The contribution of the atomic Hydrogen in the Saturnian System

Han-Wei Hsiao*
Prof. Wei-Ling Tseng*
*Department of Earth Sciences, National Taiwan Normal University
Final Report 8/28

Outline

- Introduction
- Previous work
- Sources of H atoms
- Modeling descriptions
- Future work

Introduction

- Broadfoot et al. (1981) showed that the H cloud had a very broad distribution in a doughnut-shpae region 8 to 25 R_s and with vertical thickness of 14 R_s.

- Shemansky and Hall (1992) found that H cloud in the Saturnian magnetosphere exhibited an azimuthal asymmetry that was dependent on local time with a higher intensity on the dusk side.

- Ip (1996) simulated the morphology of Titan's H cloud using Monte-Carlo calculations, this modeling showed that it was asymmetric as a function of local time.

- Ip (1996) also pointed out that Saturn's exosphere and/or the ring system could be major sources of the H atoms in Saturn's inner magnetosphere.

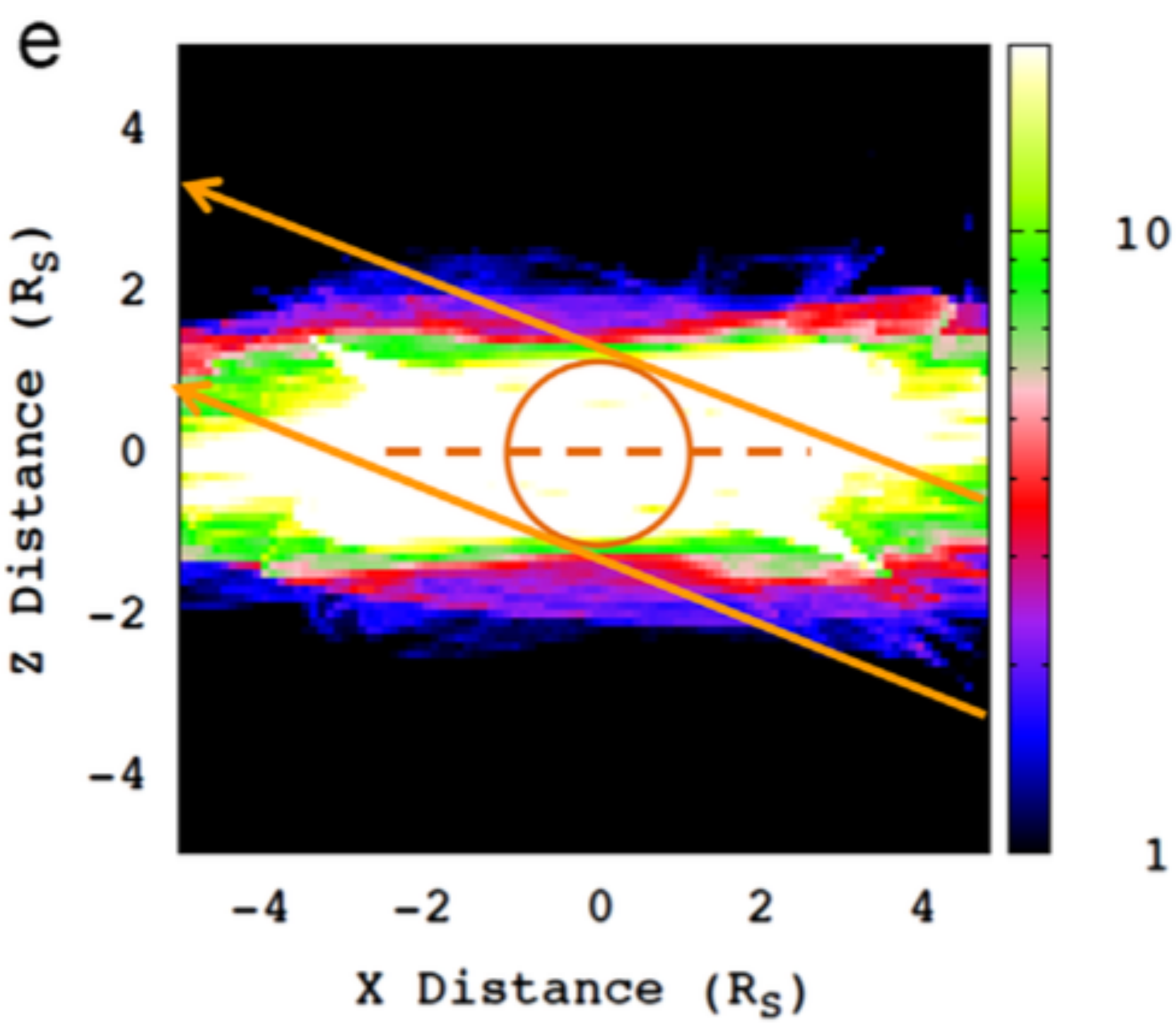
- In the H Ly-alpha intensity map observed by Cassini UVIS, the H cloud appeared to concentrate around the main ring region. (Melin et al., 2009)

