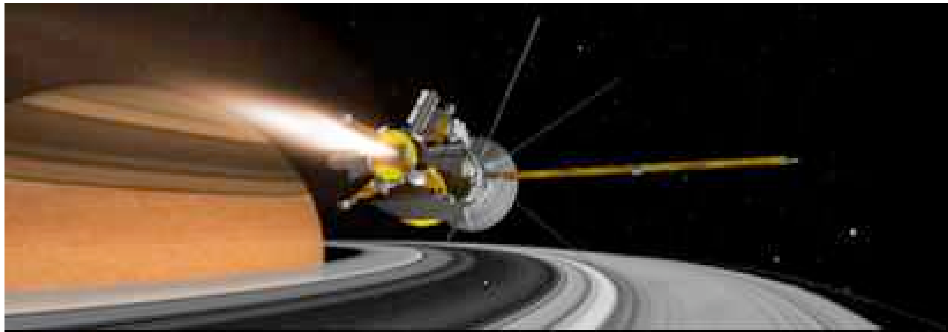

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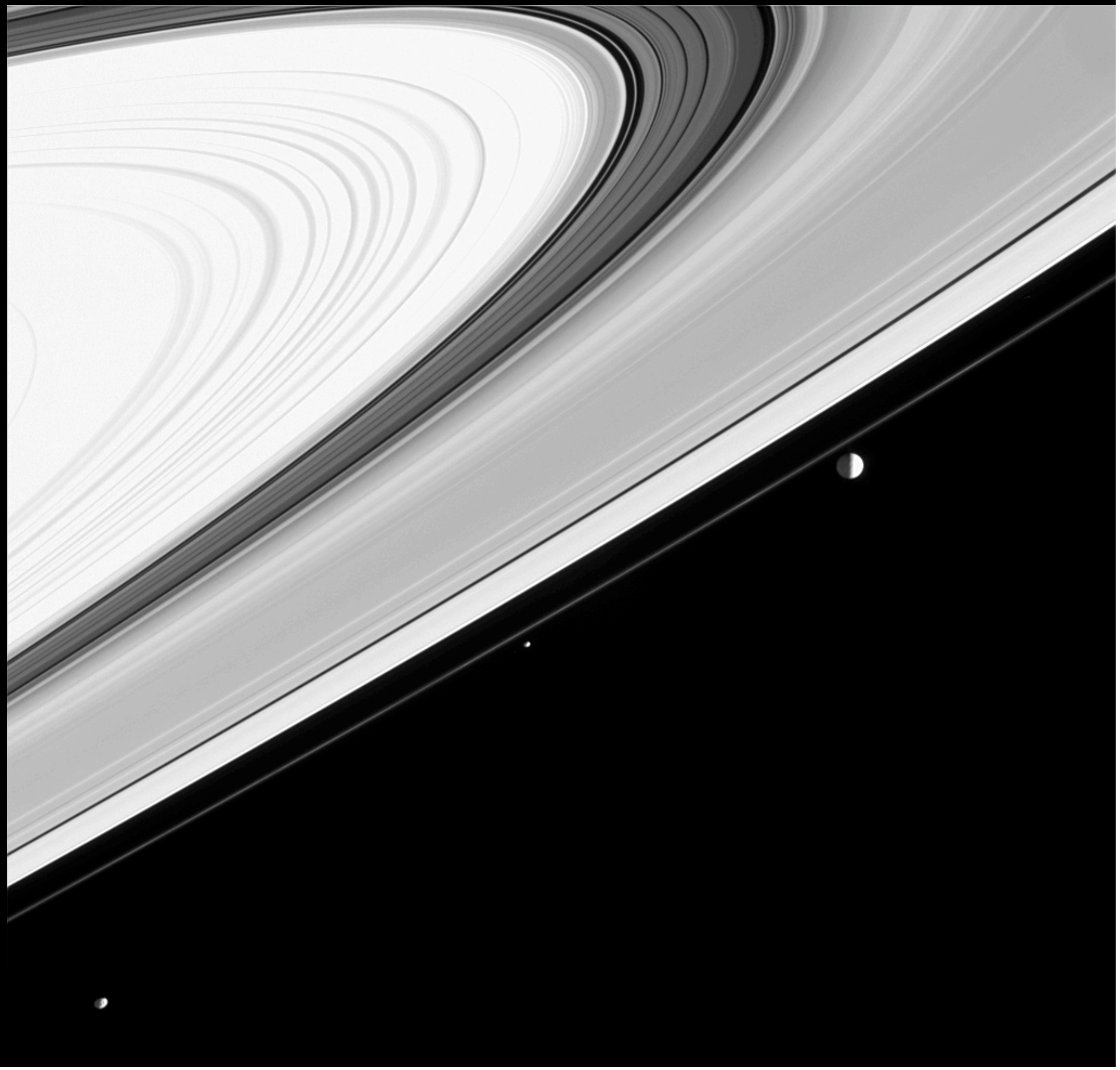
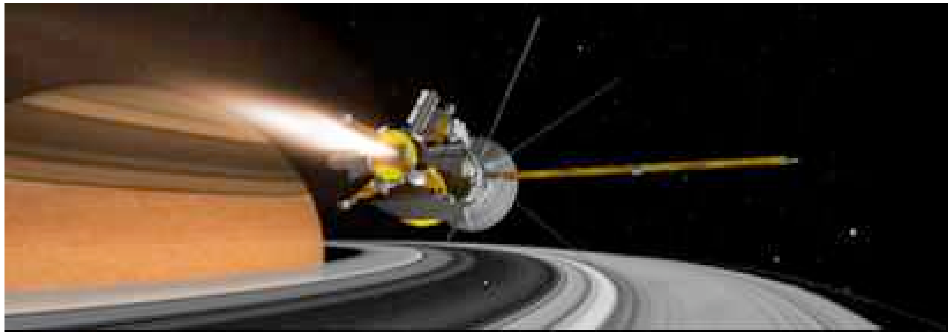


First results of the Cassini dust detector at Saturn

S. Kempf

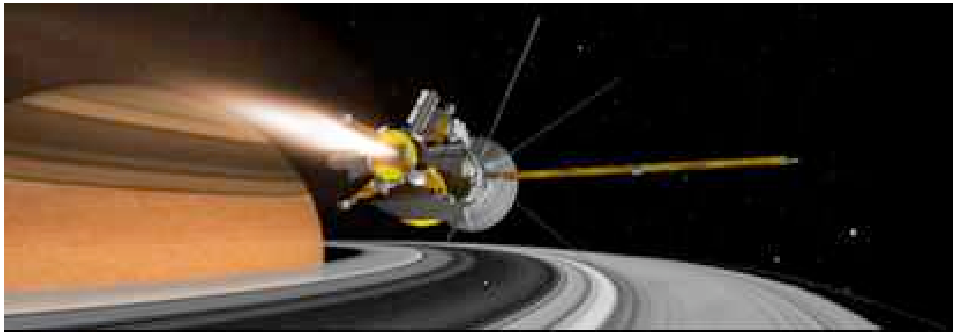
MPI für Kernphysik,
Heidelberg, Germany



Cosmic Dust Analyser (CDA)

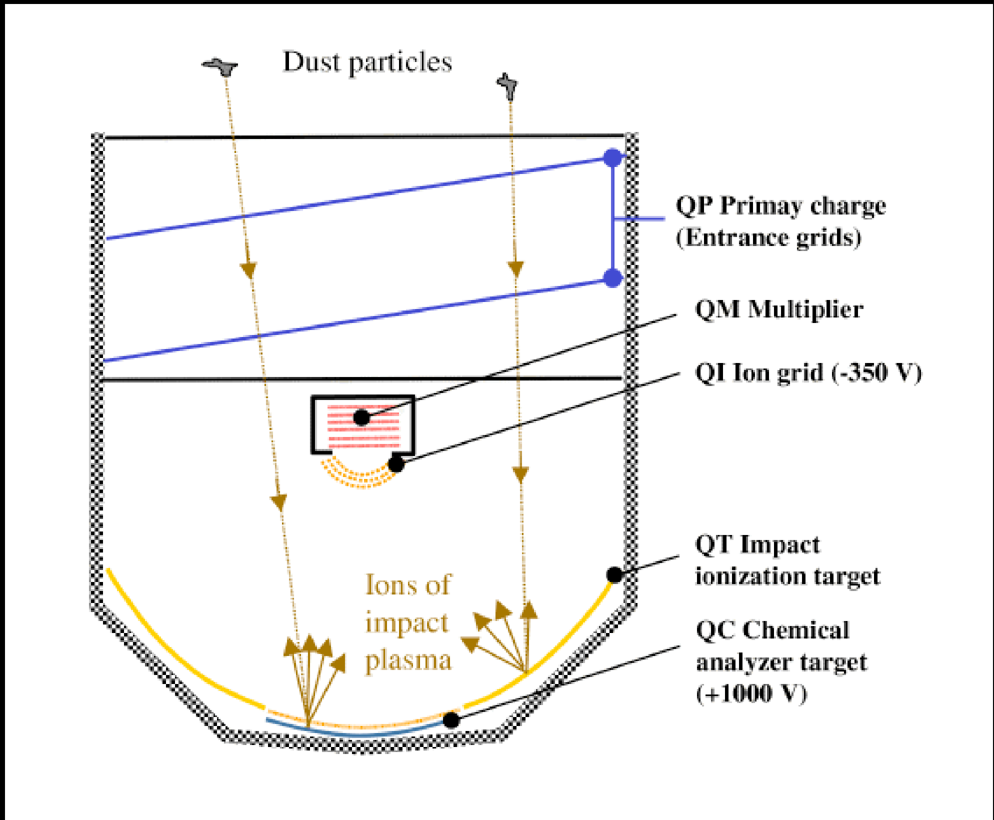
Dust detector on Cassini spacecraft:

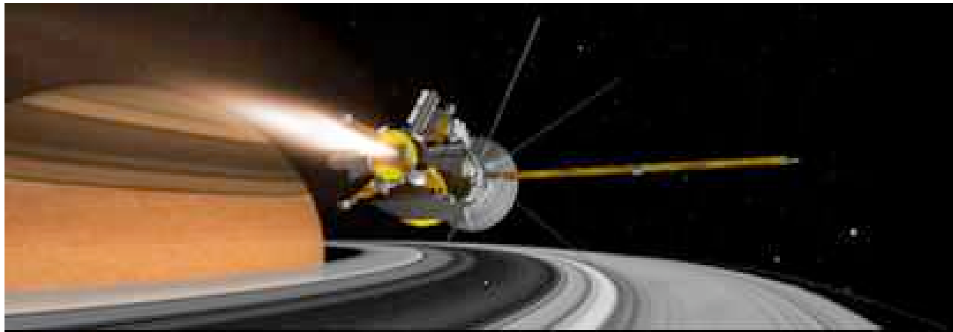
- dust mass/velocity: impact ionisation detector
- chemical composition: time of flight mass spectrometer
- dust charge/velocity/impact angle: charge sensitive entrance grids
- high rate detector



How do we derive v_{dust} & m_{dust}?

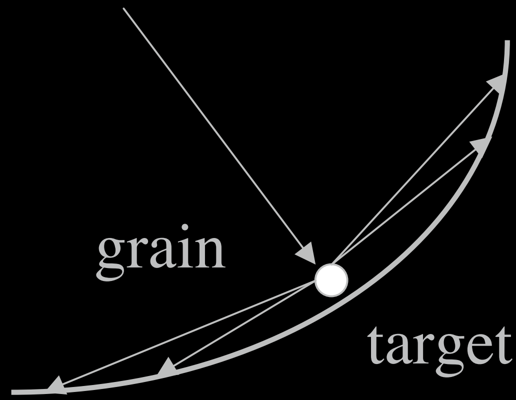
- deduce mass & speed from the evolution of the impact plasma
- plasma constituents are separated within electric field
- electrons are collected at the target
- ions collected at the ion grid

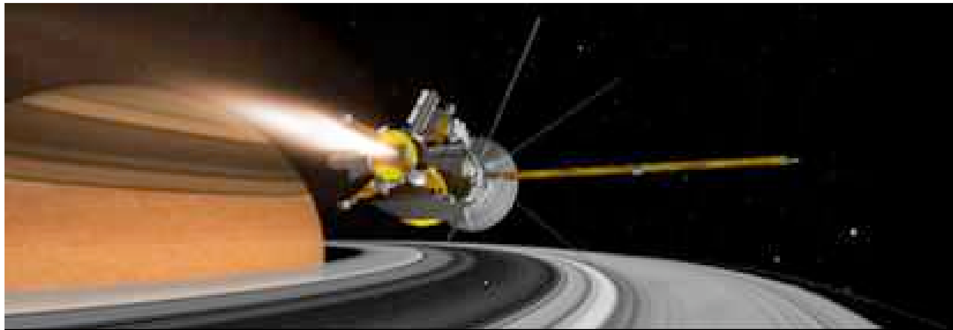




Rise time dependence on dust speed

- high-velocity impacts usually produce impact ejecta
- there is experimental evidence that $v_{ejecta} = a * v_{dust}$ (Eichorn, 1978)
- spherical target: mean ejecta flight path only depends on angular distribution
- charge is collected as long as ejecta hitting the target
- thus: $t_{rise} \sim {v_{dust}}^{\beta}$
- but: scaling factor a depends on material





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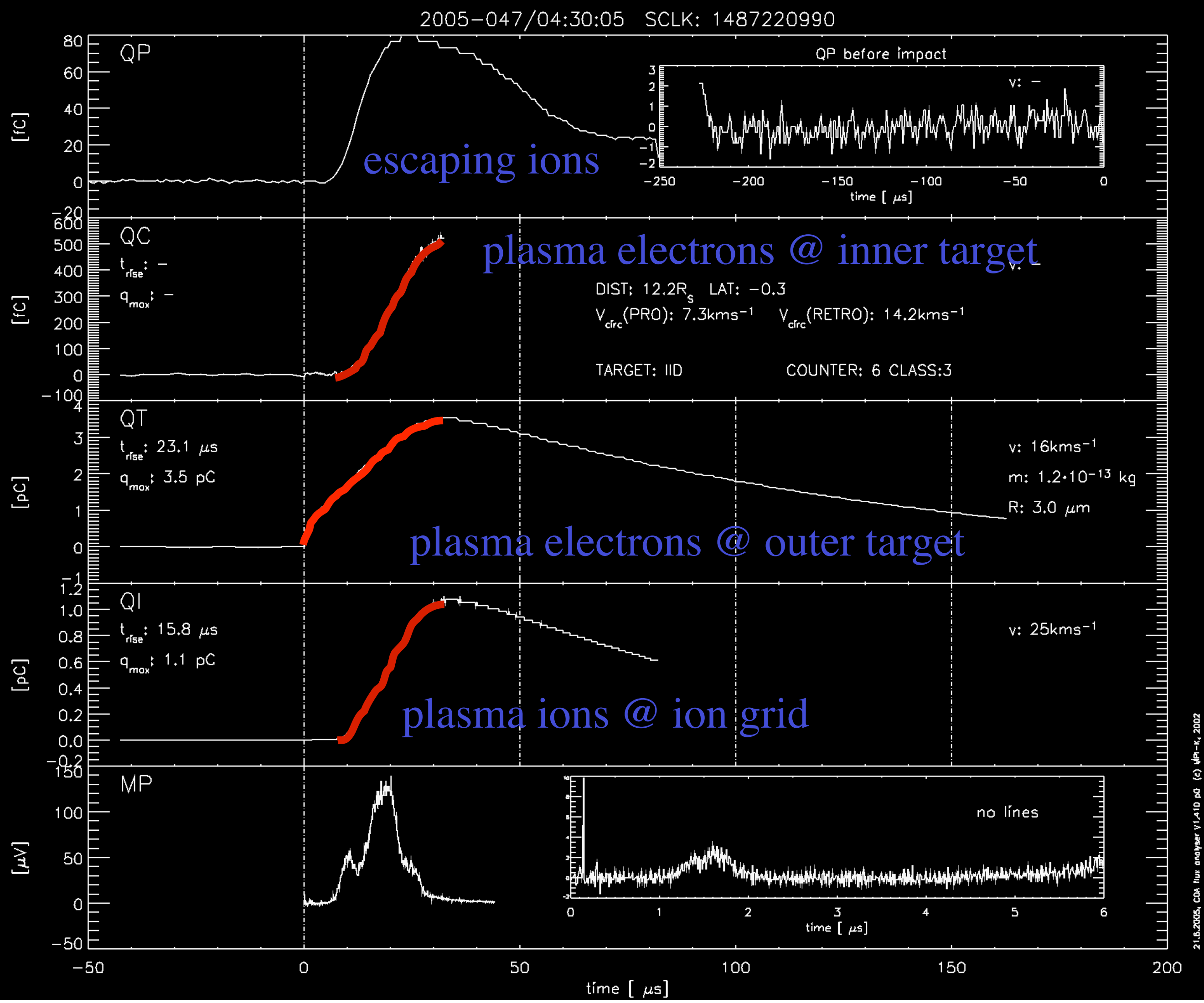
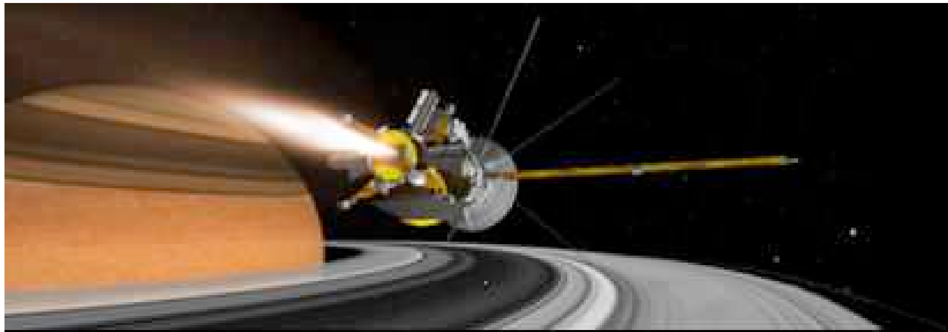


