

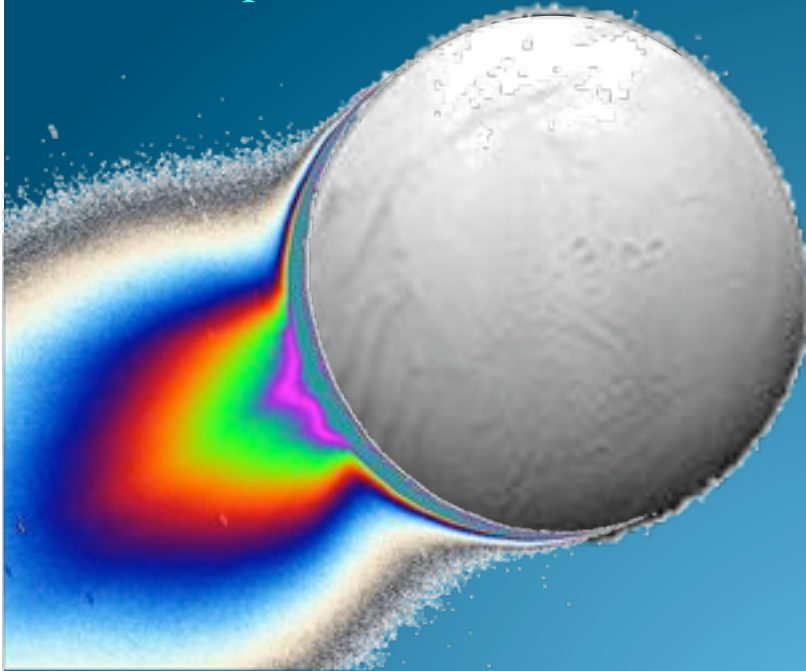


# LIFE (Life Investigation For Enceladus)

*a feasible plume sample return concept*

*A presentation to the Satellites panel of the NRC Planetary Decadal Survey*

September 21, 2009 10:30 am  
Arnold and Mabel Beckman Center  
Irvine, CA



Peter Tsou (JPL/Caltech)



# LIFE, Life Investigation For Enceladus

- Low cost flyby sample return from Enceladus
  - Capture Enceladus plume and Saturn E ring material
  - Titan upper atmospheric measurement
  - Astrobiology centric mission – preserving organics/volatiles
  - Follows STARDUST with volatiles augmentations
- Rare Opportunity to catch samples by low-cost flyby
- Returned Samples provide invaluable science

*“...perhaps the most enticing aspect of the search for life on Enceladus is that fresh samples of interest are jetting into space ready for collection.... even a mission along the lines of the STARDUST.”*



# LIFE Features

- Meet NASA “life search” targets: Europa, Titan, Enceladus
- Capitalize on newly discovered Enceladus plume, 2005
- Making use a proven sample capture & return approach
- Utilizing sophisticated/complex terrestrial instruments
- Opening to techniques not conceived or invented now
- Results subject to verification, duplication & innovation
- Provide intelligence to outer planet “life search” missions
- Enable experiments on samples to explore “life”



# LIFE's Major Challenges

- High sampling speed,  $< 6$  km/s
- Long mission duration,  $< 14$  years
- Risk of a single flyby sampling
- Fit within project cost cap



# Resolution of Challenges

- Sampling speed as low as 3 km/s
- Mission duration as low as 13.5 years
- Multiple flyby samplings
- **Fit within project cost cap**



# Recommendation

- An In-Depth Study of LIFE like mission
  - “Design to Cost” Mindset, not “business as usual”
  - Step Cost
    - Baseline: Samples kept at ambient temperature
    - Multiple Sampling: Several sample flybys
    - Frozen: Samples kept at cryotemperature
    - In Situ: Samples plus in situ instrumentation
    - Titan Measurement: Upper Atmospheric measurement/samples



# Presentation Order

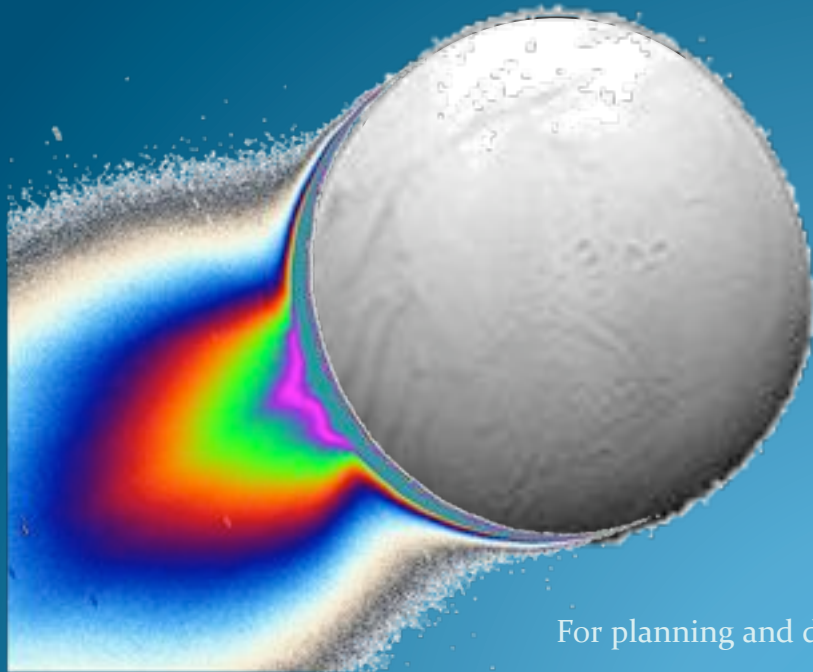
Time	Speaker	Topic
10:30 - 10:40	P. Tsou	Introduction, LIFE concept
10:40 - 10:45	L. Spilker	Characterization of Enceladus plume and E ring
10:45 - 10:50	N. Strange	Trajectory: sampling speed & mission duration
10:50 - 10:55	I. Kanik	Sampling and in situ payloads
10:55 - 11:00	J. Vellinga	“Design to Cost” on STARDUST and LIFE
11:00 - 11:10	D. Brownlee	Importance of sample return and LIFE
11:15 - 11:30	Satellite Panel	Questions and Answers



# Enceladus Plume & Saturn E Ring

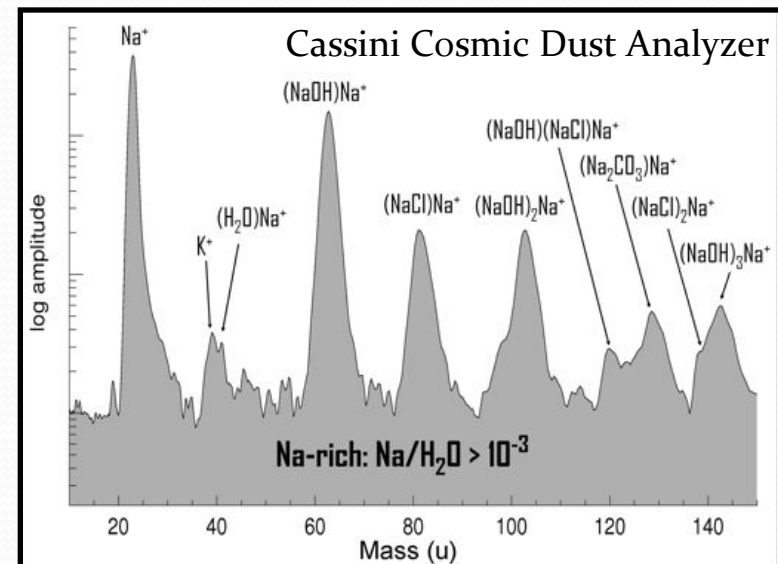
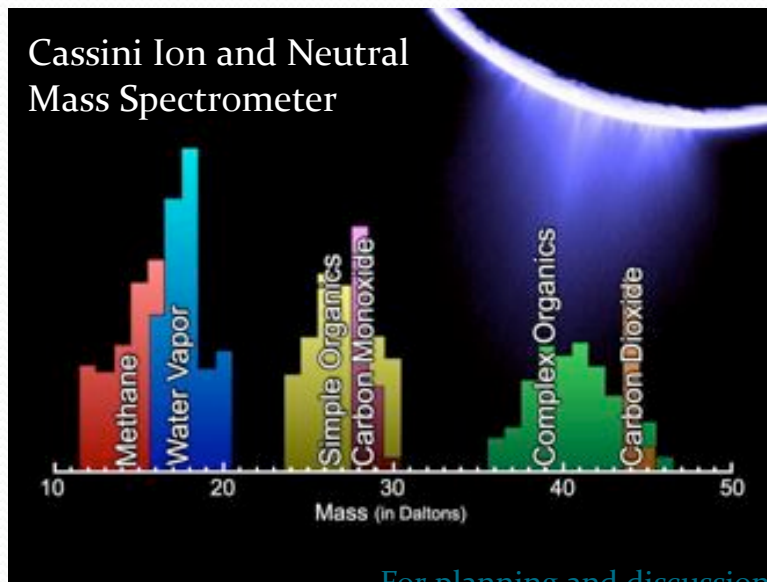
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Irvine, CA*

Linda Spilker (JPL/Caltech)



# Enceladus Plume

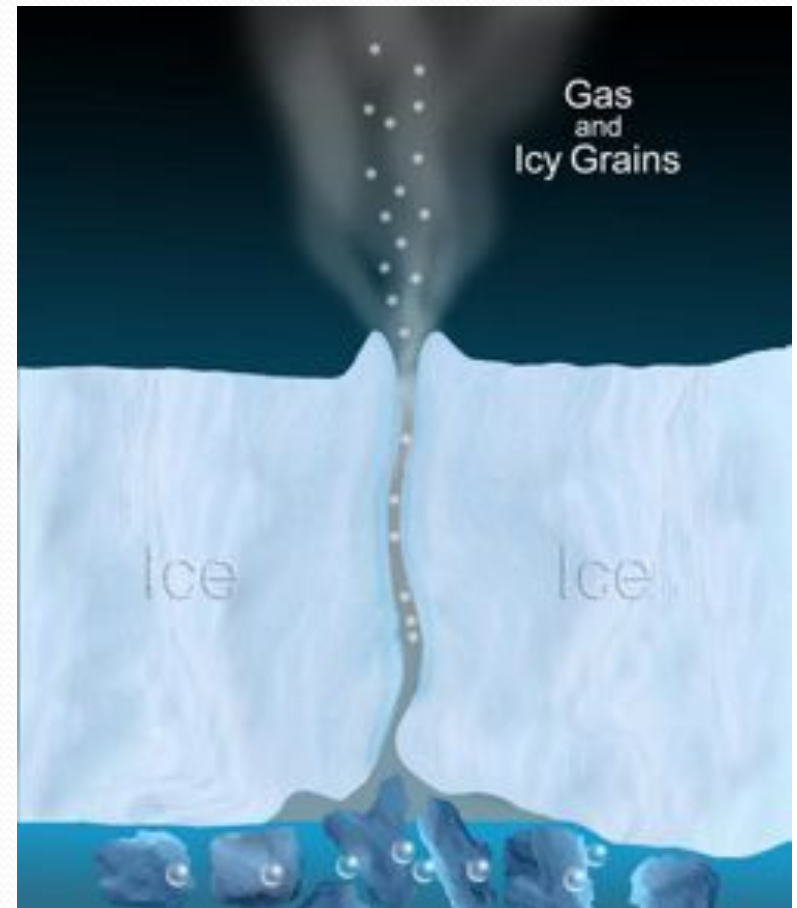
- Enceladus plume discovered by Cassini in 2005
  - Plumes extend more than Enceladus diameter (500 km)
- Plume composition is almost pure water ice or vapor
  - Plume particles include salts and carbonates
  - Gas includes organics, CO<sub>2</sub>, CO, NH<sub>3</sub>, and Ar<sub>40</sub>
- Plume particles escape to form E ring