- Tseng (2012) showed that the ring system is an important source of H2 and O2 which are injected into Saturn's magnetosphere via scattering processes.

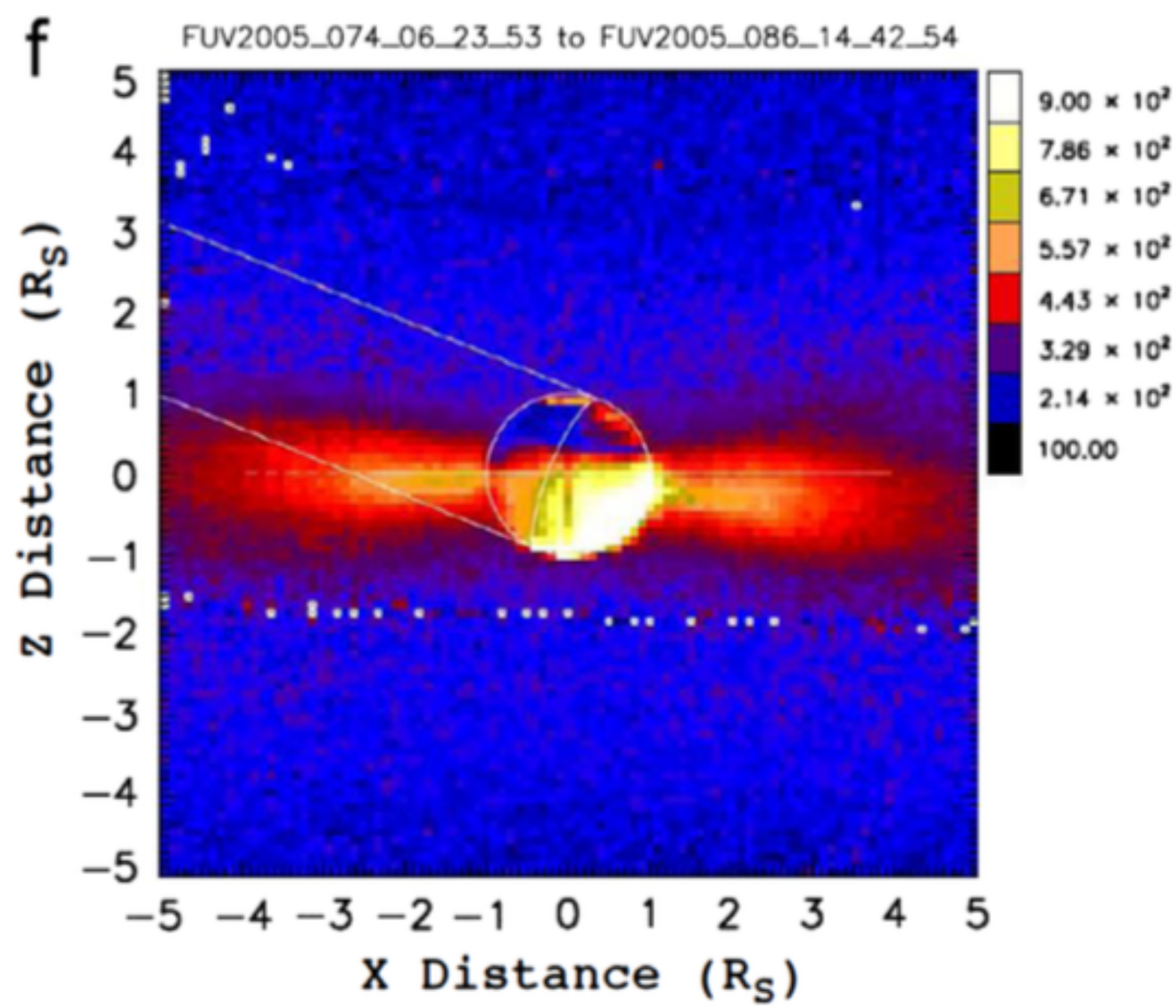
- Whether the main rings could be a significant contributor of H atoms in the inner magnetosphere?

