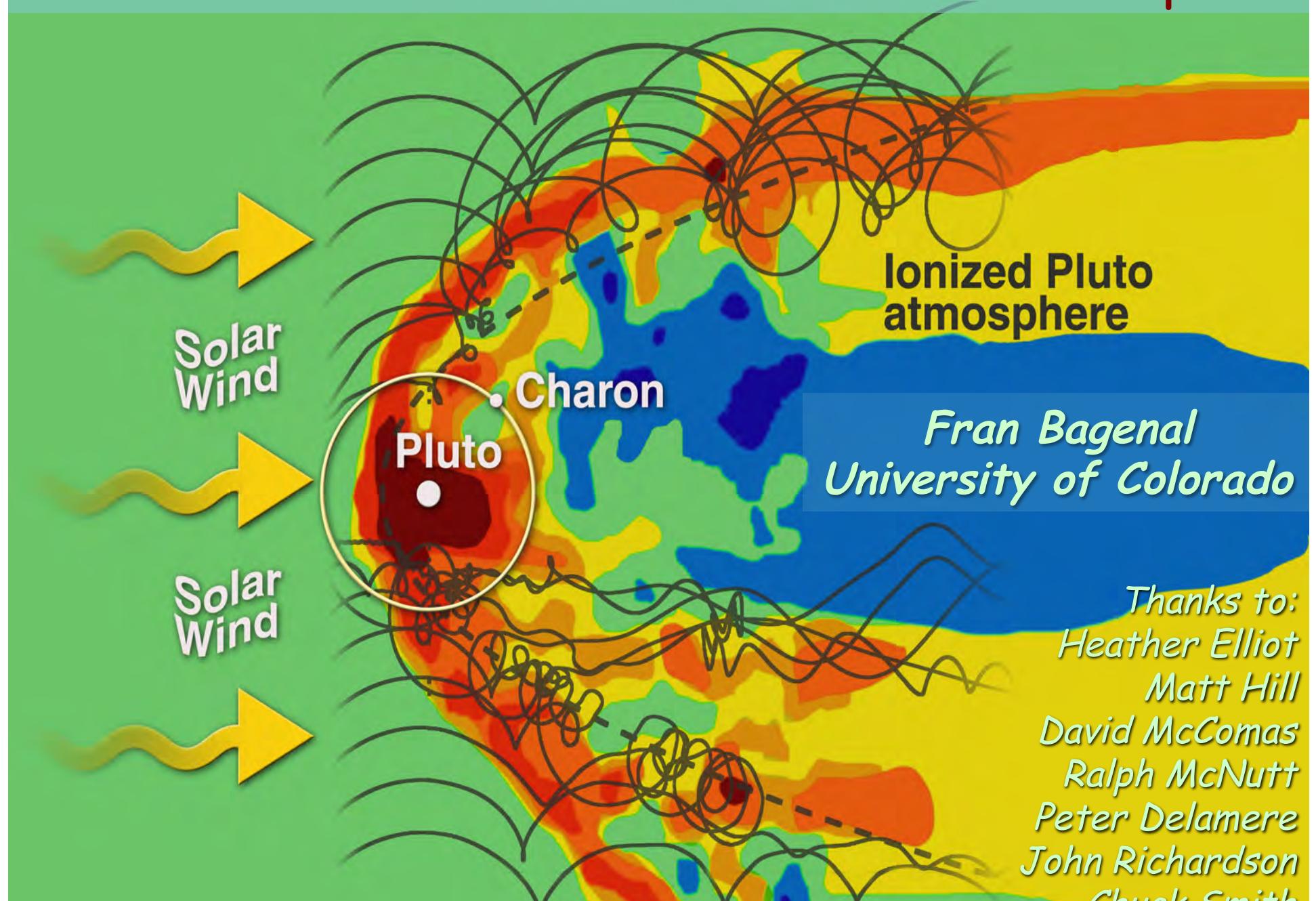
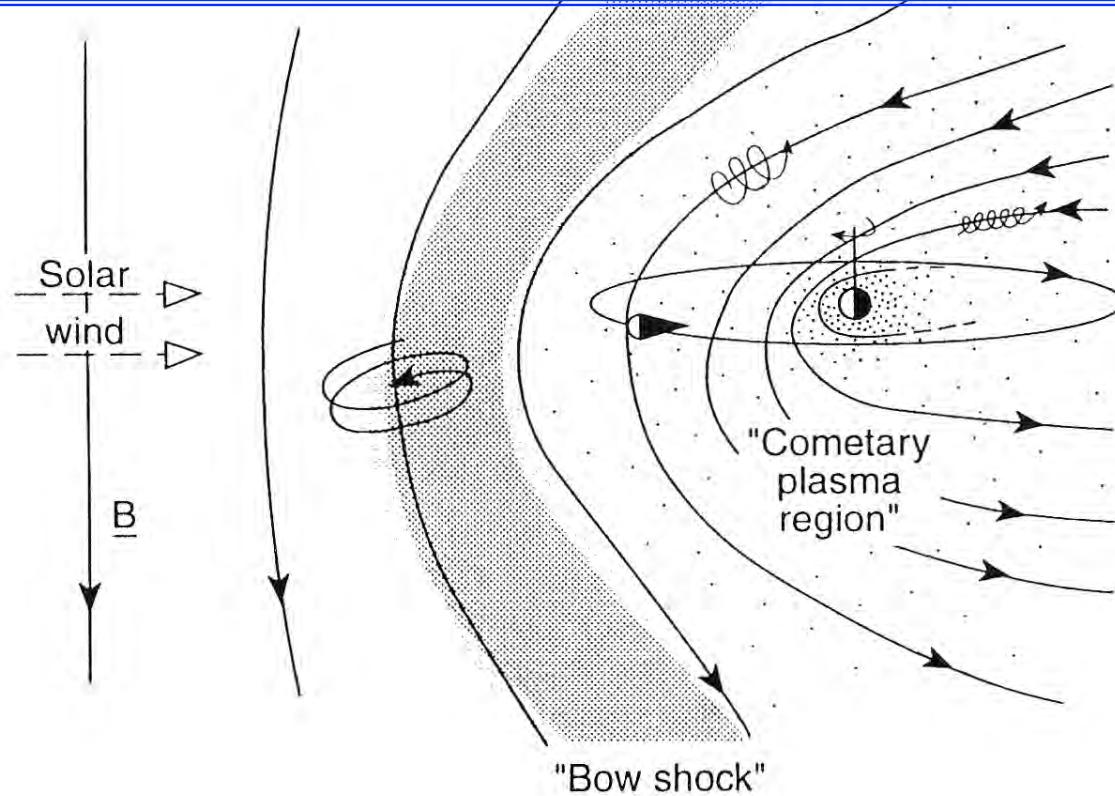


