Transport Coefficient Sensitivities in a Semi-Analytic Model for MagLIF

THE UNIVERSITY OF CHICAGO
LABORATORY FOR LASER ENERGETICS UNIVERSITY OF ROCHESTER
MICHIGAN ENGINEERING UNIVERSITY OF MICHIGAN

Yousef Lawrence[1,2] Ryan D. McBride[3] Adam B. Sefkow[2]

[1]University of Chicago, Chicago, IL, 60637
[2]TriForce Center for Multiphysics Modeling, Departments of Mechanical Engineering and Physics and Laboratory for Laser Energetics, University of Rochester, Rochester, NY, 14627
[3]Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI 48109

Abstract

In magnetohydrodynamics the magnetic field is obtained from an induction equation derived from an Ohm's law for the electric field rather than Maxwell's equations. As a result, magnetic-field evolution is determined from source, diffusion, and advection terms involving the magnetic field, plasma parameters, and proportionality constants called "transport coefficients." Thermal conduction in magnetized plasmas is also affected. The coefficients themselves have been the subject of repeated recalculation using various methods throughout the years. Using a semi-analytic MagLIF model (SAMM) [2], we compare various fits to the electron and ion transport coefficients provided by Braginskii [1], Epperlein, Haines [3], Ji, Held [4], and Davies et al [5]. The choices modify magnetic flux losses caused by the Nernst thermoelectric effect and thermal conduction losses. We present results from simulations conducted to compare the effects of the different fits on various values of interest, like the fusion yield.

Overview of SAMM

SAMM is a semi-analytic model for magnetized liner inertial fusion (MAGLIF). In MagLIF a current is sent down a cylindrical liner, compressing the target via the Lorentz Force. A laser also preheats the target, enabling the fuel to reach fusion conditions around peak compression. SAMM uses a set of ODE's, describing most of the major aspects of MagLIF, including magnetic flux compression with Nernst thermoelectric losses, and thermal conduction losses. For the rest of the poster we use a slightly modified version of the 2010 point design [2], with an initial preheat radius smaller than the gas radius. This allows the shelf region (see gas region in Fig. 1)) to form for at least a few nanoseconds, which exploits more of SAMM's modeling capabilities.

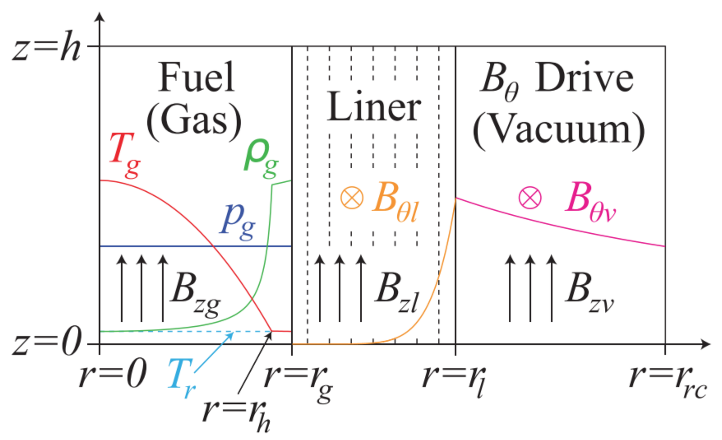

Figure 1. Schematic overview of SAMM [2]

The Transport Coefficients in SAMM

The transport coefficients used in SAMM are calculated from rational polynomial fits which are functions of the electron or ion Hall parameter: $\kappa_e^\perp = \kappa_e^\perp(\chi_e)$, $\kappa_i^\perp = \kappa_i^\perp(\chi_i)$, $\beta_\wedge = \beta_\wedge(\chi_e)$, where $\chi_e = \omega_e\tau_{ei}$, $\chi_i = \omega_i\tau_{ii}$ and ω_e (ω_i) is the electron (ion) cyclotron frequency and τ_{ei} (τ_{ii}) is the average time between electron-ion (ion-ion) collisions. SAMM is only defined in the radial direction, so only the perpendicular, or cross coefficients are relevant here.