Previous Work

- The morphology of the H cloud from photodissociation of the ring H2 atmosphere. (Tseng et al., 2013)



(Tseng et al., 2013)

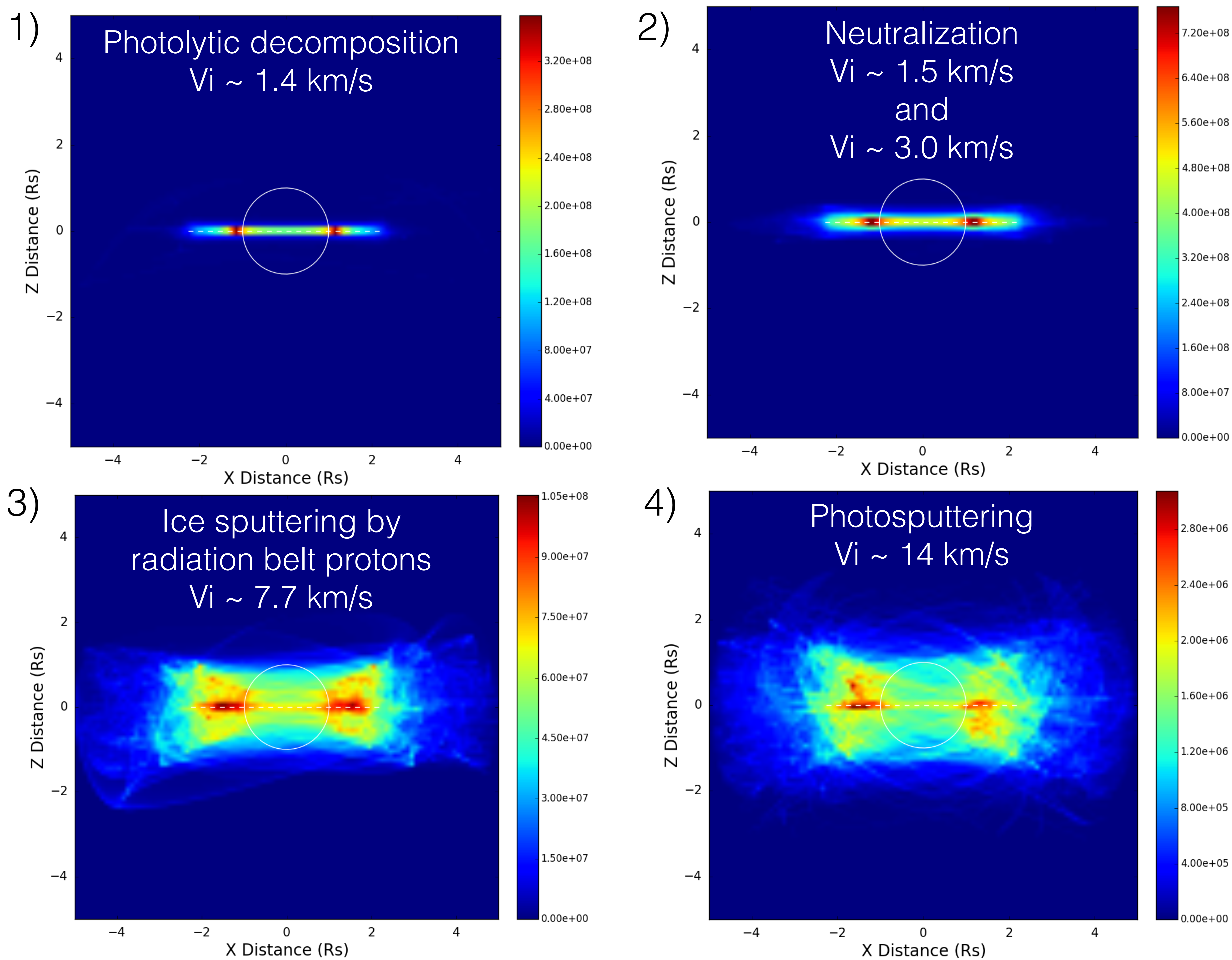


(Melin et al., 2009)

Sources of H Atoms

- The mechanisms of H atoms directly produced from Saturn's ring are considered in my simulation.
- The morphology of H cloud will be modified by different initial velocities of each mechanism.

