Time-of-Flight Dust Mass Spectrometry for Enceladus Plume Analysis: A Concept Study for the ESA L4 Mission

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Image Source: NASA/JPL

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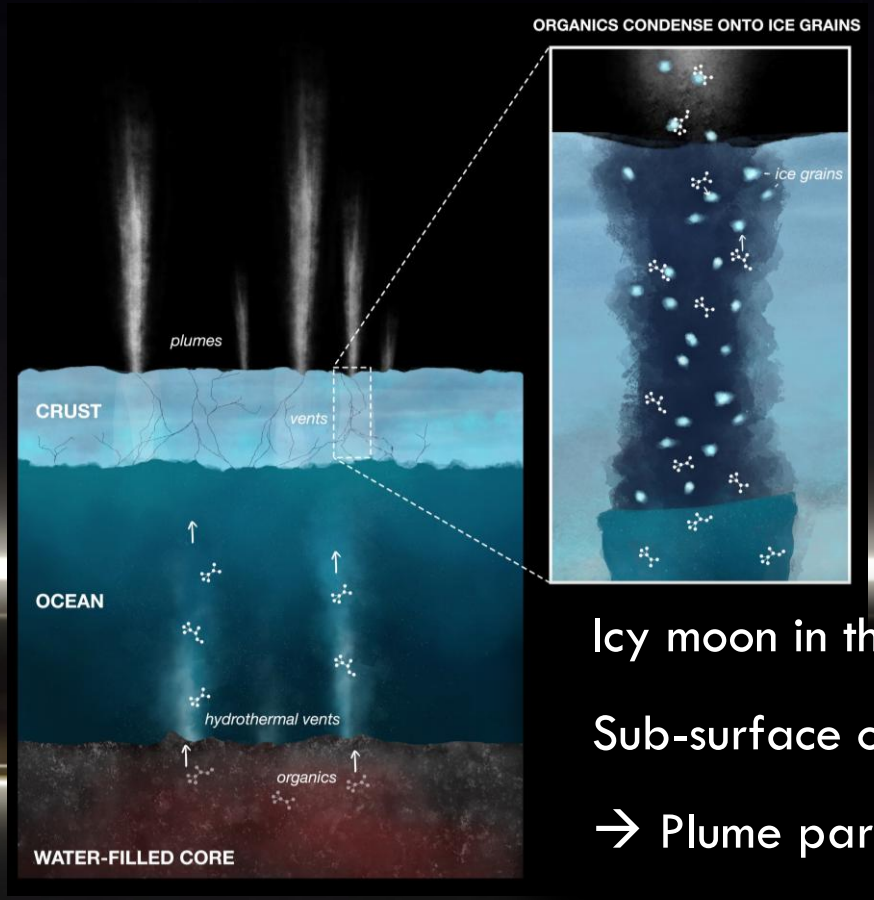
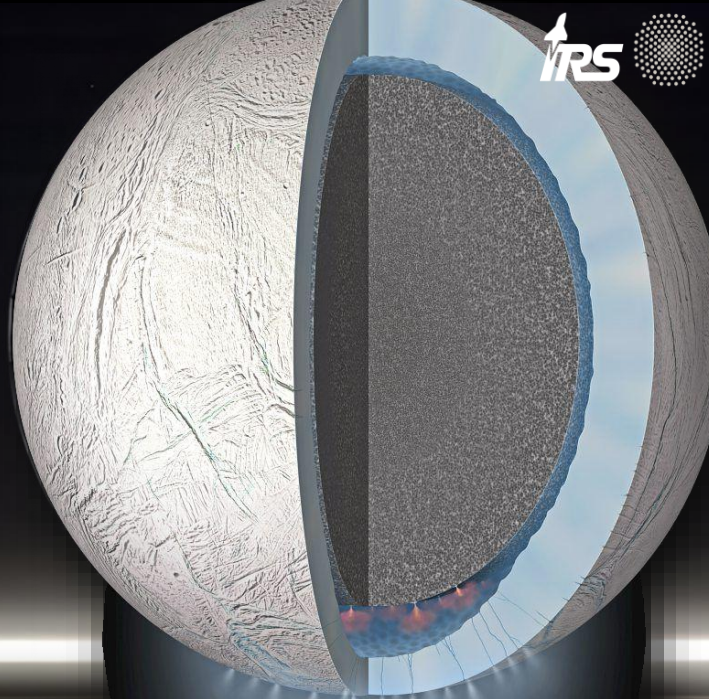
Enceladus Plume





Icy moon in the Saturnian System

Sub-surface ocean escapes through ice layer

→ Plume particles carry chemical composition of the ocean

→ Can life be found in the oceans of Enceladus?

