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ScienceDirect
Icarus 195 (2008) 361–377
ICARUS
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Properties and dynamics of Jupiter's gossamer rings from Galileo, Voyager, Hubble and Keck images

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Received 30 December 2005; revised 28 August 2007

Available online 10 January 2008

Abstract

We present a comprehensive examination of Jupiter's "gossamer" rings based on images from Voyager, Galileo, the Hubble Space Telescope and the W.M. Keck Telescope. We compare our results to the simple dynamical model of Burns et al. [Burns, J.A., Showalter, M.R., Hamilton, D.P., Nicholson, P.D., de Pater, I., Ockert-Bell, M., Thomas, P., 1999. Science 284, 1146–1150] in which dust is ejected from Amalthea and Thebe and then evolves inward under Poynting–Robertson drag. The ring follows many predictions of the model rather well, including a linear reduction in thickness with decreasing radius. However, some deviations from the model are noted. For example, additional material appears to be concentrated just interior to the orbits of the two moons. At least in the case of Amalthea's ring, that material is in the same orbital plane as Amalthea's inclined orbit and may be trapped at the Lagrange points. Thebe's ring shows much larger vertical excursions from the model, which may be related to perturbations by several strong Lorentz resonances. Photometry is consistent with the dust obeying a relatively flat power-law size distribution, very similar to dust in the main ring. However, the very low backscatter reflectivity of the ring, and the flat phase curve of the ring at low phase angles, require that the ring be composed of distinctly non-spherical particles.

Keywords: Planetary rings; Jupiter, rings; Hubble Space Telescope observations; Planetary dynamics; Photometry

1. Introduction

Jupiter's "gossamer" rings were discovered by Showalter et al. (1985) in a single Voyager image. They were seen extending outward from the main jovian ring but only a few percent as bright. The name was originally chosen because "gossamer" seemed the only suitable adjective to describe a ring far fainter than the (already exceedingly faint) main ring of Jupiter; Burns et al. (1984) had already applied other colorful adjectives, including "ethereal" and "diaphanous," to the main ring. This name has gone on to become its quasi-official moniker. This ring is composed almost exclusively of micron-sized dust, based on the fact that the ring was only detectable by Voyager at high phase angles, where fine dust grains diffract most of their light. The high dust content is a trait this ring shares with Jupiter's main ring and halo (Showalter et al., 1987).

Showalter et al. (1985) interpreted the system as a single thin, flat ring extending outward to slightly beyond the orbit of Thebe. Its detailed structure was revealed more clearly in edge-on images from Galileo in October 1997 (Ockert-Bell et al., 1999). The system actually consists of two overlapping rings, one bounded by Amalthea and the other by Thebe. Burns et al. (1999) showed in detail how the rings could be generated as dust ejected by each of these moons, which then evolves inward under Poynting–Robertson (henceforth PR) drag while preserving its initial inclination. The rings' most prominent features,

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doi:10.1016/j.icarus.2007.12.012

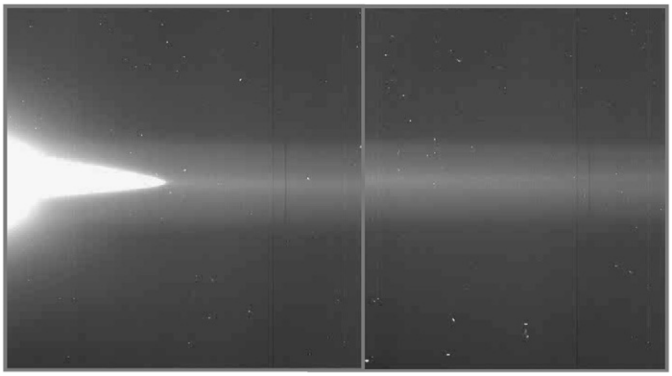

Fig. 1. A mosaic of the two gossamer ring images from Galileo's C3 encounter, taken on November 9, 1996. Images C03689915.00 (left) and C03689915.22 (right) show the over-exposed outer tip of the main ring, with the Amalthea ring extending outward to the right. The phase angle is 179.2° and the ring opening angle is 0.5°.

including their vertical and radial profiles, are all consistent with this model.

However, the images provide some suspicions that the reality may not be quite as simple as the Burns et al. (1999) model. First, the Thebe ring shows a very faint outward extension, contradicting the prediction that dust from Thebe should evolve exclusively inward. Second, the Amalthea ring shows a marked vertical asymmetry. Also, limited data obtained by the Dust Detector during Galileo's November 2002 passage through the gossamer rings suggest an inner dropoff to Thebe's dust population (Krüger, 2003; Krüger et al., 2003, 2005). Numerical integrations also raise questions—Burns et al. (2004) and Hamilton et al. (1998) find that micron-sized grains, when electrically charged by solar photons and the local plasma, ought to be scattered by the numerous Lorentz resonances distributed throughout the region.

