Hard X-Ray Spectrometers for NIF

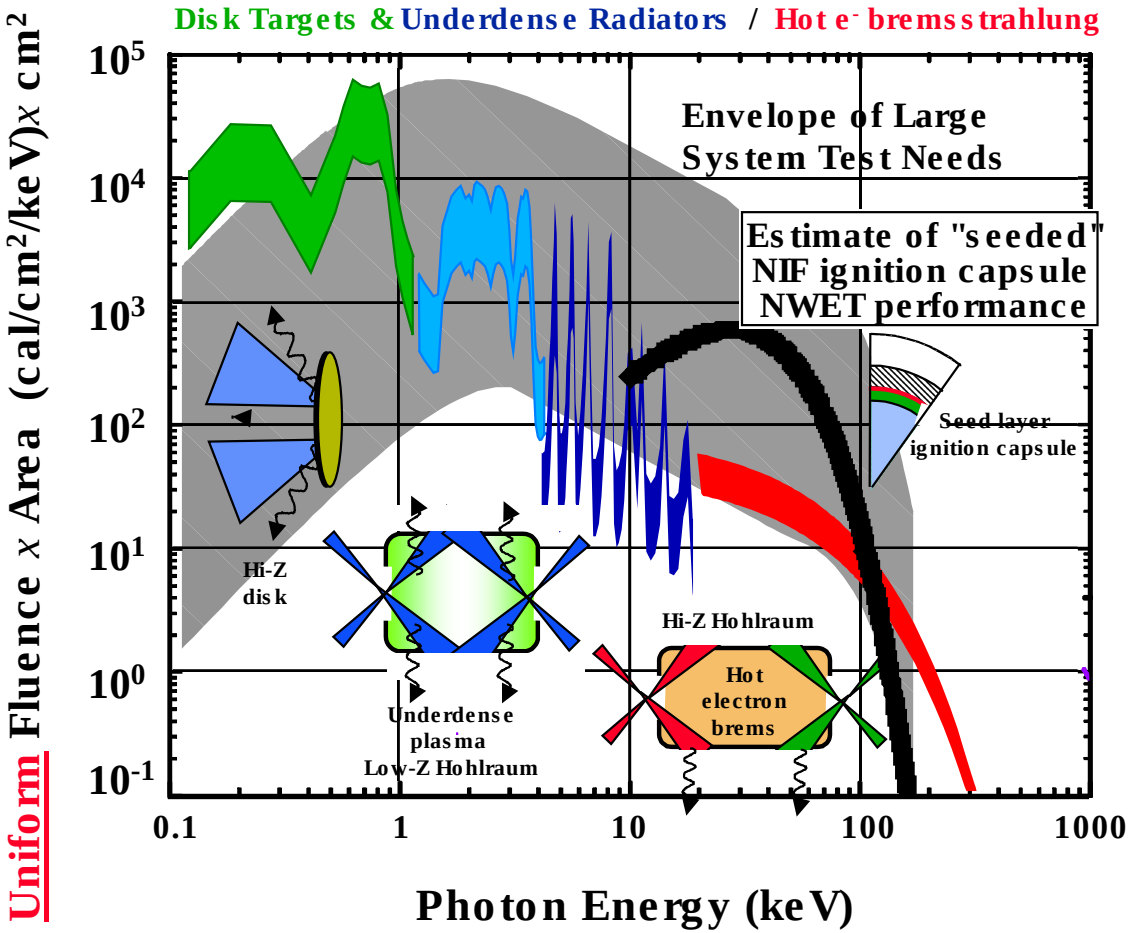
NRL

- **Naval Research Laboratory (NRL)**
  - **John Seely**
  - **Glenn Holland**
  - **Charles Brown**
- **National Institute of Standards and Technology (NIST)**
  - **Dick Deslattes**
  - **Larry Hudson**
- **Lawrence Livermore National Laboratory (LLNL)**
  - **Perry Bell**
  - **Mike Miller**
  - **Tina Back**

NWET X-Ray Sources will have High Flux

NIF
The National Ignition Facility

NIF Sources Provide Capabilities for Many Areas of X-ray Exposure Needs



NIF Target Outputs based on Nova Experiments and Lasnex modeling

Assumptions

- **Uniformity**
  - 0-15 keV ±10%
  - > 15 keV ±33%
- **Efficiency**
  - 0-2 keV 50%
  - 1-5 keV 25%
  - 5-15 keV 10%
  - > 15 keV 0.25%

NRL

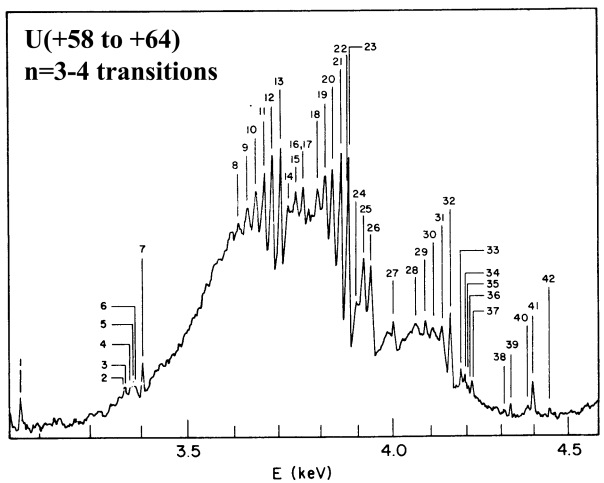
Experiments using NIF Hard X-Ray Flux

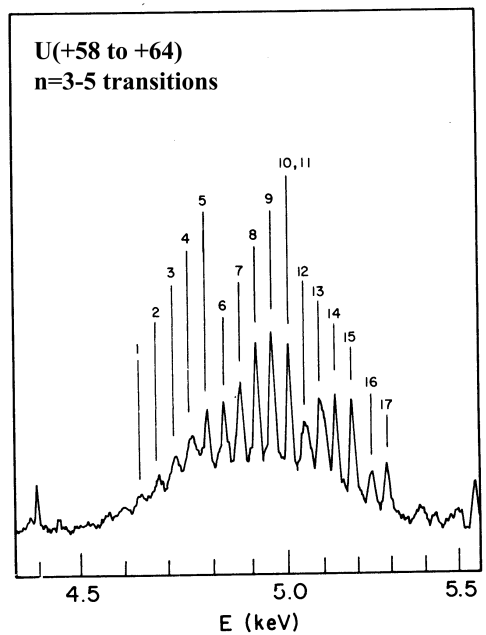
- **Continuum radiation generated by suprathermal electrons**
- **Fundamental spectroscopy of highly-charged ions**
- **High-Z corrections to energy levels**
  - **QED**
  - **Relativistic**
- **Absorption spectroscopy, code validation**

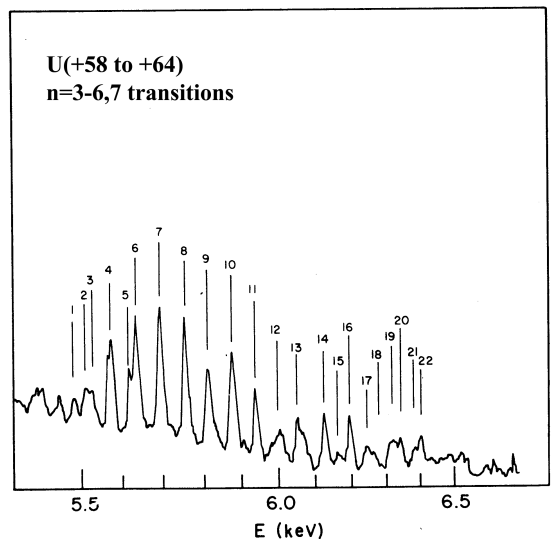
Fundamental Spectroscopy of Highly-Charged Ions

NRL

Highly-charged uranium spectra recorded at NOVA 2-beam.





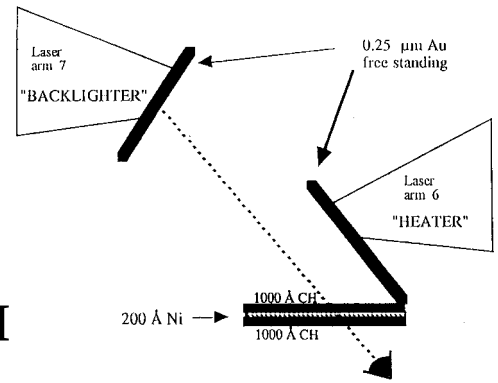


Mandelbaum, Seely, Brown, Kania, Kauffman, Phys. Rev. A **44**, 5752 (1991)

Absorption Spectroscopy and Code Validation

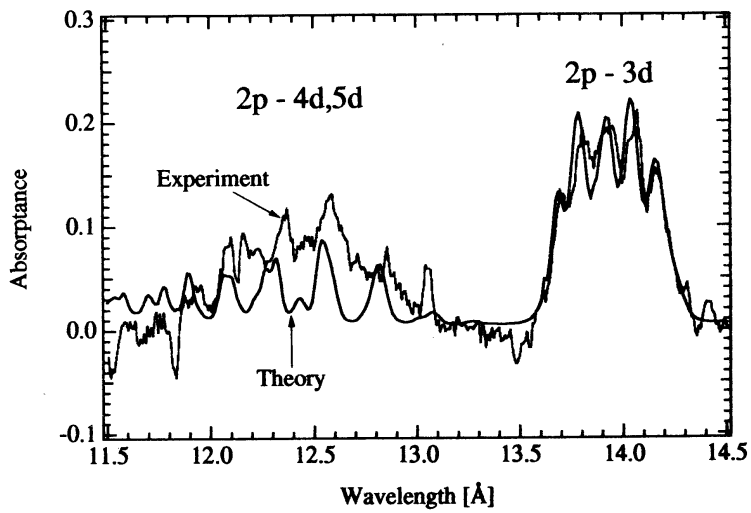
NRL

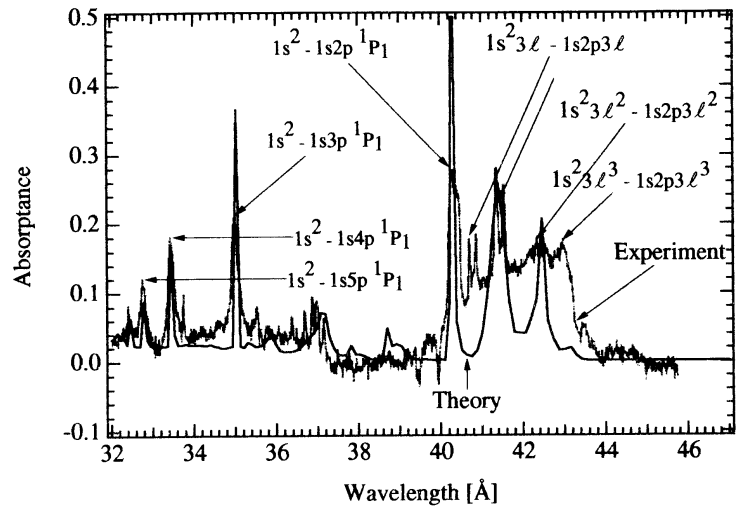
Experiments at NOVA 2-beam.



