Technische
Universität
Braunschweig

# Cassini-Huygens mission and icy moon Enceladus

Uwe Motschmann (Technical University of Braunschweig)
Patrick Meier, Hendrik Kriegel, Jürgen Schmidt, Frank Spahn, Tom W. Hill,
Yaxue Dong, Geraint H. Jones

# Outline

1: Cassini-Huygens Mission

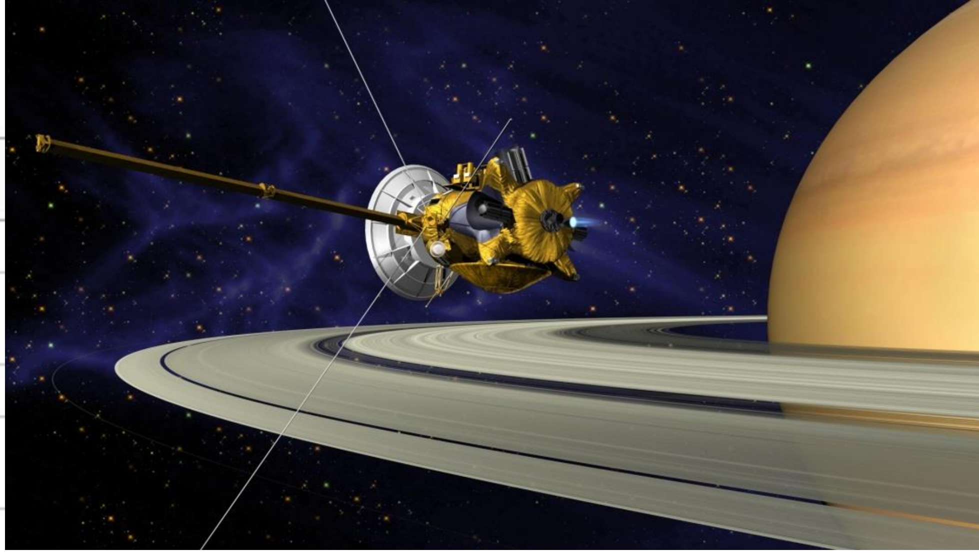
2: Saturn‘s Icy Moons

3: Plasma-Dust Interaction at Enceladus

3.1: Plasma instruments as charged dust detector

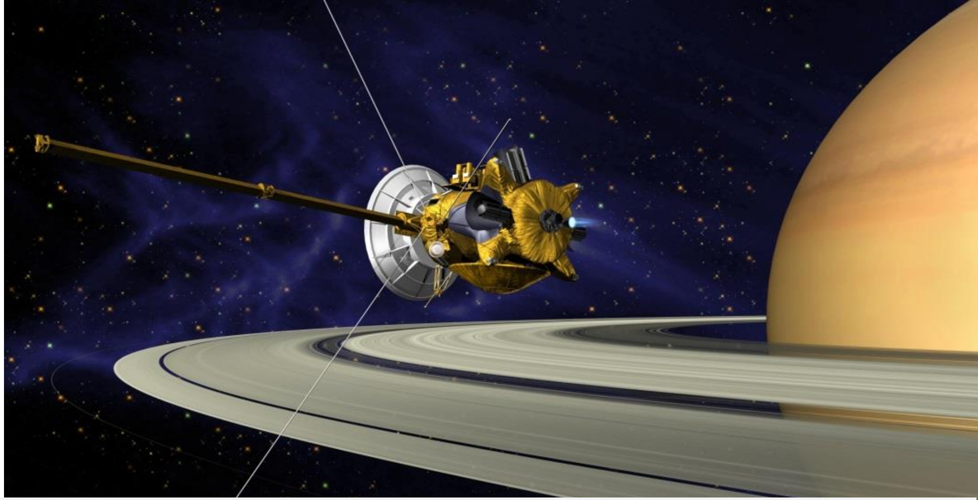
3.2: Plasma instruments as neutral dust detector

# Cassini-Huygens Mission



| Data | |
|---|---|
| Launch: | 15 October 1997 |
| Launch weight: | 5,820 kilograms (including 365 kilograms payload) |
| Fly-bys: | 2 x Venus, 1 each of Earth, Jupiter |
| Cassini enters Saturn orbit: | 1 July 2004 |
| Separation of Huygens probe: | 25 December 2004 |
| Huygens landing on Titan: | 14 January 2005 |
| Launch site: | NASA Kennedy Space Center, Cape Canaveral, Florida |
| Launch rocket: | Titan IV B/Centaur |
| Mission control center: | NASA Jet Propulsion Laboratory (JPL), Pasadena, California, USA |
| Ground stations: | NASA Deep Space Network |
| Data reception: | No real-time operation; interim data storage in mass memory onboard Cassini with download during ground station contact periods |
| Nominal mission end: | June 2008; extended until 2017 |
| Cassini lifespan: | 4 years (approx. 76 Saturn orbits) |

# Cassini Payload



**Optical Remote Sensing**
Mounted on the remote sensing pallet, these instruments study Saturn and its rings and moons in the electromagnetic spectrum.

- Composite Infrared Spectrometer (CIRS)
- Imaging Science Subsystem (ISS)
- Ultraviolet Imaging Spectrograph (UVIS)
- Visible and Infrared Mapping Spectrometer (VIMS)

**Fields, Particles and Waves**
These instruments study the dust, plasma and magnetic fields around Saturn. While most don't produce actual "pictures," the information they collect is critical to scientists' understanding of this rich environment.

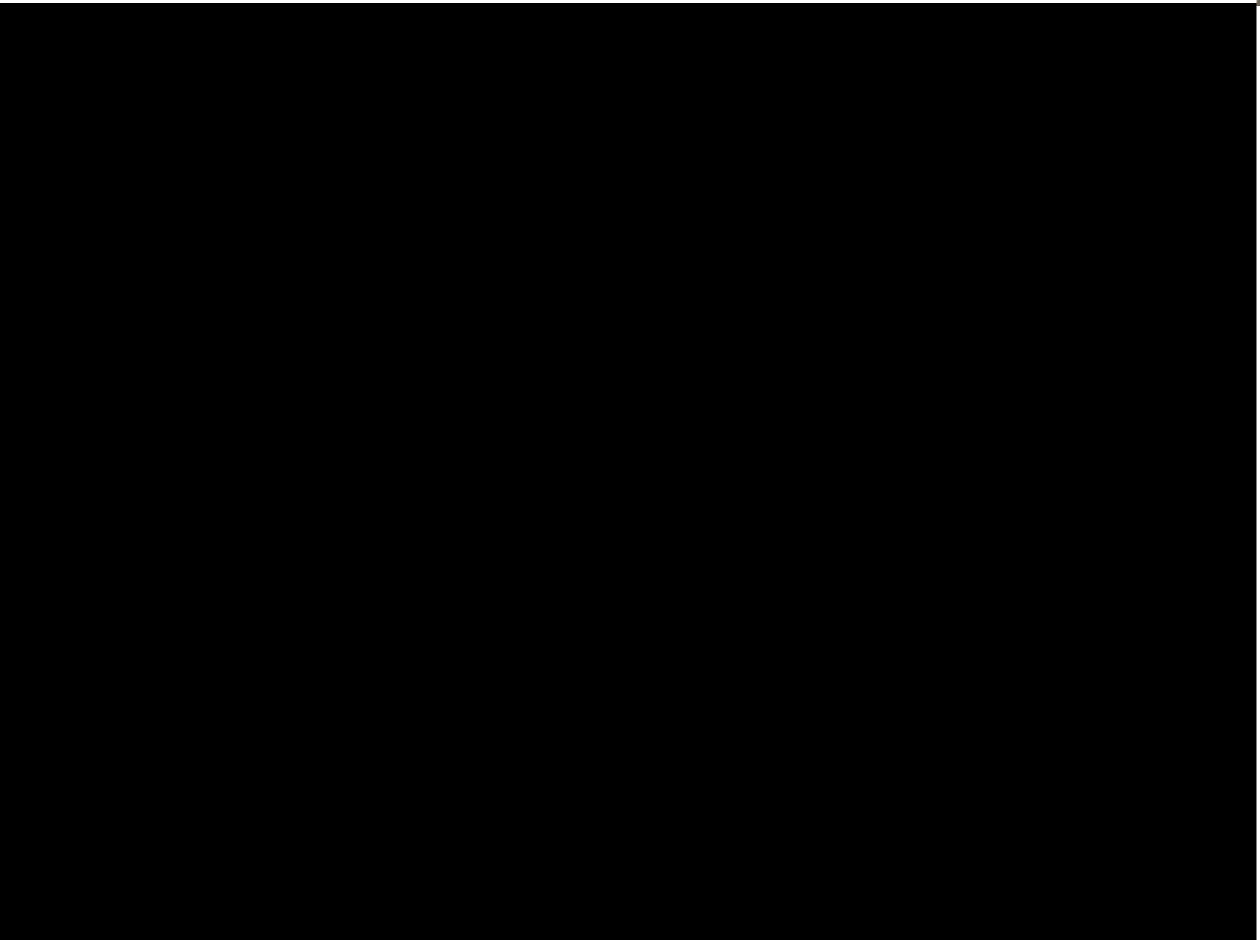
- Cassini Plasma Spectrometer (CAPS)
- Cosmic Dust Analyzer (CDA)
- Ion and Neutral Mass Spectrometer (INMS)
- Magnetometer (MAG)
- Magnetospheric Imaging Instrument (MIMI)
- Radio and Plasma Wave Science (RPWS)

**Microwave Remote Sensing**
Using radio waves, these instruments map atmospheres, determine the mass of moons, collect data on ring particle size, and unveil the surface of Titan.

