The Structure and Time Variability of the Ring atmosphere and ionosphere

W.-L. Tseng¹, W.-H. Ip¹, R. E. Johnson², T. A. Cassidy² and M. K. Elrod²

1. Institute of Astronomy, National Central University, Taiwan (contact: d9359006@astro.ncu.edu.tw)
2. Department of Materials Science & Engineering, University of Virginia, USA

Abstract

The Saturnian system is subject to constant bombardment by interplanetary meteoroids and irradiation by solar UV photons. Both effects release neutral molecules from the icy ring particles either in the form of impact water vapor or gas emission in the form of H₂O, O₂ and H₂. The SOI observations of the Cassini spacecraft have shown the existence of molecular and atomic oxygen ions. Subsequent modeling efforts have led to the picture that an exospheric population of neutral oxygen molecules is maintained in the vicinity of the rings via photosputtering and other means. At the same time, the ring system is embedded in a system of O⁺ and O₂⁻ ions threading through the Cassini division. Charge exchange and collisional interactions between the exospheric ions and neutrals will create a scattered component of O₂ molecules (and O atoms) which can be injected into Saturn’s upper atmosphere or the inner magnetosphere. In other words, the ring atmosphere could serve as a source of O₂⁺ ions in Saturn’s magnetosphere. The structure of the ring atmosphere/ionosphere complex and the injection rate of ions are, however, subject to modulation by the seasonal variation of Saturn along its orbit. In this work, we will demonstrate how the physical properties of the ring oxygen atmosphere and the scattered component (and the source rate of the magnetospheric O₂⁺ ions) would vary as the ring system going through the cycle of solar insolation.

### Source mechanisms of O₂ ring atmosphere

- Water-associated neutrals form by the bombardment of interplanetary meteoroids and photosputtering (Carlson, 1980; Ip, 1984a).
- O₂ could form via surface chemical reactions of the water-dissociated products like O and OH (Ip, 1995).
- O₂ can be directly emitted from the ring particle surfaces via photosputtering processes (Pospieszalska and Johnson, 1991).

#### Cassini Observations

**CAPS (Tokar et al., 2005)**  
**INMS (Waite et al., 2005)**

![Graph showing Cassini Observations](image)

### SOI condition & Time Variations

Left: The O₂ column density with radial distances in variations of solar condition.  
Right: The injection rate with variation of solar angle.

![Graph showing SOI condition & Time Variations](image)

### Modeling Descriptions

**Creation of O₂**  
**Ring Plane Crossing**

<table>
<thead>
<tr>
<th><strong>Surface impact with ring particles?</strong></th>
<th><strong>Re-ejection into new orbit?</strong></th>
<th><strong>Planetary ion?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Charge exchange scattering?**  
**Loss?**  
**Atmospheric precipitation**

<table>
<thead>
<tr>
<th><strong>Ejection of O₂</strong></th>
<th><strong>Loss?</strong></th>
<th><strong>Atmospheric precipitation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

**End trajectory calculation**

### Summary

- The neutral O₂ atmosphere is similar above and below the ring plane and strongly dependent on the solar conditions. The neutral O₂ density would go to the minimum when Saturn’s ring is edge-on, if the radiolysis decomposition of ices by solar photons is the main source mechanism.
- Inside of 1.625 R₆, there is an asymmetry of the ring ionosphere between the northern and southern hemispheres, with a larger southern hemisphere density. The ion scale height increases with increasing radial distances outside of 1.625 R₆.
- The neutral O₂ which were scattered into the outer magnetosphere could be ionized by photons and magnetospheric electrons and be a source of magnetospheric O₂⁺ detected by Cassini CAPS and MIMI.

### Issues to be addressed in future work

- The source mechanisms of neutral O₂ ring atmosphere
- The electrostatic charging potential of the ring plane
- The plasma-neutral atmosphere interaction outside the main ring region
- The maximum brightness at the outer edge of A-ring
- The photochemical effects of Saturn’s atmospheric precipitations of the ring-originated ions and neutrals

### References:

Carlson (1980), Nature, 283, 461-463  
Johnson et al. (2006) Icarus, 180, 393-402  
Pospieszalska and Johnson (1991) Icarus, 93, 45-52

### Acknowledgement

This work was supported by NSC Taiwan.