PLANETARY SCIENCE

The Origin of Plasmaspheric Hiss

Observations by the THEMIS spacecraft are providing a better picture of the electromagnetic environment surrounding Earth.

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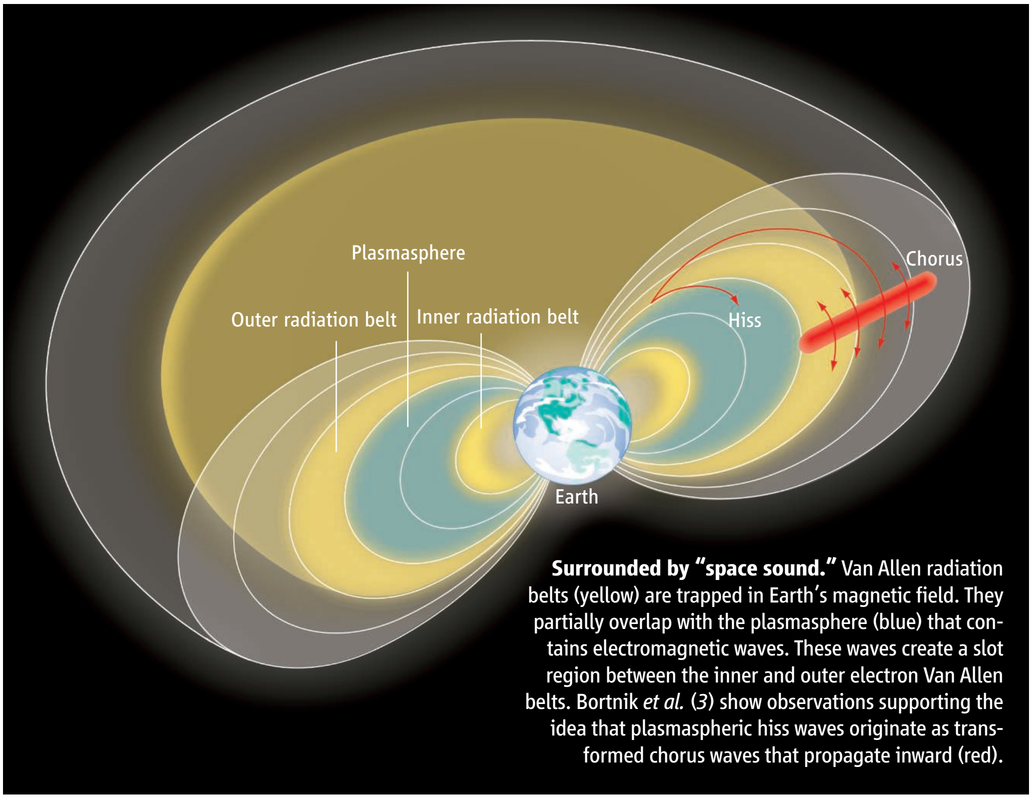
The role of electromagnetic waves in shaping the space environment around our planet has been studied since the early 1960s (*1*, *2*). Initial analysis of these waves at audible frequencies consisted of playing the recorded data through a loudspeaker. The historical terminology in this field thus resembles an experimental musical score where we can encounter whistlers, noise, hiss, and chorus. On page 775 of this issue, Bortnik *et al.* (*3*) invite us to this world of "space sound." On the basis of measurements by NASA's THEMIS (Time History of Events and Macroscale Interactions during Substorms) spacecraft mission, the authors describe two types of natural electromagnetic waves: chorus and plasmaspheric hiss. They show that plasmaspheric hiss can be interpreted as arising from transformed chorus waves, thus providing important clues as to its origin.



Surrounded by "space sound." Van Allen radiation belts (yellow) are trapped in Earth's magnetic field. They partially overlap with the plasmasphere (blue) that contains electromagnetic waves. These waves create a slot region between the inner and outer electron Van Allen belts. Bortnik *et al.* (*3*) show observations supporting the idea that plasmaspheric hiss waves originate as transformed chorus waves that propagate inward (red).

