U.S. NAVAL RESEARCH LABORATORY

Exploiting Plasma Properties to Detect Small (Sub 10 cm) Orbital Debris

Bill Amatucci

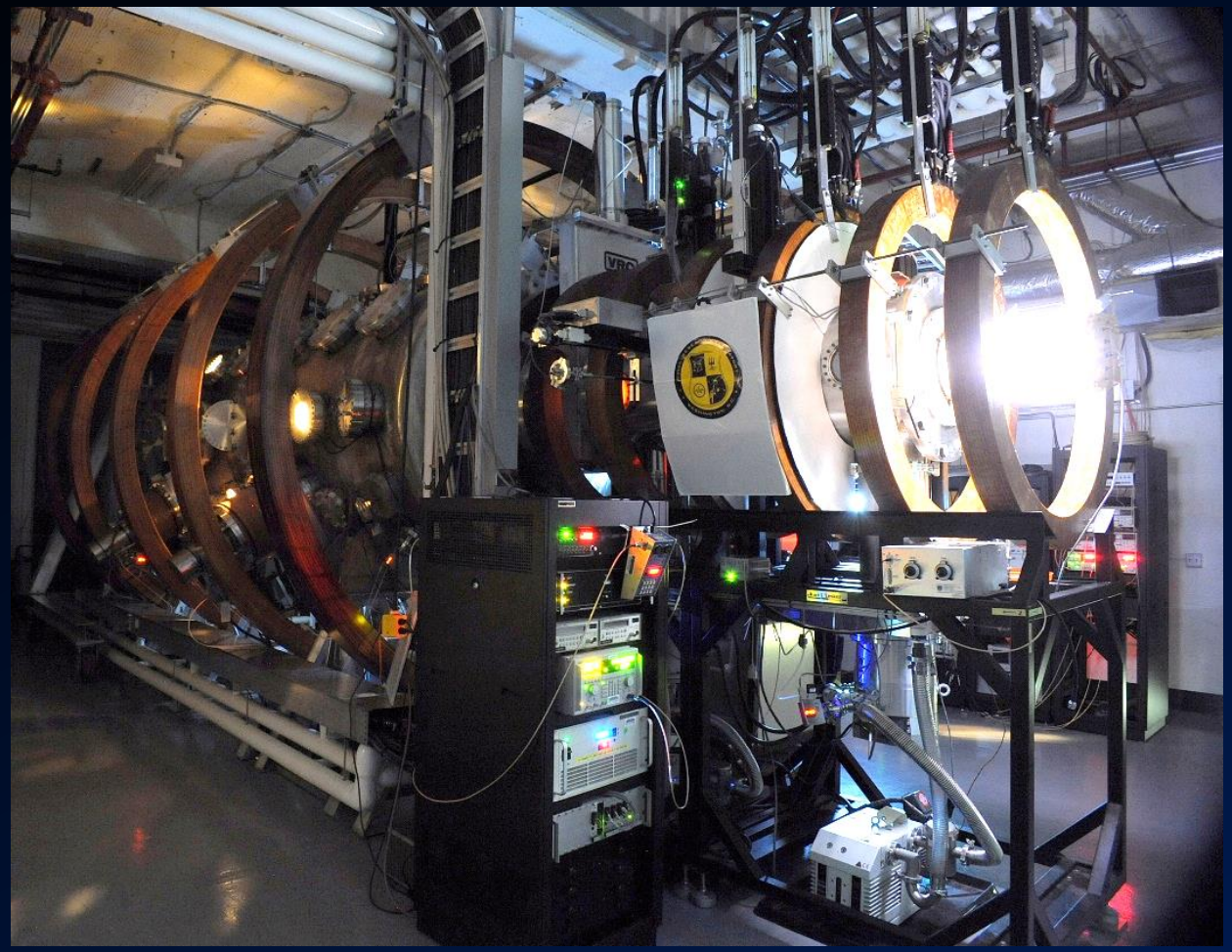
Plasma Physics Division, Naval Research Laboratory, Washington DC

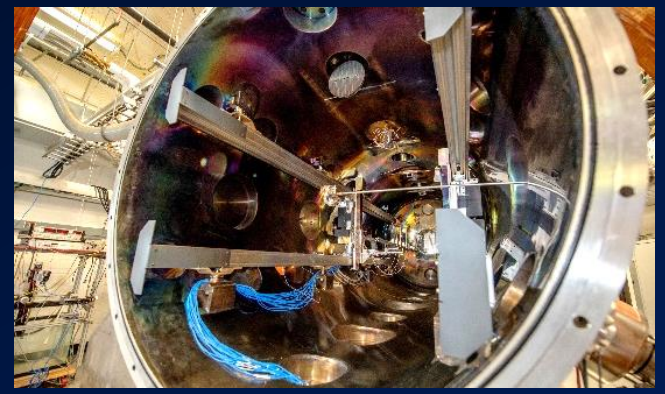
IARPA SINTRA Proposer's Day, Arlington, VA

August 10, 2022

U.S. NAVAL RESEARCH LABORATORY

Laboratory Investigation of Precursor Solitons: NRL Space Physics Simulation Chamber



