• SELF-FOCUSING AND SELF-CHANNELING OF LASER RADIATION:

• HISTORY AND PERSPECTIVES

• V. V. KOROBKIN

• *A.M. PROKHOROV GENERAL PHYSICS INSTITUTE OF THE RAS*

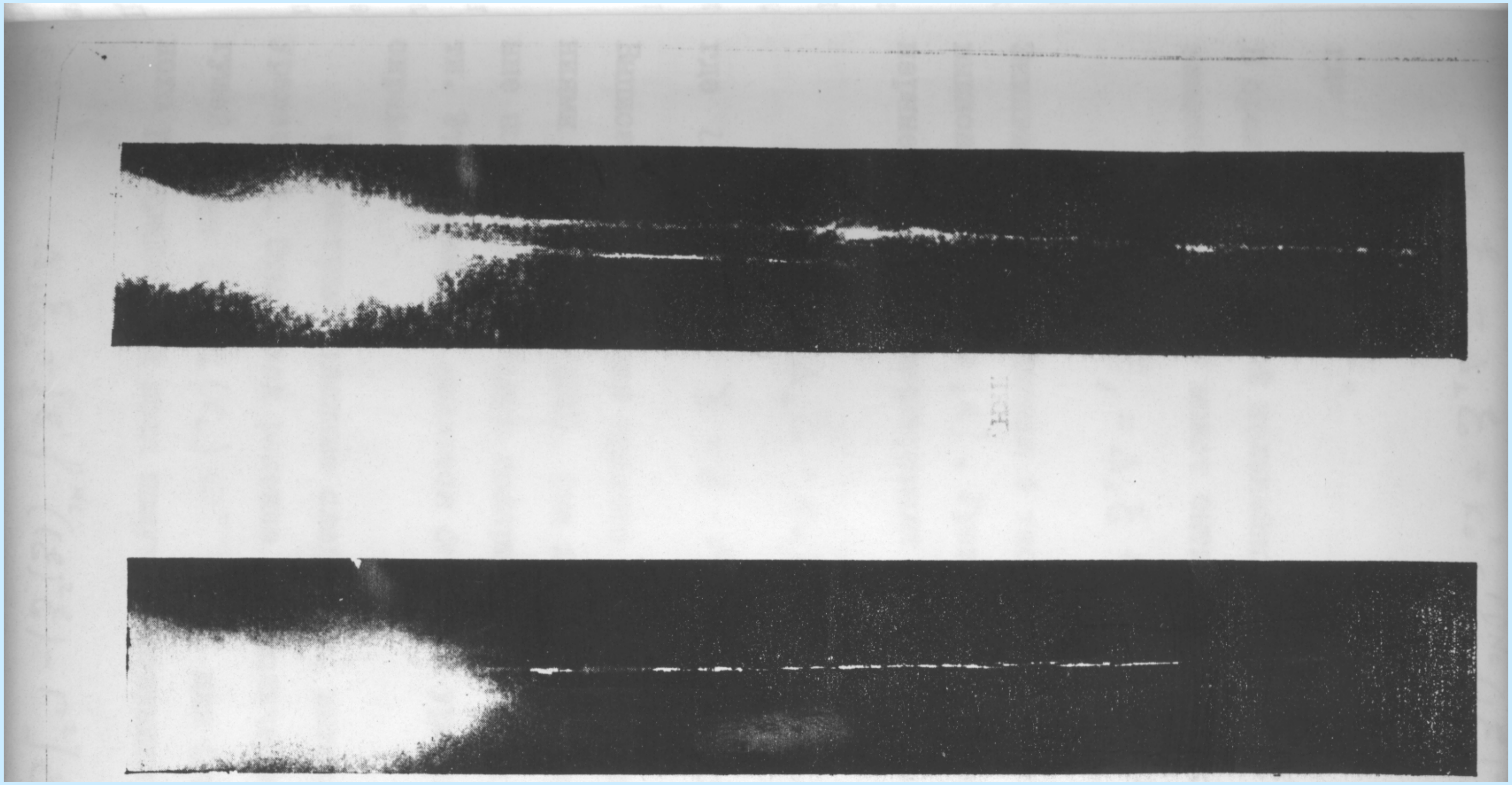
- **Prediction of the self-focusing**

- **G.A. Askar’yan**
- **Zh. Eksp. i Teor. Fiz. 42, 1567 (1962).**
- **[Sov. Phys.-JETP 15, 1088 (1962)].**

Pilipetskii N F, Rustamov A. R.

Pis'ma Zh. Eksp. i Teor. Fiz. 2, 88, (1965)

[JETP Lett. 2, 55, (1965)]

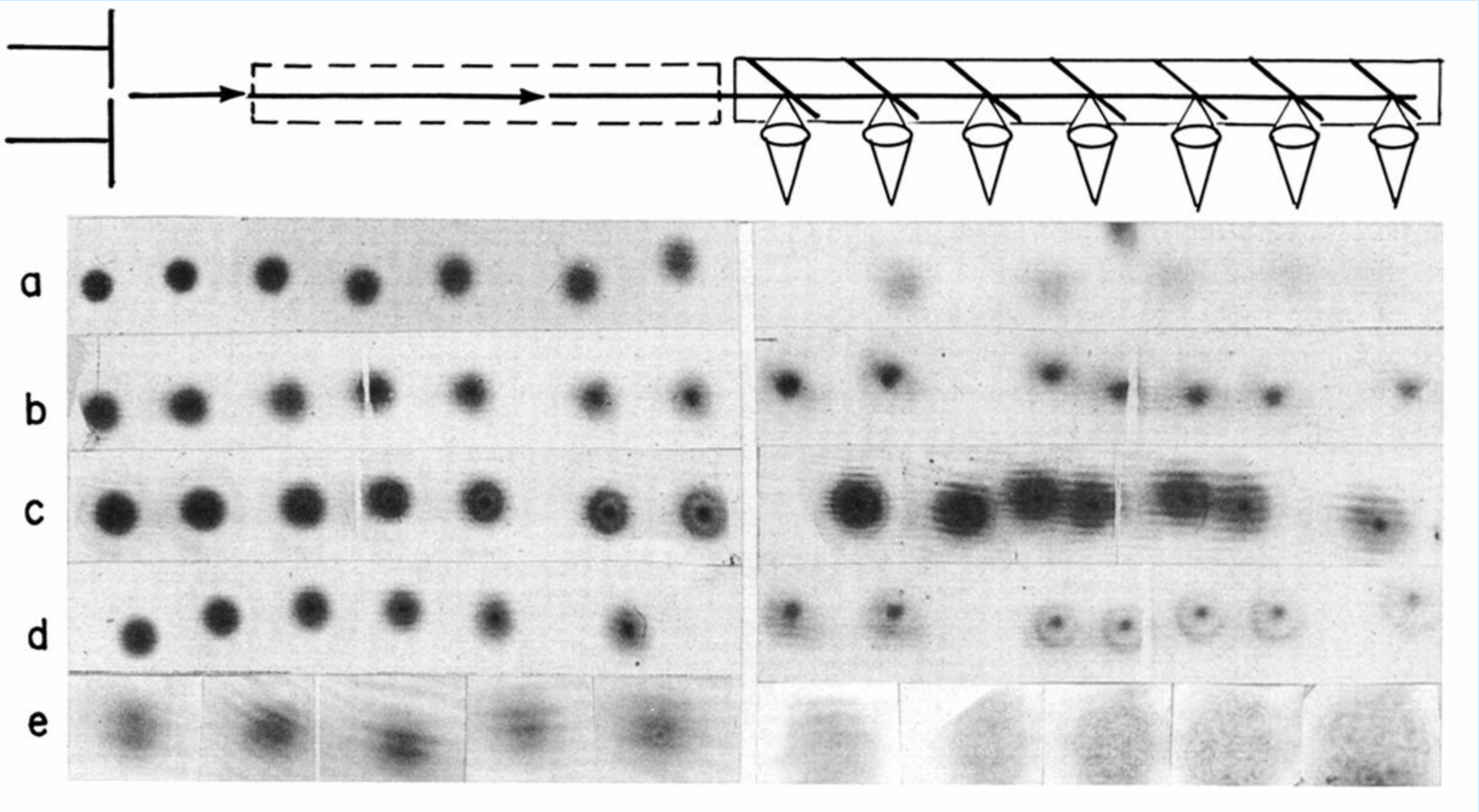


P.L. Kelley
Phys. Rev. Letters. 15, 1005 (1965).

