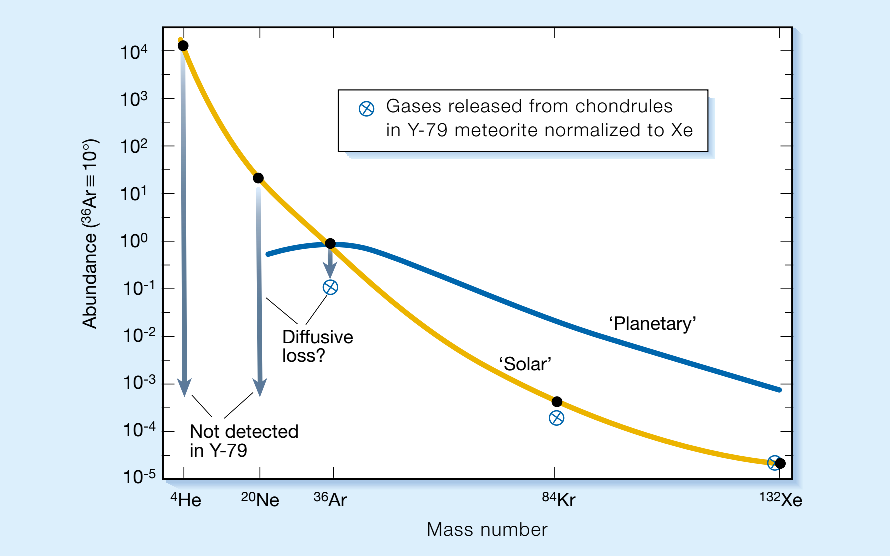

Figure 1 **Solar and planetary patterns of rare-gas abundances (modified from Wasson[4]). The 'solar' pattern arises when solar-wind particles are captured in the surface layer of lunar grains. The 'planetary' pattern resembles that of the terrestrial atmosphere. The rare gases found by Okazaki *et al.*[1] in chondrules of the Yamato-791790 enstatite meteorite are close to the solar pattern for argon, krypton and xenon. The lack of neon and helium and the slight depletion in argon (relative to krypton and xenon) are likely to be due to diffusion processes at high temperatures that preferentially remove light rare gases. The unexpected discovery of noble gases in these chondrules has implications for models of chondrule formation.**

depleted, and the heaviest gases are intact. The most common process to produce a mass-dependent loss of gases is thermal diffusion, which preferentially allows the light gases to escape. So the most plausible interpretation of the pattern of noble gases found in Y-79, as Okazaki *et al.* suggest, is that rare gases were implanted when the chondrules were exposed to the solar wind, but the lighter elements were subsequently lost through diffusion. For this to occur, the chondrules must have been heated to high temperatures.

If this explanation is correct then it offers interesting clues to the nature of the flash heating event that produced the chondrules in the first place. The origin of this heating is a century-old mystery. During their early formative years, stars like the Sun are surrounded by an accretion disk of gas and dust (the disk for our own planetary system is called the solar nebula) that adds directly to the growth of the young star. This period of growth is characterized by a very active Sun and hence a strong solar wind. But solar-wind implantation of rare gases on the surfaces of asteroids could not have taken place until the solar nebula had been dissipated (either blown away or condensed into planets). Otherwise, the asteroid belt would have been shielded from the solar wind because energetic particles cannot penetrate very far through the solar nebula.

The lack of rare gases in the matrix between the chondrules in Y-79 suggests that exposure of the chondrules to the solar wind took place before they coalesced to form larger aggregates and eventually asteroids. So these chondrules captured the solar wind at an earlier time than is possible for the fine-grained material that was exposed after the asteroids were assembled. Moreover, to be exposed to the solar wind at this earlier epoch, the chondrules in Y-79 had to be located near or outside the surface of the solar nebula. So this new result does not support models of chondrule formation that suggest they formed in the highly shielded mid-plane of the accretion disk, at distances corresponding to the current position of the asteroid belt.

In an alternative theory, known as the X-wind model[3], the interaction of the accretion disk with the young Sun's magnetic field produced flares of highly energetic particles, which may have been responsible for the initial flash heating of the chondrules. In this model, chondrules were generated near the inner edge of the accretion disk where the temperatures were high and the young solar wind was strong. The solar type of rare gases found in the chondrules of Y-79 are so readily explained by the X-wind model that it is a puzzle why so few of these gas-rich chondrules have been found. No doubt some meteoriticists will now be looking more closely. ■

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Daedalus

Neutrinos in orbit

The neutrino telescope, essentially 100,000 gallons of cleaning fluid at the bottom of a gold mine, arouses Daedalus's strong admiration: he would so like to have invented something like that himself. He now wants to make it directional, like a normal telescope. He plans a tube many metres long, underground as before, and full of dry-cleaning fluid, or another particle-detecting liquid. Only in the direction of the steerable tube, when neutrinos traverse it from end to end, is it at all sensitive. Several parallel tubes even permit energy-dispersion studies.

Solar neutrinos do not quite ignore the Sun and planets. Unlike photons, they are now known to have mass. They must be slowed by solid objects, perhaps even down to Solar or planetary orbital speeds. They could even be deviated by asymmetric encounters with matter, and so enter orbit. There could be quite a lot of neutrinos in nearby space, slowed by deep encounters with Mercury, Venus, the Sun, Earth and the Moon. They will be orbiting these solid bodies, entering them with little loss per orbit, and be topped up by new arrivals. Their equilibrium concentration will reflect the deep neutrino absorption of these objects.

Neutrinos slowed and deviated by the Moon, for example, should enter an Earth orbit from which a few of them would penetrate below the surface once per orbit, and traverse the telescope. Neutrinos slowed by the nearer planets but little deviated by them should enter a narrow elliptical Solar orbit. Some of them should traverse the telescope twice per orbit. At the other extreme, they would swing round the outer layers of the Sun, sampling its own neutrino-absorbing and -deviating properties. Daedalus's new telescope will look for these wayward particles. He hopes to calculate those orbits best configured to encounter new orbital neutrinos.

Of course, the neutrino flux of any orbit must carry the 'signature' of the whole of that orbit. Neutrinos deviated by the Moon, and passing through it once per orbit, will have an orbital equilibrium concentration reflecting its deep neutrino-absorbing and -deviating properties. These could be calculated, and would slowly give reliable information about the deep geology of the Moon. Similarly, the deep geology of the planets, and even of the Sun, would gradually become clear. It should reveal how opaque, or how deviating, these bodies are to entering neutrinos.

David Jones