Hardware Infrastructure

LAPD - Large Plasma Device

The LAPD device is housed in a vault with an area of 3300 ft^2 (30 x 110) and 18 foot ceiling; it has a 2.5 ton overhead crane. The magnet power supplies and heat exchangers are adjacent in a 900 ft^2 space. The machine vault was originally designed to accommodate a free electron laser so that the room is radiation hardened with the walls and ceiling made from five-foot-thick, triple-density concrete with two inch re-bar. Adjacent to the machine vault are two 600 ft^2 (20 x 30) rooms. One serves as the control and data acquisition room while the other houses the LIF and pulsed lasers.

The LAPD plasmas are generated by electrons emitted from a heated, Barium Oxide-coated cathode and subsequently accelerated by a semi-transparent grid anode located near the cathode. The ionizing electrons (≈ 50 eV) strike an inert, neutral gas (e.g., Helium or Argon) and generate highly ionized (up to fully ionized) plasmas. Highly reproducible, quiescent plasmas are formed, having typical discharge duration of 1-10 ms at a 1 Hz repetition rate. After the discharge pulse is terminated the electron temperature falls rapidly but the plasma density remains confined for relatively long times, thus permitting additional access to experimentation in afterglow conditions for intervals exceeding 20 ms. The heater assembly for the cathode can withstand the JxB forces encountered at the largest magnetic field values (2.5 kG).

The LAPD plasma column has a maximum length of 18 meters and 75-centimeter diameter. Plasmas of varying length can be explored by segmenting the device (i.e., inserting a terminating copper end plate at various axial locations). The confining magnetic field can achieve a steady-state value of up to 2.5 kG. Ordinarily the magnetic field is uniform, but it be can be configured to create multiple or single mirror geometries, magnetic cusps, axial field gradients and other configurations of scientific interest. The cathode is driven by a 4-Farad capacitor bank that can supply a total discharge current of 32 kA. The electron source is switched by banks of 2.5 kA, 1.5 kV transistors.

The length of the plasma column and the radial density profiles can be tailored to study various physical processes that depend on transverse or axial gradients in density and temperature. Plasmas are routinely available with densities up to $4x10^{12}$ cm^{-3} and electron temperatures in the 1-15 eV range. Presently the ion temperature is fixed by the discharge dynamics at approximately 1 eV. There are plans to add RF heating to vary the ion temperature.

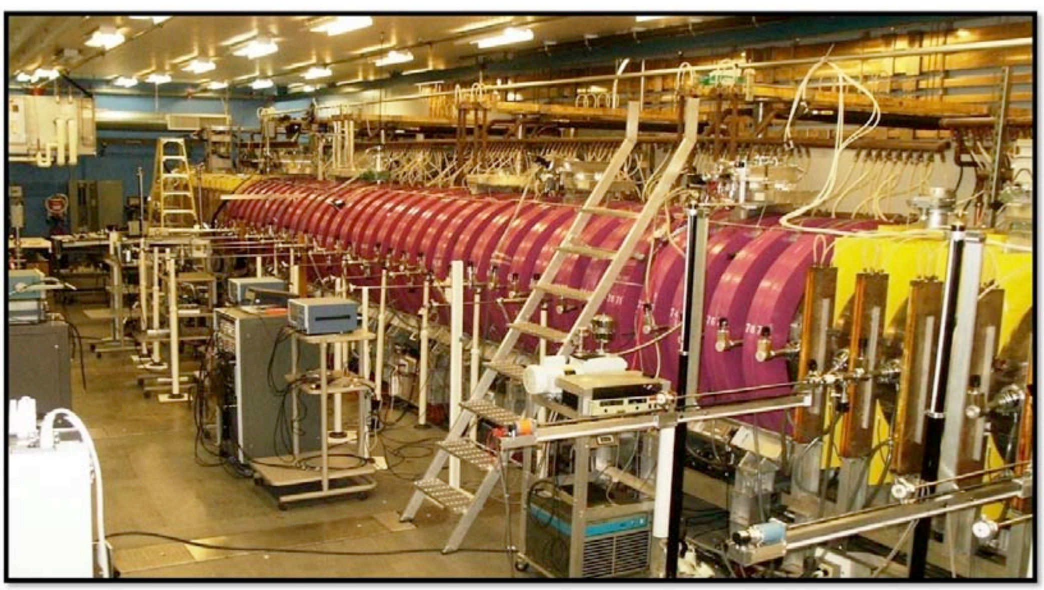


Fig. 1F. The LAPD is 22 meters in total length with an 18 meter experimental region. The machine has been operating since 2001. In the foreground are two computer controlled probe drives and a cryo-based pump down station. Note the rotatable vacuum interlocks on the center ports.

