Chaotic Particles and Drift Wave Turbulence

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A Scientific Journey from Wakefields to Astrophysics and Fusion:
A Symposium in Honor of Toshiki Tajima, Jan. 25-26, 2018, UC Irvine

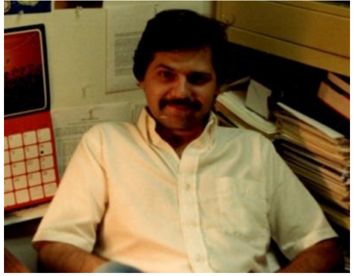
The University of Texas years, in the beginning …….

Francois Brunel

John Wagner

T. T.

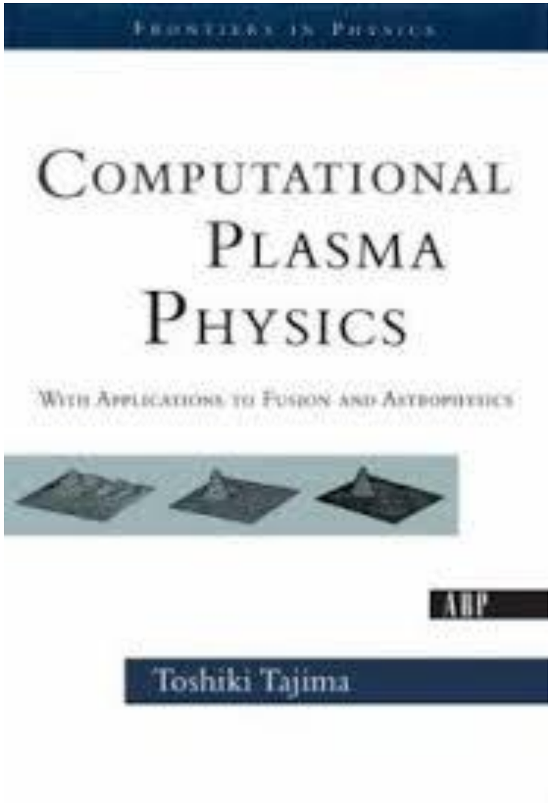
Rick Sydora



Jean-Noel Leboeuf

Circa 1980-81

Graduate course teaching



FRONTIERS IN PHYSICS

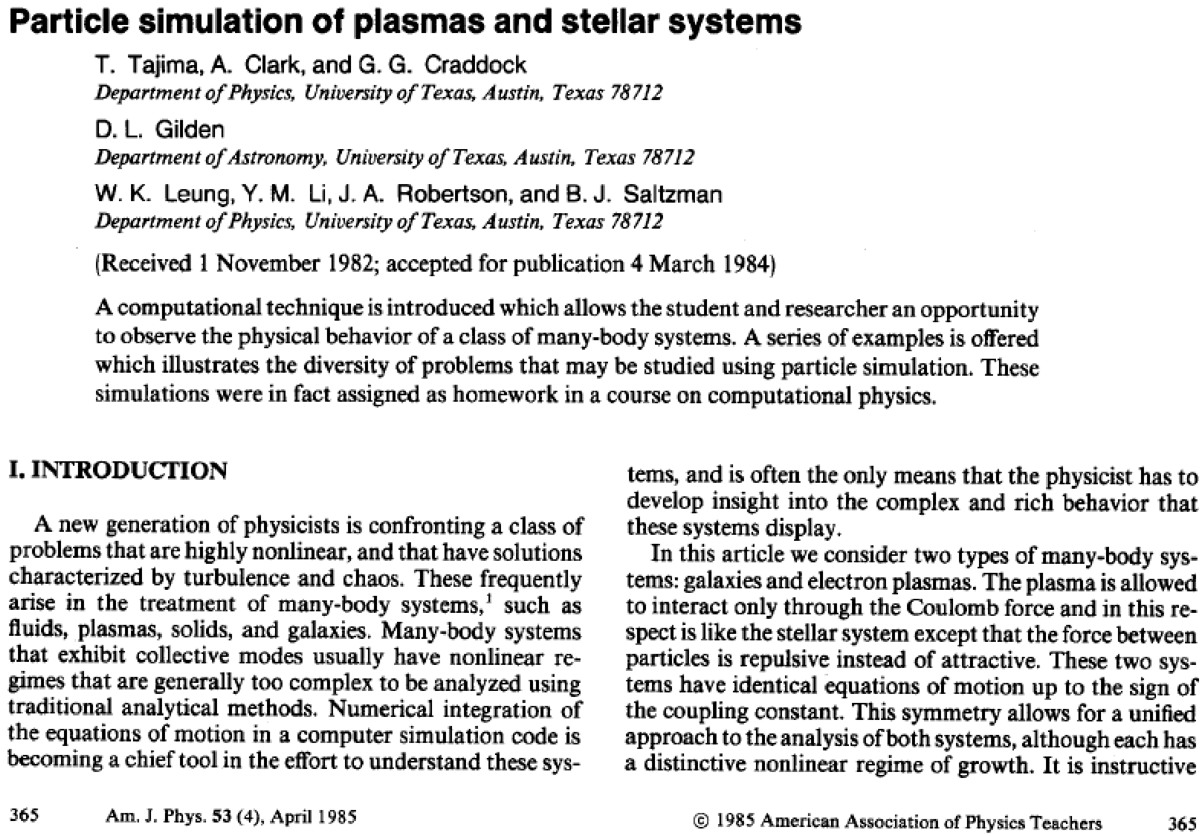
COMPUTATIONAL PLASMA PHYSICS

WITH APPLICATIONS TO FUSION AND ASTROPHYSICS

ABP

Toshiki Tajima

Graduate course project



Particle simulation of plasmas and stellar systems

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Department of Physics, University of Texas, Austin, Texas 78712
D. L. Gilden
Department of Astronomy, University of Texas, Austin, Texas 78712
W. K. Leung, Y. M. Li, J. A. Robertson, and B. J. Saltzman
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(Received 1 November 1982; accepted for publication 4 March 1984)

A computational technique is introduced which allows the student and researcher an opportunity to observe the physical behavior of a class of many-body systems. A series of examples is offered which illustrates the diversity of problems that may be studied using particle simulation. These simulations were in fact assigned as homework in a course on computational physics.

