

# Asteroids and Aliens

Steven J. Ostro

Jet Propulsion Laboratory, California Institute of Technology  
300-233, Pasadena, CA 91109-8099  
[ostro@reason.jpl.nasa.gov](mailto:ostro@reason.jpl.nasa.gov)

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Discussion of extraterrestrial life (ETL) and extraterrestrial intelligent life (ETI) is extraordinarily complex and multidisciplinary, in part because relevant questions involve both the origin/evolution of terrestrial life and the future of human civilization. The recent discovery that our planet exists in an asteroid swarm has altered ideas about the past and future evolution of life and hence about extraterrestrial civilizations, and also raises policy-making questions. The purpose of this paper is to touch briefly on these topics, in order to elicit perspectives from political scientists that undoubtedly will differ from those of astronomers like myself.

For many people, asteroids and aliens constitute parallel foci of anxieties about the physical universe. Of course, awe of the night sky has deep roots in the human psyche. Recognition by our primitive ancestors of patterns of variability in the sky (the seasons, lunar phases, the motions of the naked-eye planets) can be thought of as a milestone in the rise of human intelligence. Whereas the sun, moon and planets long ago became steady players in diverse mythologies, absolutely unpredictable celestial phenomena like bright comets and supernovae, as well as very rare (but now predictable) phenomena like total solar eclipses and multi-planet conjunctions (perhaps including the Star of Bethlehem), portentously violated the patterns. Meteorites are ET rocks whose falls to Earth were widely perceived as the actions of God or gods, at least until reports of rocks falling from the sky were finally accepted as valid by mainstream scientists two centuries ago (Burke 1986). Falls of small rocks are common and rarely dangerous. However, as discussed below, the relatively infrequent impacts by large objects can be destructive, and it has recently been suggested that large impacts may have instigated major redirections in human history (Clube and Napier 1990, Peiser *et al.* 1998).

The rise of modern science in the 19th century explained away most of the mystery of comet appearances and meteorite strikes, leaving a psychological gap that has been filled by aliens/ETI via science fiction and speculative science. Today, two of the great space-related questions are: "Will a Rock from the Sky Wipe Us All Out?" and "Are We Alone?" The current answer to the first question is that the statistical probability of such an event happening during the next century is one in a few thousand, but telescopic searches now underway will either lower that probability dramatically or, much less likely, find a threatening object. The current answer to the second question is that we have no idea if extraterrestrial intelligence exists, or what the probability of success of any given astronomical search program (SETI) might be. One of my goals here is to suggest ways in which these two questions are coupled.

Most of the objects in the solar system are small bodies: the main belt of asteroids between Mars and Jupiter, the Kuiper belt of comets beyond the orbit of Neptune, and the Oort cloud of comets that extends perhaps a thousand times further. These primary populations all feed objects into the inner solar system, occasionally on orbits that can intersect that of the Earth. Long-period comets (LPCs) come from the Oort cloud, short-period comets (SPCs) from the Kuiper belt, and near-Earth asteroids (NEAs) from the main belt, although some 10% of NEAs may be "extinct" SPCs whose near-surface volatiles have been depleted by repeated exposures to the sun's heat. The distinction between asteroids and comets is observational -- an "asteroid" looks starlike through a telescope, while a "comet" looks fuzzy because of the glowing gaseous atmosphere surrounding it -- and often arbitrary, since outgassing depends on proximity to the sun, some comets "become" asteroids and vice versa. If we had telescopes able to see comets beyond the orbit of Neptune, they would look asteroidal.

NEAs were unknown a century ago, but this population constitutes the major source of potentially threatening objects as well as the most serious source of current uncertainty about the "background" collision risk, that is, the risk due to undiscovered objects. Whereas only a few hundred NEAs have been discovered, analyses of search success rates, accidental rediscovery rates, and lunar crater statistics concur that the NEA swarm probably contains some 1500 objects larger than a kilometer and a few hundred thousand larger than 100 meters; the numbers grow exponentially with decreasing size. The NEA abundance has been in a steady state for several billion years, with depletion of objects by collisions and gravitational effects approximately matching the influx of new objects.

The threshold for global, civilization-threatening effects likely to kill over a billion people is an impact energy,  $E = 10^5$  to  $10^6$  Mt, where 1 Mt is roughly 60 Hiroshima bombs, corresponding to the impact of an object of diameter between 1 and 3 km. Such events occur on a time scale (i.e., average interval) of a few hundred thousand years (Chapman and Morrison 1993, Toon *et al.* 1997). Much lower-energy impacts ( $E = 10^4$  to  $10^5$  Mt, projectile size  $\sim 500$  m, interval  $\sim 60,000$  years) into an ocean could raise tsunamis projected to kill up to 1% of the world's population. Much higher-energy impacts ( $E > 10^7$  Mt, projectile size  $\sim 10$  km, interval  $> 20$  million years) can cause mass extinctions. The high-energy tail of the asteroid/comet collision hazard is uniquely low-probability and high-consequence, and raises unique policy problems (Gerrard and Barber 1997).

