Space Lab Technologies, LLC

PennState College of Engineering

Investigating Reentry Plasmas using Sounding Rockets

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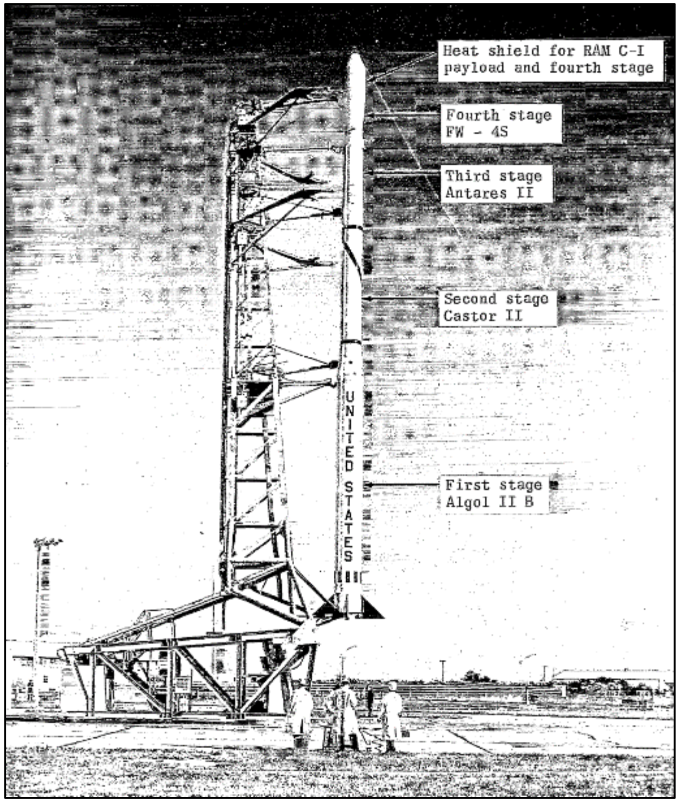
Presentation Overview

- **History of Hypersonic Flight**
- **Sounding Rocket Trajectory**
- **Reentry Plasma Formation**
- **Mitigation of Reentry Plasma Effects**
- **Previous Hypersonic Plasma Diagnostics**
- **Plasma Impedance Probes**
- **Preliminary Simulation**
- **Conclusions**

History of Hypersonic Flight

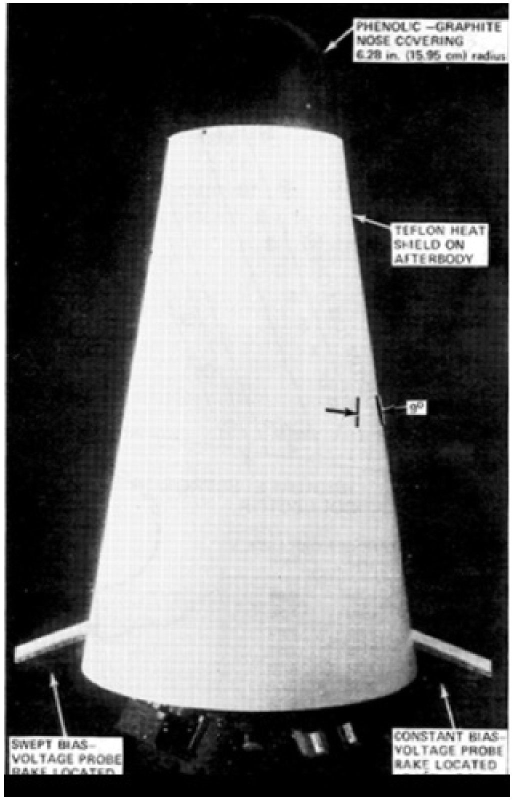
1949

Bumper Rocket Program
V2 / WAC Corporal
(Anderson, 2006)



1967

Scout Vehicle
RAM C-I
(Akey, 1970)



1970

Scout Vehicle
RAM C-III Payload
(Dunn, 1973)

