Galileo's Earth Flyby

The path to Jupiter for Galileo includes flybys of Venus (February 1990), Earth (December 1990), and Earth again (December 1992) in order to acquire the additional energy needed to reach the giant planet. Prior to the cancellation of the intended use of the Centaur rocket as an upper stage with the Shuttle, which was done after the Challenger accident, the plan was to send the Galileo spacecraft directly from Earth to Jupiter. (Launch would have been in 1986 and Jovian encounter in 1988.) Now, with the gravity assist from Venus successfully behind it, the spacecraft has been navigated to a precise encounter with Earth; closest approach took place on December 8, 1990 at 20 hours, 34 minutes, and 34 seconds (UTC) at an altitude of 960 km. This was only 8 km above the targeted altitude of 952 km.

The encounter with Earth last December increased Galileo's speed in solar orbit by approximately five kilometers per second. The gravity-assist technique captures the imagination with its bounty of added energy for

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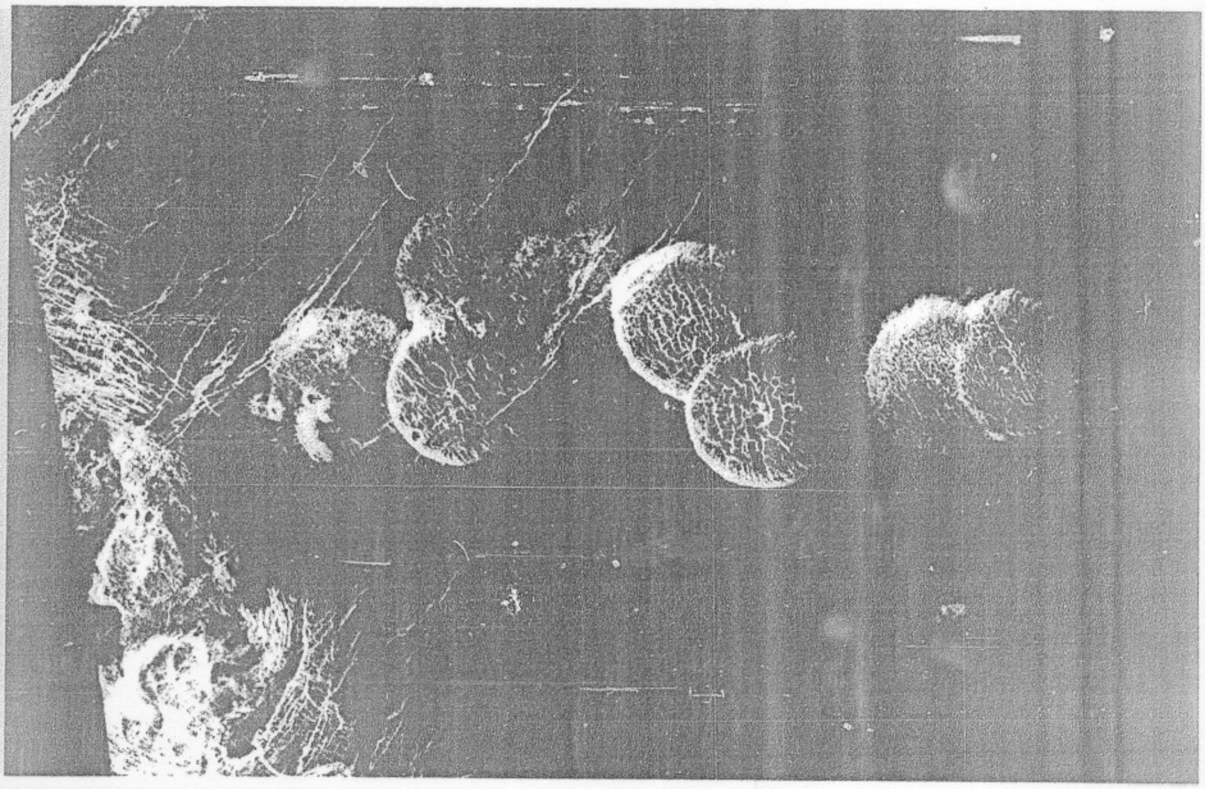
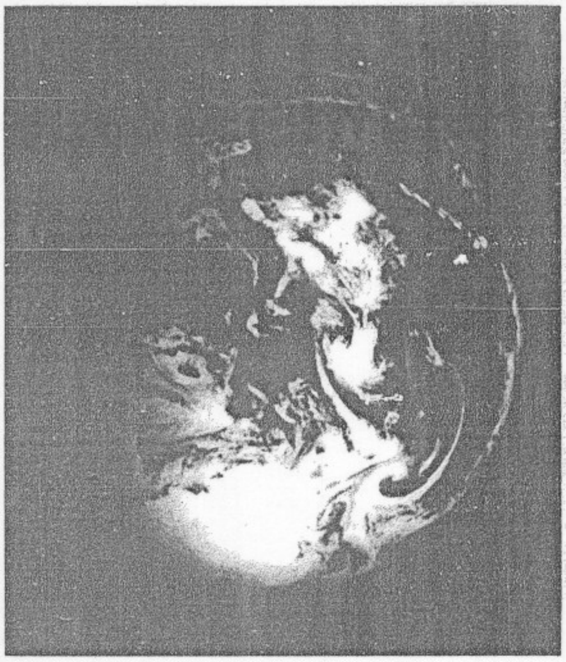
just the price of accurate navigation. Even in that other "natural" method of urging a spacecraft onward, solar sailing, a special apparatus has to be built. The gravity assist, apart from its intrinsic utility, constitutes a metaphor for the dream of controlling the world through the power of thought and "getting something for nothing". If that pronouncement seems farfetched, then please supply a second explanation for the interest which this topic in trajectory analysis excites, as shown in the inquiries received by myself and other writers on the subject of space.

