Negative ions at Titan: tholins for Titan's haze?

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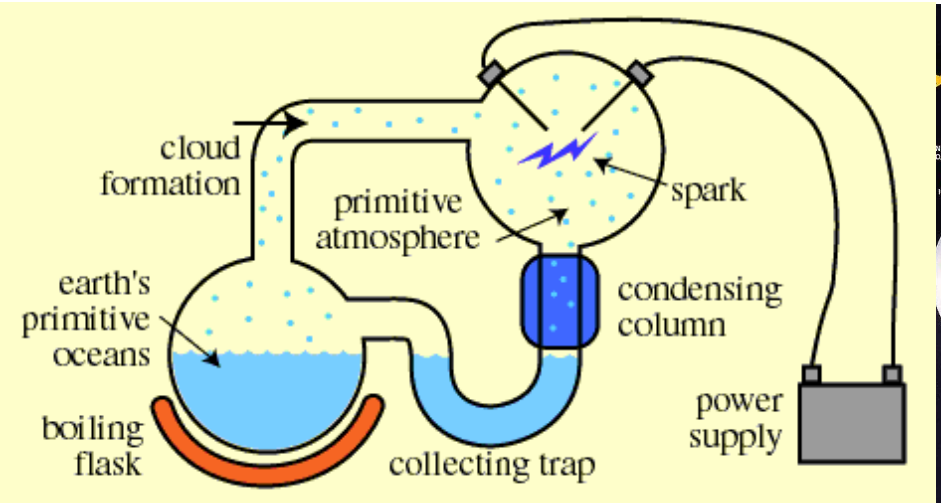
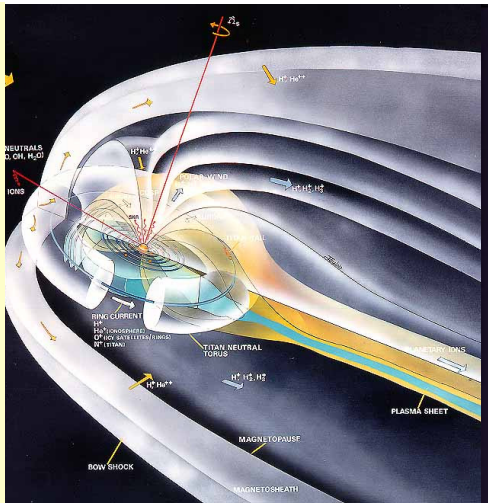
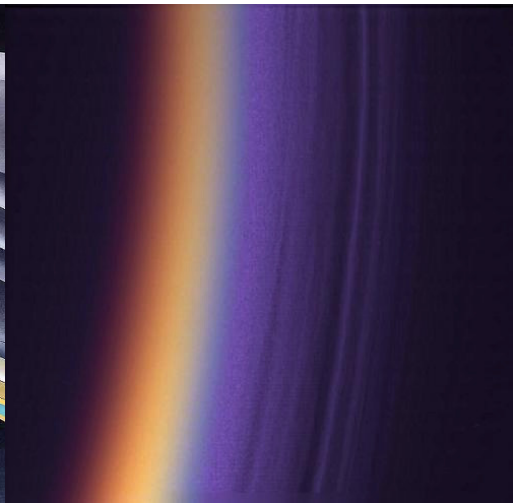
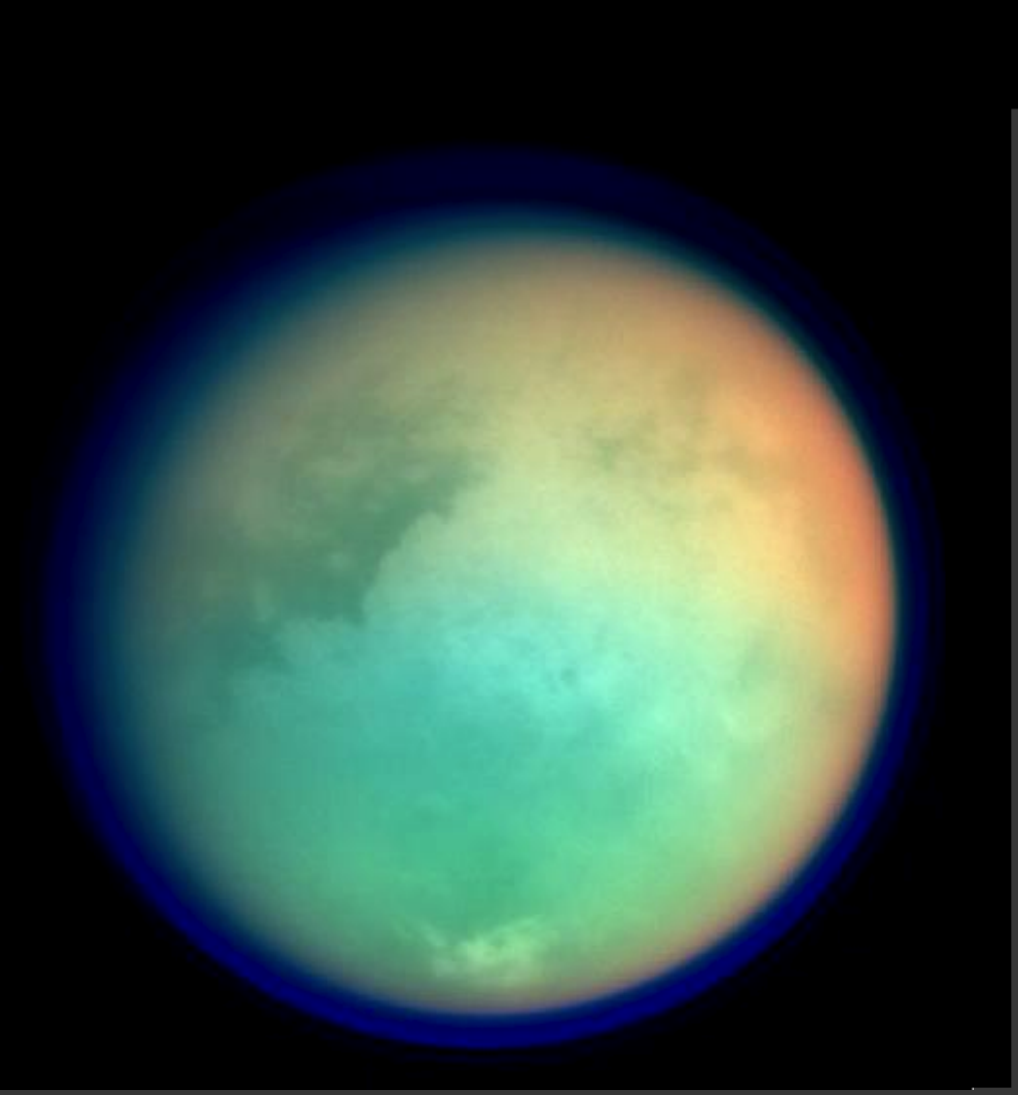
With thanks to Frank Crary, Dave Young, Hunter Waite, SwRI, Gethyn Lewis MSSL









Titan:

Radius 2575 km

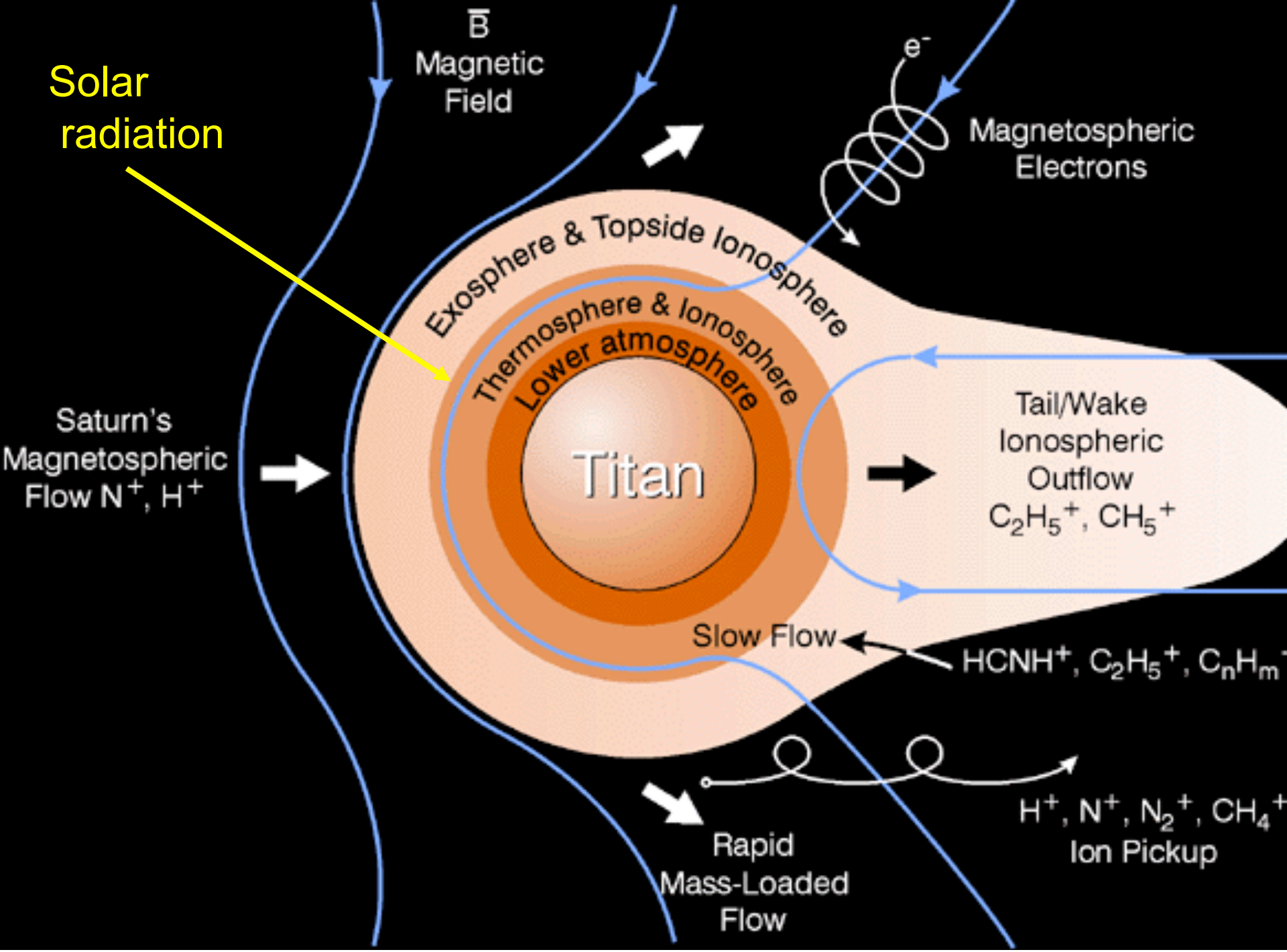
Atmosphere: mostly N_2, some CH_4 (~5% near surface),…

Unmagnetized object with an ionosphere

Haze in atmosphere, dunes, evidence for lakes and for recent surface modification

Plasma environment:

	Density (cm-3)	Temperature (eV)
Magnetosphere	0.1-1	100-1000
Solar wind (few %)	<0.1	few


Solar radiation
B
Magnetic Field
e⁻
Magnetospheric Electrons
Exosphere & Topside Ionosphere
Thermosphere & Ionosphere
Lower atmosphere
Titan
Saturn's Magnetospheric Flow N+, H+
Tail/Wake Ionospheric Outflow C2H5+, CH5+
Slow Flow
HCNH+, C2H5+, CnHm+
H+, N+, N2+, CH4+ Ion Pickup
Rapid Mass-Loaded Flow

