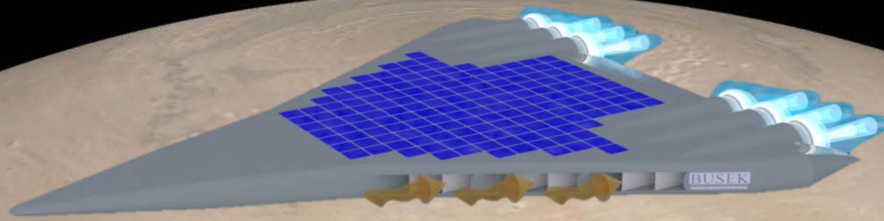
Atmospheric Breathing Electric Thruster for Planetary Exploration



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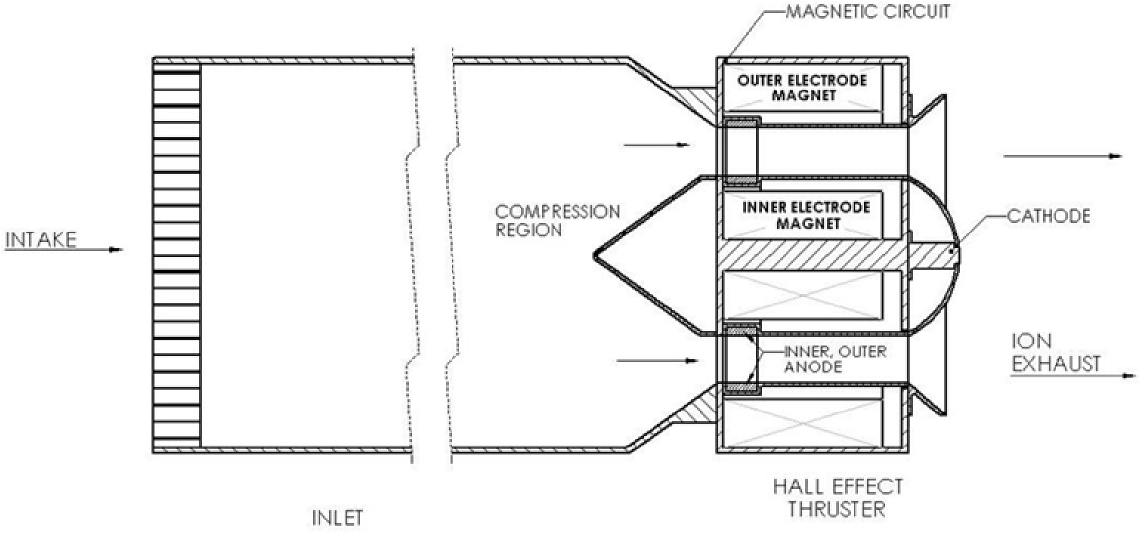
Solar Electric Power Orbiting Spacecraft that Ingests Mars Atmosphere, Ionizes a Fraction of that Gas and Accelerates the Ions to High Velocity

Does not Require Bringing Propellant from Earth or Harvesting & Storing Large Quantities In-Situ

