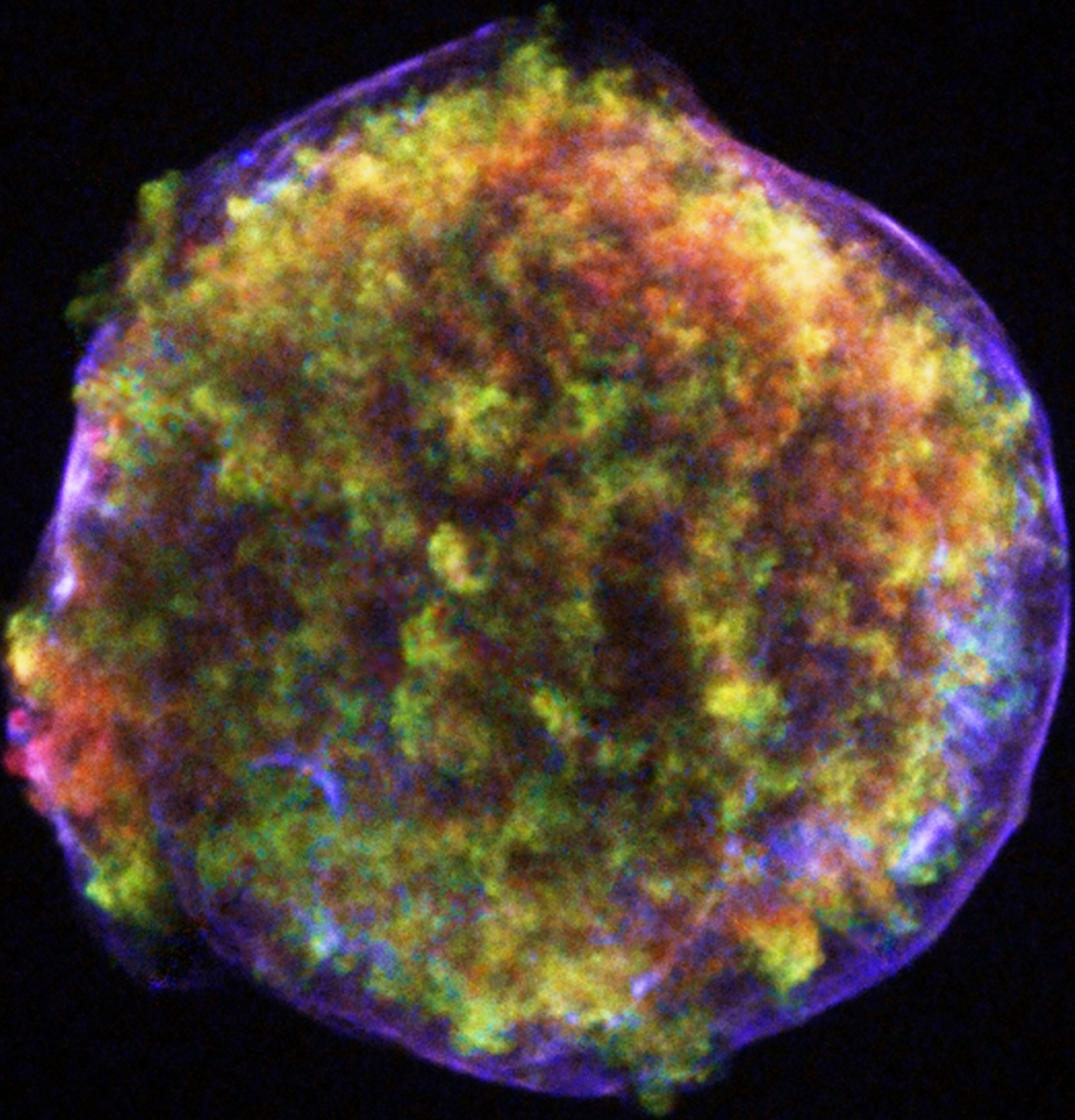


# THE SPECTRUM OF COSMIC RAY ELECTRONS

REBECCA DIESING | ICRC 2019

# INTRODUCTION

Protons and electrons are accelerated at the forward shocks of supernova remnants (SNRs) via diffusive shock acceleration (DSA).*

