Dynamics of Uranus' Dusty μ ring

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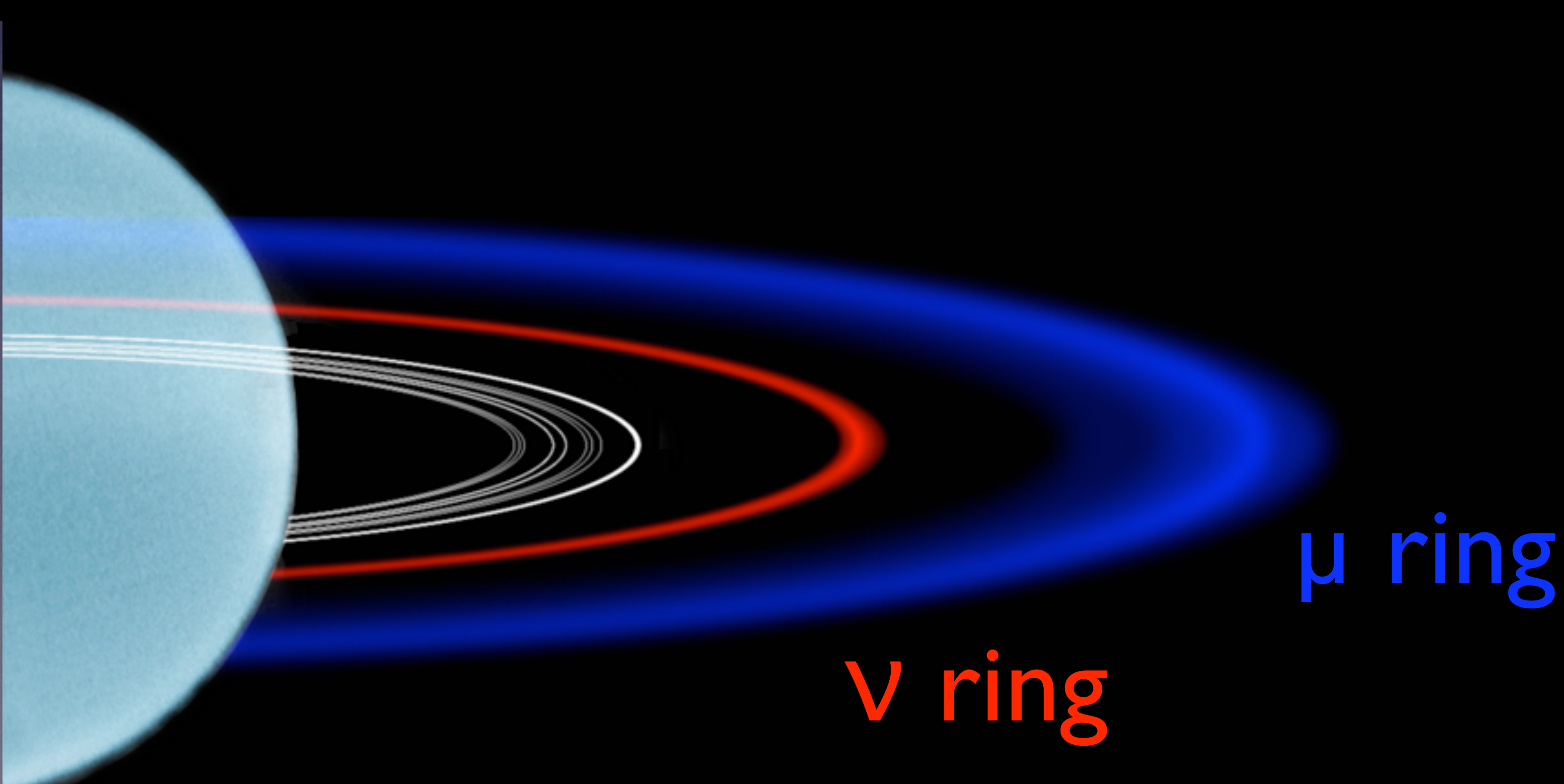
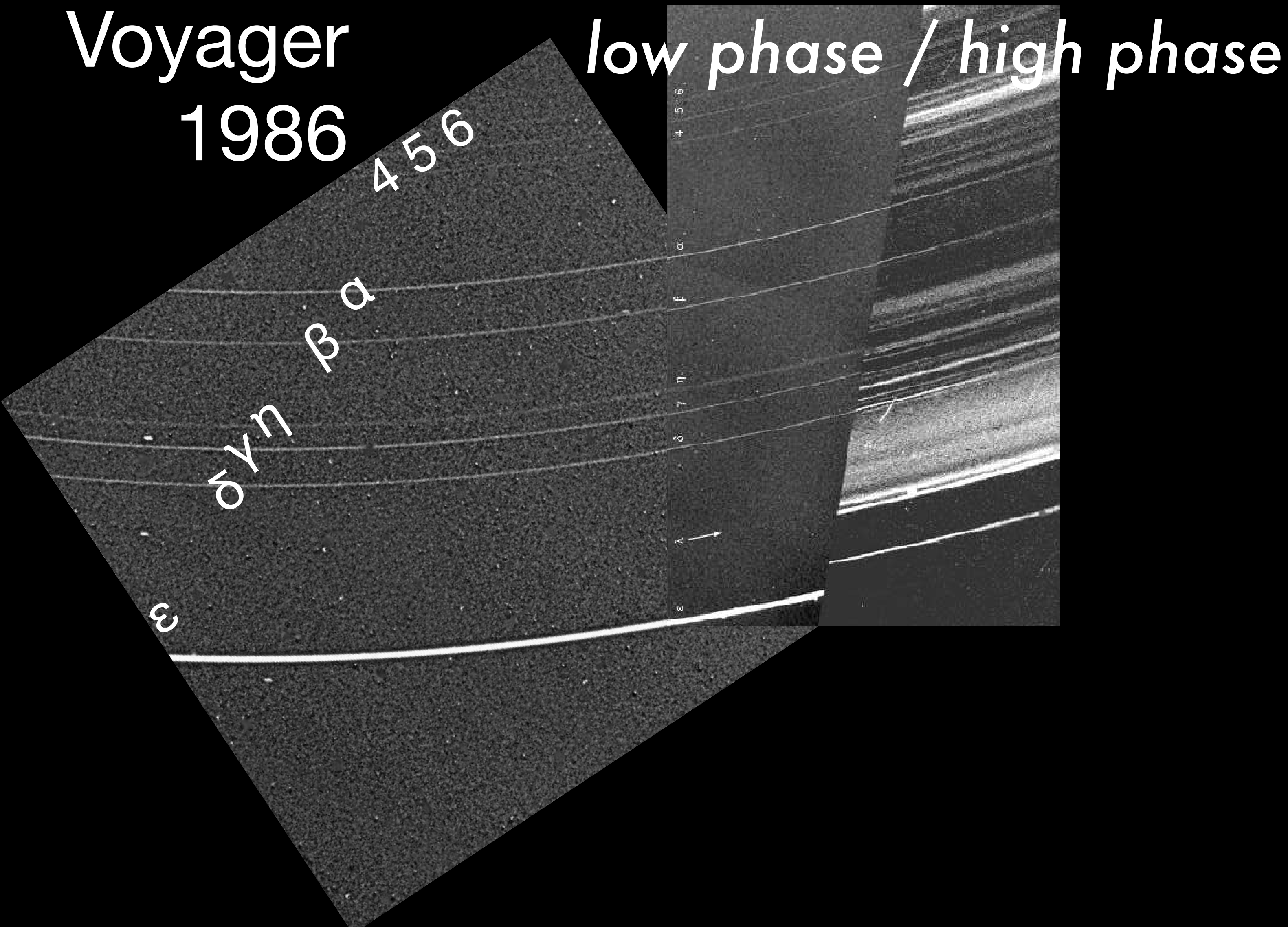
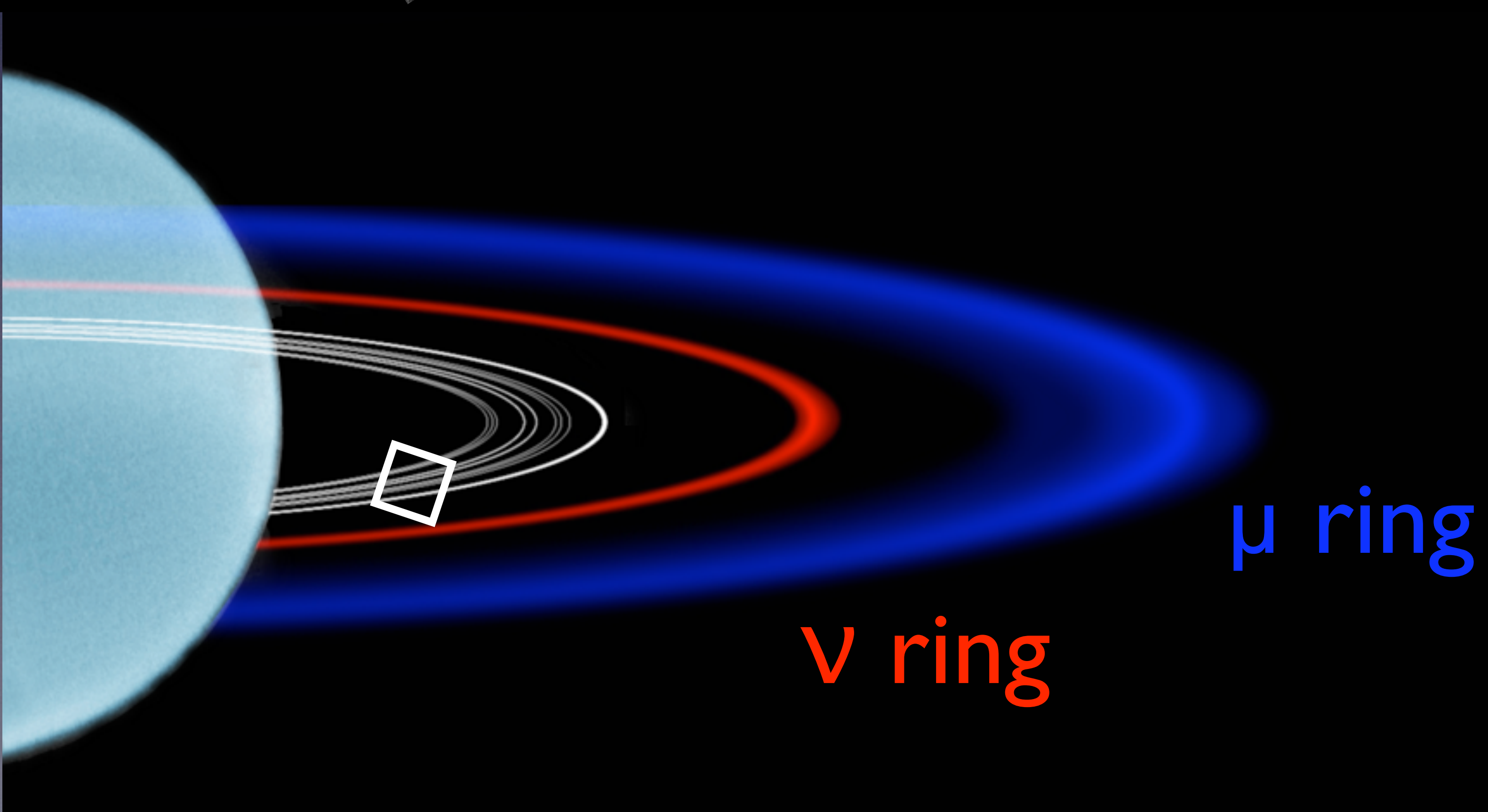
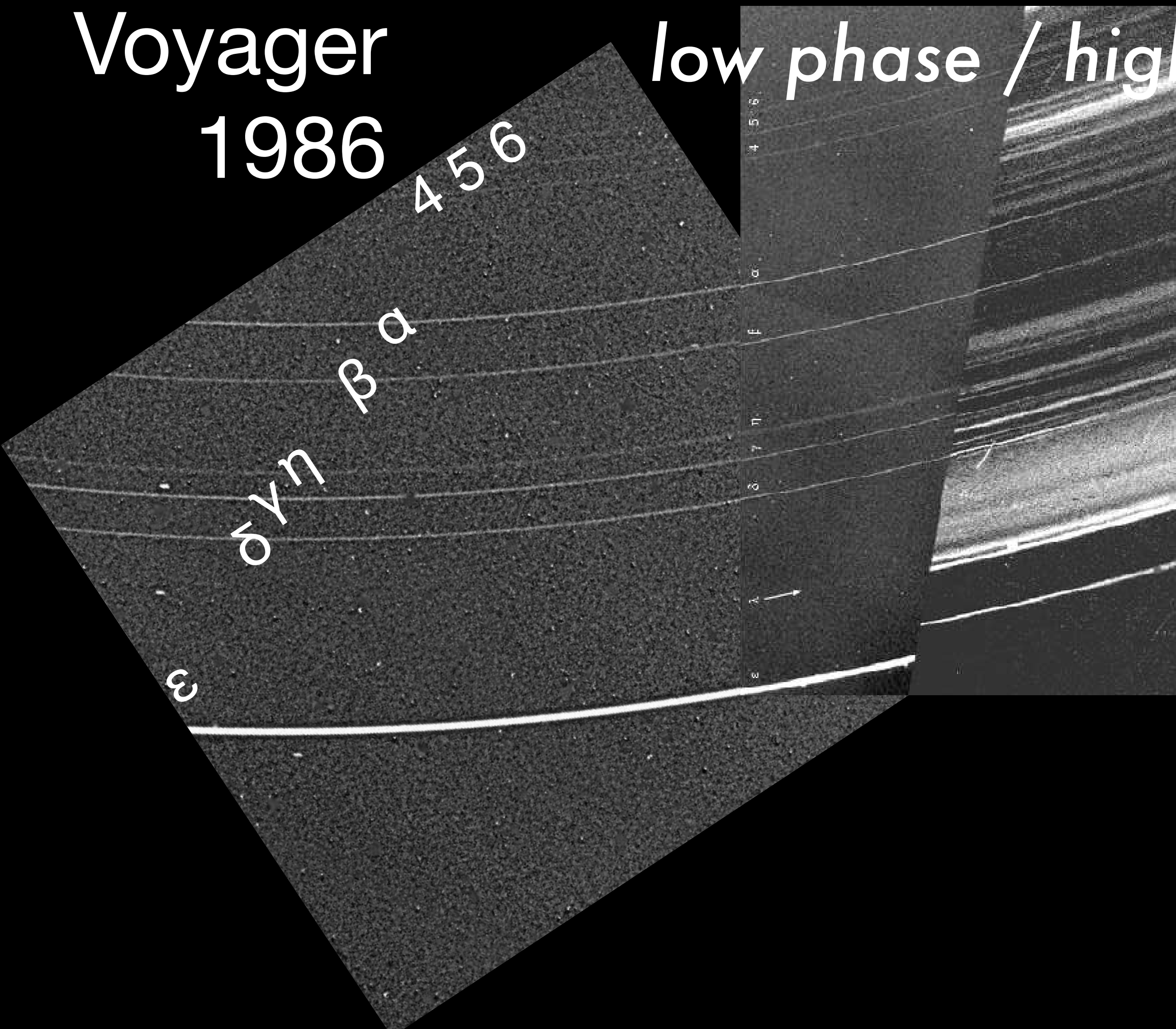
Special thanks to
M. Showalter & C. Arridge