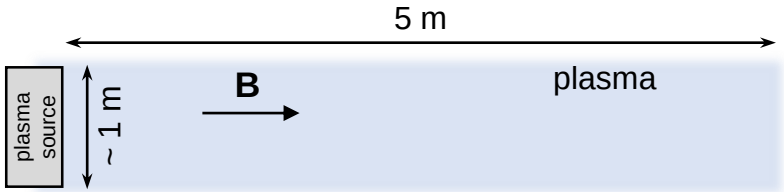


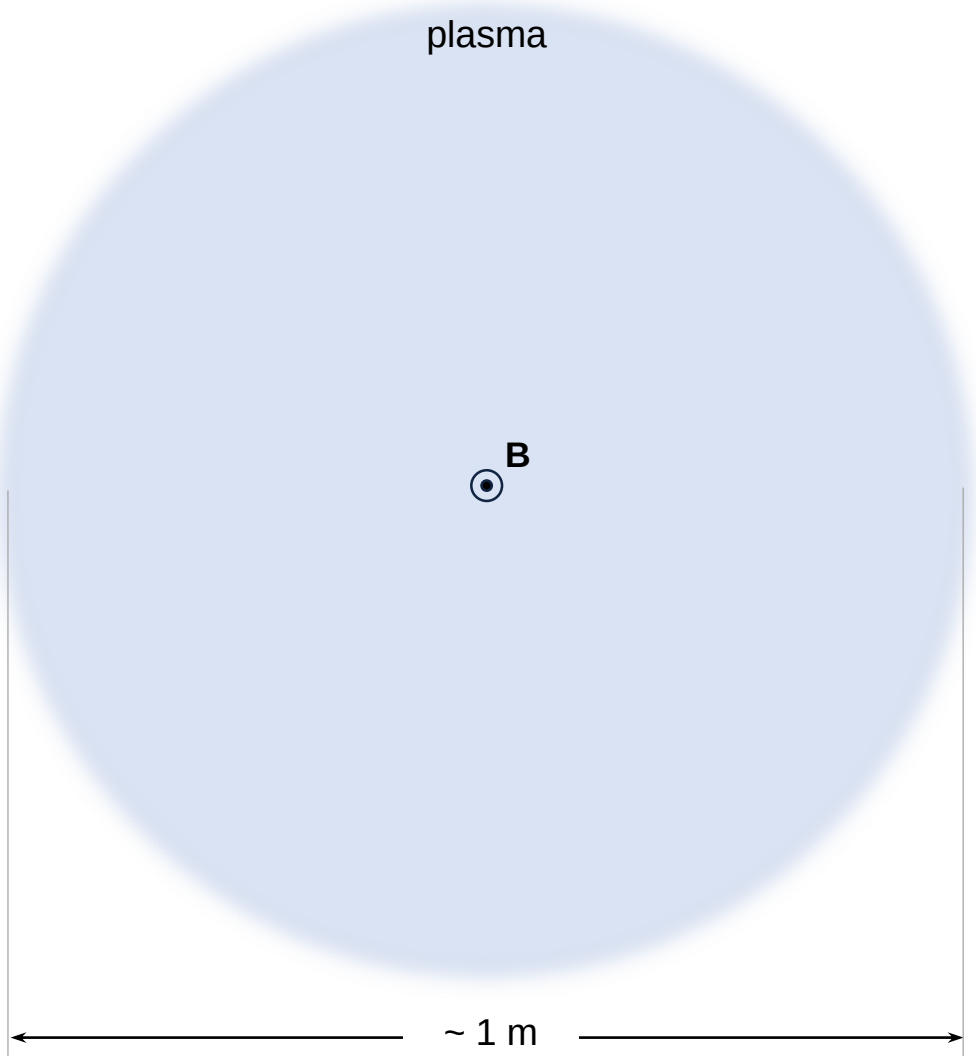
NRL Space Physics Simulation Chamber (SPSC). Scaled near-Earth space-like plasmas are created in the SPSC's 5-m long by 1.8-m diameter main chamber and 2-m long by 0.55-m diameter source chamber. Independently controllable electromagnets allow for control of the shape of the axial magnetic field.

Space Plasma - Space Chamber Parameter Comparison

parameter	ionosphere	RB (L = 2)	NRL SPSC
plasma density (cm^{-3})	10^3 – 10^6	~10^3	10^4 – 10^{12}
electron temp. (eV)	~0.3	~1	0.1 – 4
ion temp. (eV)	~0.3	0.3	0.05
magnetic field strength (G)	~0.3	~0.04	up to 750 G (SC) & 250 G (MC)
plasma frequency (Hz)	10^5 - 10^7	5×10^5	10^6 – 10^{10}
ion gyrofrequency (Hz)	~30 (O^+)	~60 (H^+)	~10^3- 10^5 (Ar^+)
electron gyrofrequency (Hz)	~10^6	~10^5	10^6 – 10^9
ω_{pe}/Ω_e	0.1 – 10	~5	0.01 - 50
ω/ν_{en}	> 1	>> 1	~5 - 600
β	10^{-7} – 10^{-4}	10^{-5}	10^{-7} – 10^{-3}

Laboratory Investigation of Precursor Solitons: Basic Plasma Column Configuration

