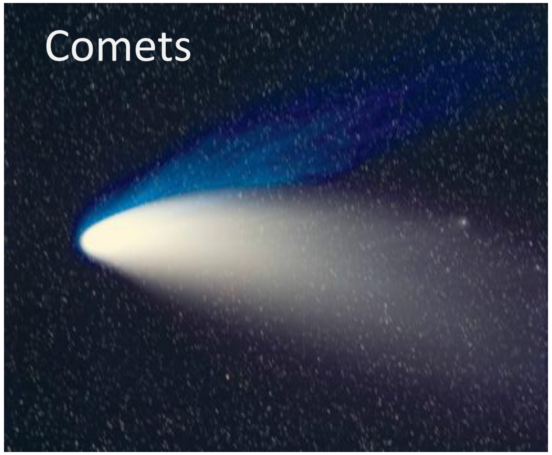
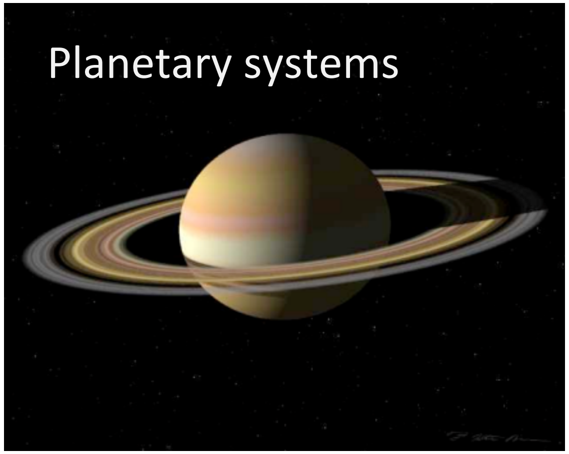
Development of Hyperdust: Advanced In-Situ Dust Telescope

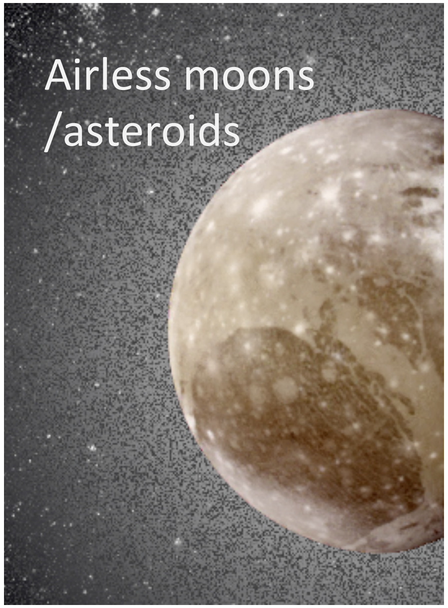
A. J. Gemer, J. R. Rocha, L. O'Brien, L. Burke, A. Yehle, K. Maute, E. Grün, S.Kempf, M. Horanyi, Z. Sternovsky

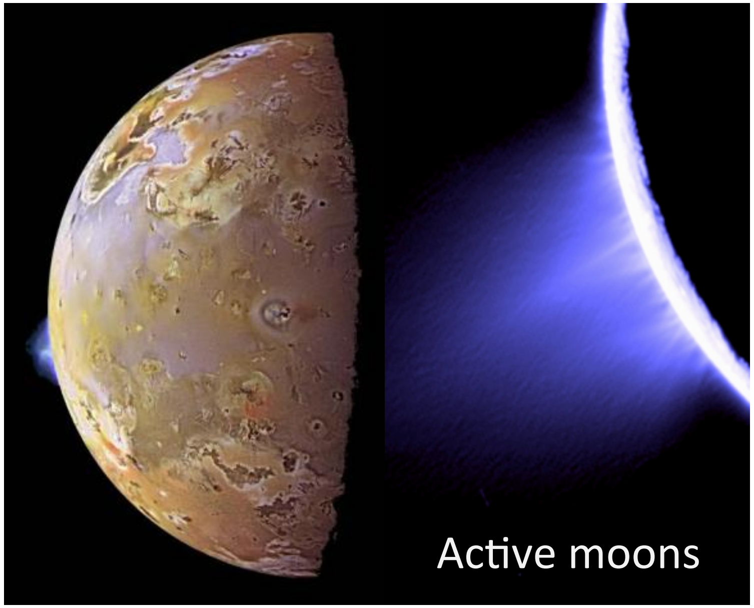
LASP, University of Colorado, Boulder, CO 80303

