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UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/449-44

**WINTER COLLEGE ON
HIGH RESOLUTION SPECTROSCOPY**

(8 January - 2 February 1990)

CHAOS IN LASERS AND BISTABILITY

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PATTERNS AND DYNAMICS IN [illegible]

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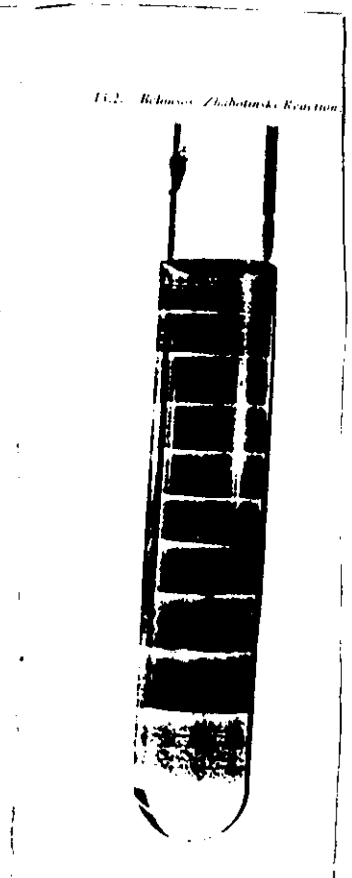
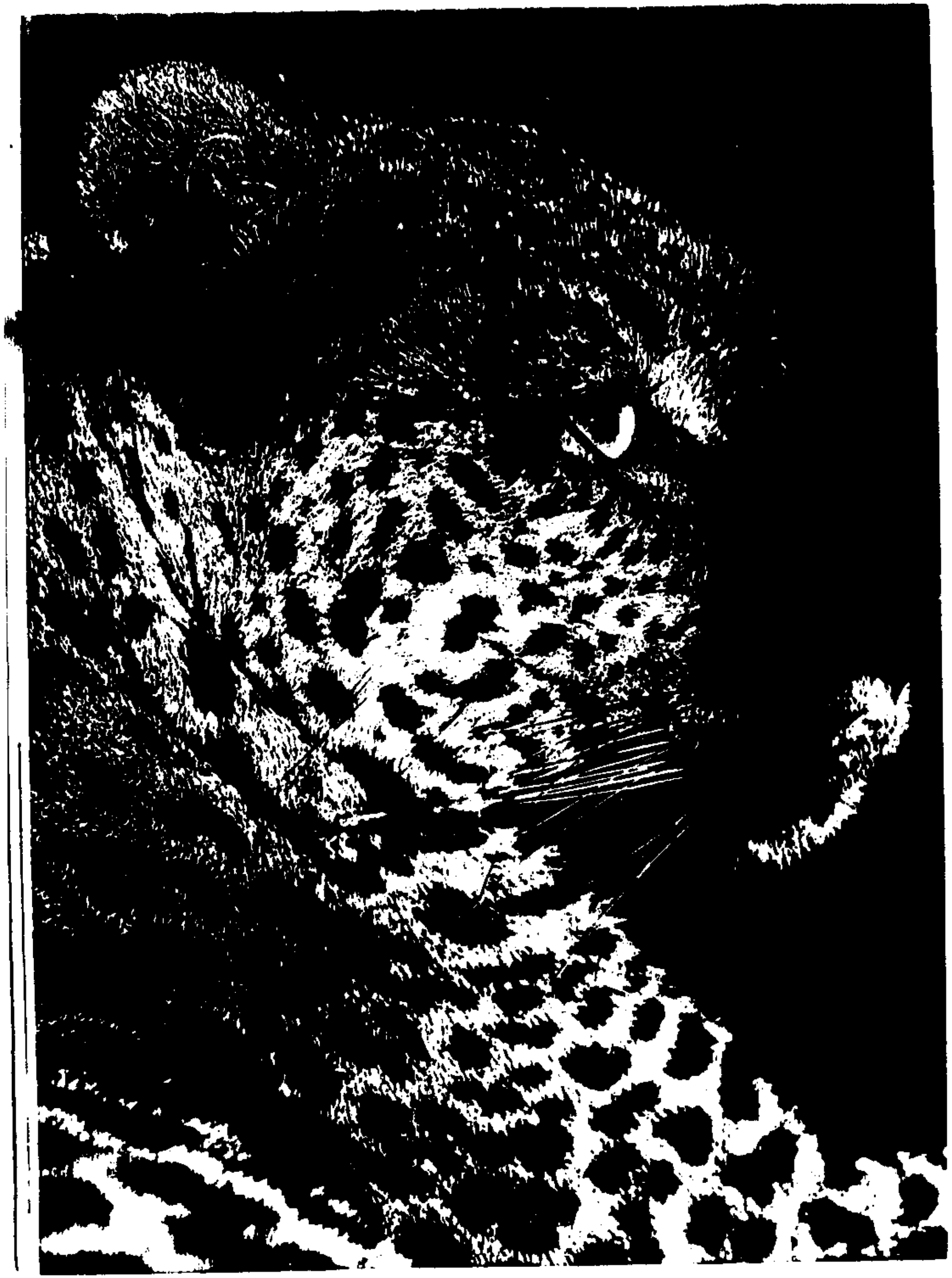


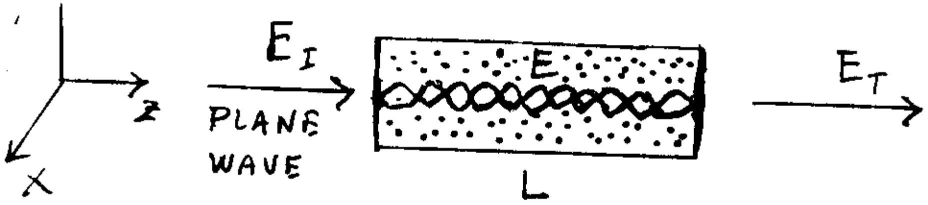
BELUSOV - ZHABOTINSKI - REACTION



OPTICAL [illegible]

OPTICAL LEOPARD

OPTICAL TURING INSTABILITY



FIELD $E \sin(k_z z) e^{-i\omega_0 t} + c.c.$

$k_z = \frac{\pi}{L} n_z$ $\quad$ ω_0 = INPUT FIELD FREQUENCY

KERR MEDIUM

$$\frac{dE}{dt} = -K \left\{ E - E_I - iE\left(|E|^2 - \theta\right) \right\}$$

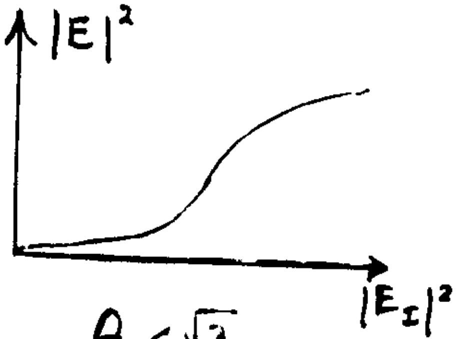
$K = \frac{cT}{2L}$ CAVITY DAMPING CONSTANT = CAVITY LINEWIDTH

T = TRANSMISSIVITY COEFFICIENT of MIRRORS

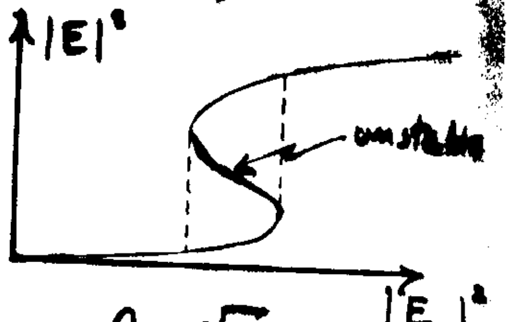
θ = DETUNING PARAMETER

STEADY - STATE EQUATION

$$|E_I|^2 = |E|^2 \left\{ 1 + \left(|E|^2 - \theta\right)^2 \right\}$$



$\theta < \sqrt{3}$



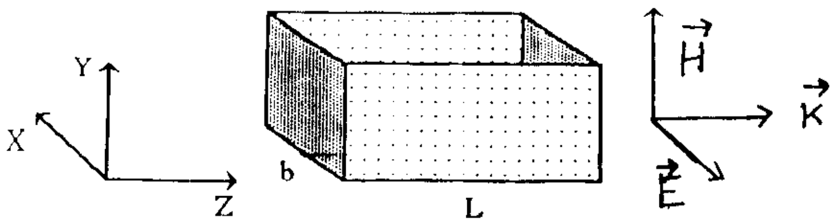
$\theta > \sqrt{3}$

INCLUSION OF DIFFRACTION

$$\frac{\partial E(x,y,t)}{\partial t} = -K \left\{ E - E_I - iE\left(|E|^2 - \theta\right) \right\} + i\frac{c}{2k_z}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) E(x,y,t)$$

THE TRANSVERSALLY HOMOGENEOUS STATIONARY SOLUTION MAY BECOME UNSTABLE UNDER TRANSVERSALLY NONUNIFORM PERTURBATIONS

WE ADD TO THE CAVITY 2 PERFECTLY REFLECTING MIRRORS ORTHOGONAL TO THE AXIS x



CAVITY MODES [illegible]

$K_x =$ [illegible]

[illegible] INTEGER

[illegible] NUMBERS

ONE LONGITUDINAL MODE : [illegible]

TRANSVERSE MODES : [illegible]

$$\mathcal{E}(x,z,t) = E(x,t)\, e^{-i\omega_0 t} \sin(K_z z) + c.c.$$

$$E(x,t) = \sum^{\infty} f(t) \cos(\pi n \tfrac{x}{\ })$$

$$\omega = c\left(K_x^2 + K_z^2\right)^{1/2} = cK_z\left(1 + \frac{K_x^2}{K_z^2}\right)^{1/2}$$

FOR $K_x \ll K_z$ $\quad \omega = cK_z\left(1 + \frac{K_x^2}{2K_z^2}\right)$

$$\mathcal{F} = \frac{b^2}{\lambda L} \quad \text{FRESNEL NUMBER}$$

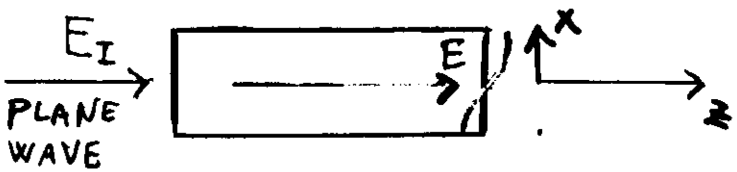
ONE OBTAINS $\left(a(n) = a\pi^2 n^2 \right)$ $\quad a = \frac{1}{2\pi\mathcal{F}T}$

$$\omega = \frac{\pi c}{L} n_z + K a(n)$$

LONGITUDINAL $\qquad$ TRANSVERSE

WE SHOW THAT UNDER APPROPRIATE CONDITIONS TRANSVERSE MODES WITH $n = 1, 2, \ldots$ CAN BECOME UNSTABLE AND GIVE RISE TO A TRANSVERSALLY NONUNIFORM STATIONARY SOLUTION, OF TYPE

$$E = \sum_n f_n \cos\left(\frac{\pi}{b} n x\right)$$



$$t' = \kappa t = \frac{cT}{2L} t \quad , \quad x' = \frac{x}{b}$$

$$\frac{\partial E}{\partial t'} = -E + E_I + iE\left(|E|^2 - \theta\right) + ia \frac{\partial^2 E}{\partial x'^2}$$

$$k_z = \frac{2\pi}{\lambda} \quad , \quad a = \frac{1}{2\pi \mathcal{F} T} \quad , \quad \mathcal{F} = \frac{b^2}{\lambda L}$$ FRESNEL NUMBER

