AVALANCHE

Avalanche Energy
Fusion Power for Space

The Orbitron
A Compact Fusion Power Source for Space

April 24, 2024

Approved for Public Release
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Orbitron Fusion Core

"Osbourne" Space Power System

Avalanche Team

Q&A

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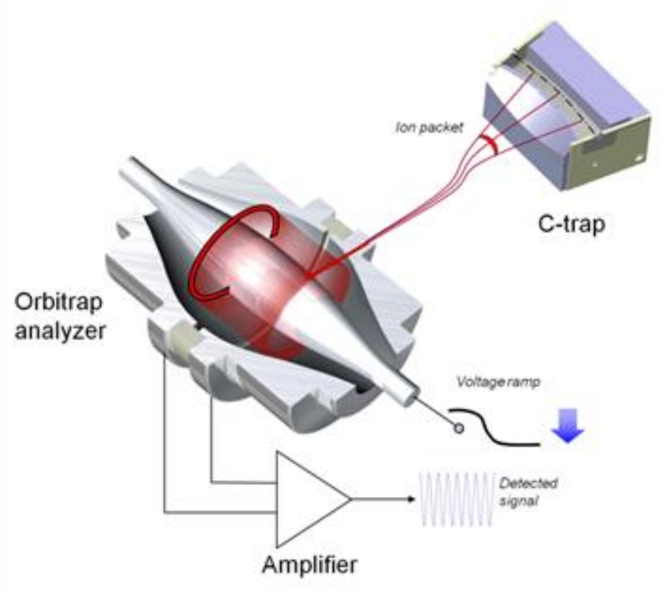
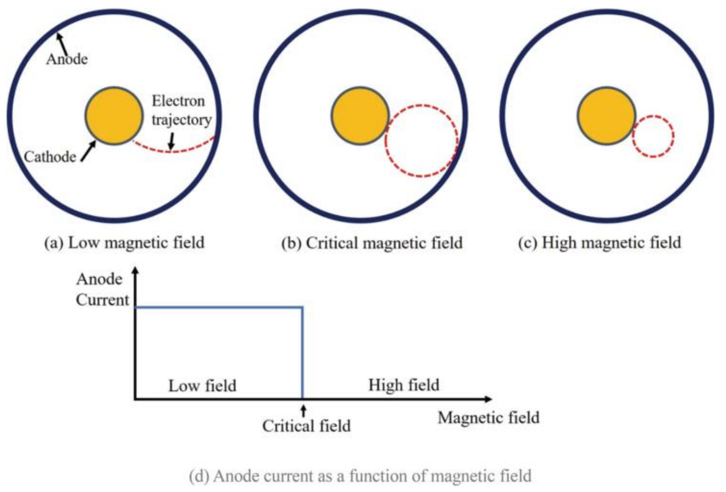
Orbitron Fusion Core| 3

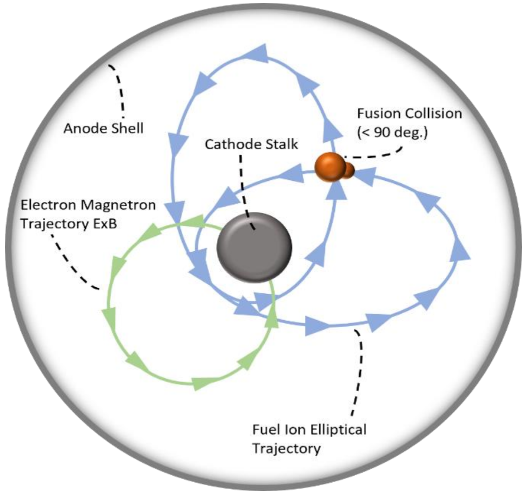
Most fusion companies use thermonuclear fusion which requires large plants that take years to build, iterate, and scale, with billions of dollars and 100s - 1000s of people.

Avalanche is using an orbiting Colliding Beam Fusion in a much smaller device, drastically lowering costs and headcount.
Build in weeks. Iterate in days. Produce en masse.

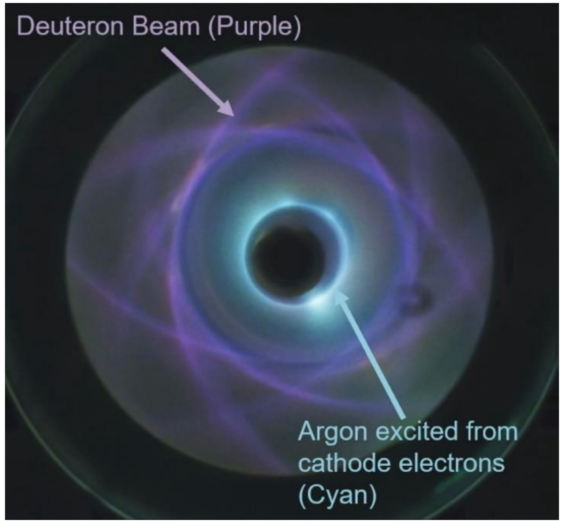
Orbitrap + Magnetron = Orbitron







Orbitron Core Reaction Diagram
(Viewed thru the Long Axis)

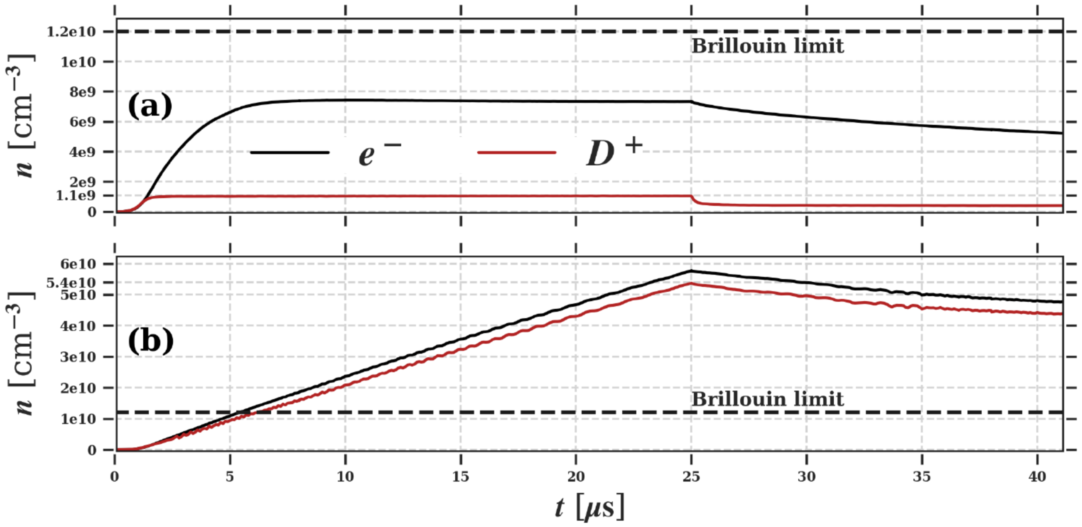


Actual Orbitron Test

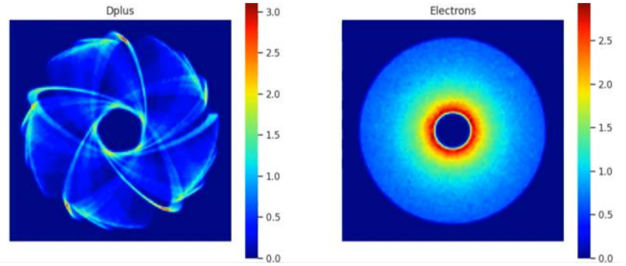
- The Orbitron achieves useful fusion ion energy, density and confinement time via electrostatic field
- The electrostatic field traps Deuterium and Tritium ions in elliptical orbits

- Electrons are introduced and confined via a magnetron electron scheme to overcome the ion space charge density limit
- Nuclear fusion occurs where orbiting ions cross paths, producing energetic particles that can generate heat or direct energy electrical power

