View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by NASA Technical Reports Server

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

University of Arizona
Department of Planetary Sciences
Lunar and Planetary Laboratory

NASA Grant NSG 7045

"Interiors of the Giant Planets"

Semiannual Report #4

Period October 1, 1975 - April 1, 1976

(NASA-CR-146984) INTERIORS OF THE GIANT PLANETS Semiannual Report, 1 Oct. 1975 - 1 Apr. 1976 (Arizona Univ., Tucson.) 12 p HC $3.50 CSCL 03B

N76-23128

Unclas
G3/91 26842

MAY 1976
RECEIVED
NASA STI FACILITY,
INPUT BRANCH

Submitted: 12 May 1976

W. B. Hubbard
Principal Investigator

I. Personnel working on this grant during this reporting period:

Dr. W. B. Hubbard (Principal Investigator, ¼ time)

Dr. R. J. Greenberg (Co-Investigator, ¼ time)

Mr. W. L. Slattery (Graduate student, ½ time)

Ms. Nancy Moore (Secretary, ¼ time)

II. Overview and Summary

Occultations and Geodesy: Reinterpretation of the 1973 mutual Galilean satellite phenomena by another NASA-supported group has led to important revisions to the satellite ephemerides. In the case of Io, we have shown these revisions to be consistent with a new interpretation of the β Sco-measured Jovian oblateness, which now agrees with the Pioneer 10/11 value. There are now no significant discrepancies between earth-based and spacecraft measurements of this important parameter.

In the area of scintillation theory, a semiquantitative result was developed for spike profiles produced by finite stellar disks viewed through Kolmogorov turbulence. We are also able to set limits for the first time on the systematic distortion of stellar occultation intensity profiles by turbulence. The limits are such that the systematic distortion is not a serious problem.

Greenberg and Hubbard carried out a study of the position of Miranda for the purpose of obtaining an accurate prediction of a possible stellar occultation by Miranda in 1977, following an occultation of the same star by Uranus. Such a measurement would be of great importance for understanding the dynamics of the Uranian system and hence the gravity field of Uranus. Present calculations indicate that the Miranda shadow will miss the earth by ~5000 km, but the study is still in progress.

High Pressure Physics and Planetary Interiors: Using thermodynamic calculations reported previously, Hubbard developed a semianalytic theory for the cooling of a Jovian-type planet. The theory is both simpler and more accurate than earlier calculations. We find that the simple cooling model fits available Jovian parameters and the age of the solar system quite well. On the basis of cooling theory, there is no strong reason for preferring the spacecraft measurement of the Jovian effective temperature over the ground-based one. The spacecraft value of $T_e \approx 127°K$ gives a cooling age of about 5×10^9 years, while the earth-based value of $T_e \approx 134°K$ gives an age of about 4×10^9 years.

We have proposed an observational test of the adiabatic cooling model for Jovian-type planets. An average pole-equator effective temperature difference of +2°K is predicted for Jupiter, and somewhat more for Saturn.

Satellite Dynamics: Greenberg's theory of the long-period variations of Miranda's longitude has been compared with Naval Observatory astrometry. Encouraging results have been obtained and incorporated into consideration of the possibility of a stellar occultation by Miranda. Work on the dynamical structure of Saturn's Rings has continued. A fundamental problem with the Franklin and Colombo model has been discovered which has important implications for the evolution of the rings and of the asteroid belt.

III. Occultation

During this period, Aksnes and Franklin published a paper in which they reinterpreted some of the 1973 observations of Galilean satellite mutual occultation and eclipse phenomena. They found that the best way to interpret these data was to introduce large corrections to the standard ephemerides of the Galilean satellites. This result was of great interest because it offered a possibility to reconcile earth-based and spacecraft-based measurements of Jupiter's oblateness. The 1971 occultation of β Sco by Jupiter was followed by an occultation by Io. Thus the position of Io with respect to Jupiter's rotation axis was precisely known. Aksnes and Franklin's new Io ephemeris permitted us to relocate Io's position with respect to the center of mass as well, which caused the occultation-derived Jovian oblateness to increase substantially from 0.060 to 0.063. The Pioneer-derived oblateness is 0.0647, so it is clear that the corrections to Io's ephemeris are in the right ball park. The discrepancy in the position of the Jovian center of mass is now down to less than 200 km. We believe that this result is an important

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

reconciliation of a number of different earth-based and spacecraft-based observations. The paper has been submitted to Icarus.