$$P_{cr} = (1.22\lambda)^2 c/512 n_2'.$$

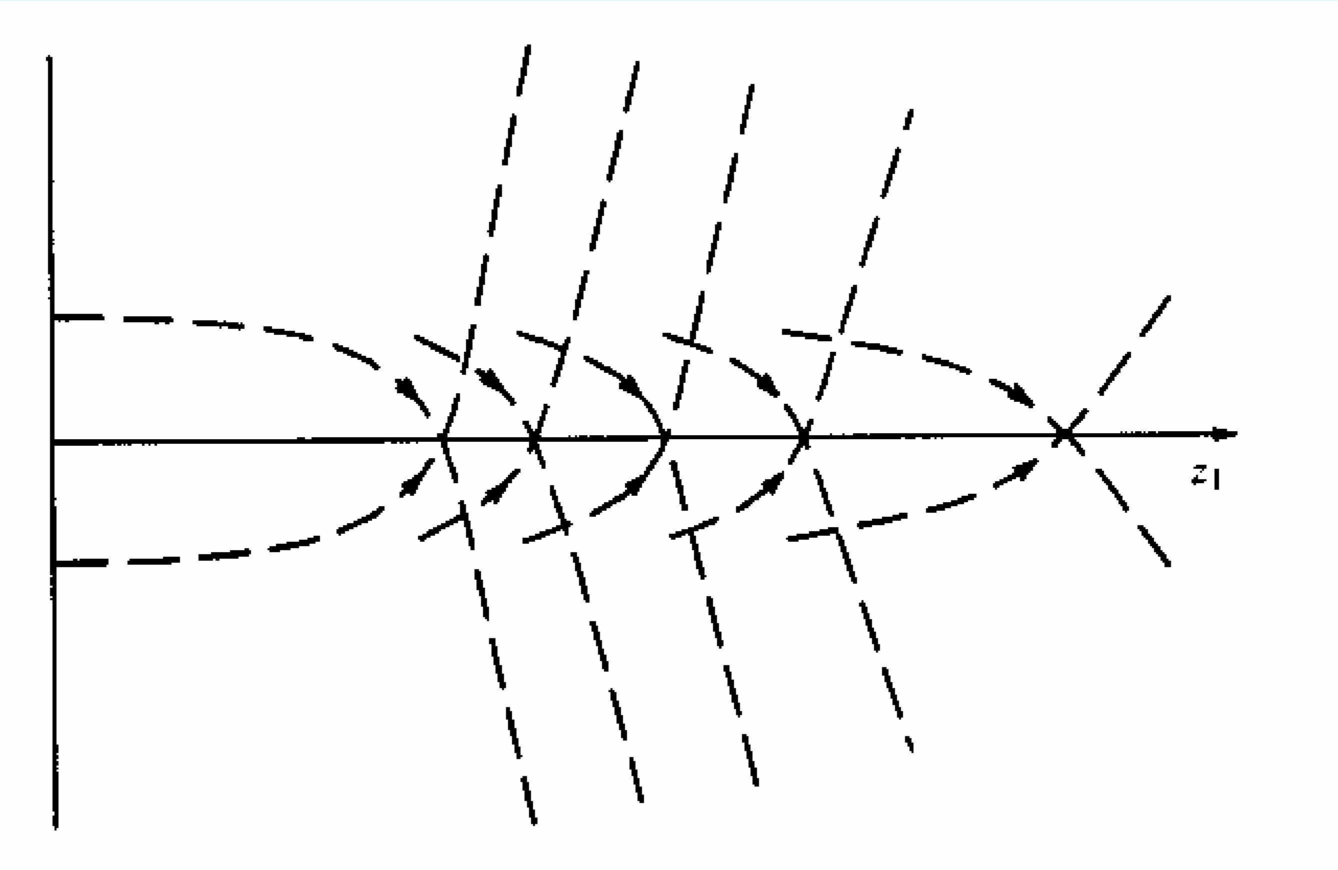
$$z_{net} = \frac{a}{2}(n_0 n_2')^{1/2}(E_m' - E_{cr})^{-1},$$

E. Garmire, R. Y. Chiao, C.H. Townes
Phys. Rev. Letters. 16, 347 (1966).



Evolution of beam trapping in CS_2. Left: without dashed cell; right: dashed cell adds 25 cm path length. (a) Gas laser control; (b), (c), and (d), beam trapping at increasing power; (e) 1-mm pinhole.

Dyshko A L, Lugovoi V N, Prokhorov A M
Pis'ma Zh. Eksp. i Teor. Fiz. 6, 655, (1967)
[JETP Lett. 6, 146, (1967)]



Talanov V. I.

Pis'ma Zh. Eksp. i Teor. Fiz. 2, 218, (1965)

[JETP Lett. 2, 138, (1965)]

Bespalov V. I., Talanov V. I.

Pis'ma Zh. Eksp. i Teor. Fiz. 3, 471, (1966)

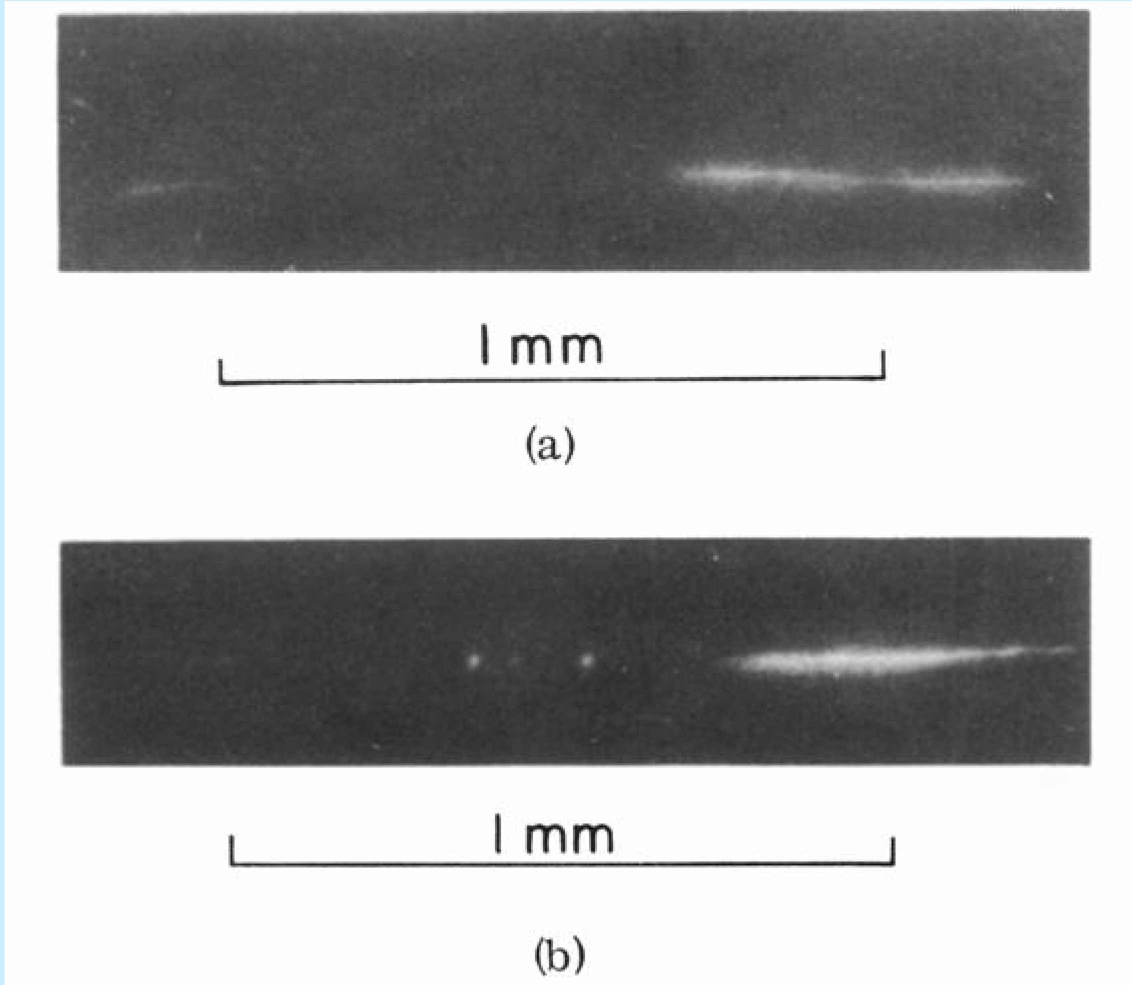
[JETP Lett. 3, 307, (1966)]

