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ARGUS Disk-Target Experiments  
at 1.06  $\mu\text{m}$ , 0.53  $\mu\text{m}$ , and 0.35  $\mu\text{m}$

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Abstract

We report on ARGUS wavelength scaling experiments on disk targets at 1.06  $\mu\text{m}$ , 0.53  $\mu\text{m}$ , and 0.35  $\mu\text{m}$ . Measurements were made of absorption, stimulated Brillouin and Raman scattering, and 3/2 harmonic light.

\*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract #W-7405-ENG-48.

Wavelength scaling measurements, using the Argus laser system to irradiate disk targets with 700-900 psec pulses at 1.06  $\mu\text{m}$ , 0.53  $\mu\text{m}$ , and 0.35  $\mu\text{m}$ , have recently been completed. Scattered light diagnostics provided information about the various processes taking place in the underdense plasma. These diagnostics included absorption measurements, and temporally and spectrally resolved measurements near; (1) the laser wavelength for stimulated Brillouin scattering (SBS); (2) wavelengths of 1.2 to 2.2 times the laser wavelength for stimulated Raman scattering (SRS); (3) and near the second and three-halves laser harmonics. All the measurements were not obtained at all 3 laser wavelengths. In particular, the low levels of instability generation at 0.35  $\mu\text{m}$  limited observations at that wavelength.

Electromagnetic radiation at the 3/2 harmonic of the laser frequency is indicative of plasma waves at the quarter critical density of the laser light. The harmonic may be generated by coalescence of three plasmons, or by the non-linear combining of a plasmon and an incident wavelength photon. The spectral features suggest that the plasma waves are generated by the two plasmon decay instability<sup>1</sup>.

Experimentally, at an angle of 30° to the laser beam, we observe two peaks (in 1.06  $\mu\text{m}$  experiments), one red shifted, the other blue shifted, as shown in Figures 1 and 2. The usual<sup>2</sup> explanation for this is that we are observing a directly backscattered ( $\theta > \pi/2$ ) red shifted wave, and a forward scattered ( $\theta < \pi/2$ ) blue shifted wave which has reflected off of its critical surface (at  $9/4 n_c$ ). Evidence in support of this hypothesis includes the following observations. The blue shifted light is reduced in amplitude compared to the red, presumably due to

absorption. In 0.53  $\mu\text{m}$  experiments, the blue shifted light is not observed, which is consistent with the higher collisionality of the plasma. This is shown in Figure 3. In burn through experiments on thin plastic foils, in which 3/2 harmonic light is observed in the forward direction, it is the red-shifted peak which is reduced or completely absent, as shown in Figure 4. Similar observations have been reported by others<sup>3</sup>. Other evidence, however, points out the limitations of this one dimensional model. Three halves spectral measurements, looking for 90° scattered light, should, according to equations (1) and (2) (discussed below), show only one peak. However, measurements (see Figure 5) show two well separated peaks. At this time, we do not have an adequate explanation for this observation. In addition, Doppler shifts, refraction, Brillouin scattering, 3-dimensional effects, the finite f-number of the focusing lens, etc. are neglected. Because of these limitations and assumptions, it is difficult to determine the validity of the temperatures derived from this data.

Avrov<sup>2</sup>, et.al., use a model where the plasmon wavenumber is that which gives the highest  $2\omega_{pe}$  growth rate<sup>1</sup>, but does not necessarily allow for phase matching with an incident photon. This model gives

$$\Delta\lambda = -22.7 T_e \cos \theta \quad (\text{\AA}) \quad (1)$$

for the wavelength shift away from the exact 3/2 harmonic, where  $T_e$  is the electron temperature in keV, and  $\theta$  the angle of the scattered light with respect to the incident laser light. The higher order (but momentum

conserving) process of 3 plasmon coalescence is calculated to give (within 5%) the same results.

Barr<sup>4</sup> gives the wavelength shift from the exact 3/2 harmonic, for a 1.06  $\mu\text{m}$  laser, as

$$\Delta\lambda = -33.9 T_e [\cos \theta - 0.919] \text{ (A)} \quad (2)$$

This equation may be derived by demanding phase matching (momentum conservation) between an incident photon and a  $2\omega_{pe}$  generated phasmon, adding together to form  $3/2 \omega$  photon. We note that the forward scattered plasmon must have a wavenumber which is small compared to the wavenumber which is expected near threshold<sup>1</sup>.

Figure 6 shows the temperature inferred from equation (1) for Be, Ti, and Au disks irradiated at a nominal intensity of  $1 \times 10^{15} \text{ W/cm}^2$ . Use of equation (2) would give one-third lower temperatures. The red peak-blue peak separation was used, rather than the absolute value of either peak, since this value is less sensitive to Doppler effect shifts. No attempt has been made to remove Doppler shift effects from the data; this requires knowledge of the velocities at both  $n_c/4$  and  $9n_c/4$ . Since we expect the lower density to have a higher velocity, Doppler effects should cause us to underestimate the temperature. In fact, the  $90^\circ$  measurements, which are less sensitive to Doppler shifts, show a wider splitting (higher temperature) than the corresponding  $30^\circ$  measurements.

Temporally and spectrally resolved measurements for stimulated Raman scattering (SRS) were obtained from 0.53  $\mu\text{m}$  laser wavelength

experiments. We did not observe significant levels of SRS during experiments at  $0.35\text{ }\mu\text{m}$ . This is not unexpected, given the low intensities ( $\leq 10^{15}\text{ W/cm}^2$ ) and modest scale lengths of these particular experiments.

Figure 7 shows the focusing scheme used in the  $0.53\text{ }\mu\text{m}$  experiments. Figure 8 shows the time integrated Raman spectrum from a gold disk target irradiated by 29 Joules of green light. The laser spot was highly structured, with some regions receiving intensities of well over  $10^{16}\text{ W/cm}^2$ . The spectrum shows the signature of the convective Raman instability; i.e., scattered light at wavelengths shorter than  $2\lambda_0$ . There is a weaker, additional scattered light signal seen at  $2\lambda_0$  ( $1.064\text{ }\mu\text{m}$ ). This double peaked structure does not resemble the spectrum expected for SRS, rather, it appears similar to the 3/2 harmonic spectra (Figures 1 and 2). It may result from the re-conversion of two plasmon decay plasma waves, or from the beating of these plasma waves with the incident light.

