Note to Paul: I’ve been going back and forth with Bob Heeter about using MSPEC and he’s not sure if it will work, but had some other thoughts. I’ve pasted his email here.

I would be happy to contribute whatever instruments make sense. But the MSPEC is probably too large and photon-inefficient for what you want to do (secondary K-alpha light if I read your other email correctly), though. Depending on what resolution and bandwidth you need, you might get more and better data from a compact, close-in (flat-crystal?) instrument using image plates. (I put the flat crystal in question because it sounds like your secondary emitter foils are going to be extended sources and source broadening will be a disaster...)

Hmm... If you were to dial down the X-ray energy band then we could do this with a grating spectrometer (more efficient). I don’t have a compact broadband spectrometer smaller than MSPEC, but would be interested in making one for other future uses, so I’d like to explore this more, but have to get over to a meeting now...

– Bob

and here’s the actual proposal...(I still need to add references)

Investigation and control of electron transport in laser x-ray sources

Principal Investigator

Carolyn Kuranz
University of Michigan
Center for Radiative Shock Hydrodynamics
Department of Atmospheric, Oceanic, and Space Science
Summary
We propose to gain a better understanding of the behavior of electrons when creating an x-ray source. X-ray sources are commonly used to diagnose high-energy-density physics (HEDP) experiments using the x-ray backlighting technique. X-ray sources are typically created by irradiating a material that is chosen for its K-α or He-α energy. The energetic electrons generated during this process can effect both the physics of the experiment and the signal levels observed by diagnostics. Overall, a lot of work has gone into creating efficient, bright x-ray sources, but in better understanding the behavior of the electrons in x-ray sources we may be able to improve methods of mitigating their effects on HEDP experiments.

Scientific Goal and Impact
One way to create an x-ray source is to laser-irradiate a target, in some cases a solid metal foil. Laser light interacts primarily with the electrons in the material because the ions move much more slowly. This interaction provides energy to the electrons either through interaction with the laser-produced plasma or by laser-plasma instabilities. Under certain conditions, using laser irradiances of $10^{14}$ to $10^{15}$ W cm$^{-2}$ can result in the production of a distribution of “suprathermal” or “hot” electrons with characteristic energies of tens of keV and having an exponential energy distribution. Creating an x-ray source using very high laser irradiances, above $10^{20}$ W cm$^{-2}$, can create a distribution of electrons having MeV characteristic energies. This can occur when using a short-pulse backlighting technique where laser irradiances are typically $10^{17}$ W cm$^{-2}$ and above.

These hot electrons can have various effects on an HEDP experiment. First, they can affect the physics of the experiment by “preheating” the experimental target that is being diagnosed with the x-ray source. Hot electron preheat is one type of preheat and refers to the deposition of energy by hot
electrons in a material prior to the intended time by the experimental design. This is a concern in Inertial Confinement Fusion (ICF) experiments, where preheat by hot electrons can cause fuel to pre-mix and affect the effectiveness of the implosion. Preheat by hot electrons can also affect precision-machined perturbations used to seed instabilities in laser-irradiated hydrodynamics experiments. In this case, the preheat can alter the initial conditions of the experiment so that they will not be precisely known.

Energetic electrons can also affect the signal levels observed by diagnostics in HEDP experiments. Two examples of this are spurious x-ray emission and “high-energy” noise. The former refers to the fact that electrons produced by laser irradiation are not confined to the region where they are produced. Laser irradiation creates large-scale magnetic fields that wrap around the target and electrons can very easily travel across the surface of a target or around shielding and penetrate surfaces far from the laser spot. This could lead to x-ray emission from unintended surfaces, which can cause noise on the image. One method of mitigation is to coat high-Z materials in a thin coat of plastic to potentially scatter the electrons. However, the effectiveness of this method is not well known as the behavior of these electrons is not well understood.

“High-energy” noise is another example of how hot electrons can affect detected signal levels in x-ray radiographs. This refers to unwanted signal that penetrates to a detectors despite the filtering that is used. An example
of this is shown in Figure 1. Note the bright circular spot in roughly the center of the image. The filters for this experiment consisted of 550 µm of beryllium and 12.5 µm of titanium. This filtering was used to allow photons from the x-ray source between about 4 - 5 keV to reach the detector (near the Sc He-α line). Due to the filters that were used, the bright emission in the image is likely above 7 keV. The source of this signal is unknown, although we presume it is from very energetic photons or electrons able to scatter to the detector and/or penetrate the shielding.

**Experimental Methodology**

We propose to perform initial experiments on Janus using 2, 2ω beams to irradiate a foil target. We plan to use laser irradiances similar to those used previously for an x-ray backlighter, mid-10^{14} to 10^{15} W cm^{-2}. These irradiances should produce a distribution of electrons with energies in the tens of keV range. The laser will irradiate an area of about 0.03 mm² on a manganese foil. The Mn foil will be immediately surrounded by a iron foil and built on a structure of vanadium and titanium. A schematic of this target is shown in Figure 2. As mentioned previously, the laser will provide energy to the electrons in the Mn and some of them will generate x-ray radiation from atomic K-shell or L-shell transitions of Mn. Some of the electrons will also move to the surrounding foils (Fe, V, and Ti) via mechanisms described above and generate additional x-ray radiation at different energies.

We plan to use the crystal spectrometer MSPEC, which has an energy range centered around 6 keV (near the He-α line of Mn) and has been previously fielded at the Jupiter facility. Using MSPEC, one can measure the x-ray emission generated by each of these elements and estimate the relative amounts of energy deposited by the electrons in the various target components. We also plan to use an electron spectrometer fielded by Hui Chen of Lawrence Livermore National Laboratory to measure the distribution of electron energies. If time permits, we will also place a magnet on or near the
target to deflect the electrons in an effort to control their behavior and minimize their effect. Prior to the experiment, we plan to model the dynamics of the hot electrons using a particle-in-cell (PIC) code. These simulations will be performed by Alec Thomas of the University of Michigan.

