On the *grad***B** and **E**x**B** drifts of alphas in burning plasmas

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Introduction

- A two dimensional multifluid code which treats the electrons, reacting ions and the generated alphas as separate fluids which interact with the electric and the magnetic fields has been developed.
- The system of equations which the code solves are the fluid equations for each of the plasma species supplemented by Maxwell's equations.

Model description

Fluid Equations for each of the species

Continuity:
$$\frac{\partial \rho_s}{\partial t}+\nabla\cdot(n_s \boldsymbol{v}_s)=0$$

Momentum:
$$\frac{\partial \rho_s \boldsymbol{v}_s}{\partial t}+\nabla\cdot(n_s \boldsymbol{v}_s \boldsymbol{v}_s+pI)=q_s n_s(\boldsymbol{E}+\boldsymbol{v}_s\times\boldsymbol{B})$$

Energy:
$$\frac{\partial \varepsilon_s}{\partial t}+\nabla\cdot(\boldsymbol{v}_s)(\varepsilon_s+p_s)=q_s n_s \boldsymbol{v}_s \boldsymbol{E}$$

and Maxwell's equations

Production of alpha particles

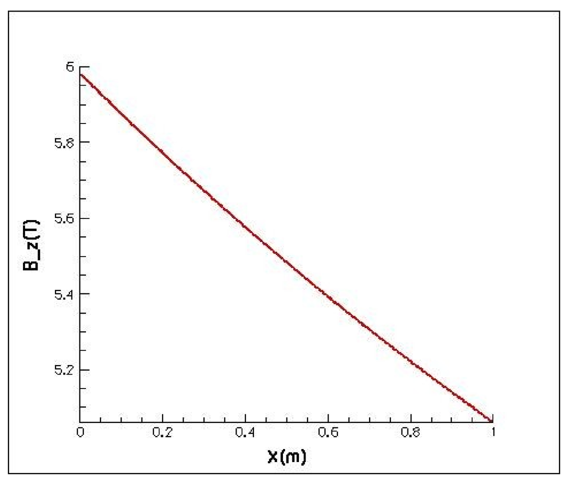
- The reacting ions are 50% Tritium – 50% Deuterium and are treated as a single fluid with particle mass $2.5m_p$
- The reaction rate is (Bosch Halle 1992): $R=\frac{1}{4}n_i^2\langle\sigma(\boldsymbol{u})\rangle$
- Appropriate sink and source terms are introduced in the fluid equations

System of equations in Cartesian geometry

Is of the form:
$$\frac{\partial \boldsymbol{q}}{\partial t}+\frac{\partial \boldsymbol{F}(\boldsymbol{q})}{\partial x}+\frac{\partial \boldsymbol{G}(\boldsymbol{q})}{\partial y}=\boldsymbol{S}(\boldsymbol{q})$$

where:
$$\boldsymbol{q}=(\rho_e,\rho_i,\rho_\alpha,\; \rho_e u_x^e,\rho_e u_y^e,\rho_e u_z^e,\; \rho_i u_x^i,\rho_i u_y^i,\rho_i u_z^i,\; \rho_\alpha u_x^\alpha,\rho_\alpha u_y^\alpha,\rho_\alpha u_z^\alpha,\; \varepsilon_e,\varepsilon_i,\varepsilon_a,\; E_x,E_z,E_z,B_x,B_y,B_z)$$

ITER-like Magnetic Field (f/r)



The above system of equations is solved using a Total Variation Diminishing method in space and Runge-Kutta in time.