CAPS instrument

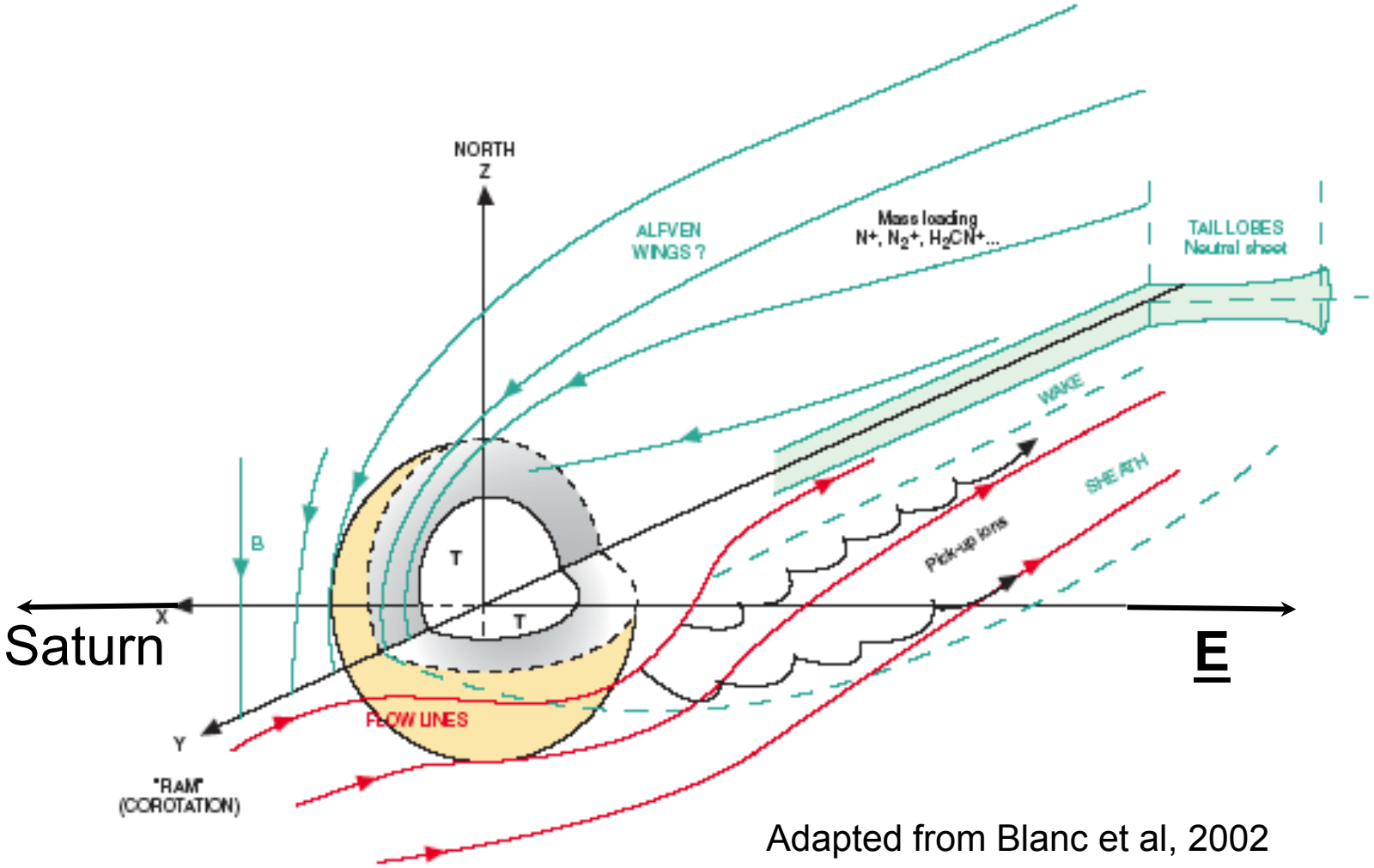
- **Three sensors + DPU, actuator**

Sensor	Measures	Energy range (eV/q)	Energy resolution (ΔE/E, %)	Angle range (°)	Angle bin (°)
Ion mass spectrometer (IMS)	Ion mass, energy and direction	1-50,000	17	160x8	20x8
Ion beam spectrometer (IBS)	Narrow ion beams; energy and direction	1-50,000	1.4	150x1.4	1.5x1.4
Electron spectrometer (ELS)	Electron energy and direction	0.6-28,000	17	160x5	20x5

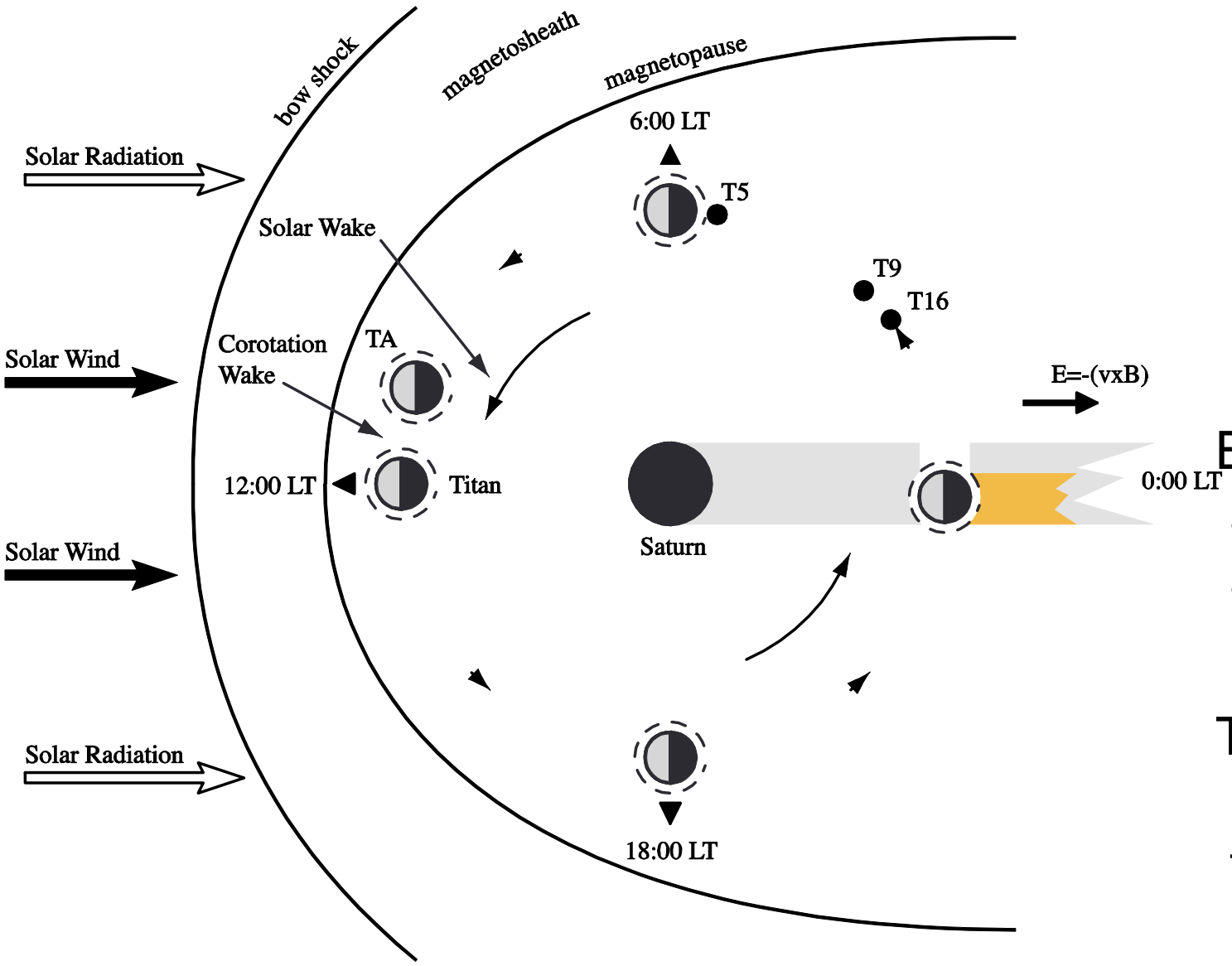
Negative ions in ionospheres

- Negative ions present in Earth's ionosphere (electronegative species e.g. O^-)
- Have also been seen in inner coma of comet Halley, mass 7-19, 22-65 and 85-110 amu (Chaizy et al, Nature 349, 393-396, 1991)
- At the comet, charge exchange processes produce positive and negative ions
- Suspected at Europa
- Negative ions were not expected high in Titan's ionosphere – electronegative species not anticipated – but were expected lower

