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Summary of Stimulated Raman Scattering Experiments in the Nova Air-Path and Projected Nova and Nova II System Performance Limits

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December 12, 1985
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TO: J. T. Hunt

FROM: M. A. Henesian, C. D. Swift and J. R. Murray

SUBJECT: **Summary of Stimulated Raman Scattering Experiments in the Nova Air-Path and Projected Nova and Nova II System Performance Limits**

Introduction:

We present below the results of high intensity beam propagation experiments conducted with the Nova laser system to investigate the occurrence of stimulated rotational Raman scattering (SRRS) from atmospheric nitrogen in the beam path.[1] Enclosed is a preprint entitled "Stimulated Rotational Raman Scattering in Nitrogen in Long Air Paths" that we have published in the November issue of Optics Letters. The physics issues associated with SRRS are discussed at length in the preprint. The small signal steady-state SRRS gain coefficient that we determined from threshold measurements is in excellent agreement with recent direct SRRS gain measurements by Bischel, et.al., at SRI,[2] and is in good agreement with early gain estimates from Averbakh, et.al., in the Soviet Union.[3] Consequently, we have a high degree of confidence in our gain coefficient. In addition, threshold SRRS experiments on the long air-path Nova II system are in substantial agreement with the earlier Nova experiments. Nova and Nova II system performance limitations were not critically addressed in our publication so we shall discuss those issues here.

Summary of Experiments:

To observe SRRS on Nova, a 20 cm diameter section of the 74 cm beam was directed into the Nova switchyard and laser bay over distances ranging from 20 to 150 meters. Most experiments were conducted with a 1 ns square laser pulse shape, with an average beam intensity from 1 to

2.5 GW/cm^2. The layout for the beamline 10 experiments is shown in Fig. 1. Distances of 65, 85, and 150 meters from the output of Nova were examined here. Beamline 8 was used for initial experiment at distances of 20, 105, and 130 meters, and for laser shots with 2.5 ns square pulses. After air path propagation, a 2.5 cm central portion of the 20 cm beam was viewed with a 1-meter grating spectrograph, and the resulting exposures in Tri-X film were compared with Neon reference spectra for wavelength verification, and were selectively digitized and processed to determine the extent of stimulated light scattering.
Table 1 is the shot log for the SRRS experiments on Nova beamlines 8 and 10. For each shot number is listed the full 74 cm beam energy, the pulse duration, path length, the estimated average intensity - path length product in units of TW/cm, and our observations. In calculating the path average I*L product we assumed an effective Nova beam area of 3500 cm^2 and took account of the mirror transmission losses for the 30 cm mirrors located in the switchyard and laser bay. Two sections of the Nova beam were sampled as shown in Fig. 2. The central 20 cm section located a few cm away from the 46 cm disk-split image was of near uniform intensity, as observed from beam photos. The upper 20 cm section was located near the edge of the 74 cm Nova beam, and contained noticeable diffraction fringes from the disk-split obscuration. Densitometry of a beam photo (shot 030607 in Table 1) taken in the switchyard at a distance of ∿20 m from the beamline 10 output showed typically a peak to average intensity modulation of 1.33 to 1 (away from damage shots). Figure 11 is a typical beam photo for this edge portion of the Nova beam (shot 030605).

The Raman scattering process in atmospheric nitrogen generates frequency components in the 1053 nm Nova beam (at 1059.6, 1061.4, and 1063.2 nm) that correspond to the S(6), S(8), and S(10) first Stokes rotatonal transitions with frequency shifts at 59, 75, and 91 cm^{-1}, respectively. Figure 3 is a high resolution spontaneous Raman light scattering spectrum of pure nitrogen at 1 atm pressure. Potential first Stokes frequency shifts can range from 12 to 170 cm^{-1}. At beam intensities greater than 15 ∿ 25% above the threshold for first Stokes scattering, higher-order (second and third Stokes) components can be generated by successive scattering, with substantial beam energy in the higher components and with noticeable beam quality deterioration. Figure 4 is a spectrum of the SRRS in atmospheric nitrogen obtained with a path length of 130 m and average beam intensity of 1.4 GW/cm^2 (shot 020105 in Table 1). The path average I*L product was estimated at 15.4 TW/cm which is 23% above SRRS threshold for 2.5 ns square laser pulses. Approximately 55% of the beam energy was transferred to first, second, and possibly higher Stokes components. From our data set we know that the S(8) and S(10) components are the first to go over threshold with increasing path length or intensity, with the S(6) component and the second Stokes components at 150 cm^{-1} (S(8)+S(8)), 166 cm^{-1} (S(8)+S(10)), and 182 cm^{-1} (S(10)+S(10)) soon following. A plot of the data points from Table 1 as a function of observed SRRS components versus the estimated path averaged I*L product gives us Fig. 5. The data for the edge and center samples of the beam are plotted separately, as is the data for the 1.0 ns and 2.5 ns pulses. We estimate from Fig. 5 that the threshold for first Stokes light scattering will occur for an I*L product of 16 TW/cm for 1 ns square pulses and at approximately 12.5 TW/cm for 2.5 ns pulses. Under conditions when the beam modulation is high, for example at the edge of the beam or near the disk-split, the SRRS threshold will decrease to 12 TW/cm for 1 ns pulses. This is consistent with the observed 1±0.33 intensity modulation for the edge sample.

For the longest Nova beamlines (3 and 7) at 65 meters, we estimate that SRRS threshold will occur at energies of 4.6-5.9 kJ at 0.5 ns, 6.6-8.6 kJ at 1.0 ns and 12.9-16.7 kJ at 2.5 ns. For the dual-beam system (Nova II) with beam 27 air-path at 105 meters, the SRRS limits are 2.8-3.7 kJ at 0.5 ns, 4.1-5.3 kJ at 1.0 ns, and 8.0-10.3 kJ at 2.5 ns. In all cases the lower estimate is for a modulated portion of the beam. The threshold energy, intensity, and I*L product are tabulated in Figs. 6 and 7 for pulse lengths from 100 ps to 5 ns for the 65 m and 105 m air-paths. These threshold estimates are plotted in Figs. 8, 9, and 10 as a function of pulse duration. The 1.0 and 2.5 ns pulse lengths used for our experiments are short enough that transient effects must be considered in the build-up of the SRRS from amplified spontaneous Raman emission. To extrapolate our 1.0 ns data to other pulse lengths we have scaled the stimulated threshold conditions according to a transient analysis available in the literature.[4] Our 1 ns results show that the

I*L product must be about 30 $\sim$ 40% higher than at 2.5 ns (limited data) to exceed SRRS threshold. This is consistent with typical models of transient scattering in the literature.[4,5]

When the SRRS thresold is greatly exceeded (say by 2X), we have photographic evidence that the beam suffers severe deterioration. An intense speckle pattern develops across the beam with "hot" spot dimensions of 1 to 3 mm diameter. Figure 11 is a photo of a 20 cm test beam (shot 030605) taken from the edge of the Nova aperture that has propagated $\sim$20 meters into the switchyard at an I*L product of 4 TW/cm. Figure 12 shows a similar beam (shot 031103) after propagating 150 meters at an I*L product of $\sim$13.9 TW/cm, which is slightly above SRRS threshold. Figure 13 shows the same beam (shot 030709) at 150 meters with an I*L product of $\sim$25.9 TW/cm ($\sim$2X over threshold). The photo shows an intense speckle pattern that is highly divergent, and there is little doubt that the "hot" spots are SRRS frequency shifted components. Figure 14 shows the frequency spectrum for a similar high energy shot (030102) at the 150 meter path length. Approximately 40% of the 1.053 nm energy has been frequency shifted to Stokes components as high as the third order.

Recent experiments on the Nova II system show that for laser shots only slightly exceeding threshold, the SRRS speckle pattern appears, and in fact is a clear signature that SRRS threshold has been exceeded. For these cases ($\sim$10% conversion to first Stokes components), severe beam degradation is not observed but of course the energy loss is undesirable. For system operation, we probably should not exceed SRRS threshold energies by more than 15 $\sim$ 25%, which is the point at which second Stokes scattering occurs. We would expect unacceptable beam degradation and energy loss at this point. Intensity modulation on the beam can significantly lower the SRRS threshold at a given average beam energy, so this must also be carefully examined.

SRRS threshold experiments using the Nova II system have verified our earlier Nova threshold data for 1 ns square laser pulses and have given some additional data on 1 ns Gaussian pulses. A view of the Nova II system as it is connected to the Nova switchyard is shown in Fig. 15. The upper beamline is designated as number 27 and the lower beamline is number 26. Our SRRS experiment was set up on a specially designed aluminum table near the end of beamline 27. The air-path length from the output of Nova beam 7 to the SRRS apparatus was ∿103 meters. In addition, a ∿55 meter section of the beamline was outfitted with vacuum flanges and windows so that the air-path could be evacuated and back-filled with an inert gas. A 20 cm diameter vacuum window concentric with the 74 cm beam, and a 20 cm window in the lower right-hand portion provided propagation ports through the vacuum chamber. A 2.5 cm diameter portion of the lower right-hand beam was sampled by our 1-meter spectrometer at the end of the air-path. The central 20 cm port was reserved for 8x10" beam photos that were taken with most of the SRRS shots. Appearance of a speckle pattern in the 8x10" photos was a clear indication that SRRS threshold for first Stokes generation was exceeded.