The Experimental Setup

Ni tamped by CH





Bar-Shalom, Oreg, Seely, Feldman, Brown, Hammel, Lee, Back, Phys. Rev. E **52**, 6686 (1995)

NRL

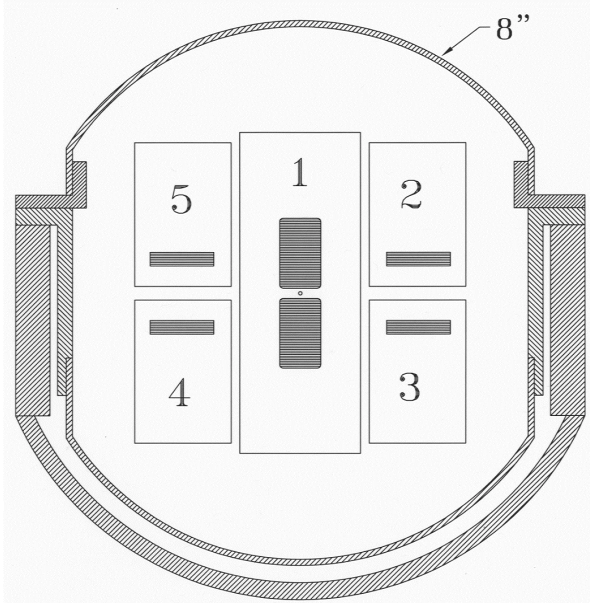
Hard X-Ray Spectrometer (HENEX)

- **High Energy Electronic X-Ray (HENEX) Spectrometer.**
- **Enhanced HENWAY capabilities:**
  - **Higher energy coverage (1.1 - 20.1 keV)**
  - **Electronic (CCD) spectral image readout**
  - **4000 dynamic range, >300 spectral resolution**
  - **DIM and TIM compatible, computer control system**
- **Six CCDs and five crystals (4 reflection and 1 transmission).**
- **HENEX was designed by an NRL/NIST/LLNL team.**
- **Five-channel HENEX spectrometer is being built by NRL/NIST for NIF.**
- **Transmission crystal spectrometer is being built by NRL/NIST for OMEGA:**
  - **One transmission crystal covers 11.6 - 60 keV**
  - **Can be absolutely calibrated**

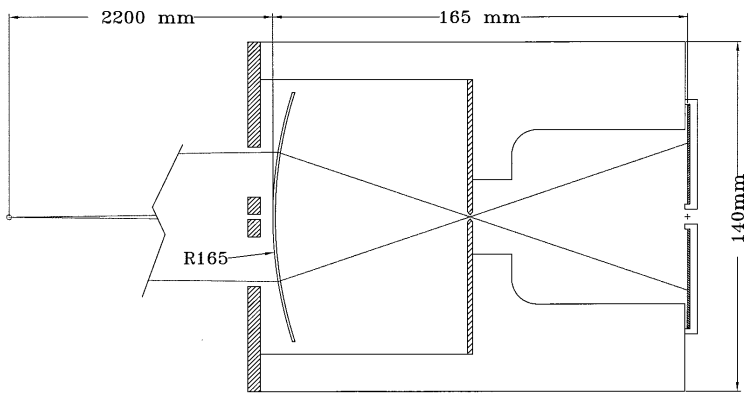
HENEX Five-Channel HXR Spectrometer

NRL

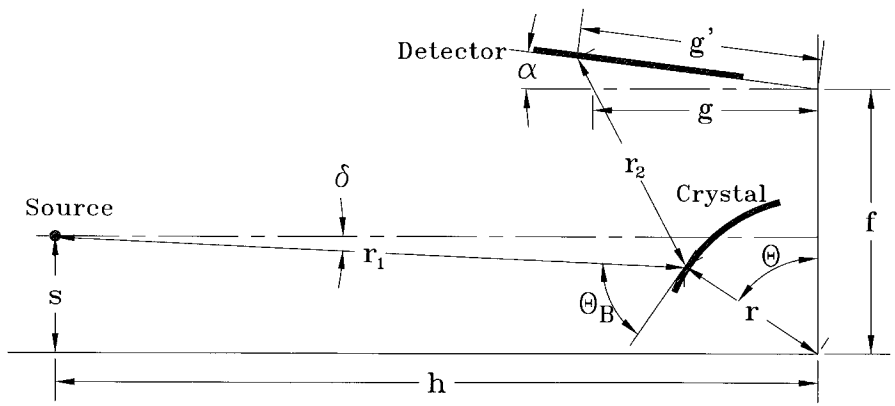
- **The instrument is TIM and DIM compatible.**
- **Standoff distance is 2.2 m at NIF, 0.5 m at OMEGA.**
- **One transmission crystal channel, 2 CCDs**
  - **Covers 8.6-20.1 keV with resolution 844-315**
  - **Based on the NIST prototype spectrometer**
- **Four reflection crystal channels, 4 CCDs**
  - **Cover 1.1-10.9 keV with resolution 900-2800**
  - **Based on the HENWAY spectrometer**



Proposed HENEX Transmission Spectrometer



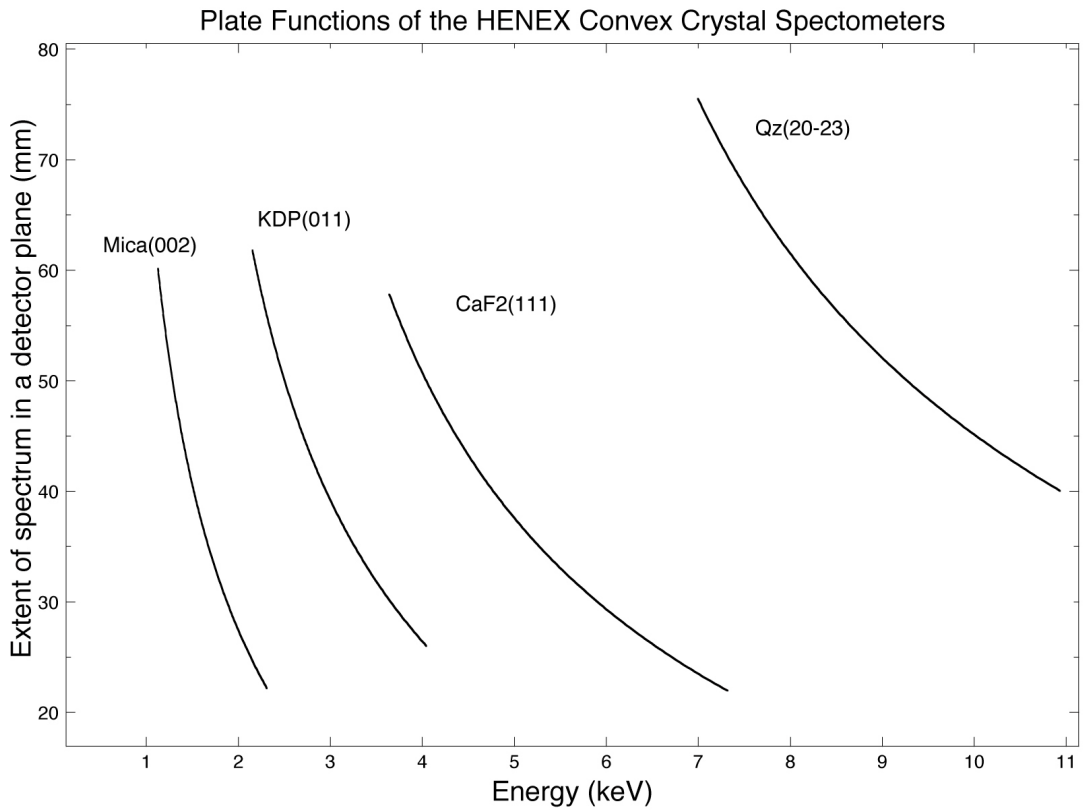
CONVEX CRYSTAL DISPERSION GEOMETRY



NRL

HENEX Energy Coverage and Resolution

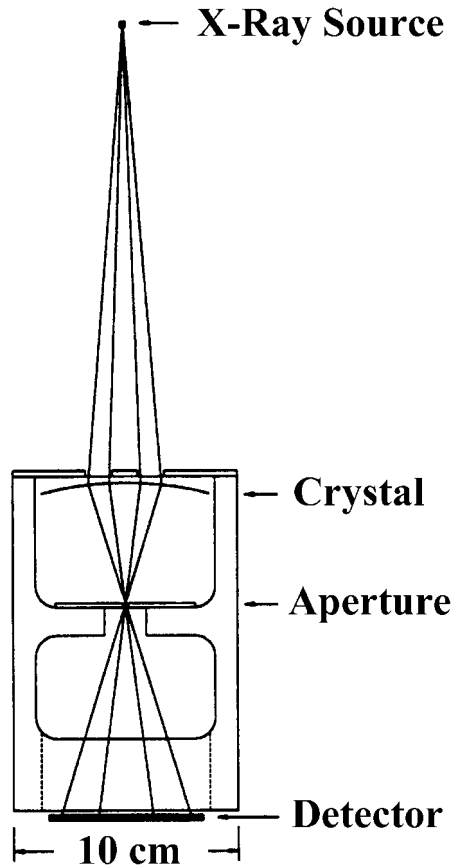
Channel	Diffraction Crystal	Lattice Spacing (Å)	Energy Range (keV)	Bragg Angle Range (deg)	Resolving Power
1	Qz(10-10)	4.26	8.6 to 20.1	9.7 to 4.2	818 to 303
2	Qz(20-23)	1.38	7.0 to 10.9	40.1 to 24.4	3060 to 1340
3	CaF2(111)	3.15	3.6 to 7.3	32.7 to 15.6	2050 to 850
4	KDP(011)	5.10	2.2 to 4.0	34.4 to 17.5	2260 to 940
5	Mica(002)	9.92	1.1 to 2.3	33.7 to 15.7	2150 to 850



