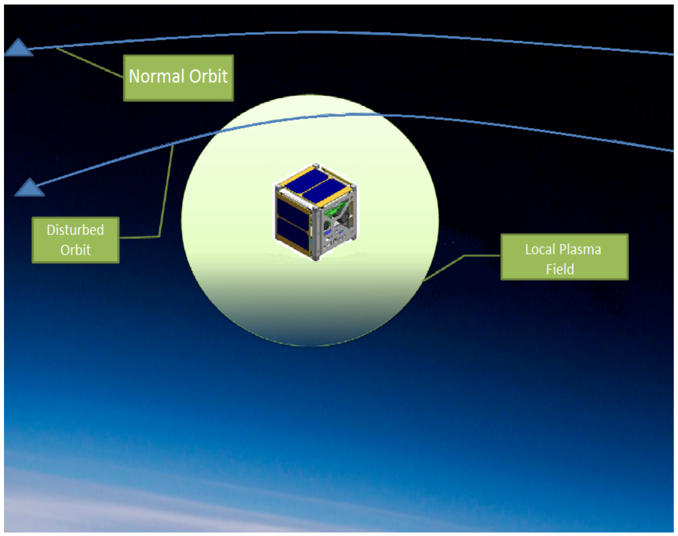
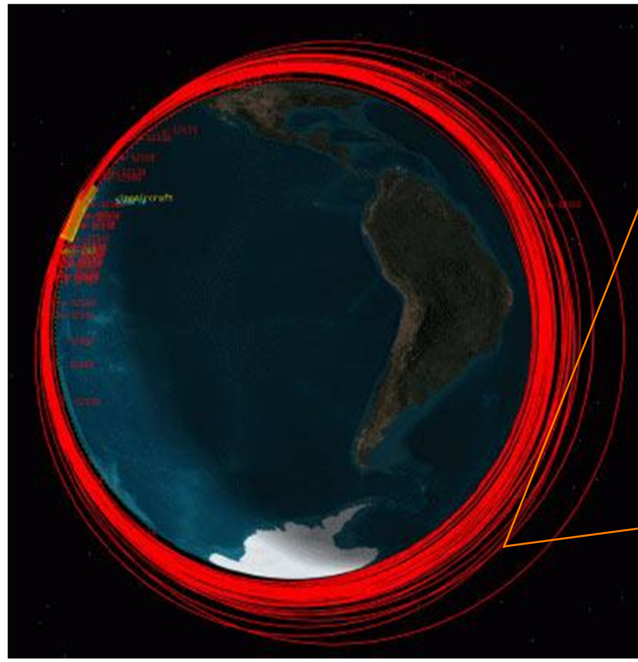
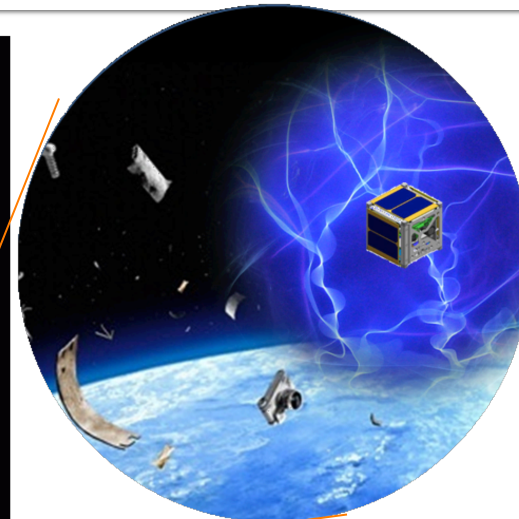
Proposed Solution

- The Idea: Use plasma for debris mitigation
- Why?
  - Plasma is readily available in LEO
- What is plasma ?
  - Plasma : Charged particles
    - Positive ions + negative electrons
- How?
  - Ions have a higher mass→ generates form drag

