Gamma-ray emission in SNR RX J1713

Don Ellison, NCSU

➔ Efficient, Nonlinear Diffusive Shock Acceleration (DSA)

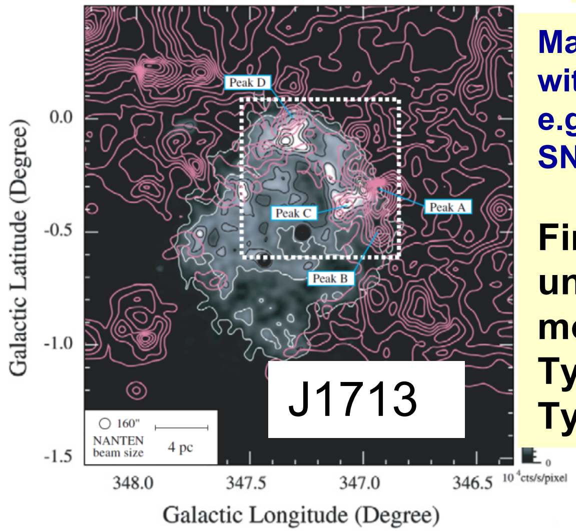
➔ Connection between GeV-TeV emission, broad-band spectrum, & Thermal X-rays

➔ Role of escaping cosmic rays (CRs)

