Plasma interactions at Titan and icy moons: evolving ionospheres

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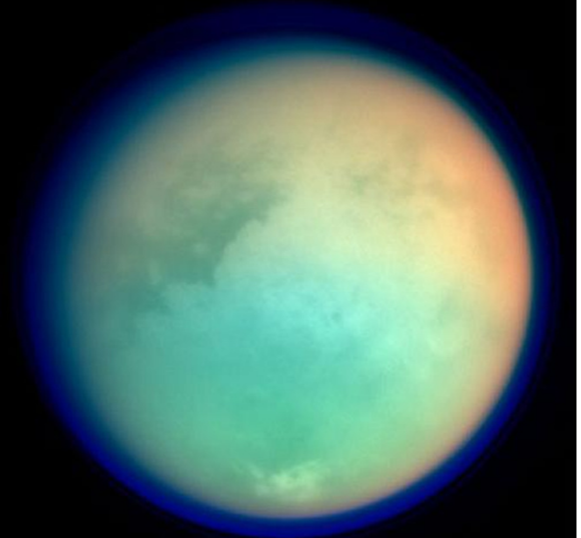
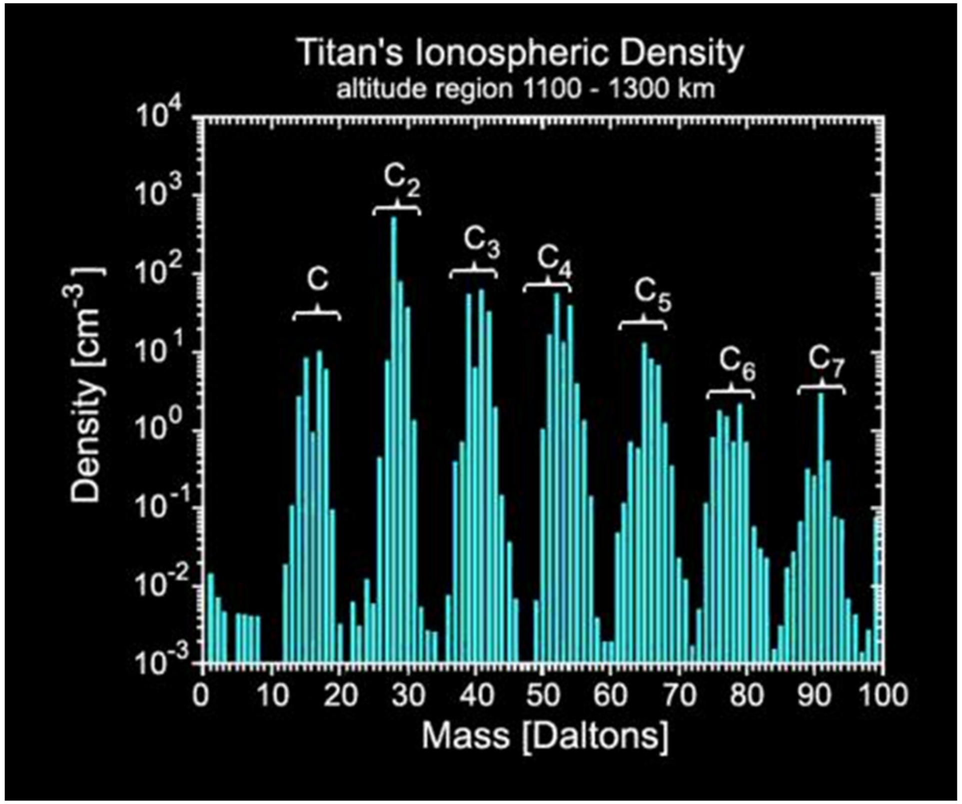


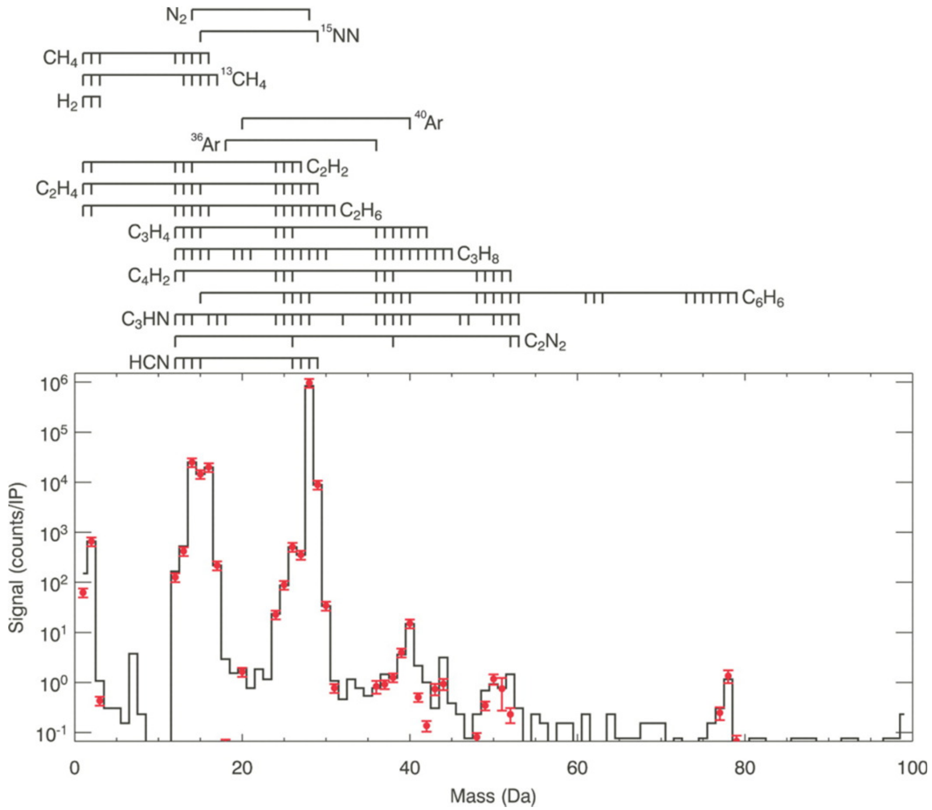
NASA/JPL/Space Science Institute

Outline:

- Titan, Enceladus, Rhea, Dione
- Ionospheric escape at solar system objects
- Ganymede, Europa, Callisto
- Conclusions

Titan flyby, 16 April 2005





Waite et al., Science 2005

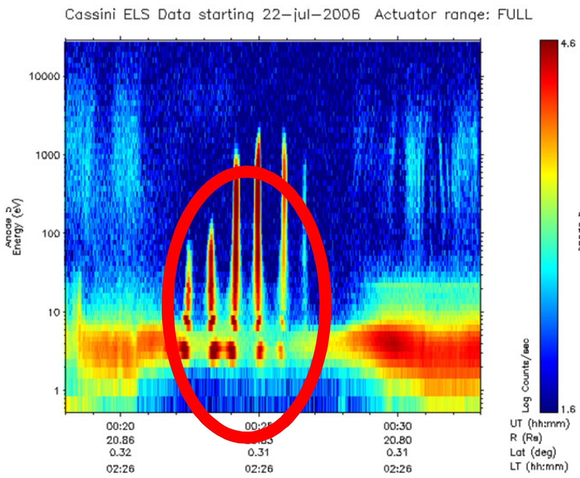
From INMS

Titan negative ions

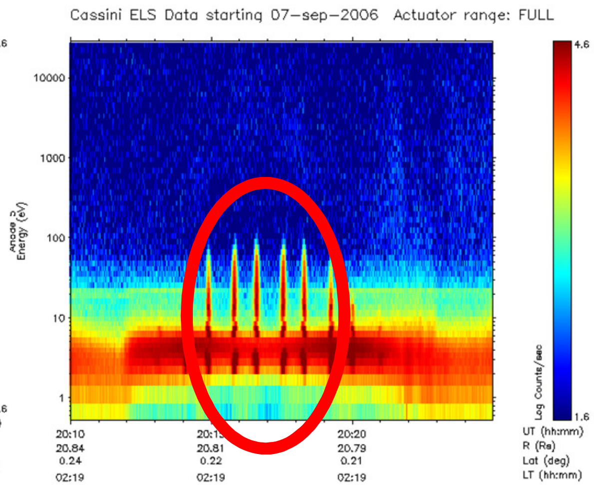
- Unexpected!
- Ram direction
- Near closest approach