Proposed Concept





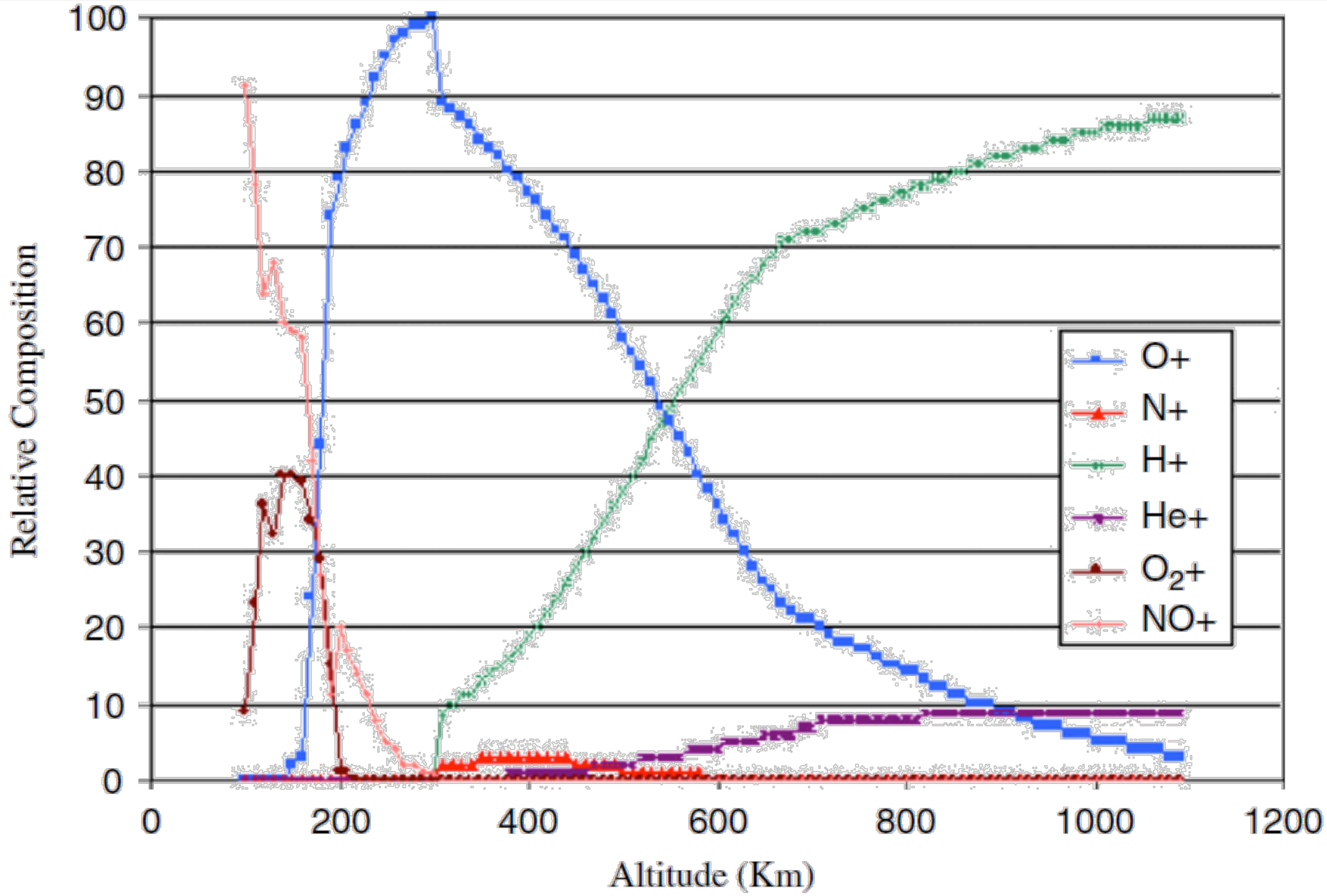


- By applying an electric field, plasma in the LEO environment can be concentrated into a higher density plasma field resulting in increased drag forces felt by traversing debris particles

