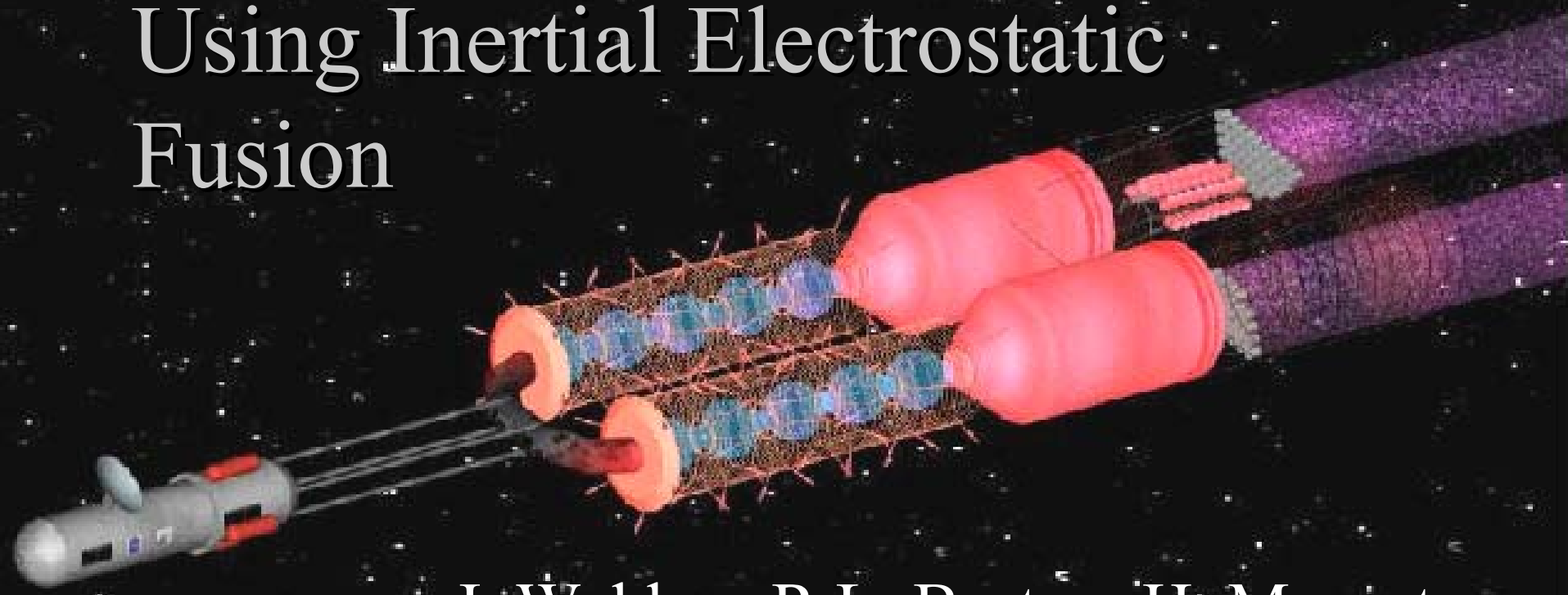
Fusion Ship II - A Fast Manned Interplanetary Space Vehicle Using Inertial Electrostatic Fusion



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NASA's Design Challenge

- Manned crew space ship
- Jupiter and back in less than 365 days
- Ship mass of under 500 MT
- Maximize transfer mass

Ship Overview

- Power generation: D-^{3}He IEC NBI reactors
- Power conversion: Traveling wave & Hexi-pole direct energy converters,
- Propulsion: Argon ion thrusters with an ISP of 35,000 seconds

FOR MORE INFO...

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More Overview

- Earth to Jupiter 210 days
- Jupiter to Earth 152 days
- Total thrust 4369 N
- Acceleration 0.0087 m/s^2

