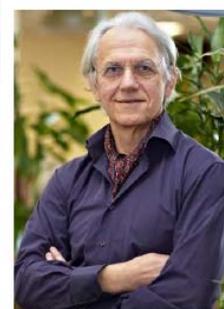
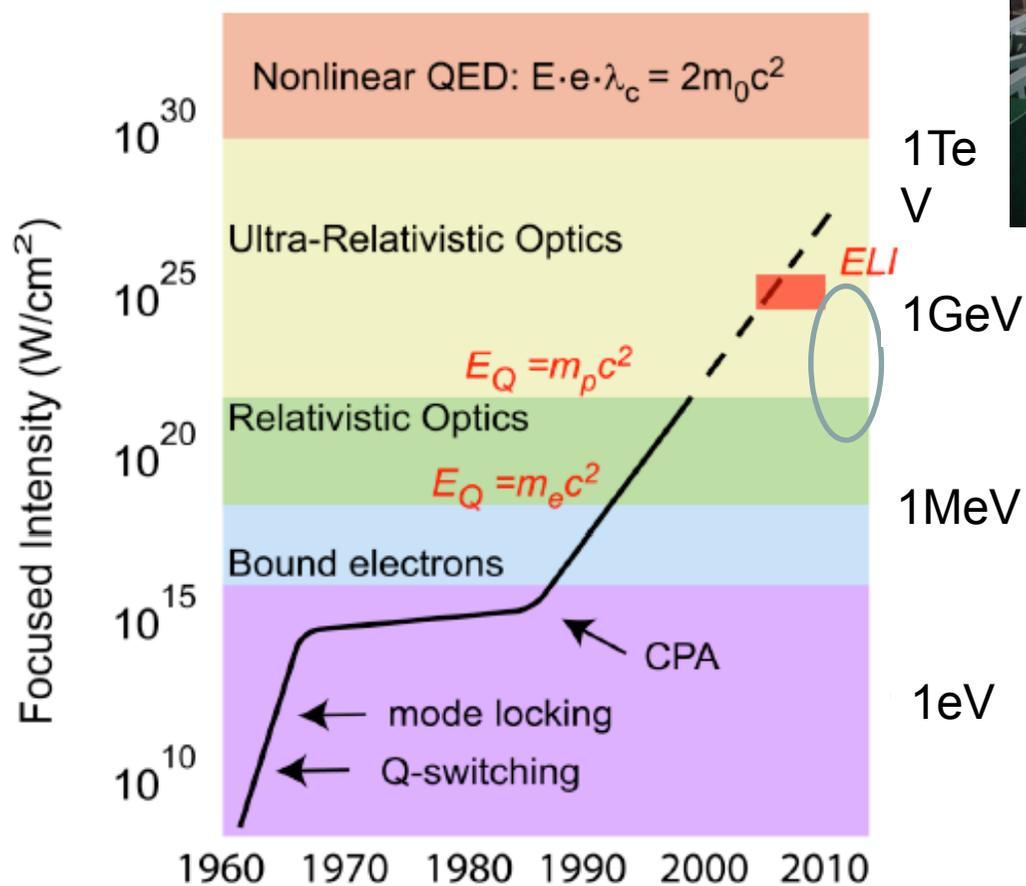


「大型レーザーを用いた新しい科学研究」 に関する意見交換会

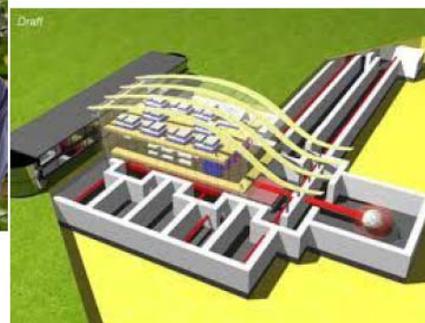
岸本泰明(京大) 岡村昇一(NIFS)

0. はじめに・趣旨説明 (京大 岸本)
1. 激光エクサ計画 (阪大 西村)
2. 大型超高強度レーザーの世界の動向と
レーザーによる真空崩壊に関する実験提案 (阪大 高部)
3. 非摂動非線形QED実験に関する考察 (原研関西 近藤)
4. 飛翔鏡の研究 (原研関西 神門)
5. 高出力レーザーの次世代半導体リソグラフィ光源への応用
(原研関西 佐々木)
6. 高出力レーザーネットワークとEXA (光産創大 三間)
7. その他 提案 および コメント (阪大産研 吉田、京大化研 阪部)
8. 総合討論

