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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4-SMR 393/20

SPRING COLLEGE ON PLASMA PHYSICS

15 May - 9 June 1989

NONLINEAR EVOLUTION OF RAMAN SCATTERING

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OUTLINE

1. INTRODUCTION
2. CHARACTERISTIC FEATURES OF EXPERIMENTAL OBSERVATIONS
3. NONLINEAR EFFECTS
4. STIMULATED RAMAN SCATTERING AND ION DYNAMICS – LOCALIZATION OF LANGMUIR WAVES
5. HOT ELECTRON PRODUCTION.
6. CONCLUSIONS

INTRODUCTION

STIMULATED RAMAN SCATTERING (SRS) IS THE RESONANT DECAY OF A PUMP WAVE $(\omega_0, \underline{k_0})$ INTO A SCATTERED PHOTON $(\omega_s, \underline{k_s})$ and AN ELECTRON PLASMA WAVE (LANGMUIR WAVE) $(\omega_L, \underline{k_L})$

THE RESONANCE CONDITIONS ARE

$$\omega_0 = \omega_L + \omega_s$$

$$\underline{k}_0 = \underline{k}_L + \underline{k}_s$$

where

$$\omega_0^2 = \omega_p^2 + k_0^2 c^2$$

$$\omega_s^2 = \omega_p^2 + k_s^2 c^2$$

$$\omega_L^2 = \omega_p^2 + 3k_L^2 V_e^2$$

$$V_e = (k_B T_e/m_e)^{1/2} \qquad \omega_p^2 = \frac{4\pi e^2 n}{m_e}$$

* SRS CAN OCCUR FOR $n \leq n_{cr}/4$ (at $n = n_{cr}$, $\omega_p = \omega_0$)

* in 1-D, for $k_L \lambda_D \ll 1$: $k_L = \frac{\omega_0}{c}\left[\sqrt{1 - \frac{n}{n_{cr}}} \pm \sqrt{1 - 2\sqrt{\frac{n}{n_{cr}}}}\right]$,

forward SRS

MAIN CONCERNS

* SRS GENERATES HOT ELECTRONS, WHICH CAN PREHEAT FUSION TARGET

* IN LONG SCALE PLASMAS SRS CAN REFLECT 10% OR MORE OF LASER RADIATION

GROWTHRATES, THRESHOLDS

see for example: W.L. KRUER, THE PHYSICS OF LASER PLASMA INTERACTIONS, Addison Wesley (1988).

THE MAXIMUM GROWTHRATE OCCURS FOR BACKSCATTERED LIGHT

$$\gamma_0 = \frac{k_L V_0}{4}\sqrt{\frac{\omega_p}{\omega_s}} \qquad \text{where} \qquad V_0 = \frac{eE_0}{m_e \omega_0}$$

THE THRESHOLD INTENSITY FOR SRS IS DETERMINED BY DAMPING OF THE UNSTABLE WAVES OR BY INHOMOGENITY.

PLASMA INHOMOGENITY LIMITS THE REGION OF RESONANT COUPLING. PROPAGATION OF WAVE ENERGY OUT OF THE INTERACTION REGION INTRODUCES AN EFFECTIVE DISSIPATION

$$\varkappa = k_0(x) - k_s(x) - k_L(x)$$

$$\varkappa = \varkappa(0) + \varkappa' x$$

FOR $\exp(2\pi)$ AMPLIFICATION THERE IS A THRESHOLD

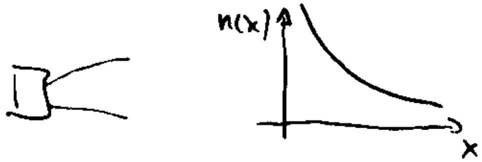
$$\frac{\gamma_0^2}{|\varkappa' V_{gs} V_{gL}|} > 1$$

EXPERIMENTS

1. CO_2 LASER - PLASMA INTERACTION

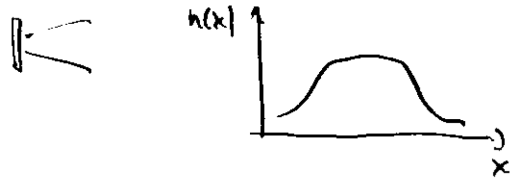
OFFENBERGER et al. PHYS. REV. LETT 49, 371 (1982); C.J. WALSH, D.M. VILLENEUVE, and H.A. BALDIS PHYS. REV. LETT. 53, 1445 (1984); D.M. VILLENEUVE, C.J. WALSH, H.A. BALDIS PHYS. FLUIDS 28, 1591 (1985); G. McINTOSH, J. MEYER, ZHANG YAZHOU, PHYS. FLUIDS 29, 3451 (1986); D. UMSTADTER W.B. MORI and C. JOSHI, PHYS. FLUIDS 31, 183 (1988).

2. OVERDENSE (DISK) TARGETS



K. TANAKA et al. PHYS. REV. LETT 48, 1179 (1982); W. SEKA et al. PHYS. FLUIDS 27, 2181 (1984); C.L. SHEPARD et al. PHYS. FLUIDS 29, 583 (1986).

3. UNDERDENSE (THIN FOIL) TARGETS



H. FIGUEROA et al PHYS. FLUIDS 27, 1887 (1984); J.A. TARVIN et al. LASER PART. BEAMS 4, 461 (1986); R.E. TURNER et al PHYS. REV. LETT 54, 189 (1985); R.P. DRAKE et al PHYS. FLUIDS 31, 1795 (1988).

