# FIRST IMAGES OF 243 IDA

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**The first images of the asteroid 243 Ida show an irregular, 56 x 24 x 21 km object. Its surface is rich in geologic features, including systems of grooves, blocks, chutes, albedo features, crater chains, and a full range of crater morphologies. The largest blocks may be distributed non-uniformly across the surface; lineaments and dark-floored craters also have preferential locations. We interpret Ida to have a substantial regolith. The high crater density and size-frequency distribution (-3 differential power-law index) indicate a surface in equilibrium with saturated cratering. A minimum model crater age for Ida -- and therefore for the Koronis family to which Ida belongs -- is estimated at one billion years, older than expected.**

The five images of 243 Ida *(1),* returned following Galileo's 28 August 1993 encounter with the asteroid *(8)* allow a preliminary characterization of its global properties and its surface geology. In comparison with 951 Gaspra, the first asteroid encountered by Galileo *(9),* Ida is more than twice as large, spins twice as fast, has a much higher pyroxene/olivine ratio, and is located in the Koronis family, a well-defined, populous group of asteroids with similar orbital properties. The Solid State Imaging (SSI) system *(10)* acquired a total of 150 images comprising 18 views of the asteroid. The 5 frames played back so far are part of a high resolution mosaic (Fig. 1) taken in the "clear" filter between 4 and 2.5 minutes before encounter when the solar phase angle varied from 48 to 60 deg. and the surface resolution from 38 to 31 m/pixel. In one area there is substantial overlap between two of the images which provides an 8 km swath of stereoscopic coverage at a convergence angle of about 10 deg.

## Rotation and General Appearance

As expected, Ida shows an irregular, elongated shape. A 56 x 24 x 21 km ellipsoid roughly fits the visible limb and terminator, ~5% larger than groundbased estimates. This model shows RMS deviations with respect to the visible limb of ±2 km or 14% of the mean radius. There are no obvious indications of a large scale binary or compound structure and it looks from this single perspective as though it could be a coherent, single body; on the other hand, it is highly angular, obviously modified by impact processes, and shows lineaments that could indicate fractures. The appropriate rotation pole (*4)* is immediately selected from the two ambiguous poles determined from groundbased data by Ida's shape and orientation (Fig. 2). Although these images cover only 1.9 deg. of rotation, displacement of shadows in overlap regions already confirms retrograde rotation. The landscape of the eastern region (see Fig. 4 for orientation) is dominated by five large ~5 to 8 km bowl-shaped craters; the central region is reminiscent of the large planar facets seen on Gaspra *(9)*. The ruggedness of the terrain is indicated by the frequent occurrence of strongly foreshortened craters away from the limb and in the region of stereoscopic overlap, which covers a ridge separating two large craters. Since only ~30% of Ida's surface is visible in this mosaic, a more detailed description of Ida's large scale properties must await more complete rotational coverage yet to be returned from the spacecraft.

## Craters

*Crater Morphology.* The ubiquitous presence of impact craters clearly indicates that collisions are the principal geologic process shaping the surface of Ida. Most craters have a simple bowl shape with a only few showing flat, sometimes crenulated floors. Several may have central mounds; these are associated with the rims of large craters and may be simply a chance effect of a substratum of blocky rim material. There is a continuous range of degradation states (Fig. 3). A few of the freshest craters have one or two short rays extending to ~1 crater diameter, but most craters with crisp rims do not have rays and there is an absence of distinct ejecta blankets, as expected for an object with low surface gravity *(11).* A few craters have polygonal shapes and others straight rim segments suggesting formation in a fractured layer or one with significant pre-existing stresses. In an area of high sun illumination (western region) is a cluster of apparently dark floored craters, some surrounded by a halo of brighter material. Stratification in the surface material and the presence of a regolith is one obvious interpretation.

*Crater Chains.* There are several linear chains of three or more craters of similar size. They range from 500 m to 2.5 km in length with component craters in the 200 to 400 m size range; their orientations and locations seem random, suggesting impacts by clusters of projectiles, perhaps trains of ejecta from other cratering impacts.

