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PRELIMINARY PERFORMANCE AND ICF TARGET EXPERIMENTS WITH NOVA

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PRELIMINARY PERFORMANCE AND ICF TARGET EXPERIMENTS WITH NOVA*

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In December, 1984, the Nova facility fired all ten laser arms, converted the output 1.05 micron energy to 0.35 micron light, and focused the 0.35 micron light through a 4 mm pinhole in the ten-beam target chamber. Since that time, we have added a two-beam target chamber, evaluated the performance of the laser, and prepared for target experiments. This paper summarizes the performance of Nova and describes our progress toward and plans for target experiments.

Nova Performance

The Nova Facility includes a ten-arm laser and five experimental stations. The facility can produce 40 to 100 kJ of laser energy in a 2.5 nsec pulse. It can do this at any of three wavelengths--1.05 microns, 0.53 microns, and 0.35 microns. The pulse width can be from 100 ps to 100 ns, and a variety of pulse shapes can be produced. In the target chambers, the beams can be focused to a 100 micron spot with f/4 optics, or to a line focus of 0 to 5 cm by using a pair of correcting lenses. The experimental stations include a ten-beam target chamber, a two-beam target chamber, and three laser physics stations.

In tests using one arm, Nova has produced 15 kJ of 1.05 micron light, and more than 7 kJ of 0.53 or 0.35 micron light, using flat, 2.5 ns output pulses. In ten-arm operation to date, Nova has produced more than 100 kJ of 1 micron light, more than 40 kJ of 0.53 micron light, and more than 20 kJ of 0.35 micron light. We infer from the one-arm tests that Nova can produce 40 to 100 kJ of 0.53 or 0.35 micron light, but we have not tried to do this for reasons discussed later. The laser arms on Nova have been fired extensively for various purposes. The most heavily used arms have fired more than 250 times at high power, and the least used arms have fired more than 60 times.

To produce temporally square output pulses from the laser chains, the input pulse must be shaped, as is illustrated in Fig. 1. To produce a flat output pulse at 15 kJ, the trailing edge of the input pulse must be 14 times more intense than the leading edge. In addition to measuring the input pulse, and the output pulse shape on each laser chain, we also measure the 1 micron energy at several locations, and the harmonically converted energy and pulse shape. Furthermore, we use a large Cassegrain telescope to measure the fluence of the laser beam at the plane of the target. This requires a dedicated shot, and Fig. 2 shows one image from such a shot. The image plane is 3 mm from best focus on the diverging side of best focus. Some structure is evident; much more structure is present on the converging side of focus.

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During the initial high-power operation of Nova, we discovered three problems. First, there are platinum inclusions in the laser glass that damage at a fluence of about 2 J/cm^2. In a typical glass disk on Nova, there are a few hundred of these inclusions. The glass companies we work with have produced improved disks with 10 inclusions, and are working toward one inclusion per disk. At that time, we will replace the glass in the output amplifiers of Nova and will be able to operate at full output energy without damage.

Second, the particular frequency conversion scheme used on Nova is sensitive to the polarization of the beam. Stress-induced birefringence in some optical components depolarizes the beam, and the polarization ellipse rotates further as the beam propagates through the air in the beam tubes. Figure 3 illustrates the consequences, showing the conversion of 1 micron light to 0.35 micron light with and without a whole-beam polarizer. The prototype whole-beam polarizer used for these tests caused part of the beam to be detuned in angle with respect to the KDP array. As the figure shows, the whole-beam performance corresponds to an average angular detuning of 200 μrad. As is also shown, more efficient conversion was obtained using a single 25 cm segment that could be accurately aligned. The solution to the polarization problem is either to add an improved whole-beam polarizer to each arm, or to adopt a less sensitive frequency conversion scheme.

Third, rotational Raman scattering is an issue for our two-beam chamber. The two beam chamber is 105 meters from the output spatial filter lens. (The ten-beam chamber 65 meters away.) Over the 105 m distance and at energies above 3 kJ per beam for pulse lengths of a few hundred psec, rotational stimulated Raman scattering can grow large enough to spoil the beam quality and frequency conversion. The solution, which has been tested, is to evacuate the beam tubes between the laser and the two-beam target chamber.

As a result of these problems, we have limited the energy output of Nova to 5 kJ per arm of 1-micron light for routine operation. This allows us to proceed with the many useful experiments that can be done at reduced energy. Once we have implemented solutions as indicated above, we will be able to operate Nova routinely at full energy.