SRS SPECTRA

ALTHOUGH THERE ARE DIFFERENCES IN THE INTENSITY OF THE SCATTERED LIGHT IN DIFFERENT EXPERIMENTS, IT IS REMARKABLE HOW SIMILAR THE SPECTRA APPEAR DESPITE DIFFERENT PULSE LENGTHS, TARGET THICKNESS, AND LASER ENERGIES, LASER BEAM NONUNIFORMITIES. ETC.

THE TYPICAL SPECTRUM HAS A PEAK INTENSITY FOR A LIGHT WAVELENGTH THAT CORRESPONDS TO AN INTERACTION AROUND 0.1 n_{cr}, SIGNIFICANTLY BELOW 0.25 n_{cr} WHERE THEORETICAL GROWTHRATE SHOULD HAVE MAXIMUM — SRS "GAP".

THE SHORTWAVELENGTH CUTOFF CORRESPONDS TO LANDAU DAMPING.

NONLINEAR EFFECTS

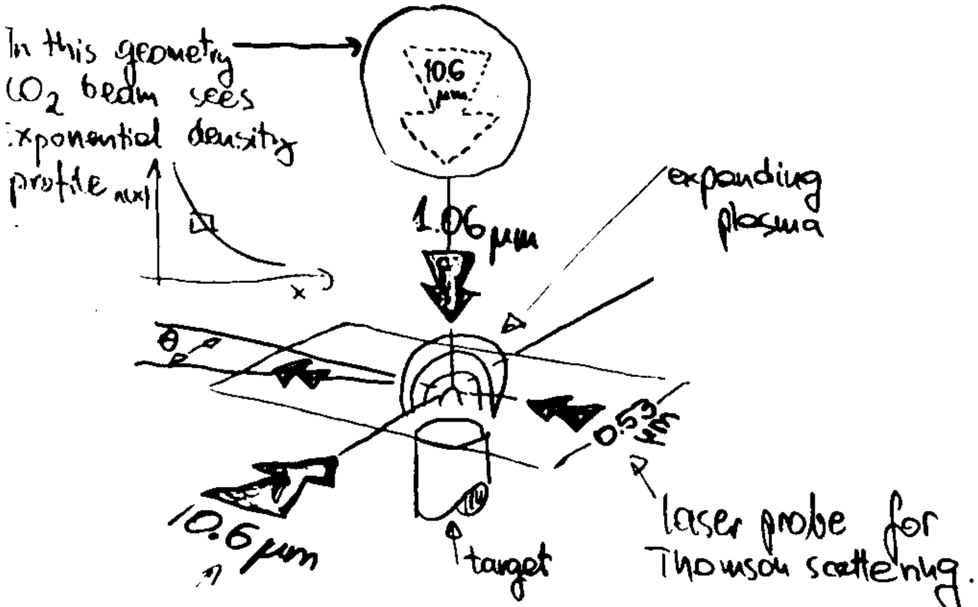
* NONLINEARITY OF LANGMUIR WAVES
  - SRS PRODUCED LANGMUIR WAVES ARE UNSTABLE DUE TO ION-ACOUSTIC DECAY OR MODULATIONAL INSTABILITY
  - HOT ELECTRON PRODUCTION — WAVEBREAKING, NONADIABATIC EFFECTS
* SRS COMPETES WITH OTHER PARAMETRIC INSTABILITIES
  - for example with SBS, or TPD
  - PUMP DEPLETION SATURATES SRS
  - ION WAVES PRODUCED BY SBS DETUNE SRS, LOCALIZE OR DAMP LANGMUIR WAVES.

G. BONNAUD, D. PESME, Laser Interaction, vol 8, 1988; G. BONNAUD LASER PART. BEAMS 5, 101 (1987); J.A. HEIKKINEN, S.J. KARTTUNEN, PHYS. FLUIDS 29, 1291 (1986); H.C. BARR, F.F. CHEN PHYS. FLUIDS 30, 1180 (1987); H.C. BARR, T.J.M. BOYD, G.A. COUTTS, PHYS. REV. LETT 56, 2256 (1986); K. ESTABROOK, W.L. KRUER, M.G. HAINES, PHYS. FLUIDS in press.

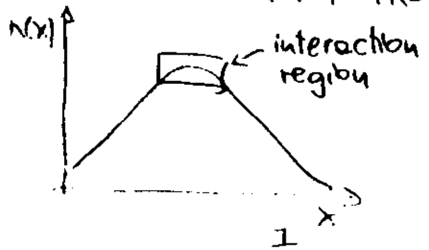
CO_2 LASER-PLASMA EXPERIMENTS

H.A. BALDIS, D.M. VILLENEUVE, J.E. BERNARD,
C.J. WALSH – NRC, Ottawa.

GEOMETRY OF THE EXPERIMENT:



CO_2 BEAM INTERACTS WITH PLASMA HAVING GAUSSIAN DENSITY PROFILE

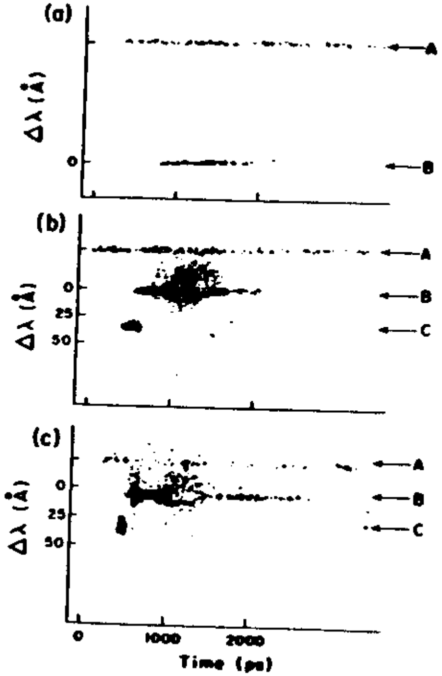


SRS-SBS COMPETITION EXP.