超高強度レーザーにおける世界的な展開



G. Mourou



線形から非線形性の制御へ

—磁場核融合におけるプラズマ乱流の取り組み—

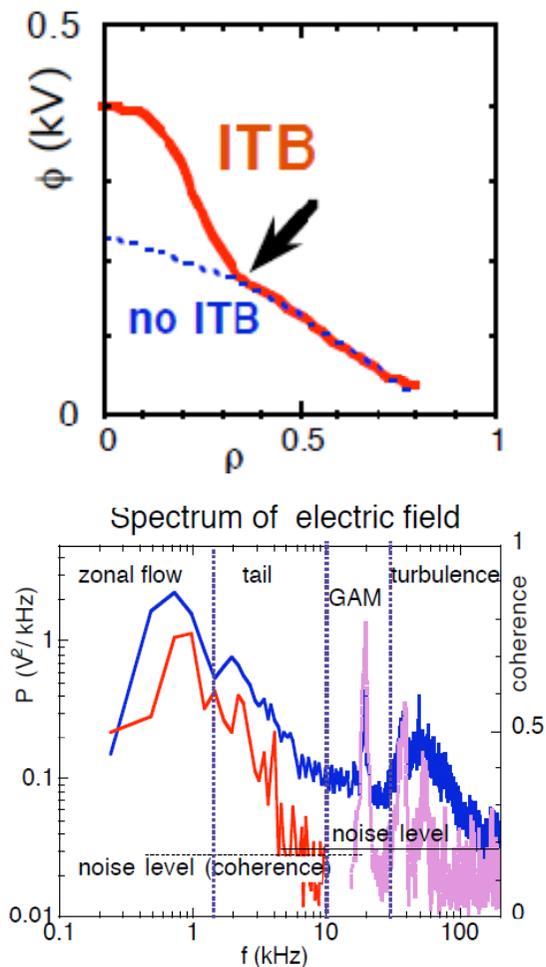
岸本泰明 (Y. Kishimoto)

京都大学大学院エネルギー科学研究科

(Graduate School of Energy Science, Kyoto University)

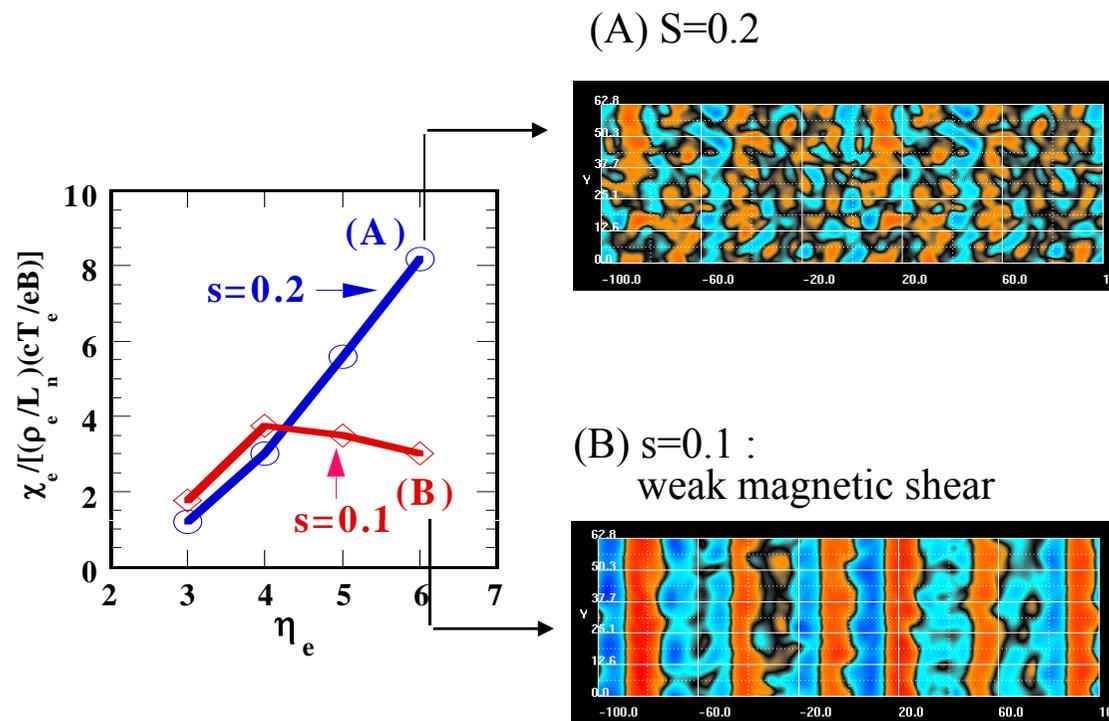
“非線形性”に準拠した磁場核融合研究

乱流駆動帯状流による ITB 形成 (CHS)