Progress Toward Target Experiments

During the past year, we have worked to make Nova ready for sophisticated, high quality experiments. By February, 1985, we were able to fire all ten arms, at 0.53 microns, at a gold disk target, and produce a pentagonal pattern on each side of the target. More laser alignment hardware was needed for accurate pointing and focusing, particularly of 0.35 micron light. This hardware was installed in April, 1985, and has since been activated.

From April through June we fired 27 target shots for diagnostic shakedown. During this period, we began to activate the scattered light photodiodes and the soft x-ray spectrometer, and activated the hard x-ray spectrometer and the 8X x-ray microscopes. The microscopes characterize the size and shape of the heated plasma by imaging the 0.5 to 5 keV x-rays it emits. Figure 4 shows results of a Nova target shot used to measure the resolution of one of the x-ray microscopes. A thin gold foil was irradiated, and the x-rays transmitted through the foil backlit a resolution grid. The image was recorded on film, digitized, and reconstructed to produce the figure. During July, we concentrated on completing the activation of the laser diagnostics, and as a result we fired no target shots.

We returned to target diagnostic shakedown in August and September, firing 23 target shots to complete the activation of the scattered light photodiodes, continue activating the soft x-ray spectrometers, and begin to activate the optical spectroscopy, optical pyrometry, and optical fiducial systems. This allowed us to obtain the first x-ray conversion measurements with more than 1 kJ of 0.35-micron light on target during October. Figure 5 shows the spectrum of the soft x-rays emitted by the hot, overdense, target material. On this shot, a gold target was irradiated with about 1.5 kJ of 0.35 micron light at an intensity of about 10^{15} W/cm^2. About 40% of the light energy was converted to x-rays, consistent with previous results at this intensity. The conversion efficiency improves at lower intensity. In late October we irradiated and diagnosed the first 10-arm hohlraum targets.

We have also begun to make our first measurements of Raman scattering from large plasmas produced with 0.35-micron light. By exploding very thin foils, we produce large plasmas that are relevant to the plasmas in future high-gain targets. In October and November, we produced such plasmas and observed Raman scattering of the laser light as expected, showing that we are ready to begin systematic experiments of this type.

In addition to the above work on the ten-beam chamber, the two-beam target chamber has also begun to produce data. The construction of this target area began less than one year ago. Two 0.53-micron beams irradiated a target with a line focus in July, and during September the first x-ray laser target was irradiated and diagnosed. Further diagnostic installation and checkout is proceeding and will lead to systematic experiments this fall.

Plans for Nova ICF Experiments

The goal of the ICF Program is to achieve high-gain ICF. Nova experiments can determine some of the requirements for high-gain ICF. However, Nova does not produce enough laser energy to achieve high gain. The steps necessary to produce high gain are as follows:

First, one must get the laser energy to the fuel capsule. The absorption of the laser light by the target should be large, and for indirect drive soft x-ray production should be efficient. In addition, the production of very hot electrons must be small, because such electrons penetrate the fuel capsule, heat the fuel, and make the fuel hard to compress. Nova can do experiments to understand absorption, soft x-ray production, and hot electron production. These experiments will be designed to explore one or two specific physical mechanisms, and to allow us to draw conclusions for future ICF systems. The Raman scattering experiments and the x-ray conversion experiments are examples. The results of these experiments will place limits on the design and performance of a high-gain system.

Second, one must implode the fuel capsule and compress the fuel to high density. In particular, the target design must produce a symmetric implosion and the fluid instabilities must not grow fast enough to prevent the compression. Nova experiments will address these issues. Some experiments will measure the growth of fluid instabilities, and especially the Rayleigh-Taylor instability, under appropriate conditions. We hope to observe ablative stabilization of this instability on Nova, which would be good news for future ICF systems. Other experiments will test our ability to produce symmetric implosions, which requires a complex, integrated target design. A more severe test of our target design capability will be experiments intended to compress the fuel to 1000 times the density of liquid DT.

Third and finally, once the fuel is compressed a fusion burn must ignite and propagate, consuming a significant fraction of the DT fuel. Nova does not have enough energy to produce a fusion burn, so laboratory experiments to study them will have to wait for an ICF facility that can deliver much more energy to the target.

In summary, the Nova ICF experiments will develop a predictive understanding of certain key physical processes, and an integrated capability to model target performance. The physical processes involve the transfer of laser energy to the capsule and the growth of fluid instabilities as the capsule implodes. We will test our integrated models with symmetry experiments and implosion experiments intended to compress the fuel to high densities. This sequence of experiments will take several years. The first Nova experiments, using the basic diagnostics, will characterize the performance of Nova and the target, and make possible the design of later, more complex experiments.