Akhmanov S. A., Sukhorukov A. P., Khokhlov R. V. Sov. Phys. JETP, 23, 1025, (1966)

Akhmanov S. A., Sukhorukov A. P., Khokhlov R. V. Sov. Phys. Usp. 10, 609, (1968) Litvak A.G.

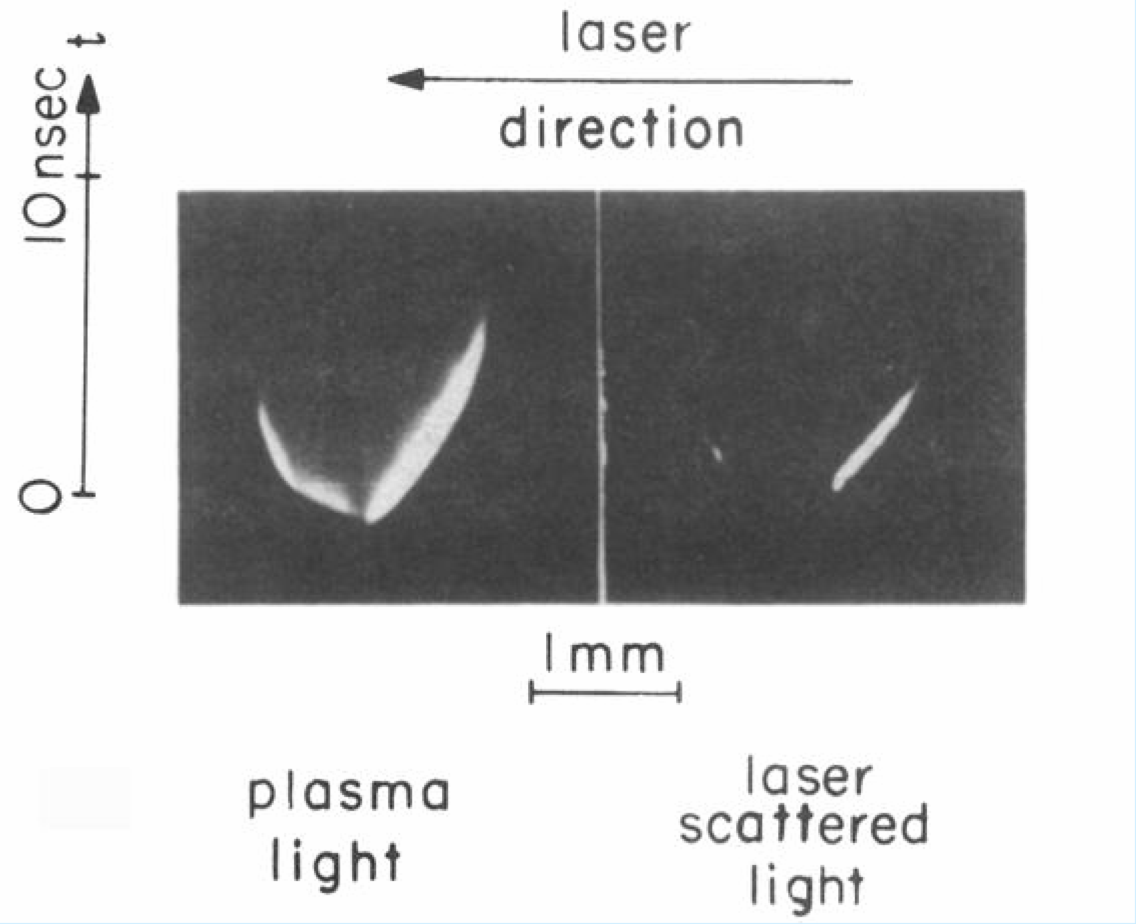
Self-focusing in plasma

V. V. Korobkin* and A. J. Alcock. **Phys. Rev. Letters. 21, 1433 (1968).**



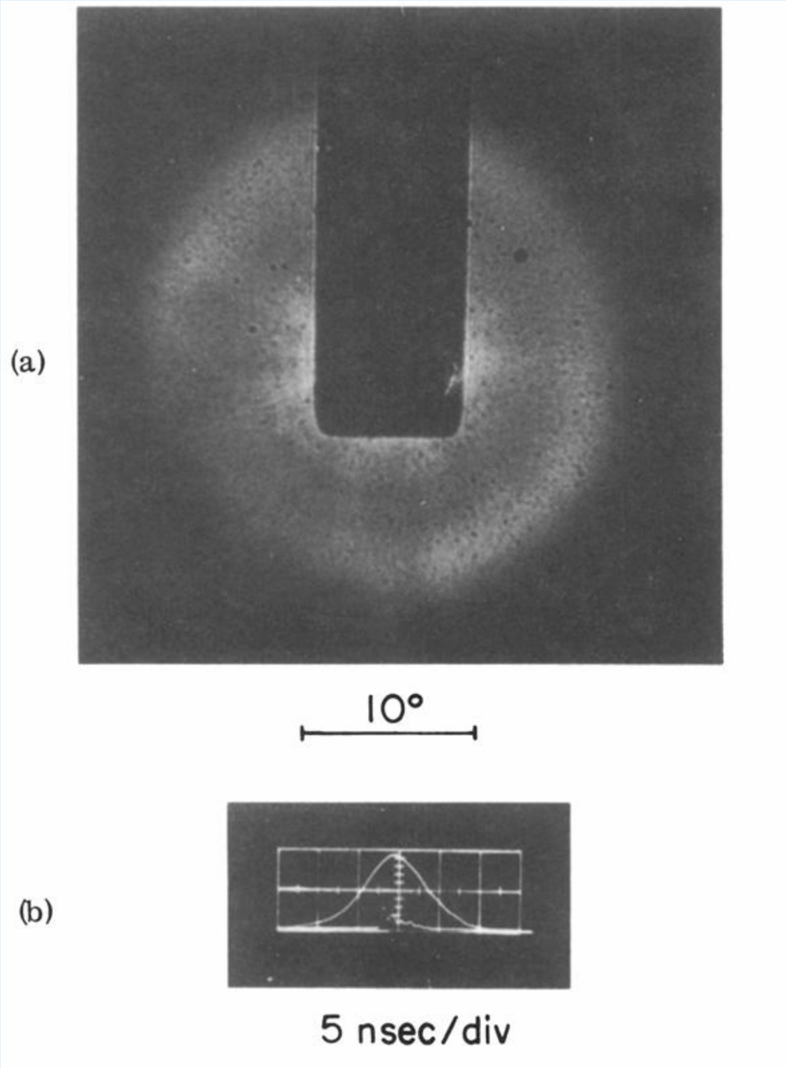
Time-integrated photographs of sparks in air showing laser radiation, scattered at 90° to the incident beam. In (a) there are two linear breakdown regions while (b) shows a number of discrete breakdown points. The direction of the laser beam is from right to left.