C.J. WALSH, D.M. VILLENEUVE and H.A. BALDIS, Phys. Rev. Lett. 53, 1445 (1984)

TEMPORALLY AND SPECTRALLY RESOLVED THOMSON SCATTERING HAS BEEN USED TO IDENTIFY SRS DRIVEN LANGMUIR WAVES AND SBS DRIVEN ION WAVES

RESULTS IN GAUSSIAN GEOMETRY.



A – 0.53 μm probe beam

B – signal shifted by $\Delta\omega \simeq 0$ – ion waves

C – satellite due to Langmuir waves ($\Delta\omega \simeq \omega_p$)

* SRS DRIVEN LANGMUIR WAVES EXIST ONLY FOR A SHORT TIME AT THE BEGINNING OF THE LASER PULSE, AND DISAPPEAR WHEN STRONG, SBS DRIVEN ION WAVES BECOME VISIBLE.

→ THE SHIFT OF LANGMUIR WAVE SATELLITE IS GIVEN BY

$$\frac{n}{n_c} = 1.4 \times 10^{-5} (\Delta\lambda)^2$$

* THE SRS DRIVEN ELECTRON PLASMA WAVES ARE OBSERVED ONLY IN THE DENSITY RANGE

$$0.01\, n_{cr} \leq n \leq 0.05\, n_{cr}$$

SRS AND ION DYNAMICS

THEORETICAL MODEL BASED ON ZAKHAROV EQUATIONS ACCOUNTING FOR SRS and SBS

C.H. ALDRICH, B. BEZZERIDES, D.F. DUBOIS, H. ROSE, Comments on Plasma Phys. and Controlled Fusion $\underline{10}$, 1 (1986).

W. ROZMUS, R.P. SHARMA, J.C. SAMSON, W. TIGHE, PHYS. FLUIDS, $\underline{30}$, 2181 (1987).

$$\left(\frac{\partial^2}{\partial t^2} + 2\gamma_A \frac{\partial}{\partial t}\right)N - \frac{\partial^2}{\partial x^2}N - \frac{\partial^2}{\partial x^2}|E|^2 = \frac{3}{16}\frac{\partial^2}{\partial x^2}\left(|U_{+1}|^2 + |U_{-1}|^2 + |U_0|^2\right)$$

$$i\left(\frac{\partial}{\partial t} + \gamma_L\right)E + \frac{\partial^2}{\partial x^2}E - NE = \frac{\sqrt{3}}{16}\frac{\partial}{\partial x}\left(U_0 U_{-1} + U_0^* U_{+1}\right)$$

$$i\left(\frac{\partial}{\partial t} + \gamma_E^r\right)U_r + \frac{1}{3}\frac{\omega_p}{\omega_r}\left(\frac{c}{v_e}\right)^2\frac{\partial^2}{\partial x^2}U_r - \frac{3}{4}\frac{m_i}{m_e}\frac{\omega_p^2 - \omega_r^2}{\omega_p\omega_r}U_r -$$

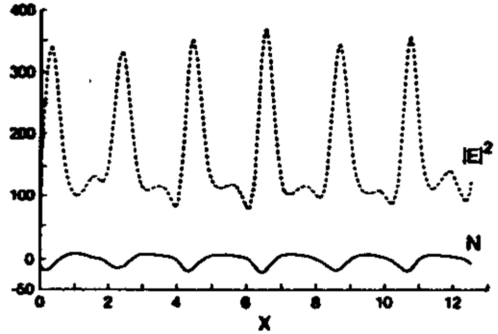
$$- \frac{\omega_p}{\omega_r}NU_r = -\frac{1}{\sqrt{3}}\frac{\omega_p}{\omega_r}S_r \qquad r = 0, +1, -1$$

$$S_r = \begin{cases} \left(\frac{\partial}{\partial x}E^*\right)U_{+1} + \left(\frac{\partial}{\partial x}E\right)U_{-1}^* & r = 0 \\ \left(\frac{\partial}{\partial x}E\right)U_0 & r = +1 \\ \left(\frac{\partial}{\partial x}E\right)U_0^* & r = -1 \end{cases}$$

EQUATIONS ARE WRITTEN IN ZAKHAROV UNITS. ZAKHAROV EQN ARE IN RED. $E(x,t)$ IS SLOWLY VARYING ENVELOPE OF LANGMUIR WAVES. U_r CORRESPOND TO ELECTRO-MAGNETIC FIELDS, ω_0 - PUMP FREQUENCY, $\omega_{\pm 1} = \omega_p \pm \omega_0$

LOCALIZATION OF LANGMUIR WAVES

SIMPLE EXAMPLE OF THE SOLUTION TO SRS+SBS+ZAKHAROV MO
SRS LANGMUIR WAVE (k_L) SCATTERS ON SBS PRODUCED ION WAVES (k_A) AND GENERATES HARMONICS AT $k_L \pm nk_A$



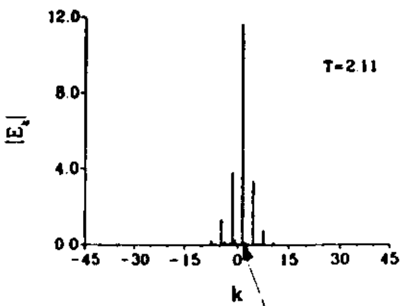
Spatial profiles of $|E|^2$ and N at T=2.11 from the run with the parameters $v_0/c = 0.01$, $v_e/c = 0.026$, $n/n_{cr} = 0.25$. The electromagnetic pump U_0 is clamped. All quantities are in Zakharov units ($m_i/m_e = 500$).

