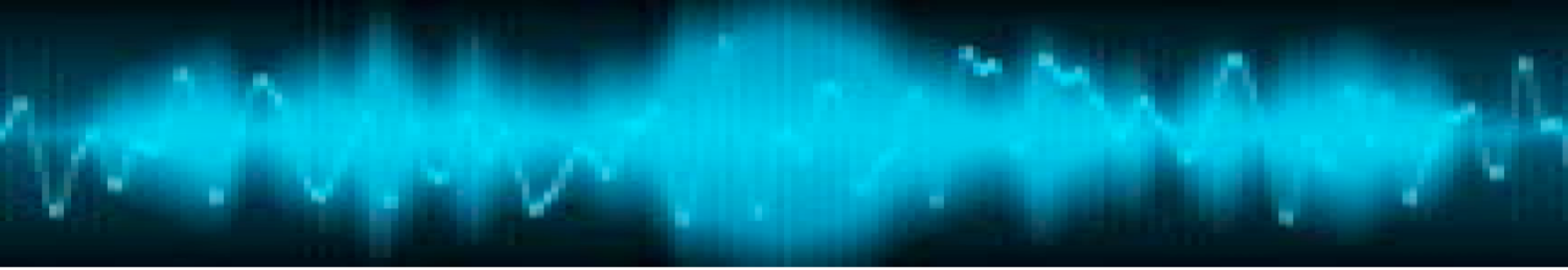

A Passive Probe for Subsurface Oceans and Liquid Water in Jupiter's Icy Moons

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In press – accepted manuscript in Icarus.

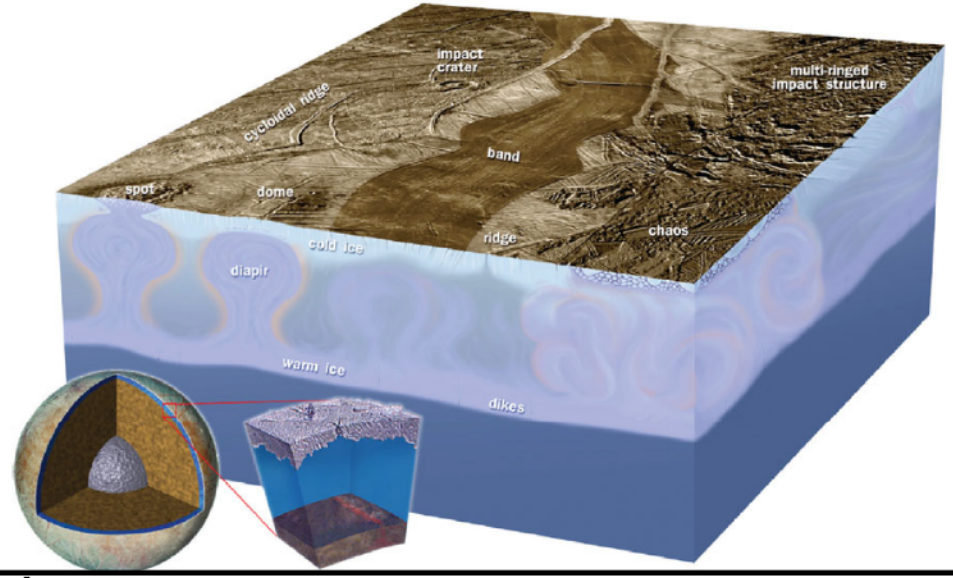
Outline

- A passive technique using Jupiter's radio emission that provides higher depth sensitivity than radar.
- We assess this methodology by direct comparison with metrics for radar.
- This method provides potential for new science using ground based measurements.

Subsurface Oceans in Jovian Icy Moons?

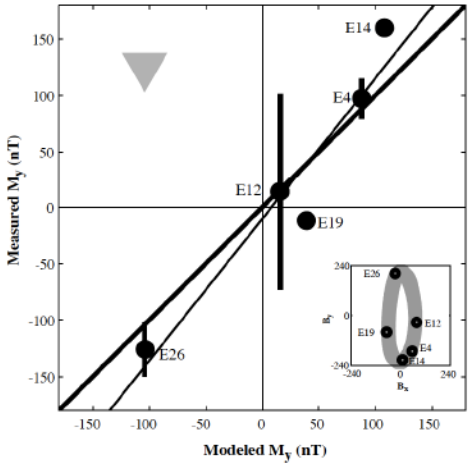
What do we know and what can we learn.

Geological Features indicate active and thin ice shells for Ganymede and Europa: "mobile icebergs" in chaotic terrain, abundant tectonic features.



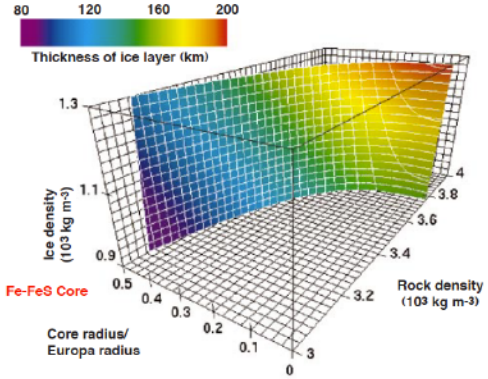
Pappalardo, 2010

The Galileo **magnetometer observed an induced magnetic field** due to Jupiter, consistent with a conductive fluid layer near the surface.



Kivelson, 2000
Zimmer, 2000

Gravity measurements from Galileo radio Doppler data shows Europa is most likely differentiated with a 80-170 km water ice-liquid outer shell.



Anderson, 1998

Jupiter is a Viable Radio Source for Sounding Ice

- **Strong radio emitter.**
  Near Europa: 40 dB above galactic background.
- **Compact source.**
  Ground based VLBI measurements show it is <400 km in spatial extent.
- **Predictable Emission.**
  The orbital phase of Io and rotational phase of Jupiter determine the occurrence of bursts.
- **Wide Band.**
  Emissions range from 300 kHz – 35 MHz

