Juno had close flybys of Jupiter’s moons Ganymede on 7 June 2021, Europa on 29 September 2022, and Io on 30 December 2023, flying within hundreds of kilometers of their surfaces. Another Io flyby is planned for 3 February 2024. During these flybys, Juno’s Microwave Radiometer (MWR) observed Europa, Ganymede, and Io, obtaining several swaths across the satellites using Juno’s spin to partially map the satellites’ surface and subsurface at six frequencies ranging from 600 MHz to 22 GHz. MWR probes successively deeper into the subsurface with decreasing frequency. For the icy satellites, MWR may probe up to a depth of tens of kilometers at 600 MHz, assuming the ice shell is pure solid water ice.

Though the first radar observations can be dated back to 1970s and the Galilean satellites have been observed extensively from the Earth and space-based platforms ever since, these observations have been mostly limited to the top surface up to a few meters, with relatively low spatial resolution (~thousands of kilometers), or hindered by the presence of Jupiter’s thermal and synchrotron emission [1,2]. MWR for the first time provides resolved microwave brightness temperature maps and associated spectra with a spatial resolution of up to 100–200 km. Multi-frequency MWR observations are sensitive to the subsurface structure and composition at various depth (e.g., thermal gradient in the upper part of the shell, extent of fractures, contaminants, density, purity, and liquid water content). On the other hand, previous unresolved microwave observations at low frequencies have been limited due to confusion from Jupiter’s synchrotron radiation. MWR observations have an inherent advantage in minimizing the confusion with Jupiter’s synchrotron as the spacecraft is between Jupiter and satellites, thus MWR is looking away from Jupiter when viewing satellites. MWR observations cover a wide range of latitudes and longitudes on Galilean satellites as shown in Figure 1, covering, bright, dark terrains and Tros crater on Ganymede (upper panel); ridged plains, and chaos terrain on Europa (middle panel); and various surface types on Io (lower panel).

Figure 1: The MWR observation coverage on Ganymede (upper panel), Europa (middle panel) and Io (lower panel). Upper/middle panel: The black ellipses show the half-power contour of each MWR sample for 2.5 GHz to 22 GHz. The dashed yellow line represents the solar terminator. Lower panel: MWR track contour on Io during PJ57 (blue) and PJ58 (black). The background Ganymede global geological map from [3], Galileo SSI Europa global mosaic from [4] and USGS Io surface map.

The brightness temperature maps and spectra are sensitive to prominent localized thermal features in addition to the various types of terrain seen in visible
and infrared images of the satellites. For the icy moons Ganymede and Europa, the obtained brightness temperatures are in general colder than the expected surface temperature in equilibrium with sunlight, suggesting the existence of reflection in the subsurface, which can arise from dielectric interfaces (surface-vacuum interface, subsurface fractures, and layering) or volume scattering from material/particles within the ice. Reflection is important for all frequencies for both satellites. However, the fact that the brightness temperature increases with frequency on Europa, while decreases with frequency on Ganymede, suggests that the reflectors might extend deeper into the subsurface on Europa. On the other hand, Europa’s brightness temperature spectra show much less geographic variation suggesting subsurface ice properties (such as temperature, composition, or fracturing) are more uniform on Europa compared to Ganymede. We observed a strong correlation between brightness temperature and surface features. The dark regions at visible wavelengths are warmer in the microwave, and vice versa, showing an interesting correlation between subsurface features and surface visible reflectivity or terrain types. This anti-correlation is much stronger on Ganymede than that on Europa.

On Europa, the brightness temperatures at 1.2 GHz, which may come from a few kilometers’ depth, are especially more uniform across the tracks, indicating uniform ice properties. On Ganymede, a significant variation in MWR brightness spectra with location is shown, suggesting that the sub-surface ice properties are not spatially uniform, which could result from variations in temperature, composition, or fracturing. We also found that the Tros crater is unique and especially colder, which is consistent with previous ALMA observations [5]. Preliminary results from the Io observations will also be presented along with a comparison to MWR measurements obtained at Ganymede and Europa. We will highlight this analysis and infer possible physical properties of the surface and sub-surface based on radiative transfer modeling.

Although MWR observations minimize the confusion with Jupiter’s synchrotron as the spacecraft is between Jupiter and the satellites, some synchrotron radiation is expected to reflect off the ice or cracks within it, especially at 600 MHz and 1.2 GHz. From our initial analysis, no specular reflection of Jupiter synchrotron radiation is observed on Ganymede and Europa, suggesting a diffusive surface at microwave wavelengths.