The LAPD has unprecedented access with eight, 12 cm diameter access ports between each magnet set (424 in total) including eight, unique "octo-ports". The octo-ports encircle the entire plasma column and have eight, 10 x 40 cm, rectangular openings, which allow for a nearly unimpeded 360^o view. These ports can be used for visible and microwave tomography, laser fluorescence, or the insertion of various large antennas or plasma terminating end plates. A photograph of the device is shown in Fig 1F.

In the summer of 2004 UCLA paid for a significant upgrade of the LAPD cooling system. Fifty degree (F) chilled water was routed into the laboratory from a nearby chilling plant. UCLA also paid for an air conditioning system in the laboratory capable of cooling a 100 kW load.

It is possible to connect several (up to four), computer-controlled, probe drive systems at once through any one of 50 adjacent ports on either side along the machine axis. If the need arises, simultaneously activated probes can acquire data at several spatial locations in the plasma volume. Probes may be introduced during machine operation through vacuum interlocks and portable pump-down stations without disturbing the vacuum system or plasma conditions. Two pump-down stations comprising a cryopump and mechanical pump, ionization gauges, mass analyzers, and vacuum fittings enable users to move instrumentation in and out of the device. The main vacuum system relies on four turbo pumps with a combined pumping speed of 9000 l/s. Two Stanford residual gas analyzers with computer interfaces monitor the vacuum and gas evolution during cathode conditioning. Neutral target gases are admitted with feedback-controlled piezoelectric valves. A gas mixing system using mass flow controllers allow for the mixing of up to six gases in precise ratios.

A large Lanthanum Hexaboride (LaB_6) cathode has been developed and successfully tested in a smaller test chamber in an adjacent space. The advantage of LaB_6 is that its emission is ten times that of Barium Oxide (the cathode material presently in use in the LAPD), it is not easily spoiled by O_2 impurities, and may be driven to higher discharge voltage because it is not easily destroyed by ion bombardment. The disadvantage is that it must be heated to 1450-1550 degrees C before it emits rather than 850-900 degrees C for BaO. Since the radiant heat is proportional to the fourth power of the temperature, a cathode using LaB_6 will produce 5 times the heat of one using BaO . This large heat load can be dissipated by aggressive cooling of the chamber wall and support structures. Figure 2F shows the LaB_6 cathode emission from a 20 cm diameter test cathode at emission.

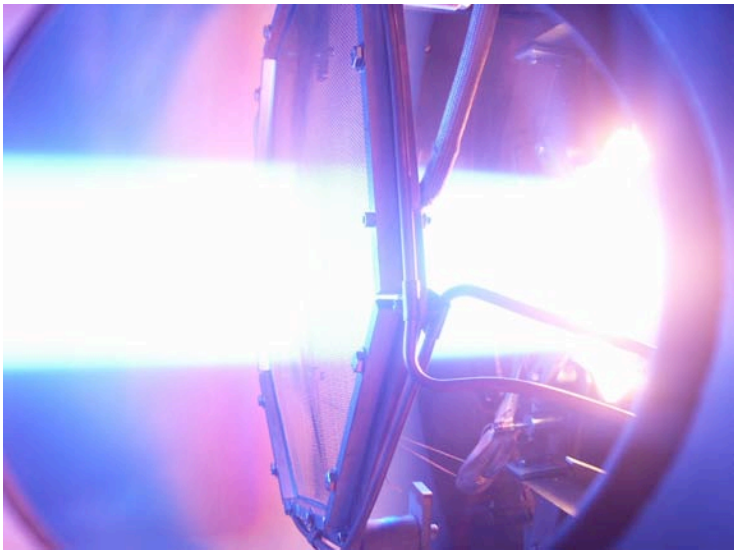


Fig 2F. Emission from a LaB_6 test cathode. The structure on the left is a molybdenum mesh anode. The background magnetic field is 1 kG.

We plan to use this cathode as a second source placed at the North end of the LAPD device. This will permit the formation of a 20 cm diameter (1/3 the background column diameter) dense hot plasma column embedded in a pre-existing plasma. The two cathode pulsers and the timing circuitry will be independent so that the second plasma can be pulsed-on, during or after, the main discharge. To implement this configuration the LAPD will be lengthened by one meter. The addition will be placed between the end of the magnets and the North pumping chamber (the existing cathode is on the South side). A schematic of the additional chamber and placement of the new source in the LAPD is shown in Fig. 3F.