- Radar
- Radio Science (RSS)

# Huygens Probe

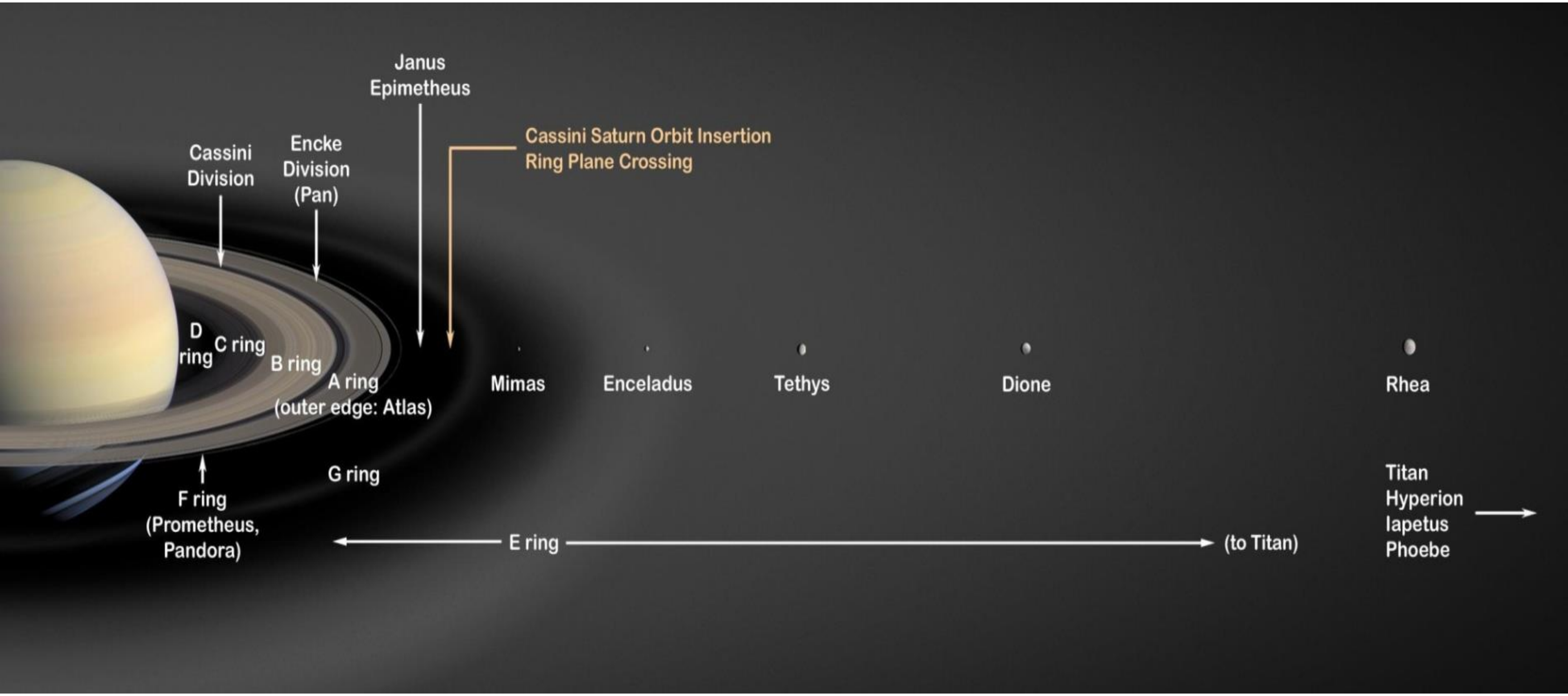
**(in-depth study of the clouds, atmosphere, and surface of Titan)**



# Huygens Payload

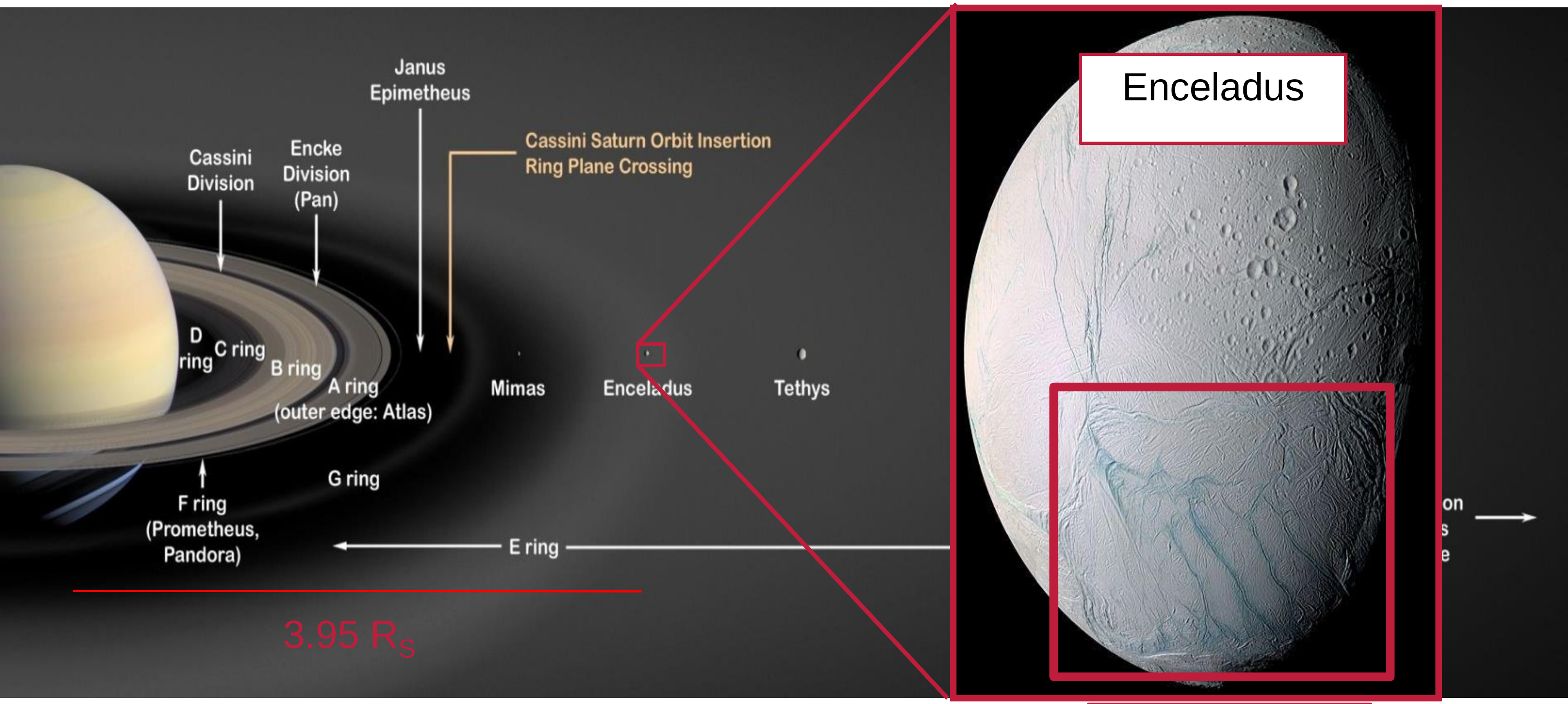
| Huygens Instruments | | |
|---|---|---|
| **Instrument** | | **Principal Investigator** |
| ACP | **A**erosol **C**ollector and **P**yrolyser | G. Israel,<br>Service d'Aéronomie, Centre National de la Recherche Scientifique (CNRS), Verrières-le-Buisson, France |
| DISR | **D**escent **I**mager and **S**pectral **R**adiometer | M. G. Tomasko,<br>University of Arizona, Tucson, USA |
| DWE | **D**oppler **W**ind **E**xperiment | M. K. Bird,<br>Universität Bonn, Germany |
| GCMS | **G**as **C**hromatograph and **M**ass **S**pectrometer | H. Niemann,<br>NASA Goddard Space Flight Center, Greenbelt, USA |
| HASI | **H**uygens **A**tmospheric **S**tructure **I**nstrument | M. Fulchignoni,<br>Université Paris VII, Paris, France |
| SSP | **S**urface **S**cience **P**ackage | J. C. Zarnecki,<br>Open University,<br>Milton Keynes, United Kingdom |

# Saturn‘s Icy Moons



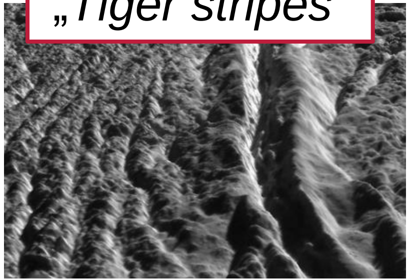

Total number of moons discoverd until August 2015: **62**
Icy moons: all ?
Major icy moons: Titan, Rhea, Iapetus, Dione, Tethys, Enceladus, Mimas, Hyperion, Phoebe

# Saturn‘s Moon Enceladus

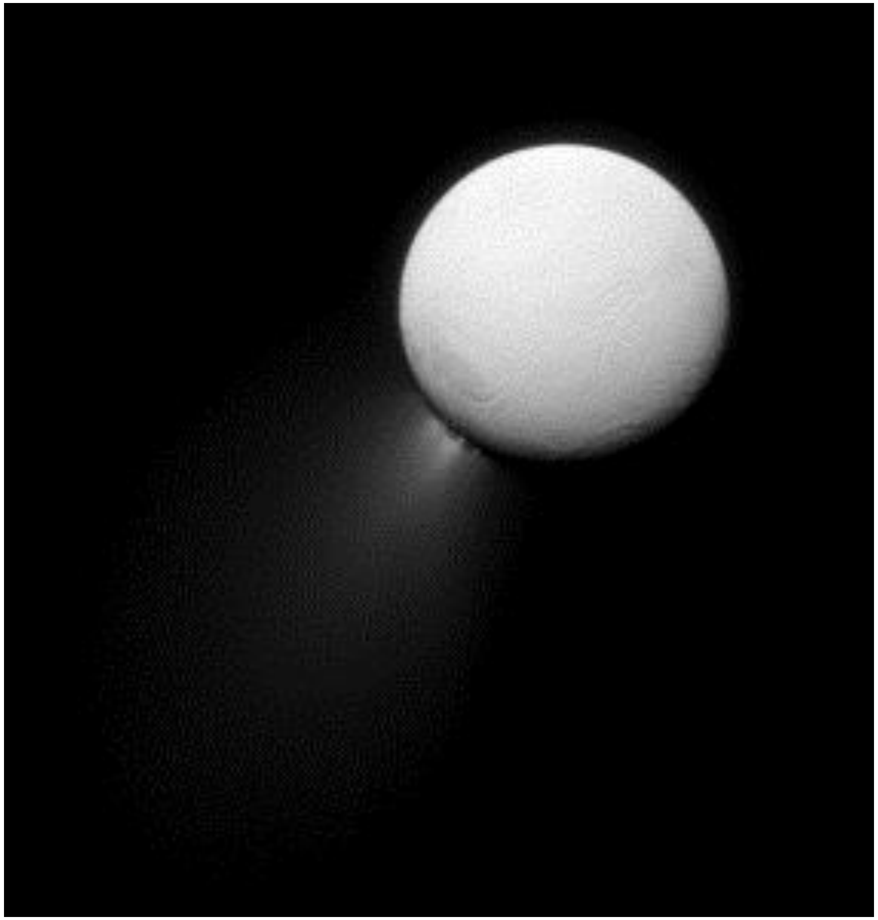



- Discovered by W. Herschel in 1789
- Inner moon of Saturn (orbit at 3.95 $R_S$)
- Radius: $R_E$ = 252.1 km