Transmitted signals of a typical dust impact



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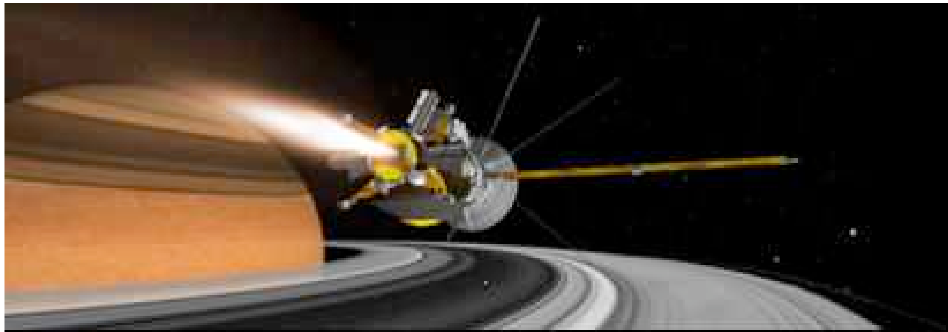
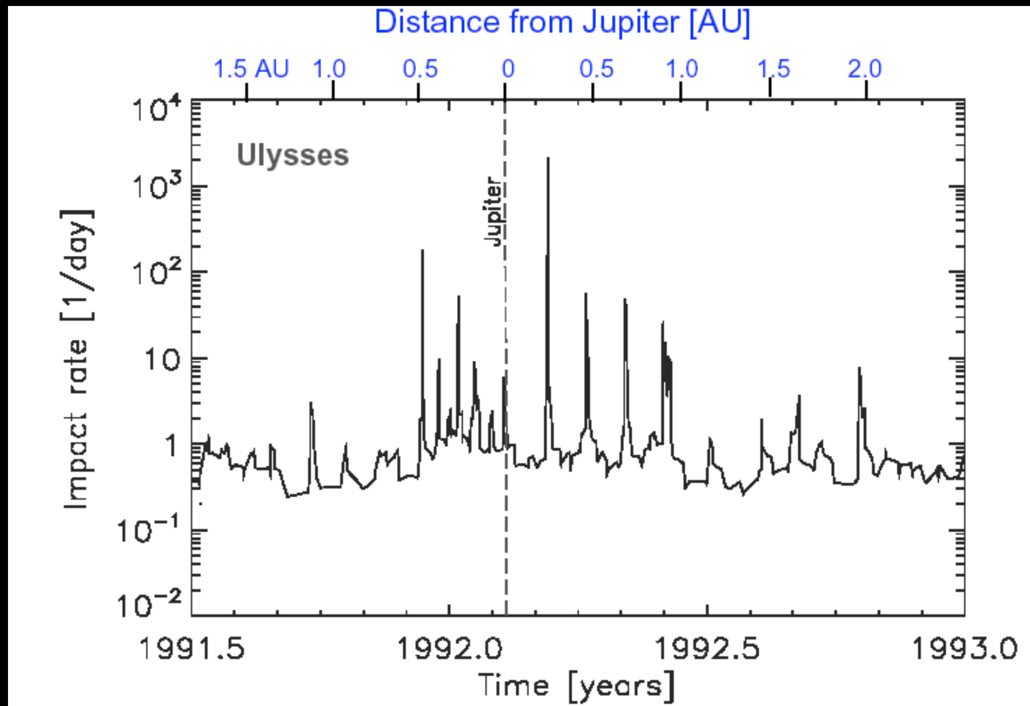
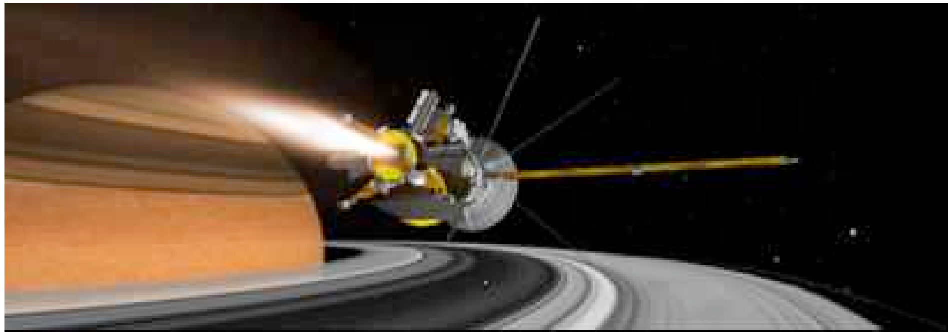
Discovery of Saturnian dust streams



Jupiter is known to be a source of high-velocity dust streams

- discovered 1992 by Ulysses dust detector
  (Grün et al., Nature, 1992)
- short impact bursts (~3 d)
- ~27 days periodicity
- collimated streams arriving close to the line-of-sight direction to Jupiter



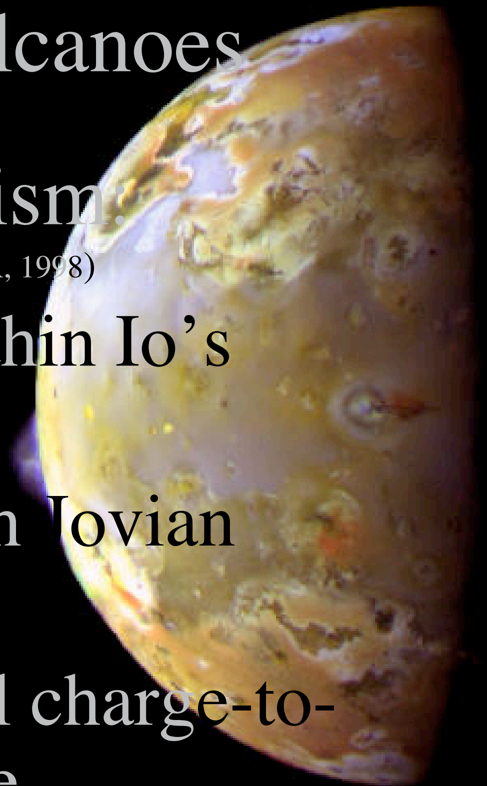


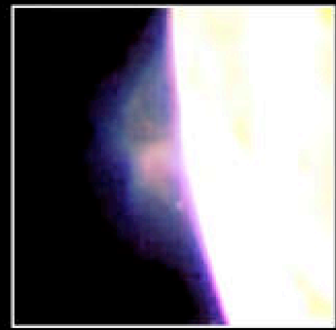
two major questions:

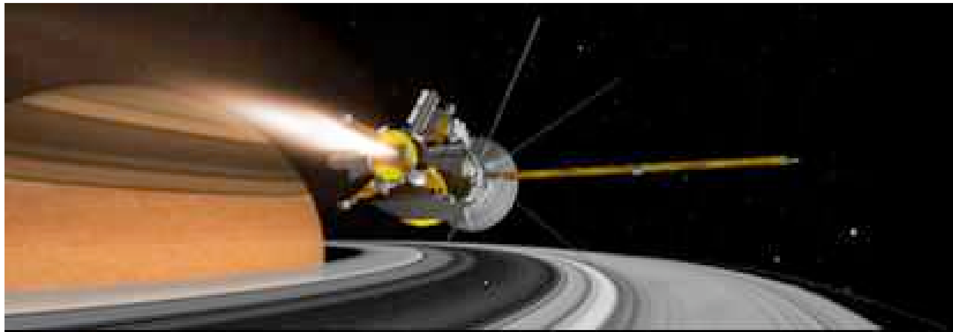
- What is the dust source within the Jovian system?
- Why are the dust streams outside the Jovian system periodic?

Source of Jovian dust streams

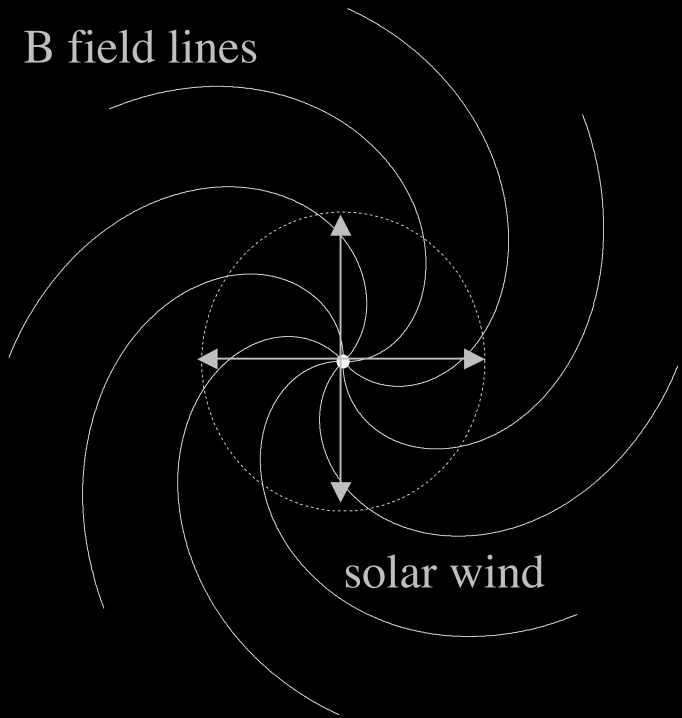
- major source: Io's volcanoes
  (Graps et al., Nature, 2000)
- Acceleration mechanism:
  (Horányi, Morfill & Grün, Nature, 1993; Grün et al., JGR, 1998)
  - dust is charged up within Io's plasma torus
  - strong interaction with Jovian magnetosphere
  - only dust within small charge-to-mass range can escape





