Ion Driven Fireballs: Calculations and Experiments

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This is the First of Six University of Wisconsin Presentations

1. **R.R. Peterson, G.A. Moses, and J.F. Santarius, "Ion Driven Fireballs: Calculations and Experiments"**
2. **D. Haynes, "Chamber Gas Density Requirements for Ion Stopping".**
3. **R.R. Peterson, I.E. Golovkin, and D.A. Haynes, "Fidelity of RHEPP and Z Experiments to Study Wall Response".**
4. **R.R. Peterson, I.E. Golovkin, and D.A. Haynes, "BUCKY Simulations of Z and RHEPP Experiments".**
5. **Mark Anderson, "Experimental Investigation of Impulsive Shock Loading". (poster)**
6. **John Santarius, "A Consideration of the Two-Stream Instability in Debris Ion Stopping". (poster)**

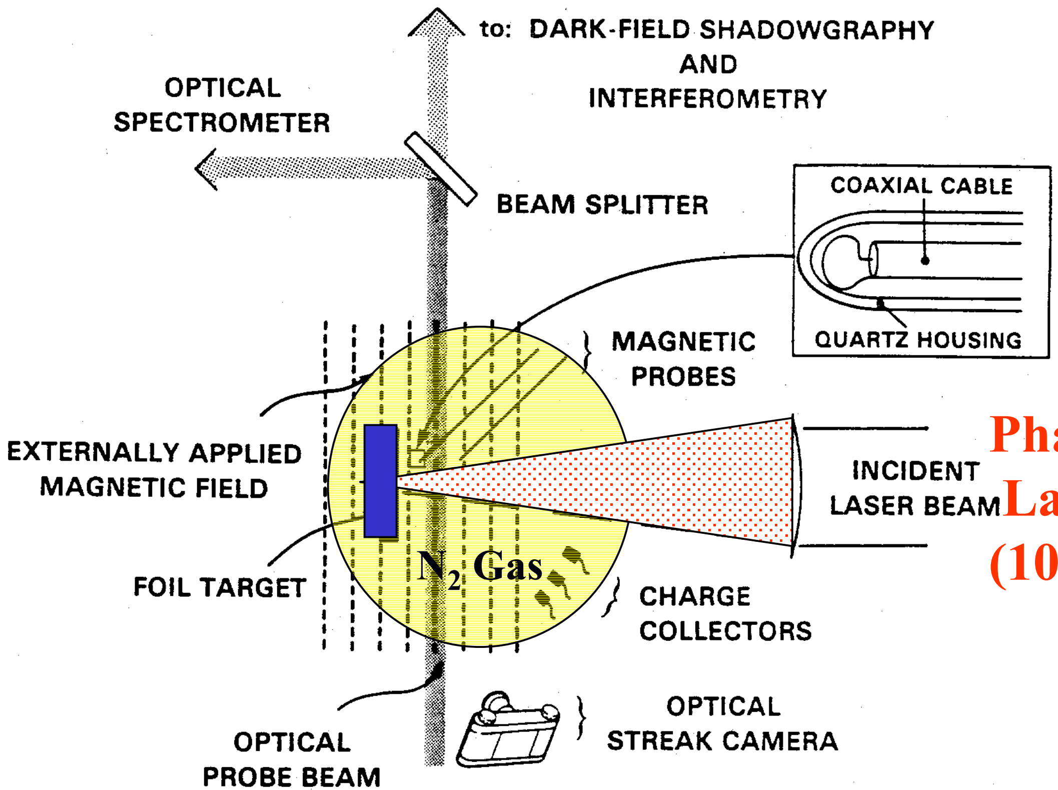
NRL Laser-Blow-Off-Ion-Driven Fireball Experiments in the 1980's Provide a Way to Validate Chamber Dynamics Simulations for Gas-Filled IFE Chambers

1. The importance of ion instabilities to gas-filled chamber dynamics can be tested with NRL fireball experiments.
2. A burst of ions is generated with an intense laser.
3. The ions generate a fireball in a gas, which is observed with shadowgraphy.
4. The observed fireball is compared with BUCKY simulations.
5. This is a test of ion deposition in chamber gases and fireball dynamics.