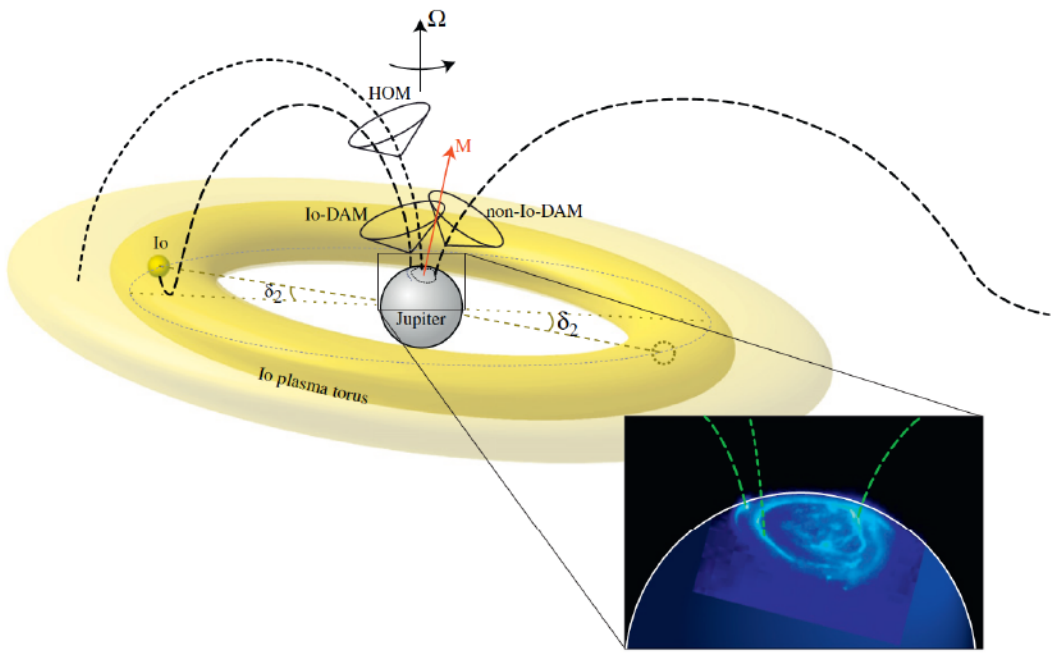
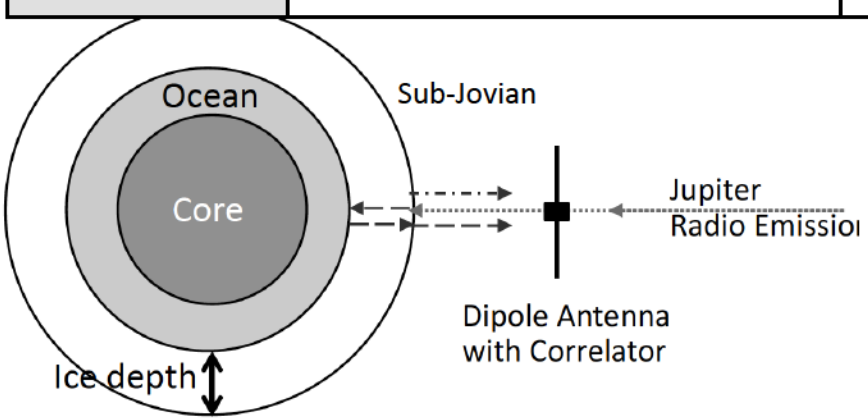


Image credit: Cecconi, 2012

Extracting Ice Depth

Signal	***Amplitude***	***Delay***	***Autocorrelation***
Direct Jovian	>40 dB above galactic background	Serves as reference.	Primary peak at zero delay. Set reference time and amplitude.
First surface reflection	Fresnel coefficient: -12 dB Radar cross-section: -3 dB Surface roughness: ~-20 dB	Determined by spacecraft altitude. 660 μs at 100 km altitude.	Peak with delay proportional to spacecraft altitude
Subsurface reflection.	>90% signal transmitted into ice Ice attenuation: -10 dB/km (attenuation length of 2.5 km)	Proportional to depth of subsurface reflector (113 μs for 10 km depth).	**Peak with delay proportional to spacecraft altitude and depth of subsurface reflector.**



<u>Extract timing via autocorrelation function</u>

$$A(\tau) = \frac{2}{T}\int_{-T/2}^{T/2} dt\ a(t)a^*(t-\tau).$$

Sensitivity to Correlation Peak

Radiometer equation
gives the minimum detectable temperature.

$$\delta T = \frac{T_{sys}}{\sqrt{\Delta f \Delta t}}$$

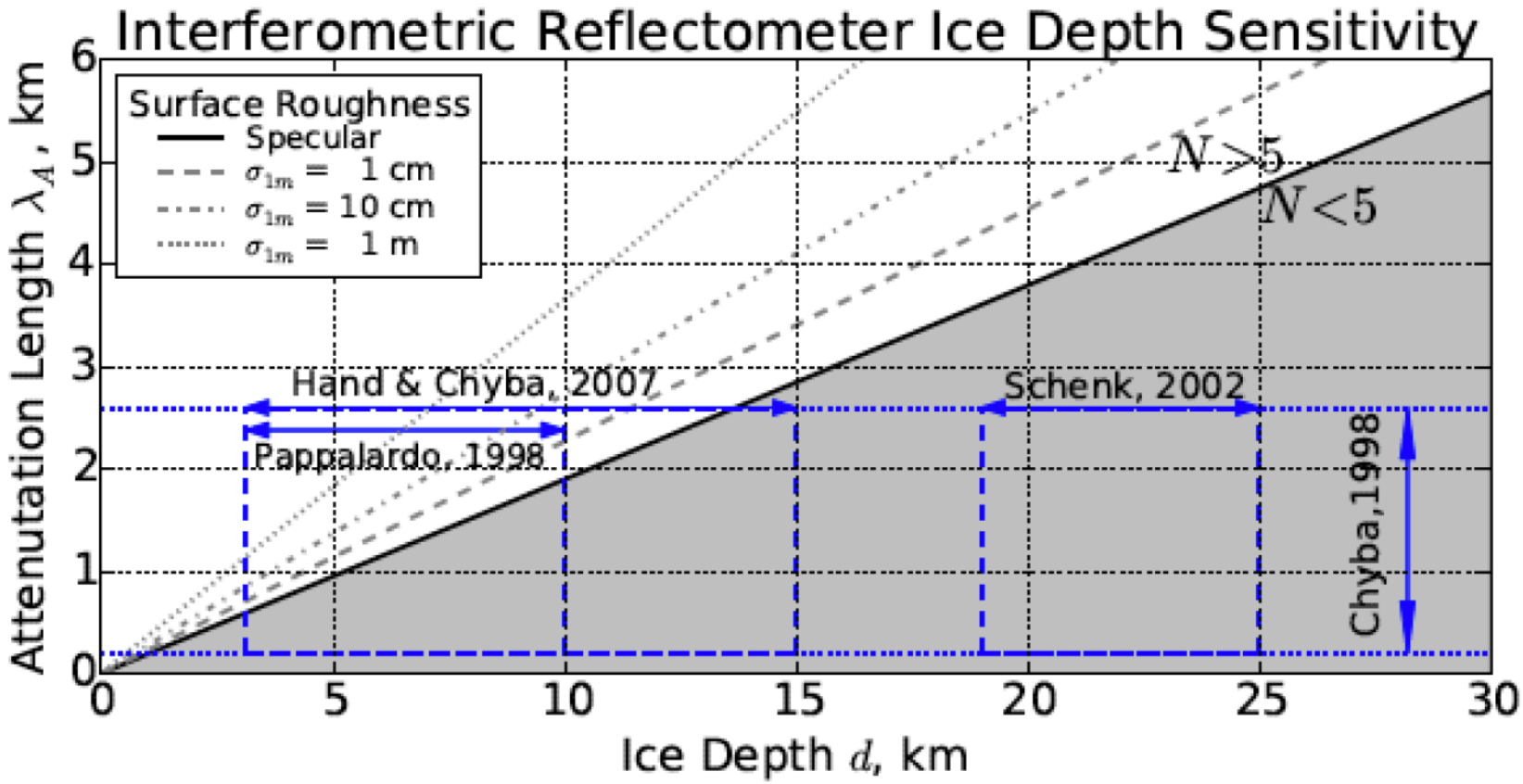
Signal amplitude
proportional to the correlation from subsurface reflection to direct emission.