Figures 9(a) and (b) show the time resolved Raman backscatter (i.e., back through the  $f/2$  focusing lens) spectra for a gold disk irradiated with green light at an intensity of  $\sim 5 \times 10^{15}\text{ W/cm}^2$ . The laser was focussed approximately  $150\text{ }\mu\text{m}$  in front of the target; thus the disk was irradiated by a diverging laser beam. Within the dynamic range of the streak camera (the S-1 photocathode is an order of magnitude more sensitive at  $800\text{nm}$  than at  $1064\text{nm}$ ) only the convective instability is observed. This light is generated in the very underdense regions of the plasma:  $0.05 \leq n/n_c \leq 0.16$ , for  $T_e \sim 3\text{keV}$  and backscatter. The time scale is correlated with the incident pulse, with zero being the peak of the incident pulse ( $\sim 100\text{psec}$ ). We observe no SRS until near the

peak of the incident laser pulse; the scattering then continues until the end of the laser pulse. The delay in SRS onset may be due to the finite length of time necessary for the plasma density scale length near  $0.1n_c$  to evolve to large enough values to allow the SRS to grow, due to being below threshold until near the time of the peak intensity. In this case, the observation that SRS continues for 500-800 psec, while the laser pulse intensity falls an order of magnitude, may be indicative of filamentation. It should be noted that the plasma expands toward the region of best focus in this experiment; this means that the plasma continues to interact with a high intensity laser beam as it expands. Due to the poor beam quality, geometric optics calculations yield poor estimates of the intensity in this region; it increases only modestly at best focus, as seen in Figure 7.

We have observed a rapid (< 50 psec) pulsation of the scattered light signal. This may be a signature of wave breaking, followed by re-growth of the plasma waves. Analysis of this aspect of the data has just begun.

Figure 9(c) shows the time integrated spectrum near  $\omega_0/2$  for this gold disk experiment. The same double peaked spectrum as shown in Figure 8 is observed. We do not, as yet, have an explanation for this spectra.

Figure 10(a) and (b) show the time resolved SRS measurements from a Be disk irradiated at normal incidence. The spectrum and temporal behavior is qualitatively similar to the gold target results.

Figure 10(c) shows the time integrated spectra near  $\omega_0/2$  for a (different) Be disk, one oriented 30° from the laser beam (target normal) in the direction of the light collector). Light near  $\omega_0/2$  is

difficult to observe when the target normal is not oriented toward the light collector. This is an expected result, since refraction will cause this light to be strongly collimated. (It originates very near its own critical surface, so refractive effects are strong.)

To summarize, scattered light measurements are useful laser plasma interaction diagnostics. In wavelength scaling experiments, they show the effects of increasing collisional absorption at shorter laser wavelengths. SRS and 3/2 harmonic measurements show the presence of plasma waves at  $n_c/4$  and lower densities; time resolved scattered light measurements give us dynamic information regarding plasma conditions and instability formation.

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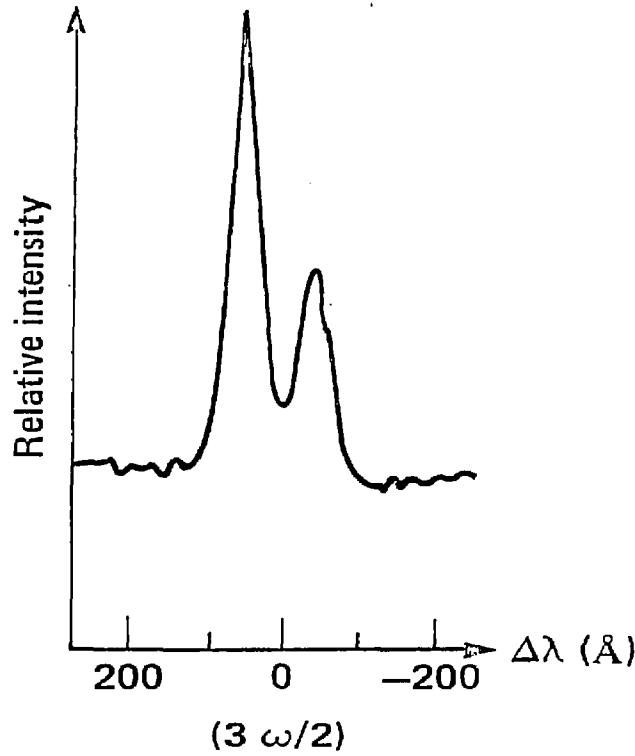
1. C.S. Liu, M. N. Rosenbluth, Phys. Fluids 19, 967 (1976).
2. A. I. Avrov, et. al., Sov. Phys. JETP 45, 507 (1977).
3. P. D. Carter, S. M. L. Sim, E. R. Wooding, Optics Comm. 32, 443 (1980).
4. H. C. Barr, Rutherford Lab. Annual Report, Sec. 8.3.3 (1979).

Figure Captions

1. 3/2 harmonic spectra from gold disk 1.06  $\mu\text{m}$  laser.
2. 3/2 harmonic spectra from Be disk, 1.06  $\mu\text{m}$  laser.
3. 3/2 harmonic spectra from Be disk, 0.53  $\mu\text{m}$  laser.
4. Forward scattered 3/2 harmonic, 1.06  $\mu\text{m}$  laser.
5. 3/2 harmonic emission at 90°, 1.06  $\mu\text{m}$  laser.
6. Temperatures inferred from Equation (1) for 1.06  $\mu\text{m}$  experiments at  $1 \times 10^{15} \text{ W/cm}^2$ . Doppler effects not deconvolved.
7. Focusing scheme used in 0.53  $\mu\text{m}$  experiments.
8. Raman light spectrum for gold disk target, 0.53  $\mu\text{m}$  experiment.
9. SRS spectra from gold disk target, 0.53  $\mu\text{m}$  experiment (a) false color contour plot of streak record. Signal at lower right is 1.06  $\mu\text{m}$  timing fiducial; t=0 corresponds to the peak of the laser pulse; (b) spectrally integrated time history and time integrated spectrum from (a) (sharp cut-off at 0.7  $\mu\text{m}$  is instrumental limit). (c) time integrated spectrum near  $\omega_0/2$ . Sharp peak at 1.064  $\mu\text{m}$  is due to residual unconverted laser light.

10. SRS spectra from Be disk target, 0.53  $\mu\text{m}$  experiment. (a) false color contour plot of streak record; (b) spectrally integrated time history, and temporally integrated spectrum; (c) time integrated spectrum near  $\omega_0/2$  for a different Be target (see text).