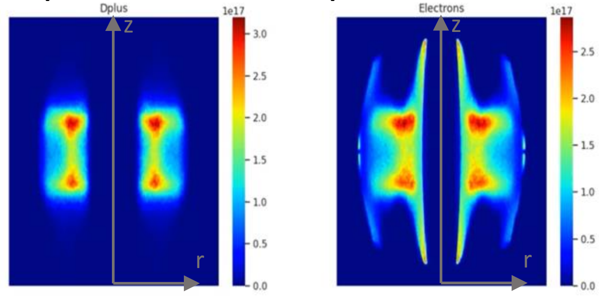
Fusion Core Details

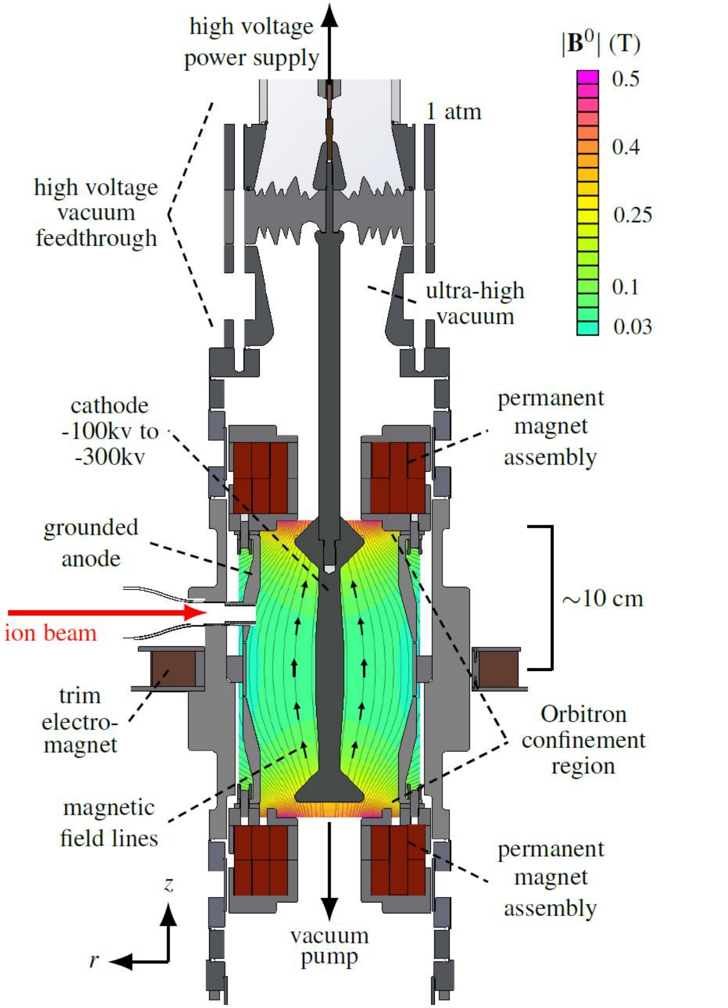


WarpX PIC Axial view of ion and electron loading



WarpX PIC Side view of Coupled Plasma Densification



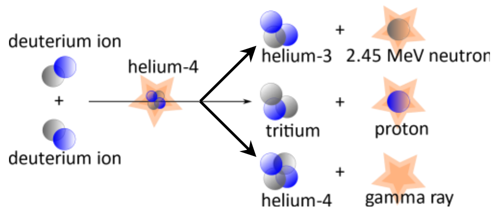


An r-z cross section of a laboratory Orbitron. Ions (red arrow) are loaded into the potential well and orbit around the cathode. The high-voltage vacuum feedthrough will enable voltages up to -300kV on the cathode. Electrons are confined through a magnetic field (colored contours) supplied by permanent magnets and an electromagnet trim coil.

- Particle-In-Cell (PIC) simulations results for -100kV, 0.05T
  - (a) pure electron or pure ion plasmas confined separately in the device
  - (b) electrons and ions are co-confined
- These simulations show the respective space charge limited density for these two charge species.
- When electrons and ions are co-confined, simulations predict that quasi-neutral plasma densities above the space charge limit are achievable.

Orbitron Lab Testing

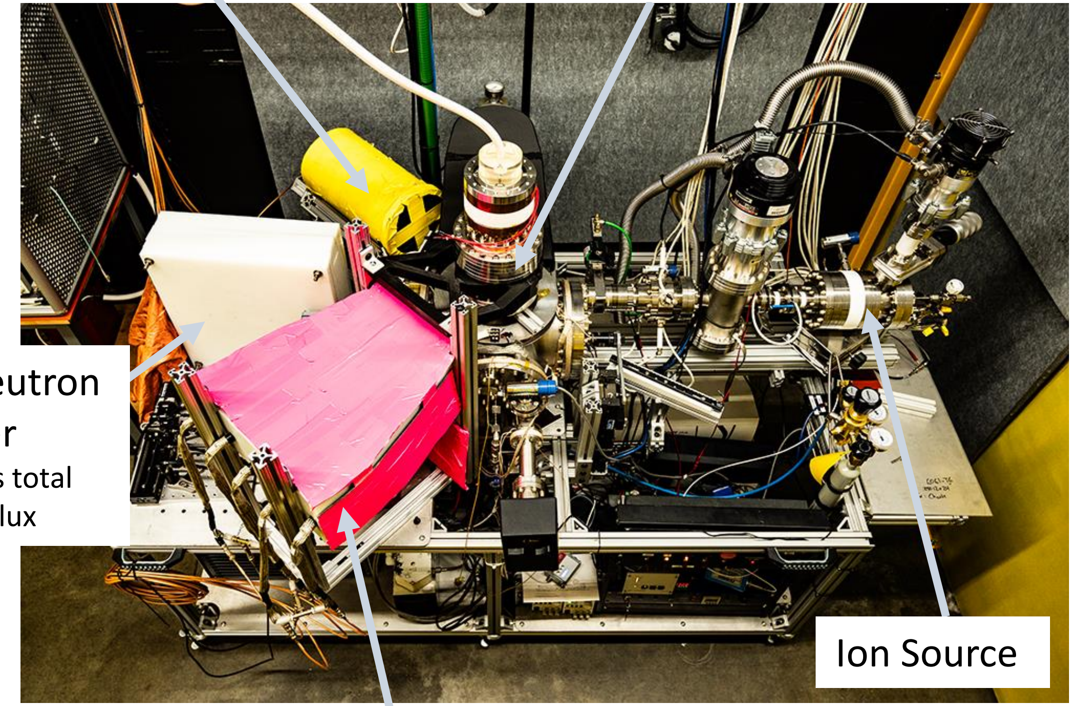
Deuterium-Deuterium Fusion



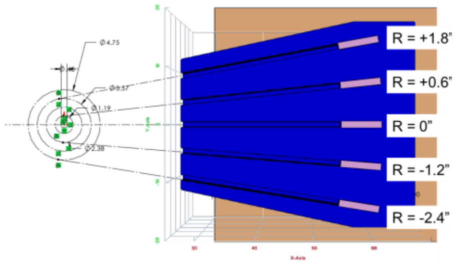
Neutron Scintillator
Measures total neutron flux

Orbitron

He3 Neutron Counter
Measures total neutron flux



Ion Source



Neutron Camera
Neutrons are collimated to "pixels" to observe spatial source of neutrons

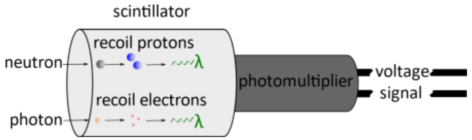
Instruments not shown:

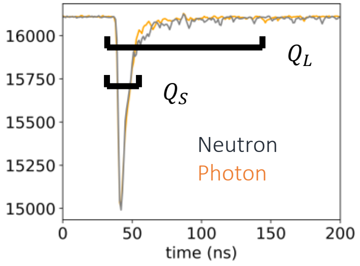
- Optical Emission Spectroscopy
- Microwave Interferometry

Neutron Instrumentation

Pulse shape discriminating (PSD) neutron counters

Detector → Digitizer → Signal



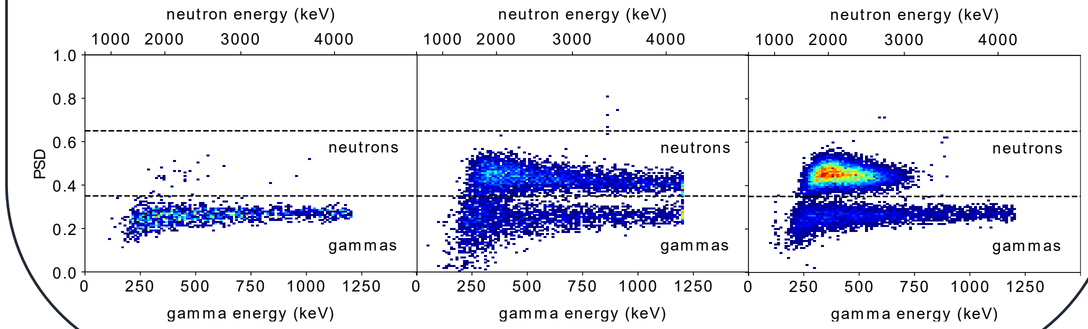


Q_L = long charge integration = energy of particle = x-axis of data

Q_S = short charge integration

$\frac{Q_L - Q_S}{Q_L}$ = PSD = particle type discrimination = y-axis of data

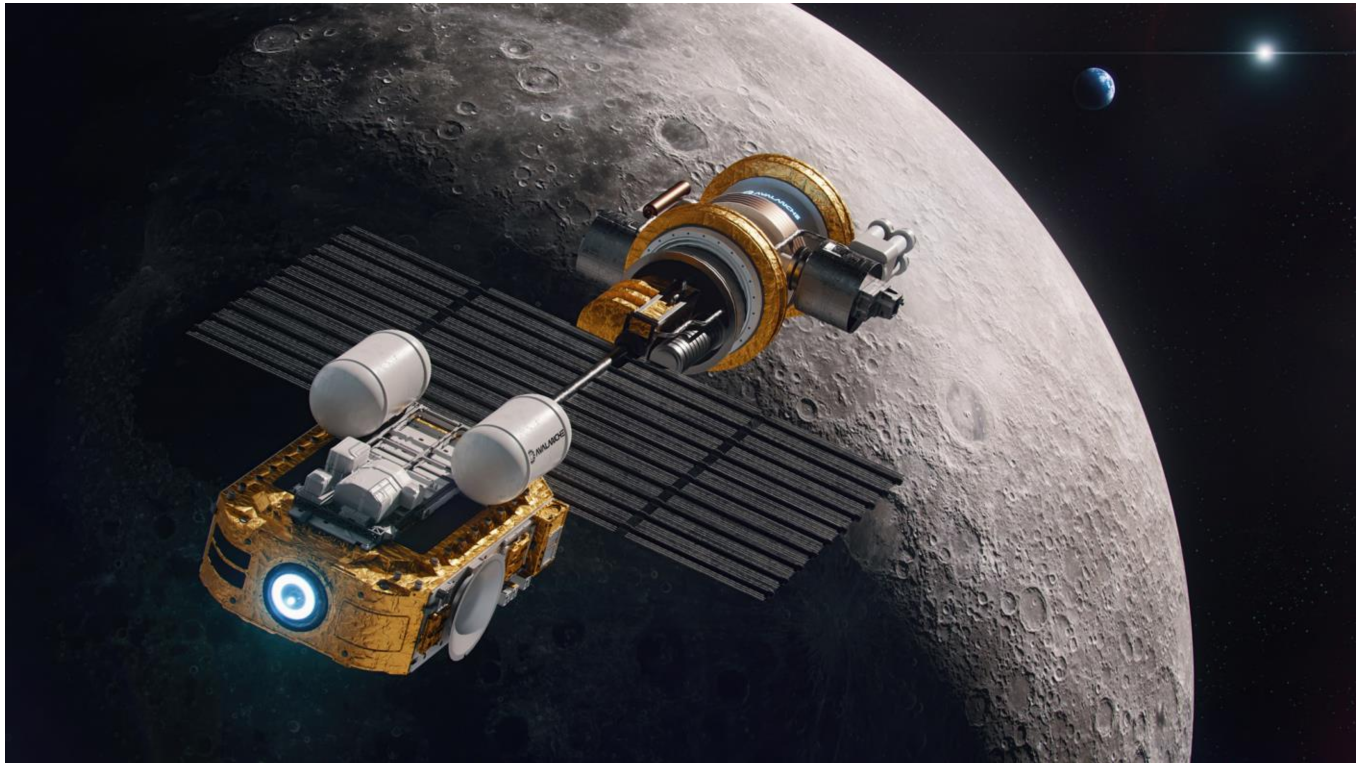
Background | Radioactive PuBe | Orbitron