I. INTRODUCTION

A new generation of physicists is confronting a class of problems that are highly nonlinear, and that have solutions characterized by turbulence and chaos. These frequently arise in the treatment of many-body systems,[1] such as fluids, plasmas, solids, and galaxies. Many-body systems that exhibit collective modes usually have nonlinear regimes that are generally too complex to be analyzed using traditional analytical methods. Numerical integration of the equations of motion in a computer simulation code is becoming a chief tool in the effort to understand these systems, and is often the only means that the physicist has to develop insight into the complex and rich behavior that these systems display.

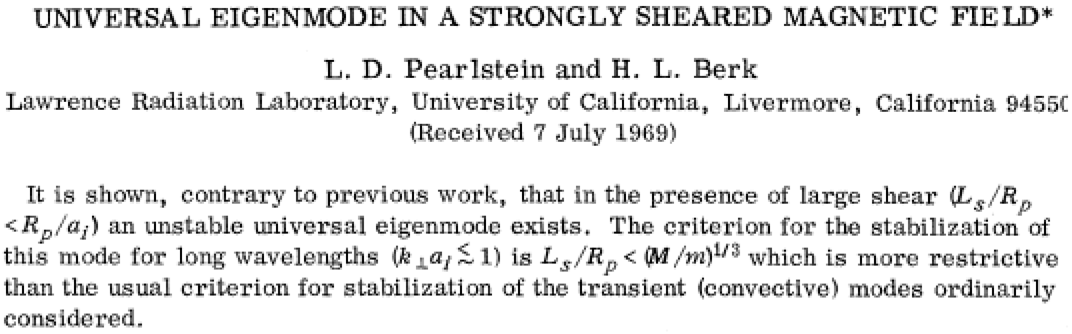
In this article we consider two types of many-body systems: galaxies and electron plasmas. The plasma is allowed to interact only through the Coulomb force and in this respect is like the stellar system except that the force between particles is repulsive instead of attractive. These two systems have identical equations of motion up to the sign of the coupling constant. This symmetry allows for a unified approach to the analysis of both systems, although each has a distinctive nonlinear regime of growth. It is instructive

Drift waves and turbulent transport: A journey with Toshi

- The question of whether drift waves (‘universal mode’) in an inhomogeneous plasma with magnetic shear were stable or unstable was controversial in the 60’s and 70’s.

- Early analysis by Coppi et al, 1965 and by Rutherford & Frieman, 1967 demonstrated magnetic shear could stabilize microinstabilities such as the drift wave.

- **Theoretical analysis by Berk & Pearlstein, 1969 predicts instability**

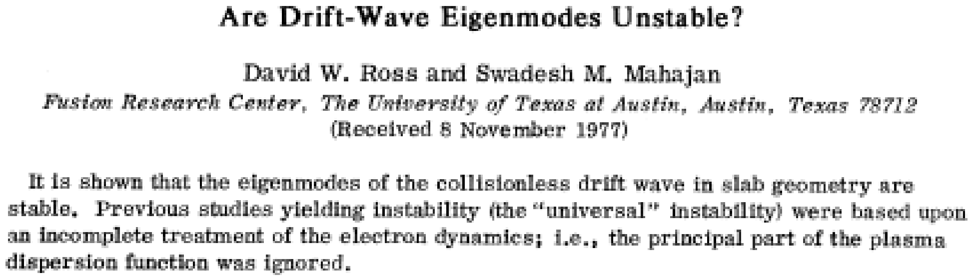


UNIVERSAL EIGENMODE IN A STRONGLY SHEARED MAGNETIC FIELD*

L. D. Pearlstein and H. L. Berk
Lawrence Radiation Laboratory, University of California, Livermore, California 9455
(Received 7 July 1969)

It is shown, contrary to previous work, that in the presence of large shear $(L_s/R_p < R_p/a_i)$ an unstable universal eigenmode exists. The criterion for the stabilization of this mode for long wavelengths $(k_\perp a_i \lesssim 1)$ is $L_s/R_p < (M/m)^{1/3}$ which is more restrictive than the usual criterion for stabilization of the transient (convective) modes ordinarily considered.

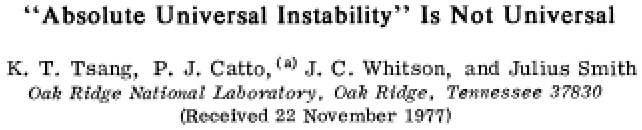
- **Numerical analysis by Ross & Mahajan, and Tsang et al show stability**



Are Drift-Wave Eigenmodes Unstable?