1) Photolytic decomposition of water ice -> Vi ~ 1.4 km/s
2) Neutralization of Saturn's ionospheric H+ outflow on the ring surface (Ip, 1978) -> Vi ~ 1.5 and 3.0 km/s
3) Ice sputtering by radiation belt protons (Cheng and Lanzerotti, 1978) -> Vi ~ 7.7 km/s [H2O —> H + H + O +0.7eV]
4) Photo-sputtering (Carlson, 1980) -> Vi ~ < 24 km/s


1)
Photolytic decomposition
Vi ~ 1.4 km/s
2)
Neutralization
Vi ~ 1.5 km/s
and
Vi ~ 3.0 km/s
3)
Ice sputtering by
radiation belt protons
Vi ~ 7.7 km/s
4)
Photosputtering
Vi ~ 14 km/s
X Distance (Rs)
Z Distance (Rs)
3.20e+08
2.80e+08
2.40e+08
2.00e+08
1.60e+08
1.20e+08
8.00e+07
4.00e+07
0.00e+00
7.20e+08
6.40e+08
5.60e+08
4.80e+08
4.00e+08
3.20e+08
2.40e+08
1.60e+08
8.00e+07
0.00e+00
1.05e+08
9.00e+07
7.50e+07
6.00e+07
4.50e+07
3.00e+07
1.50e+07
0.00e+00
2.80e+06
2.40e+06
2.00e+06
1.60e+06
1.20e+06
8.00e+05
4.00e+05
0.00e+00

Modeling Descriptions

- A Monte-Carlo test-particle model was used to describe the H cloud in Saturn's inner magnetosphere.
- The center of coordinate system is fixed at Saturn.
- In the equation of motion, the Saturn's gravity and the J2 perturbation due to the oblateness are taken into account.