Courtesy of A. Fujisawa

電子温度勾配(ETG)乱流の
流体シミュレーション

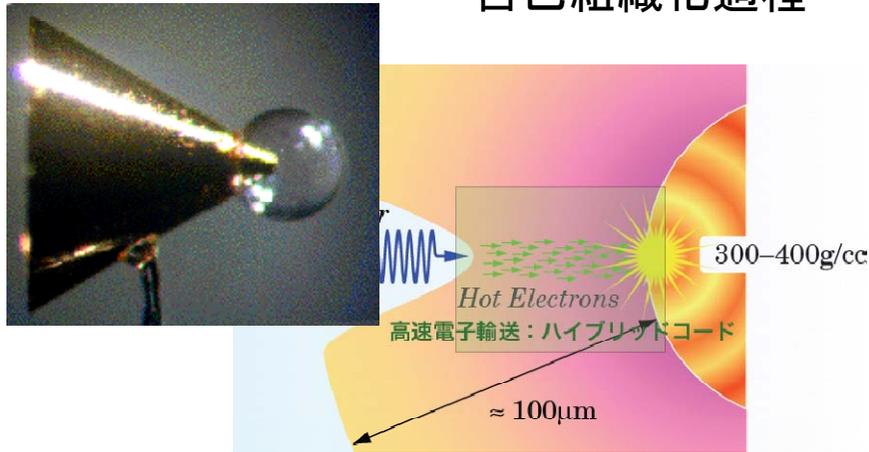


低磁気シア領域・高圧力状態
における自己組織化

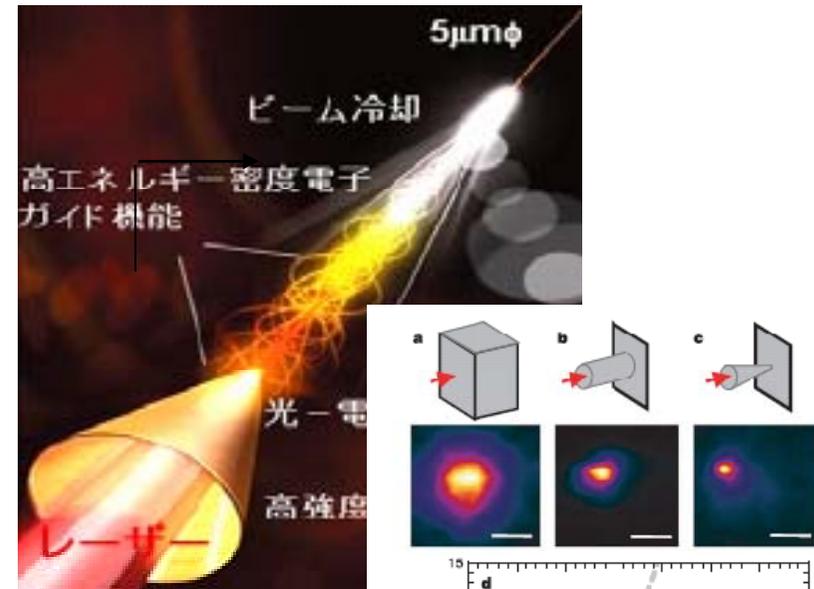
Li-Kishimoto, PoP 12, 062308⁴05

“非線形性”に準拠したレーザー核融合研究

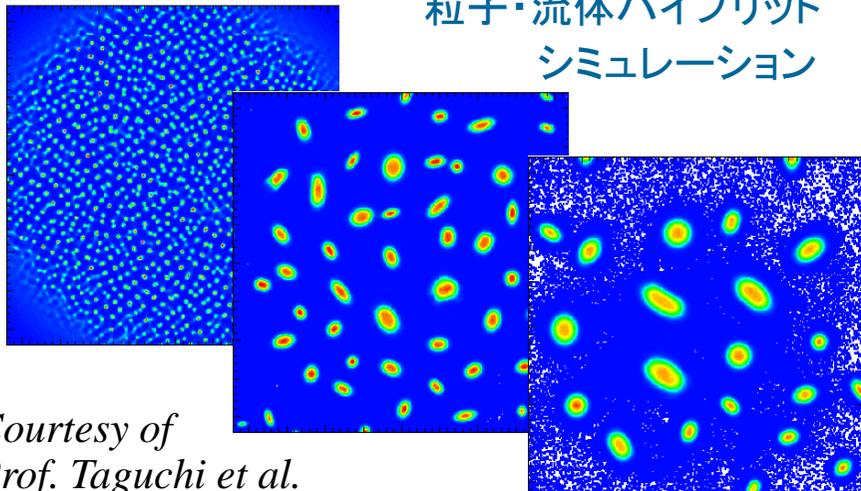
高速点火における相対論的電子ビーム
自己組織化過程



高エネルギー密度状態をデバイスとして応用

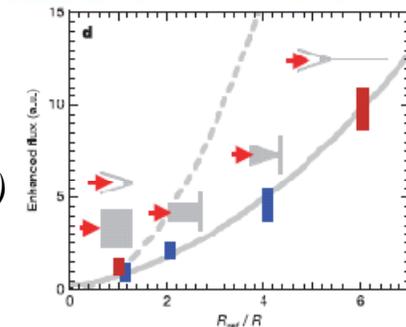


粒子・流体ハイブリッド
シミュレーション



Courtesy of
Prof. Taguchi et al.
[Taguchi et al, PRL 86, 5055 (2002)]