They directly modify the electron and ion thermal conduction losses, and the magnetic flux losses, from the gas region into the liner.

$$P_{ce}(r) = 2\pi r h \cdot \kappa_e^\perp(\chi_e) \cdot k_B \frac{\partial T_g}{\partial r} \quad (1)$$

$$P_{ci}(r) = 2\pi r h \cdot \kappa_i^\perp(\chi_i) \cdot k_B \frac{\partial T_g}{\partial r} \quad (2)$$

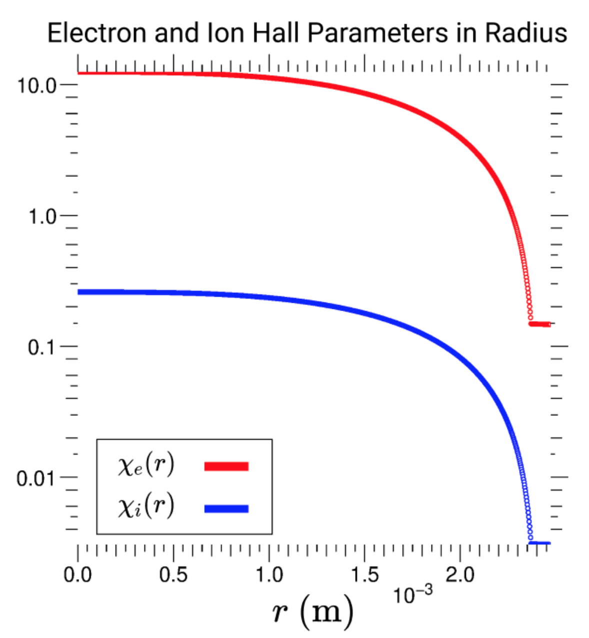

Figure 2. Electron and ion Hall parameters as a function of radius, 10 ns after laser preheat ends, when $T_g(r=0) \approx 1$ keV.

The Transport Coefficients in SAMM (cont.)