Titan interaction



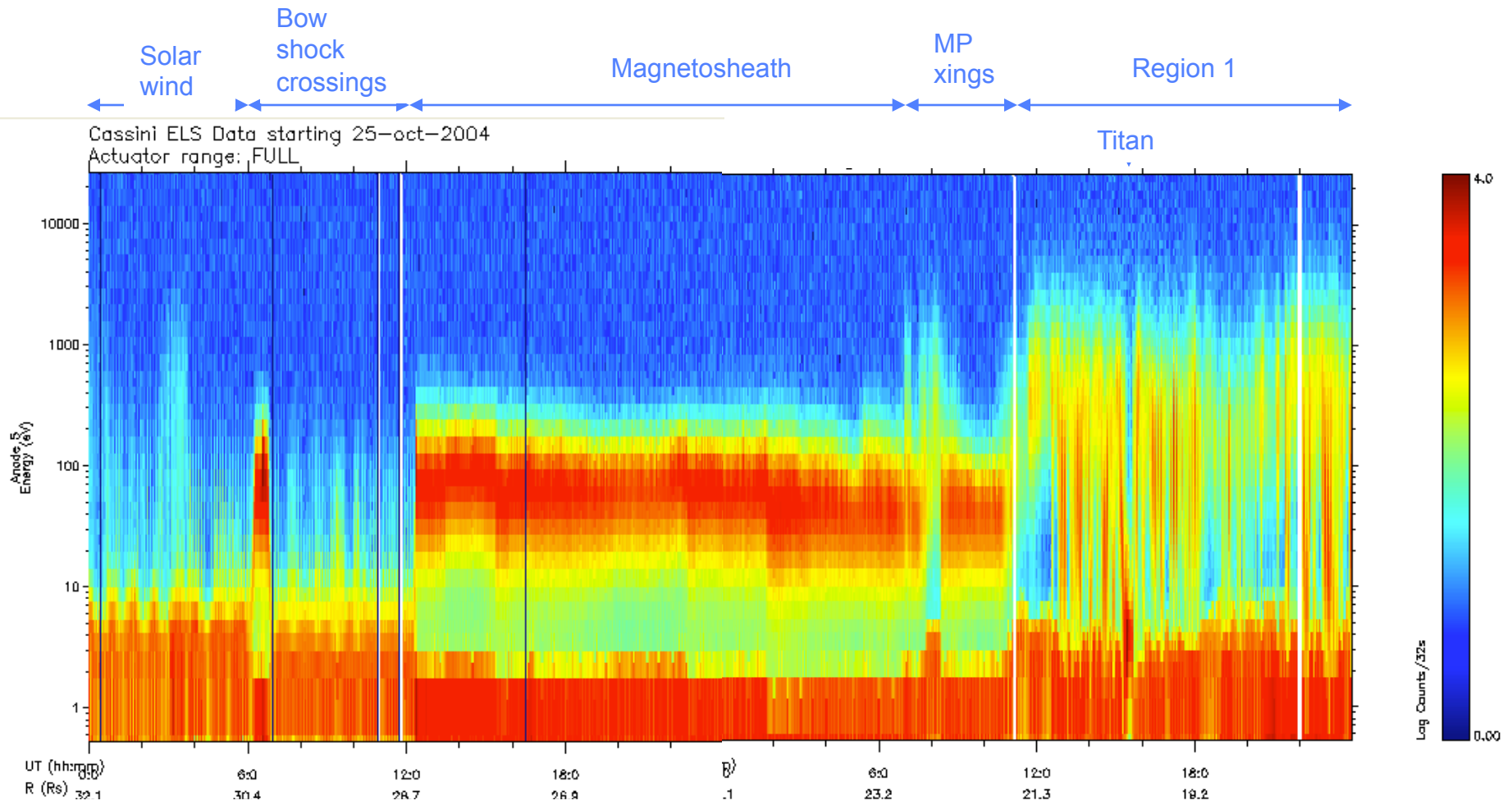
Adapted from Blanc et al, 2002

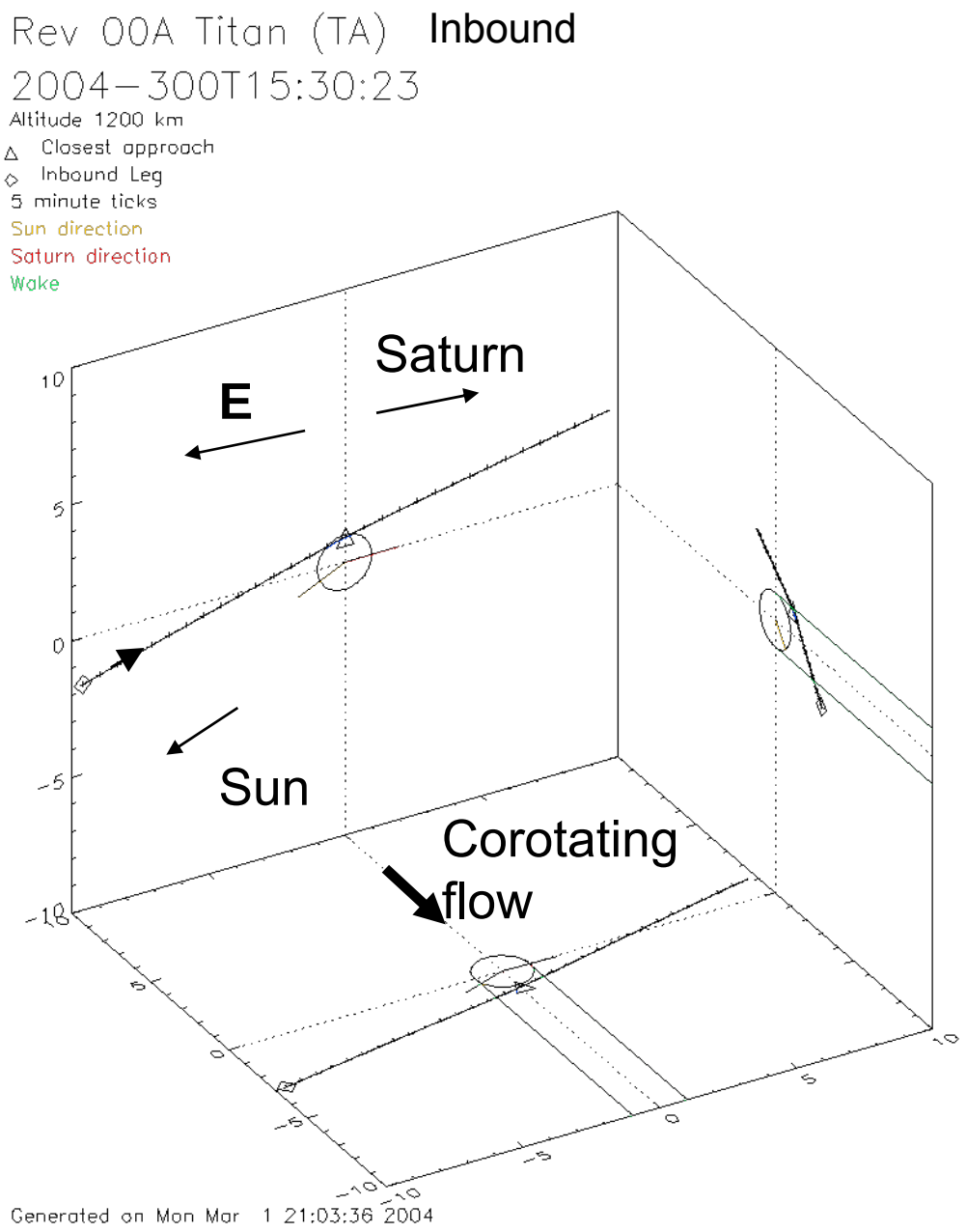


Electric field always away from Saturn

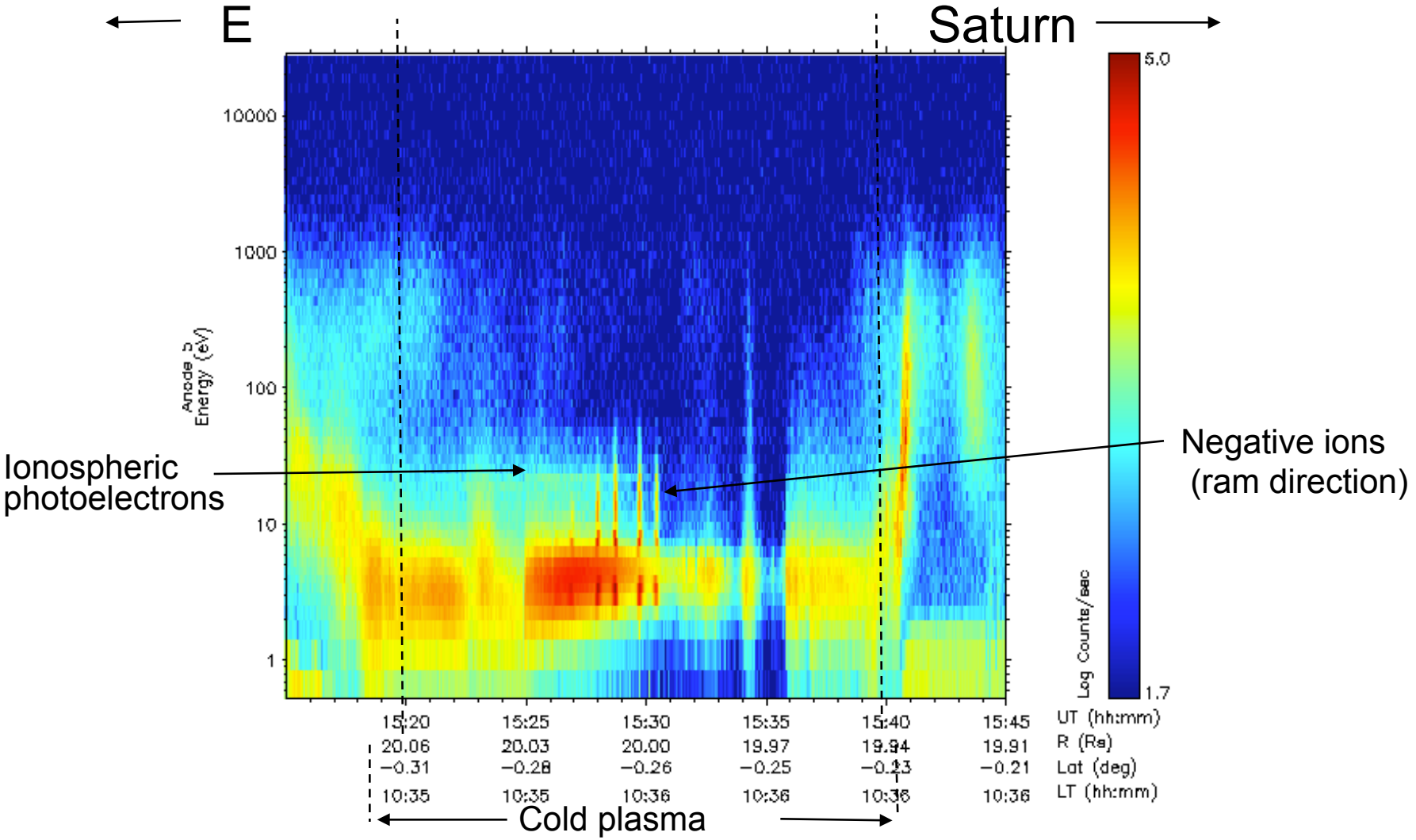
Titan always has same face to Saturn

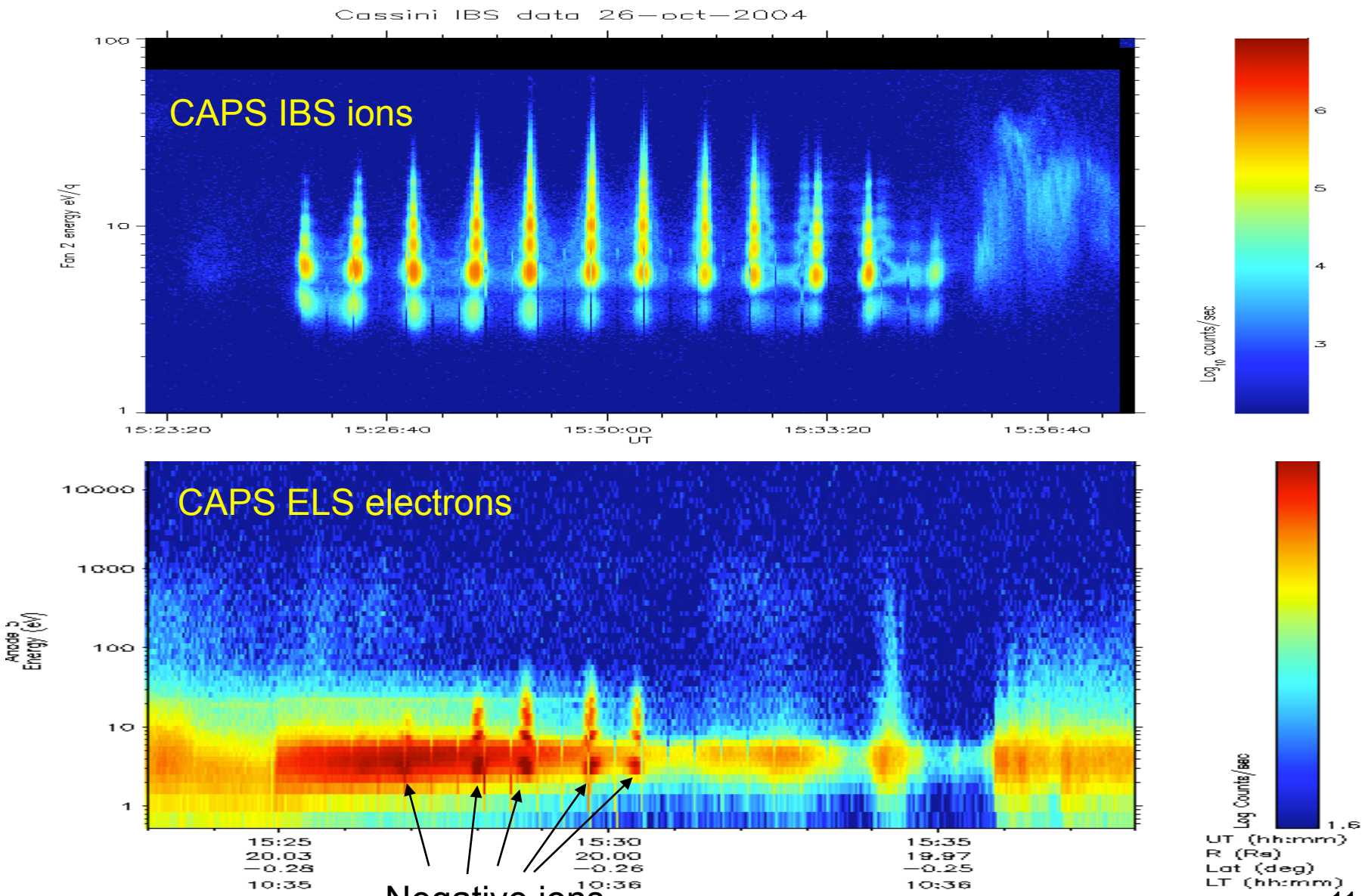
CAPS ELS overview near Ta




Rev 00A Titan (TA) Inbound
2004-300T15:30:23
Altitude 1200 km
Closest approach
Inbound Leg
5 minute ticks
Sun direction
Saturn direction
Wake
Saturn
E
Sun
Corotating flow
Generated on Mon Mar 1 21:03:36 2004

CAPS ELS high resolution data Ta




Cassini IBS data 26—oct—2004
CAPS IBS ions
Fan 2 energy eV/q
100
10
1
15:23:20
15:26:40
15:30:00
UT
15:33:20
15:36:40
Log10 counts/sec
6
5
4
3
CAPS ELS electrons
Anode 2
Energy (eV)
10000
1000
100
10
1
15:25
20.03
—0.28
10:35
15:30
20.00
—0.26
10:36
15:35
19.97
—0.25
10:36
Negative ions
Log Counts/sec
1.6
UT (hh:mm)
R (Rs)
Lat (deg)
LT (hh:mm)