$$k_B T_{ice-ocn} = \frac{C_{J,ice-ocn} A_e}{2 Z_0}$$

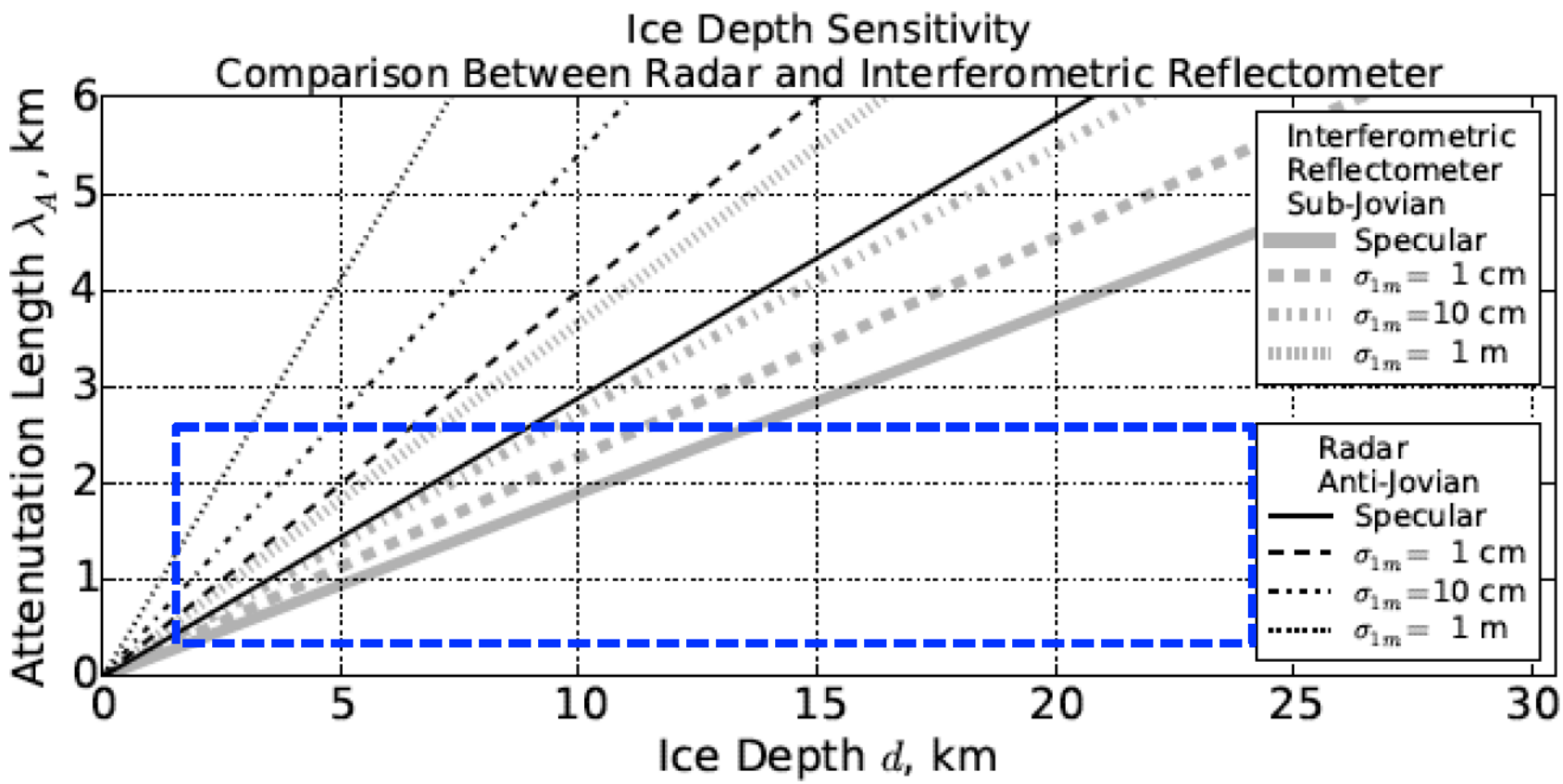
Noise Level
The system temperature is completely dominated by the Jovian emissions.

$$T_{sys} = T_{A,J}$$

Sensitivity Results



Comparison to Radar



Expect 70% greater depth sensitivity to subsurface reflections than radar.

Passive Technique Sensitivity and Resolution

Parameter	Instrument Drivers	Typical values
Sensitivity	Integration time and bandwidth.	Δt, Δf: sensitivity 1 s, 1 MHz: **60 dB** 1 s, 3 MHz: **65 dB**
Depth resolution.	Bandwidth	Δf: depth resolution 1 MHz: **300 m** 3 MHz: **100 m**
Pixel size	Spacecraft altitude and wavelength determine Fresnel zone.	Altitude 100 km, velocity = 4 km/s Wavelength: 9 MHz **Pixel size: 1.8 km**

Passive Mode for HF Radar Instruments

Science returns	Deeper view into the ice in the sub-Jovian side of Europa.
Risk reduction	Data returns possible in case of transmitter failure.
Extended observations	Can operate in bistatic geometry and at distance greater than 1000 km.
Impact on active radar instrument.	Minimal, may need higher front end attenuator range. May need 25% increase in memory modules for extended observations.

