X-Ray Photoionization Experiments with Intense Z-Pinches: Creating an X-Ray Binary in the Laboratory

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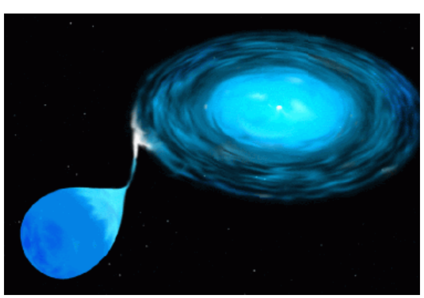
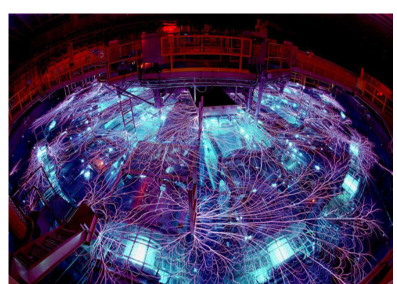
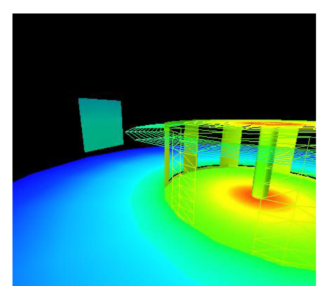
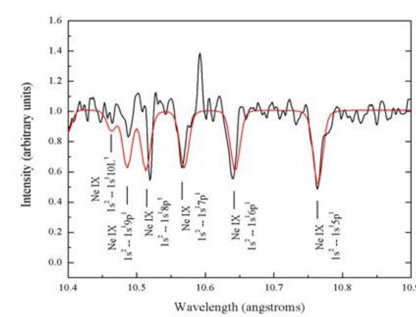
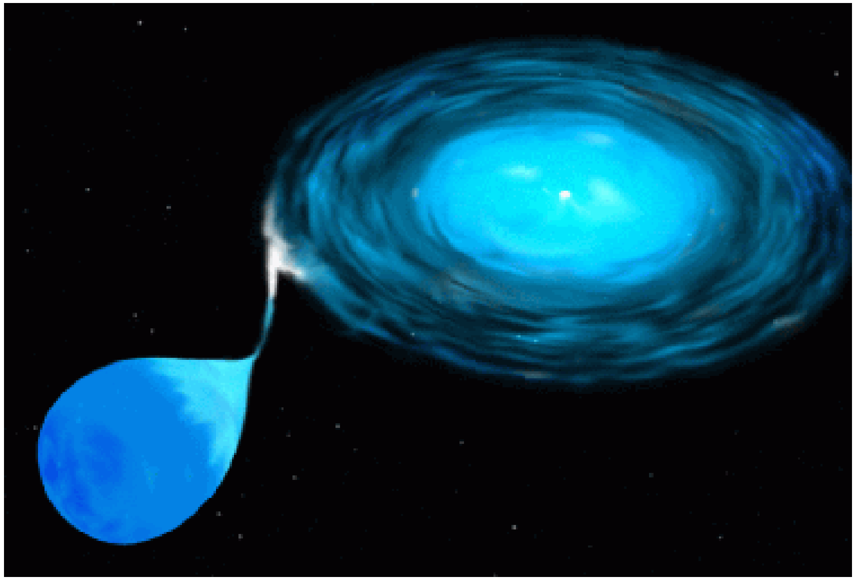








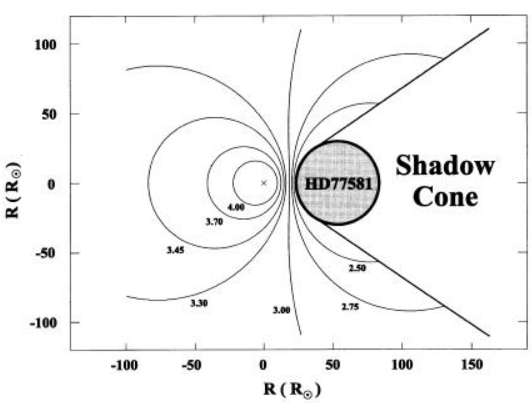


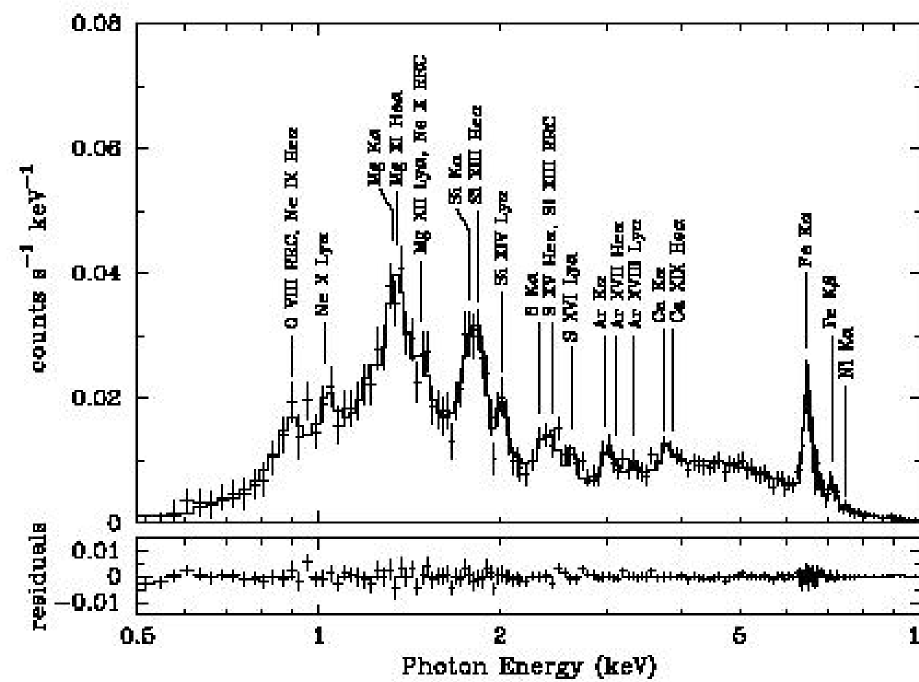
Artist's conception of a X-Ray binary with an accretion disk. Note that in eclipse, we see only X-rays reprocessed by the circumstellar material, not directly from the inner accretion disk iteslf.

