Experimental Investigation of Far Fields on OMEGA

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Abstract

On OMEGA distributed phase plates (DPP's) are placed before the focusing lens and produce far-field spots with highly reproducible spatial intensity envelopes and speckle distributions. A variety of DPP's are available on OMEGA to achieve the desired on-target laser irradiation conditions. Far field intensity distributions of a single beam on OMEGA were measured with the ultraviolet equivalent target plane diagnostic (UVETP). The measured profiles were fitted with a super-Gaussian function: $I(r)=I_o\exp[-(r/\delta)^n]$, where $I(r)$ is intensity, I_o is peak intensity, r is the radius, δ is the 1/e half width, and n is the super-Gaussian order. Image analysis software was developed to fit the azimuthally averaged measured profiles and the 2-D profiles. A survey of the far fields that can be achieved on OMEGA will be presented. The effects of 2-D smoothing by spectral dispersion (2-D SSD) and polarization smoothing on the far field envelope intensity will also be reported.

Introduction

In direct-drive inertial confinement fusion, nonuniformities in target irradiation seed the Rayleigh-Taylor hydrodynamic instability, which degrades target performance. A combination of beam smoothing techniques is therefore implemented on OMEGA in order to reduce these nonuniformities. These techniques include 2-D smoothing by spectral dispersion (2-D SSD), polarization smoothing (PS), and distributed phase plates (DPP's) [1, 2]. This report focuses mainly on the measured single beam far field intensity profiles produced with a DPP and a constant intensity laser pulse, such as the 1 ns square laser pulse shown in Fig. 1a. Far field images captured with the ultraviolet equivalent target plane diagnostic were characterized. With one exception all of the measurements were taken with 1-THz, 2-D SSD and PS. The measured profiles were fitted with a super-Gaussian function: $I(r)=I_o\exp[-(r/\delta)^n]$, where $I(r)$ is intensity, I_o is peak intensity, r is the radius, δ is the 1/e half width, and n is the super-Gaussian order. Image analysis software was developed to fit the azimuthally averaged measured profiles and the 2-D profiles. A survey of the far fields that can be achieved on OMEGA is presented.

The following sections discuss (1) the DPP's used on OMEGA to control the far field intensity distribution, (2) the ultraviolet equivalent target plane (UVETP) diagnostic that was used to measure the far field intensity distributions, (3) the fitting procedures used to characterize the envelope of the far field intensity distributions with a super-Gaussian function, and (4) the effects of 2-D SSD and PS on the far field intensity envelope.

DPP's on OMEGA

On OMEGA DPP's are placed in the near field before the OMEGA focusing lens. DPP's are used to control the intensity distribution in the far field. Fig. 1b shows the arrangement of the DPP and the OMEGA focusing lens used to produce the far field. The OMEGA lens has a clear aperture of 30 cm and a 180 cm focal length. A wide variety of DPP's are available for use in target physics experiments on OMEGA. The single beam intensity is adjusted by changing the size of the far field laser spot. Profiles can range from a very high intensity, tight focus spot, used in laser plasma interaction experiments, to a broad spot with a comparatively low, but relatively constant intensity, used for planar hydrodynamic experiments. Far field intensity profiles used on 60-beam direct-drive implosions fall in between these two extremes. Examples of a tight focus far field and a far field with a large area of constant intensity are displayed with the same spatial scale in Fig. 1c and Fig. 1d, respectively. Fig. 2 shows the range of profiles that can be obtained on OMEGA with a DPP. The calculated super-Gaussian 'n' range for profiles under these conditions is from 2 to 5, with 'δ' ranging from 80 μm to 450 μm. The highest single beam intensity available on OMEGA with a DPP assuming a 500 J, 1 ns square pulse is ~ 2×10^{15} Watts/cm². Direct drive inertial confinement fusion requires minimal beam-to-beam variations of the far field intensity profiles. Fig. 2b shows the measured azimuthally averaged far field intensity profiles for 9 different SG4 DPP's. Nearly identical far fields are produced on OMEGA with SG4 DPP's for 60-beam direct-drive implosions, providing nearly uniform irradiation of a spherical target.

