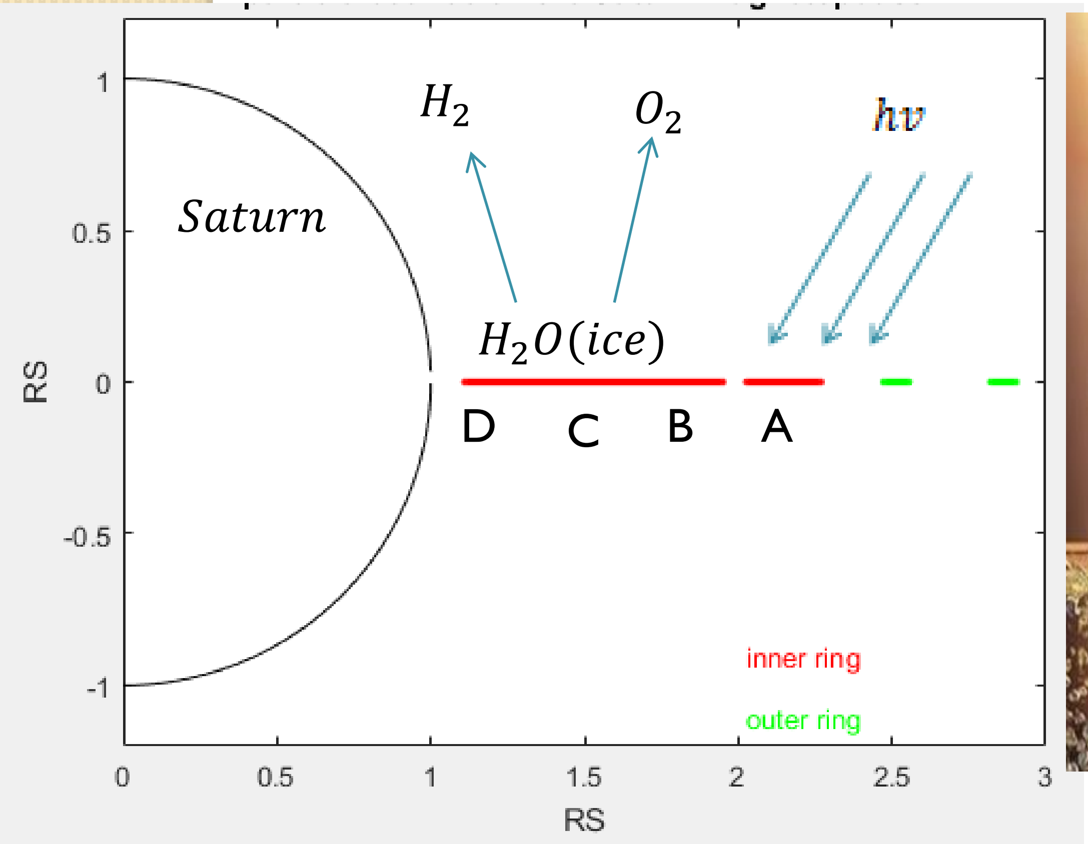
Summer Students Final report (2017/09/01) —Coupling dynamics between Saturn's upper atmosphere and the main rings

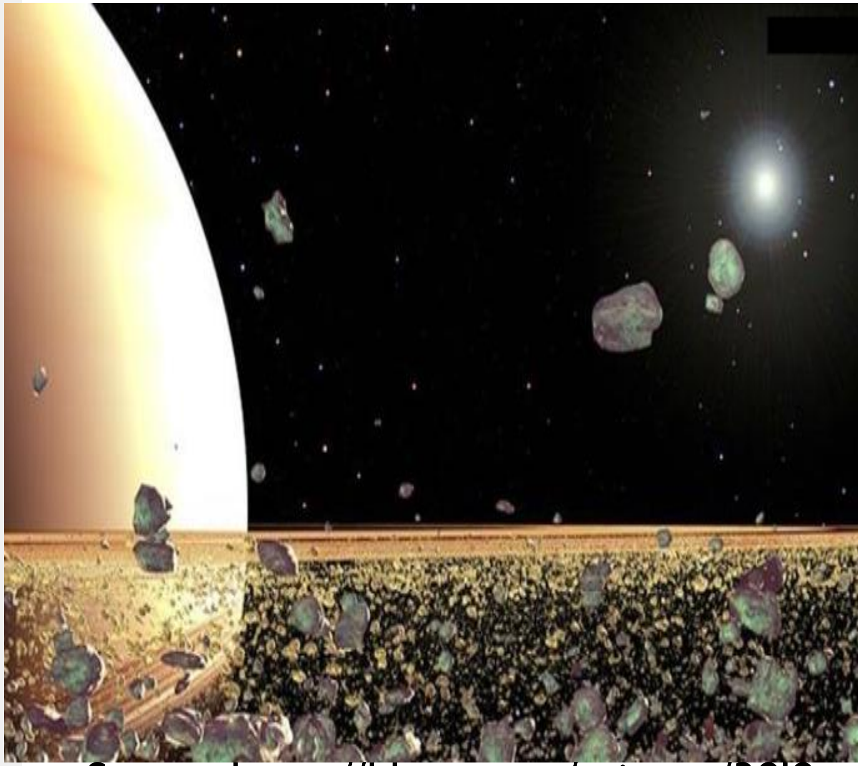
Advisor professor: 曾瑋玲Wei Ling Tseng
Professor of National Taiwan Normal University(NTNU)
Student: 徐峻彥Chun Yen Hsu
Student of National Central University(NCU)

Outline

1. Introduction : Saturn ring atmosphere and ionosphere
2. Introduction : INMS(Ion Neutral Mass Spectrometer)
3. Analysis data
4. Charged particle trajectory integrating

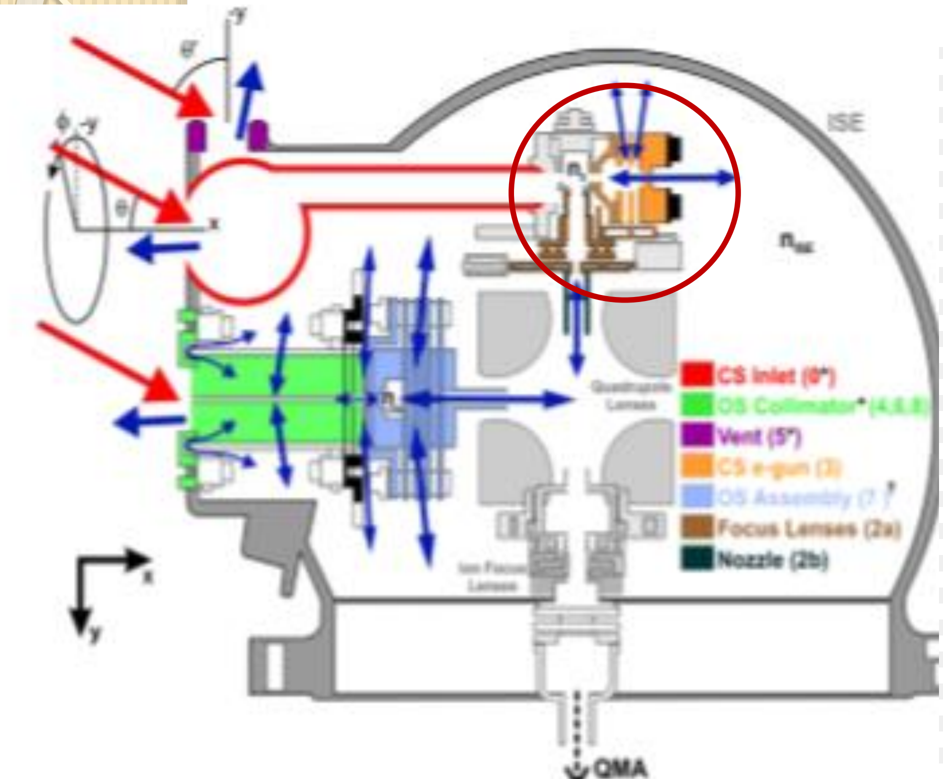
1.Introduction:Saturn ring atmosphere and ionosphere