# TIME INTEGRATED $3/2 \omega$ SPECTRUM



1.06  $\mu\text{m}$  Experiment

$I = 1 \times 10^{15} \text{ W/cm}^2$  Au disk target  
Red peak shifted  $\approx 40 \text{ \AA}$   
Blue peak shifted  $\approx 50 \text{ \AA}$

20-90-1081-3199

FIG 101

# TIME INTEGRATED $3/2\omega$ SPECTRUM



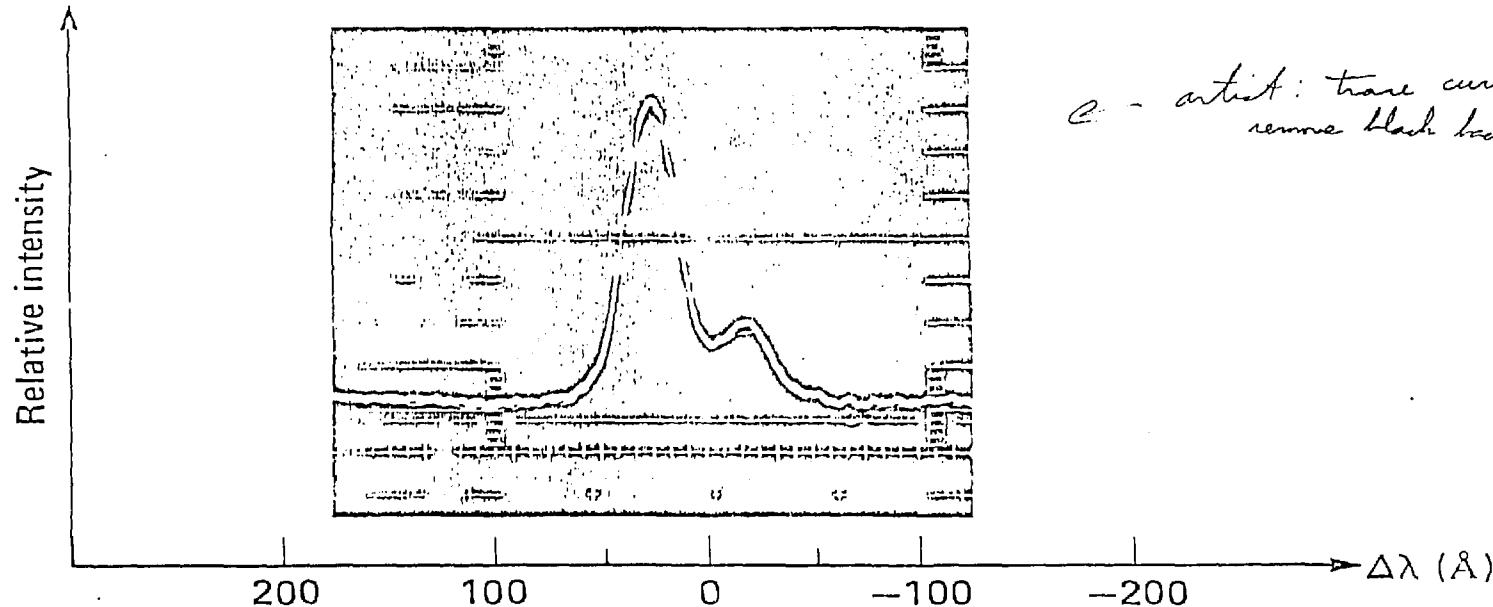
$I = 3 \times 10^{14} \text{ W/cm}^2$  Be disk target