LINEAR STABILITY ANALYSIS

$$E = E_s + \delta E$$
$$E^* = E_s^* + \delta E^*$$

$$\frac{\partial \delta E}{\partial t'} = -\delta E + i\left(2|E_s|^2 - \theta\right)\delta E + i E_s^2 \delta E^* + ia \frac{\partial^2 \delta E}{\partial x'^2}$$

$$\frac{\partial \delta E^*}{\partial t'} = -\delta E^* - i\left(2|E_s|^2 - \theta\right)\delta E^* - i\left(E_s^*\right)^2 \delta E - ia \frac{\partial \delta E^*}{\partial x'^2}$$

ANSATZ $\begin{pmatrix} \delta E \\ \delta E^* \end{pmatrix} = e^{\lambda t'} \cos \pi n x' \begin{pmatrix} \delta E_n \\ \delta E_n^* \end{pmatrix}$

$$\left(A - \lambda \mathbb{1}\right)\begin{pmatrix} \delta E_n \\ \delta E_n^* \end{pmatrix} = 0$$

$$A = \begin{pmatrix} -1 + i\left[2|E_s|^2 - \theta - a(n)\right] & i E_s^2 \\ -i\left(E_s^*\right)^2 & -1 - i\left[2|E_s|^2 - \theta - a(n)\right] \end{pmatrix}$$

$$a(n) = a\pi^2 n^2$$

$$\det\left(A - \lambda \mathbb{1}\right) = 0$$

EIGENVALUE EQUATION

$$\lambda^2 + 2\lambda + c\left[a(n), |E_s|^2, \theta\right] = 0$$

INSTABILITY FOR $\mathrm{Re}\,\lambda > 0$

$$\lambda = -1 \pm (1-c)^{1/2}$$

INSTABILITY FOR $c < 0$: A REAL EIGENVALUE BECOMES POSITIVE

$$c = 1 + \left(|E_s|^2 - \theta\right)\left(3|E_s|^2 - \theta\right)$$

$$+ a(n)\left[a(n) - 2\left(2|E_s|^2 - \theta\right)\right]$$

LINEAR STABILITY ANALYSIS

$$E = E_s + \delta E \quad , \quad E^* = E_s^* + \delta E^*$$

ANSATZ $\begin{pmatrix} \delta E \\ \delta E^* \end{pmatrix} = e^{\lambda t'} \cos(\pi n x') \begin{pmatrix} \delta E_n \\ \delta E_n^* \end{pmatrix}$

$$a(n) = a\pi^2 n^2$$

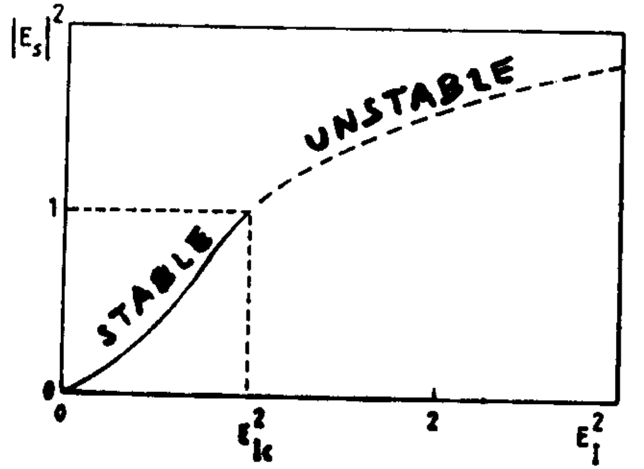
RESULT : FOR $|E_s|^2 > 1$ THE STATIONARY STATE IS UNSTABLE PROVIDED AT LEAST ONE OF THE NUMBERS $a(n)$ LIES IN THE RANGE

$$a^{(-)} < a(n) < a^{(+)}$$

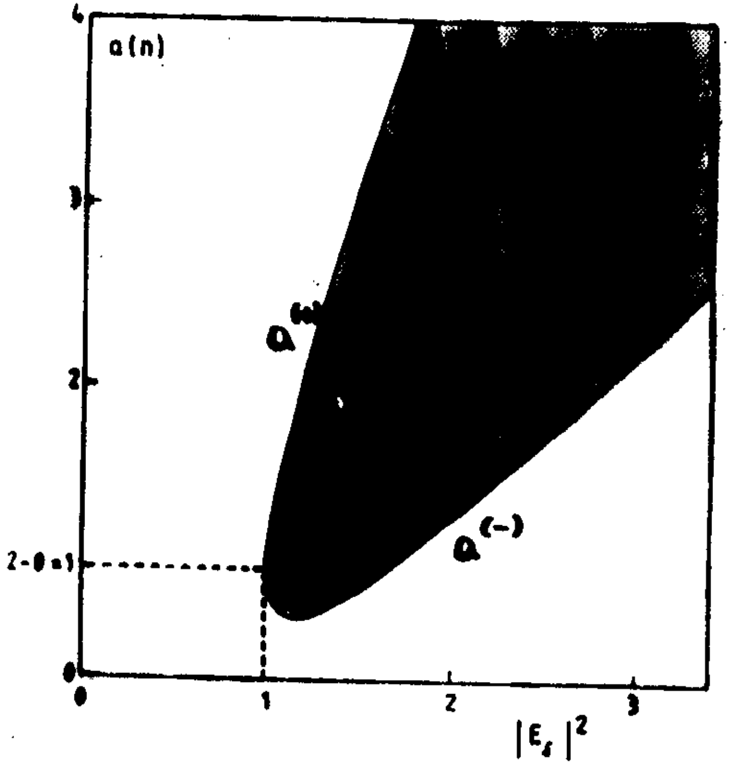
$$a^{(\pm)} = 2|E_s|^2 - \theta \pm \left(|E_s|^4 - 1\right)^{1/2}$$

TRANSVERSALLY HOMOGENEOUS STEADY-STATE

$\theta = 1$



$$\theta = 1 \; ; \quad a^{(\pm)} = 2|E_s|^2 - \theta \pm \sqrt{|E_s|^4 - 1}$$



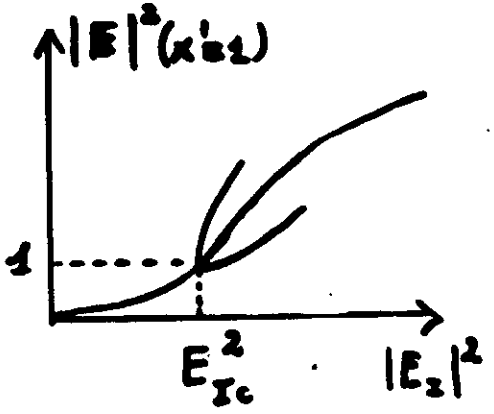
$E_1 = \mathrm{Re}\, E \qquad E_2 = \mathrm{Im}\, E$

$$\begin{cases} E_{1,st} = \dfrac{E_I}{1+(|E_{st}|^2-\theta)^2} \\ E_{2,st} = E_{1,st}\left(|E_{st}|^2-\theta\right) \end{cases}$$

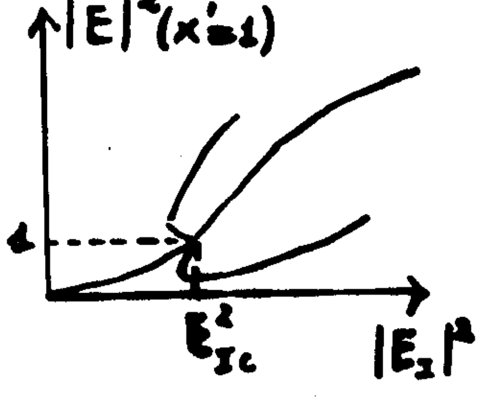
$E_1 = E_{1,st} + u(x') \qquad E_2 = E_{1,st} + v(x')$