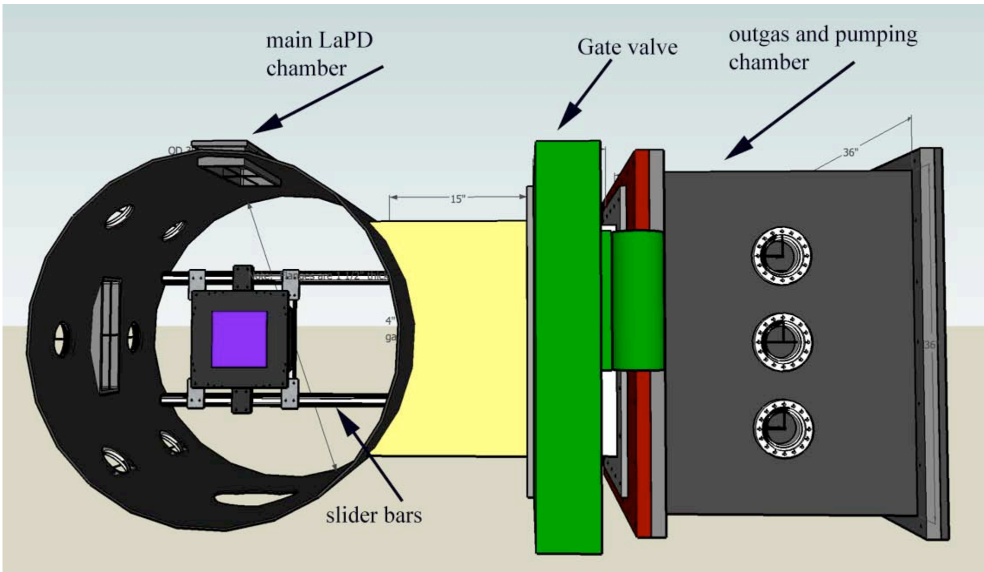


Fig. 3F. Drawing of the new chamber and LaB_6 cathode system that will be installed in the LAPD. The LaB_6 cathode, shown as a purple square, is on slider bars that will allow it to be fully retracted from the machine. The cathode can be moved into the out-gassing chamber on the right. The chamber will have 2 turbo pumps (donated from industry) and all the power and water-cooling lines necessary for the cathode. A water-cooled copper shroud will be placed in the LAPD and in the out-gassing chamber to cool them.

The chambers shown in Fig. 3F have been fabricated and leak tested. A custom gate valve has been delivered and mounted on the chamber as shown. We are in the processes of constructing the specialized cathode for this chamber as well as the discharge pulser based on a transistor switch, to make the secondary plasma. These activities are financed from that part of the existing BaPSF budget targeted for facility upgrades.

Some users have requested that LAPD operate with plasmas of yet higher density for specific studies (e.g., magnetic field line reconnection, shock wave formation). Preliminary results indicate that the new cathode may satisfy these needs.

The LAPD magnetic coil system consists of 90 pancake magnets placed at 15 cm intervals along the machine length. The magnets are controlled by ten separate power supplies, specifically designed for this system. The power supplies can be controlled manually or by computer, and allow operation of up to 2.5 kG uniform axial magnetic field with 0.1% current ripple. The magnet power supplies (4 supplies: 9.6 kA, 40 V; 6 supplies : 3600 A, 84 V) are fed by a 4.0 MW substation acquired for this project. An additional MW of power is available in the laboratory for general use. The building is unique in its electrical capabilities; it is designed to accommodate large experiments that require high power levels. Presently there is 15 MW available in the building switchyard, and this can be doubled if necessary.

ETPD - Enormous Toroidal Plasma Device

The ETPD device is housed on the main floor of the STRB building. The device was originally constructed as a tokamak and if run in that mode, it would still be the physically-largest tokamak in the world. The vacuum system interior dimensions are 2 m wide and 5 m high. The chamber is made from 1inch-thick stainless steel. The 32 toroidal magnets are made of Al slabs separated by glass insulators. Magnets plus chamber weigh in at 300 tons. The device is shown in Fig. 4F. The long-term vision of BaPSF is to convert this chamber into a 24/7 operating basic plasma device with diagnostic capabilities equal to the LAPD. To attain that level of performance a separate infrastructure grant will be pursued in the future.