THIS PROCESS RESULTS IN LOCALIZATION OF LANGMUI FIELDS.

A NECESSARY CONDITION

$$\frac{\gamma_{SRS}}{\gamma_{SBS}} > 1$$

RESULTS ARE FROM SIMPLE PERIODIC SIMULATIO (W. Rozmus et al. Phys. Fluids 1987)



FOURIER SPECTRUM CORRESPONDI TO THE FIELD SHOWN ABOVE

$k_L = 1.5$, $k_A = 3$

DRIVEN COLLAPSE

OF LANGMUIR WAVES IN 1-D SRS+SBS+ZAKHAROV SIMULATIONS

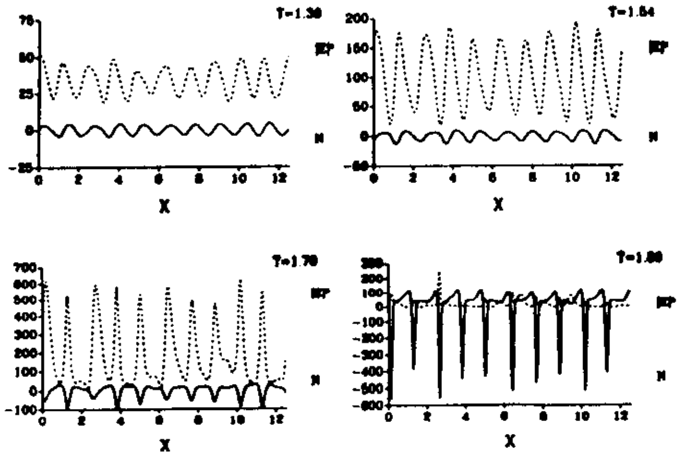
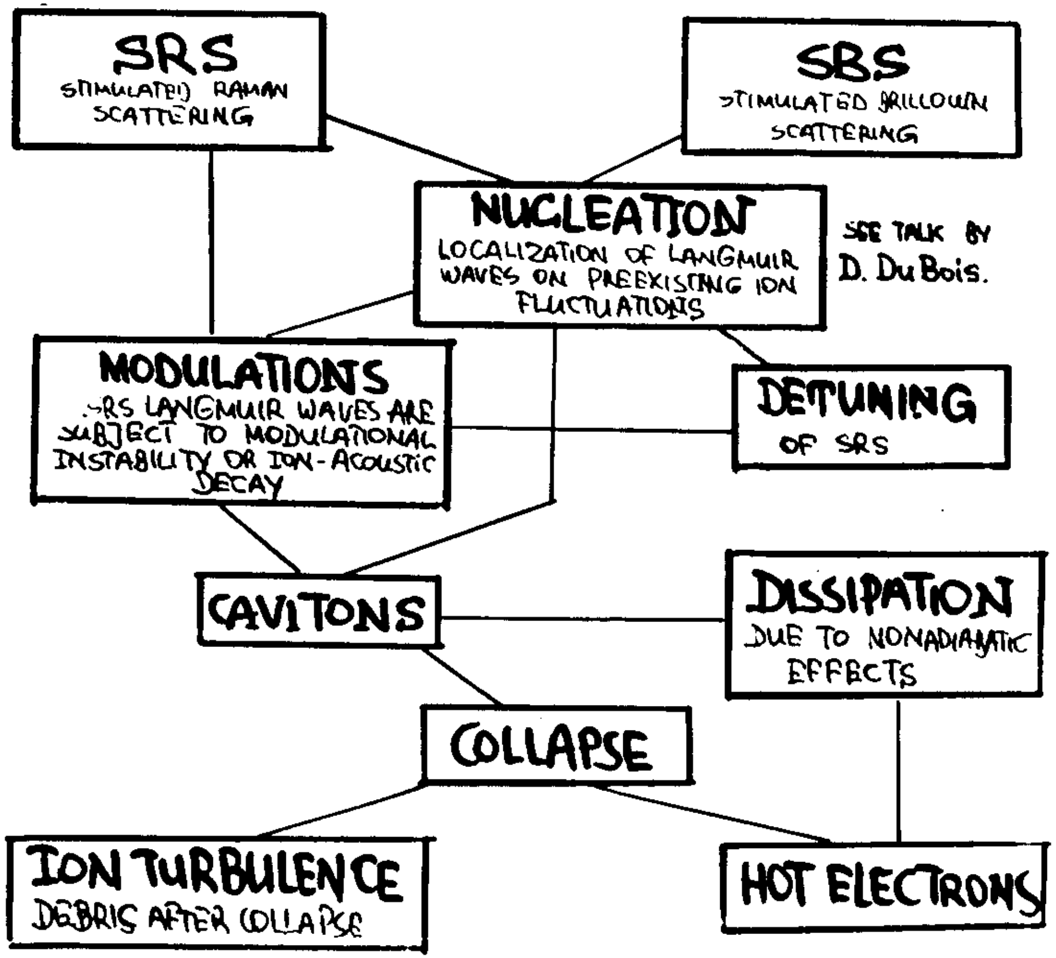


Fig. 3. Spatial profiles of $|E|^2$ and N at four different times. The parameters of the run are $v_0/c = 0.016$, $v_e/c = 0.043$ and $n/n_{cr} = 0.25$.