X-ray spectra of photoionized sources are dominated by recombination lines and narrow recombination continua

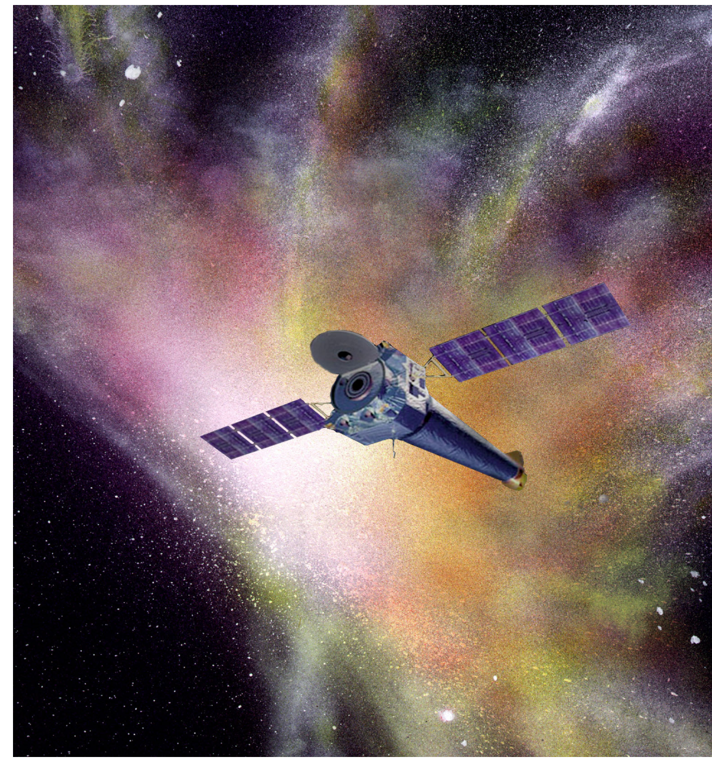
Figures from Sako et al. *Ap.J.*, 525, 921 (1999)

Ionization parameter, $\xi \sim L/nr^2$, governs line strengths



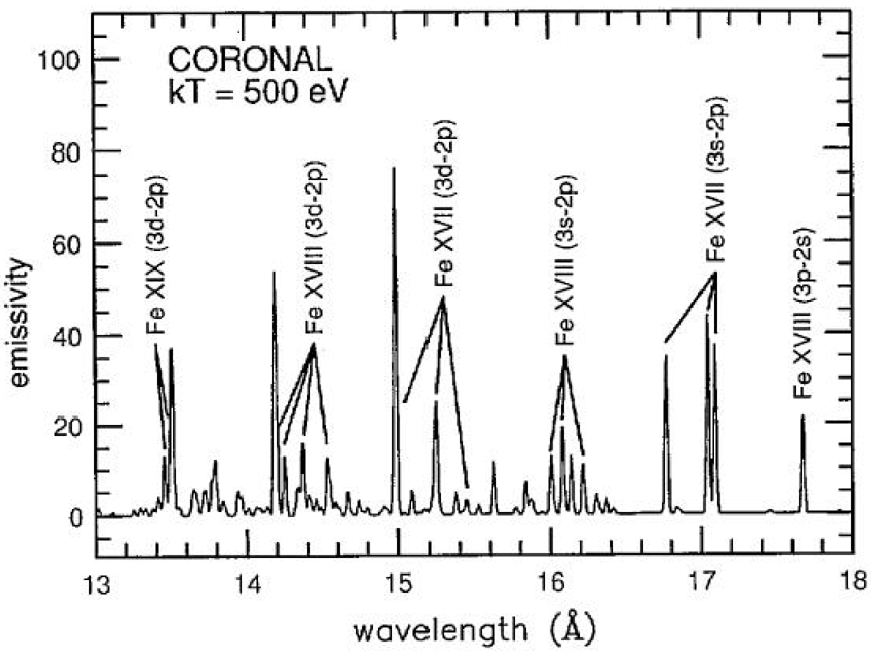


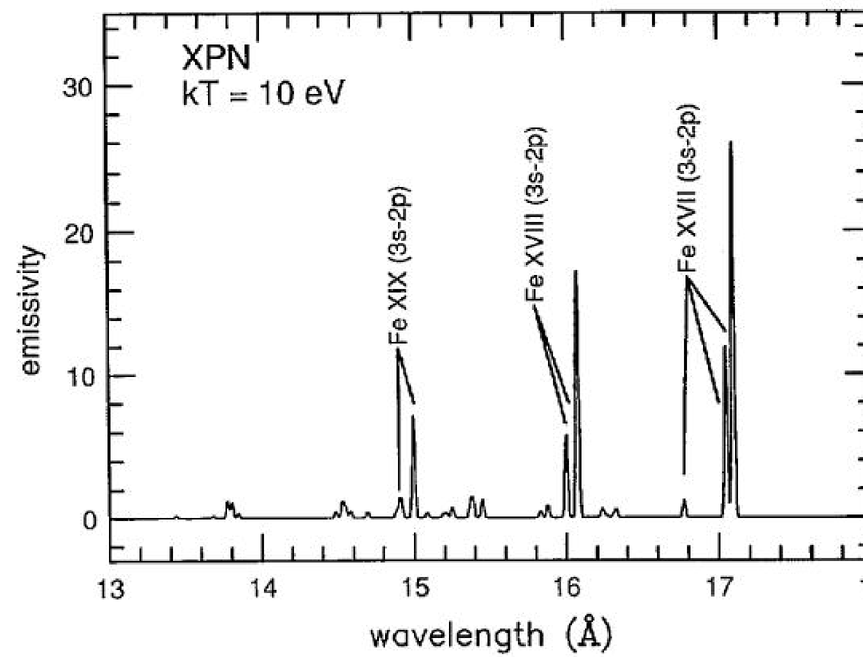
Our goal is to perform **laboratory experiments** that will enable us to understand X-ray photoionized plasmas well enough, that we can interpret the **new high-resolution X-ray spectra** of XRBs coming from *XMM* (left) and *Chandra* (right).



Photoionized plasmas are very different than coronal plasmas

You can't just use the same Raymond-Smith models you do for stars and the photoionization codes have been less-thoroughly tested and can, in principle, be validated in the laborotory