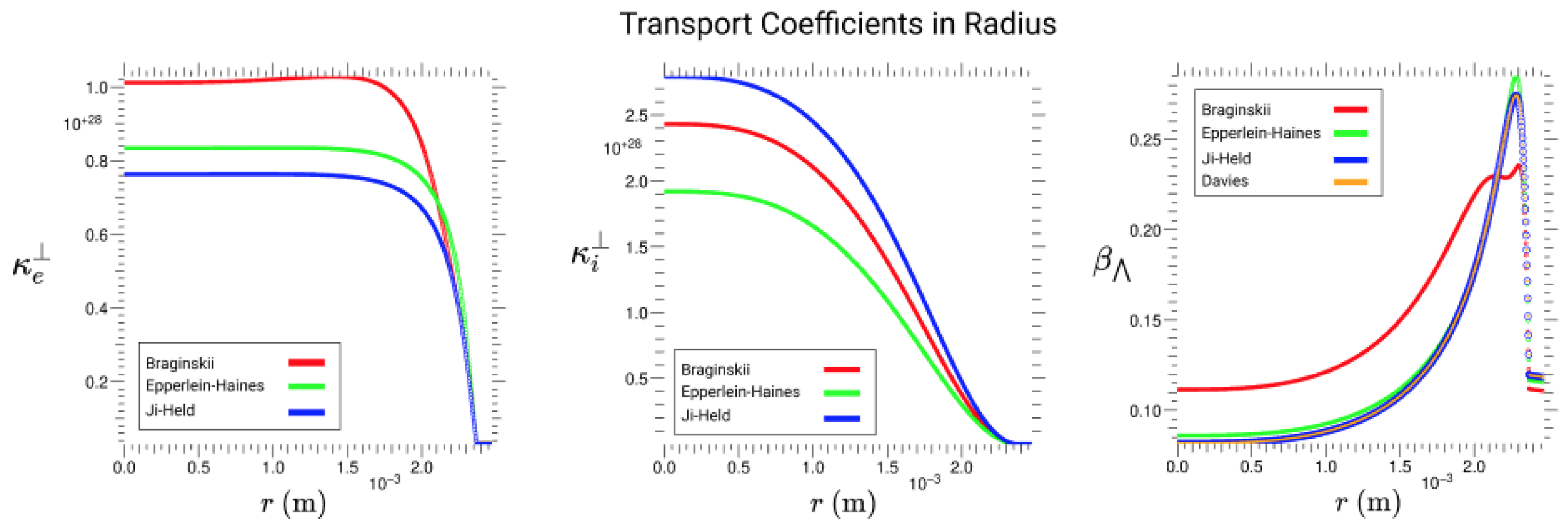

Figure 3. Transport coefficients as a function of radius, up to r_g, about 10 ns after laser preheat ends, when $T_g(r=0) \approx 1$ keV

$$\dot{\Phi}_{zg} = \left[-2\pi r h \cdot \beta_\wedge(\chi_e) \cdot \frac{k_B}{q_e}\frac{\partial T_g}{\partial r}\right]_{r=r_g} \quad (3)$$

In Fig (3), we see a snapshot in time of the different transport coefficients, with appreciable differences among them, particularly in the hotspot region, away from the maximum radius. There, the Hall parameters are still at relatively low values on the order of 10^{-1} to 10^{1}.

Transport Coefficient Testing

To test the different models, we set all the transport coefficients according to a single model. Davies only provides a new fit for the Nernst velocity coefficient, $\beta_\wedge$, however, so we test Ji-Held's thermal transport coefficients along with Davies' Nernst velocity coefficient.

To compare the different transport models, we compare the coefficients' integrated effect on the fusion yield. Parameter scans across the laser preheat energy, E_{ph}, from 500 J to 20 kJ, and the initial axial magnetic field, B_{z0}, from 0 T to 50 T sample a large region of parameter space for each transport model. Using the parameter scans, we quantify the differences between each transport model.

