Fast Visible and IR Imaging in Alcator C-Mod

R. J. Maqueda and G. A. Wurden
Los Alamos National Laboratory

J. L. Terry and J. A. Stillerman
PSFC-MIT

S. J. Zweben
PPPL

ABSTRACT

Two imaging systems have been installed on C-Mod as part of the LANL/MIT collaboration. The first one is a fast Kodak digital camera system that can store 1600 full frames at rates up to 1000 frames/sec and with gating times from a few microseconds to 1 millisecond. The second system uses an Amber Radiance IR camera (3-5 μm band and 30 frames/sec) and should be able to measure heat loads on the divertor surfaces. A re-entrant periscope viewing the lower, closed divertor (30 cm x 30 cm region) from above and based on ZnSe optics is used to transport the image to the IR camera located 5 m away. The data acquisition and camera control of the IR system is performed remotely through fiber optic links by a PC running Windows 95 and using a MuTech MV-1000 video grabber board. Results obtained during the 1997 campaign will be presented. These might include: edge turbulence, fast-scanning probe injection of impurities, radiation from runaway electrons, heat loads during attached/detached plasma operation and disruptions; as well as localization of hot spots, possible sources of molybdenum.

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IR Imaging System

- **Issues**

  * Measure heat loads on divertor surfaces.
  * Search for hot spots, possible sources of molybdenum.

- **Approach**

  * Use an Amber Radiance 1 video camera sensitive in the mid IR range: 3-5 μm.
  * Use an IR periscope to view the lower, closed divertor and locate the IR camera where the magnetic field is manageable.
  * Capture the standard video output of the IR camera with a MuTech MV-1000 PCI video grabber board located in a PC running Windows 95.

- **The IR periscope**

  * Use ZnSe lenses and wedges to transport the image a distance of ~5 m.
  * Design optimized with ZEMAX-SE ray tracing code.

- **Result**

  * A 30 cm x 30 cm region of the divertor is imaged with spatial resolution better than a few millimeters.

Amber Radiance 1 IR camera

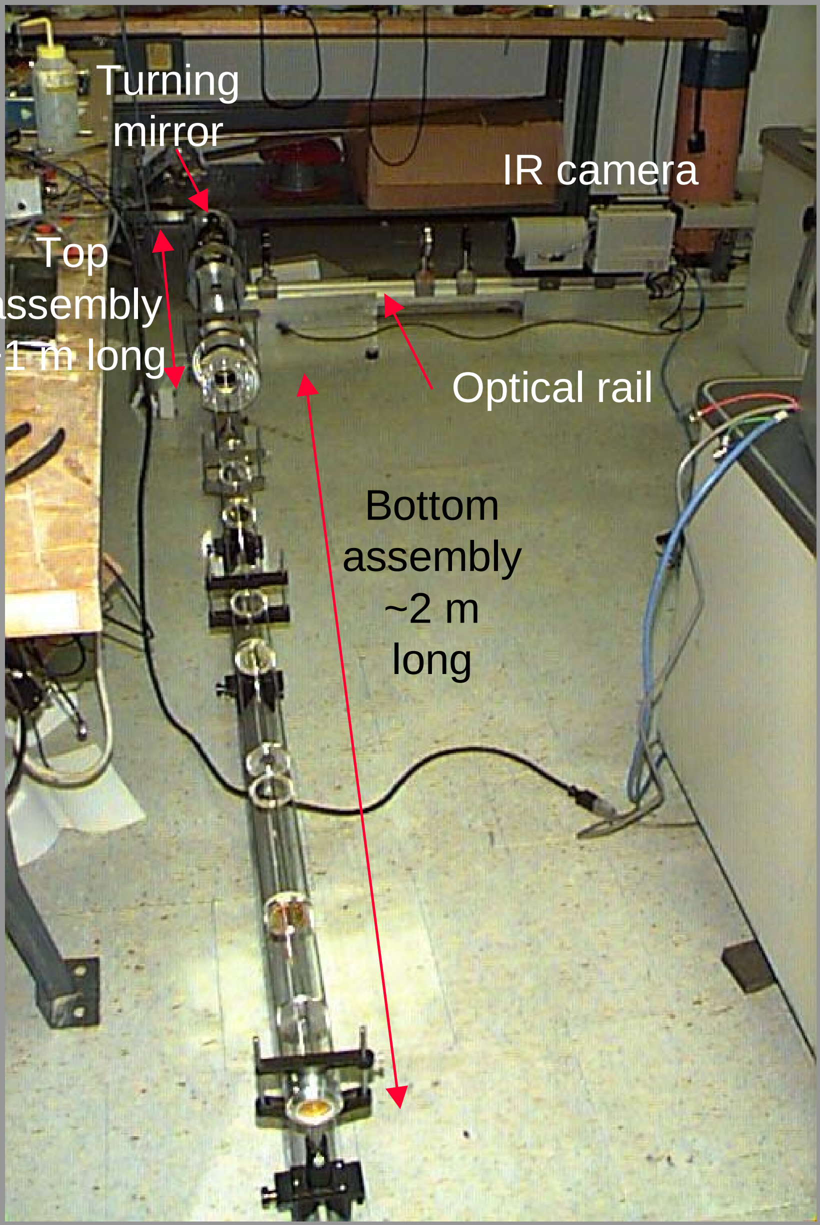
- 256 x 256 element array.
- Gated from <10 µs to 16 ms.
- Full remote control through RS-232 link.
- 2.23°/7.4° Dual Field of View lens.
- Filter wheel with CO_2 narrowband or 10%, 1% , and 0.1 % neutral density.
- NTSC, S-Video or 12 bit digital output.