R. Kodama et al.,
Nature 432, 1005 (2004)



「強非線形性」に伴う構造と
「過渡過程」の制御

超高強度レーザーにおける世界的な展開

強非線形科学・非摂動論科学への展開

原子相互作用(非摂動論)

Atomic
nonlinear potential

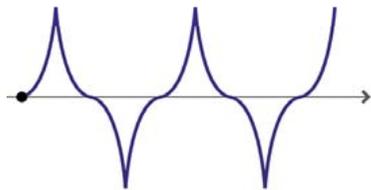


Keldysh field for
laser atomic
ionization

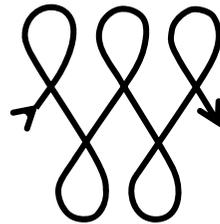
Tajima, PIF 2010

粒子・プラズマ相互作用

$$I_L > 10^{21} \text{ W/cm}^2$$



$$I_L \sim 10^{18} \text{ W/cm}^2$$

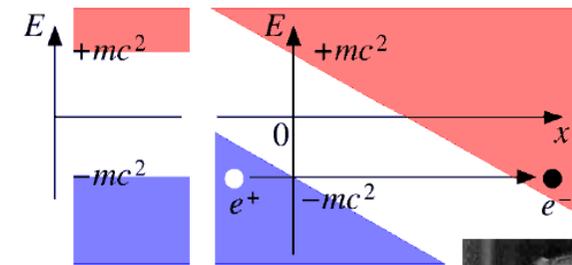


$$I_L \ll 10^{18} \text{ W/cm}^2$$



$$U = \frac{e^2 E^2}{4m\omega^2}$$

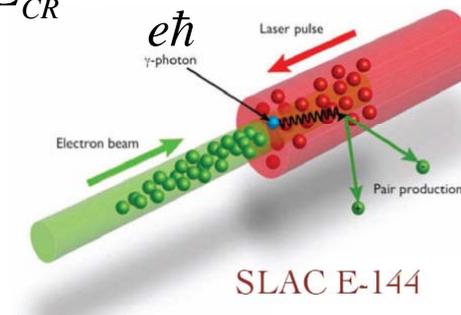
真空相互作用



Schwinger field for
vacuum breakdown



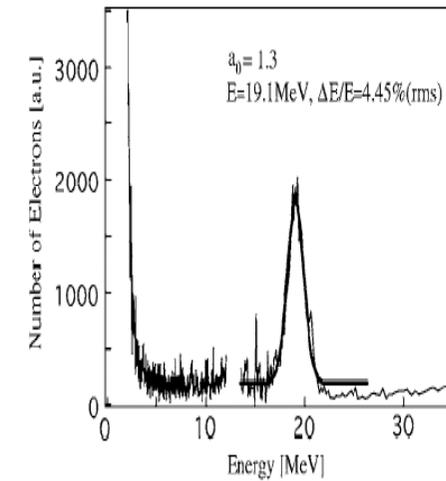
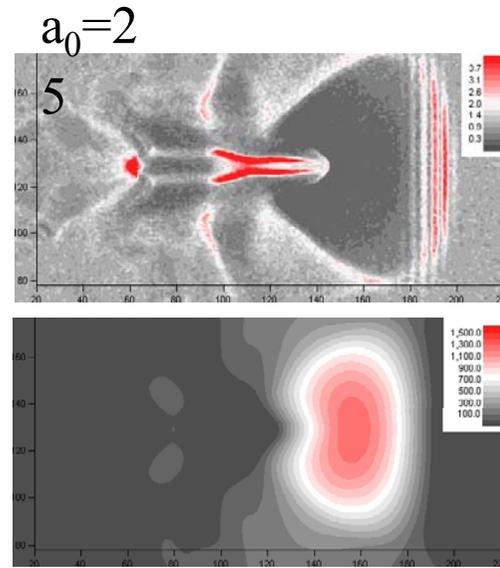
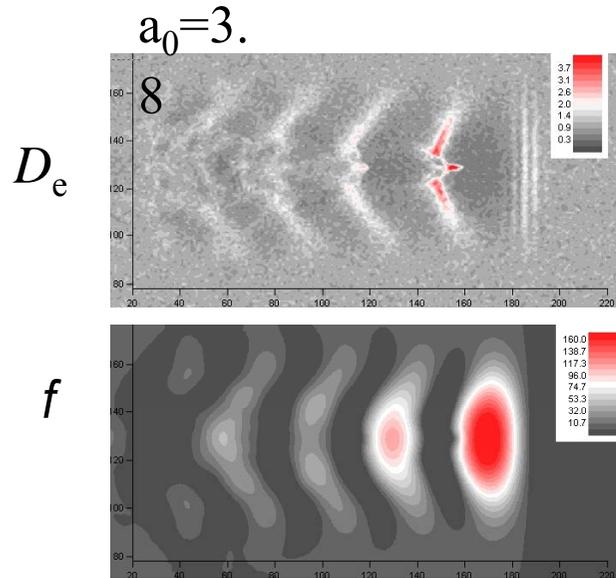
$$E_{CR} = \frac{m^2 c^3}{e\hbar}$$



