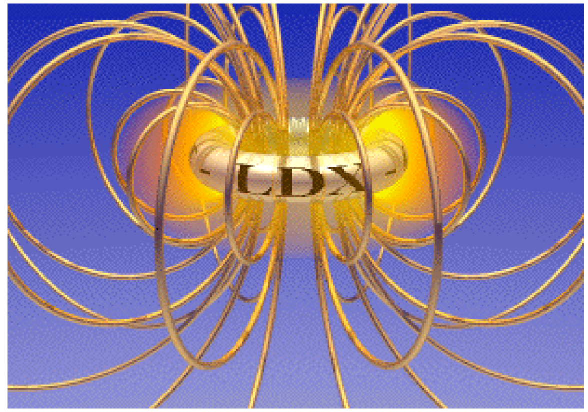

X-Ray Measurements of the Levitated Dipole Experiment

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Abstract

Initial plasma experiments in the Levitated Dipole Experiment focus on producing hot electron, high beta plasmas using a supported dipole configuration. Plasmas were created using multi-frequency ECRH, and we find that most of the plasma energy is stored in the fast electrons. The energy spectrum of the x-ray emission below 740 keV is measured by a four channel pulse height analyzer using CZT detectors. Temporal resolution is achieved by collecting multiple spectra during each shot. The electron temperature is inferred from the x-ray energy. A hard x-ray camera[2] is used to view the spatial distribution of x-ray intensity in the plasma at a maximum of 60 fields per second. In addition, a single NaI detector (which views energies up to 3 MeV) measures the temporal fluctuations of x-ray emission from the plasma. X-ray measurements have shown the profile changes resulting from various ECRH configurations, and they are used with other diagnostics to determine plasma profiles and parameters.

[1] This work supported by USDOE OFES.

[2] S. von Goeler et. al. *Rev. Sci. Instrum.* **65** 1621 (1994).}

What’s new?

✓Time resolved pulse height analysis.

✓X-ray camera footage of LDX plasmas.

✓Time resolved chordal x-ray intensity measurement.

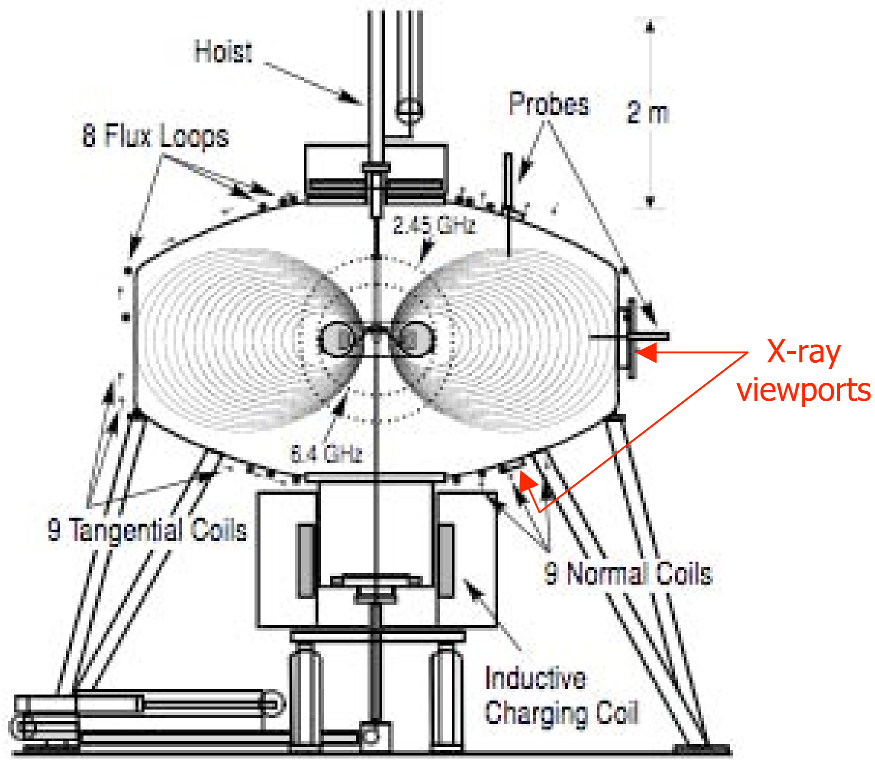
✓Data collected for three difference C-Coil charges, I_C = 250A, 300A, 400A.

✓Time resolution allows us to see the difference in x-ray emission between the low-beta regime, high-beta regime and afterglow.

X-Ray Diagnostic Capabilities

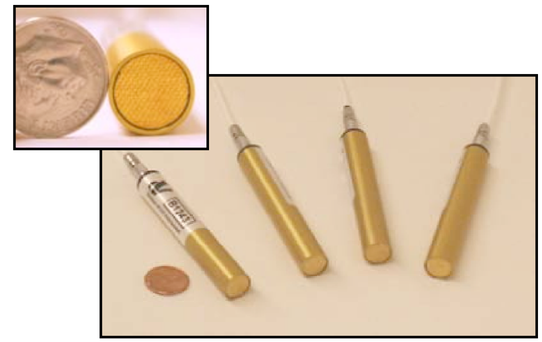
A cross-sectional view of the levitated dipole experiment is shown on the right. Note the locations of the x-ray viewports in red. Equilibrium flux surfaces, the internal ring, and the locations of the ECRH resonance zones are shown in addition to the locations of the probes and magnetic diagnostics. X-ray diagnostics include

- a 4 channel pulse height analyzer with views from both the side and the bottom of the vacuum vessel,
- a single channel NaI intensity diagnostic that views from the side of the vessel, and
- an x-ray camera that also views from the side of the vessel.