IR camera control and data acquisition

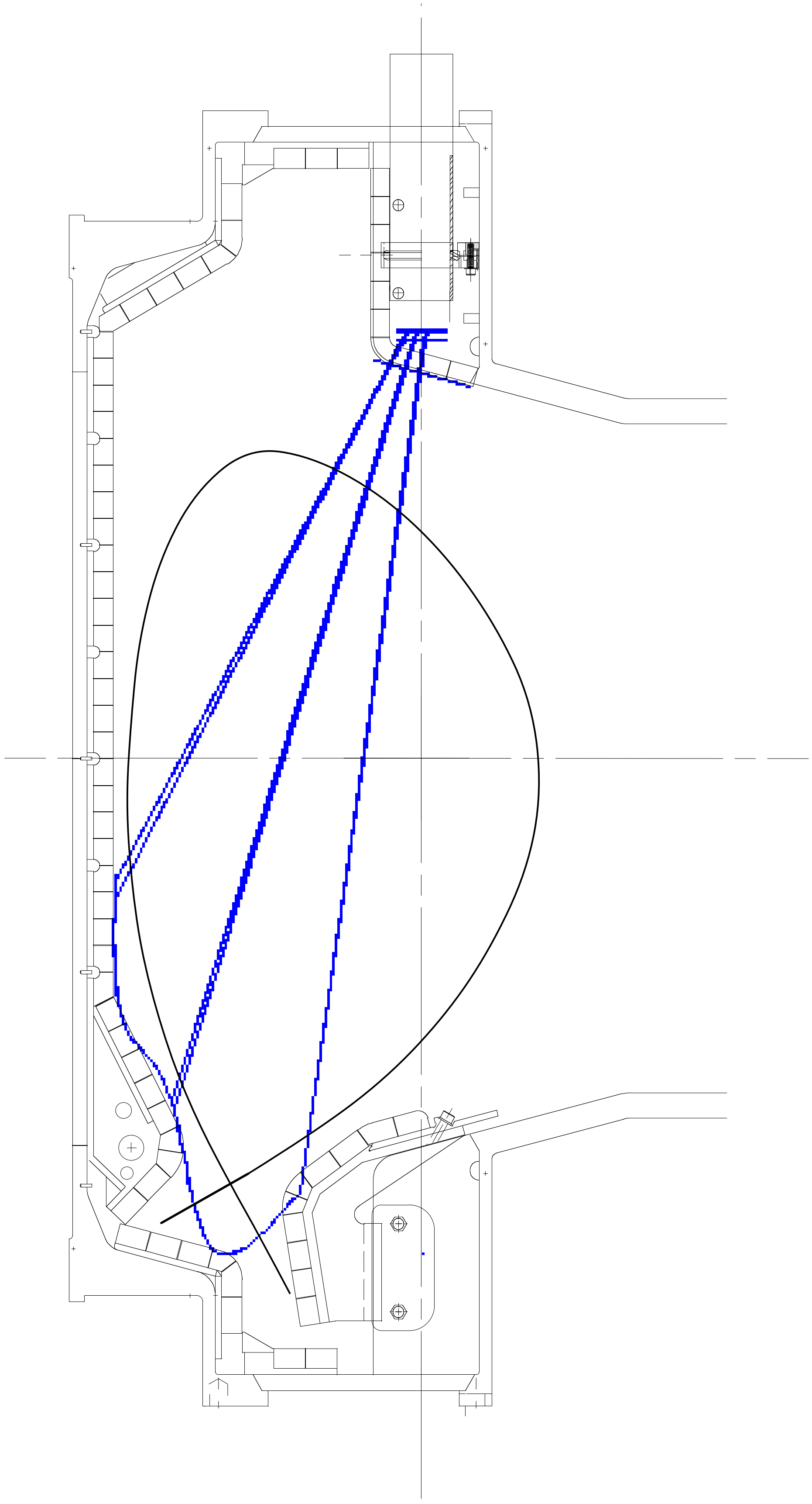
- A 100 MHz Pentium PC located in C-Mod's control room and running Windows 95 is used to capture and store the IR images, as well as control the IR camera.
- A fiber optic video link transmits the standard NTSC output of the IR camera from the test cell to the control room. The RS-232 remote control of the IR camera is also achieved through fiber optic links.
- A MuTech MV-1000 PCI video grabber board is used in the 100 MHz PC to capture the IR images. An external trigger supplied to this board allows the data to be synchronized with the experiment.
- A Windows C++ program developed by PSFC-MIT is used to control the video grabber board and store the data. This program can also replay captured and/or stored video clips.
- The data can be stored in several formats: JPEG, GIF and Motional GIF. The MGIF files can then be transferred to the DEC cluster for analysis with IDL.
- As a backup, the video signal from the IR camera is also stored in NTSC/VHS video tape.

IR periscope

- The periscope is composed of the following optical elements:
  * 7 lenses and 4 wedges (ZnSe with AR coating for 3-5 µm) and
  * 1 Al & SiO coated mirror.
- The periscope is assembled and focused on the floor (a.k.a. bench).
- The bottom assembly is then inserted downward in the A top re-entrant tube of C-Mod (2.5" OD). The top assembly is placed through the igloo cover and the optical rail (with the IR camera) is secured on top of the igloo.