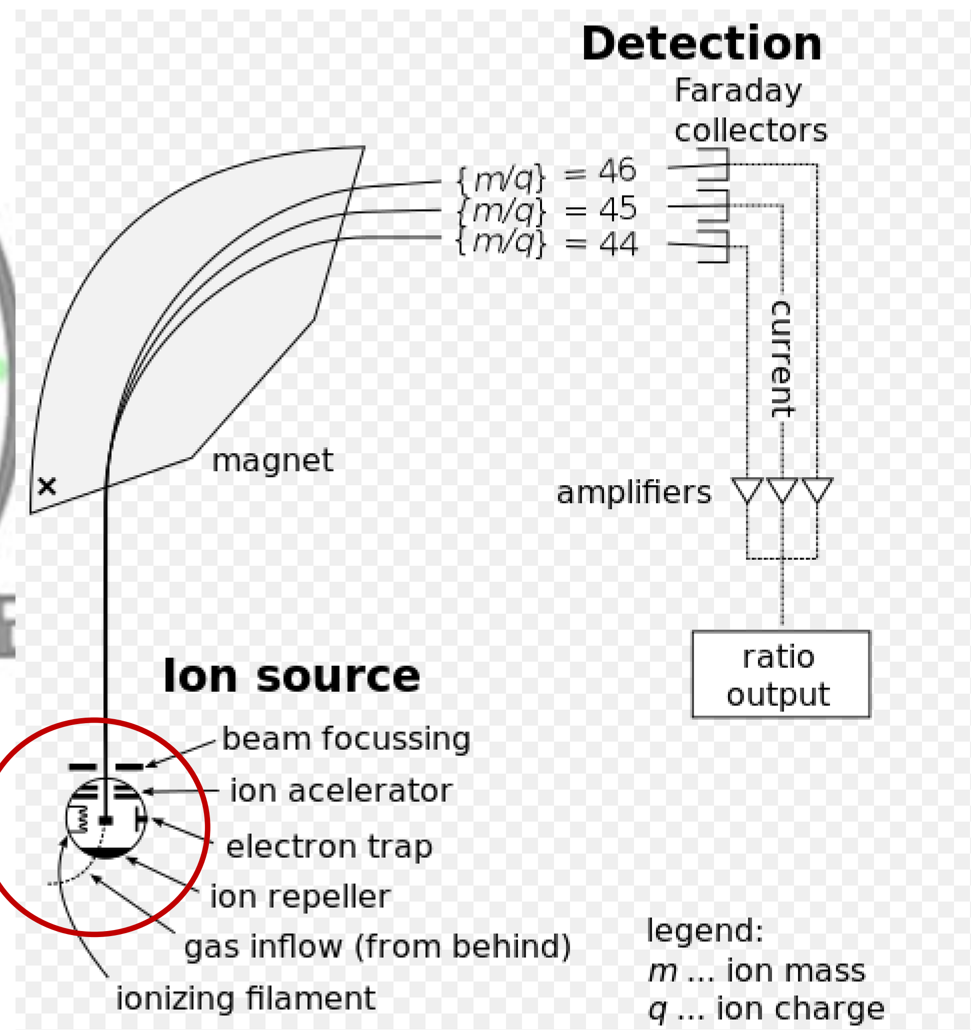




Source:https://kknews.cc/science/38l8rm8.html

2. Introduction : Cassini INMS(Ion Neutral Mass Spectrometer)



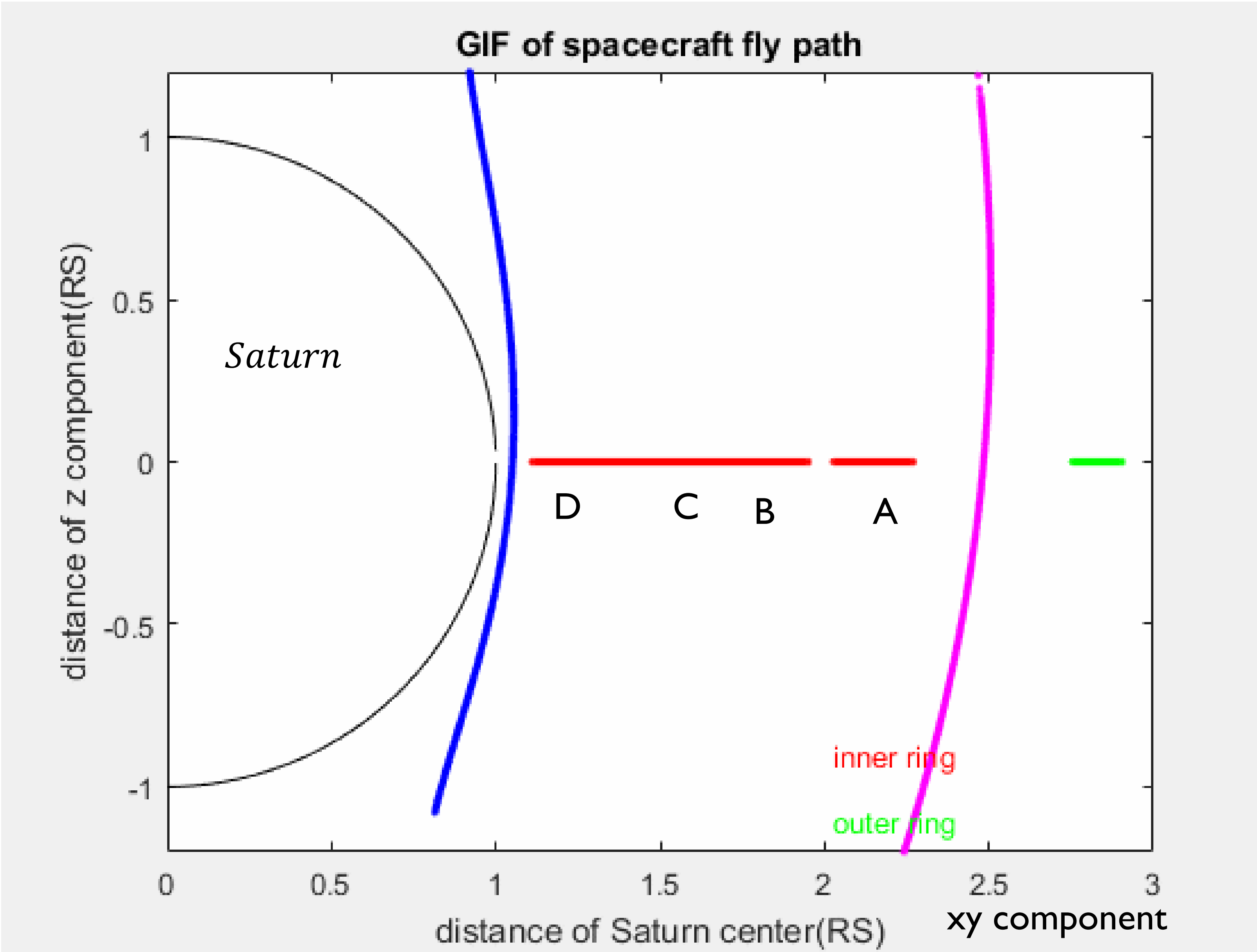


Can know:

Chemical composition

$\frac{q}{m}, gas\ density$

3.Analysis data



4.Charged particle trajectory integrating

1. Steady state

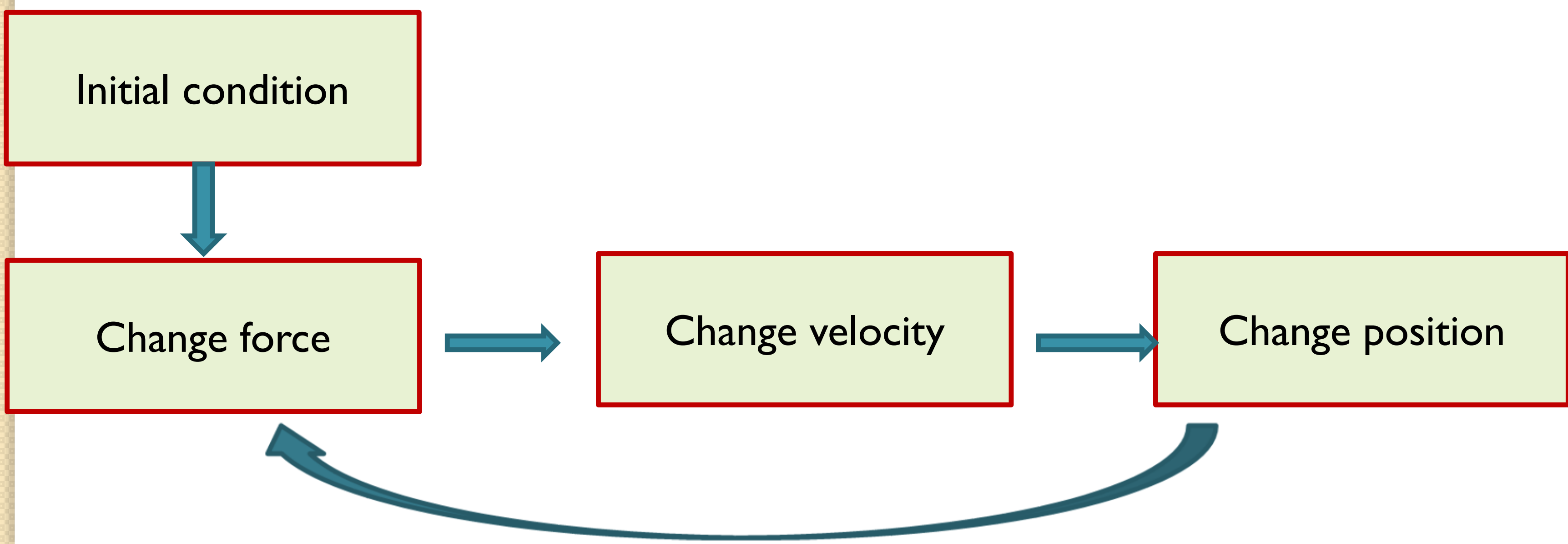
2. Changing charge

1.Steady state

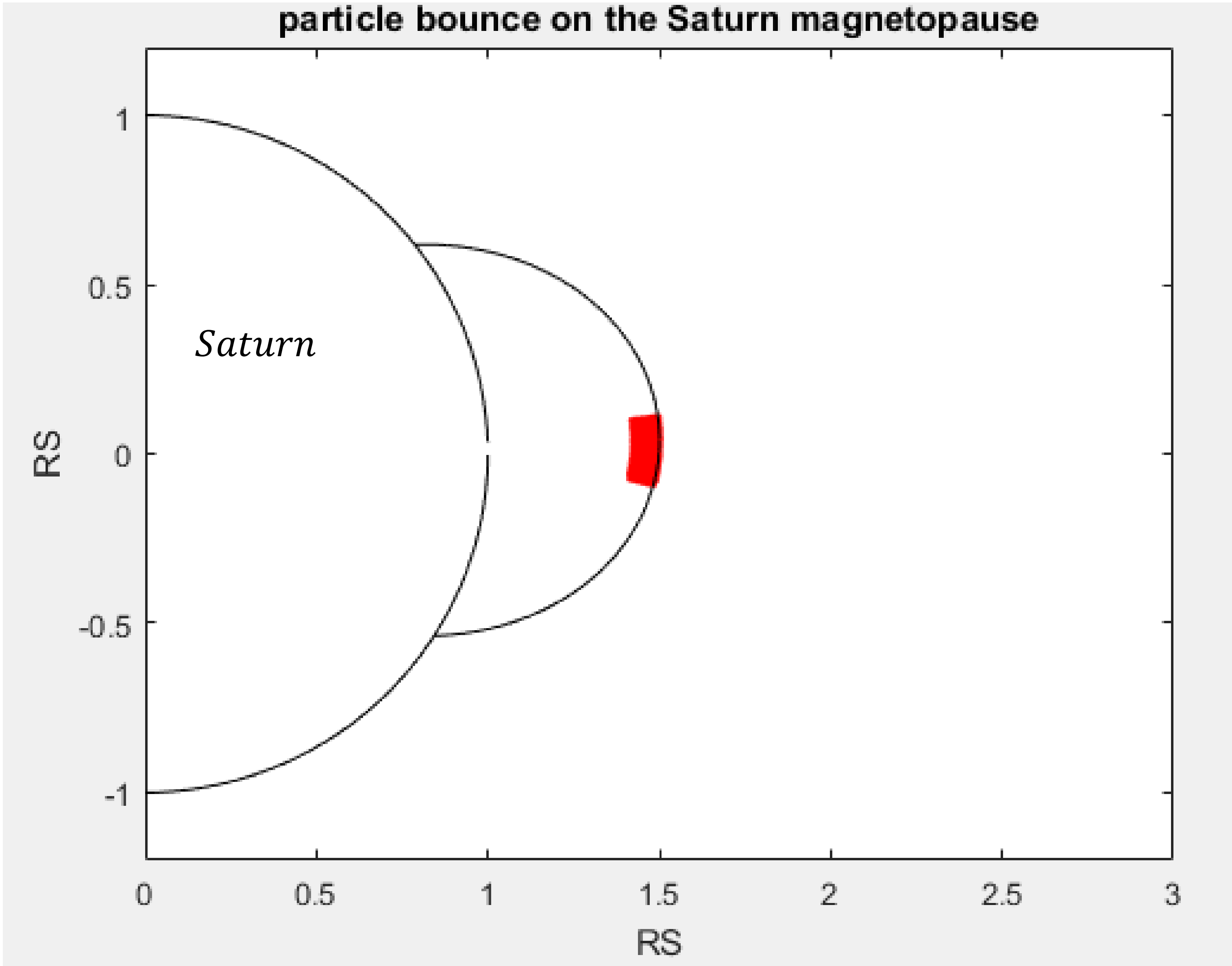
Motion equation:

$$\frac{dv}{dt} = \frac{q}{m}(E + V \times B) - \frac{GM}{r^2}\hat{r}$$

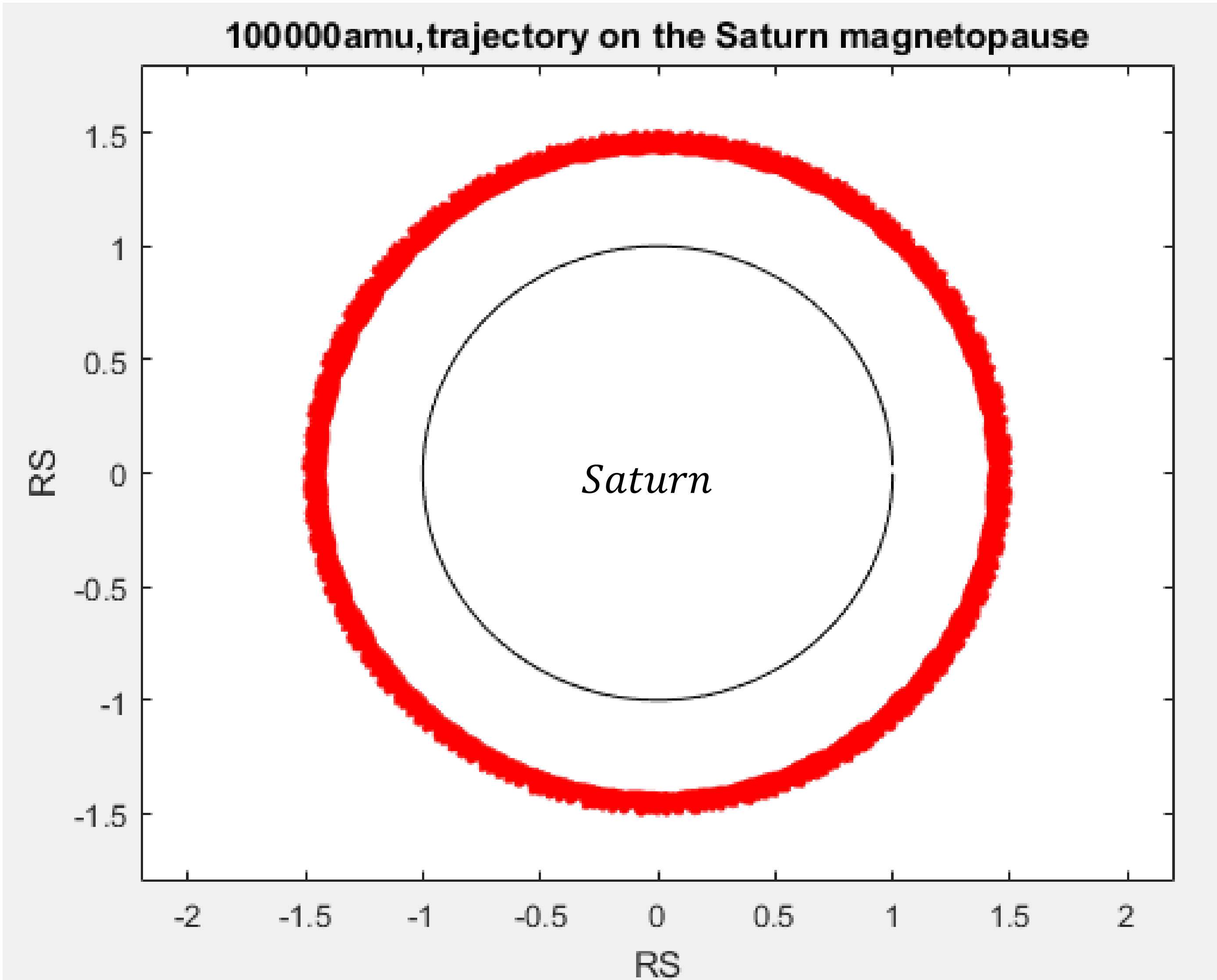
$$\vec{E} = -\overrightarrow{V_c} \times \vec{B}, \overrightarrow{V_c} = \vec{r} \times \overrightarrow{\omega_s}$$



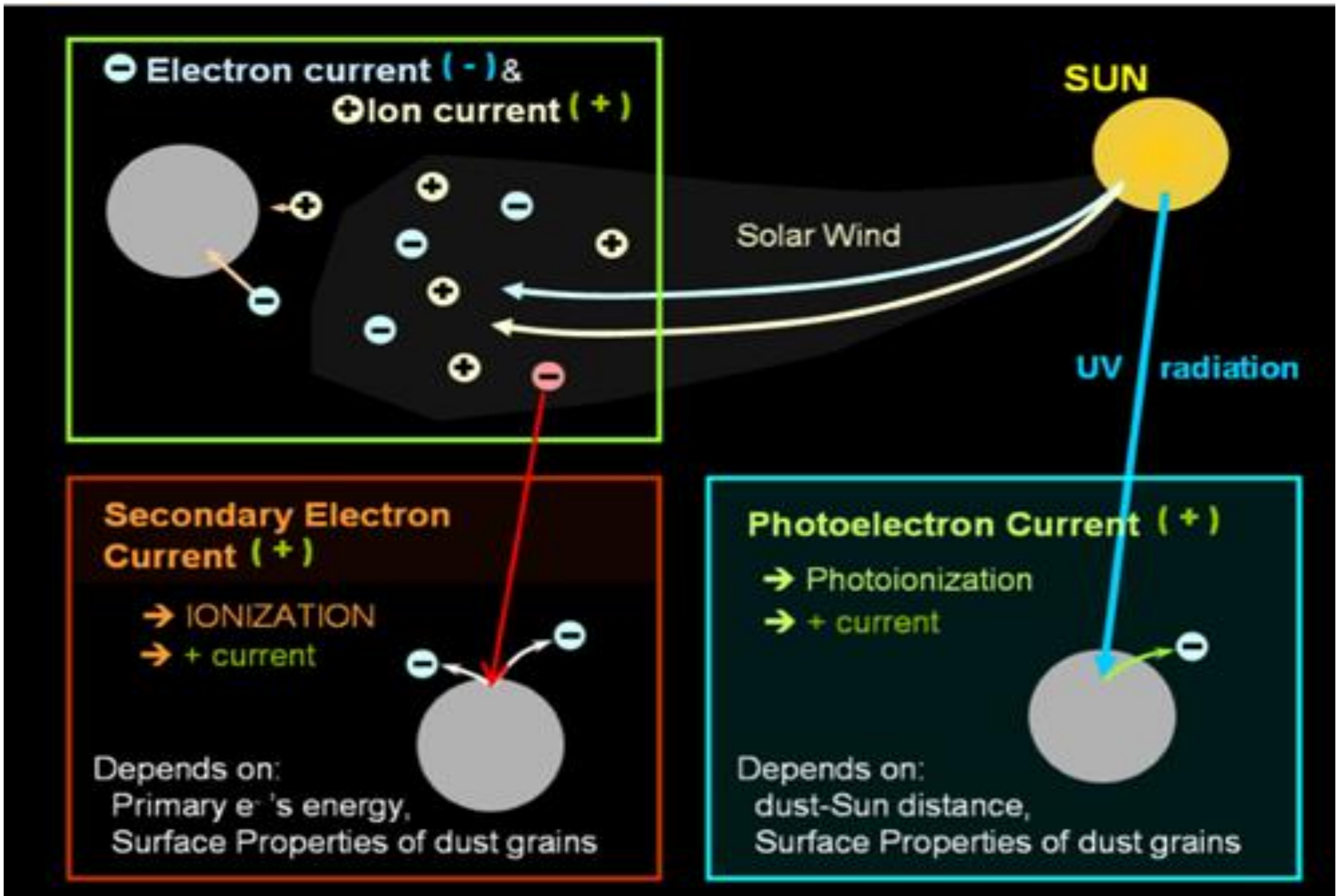
Simulate the trajectory of particle



Simulate the trajectory of particle



2.Changing charge



Source: 許翔聞 2004

ion、electron current:

$$J_a = J_{0a} \times \begin{cases} \exp(-x_a)\ for\ x_a > 0 \\ 1 - x_a \quad for\ x_a < 0 \end{cases}$$

$$J_{0a} = 4\pi e a^2 n_a \left(\frac{kT_a}{2\pi m_a}\right)^{\frac{1}{2}}, x_a = \pm\frac{e\varphi}{kT_a}$$

$$\varphi = \frac{1}{4\pi\epsilon_0}\frac{q}{\sigma}, \sigma\ is\ particle\ size$$

Non-isotropic plasma effect current:

$\varphi > 0$: $\qquad\qquad \varphi\ is\ potential$

$$J_i = \frac{J_{0i}}{4}\left\{\begin{array}{c}(M^2 + \frac{1}{2} - x_i)\frac{\sqrt{\pi}}{M}(\operatorname{erf}(M + \sqrt{x_i}) + \operatorname{erf}(M - \sqrt{x_i})) \\ + \left(\frac{\sqrt{x_i}}{M} + 1\right)\exp(-(M - \sqrt{x_i})^2) \\ - \left(\frac{\sqrt{x_i}}{M} - 1\right)\exp(-(M - \sqrt{x_i})^2)\end{array}\right\}$$

$\varphi < 0$:

$$J_i = \frac{J_{0i}}{2}\left\{\left(M^2 + \frac{1}{2} - x_i\right)\frac{\sqrt{\pi}}{M}\operatorname{erf}(M) + \exp(-M^2)\right\}$$

$$x_i = \frac{e\varphi}{kT_i}, J_{0i} = 4\pi e a^2 n_i\left(\frac{kT_i}{2\pi m_i}\right)^{\frac{1}{2}}, M = \frac{V_f}{\sqrt{\frac{2kT_i}{m_i}}}$$

Photoelectron current:

$$J_{photo} = \pi\sigma^2 e\aleph f \begin{cases} 1, & \varphi < 0 \\ \exp(\frac{-e\varphi}{kT_{photo}}), & \varphi \geq 0 \end{cases}$$

$$f \approx 2.5 * 10^{14} * d^2 m^{-2} sec^{-1}, d\ is\ AU\ unit;$$

$$\aleph \sim 0.1, kT_{photo} = 2.5eV$$

Secondary electron current:

$\varphi < 0$: φ *is potential*

$$J_{sec} = 3.7\delta_M J_{0e}\exp(-x_e)\,F_5\left(\frac{E_M}{4kT_e}\right)$$

$\varphi > 0$:

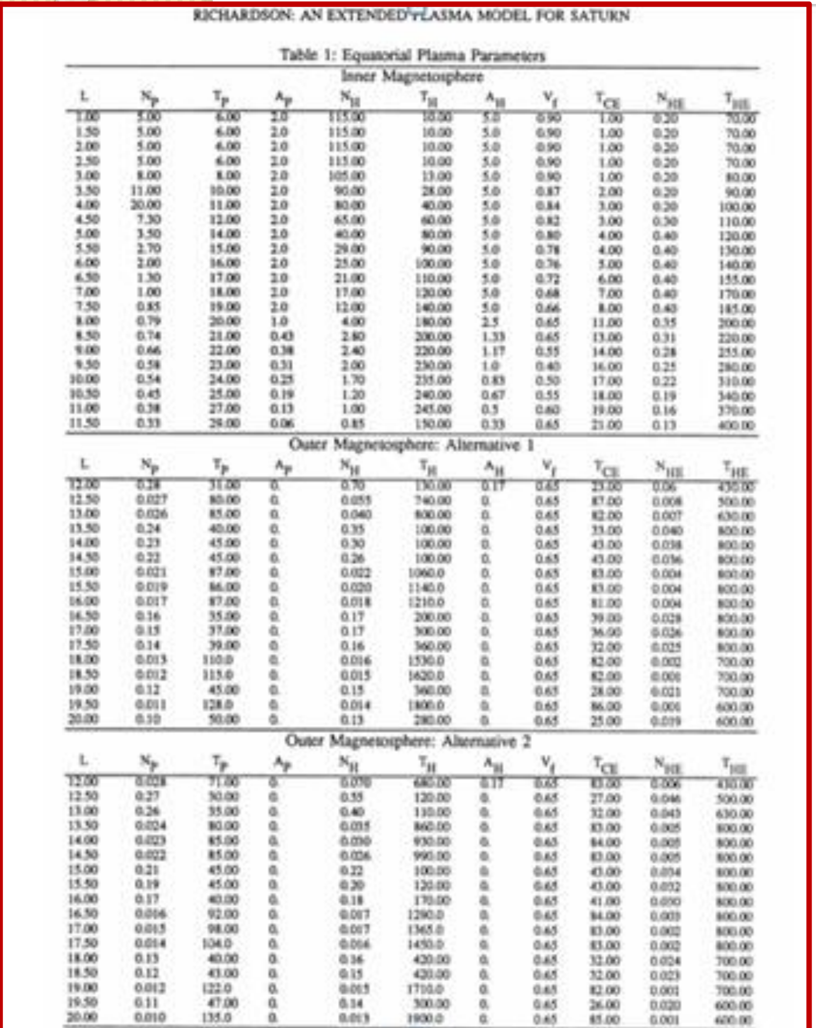
$$J_{sec} = 3.7\delta_M J_{0e}(1 - x_{sec})\exp(x_{sec} - x_e)\,F_{5,B}\left(\frac{E_M}{4kT_e}\right)$$

$$F_{5,B}(x) = x^2 \int_B^{\infty} u^5 exp - (xu^2 + u)du$$

$$B = \sqrt{\frac{-x_e}{\frac{E_M}{4kT_e}}}, x_{sec} = \frac{-e\varphi}{kT_{sec}}, kT_{sec} = 1\sim5eV\ Maxwellian\ distribution$$

$$J_{0e} = 4\pi e a^2 n_e\left(\frac{kT_e}{2\pi m_e}\right)^{\frac{1}{2}}, x_e = -\frac{e\varphi}{kT_e}$$