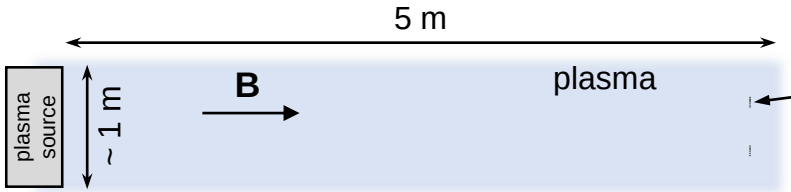


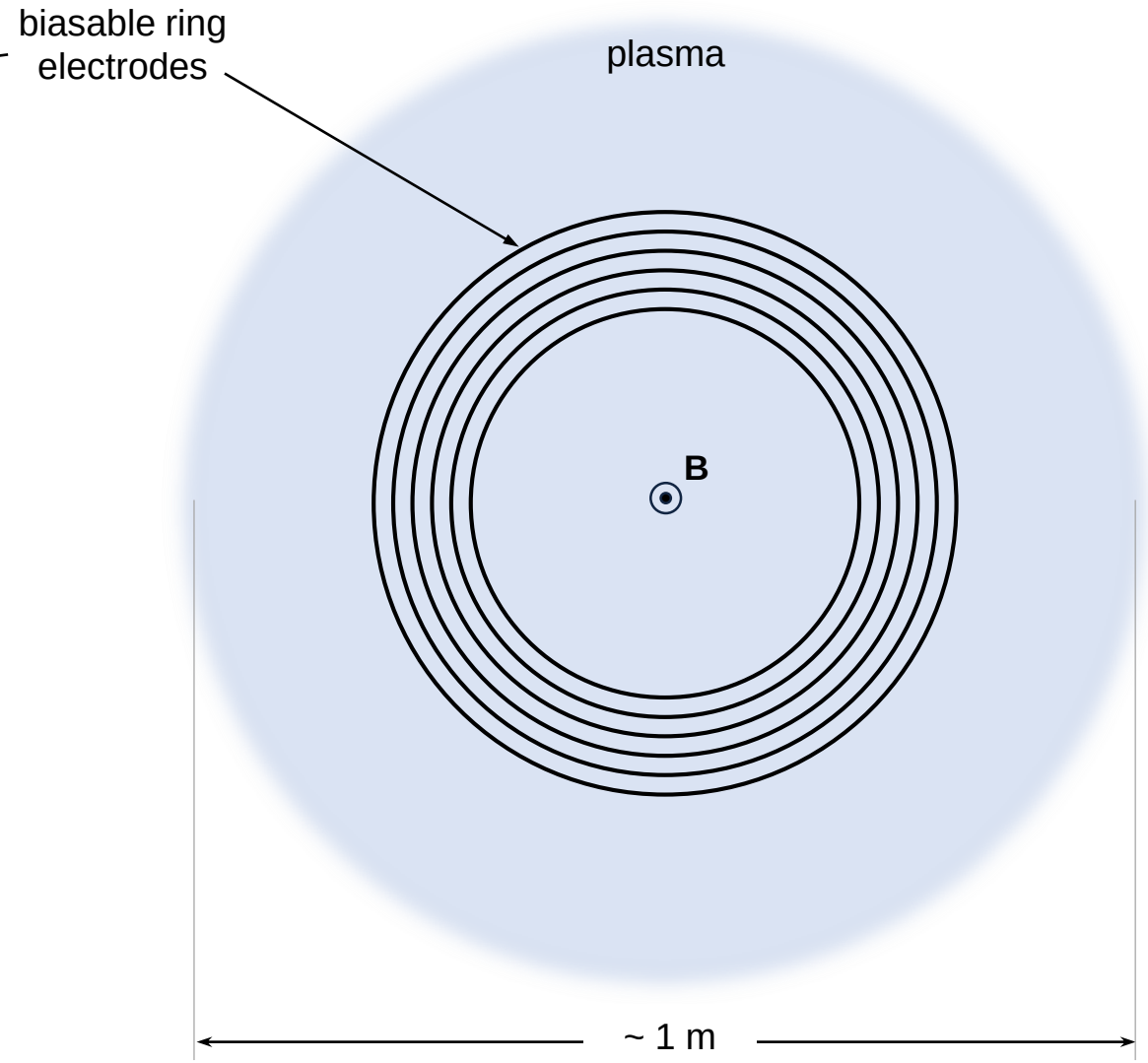


The NRL Space Chamber plasma is ~1-m dia × 5-m long, surrounded by ~0.5-m vacuum gap to minimize boundary effects.

The axial magnetic field is created by 12 independent, water-cooled electromagnets.

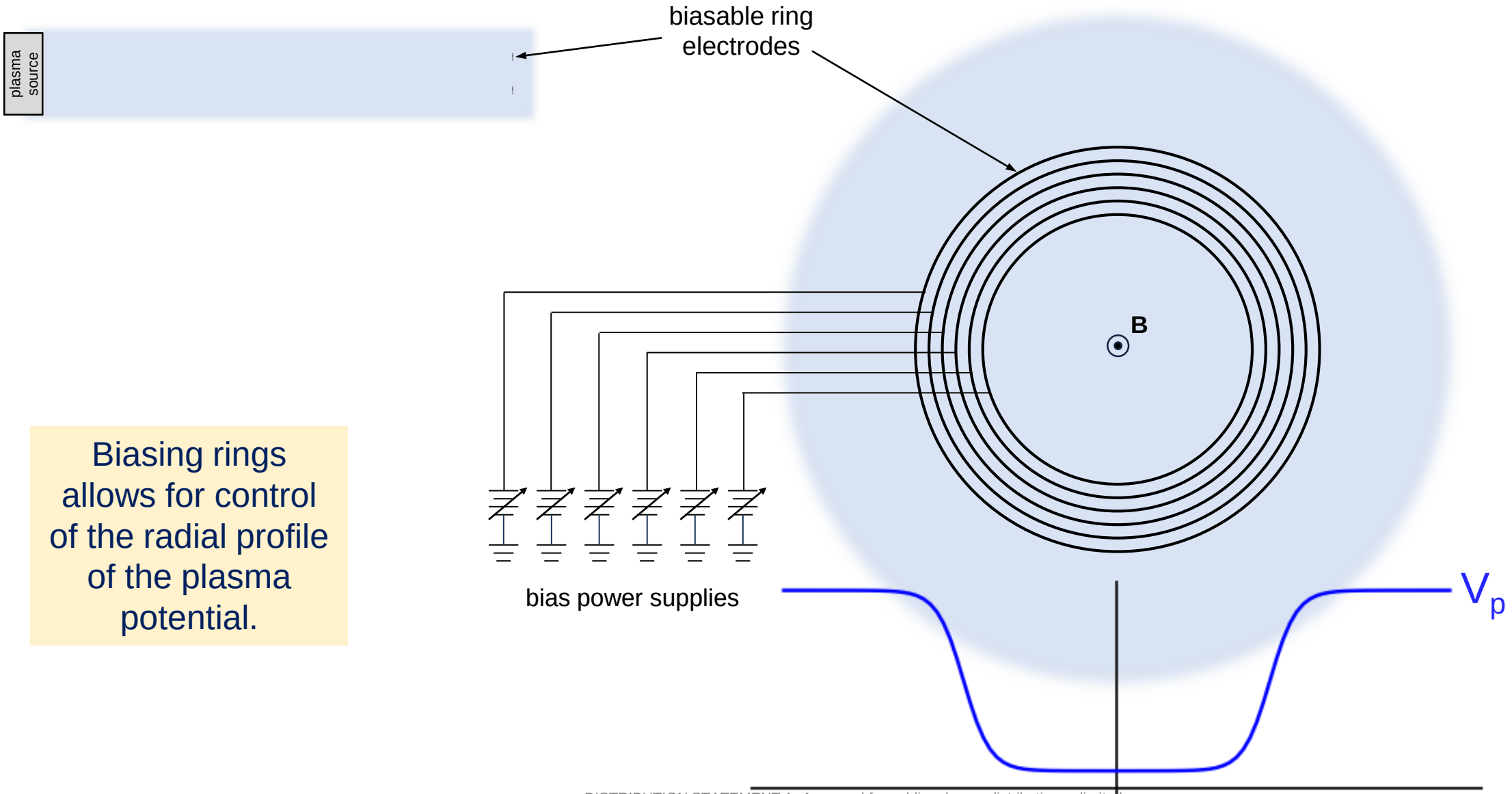
Laboratory Investigation of Precursor Solitons: Technique for Supersonic Flow Generation