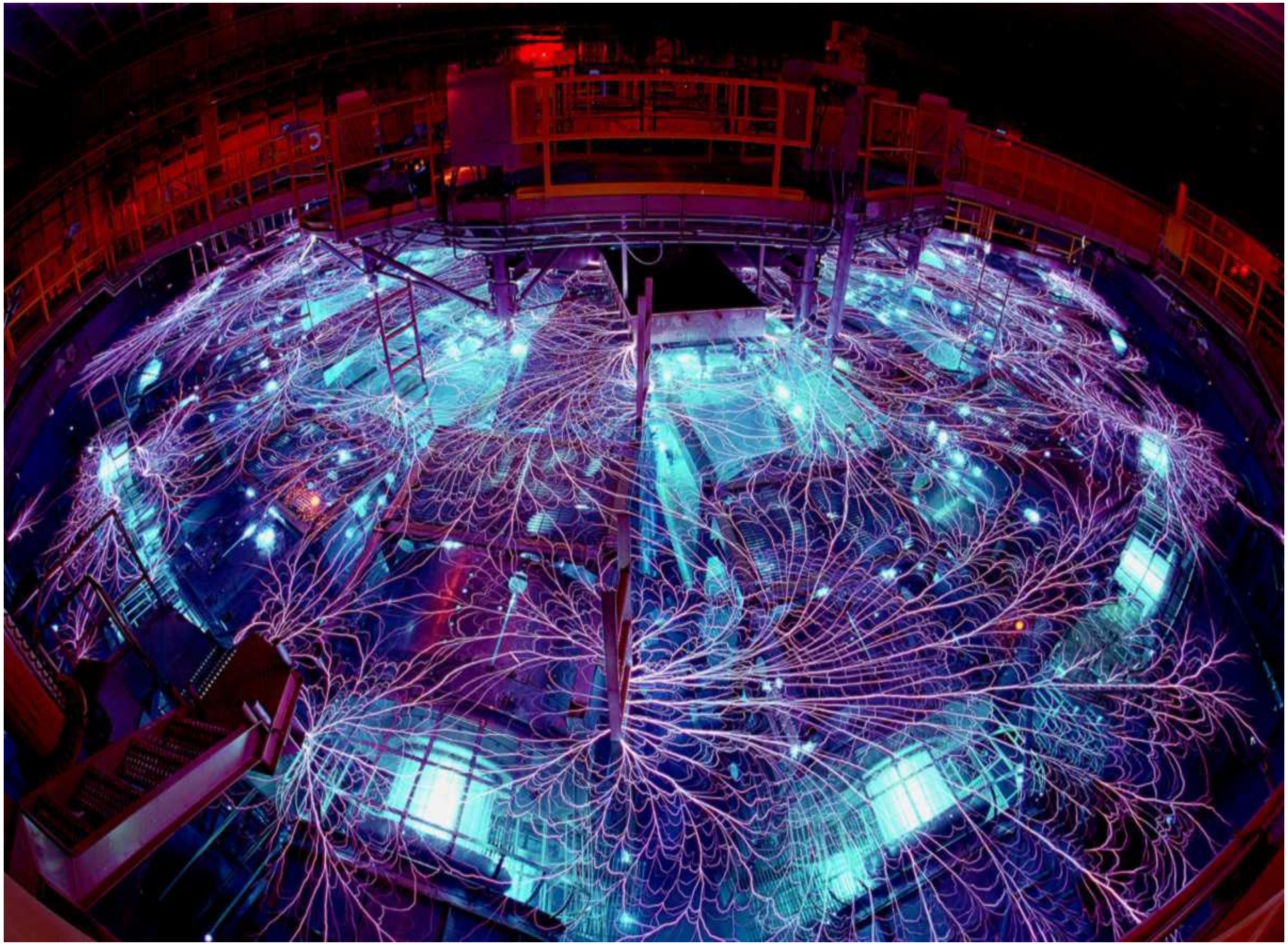




Note that even though the ionization blance and electron density ($n_e = 10^{11}$ cm^{-3}) for each of these simulations is the same, the photoionized (XPN) plasma (right) is significantly cooler than the coronal plasma (left), and its iron spectrum is marked by a lack of emission lines originating from the *3d* level.

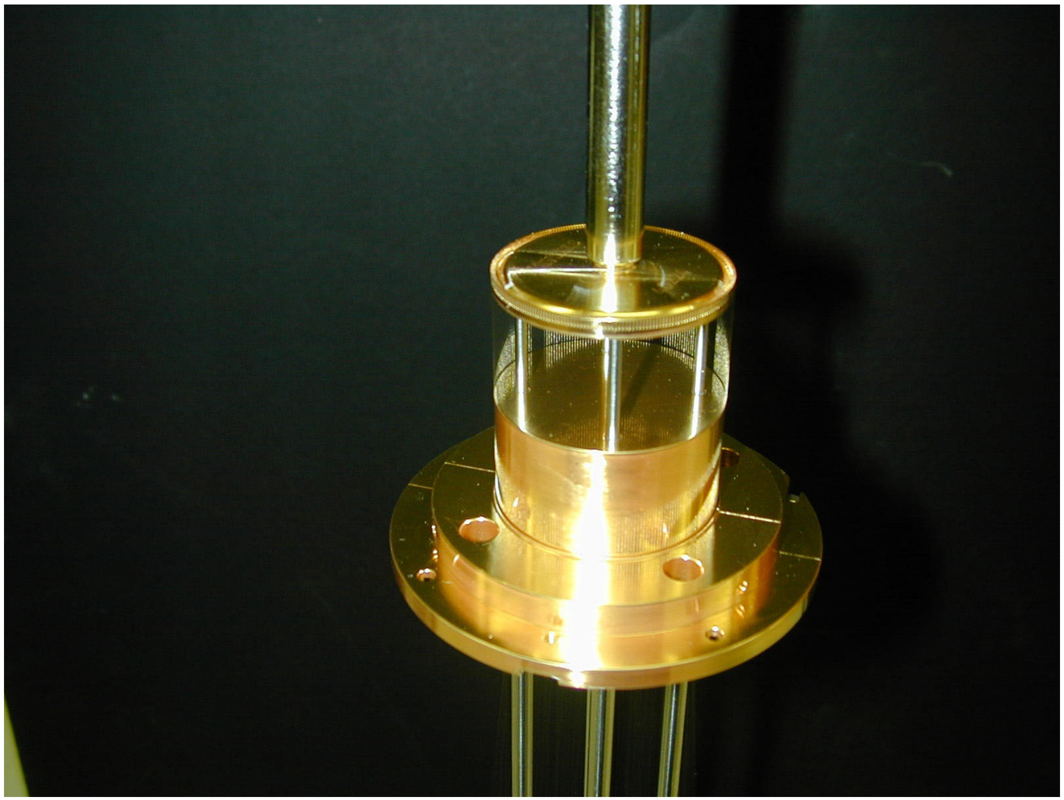
Figures taken from Liedahl et al. *Ap. J.*, 350, L37 (1990).

The “Z-Machine” at Sandia National Lab’s pulsed power facility is the world’s most powerful X-ray source



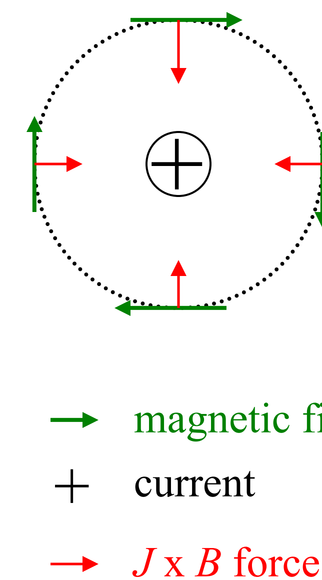
The Z Accelerator at Sandia National Laboratories banking its pulse-forming switches before a shot

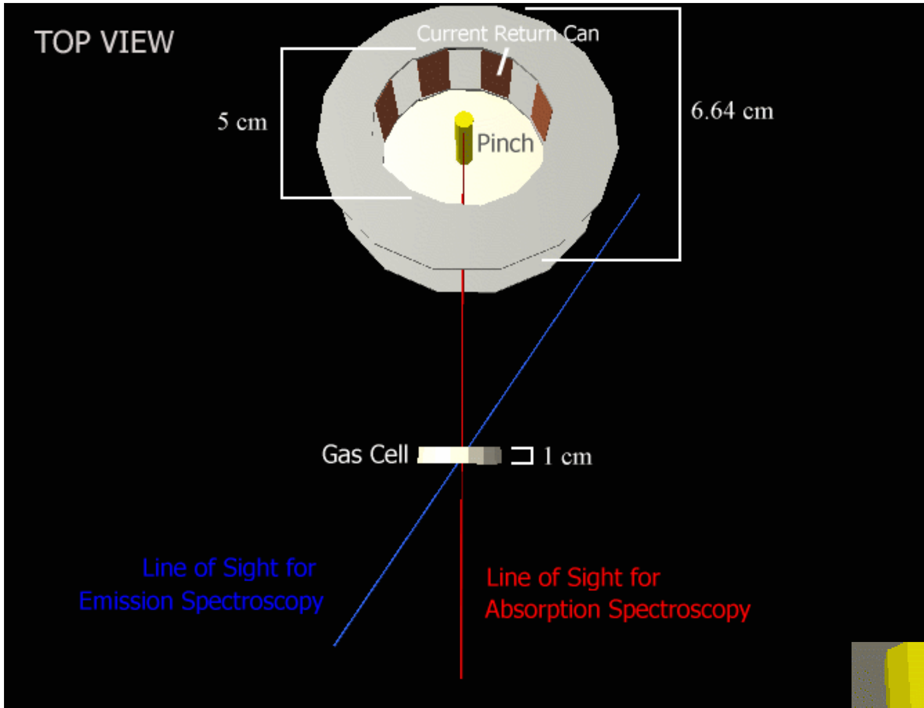
A pulse of current (~20 MA) compressed into ~ 10 ns can be driven by the Z-Machine