DSA predicts power law distributions of CRs:

$$\Phi_{\mathrm{inj,\ p}} \propto E^{-q_{\mathrm{p}}}$$

$$\Phi_{\mathrm{inj,\ e}} \propto E^{-q_{\mathrm{e}}}$$

Common assumption: $q_p = q_e$

*See Bell 1978; Blandford & Ostriker 1978.

# STEEPENING THE ELECTRON SPECTRUM

**CR electrons experience synchrotron losses in the amplified magnetic fields of SNRs.**

$$\tau_{\rm synch} \simeq 7 \times 10^3 \ {\rm yr} \ \left(\frac{B}{300 \ \mu{\rm G}}\right)^{-2} \left(\frac{E}{10 \ {\rm GeV}}\right)^{-1}$$

$$\tau_{\rm SNR} \lesssim 10^5 \ {\rm yr}$$

# How much steeper is the CR electron spectrum?

# PARTICLE ACCELERATION

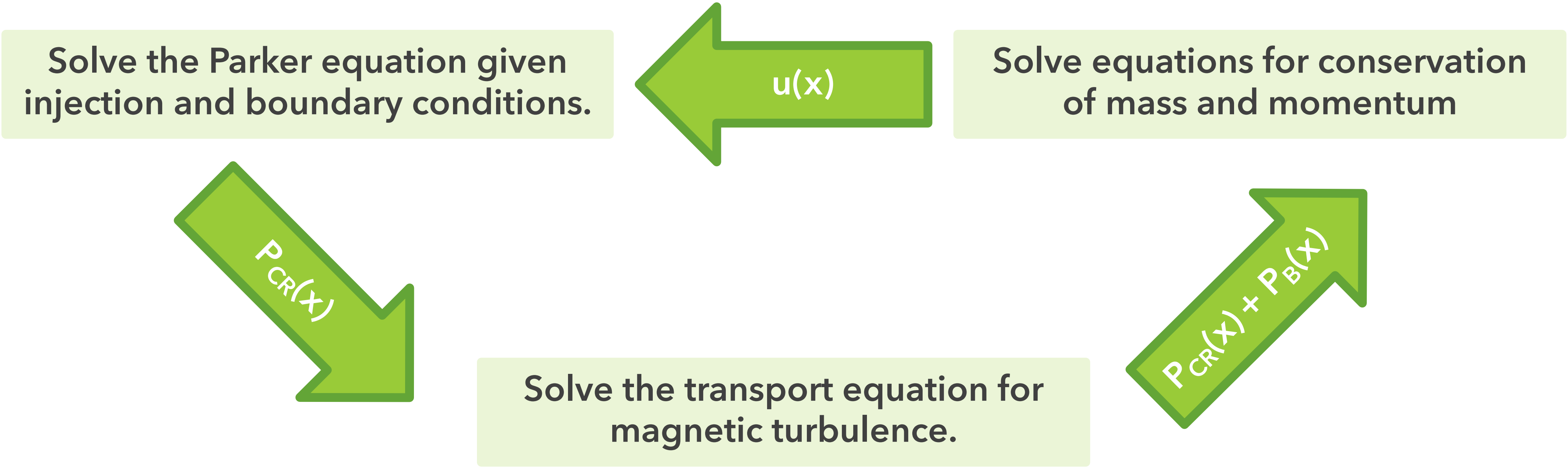
Calculate the **CR proton spectrum** by solving the Parker transport equation.

