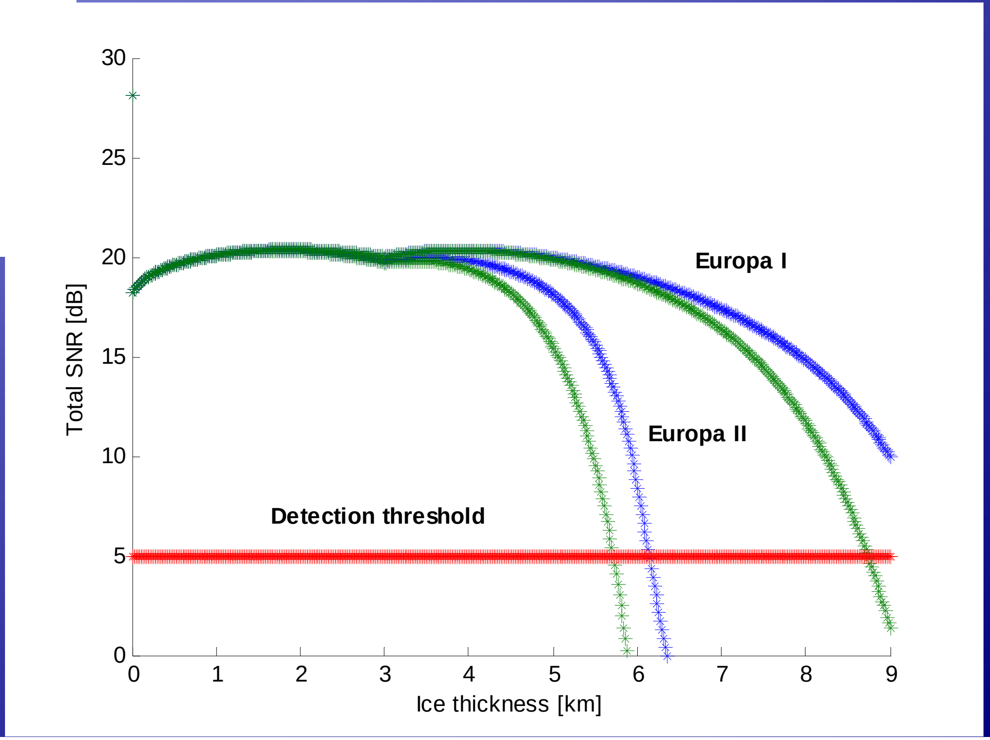
Performance model



SNR results

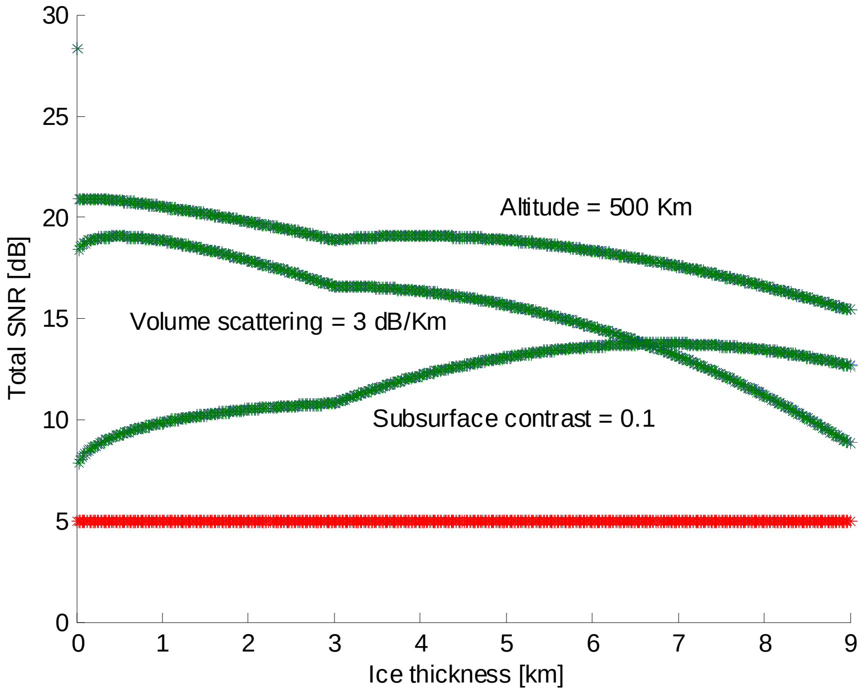


Ganymede

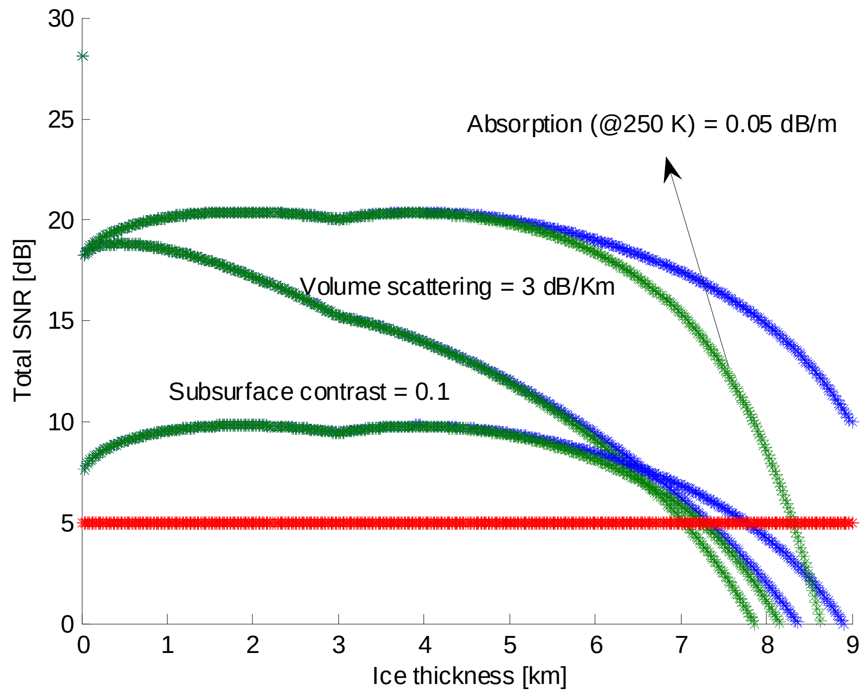


Europa

SNR results



Ganymede



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Conclusions

- RIME is a crucial instrument for the JUICE mission. This is the only instruments capable of direct measures of the icy moons subsurface. These measures are acquired for the first time in the Jupiter system!
- RIME is associated with fundamental science goals with potential strong impact on the science returns of the mission.
- Recently (Oct. 2012) a proposal to ESA for the development of the instrument has been sent, in response to the AO
- The performance of the instrument have been evaluated taking into account the expected signal attenuation in ice and the effects of disturbing contribution such as surface clutter and Jovian radio noise
- The resulting trade-off analysis has allowed the choice of transmitted frequency, bandwidth and radar operation (anti-Jovian part of the orbit) strategy