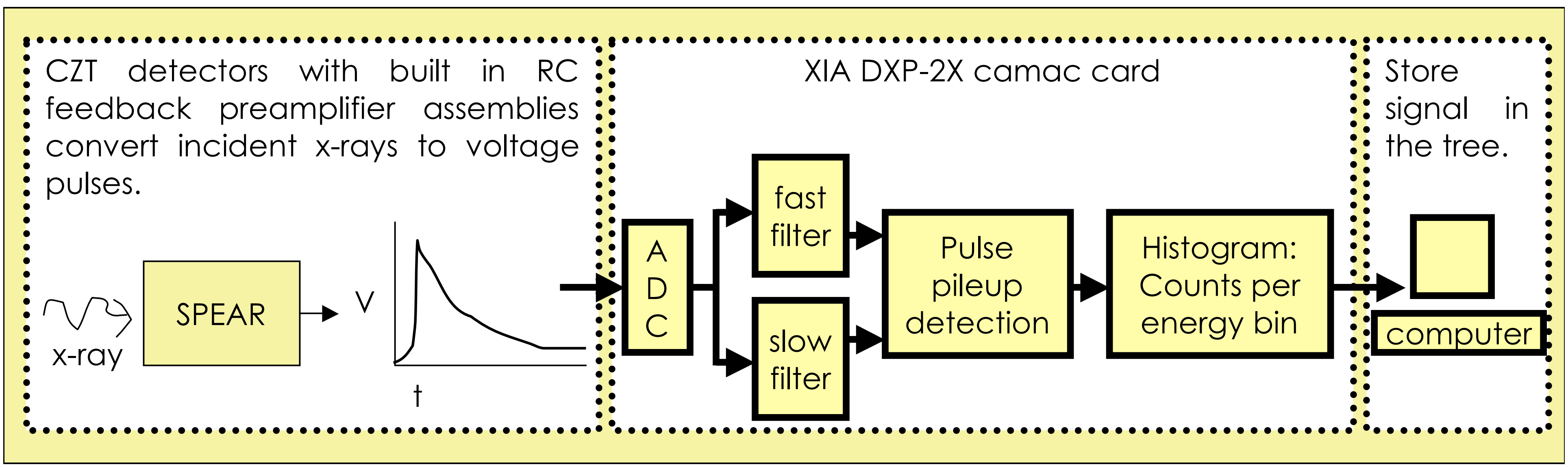


The LDX x-ray pulse height analyzer

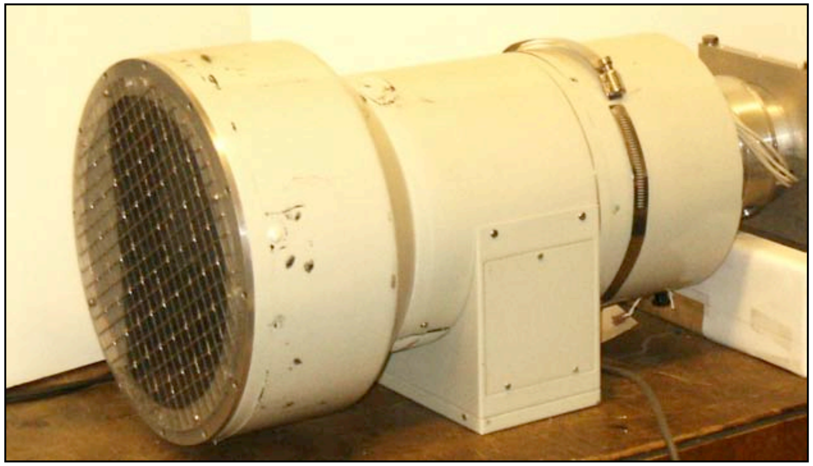
- 4 Channels
- Designed for 500 kcps count rates.
- CZT 5x5x5mm detectors view energy range of 10 keV-720 keV
- NaI 2x2x2" detector views an energy range of 1 keV-3 MeV

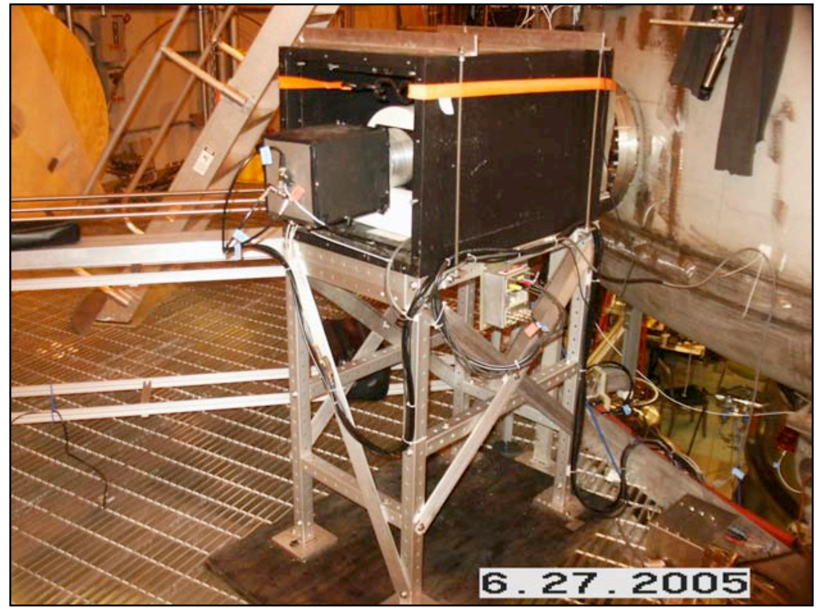


Photographs of the CZT (cadmium zinc tellurize) SPEAR detectors used in the PHA.



Smile for the camera…



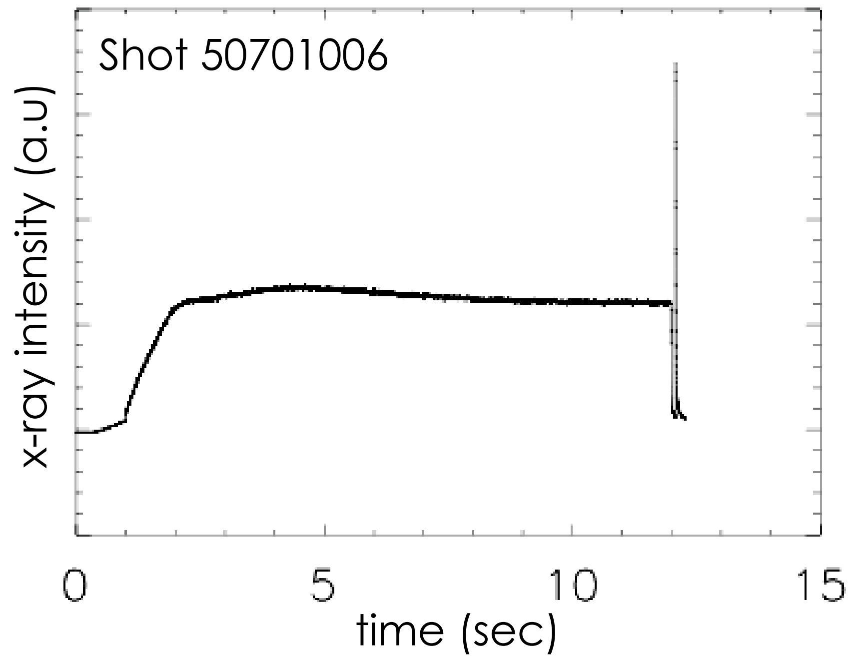


Right: Photograph of the x-ray camera (on loan from PPPL). A lead grid is placed in front of the aluminum entrance window to aid in reconstructing the images. Inside a CsI crystal converts x-ray photons to visible light. A coating on the back side of the crystal converts the visible light to photoelectrons which are electrically focused, then intensified and imaged onto a 25 mm diameter phosphor display. The display is filmed by a monochromatic CCD camera and digitized at a maximum rate of 30 frames per second.

Left: Photograph of the x-ray camera in it's shielding installed on the Levitated Dipole Experiment. A probe stand is beside the camera support.

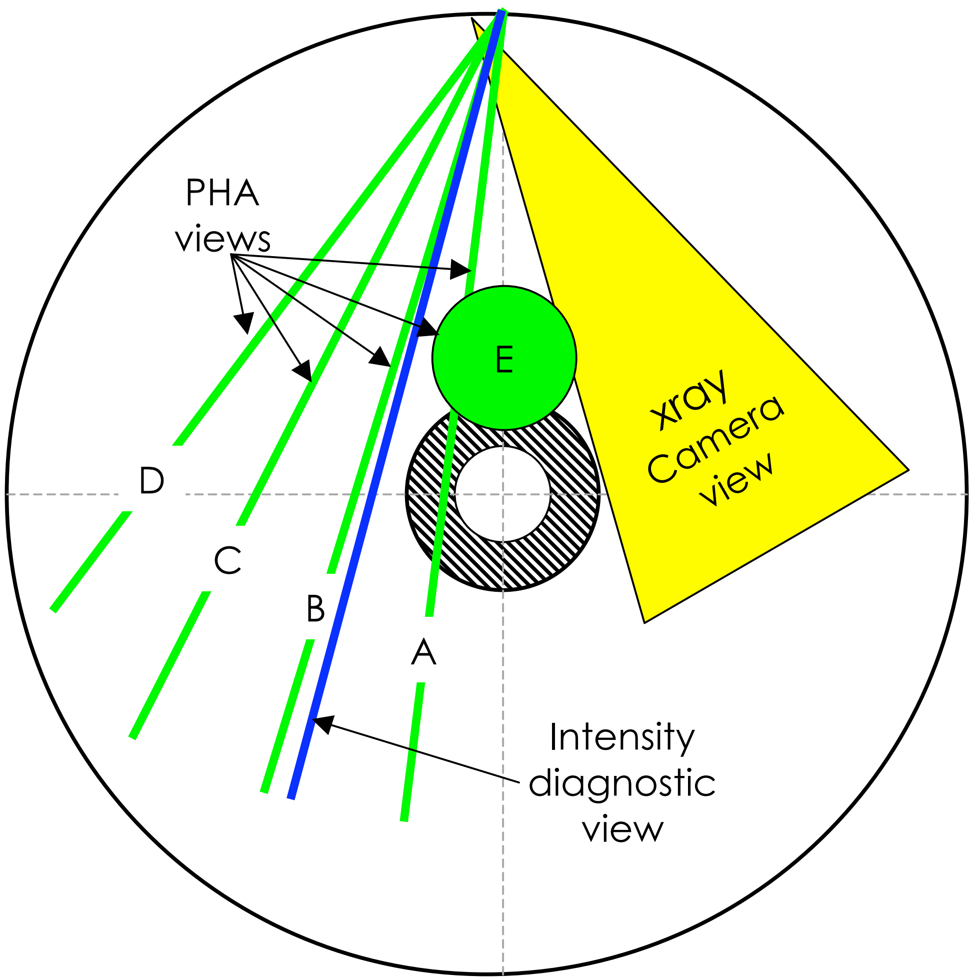
X-Ray Intensity Time Resolved Measurement