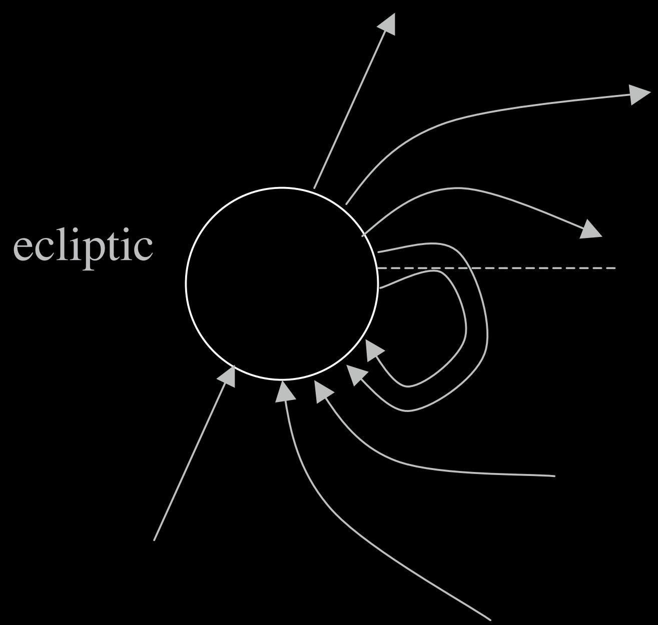


Large scale structure of the interplanetary magnetic field (I)

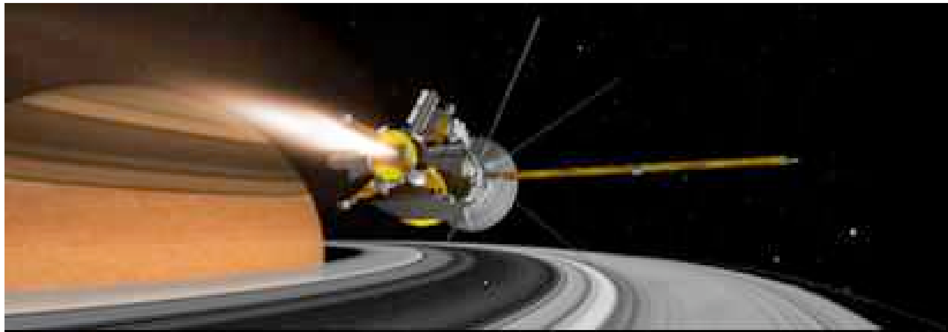


- outside solar source radius: $M_A>1$ plasma flows radially outwards (solar wind), solar B field is frozen in
- B field lines stay attached to source surface rotating with the Sun (1/27 d)
- on average “Parker spiral”
- @ Earth orbit: $\angle(b, r) = 45°$

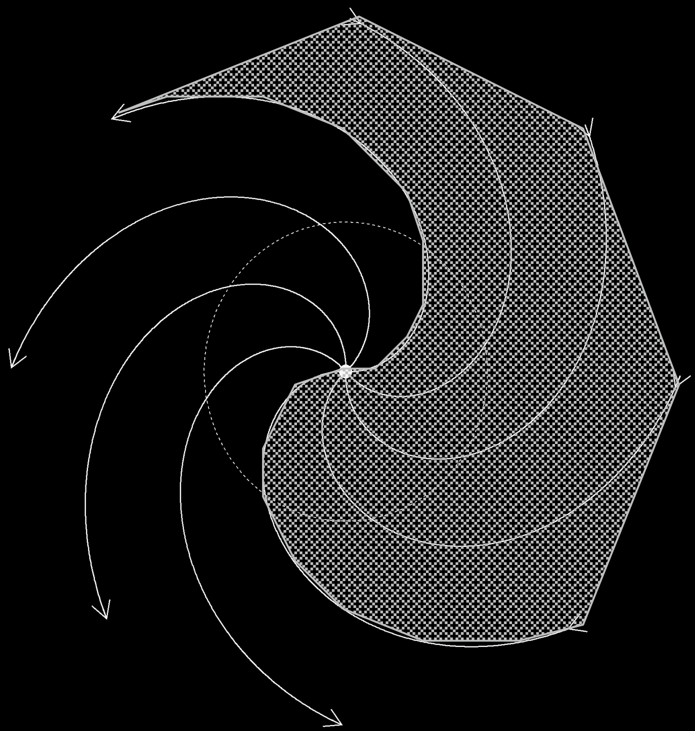
Large scale structure of the interplanetary magnetic field (II)



- Sun’s rotation axis is tilted wrt. ecliptic plane

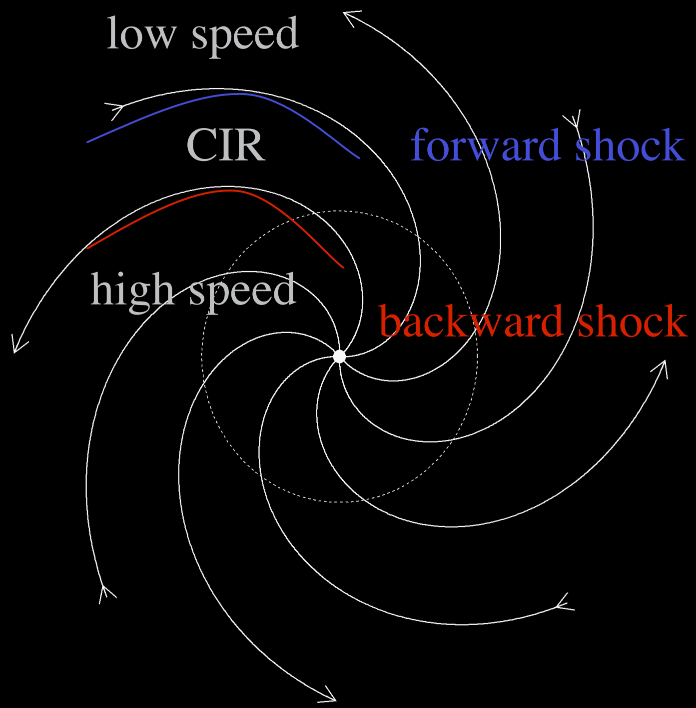


Large scale structure of the interplanetary magnetic field (III)

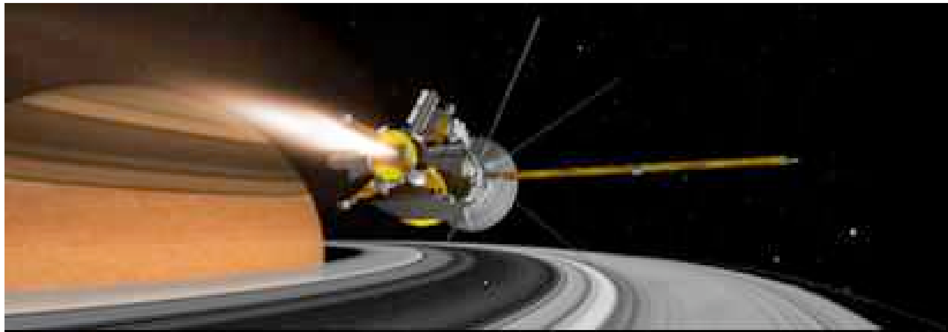


- tilted solar dipol separates IMF into 2 sectors of opposite magnetic polarity (caveat: this is the simplest case!)
- on average, the IMF sector structure is repeated in time with a 27 days period.

Large scale structure of the interplanetary magnetic field (IV)

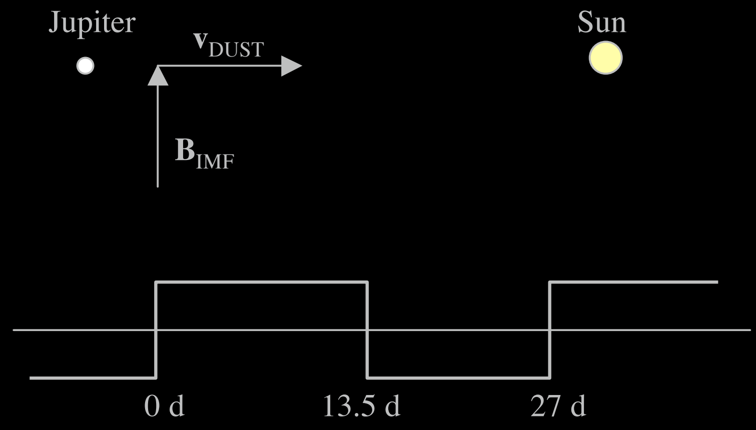


- solar wind is composed of slow streams (~350 km s^{-1}) and fast streams (~750 km s^{-1}) originating from different regions of the Sun
- stream-stream interaction leads to regions of compressed solar wind -> corotating interaction regions (CIR)
- characterised by compressed plasma, increased wind speed & magnetic field



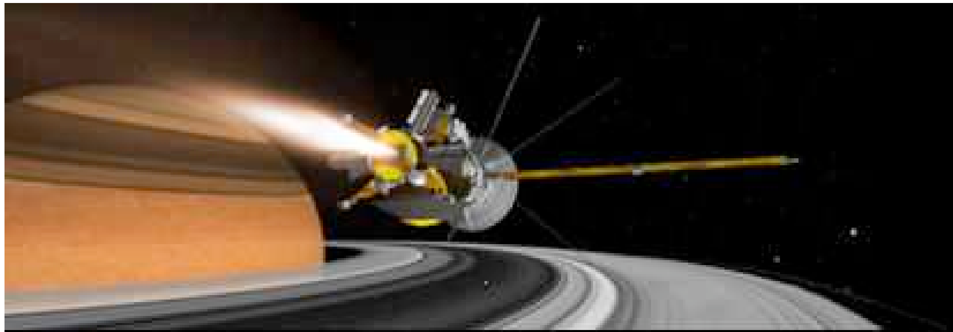
Dust streams periodicity

- 27 d periodicity of impact bursts indicates for strong dust-IMF interaction
- Lorentz force acting on charged grains lead to an off-ecliptic force bending the dust trajectories
(Hamilton & Burns, Nature, 1993; Horányi, Morfill & Grün, Nature, 1993)



acceleration acting on charged grains emerging from Jupiter

- Simulations showed that only grains with v_{dust}~400 kms^{-1} and sizes < 14 nm could reach detector
(Zook et al., Science, 1996)