$|E_{st}|_c^2 = 1$

$E_{Ic}^2 = 1 + (1-\theta)^2 \qquad (n_c \pi)^2 = \dfrac{2-\theta}{a}$



SUPERCRITICAL

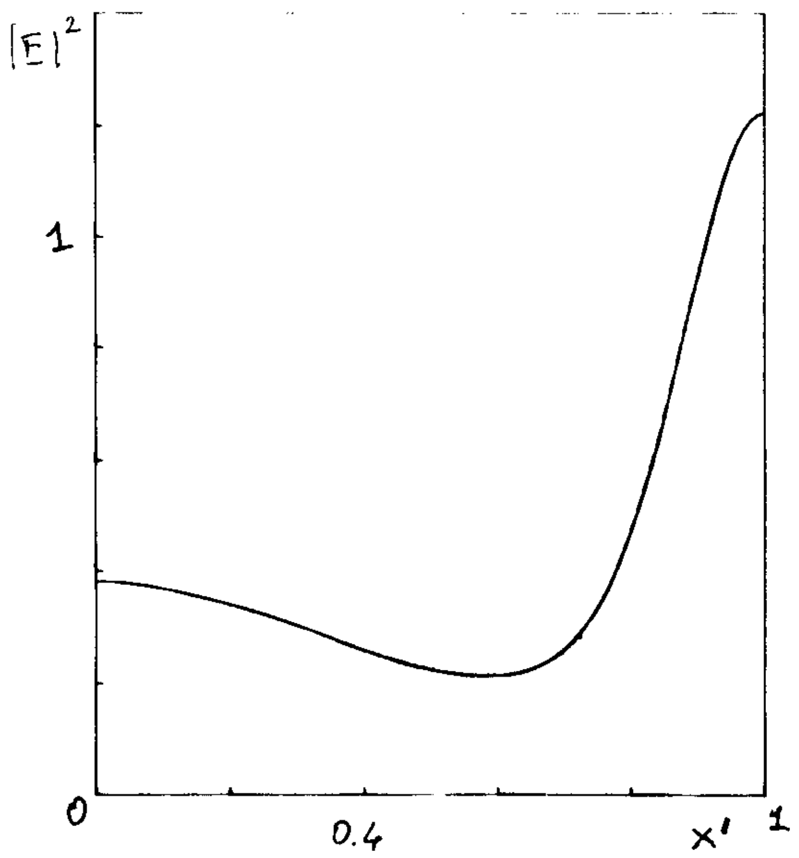


SUBCRITICAL

5

THE OPTICAL ZEBRA

$\theta = 1.6$, $a\pi^2 = 0.4$, $|E_s|^2 = 1.4$



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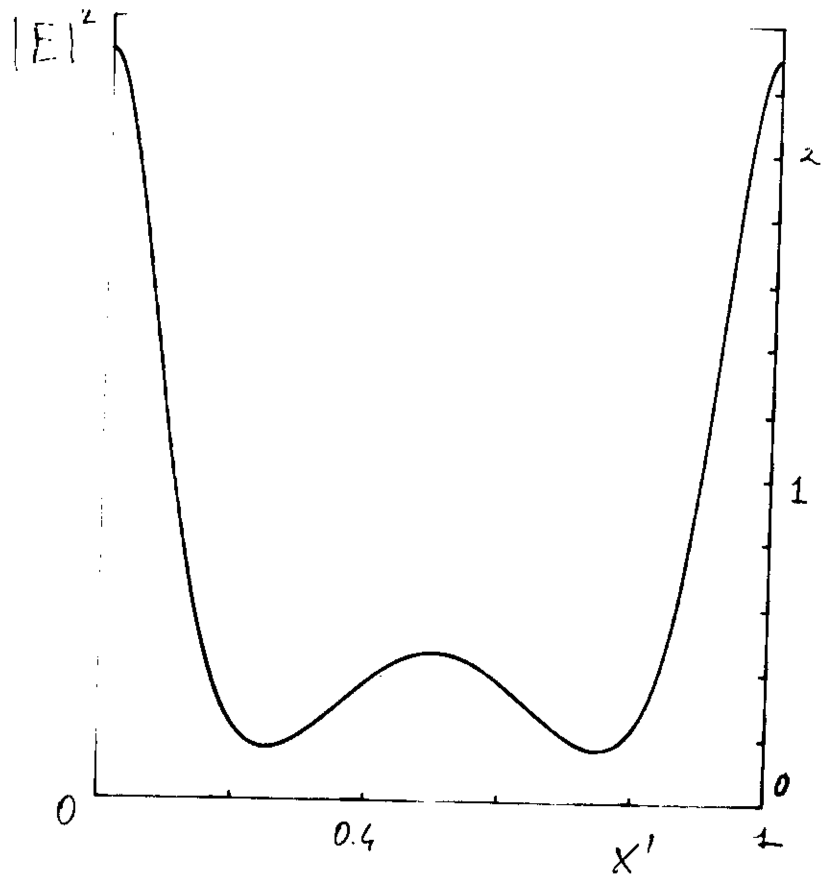
OPTICAL TURING INSTABILITY

$\theta = 1.6$ $a\pi^2 = 0.4$ $|E_s|^2 = 2.45$



SPATIO-TEMPORAL INSTABILITIES IN LASERS

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G. TREDICCE

1D

- SPONTANEOUS SPATIAL PATTERN FORMATION (SPONTANEOUS BREAKING OF THE TRANSLATIONAL SYMMETRY)
- COOPERATIVE FREQUENCY LOCKING
- SPATIO-TEMPORAL OSCILLATIONS

THEORY + EXPS

2D

- SPONTANEOUS BREAKING OF THE CYLINDRICAL SYMMETRY
- SPATIAL MULTISTABILITY
- OPTICAL VORTICES

THE SINGLEMODE LASER MODEL

$$\frac{dE}{dt} = -\kappa\left\{(1-i\Delta)E - 2CP\right\}$$

ATOMIC POLARIZATION $$\frac{dP}{dt} = -\gamma_\perp\left\{(1+i\Delta)P - ED\right\}$$

POPULATION INVERSION $$\frac{dD}{dt} = -\gamma_\parallel\left\{D - 1 + \frac{1}{2}\left(E^*P + EP^*\right)\right\}$$

κ = CAVITY LINEWIDTH

$\gamma_\perp$ = ATOMIC LINEWIDTH (HOMOGENEOUS BROADENING)

C = PUMP PARAMETER

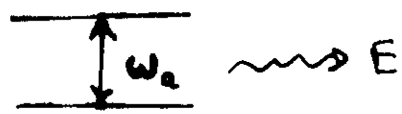
ELECTRIC FIELD $$\mathcal{E}(z,t) = E(t)\, e^{-i\omega_0 t} \sin(K_z z) + c.c.$$

$$K_z = \frac{\pi}{L} n_z$$

ω_0 = OSCILLATION FREQUENCY OF THE LASER ABOVE THRESHOLD

$$\Delta = \frac{\omega_0 - \omega_c}{\kappa} = \frac{\omega_a - \omega_0}{\gamma_\perp} \quad \text{DETUNING PARAMETER}$$

$$\omega_c = c K_z$$



$$\omega_0 = \frac{\kappa\omega_a + \gamma_\perp\omega_c}{\kappa + \gamma_\perp} \quad \text{MODE-PULLING FORMULA}$$

STATIONARY SOLUTIONS

1) TRIVIAL SOLUTION $E=0$, $P=0$, (NO LASER EMISSION) $D=1$

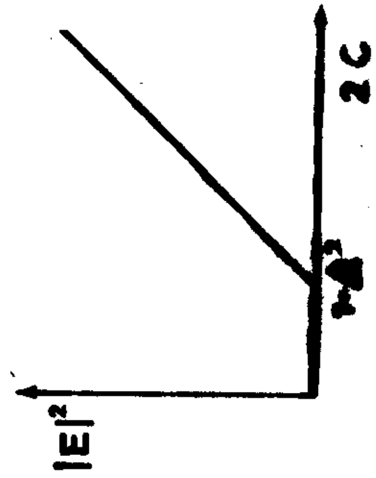
2) NONTRIVIAL SOLUTION

$$|E|^2 = 2C - 1 - \Delta^2 \qquad P = \frac{1-i\Delta}{2C}E$$

PHASE OF E ARBITRARY

$$D = \frac{1+\Delta^2}{2C}$$

LASER THRESHOLD $2C = 1+\Delta^2$



IN THE RESONANT CASE **$\Delta = 0$** THE SINGLEMODE LASER MODEL IS EQUIVALENT TO THE **LORENZ** MODEL (LORENZ-HAKEN MODEL)

IF $\quad K > \gamma_\perp + \gamma_\parallel$ (BAD-CAVITY CONDITION)

AND $$2C > 2C_{crit} = 1 + \frac{(K+\gamma_\perp+\gamma_\parallel)(K+\gamma_\perp)}{\gamma_\perp(K-\gamma_\perp-\gamma_\parallel)}$$

THE LASER DEVELOPS SPONTANEOUS OSCILLATIONS (LORENZ CHAOS)

IN THE PARAXIAL APPROXIMATION, DIFFRACTION IS DESCRIBED BY INCLUDING IN THE FIELD EQUATION THE TERM

$$\frac{ic}{2k_z} \nabla_T^2 E$$

$$\nabla_T^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$$

LASER

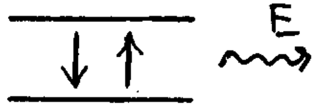
PUMP PARAMETER

$$\frac{\partial E}{\partial t} = -\kappa \left\{ (1 - i\Delta) E - 2\overset{\downarrow}{C} P - i a \frac{\partial^2 E}{\partial x'^2} \right\}$$

$$\frac{\partial P}{\partial t} = -\gamma_\perp \left\{ (1 + i\Delta) P - E D \right\}$$

$$\frac{\partial D}{\partial t} = -\gamma_\parallel \left\{ D - 1 + \frac{1}{2}\left(E^* P + E P^* \right) \right\}$$

$x' = \frac{x}{b}$ $\quad a = \frac{1}{2\pi T \mathcal{F}}$



TWO-LEVEL ATOM

NEGLECTING DIFFRACTION $(a = 0)$

$\Longrightarrow$ HAKEN - LORENZ MODEL

TRANSVERSALLY HOMOGENEOUS STATIONARY SOLUTIONS

1) TRIVIAL SOLUTION $E = 0$
(NO LASER EMISSION)

2) NONTRIVIAL SOLUTION
$|E|^2 = 2C - 1 - \Delta^2$
PHASE OF E ARBITRARY

$$P = \frac{1 - i\Delta}{2C} E$$

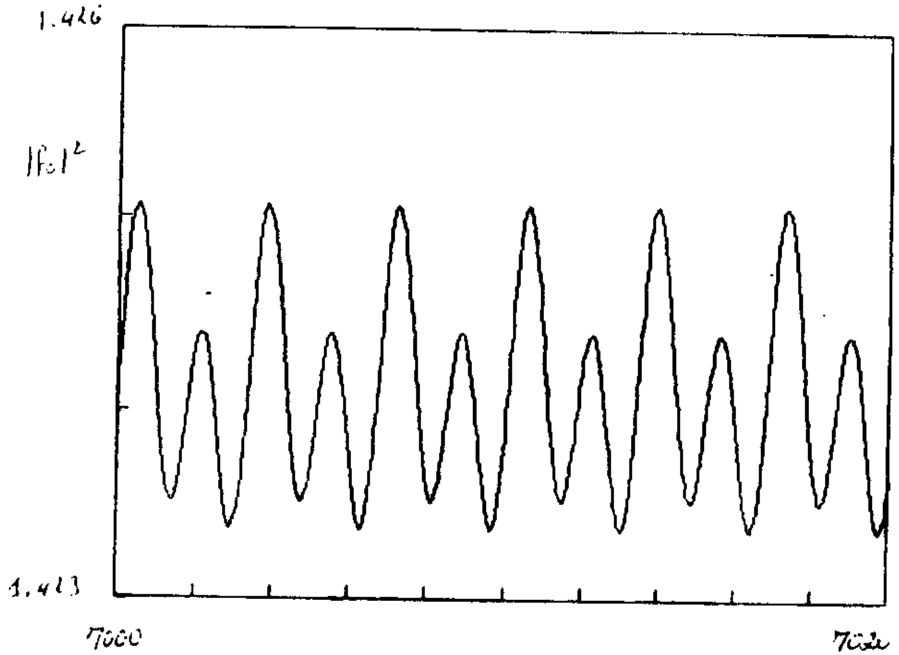
$$D = \frac{1 + \Delta^2}{2C}$$

LASER THRESHOLD $2C = 1 + \Delta^2$

$$E(x',t) = \sum_{n=0} f_n(t) \cos(\pi n x')$$

- THE TRANSVERSE MODES ARE LALELLED BY THE INDEX $n = 0, 1, 2, \ldots$
- THE MODE $n = 0$ IS TRANSVERSALLY HOMOGENEOU
- THE **FREQUENCY** OF MODE n IS

$$\omega_n = \omega_0 + \kappa\, a(n) \qquad a(n) = a\pi^2 n^2$$



LINEAR STABILITY ANALYSIS

$$E(x',t) = E_{st} + \delta E(x',t)$$
$$P(x',t) = P_{st} + \delta P(x',t)$$
$$D(x',t) = D_{st} + \delta D(x',t)$$

LINEARIZE THE SET OF DYNAMICAL EQUATIONS WITH RESPECT TO $\delta E, \delta P, \delta D$

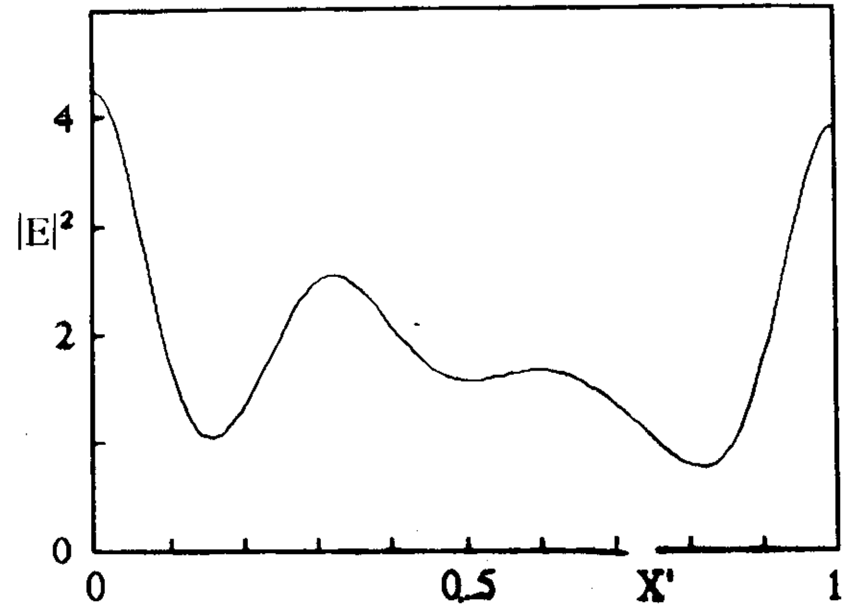
ANSATZ $$\begin{pmatrix} \delta E \\ \delta P \\ \delta D \end{pmatrix} = e^{\lambda t} \cos(\pi n x') \begin{pmatrix} \delta E_n \\ \delta P_n \\ \delta D_n \end{pmatrix}$$