Dust is abundant in the solar system



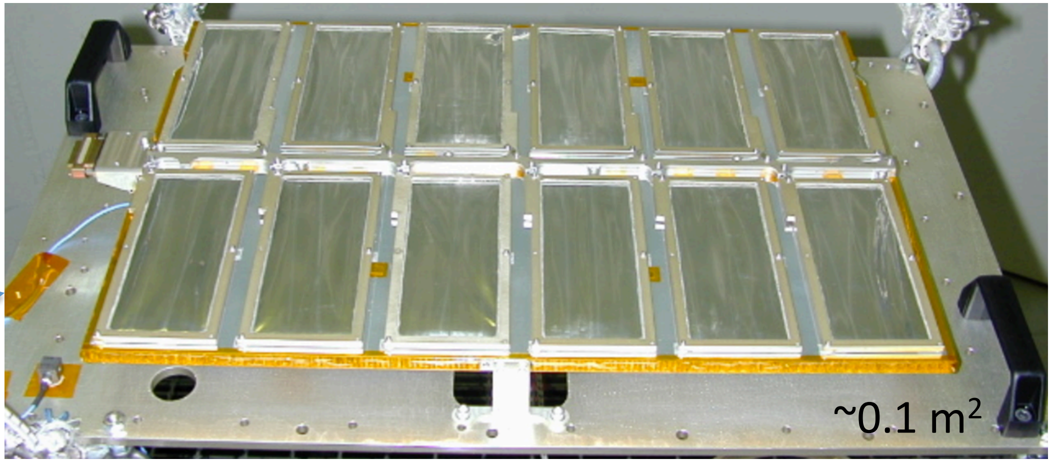


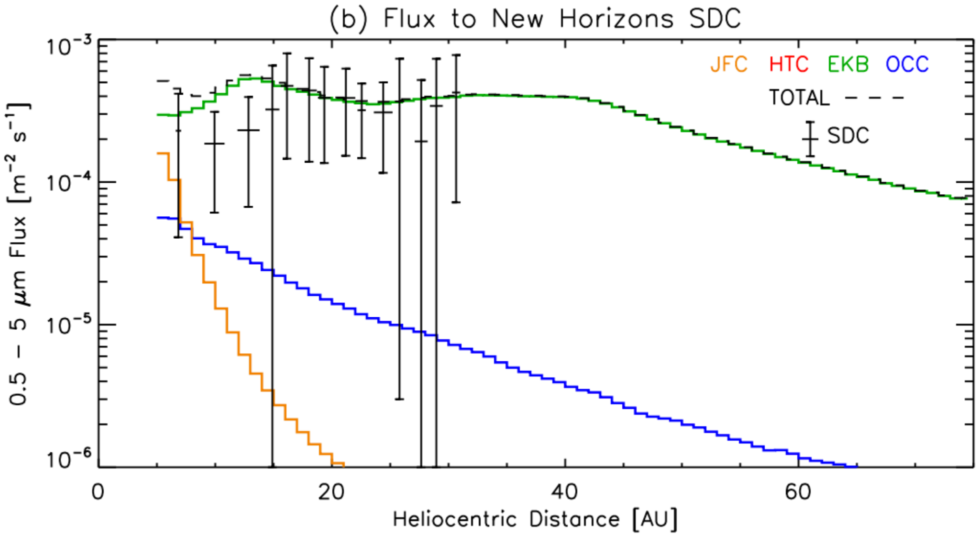


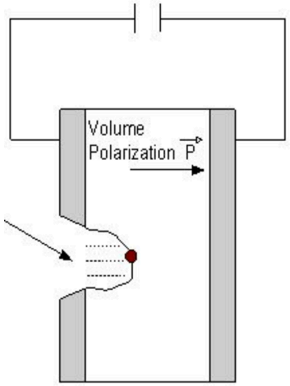


Student Dust Counter (SDC) operating in the outer solar system

Depolarization dust detector







Dust ***mass*** obtained from signal amplitude using the calibration relation

$$N_e = 5.63 \times 10^{17} m[\mathrm{g}]^{1.3} v[\mathrm{km/s}]^{3.0}$$

Poppe, 2016

Horanyi et al, 2008

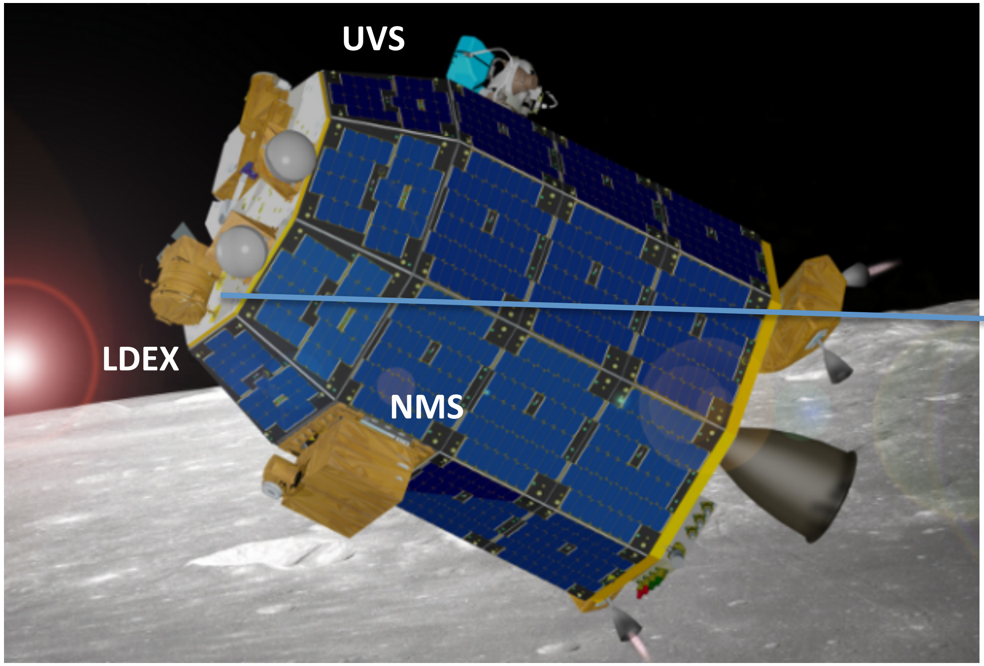
The LADEE mission and LDEX

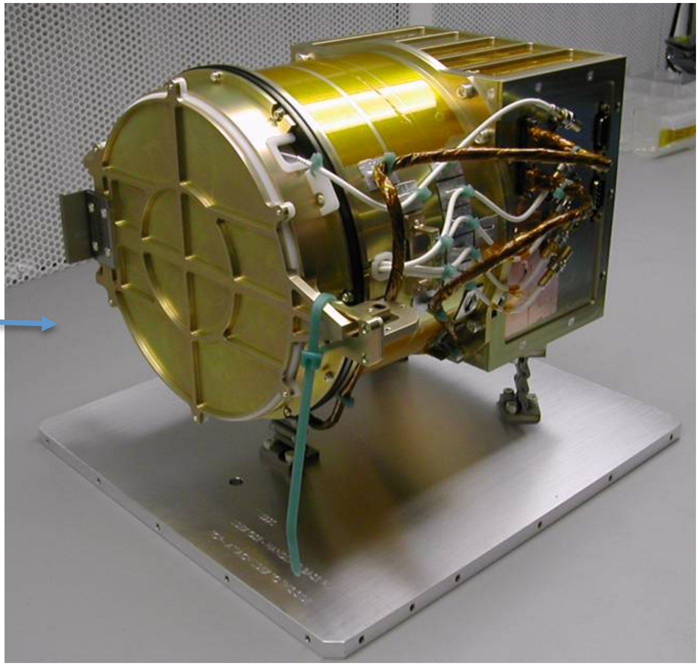
LADEE = Lunar **A**tmosphere and **D**ust **E**nvironment **E**xplorer

LDEX = Lunar **D**ust **EX**periment (LDEX)

