Research Horizons Day
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Modeling the Hydrogen-Proton Charge-Exchange Process in Global Heliospheric Simulations

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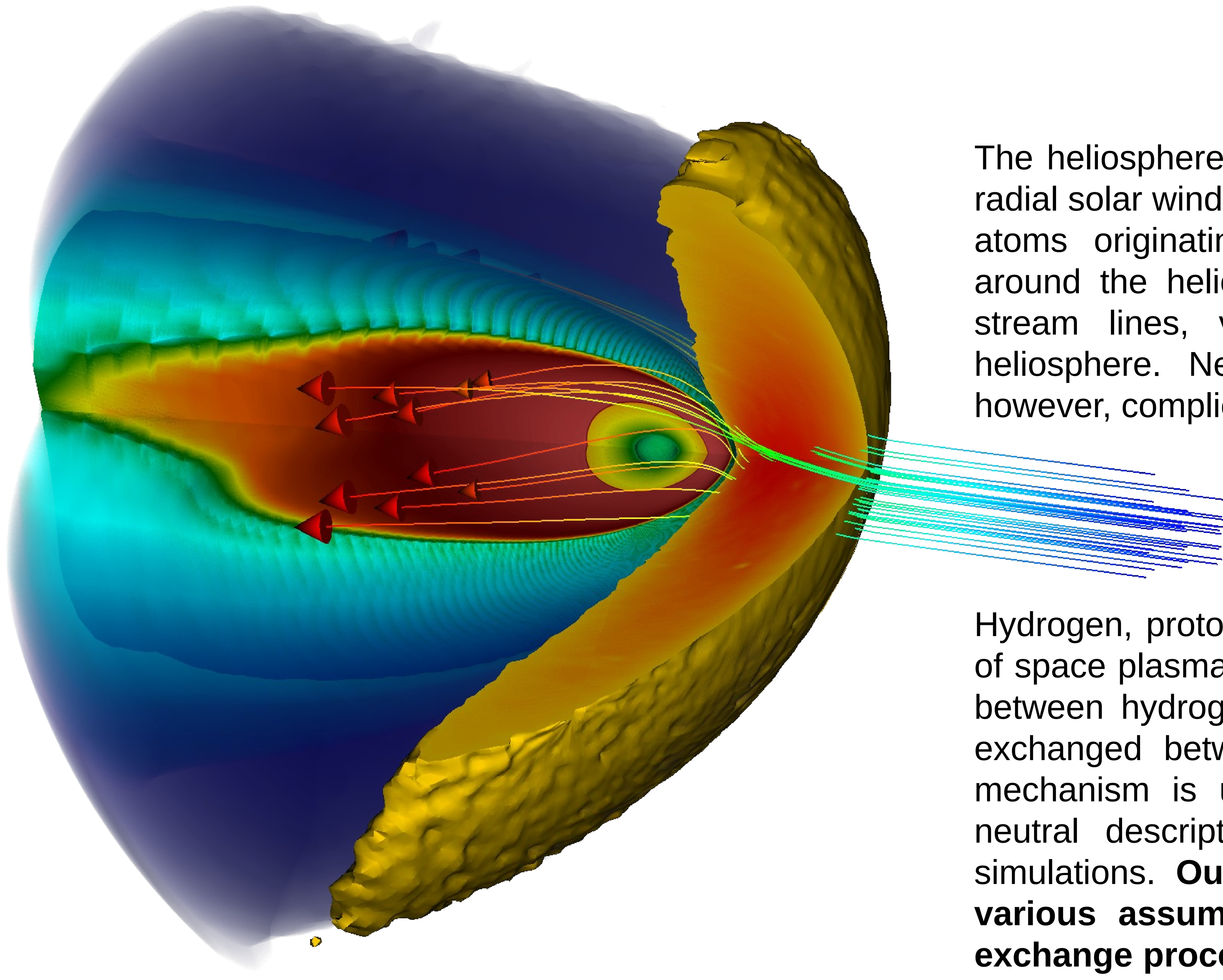
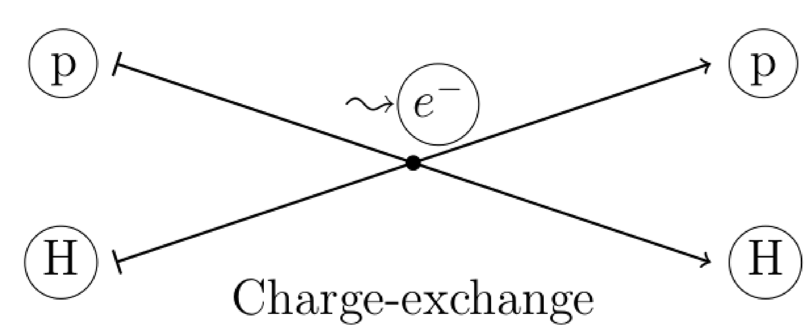


Overview

The heliosphere is forged by competing flows between the radial solar wind and streaming interstellar plasma. Charged atoms originating from interstellar space are deflected around the heliopause, shown in the left graphic by the stream lines, via the magnetic field surrounding the heliosphere. Neutral atoms may penetrate this barrier however, complicating the dynamics.



Hydrogen, protons, and electrons are the bulk constituents of space plasmas. Every so often a close encounter occurs between hydrogen atoms and protons and an electron is exchanged between them, i.e. a charge-exchange. This mechanism is used to couple the fluid ion and kinetic neutral descriptions of the plasma in the heliospheric simulations. **Our goal is to understand the effects of various assumptions and techniques of the charge-exchange process in the heliosphere & local interstellar medium.**

Ideal MHD

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \qquad \rho \frac{d\mathbf{v}}{dt} = -\nabla P - \frac{1}{\mu_0}\mathbf{B} \times (\nabla \times \mathbf{B})$$

$$\frac{d}{dt}\left(\frac{P}{\rho^\gamma}\right) = 0 \qquad \frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B})$$

Fluid ions and neutral atoms

Charge-exchange source terms

$$\int\int d\mathbf{v}_i d\mathbf{v}_j v_{rel} \sigma_{ex}(v_{rel}) f_i f_j (\mathcal{T}_j - \mathcal{T}_i)$$

Boltzmann

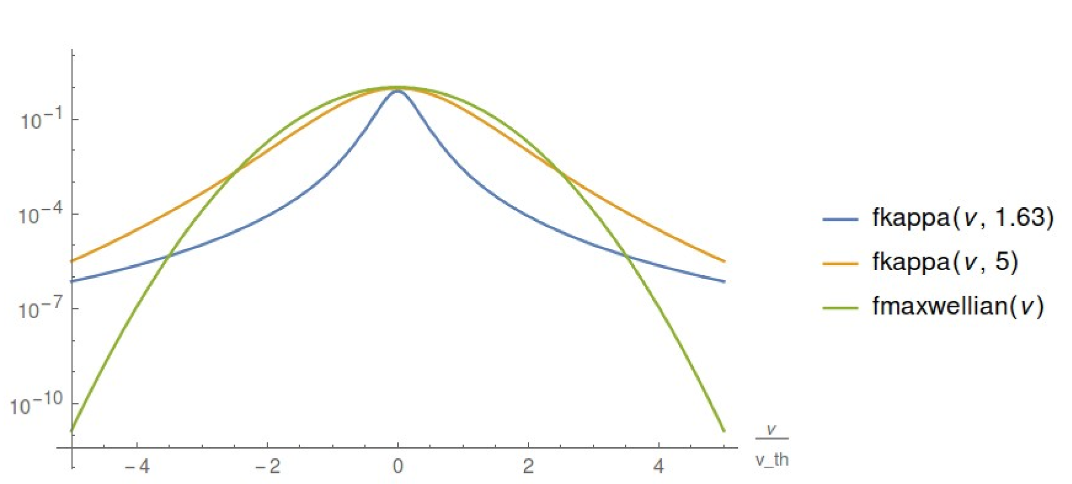
$$\frac{\partial f}{\partial t} + \frac{\mathbf{p}}{m} \cdot \nabla f + \mathbf{F} \cdot \frac{\partial f}{\partial \mathbf{p}} = 0$$

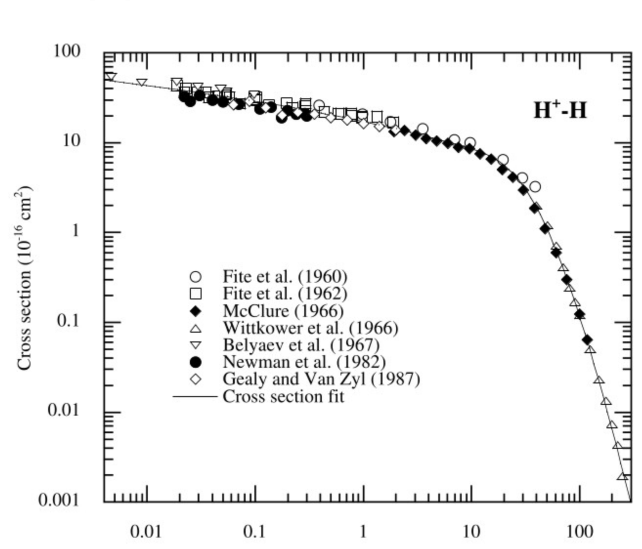
Kinetic ions and neutral atoms

Model

We have tested the following cases, all under the hard-sphere assumption for collisions, using the full 6D hydrogen distribution (3 space + 3 velocity):

- Charge exchange rate, and momentum/energy source terms
- Maxwellian and kappa protons
- Exact and Taylor/asymptotic series approximation



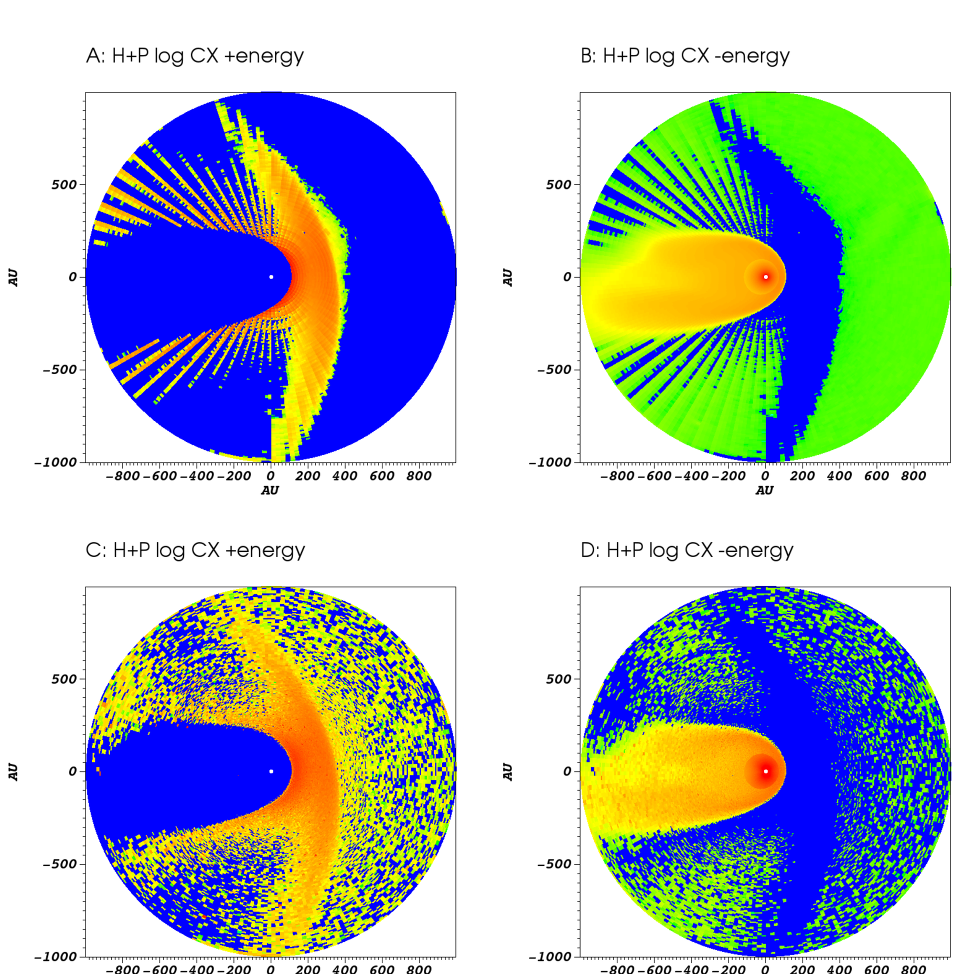


Lindsay & Stebbings 2005, JGR

Results

Comparisons were made between the semi-analytic integral (A & B) and the Monte Carlo accumulated (C & D) energy source terms.

- Momentum and energy source terms agree
- Hard-sphere premise for kappa protons is incorrect → suprathermal protons are affected by exponential cut-off of charge-exchange cross section



Acknowledgments

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