Orbits in Superconducting RF Cavities: A Challenge for Established Physics II

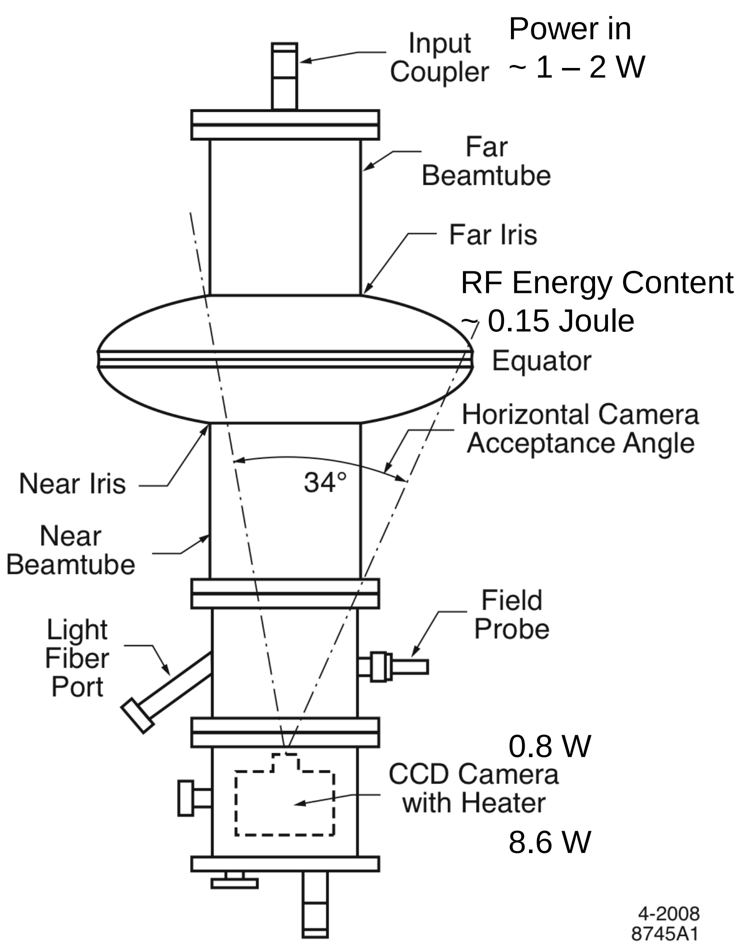
I. **Experimental Collaboration and Some References**

- ALE (Anomalous Light Experiment) Collaboration
- P. L. Anthony, J. R. Delayen, D. Fryberger. W. S. Goree, J. Mammosser, Z. Szalata, and J. G. Weisend II, "Experimental studies of light emission phenomena in superconducting cavities," *Nucl. Instr. and Meth.,* **A 612**, 1 (2009); (M. Sullivan[SLAC], B. Terzić[JLAB], L. Phillips[JLAB], and G. Ciovati[JLAB] have also joined the ALE collaboration.)
- J. R. Delayen and J. Mammosser, *Proc. of PAC*, New York ('99).
- D. Fryberger, "A small particle model as a possible explanation of recently reported cavity lights," *NIM* **A**, **459**, 29 (2001).
- D. Fryberger, "On the Formulation of a Viable Model to Explain Recently Reported Cavity Lights," To be submitted for Publication.

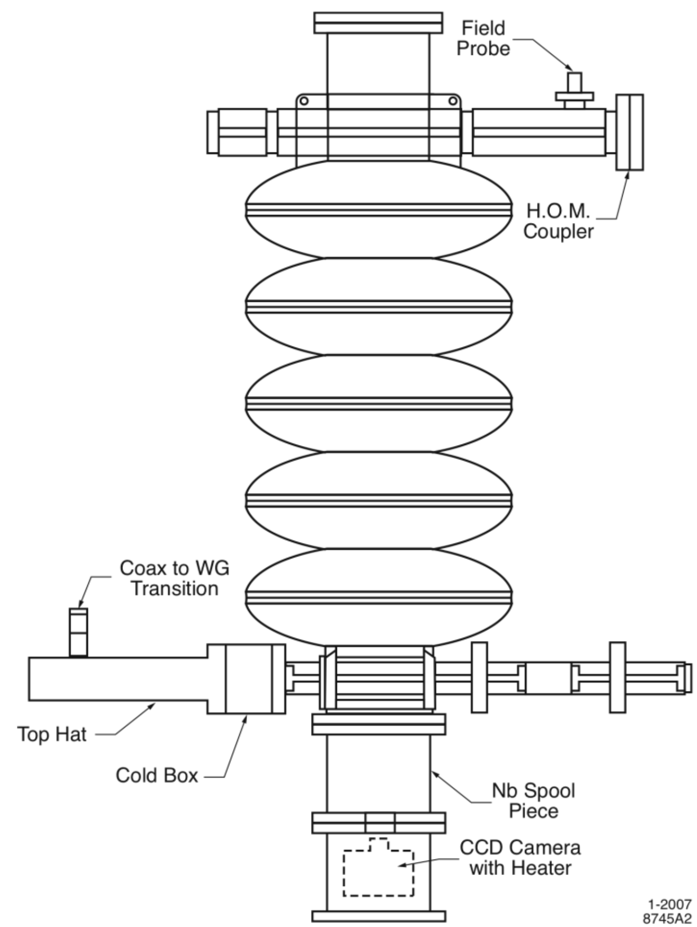
II. **Experimental Set-up**

Depiction of Cavities (1.5 GHz) with CCD Cameras

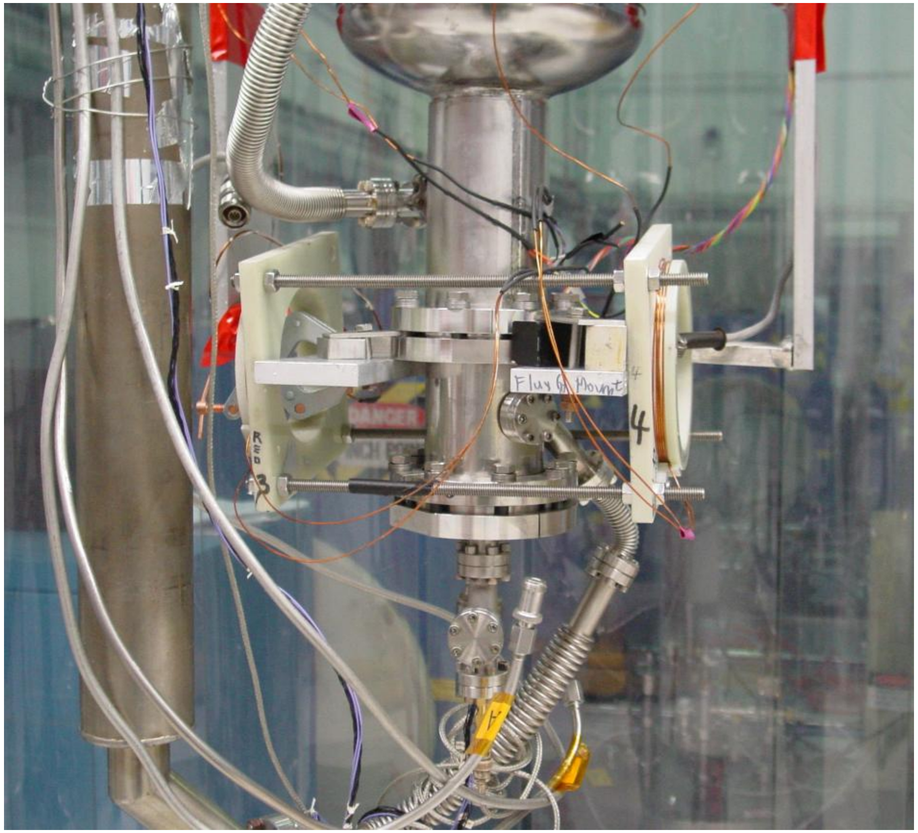
Single-Cell



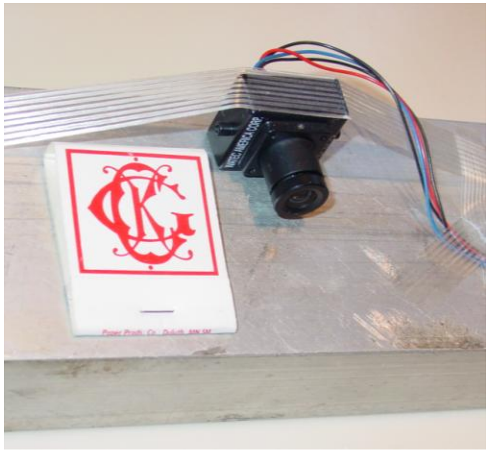
Five-Cell



Cavity mounted on stand + photo of Micro Camera



P4-1311



WATEC Model WAT-660A
CCD Monochrome Camera
Pixel Count: 537(H)X505(V)

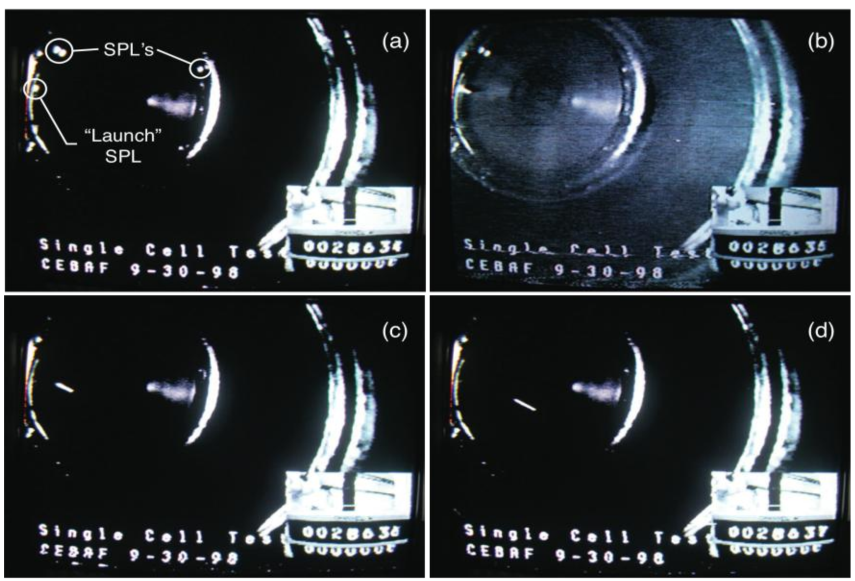
➔ 271,185 Pixels

III. Particle Tracking by VHS Video

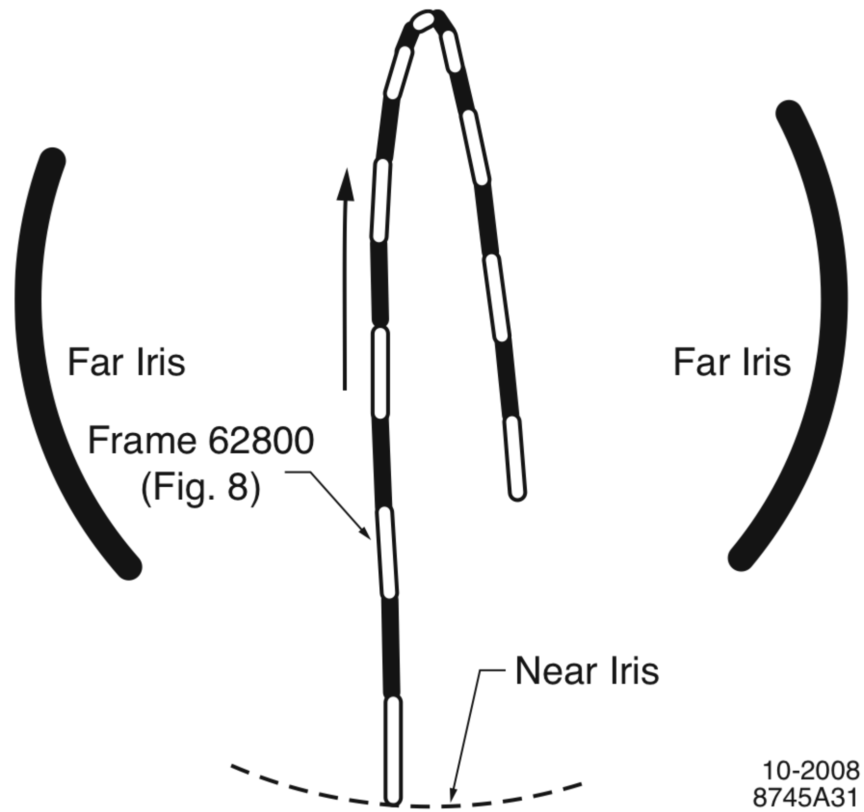
MLO's as seen in Interlaced Fields in (30 Hz) VHS Frames