Some relevant publications:

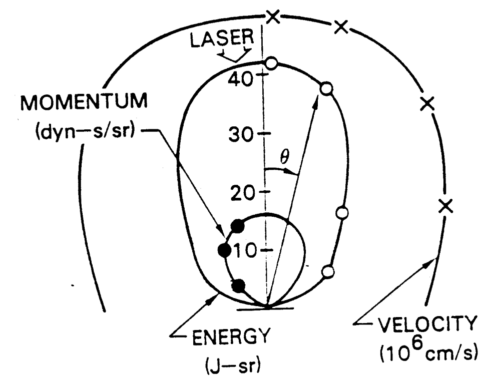
1. B.H. Ripin, et al., in *Laser Interaction and Related Plasma Phenomena* (Plenum, 1986).
2. J.J. MacFarlane, G.A. Moses, and R.R. Peterson, *Phys. Fluids B* **1**, 635 (1989).
3. J. Grun, et al., *Phys. Fluids* **29**, 3390 (1986).
4. J.F. Santarius. Poster today.

Experimental Set Up



Pharos-II Laser (100 J)

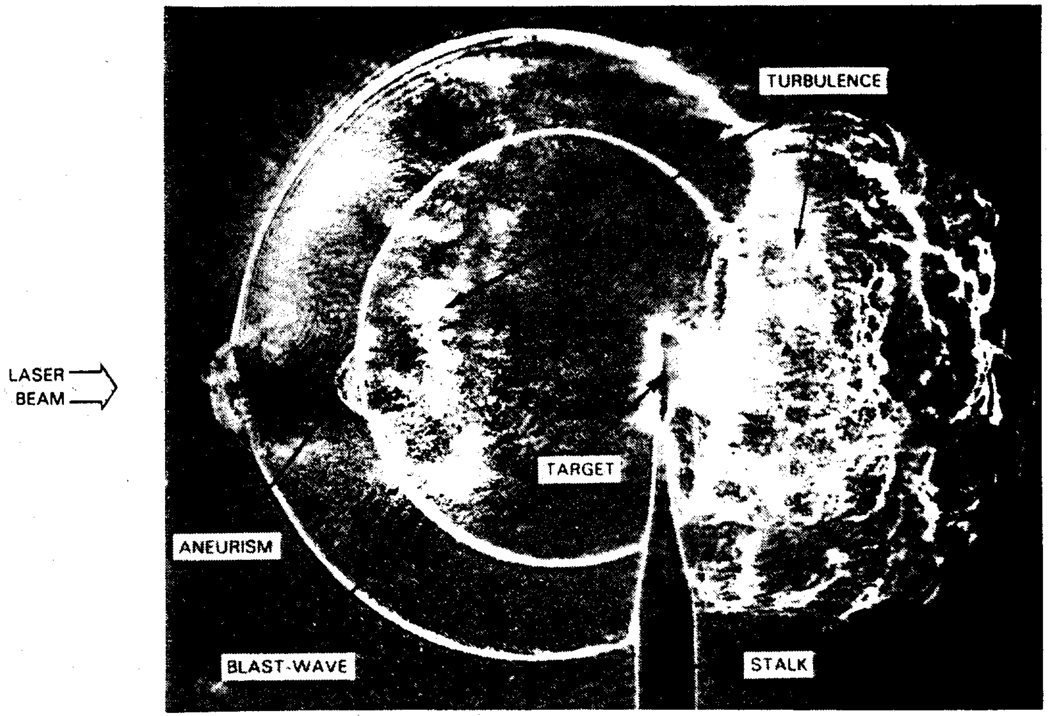
Aluminum Ions Produced by Laser



	Pharos-II	IFE Chamber
Gas Species	**N_2**	**Xe**
Ion Species	**Al**	**Target Debris**
Gas Density (cm^{-3})	**1.e15 – 1.e17**	**1.e15 – 1.e16**
Gas Radius (cm)	**5**	**650**
X-ray Pre-heat	**Yes**	**Yes**

Shadowgram Images Give Position of Shock at Various Times and Shows “Aneurism” in Laser Track

X-rays from laser-generated Al plasma pre-heats gas to ~ 100 eV, much like in gas-filled IFE chambers.