Assume a fraction η of particles crossing the shock are injected into DSA.

$$\underbrace{\boxed{\tilde{u}(x)\frac{\partial f(x,p)}{\partial x}}}_{\text{Advection}} = \underbrace{\boxed{\frac{\partial}{\partial x}\left[D(x,p)\frac{\partial f(x,p)}{\partial x}\right]}}_{\text{Diffusion}} + \underbrace{\boxed{\frac{p}{3}\frac{d\tilde{u}(x)}{dx}\frac{\partial f(x,p)}{\partial p}}}_{\text{Adiabatic compression}} + \underbrace{\boxed{Q(x,p)}}_{\text{Injection}}$$

# PARTICLE ACCELERATION

**Use CRAFT (method paper in prep.), a semi-analytic model of non-linear DSA which self-consistently accounts for particle acceleration and magnetic field amplification.**



Solve the Parker equation given injection and boundary conditions.

Solve equations for conservation of mass and momentum

Solve the transport equation for magnetic turbulence.

See also Amato & Blasi 2006; Caprioli et al., 2010; Caprioli 2012.

# PARTICLE ACCELERATION

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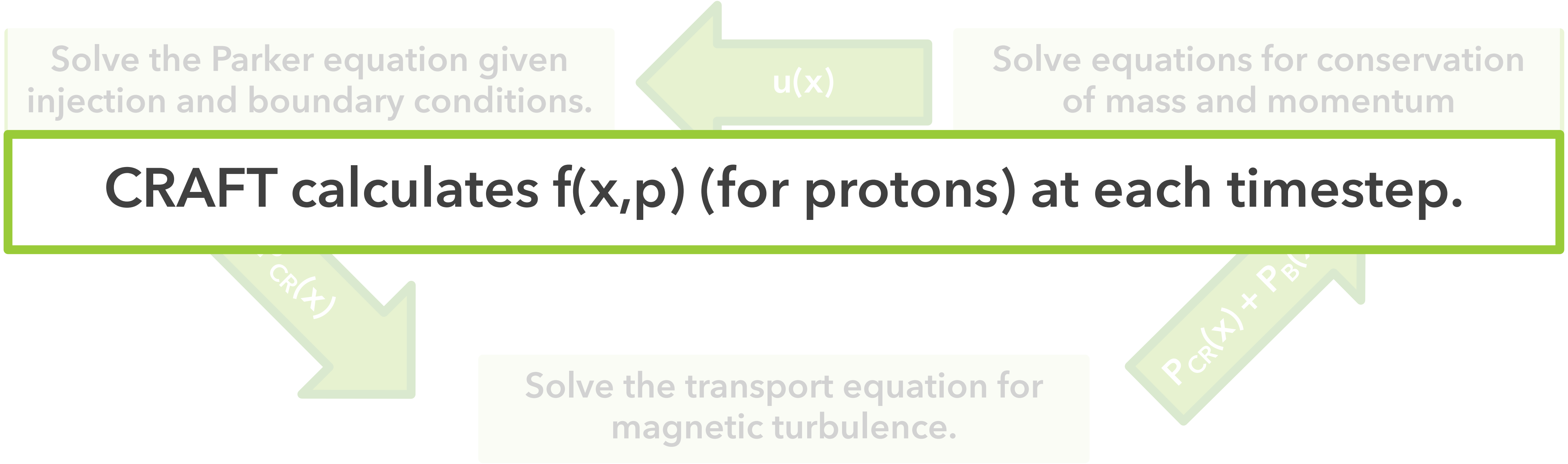


Solve the Parker equation given injection and boundary conditions.

Solve equations for conservation of mass and momentum

Solve the transport equation for magnetic turbulence.

**CRAFT calculates f(x,p) (for protons) at each timestep.**

See also Amato & Blasi 2006; Caprioli et al., 2010; Caprioli 2012.

# ELECTRON ACCELERATION

Use an analytical approximation* to go from a proton spectrum to an electron spectrum, with a cutoff determined by synchrotron losses.