Recent History of Hypersonic Test Flights

2005
DLR SHEFEX

2010–2011
DARPA HTV-1/2

2012
DLR SHEFEX II

2009-2017
AFRL, NASA,
Australian DSTO
HIFiRE

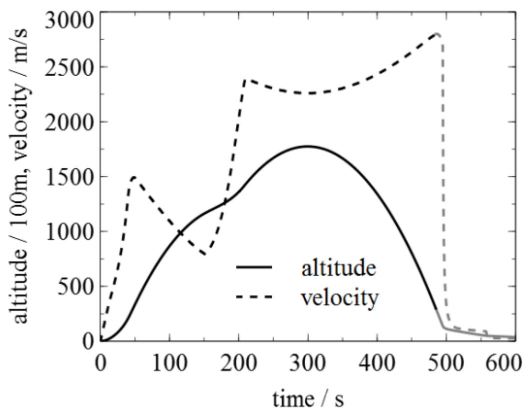
2012
NASA Langley IRVE-3

Required Sounding Rocket Trajectory

~2.6 km/s
@ 101 km

~2.8 km/s
@ 30 km

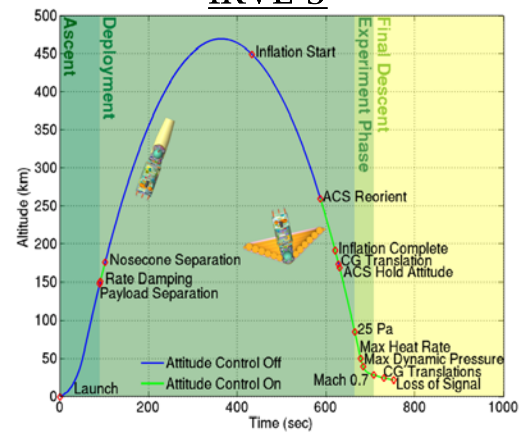
SHEFEX II



Böhrk, 2015

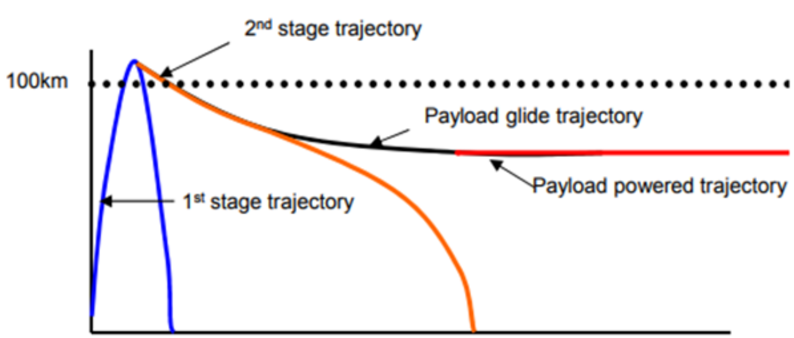
~2.0 km/s
@ 85 km

IRVE-3



Olds, 2013

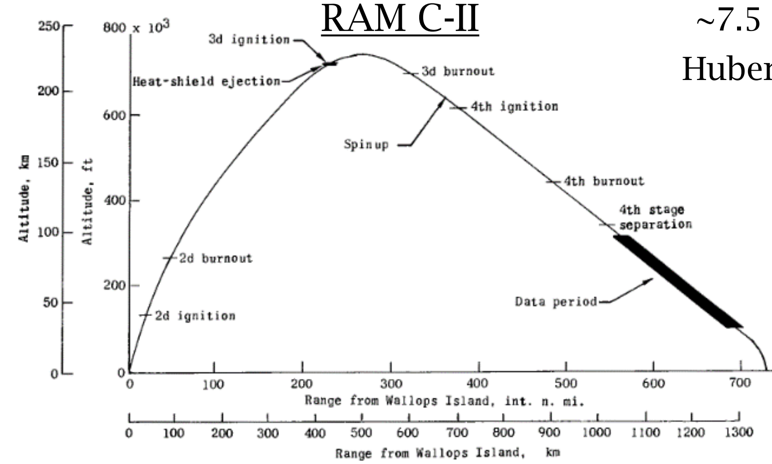
HIFiRE



Bowcutt, 2012

RAM C-II

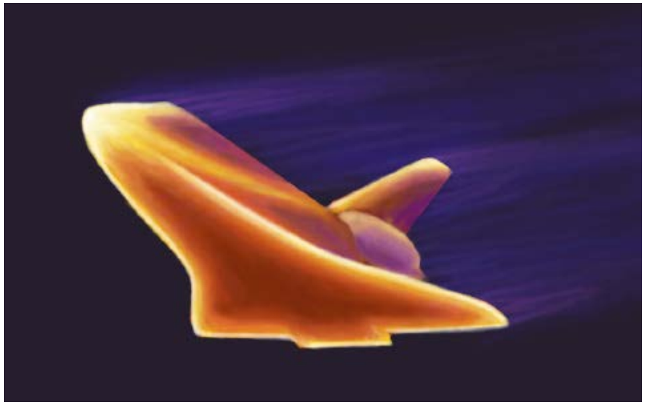
~7.5 km/s
Huber, 1971



Jones, 1972

Comparison to Shuttle & Exploration

Space Shuttle
7.8 km/s (17,500 mph)