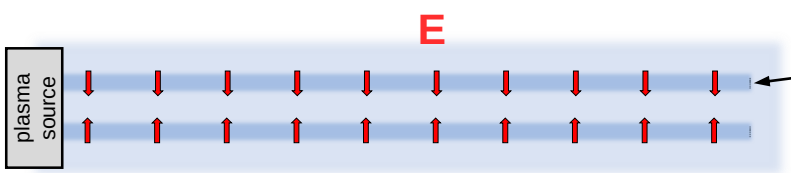
Individual concentric, isolated, conducting ring electrodes are used to create and maintain supersonic plasma flow.

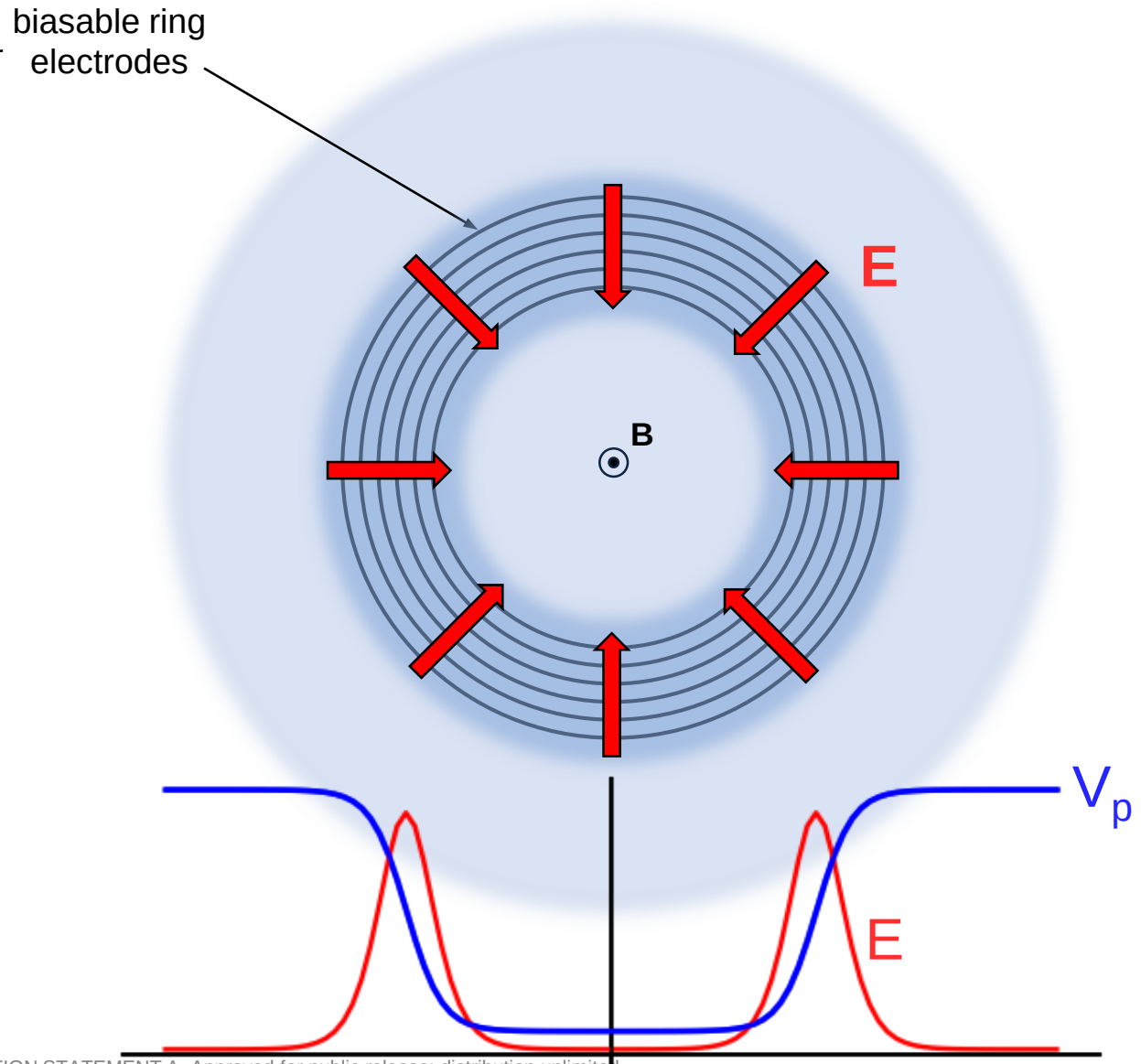
Laboratory Investigation of Precursor Solitons: Creation and Control of the Radial Plasma Potential Profile



Biasing rings allows for control of the radial profile of the plasma potential.

