Enceladus: Results from Recent Cassini Flybys of the Active Moon

CHARM telecon

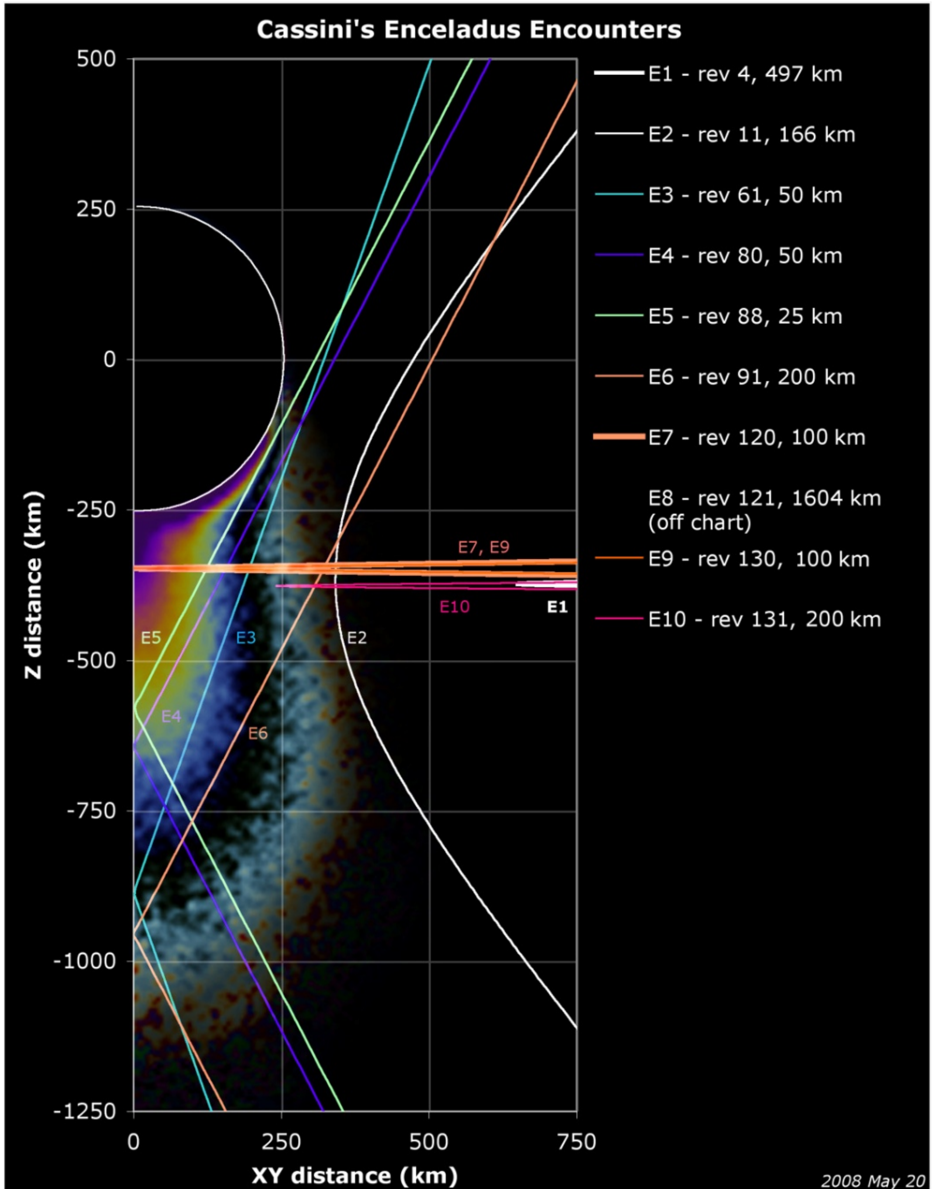
25 November 2008

Paul Helfenstein

Sascha Kempf

John Spencer

Overview of Recent Enceladus flybys



Rev 11 (E2): 14 July 2005

168 km altitude flyby, with closest approach at 16° S/332° W. The flyby when geologic activity was discovered.

Rev 61 (E3): 12 Mar 2008

50 km altitude flyby, with closest approach at 15° S/92° W. MAPS flyby.

Rev 80 (E4): 11 August 2008

50 km altitude flyby, with closest approach at 28° S/98° W

Rev 88 (E5): 9 Oct 2008

25 km altitude flyby, with closest approach at 28° S/97° W

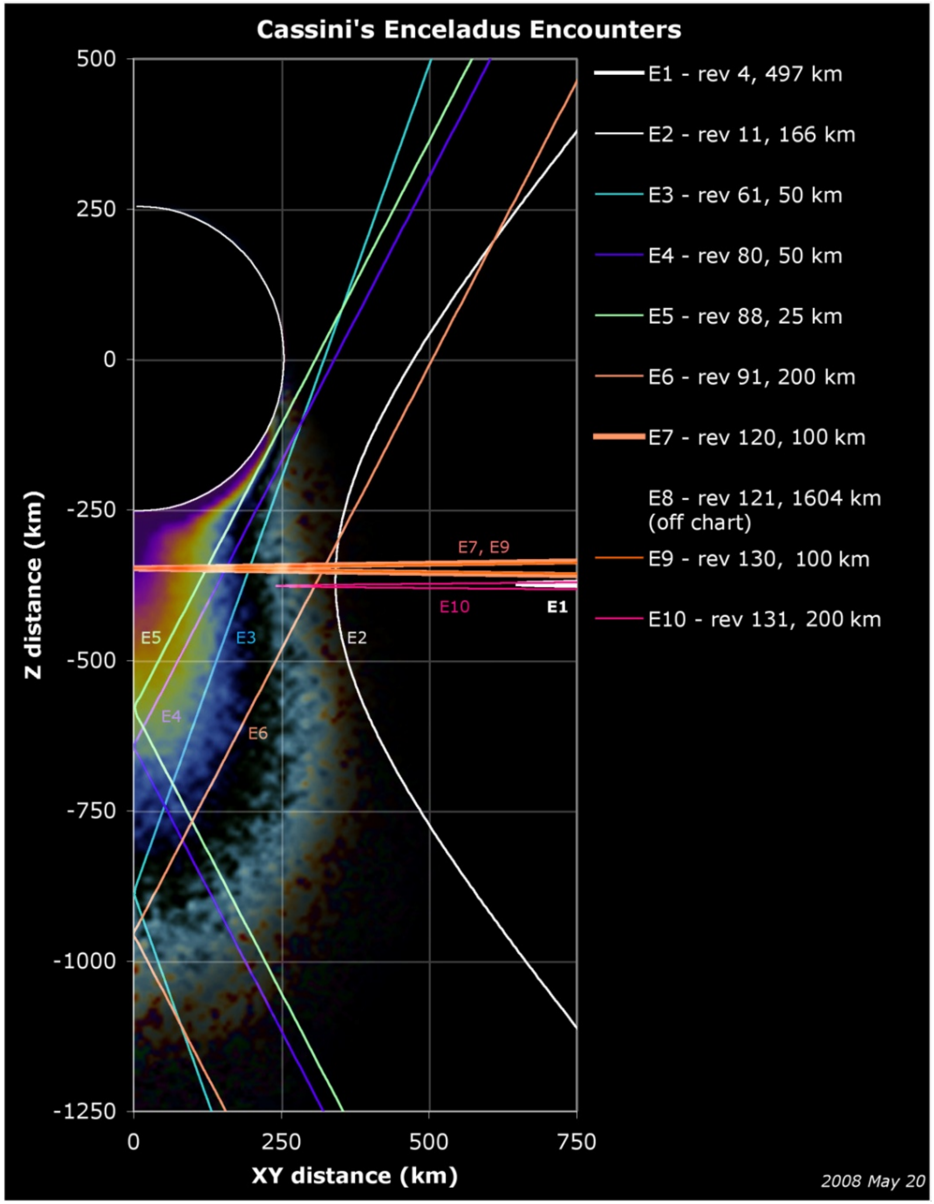
Rev 91 (E6): 31 Oct 2008

200 km altitude flyby, with closest approach at 28° S/97° W

Science from the Flybys

- All 12 Cassini instruments have obtained important data from Enceladus that will ultimately provide many clues to its surface composition, interior structure, evolution, and plume activity
- Here we focus on Imaging, Thermal and Dust results.

Future Enceladus flybys



Rev 120 (E7): 2 Nov 2009

100 km altitude flyby, with closest approach at 88° S/339° W. MAPS at C/A - plume fly-through.

Rev 121 (E8): 21 Nov 2009

1600 km altitude flyby, with closest approach at 82° S/117° W. ORS flyby.

Rev 130 (E9): 28 April 2010

100 km altitude flyby, with closest approach at 88° S/147° W. Radio science flyby.

Rev 131 (E10): 18 May 2010

200 km altitude flyby, with closest approach at 59° S/304° W. UVIS solar occultation at C/A.

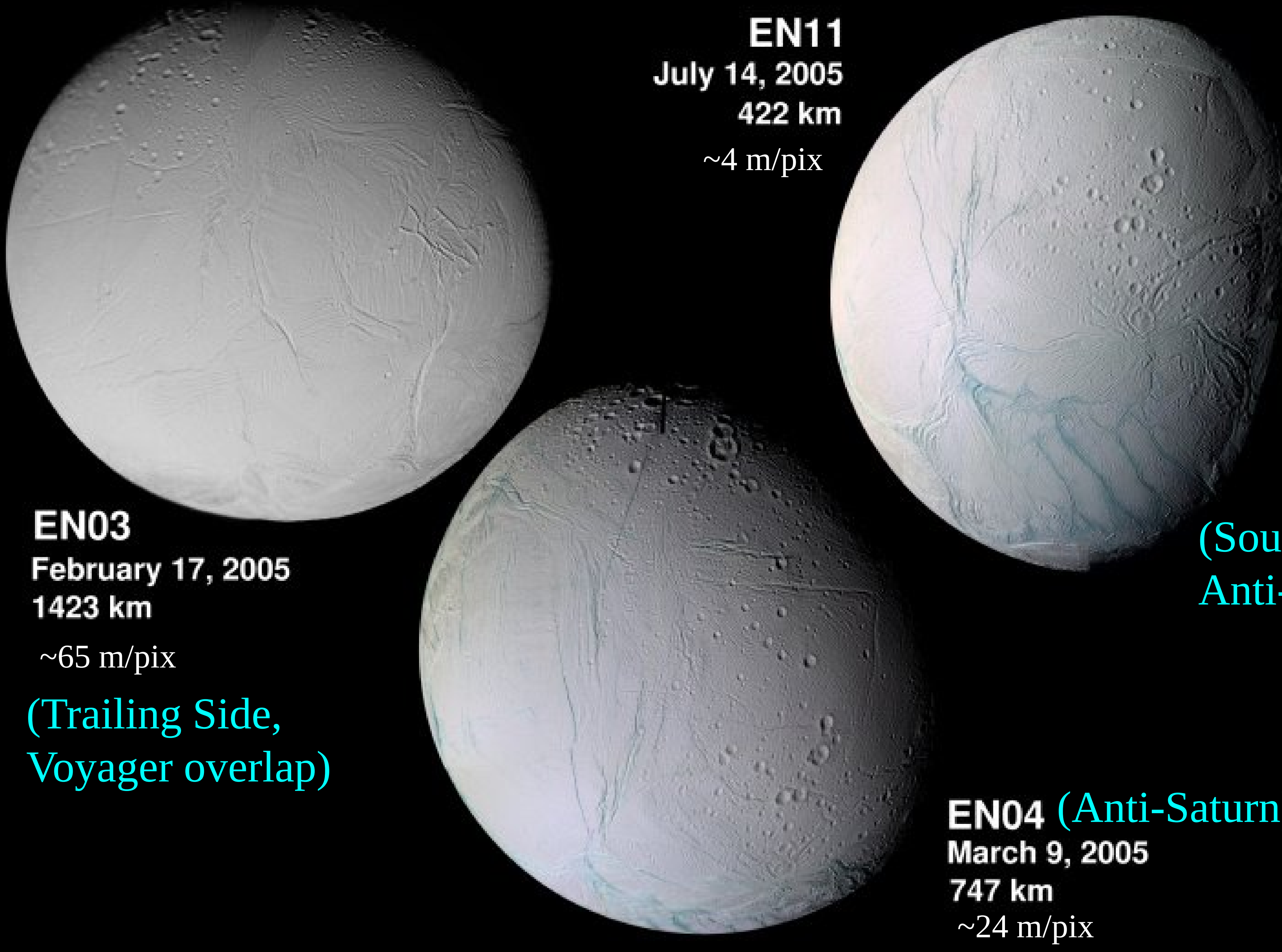
Stay tuned for more exciting results!

Cassini High-Resolution Imaging of Enceladus from the REV 80 and REV 91 “Skeet Shoot”

Paul Helfenstein
Cassini ISS Team
Cornell University

November 25, 2008

Cassini Close Flybys of Enceladus in 2005



~4 m/pix

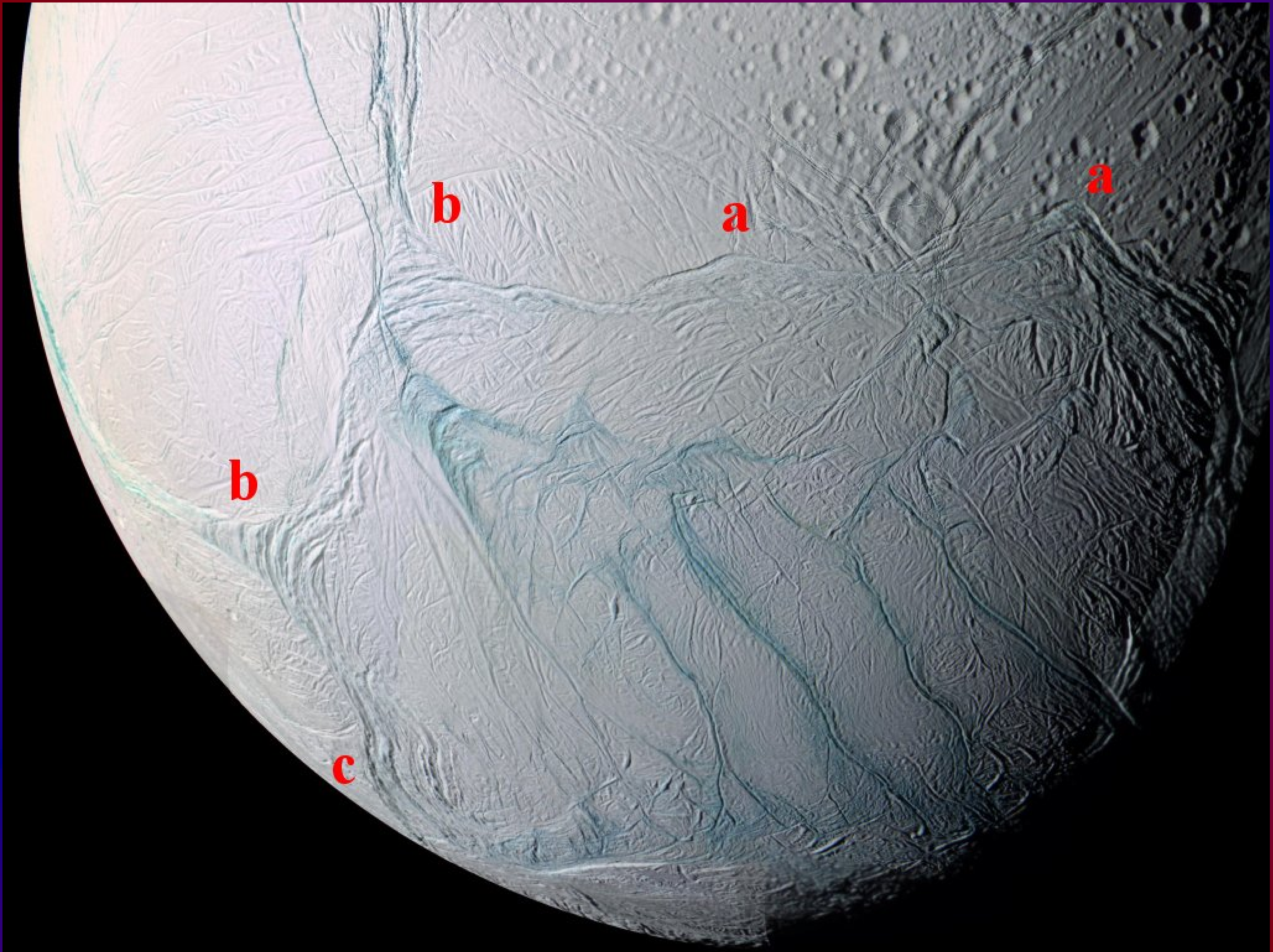
(South Polar-
Anti-Saturn)

~65 m/pix

(Trailing Side,
Voyager overlap)

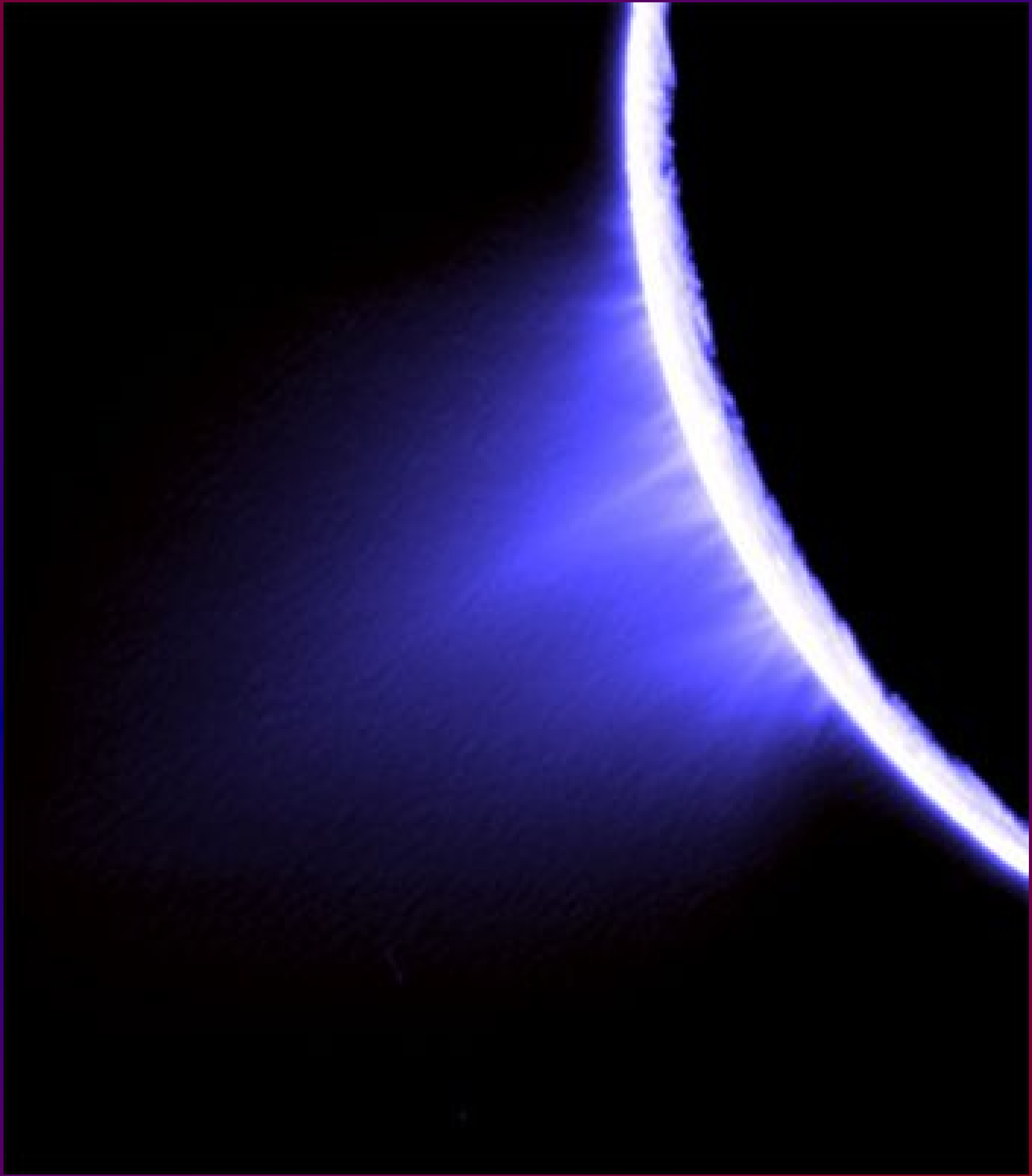
(Anti-Saturn)