Takabe, PIF 2010

強非線形領域における構造とコヒーレンス性 (2)

線形か、非線形か、強非線形か

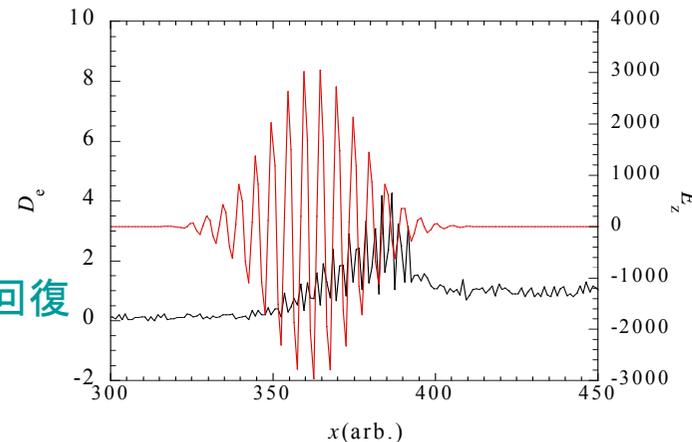


A. Yamazaki, et al.,
Phys. Plasmas 12, 093101 (2005)

$$\frac{n}{\gamma} \sim \text{const.}$$

Frozen-in condition

非線形領域における線形構造の回復

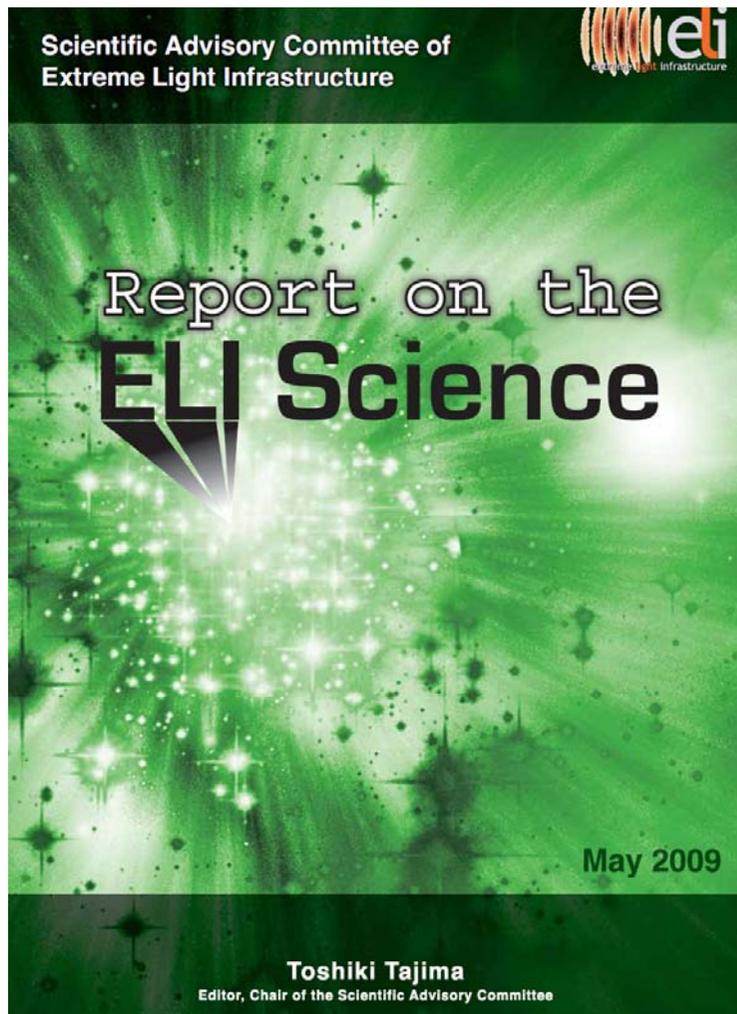


Below wave-breaking
condition

($a=1.3-1.6$)

Lower than critical power
for relativistic channeling

(1)	The Overall Philosophy of the ELI Science Case and the Four Pillars	1
(2)	Site-related issues	3
(3)	Facility and its characteristics	3
(4)	Management	5
(5)	Recommendations on specific science issues	5
(6)	Conclusions	17