Mass Breakdown

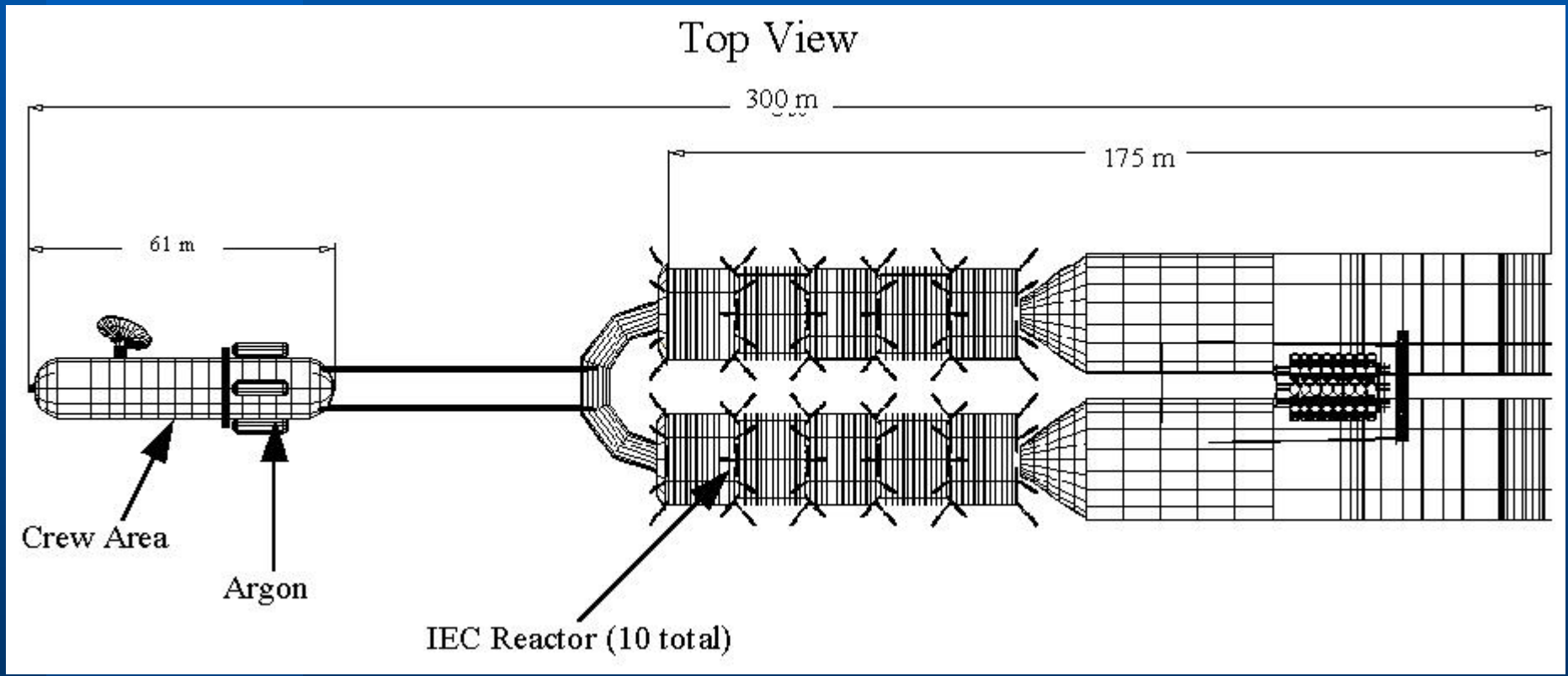
- **Argon Propellant Mass 220 MT**
- **Transfer Mass 100 MT**
  - **Includes electronics, crew compartment and equipment, shielding, food, life support, shield tanks, & refrigerant radiator**

System	Mass (MT)
m_{pow}	178.0
IEC	83.7
TWDEC's	44.2
He3, D2 and Tanks	0.3
Argon tanks	5.6
Ion Engines and Structure	12.3
Transformers	6.5
Rectifiers	13.6
Meteor Shields	2.0
Magnetic Channel	9.8

