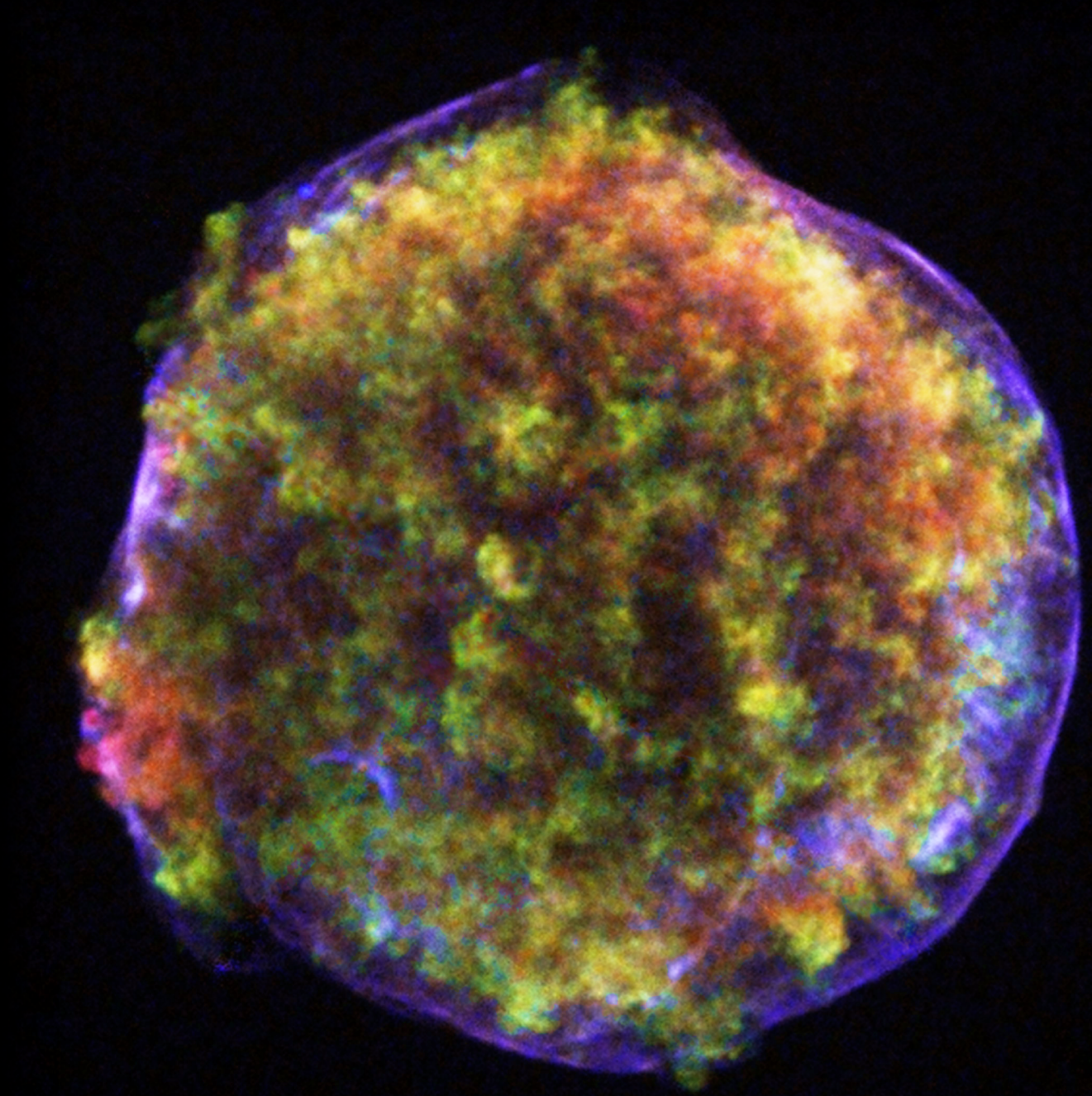

THE SPECTRUM OF COSMIC RAY ELECTRONS

REBECCA DIESING | U CHICAGO

IMAGE: TYCHO SUPERNOVA REMNANT. CREDIT: CHANDRA X-RAY OBSERVATORY.

