LETTERS

IUE detection of bursts of H LYα emission from Saturn

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An extended source of H Lyα emission (1,216 Å) from the vicinity of Saturn has been detected previously by a rocket-borne spectrometer[1], the OAO-Copernicus satellite[2], and the Pioneer 11 spacecraft[3]. During the rocket experiment, in which Saturn was observed on 15 March 1975, 700 R±50% of Lyα emission was detected from the planet and an additional 200 R±50% from a 53 arc s diameter circular area centred on the planet. This additional emission was believed to emanate from the ring system. The Copernicus observations, carried out in April 1976 and April 1977, yielded Lyα intensities of 1.40±0.45 kR for the saturnian disk, <100 R for the rings, and 200±100 R for Titan's torus. During the Pioneer 11 Saturn flyby in August–September 1979, the long-wavelength channel UV photometer detected emissions from the planet, the vicinity of the rings, and the orbital path of Titan; these emissions were interpreted as resonant scattering of solar Lyα radiation by H atoms and possibly auroral Lyα emission from the planet. Several mechanisms for producing H atoms outside of Saturn's atmosphere have been proposed, including sputtering of water ice from the rings by magnetospheric charged particles[4], 'photo-sputtering' of the ring water ice by solar UV radiation[5], and escape of H atoms from Titan's atmosphere[6]. A more recent suggestion is the possible impact on the rings and subsequent neutralization of the protons from an extended saturnian ionosphere[15]. We report here a new investigation of these potential sources of Lyα emission in a series of observations of the saturnian system carried out between January and July 1980 using the short wavelength (SWP) spectrograph of the IUE Observatory[7,8]. North–south maps of the Lyα emission across the planet disk have shown pronounced spatial asymmetries in emission brightness. These asymmetries vary markedly on a time scale of days and are interpreted as bursts of Lyα emission of as much as 1 kR brightness averaged over a 6×10 arc s area, above a constant planetary emission level of 700–800 R. In fact, the Lyα emission peaks appear as essentially point source features in these data: if the emitting region is smaller than the 6×10 arc s instrumental resolution, the surface brightness must be proportionally higher.

Spatial imaging with the IUE has been accomplished both in a series of exposures of different regions of the saturnian system and by sampling within the field-of-view of the large spectrograph entrance aperture in single exposures. The image of the field-of-view subtended by the aperture is focused directly onto the detector at each wavelength; because the angular resolution of the instrument is 5–6 arc s on planetary objects and the large aperture extends 10×23 arc s, imaging perpendicular to dispersion is possible in a single exposure. By moving the ~16 arc s diameter image of Saturn 5–10 arc s between exposures along the major axis of the aperture (which is constrained to point roughly north–south), maps of the disk emission plus the background geocoronal and interplanetary Lyα emission immediately north and south of Saturn have been obtained with 6 arc s spatial resolution. In each of the exposures centred on the polar regions, therefore, the level of background Lyα is directly measured and subtracted from the planetary emission; in exposures centred on Saturn the background level has been determined by matching the level of planetary emission to that observed in the polar exposures immediately preceding or following. A relative sensitivity correction in the direction perpendicular to dispersion has been derived from exposures of the background Lyα emission and applied to the data reported here. The error in applying this correction has been determined by testing it on other exposures of background Lyα emission and measuring the average deviation from the mean level of emission; this error is ±200 R. The pointing of the spacecraft during the north–south maps has been determined by noting the position in the aperture of the sharp drop in grating-scattered long wavelength radiation at the northern and southern edges of the saturnian disk. The north–south positioning of the aperture is believed to be accurate to within 1–2 arc s. This same technique of north–south mapping has been used in observations of the polar auroral Lyα emission from Jupiter[9].

