Formation and self-similar expansion of a spheromak configuration in the absence of a flux-conserving boundary

P. M. Bellan, Caltech

(J. Yee PhD thesis)

Overview

- Experimental study of spheromak formation physics
  - how helicity is injected
  - dynamics of topology

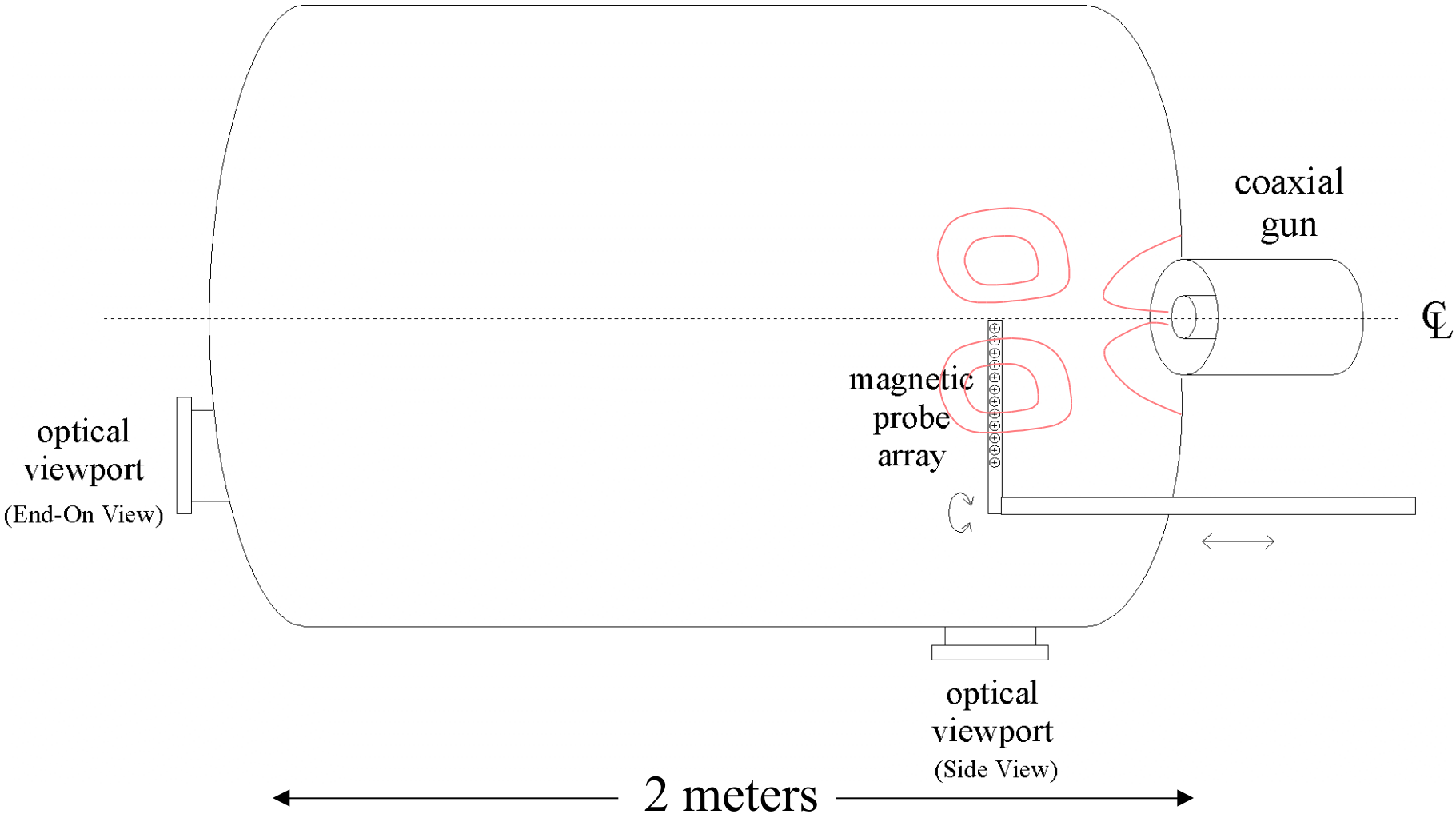
Experimental method

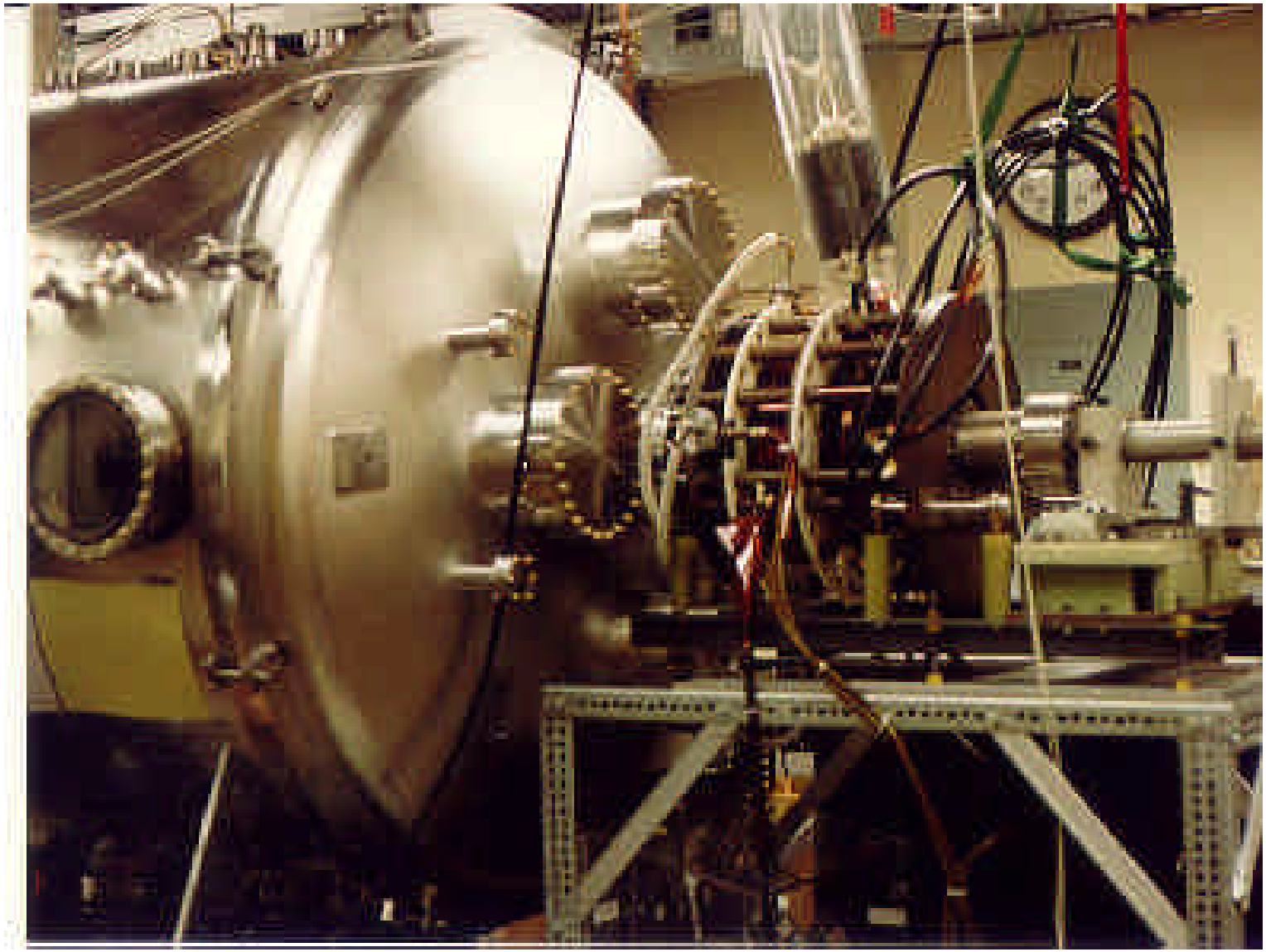
- Use a coaxial magnetized plasma gun
- Inject helicity into a very large vacuum chamber
  - effectively no flux conserver (wall)
  - plasma can freely expand
- Follow what happens on fast time scale
  - using high speed cameras, B-probe array

Main results

- Find that spheromak configuration (closed flux surfaces) formed even though there is no flux conserver
- Lamba profile is peaked at magnetic axis indicating that spheromak is decaying
- Lambda profile decay consistent with self-similar geometric expansion

Setup


coaxial
gun
℄
magnetic
probe
array
optical
viewport
(End-On View)
optical
viewport
(Side View)
2 meters



