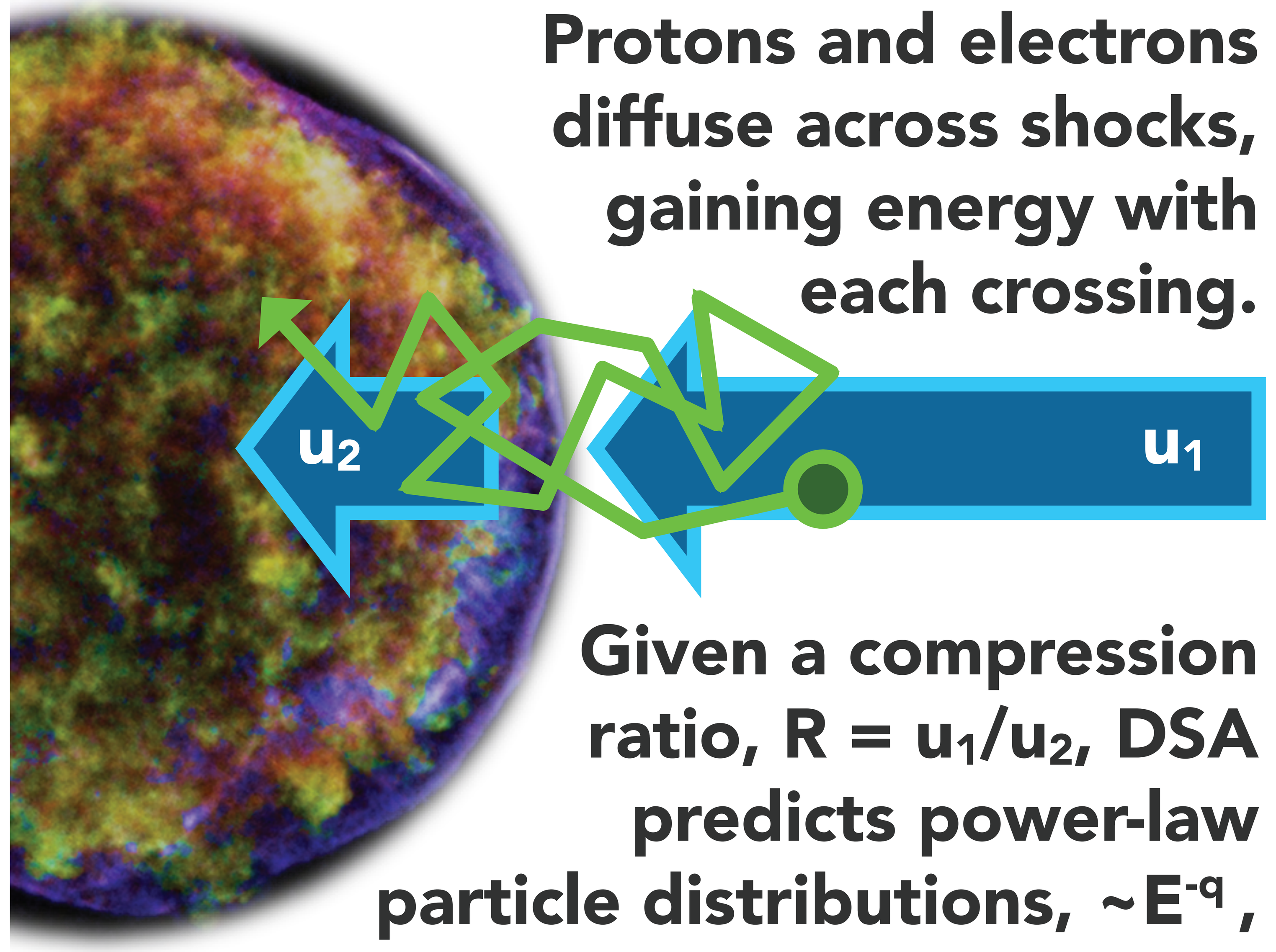
Understanding the Multi-Wavelength Emission from Astrophysical Shocks

REBECCA DIESING AND DAMIANO CAPRIOLI

MOTIVATION

Interpreting observations of astrophysical shocks from radio to gamma-rays requires a detailed understanding of how shocks accelerate particles over the course of their evolution.

