PASSIVE RADAR INVESTIGATIONS OF IO USING JUPITER'S RADIO EMISSIONS.

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Introduction: The Passive Radar Io Magma Explorer (PRIME) has been previously introduced as an instrument concept to perform passive radar sounding of Io's near subsurface [1,2]. Using Jupiter's decametric radiation as a source for echo detection, PRIME aims to investigate the physical state of Io, its crustal thickness, and the presence of a global subsurface magma ocean and local magma reservoirs [3,4].

While Io is a crucial target to obtain a comprehensive view of the Jovian system and its evolution [5-8], it is not covered by the current Europa Clipper mission by REASON [9] and ESA's Jupiter Icy Moon Explorer (JUICE) by RIME [10] that focus on the icy moons - Europa and Ganymede. A smaller scale flyby mission on a high inclination orbit could be used to answer some of the most relevant science questions to understand the formation and evolution of the Jovian system. Such a mission could help answer some of the scientific goals outlined in [5-8], such as (1) investigate Io's near subsurface geology, (2) search for subsurface magma reservoirs, (3) investigate Io's Sulfur cycle, (4) measure the radial tidal deformations.

However, Jupiter's large distance from the Earth and Sun, as well as the harsh Jovian environment, make Io an extraordinarily difficult target when considering mass and power constraints. While active radar sounding techniques are heavily used terrestrially and will also be represented aboard NASA's upcoming Europa Clipper mission by REASON [9] and aboard JUICE [10], ground penetrating radars typically have significant power consumption and suffer from radio noise. Additionally, recent work has highlighted that active sounding operation may be limited and severely degraded on the sub-Jovian side [11].

Passive Sounding: By eliminating the need to actively transmit a signal for echo detection, a passive radar sounder that uses external sources for echo detection presents a low-resource approach to address these challenges [12]. For sub-Jovian operation, the concept of passive radar sounding has been previously suggested in the context of Ganymede and Europa [13-16], where a receiver from orbit [13-15] or on a ground-based lander [16] receive the direct and subsurface reflected signals from Jupiter in the radio frequency range. Similarly, PRIME would use the radio noise emissions of Jupiter at frequencies below 40 MHz to investigate the subsurface of Io. While a mission to Io would face constraints in terms of power, mass and significant radiation, a passive radar would thus be an ideal instrument due to its low power consumption and reduced mass.

Method: As Jupiter is one of the brightest objects of the solar system in the radio frequency spectrum [11], its radio emissions would serve as the source for passive sounding the subsurface of Io. Orbiting Jupiter with regular Io flybys, a spacecraft crossing between Io and Jupiter would receive the incoming direct and reflected signals [1,2]. The instrument would then correlate the direct signal received by the radar with the signals reflected by Io's surface and subsurface to obtain the passive measurement (Figure 1). Finally, a high inclination orbit around Jupiter would enable both the minimization of the time spent within the highly energetic Jovian radiation belt, and a large latitudinal coverage at each flyby of Io [1,2].

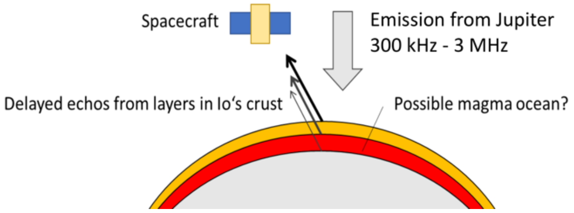

Figure 1. Measurement concept of a passive radar survey of Io's subsurface using Jupiter's radio emissions. An onboard passive receiver would correlate the incoming direct and reflected surface and subsurface signals to investigate Io's subsurface.

System Design: Jupiter's radio emissions are characterized by a very strong band in the decametric domain that surpasses other ambient noise sources at Io [11]. Our system study therefore considers a sensor onboard a spacecraft that receives Jupiter's radio emissions in the 300 kHz – 3 MHz frequency band. The upper limit of the 3 MHz bandwidth would provide a range resolution of 100 meters. While the lower frequency 300 kHz system is anticipated to obtain a greater penetration depth, it would degrade the range resolution to 1000 meters. Finally, the receiving window sizes are chosen to fit within the maximum integration time obtained when using the potential center frequencies of Jupiter's radio emissions and a range of sensor velocities at an altitude of 400 km. These parameters are summarized in the table below.

Table 1. Passive Radar System Parameters

Signal Flux Density	10^{-14} Wm^{-2}Hz^{-1}
Galactic Background Noise	10^{-19} Wm^{-2}Hz^{-1}
Center frequency	300 kHz – 3 MHz
Altitude	400 km
Sensor Velocity	5 - 20 km/s
Integration Time	0.34 sec – 138 sec

System Analysis: We calculated the Signal-to-Noise-Ratio (SNR) as a function of radar center frequency for different flyby velocities and penetration depths (Figure 2). The two-way attenuation and scattering losses are determined from typical crustal parameters for analog volcanic terrains [17]. We assume a negligible surface characteristic slope so that the geometric spreading losses are negligible as shown in [13]. As the passive radar's sensitivity is limited by the maximum integration time allowed by the orbital motion of the spacecraft, we assume the onboard sensor would receive for its maximum integration time to obtain the greatest time-bandwidth coherent gain. At an altitude of 400 km, and for center frequencies up to 3 MHz, the SNR for the echo peak in the squared-autocorrelation could exceed 10 dB for depths up to 1000 m.

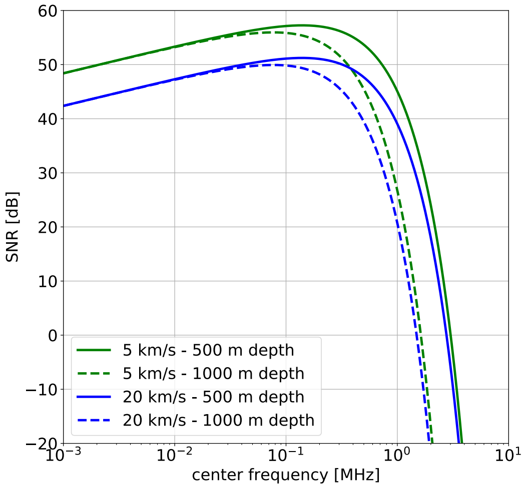

Figure 2. SNR for the subsurface echo's peak in the squared correlation function over radar center frequency. The green lines are for a 5 km/s flyby velocity and the blue lines are for a 20 km/s flyby velocity. The solid and dashed lines show the SNR for penetration depths of 500m and 1000 m, respectively.

Conclusions and Future Work: The passive instrument concept presented has the potential to provide a low-resource survey of Io's near subsurface. We investigated the performance of the instrument concept in terms of signal to noise ratio and potential penetration depths. Our future work includes studying the passive radar's SNR over a variety of potential Io crustal parameters, as well as further investigating when and how Jovian radio bursts illuminate Io. Since the strongest and widest band emissions are driven by Io in particular, further analysis of Jupiter's radio emissions is needed to determine the properties of the Jovian bursts at Io.

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