Solar Wind Interaction with Pluto's Atmosphere

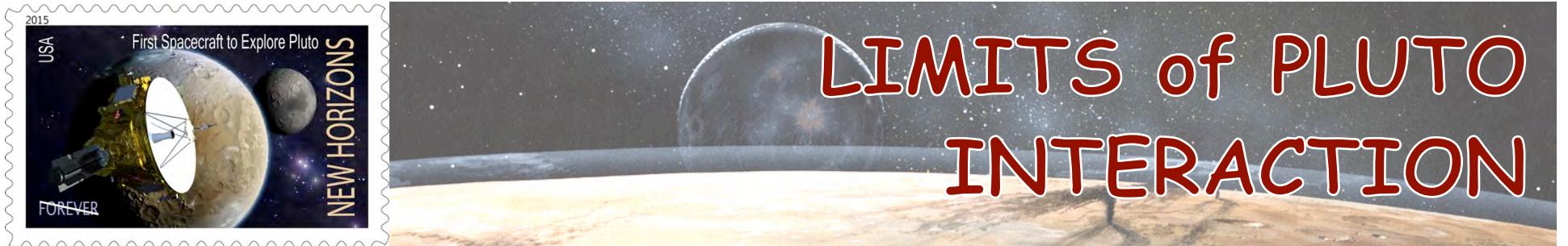




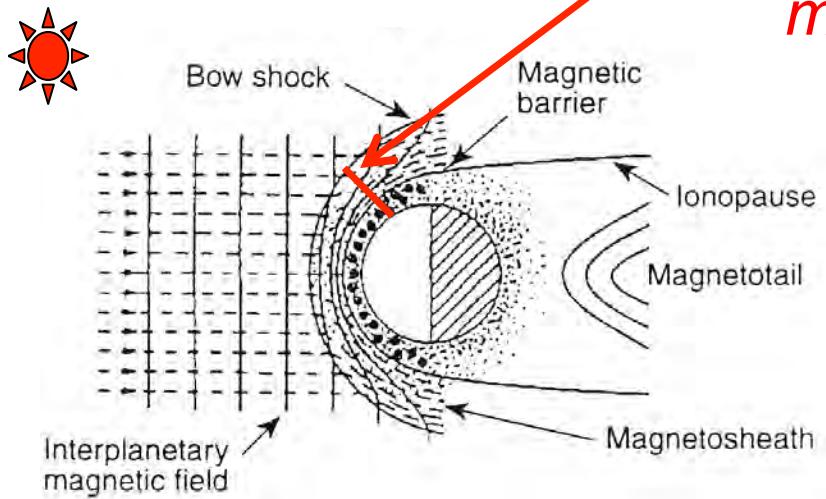
The solar wind interacts with Pluto's escaping atmosphere like a comet



Trafton 1981
Bagenal & McNutt 1989
Kecskemeti & Cravens
1993
Bagenal, Cravens,
Luhmann, McNutt &
Cheng 1997
Sauer, Lipatov,
Baumgartel, Dubinin
1997
Ip, Kopp, Lara & Rodrigo
1999
Lipatov, Motschmann,
Bagdonat 2002
Delamere & Bagenal 2004
Harnett, Winglee &
Delamere 2005
Delamere 2009



Venus-like
(Small escape rate)



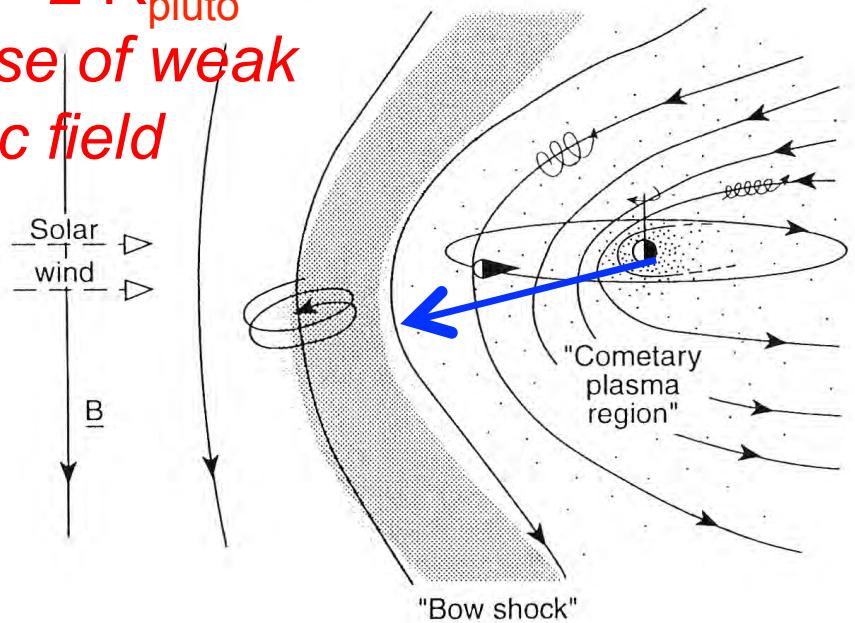
Scale size interaction

$$\text{LAYER } L \sim c/\omega_{pi} \\ < 2200 \text{ km} \sim 2 R_{\text{pluto}}$$

Large because of weak magnetic field

Comet-like
(Large escape rate)

View looking down on ecliptic plane



Scale size L of whole interaction
= photo-ionization scale for of escaping atmosphere



Cometary Interaction Region

Galeev,
Cravens &
Gombosi
(1985)

$$\frac{d}{dx} [\rho_i u f(u, \mu)] = \frac{Q_n m_i}{4\pi V_g \tau r^2} \delta\left(\mu - \frac{m_i u^2}{2B}\right) \text{ Mass}$$

$$\frac{d(\rho u)}{dx} = \frac{Q_n m_i}{4\pi V_g \tau r^2}, \quad \text{Momentum}$$

$$\frac{d}{dx} \left(\rho u^2 + p_{\perp} + \frac{B^2}{8\pi} \right) = 0, \quad \text{Energy}$$

Distance to Bow Shock

$$R_{BS} \sim \frac{Q_n m_i}{4 \pi V_g \tau \rho_{sw} V_{sw}}$$

Q_n = neutral escape rate

m_i = atomic mass of pickup ion

τ = ionization time

V_{sw} = solar wind speed

V_g = neutral gas escape flow

ρ_{sw} = solar wind mass density

$\tau \rho_{sw} \sim$ constant with distance from Sun



Ionization of escaping atmosphere
→ mass-loading of the solar wind

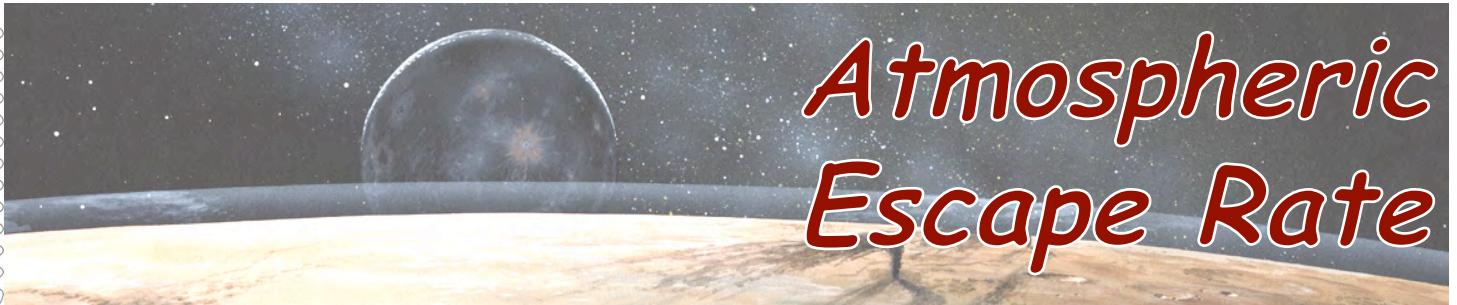
$$\frac{R_{\text{mass-loading}}}{R_{\text{pluto}}} \sim \frac{Q}{Q_o} \frac{P_o}{P_{\text{sw}}}$$

$$R_{\text{pluto}} \sim 1184 \text{ km}$$

$$Q_o \sim 1.5 \times 10^{27} \text{ N}_2 \text{ molecules/s}$$

$$P_o \sim 0.05 \text{ nPa}$$

For $Q > 1.5 \times 10^{27} \text{ N}_2 \text{ s}^{-1}$
the interaction is bigger than Pluto