DIFFUSIVE SHOCK ACCELERATION



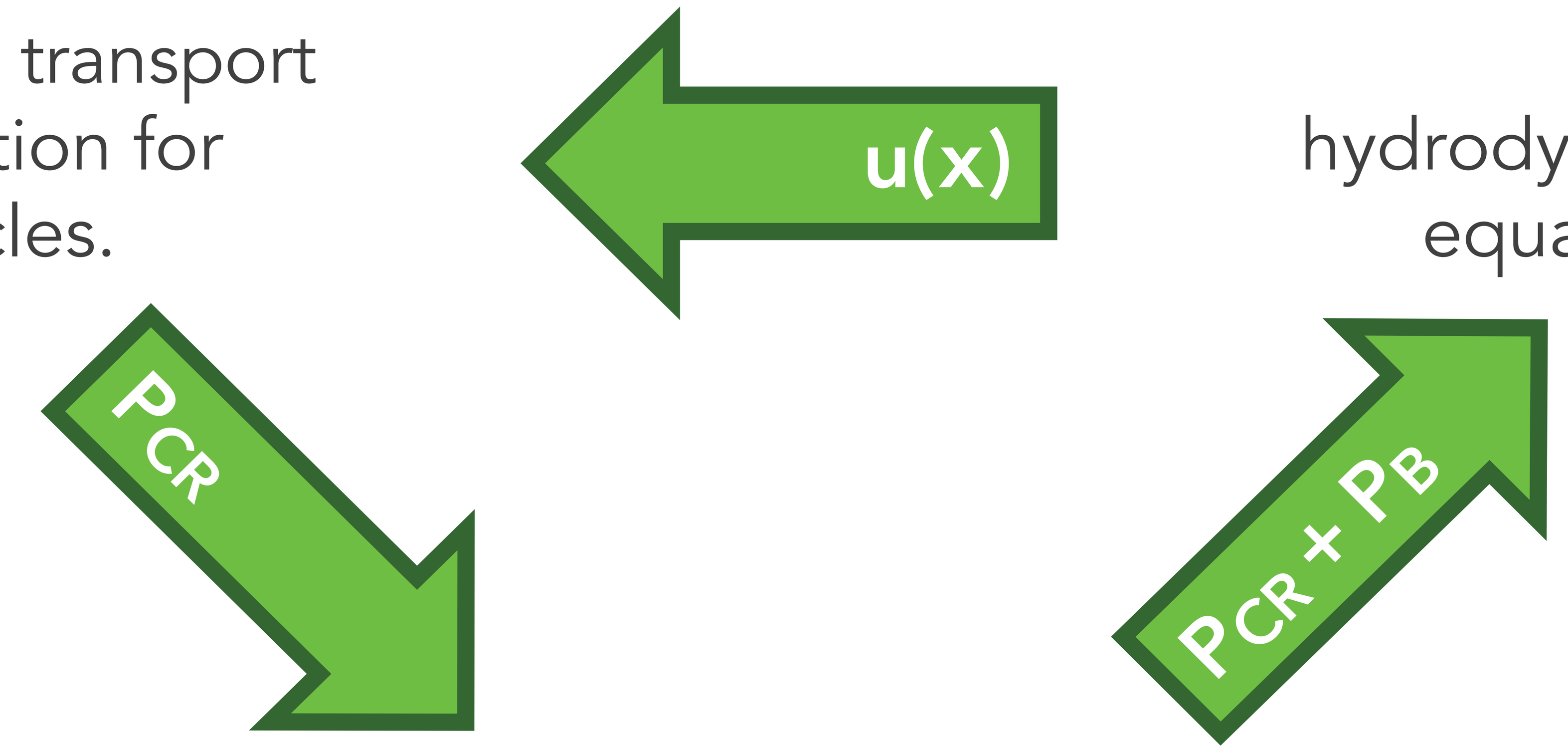
Protons and electrons diffuse across shocks, gaining energy with each crossing.

Given a compression ratio, $R = u_1/u_2$, DSA predicts power-law particle distributions, $\sim E^{-q}$, where $q=(R+2)/(R-1)$. This is a univeral acceleration mechanism [1-3].

METHOD

CRAFT (COSMIC RAY ANALYTICAL FAST TOOL)

CRAFT is fast, multi-zone model of particle acceleration that self consistently accounts for magnetic field amplification and shock modification due to the presence of non-thermal particles (method paper in prep; see also [4-6]).

