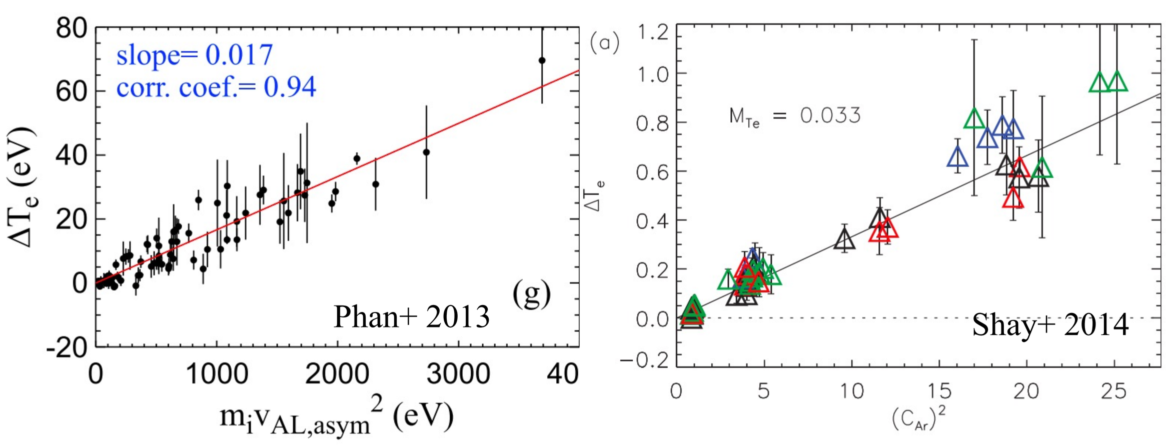
The Scaling of Electron Heating in Low-beta Reconnection Exhausts with Kinetic Reconnection Simulations

Qile Zhang[1], Fan Guo[1], Marit Oieroset[2], Tai Phan[2], Mike Shay[3], James Drake[4], Marc Swisdak[4]

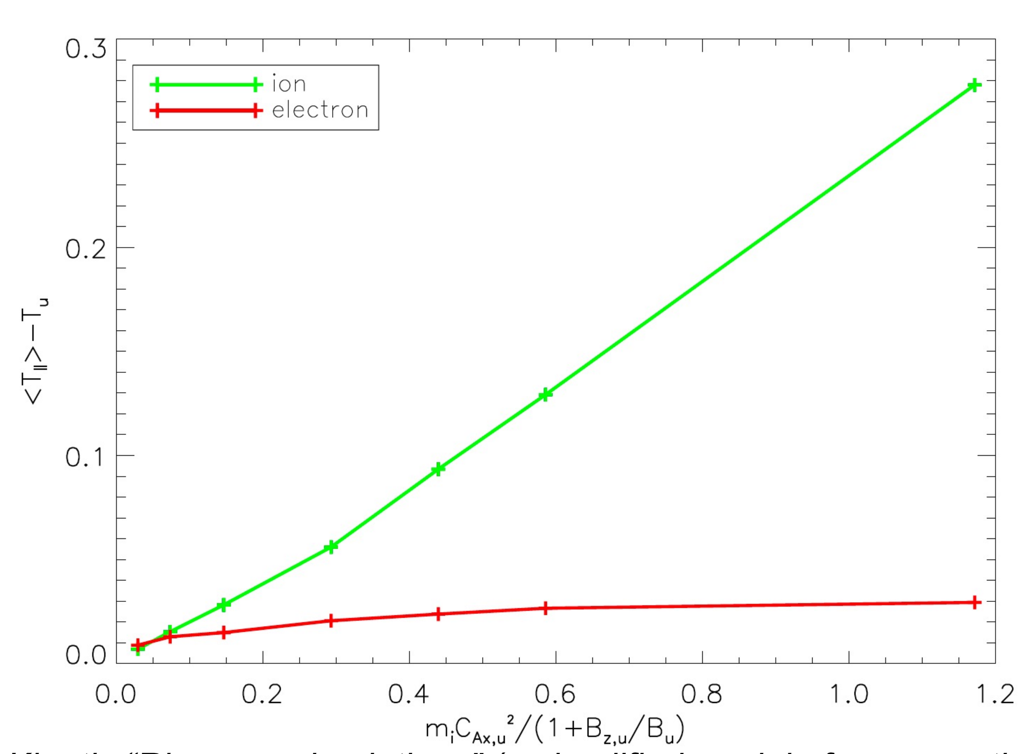
[1]Los Alamos National Laboratory [2]University of California, Berkeley
[3]University of Delaware [4]University of Maryland College Park

Introduction

Particle heating in reconnection is essential to understand the heating in the solar corona, solar flares and the magnetotail. It plays an important role distributing magnetic energy into different species and between thermal and nonthermal components.