➔ Pion-decay vs. Inverse Compton origin of TeV emission in J1713

Work with Pat Slane, Dan Patnaude, Andrei Bykov & John Raymond

Apologies for the many papers on J1713 I won't mention

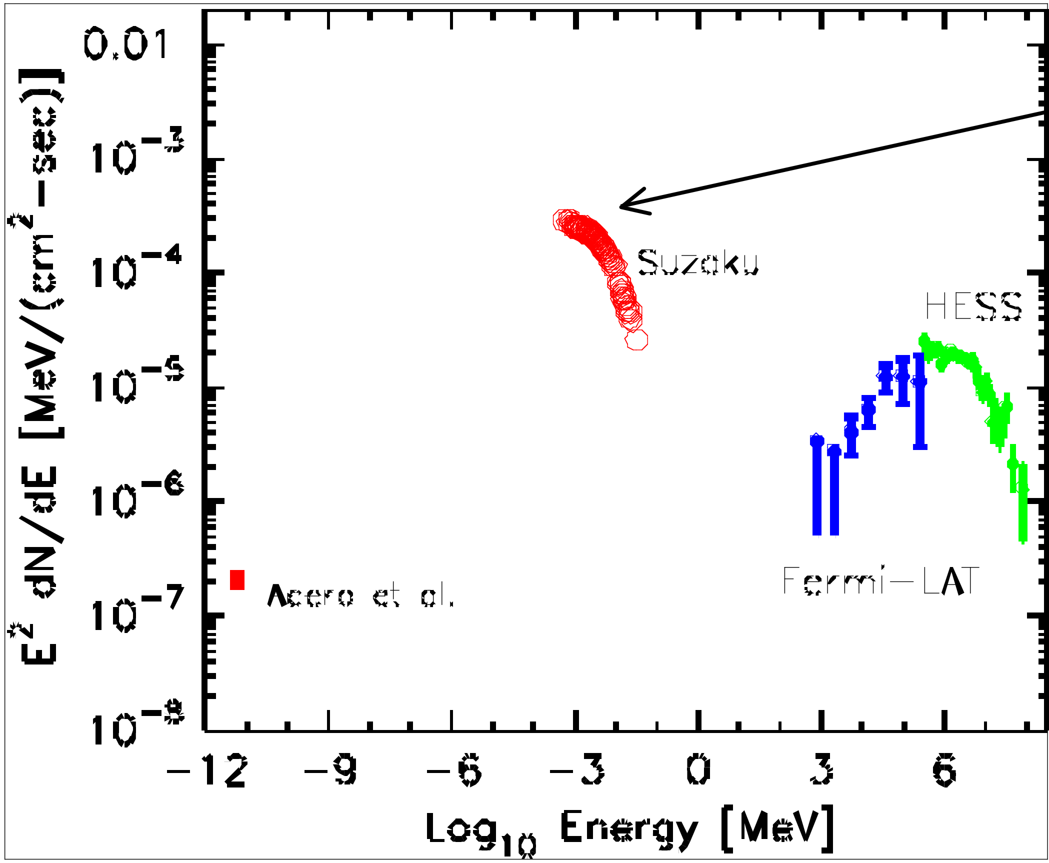


Sano et al 2010

May be interacting with dense material, e.g., core-collapse SN

First, consider uniform ISM model
Typical of Type Ia supernova

Thermal & Non-thermal Emission in SNR RX J1713



1) Suzaku X-ray observations ➔ smooth continuum well fit by synchrotron from TeV electrons

2) No discernable line emission from shocked heated heavy elements

➔ Strong constraint on Non-thermal emission at GeV-TeV energies

Must calculate thermal & non-thermal emission consistently with Diffusive Shock Acceleration (DSA) and SNR dynamics

Composite SNR Model (CR-hydro-NEI code)
SNR hydrodynamics, Nonlinear Shock Acceleration, Continuum and Line Radiation ➔ reasonably self-consistent

1)VH-1 code for hydro of evolving SNR (e.g., Blondin)

2)Semi-analytic, nonlinear DSA model from Blasi, Gabici et al.

3)Ad hoc model of magnetic field amplification

4)Approximate shape of trapped CR distributions at max. energy turnover

5)Continuum photon emission from radio to TeV

➔ **6)Non-equilibrium ionization (NEI) thermal X-ray line emission**

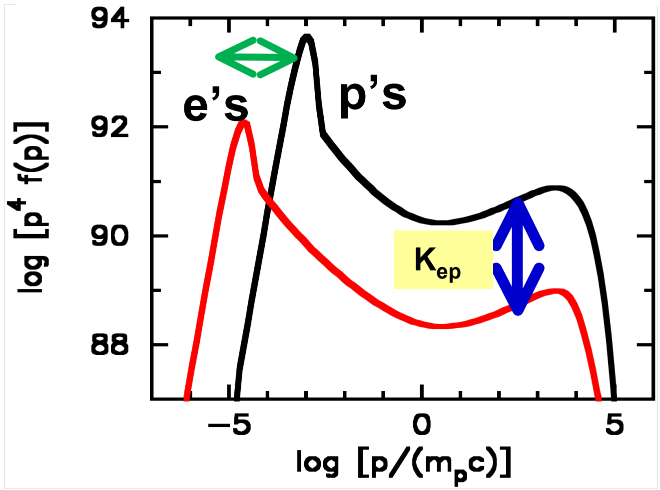
➔ **7)NL shock acceleration coupled to hydro through equation of state**