~24 m/pix

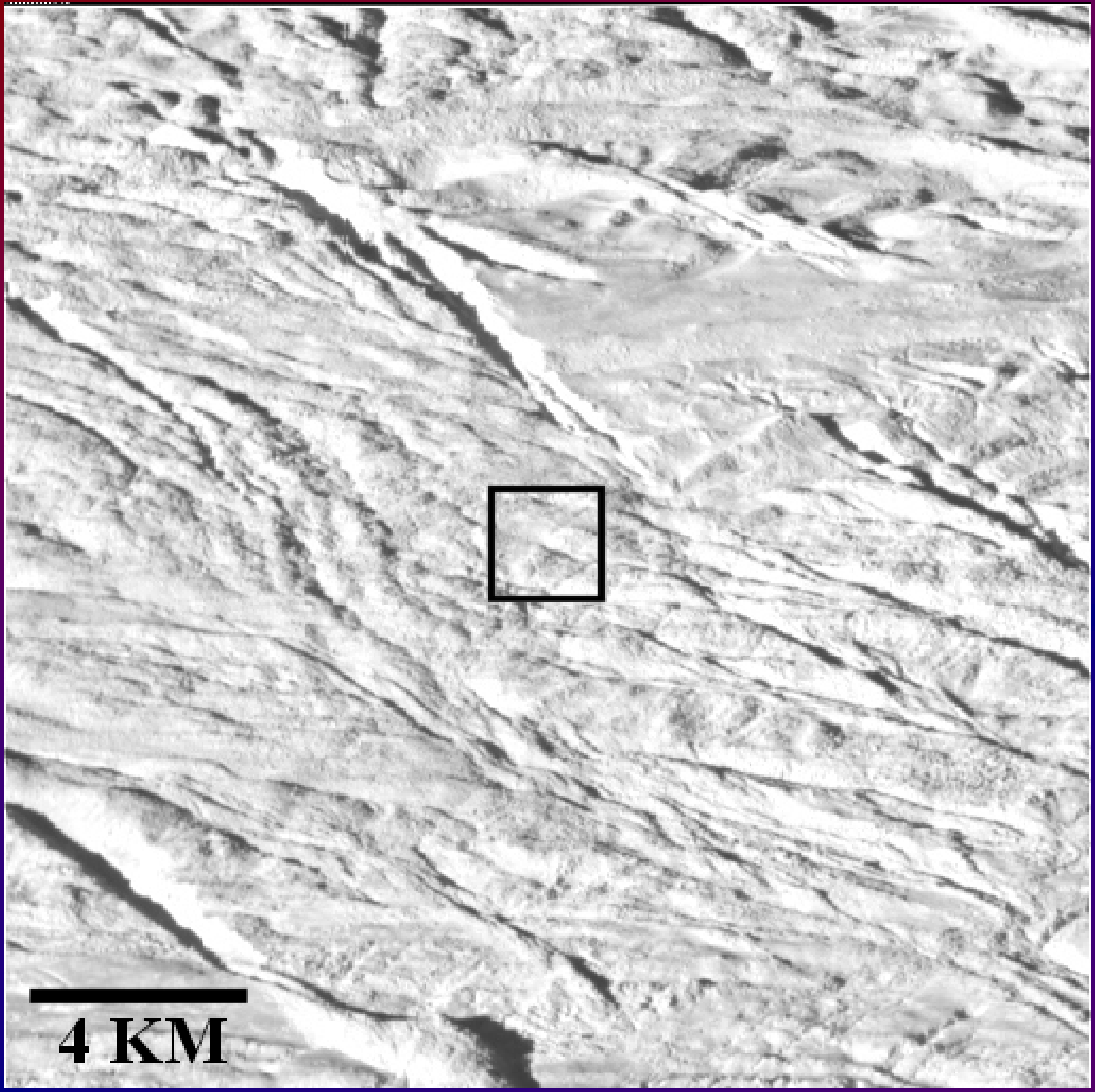

b
a
a
b
c

Enceladus:

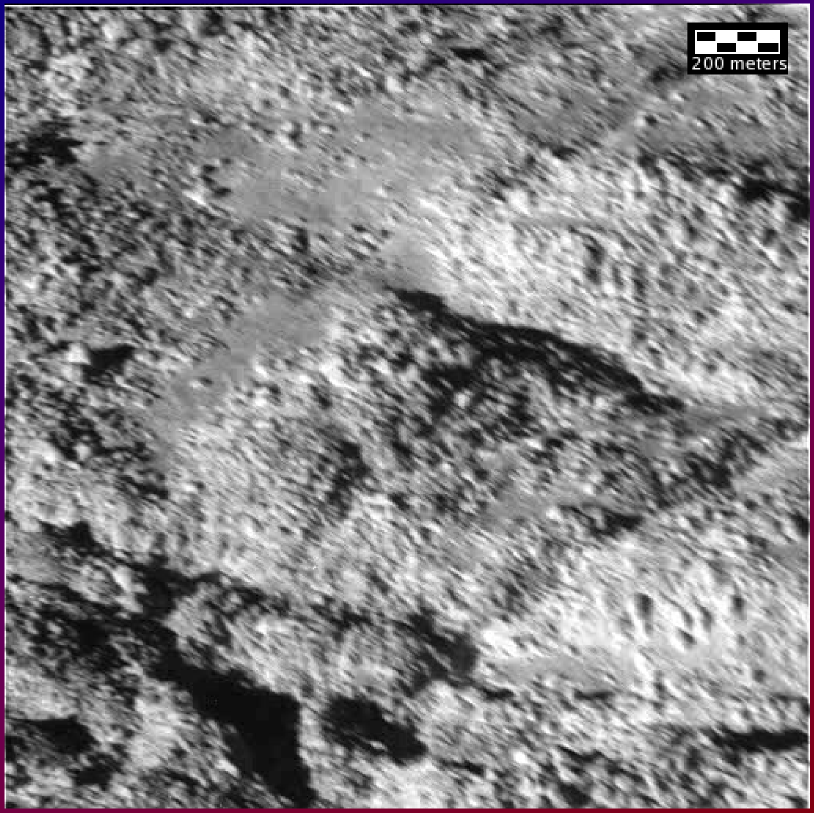
South Polar Plume Eruptions (Nov. 2005)



LOCATION OF HIGH RESOLUTION (4m/pixel) NAC IMAGE and (40m/pixel) WAC BOTSIM from EN05 Flyby (July 05)



EN05 HIGH RESOLUTION BOTSIM: 40m/pixel WAC 2x2 Frame (left) and 4m/pixel NAC 2x2 Frame (below).



SCIENTIFIC OBJECTIVES

1) Observe morphological details of volcanically erupting features at high resolution (better than 10's of meters/pixel), look for structural variations related to their age and evolution.

2) Use high-resolution images as rosetta stones for understanding the wider distribution of other examples viewed at lower resolution.

3) Map terrain units, identify systematic geological and tectonic relationships, and interpret their physical significance.

Enceladus “Skeet Shoot”: Why?

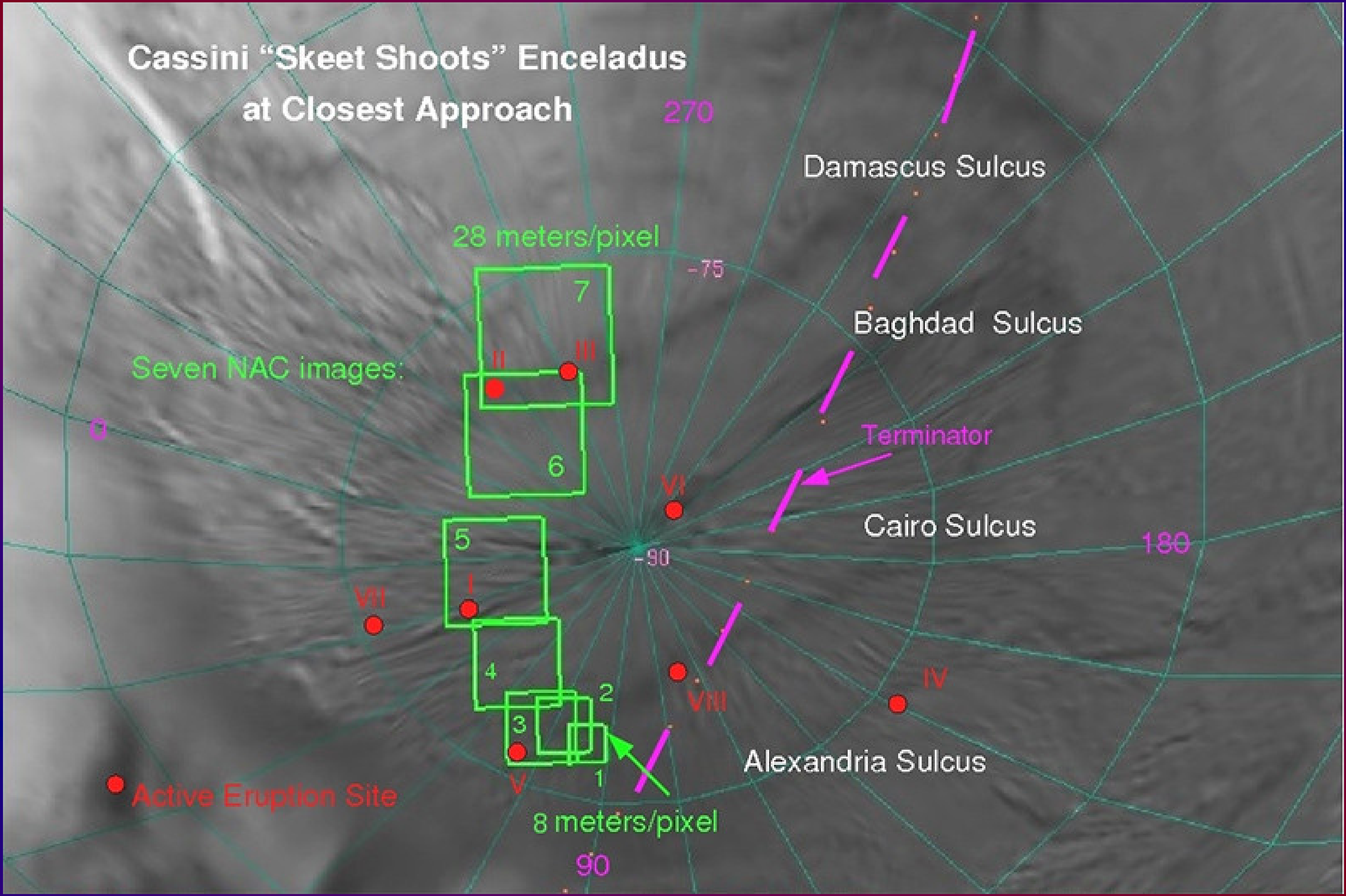
- At closest approach:
  - altitude is 50 kilometers (30 miles)
  - flyby velocity is 40,000 km/hr (24,000 miles/hour)

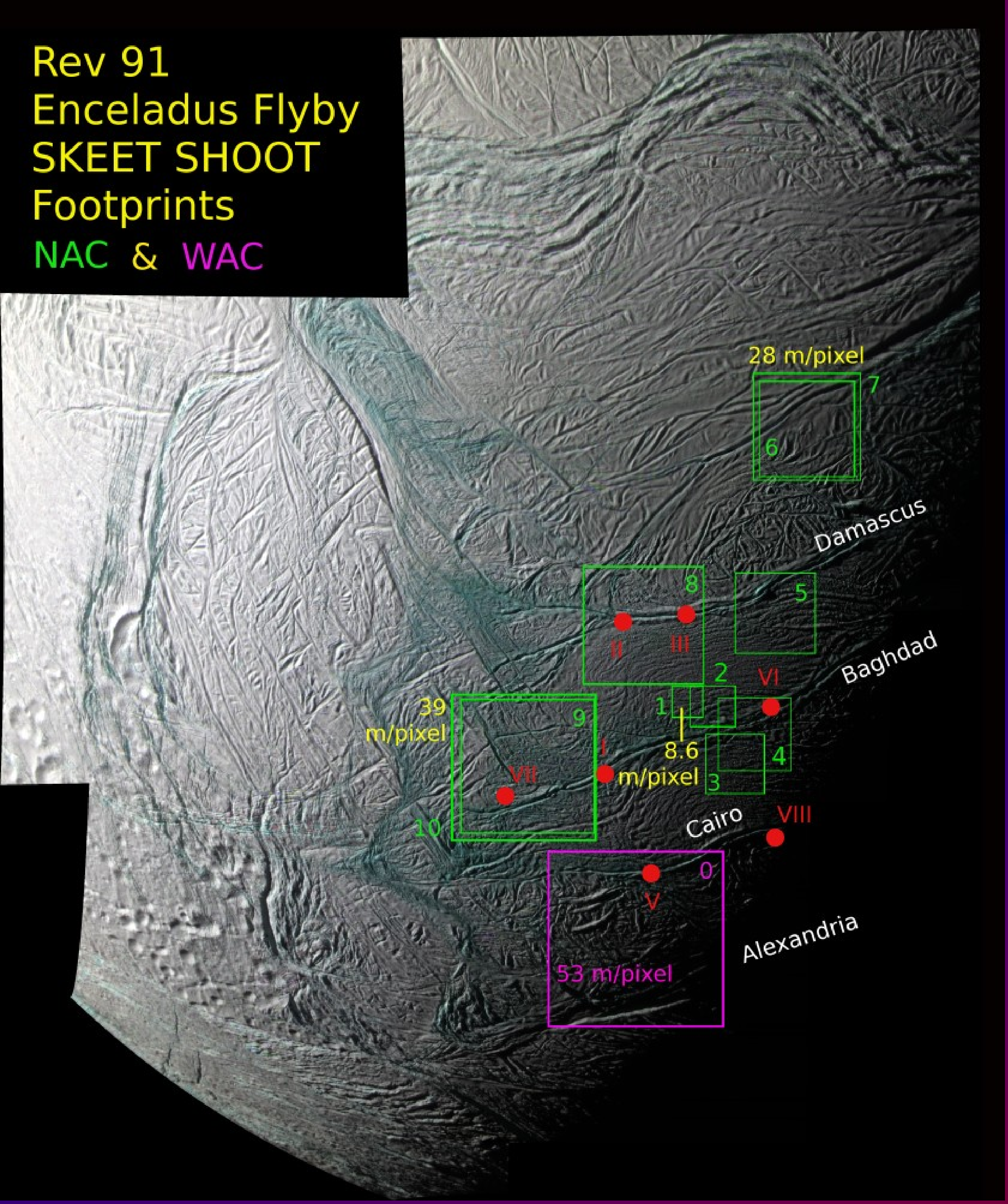
- Imaging camera is bolted to the side of the spacecraft
  - must turn entire spacecraft to point camera

- Spacecraft is as big as a bus
  - angular turn rate on reaction wheels too slow to track
  - angular acceleration rate is too slow to catch up

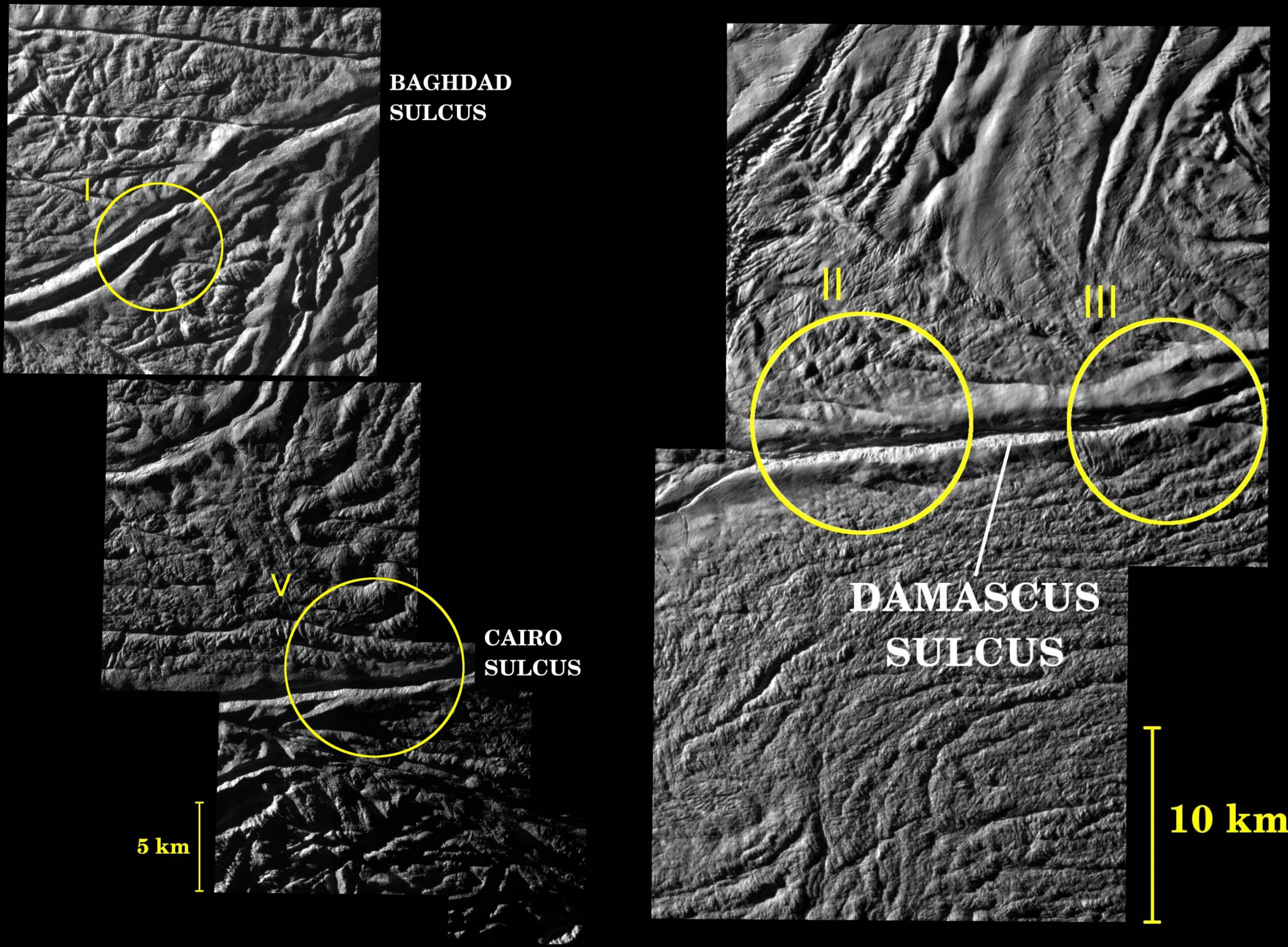
- Strategy:
  - position spacecraft early at a “staging attitude”
  - spin spacecraft on its Z axis (the fast one)
  - orient the Z axis so spin direction matches Enceladus path
  - time departure from staging attitude to hit geology targets

Enceladus E4 Flyby (August 11, 2008)