David W. Ross and Swadesh M. Mahajan
Fusion Research Center, The University of Texas at Austin, Austin, Texas 78712
(Received 8 November 1977)

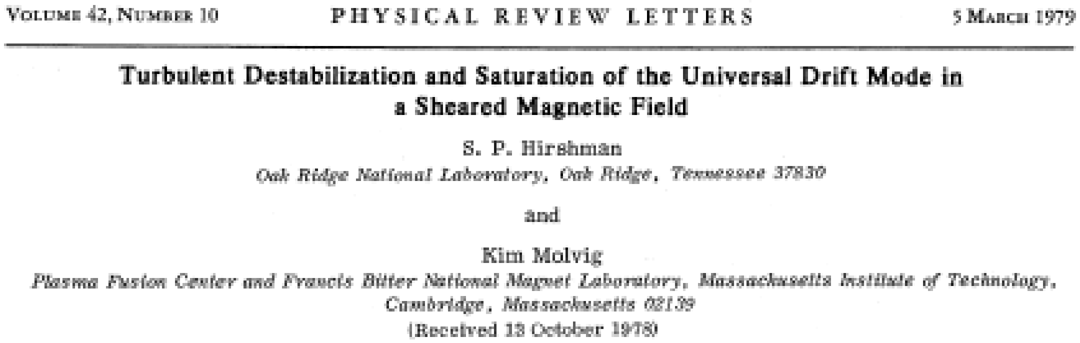
It is shown that the eigenmodes of the collisionless drift wave in slab geometry are stable. Previous studies yielding instability (the "universal" instability) were based upon an incomplete treatment of the electron dynamics; i.e., the principal part of the plasma dispersion function was ignored.



"Absolute Universal Instability" Is Not Universal

K. T. Tsang, P. J. Catto,$^{(a)}$ J. C. Whitson, and Julius Smith
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830
(Received 22 November 1977)

- Hirshman & Molvig, ‘79 demonstrate instability, 3D stochastic e^-



Volume 42, Number 10 PHYSICAL REVIEW LETTERS 5 March 1979

Turbulent Destabilization and Saturation of the Universal Drift Mode in a Sheared Magnetic Field

S. P. Hirshman
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830

and

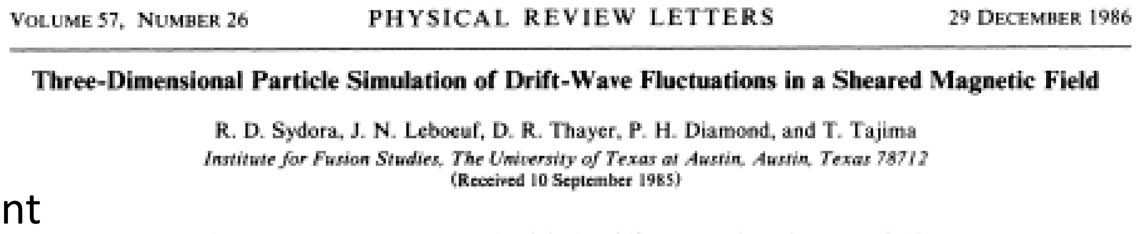
Kim Molvig
Plasma Fusion Center and Francis Bitter National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

(Received 13 October 1978)

- Diamond & Rosenbluth, ‘81 demonstrate stability with renormalized kinetic theory and ion nonlinear effects

- Fully kinetic plasma simulation (particle-in-cell), 3D, were needed to resolve whether universal mode is stable or unstable.

➢3D simulations demonstrated instability via Hirshman-Molvig mechanism, however, saturation at low level



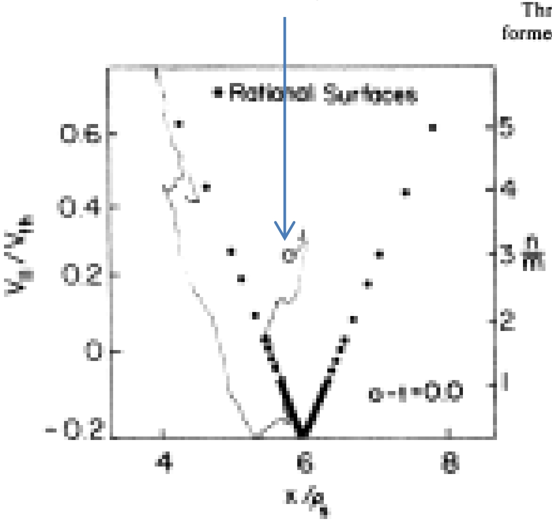
VOLUME 57, NUMBER 26 PHYSICAL REVIEW LETTERS 29 DECEMBER 1986

Three-Dimensional Particle Simulation of Drift-Wave Fluctuations in a Sheared Magnetic Field

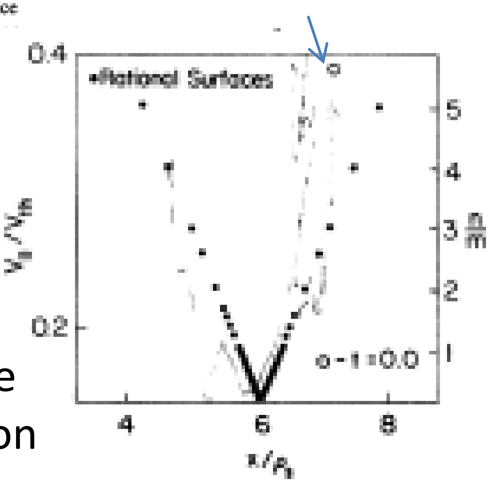
R. D. Sydora, J. N. Leboeuf, D. R. Thayer, P. H. Diamond, and T. Tajima
Institute for Fusion Studies, The University of Texas at Austin, Austin, Texas 78712

(Received 10 September 1985)

Three-dimensional particle simulations of collisionless drift waves in sheared magnetic fields were performed in order to determine the nonlinear behavior of inverse–electron-resonance dynamics in the pres-
f thermal fluctuations. It is found that stochastic electron diffusion in the electron-resonance
p region can destabilize the drift-wave eigenmodes. Numerical evaluations based on a non
n-resonance broadening theory give predictions in accord with the frequency and growth
in the simulation of short-wavelength modes ($k_y\rho_s \gtrsim 1$).