➔ **8)Simple, Monte Carlo Model of escaping CR propagation**

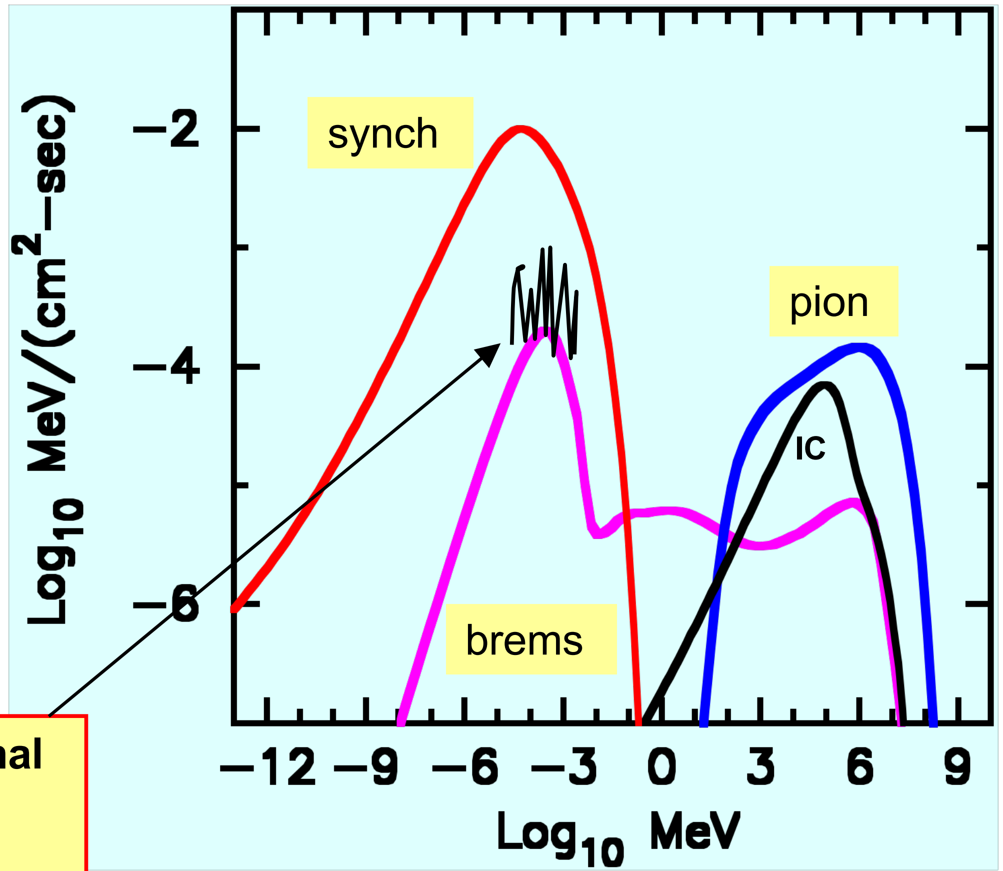
Apply to SNR RX J1713

Ellison et al ApJ (2001, 2007, 2010); Patnaude et al ApJ (2009, 2010);
Ellison & Bykov ApJ (2011)

2 trapped particle distributions



continuum emission



Many parameters needed for modeling !!

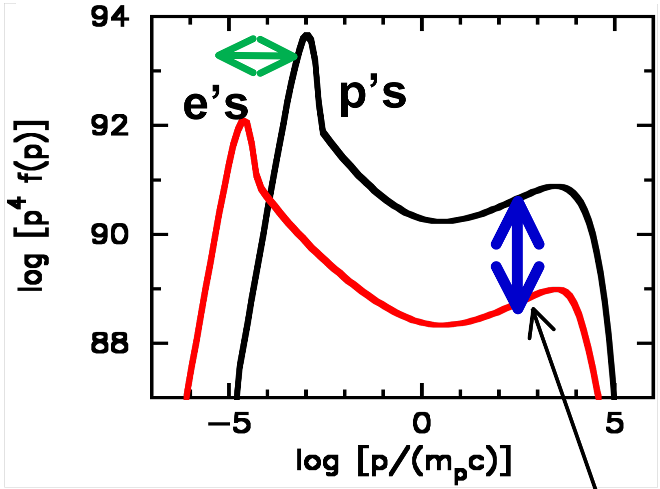
e.g., Electron/proton ratio, K_{ep}

In addition, emission lines in thermal X-rays. Depends on T_e/T_p and electron equilibration model

In nonlinear DSA, Thermal & Non-thermal emission coupled
➔ big help in constraining parameters