For planning and discussion purposes only

# Plume Source

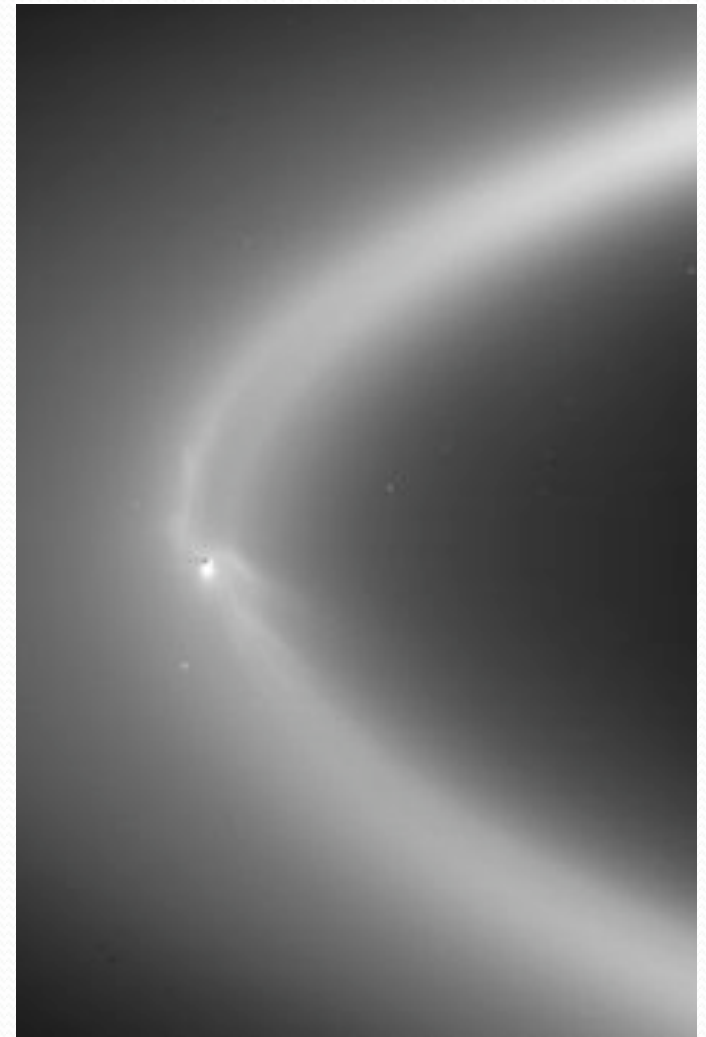
- Strong evidence that plume source is liquid water
- Salt-rich particles in plume imply liquid water at plume source as well as contact between water and rock [Postberg et al., 2009]
- $\text{NH}_3$  detection [Waite et al., 2009] lowers freezing point of water
  - Temperatures in excess of 170 K measured in fractures by Cassini CIRS [NASA/JPL image release, June 2009]





# Saturn E Ring

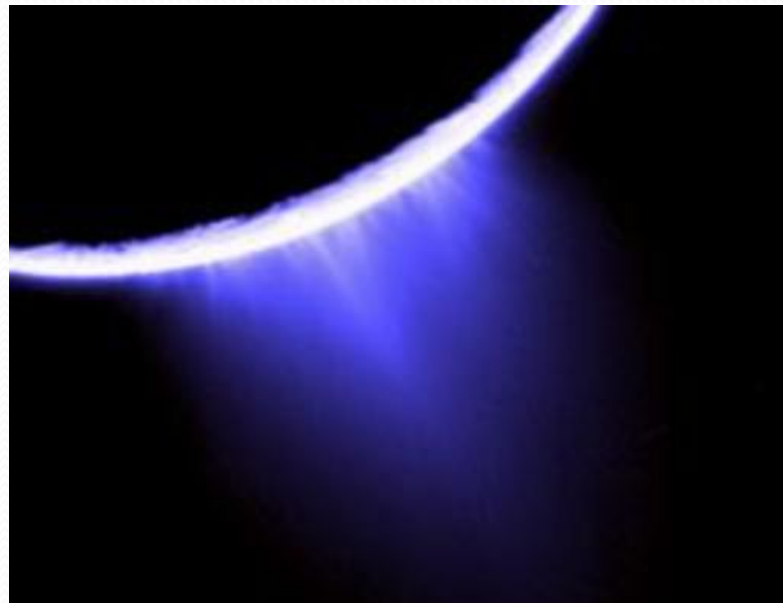
- E ring first discovered in 1966
- Enceladus geysers are dominant source of E ring material [Spahn et al., 2006a, 2006b]
- E ring grains extend past Titan's orbit
- Lifetimes of micron-sized particles [Horanyi et al., 2008]
  - 50 years at 4 Rs
  - 200 year at 20 Rs





# Enceladus Plume Lifetime

- Modeling of Cassini Cosmic Dust Analyzer (CDA) data indicates that Enceladus geysers supplying E ring material at approximately constant rate for last 300 years [Horanyi et al., 2008]
- Plume is likely to be active when LIFE spacecraft arrives

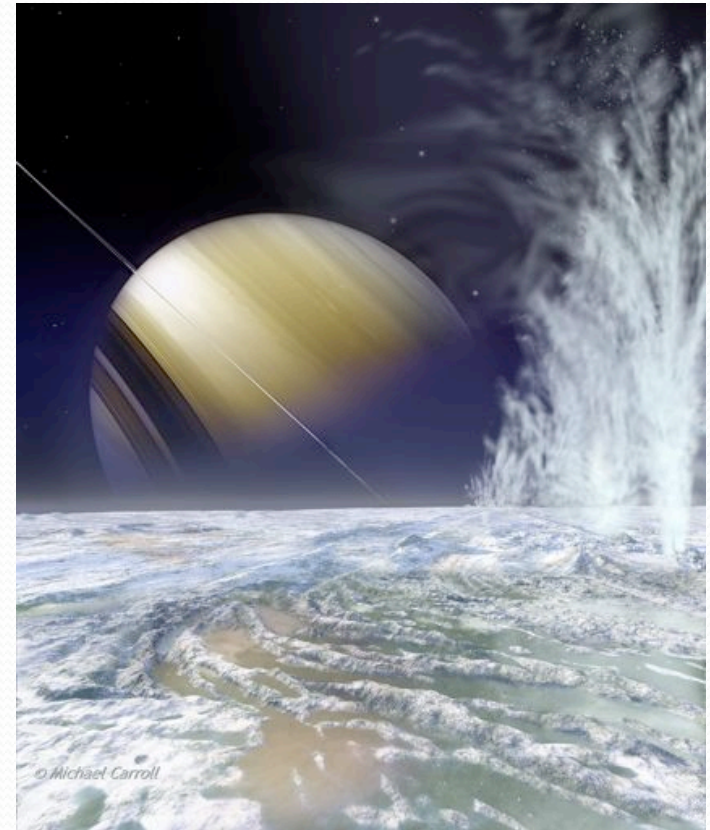


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# Why Enceladus Now?

- Comet or asteroid sample return valuable but numerous targets are available
- LIFE provides multiple samples of Enceladus plume and E ring
- Given 300 years of activity, plume is likely to be active when we arrive to sample it
- With organics and liquid water is there prebiotic chemistry or even life?
  - Promising target to search for life
- Prepare for future missions

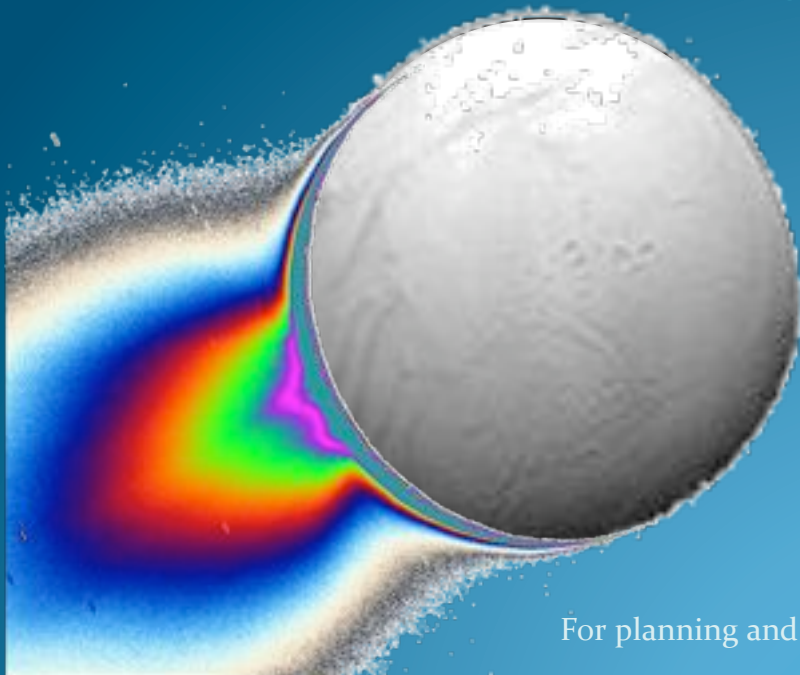




# LIFE Trajectory

*A presentation to the Satellites panel of the NRC Planetary Decadal Survey*

September 21, 2009 10:30 am  
Arnold and Mabel Beckman Center  
Irvine, CA



Nathan Strange  
JPL/Caltech

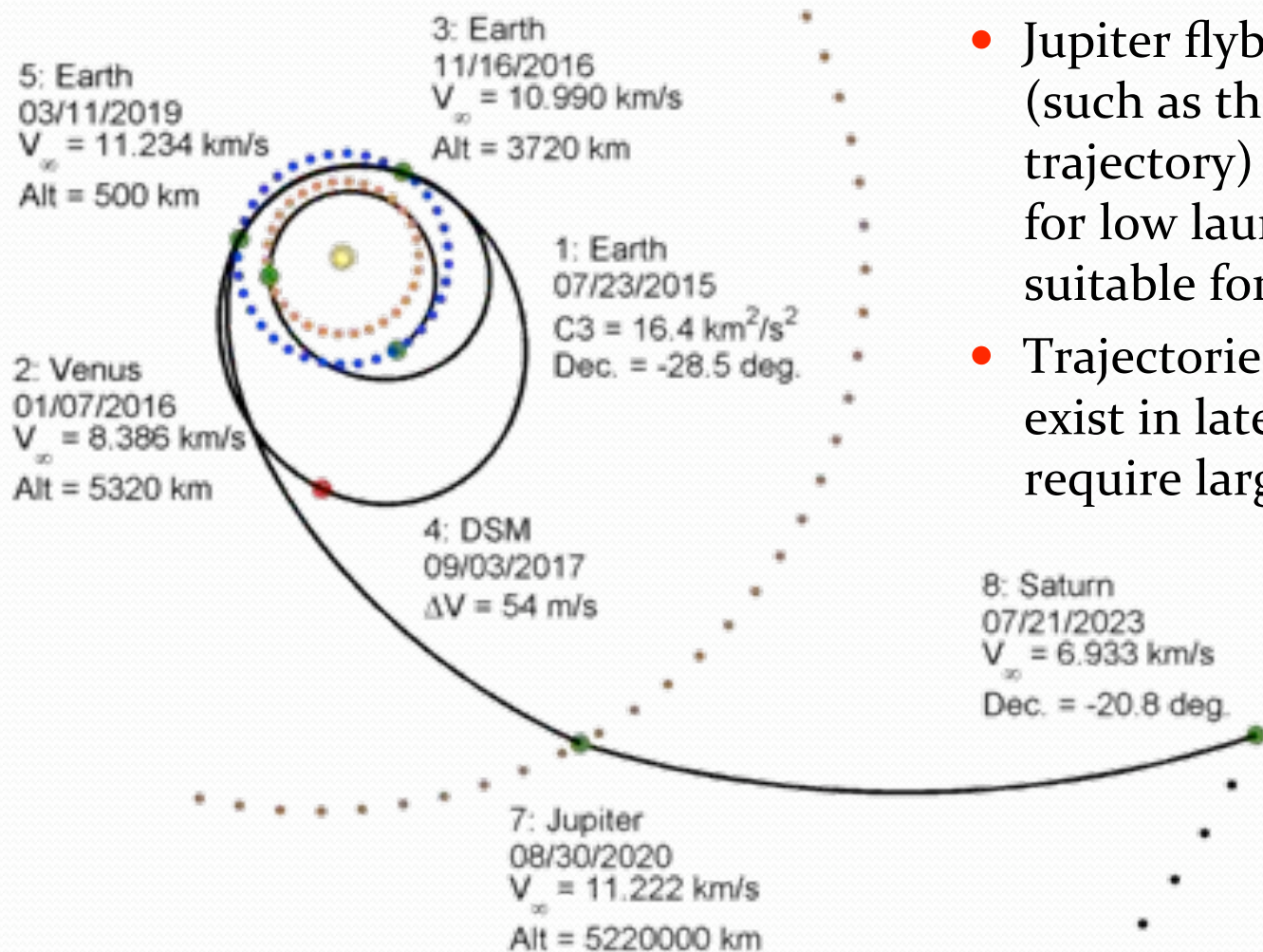
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# Trajectory Approach

- Returning a sample from Enceladus' plume has been identified as a challenging problem both by the 2007 Flagship study and the 2006 "Billion-Dollar Box" study.
- Free return trajectories either take much longer than the 14 year lifetime of RPS power supplies, or require collection speeds much higher than Stardust.
- Our solution is to find an economical way to enter and then leave Saturn orbit. This approach enables **low speed sample collection** and a total mission duration less than 14 years.