Voyager 1 background data



RICHARDSON: AN EXTENDED PLASMA MODEL FOR SATURN

Table 1: Equatorial Plasma Parameters

Inner Magnetosphere

L	N_P	T_P	A_P	N_H	T_H	A_H	V_f	T_{CE}	N_{HE}	T_{HE}
1.00	5.00	6.00	2.0	115.00	10.00	5.0	0.90	1.00	0.20	70.00
1.50	5.00	6.00	2.0	115.00	10.00	5.0	0.90	1.00	0.20	70.00
2.00	5.00	6.00	2.0	115.00	10.00	5.0	0.90	1.00	0.20	70.00
2.50	5.00	6.00	2.0	115.00	10.00	5.0	0.90	1.00	0.20	70.00
3.00	8.00	8.00	2.0	105.00	13.00	5.0	0.90	1.00	0.20	80.00
3.50	11.00	10.00	2.0	90.00	28.00	5.0	0.87	2.00	0.20	90.00
4.00	20.00	11.00	2.0	80.00	40.00	5.0	0.84	3.00	0.20	100.00
4.50	7.30	12.00	2.0	65.00	60.00	5.0	0.82	3.00	0.30	110.00
5.00	3.50	14.00	2.0	40.00	80.00	5.0	0.80	4.00	0.40	120.00
5.50	2.70	15.00	2.0	29.00	90.00	5.0	0.78	4.00	0.40	130.00
6.00	2.00	16.00	2.0	25.00	100.00	5.0	0.76	5.00	0.40	140.00
6.50	1.30	17.00	2.0	21.00	110.00	5.0	0.72	6.00	0.40	155.00
7.00	1.00	18.00	2.0	17.00	120.00	5.0	0.68	7.00	0.40	170.00
7.50	0.85	19.00	2.0	12.00	140.00	5.0	0.66	8.00	0.40	185.00
8.00	0.79	20.00	1.0	4.00	180.00	2.5	0.65	11.00	0.35	200.00
8.50	0.74	21.00	0.43	2.80	200.00	1.33	0.65	13.00	0.31	220.00
9.00	0.66	22.00	0.38	2.40	220.00	1.17	0.55	14.00	0.28	255.00
9.50	0.58	23.00	0.31	2.00	230.00	1.0	0.40	16.00	0.25	280.00
10.00	0.54	24.00	0.25	1.70	235.00	0.83	0.50	17.00	0.22	310.00
10.50	0.45	25.00	0.19	1.20	240.00	0.67	0.55	18.00	0.19	340.00
11.00	0.38	27.00	0.13	1.00	245.00	0.5	0.60	19.00	0.16	370.00
11.50	0.33	29.00	0.06	0.85	150.00	0.33	0.65	21.00	0.13	400.00

Outer Magnetosphere: Alternative 1

L	N_P	T_P	A_P	N_H	T_H	A_H	V_f	T_{CE}	N_{HE}	T_{HE}
12.00	0.28	31.00	0.	0.70	130.00	0.17	0.65	23.00	0.06	430.00
12.50	0.027	80.00	0.	0.055	740.00	0.	0.65	87.00	0.008	500.00
13.00	0.026	85.00	0.	0.040	800.00	0.	0.65	82.00	0.007	630.00
13.50	0.24	40.00	0.	0.35	100.00	0.	0.65	33.00	0.040	800.00
14.00	0.23	45.00	0.	0.30	100.00	0.	0.65	43.00	0.038	800.00
14.50	0.22	45.00	0.	0.26	100.00	0.	0.65	43.00	0.036	800.00
15.00	0.021	87.00	0.	0.022	1060.0	0.	0.65	83.00	0.004	800.00
15.50	0.019	86.00	0.	0.020	1140.0	0.	0.65	83.00	0.004	800.00
16.00	0.017	87.00	0.	0.018	1210.0	0.	0.65	81.00	0.004	800.00
16.50	0.16	35.00	0.	0.17	200.00	0.	0.65	39.00	0.028	800.00
17.00	0.15	37.00	0.	0.17	300.00	0.	0.65	36.00	0.026	800.00
17.50	0.14	39.00	0.	0.16	360.00	0.	0.65	32.00	0.025	800.00
18.00	0.013	110.0	0.	0.016	1530.0	0.	0.65	82.00	0.002	700.00
18.50	0.012	115.0	0.	0.015	1620.0	0.	0.65	82.00	0.001	700.00
19.00	0.12	45.00	0.	0.15	360.00	0.	0.65	28.00	0.021	700.00
19.50	0.011	128.0	0.	0.014	1800.0	0.	0.65	86.00	0.001	600.00
20.00	0.10	50.00	0.	0.13	280.00	0.	0.65	25.00	0.019	600.00

Outer Magnetosphere: Alternative 2

L	N_P	T_P	A_P	N_H	T_H	A_H	V_f	T_{CE}	N_{HE}	T_{HE}
12.00	0.028	71.00	0.	0.070	680.00	0.17	0.65	83.00	0.006	430.00
12.50	0.27	30.00	0.	0.35	120.00	0.	0.65	27.00	0.046	500.00
13.00	0.26	35.00	0.	0.40	110.00	0.	0.65	32.00	0.043	630.00
13.50	0.024	80.00	0.	0.035	860.00	0.	0.65	83.00	0.005	800.00
14.00	0.023	85.00	0.	0.030	930.00	0.	0.65	84.00	0.005	800.00
14.50	0.022	85.00	0.	0.026	990.00	0.	0.65	83.00	0.005	800.00
15.00	0.21	45.00	0.	0.22	100.00	0.	0.65	43.00	0.034	800.00
15.50	0.19	45.00	0.	0.20	120.00	0.	0.65	43.00	0.032	800.00
16.00	0.17	40.00	0.	0.18	170.00	0.	0.65	41.00	0.030	800.00
16.50	0.016	92.00	0.	0.017	1290.0	0.	0.65	84.00	0.003	800.00
17.00	0.015	98.00	0.	0.017	1365.0	0.	0.65	83.00	0.002	800.00
17.50	0.014	104.0	0.	0.016	1450.0	0.	0.65	83.00	0.002	800.00
18.00	0.13	40.00	0.	0.16	420.00	0.	0.65	32.00	0.024	700.00
18.50	0.12	43.00	0.	0.15	420.00	0.	0.65	32.00	0.023	700.00
19.00	0.012	122.0	0.	0.015	1710.0	0.	0.65	82.00	0.001	700.00
19.50	0.11	47.00	0.	0.14	300.00	0.	0.65	26.00	0.020	600.00
20.00	0.010	135.0	0.	0.013	1900.0	0.	0.65	85.00	0.001	600.00

