LhARA Capture Meeting

26th August 2021

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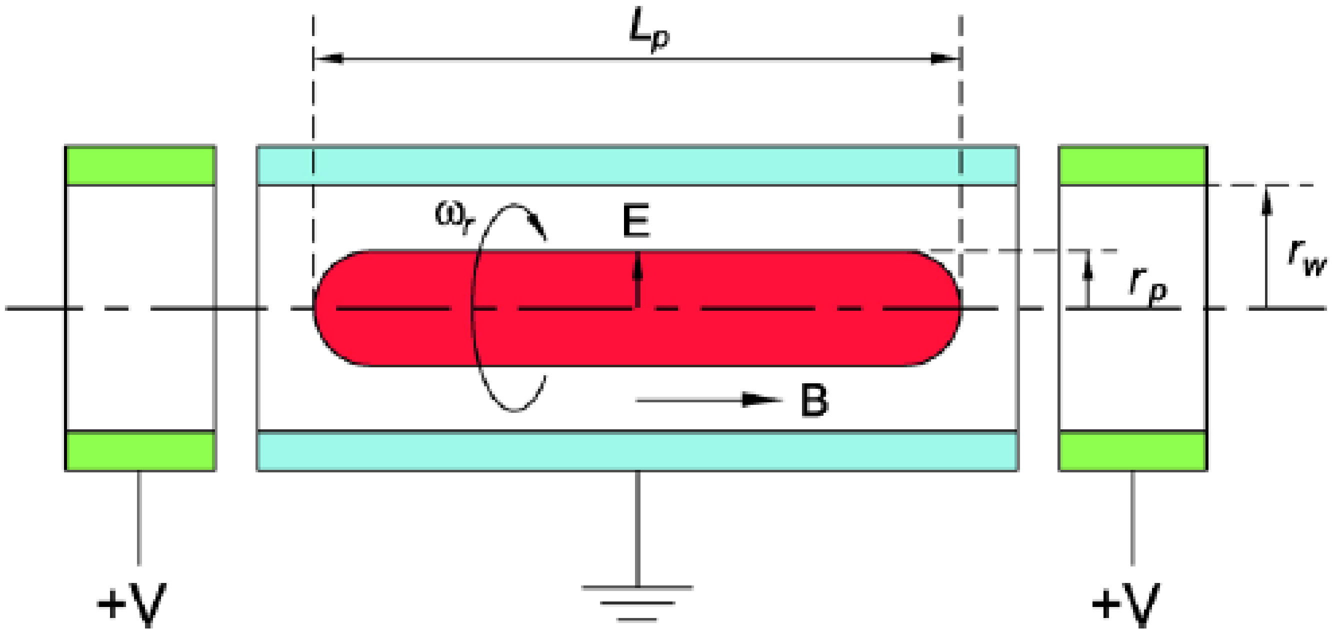
Transverse size of high-density plasmas in thermal equilibrium

Finite temperature equilibria

- Measurements indicate relaxation to rigid rotor thermal equilibrium in less than ≈ 10 s for $B \lesssim 1000$ G