For those with a modicum of mathematical skills, Robert J. Cesarone of JPL has written a tutorial on gravity assists: "A Gravity Assist Primer" (AIAA Student Journal, Vol. 27, pp. 16-22, Spring 1989). An intuitive feel for the process may be acquired by considering a spacecraft passing behind the trailing hemisphere of a planet moving in its orbit. The tug of gravity by the spacecraft on the planet, feeble though that may be, works against the motion of the planet and subtracts from it a small amount of energy. In turn, the spacecraft receives energy in the transaction. The second ingredient in the gravity assist is a change in direction, bending the spacecraft's trajectory, which is easy to accept as a result of the gravitational pull of planet upon vehicle.

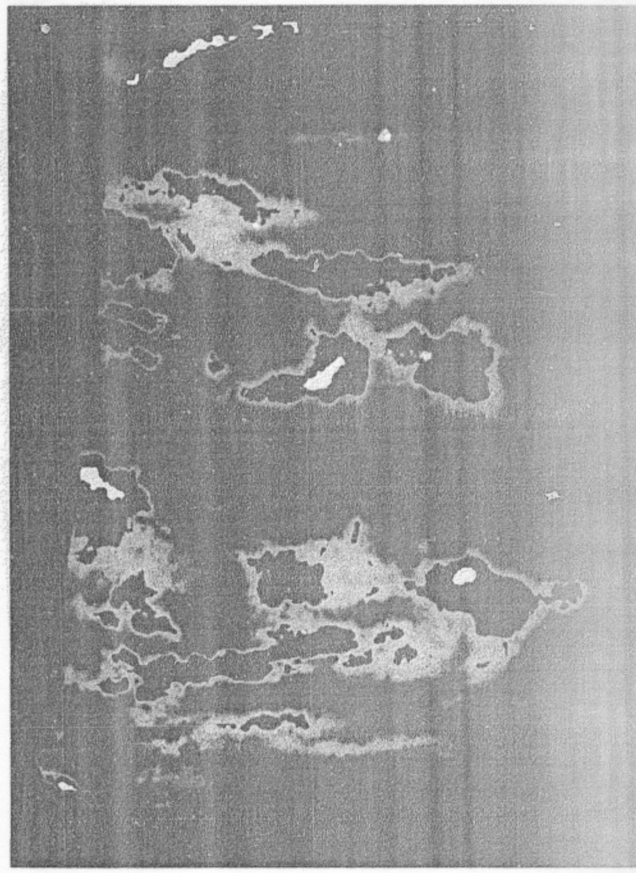
The kind of qualitative explanation that I have sketched above for the gravity assist was adopted as a full program of exposition by Sir George Biddell Airy (1801-1892) in his 1884 book *An Elementary Explanation of the Principal Perturbations of the Solar System* (Macmillan and Co.). Although "elementary" in only a relative sense, it is a refreshing alternative to exclusively symbolical treatments of celestial mechanics and represents an attempt to get behind the formalism to reach a deeper level of understanding. Ironically, it may have been this usually admirable trait which led Airy, the Astronomer Royal, to put aside the calculations of John Couch Adams (1819-1892) on the location of a planet