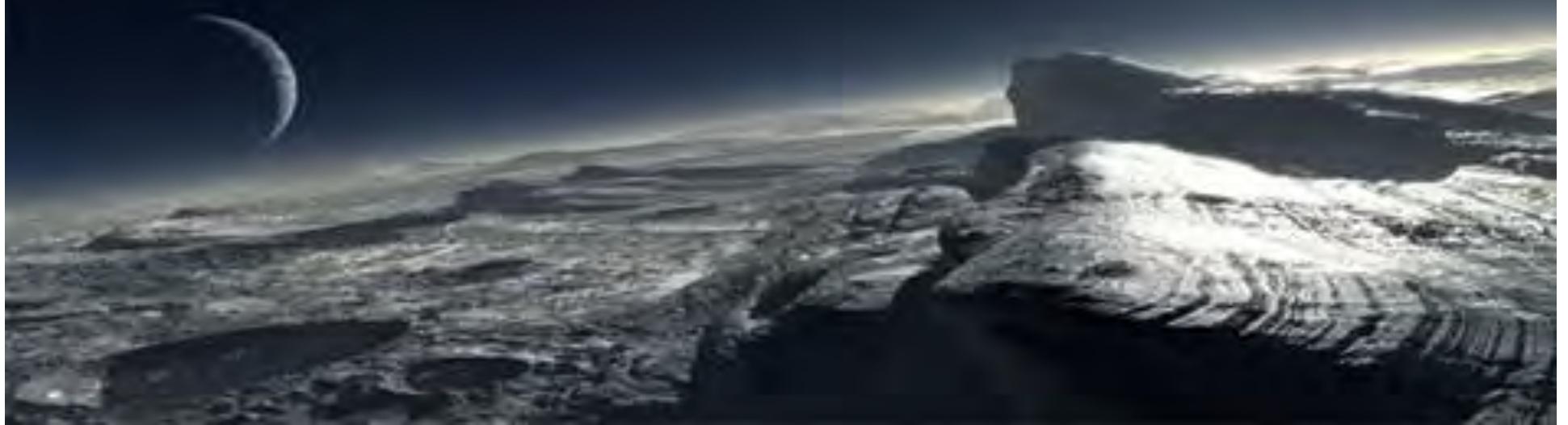


Atmospheric Escape Rate

	Mol. /second	
McNutt 1989	$2.3\text{-}5.5 \times 10^{27}$	CH_4
McNutt 2000	1.5×10^{25}	N_2
Krasnopolsky 1999	$2.0\text{-}2.6 \times 10^{27}$	N_2
Tian & Toon 2005	$1.5\text{-}2.0 \times 10^{28}$	N_2
Strobel 2008	9.4×10^{26}	N_2
Tucker et al. 2011	$4\text{-}5 \times 10^{25}, 1.7 \times 10^{27}$	N_2
Ewin et al. 2012	$1.2\text{ - }2.6 \times 10^{27}$	N_2
Strobel 2012	$2\text{-}5 \times 10^{27}$	N_2

For $Q > 1.5 \times 10^{27} \text{ N}_2 \text{ s}^{-1}$
the interaction is bigger than Pluto

*~1 km ice lost
over age of Pluto*



Escape rate: if 3×10^{27} nitrogen molecules / second
 $= 3 \times 10^{27} \text{ kg/amu} \times 28 \text{ amu} \times 1.7 \times 10^{-27} \text{ kg/s}$
 $= 140 \text{ kg/s}$

Assuming a density of ~ice 1000 kg/m^3

This is then $0.14 \text{ m}^3/\text{s}$

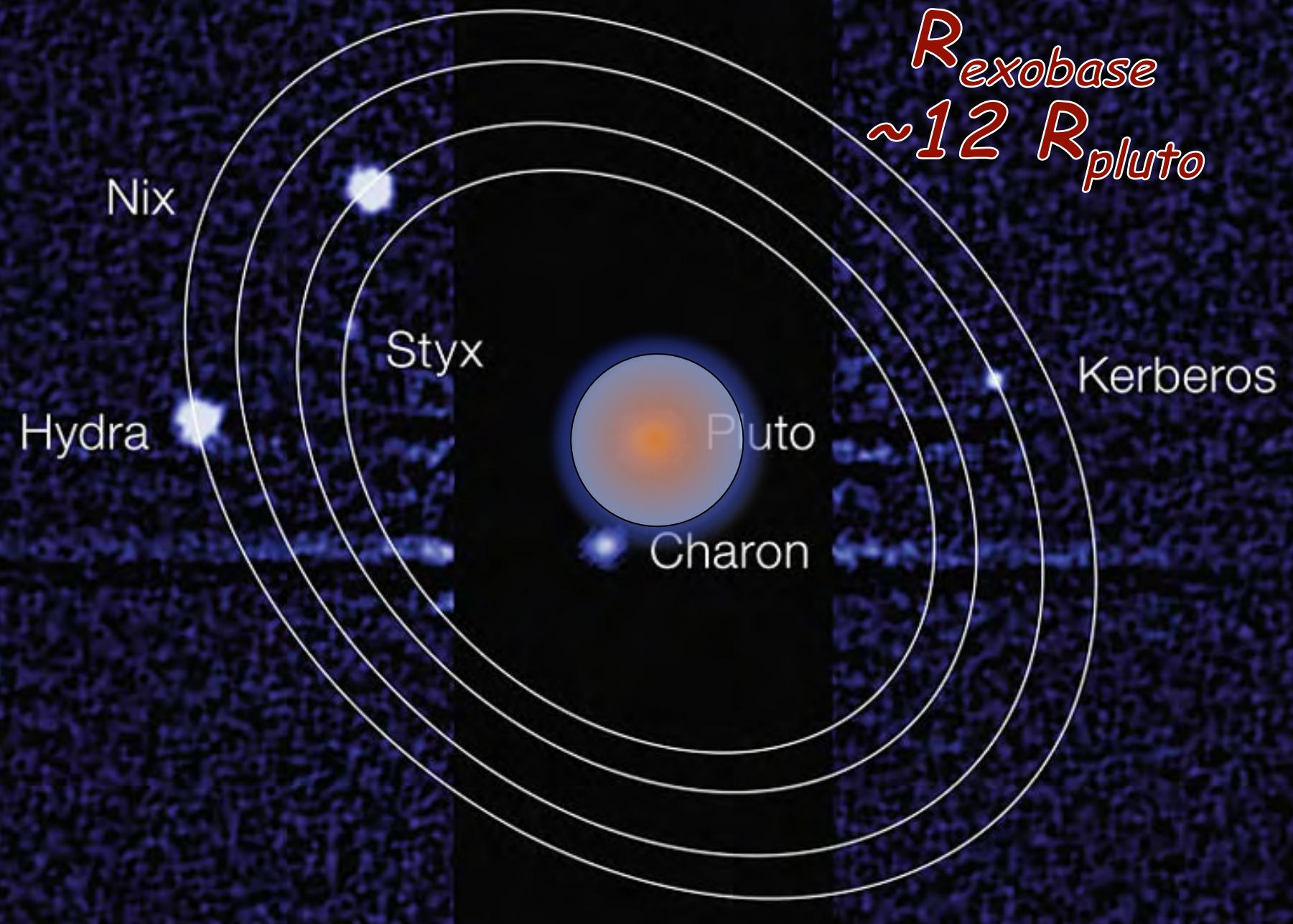
Or roughly $4400 \text{ km}^3 / \text{million years}$