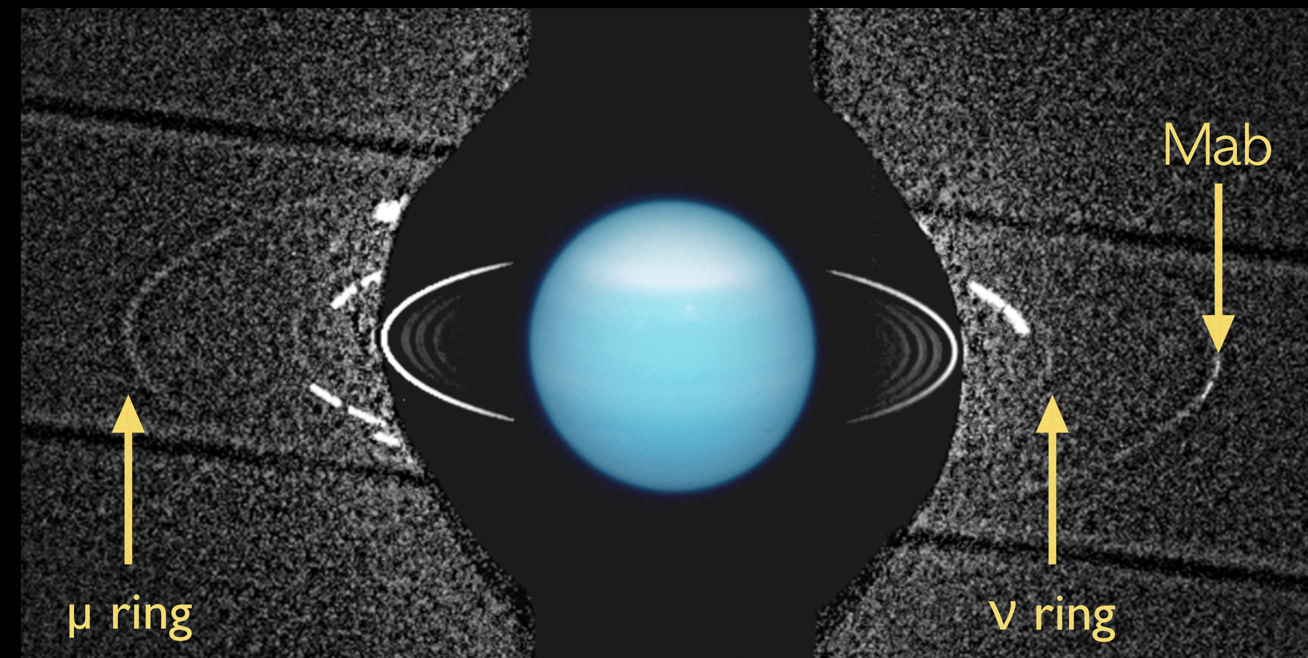
Planetary Rings Workshop
2014/08/13-15
Boulder, CO USA