Elliptical DPP's can produce round far field spots for non-normal incidence beams on planar targets. The UVETP diagnostic can only measure a far field spot at normal incidence, so the far field images measured with an elliptical DPP installed are elliptical in shape. However on target, at non-normal incidence, the spot is round. Image analysis software has been developed to project the beam as it is on-target. Fig. 3a shows the image measured with the UVETP diagnostic, while Fig. 3b shows the projected image for a 48° angle of incidence.

UVETP Diagnostic

Fig. 4 shows a schematic of the UVETP diagnostic used to capture the far field images. As the beam travels toward the target a full-aperture optical wedge sends 4% of the laser light through an OMEGA lens. A DPP is placed in the near field, thus duplicating the on-target conditions. The beam is then brought to focus in a vacuum vessel, down collimated, and brought to focus before passing through a final lens and a series of filters producing a magnified image on the CCD camera. The CCD camera is a 1024 x 1024 array of pixels. Each pixel has an area of 24μm x 24μm.

Super-Gaussian Fitting

The azimuthal average of the measured intensity profile is modeled with a super-Gaussian function. The azimuthal average is calculated by dividing the beam into concentric rings that are centered on the beam. Starting in the center of a measured far field image and moving outward in concentric rings, the average intensity of each of these rings is calculated. The super-Gaussian function is: $I(r)=I_o\exp[-(r/\delta)^n]$ where I_o is peak intensity, r is radius, δ is the 1/e half width, and n is super-Gaussian order. Software that has been developed performs a least squares fit to generate a model super-Gaussian curve. Fig. 5a shows an example of an azimuthal average fit for a SG3 DPP with 1THz SSD and PS. The model is fitted to the azimuthal average down to 10% of the peak intensity in Fig. 5a. The program allows the user to select this percentage (10%, 5%, or 1%). The model accurately fits the profile down to approximately 5% of the peak intensity at which point the two curves begin to diverge. Similarly a 2-D fit can also be performed to model the far field with a super-Gaussian function. Fig. 5b shows contour intensity rings of the far field and the model, representing from the inside to the outside, 90%, 50%, 10%, 5%, and 1% of peak intensity. Once again the model is fitted to the far field down to 10% of peak intensity, with little variation between the rings until you get out to the 5% and 1% rings. Below the 10% of peak intensity the super-Gaussian model does not fit the intensity envelope very well.

2-D SSD and PS

2-D smoothing by spectral dispersion (SSD) and polarization smoothing (PS) are implemented to reduce laser-beam nonuniformities. 2-D SSD reduces nonuniformities as a function of time while PS produces an instantaneous result. Fig. 6 shows the azimuthal average profile for SG4 DPP(249) without any smoothing and the profile with 1THz, 2-D SSD and PS. Without any smoothing, the n(1-D) value is 5.6, the n(2-D) is 5.08, δ(1-D) is 344μm, δ(2-D) is 345μm. With 1THz, 2-D SSD and PS, the n(1-D) value is 4.40, n(2-D) is 4.12, δ(1-D) is 353μm, δ(2-D) is 352μm. 2-D SSD and PS broaden the laser spot. Broadening the laser spot has the effect of decreasing n and increasing δ.

Conclusion

Far field intensity distributions measured on OMEGA with DPP's were characterized. DPP's used on OMEGA produce highly reproducible spatial intensity envelopes and speckle distribution. The ultraviolet equivalent target plane diagnostic (UVETP) was used to capture far field images of a single beam on OMEGA. A variety of DPP's are available for experimental use on OMEGA. Image analysis software was developed to fit measured profiles with a super-Gaussian function, $I(r)=I_0\exp[-(r/\delta)^n]$.