*Size-Frequency distribution.* The differential size-frequency relationship *(12)* is shown in Fig. 5*a* for the crater population on Ida. Cumulative frequencies are plotted in Fig. 5*b* for three different morphological classes (fresh, intermediate, and degraded) of craters. The overall slope (exponent of a differential power-law fit to the data) is -3.3 in the range 200 m to 3 km diameter, considerably shallower than for Gaspra *(9)*; for craters <1 km in diameter, it is near the -3.0 slope characteristic of equilibrium by saturated cratering by populations having slopes steeper than -3.0 *(13).* The approximately parallel relationships found for the three morphological classes is expected for saturation equilibrium *(14).* An R-plot comparing Ida crater densities with other bodies is shown in Fig. 5*c*. Although statistics are poor, there is an indication that frequencies of craters >1 km may begin to depart below saturation equilibrium densities. In that case, the population of larger craters, yet to be revealed in the remaining images of Ida, may reflect the production population rather than equilibrium.

*Cratering "Age."* At diameters of ≥1 km, the crater density is ~5 times greater on Ida than on Gaspra, whose surface age has been estimated at ~200 My *(9).* To first order, it is expected that Gaspra and Ida are subject to impact by the same population of projectiles. Studies of the orbital distributions of larger asteroids *(15)* show that over half of the objects that could intersect one body would intersect the other, and vice versa, with similar impact velocities. Since the smaller projectiles responsible for cratering are believed to be the widely dispersed collisional fragments of larger asteroids, the cratering flux hitting both bodies should be roughly the same. Then there are two possible interpretations for the different crater populations: *(i)* the strength of the surface material is much greater on Gaspra and projectiles make smaller craters on Gaspra than on Ida, or *(ii)* projectiles make the same size craters on both bodies but Ida's surface is about 5 times older than Gaspra's. While emphasizing that *(i)* cannot, at present, be ruled out, we prefer the second interpretation, which yields a minimum age of ~1 By for Ida's surface and, therefore, for the Koronis family as a whole. This is much older than the expectations of Binzel *et al (7)* based on considerations of the dynamics of the Koronis family.

## Blocks, Chutes, Grooves, and Regolith

*Blocks.* Many isolated positive relief features are evident on the surface. Among them, we have confidently distinguished about 20 independent blocky features larger than 1 pixel across which distinctly contrast with their local background (most are indicated in Fig. 4). Six of the blocks are larger than 100 m across; the largest are ~150 m (~4 pixels) long, similar to the maximum sizes of blocks found on Phobos, Deimos, and the Moon *(16)*. Generally it is not possible to say whether they are perched on the surface or partially buried larger objects. However, at least one object has an associated trail suggestive of a low velocity impact by a block now sitting on the surface or of a dislodged boulder rolling across the surface. The spatial distribution of clearly identified blocks is non-uniform. There is a clustering of the majority in the eastern region, many within the two largest (~8 km diameter) craters that define Ida's shape in that region. There is a possible second cluster of blocks near the western end of Ida. In contrast, no blocks were identified with such high confidence in the well-imaged central region nor along Ida's limb, outside of the large craters. The spatial non-uniformity seems to be real, despite potential biases due to variable lighting geometry and resolution across the mosaic, foreshortening, smear, and local topographic effects.

Blocks are likely to be impact ejecta and to be the largest components of a size distribution of particles that make up Ida's regolith. Their emplacement on the surface may have been affected by the rapid rotation of Ida, which substantially reduces the effective gravity at the two ends of the asteroid *(11).* Preliminary calculations indicate that blocks launched randomly from the surface at velocities just below the escape velocity, and which achieve a temporary orbit around Ida, will impact preferentially on the leading rotational face (which coincides roughly with the eastern region), just as observed. Some blocks may have followed suborbital trajectories to their present positions. Alternatively, block distribution could reflect underlying lithology or regolith thickness. Some of the numerous blocks located near or within large impact craters may be directly associated with them (e.g. excavated by them or exposed by mass wasting).