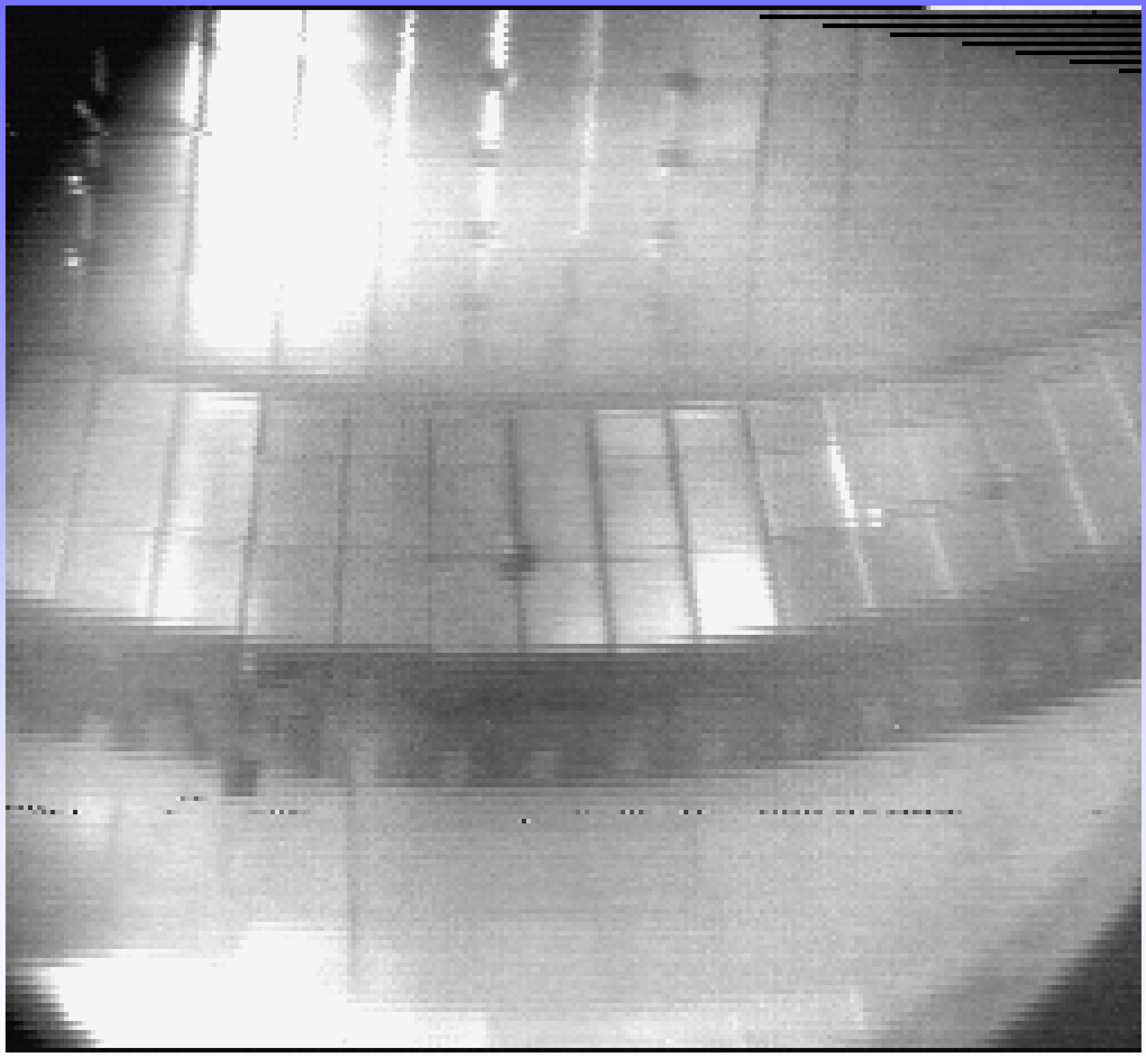


View with periscope in 0 deg. position



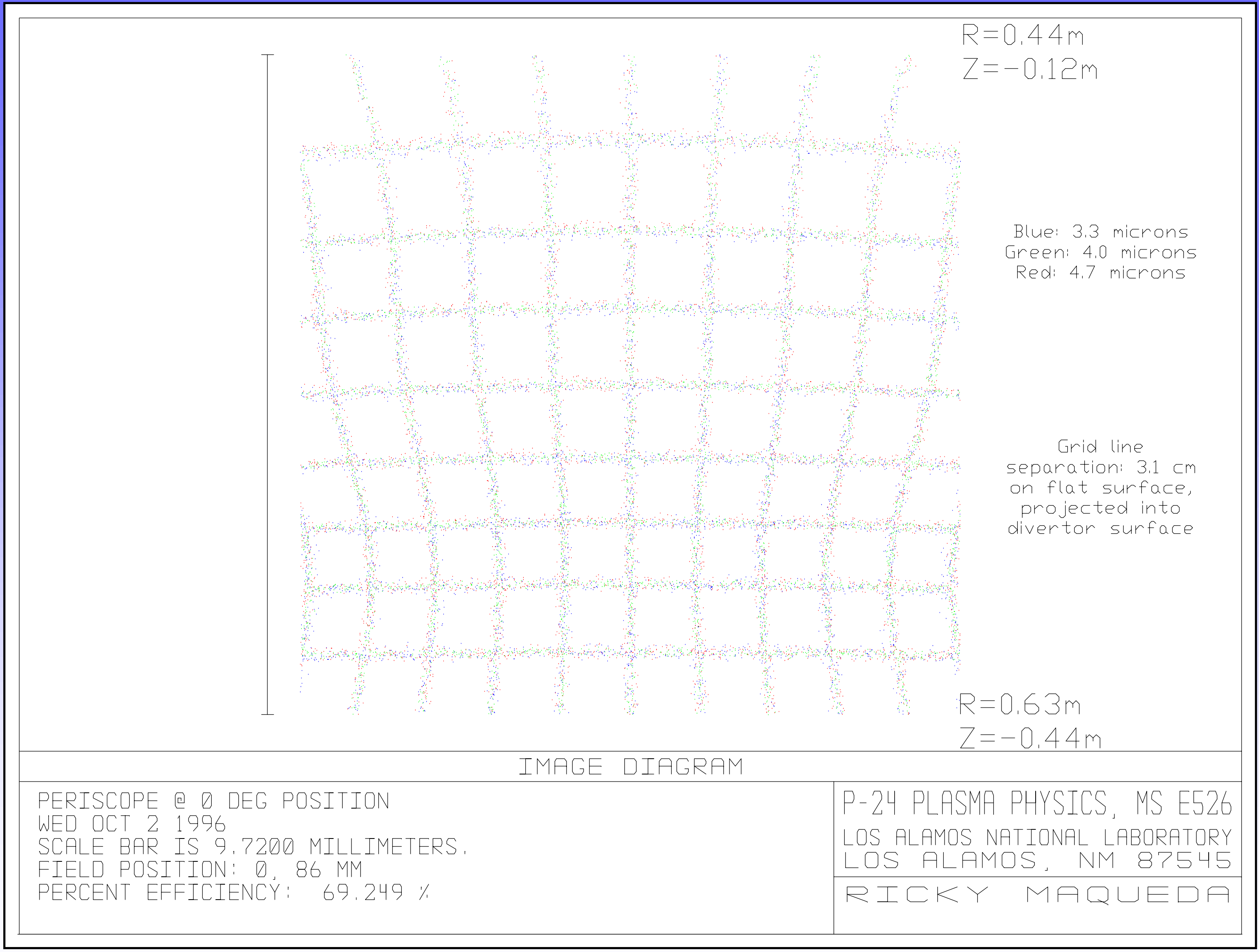
Infrared periscope
Drawing 30
Ricky Maqueda
LANL

IR image of C-Mod's lower divertor



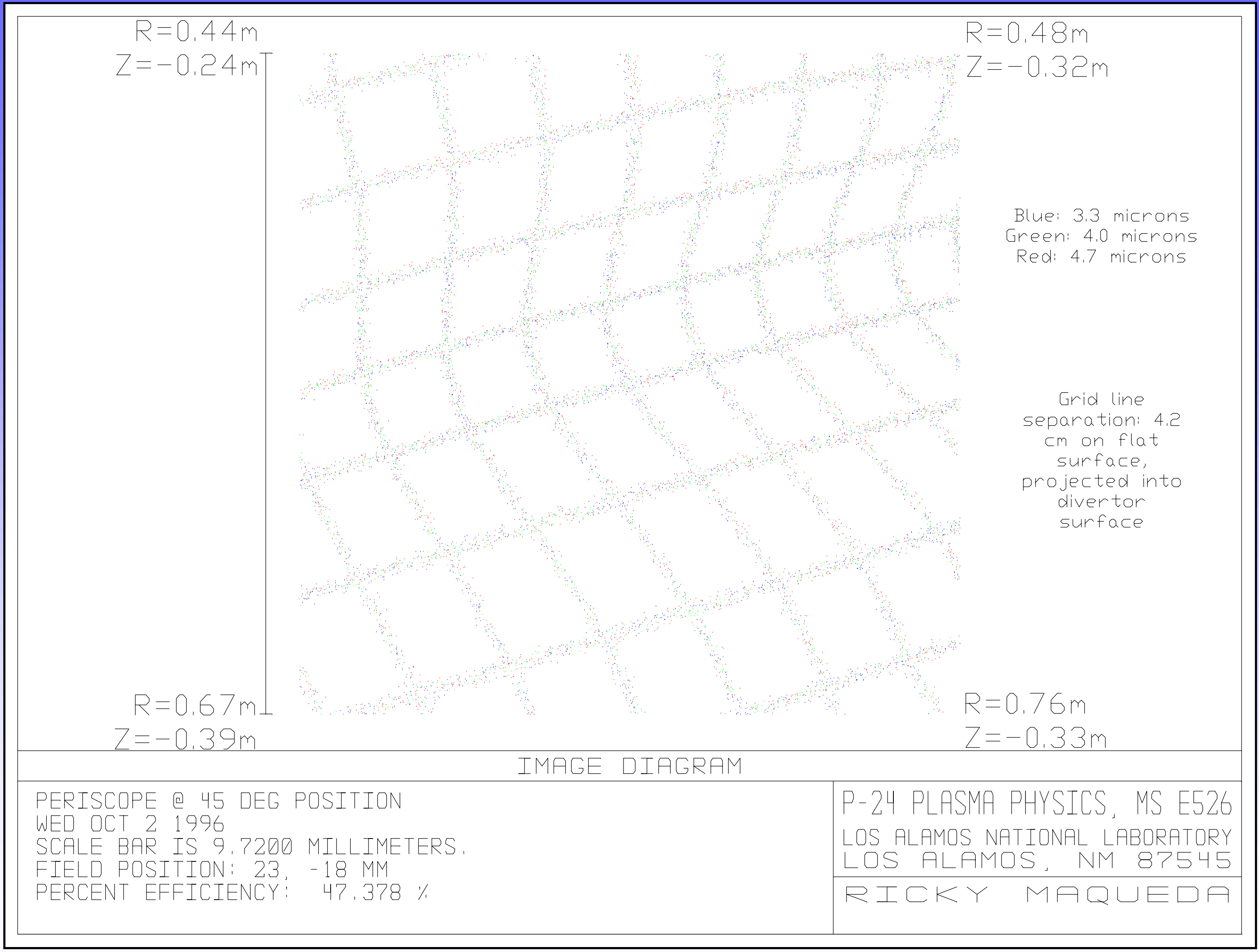
- Bay A section of the lower divertor is viewed from the top through re-entrant periscope.
- Electron Cyclotron Discharge Cleaning (ECDC) heats the plasma facing components of the divertor.
- Slots between molybdenum tiles can be clearly seen indicating better than a few millimeters spatial resolution.