NRL

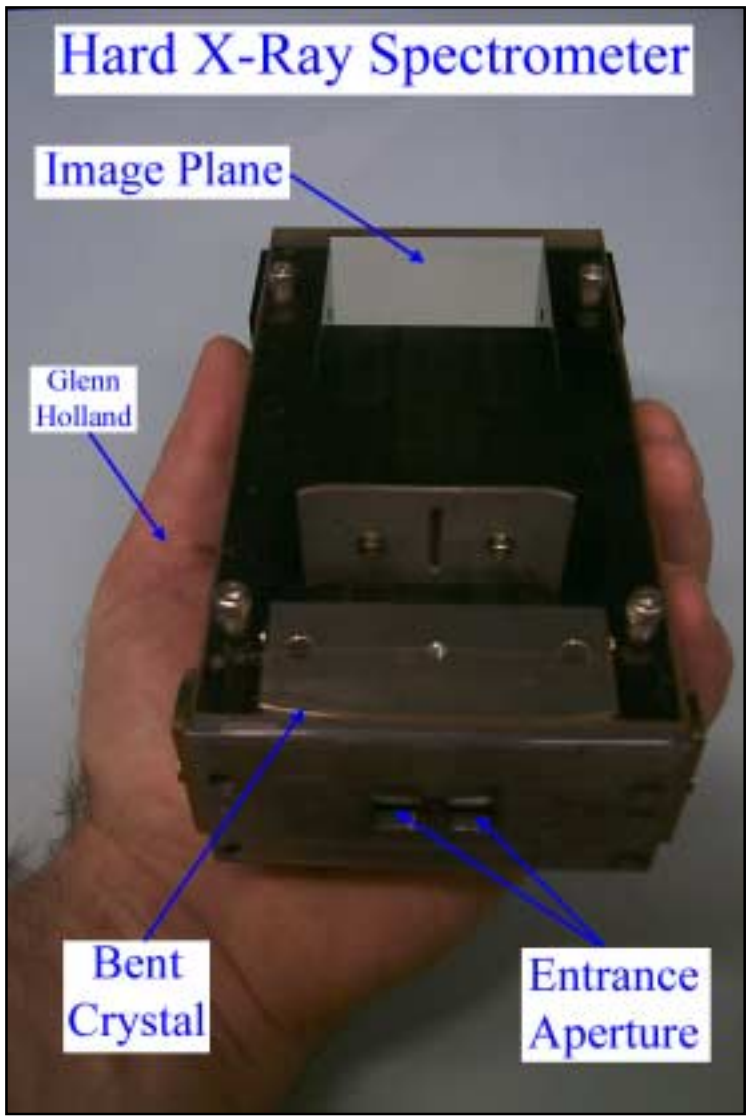
NIST Transmission Crystal Spectrometer

- **Laue geometry, transmission crystal**
- **Cylindrically bent crystal**
- **Two spectra on either side of central image**
- **Apertures shield detector from straight-through flux**
- **Linear geometry (TIM compatible)**
- **Large source-crystal distance**
- **Developed at NIST for radiography calibration**



NRL

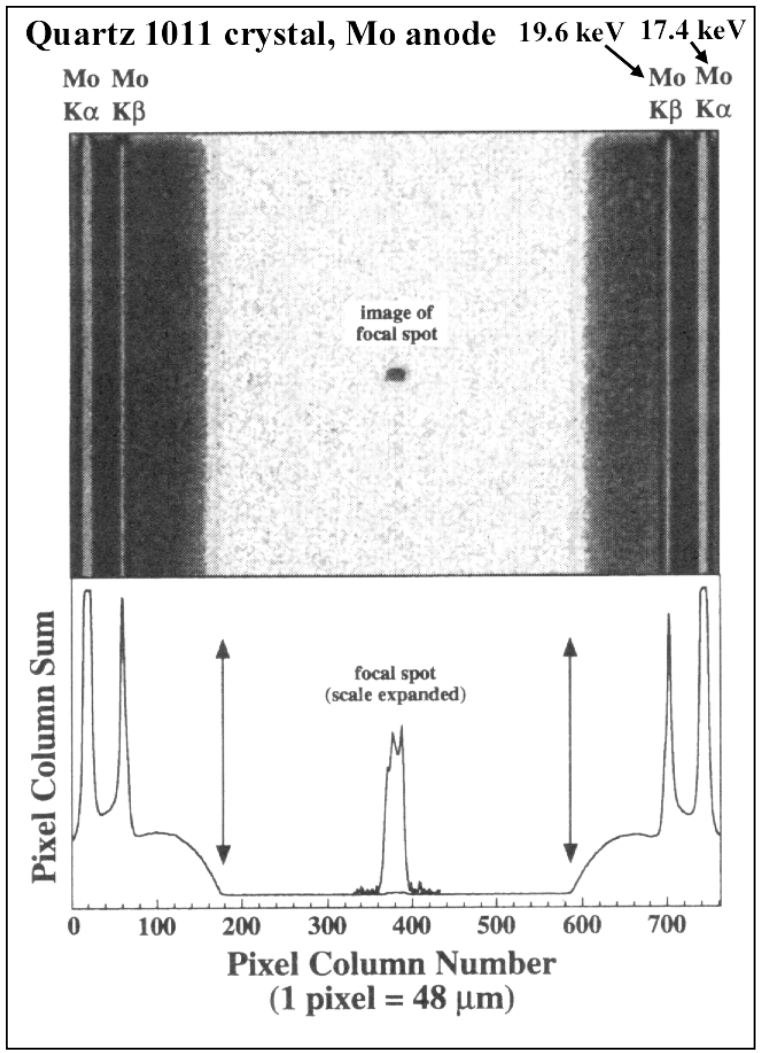
NIST Transmission Crystal Spectrometer

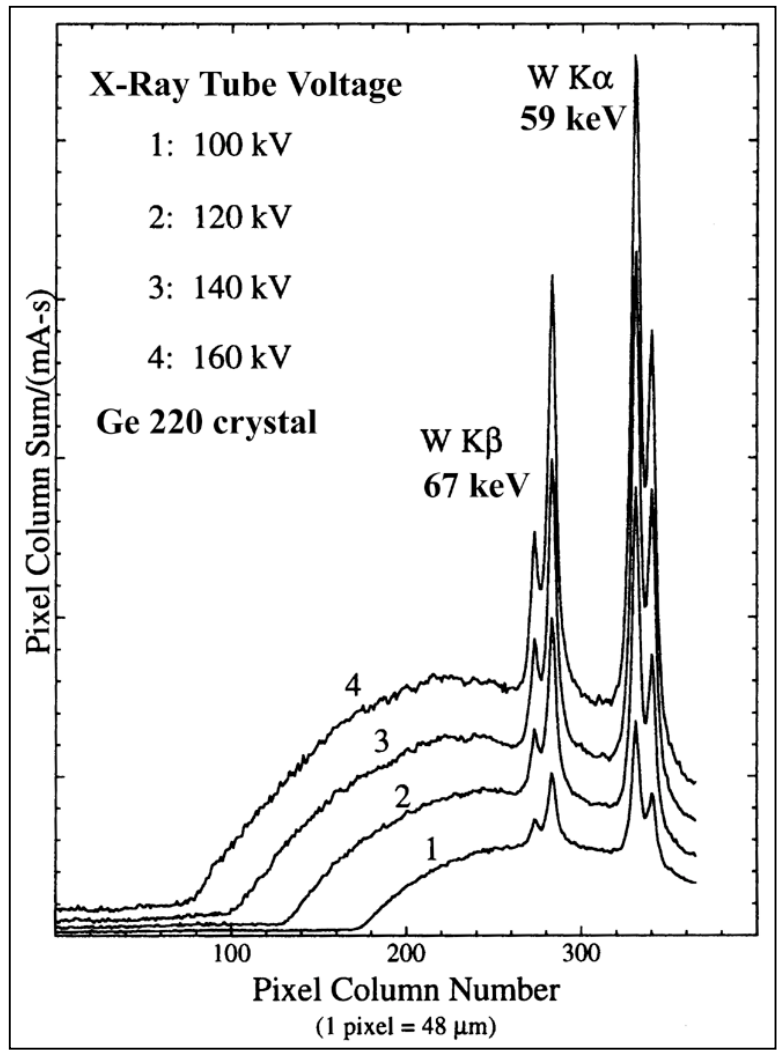


The spectrometer is compact and robust.