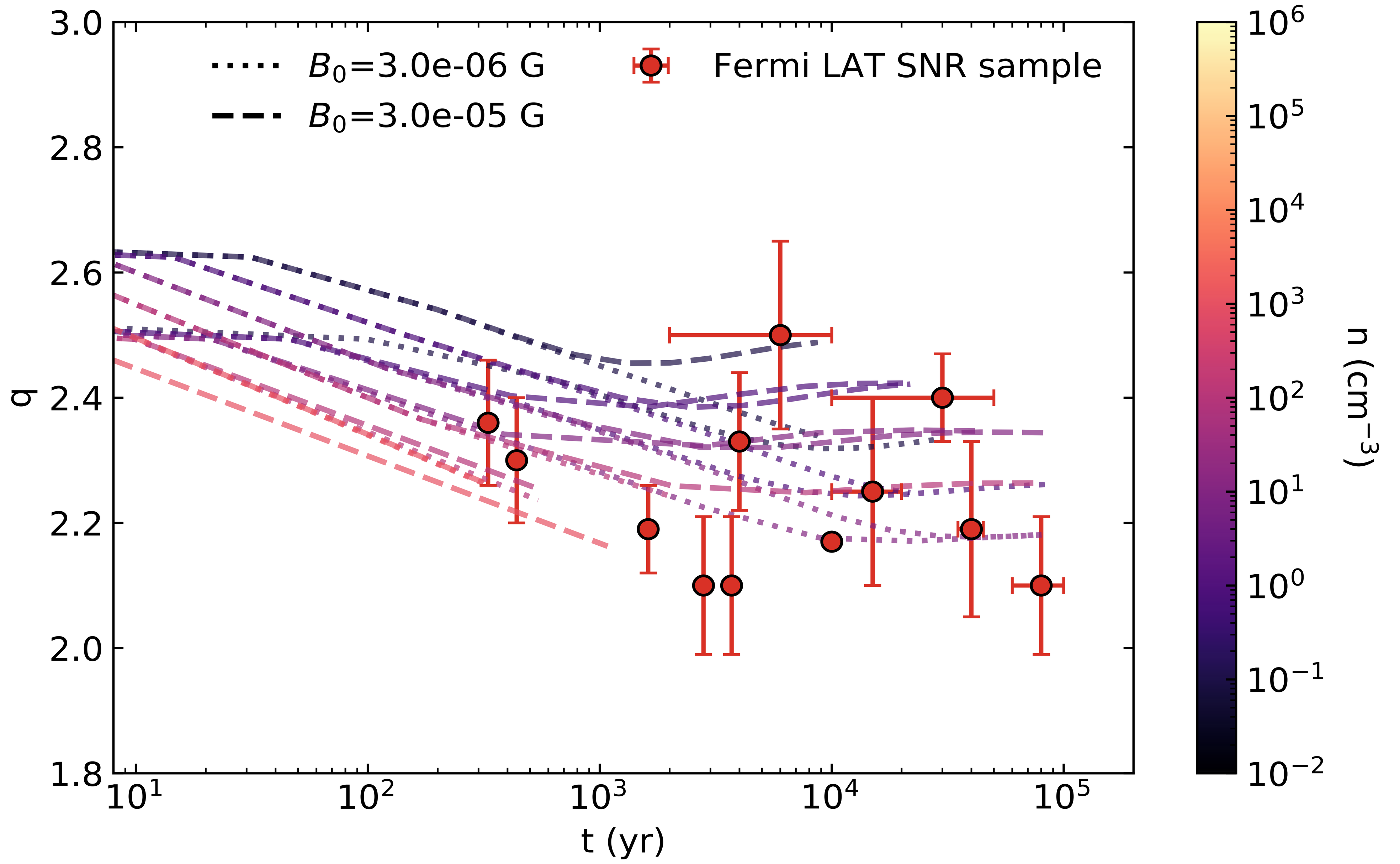


CRAFT calculates instantaneous proton distributions (from which we also compute electron distributions), which are weighted to account for losses and added to produce a cumulative distribution. This can be combined with radiation processes code naima [7] to predict photon spectra.

RESULTS

EXAMPLE I: SUPERNOVA REMNANTS

Using results from state-of-the-art simulations, we self-consitently reprouce the steep spectra (q > 2) inferred from Galactic supernova remnants and young, extragalactic supernovae (radio SNe).



Spectral slopes (q) vs. shock age inferred from a sample of Galactic SNRs observed by Fermi LAT [8]. Our model results (lines) are in good agreement with these data.

Additional details in Diesing & Caprioli 2021 (ApJ) & Fermi-LAT collaboration, Diesing & Caprioli 2021 (ApJ).

[1] G. F. Krymskii, Akad. Nauk SSSR Dokl. (1977)
[2] A. R. Bell, MNRAS (1978)
[3] R. D. Blandford and J. P. Ostriker, ApJL (1978)
[4] E. Amato and P. Blasi, MNRAS (2006)
[5] D. Caprioli,et al., Astropart. Phys. (2010)
[6] D. Caprioli, J. Cosmol. Astropart. Phys. (2012)
[7] V. Zabalza, PoS (2015)
[8] Acero et al., ApJS (2016)
[9] H.E.S.S. collaboration, Science (2022)
[10] MAGIC collaboration, Nat. Astron. (2022)