Voyager
1986
low phase / high phase
4 5 6
β α
δ γ η
ε

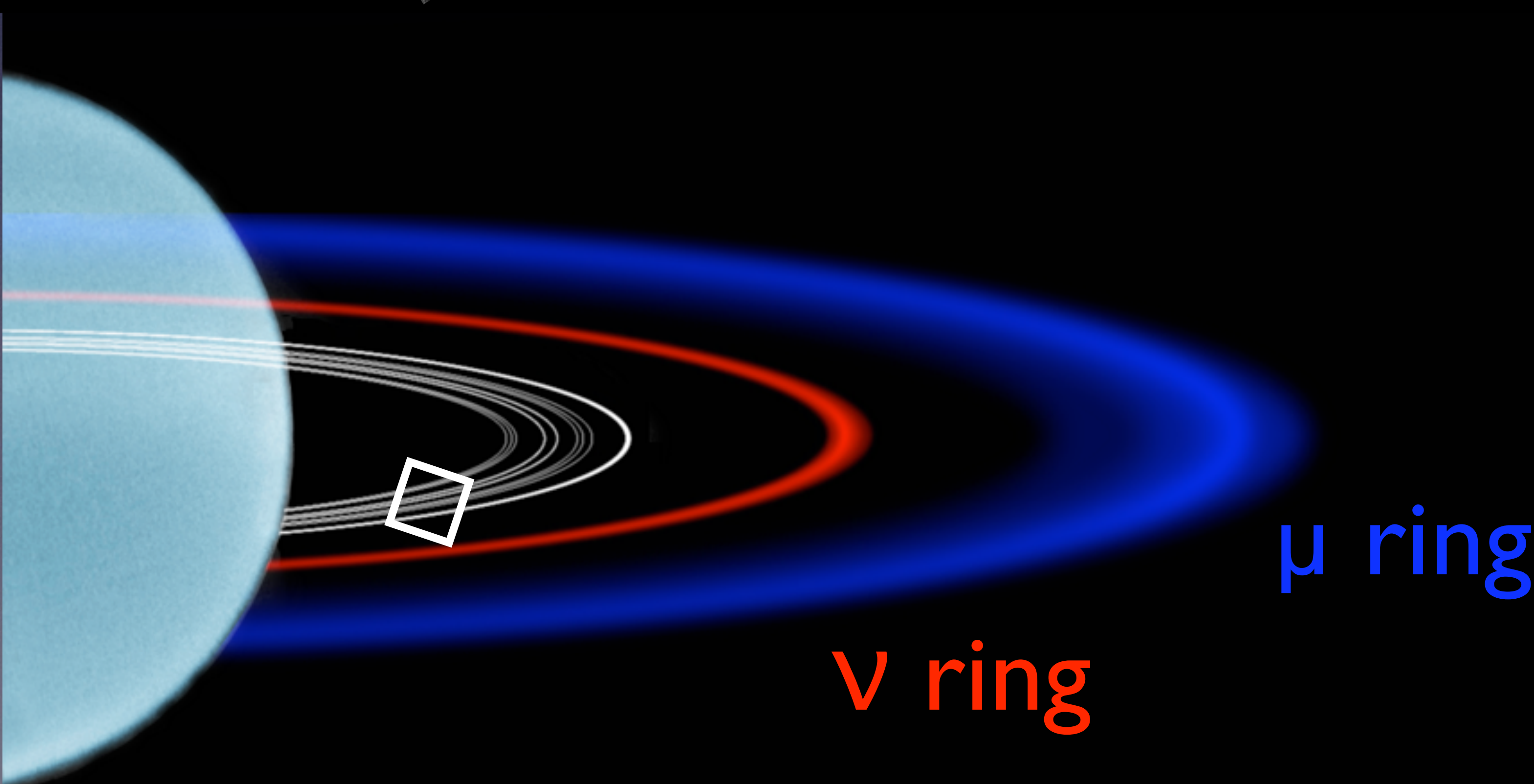

μ ring
ν ring



HST/ACS, August 2003

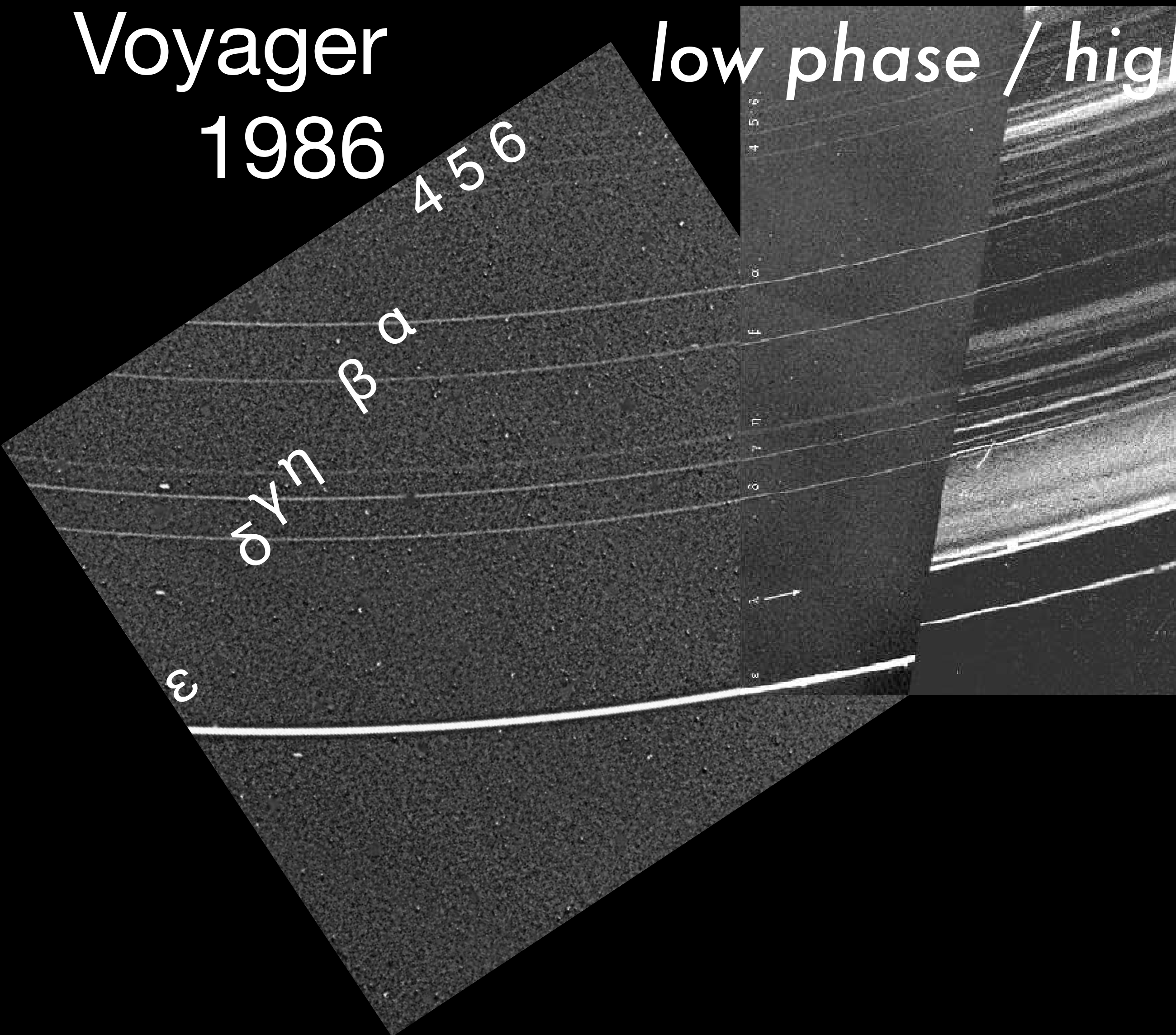


Showalter & Lissauer 2006



Voyager 1986

low phase / high phase



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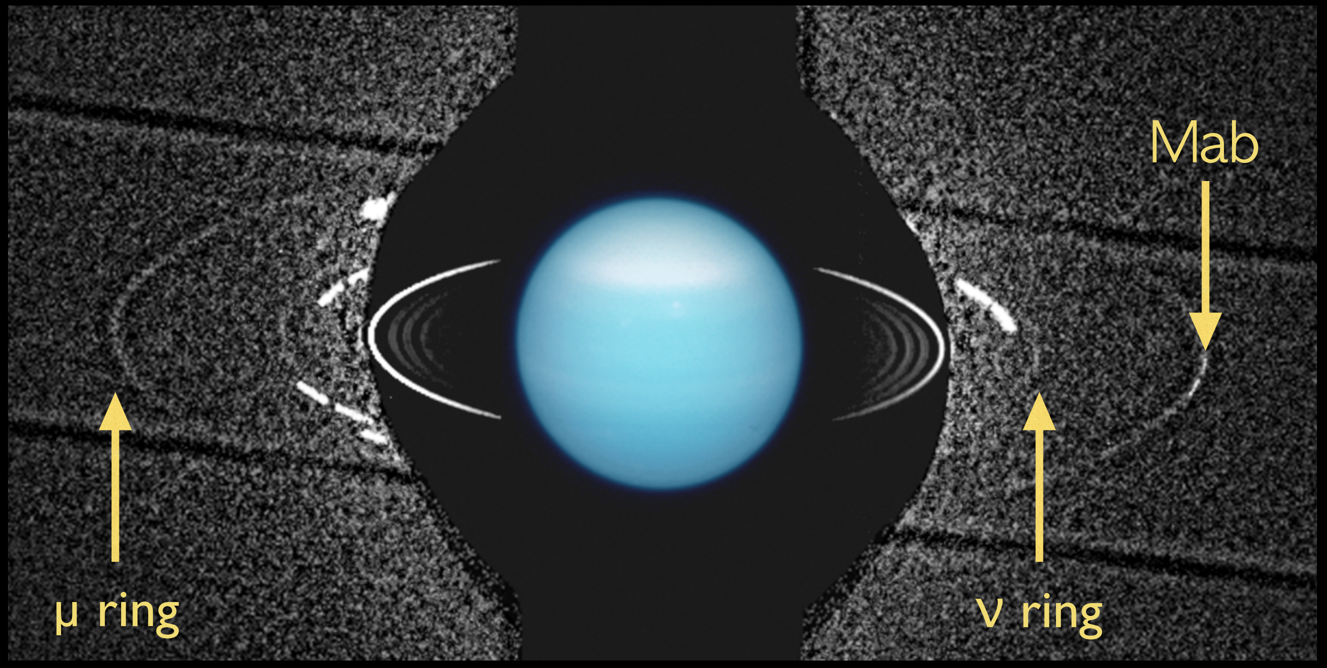