THEORETICAL SCENARIOS

BASED ON SRS + SBS + ZAKHAROV MODEL



SRS-SBS COMPETITION THEORY

H.A. ROSE, D.F. DUBOIS and B. BEZZERIDES, Phys. Rev. Lett. 58, 2547 (1987).

THE EXPERIMENT BY WALSH, VILLENEUVE and BALDIS (1984) HAS BEEN EXPLAINED (QUNTATIVELY AND QUALITATIVELY) BY NUMERICAL SOLUTIONS TO SRS+SBS+ZAKHAROV MODEL IN SLAB GEOMETRY.

IMPORTANT NEW PHYSICAL PROCESSES

1. SRS PRODUCED LANGMUIR WAVES ARE MODULATED BY THE COUPLING TO SBS PRODUCED ION WAVES
2. SRS SATURATES BY COLLAPSE OF LANGMUIR WAVES
3. FOR $\frac{n}{n_{cr}} > 0.05$ THE TEMPORALLY GROWING SBS ION WAVES DETUNE AND SUPPRESS SRS.

PREDICTIONS OF THIS THEORY ABOUT SUPPRESSION OF SRS BY SEEDING ION WAVES WHICH ENHANCE SBS, WERE CONFIRMED IN MORE RECENT EXPERIMENT (D.M. VILLENEUVE, H.A. BALDIS and J.E. BERNARD PHYS. REV. LETT. 59, 1585 (1987)).

ABSOLUTE SRS

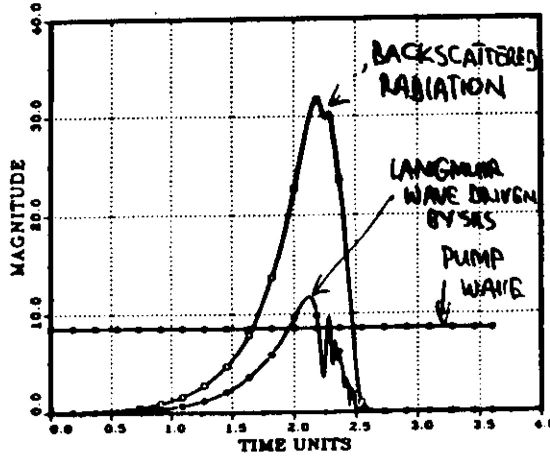
D.M. VILLENEUVE, C.J. WALSH and H.A. BALDIS, PHYS. FLUIDS 28, 1591 (
W. ROZMUS, H.A. BALDIS, D.M. VILLENEUVE, COMMENTS PLASMA PHYS. CONTROLLED FUSION 12, 1 (198

NO SRS LIGHT AT $\omega_0/2$ WAS OBSERVED TO THE LEVEL 50 TIMES BELOW THAT PREDICTED FROM THOMSON SCATTERING OFF LANGMUIR WAVES.

THE EFFECT OF ALMOST ISOTROPIC ION FLUCTUATIONS PRODUCED DURING COLLAPSE OF LANGMUIR WAVES HAS BEEN DESCRIBED IN 1-D CODE BY THE EFFECTIVE DAMPING COEFFICIENT (cf. FAEHL and KRUER, 1977)

$$\gamma_{-1} = \frac{|\omega_{-1}|}{4}\left(\frac{\Delta n}{n_{cr}}\right)^2 \left\langle \operatorname{Im} \frac{1}{\epsilon(k,\omega_{-1})} \right\rangle$$

$(\Delta n)^2$ - MEAN SQUARE DENSITY FLUCTUATION, $\langle ... \rangle$ AVERAGE WITH RESPECT TO WAVENUMBERS OF THE BACKSCATTERED RADIATION.



TIME EVOLUTION OF THREE WAVES RESONANTLY COUPLED BY SRS

DUE TO ANOMALOUS ABSORPTION ON ION WAVE BACKSCATTERED RADIATION IS REABSORBED IN THE DENSITY RANGE

$$0.125 \le n/n_{cr} \le 0.25$$

EFFECT OF PLASMA NOISE ON SCATTERING INSTABILITIES

R.L. BERGER, E.A. WILLIAMS and A. SIMON, PHYS. FLUIDS $\underline{1}$, 414 (1989).

SIMULTANEOUS SRS-SBS EVOLUTION DEPENDS ON THE NOISE LEVELS FROM WHICH BOTH INSTABILITIES TAKE OFF.

CALCULATION OF THE INDUCED EMISSION OF LIGHT FOR STABLE OR CONVECTIVELY UNSTABLE (BUT ABSOLUTELY STABLE) SRS (SBS), WITH BREMSSTRAHLUNG AND CHERENKOV EMISSION OF PLASMA WAVES SOURCES.

$$\frac{\langle E^2(x,t)\rangle}{4\pi k_B T} = \frac{1}{8\pi^3}\int d^3k\, I_k \qquad \cos\theta \sim (\underline{k}_L \cdot \underline{E}_0)$$

$$I_k = \frac{A(k)}{\nu_{NL}} \; \frac{\omega_s \cos\theta \, e^{-\frac{\omega_L^2}{2k_L^2 v_e^2}}}{\left[1 - \frac{\omega_p^2}{\omega_s^2} - \sin^2\theta\right]^{1/2}} \; \frac{\left(1 - e^{G_0}\right)}{|\epsilon(k_L \omega_L)|^2}$$

$$G_0 = -2\nu_{NL}\,(X_{max} - X_{min})/V_{gs} \;; \quad \nu_{NL} = -V_{gs}\,\mathrm{Re}(\Gamma)$$

$$A(k) = (\underline{e}_0 \underline{e}_s)^2 \left(\frac{E_0^2}{4\pi n_0 T_e}\right)\left(\frac{\omega_p}{\omega_0}\right)^3 \sqrt{\frac{\pi}{32}}\;\frac{1}{k_L \lambda_D}$$

FOR STABLE PLASMA $\nu_{NL} > 0$, BUT EXPRESSION IS ALSO CORRECT FOR $\nu_{NL} \to 0$, $\nu_{NL} < 0$.

