THE GRANDEUR OF GANYMEDE: SUGGESTED GOALS FOR AN ORBITER MISSION.

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Introduction: Ganymede is an icy satellite of planetary grandeur, with alluring surface geology and chemistry, an internally generated magnetic field, a differentiated interior and hot iron core, and a tenuous but dynamic atmosphere. Its linked surface, interior, and orbital evolution recount the history of the jovian system. Moreover, an induced magnetic field component and warm interior imply a liquid water deep within the moon, and the potential for harboring primitive life. Broad goals of *surface*, *magnetosphere*, *interior*, and *atmosphere*--and overarching themes of *water* and *organics*--tie to high priority to NASA's exploration objectives. All can be thoroughly addressed by a dedicated Ganymede mission.

Surface: Ganymede has fascinating and diverse surface geology. Its relatively young bright "grooved terrain" is shaped by Earth-like tectonism [1], with faults and fractures that deform its surface ice. Icy volcanism may have paved its smoothest terrains [2]. Its ancient cratered "dark terrain" shows a complex geological history [3]. The dark terrain probably dates from the earliest days of the Galilean satellite system [4] and offers the best promise for unraveling its cratering history. Multi-ringed structures and palimpsests are impacts that probe to warm and perhaps liquid-rich layers [5]. Galileo succeeded in sampling Ganymede's surface features, but coverage is extremely limited, and regional relationships and distributions remain uncertain [6]. Topographic data has been extremely important to understanding Ganymede's surface geology, but is of relatively coarse resolution and very limited areal extent [7].

Ganymede's dark terrain material contains clays and organic materials [8] that may indicate the composition of the impactors from which jovian satellites accreted. Hydrated minerals may be salts similar to those inferred on Europa [9]. Ganymede is a significant dust source [10], implying that its surface composition could be sampled directly from orbit. Surface oxygen and ozone are probably the products of charged particles which tear the bonds of surface water-ice [11]. Many additional irradiation products, including simple organics, are predicted [12].

Magnetosphere: Ganymede is the only satellite known to have an internally generated magnetic field [13]. Its inferred equatorial surface field strength of ~750 nT is great enough to stave off Jupiter's field and carve out its own magnetospheric bubble. The interactions between Jupiter's and Ganymede's magnetic fields are analogous to those between the Earth and Sun, with the added advantage that the upstream field and plasma conditions are highly predictable. Equatorial latitudes are shielded from most charged particles, while polar latitudes are open to particles from the Jovian magnetosphere. Monitoring of the location and character of this boundary would provide a measure of the nature of both Jupiter's and Ganymede's fields. Galileo magnetometer measurements imply that Ganymede generates an induction response to Jupiter's rotating field, presumably from a subsurface salty water layer [14]. Continuous observations from orbit would measure the induction at multiple frequencies, constraining the conductivity and thickness of the water layer, and providing information on the solid metallic core where the magnetic field is thought to be generated. An orbiter would also measure higher order spherical harmonics of the internal field and determine secular changes in the field since the Galileo era measurements.

Interior: Galileo gravity data indicate that Ganymede is highly differentiated, with an ice-rich crust ~800 km thick above a rock mantle and iron core [15]; the magnetic field data imply that this iron core is hot and partially molten today. Its hot core and crustal water layer imply that Ganymede is cooling from a tumultuous heating event that may have occurred as recently as ~1 Gyr ago, plausibly from a huge pulse of tidal heat as Ganymede entered the Laplace resonance [16]. Measurements of Ganymede's gravitational field will refine models of its internal density and so its differentiation history. In combination with magnetometry, interior thermal profiles can be constrained. Detailed gravity data may determine if mass anomalies are associated with grooved terrain or impact palimpsests.

Atmosphere: Ganymede has a tenuous atmosphere driven by sublimation, sputtering, and dissociation of surface water-ice. The atmosphere is probably dynamic, sensitive to diurnal insolation, magnetospheric fluctuations, and geological terrain type [17]. Observed ultraviolet polar aurorae, equatorial visible airglow, and extended Lyman-α emission all attest to interactions between the magnetosphere and atmosphere [18, 19]. However, observational constraints are extremely limited regarding composition, density, transport, redeposition, loss, and magnetospheric interactions pertinent to Ganymede's atmosphere.

Suggested Objectives and Investigations: To address goals of *surface*, *magnetosphere*, *interior*, and *atmosphere* and tracking of the satellite's *water* and *organics*, we suggest the following science objectives (and measurement techniques) for a dedicated Ganymede mission:

- Characterize the global distribution, regional relationships, and detailed topography of geological features (global high-resolution imaging; laser altimetry).
- Determine the composition, distribution, and state of ice and non-ice surface components, notably organic materials and irradiation products (infrared spectroscopy; ultraviolet spectroscopy; orbiting mass spectroscopy).
- Measure and monitor magnetic field and plasma energy spectrum over time from a variety of altitudes (magnetometry; plasma measurement).
- Measure gravity field to high accuracy (radio science).
- Characterize the neutral atmosphere and ionosphere, including composition, source, and escape mechanisms (ultraviolet spectroscopy; radio science).
- Determine the characteristics, causes, and spatial/temporal variability of emissions (ultraviolet spectroscopy; imaging; plasma measurement; magnetometry).

Desirable Mission Characteristics: A Ganymede orbiter could perform the investigations outlined above. An initial highly elliptical orbit would allow for global reconnaissance, magnetopause studies, and atmospheric and auroral observations. A subsequent low-altitude, highly inclined, near-circular orbit would shield the spacecraft from damaging particle radiation during half of each orbit, and allows: uniform coverage for imaging, spectroscopy, altimetry, and magnetometry; ideal Doppler tracking data for gravity studies; repeated crossings of magnetospheric boundaries to understand interactions with Jupiter's field; and in situ compositional sampling of particles ejected from the surface. An orbiter would permit long-term, dedicated study of Ganymede as an integrated system, tracing its water and organics from interior to magnetosphere, to unlock secrets of this recently active world which holds the secrets to the evolution of the Galilean satellites.

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