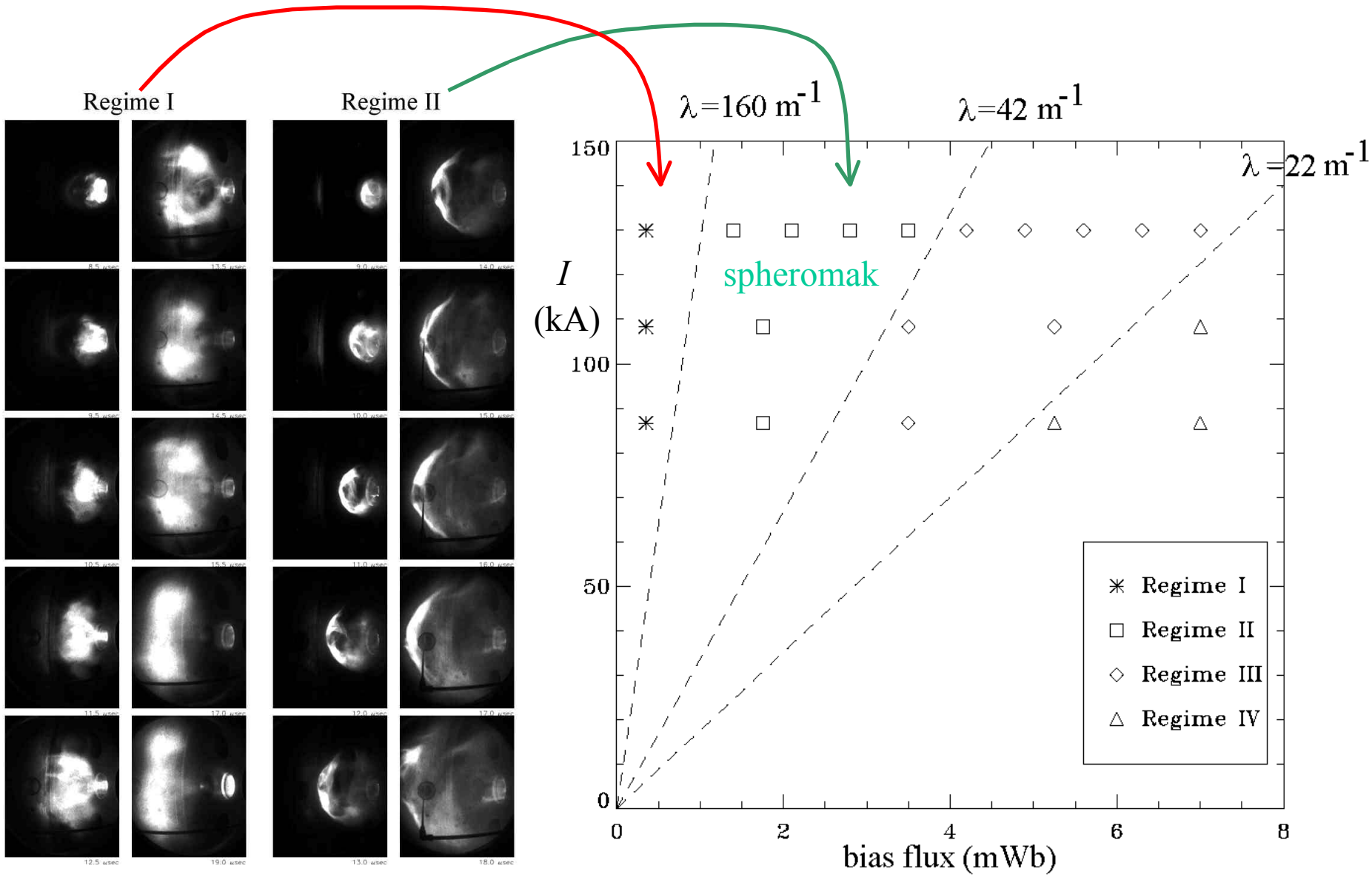
A coaxial spheromak source has essentially two knobs

1. The gun current I
2. The gun bias flux Φ

What counts is the ratio:

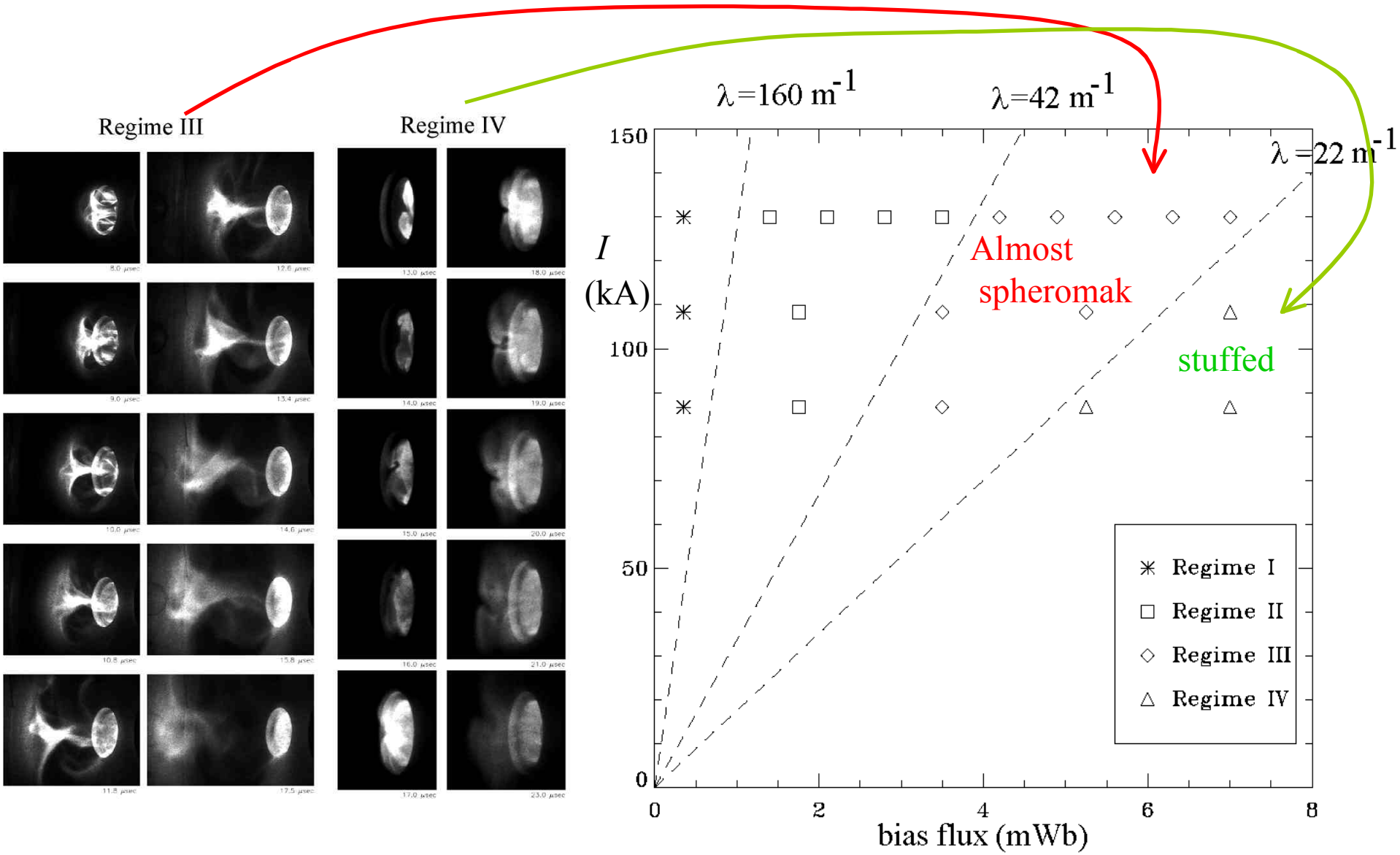
$$\lambda_{\text{gun}} = \frac{\mu_0 I}{\Phi}$$

Four Distinct Operational Regimes:



Side view photos

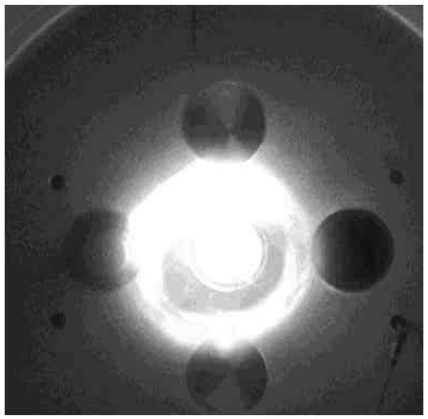
Four Distinct Regimes:



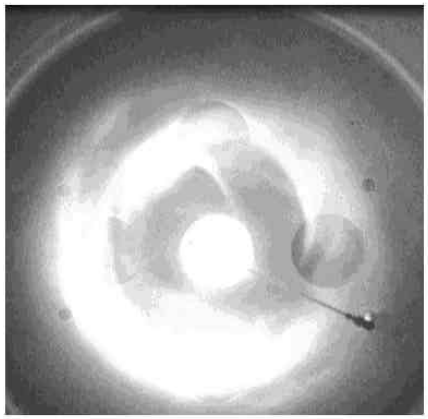
Regime II

Spheromak

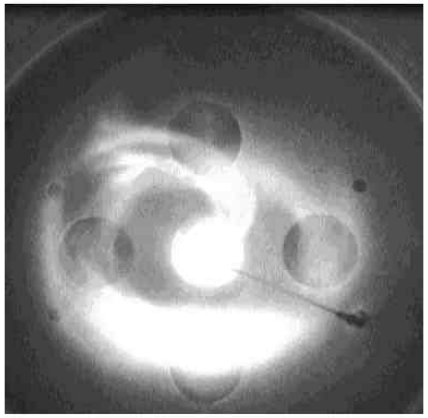
End-on view



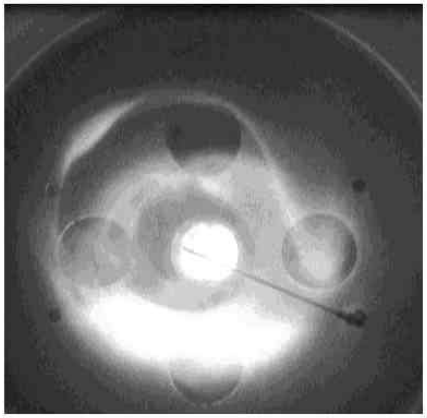
11.0 μsec



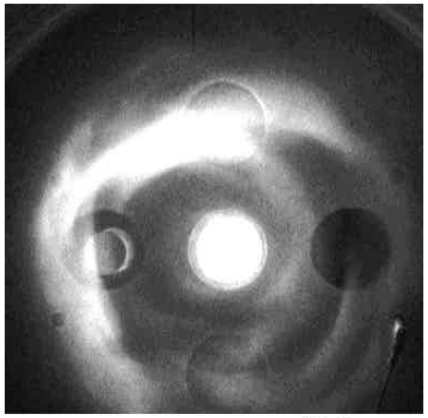
14.0 μsec



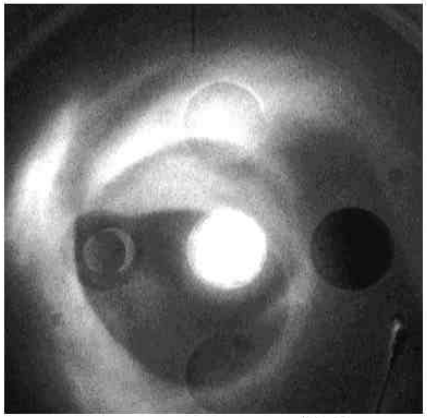
14.5 μsec



15.0 μsec

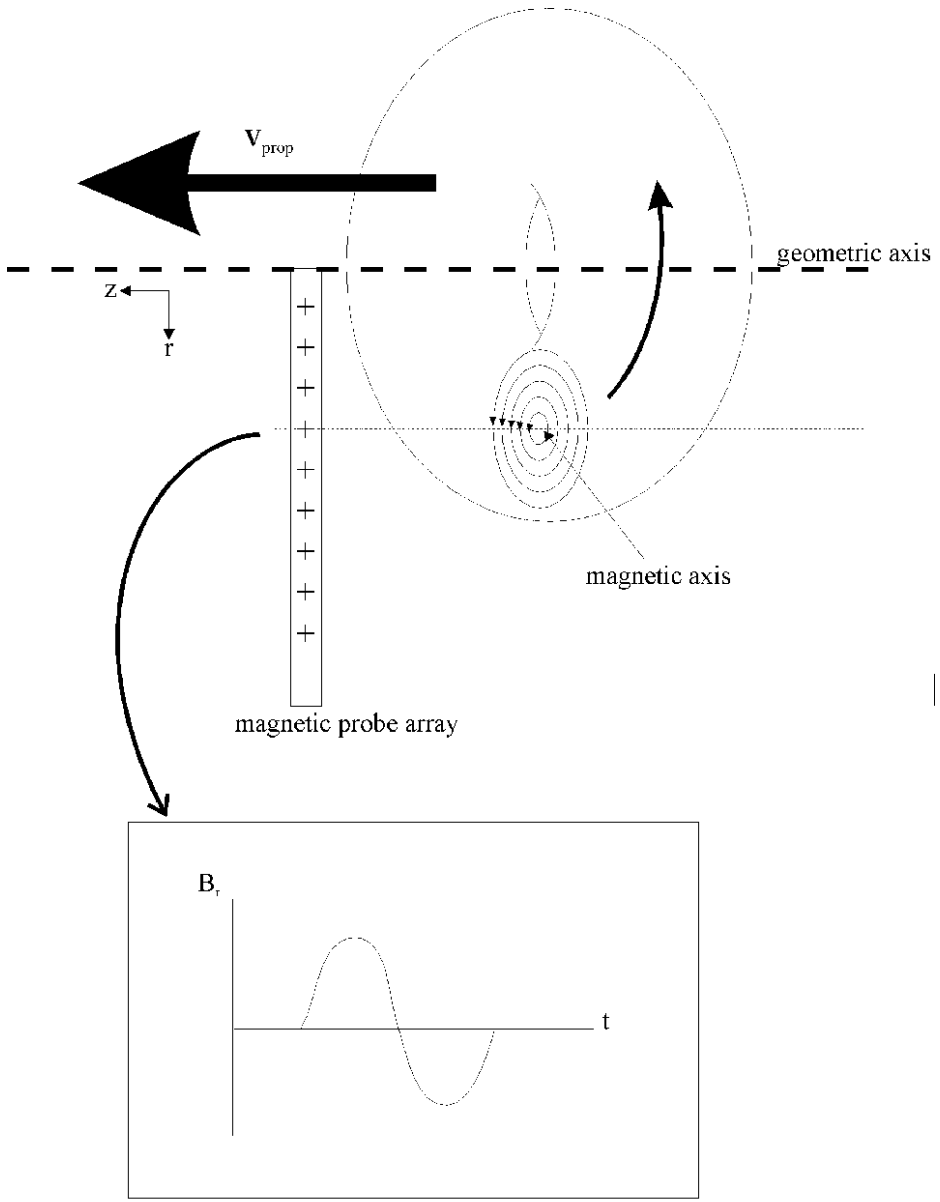


15.5 μsec

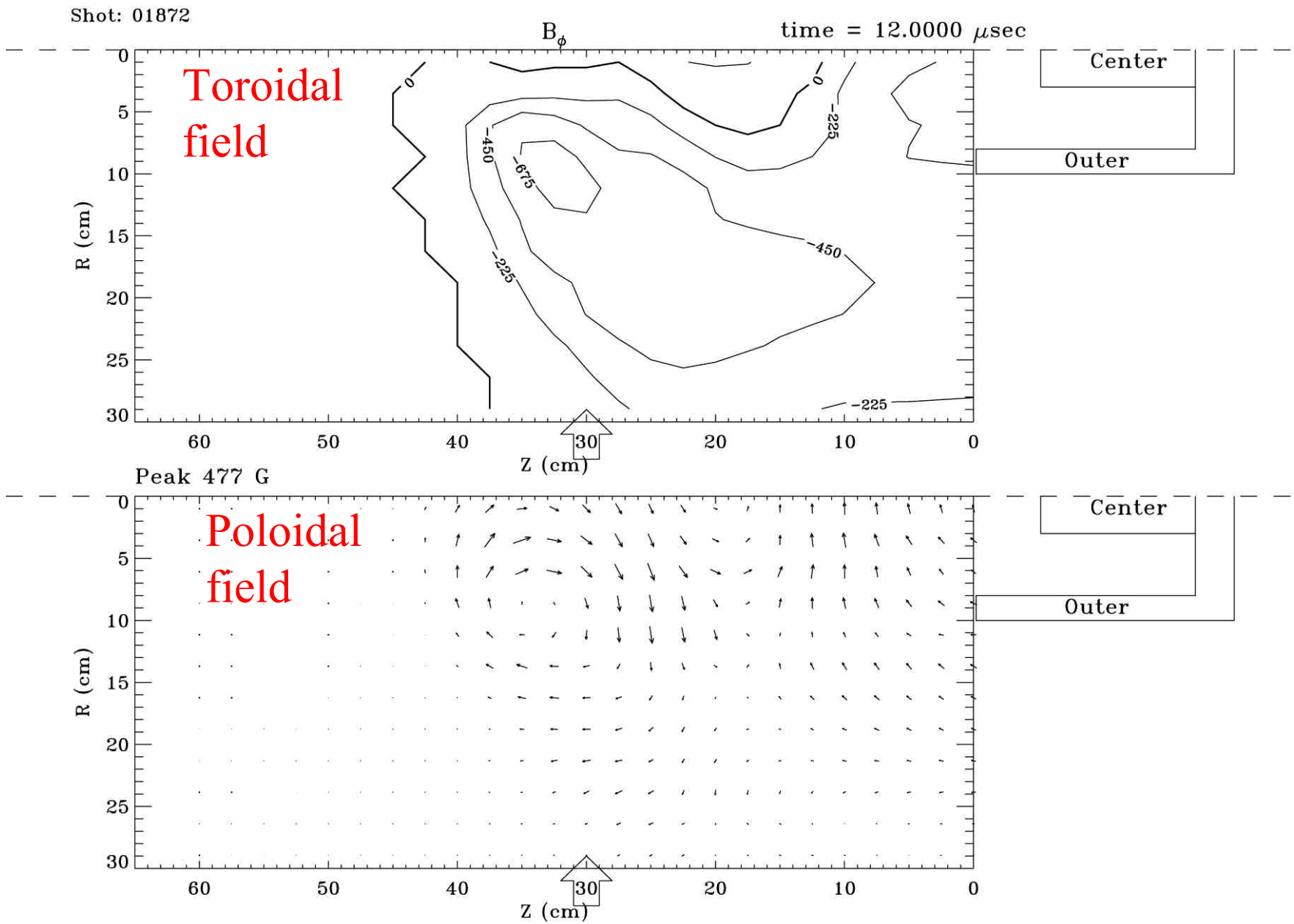


16.0 μsec

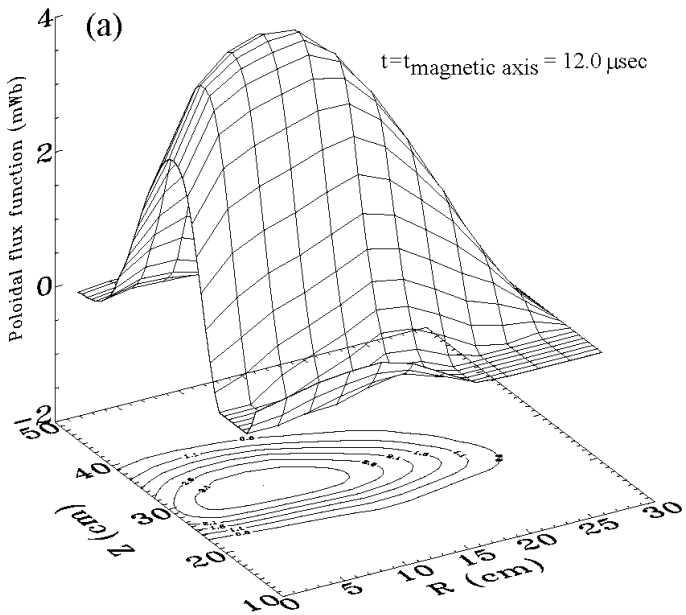
Infer 3D magnetic field profile in single shot using axial propagation

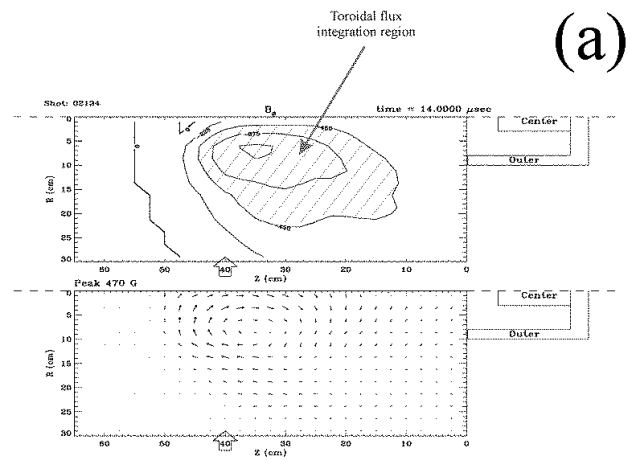


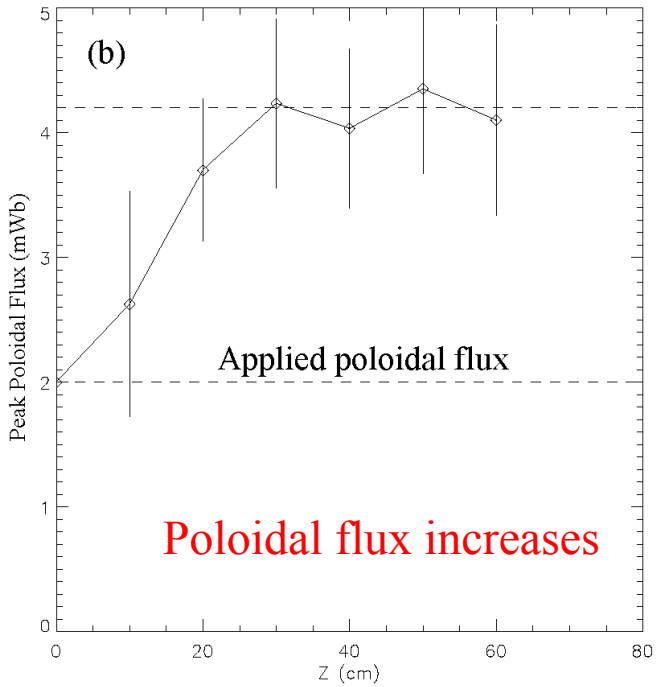
Data from a single shot (using propagation technique)