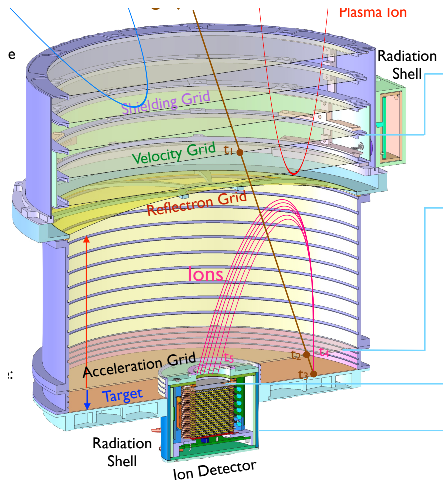
Operation: 2013-2014

Orbit: ~50x200 km elliptical orbit, 100 days of operation

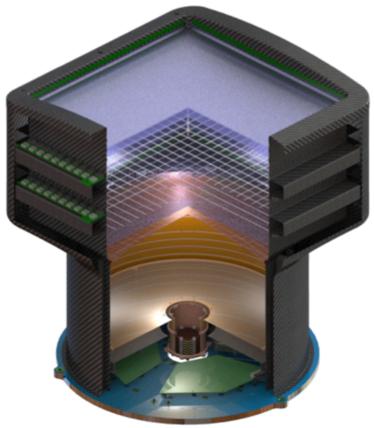




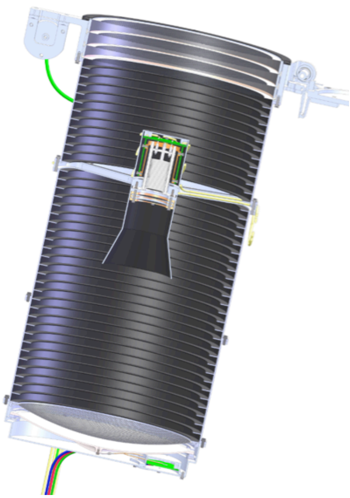
Instruments currently in development



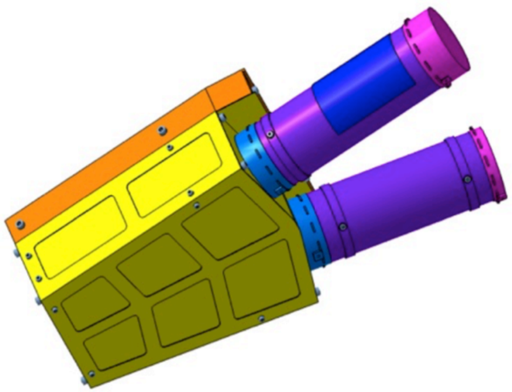
SUDA
Selected for flight (approx. 2022)



Hyperdust
Proposed for asteroid missions (with DTS)



NDA/DANTE
Proposed for inner solar system dust investigations

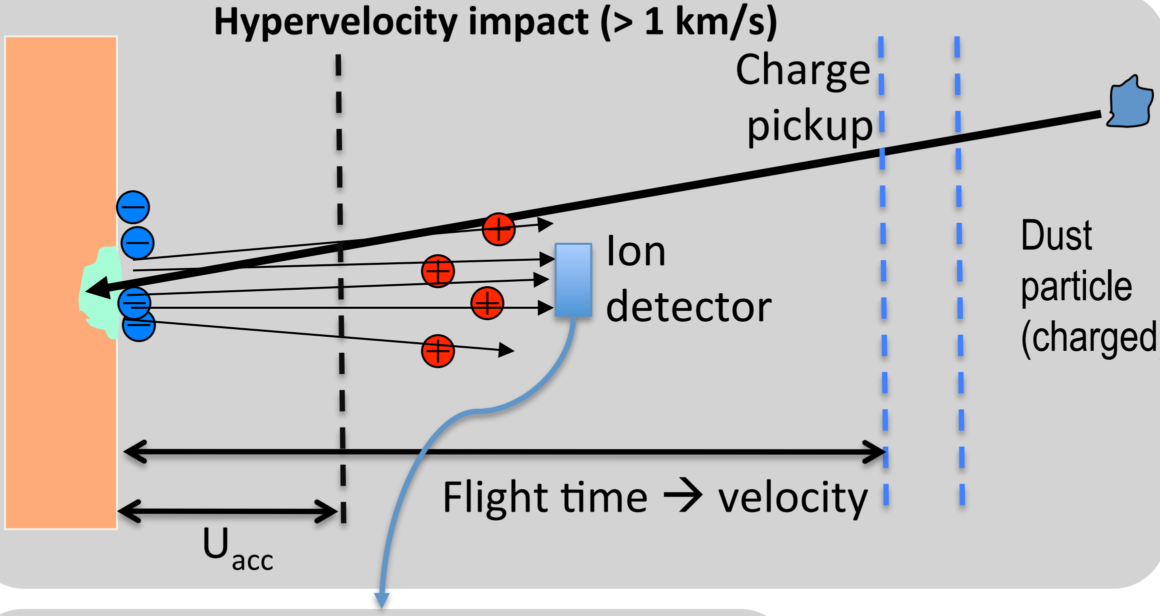


ENIJA
Proposed for Enceladus mission

Common theme: **Compositional analysis**

Instrument concepts developed at: LASP/University of Colorado and MPI-K/Heidelberg (now University of Stuttgart)

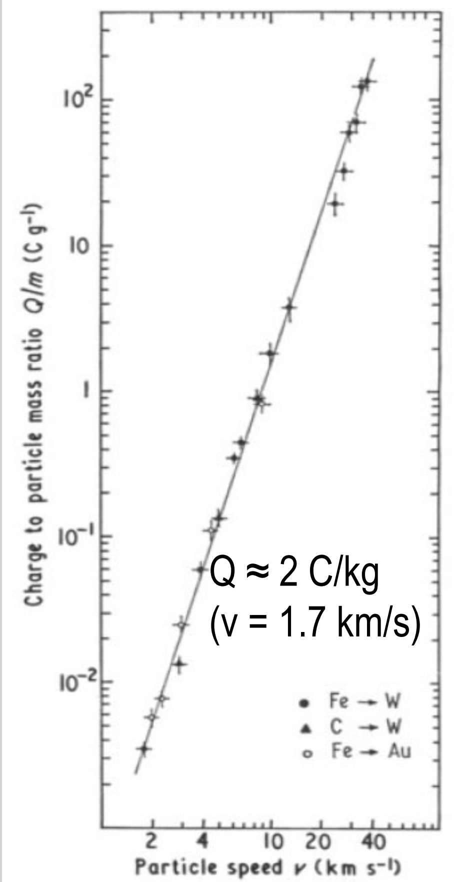
In-situ detection/analysis principle - *Impact Ionization*



Total impact charge:

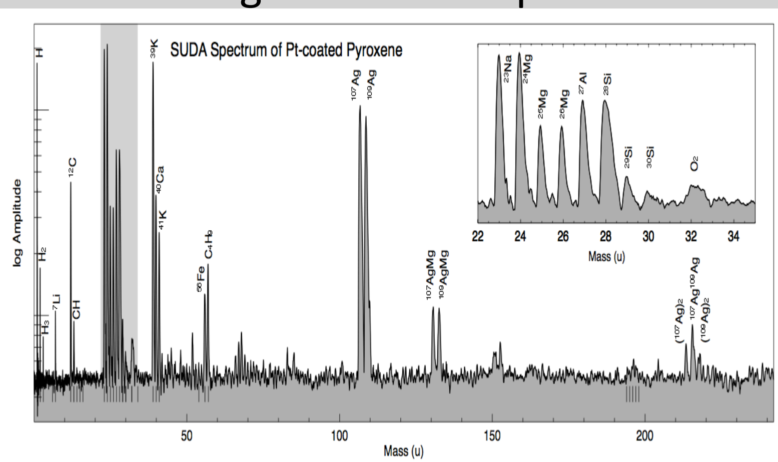
Q[C] ≈ 0.5 mv$^{3.5}$

Q[C], m[kg], v[km/s]