Conversion of energy to negative ion mass

$$\frac{1}{2} m_{amu} m_p v^2 = qE_{eV}$$

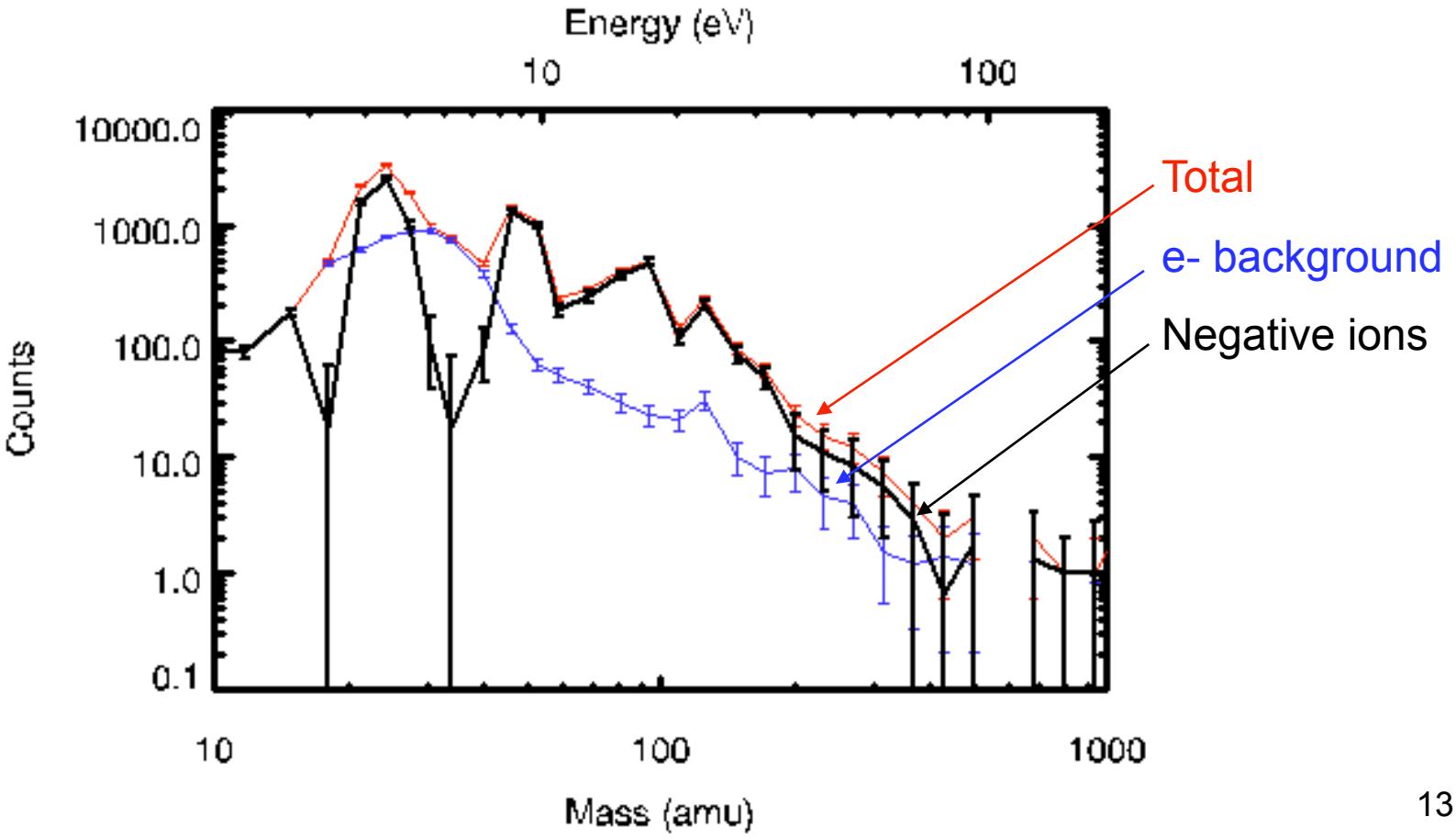
or

$$m_{amu} = \frac{2qE_{eV}}{m_p v^2}$$

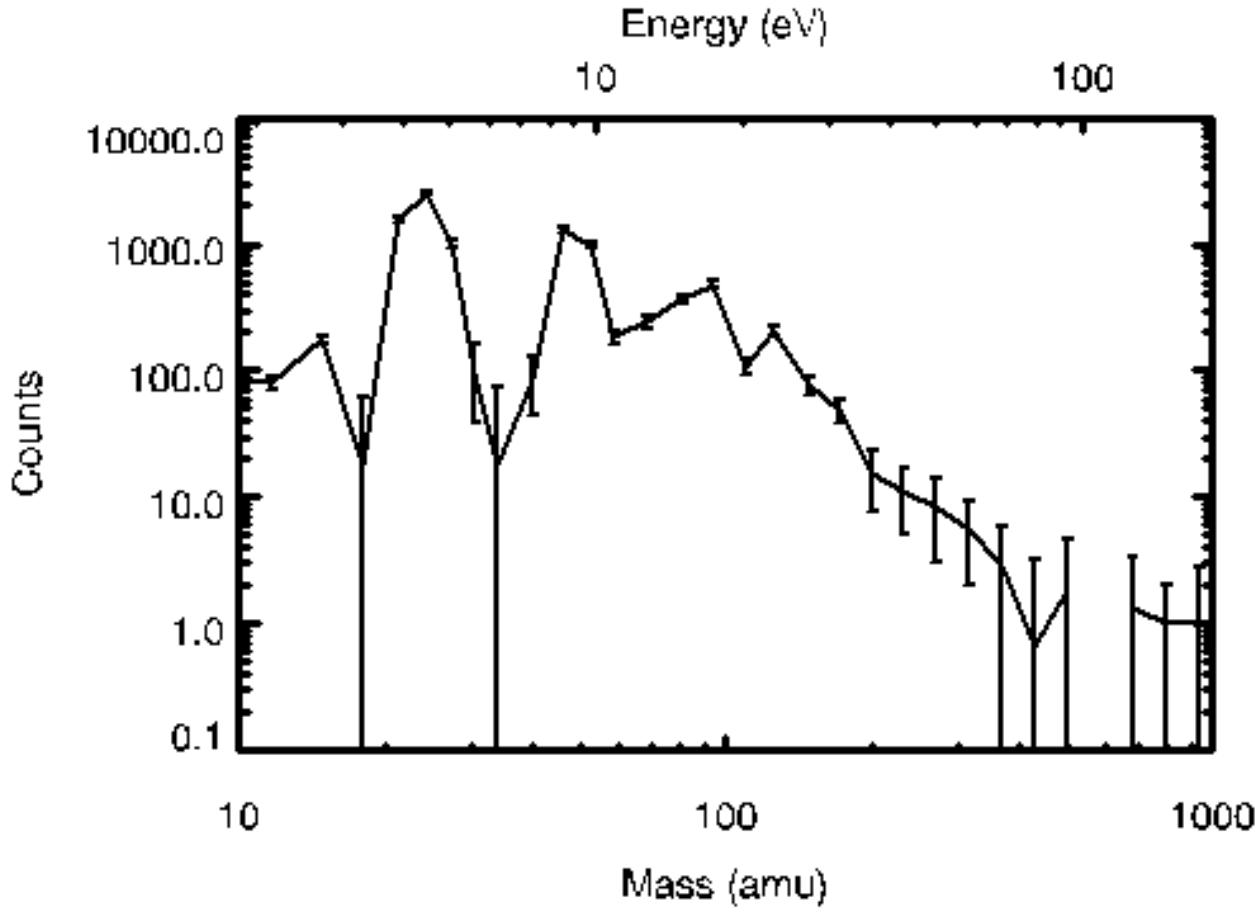
For Cassini Titan encounters,

$$m_{amu} \approx 5.32 E_{eV}$$

Ta spectrum at 15:28:42



Ta spectrum at 15:28:42



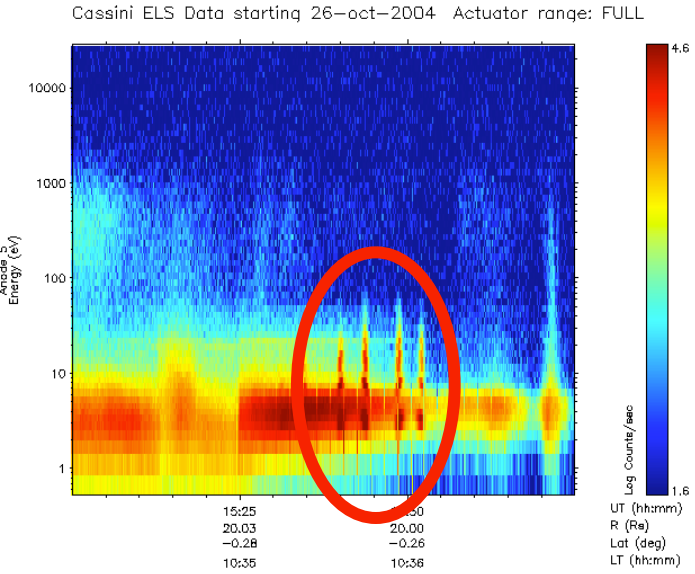
Evidence that these are negative ions

- In ram direction
- Narrow distributions in energy and angle
- Cannot be electrons – would have to be highly non-gyrotropic and seen several times
- Instrumental effects (e.g. discharge, scattering, etc) ruled out

Observed as mass groups 10-30, 30-50, 50-80, 80-110, 110-200, (200-500, 500+)

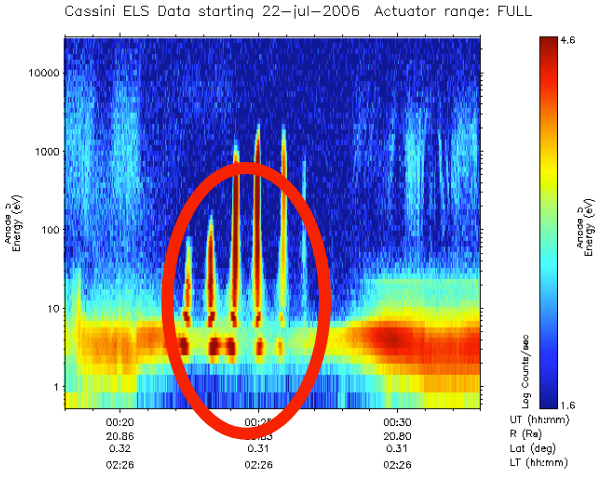
Titan negative ions
- Unexpected!
- Ram direction
- Near closest approach

