L17 Meteorites < asteroids, meteoroids; clues to the age of the solar system >

> It usually ends with laughter and a delight in the futility of trying to understand what this atom in the universe is, this thing–atoms with curiosity–that looks at itself and wonders why it wonders. —Feynman.[5]

Meteoroids heated to incandescence during their passage through the atmosphere are called *shooting stars*. Their photographed trajectories show that almost all are *asteroids* (which means "starlike," and this misnomer is because when Guiseppi Piazzi in1801, guided in his search by nomistic Bodes's Law, found the first, Ceres, his telescopes could only image it as a point, not a disk). Asteroids are small, cold, solid bodies, that orbit mostly between Mars and Jupiter. Any will fall to Earth when its orbit about Sun has chanced to bring it close enough. Those that impact Earth's surface are called *meteorites*. The infall totals some 1,000 tons per year (but, given Earth's enormous surface area, startling only were it to arrive all at once in your backyard).[6]

Cosmic-ray particles that injected themselves into meteoroids show by their count that most meteorites (fallen-to-Earth rocks) have been exposed asteroids for a mere tens of millions of years. The only candidate for the process that newly creates such is collision fragmentation of older asteroids. Discounting Ceres (diameter a quarter the measure of Moon's, and held to the shape of a sphere by its own gravitation), corroboration is that large irregular-shaped asteroids as 6 Hebe, 4 Vesta, and 8 Flora, are associated with swarms of small asteroids (total some 66 million). In the 1980s, zones within the asteroid belt were identified to be where the gravity of Jupiter and Saturn can perturbate the ellipticity of an asteroid's orbit so that it comes to intersect the orbits of the inner planets. Asteroids from throughout the inner half of the main asteroid belt, can be pushed into those regions by sunlight that, unevenly absorbed and reradiated, causes small rotating asteroids to spin up (the smallest thereby disintegrate)[7] and also move into higher orbits.[8] This Yarkovsky effect, named for the Polish engineer I. O. Yarkovsky who first described the phenomenon ca.1900 in a pamphlet (lost after 1909 but in 1951 Ernst J. Öpik (1893-1985) recalled its gist),[9] can move asteroids with diameters less than 20 km by kilometers in 1 to 10 million years.

In 1989, a quarter-mile (0.4 km) wide asteroid missed Earth (***Footnote L17.1***, page 675) by just 400,000 miles (640,000 km) and Earth passed the same point in space just six hours later. A kilometer-wide asteroid called *Hermes* passed within 800,000 km of Earth in 1937 and, as Lutz Schrnadel and Joachim Schubart predicted in 2001, it turned up again in 2003 (and missed us by 3,000,000 km).[10] Asteroids are rocks as the *Shoemaker* spacecraft NEAR Orbit Around Asteroid 433 Eros study was able to prove. Also, giving the lie to spectrographic analysis of this, and generalizations to other, so-called "igneously differentiated" S-type (i.e. spinning irregular shaped) asteroids, 433 Eros is a uniformly bland, ordinary, chondrite.[11]

Earth (average orbital velocity, 29.78 km/s) and meteoroid intersecting orbits have vector-sum velocities of 70 km/s for the head-on, to 19 km/s for the catchup sideswiping majority (slow speed strongly favors survivability as meteorites). Atmosphere-friction heating of meteoroid surfaces is to incandescent-vapor temperature of 1,650 °C. Small meteoroids vaporize completely as shooting stars. Boulder-sized meteoroids that survive as meteorites are found buried commonly at the bottom of craters 2 m in diameter. Meteoroids >30-50 m in diameter,[12] explosively impact-vaporize on ground. They are called *bolides*. Since 1969, about 3,000 meteorites (37,000 fragments of which were listed by 2004) are chance finds from Antarctica. There, meteorites plunged into the ice occur exhumed and concentrated where wind-ablated blue-ice streams slow on approach and leaving topographic barriers over which they flow (as before the Transantartic Mts., and as after Frontier Mt., an 8-km-long granitic ridge in Northern Victoria Land).[13]

Meteorites are made of materials that record a wide range of temperatures of formation: high temperature silicates (olivine, pyroxene); rapidly cooled droplets (silicate glasses) called *chondrules*; and, slowly cooled iron and nickel alloys.

93% of meteorites are **stony**. These are of three types:

Ordinary chondrites are made of high temperature silicates and contain some chondrules.