The single beam intensity profiles measured in this investigation had n range from 2 to 5 and δ range from 80μm to 450μm. The highest single beam intensity produced on OMEGA with a DPP assuming a 500 J, 1 ns square laser pulse was ~2 x 10^{15} Watts/cm^2. The beam smoothing techniques of 2-D smoothing by spectral dispersion and polarization smoothing have the effect of broadening the laser spot in the far field.

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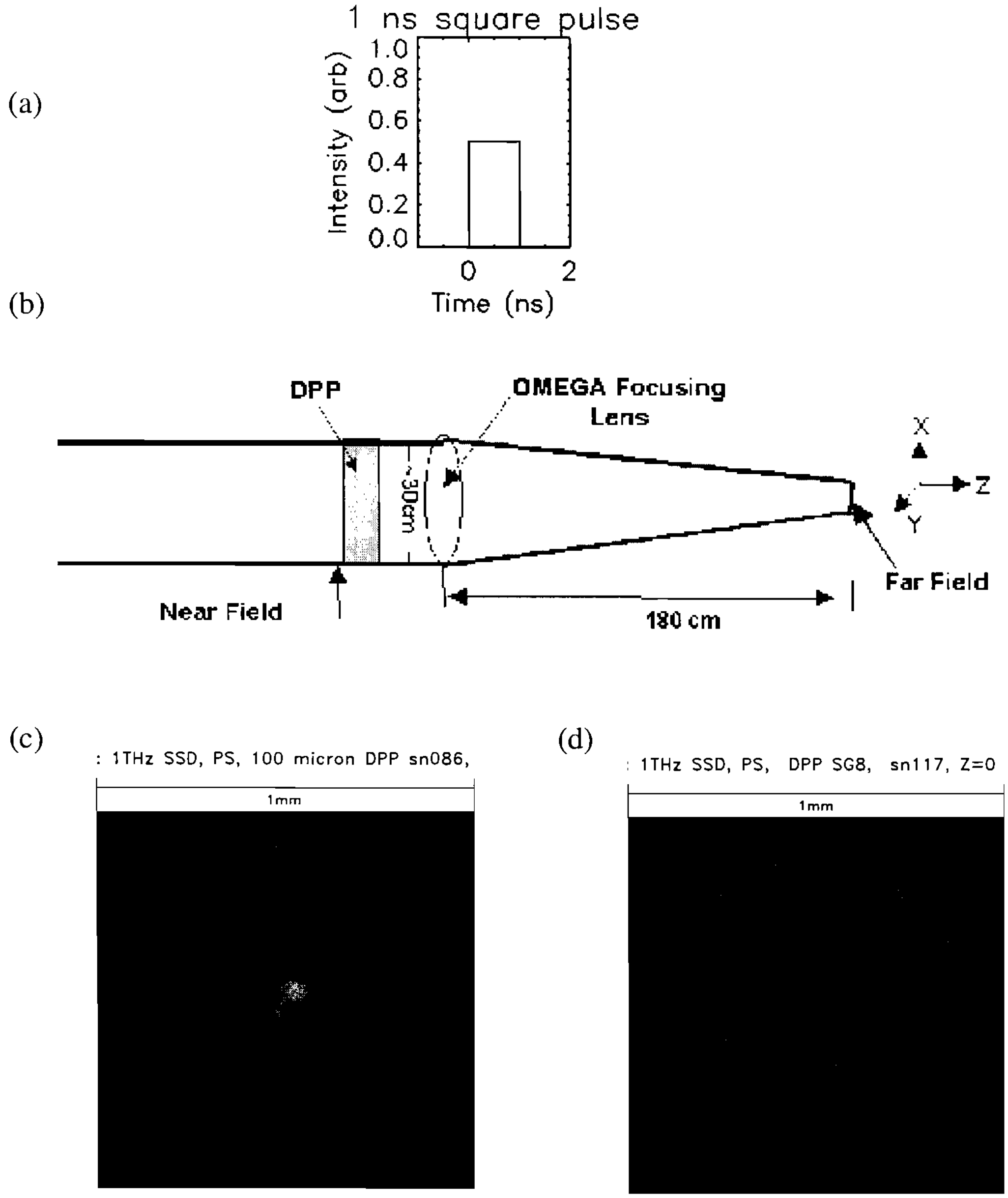
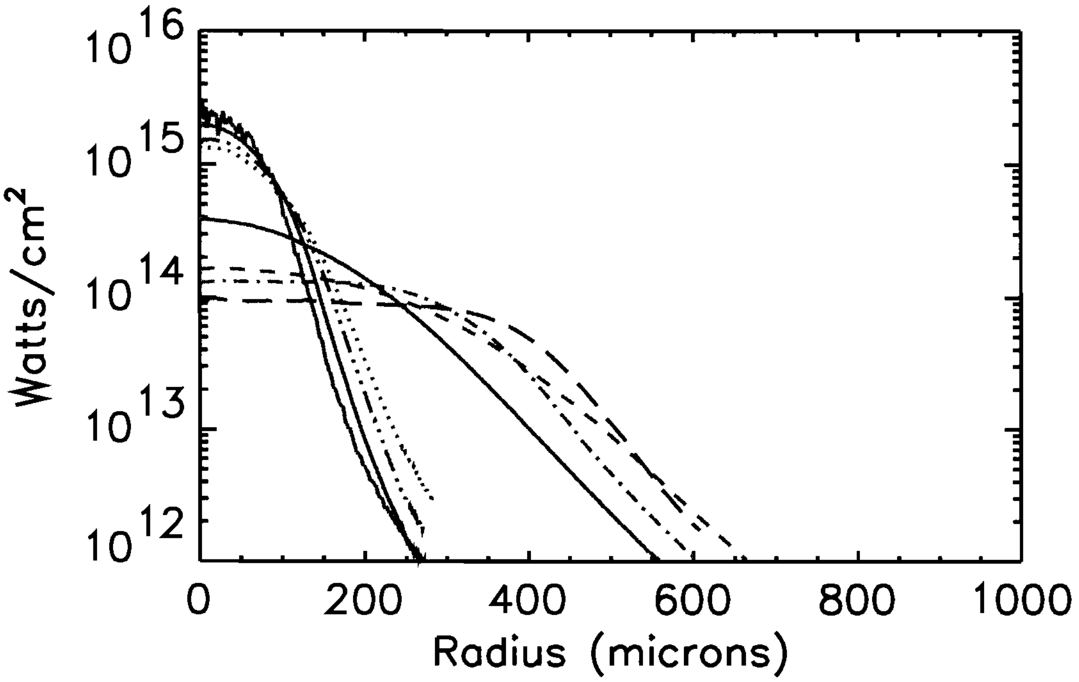