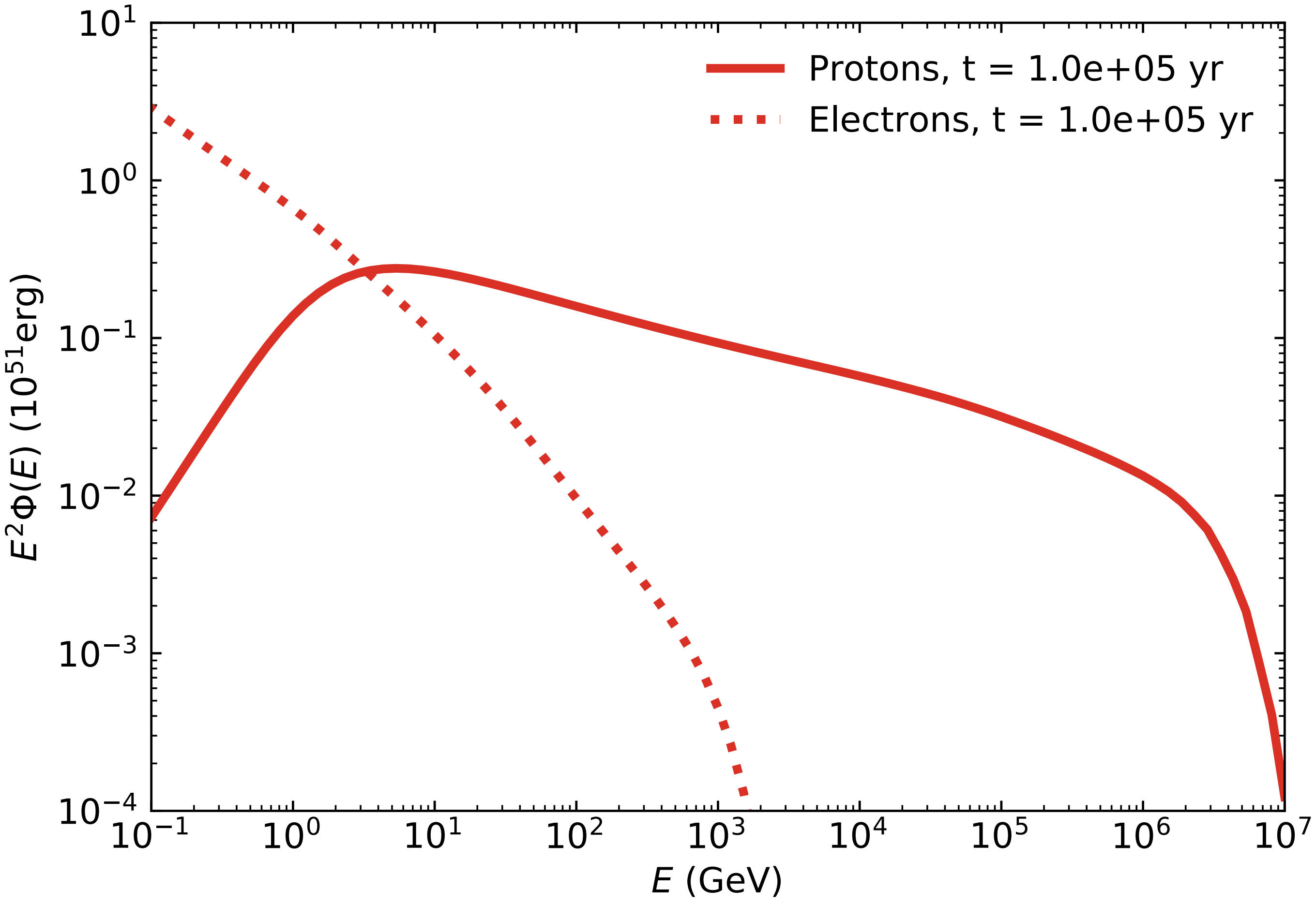
Weight the electron spectrum at each timestep to account for energy losses.