MLO = **M**obile **L**uminous **O**bject (Usually follows a **Flash**)

SPL = **S**tationary **P**oint of **L**ight
(Attributed to Field Emission Sites)



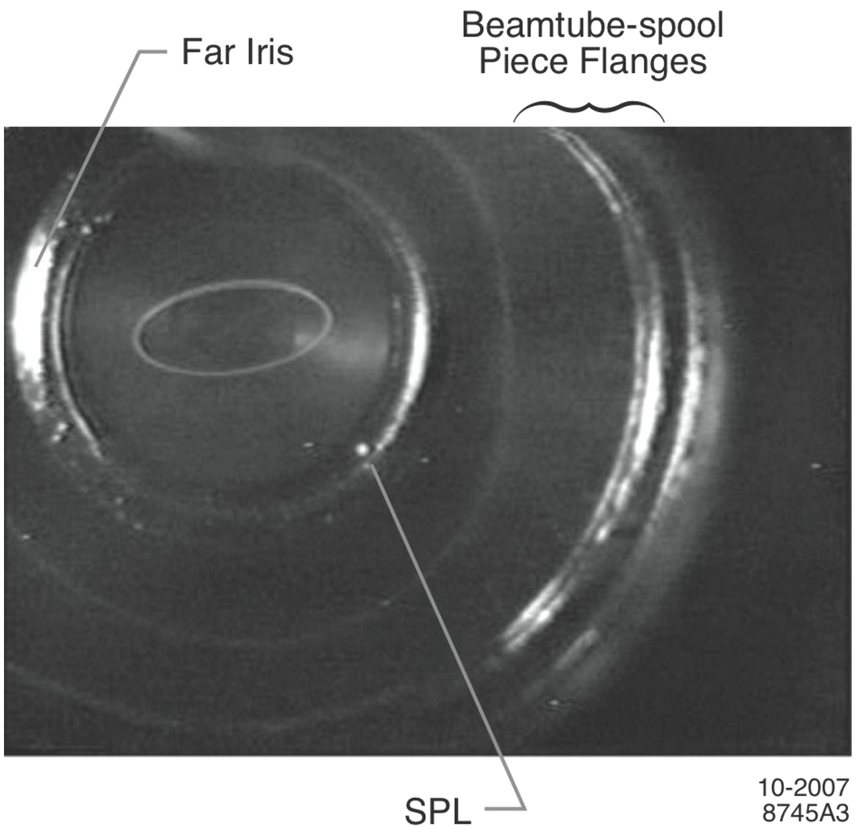
Note PIP Insert for Frame Counter



Two Fields/Frame

IV. Some Stable Closed Orbits (One VHS Field)

Mode I behavior – Ballistic in Nature



A Beautiful Ellipse! (80 Hz, > 1 s, Run 1)

537 Pixels

505

An Elliptical Orbit (40 Hz, 40 s)

(Run 10)

Elliptical orbits are nicely described (to 1st order) by ballistic motion in a cylindrically symmetric harmonic oscillator potential well.

Track ~ 13(w) X 200(l) = 2600 Pixels

Rate ~ 10^{15} (optical) photons/s or ~ 0.3 mW

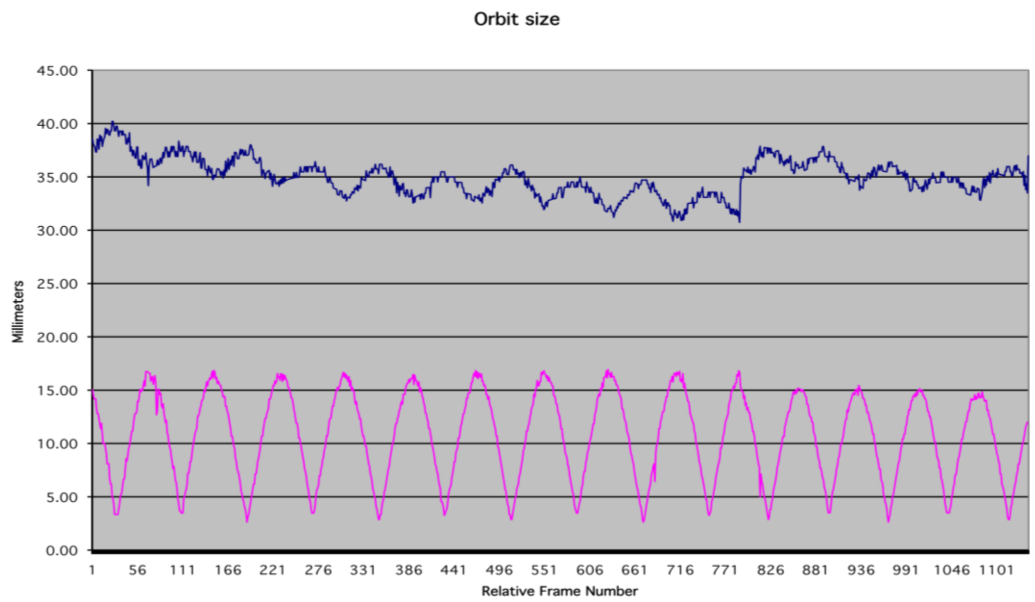
V. Video of (Mode I) Orbits and Flashes

Features to look for:

- Orbits in a Single-Cell Cavity. Note the MLO Reflections in the Beam-Tube
- Orbits in 5-Cell Cavity: Flash, Orbit Formation, and Precession of Pair of Orbits
- Orbit in a (different) Single-Cell Cavity: Flashes, Onset of MLO Tracks, and the Rocking and Precessing of the Elliptical Orbit. Note the Track Reflections in the Beam Tube near the Weld Seam.
- Note that these orbits are all ballistic in nature

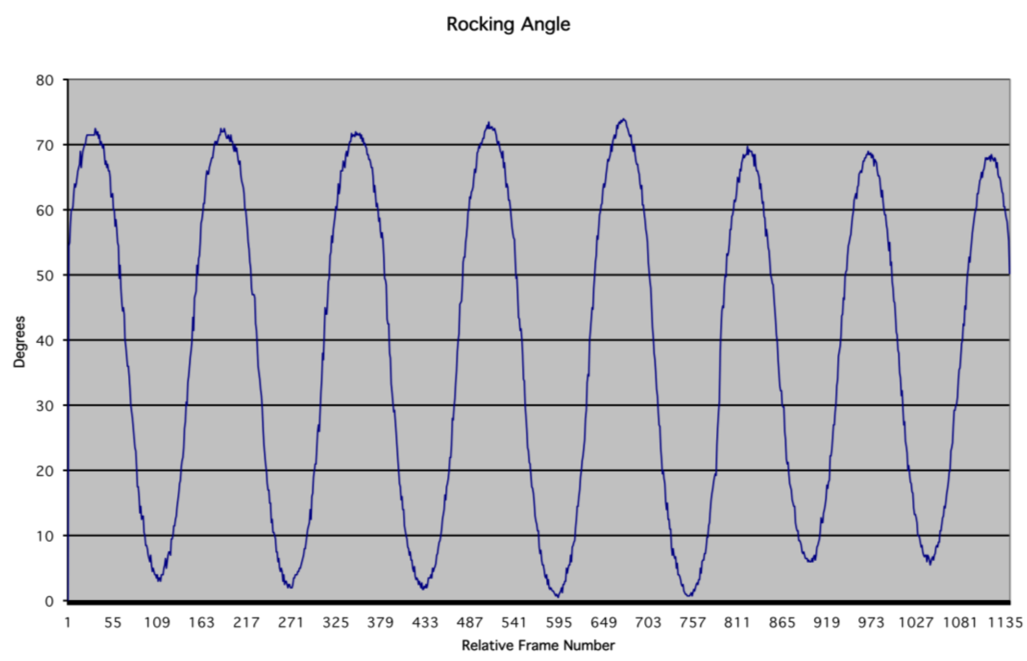
Experimental Plots obtained from the 40 s, 40 Hz Orbit

Orbit Size
(Millimeters)



Rocking Angle
(Degrees)

Rocking Period ~ 5 s



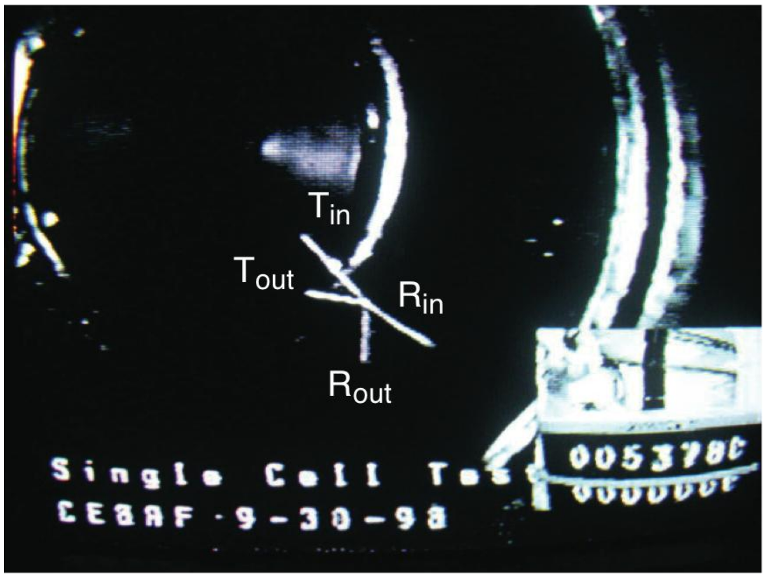
VI. Salient Physics Questions about MLOs

- What is the process of MLO formation?
- How is the flash related to the MLO formation process?
- **What is the MLO made of? What holds it together?**
- **How large is the MLO? Where is it in the cavity?**
- **What are its interactions? (Assume Electromagnetism)**
- **What accounts for the tendency to elliptical orbits?**
- **What accounts for radial and axial stability of orbits?**
- **What factors determine the orbital frequency?**
- **Why do orbits precess? What determines the rate?**
- **What causes the rocking of the orbital precession?**
- What is the mechanism for light emission?
- What causes MLO disappearance?

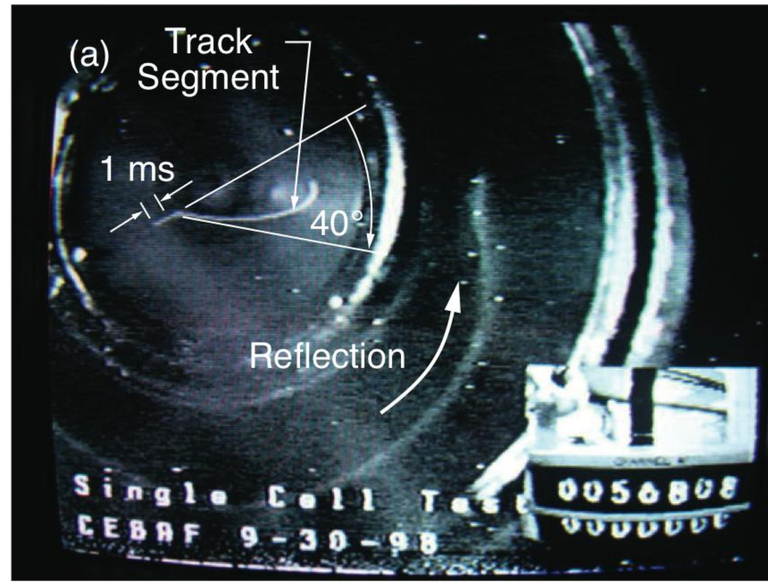
VII. Data Indicates MLOs are Small Discrete Objects

And that these objects carry mass and momentum

- Wall-Bounce Event



An apparent MLO mid-vacuum collision



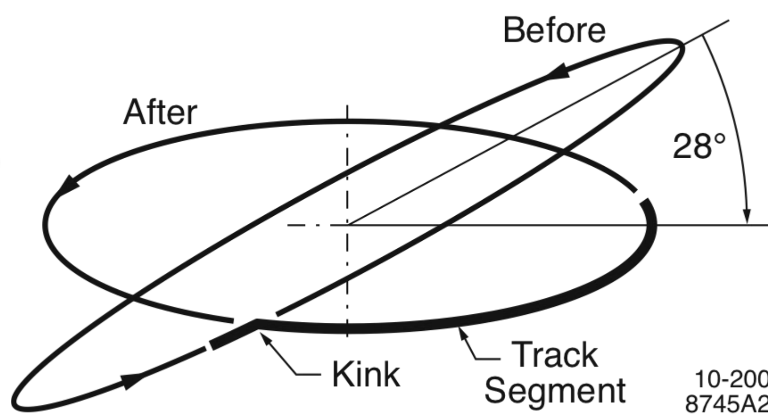
(b)