V. V. Korobkin* and A. J. Alcock. **Phys. Rev. Letters. 21, 1433 (1968).**



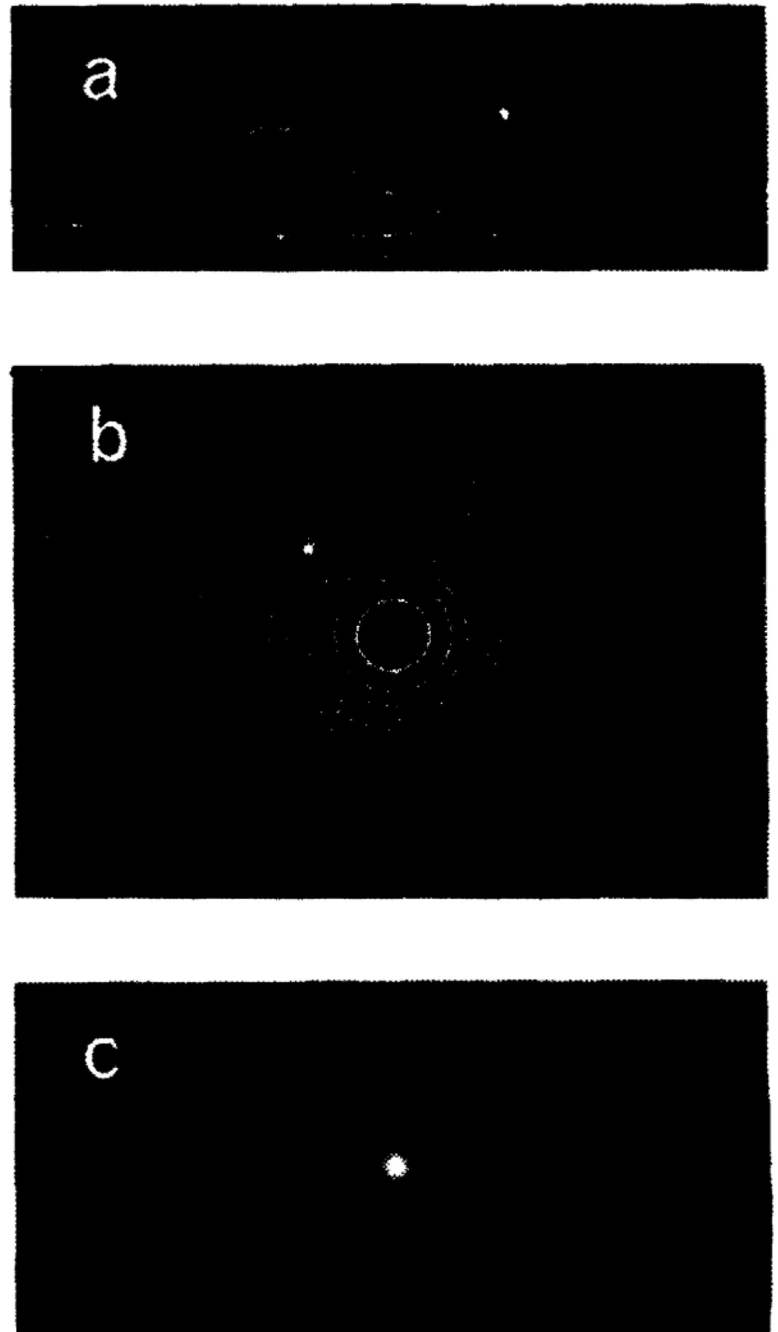
Streak photographs of air sparks showing both the plasma luminosity and the scattered laser radiation.

V. V. Korobkin* and A. J. Alcock. **Phys. Rev. Letters. 21, 1433 (1968).**



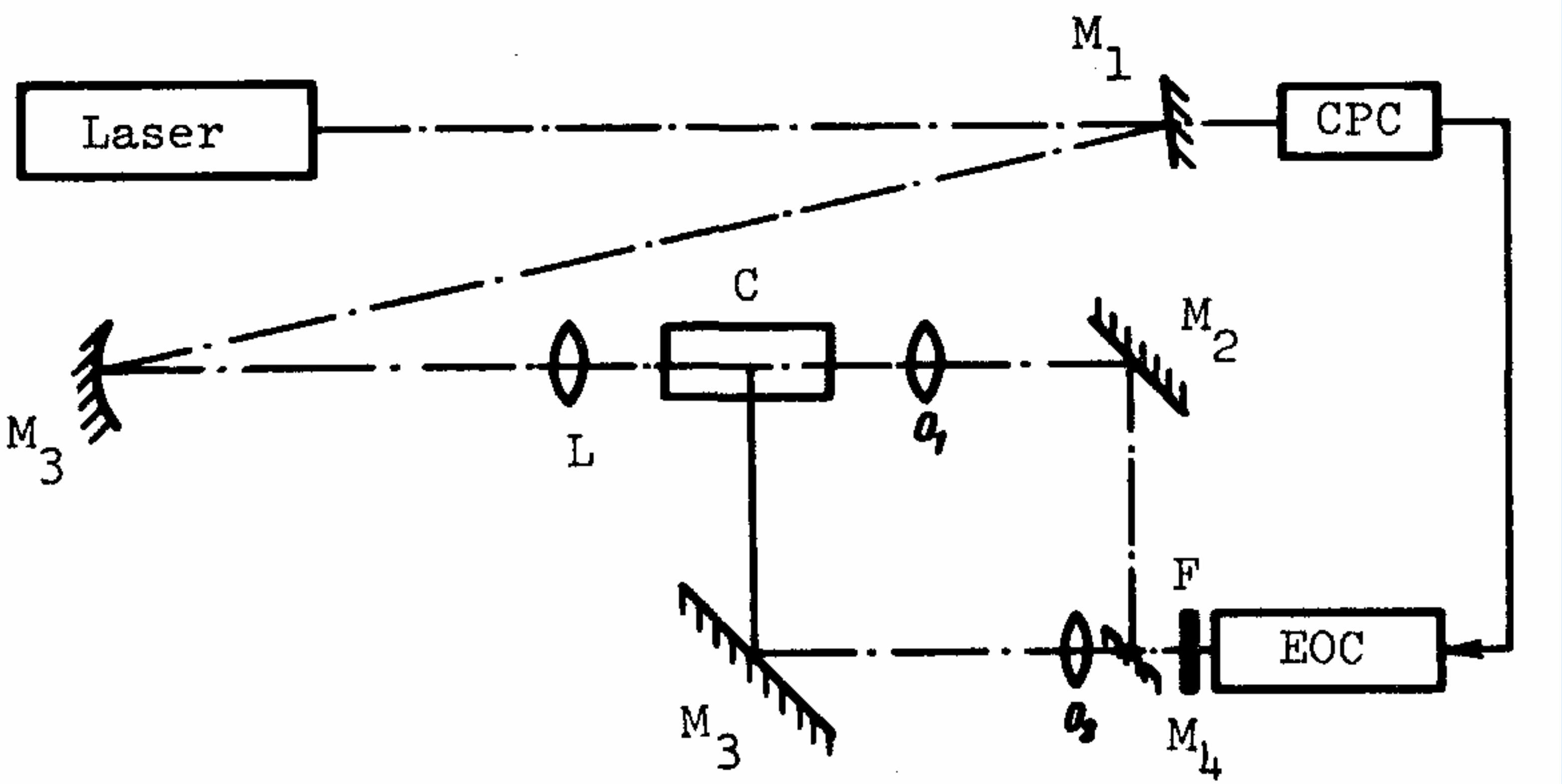
(a) Photograph of forward-scattered radiation. (b) Oscilloscope trace showing both the incident laser pulse and the forward-scattered pulse.

Michael M. T. Loy and Y. R. Shen.
Phys. Rev. Letters. 22, 994 (1969).



