High Speed **I**nterplanetary **T**ug/Cocoon **V**ehicles

(HITV)

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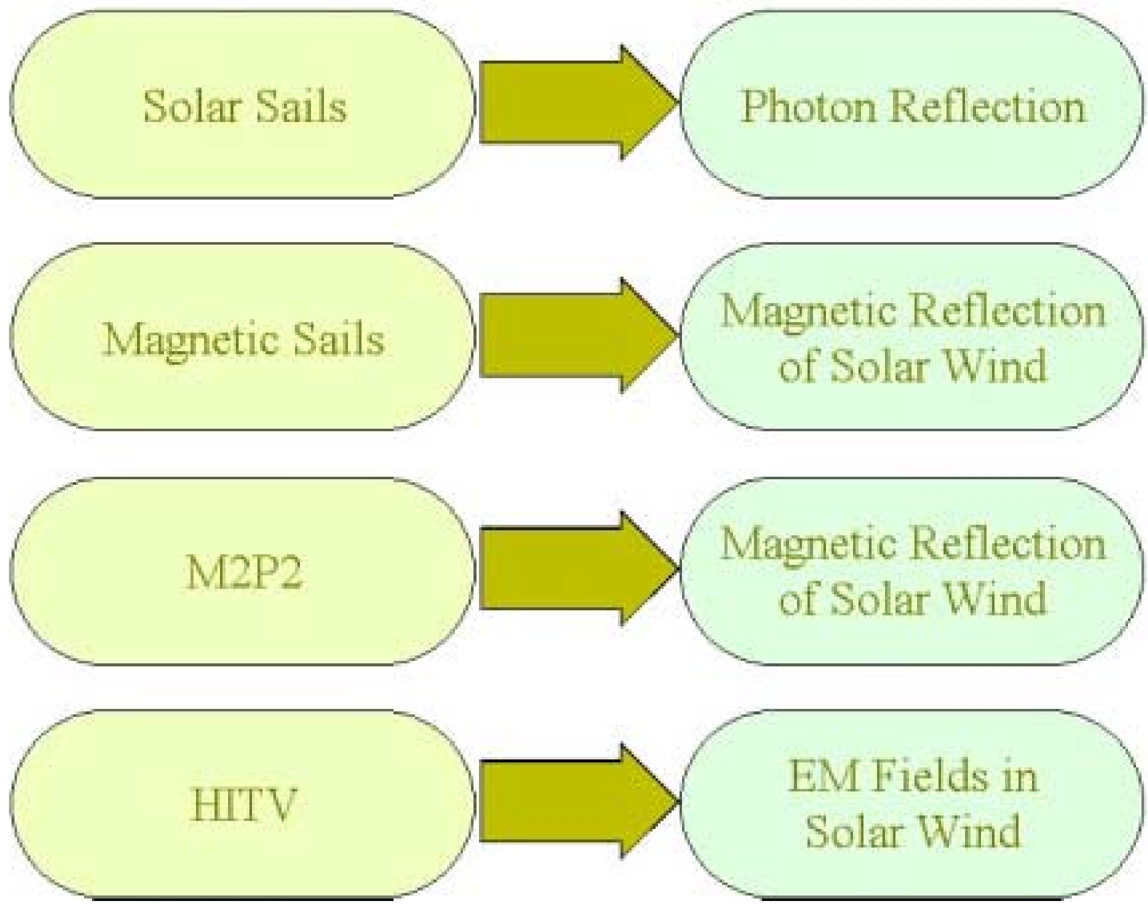
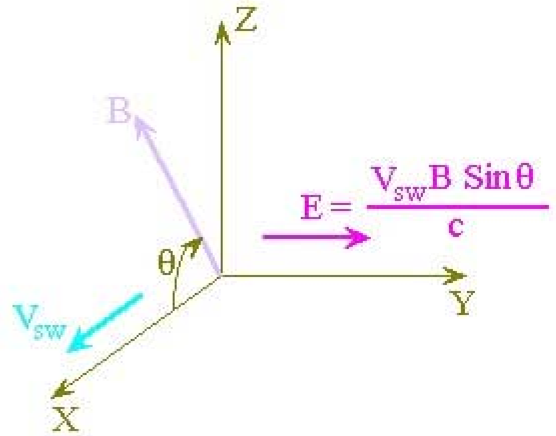
H. Karimabadi

SciberNet Inc.

Propellantless Propulsion Based on Solar Energy



Pick Up of Charged Particles by the Solar Wind

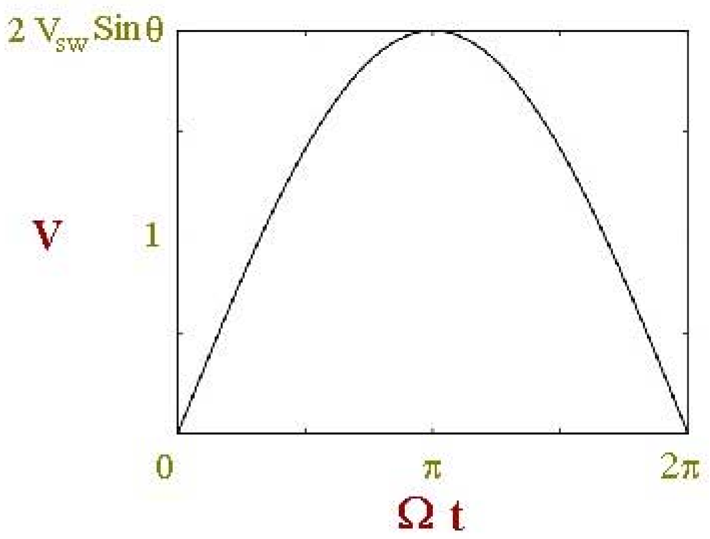


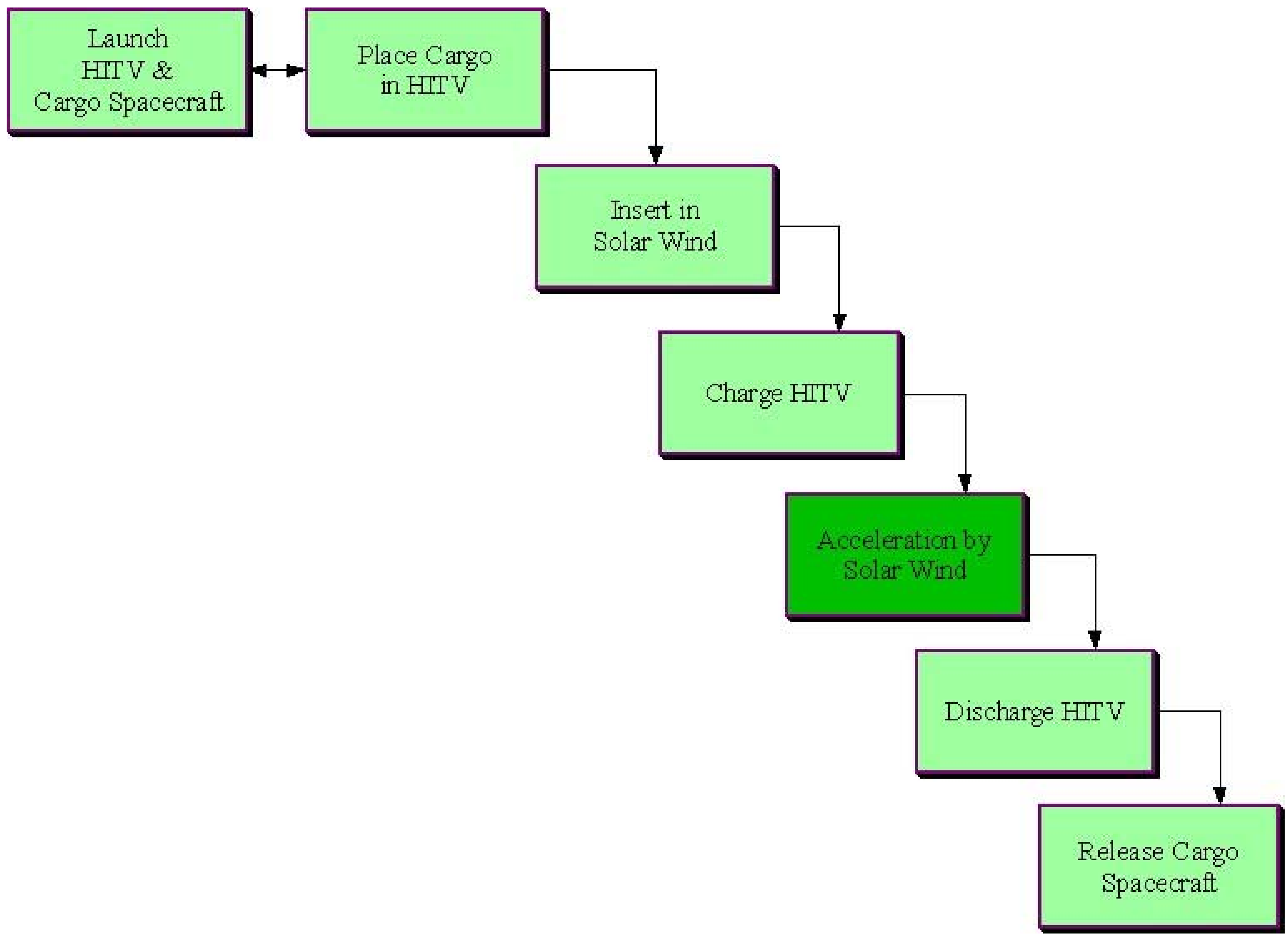
$$m\frac{dv}{dt} = q\left(E + \frac{V \times B}{c}\right)$$

Motion consists of gyration about B and a drift given by ExB vector.

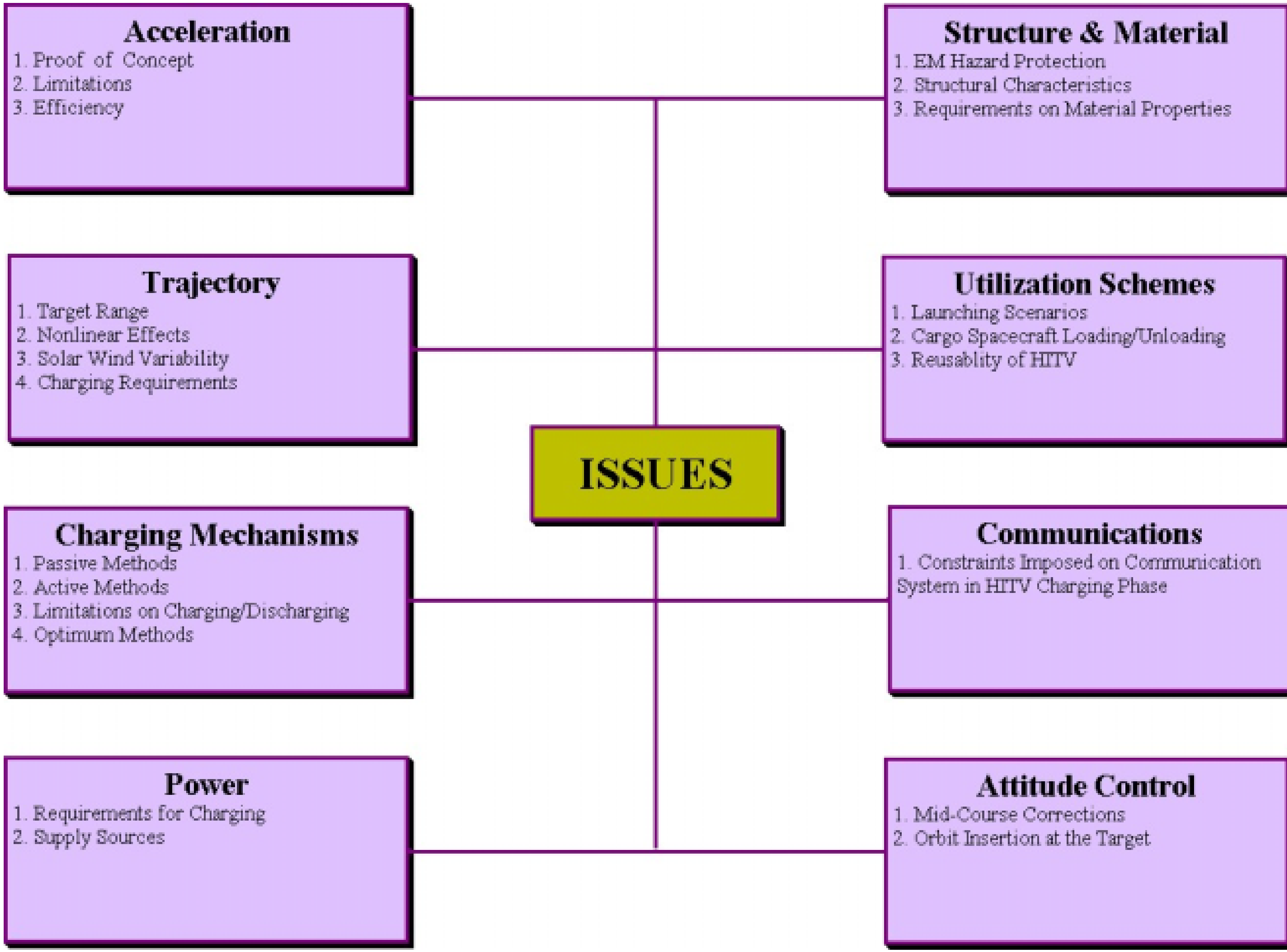
$$V = V_{sw} \sin\theta \, (2 - 2\cos\Omega t)^{1/2}$$

$$\Omega = \frac{qB}{mc}$$





Launch HITV & Cargo Spacecraft
Place Cargo in HITV
Insert in Solar Wind
Charge HITV
Acceleration by Solar Wind
Discharge HITV
Release Cargo Spacecraft