Confirmed in later low altitude encounters

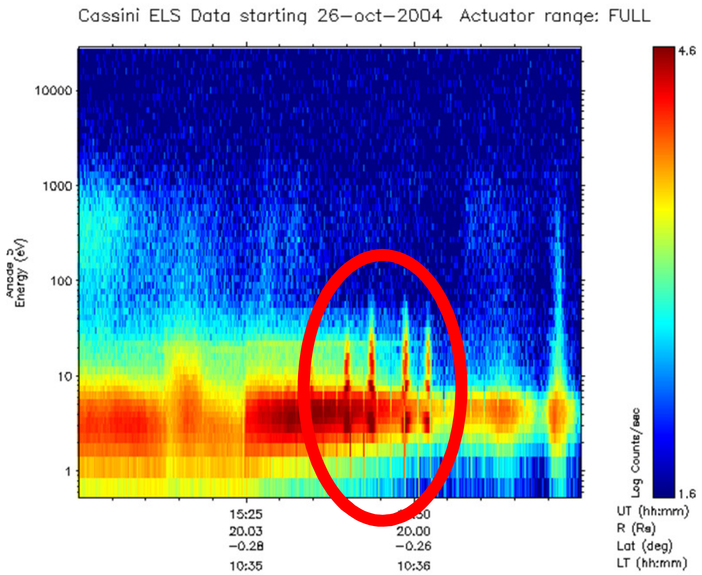
T16



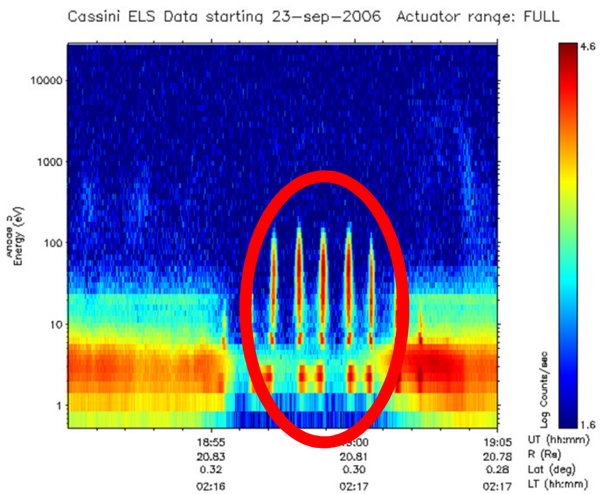
T17



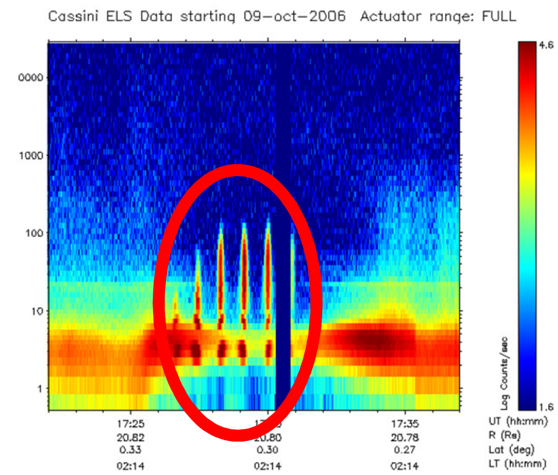
Originally seen on TA in 2004…



T18

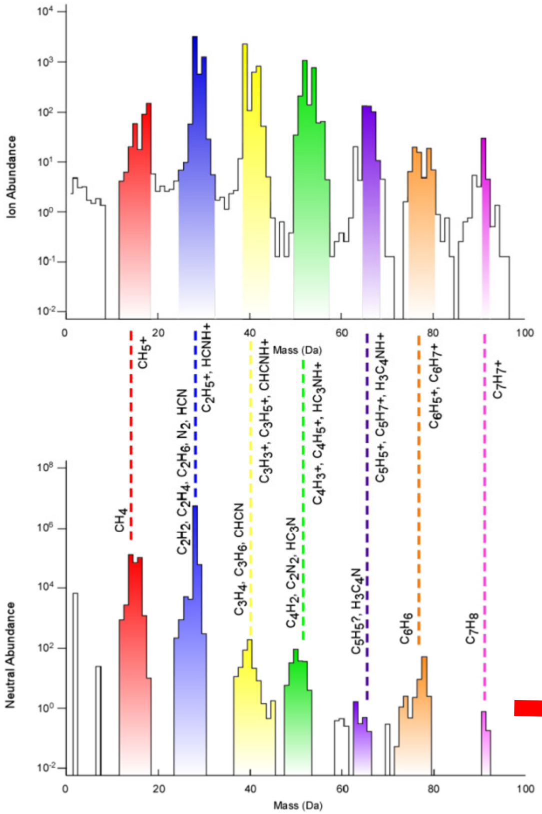


T19

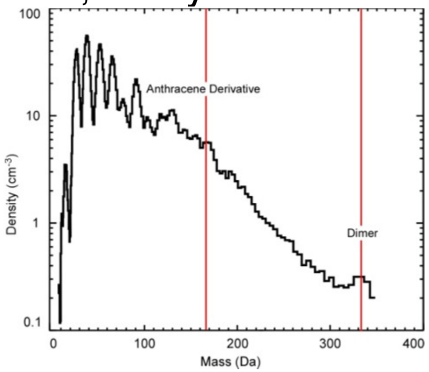


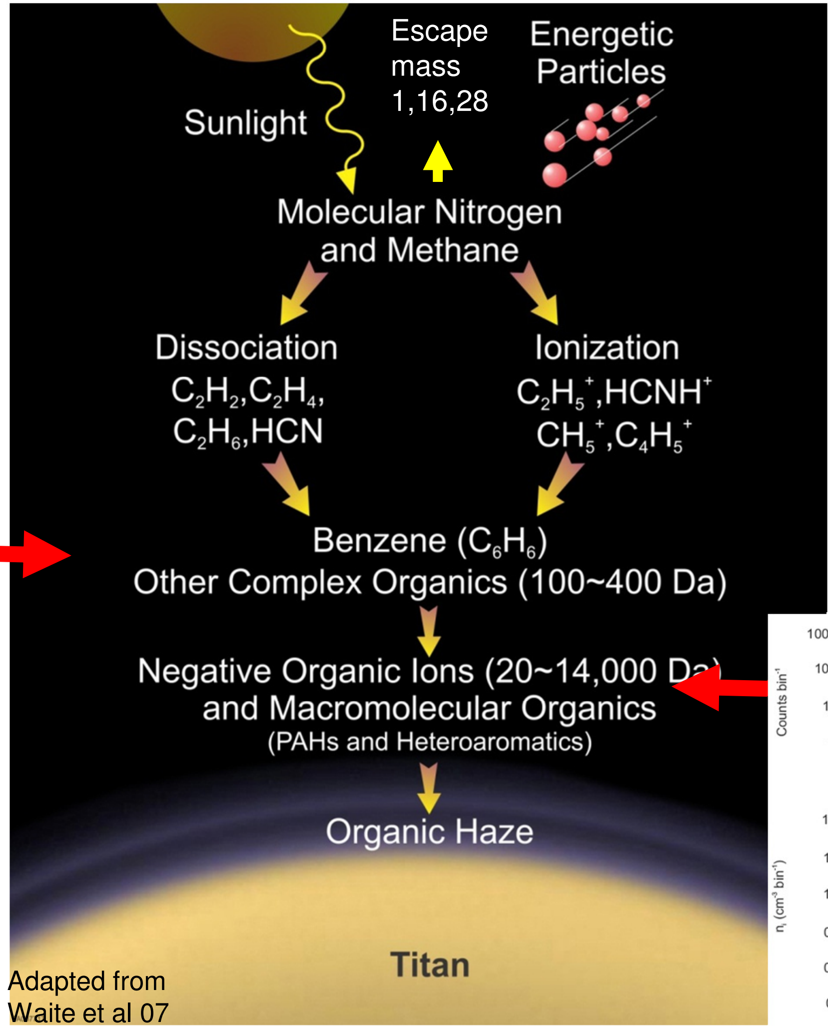
Coates et al., GRL 2007

Titan's atmosphere: a hydrocarbon chemical factory producing haze in Titan's atmosphere and tholins for the surface

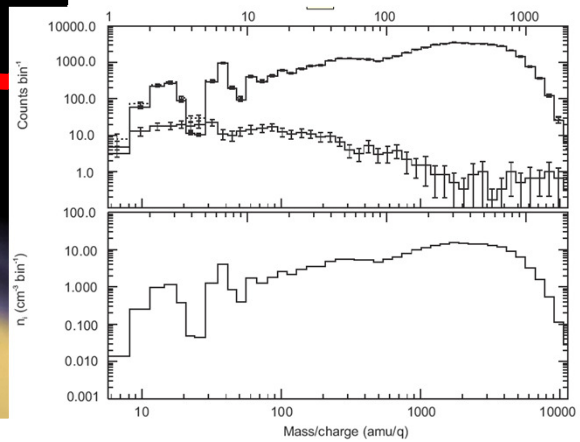


Heavy **neutrals and positive ions**: Waite et al, 2007, Crary et al. 2009

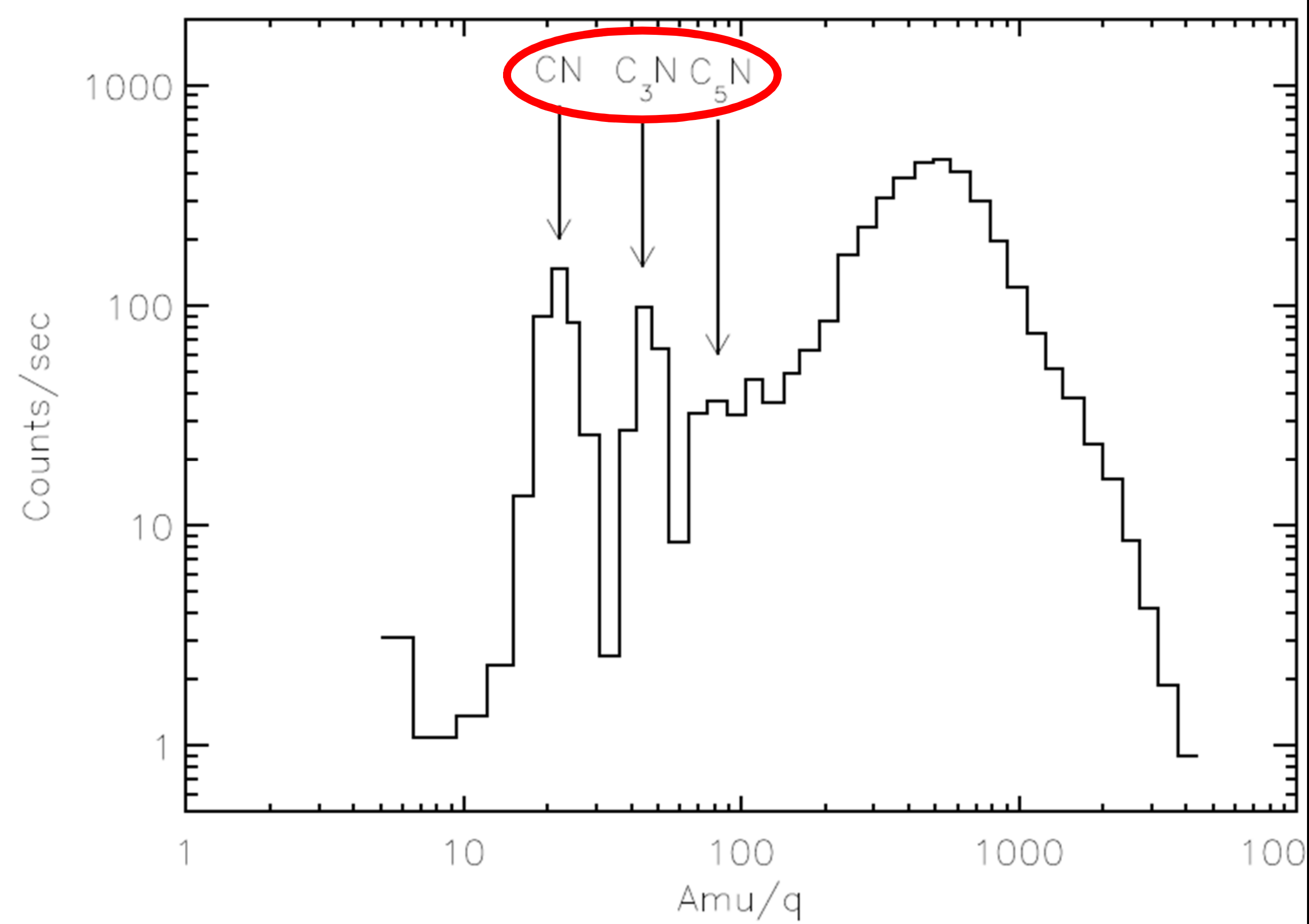




Unexpected heavy **negative ions**: Coates et al, 2007, 2009, 2010
Escape - Coates et al 2012