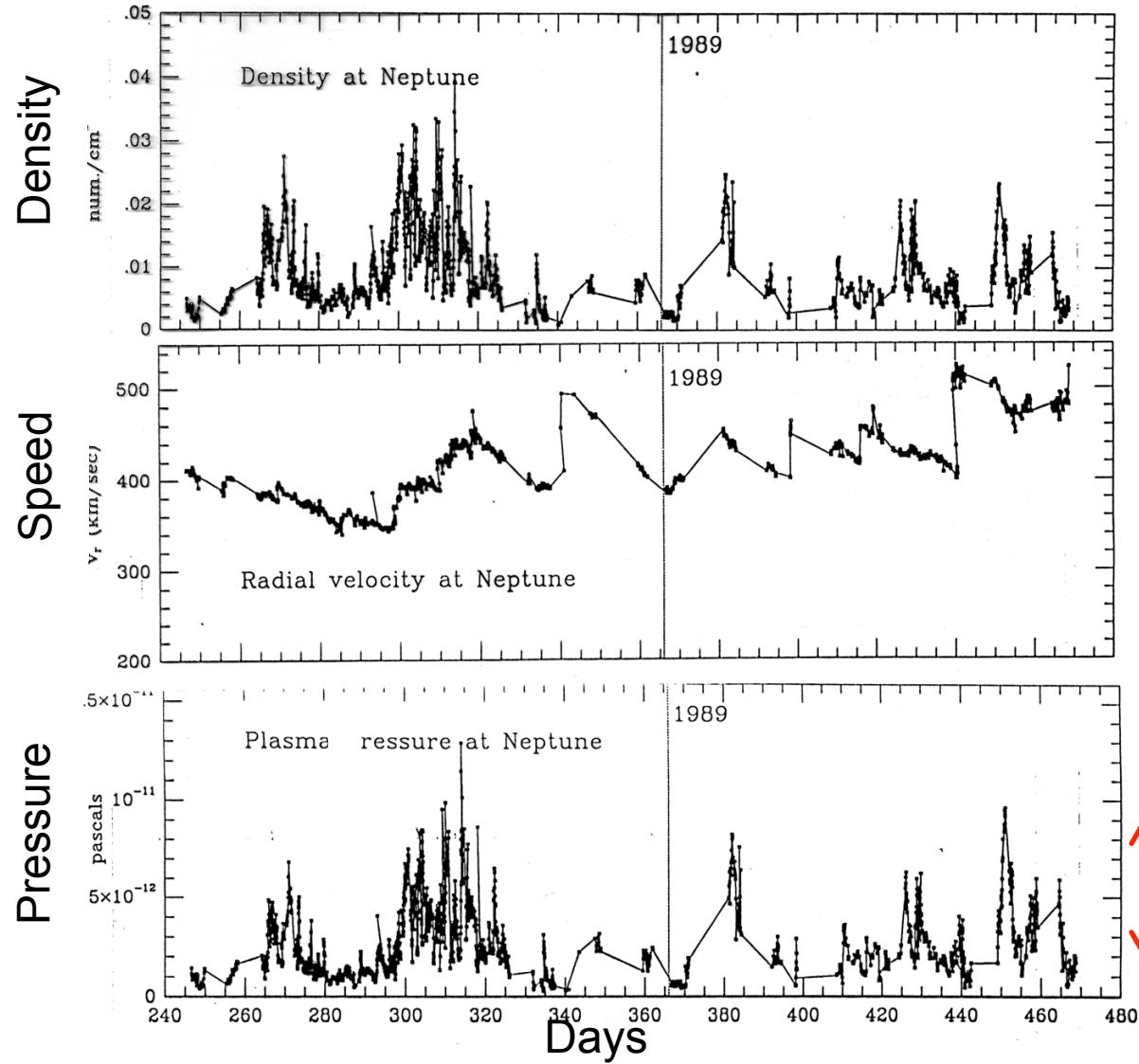
Or 20 million km^3 in age of the solar system.

Dividing by the area of Pluto (16 million km^2)

Darrell Strobel:

R_{exobase}
 $\sim 12 R_{\text{pluto}}$



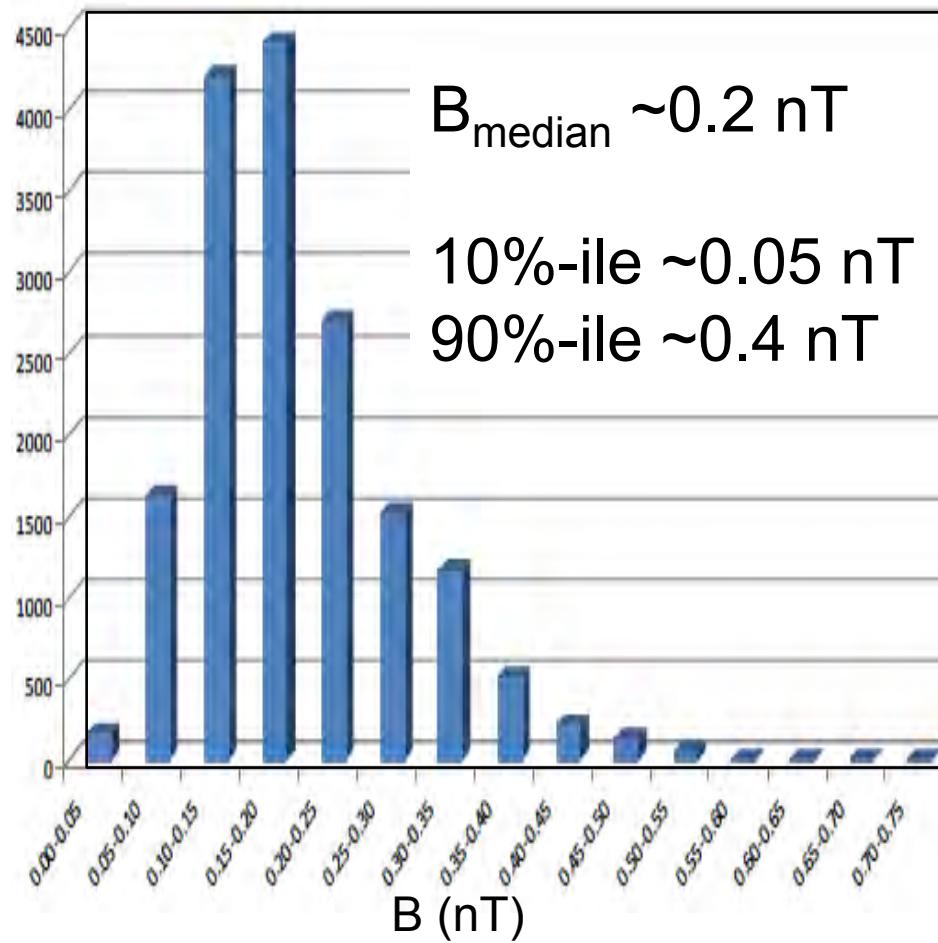


$$\frac{R_{\text{mass-loading}}}{R_{\text{pluto}}} = \frac{Q}{Q_o} \frac{P_o}{P_{\text{SW}}}$$