Because of their relatively small size, blocks have only a short lifetime against collisional disruption, about 30 - 80 My for the largest ones *(17)*. Their presence on the surface indicates that one or more craters in the 1 - 10 km size range were formed during the last 30 - 80 My (only impacts that produce craters in this size range can be expected to produce 100 m sized blocks).

*Linear features.* Lineaments are relatively common on Ida, including systems of grooves, albedo stripes, and short crater chains. The most prominent system of grooves (*i.e.* linear depressions of uniform width), is located at the eastern limb; a second system stretches across the central region (Fig. 4). Grooves range up to 4 km in length and from 100 to 350 m in width, with depths probably no more than a few tens of meters. They range from having beaded outlines, suggesting a series of coalescing pits, to having sharply linear forms. Some grooves intersect craters, but they rarely intersect or bifurcate each other. They show no preferred orientation with respect to local slopes. Although comparable in morphology with grooves on Phobos and Gaspra, the global organization of Ida's grooves is less clearly defined than on these other objects *(20)*. Since at least one groove terminates adjacent to a large block, a subset of grooves may simply be boulder tracks. In addition, grooves may be the surface expressions of massive planar fractures and joints in the underlying bedrock of Ida, caused by the stress of large impacts.

Albedo stripes and patches are seen within the large craters of the eastern region and are commonly oriented downslope, although it is difficult to separate true albedo variations from abrupt changes in local slopes at projected ridge lines. Generally stripes are 50 to 100 m wide and range from 400 m to 4 km in length. These features may be the courses of optically immature regolith exposed during downslope movement, although some could be rays of ejecta from a hidden crater or grooves. There is a bright triangular feature 2.5 km long and 500 m wide in the eastern region (Fig. 4), which could be the result of mass wasting. There is also at least one dark feature, besides the dark-floored craters.

*Chutes.* Inside the rim of one 8 km crater we have found three examples of shallow depressions oriented upslope from small degraded craters. The largest is 1 km long and 400 m wide. The depth of these features is unlikely to be more than a small fraction of their width. They appear to be scars produced by failure of weak material on an oversteepened slope triggered by an impact. This again seems to imply the presence of a regolith.

*Regolith.* There is abundant evidence for a regolith on Ida. The downslope orientation of chutes and bright stripes, the morphology of pitted grooves, the range of crater morphologies, dark floored craters, and craters with bright rims are all most simply explained in terms of a ubiquitous regolith. The size of craters showing flatbottomed topography suggests a depth, in those localities, of a few hundred meters. Photometric studies, which may clarify the relationship of all these features to the properties of the regolith, must await a more accurate shape model that can be derived only after images with complete rotational coverage are returned later in 1994.

## Comparisons with Gaspra

Both objects share an elongated, irregular shape, apparently with at least some large planar facets. Grooves exist on both asteroids. The two asteroids show major differences in their cratering records and in the nature of their surface layers. Ida's surface has been exposed to sufficient cratering to have reached equilibrium, at least for craters up to diameters of ~1 km. Unlike Gaspra *(9),* Ida has many large craters up to a sizable fraction (~0.7) of Ida's mean radius. Gaspra's surface appears to have been "reset" at least once and the present population of resolved craters (>100 m diameter) is so sparse that it represents the production function. Based on the reasonable assumptions that the inherent cratering rate and size distribution of impacting objects should be similar at Ida and Gaspra *(15)* and that both bodies have similar impact strengths, Ida's surface must be much older (perhaps 5 to 10 times) than Gaspra's. Ida's largest impacts failed to have the resetting effects observed on Gaspra, possibly reflecting a dependence on body size of response to such events.

Although they share many geologic features (*e.g.* craters, grooves, regolith), Ida is much more geologically diverse than Gaspra. This substantially reflects the presence of deeper regolith on Ida, whose stronger gravity will naturally retain a greater fraction of ejecta; an indication of this may be the presence of a few incipient rayed craters on Ida but not on Gaspra. A second factor is Ida's longer lifetime against catastrophic disruption, which we estimate at 1.5 By *(21)*. The asteroid has survived long enough to both generate and accumulate more ejecta on its surface.