A tungsten wire array which acts as the Z-pinch in the experiment: There are several hundred wires in the array – scales here are a few centimeters

When this current passes through a cylindrical wire array, the self-pinching of $J \times B$ implodes the array with velocities of $>10^7$ cm/s



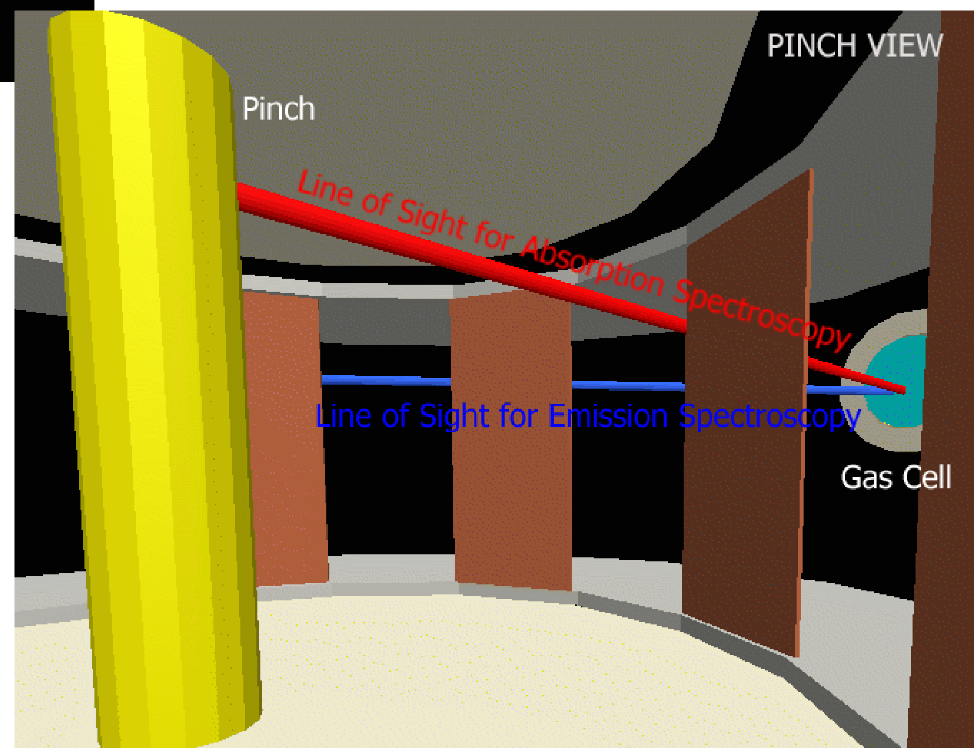


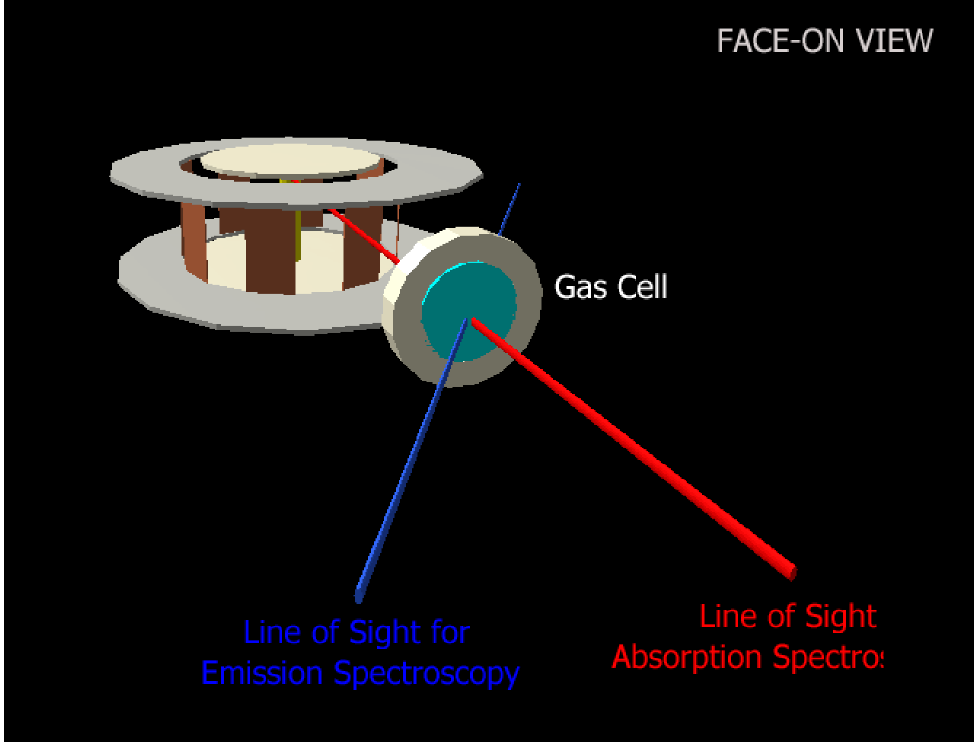
Two views of a schematic of the experiment.

Note that the pinch (i.e. the imploding wire array) is enclose in a larger metal cylinder – the 'current return can' – with slots through which X-rays propagate.

A gas cell filled with neon is irradiated with hard X-rays from the pinch.

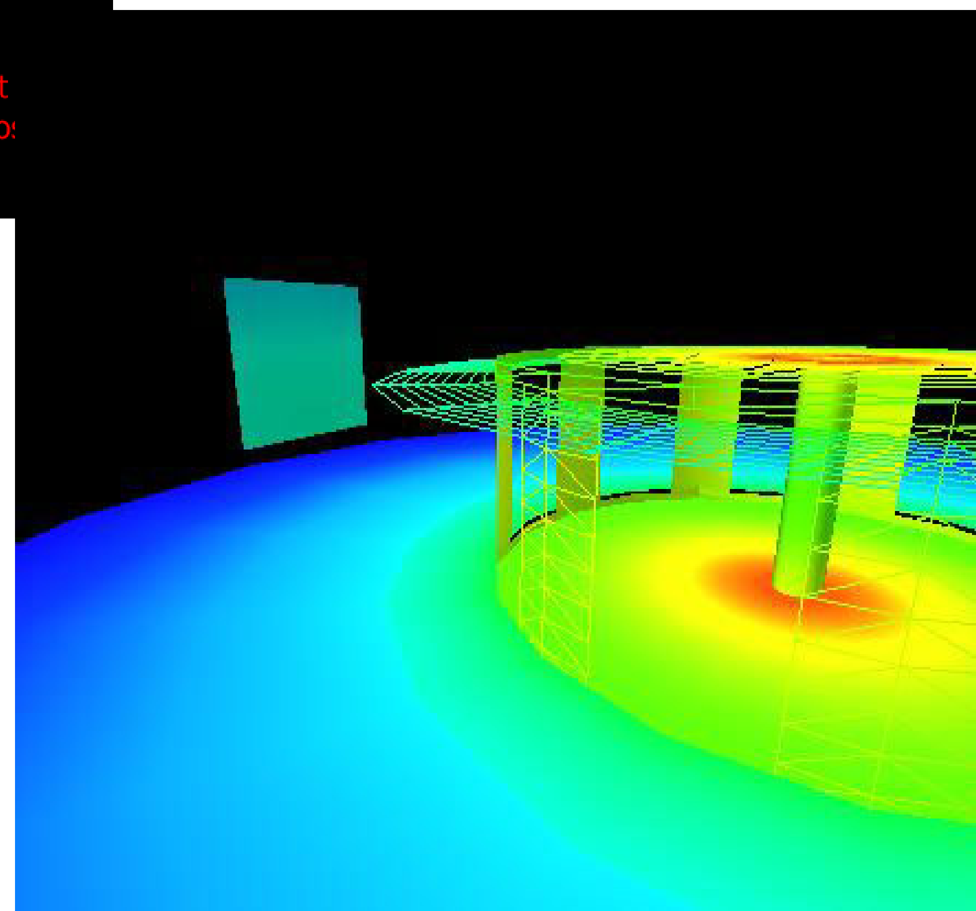
The pinch is the analog of the inner accretion disk, and the gas cell is the analog of the wind of the donor star of the X-ray binary, which reprocesses the X-rays that we observe.