Data indicates visible MLO diameter ≤ 1.5 mm

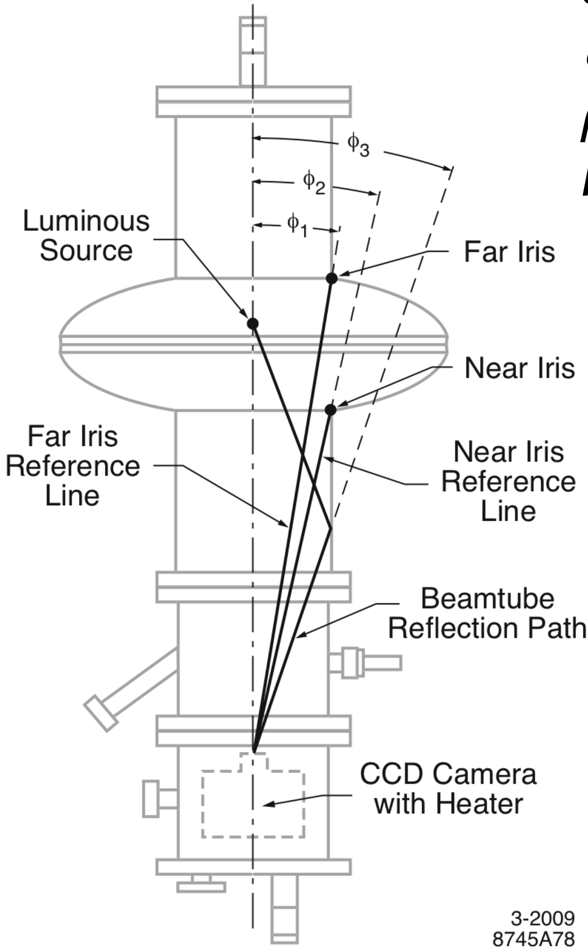
Eccentricity:

$$\text{Before:}\quad \varepsilon = 0.99$$
$$\text{After:}\quad \varepsilon = 0.95$$

$$\varepsilon \equiv \frac{\sqrt{a^2 - b^2}}{a}$$



VIII. Use geometry to find *z*-location of MLO orbit



d_i = i^{th} distance (in cm) from lens along the *z*-axis
d_{ep} = distance from lens to equatorial plane = 22 cm
ϕ_i = angle (in degrees) from z-axis to i^{th} ray
ρ_i = radius (in cm) of i^{th} ray in the equatorial plane
R_i = radius of measurement of i^{th} point in cavity image

$$\phi_i = \mathrm{a}\tan(3.5/d_i) \qquad \rho_i = d_{ep}\tan\phi_i$$

i	d_i	ϕ_i	ρ_i	R_i	ρ_i/R_i
1	26	7.67	2.96	2.0	1.481
2	16.8	11.77	4.58	3.18	1.441
AVE					1.461+-0.02
					↓
3	21.95	17.8	7.04	4.82	← 1.461

$d_3 - d_{ep}$ = – (0.05+-0.4) cm

$\cos^2(17.8) = 0.91$

IX. Five Criteria for successful MLO Model Calculation for Mode I Behavior

(Derived from the Mode I Behavior of the MLO orbits)

- Does the Model afford Radial Stability?
- Does the Model afford Axial Stability?
- Is there a Positive Correlation between Orbit Direction and Precession Direction?
- Is there a Mechanism to enable the Rocking of the Orbital Precession? (What breaks the cylindrical symmetry?)
- Is there an Adequate (radial) Force to Orbit an ordinary Solid or Liquid Material?

X. EM Field Plots in the Equatorial Plane (TM_{010} Mode)

E field is peak in the center of the cavity and diminishes with radius in the equatorial plane:

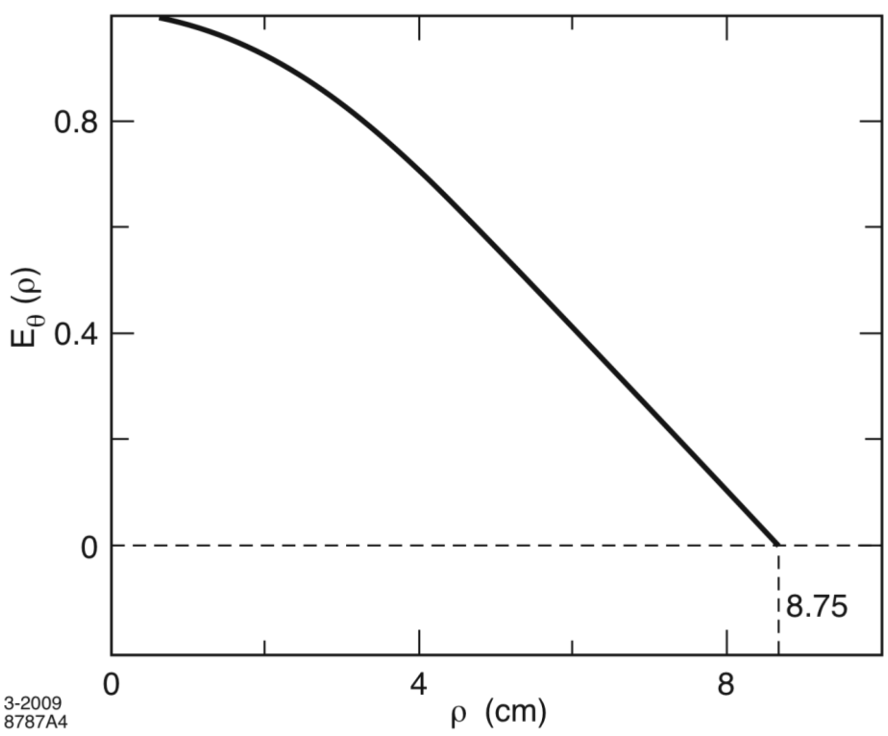
B field is null on the *z*-axis and "linear" with radius

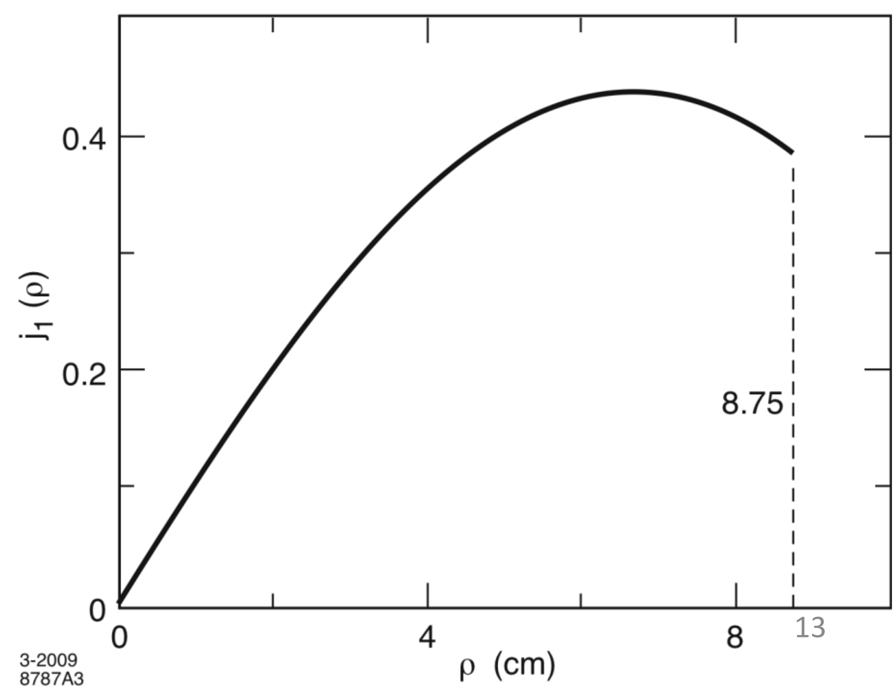
R_S is radius of spherical cavity of 1.5 GHz

(R_S = 8.75 cm)
(R_A = 9.4 cm)
or ~ 7.5%

$$E_\theta \sim \frac{R_S}{2.75\,\rho}\left[\frac{2.75\,\rho}{R_S}\, j_1\!\left(\frac{2.75\,\rho}{R_S}\right)\right]'$$

$$B_\phi \sim j_1\!\left(\frac{2.75\,\rho}{R_S}\right)$$



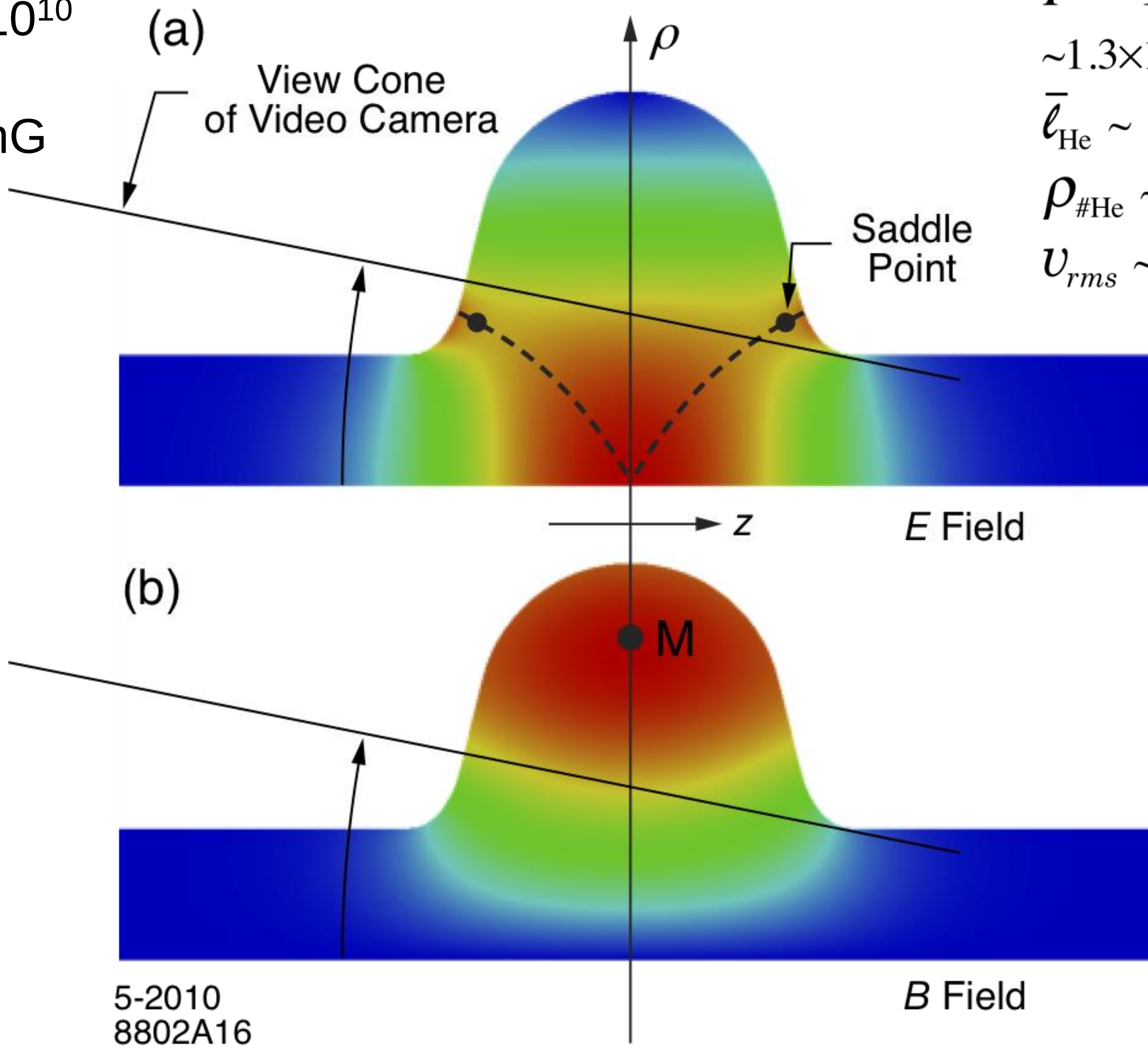


EM Fields in TM_{010} Mode in (Nb) SC RF Cavity

1.5 GHz (CW)
4-6 MV/m
$Q \sim 10^9 - 10^{10}$

$\boldsymbol{B}_{dc} < 20$ mG

$T = 2$ K
$P \sim 10^{-8}$ Torr
$\sim 1.3\times10^{-7}$ dynes/mm^2
$\bar{\ell}_{He} \sim 100$ m
$\rho_{\#He} \sim 5\times10^{10}$ /cm^3
$v_{rms} \sim 10^4$ cm/s



OMEGA3P
(Z. Li)

Calculations for Orbit Simulations

Newton's Equations for the Iterative Orbital Calculation

$$\boldsymbol{F} = M\boldsymbol{a} = M\frac{\Delta \boldsymbol{v}}{\Delta t}\ ;\ \ \boldsymbol{v} = \frac{\Delta \boldsymbol{x}}{\Delta t}$$

Assume that Δt is small enough for a linear approximation.

