Chaotic Zone Yields Meteorites

For 200 years, astronomers have known that meteorites found on the ground had fallen from the sky. But from where in the sky? The asteroid belt between Mars and Jupiter has seemed a likely source, but theorists could find no likely mechanism that would drive enough asteroid fragments as far inward as the orbit of Earth. Now it appears that the gravity of Jupiter can so disturb the asteroids in one part of the belt that their orbital behavior becomes chaotic and carries them as far as Earth. The mechanism seems to throw material into orbits characteristic of ordinary chondrites, the most common type of meteorite.

The exact spot in the asteroid belt now shown to be a likely meteorite source has long been under close scrutiny. At two and one-half times Earth's distance from the sun, there is an empty gap in the asteroid belt. Particles orbiting at that distance repeatedly feel the tug of Jupiter's gravity at the same point in their orbit when three of their revolutions bring them abreast of Jupiter after one revolution along its larger orbit. The coincidence between the gap and this so-called 3:1 orbital resonance has remained unexplained for more than a century. George Wetherill of the Carnegie Institution of Washington, after studying the orbits of ordinary chondrites that fell to Earth, suggested that the chondrites probably came from a gap, but the only apparent mechanism at the 3:1 resonance, even with an assist from Mars, required 100 million years for the trip. In that time, the smaller asteroids would be smashed to smithereens in the segment of their orbits still in the asteroid belt and the orbits of the survivors would not match those of ordinary chondrites.

Jack Wisdom of the Massachusetts Institute of Technology recently found that chaos can quickly transport material from the 3:1 gap to Earth without help from Mars. Asteroid behavior would be chaotic if an eventual orbit depends sensitively on initial conditions. Under chaotic conditions, two asteroids starting out in nearly identical orbits can end up in wildly different orbits. They obey Newton's laws of motion, but their sensitivity to initial conditions is so great that prediction is impractical.

Wisdom found that Jupiter does indeed induce a relatively broad chaotic zone that coincides with the gap at the 3:1 resonance (*1*). A fragment of any size scattered into this zone might orbit for a million years in apparent placidity only to have its nearly circular orbit suddenly stretched into a long ellipse whose innermost point extends inside the orbit of Mars. Mars could then remove it and any other objects from the gap. But Wisdom had used a computational shortcut that raised doubts in the minds of others. So he did straightforward, brute force numerical integrations to show that the chaotic zone at the 3:1 resonance exists and that rapid shifts in orbital shape do occur there. He also found that in one of five cases a chaotic jump stretched the orbit all the way to the vicinity of Earth (*2*). Thus, chaotic behavior could also deliver meteorites to Earth.

Getting a rock to Earth's orbit once does not ensure that it will become a meteorite. Wetherill (*3*) used a Monte Carlo simulation to evaluate the effect of several other processes, such as close encounters with planets and fragmentation, on the eventual fate of a rock supplied by the chaotic zone. Two-thirds of the resulting meteorites would have orbits that would cause them to fall to Earth during the afternoon, as is the case with ordinary chondrites, and the amount predicted to fall fits the observed amount within the errors. In a preliminary search, Wetherill cannot find any other resonances that would work the way the 3:1 resonance does.

The case for the 3:1 resonance is strong, but Wisdom must now show that not just one but all chaotic orbits become Earth-crossing within a few million years. There is also the problem that many spectroscopists do not find asteroids near the gap that resemble chondrites. That matter may be resolved if, as hoped, the Galileo spacecraft passes the asteroid Amphitrite near the 3:1 resonance on its way to Jupiter.—**RICHARD A. KERR**

References

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The galactic nucleus turns out to be an exceedingly complex place; features include a series of looping magnetic field lines that resemble nothing so much as a solar flare expanded to the scale of a galaxy; a fragmented structure that looks like a spiral but is probably a disk some 5 light-years out from the center; an abundance of red supergiant stars; and a compact radio source, first observed in 1974, right at the galactic center.

In the midst of all these other fireworks the compact source itself is relatively faint and difficult to study. Even with very long baseline interferometry, which produces ultrahigh resolution images by combining the signals from widely spaced radio telescopes, nothing much can be seen except a circular blob. For years, observers could only set an upper size limit.

Now, however, Lo and his colleagues have used more sensitive receivers and higher frequencies to cut the previous size limits by a factor of 7, to 20 astronomical units. Moreover, they have found the first suggestions of structure in the source: it seems to be slightly elongated in a direction about 8 degrees from the galaxy's axis of rotation.

This new upper limit on the size makes it harder than ever to imagine a plausible alternative to the black hole model. In principle the source might be, say, a cluster of hot young stars. But 20 astronomical units is about the size of the orbit of Saturn; how could enough stars be crammed into such a small space? On the other hand, 20 astronomical units is also about the size of the emission region one would expect from gas and dust falling into a modest-sized black hole. (Other evidence suggests that the Milky Way's black hole, if it exists at all, is only about 5 million solar masses.) Moreover, the elongation is reminiscent of the jet structures seen in other active galaxies, where rotating holes seem to be squirting out material along their axes.

The possibility of a central black hole in the Milky Way thus seems stronger than ever. However, the researchers are careful to point out that they do not yet have detailed maps of the source, and in particular, that the observed elongation is very slight and needs to be confirmed. The real proof will probably have to await the Very Long Baseline Array of radio telescopes now under construction by the National Science Foundation.

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References

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