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THE "ATMOSPHERE" OF THE RINGS OF SATURN

The question I would like to address is the outgassing of Saturn's rings and the possibility of detecting it.

After discovery of the hydrogen Lyman-alpha emission around comet Tago Sako Kosaka by OAO II, observations we made on comets Bennett and Encke from OGO V in 1971 have shown that it is possible to deduce the source intensity of the hydrogen atoms from the Lyman-alpha emission intensity.

The total source intensity was of the order of 10^{29} atoms of hydrogen per second for comet Bennett and something like 10^{27} atoms of hydrogen per second for Encke.

Comets may well be ice-covered bodies, and this is also probably true for Saturn's rings.

I would like to make one suggestion. Dr. Franklin mentioned yesterday that it would be interesting to obtain the scattering diagram of an ice particle in space. Maybe one could obtain such a diagram from a comet nucleus, at a distance of the order of two A.U. from the Sun when the comet, being far away from the Sun, does not change from day to day. You just have to wait for a comet and there are 15 comets a year to try.

From our comet observations, we decided to look for the possibility of the same outgassing of H and OH from Saturn's rings. This work was carried out by my student, Michel Dennefeld.

First of all, the source of gas around Saturn's rings is computed. The products of ice will be essentially H_2O, H, and OH. There are different physical mechanisms for producing these species, and the corresponding production rates are given in table I. In order to decide if the source is significant, these rates can be compared with the rate for comets, which is of the order of 10^{28} s^{-1}; that is a significant source and can be detected easily, but a source of 10^{20} s^{-1} cannot be detected.

Ice sublimation at a temperature of 80 K is a source of the order of 10^{20} s^{-1}.

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However, I heard yesterday that the temperature may be as high as 95 K. Then we have a source intensity like 5×10^{26} s^{-1}, which is in the range of detectability.

If the temperature is 80 K, the most intense source is meteoroid bombardment. We have used the Cook and Franklin (1970) value for meteoroidal bombardment. In this mechanism, the meteoroid hits a particle, and local heating vaporizes H_2O.

Solar wind bombardment does not have a large effect.

Interstellar gas (hydrogen, helium), which hits Saturn's rings, has a small effect.

The most intense source of gas in the whole Saturnian system is the Titan atmosphere, which produces 4×10^{28} s^{-1} of atomic hydrogen.

For OH, bombardment by solar wind creates 10^{24} radicals per second.

Once the source strength has been computed, the subsequent history of the gases has to be determined.

Table II gives the lifetimes of those molecules and atoms in the vicinity of Saturn. All the lifetimes are long compared to the orbital period of atoms, molecules, or radicals around Saturn. For instance, the photodissociation time of H_2O, approximately 10^7 s, is 10^3 times the orbital period; therefore, something like

TABLE I.—*Sources and production rates.*

Species	Source	Rate, s^{-1}
H_2O	Ice sublimation T = 80 K	1.4×10^{20}
	T = 100 K	5×10^{26}
	Meteoroid bombardment	4×10^{26}
	Solar wind bombardment	5×10^{25}
	Interstellar helium bombardment	5×10^{24}
H	Solar wind bombardment	10^{23}
	Titan	4×10^{28}
OH	Solar wind bombardment	10^{24}

TABLE II.—*Lifetime at Saturn.*

Atom or molecule	Lifetime, s	Process
H_2	3×10^9	Photodissociation → H + H
H	15×10^8	
H_2O	9×10^6	Photodissociation
OH	6.5×10^7	Photodissociation
Orbital period	4×10^4	

1000 encounters between one molecule of H_2O and the ring will take place before the production of an atom of hydrogen.

The sticking coefficient of H_2O over the ring is unknown since the very nature of the ring is unknown. It has to be of the order of 10^{-2} if we want to have a serious production of hydrogen. However, if we obtain a large source by having a higher temperature of the rings (about 100 K), we may, even with a larger sticking coefficient, obtain quite a number of hydrogen atoms.

After the computation of the lifetime, the distribution of molecules and atoms among the different orbits has been determined.

The number densities of different species are given in table III.

The orbits depend greatly on the formation processes, because the velocity is a function of the energy of the atoms or molecules.

For instance, an atom of hydrogen, when created by bombardment, will have a very low velocity on the order of 1 km s^{-1}; if it has been created by photodissociation of H_2O, it will have a velocity around 18 km s^{-1}. Therefore, hydrogen created by bombardment will stay in the plane of the ring; if it has been created by photodissociation of water, it will fill a sphere around Saturn.

