AGE AND FATE OF SATURN'S RINGS

Abstract

When Saturn was the only known ringed planet, the rings were believed to be as old as the solar system, some 4.5 billion years old in the conventional chronology. The existence of the rings to the present day was taken as evidence of this chronology. In the 1970s and 1980s, other planets were found to have short-lived, rapidly dissipating rings with life times of the order of millennia. Subsequently, the view of Saturn's rings' age began to change. They are now viewed conventionally as no more than hundreds of millions of years old, and a former prop of the conventional chronology has now vanished. Furthermore, an examination of ring observations and data unconstrained by conventional chronology indicates that the actual life time of Saturn's rings may be of the order of tens of thousands of years, and possibly less.

INTRODUCTION

A puzzle for evolutionary chronology began with the Voyager 1 flyby past Saturn's rings in 1980. Before then, earth bound telescopes provided little ring detail, and planetary rings were assumed to have endured virtually changeless since the emergence of the solar system from the solar nebula -- a vast cloud of gas and dust -- some 4.6 billion years ago.[1-3] "Everyone had expected that collisions between particles in Saturn's rings would make the rings perfectly uniform."[4]

In 1916 Jeffreys had claimed that "the frequency of collision [of ring particles] is very great, and ... on account of the loss of relative motion at every collision, the rings must long ago have reached a state in which all the particles are moving in very accurate circles, all in the same plane."[5-7] This view arose from belief in the rings' great age,[8] but Voyager 1 showed that the rings are highly structured and probably young.[9] There was more structure than could be expected to persist over 4.6 billion years, unless all ring-binding forces were accounted for. Efforts to locate sufficient binding forces have failed, and a "growing number [of astronomers] believe that the rings of Saturn are constantly ... changing due to fragmentation of moonlets and input of new ring particles."[10,11]

Even so, there is a reluctance to associate ring change with ring dissipation,[12] since this could imply a young solar system. This reluctance did not exist before the ascendancy of evolutionary chronology.[13] In that day Saturn's rings were acknowledged to be rapidly changeable and possibly dissipating. Space probes have rediscovered rapid ring change and dissipation. For Jupiter's rings, "[Ring] particles should last only a very short time -- perhaps only a few thousand years ..."[14,15]

Of Saturn's rings and planetary rings generally, "it now appears that the length of time for planetary rings to dissipate is relatively short."[16,17] Regarding Uranus' rings, "The thin outer atmosphere of Uranus extends into the rings, so it should slow down very tiny dust particles and cause them to sink into the inner atmosphere in a few thousand years or less ... Collisions between ring particles ... slowly [make] the ring wider."[18,19]

SATURN'S RINGS HAVE BEEN WIDENING RAPIDLY

Since Jupiter's rings have dissipation times of a few millennia, and Uranus' rings maybe less, could Saturn's rings be dissipating this fast? Saturn's rings have little matter, "only about a millionth of the mass of our moon,"[20] similar to that of smaller asteroids such as 243 Ida or 253 Mathilde.[21] Their small mass suggests that the rings could "empty out" fairly quickly. Indeed, Jupiter's rings are thought to be in part the product of the dissolution of two moons, Adrastea and Metis,[22] both with masses comparable to the mass of Saturn's rings.[23]

Alexander documented 350 years of widening in Saturn's A and B rings.[24,25] In the 1850s Otto Struve assessed observations from the previous two centuries which indicated ring-spreading into Saturn at a rate of some 60 miles per year.[26-28] But with hypothetical assumptions from the popular nebular hypothesis which claimed a naturalistic origin, an old age, and little change in the solar system presently, Struve's analysis was considered questionable.[29] So strong had belief in the nebular hypothesis become that Taylor inconsistently claimed ring spreading was compatible with it.[30] However, Maxwell had shown that Saturn's rings are particulate and not rigid disks or liquid. Maxwell's theoretical predictions were confirmed by observation,[31,32] and Maxwell considered Struve's analysis consistent with theory.[33]

Nevertheless, Struve had failed to measure continued ring spreading,[34] and in 1895 Lewis concluded that ring observations were not in agreement ("accordant") because of "the great difficulty in making these measures."[35] But then he dogmatically stated that Saturn's rings were "certainly" not undergoing long-term change, even though his data showed C-ring spreading.[36] Lewis thus laid the groundwork for Jeffreys' concept of virtually changeless, very old rings.