Requires Collecting Significant Fraction of Incidence Atmosphere

Requires Efficient Solar Flux Collection by Arrays

If Successful, provides Extremely Long Mission Capabilities



Mars atmosphere is thin (6-7 Torr at ground) and composed mainly Carbon Dioxide

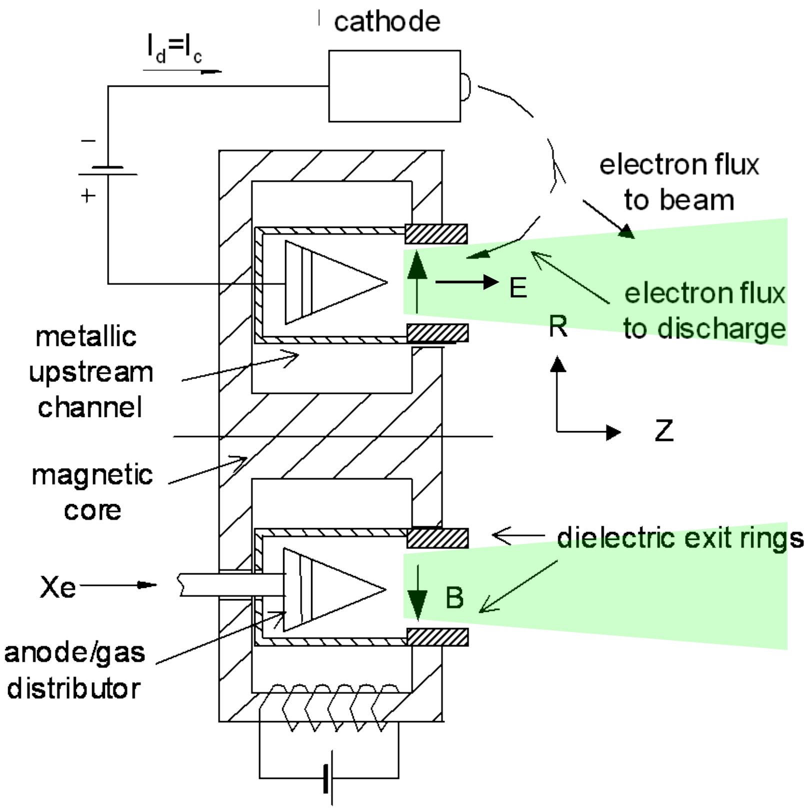
The altitudes of interest are 120-180km due to drag and power requirements

The orbital velocity is around 3400m/s (Earth – 7800m/s)

Solar Flux is about 584 W/m^2 (Earth ~1350 W/m^2)

Lift is not a factor down to <100km

- Form of electric propulsion used for in-space maneuvers
  - Well understood
  - High thrust density
  - Low cost
  - Highly throttle-able
- Plasma is ionized in an electron-impact cascade and accelerated by an applied electric field
- Beam neutralized by a cathode
- Typical propellant is xenon
  - Many potential alternatives
  - Innovation is Atmospheric Breathing