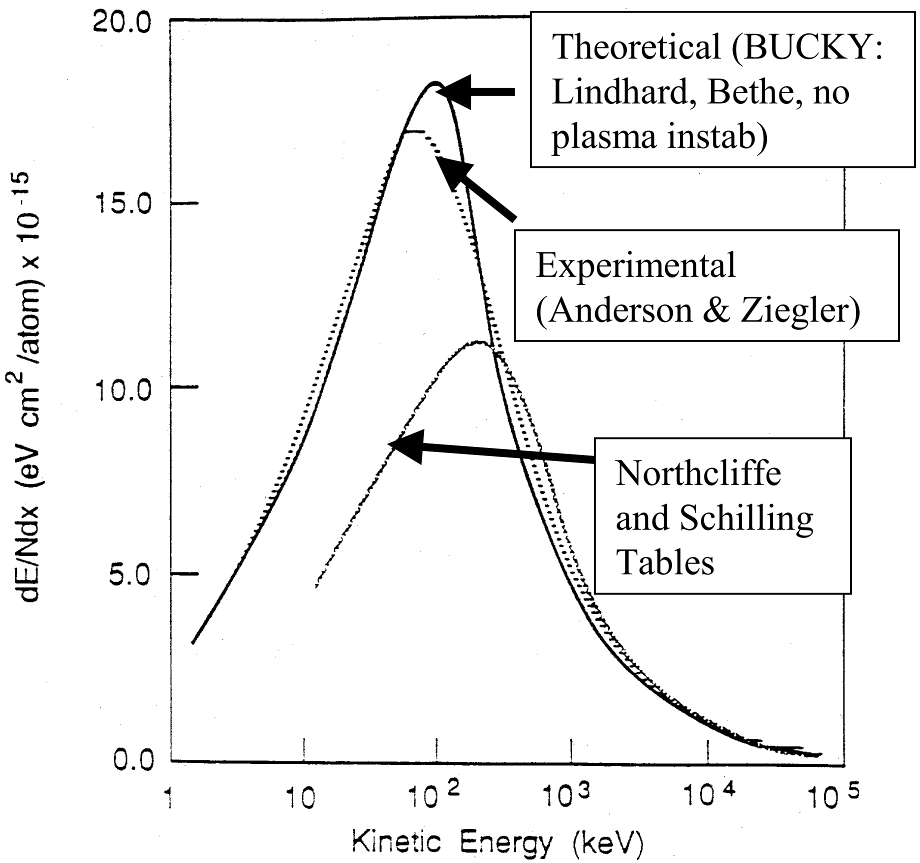


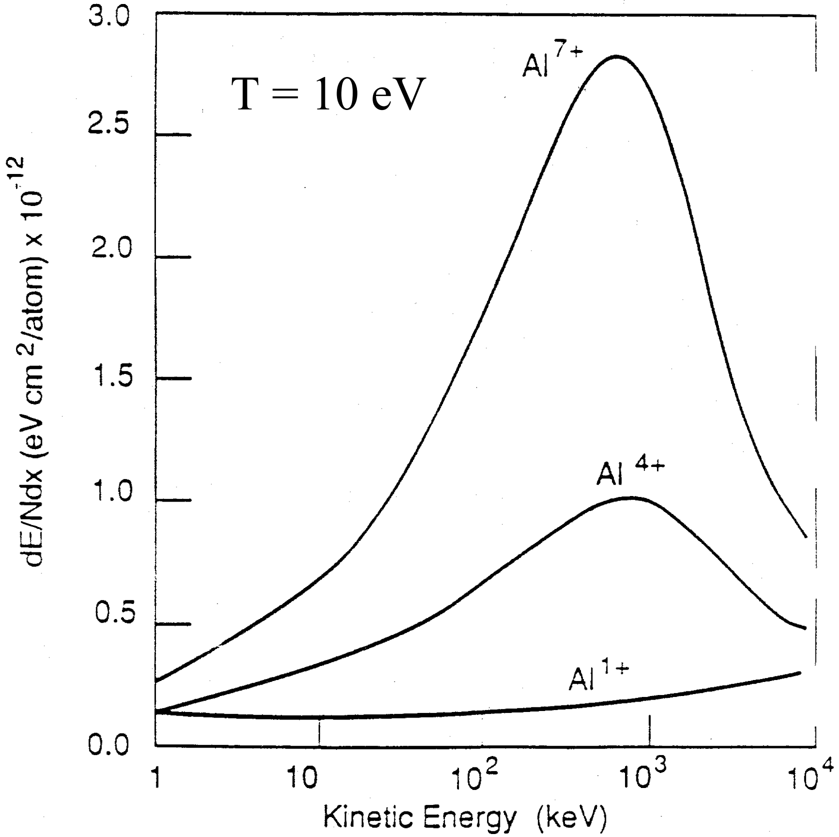
5.0 Torr of $90\%N_2 + 10\%H_2$

B=0

Ion Stopping Model in BUCKY is in Good Agreement With Experimental Data for Protons in Cold N_2