Previous studies suggest a linear scaling of electron heating in beta~1 regime, where the electron heating is proportional to the magnetic energy per particle.



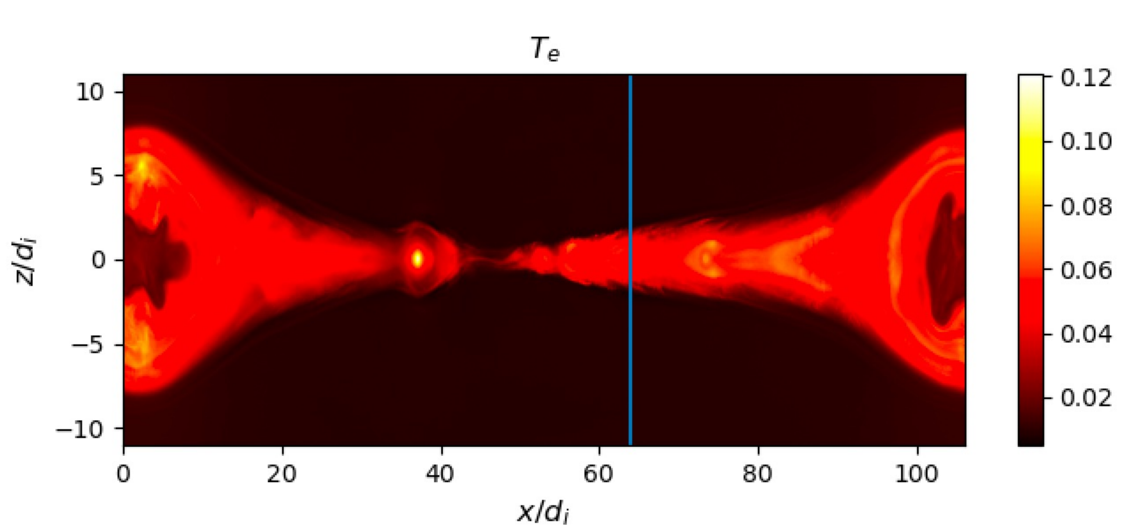
Kinetic "Riemann simulations" (a simplified model of reconnection exhausts) first suggested a sub-linear scaling for electron heating in low-beta guide-field reconnection (Zhang+ 2019a, b)

Here we use kinetic reconnection simulations to fully explore the scaling of electron heating.