What happened so far…

Cassini-Huygens mission in the Saturinan System

23 Enceladus flybys 2005-2015

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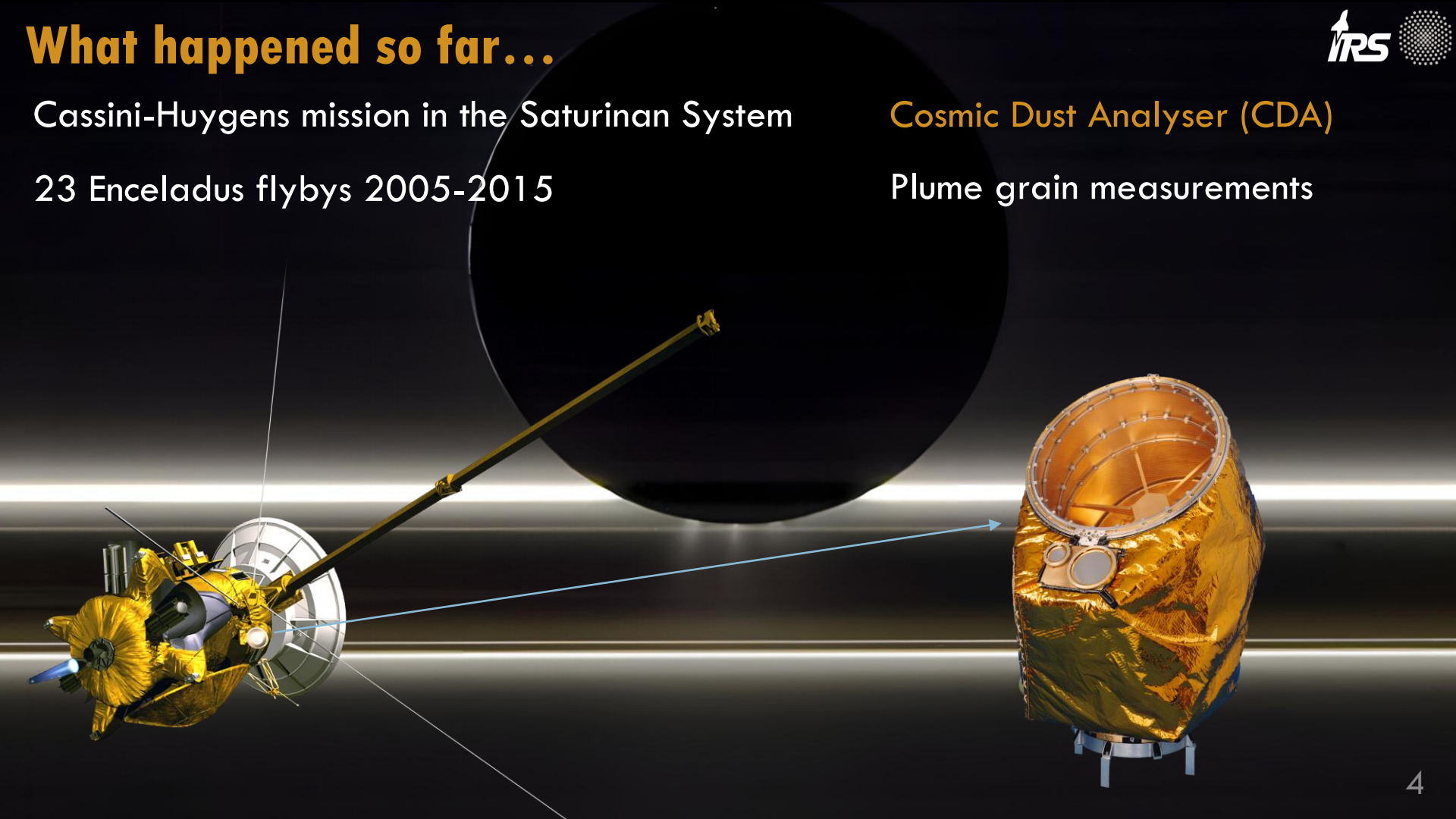
Cassini-Huygens mission in the Saturinan System

23 Enceladus flybys 2005-2015

Cosmic Dust Analyser (CDA)

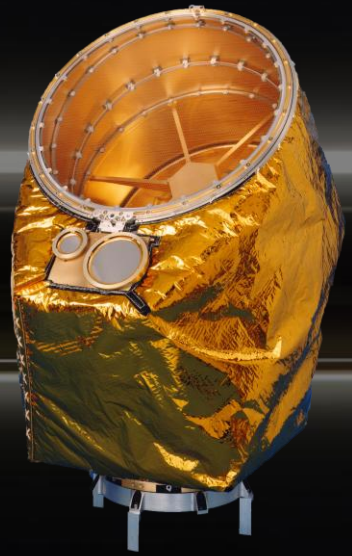
Plume grain measurements



Cosmic Dust Analyser (CDA)

„Jack-of-all-Trades“ Dust Detector:

- Interstellar and Interplanetary Dust
- Saturnian Ring & moon composition
- Determine particle velocity



Sensitive area: 900 cm^2

Mass resolution: $m/dm \approx 50$

Mass range: 1-200 amu

Designed for anorganic particles with low number density.

Plumes like these were not expected during CDA‘s design phase

Only faint clues from Voyager 1 (1980)….

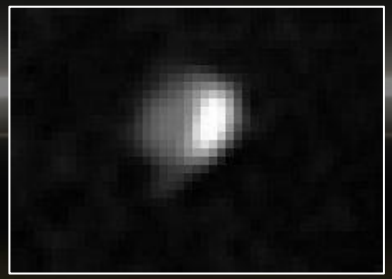


Image Source: NASA/JPL

→ ESA L4 needs a dust detector designed for the plume environment!