Zero-dimensional alpha heating model

- Multi-fluid plasma burning model
- Conservation of the various plasma species particles (electrons, reacting ions and alphas generated by nuclear reactions)
- Energy balance of plasma species
- System of 8 ODEs for D/T plasma

- Output:
  - Power output
  - Reacting ions and alpha particle densities and temperatures
  - **Under what initial conditions will the reactor operate in a steady state**

2D Scenario: Early stage of burning process

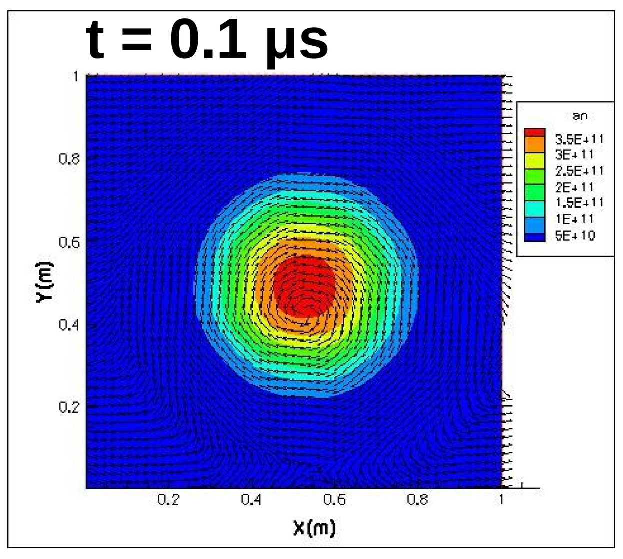
A high pressure circular plasma blob is placed in the center of the two-dimensional computational domain.

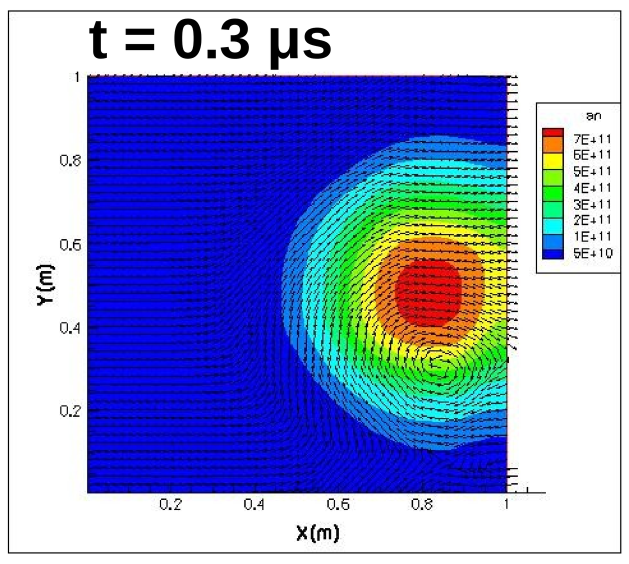
Parameters of the blob
Plasma temperature = 22.5 keV
Plasma density = 2×10^{20} m^{-3}
Blob radius = 0.2 m

Background plasma
Plasma temperature = 5 keV
Plasma density = 10^{20} m^{-3}

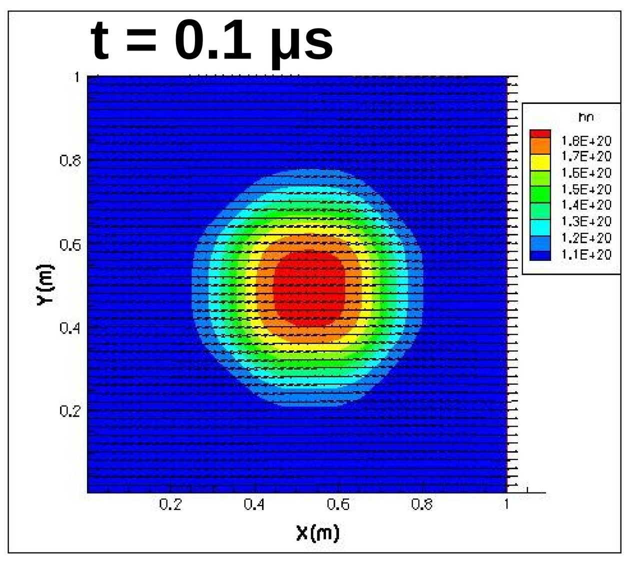
Positive magnetic field

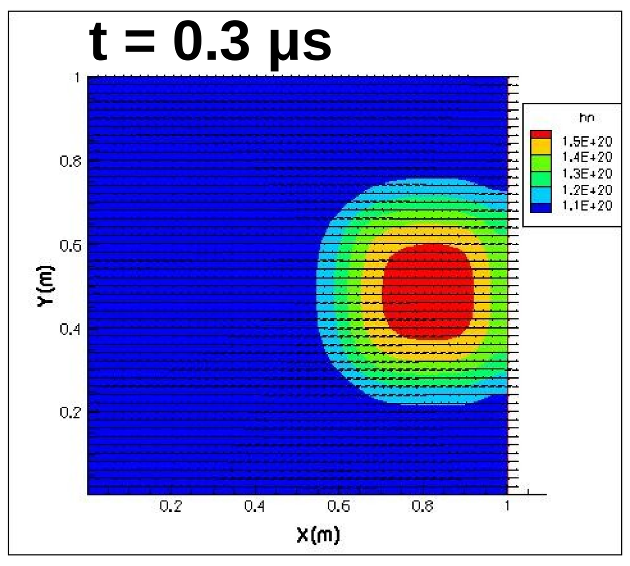
Alpha particles densities and velocities





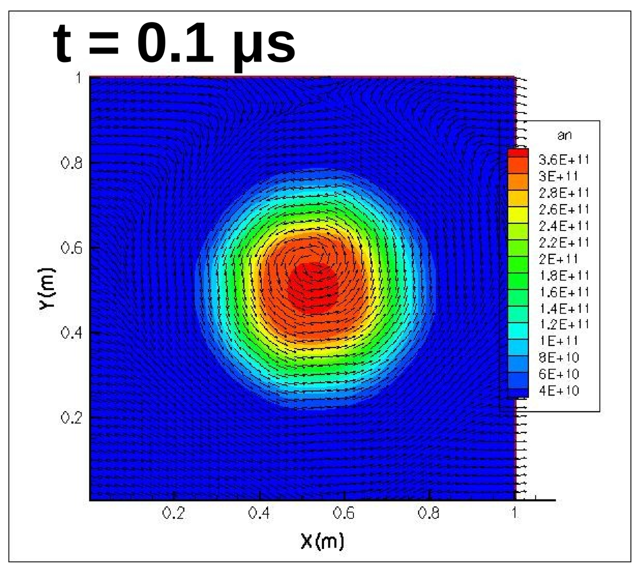
Reacting ions densities and velocities

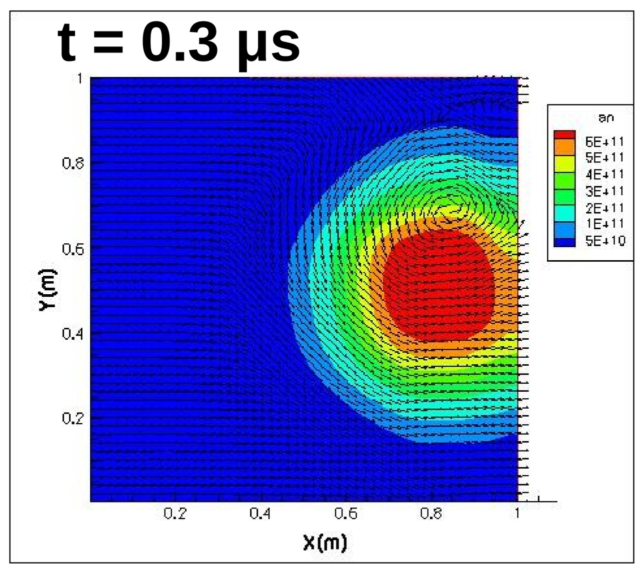




Negative magnetic field

Alpha particles densities and velocities



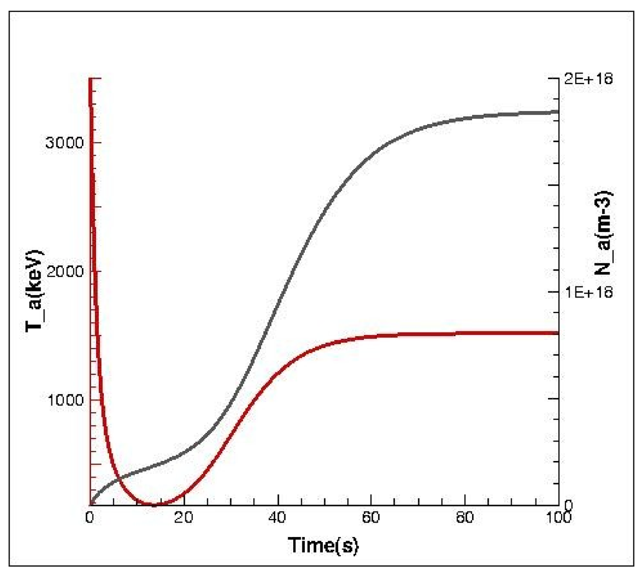


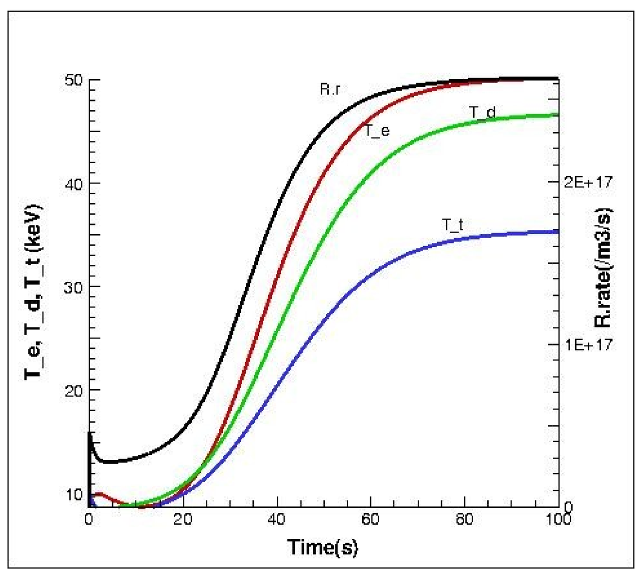
Results from zero-dimensional model

Alpha heating

Initial Conditions:
T_e = 10 keV
$n_e = 0.4\times10^{20}$ m^{-3}

Alpha particles, originally generated with 3.5 MeV of energy, heat the rest of the plasma species



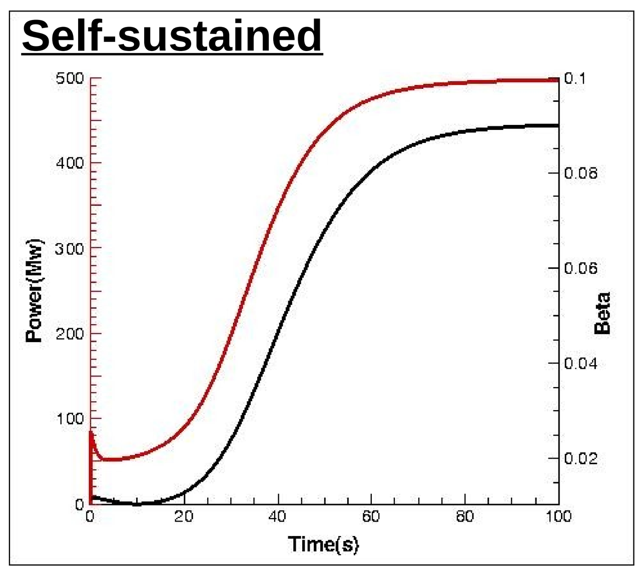


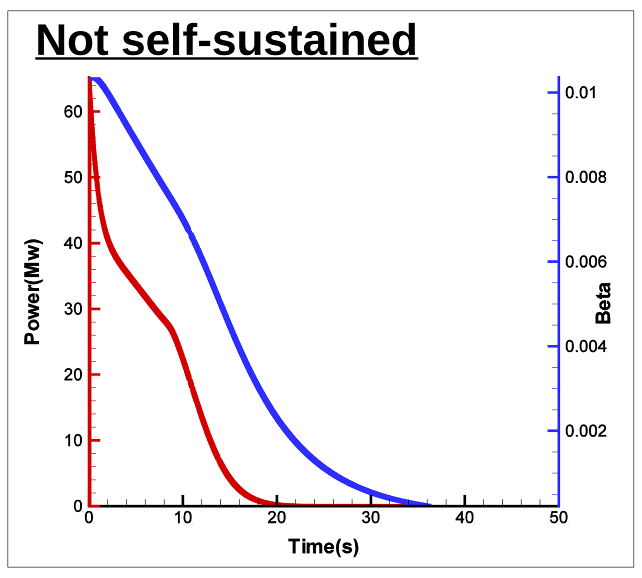
Steady state

Depending on the initial conditions the burning plasma can either reach a steady state or extinguish.