IN THE PRESENCE OF HOT ELECTRONS THERE IS BIG ENHANCEMENT OF ION SOURCES — IN FAVOUR OF SBS

MODULATIONAL INSTABILITY

P.P. GOLDSTEIN, W. ROZMUS to be published.

WE HAVE SOLVED VARIATIONAL PROBLEM FOR THE NONLINEAR SCHRÖDINGER EQUATION (NLS)

$$i\partial_t E + \frac{\partial^2}{\partial x^2}E + |E|^2 E = 0$$

BY MINIMIZING THE ACTION INTEGRAL WITHIN THE SET OF TRIAL FUNCTIONS OF THE FOLLOWING FORM

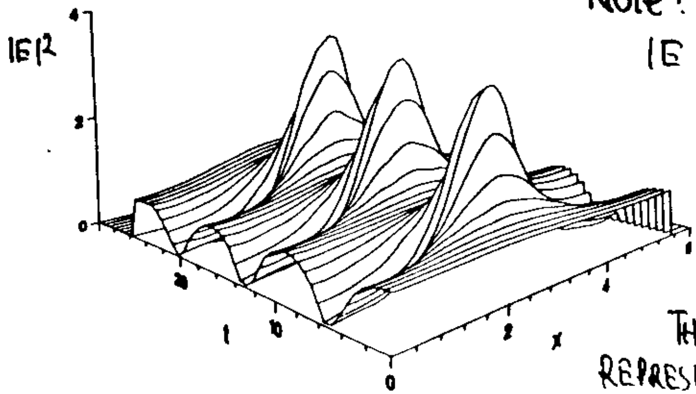
$$E(x,t) = A(t)\left[\mathrm{dn}\big(\alpha(t)(x-x_0(t));\beta(t)\big) + \beta(t)\,\mathrm{cn}\big(\alpha(t)(x-x_0(t));\beta(t)\big)\right] \times$$
$$\times \exp\left\{i\left[k_0(x-x_0(t)) + c(t)\cos\left(\tfrac{2\pi}{\Lambda}(x-x_0(t))\right) + \varphi(t)\right]\right\}$$

ANALYTICAL SOLUTION TO NLS

INITIAL CONDITIONS
BETA-2*C-0.1
A-1, LAMBDA-N-5.236
T-24

$$|E| = A\left(\mathrm{dn}(\alpha(x-x_0);\beta) + \beta\,\mathrm{cn}(\alpha(x-x_0);\beta)\right)$$

WE FOUND GOOD AGREEMENT WITH DIRECT INTEGRATION OF NLS.



Note: $\beta \to 0$

$|E| \to A\,(1+\beta\cos\alpha(x-x_0))$

$\beta \to 1$

$|E| \to A(1+\beta)\,\mathrm{sech}(\alpha(x-x_0))$

THIS IS USEFUL ANALYTICAL REPRESENTATION OF LOCALIZED LANGMUIR WAVES

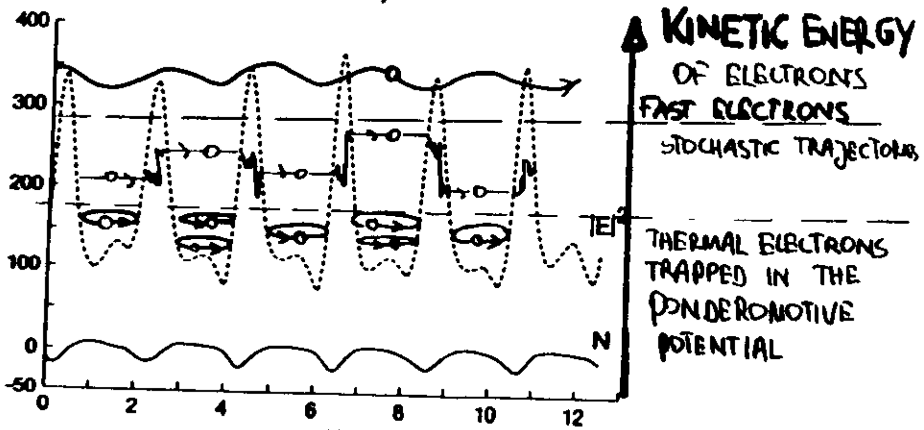
LANGMUIR CAVITIES AS A STOCHASTIC ACCELERATOR

A SIMPLE MODEL FOR HOT ELECTRON PRODUCTION IS PROPOSED. ELECTRONS INTERACT WITH PERIODIC, LOCALIZED LANGMUIR FIELDS WHICH APPROXIMATE SOLUTIONS TO SRS/SBS PROBLEM OR WHICH ARE FORMED DUE TO MODULATIONAL INSTABILITY.

BY SOLVING EQUATION OF MOTION

$$\ddot{x}(t) = -\frac{e}{m_e} E_L(x,t)$$

ONE CAN IDENTIFY THREE TYPE OF ELECTRON TRAJECTORIES: (1) REGULAR, TRAPPED IN THE PONDEROMOTIVE POTENTIAL; (2) STOCHASTIC (DIFFUSIVE); (3) REGULAR, CORRESPONDING TO FAST ELECTRONS WEAKLY AFFECTED BY THE FIELD.

