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Photophoretic Analog to the Yarkovski-Effect

G. Wurm, A. Hesse, J. Teiser, C. Lösche
Faculty of Physics, University of Duisburg-Essen, Germany (gerhard.wurm@uni-due.de)

Abstract

Asteroids can change their orbits due to the Yarkovski effect. Due to the similarity of radiation pressure and photophoresis, the same effect can occur in a gaseous environment due to photophoresis. As photophoresis can be orders of magnitudes stronger than radiation pressure the effect can well be simulated in laboratory experiments. We present first experimental evidence from drop tower experiments backed up by numerical simulations.

1. Introduction

Asteroids in the solar system are illuminated by sunlight. This radiation heats one side and leads to a radial temperature gradient across the asteroid. On the warm sun-facing side the body radiates more thermal emission ($\sim\sigma T^4$) than on the dark side. As the emission is connected to momentum the body is subject to a radial force for reasons of momentum conservation. However, as this force is directed radially and in total is linear on the light flux this force does not have secular effects and orbits do not change.

However, if the asteroid rotates the warm side is no longer sun facing but trails into the dark side and vice versa. This leads to an asymmetry in the emitted radiation and the asteroid might experience a force accelerating or decelerating it along the orbit. This will change the orbit on long term. The effect is known as Yarkovski effect. Small changes due to the Yarkovski effect can bring an asteroids into resonance with Jupiter which will strongly change the orbit, eventually [1].

2. Photophoresis

Photophoresis is based on momentum transfer by gas molecules on a particle surface with inhomogeneous temperature distribution. The simplest case of photophoresis for a homogeneous surface has identical effects as radiation pressure. However, it can be orders of magnitude stronger in the right pressure range [2]. Therefore, for small but macroscopic particles the change of motion of a particle perpendicular to the direction of illumination is measurable and can be correlated to the particle rotation.

3. Experiments and Heat Transfer

In a drop tower experiments we observed the accelerated motion of mm-size chondrules. We find that in some cases a sideward motion (perpendicular to the direction of light) occurs which fits the assumptions of a photophoretic analog to the Yarkovski effect.

In a heat transfer calculation we simulated a rotating particle and find that the direction of acceleration is in agreement to the observed one.

4. Conclusions

We present first experimental evidence that a rotating particle indeed experiences a sideward force. For particles embedded in optically thin protoplanetary disks the analog to the Yarkovski effect would occur and move particles radially in- our outwards. Scaling parameters like thermal conductivity and size detailed mm- to cm-size shape models of asteroids might be used to measure the Yarkovski effect analog and predict the evolution of asteroid orbits.

Acknowledgements

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References

[1] Chesley, S.R. et al., Science, 302, 1739-1742, 2003.

[2] Krauss, O. and Wurm, G., ApJ, 630, 1080-1092, 2005.