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MINOR SATELLITES AND THE GASPRA ENCOUNTER

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Abstract. Observational evidence, especially from occultations and radar, indicate that satellites of minor planets are numerous and commonplace. This leads to the prediction that the Galileo spacecraft will find many such "minor satellites" at the upcoming close encounter with minor planet 951 Gaspra.[1] If such objects are found, this argues strongly against the current theory of minor planet origin from the primeval solar nebula.

Introduction. On October 29, 1991 the Galileo spacecraft will encounter the minor planet 951 Gaspra. This will be our first close up view of a minor planet. However if the spacecraft high-gain antenna remains undeployed, the results will not be known until the spacecraft approaches Earth again in December, 1992. On that occasion, we should learn a great deal about the nature and the origin of minor planets. The encounter provides a crucial test of the prevailing theory of origin of minor planets: a test which the theory might not pass!

Most planetary astronomers believe that each minor planet consists of a single, isolated rocky body which, except for collisional fragmentation, should have remained substantially unchanged since it condensed from the primeval solar nebula 4.6 billion years ago. The chief challenger to this model is the view that each minor planet consists of a rocky nucleus, surrounded by a cloud of orbiting debris. The debris would contain rocky fragments of a variety of sizes, from many kilometers in diameter down to dust size. Such abundant orbiting debris fragments have too much angular momentum to have originated in collisional events. If they exist, origin in a planetary breakup event is indicated.

History. The United States spacecraft Galileo, launched October 18, 1989, is on an extended 6-year mission to the planet Jupiter. The spacecraft trajectory cuts through the asteroid belt twice. Between these passages the spacecraft comes back near the Earth for a gravity assist. During its first excursion of the asteroid belt, the Galileo spacecraft will pass close to the minor planet 951 Gaspra. Pre-encounter, we know the following about Gaspra: diameter, roughly 16 km; rotation, 7.03 hours; amplitude of light variation, 0.8 magnitudes (Binzel R.P., 1991, private communication); "unusual" type S asteroid.

[1] Note added in proof: This paper is presented exactly as originally submitted to preserve the integrity of its prediction. One picture of Gaspra from the Galileo encounter has since been transmitted to Earth, in which no satellites are seen. The downloaded image frame reveals only 0.001 of the volume of space within which Gaspra might have stable moons. Images still on-board the spacecraft will tell us more about the remaining space. However the synchronous orbit, at about 3-4 radii from Gaspra's center, is the most stable orbit for satellites; and the absence of large moons in the portion of it which can be seen does significantly lower the probability of finding moons in the rest of the volume.

Observations. As a result of predictions made chiefly by D.W. Dunham, several dozen occultations of stars by minor planets have been successfully observed over the past 15 years. On the majority of occasions when multiple observers were involved, secondary occultations have been reported as well (Binzel & Van Flandern, 1979). Although the nature of these secondary occultations is ambiguous in some cases, in others it is not. Cases where the light drops by several magnitudes, but where the minor planet remains faintly visible to the observer after the star has disappeared, cannot be due to causes in the observer's environment or near the Earth. In two cases, such secondary occultations were confirmed by a second, independent observer. The only plausible explanation is that additional bodies in the immediate environment of the minor planet occulted the star (Van Flandern, 1980).

There is also asteroid lightcurve evidence of multiplicity (Van Flandern, Tedesco, & Binzel, 1979); doublet craters and crater chains evidence on many planetary surfaces; and the suggestion that meteorites often "break up" at altitudes over 100 km above the Earth's surface, where the atmospheric shearing forces are still negligible (Wetherill & Revelle, 1982). All of this supports the multiple-body nature of at least some minor planets.

One other line of direct evidence involves radar ranging to Apollo asteroids passing quite close to the Earth. Although such events are rare, in two of the nine asteroids targeted to date (the two with the highest available resolution: 1627 Ivar and 1989 PB), more than one radar echo in the image was seen. In the latest passage, asteroid 1989 PB was found to be at least a contact binary asteroid by means of radar echoes (Ostro et al., 1990).

Since so few minor planets have occulted stars or been observed by radar, yet so many of these few have shown evidence of companions (dubbed "minor satellites"), the author has concluded that minor satellites are numerous and commonplace. There is evidence that minor planets are surrounded by debris clouds containing a range of bodies from kilometer size down to dust size. E.g. a few minor planets have shown "halos" on long exposure photos. And during occultations of stars by minor planets, unusual scintillation of the starlight for brief periods has twice been seen visually, and once recorded photoelectrically (Van Flandern, Tedesco, & Binzel, 1979). The apparent explanation is partial occultations of the starlight by numerous bodies near the minor planet too small to produce total occultations.