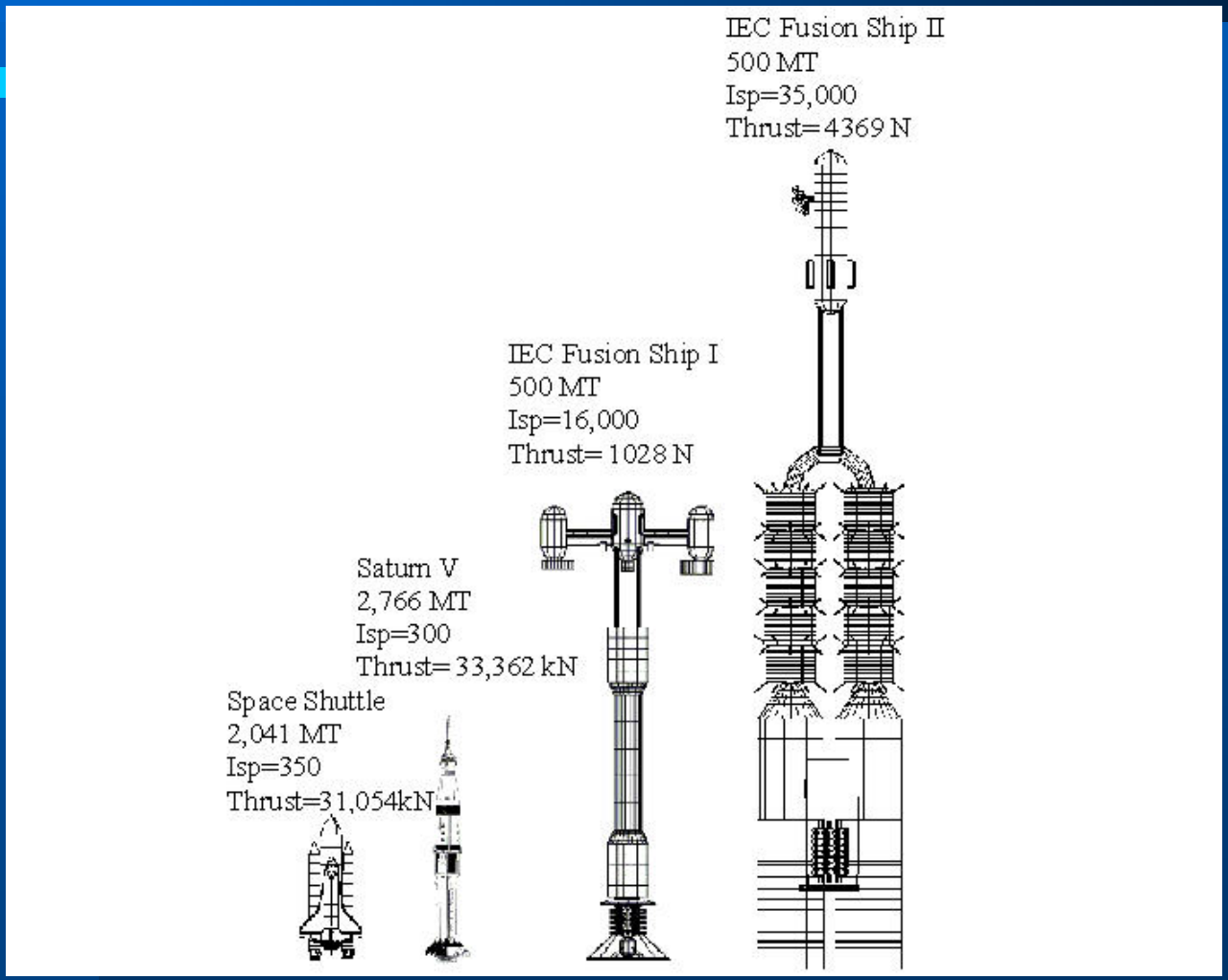
Comparison of IEC and Magnetic Fusion Designs

	Fusion Ship I	Fusion Ship II	Magnetic Fusion Design
Overall Mass, MT	500	500	1690
Overall Length, m	174	300	240
Number of crew	10	10	6 – 12
Thrust Power, MW	86	750	4830
Reactor gain	4	9	73
Reactor power, MW	296	2178	7895
Thrust system	Krypton ion	Argon ion	H_2 – magnetic nozzle
Specific impulse	16,000	35,000	35,435
Jupiter one way trip time, days	400	210	118

Space Ship Dimensions



Size Comparison

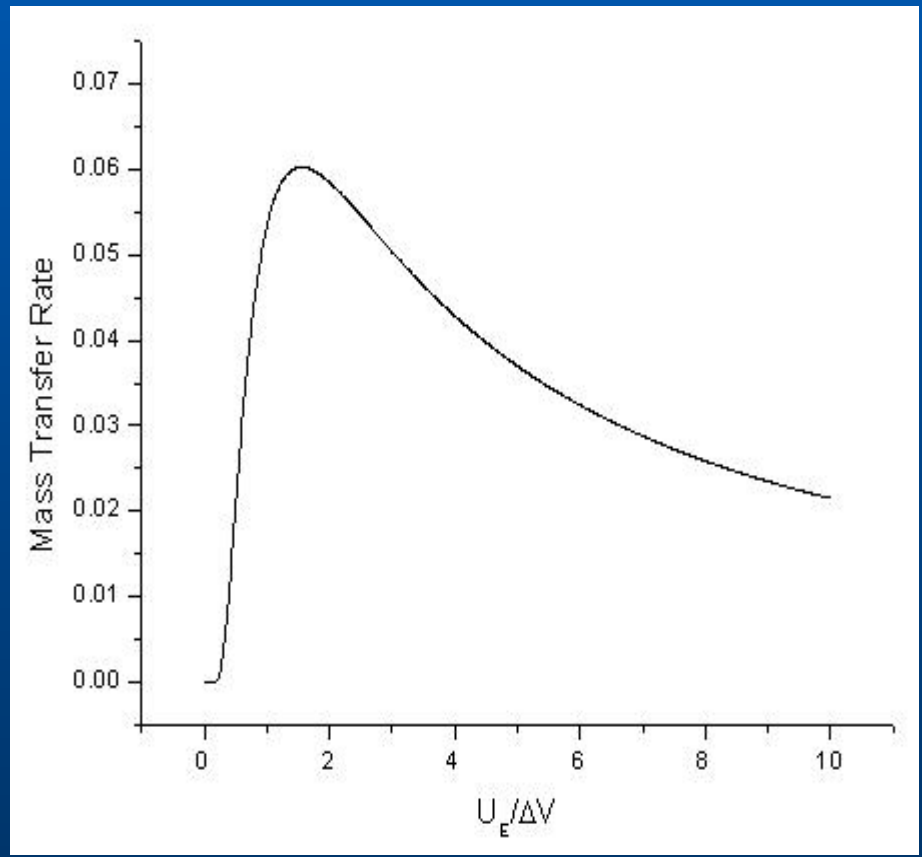


How did we come up with this?