THE STANDARD PARADIGM

Diffusive shock acceleration predicts a power law distribution of CRs.

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

Propagation will result in spectral steepening.

$$\Phi_{\mathrm{obs,\ p}} \propto E^{-(q_{\mathrm{p}}+\delta)}$$

SEE, E.G., AMATO & BLASI 2018; LIPARI 2019

THE STANDARD PARADIGM

Leptons also experience synchrotron and inverse Compton losses.

- This induces further steepening at high energies, where $\tau_{loss} < \tau_{esc}$.

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

$$\Phi_{\mathrm{obs},\ \mathrm{e}^-} \propto E^{-(q_\mathrm{e}+\beta)}, \quad \beta \geq \delta$$

SEE, E.G., AMATO & BLASI 2018; LIPARI 2019

THE POSITRON "EXCESS"

In the standard paradigm, positrons are secondaries, produced in p-p interactions.

- The positron spectrum should follow that of protons, modulo losses.

$$\Phi_{\mathrm{obs,\ p}} \propto E^{-(q_{\mathrm{p}}+\delta)}$$

$$\Phi_{\mathrm{obs,\ e^+}} \propto E^{-(q_{\mathrm{p}}+\delta+\beta)}$$

THE POSITRON "EXCESS"

The positron flux is often normalized by the total lepton flux.

$$\chi \equiv \frac{\Phi_{\mathrm{obs},\ e^+}}{\Phi_{\mathrm{obs},\ e^+} + \Phi_{\mathrm{obs},\ e^-}} \simeq \frac{\Phi_{\mathrm{obs},\ e^+}}{\Phi_{\mathrm{obs},\ e^-}}$$

THE POSITRON "EXCESS"

Recall our prediction for the electron flux.

$$\Phi_{\mathrm{obs},\ \mathrm{e}^-} \propto E^{-(q_\mathrm{e}+\beta)}$$

Combining this with our prediction for the positrons gives,

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

THE POSITRON "EXCESS"

Recall our prediction for the electron flux.

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Combining this with our prediction for the positrons gives,

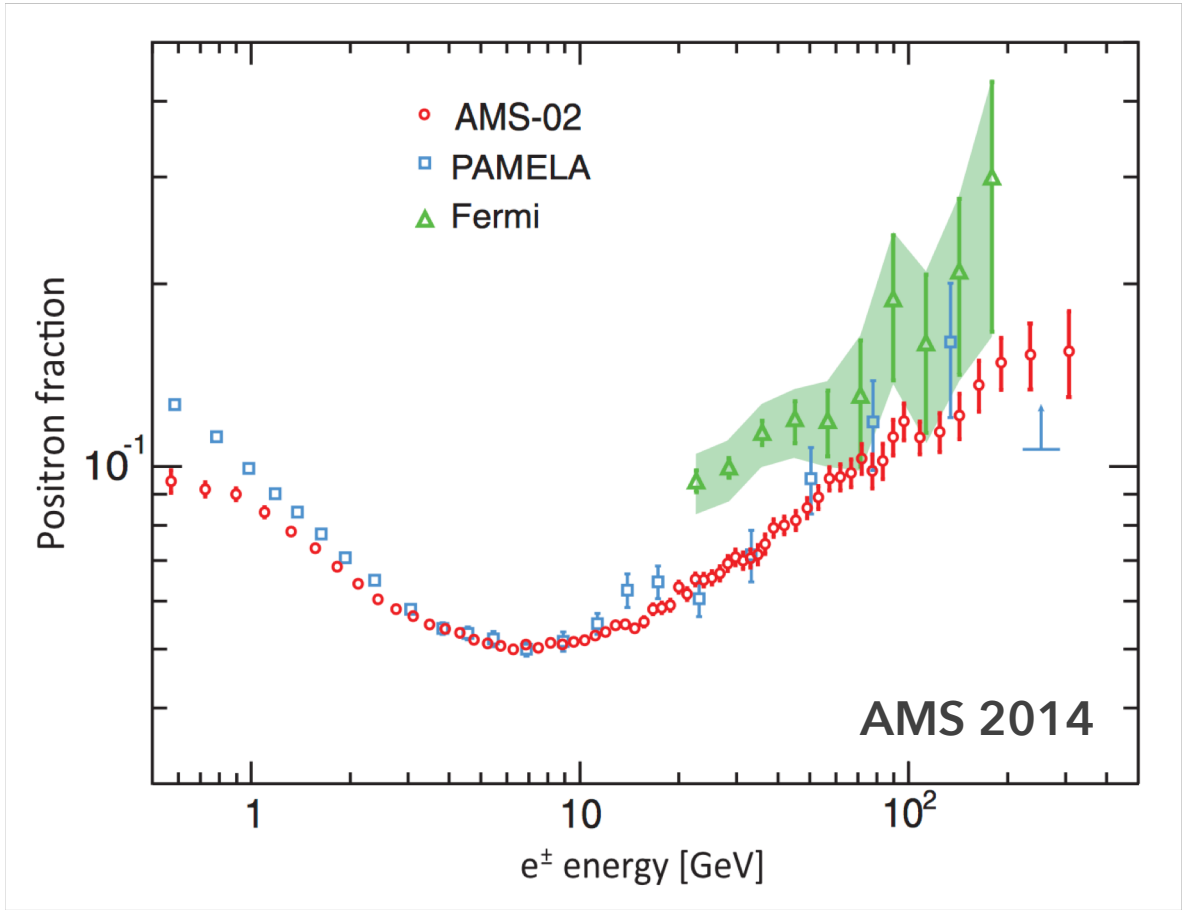
$$\chi \simeq \frac{\Phi_{\mathrm{obs},\ \mathrm{e}^+}}{\Phi_{\mathrm{obs},\ \mathrm{e}^-}} \propto \frac{E^{-(q_\mathrm{p}+\delta+\beta)}}{E^{-(q_\mathrm{e}+\beta)}} \boxed{\propto E^{-\delta}}$$