$1.06 \mu\text{m}$  Experiment

Red peak shifted  $\approx 30 \text{ \AA}$

$\zeta_{\text{add}}$

Blue peak shifted  $\approx 20 \text{ \AA}$



$\zeta$  - artist: trace curve  
remove black background

20-90-0581-1340

$(3/2\omega)$

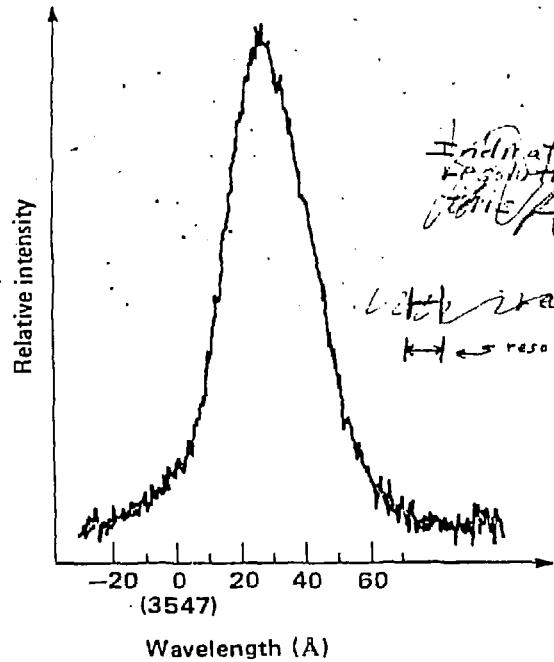
FIG 2

### ~~3/2 HARMONIC SPECTRUM~~

0.53  $\mu\text{m}$  Light At  $6 \times 10^{15} \text{ W/cm}^2$

Be Disk Target

~~more integrated~~



Be Disk Target



20-90-1081-3201

Only a red shifted peak is observed in green light experiments

Fig 12 3

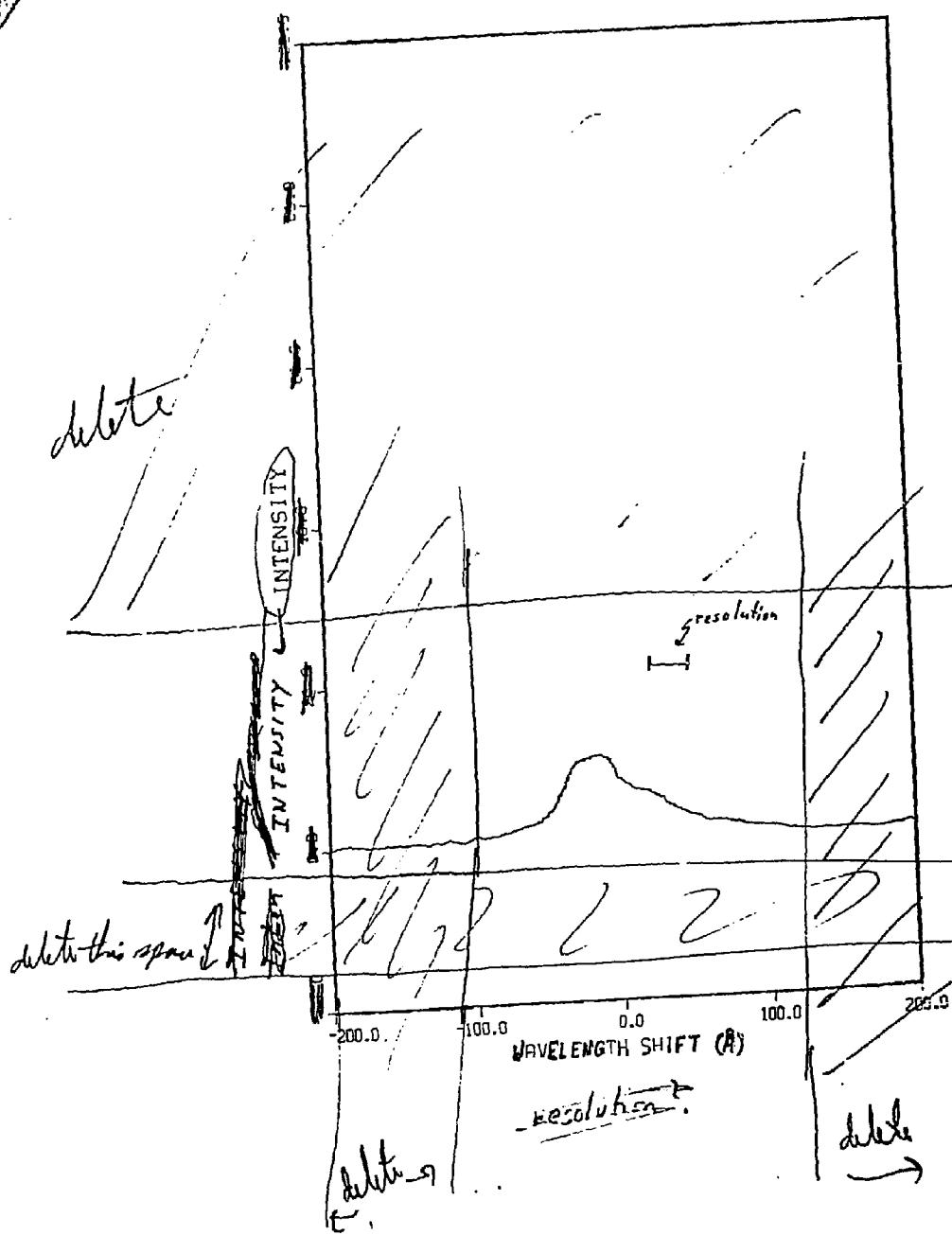


Fig 4

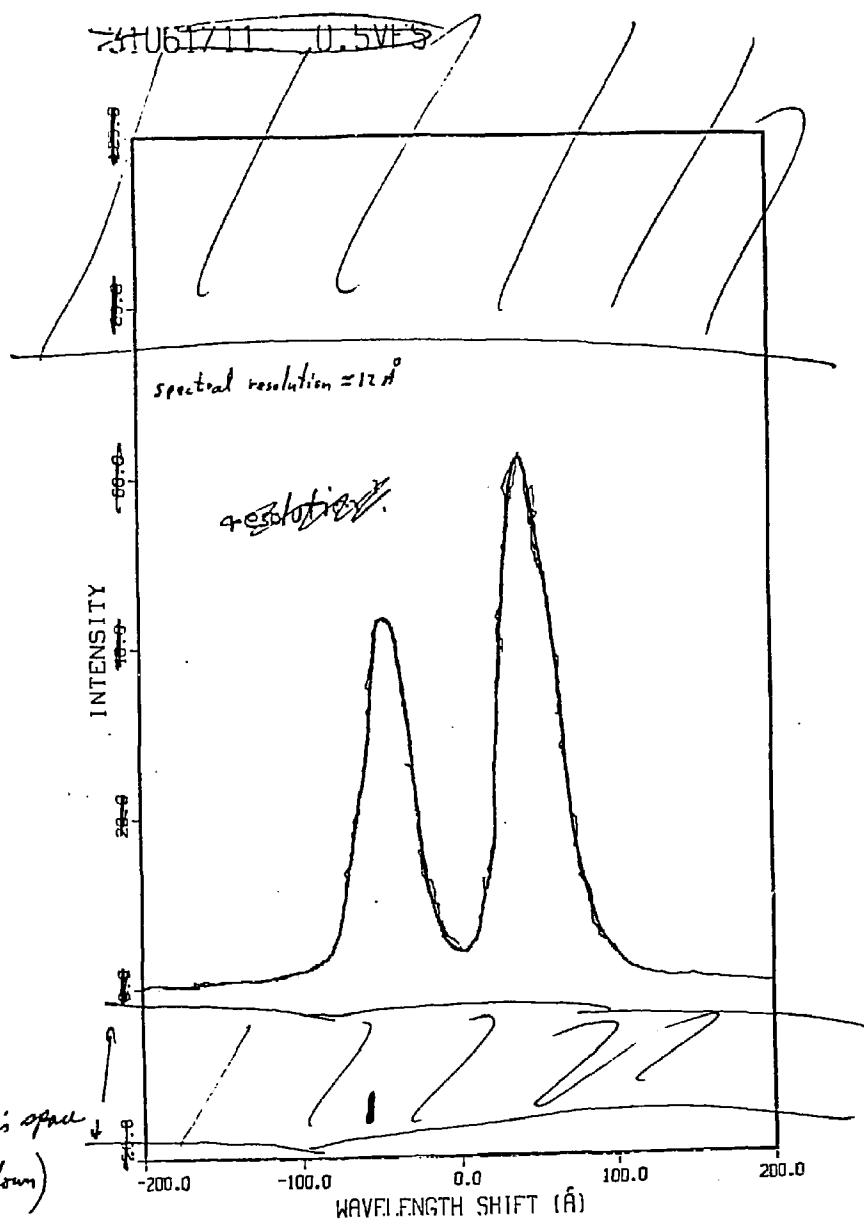
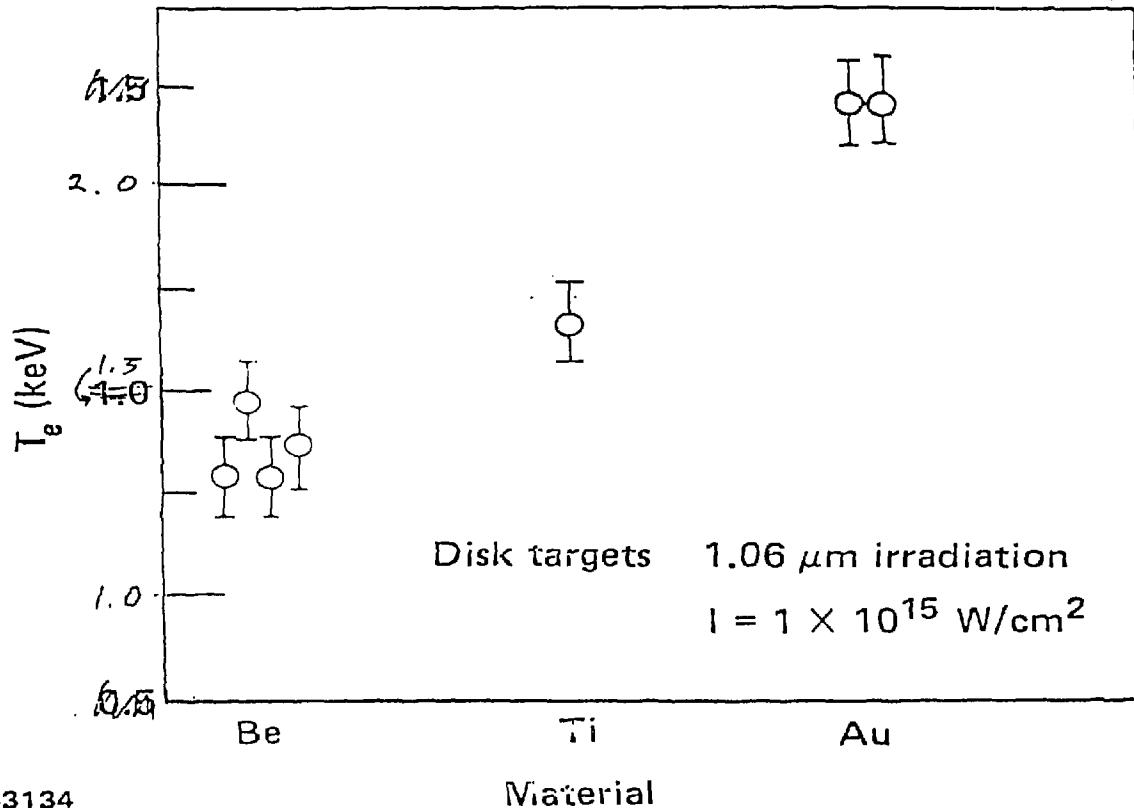