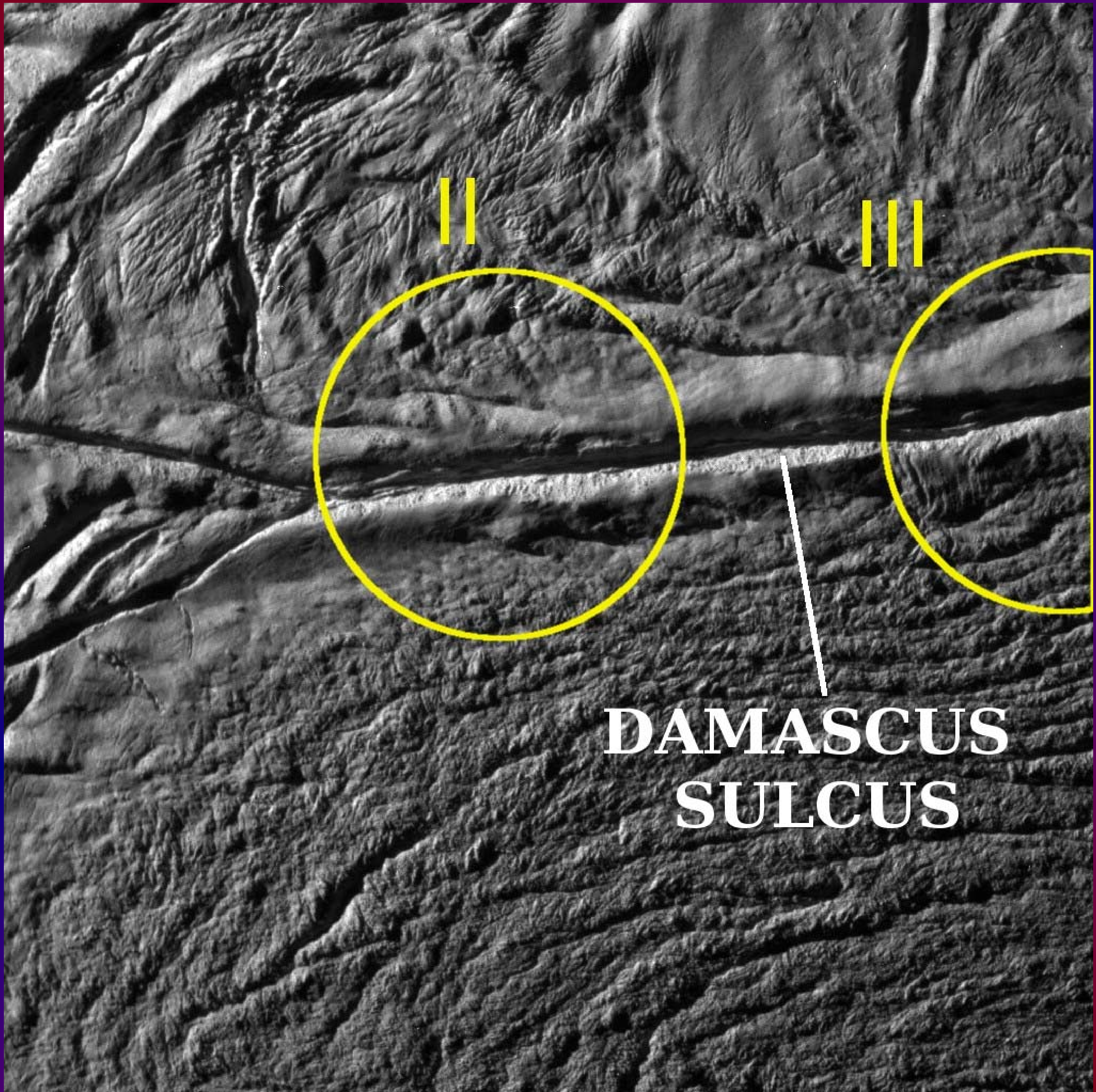


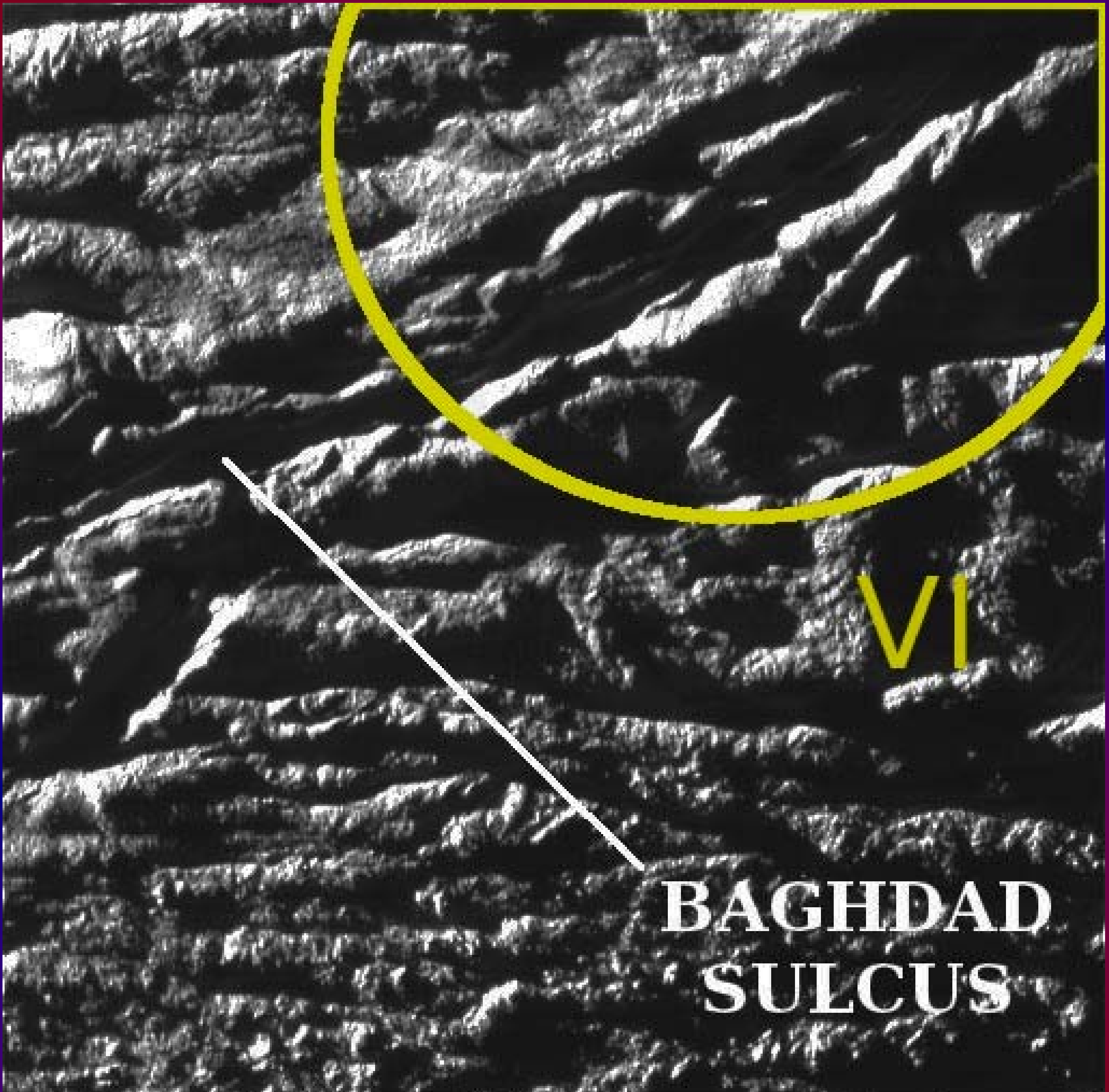


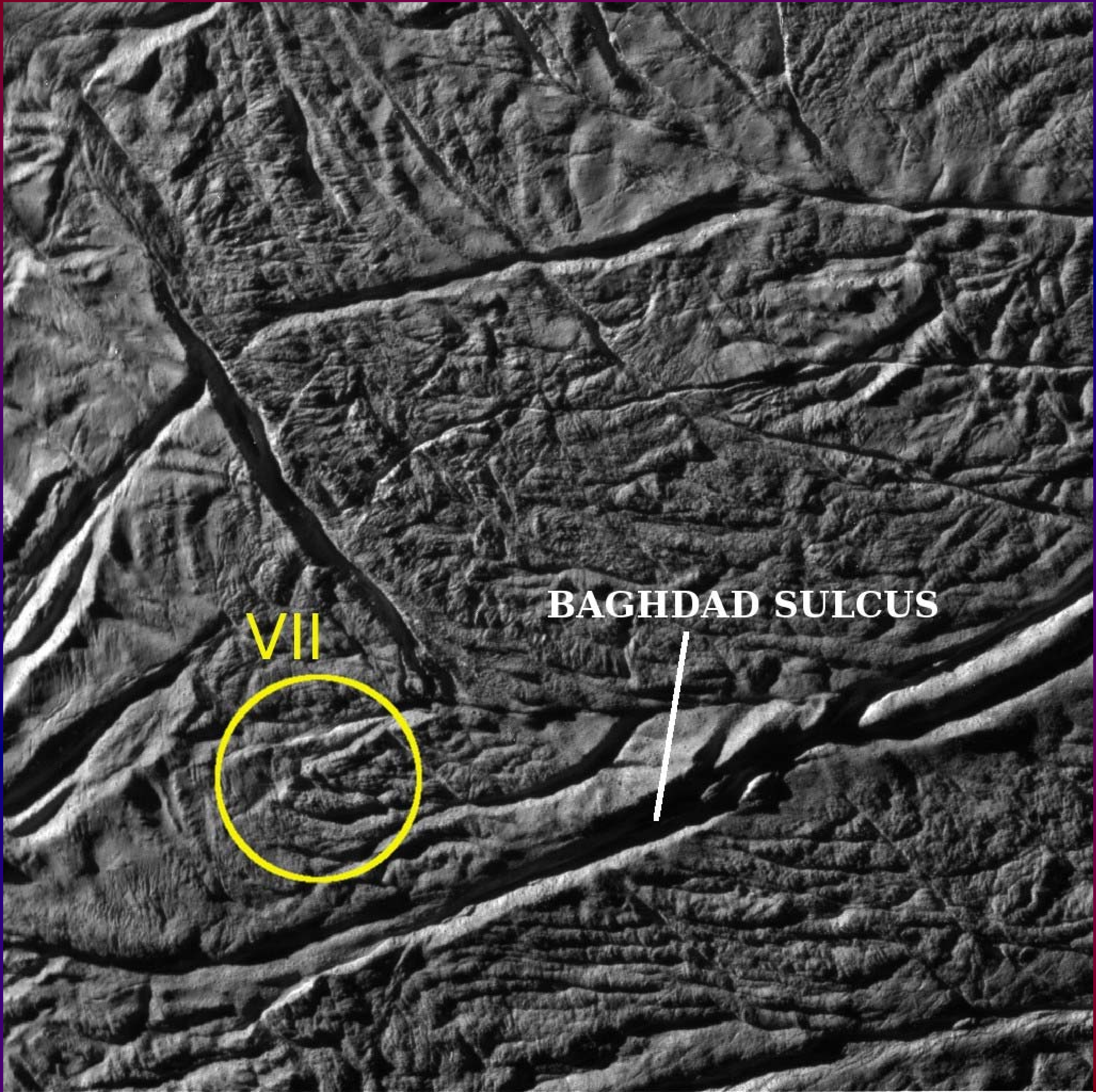
October 31, 2008



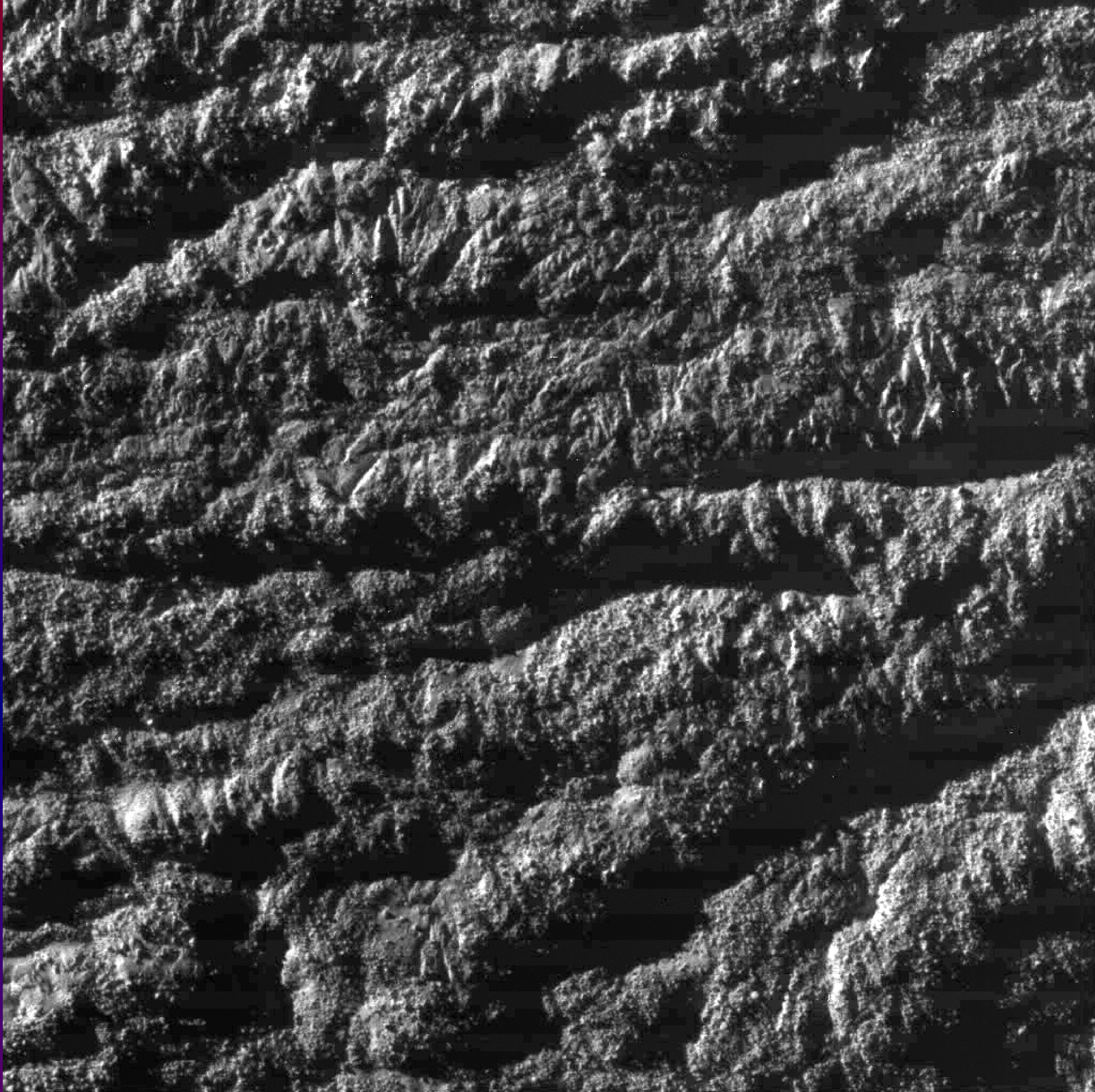
BAGHDAD SULCUS
I
V
CAIRO SULCUS
5 km
II
III
DAMASCUS SULCUS
10 km


II
III
DAMASCUS
SULCUS


VI
BAGHDAD
SULCUS

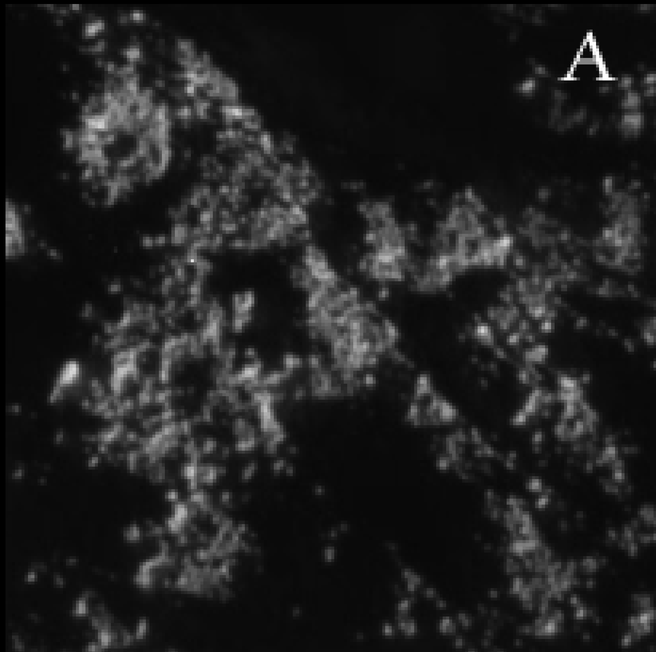

BAGHDAD SULCUS
VII

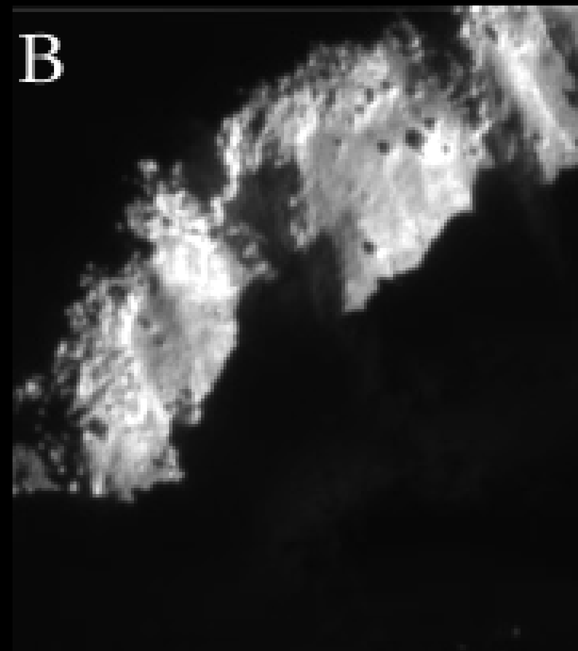
Funiscular (ropy) Plains Near Baghdad Sulcus (9m/pixel)



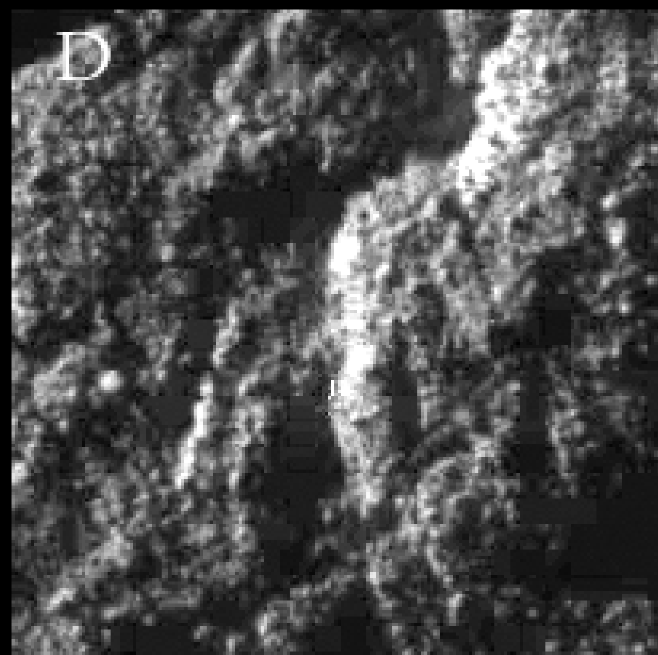
10 m/pixel
Between
Alexandria
Sulcus
and
Cairo
Sulcus

