

may have been domesticated some hundreds, or even thousands, of kilometers away from the center of its founder-stock germ plasm. Thus, the location of founder germ plasm stocks without supplemental evidence cannot be used for confident reconstruction of the locale of final domestication.

Increasing archaeobotanical evidence indicates that the beginning of agriculture, as well as of crop domestication, was not necessarily a single event but a process of trial and error. For oats and rye, for example, the beginnings of cultivation and subsequent domestication are separated by millennia and great distances. For the Near East, current data suggest that at least three or four species can be considered as early pioneer crops, which predate the seven well-recognized species of founder crops. Because two of these pioneer species—barley and lentil—belong to the group of founder crops as well, our understanding of the domestication of these species must be revised. In the PPNA, Near Eastern human groups in two regions already possessed and applied agricultural knowledge: In the north, they planted lentil and perhaps rye; and in the south, they raised barley and probably oat, together with imported lentil. Although this early barley and lentil was eventually domesticated in the region, two of the crops raised or gathered there—rye and oats—were abandoned.

The transition to food production in eastern North America shows a notable similarity to the Near East. There, indigenous plants—chenopod (*Chenopodium berlandieri* subsp. *jonesianum*), marsh elder (*Iva annua* var. *macrocarpa*), squash (*Cucurbita pepo* subsp. *ovifera*), and sunflower (*Helianthus annuus* var. *macrocarpus*)—became domesticants under indigenous group management between 5000 and 4000 years before the present. In contrast, the cereal-like erect knotweed (*Polygonum erectum*), little barley (*Hordeum pusillum*), and maygrass (*Phalaris caroliniana*), though clearly of economic importance as cultivated crops by about 2500 to 2200 years before present, never became morphological domesticates. With the shift to maize-centered agriculture about 900 C.E. and the arrival of the common bean (*Phaseolus vulgaris*) several centuries later, local eastern crops became less important, and by 1800 C.E., only sunflower and squash were still being grown (17).

Thus, both in the Near East and early eastern North America, the first stage of agriculture was cultivating annual wild plants; the second stage was cultivating both wild types and domesticants; and the last stage was the cultivation of domesticants alone. Finally, the recent discovery of PPNA fig domestication (18) raises the question of whether, in worldwide locales of agriculture origin, fruit trees were domesticated contemporaneously with the annuals.

References

1. F. Salamini, H. Özkan, A. Brandolini, R. Schäfer-Pregl, W. Martin, *Nat. Rev. Genet.* **3**, 429 (2002).
2. D. Zohary, M. Hopf, *Domestication of Plants in the Old World* (Oxford Science, Oxford, ed. 3, 2000).
3. M. Kislev, *Isr. J. Bot.* **50**, 585 (2002).
4. Y. Garfinkel, M. Kislev, D. Zohary, *Isr. J. Bot.* **37**, 49 (1988).
5. W. van Zeist, J. A. H. Bakker-Heeres, *Palaeohistoria* **26**, 151 (1984).
6. S. Colledge, in *The Origins of Agriculture and Crop Domestication of Crop Plants in the Near East*, A. B. Damania et al., Eds. (FAO/IPGRI/GRCP/ICARDA, Aleppo, Syria, 1998).
7. A. Hartmann, unpublished data.
8. A. Badr et al., *Mol. Biol. Evol.* **17**, 499 (2000).
9. M. E. Kislev, in *An Early Neolithic Village in the Jordan Valley, Part 1, The Archaeology of Netiv Hagdud*, O. Bar-Yosef, A. Gopher, Eds. (Peabody Museum of Archaeology and Ethnology, Harvard Univ., Cambridge, MA, 1997), pp. 209–236.
10. G. C. Hillman et al., *Holocene* **11**, 383 (2001).
11. G. C. Hillman, *Anatolian Stud.* **28**, 157 (1978).
12. K.-E. Behre, *Veg. Hist. Archaeobot.* **1**, 141 (1992).
13. G. Willcox, *Veg. Hist. Archaeobot.* **11**, 55 (2002).
14. G. Ladizinsky, *Econ. Bot.* **41**, 60 (1987).
15. G. Ladizinsky, *Genet. Resour. Crop Evol.* **46**, 115 (1999).
16. J. Yellin, in *An Early Neolithic Village in the Jordan Valley, Part 1, The Archaeology of Netiv Hagdud*, O. Bar-Yosef, A. Gopher, Eds. (Peabody Museum of Archaeology and Ethnology, Harvard Univ., Cambridge, MA, 1997), pp. 193–196.
17. B. D. Smith, *Rivers of Change* (Univ. of Alabama Press, Tuscaloosa, AL, ed. 3, 2006).
18. M. E. Kislev, A. Hartmann, O. Bar-Yosef, *Science* **312**, 1372 (2006).

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ASTRONOMY

A Key Molecular Ion in the Universe and in the Laboratory

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The molecular ion H_3^+ is abundant in interstellar clouds and presents many interesting puzzles in the laboratory. A recent conference explored the current knowledge about this species and its implications for astrophysics.

The protonated hydrogen molecule, H_3^+ is the most abundant molecular ion in the universe and plays a pivotal role in interstellar chemistry. As the simplest of all polyatomic molecules, H_3^+ is fascinating to both physicists and chemists, but lately research in astronomy has been an important driver of both laboratory work and theory. Interstellar clouds are almost entirely molecular hydrogen, and anything that causes ionization of H_2 in them should lead to the production of H_3^+ . On 16 to 18 January 2006, researchers from different fields in which H_3^+ plays a major role met in London, at the Royal Society and at University College London, to discuss this fundamental molecular ion from a variety of perspectives. A similar meeting on H_3^+ took place in 2000, but since then many exciting developments related to this ion and its deuterated species, both in the laboratory and in space, made a new discussion meeting a necessity.

H_3^+ was discovered in 1911 by J. J. Thomson (1). First observed as an “evanescent” trace product of a discharge in H_2 , its abundance was soon found to exceed that of both H^+ and H_2^+ in most hydrogen plasmas, demonstrating both its ease of formation and stability. It was realized that H_3^+ was being formed by the efficient reaction, $H_2^+ + H_2 \rightarrow$

$H_3^+ + H$ (2). H_3^+ is highly reactive, happily donating a proton to almost every atom and molecule it encounters. In astrophysical environments, the principal seed is cosmic rays, which, as they traverse interstellar clouds, leave trails of H_2^+ ions in their wakes, which are rapidly converted to H_3^+ by the aforementioned reaction. The importance of H_3^+ for interstellar chemistry was recognized in 1973 in two seminal papers (3, 4), both of which demonstrated that H_3^+ is the base of a tree of ion-molecule reactions that produce many of the molecules found in space.

Although the presence of H_3^+ in dense clouds could be inferred, direct detection of H_3^+ proved to be elusive. The only method of observing the molecule in space is via the v_2 vibration-rotation band whose fundamental occurs near a wavelength of 4 μm . This spectrum was observed in the laboratory in 1980 (5). It took 16 additional years before H_3^+ was detected in interstellar space (6).

The 2000 Discussion Meeting took place less than 4 years after this detection, and roughly a decade after the ion had been found in the aurorae of Jupiter, Saturn, and Uranus (7–9). At that time it was already clear that there was a problem in understanding the interstellar data. Although the abundance of H_3^+ in dense clouds was roughly as expected, it was more than an order of magnitude higher than predicted in diffuse clouds where abundant electrons destroy H_3^+ (10). That difference has only become more striking in subse-

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