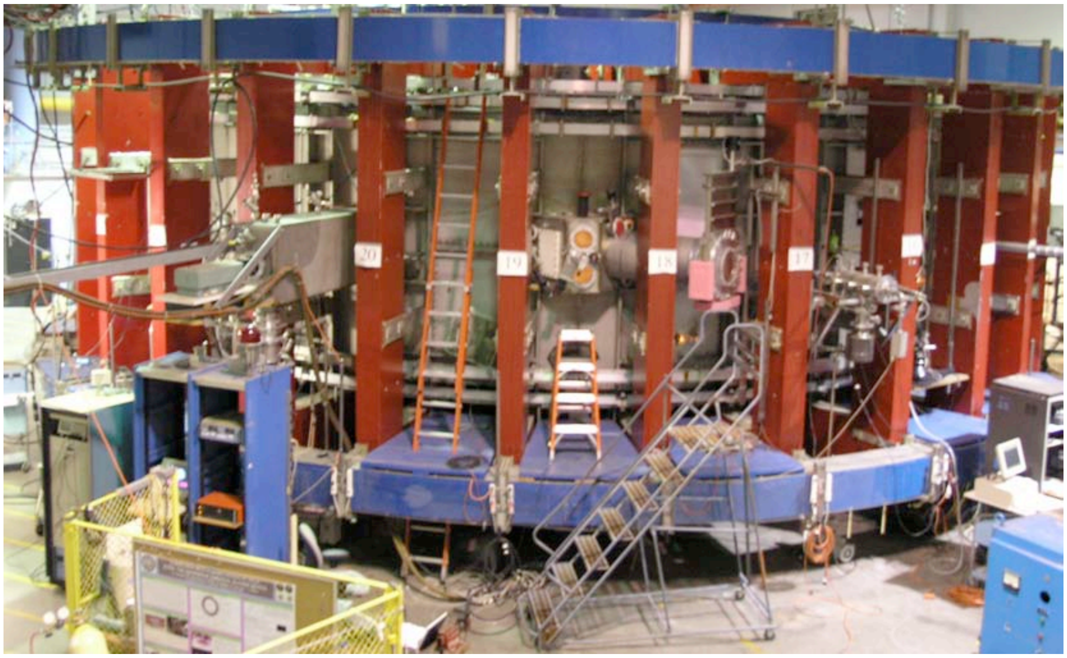
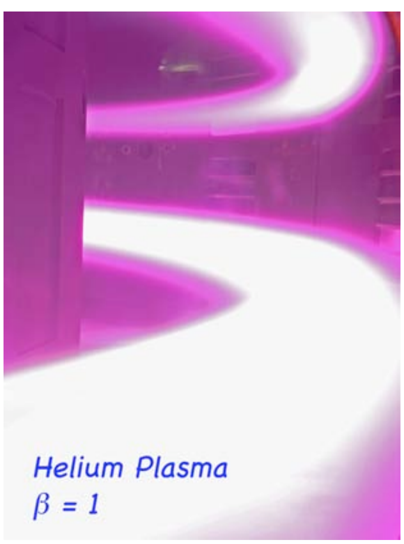
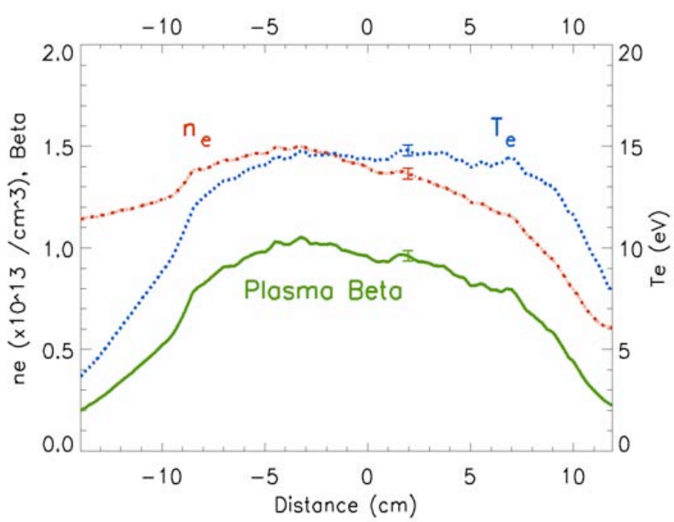


Fig. 4F Photograph of the ETPD device. The toroidal magnets are painted red and the vertical field coils are blue. The machine will be modified to accommodate many more access ports and a 60 cm diameter high current discharge source will be placed inside. The toroidal coils will be run with DC power and cooled by forced air.

Fig. 5 is a photograph of the ETPD plasma together with profiles, across the plasma column, of



5Fa. Photograph of He plasma. Each ring is 30 m in circumference. The longest plasmas are 120 meters.



5Fb. Plasma density and temperature measured with a Langmuir probe. The ion temperature measured spectroscopically equals Te. The central plasma beta is 1 at Bo = 150G. A vertical field makes the plasma spiral.

measured plasma parameters. The ETPD and its immediate diagnostics occupy 5760 ft^2 of high-bay space. This area has a 25 foot ceiling and a 10 ton crane. There is an additional 2880 ft^2 of low bay space for power supplies to service the ETPD. There is 1.3 MW available raw power fed by 12 kV lines and an additional 3 MW of 480/220 power in "rails" lining the walls surrounding ETPD to which circuit breakers may be attached. The STRB also has 2048 ft^2 of machine shop space to service the building. The machines available are end mills, lathes, band-saws, several welders and cut-off saws. Presently the plasma source has a 20 cm diameter LaB_6 cathode and plans are underway to upgrade this to a 60 cm source.