Ground Based Efforts

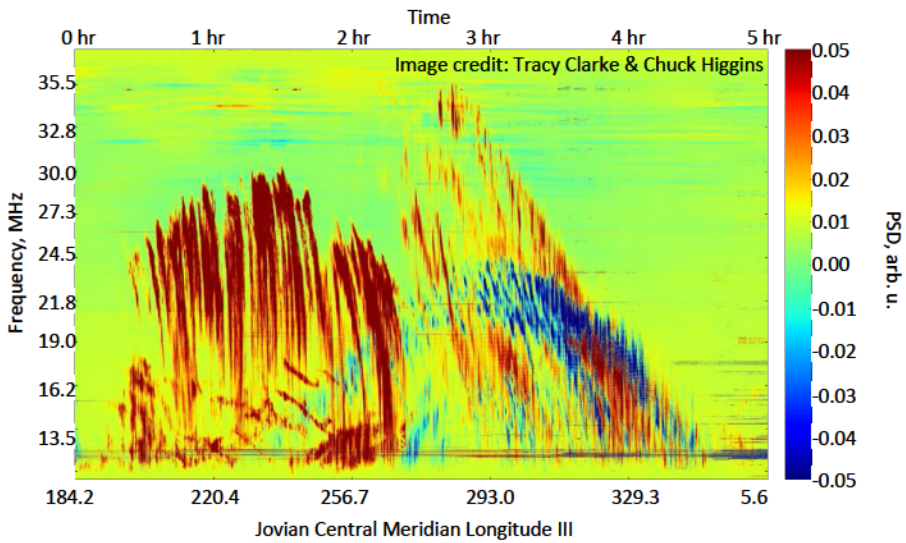
- Radio astronomical observation of reflections of the Jovian decametric signal off an icy moon is possible.

	Europa	Ganymede
Radar Cross-section	-59 dB	-58 dB
Typical reflection coefficient	-10 dB	-10 dB
Surface roughness and clutter	< -3 dB	< -3 dB
Total Losses	- 72 dB	- 71 dB
Reflected signal flux	< 250 mJy	< 320 mJy

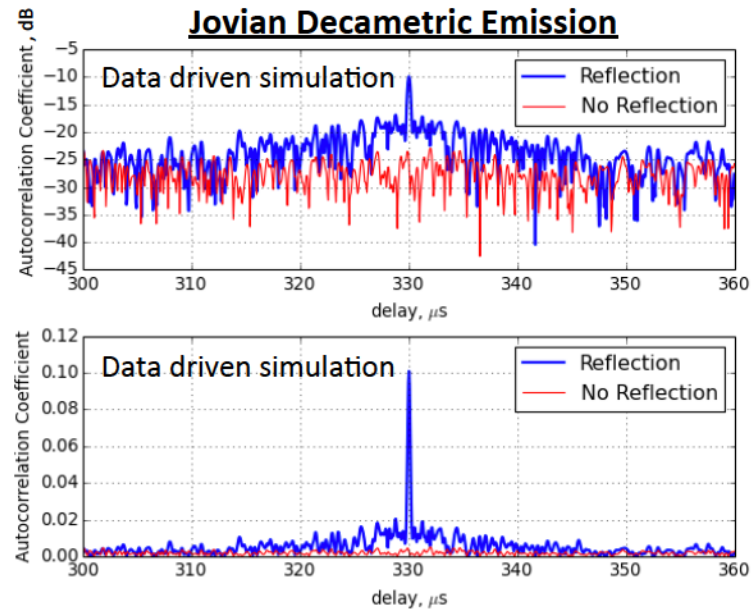
Detectable Fluxes with the LWA and LOFAR are at the level of 20 mJy.

Time-Domain Sampling

Jovian Burst observed with the LWA

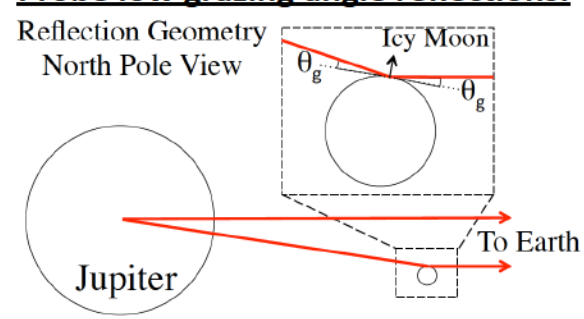


Characterizing the Autocorrelation of the Jovian Decametric Emission



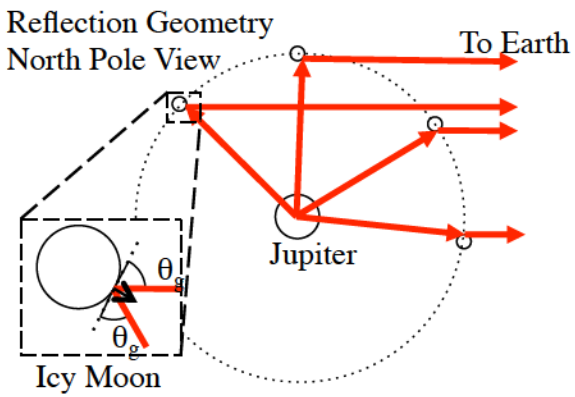
- Validate the passive technique by searching for the reflection in the autocorrelation.
- Characterize the signal autocorrelation structure.

Probe low grazing angle reflections.