The shot log for the Nova II SRRS experiments is shown in Table 2. The estimated I*L product includes the transmission losses of the vacuum windows (when in place) and the four switchyard turning mirrors. A particular difficulty with these experiments was the large intensity variation from the top to the bottom of the 74 cm beam. For the lower right-hand beam samples, the local intensity was 20 ∿ 24% lower than the beam average (shots 061803 to 071706). The input and output vacuum flanges were rotated so as to move the 20 cm port to the upper right-hand section of the 74 cm beam. For these experiments (shots 072205 to 080802) the local intensity measured ∿22% higher than the beam average. The data points from Table 2 are plotted in Fig. 16 as a function of estimated I*L product. The 1 ns Gaussian pulse data are plotted separately from the 1 ns square pulse data. Both data sets indicate an SRRS threshold in the vicinity of I*L ∿15 TW/cm, which is in excellent agreement with the Nova data. The 1 ns Gaussian data point at 14.1 TW/cm is marked as being below threshold in Fig. 16. On the spectrometer film this shot showed an extremely weak first Stokes line, and the 8x10" photo of the beam center showed no SRRS. Therefore, we take this point to be below threshold, since the observed SRRS component is probably below the 1% conversion criterion. The 1 ns square pulse data point at 17.5 TW/cm (shot 062703) marked with a square in Fig. 16 is somewhat puzzling since no SRRS was observed by the spectrometer or on the 8x10" photo, yet the shot should have been above threshold. Alignment difficulties on beamline 27 during the early shots and/or larger intensity variation at the bottom of the beam than expected might account for the discrepancy here. The last three data points in Table 2 are particularly significant. Shot 080604 at I*L ∿24.4 TW/cm showed no SRRS scattering as expected, since the 55 meter section between vacuum windows was fully evacuated. Filling the 55 meter section with Argon gas at 1 atm gave a similar result for shot 080702. Shot 080802 with the 55 meter section once again at air, with an I*L ∿25.4, showed strong SRRS scattering and first Stokes conversion of 20 ∿ 25%. The 8x10" photo of the beam center, however, showed no obvious SRRS. Here again, strong intensity variation across the beam might be responsible for our observations.

Performance Limitations and Conclusions:

Substantial energy loss and beam deterioration from SRRS in the Nova or Nova II air-path is likely when the peak intensity - path length product exceeds 12 ∿ 12.5 TW/cm for 2.5 ns or longer laser pulses, and 16 TW/cm for 1 ns pulses. From limited data at this time we see no threshold difference between Gaussian and square shaped laser pulses. For the longest Nova beamlines 3 and 7 at 65 meters, or the Nova II beamlines, top-end performance will require evacuating a major portion of the beamlines and replacing with an inert gas such as Neon or Argon. The threshold for first Stokes generation should not be exceeded by more than 15% to avoid unacceptable energy loss at 1053 nm and beam deterioration. Assuming an intensity modulation of 1.0±.33 that might be typical of high laser drive conditions on Nova, the average beam power, intensity, and energy for the 65 meter air-path will be limited to:

Pulse duration (ns)	Power (TW)	Intensity (GW/cm^2)	Energy (kJ)
0.5	10.3	2.9	5.1
1.0	7.5	2.1	7.5
2.5	5.8	1.6	14.4

For beamline 27 on Nova II, the performance limits are:

Pulse durations (ns)	Power (TW)	Intensity (GW/cm^2)	Energy (kJ)
0.5	6.3	1.8	3.2
1.0	4.6	1.3	4.6
2.5	3.6	1.0	8.9

Note that strong intensity modulation on the Nova beam and/or large variations across the aperture might significantly lower the above performance limits. Nova and Nova II beam quality at or slightly above threshold, and the extent to which we might safely exceed threshold is an issue that requires more examination. The SRRS threshold scaling at short pulses also requires further experiment. Appearance of speckle on inline 8x10" beam photos is a clear indication that SRRS threshold has been exceeded by a few percent. We would suggest that beam photos at dedicated locations near the target chambers on Nova and Nova II could serve as a convenient and routine diagnostic to monitor SRRS at different pulse lengths and system performance levels. The beamsplitting optics to accomplish this must have high reflectivity at the 1053 nm fundamental and Stokes shifted wavelengths.

References:

1. M. A. Henesian, C. D. Swift, and J. R. Murray, "Stimulated Rotational Raman Scattering in Nitrogen in Long Air Paths", Optical Society of America Annual Meeting 1985, Washington, D.C., paper TUAG.

2. G. C. Herring, M. J. Dyer, and W. K. Bischel, "Density and Temperature Dependance of the Rotational Raman Gain in N_2", Optical Society of America Annual Meeting 1985, Washington, D.C., paper TUQ5.

3. U. S. Averbakh, A. I. Makarov, and U. I. Talanov, "Stimulated Raman Scattering on Rotational and Vibrational Transitions in Nitrogen Gas", Sov. J. Quantum Electron. 8, 472-476 (1978).

4. A. Laubereau and W. Kaiser, "Vibrational Dynamics of Liquids and Solids Investigated with Picosecond Light Pulses", Rev. Mod. Phys. 50, 607-665 (1978).

5. R. L. Carman, F. Shimizu, C. S. Wang, and N. Bloembergen, "Theory of Stokes Pulse Shapes in Transient Raman Scattering", Phys. Rev. A2, 60-72 (1970).

Table 1
Shot Log of Significant Events for Stimulated Rotational Raman Scattering

Nova Beamlines 8 and 10 --

Date	Shot No.	Energy (kJ)	Pulse (ns)	Path (m)	Est. I*L (TW/cm)	Comments
		(c)-center of beam (e)-edge of beam (*)-digitized film record				
1/15/85	011504	7.7 (c)	1.0	20		No SRS Observed
	011507	7.8 (c)	1.0	20		No SRS Observed
	011510	1.5 (c)	1.0	20		No SRS Observed
1/16/85	011602	1.6 (c)	1.0	20		No SRS Observed
	011608	7.7 (c)	1.0	20		No SRS Observed
1/24/85	012406	9.0 (c)	2.5	105	9.3	No SRS Observed
	012409	6.7 (c)	2.5	105	6.9	No SRS Observed
1/25/85	012503	8.3 (c)	2.5	105	8.6	No SRS Observed
1/28/85	012807	7.5 (c)	2.5	105	7.7	No SRS Observed
	012809	9.5 (c)	2.5	105	9.8	No SRS Observed
1/29/85	012905*	7.8 (c)	1.0	105	20.1	1st Stokes Obs.
1/30/85	013007	10.8 (c)	2.5	105	11.1	No SRS Observed
2/01/85	020105*	12.2 (c)	2.5	130	15.4	1st, 2nd Stoks Obs.
2/08/85	020803*	6.7 (c) +1.5x Telescope	2.5	130	19.0	1st, 2nd, 3rd Stokes Observed
3/01/85	030102*	8.5 (e)	1.0	150	30.2	1st, 2nd, 3rd Stokes Observed
	030104	8.4 (e)	1.0	150	29.9	1st, 2nd, 3rd, 4th Stokes + 1st anti-Stokes Obs.
3/04/85	030403	7.2 (e)	1.0	150	25.6	1st, 2nd, 3rd Stokes Observed
	030410	5.8 (e)	1.0	150	20.6	1st, 2nd, 3rd Stokes Observed
3/05/85	030502*	4.3 (e)	1.0	150	15.3	1st Stokes Observed
	030504	3.0 (e)	1.0	150	10.7	No SRS Observed
3/06/85	030603	6.3 (e)	1.0	20		8x10" Photo-No SRS
	030605	7.0 (e)	1.0	20		8x10" Photo-No SRS
	030607*	7.0 (e)	1.0	20		8x10" Photo-No SRS
3/07/85	030702*	7.0 (e)	1.0	150	24.9	8x10" Photo-Strong SRS Observed
	030706	7.0 (e)	1.0	65	12.0	8x10" Photo-No SRS
	030709	7.3 (e)	1.0	150	25.9	8x10" Photo-Strong SRS Observed
	030709	7.3 (e)	1.0	20		No SRS Observed-Same Shot Above
3/08/85	030804*	7.3 (e)	1.0	65	12.5	1st Stokes Observed
3/11/85	031103	3.9 (e)	1.0	150	13.9	8x10" Photo-Weak SRS Observed
3/12/85	031202	7.8 (e) +Polarizer at 20 m	1.0	65	13.4	1st Stokes-Weak SRS Observed
	031205	6.1 (e) +Polarizer at 20 m	1.0	150	21.7	1st, 2nd, 3rd Stokes Observed

3/20/85	032002	8.4 (e)	1.0	85	18.7	1st, 2nd Stokes Obs.
	032005	8.1 (e)	1.0	85	18.1	1st, 2nd Stokes Obs.
3/21/85	032107	5.9 (e)	1.0	85	13.2	1st Stokes Observed
3/22/85	032202*	6.9 (e)	1.0	85	15.4	1st, 2nd Stokes Obs.
	032204	6.8 (e)	1.0	85	15.2	1st, 2nd Stokes Obs.
3/25/85	032502	4.6 (e)	1.0	85	10.3	No SRS Observed
	032504	5.0 (e)	1.0	85	11.1	No SRS Observed
	032506*	5.8 (e)	1.0	85	12.9	1st Stokes Observed
3/26/85	032602	5.5 (c)	1.0	85	12.3	No SRS Observed
	032605	5.6 (c)	1.0	85	12.5	No SRS Observed
	032608	6.7 (c)	1.0	85	14.9	No SRS Observed
3/27/85	032702	6.6 (c)	1.0	85	14.7	No SRS Observed
	032704*	7.4 (c)	1.0	85	16.5	1st Stokes-Weak SRS Observed
4/16/85	041607*	7.7 (c)	1.0	15		8x10" Photo-No SRS
	041607*	7.7 (e)	1.0	15		8x10" Photo-No SRS

