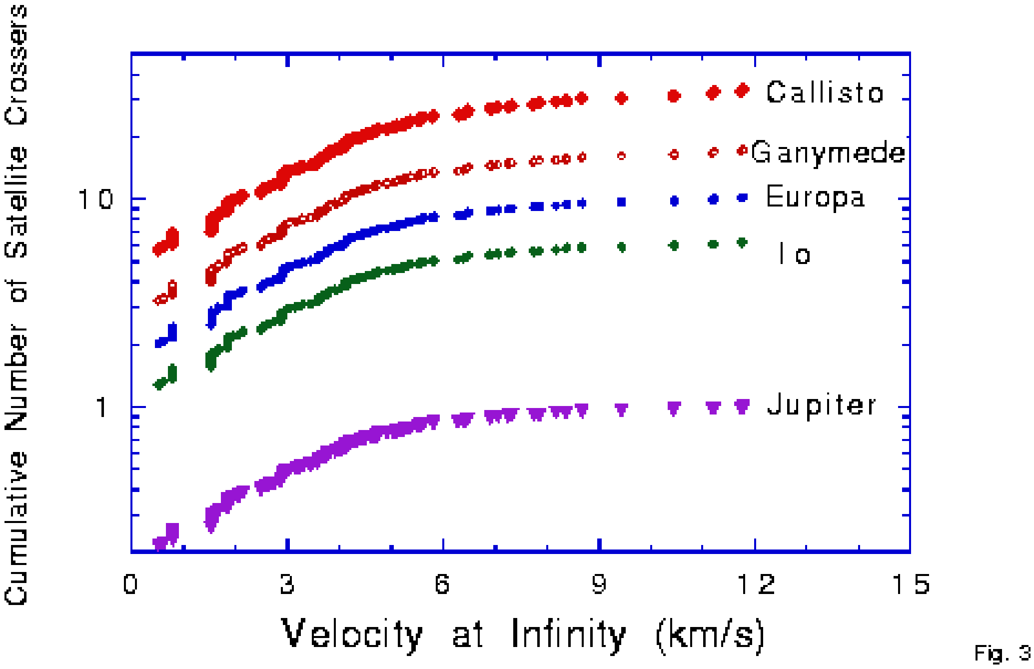

Figure 3. Cumulative v_∞ distributions for JFCs hitting Jupiter (normalized to unity) and the relative number crossing the orbits of the Galilean satellites. The fraction in orbit around Jupiter ranges from 21% of those hitting Jupiter to 4% of those passing Callisto.

as these objects are the most strongly focused gravitationally. Only 4% of the JFCs crossing Callisto's orbit are in weakly-bound orbits vs. 17% at Io. On the other hand, the number of comets crossing Callisto's orbit is larger—35 comets pass Callisto for every one that hits Jupiter.

Impact velocity distributions for the simulated JFCs at the various satellites are shown in Figure 4. Satellite parameters, impact probabilities relative to impact on Jupiter, average impact velocities, and a fair amount of other material to be discussed below, are listed in Table 1. NY95 also estimate relative impact probabilities on the satellites and Jupiter, but they do not use Öpik's equations. Rather, they use approximate expressions of their own devise. Impact rates relative to impacts on Jupiter are roughly 60% of what we find. The source of this difference is unclear.

2.2. Crater diameter

We use the expression

$$D_\mathrm{s} = 1.65 \left(\frac{m_\mathrm{i}}{2\rho_\mathrm{t}}\right)^{0.26} g^{-0.22} v_\mathrm{i}^{0.44} \left(\frac{\rho_\mathrm{i}}{\rho_\mathrm{t}}\right)^{0.073} (\cos\theta)^{0.44} \ \mathrm{cm} \qquad (12)$$

for the diameter of a simple crater given impactor mass m_i, impact velocity v_i, incidence angle θ measured from the vertical, surface gravity g, and impactor and target densities ρ_i and ρ_t. It is to be evaluated in cgs units. The appearance of three significant digits is an illusion; the leading factor is better regarded as being between 1.3 and 2. Eq 12 is essentially the expression recommended by

