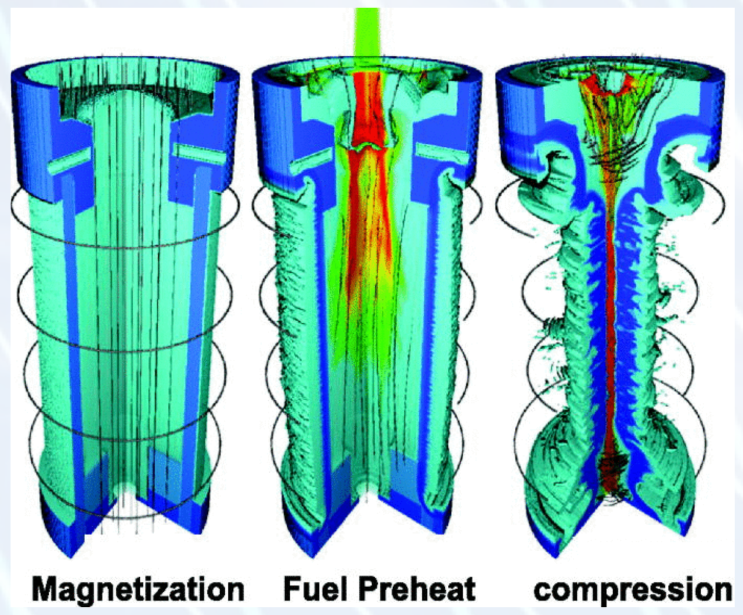
E. E. Los

Laser-Plasma Interactions with and without a Magnetic Field

Inertial Confinement Fusion (ICF) with Magnetic Field

MagLIF [Sandia]

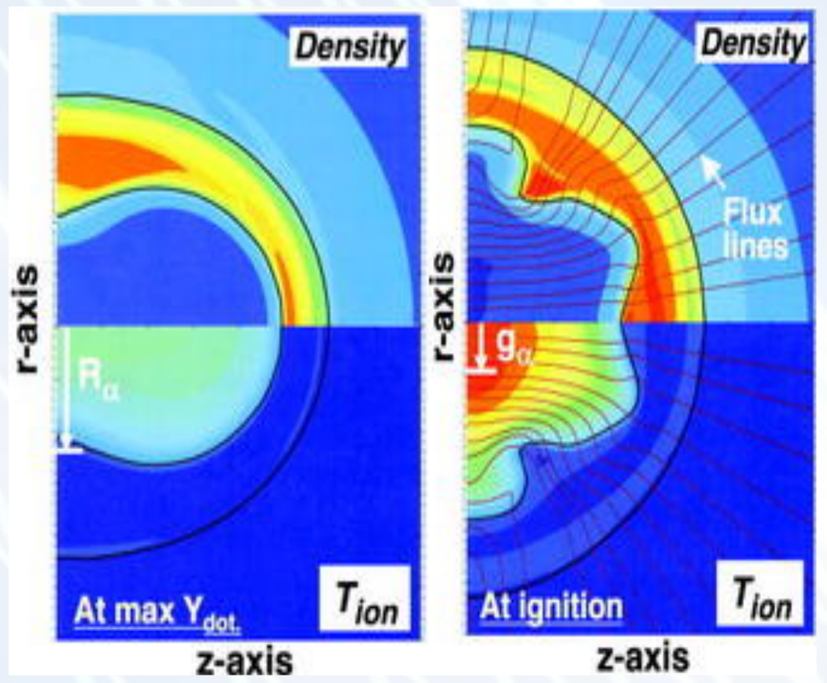
Laser preheat:~10 kJ, T_{ion} ~ 500 eV
B_{z0} ~ 30 T to confine fusion alpha 's
Cylindrical liner implosion



S. Slutz et al *Phys. Plasmas* 2016

Spherical implosion with imposed B field

Frozen In law: $B_z \pi r^2$ constant.