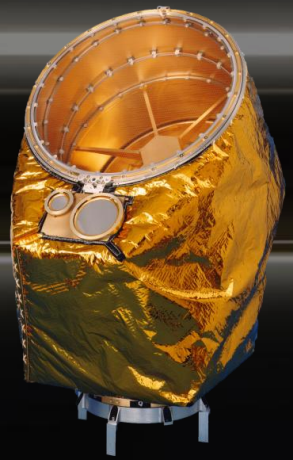
Optimizing for the Enceladus plume environment

Starting at CDA…

Sensitive area: 900 cm^2 → Way too large: >3000 particles/cm^2/s expected!

Mass resolution: m/dm≈50 → Higher resolution required: Identifing organic molecules (isobars) without ambiguities

Mass range: 1-200 amu → Higher mass range required: Organic compounds occur in larger moleculear complexes



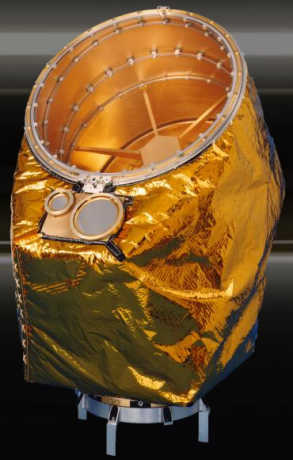
Optimizing for the Enceladus plume environment

Starting at CDA…

Sensitive area: 900 cm^2 → …arriving at ENIJA: Sensitive area: 1 cm^2

Mass resolution: m/dm≈50 → Higher resolution required: Identifing organic molecules (isobars) without ambiguities

Mass range: 1-200 amu → Higher mass range required: Organic compounds occur in larger moleculear complexes



Optimizing for the Enceladus plume environment

Starting at CDA…

Sensitive area: 900 cm^2 → …arriving at ENIJA: Sensitive area: 1 cm^2

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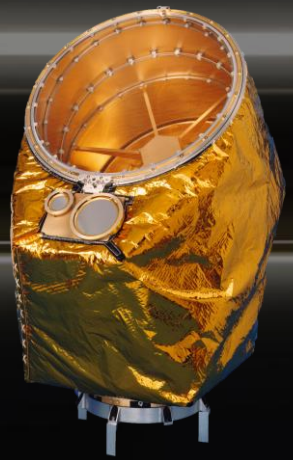
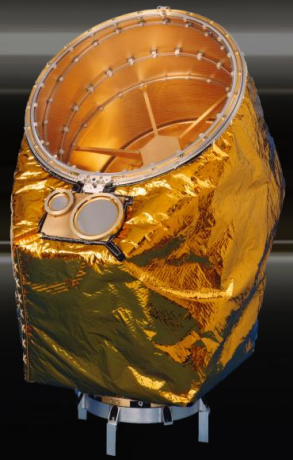
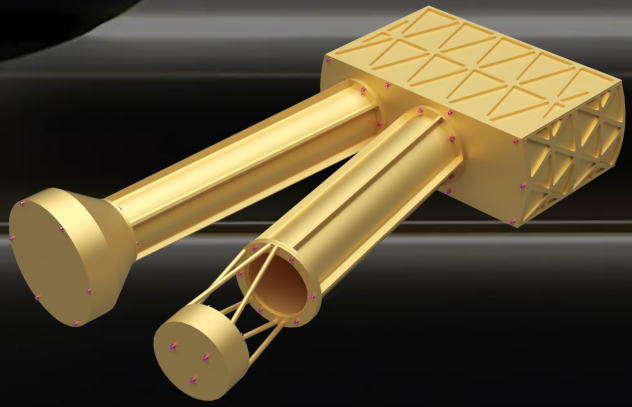


Optimizing for the Enceladus plume environment

Starting at CDA…	…arriving at ENIJA:
Sensitive area: 900 cm^2	Sensitive area: 1 cm^2
Mass resolution: m/dm≈50	Mass resolution: m/dm≈500…1000
Mass range: 1-200 amu	Mass range: 1-1000+ amu

