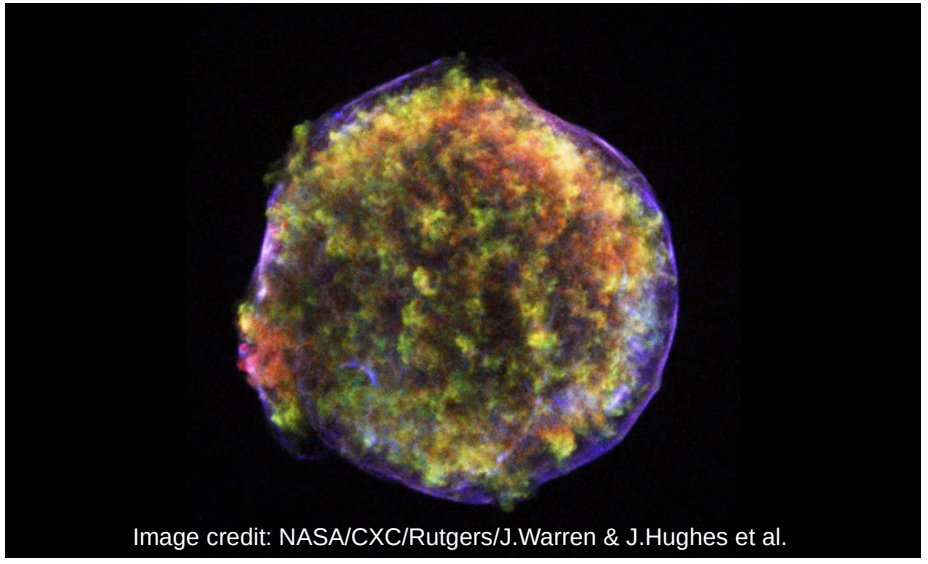


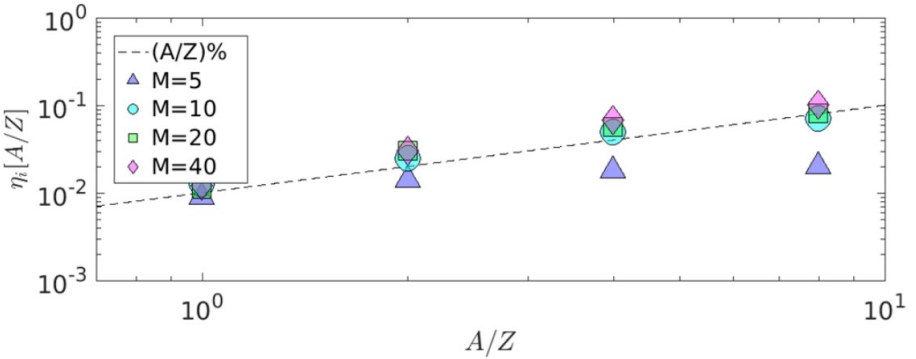
Image credit: NASA/CXC/Rutgers/J.Warren & J.Hughes et al.

THE UNIVERSITY OF CHICAGO

Acceleration of Helium Nuclei at Non-Relativistic Shocks

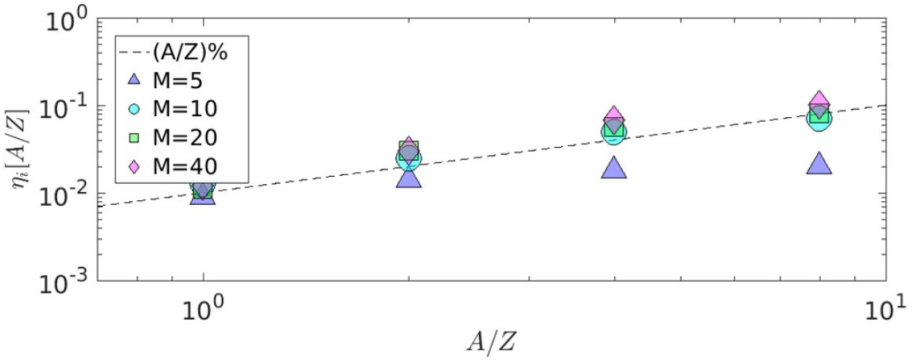
Cory Cotter, Marwah Roussi, Damiano Caprioli