Particle spectra calculated with semi-analytic code of Blasi and co-workers

2 trapped particle distributions

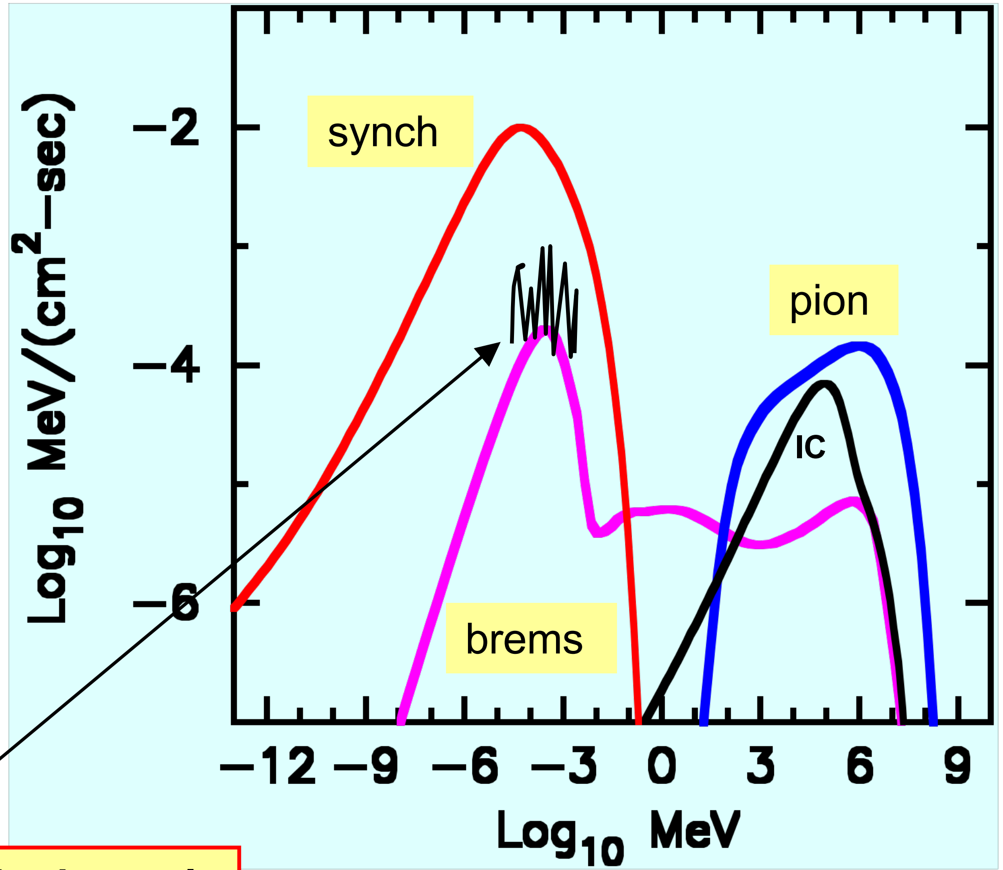


Many parameters needed for modeling !!