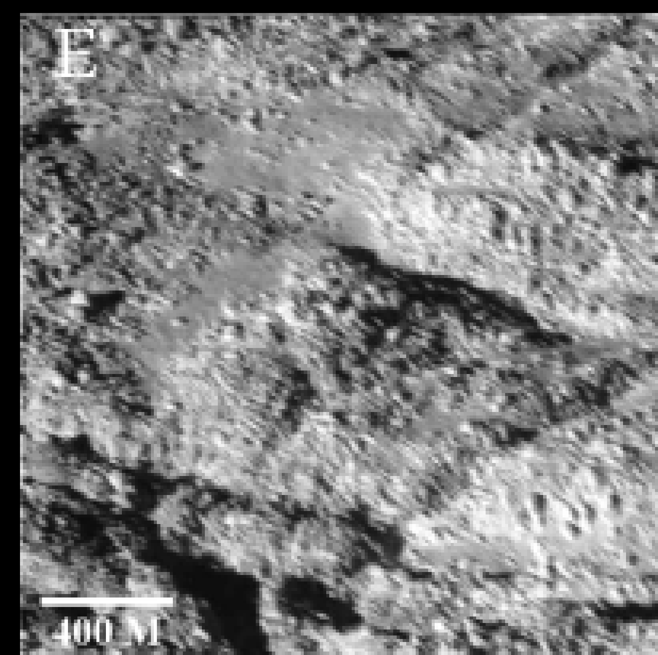
COMPARISON AT 10 meters/pixel

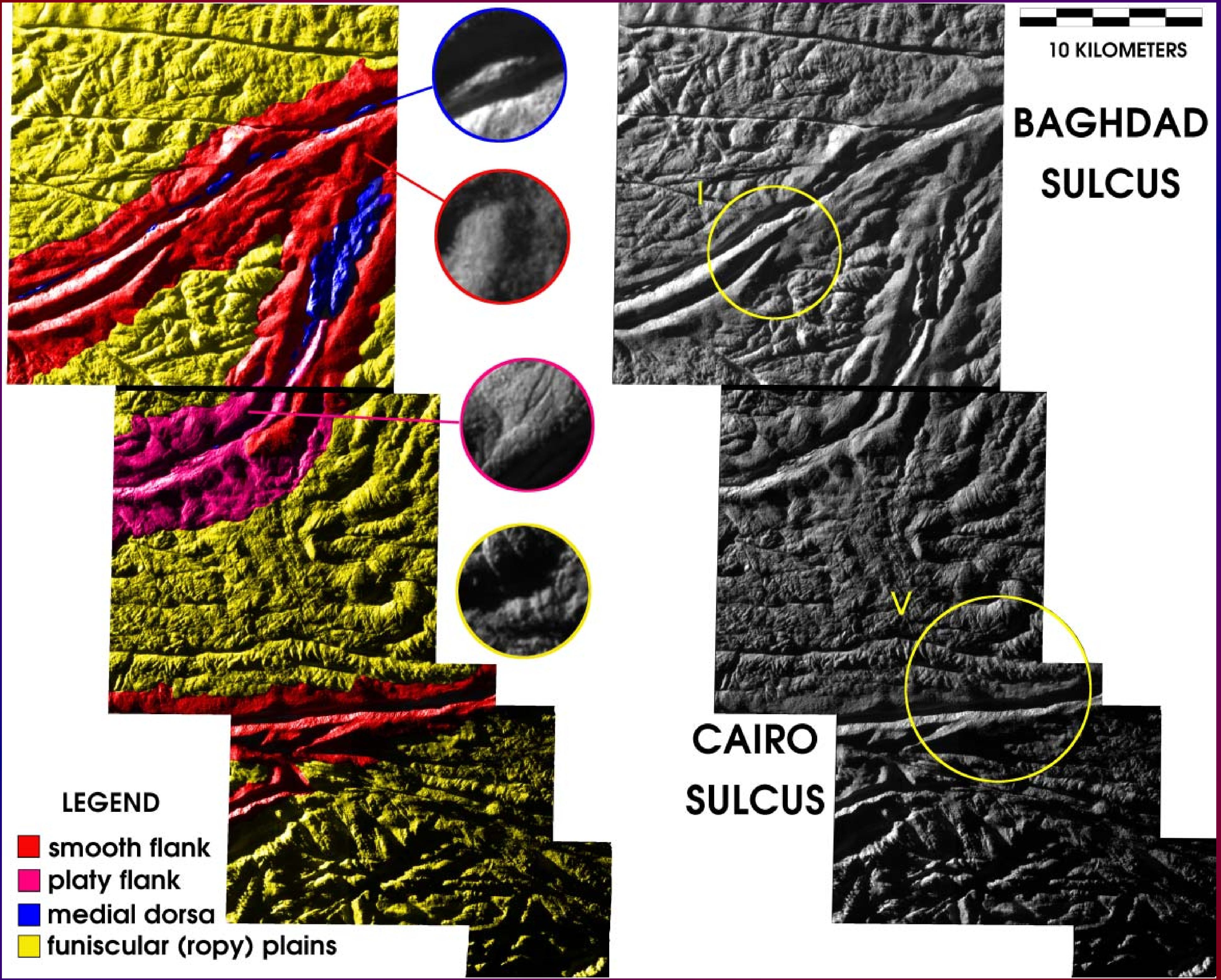




A. Funiscular Plains
B. Smooth Flank
C. Funiscular Plains
D. Funiscular Plains
E. Reticulated Plains

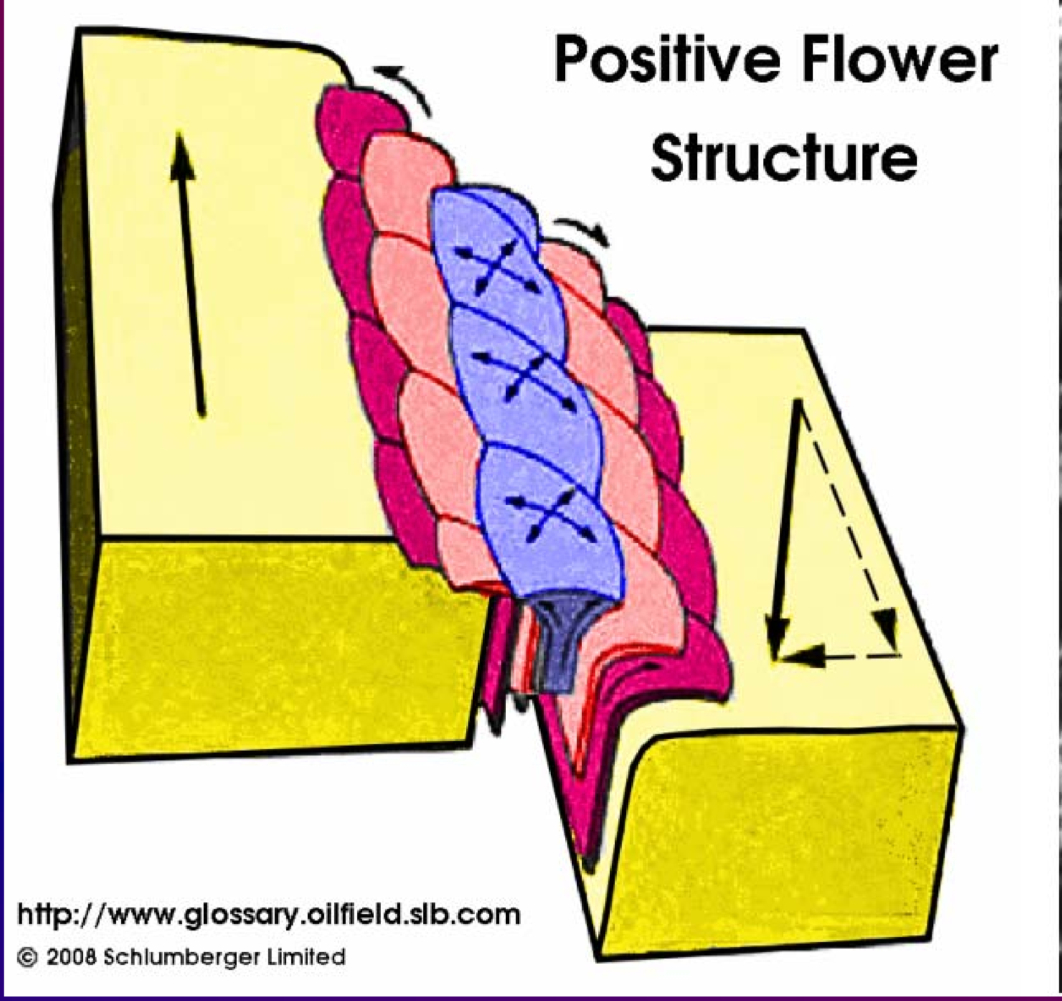


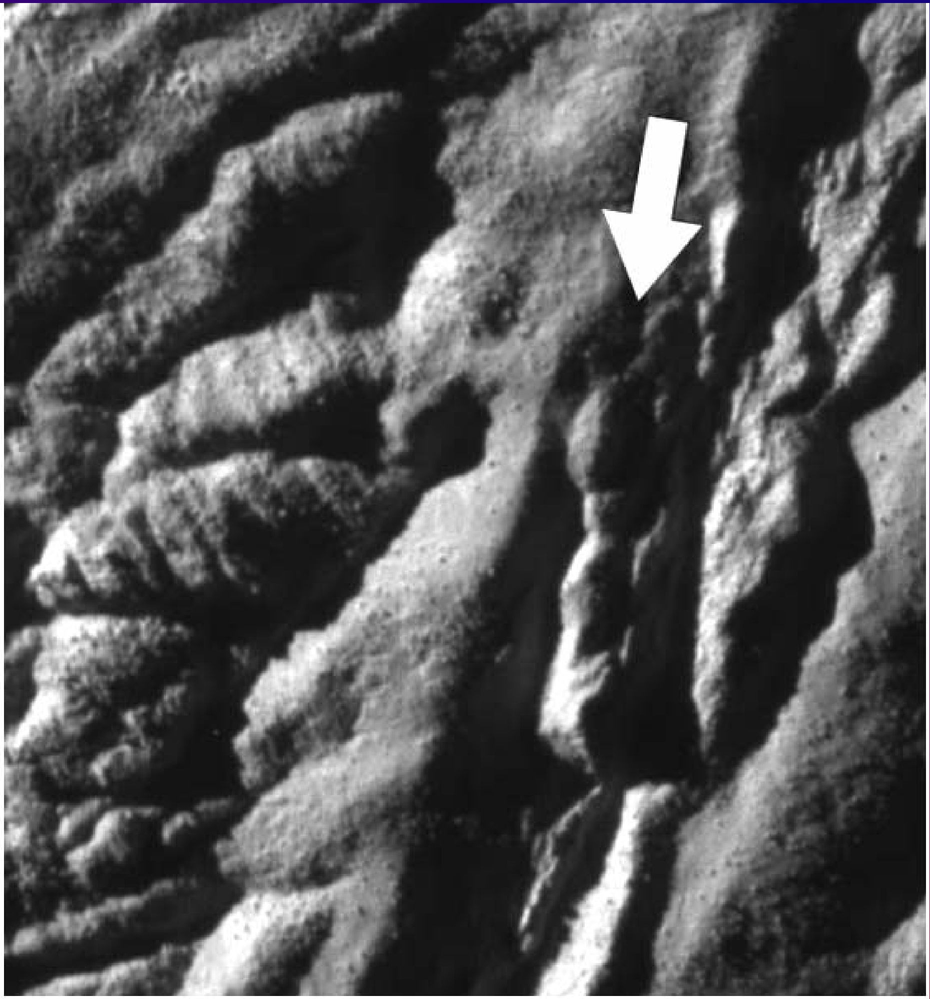




10 KILOMETERS
BAGHDAD SULCUS
I
V
CAIRO SULCUS
LEGEND
smooth flank
platy flank
medial dorsa
funiscular (ropy) plains

TIGER STRIPE MEDIAL DORSA (A.K.A. “SHARK FINS”): POSITIVE FLOWER STRUCTURES?





CIRS Observations of Enceladus in 2008

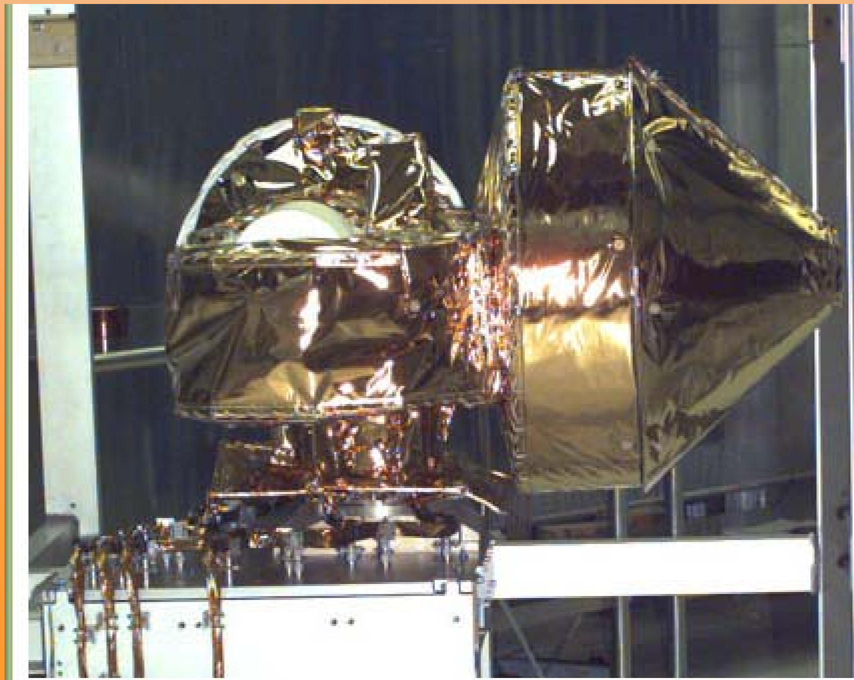
John Spencer[1], John Pearl[2], Carly Howett[1], Marcia Segura[2], and the CIRS team

[1]Southwest Research Institute, Boulder
[2]NASA-Goddard Spaceflight Center

Cassini CHARM Telecon, November 25th 2008

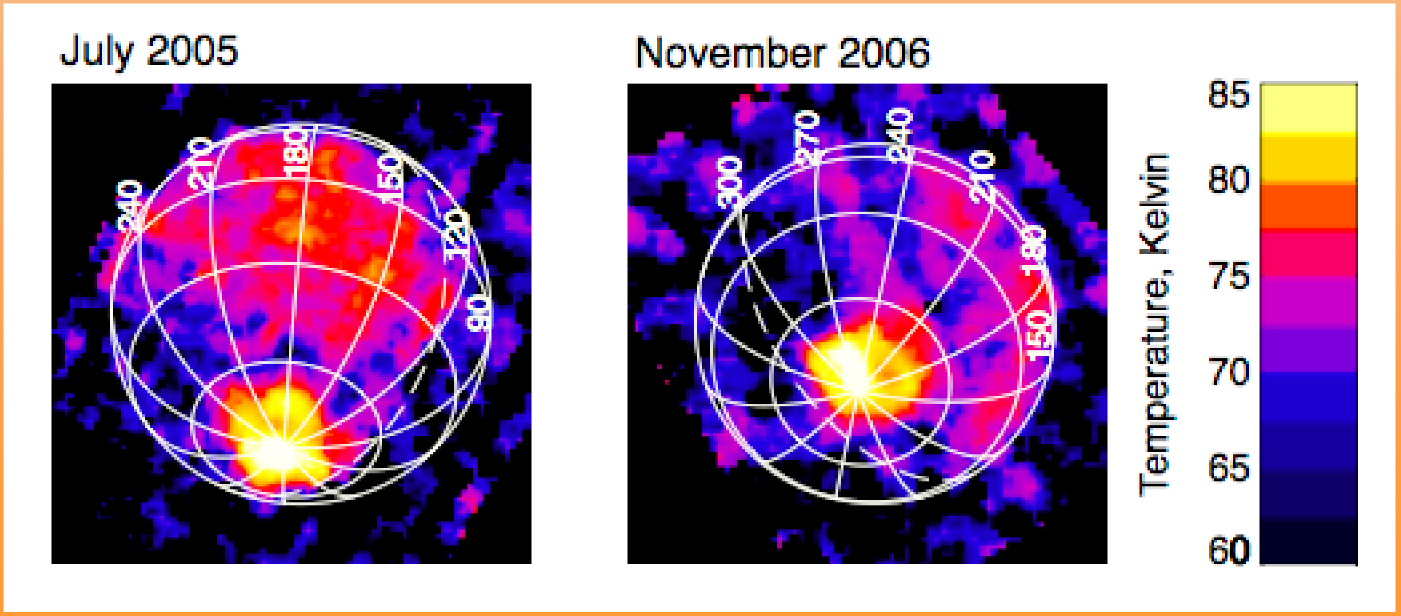
CIRS: Composite Infrared Spectrometer

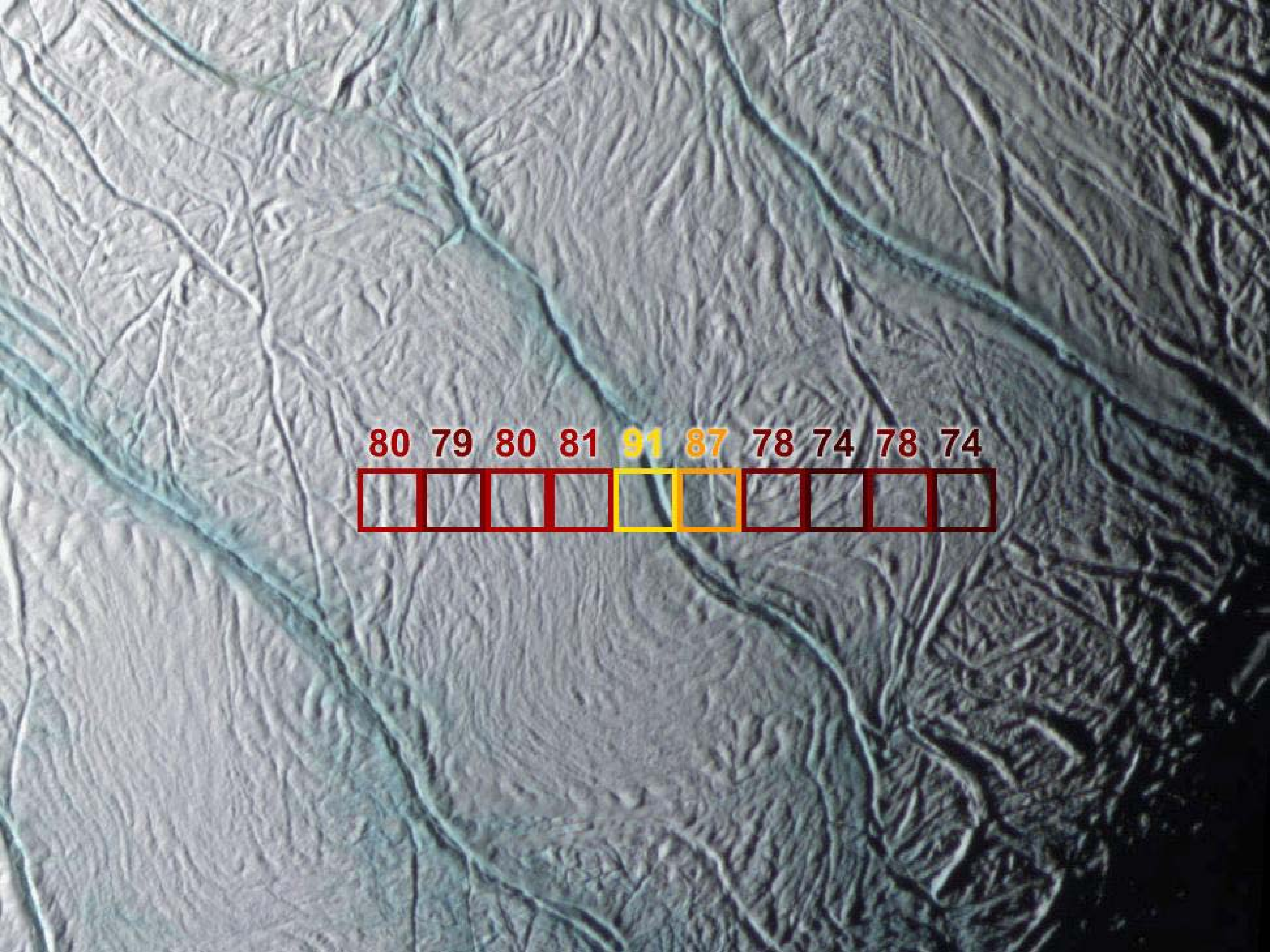
- Measures long-wavelength infrared (heat) radiation from Saturn, its rings, and moons.
- Sensitive to wavelengths between 7 and 300 microns (14 – 600 times longer wavelength than visible light)
- For objects with atmospheres (Saturn and Titan), CIRS provides detailed information on atmospheric composition and temperature.
- For objects without substantial atmospheres (Saturn's rings, and its smaller moons) CIRS provides mostly temperature information (though we might learn something about composition if we're lucky).



Enceladus South Polar Hot Spot

- Discovered in July 2005
- Seen again (from a distance) in November 2006
- Heat emitted by the "tiger stripe" fractures
- Temperatures up to 145 K (-198 F)

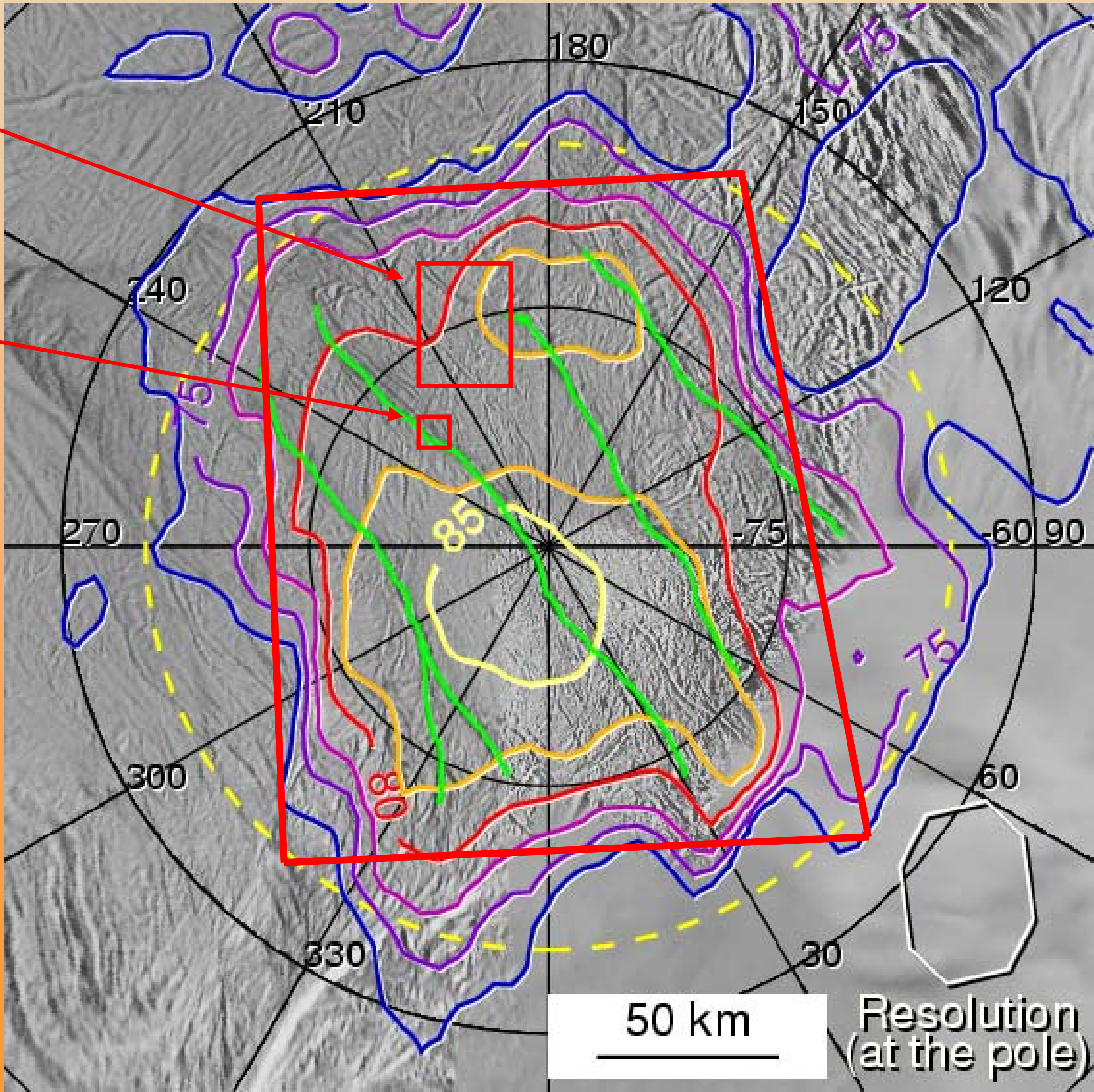



80 79 80 81 91 87 78 74 78 74

Improved Mapping in March 2008

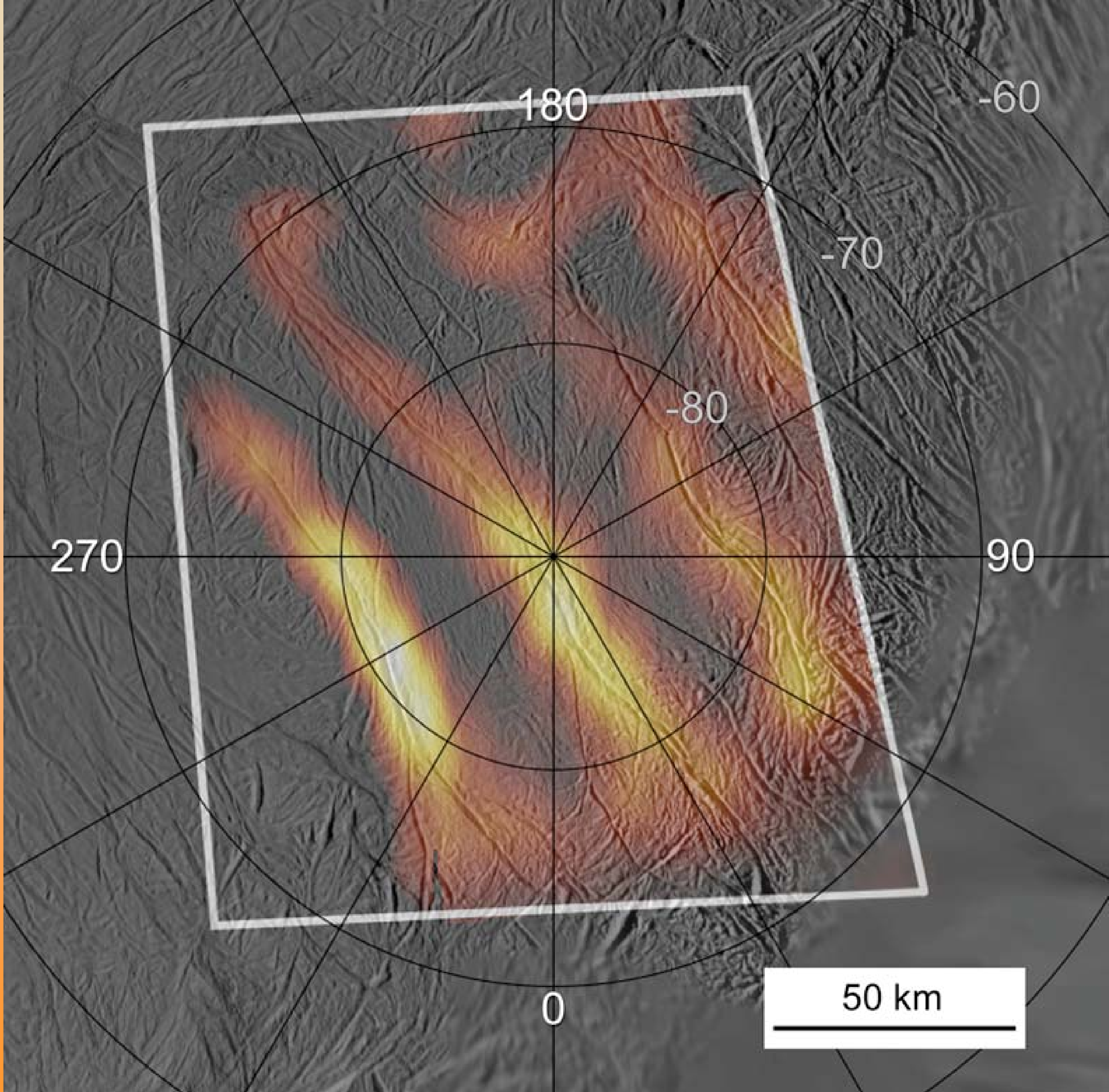
- July 2005 map:
  25 km resolution…
- Typical 10 km resolution of Rev. 61 map
- Easily resolve the tiger stripes, map temperatures along them