- Single channel
- NaI (sodium iodide) detector
  - 2x2" crystal
  - Energy range: 10keV - 2MeV
- Electrical current output from the detector is proportional to x-ray intensity.
- Occasional bursts of x-rays are used to trigger window of fast digitizer for probes signals and Mirnov coils.
- Considerably higher intensities are observed during shots that include 6.4 GHz heating.



X-ray intensity versus time is shown for a shot taken with I_c=400 A. 2.45 GHz heating is on from 1-12 seconds and 6.4 GHz heating is on from 0-12 seconds.

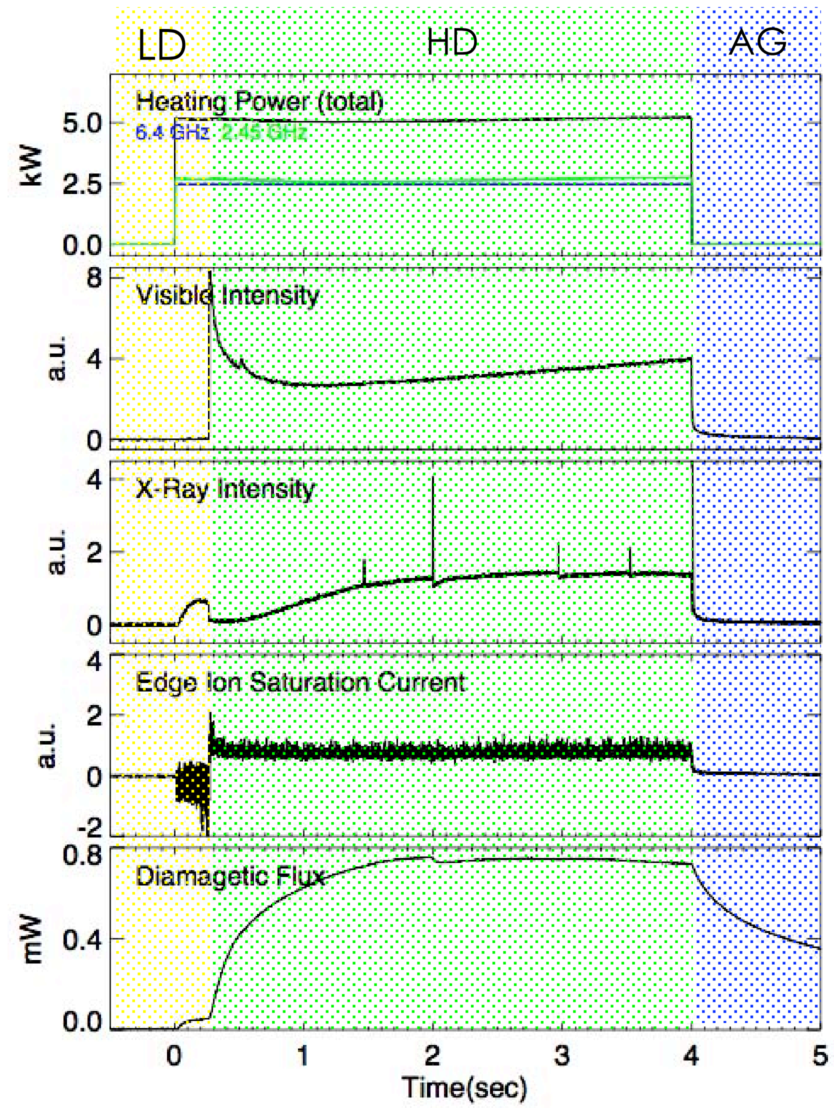
X-Ray Diagnostic Views



Viewing chords for the pulse height analyzer are shown in green. Although five views are shown, only four may be used simultaneously. For many runs the viewing angles for these chords are quite large so views sometimes overlap. The view of the intensity diagnostic is shown in blue, and the x-ray camera view is shown in yellow.

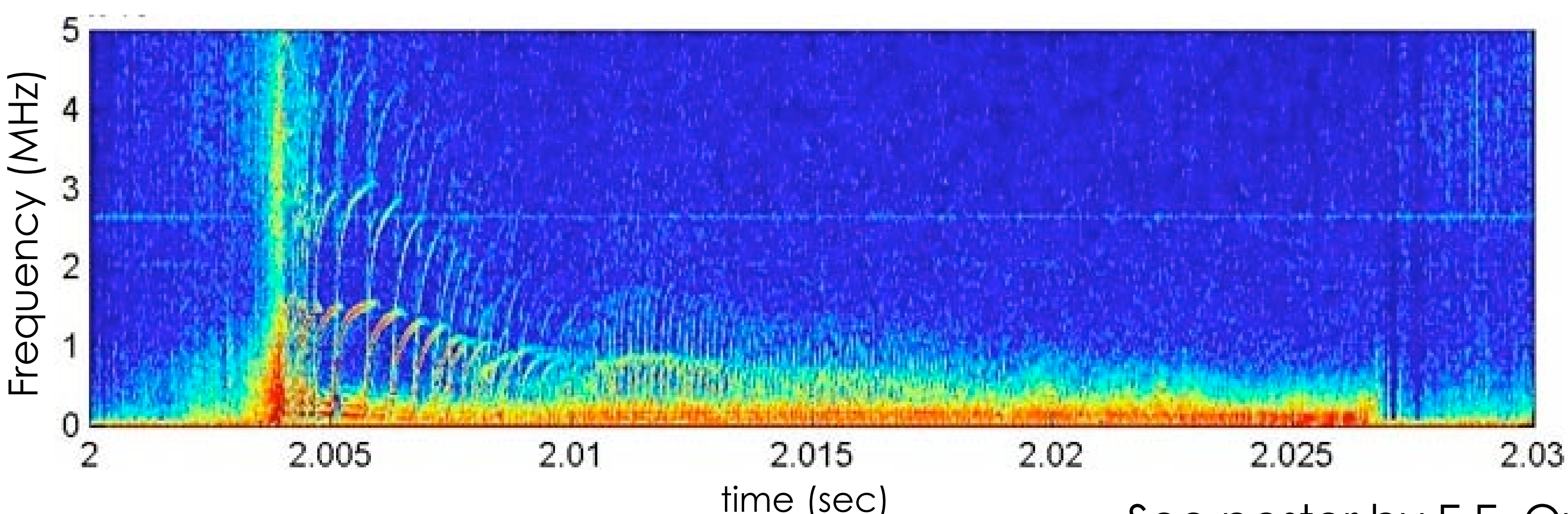
Three Operating Regimes

The three operating regimes observed in LDX, low density mode, high density/high beta mode, and the afterglow, are shown in this figure. Low density mode is shown in yellow and is marked by a small rise in x-ray intensity and diamagnetic flux. After the transition into high density mode (shown in green), we see that the visible light, diamagnetic flux and edge ion saturation current are all increased, and that these high values are sustained until the heating is turned off. The afterglow (shown in purple) is long lived. Visible light, x-ray intensity and diamagnetic flux slowly decay.