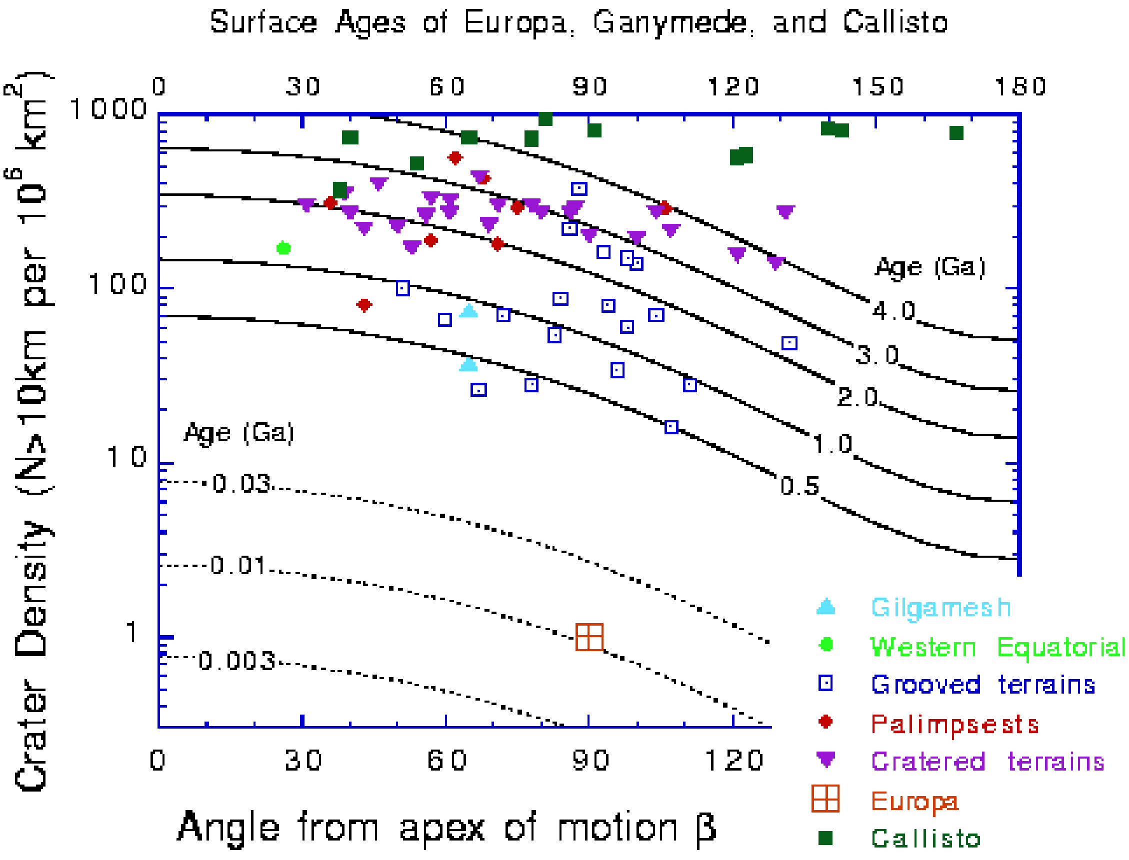

Figure 7. Crater densities on various types of surfaces on Ganymede and Callisto as a function of the angle β from the apex of motion. Data are those tabulated by Shoemaker et al. (1982). All data are expressed in terms of the equivalent number of 10 km craters that would be extrapolated using Shoemaker's $N(>D) \propto D^{-2.2}$ power law. Gilgamesh and the Western Equatorial basin are large young impact basins. The grooved terrains are generally although not always young, while the cratered terrains and palimpsests (ghostly imprints of lost impact basins) are old. The datum for Europa is the nominal equivalent of five 20 km craters scattered over the moon's surface. The curves are the surface ages that correspond to these crater densities at these apex angles—solid curves are ages relevant to Ganymede, the dotted curves are ages relevant to the higher cratering rate at Europa—calculated according to the assumption that the satellites have been in synchronous rotation throughout. The surface ages are those predicted using our nominal cratering rate, with the additional assumption that the Kuiper belt decays as $1/t$ (Holman and Wisdom 1993). These are thus uncertain by as much as a factor five. Ages for Callisto are not shown, but are consistent with the age of the solar system.