$\Longrightarrow$ CHARACTERISTIC EQUATION FOR λ

$$\lambda^5 + c_1^{(n)} \lambda^4 + c_2^{(n)} \lambda^3 + c_3^{(n)} \lambda^2 + c_4^{(n)} \lambda + c_5^{(n)} = 0$$

THE COEFFICIENTS $c_i^{(n)}$ $(n = 1, \ldots, 5)$ ARE FUNCTIONS OF $a(n) = a\pi^2 n^2$ AND OF THE PARAMETERS $C, \Delta, \kappa, \gamma_\perp, \gamma_\parallel$

THE OPTICAL ZEBRA



$$\Delta = 0.6 \quad , 2C = 3.36$$

$$\frac{\kappa}{\gamma_\perp} = 0.1 \quad , \quad \frac{\gamma_\parallel}{\gamma_\perp} = 1 , \quad a(t) = 0.05$$

Fig 6.D
Lugiato et al

STATIONARY INTENSITY SOLUTIONS

$$E(x', t) = E_s(x')\, e^{-i\omega t}$$

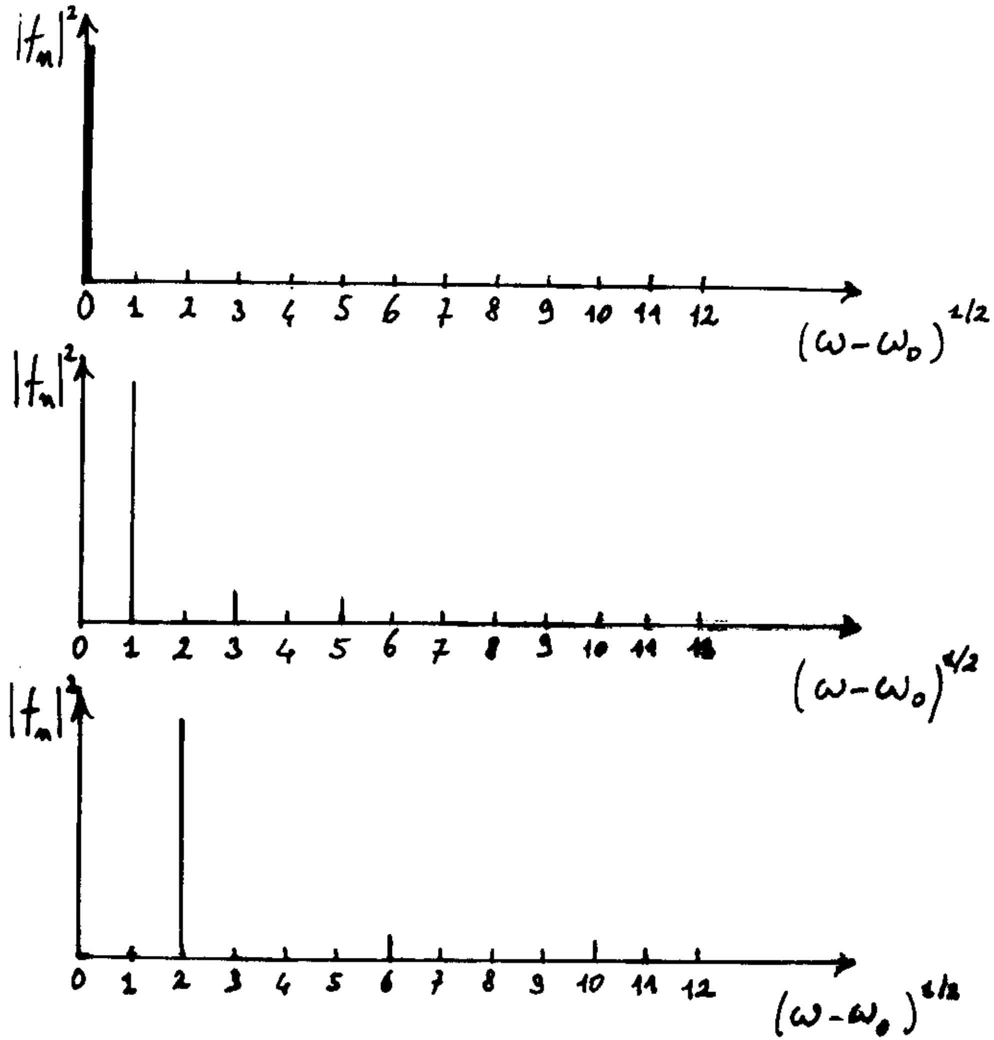
$$\text{INTENSITY} = |E(x', t)|^2 = |E_s(x')|^2 \quad \text{STATIONARY}$$

$$E(x', t) = \sum_{n=0}^{\infty} f_n(t) \cos(n\pi x')$$

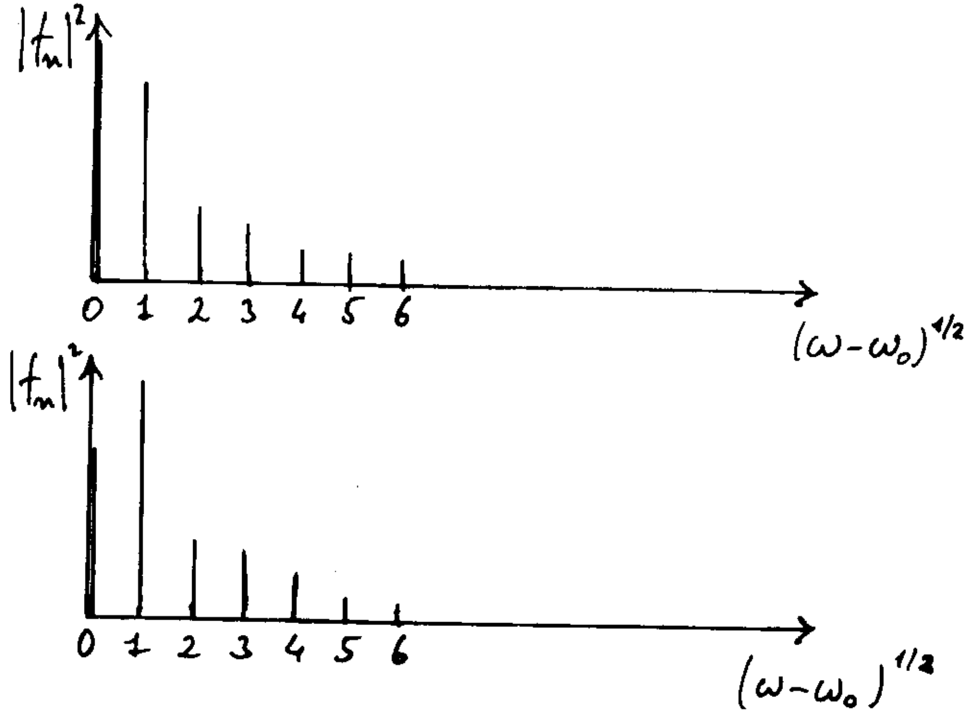
$$f_n(t) = f_{n,s}\, e^{-i\omega t}$$

$$|f_n(t)|^2 = |f_{n,s}|^2 \quad \text{STATIONARY}$$

SINGLEMODE SOLUTIONS



MULTIMODE STATIONARY SOLUTIONS



COOPERATIVE FREQUENCY LOCKING

OSCILLATION FREQUENCY = AVERAGE OF THE MODAL FREQUENCIES WEIGHTED OVER THE MODE INTENSITIES $|f_n|^2$

– SINGLE MODE OPERATION

$$E(\underset{\sim}{x},t) = f_n\, g_n(\underset{\sim}{x})\, e^{-i\omega_n t}$$

$$|E(\underset{\sim}{x},t)|^2 = |f_n|^2\, |g_n(\underset{\sim}{x})|^2$$

– MULTIMODE OPERATION

$$E(\underset{\sim}{x},t) = \sum_n f_n\, g_n(\underset{\sim}{x})\, e^{-i\omega_n t}$$

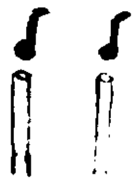
$$|E(\underset{\sim}{x},t)|^2 = \sum_{n,n'} f_{n'}^{*} f_n\, g_{n'}^{*}(\underset{\sim}{x})\, g_n(\underset{\sim}{x})\, e^{-i(\omega_n-\omega_{n'})t}$$

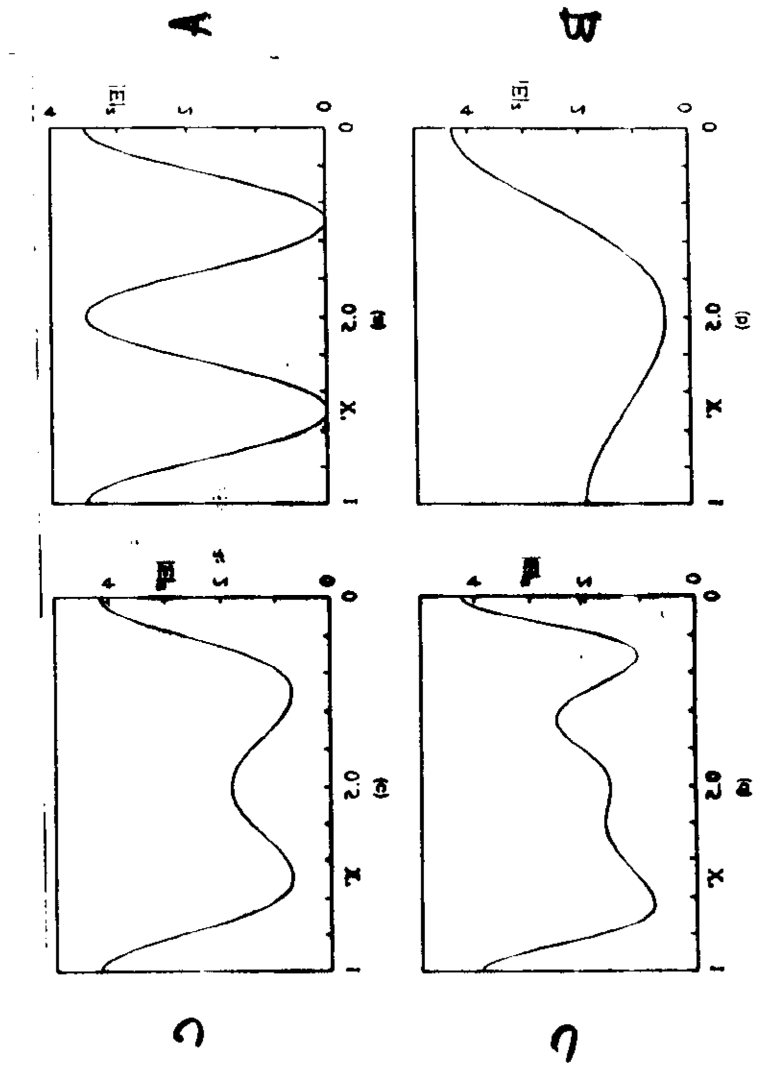
– COOPERATIVE FREQUENCY LOCKING

$$E(\underset{\sim}{x},t) = \sum_n f_n\, g_n(\underset{\sim}{x})\, e^{-i\omega t}$$

$$|E(\underset{\sim}{x},t)|^2 = \sum_{n,n'} f_{n'}^{*} f_n\, g_{n'}^{*}(\underset{\sim}{x})\, g_n(\underset{\sim}{x})$$