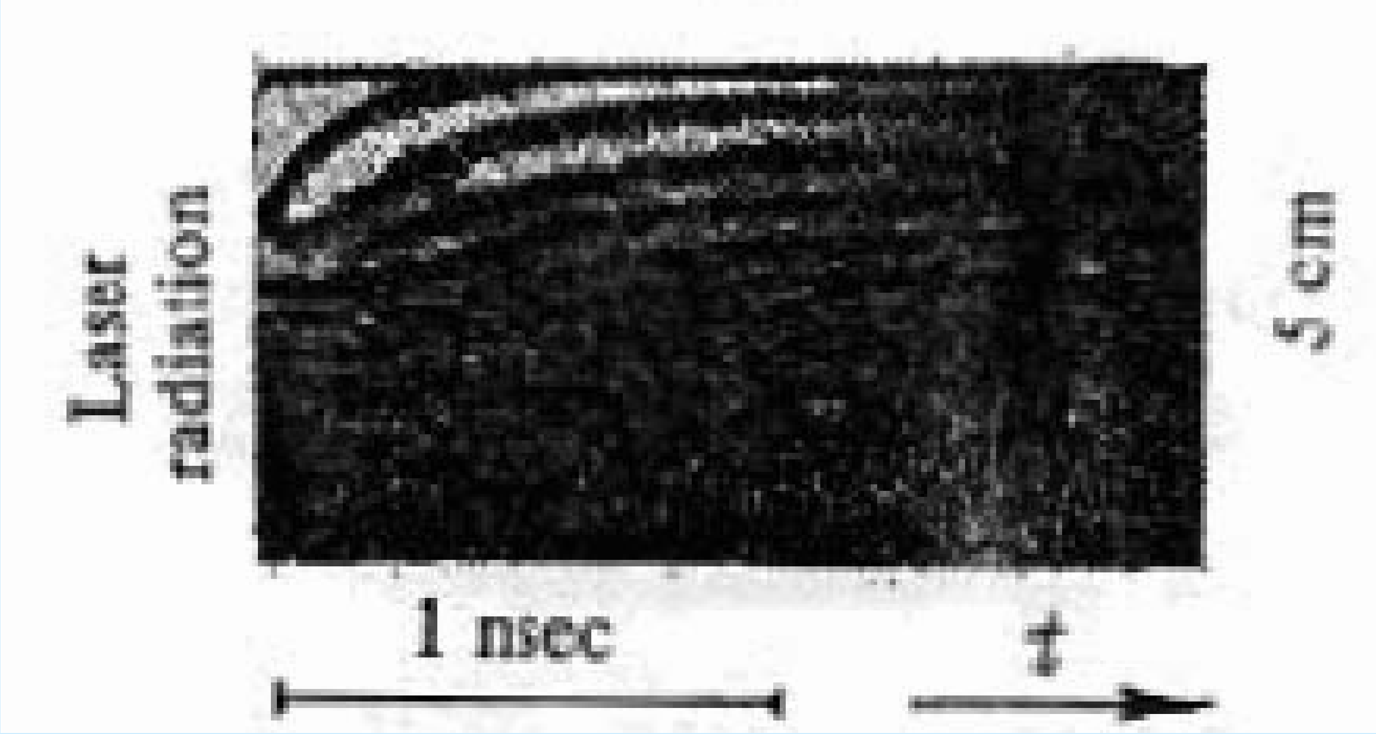
(a) A typical oscilloscope trace (5 nsec/div) of an input laser pulse. (b) A Fabry-Perot pattern (1.25-cm spacing between plates) of an input laser pulse. (c) A typical "filament" in toluene. The picture was taken by focusing the camera at the end of the cell with a 125X magnification. 994

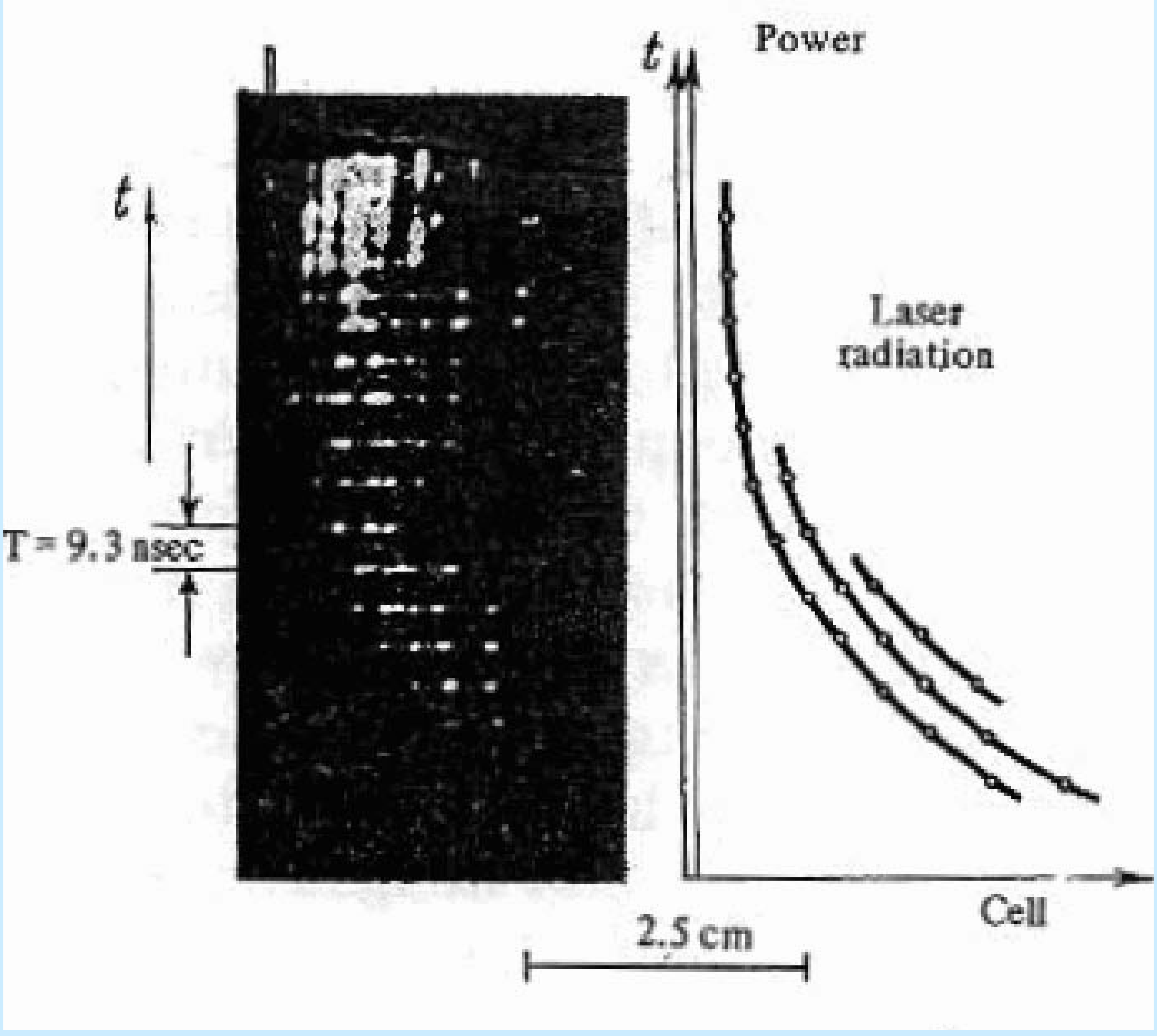
[Korobkin V.V., Prokhorov A.M., Serov R.V., Schelev M.Ya.
Pis'ma Zh. Eksp. i Teor. Fiz. 11, 153, (1970)
[JETP Lett. 11 94 (1970)]



Experimental setup: EOC – electron-optical converter, CPC – coaxial photocell to trigger the EOC, C – cell with investigated substance, M_1 – light-delay mirror, M_2 and L – telescopic system, O_1 and O_2 – objectives, M_3 – flat mirror, M_4 – removable flat mirror used when the cell is photographed from the rear. F – light filter for λ = 6943 Å.