Representative north–south maps of the Lyα emission are plotted in Fig. 1 from observations performed on 19 January, 5 May and 22 July (all 1980). Non-equatorial peaks in the emission are apparent in the data from the first two days, while the July data are symmetric north–south with an equatorial brightness of 800 R. This equatorial brightness in the individual exposures on 22 July was measured over one-half of a rotation of the planet; therefore, 700–800 R is interpreted as a constant level of planetary emission from Saturn's upper atmosphere. The data of 22 July provide a good fit to a model emission profile

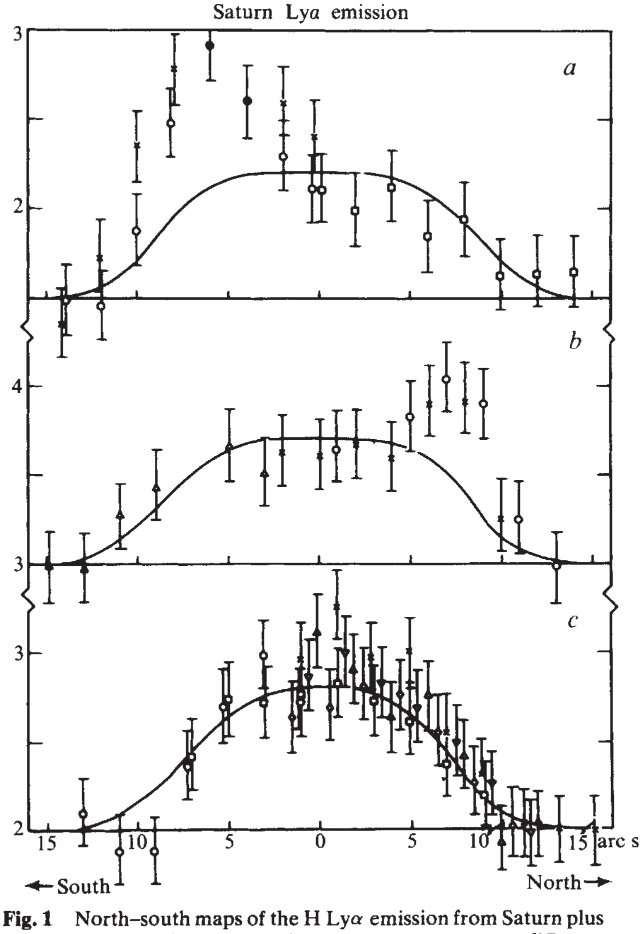

Fig. 1 North–south maps of the H Lyα emission from Saturn plus sky background. Different point characters represent different camera exposures, and the ±200 R error bars are discussed in the text. The measured background varied by as much as ±500 R in a series of exposures, and the exposures plotted have been normalized to the same level of background (set at the average background level observed on a given day). *a*, 19 January 1980; *b*, 5 May 1980; *c*, 22 July 1980.

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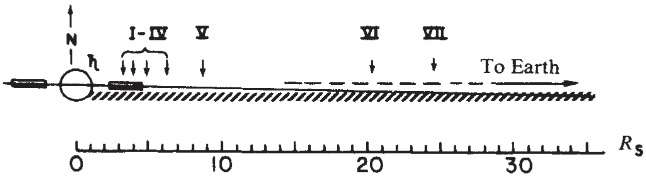

Fig. 2 Observing geometry during the exposures of 19 January 1980. The dashed line and arrow indicate the line-of-sight from the Earth, and the solid line represents the ring plane (which is tilted 1.6° south of the line-of-sight). The enhanced Lyα emission observed apparently from the south pole of Saturn could actually have come from anywhere in the shaded region. Roman numerals indicate the orbital radii of Saturn's inner moons (VI is Titan).

(the solid line in Fig. 1) representing a uniformly emitting disk of 800 R brightness smoothed by the 6 arc s instrumental resolution. Note that the decrease in emission from the equator to the poles in the model profile is due to the spatial resolution of the instrument, not limb darkening. If this emission is completely produced by resonant scattering of solar Lyα from upper atmospheric H it corresponds to an H column abundance on the order of 10^{14} cm^{-2}, following the simple resonant scattering model for Jupiter outlined by Clarke *et al.*[10]. This model assumes an exospheric temperature of 1,200 K, a solar flux at line centre at the Earth of 5.14×10^{11} photons cm^{-2} s^{-1} Å^{-1} (ref. 11), and no absorption by interplanetary H along the path to and from Saturn. The assumed temperature value is uncertain, but 1,200 K is consistent with the Pioneer 11 radio occultation data[12]. A disk-averaged Lyα intensity of 700–800 R implies that a homopause value of the eddy diffusion coefficient is in excess of 10^7 cm^2 s^{-1}. Uncertainties about the role of particle precipitation and the methane density distribution and temperature structure of the mesosphere and thermosphere prevent an exact calculation of the eddy diffusion coefficient at this time. Interplanetary absorption of Lyα on the round trip to Saturn has been modelled by Bertaux *et al.*[13], who predict 40% absorption at the time of these observations; thus, Saturn's Lyα emission could be significantly brighter as measured by a spacecraft in the vicinity of the planet. An H column of 10^{14} cm^{-2} is optically thick and Saturn should exhibit limb darkening at Lyα; however, with the existing spatial resolution it is not possible to distinguish between a cosine darkening function and a uniformly emitting disk. Note that the points plotted in Fig. 1 represent average brightness over an area extending 10 arc s in the east–west direction; assuming a cosine darkening east–west (as well as north–south), the actual sub-solar point brightness would be ~5% higher than that measured.