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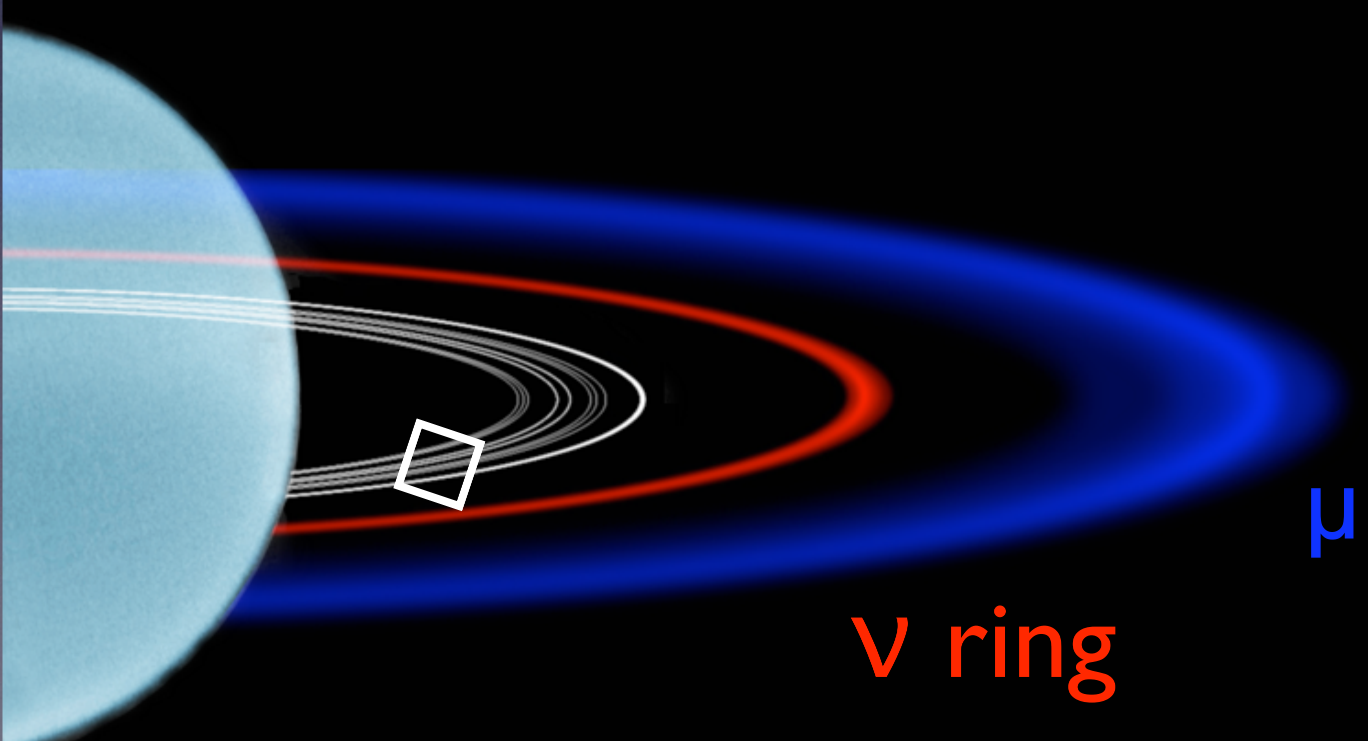
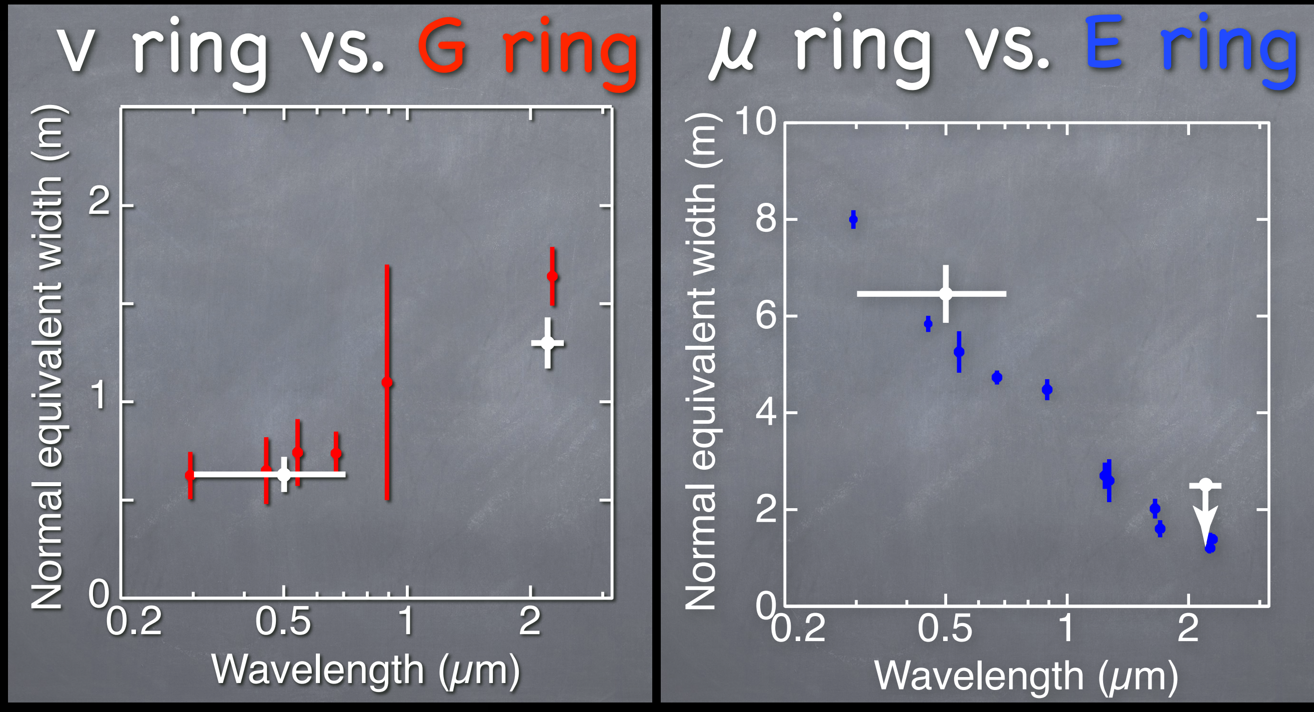
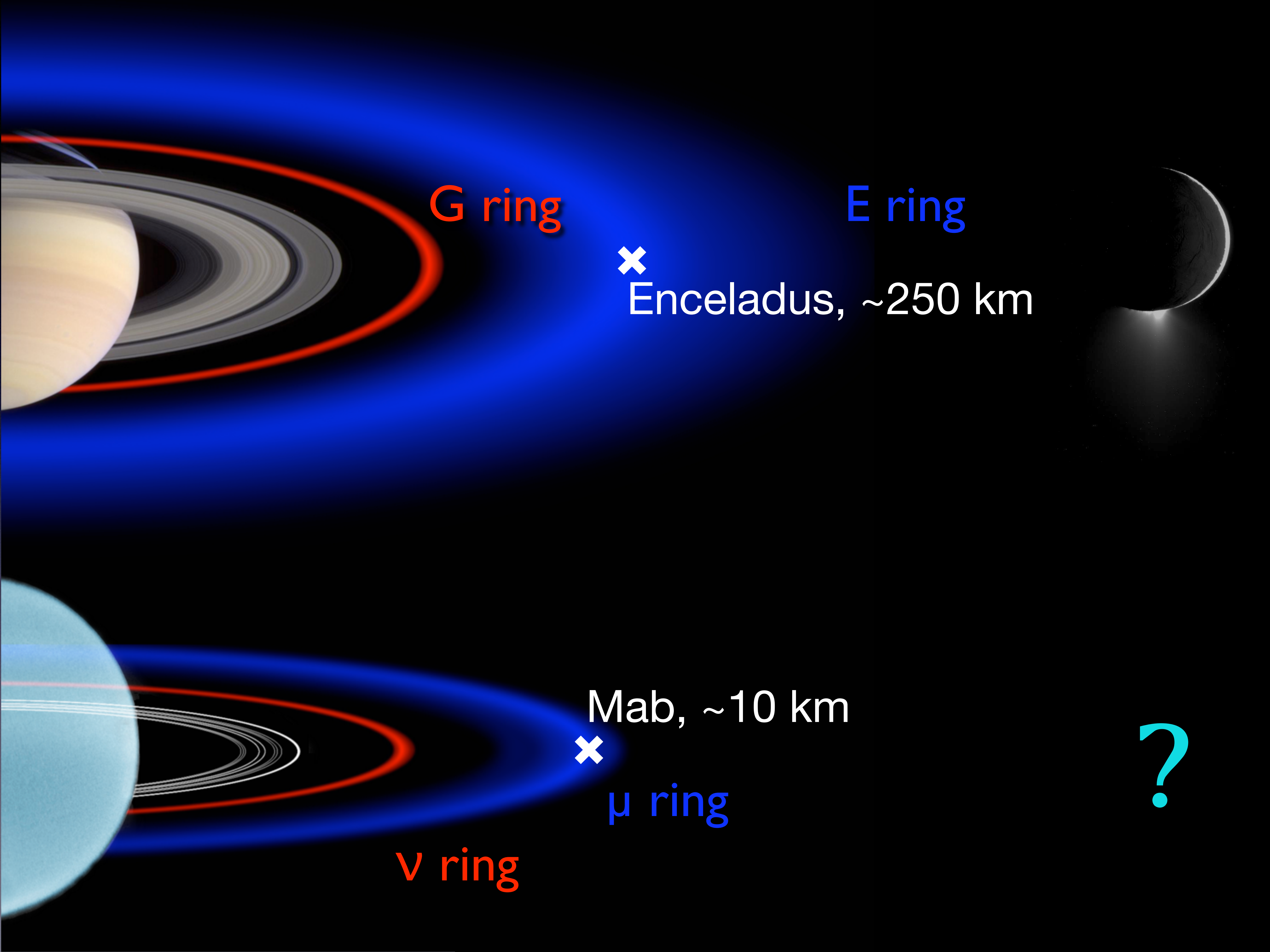