Carbonaceous chondrites have the same general composition as ordinary chondrites but about 5% of their volume is made of organic compounds, which include inorganically produced amino-acids, and they have a high volatile content, which indicates a low temperature of formation. In 2001, George Cooper reported the presence of trace concentrations (in the Murchison and Murray meteorites) of other key components of RNA, DNA, and cell membranes: simple sugars, sugar acids (including dihydroxyacetone), and sugar alcohols (including glycerols) with Carbon-13 to Carbon-12 ratios that indicate extraterrestrial sources (so are not contaminates).[14]

Achondrites have the composition of basalts and have an impact brecciated texture. As their name stipulates, they do not contain chondrules.

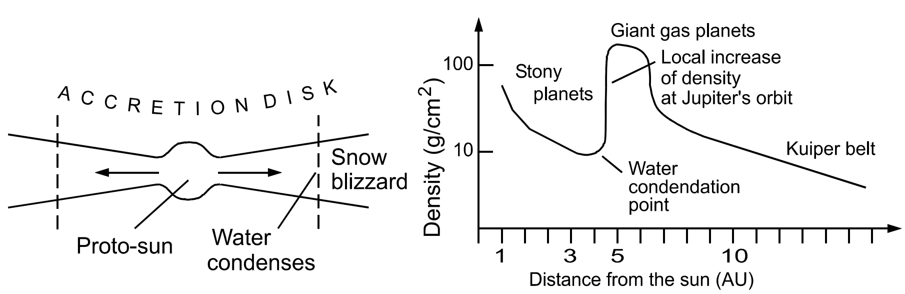
6% of meteorites are **irons**. These are entirely composed of coarsely crystalline Widmanstätten pattern of intergrowths of two varieties of iron that are alloyed with small amounts of nickel. Their composition and texture indicate that from a molten state they cooled at a rate of ~1ºC per million years. This is evidence that they were originally deep in large condensed bodies. They are considered to be fragments of the solidified core of large differentiated and subsequently collision-disrupted asteroids.

1% of meteorites are **stony-irons** that are made of nearly equal amounts of silicate minerals and iron-nickel alloy. They are considered to be fragments of the core-mantle boundary zone of large differentiated, and subsequently collision disrupted, asteroids.

The oldest materials in meteorites are refractory *calcium and aluminum-rich inclusions* (CAIs) in chondrules. Significantly, CAIs have an excess of ^{26}Mg compared to this isotope in the chondrules that condensed later to contain them. The excess is explained by Gerald Joseph Wasserburg in 1995 as being radioactive ^{26}Al at the time the CAIs solidified for its abundance follows that of stable ^{27}Al in sampled CAIs. The half-life of ^{26}Al is a scant 0.7 My.[15] "Live" ^{26}Al in the CAIs implies that they formed when dust and gas was triggered (by compression) to begin its gravitational collapse into the solar system. Its inception, defined as the absolute age of CAIs, being 4.5672 ±0.0006 Ga (as obtained by Yuri Amelin in 2002 from the Efremovka meteorite). One older described in 2010 dates to 4.5682 Ga.[16] The trigger could have been a shockwave from a supernova explosion which also injected a potpourri of star made isotopes including ^{26}Al torn from a nearby red-giant star.[17]

And yes, we are made of star dust (or of thermonuclear waste, as some wag has put it).[18] ❑

Figure L20.1 [1] In the vacuum of space, a rotating sphere of gas and solids can gravitationally collapse axially into a turning disk and spinning core. In the process, angular momentum creeps outward while disk material moves inward along the equatorial plane to either feed the core or form other orbiting condensed bodies around the core.[2] Earth's accretion during the Early Hadean at 1 AU from proto-Sun, would have been from dry materials. This neat vision has been compromised ever since 1995 when, orbiting Sun-like star 51 Pegasi, the first agreed-to extrasolar planet found is with half the mass of Jupiter and orbits closer than does Mercury about Sun. Our solar system is atypical of the many other star systems now described.[3] "Every sort of star we've looked at has a planet of some sort," notes Alan Boss: "Planetary systems are not rare oddballs. They really are quite common."[4]



Kuiper-belt watery bodies (comets when in near-Sun visits) have sooty-black surfaces (indicating coatings of amorphous carbon, iron-bearing minerals, and some quantity of complex-organic compounds. Organic molecules tend to impart red coloration to a planetary surface.[5]