Supporting Online Material for

The Dark Side of the Rings of Uranus

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We observed Uranus and its ring/moon system between 14:20 and 15:20 UT on 28 May 2007 with the Keck II telescope on Mauna Kea, Hawaii. We used the adaptive optics (AO) system (SI) with the facility near-infrared camera NIRC2, a 1024 × 1024 detector array. In March 2007, this AO system was upgraded with a new wavefront sensor and a new wavefront controller, to improve image quality. The data presented here were taken during an engineering night, as part of an effort to characterize the performance of the AO system when guiding on extended sources (S2). As shown in the main paper, the system worked very well, and the image quality is superb.

All observations were obtained in the K’ band (1.95–2.30 µm). We used NIRC2 in high angular resolution mode, 0.00994” ± 0.00003” per pixel (S3), which translates to 146 km/pixel on May 28, yielding effective resolution of ~ 660 km. The ring opening angles with respect to the Earth (B) and the Sun (B_o) were, 0.7° and -2.0° (Fig. 1 in main text), respectively; we thus observe the dark (unlit) side of the rings. We combined 30 images, each with an integration time of 60 seconds, for a total integration time of 30 minutes.

All images were processed using standard near-infrared data reduction techniques (flat-fielded, sky-subtracted, with bad pixels replaced by the median of surrounding pixels). The telescope performed essentially at its diffraction limit, which is 0.046” at K’ band (S4). The Strehl ratio, the ratio of the peak intensity of the observed point spread function (PSF) to the theoretical maximum for the telescope aperture, was typically ~ 0.4 while guiding on Uranus, and between 0.5 and 0.65 on bright point sources.

The May 2007 image is compared with data of the lit side of the rings, which were taken in July 2004 (S3) and on 01 August 2006. The latter data have not been published.
elsewhere, and form part of our long-term monitoring program of Uranus. The data were processed using the same techniques as used in (S3) and in this paper.

Using our data from July 2004 and the planet itself for calibration (there were no photometric stars observed during our observing run), we converted the number of counts per second into units of \( I/F \), a dimensionless quantity, where \( I \) is the observed intensity and \( \pi F \) is the solar flux density as received by Uranus at \( K' \). We assumed the \( I/F \) did not change between 2004 and 2007, a reasonable assumption based upon prior observations (S3, S5).

After shifting all images to a common center, we averaged the data on each day. We used both median and regular averaging techniques; we present only median averaged images here, where all satellites have been successfully rejected.

North-south scans through the north side of the images were shown in Fig. 4a. In Fig. S1 we show scans through both the north and south sides of the rings, to illustrate the asymmetries and changes therein between the two sides. These scans were corrected for scattered light from Uranus by subtracting a radial scan obtained in the same way as the ring scans, but after rotating Uranus by 15° on the sky.

Because of the change in ring inclination angles, one would expect the \( \varepsilon \) ring—with an optical depth \( \tau \sim 0.25 \) (S3)—to brighten by approximately a factor of \( \sim 2.5 \) between 2004 and 2006 based upon the geometry factors in (S3). Instead, the \( \varepsilon \) ring decreased in intensity at both the north and south ansae (Fig. S1), which implies that the particles in the \( \varepsilon \) ring are beginning to occult each other at this particular geometry.

Profiles of the uranian rings were generated from several Voyager images, as discussed in the main text. Each image was calibrated according to standard techniques using the VICAR image processing package distributed by the Multi-Mission Image Processing Laboratory at JPL. Procedures remove reseau markings and hot pixels,
subtract a background or “dark current”, convert to $I/F$, and remove geometric distortion from the frame. The image geometry is reconstructed from the spacecraft position and camera orientation, as recorded in the Supplemental Experiment Data Record (“SEDR”) file. From this information we derive the radial position in the ring plane corresponding to each pixel. The pixels are grouped into narrow radial bins and their values are coadded to enhance signal-to-noise. This produces a profile $I/F$ vs. radius. For optically thin rings, we multiply by $\sin(B)$ to obtain the “normal $I/F$,” i.e., that which would be measured from a normal view of the rings at the same phase angle.

**Figure S1:** Radial profiles through the main ring system for three different dates. (A) The northern ansa in sunlight in 2004 (black) and 2006 (cyan) and the dark side of the northern ansa in 2007 (red). (B) The southern ansa in sunlight in 2004 (black) and 2006 (cyan) and the dark side of the southern ansa in 2007 (red). Note the difference in scale between panels A and B.

**REFERENCES AND NOTES**

Fig. S1