Keck II/NIRC2, de Pater et al., 2006


G ring
E ring
Enceladus, ~250 km
Mab, ~10 km
μ ring
ν ring
?

Uranus vs. Saturn

	Mass (kg)	R	Equator Surface |B| (Gauss)	Semi-major axis (AU)
Saturn	5.865 10	60,268	0.2	9.6
Uranus	8.681 10	25,559	0.3 - 0.5	19.2
ratio (X	~6.5	~2.4	~0.5	0.5

Force on a charged dust particle at the same R_P

	gravity $\frac{GM_p}{r^2}$	Lorentz force $\frac{Q_d}{m_d}\Delta V \times B$	Radiation Pressure F_{rad}
ratio (F	1.2	4.7	4

Dynamics of Saturn’s E ring particles

Horányi et al., 1992

Orbit precession rate caused by

planet oblateness

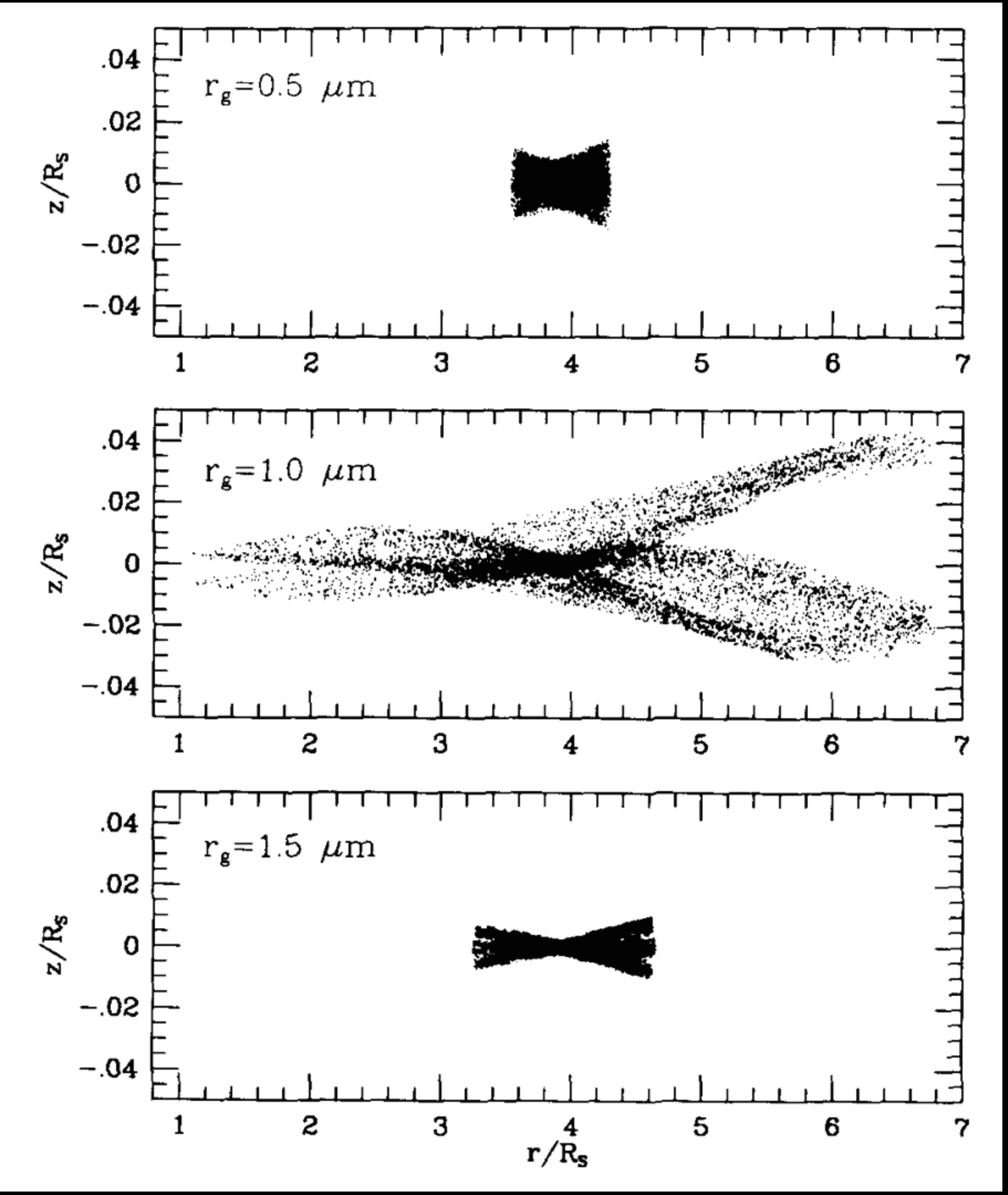
$$\dot{\tilde{\omega}}_{J_2} = \frac{3}{2}\omega_{\mathrm{k}} J_2 \left(\frac{R_{\mathrm{S}}}{a}\right)^2$$

Lorentz force

$$\dot{\tilde{\omega}}_{\Phi} = -2\frac{QB_0}{mc}\left(\frac{R_{\mathrm{S}}}{a}\right)^3$$

for low *e*, low ***i*** particle orbit.

ice grain from Enceladus



1st order comparison

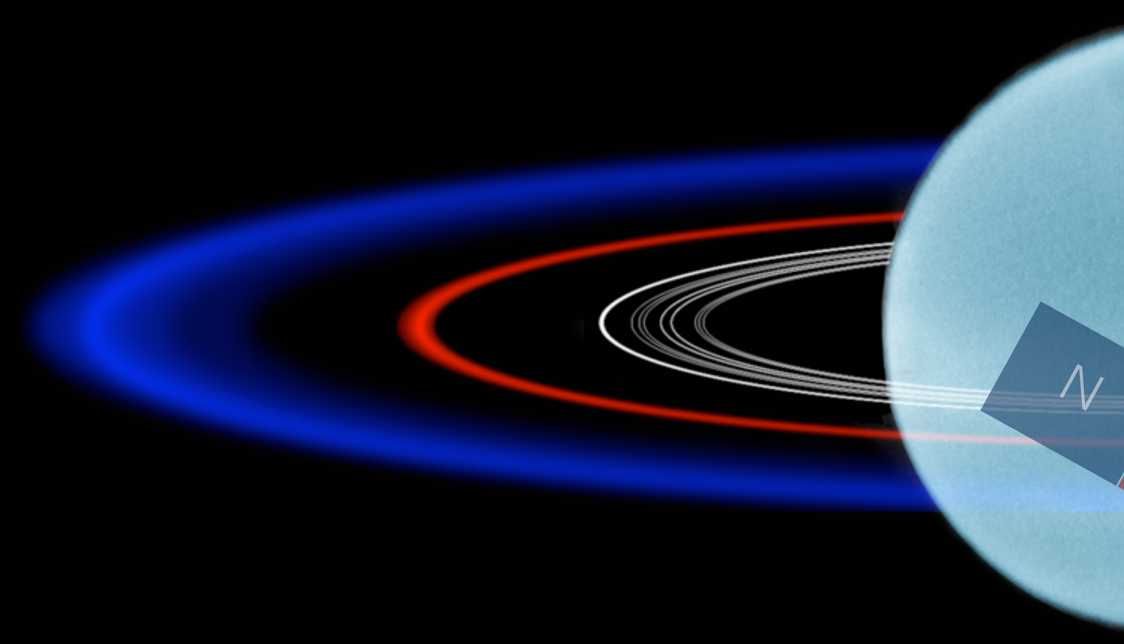
Orbit precession rate caused by

planet oblateness

$$\dot{\omega}_{J_2} = \frac{3}{2}\,\omega_{\mathrm{k}}\,J_2\left(\frac{R_{\mathrm{S}}}{a}\right)^2$$

Lorentz force

$$\dot{\omega}_{\Phi} = -2\,\frac{QB_0}{mc}\left(\frac{R_{\mathrm{S}}}{a}\right)^3$$



for low *e*, low ***i*** particle orbit.