Plasma Processing Device.

A series of experiments on low temperature plasmas have been initiated at BaPSF with industrial partners. The experiments have studied self-generated modes above a silicon wafer using correlation functions between emissive probes. Laser Induced Fluorescence (LIF) has been used to measure the ion distribution as a function of height and phase during RF-biased acceleration in a plasma etching tool. One such tool was donated by industry and is shown in Fig. 6F.

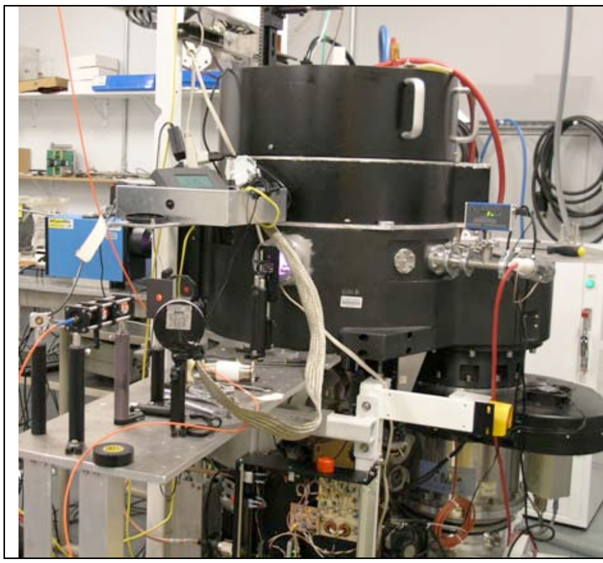


Fig. 6F.

Plasma etching tool donated by the Intevac Corp. The tool was modified to allow LIF experiments and mount 2-D probe drives for wave studies. The plasma is generated inductively and two separate frequencies are used for RF-bias (to accelerate ions to etch the wafer). The gases are fed by multiple mass-flow controllers and the machine is microprocessor controlled.

LAPTAG High School Plasma Laboratory

The BaPSF sponsors a high school outreach program known as the Los Angeles Physics Teachers Alliance Group (LAPTAG). High school students from the LA area use a small machine constructed especially for them out of spare parts and hand-me-down equipment from the facility. The LAPTAG device is shown in Fig. 7F. Any high school or community college student is welcome to participate in this program. The students learn lab skills, build electronics and get lectures on plasma

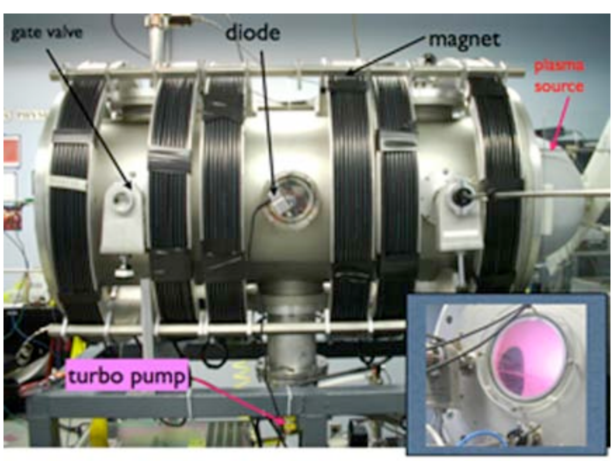


Fig. 7F. LAPTAG plasma physics device. An inductively coupled plasma source makes a pulsed ($n \leq 10^{11} cm^{-3}$) plasma with a background field of up to 100G. The plasma is 2 m long and 40 cm in diameter physics. The LAPTAG students attend scientific meetings, the latest being the Spring 2010 APS meeting where they presented experimental results on whistler waves. LAPTAG meets every Saturday and nearly every day during in the summer.

SMPD – Small Plasma Device

A small test device, shown in Fig. 8F, was constructed using power supplies, a vacuum chamber and other hardware left over from the original 10 m-long LAPD device. Magnetic field coils were wound from water-cooled welding cable that limits the background magnetic field to 300 G. The plasma source is a 20 cm diameter LaB_6 cathode which makes plasmas of density $n \simeq 10^{12}\,cm^{-3}$ and the plasma is pulsed at 1 Hz. The machine is an excellent device for testing probes, small beams and experimental techniques before using them in the LAPD device. Users are welcome to utilize this machine for testing. Presently it is also being used to conduct a solar flare experiment that involves installation of internal field coils that are not possible to move in and out of the LAPD.