Table 2

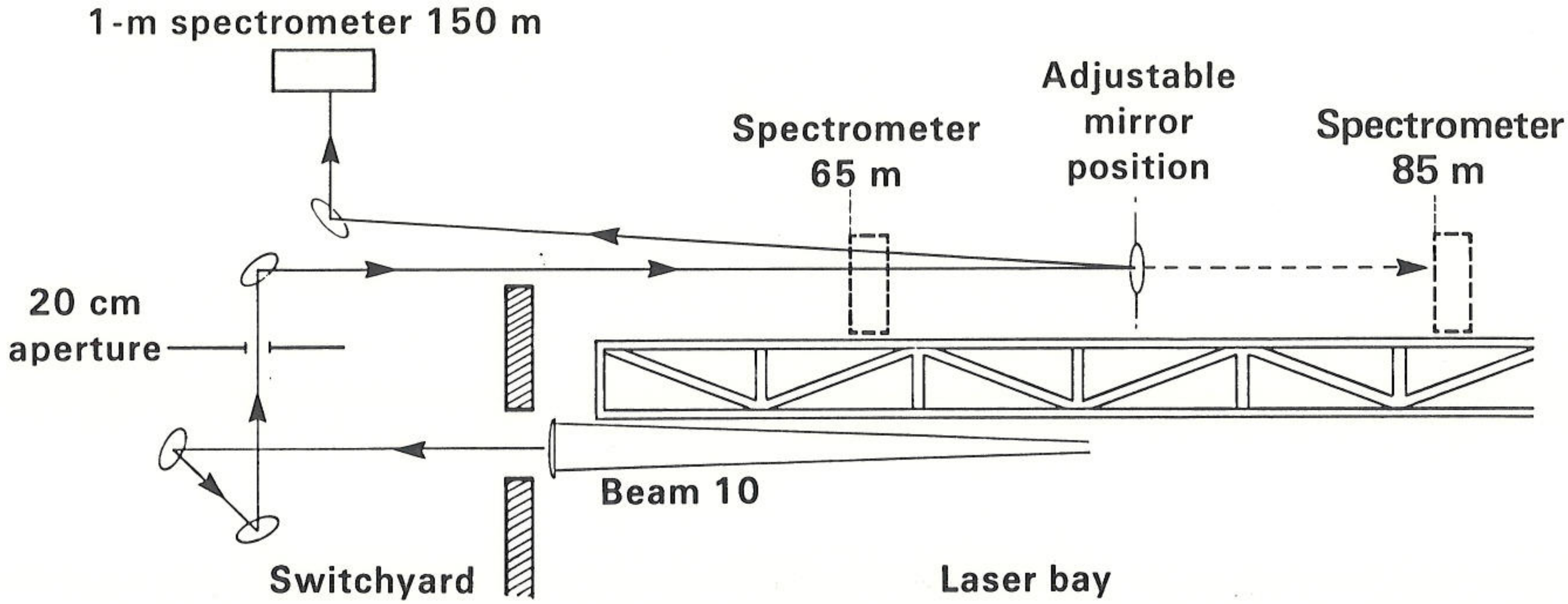
Shot Log of Significant Events for Stimulated Rotational Raman Scattering

Nova II Beamline 27 -- Experiment propagation air-path = 103 meters.

(l)-lower edge of beam
(c)-central portion of beam (for 8x10" photos only)
(u)-upper edge of beam

Date	Shot No.	Energy (kJ)	Pulse (ns)	Est. I&L (TW/cm)	Comments
6/18/85	061803	4.7 (l)	1.0 sq.	11.0	No SRS Observed
6/19/85	061902	4.6 (l)	1.0 sq.	10.7	No SRS Observed
	061905	5.2 (l)	1.0 sq.	12.1	No SRS Observed
6/20/85	062006	7.5 (l)	1.0 sq.	17.5	No SRS Observed
6/21/85	062105	7.8 (l)	1.0 sq.	18.2	1st Stokes Obs. <5% Conversion 8x10" Photo(c)
6/27/85	062703	7.5 (l)	1.0 sq.	17.5	No SRS Observed 8x10" Photo(c)
7/15/85	071503	5.6 (l)	1.0 gauss.	11.8	No SRS Observed 8x10" Photo(c)
7/16/85	071602	6.7 (l)	1.0 gauss.	14.1	1st Stokes Obs. very weak 8x10" Photo (c) shows no SRS
	071604	7.5 (l)	1.0 gauss.	15.8	1st Stokes Obs. - weak 8x10" Photo(c) shows SRS speckle
7/17/85	071704	6.0 (l)	1.0 sq.	13.5	No SRS Observed 8x10" Photo(c) shows no SRS
	071706	7.3 (l)	1.0 sq.	16.4	1st Stokes Obs. 15~20% Conversion. 8x10" Photo(c) shows SRS speckle
7/22/85	072205	7.1 (u)	1.0 sq.	25.5	8x10" Photo(u) shows strong SRS
8/06/85	080604	6.8 (u)	1.0 sq.	24.4	Beamtube evacuated- 8x10" Photos(u,c) show no SRS
				(11.3)	Air-path alone
8/07/85	080702	6.9 (u)	1.0 sq.	24.7	Beamtube filled with Argon-No SRS Obs. 8x10" Photo(c) shows no SRS
				(11.6)	Air-path alone
8/08/85	080802	7.1 (u)	1.0 sq.	25.4	1st Stokes Obs. 20~25% Conversion. 8x10" Photo(c) shows no SRS(?)

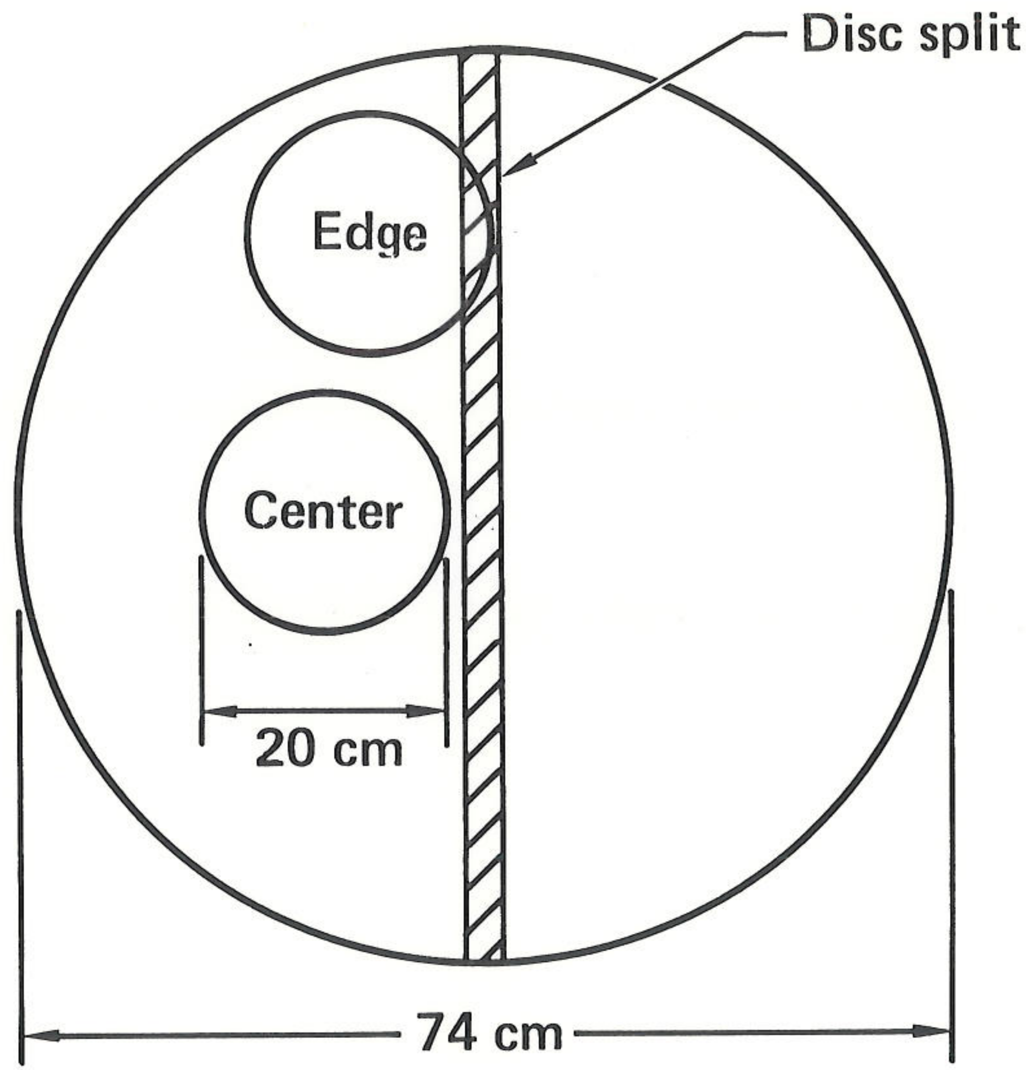
Layout of Beam 10 stimulated Raman experiments in Nova switchyard and laser bay



Top view

Figure 1

Center and edge portions of Nova beam were used for the SRS threshold experiments