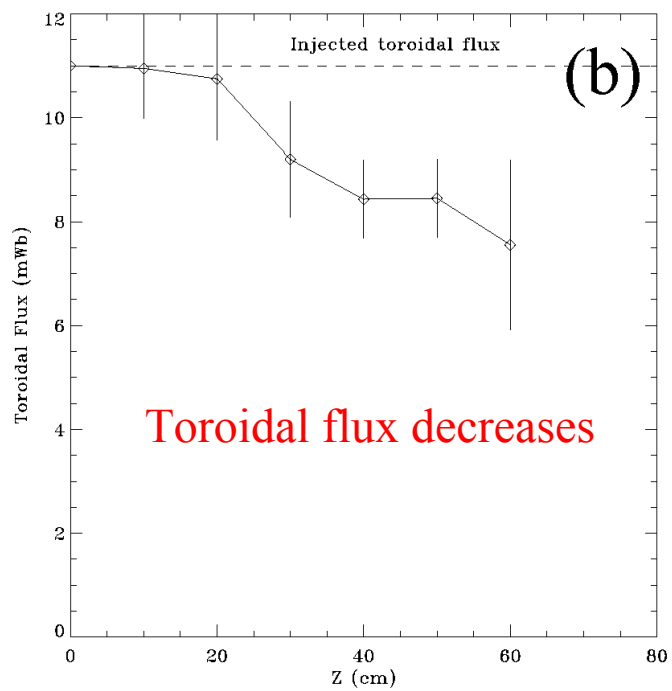


Evidence of flux amplification

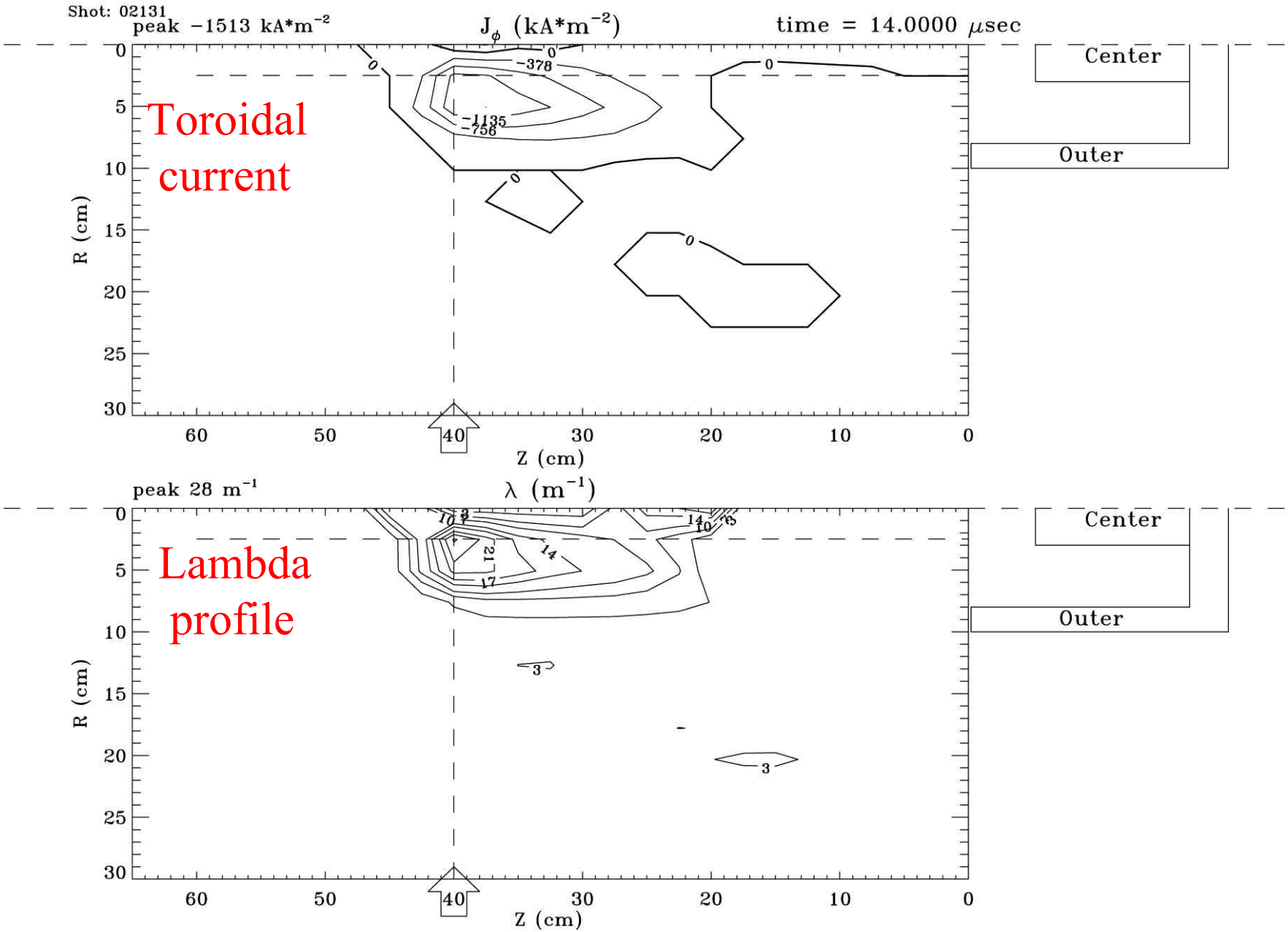




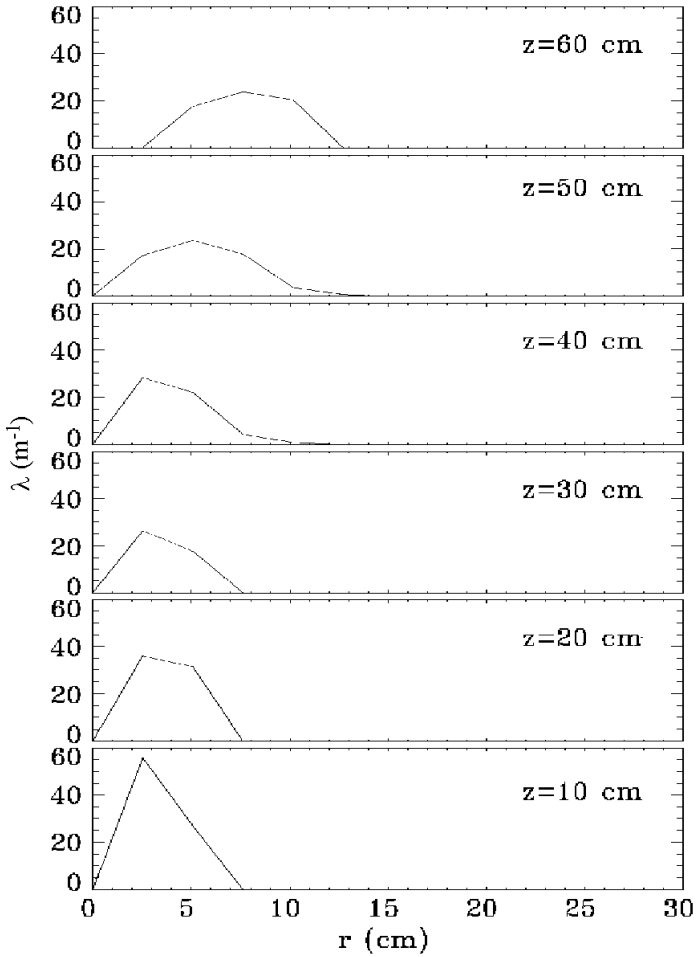


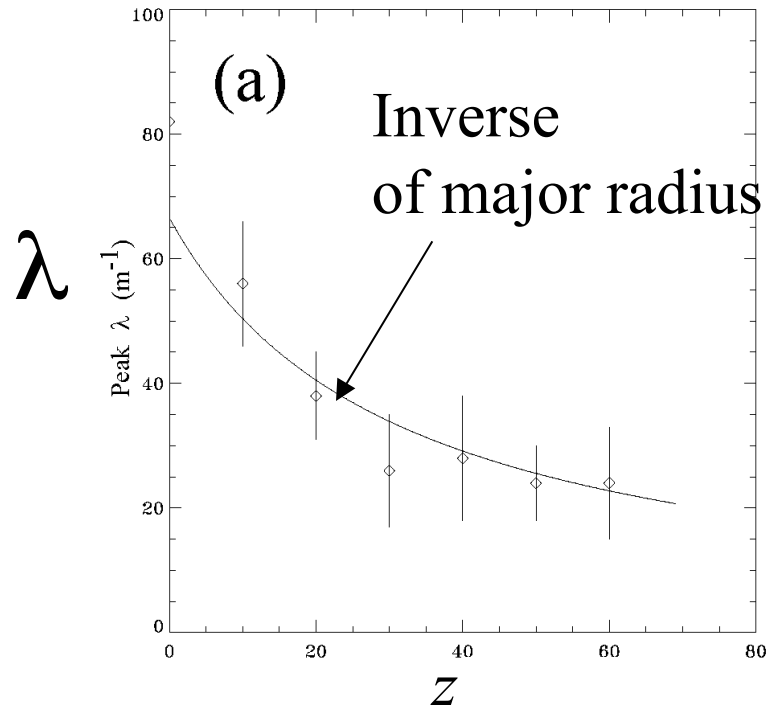


Measurement of lambda profile



Lambda decay





Entire λ decay explicable in terms of self-similar expansion (no helicity decay)

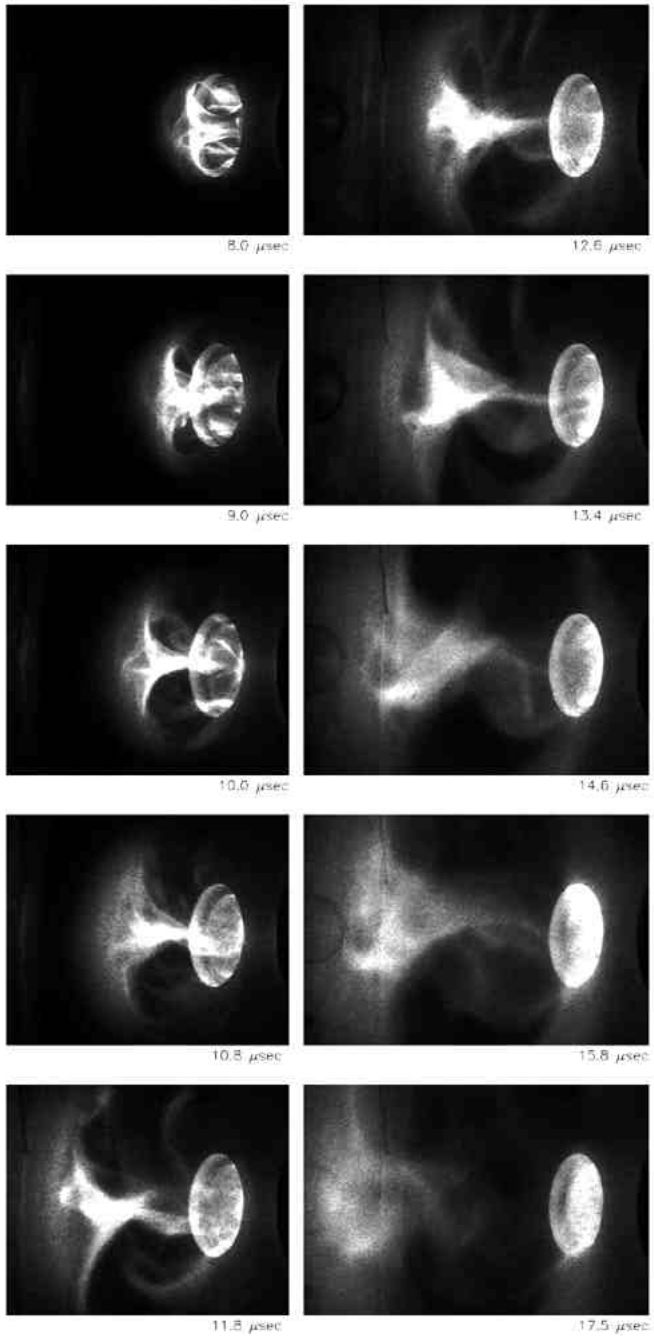