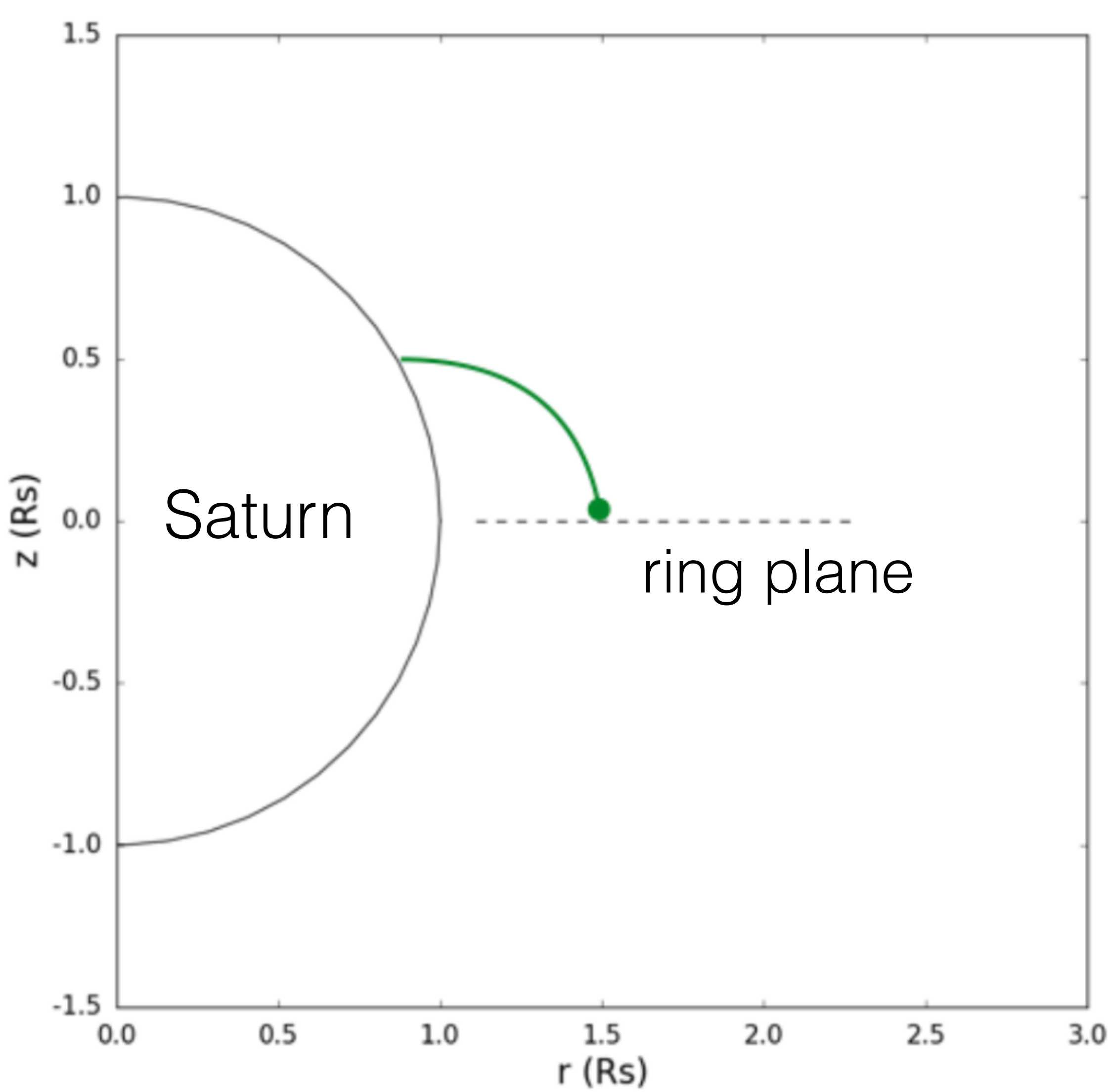
$$\frac{d\vec{v}}{dt} = Saturn's\ \ gravity + J2\ \ perturbation$$

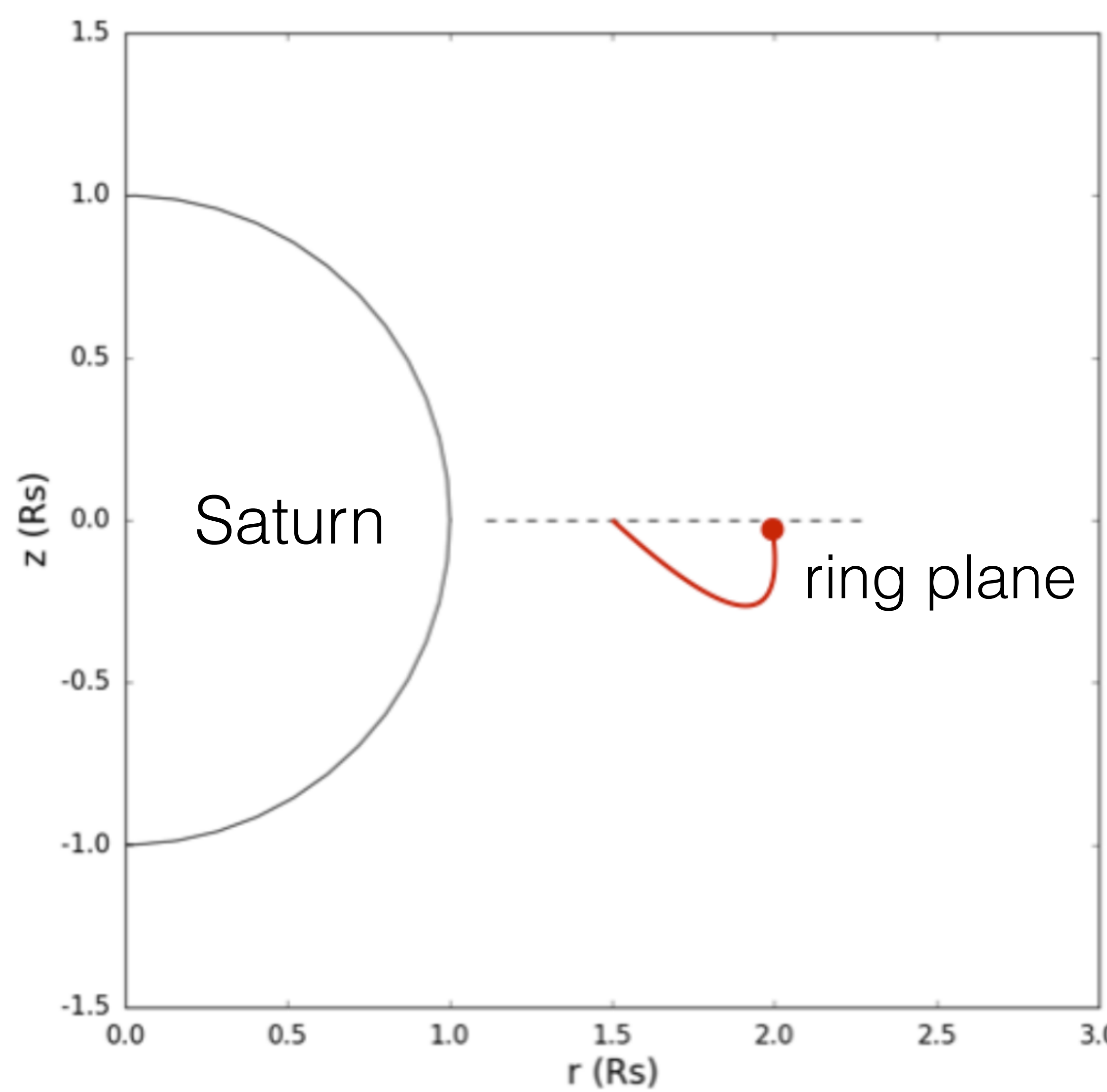
- The test particle is assumed to be isotropically launched from the ring plane with a local Kepler velocity of Saturn plus an initial velocity.