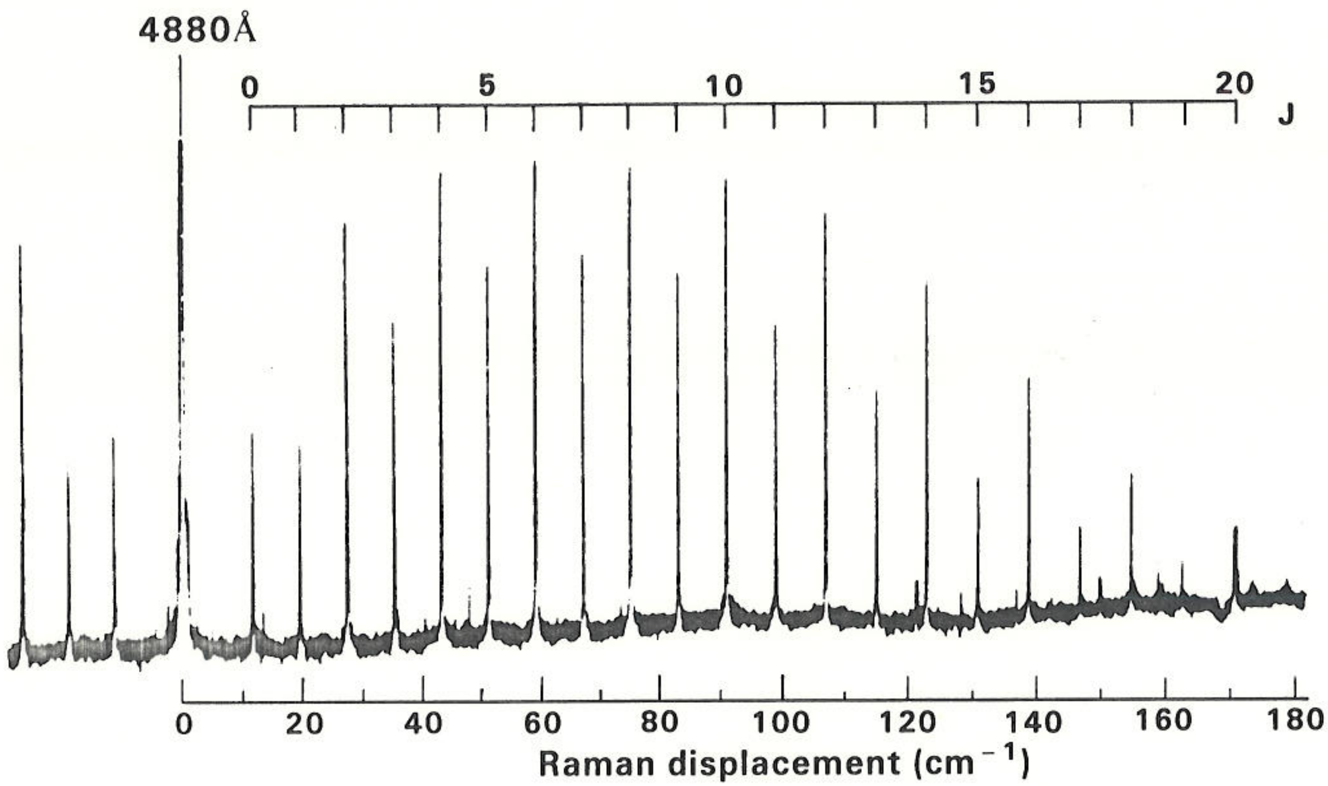


40-00-0585-1881

Figure 2

Spontaneous rotational Raman spectrum of pure N_2 and calculation of Stokes wavelengths

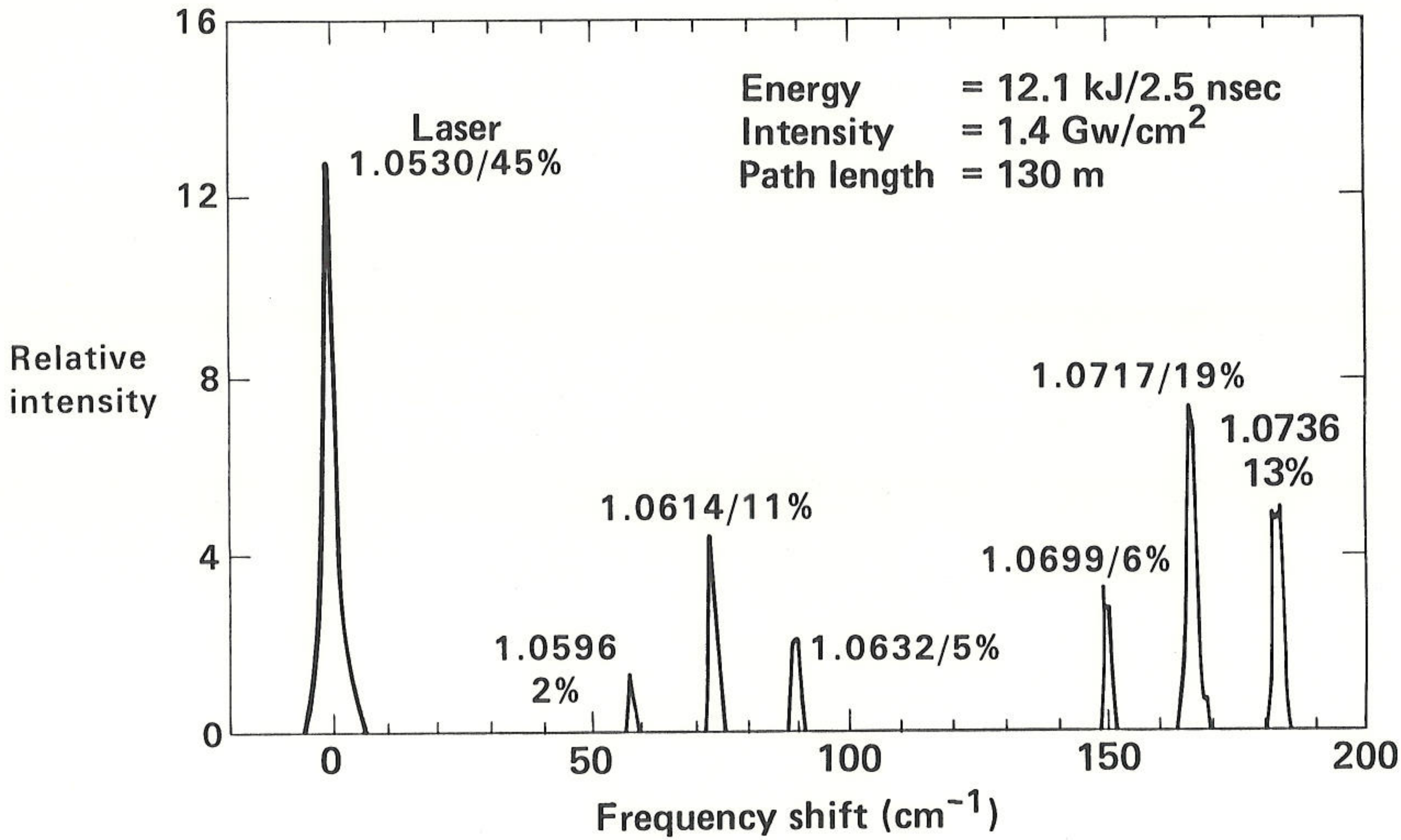
Rotational Transition	Shift (cm^{-1})	Wavenumbers	Pump wavelength is 1.053 μm Stokes wavelengths (μm)
J = 6 to J′ = 8	59	9437.7	1.0596
J = 8 to J′ = 10	75	9421.7	1.0614
J = 10 to J′ = 12	91	9405.7	1.0632



Ref: A. Weber, Chapter 3 in Raman spectroscopy of gases and liquids, ed. by A. Weber

Figure 3

Relative intensities for rotational SRS in nitrogen — shot 15020105



40-00-0485-1356

Figure 4

NOVA rotational SRS results for air path propagation plotted as a function of intensity–length product