$$\frac{dE}{dt} = -\underbrace{\boxed{\frac{4}{3}\sigma_{\mathrm{T}} c \left(\frac{E}{m_{\mathrm{e}} c^2}\right)^2 \frac{B_2^2}{8\pi}}}_{\text{Synchrotron losses}} - \underbrace{\boxed{\frac{E}{R_{\mathrm{sh}}} \frac{dR_{\mathrm{sh}}}{dt}}}_{\text{Adiabatic losses}}$$

*Zirakashvili & Aharonian 2007

# SAMPLE SPECTRUM

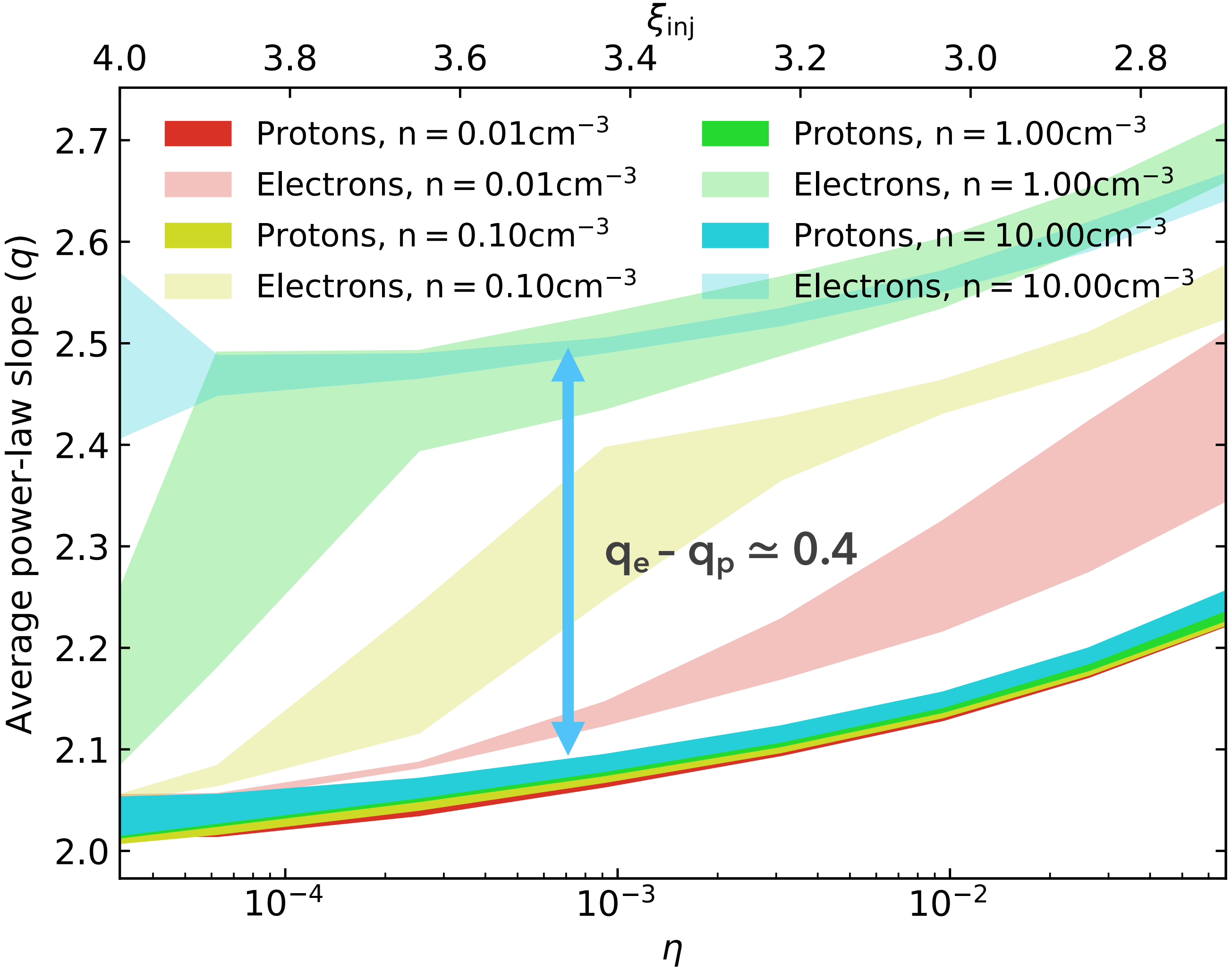
**Shown here is a typical SNR***
**($n_{ISM}$ = 1 $cm^{-3}$, $M_{ej}$ = 1 $M_{\odot}$)**