July 2005 Temperature Map



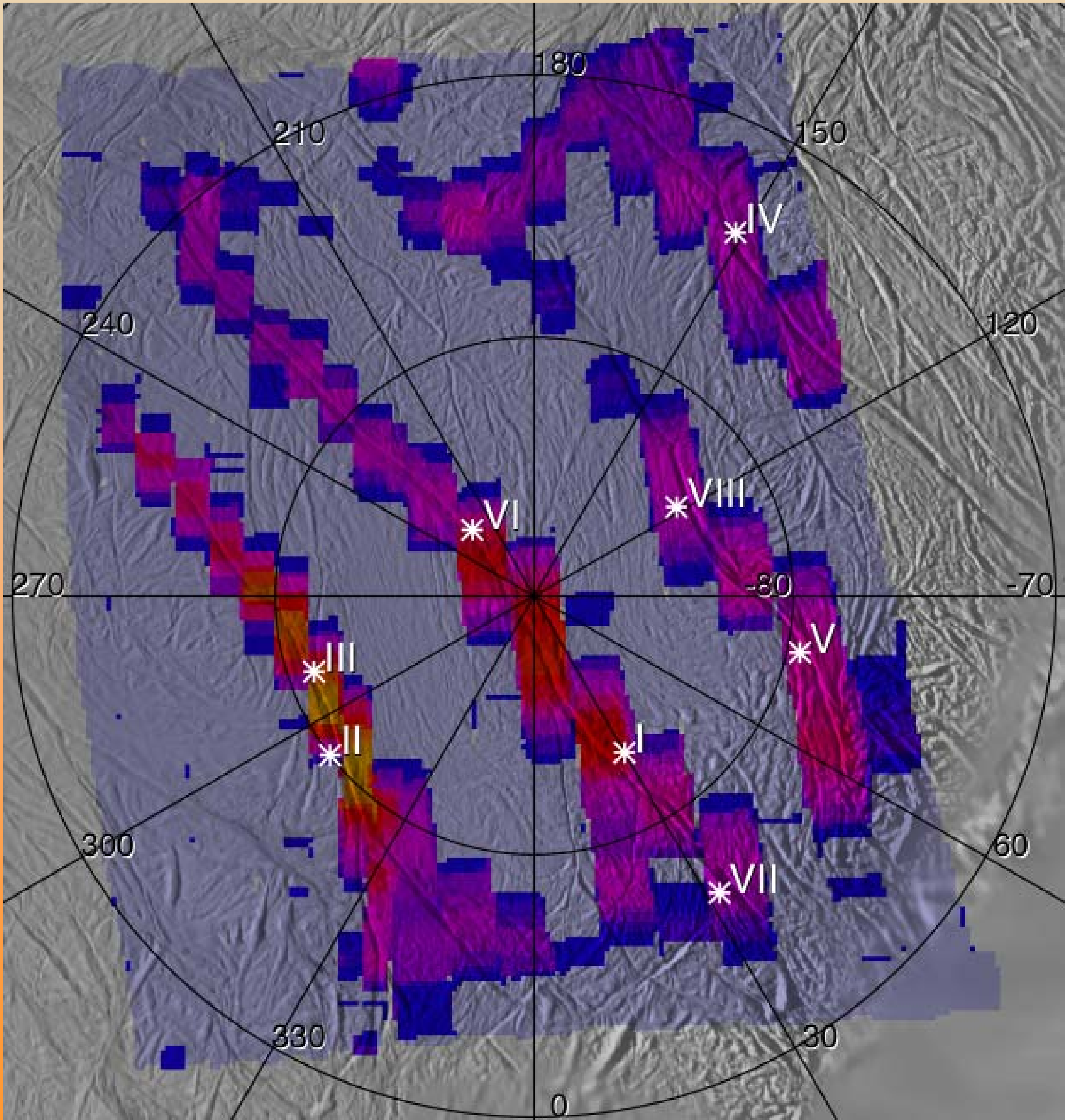
March 2008 Map

- Temper-atures of at least 180 K



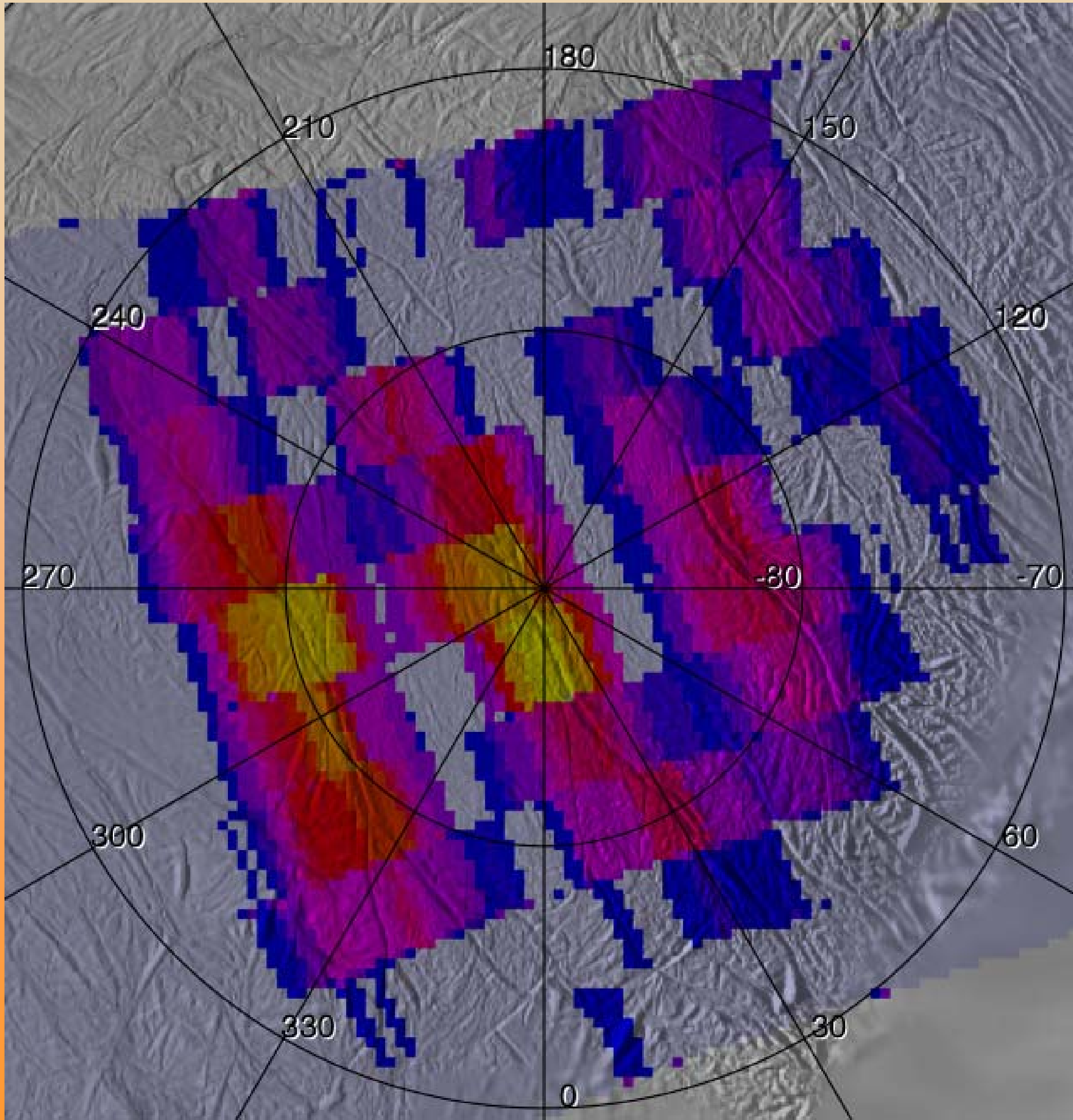
March 2008 Tiger Stripe Map: Full Resolution

- Continuous radiation along the tiger stripes
  - Large, ~smooth, variations
- Plume sources tend to be warm (Spitale and Porco 2007)
  - But flux is not strongly peaked there



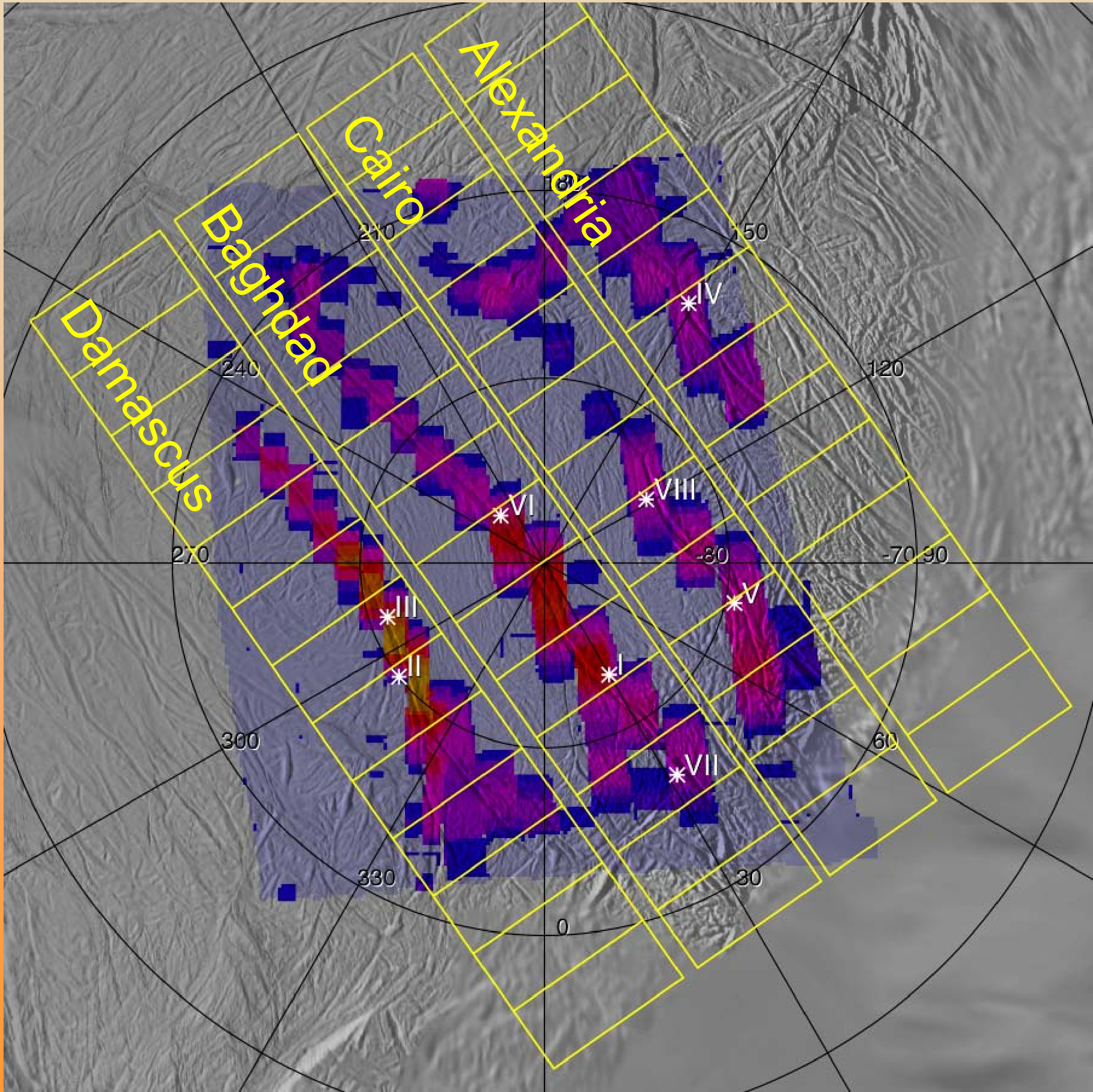
August 2008 Tiger Stripe Map

- Resolution 17 km
- Broadly similar distribution to March 2008

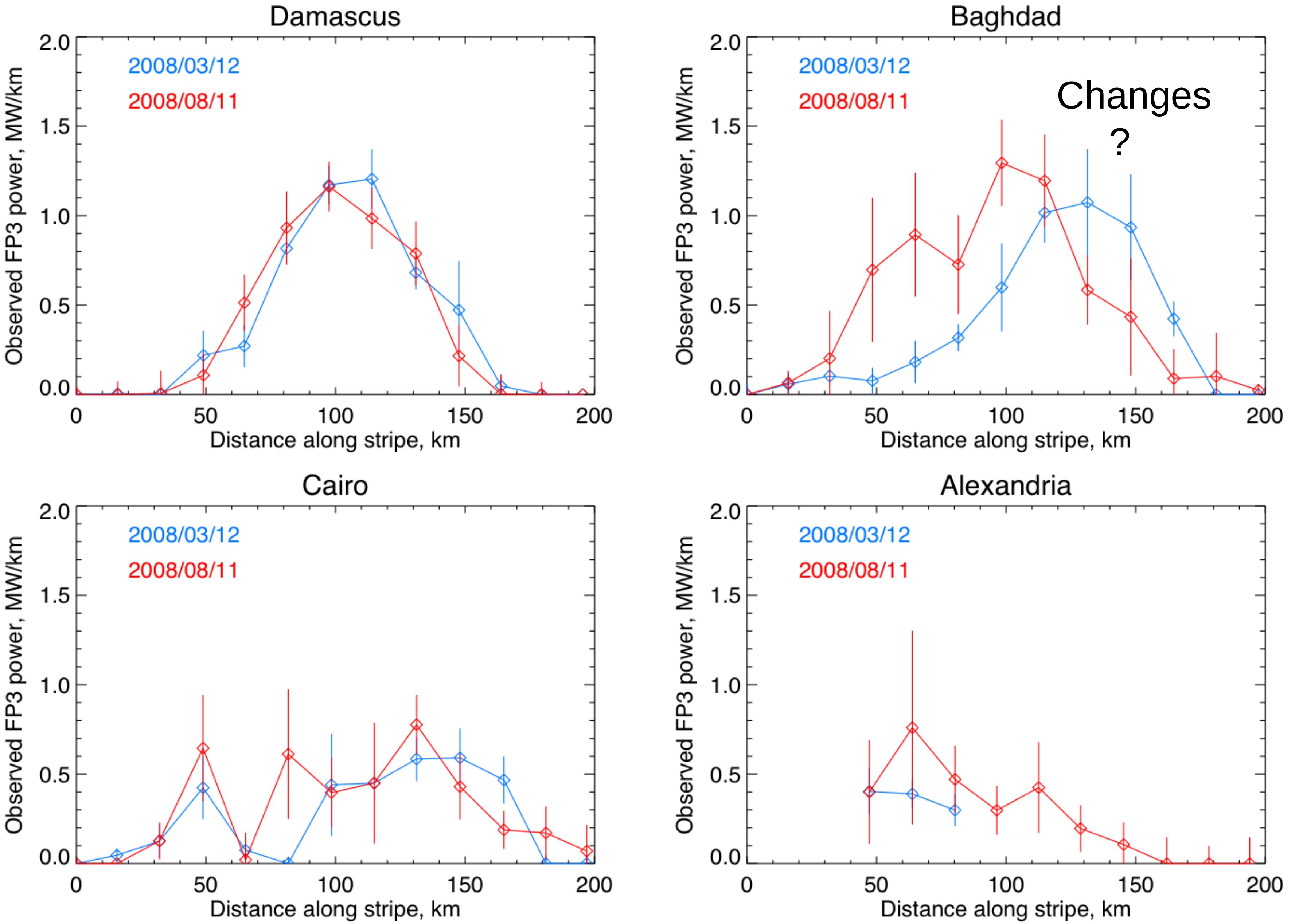


Longitudinal Profiling

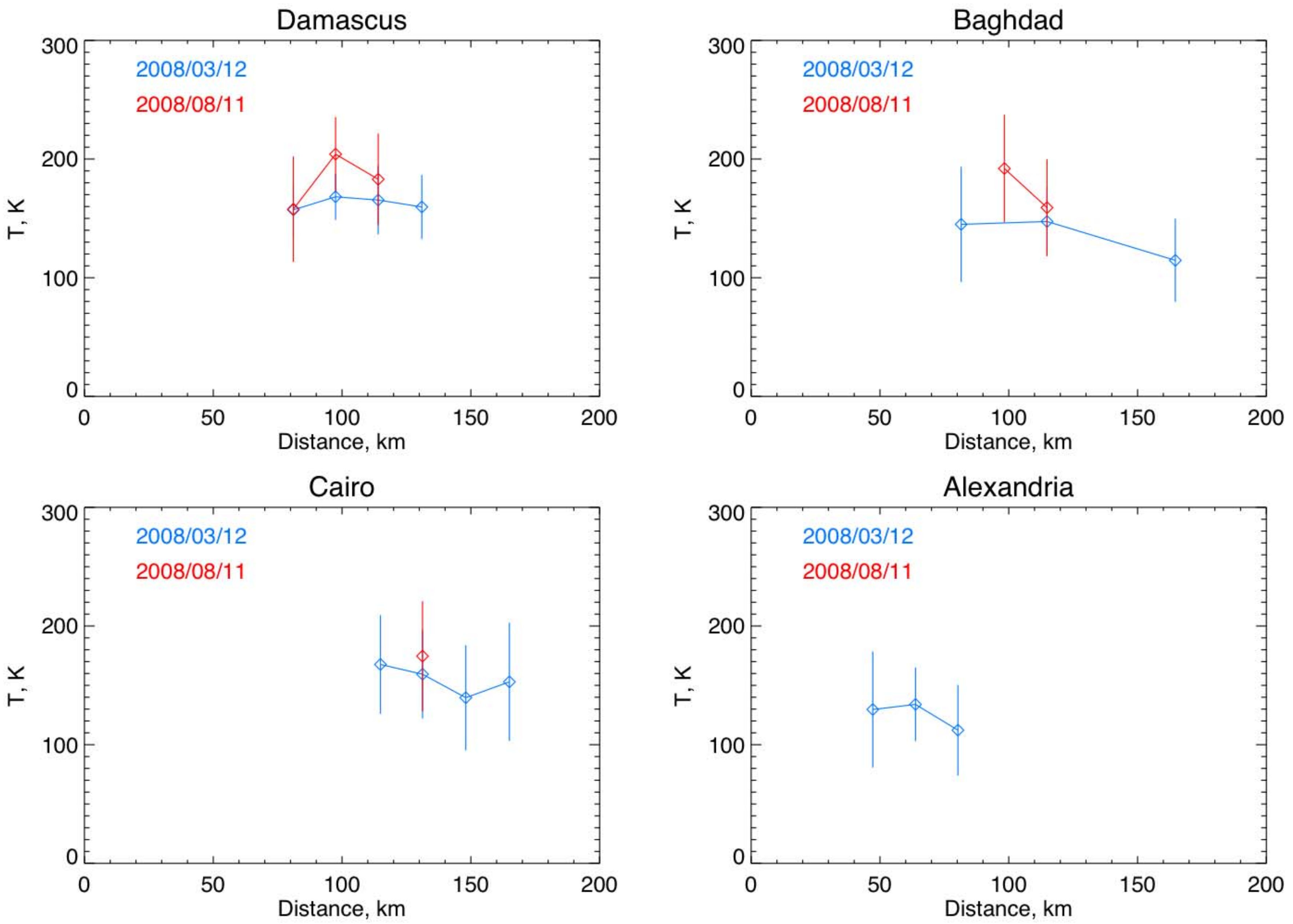
- Add up the radiation in each box for each observation