Dietzel et al., J Phys E (1973)

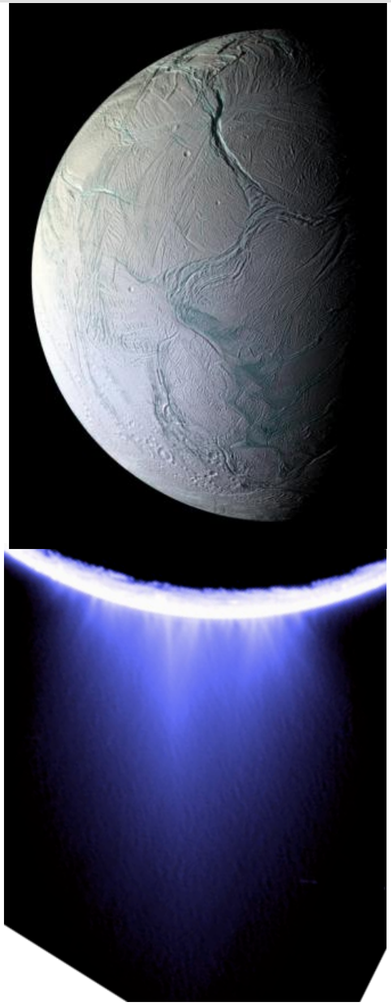
Time-of-flight ion mass spectrum

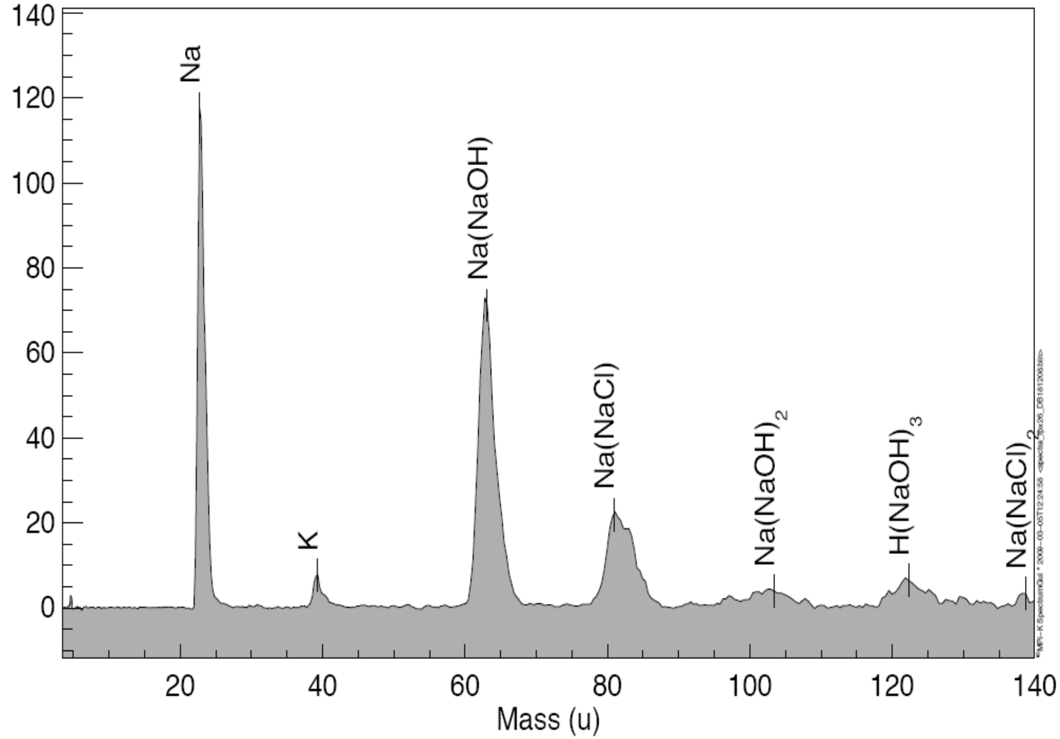


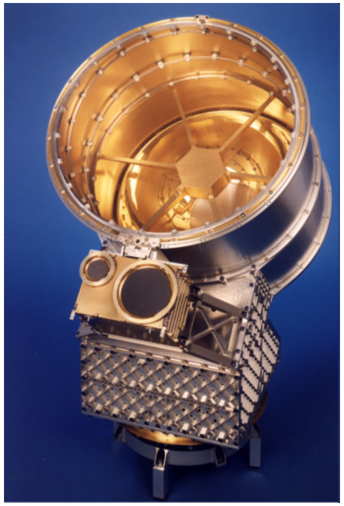
Measureable parameters:

- Velocity
- Mass
- Ion composition

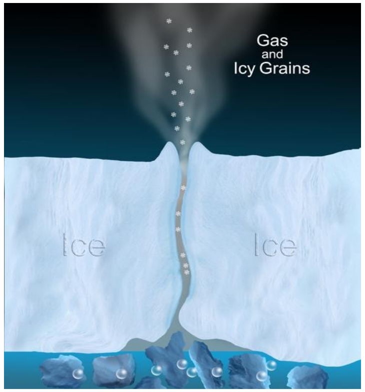
CDA made important science contributions to the Cassini mission