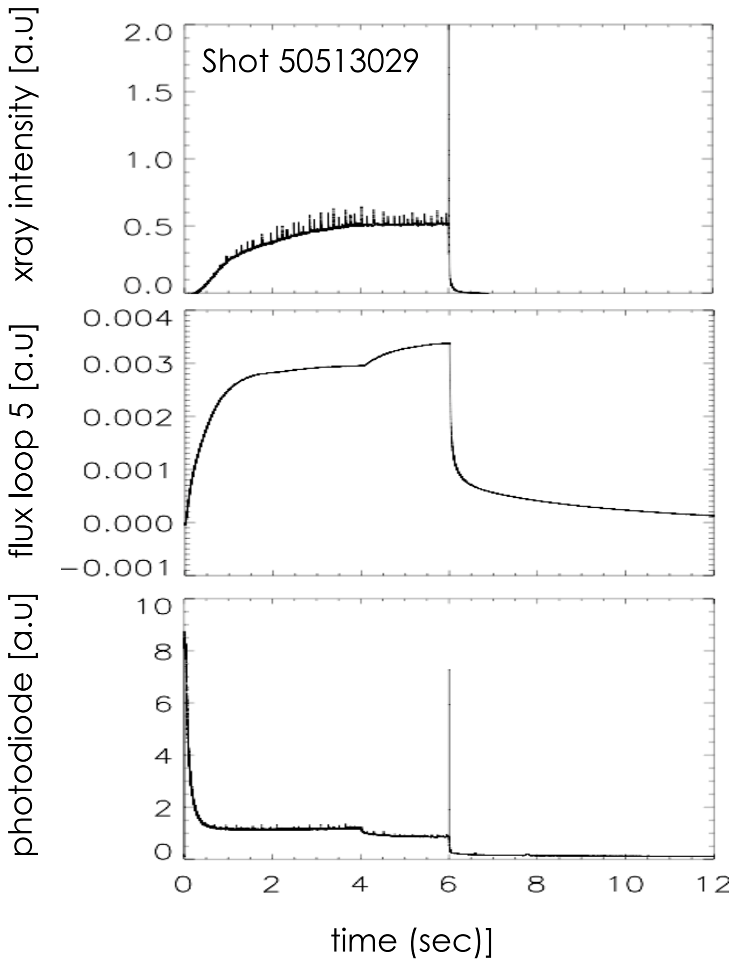
Hot Electron Interchange Mode

Evidence of the presence of fast electrons is given from the observation of hot electron interchange modes.



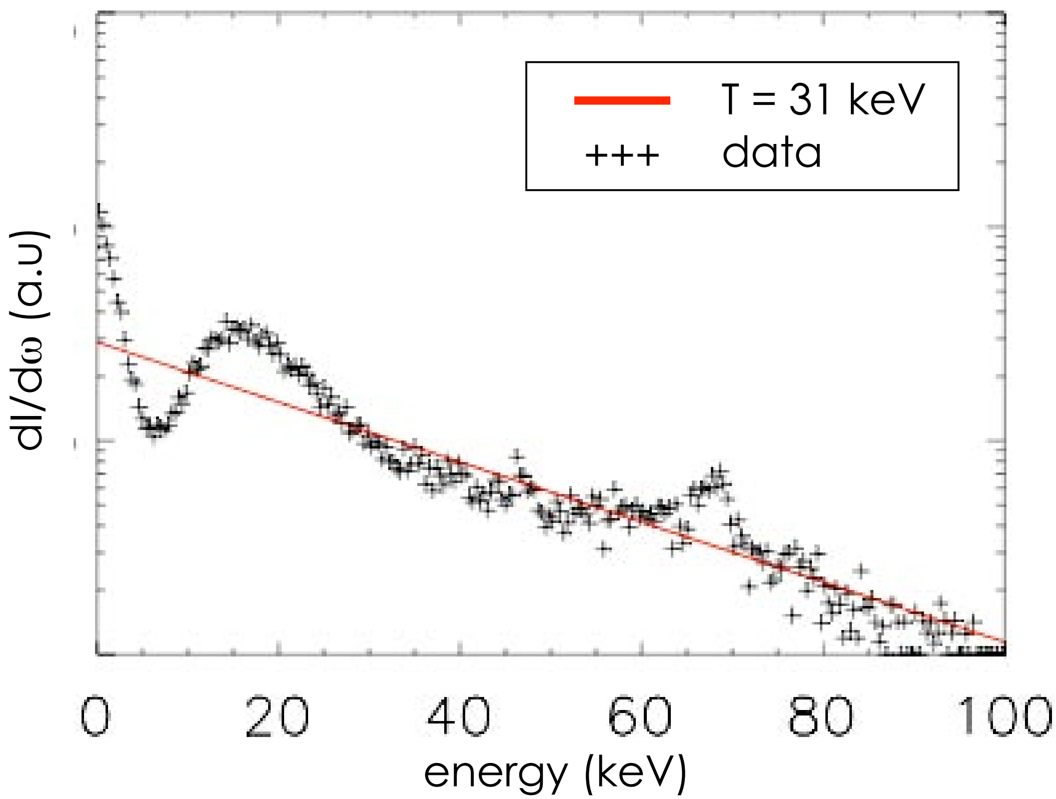
See poster by E.E. Ortiz.

Probe scan shots



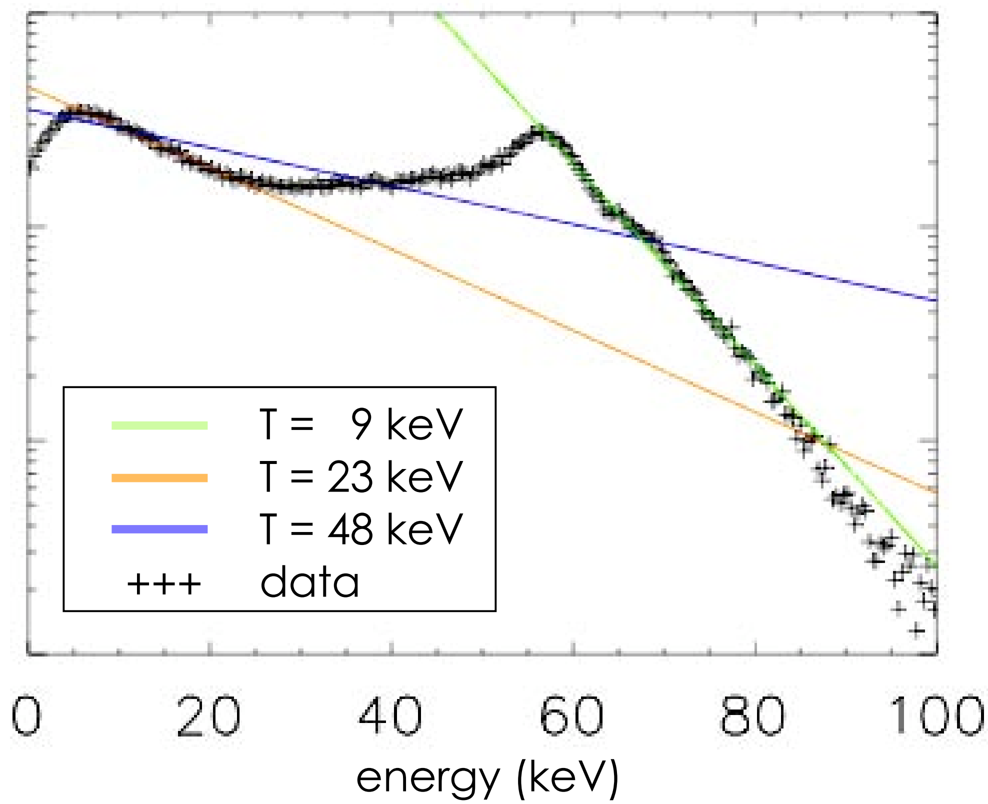
- A series of 8 shots taken under identical conditions (shot numbers 50513027-32,34-35)
- Both sources (2.45 and 6.4 GHz) were on from 0-6 seconds for these shots.
- C-coil current is 300A