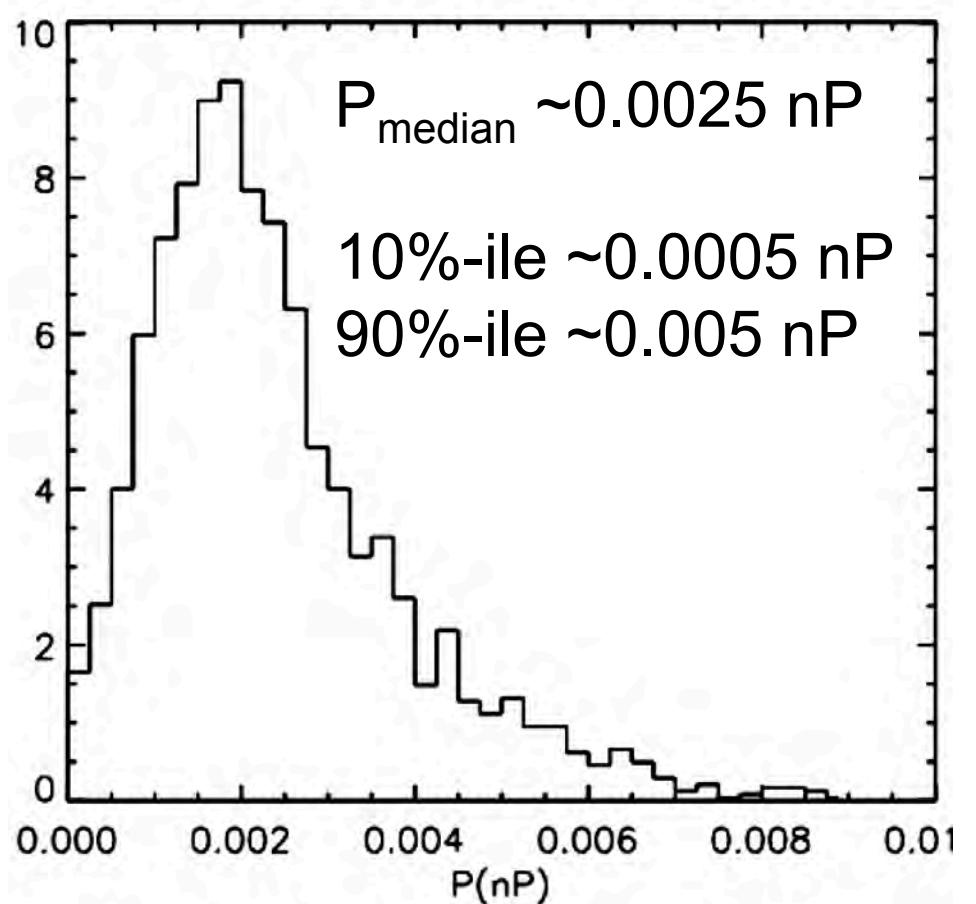
Factor 10
in SW
pressure



Interplanetary Magnetic Field

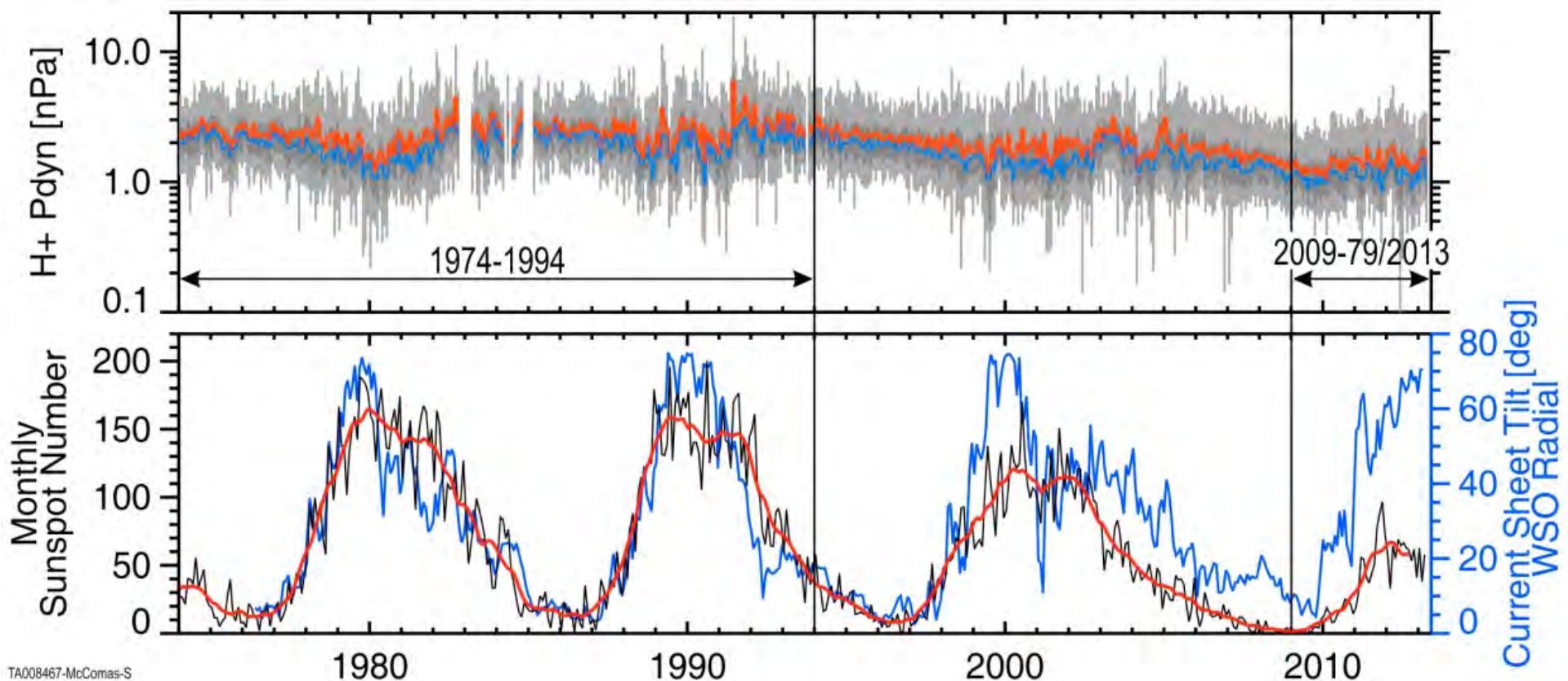


SW Dynamic Pressure
normalized to 30 AU





McComas et al. 2013

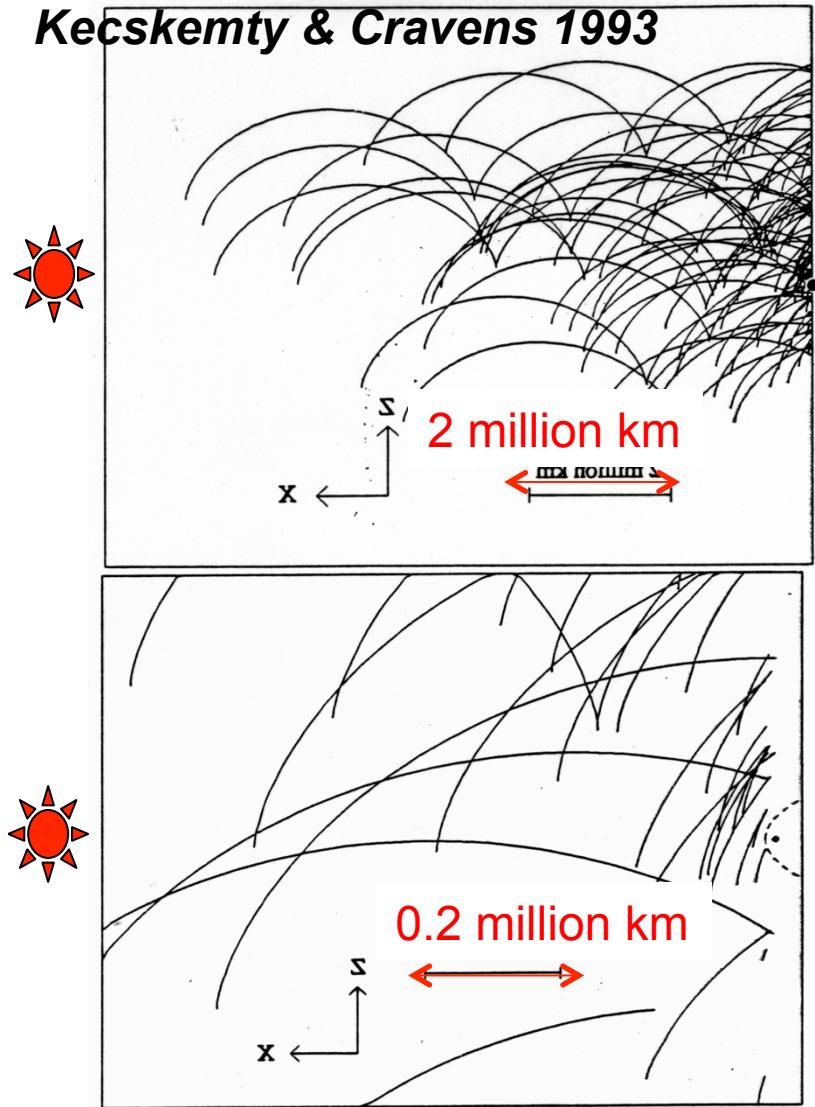




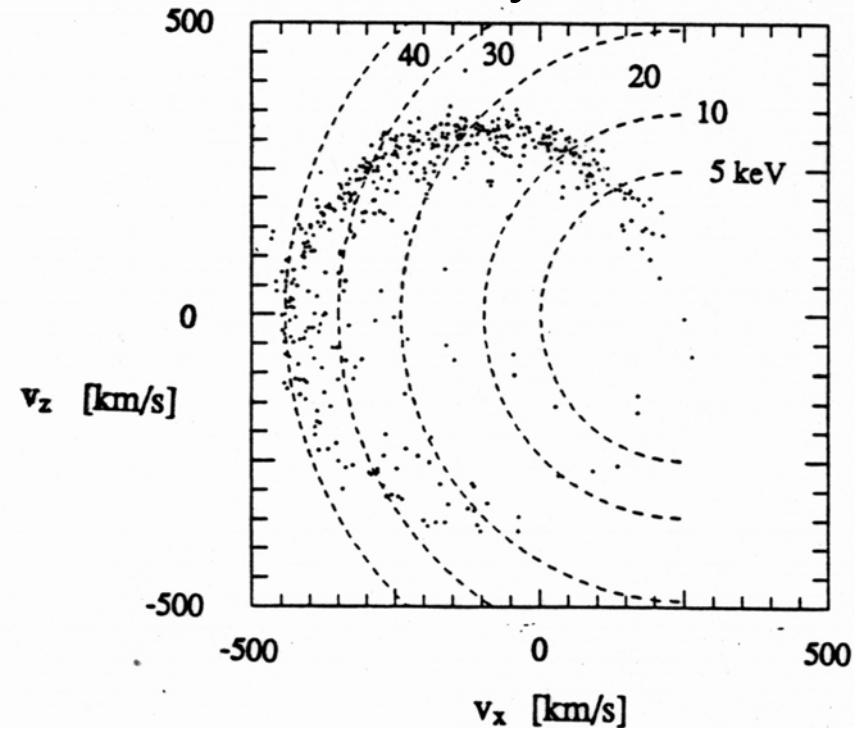
Ionized Pluto Atmosphere

Pick-up Ions

Kecskemety & Cravens 1993



- Weak B-field \rightarrow LARGE gyro-radii
- Extend millions km upstream
- ring-beam, shell velocity distribution