Previous studies



- Hybrid kinetic PIC simulations
- Caprioli et al. (2017)
  - He and other nuclei as test particles
  - Selection rate goes as $(A/Q)^2$

Previous studies



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  - 1D simulations up to A/Q of 16
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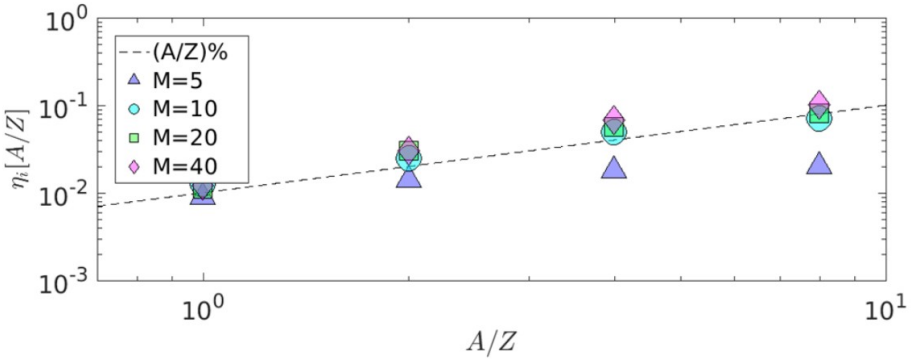

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- Hanusch et al. (2019)
  - 1D simulations up to A/Q of 16
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- This work
  - Changes in dynamics

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- He should contain a comparable amount of energy to protons
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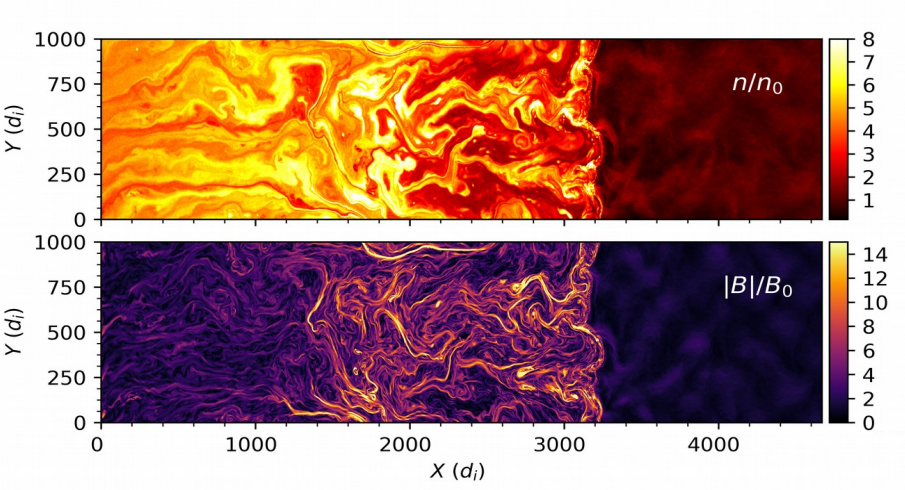
- Has yet to be studied in detail in simulations
- May alter expected CR spectrum and γ-ray spectrum