THE POSITRON "EXCESS"

The observed positron fraction *rises* with energy.

Two solutions:

1. A primary positron source (most notably, **dark matter**)



SEE, E.G., SERPICO 2012 FOR A REVIEW OF POTENTIAL POSITRON SOURCES

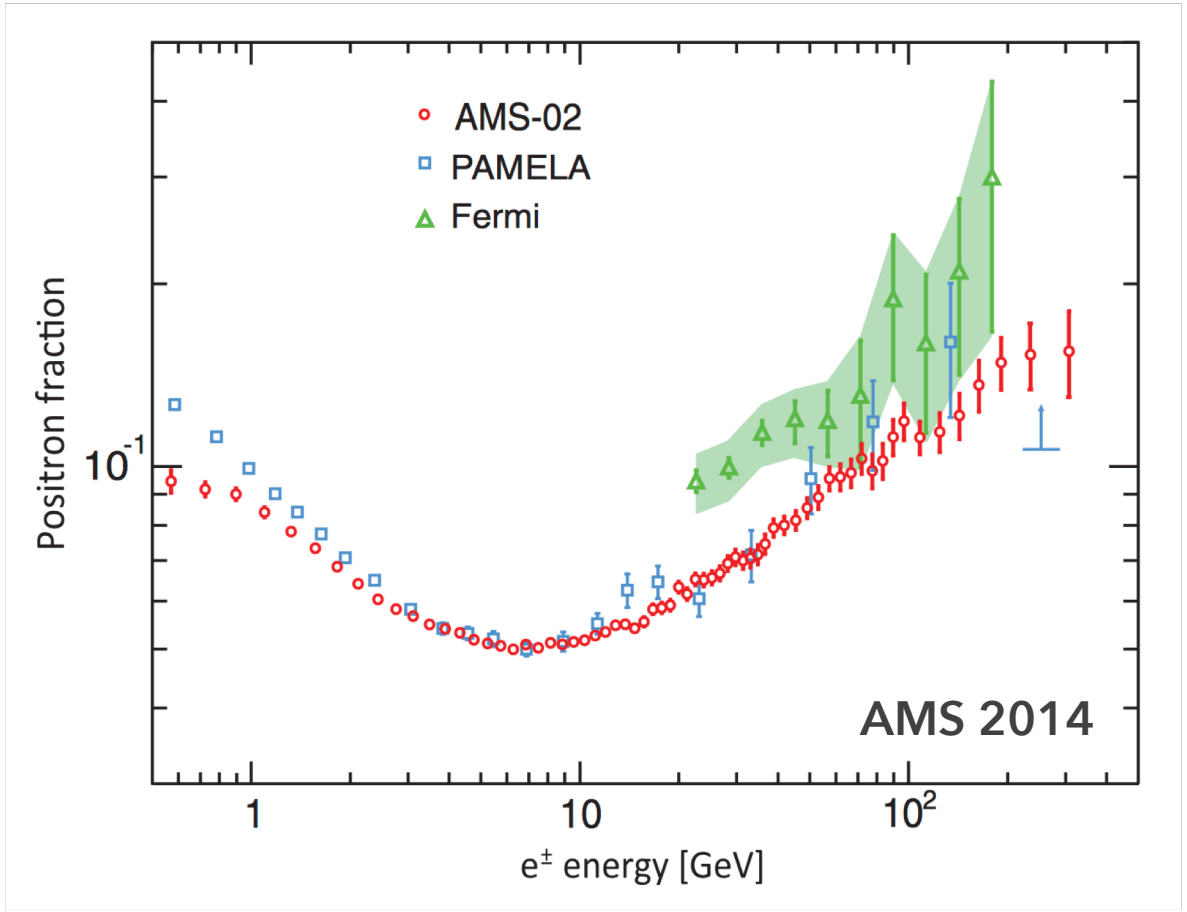
THE POSITRON "EXCESS"