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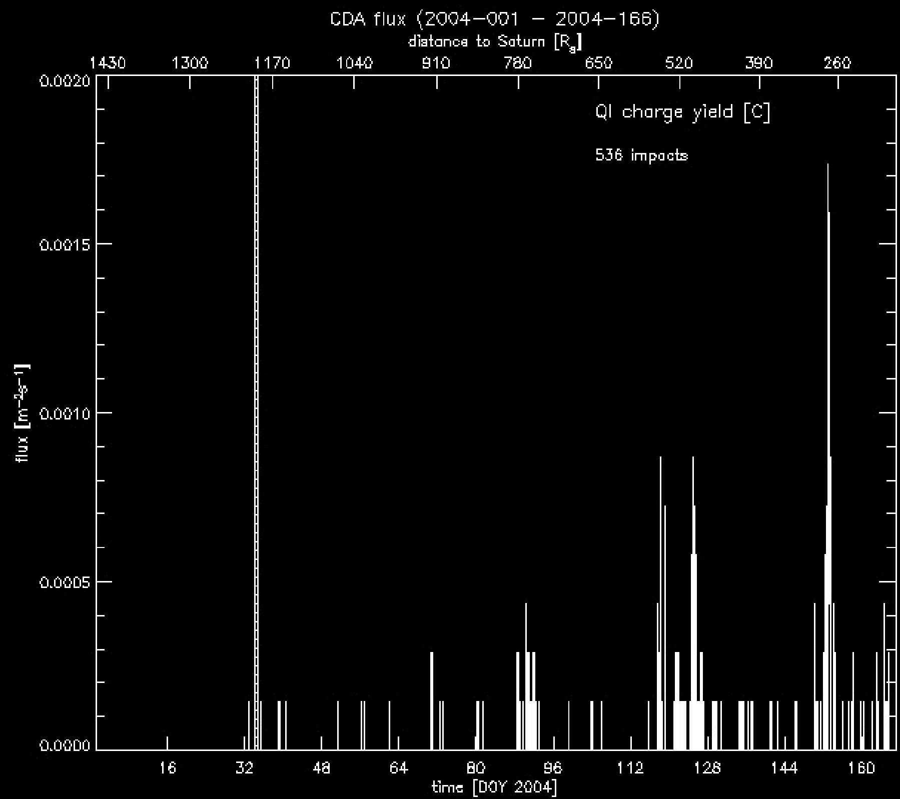
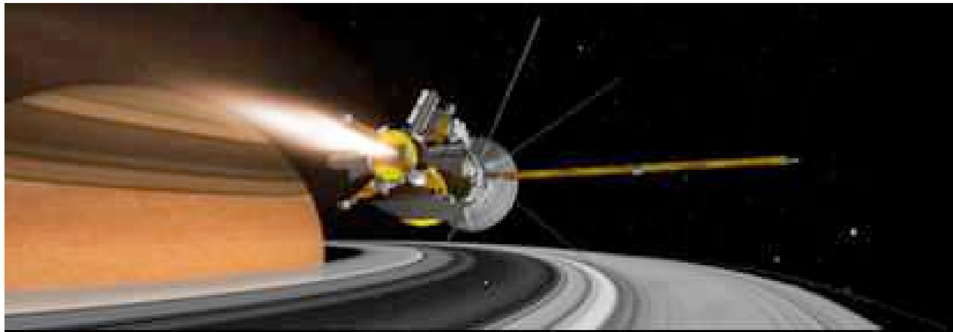
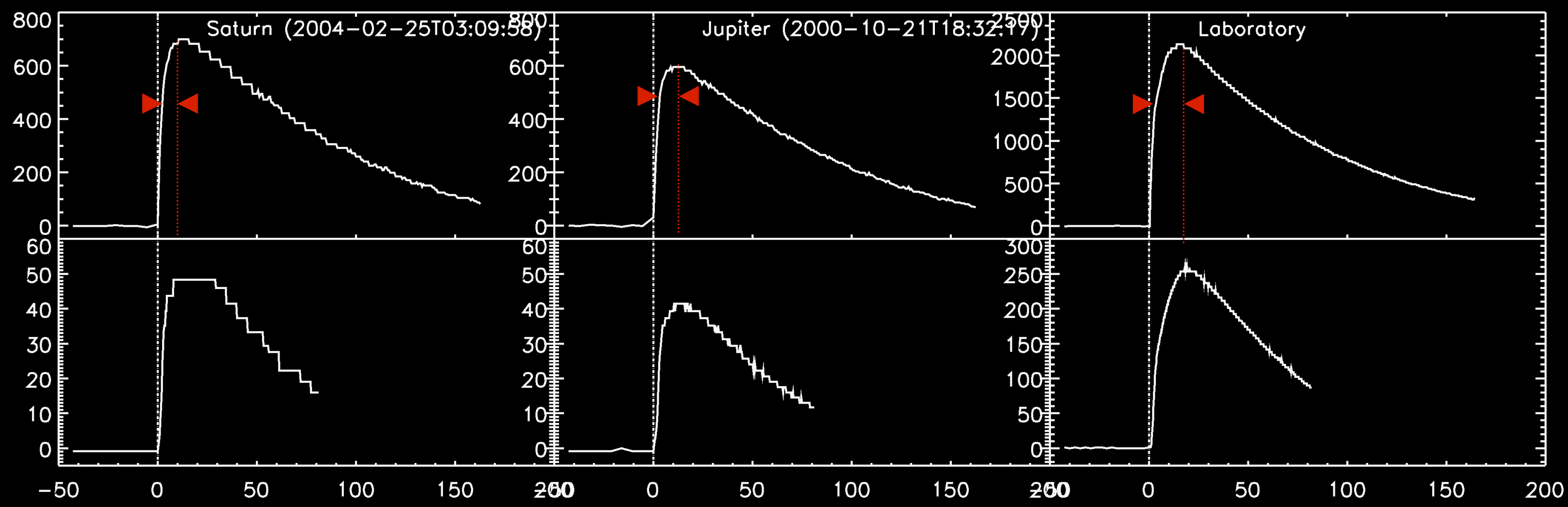
Is Saturn also Source of Dust Streams?

- Horányi (2002) pointed out that Saturn may also be a source of stream particles
- Cosmic Dust Analyser:
  - registered between during approach to Saturn about 1700 hyper-velocity impacts
  - pronounced bursts
  - peak amplitude decreases with distance





Comparison with Jupiter/Lab data

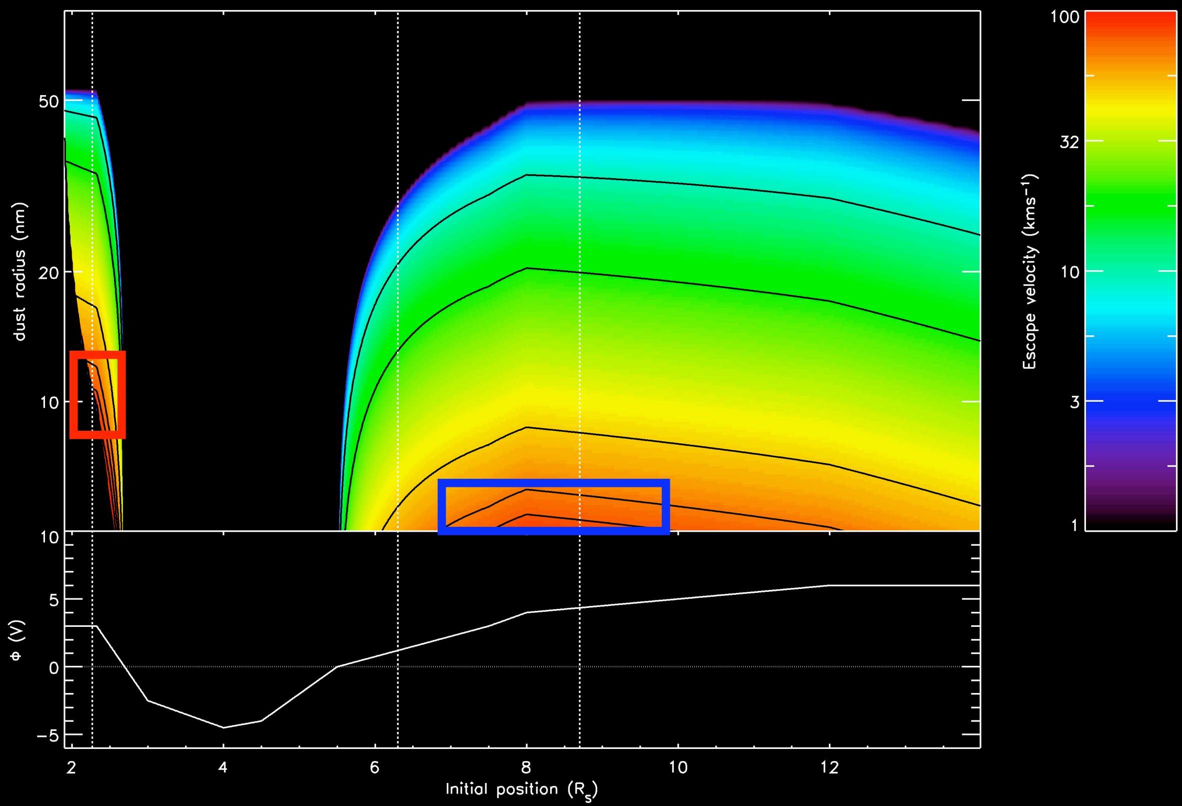


registered features were due to impactors with similar properties as Jovian stream particles