Fig. 1. (a) An intensity versus time graph for a 1 ns square laser pulse. (b) The arrangement of the DPP and the OMEGA focusing lens used to produce the far field intensity distribution. (c) Measured far field images produced with a tight focus DPP in (c) and with an SG8 DPP in (d). Changing the spot size of the far field varies the intensity on target.

(a)



(b)

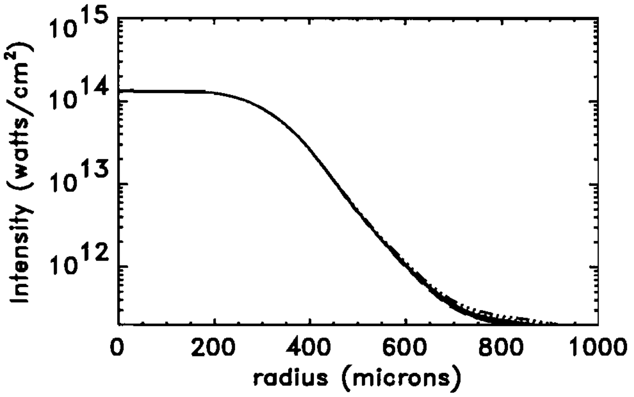


Fig. 2. The azimuthally averaged single beam intensity profiles measured on OMEGA with the variety of available DPP's. Intensity calculations assume irradiation with a 500 J, 1 ns square laser pulse. (b) The measured azimuthal averages for 9 nearly identical SG4 DPP's.