The observed positron fraction *rises* with energy.

Two solutions:

1. A primary positron source (most notably, **dark matter**)

2. A steeper electron injection spectrum ($q_e > q_p$).



STEEPENING THE ELECTRON SPECTRUM

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

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

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

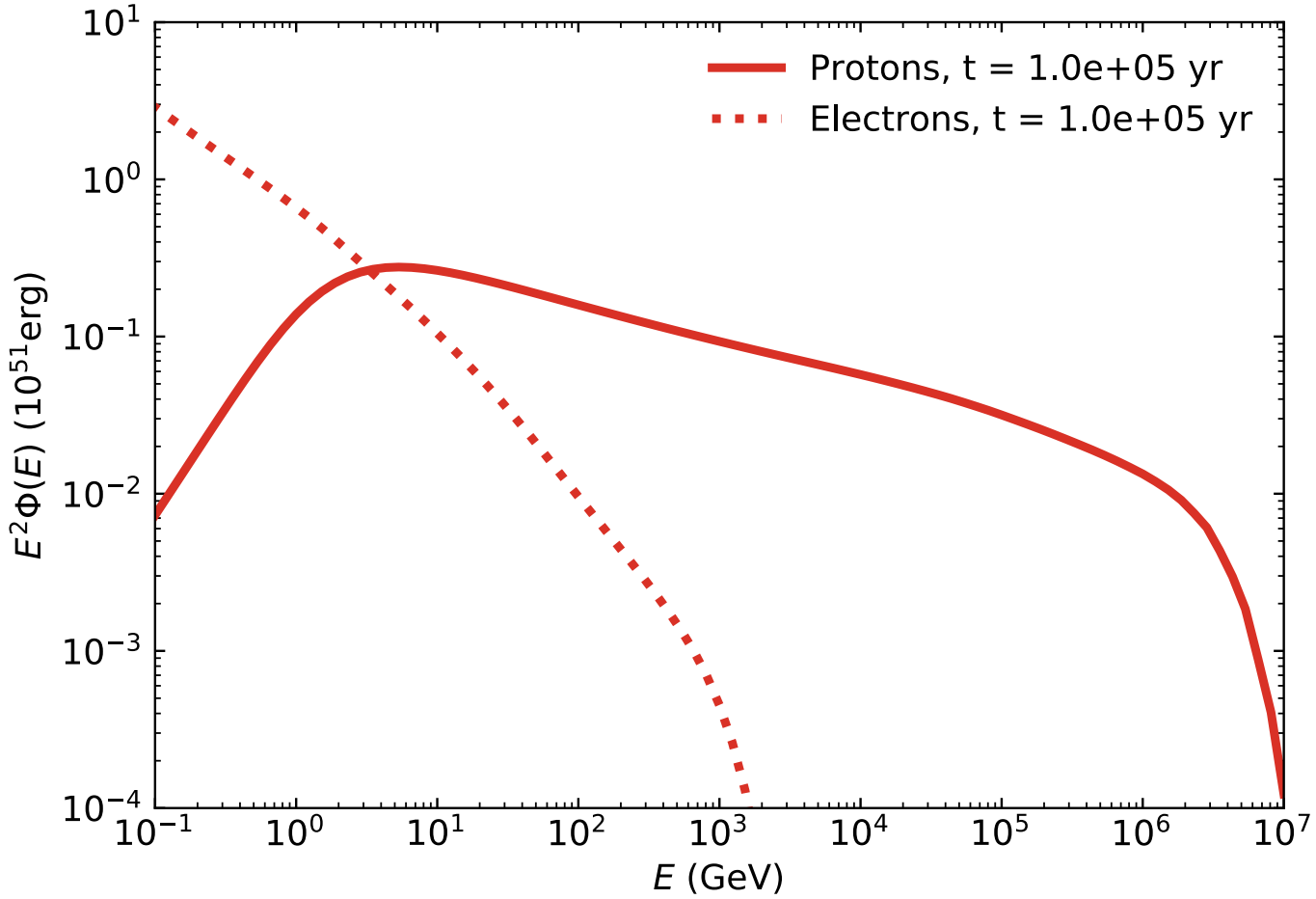
How much steeper is the CR electron spectrum?