Fusion Power for Space

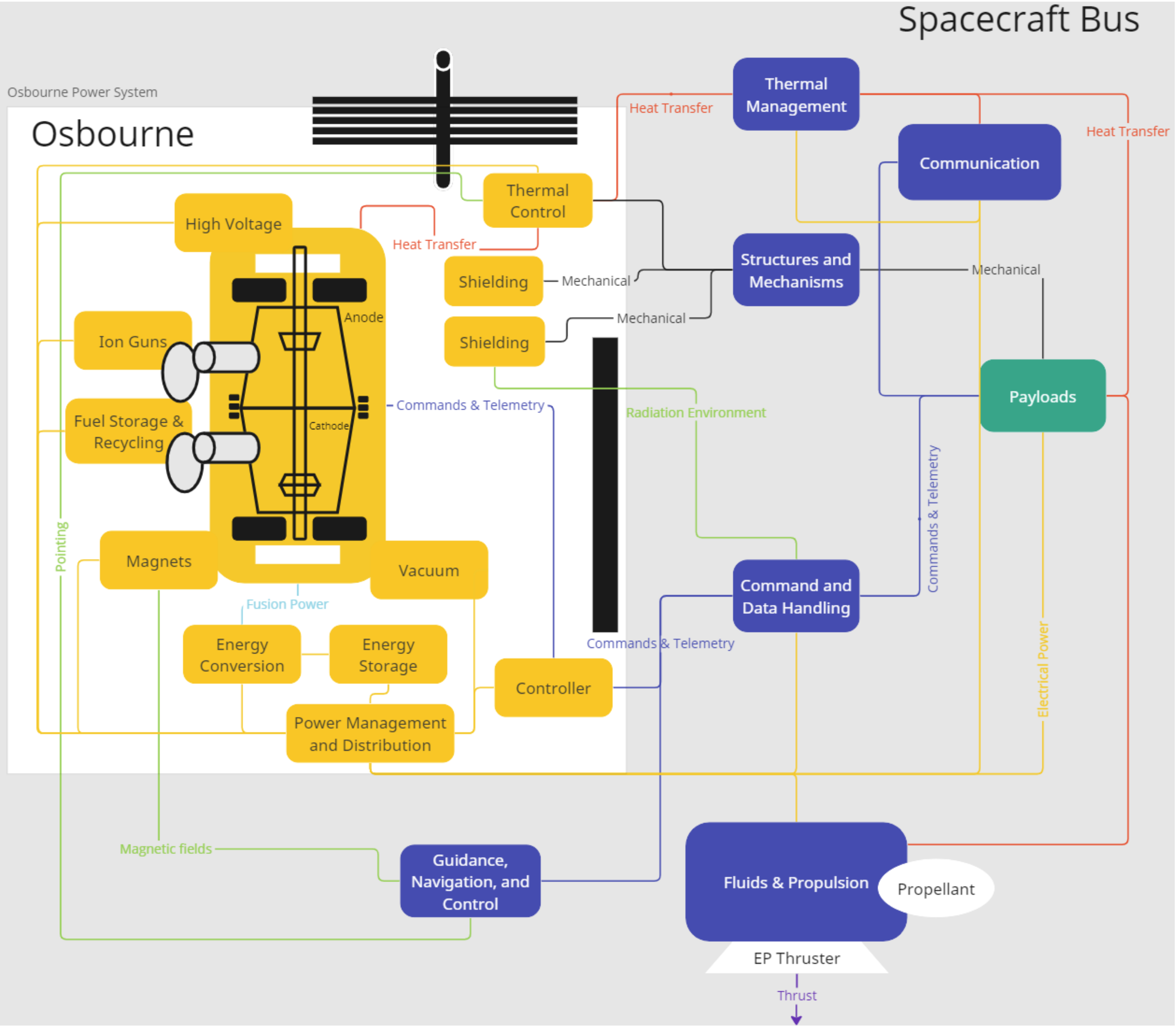
- Under the Defense Innovation Unit (DIU) Nuclear Advanced Power Propulsion (NAPP) project, Avalanche is studying how a spacecraft power and propulsion system would be architected around the Orbitron fusion reactor.

- The “Osbourne” (Orbitron Space Bourne) spacecraft power system includes all the subsystems necessary to generate, convert, store, and distribute nuclear fusion power to useful electrical power for a spacecraft.



Osbourne System Overview

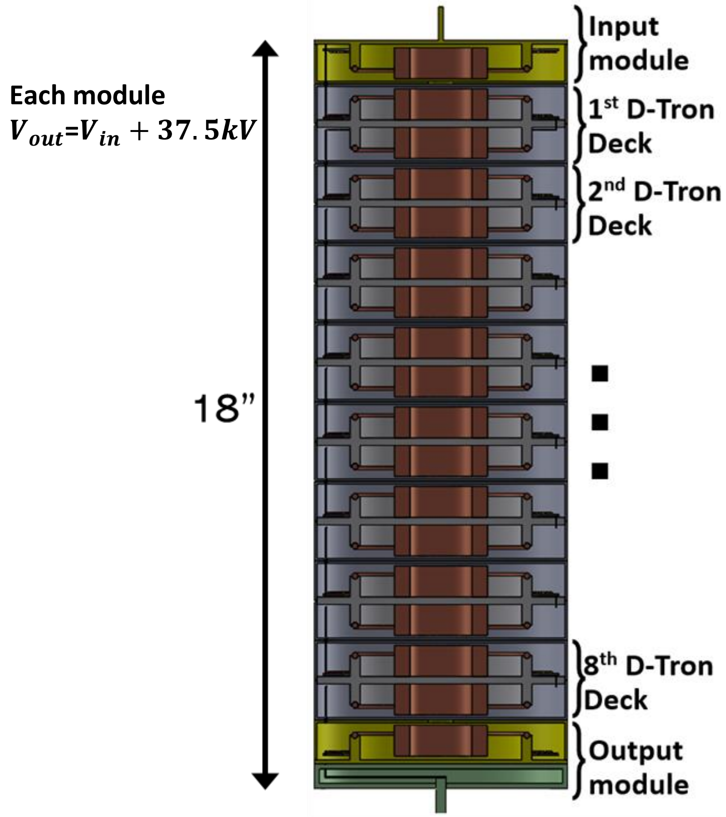
- Orbitron Reactor Core
  - Anode
  - Cathode
  - High Voltage
  - Ion Source
  - Fuel Storage and Recycling
  - Vacuum
  - Magnets
- Energy Conversion
- Power Management and Distribution
- Energy Storage
- Controller
- Shielding
- Thermal Control
- Structure



Compact High Voltage Supply

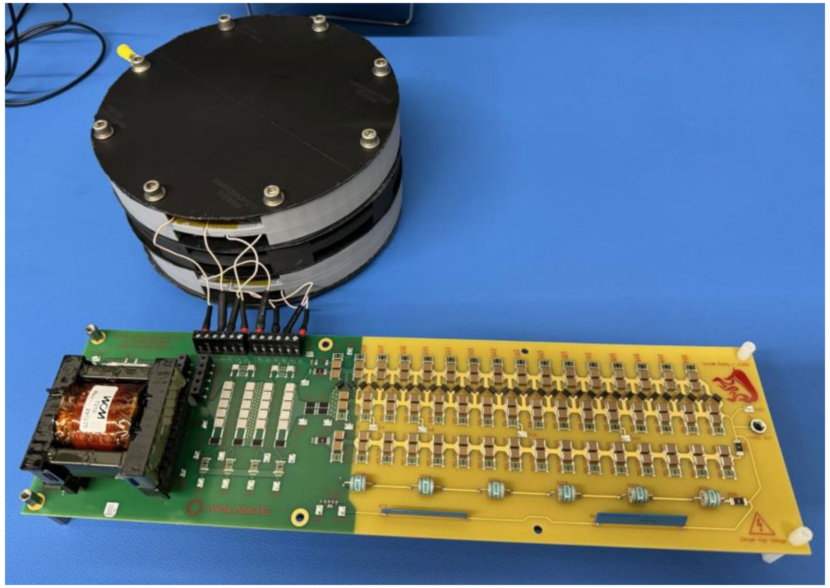
Orbitron System Concept Design
Deltatron Stack

