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Aegaeon (Saturn LIII), a G-ring object ☆

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ABSTRACT

Aegaeon (Saturn LIII, S/2008 S1) is a small satellite of Saturn that orbits within a bright arc of material near the inner edge of Saturn's G-ring. This object was observed in 21 images with Cassini's Narrow-Angle Camera between June 15 (DOY 166), 2007 and February 20 (DOY 051), 2009. If Aegaeon has similar surface scattering properties as other nearby small saturnian satellites (Pallene, Methone and Anthe), then its diameter is approximately 500 m. Orbit models based on numerical integrations of the full equations of motion show that Aegaeon's orbital motion is strongly influenced by multiple resonances with Mimas. In particular, like the G-ring arc it inhabits, Aegaeon is trapped in the 7:6 corotation eccentricity resonance with Mimas. Aegaeon, Anthe and Methone therefore form a distinctive class of objects in the Saturn system: small moons in corotation eccentricity resonances with Mimas associated with arcs of debris. Comparisons among these different ring-arc systems reveal that Aegaeon's orbit is closer to the exact resonance than Anthe's and Methone's orbits are. This could indicate that Aegaeon has undergone significant orbital evolution via its interactions with the other objects in its arc, which would be consistent with the evidence that Aegaeon's mass is much smaller relative to the total mass in its arc than Anthe's and Methone's masses are.

1. Introduction

Beginning in early 2004, images from the cameras onboard the Cassini spacecraft revealed the existence of several previously unknown small saturnian satellites: Methone, Pallene, Polydeuces, Daphnis and Anthe (Porco et al., 2005; Murray et al., 2005; Spitale et al., 2006; Cooper et al., 2008). Two of these moons – Anthe and Methone – are in mean-motion resonances with Saturn's moon Mimas. Specifically, they occupy the 10:11 and 14:15 corotation eccentricity resonances, respectively (Spitale et al., 2006; Cooper et al., 2008; Hedman et al., 2009). Both of these moons are also embedded in very faint, longitudinally-confined ring arcs (Roussos et al., 2008; Hedman et al., 2009). This material probably represents debris that was knocked off the relevant moons at low velocities and thus remains trapped in the same corotation resonance as its source body.

Images from Cassini also demonstrated that a similar arc of material exists within Saturn's G-ring, around 167,500 km from Saturn's center (Hedman et al., 2007). Images of this structure taken over the course of several years showed that it was also confined by a (7:6) corotation eccentricity resonance with Mimas. Furthermore, in situ measurements of the plasma environment in the vicinity of the arc suggested that it contains a significant amount of mass in particles larger than the dust-sized grains that are the dominant source of scattered light observed in images (Hedman et al., 2007).

In late 2008, during Cassini's Equinox Mission (2008–2010), images of the arc taken at lower phase angles and higher resolutions than previously possible revealed a small, discrete object. Since the object was most visible at low phase angles and could be tracked over a period of roughly 600 days, it is almost certainly not a transient clump of dust but instead a tiny moonlet that represents the largest of the source bodies populating the arc. The discovery of this object was therefore announced in an IAU circular, where it was designated S/2008 S1 (Porco et al., 2009). More recently the International Astronomical Union has given it the name Saturn LIII/Aegaeon. As will be shown below, Aegaeon, like Anthe and Methone, occupies a corotation eccentricity resonance with Mimas, and all three of these small moonlets are associated with arcs of debris. These three objects therefore represent a distinct class of satellites and comparisons among the ring–moon systems have the potential to illuminate the connection between moons and rings.

Section 2 below describes the currently available images of Aegaeon and how they are processed to obtain estimates of the brightness and position of this object. Section 3 presents a preliminary analysis of the photometric data, which indicate that this object is approximately 500 m in diameter. Section 4 describes

☆ This paper is dedicated to the memory of Kevin Beurle.

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the orbital solutions to the astrometric data, which demonstrate that Aegaeon's orbit is indeed perturbed by the 7:6 corotation eccentricity resonance with Mimas. However,we also find that a number of other resonances, including the 7:6 Inner Lindblad Resonance, strongly influence Aegaeon's orbital motion. Finally, Section 5 compares the various resonantly-confined moon/ring-arc systems to one another in order to clarify the relationship between Aegaeon and the G-ring.

2. Observational data

The images discussed here were obtained with the Narrow-Angle Camera (NAC) of the Imaging Science Subsystem (ISS) onboard the Cassini spacecraft (Porco et al., 2004). All images were initially processed using the CISSCAL calibration routines (Porco et al., 2004) that remove backgrounds, flat-field the images, and convert the raw data numbers into I/F, a standardized measure of reflectance. I is the intensity of the scattered radiation while πF is the solar flux at Saturn, so I/F is a unitless quantity that equals unity for a perfect Lambert surface viewed at normal incidence.