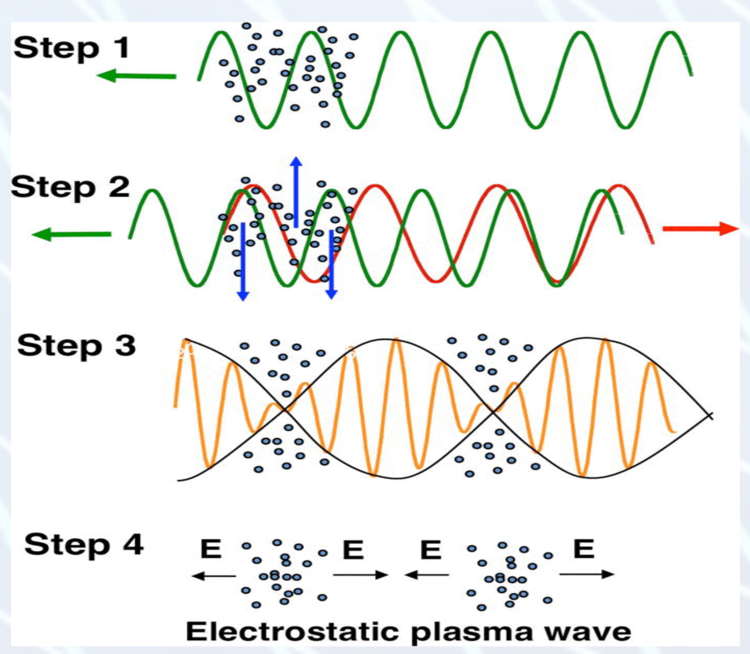


L. J. Perkins et al *Phys. Plasmas* 2017

Parametric Decay of Light Waves in a Plasma

Stimulated Brillouin scattering (SBS):
EMW (0) → IAW (2) + EMW (1)
Stimulated Raman scattering (SRS):
EMW (0) → EPW (2) + EMW (1)

- EMW: electromagnetic wave
- EPW: electron plasma wave
- IAW: ion acoustic wave



D. S. Montgomery, *Phys. Plasmas* 2016

Phase Matching: Conserve Energy and Momentum

$\omega_0 = \omega_1 + \omega_2 \qquad \vec{k}_0 = \vec{k}_1 + \vec{k}_2$

Parametric Instabilities can impede ICF

- Decay produces waves which are resonant in the plasma (SRS, SBS)
- Scattered light removes energy from target, damages optics
- EPW's from SRS produce "hot" electrons, can preheat capsule

B Fields can play a role in ICF:

- Imposed axial B field in MagLIF to confine thermal electrons and alphas
- Imposed field under consideration for NIF hohlraums
- Plasmas can self-generated B fields

Governing Equations for Cold Electrons and Fixed Ions

Maxwell's equations

$$\nabla . E = \frac{n}{\varepsilon_0}$$
$$\nabla . B = 0$$
$$\nabla \times E = -\frac{\partial B}{\partial t}$$
$$\nabla \times B = \mu_0 \left(\varepsilon_0 \frac{\partial E}{\partial t} + J\right)$$

Continuity and fluid momentum equations

$$\frac{\partial n}{\partial t} + \nabla . (nv) = 0$$
$$m\frac{\partial v}{\partial t} + eE = -m(v.\nabla)v - ev \times B$$