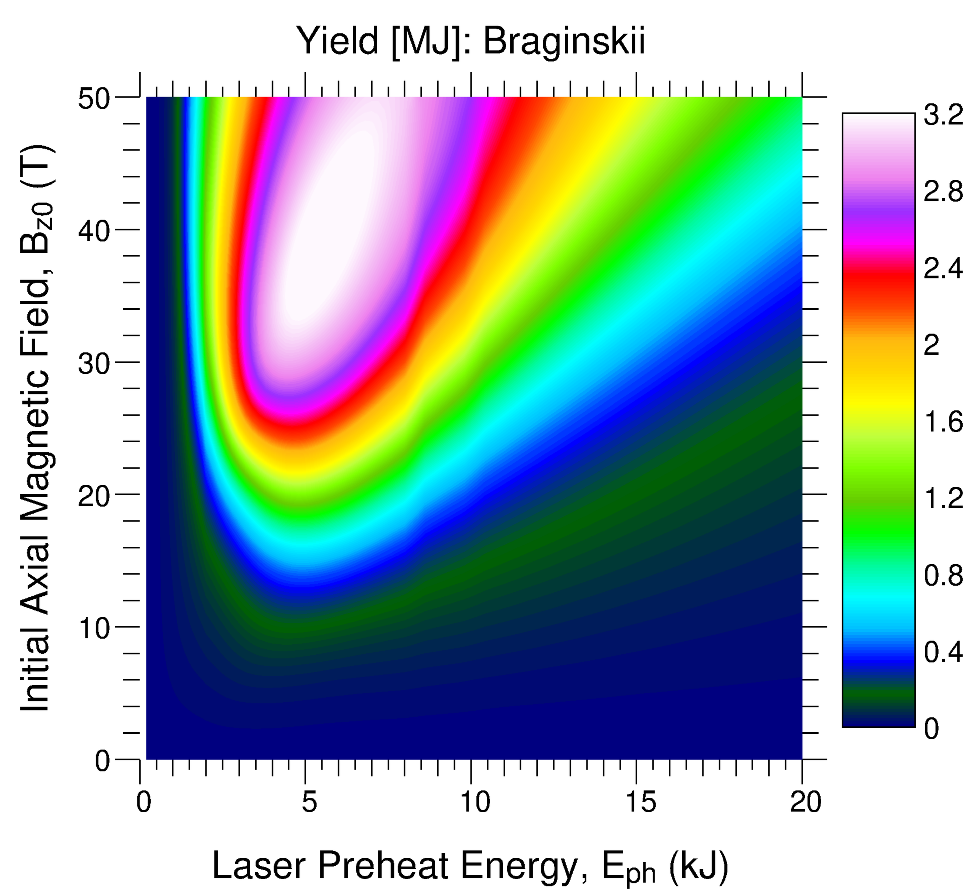

Figure 4. Parameter scan across E_{ph} and B_{z0} for the fusion yield, using Braginskii's set of transport coefficients.

In Fig. (4), where we have used Braginskii's transport coefficients, we see that there is an optimal E_{ph} and B_{z0} that maximizes the fusion yield, given the initial conditions for this slightly modified version of the 2010 point design. And Figures (5) and (6), show how the other transport models lead to

Transport Coefficient Testing (cont.)