- Mass optimization
- Propulsion survey
  1. ΔV requirement to get to Jupiter
  2. How much propellant will we need
  3. Ion engine and ship sizing
     - Economics of Ion propellant Chosen
     - Thrust vs. ISP to get there in about ½ year
  4. Power needed from the IECs to run the engines and the ship
- IEC and DEC survey
  - How much power can IEC produce
  - Efficiency of the DECs
  - Structural limitations and shielding

Optimization Results

- ΔV = 220 km/s
- m_t/m_o of .264
- Isp ~ 35,000 sec
- Thruster grid voltage 25 kV
- 750 MW for Ion thrusters



Ion Thruster Selection

- **Argon over Xenon or Krypton**

  Advantages

  – **Highly abundant (cheaper)**
  – **Lower grid voltage required**
  – **Longer service life**

  Disadvantages

  – **Lower molecular weight**
  – **Higher Ionization potential**
  – **Slightly lower efficiency compared to Xe, Kr**

Critical Ion Engine Design Issues

- High power without large number of thrusters
- Very high electric field between the grids
- Ratio of diameter to grid spacing
- Material sputtering containment

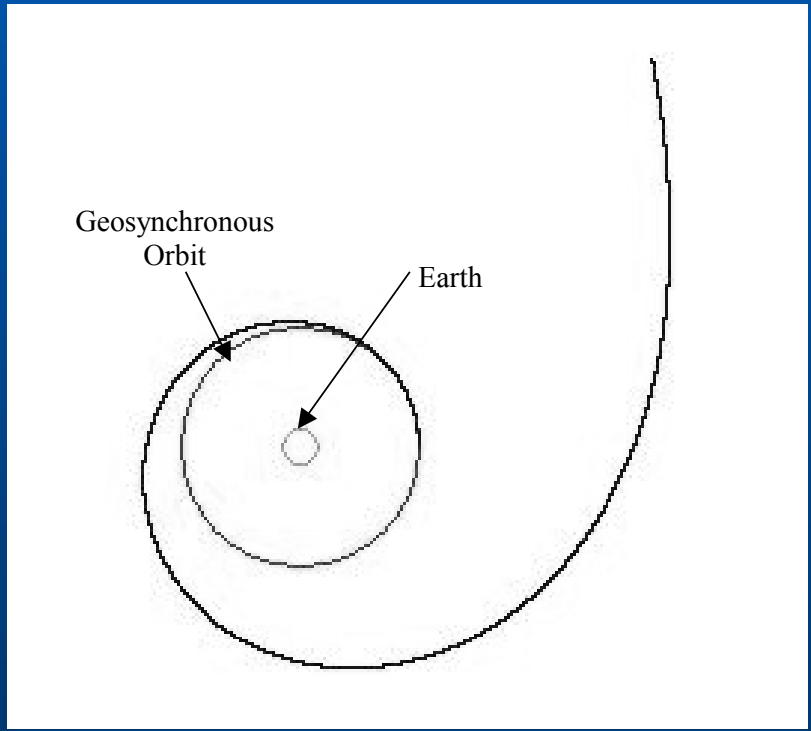
Determination of the ΔV

- Trip broken into 3 parts
  1. Achieving escape velocity from Earth
  2. Heliocentric transfer from Earth to Jupiter
  3. Planetary capture orbit at Jupiter