Electron/proton ratio, K_{ep}

K_{ep} important for proton-proton/IC ratio at GeV-TeV

continuum emission



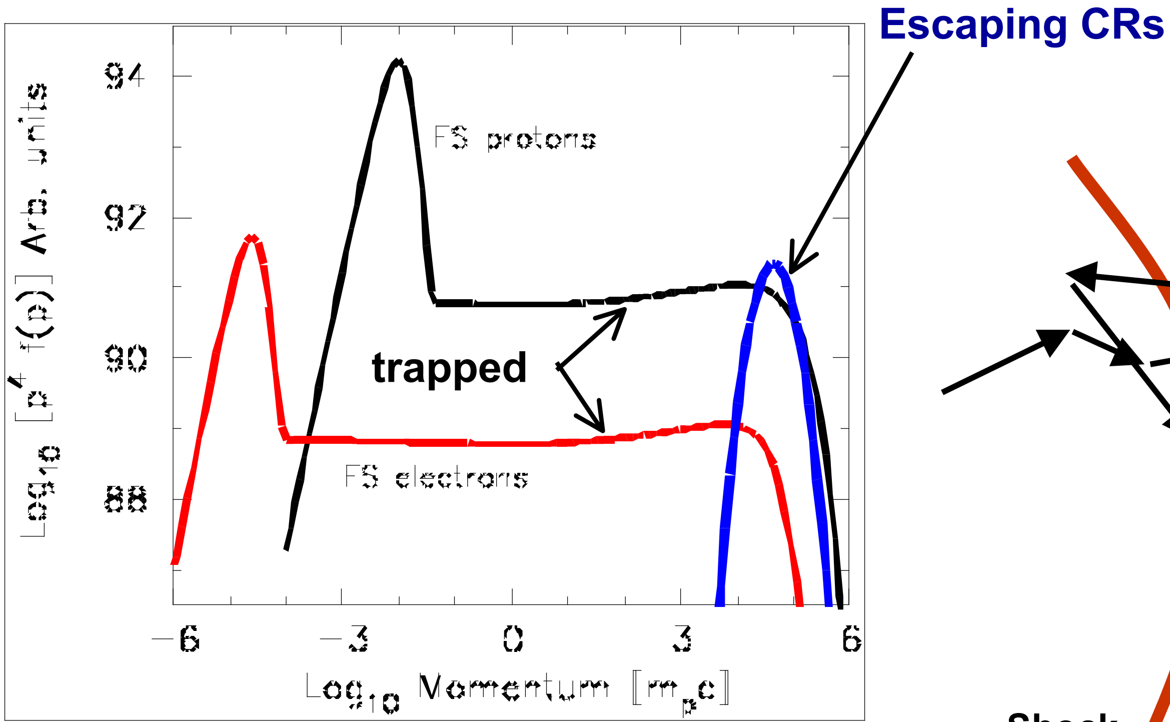
In addition, emission lines in thermal X-rays. Depend on T_e/T_p

K_{ep} and T_e/T_p not yet determined by theory or plasma simulations!

In nonlinear DSA, Thermal & Non-thermal emission coupled

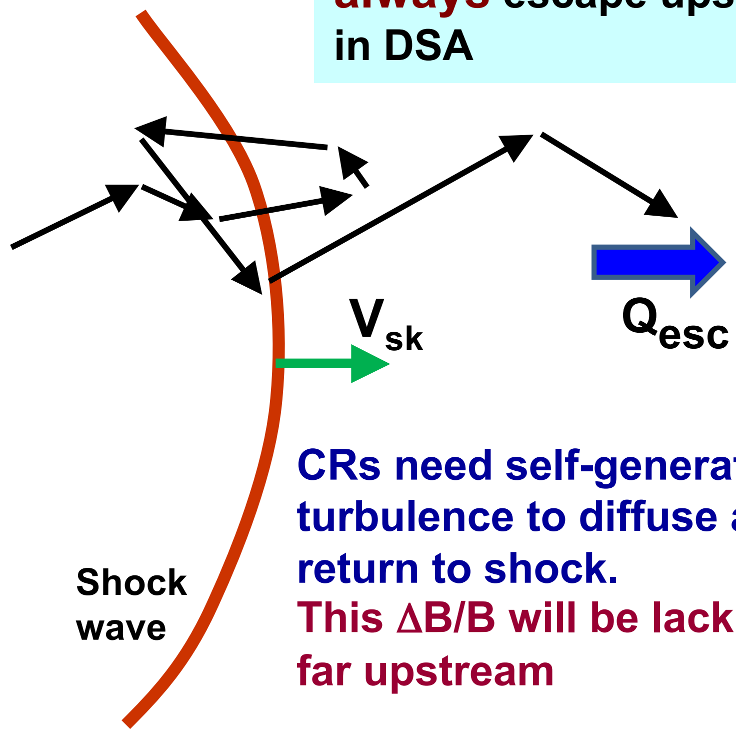
Forward shock of SNR produces 3 particle distributions that will contribute to the photon emission