Dual frequency Low Beta Mode Spectra and Temperatures



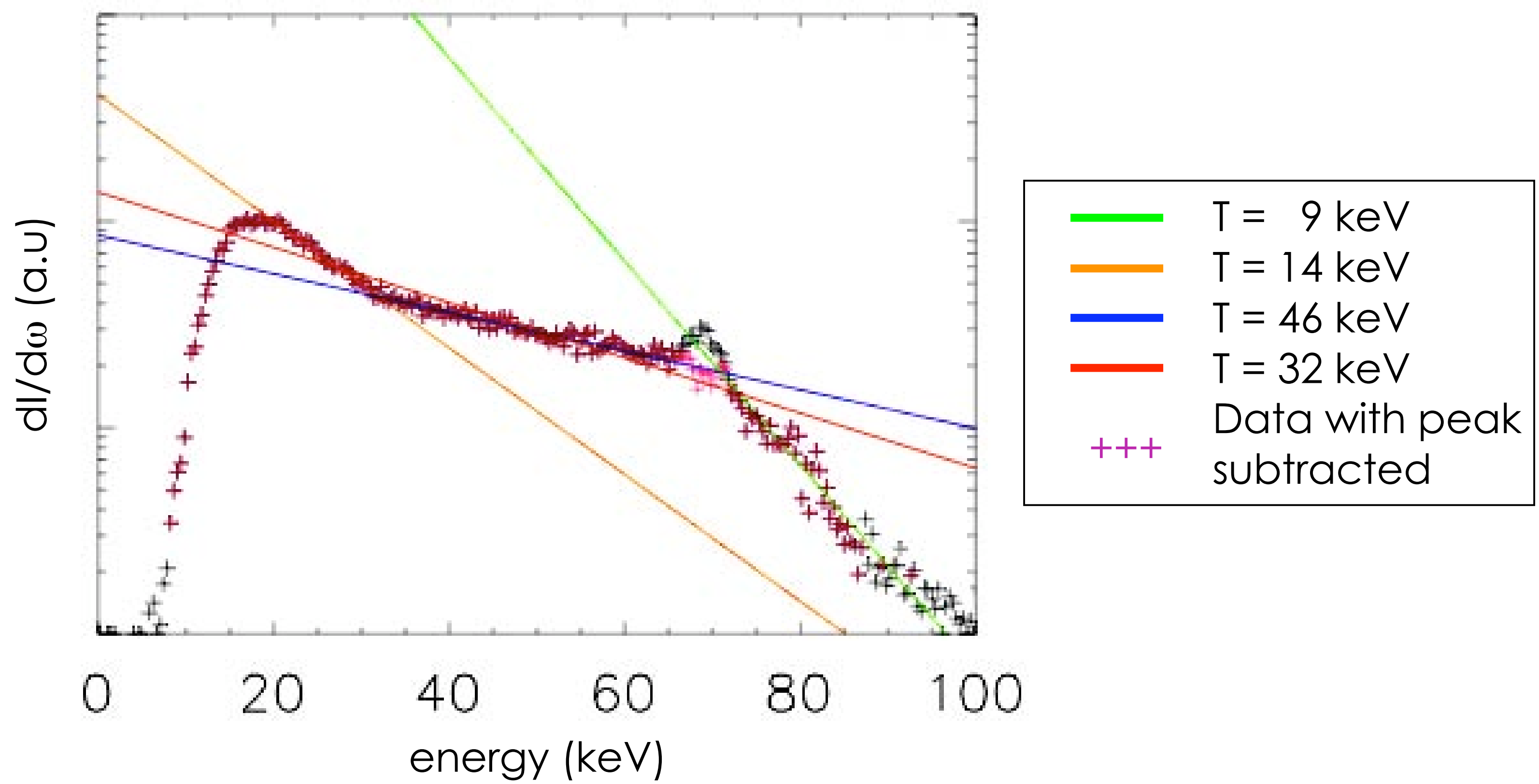
Sum of spectra acquired during probe scan shots between t=0 and t=0.25.

Dual Frequency Heating High Beta Regime



Sum of spectra acquired during probe scan shots between t=0.75 s and t=4.75 s. Solid lines are fits to exp(-E/kT).

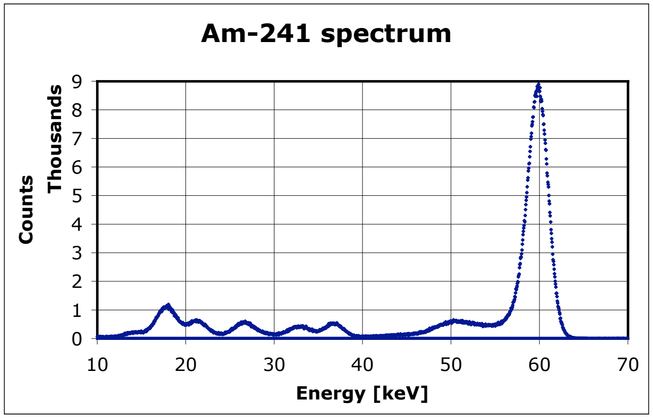
Dual frequency Afterglow Spectra and Temperatures



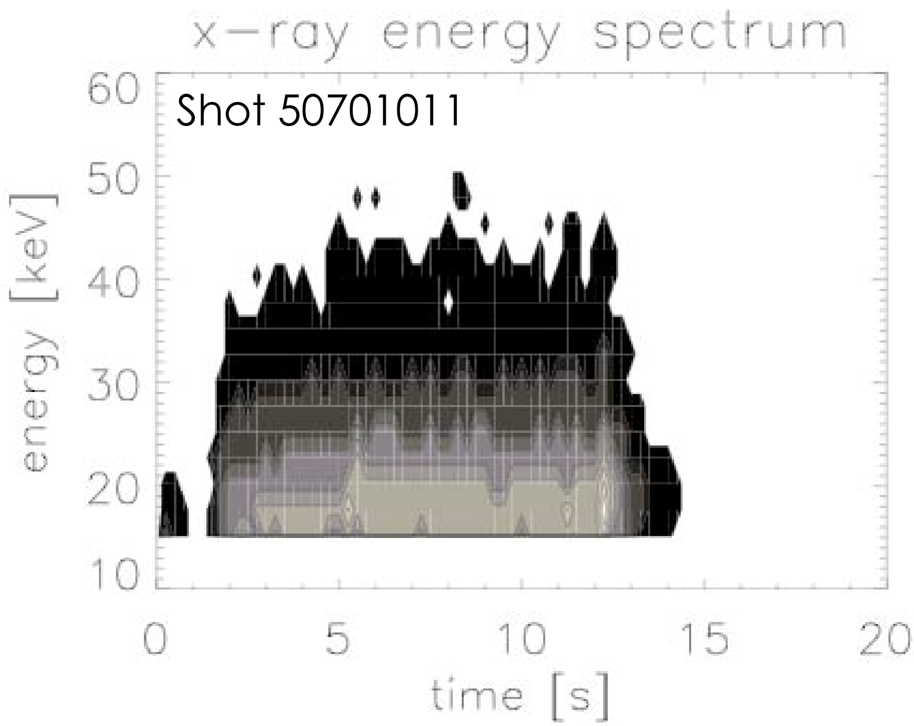
Sum of spectra aquired during probe scan shots between t=6.75 and t=15.75 seconds.