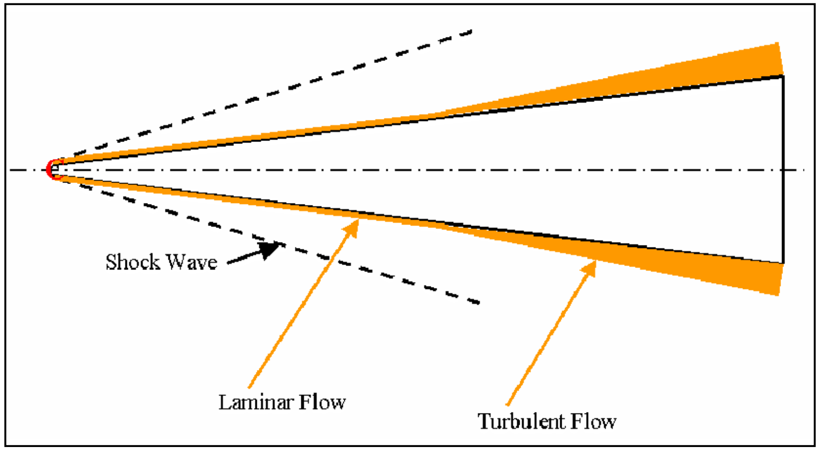


Exploration Flight Test 1
8.9 km/s (20,000 mph)

Reentry Plasma Formation

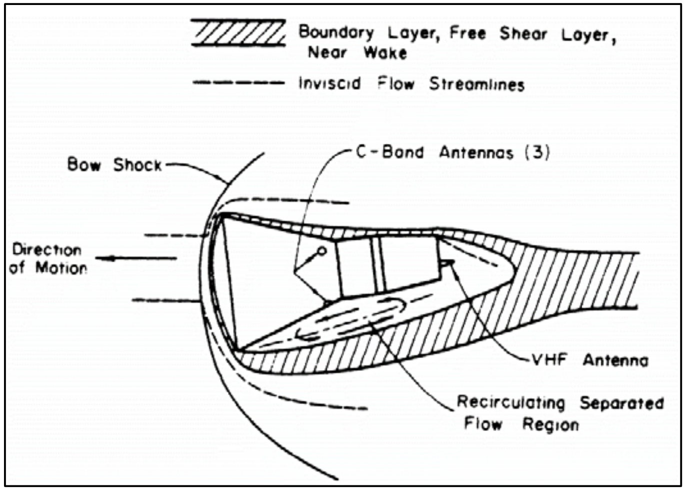
- **Compression of air between shock front and vehicle causes a dense highly collisional plasma to form**
- **Why care about the plasma formed?**
  - RF Communications Blackout (NASA Technology Roadmap – TA 5.2)
  - Boundary Layer Flow Analysis
  - Atmospheric Composition Determination