Proton Stopping in Cold N_2 Gas

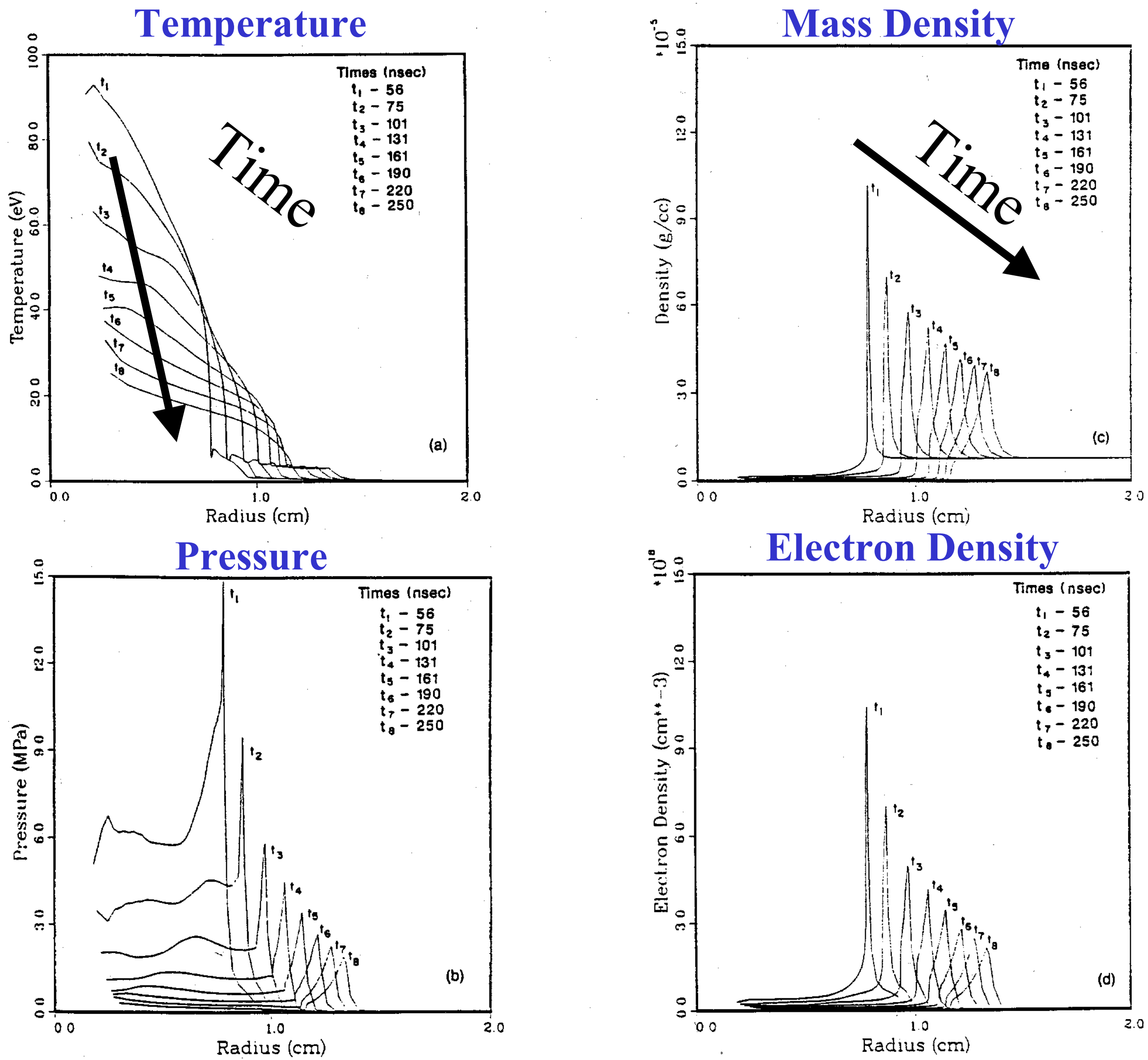




Ion stopping becomes much more complicated at higher temperatures and for more complicated projectile ions.