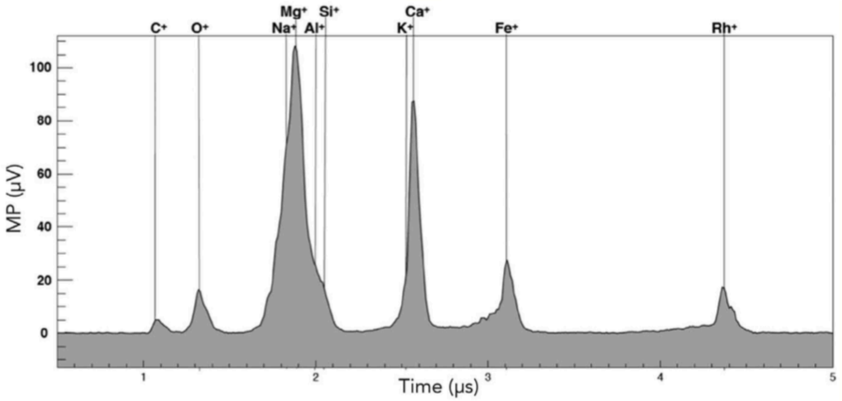


CDA on Cassini
M/dM ~ 20-30

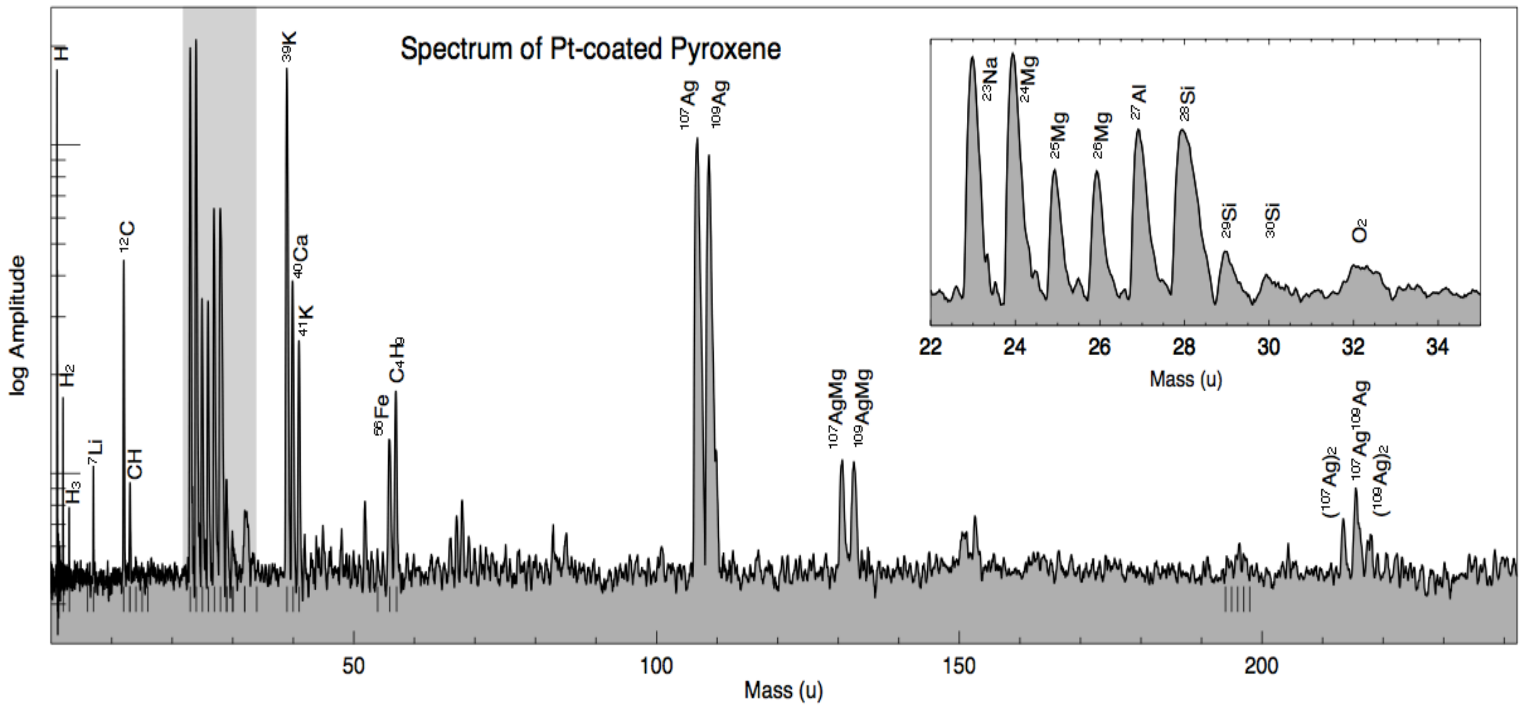


- Pronounced signatures of sodium and potassium salts in a water matrix
- NaCl, KCl, NaHCO3 are identified.
- Important implications for subsurface water reservoir (Postberg et al., Nature 2009)

Hyperdust improvement over CDA



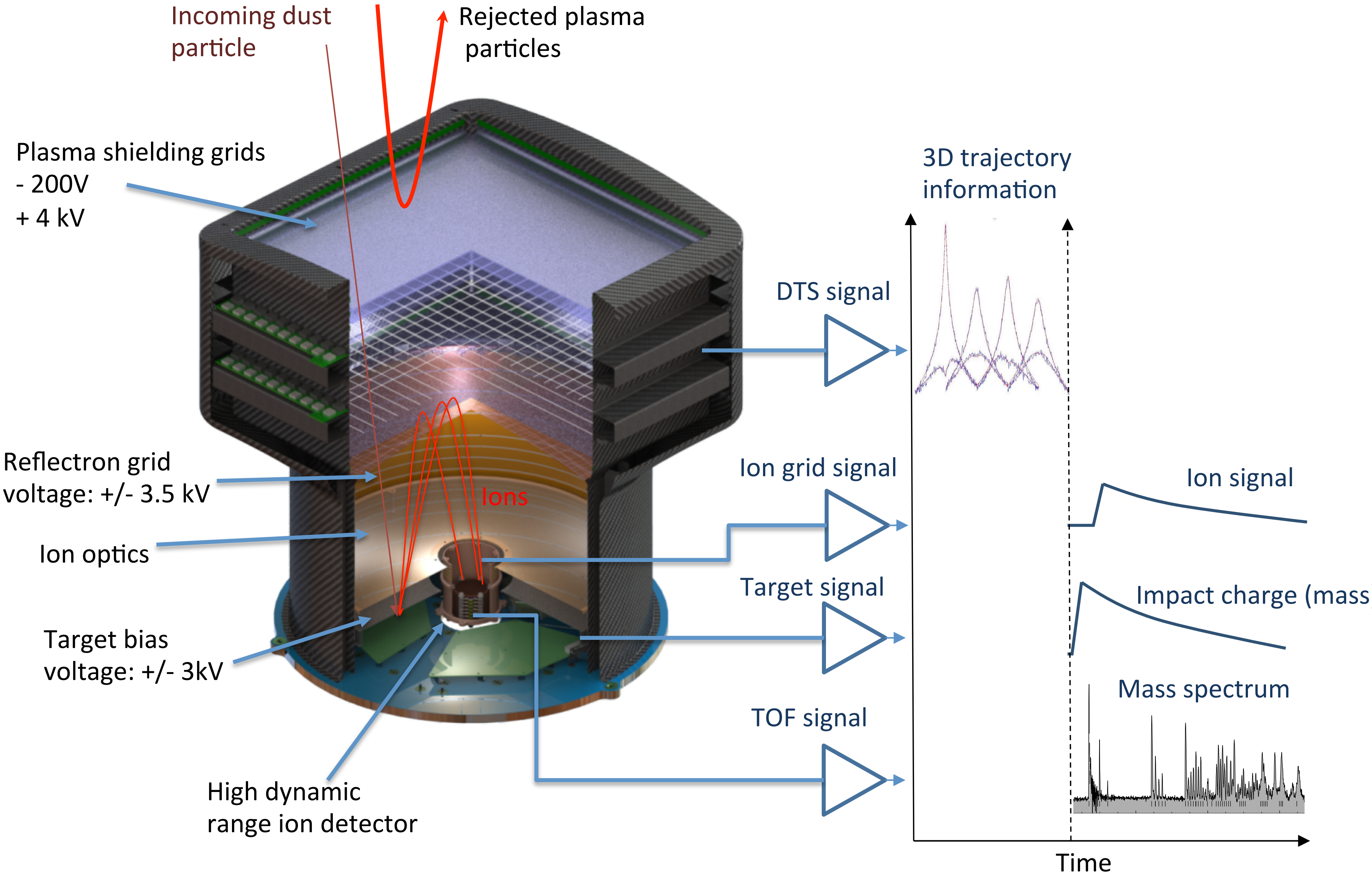
From M/dM ~ 30 (CDA)
To
M/dM ~ 200 (IDEX)