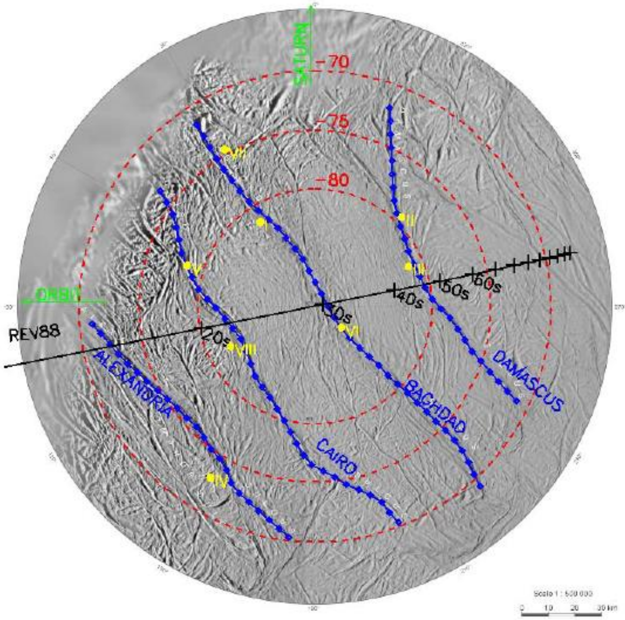
*„Tiger stripes“*



# Enceladus‘ South Polar Geysers

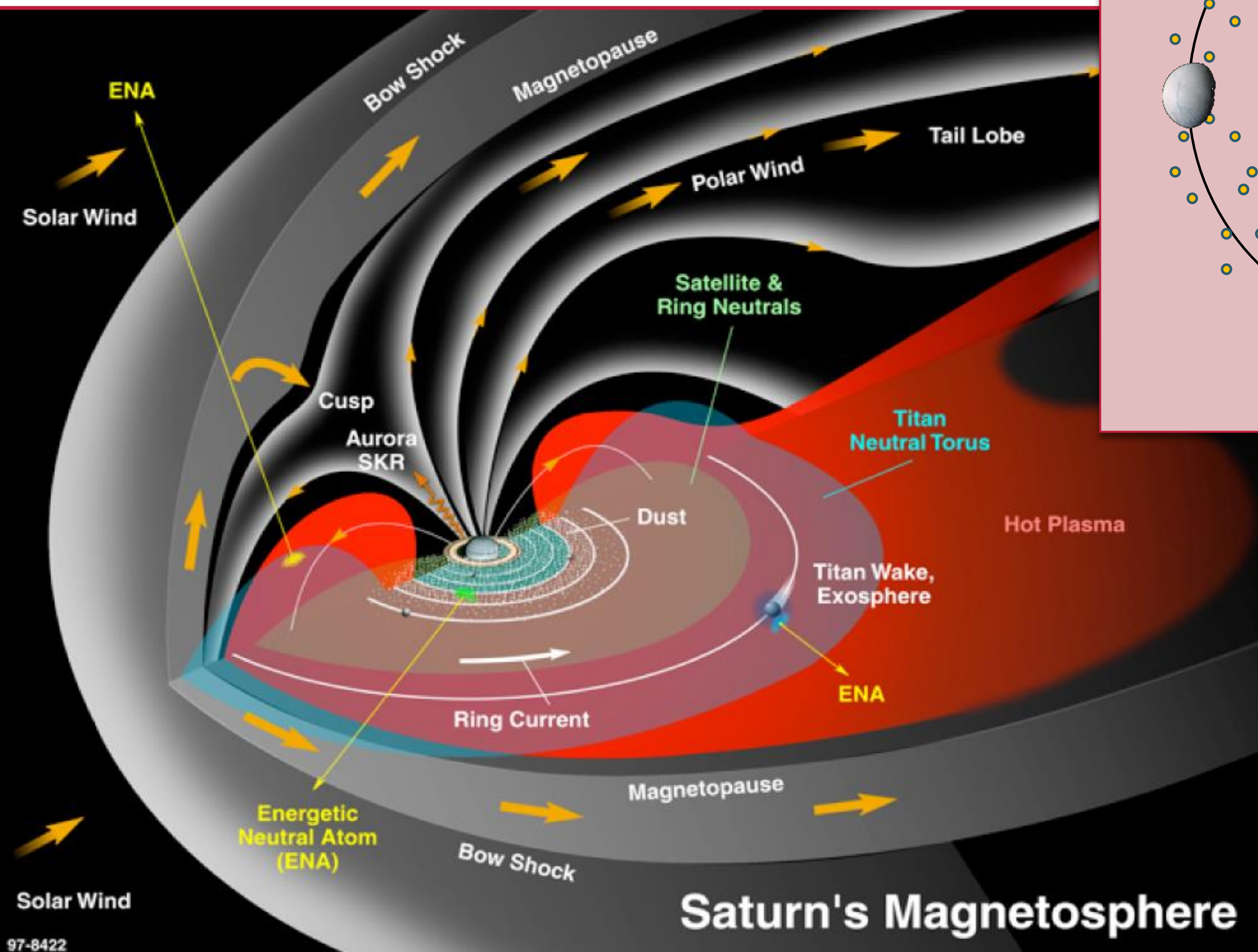


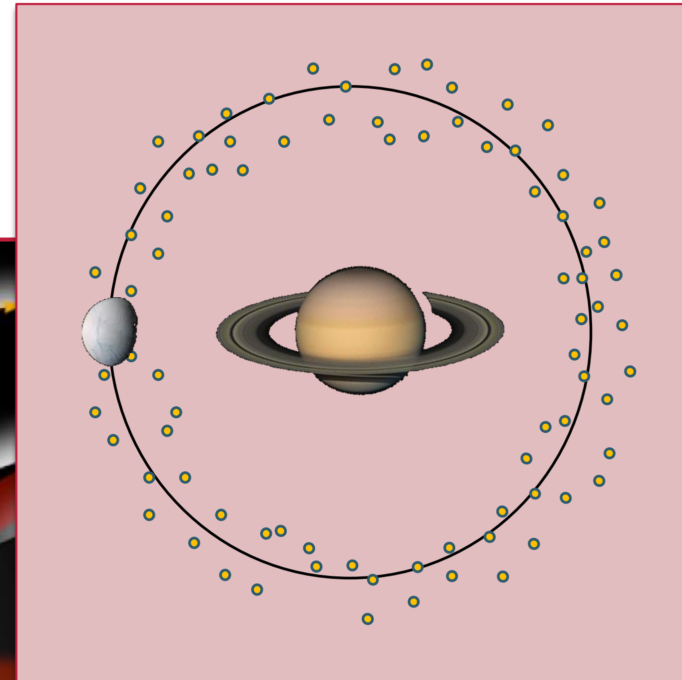
[*Spitale & Porco, 2007*]




[*Postberg et al., 2011*]