- Ionization state
- Range shortening
- Plasma instability

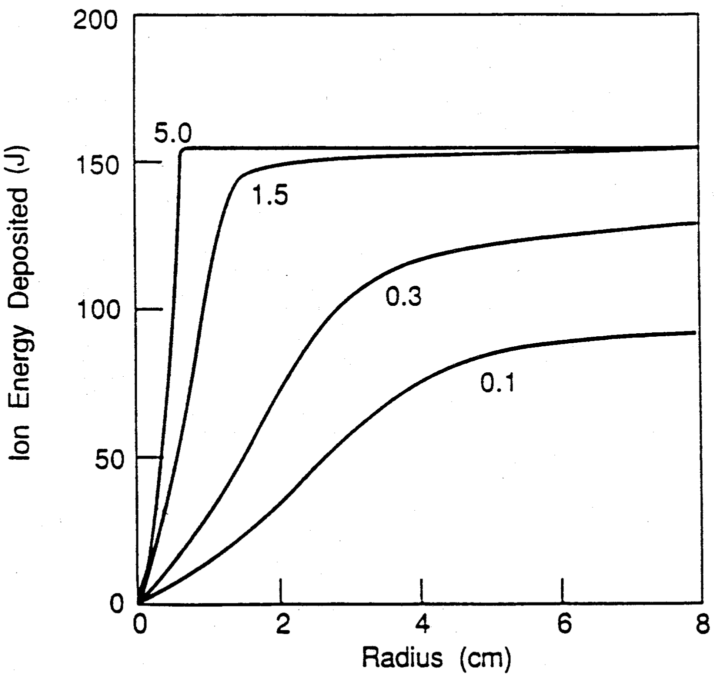
BUCKY Calculations for NRL Laser-Blow-Off-Ion-Driven Nitrogen Gas Fireball Experiments

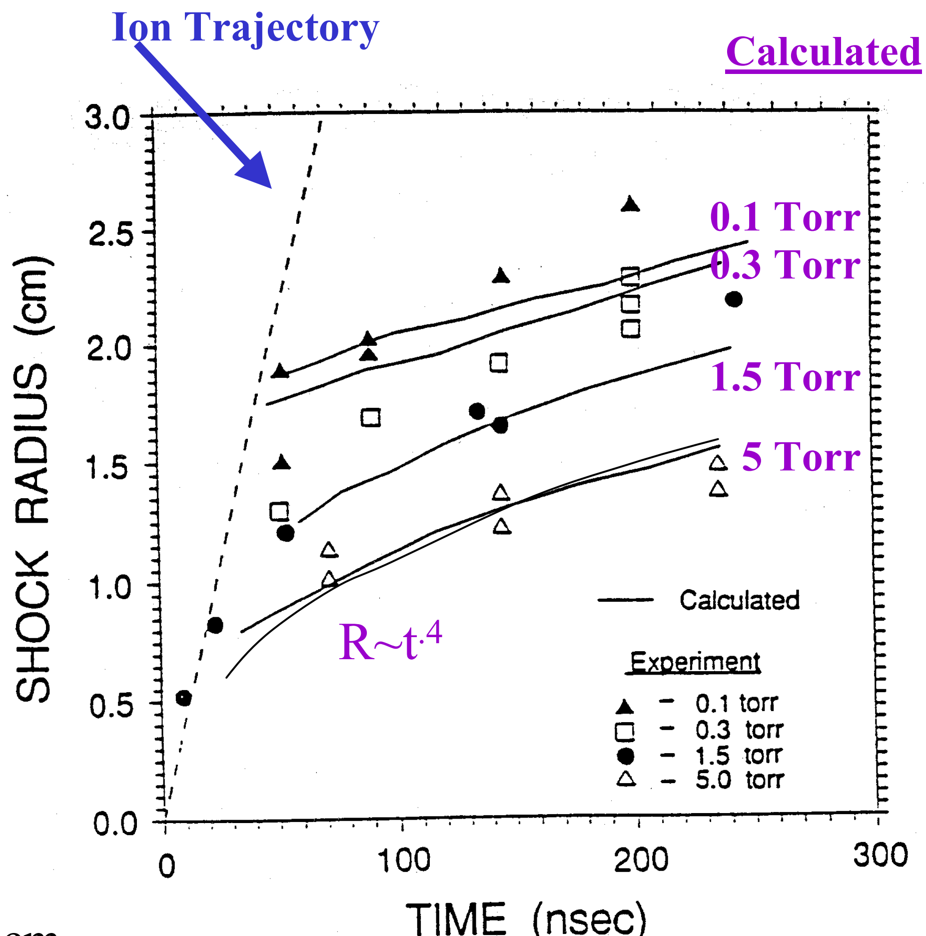


BUCKY Simulations with Radiation Transport Are in Good Agreement With NRL Experiments