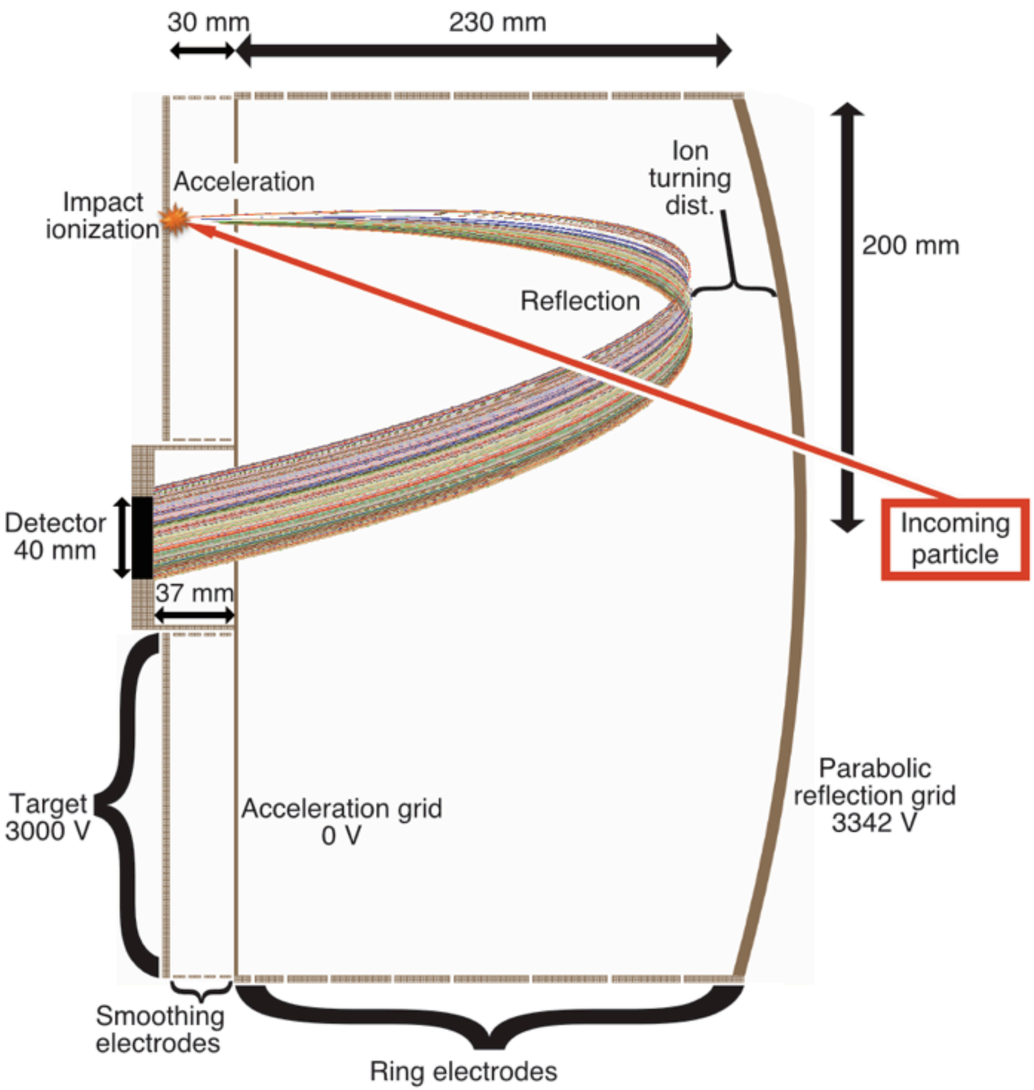
Key Hyperdust requirements/features

Requirement	Justification
Effective target area: ≥ 600 cm^2	To detect a statistically significant number of interplanetary and/or interstellar particles (interstellar dust flux on the order of 10^{-5} $m^{-2}s^{-1}$)
Mass resolution m/dm ≥ 200	To analyze the elemental/chemical/isotopic composition of ISDs
Dual polarity	To extend the chemical analysis capabilities by measuring both cation/anion TOF spectra (**optional**)
Ion detector dynamic range ≥ 10^6	To measure the TOF mass spectrum over a wide impact velocity and mass ranges
Dust charge sensitivity ≤ 150 e^- rms noise	To measure the velocity vector of interstellar particles (submicron in size)
Low mass	Large size instrument requires composite structure

Hyperdust functionality



Hyperdust ion optics is optimized through numerical simulations



- Incoming dust particle
  - Size: ~1 µm
  - Speed: 1 – 70 km/s
- Energy goes to
  - Deforming target material
  - Heating
  - Breaking chemical bonds
  - Ionization