v ~ 100…400 kms^{-1} R < 20 nm

Escape speed as function of initial position and grain radius

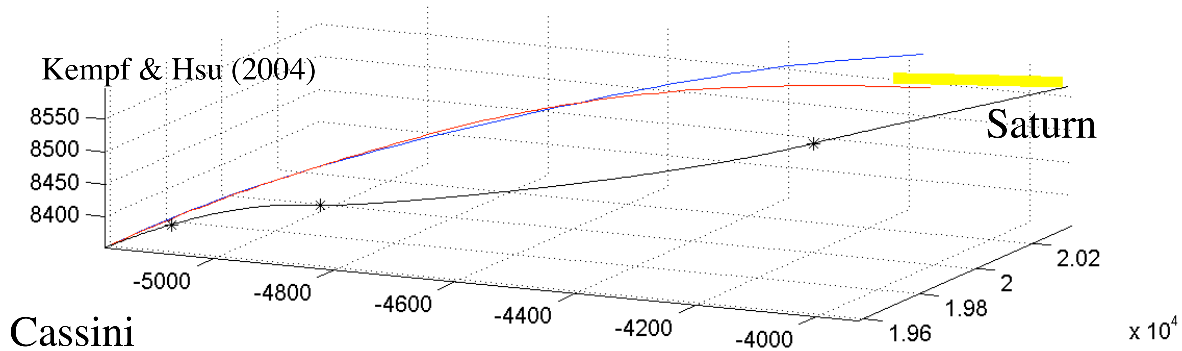
- two possible sources
  (Kempf et al., Nature, 2005)
- beyond Dione's orbit
  – tiny grains < 2nm
- outskirts of A ring
  – grains > 10 nm



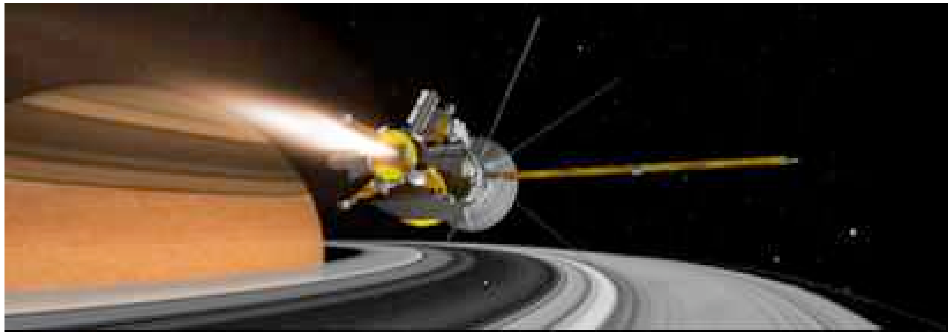
How to Constrain Origin?

- only grains within narrow speed & mass range could hit the detector
- traced dust trajectories by simulating grain dynamics:
  - released particles @ Cassini's location
  - simulated interaction with IMF
  - grains ≥10 nm $v_{dust} \geq 100\ kms^{-1}$ reached Saturn

simulation of an impact event on 2004-011:

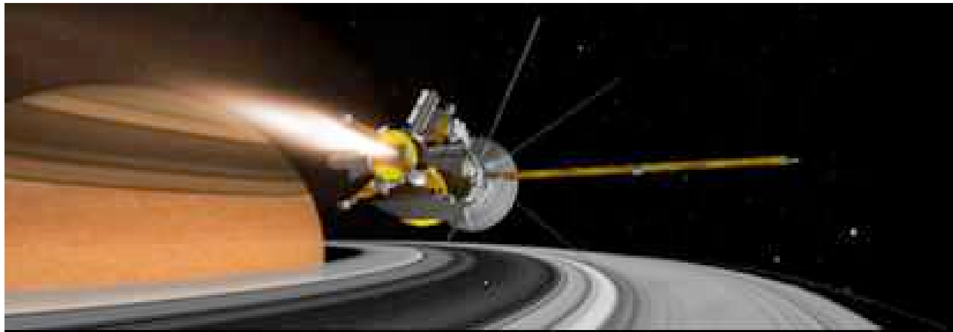


5nm, 10nm, 28nm



Source of Saturnian dust streams

- at least the impacts detected at large distances can only be explained by sources within Saturn’s main A ring (Kempf et al., Nature, 2004)
- main rings cannot be studied in-situ
- some of the Saturnian stream particles are “messengers” from the main rings!



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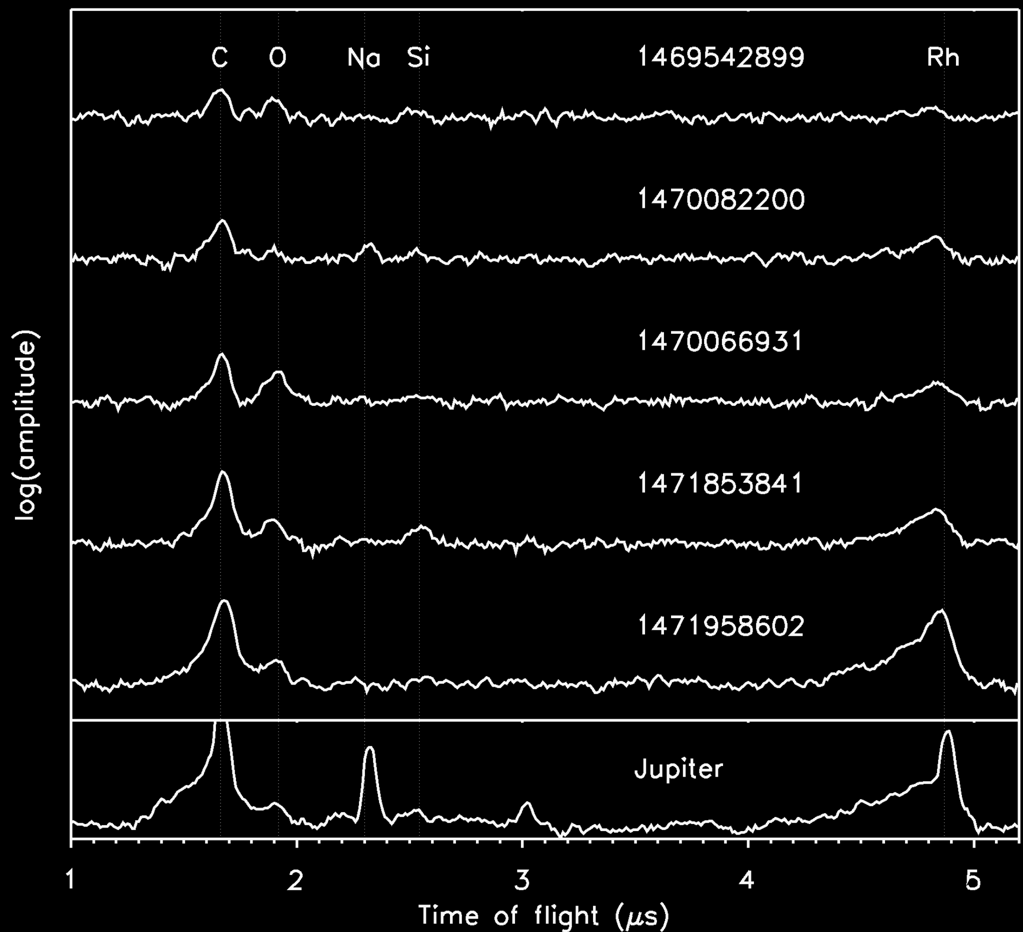
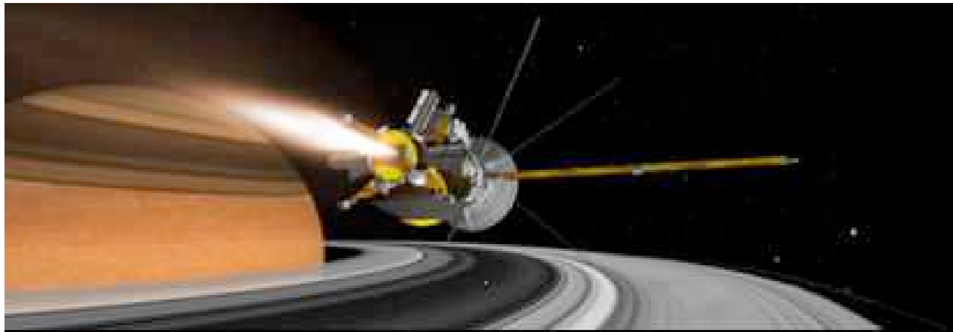
Composition of stream particles



- obtained mass spectra differ significantly from Jovian particles
- mass spectra are very faint
- composed of ~30000 ions
- dominated by O, C, Na, Si, SiO_2, Rh