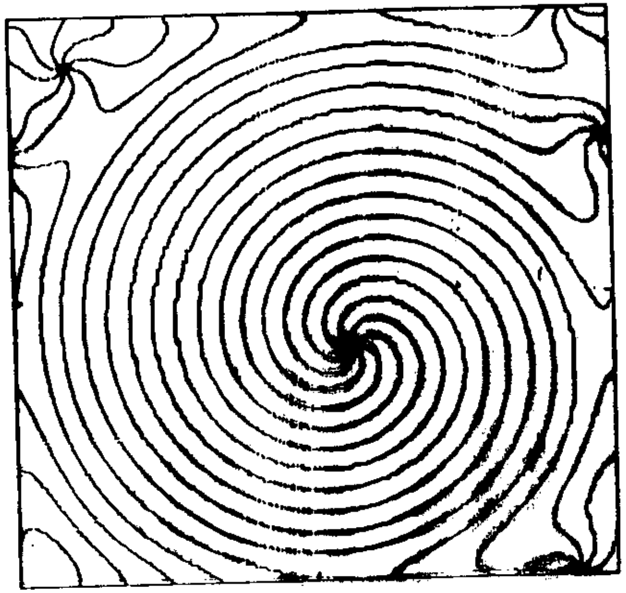
STATIONARY !

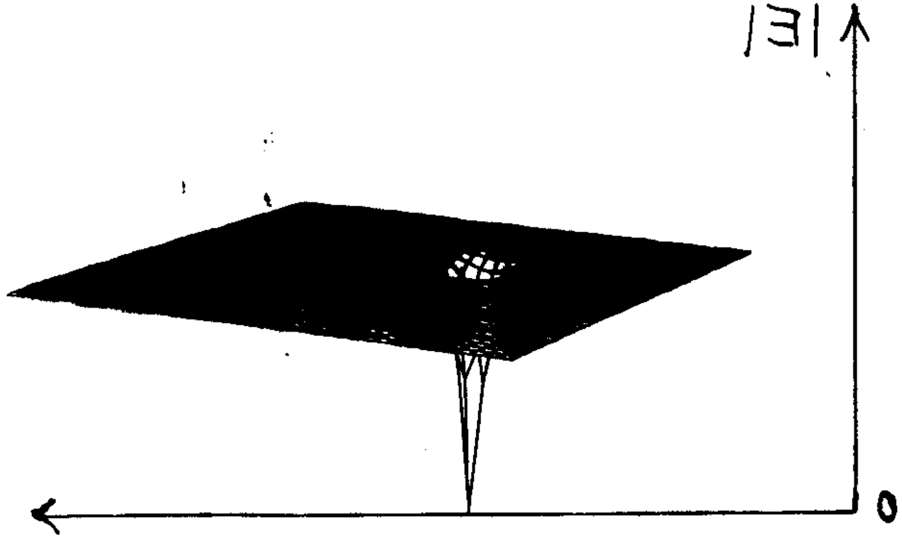




COULLET, GIL, ROCCA

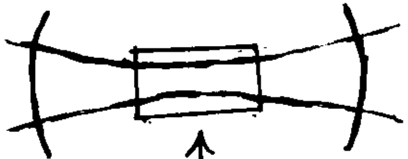
OPTICAL VORTICES IN LASERS





CAVITY WITH SPHERICAL MIRRORS

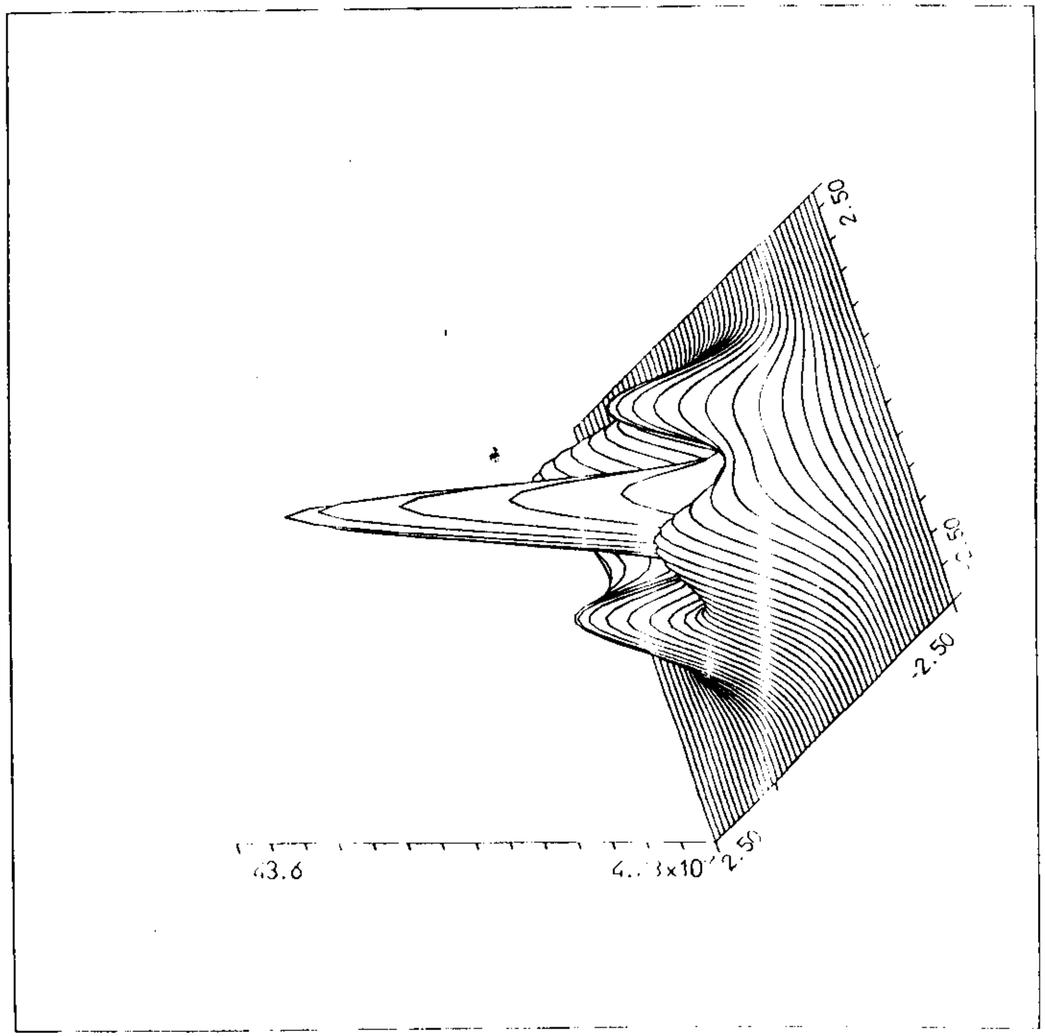
AND NO LATERAL MIRRORS



BEAM
WAIST W.

LASER WITH SPHERICAL MIRRORS

$$E(r,t) = \sum_{p=0} f_p(t)\, \underbrace{e^{-\frac{r^2}{W^2}}\; L_p\left(2\,\frac{r^2}{W^2}\right)}_{A_p(\rho)}$$



SPONTANEOUS BREAKING OF CYLINDRICAL SYMMETRY

3 MODAL INDICES
$$\begin{cases} n_z & \text{LONGITUDINAL} \\ p & \text{RADIAL} \longrightarrow r \\ \ell & \text{ANGULAR} \longrightarrow \varphi \end{cases}$$

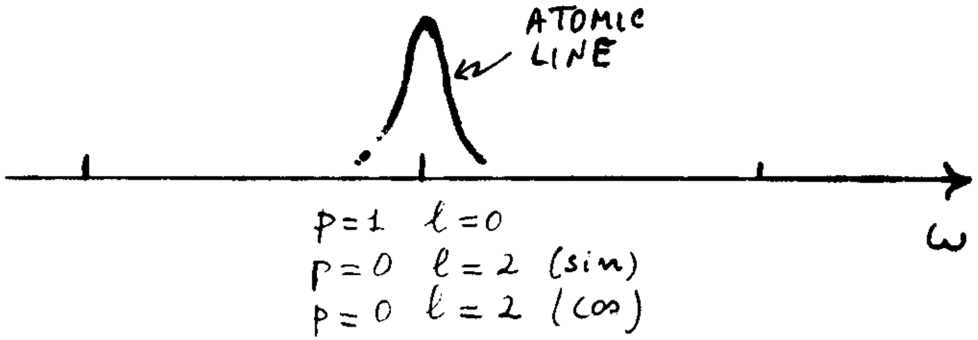
TRANSVERSE STRUCTURE OF MODES

$$A_{p\ell}(r,\varphi) = \left(\frac{r}{w}\right)^{\ell} L_p^{\ell}\left(2\frac{r^2}{w^2}\right) e^{-\frac{r^2}{w^2}} \begin{Bmatrix} \sin \ell\varphi \\ \cos \ell\varphi \end{Bmatrix}$$

w = BEAM WAIST

MODE FREQUENCIES $\quad c_1 n_z + c_2\left(2p+\ell+1\right)$

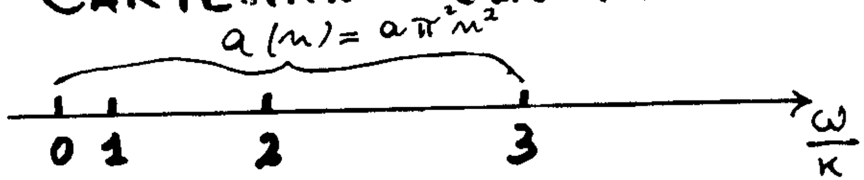
LASER WITH 3 DEGENERATE MODES



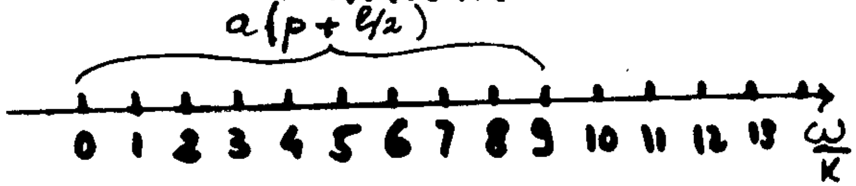
GAUSSIAN PUMP REGION

$$\exp\left(-\frac{r^2}{2R_p^2}\right) \qquad \psi = 2\frac{R_p}{w}$$

CARTESIAN CAVITY



CAVITY WITH SPHERICAL MIRRORS



a = FREQUENCY SPACING

THE MODEL

$$\frac{\partial E}{\partial t} = -\kappa\left\{(1-i\Delta)E - 2CP - i\,\frac{a}{2}\left(\frac{1}{4}\nabla_\perp^2 - \rho^2 + 1\right)E\right\}$$

$$\frac{\partial P}{\partial t} = \gamma_\perp\left\{ED - (1+i\Delta)\,P\right\}$$

$$\frac{\partial D}{\partial t} = -\gamma_\parallel\left\{\frac{1}{2}\left(E^*P + EP^*\right) + D - 1\right\}$$

$$\rho = r/w, \quad \nabla_\perp^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} = \frac{\partial^2}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial}{\partial \rho} + \frac{1}{\rho^2}\frac{\partial^2}{\partial \varphi^2}$$