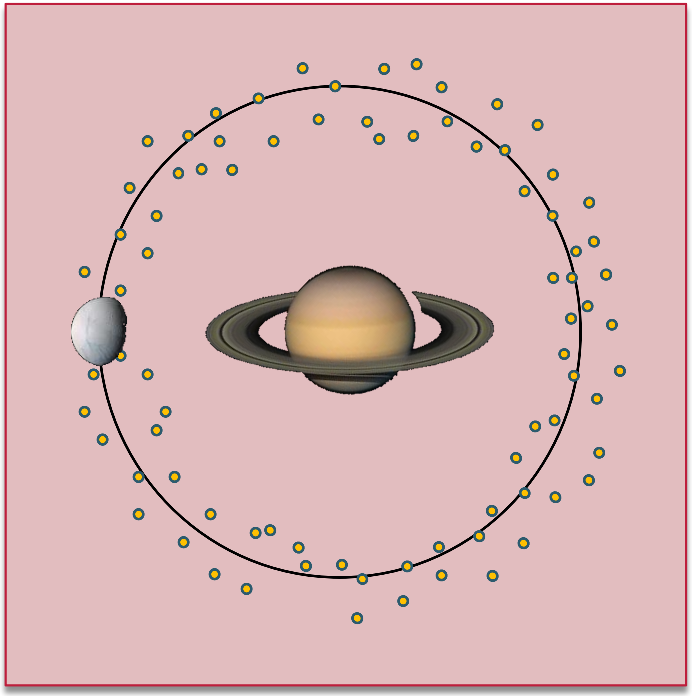
# Saturn's Magnetosphere



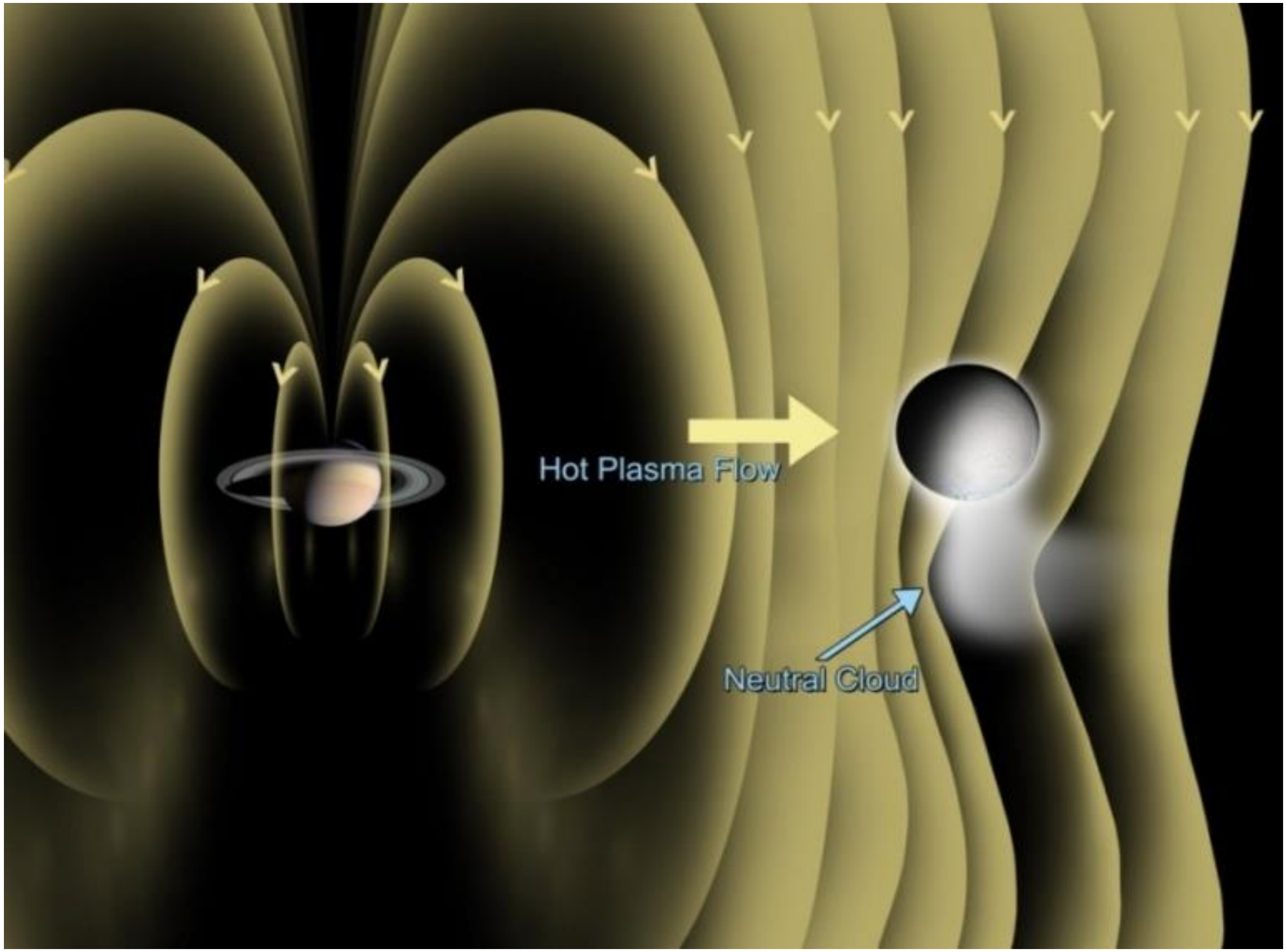



# Interaction of Enceladus with Saturn's Magnetic Field

- Saturn's dipole field: $B_0$ = 325 nT
- Magnetospheric plasma:
  - Species: $H^+$, $O^+$, $OH^+$, $H_2O^+$, $H_3O^+$
  - Density: $n_0$ = 45 - 90 $cm^{-3}$
  - (Sub-)Corotating with Saturn ( T≈10h )
- → Plasma velocity $u$ = 30 - 39 km/s
  - Orbital velocity of Enceladus: $v$ = 13 km/s
- → Relative speed $u_0 = u - v$ = 17 - 26 km/s
- → Sub-Alfvenic



# Interaction of Enceladus with Saturn‘s Magnetic Field




[*Dougherty et al., 2006*]

## Outline

1: Cassini-Huygens Mission

2: Saturn‘s Icy Moons

3: Plasma-Dust Interaction at Enceladus

3.1: **Plasma instruments as charged dust detector**

3.2: Plasma instruments as neutral dust detector

## Outline

1: Cassini-Huygens Mission

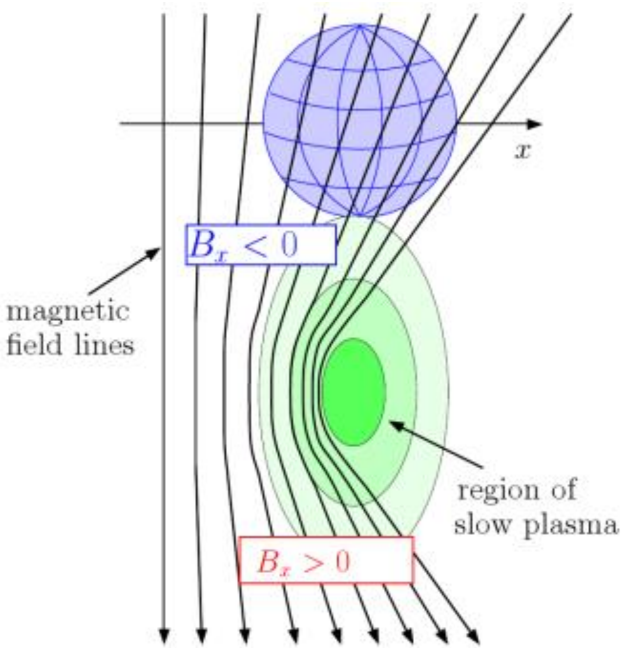
2: Saturn‘s Icy Moons

3: Plasma-Dust Interaction at Enceladus

3.1: **Plasma instruments as charged dust detector** in virtue of **anti-Hall effect**

3.2: Plasma instruments as neutral dust detector

# B-Field Draping and Twisting: Alfven Wing




$$+ B_y$$

$$J_x = \sigma_H \; E_y$$

*$\sigma_H < 0$ or $\sigma_H > 0$ : Hall conductivity*

**Pedersen Conductivity**

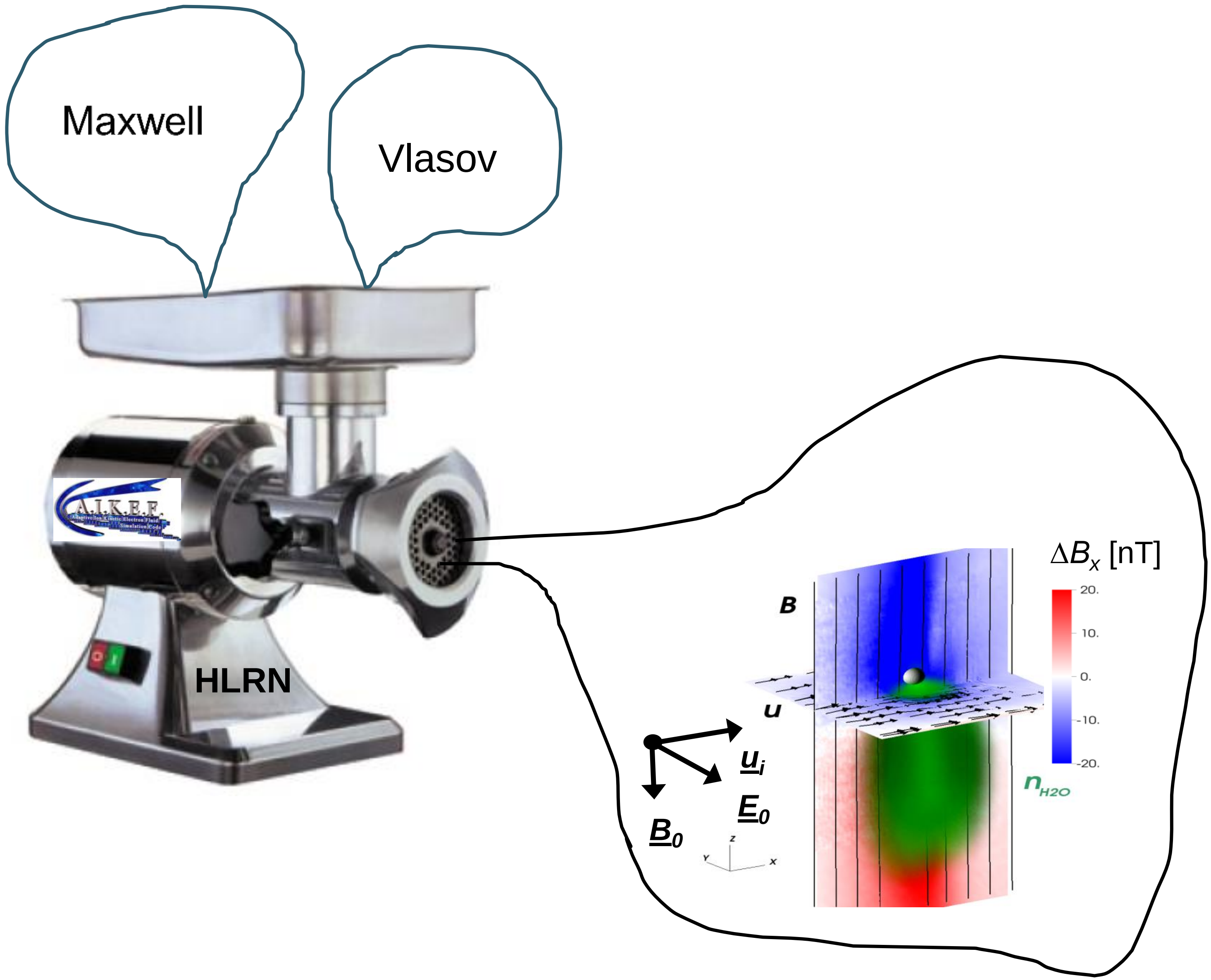
$$\sigma_P = \sum_{\alpha=i,e,D} \frac{n_\alpha q_\alpha^2}{m_\alpha} \frac{\nu_\alpha}{\nu_\alpha^2 + \Omega_\alpha^2}$$