NRL

Spectra Recorded on a CCD using an X-Ray Tube



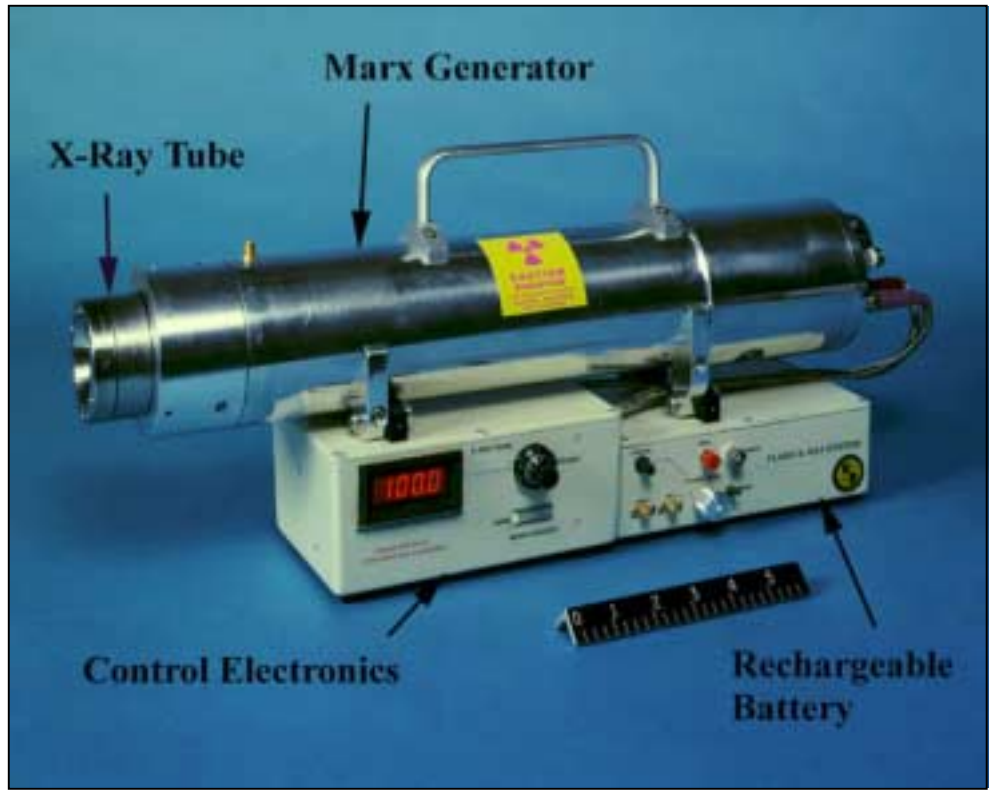


Pulsed Electric-Discharge X-Ray Source

NRL

NRL Pulsed Marx Generator

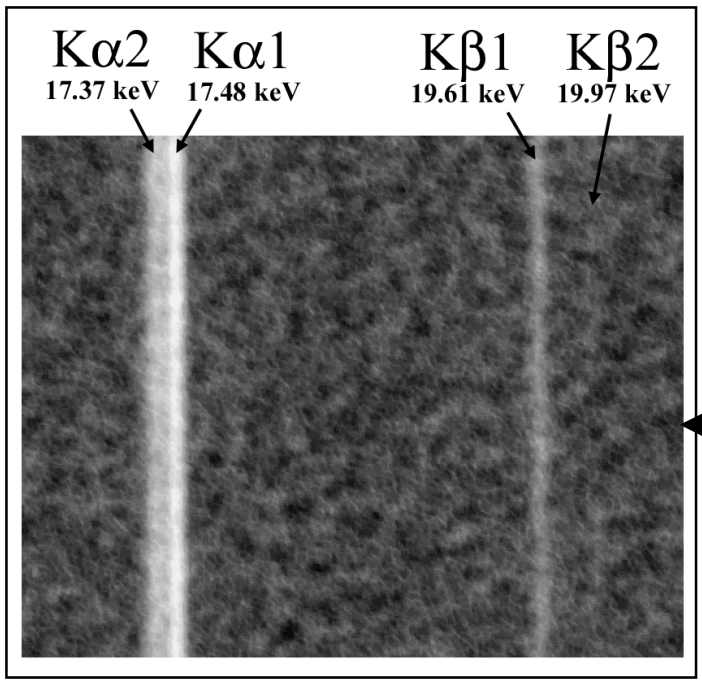
- **Up to 200 keV x-rays**
- **Nanosec risetime**
- **2 mm source size**
- **>40 mR exposure at 30 cm**
- **Single-shot x-ray spectra**
- **Portable and convenient**
- **Integrated system tests**



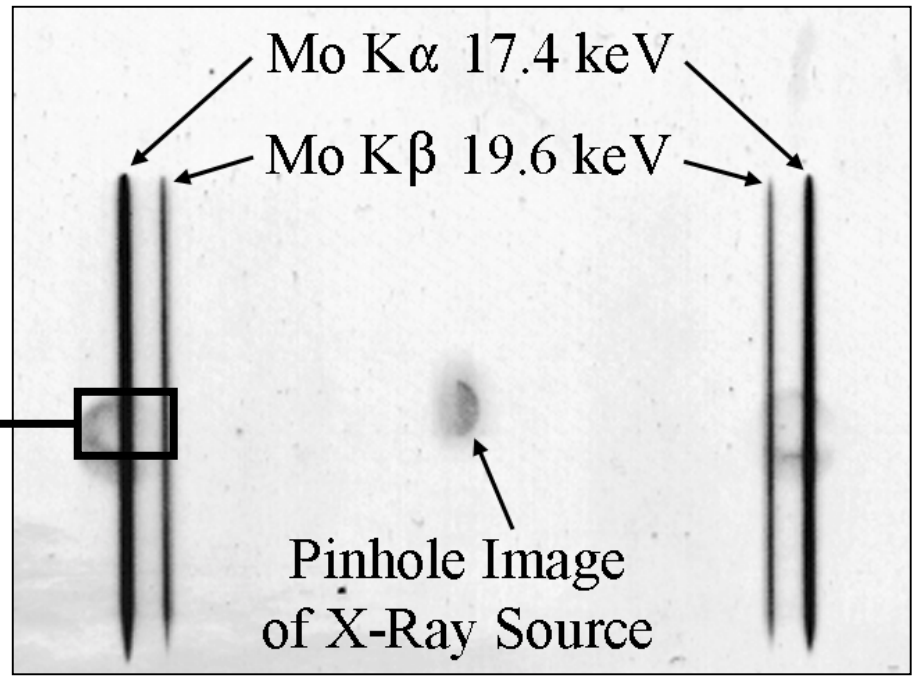
Spectra Recorded on Film using the NRL X-Ray Source