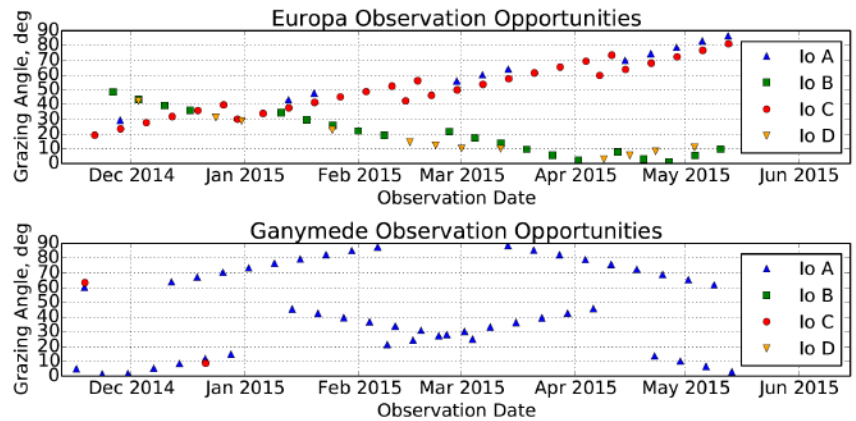


Imaging and Polarimetry

Bistatic Probe of Jovian Moon Ice Shells

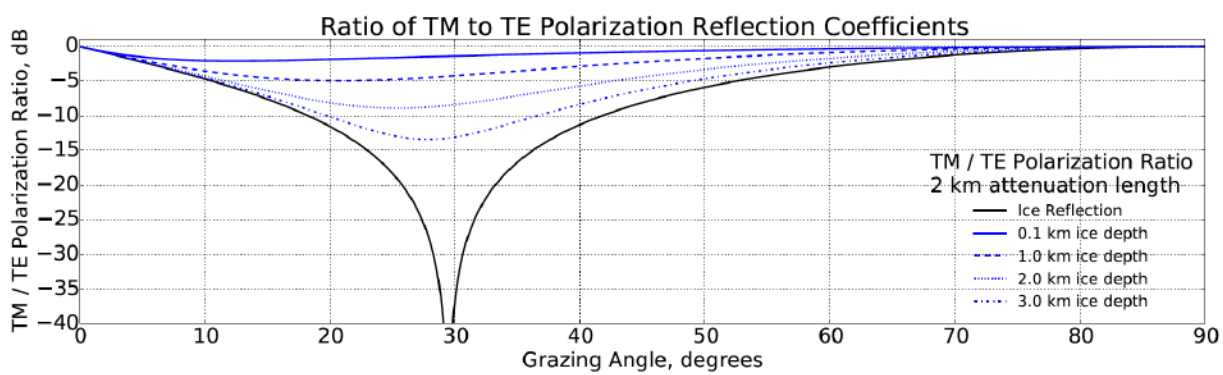


Ample Observation Opportunities



Polarization Probe:

- Surface roughness via polarization fraction.
- Index of refraction via polarization angle.
- Subsurface oceans up to 3 km deep via modifications to polarization angle.



Ground Based Science

Instrument	Detection Mode	Objective
LWA1 New Mexico	Time-domain 19 MHz sampling.	Prove concept. Test autocorrelation of direct and reflected emission.
LWA-OVRO California	Continuous sky imaging and polarization.	Detect reflection. Characterize backgrounds. Large exposure to Jovian system allows for statistical search of reflections and characterization of Jovian background emissions.
LOFAR Europe	Resolved imaging and polarization.	LOFAR's long baselines resolve Jupiter and its icy moons allowing for clear distinction between sources.

Conclusions

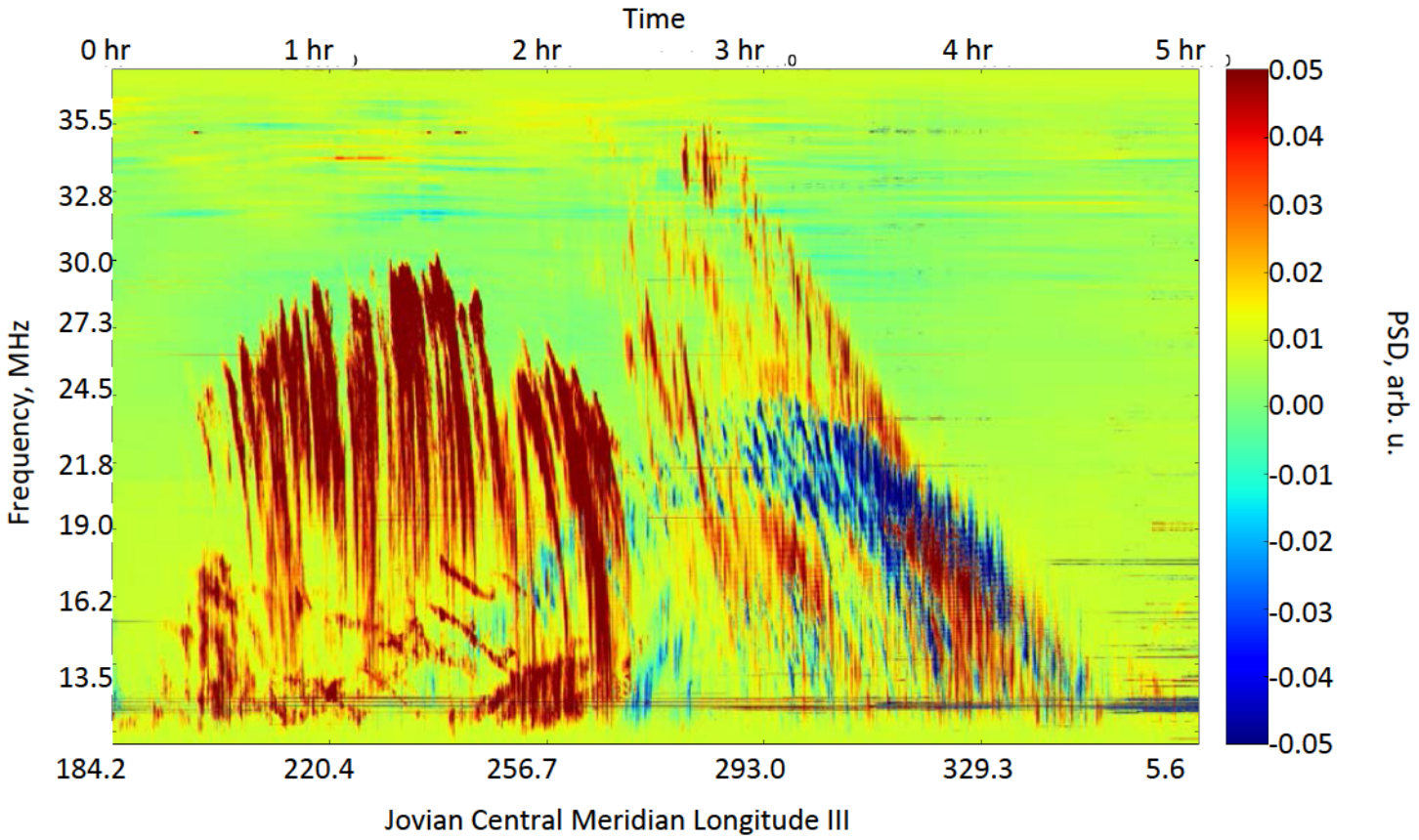
- Jovian decametric emission can provide deeper view into the ice shell of Europa than radar.
- This technique can be added to as a passive mode to a radar instrument with minimal modification.
- Risk reduction in case of transmitter failure.
- Ground based validation could occur within a year.