Sharp Tip



Hartunian, 2007

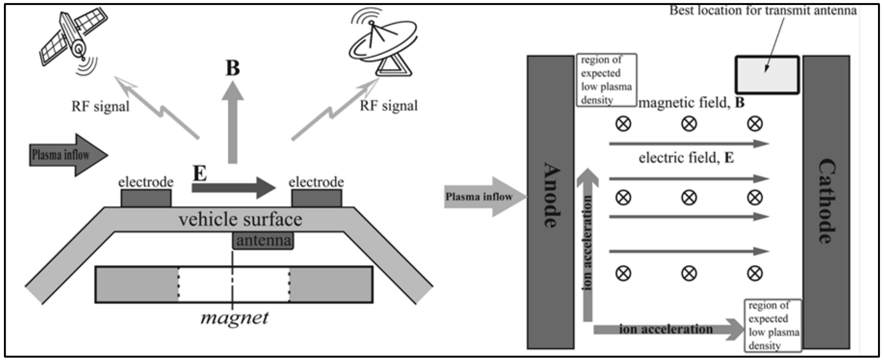
Blunt Body



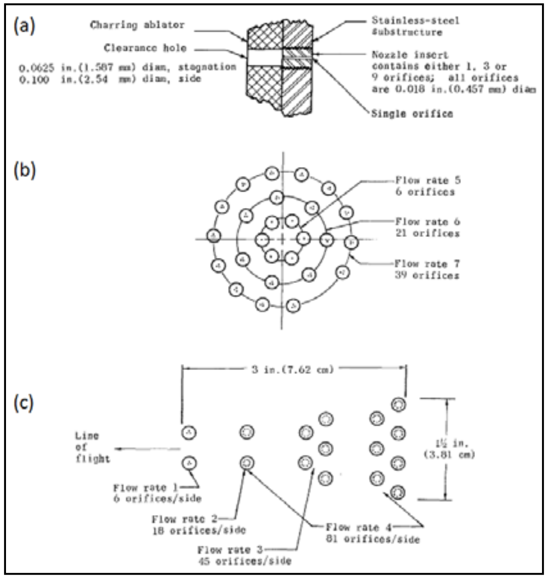
Rybak, 1971

Mitigation of Reentry Plasma Effects

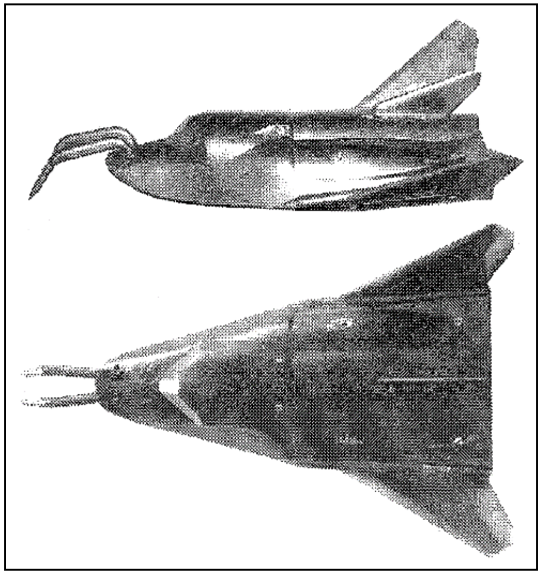
- Electrophilics / Ablatives
- Sharp Tip
- E × B Drift
- Matching Plasma Impedance
- Higher Frequencies / TDRSS