Spheromak configuration formed even though there is no flux conserver

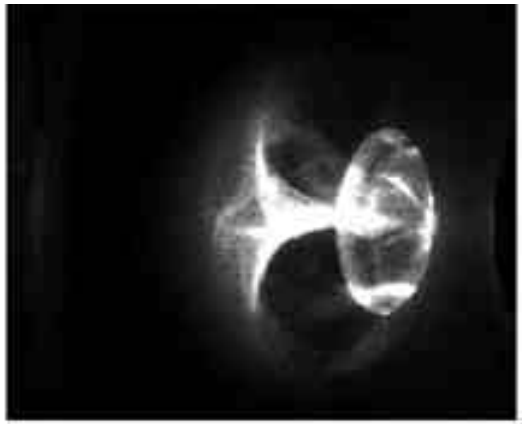
Hypothesize that inertia plays role of wall

Regime III

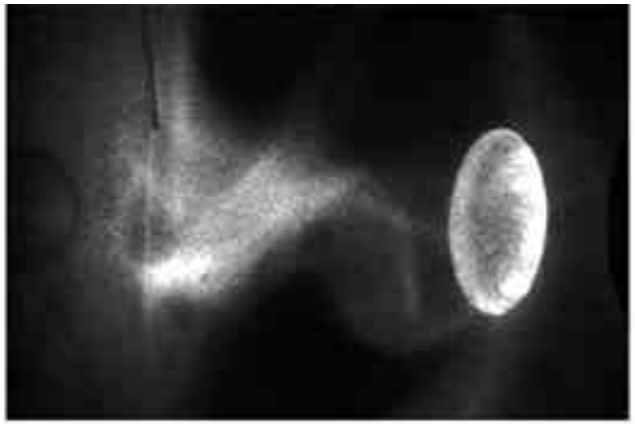
Almost spheromak

Regime III

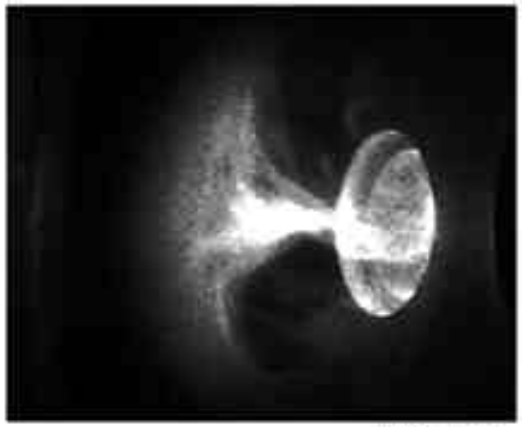

8.0 μsec
12.6 μsec
9.0 μsec
13.4 μsec
10.0 μsec
14.6 μsec
10.8 μsec
15.8 μsec
11.8 μsec
17.5 μsec