(c) 2014 California Institute of Technology. Government sponsorship acknowledged.

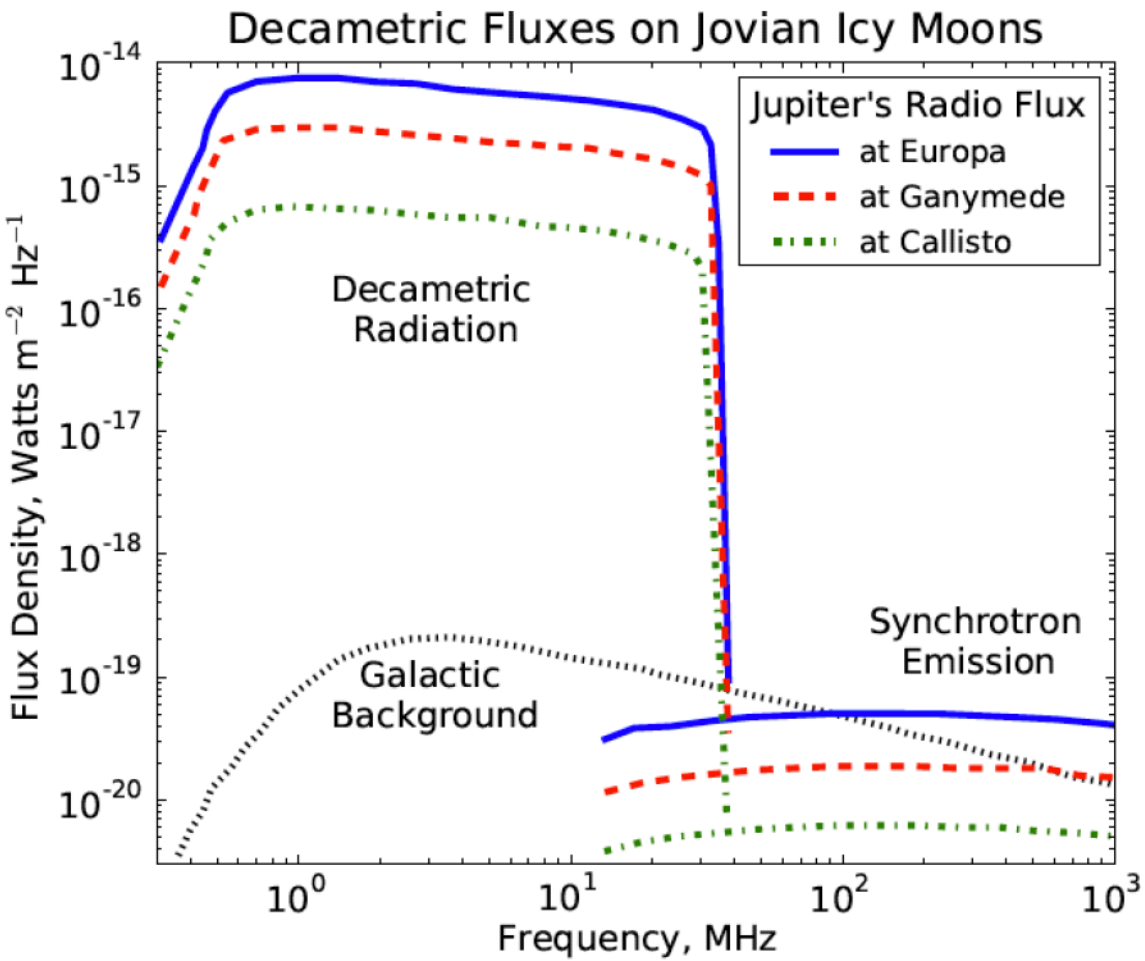
Backup Slides

Jovian Emissions

Jovian Burst observed with the LWA

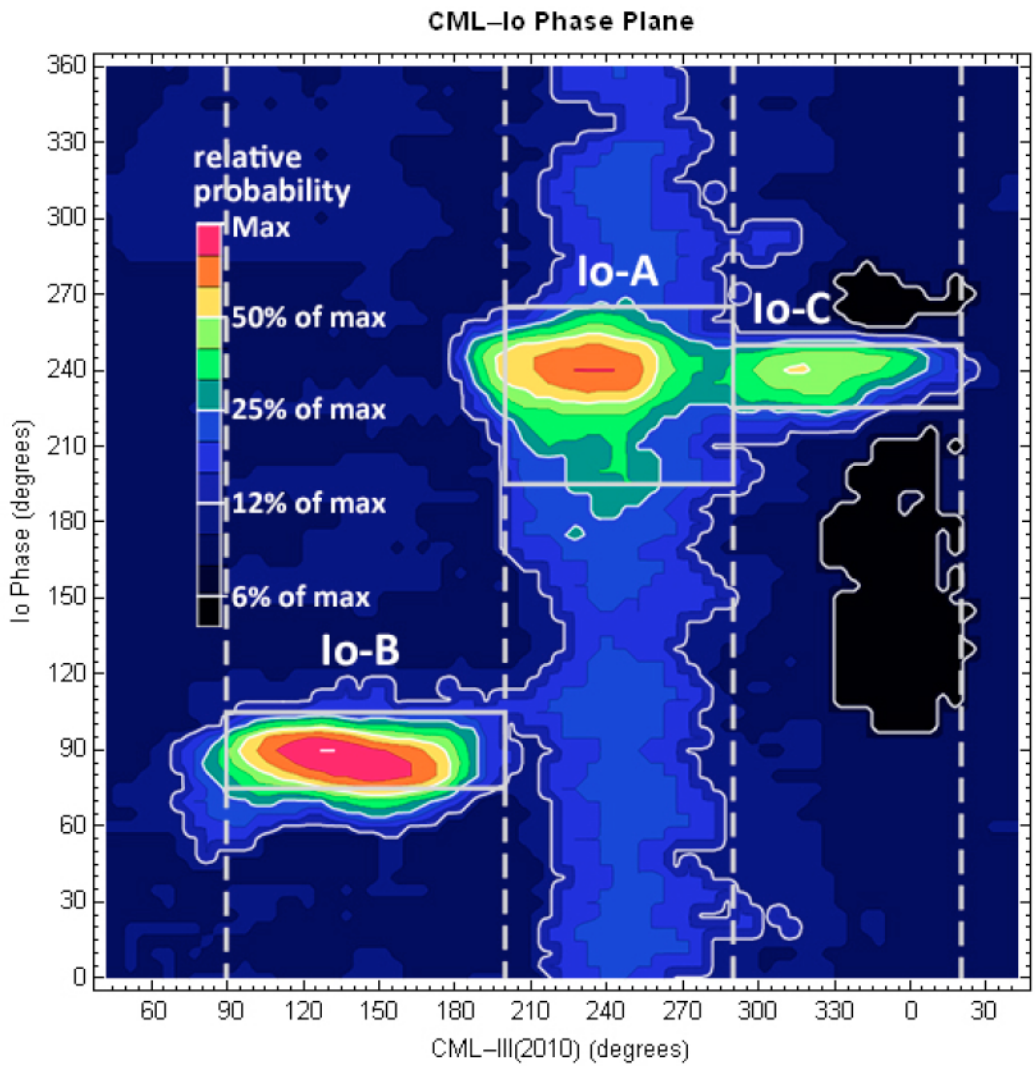


Jovian Decametric Signal Spectrum



Data from average Voyager PRA-spectra summarized in Cecconi, 2012