THE UNIVERSITY OF CHICAGO

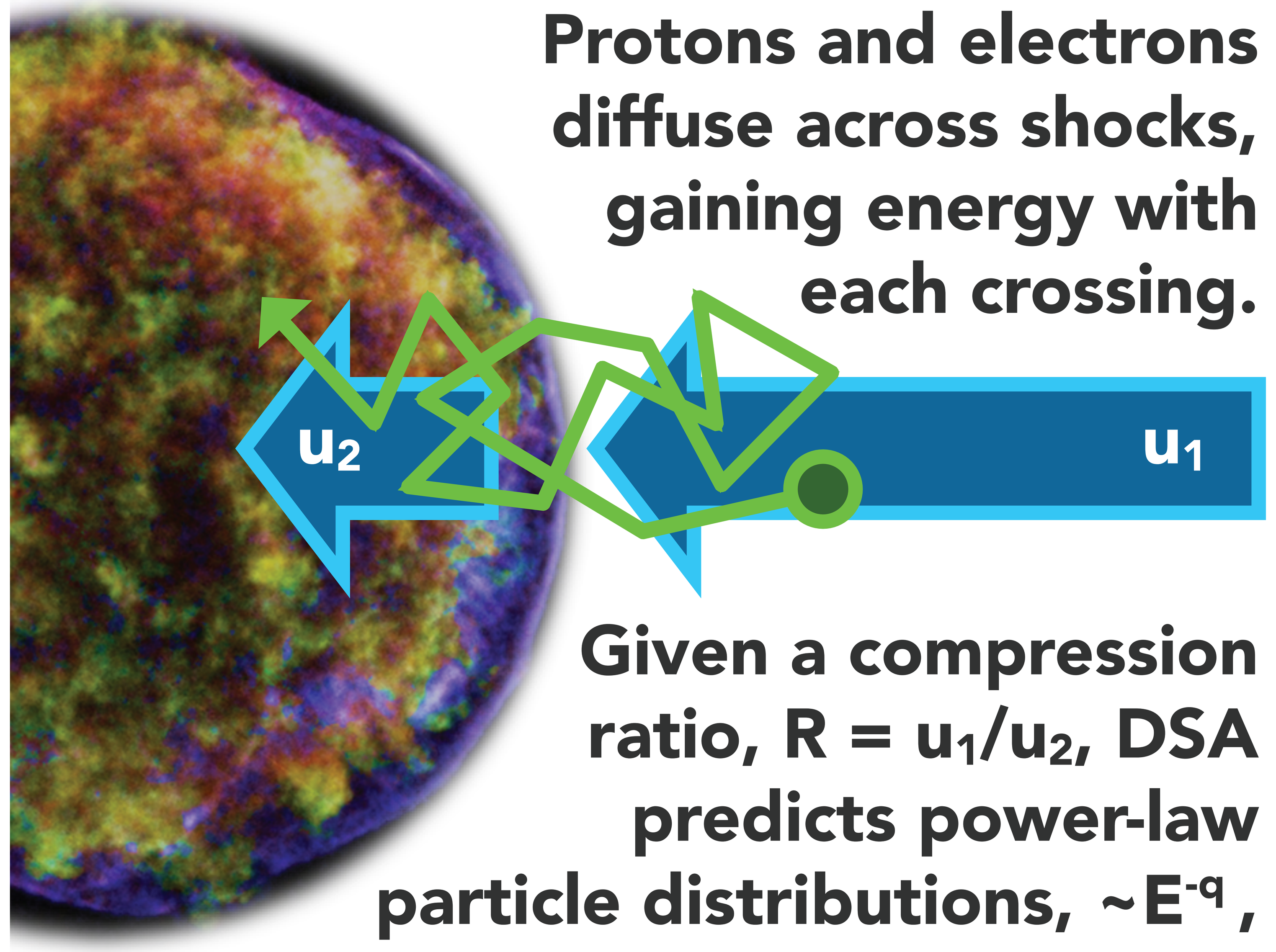
Understanding the Multi-Wavelength Emission from Astrophysical Shocks

REBECCA DIESING AND DAMIANO CAPRIOLI

MOTIVATION

Interpreting observations of astrophysical shocks from radio to gamma-rays requires a detailed understanding of how shocks accelerate particles over the course of their evolution.

DIFFUSIVE SHOCK ACCELERATION



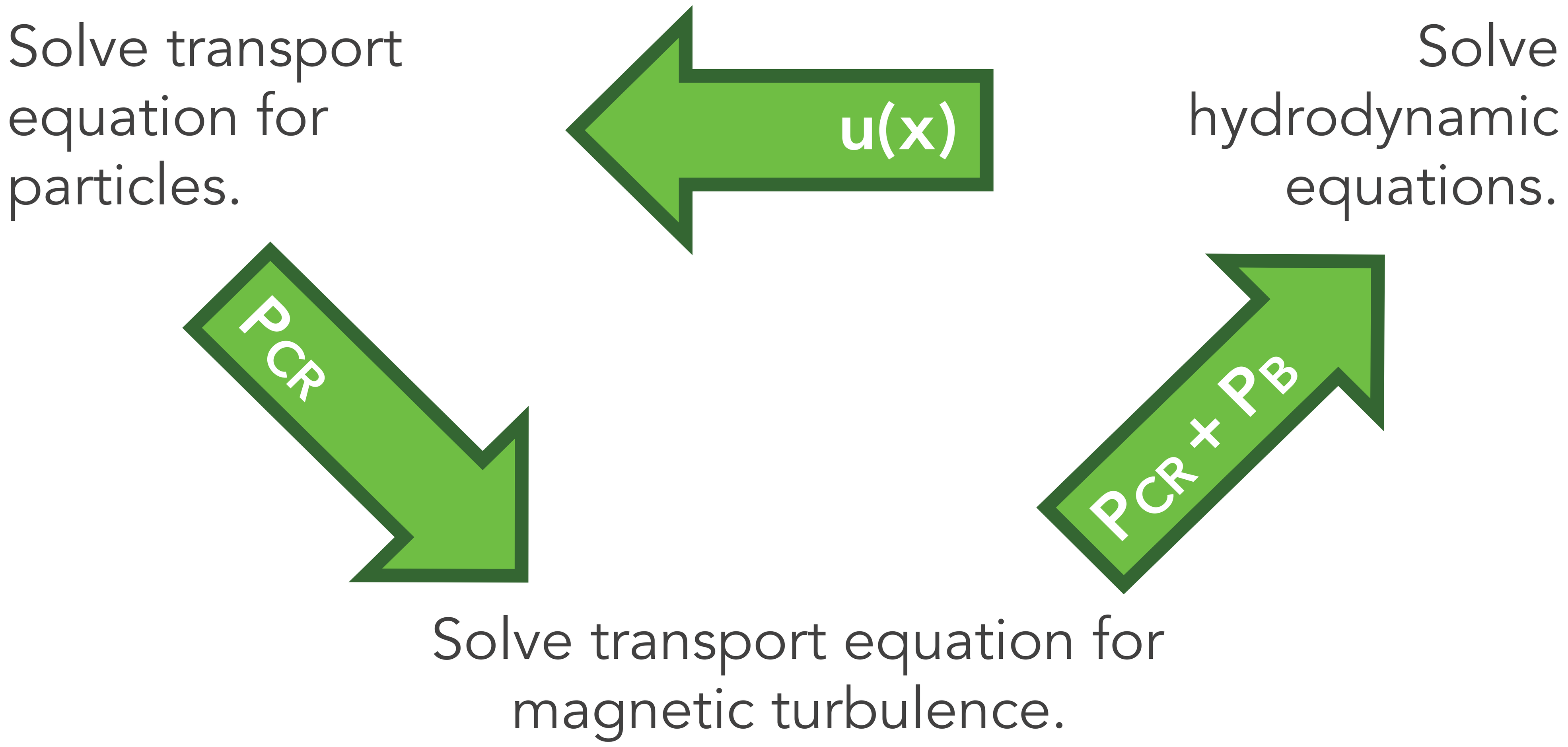
Protons and electrons diffuse across shocks, gaining energy with each crossing.