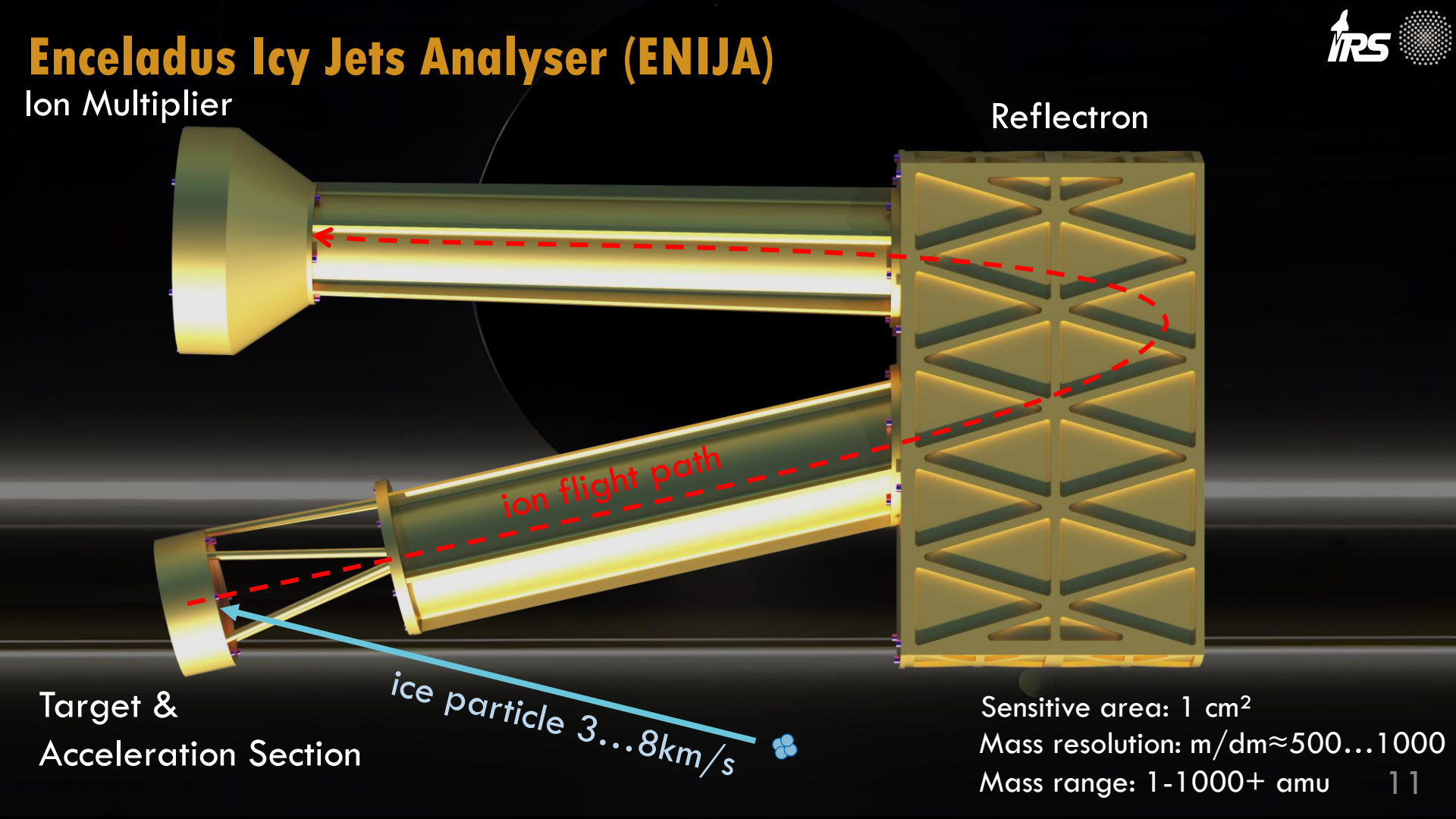




Enceladus Icy Jets Analyser (ENIJA)

Sensitive area: 1 cm²
Mass resolution: m/dm≈500…1000
Mass range: 1-1000+ amu

Enceladus Icy Jets Analyser (ENIJA)