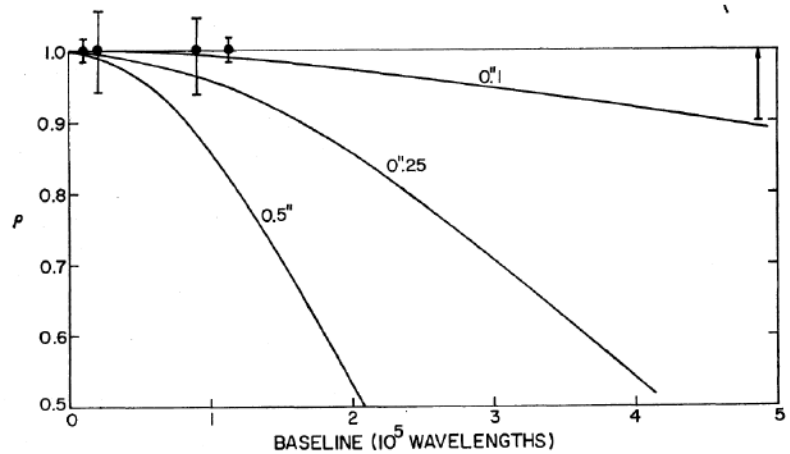
Jovian Decametric Emission Probability



Jupiter's Decametric Emission Spatial Structure

Dulk, 1970, 34 MHz VLBI with stations in Clark Lake CA, Boulder CO and Arrecibo

Source structure < 1,000 km



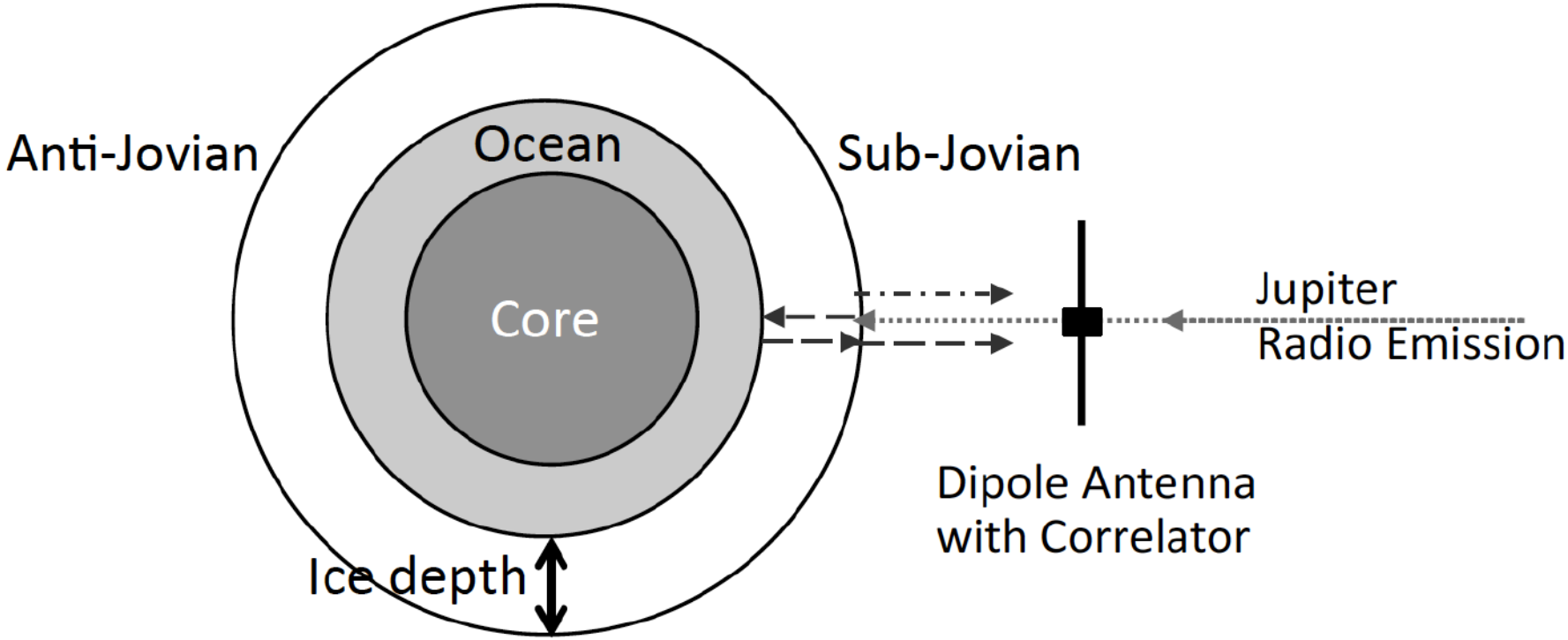
Carr, 1970, Kentucky – Chile baseline 18 MHz VLBI.