This image of the eastern edge of Alpha Regio was acquired on November 7, 1990 by the Magellan spacecraft now in orbit about Venus. The spacecraft's synthetic aperture radar, cutting through the obscuring layers of clouds, has revealed seven circular, domical hills averaging about 25 km in diameter. They may have been formed by lava flows from central vents and have undergone considerable fracturing. *NASA/JPL*



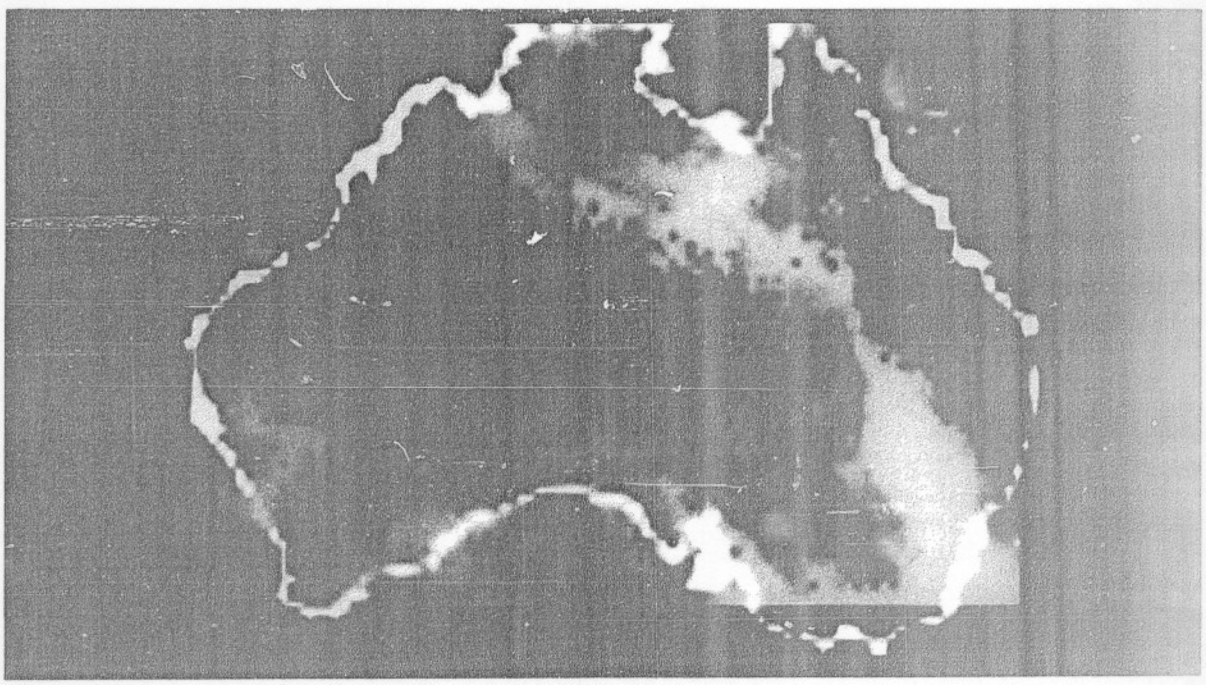


Above: A view of South America on December 8, 1990 is shown in this image obtained by the interplanetary spacecraft, Galileo, as it swung through the Earth-Moon system, bound for an eventual insertion into orbit about Jupiter in December 1995. *NASA/JPL*