ELECTRIC FIELD

$$\mathcal{E}(z,\rho,\varphi,t) = E(\rho,\varphi,t)\,e^{-i\omega_0 t}\sin(K_z z) + c.c.$$

ω_0 = OSCILLATION FREQUENCY OF THE LASER WHEN IT OPERATES WITH THE MODE $p = l = 0$

$$K_z = \frac{\pi}{L}\,n_z$$

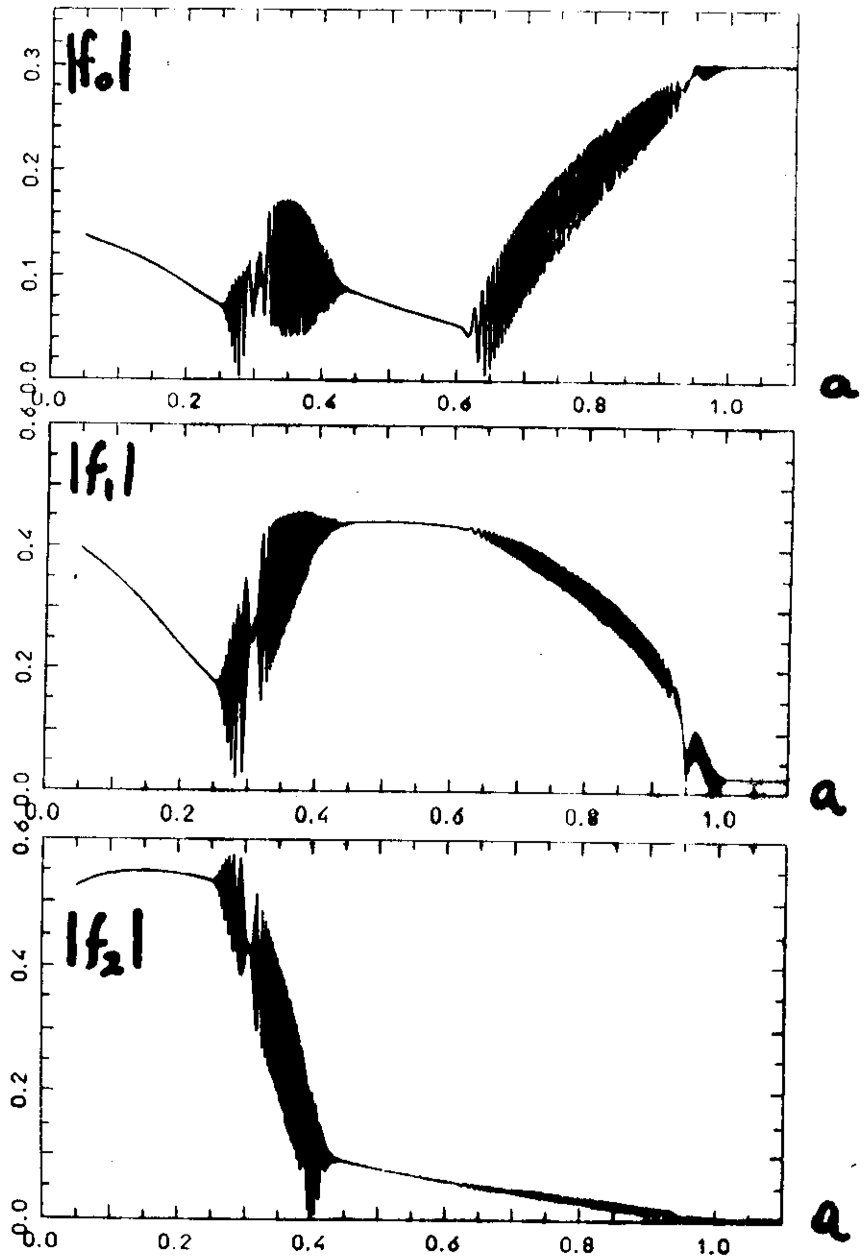
$P(\rho,\varphi,t) \propto$ ATOMIC POLARIZATION

$D(\rho,\varphi,t) \propto$ POPULATION INVERSION

$$\Delta = \frac{\omega_a - \omega_0}{\gamma_\perp}$$ DETUNING PARAMETER

a = FREQUENCY SPACING

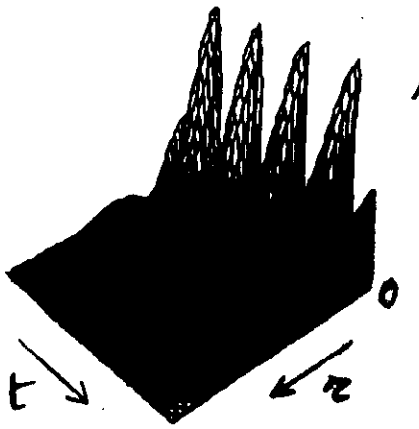
$C = 0.6 \quad \frac{\kappa}{\gamma_\perp} = 1 \quad \frac{a_n}{\gamma_\perp} = 0.05 \quad \Delta = 0.1$



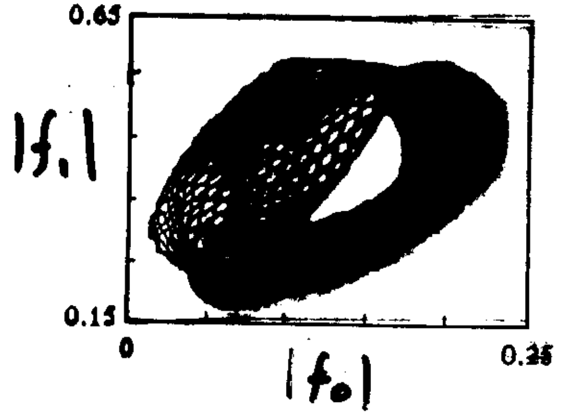
$C = 0.6 \quad \frac{K}{\gamma_\perp} = 1 \quad \frac{\gamma_\parallel}{\gamma_\perp} = 0.05$

$\Delta = 0.1$

PERIODIC OSCILLATIONS, $a = 0.7$



QUASIPERIODICITY, $a = 0.32$



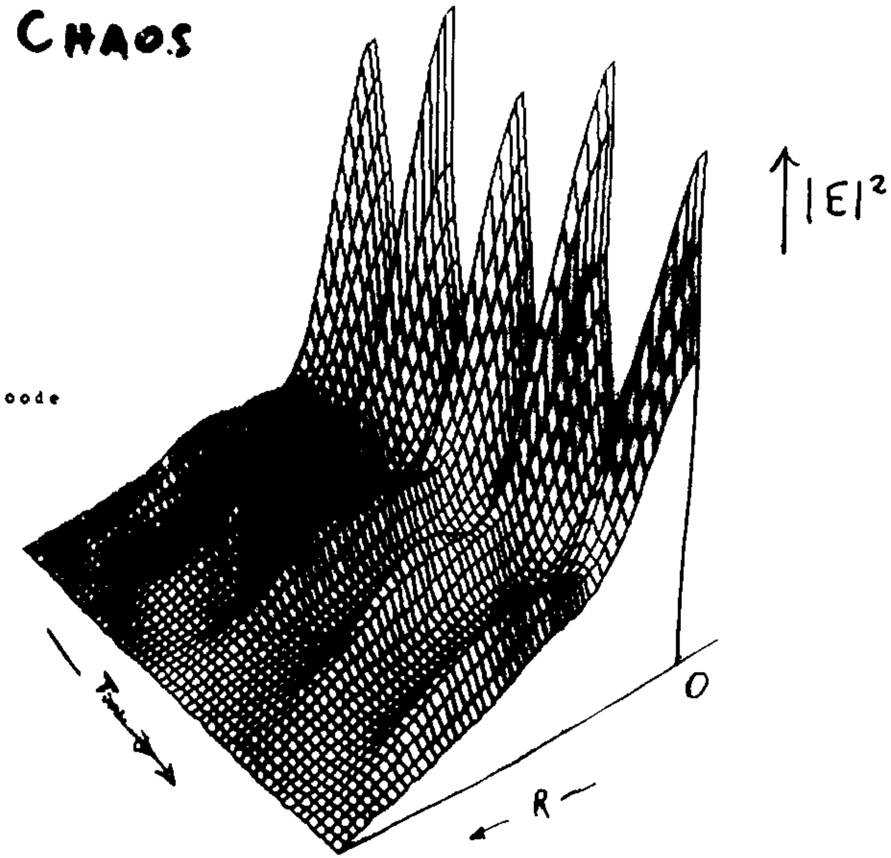
HOLLINGER
JUNG
WEBER

$\frac{K}{\gamma_\perp} = 1 \quad \beta = 0.00 \quad \frac{\gamma_\parallel}{\gamma_\perp}$