150 J of ions (over 4π steradians)

20 to 40 J of ions are in fact emitted in a cone with a solid angle of ~ π/2 steradians

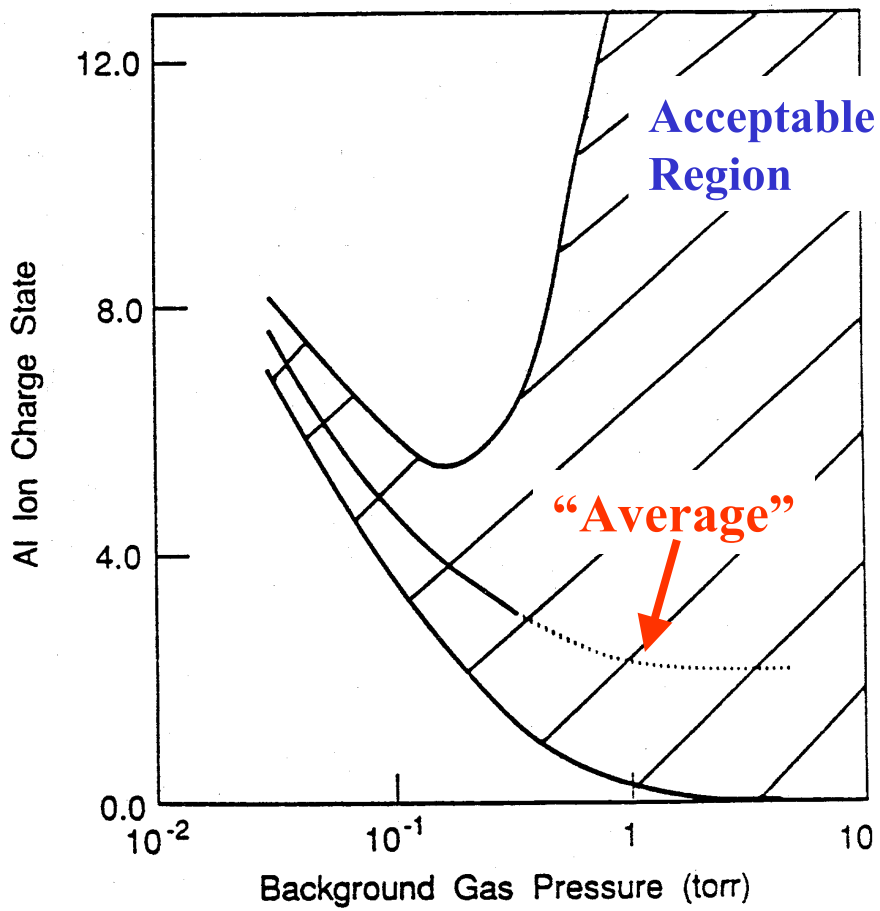


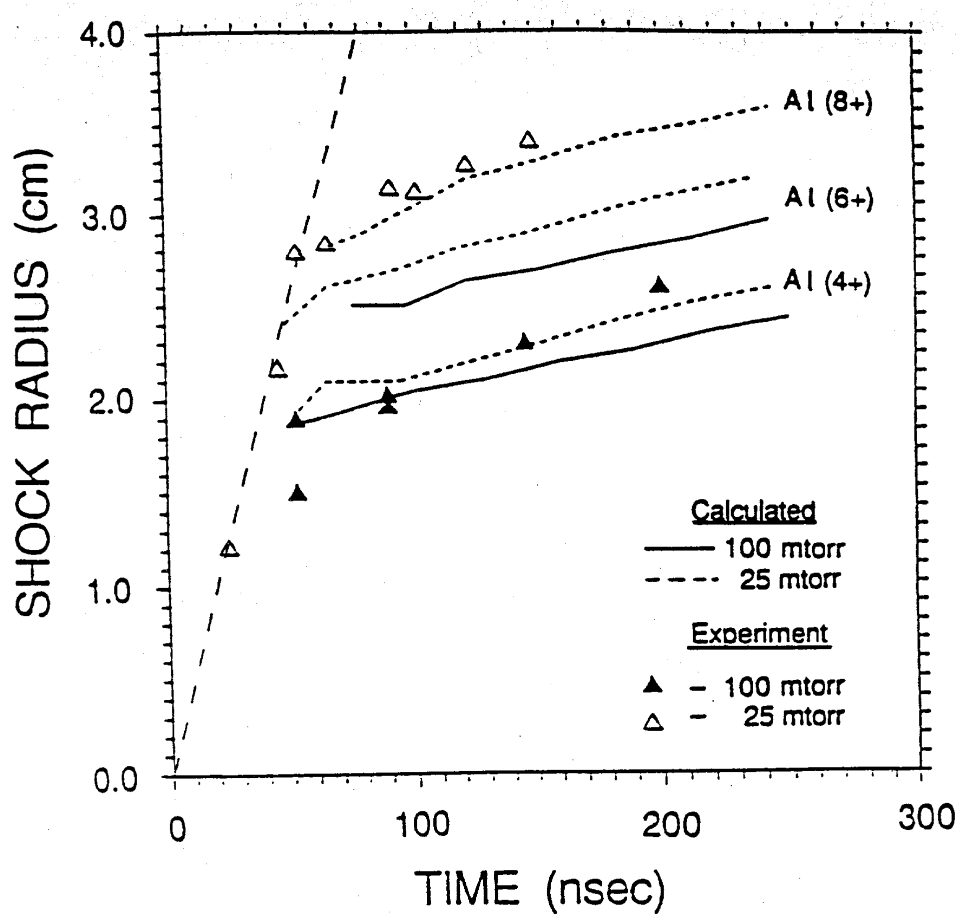


- At 5 Torr, ions are stopped in 0.5 cm
- At 0.1 Torr, ion deposition is spread over whole gas with some ions not being stopped at all.

The radiation diffusion in lowest density cases over-predicted radiative cooling.

Experimental Shock Front Trajectories Are Matched by BUCKY When Ion Effective Charge State Is Properly Chosen. At Low Gas Density the Result Is a Sensitive Function of Charge State.





BUCKY now allows on-line charge exchange calculation to get time-dependent projectile ion charge state.

NRL Fireball Experiments Do Not Show Evidence of Anomalous Ion Stopping for N_2 Between 25 and 5000 mTorr: Idealized 2-Stream Assumptions Are Not Valid

- Instability would primarily affect electrons.
  - Short Debye length (~10^{-7} m) in the "beam" should shield ions from fluctuations induced by the instability.