Formation of low mass negative ions



Production processes:
•Several considered and rates estimated
•Mainly dissociative electron attachment

Loss processes:
•Several considered and rates estimated
•Mainly associative detachment
•Some photodetachment

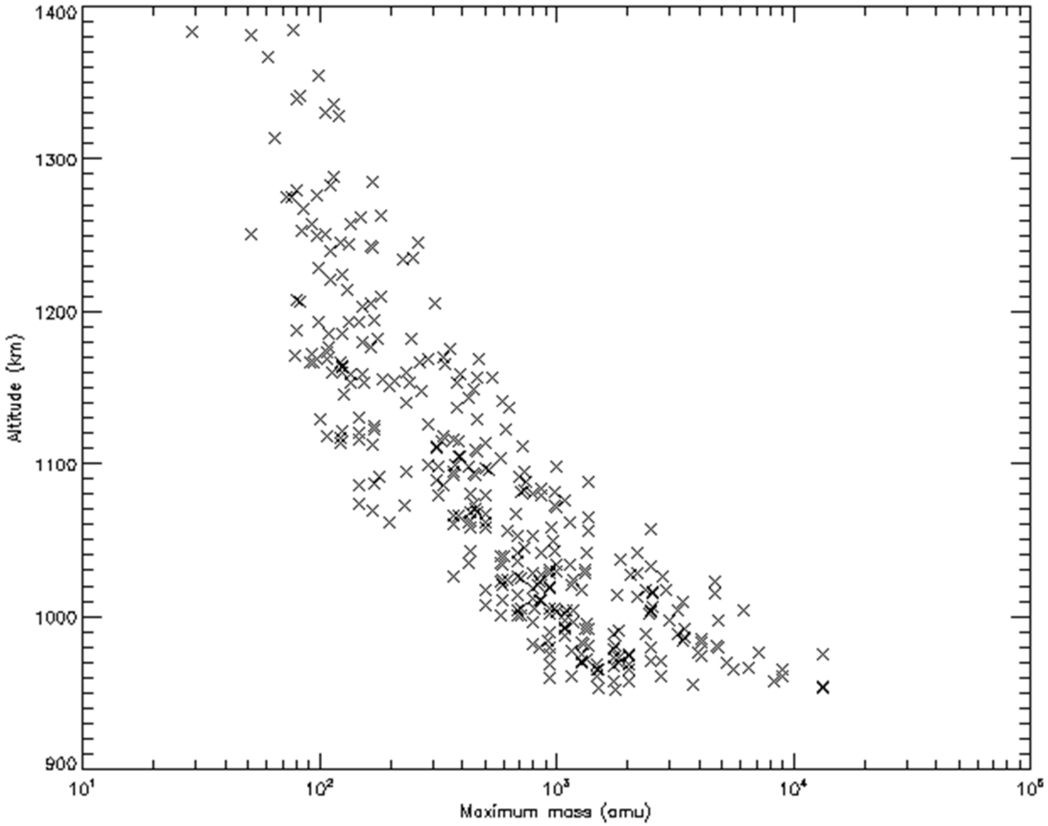
First chemical model including negative ions (low mass), c.f. ELS data at 1015 km (T40) (Vuitton et al., PSS 2009)

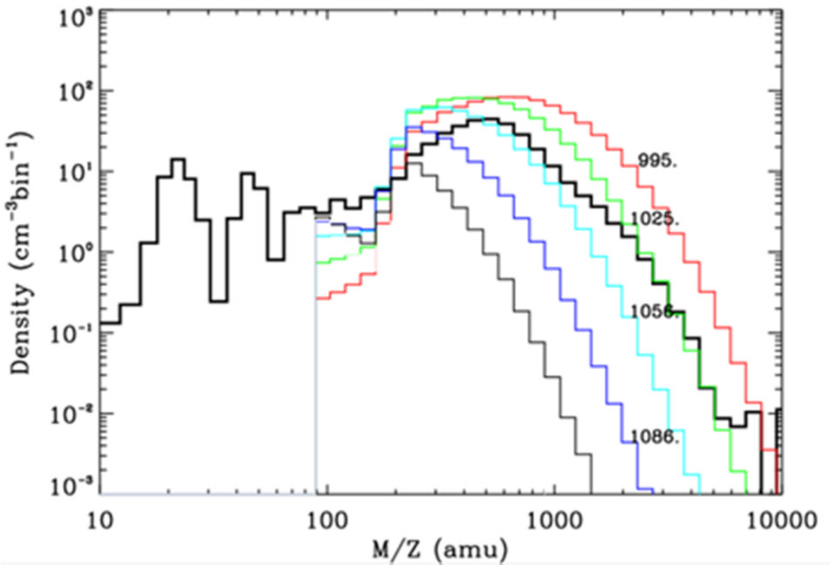
High mass population: chains, rings, higher? PAHs (Waite et al., 2007, Coates et al., 2007)? Fullerenes (Sittler et al., PS 2009) at high masses?

Evolution of Titan ionosphere composition with altitude

Maximum mass of negative ions at Titan increases with decreasing altitude

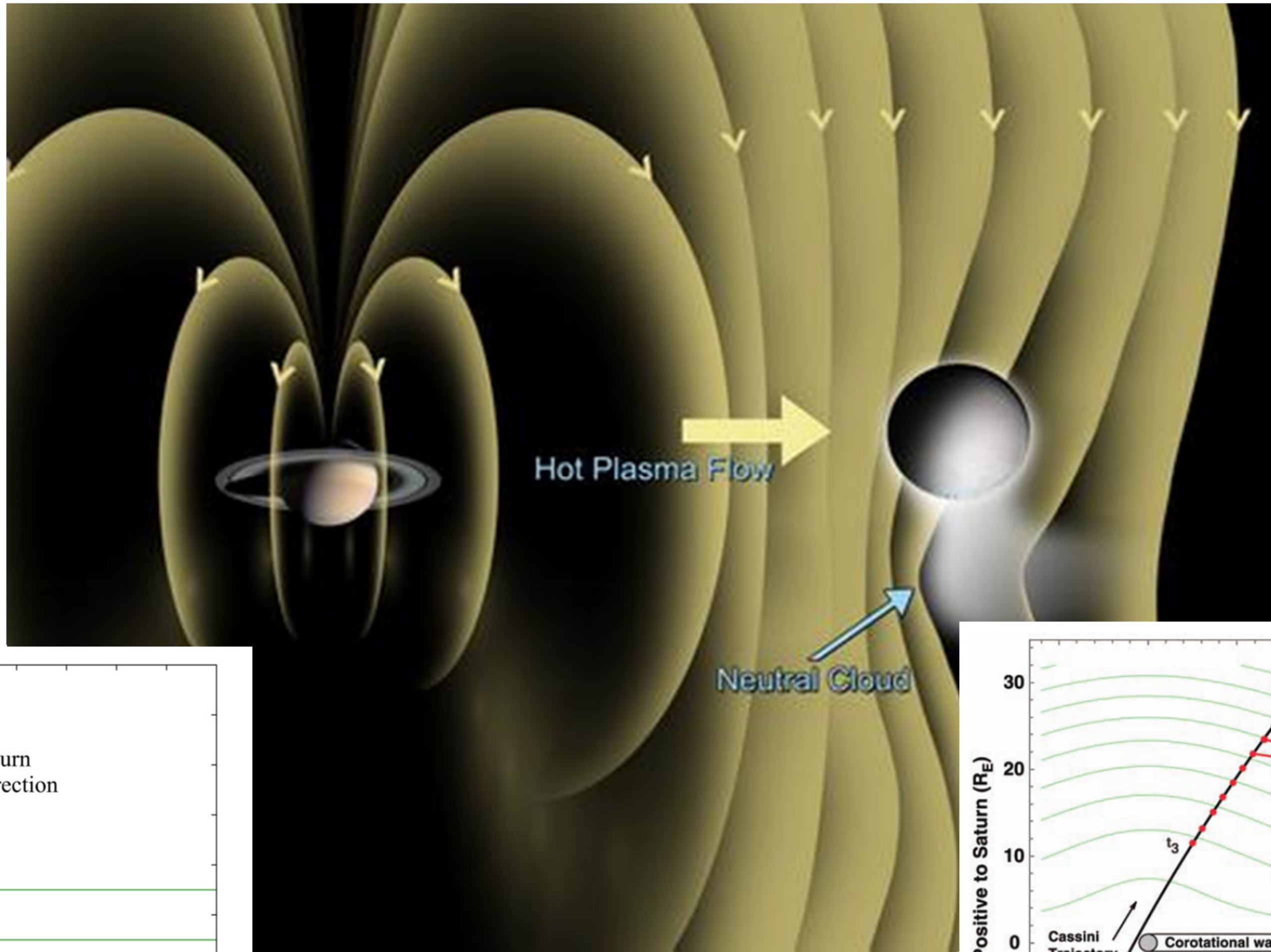
Adapted from Coates et al., PSS 2009



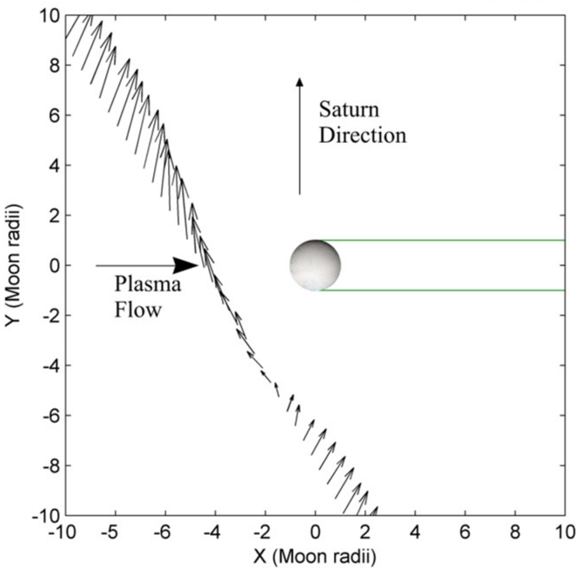


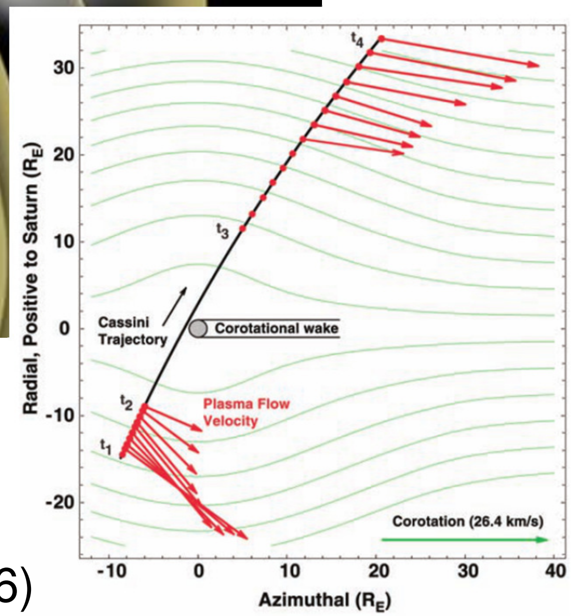
New work on formation of large ions, Lavvas et al., 2012