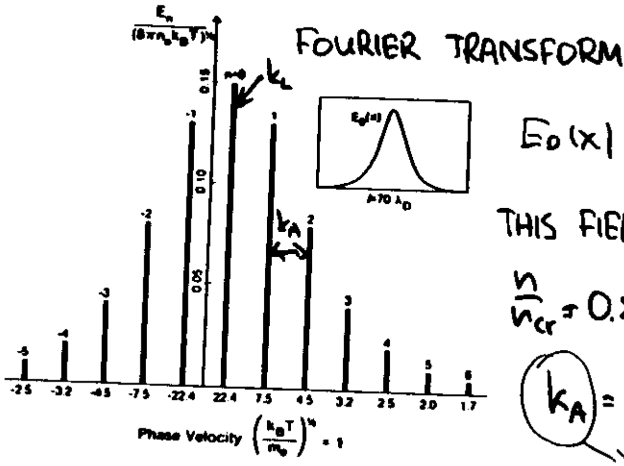


SCHEMATIC DIAGRAM OF ELECTRON TRAJECTORIES IN THE FIELD OBTAINED FROM SRS+SBS+ZAKHAROV MODEL

DYNAMICS OF ELECTRONS

IN LOCALIZED LANGMUIR WAVES

AS AN EXAMPLE WE TOOK A PERIODIC CHAIN OF SOLITONS WITH SIMILAR RESULT WE COULD ANAYZE FIELDS MODELLED BY THE COMBINATION OF JACOBIAN ELLIPTIC FUNCTIONS, AND DERIVED IN THE CONTEXT OF MODULATIONAL INSTABILITY.



$$E_0(x) = E_0 \,\mathrm{sech}(E_0 \alpha x)$$

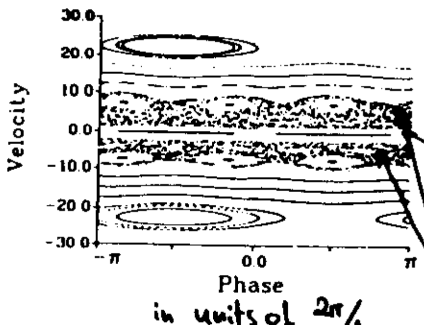
THIS FIELD CORRESPONDS TO

$$\frac{n}{n_{cr}} = 0.25\,, \quad \frac{E_0^2}{8\pi n k_B T} = 0.53\,.$$

$$k_A = 2k_L = 0.09\, k_D$$

SBS PRODUCED SOUND WA

THE POINCARÉ SURFACE OF SECTION PLOT, BASED ON NUMERICAL SOLUTIONS TO THE EQUATIONS OF MOTION. POINTS ARE MAPPED EVE $T = 2\pi/\omega_p$.



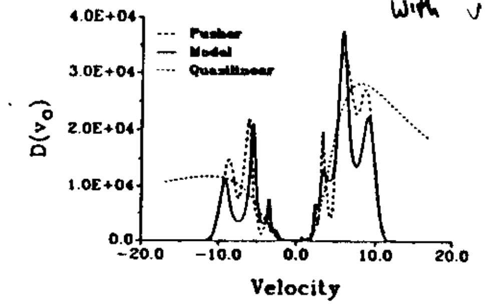
STATISTICAL MODEL

W. ROZMUS, J.C. SAMSON, PHYS FLUIDS, 31 2904 (1988).

EVOLUTION OF THE ELECTRON DISTRIBUTION FUNCTION IN THE STOCHASTIC PART OF A PHASE SPACE IS DESCRIBED BY THE LOCAL IN TIME DIFFUSION MODEL $\frac{\partial}{\partial t} f = \frac{\partial}{\partial v} D(v) \frac{\partial}{\partial v} f$

$$D(v) = \frac{1}{4}\left(\frac{e}{m_e}\right)^2 \sum_n |E_n|^2 \left[\frac{\gamma_n}{\gamma_n^2 + (\omega_p + \delta\omega_n - k_n v)^2} + \frac{\gamma_n}{\gamma_n^2 + (\omega_p - \delta\omega_n - k_n v)^2} \right]$$

$\gamma_n^{-1} \sim \tau_D$ - decay time of the autocorrelation function for particles moving with $v \sim \omega_p / k_n$.



iffusion coefficients. Solid curve - theoretical predictions ased on Eq. (9), long dash - numerical results (11), short dash quasilinear theory (10).

$$\gamma_n = \alpha_n \frac{v}{l} \qquad l \text{ - periodicity length}$$

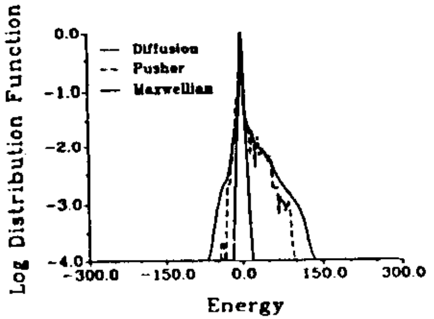
$$\alpha_n > 1$$

$$\delta\omega_n = \beta_n \, 2 \sqrt{\frac{k_n e E_n}{m_e}} \qquad \beta_n < 1$$

→ ONE RECOVERS QUASILINEAR DIFFUSION

$$D_{QL} = \left(\frac{e}{m_e}\right)^2 \frac{1}{4} \, l \, \left|E_{k=\frac{\omega_p}{v}}\right|^2 \frac{1}{|v|}$$

$$\left(\alpha_n \to 0, \ \beta_n \to 0 \quad \sum_k \to \int dk \right)$$



arithm of the distribution functions, plotted with respect to times the sign of velocity. Dotted line - initial Maxwellian, id line - diffusion model (t=20 T_p), dashed line - pusher code 20T_p).