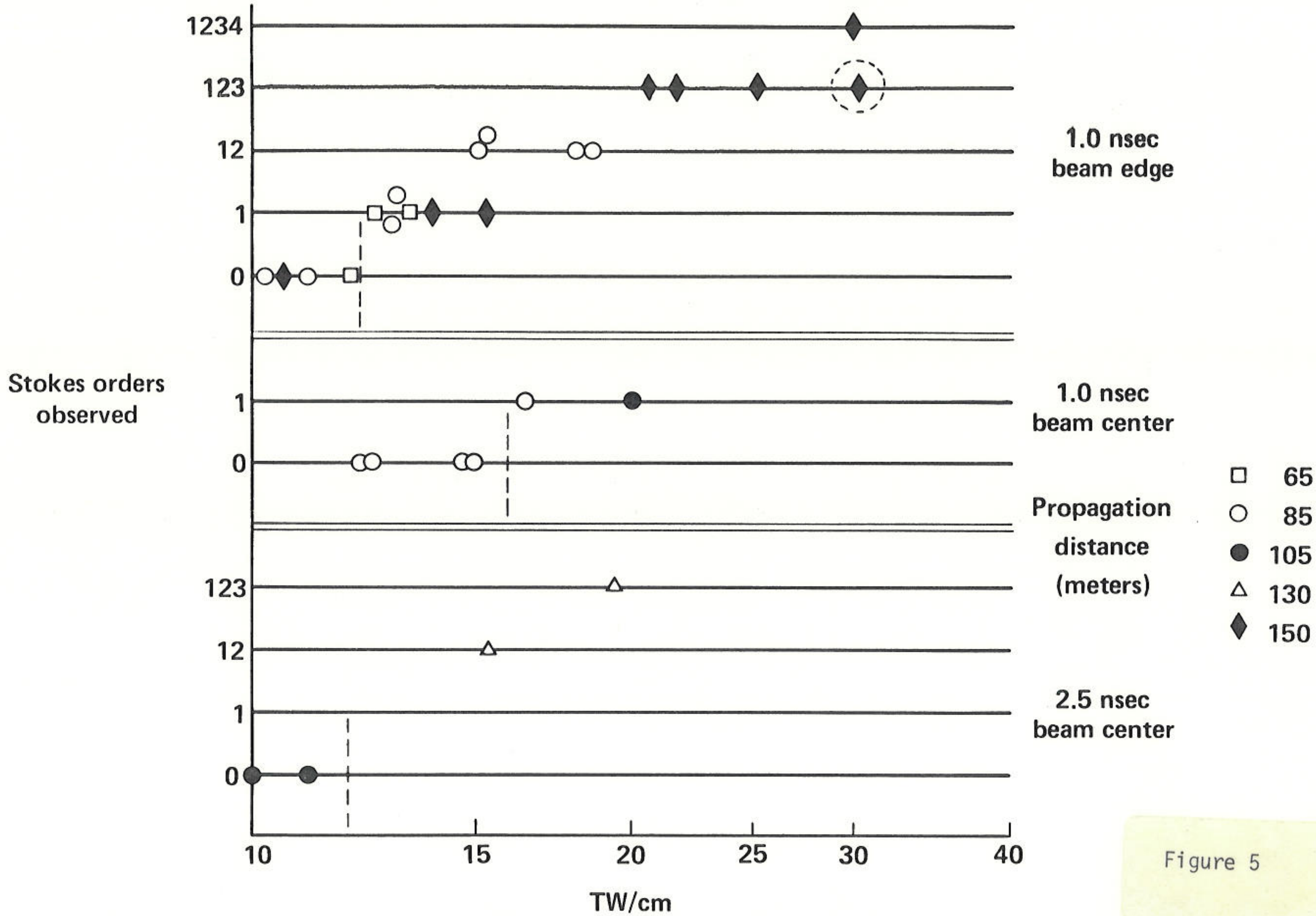


Figure 5

40-00-0485-1608

Threshold intensity and energy for 65 meter Nova air path

Pulse duration (nsec)	Beam center			Beam edge		
	TW/cm	GW/cm^2	Energy (kJ)	TW/cm	GW/cm^2	Energy (kJ)
0.10	78	12.0	4.2	60	9.2	3.2
0.25	36	5.5	4.8	28	4.3	3.8
0.50	22	3.4	5.9	17	2.6	4.6
1.0	16	2.5	8.6	12.3	1.9	6.6
2.5	12.4	1.9	16.7	9.6	1.5	12.9
5.0	11.5	1.8	31.0	8.8	1.4	23.7

Figure 6

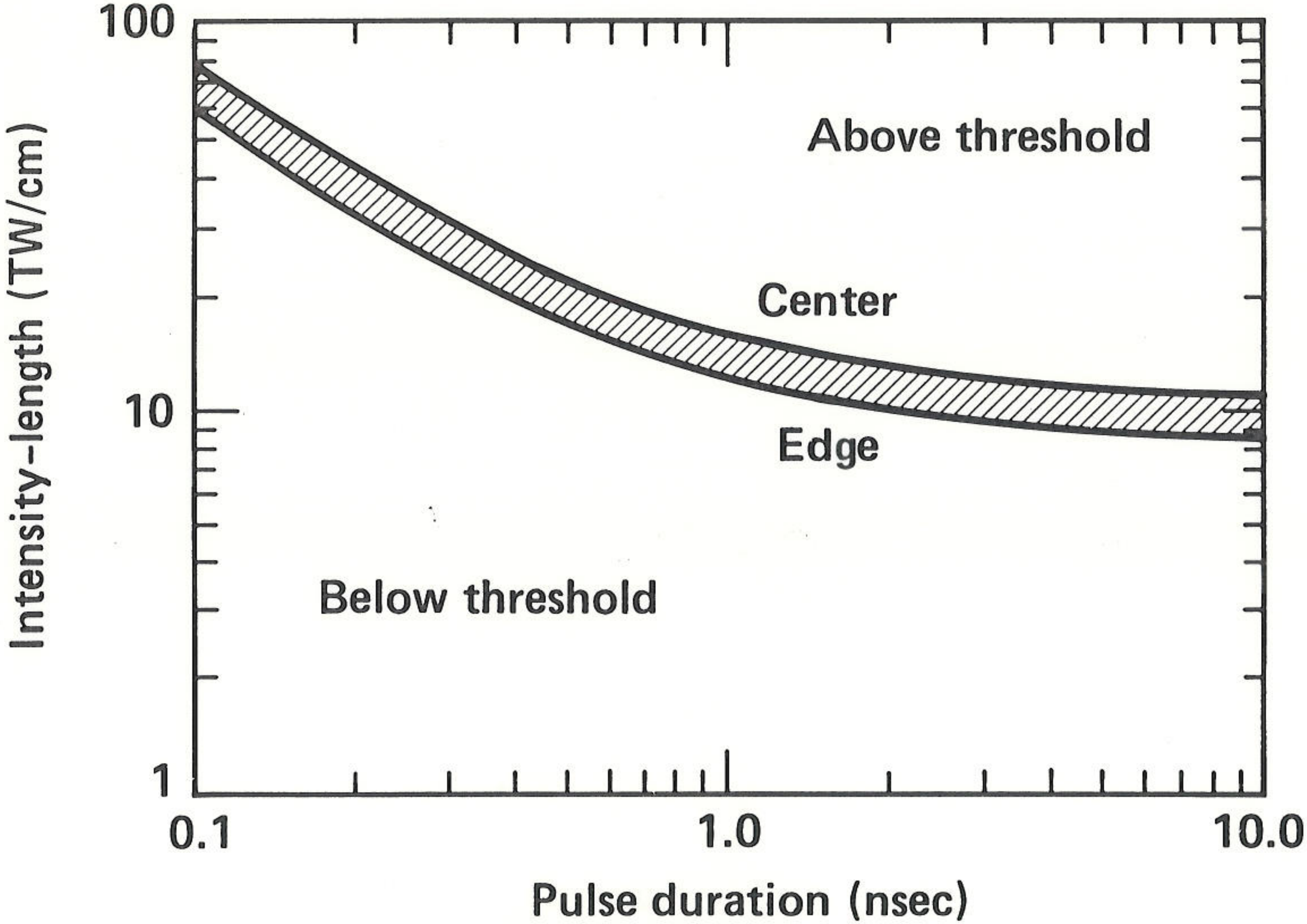
40-00-0585-1812

Threshold intensity and energy for 105 meter dual-beam chamber air path

	Beam center			Beam edge		
Pulse duration (nsec)	TW/cm	GW/cm^2	Energy (kJ)	TW/cm	GW/cm^2	Energy (kJ)
0.10	78	7.4	2.6	60	5.7	2.0
0.25	36	3.4	3.0	28	2.7	2.3
0.50	22	2.1	3.7	17	1.6	2.8
1.0	16	1.5	5.3	12.3	1.2	4.1
2.5	12.4	1.2	10.3	9.6	0.91	8.0
5.0	11.5	1.1	19.2	8.8	0.84	14.7

Figure 7

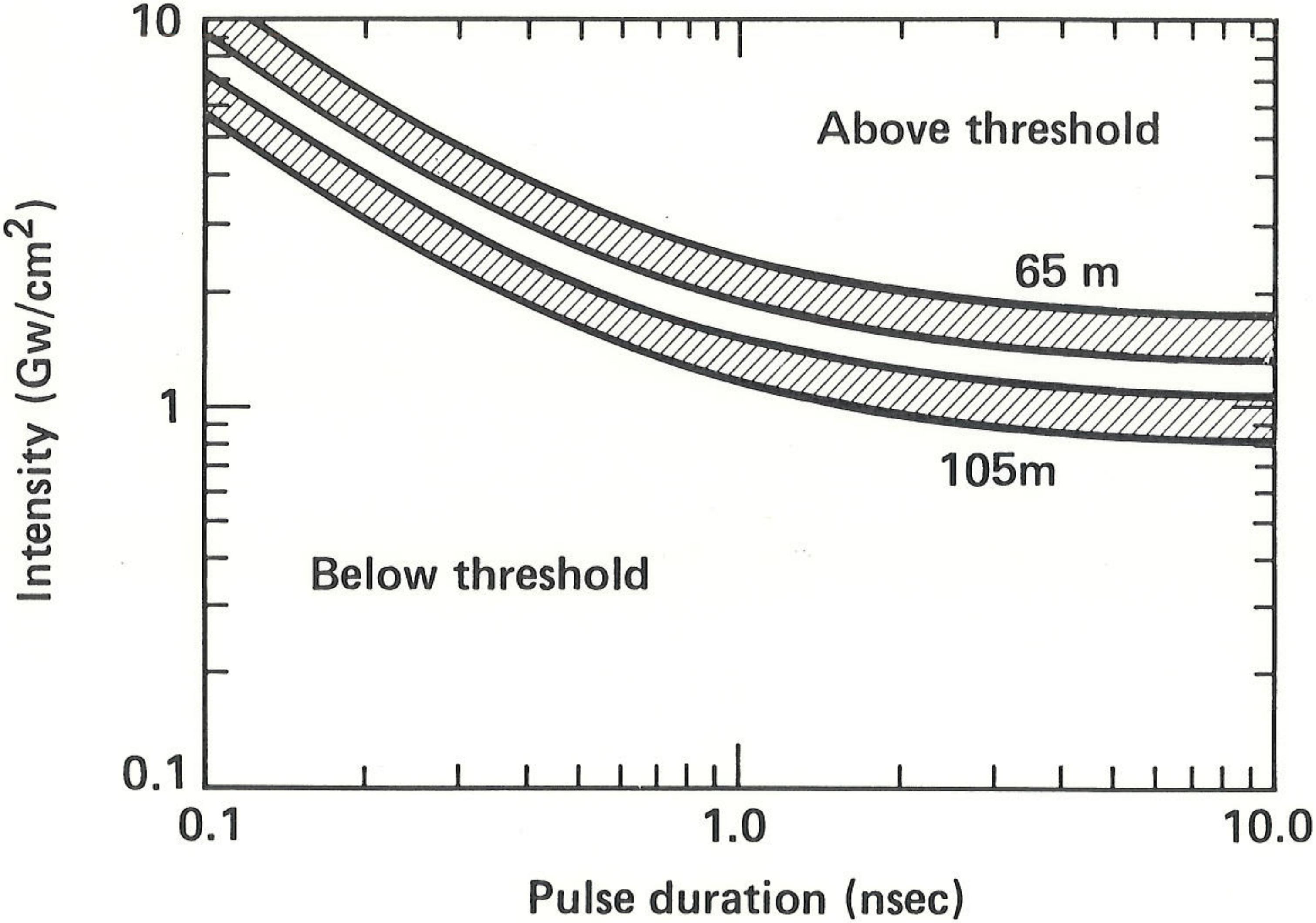
Threshold intensity-path length product for rotational SRS depends on position in Nova beam