Enceladus plume

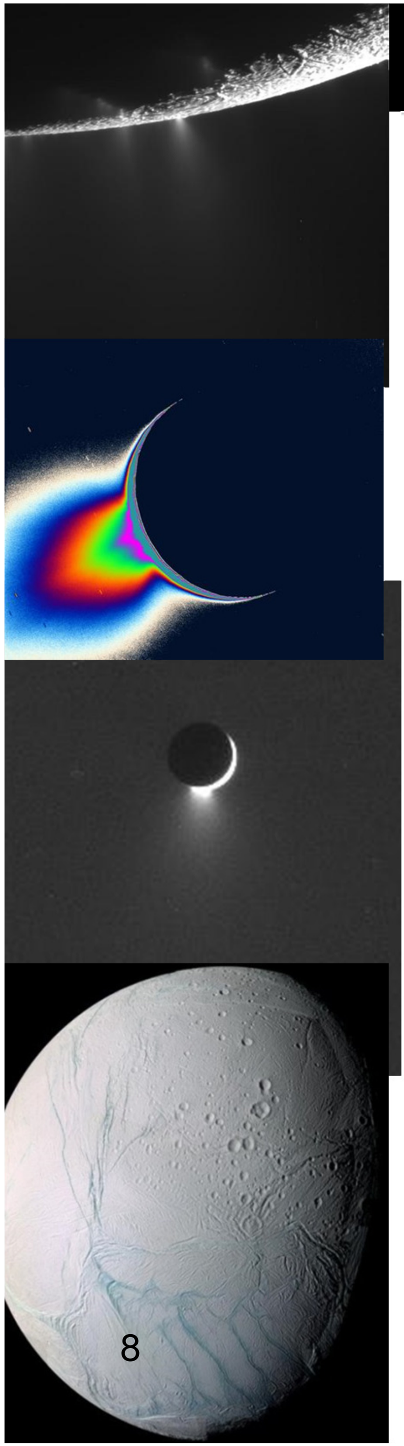


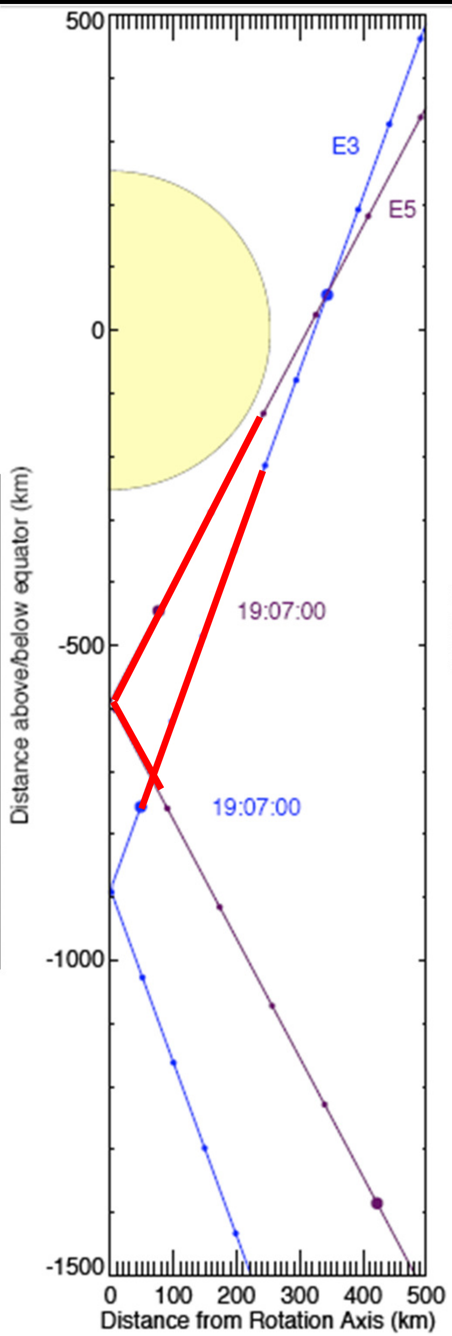
Magnetometer data indicates plasma source (Dougherty et al., 2006)



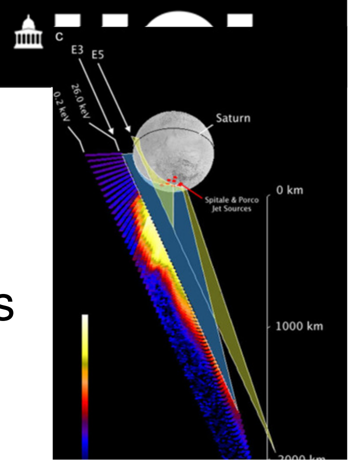


Flow deflection indicates rate ~100-300 kgs^{-1} (Tokar et al., 2006)

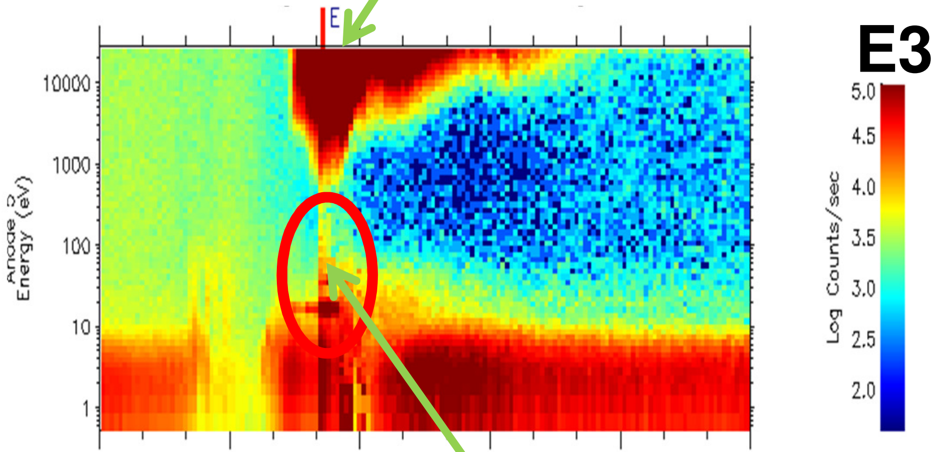


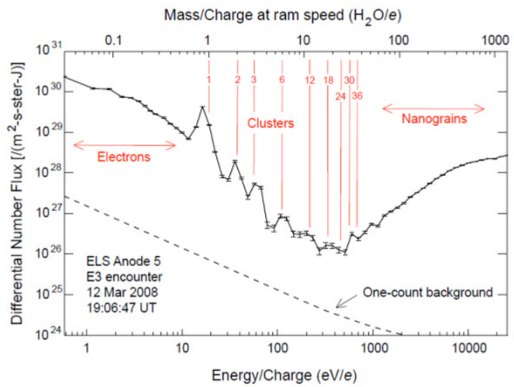


Unexpected discoveries from Cassini at Enceladus



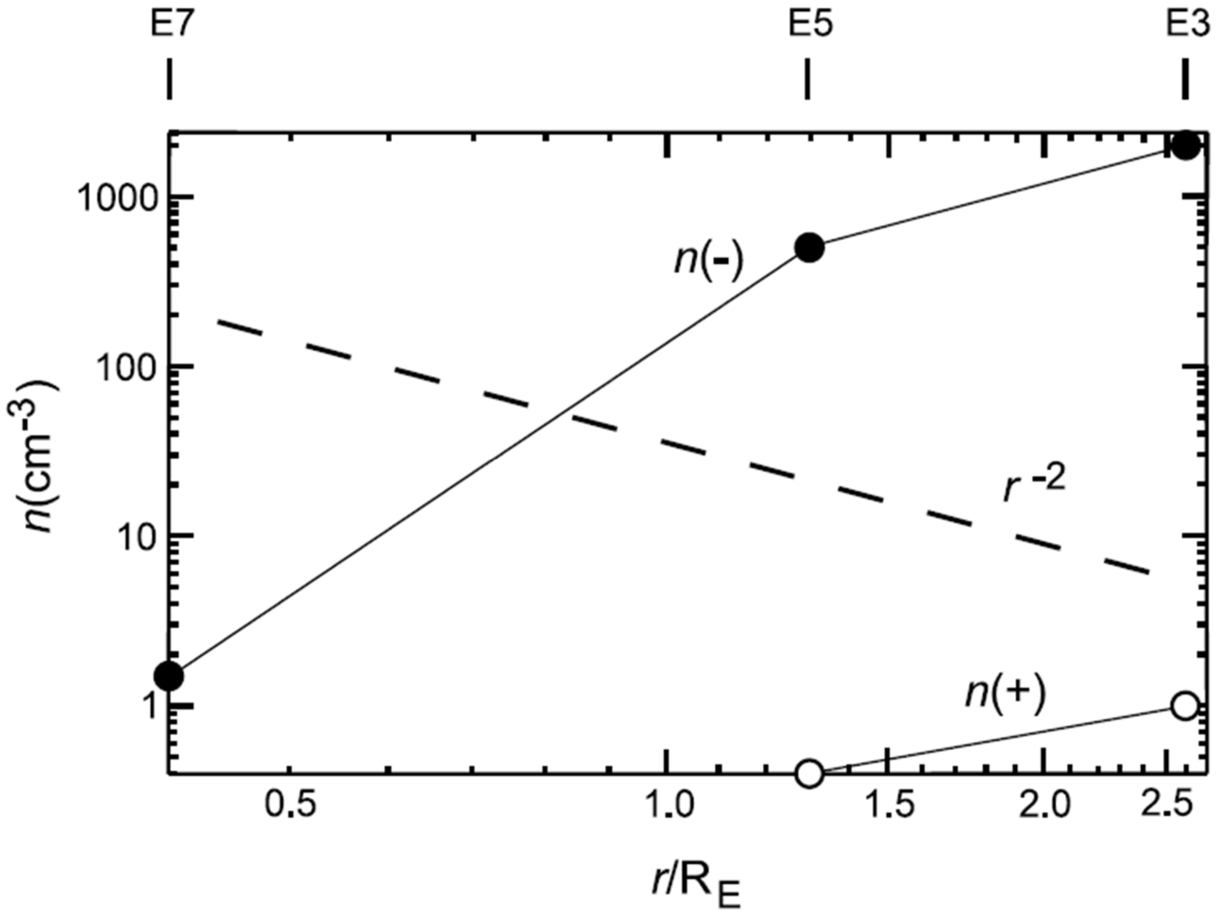
Charged nanograins
Jones et al., GRL, 2009