Given a compression ratio, $R = u_1/u_2$, DSA predicts power-law particle distributions, $\sim E^{-q}$, where $q=(R+2)/(R-1)$. This is a univeral acceleration mechanism [1-3].

METHOD

CRAFT (COSMIC RAY ANALYTICAL FAST TOOL)

CRAFT is fast, multi-zone model of particle acceleration that self consistently accounts for magnetic field amplification and shock modification due to the presence of non-thermal particles (method paper in prep; see also [4-6]).

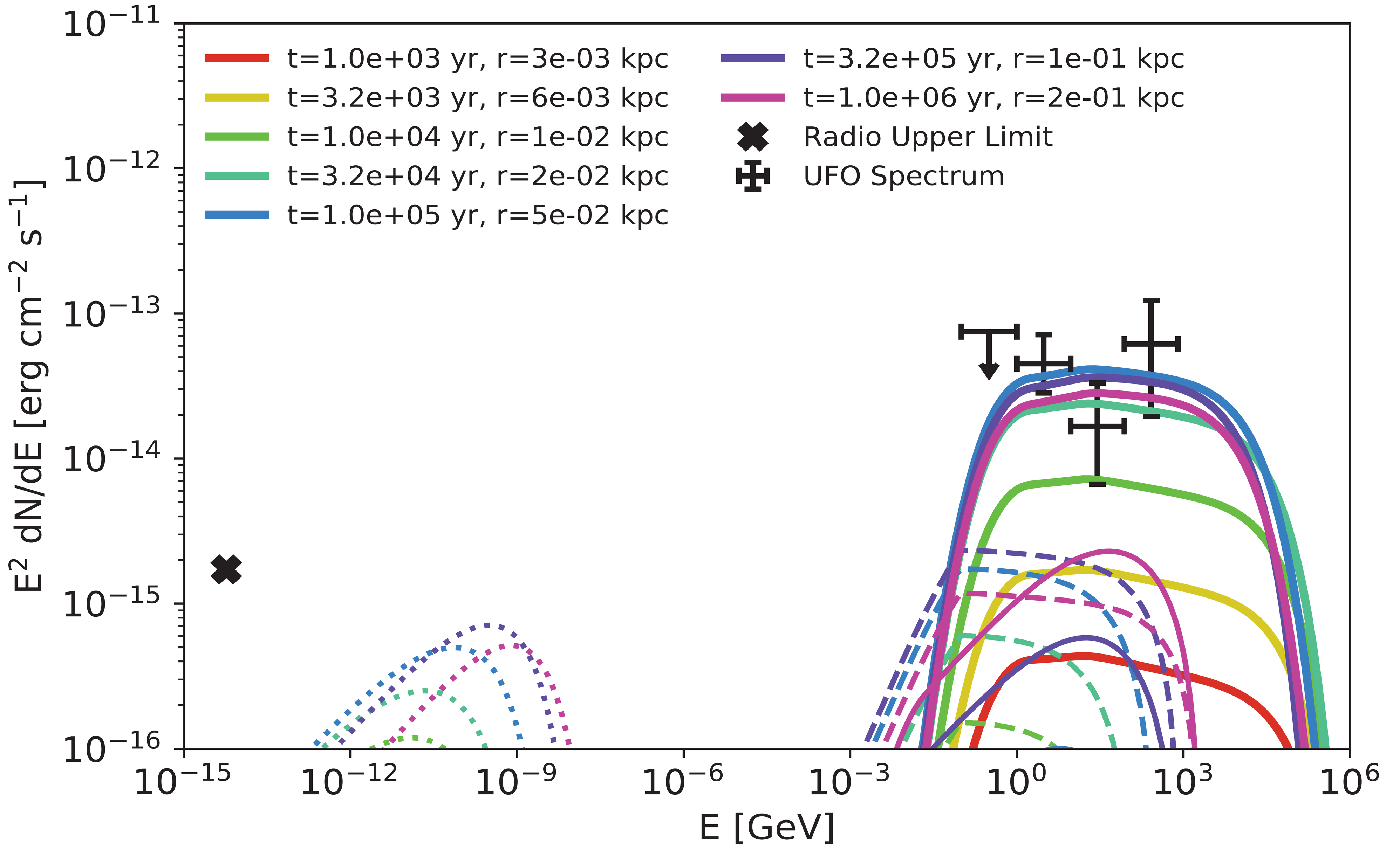


CRAFT calculates instantaneous proton distributions (from which we also compute electron distributions), which are weighted to account for losses and added to produce a cumulative distribution. This can be combined with radiation processes code naima [7] to predict photon spectra.