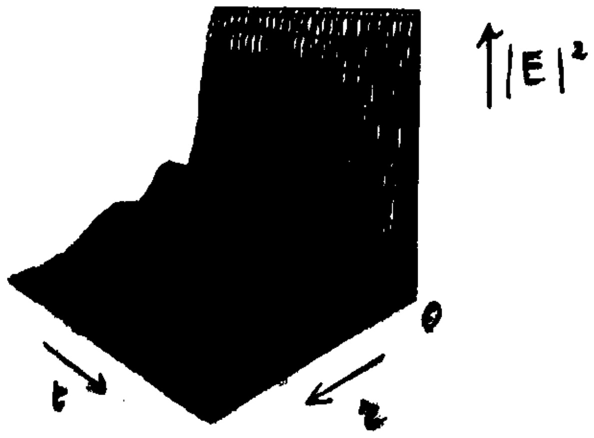
$\Delta = 0 \quad 2C = \quad a = 0.28$

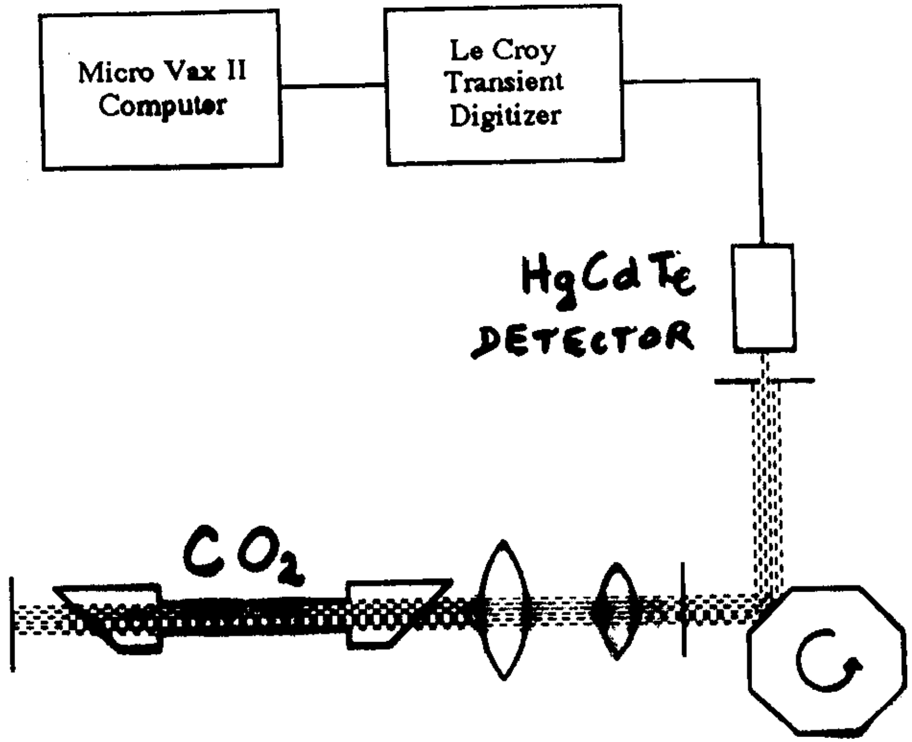
CHAOS

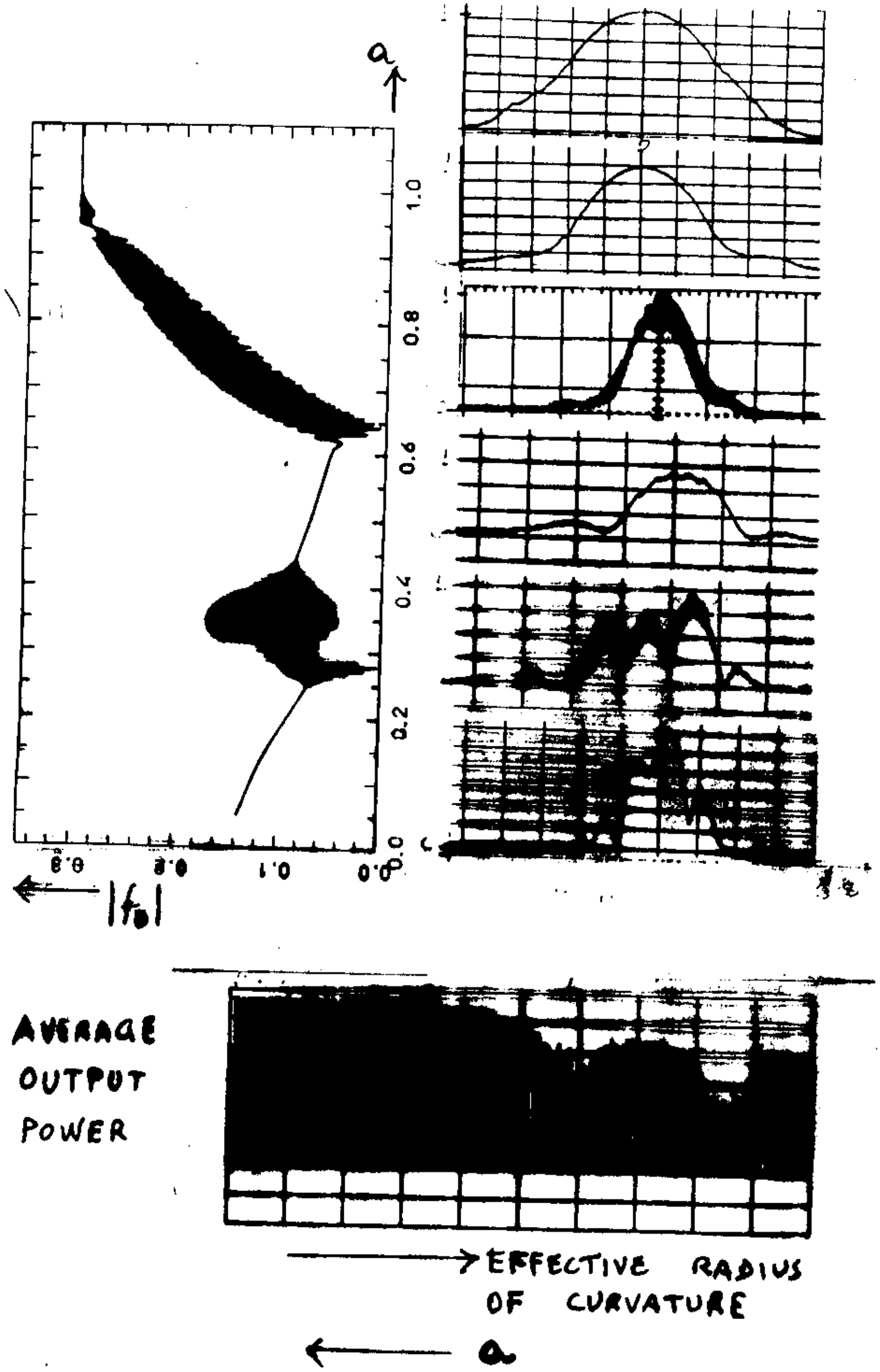
End of metacode
<READY>



COOPERATIVE FREQUENCY LOCKING , $a = 0.1$



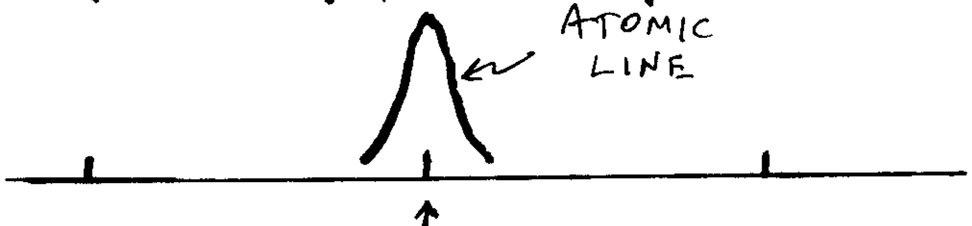




VARIATIONAL PRINCIPLE FOR TRANSVERSE PATTERN FORMATION IN LASERS

DEGENERATE FAMILY OF MODES

$2p + l = q$, WITH q FIXED



COMMON FREQUENCY OF THE MODES

$$E(r,\varphi) = {\sum_{pl}}' f_{pl} \, A_{pl}(r,\varphi)$$

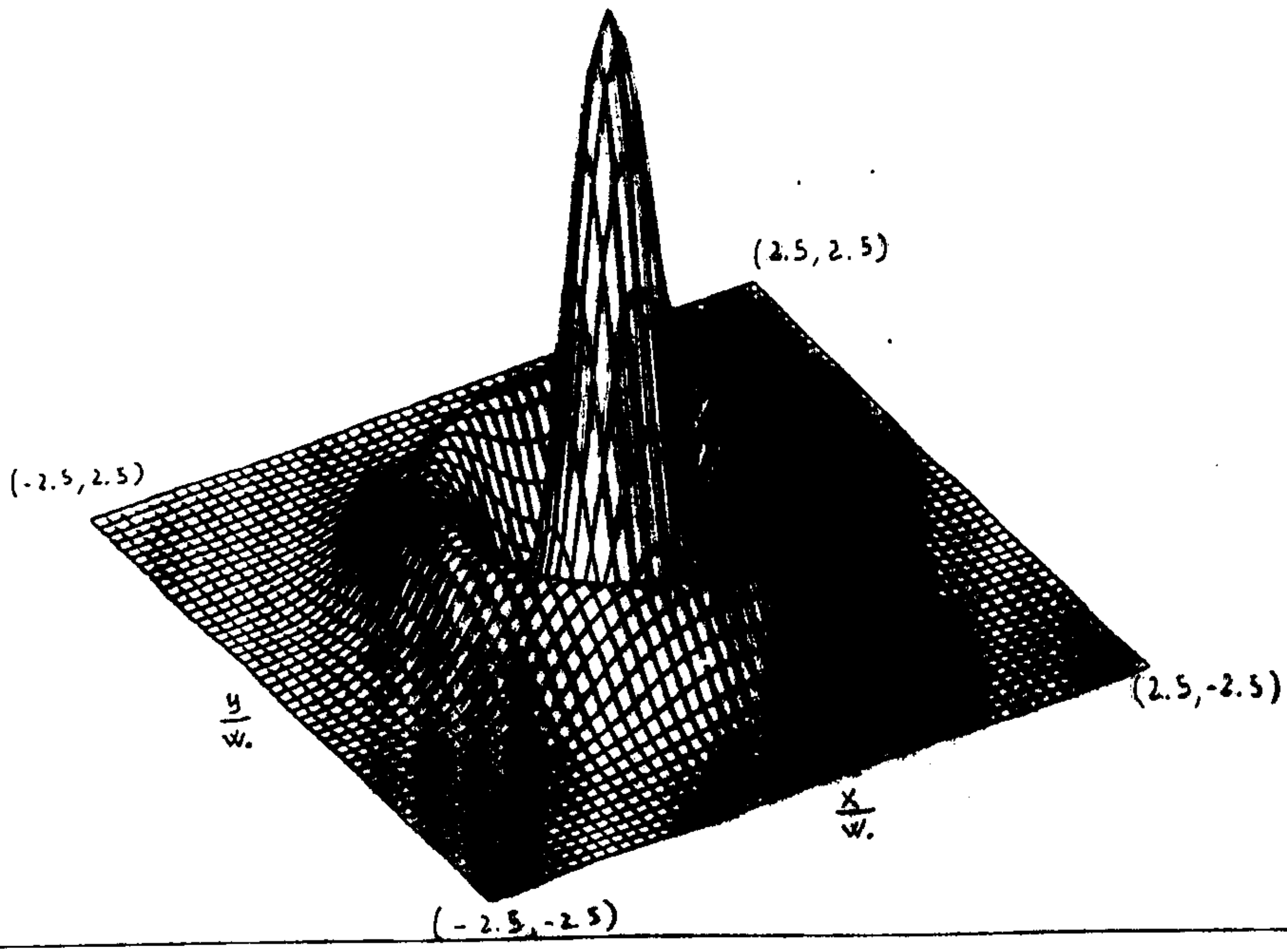
GENERALIZED FREE ENERGY

$$V = \int_0^{2\pi} d\varphi \int_0^{\infty} dr \, r \, \Big\{ |E(r,\varphi)|^2 - 2C \exp\left(-\frac{r^2}{2R_p^2}\right) \ln\left[1 + |E(r,\varphi)|^2\right] \Big\}$$

THE STABLE PATTERNS REALIZED BY THE LASER CORRESPOND TO THE MINIMA OF V

$\psi = 1.5$ $\qquad$ $\dfrac{C}{C_{thr}} = 1.5$

INITIAL CONDITION



$\frac{C}{C_{thr}} = 1.50$

$t = 0$

CONDIZIONE INIZIALE

gli estremi per x e y sono quelli in tutti i grafici

Per l'asse z l'unità di misura varia di volta in volta.