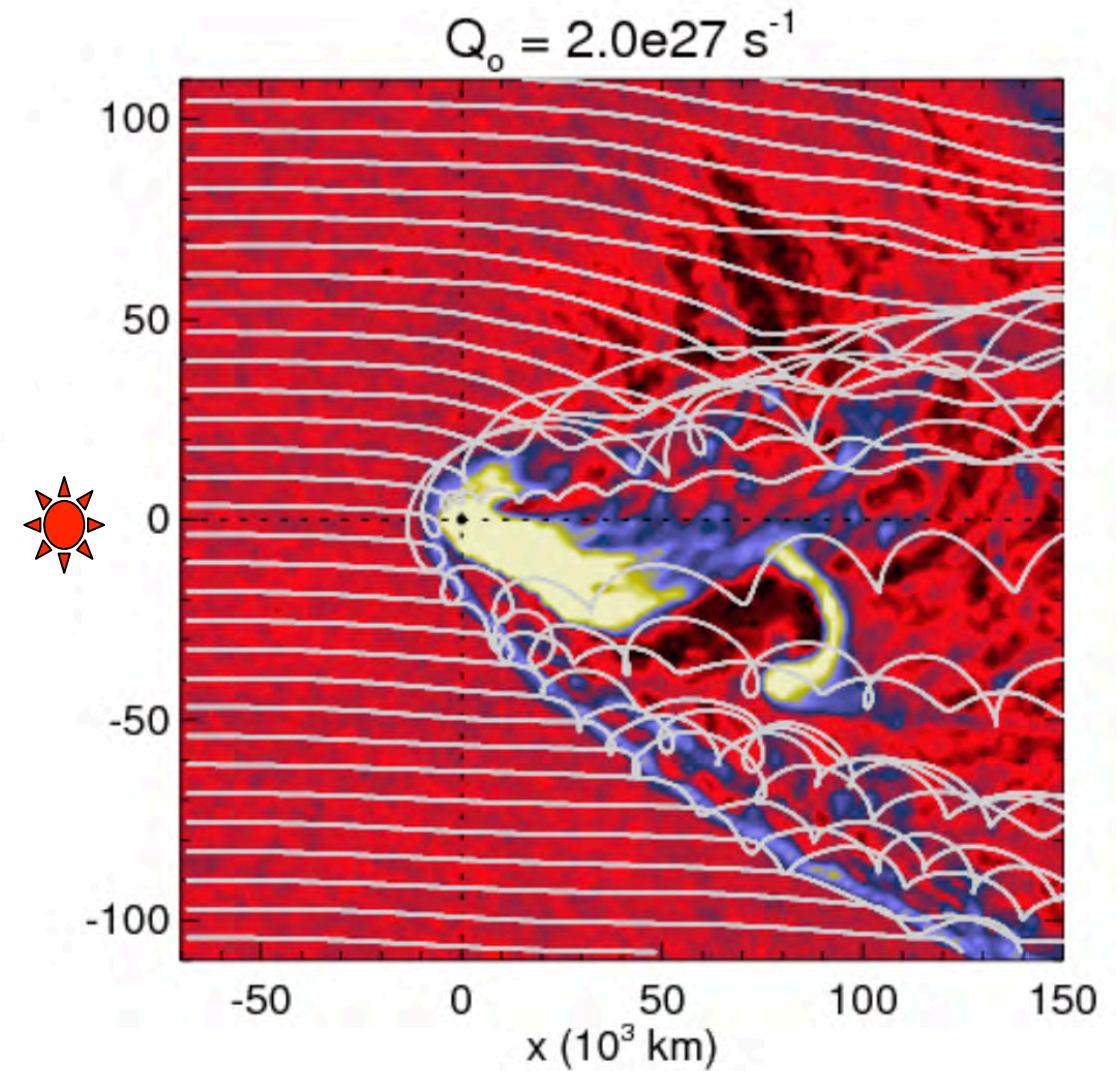
- eventually scattered - probably not before solar wind swept past Pluto