<0.1'' source

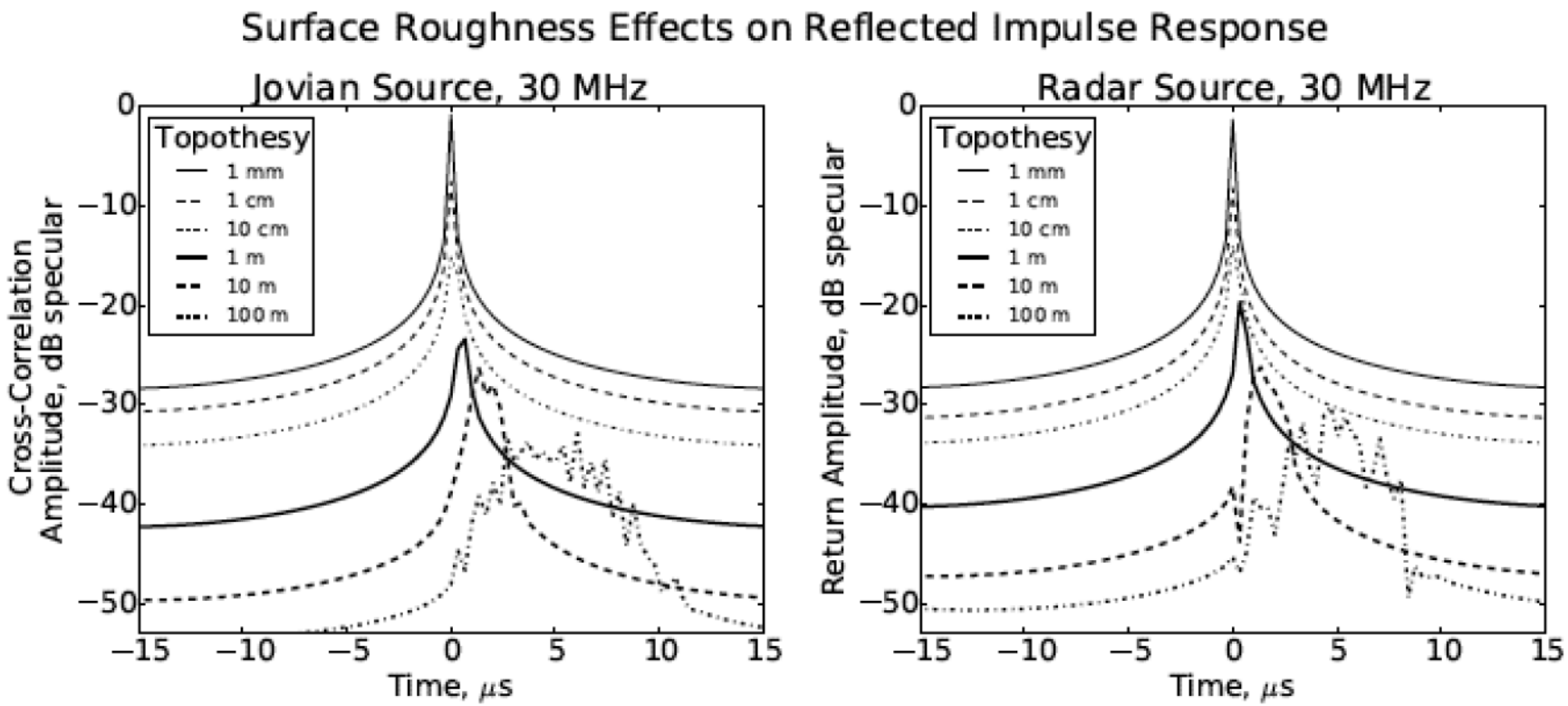
TABLE 1. Summary of results obtained with four baselines

Observation Year	Baseline km	Baseline Wave-lengths	Maximum Correlation	Equivalent Source Width
1964	55	3,300	Between 0.5 and 1.0	≪1′
1967	216	13,000	0.9	2″
1968	880	52,800	0.9	0.7″
1969	7500	450,000	0.9	0.1″

Passive Sounding Concept



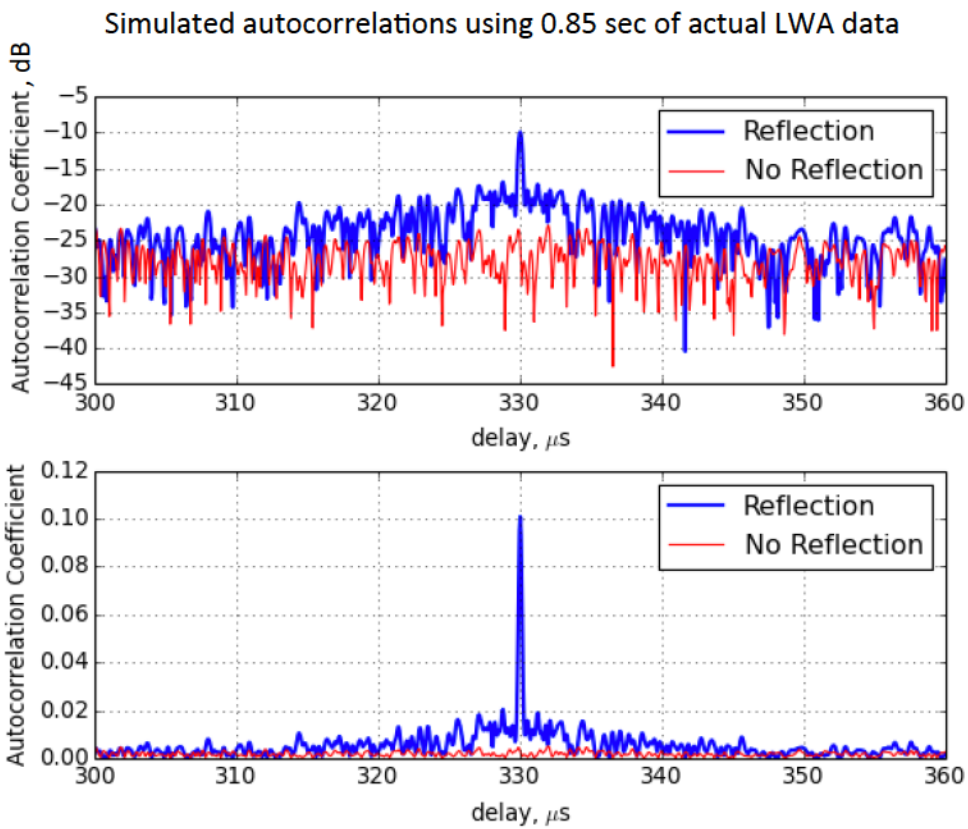
Estimated Roughness Losses



Preliminary Characterization of the Autocorrelation

Autocorrelation of the Jovian DAM.

Sidelobes 7 dB below main peak.

Autocorrelation decays to thermal levels in 20 µs time-scales.

Of sufficient quality for > 3 km subsurface sharp reflective boundaries.