ZEMAX-SE simulation, “inward” periscope



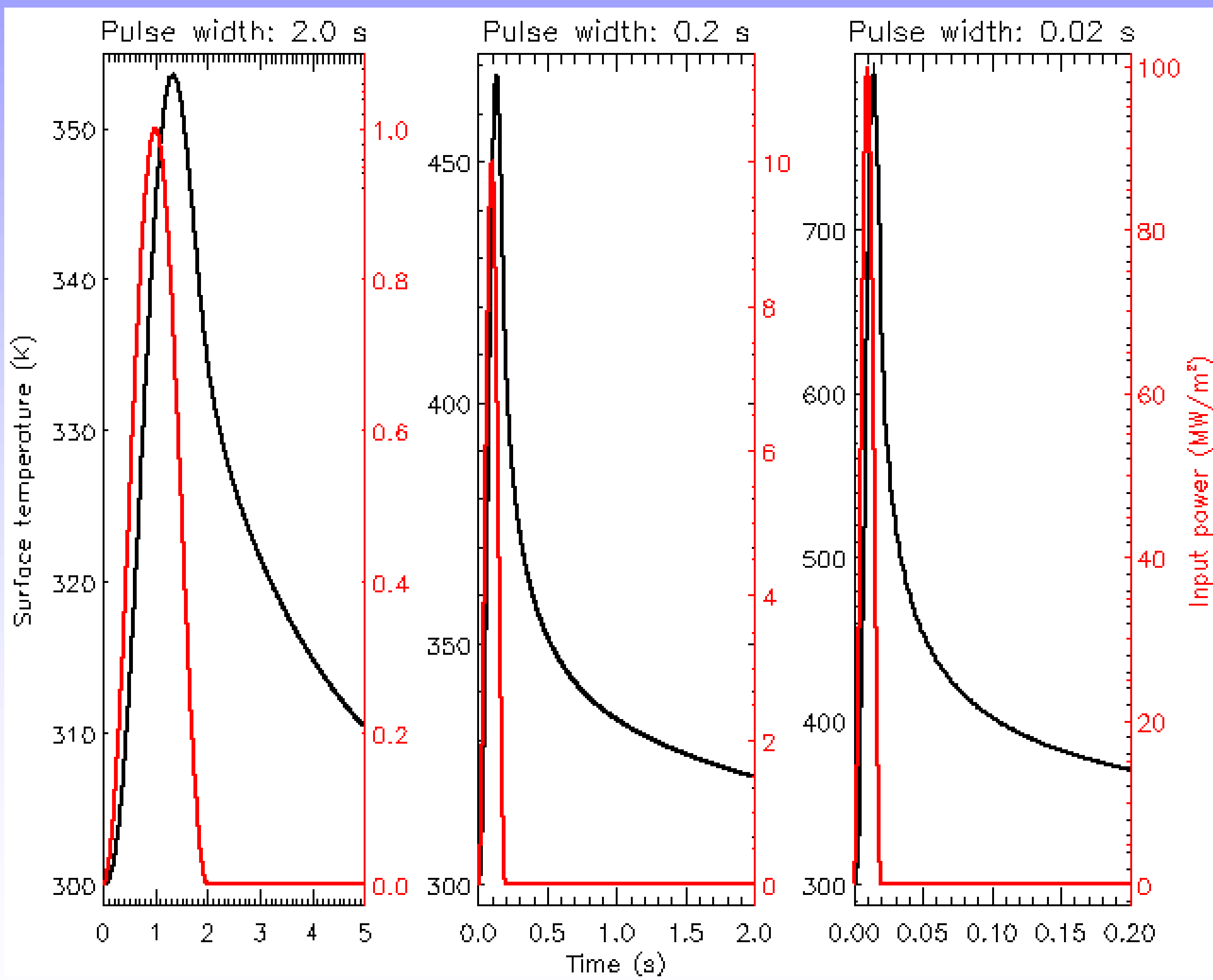
Periscope layout (45 deg. position)

ZEMAX-SE simulation, rotated periscope



Thermal response of Molybdenum tiles

- A simple 1-D model is used to estimate the response of a 2 cm thick Molybdenum tile. Only thermal conduction is considered in this model.
- The back surface of the tile is held at a fixed temperature of 300° K while a heat pulse is applied to its front surface (i.e., plasma facing surface).
- In the examples below 1 MJ/m^2 is deposited onto the tile surface with different time scales.