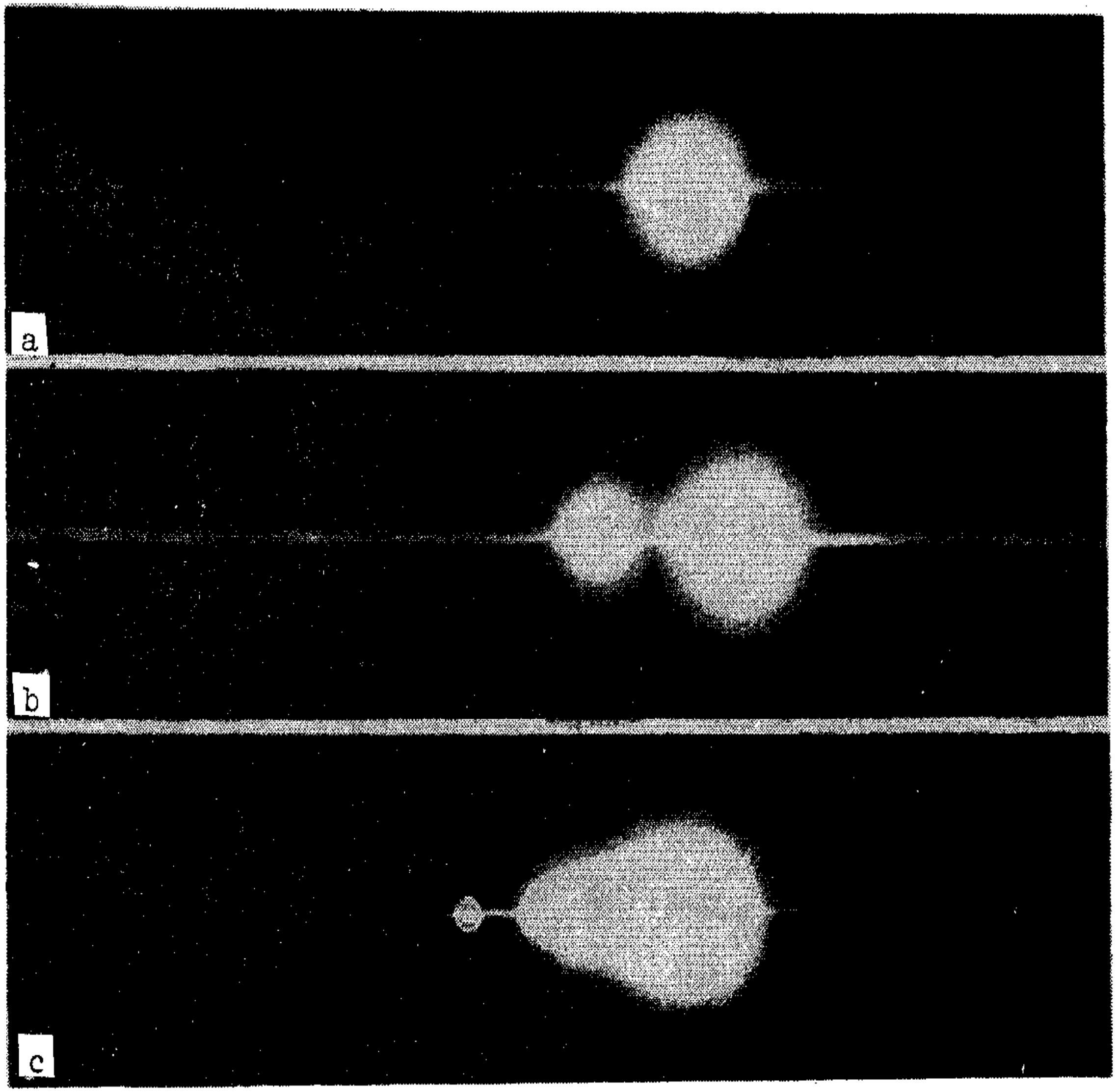
Korobkin V.V., Prokhorov A.M., Serov R.V., Schelev M.Ya.
Pis’ma Zh. Eksp. i Teor. Fiz. 11, 153, (1970)
[JETP Lett. 11 94 (1970)]





t
T = 9.3 nsec
t
Power
Laser
radiation
Cell
2.5 cm

Lipatov N. I., Manenkov A. A., Prokhorov A.M
Pis’ma Zh. Eksp. i Teor. Fiz. 11, 444, (1970)
[JETP Lett. 11 300 (1970)]



Pattern of scattering of laser radiation (rectangular pulse) in Tf-105 glass at different values of power: a) $\eta = P_i/P_d \approx 1$; b) $\eta \simeq 3$, distance between scattering centers ∿5 mm; c) $\eta \simeq 6$. Bright scattering halos are seen around the damage points, as well as a weak trace of the ordinary scattering in the glass. The laser beam propagates from left to right.

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Experimental studies examining a new relativistic regime of high-intensity short-pulse propagation in plasmas have been performed which present evidence for the formation of a stable mode of spatially confined (channeled) propagation. For an electron density of $\sim 1.35\times 10^{21}$ cm^{-3} and a power of $\sim 3\times 10^{11}$ W, the results indicate a channel radius < 1 μm and a peak intensity $\sim 10^{19}$ W/cm^2. Comparison of these findings with a dynamical theory yields agreement for both the longitudinal structure and the radial extent of the propagation observed.

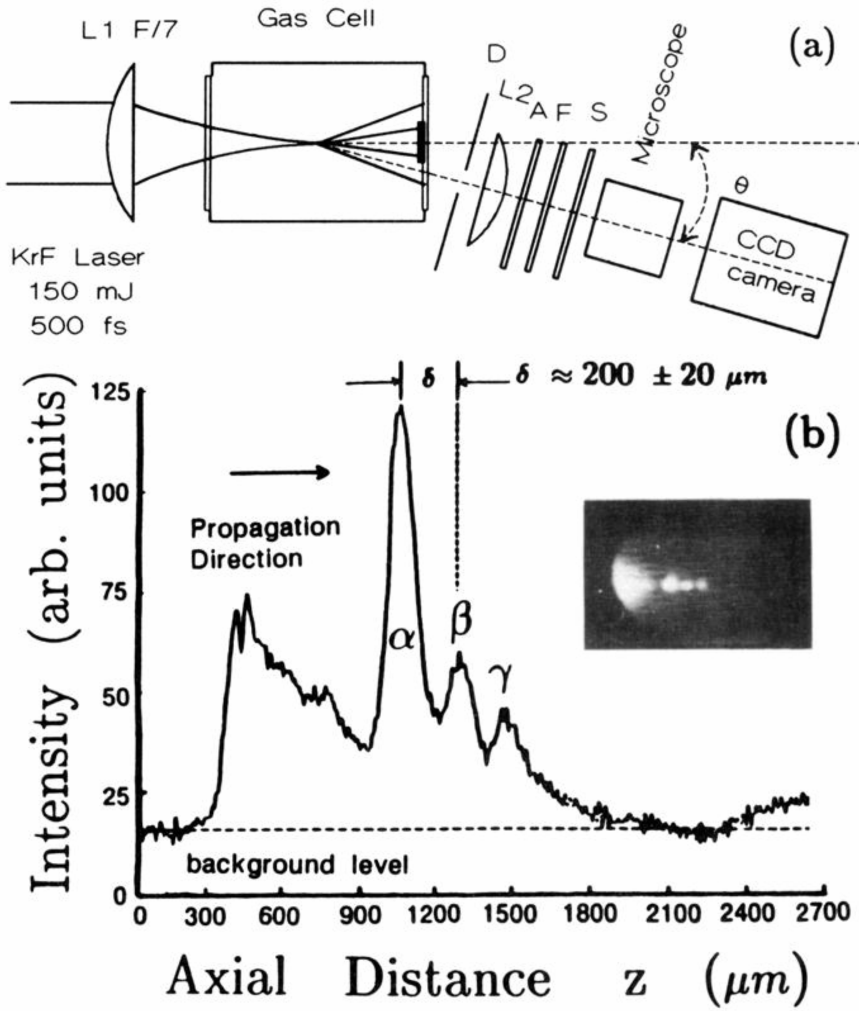


FIG. 1. (a) Experimental apparatus used in studies of propagation. See text for description. (b) Data concerning the pattern of propagation observed with a single pulse in N_2 at a density of $\sim 1.35 \times 10^{20}$ cm^{-3}. The maximum intensity is half the detector (CCD) saturation. The radiation is incident from the left. Inset: Photographic data with a vertical spatial resolution of ~ 10 μm. The graph illustrates the one-dimensional axial profile taken along the direction of propagation (z) of the photographic data (inset). The spacing of the maxima, $\delta \simeq 200 \pm 20$ μm, is indicated.