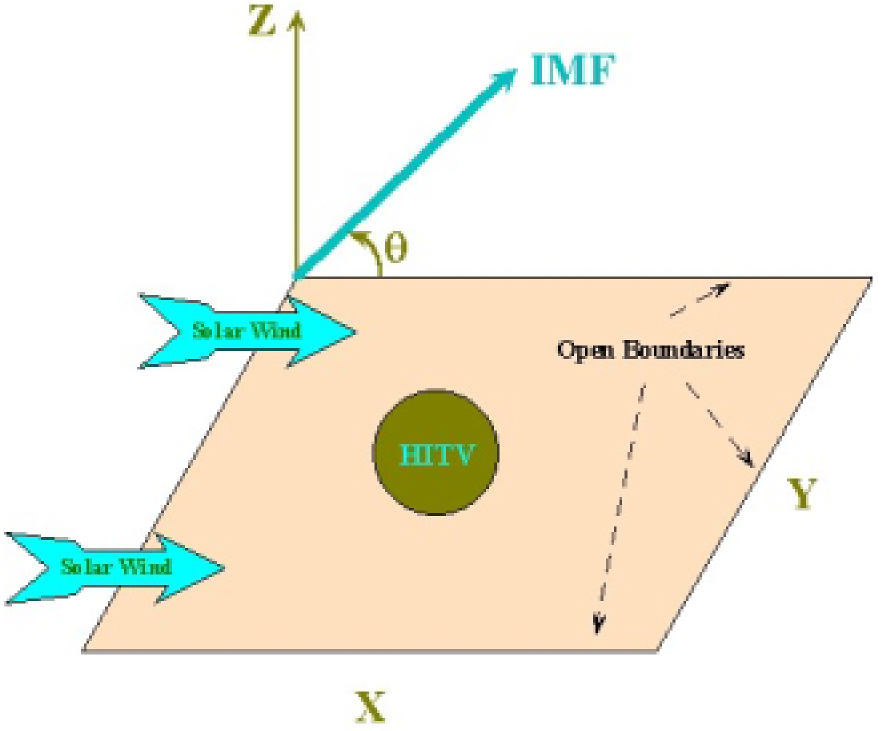

ISSUES
Acceleration
1. Proof of Concept
2. Limitations
3. Efficiency
Structure & Material
1. EM Hazard Protection
2. Structural Characteristics
3. Requirements on Material Properties
Trajectory
1. Target Range
2. Nonlinear Effects
3. Solar Wind Variability
4. Charging Requirements
Utilization Schemes
1. Launching Scenarios
2. Cargo Spacecraft Loading/Unloading
3. Reusablity of HITV
Charging Mechanisms
1. Passive Methods
2. Active Methods
3. Limitations on Charging/Discharging
4. Optimum Methods
Communications
1. Constraints Imposed on Communication System in HITV Charging Phase
Power
1. Requirements for Charging
2. Supply Sources
Attitude Control
1. Mid-Course Corrections
2. Orbit Insertion at the Target

Modeling the Acceleration Process

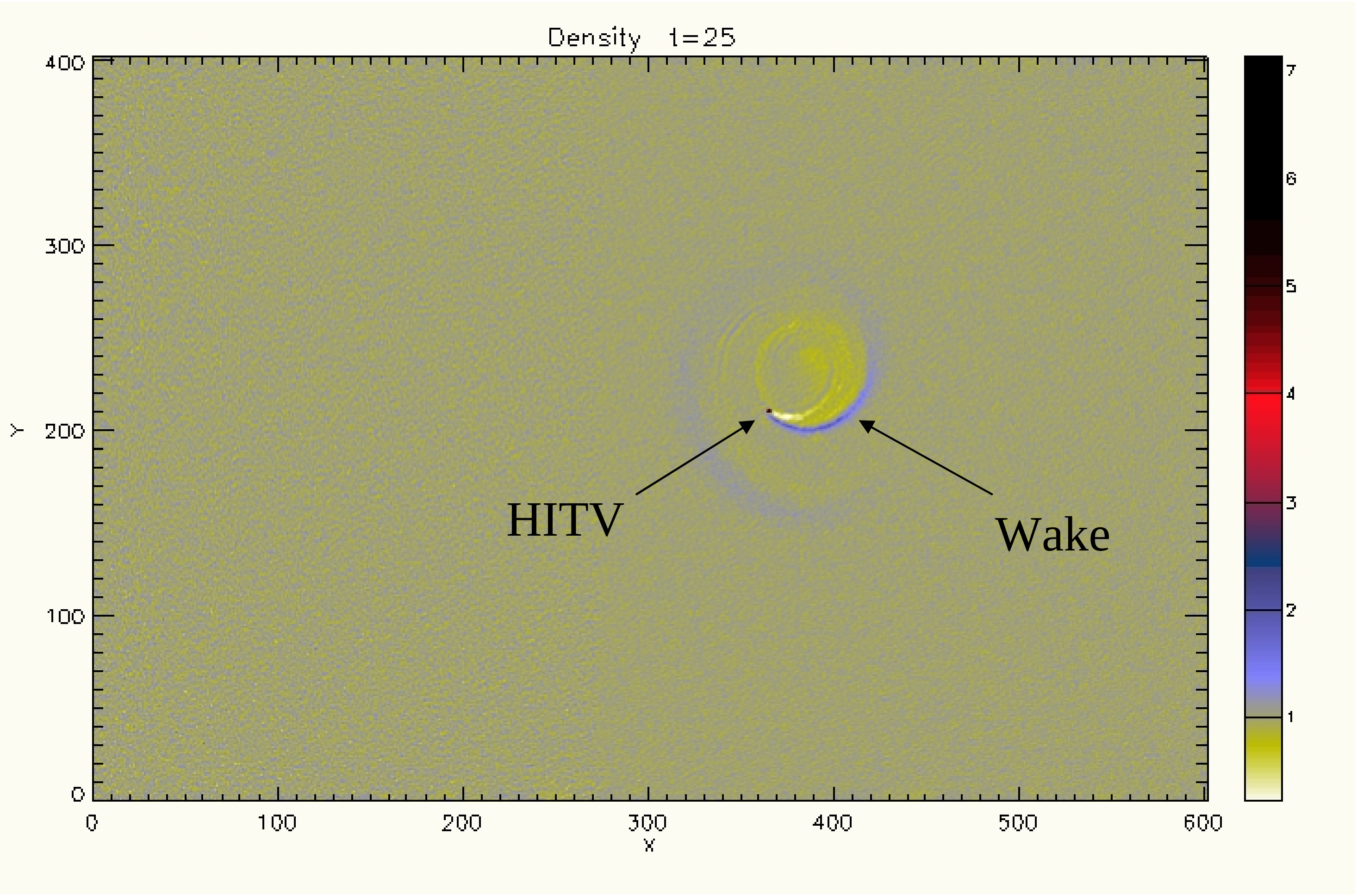
1. Ions carry most of the momentum & need to be treated kinetically

2. Electron physics adequately described by a fluid model

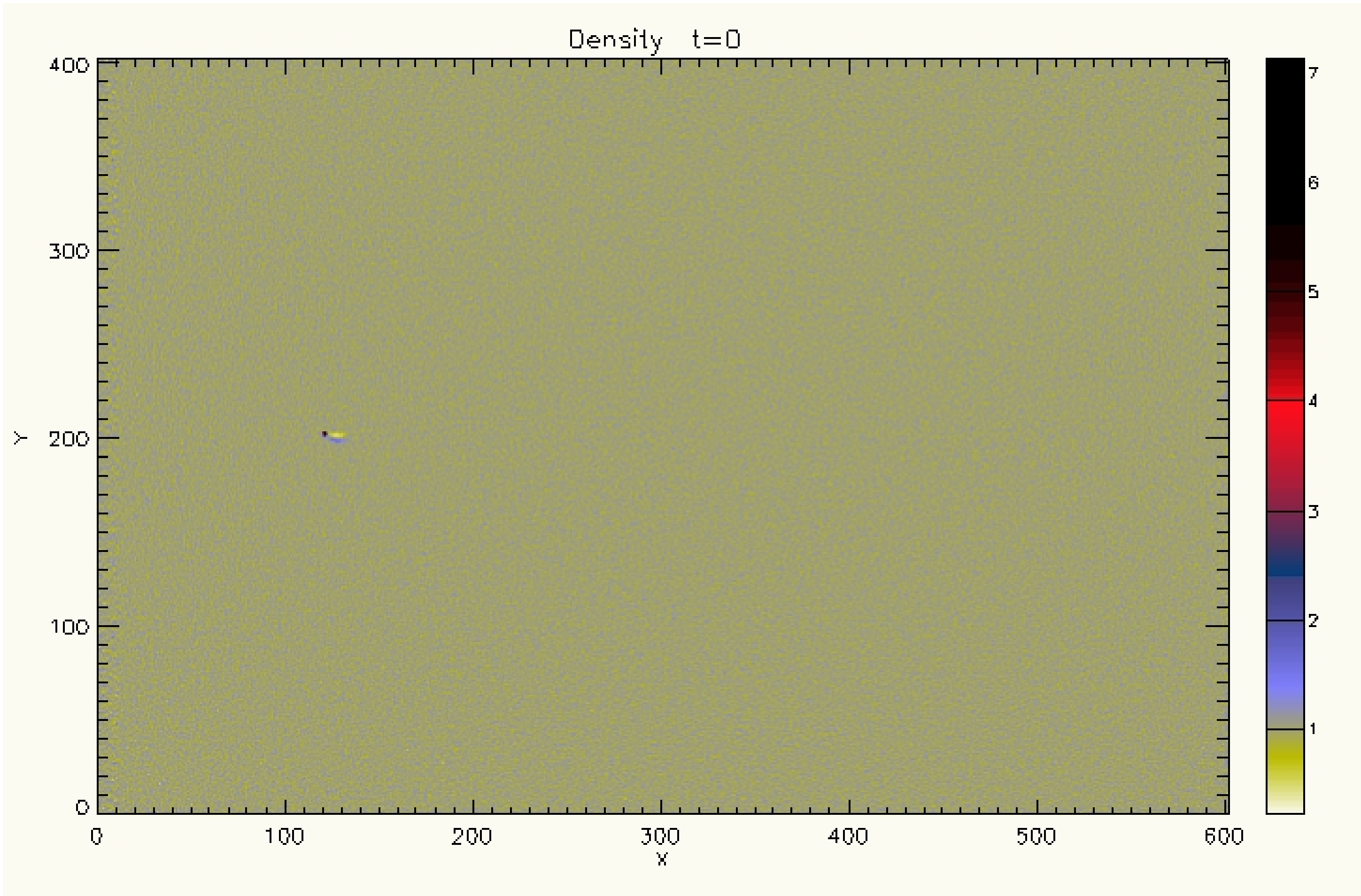
3. Use electromagnetic hybrid simulations