Earth Escape Velocity

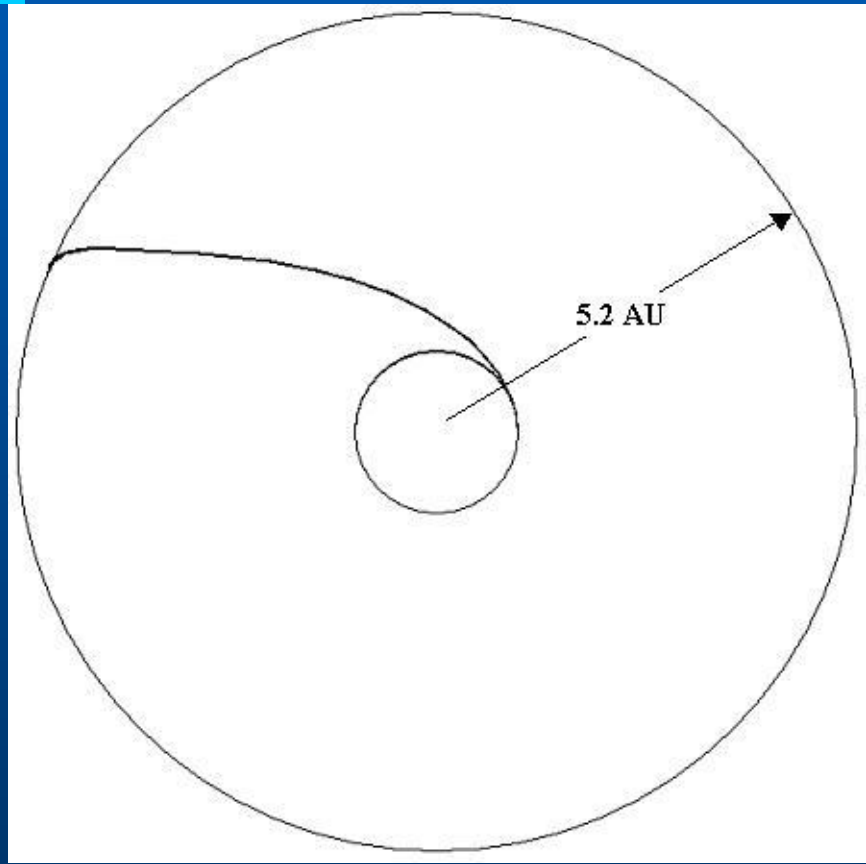
$$E = -\frac{\mu}{2a} + \frac{V^2}{2}$$

$$a = \left(\frac{2}{r} - \frac{V^2}{\mu} \right)^{-1}$$



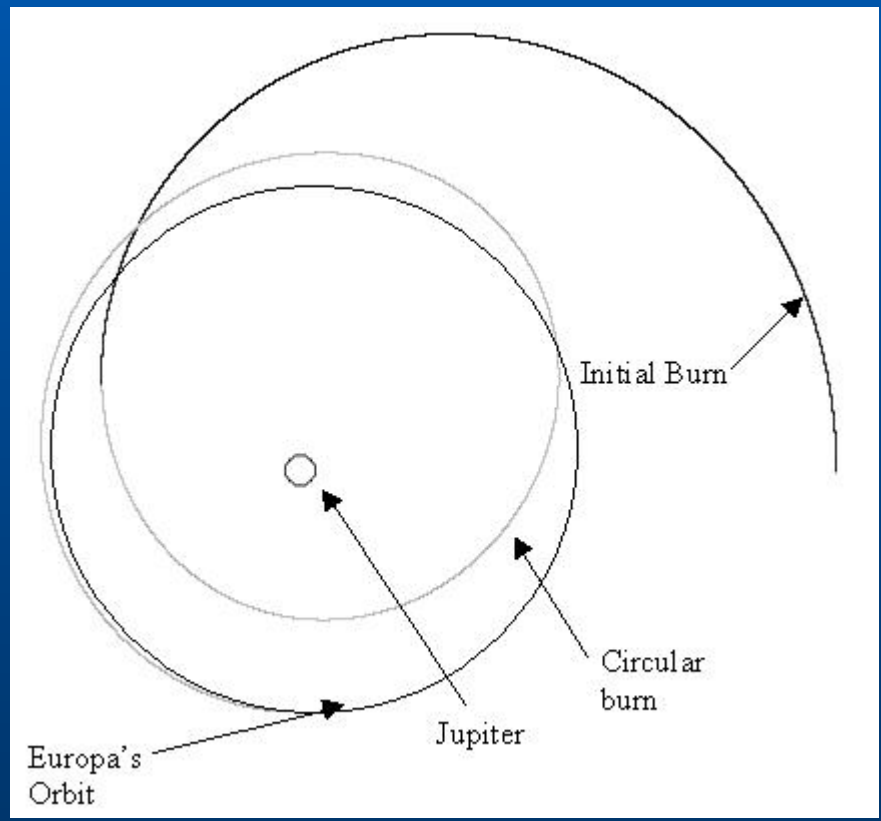
From Earth to Jupiter

- Heliocentric orbit transfer
- Initial thrust
- Coast time
- 2nd thrust to convert form elliptical to circular orbit