Impacts early in Earth's history may have played a role in the origin of life, both in preventing its "permanent" establishment during the post-accretional heavy bombardment and in delivery of volatiles and prebiotic organic molecules. Our Moon, which is thought to have formed by the impact of a Mars-sized planetesimal into the proto-Earth, has prevented fluctuations in Earth's obliquity that would have destabilized the climate and short circuited evolution. High-energy impacts are thought to have caused at least some, if not most, of Earth's mass extinctions and may have increased the rate of evolution. More frequent, lower-energy impacts may have catalyzed the evolution of biological diversity between mass extinction events. Ostro and Sagan (1998; see also Ostro 1987) conjecture that

"Earth's rich and complex history of asteroid/comet collisions has accelerated the appearance of intelligent life on our planet, and that the time scale for the evolution of life and the emergence of extraterrestrial technological civilizations depends on the distribution and dynamics of small bodies left over from planet formation. Large impact fluxes might increase the rate of evolution, whereas too high a flux clearly would be inimical to the development of civilization. Conversely, too low a flux might forestall the appearance of intelligent life. In any event, for our single available sample of a technological civilization, the same interplanetary collision flux that may have been instrumental in its creation also constitutes a definite threat to its long-term existence."

The so-called Spaceguard Survey has just begun to inventory potentially civilization-threatening ( $> 1$ -km-diameter) NEAs. At the current discovery rate, the survey will be finished in a century, but it would not be very challenging or costly ( $< \$40$ M) to complete the survey within a decade. In any event, the odds are about 1000 to 1 that no discovered object will be

found to threaten collision during the next century. At that point, the background hazard from undiscovered NEAs will be negligible compared to that from undiscovered LPCs.

The odds of a very-long-period comet (LPC) collision in a millennium are similar to odds of an equally energetic asteroid collision in a century, but dealing with the LPC component of the impact hazard is orders of magnitude more challenging. Reconnaissance is intrinsically much more difficult than for NEAs, so deflection or destruction would require more exotic weaponry and very much longer warning times. However, we cannot detect LPCs much more than a few months before their arrival, because coma-producing evaporation of volatiles by insolation doesn't turn on until a comet gets within about Jupiter's distance from the Sun, because inactive nuclei far beyond that distance are too dim for telescopic detection, and because LPC motion against the star background is inconspicuous.

The LPC hazard is unique: the a priori probability is extremely small (~1/30,000 per century), but mitigation would be impossible without enormous expenditure of resources, even if the warning time were ten times longer than is likely. Future technological advances eventually will increase the warning time and may make dealing with the LPC hazard less intractable than it now seems, but I think the time scale for mitigation of the LPC hazard to become within reach (and for opportunity costs to become acceptable; Rubin 1978) may be at least several centuries. Sooner or later, we will have to become spacefaring or we will become extinct.

It seems plausible to me that the LPC hazard is so formidable that human civilization may never deal with it adequately. As noted by Ostro and Sagan, time scales associated with the collision hazard on other intelligent-life-bearing planets (if they exist) may be very different from ours. Nonetheless, the collision hazard may be a nearly universal longevity-limiting factor. On the other hand, at least for us, many other longevity-limiting factors act on time scales that are tiny compared to the approximately 3-million-year average interval between civilization threatening LPC impacts. Moreover, a spacefaring civilization that dispersed to multiple colonies independent of Earth could avoid ever having to deal directly with LPCs.

Over much shorter time scales, namely the next century, the existence of Earth-approaching objects is most likely to have positive implications. The current cost of launching something from the ground to low-Earth orbit (LEO) is several thousand dollars per pound. The cost of retrieving mass from NEAs is, for some 10% of the population, two to three orders of magnitude cheaper, because their orbit geometry and low mass make the cost of round-trip missions to them energetically very easy compared to missions to the moon, Mars, or the moons of Mars. Asteroid minerals include hydrated silicates, complex organics, and nickel-iron alloy. Recent experiments suggest that carbonaceous asteroids can sustain soil microbial activity and provide essential macronutrients for future space-based ecosystems (Mautner *et al.* 1997, 1999). Therefore, NEAs have commercial potential as sources of protective shielding, life-support (water, oxygen, biomass), fuel (hydrogen, oxygen, hydrocarbons) and construction materials.

Of course, establishing a minimal infrastructure for extracting and retrieving space resources will require some large-scale, high-risk investment to prove profitable. The first private spacecraft targeted beyond the Earth-Moon system may be the SpaceDev, Inc., Near-Earth Asteroid Prospector (<http://www.SPACEDEV.com/NEAP/NEAP.html>). NEAP, which

will be commercially financed with no government subsidies, will rendezvous with a very accessible NEA, land one or more modules on it, and claim ownership of the object, setting a precedent for assertion of private property rights in space (Sterns *et al.* 1997a). Oberg (1998) has suggested that NEAs resources will inevitably be of military interest:

"And perhaps these asteroids' greatest resource -- one which military space planners half a century from now should be very interested in -- is simply the slag and dirt left over from mining. This material would provide shielding -- against impacts, against radiation, against visual inspection -- for otherwise-vulnerable space-based systems. Such mini-Gibraltars in high orbit could become the literal "high ground" that space strategists have so far sought in vain."