Exposures were also taken of Titan near western elongation on 5 May 1980, of the sky background 4 arc min north of Saturn on 9 May 1980, and of the region of the outer rings 20 arc s east of the centre of Saturn on 9 May 1980. To within ±200 R no Lyα emission above the level of sky background was detected from either Titan or the rings, although the ring exposure was taken on a day when no bursts of Lyα emission above the 700–800 R level were detected on the saturnian disk. The additional sky background exposure was taken to check for a possible extended H atmosphere around the saturnian system, as hypothesized by McDonough and Brice[6]; however, the background brightness 4 arc min north of Saturn was the same within ±200 R as that measured immediately north and south of Saturn in the preceding and following exposures. All exposures to date are listed in Table 1, specifying the target area, the longitude of the central meridian of Saturn, the tilt angle of the ring plane north or south of the line of sight from Earth, and the observed level of emission above the 700–800 R planetary level. The longitudes listed are in the Saturn longitude system (λ_{SLS}) defined by the recent observations by the Voyager Planetary Radio Astronomy Group[14]. A comparison was also made between the data in Table 1 and the occurrence of radio emission from Saturn, but no direct correlation was discovered.

Unfortunately, the angular resolution of the IUE is not sufficient to pin down the source of the enhanced Lyα emission. The excess emission from the southern half of the saturnian disk observed on 19 January, for example, could have originated anywhere along the shaded region shown in Fig. 2 and satisfied our viewing constraints. However, because the rings were within ±2° of being edge-on to the Sun throughout these observations and the Lyα bursts were variable on a time scale of days, it seems unlikely that photo-sputtering of ring particle ice is a plausible source mechanism for these bursts. In addition, <200 R of Lyα emission was seen from the vicinity of Titan on the same day that a burst of brightness 600 R was detected from the northern half of the saturnian disk, implying that the source of this enhanced emission was not Titan or an associated torus. The most plausible production mechanisms seem to be either: (1) aurora in Saturn's upper atmosphere or (2) a cloud of H atoms in the vicinity of the rings which are released by charged particle sputtering and radiate through resonant scattering of solar Lyα radiation (and possibly through charged particle excitation). More accurate knowledge of the source of these bursts of Lyα emission requires better spatial resolution and more flexibility in the angle of view, as will be available from the Voyager 1 and 2 spacecraft now approaching encounter with Saturn.

Table 1 Observations of H Ly emission from Saturn

Date (1980)	Target	Ring plane tilt angle	λ_{SLS} (CML)	Average background level (kR)	Emission above model level (R)
19 January	5″ S	1.6° S	319°	1.5	+900
	5″ S	1.6° S	346°	1.5	+900
	5″ N	1.6° S	34°	1.5	—
12 March	8″ N	0°	306°	2.5	—
	Centre	0°	338°	2.5	—
13 March	8″ S	0°	10°	2.5	—
3 May	8″ N	1.5° N	315°	1.4	+300
	8″ S	1.5° N	350°	1.4	+300
	Centre	1.5° N	25°	1.4	+300
5 May	8″ N	1.5° N	355°	3.0	+600
	Centre	1.5° N	32°	3.0	—
	8″ S	1.5° N	75°	3.0	—
	Titan	1.5° N	117°	3.0	—
9 May	8″ N	1.5° N	76°	1.8	—
	4′ N	1.5° N	112°	1.8	—
	8″ S	1.5° N	149°	1.8	—
	20″ E	1.5° N	189°	1.8	—
22 July	7″ N	0°	118°	2.0	—
	7″ S	0°	155°	2.0	—
	7″ N	0°	189°	2.0	—
	Centre	0°	223°	2.0	—
	7″ N	0°	262°	2.0	—
	7″ N	0°	296°	2.0	—

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