Hubbard continued work in collaboration with Jokipii on scintillation theory applied to stellar occultations by planetary atmospheres, with the objective of understanding more clearly what the possible systematic effects of turbulence on such data might be. The 1971 β Sco data were reexamined in detail by applying a semi-quantitative theory of scintillation to high time resolution data from the Cornell group as well as the lower time resolution data from Texas. We were able to confirm most of the preliminary results of Young, although our more quantitative calculations show that there is no substantial evidence for anisotropic turbulence in the Jovian atmosphere. Our theory agrees well with observed spike properties. However, we anticipate a continuing lively debate in this somewhat contentious field.

Hubbard and Jokipii also looked into the systematic effects of scintillation on intensity profiles. Young suggested that the scattering could distort the profiles, which would gravely reduce the utility of stellar occultation as a tool for studying planetary dimensions and planetary atmospheres. Although the systematic effects are indeed present, one requires implausible levels of turbulence to produce an important distortion.

Both of the scintillation papers have been submitted to Icarus, and were presented in brief form at the Austin DPS meeting.

Greenberg and Hubbard started a new analysis of the position of Miranda, for the purpose of predicting a possible stellar occultation by Miranda in 1977, following an occultation by Uranus two hours previously. We used Greenberg's theory of perturbations on Miranda's orbit by other satellites to evaluate the magnitude of possible uncertainties in the longitude of Miranda. New observations supplied by the Naval Observatory seem to confirm the correctness of Greenberg's theory, and we presently calculate that the shadow of Miranda will pass to the north of the earth by several thousand km. After we have analyzed data from the 1976 apparition, we plan to issue a prediction. Unfortunately, an occultation by Miranda appears unlikely.

IV. Interior Structure and Equations of State

Hubbard carried out an independent study of cooling rates for Jovian-type planets. This work was motivated by reports from other groups that the present effective temperature of Jupiter as measured by the Pioneer spacecraft was consistent with a primordial cooling model, while an earlier earth-based determination was not. Specifically, Low and his collaborators obtained a Jovian $T_e \approx 134°$, while Orton and colleagues recently reported $T_e \approx 127°K$. Pollack and his coworkers found that Jupiter would cool to $T_e = 134°K$ within about $2.6{\times}10^9$ years, thus seemingly eliminating this model from consideration.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

In view of our recent work on obtaining Jovian interior thermodynamics to improved accuracy, these results were incorporated in a semianalytic cooling model for the purpose of providing an independent check on the other calculations. We find that the age of Jupiter varies approximately as $T_e^{-11/4}$, and that the age difference between 134°K and 127°K is a little more than 10^9 years. Furthermore, we get a total cooling age to 134°K of approximately 4.0×10^9 years, significantly longer than the earlier study. It turns out that the cooling time is most sensitive to T_e, and only weakly sensitive to the ratio of solar influx to interior heat flux. Uncertainties in the cooling time due to unknown parameters pertaining to the interior structure are probably less than 20%. Thus we conclude that the adiabatic cooling model works well for Jupiter, and at present the earth-based value and the spacecraft value for T_e lie on either side of the "correct" value, with neither to be preferred for theoretical reasons at the moment.

As a byproduct of the study of Jovian adiabatic cooling models, an interesting prediction resulted. In order to match interior convection to the surface boundary condition provided by the atmosphere's heat radiation, the variation of gravity over the surface of Jupiter tends to produce a "polar brightening". It turns out that the solar input flux is distributed uniformly by convection, but the variation of g causes an asymmetry. In the case of Jupiter, the average polar effective temperature should exceed the equatorial value by about 2°K.