  - Ion-electron collision frequency in the "beam" is ~$2x10^8$ s^{-1}, so electrons do not have time to transmit the instability.
- Dissipative effects should reduce the growth rate.
  - Landau damping.
  - Non-chromatic ion velocities in "beam".
- Definitive calculations would be very complicated!
- See Poster by J.F. Santarius for discussion.

Summary: BUCKY Simulations Agree Fairly Well with NRL Experiments: No Evidence of Instability Enhanced Ion Deposition

- Ion-generated fireballs can be simulated with BUCKY using "classical" ion deposition physics.
- Projectile ion charge states and radiation transport were seen as issues to study.
- In the last 13 years BUCKY has evolved significantly (CRE radiation, better opacities, more energy groups, in-line projectile ion charge state) and this validation should be tried again.
- 2-stream instabilities may be mitigated by plasma non-ideal conditions.
- Experiments show aneurisms and instabilities that BUCKY , being 1-D, cannot address.

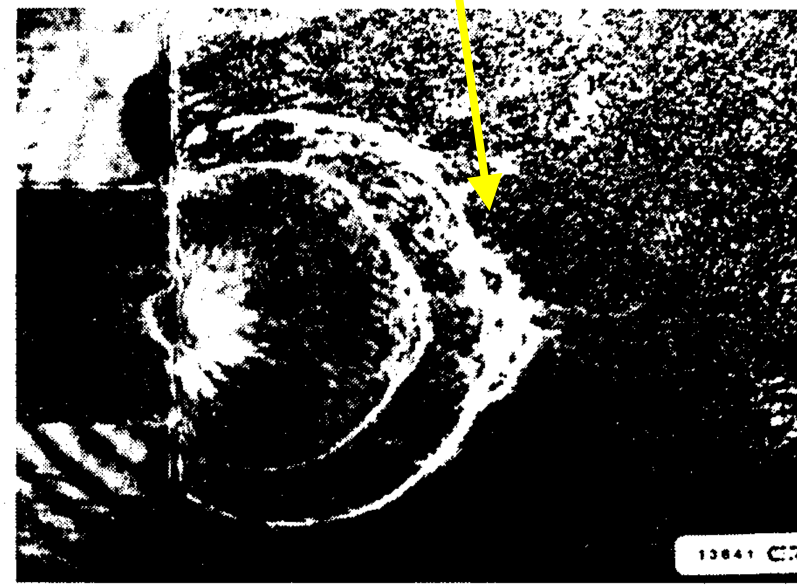
Magnetic Fields Make "Aneurisms" Much More Turbulent