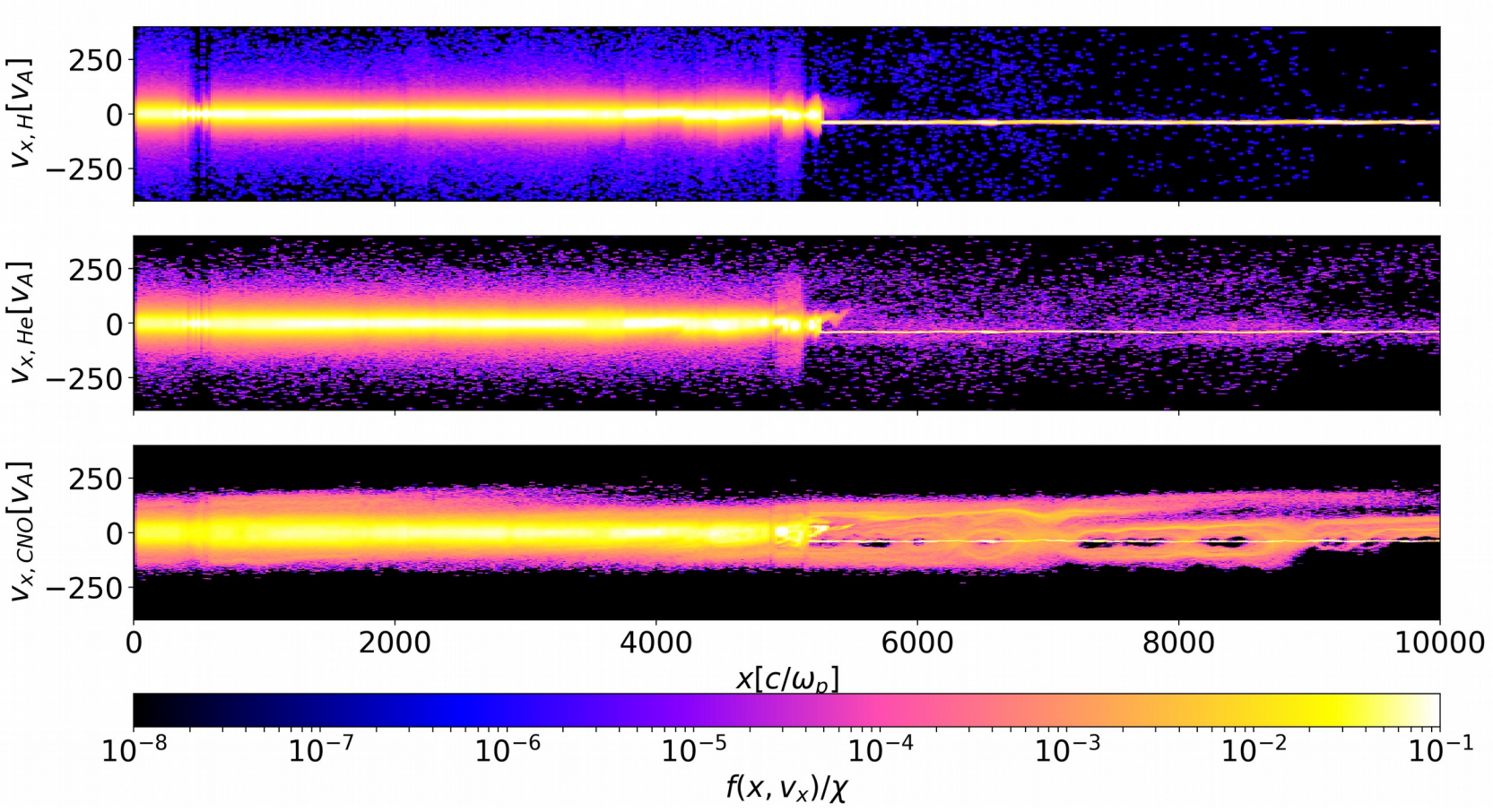
Simulation Setup

- 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*10^{-4}



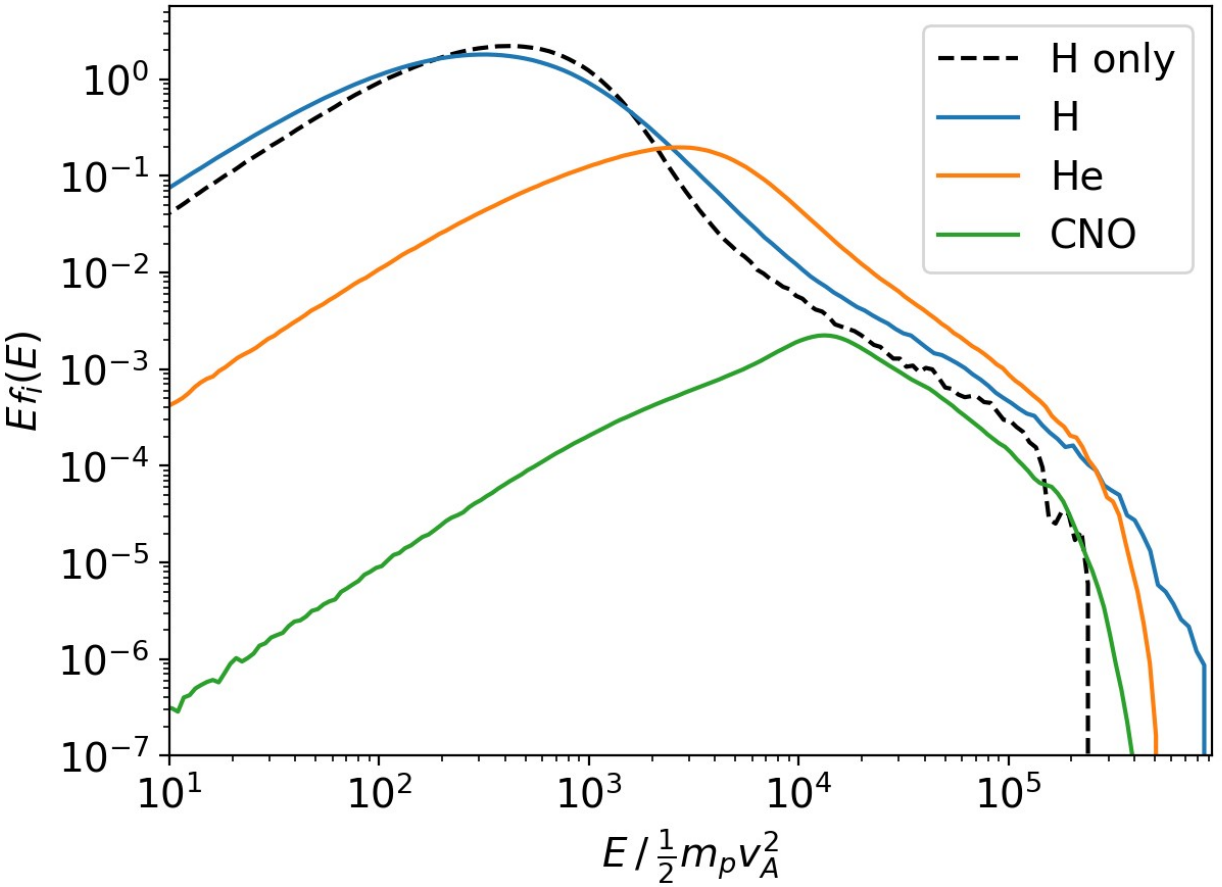
Credit: Colby Haggerty

Phase Space


$v_{x,H}[v_A]$
$v_{x,He}[v_A]$
$v_{x,CNO}[v_A]$
250
0
−250
0
2000
4000
6000
8000
10000
$x[c/\omega_p]$
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
$f(x, v_x)/\chi$

