Effects of local field enhancement on the laser-driven Rayleigh-Taylor instability

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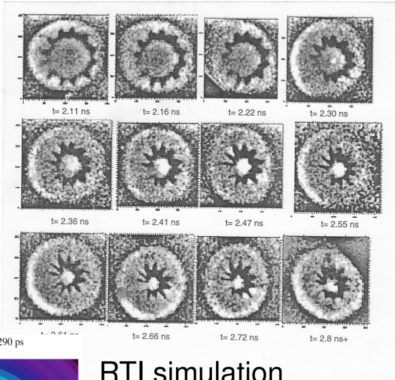
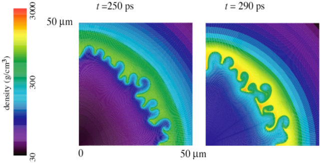
Rayleigh-Taylor Instability in space and lab plasmas

Crab Nebula, Hubble Space Telescope

Laser-driven implosion for Inertial Confinement Fusion studies, 1995 (Wikipedia)

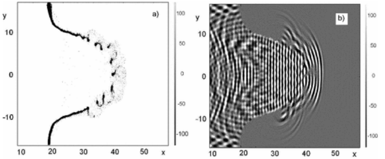




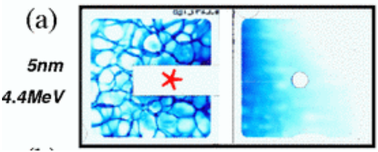
RTI simulation GAPS group, Roma (S.Atzeni et al)

RTI in Radiation Pressure Acceleration?

Thin foil target of areal density σ accelerated by a laser of intensity I is unstable with growth rate $\gamma = (P_0 q/\sigma)^{1/2}$ with $P_0 = 2I/c$ and q the wavevector [Ott, PRL **29** (1972) 1429]

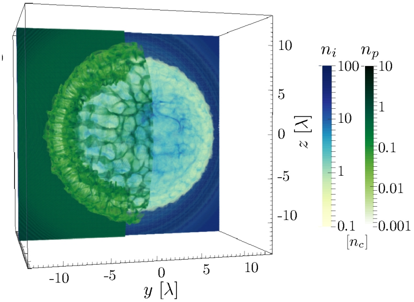


2D simulation [F.Pegoraro & S.V.Bulanov, PRL **99** (2007)065002]



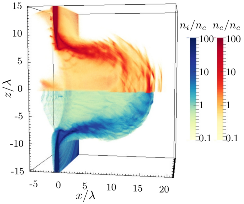
Experimental indication from accelerated ion beam profile structures [Palmer et al, PRL **108** (2012) 225002]

3D simulation of thin foil RPA



- Code: `ALaDyn` (originally developed by Benedetti, Londrillo, Sgattoni, Turchetti – Bologna University)
- Machine: FERMI BlueGene/Q at CINECA sponsored by PRACE
- Set-up: 4096×1792^2 grid points, 2×10^{10} particles, 16384 cores used
- 10^{23} W cm^{-2} laser pulse on solid target (sub-μm thickness)

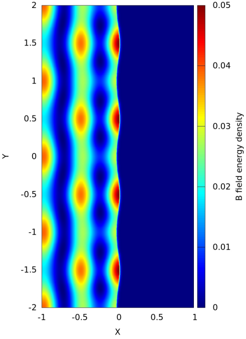
[Sgattoni et al, APL **105** (2014) 084105]

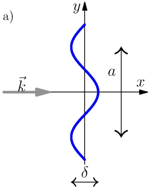


Formation of net-like structures with size $\sim \lambda$ (laser wavelength)
What sets the dominant scale?

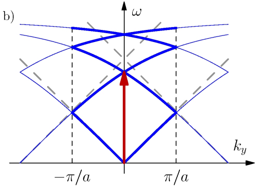
Plasmonic modulation of radiation pressure

The EM field at a rippled surface (e.g. 2D reflecting, sinusoidal grating of period d) is modulated with plasmonic enhancement of the P-component when $d \sim \lambda$





Geometry



Matching with surface plasmons

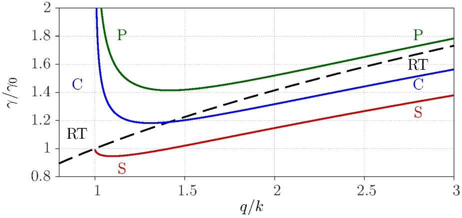
The resulting modulation of laser light pressure provides a spatial seed for RTI [A.Sgattoni et al, arXiv:physics/1404.1260]

Thin foil RTI with self-consistent pressure modulation

Model: reflection from shallow 2D grating of depth δ (first order in δ/λ) + modified Ott's theory with modulated pressure:

$$P \simeq P_0(1+K(q)\delta\cos qy)\,, \qquad K(q) = \begin{cases} -(q^2-k^2)^{1/2} & (S) \\ k^2 q(q^2-k^2)^{-1/2} & (P) \\ (k^2-q^2/2)(q^2-k^2)^{-1/2} & (C) \end{cases}$$

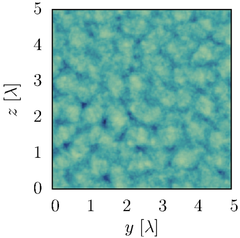
$$\gamma = (P_0/\sigma)^{1/2}\left[\left(q^2+K^2(q)/4\right)^{1/2} + K(q)/2\right]^{1/2}$$



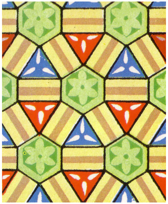
S-polarization
P-polarization
C-ircular polarization
RT: no modulation ($\delta = 0$)

Symmetry of RTI structures

Nonlinear hexagonal-like structures generated by RTI: an example of sponta-neous symmetry breaking in a classical system with "wallpaper" p6m symmetry



3D sim. (plane wave)



Persian glazed tile

3D simulation on FERMI with the Open Source code PICcante (L.Fedeli, A.Sgattoni, S.Sinigardi, A.Marocchino et al)

`github.com/ALaDyn/piccante`

Conclusions

- Field modulation and plasmonic enhancement affect the laser light pressure-driven Rayleigh-Taylor instability of a thin foil
- The effect accounts for the dominant scale ($\sim$ laser wavelength) observed in 3D simulations
- RTI may be an issue for ion acceleration in ELI experiments at $> 10^{23}$ W cm^{-2}
- Structures observed in the nonlinear 3D evolution provide an example of “classical” spontaneous symmetry breaking