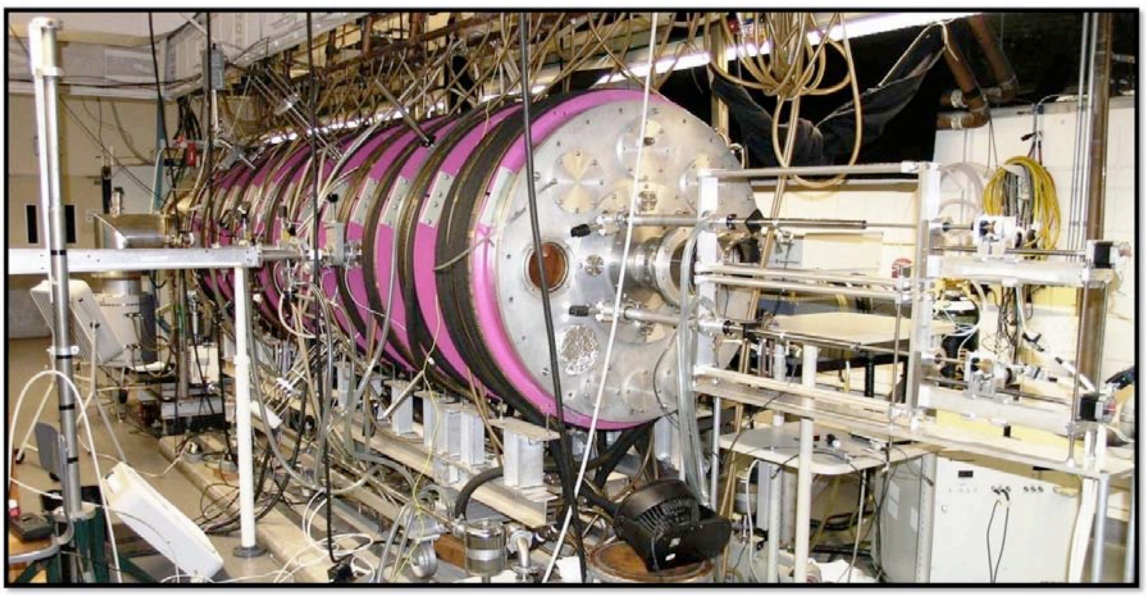


Fig. 8F The SMPD four meter test chamber. Probe drives for use in the solar flare experiment are on the right.

Science and Technology Research Building (STRB)

The LAPD and ETPD experiments and the low temperature physics laboratory are housed on two levels of the Science and Technology Research Building (STRB) on the West campus of UCLA. The STRB is a relatively new (completed 1997) building which was designed to accommodate large experiments and/or those which require substantial electrical power. There is 30 MW capability in the building. A chilled water plant, recently upgraded, provides 55-degree (F) water to the STRB which is sufficient to cool 10 MW. There is an additional chilled water system in the STRB. There is ample electrical power at 480, 220 and 120 Volts distributed throughout the building. The ETPD area has several multi-megawatt transformers fed by 12 kV lines

Communications and Computing

The computer network at the BaPSF comprises its own public class-C network for general computing and several internal private subnets for data acquisition and machine control. Gigabit network switches are available throughout the facility. In 2009 UCLA invested $80k (at no cost to the facility) to replace the three main, but aging, Cisco switches in the STRB with state-of-the-art versions, having 10

GBit uplinks to the UCLA campus backbone. Wireless (B/G/N) network connectivity is also provided to the users in both the STRB and offices.

Data storage resources at BaPSF include a 16TB RAID 6 centralized network storage server, with a second server providing daily, incremental disk-to-disk backups; a tape backup system is also used for data archiving. Facility users have access to several Linux workstations as well as a main computer server with 64GB RAM and 8 Intel Xeon processor cores. In addition, the facility and local resources include 6 Windows systems (for experiment data acquisition, automated probe motion, machine state monitoring, diagnostics, and control) and 7 Mac computers; one Mac is configured for advanced data visualization using Maya software with custom data import and analysis plug-ins. Output from this visualization computer can be viewed on a 72-inch, 3D HDTV using LED shutter glasses. Workstations have IDL and AVS for scientific visualization as well as several language compilers (C, C+, and Fortran). A Xerox color laser printer, slide scanner, and flatbed scanner are also available. The facility website is hosted by a dedicated departmental server, and may be accessed at this URL: http://plasma.physics.ucla.edu/bapsf/

Equipment Available to Users

Diagnostic Equipment:

Fifteen Digital Oscilloscopes ranging from 2 channel-175 MHz/channel to one 4-channel 40 GHz scope (f_{pe} < 12GHz in LAPD), 6 Stanford digital delay generators (1 ps accuracy), 2 BNC 8 channel pulse generators (1 ns accuracy), 1 LeCroy arbitrary waveform generator (10 MHz), 2 Agilent arbitrary waveform generators (80 MHz), HP 8568B spectrum analyzer, Agilent Network Analyzer (to 180 MHz), 12 channels of Tektronix-Sony 100 MHz optical isolators, 2 microscopes for probe construction (one with micro-manipulators.)