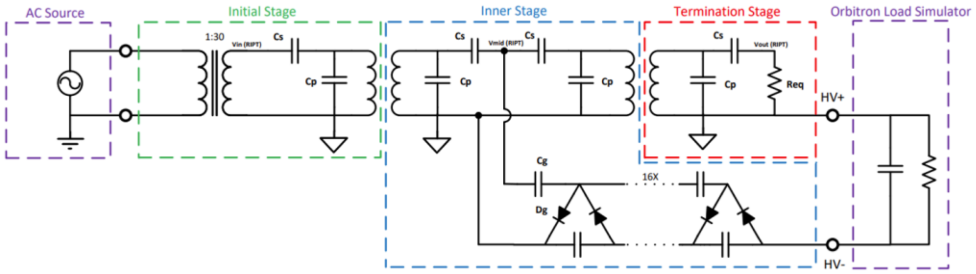
$V_{in} = 400\ V$



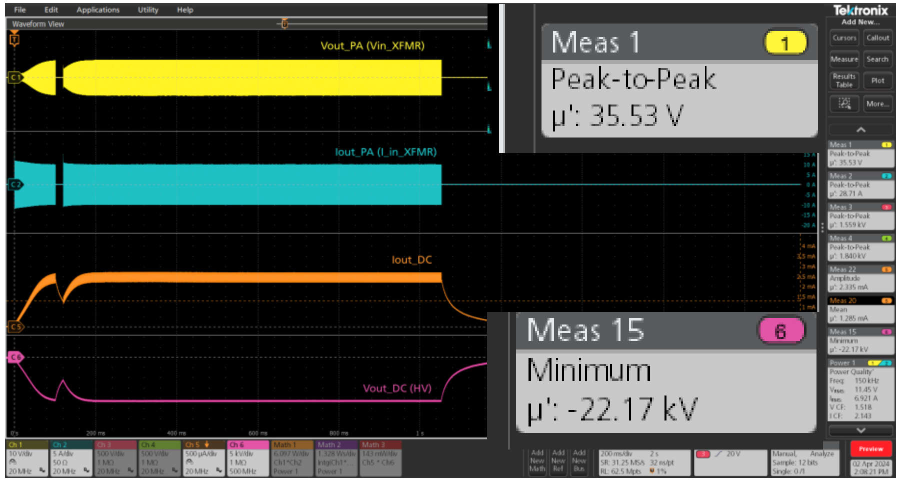
V_{out}= 300,000 V

Deltatron Prototype Hardware



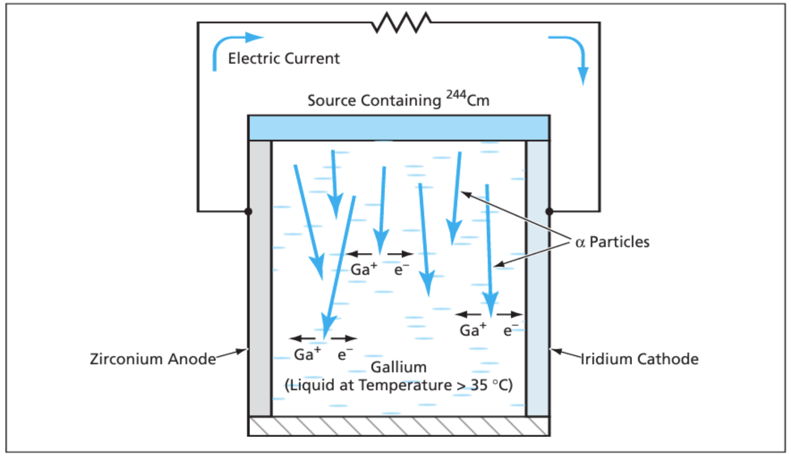


Successfully achieved 22kV gain!



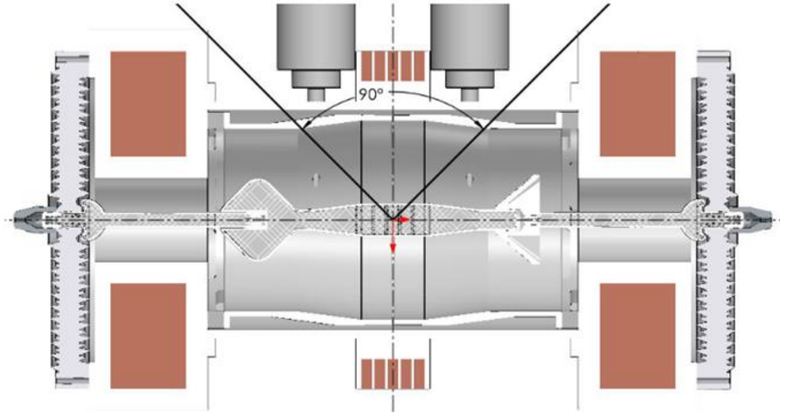
Energy Conversion

Baseline Concept:
Alpha Voltaic Direct Energy Conversion



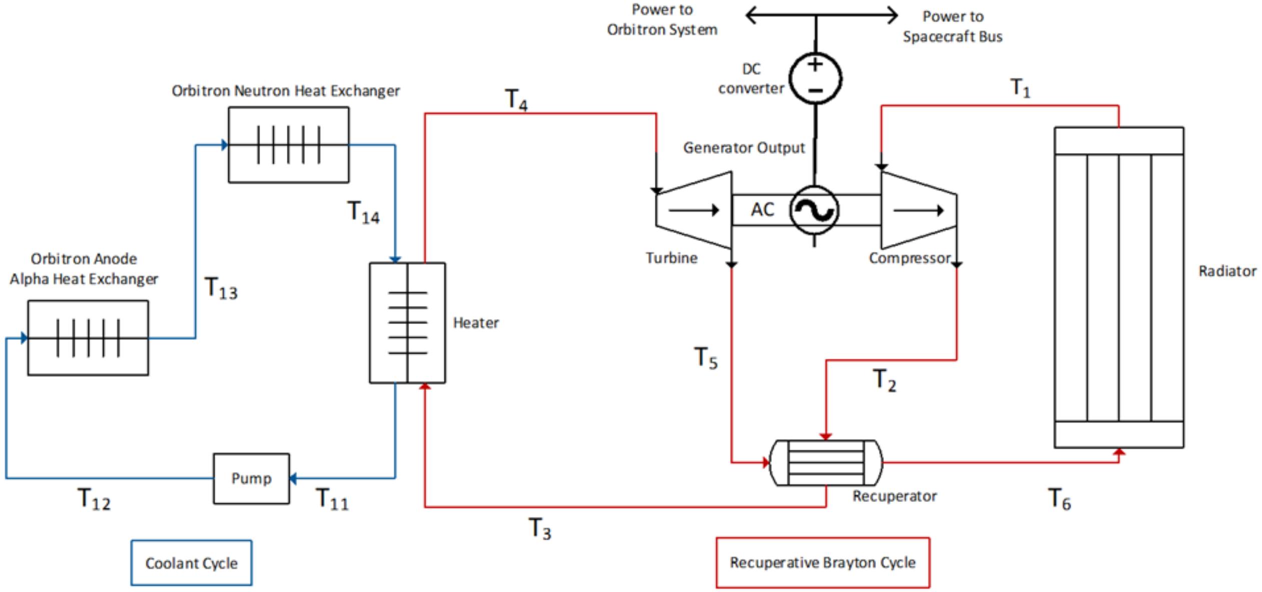
Liquid Gallium in an Electrolytic Cell would be ionized by impinging α particles. The resulting electric charges would be collected at the electrodes.

NASA Tech Briefs, July 2006



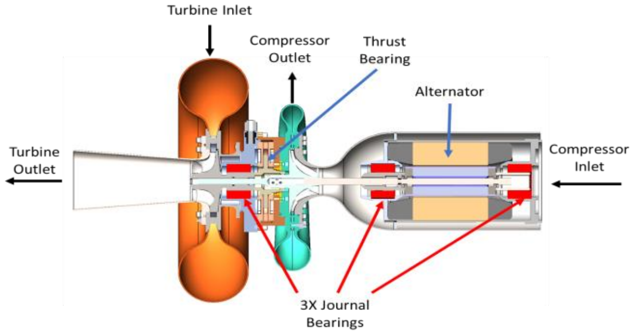
Orbitron Cross Section and illustrative alpha view factor

Fallback Option:
Thermodynamic power conversion concept with closed Brayton cycle



