PLANETESIMAL INTERACTIONS IN THE EARTH-VENUS ZONE.

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Monte Carlo models of planetesimal scattering by Jupiter (1) were modified to include perturbations by close approaches to both Jupiter and the earth. For any plausible choice of parameters, the most probable outcome in each case is ejection by Jupiter (2). As a result, estimation of the implications of Jupiter scattering for the inner solar system becomes quite sensitive to rather poorly known parameters of the nebula (3). Attention has therefore been shifted to the more tractable problem of the dynamical interactions occurring when the earth and Venus embryos became large enough to scatter planetesimals to each other's vicinity, i.e., after their masses became about one-third their final masses.

As discussed in 1975 (1), a major motivation for considering planetesimal scattering is to account for the iron and volatile depletions and the plagioclase enrichment in the moon relative to the earth in a manner consistent with the dynamically plausible origin of the moon from a swarm of bodies about the earth. The modelling of planetesimal collisions has therefore been extended to include composition and differentiation. A simple four part composition was assumed: 1. iron, 2. ferromagnesian silicates, 3. calc-alumino silicates, and 4. ice. For a planetesimal, these are prescribed total abundances $P_1, P_2, P_3, P_4$, $\Sigma_i P_i = 1$, and a degree of differentiation $x$, $0 < x < 1$. Then the local relative abundance $p_i(r)$ at radius $r$ within the planetesimal can be obtained from

$$p_i = \begin{cases} B_i \exp\left(\frac{(v-b_i)}{\ell}\right), & v < b_i \\ B_i \exp\left(\frac{(t_i - v)}{\ell}\right), & v \geq t_i \end{cases},$$

where $\ell = -\ln x$, $v = (r/R)^3$, $R$ is planet radius, $b_1 = 0$, $t_i = b_i + 1$, $b_4 = 1$, and the $B_i$'s are adjustable so that $\Sigma_i P_i = 1$. The modification of the degree of differentiation $x$ by the heat $H$ from a collision depends upon a minimal energy density $H_m$ and a decay constant $\Delta H$, such that:

$$x^1 = \begin{cases} x, & H < H_m \\ 1 - (1-x)\exp\left(-\frac{H-H_m}{\Delta H}\right), & H > H_m \end{cases}.$$
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to a portion \( h_i \) from the heat \( H_{mi} \) to a heat \( H_{xi} \); and to drop off exponentially above \( H_{xi} \) with a decay constant \( \lambda_i \), so that in the fragment of heat energy density \( H_f \) the portion \( P_{fi} \) is:

\[
P_{fi} = \begin{cases} 
  p_i(r), & H_f < H_{mi} \\
  p_i(r)[1 - (1 - h_i) \{(H_f - H_{mi})/(H_{xi} - H_{mi})\}]^2, & H_{mi} < H_f < H_{xi} \\
  p_i(r)h_i\exp[-(H_f - H_{xi})/\lambda_i], & H_f < H_{xi}
\end{cases}
\]

Also added to the program were provisions for planetesimal-planetesimal collision and tidal disruption by close approach to a planet. Thus for each Monte Carlo step there are six possible outcomes for a test planetesimal: (1) collision with another planetesimal, (2) collision with a planet, (3) collision with a moon, (4) close approach to a planet with a modified elliptic orbit resulting, (5) close approach to a planet with ejection in a hyperbolic orbit resulting, and (6) close approach to a planet with tidal disruption resulting. For a model where Venus and the earth are half formed, relatives velocities between planetesimals are slightly more than 3 km/sec rms as given by \( \beta = 4 \) in the Safronov formula \( v^2 = GM/r \), and the mass distribution of planetesimals is from a maximum of \( M/200 \) downward by a spectrum \( n(m)\propto m^{-q} \) with \( q = 1.6 \), planetesimal collision is the most probable outcome by far except for orbits whose apohelion is just beyond the earth or whose perihelion is just within Venus. This latter circumstance may have some implications for planetary rotation.

The above relative probabilities depend on two assumptions: 1) the ratio of encountered planetesimal mass to scattered planetesimal mass is greater than 0.001 for a significant collision; 2) the minimum deflection angle is 5.7° for a significant close approach. Under these constraints, the most probable outcome per element of matter with plausible values for the comminution, melting, and vaporization parameters is breakup into small pieces: less than \( 10^{-6} \) times the selected planetesimal (which normally falls in the range \( 10^{22}-10^{25} \) grams). This outcome occurs for almost 60 percent of cases.

So far, iron depletion and aluminum enrichment of the moon relative to the earth has not been obtained. Because of computational expense, a better means of characterizing the extreme outcome of encountering the proto-moon is needed. The main emphasis in the results which is new is that there apparently was a considerable cycling of material through being ground down to smaller bodies after the earth and Venus became appreciable in size, thus allowing wider scope for differentiation effects. Yet to be explored are higher ratios than 1/200 of maximum planetesimal to planet mass, as suggested by Wetherill (4).
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REFERENCES