Both chorus and plasmaspheric hiss are attracting attention as key ingredients in modeling the Van Allen radiation belts—regions that contain high-energy particles trapped in Earth's magnetic field (*4*). The Van Allen belts partially overlap with the plasmasphere where co-rotating low-energy plasma is confined (see the figure). This medium creates a bubble of higher refractive index for electromagnetic waves at audible frequencies. These waves are believed to release energetic electrons in the Van Allen belts from the magnetic trap down to Earth's atmosphere (*5*, *6*). As a result, a slot region is created in the area where this interaction takes place, between the inner and outer electron Van Allen radiation belts.

The origin of plasmaspheric hiss has been a puzzle for a long time, with three basic hypotheses having been put forward. The first proposes that hiss is spontaneously amplified from preexisting weak waves, arising thus from free energy of unstable electron populations. However, waves cannot grow to the observed intensities from weak background turbulence under typical conditions—this mechanism requires an unknown "embryonic" source of sufficiently intense waves to initiate the growth (*7*). The second mechanism consists of an accumulation of whistlers (*8*), waves coming from lightning discharges in the atmosphere (*9*). This hypothesis has recently been favored by a statistical study (*10*), but the results and data interpretation have led to a lively discussion (*11*).

The third proposed mechanism (*12*, *13*) explains plasmaspheric hiss as coming from the inward propagation of chorus into the plasmasphere from an outside source located close to the geomagnetic equatorial plane. The problem here is that chorus can sound very different from hiss, being composed of short chirplike tones lasting for a fraction of a second and resembling a sound "of a rookery heard from a distance" (*9*). However, these tones can superpose and merge during their propagation and transform themselves into hiss (see supporting online material).

Bortnik *et al.* use measurements of two THEMIS satellites, fortuitously located at two different positions—one outside the plasmasphere and the other inside. They show a good correlation of enhancements of average chorus intensity with enhancements of plasmaspheric hiss at time scales from several seconds to tens of seconds. The correlation is maximum at a time delay that corresponds to the expected propagation time. This is exciting evidence in favor of the inward propagation of chorus scenario. In fact, chorus appears in a double role in this story. First, intense chorus is considered to act as local accelerator of energetic electrons to high energies (*14*) in the outer Van Allen belt. Then, after it propagates inward and transforms itself into plasmaspheric hiss, it can act as a destroyer of energetic electrons in the slot region.

The story would thus seem to be concluded, with no mysteries left. But controversies around the origin of plasmaspheric hiss will probably not disappear. Technical problems remain to be solved by adding a third dimension to the ray-tracing simulation; the simulated waves also need to propagate azimuthally

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toward the local evening to explain the observations. But the most important source of controversy could be that Bortnik *et al.* analyze a single data interval, and although the results are convincing in this case, other mechanisms may also be operating at different times. An open question is what percentage of plasmaspheric hiss is generated by each of the different mechanisms. It may well turn out that chorus is a dominant source, but it will take further measurements to determine the relative contributions of the other "voices" to the cacophony of plasmaspheric hiss.

References and Notes

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15. The authors acknowledge support from grants GACR-205/09/1253 and GAAV-IAA301120601.