Sixty-four channels of 100 MHz/chan, 128kS/chan, 14-bit digitizers are available for low-frequency data acquisition and 10 channels at 5GHz, with 15kS/chan, 8-bit digitizers for high-frequency acquisition. Additionally, the 40GHz (2-chan, 20GHz 4-chan mode, with 8MS/chan) oscilloscope is also integrated into the data acquisition system.

An array of 7 microwave interferometers operates in LAPD at 1Hz providing diagnostic density measurements at 7 axial locations along the plasma column.

Amplifiers, Sources for Launching Waves:

One custom-built 30 kW amplifier (may be tuned for 200 kHz-5 MHz operation), 1 Velonix 360 high voltage pulser (up to 30 kV pulses, 100 ns rise-time), 1 AR 2500L, 10 kHz-220 MHz, 2.5 kW broadband amplifier, 1 AR 2000L, 10 kHz-220 MHz, 2 kW broadband amplifier, 1 AR 200L 1 MHz-200 MHz, 200 W broadband amplifier, 1-250 kW (2.5 ms pulse) 9 GHz source,

Lasers:

Two Nd-YAG pumped lasers with 7 ns, 150 MW pulse (up to 10 Hz); one with a frequency doubling (532-nm) crystal. One CW tunable dye laser: bandwidth 1 MHz, free spectral range 30 GHz, power up to 1-Watt (Coherent 899 driven by an INNOVA Argon ion laser) mounted on an air-isolated optical bench (Spectra Physics Pro 290). Optics are on hand to operate in the blue to far red depending upon choice of dye. Equipment associated with this laser is: a confocal spectrum analyzer, New-Focus 7711 Fizeau Wavelength meter, iodine cell, opto-acoustic light chopper and light detection phototubes, amplifiers and power supplies. The newest addition is a pulsed dye laser (10 ns pulse and 100 ns pulse stretcher) 2-12 MW programmable, spectral output from 270-700 nm for LIF photography. This is coupled with a Cooke Gen III, high speed (t_{min} = 3 ns), (1024X1280 pixel CCD), computer controlled camera with averaging and background subtraction capabilities. This camera is for the imaging of planar LIF signals. Both lasers are interfaced to computers and can be driven by the data acquisition system or used independently.

Energetic Ion Beam

An ion beam source has been developed at BaPSF to perform experiments related to the Fast-Ion Campaign. The beam source was constructed by Drs. S. Tripathi and P. Pribyl, and Prof. W. Gekelman. It delivers an 18 kV, 3 Amp, He-ion beam. The energy is chosen to match the phase velocity of Alfvén waves in the LAPD. Figure 9F is a photograph of the beam source attached to the LAPD device. The beam source consists of a plasma generator, which is based on a pulsed, inductively-coupled antenna. A pulsed 25 kV power supply was designed and constructed to accelerate the beam. This design has the safety feature that high-voltage on the grids is present for only a few milliseconds. The beam uses three focusing grids (obtained from an old neutral beam source used at PPPL) and enters into a drift chamber where several turbo pumps and Carbon baffles remove neutrals that drift-in from the plasma-source region. This configuration is also necessary to prevent excessive beam loss due to charge exchange collisions.

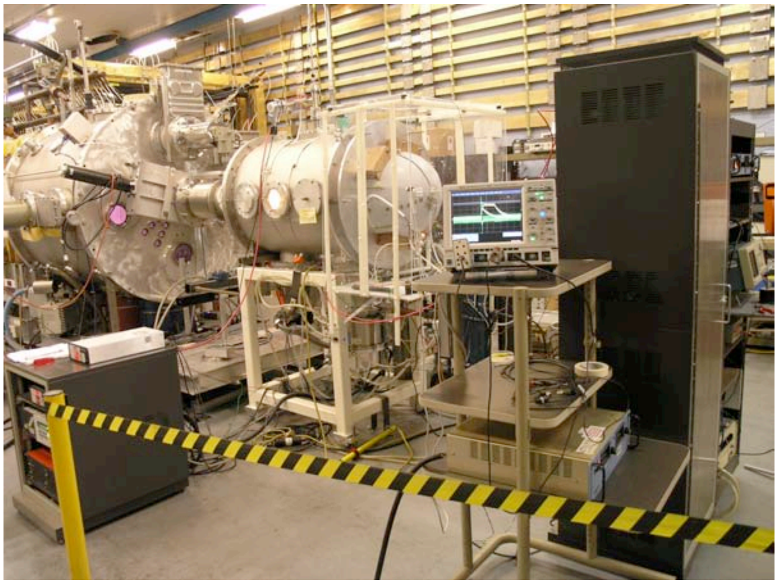


Fig. 9F. Ion beam attached to the end of the LAPD device. The beam is on a bellows and can be rotated about the center axis of the device, allowing injection at angles up to 15 degrees. The gate valve at the end allows the beam to be introduced without letting the machine up to air.