It remains to be seen whether the two asteroids have similar photometric and spectral properties when compared at high spatial resolution. Globally integrated groundbased data indicate that intriguing albedo and spectral variations may be present on the largest scale on Ida *(4).* This suggests that compositional contrasts may also be present on this object that are even more extreme than on Gaspra, despite the homogeneity already reported for this face of Ida by the Galileo NIMS investigators *(22)*. Images that provide data on color and on the true shape of the object have high priority for transmission to the ground in mid-1994. Recent discovery of a satellite of Ida in SSI and NIMS data, reported and analyzed in a separate paper *(23)*, will modify data return priorities *(24)*.

## References and Notes


1. Ida is an S-type *(2)* main-belt asteroid and a member of the Koronis family *(3).* Groundbased observations *(4)* indicate an elongated object (axial ratios a/b=1.82, b/c=1.15), with mean diameter ~28 km, and geometric albedo 0.25. It has retrograde spin with a period of 4.633 h about an axis that points in one of two possible directions *(4),* indistinguishable in telescopic data. Variations observed during a rotation period indicate possible albedo *(4)* and compositional variations *(5)* across its surface. The brighter members of the Koronis family are taxonomically homogeneous *(6),* and the observed distribution of spin states has been interpreted in terms of a young age for the Koronis family relative to the age of the solar system *(7).*

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8. Galileo encountered Ida on UT 28.703 Aug., 1993, at a heliocentric distance of 2.95 au. The spacecraft flew south of the asteroid (-75$^{\circ}$ S ecliptic latitude) at a speed of 12.4 km/sec, and at a range of 2400 km.

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11. Because of its shape and rotation, Ida's effective surface gravity must vary by as much as a factor of 2 across its surface. For a density of 3.5 $g.cm^{-3}$, we estimate mean surface gravity of ~1.4 $cm/sec^2$ (*i.e.* an escape velocity ~11 m/sec.). Centrifugal accelerations of ~0.4 $cm/sec^2$ apply at the ends of the asteroid.

12. Craters >500 m diameter were identified, classified, and measured in a region of ~320 sq. km., mostly in the central region where the lighting is good and the slant angle not too great. Craters down to about one third that size were studied in a 25 sq. km. subregion (craters <100 m diameter are visible in the image but have not been examined in this preliminary study). A larger area (723 sq. km.) was used to obtain better statistics for craters 1 to 4 km in diameter. About 470 craters are in the total sample; the image scale (used for crater diameters and area calculation) was known to about 5% when these studies were done.

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17. Using the rate dependent strength-scaling law from Housen and Holsapple *(18)* and an RMS collision velocity of 3.92 km/s *(15)* and assuming half of the energy is partitioned into disruption of the target, we find that blocks of 30 - 100 m diameter can be disrupted by impactors which are 1.3 - 4 m in diameter. The adopted collision probability *(15)* is $3.8 \times 10^{-18}$ $km^{-2}$ $yr^{-1}$. Assuming a power law exponent of -4.0 for small projectiles yields 30 - 80 m.y. for block lifetime against disruption (possibly younger if there are enhanced collisions by Koronis family asteroids). These results are in accord with meteorite exposure ages *(19)*, which suggest that meter sized objects survive a few tens of millions of years.

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19. D. Bogard, in *Asteroids,* (Ed. T. Gehrels, Univ. of Arizona Press, Tucson), 558-578 (1979).

20. P. Thomas *et al., J. Geophys. Res.,* **84**, 8457-8477 (1979); J. Veverka *et al., Icarus,* **107**, 72-83 (1994). Because recognizability of lineaments can be strongly influenced by the single azimuth of illumination geometry, our knowledge of lineament orientations could be strongly biased.