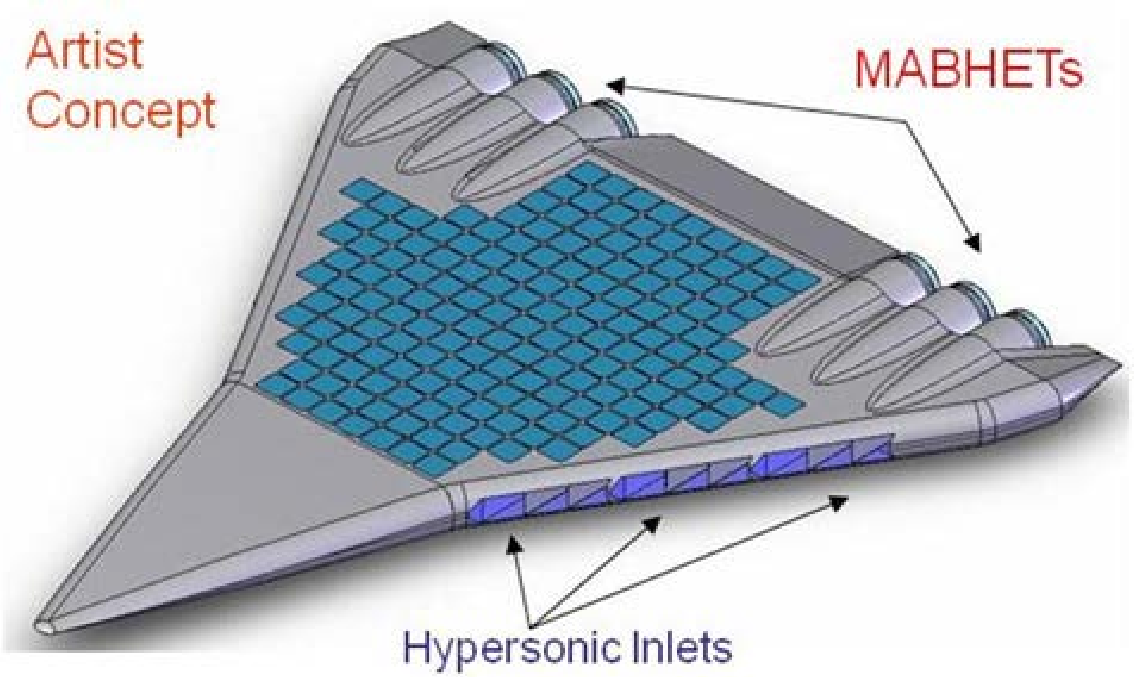


Need low drag design

Minimize frontal area

Majority of front for inlet

Large surface area for solar array – will increase drag



MABHET occupies the tail end

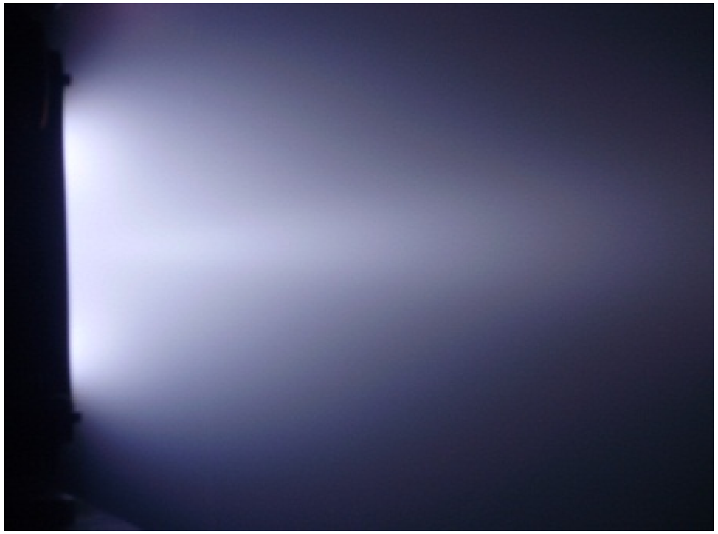
Payload needs to be well-integrated – utilize space efficiently

Vehicle is power limited – indicates that Thrust/Power will be key performance

Our 1500W thruster topped out at ~31mN/kW @ just about 25% efficiency

Additional testing at 1kW and below will performed – may switch to smaller thruster

Power	Thrust	Thrust/power	Efficiency
Watts	mN	mN/KW	%
2240	66.8	29.80	26.46%
2430	71.4	29.38	26.73%
2090	62.6	29.95	26.06%
1755	53.2	30.31	24.66%
1418	43.8	30.90	22.99%
1125	34.7	30.84	20.46%



Busek 1500W HET with CO_2

The MABHET must overcome the drag plus margin – thus drag coefficient is critical

- Frontal area is highest drag – sides are secondary
- Required to collect our propellant – larger cross section
- Larger the s/c the higher the power – larger surface area

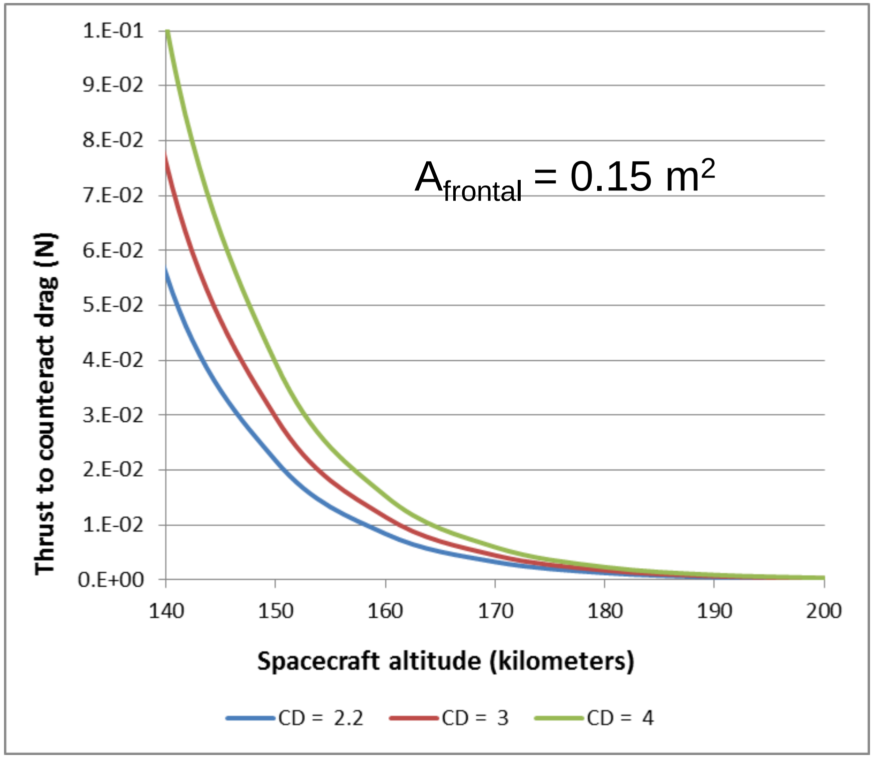
We will analyze C_D from 2.2 (unlikely this low) to 4 (unlikely this high)