For Saturn, the variation should be somewhat larger because of the greater g-variation. No observational data as yet confirm or refute this prediction.

The above results have been submitted to Icarus.

Slattery is nearing completion of a thorough study of Jovian and Saturnian interior models fitted to presently available constraints. These results will be reported in detail in the next semiannual report.

V. Satellite Dynamics

Greenberg's theory of the effect of Ariel and Umbriel on Miranda's motion predicted that in the mid to late 1970's Miranda would be ~10° in orbital longitude ahead of the position obtained from extrapolation of the elements published by previous authors. (A paper describing this theory is in press in Icarus.) We have compared recent Naval Observatory astrometry with the theory and find good agreement. The 10° correction was a crucial factor in our computation regarding the possibility of a stellar occultation by Miranda next year (See section III). Only a few more degrees would have made an occultation observable from earth.

Greenberg visited the Center for Astrophysics in Cambridge, Mass, in January for consultation on the problem of the dynamics of Saturn's rings. Our correction to the dynamically determined density of ring B was confirmed. It now agrees closely with optically determined values as Greenberg reported at the December meeting of the AAS Division on Dynamical Astronomy. On the other hand, we have discovered a new problem with Franklin and Colombo's theory. It is still not understood how a resonance with Mimas could clear a region as wide as Cassini's Division. Ring particles' eccentricities are enhanced over the entire region, but these disturbances are coherent so particles can still remain densely packed without collisions. Only particles in a very narrow band of semi-major axes near the resonance receive forced eccentricities great enough to require collisions. If the resonance hypothesis is accepted, it would appear that these relatively few particles have swept clear the entire Division. This result lends support to suggestions that an analogous mechanism created the Kirkwood Gaps or even prevented the growth of a full-sized planet at the asteroid belt.

VI. Publications and Presentations during this reporting period

(a) Published Papers:

1. "Comparison of Geometrical Effects in Radio and Stellar Occultations", by W. B. Hubbard, Icarus, 26, 175 (1975).
2. "Ray Propagation in Oblate Atmospheres", by W. B. Hubbard, Icarus, 27, 387 (1976).
3. "Temperature of the Atmosphere of Jupiter from Pioneer 10/11 Radio Occultations", by A. Kliore, P. Woiceshyn, and W. B. Hubbard, Geophys. Res. Letters, 3, 113 (1976).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

(b) Papers submitted for publication:

1. "Orbit-orbit Resonances in the Solar System", by R. Greenberg, Vistas in Astronomy, in press.
2. "Stellar Occultations by Turbulent Planetary Atmospheres: A Heuristic Scattering Model", by W. B. Hubbard and J. R. Jokipii, submitted to Icarus.
3. "Stellar Occultations by a Turbulent Planetary Atmosphere: The β Sco Events", by J. R. Jokipii and W. B. Hubbard, submitted to Icarus.
4. "DeSitter's Theory Flattens Jupiter", by W. B. Hubbard, submitted to Icarus.
5. "The Jovian Surface Condition and Cooling Rate", by W. B. Hubbard, submitted to Icarus.