9 - 16 µm Power Profiles

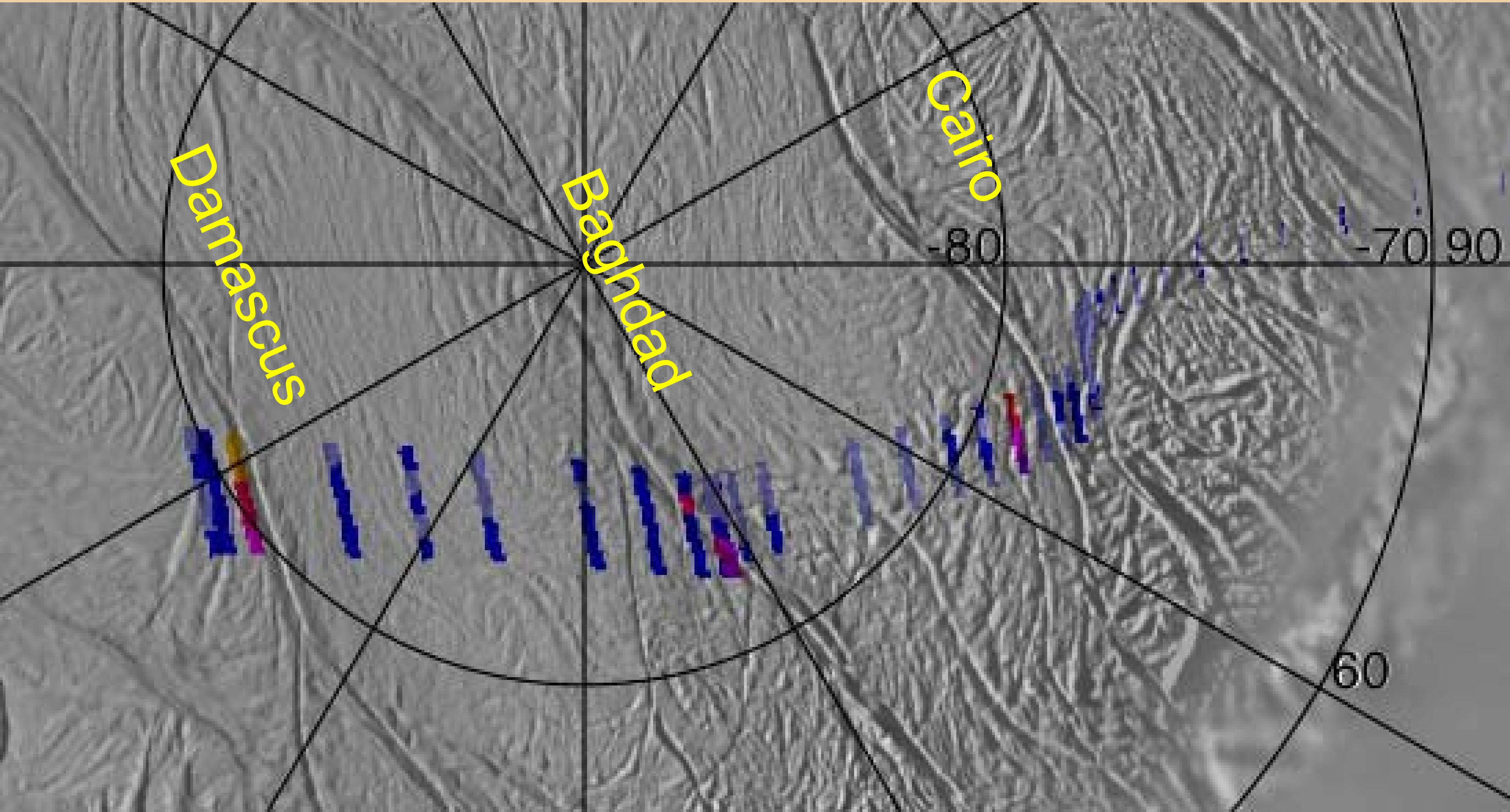


9 - 16 μm Temperature Profiles



August 2008 High Resolution Scan

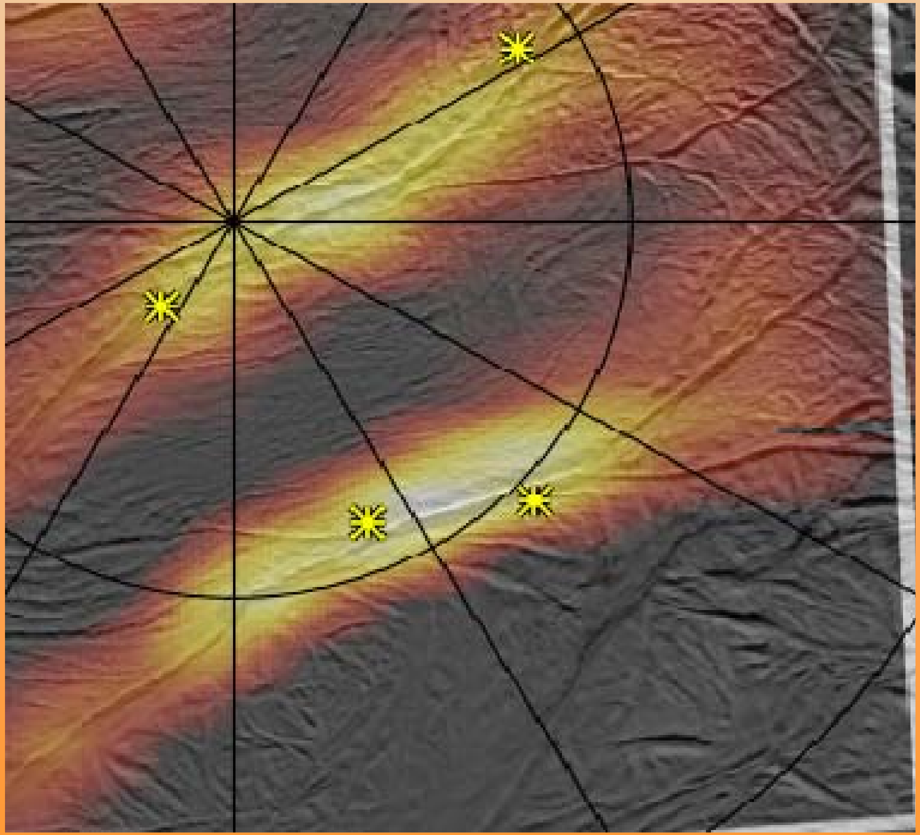
- ~1 - 2 km resolution



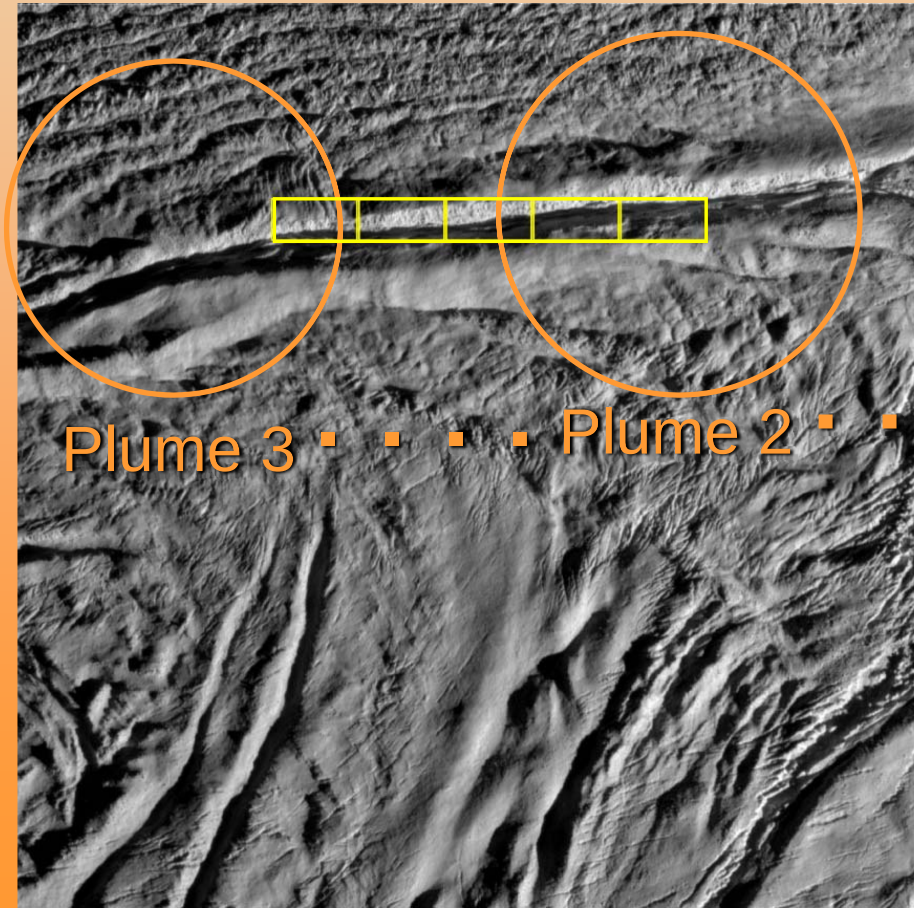
August 2008 Damascus Sulcus Stare

- 7 - 9 µm detector perfectly targeted on the fracture
- 2 x 4 km pixels

ISS image location relative to March 2008 CIRS data

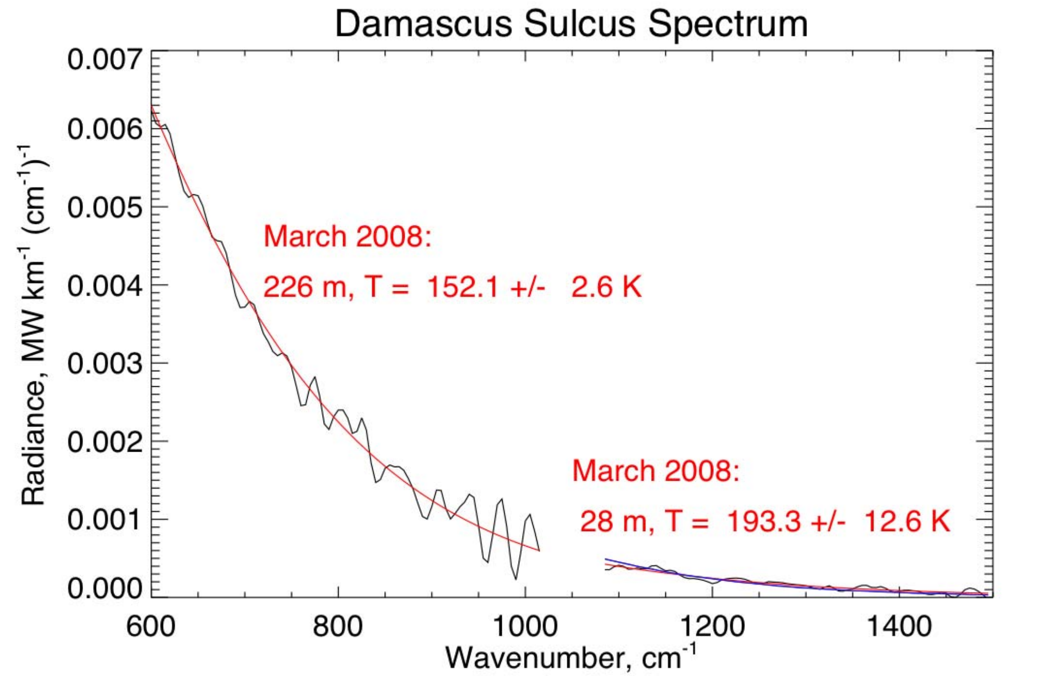


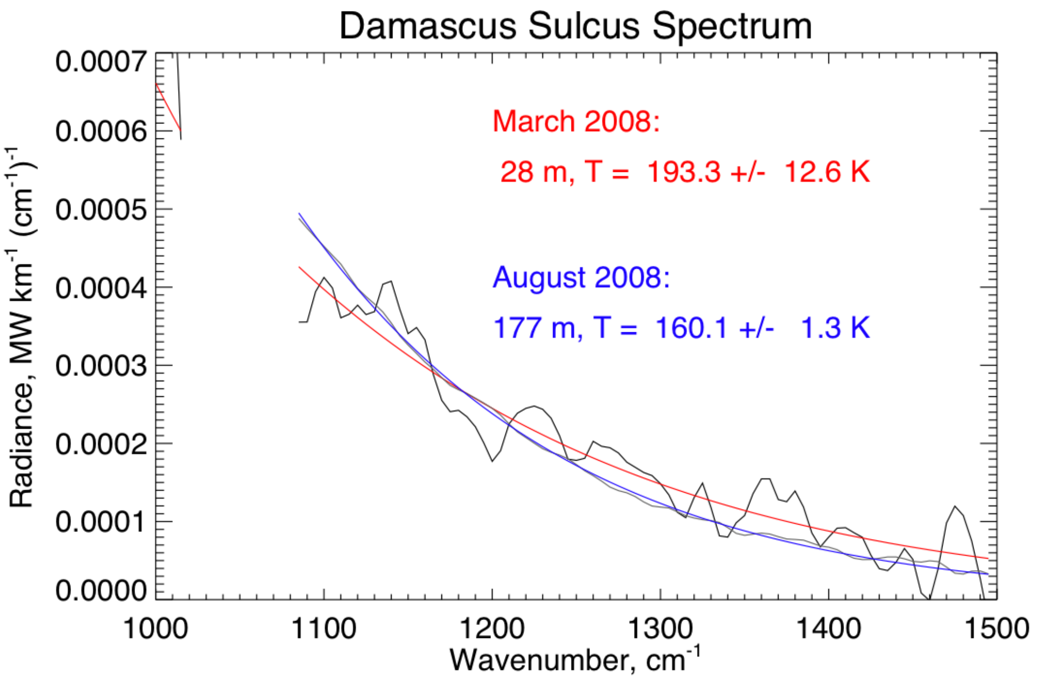
ISS image with CIRS locations



Damascus Sulcus Spectrum

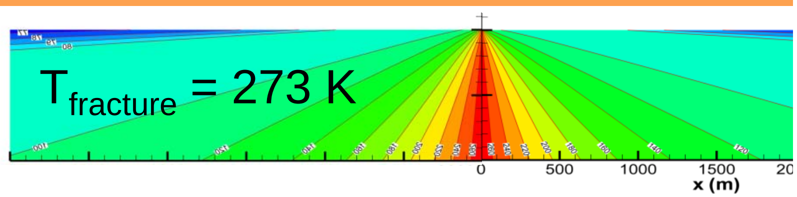
- The 2 CIRS detectors give ~consistent results
- Temperatures
  - March 2008: 190 - 200 K
  - August 2008: 158 - 167 K
- Real change?
  - Maybe not: August data much higher quality

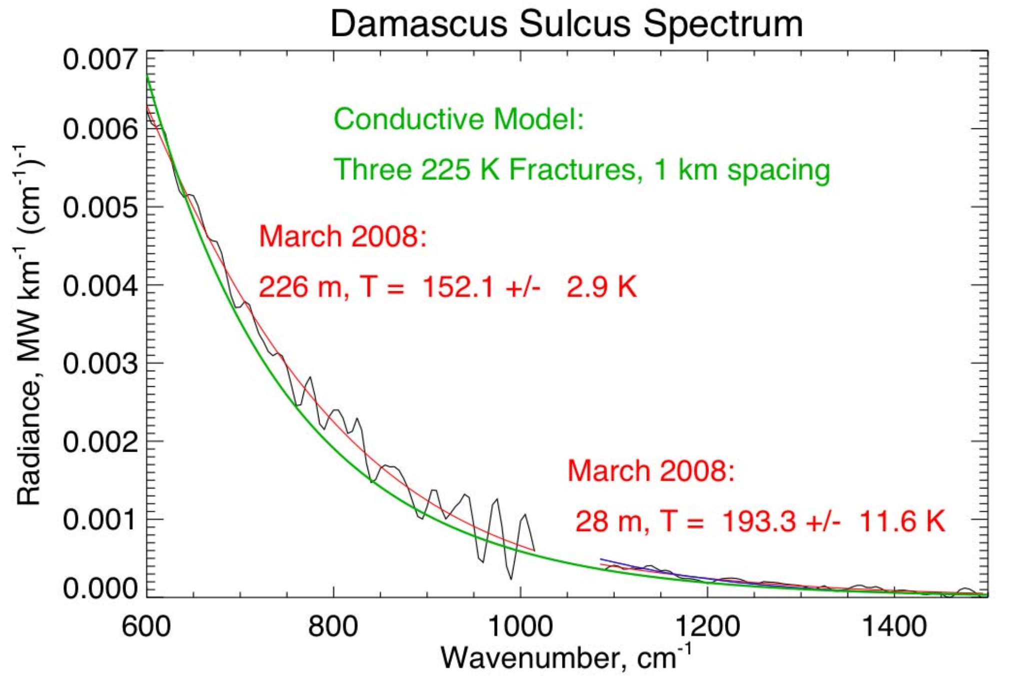


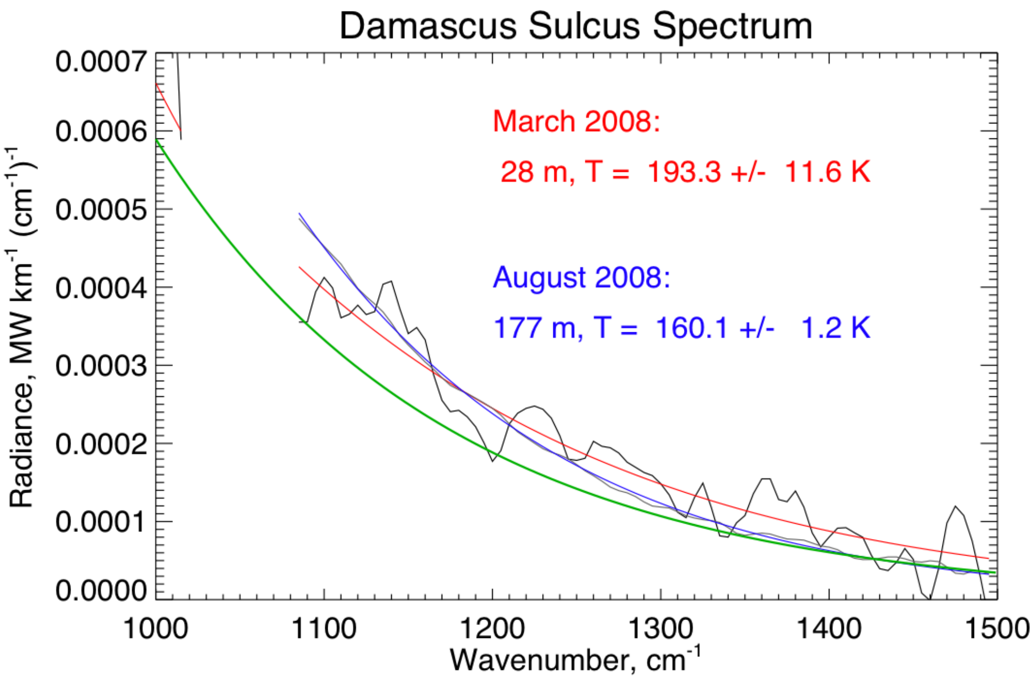


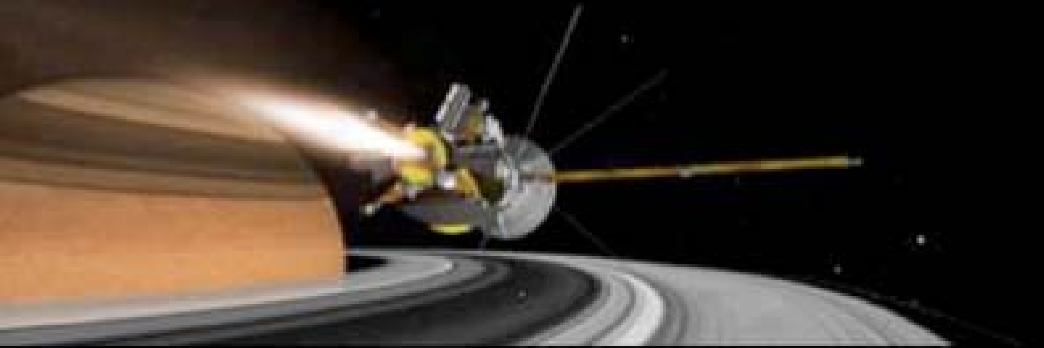
Modeling

- Conductive heating heating of surface by narrow vertical fracture (Abramov and Spencer 2008)
- Need multiple fractures to ~fit the observed fluxes



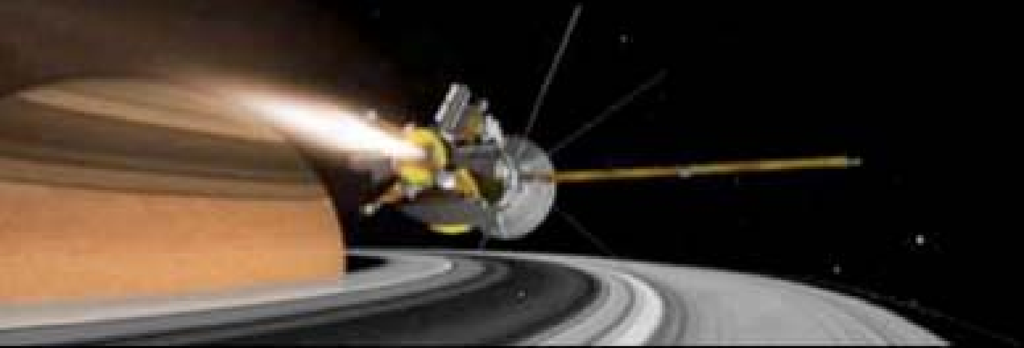




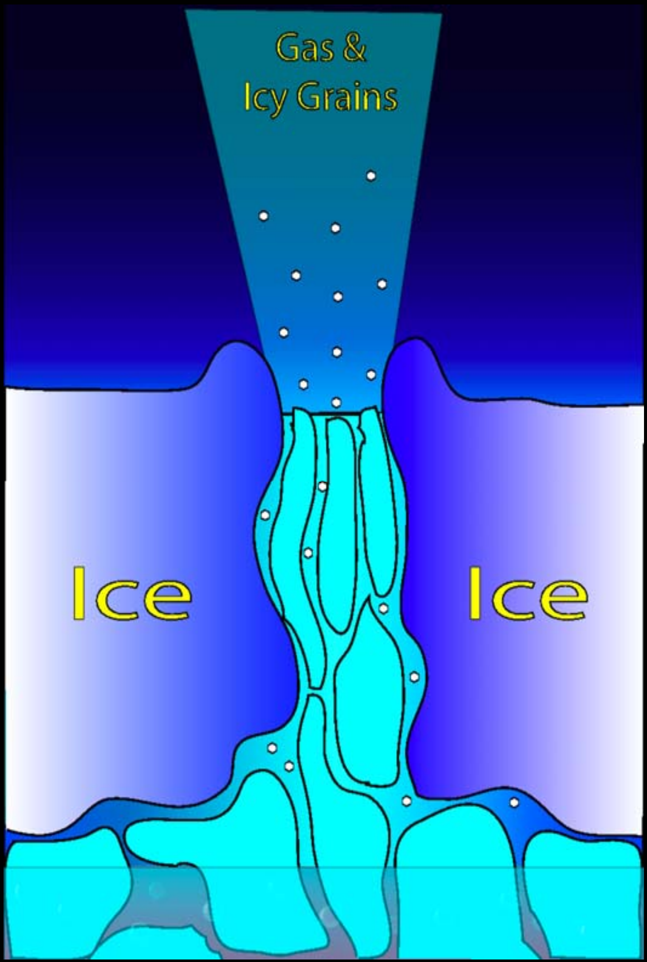


Cosmic Dust Analyser (CDA)