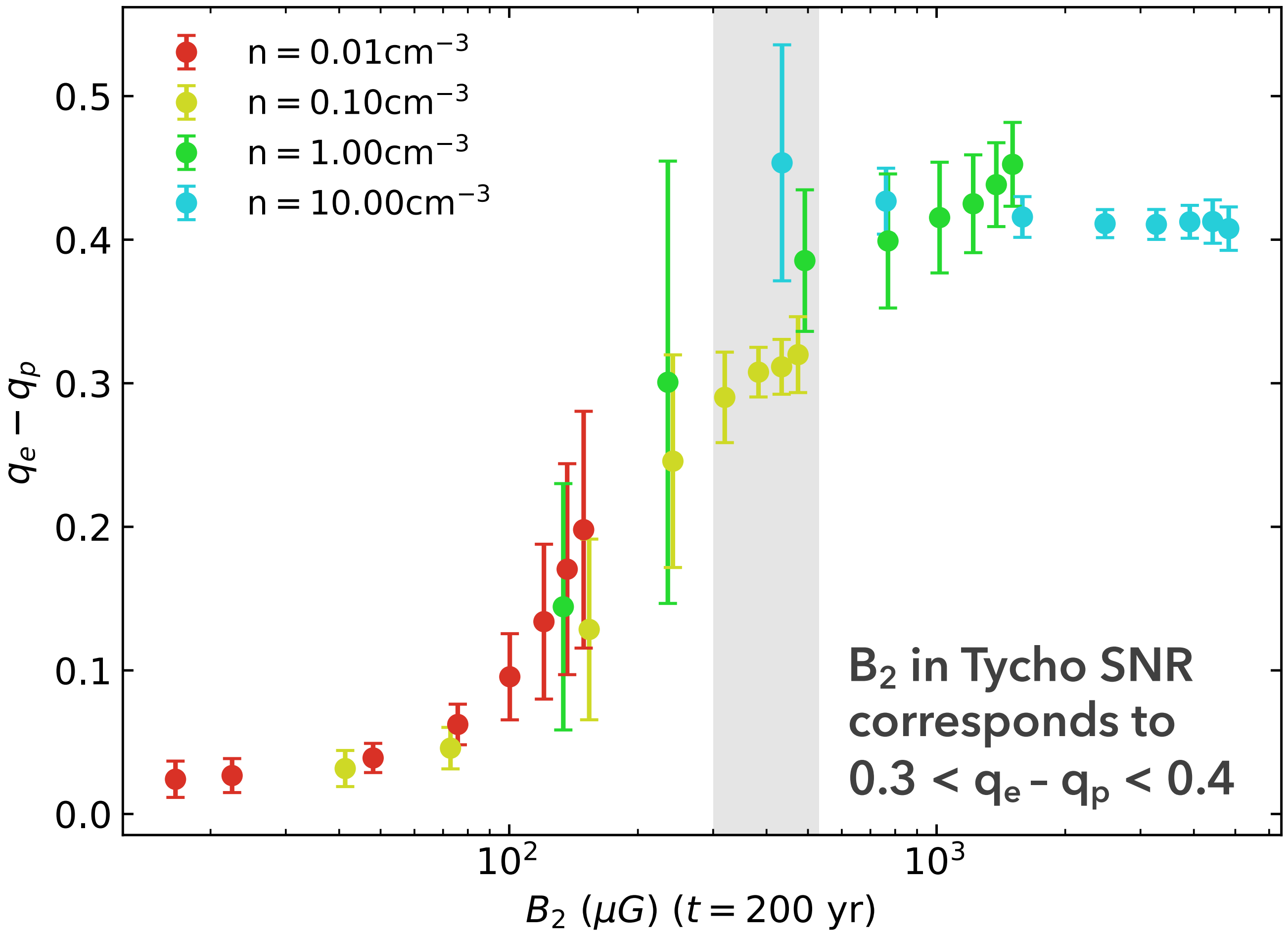
*For more on SNR evolution, see Diesing & Caprioli 2018; our poster, **PS3-160**.