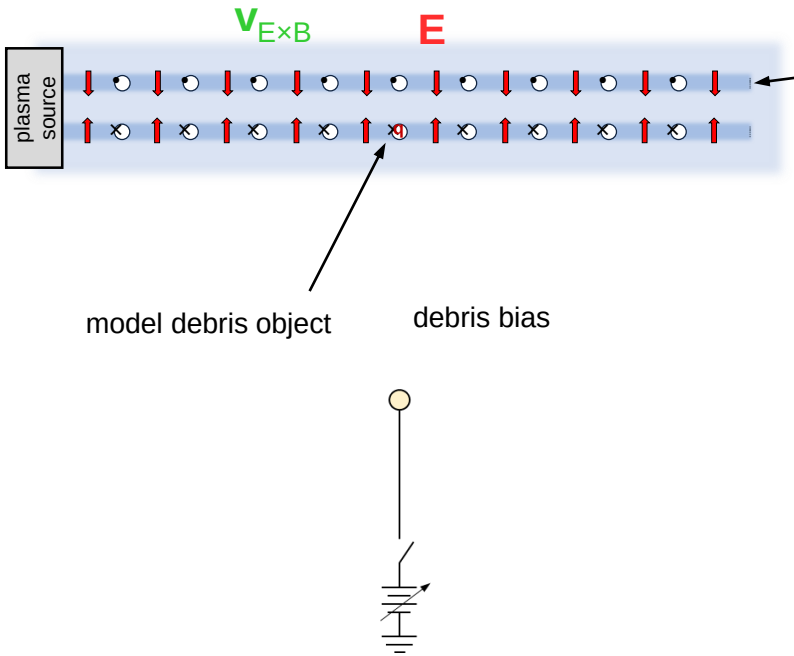
Laboratory Investigation of Precursor Solitons: Creation and Control of Transverse Electric Field

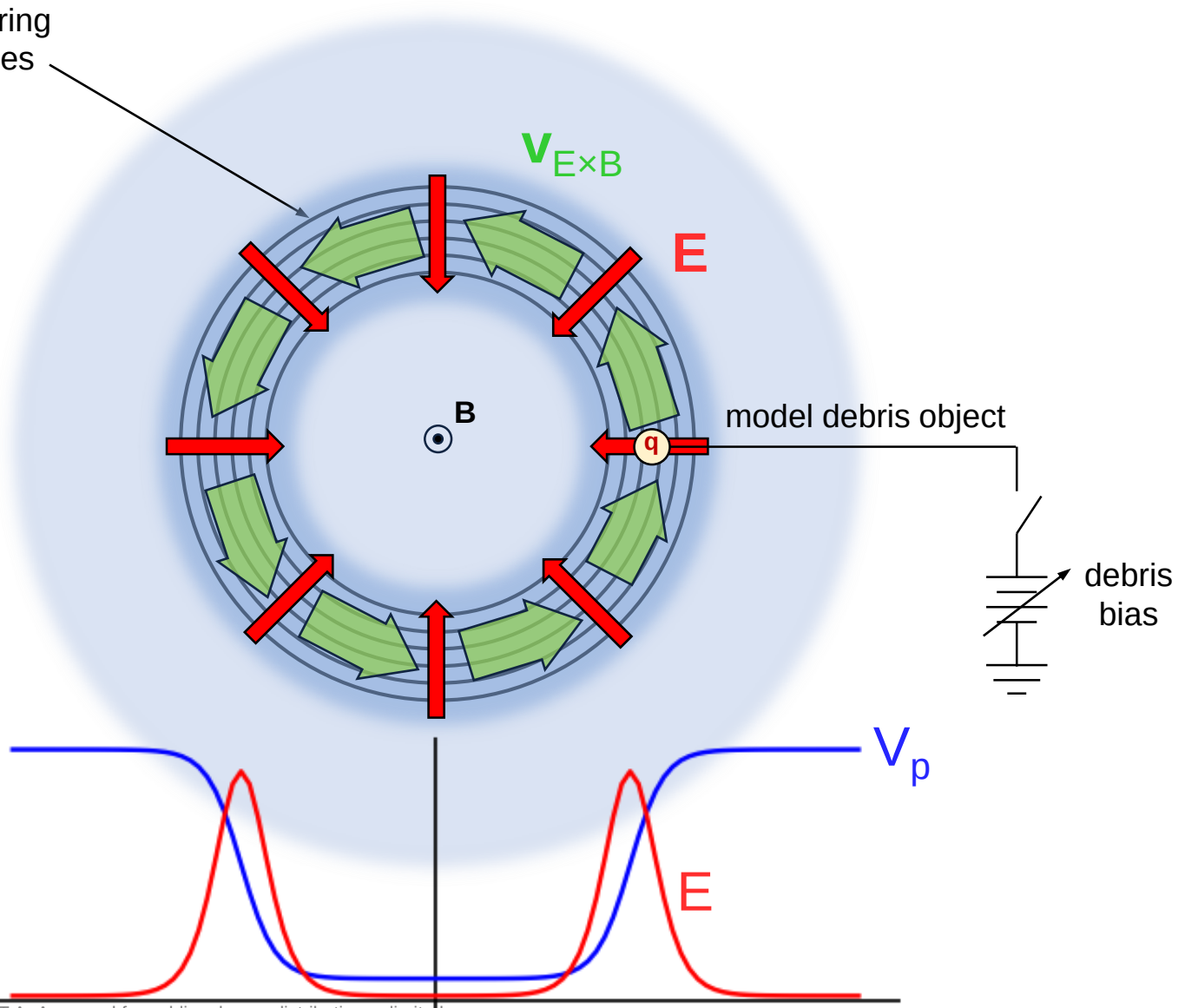




Biased rings create a localized radial electric field along plasma column axis.

