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ANALYSIS OF PLANETARY EVOLUTION WITH EMPHASIS ON DIFFERENTIATION AND DYNAMICS

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Task #1: Collapse of the Proto Solar System Cloud

In order to address the early stages of nebula evolution, we are developing a three-dimensional collapse code which includes not only hydrodynamics and radiative transfer, but also the effects of ionization and, possibly, magnetic fields. We intend to focus on understanding the properties of a protostellar cloud which lead to the formation of a Jupiter-like second largest body, since such a body would have had a significant influence on the subsequent dynamics of the circumsolar material from which the planets formed. Ultimately, we intend to couple this collapse code with the accretionary N-body being developed in task #2 which addresses the problem of planet formation.

Over the past few months, we have developed a numerical model for protostellar collapse similar to one developed by Boss in 1979. We are developing a hydrodynamic scheme that minimizes the effect of numerically-induced artificial diffusion and expect to improve upon the overall accuracy by replacing the first order finite difference scheme with a higher order difference scheme or, preferably, a spectral or Galerkin technique.

In order to define the specific numerical technique that we intend to use, we have surveyed the current literature for a method which minimizes boundary errors while remaining computationally efficient. Glatzmaier (1984) developed spectral and Galerkin techniques to model magnetohydrodynamic problem in solar physics, methods that are well-suited to the protostellar collapse problem. However his model accommodates only the shell of a sphere. Currently, we are adapting this technique to full spherical geometry by reducing the lower boundary to the sphere's center. Thus we hope to minimize the problem of artificial diffusion and develop an accurate means for dealing with the inner region of the nebular cloud where the important physical changes take place.

Task #2: Formation of the Post-Jovian Planets

As part of our examination of solar system evolution, we have developed an N-body code describing the latter stages of planet formation from the accretion of planetesimals. It is based on Aarseth's (1972) scheme and is a sixth order, three dimensional code which solves the equations of motion precisely for N mutually attracting bodies. In practice, the run-time for such a code varies as N^3. It is our goal to reduce this cubic exponent through efficient vectorization.

To test our code for accuracy and run-time efficiency, and to develop a stronger theoretical foundation for our study, we have used it to study problems in orbital dynamics. This summer, we examined resonant interactions between Neptune and Pluto, with Jupiter as the single other perturbing body. We observed significant exchange of angular momentum over the equivalent of 1.9 million years. Our results support conclusions made by others (Nacozy and Diehl; 1978, Williams and Benson, 1971), who found that resonance improved the stability of the Neptune-Pluto system. We have reproduced periodicities they found in eccentricity and inclination. Understanding such resonant effects is basic to understanding mechanisms which may be important to solar system formation. Other planetary problems we shall examine are the stability of orbits between Jupiter and Saturn, possible rounding of Neptune's orbit by smaller bodies, and the effect due to the 2:1 resonance with Jupiter on diffusion of planetesimal sized bodies at that orbit. The last problem is essential to a theory of planet formation.

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In the beginning of this year, we converted our code to run on the CRAY computers at Los Alamos National Laboratory, and later at the San Diego Supercomputer Center. The Neptune-Pluto problem took nearly two hours of computer time. In anticipation of problems with many more bodies, we have updated the subroutines which perform the force calculations to enhance vectorization. These routines occupy approximately 90% of the CPU time used by our program. Test runs show that the combined effect of moving the code onto the CRAY and vectorizing the force routines has been a twelvefold increase in speed over that of scalar machines.

The next step in suiting our code for planetesimal accretion is to invoke the ability to handle collisions. We have now written the routines to identify and service two-body interactions. With this capability, we intend next to compare our results to those of other investigators, such as Wetherill (1985). Wetherill simulated the accumulation of 500 moon-sized bodies in a gas free environment. His Monte Carlo simulations typically produced four roughly earth sized planets in the order according to mass like that of our own solar system. We shall examine the sensitivity of the outcome (i.e. number and location of planets) to initial conditions. We also intend to develop more precise values for certain parameters, such as gravitational cross section, collision frequency and impact energies, which are essential to analytical treatment of the problem.

Task #3: Regional Tectonics of Venus

We are performing a regional analysis of the correlation between the gravity and topography fields of Venus, in an effort to determine the small and intermediate scale subsurface structure. This subsurface structure will provide us with valuable information concerning the depth of compensation, flexural rigidity of the lithosphere, thermal profile, and ultimately, the tectonic regimes characterizing Venus. Knowledge of Venus tectonics will then allow us to make inferences concerning reasons for the apparent differences between the earth and Venus in terms of global tectonics.

The analysis of the gravity and topography of Venus is done using a two-dimensional Fourier admittance function technique, developed by Dorman and Lewis (1970) and McNutt (1979). This technique allows us to analyze the correlation between gravity and topography at different wavelengths, and to compare these correlations with model admittances. The main complication involved with this technique is the nature of the Venus gravity measurements. While a vertical gravity field is required for this admittance analysis, the Pioneer Venus Orbiter data consists of accelerations measured in the line-of-sight (LOS) direction - that is, accelerations along a line between the Venus surface, the spacecraft, and earth.

We have written the computer programs necessary to convert this LOS gravity field to vertical gravity using quadratic sum minimization, an inverse method described by Kaula (1966), Jackson (1979), and Jackson and Matsu'ura (1985). This method combines the measured data, using a matrix representing the complete LOS observation geometry, the LOS data, and a covariance matrix of the measurement errors, with a priori information, in the form of a covariance matrix of resolving errors. This method involves two major parts. The first is representation of the LOS observation geometry in a 2° by 2° matrix form, involving averaging of the spacecraft altitudes, LOS azimuths and declinations, and the LOS gravity measurements. The solution of this problem is nearly complete. The other part involves the quantification of the a priori assumptions on the form of a covariance matrix. The assumption being made is that the topography and compensation are linearly related, but we don not know the amplitude (i.e. the depth of compensation) of this relationship. It now appears the best way to deal with this problem is to use a range of depths of compensation for our covariance matrices, and find the one which minimizes the chi-squared residuals. The programming for this method is also nearly completed.

Choosing regions of study based on evidence of consistent tectonics has also been a problem. Division of the surface into radar units based on reflectivity and rms slope (Davis et al., 1986, Head et al., 1985) shows very complex relationships. Since the LOS gravity and topography show good correlation on a long-wavelength, regional scale, we have decided to delineate regions based on topography, and will use the residuals of the admittances to help decide if this delineation is justified. The programs to invert the data and solve for the equivalent surface mass distribution, and hence the vertical gravity field, have been completed, as have the programs to determine the admittance functions for the regions. Theoretical models have been derived for various compensation mechanisms for comparison with these results. All these programs have been tested with synthetic data and actual data is now being compiled. Preliminary results are expected shortly, to be followed by appraisal and interpretation.

Task #4: Contrasts in the Evolutions of Venus and Earth

The analyses related to the Earth's archean are being pursued.

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