$$\frac{N}{N_{sw}} = 20$$

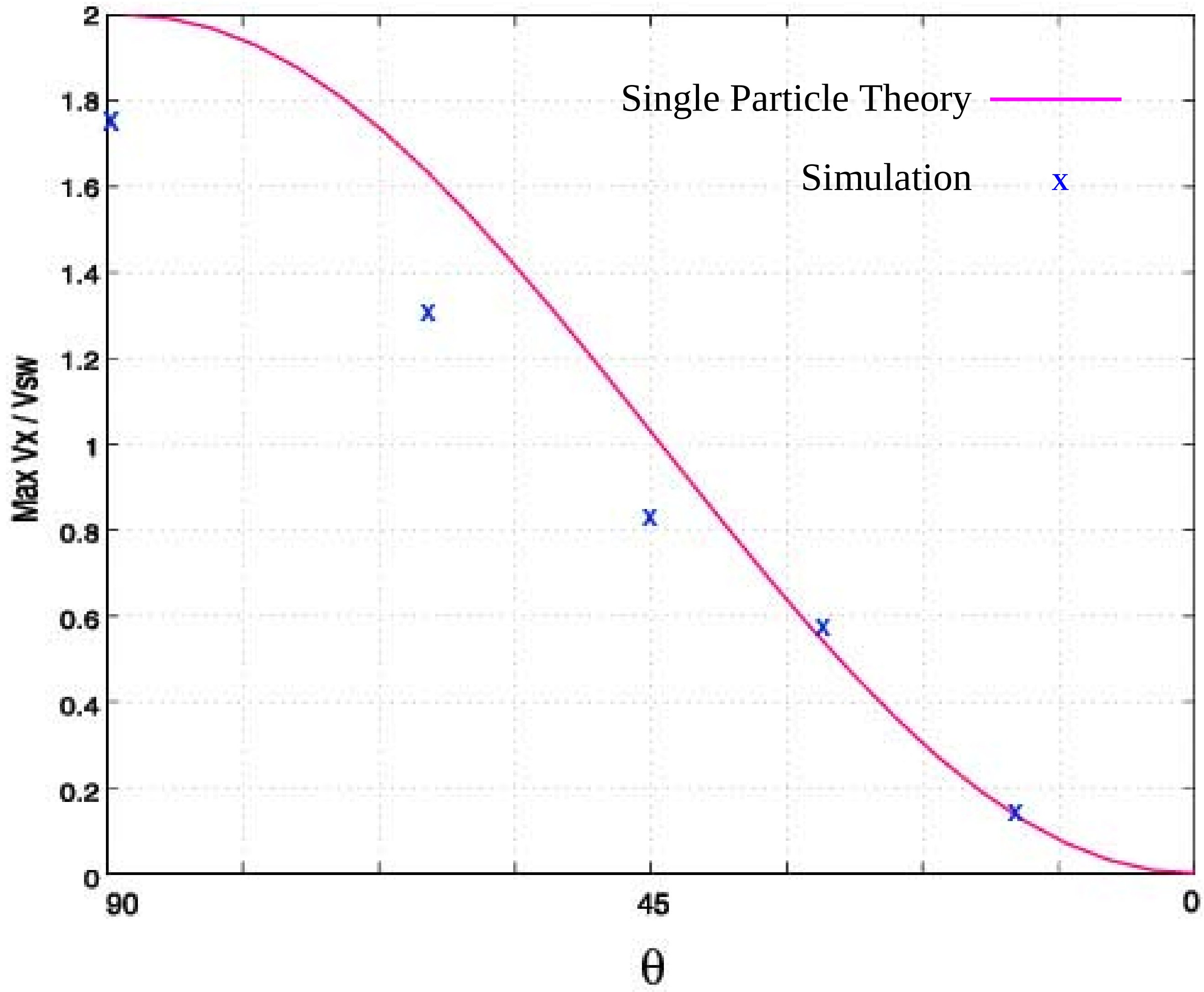


Density t=25
400
300
200
100
0
Y
0
100
200
300
400
500
600
X
7
6
5
4
3
2
1
HITV
Wake

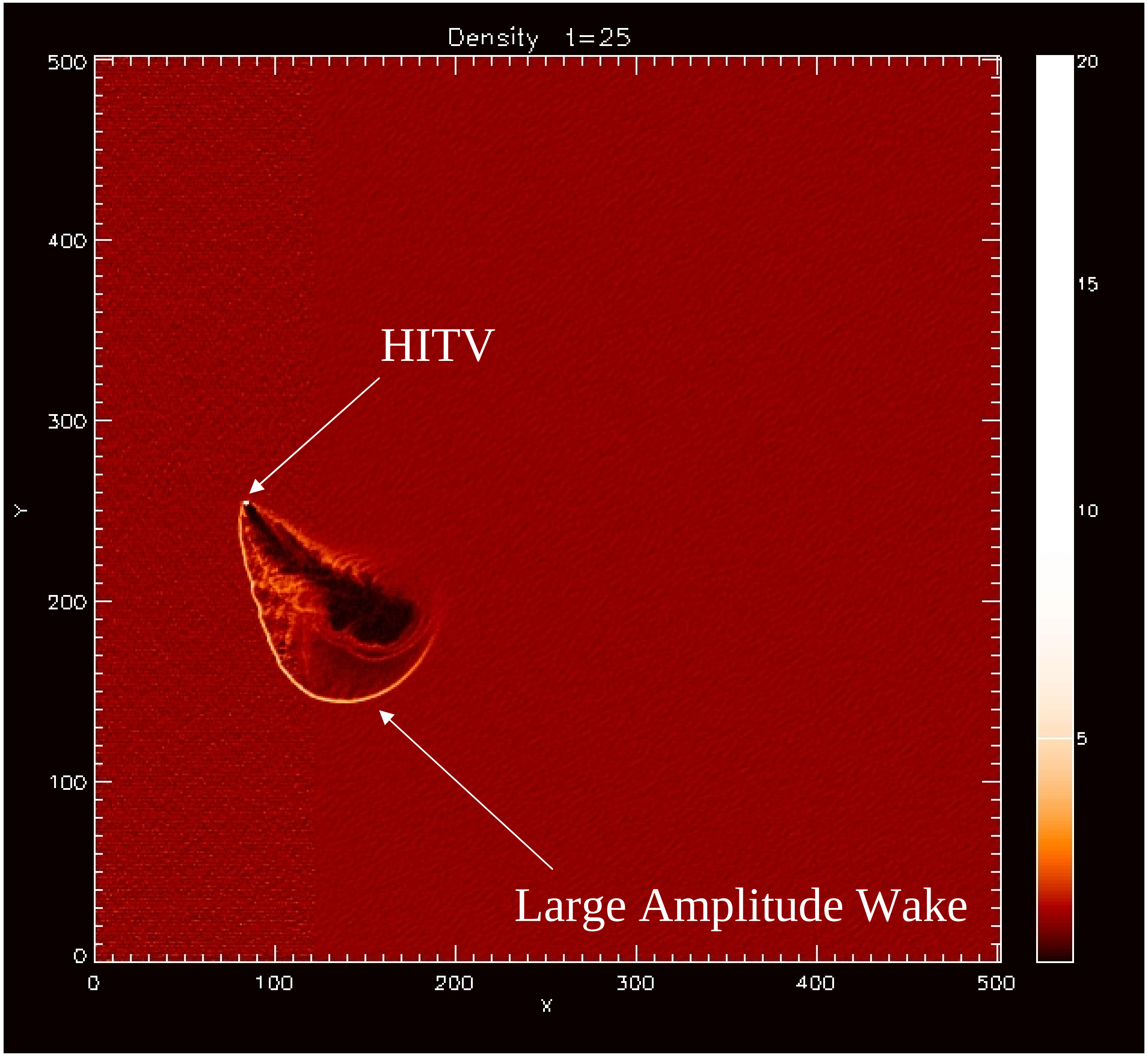


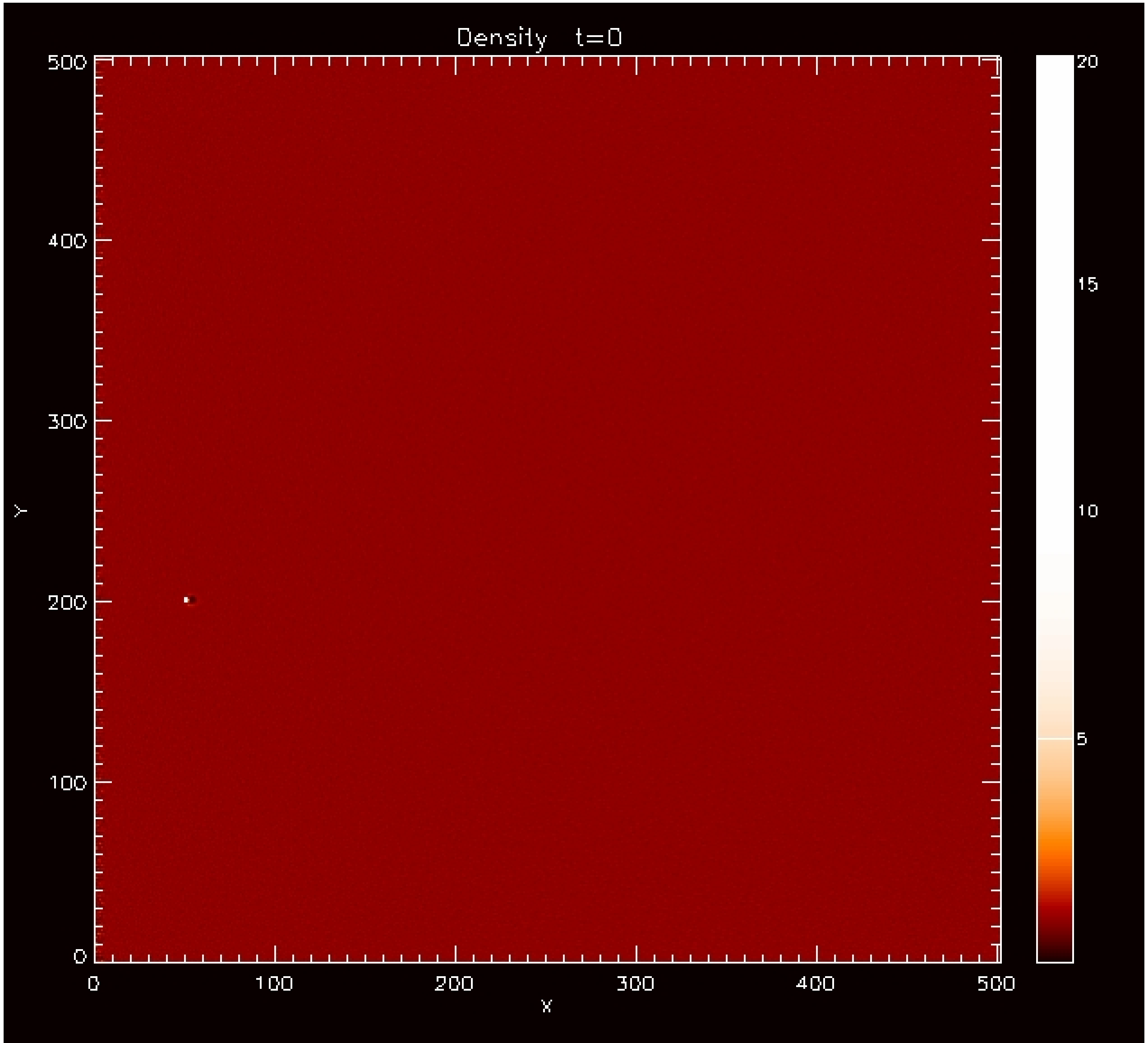
Density t=0
Y
400
300
200
100
0
0
100
200
300
400
500
600
X
7
6
5
4
3
2
1