Working Fluid: NaK

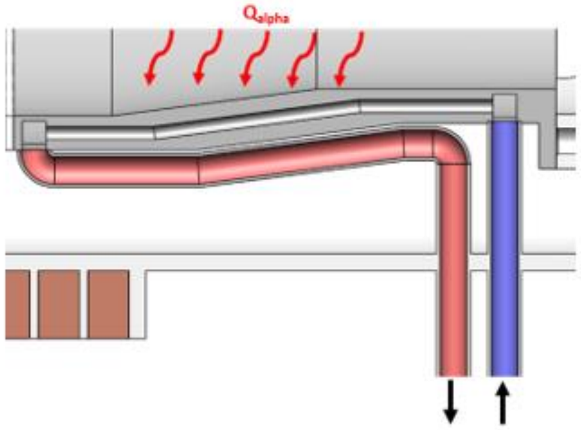
Working Fluid: HeXe



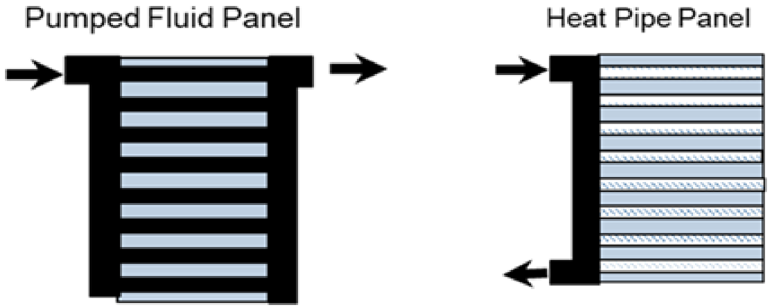
Turbo alternator concept

Thermal Subsystem

Alpha Voltaic, Heat Rejection System

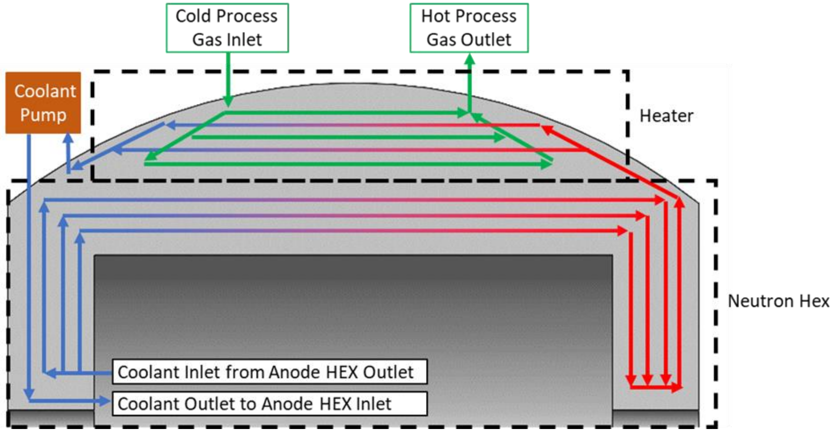


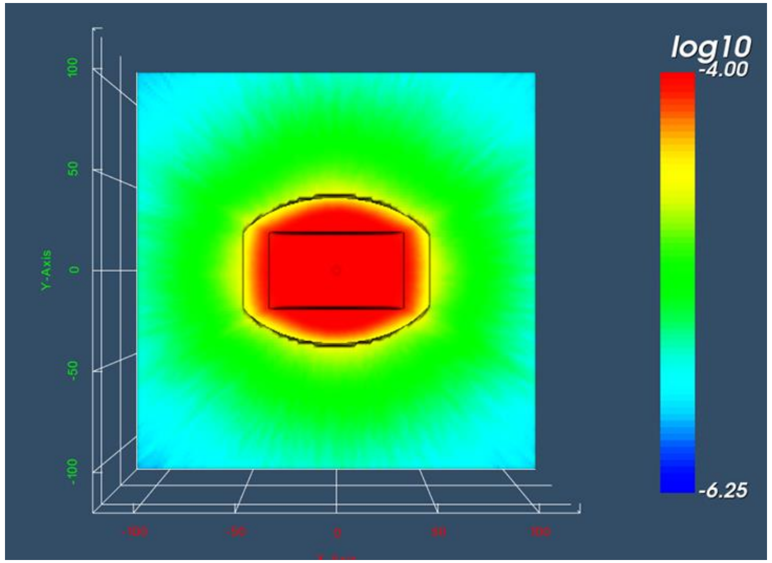
Integral reactor core coolant channels



Radiator options in trade.
Panels deploy to planar layout with 2-sided heat rejection.
System optimized rejection temperature is typically ~400K.
NaK working fluid enables electromagnetic pump.

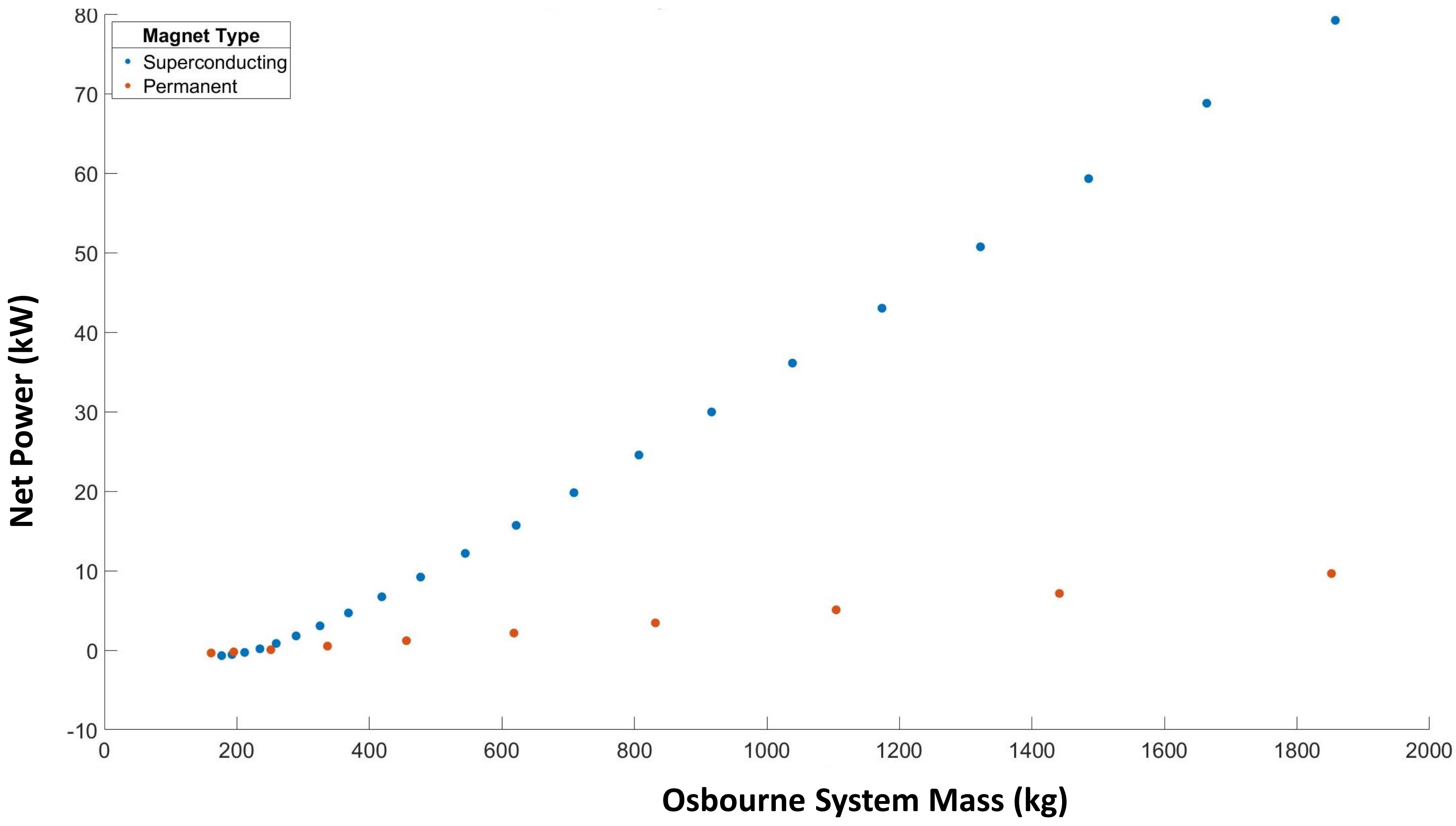
Neutron Heat Exchanger for Fallback Option





MCNP analysis of neutron energy absorbed

Osbourne System Performance

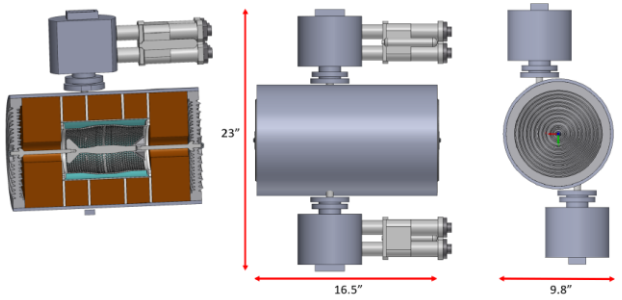


Osbourne MATLAB System Model Sub-Modules

Module	Performance Basis
Reactor Core	PIC Sims, 0D model
High Voltage	Scaling based on preliminary designs
Energy Conversion	
Fuel System	
Magnets	
Neutron HEX	MCNP Sims
Shielding	
Structure	Literature
Thermal	
Vacuum	
PMAD	

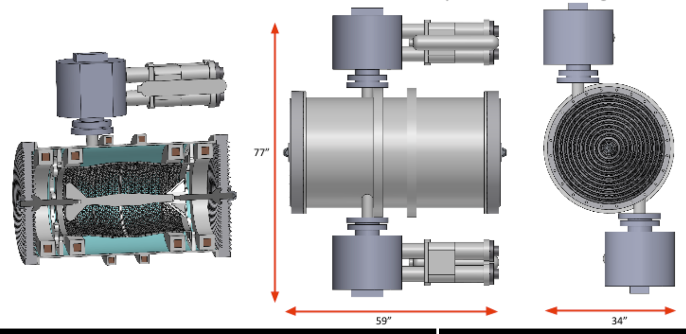
Osbourne Design Point Examples

Config 1: Rideshare Optimized - Permanent Magnets



Parameter	Value (Units)
Anode Radius	5 cm
Fuel	D-T
Deuterium Rate	2 g/y
Tritium Rate	4 g/y
Captured Waste Heat	1 kWth
Radiator Temperature	400 K
Radiator Size	0.5 m^2
Orbitron Mass (Reactor Only)	130 kg
Osbourne System Mass	337 kg
Net System Power Output	0.5 kWe
Q Engineering	1.5