Originally seen on TA in 2004…

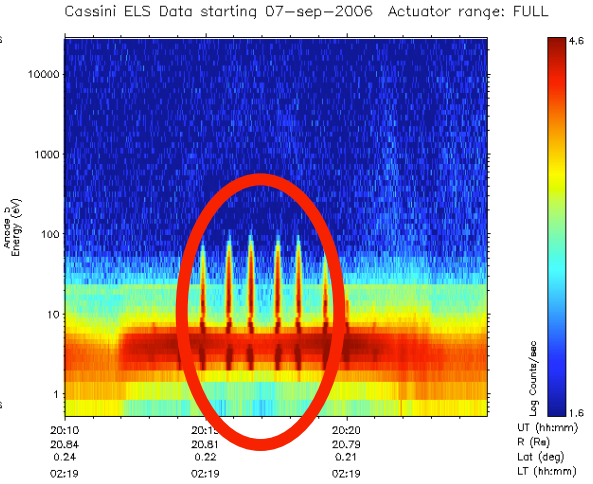


Confirmed in more recent low altitude encounters

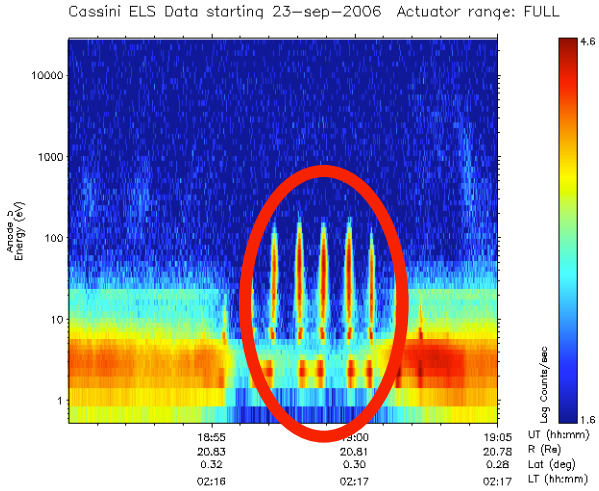
T16



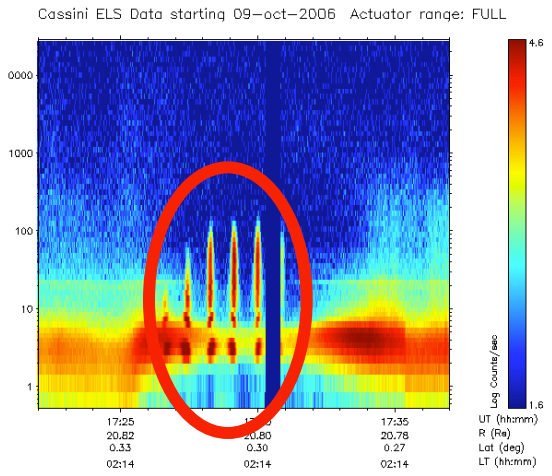
T17



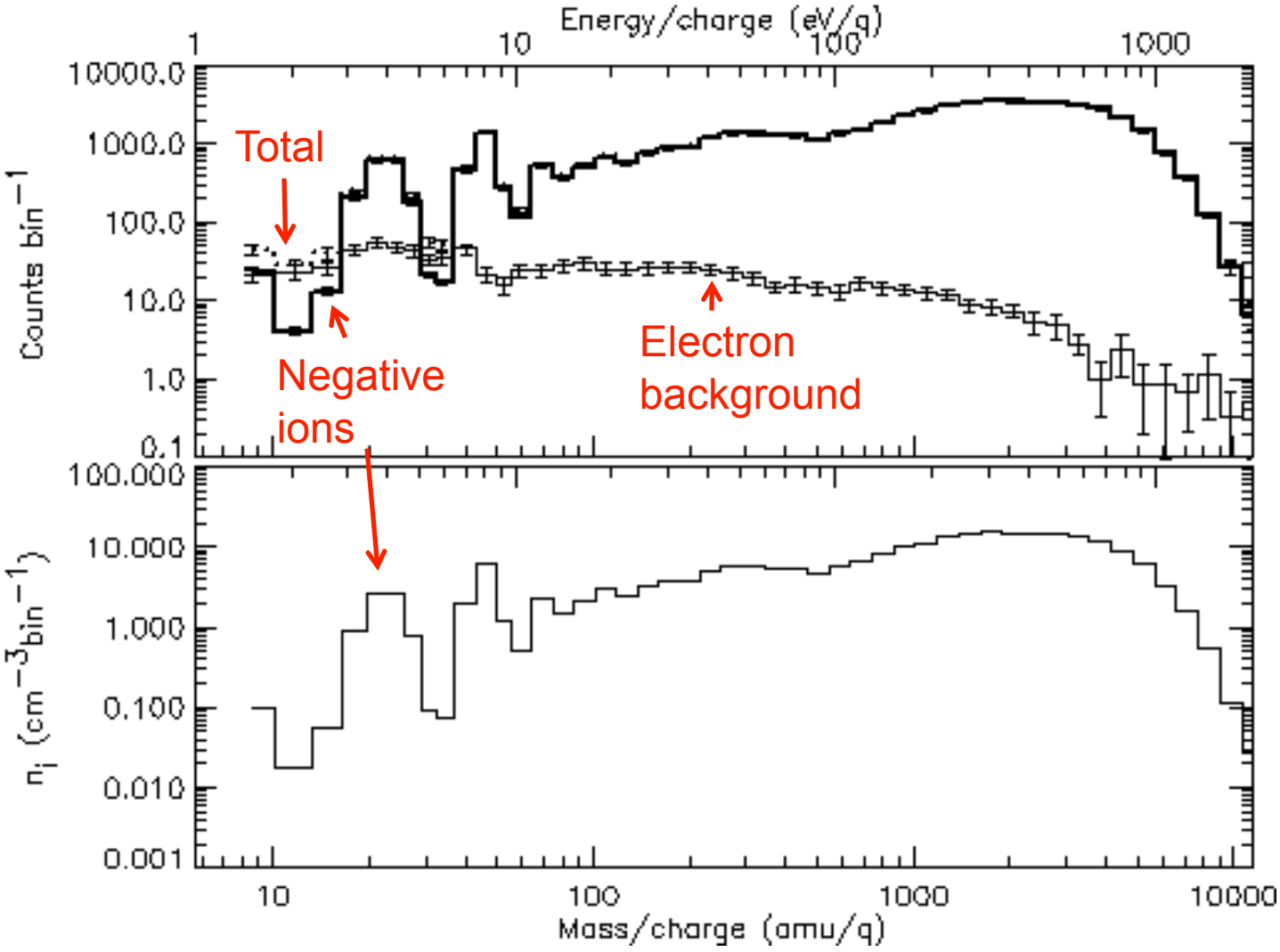
T18



T19



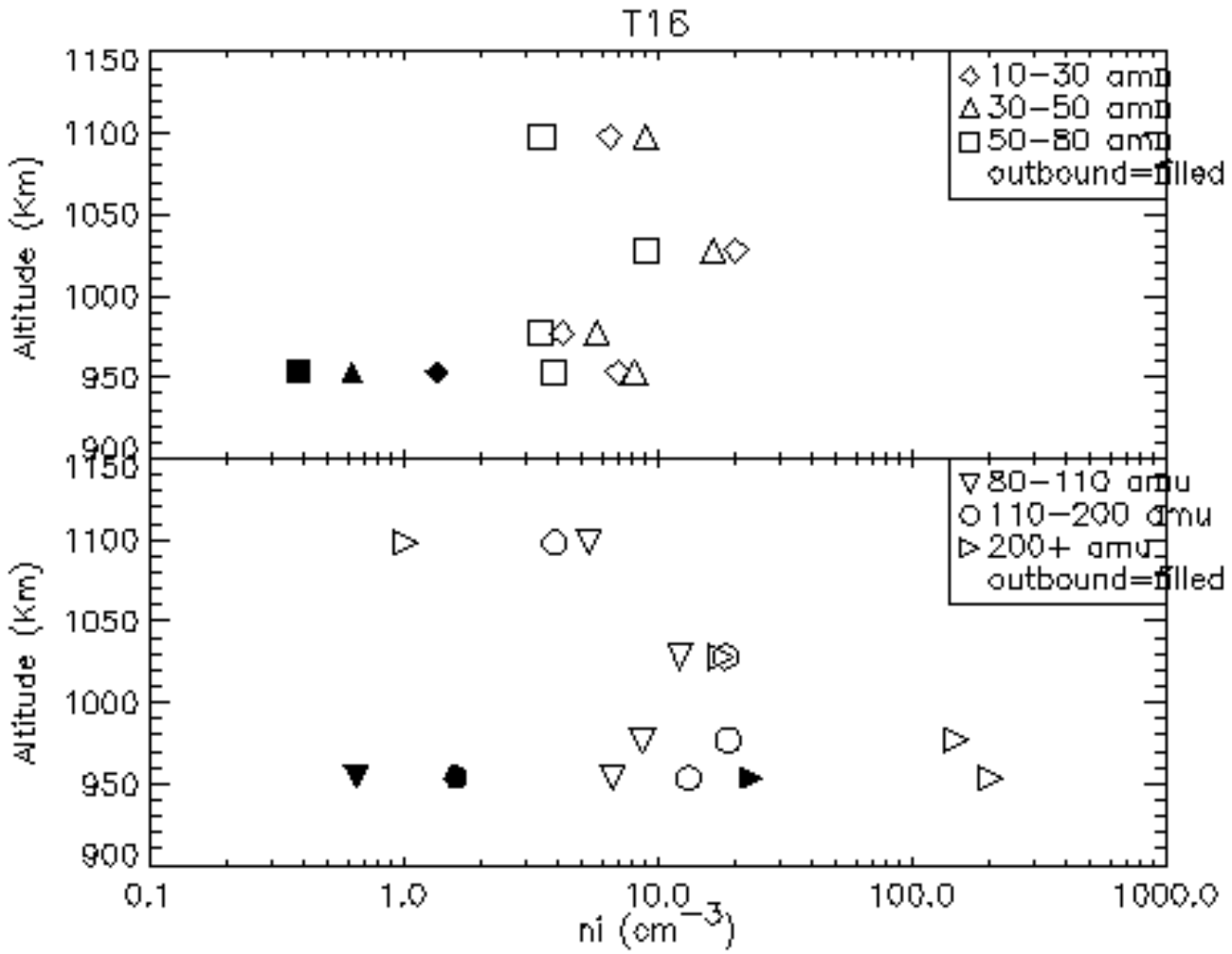
T16
953 km


Energy/charge (eV/q)
1
10
100
1000
10000.0
1000.0
100.0
10.0
1.0
0.1
Counts bin^{-1}
Total
Negative ions
Electron background
100.000
10.000
1.000
0.100
0.010
0.001
n_i (cm^{-3}bin^{-1})
10
100
1000
10000
Mass/charge (amu/q)

Charge on these large ions

- ELS measures energy/q – what is q?
- 10,000 amu ions are the size of aerosols (~10 - 30 nm).
- Assuming T_e~1000K and n_e~1x$10^3$$cm^{-3}$, λ_D~0.07m
- ~30nm grains would assume a potential (Goetz, 1989) of φ~-2.5 kT_e/e~-0.25 V
- Charge given by $Q=4\pi\varepsilon_0 a\varphi exp(-a/\lambda_D)$
- Corresponds to ~5 electrons
- Actual mass could then be ~50,000 amu !

Using ram assumption to calculate density
Total density ~200 cm^{-3} (T16)



Possible negative ions

Mass group (amu/q)	Identification
10-30	CN^-,NH_2^-,O^-
30-50	NCN^-, $HNCN^-$, C_3H^-
50-80	$C_5H_5^-$, C_6H^-, $C_6H_5^-$
80-110	Polyyines, high order nitriles, PAHs, cyano-aromatics
110-200	
200-500	
500-10,000	

Observed on 16 encounters between Ta & T36

Table 1. Encounters on Which Negative Ions are Seen. Parameters are Given at Titan Closest Approach in Each Case

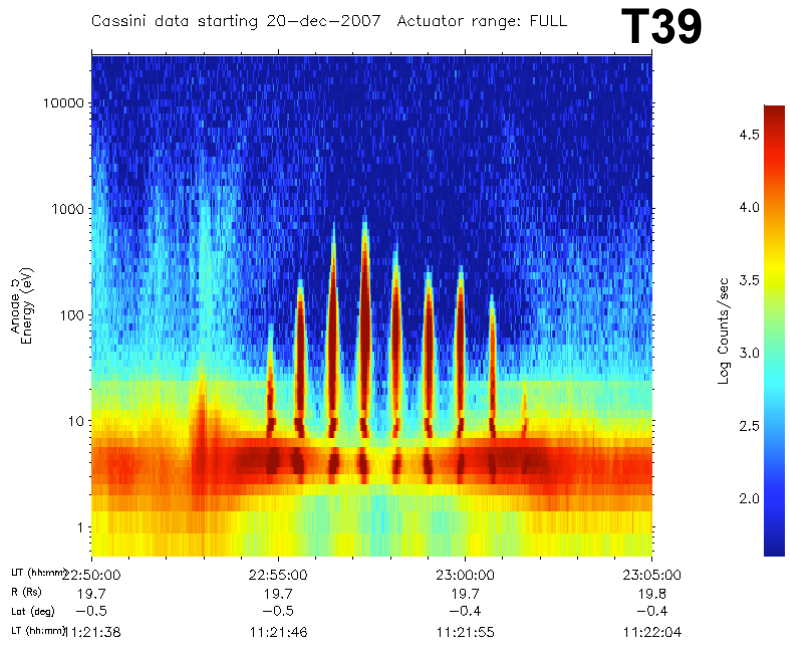
	Date	DOY, UT	Altitude (km)	Local time Saturn (hh:mm)	Local time Titan (hh:mm)	Latitude (°N)	Relative velocity (km s^{-1})	Solar zenith angle (sza[a]) (°)	Cassini in Titan shadow (night)
Ta (in)	26/10/04	300, 15:30	1174	10:36	16:45	38.78	6.05	91.00	no
T16 (in)	22/7/06	203, 00:25	950	02:27	17:17	85.15	5.97	105.32	no
T17 (in)	7/9/06	250, 20:17	1000	02:20	10:28	22.82	5.96	44.54	no
T18 (in)	23/9/06	266, 18:59	960	02:17	14:24	70.92	5.96	89.81	no
T19 (in)	9/10/06	282, 17:30	980	02:14	14:20	60.75	5.96	80.96	no
T20 (in)	25/10/06	298, 15:58	1029	02:12	11:10	6.36	5.96	24.65	no
T21 (in)	12/12/06	346, 11:41	1000	02:03	20:20	43.12	5.96	125.18	no
T23 (in)	13/1/07	013, 08:39	1000	01:57	14:01	30.68	5.96	53.28	no
T25 (out)	22/2/07	053, 03:12	1000	13:51	00:34	30.35	6.23	161.24	yes
T26 (out)	10/3/07	069, 01:49	981	13:49	01:45	31.70	6.23	149.50	yes
T27 (out)	26/3/07	085, 00:23	1010	13:46	01:42	40.93	6.23	144.13	yes
T28 (out)	10/4/07	100, 22:58	991	13:43	01:39	50.17	6.23	137.37	yes
T29 (out)	26/4/07	116, 21:33	980	13:41	01:36	59.38	6.23	129.81	no
T30 (out)	12/5/07	132, 20:10	959	13:38	01:32	68.61	6.23	121.71	no
T32 (out)	13/6/07	164, 17:46	965	13:35	01:17	84.46	6.23	107.00	no
T36 (out)	2/10/07	275, 04:42	975	11:29	16:08	−59.90	6.31	67.40	no