Variation of Maximum V_X with IMF Direction

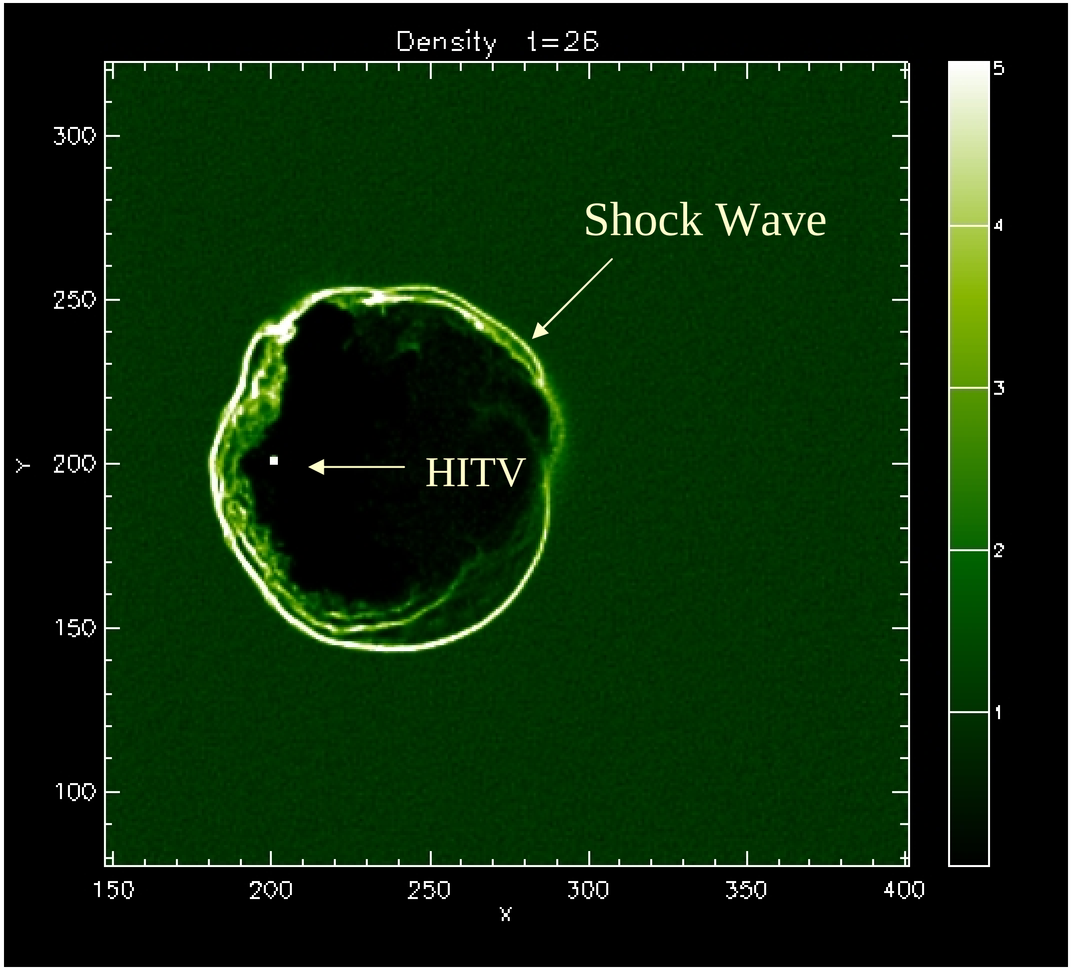


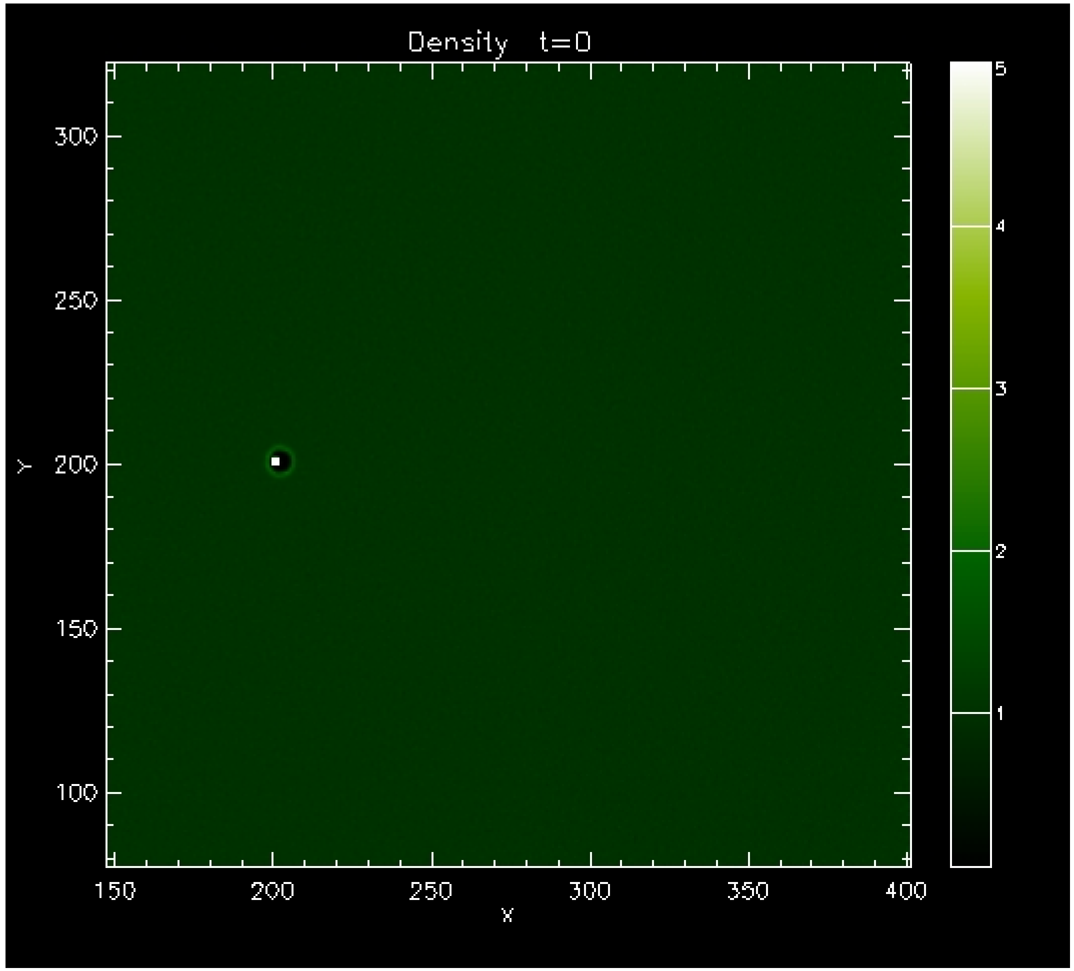
$$\frac{N}{N_{sw}} = 100$$




Density t=0
500
400
300
200
100
0
Y
0
100
200
300
400
500
X
20
15
10
5

$$\frac{N}{N_{sw}} = 500$$




Density t=0
300
250
200
150
100
Y
150
200
250
300
350
400
X
5
4
3
2
1

Acceleration Time Scales

$$\tau_a \equiv \frac{\tau_g}{2} \propto \frac{m}{q} = \frac{m_c + 4\pi R^2 \Delta r\, \rho_m}{4\pi R^2 \Delta r\, \rho_c}$$

m_c = mass of cargo spacecraft

R = radius of HITV

$\rho_m = 600$ kg/m^3

$\Delta r = 10$ microns

$\rho_c = 10^5$ C/m^3 Deep Dielectric Charging

Specific Impulse

$$m_f = m_i \exp\left(-\frac{\Delta V}{g I_{sp}}\right)$$

or

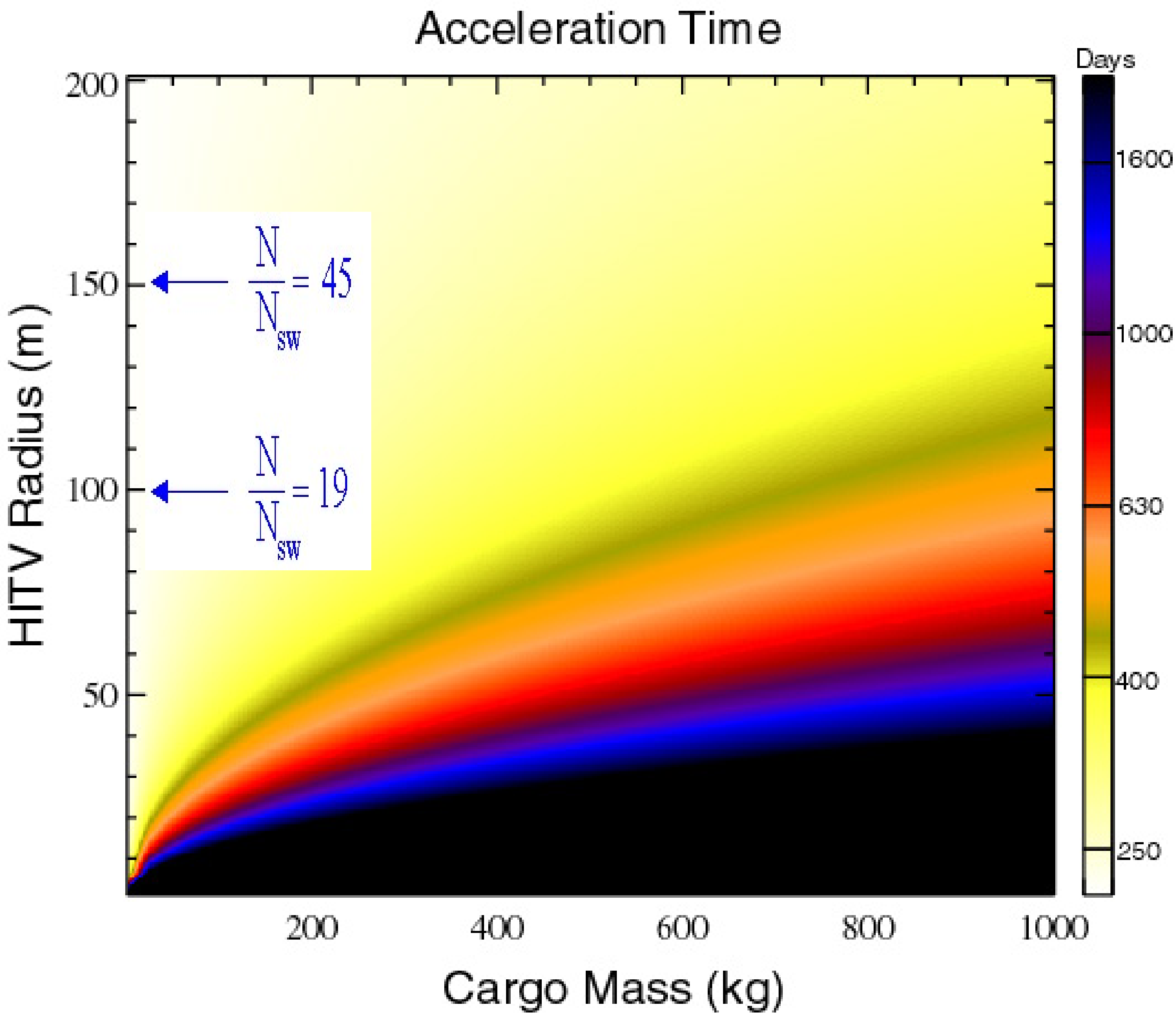
$$I_{sp} = \frac{\Delta V}{g} \left[\mathrm{Ln}(m_i / m_f) \right]^{-1}$$