MODELING PARTICLE ACCELERATION

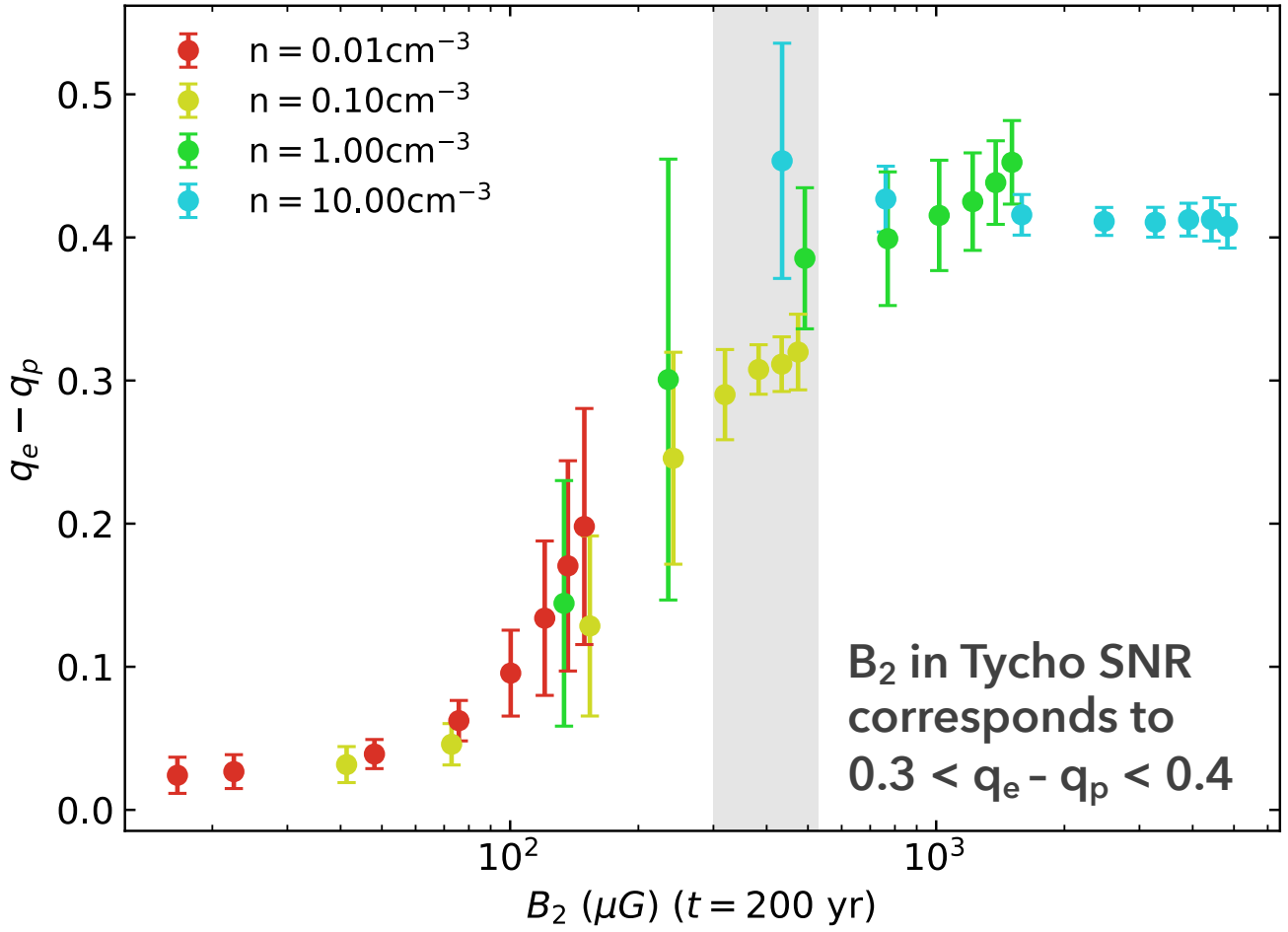
Use CRAFT (method paper in prep.), a semi-analytic model of DSA which self-consistently accounts for particle acceleration and magnetic field amplification.