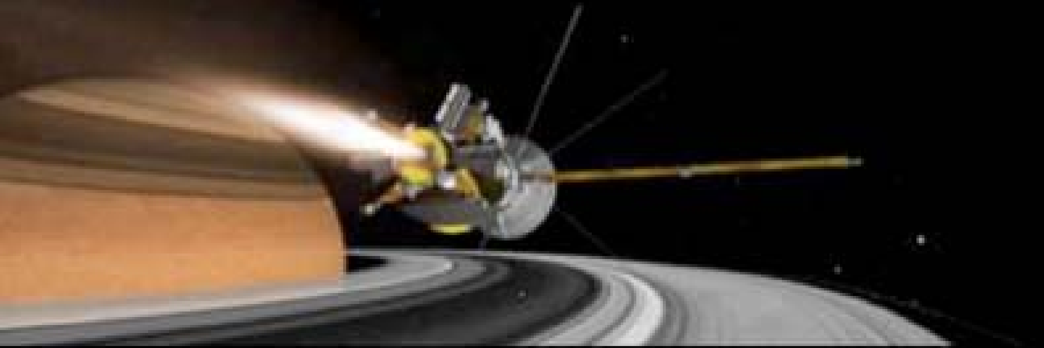
- Impact Ionisation Detector:
  - Dust mass and impact speed
- Time-of-Flight Mass Spectrometer:
  - Dust composition
- Charge Sensitive Grids:
  - Dust charge
- High Rate Detector



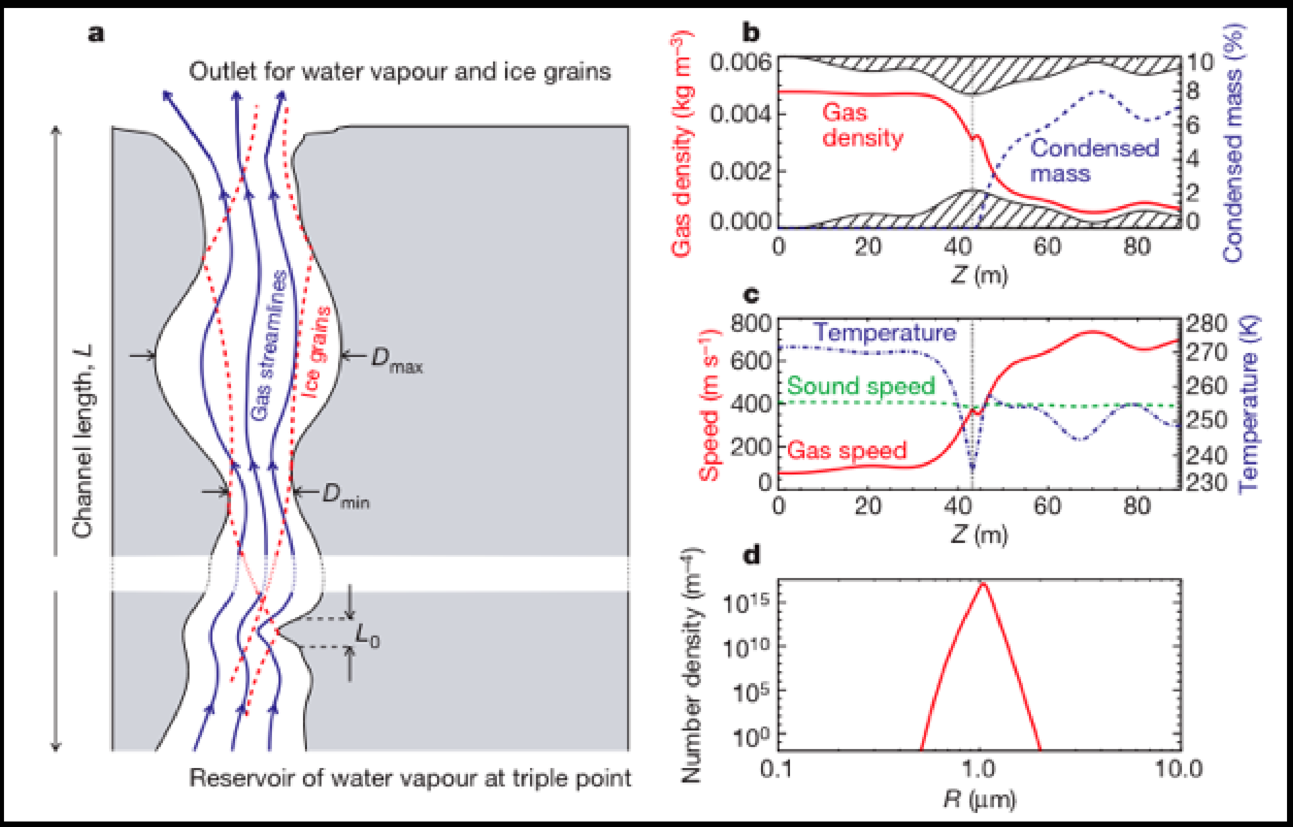
Dust Production Within Ice Cracks



- to explain:
  - dust speed (250m/s) much slower than speed of emerging gas (500m/s)
  - plumes are stratified: correlation between mass and speed
  - gas-to-dust ratio: 10%
  - in-situ size distribution

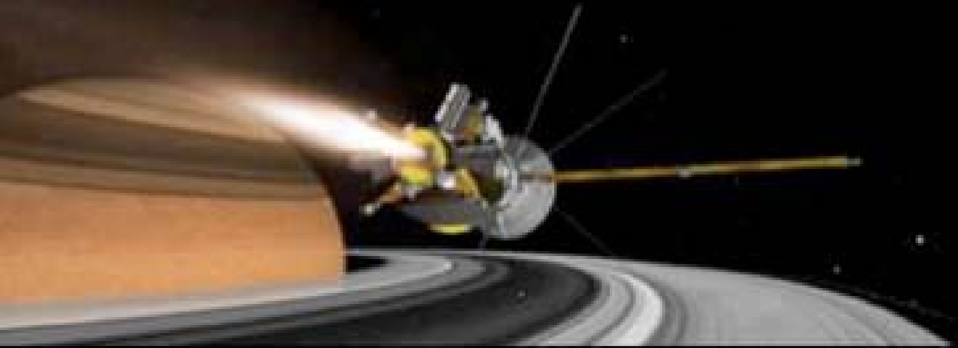


Dust Production Within Ice Cracks



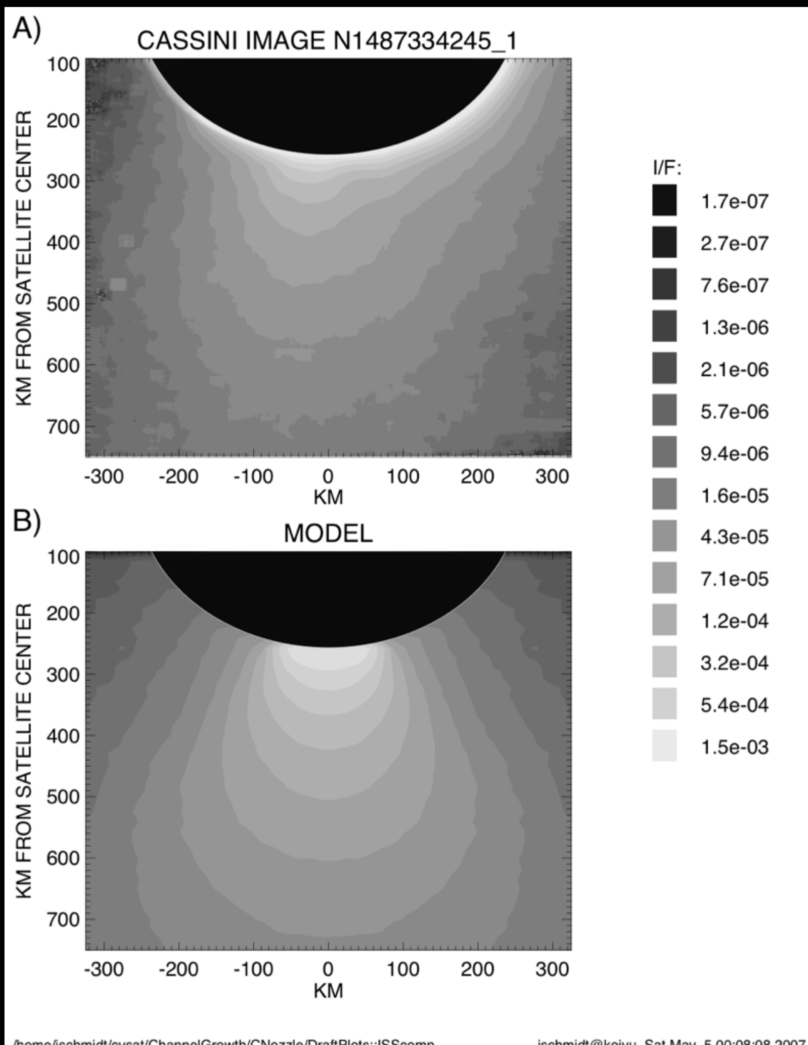
Schmidt, Brillantov, Spahn and Kempf, Nature, 2008

- growing dust coupled to gas flow
- dissipative collisions with the walls control final dust size and speed
- ensembles of random channels
- Control parameter:
  L_{col} - smallest structure
  d_s - min/max width

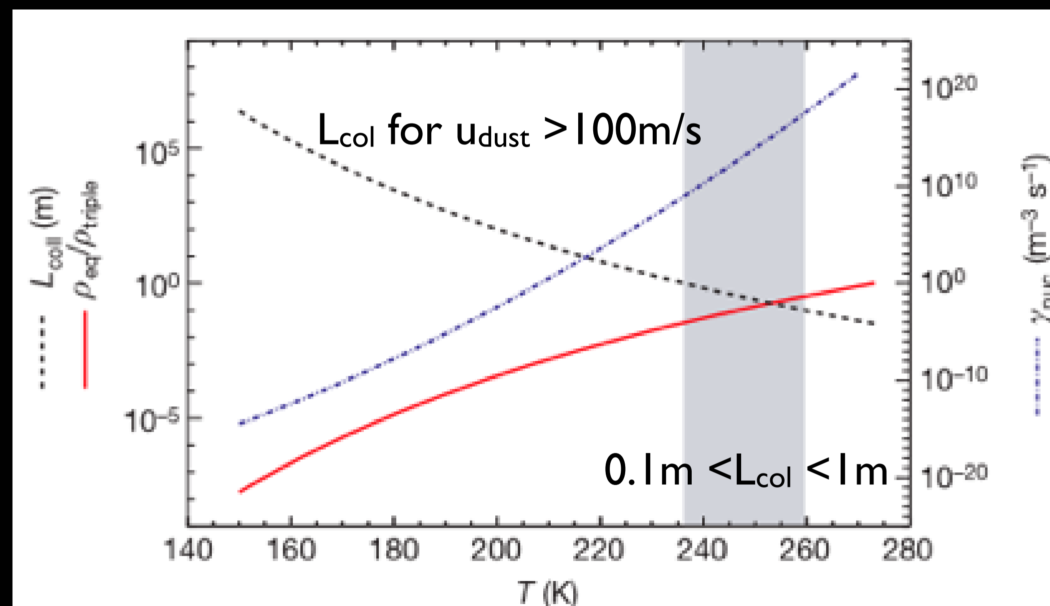


Dust ProductionModel

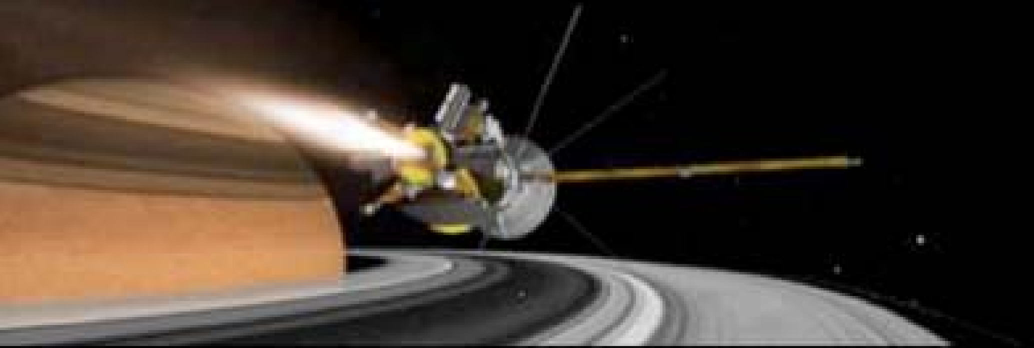
- Model reproduces: remote Sensing, dust, and gas data
- Model gives temperature at the bottom of the cracks



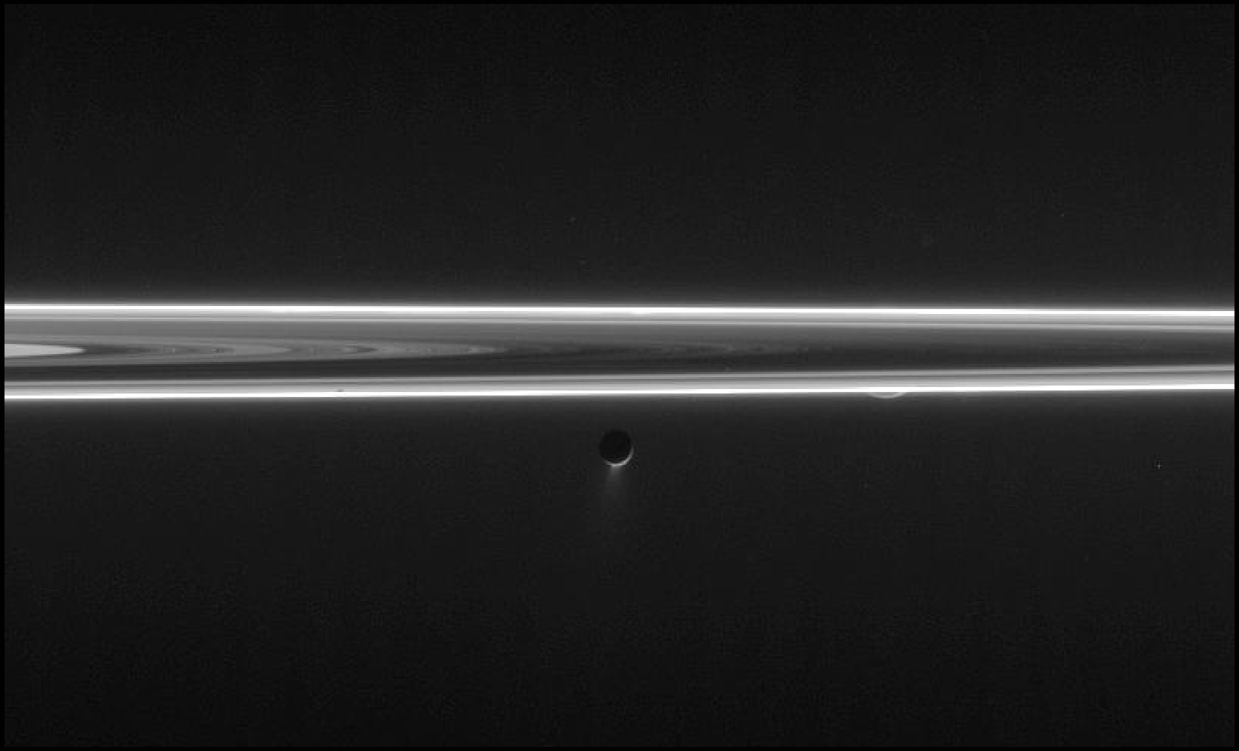
Schmidt et al., Nature, 2008



Liquid water within cracks

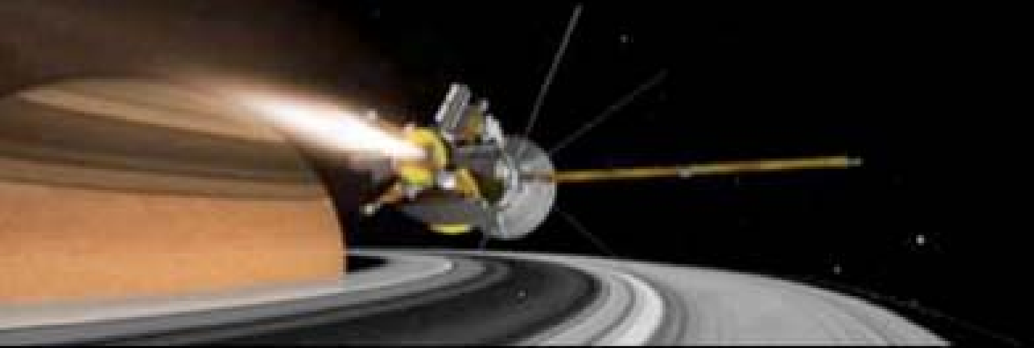


Vertical Ring Profile is due to Enceladus Dust Jets

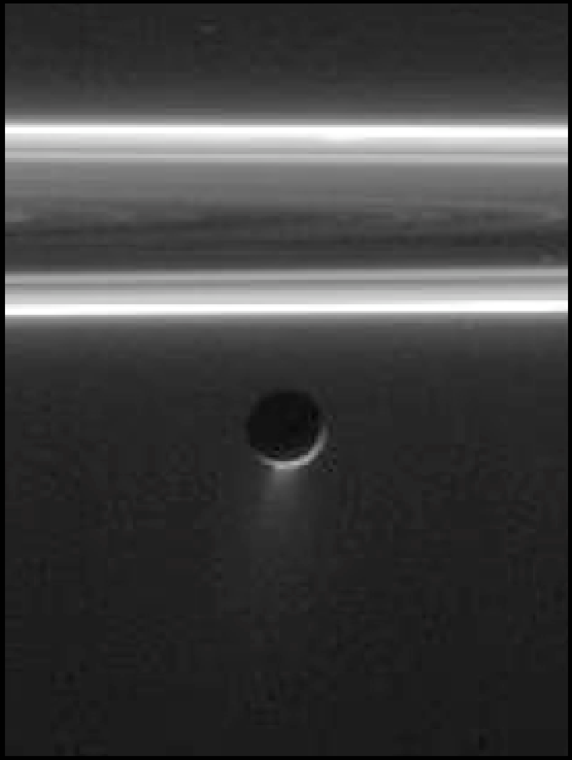


Cassini ISS, 2006

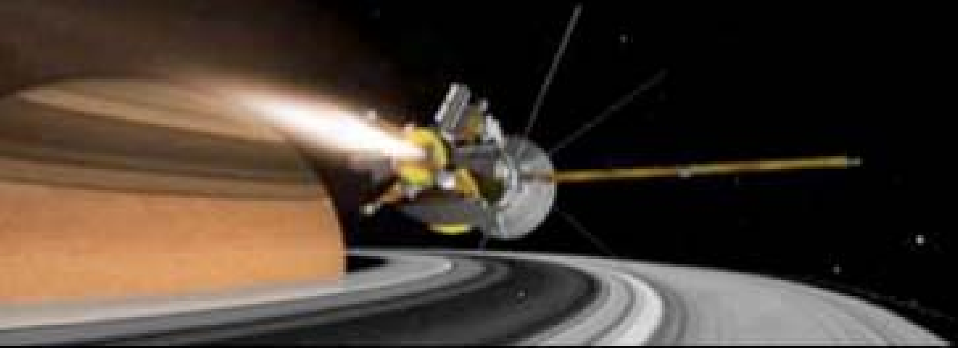
- Enceladus plumes inject fresh dust grains preferably in -z direction
- only particles launched faster than the 3 body escape speed can populate the ring



Enceladus Dust Ejection

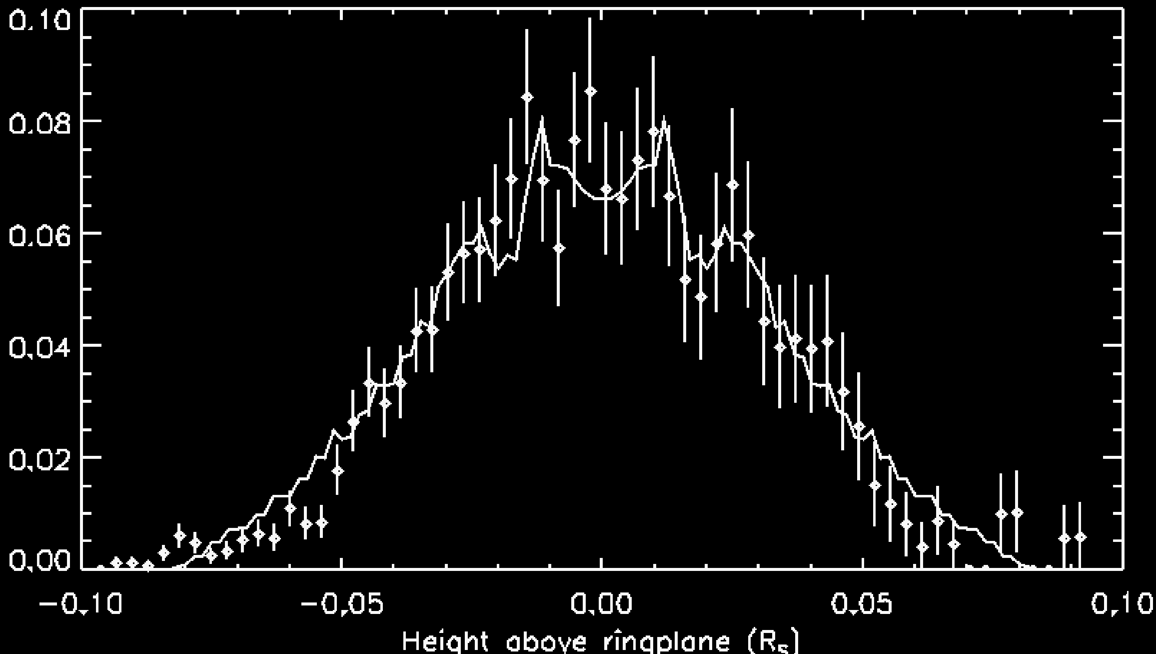


- performed numerical simulations of the plume particle ejection process
  - J2 and EM
  - RP doesn‘t matter here
  - particles initially uncharged
  - initial speed and mass distribution given by Schmidt et al. 2008 model
  - jet location given by Spitale & Porco



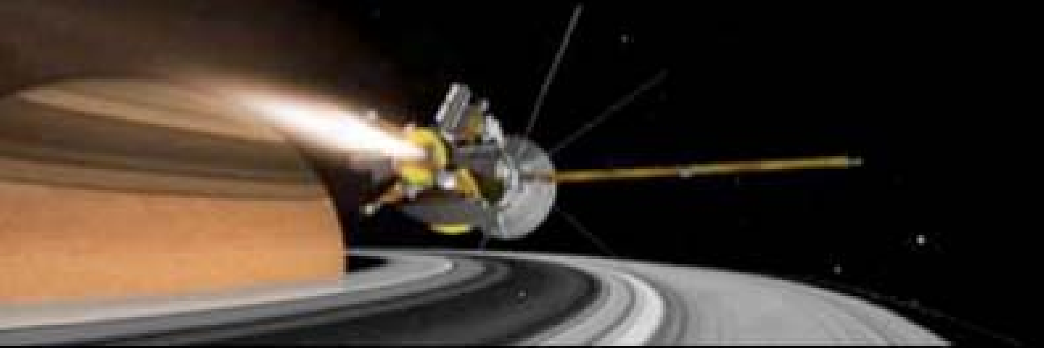
Simulated Ring Profile Matches CDA Data

Model versus CDA data



HRD data obtained during steep ring plane crossing in orbit 10 at about the Enceladus orbit.