# Example 2015 launch opportunity



- Jupiter flyby opportunities (such as the this 8 year trajectory) in 2015-2019 allow for low launch energies suitable for smaller EELVs.
- Trajectories without Jupiter exist in later years, but require larger EELVs.



# Sample Collection Phase

- Samples are collected with spacecraft in Saturn orbit, this enables:
  - Sample **collection speed of 3-4.5 km/s** (which is less than Stardust's 6 km/s)
  - **Multiple plume sampling opportunities**
  - **E-ring sampling opportunities**

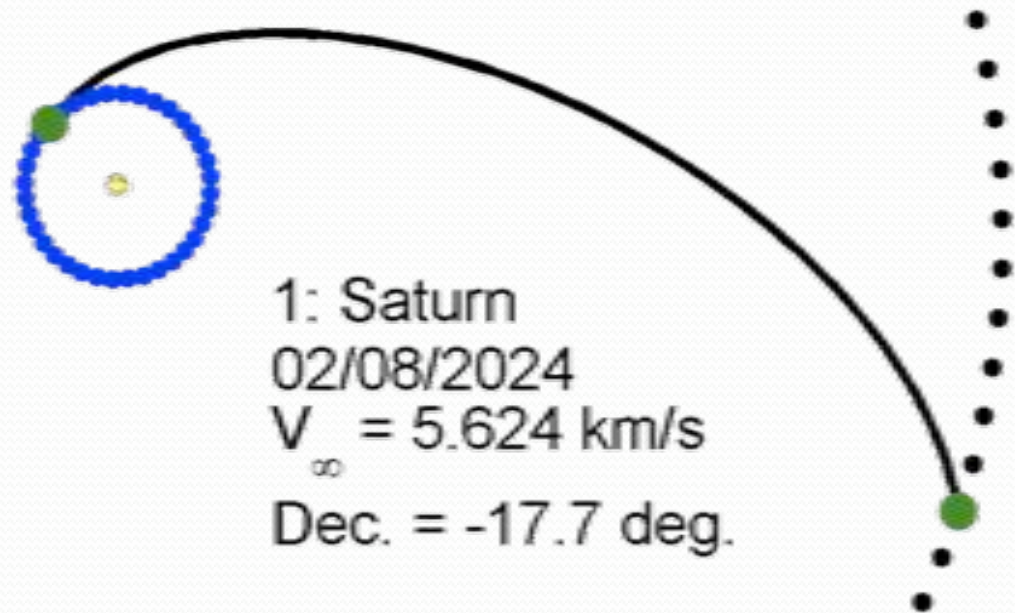


# Return Trajectory

- 5 year return trajectory enables a total mission **duration of 13.5 years.**
- Multiple return opportunities are available, allowing for a great deal of operational flexibility.

2: Earth  
02/06/2029  
 $V_{\infty} = 11.498 \text{ km/s}$   
Dec. = -5.1 deg.

1: Saturn  
02/08/2024  
 $V_{\infty} = 5.624 \text{ km/s}$   
Dec. = -17.7 deg.





# Mission $\Delta V$ and LV Capability

- Total mission  $\Delta V$  of 2.8-3.2 km/s.
- The top of this  $\Delta V$  range would allow a ~785 kg dry mass with an Atlas V 401 (the smallest Atlas V).
  - This allows more than double the STARDUST dry mass.
- The propellant mass required would be 1650 kg or less. This is less than the propellant mass carried by Juno (which carries ~2000 kg).
- The propulsion system would likely be a bi-prop system similar to that used by Juno or Mars Odyssey.

# The LIFE Mission Payload

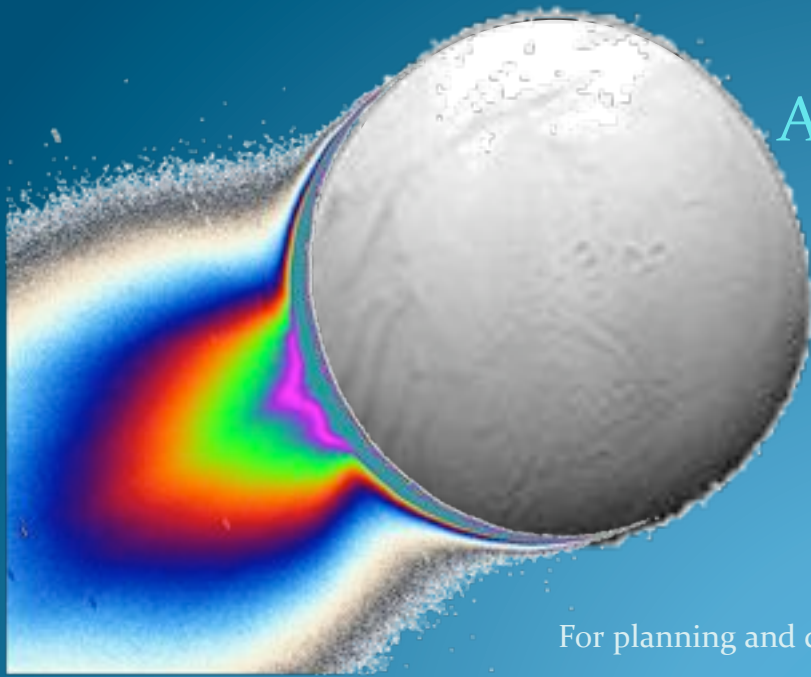
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September 21, 2009 10:30 am

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Irvine, CA

Isik Kanik (JPL/Caltech)





# Instruments

## Sample Return:

- *Aerogel collector*
- *Volatiles trap and sealed collector*

## In Situ:

- *Mass Spectrometer, e.g., ROSINA*
- *Magnetometer*
- *Navigation Camera*
- *Dust Counter, e.g., acoustic counter*
- *Plume/jets Imager - There are some possibilities. An imager that has IR is desirable so we can do some jet chemistry.*



# Objectives

## **Sample Return:**

- *Sample the plume*
  - Capture & Return to Earth (100 particles for each sample type)
  - Trap, Seal & return to Earth impinging volatiles (100 seconds)
- *Sample the E-Ring*
  - Capture & Return to Earth (100 particles for each flyby)
  - Trap, Seal & return to Earth impinging volatiles (100 seconds)

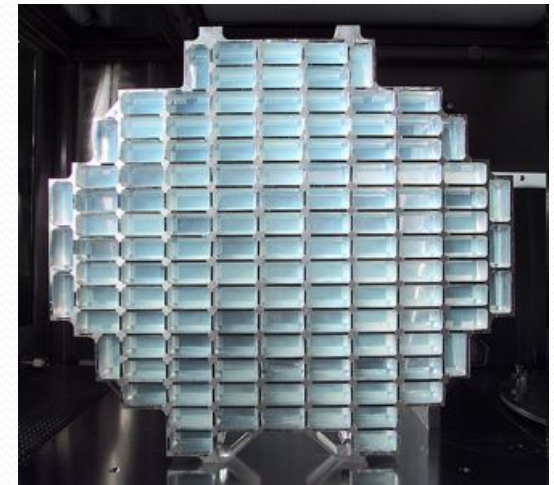
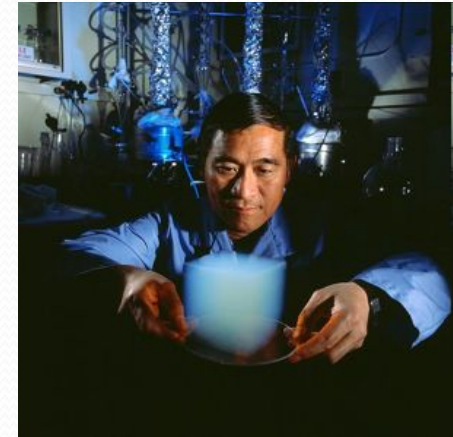
## **In Situ:**

- *Sample the plume & transmit data to Earth*
- *Sample the E-ring and transmit data to Earth*
- *Sample Titan's upper atmosphere between 800-1000km (1-2 flybys) where larger mass hydrocarbons (100-350 amu) are present*
- *Obtain imaging of the jet profile and transmit data to Earth*
- *Measure and characterize gravity field and magnetic field of Enceladus and Saturn ?*
  - Determine if a global ocean exists under the ice shell of Encaladus

# Volatiles Trap and Sealed Collector

Use the Stardust heritage but LIFE would augment the Stardust success on capturing volatiles/organics by:

- Reducing impact energy by a factor of  $\sim 8.5$  by reducing the sample capture speed to  $\sim 3$  km/s
- Reducing the initial shock energy by a factor of 4 by reducing aerogel entry density to .0025g/cc
- Maintaining sample temperature well below ( $\sim 150$ K) the sample ambient temperature, and
- Carrying a “*volatiles trapping and sealing deposition*” collector to seal the samples at capture



- The Stardust tennis racket sized collector with 90 aerogel blocks.
- $>1000$  cm<sup>2</sup> collection area was available.



