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Orbital dynamics of the Uranian moon Mab

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Abstract

The Uranian moon Mab, located in Uranus' outer ring system, has been observed to be undergoing significant changes in its orbit about Uranus. These changes are not attributable to gravity flattening effects or mean-motion resonances, which suffice to elucidate the motion of all other known Uranian moons. Mab was discovered in 2006 [1], along with the dusty μ-ring through analysis of images obtained using the High Resolution Channel (HRC) on the Hubble Space Telescope (HST). The HST images catalogue the behavior of Mab during the period 2003 to 2007. In this paper, we explore the influence of the presence of other small moonlets in the neighborhood of Mab. In particular, we examine the dynamics of non-collisional orbital interactions between Mab and a cloud of thus far undetected moonlets.

1. Introduction

Over twenty years after Voyager's Uranus encounter, Showalter and Lissauer [1] announced the discovery of an outer ring system composed of the ν-ring and the μ-ring. Deep exposures from July 2003 to August 2005, taken using the HRC of HST's Advanced Camera for Surveys (ACS), revealed the existence of two new dusty rings: the ν-ring and the μ-ring. Two new moons were discovered too: Mab and Cupid [1]. The system, as a whole, is described as constituting "a densely packed, rapidly varying, and possibly unstable dynamical system." [1] The focus of this paper is on the moon Mab, which shares its orbit with the dusty μ-ring.

Mab is situated in what Showalter and Lissauer [1] term Uranus' "second ring system"; the first ring system consists of inner rings accompanied by the "Portia group". The innermost of the five large Uranian moons, Miranda, lies to the outside of Mab's orbit, with Puck flanking Mab's orbit on the inside. They state that, assuming that Mab shares compositional similarities with Puck or Miranda, its size is likely between $6km$ and $12km$; hence based on current observations, it competes with Cupid for the title of smallest detected moon in the Uranian system. They show that the orbit of Mab is not well understood after comparing its orbital position derived from the Voyager flyby data (1986) to HST data (2003-2006). The orbit of Mab does not fit the expected precessing Keplerian ellipse resulting from the oblateness of Uranus; the fit residual is approximately 0.8 pixels, which equates to approximately $280km$, given that the pixel size is $350km$ at Uranus' opposition distance [1]. This large residual is not likely to be due to measurement errors, given the fact that Mab is fairly isolated from other moons and is bright. This indicates that we are currently overlooking an essential part of the dynamics that determines the orbit of Mab.

In this paper, we address the apparently anomalous motion of Mab around Uranus and propose that the dynamics we are missing is the gravitational effects of a belt of undetected moonlets in the neighborhood of Mab that push and tug on it along its orbit. This pushing and tugging results in significant variations in the orbit of Mab, altering its orbital elements sufficiently to appear as though Mab is off from its expected orbital position. We explore parameter space and discuss the likelihood of additional moons causing the observed anomalous motion of Mab.

2. Problem Statement and Model

The problem statement we treated can be stated as follows: "Can the anomalous motion of Mab be explained by the presence of additional undetected moonlets in its neighborhood?" We answered this question by making use of a simplified dynamical model that allowed us to scan parameter space efficiently and thoroughly. Here, we present the model that we used and justify the assumptions that we made.

We setup a random walk-type model (RW) to analyze the dynamics of Mab's orbit. The RW model is based on reduced dynamics of the full gravitational N-body problem. As the state of each moon is determined by six parameters, and with the mass unknown too, for N hypothetical moons in the system, there are $7N$ unknowns. This rapidly leads to numerical difficulties when exploring parameter space. To make the problem numerically tractable, we made a number of simplifying assumptions:

- The moons are all assumed to be small with respect to Mab, i.e., Mab is assumed to be at the top end of a distribution of moons in the neighborhood of the μ-ring.
- Encounters between Mab and other moons in its vicinity can be modeled as impulsive fly-bys.

These assumptions enabled us to consider a reduced-dynamics model, illustrated in Fig. 1. Here, we describe the dynamics during each panel in Fig. 1:

a During this stage, Mab is in quiescence, as it does not experience encounters with any neighboring moons.

b At a random time, Mab experiences a "kick". This is effectively an impulsive kick that causes its velocity to change instantaneously, whilst its position remains unchanged. The net effect is that Mab's orbit changes instantaneously. We generated the time of the kick and its components based on a realistic impulsive kick spectrum.

c During this stage, Mab is once again in quiescense.

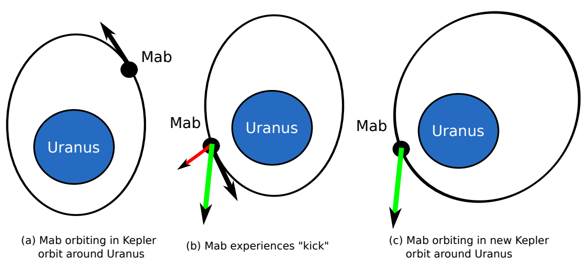

Figure 1: Random walk model describing Mab's motion around Uranus

3. Summary

We studied a reduced-dynamics model of the orbital motion of Mab due to the presence of other undetected moonlets in its vicinity. In particular, we studied parameter space to determine the likelihood of a suite of such moonlets causing the observed anomalous motion of Mab. We discuss the results obtained with a view to the current observations of the system.

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References

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