Negative ions in the plume

Coates et al., Icarus 2010, Faraday Discussions 2010

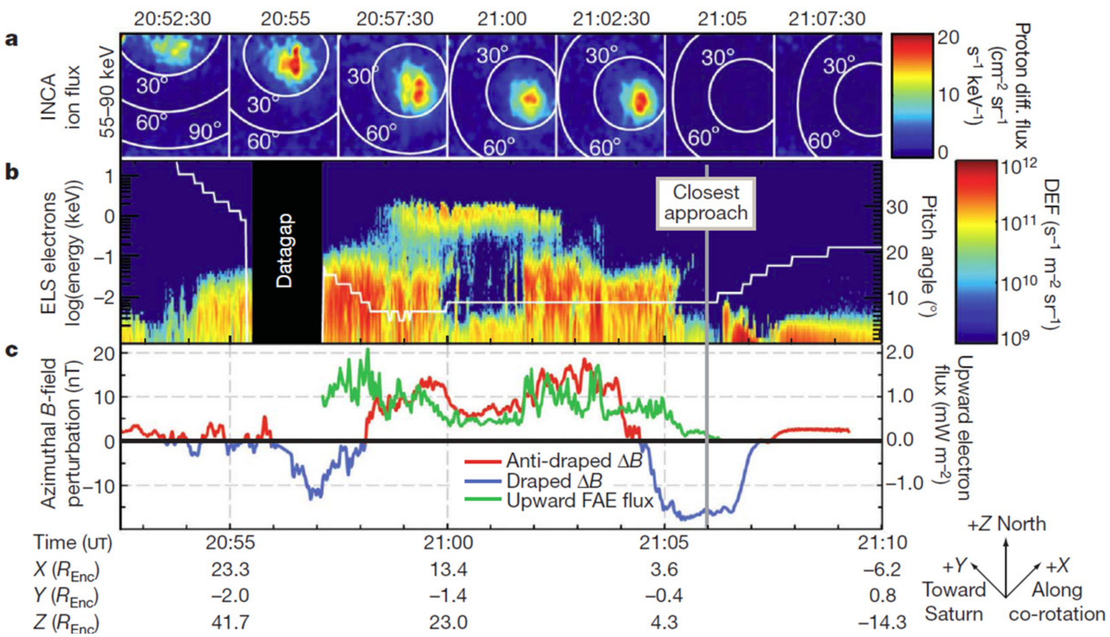


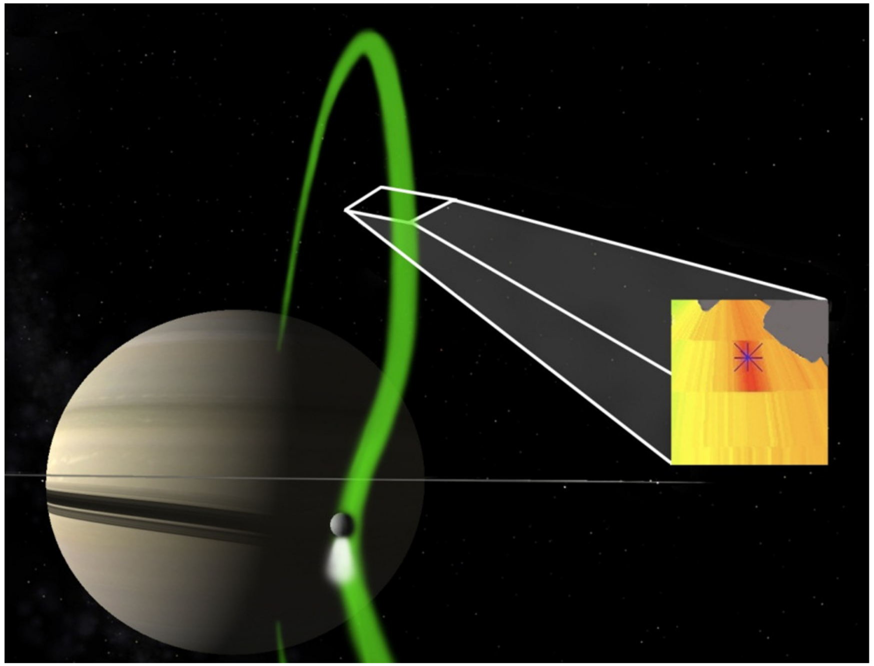
Number density evolving with distance in plume:
Indicates charging by ambient plasma particles (Hill et al., 2012)

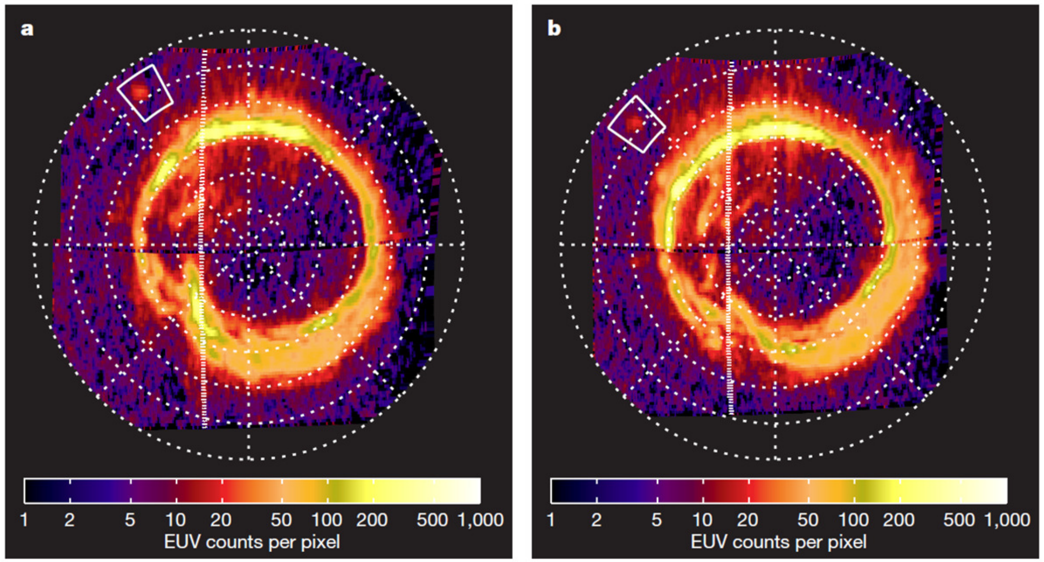
Additional charged particle population: a 'dusty plasma'?
(Morooka et al., 2011)