[Used 400 calculations per (40 Hz) orbit = 16,000/s. Δt = 62.5 μs.
i is the iteration index.]

$$\Delta \boldsymbol{x} = \boldsymbol{x}_{i+1} - \boldsymbol{x}_i = \boldsymbol{v}_i \Delta t \qquad \Delta \boldsymbol{v} = \boldsymbol{v}_{i+1} - \boldsymbol{v}_i = \frac{\boldsymbol{F}_i}{M}\Delta t$$

or

$$\boldsymbol{x}_{i+1} = \boldsymbol{x}_i + \boldsymbol{v}_i \Delta t \qquad \boldsymbol{v}_{i+1} = \boldsymbol{v}_i + \frac{\boldsymbol{F}_i}{M}\Delta t$$

Now we need to get suitable expressions for the forces to study the various (Electromechanical) Models.

N. B. Gaussian Units are used.

XI. MLO Models using Established Physics

- **Neutral Conducting Sphere (NCS)**

Lorentz Force

Forces: $\boldsymbol{v} \times \boldsymbol{B}$ $\quad \nabla E^2$ $\quad \nabla B^2$

$$\boldsymbol{F}_{\mathrm{L}}^{(q)} = q\left(\boldsymbol{E} + \frac{\boldsymbol{v}}{c} \times \boldsymbol{B}\right)$$

- **Neutral Dielectric Sphere (NDS)**

Forces: $\boldsymbol{v} \times \boldsymbol{B}$ $\quad \nabla E^2$

- **Electrically Charged Particle (ECP)**

Pondermotive Force:

$$\boldsymbol{F}_{\mathrm{pm}}^{(q)} = \frac{-q^2 \nabla \boldsymbol{E}_0^2}{4 m \omega^2} \qquad \boldsymbol{E} = \boldsymbol{E}_0 \cos \omega t$$

- **Permanent Magnetic Dipole (PMD)**

Rare Earth Magnet (Nd-Fe-B)

SC Sphere (with trapped flux)

SC Toroid (with linked flux)

SC Spherical Shell (with trapped flux)

$$F_r^{(\mu_{\mathrm{m}})} = -\frac{3(\mu_{\mathrm{m}})^2 r}{a_{\mathrm{C}}^5 \left(1 - \frac{r^2}{a_{\mathrm{C}}^2}\right)^4} (1 + \cos^2 \theta_1) \mathbf{1}_r$$

a_{C} = equivalent radius of cavity

Neutral Conducting Sphere (NCS) [*NIM A*, **459**, 29 (2001)]

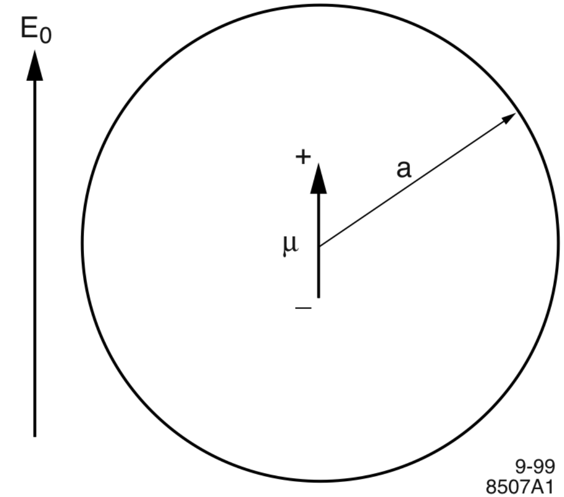
- TM_{010} mode in cavity

$$\boldsymbol{E} = E_{\mathrm{cc}} \mathbf{1}_z \cos\omega_{\mathrm{a}} t \qquad \boldsymbol{\mu}_{\mathrm{e}} = \boldsymbol{E} a^3$$

$$\boldsymbol{B} = \frac{-\rho\omega_{\mathrm{a}} E_{\mathrm{cc}}}{2c} \mathbf{1}_\phi \sin\omega_{\mathrm{a}} t$$

$$\boldsymbol{F}^{(\upsilon B)} = \frac{\dot{\boldsymbol{\mu}}_e}{c} \times \boldsymbol{B}$$

$\boldsymbol{\upsilon} \times \boldsymbol{B}$ Force (υB)



Induced Electric Moment μ_{e} in NCS

<u>Forces in the Equatorial Plane</u>:

$$F_{0,\rho}^{(\upsilon B)} = \frac{-E_{\mathrm{cc}}^2 \omega_{\mathrm{a}}^2 \rho\, a^3 \mathbf{1}_\rho}{2c^2} \sin^2 \omega_a t$$

$$F_{0,\rho}^{(\upsilon B)} = -k_0^{(\upsilon B)} \rho \mathbf{1}_\rho \qquad \langle \sin^2 \omega_{\mathrm{a}} t \rangle = \tfrac{1}{2}$$

$$k_0^{(\upsilon B)} = \frac{E_{\mathrm{cc}}^2 \omega_{\mathrm{a}}^2 a^3}{4c^2}$$

$$\omega_{\mathrm{o}}^{(\upsilon B)} = \sqrt{\frac{k_0^{(\upsilon B)}}{M}} = \frac{E_{\mathrm{cc}}}{2\lambda_{\mathrm{a}}} \sqrt{\frac{3\pi}{\rho_M}}$$

- Two dimensional Harmonic Oscillator
- Solutions are Elliptical Orbits centered on the *z*- axis

Measurement of ω_{o} yields a measurement of ρ_{M}.

$$M = \frac{4\pi a^3}{3} \rho_M$$

NCS continued $\boldsymbol{v}\times\boldsymbol{B}$ Force:

(1) <u>Too weak to orbit ordinary liquids or solids</u>

$$\rho_M = \frac{3\pi E_{cc}^2}{4\lambda_a^2\omega_o^2} = \frac{3E_{cc}^2}{16\pi\lambda_a^2 f_o^2}$$

For $\bar{E}_a = 4\times10^6$ V/m
and $f_o = 80$ Hz,

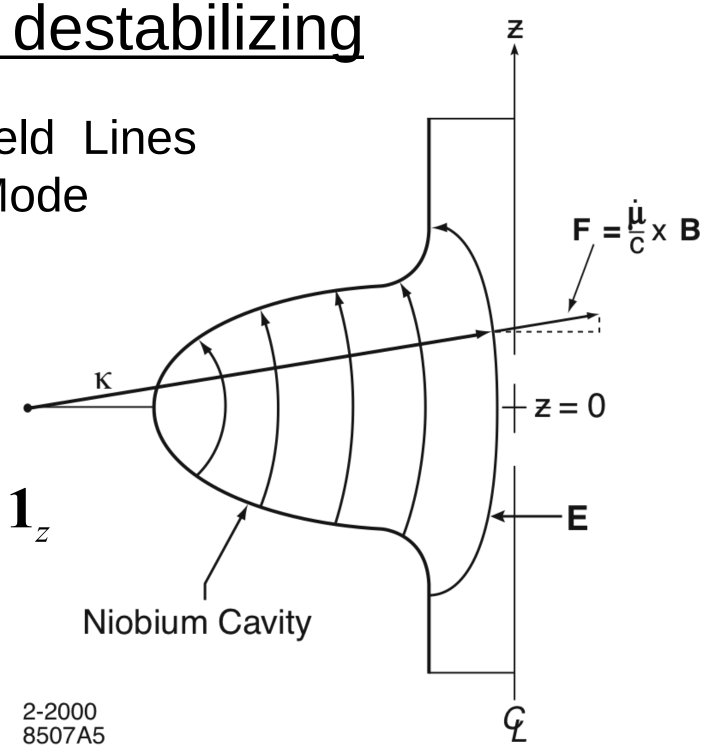
$$\rho_M = 0.00166 \text{ g/cm}^3$$

Air at STP: 1.225 mg/cm^3

(The other forces improve the ρ_M situation, but only by a factor of ~ 3.)

(2) <u>Axially destabilizing</u>

Electric Field Lines
of TM_{010} Mode



$$F_{0,z}^{(vB)} \;;\; \frac{k_0^{(vB)}\rho z}{\kappa_E}\mathbf{1}_z$$

κ_E = 50 cm at (ρ, z) = (1, 0) determined using SUPERFISH calculation

<u>Roughly a 2% effect</u>.

NCS continued: Induced Dipole Forces

∇E^2 Forces

$$\boldsymbol{F}^{(\nabla E^2)} = -\nabla(-\boldsymbol{\mu}_e \cdot \boldsymbol{E}) = a^3 \nabla E^2$$

<u>Radially Stabilizing</u>

Harmonic Oscillator Potential centered on *z*-axis

$$k_{0,\,\rho}^{(\nabla E^2)} \approx \frac{1.4\ E_{\rm cc}^2 \omega_{\rm a}^2 a^3}{4c^2} = 1.4\ k_0^{(vB)}$$

<u>Axially stabilizing</u>

$$k_{0,\,z}^{(\nabla E^2)} \approx \frac{2\ E_{\rm cc}^2 \omega_{\rm a}^2 a^3}{4c^2} = 2\ k_0^{(vB)}$$

Enough to overcome the axially destabilizing forces

∇B^2 Forces

$$\boldsymbol{F}^{(\nabla B^2)} = -\nabla(-\boldsymbol{\mu}_m \cdot \boldsymbol{B}) = a^3 \left(\frac{\mu_{\rm r} - 1}{\mu_{\rm r} + 2} \right) \nabla B^2$$

<u>Radially Stabilizing</u> (if $\mu_{\rm r} < 1$)

Harmonic Oscillator Potential centered on *z*-axis

$$k_{0,\,\rho}^{(\nabla B^2)} \approx \frac{E_{\rm cc}^2 \omega_{\rm a}^2 (a - \delta)^3}{8c^2} \le \frac{1}{2} k_0^{(vB)}$$

(For Cu at 300K and 1.5 GHz,

$\delta = c(2\pi\mu_{\rm r}\omega_{\rm a}\sigma)^{-1/2} \sim 2\times10^{-3}$ mm)

<u>Axially destabilizing</u>

$F_{0,\,z}^{(\nabla B^2)} \sim F_{0,\,z}^{(vB)}$ (2% effect)

NCS, Revisit the radial force question (MLO density)

Recall that a measurement of orbital frequency gives an Estimate of (maximum) MLO mass density

$$\omega = \sqrt{\frac{k}{M}}$$

We now include the additional dipole forces:

$$\rho_M \le 2.9\,\frac{3\pi E_{cc}^2}{4\lambda_a^2\omega_o^2} = 2.9\,\frac{3E_{cc}^2}{16\pi\lambda_a^2 f_o^2}$$

$$\rho_M \le 2.9 \times 0.00166 = 4.8\ \mathrm{mg/cm^3}$$ (For 80 Hz orbit)

<u>What material could this be?</u>

Air at STP: = 1.225 mg/cm^3

Nanofoam: ~ 1 mg/cm^3

Aerogel: ≥ 1.9 mg/cm^3

<u>Geometry</u>?