21. Using the Holsapple scaling law [K. A. Holsapple, *Ann. Rev. Earth Planet. Sci.*, **21**, 333-373 (1993)] with an experimentally measured gravitational self-compression term (plus other assumptions as in *(17)*, we estimate that Ida can be shattered by a 1.7 km diameter projectile. Ida is in the size range at which the collisional energy needed to shatter it is comparable to that needed for fragments to escape from Ida's gravity. Thus the lifetime against dispersal is about the same as the lifetime against shattering. Here we assume that Ida responds to collisions as if it were a strong rocky body; the uncertainties in the lifetime of 1.5 By are at least a factor of 2, due mostly to the uncertainties in (a) the effective strength and (b) the asteroid size distribution at sizes between 1 and 25 km.

22. R. W. Carlson *et al.*, *EOS (Trans. A.G.U.)*, **74** (43), 384.

23. Manuscript in preparation for submission.

24. We thank the Galileo project and the National Aeronautics and Space Administration for support; in particular we wish to recognize the success of the Galileo Flight Team lead by W. O'Neil, N. Ausman and M. Landano in the face of many difficulties. In particular, the playback tape management work of O. Adams was critical to the acquisition of the images discussed here. The (beautiful) Ida mosaic used in this work was constructed within L. Wainio's group at MIPS. In this respect we particularly wish to recognize the professionalism of Ms. Helen Mortensen. We also acknowledge the substantial inputs that have been made to this work by the following colleagues: D.J. Tholen, R.P. Binzel, P. Magnusson, A. Barucci, S. Mottola, R. Sullivan, R. Pappalardo, P. Geissler, J-M Petit, J. Moore, W. F. Bottke, M. Nolan, E. Ryan, W. Merline, B.E.A. Mueller, E. Asphaug, B. Carcich, P. Lee, D. Simonelli, R. Wagner, P. J. Guske, J. Yoshimizu and R. Hasegawa. A portion of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. The National Optical Astronomy Observatories are operated by the Association of Universities for Research in Astronomy, Inc. (AURA), under cooperative agreement with the National Science foundation.

## Figure Captions

**Figure 1.** Mosaic of Ida with Gaspra included for comparison.

**Figure 2.** Ida with a model ellipsoid superposed and oriented according to the two possible rotation poles *(4)*. The solution in the top panel, with the north pole in the direction of RA = $50^{o}.25$, Dec(deg.): = $76^{o}.32$ (J2000), is clearly preferred.

**Figure 3.** Examples of a groove, boulders, and a range of crater degradation states. (a) Enlargement of the eastern end of Ida showing the location of several prominent boulders (arrows at left) on the inner wall of a large crater. Arrows at the top point to a prominent groove, extending for at least 3 km. The image is ~12 km in height; north is approximately toward the top. (b) Range of crater degradation states in the western central region of Ida. The large central crater is ~4.5 km in diameter and has been modified by many subsequent impacts on its rim and in its interior, as has the smaller crater on its eastern rim. Several relatively fresh craters with linear rim crests are along its southern rim. The image is ~8.5 km wide; north is toward the top.

**Figure 4.** Map of geological features on Ida. Locations of the five frames which make up the Ida picture (UT, phase [deg.], range [km]): (A) 16:47:56.266, 48.3, 3821; (B) 16:48:04.933, 49.3, 3738; (C) 16:48:13.600, 50.3, 3656; (D) 16:48:22.266, 51.3, 3575; (E) 16:49:22.933, 60.0, 3057. The major regions used in the text are identified.

***NOTE: THIS FIG. IS SUPPLIED IN 2 VERSIONS, ONLY ONE OF WHICH SHOULD BE USED (WE PREFER THE COLOR MAP RATHER THAN THE DRAWING)***

**Figure 5.** *(a)* Differential size-frequency (per sq. km per km diameter increment) relationships were sampled in 3 different counting regions. Incomplete data at small diameters have been omitted. The line is a least squares fit to the solid data points and has a slope of -3.3. *(b)* Cumulative size-frequency (per sq. km) relationships are plotted for all craters and for the three morphological classes noted in the text. *(c)* R-plot of crater densities (differential crater densities from the two smaller counting areas divided by diameter$^{-3}$). Ida data are shown as open circles. The horizontal line has been set at a density of 0.3 typical of the most heavily cratered terrains known on planetary satellites.