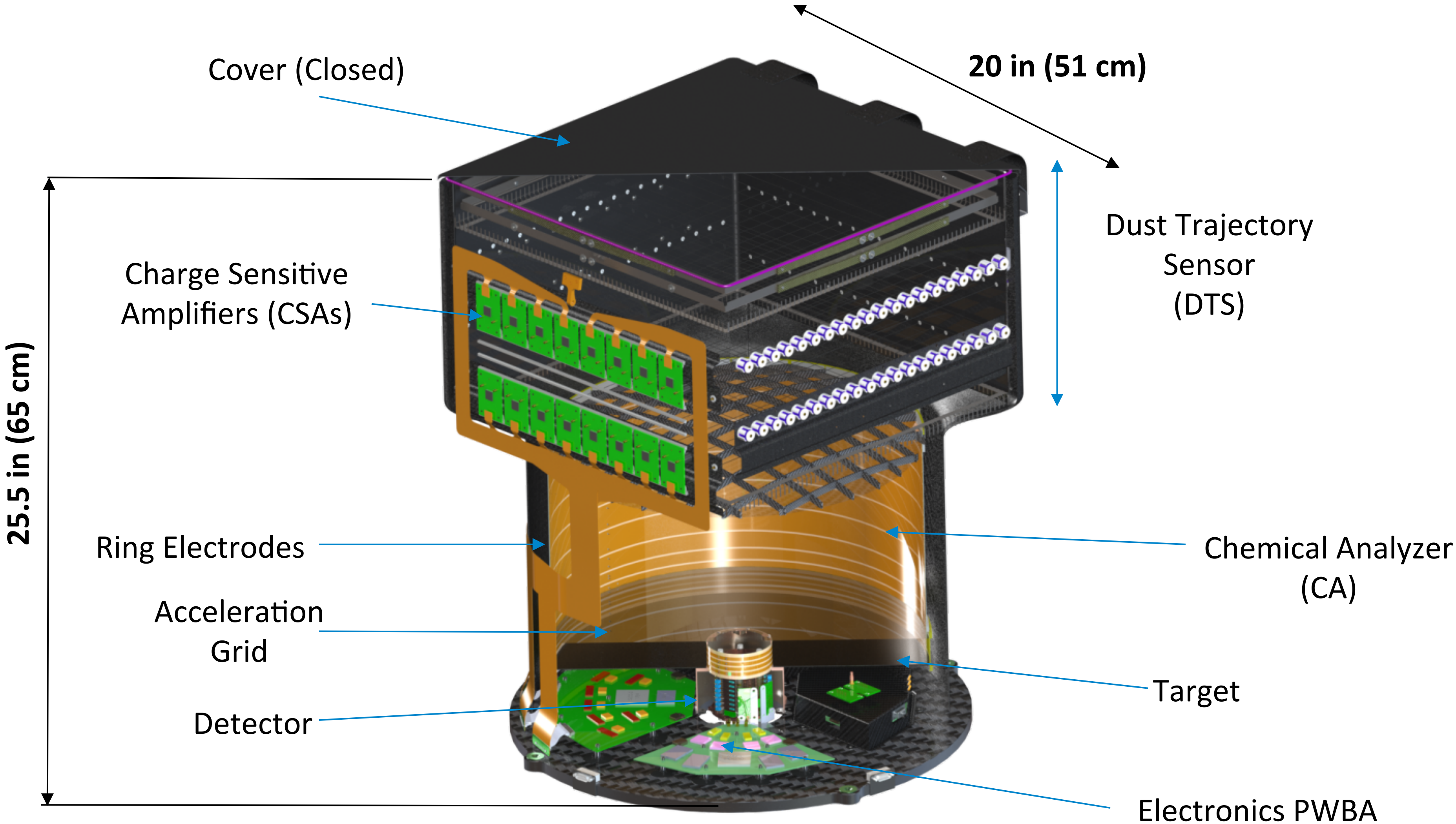
Time of flight of ions:

$$t(r_i, m) = b(r_i)\sqrt{m}$$

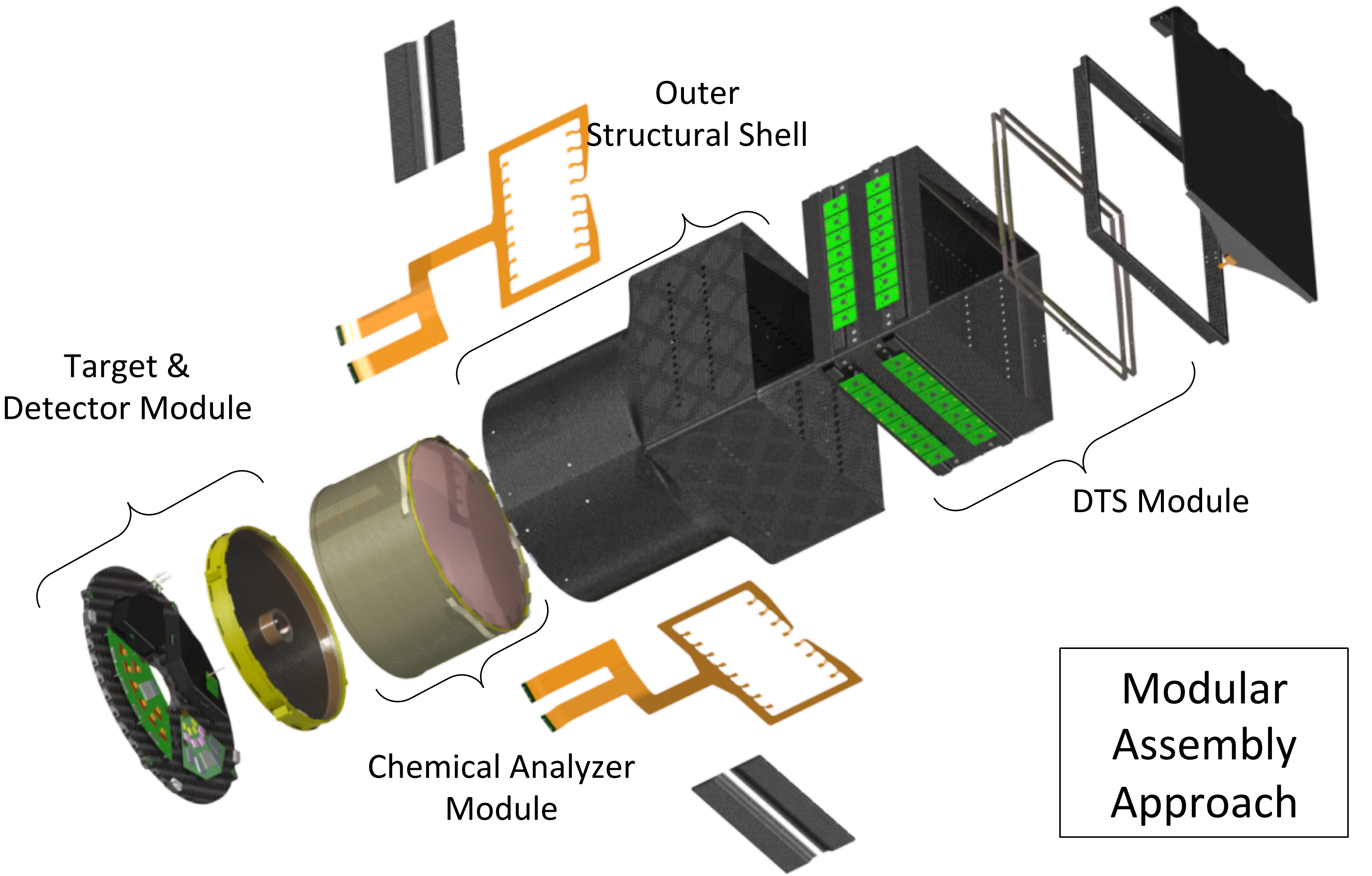
Mass resolution:

$$\frac{m}{\Delta m} = \frac{t}{2\Delta t}$$

Hyperdust mechanical design



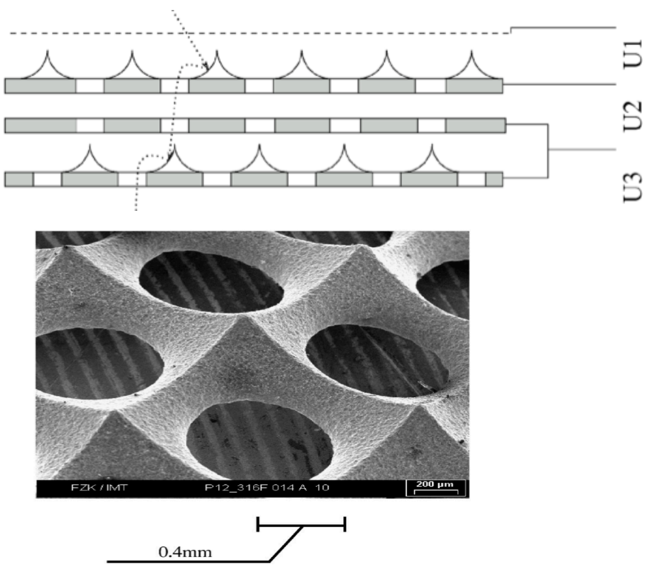
Hyperdust mechanical design – cont.