RESULTS

EXAMPLE II: ULTRA-FAST OUTFLOWS (UFOs)

Fermi-LAT detected gamma-rays from fast black-hole winds in a stacked sample of AGN. We were able to reproduce the observed emission.



UFO stacked spectrum observed by Fermi LAToverlaid with the multiwavelenth emission predicted by our model. Each color represents a different epoch in the evolution of the shock. Thick, solid lines represent emission from π_0 decay.

Additional details in Diesing & Caprioli 2021 (ApJ) & Fermi-LAT collaboration, Diesing & Caprioli 2021 (ApJ).

[1] G. F. Krymskii, Akad. Nauk SSSR Dokl. (1977)
[2] A. R. Bell, MNRAS (1978)
[3] R. D. Blandford and J. P. Ostriker, ApJL (1978)
[4] E. Amato and P. Blasi, MNRAS (2006)
[5] D. Caprioli,et al., Astropart. Phys. (2010)
[6] D. Caprioli, J. Cosmol. Astropart. Phys. (2012)
[7] V. Zabalza, PoS (2015)
[8] Acero et al., ApJS (2016)
[9] H.E.S.S. collaboration, Science (2022)
[10] MAGIC collaboration, Nat. Astron. (2022)

THE UNIVERSITY OF CHICAGO

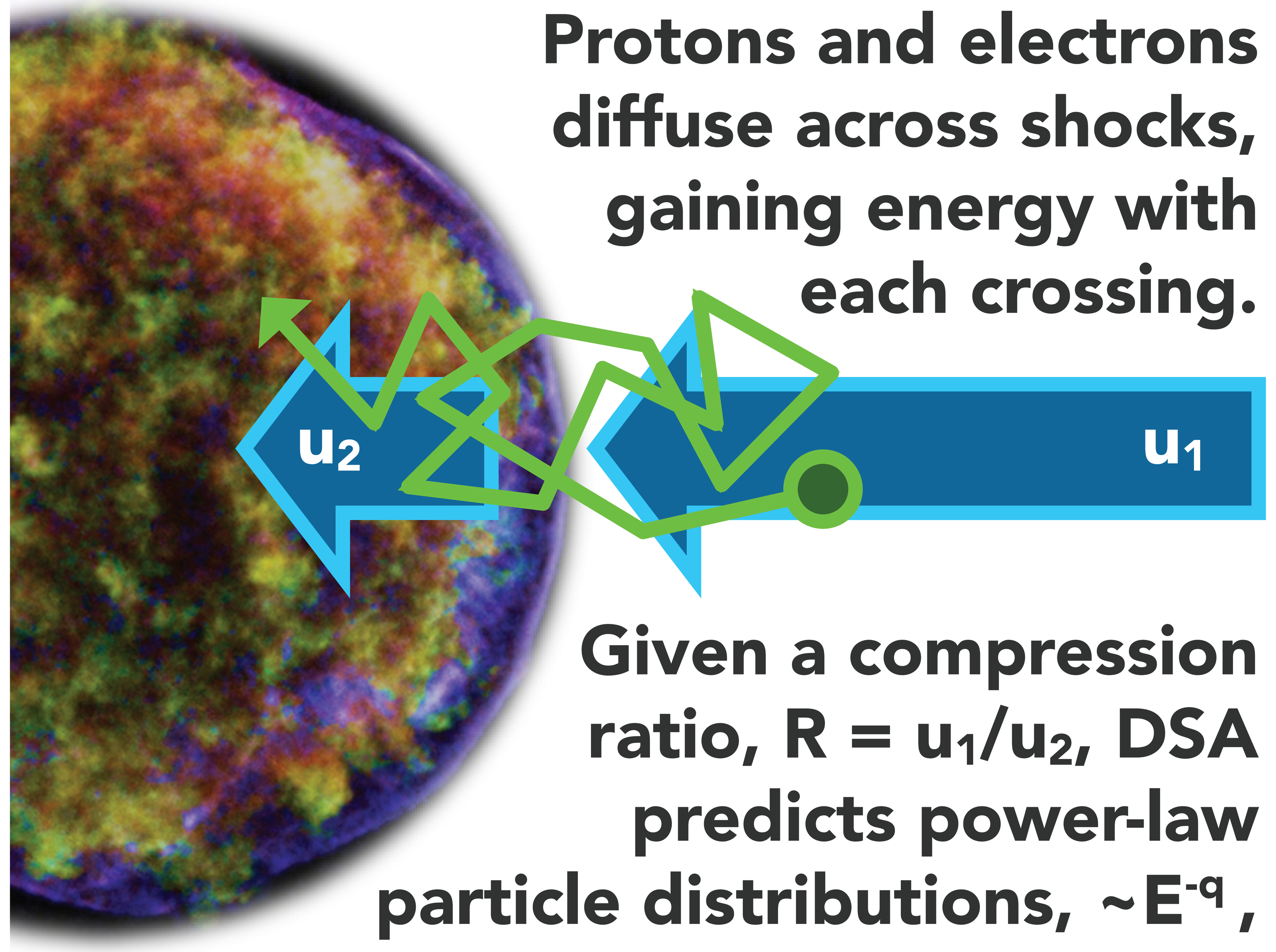
Understanding the Multi-Wavelength Emission from Astrophysical Shocks

REBECCA DIESING AND DAMIANO CAPRIOLI

MOTIVATION

Interpreting observations of astrophysical shocks from radio to gamma-rays requires a detailed understanding of how shocks accelerate particles over the course of their evolution.