NRL

DEF Film



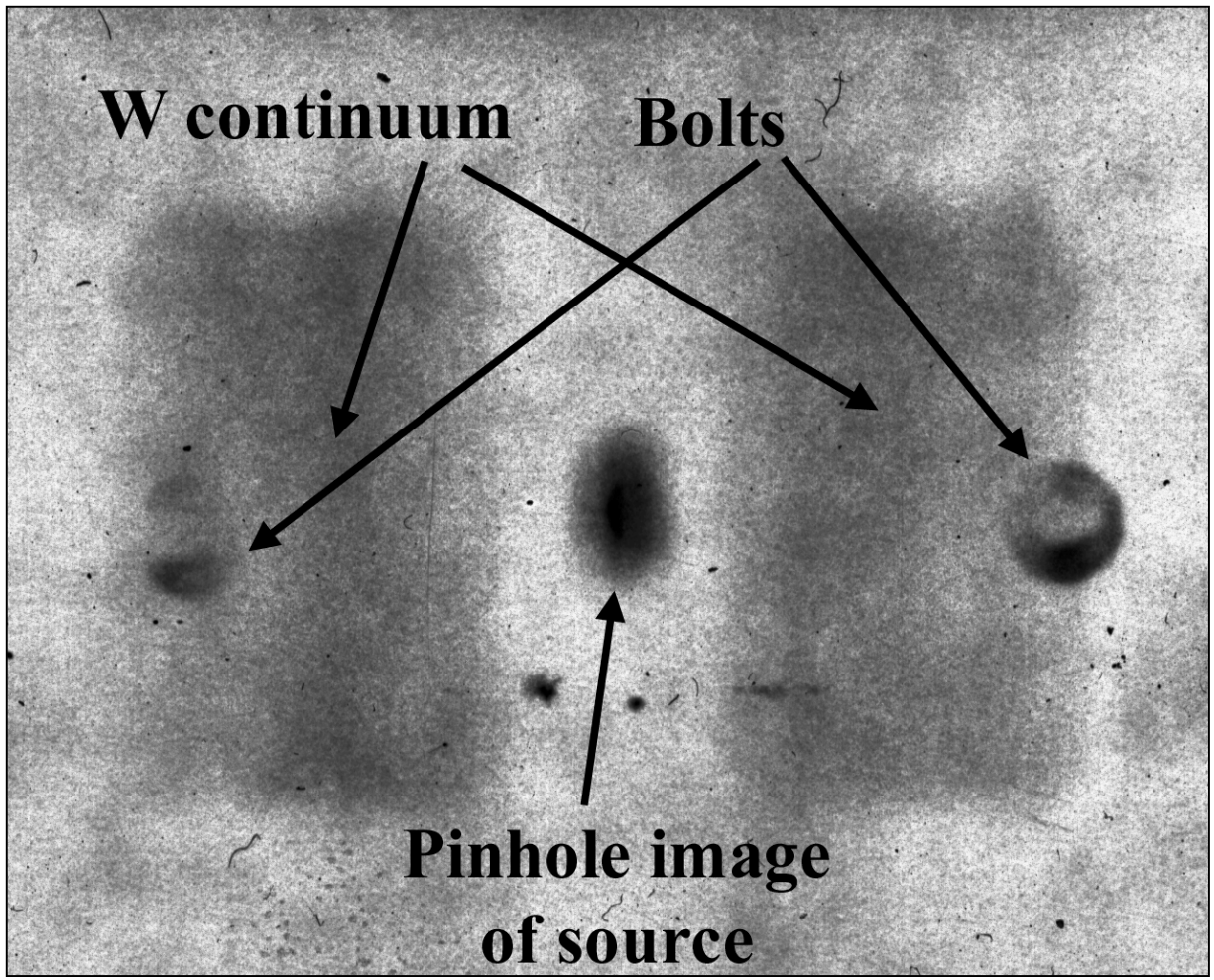
Single-shot spectrum on Polaroid Film



Tungsten Continuum Spectrum

NRL

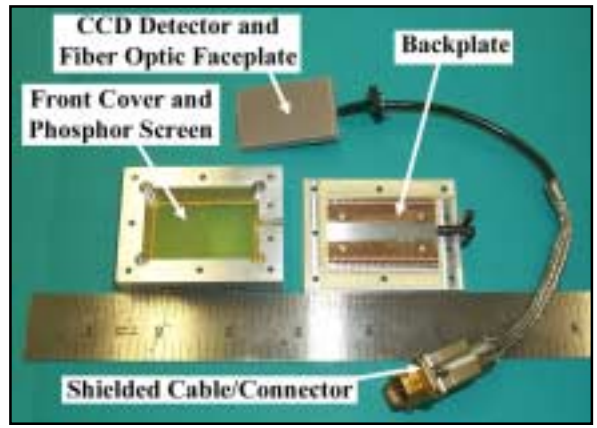
20 keV → 50 keV **50 keV ← 20 keV**

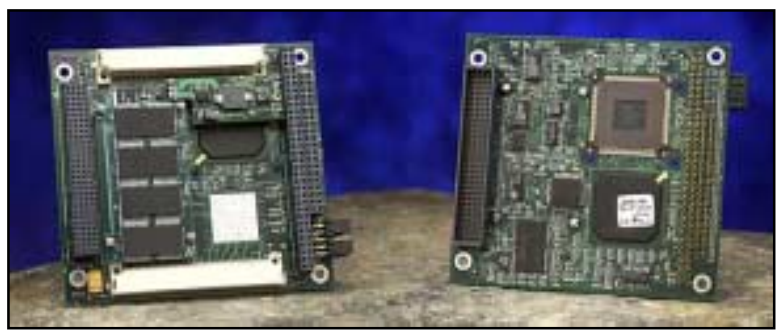


CCD and Computer Control System

NRL

- **CCD is a repackaged commercial dental x-ray unit:**
  - **Vacuum compatible, shielded against EMP**
  - **Phosphor screen is optimized for each energy range**
  - **36 mm length provides good energy coverage**
- **HENEX computer control system:**
  - **Based on commercial PC104 boards**
  - **On-board image storage**
  - **USB hub or PCI interface**
  - **CCDs are triggered by laser facility fiducials**

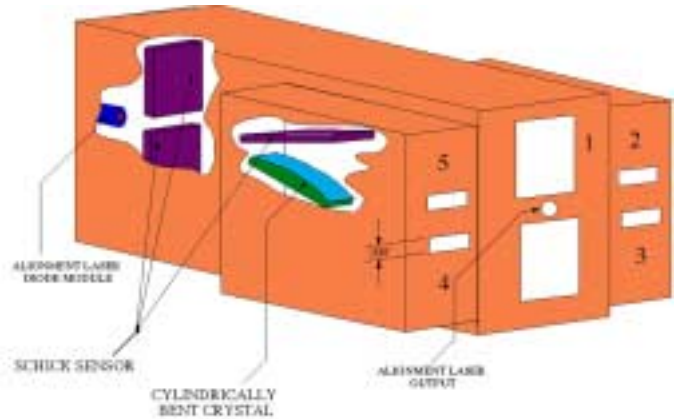


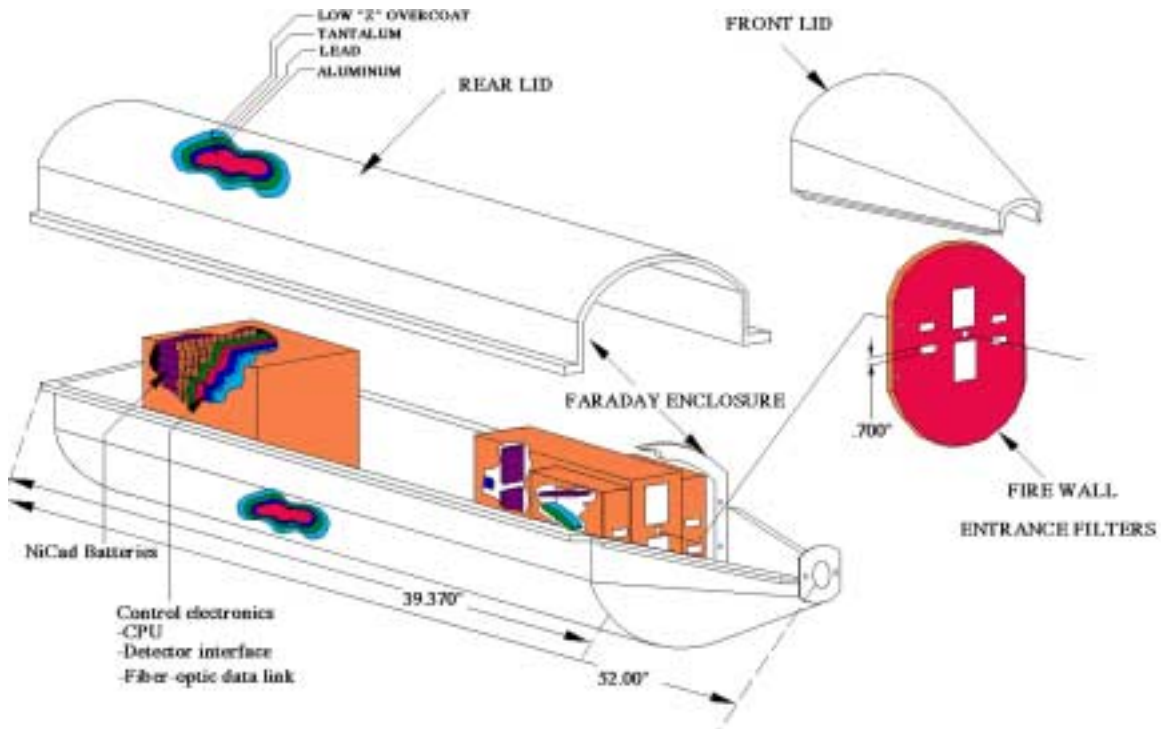


HENEX Is Packaged for DIM/TIM Operation

NRL

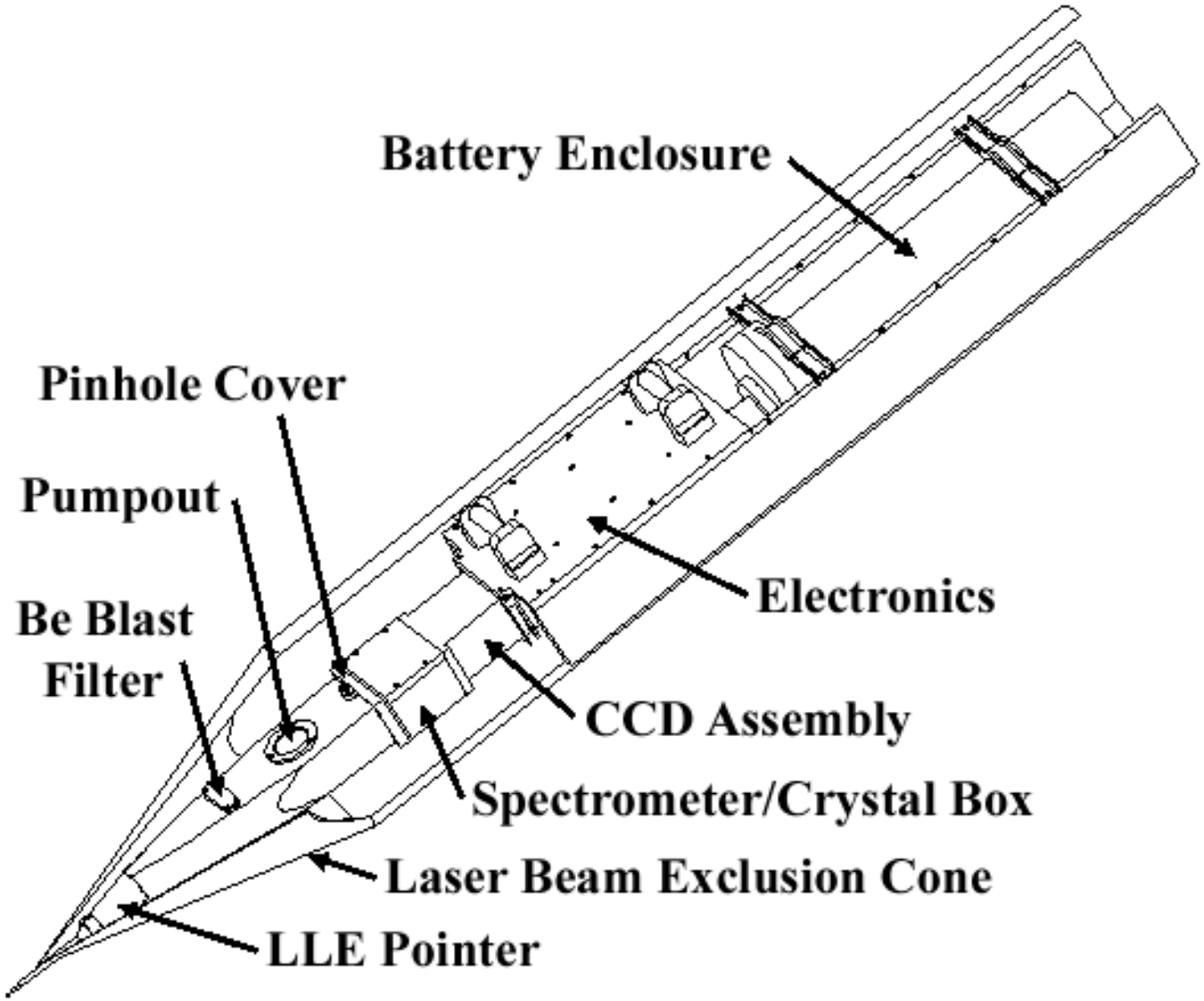
- **Computer control system**
- **X-ray, neutron, and debris shielding**
- **Faraday enclosure shields against EMP**
- **Diode laser and pointer for alignment**