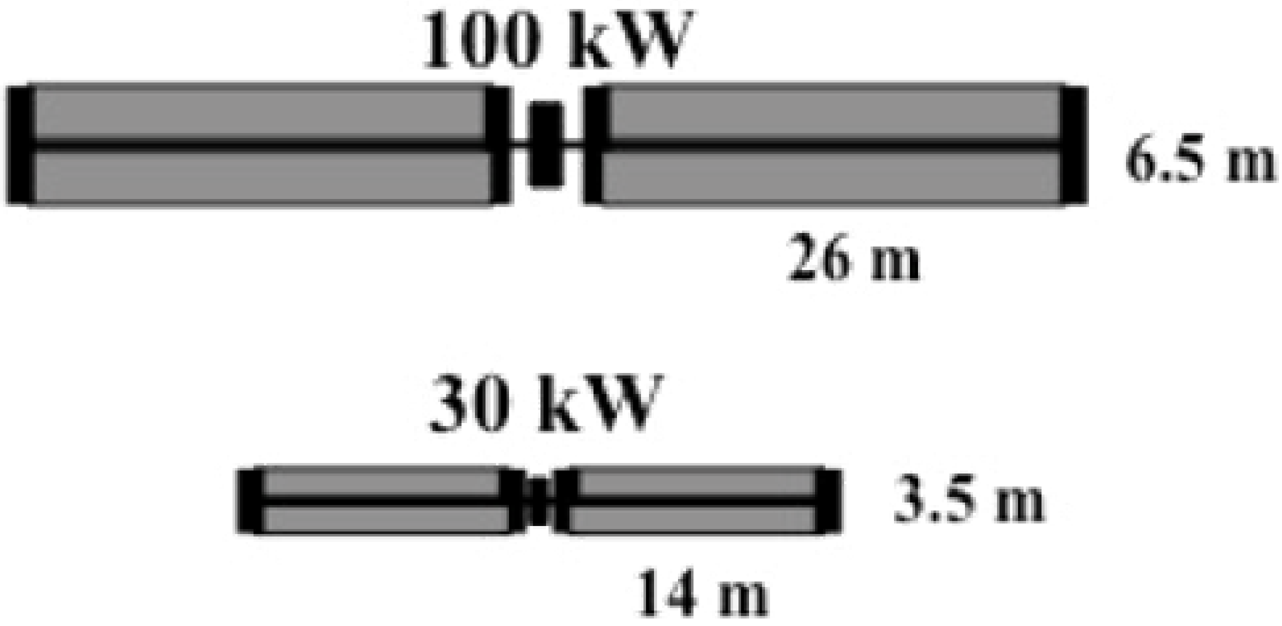
Config 2: Specific Power Optimized – Superconducting



Parameter	Value (Units)
Anode Radius	22 cm
Fuel	D-T
Deuterium Rate	159 g/y
Tritium Rate	359 g/y
Captured Waste Heat	119 kWth
Radiator Temperature	400 K
Radiator Size	40 m^2
Orbitron Mass (Reactor Only)	715 kg
Osbourne System Mass	1809 kg
Net System Power Output	76 kWe
Q Engineering	2.46

Spacecraft Fusion Power Size Comparison

Space Solar Arrays[1]

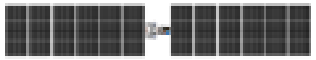


The results of this study strongly emphasize the need to develop technologies that will enable the operation of large solar arrays in the natural frequency range of 0.05 Hz. Examples of such technologies are micro thrusters, advanced active controls, and tension guy wires.

[1]Mikulas, Martin & Pappa, Richard & Warren, Jay & Rose, Geoff. (2015). Telescoping Solar Array Concept for Achieving High Packaging Efficiency. 10.2514/6.2015-1398.

Osbourne Fusion Power

76 kW



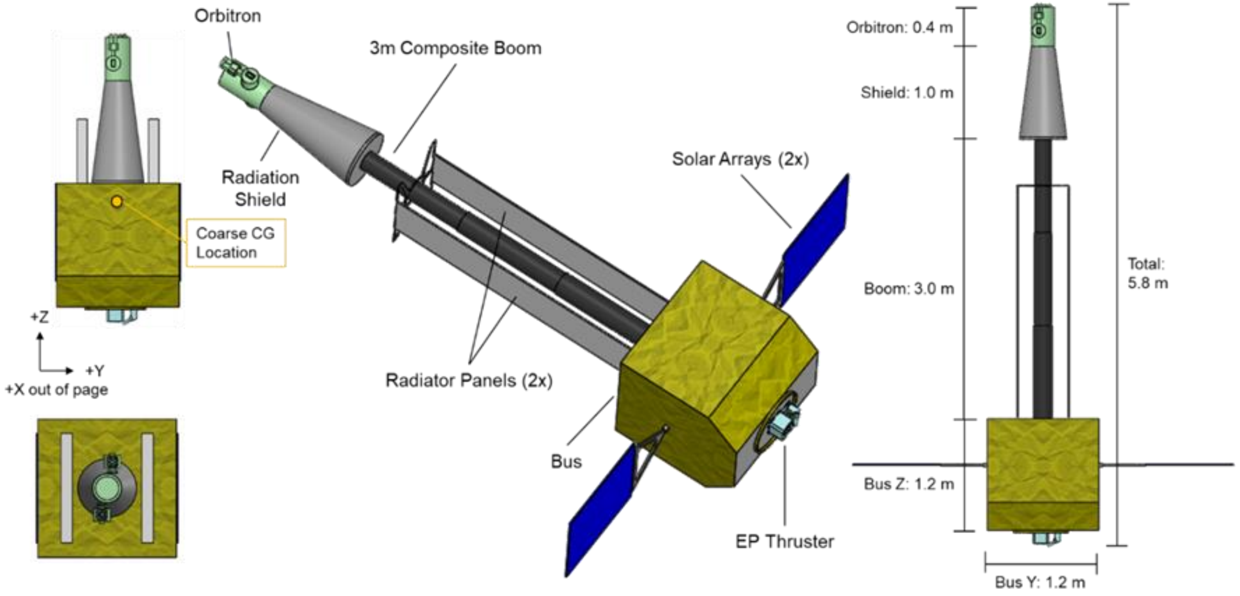
2.7 m

7.7 m

Fusion power enables higher power levels before encountering large-structure natural frequency challenges.

Spacecraft Fusion Demo Mission Concept Spacecraft[1]

‘Mass-Optimized’ 1kWe Fusion Spacecraft Concept



	CBE Mass (kg)	Cont. (kg)	MEV Mass (kg)	% Dry	Solar Power CBE OAP (W)	Solar Power Cont. (W)	Solar Power MEV OAP (W)	Nuclear Power Peak Power Draw (W)
Spacecraft Total	**488.7**	**136.4**	**625.1**	**100.0%**	**159.5**	**41.1**	**200.6**	**800.0**
Payload Total	**210.7**	**62.3**	**273.0**	**43.7%**	**0.0**	**0.0**	**0.0**	**0.0**
Orbitron Reactor	86.4	25.9	112.3	18.0%	0.0	0.0	0.0	0.0
Orbitron Shielding	34.5	10.3	44.8	7.2%	0.0	0.0	0.0	0.0
Orbitron Energy + Voltage Conversion	15.0	4.5	19.5	3.1%	0.0	0.0	0.0	0.0
Orbitron Other	71.9	21.6	93.5	15.0%	0.0	0.0	0.0	0.0
Nuclear Radiator	2.6	0.3	2.9	0.5%	0.0	0.0	0.0	0.0
Bus Total	**278.0**	**74.1**	**352.1**	**56.3%**	**159.5**	**41.1**	**200.6**	**800.0**
Attitude Determination and Control	23.9	6.0	29.8	4.8%	48.1	12.0	60.1	0.0
Command and Data Handling	10.9	2.7	13.6	2.2%	52.7	13.2	65.9	0.0
Communications/TT&C	13.8	3.5	17.3	2.8%	40.5	10.1	50.6	0.0
Electrical Power	22.3	6.1	28.3	4.5%	9.7	2.4	12.1	0.0
Harness	14.9	11.1	26.0	4.2%				
Propulsion	57.4	14.4	71.8	11.5%	0.1	0.0	0.1	800.0
Structure/Mechanisms	127.7	27.6	155.2	24.8%				
Thermal Control	7.2	2.9	10.0	1.6%	8.4	3.4	11.8	0.0
Systems Reserve Contingency		0.0	0.0	0%		0.0	0.0	