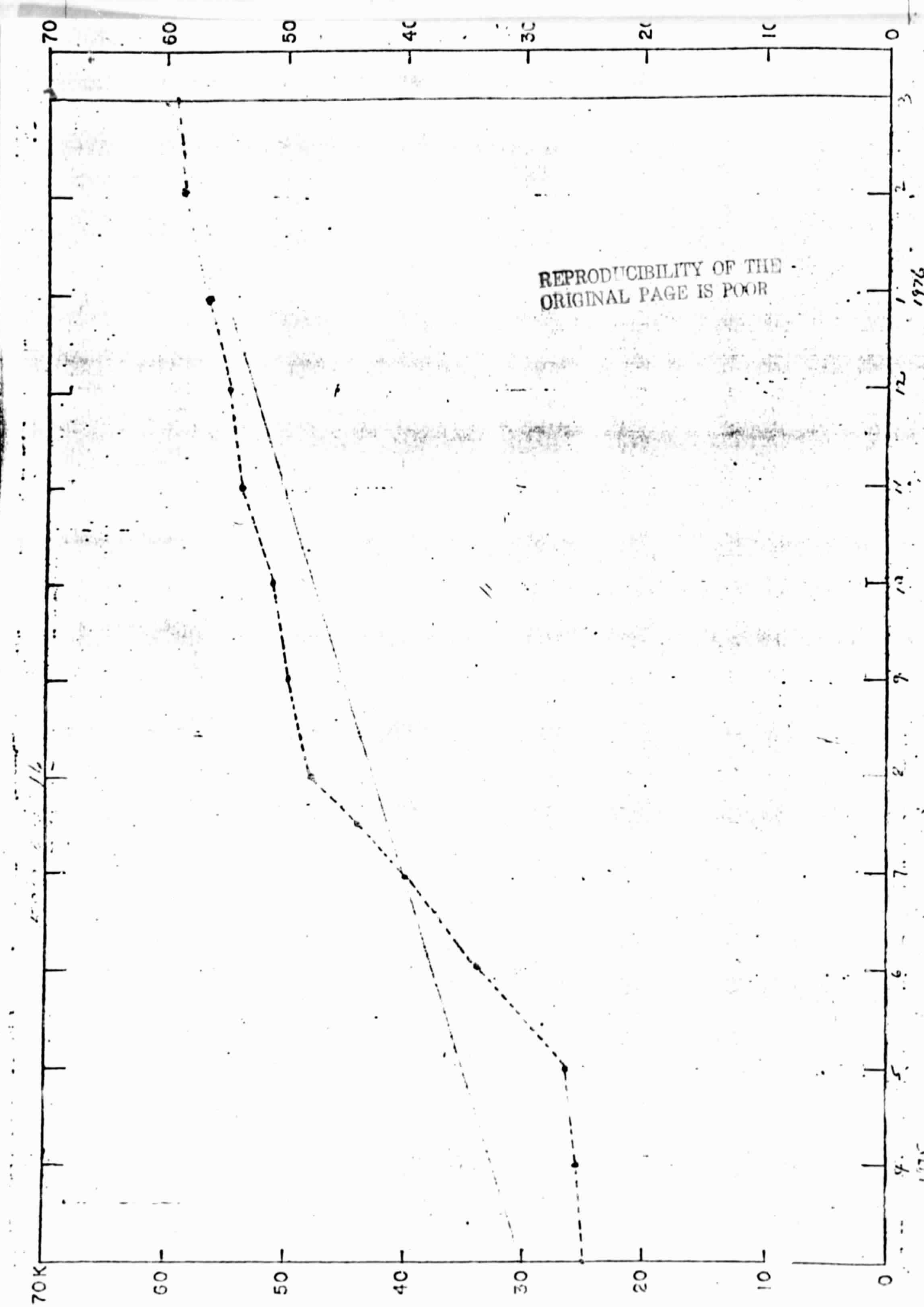
(c) Presentations:

1. "The Location of Cassini's Division in Saturn's Rings", by R. Greenberg, AAS Div. on Dynamical Astronomy, Pasadena, December. Abstract to appear in B.A.A.S.
2. "Dynamics of Cassini's Division in Saturn's Rings", by R. Greenberg, AAS/DPS, Austin, March. Abstract to appear in B.A.A.S.
3. "Effects of Turbulence on Atmospheric Profiles from Radio and Stellar Occultations", by W. B. Hubbard and J. R. Jokipii, AAS/DPS, Austin, March. Abstract to appear in B.A.A.S.

4. Invited review paper by W. B. Hubbard on Giant Planet Interiors, AGU, San Francisco, December.

VII. Financial Status

Expenditures are on schedule (see attached graph).



REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR