Implementation of Interacting & Reacting Plasma Model

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

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

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

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

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

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

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

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

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

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

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

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

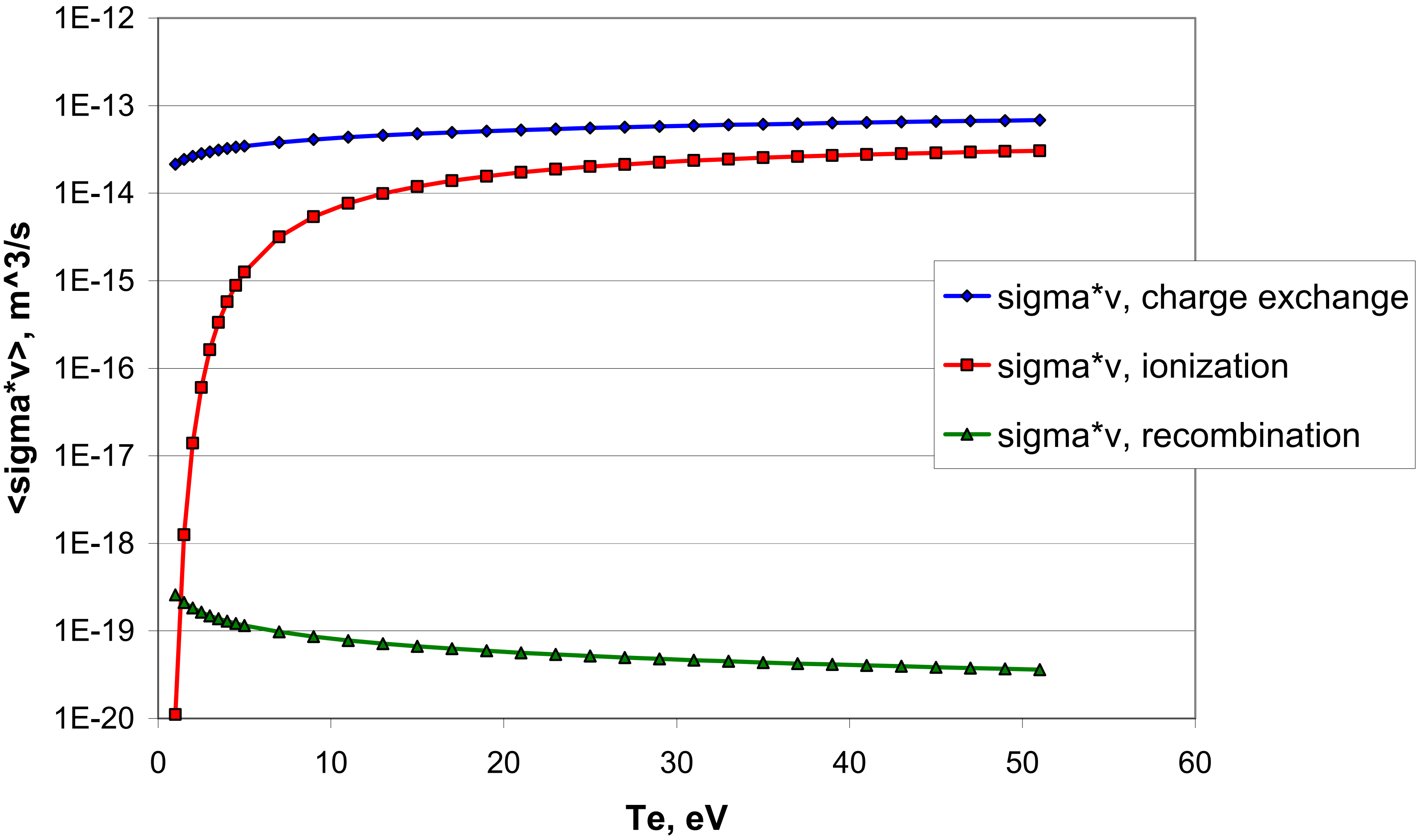
Recombination**: $\Gamma_{rec} = 7 \times 10^{-20} n_i{}^2 \left(\frac{\phi_{ion}}{\mathrm{T_{eV}}} \right)^{1/2} \quad \frac{1}{\mathrm{m^3 s}}$

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

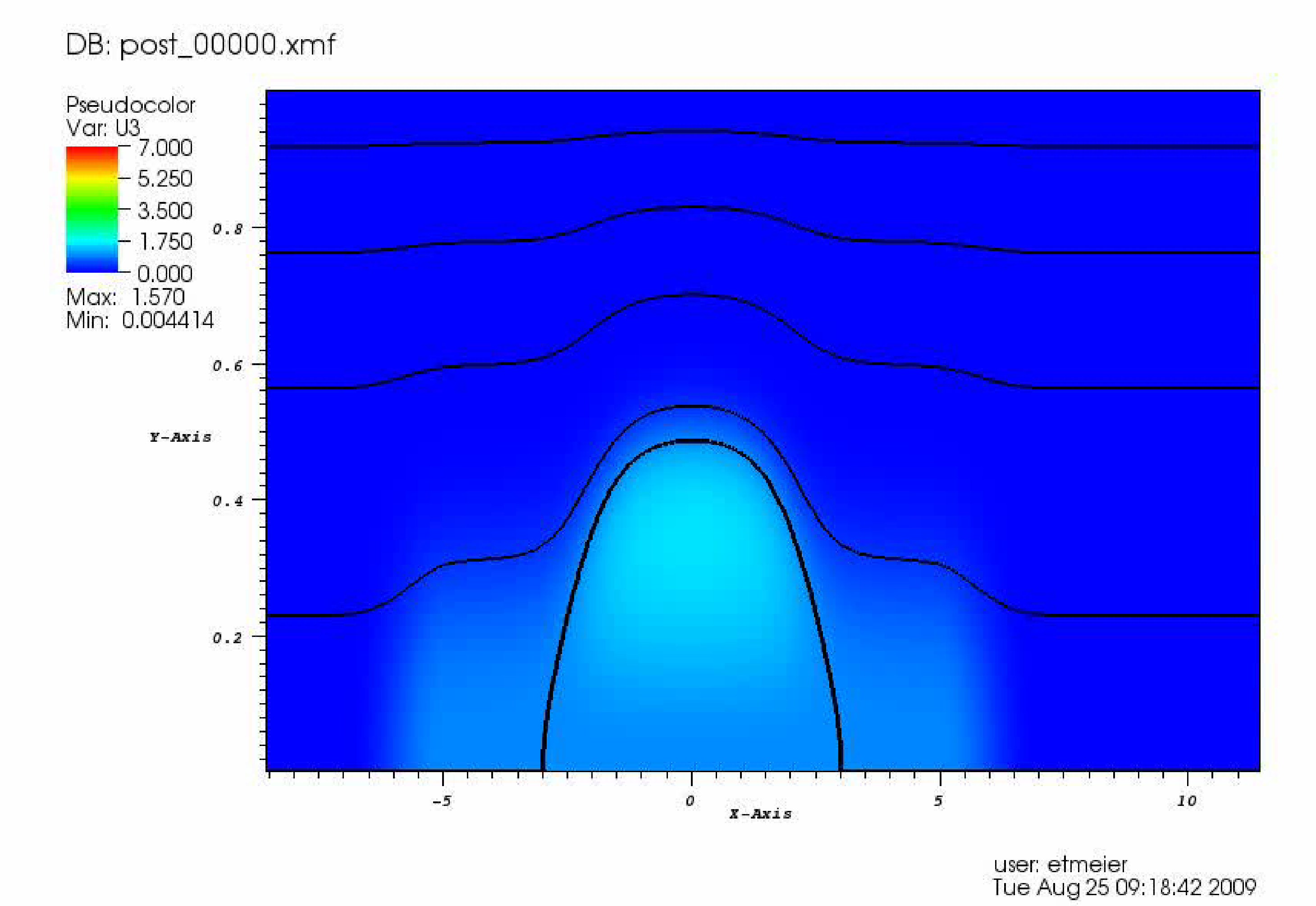
* B.J. Nichols and F.C. Witteborn, Measurements of resonant charge exchange cross sections in Nitrogen and Argon between 0.5 and 17 eV, 1966 NASA Technical Note
** R. J. Goldston, P. H. Rutherford, Introduction to Plasma Physics, IOP Publishing Ltd., 1995

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

<sigma*v> (m^3/s) vs. T (eV)

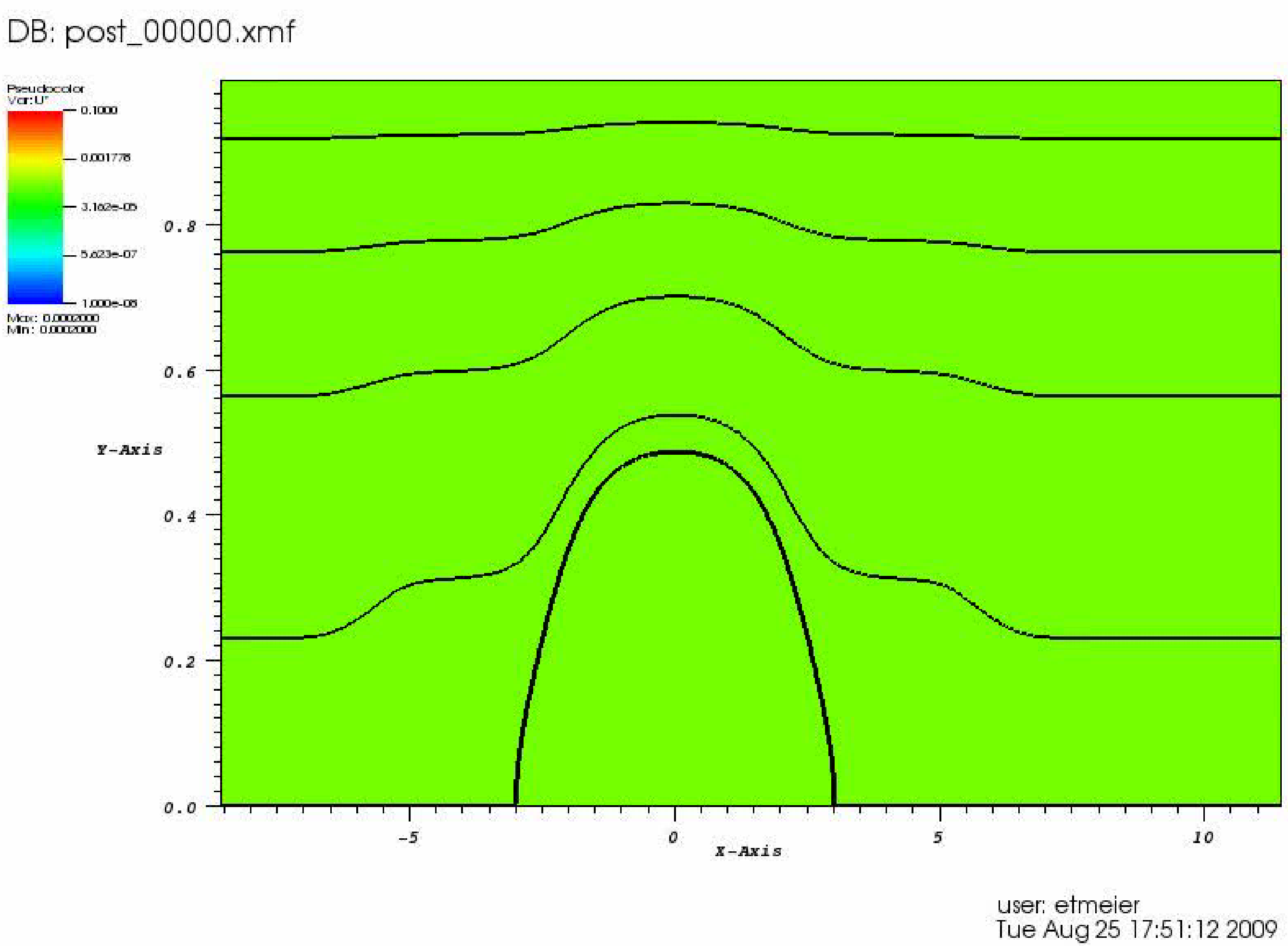


Plasma only result

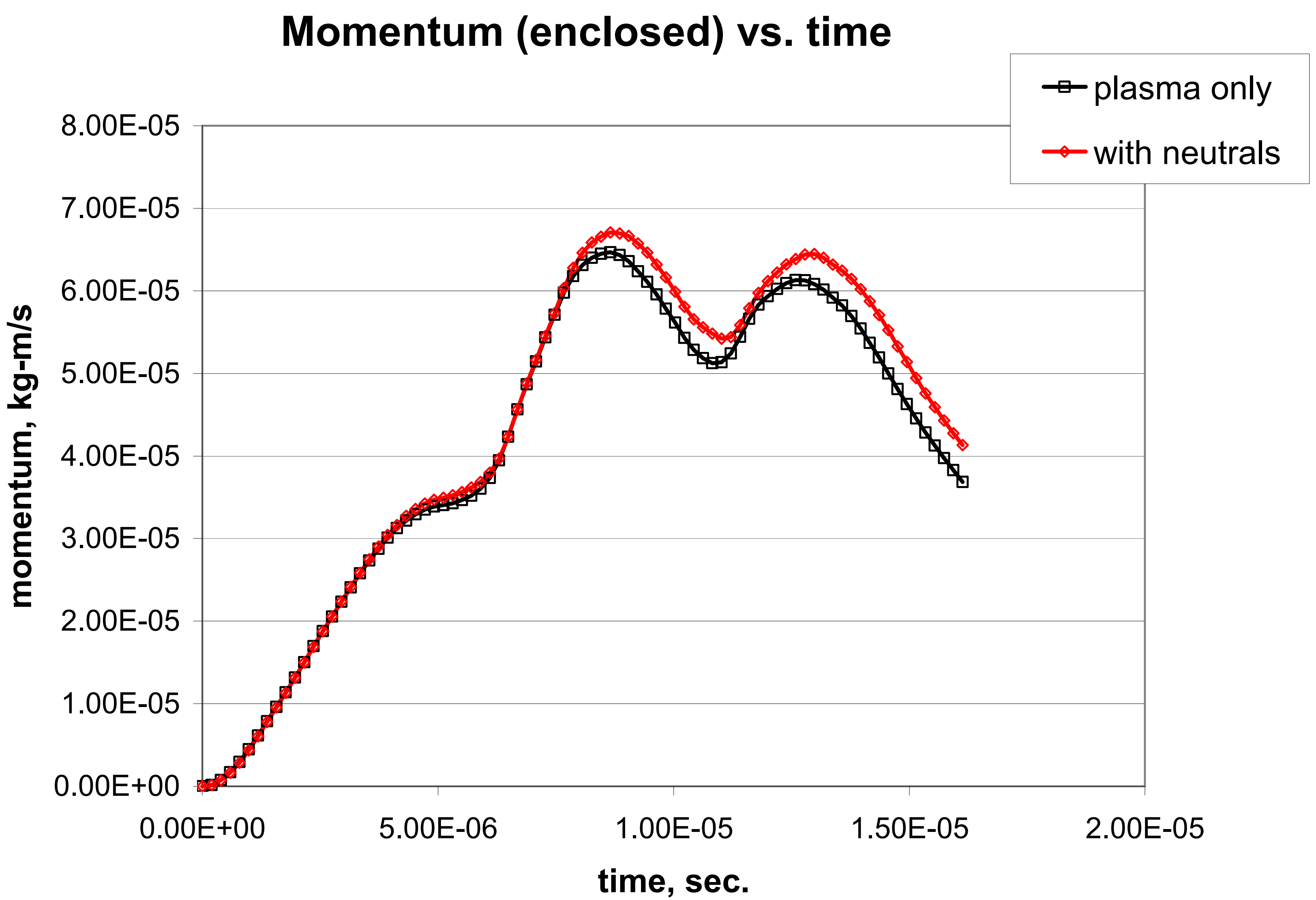


Interacting & reacting plasma model development run result

Initial condition
- rhon= 0.1*rho_max
- Tn=300 K



Development run result



Future work

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