Fig. 45

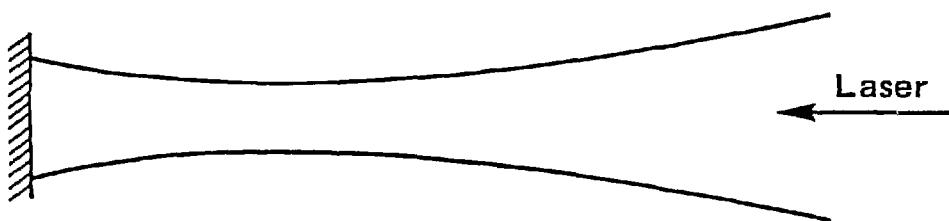
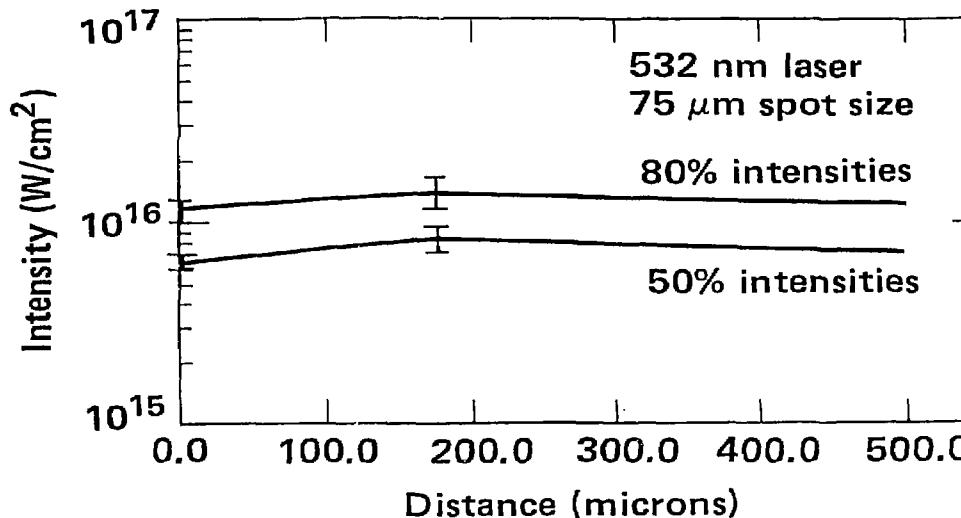
ELECTRON TEMPERATURES AT  $n_c/4$  INFERRED FROM  
3/2 HARMONIC SPECTRAL SPLITTINGS