Start point



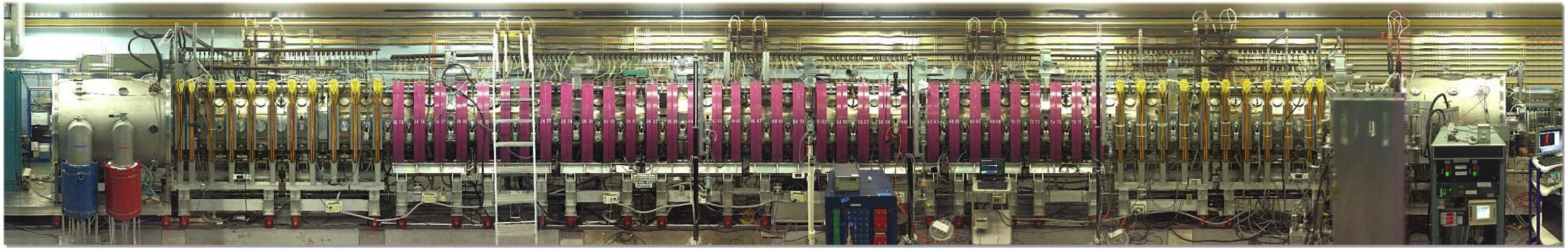
Start point

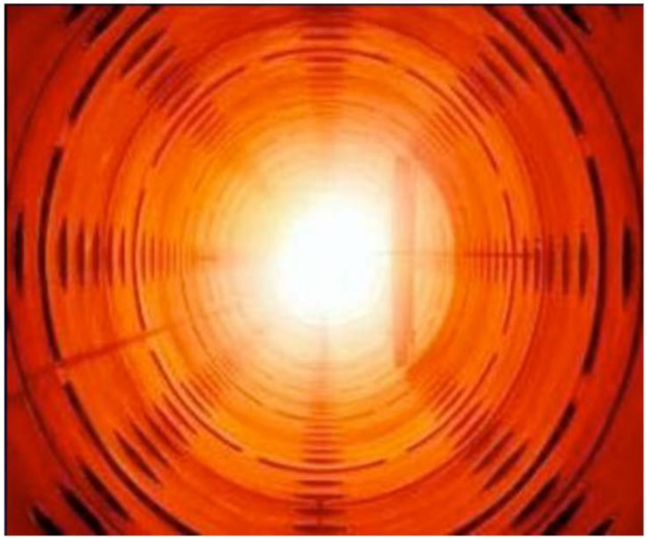
Particle trajectories in ($V_{||}$ – x) phase space demonstrate stochastic cross-field diffusion

- Now, new experiments in large linear magnetized plasma device (LAPD) at UCLA are being performed to study chaotic heat flow and plasma transport across magnetic fields.

- These ideas are inspired by the work done with Toshi and colleagues on stability of drift waves in the presence of stochastic electron dynamics.

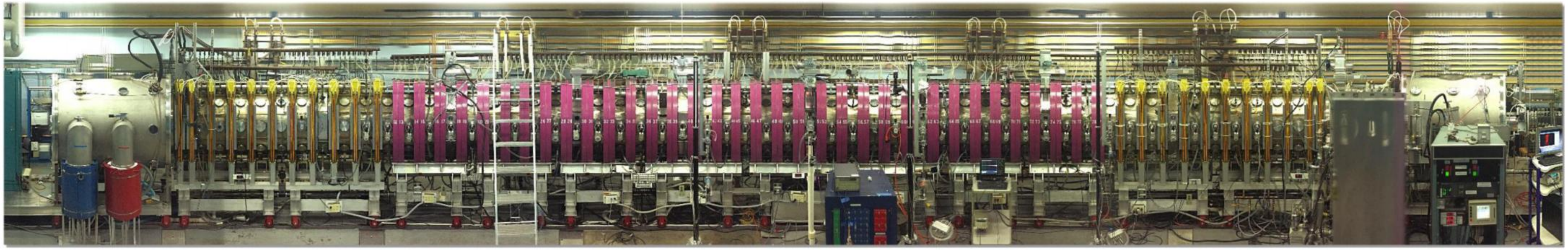
Experiment Setup:
LArge Plasma Device (LAPD)

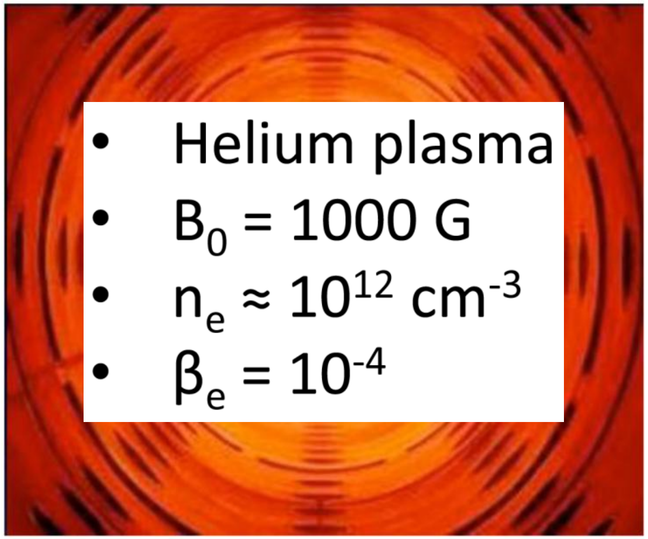




BaO – Cathode source

Experiment Setup:
LArge Plasma Device (LAPD)