We plan to vary the pulse length of the laser beams between 500 ps to 5 ns and measure the effect on the amount of signal generated from suprathermal electrons. Recent long-pulse backlighting experiments have shown evidence of high background noise on the detector that presumably was from hot electrons (cite private communication with Amy?). Initially, we plan to use 500 ps, 1 ns, 2.5 ns, and 5 ns pulse lengths at various energies so that the total laser irradiance is between mid-10^{14} to 10^{15} W cm^{-2} with a 200 µm laser spot. If time permits we will also use the 250 ps pulse length to begin exploring shorter pulses and perhaps explore pulse lengths longer than 5 ns. Also, as time permits, we would like to explore electron transport when generating an x-ray source with a 1ω laser beam. This frequency of laser light is not generally used in generating x-ray sources for backlighting. However, 1ω lasers can typically reach higher intensities, which may become necessary when using higher-Z elements as x-ray sources. Also, we expect the effects from electron transport to be larger with a 1ω laser because the effects of laser-plasma instabilities are greater for lasers with a wavelength of 1 µm or greater.

Figure 2: Schematic of the laser-irradiated target surface showing the laser spot on the Mn foil and various nearby, but not irradiated materials (not to scale).
As mentioned above, the proposed experiment will focus on laser irradiances in the mid-$10^{14}$ to $10^{15}$ W cm$^{-2}$ range using pulse lengths from 500 ps - 5 ns. However, we plan to study shorter pulse lengths and higher irradiances in the future, possibly on Titan, since laser irradiances of order $10^{20}$ W cm$^{-2}$ should produce a distribution of electrons with MeV energies. These types of laser irradiances will be necessary for higher-energy x-ray sources, which will be required to diagnose the larger and denser targets in experiments at the National Ignition Facility. However, the experiments proposed here will focus on longer laser pulses (500 ps - 5 ns) with relatively lower laser irradiances.

These experiments will be funded by the University of Michigan grant from the Defense Threat Reduction Agency. This support will include fabrication of targets for the proposed experiments and travel and lodging of the University of Michigan experimentalists during the proposed experiments. Also, University of Michigan faculty and students plan to travel to LLNL prior to the proposed experiments for discussions with collaborators and to observe the experiments of collaborators.

Stuff from online (this is part of the online form, but I wanted you to look at it)
 PI: Carolyn Kuranz
 Co-I: Paul Drake
 Co-I: Hu Chen
 Co-I: Bob Heeter
 Co-I: Kevin Fournier (probably)
 Co-I: Alec Thomas

**Primary LLNL contact:** Kevin? Hui?

**Expertise** (Please describe the fields of expertise represented by the proposal team, and the level of experience in using intermediate scale laser
Carolyn C. Kuranz is an Assistant Research Scientist at the University of Michigan. She was advanced to this faculty rank ahead of the normal schedule, in view of her 27 refereed publications, high-profile invited talks, and other accomplishments. She has more than 5 years of experience with target experiments using lasers and x-ray diagnostics.

R. Paul Drake is the Henry Smith Carhart Professor of Space Science at the University of Michigan, where he directs the Center for Radiative Shock Hydrodynamics. He has more than 25 years of research experience with target experiments using lasers, and has performed experiments at facilities ranging from small laboratory lasers to mid-scale facilities (Trident and LULI) to major facilities (Nova and Omega). He has published more than 150 refereed journal publications and has been a fellow of the American Physical Society since 1989. He published the first textbook on High Energy Density Physics in 2006.

Hui Chen is a scientist at Lawrence Livermore National Laboratory. She has been measuring electrons from laser plasma interactions for many years, and she has built various electron spectrometers that are used at the Jupiter Laser Facility, Vulcan, and OMEGA lasers.

Need to get stuff from other collaborators...

**Laser Config** (Number of beams, wavelengths, energies and pulse-lengths)

We plan to use the 2 Janus laser beams to irradiate a solid foil target. Initially, we will be using $2\omega$ light and vary the pulse-lengths between 500 ps, 1 ns, 2.5 ns and 5 ns at laser energies of 70 J/beam, 130 J/beam, 250 J/beam, and 425 J/beam respectively. If time permits we may also use a 250 ps pulse-length at 40 J/beam and possibly use pulse-lengths longer than 5 ns. Depending on our results we may attempt to repeat the experiment using $1\omega$ to investigate the difference in electron transport with a different frequency of laser light.
**Previous Access** (Mention previous experiments conducted at Jupiter by the group and, if any, relevant publications.)

Need to get something from collaborators for this part.

**Proposal Summary** (Target chamber, laser beam configuration, beam energies and durations, diagnostics. Be explicit about what you expect Jupiter to provide, and what you plan to provide.)

We propose for this experiment to be executed on the Janus laser. We plan on using 1 target per shot comprising of multiple foils. In some cases, the target will also have a small magnet attached to it in an effort to deflect electrons. University of Michigan will be fabricating all targets. In all cases, the target will be irradiated with 2 laser beams. We plan to vary the pulse-lengths from 500 ps to 5 ns and vary the laser energy to have irradiances of mid-10^{14} to 10^{15} W cm^{-2} with a 200 μm diameter laser spot. We will start with 2ω laser light, but repeat the experiment with 1ω laser light if time permits. We plan to use an electron spectrometer to measure the energy distribution of the electrons and an x-ray spectrometer to measure the x-ray emission from the target. The electron spectrometer will be fielded by Hui Chen and the x-ray spectrometer will be fielded by Bob Heeter.