Preliminary Analysis

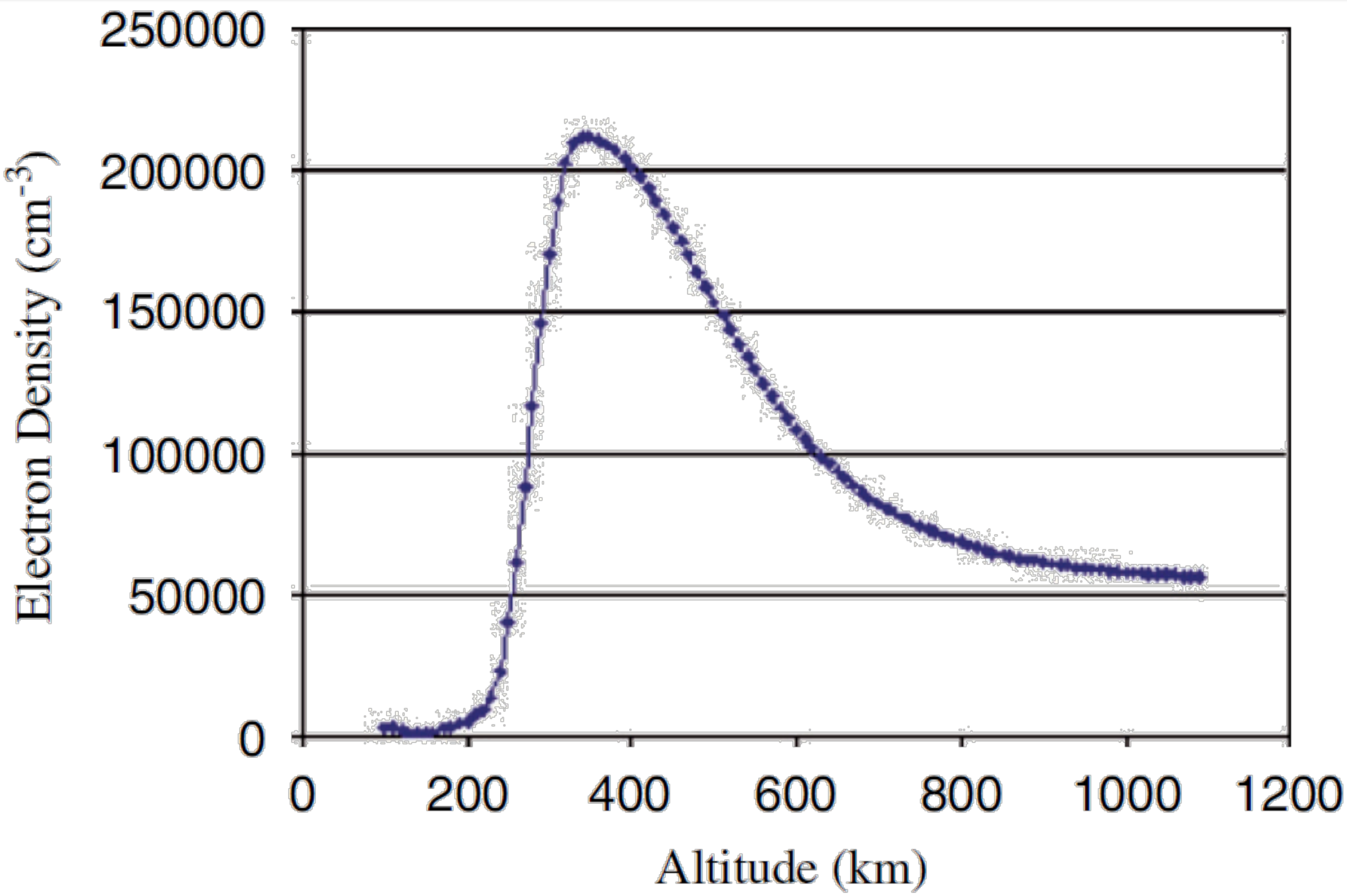
- Model current environment
  - Atmospheric model and plasma density model
- Simulation
  - Simulate plasma drag environment to characterize effectiveness
  - Generate drag model
- Ground testing
  - Verify drag model with experiments

Plasma model: LEO



Relative Composition of the Constituent Ionospheric Gases vs. Altitude[5]

Electron density Model



Electron Density vs. Altitude[5]

Combined Model

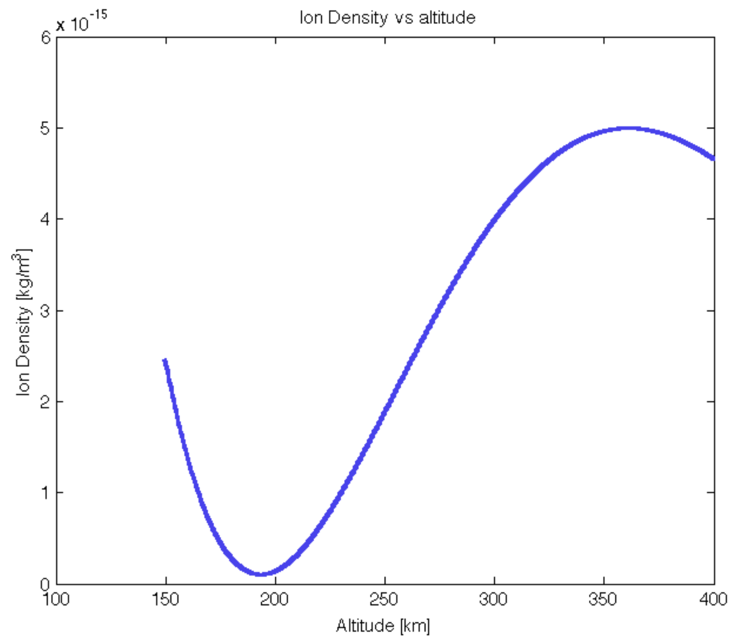
Plasma Density Model, derived from Electron Density curve and Ionospheric Constituent Gases

$$\rho_{ion}(h) = C_1 h^6 + C_2 h^5 + C_3 h^4 + C_4 h^3 + C_5 h^2 + C_6 h + C_7$$