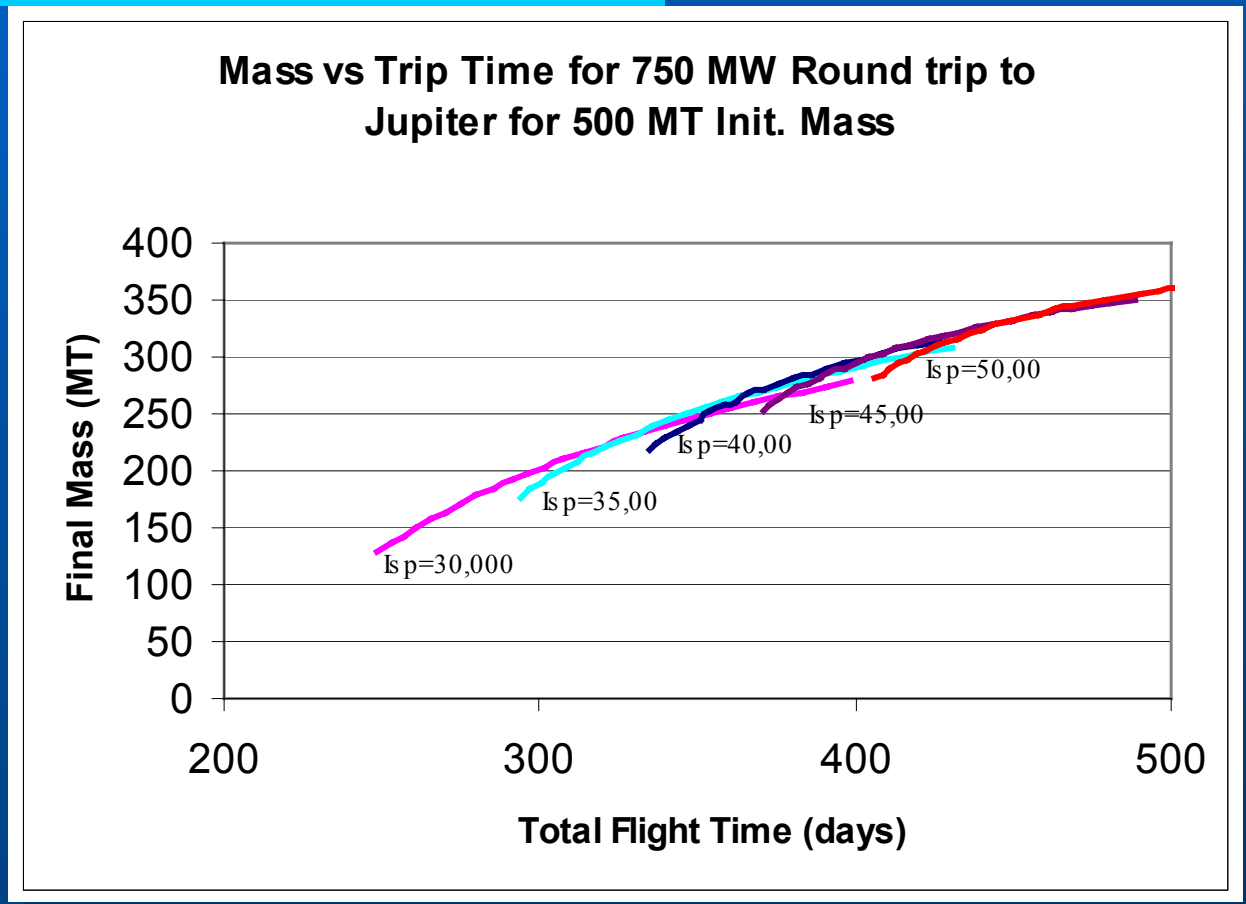


Entering the Jovian System

- 34 Jovian radii
- Descent to 9.6 JR
- Minimum orbit 1.36 JR requirement
- 2nd burn to enter circular orbit at Europa



ΔV = 220 km/sec

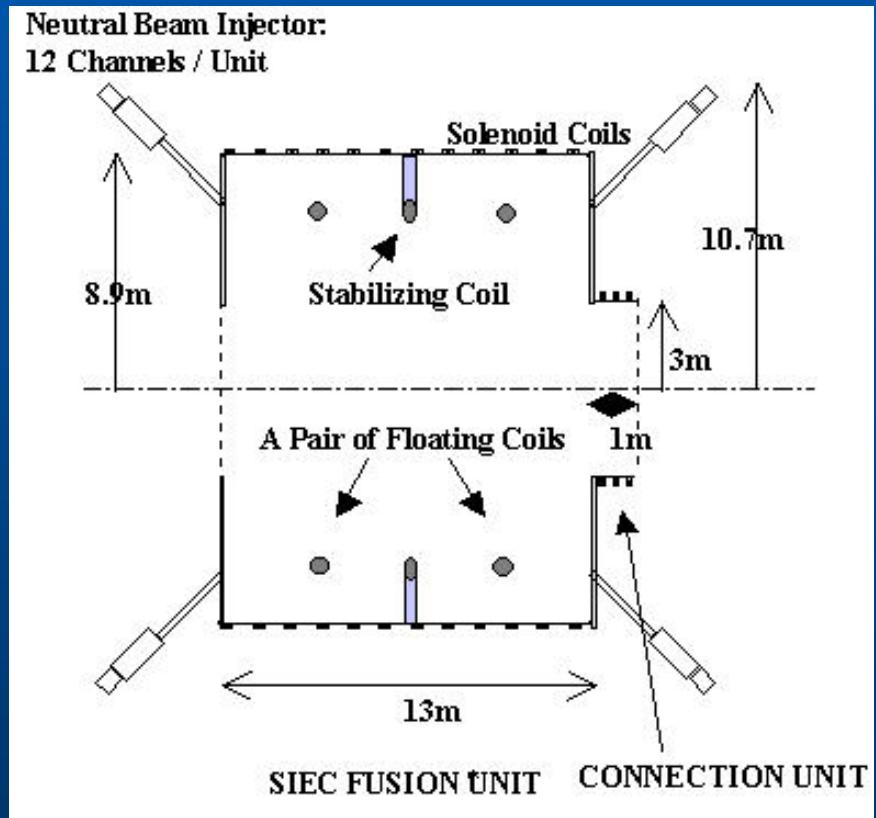

Mass vs Trip Time for 750 MW Round trip to Jupiter for 500 MT Init. Mass
Final Mass (MT)
400
350
300
250
200
150
100
50
0
200
300
400
500
Total Flight Time (days)
Isp=30,000
Isp=35,00
Isp=40,00
Isp=45,00
Isp=50,00