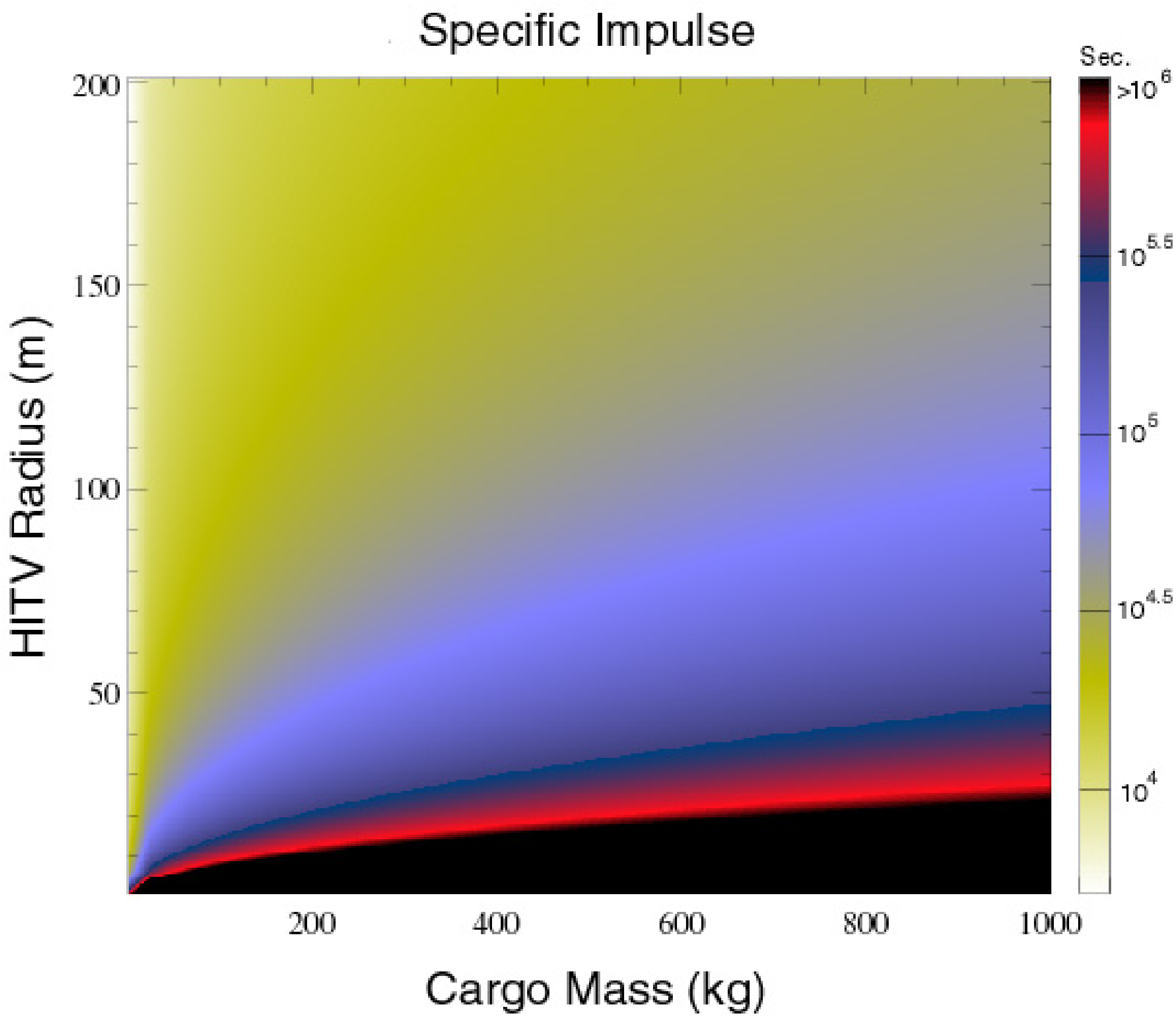
$m_f = m_c$

$g = 9.81$ m/s^2

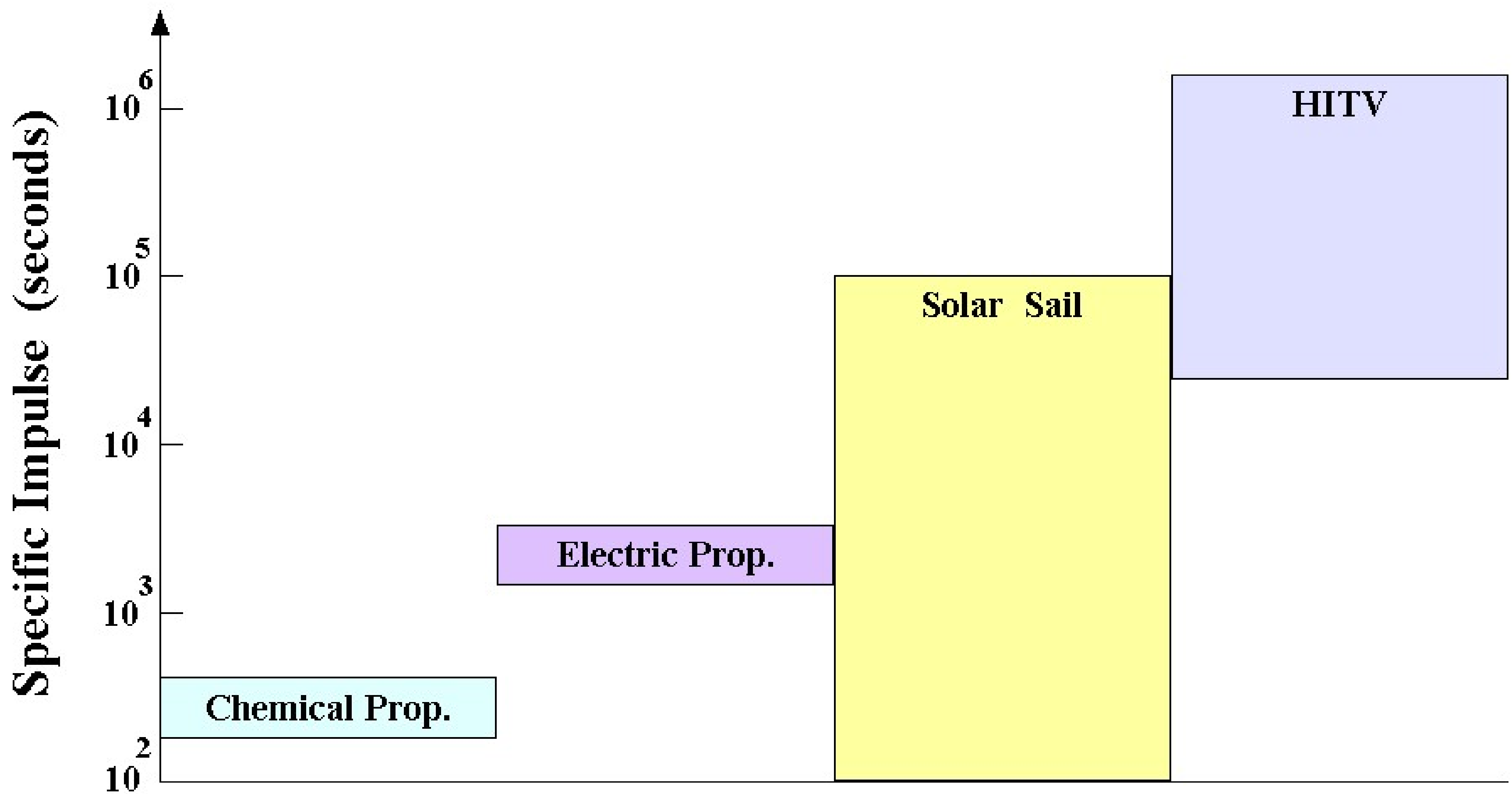
$m_i = m_c + 4\pi R^2 \Delta r\, \rho_m$

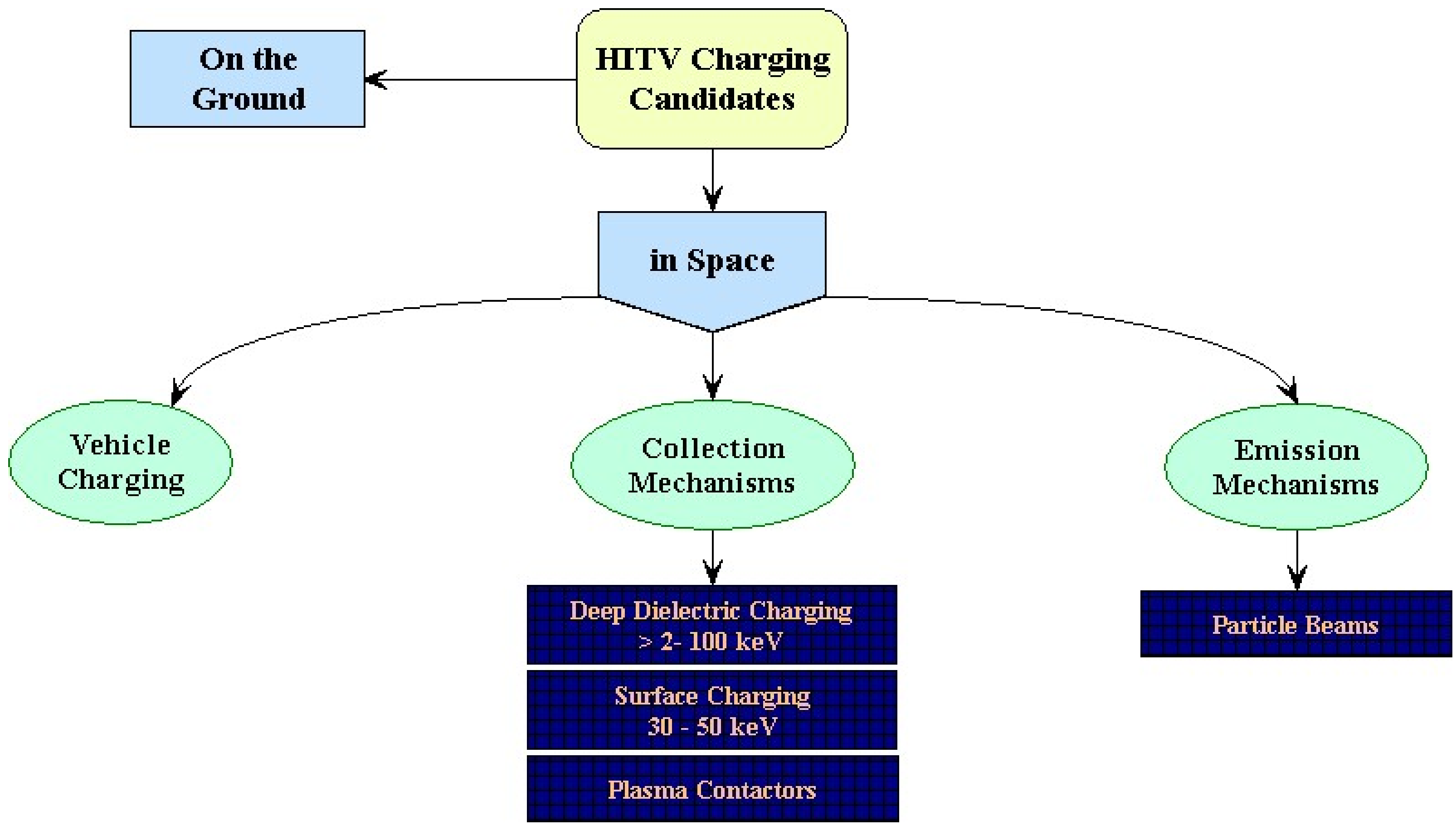
$\Delta V \approx V_{sw} \approx 400$ km/s


Acceleration Time
HITV Radius (m)
200
150
100
50
Cargo Mass (kg)
200
400
600
800
1000
Days
1600
1000
630
400
250
N/N_sw = 45
N/N_sw = 19