# RESULTS

Electron spectra are steeper!



# RESULTS



**$B_2$ in Tycho SNR corresponds to $0.3 < q_e - q_p < 0.4$**

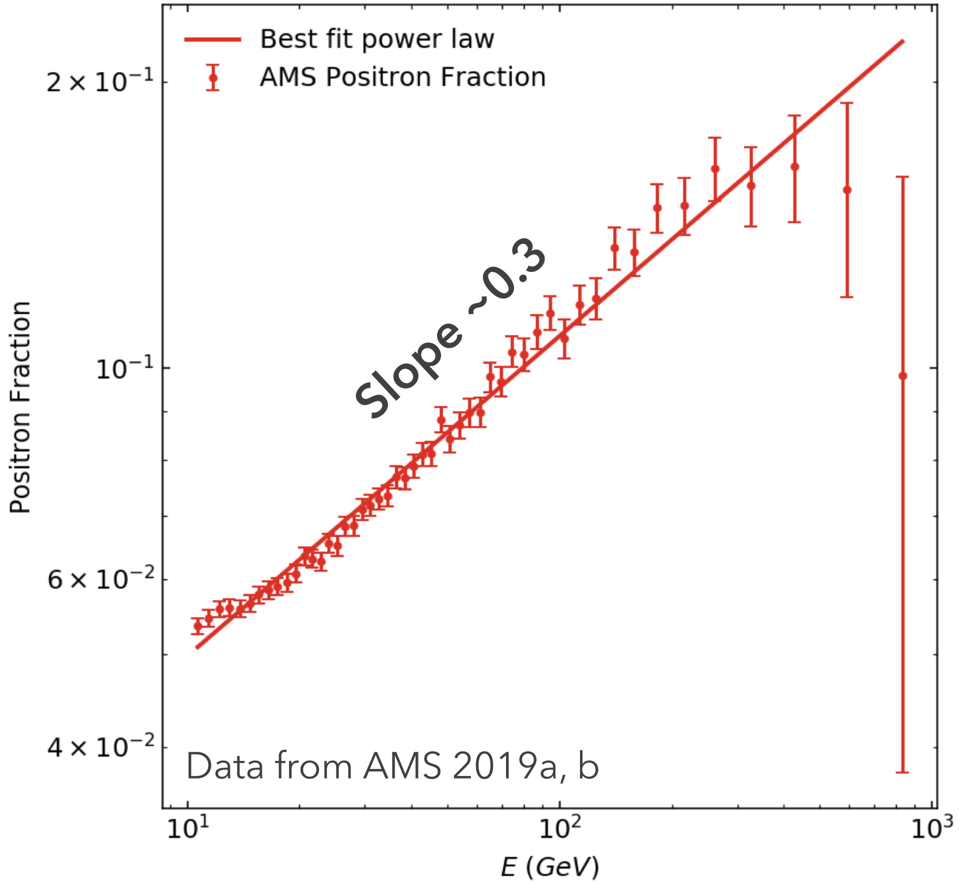
# IMPLICATIONS FOR THE POSITRON "EXCESS"

The positron fraction depends on $q_p - q_e$, secondary production, and propagation.