Hollow (Nb) Sphere: $\delta r/r \sim 1.7\times10^{-3}$

Niobium needle: aspect ratio ~ 180:1

Neutral Conducting Sphere (NCS)

Some useful additional references

- J. D. Jackson, *Classical Electrodynamics* (J. Wiley & Sons, Inc., New York, 1962)
- W. R. Smythe, *Static and Dynamic Electricity*, 2nd Ed. (McGraw Hill Book Co., Inc., New York, 1950)
- J. A. Stratton, *Electromagnetic Theory* (McGraw Hill Book Co., Inc., 1941)
- H. Padamsee, J. Knobloch, T. Hayes, *RF Superconductivity for Accelerators* (J. Wiley & Sons, Inc., New York, 1998)
- J. Knobloch, "Advanced Thermometry Studies of Superconducting Radio-Frequency Cavities," PhD. Thesis for Cornell University, 1997
- F. F. Chen, *Introduction to Plasma Physics* (Plenum Press, New York, 1974)

NCS extended to include Orbit Precession

E field diminishes with radius in the equatorial plane:

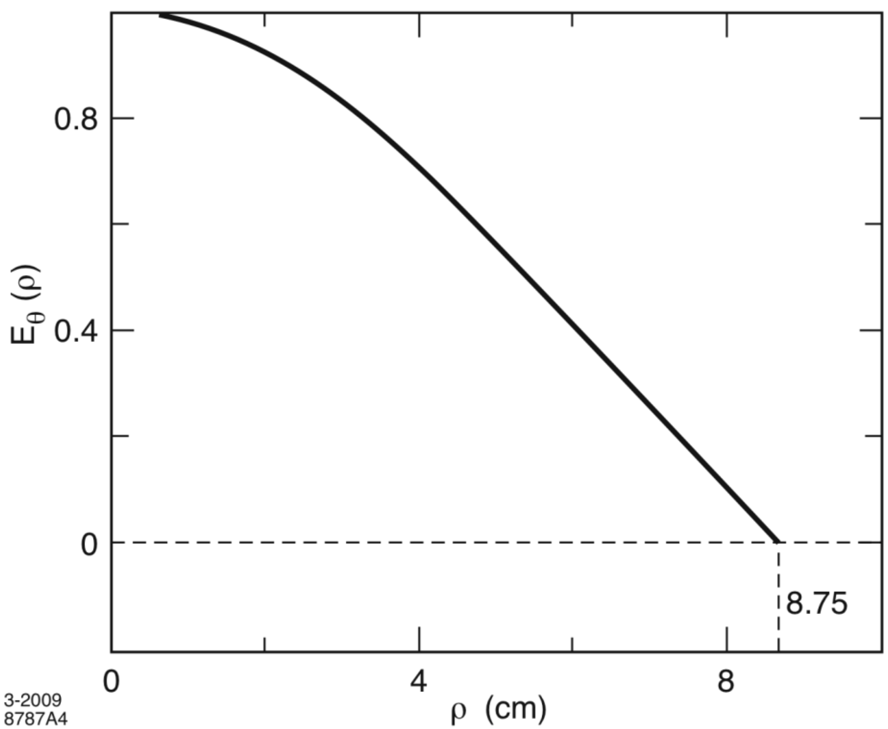
$$E_\theta \sim \frac{R_S}{2.75\,\rho}\left[\frac{2.75\,\rho}{R_S}\,j_1\!\left(\frac{2.75\,\rho}{R_S}\right)\right]'$$

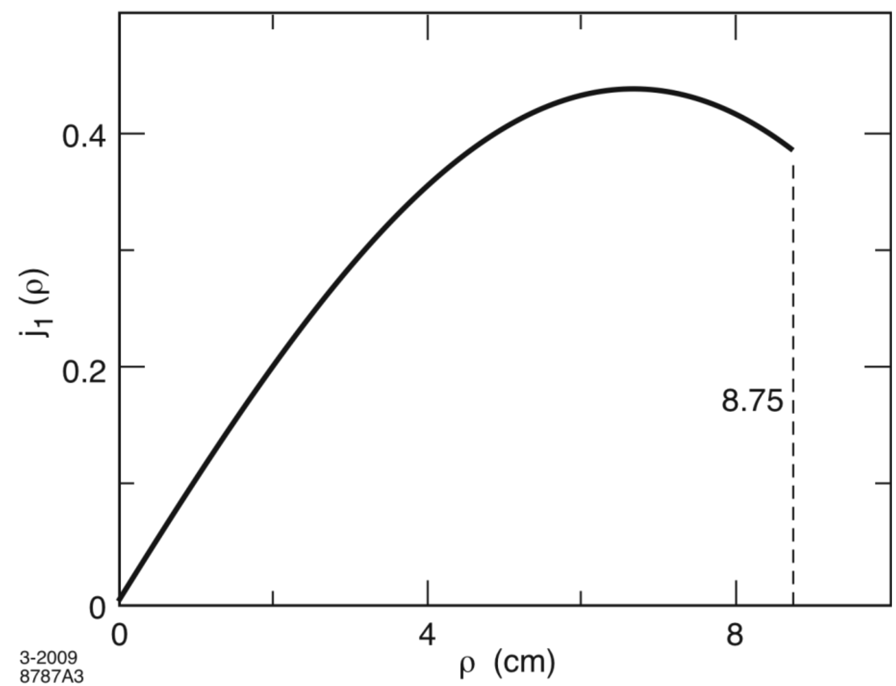
B field is "linear" with radius

R_S is radius of spherical cavity of 1.5 GHz

$$B_\phi \sim j_1\!\left(\frac{2.75\,\rho}{R_S}\right)$$

(R_S = 8.75 cm)
(R_A = 9.46 cm)
or ~ 7.5%





Precession correction to (vB) force: $k^{(vB)} = (1-\alpha\rho^2)\; k_0^{(vB)}$ with $\alpha = 0.03/\text{cm}^2$

All Forces in the **NCS** with precession included.

In the equatorial plane:

$$F_{\rho}^{(\mathrm{NCS})} \approx -(1-\alpha\rho^2)\ 2.9\ k_0^{(vB)}\rho\,\mathbf{1}_{\rho}$$

$$\alpha \approx 0.03/\mathrm{cm}^2$$

N. B. The NCS has
a positive correlation
between orbit and precession,
but no rocking mechanism

Along the *z*-axis:

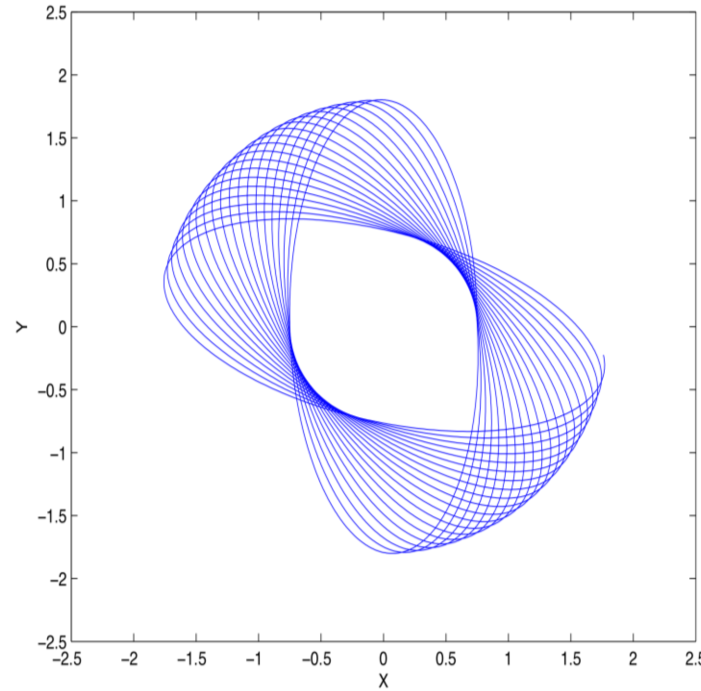
$$F_{z}^{(\mathrm{NCS})}\ ;\ -(1-\alpha\rho^2)\ 1.9\ k_0^{(vB)} z\,\mathbf{1}_{z}$$

Essentially a harmonic oscillator

x-y motion based upon calculated spring constants and using the (arbitrary) MLO radius a = 50μ and M (or ρ_M) "tuned" to yield 40 Hz orbit.

First 20 orbits (at 40 Hz)

x_0 = 0.75 cm, v_{y0} = 455 cm/s



x-y plane

Aspect ratio $a/b = 2.4$

Recall: $\omega = \sqrt{\dfrac{k}{M}}$

Possible Symmetry Breaking Mechanisms (Basis for Rocking Mechanism?)

- Cavity out of round

Possible $\delta r/r$ at equatorial weld seam will break the symmetry of TM_{010} (turning it into an "elliptical" mode). Are mechanical imperfections enough?… (Simulation indicates that 2% would do it)

No! Measurements on actual cavity give $\delta r/r \sim 0.0015$

- Higher order modes

Resonant frequencies of HOMs not integrally related to the fundamental (roots of Bessel functions) HOMs leak out ends

- Transverse (static) magnetic field

Residual earth's magnetic field < 20 mG inside the Test Stand

- Other?

XII. MLO Model using Dirac Monopole*

Magnetic Pondermotive Force: $$\boldsymbol{F}^{(g)}_{\mathrm{mcp}} = \frac{-g^2 \nabla \boldsymbol{H}_0^2}{4 m_{\mathrm{mcp}} \omega^2} = \frac{-g^2 \rho E_{\mathrm{cc}}^2}{16 m_{\mathrm{mcp}} c^2} \mathbf{1}_\rho$$

We have a Cylindrical Harmonic Oscillator Potential Well

- A single Dirac Monopole (g = 68.5 e) can orbit solid materials
- It has radial stability (with elliptical orbits)

The Spring Constant for the magnetic MLO is: $$k^{(g)}_{\mathrm{mcp}} = \frac{g^2 E_{\mathrm{cc}}^2}{16 m_{\mathrm{mcp}} c^2}$$

The orbital frequency is: $$\omega_{\mathrm{o}}^{(g)} = \sqrt{\frac{k^{(g)}_{\mathrm{mcp}}}{m_{\mathrm{mcp}}}} = \sqrt{\frac{g^2 E_{\mathrm{cc}}^2}{16 m_{\mathrm{mcp}}^2 c^2}} = \frac{g E_{\mathrm{cc}}}{4 m_{\mathrm{mcp}} c}$$

For f_{o} = 80 Hz, $m_{\mathrm{mcp}} = 1.2\times10^5$ GeV/c^2

- Axially unstable (unless ≥200 monopoles trapped in the MLO)

*See, e. g., Jackson, *Classical Electrodynamics,* 2nd Ed.,(Wiley, 1975), p. 253.

XIII. Results for Establishmentarian MLO Models Used to Explain Mode I Type of Closed Orbits

Model	Radial Stability	Axial Stability	Positive Orbit and Precession Correlation	Mechanism for Rocking Motion of Orbital Precession	Adequate Force to Orbit a Solid (or liquid) MLO at Observed f_o
ECP	No	No	No Orbits	No Orbits	No Orbits
NCS	Yes	Yes	Yes	No	No
NDS	Yes	Yes	Yes	No	No
PMD	Yes	Yes	No	No	No
MCP	Yes	No – Yes*	Yes	No	Yes

*Yes, if there are enough Dirac monopoles (~200) trapped in the MLO.