Enceladus' auroral spot

Pryor, Rymer et al., Nature
21 April 2011



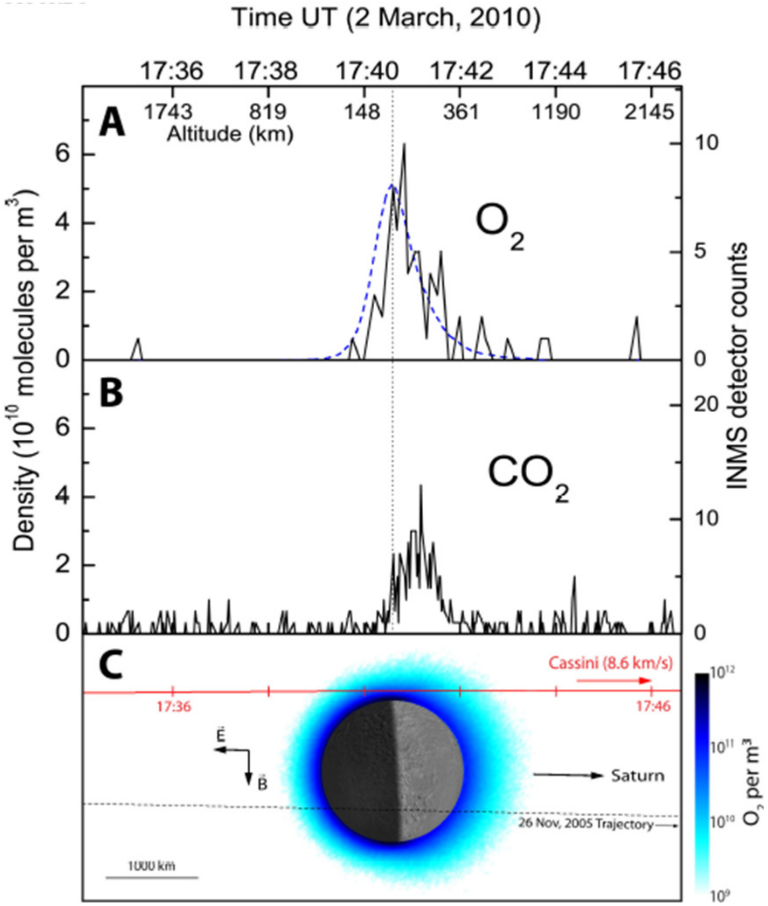




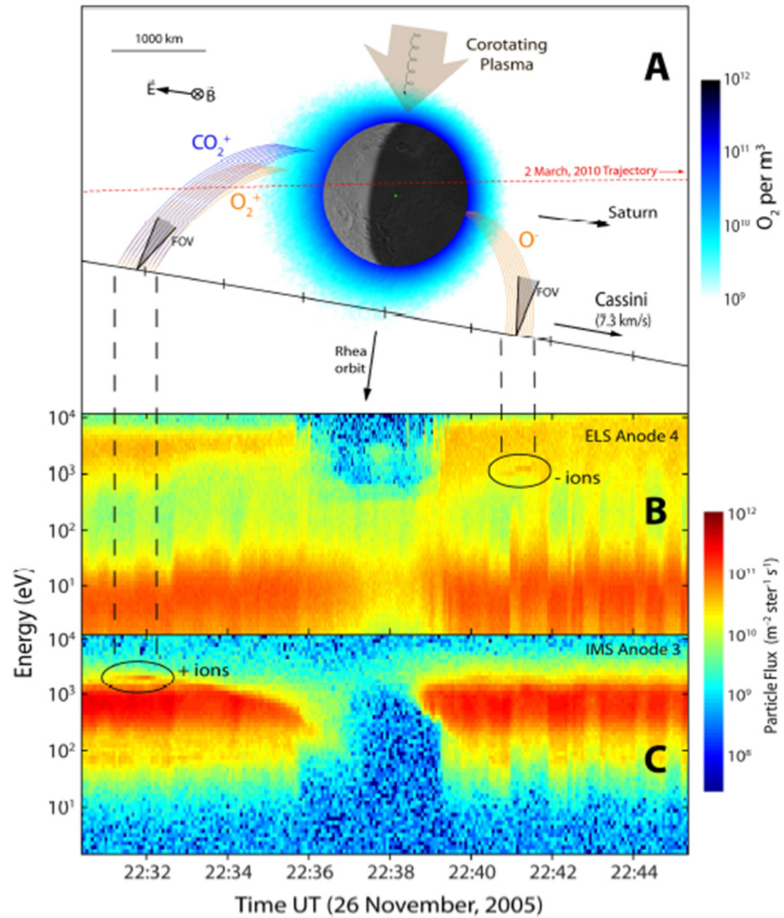
Rhea's O_2 and CO_2 atmosphere – from INMS and CAPS

Teolis, B.D., G.H. Jones, P.F. Miles, R. L. Tokar, B. A. Magee, J. H. Waite, E. Roussos, D.T. Young, F. J. Crary, A. J. Coates, R. E. Johnson, W.-L. Tseng, R. A. Baragiola

Science Express – 25 Nov 2010

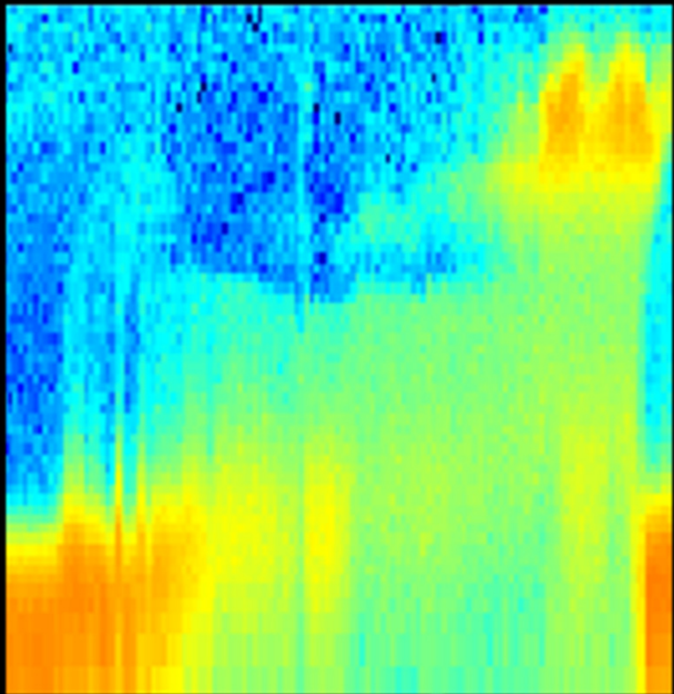


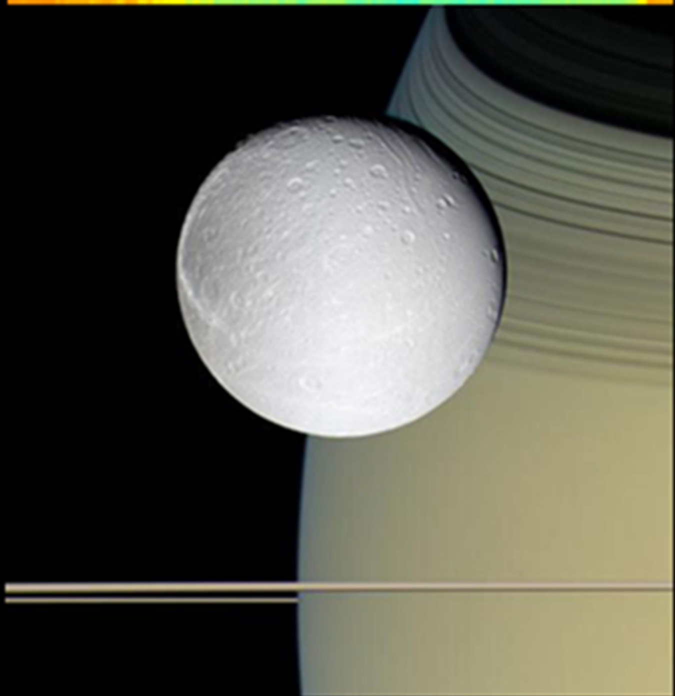
In-situ neutral atmosphere measurements (INMS)



Negative and positive ions picked up from atmosphere pinpoint near-surface source (CAPS)

Dione’s oxygen exosphere

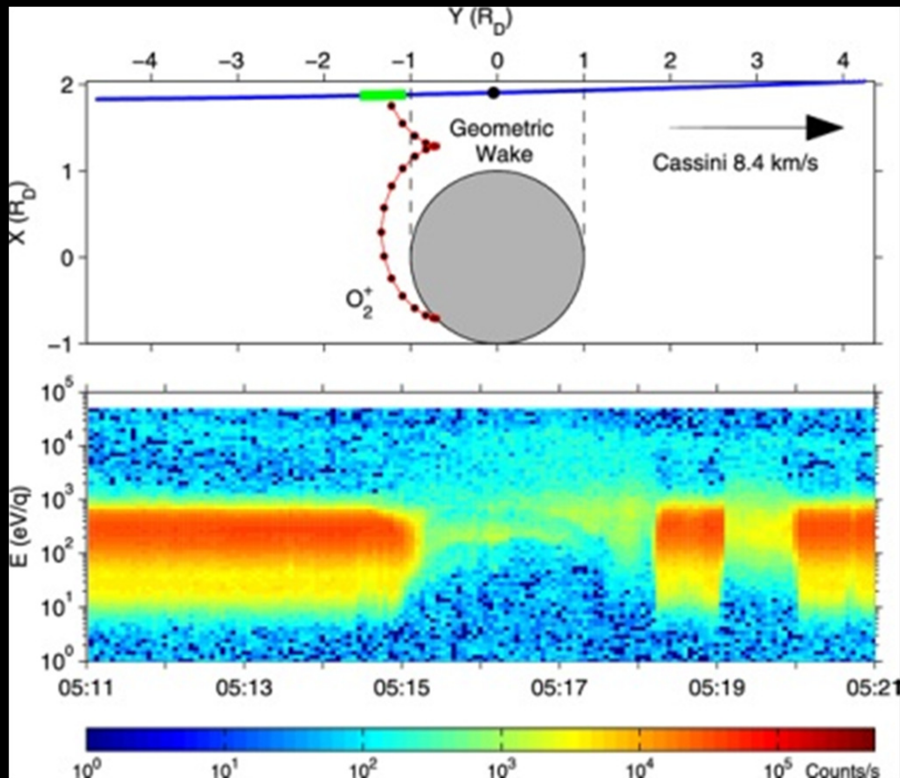




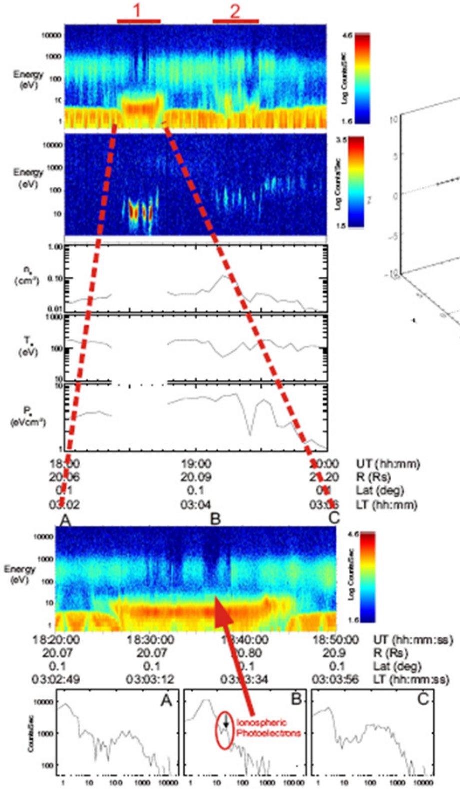
Tokar et al., Geophys Res Lett., Feb 2012

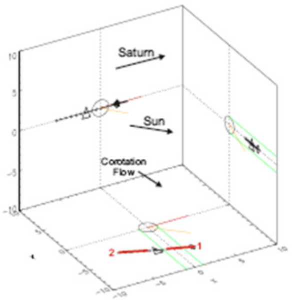
Icy Dione is within Saturn’s trapped radiation belts – oxygen forms and is recycled via the surface

Process occurs at Dione, Rhea and Saturn’s main rings, also at Ganymede, Europa and Callisto in Jupiter's - targets for ESA's proposed JUICE (JUpiter ICy moons Explorer) mission for launch in 2022