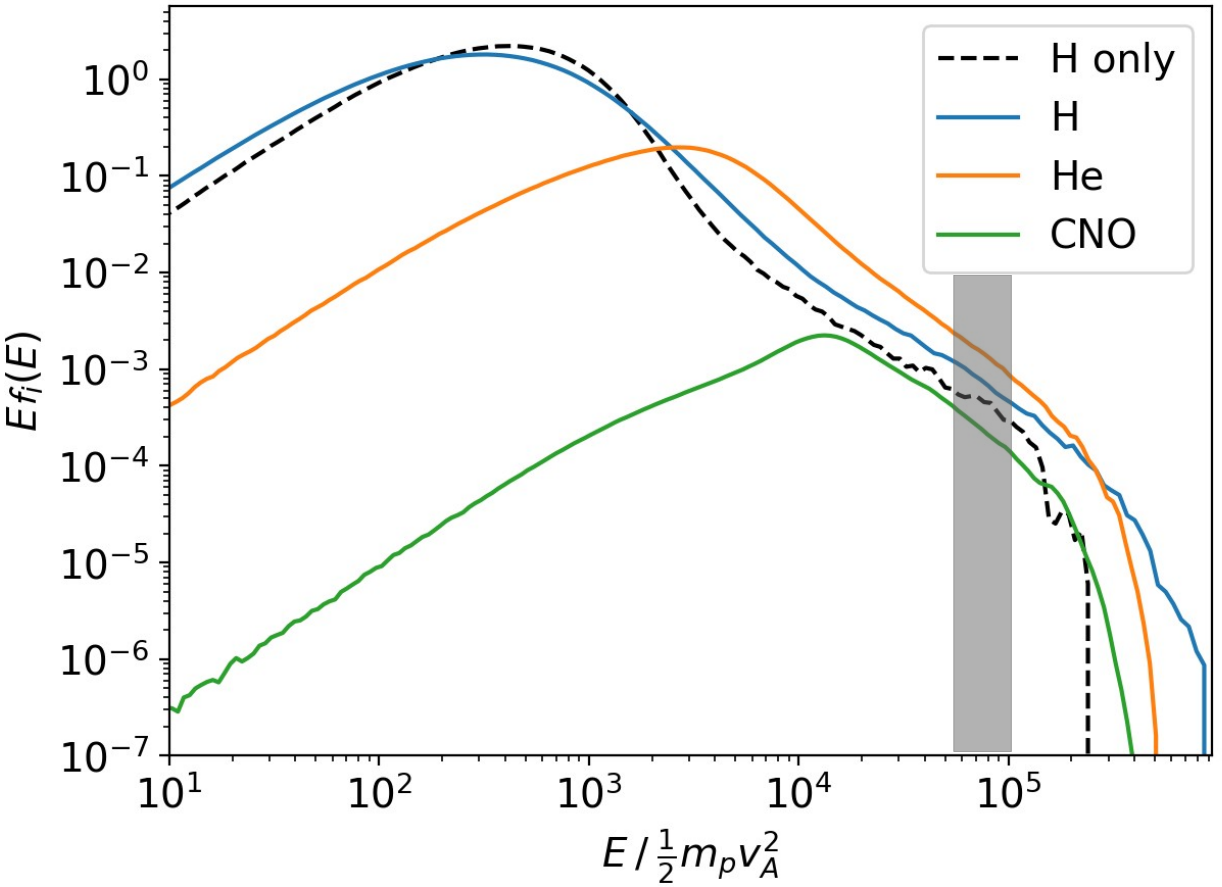
Energy Spectra

- Taken at t = 520ω_c
- M=40
- Max energy increased by ~2-3



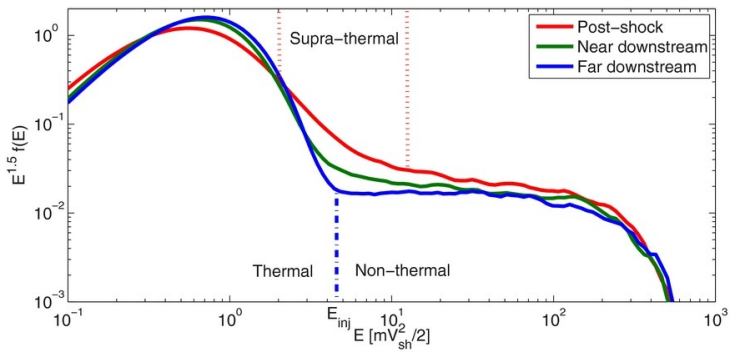
Energy Spectra

- Taken at t = 520ω_c
- M=40
- Max energy increased by ~2-3
- He contains most energy



Acceleration Efficiency

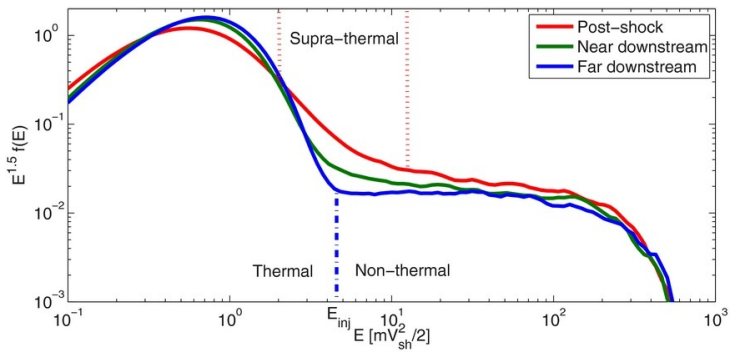
- Energy in accelerated particles over total energy in simulation