# Mass Spectrometer -Rosina

- Determine the elemental, isotopic and molecular composition of the Encaladus plume and Saturn's E-Ring
- Determine density and velocity of plume particles/gases
- Sample Titan's upper atmosphere between 800-1000 km (1-2 flybys)
  - Cassini CAPS data is indicative of complex organic chemistry occurs in Titan's upper at (larger hydrocarbons with 100-350 amu)

ROSINA consists of:

- 1) a double focusing magnetic mass spectrometer (**DFMS**) with a mass range from 1-150 amu
- 2) a reflectron type time-of-flight mass spectrometer (**RTOF**) with a mass range of 1 to >300 amu
- 3) two pressure gauges (**COPS**) to provide density and velocity measurements

## Specs:

- Wide mass range (1 Da to >300 Da)
- Very high mass resolution ( $m/\Delta m > 3000$  - ability to resolve CO from N<sub>2</sub> and <sup>13</sup>C from <sup>12</sup>CH)
- Very wide dynamic range (10<sup>8</sup>)
- High sensitivity (10<sup>-3</sup> A/torr)

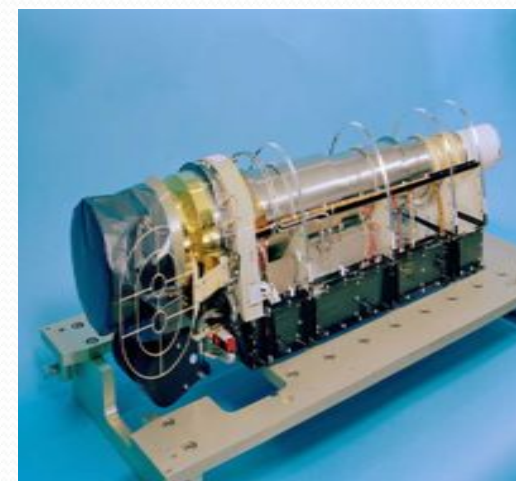
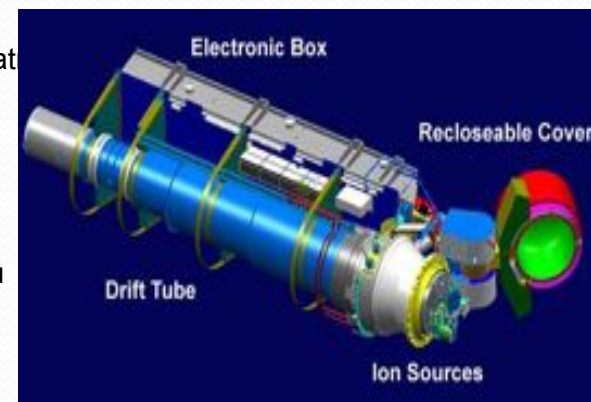
Unit	Mechanical dimensions (cm)	Mass (kg)	Mean power (W)
DFMS	63 × 63 × 26	16.2	19
RTOF	114 × 38 × 24	14.7	24
COPS	26 × 26 × 17	1.6	3

**Total**

**32.5**

**46**

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# Magnetometer

Magnetometers are direct-sensing instruments that detect and measure the strength of magnetic fields in the vicinity of the spacecraft. They allow you to 'see' inside planets such as Saturn and moons such as Enceladus," by measuring the magnetic field.

- We envision that LIFE would use a magnetometer similar to the Cassini Magnetometer (MAG).

- Low mass ~ 3 kg
- Low power ~ 3 W

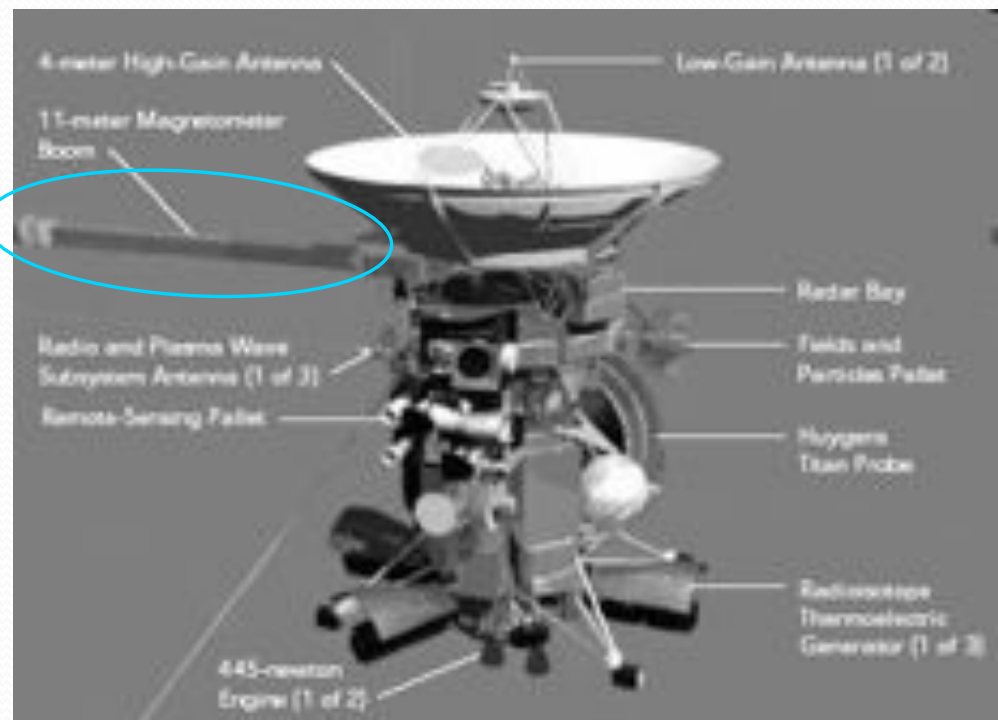
- Objectives:

- **Characterize Saturn field**

- time variation
    - spatial variation

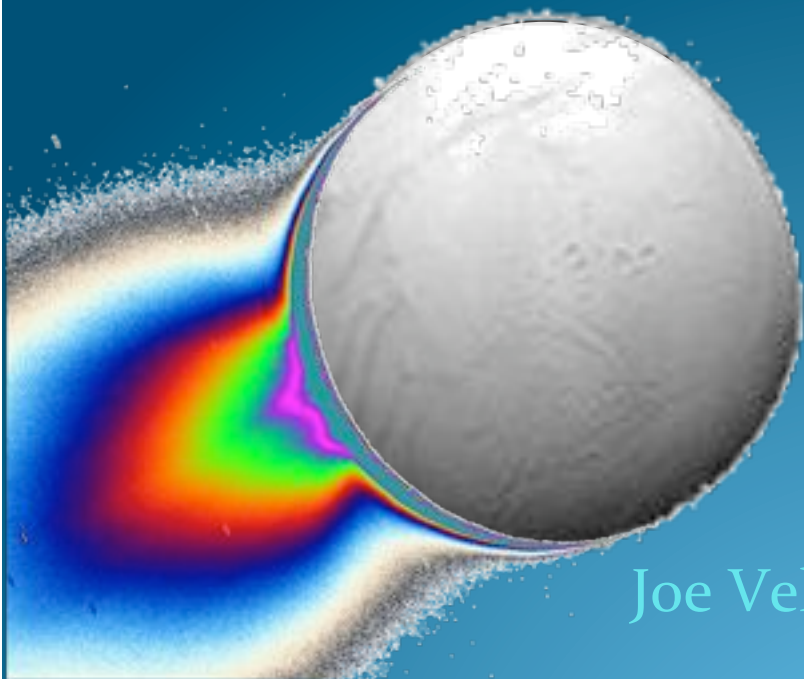
- **Characterize Enceladus field**

- global subsurface ocean?
    - intrinsic field
    - magnetic materials



# Costing

*A presentation to the Satellites panel of the NRC Planetary Decadal Survey*  
September 21, 2009 10:30 am  
Arnold and Mabel Beckman Center  
Irvine, CA



Joe Vellinga (Lockheed Martin Space Systems)  
Peter Tsou (JPL-Caltech)



# LIFE Cost Approach

- No funded cost analysis, but analogies with past missions (i.e. STARDUST, NEAR, and Juno) show that there is potential for a low cost sample return mission.
- Keys to keeping cost low:
  - Emphasis on maintaining similarities to proven STARDUST sample collection system
  - Emphasis on keep operations costs low, particularly during interplanetary cruise using spacecraft hibernation methods like those on New Horizons
  - Infusing the entire project with a top-to-bottom “Design to Cost” philosophy as was done on STARDUST



# “Billion Dollar Box” Costing

- The “Billion Dollar Box” (BDB) study estimated that an Enceladus plume sample return would be a small flagship, costing from \$1.3B to \$1.8B (FY06).
- However, the LIFE concept has addressed two of the cost drivers in the BDB study:
- We expect LIFE to cost less than the BDB estimate.



# Design to Cost Was Accomplished

- **STARDUST On-cost & On-schedule**
  - \$164M Cost Commitment (w/o LV): \$1M Cost Reserve Left at Launch Rolled Over from Phase C/D to Phase E
  - Design Had to Evolve Considerably from Initial Proposal BUT Cost was Driver in all Design Changes
  - Opportunities to Improve Science & Instrument Heatshield were NOT Adopted because of Cost Impact/Risk
  - Cost-to-Go Reserve of 10% was Maintained – Uncommitted Reserve Applied to Reducing Risk, Particularly in ATLO



# Recommendation

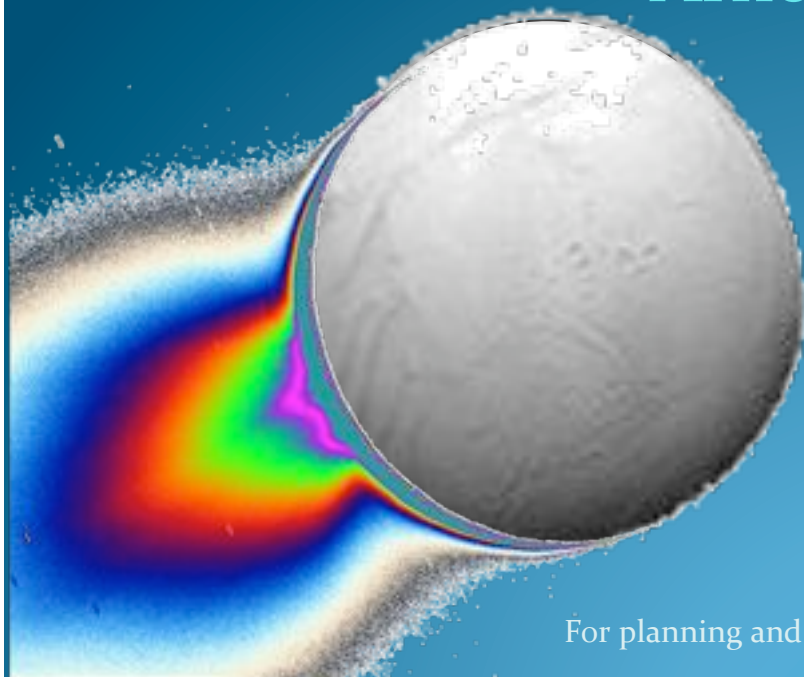
- An In-Depth Study of LIFE like missions
  - “Design to Cost” Mindset, not “business as usual”
  - Step Cost
    - Baseline: Samples kept at ambient temperature
    - Multiple Sampling: Several sample flybys
    - Frozen: Samples kept at cryotemperature
    - In Situ: Samples plus in situ instrumentation
    - Titan Aerosol: Upper Atmospheric Samples



# LIFE Trajectory

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Irvine, CA



Don Brownlee  
University of Washington

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# The Importance of Samples

- Samples can be studied by the best possible methods
- Samples studied by many groups & many methods
- Samples are a long-term resource
- Analysis methods not limited by present technology
- Analysis methods not limited by pre-conceived plans