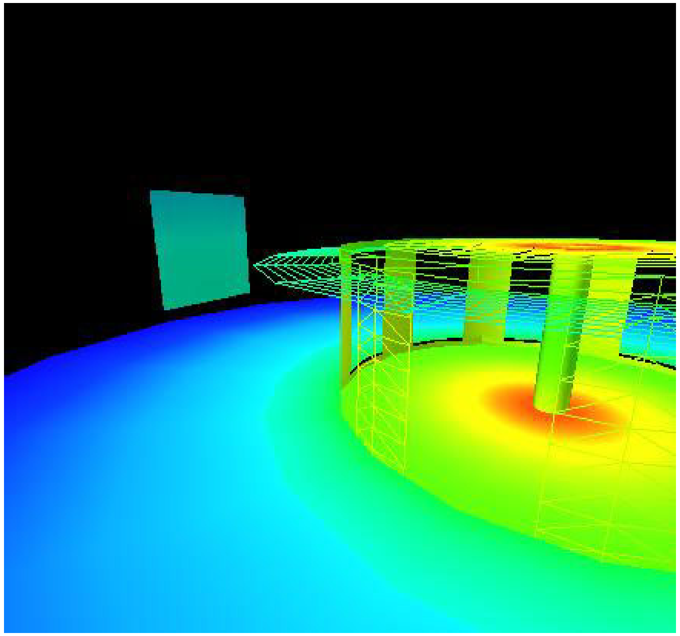




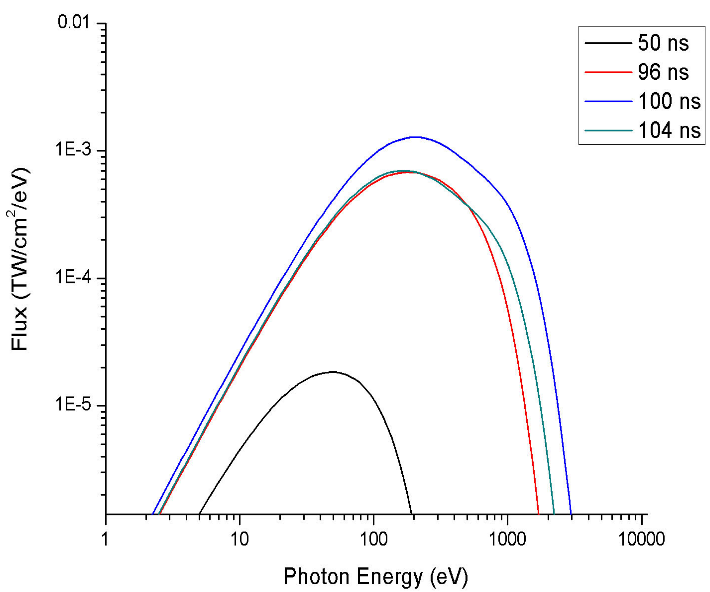
By looking through the gas cell with two spectrometers on two sightlines, we can measure simultaneous absorption and emission spectra.

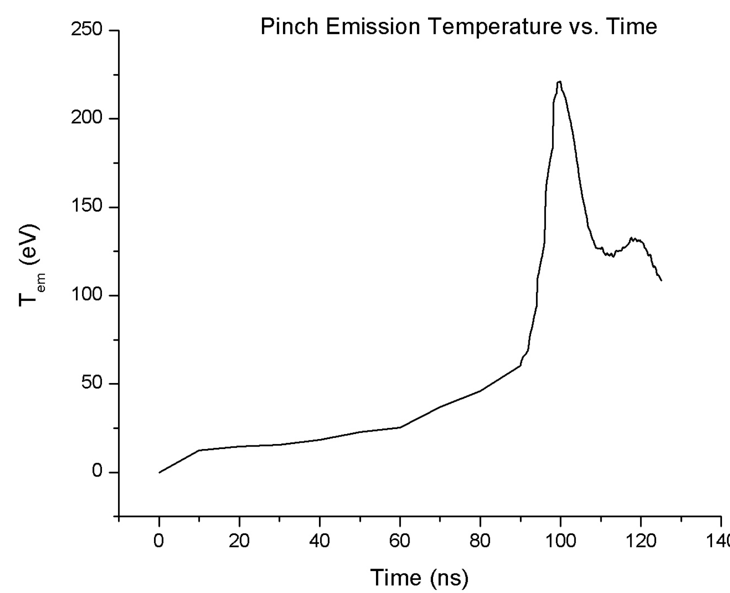
The pinch X-rays irradiate the metal surfaces (e.g. the current return can) in the vicinity. The direct emission from the pinch onto the gas cell as well as the reemission from these surfaces must be modeled.