Ionospheric plasma near unmagnetized objects

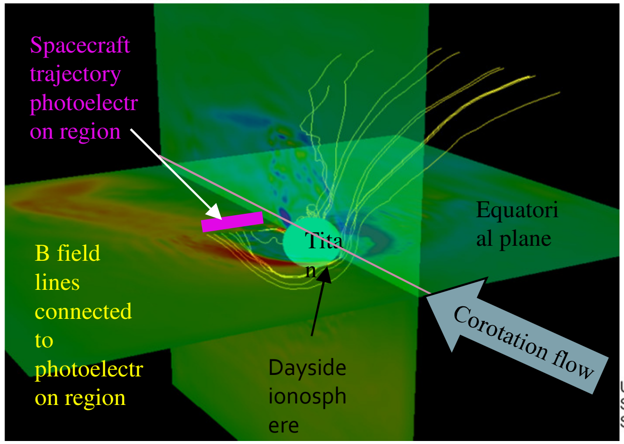


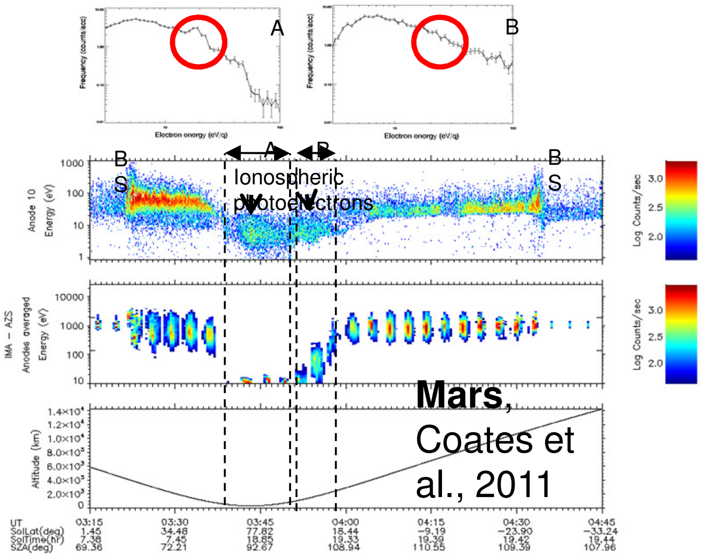


Titan, Coates et al., 2007, Wellbrock et al., 2012

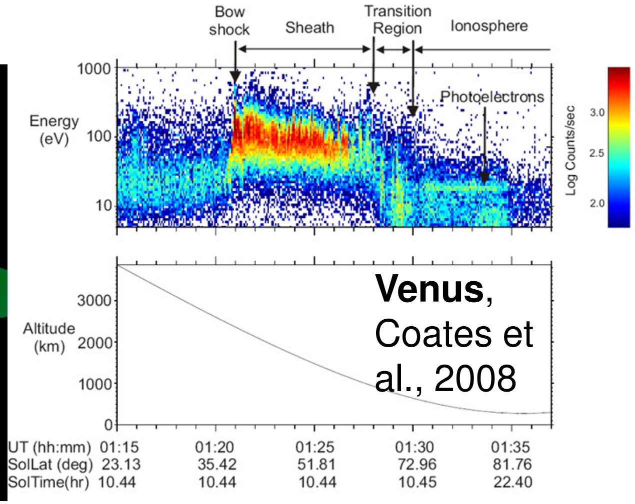
Ionospheric photoelectrons – from measured electron spectrum, found well away from the objects

Also related ion escape

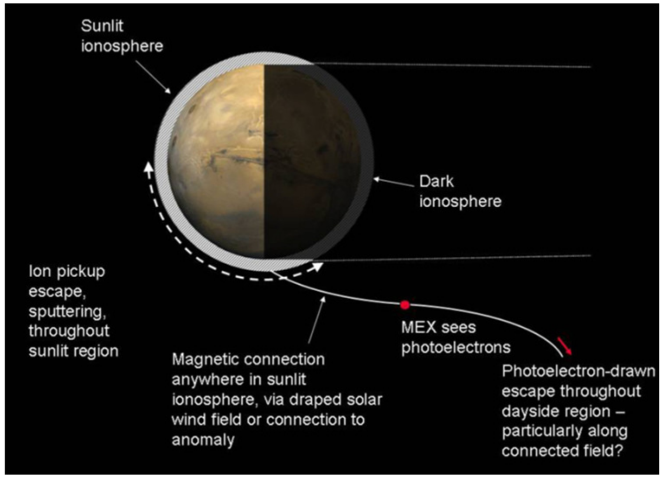




Mars, Coates et al., 2011



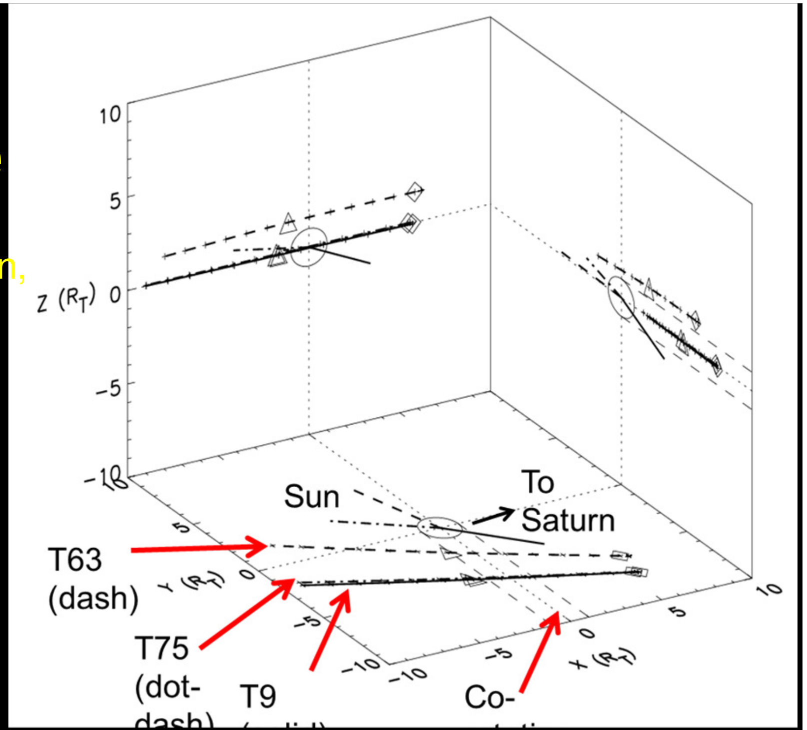
Venus, Coates et al., 2008

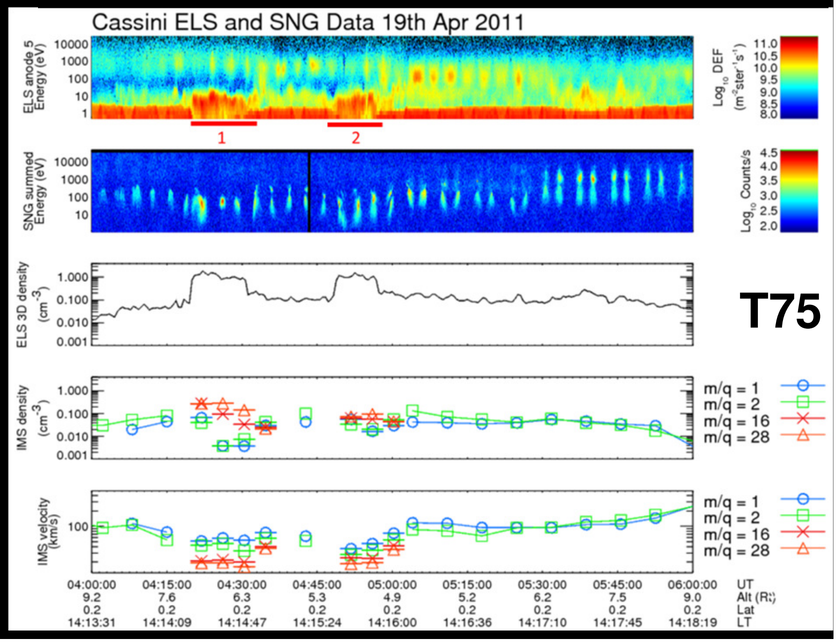


Cassini in Titan's tail: CAPS observations of plasma escape

A.J. Coates, A. Wellbrock, G.R. Lewis, C.S. Arridge, F.J. Crary, D.T. Young, M.F. Thomsen, D.B. Reisenfeld, E.C. Sittler Jr, R.E. Johnson, K. Szego, Z. Bebesi, G.H. Jones, JGR Space Physics, 2012

- Only 3 distant tail encounters so far
- T9, T75 ~10,000 km tailward from Titan, T63 ~5,000 km
- Escaping ionospheric plasma seen well away from Titan – key is 'fingerprint' from ionospheric photoelectrons
- Split tail seen all 3 – common feature
- Escaping ionospheric ions mass-separated to give escape rate, combine with electron density gives flux
- 2.5×10^{24} ions s^{-1} (average)
- 4.8×10^{25} amu s^{-1} (average)
- …or 7 metric tonnes per day lost from atmosphere – significant on solar system timescale – but ~1/4000 Enceladus rate





Comets – gas production rates

Object	Spacecraft	Production rate (s^{-1})	Ratio (Halley=100)	Reference
Giacobini-Zinner	ICE	$4x10^{28}$	5.8	Mendis et al, 96
Halley	Giotto, Vega, Suisei, Sakigake	$6.9x10^{29}$	100	Krankowsky et al, 86
Grigg-Skjellerup	Giotto (GEM)	$7.5x10^{27}$	1.1	Johnstone et al, 93
Borrelly	DS1	$3.5x10^{28}$	5.1	Young et al, 2004
Churyumov-Gerasimenko	Rosetta	$3x10^{24}$-$5x10^{27}$	$4.3x10^{-4}$-0.7	Hansen et al., 07, Motschmann & Kuehrt, 06