[a] Attosecond science

[b] Laser acceleration

[c] Photonuclear physics

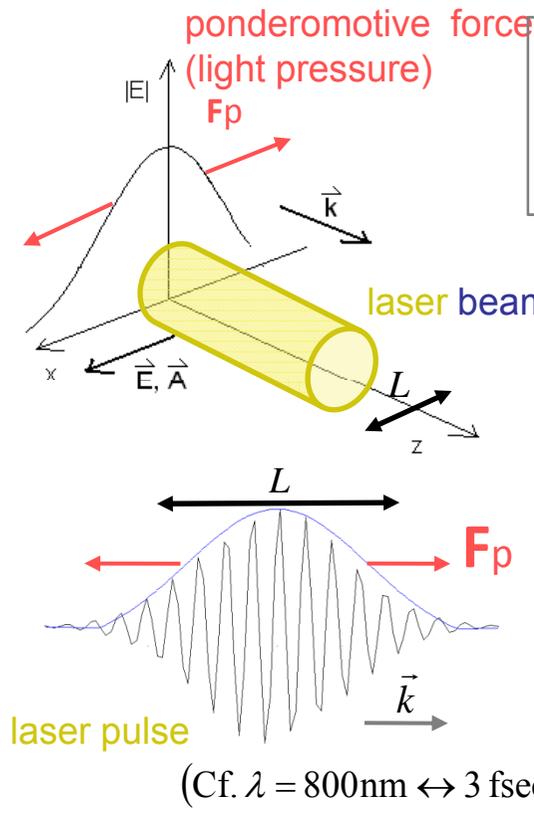
[d] Vacuum physics

- High energy beam physics
- High energy physics
- Nuclear Physics
- Energetic radiation

High-intensity lasers

↓ **Focusing of the laser power is necessary.**

GEKKO-X II	$10\text{PW} = 10^{16}\text{ W}$, $30\mu\text{m}$ spot, 1ps pulse $\Rightarrow 10^{21}\text{ W/cm}^2$
GEKKO-EXA	$0.2\text{EW} = 2 \times 10^{17}\text{ W}$, $1\mu\text{m}$ spot, 10fs pulse $\Rightarrow 10^{25}\text{ W/cm}^2$
<small>(H.Azechi, Symposium 2010, Institute of Laser Engineering, Osaka Univ., April 27, 2010)</small>	
JAEA J-KAREN	$0.2\text{PW} = 2 \times 10^{14}\text{ W}$, $5\mu\text{m}$ spot, 50fs pulse $\Rightarrow 10^{21}\text{ W/cm}^2$



- Ponderomotive force appears in the direction of $\nabla |A|$
- $|F_p| \propto \nabla |A|^2$ in the 1st order of $\epsilon \sim \lambda/L$.

→ Charged particles will be ejected out from the laser field immediately.
 → A mechanism to trap the particle:



... The curvature of the laser amplitude will appear in the 2nd order. may become important.

■ The 2nd-order trajectory

(Backward-Lie transformation contains only the rapid-oscillation $\rightarrow Z^{ni} = \bar{Z}^i$)

\rightarrow The slow time scale motion in the original oscillation-center coordinate:

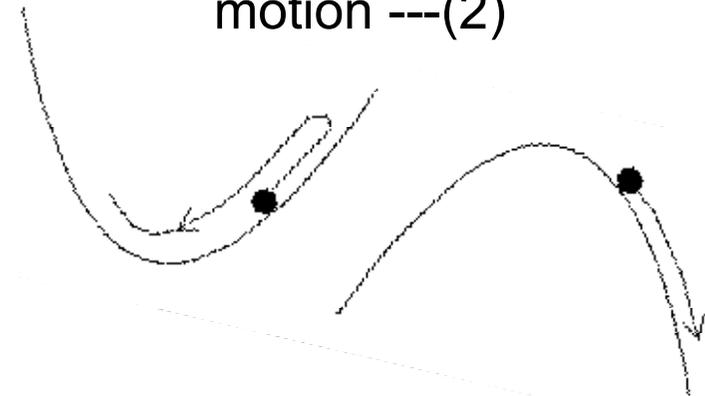
$$\begin{cases} \bar{P}_x = \alpha \sin(\theta \eta) & \text{for } \frac{1}{L^2} + \frac{1}{R} \geq 0 \\ \bar{P}_x = \beta [\exp(\theta \eta) - \exp(-\theta \eta)] & \text{for } \frac{1}{L^2} + \frac{1}{R} < 0 \end{cases}$$

... **slow oscillation** ---
(1) (bounded solution)

... unbounded secular motion ---(2)

$$\theta = \frac{a_{0x0}}{k_z \zeta_0} \sqrt{\frac{1}{2} \left| \frac{1}{L^2} + \frac{1}{R} \right|}, \quad \alpha = \frac{mca_{0x0}}{\sqrt{2 \left(\frac{1}{L^2} + \frac{1}{R} \right)}} \left[-\frac{1}{L} + \frac{a_{0x0}}{k_z \zeta_0} \left(\frac{1}{L^2} + \frac{1}{R} \right) \right]$$

$$\beta = \frac{mca_{0x0}}{2 \sqrt{2 \left| \frac{1}{L^2} + \frac{1}{R} \right|}} \left[\frac{1}{L} - \frac{a_{0x0}}{k_z \zeta_0} \left(\frac{1}{L^2} + \frac{1}{R} \right) \right]$$