2.1. Image selection

The object was first noticed in two images taken on August 15 (DOY 228), 2008 (see Fig. 1). These images were part of a sequence designed to image the arc in the G-ring for the purposes of refining its orbit. Compared with previous imaging of the G-ring arc, the images used in this campaign were taken at lower phase angles and had better spatial resolution. This was more a result of the constraints imposed by the orbit geometry than a conscious effort to search for discrete objects in this region. When these images were taken, Cassini was in a highly inclined orbit with the ascending node near apoapse on the sunward side of the planet close to Titan's orbit. During these ringplane crossings, the faint rings could be imaged at high signal-to-noise, and the low-phase angles were considered desirable because this geometry was comparatively rarely observed prior to this time. However, this geometry also turned out to be useful for detecting small objects in the G-ring.

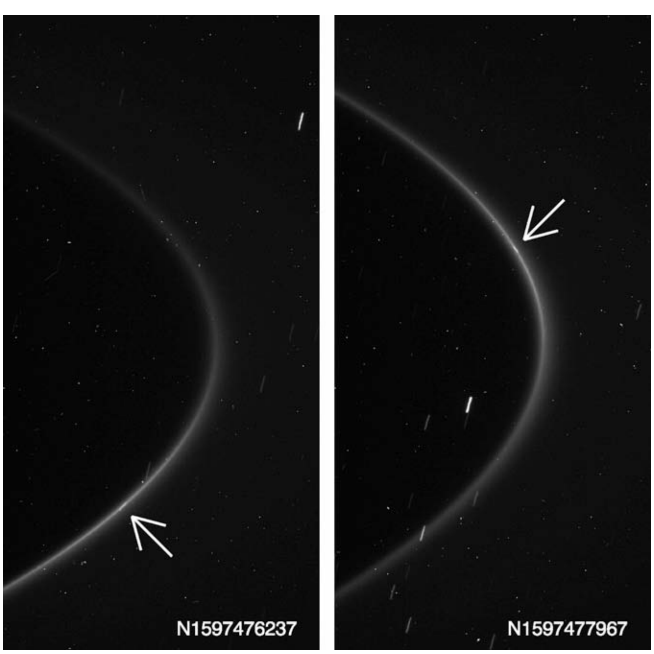

Fig. 1. The pair of images taken on August 15 (DOY 228), 2008 in which Aegaeon was first noticed. The arrows point to this object, which appears as a small streak within the core of the G-ring due to its orbital motion through the field of view over the course of these long-exposure images. Both images are rotated so that Saturn's north pole would point towards the top of the page.

Two images from this sequence (Fig. 1) contained the core of the arc and also showed a short, narrow streak in the G-ring. The streaks are aligned with the local orbital motion of the arc and are clearly not aligned with the streaks associated with stars in the field of view. The lengths of the streaks are consistent with the expected movement of an object embedded in the arc over the exposure time, and the positions of the streaks in the two images are consistent with such an object's motion over the $\sim$30 min between the two images.

Since this sequence was part of a larger campaign designed to track the arc and refine its orbit, this object was quickly recovered in subsequent image sequences targeted at the arc with comparable viewing geometries, yielding 17 additional images of the object (Fig. 2). With these data, a preliminary orbit fit was used to search for earlier images of the object. However, only two images from the prime mission turned out to provide clear detections of Aegaeon (Fig. 3). This paucity of pre-discovery images is because this object is both extremely faint and embedded in the G-ring arc. While the object's faintness means that it cannot be clearly detected in images where the exposure times are too short, its proximity to the G-ring arc means that its signal cannot be isolated if the image resolution is too low or the phase angle is too high.

Table 1 lists the 21 NAC images used in this analysis, which are all the images prior to February 20 (DOY 051), 2009 in which Aegaeon has been securely identified. These images cover a time interval of almost 600 days and a range of phase angles from 13° to 43°.

2.2. Image data reduction

Since Aegaeon is not resolved in any of the images listed in Table 1, the only data we can extract from each image are its position in the field of view and its total integrated brightness. However, estimating even these parameters from these images is challenging because the light from Aegaeon is smeared out into a streak and because the light from the object must be isolated from the background signal from the G-ring arc. The following procedures were used to obtain the required photometric and astrometric data.

In order to isolate the moon's signal from that of the G-ring, each image was first roughly navigated based on stars within the field of view. Then, the radius and longitude in the ringplane observed by each pixel was computed. Based on visual inspection of the image, a region of the image containing the arc was selected (in general these regions are 10–20 pixels across). A second region extending 10 pixels beyond this zone on either side along the ring was then used to construct a radial profile of the G-ring and arc in the vicinity of the moon. A background based on this profile was then subtracted from the pixels in the selected region, which removes the signal from the G-ring and arc, leaving behind only the signal from Aegaeon itself.

Two images were handled slightly differently because they were taken in a nearly-edge-on viewing geometry (N1563866776 and N1603168767). In these cases instead of computing radius and longitude for each pixel, we compute the radius and vertical height above the ringplane and remove a vertical brightness profile from the region around the object.

After separating Aegaeon's signal from the G-ring, the total brightness of the object in each image is estimated in terms of an effective area, which is the equivalent area of material with $I/F = 1$ required to account for the observed brightness:

$$A_{eff} = \sum_x \sum_y I/F(x,y) * \Omega_{pixel} * R^2, \tag{1}$$

where x and y are the line and sample numbers of the pixels in the selected region, $I/F(x,y)$ is the (background-subtracted) brightness