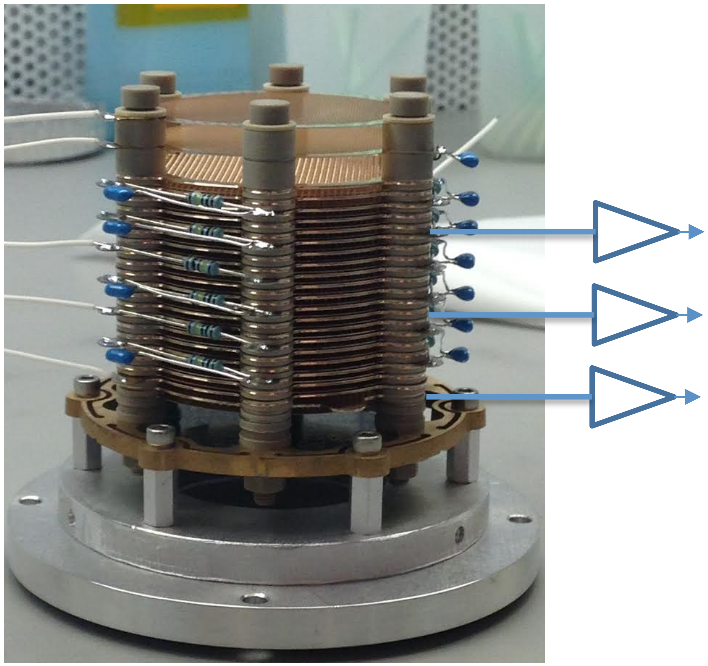


Modular
Assembly
Approach

High dynamic range ion detector

- Custom made focused mesh electron multipliers
- Modeled after the MM1 detector (Johnston Tech), CDA heritage
- Existing functional TRL 6 prototype

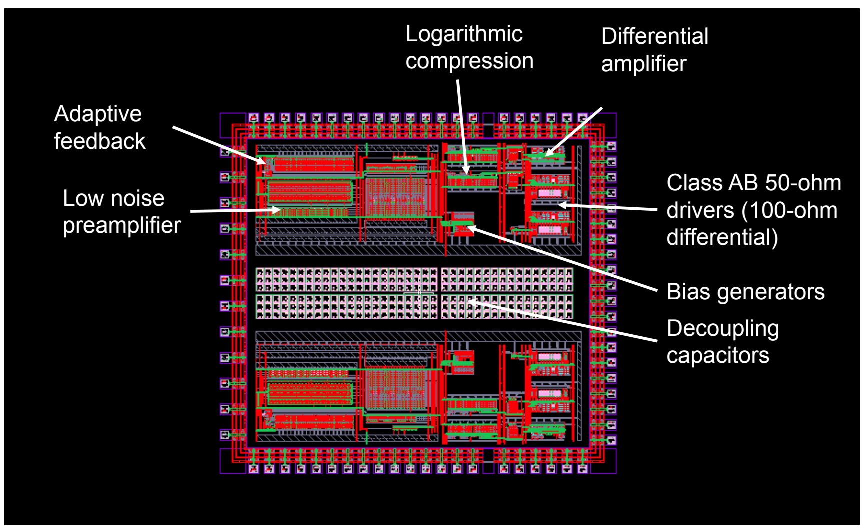


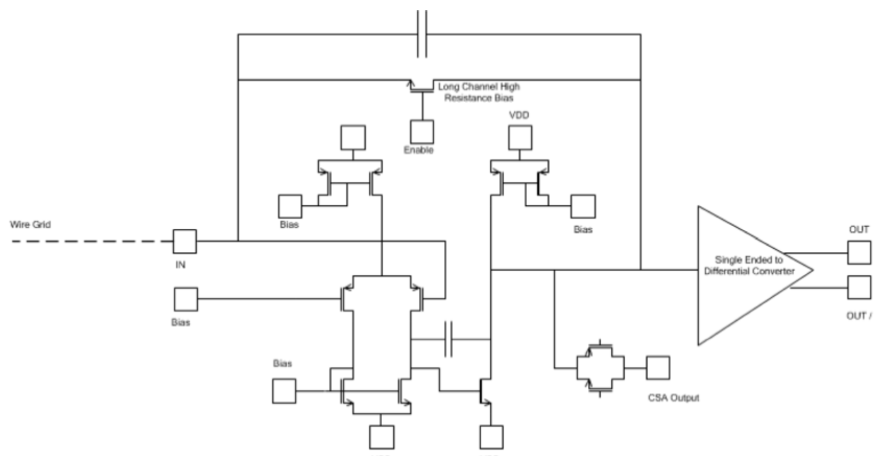


Detector tapped at different stages provides high dynamic range

ASIC CSA development for DTS

- ASIC = Application Specific Integrated Circuit
- CSA = Charge Sensitive Amplifier
- 64 parallel channels
- Charge on 1 micron radius dust at 5 V surface potential: 3500 electrons
- < 150 e^- rms noise requirements (10 kHz – 10 MHz bandwidth)
- Older tested ASIC performs with < 250 e^- rms noise
- New ASIC with 0.18 micron technology designed to 150 e^- rms noise
- New ASIC currently in fabrication (done by Nov 2016)





THE END

Enabled science – variation with impact velocity

Impact velocity	Science capability
> 1.0 km/s	**Impact detection** – characterization of ejecta distribution (mass, density, dynamics)
> 1.5 km/s	**Identification of basic compositional types** (e.g., ice, rocky, metallic, organic)
> 3.0 km/s	**Basic compositional analysis** – distinguishing between different sub-types based on low-ionization potential species
> 3.0 km/s	**Detailed compositional analysis of icy particles** – identification of even minor components embedded in the ice matrix
5 – 15 km/s	**Detailed compositional analysis*** – full range of molecular fragments identified in impact ionization mass spectra
> 15 km/s	**Elemental composition** – easy to interpret, relevant to interstellar and interplanetary particle

* For best science results it requires a comprehensive laboratory calibration campaign using analogue dust particles.

Postberg, personal comm.