# Plume samples captured in aerogel

Components trapped even at room-temperature preservation state

- Dissolved salts
- Dissolved organics
- Insoluble particulates



# What Stardust found in comet samples

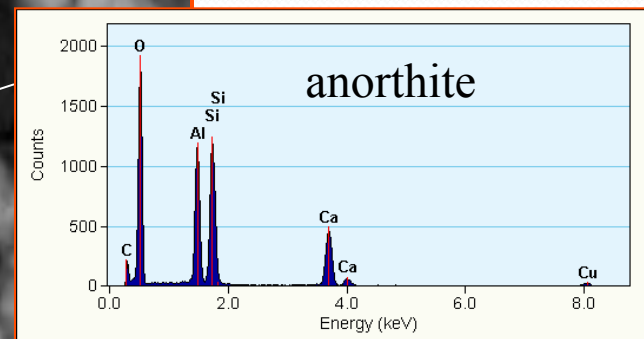
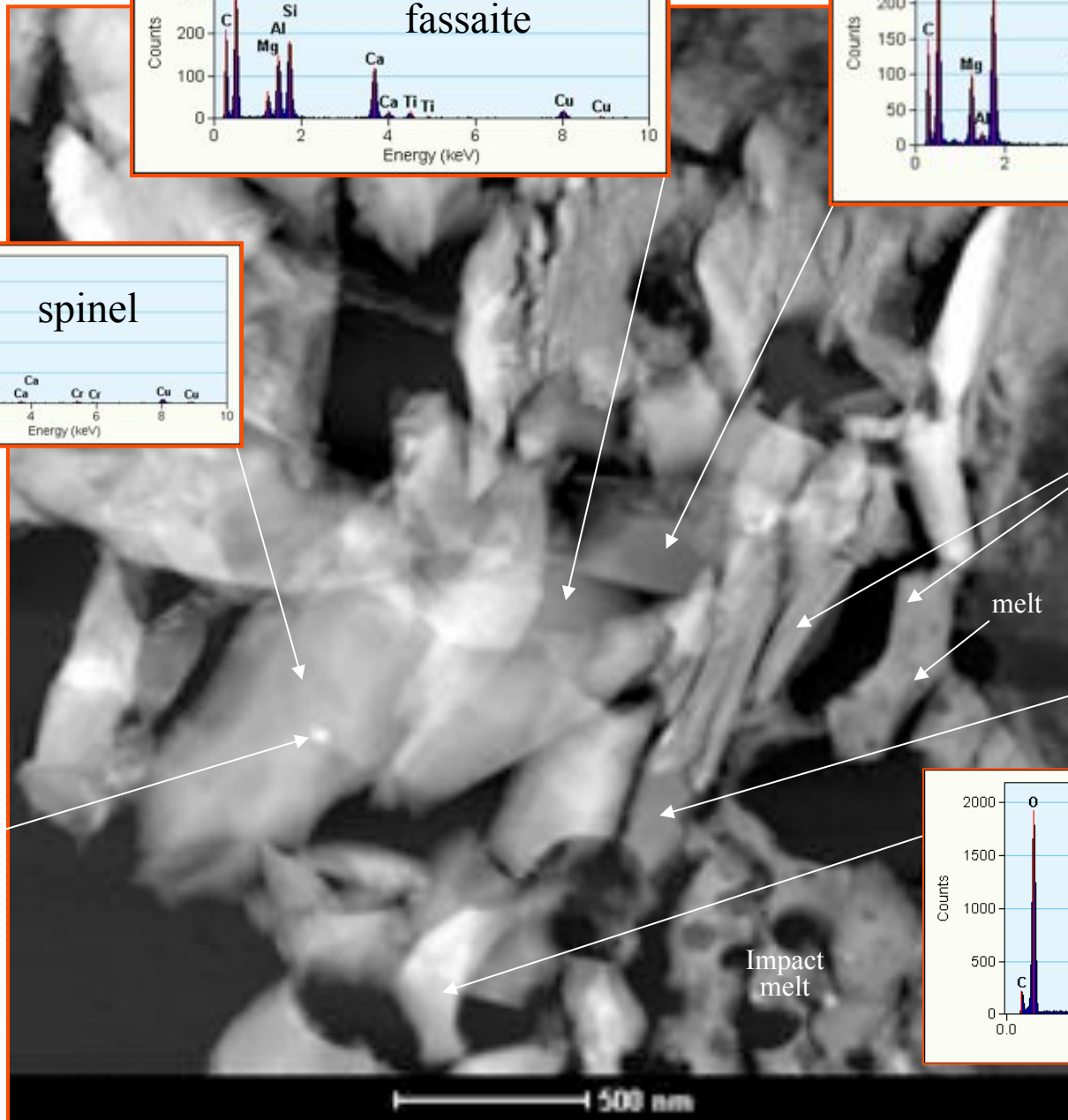
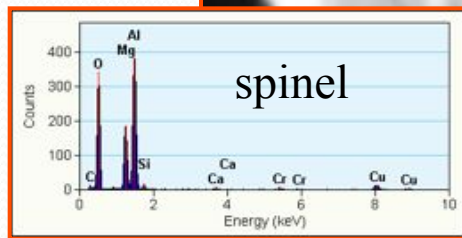
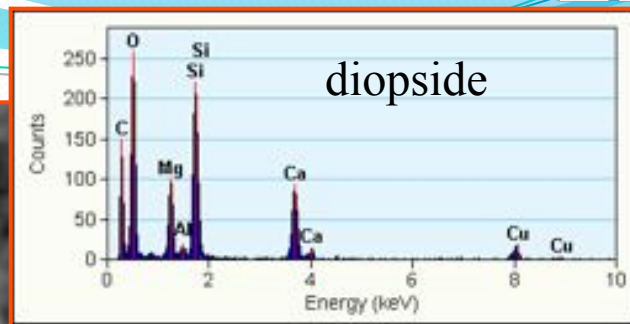
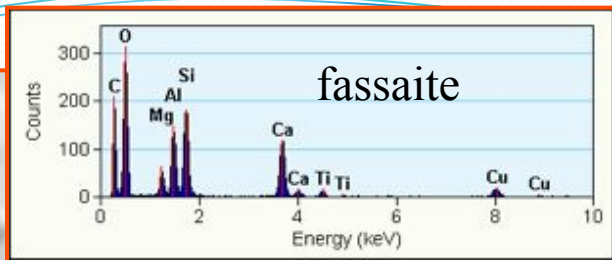
(that could not have been found w/o return)

*partial list*

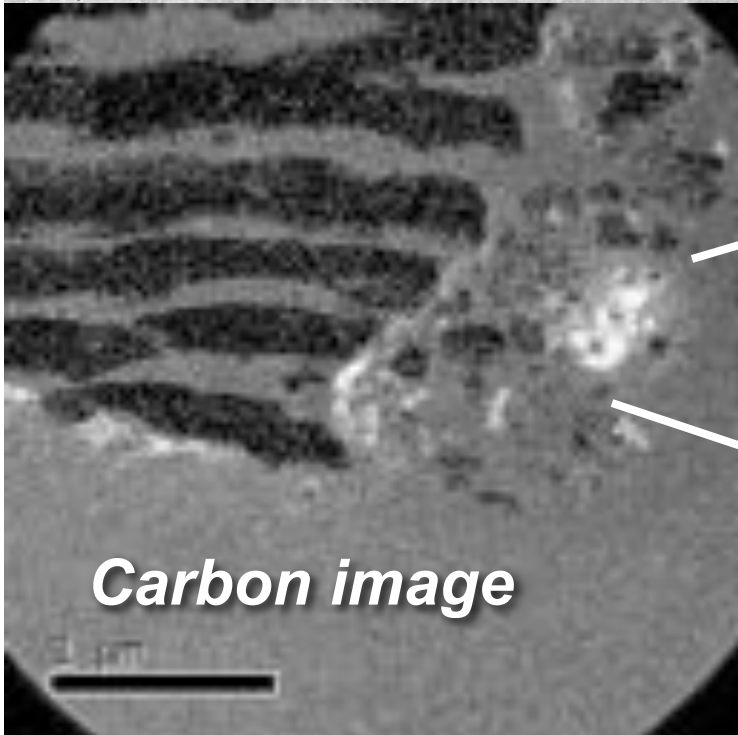
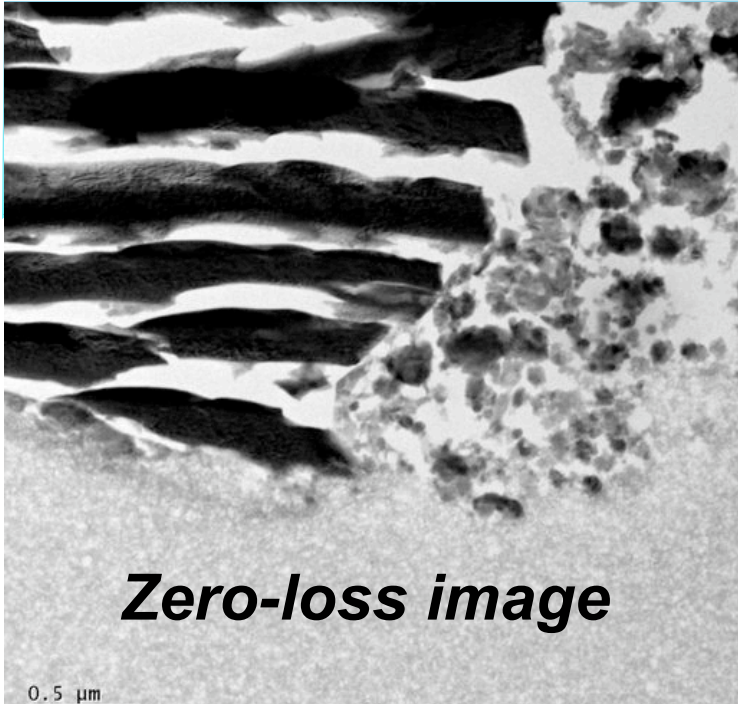
- Pre-solar grains in low abundance (<200 ppm)
- Comet rocks
  - dominated by high temperature materials that formed in the solar nebula
- Chondrule & Calcium Aluminum Inclusions
  - proof of large-scale mixing in nebula disk
- Coarse-grained rocks are common
- CAI refractory minerals contain nm “first condensates”  
(Ti,Va)N & Mo, W, Pt alloys
- Most cometary organics are <sup>15</sup>N rich
- Glycine exists in comet Wild 2



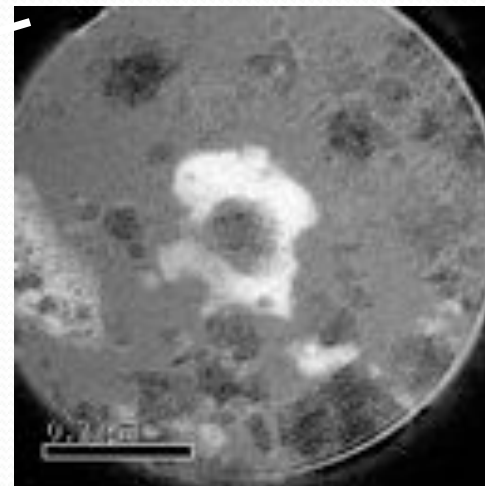
# Inti - HAADF image



***Energy filtered imaging  
of Febo***

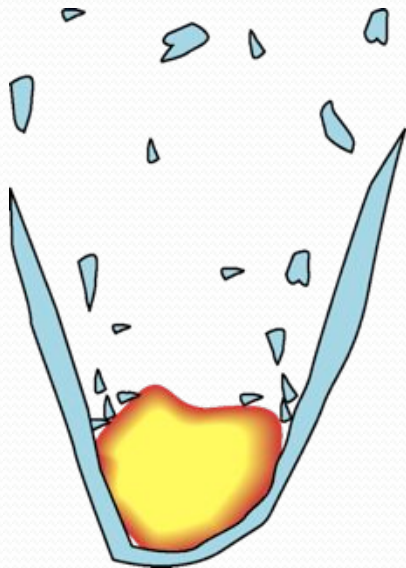


*Organic carbon  
with N and Fe* Or



## Aerogel Capture effects

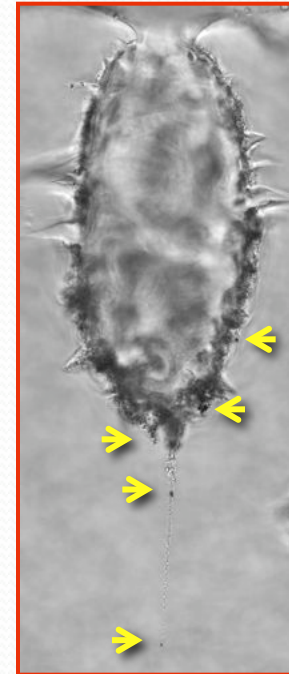
All micron- sized Stardust particles made deep tracks and had well preserved components