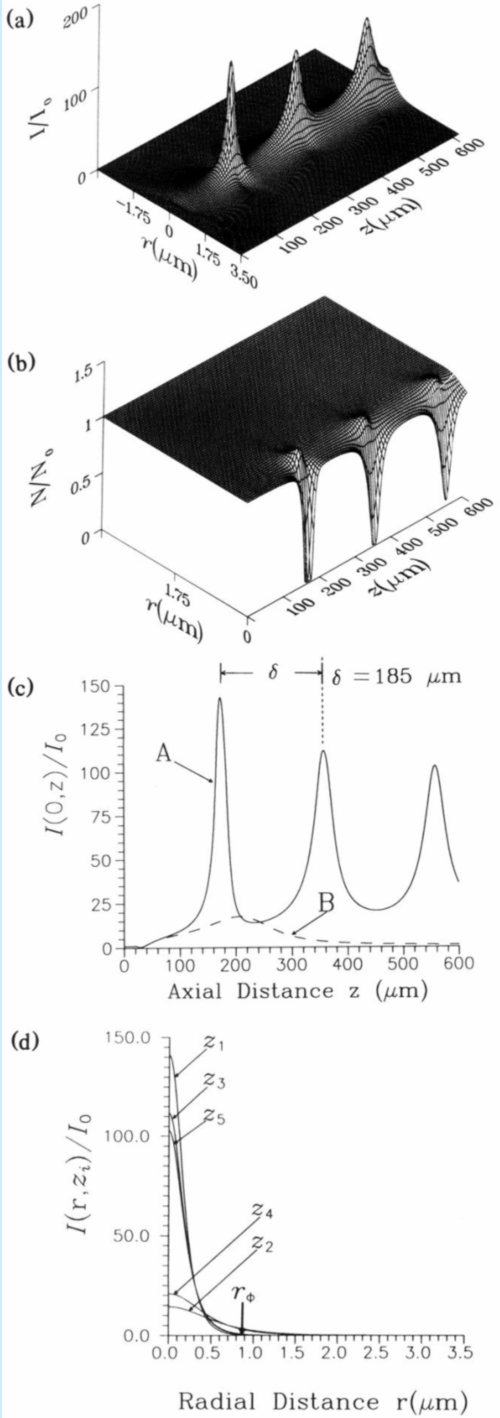
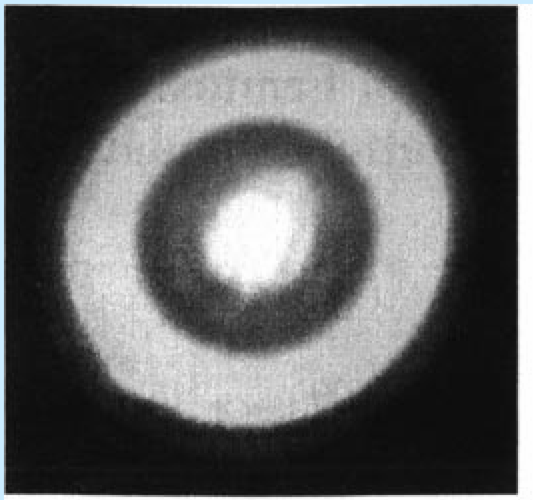
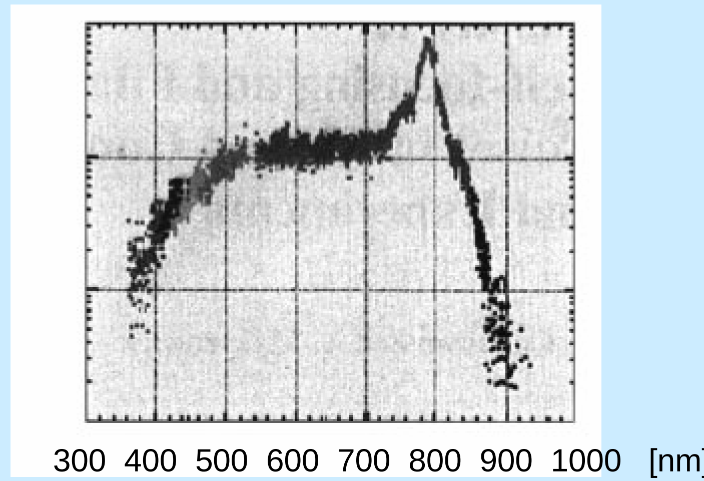


FIG. 2. Calculations for N_2 with $P=3\times10^{11}$ W, $r_0=3.5$ μm, $n_e=1.35\times10^{21}$ cm^{-3}, and $I_0=8.6\times10^{17}$ W/cm^2. (a) Normalized intensity $I(r,z)/I_0$. (b) Normalized electron density $N(r,z)/N_0$ for N_2 with $N_0=n_e$. (c) Normalized one-dimensional axial intensity profiles $I(0,z)/I_0$. Curve *A*, full theory for data in panel (a), $\delta=185$ μm. Curve *B*, calculation with charge-displacement term neglected. (d) Normalized radial intensity profiles $I(r,z_i)/I_0$ corresponding to panel (a). Longitudinal positions $z_1=172$ μm, $z_2=245$ μm, $z_3=358$ μm, $z_4=441$ μm, and $z_5=559$ μm and $r_\phi=0.9$ μm.

Couairon A, Mysyrowicz A, in Self-focusing: Past and Present (Eds RWBoyd, S G Lukishova, Y R Shen) (New York: Springer, 2009) Ch. 12, p. 297