Above right: Clouds on the night side of Venus are shown in this false-color image. Data were taken by the Galileo spacecraft as it approached the planet on February 10, 1990. Viewed from an altitude of about 100,000 km, the map (by the Near Infrared Mapping Spectrometer) shows the turbulent atmosphere some 50 km above the surface and 10-15 km below the visible cloudtops. *NASA/JPL*

Below: This multispectral map of Australia and surrounding seas was obtained by the Galileo spacecraft's Near Infrared Mapping Spectrometer shortly after closest approach on December 8, 1990 from an altitude of about 85,000 km. The wavelength of 0.873 microns is represented by blue, 0.939 microns by green, and 0.984 microns by red (visible light spans the range from 0.4 to 0.7 microns). The purplish color off the northeast coast marks the shallow waters of the Great Barrier Reef and the Coral Sea. Here the blue, from water absorption, combines with the red, from reflection from coral and surface marine organisms, to produce the blend of colours. *NASA/JPL*



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beyond Uranus. The honor of the visual discovery (1846) of Neptune went to Johann Galle (1812-1910) at the Berlin Observatory, based upon the calculations of Urbain Leverrier (1811-1877). Colin Ronan discusses the circumstances of the chase in *Their Majesties' Astronomers* (The Bodley Head, London, 1967).

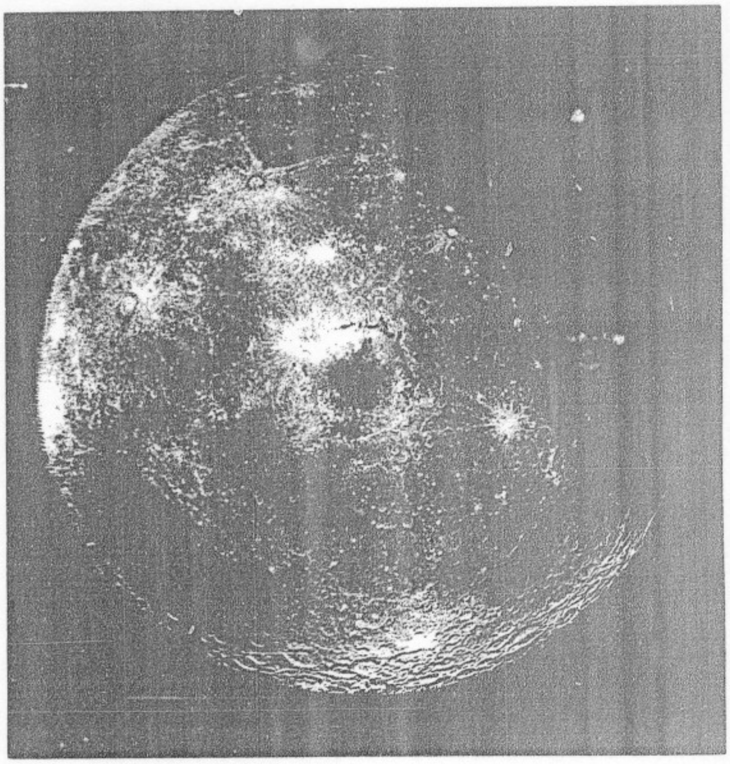
Although the three gravity assists, which give rise to the "VEEGA" (Venus-Earth-Earth Gravity Assist) name commonly applied to the trajectory, are the reasons for passing closely by Venus and Earth, they are not the only benefits to be obtained. A preview of some results from Venus was given in the May 1990 edition of this column, and more information will be forthcoming since Galileo dumped the Venusian contents of its tape recorder to ground antennas as the spacecraft moved closer to Earth. (Galileo's high-gain antenna has been furled for thermal-protection reasons during its passage through the warm environs of the inner solar system.)