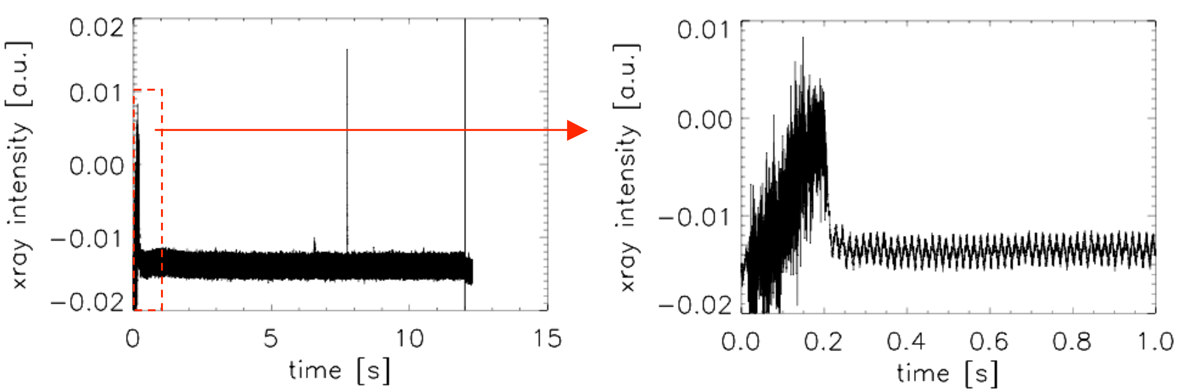
Comments on Spectra

- Cs-122 source with line at 661 keV is not visible using the experimental configuration, which suggests that high energy x-rays are not being recorded.
  - Either the energy range of the detectors is not as high as advertised, or
  - We may have some systematic error that causes a failure to record higher energy x-rays. One possible culprit is the set of digital pulse shaping/filtering parameters used. This is currently under investigation.
- Peaks near 70 keV may be caused by interactions between higher energy x-rays and the lead collimators. Improved collimation will be used in the future.



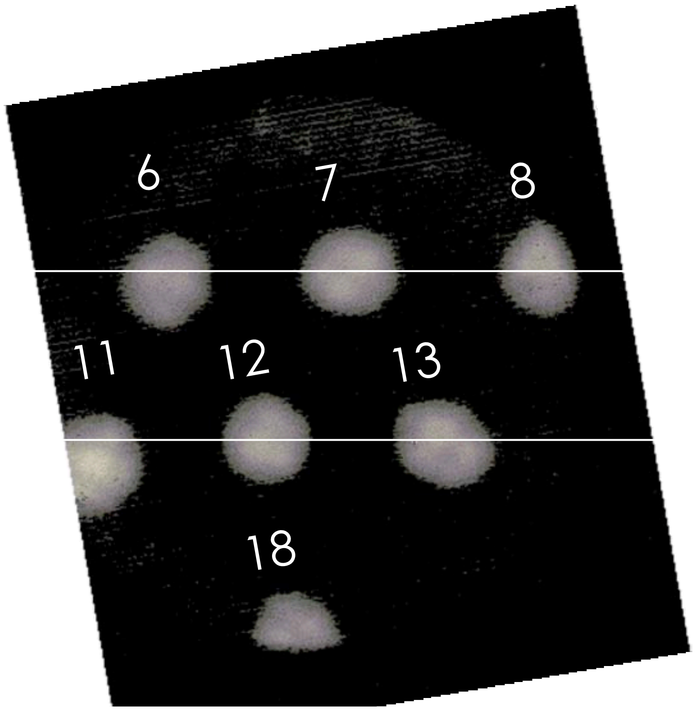
2.45 GHz Heating Only





- $I_{c\text{-}coil}$ = 400A
- Low x-ray intensity compared to 6.4 GHz only shots and mixed heating shots.
- Notice spike of x-rays early in the shot during low density mode (see lower figures).
- PHA suggests these x-rays have relatively low energies (see upper figure).

Images from X-Ray Camera Calibration



Conglomeration of images taken with the Am-241 source at different locations behind a pinhole. Each image has been averaged over 60 frames (2 sec) and the entire image has been byte scaled. Using these images, we determine that the CCD camera is tilted by 10 degrees from vertical.

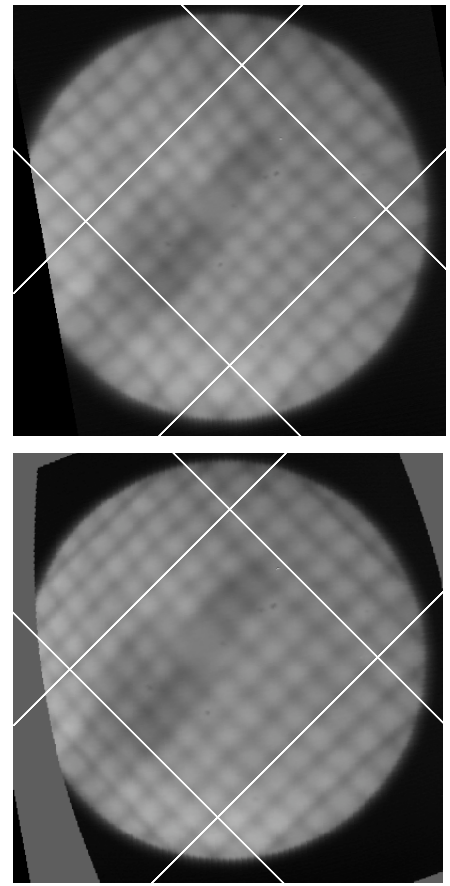
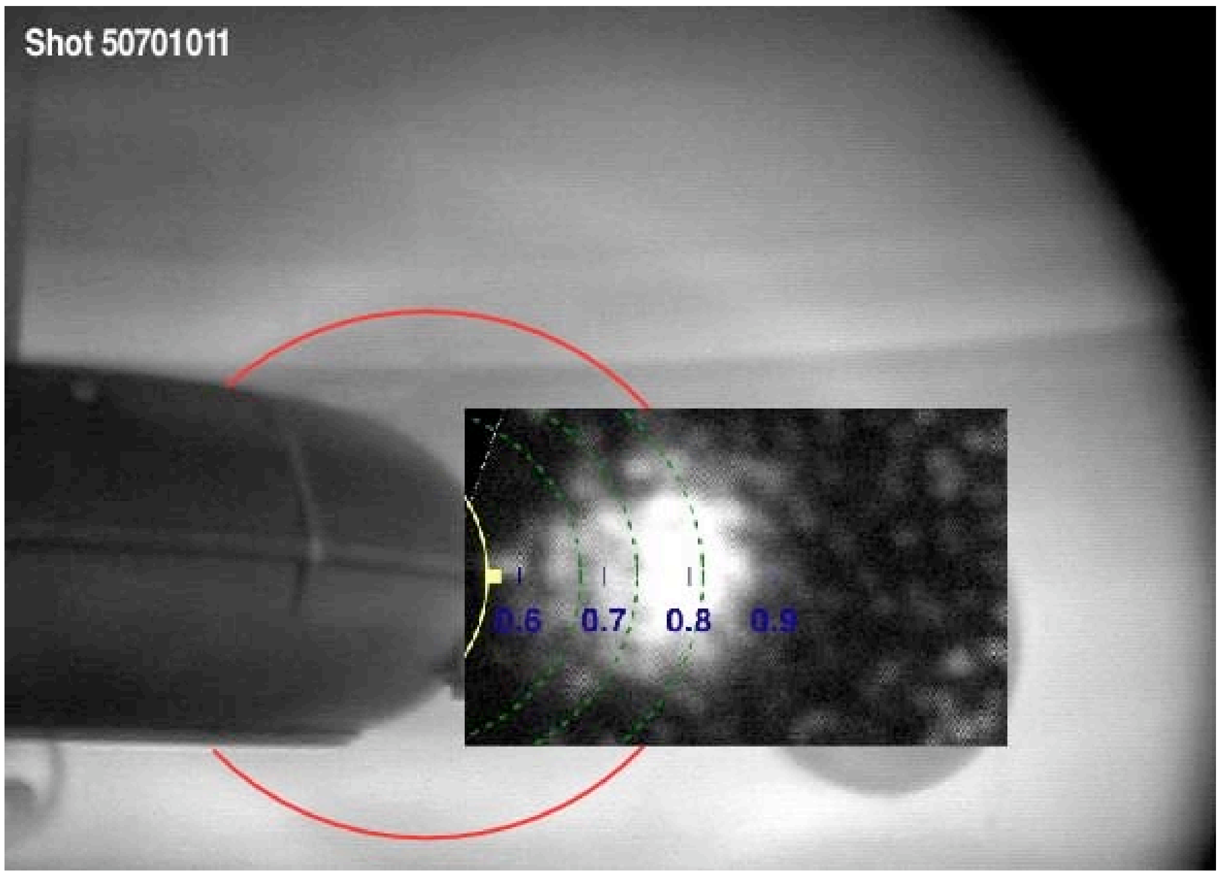
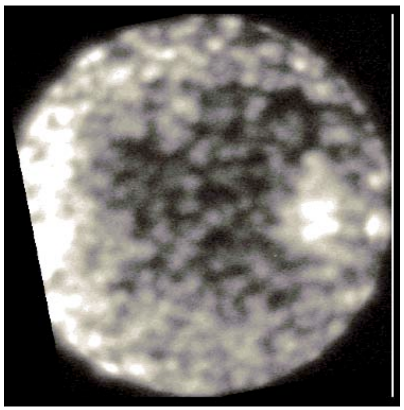