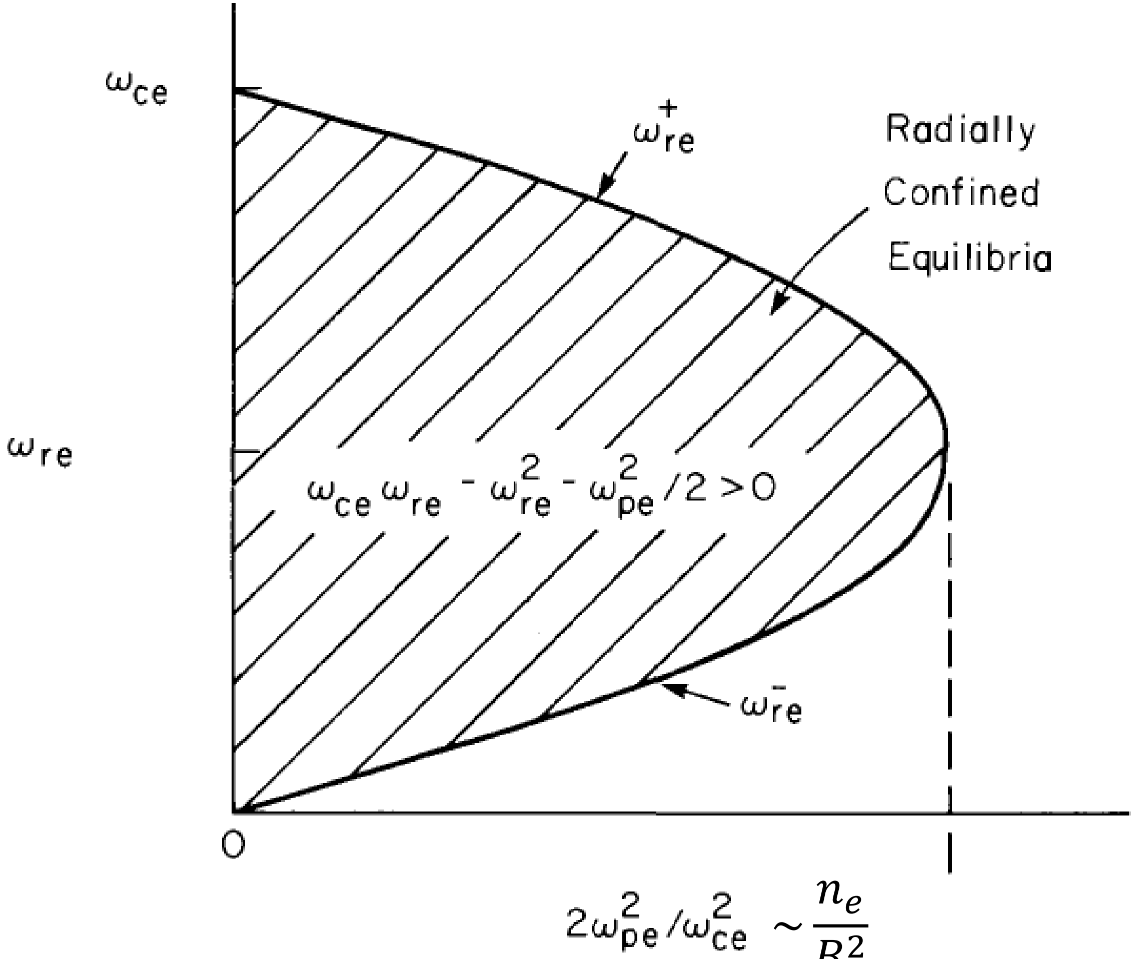


10.1103/RevModPhys.87.247

https://doi.org/10.1103/PhysRevLett.60.1290

Finite temperature equilibria

- Uniform temperature T (global thermal equilibrium)
- Viscosity acts to remove shears in angular velocity