Particle trajectories for 2-D Pluto hybrid simulation

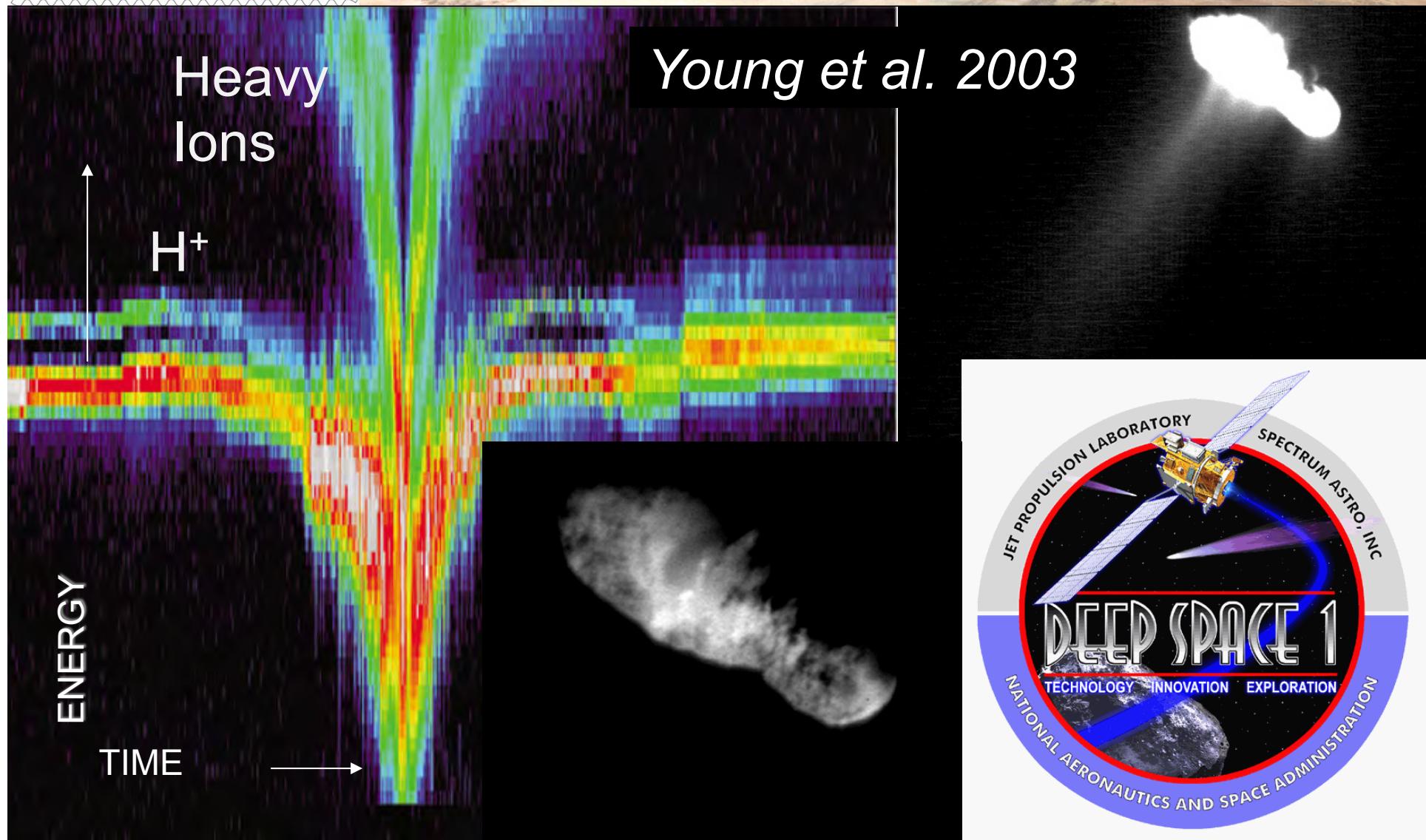
Electrons=fluid
Ions = particles

Delamere 2009

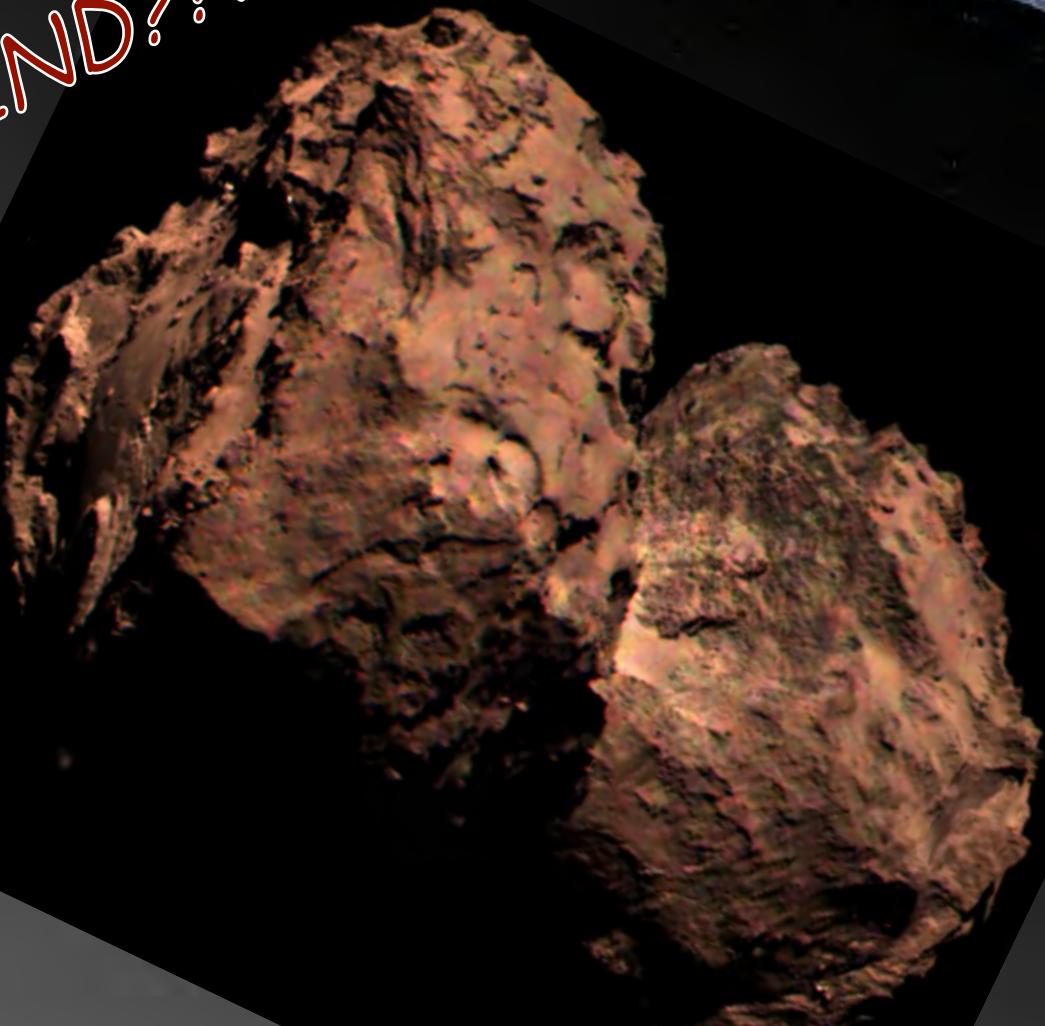


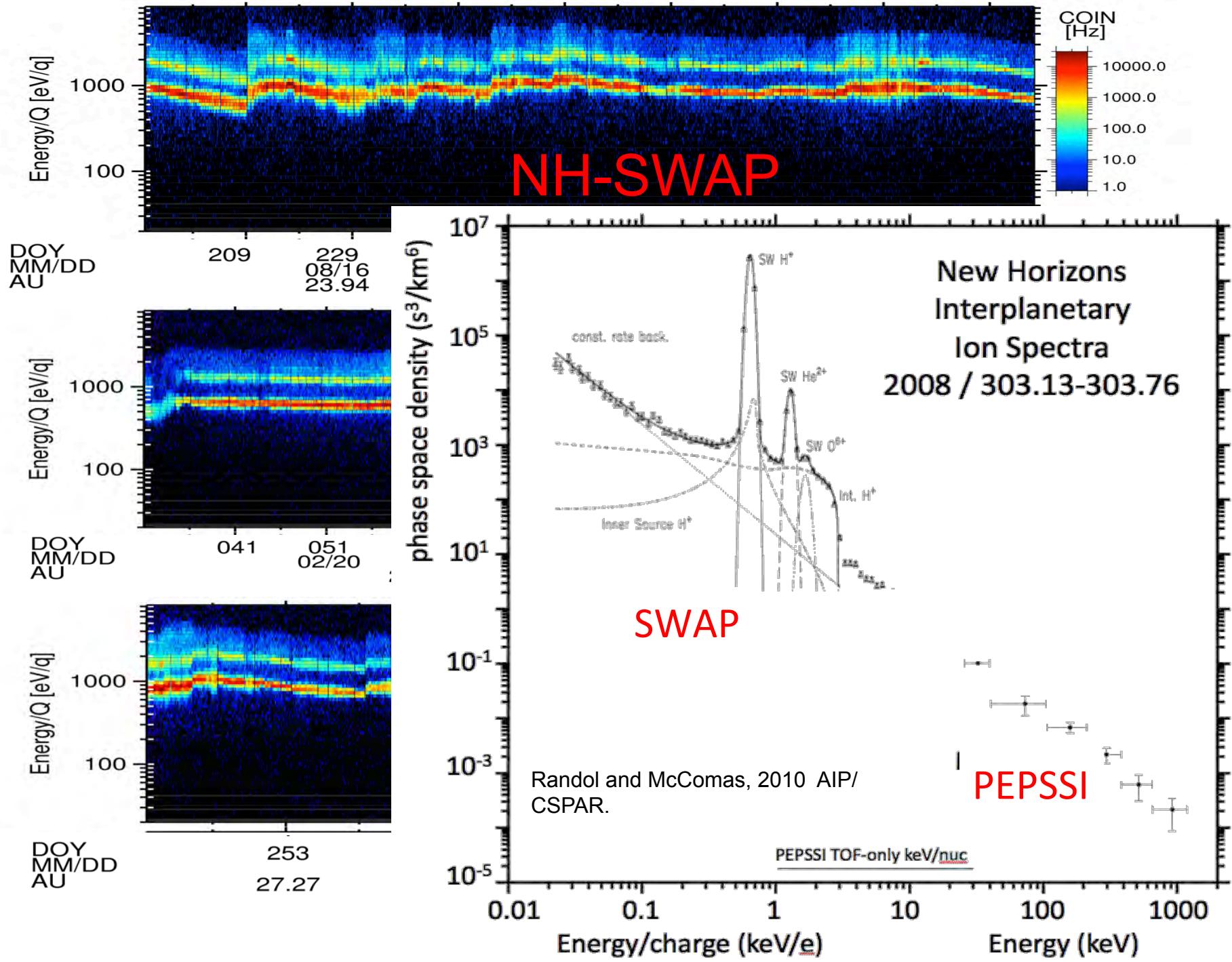


Comet 19/P Borrelly



WHAT WILL
ROSETTA
FIND??!!





New Horizons'
particle measurements
will tell us what's
really happening