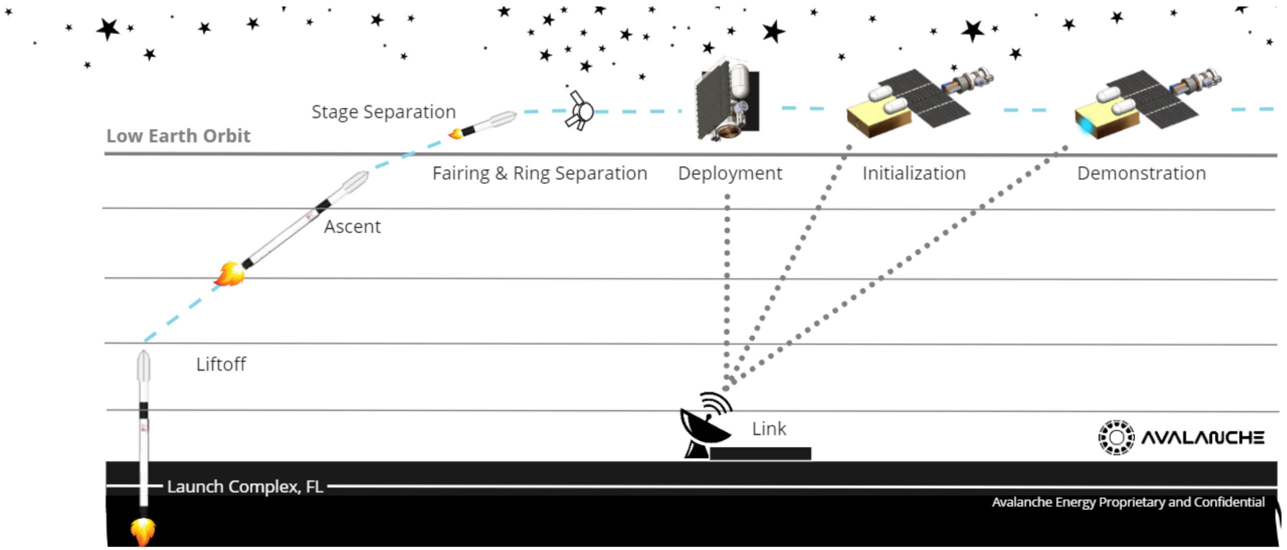
Total Propellant Mass	**80.6**
EP Propellant (Xe)	55.0
Monopropellant (N2H4)	25.6
Pressurant	0.0
Top-off propellant	0.0
Single Spacecraft Wet Mass	**705.8**

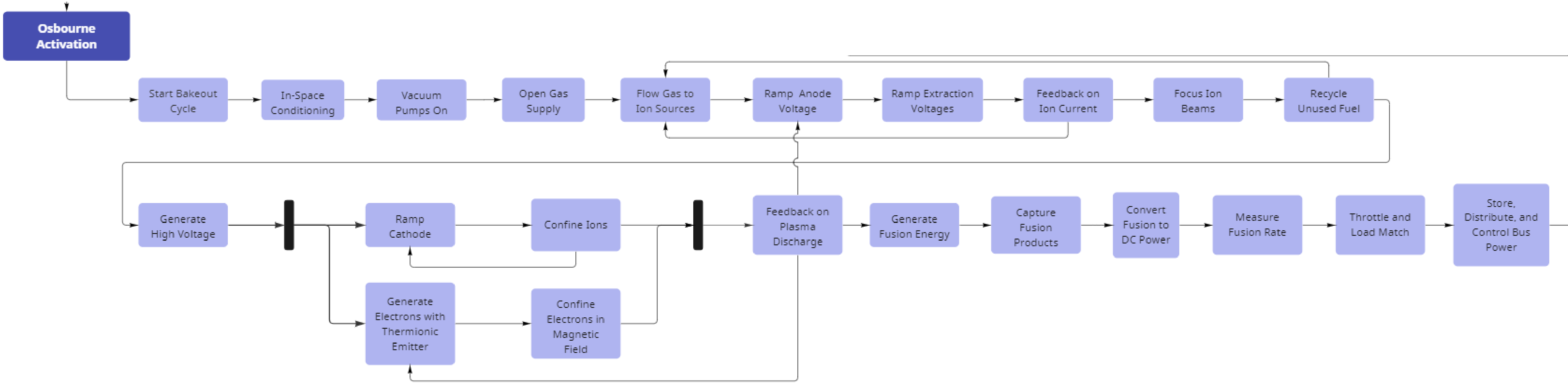
Power Summary [W]		**Nuclear**
Total Orbit Avg Power Load	200.6	800.0
Orbit Avg Power Gen (BOL)	248.3	960.0
Orbit Avg Power Gen (EOL)	240.7	960.0
Power Margin	20.0%	16.7%

Higher Power Fusion Spacecraft Concept In Work

[1]Prasadh, N., McHale, J., Simpson, B., Szogas, S., Schilling, J., Ottaviano, A., Thuppul, A., Smedley, J., Agramonte-Moreno, A., Bell, R., Ferrone, K., & Reiss, J. (2024). Avalanche Energy Study: Task 1 Summary Report.

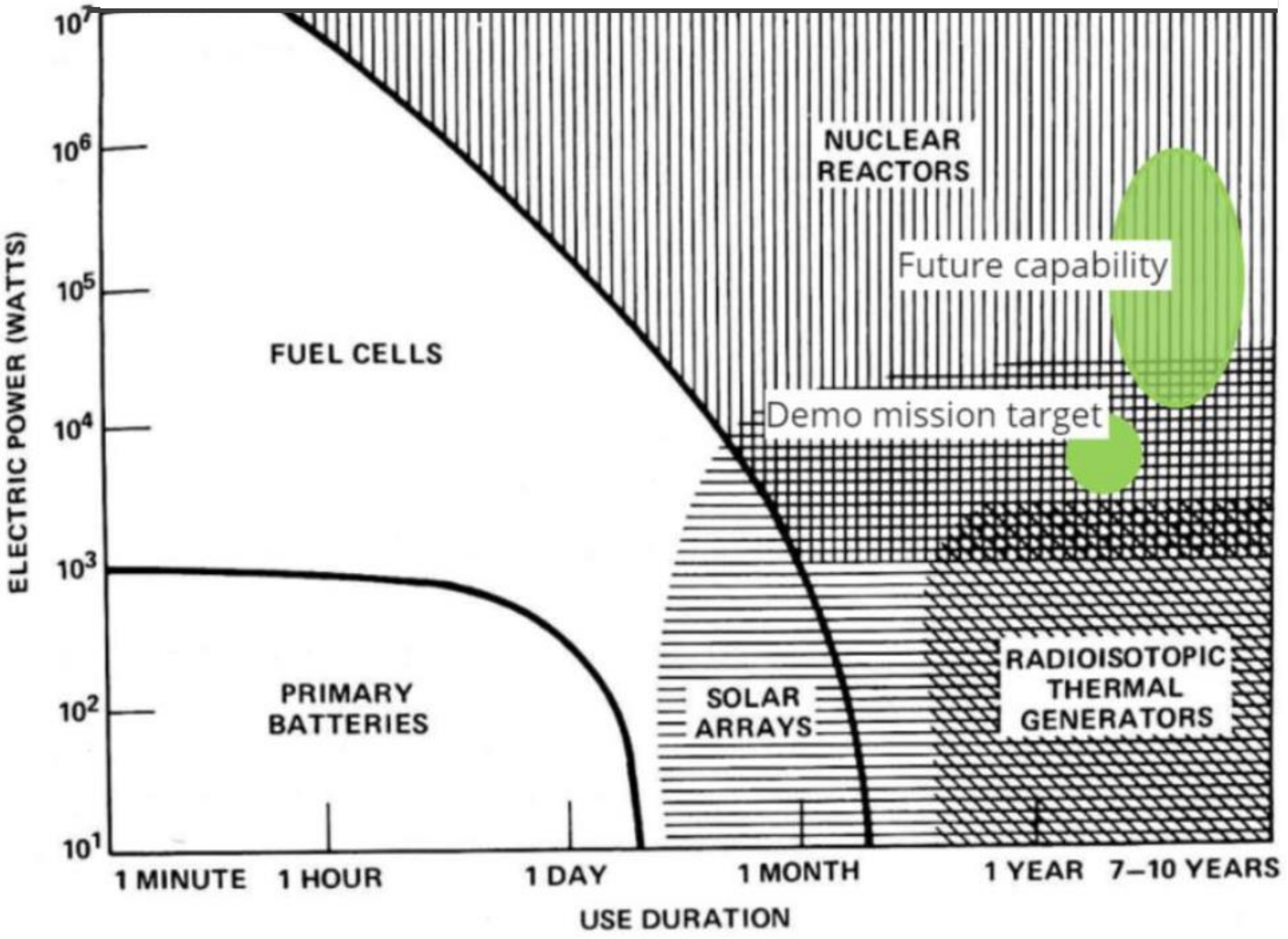
CONOPS


Low Earth Orbit
Stage Separation
Fairing & Ring Separation
Deployment
Initialization
Demonstration
Ascent
Liftoff
Link
AVALANCHE
Launch Complex, FL
Avalanche Energy Proprietary and Confidential


Osbourne Activation
Start Bakeout Cycle
In-Space Conditioning
Vacuum Pumps On
Open Gas Supply
Flow Gas to Ion Sources
Ramp Anode Voltage
Ramp Extraction Voltages
Feedback on Ion Current
Focus Ion Beams
Recycle Unused Fuel
Generate High Voltage
Ramp Cathode
Confine Ions
Generate Electrons with Thermionic Emitter
Confine Electrons in Magnetic Field
Feedback on Plasma Discharge
Generate Fusion Energy
Capture Fusion Products
Convert Fusion to DC Power
Measure Fusion Rate
Throttle and Load Match
Store, Distribute, and Control Bus Power

<u>Advantages of fusion for space applications</u>:

- kW class power output
  - Higher power output than primary batteries and RTGs
- Freedom from design reference mission limitations
  - No constraints on mission due to lighting—eclipse, lunar night, permanently shadowed regions, and deep space
  - Smaller and more maneuverable than comparable solar array size
- Long-duration operation
  - High specific energy fuel options, allowing long duration mission
  - No infrastructure requirements for storage, cryogen densification, liquefaction, or refueling
- Safe operation vs. fission
  - Reduced launch restriction and no nuclear proliferation concerns
  - D-T reactor would fall into Tier 1 per NSPM-20 (head of the sponsoring agency shall be the launch authorization authority)



M. Griffin and J. French, Space Vehicle Design, Second Edition, Reston: American Institute of Aeronautics and Astronautics, Inc., 2004.