$$\frac{d\vec{r}}{dt} = Kepler\ \ velocity + Initial\ \ velocity$$

- The position and the velocity of each test particle can be calculated by the 4th Runge Kutta Method (RK4).

- When the test particle hits Saturn or when it is absorbed by the ring plane, the trajectory calculation is terminated.





- The first step in the Monte-Carlo simulation is the emission of test particles from the ring plane (1.11 Rs ~ 2.27 Rs).

- The outward flux of hydrogen atom is assumed to be proportional to the value of optical thickness at the point of emission. (Ip, 1984)

$\tau_A = 0.5$ (Esposito et al., 1983)

$\tau_{CD} = 0.001$ (KA Hameen-Anttila, 1977)

$\tau_B = 1.0$ (Esposito et al., 1983)

$\tau_C = 0.01$ (Esposito et al., 1983)

$\tau_D = 1.0*10\wedge{-6}$ (Ellis D. Miner, 2007)

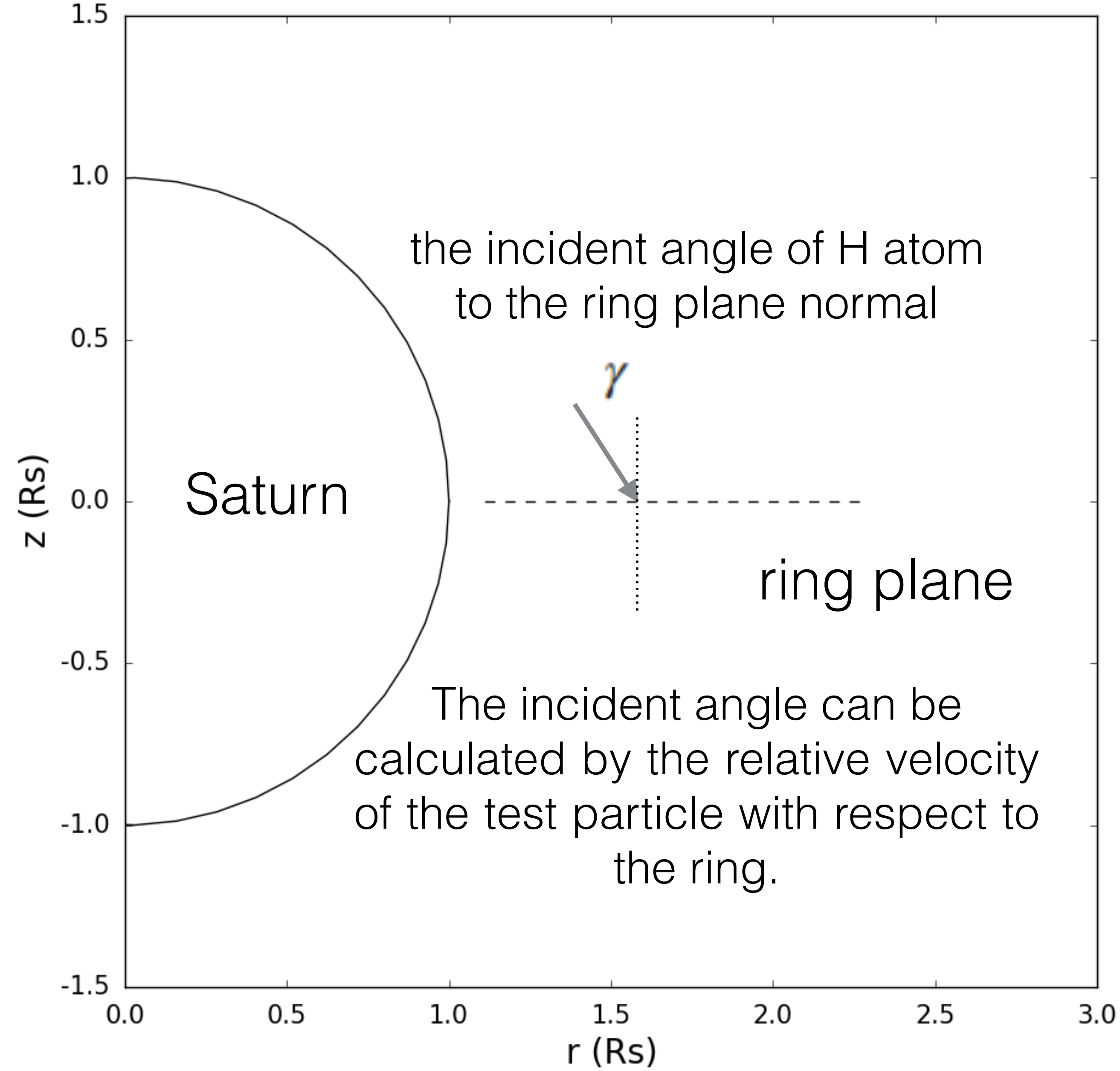
- Ring absorption occurs when the test particle crosses the ring plane. The loss probability is given as

$$1 - \exp\left(-\tau / \cos\gamma\right)$$

the relative velocity component normal to the ring plane

$$\cos(\gamma) = \frac{v_{relative\ z}}{v_{relative}}$$

the total relative velocity at the point of crossing



- The H lifetime is constrained by the solar photon flux.
- The main mechanism of H loss in the inner magnetosphere is photoionization.
- In order to calculate the chemical loss rate (photoionization), the weighting factor of each test particle is reduced by a value of

$$exp(-dt / L)$$

dt : integration time step

L : local destruction timescale.

- H atoms will collide with ions in Saturn's inner magnetosphere. After a collision, each H atom has a new velocity in the inertial frame. [W.-L. Tseng et al., 2009]

- Momentum transfer is the mechanism of ion-neutral collision effect in this model.

- The out-going velocity after a collision can be calculated by [W.-L. Tseng et al., 2009]