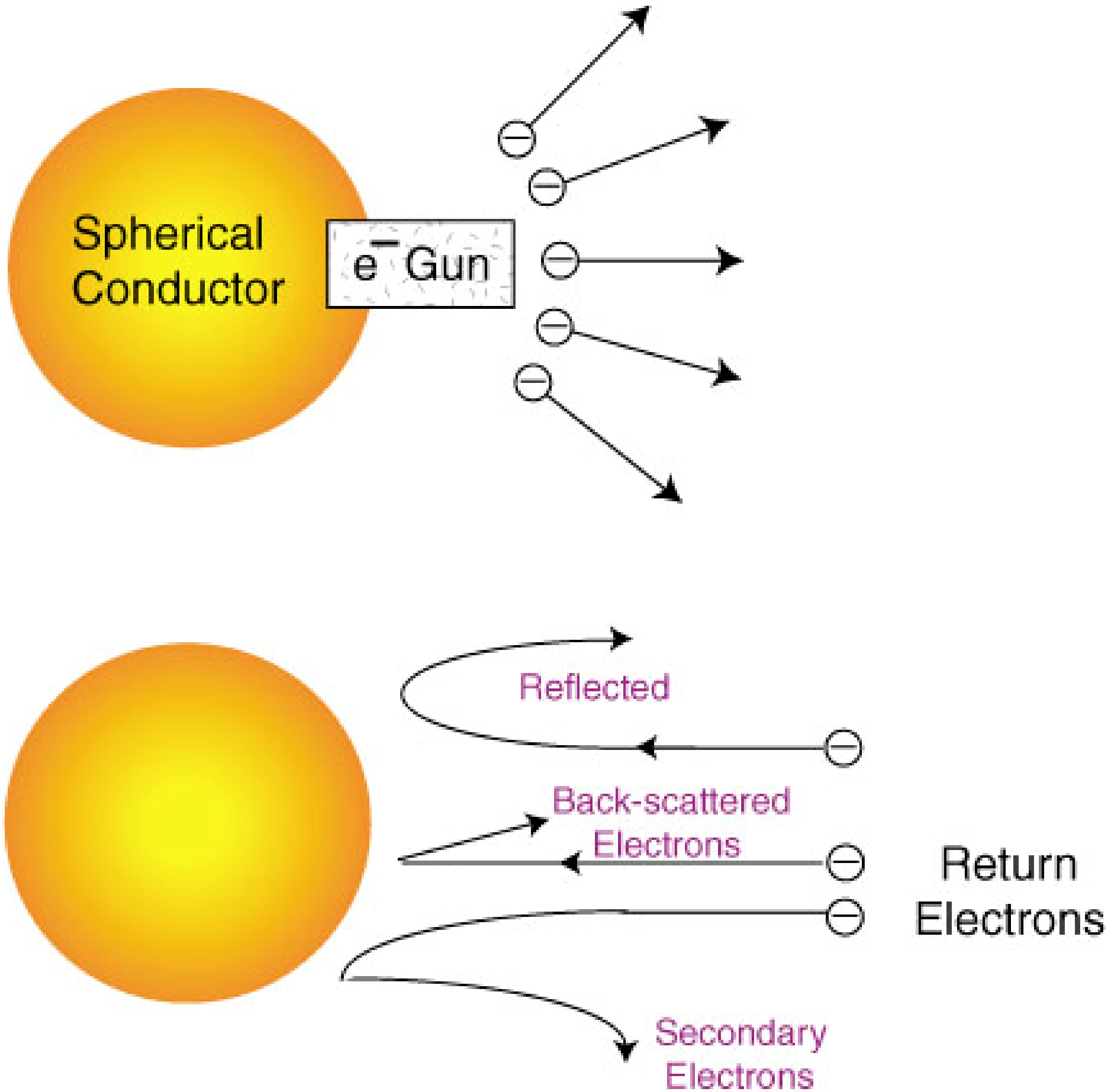


Specific Impulse
HITV Radius (m)
200
150
100
50
200
400
600
800
1000
Cargo Mass (kg)
Sec.
>10^6
10^5.5
10^5
10^4.5
10^4


Specific Impulse (seconds)
10^6
10^5
10^4
10^3
10^2
Chemical Prop.
Electric Prop.
Solar Sail
HITV


HITV Charging Candidates
On the Ground
in Space
Vehicle Charging
Collection Mechanisms
Emission Mechanisms
Deep Dielectric Charging > 2- 100 keV
Surface Charging 30 - 50 keV
Plasma Contactors
Particle Beams

Electrostatic Simulation Model



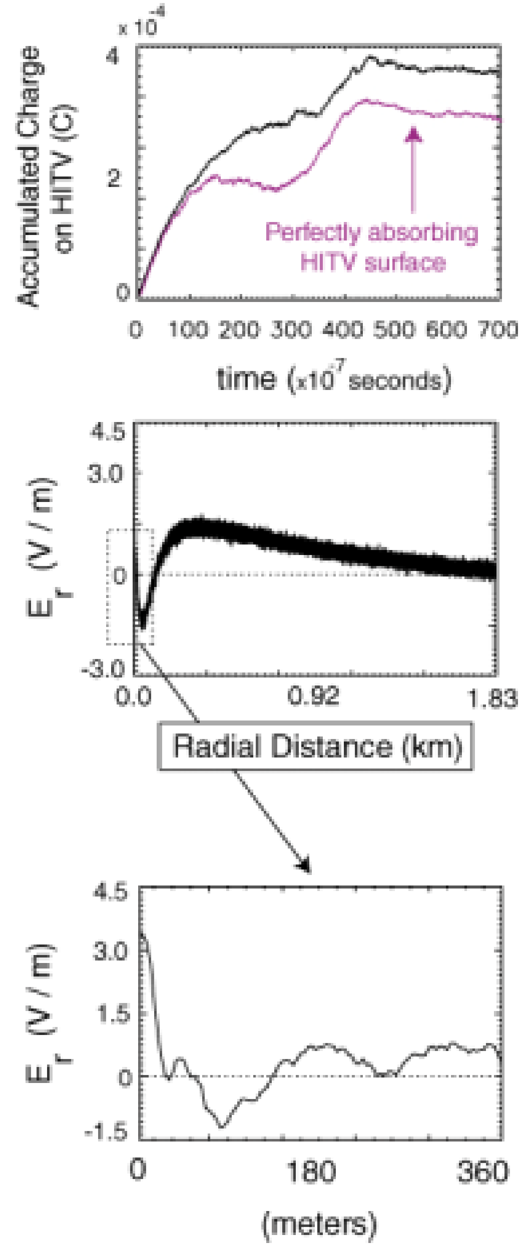
Electron Gun Simulation
Case I

$N_{beam} = 0.1\ N_o$

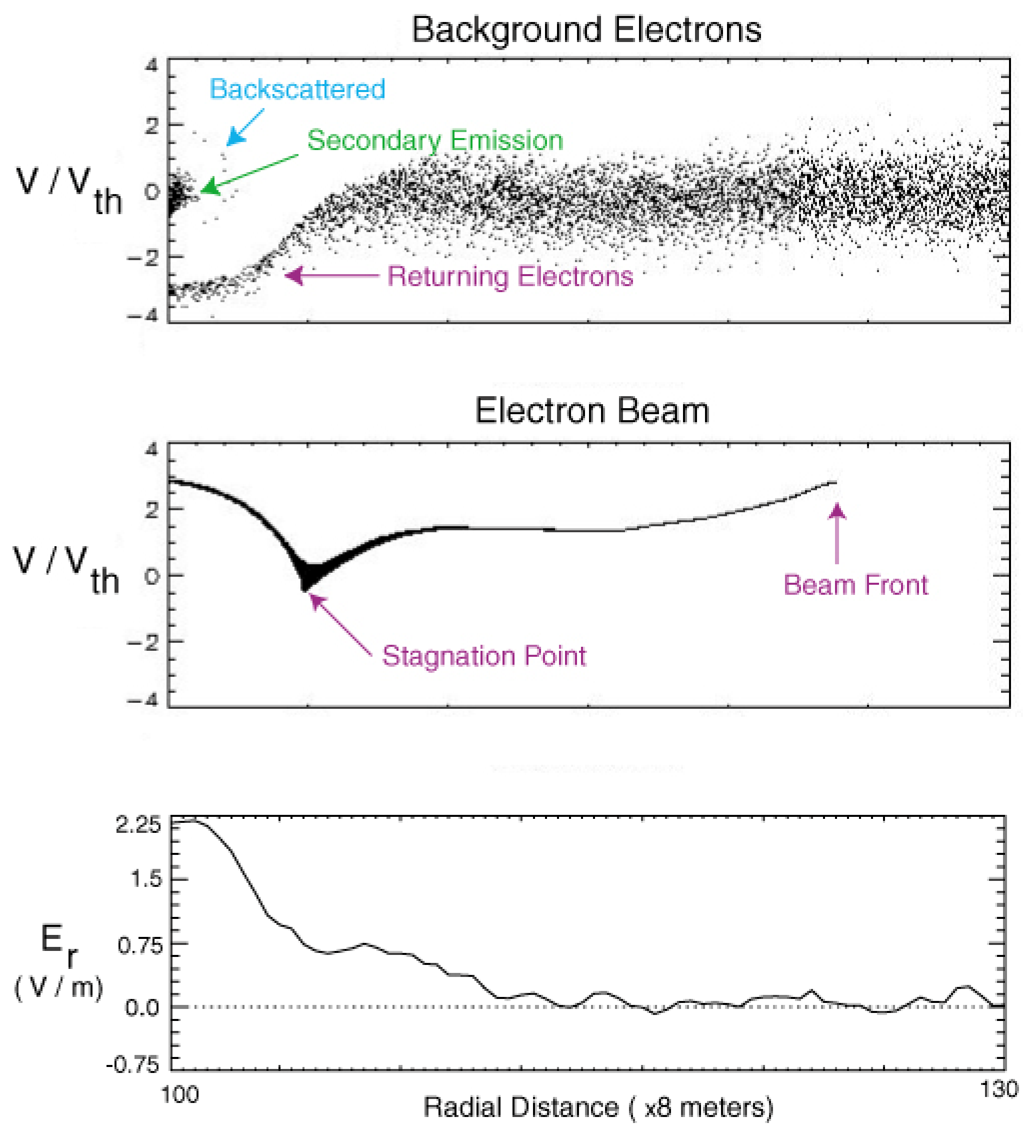
$E_{beam} = 100$ eV

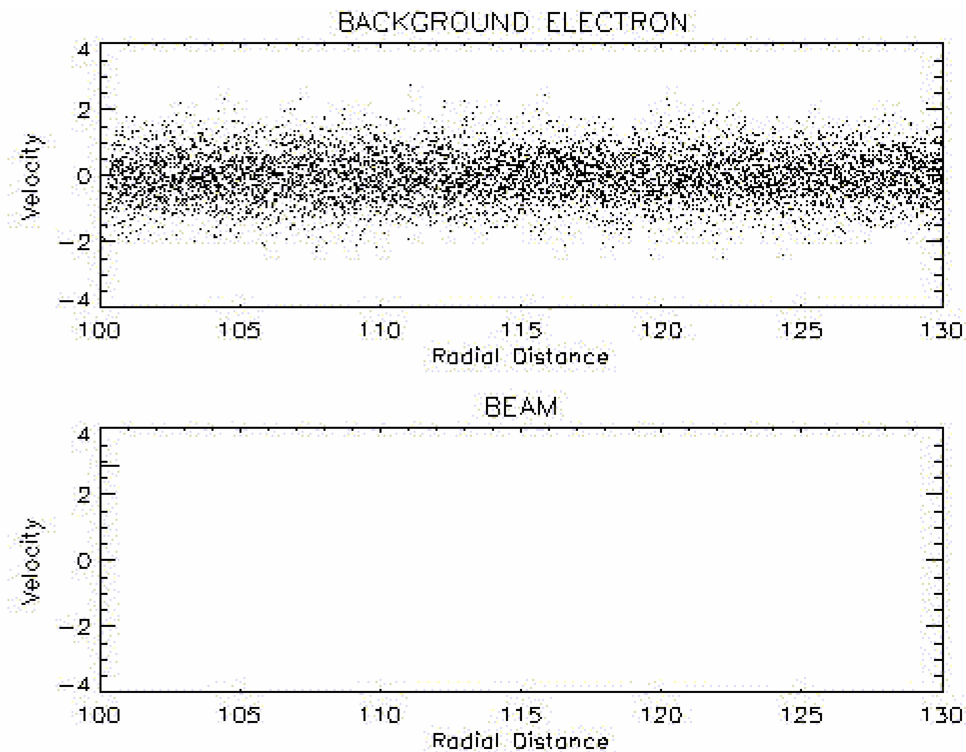
All return electrons are captured by HITV

Power = 1 kW



Accumulated Charge on HITV (C)
x 10^-4
4
2
0
Perfectly absorbing HITV surface
0 100 200 300 400 500 600 700
time (x10^-7 seconds)
E_r (V / m)
4.5
3.0
0
-3.0
0.0
0.92
1.83
Radial Distance (km)
E_r (V / m)
4.5
3.0
1.5
0
-1.5
0
180
360
(meters)


Background Electrons
Backscattered
Secondary Emission
Returning Electrons
V / Vth
Electron Beam
Beam Front
Stagnation Point
V / Vth
Er
(V / m)
2.25
1.5
0.75
0.0
-0.75
100
130
Radial Distance (x8 meters)



BACKGROUND ELECTRON
Velocity
4
2
0
−2
−4
100
105
110
115
120
125
130
Radial Distance
BEAM
Velocity
4
2
0
−2
−4
100
105
110
115
120
125
130
Radial Distance