Conclusion: Established Physics cannot explain the Long Lived Stable (Mode I) Orbits observed in SC RF Cavities

XIV. Video of (Mode II) Orbits and Flashes

Features to look for:

(In particular, Macromolecular Behavior)

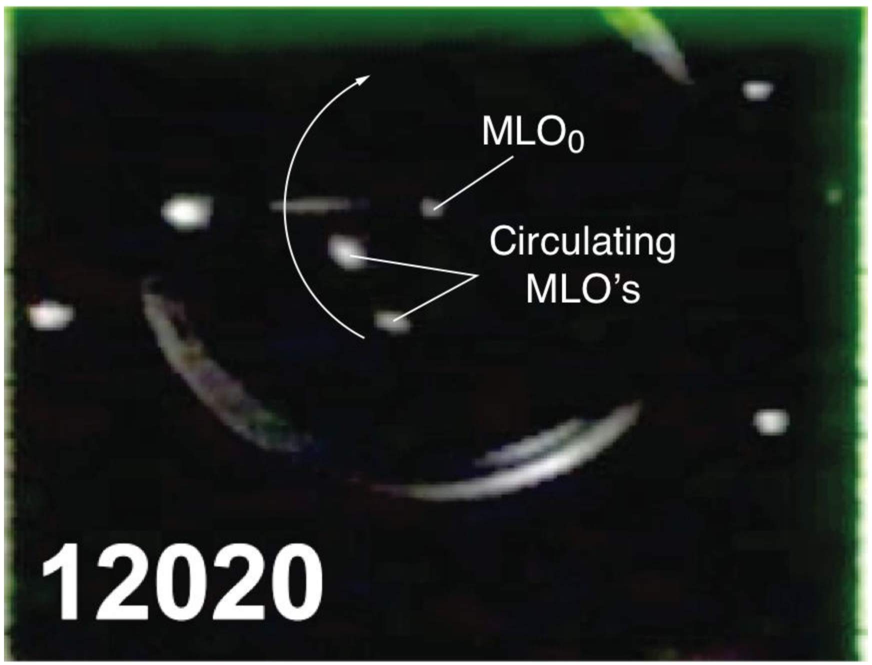
- Illumination of the Cavity interior (Full Video Screen, PIPs)
- Flash and some ballistic (Mode I) tracks (Crop to the cavity)
- Several MLOs "dancing"
- Two MLOs at rest in center of Cavity, then Merging
- More MLOs dancing
- MLO Circulation (> 20 s) (Three or more) 12000 et seq
- Circulation Stops, followed by jumps and jiggles
- With higher cavity excitation, more MLOs appear
- Two MLOs interchange position in pattern 13528-13539

XV. **Mode II Behavior**, Continued

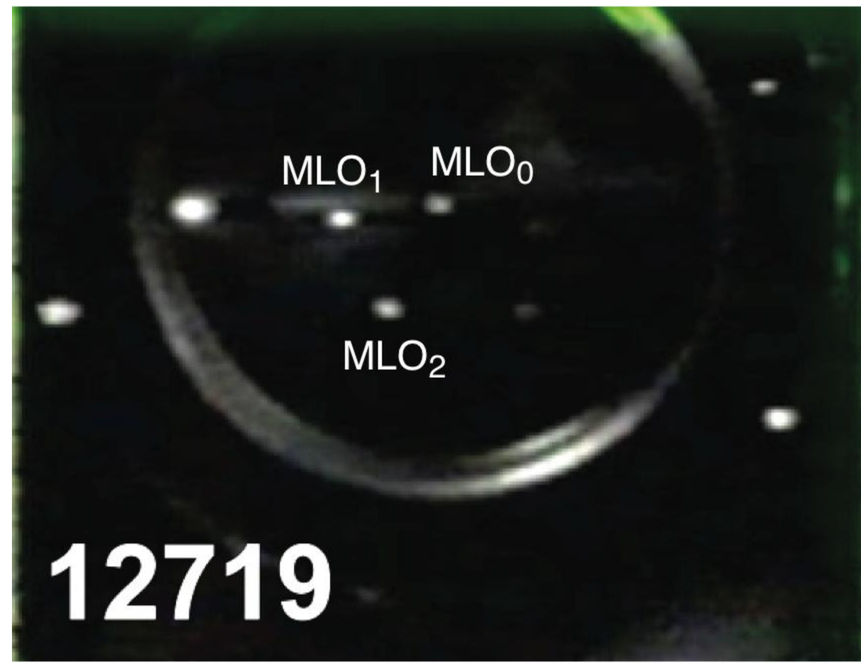
Multiple MLO's in Superconducting RF Cavity (Run 7)

See Anthony et al, *NIM A*, **612**, 1 (2009)

[Multiple BL, seemingly connected, have also been observed: W. R. Corliss, *Remarkable Luminous Phenomena in Nature,* The Sourcebook Project (2001).]



2-2009
8745A57



2-2009
8745A58

Frame as Circulation is beginning

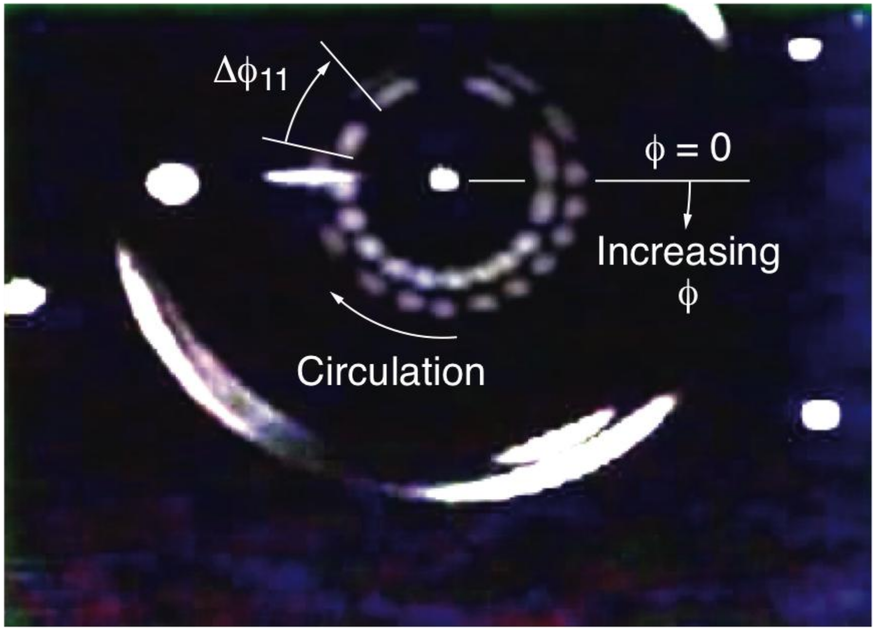
Frame after Circulation stopped

Circulation (~2.1 Hz) lasted > 650 frames or > 20 s

The three MLOs maintained their relative positions throughout the episode

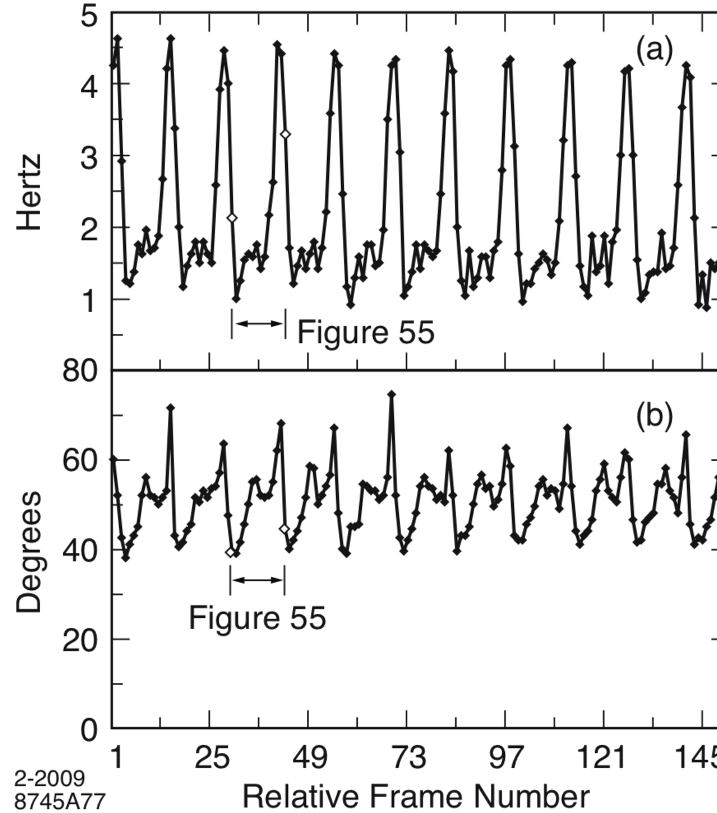
During the Circulation (~2.1 Hz)

Stacked Image of 14 Frames
during the Circulation



2-2009
8745A72

(Fig. 55)



Note that the MLO orbits are nearly circular, <u>not elliptical</u>, and the observed variation of the (projected) bond length (>1.5) between MLO_1 and MLO_2. And notice the frequency variation of ~3. Thus, the centripetal force is not due to a simple harmonic oscillator potential well, $\boldsymbol{F} = -k\boldsymbol{r}$. Recall the centrifugal $\boldsymbol{F} = m\boldsymbol{r}\omega^2$.

- Spiky motion implies some new "local" short-range force.

XVI. Modeling requirements for Mode II Behavior (Macromolecular)

- A mechanism to maintain MLOs at stably at rest for extended durations away from the cavity walls and not (necessarily) on the cavity axis
- An MLO-MLO interaction must be identified that will enable MLOs to form multiple, stable, long-lived bonds, with bond lengths significantly greater than the MLO size, both in orbit and at rest in the cavity
- The framework for the above two points must be broad enough to allow for significant exceptions, e. g., the “merger” and the variable bond lengths.

XVII. Available MLO Model Forces

Characteristics of MLO Models for a (paired) MLO-MLO Bonding Force

Model	Source Orientation	Radial Character of Force between Pairs	Nature of Force	Comment
ECP	Isotropic	$1/r^2$ (Long Range)	Electric Coulomb	Pairs of like charge will repel, Opposite charges attract
NCS	Along RF ***E*** Field	$1/r^4$ (Short Range)	Electric Dipole	Attraction/repulsion depends upon relative orientation/position
NCS	Along RF ***B*** Field	$1/r^4$ (Short Range)	Magnetic Dipole	Attraction/repulsion depends upon relative orientation/position
NDS	Along RF ***E*** Field	$1/r^4$ (Short Range)	Electric Dipole	Attraction/repulsion depends upon relative orientation/position
PMD	Tumbles	$1/r^4$ (Short Range)	Magnetic Dipole	Attraction/repulsion depends upon relative orientation/position
MCP	Isotropic	$1/r^2$ (Long Range)	Magnetic "Coulomb"	Pairs of like charge will repel, Opposite charges attract

XVIII. Generic Bonding Mechanism

- The (Ionic) Chemical Bond is a good example: Two Opposing Monotonic Forces
- Long Range Attraction, e. g., Na^+ and Cl^-
- Short range repulsion: Partially shielded nuclei

Toy Model using the possibilities from above Table:

$$\boldsymbol{F}_{\mathrm{LR}}^{(q_1 q_2)} = \frac{q_1 q_2}{r_{12}^2}\mathbf{1}_{r_{12}}$$

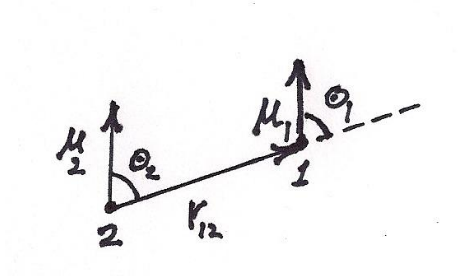
Charges must be of opposite sign for this force to be attractive. Not possible for > 2 MLOs (*e* or *g*)

$$\boldsymbol{F}_{\mathrm{SR}}^{(\mu_1 \mu_2)} = \frac{3\mu_1\mu_2}{r_{12}^4}\mathcal{A}\mathbf{1}_{r_{12}}$$

where $\mathcal{A} = \sin\theta_1 \sin\theta_2 \cos\psi - 2\cos\theta_1 \cos\theta_2$

Since $-2 \le \mathcal{A} = \le 2$, repulsion is not assured.

N.B., $\theta_1 = \theta_2$ and $\psi = 0$, hence $\mathcal{A} = 0$ at $\theta = 54.7^{\mathrm{o}}, 125.3^{\mathrm{o}}$



ΔΩ/4π: Repulsion, 57.7%, Attraction, 42.3%.

Remarks about the NCS harmonic oscillator potential paired with the dipole-dipole force

$$\boldsymbol{F}_{\mathrm{LR}}^{(\mathrm{NCS})} = -k_{0\ \mathrm{ncs},\ \rho}^{(\mathrm{NCS})}\ \rho_{1,\,2}\mathbf{1}_{\rho_{1,\,2}} \qquad\qquad \boldsymbol{F}_{\mathrm{SR}}^{(\mu_1\mu_2)} = \frac{3\mu_1\mu_2}{r_{12}^4}\mathcal{A}\mathbf{1}_{r_{12}}$$

- The force from NCS harmonic oscillator potential will urge the MLOs toward the center of the cavity, but it cannot furnish a solution the circular MLO orbits seen in Run 7: the angular velocity in that orbit varies a factor of ~3, yet the orbits are seen to remain circular. Also, there is no mechanism to furnish the relatively stiff bond between MLO_1 and MLO_2. Rather, moving under the influence of the above pair of forces, the MLOs would behave like atoms of a gas under the influence of a central attractor, but with a short range repulsion (or attraction) force. This is a ballistic formulation rather that a macromolecular one.
- And, as with the Toy Model, since $\mathcal{A}$ can be positive or negative, mutual MLO-MLO repulsion is not assured.

The Challenge of Observed Mode II Behavior

- Electromagnetism, that is Established Physics, evidently cannot furnish even a framework for the description of the Mode II behavior (macromolecular) of MLOs observed in the SCRF cavities at JLAB.

- If this statement is true, it follows that New Physics is necessary for the understanding of MLOs.