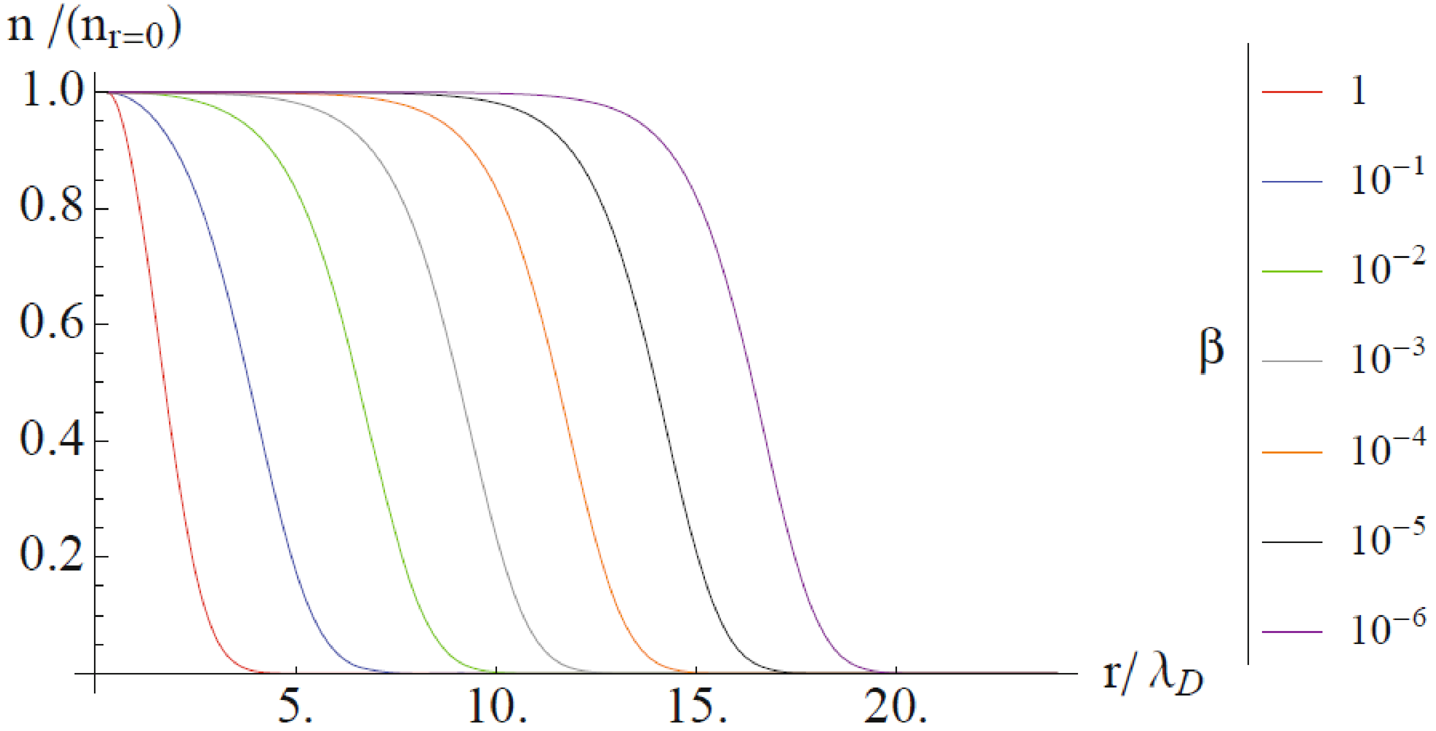
$\sim \frac{n_e}{B^2}$

$\omega_{re}^{-} < \omega_{re} < \omega_{re}^{+}$

Define β from

$\omega_{re} = \omega_{re}^{+}(1-\beta)$

Finite temperature equilibria



$$\omega_{re} = \omega_{re}^{+}(1-\beta)$$

https://doi.org/10.1140/epjd/e2014-40700-0

https://doi.org/10.1063/1.862577

Transverse size of plasma in thermal equilibrium

Density [m^{-3}]	Temperature [eV]	Debye length [mm]
1×10^{15}	0.01	0.024
	0.1	0.074
	1	0.235
	10	0.743
	100	2.351
5×10^{15}	0.01	0.011
	0.1	0.033
	1	0.105
	10	0.332
	100	1.051

LhARA Conceptual Design

- Gabor lens anode radius $r_w = 3.65$ cm
- Beam size $\sigma_{x,y} \approx 1.4$ cm

$$\lambda_D = \sqrt{\frac{\varepsilon_0 k_B T}{n_e e^2}}$$ (Debye length)

Finite temperature equilibria

Comments

- No heating or cooling of the plasma is considered here
- The only cross-field particle transport mechanism considered is that of the Boltzmann theory
- Different scaling for r_p may be obtained if we consider
  - Outward transport (neutral collisions, field asymmetries)
  - Heating and cooling rates

- E.g. if neutral collisions dominate both the transport and the cooling

$$\left(\frac{n_e}{n_B}\right)^2 = \frac{8\upsilon_j\varepsilon_j}{\upsilon_e T}\left(\frac{r_c}{r_p}\right)^2$$

→ depend on the choice of neutral gas

Backup

Cold-fluid equilibrium

- Momentum balance equation for a cold fluid

$$mn\boldsymbol{v}\cdot\boldsymbol{\nabla}\boldsymbol{v} = qn(\boldsymbol{E} + \boldsymbol{v}\times\mathbf{B})$$

$$q(E_r + v_\theta B) + \frac{mv_\theta^2}{r} = 0$$

$$-\omega_{re}^2 = \frac{1}{2}\omega_{pe}^2 - \omega_{re}\omega_{pe}$$

$$\omega_{re}^{\pm} = \frac{1}{2}\omega_{ce}\left[1 \pm \left(1 - \frac{2\omega_{pe}^2}{\omega_{ce}^2}\right)^{1/2}\right]$$