From Coates, AIP proceedings, 2010

Planets – gas production rates

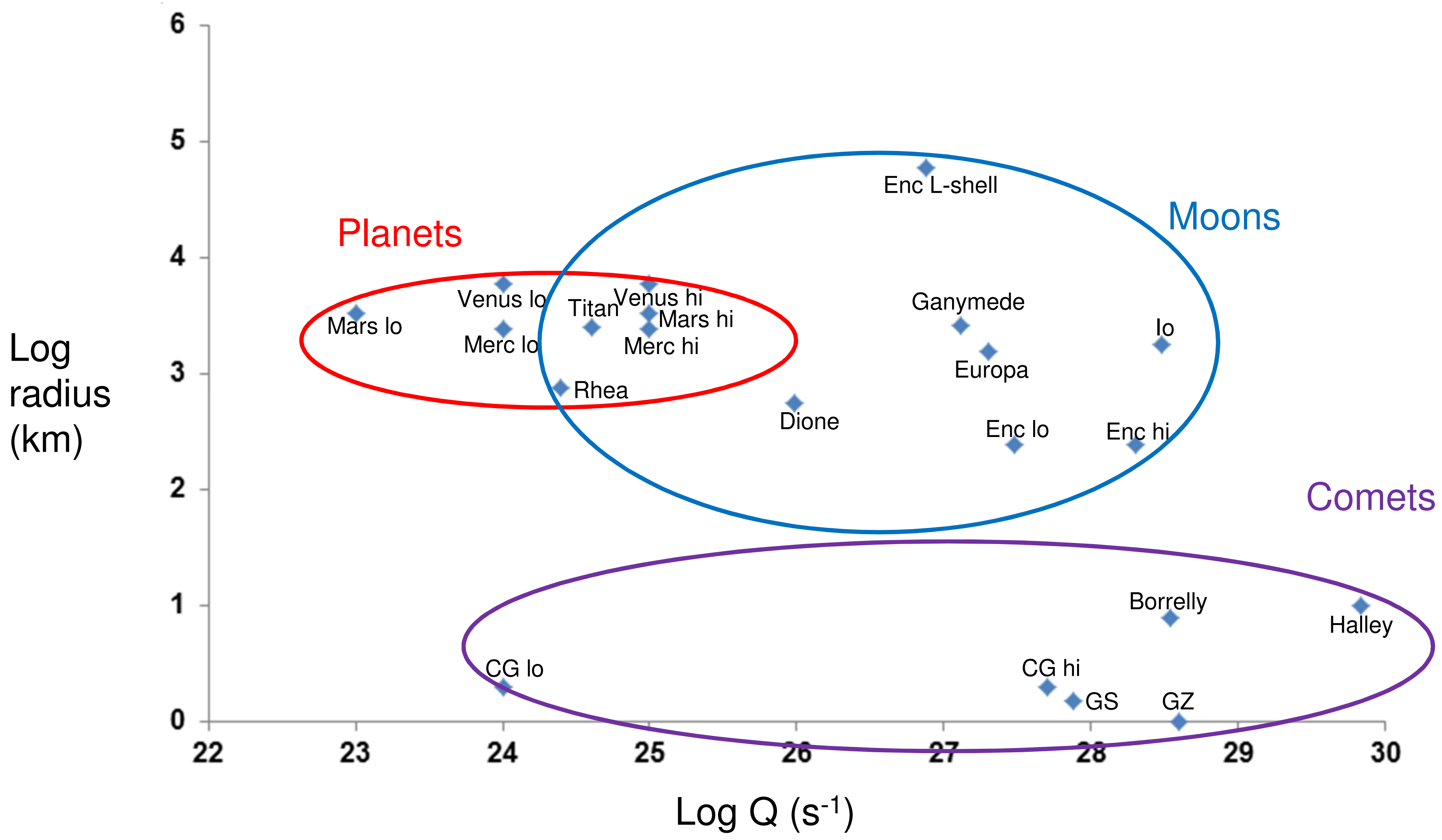
Object	Spacecraft	Q (s^{-1})	Q (Halley=100)	Reference
Mercury	Ground based	10^{24}-10^{25}	1.5×10^{-4}- 1.5×10^{-3}	Potter et al., 02
Venus	VEx, PVO	10^{24}-10^{25}	1.5×10^{-4}- 1.5×10^{-3}	Brace et al., 87 Barabash et al., 07a
Mars	MEx, Phobos	10^{23}-10^{25}	1.5×10^{-5}- 1.5×10^{-3}	Barabash et al., 07b Lundin et al., 08, 89

Adapted from Coates, Ion Pickup and Acceleration: Measurements From Planetary Missions, AIP proc. ‘Physics of the heliosphere: a 10-year retrospective’, 10th Annual Astrophysics Conference, 2012

Moons – gas production rates

Object	Spacecraft	Q (s^{-1})	Q (Halley=100)	Reference
Io	Galileo	$3x10^{28}$	4.3	Bagenal, 94
Europa	Galileo	$2x10^{27}$	0.29	Smyth & Marconi, 06
Ganymede	Galileo	$1.3x10^{27}$	0.19	Marconi, 07
Titan	Cassini	$4x10^{24}$-10^{25}	1-$1.5x10^{-3}$	Coates et al., 12, Wahlund et al., 05
Enceladus	Cassini	$3x10^{27}$ – 1-$2x10^{28}$	0.43- 2.9	Tokar et al., 06 Smith et al.
Enceladus L-shell	Cassini	3.8-$7.6x10^{26}$	0.06-0.12	Cowee et al., 09
Rhea	Cassini	$2.45x10^{24}$	$3.6x10^{-4}$	Teolis et al., 10
Dione	Cassini	$9.6x10^{25}$	0.01	Tokar et al., 12

Adapted from Coates, Ion Pickup and Acceleration: Measurements From Planetary Missions, AIP proc. 'Physics of the heliosphere: a 10-year retrospective', 10th Annual Astrophysics Conference, 2012



Planets
Moons
Comets
Mars lo
Venus lo
Merc lo
Titan
Venus hi
Mars hi
Merc hi
Rhea
Dione
Enc L-shell
Ganymede
Europa
Io
Enc lo
Enc hi
Borrelly
Halley
CG lo
CG hi
GS
GZ
Log radius (km)
Log Q (s^{-1})
0
1
2
3
4
5
6
22
23
24
25
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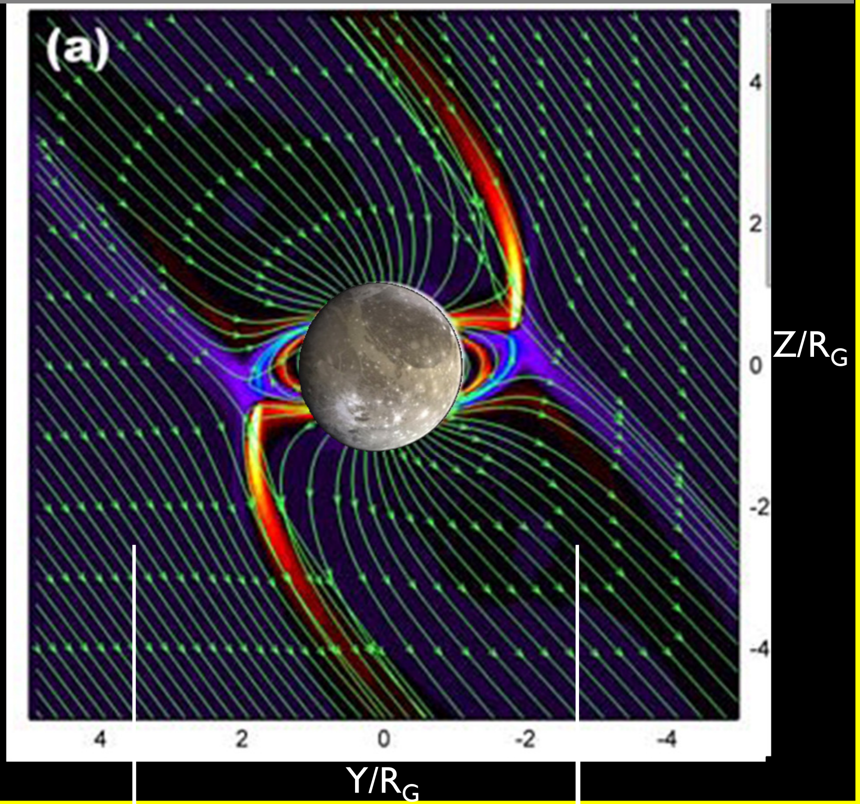
28
29
30

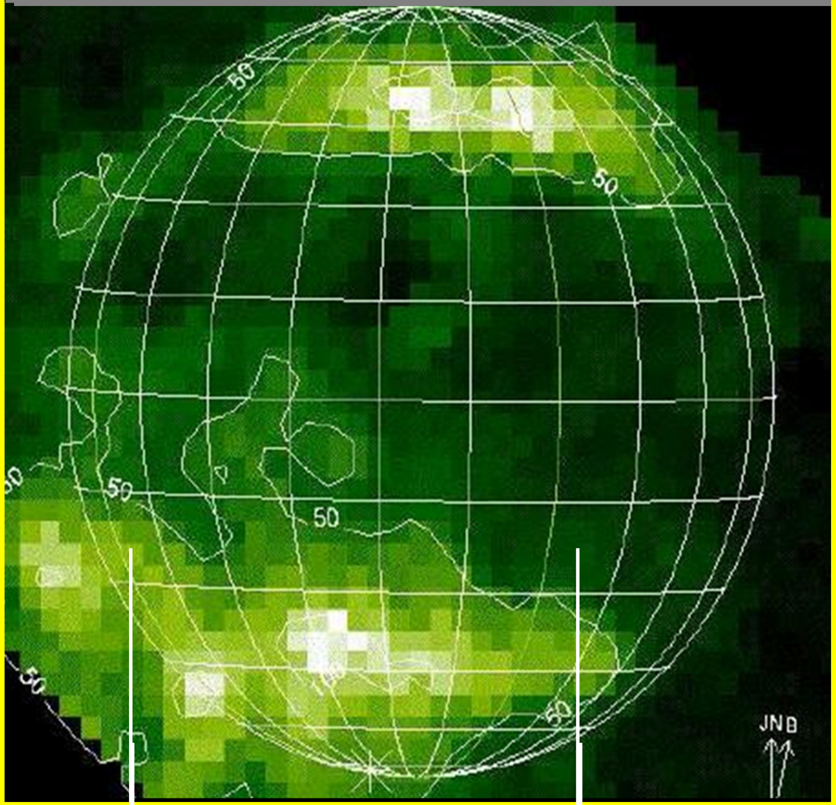
Magnetosphere Science with JUICE

GANYMEDE ENVIRONMENT | JUPITER MAGNETOSPHERE | EUROPA FLYBYS

Dipole magnetic field and mini-magnetosphere



Coupling to Jupiter's magnetosphere



Conclusions

- Titan atmosphere – evolution with altitude, and plasma escape causing evolution with time
- Enceladus – evolution with distance, plasma escape
- Rhea and Dione – weak atmospheres (cf. Saturn rings, Europa, Ganymede, Callisto…)
- Planets, comets, moons group in production rate v size
- Anticipate JUICE in-situ characterisation of Galilean satellites in 2030s