Methodology

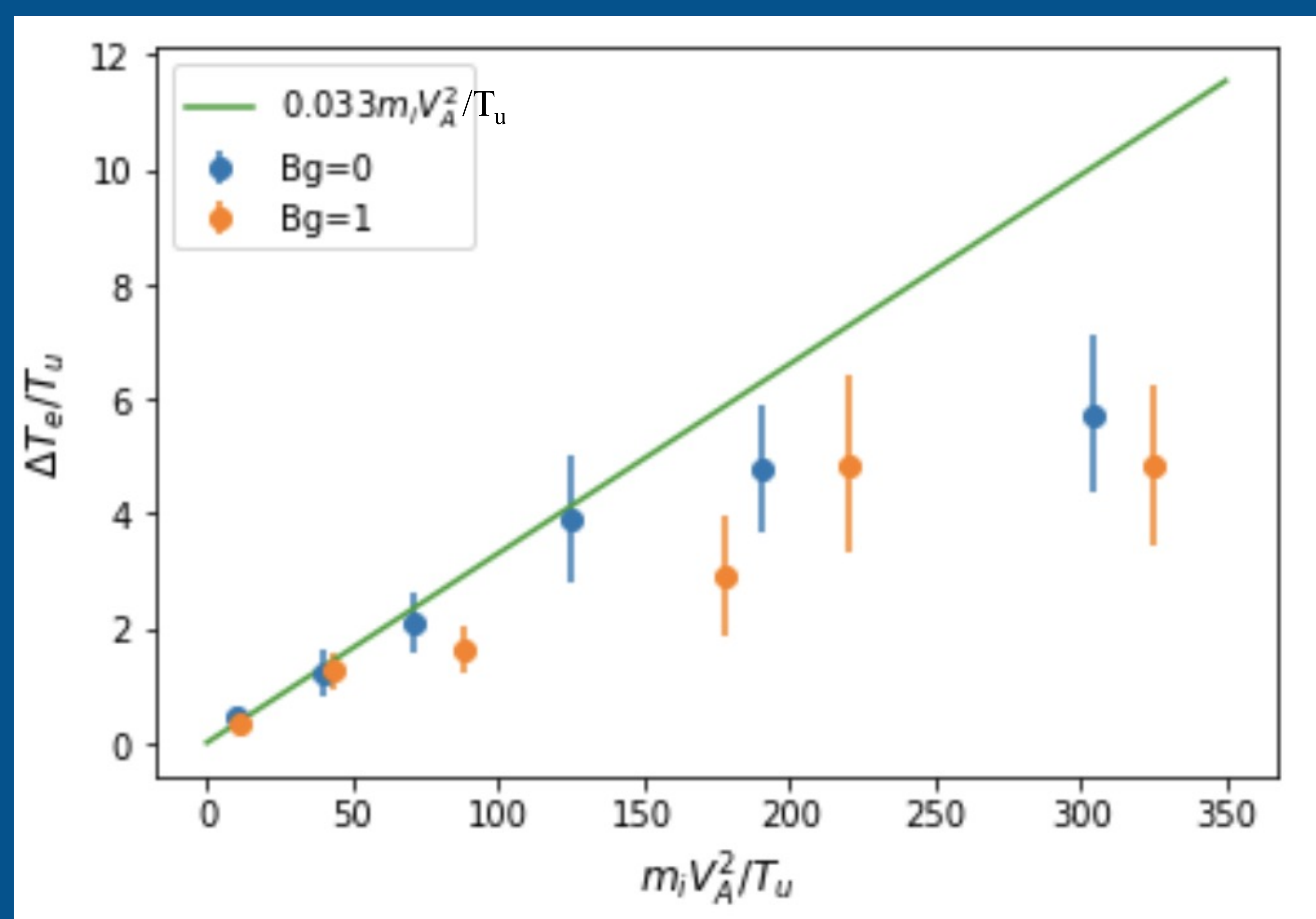
We perform low-beta particle-in-cell reconnection simulations:

Upstream beta_e=beta_i down to 0.005
Proton-electron mass ratio 400
Domain size 150*62.5 di^2
Force-free initial current sheet
Guide field to reconnecting field ratio bg=0 or 1



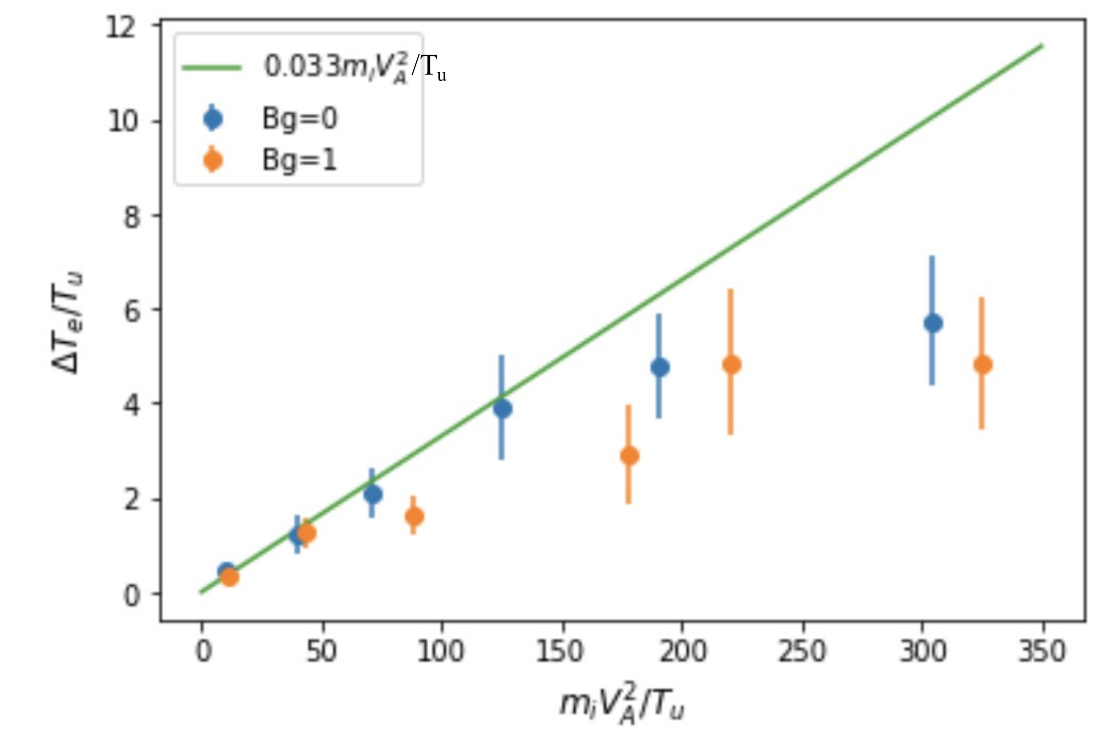
Electron upstream and downstream temperatures are estimated across the exhaust about 20di downstream of the x-line.