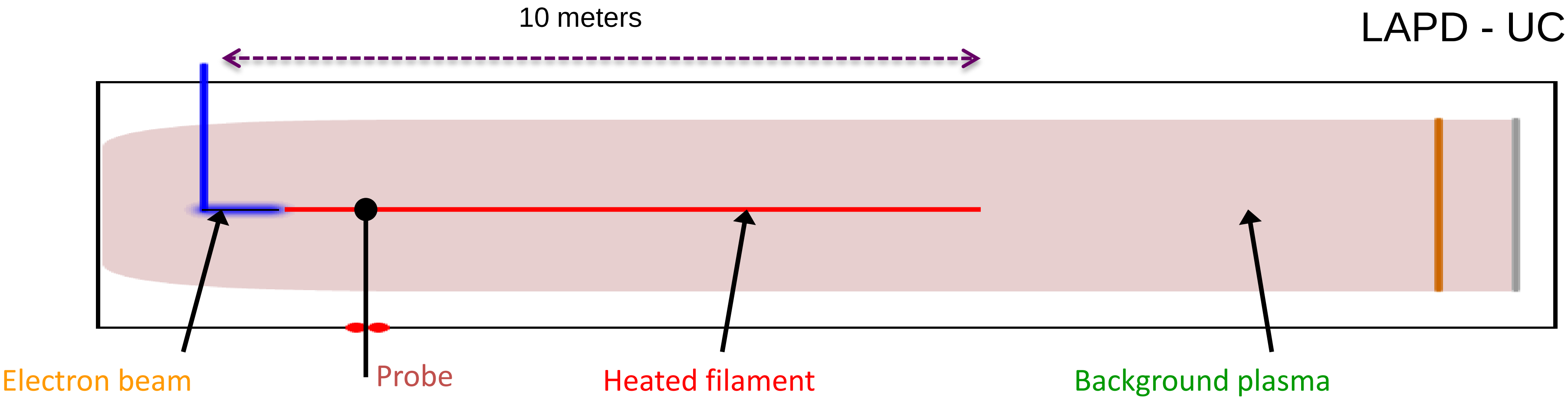
- Helium plasma
- $B_0 = 1000$ G
- $n_e \approx 10^{12}$ cm^{-3}
- $\beta_e = 10^{-4}$

BaO – Cathode source

Experiment Setup: T_e Filament

A long, narrow temperature filament in an afterglow plasma

LAPD - UCLA



10 meters

Electron beam

Probe

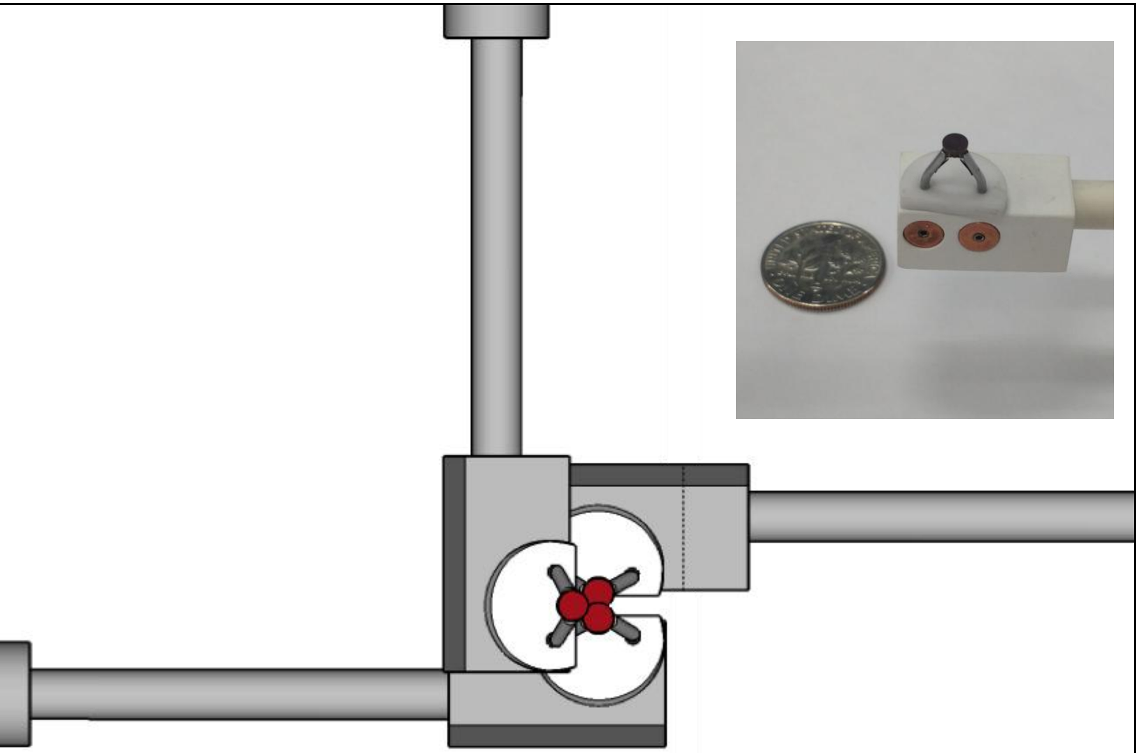
Heated filament

Background plasma

$$\sim 5eV \qquad \sim 0.25eV$$

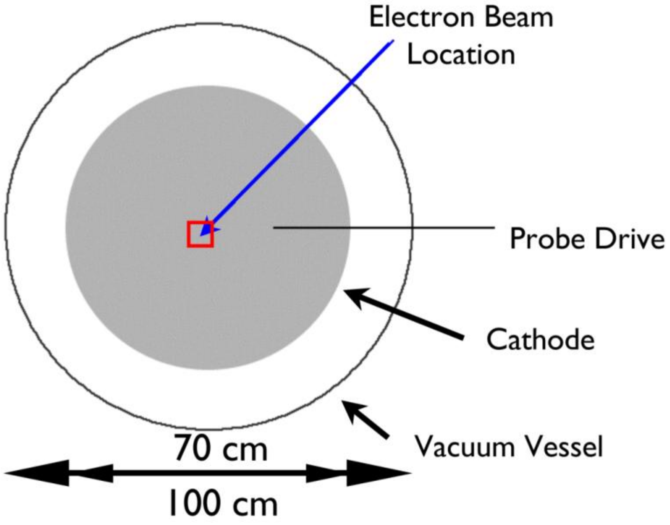
$$\text{Parameters: } B_o = 1kG,\ T_e = 5eV,\ n_o = 10^{12}cm^{-3},\ m = m_{He}$$