Sensitive area: 1 cm²
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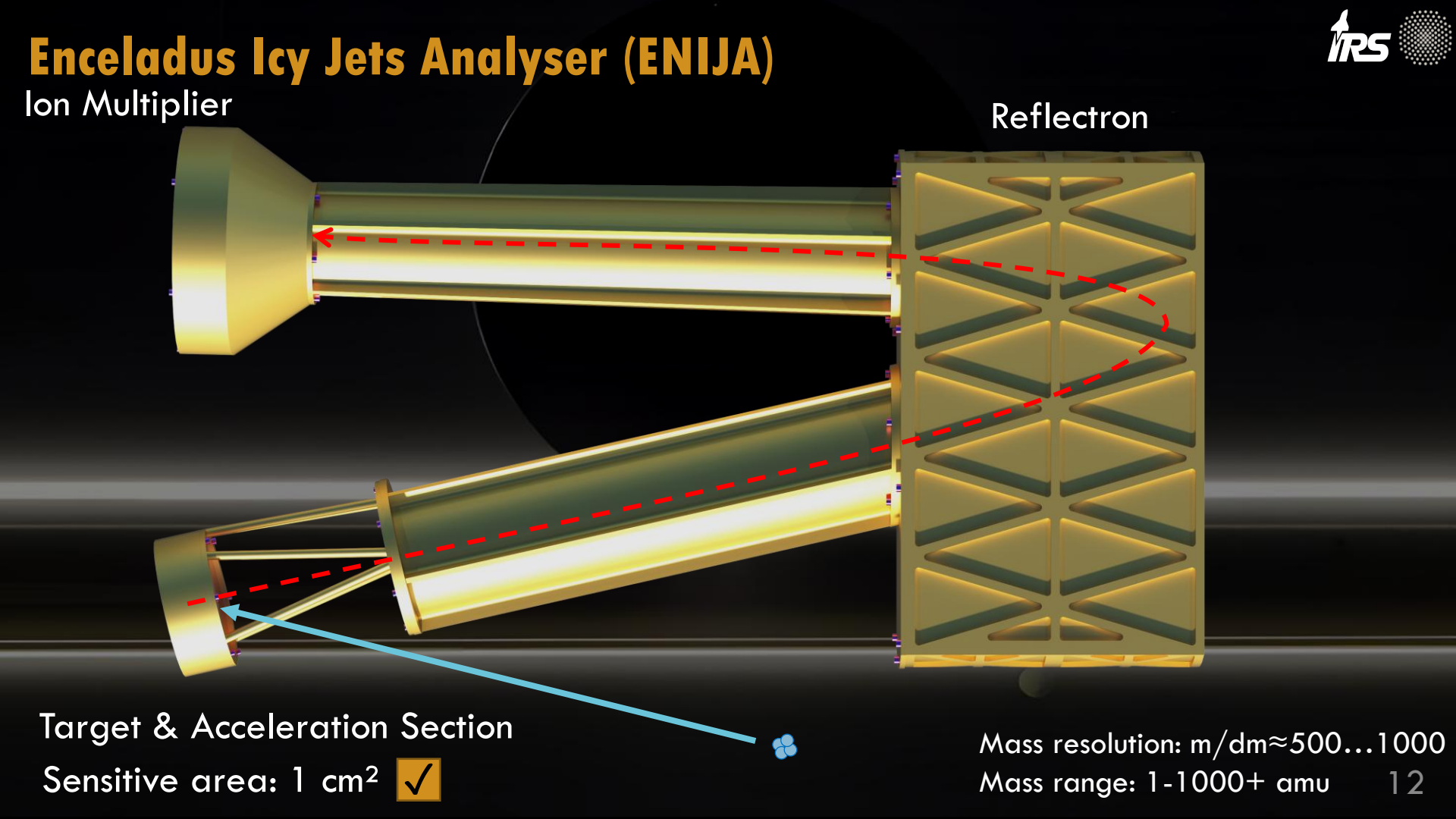
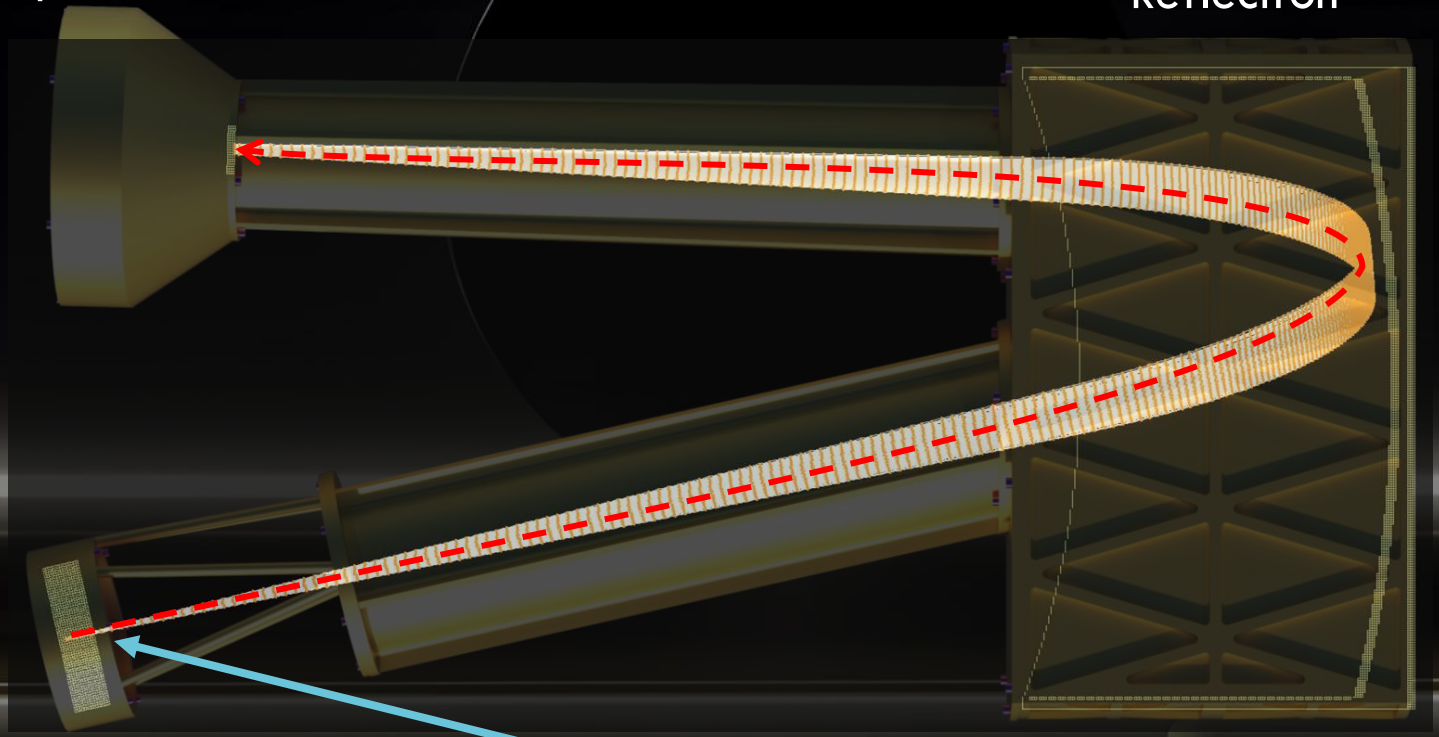
Enceladus Icy Jets Analyser (ENIJA)