40-00-0585-1815

Figure 8

Threshold intensity for rotational SRS in the 65 and 105 meter air paths



40-00-0585-1816

Figure 9

Threshold energy in Nova beam for rotational SRS in the 65 and 105 meter air paths

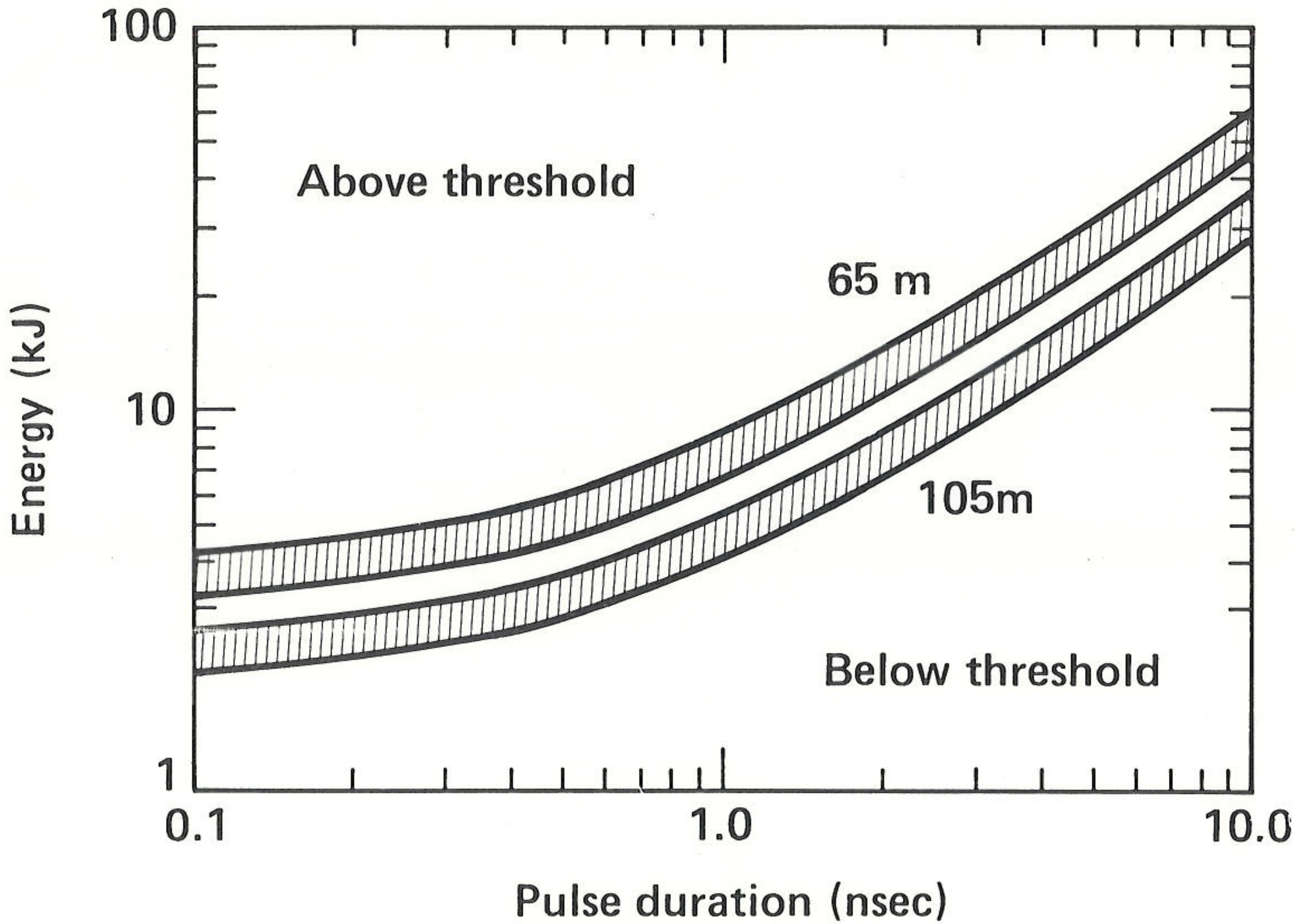