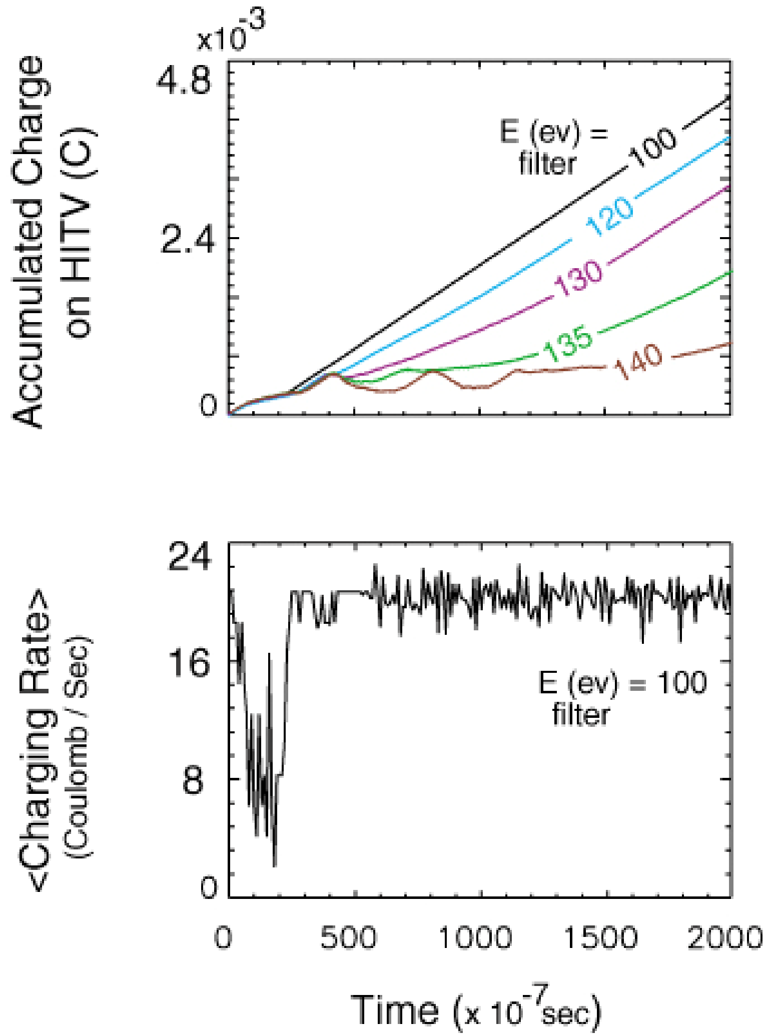
Electron Gun Simulation
Case II

$N_{beam} = 0.1\ N_o$

$E_{beam} = 100$ eV

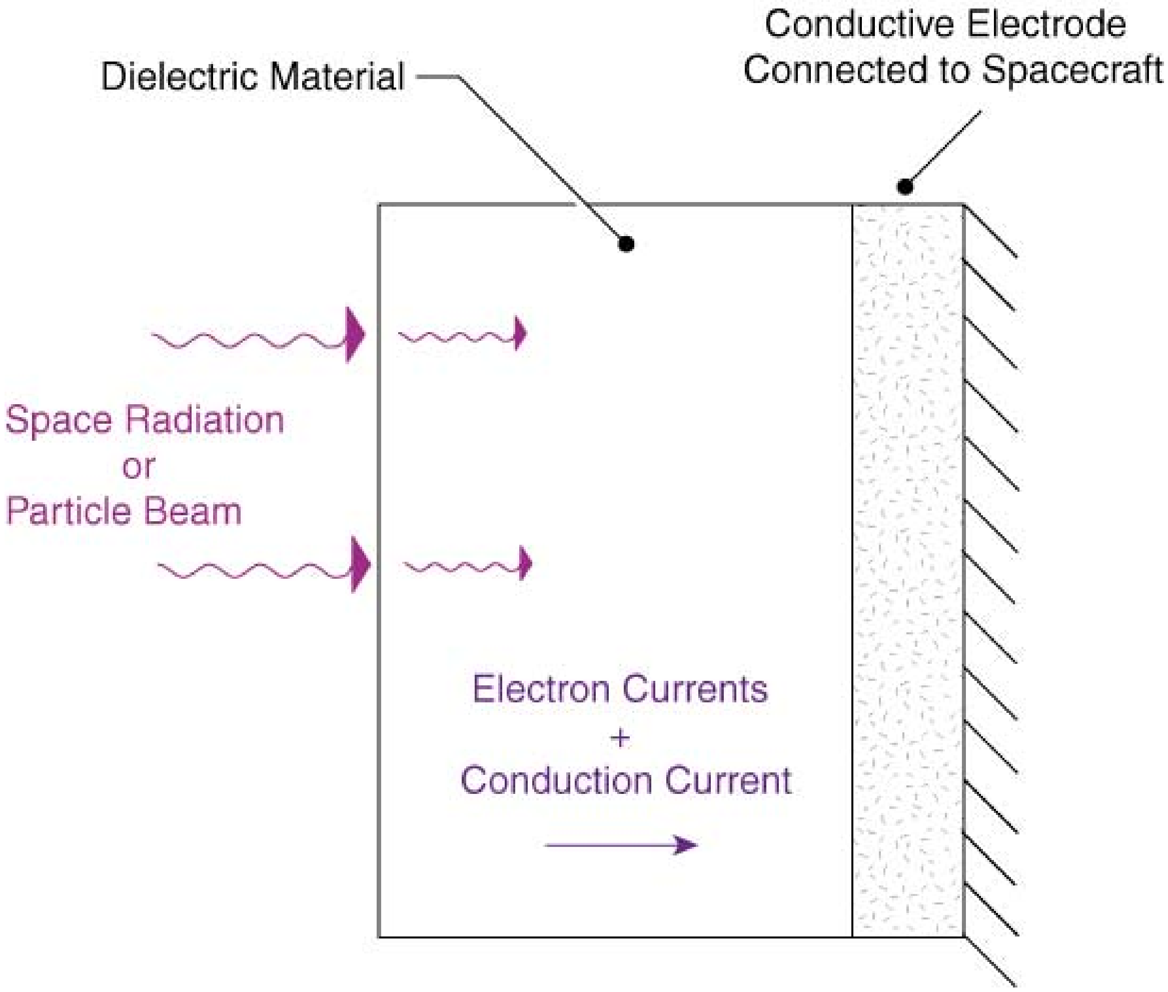
Energy Filter on Return
Electrons

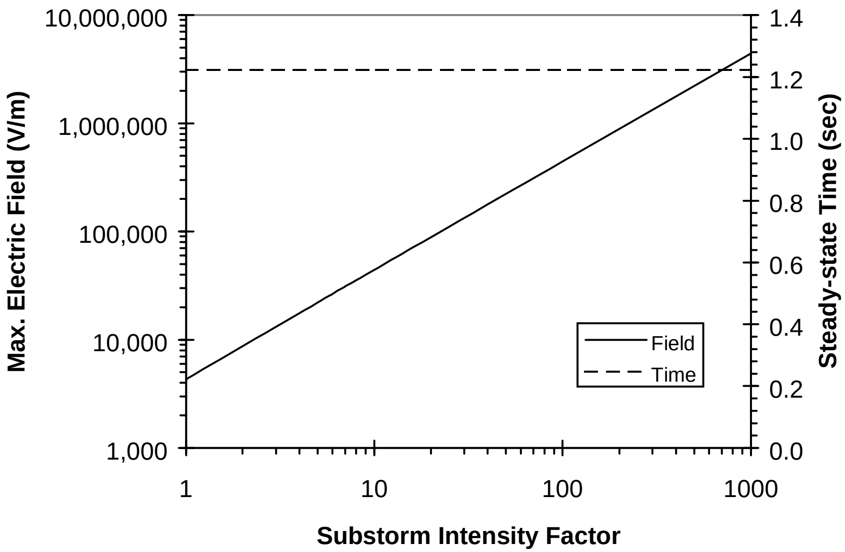
Power = 1 kW

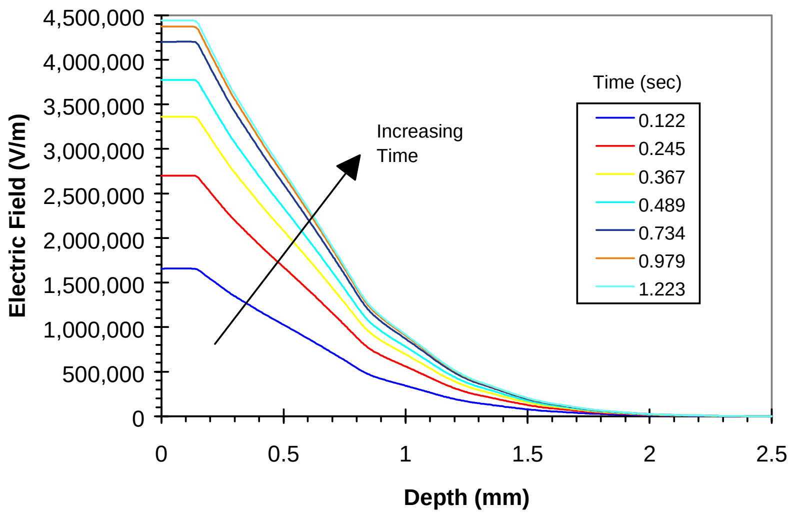


Required Charging time is under 5 minutes

Deep Dielectric Charging



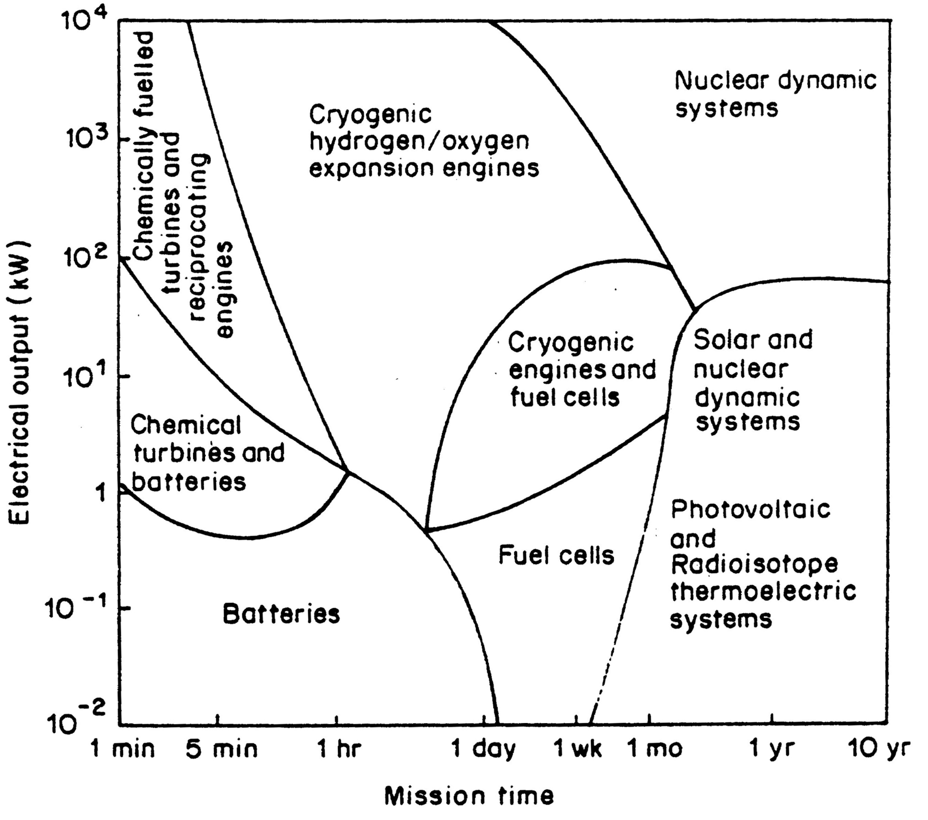




Electric field with a substorm intensity of 1000

From Czepiela, S. A., M.S. Thesis, MIT, 1997

Energy Source and Appropriate Operational Scenario

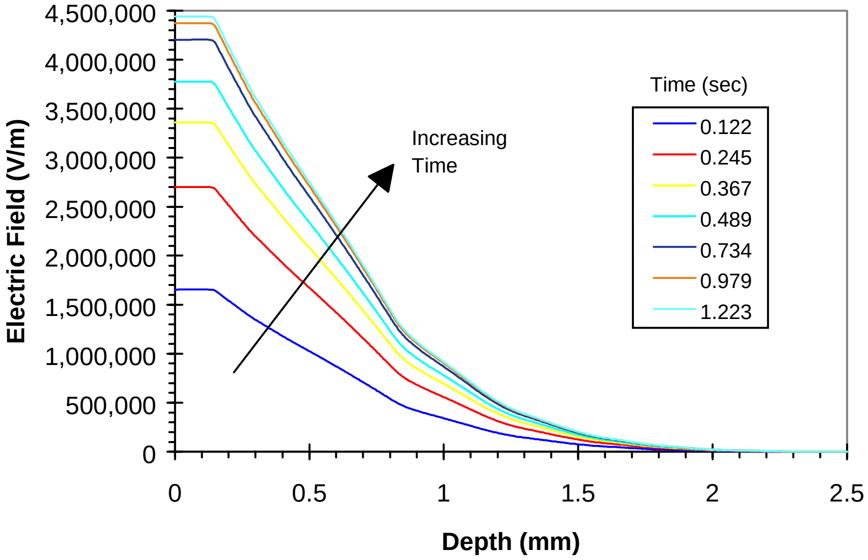


Source: Angrist, S. W., 1982 Direct Energy Conversion, 4th edn., Allyn and Bacon, NY

Summary

Acceleration	EM hybrid simulations show that macroscopic objects can be acclelrated by the solar wind. Largest specific impulse.
Charging	Active charging required. Two candidate mechanisms have been identified.
Power	Estimated 1 KW of power is required for charging using electron guns.
Materials	Depending on charging mechanism conductors or dielectric material (e.g. mylar, composite material) may be used. Tailorable composite materials hold considerable promise for future.
Trajectory	Non-Keplerian orbits can be acheived. Development of trajectory codes which include EM forces and solar wind model is required.