By the end of the 21st century, commercial exploitation of asteroid resources may have matured to the point that asteroid orbit modification becomes routine. First pieces of asteroids will be retrieved (to LEO or to geosynchronous Earth orbit, high Earth orbit, or an Earth-Moon Lagrangian point), then entire several-decameter objects like 1998 KY26 (Ostro *et al.* 1999) and eventually much larger objects. Orbit modification is the preferred way to deal with NEAs on collision trajectories when warning times are long enough, so experience with transporting asteroids ultimately will be useful when an asteroid is found to threaten collision with Earth. The likelihood of this happening during the next few centuries is of order 1/1000. Nonetheless, it has been argued that deflection experiments should be undertaken soon (Teller 1992). However, with a launch-ready deflection system, it would not be difficult to redirect a harmless large asteroid into collision course with the Earth (Harris *et al.* 1994), so such technology is a double-edged sword. Industrial-scale manipulation of asteroid orbits for any purpose would add a new, man-made dimension to the impact hazard (Sagan and Ostro 1994a,b).

The economic realities of life support in space dictates that if we choose to establish "permanent" human outposts in space, we will take advantage of NEAs, hollowing them out to use as space habitats shielded from cosmic radiation and micrometeor bombardment, using their rock as potting soil to grow food, distilling some of the soil to extract water, and using the metal-rich slag residue for construction. That is, we will assimilate a subset of NEAs. Self-sufficient human colonies living off NEA resources may be only a century away.

The first generation born in such colonies, perhaps the first true extraterrestrials, will be asteroid people. Exhaustive reproduction experiments on mammals with very short gestation periods and lifetimes surely will be tried first, perhaps in conjunction with genetic alteration experiments designed to identify markers for survival in zero/low-gravity. Genetic engineering of humans for resistance to disease and mortality may be within our grasp before long (e.g., Lee *et al.* 1999). If so, laboratory (as opposed to natural) selection of a genome optimized for space survival may not be very difficult.

If human expansion into space is to happen, the material resources of the main asteroid belt, which dwarf those of the NEA swarm, will be the cost-effective means to sustaining it (Lewis 1998). Interestingly, it has been suggested (Papagiannis 1978) that colonization of the main asteroid belt by aliens might answer the question, "If ETI is sufficiently common, then

unless no ETI has ever undertaken interstellar migration, physical evidence for ETI should exist in the solar system, so where are they?" [This paraphrase of a question asked by Enrico Fermi at a dinner party at Los Alamos during the Manhattan Project has been central in many debates about ETI since Hart (1975) argued, essentially, that "They are not here because they do not exist." See also Brin (1983), Regis (1985), and Zuckerman and Hart (1995).]

Prospects for finding ETI in the main belt may seem far-fetched, but remnants of past ETL may well exist among the asteroids. Meteorites are NEAs intercepted nondestructively by Earth. It has been claimed that the Antarctic meteorite ALH 84001, which is known (on the basis of isotope ratios) to be a piece of Mars, contains chemical signatures and even microfossils of ancient Martian organisms (McKay *et al.* 1996). Whereas the validity of that claim has been questioned (e.g., Bradley *et al.* 1998), its plausibility has not. In any event, some 1/1000 of our meteorites are Martian, so a comparable fraction may apply to the NEA population. Mars samples are of exceptional value, scientifically and otherwise: Pieces of Martian meteorites are priced at up to \$70,000 per ounce (<http://www.scibid.com/MET-0030.htm>), NASA's Mars Sample Return spacecraft will retrieve material at a cost of at least \$25,000,000 per ounce (S. Squyres, pers. comm.).

McKay *et al.* (1996) is the only the most recent in a colorful history (Pillinger and Pillinger 1997) of purported discoveries of fossilized ETL in meteorites, dating to at least 1880. So far, no such claim has proven convincing. Nor have much more exotic arguments, primarily by two prominent physicists, that Earth's pathogenic viruses and bacteria originated in comets (Hoyle and Wickramasinghe 1979) and are a prime component of interstellar dust, and moreover that terrestrial life originated as organisms that have spread via dust throughout the Galaxy [e.g., Wickramasinghe, N. C., F. Hoyle (1998); this is a version of Arrhenius (1907) panspermia hypothesis]. As far as I know, those authors have yet to embrace the speculation (Yokoo and Oshima 1979) that micro-organisms' genomes might be messages from ETI.

Amino acids and nucleic acids, chain polymers of which constitute proteins and DNA, have been found in carbonaceous meteorites, but no chains of those components and no trace of any other sort of biogenic, much less pathogenic, ET material has ever been identified in a meteorite. The stringent quarantines on any samples returned from asteroids, comets, or Mars (de Vincenzi *et al.* 1998, Sterns and Tennen 1997b) hardly seem necessary given the natural influx of meteoritic debris: Several tons of material, the small-particle tail of the NEA size distribution, falls to Earth each day. We may or may not be alone, but as far as we know, rocks and dust are the only alien entities that have ever contacted our planet.

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