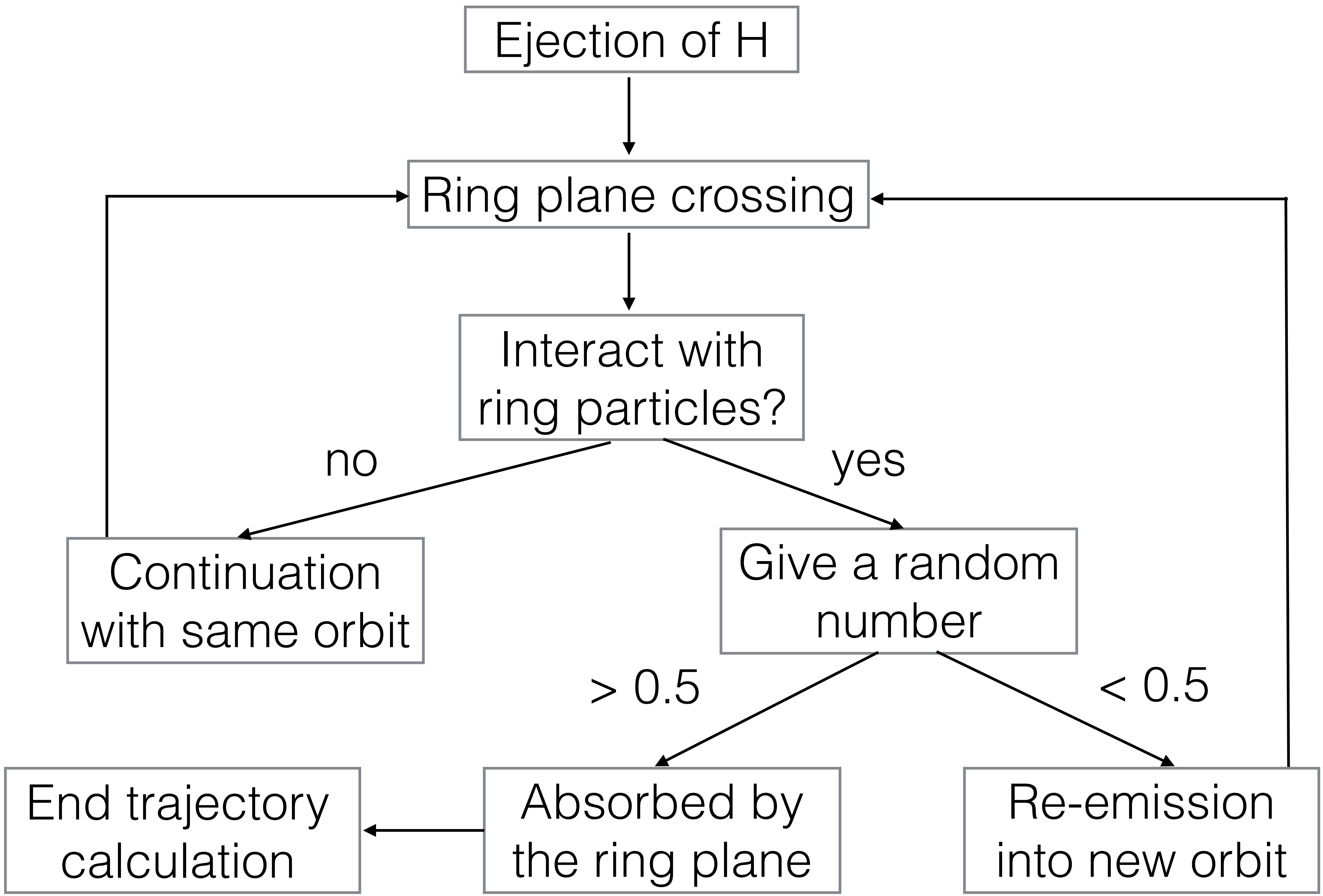
$$v_x = V_{CM\_X} + (m/M) \times v_{rel} \times \cos(\alpha) \times \sin(\theta)$$
$$v_y = V_{CM\_Y} + (m/M) \times v_{rel} \times \sin(\alpha) \times \sin(\theta)$$
$$v_z = V_{CM\_Z} + (m/M) \times v_{rel} \times \cos(\theta)$$

V_{CM} : the velocity of the center of mass

V_{rel} : the relative velocity of H with respect to ion

m : H atom mass

M : H atom mass plus ion mass


Ejection of H
Ring plane crossing
Interact with ring particles?
no
yes
Continuation with same orbit
Give a random number
> 0.5
< 0.5
End trajectory calculation
Absorbed by the ring plane
Re-emission into new orbit

Future Work

- Investigate other possible sources of H atoms.
- The collision probability which is dependent on the plasma density will be considered.
- A radiative transfer model for an optical thick will be developed which may explain the asymmetric distribution of the H cloud.