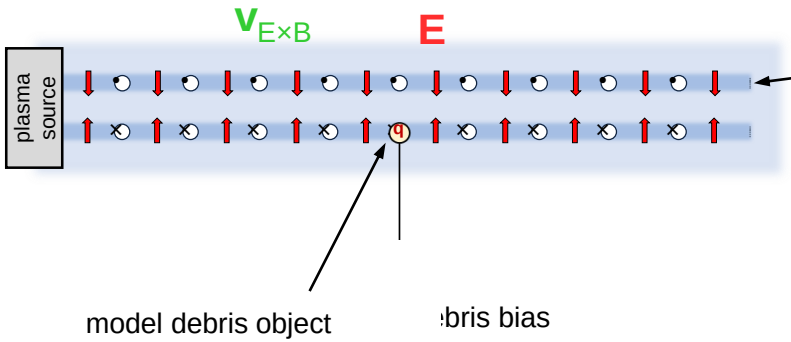
Laboratory Investigation of Precursor Solitons: Generation of Supersonic Plasma Flow

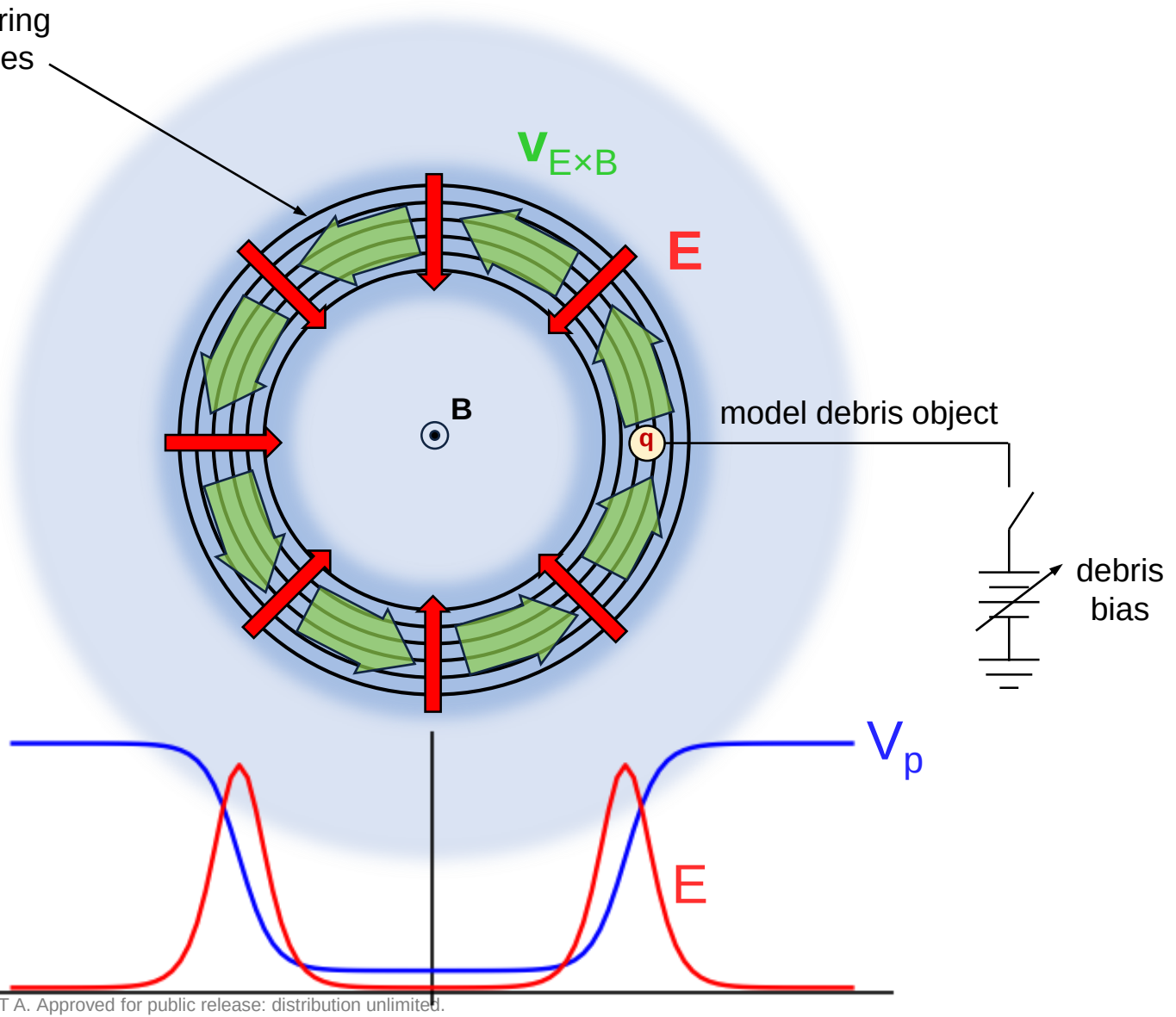




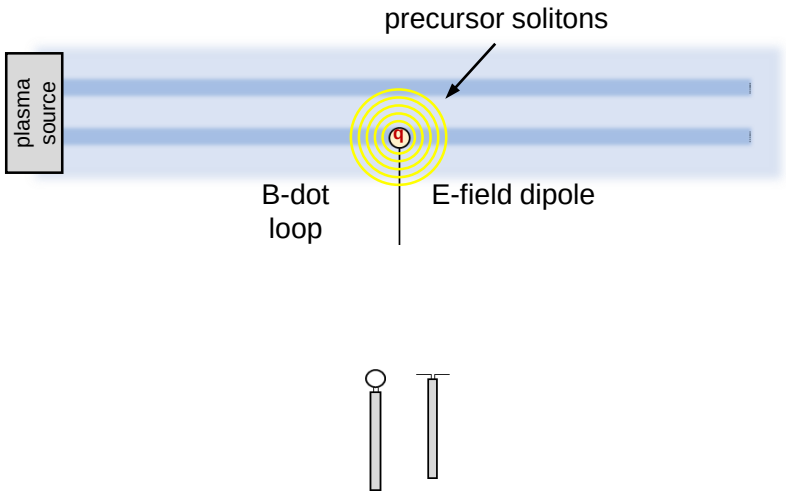
- Radial **E**-field & axial **B**-field create controlled azimuthal **E** × **B** flow.
- Flows up to 25 km/s have been created in the Space Chamber using this technique.