LLE Instrument Schematic

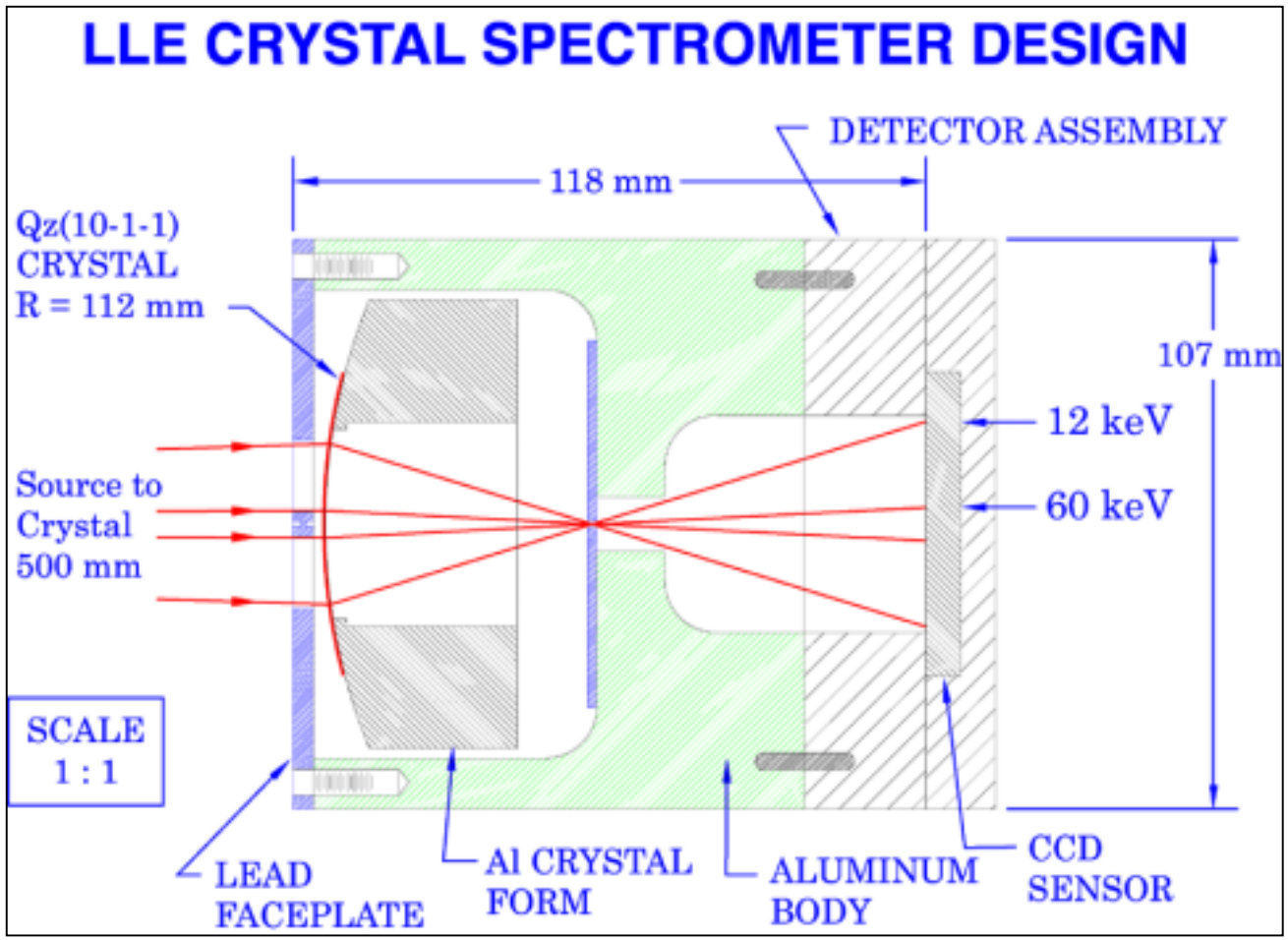
NRL



NRL

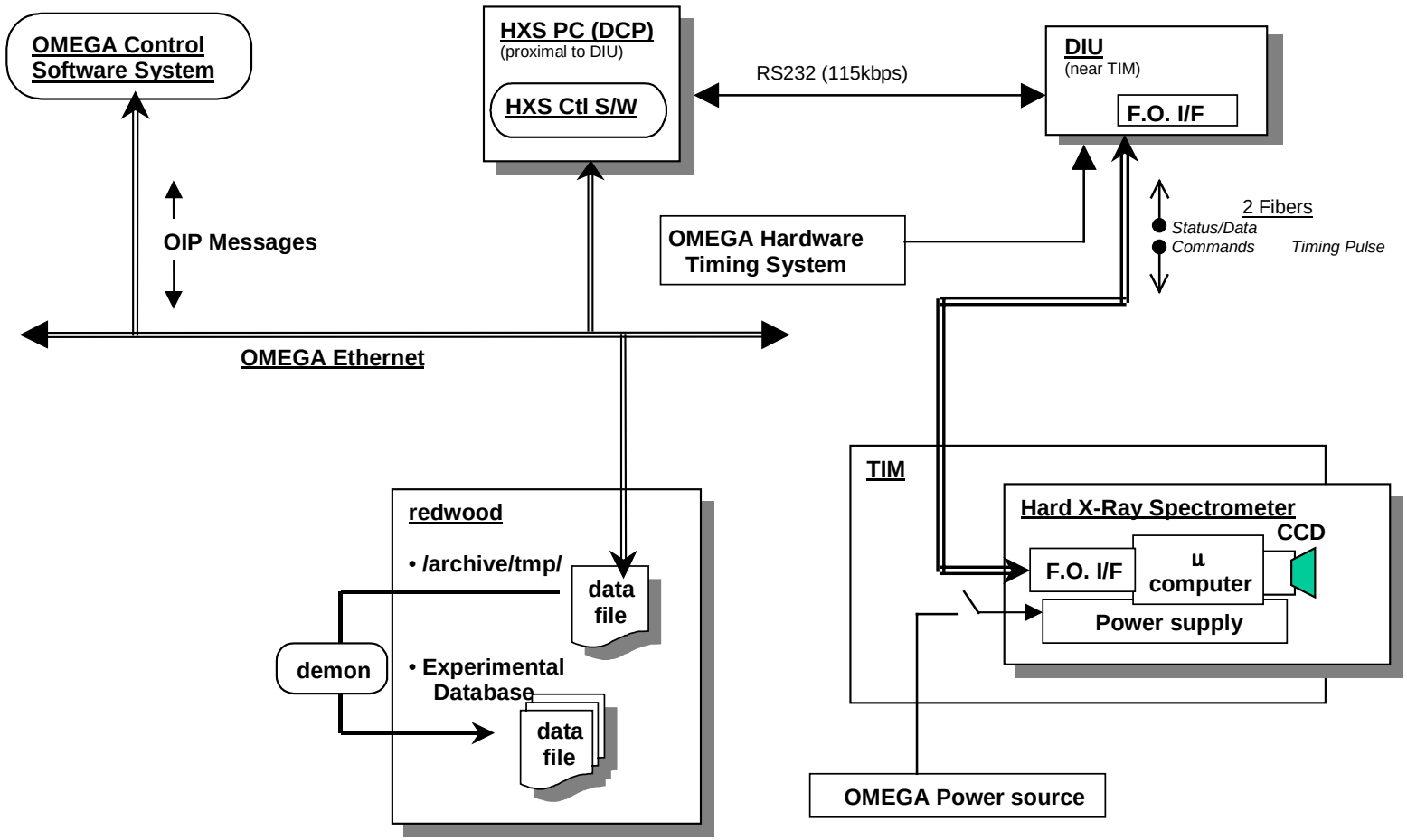
Spectrometer Module

Transmission crystal spectrometer is modular in design.



Data Acquisition System

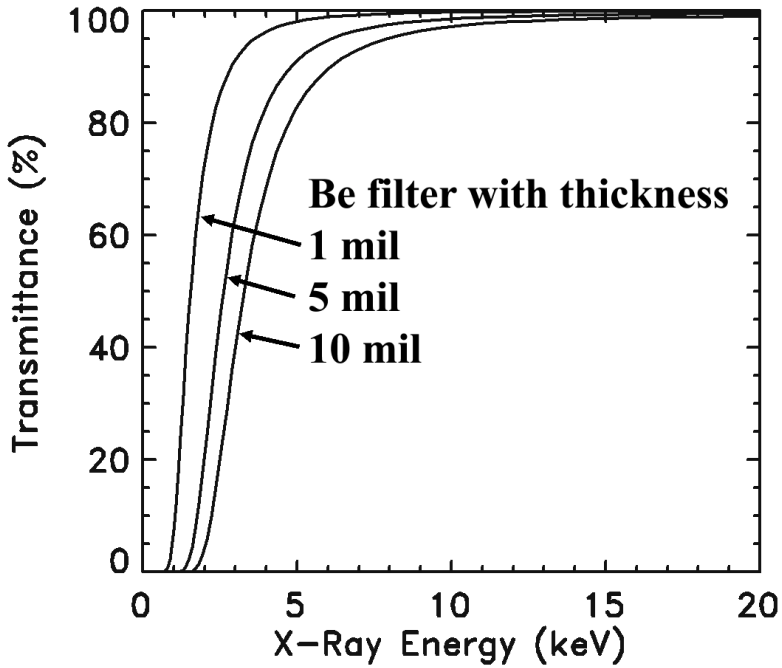
NRL

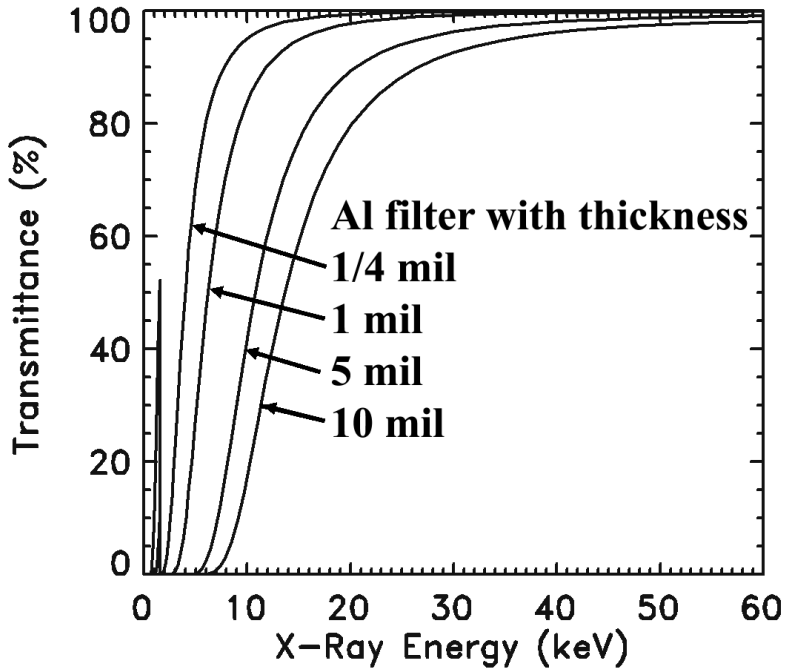


X-Ray Filters

NRL

- **A thick beryllium entrance aperture filter serves as a debris shield.**
- **Aluminum filters provide stepwedge control of the CCD exposure.**