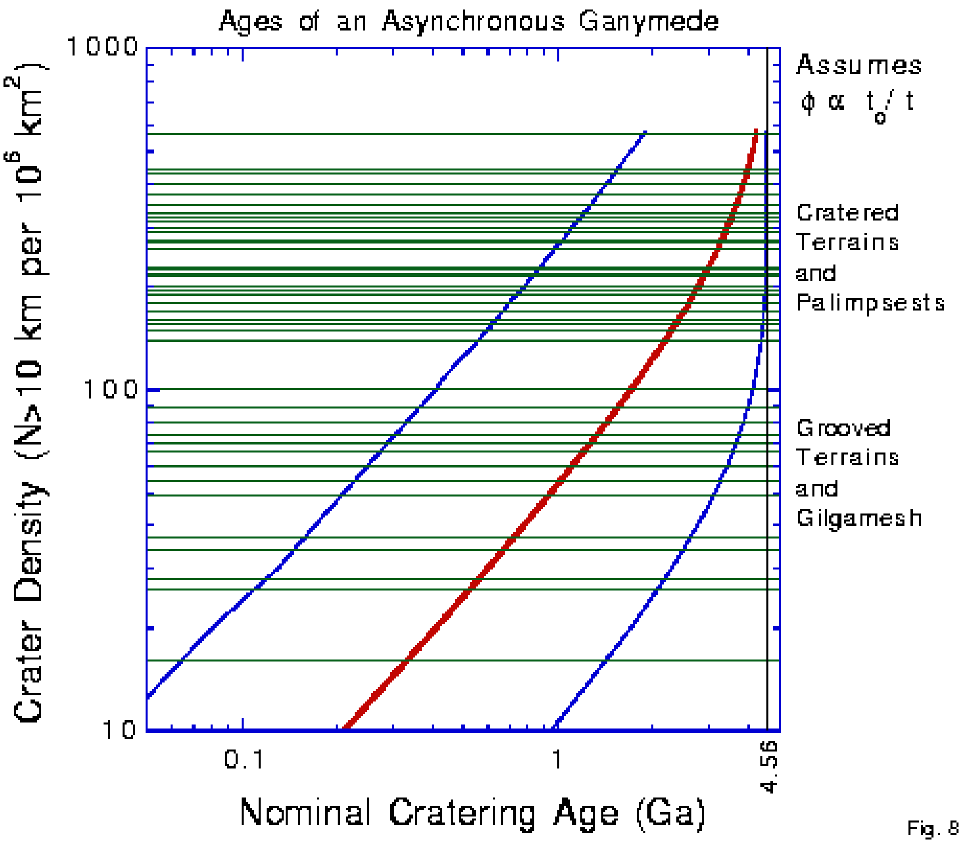

Fig. 8

Figure 8. Crater densities and ages of various surfaces on Ganymede. Ages for the nominal cratering rate, and rates five times higher and lower are shown. This spans the range of formal uncertainty. Here we use only the global average cratering rate to set ages; this is equivalent to Ganymede rotating nonsynchronously.

nally generated magnetic field than a more conventionally ancient age would be (Stevenson 1986).

Any lack of apex-antapex asymmetry on Europa could probably be explained away as secondaries or, for the larger craters, as small number statistics, but it is not altogether unlikely that the Europan surface moves, either slowly on some glacial timescale, or in response to tidal heating, or catastrophically in the manner of true polar wander. Such phenomena have been predicted (e.g., Greenberg and Weidenschilling 1984) and continue to be seriously discussed (Geissler et al. 1998). Nonsynchronous rotation seem most likely if the ice is really a shell floating on a liquid ocean. It is harder to envision if the water layer is solid ice everywhere. In this context Ganymede again raises deep issues: how, other than by rotation, is Ganymede to avoid a pronounced apex-antapex cratering asymmetry? And if there is no other choice, does this not require that Ganymede too was once, and perhaps not so long ago, home to a liquid ocean?

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