Fourier representation of E field

$$E = \sum_j E_j e^{i(k_j x - \omega_j t)} + c.c$$

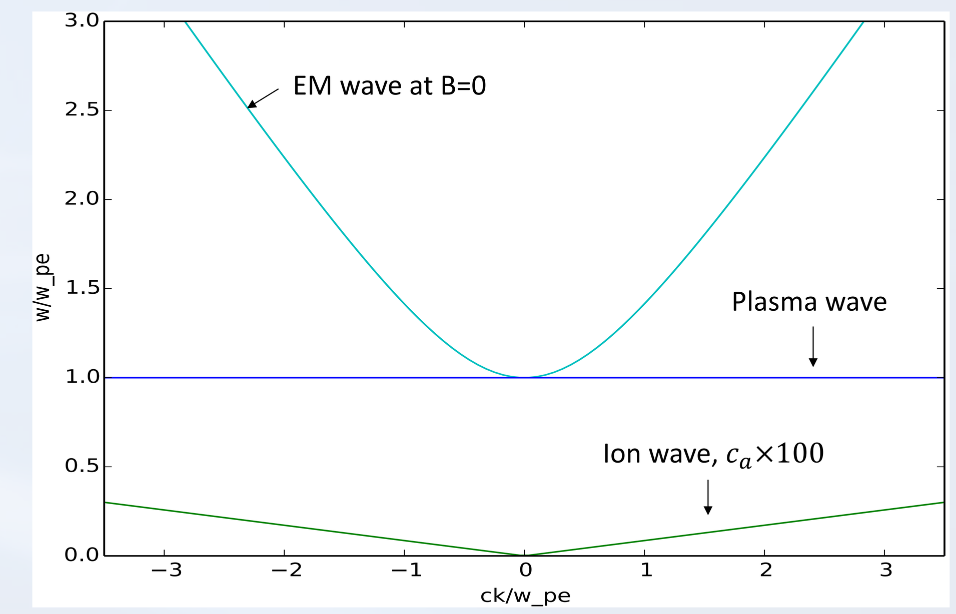
second order coupling terms in red

Reference Parameters

- $\frac{\omega_0}{\omega_{pe}} = 2.24$
- $\frac{\omega_{ce}}{\omega_{pe}} = 1.04$
- $m_i = 4.00\ au$
- $\frac{n_e}{n_{crit}} = 0.2$
- $\lambda_0 = 1.00\ \mu m$
- $\frac{c_a}{c} = 8.5895 \times 10^{-4}$
- $n_e = 5.73 \times 10^{20}\ cm^{-3}$
- $T_i = 0.25\ keV$
- $T_e = 1.00\ keV$
- $B = 5.00\ kT$

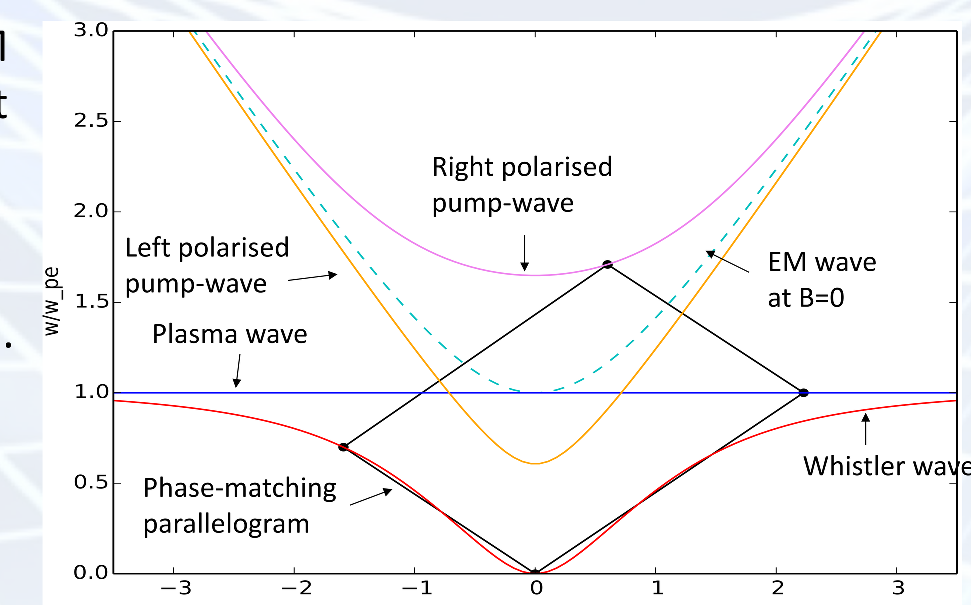
Waves in an Unmagnetized Plasma

- IAW: $\omega = c_a k$, where $c_a = \left(\frac{ZT_e + 3T_i}{m_i}\right)^{\frac{1}{2}}$
- EMW: $\omega = c^2k^2 + \omega_{pe}{}^2$
- EPW "(cold)": $\omega = \omega_{pe}$



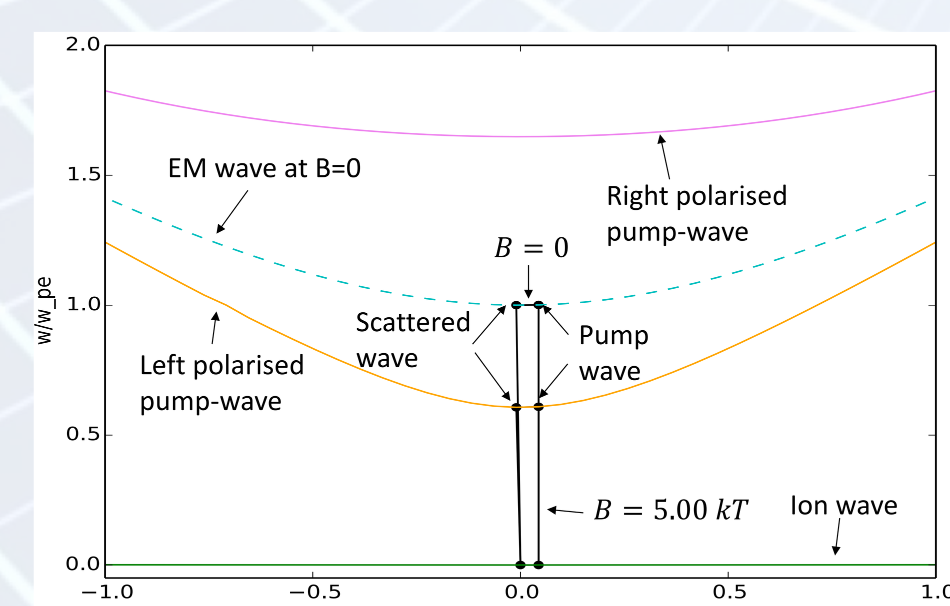
Parametric Coupling in a Magnetized Electron Plasma: EMW -> Whistler + EPW