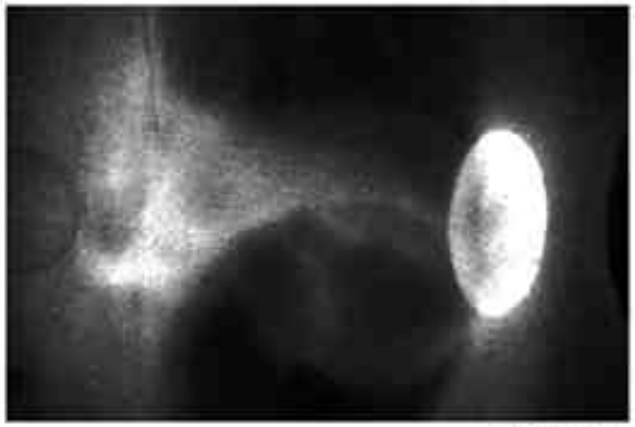
10.0 μsec



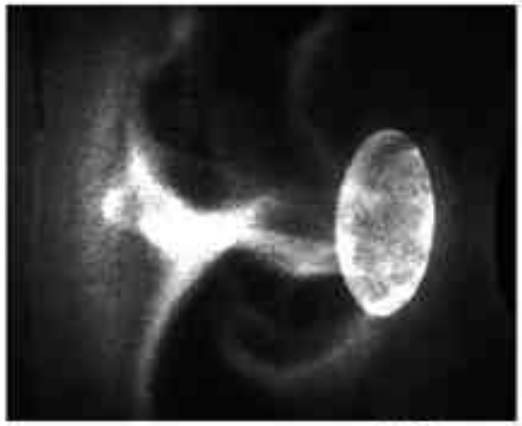
14.6 μsec

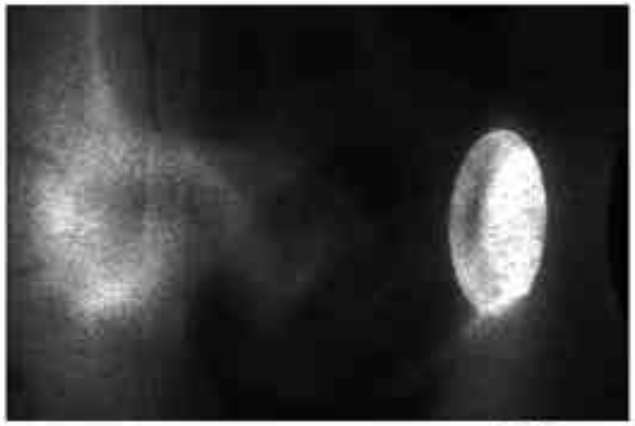


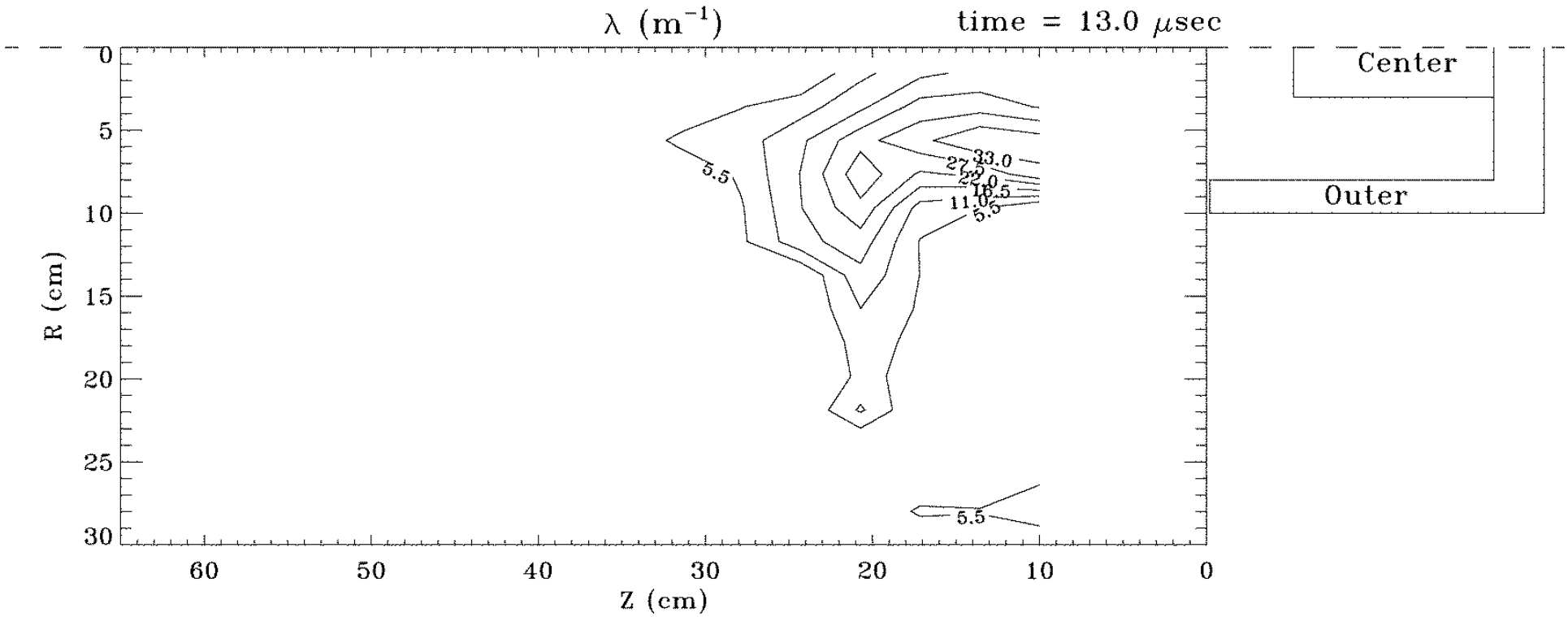
10.8 μsec



15.8 μsec