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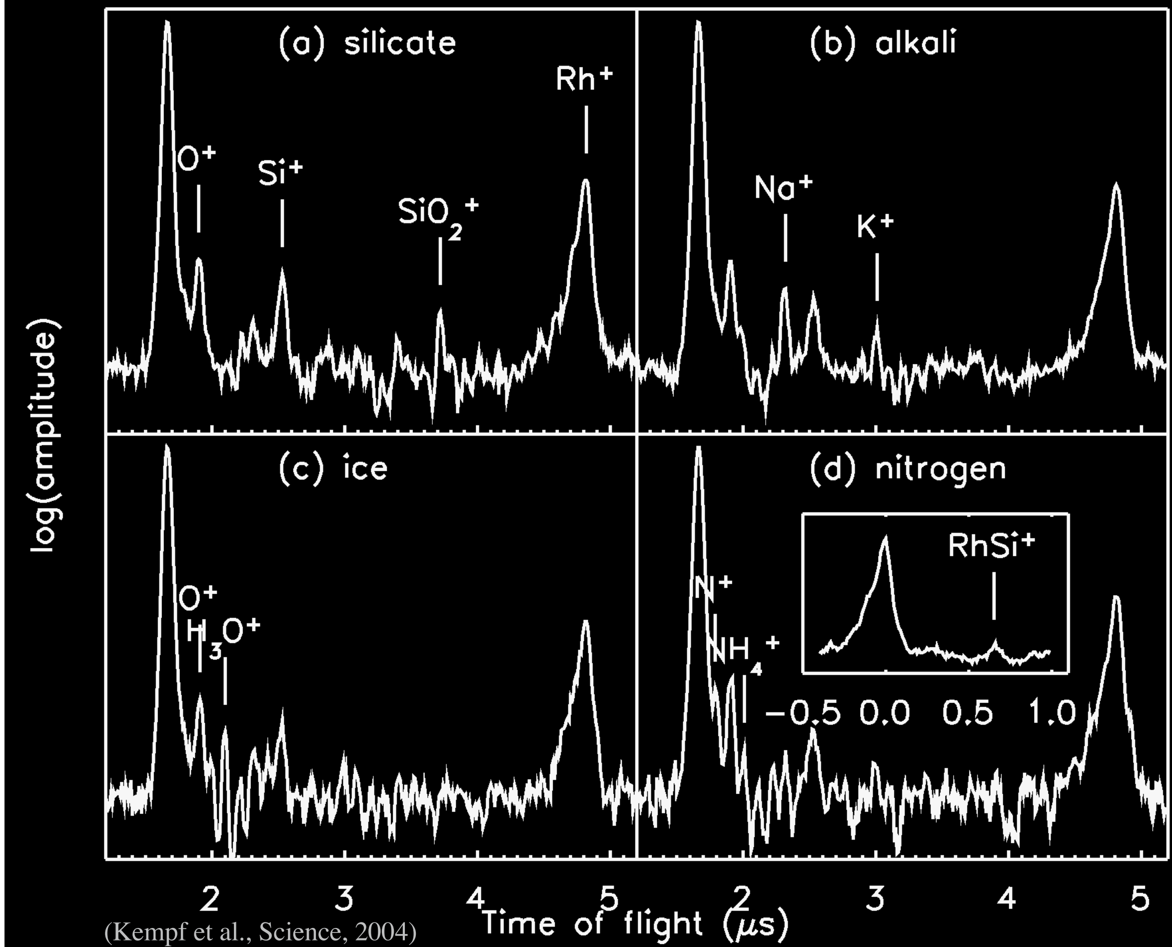
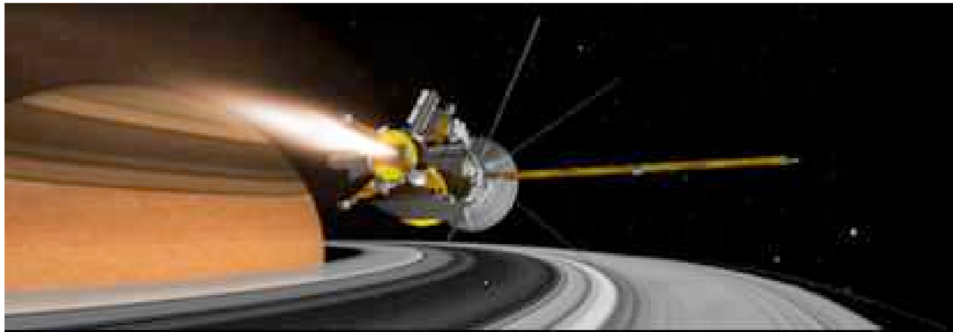
Stream particles are mostly silicates!



(Kempf et al., Science, 2004)

- there is no simple relation between spectrum & projectile
- 4 composition types:
  - silicate: O^+, Si^+, SiO_2^+
  - alkali: Na^+, K^+
  - ice: H_3O^+
  - nitrogen: N^+, NH_4^+
- target-projectile ion $RhSi^+$:
  - only possible if Si is dominant projectile material
- Stream particles dominantly consist of silicates
- But: Saturn's rings consist of water ice



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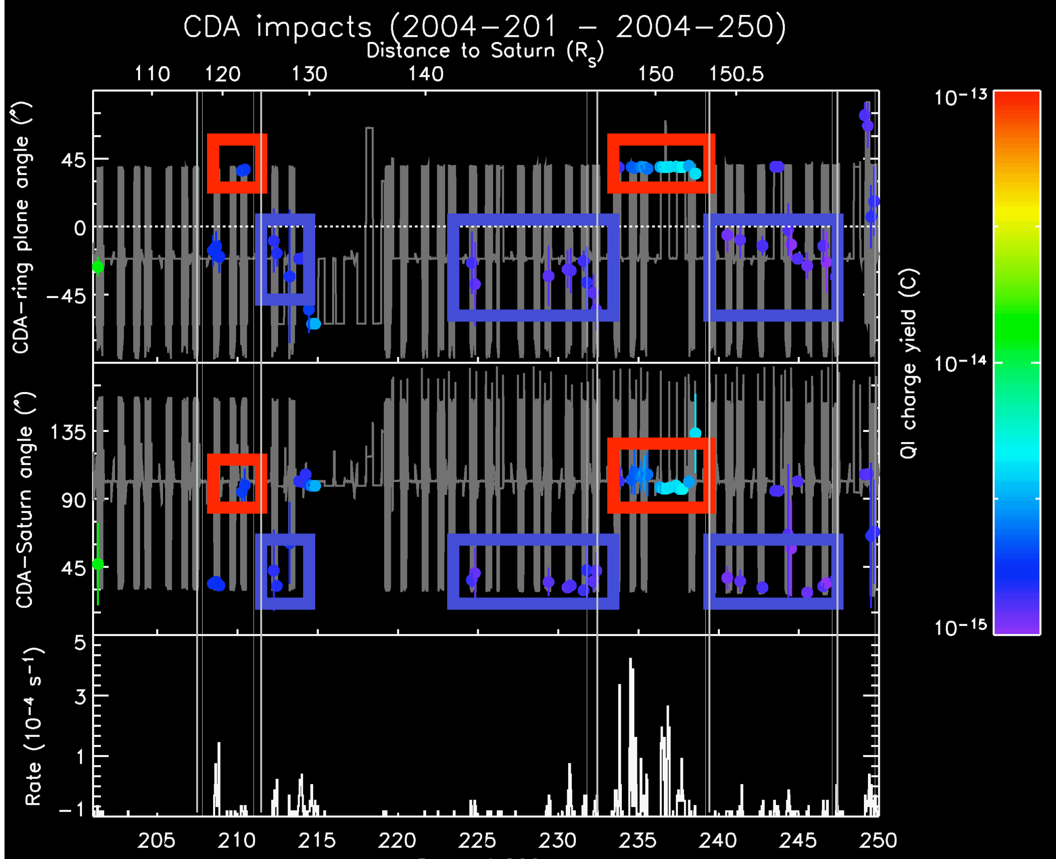
Stream directionality

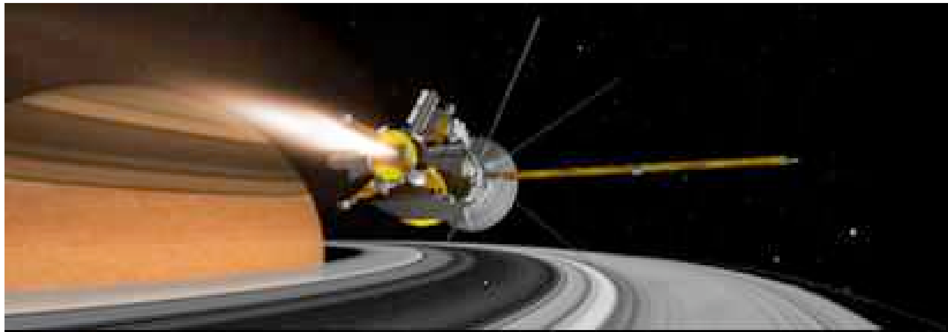


(Kempf et al., Nature, 2004)

