The Enceladus Auroral Footprint at Saturn – and Lack Thereof

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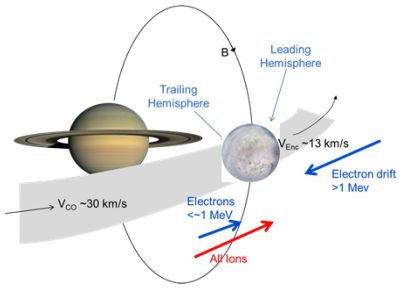
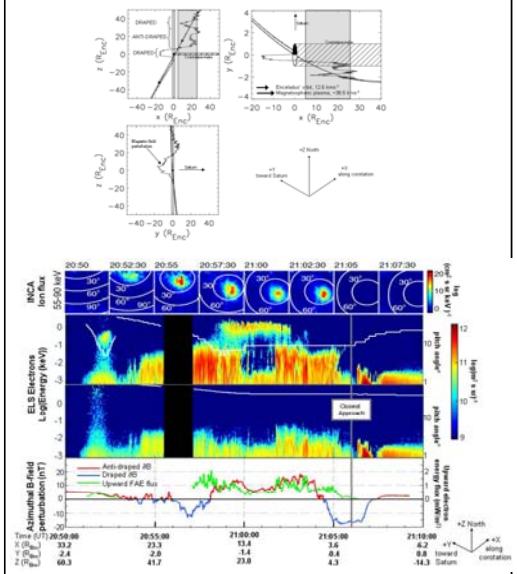
Summary: Cryovolcanic activity at Enceladus leads to electrodynamic coupling between Enceladus and Saturn like that which links Jupiter with Io, Europa and Ganymede. Powerful field-aligned electron beams associated with the Io–Jupiter coupling, for example, create an auroral footprint in Jupiter's ionosphere. Auroral UV emission associated with Enceladus-Saturn coupling is anticipated to be just a few tenths of a kR[1], about an order of magnitude dimmer than the Io footprint and below the threshold of the Hubble Space Telescope (HST), consistent with its non-detection[2]. In August 2008 magnetic field-aligned ion and electron beams with sufficient power to stimulate detectable aurora were observed leading to the subsequent discovery of Enceladus-associated aurora in 7 of 317 Cassini Ultraviolet Imaging Spectrograph (UVIS) scans of the moon's footprint[3]. In addition to the intermittent nature of the emission, other notable differences between the Enceladus-Saturn coupling and the Io–Jupiter coupling, include 1) the beams are offset several moon radii co-rotationally downstream from Enceladus; 2) co-aligned energetic ion and electron beams are observed; and 3) electron beams in the wake of Enceladus flicker in energy by at least an order of magnitude on timescales of a few minutes.



QUICK FACTS – Enceladus

Radius:	252 km
Semi-major axis:	237,948 km (3.94 Rs)
Orbital period:	32.89 hours

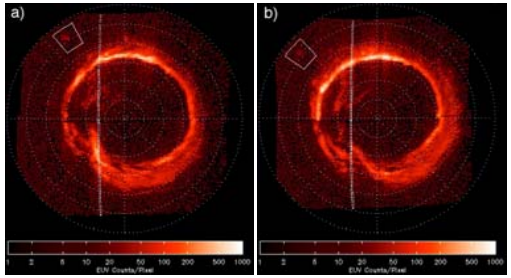
In-situ observations



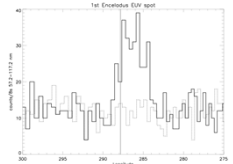
Above: Cassini particle and field observations on 11 August 2008.

- Top panel shows 55-90 keV **protons** observed by the Cassini Ion and Neutral Camera (INCA), contours 30º and 60º from the magnetic field direction are overplotted in white.
- Middle two panels show 1 eV to 22 keV **electrons** measured by the most (top) and least (bottom) field-aligned anodes of the CAPS ELectron Spectrometer (ELS) with the measured pitch angle overplotted in white.
- Bottom panel shows an azimuthal perturbation (ΔB) in the **magnetic field** during this interval[4]. Positive ΔB (red) is in the direction of corotation.
- The magnetic signature expected from simple field line draping around an obstacle is characterised by negative ΔB (blue) above the equator. Positive ΔB (red) indicates a perturbation in the super-corotational sense.
- Overplotted on the bottom panel in green is the total **upward field-aligned electron energy flux** derived by numerical integration of the electron data in panel 2 yields energy fluxes in the range **0.4 to 1.3 mW/m2**. Calculations of electron energy loss in Jupiter's atmosphere indicate that 1 mW/m^2 of particle energy input produces ~ 10 kilo-Rayleighs (kR) of auroral UV emission[5].
- **The observed electron energy flux is expected to produce a UV emission brightness ~ 4 - 13 kR.**

Remote observations



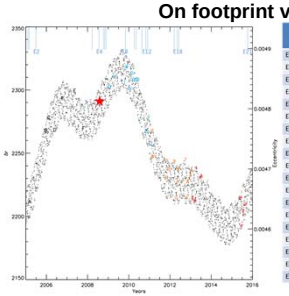
Above: Successive UVIS EUV polar-projected images of Saturn's north polar region from 2008 Aug 26 (DOY 239) 02:16-03:28 and 03:38-04:50 UT formed by slowly slewing the spacecraft and its long-slit UV spectrometer. The white boxes are centred on 64.5 N and the sub-Enceladus longitude, cover 4 degrees in latitude and 10 degrees in longitude, and enclose the predicted magnetic mapping of the satellite Enceladus to Saturn's dayside atmosphere. Satellite footprint emission is visible in both boxes. The latitude grid has 5 degree spacing and the hashed white line indicates the day/night terminator. The Sun is to the left.