Caprioli & Spitkovsky (2014)

Acceleration Efficiency

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



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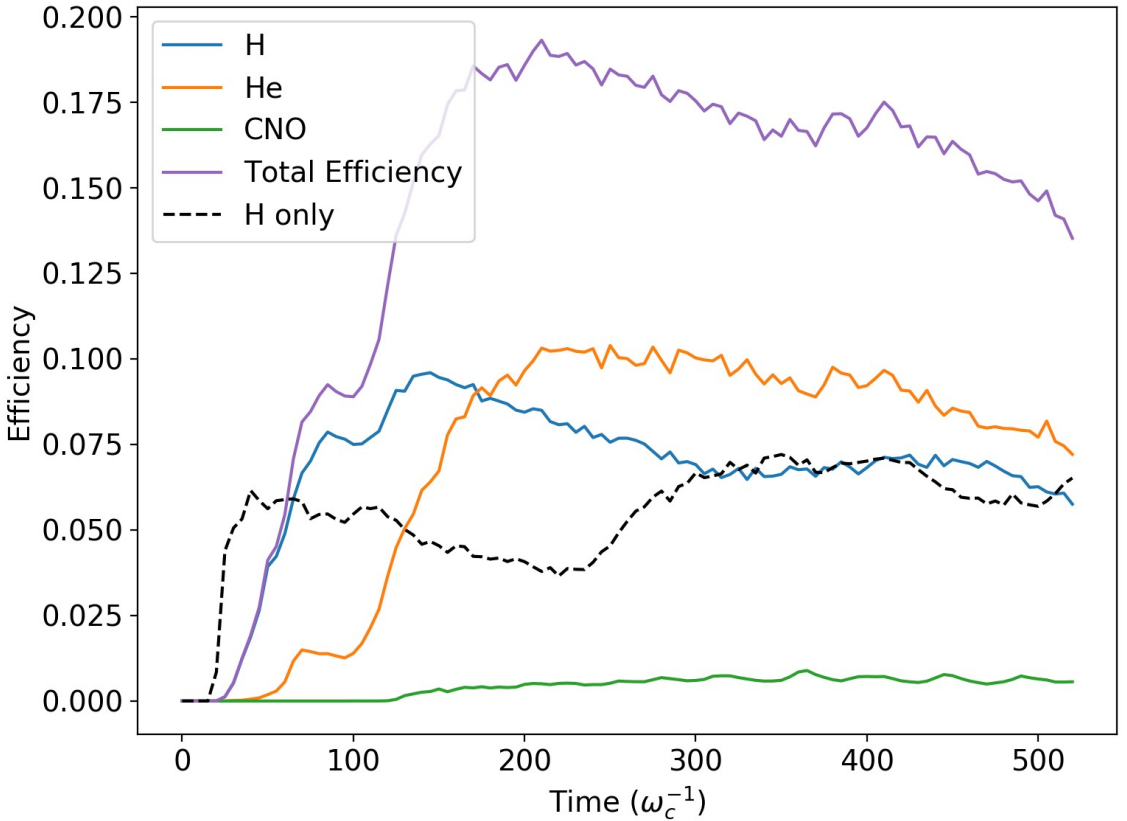
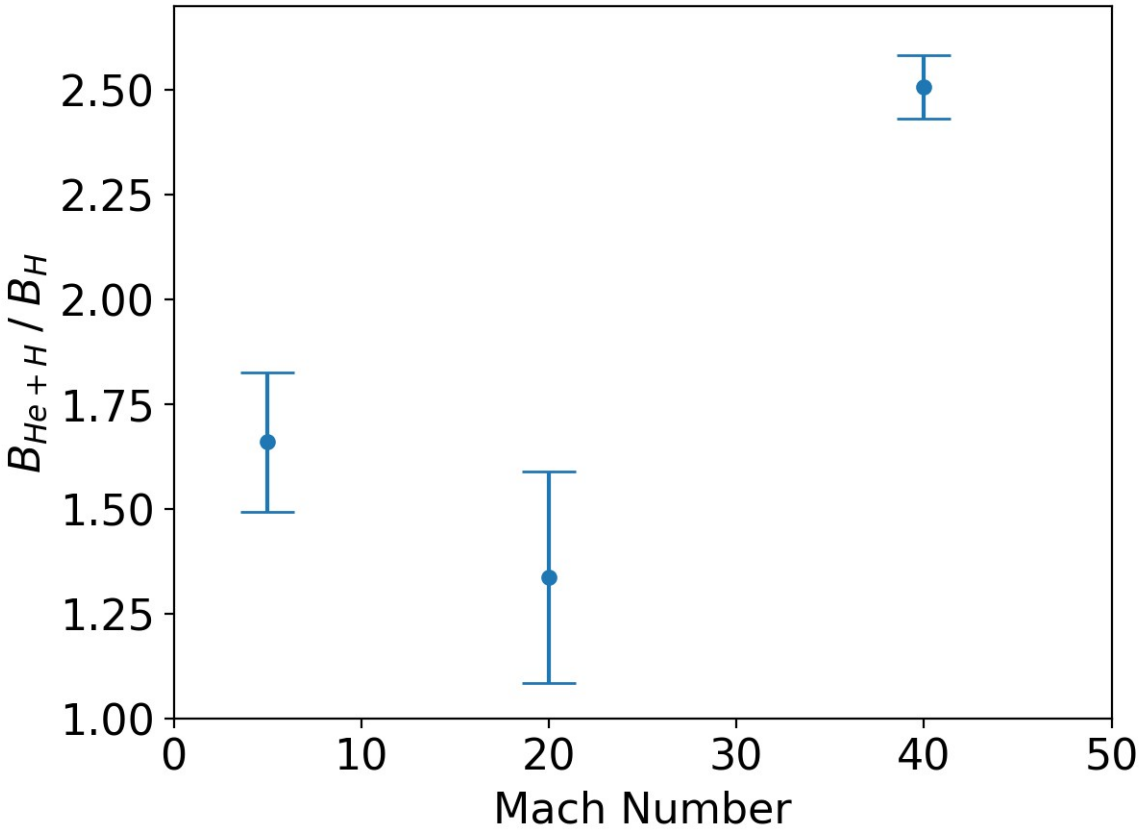