$$p = 1 \quad e^{-\frac{r^2}{w^2}} L_1 \left(2 \ldots\right.$$
$$l = 0$$

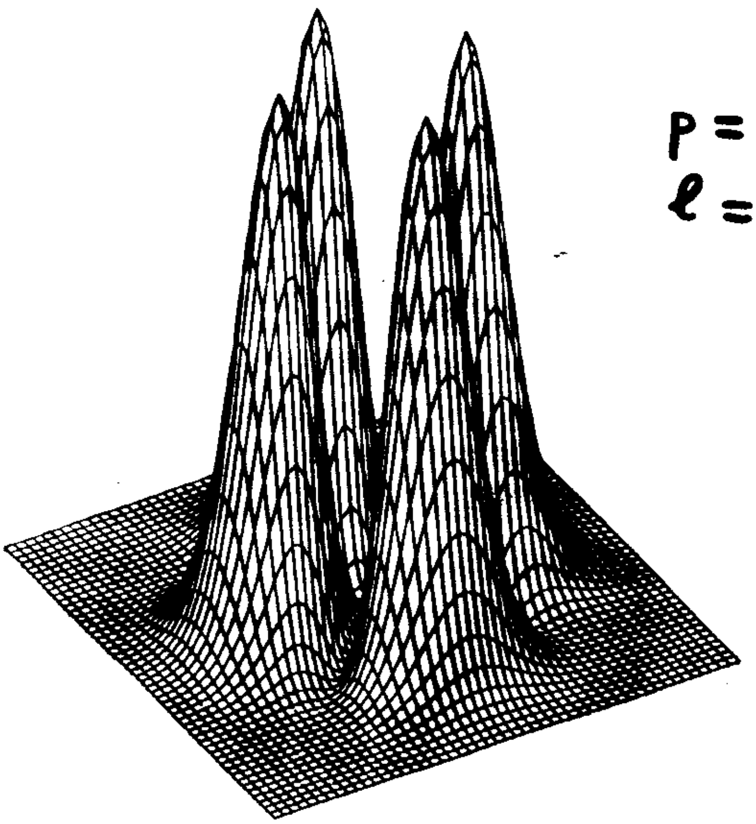
DEGENERATE WITH

$$p = 0 \quad l = 2$$

$$\left(\frac{r}{w}\right)^2 e^{-\frac{r^2}{w^2}} \cdot \begin{Bmatrix} \cos 2\varphi \\ \sin 2\varphi \end{Bmatrix}$$

ASYMMETRICAL STATIONARY SOLUTION

$p = 0$
$\ell = 2$

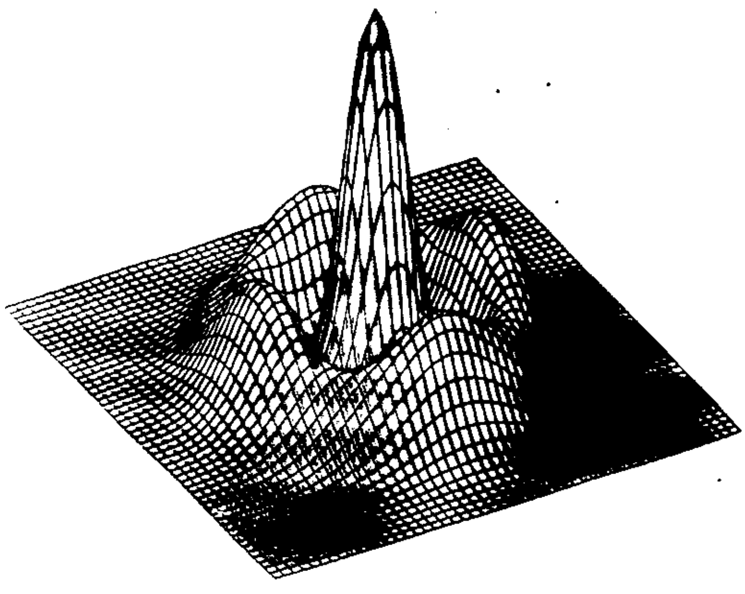


THE OPTICAL LEOPARD

$\Psi = 1.5$

$\frac{C}{C^{(1)}} = 1.50$

$\gamma_\perp t = 300$



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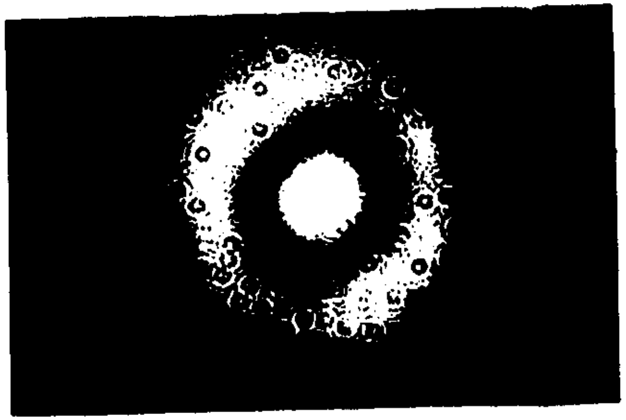
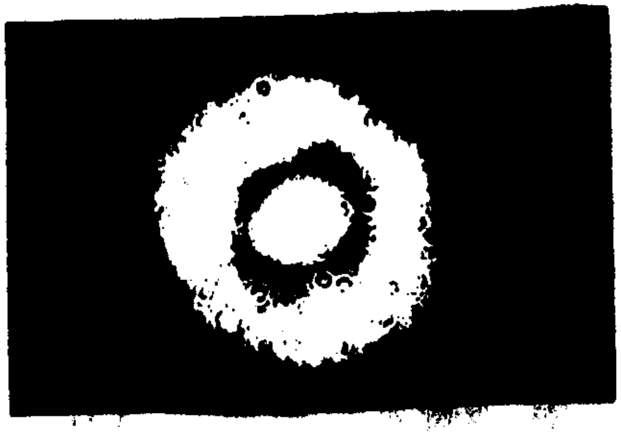
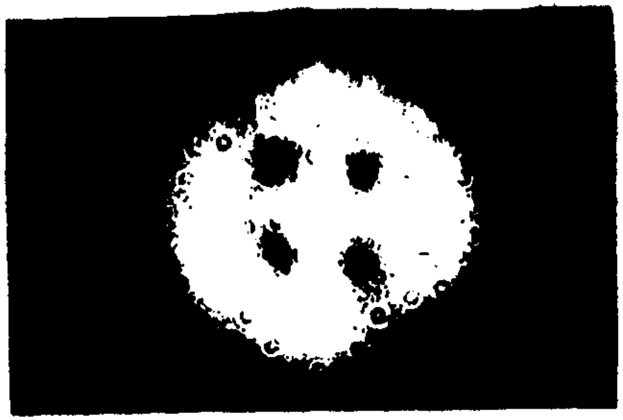
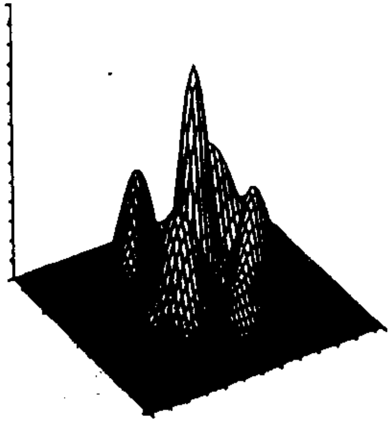
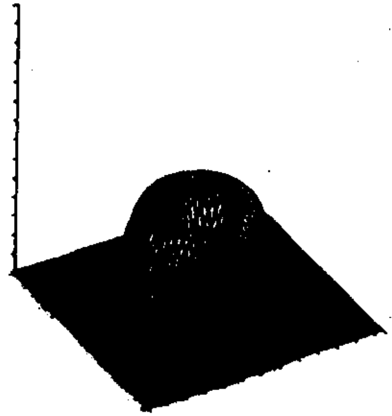


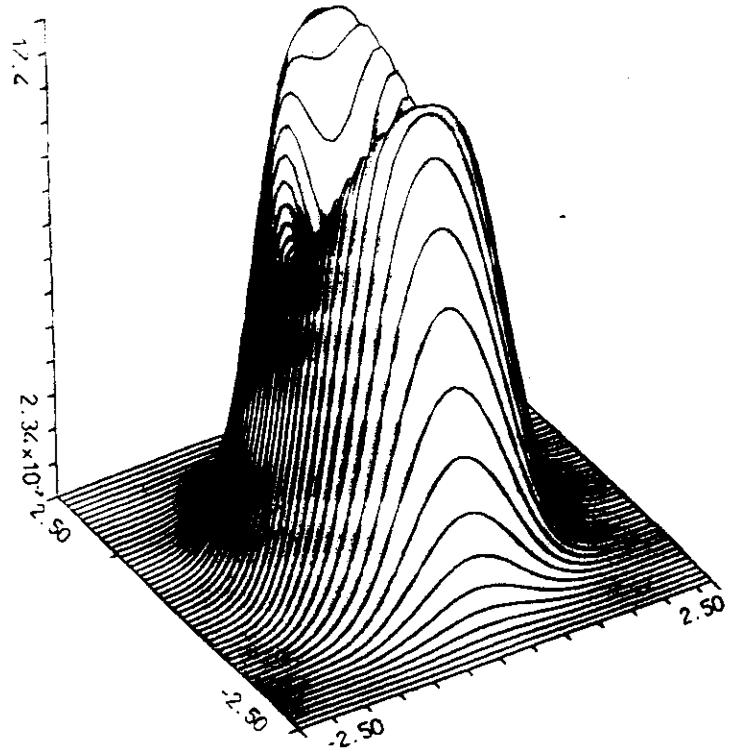








Two different transverse configurations for the laser output intensity, obtained under the same operating conditions



SPATIAL

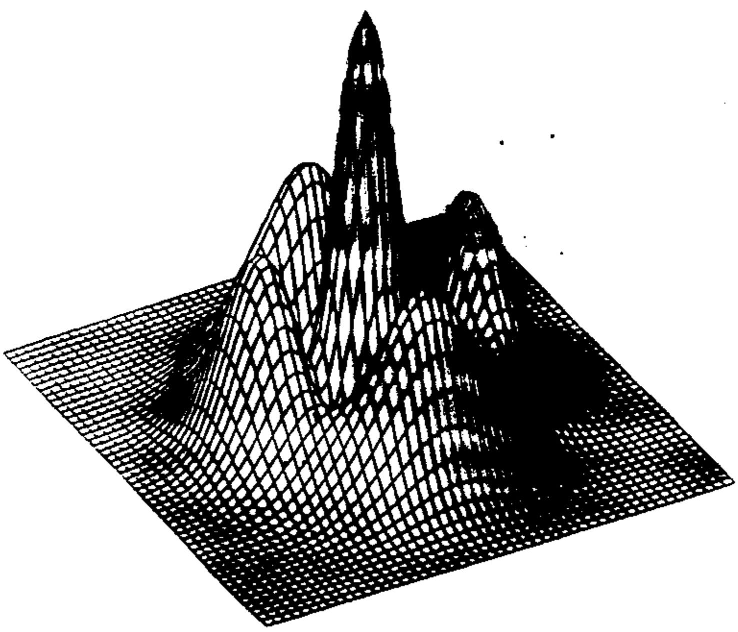
MULTISTABILITY

1

$\frac{C}{C_{thr}} = 2.41$

$\gamma_{\perp} t = 300$

$\psi = \infty$ $\frac{C}{C_{thr}} = 2.41$



SPATIAL

MULTISTABILITY

C. TAMM, PTB BRAUNSCHWEIG