After all processes have been taken into account, a number density of 10 atoms of hydrogen per cm^3 is formed from outgassing of Saturn's rings.

Table IV gives the luminosity expressed in Rayleighs (1 Rayleigh corresponds to 10^6 photons per m^2 emitted in 4π steradians). Around the rings of Saturn, an emission strength of 10 Rayleighs of Lyman-alpha and 10 Rayleighs of OH resonance line has to be expected. The intensity of 500 Rayleighs of Lyman-alpha emitted by the Titan torus has been computed in the case of an optically thin

TABLE III.—*Number densities of species.*

Species	Number density, cm^{-3}
H_2O	10–100
OH	1–10
O	1–10
H (Saturn)	1–10
H (Titan)	10–10^3

TABLE IV.—*Luminance.*

Species (and source)	Luminosity, Rayleighs
H (Titan)	500–1000
H (Saturn's rings)	1–10
OH (Saturn's rings)	10

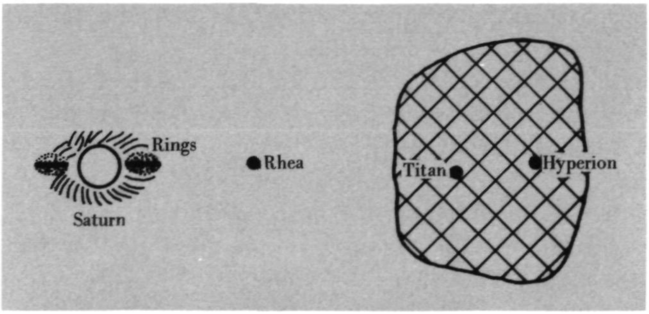

FIGURE 1.—*Schematic view of a cross section through the Saturn system as seen in Lyman-alpha.*

medium. Actually, the center of the torus is optically thick, and an exact computation for an optical thickness of 4 would provide an emission intensity of 100 Rayleighs.

This is a very easily detected phenomenon from MJS.

Figure 1 gives you some feeling for what it would look like. This would be the system seen in Lyman-alpha. It has an odd shape because of the properties of the orbits of the atoms of hydrogen around Titan, but it should be the most spectacular phenomenon in the Saturn system in the ultraviolet. Around the rings you have a very small emission of Lyman-alpha due to the atoms that have been created by meteoroid bombardment, and all around the system you will have a weak but detectable glow due to the atoms created by photodissociation.

DISCUSSION

James Pollack How did you compute the evaporation rate of the water vapor from the ring particles?

Jacques Blamont It is a cocktail of basic thermodynamics and measurements that have been published.

Charles Lillie What is the extent of that cloud around Titan?

Blamont It's of the order of 1 Mkm in diameter. As seen from the Earth, it would have a diameter of 5 min of arc. The existence of the torus has been proposed by Neil Brice (1973) and was discussed extensively last week at the Titan atmosphere workshop held at the Ames Research Center.

William Irvine You are saying that Titan is the source for that?

Blamont Yes.

Irvine You have to assume things about the atmosphere of Titan to make that prediction.

Blamont You have to assume an exospheric temperature of 100 K and a flux of hydrogen, which I think almost everyone agreed on at the Titan atmosphere workshop.

Brad Smith This would be a toroidal ring that would surround Saturn?

Pollack Yes, essentially because Titan loses hydrogen fairly rapidly. We have evidence that there is a significant amount of hydrogen in its atmosphere, which would suggest that a steady state has been established.

Lillie We had some observations of Saturn in Lyman-alpha with the satellite OAO II. It is possible to set upper limits on the surface brightness around the system. The photometer had a 10-min field of view, and it observed a surface brightness, assuming it is filled, of about 59 Rayleighs, plus or minus about 30. It is dominated by the noise of the system.

Blamont You mean around Titan or around Saturn?

Lillie This observation was centered on Saturn.

Blamont That is quite comparable to what I am talking about; I am thinking of 100 Rayleighs for Titan.

Lillie We are almost just about right. You are almost permitted.

Irvine Do you know if Titan was in the field of view?

Lillie Yes, I think it would have been. I don't know the distance of Titan from the primary at the time. I don't know the radius of Titan's orbit.

Fred Franklin It is 20 Saturn radii.

Lillie All that has to be in the instrument field of view is the toroid; you don't have to see Titan physically. As long as you hit the toroid, it's in the bag.

Blamont Yes, but the toroid is an extended source, with varying optical thickness in Lyman-alpha.

Lillie I calculated that if we could get about a 70-Rayleigh toroidal cloud, we would come out about right, which is permitted by the observation.

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