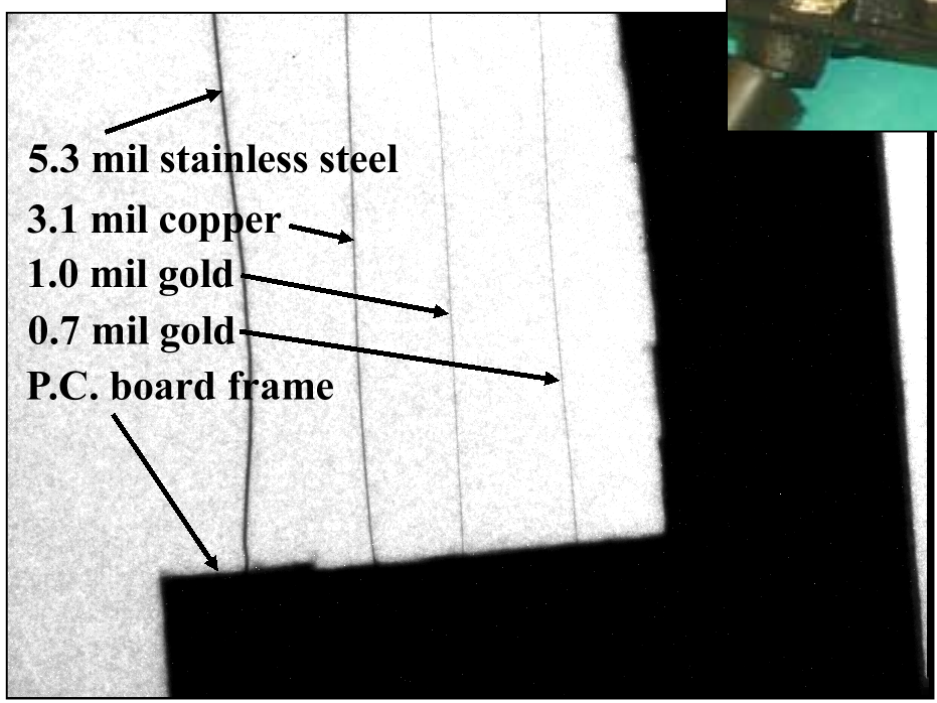




Hard X-Ray CCD Detector

NRL

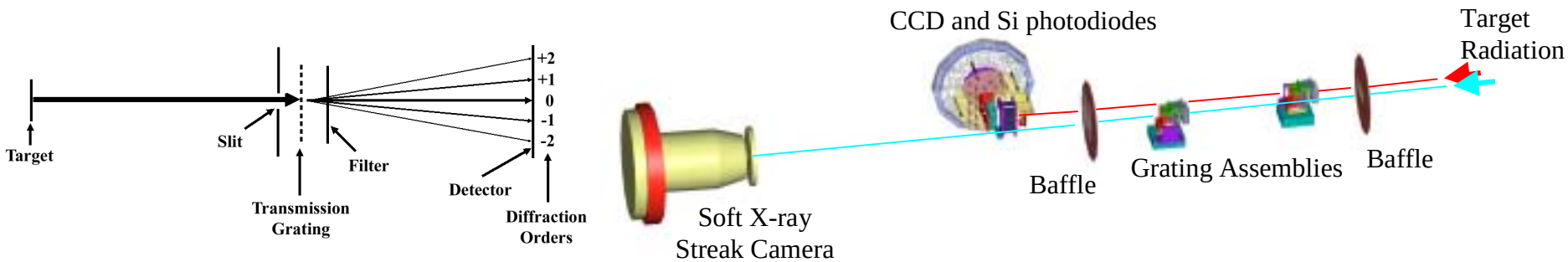
- **Trex Medical Corporation dental x-ray system.**
- **19.5 μm pixels, 1800x1400 format 36x27 mm^2, 12 bits, >20 lp/mm.**
- **Test image recorded with a single shot of the NRL x-ray source.**

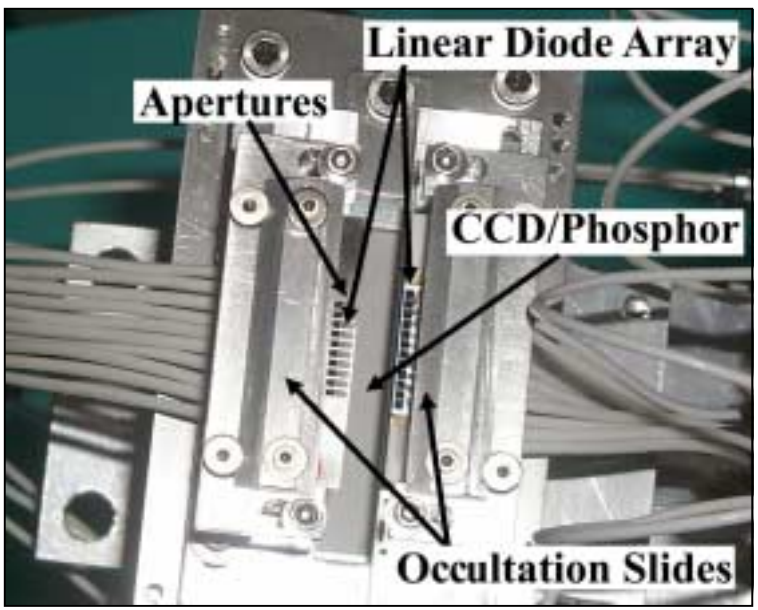


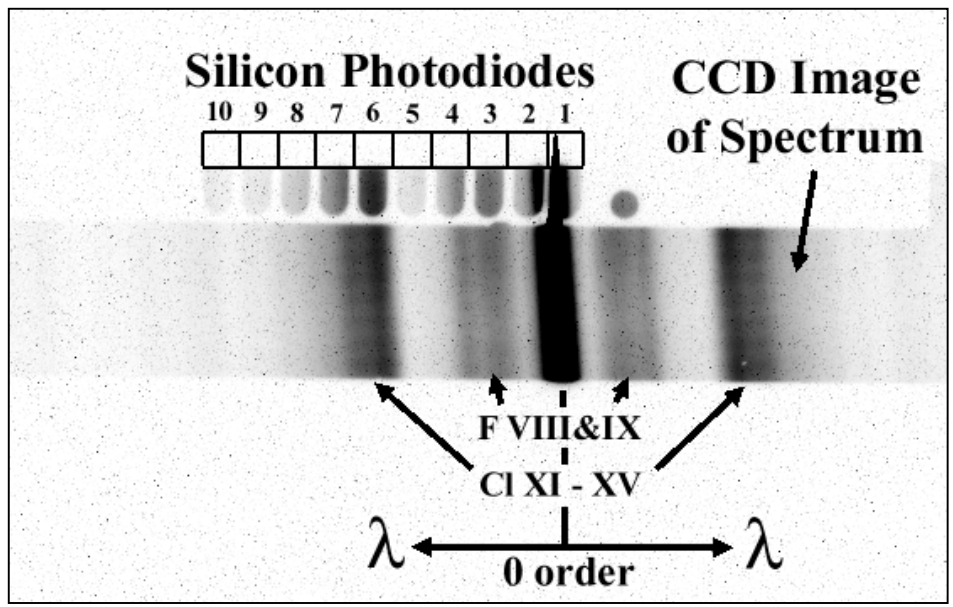
CCD was Implemented on a Transmission Grating Spectrometer

NRL

Schematic of the Transmission Grating Spectrometer



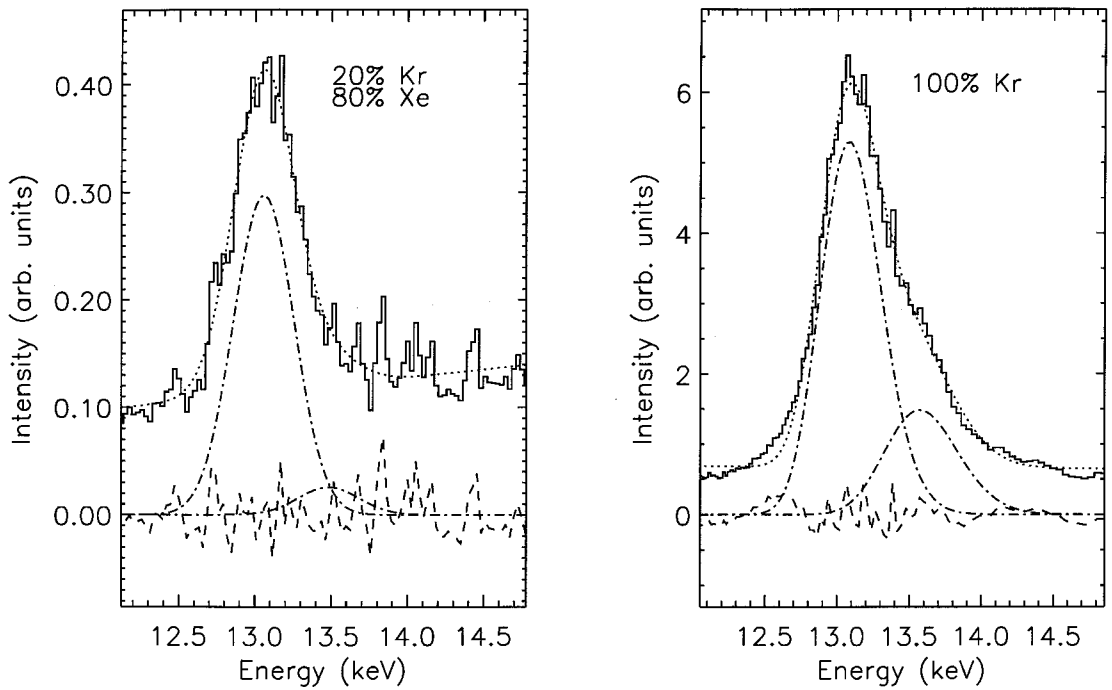




Krypton K-Shell Diagnostic

NRL

Krypton K-shell resonance lines have been observed and can be used for high-temperature ICF diagnostics (extension of argon diagnostic).