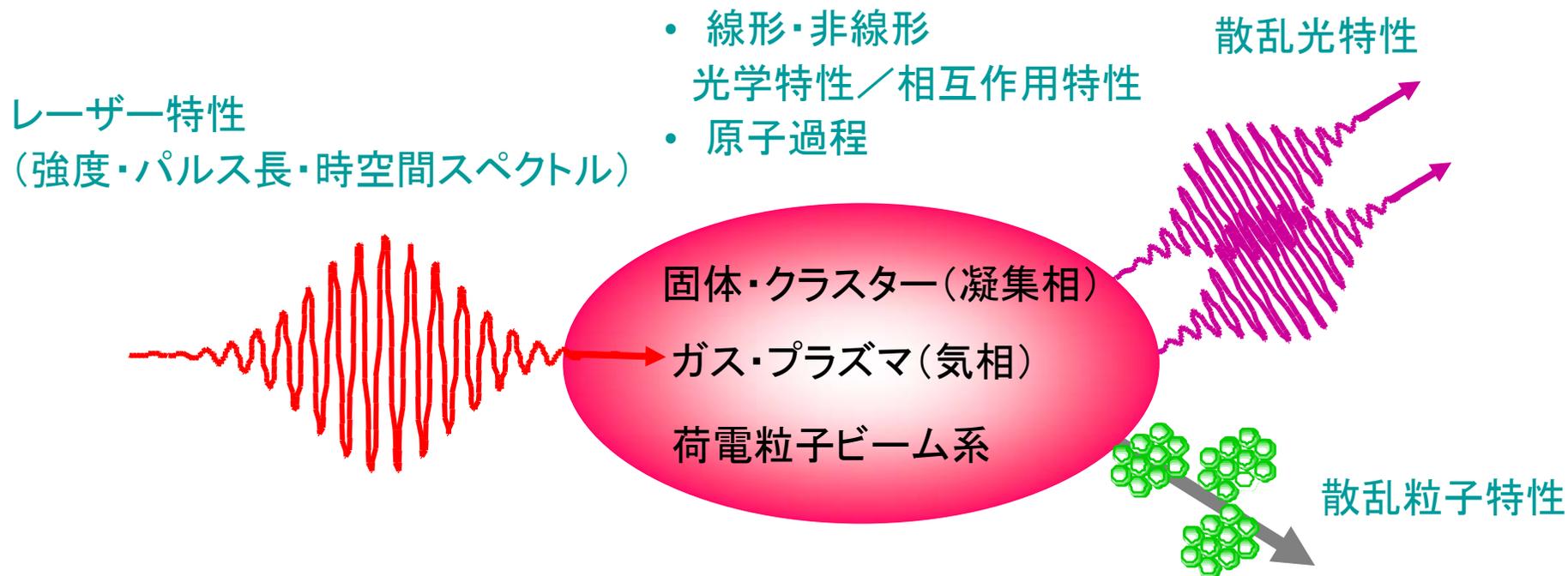


Cf. The orbit obtained by the perturbation analysis directly to the eq. of motion:

$$\bar{P}_x = -\frac{mca_{0x0}^2}{2k_z \zeta_0} \left[\frac{1}{L} - \frac{a_{0x0}}{k_z \zeta_0} \left(\frac{1}{L^2} + \frac{1}{R} \right) \right] \eta \quad \text{---(3) unbounded solution}$$

- (1)=(2)=(3) up to the 2nd order if we expand $\theta \eta$ in Eqs. (1) and (2).

高強度レーザーと物質との相互作用の特性



非熱平衡: “輻射場(photon gas)”と“荷電粒子多体系(プラズマ系)”の結合
cf. photon-photon, photon-electron, electron-electron/ion

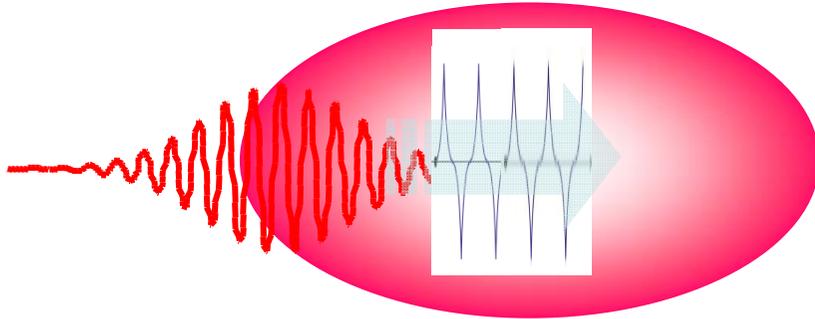
非定常性: “輻射場”と“荷電粒子多体系”の過渡特性

非線形性: 輻射場の摂動(dg) vs. 密度の変調(dn) cf. $\xi = \frac{n}{\gamma} \cong \frac{n_0}{\gamma_0} \left(\frac{\Delta n + \delta n}{n_0} - \frac{\delta \gamma_0}{\gamma_0} \right)$