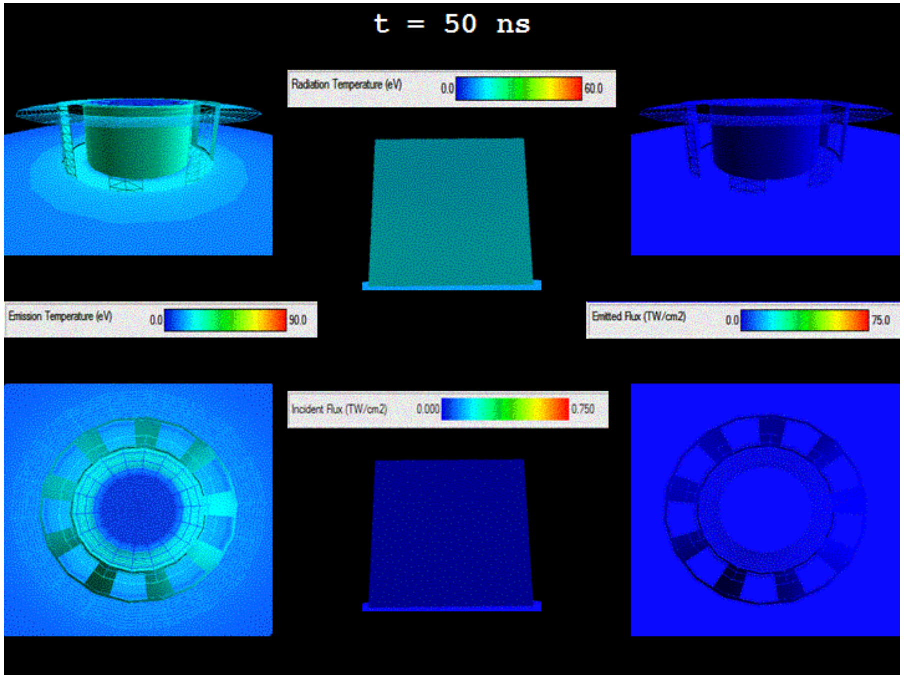


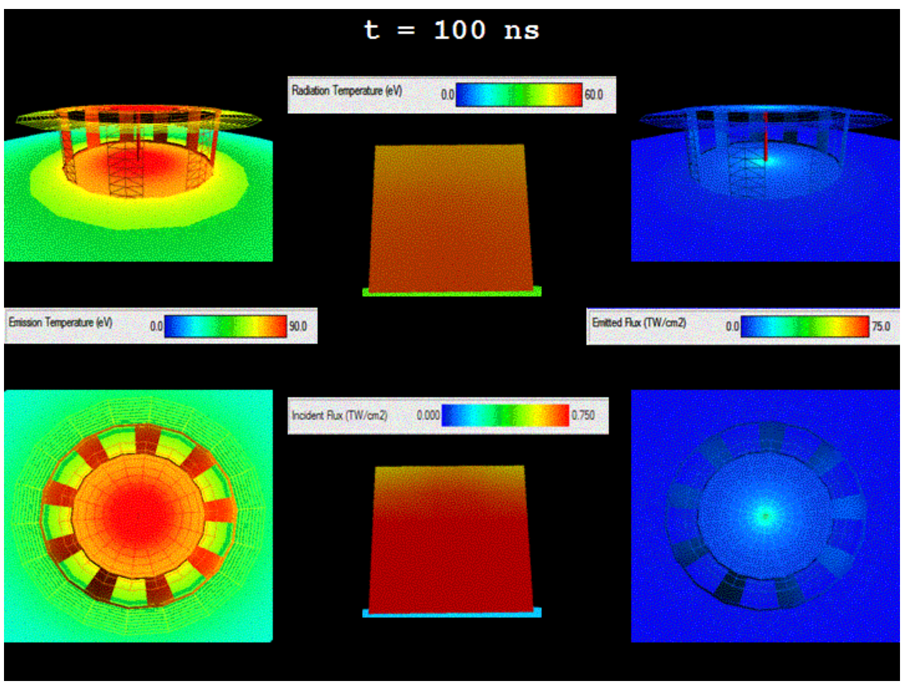


The pinch power profile has a slow (100 ns rise, then a narrow (10 ns) peak, when the imploding wire array stagnates on the cylindrical axis.