SATURN'S C RING FORMED RECENTLY

Saturn's most prominent rings are the A, B, and C rings.[37,38] However, the C ring was not visible until the 1800s: "William Herschel, the foremost astronomical observer of his time (1738-1822), makes no mention of the [C ring] in any of his writings, and it is inferred that it was not then a conspicuous object. If this inference be correct, we must conclude that this ring is rapidly growing, and that the rings of Saturn are probably comparatively recent introductions to the solar system."[39] Yet the C ring now can be seen "with telescopes of moderate size."[40] Since Herschel's telescopes were among the best of his day, with Saturn a "favourite object of study,"[41] one is led to conclude that he missed the C ring because it was absent. The first recorded observation was in 1848.[40,42] Thus one of the three prominent rings of Saturn has evidently developed since the early 1800s. The inner edge of the C ring is approaching the planet,[36] and Napier and Clube calculated the rate of approach as 60 miles per year.[43]

The history of C ring observations implies rapid ring spreading and dissipation. The inner edge of the B ring is now 91,975 km from the center of Saturn, and the inner edge of the C ring is at 74,658 km.[44] Thus the width of the C ring is 17,317 km,

or about 15,000 km, a width which developed since about 1850. This implies an infall of ring particles over some 100 km/yr, or 60 mi/yr, in agreement with the in-spreading computation of Napier and Clube. Like Jupiter's and Uranus' rings, Saturn's rings appear to be decaying in a millennial time-frame. Ring dissipation does not require millions of years. When planetary rings were thought to be old, they were taken as evidence for an old solar system. Intimation of their youth therefore obliterates a prop of the conventional chronology.

HAVE NEW SATURNIAN RINGS FORMED SINCE THE C RING?

Baum in 1954 reported "dusky nebulous matter in the form of an additional ring" beyond ring A, with "a diffuse fringe [extending] the ring system beyond its normal limits."[45] Baum may have been seeing one or more of the now-recognized tenuous outer rings (the F, G, and E rings). On the other hand, he may have been seeing dissipation of A ring material outward, and if ring particles "reach the outer edge of the rings, they leave the ring system."[16] In 1967 Feibelman likewise reported "an extension or at least a gradual tapering of the outer edge of the A ring."[46] Thus it appears that the A ring is losing particles to the outer F, G, and E rings, and eventually to space beyond. How trustworthy are such ground-based observations? Dismissing them as subjective phenomena would be premature. In fact existence of the F ring had been theorized before the Voyager flybys, though in characteristic fashion Jeffreys discounted this prediction.[47]

Further, inside the C ring, "the possibility of a faint ring ... was raised some time ago [from ground-based observations], and this D ring was actually found."[38,48] Ground-based discovery of the D ring before its Voyager detection implies validity for ground-based ring-spreading observations. Like the outer F, G, and E rings, the D ring seems to be composed of small particles. These particles are spiralling into Saturn: "individual ring particles work their way slowly inward ... If they move inward far enough, they encounter the tenuous outer layers of the planet's atmosphere and are destroyed."[16] Ring particles of Jupiter and Uranus also show this behavior.[49,50] To sum up, particles in outer rings dissipate into space; those in innermost rings fall toward the planet.

EFFORTS TO SAVE LONG RING CHRONOLOGIES HAVE FAILED

The Uranian and Jovian ring systems were discovered shortly before the Voyager views of Saturn's rings, and according to NASA appeared too young to exist in an old solar system: "The theory that explained how Saturn's rings could persist through 4.6 billion years of solar system evolution also explained why Saturn was the only planet that could have a ring. Then those theories had to be revised to account for the rings of Uranus. The revisions implied that Jupiter would not have a ring. Now Jupiter has been found to have a ring and we have to invent a theory to explain it."[51]

The older unworkable theory was the orbital resonance hypothesis.[52] When Saturn was the only known ringed planet, orbital resonances, due to moons of Saturn gravitationally acting on ring particles, could account for the limited ring structure visible from earth. The resonance hypothesis "had been worked out with fewer than a half-dozen rings [of Saturn] known. The ring structure the Voyagers discovered is too complex to ... explain thousands of rings."[53] "A thousand rings seemed a monumental problem for theorists. They had run out of resonances long ago."[54,55] NASA's conclusion: "No theory has yet been developed that explains how all three of these planets could have rings for so long," i.e., 4.6 billion years.[51]

The "shepherd moon hypothesis" was then proposed to give planetary rings a long lifetime. As originally conceived, shepherd moons were supposed to corral ring particles, keeping entire ring systems together over eons.[56,57] The shepherd moon theory was therefore once used to account for *all* ring structures of Saturn, Jupiter, and Uranus.[22,58,59]

After the Voyager 2 flyby of Uranus' rings in 1986, NASA scientist Bradford Smith stated, "We are assuming [the existence of shepherds], because we don't know any other way to do it [i.e., preserve the rings]."[60] Since then, conventional opinion on the antiquity of planetary rings has changed due to difficulties in the shepherd moon theory. Rings are no longer viewed as debris from the solar nebula with an age of billions of years.[61] Instead the rings have formed by the fracturing of one or more moons, and therefore must have formed "recently."[63] "Recently," however, is a relative term, and may signify millions of years.[19,64]