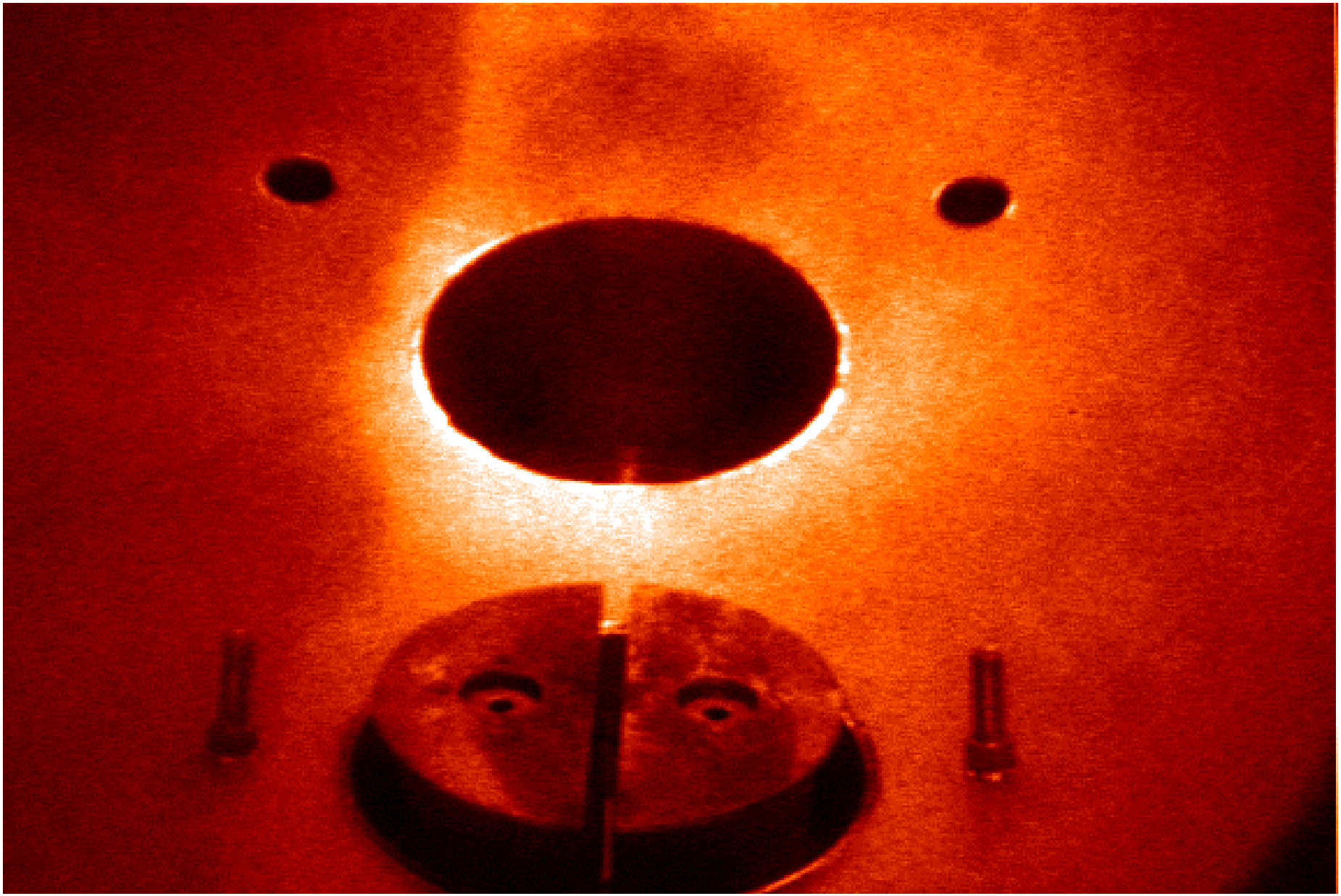


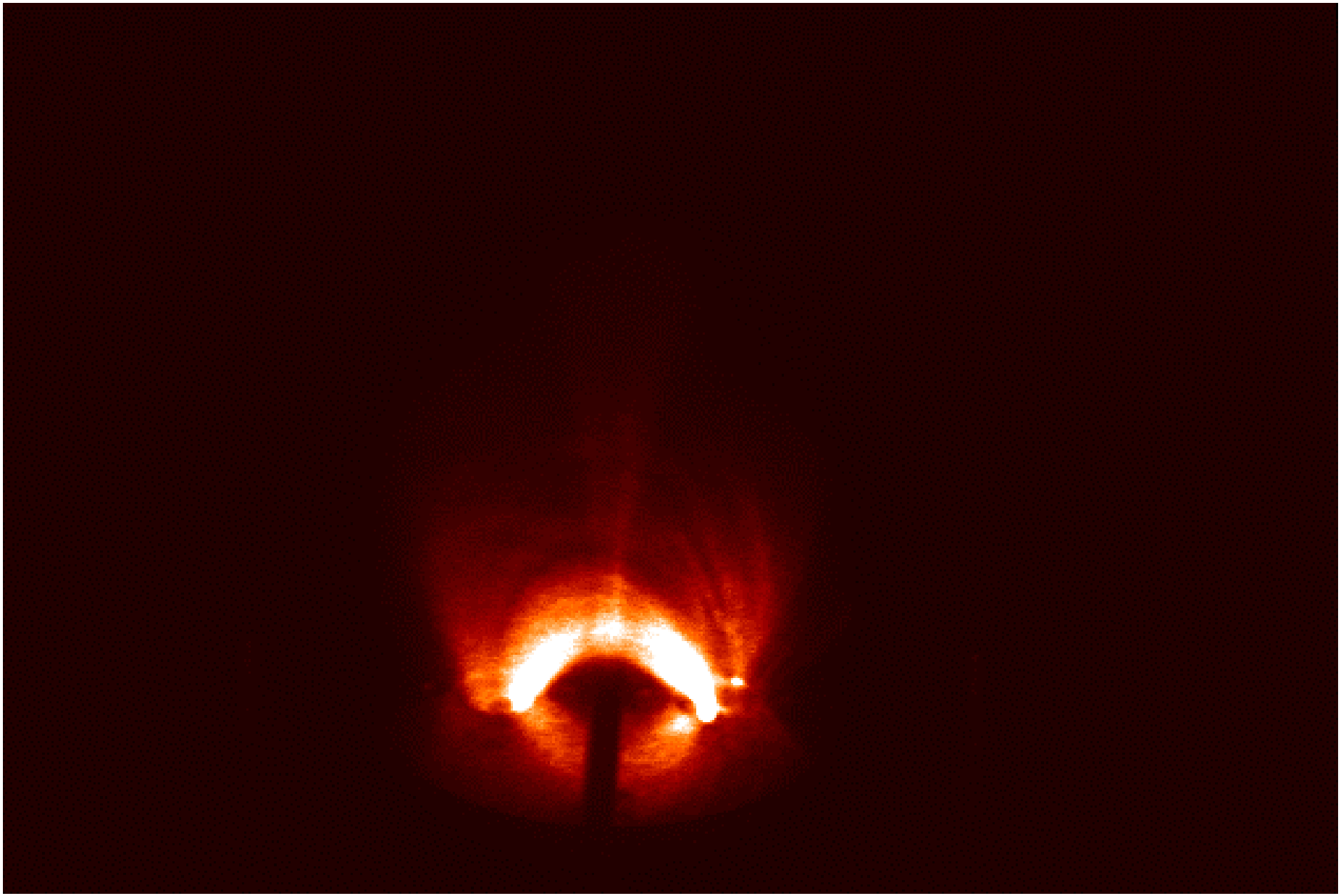


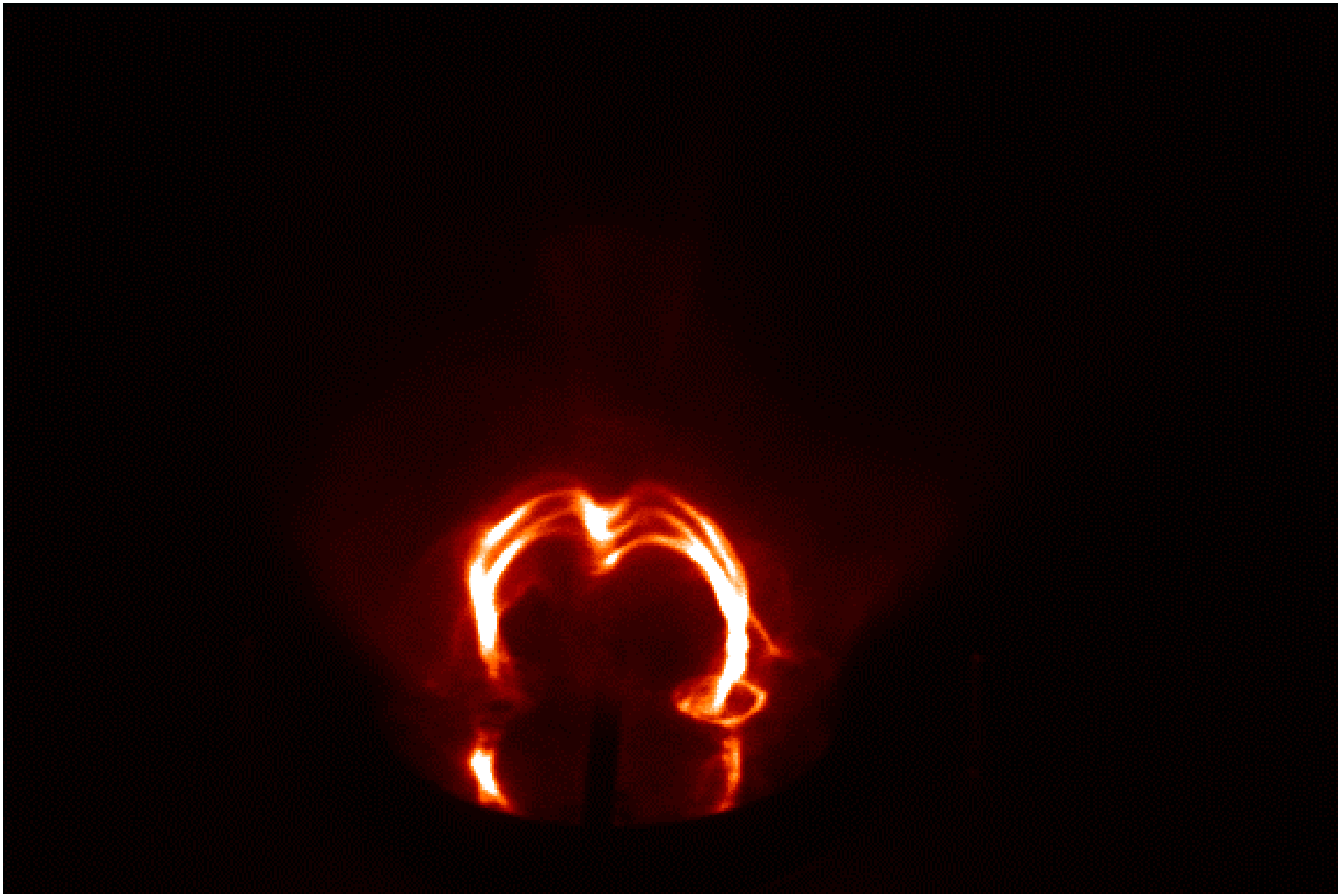

λ (m⁻¹)
time = 13.0 μsec
Center
Outer
R (cm)
Z (cm)
0
5
10
15
20
25
30
60
50
40
30
20
10
0
5.5
33.0
27.5
22.0
16.5
11.0
5.5
5.5

