Investigating the Ice Shell and Buried Ocean on Europa with the Schumann Resonance

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A Schumann Resonance is an electromagnetic oscillation in a closed waveguide formed by the ionosphere and the surface or interior of a planetary body, the waveguide being a resonant cavity with a fundamental wavelength of $\sim$ the circumference of the body. The terrestrial Schumann Resonance is formed by the cavity between the ionosphere and the surface of the Earth, with the resonance being excited by lightning. A Schumann Resonance was detected on Titan by the *Huygens* probe, with the resonant cavity being between the Titan ionosphere and the subsurface ocean (i.e., including both the atmosphere and icy shell of Titan); the resonance excitation for Titan is thought to result from currents in the ionosphere induced by the Saturnian magnetic field flowing across the moon.

Observations by the *Galileo* spacecraft reveal that Europa also has a charged particle ionosphere, with particle densities being as high as 10^4 cm^{-3}. This density is comparable to the densities observed in the ionosphere of Titan, but in the case of Europa these densities are present at or immediately above the surface due to the lack of a neutral particle atmosphere on that body. A Schumann Resonance should thus exist on Europa, with the resonant cavity consisting of the ice between the ionosphere and the surface of the buried ocean, and the excitation arising from currents induced by the strong Jovian magnetic field.

The eigenfrequencies, f_n, of a homogenous non-conducting cavity of a radius R and thickness d are given by

$$f_n = \frac{c}{2\pi\ R} \sqrt{n(n\ +\ 1)\ \frac{1 - \frac{d}{R}}{\epsilon_r}} \qquad (1)$$

where c is the speed of light in a vacuum and ϵ_r is the relative permittivity of the material in the waveguide. Equation 1 assumes that the ice has negligible conductivity; inclusions of brine in the ice shell could cause an effective conductivity in the shell and thus give the eigenfrequencies complex components. For the Earth, observations reveal a complicated modal structure with many excited eigenfrequencies, while for Titan only the f_2 mode, at a frequency $\sim$36 Hz, was detected in the *Huygens* data.

The Europan Schumann Resonance should be excited by the Jovian magnetic field and thus could be detected by a European lander or orbiter or even during a close flyby of Europa. In the case of pure ice, ϵ_r is $\sim$3.15 at radio frequencies. For Europa, with a total radius of 1560.8 km, if the ice shell is assumed to be pure ice with a 30 km thickness, f_n would be $\sim$ 24, 42 and 59 Hz for n = 1, 2 and 3, respectively. Observations of the Schumann Resonance could be used, as in the case of Titan, to determine the thickness, effective permittivity and conductivity of the ice shell of the moon and confirm the existence of its buried ocean. Regional variations in these properties should cause mode splitting and broadening, and thus could also be constrained by surface observations,