Eq. 1: 6th-order approximation of ion density as a function of altitude

where:

C_1 = -6.978441E -30
C_2 = 2.41493 E -26
C_3 = -3.46545 E-23
C_4 = 2.642054 E-20
C_5 = -1.12625 E-17
C_6 = 2.519352 E-15
C_7 = -2.238598 E-13



Approach : Energy

$$E = \frac{1}{2} m \cdot v^2 - \frac{\mu m}{R} \quad (1)$$

Energy Equation: Mechanical Energy of an orbiting object

$$\Delta\varepsilon = -2\pi \cdot R \cdot \frac{F_D}{m} \quad (2)$$

Change In Specific Mechanical Energy due to drag forces

$$F_D(R) = \frac{1}{2} \rho_{air}(R) \cdot v(R)^2 \cdot C_D \cdot A \quad (3)$$

Drag Equation as a function of Radius of the orbit from the center of the earth

Approach : Energy (contd.)

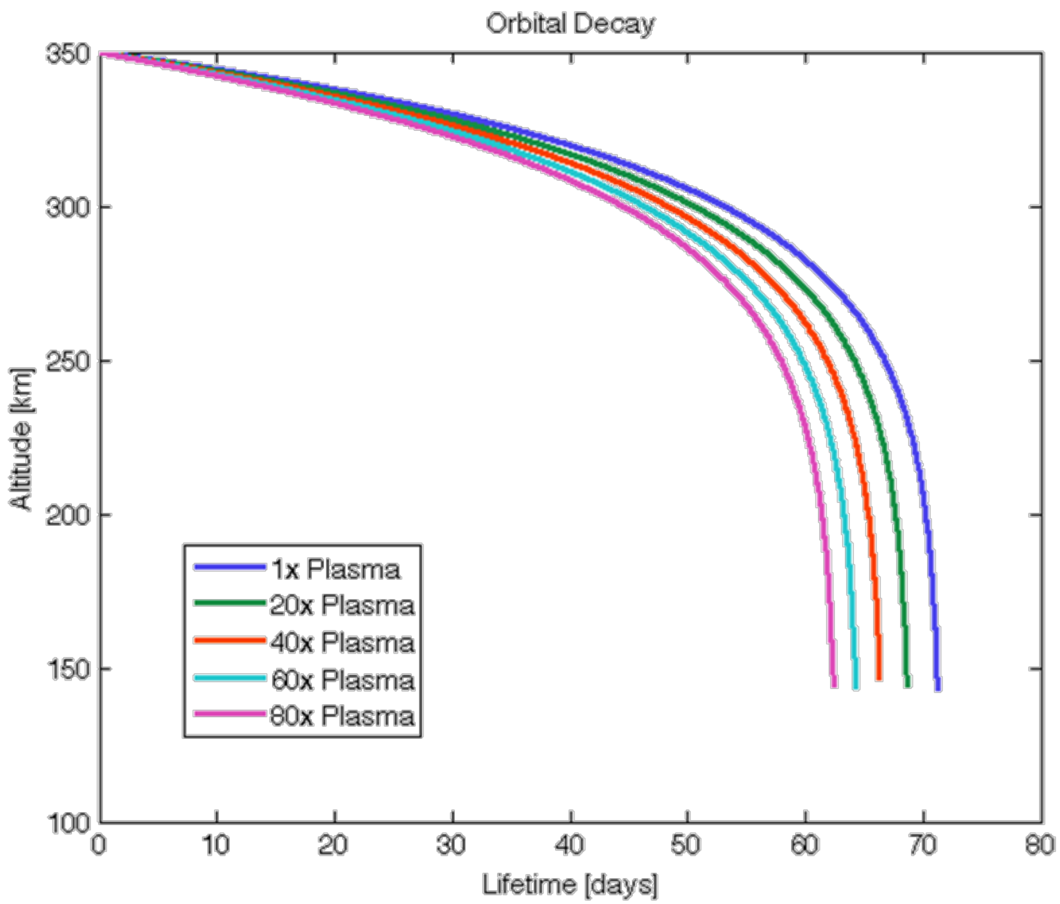
- “Finite Difference” numerical approach of subsequent orbits
- The code takes in several inputs of mass, starting radius, plasma density at starting orbit, drag co-efficient
- Three energy components of debris: kinetic, potential and energy loss due to drag