**Hall Conductivity**

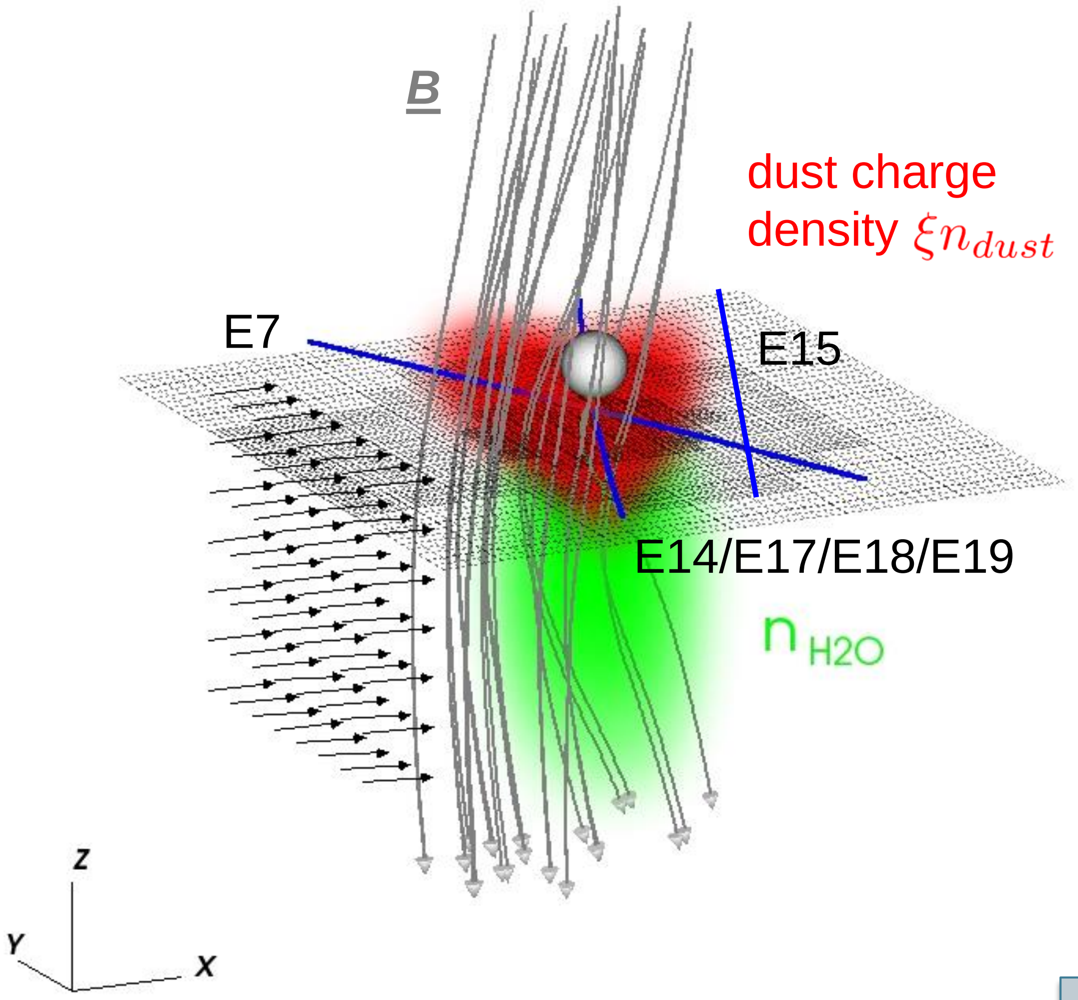
$$\sigma_H = -\sum_{\alpha=i,e,D} \frac{n_\alpha q_\alpha^2}{m_\alpha} \frac{\Omega_\alpha}{\nu_\alpha^2 + \Omega_\alpha^2}$$

**Anti-Hall Effect**

# Modeling of the Interaction

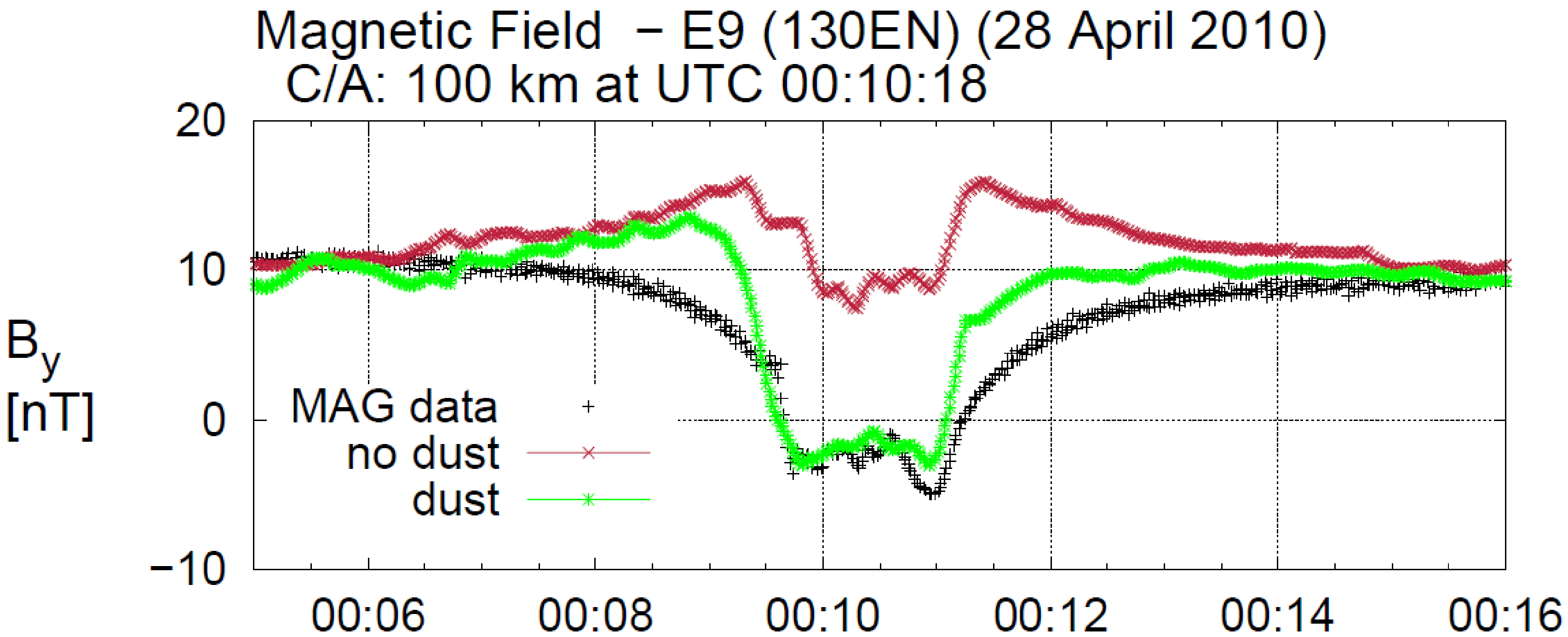


# Simulation Results: Magnetic Field




[Kriegel et al JGR 2014]

# Magnetic Field With and Without Dust

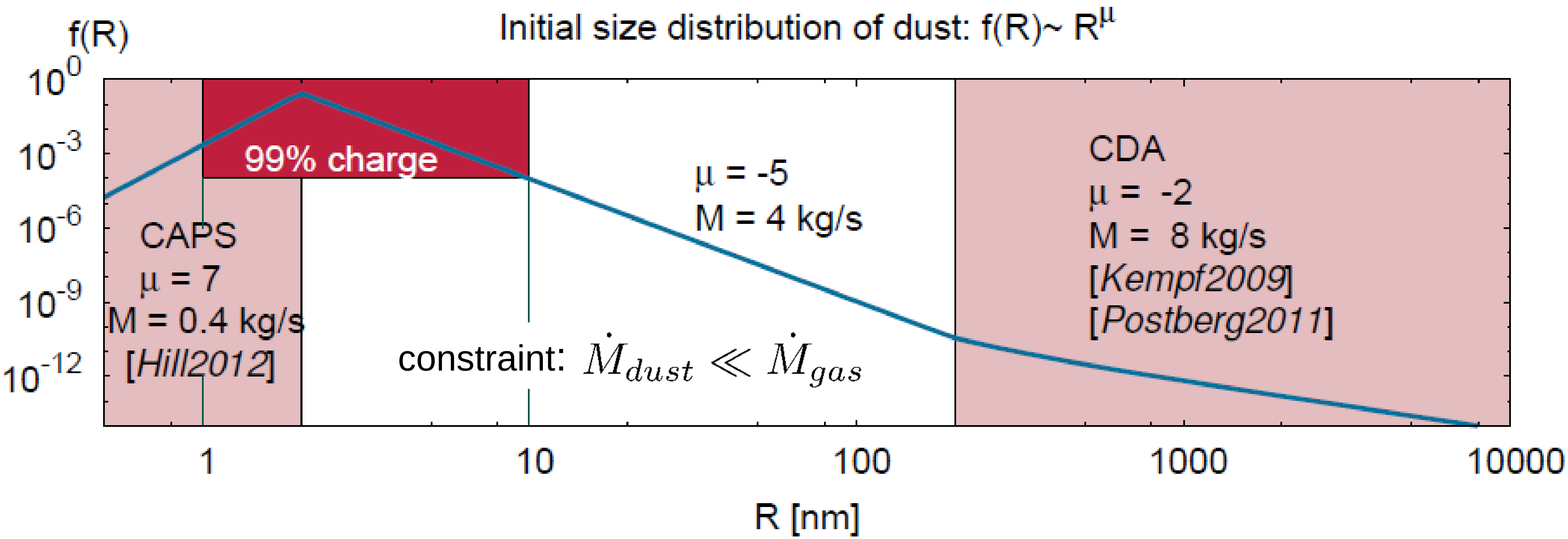



**Anti-Hall Effect**

[Simon et al JGR 2012]

[Kriegel et al JGR 2014]

# Summary of Charged Dust Modeling




[Meier et al PSS 2014]

# Outline

1: Cassini-Huygens Mission

2: Saturn‘s Icy Moons

3: Plasma-Dust Interaction at Enceladus

3.1: Plasma instruments as charged dust detector

3.2: **Plasma instruments as neutral dust detector**

# Outline

1: Cassini-Huygens Mission

2: Saturn‘s Icy Moons

3: Plasma-Dust Interaction at Enceladus

3.1: Plasma instruments as charged dust detector

3.2: **Plasma instruments as neutral dust detector**
in virtue of **Stochastic Equilibrium Model**