XIX. Recapitulation and Conclusion

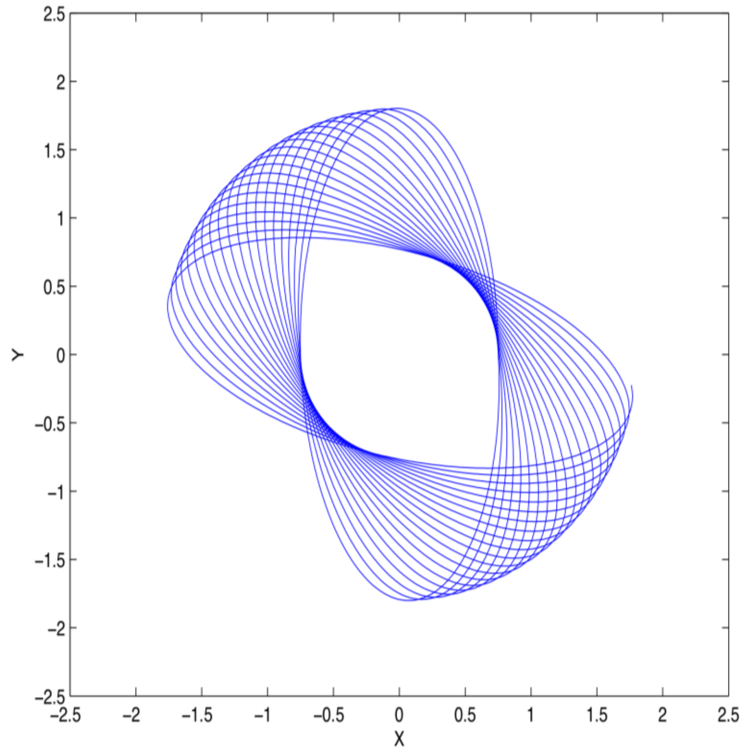
- Described Experimental set up (SC RF cavity)
- Illustrated data taken in several runs. Saw (Mode I) MLO's and SPL's
- Most interesting (perplexing) sequence is 40 s 40 Hz MLO orbit
- Developed Criteria for a successful MLO Model for Mode I Behavior
- Described NCS Model based upon established physics
- Described electromagnetic forces for other possible MLO Models
- Confronted Models with Mode I Criteria – None satisfied All Criteria
- Illustrated Mode II (Macromolecular) Behavior with video and stills
- Developed Criteria for a successful MLO model for Mode II Behavior
- Argued that Standard Electromagnetism **cannot even furnish a framework** for the description of Mode II Behavior
- **Conclude that something new is required to explain the full variety of MLO behavior**
- In the Coda show some simulation results of a model based upon Ball Lightning as a Neutral Conducting Sphere (NCS)

XX. Coda: Preview of a Model Incorporating New Physics (The Vorton BL Model)

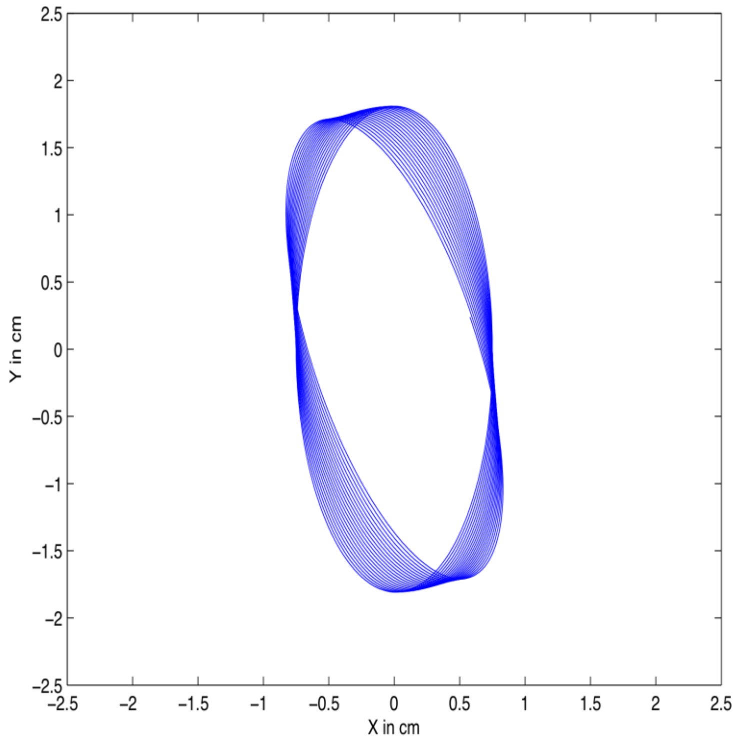
- The Vorton Model originally proposed to explain Ball Lightning (D. Fryberger, *First International Workshop on the Unidentified Atmospheric Phenomena at Hessdalen, Norway* (Mar 23-27, ’94)
- Exploits the intrinsic Dyality Symmetry of Maxwell’s Equations. (Sometimes called Duality Symmetry)
- This leads to a conserved quantity: Dyangular Momentum (Noether’s Theorem, 1918), magnetic charge, and a force opposing the Coulomb force.

Mode I Behavior: First 20 orbits of 40 Hz Orbit

NCS



NCS + Vorton BL Model

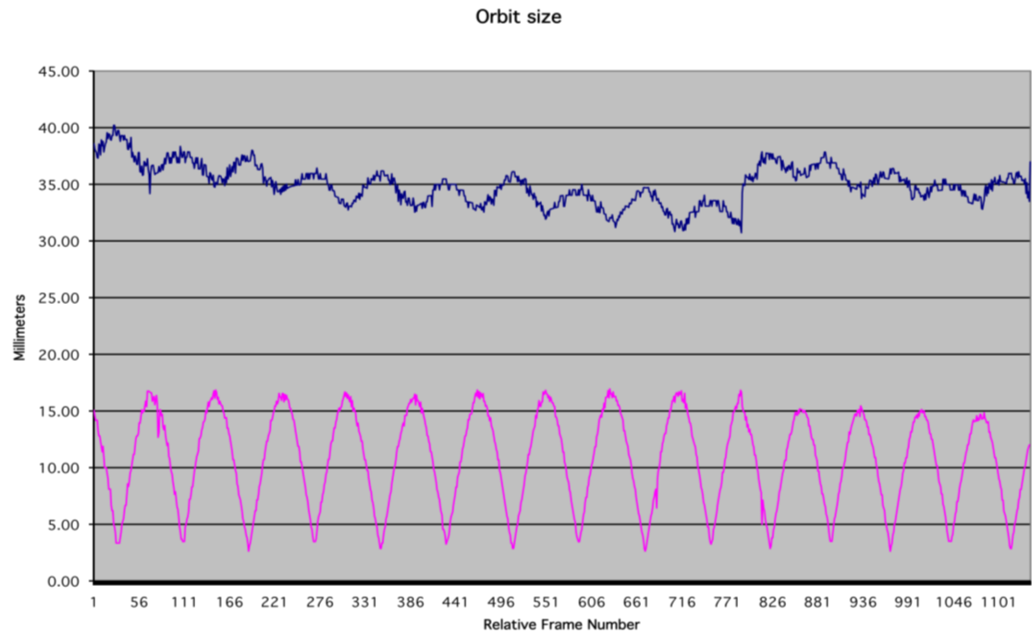


The rate of orbital precession has been reduced.
(The magnetic image force rises with increasing ρ.)

MLO Orbits : Experiment vs Theory (NCS + Vorton BL Model)

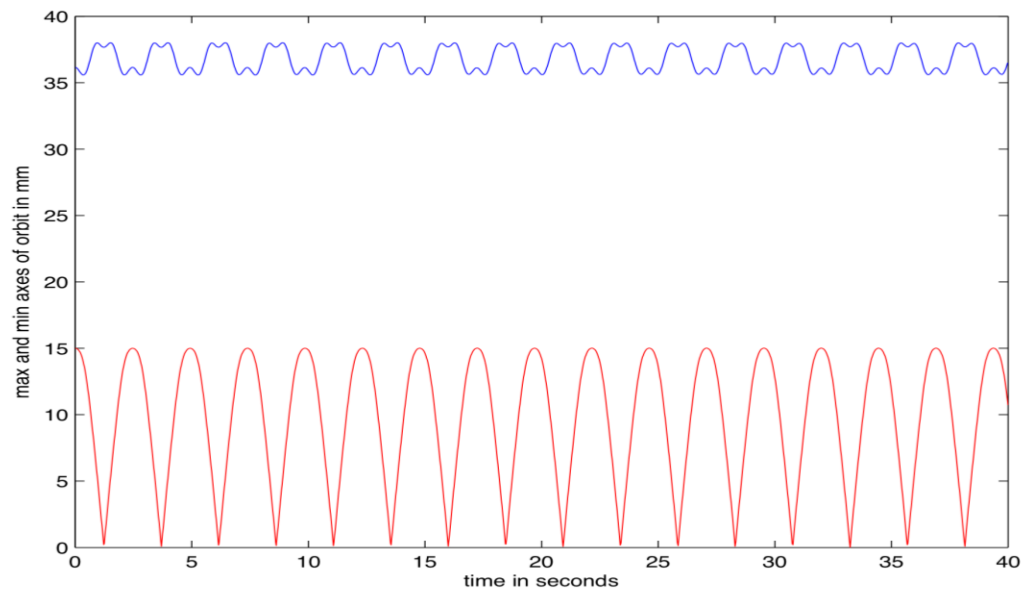
Orbit Size:

Experiment: Run 10, 40 s, 40 Hz Orbit



Theoretical Calculation: NCS + Vorton BL Model

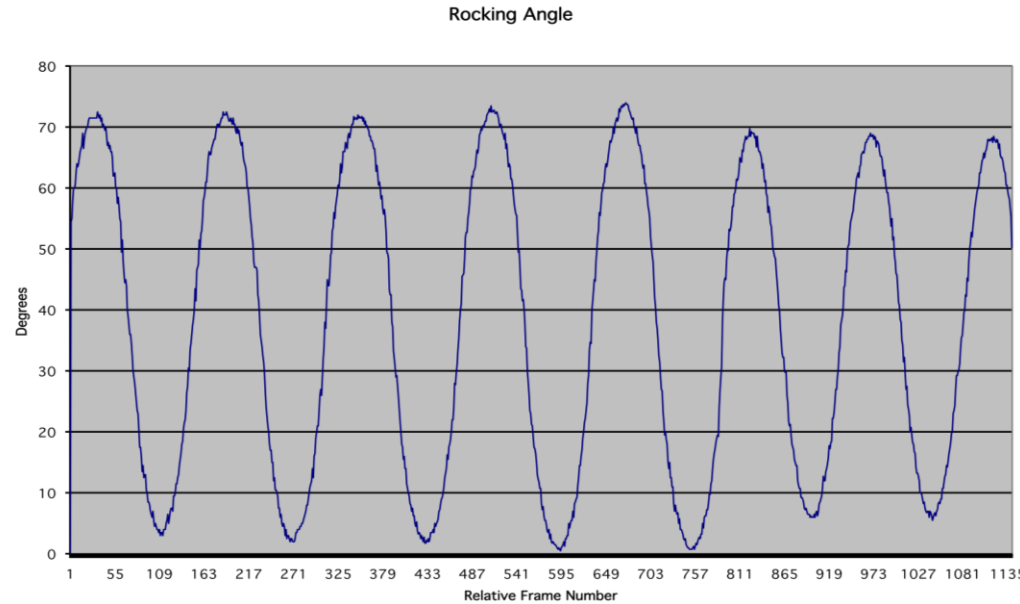
The intrinsic magnetic charge of the MLO is assumed to interact with a residual dc magnetic field in the cavity.