Present (and future) work

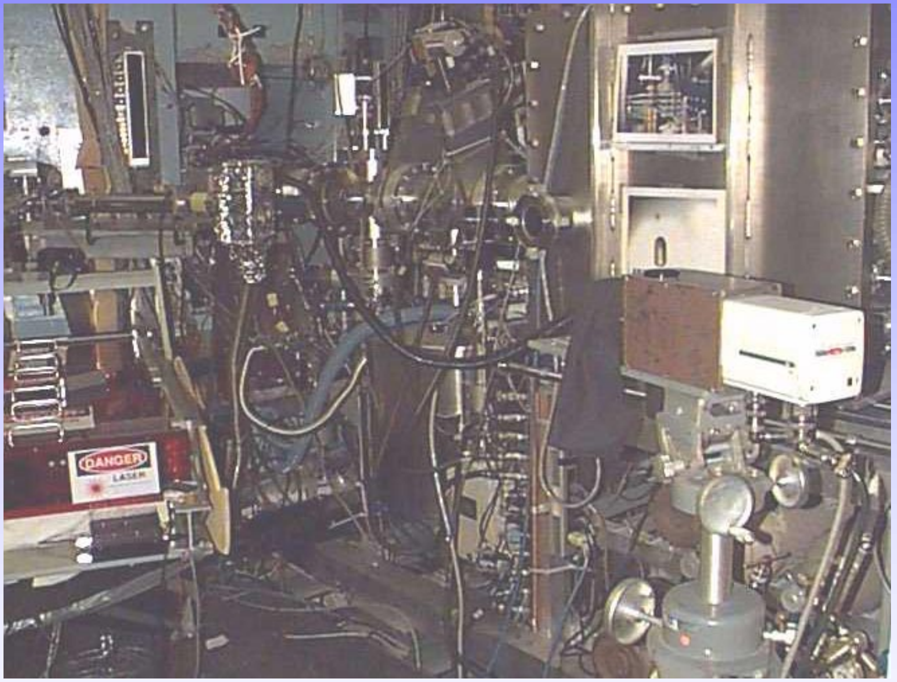
- The re-entrant section of the periscope (i.e., bottom assembly) is being modified to have a continuous flow of "room temperature" Nitrogen in order to stabilize its temperature. In the first version of the periscope, 4 of the bottom 5 optical elements were destroyed when the heaters on C-Mod's vessel failed and the machine cooled down to liquid N_2 temperatures. The aluminum holder for these optical elements contracted over the ZnSe pieces breaking them! On the other hand, one of the middle lenses was being heated over the flow temperature of Teflon (presumably by the RF discharge), making the assembly difficult to retrieve from the re-entrant tube!
- Once the IR system is commissioned the heat load to the divertor surfaces will be studied. Of particular interest are the heat loads during attached/detached plasma operation and disruptions. In addition, hot spots on the plasma facing surfaces, possible sources of molybdenum, will be searched for.

Fast Visible Imaging System

- A fast Kodak digital camera system that can store 1600 full frames at rates up to 1000 frames/sec and with gating times from a few microseconds to 1 millisecond has been installed at C-Mod.
- This visible imaging system was previously used at TFTR where numerous visible phenomena were recorded and studied. These phenomena include: disruptions, runaway electron effects, lithium injection by means of pellets and DOLLOP, and edge band structures. (Video clips obtained from TFTR can be seen at:
  http://wsx.lanl.gov/ricky/disrupt.htm)
- This system is currently installed at C-Mod with a “quasi” tangential view and is used with and without bandpass filters to study edge phenomena.
- Using this diagnostic edge turbulence filaments have been observed near the higher recycling region at the bay F edge of the RF antenna of C-Mod. The study of these edge filaments continues.
- Other applications for this imaging system in C-Mod are: the redistribution of impurities injected by the fast-scanning probe, the radiation from runaway electrons, and disruption phenomena.