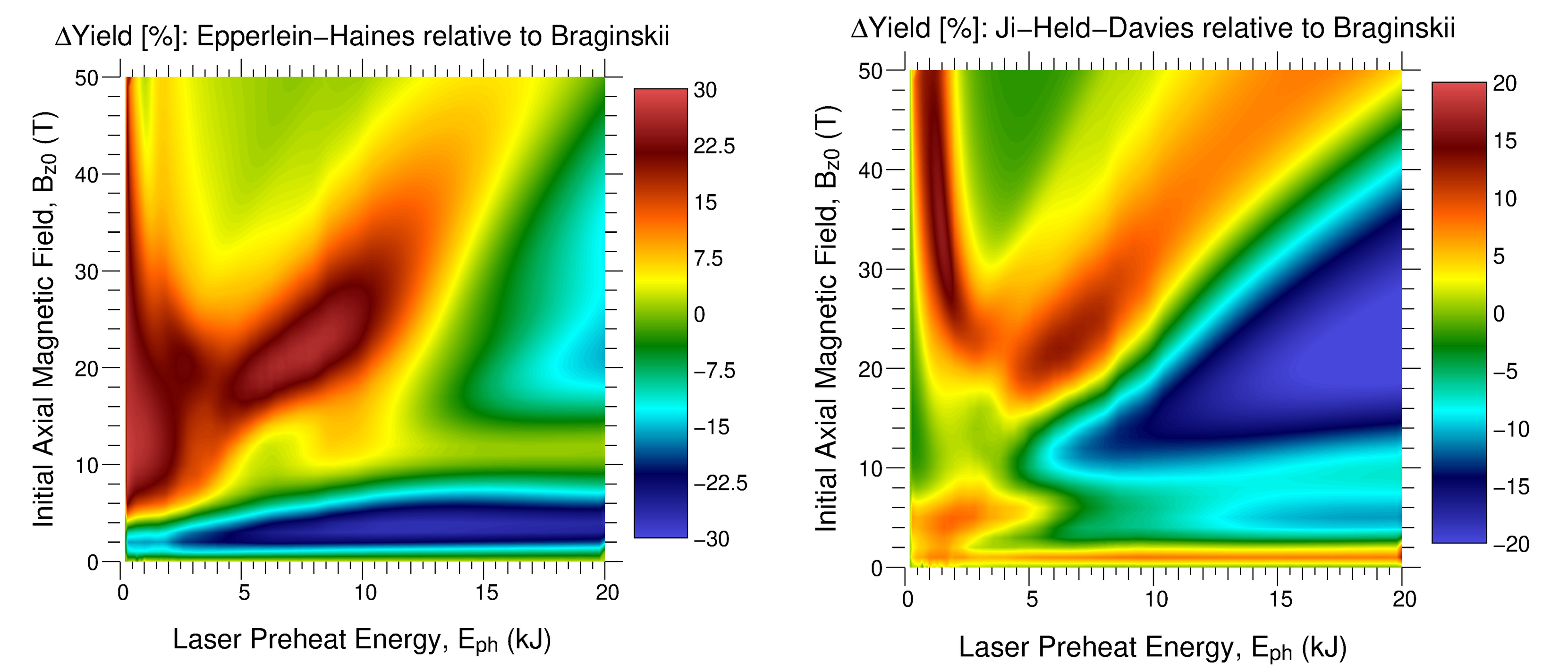

Figure 5. Percent differences in yield for Epperlein-Haines and Ji-Held-Davies transport models, relative to Braginskii's.

different yields in various regions of parameter space. There are significant differences, up to 20 to 30% depending on E_{ph} and B_{z0}. Beyond that, the fusion yields differ from one transport model to another depending on the region of parameter space.

We can make a few conclusions from these results. We see that relative to Braginskii's model, the models of Epperlein-Haines and Ji-Held-Davies exhibit similar percentage difference profiles, in (E_{ph}, B_{z0}) space, as seen in Fig. (5), with up to 30% greater yields at intermediate E_{ph} and B_{z0} values, agreement in the region with the highest yields (see Fig. (4)), and up to 20% lower yields at higher preheat energies and where $B_{z0} \gtrsim 10$ T. In Fig. (5), we also see that the Epperlein-Haines and Ji-Held-Davies models are generally in more agreement, except at low B_{z0} values, corresponding to lower Hall parameters, with stark differences of up to 30%.

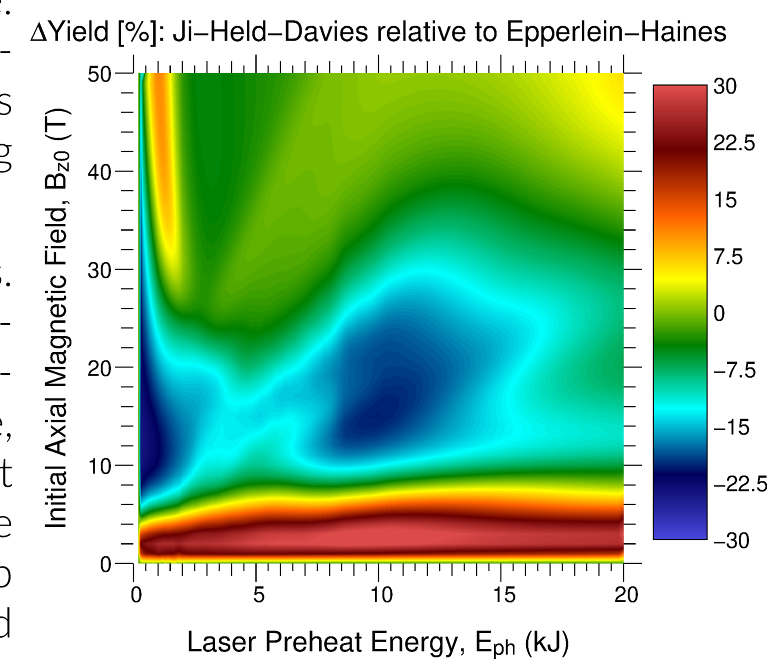

Figure 6. Percent difference in yield for Ji-Held-Davies transport model, relative to Epperlein-Haines's.

Conclusions

- There are small to moderate changes in the transport coefficients themselves, based on the specific fitting model that is used.
- The different transport models can lead to significantly different integrated outcomes (e.g. fusion yield), for example at smaller Hall parameters.

References

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ylawrence@uchicago.edu