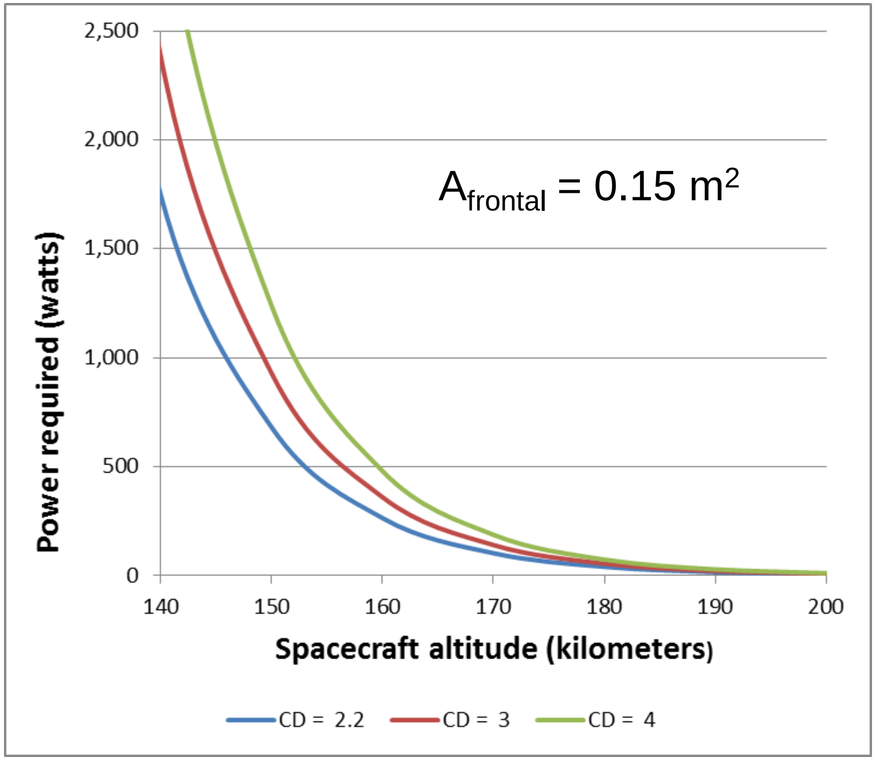
- Most s/c are 2.2-3 & Magellan measured 0.63 energy accommodation on Venus re-entry

First cut analysis indicates nominal 1KW power level is favorable

- Requires about 5m^2 of solar arrays

- Assume a frontal area, efficiency & C_D, then calculate the drag/required thrust
- Then required power, surface area, gas fraction collected can be calculated