1st order comparison

Orbit precession rate caused by

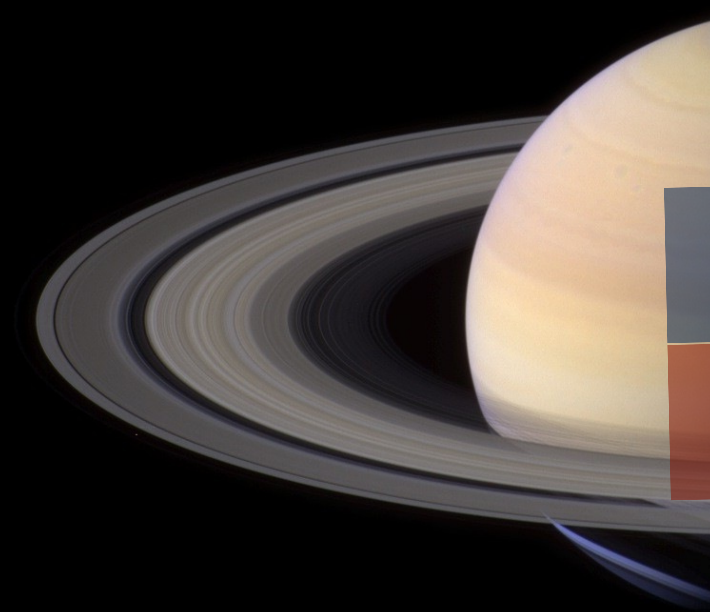
planet oblateness

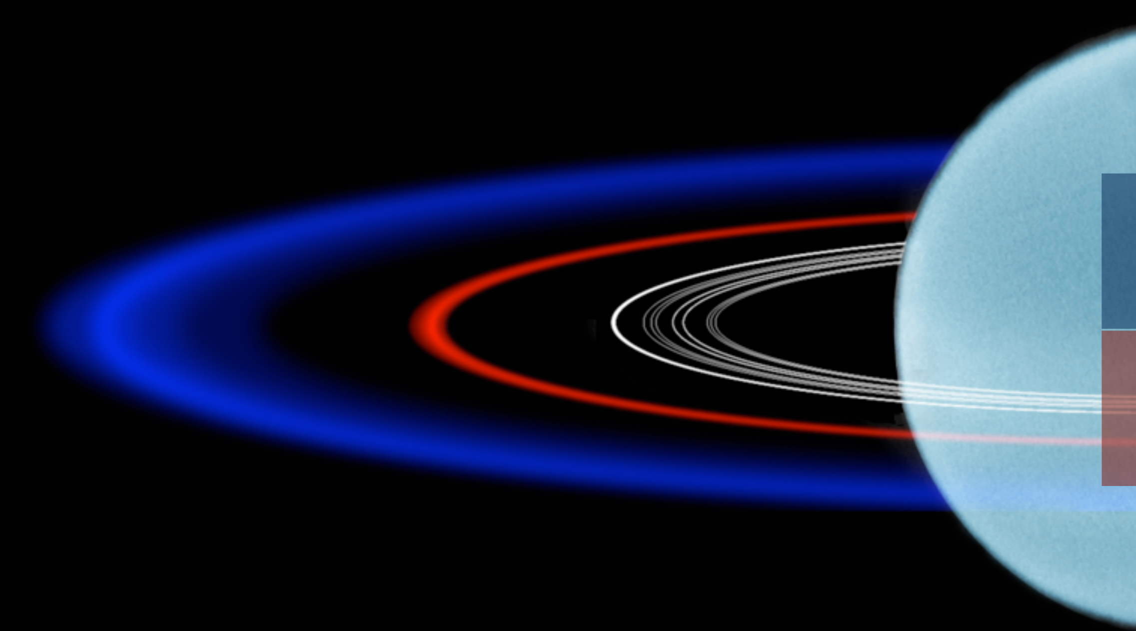
$$\dot{\varpi}_{J_2} = \frac{3}{2}\,\omega_k\,J_2\left(\frac{R_S}{a}\right)^2$$

Lorentz force

$$\dot{\varpi}_{\Phi} = -2\,\frac{QB_0}{mc}\left(\frac{R_S}{a}\right)^3$$

for low *e*, low ***i*** particle orbit.





1st order comparison

Orbit precession rate caused by

planet oblateness

$$\dot{\bar{\omega}}_{J_2} = \frac{3}{2}\omega_k J_2 \left(\frac{R_S}{a}\right)^2$$

Saturn → $50.4 \cdot (\frac{R_S}{a})^{3.5}$ °/day

Uranus → $14.7 \cdot (\frac{R_U}{a})^{3.5}$ °/day

Lorentz force

$$\dot{\bar{\omega}}_{\Phi} = -2\frac{QB_0}{mc}\left(\frac{R_S}{a}\right)^3$$

Saturn → $198 \cdot \frac{Q_d}{m_d} (\frac{R_S}{a})^3$ °/day

Uranus → $396 \cdot \frac{Q_d}{m_d} (\frac{R_U}{a})^3$ °/day

for low *e*, low ***i*** particle orbit.

1^{st} order comparison

Orbit precession rate caused by

planet oblateness

$$\dot{\tilde{\omega}}_{J_2} = \frac{3}{2}\omega_k J_2 \left(\frac{R_S}{a}\right)^2$$

Lorentz force

$$\dot{\tilde{\omega}}_{\Phi} = -2\frac{QB_0}{mc}\left(\frac{R_S}{a}\right)^3$$

for low *e*, low ***i*** particle orbit.

For $\dot{\tilde{\omega}}_{\phi} \approx \dot{\tilde{\omega}}_{J2}$, a charged dust particle at 4 R_P, should have

-0.13 C/kg [Saturn]
-0.02 C/kg [Uranus]

or

1 μm ice grain with potential of

-5 Volt [Saturn]
-1 Volt [Uranus]

Equation of Motion

Not considered

$$m_d \cdot a_d = F_{G,Uranus,J2} + F_{EM} + F_{RP} + F_{PR} + F_{GD}$$

Gravitational Forces

from the **Sun** & ***Uranus*** (J2 included)

Electromagnetic Force

assuming *constant* dust charge

Radiation Pressure

adopted β = 0.57

Gas Drag

from Uranus' exosphere

[Broadfoot et al., 1986]