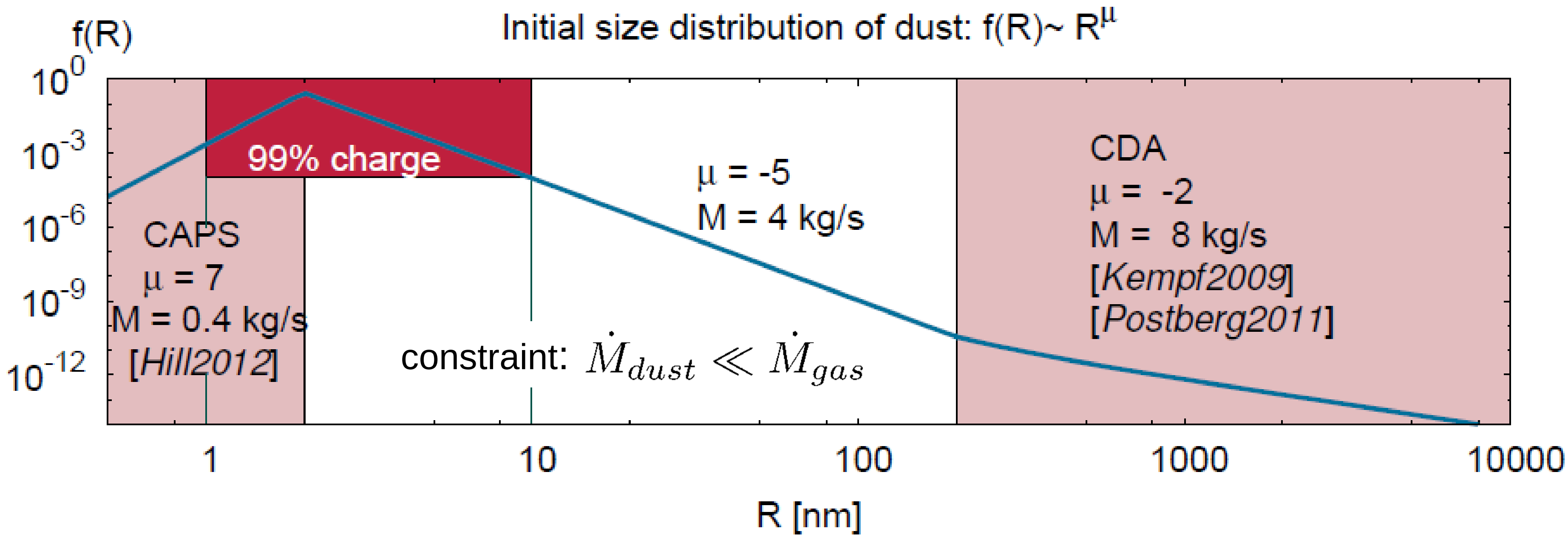
# MAG as detector of neutral dust

| | Rev. | Date & Year | | | (DOY) | Time [UTC] | Dist. [km] |
|---|---|---|---|---|---|---|---|
| E0 | 003 | 17 | Feb | 2005 | (48) | 03:30:29 | 1261 |
| E1 | 004 | 9 | Mar | 2005 | (68) | 09:08:02 | 500 |
| E2 | 011 | 14 | Jul | 2005 | (195) | 19:55:21 | 171 |
| E3 | 061 | 12 | Mar | 2008 | (72) | 19:06:12 | 52 |
| E4 | 080 | 11 | Aug | 2008 | (224) | 21:06:18 | 51 |
| E5 | 088 | 9 | Oct | 2008 | (283) | 19:06:40 | 26 |
| E6 | 091 | 31 | Oct | 2008 | (305) | 17:14:51 | 171 |
| E7 | 120 | 2 | Nov | 2009 | (306) | | |
| E8 | 121 | 21 | Nov | 2009 | (325) | | |
| E9 | 130 | 28 | Apr | 2010 | (118) | | |
| E10 | 131 | 18 | May | 2010 | (138) | | |
| E11 | 136 | 13 | Aug | 2010 | (225) | | |
| E12 | 141 | 30 | Nov | 2010 | (334) | | |
| E13 | 142 | 21 | Dec | 2010 | (355) | | |
| E14 | 154 | 1 | Oct | 2011 | (274) | | |
| E15 | 156 | 19 | Oct | 2011 | (292) | | |
| E16 | 156 | 6 | Nov | 2011 | (310) | | |
| E17 | 163 | 27 | Mar | 2012 | (87) | | |
| E18 | 164 | 14 | Apr | 2012 | (105) | | |
| E19 | 165 | 2 | May | 2012 | (123) | | |


**Cassini Dust Observations**

- only charged dust is observed
- CDA µm
- CAPS 0.5….2 nm (slope)
- **no direct neutral dust observation !**

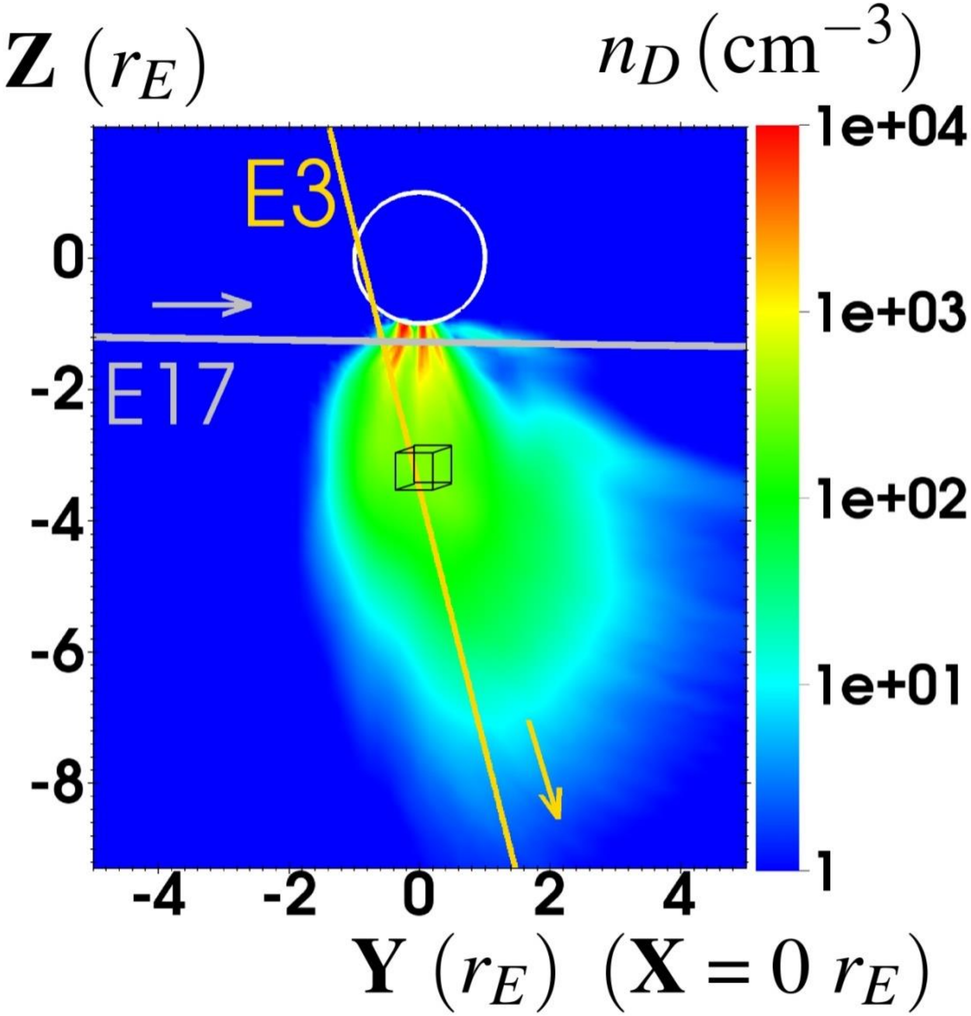
# Grain Size Modeling of Charged Dust




[Meier et al PSS 2014]

- Charged dust and plasma are coupled to the uncharged dust
- Estimation of uncharged dust from its feedback