Image of Am-241 source, taken without collimation. Images are shown before an after correction for the pincushion type distortion. Lines have been overlaid to serve as guides.

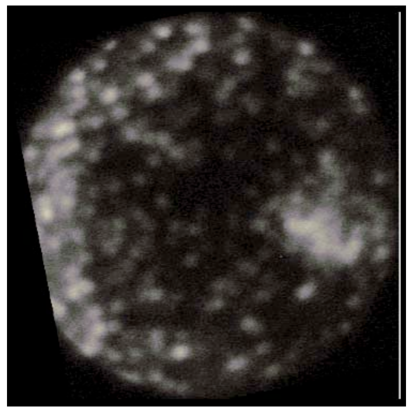
X-Ray Image Overlaid on Visible Image



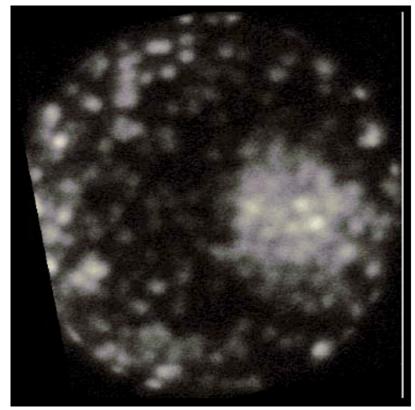
X-Ray Images of 2.45 GHz only shot



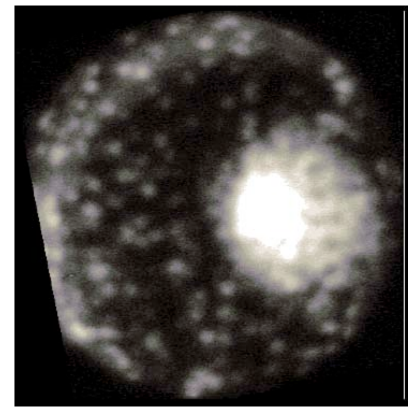
Field 52
(t = 0.866 sec)
Image during
low beta mode



Field 55
building up of
more intensity
during high
beta

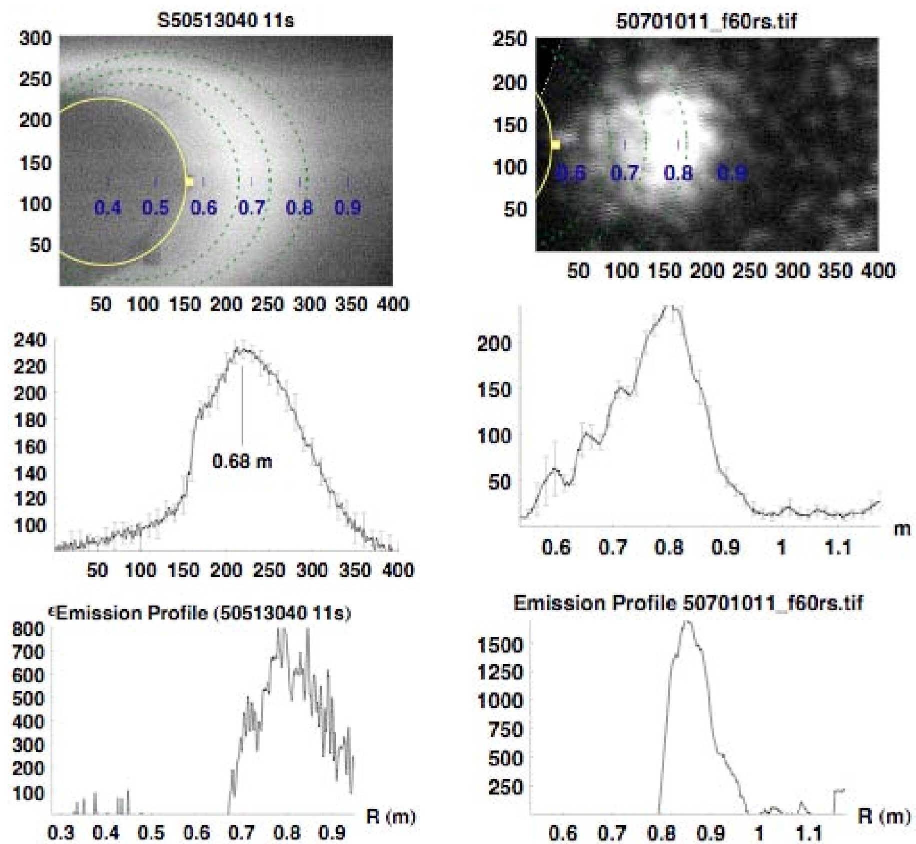


Field 62



Field 90
Image is
saturated at
peak.

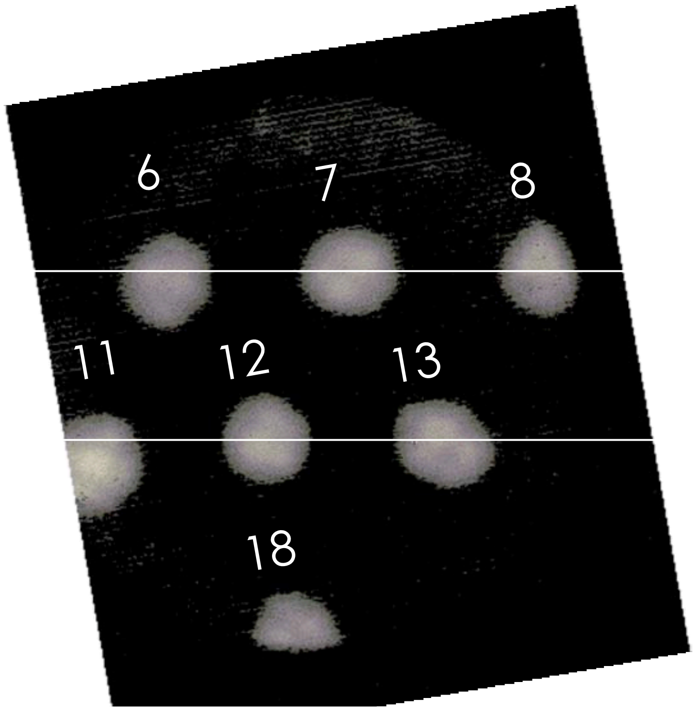
- Need to replace these with reconstructed profiles from distortion corrected data.