DIFFUSIVE SHOCK ACCELERATION



Protons and electrons diffuse across shocks, gaining energy with each crossing.

Given a compression ratio, $R = u_1/u_2$, DSA predicts power-law particle distributions, $\sim E^{-q}$, where $q=(R+2)/(R-1)$. This is a univeral acceleration mechanism [1-3].

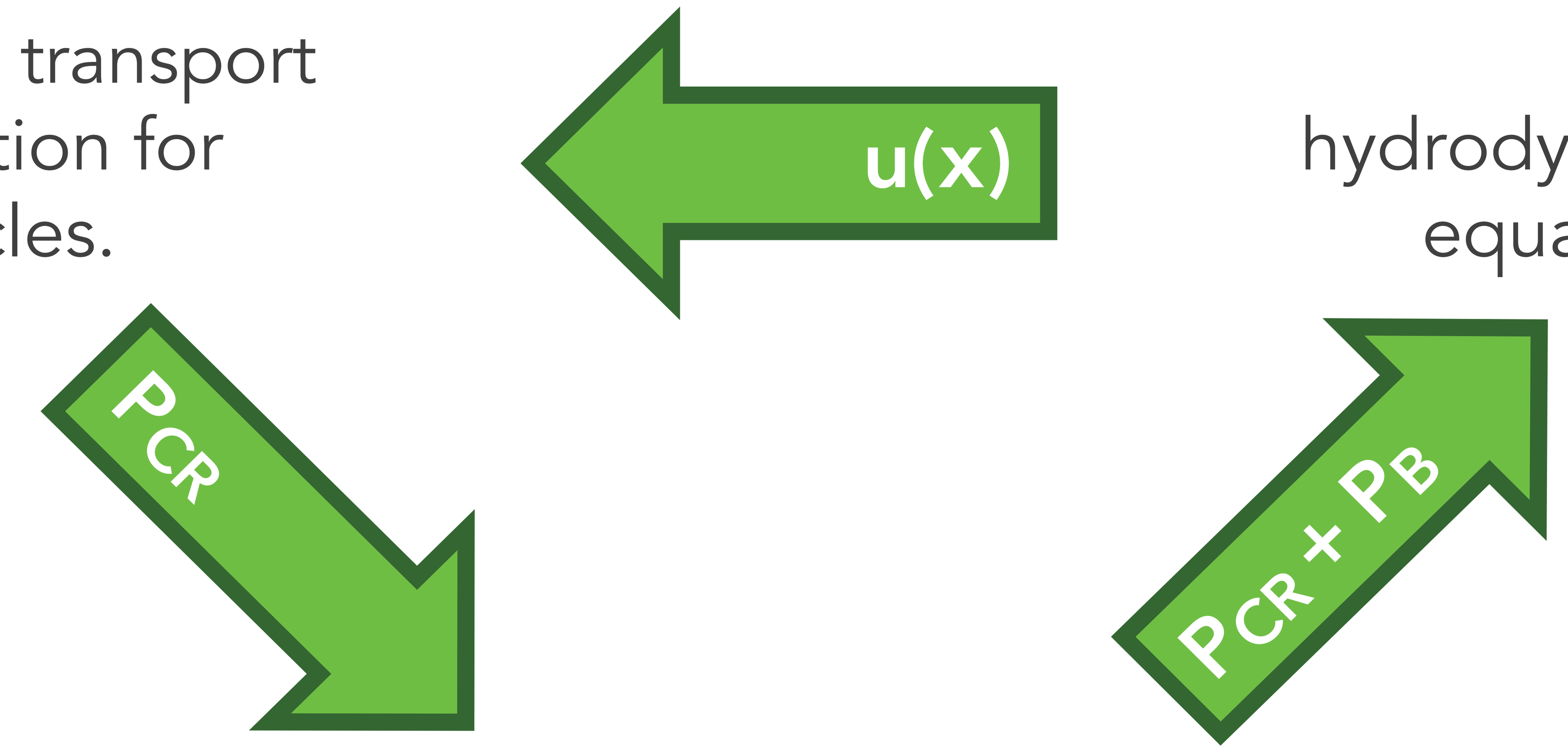
METHOD

CRAFT (COSMIC RAY ANALYTICAL FAST TOOL)

CRAFT is fast, multi-zone model of particle acceleration that self consistently accounts for magnetic field amplification and shock modification due to the presence of non-thermal particles (method paper in prep; see also [4-6]).

Solve transport equation for particles.

Solve hydrodynamic equations.