- Right and left polarized EM waves rotate with different velocities: Faraday rotation.
- Additional "whistler wave" (WW), exists only in B field.
- Phase matching diagram

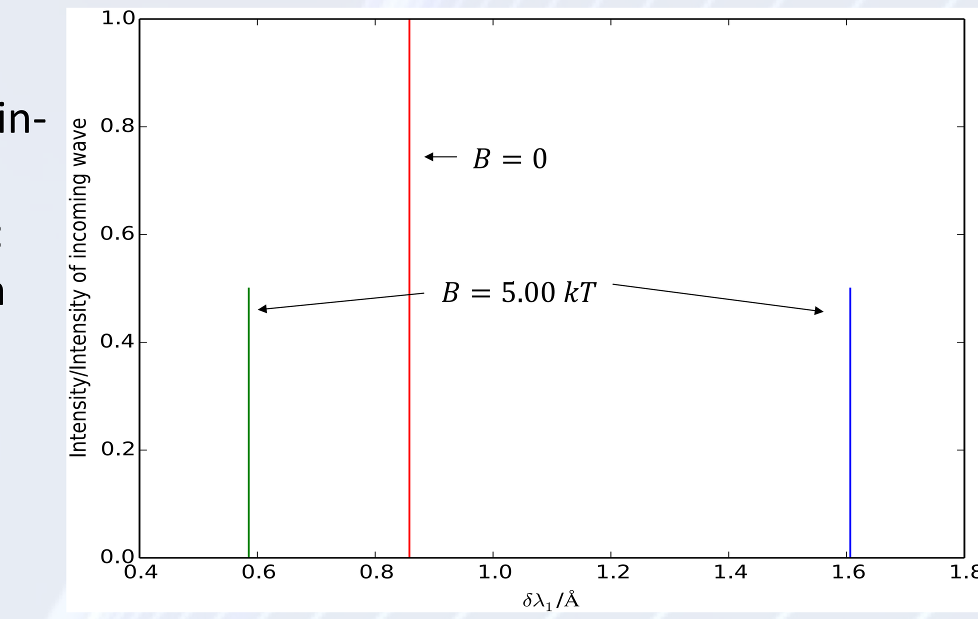


Electrostatic Waves in a Magnetized Plasma (Electrons and Ions)

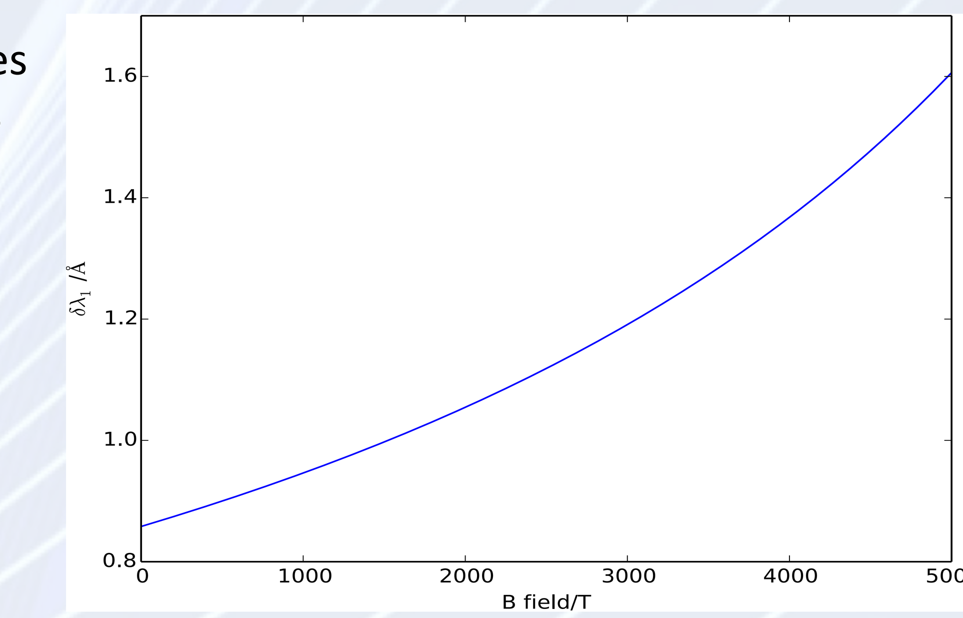
- Phase matching for SBS
- Splitting of pump into left and right polarized waves results in additional decays
- $B = 0$ T case shown



