

Implementation of Interacting & Reacting Plasma Model



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Resources used:

- PSI-Center SGI Altix 350 cluster
- PSI-Center SGI ICE Altix 8200 cluster (funded by an Air Force grant)

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Motivation:

- Properly capturing atomic physics is often crucial for predictive simulation. Atomic physics is important in:
 - Thermal transport in magnetically confined plasmas
 - Energy losses and neutral gas capture in plasma thrusters
- This work represents an extension of PSI-Center capability from our previous cold static neutral model.

Outline:

- Physics description
- Development run result

Interacting and reacting plasma model

allows $\int C_{\alpha\beta} d\mathbf{v} \neq 0$



$$\frac{\partial \rho_i}{\partial t} + \nabla \cdot (\rho_i \mathbf{v}_i) = m_i (\Gamma_{ion} - \Gamma_{rec})$$

$$\frac{\partial \rho_n}{\partial t} + \nabla \cdot (\rho_n \mathbf{v}_n) = m_i (\Gamma_{rec} - \Gamma_{ion})$$

$$\frac{\partial}{\partial t} (\rho_i \mathbf{v}_i) + \nabla \cdot (\rho_i \mathbf{v}_i \mathbf{v}_i + p \tilde{\mathbf{I}}) = \mathbf{j} \times \mathbf{B} - \Gamma_{rec} m_i \mathbf{v}_i + \Gamma_{ion} m_i \mathbf{v}_n + \Gamma_{cx} (m_i \mathbf{v}_n - m_i \mathbf{v}_i)$$

$$\frac{\partial}{\partial t} (\rho_n \mathbf{v}_n) + \nabla \cdot (\rho_n \mathbf{v}_n \mathbf{v}_n + p_n \tilde{\mathbf{I}}) = \Gamma_{rec} m_i \mathbf{v}_i - \Gamma_{ion} m_i \mathbf{v}_n + \Gamma_{cx} (m_i \mathbf{v}_i - m_i \mathbf{v}_n)$$

$$\frac{1}{\gamma - 1} \frac{\partial p}{\partial t} + \nabla \cdot \left(\frac{\gamma}{\gamma - 1} p \mathbf{v}_i \right) = \mathbf{v}_i \cdot \nabla p + (\Gamma_{cx} + \Gamma_{ion}) (KE_n + KE_i - m_i \mathbf{v}_i \cdot \mathbf{v}_n) + \Gamma_{ion} (KE_n - \phi_{ion})$$

$$\frac{1}{\gamma - 1} \frac{\partial p_n}{\partial t} + \nabla \cdot \left(\frac{\gamma}{\gamma - 1} p_n \mathbf{v}_n \right) = \mathbf{v}_n \cdot \nabla p_n$$

$$+ \Gamma_{rec} (KE_i + KE_n - m_i \mathbf{v}_n \cdot \mathbf{v}_i - \phi_i) + \Gamma_{cx} (KE_i + KE_n - m_i \mathbf{v}_n \cdot \mathbf{v}_i)$$

Atomic reaction source rates are empirical (Cx.) and semi-empirical (Ion. and Recomb.).

In general: $\Gamma = \langle \sigma v \rangle n^2$

Charge exchange*: $\Gamma_{cx} = f_{cx} 5.48 \times 10^{-19} T_{eV}^{-.2057} v_{in} n_n n_i \frac{1}{m^3 s}$

Ionization**: $\Gamma_{ion} = \frac{2 \times 10^{-13}}{6 + T_{eV} / \phi_{ion}} \left(\frac{T_{eV}}{\phi_{ion}} \right)^{1/2} e^{-\phi_{ion}/T_{eV}} n_i n_n \frac{1}{m^3 s}$

Recombination**: $\Gamma_{rec} = 7 \times 10^{-20} n_i^2 \left(\frac{\phi_{ion}}{T_{eV}} \right)^{1/2} \frac{1}{m^3 s}$

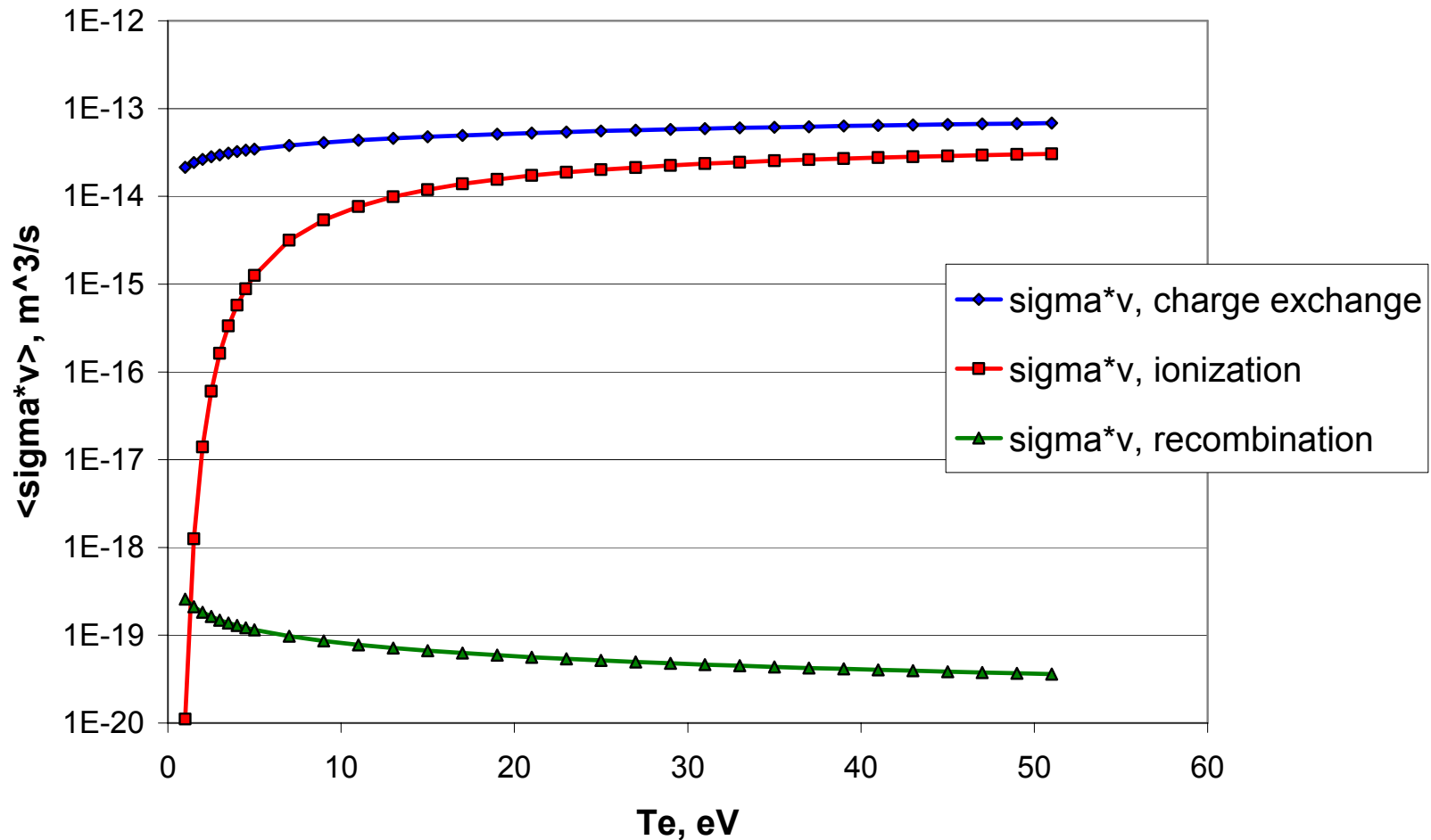
Ion-neutral relative velocity: $v_{in} = \left(\frac{2}{m_i} k T_i \right)^{1/2} \frac{m}{s}$

* B.J. Nichols and F.C. Witteborn, Measurements of resonant charge exchange cross sections in Nitrogen and Argon between 0.5 and 17 eV, 1966 NASA Technical Note

** R. J. Goldston, P. H. Rutherford, Introduction to Plasma Physics, IOP Publishing Ltd., 1995

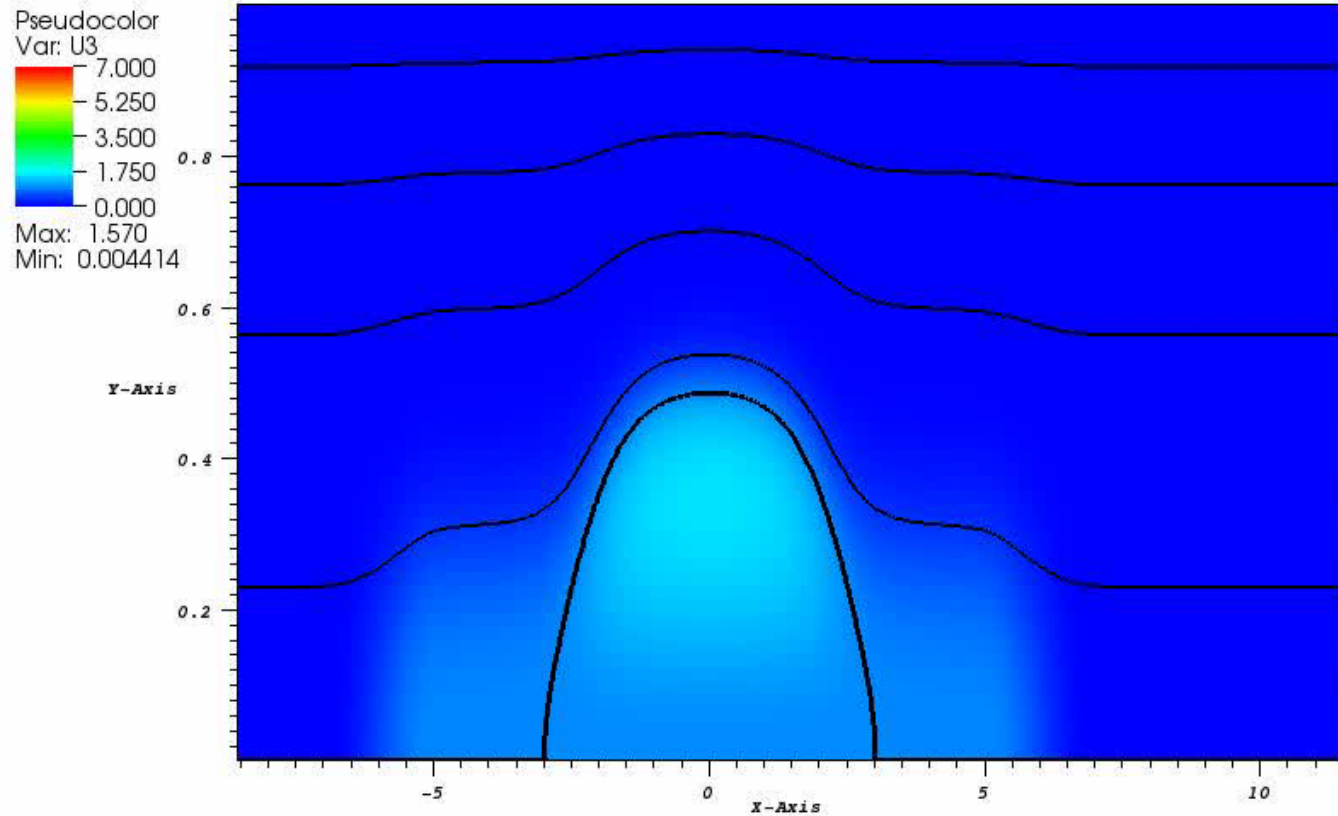
Charge exchange is dominant at low temperatures (< 10 eV).

$\langle \sigma^*v \rangle$ (m^3/s) vs. T (eV)



Plasma only result

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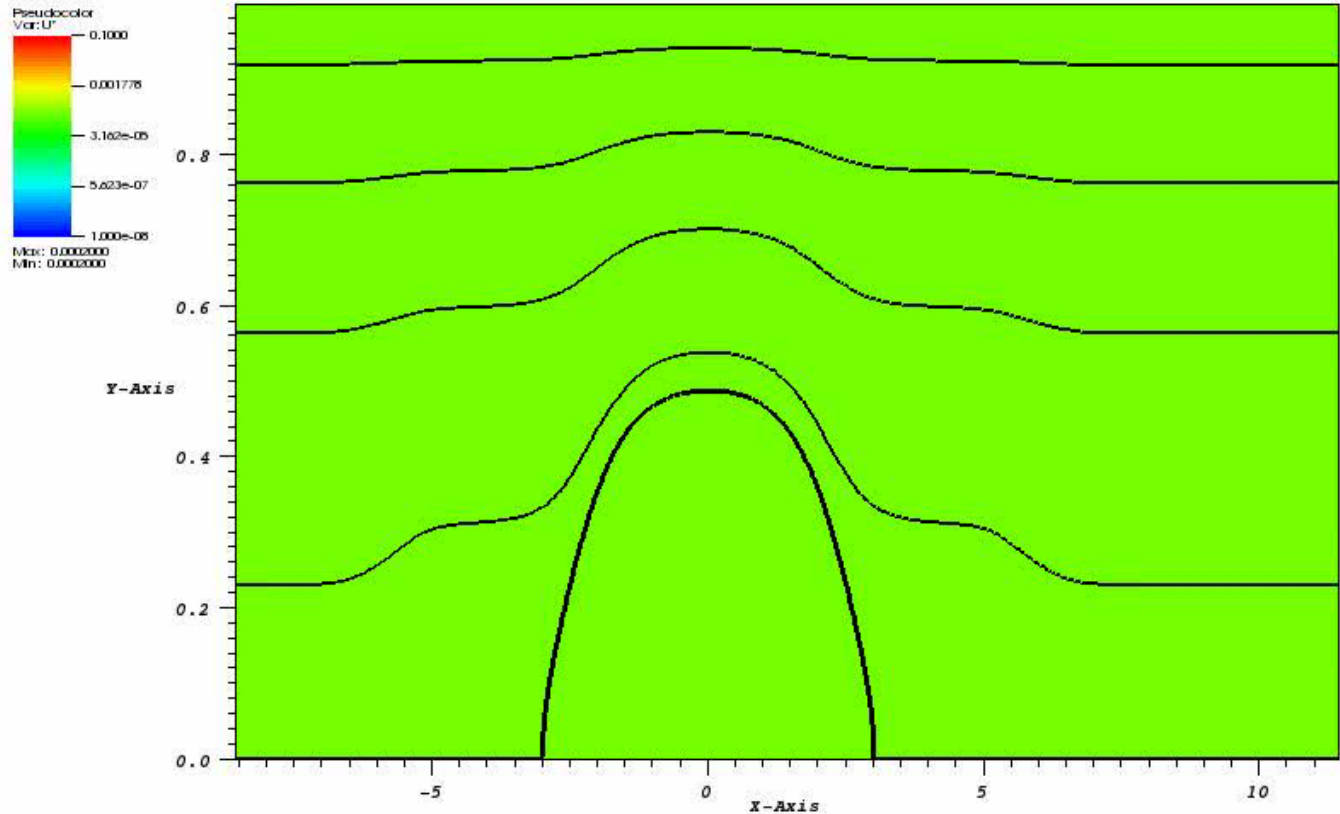
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Interacting & reacting plasma model development run result

Initial condition

- $\rho_{\text{on}} = 0.1 \cdot \rho_{\text{max}}$
- $T_{\text{n}} = 300 \text{ K}$

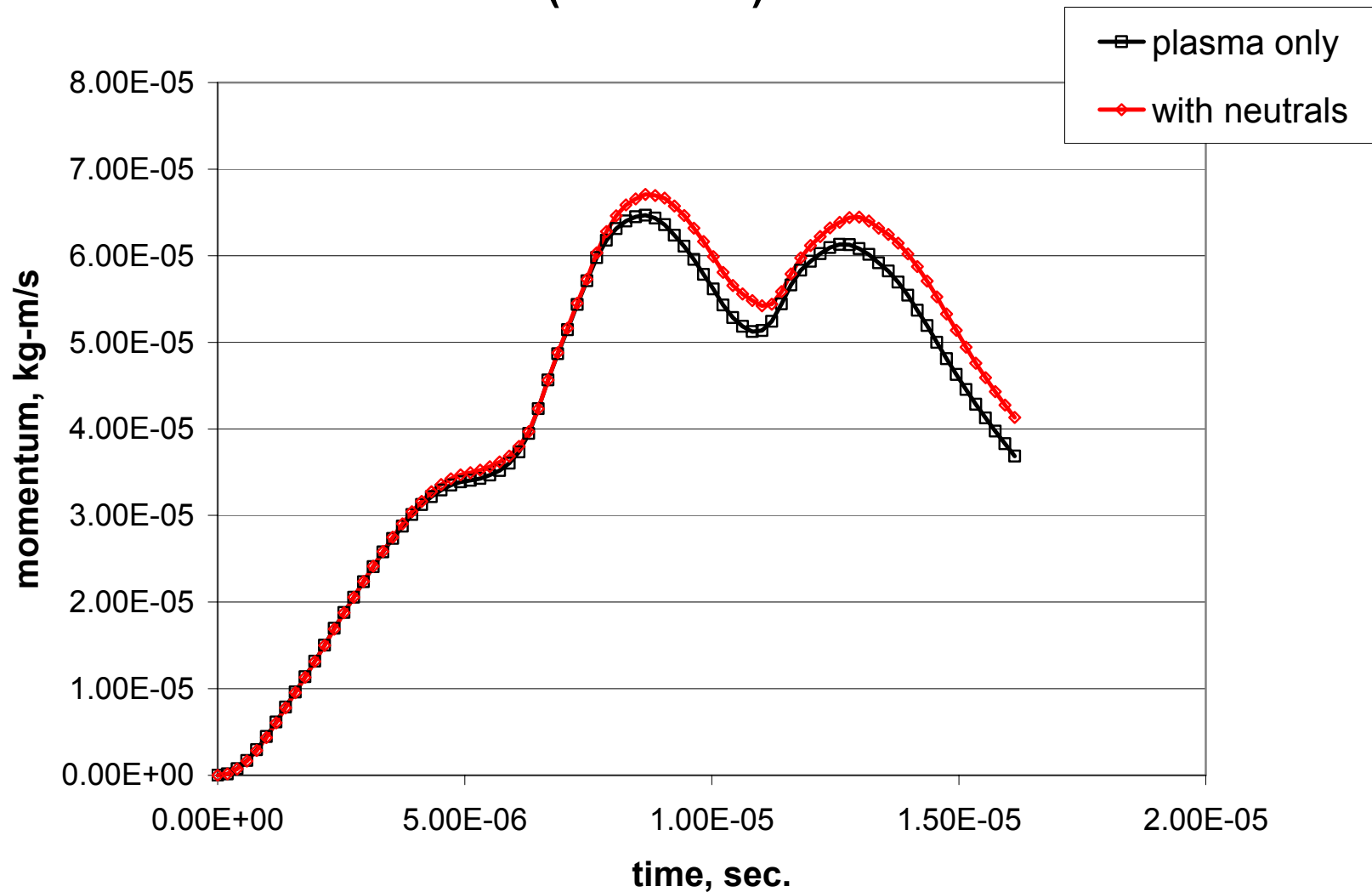
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Development run result

Momentum (enclosed) vs. time



Future work

- Refine interacting & reacting plasma model and do physics study.