BACK-UP #1

"Aneurism"

5.0 Torr of 90%N_2 + 10%H_2
B=0

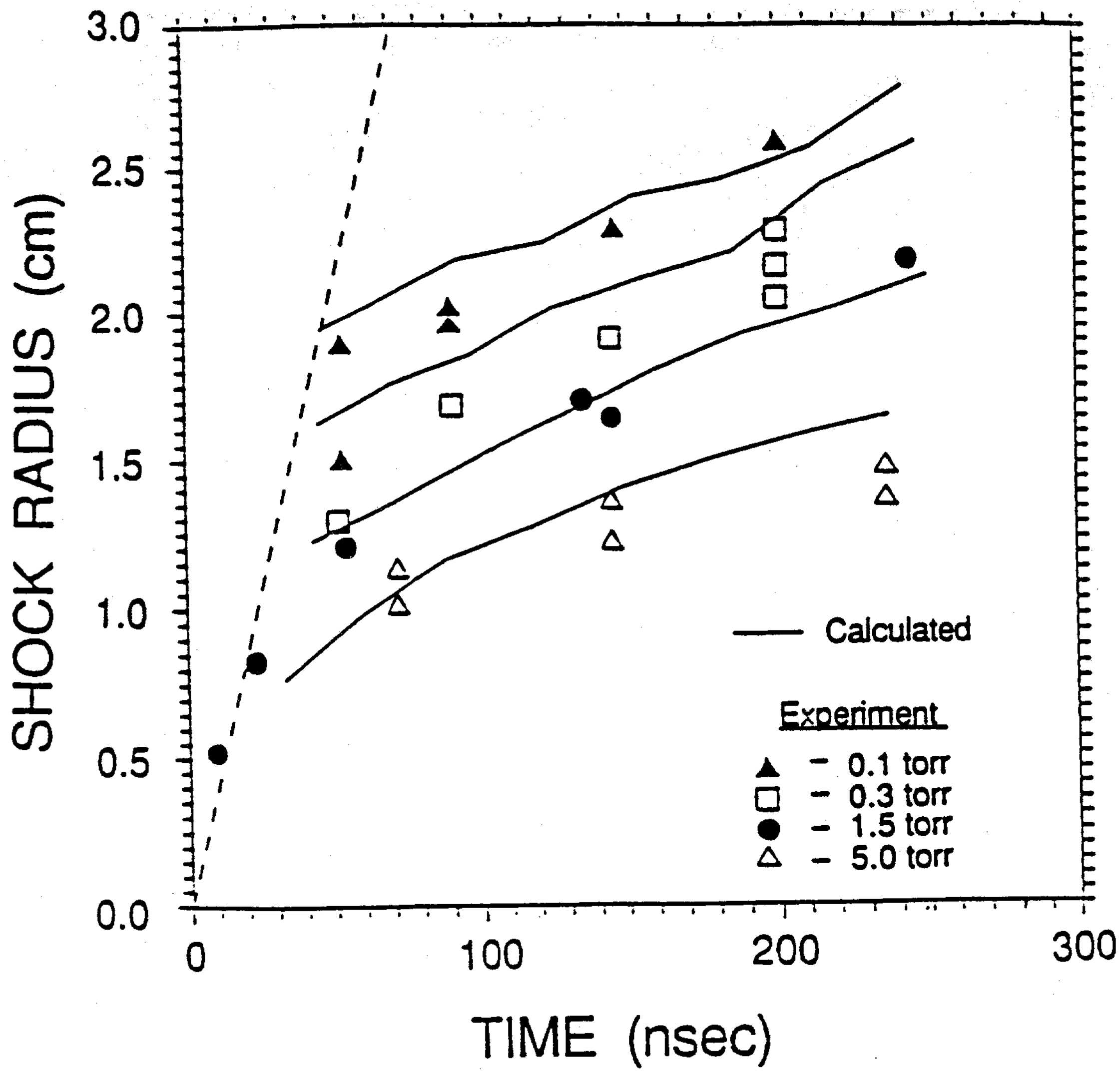
Magnetic Turbulence



1.5 Torr of 90%N_2 + 10%H_2
B=600 G

BUCKY Simulations Versus Gas Density without Radiation Transport

BACK-UP #2



Without radiation transport, predicted shock speeds for high gas densities were too high.