Conclusion

You have seen our progress and plans for target experiments using the Nova facility. We have begun simple irradiations using up to ten arms at 0.35 microns, and have diagnosed them with our basic target diagnostics. We are building and installing additional hardware to allow us to carry out more complex irradiations, such as short-pulse backlighting, and more detailed measurements,such as streaked x-ray spectroscopy. The resulting facility will allow us to study important physical processes, such as the Rayleigh-Taylor instability, under conditions relevant to high-gain targets, and will allow us to develop our integrated target design capability in preparation for high-gain experiments.

Acknowledgment

The effort to bring Nova into full operation involves hundreds of participants in experiments and diagnostics, laser systems, and target fabrication, and target design. A large fraction of these people contributed, one way or another, to the Nova results and plans presented above. My thanks to them all.

Figure Captions

1. The intensity of the input and output pulses is shown as a function of time. The pulses are measured using optical streak cameras.

2. A Cassegrain telescope obtains images of the high power beam in the target plane. The data was recorded on film, digitized, and reconstructed to produce the enhanced image shown here.

3. With the present harmonic conversion scheme on Nova, the output beam must be well-polarized to convert efficiently. The conversion efficiency is shown as a function of one-micron intensity at the harmonic converter. See text for discussion.

4. An x-ray microscope image, obtained during a resolution test of a Kirkpatrick-Baez x-ray microscope with 8X magnification.

5. The soft x-ray spectrum from a gold target, discussed in the text.

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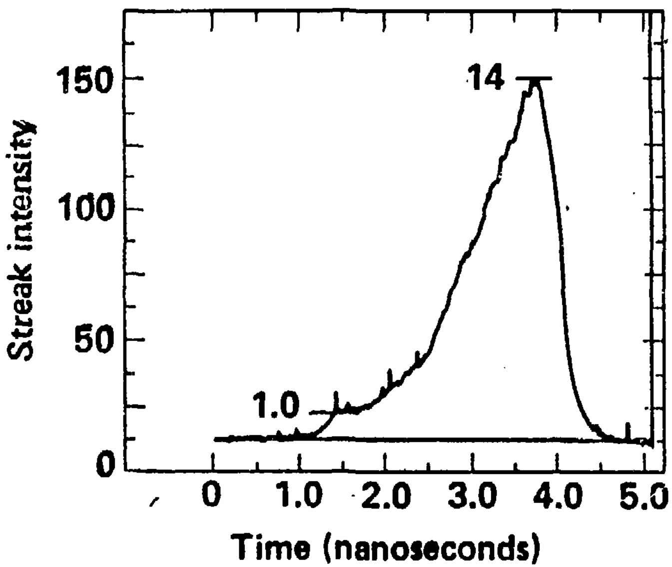
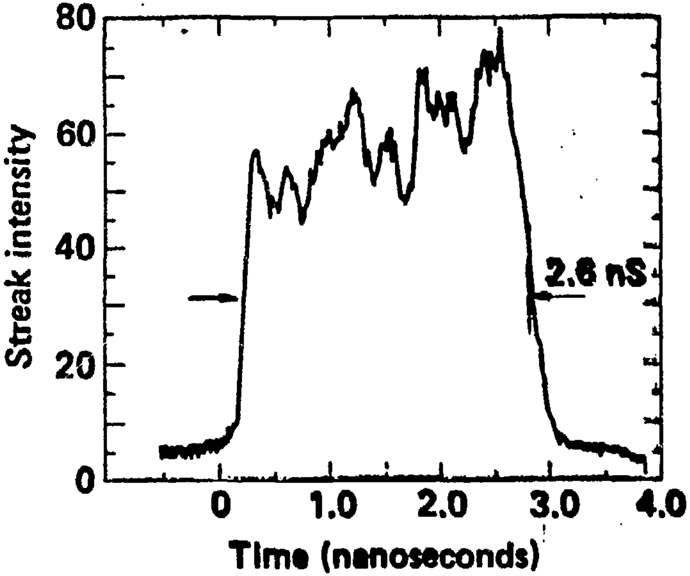
NOVA pulse shaping

Shot 15020604
Beam 10 output energy 15.0 KJ
Input pulse shaped to compensate for saturation to produce a square output pulse