Fast imaging system components

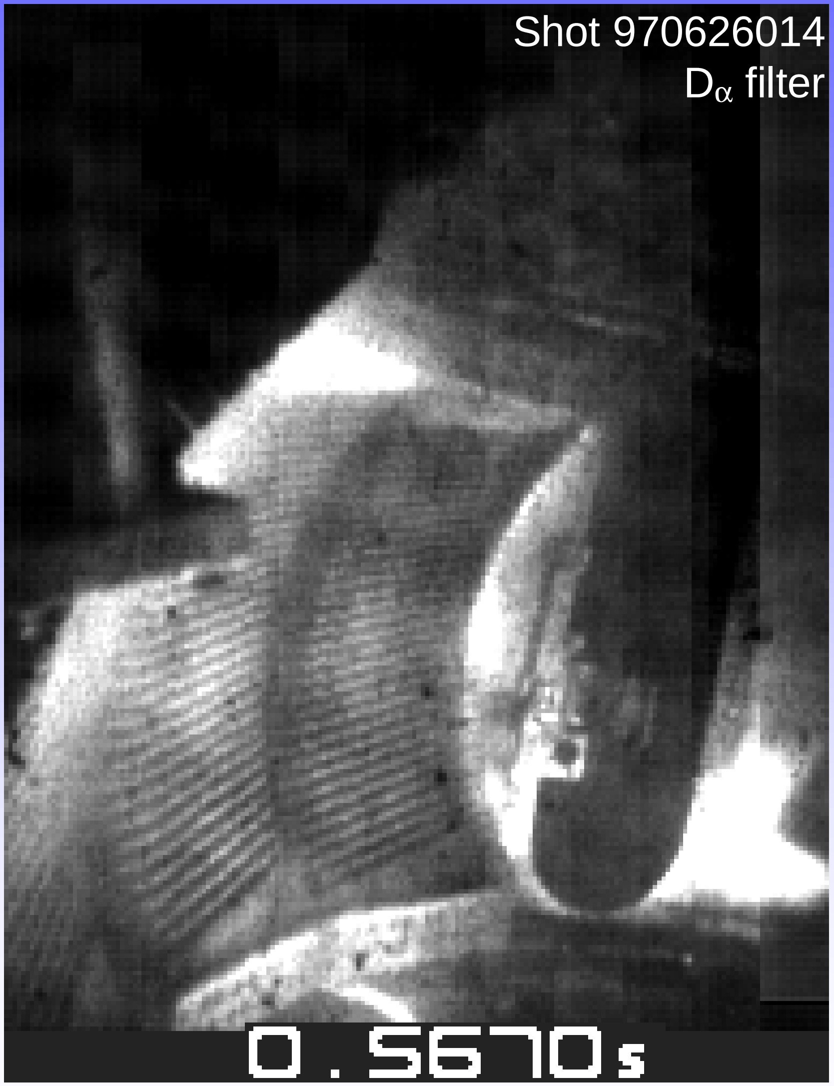
- Intensified Kodak EktaPro EM1012 camera system:
  - Intensified imager
  - Intensified imager controller
  - Motion analyzer processor



- Fiber optic links for processor control (GPIB link) and analog video signal transmission.
- Intel based computer running a LabView virtual instrument controller, either under Windows NT or Windows 95.
- VCR for analog data storage.