IC for steady state:
T_e = 10 keV / $n_e = 0.4\times10^{20}$ m^{-3}

IC for extinguishing plasma:
T_e = 9 keV / $n_e = 0.4\times10^{20}$ m^{-3}





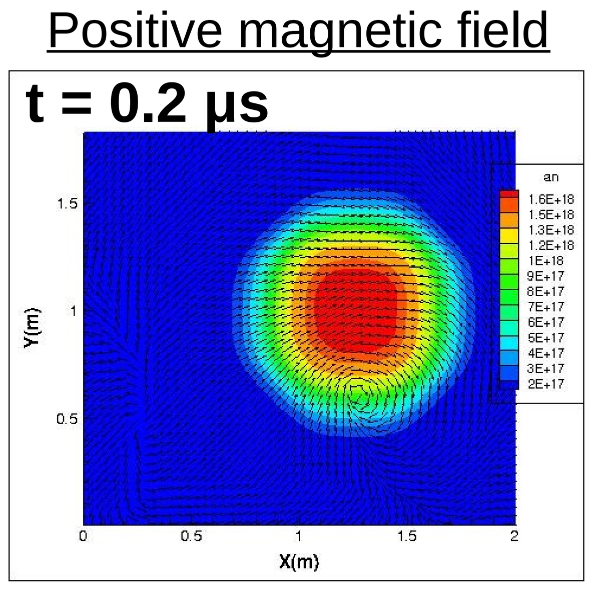
2D Scenario: Initial conditions from steady state

A plasma blob with it's initial conditions taken from the zero-dimensional model operating at steady state is placed at the center of the two dimensional computational domain

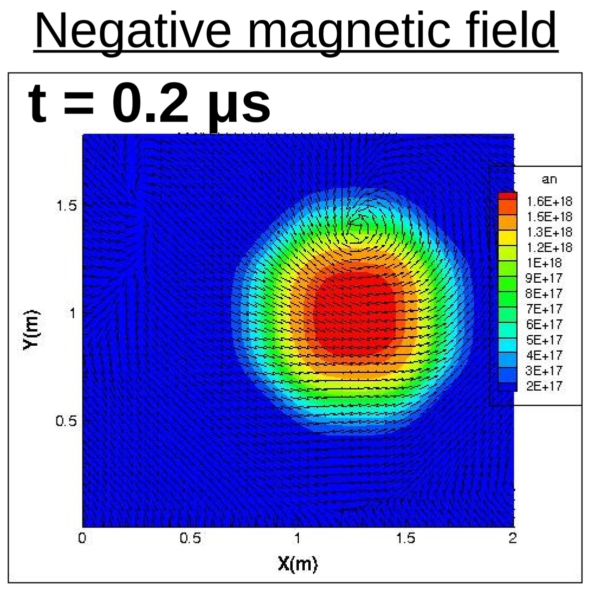
Parameters of the blob:
Ion temperature = 40.5 keV
Ion density = 0.36×10^{20} m^{-3}
Alpha temperature = 1.5 MeV
Alpha density = 1.85×10^{18} m^{-3}

Alpha particles densities and velocities

Positive magnetic field



Negative magnetic field



Summary

- For ITER-like magnetic fields: a) For electrons and reacting ions the *grad***B** drift dominates.
  b) For the alpha particles the **E**x**B** rotations are substantial
- The two-fluid approximation allows the study of **E**x**B** rotations
- Similar 2D code in R-Z geometry and separate fluid for each reacting ion is under development

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