Deceleration process

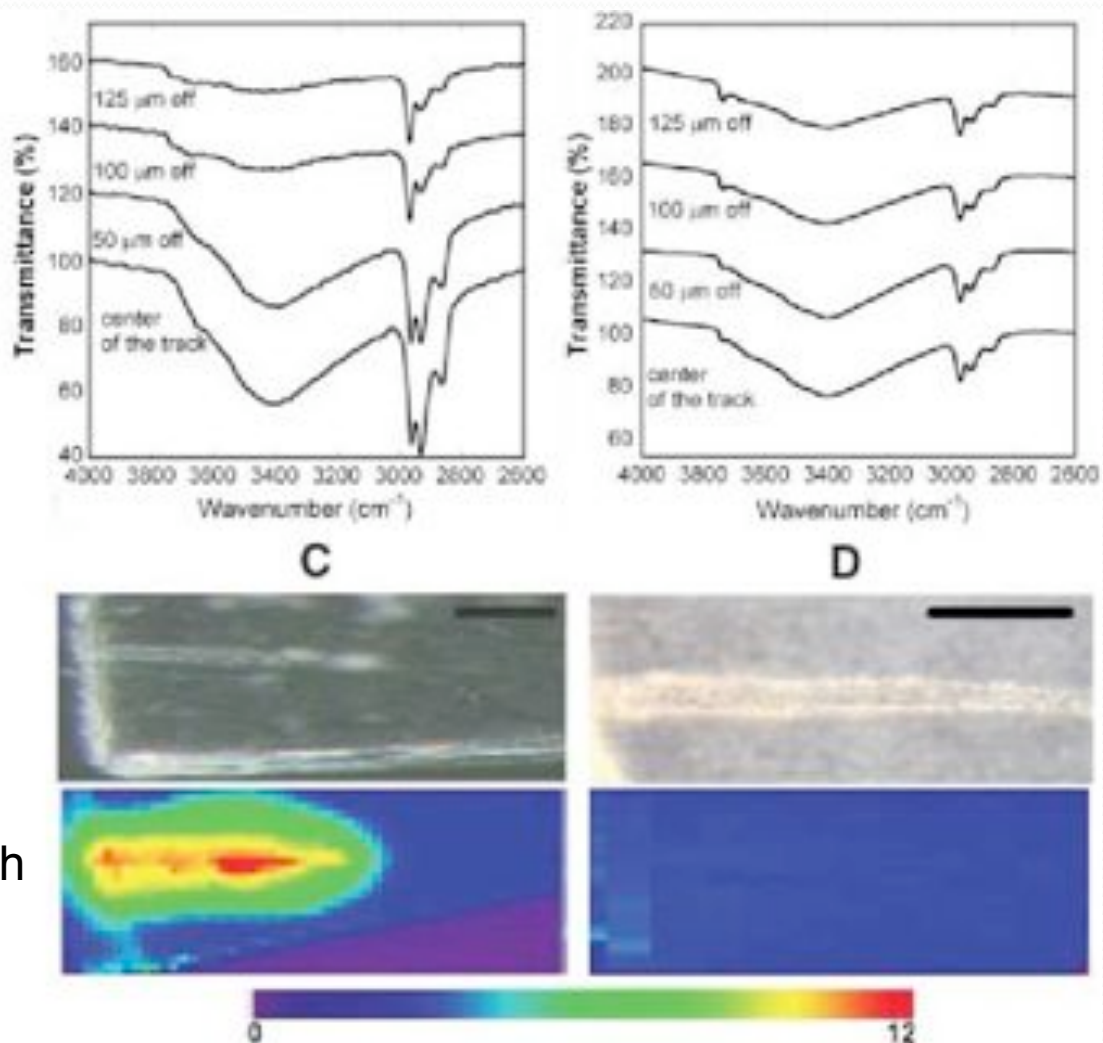


Strong particle

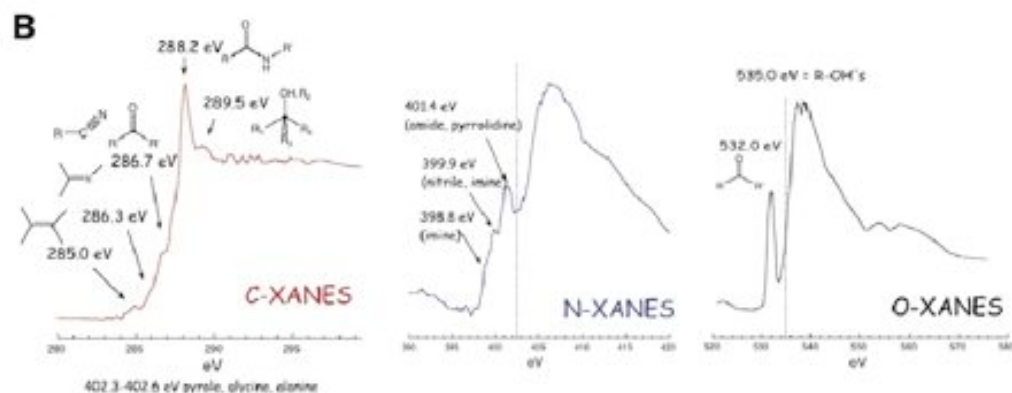
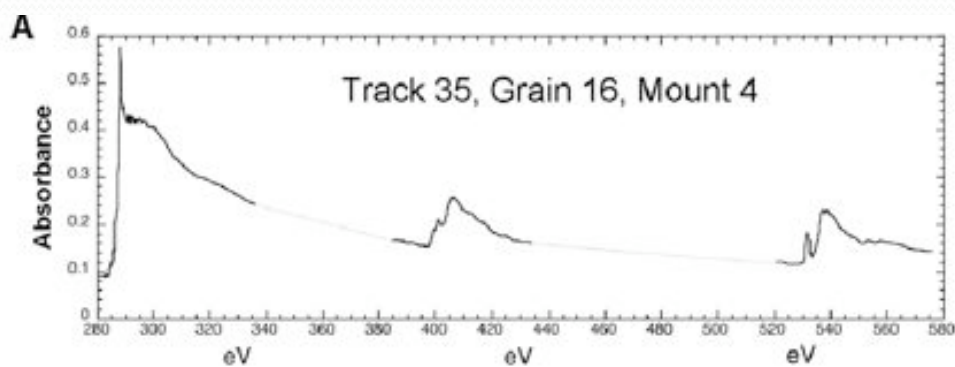
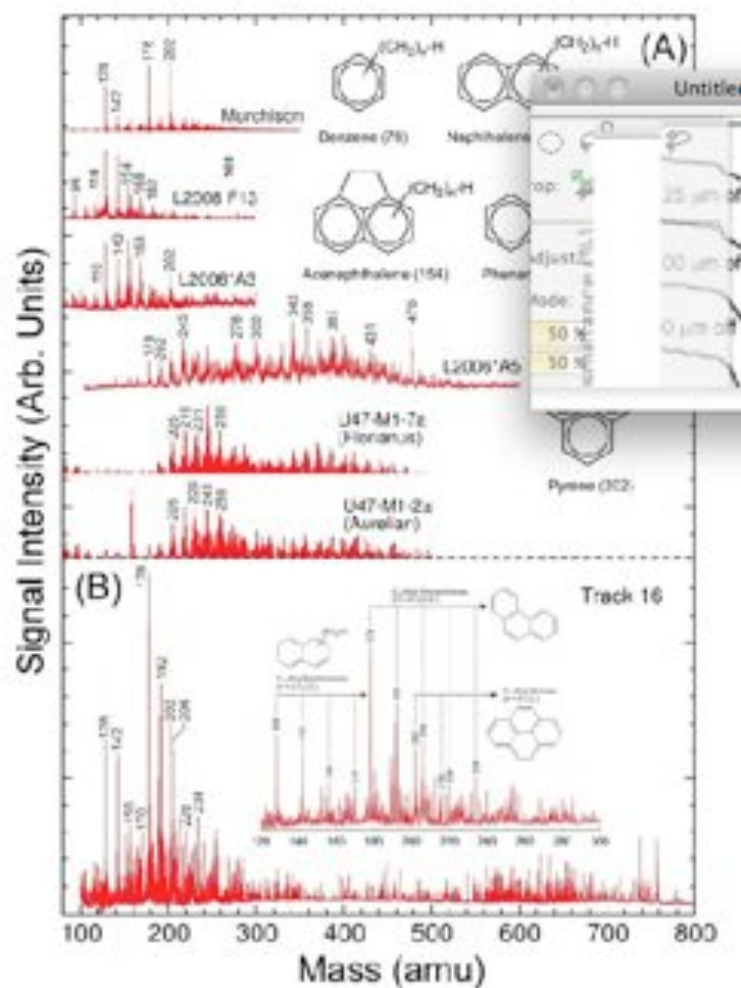


Weak particle

# Mobilized organics in tracks



# Analysis of returned cometary organics





ET Glycine discovered  
In comet Wild 2  
>3 years after sample return

**Elsila et al 2009**

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### From a Distant Comet, a Clue to Life



NASA's sample return capsule contained comet and interstellar samples gathered by the Stardust spacecraft.

By KENNETH CHANG  
Published: August 18, 2009

For the first time, a building block of proteins — and hence of life as we know it — has been found in a comet.

SIGN IN TO RECOMMEND

TWITTER



## What LIFE can provide

Samples of Enceladus ejecta

Captured at ~3 km/s in lowest density aerogel

Stardust captured comet samples

At 6.1 km/s

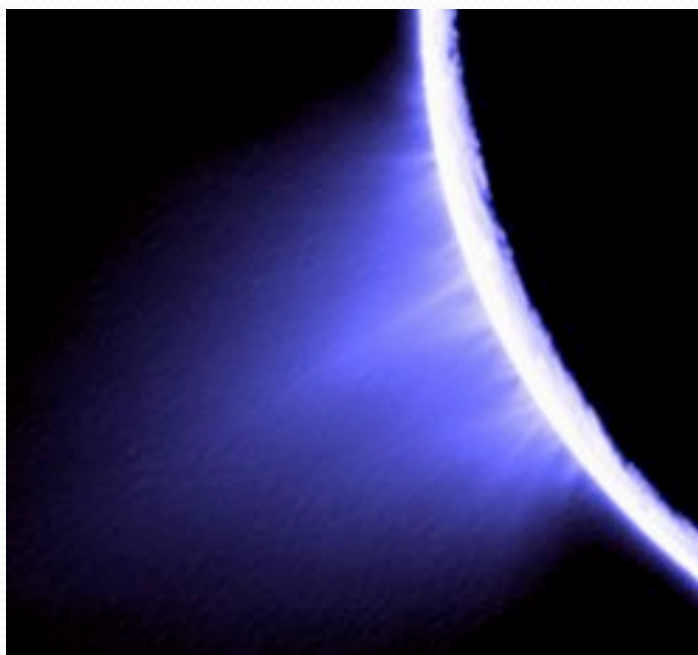
In aerogel > 5-10mg/cc

Power generated during capture  $\propto$  (aerogel density)  $\cdot$  (velocity)<sup>3</sup>