Poynting-Robertson Drag

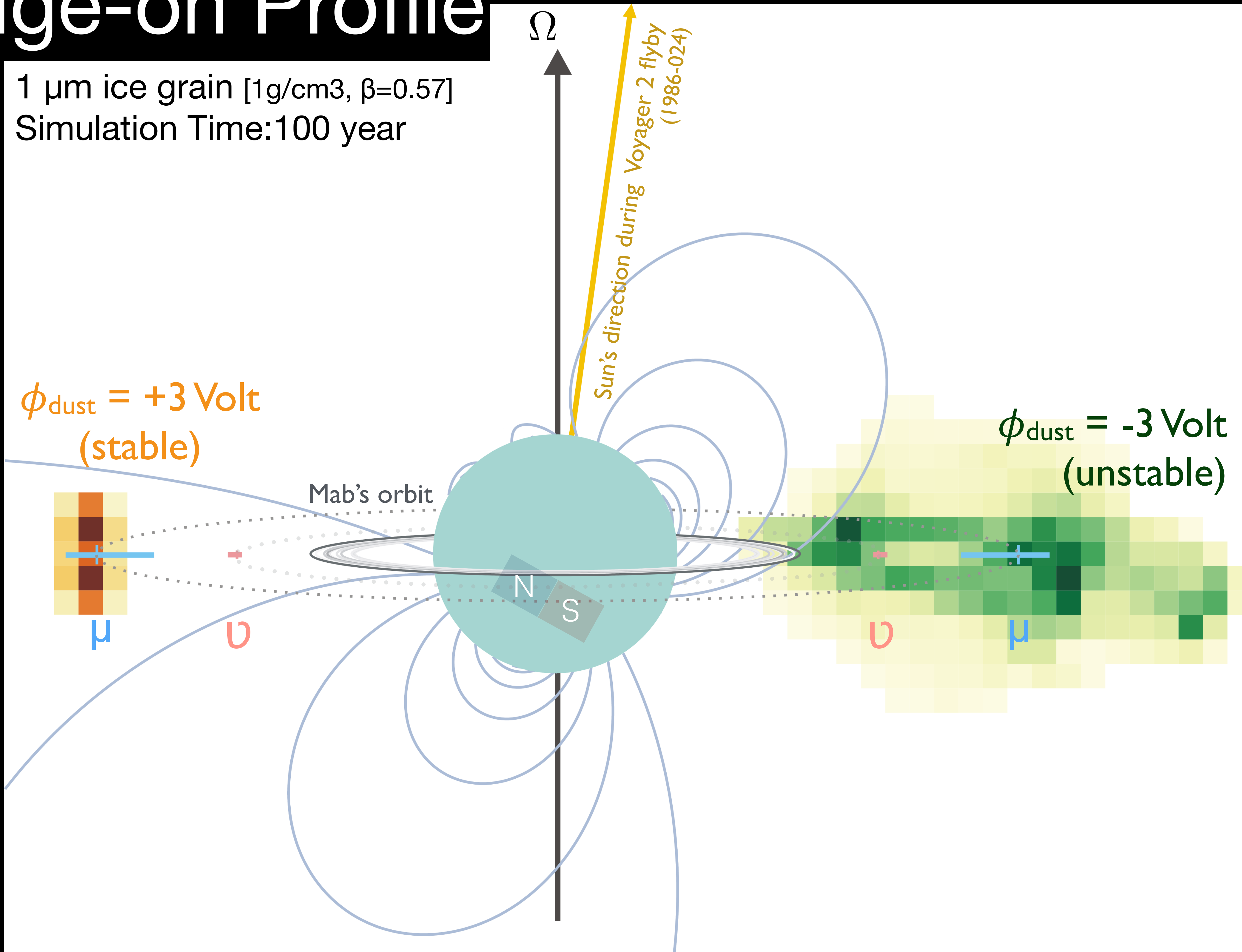
decrease of particle's semi-major axis

(0.23 km/yr for a μ ring particle

[Sfair & Giuliatti Winter, 2009])

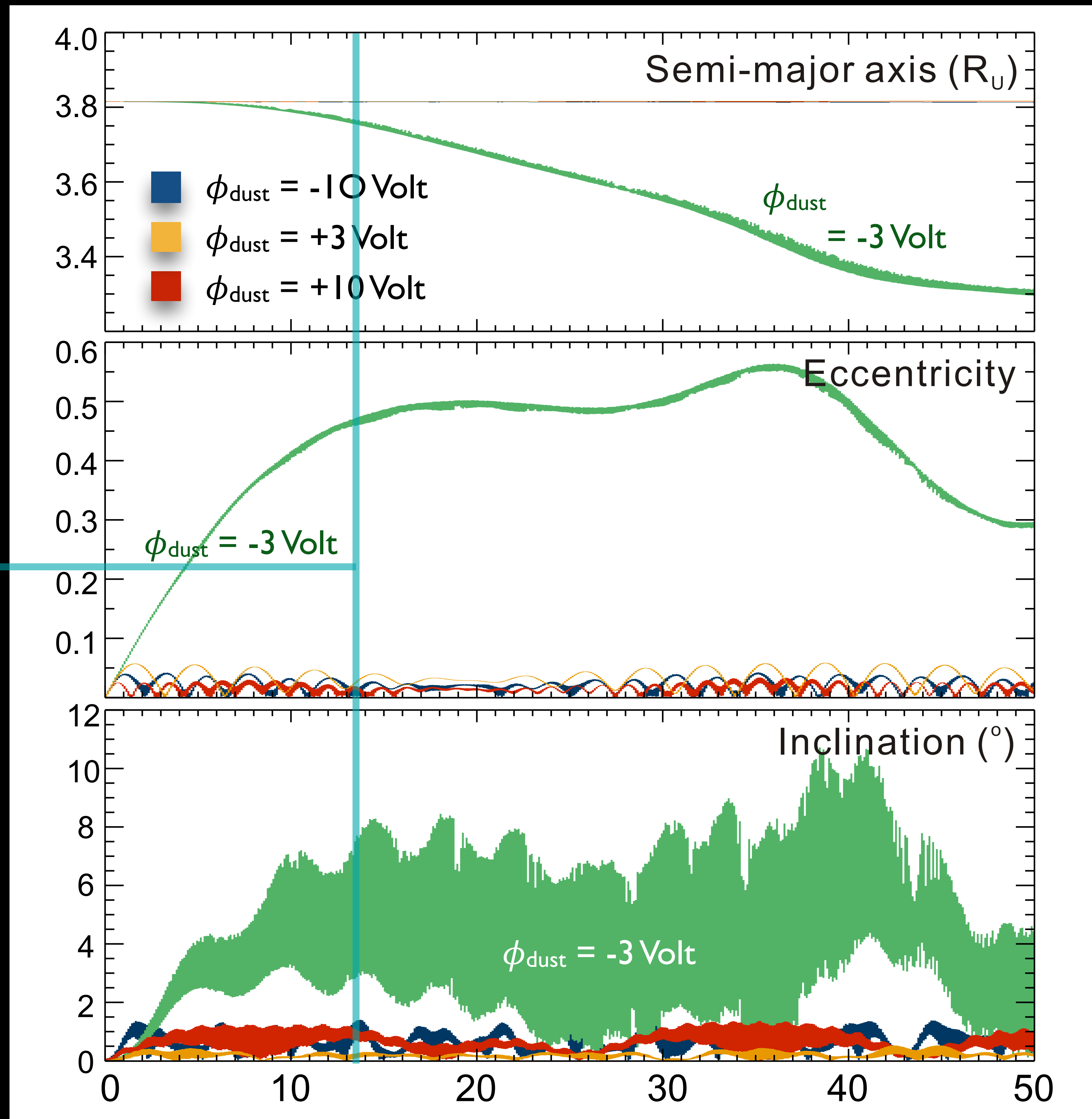
Edge-on Profile

1 μm ice grain [1g/cm3, β=0.57]
Simulation Time:100 year



Orbital Evolution

1 μm ice grain [1g/cm3, β=0.57]