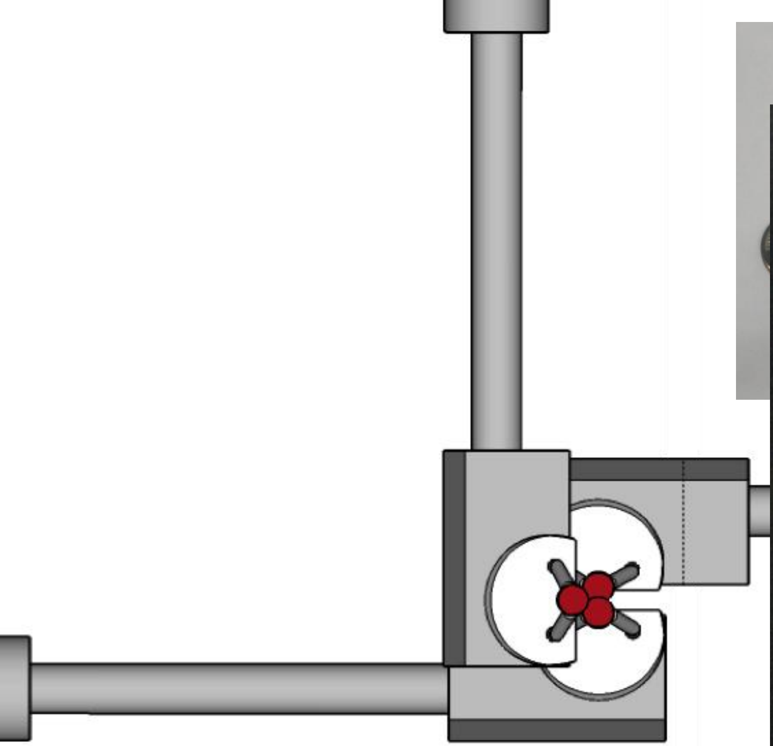
Heat Souces →T_e Filament



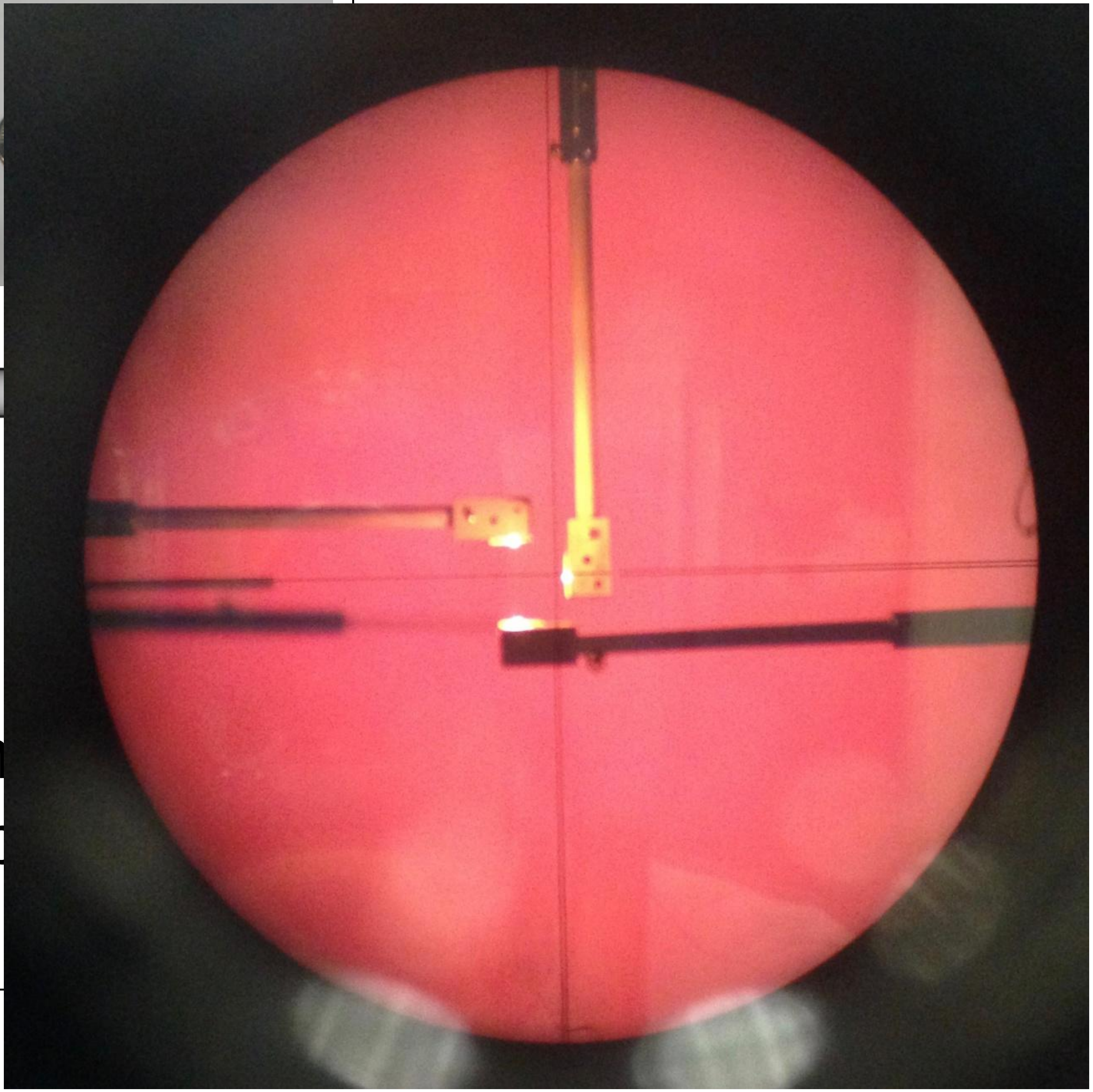
3 CeBix (Cerium Hexaboride) Crystals mounted on probe drives with independent circuitry.