CRAFT calculates the proton and electron spectrum at each timestep. We weight these spectra to account for energy losses (adiabatic and synchrotron) before summing them.

SAMPLE SPECTRUM



RESULTS


n = 0.01cm^{-3}
n = 0.10cm^{-3}
n = 1.00cm^{-3}
n = 10.00cm^{-3}
$q_e - q_p$
0.0
0.1
0.2
0.3
0.4
0.5
10^2
10^3
B_2 (μG) ($t = 200$ yr)
B_2 in Tycho SNR corresponds to $0.3 < q_e - q_p < 0.4$

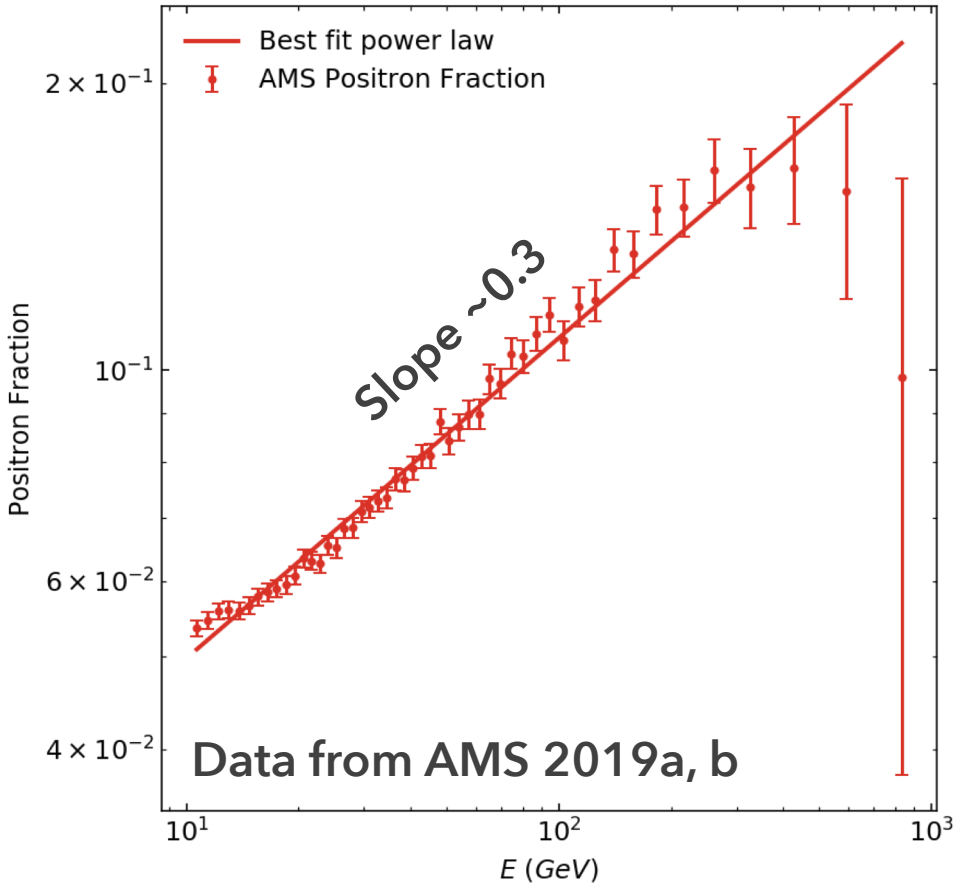
IMPLICATIONS FOR THE POSITRON "EXCESS"