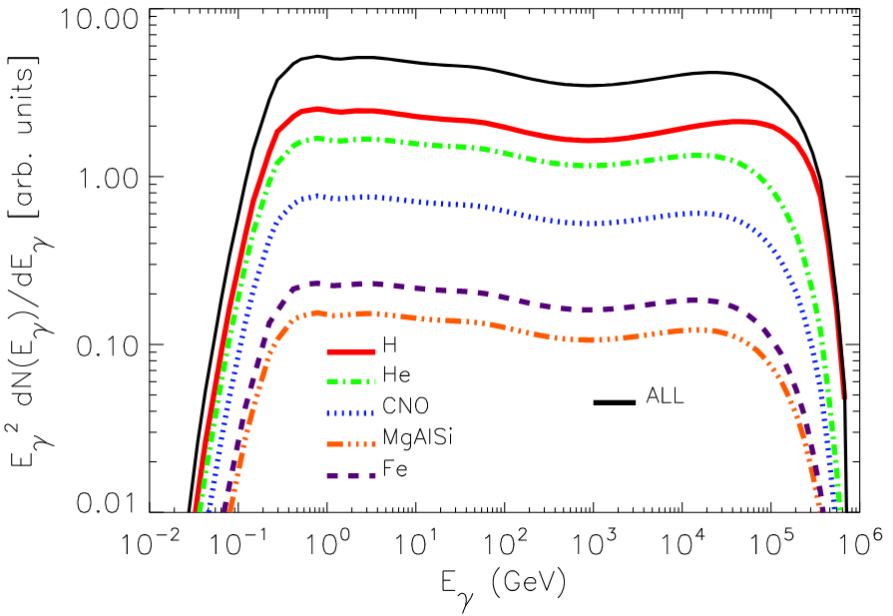
Magnetic Field Amplification

- 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)



Caprioli, Blasi, & Amato (2010)

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