Electron heating at reconnection exhausts is limited even with large available magnetic energy per particle, with or without guide fields.



Electron heating follows a sub-linear scaling below beta ~0.01, with or without guide fields, which may be tested by MMS magnetotail observations

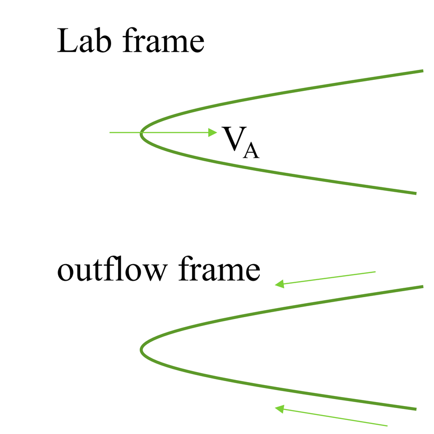
Results



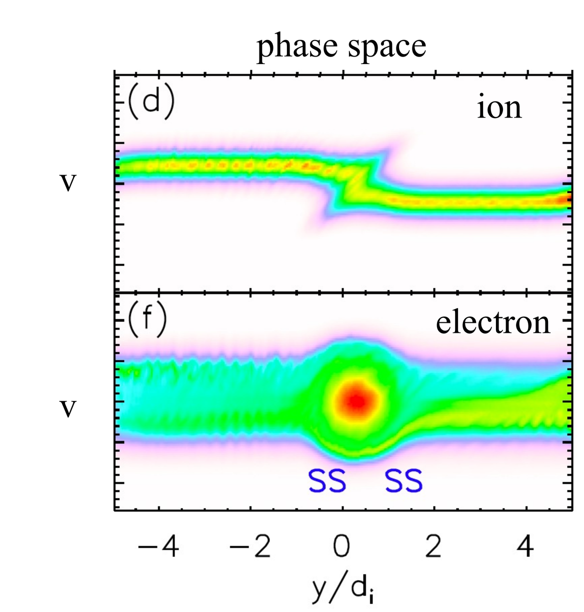
Electron heating follows a sub-linear scaling below beta ~0.01, with or without guide fields, which may be tested by MMS magnetotail observations

As a result, the maximum heating is limited to only ~5 times of upstream electron temperature, even with large available magnetic energy per particle. This new finding has strong implications for the efficiency of electron heating in reconnection at low-beta environments throughout heliophysics.

Possible Mechanism



Counter-streaming plasma flows are driven at reconnection exhausts.



The mechanism could be counter-streaming ions + trapped electrons (Zhang+2019a, b)

Counter-streaming ion beams create a density twice of the upstream density in the overlap region. For quasi-neutrality, a electric potential forms to trap electrons in that region. The trapped electrons contribute to the electron heating with a temperature comparable to the potential. To match a density only twice of the upstream density, the potential can not be much higher than the upstream temperature, so the heated electron temperature can't either. This leads to a constrain on the heating ratio, the vertical axis of the scaling result above, so the scaling has to plateau and become sub-linear.