Left: Sequential 8-s readouts from the sum of two EUV spatial pixels that cross the spot in Figure 2a (solid line) are compared to the sum of two neighboring spatial pixels off the spot (dashed line). The sub-Enceladus longitude is indicated by a vertical line.

The combined EUV and FUV brightnesses derived from the excess counts in the brightest time step of each of 3 accumulated images were 1550±620 R, 1130±230 R and ~90 R.
These should be considered lower limits, assuming the spatial pixel is uniformly filled by signal, as the true emission region size is not known.

On footprint variability



		Date (DOY)	Year	Dist. (km)	CAPS Pitch angle (°)	Comments
E0	17	Feb (48)	2005	1259	80 - 135	No beam
E1	9	Mar (68)	2005	497	45 - 120	No beam
E2	14	Jul (195)	2005	168	80 - 140	Plume discovered[6]
E3	12	Mar (72)	2008	49	90 - 170	No beam
E4	11	Aug (224)	2008	48	0 - 90	Auroral footprint discovered[1]
E5	9	Oct (283)	2008	23	90 - 180	No beam
E6	31	Oct (305)	2008	168	0 - 120	Actuating, beams
E7	2	Nov (306)	2009	95	80 - 100	No beam
E8	21	Nov (325)	2009	1593	0 - 180	Actuating, no beam
E9	28	Apr (118)	2010	97	100 - 180	No beam
E10	18	May (138)	2010	437	20 - 180	No beam
E11	13	Aug (225)	2010	2552	0 - 90	Actuating, no beam
E12	30	Nov (334)	2010	43	60 - 100	No beam
E13	21	Dec (355)	2010	46		CAPS off
E17	27	Mar (87)	2012	70	80 - 100	No beam
E18	14	Apr (105)	2012	70	80 - 100	No beam
E19	2	May (123)	2012	70	80 - 100	No beam
E20	14	Oct	2015	1840		CAPS off
E21	28	Oct	2015	49		CAPS off

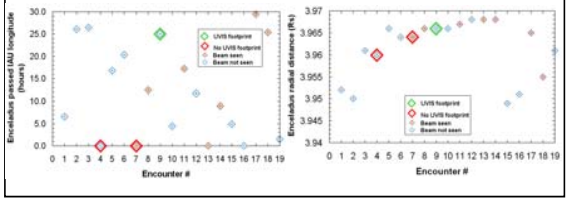
From Ingersoll and Ewald 2017. Variation in orbital eccentricity versus year. Y-axis left is the Saturn-Enc distance at apocenter minus that at pericenter. Y-axis right is the eccentricity. See Ref for more detail. The red star shows when the Enceladus auroral footprint was observed and the blue tick marks the Enceladus flybys with additional information provided in the table.

- During the mission so far 7 of a potential 317 images that could have shown a footprint do, 2.2 %.
- During August 2008 16% of the images showed a footprint, suggesting that ionization near Enceladus was enhanced during that interval.

Table above shows the times that the INCA camera or ELS observed field aligned ion beams both near and along Enceladus' orbit.

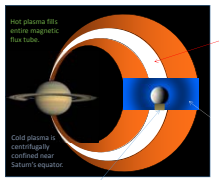
- Field aligned beams were observed during only 2 Enceladus flybys.
- There were no field aligned beams observed on the day that the Enceladus auroral footprint was observed, NB the INCA non-observation was 11 hours later.

We also checked for beams near L=4 when Enceladus is not present and found no correlation between the beam observations and the distance from Cassini to Enceladus.



Summary and Musings

Saturn's magnetic dipole is offset North (by 0.05 Rs, ~3000 km), maybe that is related to why auroral footprint and beams are in/from Northpole.



Nano-grains and dust are only observed very close to the moon's South pole and highly collimated in the SC ram direction.

Hot plasma hits the moon's surface and is almost completely evacuated from the Enceladus flux tube.

Cold plasma is more centrifugally confined and is observed throughout the equatorial region Enceladus flux tube.

References:

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[4]Jia, Y.-D., C. T. Russell, K. K. Khurana, J. S. Leisner, Y. J. Ma and M. K. Dougherty (2010), Time varying magnetospheric environment near Enceladus as seen by the Cassini magnetometer, *Geophys. Res. Lett.*, 37.

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