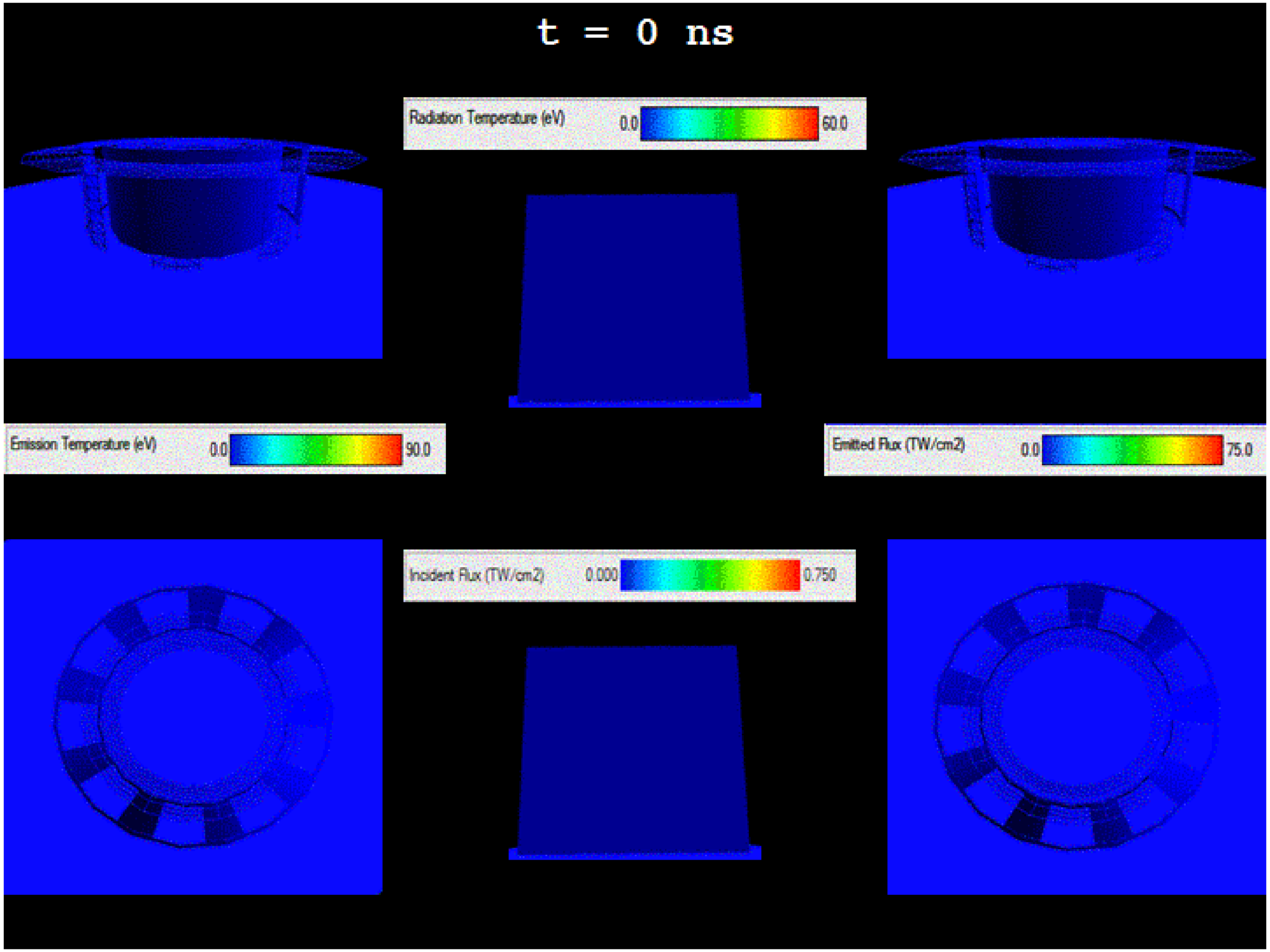




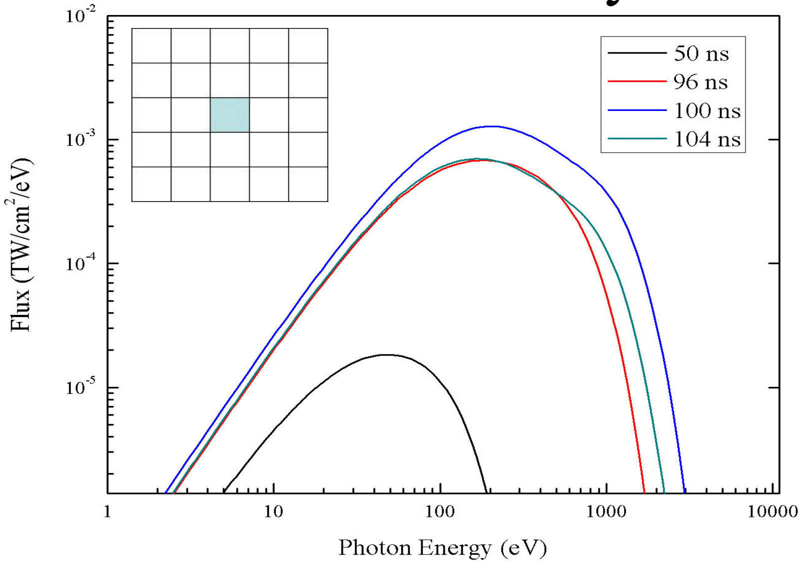


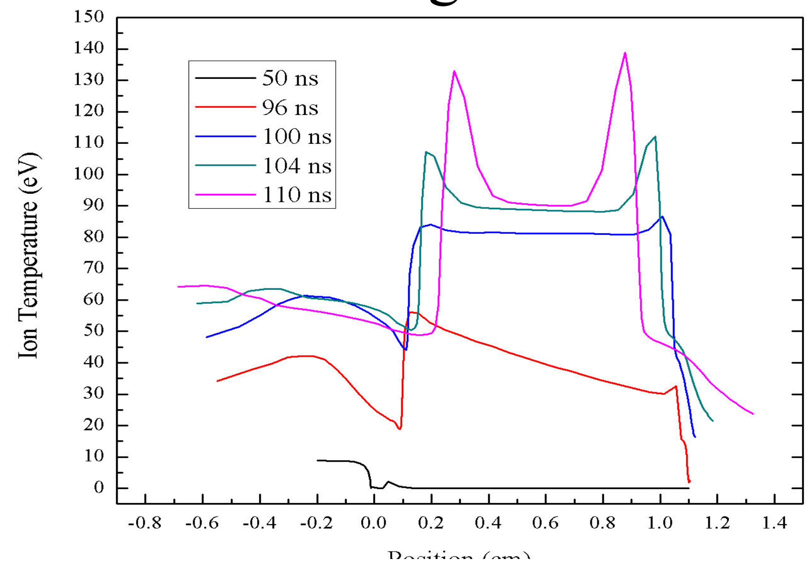
We model the time-dependent pinch radiation, all the absorption and reemission from various surfaces, and ultimately, the spectrum incident on the gas cell using the *VisRad* viewfactor code, written by Joe MacFarlane.

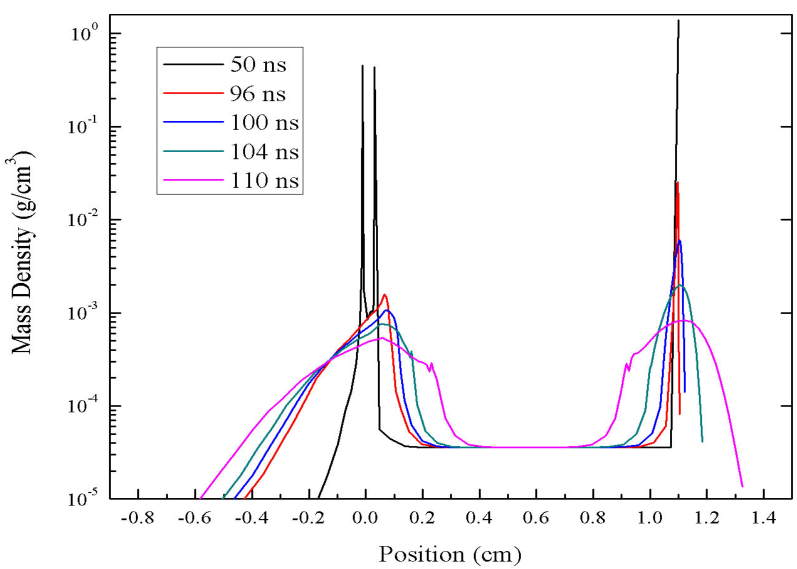
Here are several views of the experiment at two different times.

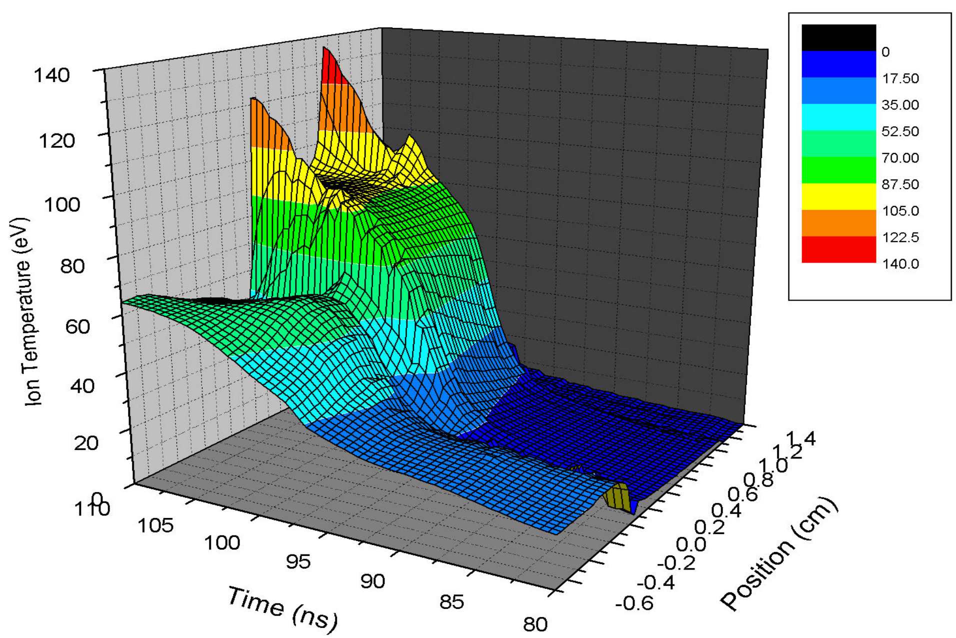

t = 0 ns
Radiation Temperature (eV) 0.0 60.0
Emission Temperature (eV) 0.0 90.0
Emitted Flux (TW/cm2) 0.0 75.0
Incident Flux (TW/cm2) 0.000 0.750

The time-dependent x-ray spectrum calculated with *VisRad* is next fed into a hydrocode simulation of the gas cell.