The End



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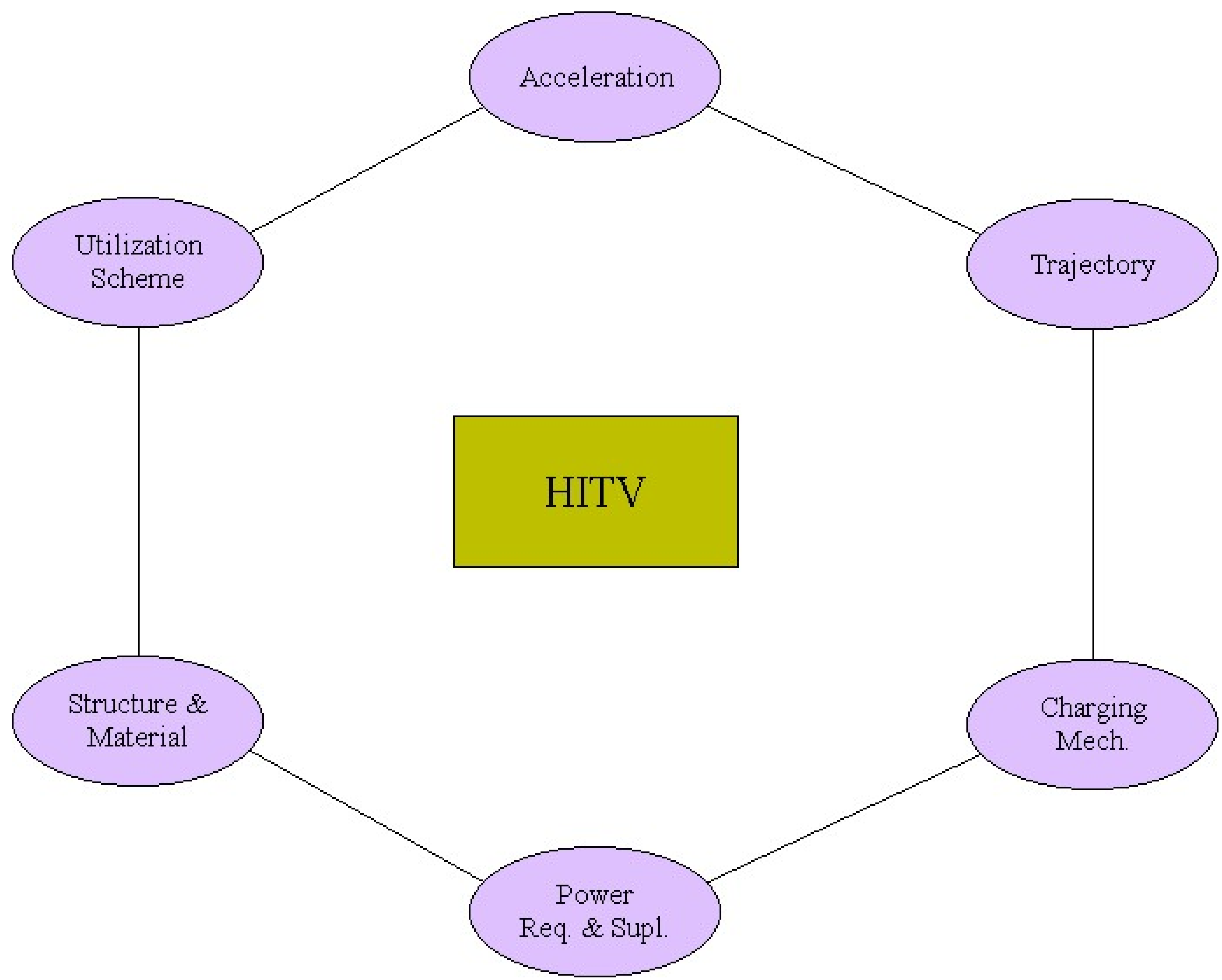
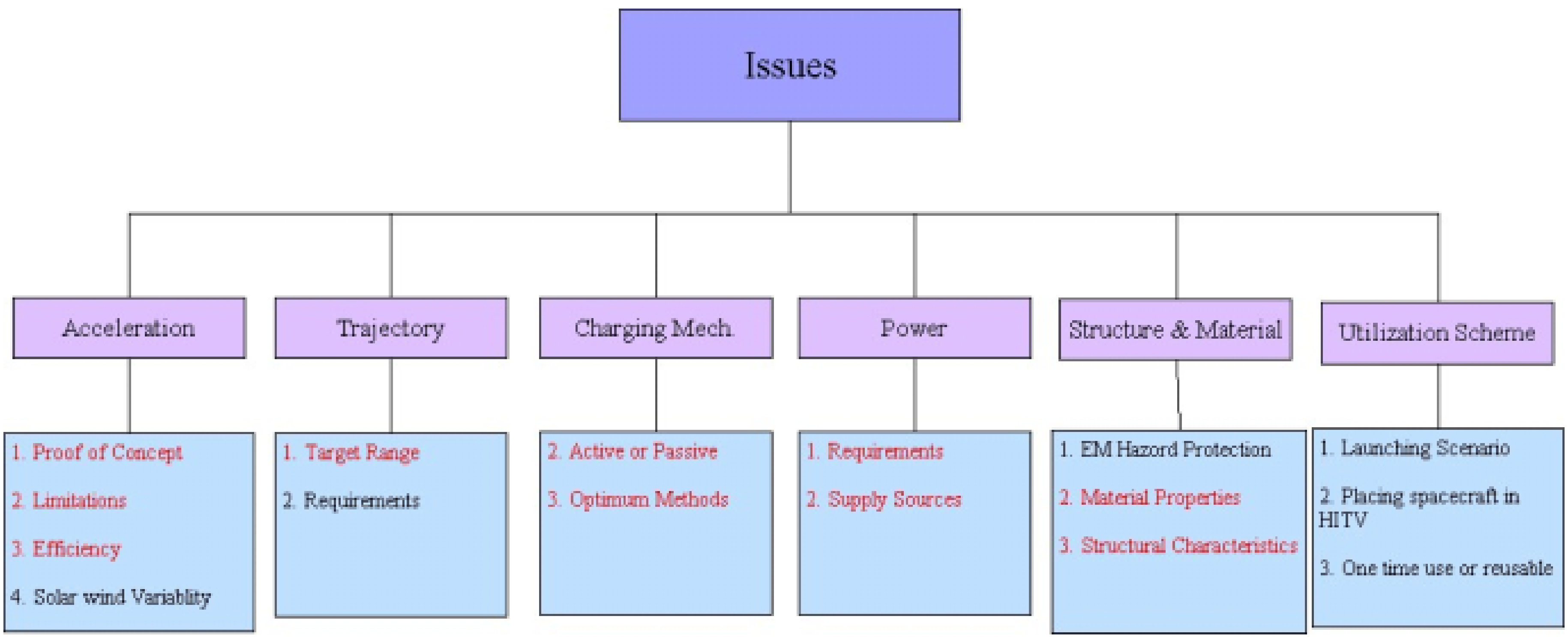

Acceleration
Utilization Scheme
Trajectory
HITV
Structure & Material
Charging Mech.
Power Req. & Supl.


Issues
Acceleration
1. Proof of Concept
2. Limitations
3. Efficiency
4. Solar wind Variablity
Trajectory
1. Target Range
2. Requirements
Charging Mech
2. Active or Passive
3. Optimum Methods
Power
1. Requirements
2. Supply Sources
Structure & Material
1. EM Hazord Protection
2. Material Properties
3. Structural Characteristics
Utilization Scheme
1. Launching Scenario
2. Placing spacecraft in HITV
3. One time use or reusable

Acceleration

	Proof of Concept	Limitations	Efficiency	Solar wind Variablity
Questions	1. Can a large object (L ~ m-km, M~1000kg) be accelerated by S.W. ? 2. What are the nonlinear interactions and conseq.?	What are the limitations due to : 1. Non-linear effects? 2. IMF Directions? 3. Q/M restrictions?	1. What speeds are acheivable? 2. What is the efficiency defined as Vmax/Vsw?	1. What are the effects of gradual or sharp (due to interplanetary discont.) changes in solar wind density, flow speed and IMF?
Methods	1. Hybrid Simulations	1. Hybrid Simulations 2. Analytic Modeling	1. Hybrid Simulations	1. Hybrid Simulations

Trajectory

	Target Range	Charging Requirements
Questions	1. What is the range of possible trajectories based on single particle theory? 2. How do nonlinear effects modify the trajectory? 3. What are the effects of solar wind variability?	What are the requirements on charging/discharging levels and time scales for : 1. Initial acceleration phase? 2. Orbit correction and cargo release phases? 3. A round trip?
Methods	1. Hybrid Simulations 2. Single Particle Calculations 3. Solar wind Modeling 4. EM Celestial Mechanics Code	The same as in "Target Range".

Charging

	Active or Passive Methods	Optimum Methods
Questions	1. What are the possible mechanisms? 2. How effective are they? 3. What are the inherent limitations?	1. Can a single mechanism address all the charging requirements? 2. What is the optimum solution given the constraints associated with trajectory, power, structure and materials?
Methods	1. Full Particle Electrostatic Simulations 2. Charging Code 3. Literature Search	The same as in "Active/Passive Methods".

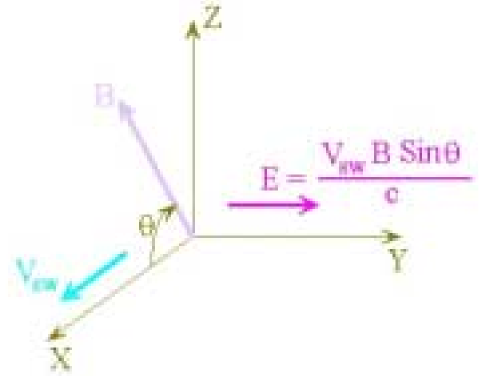
Power

	Requirements	Supply Methods
Questions	1. What is the power requirement for various charging/discharging methods?	1. Can naturally occuring radiation in space provide all or significqant portion of the required power? 2. Can present or near future devices provide the required power? 3. What role can land based power supply play?
Methods	1. Full Particle Electrostatic Simulations 2. Charging Code 3. Literature Search	The same as in "Requirements".

Structure & Material

	EM Hazord Protection	Material Properties	Structural Characteristics
Questions	1.What is the expected plasma & EM field environment around HITV under various conditions? 2. What are the ways in which cargo spacecraft can be protected?	1. What are the desired electromagnetic and mechanical properties of HITV material? 2. What regular or composite materials are likely candidates?	1. What are the constraints imposed by EM hazard protection & charging methods? 2. How do material properties (electric and mass density) of HITV affect its size and general configuration?
Methods	1. Hybrid Simulations 2. Full Particle Simulations 3. EM Theory & Modeling	1. EM Theory and Modeling 2. Literature Search	1.

Charged Particle Pick Up by the Solar Wind



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Motion consists of gyration about B and a drift given by ExB vector.

$$V = V_{sw} \sin\theta \, (2 - 2\cos\Omega t)^{1/2} \qquad \Omega = \frac{qB}{mc}$$