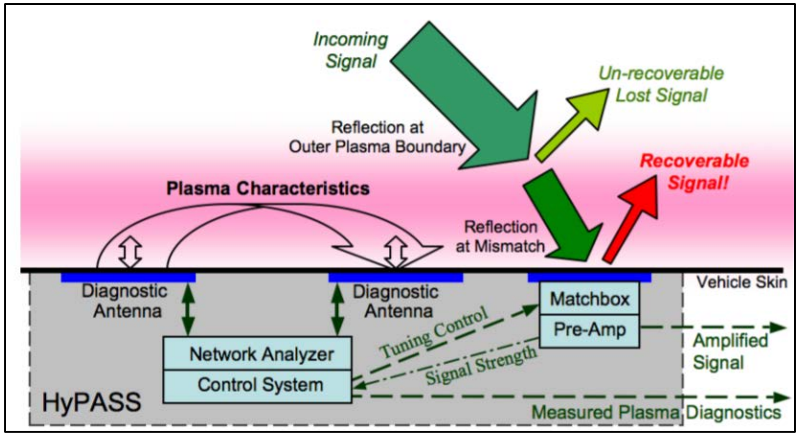
Kim, 2008



Akey, 1970



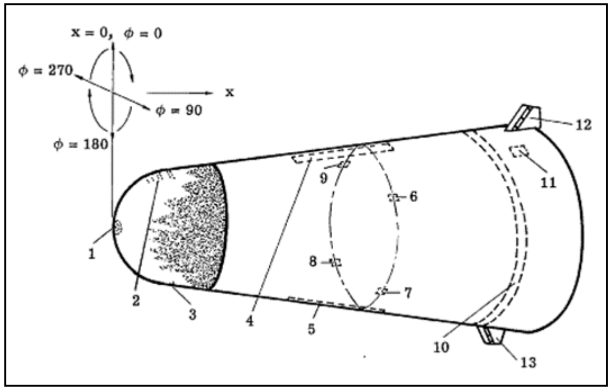
Belov, 2001



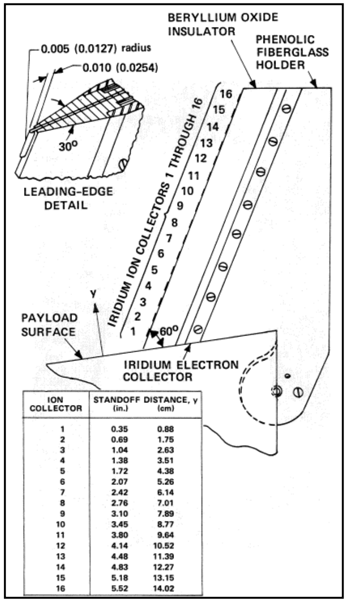
Davis, 2011

Previous Hypersonic Plasma Diagnostics

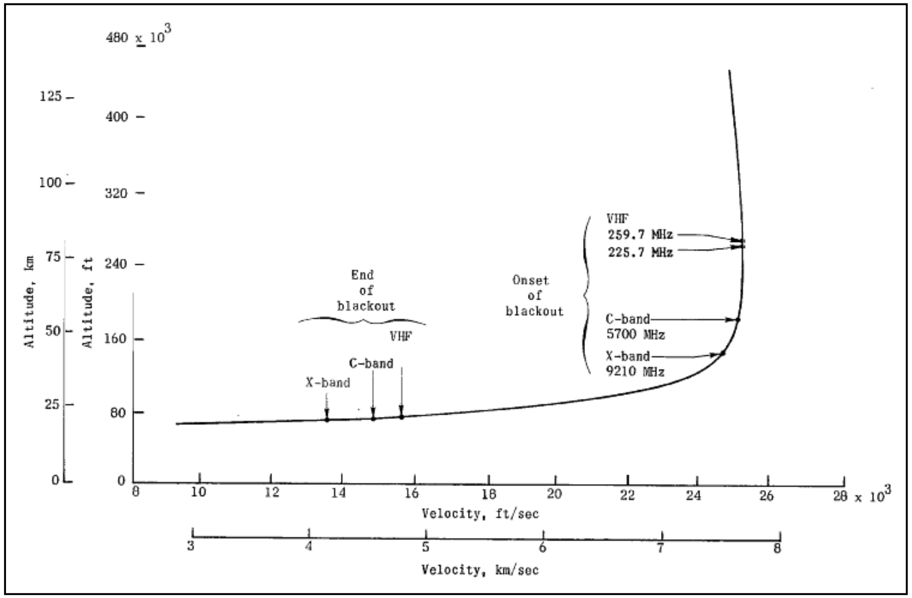
Index	Band	Frequency [MHz]
10	VHF	225.7
4, 5	VHF	259.7
11	C	5700 (5800*)
6, 7, 8, 9	X	9210