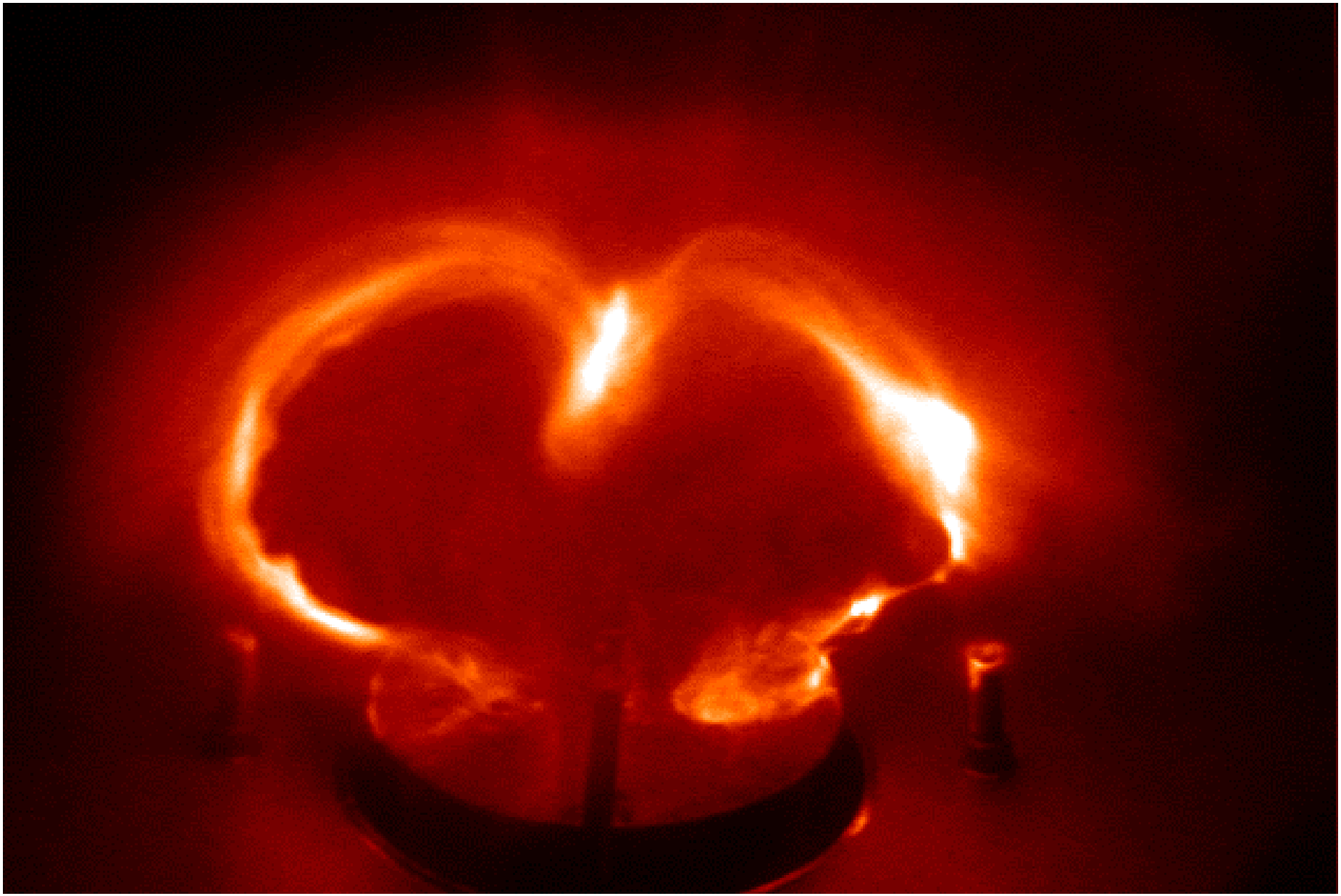
Solar prominence simulation (uses spheromak technology)

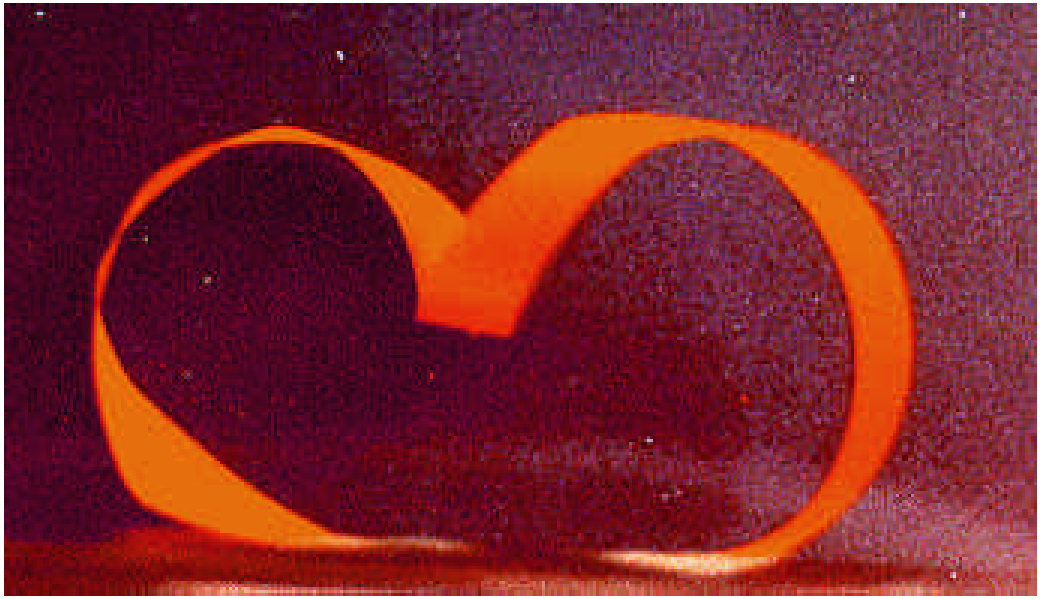
P. M. Bellan and J. F. Hansen



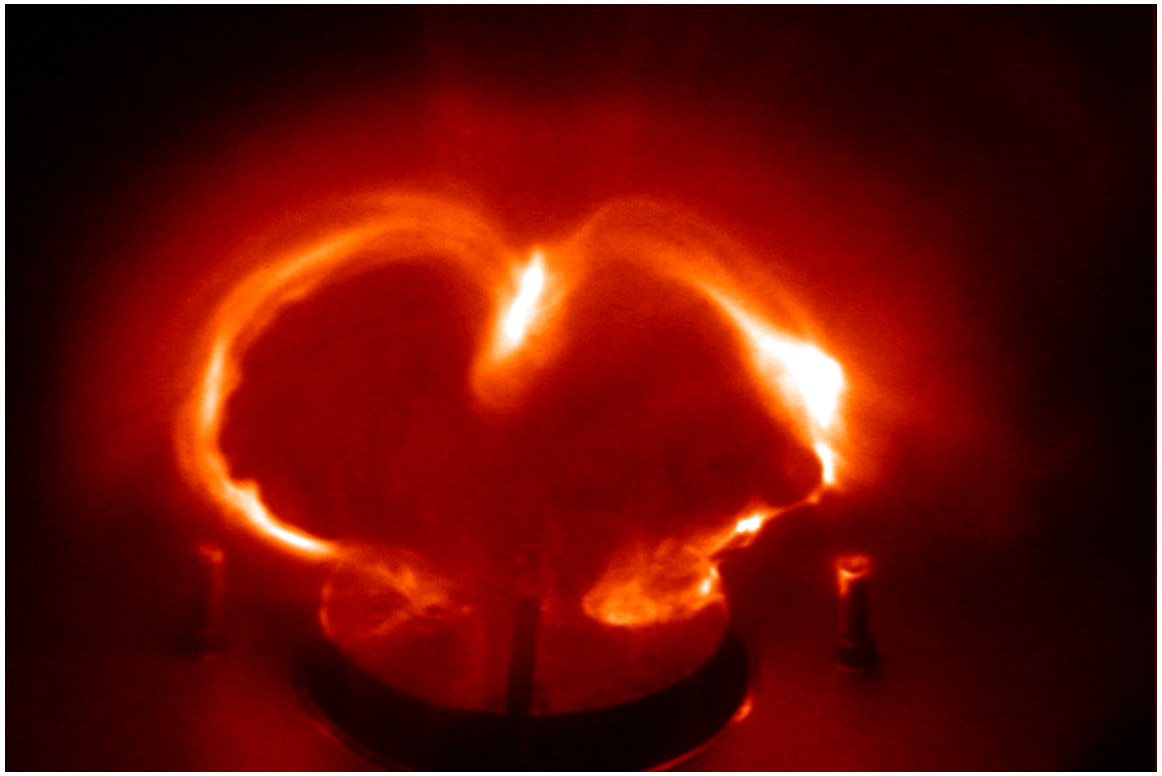






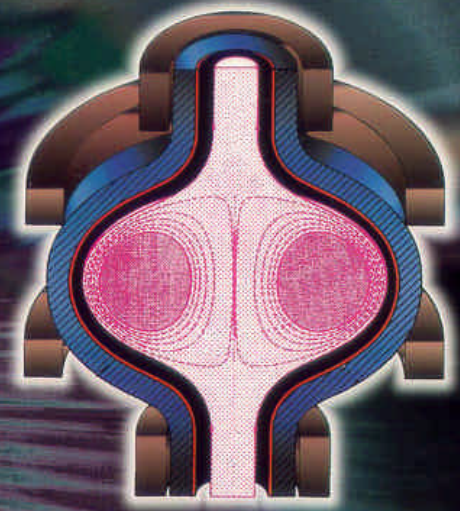


Twisted ribbon
(gift wrapping)



Experiment

Paul M. Bellan



A Practical Application of Magnetohydrodynamic Dynamos and Plasma Self-Organization

SPHEROMAKS

Imperial College Press