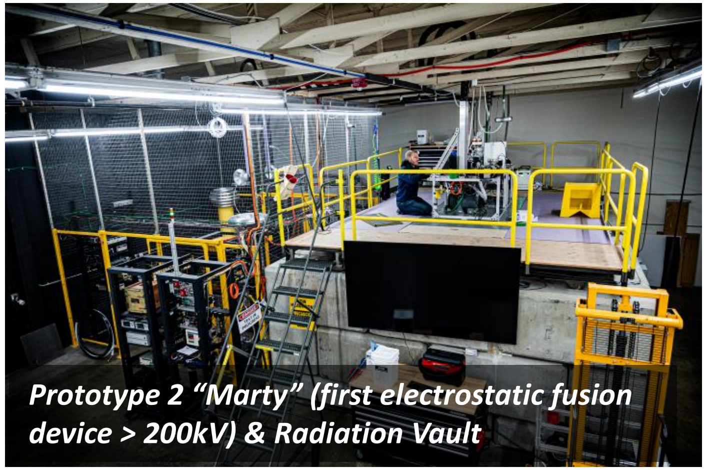
Meet the team

Avalanche comprises a high-powered team of 45 scientists, engineers, and business professionals, including 16 PhDs and 5 plasma physicists. The initial team members rapidly advanced Orbitron from a paper concept to lab hardware that produced neutrons from deuterium fusion in just under seven months.

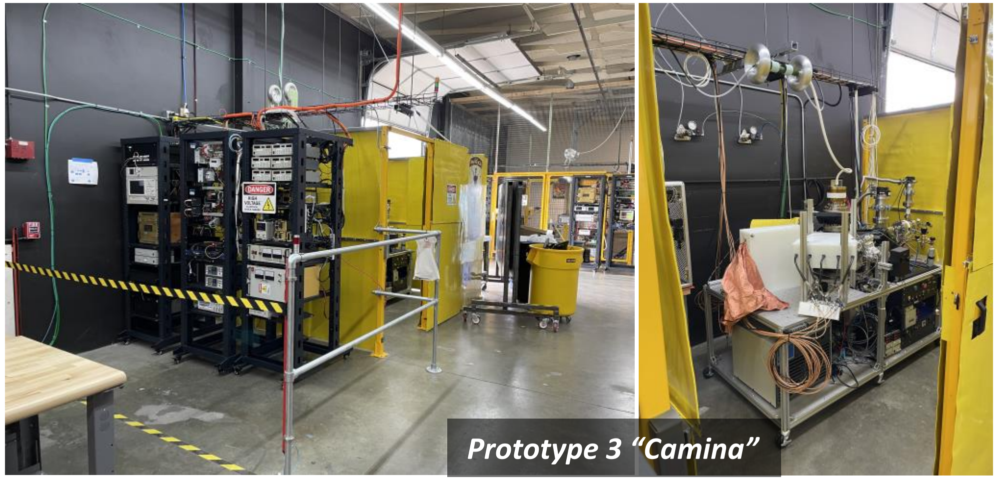
We are supported by major investors (>$1B AUM) including Lowercarbon and Founders Fund and are the largest, most well-resourced team that has ever worked on inertial electrostatic fusion.

Avalanche Energy recently expanded its facility to 25,000ft^2, which enables the company to grow more rapidly and increase its R&D capacity. Also, Avalanche is contracted with Canadian Nuclear Laboratories to advise on the design of an in-house tritium handling facility, which is planned for 2025 and would make Avalanche Energy only the second commercial entity to handle tritium on site (pending WA state approval). The company is presently funded via a successful $40M Series A investment round.

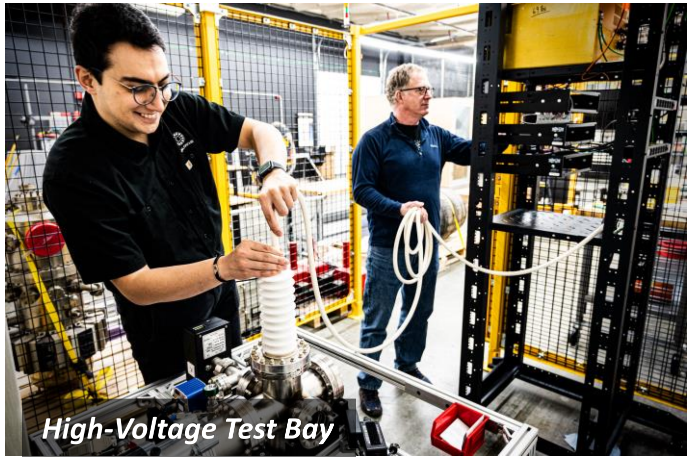
Prototype 1 "Neo" with High Temp Superconducting Magnets



Prototype 2 "Marty" (first electrostatic fusion device > 200kV) & Radiation Vault

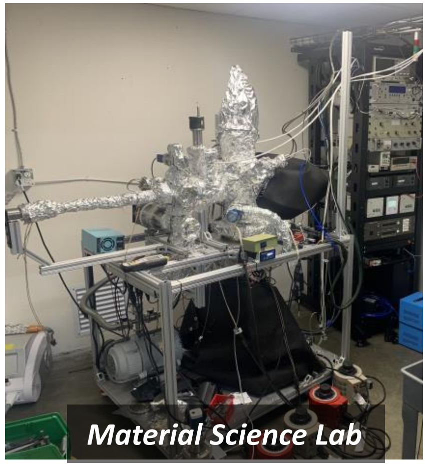


Prototype 3 "Camina"



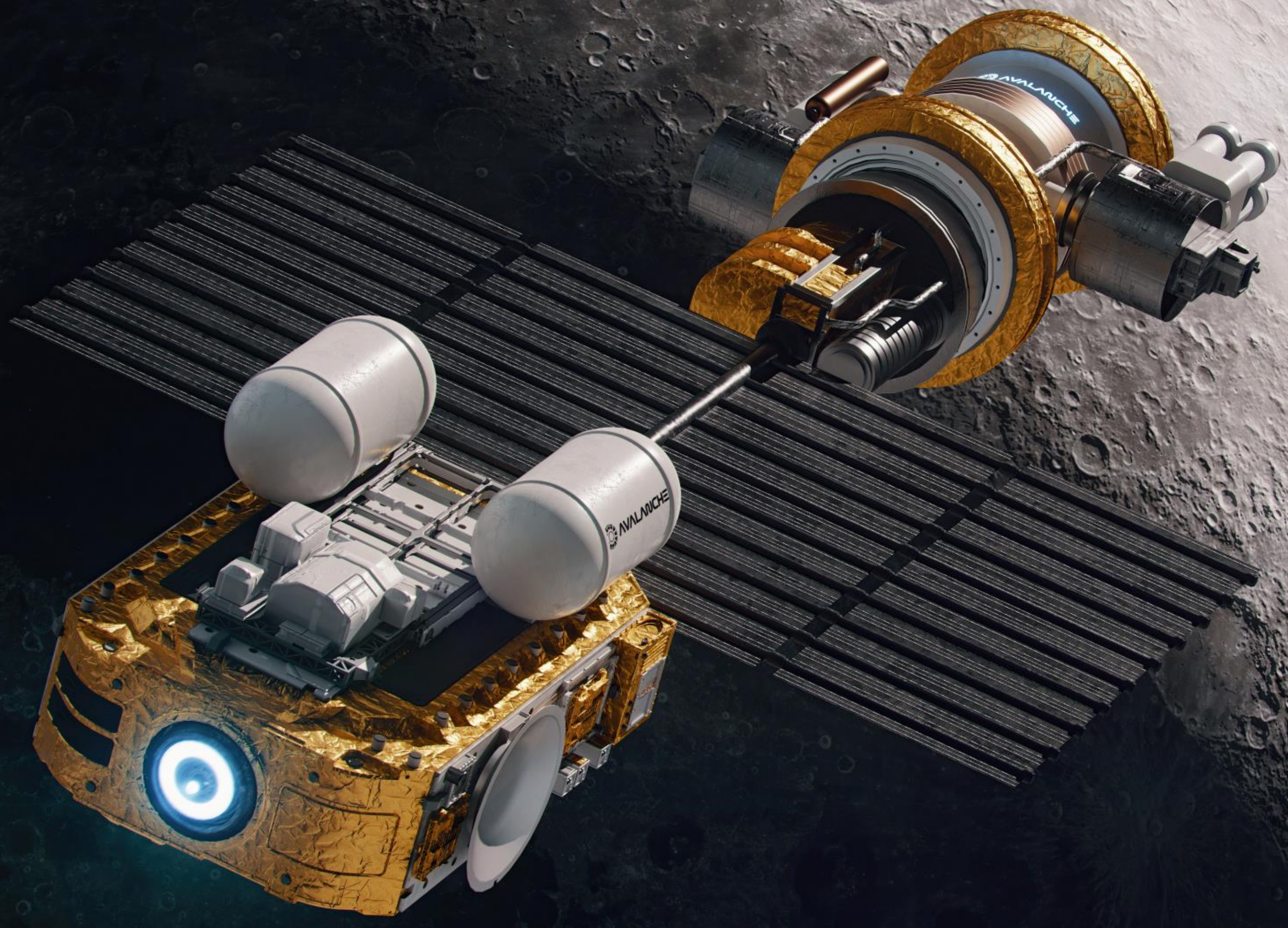
High-Voltage Test Bay

Advanced Machine Shop



Material Science Lab

Questions



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