ASTROPHYSICS

Fingerprints in Saturn's F ring

A planet's rings can be distorted by the gravitational pull of its satellites, and these complex interactions have been difficult to disentangle. Saturn's moon Prometheus, however, has now been caught returning to the scene of the crime.

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Saturn's narrow, tortured F-ring confounded scientists when the first images of it were beamed back from the Voyager spaceprobes more than 25 years ago. The ring — outside the main band of Saturn's rings — seemed to be composed of three to four separate but possibly intertwined strands of material, confined radially by two nearby small satellites, Prometheus and Pandora. It has long been suspected that the gravitational tugs from these moonlets perturb the ring, contributing to its bizarre appearance (Fig. 1). The details of this process, however, remained murky for a quarter of a century until the Cassini orbiter arrived at Saturn last year. Now Carl Murray and others on the Cassini Imaging Team present[1], in *Nature*, incredible images of regular structure in the F ring that, coupled with numerical simulations, reveal exciting new details of the gravitational interactions between ring and moons.

Thirty years ago, Saturn was thought to be the only ringed planet, surrounded by three broad and presumed featureless swaths of unused debris left over from the age of satellite formation. Within a single decade, however, this established order was overturned by a rash of ground- and space-based discoveries. The three other giant planets were all found to have ring systems and, on closer inspection, the 'featureless' rings of Saturn broke up into thousands of closely spaced ringlets with structure as small as camera resolutions could reveal. Perhaps most surprisingly, the rings of Jupiter were found to be totally unlike those of Saturn, and the uranian and neptunian ring systems were different still.

We now recognize three main types of planetary rings in the Solar System. The first are broad massive rings, replete with fine-scale structure, some of which is produced by embedded moonlets and some by gravitational resonances with both nearby and distant satellites. Saturn provides the only example of this type. Second are broad sheets of dusty debris that are found in close association with small source satellites. All of Jupiter's rings appear to be of this type, and additional examples are found around each of the other giant planets. The third ring type consists of sharply defined narrow rings found primarily at Uranus and Neptune.

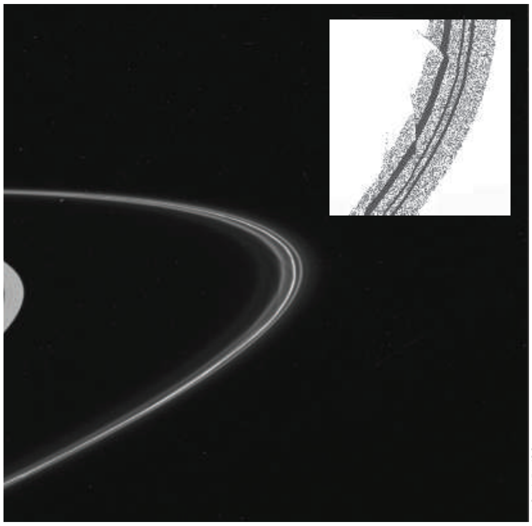

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Figure 1 Saturn's F ring. This wide-angle camera view of the F ring was captured by Cassini shortly after the spacecraft was put into orbit around Saturn in July 2004. The outer edge of the main rings are visible on the left. Several strands of F-ring material are visible, as well as a broadly extended and more tenuous sheet of orbiting debris. The nearby satellite Prometheus is just interior to the ring at the upper left of the image. Simulations of the ring's structure (such as the example inset), showing a stream of particles pulled periodically towards Prometheus, match the exquisite detail of the new images[1].

When they were first discovered, narrow rings came as a complete surprise because mutual collisions among orbiting debris, which dissipate orbital energy while preserving angular momentum, lead inexorably to radial spreading. The presence of shepherding satellites resolves this paradox, as these exchange energy and angular momentum with ring particles, slowly separating from each other while keeping ring material radially confined between them. Shepherding satellites were eagerly sought in Voyager images and several examples were found: Cordelia and Ophelia confine Uranus's Epsilon ring, and Neptune's Galatea keeps the Adams's ring confined while simultaneously forcing its unusual azimuthal asymmetry.

Nearly all isolated narrow rings are found around the ice giants, but an exception is Saturn's F ring — the closest and, accordingly, best-studied archetype. Located just 3,500 km exterior to the outer edge of the Saturn's main rings, the F ring seems to be confined by two shepherding satellites, Prometheus and Pandora. This system has been studied by a number of scientists[2–4], who found that a nearby satellite imposes periodic structure on the ring with a characteristic wavelength, $\lambda = 3\pi\delta a$, where δa is the difference between the ring and moon orbital radii.

Thus the perturbations of Prometheus, and perhaps also those of the smaller and more distant Pandora, are imprinted on the F ring. Similarly, small satellites embedded in Saturn's main ring clear out gaps and induce wavy features along the gap edges.

Prometheus makes regular forays into the inner dusty edge of the F ring with each half-day orbit around Saturn. But what happens when a satellite approaches its neighbouring ring even more closely? Over 20 years ago, Nicole Borderies and colleagues[5], followed later by Murray and Giuliatti Winter[6], showed that long-term oscillations in the slightly elliptical orbits of both the shepherding satellites and the F ring itself would, over a decade-long timescale, bring Prometheus into the very core of the ring. The new images[1] recorded by the Cassini Imaging System show the results of these strong interactions, and fresh numerical simulations[1] using these data paint an elaborate picture. Both images and simulations show that, as Prometheus moves close to the ring, a stream of ring particles is pulled gravitationally towards the moon, and long-lasting channels are opened in the ring, due to systematic kicks to ring-particle orbital energies (Fig. 1). The channels evolve over the period of Prometheus' orbit around Saturn, shear out with time, and preserve a record of the last few dozen encounters. And the periodic spacing of these features fits the wavelength prediction of $\lambda = 3\pi\delta a$.

In the current epoch, Prometheus affects only the relatively broad sheet of background material and the innermost of the F ring's denser strands. Over the next four years, however, the most distant point of Prometheus's orbit will march slowly outwards into the denser portions of the F ring. The gravitational interactions will become more intense and should result in more pronounced streamers and channels. When the dense strands themselves are significantly perturbed, they might clump and display unusual time-variable behaviour[7]. And what will happen when the shepherd begins to feed upon its flock? Time, and an on-call orbiting spacecraft, will tell.

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