SIMION Ion Optics Simulation

Ion Multiplier

Reflectron



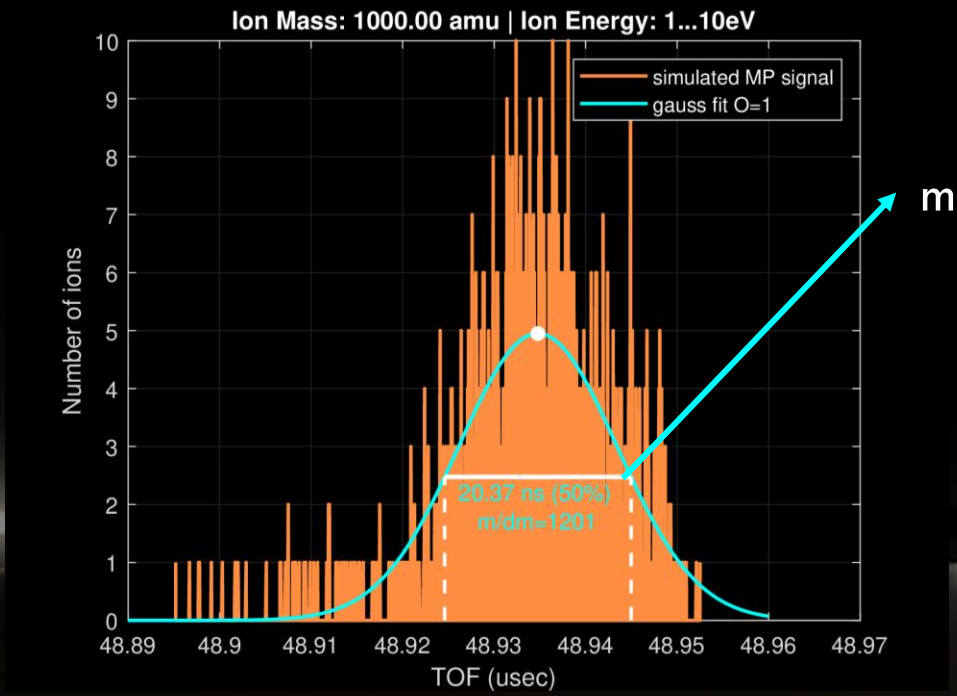
Target & Acceleration Section

Sensitive area: 1 cm² ✓

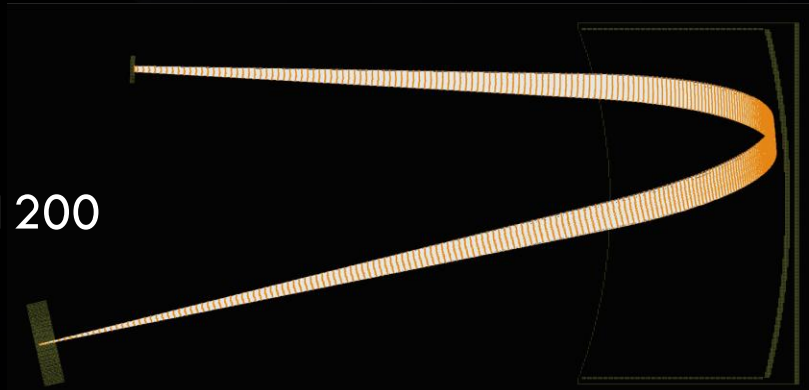
Mass resolution: m/dm≈500…1000

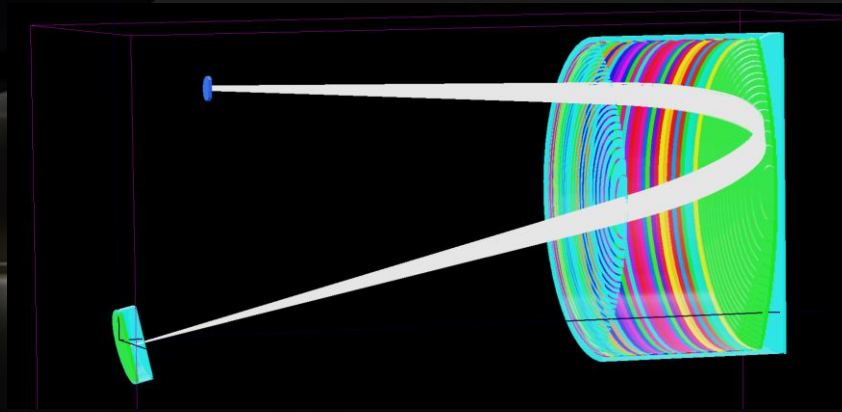
Mass range: 1-1000+ amu

SIMION Ion Optics Simulation



m/dm=1200





Mass resolution: m/dm≈500…1000 ✓

Mass range: 1-1000+ amu ✓

(~50μs TOF << 1s/3000= 333μs)