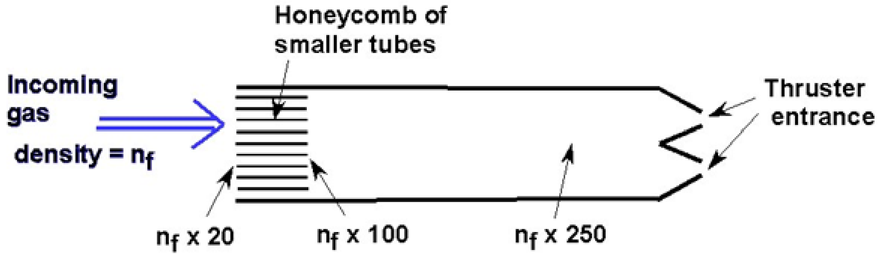


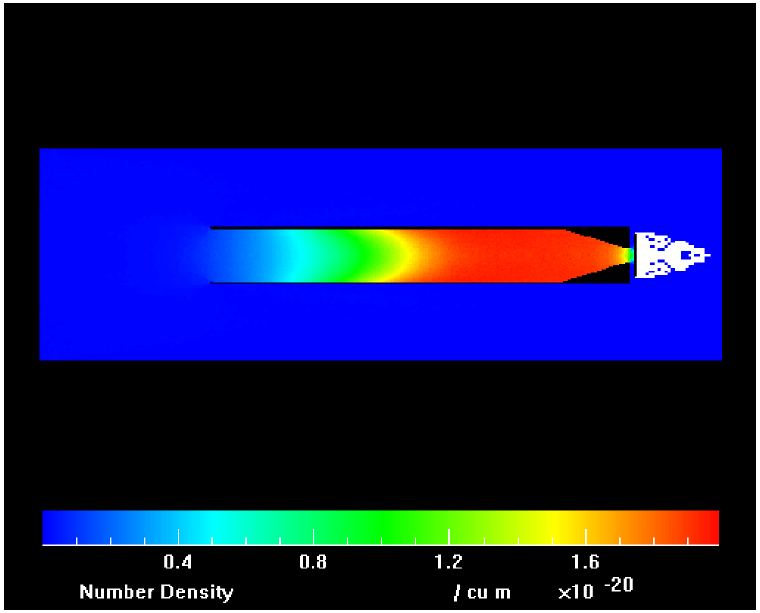
NASA NIAC BU Advanc

Hypersonic – Rarefied Gas Inlet & Collection

Concept – Utilize the Ram Velocity to Compress Gas

Honeycomb Passes Collimated Flow – while Reducing Random Gas Exiting





DSMC Model of Inlet for Mars

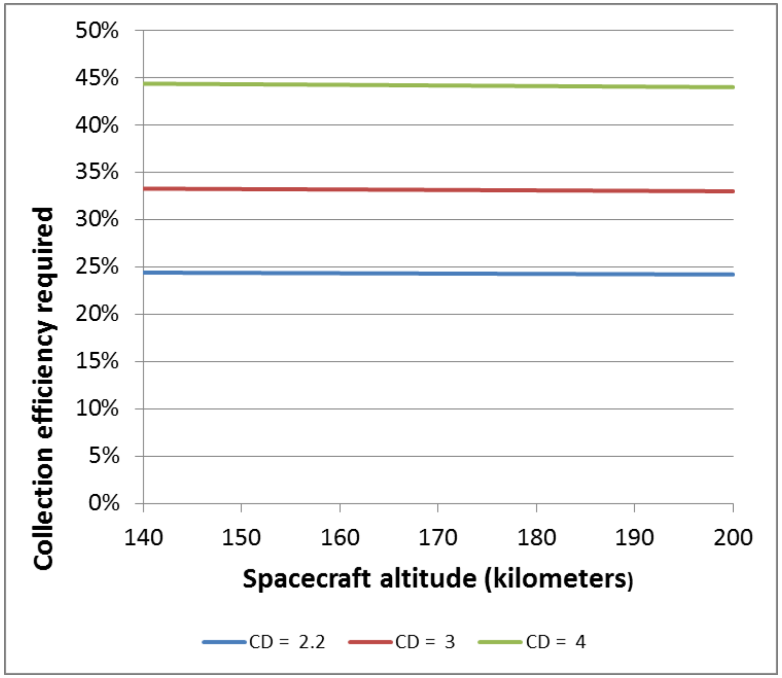
Use DSMC to Model Inlet (Testing in Phase II)

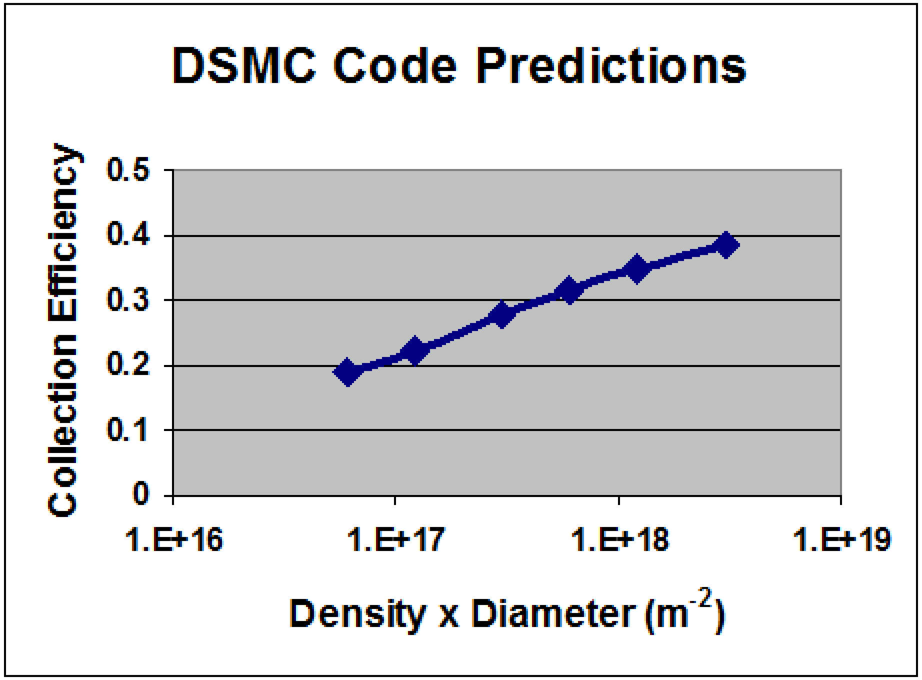
Circular duct studied first – Rectangular/Narrow to come