20-90-1081-3134

FIG 1 FIG 6

## LASER INTENSITIES AT VARYING DISTANCES FROM THE TARGET

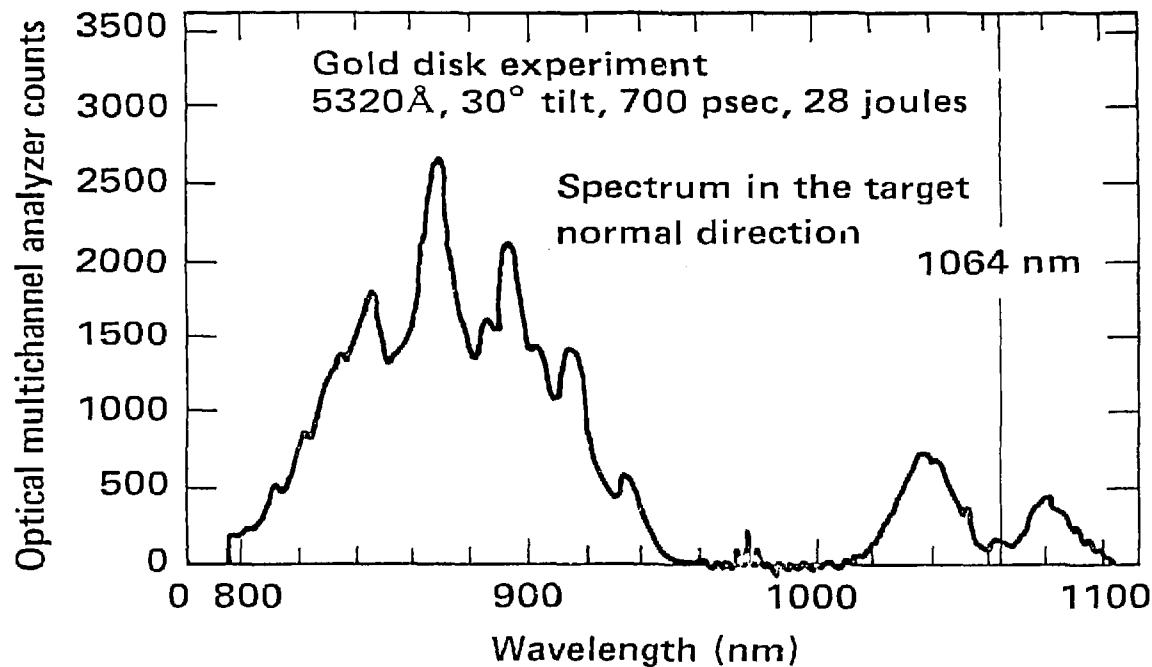


20-01-0182-0053

Fig 7

RAMAN LIGHT SPECTRUM FOR A DISK TARGET  
IRRADIATED WITH 5320 Å LIGHT

5

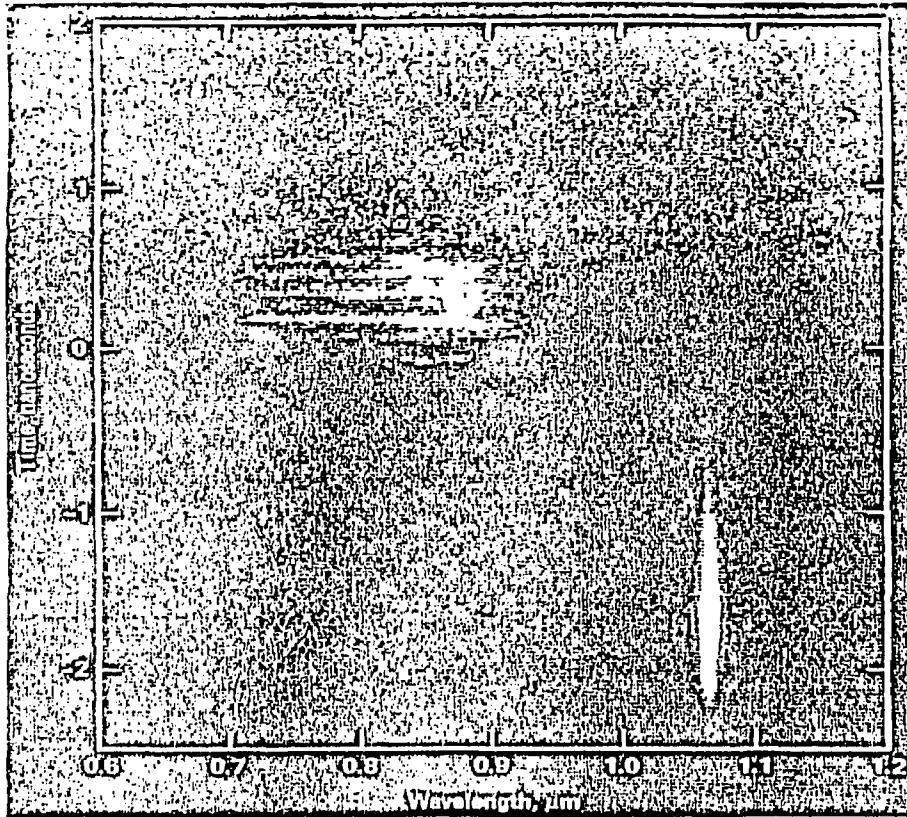


20-90-1081-3129

FIG 8

TIME-RESOLVED RAMAN-LIGHT SPECTRUM FOR A GOLD DISK IRRADIATED  
BY 5320 \ LASER LIGHT AT  $5 \times 10^{15}$  W/cm<sup>2</sup>, 132 JOULES, 700 PSEC

5

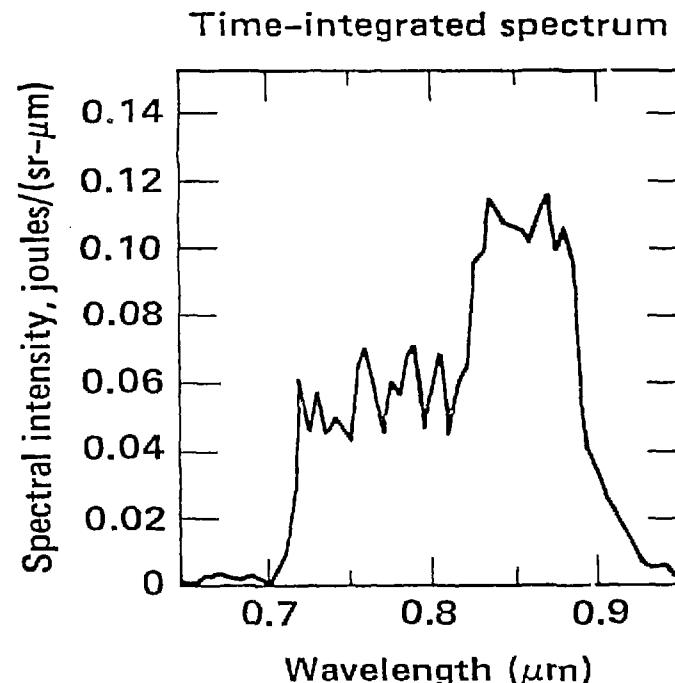
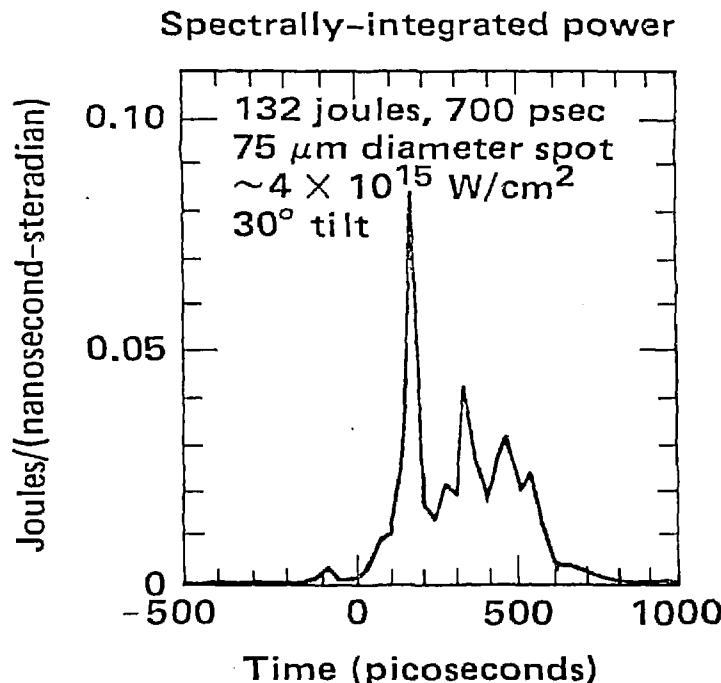