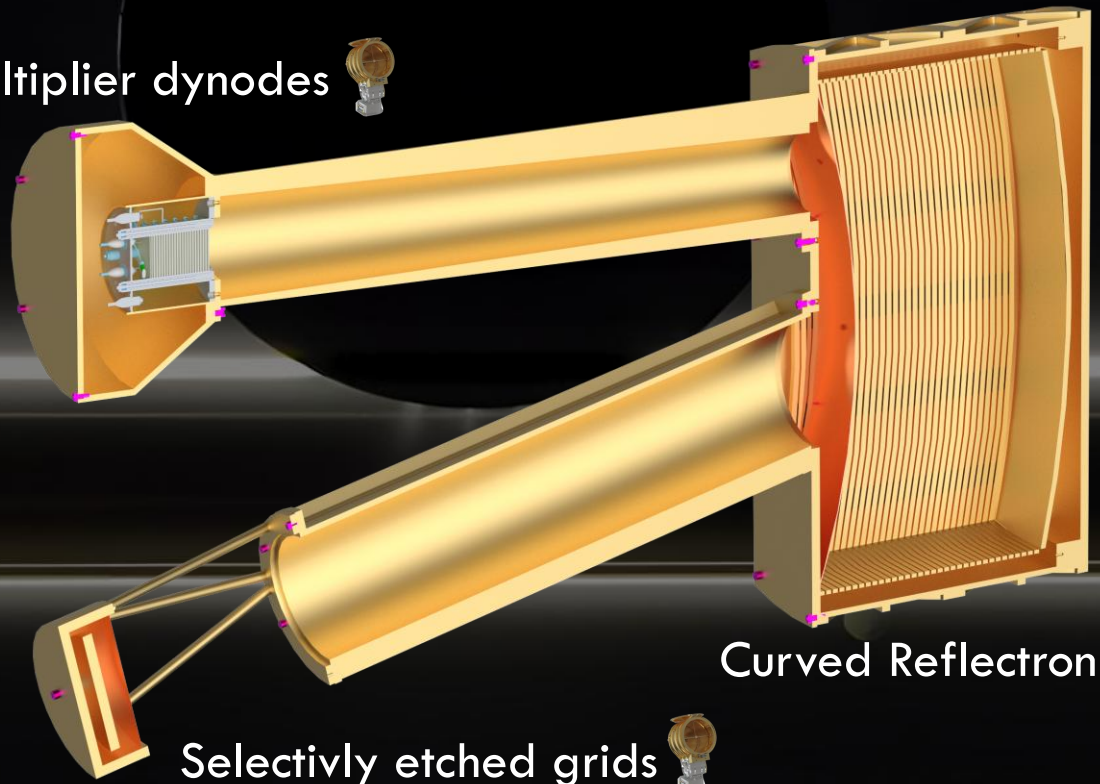
ENJIA is propelled by the heritage of previous instruments

Destiny^{+} Dust Analyser (DDA) & Cosmic Dust Analyser (CDA)

taps on different multiplier dynodes

Curved electrodes

high-speed triggered sampling & low-noise signal recording



Curved Reflectron grid

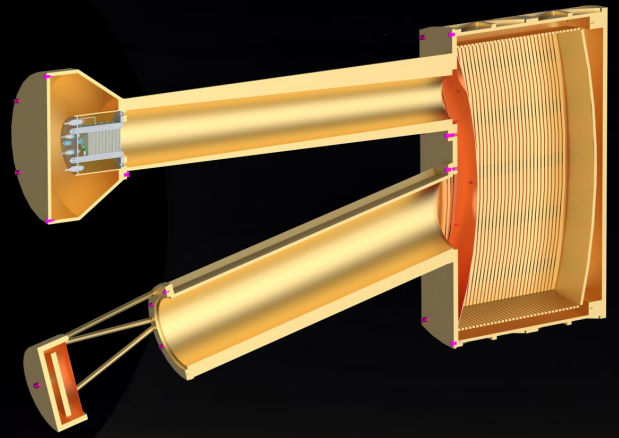
Selectivly etched grids

Next steps?

Further refinement of ion optics and CAD model

Buildup of lab model (w/ DDA EM electronics)

Dust test in the Stuttgart Dust Accelerator



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Thank you!

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Still got questions?
Join the science and instrument team?