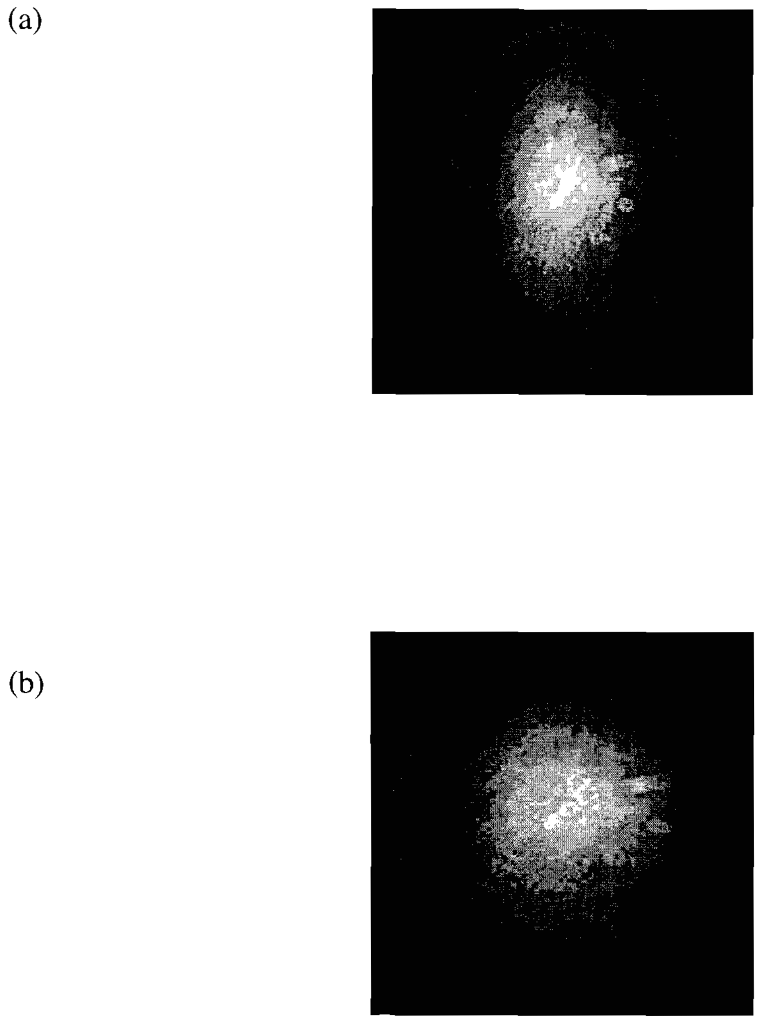


Fig. 3. (a) The measured far field spot produced with an elliptical DPP and measured at normal incidence. (b) The projected far field spot on target with a 48 degree angle of incidence.