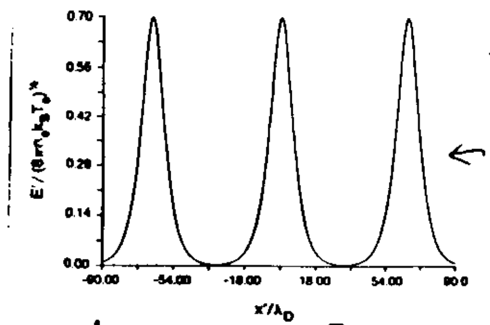
* NUMERICAL CALCULATIONS FROM PUSHER CODE

$$D(v_0) = \frac{1}{2T} \left\langle (v(T) - v_0)^2 \right\rangle$$

$$T = l/v$$

PONDEROMOTIVE POTENTIAL

W. ROZMUS, P. GOLDSTEIN, PHYS. REV. A38, 5745 (1988)



THE LANGMUIR FIELD ENVELOPE IS MODELLED BY

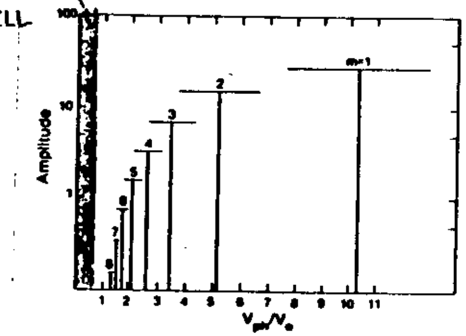
$$E(x) = \frac{\alpha}{\sqrt{2}} \left[dn(\alpha x, \beta) + \beta \, cn(\alpha x, \beta) \right]$$

IN THE LIMIT OF INTENSE FIELDS THE PONDEROMOTIVE POTENTIAL APPROXIMATION BREAKS DOWN

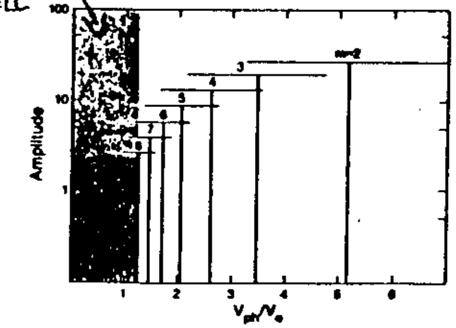
$$\frac{v_0}{v_e} = 0.97 \qquad v_0 = \left(\frac{E_{max} e}{m_e \omega_p}\right)$$

$$\frac{v_0}{v_e} = 1.8$$

POND. POTENTIAL WELL

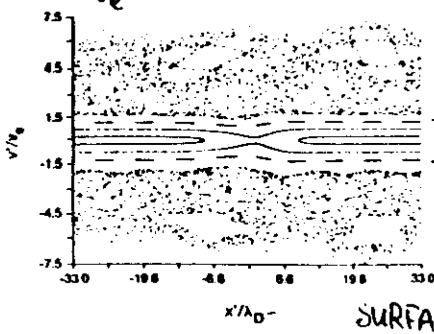


PONDEROMOTIVE POTENTIAL WELL

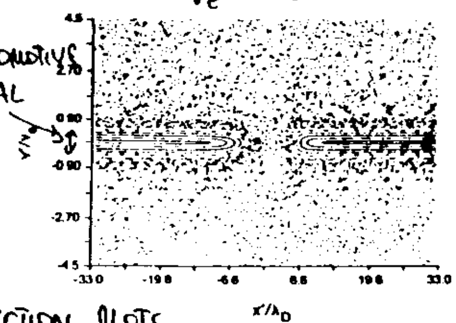


MODE OVERLAPING

$$\frac{v_0}{v_e} = 0.97 \qquad \frac{v_0}{v_e} = 1.8$$



PONDEROMOTIVE POTENTIAL

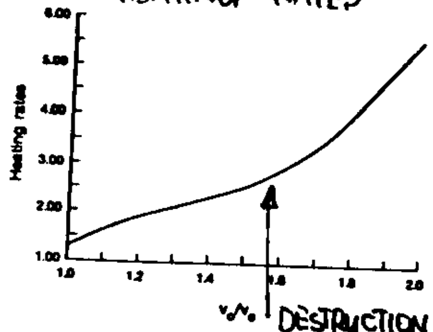


SURFACE OF SECTION PLOTS

BEYOND PONDEROMOTIVE APPROXIMATION

IN OUR STUDY WE HAVE ANALYZED MOTION OF THE OSCILLATION CENTER KEEPING THE COUPLING TERM BETWEEN FAST AND SLOW MOTION AS A DISTURBANCE.

HEATING RATES



NONADIABATIC EFFECTS ARE RESPONSIBLE FOR THE DESTRUCTION OF THE PONDEROMOTIVE POTENTIAL WELL AND PARTICLE HEATING.

IT IS A NEW MECHANISM LIMITING VALIDITY OF HYDRODYNAMICAL MODEL FOR

$$\frac{V_0}{V_e} \geqslant 1.5$$

DISTRIBUTION FUNCTION

dots - INITIAL MAXWELLIAN
long dash - $V_0/V_e \simeq 1$
solid curve - $V_0/V_e \simeq 2$