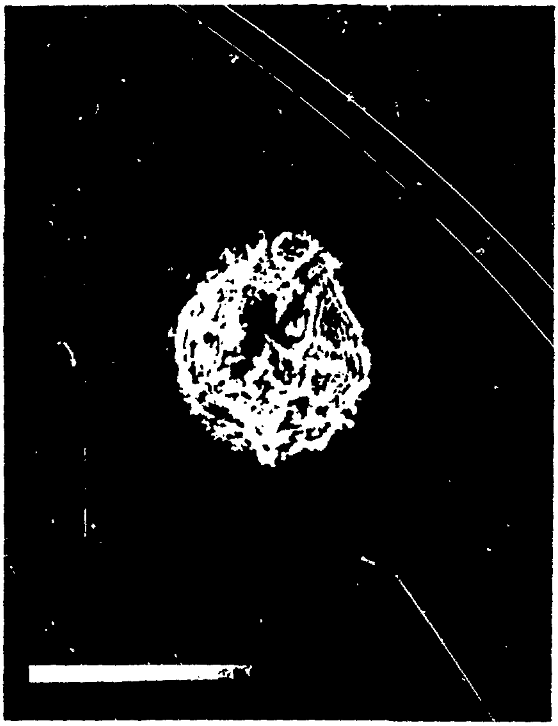
Input pulse



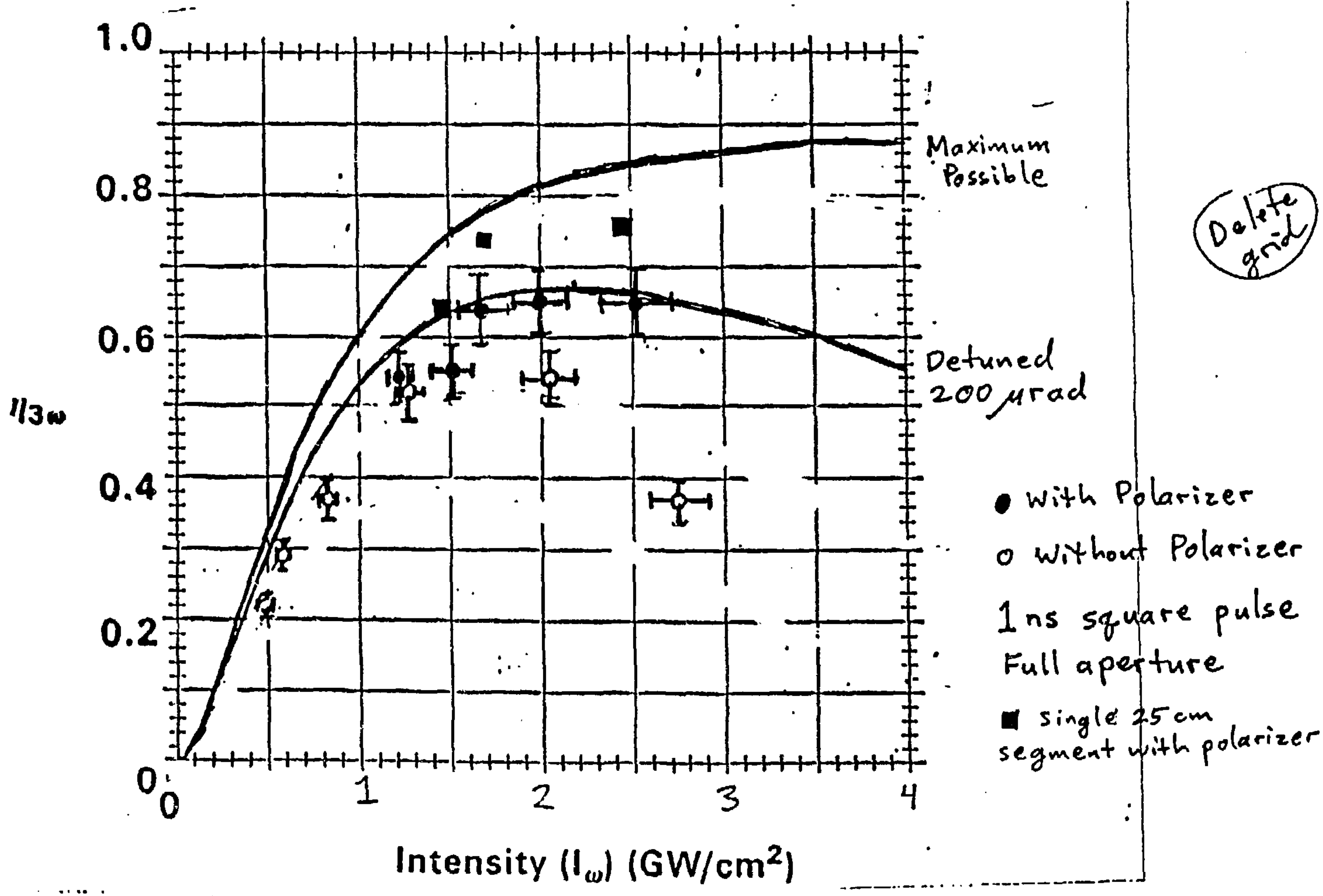
Output pulse



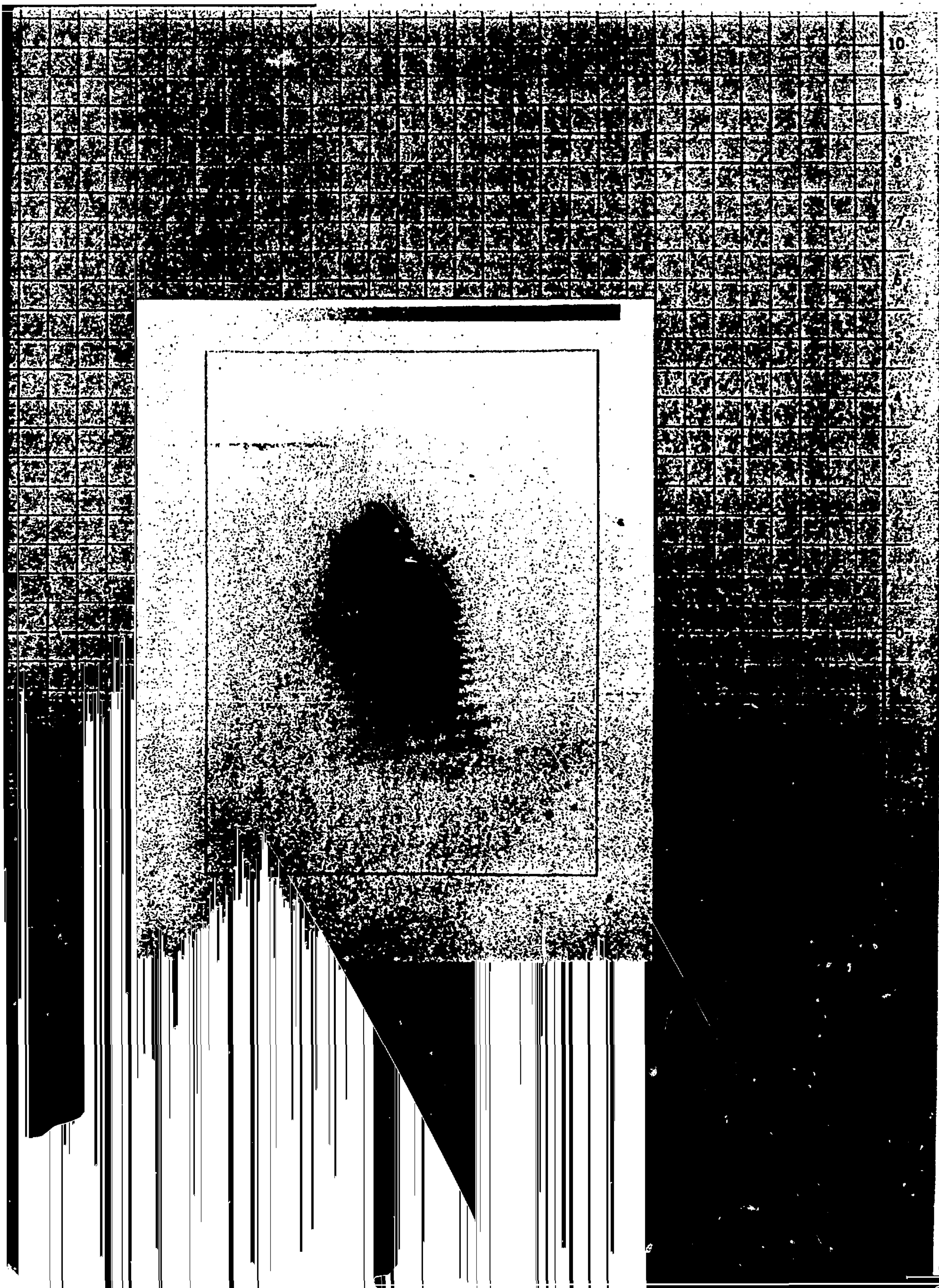
40-00-0285-0540



Effect of polarization mismatch on frequency conversion efficiency



Delete grid


10
9
8
7
6
5
4
3
2
1
0

Soft x-ray spectrum from a gold disk target