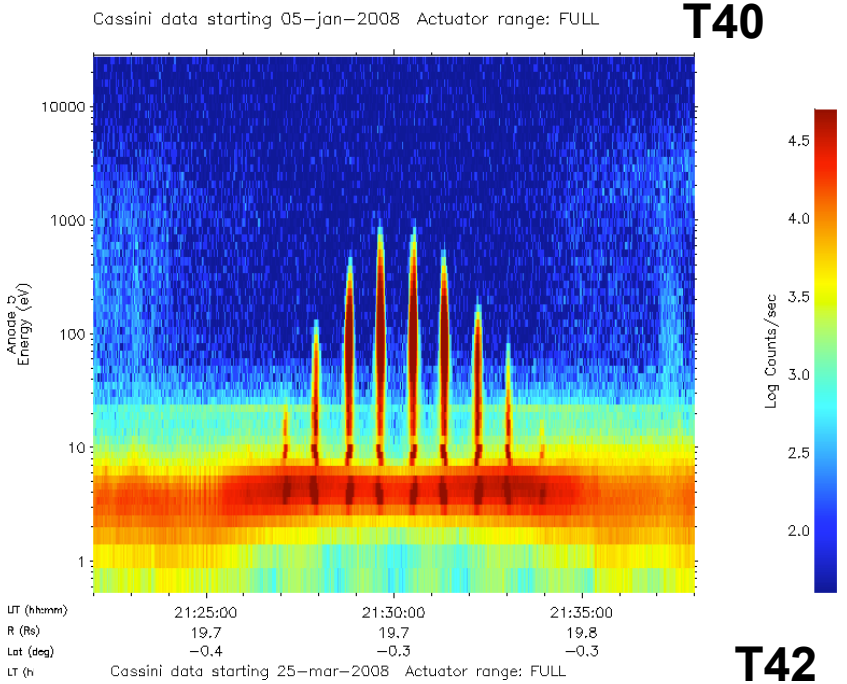
[a]For SZA > 100°, sunlight will be highly attenuated by Titan's atmosphere.

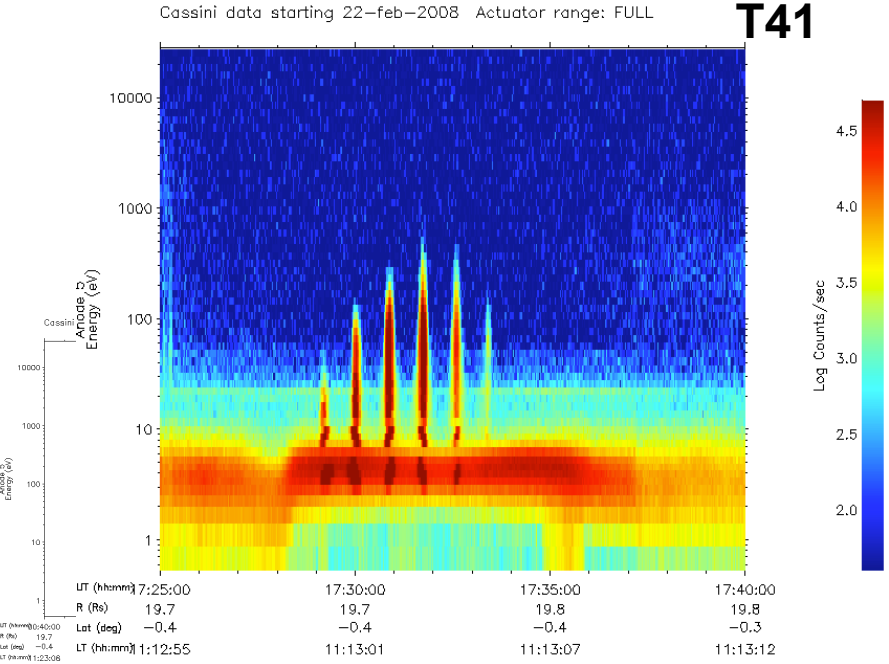
See Coates et al, GRL Nov 07

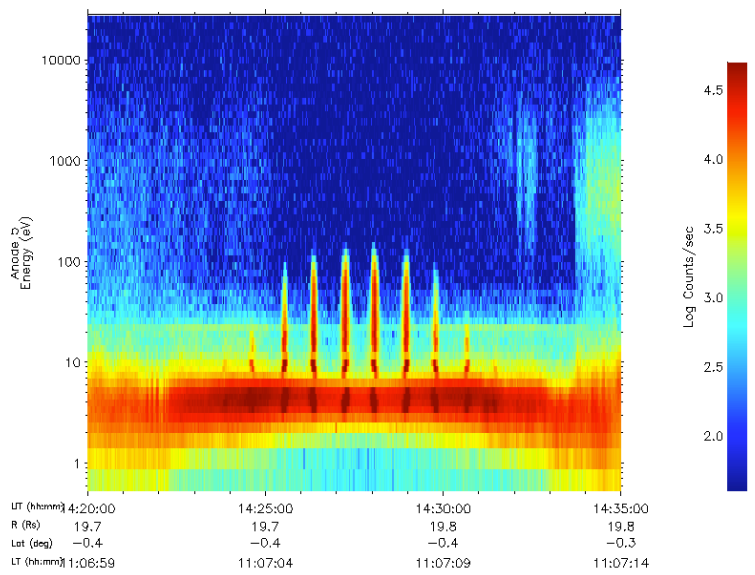
...and on 6 more recent encounters

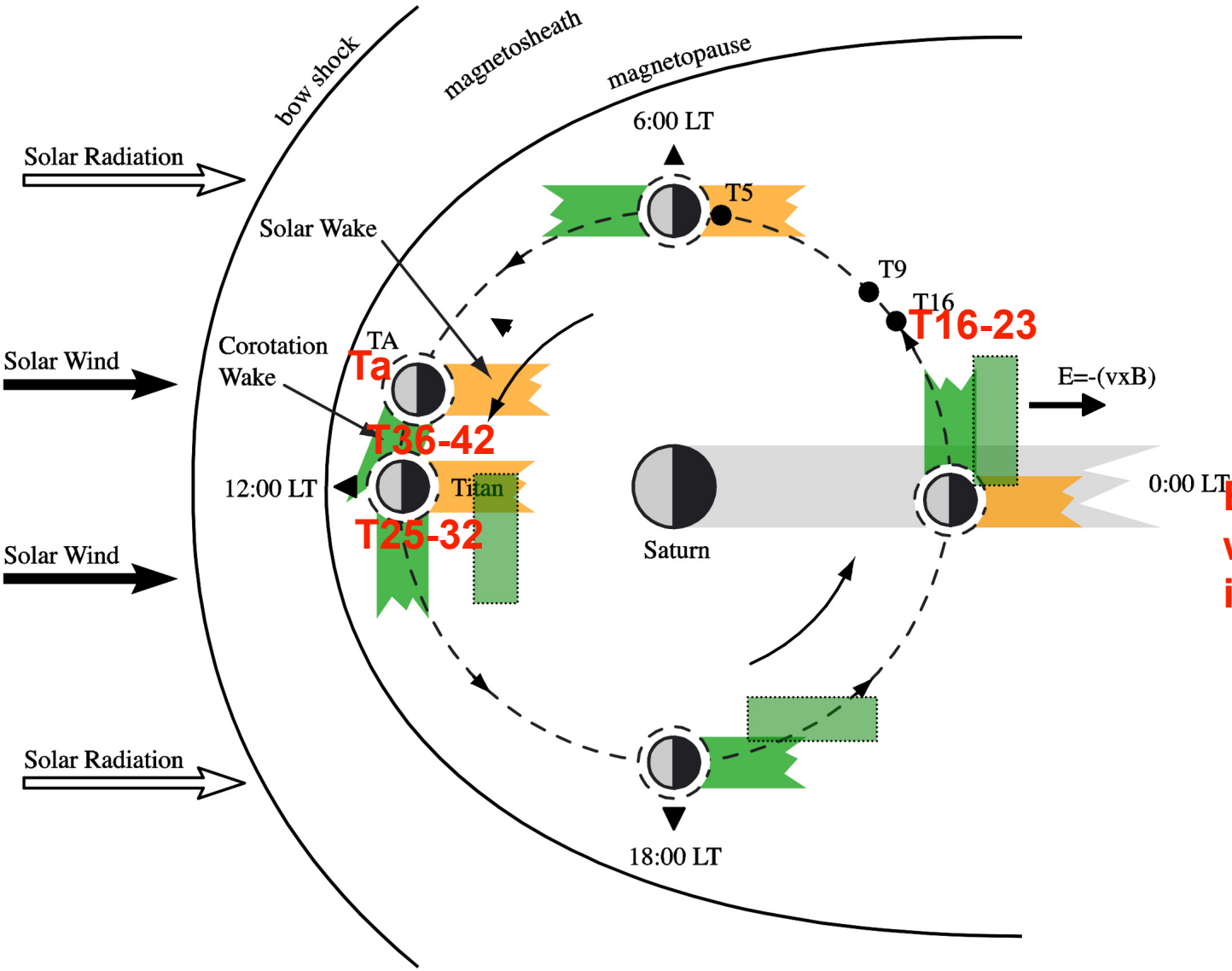
	Date z	UT z	Altitude z (km) z	Local z time z Saturn z (hh:mm) z	Local z time z Titan z (hh:mm) z	Latitude z (ºN) z	Relative z velocity z (km s^{-1}) z	Solar z enith z angle z SZA z (º) z	Cassini in z Titan z shadow z (night) z
T37 z	19/11/07 z	partial z							
T39 z	20/12/07 z	22:58 z	970 z	11:30 z	11:22 z	-70 z	6.33 z	61.4 z	No z
T40 z	05/1/08 z	21:30 z	1010 z	14:32 z	11:20 z	-12 z	6.32 z	37.5 z	No z
T41 z	22/2/08 z	17:32 z	1000 z	13:00 z	11:13 z	-35 z	6.34 z	30.2 z	No z
T42 z	25/3/08 z	14:28 z	1000 z	12:36 z	11:07 z	-27 z	6.35 z	21.4 z	No z
T43 z	12/5/08 z	10:02 z	1000 z	13:44 z	10:59 z	18 z	6.33 z	35.8 z	No z


Cassini data starting 20–dec–2007 Actuator range: FULL
T39
Anode 5 Energy (eV)
Log Counts/sec
LT (hh:mm) 22:50:00 22:55:00 23:00:00 23:05:00
R (Rs) 19.7 19.7 19.7 19.8
Lat (deg) −0.5 −0.5 −0.4 −0.4
LT (hh:mm) 11:21:38 11:21:46 11:21:55 11:22:04


Cassini data starting 05–jan–2008 Actuator range: FULL
T40
Anode 5 Energy (eV)
Log Counts/sec
LT (hh:mm) 21:25:00 21:30:00 21:35:00
R (Rs) 19.7 19.7 19.8
Lat (deg) −0.4 −0.3 −0.3