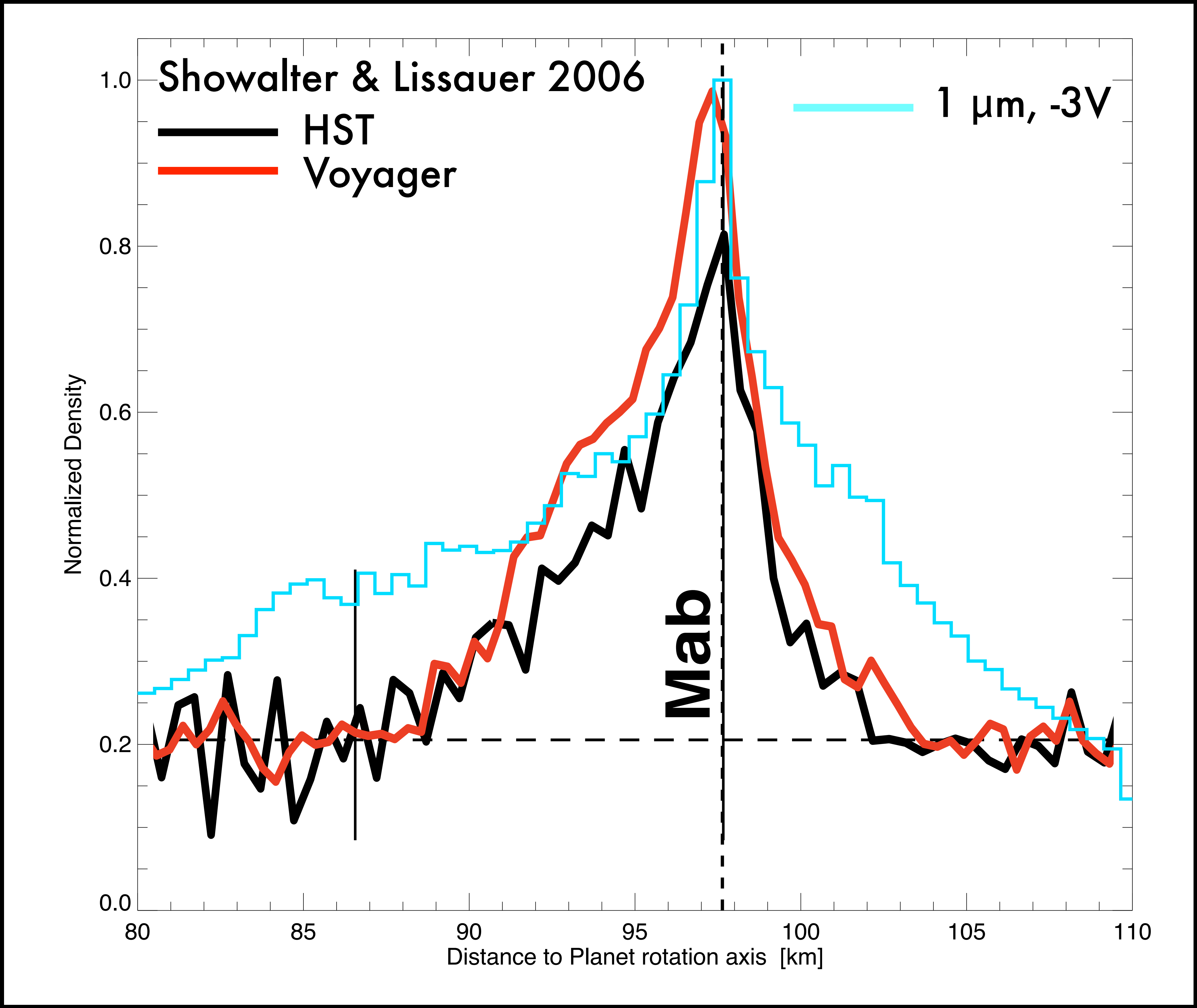


Lifetime < 20 year

pericenter crosses

ε ring @ ~2R_U

Radial Profile

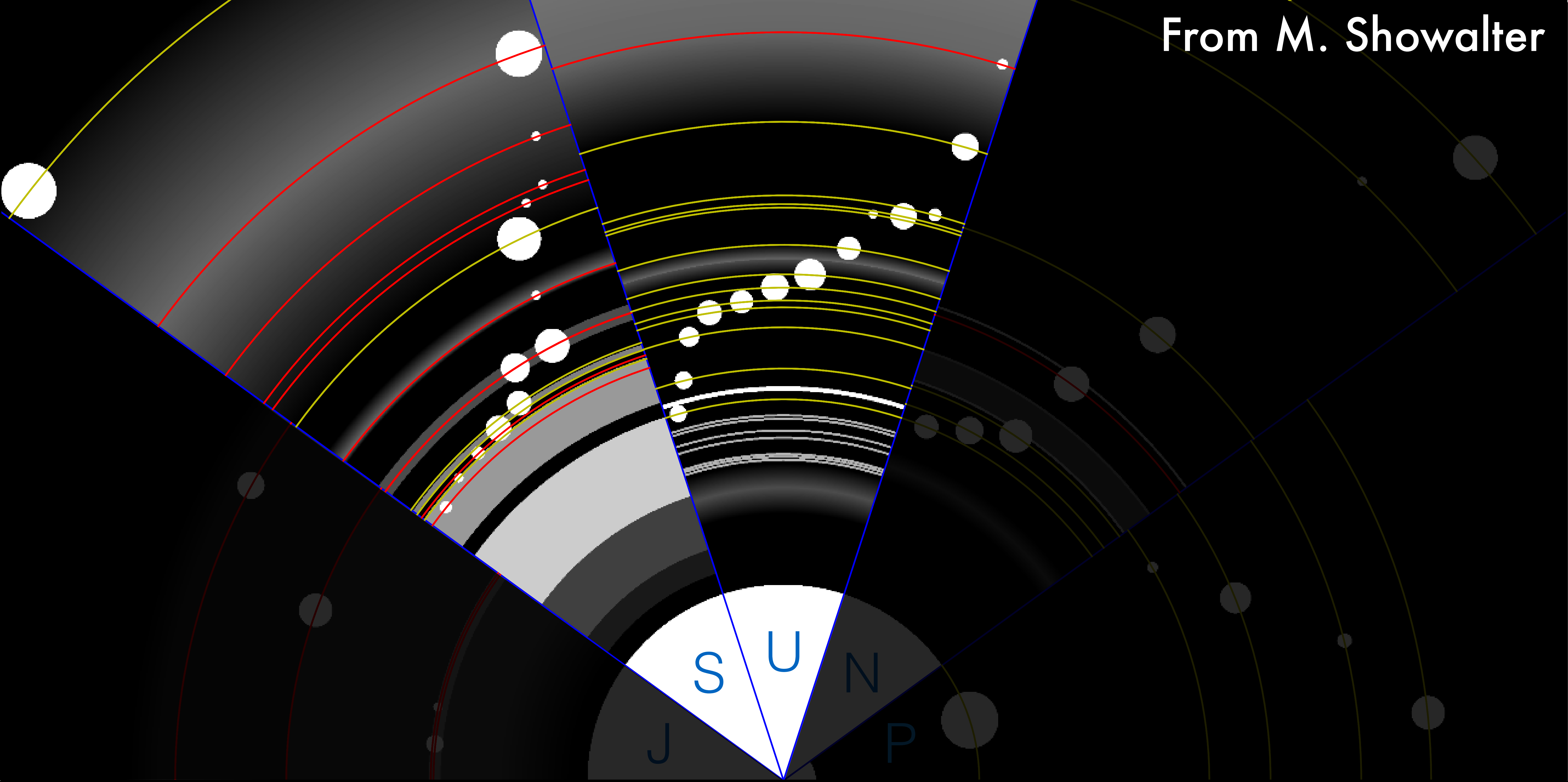


Mab as a source of the μ ring?

- Sfair and Giuliatti Winter 2012
  - μ ring particle dynamics simulation, no EM force
    ⇒ long particle lifetime ~ 10^3 year
  - $M_{\mu\ ring}$ ~ 6×10^6 kg (power-law, 1-10 μm, slope of -3.5)
    M^{+}_{Mab} ~ 2.7×10^{-3} kg/s
    ⇒ ~80 years to produce μ ring from Mab via impactor-ejecta process

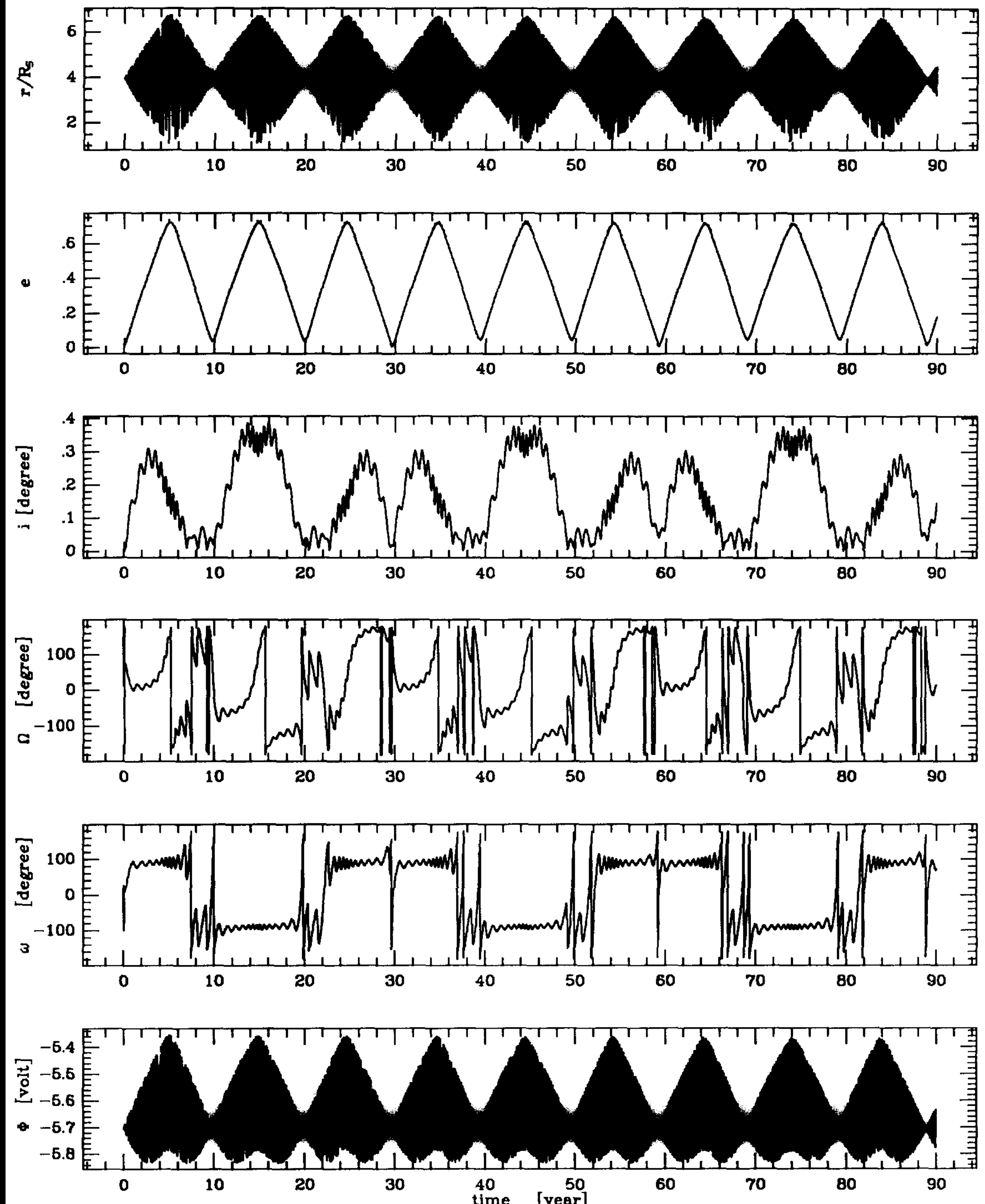
- This work
  - μ ring dust particles with a certain q/m are dynamically unstable
  - Lifetime ≲ 20 year

- We need:
  - IDP flux measurements from New Horizon at Uranus orbit
  - Dust charging condition in the μ ring region



Key

- The four giant planets are scaled to a common radius.
  - The Pluto-Charon separation is scaled to the same radius.
- Major rings are shown in grayscale.
- Moon orbits with dust rings are shown in red; otherwise yellow.
- Moon radii are are shown in proportion to log(physical radius).



r/R_S
e
i [degree]
Ω [degree]
ω [degree]
Φ [volt]
time [year]