Source: 許翔聞 2004

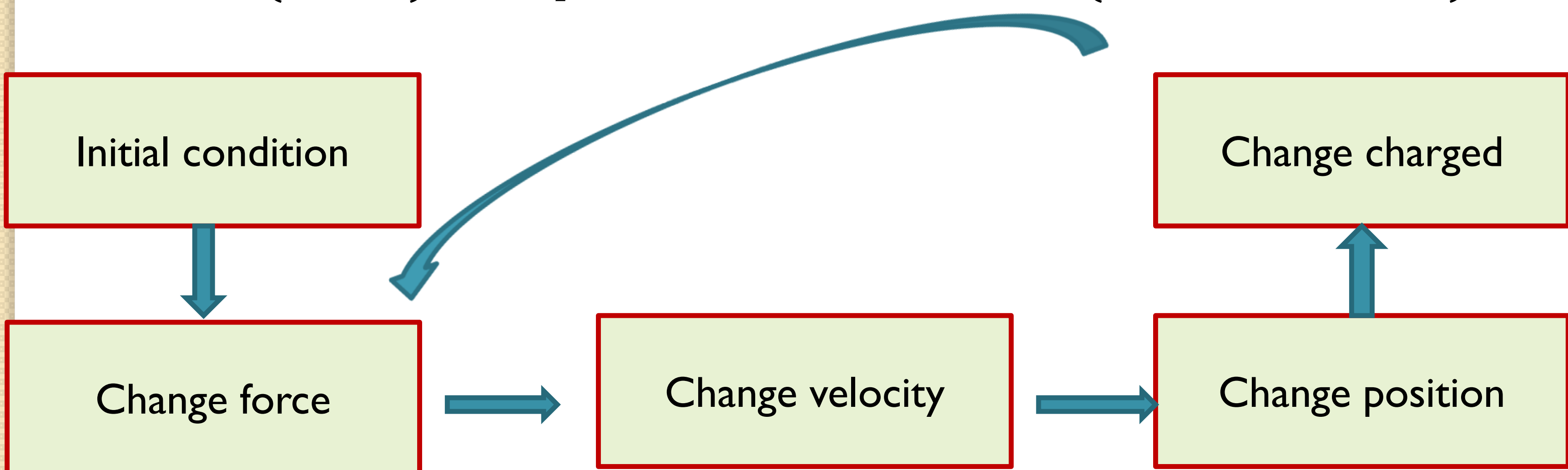
- Source:http://blogs.discovermagazine.com/crux/2013/03/20/did-voyager-1-leave-the-solar-system-or-not/#.WaUiBj4jHIU

2.Changing charged

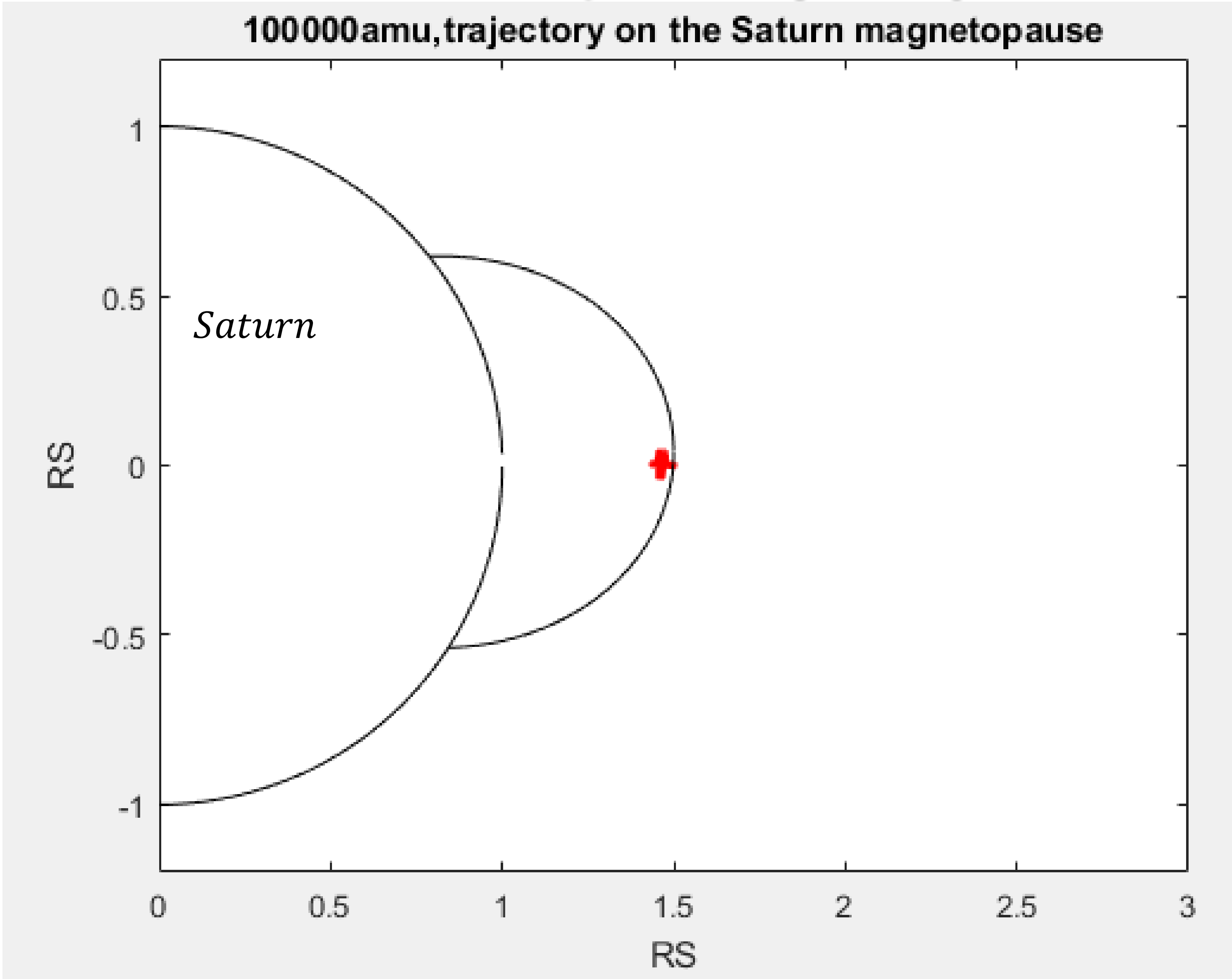
The charging equation:

$$\frac{dq}{dt} = \sum_{k} J_k$$

$$= J_{i(H+O)} + J_{photo} + J_{sec} - J_{e(cold\ e+hot\ e)}$$



Simulate the trajectory of particle



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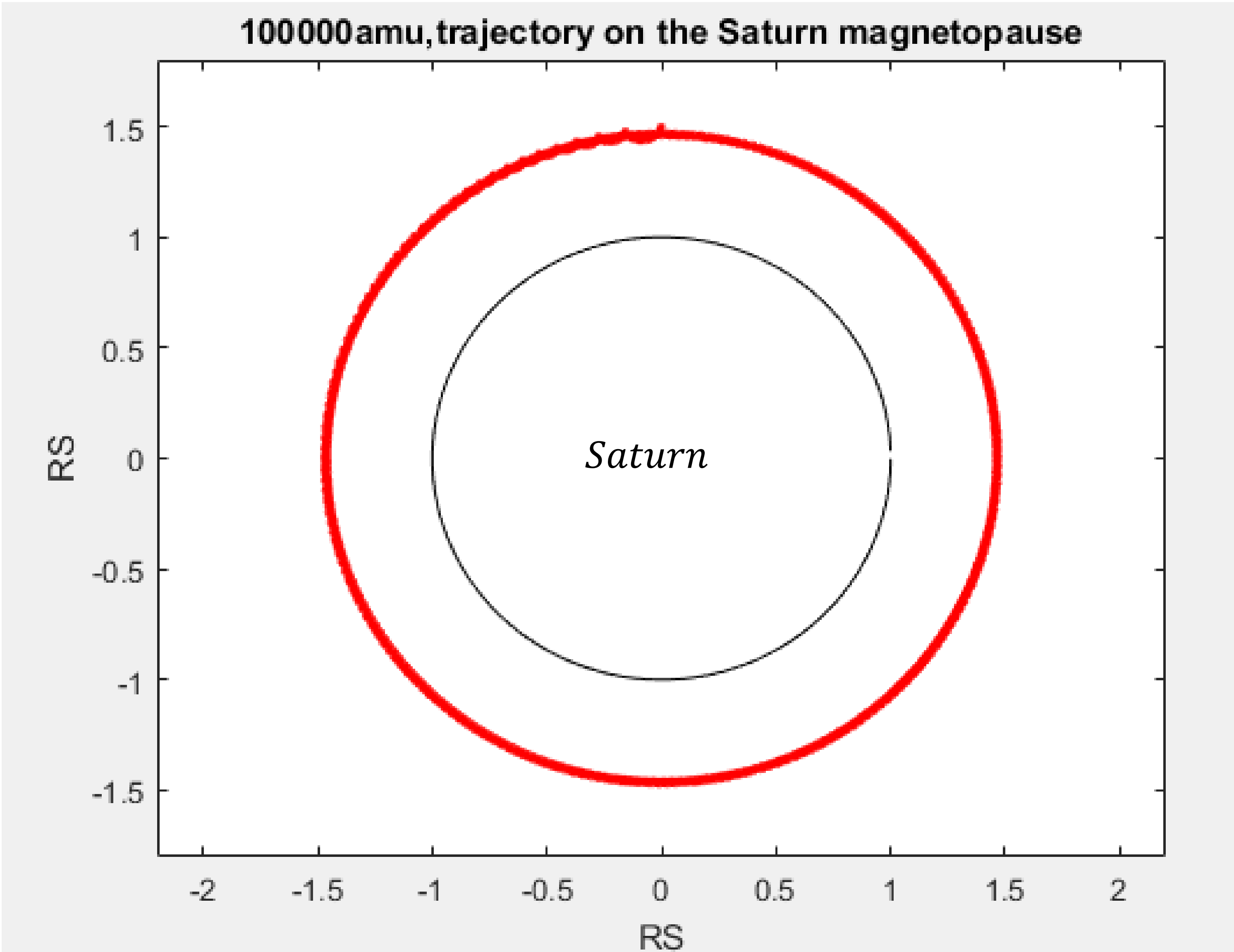
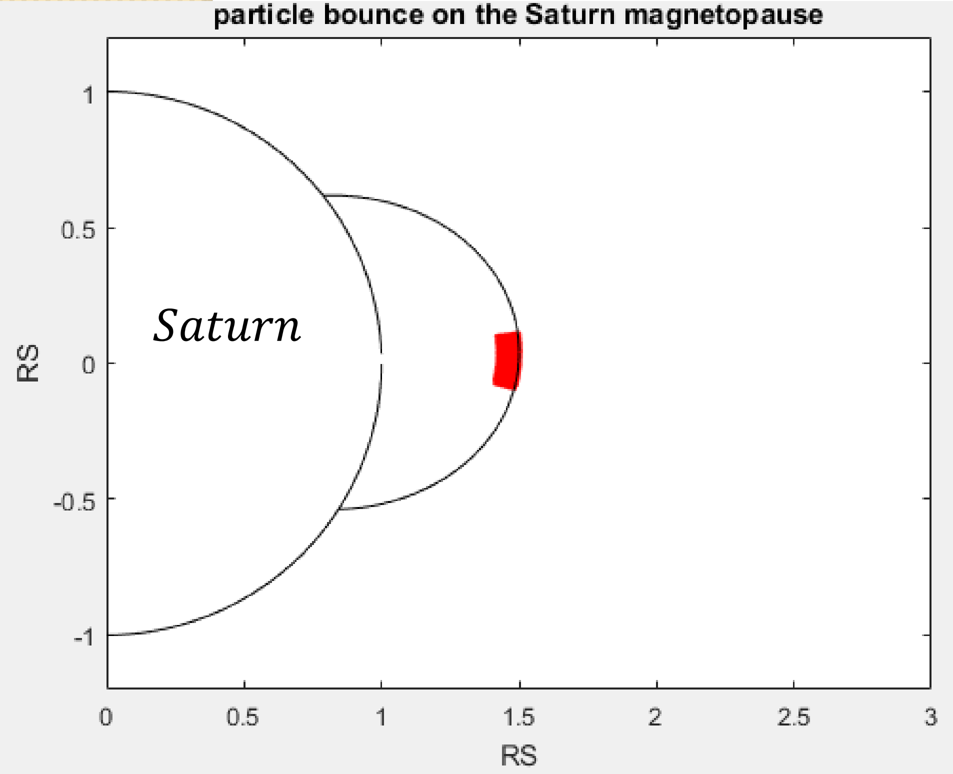
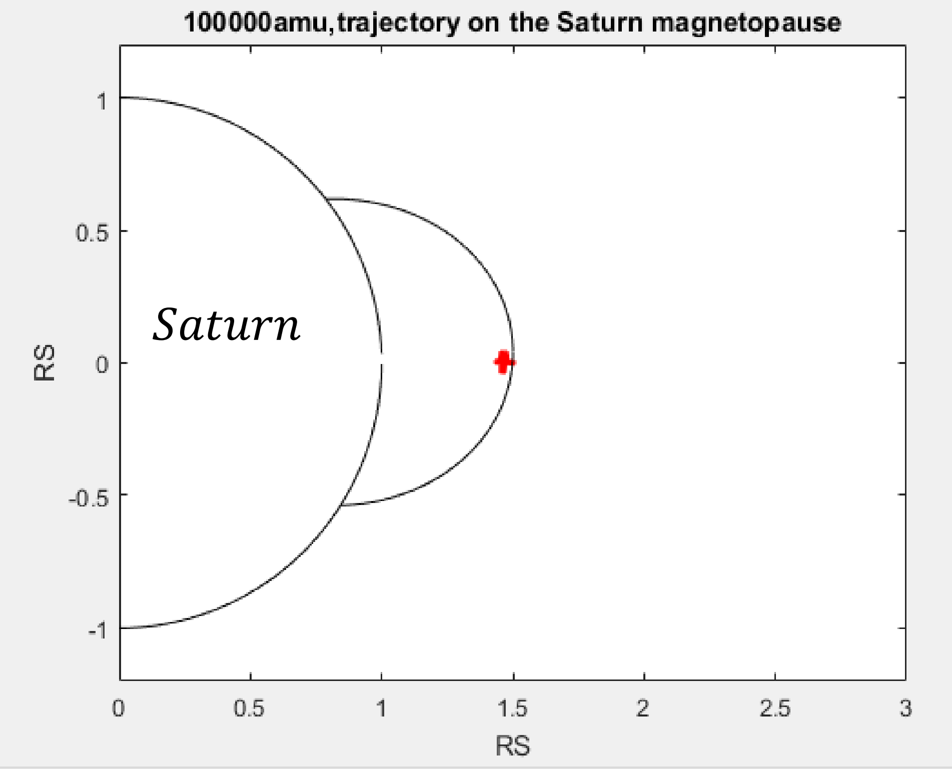


Compare of stable charged and changing charged

steady state

changing





Future work

1. Add Cassini background data
2. chemistry of Saturn atmosphere

Reference:

1.許翔聞 2004

2. https://kknews.cc/science/38l8rm8.html

3. http://blogs.discovermagazine.com/crux/2013/03/20/did-voyager-1-leave-the-solar-system-or-not/#.WaUiBj4jHIU

4.潘昆慶 2016

5. Teolis_2015_sensitivity.pdf

6. AnalysisGuide.pdf