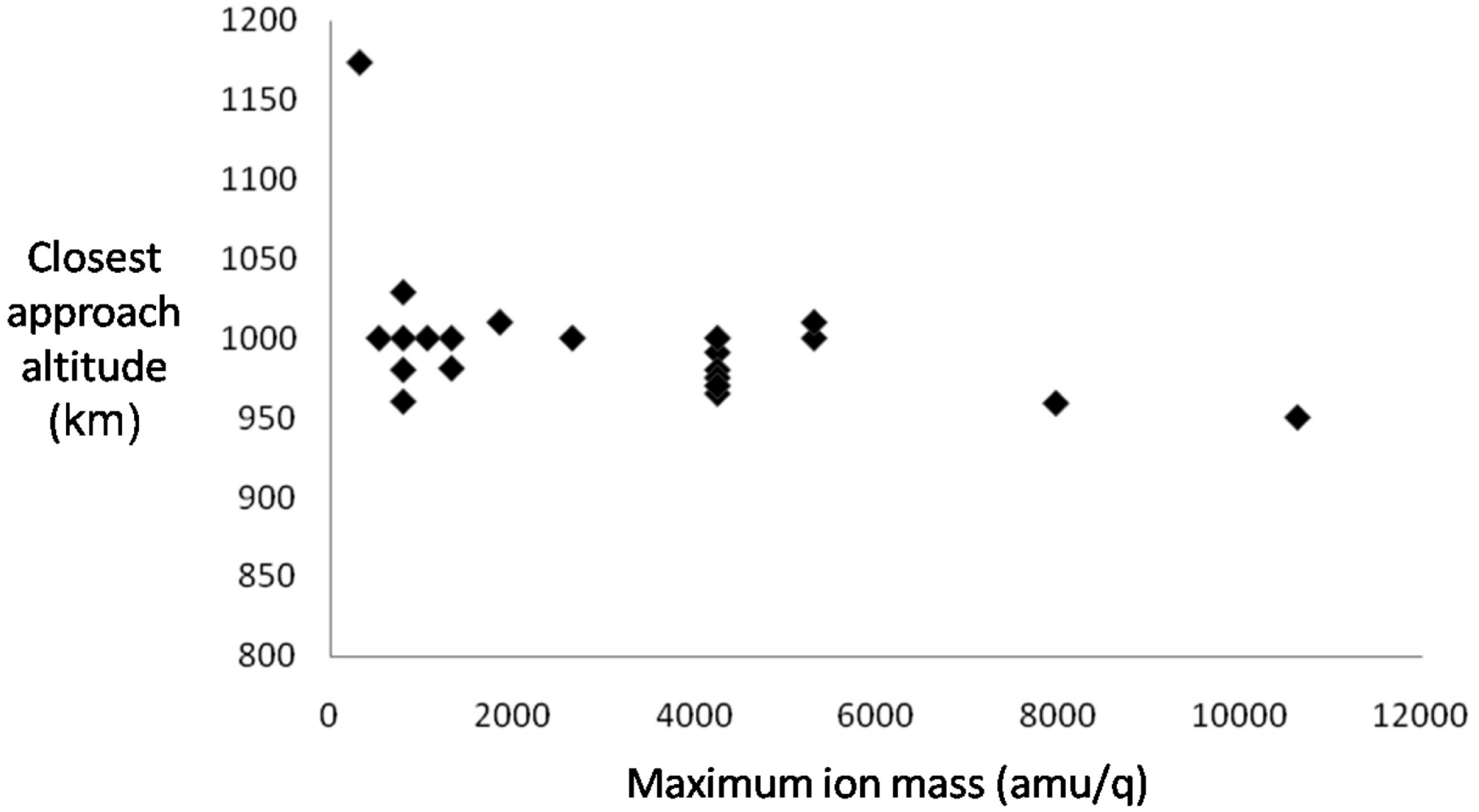

Cassini data starting 22–feb–2008 Actuator range: FULL
T41
Anode 5 Energy (eV)
Log Counts/sec
LT (hh:mm) 17:25:00 17:30:00 17:35:00 17:40:00
R (Rs) 19.7 19.7 19.8 19.8
Lat (deg) −0.4 −0.4 −0.4 −0.3
LT (hh:mm) 11:12:55 11:13:01 11:13:07 11:13:12


Cassini data starting 25–mar–2008 Actuator range: FULL
T42
Anode 5 Energy (eV)
Log Counts/sec
LT (hh:mm) 14:20:00 14:25:00 14:30:00 14:35:00
R (Rs) 19.7 19.7 19.8 19.8
Lat (deg) −0.4 −0.4 −0.4 −0.3
LT (hh:mm) 11:06:59 11:07:04 11:07:09 11:07:14