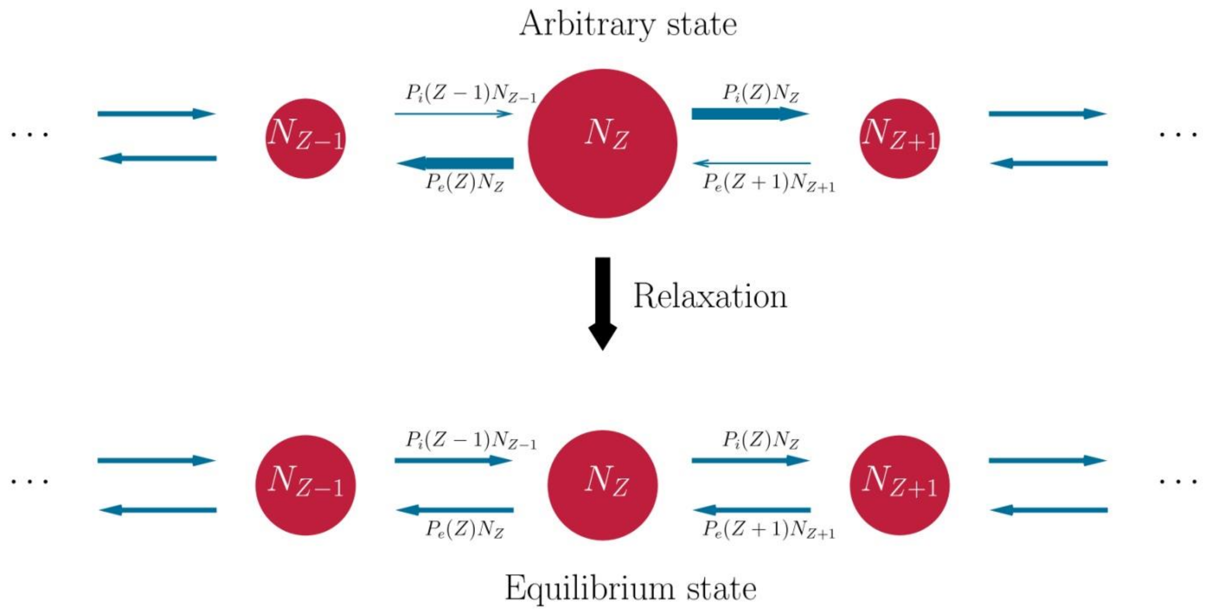
# Uncharged Dust Modeling



# Stochastic Equilibrium Model

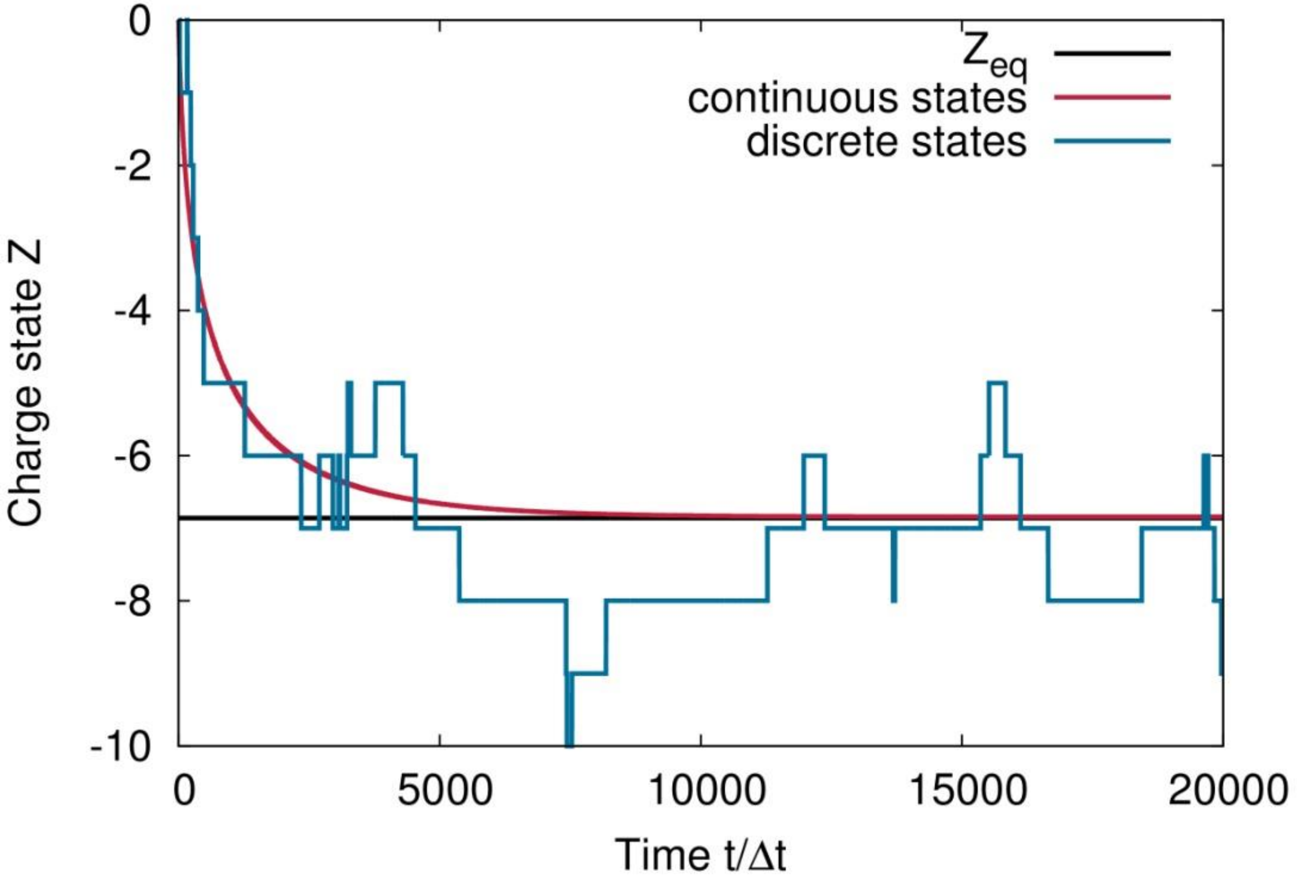
$N_Z$ : number of grains in charge state $Z$ in volume $V$

$N_0$ : number of uncharged grains $(Z=0)$ in volume $V$

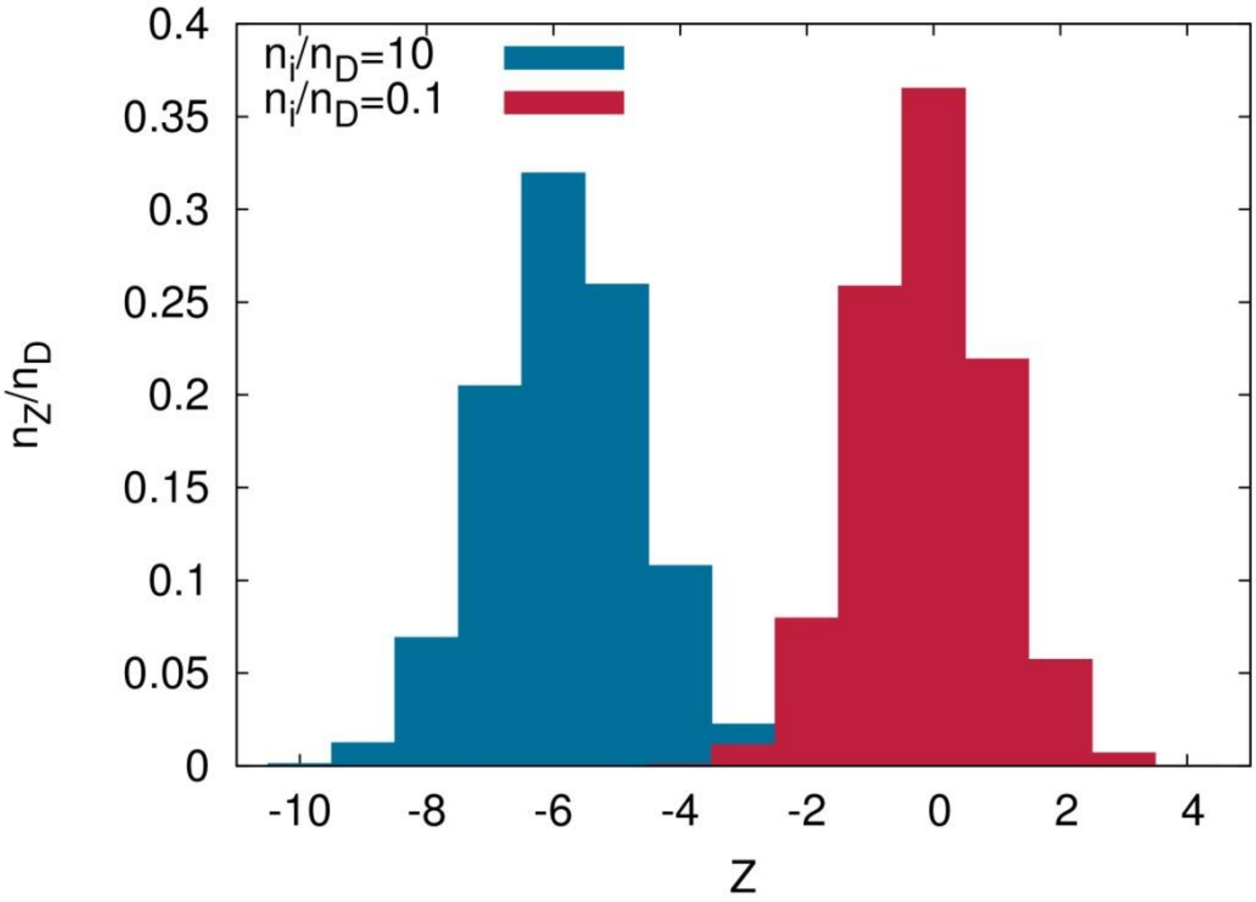



[Meier et al PSS 2015]

# Stochastic Charging vs. Continuous Charging of a Grain



# Equilibrium States for Low and High Plasma Density



# Eigenvalue Problem for the Dust Densities $n_Z$ at Charge States $Z$

$$\begin{pmatrix} & & \vdots & & \\ & P_e(Z-1) & 0 & 0 & \\ & 1-P_e(Z-1)-P_i(Z-1) & P_e(Z) & 0 & \\ \cdots & P_i(Z-1) & 1-P_e(Z)-P_i(Z) & P_e(Z+1) & \cdots \\ & 0 & P_i(Z) & 1-P_e(Z+1)-P_i(Z+1) & \\ & 0 & 0 & P_i(Z+1) & \\ & & \vdots & & \end{pmatrix} \begin{pmatrix} \vdots \\ n_{Z-1} \\ n_Z \\ n_{Z+1} \\ \vdots \end{pmatrix} = \begin{pmatrix} \vdots \\ n_{Z-1} \\ n_Z \\ n_{Z+1} \\ \vdots \end{pmatrix}$$

