Acceleration of Helium Nuclei at Non-Relativistic Shocks

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Previous studies

- Hybrid kinetic PIC simulations
- Caprioli et al. (2017)
  - He and other nuclei as test particles
  - Selection rate goes as \((A/Q)^2\)
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  - 1D simulations up to \(A/Q\) of 16
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- This work
  - Changes in dynamics
Motivation

- He should contain a comparable amount of energy to protons
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- May alter expected CR spectrum and $\gamma$-ray spectrum
Simulation Setup

- 2D hybrid simulation code dHybrid (Gargaté et al. 2007)
- Supersonic flow against reflecting wall
- Mach numbers: 5, 20, 40
- Solar abundances for H, He, CNO
  - $x_H = 1$, $x_{He} = 0.0963$, $x_{CNO} = 9.54 \times 10^{-4}$
Phase Space
Energy Spectra

- Taken at $t = 520\omega_c$
- $M=40$
- Max energy increased by $\sim 2-3$
Energy Spectra

• Taken at $t = 520\omega_c$
• $M=40$
• Max energy increased by $\sim 2-3$
• He contains most energy
Acceleration Efficiency

- Energy in accelerated particles over total energy in simulation

Caprioli & Spitkovsky (2014)
Acceleration Efficiency

- Energy in accelerated particles over total energy in simulation
- He dominates
- CNO not important

Caprioli & Spitkovsky (2014)
Magnetic Field Amplification

- Average upstream $B_{\perp}$ field over $100\omega_c$
- Most important for higher mach number
- Reduces the tension on galactic sources (Bell et al. 2013, Cardillo et al. 2015)
Gamma Ray / Neutrino Emission

- Production via nuclear interactions with thermal particles
- He becomes the primary source of emission
- Parent protons now have a maximum energy 20 times larger than photons (instead of 10)
Conclusions

- Simulations w/o heavy ions leave out physics at higher mach numbers
- More energy in He than H
- B field and maximum energy of H increase by ~2-3 at M=40
- Gamma ray emission dominated by He
- Cotter, Roussi, & Caprioli (in progress)
B Field spectrum