35,000 s. Argon Thrusters

Specific Impulse	70000	50000	40000	35000
Exhaust Velocity	686000	490000	392000	343000
Exhaust energy, V	98237	50121	32077	24559
E Field V/Xa	776497	918764	1452693	1552994
Xa, mm	126.5	54.6	22.1	15.8
j, A/m^2	17	32	101	132
D, m	12.1	4.4	1.8	2.00
No of units, N	4.0	20.0	98	78
Thrust, N	2187	2041	4082	4665

IEC Fusion Power Plant

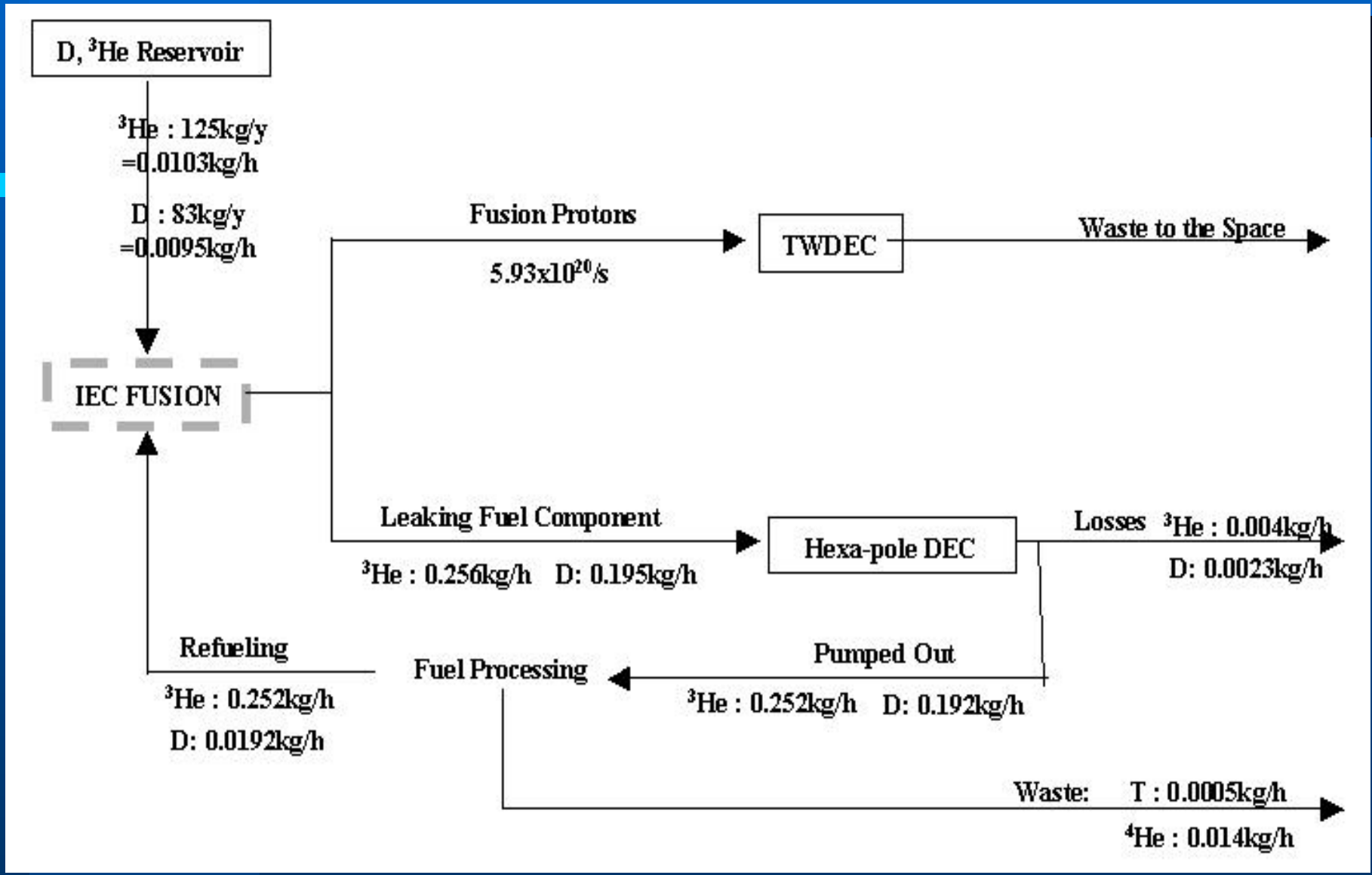
- Fusion plasma is generated by NBI
- Core B-field approaches zero
- Helmholtz coils eliminate B produced by solenoid coils
- Solenoid coils collimate the fusion protons axially