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FIG 9(a)

TIME-RESOLVED RAMAN LIGHT SPECTRUM FOR A GOLD  
DISK IRRADIATED WITH 5320 Å LIGHT

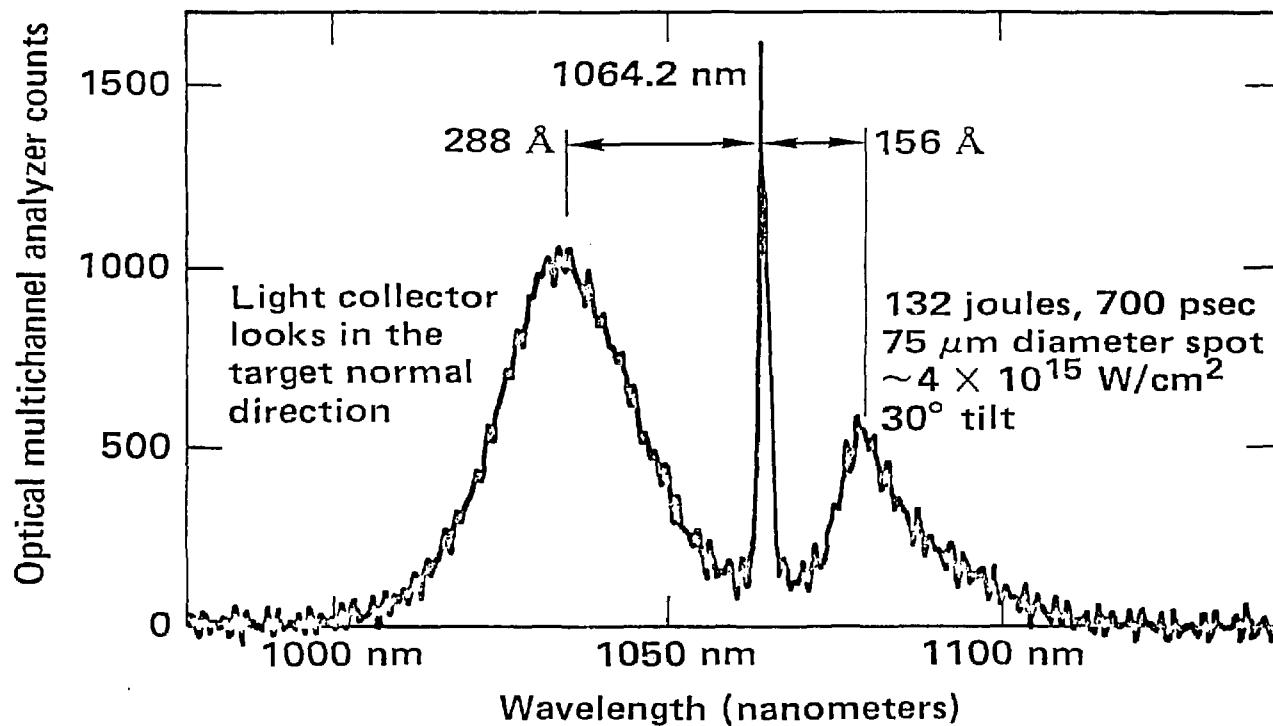
50



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FIG 9(b)

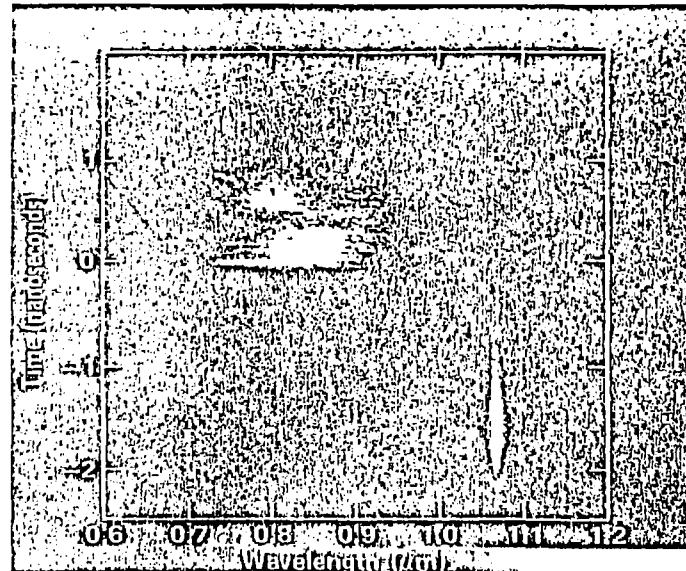
SPECTRUM OF THE  $\omega_0/2$  LIGHT FOR 5320 Å IRRADIATION OF  
A GOLD DISK



20-90-1081-3177

FIG 9(c)

TIME RESOLVED SPECTRUM FOR THE RAMAN LIGHT FOR  
5320Å LASER IRRADIATION AT  $5 \times 10^{15}$  W/cm<sup>2</sup>, 132 JOULES,  
700 psec