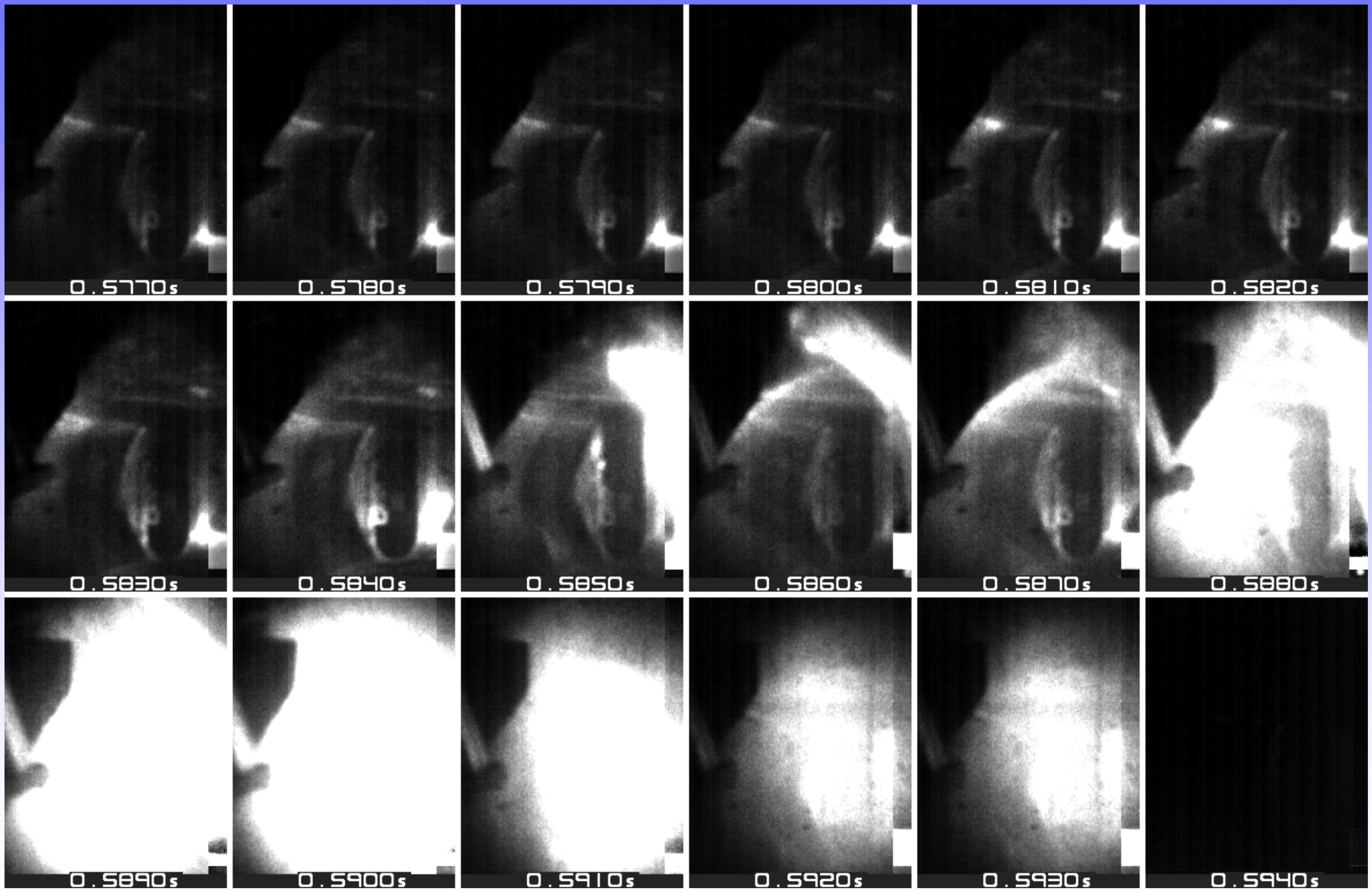
Installation at C-Mod

- The intensified imager is installed on the diagnostic stand (Bay C).
- An imaging fiber bundle is used to couple the imager (i.e. camera) to the “quasi” tangential view from Bay C into Bays E and F.
- The intensified imager controller and motion analyzer processor are located on the ground floor of C-Mod.
- The control computer (133 MHz Pentium PC) is located in C-Mod’s control room.



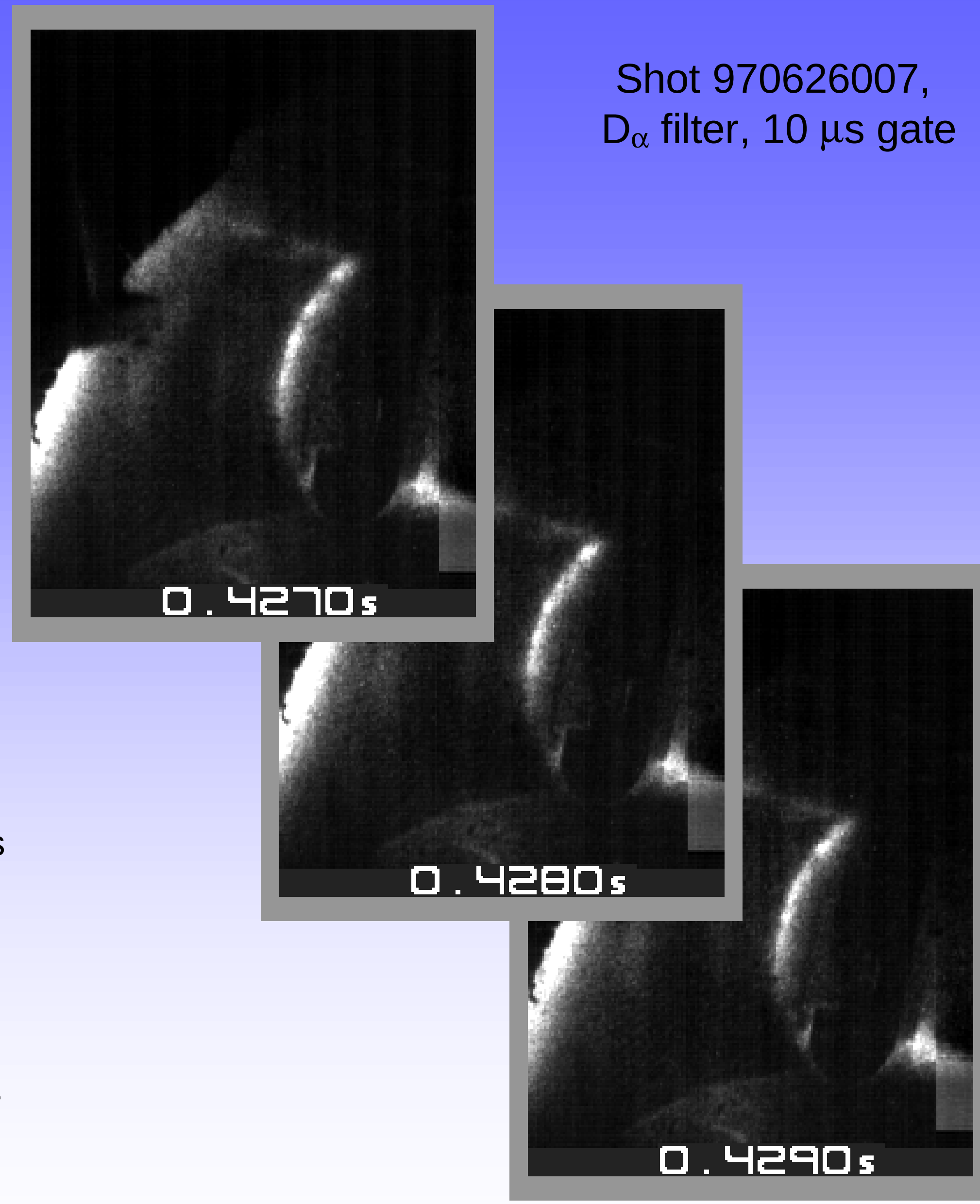
Disruption induced by impurity gas puff from fast-scanning probe

Shot 970619031, no filter, 10 μs gate



Edge turbulence

- Edge turbulence filaments are observed near the higher recycling region at the bay F edge of the RF antenna.
- These filaments with approx. 2-4 cm poloidal wavelength (as observed with 10 μs exposure) are probably the low frequency (~50 kHz), largest-scale part of the normal edge turbulence spectrum.
- No correlation from frame to frame is observed at 1 kHz framing rate.
- Plans to improve the imaging of this turbulence include: increase the D_α brightness by local gas puffing, use a closed-up view and shorter exposures to see smaller scales, and reduce the RF pickup for better viewing of the L-H transition.



Shot 970626007,
D_α filter, 10 μs gate