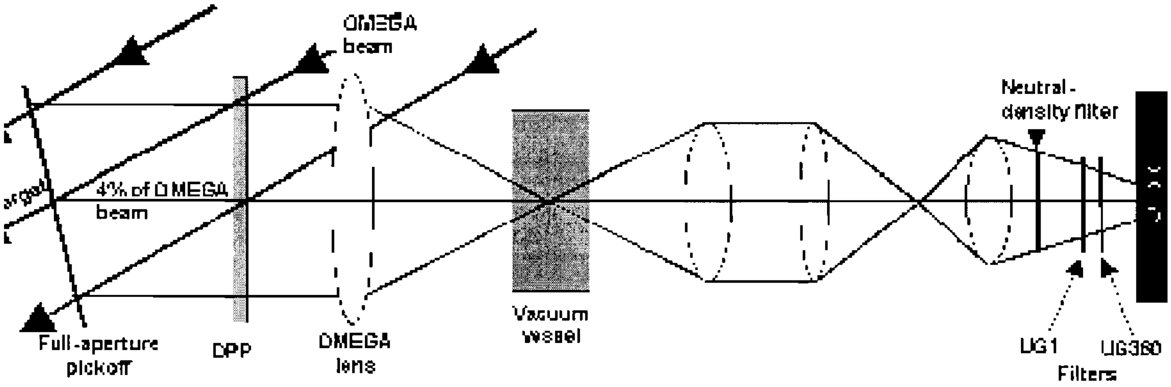


Fig. 4. A schematic of the OMEGA ultraviolet equivalent target plane (UVETP) diagnostic. An uncoated wedge positioned in one of the 60 OMEGA beams directs 4% of the laser light to a DPP and an OMEGA lens. A magnified far field image is recorded on a CCD camera.