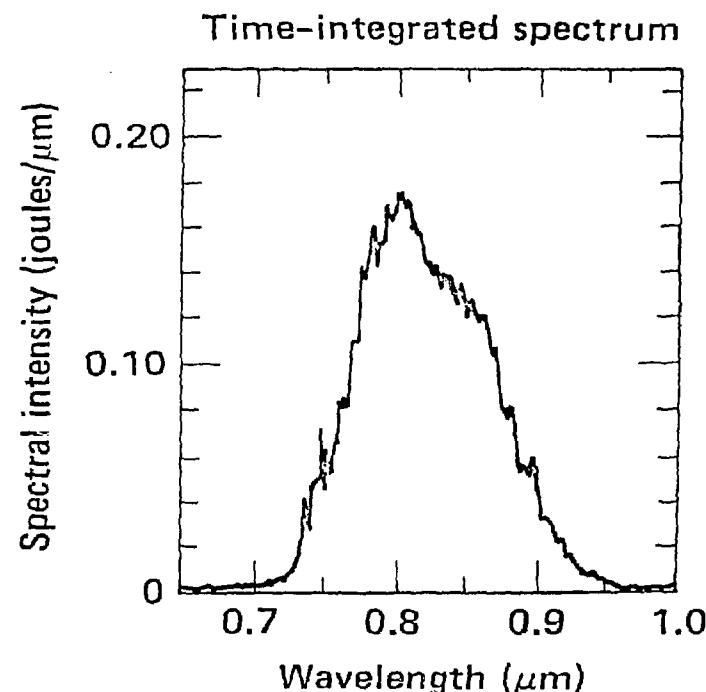
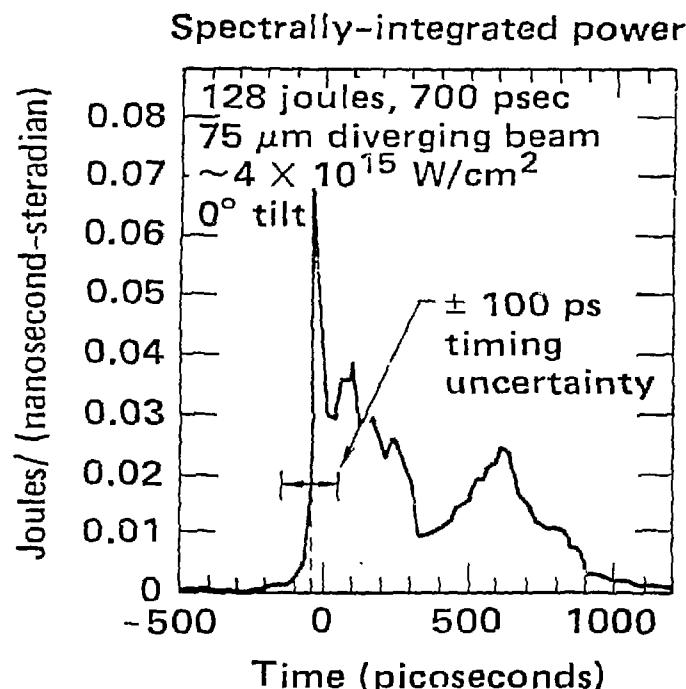


20-90-1081-3205

FIG 10(a)

TIME-RESOLVED RAMAN LIGHT SPECTRUM FOR A BERYLLIUM  
DISK IRRADIATED WITH 5320Å LIGHT

LE

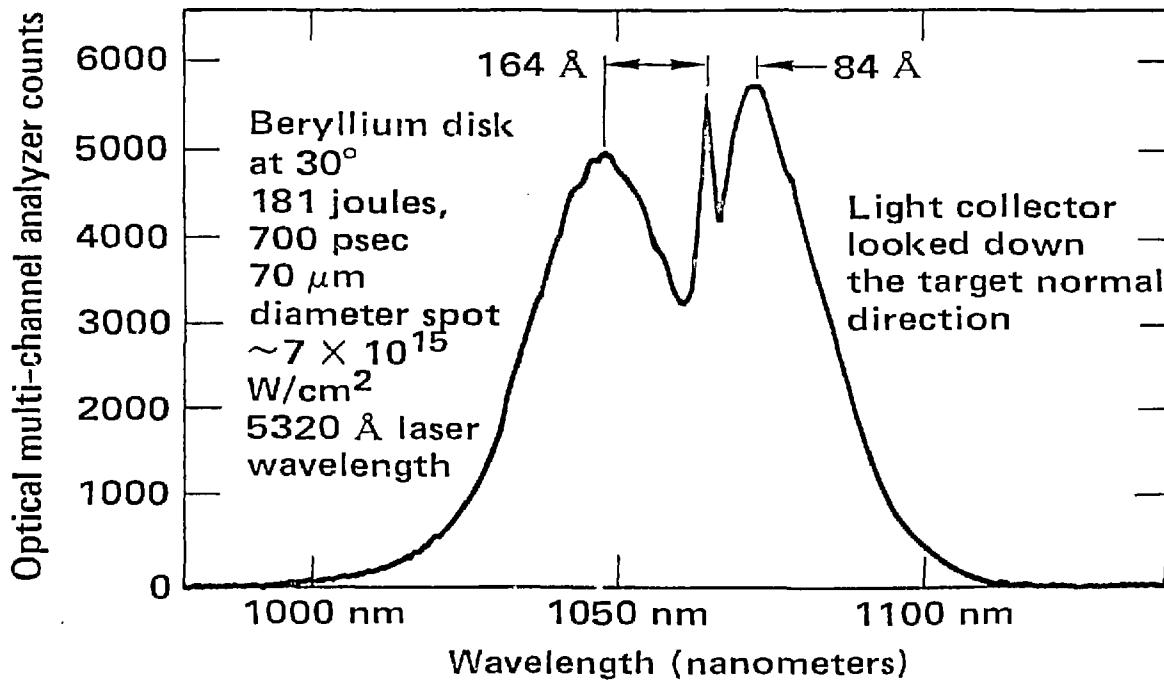


20-90-1081-3163

FIG 10(b)

SPLITTING OF THE  $\omega_0/2$  LIGHT SPECTRUM IS MUCH LESS FOR  
A BERYLLIUM DISK THAN FOR A GOLD DISK FOR THE SAME  
IRRADIATION CONDITIONS

16



20-90-1081-3182

FIG 10(c)