Akey, 1970



Dunn, 1973



Akey, 1970

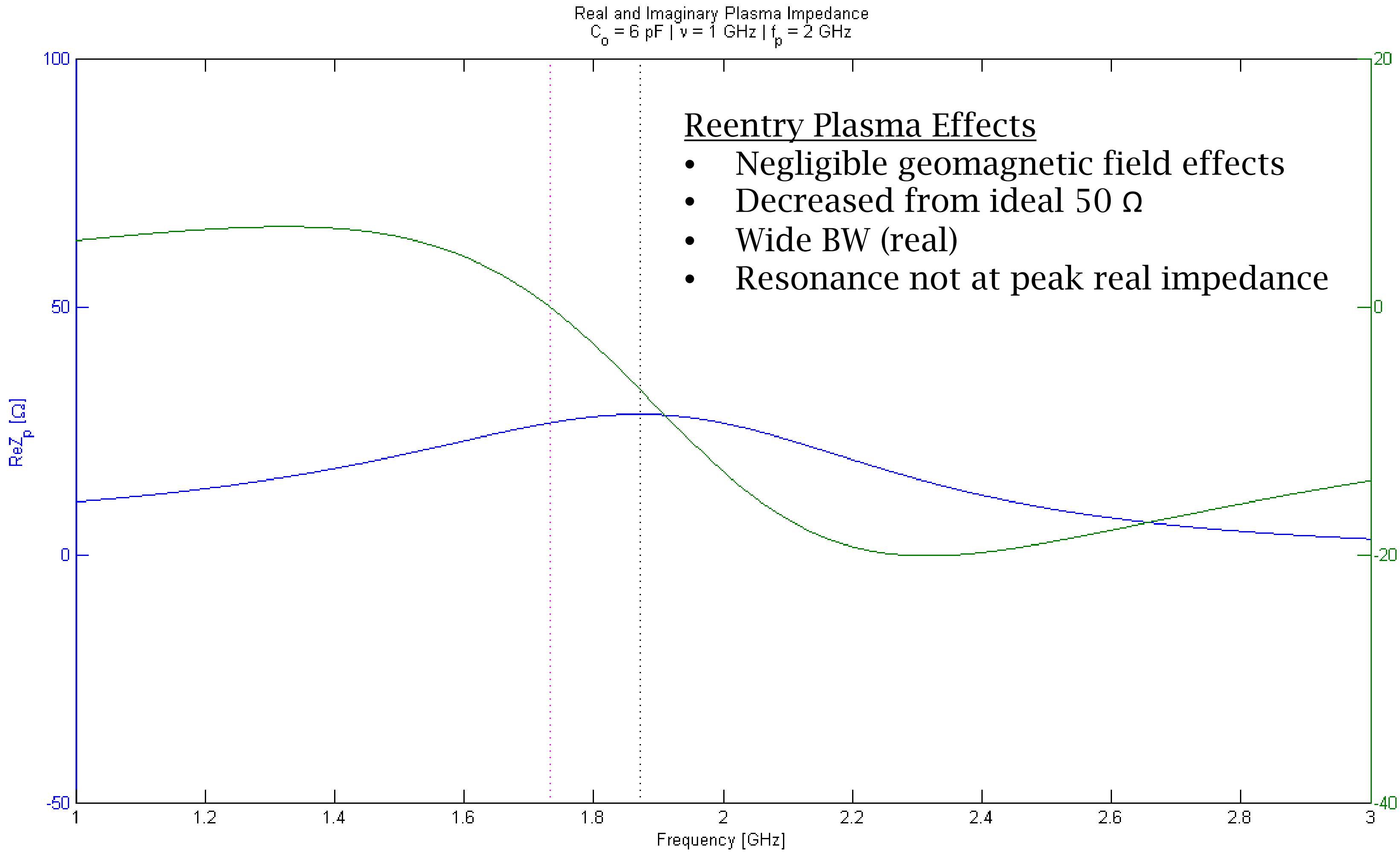
Reentry Plasma Parameters

Parameter	Min Value	Max Value	Unit	Source
Electron Density	3×10^{14}	6×10^{17}	m^{-3}	Dunn, 1973
Collision Frequency	6.3×10^{7}	1.3×10^{11}	s^{-1}	Hartunian, 2007
*Peak Plasma Layer Distance	0	11	cm	Dunn, 1973
Electron Temperature	4000	10000	K	Dunn, 1973

Plasma Impedance Probes

- **RF stimulus to Probe (Antenna) with the excitation signal swept in frequency.**
- **The reflected magnitude and phase response provides the plasma impedance.**
- **The plasma impedance determines the plasma parameters:**
  - Electron Plasma Density
  - Electron-Neutral Collision Frequency
  - Electron Temperature (Under Investigation)
  - Plasma Layer Thickness (Under Investigation)
- **Space Lab and Penn State investigating new methods to determine these plasma parameters.**

Preliminary Impedance Simulations



Conclusions

- **Why care about reentry plasma formation?**
  - RF Communication Blackout (NASA Technology Roadmap)
  - Boundary Layer Flow Analysis
  - Atmospheric Composition
- **Sounding rockets can provide a low-cost test platform for reentry plasma studies.**
- **Needs for further understanding of reentry dynamics:**
  - New Sounding Rocket trajectory required utilizing high thrust configurations and attitude adjustments prior to motor burn phases (i.e. Black Brant XII-A or similar)
  - Partnerships in investigation of multiple reentry technology areas
- **Needs for further understanding of the reentry plasma environment:**
  - New Theory Development & Simulation
  - Wind Tunnel Verification
  - Sounding Rocket Flight Verification

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