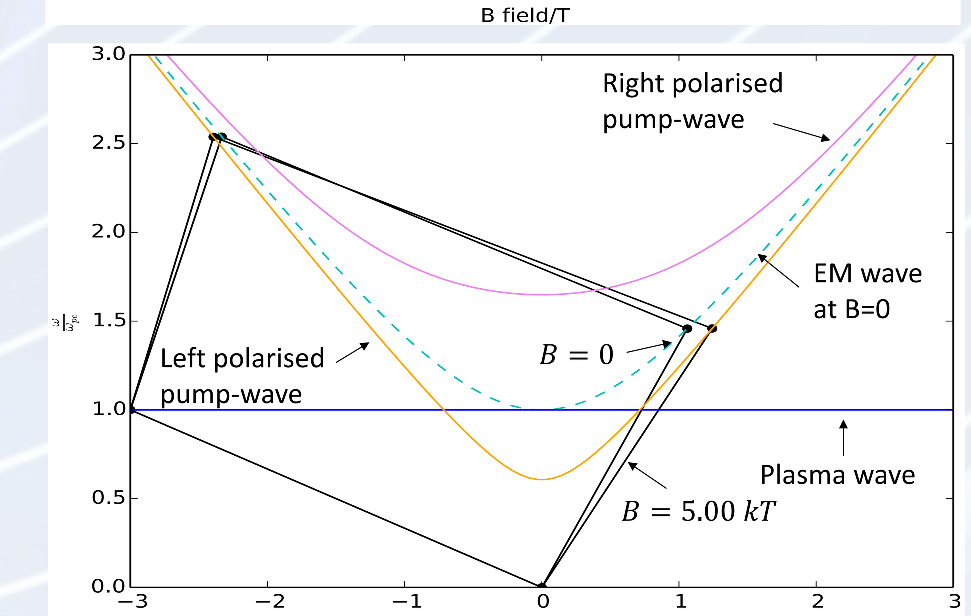
- B field causes shift in the wavelength of the Brillouin-scattered EMW
- SBS light split into 2 lines: linearly polarized EMW in vacuum → both R and L waves in magnetized plasma



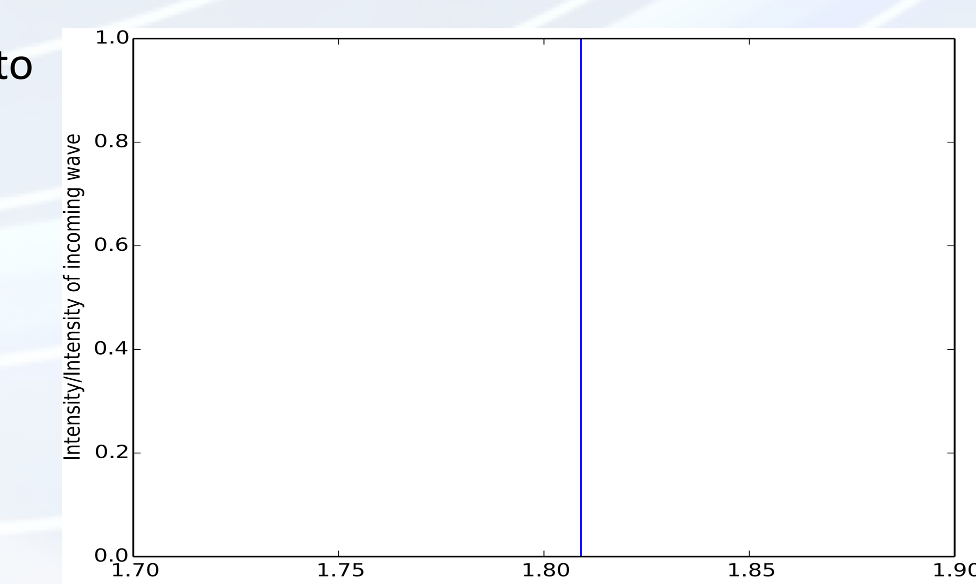
- Wavelength shift increases linearly with B for small B



- Phase matching for SRS
- $B = 0$ T case shown



- No wavelength shift due to B field for SRS



Conclusions

- B field generates additional waves, greater number of parametric processes can occur
- B field induces a wavelength shift in the Brillouin-scattered pump waves, but not for Raman-scattered pump waves
- Wavelength shift of SBS light increases linearly for small B

Acknowledgements

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