Normalization of the Eigenvector: $$n_D = \sum_{Z=-\infty}^{\infty} n_Z$$

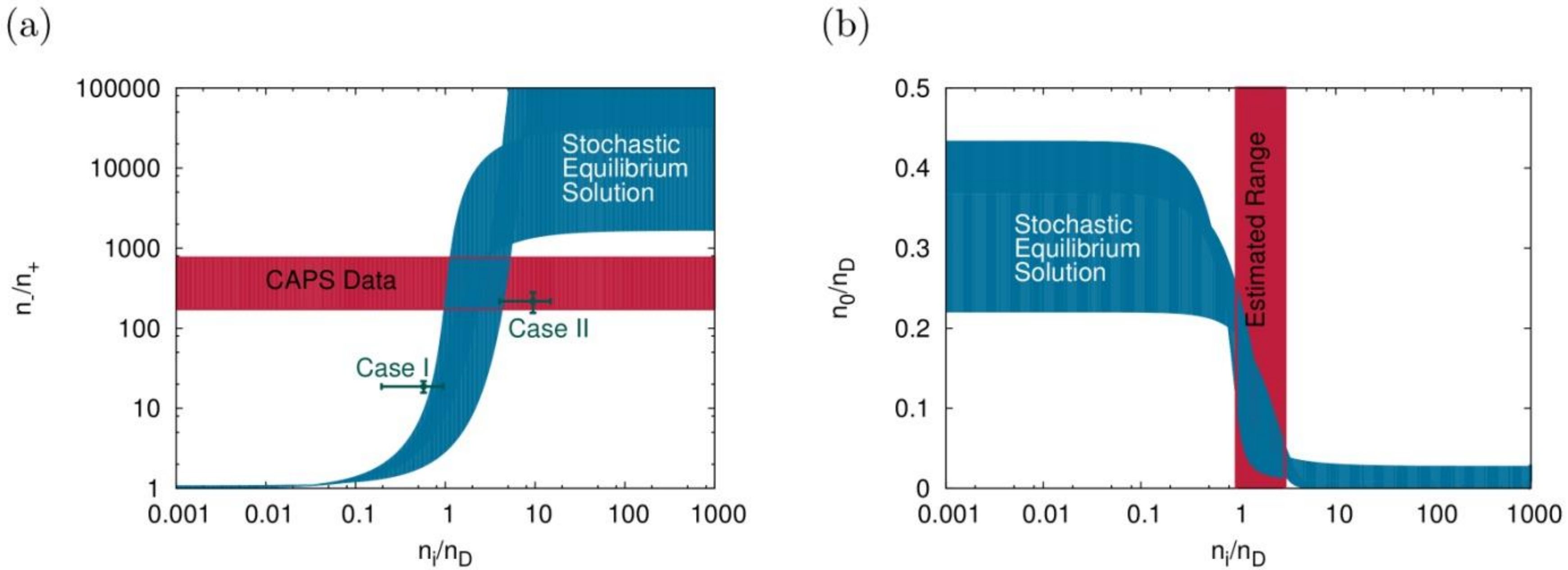
# Transition Probabilities Between Neighboring Charge States

$$Z \rightarrow Z-1 : \qquad P_e(Z) = \frac{I_e(Z)}{I_{elem}} = \frac{I_{0e}\Delta t}{e} \begin{cases} \exp\left(\frac{ZR_{Le}}{R}\right) & , Z \leq 0 \\ 1 + \frac{ZR_{Le}}{R} & , Z > 0 \end{cases}$$

$$Z \rightarrow Z+1 : \qquad P_i(Z) = \frac{I_e(Z)}{I_{elem}} = \frac{I_{0i}\Delta t}{e} \begin{cases} 1 - \frac{ZR_{Li}}{R} & , Z \leq 0 \\ \exp\left(-\frac{ZR_{Li}}{R}\right) & , Z > 0 \end{cases}$$

$P_e(Z)$, $P_i(Z)$ are dependend on the embedding plasma density and temperature

# Solutions of the Stochastic Equilibrium Model

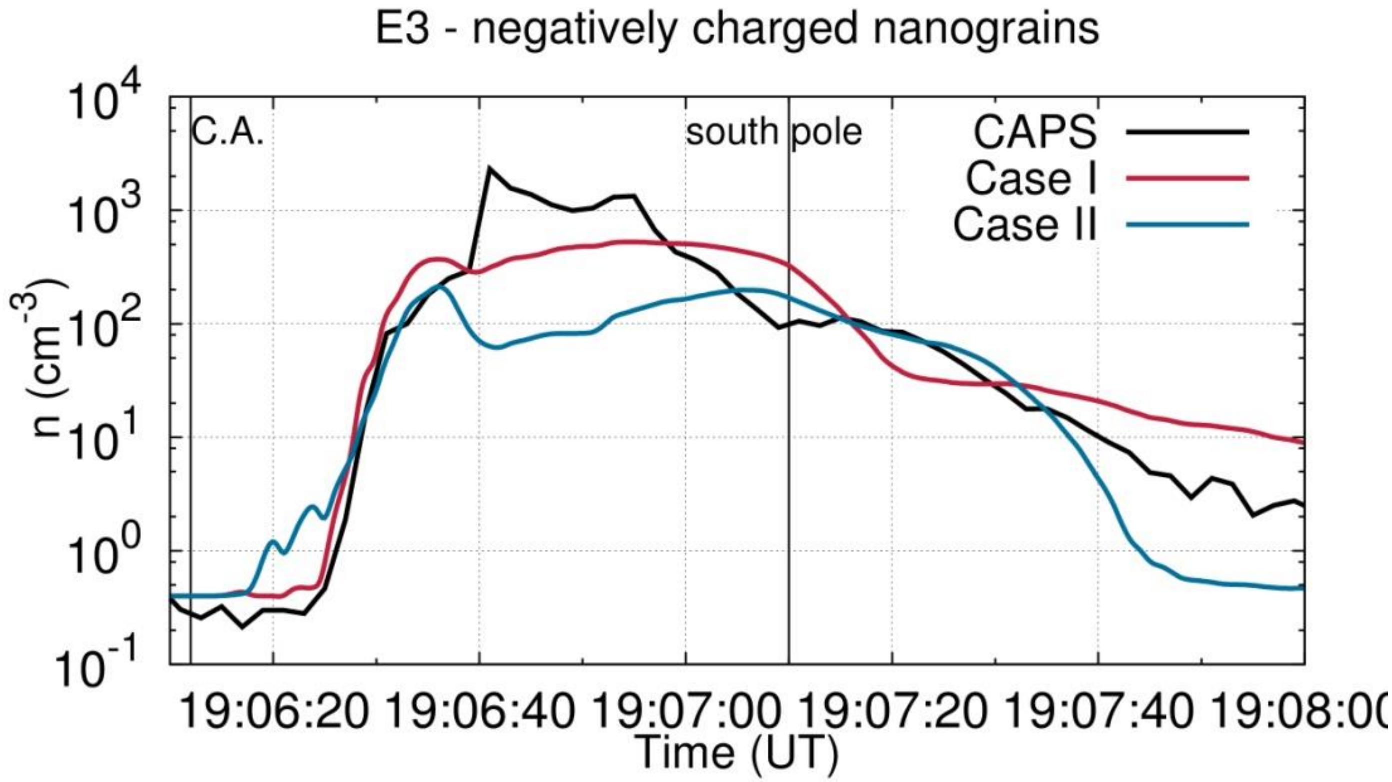



Range of solutions by:

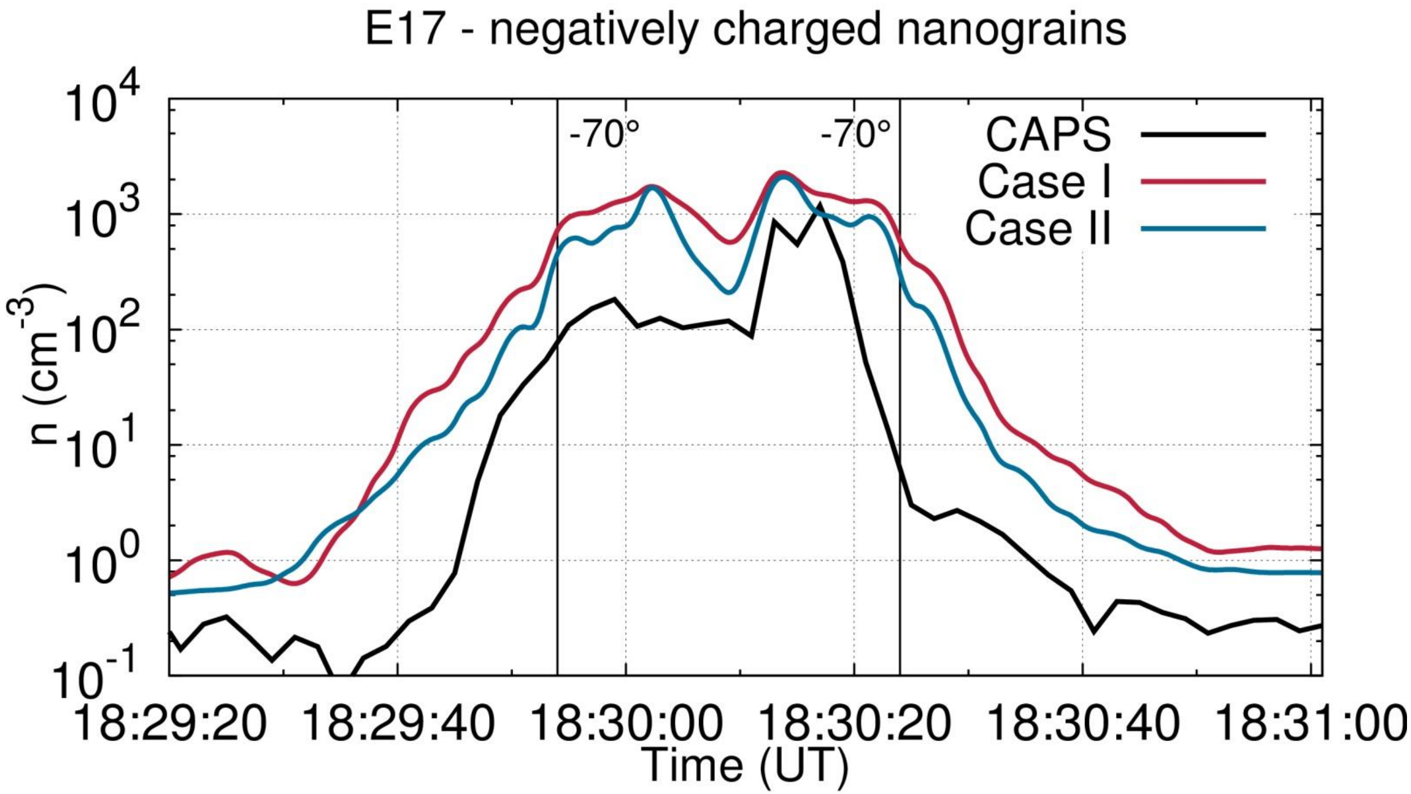
-$T_i$ = 1….35 eV

- Single…..multiple charging of a grain

# CAPS Data and Dust-Plasma Simulation Results for E3



# CAPS Data and Dust-Plasma Simulation Results for E17



## Summary

1: No Cassini instrument for neutral Enceladus dust

2: Interaction with plasma and charged dust allows determination of neutral dust properties

3: Total nanograin density ~ ⅓ ….1 ion density

4: Most nanograins are charged

5: Neutral grains ~ 1% for singly chargeable grains<br>~ 25% for multiply chargeable grains