A press conference was held on December 19 in von Karman Auditorium at JPL to present some of the scientific results from Galileo's passage through the Earth-Moon system.

The Project Scientist, Dr. Torrence Johnson, provided some feeling for the scope of the investigations with a summary of hypothetical report if Galileo were an "Arcturan" probe going through the Earth-Moon system for the first time. The Arcturans would be able, for example, to assert that the extensive covering of Earth by water could only be a thin veneer, a fact known from the deduction of Earth's density from mass and volume measurements. The presence of a magnetic field would allow them to infer that the Earth possesses a fluid, conducting core. The south polar region features an ice continent, but the north polar region could not be observed. The atmosphere contains surprisingly little carbon dioxide and its general composition could be the consequence of life on the planet. Support for this hypothesis comes from detection of radio signals which were probably not of natural origin. Volcanism could only be inferred and plate tectonics were not detected.

Johnson closed with the comment that the Arcturan Academy of Sciences would certainly recommend that their government fund another mission to Earth, preferably an orbiter.

Various scientific investigators continued the press conference with a presentation of highlights. A significant characteristic of the Galileo encounter was the rapidity with which this interplanetary spacecraft moved through the magnetosphere, permitting a "snapshot" of the system to be obtained. It was also fortunate that passage occurred at a time of a high level of disturbance, allowing, for example, observation of disruptions in the plasma sheet contained in the tail of the magnetosphere. Knowledge of the plasma sheet relates to understanding the processes that drive the auroral phenomena which diversify skies in higher latitudes on Earth. "Lightning whistlers" were detected; they travel outward from Earth along magnetic field lines.



The solid-state imaging system onboard Galileo captured this picture of the Moon on December 9, 1990 from a range of somewhat over 550,000 km. The large, circular feature is Mare Orientale which was formed about 3.8 thousand million years ago by the impact of an asteroid-size body. *NASA/JPL*

A preview of an Earth-rotation movie was shown: 600 of the ultimate 1500 frames of the movie were strung together to display our blue-and-white planet in motion. The clarity of the imaging results was striking and the reflective zone of sunlight-on-water added to the effect. The slowness of the visible evolution of weather patterns compared to the rate of Earth's rotation surprised me, an Earthling immersed in daily weather. Of course, it is a question of the spatial scale seen from the two perspectives.

The Moon was not neglected during the flyby. Lunar mapping with the Near Infrared Mapping Spectrometer (NIMS) certified the operation of that instrument as performing even better than specification (the entire Galileo encounter served to calibrate and characterize instruments for their use at Jupiter). The NIMS has spectral resolution about 50 times better than the camera ("SSI", which stands for "Solid State Imaging" system), but the camera has about 50 times better spatial resolution; hence their results are complementary.

The objectives of lunar imaging science were directed toward: (1) composition of farside crust, (2) structure of the Mare Orientale impact basin, (3) character of unexplored regions near the south pole and (4) improved coordinates for lunar features. With regard to the second objective, some confirmatory evidence was obtained for a hidden mare ("mare", the Latin for "sea", denotes the dark, flat regions of the Moon so prevalent on the side visible from Earth), which had previously been suspected. This mare would predate the formation of the Orientale basin.

Preparations are underway for Galileo's encounter with the asteroid Gaspra in October of this year. The path to Jupiter is demonstrating the power of a fully instrumented spacecraft to derive value from a variety of solar-system environments. At present, our images of the Jovian system are dominated by the results from the two Voyager flybys. But, like the Arcturans, we have a lot to learn. Galileo will be our teacher.