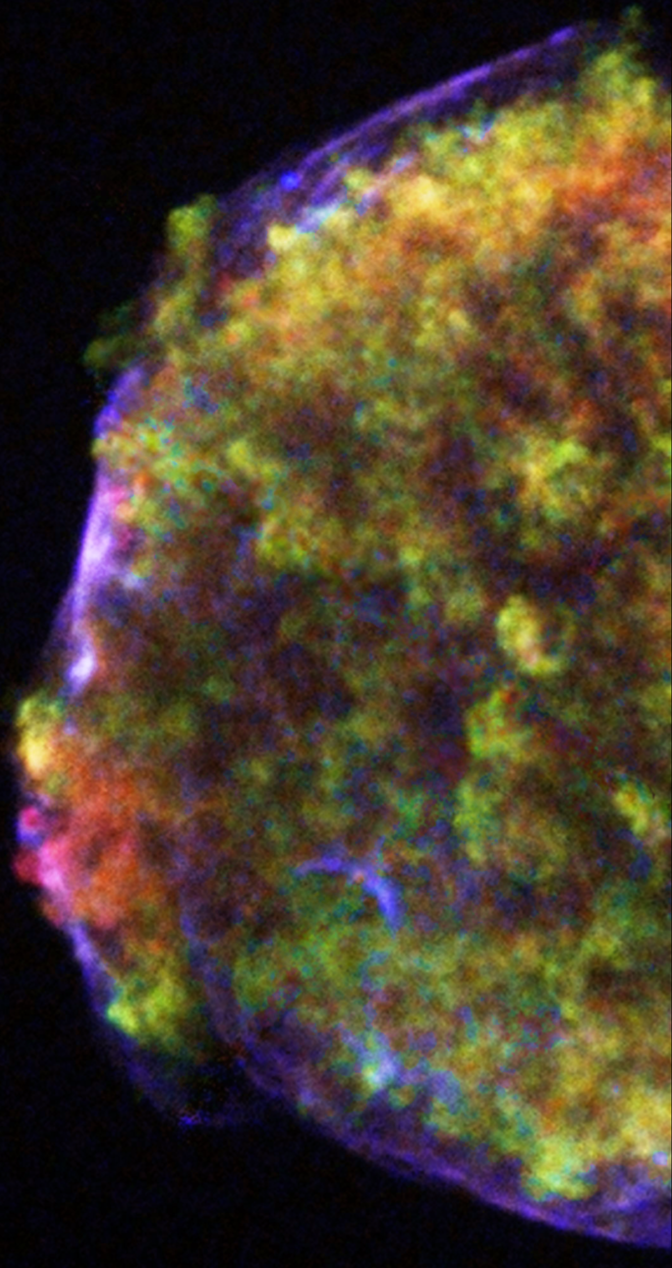
$$\chi \simeq \frac{\Phi_{\mathrm{obs,\ e^+}}}{\Phi_{\mathrm{obs,\ e^-}}} \propto E^{-(q_{\mathrm{p}} - q_{\mathrm{e}} + \epsilon)}$$

$$q_{\mathrm{e}} - q_{\mathrm{p}} = \epsilon + 0.3$$

If $\epsilon < 0.1$, $q_e - q_p < 0.4$ (from our calculation) could fully account for the "excess."



# CONCLUSIONS



1. **Electrons experience synchrotron losses in the amplified magnetic fields of SNRs, resulting in a steepening of their spectrum.**
2. **The steepening of the electron spectrum suggests that the positron "excess" may in part be an electron deficit.**
3. **Regardless of secondary production, this steepening may have significant implications for CR propagation models.**
   See, e.g., Orlando 2018, which assumes $q_e - q_p \simeq 0.35$.

FOR MORE INFORMATION, PLEASE SEE **DIESING** & CAPRIOLI 2019 (ACCEPTED TO PRL), **ARXIV:1905.07414**