Enceladus capture can be vastly more gentle than for Stardust



**LIFE can collect particulate matter from  
Enceladus plumes and return them to Earth  
For Laboratory analysis!**



For planning and discussion purposes only





# Recommendation

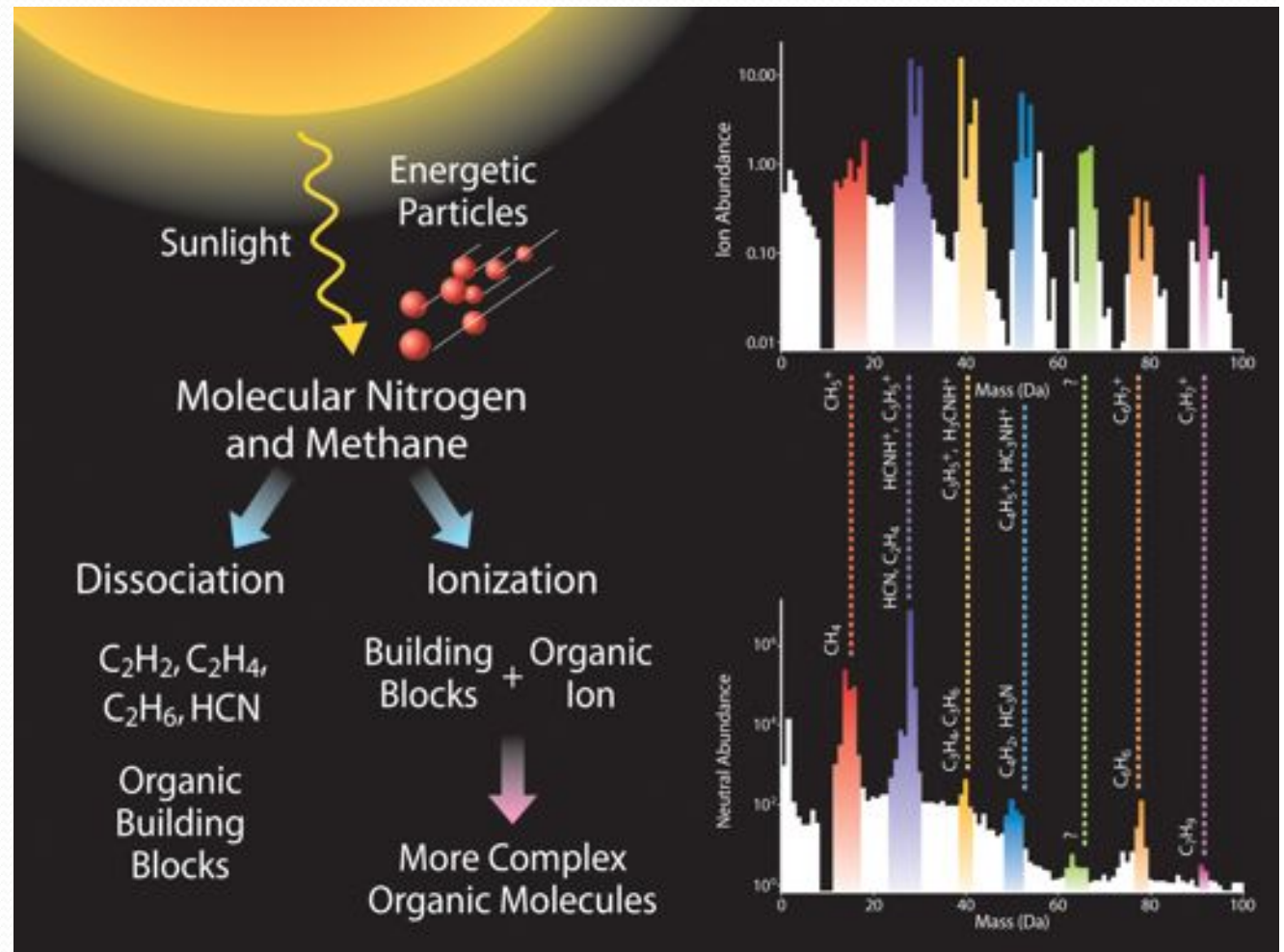
- Enceladus provides a unique opportunity to sample a region of high astrobiological potential from flybys.
- We recommend that the panel commission an in-depth study to provide clear science return vs. cost options.



# Backup Slides

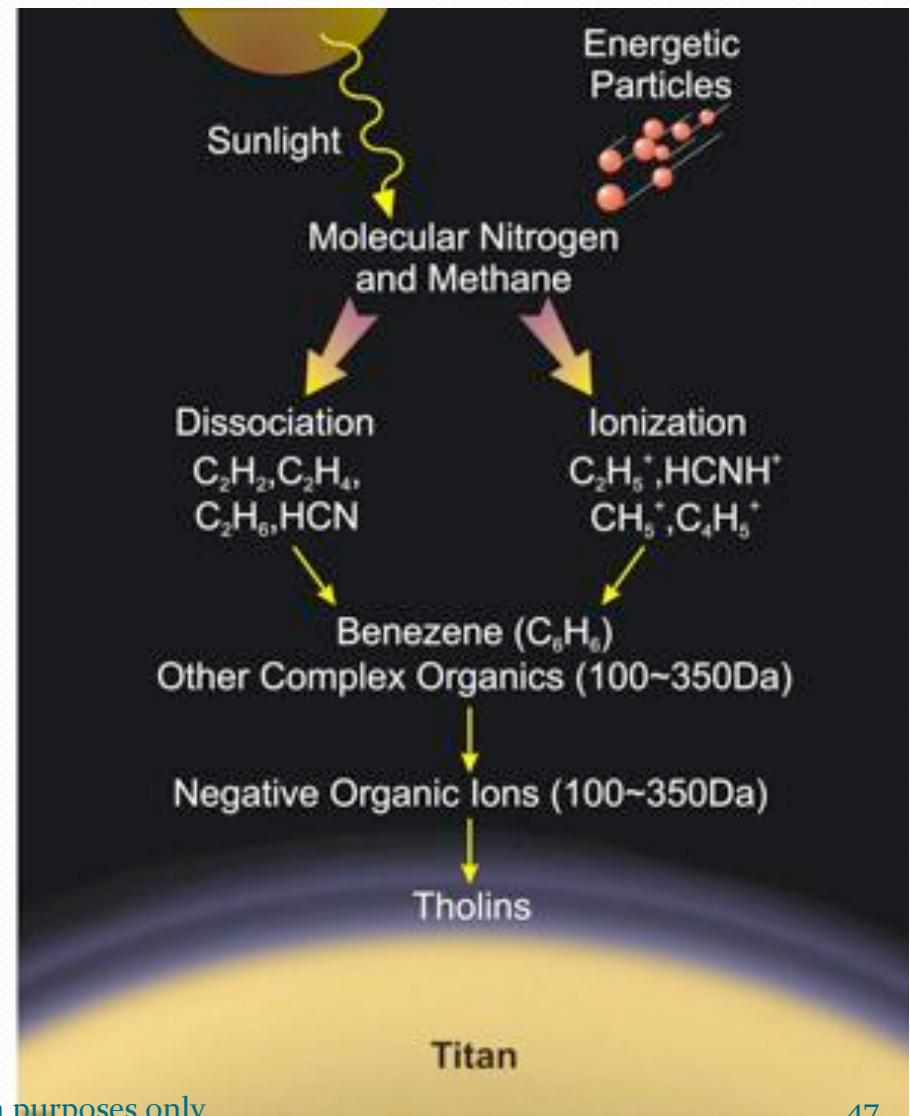
# Titan Atmospheric Composition

- Nitrogen and methane dissociated by sunlight and energetic particles
- Complex organics exist as ions and neutrals in Titan's upper atmosphere

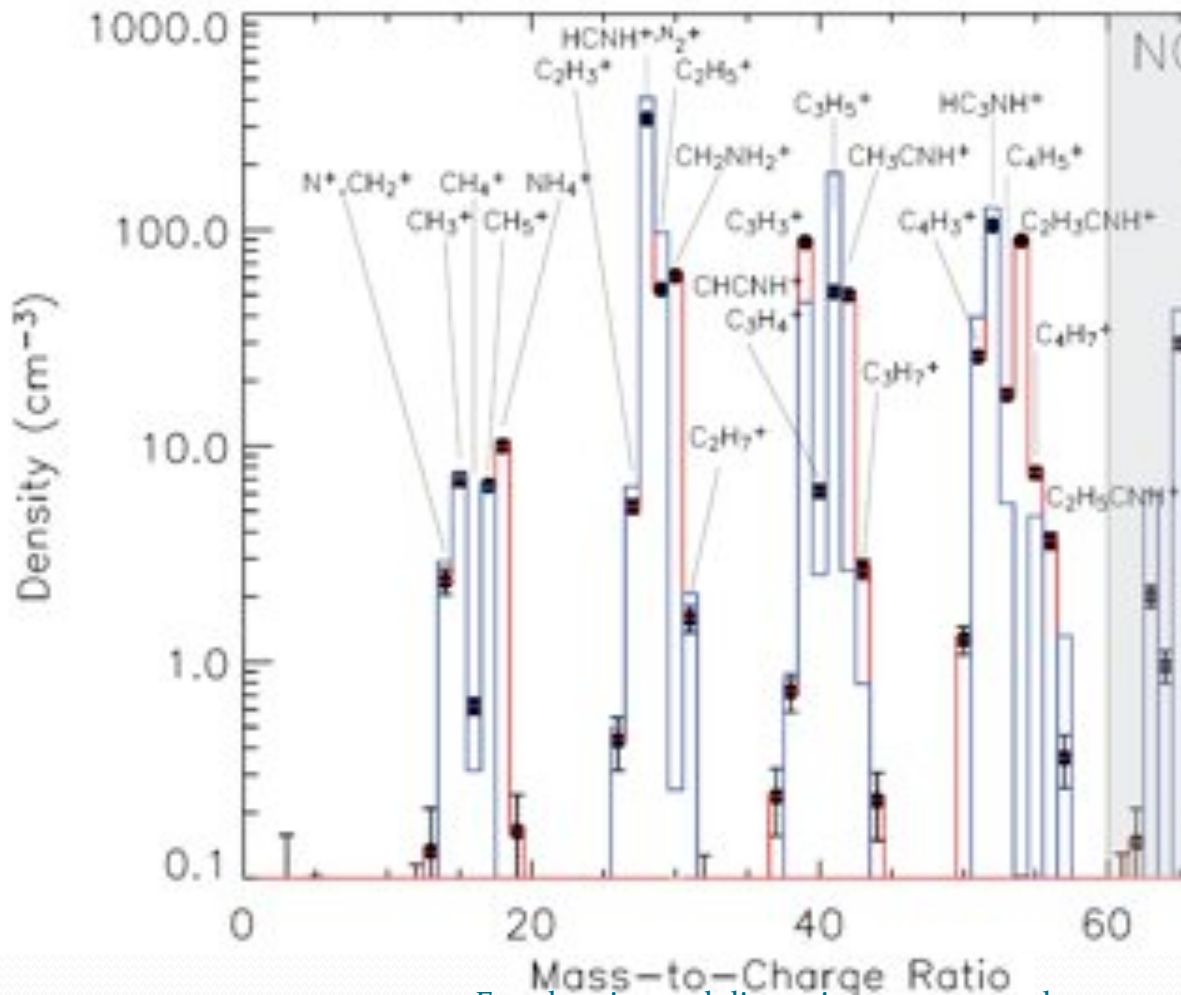


# Tholin Production on Titan

- Complex organic chemistry occurs in Titan's upper atmosphere
- Tholins form and rain down on Titan, perhaps creating dunes
- Measure tholin composition
- Return samples of tholins