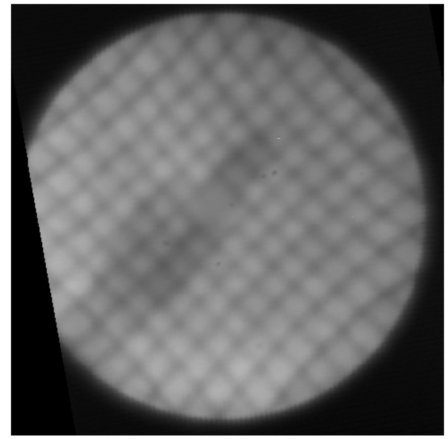
Summary

- Time resolution was achieved for PHA.
- X-ray camera has been installed and operated successfully.
- Observe some anisotropy of the plasma with the x-ray camera.
- Observe more heating from 6.4 GHz and multifrequency heating than from 2.45 only.
- Future upgrades…
  - Need to remake pinholes for diagnostics to improve performance.
  - Add NaI detector with larger energy range into PHA.
  - Need to redo filtering parameters in order to see higher energy x-rays.

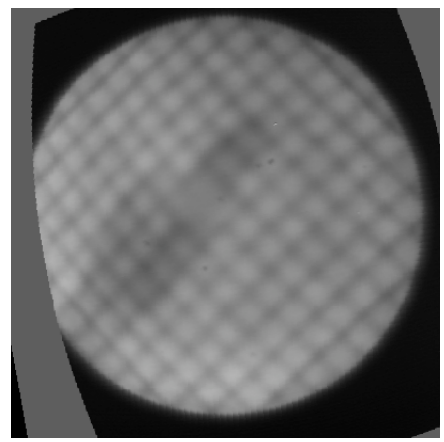
Images from X-Ray Camera Calibration



Conglomeration of images taken with the Am-241 source at different locations behind a pinhole. Each image has been averaged over 60 frames (2 sec) and the entire image has been byte scaled. Using these images, we determine that the CCD camera is tilted by 10 degrees from vertical.



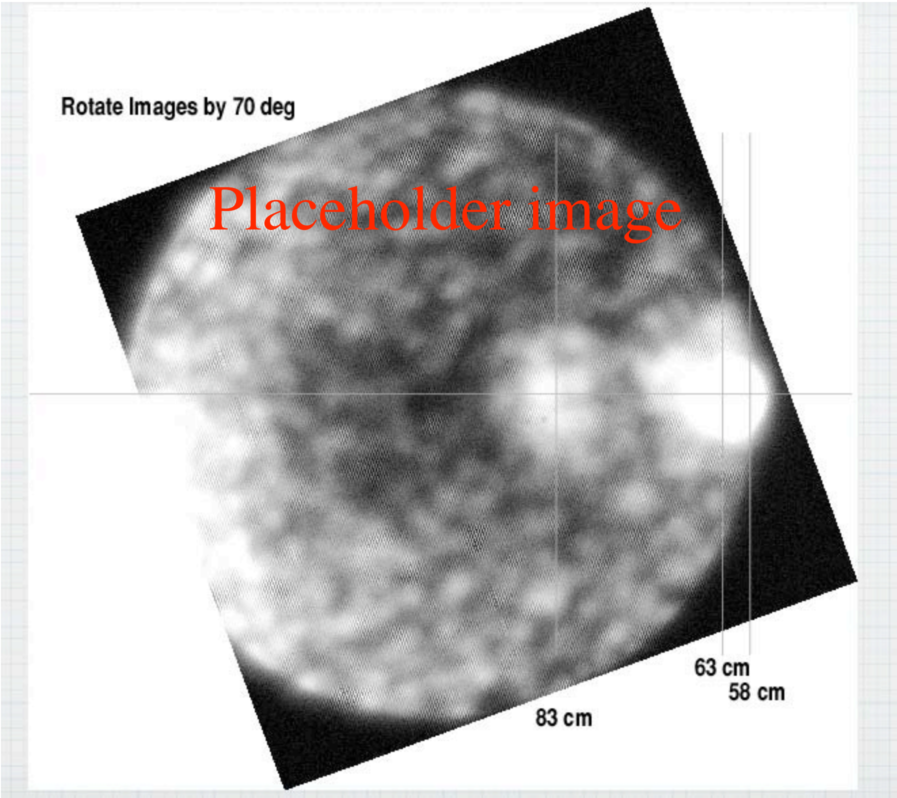
before



after

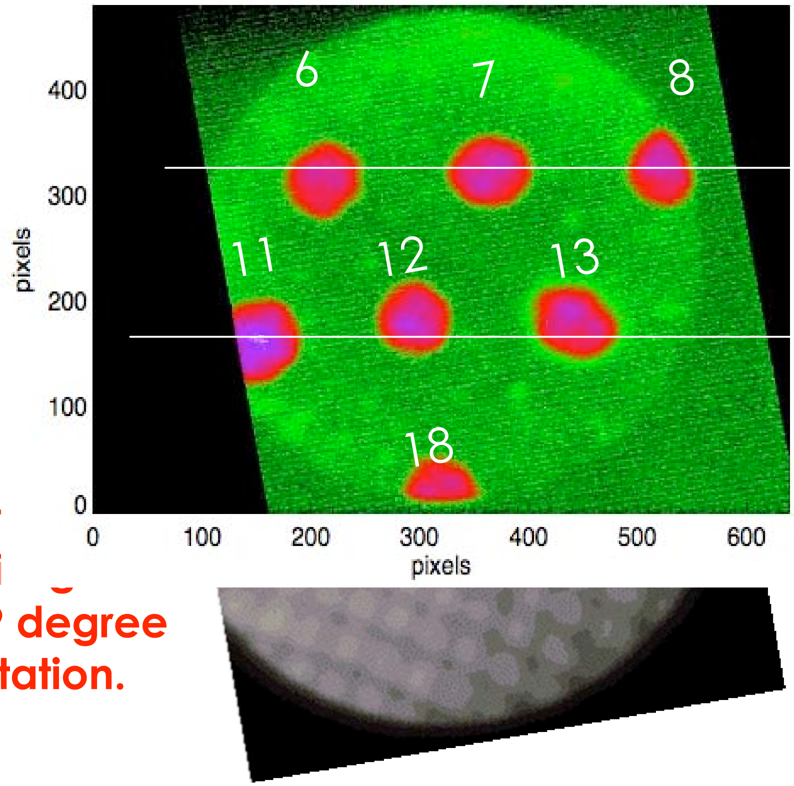
Image of Am-241 source, taken without collimation. Images are shown before an after correction for the pincushion type distortion.

RF Resonance Locations



- Show how many cm viewing window is.

Images from X-Ray Camera Calibration



A
gr
79 degree rotation.

Left: Am-241 source, without collimation, at position 13. *Right:* Conglomeration of images taken with the Am-241 source behind a pinhole. Positions 6; 7; 8; 11; 12; 13; 18 are shown. Each image has been averaged over 60 frames (2 sec). Note that the grid was not horizontal on the camera when these images were recorded. The grid was horizontal on the camera for the 7/1/05 run.