Recall our prediction for the positron fraction.

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

$$q_e - q_p = \delta + 0.3$$

If $\delta < 0.1$, $q_e - q_p < 0.4$ could fully account for the "excess."

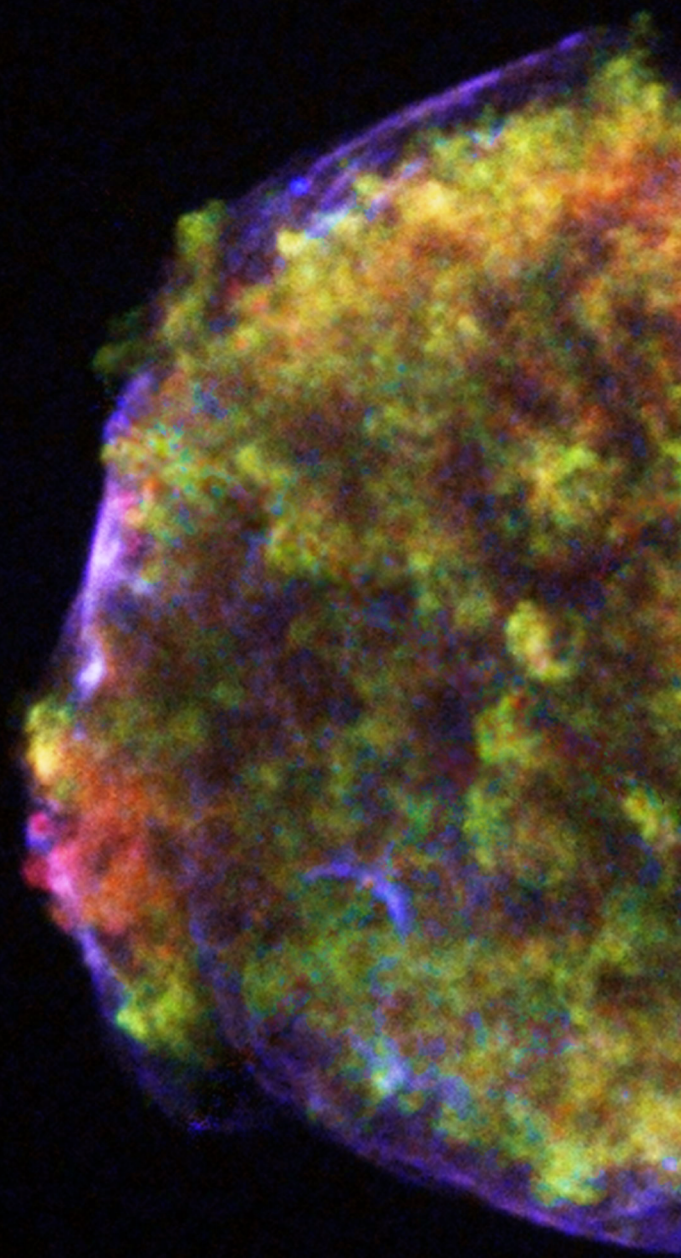


CONCLUSIONS

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 fact be an electron deficit.

3. Regardless of secondary production, this steepening may have significant implications for CR propagation models.



FOR MORE INFORMATION, PLEASE SEE **DIESING** & CAPRIOLI 2019, **ARXIV:1905.07414**