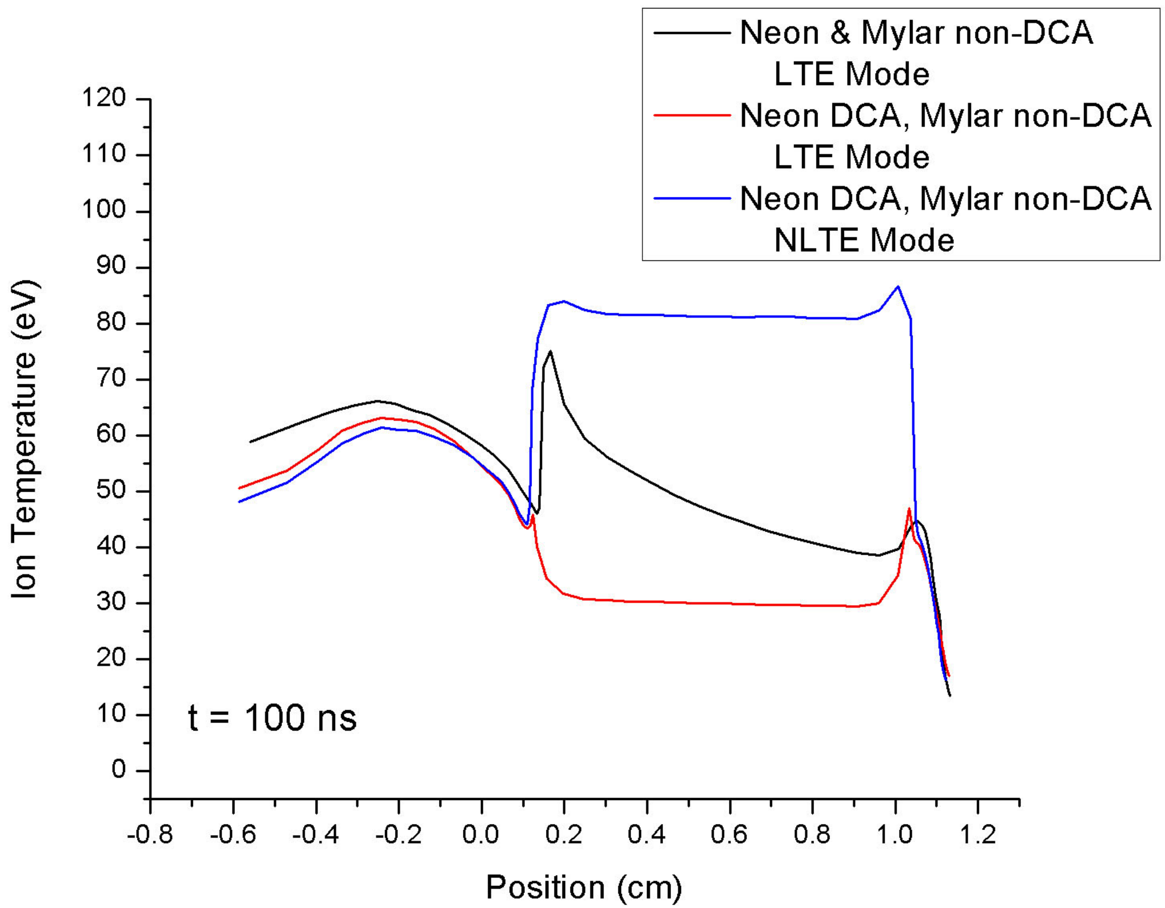






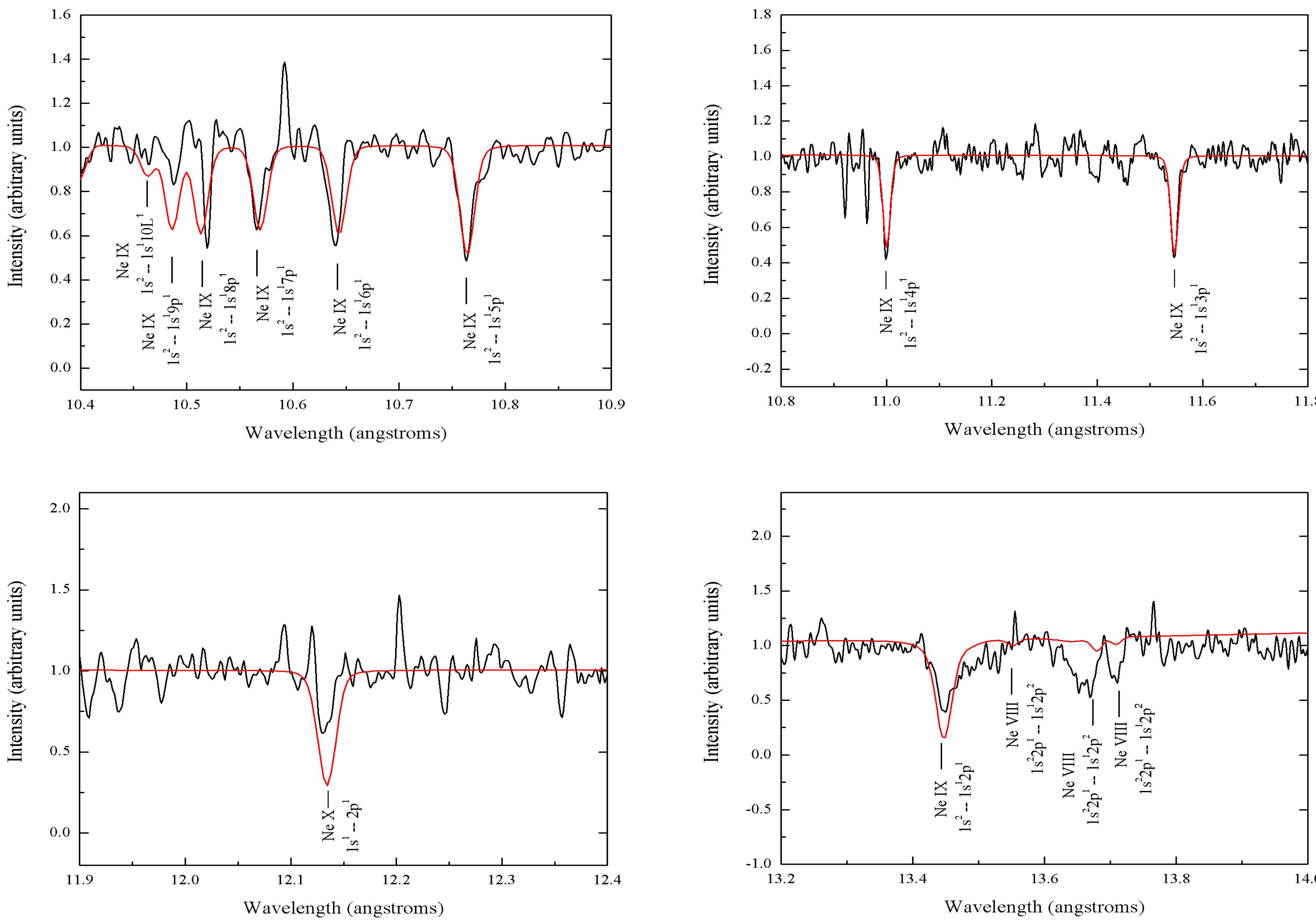


We use the *Helios* radiation-hydrodynamics code, which can account for non-LTE opacities in the neon in the gas cell



The final step in the modeling is to synthesize spectra

Using Spect3D, also written by Joe MacFarlane, we get good agreement between the measured and predicted neon absorption spectrum



Future Work

- Measure an emission spectrum in addition to the absorption spectrum
- Use streak cameras in conjunction with the spectrometers to obtain time-dependent spectra
- Optimize gas cell fill density and mylar window thickness and possibly dopant level (to filter soft X-rays)
- Field gas cells with other elements of astrophysical interest
- Benchmark Cloudy and XSTAR – photoionization codes used to model astrophysical X-ray spectral data – against our experimental results