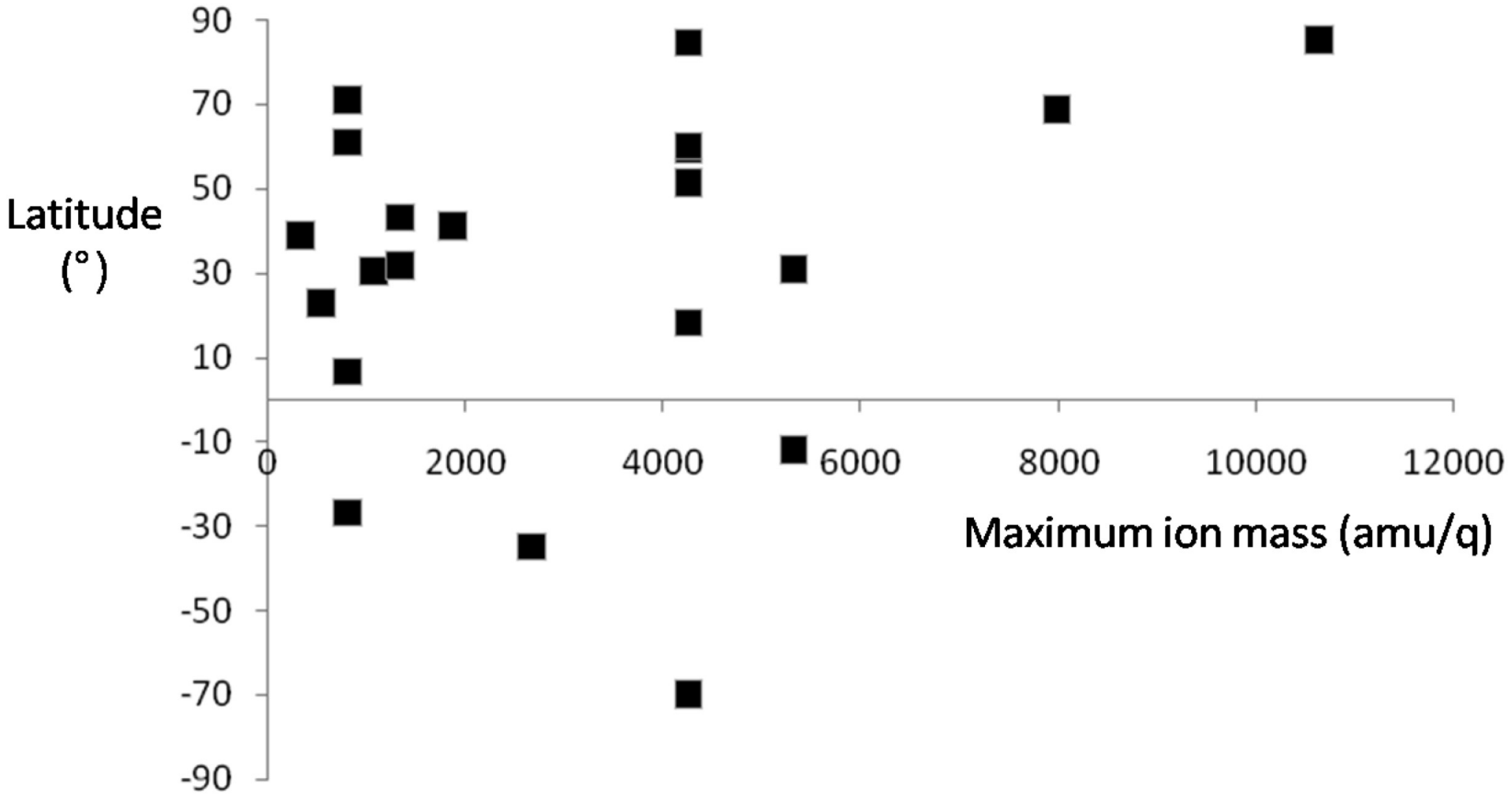
Encounters where negative ions are seen

Highest masses at low altitudes



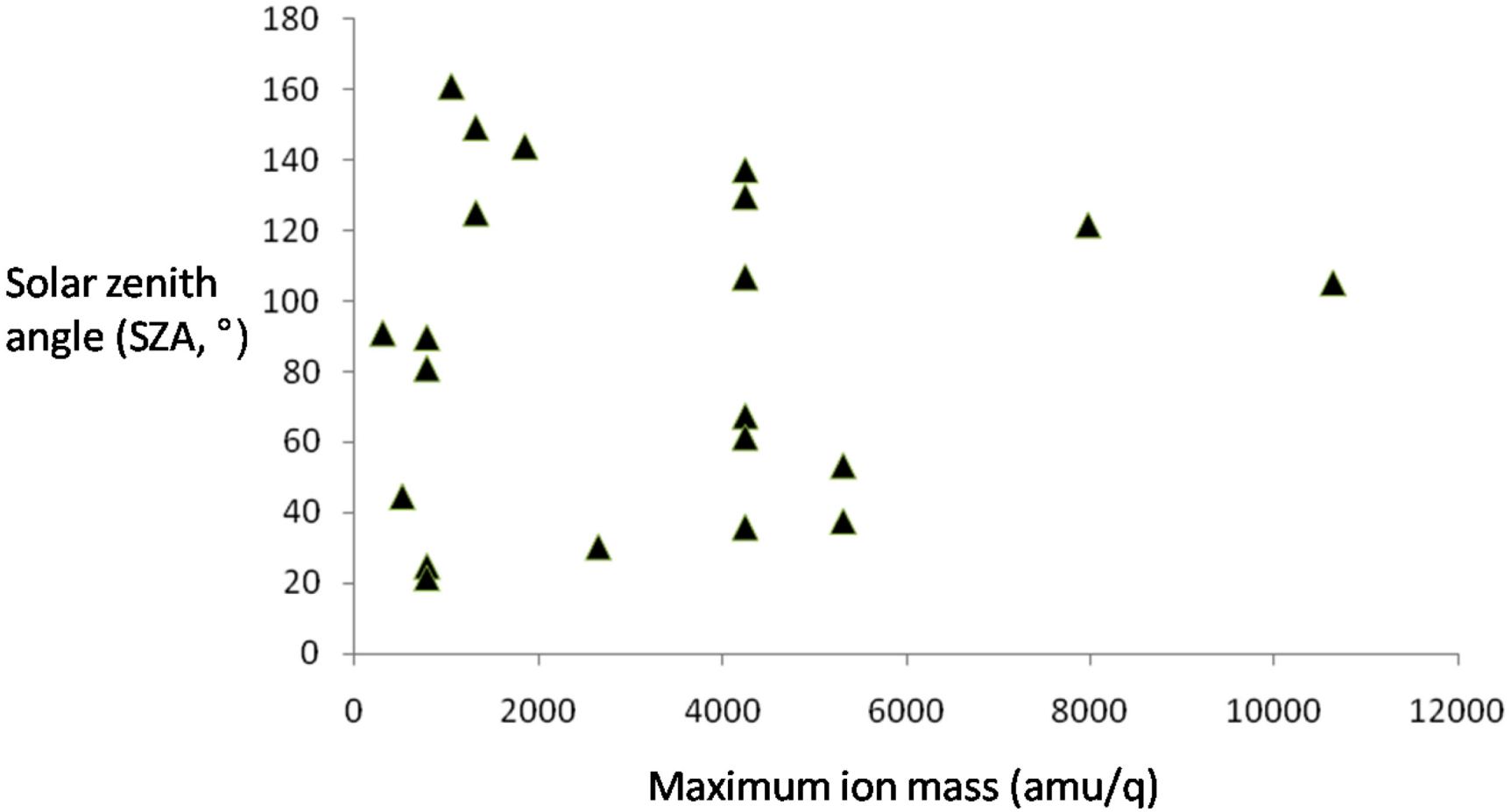
...so may descend through atmosphere

Highest masses at high latitudes



...so may be larger if less sunlit

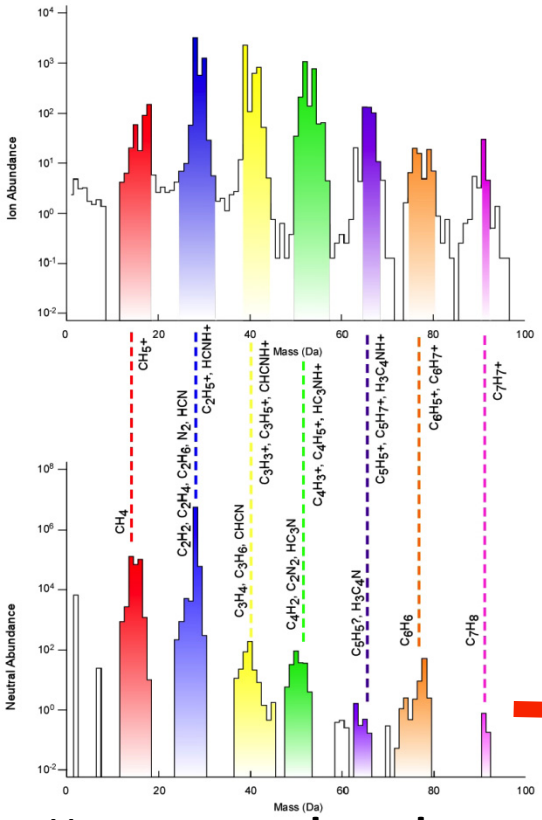
Highest masses near terminator



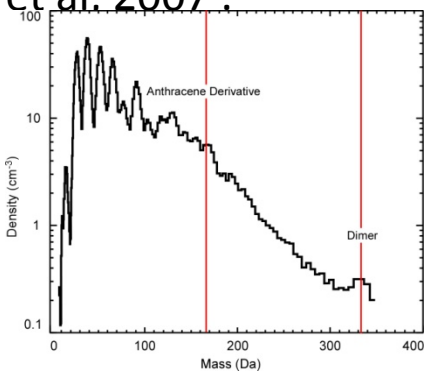
...so may be larger if less sunlit

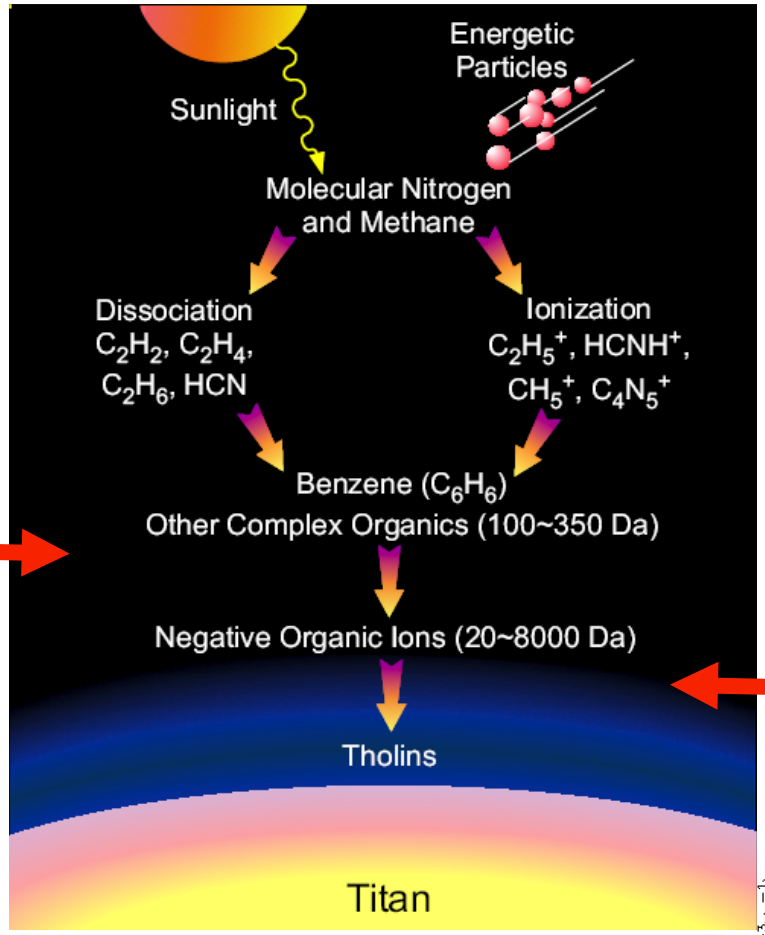
Titan's atmosphere: . hydrocarbon-rich .

Effect on surface? . E.g., dunes… .

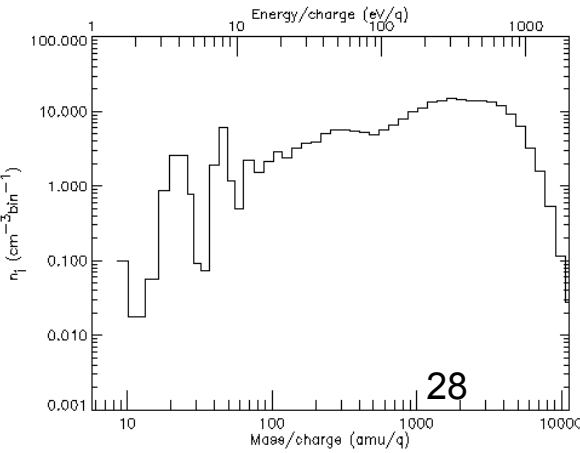


Heavy **neutrals and positive ions**: Waite . et al. 2007 .





Unexpected heavy . **negative ions**: Coates . et al, 2007 .

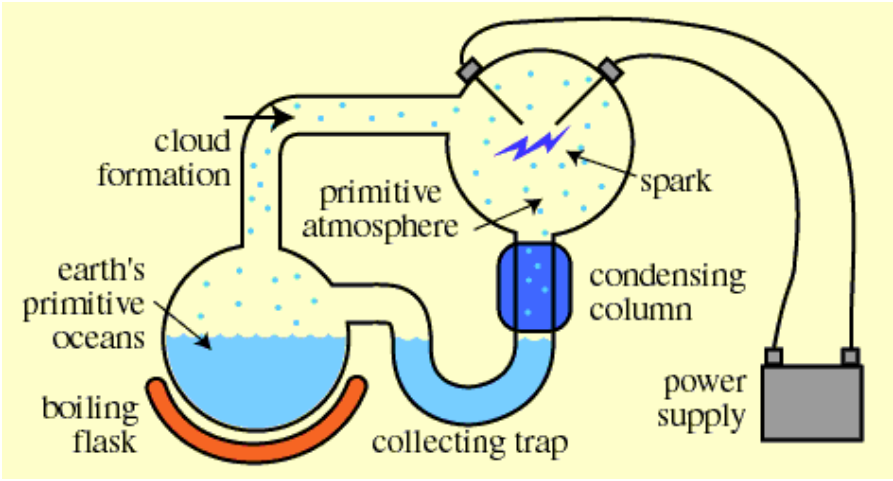


Recent relevant work

- **Additional supporting evidence:** UVIS stellar occultation measurements supportive of heavy organics to >1000 km (Shemansky et al, 2006, Liang et al, 2007)
- **Additional supporting evidence:** discrepancy of ~10^3 cm^{-3} between RPWS-LP (n_e) and INMS (n_i) density measurements on encounters where we see negative ions (Wahlund et al, personal communication) explained by our negative ion density observations
- **Theoretical approach:** heavy positive ions from lower altitudes ions may be levitated at higher altitudes by upward pointing, ambipolar electric fields in the homosphere (Gombosi et al). Heavy species can then acquire negative charge and are accelerated downwards

What are tholins?

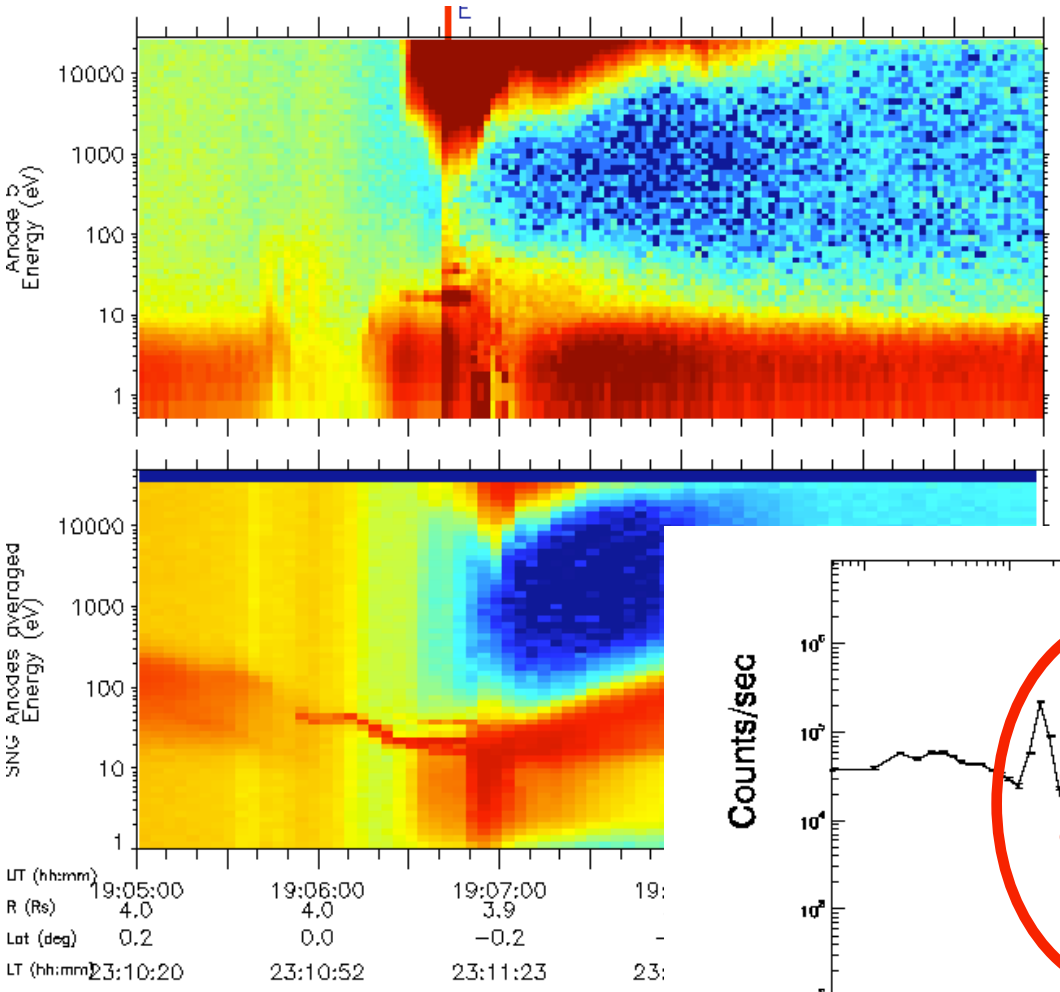
- Term “tholin” coined by Sagan and Khare, 1979
- Products from energetic processing of mixtures of gases such as CH_4, N_2, and H_2O.
- Tholin from Greek for “muddy”
- Brownish, sticky residues formed by extensions of the Miller-Urey experiment (Miller and Urey, 1953) to simulate early Earth atmosphere.
- Can use electrical discharges or ultraviolet radiation
- Sagan and others tried to simulate the atmospheres of planets and moons, e.g. Titan, Triton (McDonald, et al.,1994) and Jupiter (Khare and Sagan, 1975).

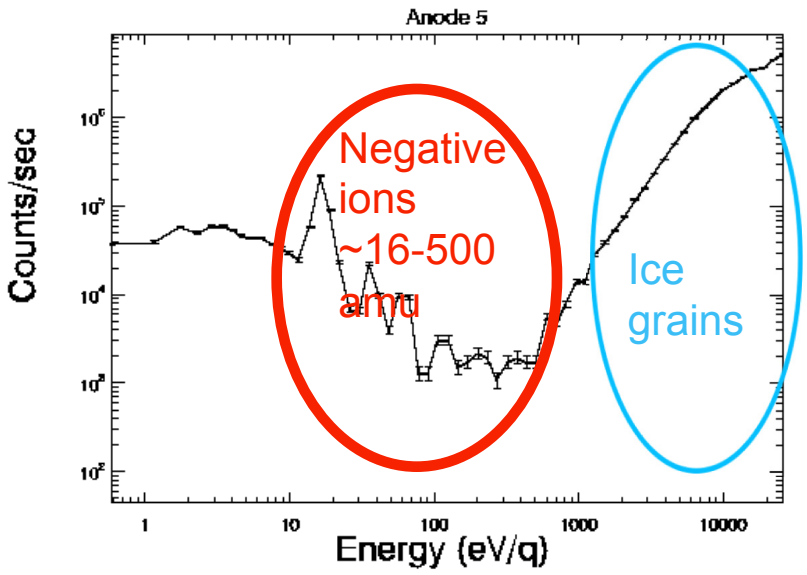


Enceladus – actuator fixed
Negative ions also seen at Earth, comets, Titan; Europa?

Electrons

Positive ions





Conclusions

- Negative ions seen on 22 Titan encounters so far, when CAPS sees ram direction and altitude is low enough
- Lower mass groups similar at all encounters
- Extremely high masses (few thousand AMU) on T16
- Significant in upper atmosphere chemistry
- Higher mass negative ions are observed preferentially:
  - At low altitudes, with the highest mass ions (~10,000 amu) at 950 km (Cassini's lowest altitude so far)
  - At high Titan latitudes
  - In the region of the terminator
- Early stage of tholins formation c.f. Sagan and colleagues?
- **Links plasma interaction directly with the surface**
- Waite et al, Science May 07, Coates et al, GRL Nov 07
- Also at Enceladus?