rigid rotation

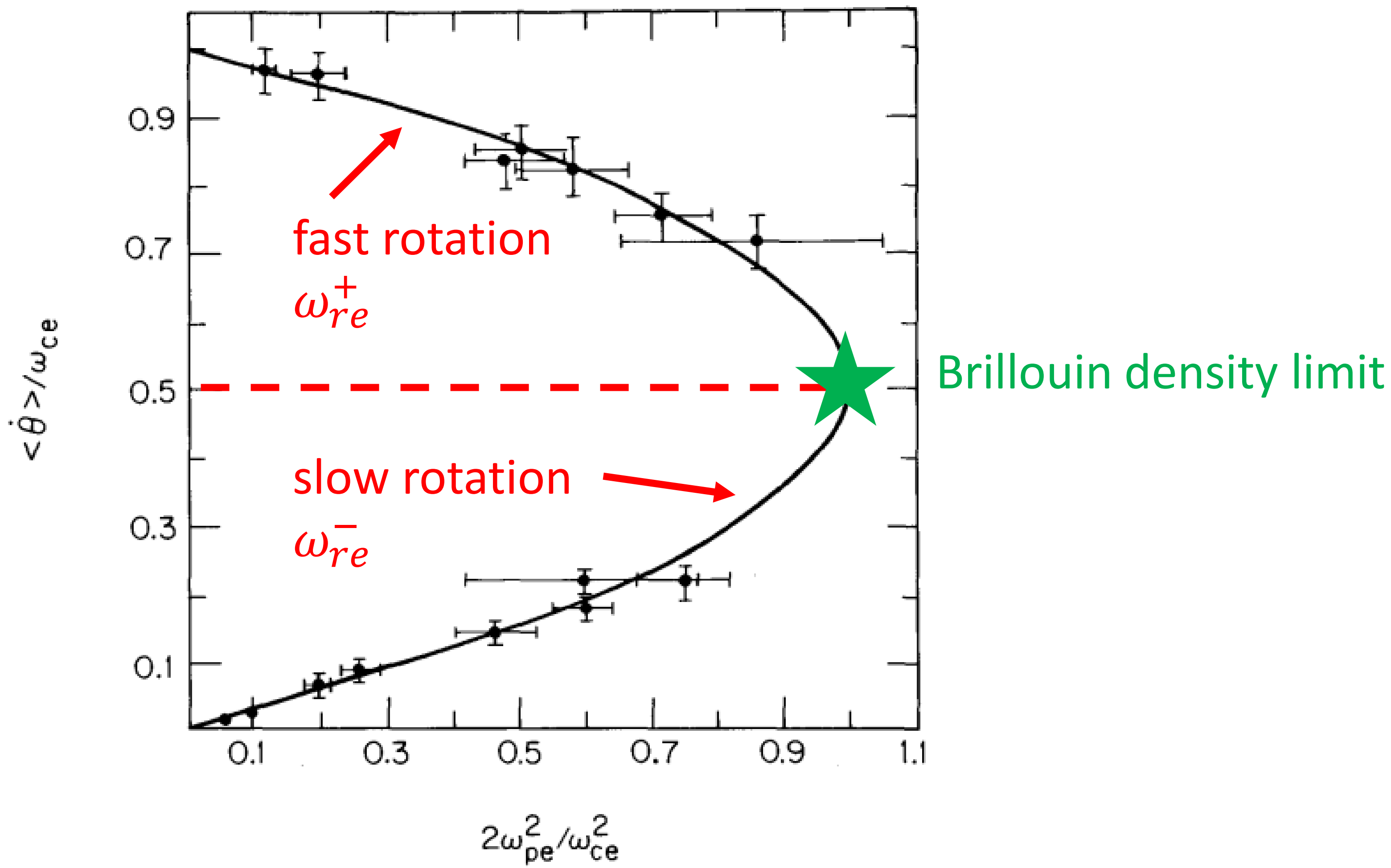
($\omega_{re}^{\pm}$ independent of r)

$\omega_{pe}^2 = n_e e^2/\varepsilon_0 m_e$

$\omega_{ce} = eB/m_e$

ω_{re} - angular velocity of plasma

Cold-fluid equilibrium



https://doi.org/10.1142/p251

Finite temperature equilibria

$$mn\boldsymbol{v}\cdot\nabla\boldsymbol{v} = qn(\boldsymbol{E}+\boldsymbol{v}\times\mathbf{B}) - \boldsymbol{\nabla} p$$

- Uniform temperature T
- $p = nk_BT$
- Viscosity acts to remove shears in angular velocity

$$n_e(r,z) = Ce^{\phi_{eff}(r,z)e/k_BT}$$

$$e\phi_{eff}(r,z) = -\frac{1}{2}m\omega_{re}(\omega_{ce}-\omega_{re})r^2 + e\phi(r,z)$$

$$\nabla^2\phi(r,z) = \frac{en_e(r,z)}{\varepsilon_0}$$

Poisson-Boltzmann system