Density x Diameter models consistent for various diameters and density at altitude

For the 1kW @ 160km we need 25-33% collection efficiency

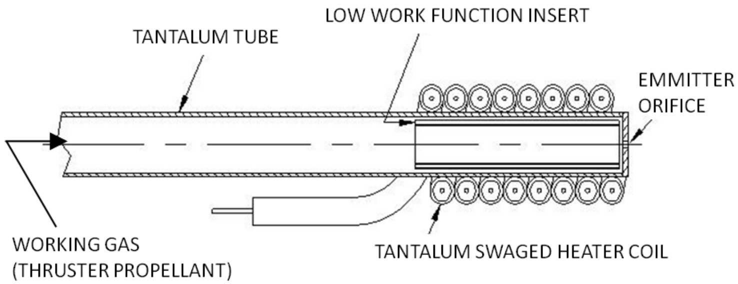
First cut model indicates 20-40% is possible





HET require neutralizing cathode to prevent s/c charging

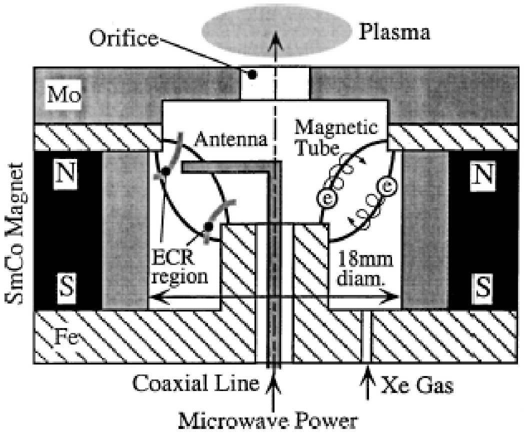
Typical solution is Hot Hollow Cathode



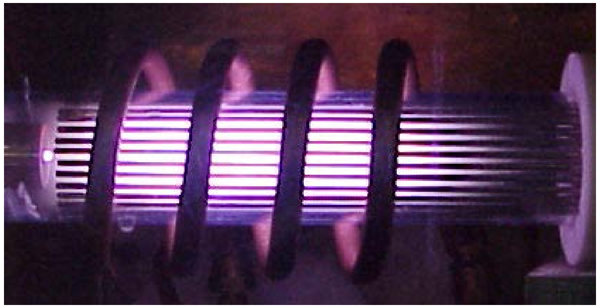
CO2 will likely dissociate in HHC & oxidize the emitter

ECR or RF cathode have shown functionality in oxidizing environment

ECR Cathode



RF Cathode



Efficient Solar Arrays will be required – analysis assumes 35% efficiency – current terrestrial SOA

Efficient power processing and management – also high temperature operation – current space SOA = 93% - 65C

High density batteries would increase mission recipe – eclipse operation or atmospheric dipping

Innovative drag reduction would increase vehicle performance

Solar concentrators – energy beaming – other advanced power management

Measure crustal magnetism

Atmospheric sampling – composition/chemistry – in-situ, real time, continuous

Surface mapping – can map the entire planet

Measure near surface water

Other planets are possible: Venus, Earth

- MABHET is a unique propulsion system that creates a new paradigm
- Creative missions to Mars become possible when one utilizes in-situ propellant versus launching from Earth
- Lower cost, longer missions, increased science
- We have begun to show feasibility – no show stoppers
- Required performance is within 10-15 year reach
- Difficult to test inlet on ground – we have a plan