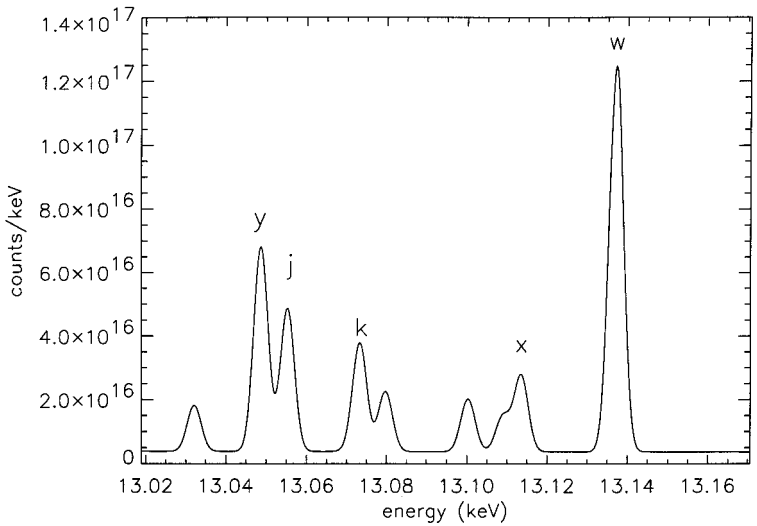


The experimental spectra from 20%/80% and 100% Kr hohlraums (Tina Back). The dot-dashed curves are fits of the He-like resonance line (w) and H-like resonance line (Lyman-α) to the experimental spectra (Martin Laming).

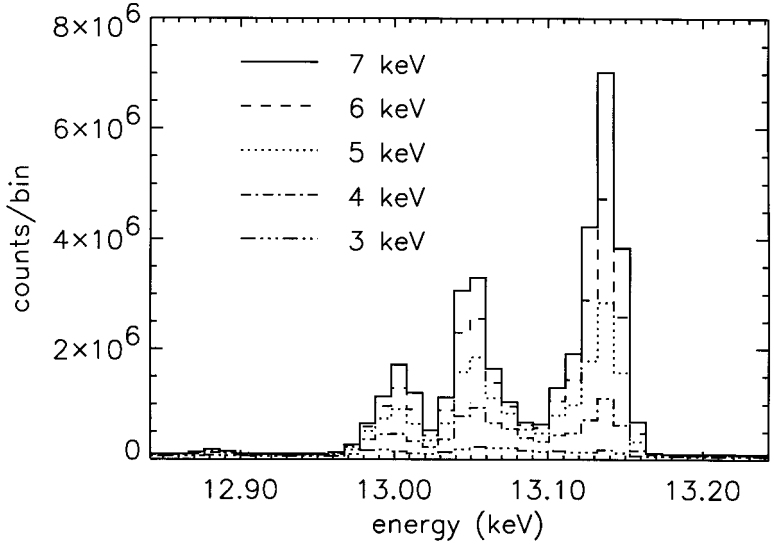
NRL

Modest Spectral Resolution and Coverage is Required

Identification	Transition	Wavelength (Å)	Energy (keV)	Interval from Previous Transition (eV)
Kr^{+35} ($L\alpha_1$)	$1s\ ^2S_{1/2}$ - $2p\ ^2P_{3/2}$	0.91783	13.509	-
Kr^{+35} ($L\alpha_2$)	$1s\ ^2S_{1/2}$ - $2p\ ^2P_{1/2}$	0.92327	13.429	80
Kr^{+34} (DS)	$1s2p\ ^1P_1$ - $2p^2\ ^1D_2$	0.9360	13.25	180
Kr^{+34} (w)	$1s^2\ ^1S_0$ - $1s2p\ ^1P_1$	0.94540	13.115	135
Kr^{+34} (y)	$1s^2\ ^1S_0$ - $1s2p\ ^3P_1$	0.95181	13.026	89
Kr^{+34} (z)	$1s^2\ ^1S_0$ - $1s2s\ ^3S_1$	0.95520	12.980	46



Simulated krypton emission spectrum for a 20%Kr/80%Xe hohlraum and assuming a spectral resolution of E/ΔE=3000.

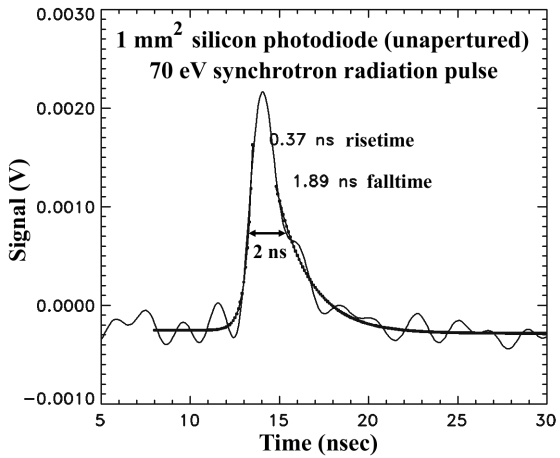


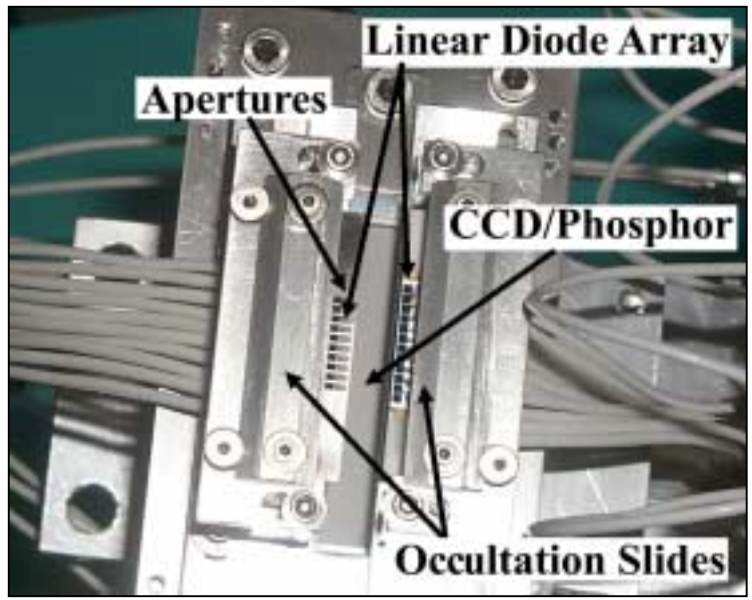
Simulated krypton spectrum for a 100%Kr hohlraum and assuming a spectral resolution of E/ΔE=600.

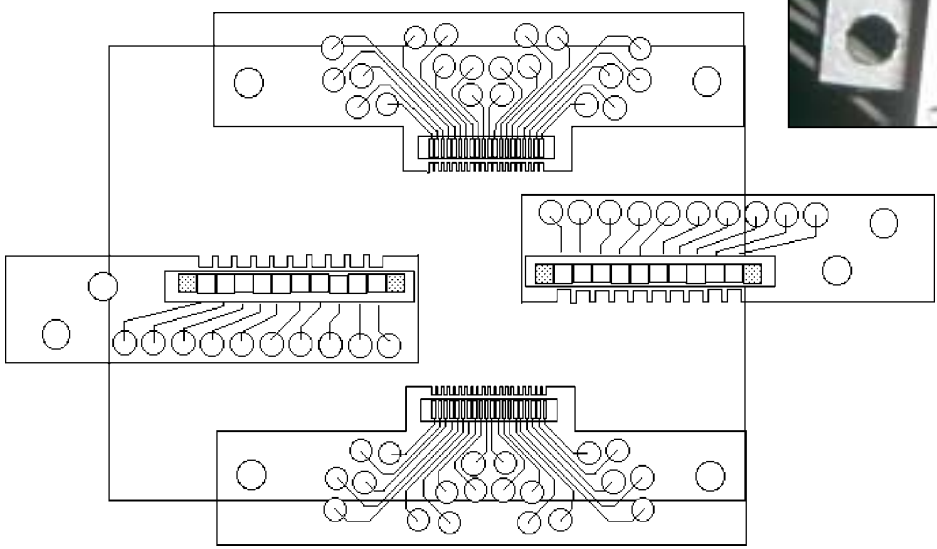
Photodiode Arrays can Recorded Absolute Temporal Flux

NRL

Linear arrays of 1x1 mm^2 and 0.2x2 mm^2 silicon photodiodes have 0.4 nsec risetime.







Summary

NRL

- **The HENEX/NIF 5-channel HXR spectrometer is being designed.**
- **The OMEGA 1-channel instrument has many of the same features.**
- **The instruments are based on proven spectrometers & CCD detectors.**
- **Exciting physics experiments can be carried out with these instruments!**