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Figure 10

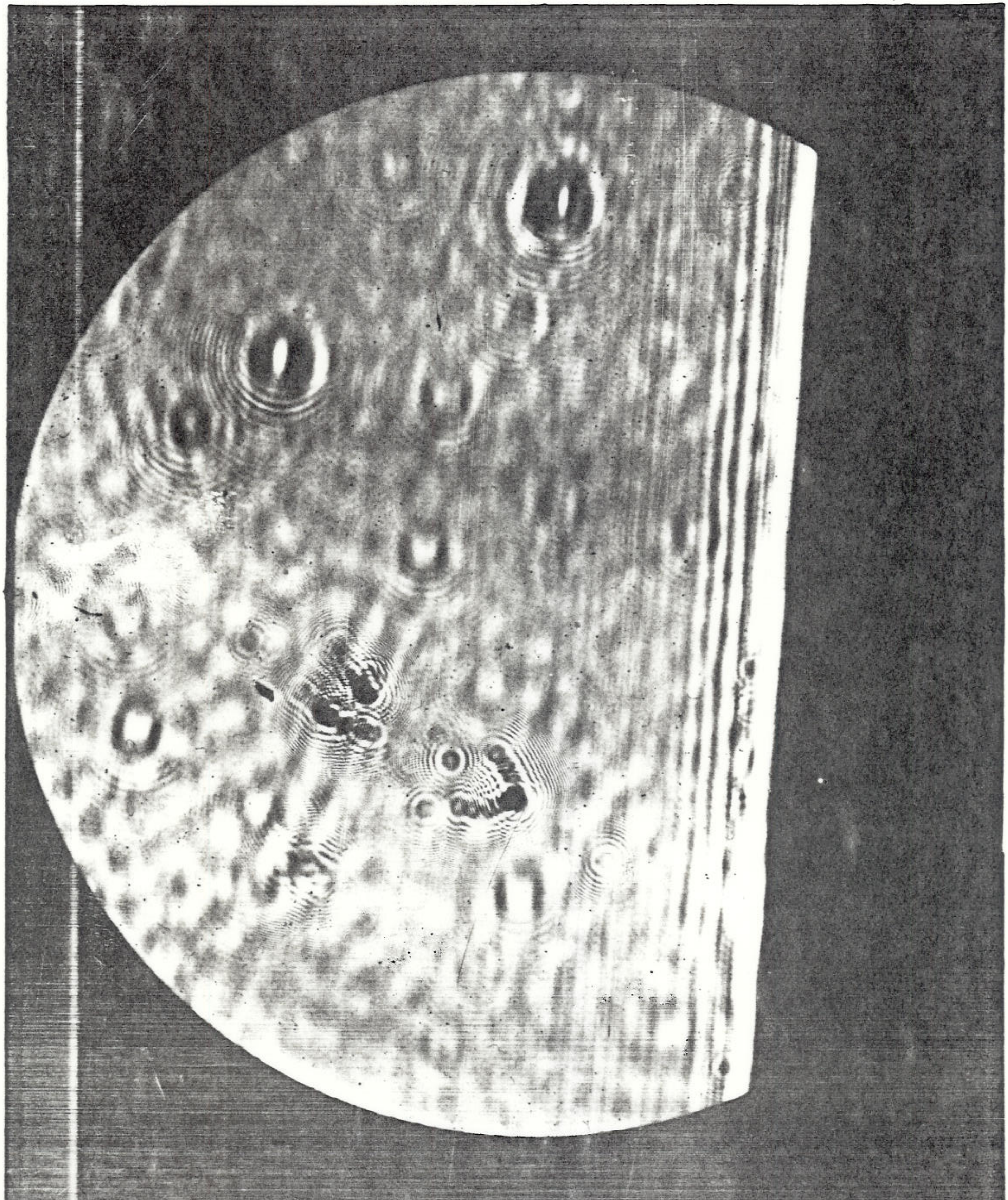


Figure 11

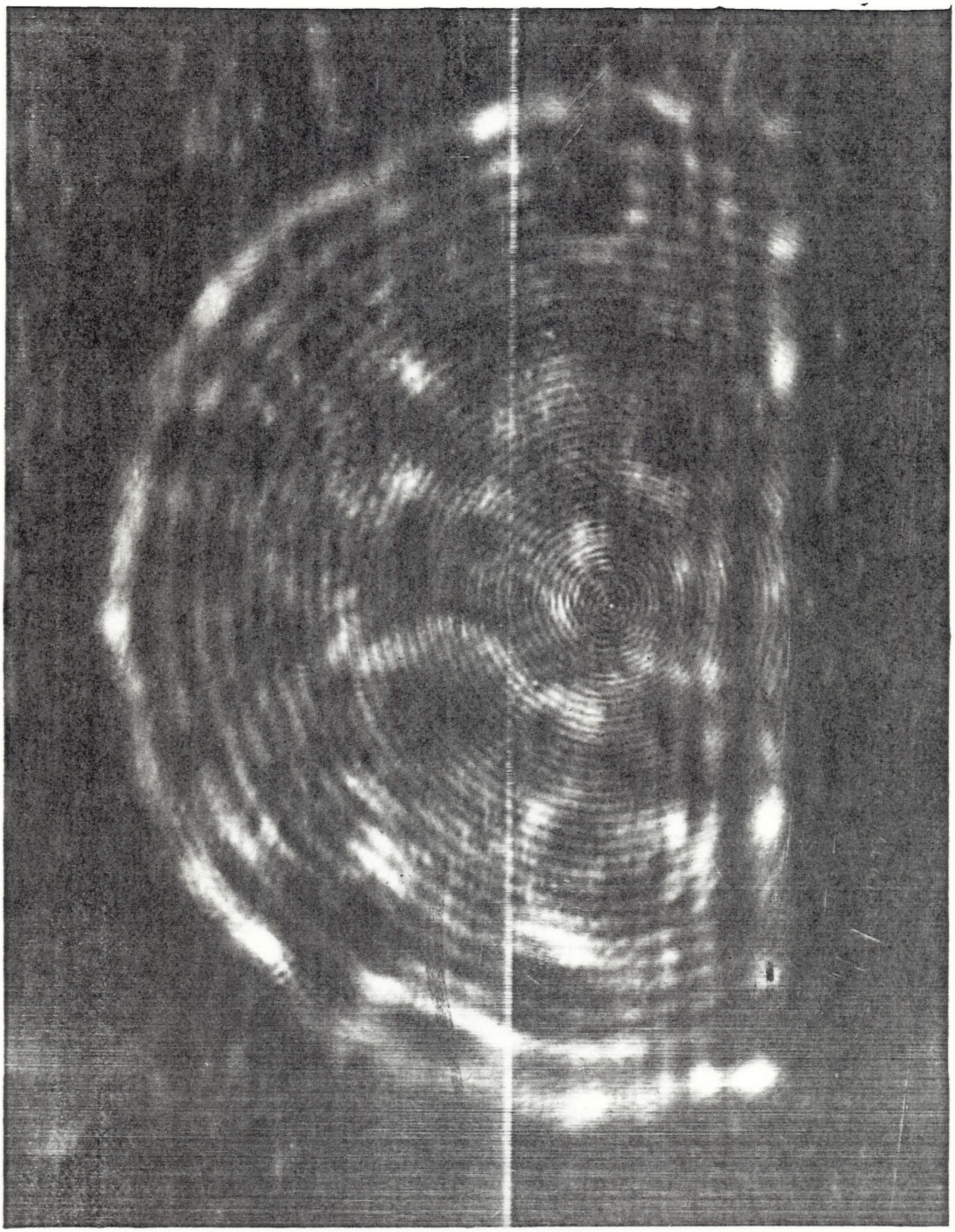


Figure 12

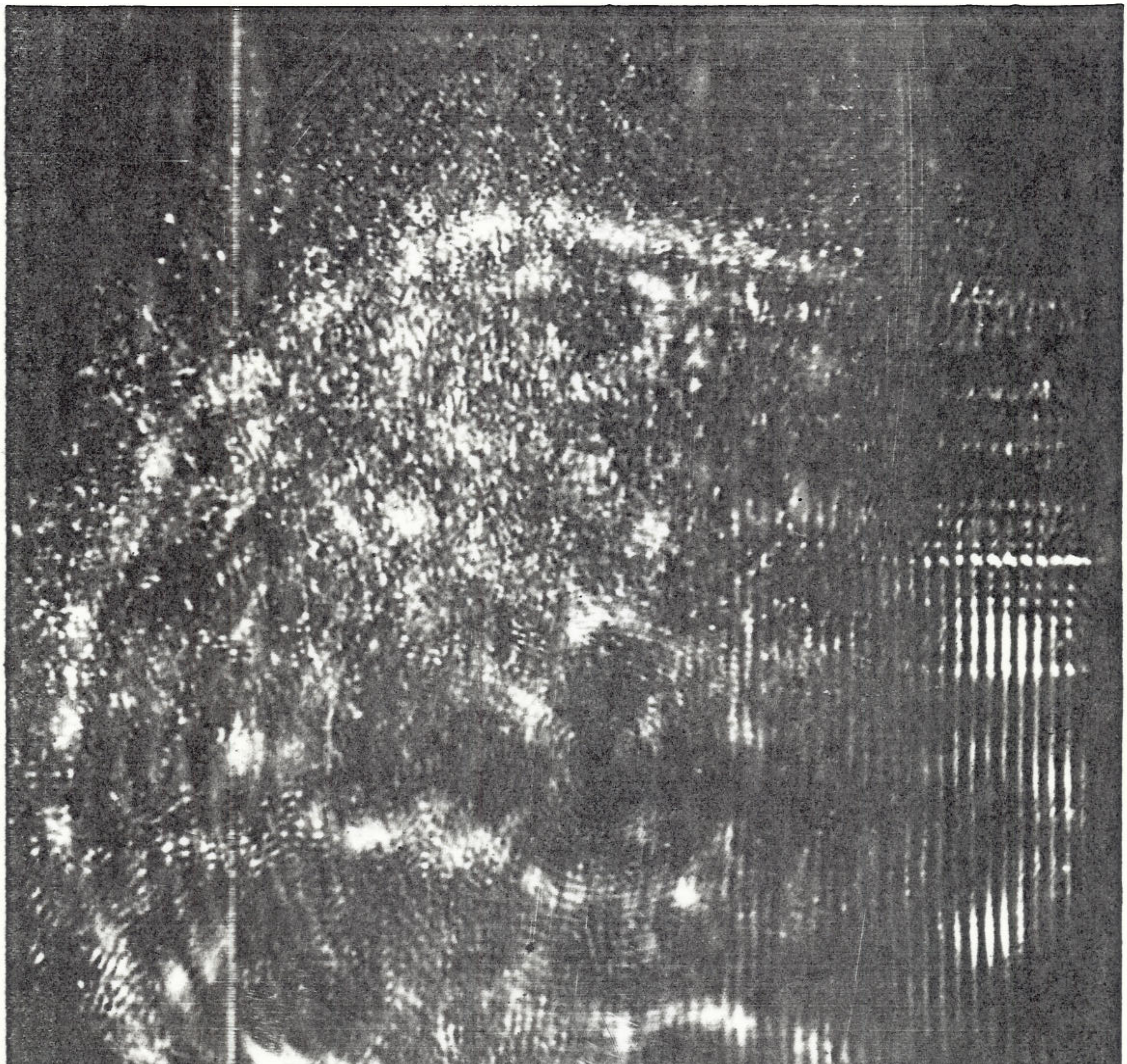
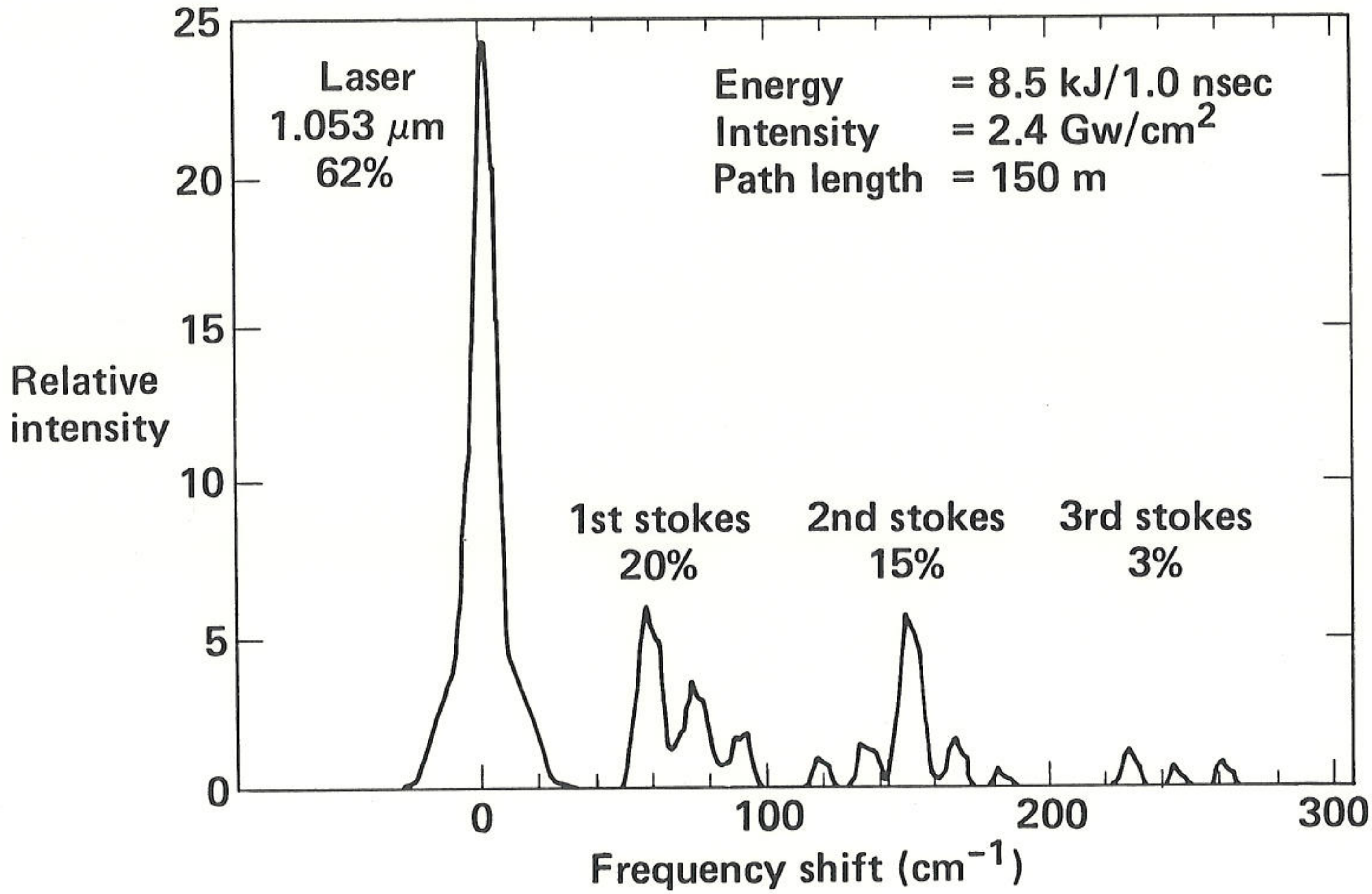