- Model debris object inserted into flow layer.
- Model debris object charges to floating potential or to bias voltage.

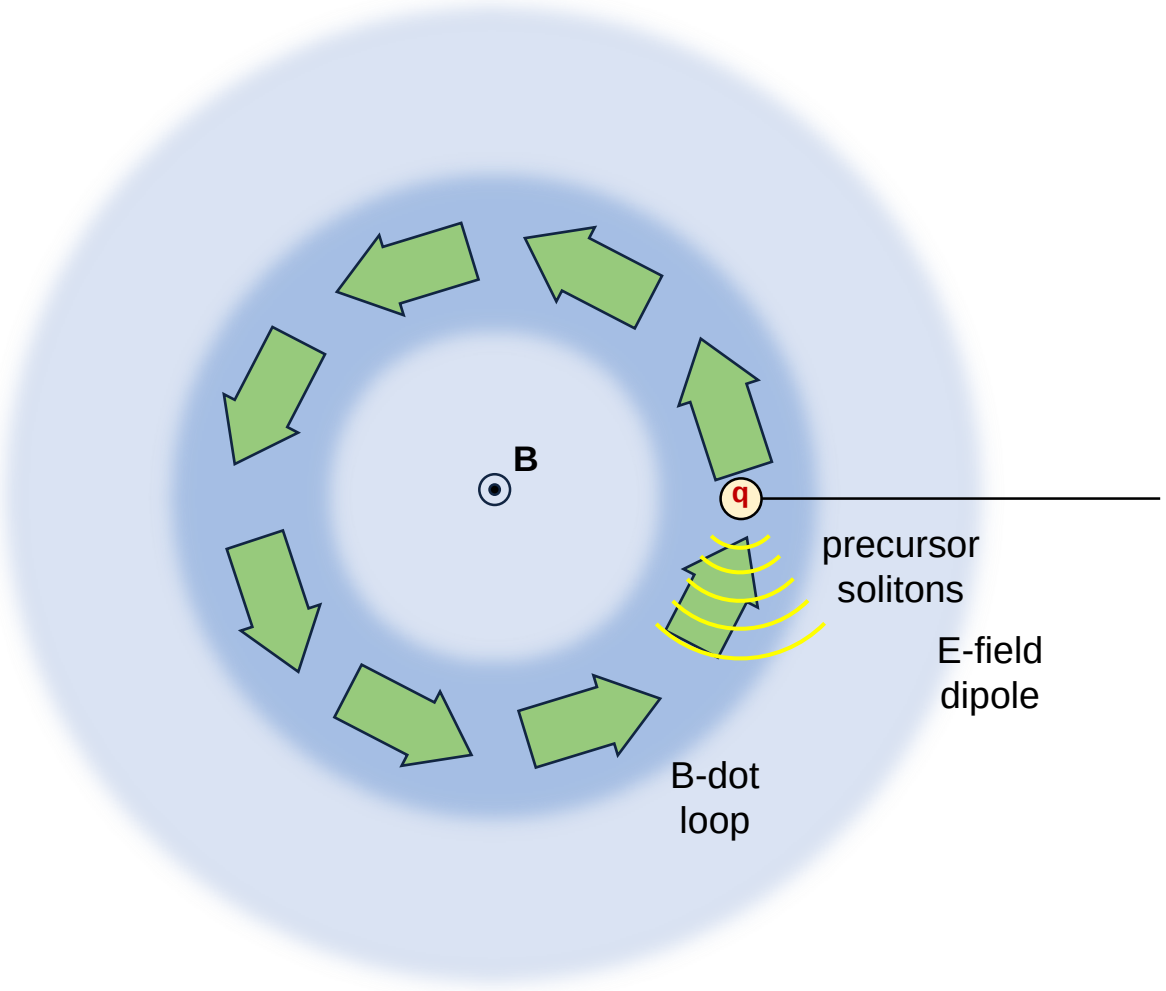
Laboratory Investigation of Precursor Solitons: Generation of Supersonic Plasma Flow





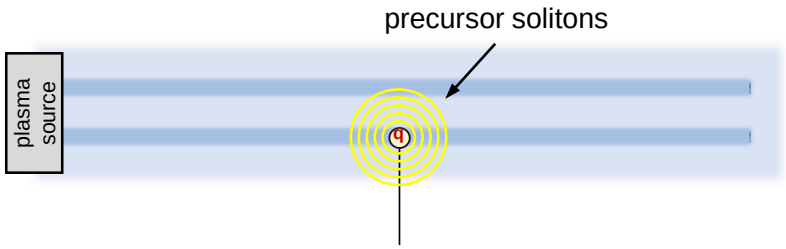
Laboratory Investigation of Precursor Solitons: Charged Debris Object Generates Solitons