To study:

- Double Spectrometer for simultaneous Cation and Anion Measurements
- Hybrid Spectrometer (TOF + Orbitrap)
- High-rate PVDF subsystem

v1.2

ENCELADUS ICY JET ANALYSER (ENIJA)

5000
event memory

Non-Volatile
RAM

ARM CPU
SAMRH71 60 MHz
32 bit, FPU

100 krad
radition hardness

18W
Power Consumption

500 kbit
event raw data

Compressor
PXE amplifer

0.005 s
dead time
Smart FPGA Trigger

FPGA
data aquistion

Boot ROM
internal

Continuous Sampling

Real-Time Digital Filter

High Flux Analyser

128 kbps IF

3 x 5000 V
High Voltages

JFET
low-noise
CSA PXE

1-2000 amu
TOF-MS Mass Range
High-Mass-Organics

50°
Field of View

Nano-dust
Composition

HDR+ TOF-MS

Differential
Signal connections

1000
TOF-MS Mass Resolution

0.2 fC
sensitivity

3-channel
Charge Sensitive Grids

3x40 MHz
data sampling

3x350 MHz
TOF-MS recording

SIMION-3D
ion optics

0.0001 m²
sensitive MS area

REFLECTRON
TOF-Mass Spectrometer

Cation+Anion
Mode

8 kg
Mass

Ejecta Suppression

6 Channel
Signal recording

Hydrogen
MS-Measurement

Single
Ion Detection

12 bit
Signal resolution

Habitability and Biomarkers

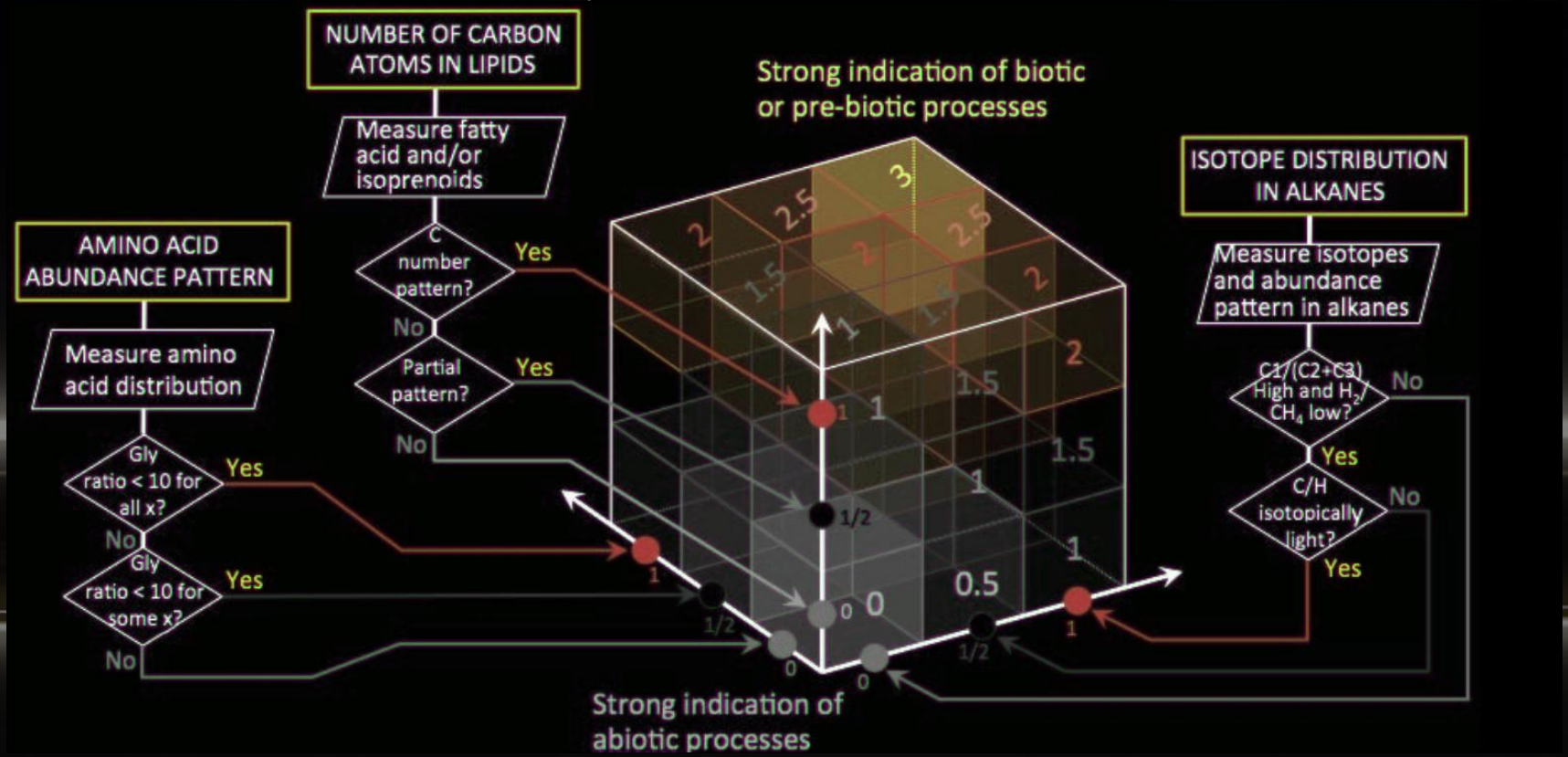

Image Source: Reh et. al: Enceladus Life Finder: The Search for Life in a Habitable Moon, 2016

ENIJA Mass Resolution