- Electron energy set by $V_{beam} < 20$ V
  negligible ionization produced

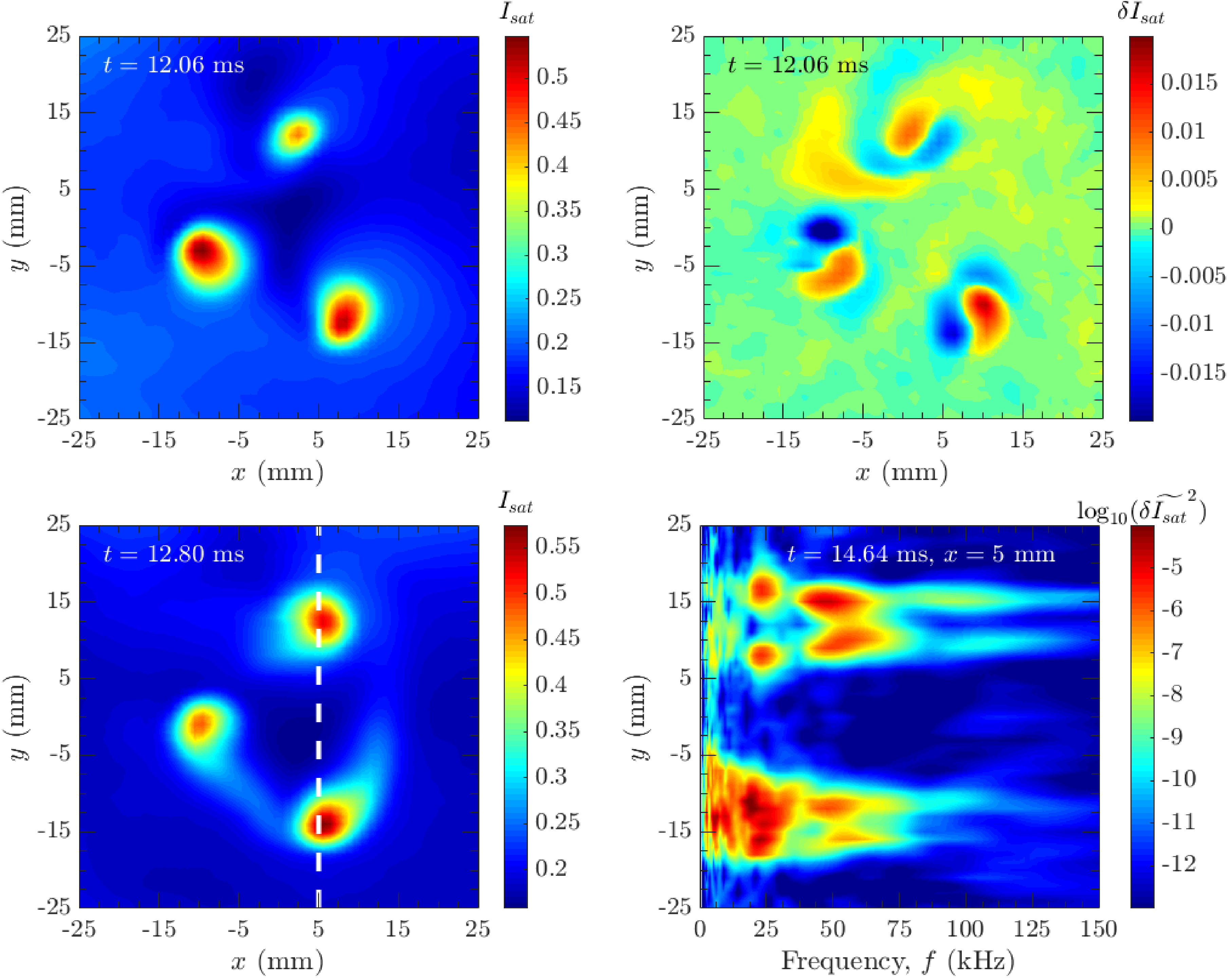


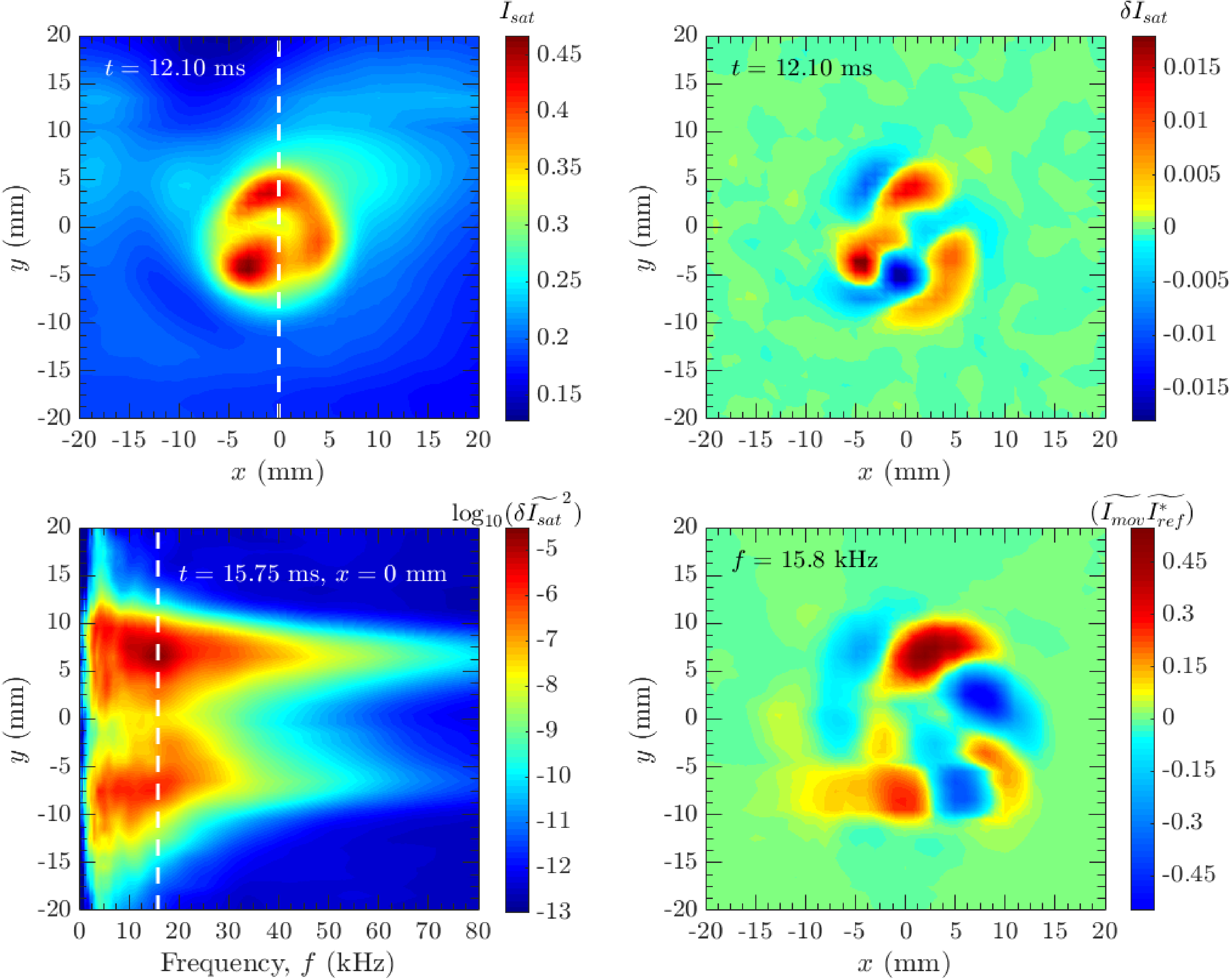


3 CeBix Crystals moun
probe drives with indep
circuitry.



Multiple filament arrangement seen from the end of the LAPD.


I_{sat}
$t = 12.06$ ms
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
y (mm)
x (mm)
25
15
5
-5
-15
-25
δI_{sat}
$t = 12.06$ ms
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
I_{sat}
$t = 12.80$ ms
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
$\log_{10}(\widetilde{\delta I_{sat}}^2)$
$t = 14.64$ ms, $x = 5$ mm
-5
-6
-7
-8
-9
-10
-11
-12
0
25
50
75
100
125
150
Frequency, f (kHz)

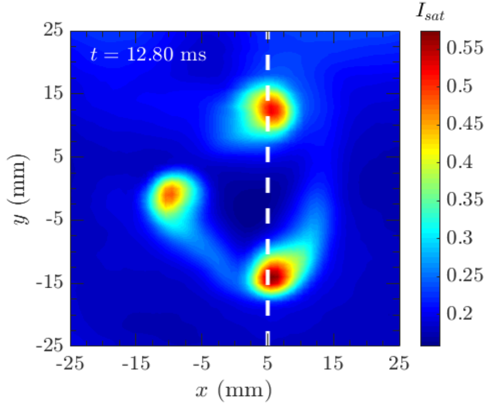

I_{sat}
$t = 12.10$ ms
x (mm)
y (mm)
δI_{sat}
$t = 12.10$ ms
x (mm)
y (mm)
$\log_{10}(\widetilde{\delta I_{sat}}^2)$