$\Lambda =$ 800 nm, $\tau =$ 70 fs, P = 3 TW), L = 10 m

SOME POSSIBLE APPLICATIONS

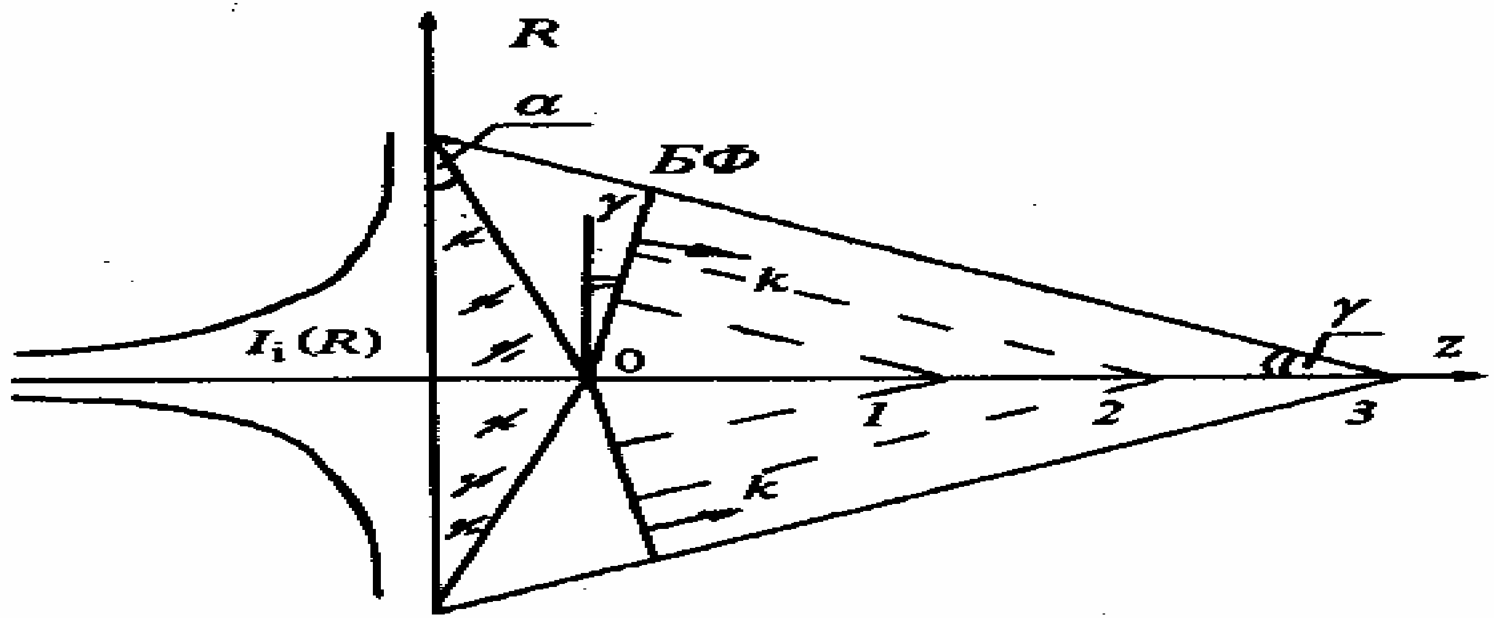
1. INCREASING THE SELF-CHANNELING PULSE PROPAGATION LENGTH VIA AN EXTERNAL SOURCE OF ENERGY [AXICON LENS].
2. X-RAY LASER
3. GENERATION OF STRONG MAGNETIC FIELDS
4. GENERATION OF ELECTRON-POSITRON PAIRS

INCREASING THE SELF-CHANNELING PULSE PROPAGATION

The self-channeling pulse propagation length L is determined by energy losses. The energy loss mechanisms arenumerous. Let us list a few of them: ionization and excitation of the atoms and ions of the medium, reverse braking absorption,generation of plasma oscillations, harmonicgeneration, scattering of radiation by turbulence in the plasma and by the plasma oscillations, partial defocusing of the radiation due to refraction by a nonuniform transverse electron density profile, generation of spontaneous magnetic fields, etc.

An important circumstance in all this is the fact that the walls of the cavitation region that exist inside the traveling pulse can be partially transparent to the laser radiation propagating in it. The reason is that the walls can oscillate with the plasma frequency wp, since with the formation of the cavity the electrons are repelled in the transverse direction by the ponderomotive force while the Coulomb attraction force, due to ions remaining in the channel, pulls them back.

The partial transparency of the cavity walls can be used to allow additional energy into the cavity from the region surrounding it. For this purpose, the wavefront of the laser radiation should have a phase component in the form of a cone. Replenishment of the electromagnetic wave inside the cavity might be possible by means of axicon focusing of the laser With external replenishment, one might hope to obtain much longer selfchanneling lengths.



R
α
БФ
γ
k
$I_1(R)$
O
1
2
3
γ
z
k

X-RAY LASER

In the self-channeling regime the pulse leaves behind a long narrow filament of plasma consisting of multiply charged ions mainly in excited states and free electrons. In the very near future it may be possible to obtain long plasma filaments, which is sufficient for the generation of stimulated x-ray emission.

Four different mechanisms of such generation are possible.

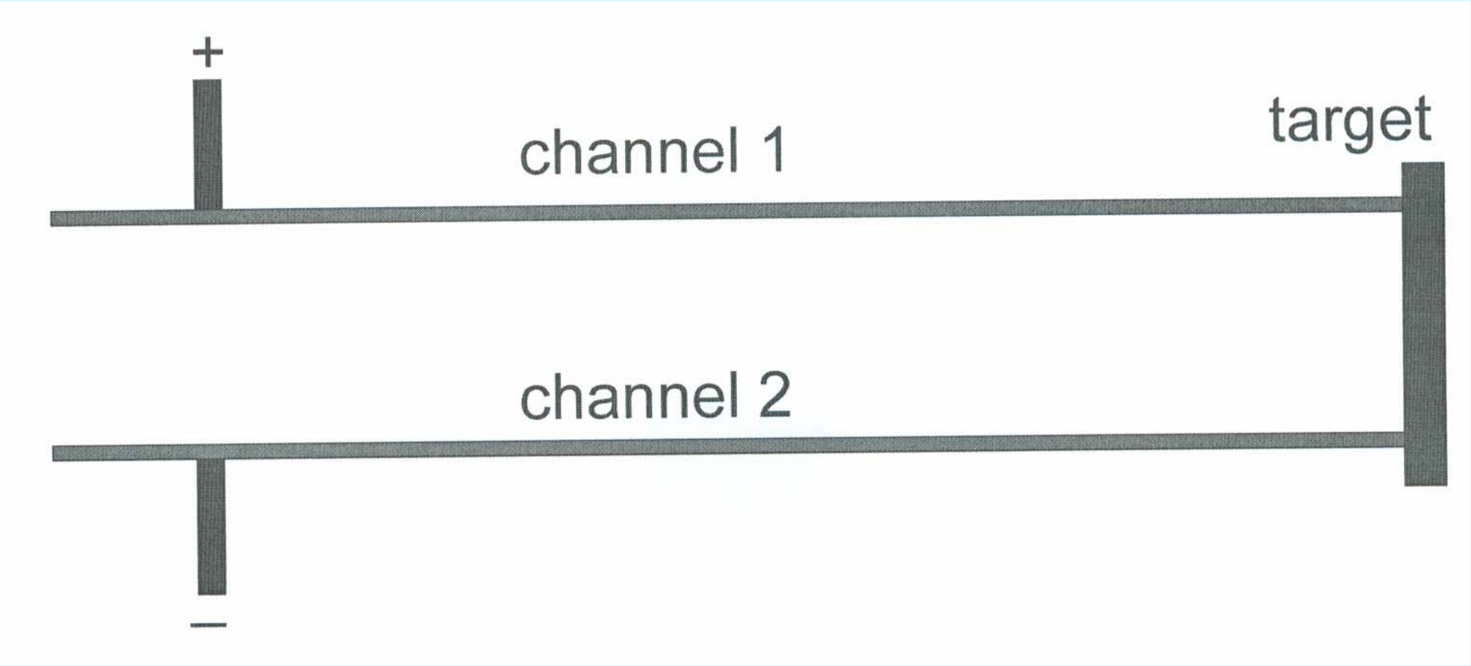
The first is due to multiphoton excitation of multiply charged ions with subsequent stimulated emission. This mechanism ensures good selectivity of the corresponding levels and has probably been observed in a xenon plasma.

The second mechanism is the so-called self-excitation of the internal electron shells of the ions by collisions withthe outer electrons that belong to the same atom and oscillate with relativistic energies sufficient for inelastic processes.This mechanism leads to the appearance of holes in the electron shells. Subsequent dynamics of the holes undera favorable course of events can lead to population inversion of certain transitions.

The third mechanism is ordinary three-particle recombinationof electrons and ions in the plasma filament leftbehind the pulse. This process usually populates the upperlevels of the working ions, and in conjunction with radiativedepletion of the lower levels leads to populationinversion.

A possible fourth mechanism may be optical pumping of the surrounding gas by soft x rays emitted by the plasma filament. In this regard, selective photoionization of subvalence electron shells of heavy atoms in the ambient gas may be promising.

ELECTRIC DISCHARGE IN CHANNELS



СПАСИБО ЗА ВНИМАНИЕ

THANK YOU FOR YOUR ATTENTION