Prediction. The radius of the gravitational sphere of influence, within which satellites are dynamically stable against the force of the Sun, is approximately given by 100 times the perihelion distance in astronomical units (au) times the diameter of the parent minor planet (Van Flandern, Tedesco, & Binzel, 1979). For example, a 50 km minor planet which reaches perihelion at 2 au from the Sun has a sphere of influence extending out to about 10,000 km. All of the minor satellite detections to date have been far inside of the theoretical sphere of influence for their parent.

Gaspra's calculated sphere of influence extends to approximately 3000 km. The Galileo spacecraft is targeted to approach the minor planet to within about 1600 km. But since tidal forces are significant for evolving the orbits of minor satellites, it is expected that long-term stable orbits will lie mostly within about 1/3 of the theoretical radius of the sphere of influence. Objects farther out will evolve outward under tidal forces until they escape into the minor planet's solar orbit. So these outer regions should only be populated sparsely by objects in transition to escape from the minor planet. And the collision hazard should be only a small fraction of what it would be farther in. But note that, at the 8 km/s relative speed between spacecraft and asteroid, collisions with even dust particles can do extensive damage.

From observational and theoretical considerations, we expect that Galileo will photograph a Gaspra surrounded by a cloud of debris ranging in size from kilometers down to dust. From a distance, this debris cloud may resemble a faint comet coma. Gaspra should have several satellites plainly visible to Galileo when it arrives. The only reservation about this prediction is that if Gaspra was involved in a major collision, all its satellites could have been stripped off. But in any case, if the model is correct, the nucleus of Gaspra should still show the accretion of several tidally-decayed former minor satellites. And whether Gaspra does or does not exhibit orbiting satellites, observations with the Hubble Space Telescope will soon prove whether the minor satellite phenomenon is commonplace or rare.

Origins. Planetary astronomers have been reluctant to accept the observational evidence for minor satellites. In the prevailing viewpoint, minor planets condensed from a primeval solar nebula 4.6 billion years ago, and have remained much the same ever since, except for collisional evolution. Present-day satellites could only arise through collisional fragmentation. But since the mean velocity between asteroids is about 5 km/s, collisions are generally violent and highly destructive affairs, unlikely to leave behind stable satellites. And if any did somehow form, they would be soon removed by tidal forces and subsequent collisions.

The laws of gravitation forbid permanent capture of satellites by gravitational forces alone. Capture needs the assistance of non-gravitational forces; for example, tidal forces, collisions, drag, or solar radiation pressure. Of these, only collisions are strong enough to affect kilometer-sized bodies significantly. The other forces are so slight that they have an insignificant effect during the short time intervals when capture conditions might be operative. Capture could occur from these other forces only under the rarest and most improbable of circumstances.

Even with collisions, stable satellite survival must be quite rare. A collisional fragment which does not have escape velocity enters an elliptical orbit which intersects the surface from which it came; so it just falls back. Even if secondary collisions alter its orbit a bit, tidal forces soon bring it back down. Attaining a stable orbit requires that the satellite be supplied with ample orbital angular momentum. But it is precisely orbital angular momentum which is absent from fragments when two minor planets collide. Hence collisional processes cannot lead to the formation of abundant stable satellites under plausible circumstances. It is for this reason that the credibility of the observational evidence suggesting that minor satellites may be abundant has been attacked so tenaciously (Reitsema, 1981; note reply by Van Flandern, 1981).

We therefore conclude that, if minor satellites are found to be numerous and commonplace (as would be strongly suggested if Gaspra, a randomly-selected asteroid for this purpose, is found to possess numerous minor satellites and a debris cloud), the origin of these satellites and debris clouds must date from the origin of the minor planets themselves. For example, if all minor planets originated from the disintegration of a much larger body, then each would trap some escaping debris and fragments within its own sphere of influence once it escaped the gravitational sphere of influence of the disintegrated parent body. Any such formation event must have been astronomically recent because collisions over 4.6 billion years would eliminate most minor satellites. But other evidence already exists to support this hypothesis (Van Flandern, 1978).

Conclusions. Gaspra and the Hubble Space Telescope will determine whether minor satellites are abundant or rare. This in turn will provide a test of the prevailing model that asteroids originated as small bodies from the primeval solar nebula 4.6 billion years ago, and have undergone only collisional evolution since then. If the observational evidence for abundant minor satellites from occultations of stars by asteroids, lightcurves, and radar ranging is enhanced by finding minor satellites in this encounter, the theory of origin of minor planets which has prevailed over most of the past two centuries will be dealt a severe blow to its continued credibility. Luckily, we don't have long to wait to find out!

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