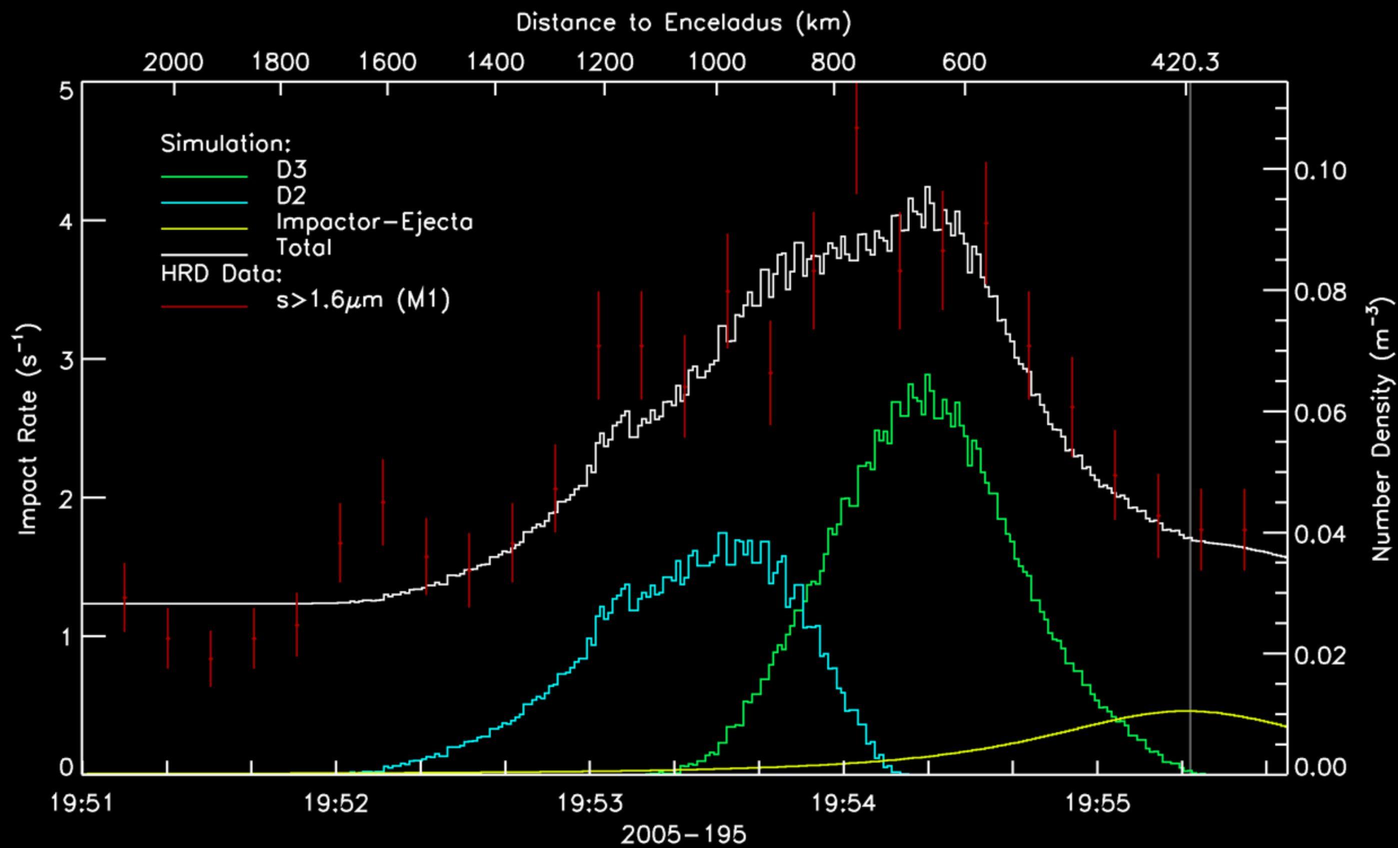
- Ring profile reproduced by model that only considers freshly ejected Enceladus dust jets particles:
  - initial inclination is preserved at least until particles start to migrate outwards
  - contribution by ejecta grains may be „disguised“:
    - rather flat inclination distribution

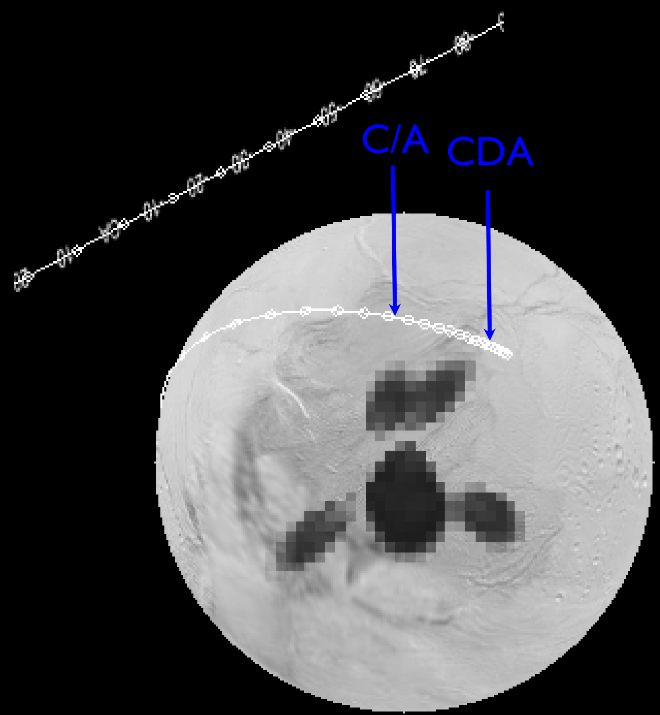


cosmic dust analyser

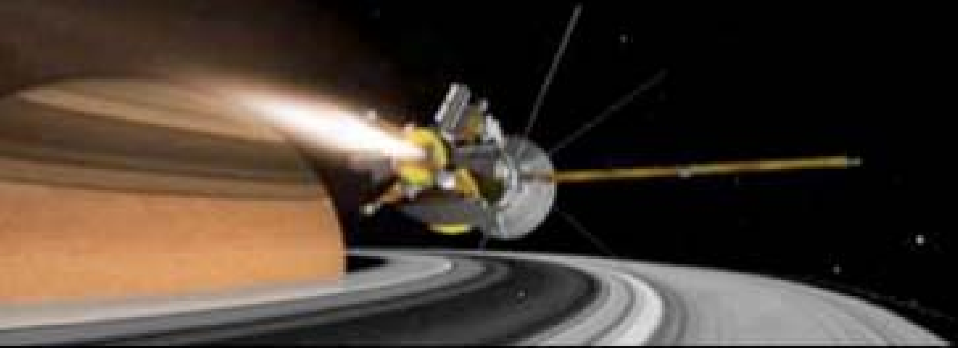
Max-Planck-Institut für Kernphysik

Best Model Fit to CDA E11 Data

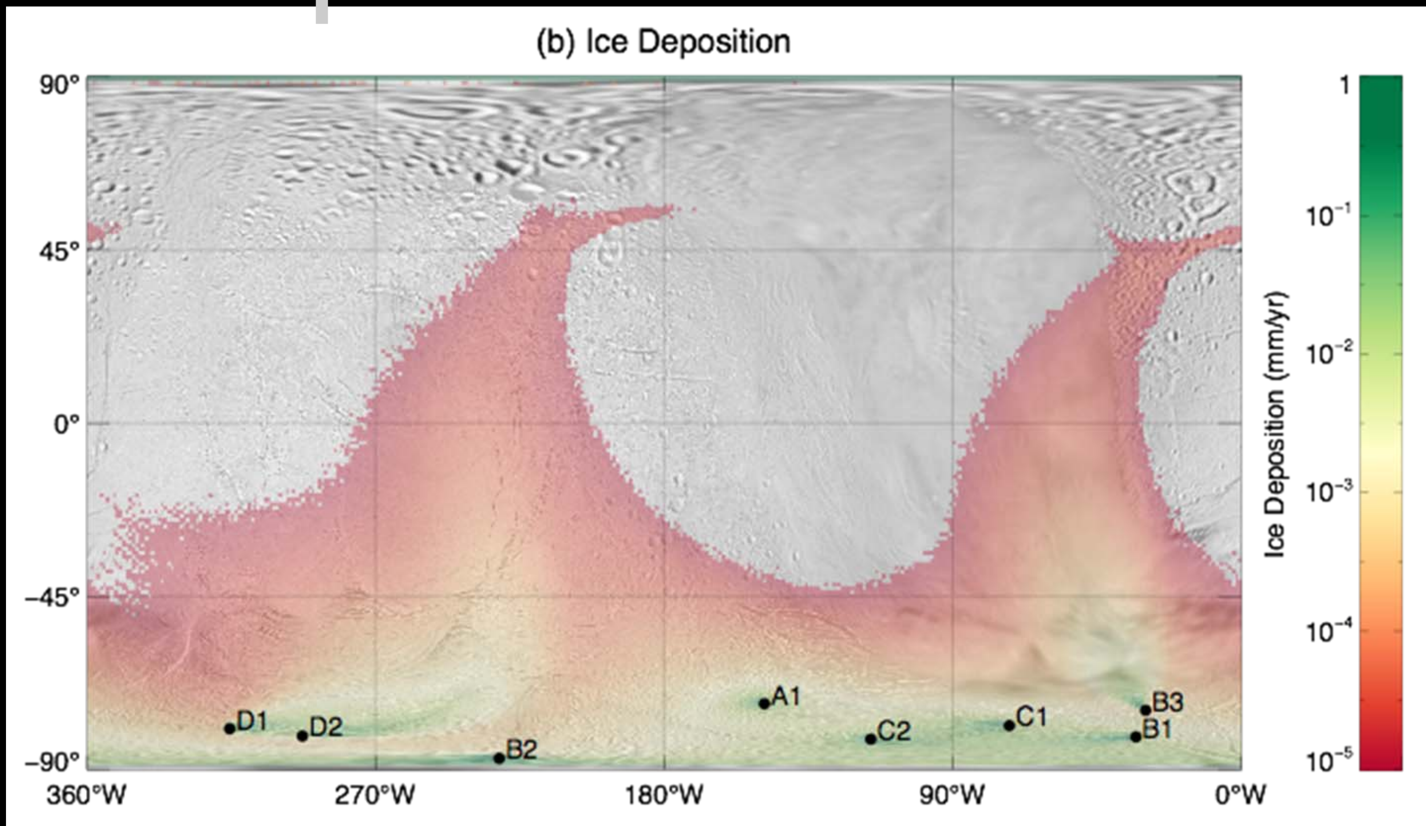




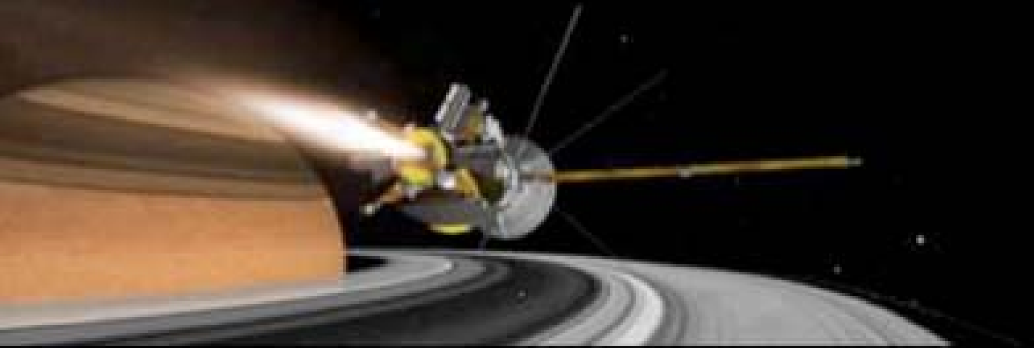
- only Damascus jets were observed during E11
- plume mass production: 5 kg/s, active venting area: 225m^2



Ice Deposition on Enceladus

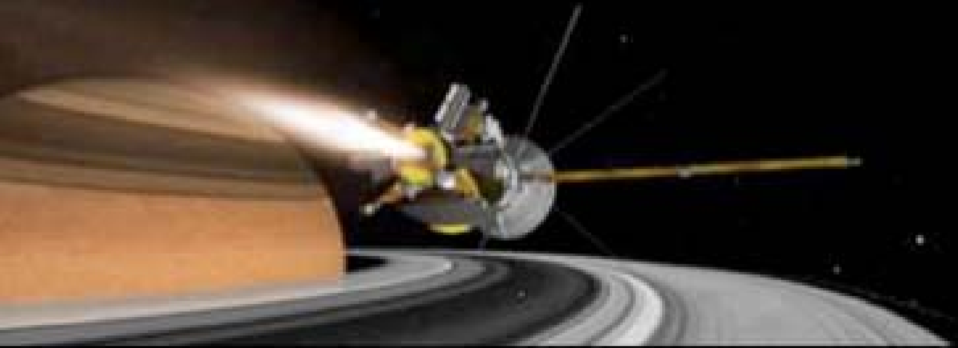


- mass deposition mostly at the locations of the jets
- 90% of the plume particles recollide with Enceladus



Composition of Enceladus Dust

- E ring dust consists of water ice, but ....
- There are 4 composition types:
  - Population I:
    pure water ice
  - Population II:
    water ice with rocky or organic impurities
  - Population III:
    Sodium-rich water ice
  - Population IV:
    Iron-rich non-water material



cosmic dust analyser

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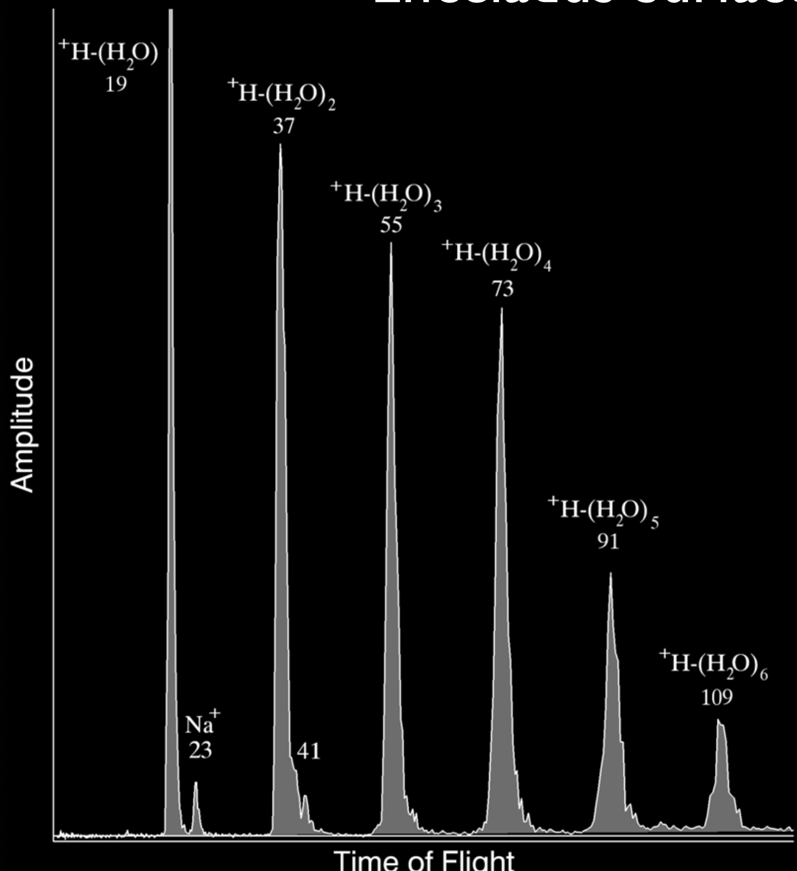
Most Abundant Composition Types

Population I: Pure Water Ice

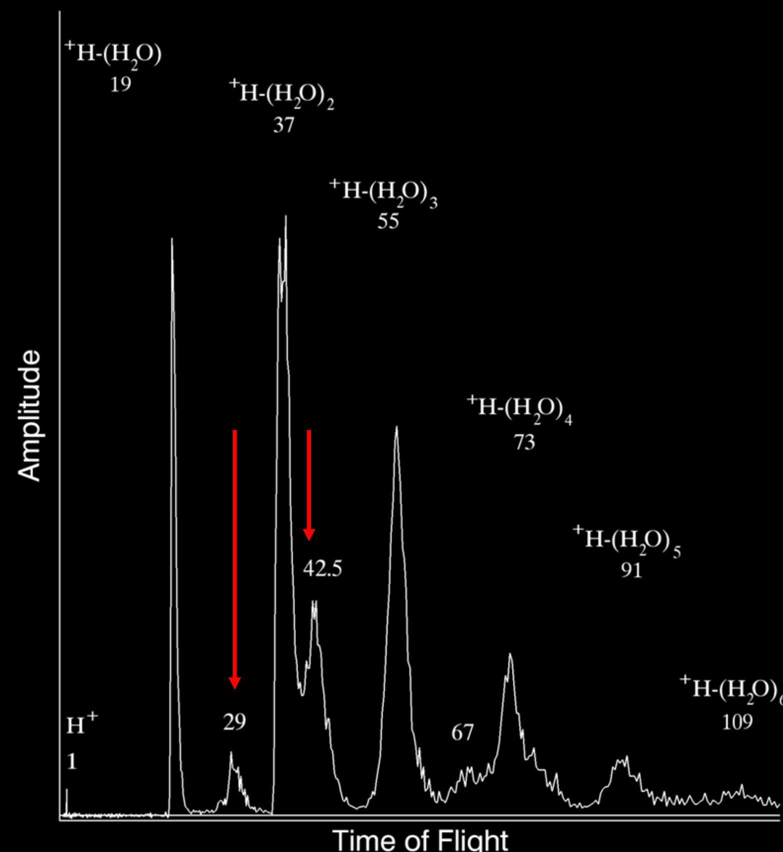
Enceladus Surface ?

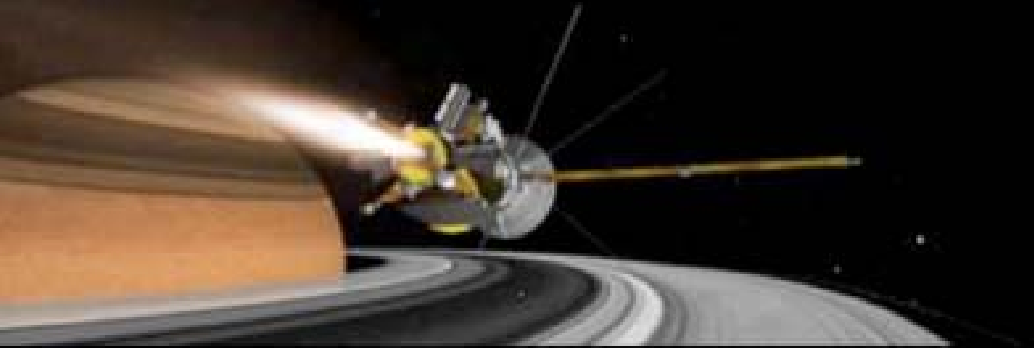


Postberg et al., Icarus, 2008

Population II: Water Ice + Impurity

Enceladus Plumes ?





Where and When are the Observed Mass Lines Formed?

- mass lines are formed within the cloud of neutrals and ions produced by the dust impact onto the instrument‘s rhodium target
- dominating process is hydration:
  - $H^+ + H_2O \Rightarrow H_3O^+$
  - $H_3O^+ + H_2O \Rightarrow (H_2O)\ H_3O^+$
  - ....