Supporting Online Material

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10.1126/science.1172878

ARCHAEOLOGY

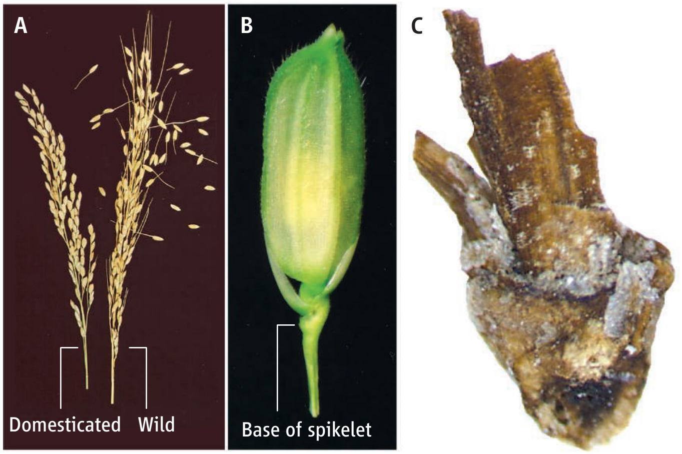
Origins of Agriculture in East Asia

During the initial phase of cereal cultivation in East Asia, domesticated traits emerged only slowly.

Martin K. Jones and Xinyi Liu

Some of the world's most important crops, including rice and soybean, originate from eastern Asia. This region is also the original home of several minor crops, such as buckwheat and certain types of millet. In their search for the earliest farms, archaeologists have been drawn to China's two major river valleys: the Yellow River in the north and the Yangtze River in the south. Grains of broomcorn and foxtail millet have been found in Neolithic farmsteads in the Yellow River region (*1*, *2*), and sites in the Yangtze River region have yielded the world's earliest evidence of harvested rice grains (*3*).

These discoveries contribute to a growing picture of the greatest revolution in human ecological history: the transition from gathering foods from the wild to producing them in farms. The remains of wheat and barley chart a similar story in southwest Asia, as does maize in Central America. It is easy to imagine how momentous this revolutionary transition must have been, to envisage the shockwaves it dispatched through communities. Yet recent research is changing our understanding of the geography and timing of the transition. It may have started out so gradually that individuals immersed in it may have hardly noticed the change.



Toward rice domestication. (**A**) In wild rice (right), the grain head breaks up as soon as the grains within it are fully formed, whereas in domesticated rice (left), grains enclosed in their husks remain attached to the stem. In the latter case, detachment and propagation depend fully on the farmer. (**B**) The natural point of breakage in the grain head is at the base of the spikelet (the dispersal unit of grains enclosed in their husks). The shape of the spikelet base provides direct morphological evidence for domestication. (**C**) This rice spikelet base from the Neolithic site of Tianluoshan in the Lower Yangtze River Valley is of the domesticated type.

CREDIT: PANELS A AND B FROM (8), PANEL C FROM (6)

Improvements in methods for recovering archaeological plant remains have pushed the earliest records for a number of crops back in time (*2*, *4*). Charred rice remains have been found embedded in 10,000-year-old pottery from the Lower Yangtze River region (*5*). Even older are phytoliths (microscopic fragments of intracellular silica) of rice recovered from caves in the Middle Yangtze River region, for example, at Diaotonghuan in levels dated to 12,000 years ago (*3*). However, the morphological traits associated with domesticated rice did not become fixed for another five millennia (*6*). (Fixation refers to a genetic trait that has replaced all others across a population.)

Evidence for the timing of fixation comes from archaeological fragments of the stem and chaff that surrounded the grain (see the first figure). These features provide direct morphological evidence for the genetic changes associated with domestication—in particular, the change from a form that freely disperses in the wild to one whose reproduction depends on the farmer.

In the case of rice, this transformation can be effected by a substitution in a single transcription factor (*7*, *8*). In terms of genetic change, this is a very small step. Yet archaeological rice chaff recovered from the Lower Yangtze indicates that fixation of the resulting trait in rice populations was slow (*6*). Many generations of early farmers were cultivating plots of land by preparing soil and removing weeds long before most plants harvested from those plots showed the morphological traits of domestication. The proportions of harvested plants with or without the domesticated stem trait changed by just a few percent in each human lifetime. What was happening in the rice fields during that long period of pre-domestication cultivation?

Between 9000 and 4500 years ago, in the heartlands of its domestication, rice appears to have been harvested but was not the only plant food; people were also gathering fruits, nuts, and acorns (*6*, *9*). Genetic evidence suggests that the rice they exploited was interbreeding

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