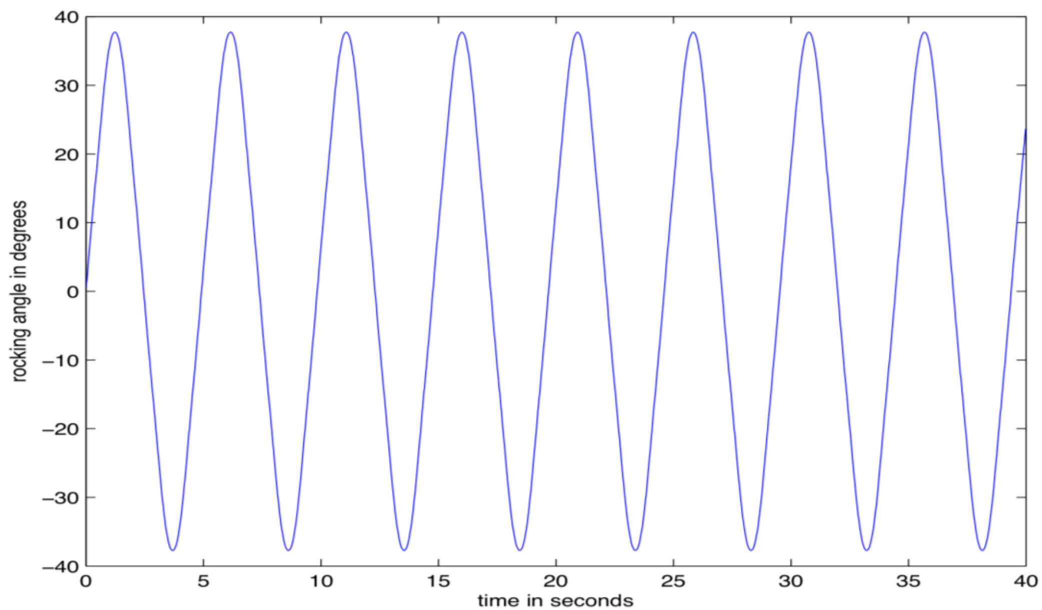
Orbit calculations using NCS and Vorton BL Model, cont.

Rocking Angle

Experiment: Run 10,
40 s, 40 Hz Orbit



Theoretical Calculation:
NCS + Vorton BL Model



It is assumed that dyangular rotation is synchronized with the orbital rotation.

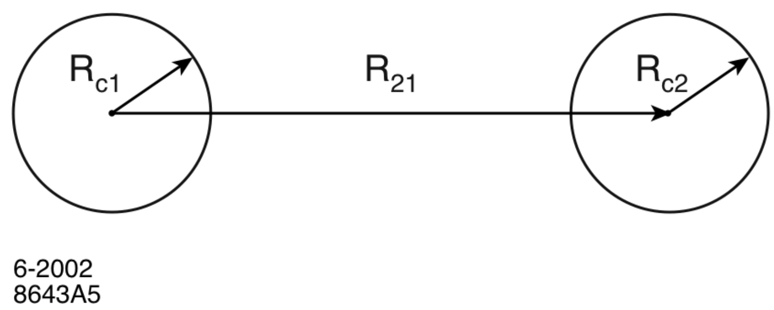
Mode II Behavior: Multiple MLOs as Macromolecules

Configurations of multiple MLO's (and BL), seemingly joined by a bond that exceeds the visible diameters, i. e., Macromolecular Behavior, can be accommodated by the Vorton BL Model, in which a long range Dyangular force opposes the mutual MLO-MLO Coulomb force.

Equilibrium conditions for more general distributions, described by several parameters χ_i, are governed by the set of equilibrium equations:

$$F_i = -\frac{\partial E_{tot}}{\partial \chi_i} = 0$$

For example, consider
a pair of MLO's (or BL):



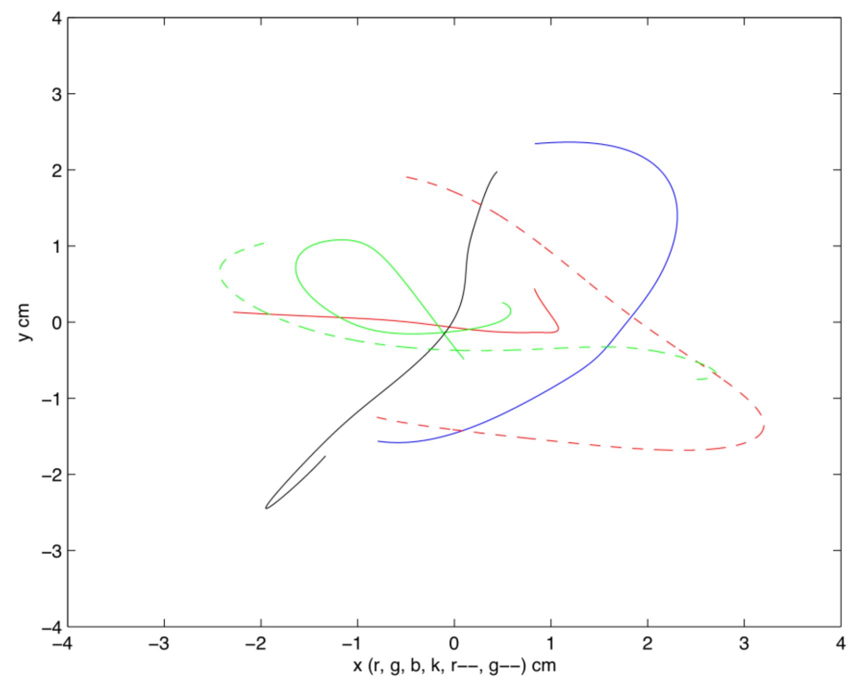
The parameters R_{c1}, R_{21}. and R_{c2} will all be stabilized by the above equilibrium equation(s). And this result generalizes in a straightforward way to larger numbers of MLO's (or BL).

Some Simulations of Mode II Behavior

"Chaos" early in a 6 MLO simulation run. All MLOs interacting. Initial conditions: random locations in cavity, random velocities N. B., The cavity fields furnish an ellipsoidal potential well. (Recall Mode I analysis)

$\Delta t = 2X10^{-6}$ s
$\Delta n = 5000$ or
10 msec

Five stacked fields (Run 7)

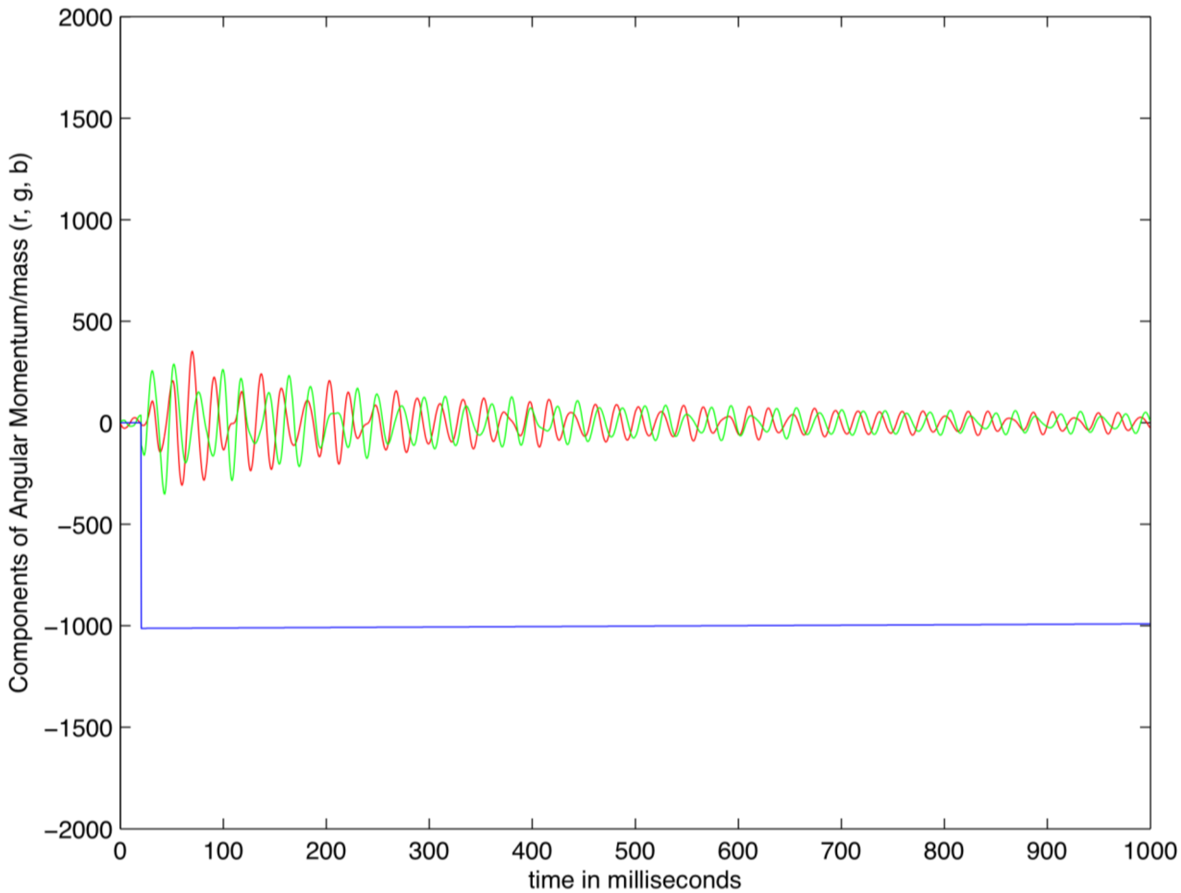


A 6 MLO run starting from “rest”

Components of Angular Momentum of Configuration

$\Delta t = 2X10^{-6}$ s
$n = 5X10^5$
Kick at $n = 10^4$
introduces an L_z

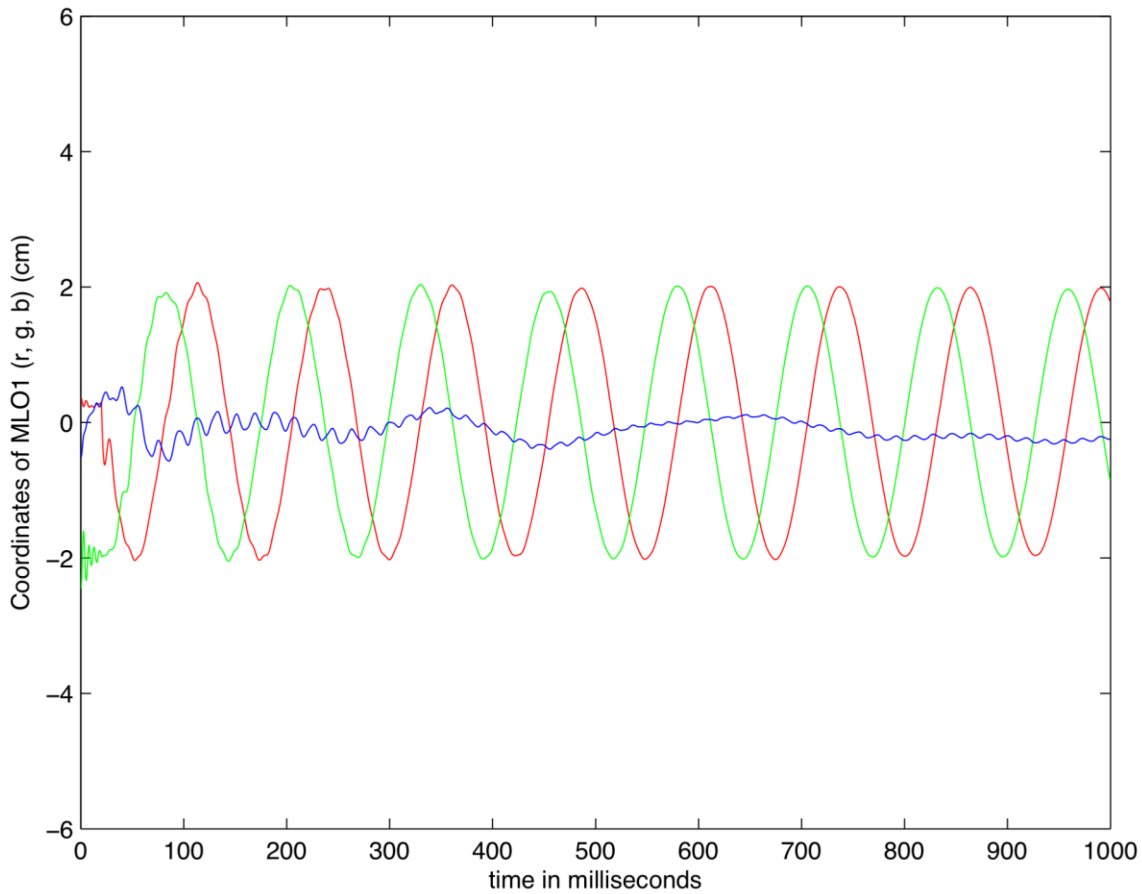
There are two kinds
Of damping present:
1)velocity, and
2)“inelastic.”



L_z is conserved by cylindrical symmetry of cavity

x , y, z (r, g, b) Coordinates of MLO_1

Kick at $n = 10^4$ introduces an L_z



Note that the motion settles into a steady rotation about *z*-axis.

The velocity damping time constant is ~ 45 s, the inelastic damping time constant is 25 ms.