Assumptions

- Circular orbit below 350 km altitude
- Atmosphere at LEO altitudes behaves as a fluid
- Atmosphere rotates with the earth at a particular angular velocity

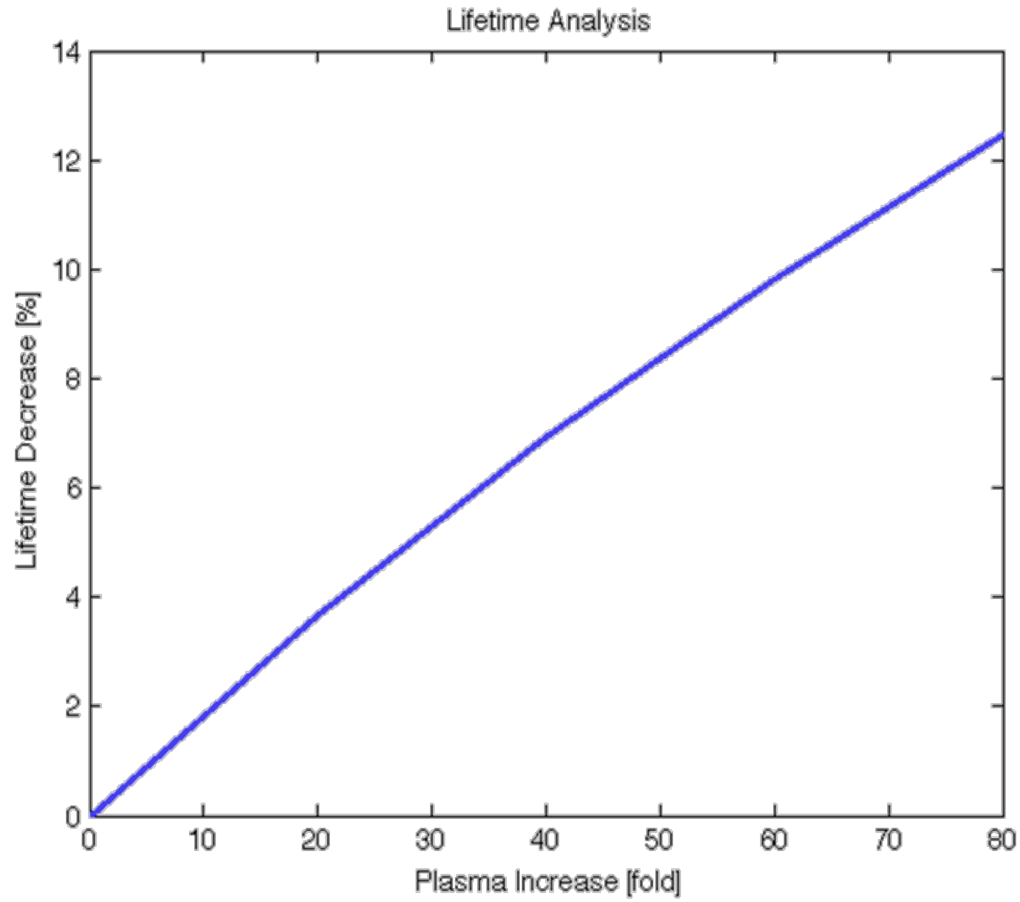
$$\omega_a(R) = \omega_{Earth} \cdot \frac{R_{Earth}}{R} \quad (4)$$

Results



Altitude(km) vs. Lifetime(days) 1-80 x concentration of plasma

Results



Lifetime Decrease vs. Plasma Increase (up to 80x)

Discussion

- Decrease in orbital lifetime is proportional to the amount of plasma increase
- Assuming a roughly linear relationship, the slope of the curve is 0.16 % decrease in lifetime per fold increase in plasma.
  - An 80-fold increase in plasma density →12% reduction in orbital lifetimes

Discussion (Contd.)

- From this data
  - An experiment will be designed to determine whether such densities are achievable in orbit
  - Amount of plasma in orbit is limited→ An upper limit to the amount of orbital decay exists
  - This will be determined by the limitations of the experimental payload

Conclusion

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- Preliminary analysis Results
  - Concept has merit
- Orbital lifetime is lowered by increasing the local density of plasma
  - Drag forces experienced by space debris can be increased
  - An energy approach taken and applied to a “finite difference” numerical method

Future Work

- To expand the simulation
- Fabrication of a test platform
  - Verification of simulation results
- Once verified, the experiment can be redesigned to be implemented onto a future small satellite mission
  - In orbit testing
  - Self Data Acquisition

References

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Questions?