In this paper, we explore these properties of the gossamer rings in greater detail, via a more complete analysis of the best available data from the Galileo, Voyager 2, the Hubble Space Telescope (HST) and the W.M. Keck Telescope on Mauna Kea. The primary goal is to ascertain how well the current model conforms to the data, using deviations to illuminate the nature of any additional physical processes that may be at work. We also employ the limited available photometry to place, for the first time, quantitative constraints on the particle sizes in the gossamer rings.

2. Image summary

2.1. Galileo images

The Galileo spacecraft imaged the gossamer rings only twice during its tour of the jovian system. During the C3 and C10 encounters it passed through Jupiter's shadow, making it safe to point the camera close enough to the Sun and observe the highest phase angles. Table 1 summarizes all the images obtained.

The first look was in a pair of images from the C3 encounter, taken on November 9, 1996 (Fig. 1). Here the ring is nearly edge-on and shows a puzzling form, incompatible with the flat, equatorial ring that Showalter et al. (1985) had originally assumed. The geometry became clear during the C10 encounter 11 months later, when more extensive imaging was performed. A four-image mosaic shows the edge-on gossamer ring from the main ring's tip out to well beyond the orbit of Thebe. Fig. 2 shows this mosaic in three linear stretches. Here it is oriented with Jupiter's north pole up and celestial east increasing toward the left. [Note that this is rotated 180°, from the orientation shown by Burns et al. (1999).] The borders between individual frames of the mosaic are visible as jumps in the noise level; these occur because the exposure times of the images grow progressively longer from right to left. This set of images revealed the gossamer ring's morphology for the first time, as a set of two vertically extended, overlapping rings, one bounded by Amalthea's orbit and the other by Thebe's (Ockert-Bell et al., 1999; Burns et al., 1999).

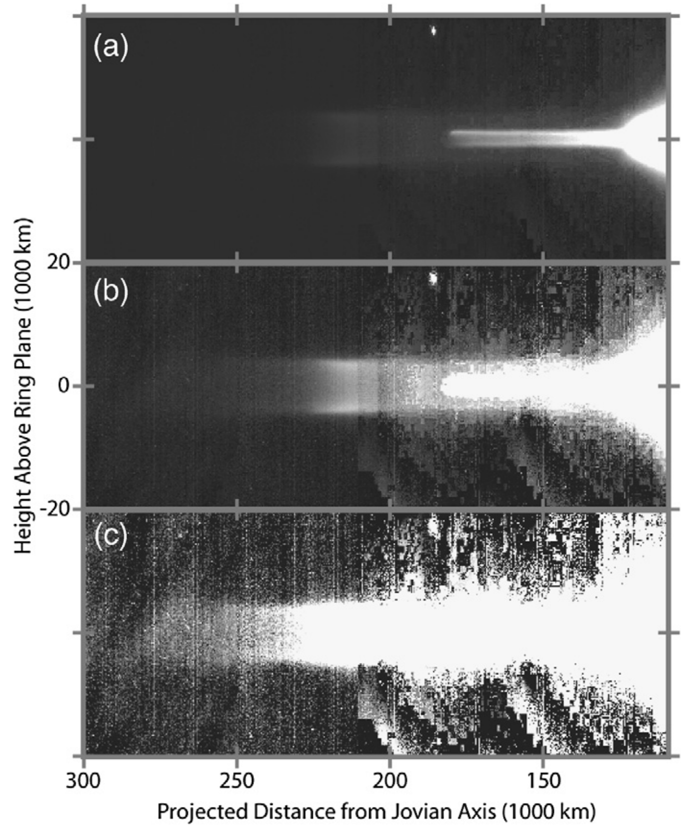

Fig. 2. A mosaic of four edge-on images of the gossamer rings from Galileo's C10 encounter, taken on October 5, 1997. Images C04160889.22–C04160890.45 have been overlaid and expanded vertically by a factor of roughly two (cf. Fig. 1a of Burns et al., 1999). The same mosaic is shown with three different enhancements, each successively showing material fainter by roughly a factor of ten. (a) The main ring and halo are visible at right, with the Amalthea ring extending outward; the Thebe ring is only marginally visible. (b) Thebe's ring is plainly visible. (c) The Thebe ring reveals its outward extension, which matches the thickness of the ring itself in panel (b). The increasing background noise toward the left side of the image is an artifact, due to the decreasing exposure times of the mosaicked frames. The mosaic is oriented with Jupiter's north pole pointed upward. The phase angle ranges from 177.3° at left to 178.9° at right. The ring is open by only 0.15°.