線形構造 → 弱非線形構造 → 強非線形構造

非ポテンシャル動重力(1)

L.N. Tsintsadze, T. Tajima, K. Nishikawa, J. Koga, K. Nakagawa, Y. Kishimoto
 Physic Scripta. Vol. T84, 94-97, 2000



レーザーと伝播する“流れ”のあるプラズマ
 (flowing plasma or current carrying plasma)

$$U = m_0 c^2 \left\{ \left(1 + u^2 \right)^{1/2} - 1 \right\}$$

$$u^2 = \frac{p_{\perp}^2(\mathbf{r}, c)}{m_0 c^2} \left(1 + p^2 \right)^{1/2} = 2 \int \frac{d\mathbf{k}}{(2\pi)^3} \mathbf{P}(\mathbf{k}, \omega, \mathbf{r}, t)$$

$$\mathbf{P}(\mathbf{k}, \omega, \mathbf{r}, t) = \frac{e^2 |E(k, \omega, \mathbf{r}, t)|^2}{m_0^2 c^2 \omega^2}$$

$$\omega = \omega' + \mathbf{k}' \cdot \mathbf{v} \quad k = k' + \frac{\omega' \mathbf{v}}{c^2}$$

$$U = m_0 c^2 \left\{ \left(1 + \frac{e\Phi_p}{m_0 c^2} \right)^{1/2} - 1 \right\} - \frac{e\mathbf{v}}{c} \mathbf{A}_p$$

$$e\Phi_p = 2 \int \frac{d\mathbf{k}'}{(2\pi)^3} \mathbf{P}(\mathbf{k}', \omega', \mathbf{r}, t) = 2 \int \frac{d\mathbf{k}'}{(2\pi)^3} \frac{e^2 |E_{k'}|^2}{m_0 \omega'^2}$$

$$e\mathbf{A}_p = \int \frac{d\mathbf{k}'}{(2\pi)^3} \frac{\mathbf{k}'}{\omega'} \frac{e^2 |E_{k'}|^2}{m_0 \gamma_1 \omega'^2}$$

$$\frac{\partial \mathbf{p}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{p} = -e \left\{ \mathbf{E}_p + \frac{1}{c} \mathbf{v} \times \mathbf{B}_p \right\} - m_0 c^2 \nabla \gamma - m_0 c^2 \mathbf{Q} \frac{\partial \gamma}{\partial t}$$

$$m_0 c^2 \nabla \gamma$$

$$m_0 c^2 \mathbf{Q} \frac{\partial \gamma}{\partial t}$$

$$\mathbf{E}_p = -\frac{1}{c} \frac{\partial A_p}{\partial t} - \nabla \Phi_p$$

$$\mathbf{B}_p = \nabla \times \mathbf{A}_p$$

非ポテンシャル動重力(2)

$$\nabla \times \mathbf{p} = \frac{e}{c} \mathbf{B} + \frac{e}{c} \mathbf{B}_p$$

$$\nabla^2 \mathbf{B} - \frac{1}{c^2} \frac{\partial^2 \mathbf{B}}{\partial t^2} - \frac{\omega_p^2}{c^2} \mathbf{B} = \frac{\omega_p^2}{c^2} \mathbf{B}_p + \frac{\nabla \omega_p^2}{ce} \times \mathbf{p}$$

生成源

- 低周波電磁場
- 運動量渦

$$\frac{e|\mathbf{B}_p|}{m_0 c} \cong \left| eA_p = \int \frac{d\mathbf{k}'}{(2\pi)^3} \times \nabla \frac{\mathbf{k}'}{\omega'} \frac{e^2 |E_{k'}|^2}{m_0 \gamma_1 \omega'^2} \right| \cong \frac{2c}{r_\perp} \frac{u^2}{(1+u^2)^{1/2}} \propto \gamma \quad (\text{cf. } \sim 30\text{MG})$$

$$\omega \rightarrow \omega' + \Omega \begin{cases} \delta n & : \text{ plasmon} & \Omega \sim \omega_p \\ \delta \gamma & : \text{ photon (dn} \sim 0) & \Omega \ll \omega_p \end{cases}$$

$$\Omega = qu_g \cos \theta$$

チェレンコフ放射

様々な非線形相互作用と制御

- パラメトリック不安定性・共鳴
 - 相対論的変調不安定性・線素 (filamentation) 不安定性
 - 非ポテンシャル動重力
(低周波電磁場・チェレンコフ放射・ Bose-Einstein 凝縮)
 - 大振幅プラズマ波励起・ソリトン励起
 - 相対論的波動破壊 (wave breaking) ・無衝突衝撃波
 - 相対論的自己集束
 - 電離不安定性 etc.
-
- ✓ **非線形構造**の同定(構造の過渡的ダイナミクスと安定性)
 - ✓ 物理過程の同定と応用の可能性
 - ✓ 制御の理論と手法の開拓