$t = 15.75$ ms, $x = 0$ mm
Frequency, f (kHz)
y (mm)
$(\widetilde{I_{mov}}\widetilde{I^*_{ref}})$
$f = 15.8$ kHz
x (mm)
y (mm)

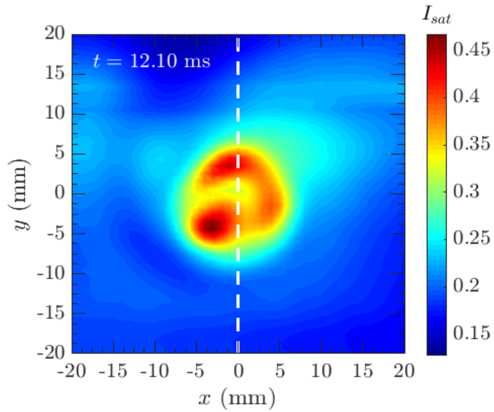
Summary

- Three filaments with <u>far separation</u> results in slight global rotation (from radial electric field) of the filaments before becoming stationary. At turn-on each filament has its own clear independent mode. Convection tails indicate spatial interaction between the filaments.

- Three filaments with <u>close separation</u> show clear interaction from overlapping eigenmodes and have global rotation at turn-on, accompanied by rapid cross-field transport.

  Drift modes appear to be driven by the outer temperature gradient of the filament group.





Thank you!

Congratulations Toshi on your 70th
May you continue the Journey….