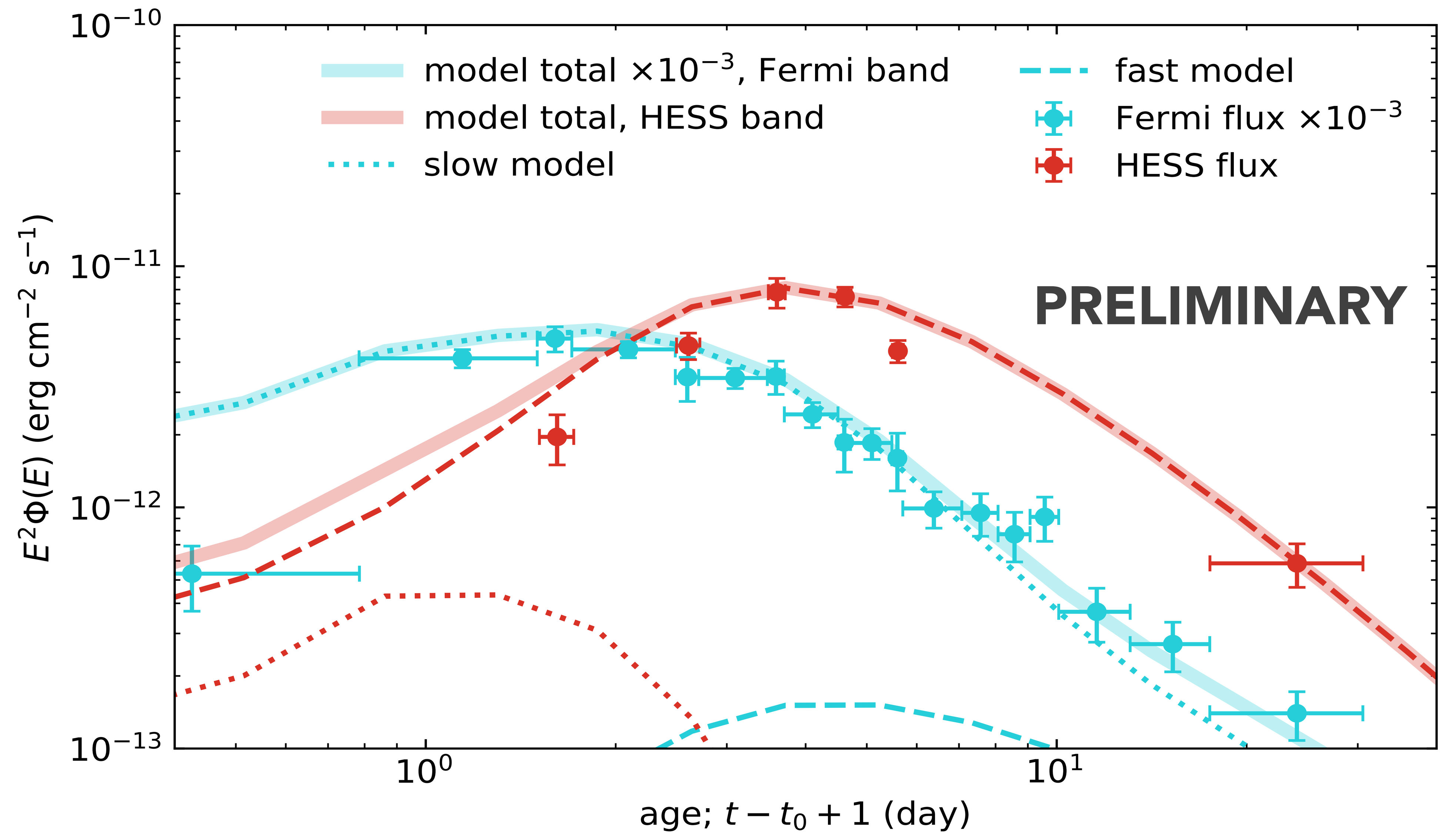
Solve transport equation for magnetic turbulence.

CRAFT calculates instantaneous proton distributions (from which we also compute electron distributions), which are weighted to account for losses and added to produce a cumulative distribution. This can be combined with radiation processes code naima [7] to predict photon spectra.

RESULTS

EXAMPLE III: NOVAE

In 2021, H.E.S.S. and MAGIC detected the first TeV gamma-ray emission from a nova, RS Ophiuchi [9-10]. We find that this emission, when combined with Fermi LAT data, cannot be explained by a single, external shock. Instead, we reproduce the observed emission using a two-shock model.



Modeled GeV and TeV light curves from our best-fit two-shock model. H.E.S.S. and Fermi LAT data are overlaid.

Additional details in Diesing & Caprioli 2021 (ApJ) & Fermi-LAT collaboration, Diesing & Caprioli 2021 (ApJ).

[1] G. F. Krymskii, Akad. Nauk SSSR Dokl. (1977)
[2] A. R. Bell, MNRAS (1978)
[3] R. D. Blandford and J. P. Ostriker, ApJL (1978)
[4] E. Amato and P. Blasi, MNRAS (2006)
[5] D. Caprioli,et al., Astropart. Phys. (2010)
[6] D. Caprioli, J. Cosmol. Astropart. Phys. (2012)
[7] V. Zabalza, PoS (2015)
[8] Acero et al., ApJS (2016)
[9] H.E.S.S. collaboration, Science (2022)
[10] MAGIC collaboration, Nat. Astron. (2022)

THE UNIVERSITY OF CHICAGO