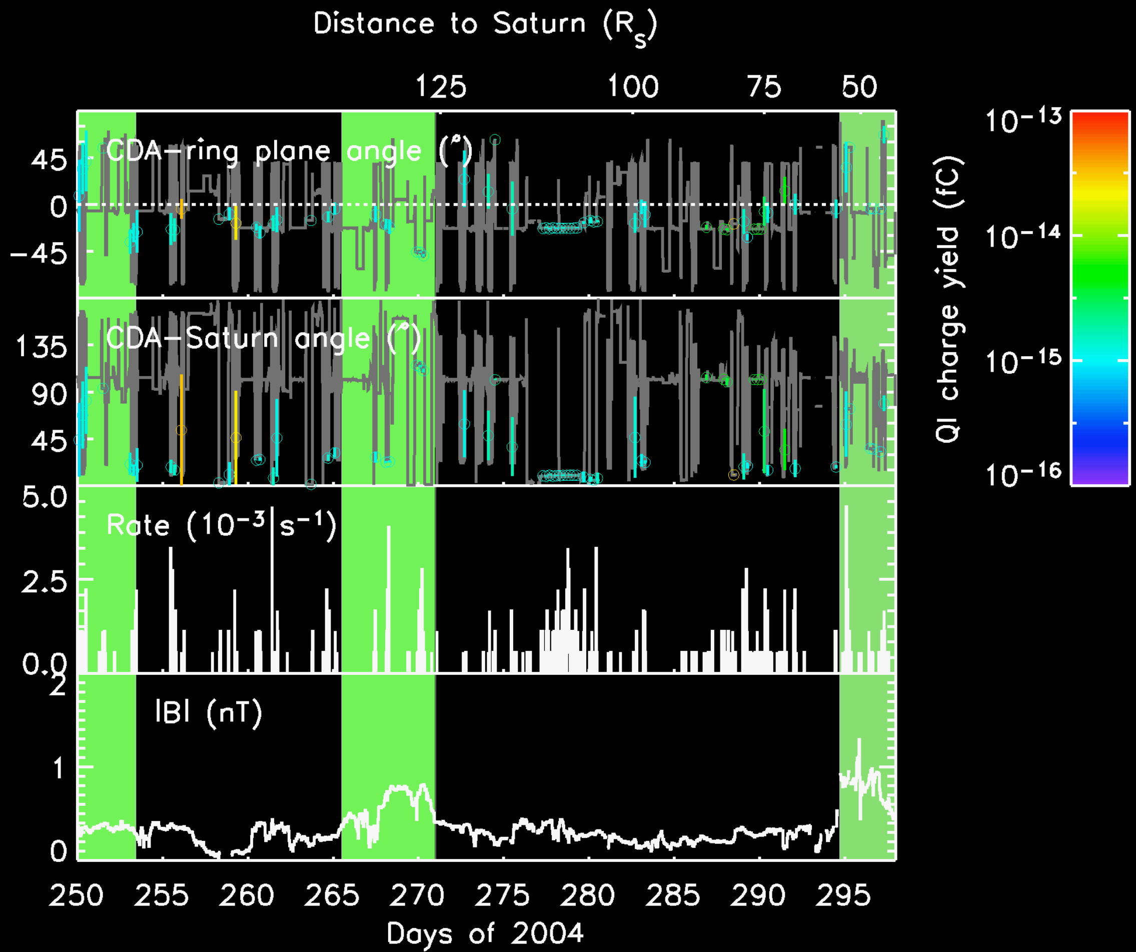
stream directionality changed during Cassini's traversals through streams in the solar wind (CIRs):

- outside CIRs:
  parallel to ring plane, Saturn direction
- inside CIRs:
  perpendicular to ring plane, 100° off Saturn

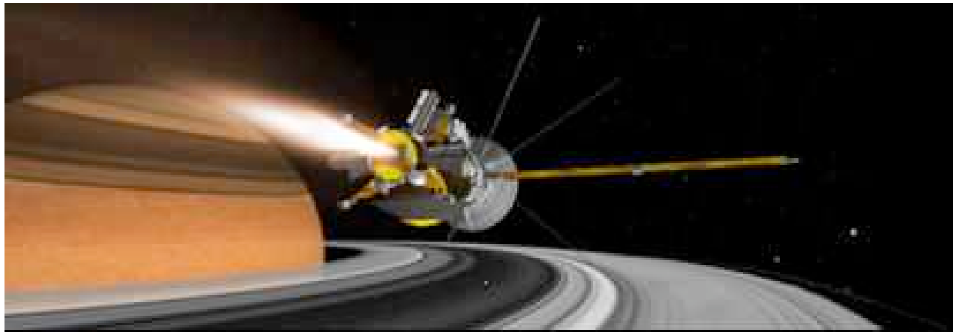
bursts are due to CIRs



Stream directionality

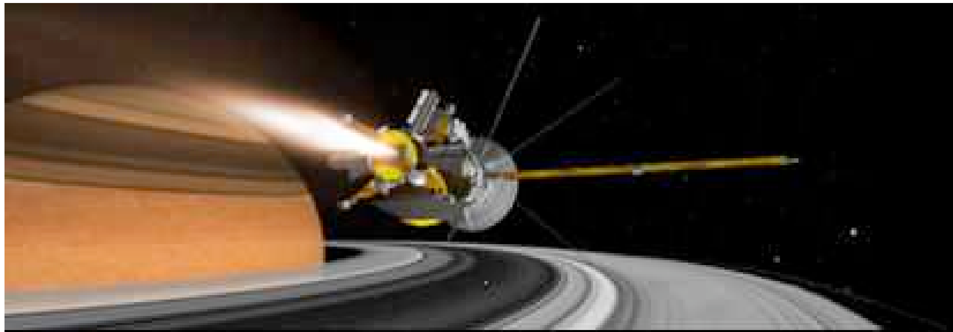


- all CIR-traversals after the SOI were associated with changes of the stream directionality



So how are “dust streams” formed?

- inside Saturn’s magnetosphere a thin sheet of radially escaping grains is formed
- “streams” are formed when the dust traverses through CIR - regions with enhanced B field, enhanced plasma density, and increased wind speed:
  - enhanced co-moving E field increases dust speed
  - leads to increased impact rate
  - B field bends trajectories



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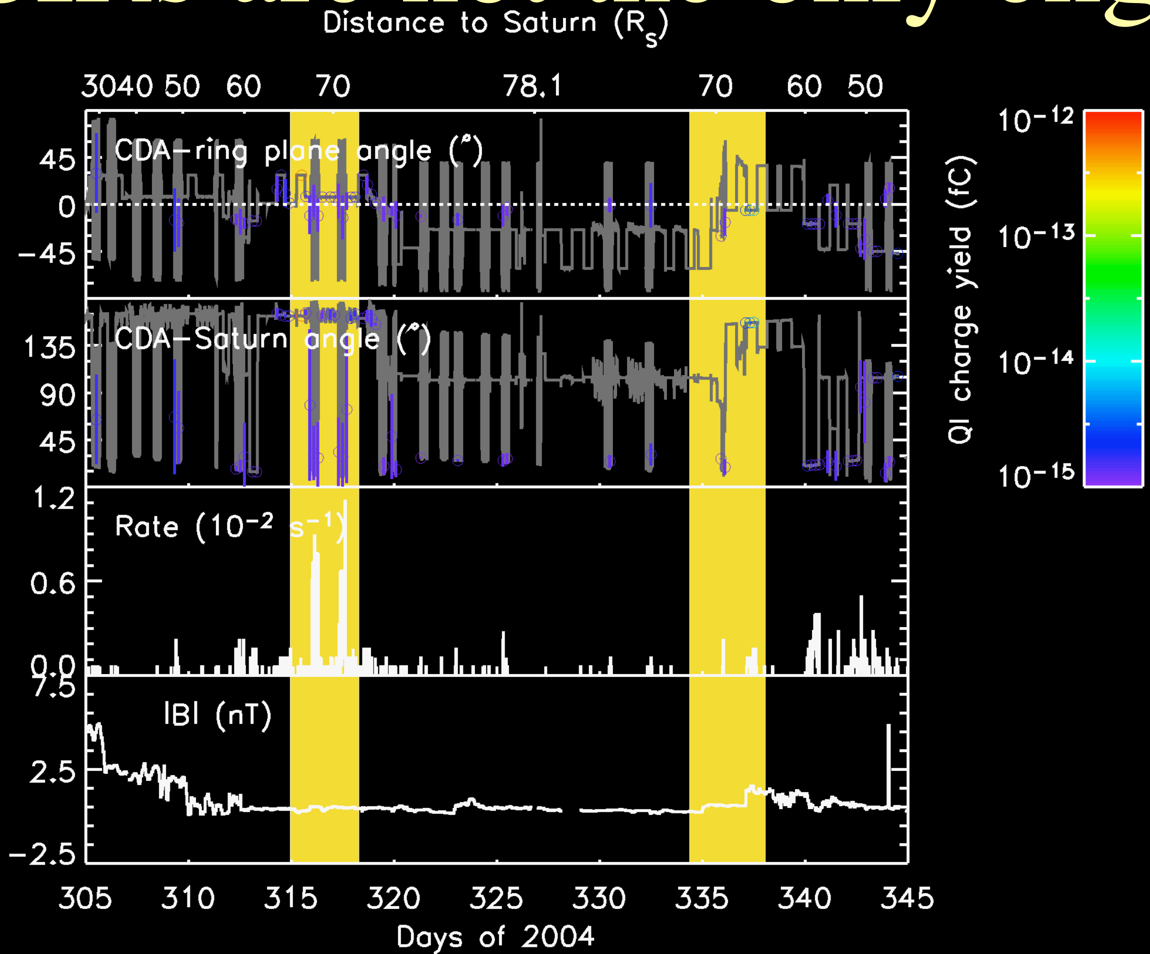
CIRs are not the only engines for bursts



- impact burst also when traversing CME events
- no change of stream directionality