Figure 13

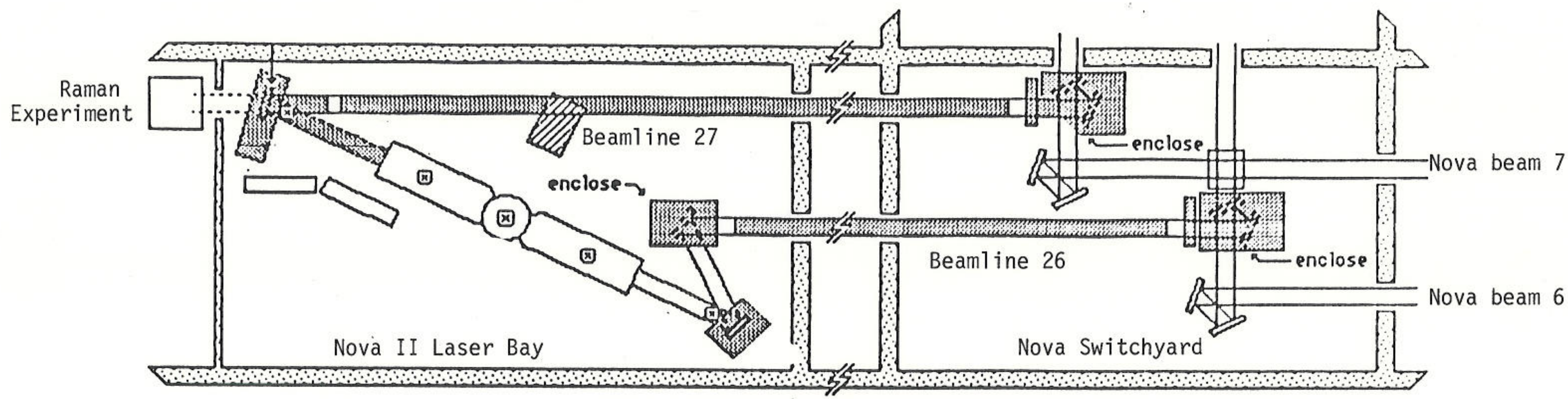
Relative intensities for rotational SRS in nitrogen — shot 15030102



40-00-0485-1355

Figure 14

Nova II Schematic (7/17/85)



(Nova II Schematic drawn by)
Erlin Bliss

Figure 15

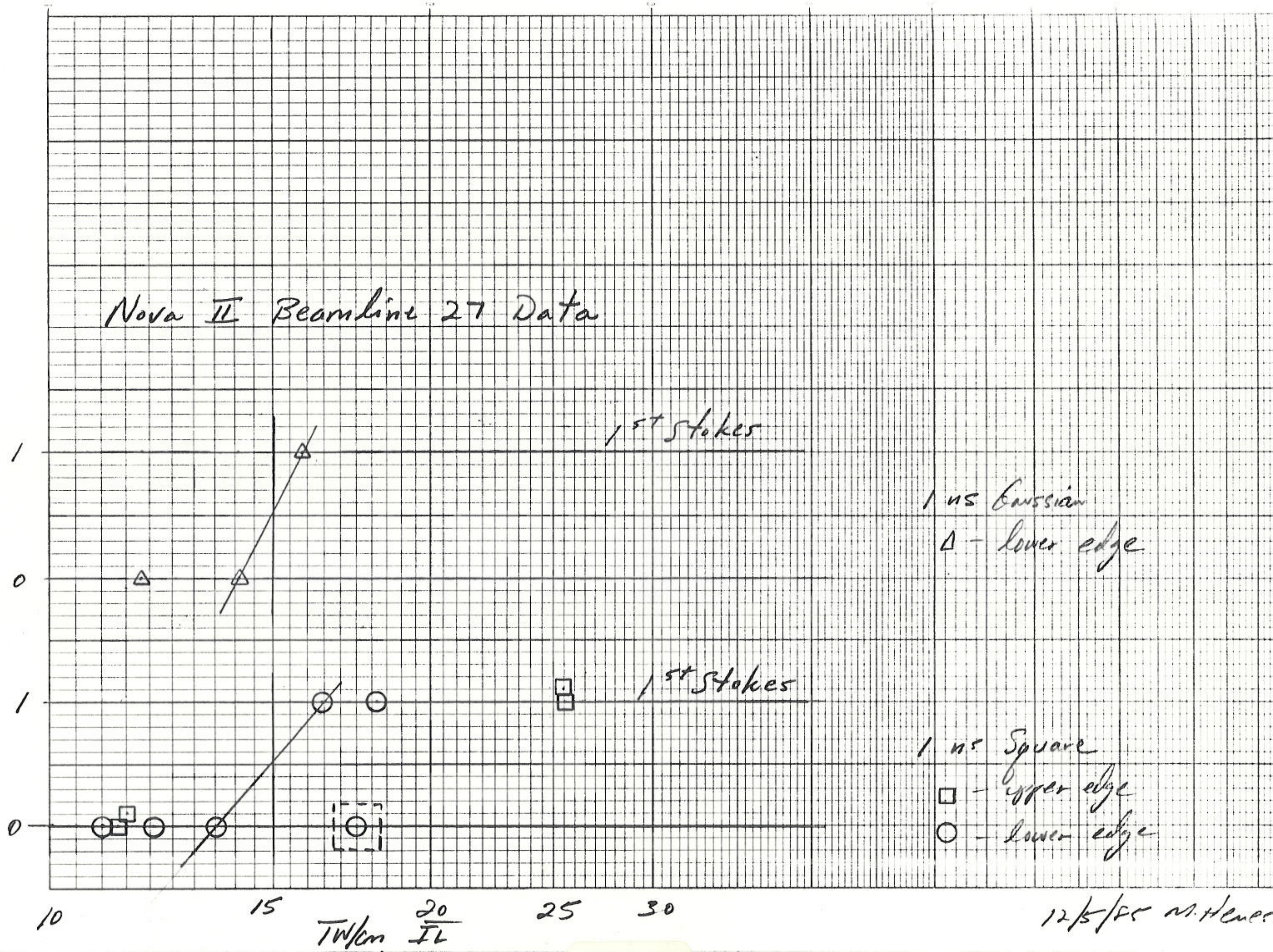

Nova II Beamline 27 Data
1st Stokes
1st Stokes
1
0
1
0
10
15
20
25
30
TW/cm
IL
1 ns Gaussian
Δ - lower edge
1 ns Square
□ - upper edge
○ - lower edge
12/5/85 M. Henes

Figure 16

Distribution:

C. Annese	L-492
E. Bliss	L-492
R. Boyd	L-492
R. Briggs	L-626
D. Browning	L-484
M. Campbell	L-473
L. Coleman	L-481
P. Chaffee	L-494
P. Drake	L-473
D. Edwards	L-332
D. Eimerl	L-490
J. Emmett	L-488
D. Fisher	L-332
D. Foley	L-493
F. Frick	L-496
W. Hagen	L-490
R. Hargrove	L-467
G. Hermes	L-483
S. Hildum	L-493
J. Holzrichter	L-490
J. Hunt	L-493
C. Hurley	L-496
R. Jandrisevits	L-332
T. Kan	L-490
T. Karr	L-626
W. Krupke	L-488
A. Levy	L-493
H. Lowdermilk	L-490
K. Manes	L-490
T. Marchi	L-491
D. Milam	L-490
F. Milanovich	L-524
E. Moses	L-462
J. Murray (Jim)	L-490
J. Murray (John)	L-490
D. Myers	L-492
J. Paisner	L-464
H. Patton	L-496
H. Powell	L-490
D. Prosnitz	L-626
G. Ross	L-483
L. Seppala	L-491
W. Sooy	L-488
R. Speck	L-493
S. Stokowski	L-490
E. Storm	L-481
E. Stower	L-332
M. Summers	L-487
G. Suski	L-493
C. Swift	L-492
J. Swingle	L-626
D. Templeton	L-489
J. Trenholme	L-487
P. Wallerstein	L-491
P. Wegner	L-395
T. Weiland	L-478
R. Wilcox	L-494
R. Wirtenson	L-491