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Jovian lightning whistles a new tune

The Juno spacecraft has detected unprecedented numbers of 'whistlers' and 'sferics' in its orbits around Jupiter, both indications of high lightning flash rates in the atmosphere of the gas giant planet.

Jacob Bortnik

Almost forty years ago the Voyager 1 spacecraft performed its first flyby of Jupiter, and detected very low frequency radio emissions called whistlers that were attributed to lightning on the gas giant[1]. Combined with optical images from the dark side of the planet[2] these observations directly confirmed the existence of lightning in the Jovian atmosphere, which had been hypothesized a few years earlier in order to explain the observed abundance of acetylene[3]. Now, the Juno spacecraft is visiting the giant planet and revealing new, and sometimes surprising features of Jovian lightning. Writing in *Nature*, Shannon Brown et al.[4] have measured the high-frequency components of the lightning emissions for the first time, placing new constraints on the speed and nature of the lightning process. In complementary observations reported in *Nature Astronomy*, Ivana Kolmašová et al.[5] have used data from Juno's Waves instrument to compile the largest database of Jovian lightning-generated whistlers to date (larger than all previous whistler compilations combined), consisting of more than 1,600 individual whistler events.

Voyager 1's whistler observations consisted of 167 individual events, with frequencies in the range of ~2–7 kHz and durations of one to a few seconds. Based on these and subsequent (mainly optical) observations made by the two Voyager spacecraft, the Galileo probe, Cassini and New Horizons, a number of characteristics were deduced, among which was that lightning flash rates spanned a range of possible values from 0.0001 to 0.07 flashes per square kilometre per year. A revised and anomalously large value of 40 flashes km^{-2} yr^{-1} was put forward by Scarf et al.[6] soon afterwards, but this was generally considered unrealistic at the time[7,8]. Juno's whistlers were recorded at distances of less than five Jovian radii and are significantly shorter in duration than the whistlers observed by Voyager 1, in the range of several milliseconds to several tens of milliseconds (Fig. 1). This observation could have been expected on theoretical grounds, due to the shorter propagation paths between Juno and the lightning locations as well as the more tenuous plasma in the intervening region, but the observations are an elegant confirmation of the theory, and are the first observations of this kind of 'short-duration' whistler. The expanded whistler database also permits a more accurate estimation of the lightning flash rate, which is calculated at ~1–30 flashes km^{-2} yr^{-1} by Kolmašová et al.[5], depending on the chosen parameters in their model. This result is significantly larger than most previous estimates, is fairly close to the estimates made by Scarf et al.[6] previously considered too large, and is comparable to terrestrial lightning flash rates of ~6 flashes km^{-2} yr^{-1} (ref. [9]).

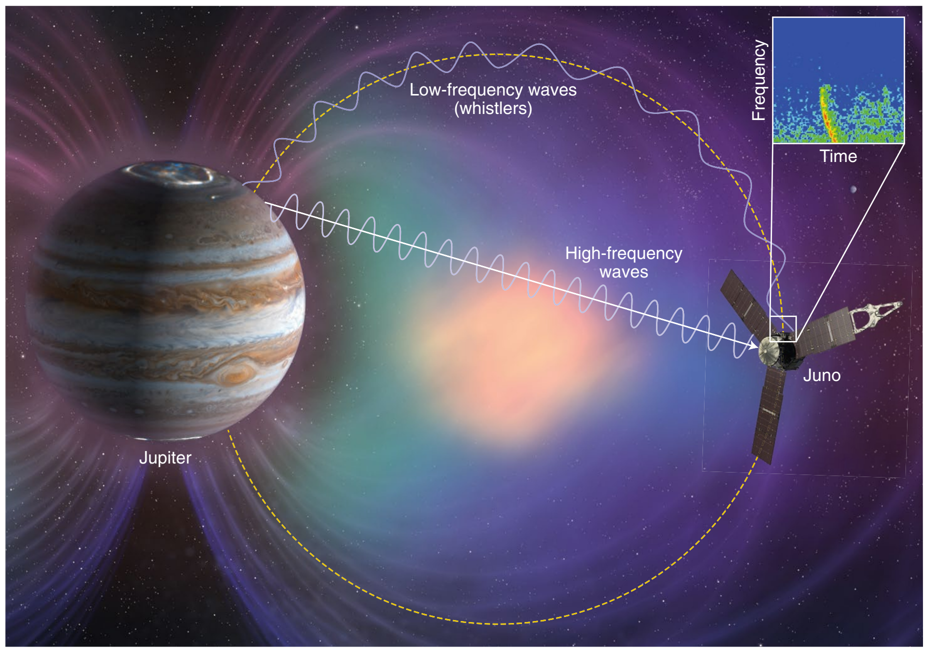

Fig. 1 | The Juno spacecraft detected both high-frequency and low-frequency Jovian whistlers while passing close to the planet. Credit: Background image, Jupiter and Juno image, NASA/JPL; inset reproduced from ref. [5], Macmillan Publishers Ltd

Terrestrial lightning involves the flow of large electrical currents (a few to tens of kiloamperes) over very short timescales (microseconds), which releases a pulse of radio waves spanning the frequency spectrum from a few hertz to several gigahertz, but typically peaking in the range of a few kilohertz. The radio waves can leak out through the ionosphere into the near-Earth space environment where they propagate in one of two basic ways: low-frequency waves (a few to tens of kHz) roughly follow geomagnetic field lines and propagate in the so-called whistler mode, below the electron gyrofrequency. High-frequency waves (>10 MHz) propagate above the plasma frequency in roughly straight paths, unaffected by the plasma in the ionosphere and magnetosphere. A similar physical process is believed to be at work in the Jovian space environment, although the high-frequency component of the lightning spectrum had not been previously observed at Jupiter.

Looking specifically at these higher-frequency components of Jupiter's lightning-generated radio wave spectrum (which the authors call sferics), Brown et al.[4] used Juno's Microwave Radiometer to identify 337 events of the lightning spectra extending to 600 MHz, and a further 12 events extending as high as 1.2 GHz, with the lower number of detections expected due to the rapid roll-off of power as a function of frequency. This is a significant result and comes as a surprise, since Jovian lightning was previously thought to be dominated by low-frequency components[10] and to be much slower than terrestrial lightning. No wave power was observed at frequencies larger than typical whistler frequencies, and hence the duration of the lightning pulse was hypothesized to be a few hundred microseconds long, and much more energetic than terrestrial lightning. In light of these new observations, that hypothesis will need to be reconsidered. Using their database of high-frequency observations, a distribution of estimated lightning locations was plotted by the researchers, showing lightning in both hemispheres (see figure 1 in ref. [4] and figure 2 in ref. [5]), ranging essentially from pole to pole, with a minimum near the equator, hence confirming and extending previous lightning distribution maps.

Lightning at Jupiter is an important topic. Atmospheric convection powered by energy loss from the planet's interior results in storms that contain electrical discharges, and these radiate electromagnetic power into space that can interact with Jupiter's intense radiation belts, contribute to non-thermal dynamic equilibrium chemistry, and have even been implicated in the creation of prebiotic and biotic molecules[11]. Clearly more mysteries remain and the latest studies by Kolmašová et al.[5] and Brown et al.[4] bring us a step closer to understanding these important phenomena. ❐

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