Nevertheless, shepherd moons continue to be presented as the reason planetary rings exist.[65] Though ring decay occurs, it is still not acceptable to allow this fact to imply a young solar system, and shepherds are invoked to extend a ring's chronology. Therefore, rings must be simultaneously decaying, yet confined by shepherds: "[Planetary rings] tend to spread ... Sometimes planetary rings are kept in place by the gravitational force of shepherd moons. Saturn has a very intricate ring system with lots of moons helping to keep its rings together."[66] This is false -- "lots" of shepherds have not been found. Another false claim is that the "`shepherding' effect has been found to confine a number of rings in the solar system."[67] Out of hundreds of thousands of ringlets in planetary ring systems, only a few have been found with nearby moonlets interpreted as shepherds. Most notable are the F ring of Saturn, Jupiter's ring system, and Uranus' thick ring. As mentioned above, the last two are now viewed primarily as rapidly decaying, despite putative shepherding effects.

WHERE ARE THE SHEPHERD MOONS?

"Shepherd moons" such as Prometheus and Pandora, moons of Saturn near the F ring, have been photographed,[68] but mere existence does not confirm they are acting as shepherds. Further, moons once described as "shepherds" seem to be disintegrating into the ring structure. This is acknowledged for Jupiter and Uranus.[69] During the 1995 Saturn ring plane

crossing, the Hubble Space Telescope looked for new satellites. Two were announced as new in a press release and were designated 1995S1 and 1995S2. They turned out to be the already-known moons Atlas and Prometheus. Even more interesting, five other bodies, 1993S3 to S7, were observed, but were later "hypothesized to be shattered moonlets" in the F ring.[70] Conclusion: bodies perceived as "shepherd" moons of Saturn are undergoing disintegration within the ring structure.

Discussing these fragmented satellites, Philip Nicholson of Cornell University said, "[O]ne scenario for the origin of Saturn's ring system is that it is made up of countless fragments from several pulverized moons. ... [T]he new objects orbit Saturn near the narrow F ring, which is a dynamic transition zone between the main rings and the larger satellites. [Fragmented moons would eventually] spread around the moon's orbit to form a new ring."[71] Showalter surmised that Saturn's narrow G ring, thought to be composed of very fine dust, may in fact be "the `decaying corpse' of a moon destroyed by meteoroid impact."[72] Since the F ring is a "dynamic transition zone" where satellite fragmentation is likely to occur, what is the possibility that the so-called "shepherds," Prometheus and Pandora, could be undergoing the same type of dissolution?

A stunning observation answered this question. The reason the previously mentioned satellite 1995S2 was not initially recognized as Prometheus is that its location did not match the position expected. Prometheus had "slipped in its orbit by 20 degrees from the predicted position ... a consequence of a `collision' of Prometheus with the F ring, which is believed to have occurred in early 1993."[71] Thus Prometheus is not so much "shepherding" the F ring as mutually interacting with it, sometimes colliding with it, and likely disintegrating as a result.

It is doubtful that the so-called shepherds of the F ring ever fulfilled that function. In 1980, Voyager 1 detected a twisting or "braiding" in the F ring attributed to Prometheus and Pandora, but Voyager 2 in 1981 detected "no signs of braiding in the F ring."[53,73] Thus the "shepherds" Prometheus and Pandora are not shepherds after all. Instead, Prometheus and Pandora are fragments of larger bodies en route to further disintegration, the same process thought to have produced the moonlets 1995S3 to S7. Prometheus and Pandora are not spherical and have an irregular shape.[74] They seem either to be captured asteroids or fragments of a larger moon. The F ring itself is expected to widen over time, eventually dissipating altogether.[75]

The Voyager missions demolished the belief that planetary rings must be old. The Cassini probe began orbiting Saturn in 2004. The creationary implications of its data are awaited with anticipation.

Conclusions

Longevity estimates for Saturn's rings have undergone steady downward revision since the 1970s. The resonance theory was invoked to prevent such downward revision, but failed to counter indications that planetary rings are much younger than the conventional age of the solar system. The shepherd moon theory continues to be employed to minimize the downward revision. Despite widespread belief that shepherd moons such as Prometheus and Pandora have preserved Saturn's rings for possibly hundreds of millions of years, the putative shepherd moons appear to be pulverized and dissipating along with the ring structure. The origin of Saturn's rings seems to be the "destruction" of once-existing moons.[76] The rings appear to be a short-lived phenomenon which will have dissipated in a time frame of order tens of thousands of years at most, and possibly millennia.

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