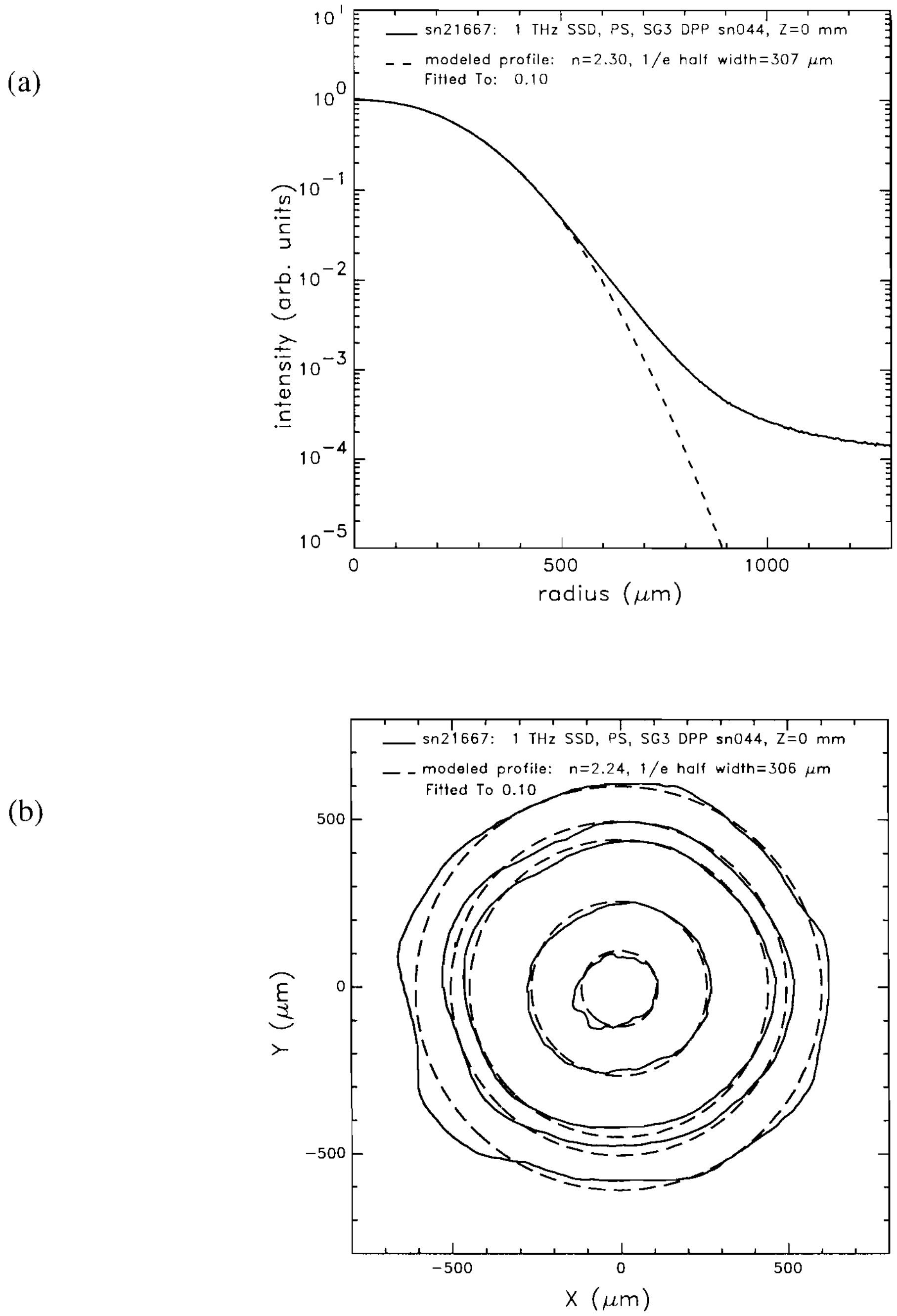


Fig. 5. (a) An example of a 1-D fit for sn21667, a SG3 DPP(044), with 1THz SSD and PS. The calculated n value is 2.30, δ is 307μm. (b) An example of a 2-D fit also for sn21667. The fitted n value is 2.24 and δ is 306μm.

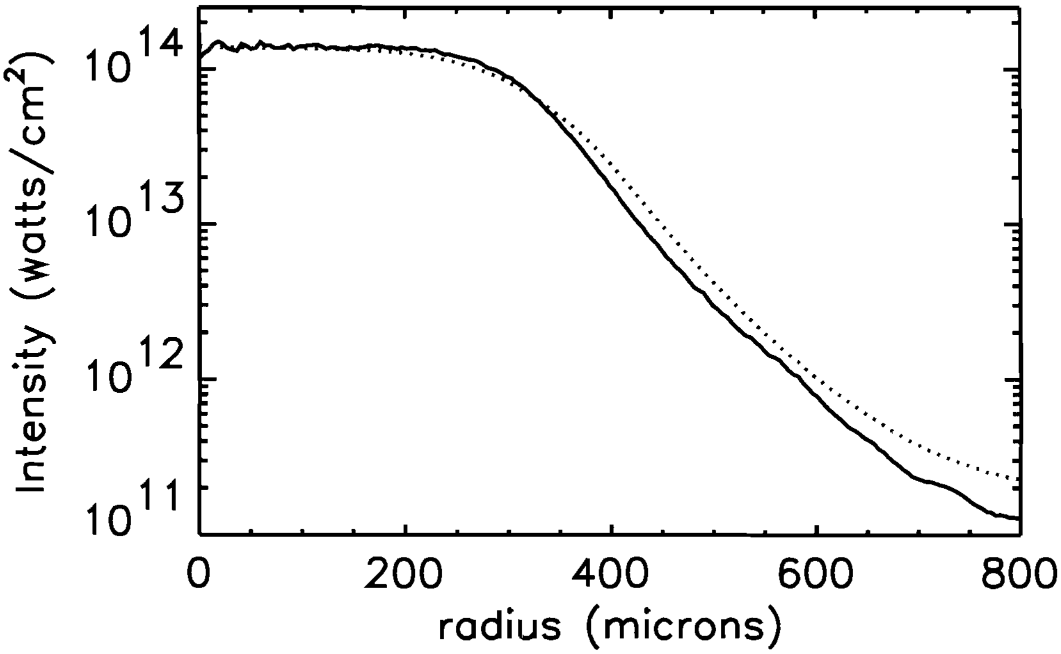


Fig. 6. The measured azimuthally averaged intensity profiles for SG4 DPP(249) on two different shots. The dark solid line is a shot without any smoothing, the n(1-D) value is 5.6, the n(2-D) is 5.08, δ(1-D) is 344μm, δ(2-D) is 345μm. The light dashed shows a shot with 1THz SSD and PS(in), the n(1-D) value is 4.40, n(2-D) is 4.12, δ(1-D) is 353μm, δ(2-D) is 352μm.