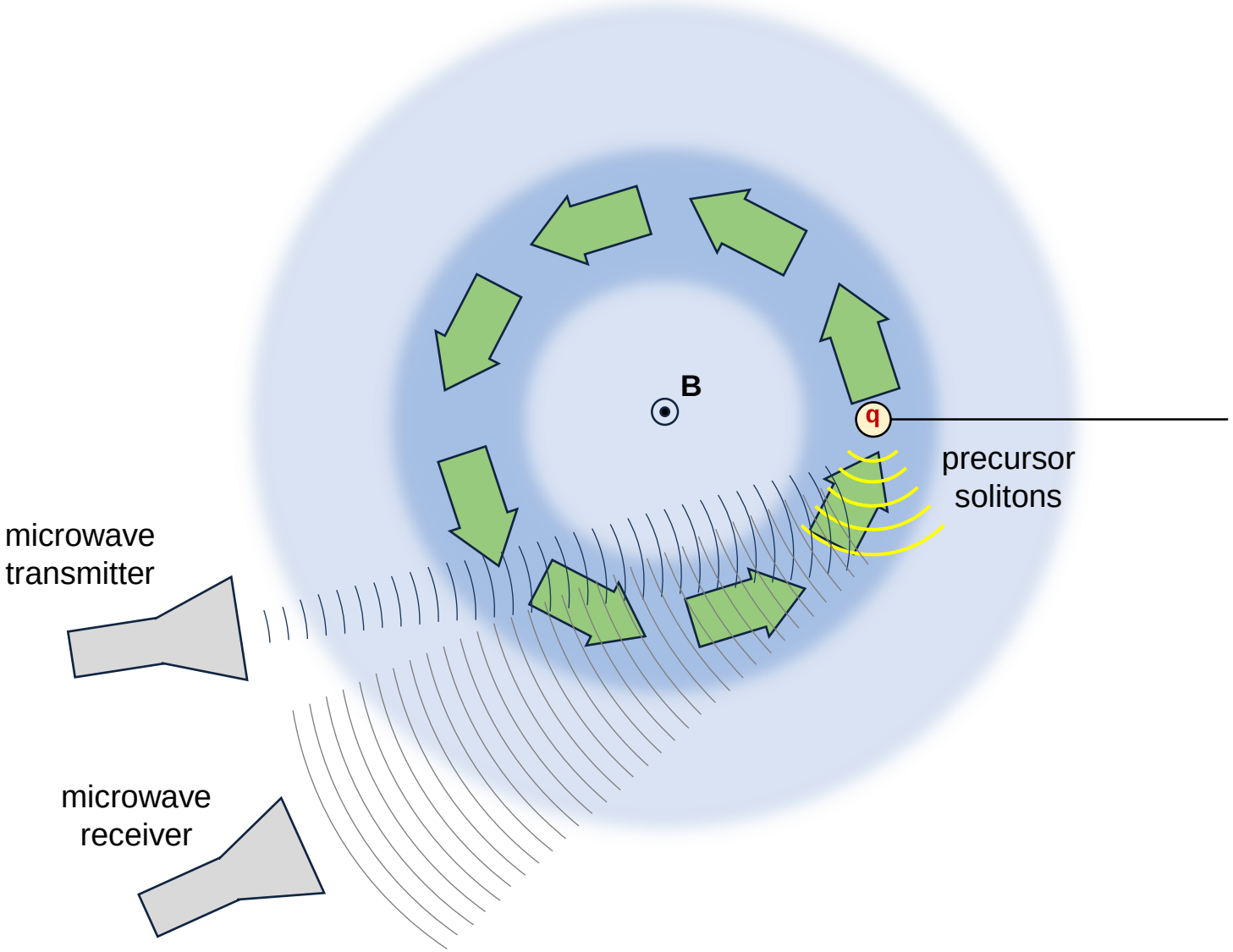




- Solitons are generated by the charged debris object.
- The solitons are characterized by the Space Chamber plasma diagnostic tools.

Laboratory Investigation of Precursor Solitons: Remote Detection of Precursor Solitons





Movable microwave transmitter and receiver pair located inside Space Chamber used to test remote soliton detection

U.S. NAVAL RESEARCH LABORATORY

Relevant References

1. A. Sen, S. Tiwari, S. Mishra, and P. Kaw, *Advances in Space Research*, **56**, 429 (2015).
2. S. Jaiswal, P. Bandyopadhyay, and A. Sen, *Phys. Rev. E*, **93**, 041201(R) (2016).
3. S. K. Tiwari and A. Sen, *Physics of Plasmas*, **23**, 022301 (2016).
4. S. K. Tiwari and A. Sen, *Physics of Plasmas*, **23**, 100705 (2016),https://doi.org/10.1063/1.4964908.
5. G. Arora, P. Bandyopadhyay, M. G. Hariprasad, and A. Sen, *Physics of Plasmas*, **26**, 093701 (2019), https://doi.org/10.1063/1.5115313.
6. Alexis S. Truitt and Christine M. Hartzell, First Int'l. Orbital Debris Conf., 6035, (2019)
7. A. S. Truitt and C. M. Hartzell, *Journal of Spacecraft and Rockets*, **57**, 876 (2020), https://doi.org/10.2514/1.A34652
8. A. Kumar and A. Sen, *New Journal of Physics*, **22**, 073057 (2020).
9. G. Arora, P. Bandyopadhyay, M. G. Hariprasad, and A. Sen, *Phys. Rev. E*, **103**, 013201, (2021)
10. A. Sen, A. Kumar, S. Yadav, G. Ganguli, and C. Crabtree, 2021 International Conference on Electromagnetics in Advanced Applications (ICEAA), Honolulu, Hawaii, U.S.A., 09 -13 August 2021, 32 (2021)
11. Abhijit Sen, Rupak Mukherjee, Sharad K. Yadav, Chris Crabtree, and Gurudas Ganguli, Electromagnetic Pinned Solitons for Space Debris Detection, *Phys Plasmas*, (to be submitted 2022)