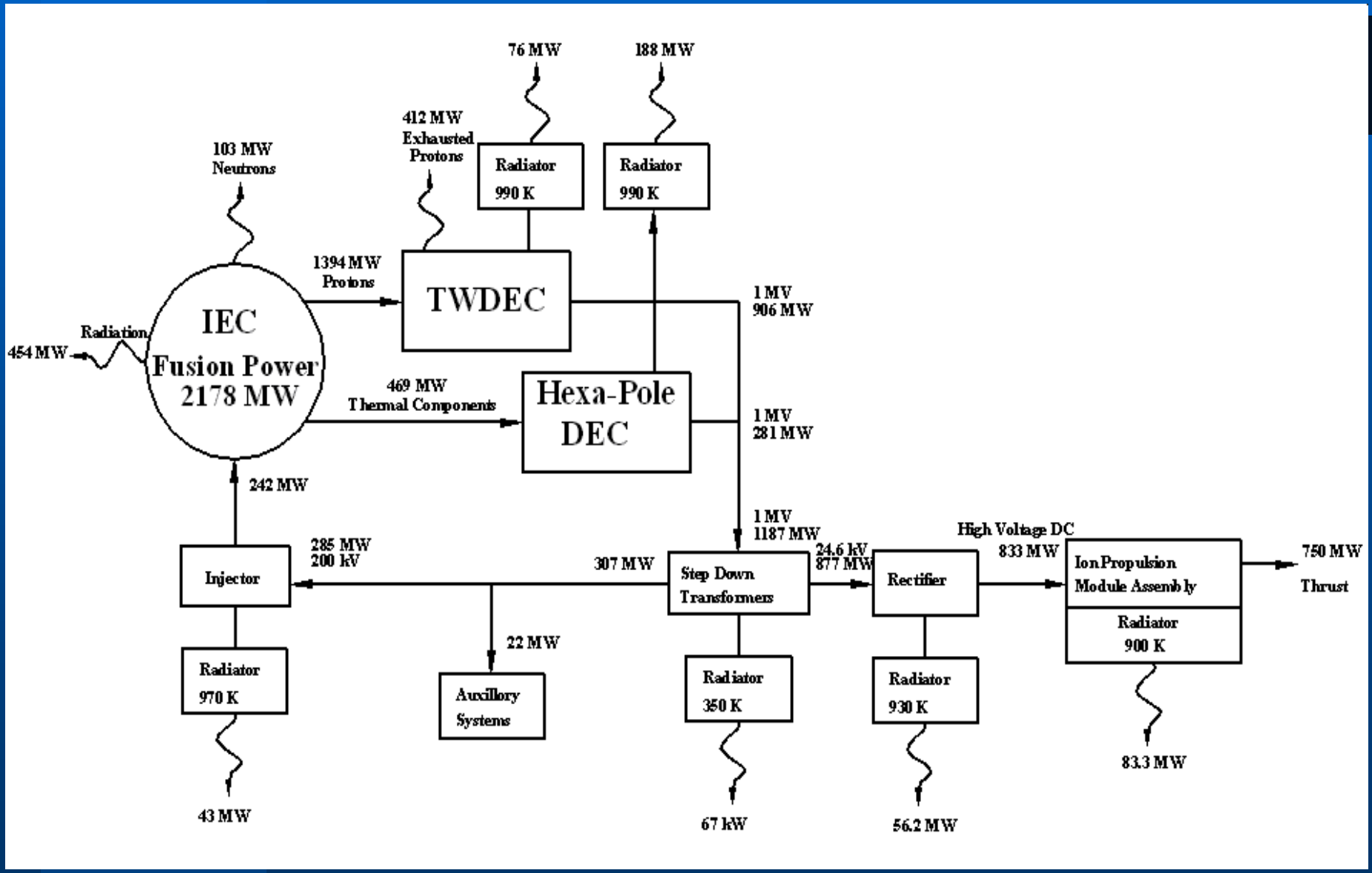
Particle Confinements in SIEC

- Electrons limited to hot core radius 0.22 m except for thin axial channel escape
- Ions are trapped by negative electric potential from the trapped electrons
- Small loss cones allow confinement time up to 49 ms for each unit
- 10 serial IECs can yield confinement time of nearly 1/2 second and produce 218 MW power per unit

Particle Flow Diagram



IEC/TWDEC Power Flow



Summary of Developmental Challenges

- Development of a 9:1 gain IEC rector
- Improvement of direct energy converters
- High-power ion thruster components and technology in the area of ion optics