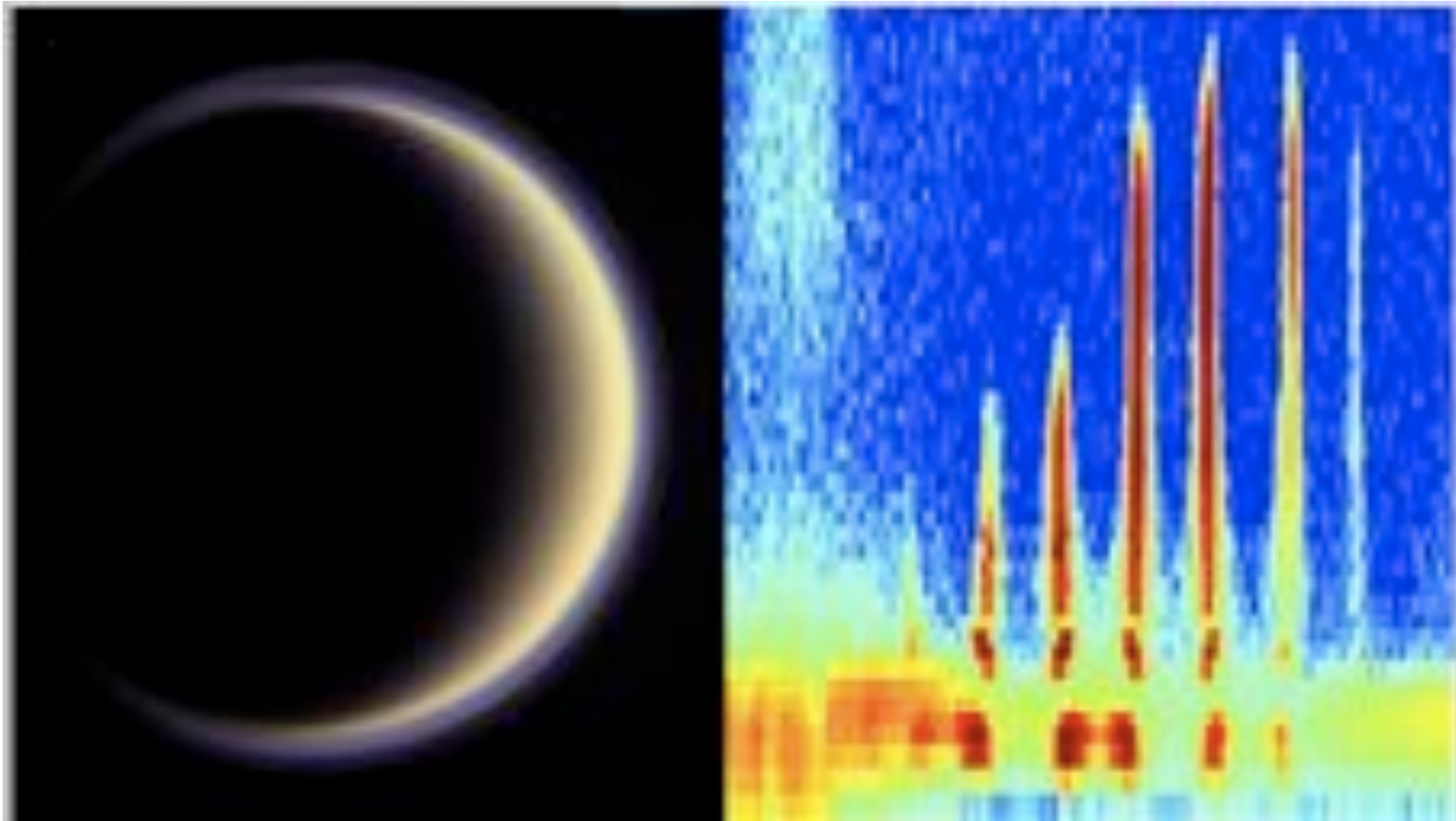
# Titan Atmospheric Composition



	mole fraction
$C_2H_4$	$6 \times 10^{-3}$
$C_4H_2$	$6 \times 10^{-5}$
HCN	$2 \times 10^{-4}$
$HC_3N$	$2 \times 10^{-5}$
$CH_3CN$	$1 \times 10^{-5}$
$C_2H_3CN$	$1 \times 10^{-5}$
$C_2H_5CN$	$5 \times 10^{-7}$
$NH_3$	$7 \times 10^{-6}$
$CH_2NH$	$< 1 \times 10^{-5}$

For planning and discussion purposes only

# Negative Ions in Titan's Ionosphere

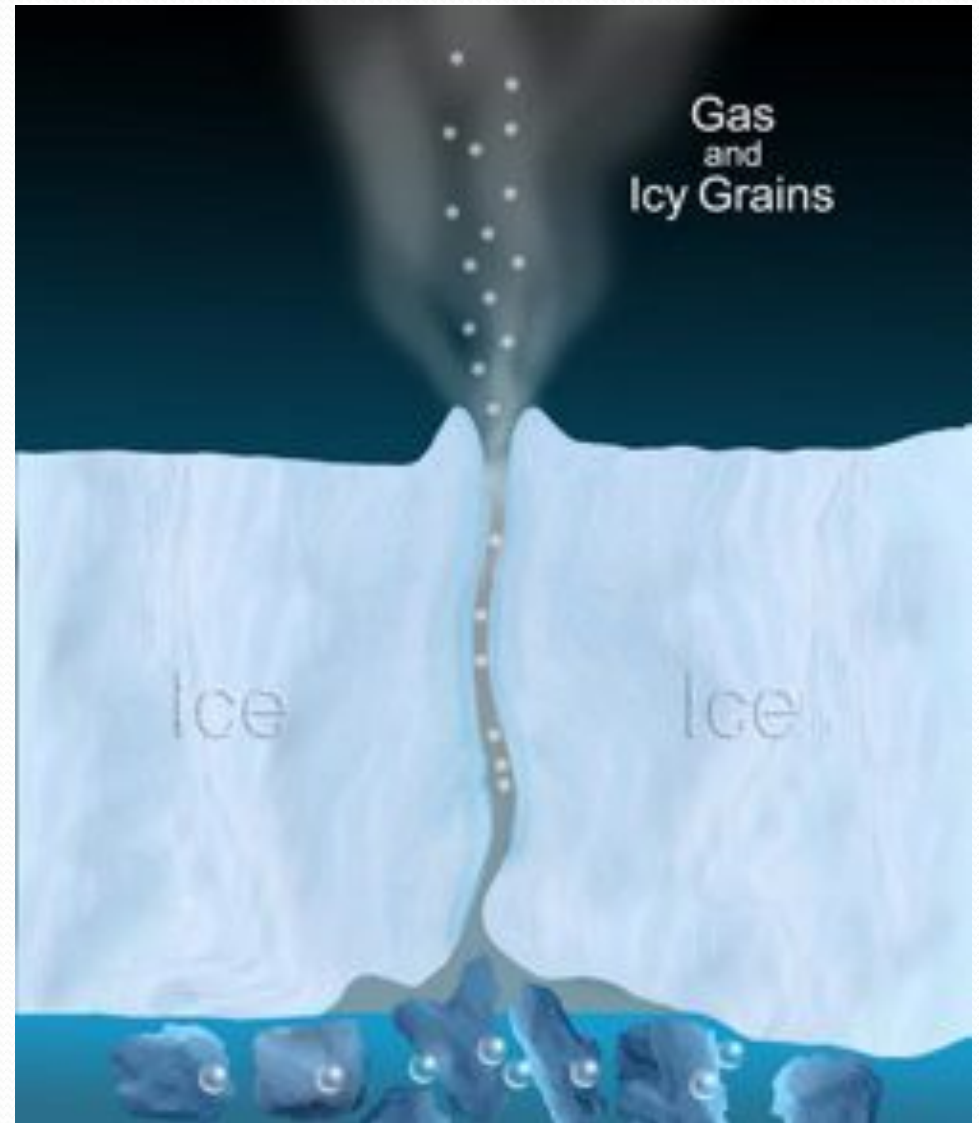


- Discovery of large numbers of heavy (masses up to 10,000 amu) negative ions. Heavy ion chemistry takes place in Titan's upper atmosphere at altitudes much higher than had been predicted by models. Coates et al., Geophysical Research Letters, Nov. 2007

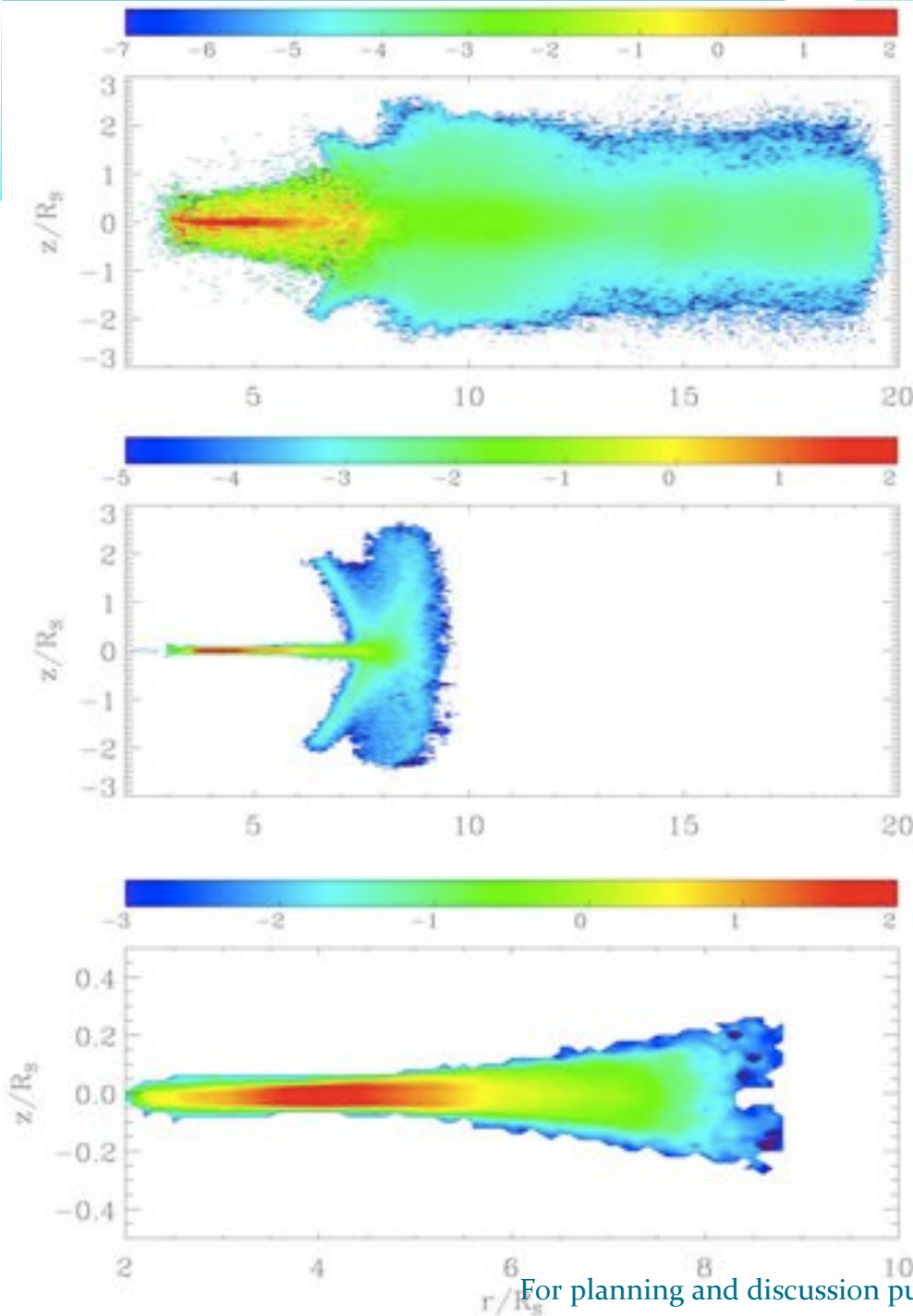
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# Plume Source?

- Boiling of near-surface liquid water ? (Porco et al. 2006)
  - Easy way to make ice particles
  - Why near-surface liquid?
- Warm vapor from frictionally-heated ice? (Nimmo et al. 2007)
  - Can give right numbers for heat flow, vapor production
  - Requires ocean at depth
- Decomposing clathrates? (Kieffer et al. 2007)
  - Explains other gases in plume
  - Hard to explain water vapor
- Dense condensing vapor from deep H<sub>2</sub>O reservoir? (Schmidt et al. 2008)
  - Explains number and speed of ice particles



# E ring grains: Density distribution



- Radii in microns:
  - Top:  $0.1 < r_m < 0.5$
  - Middle:  $0.5 < r_m < 1$
  - Bottom:  $1 < r_m < 3$
- Smallest particles reach Titan orbit
- Largest grains remain in classical E ring

From Horanyi et al., 2008