Recently, the performance of the ion beam source has been greatly improved by replacing the Copper grids with grids made of Molybdenum, and by optimizing the grid spacing. Figure 10F shows the radial profile of the measured beam-current density 4.28 meters from the beam injection point in the LAPD. The maximum beam density is $n_b = 10^8$ cm^{-3}. Fifty-eight percent of the beam particles generated by the ion source reached the measurement position.

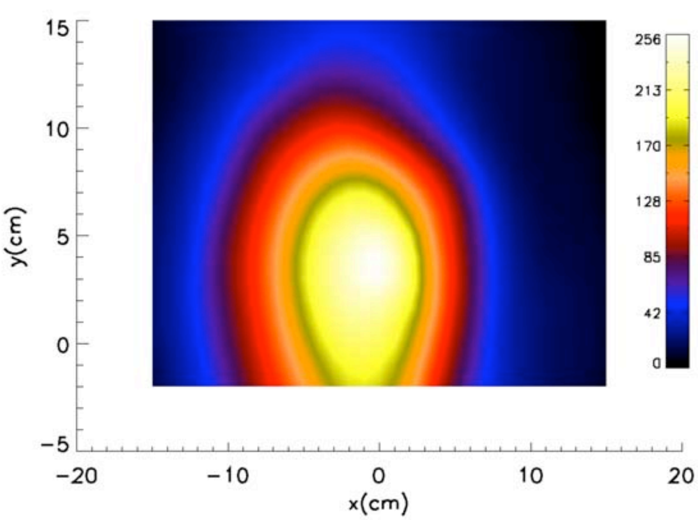


Fig. 10F He ion beam (V_{beam} = 22 keV) profile 4.28 m away from the beam source. The brightest region corresponds to $n_b = 10^8$ cm^{-3}.

The effect of the injected beam on the ambient LAPD plasma has been documented; a wave generated, probably by Cherenkov radiation, is observed. Figure 11F shows a snapshot of the fluctuating vector magnetic field triggered by the beam injection. The ion beam will become an important tool of the

‘Fast-Ion Campaign’ lead by Prof.W. Heidbrink, but it will also be available to all BaPSF users who request it for their projects.

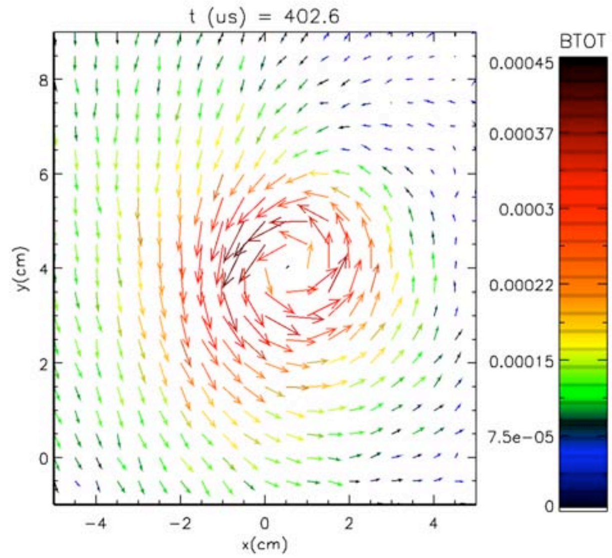


Fig. 11F. Vector map of the fluctuating magnetic field excited by the ion beam . Mode frequency is 510 kHz, ion cyclotron frequency 513 kHz. V_{beam} = 22 keV, I_{beam} = 0.42 A, LAPD magnetic field is 1.35 kG, background plasma density n = 1.8 10^{12} cm^{-3}.

Additional Experimental Capabilities

a. A 500V, 5kA pulser is available to bias the LAPD vacuum chamber with respect to the cathode in order to produce a rotation of the plasma column.
b. Several LaB_6, cathodes are available to produce cylindrical density enhancements within the main plasma. Plasma source development in the last funding cycle has resulted in the creation of several high-performance cathodes available to users. These range from a 3mm to 10-cm diameter version. A factor of 10 increase in background plasma density can be achieved with these cathodes.
c. Mass flow controllers provide the ability to simultaneously mix up to four gases (H, He, Ne, Ar) for multi-ion species experiments.