1) Ions accelerated and trapped within SNR
2) Electrons accelerated and trapped within SNR
3) CRs escaping upstream (mainly ions)



Ellison & Bykov 2011

If the shock is producing relativistic particles, some fraction of the highest energy CRs **will always** escape upstream in DSA



CRs need self-generated turbulence to diffuse and return to shock.
This $\Delta B/B$ will be lacking far upstream

First, uniform ISM

SN exploding in constant ISM (e.g., Type Ia) , or

Core-collapse exploding in pre-SN wind

with no dense shell or nearby mass concentration

Are highest energy photons produced by

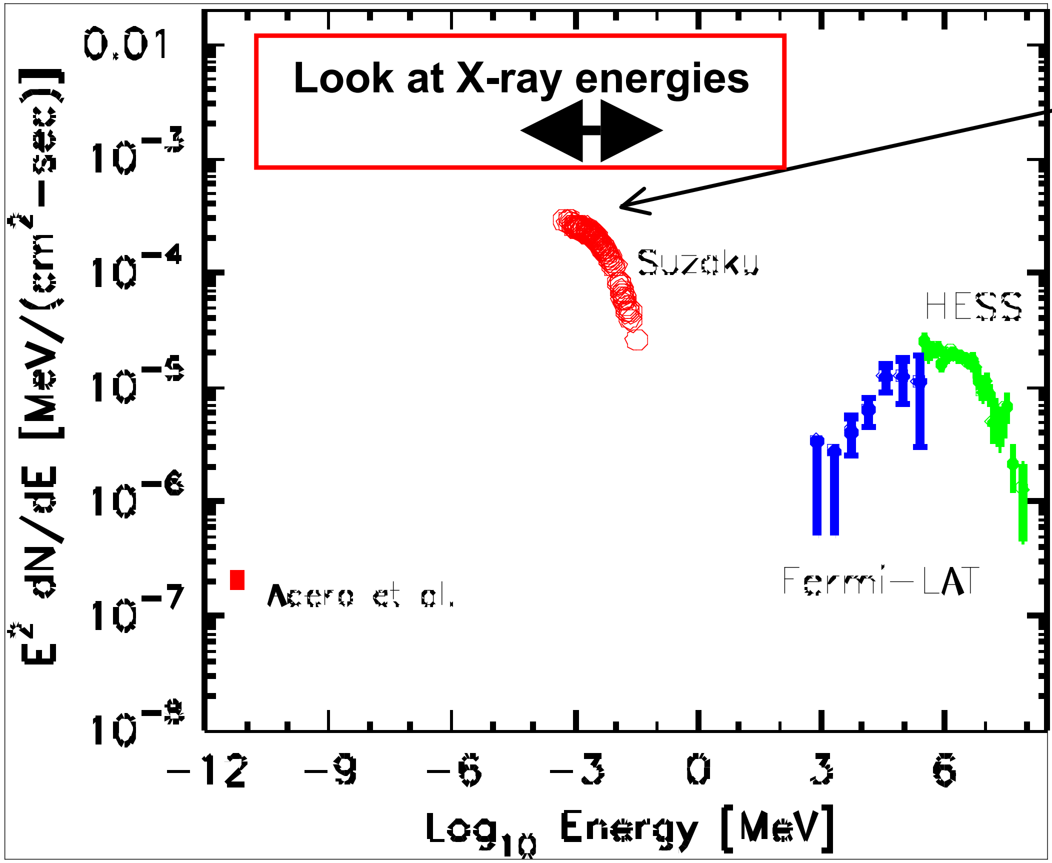
Ions (p-p collisions and pion decay) or

Electrons (IC off background photons) ?

(or some combination) ?

Self-consistently calculate thermal X-rays (Non-equilibrium ionization) with nonthermal continuum

Thermal & Non-thermal Emission in SNR RX J1713



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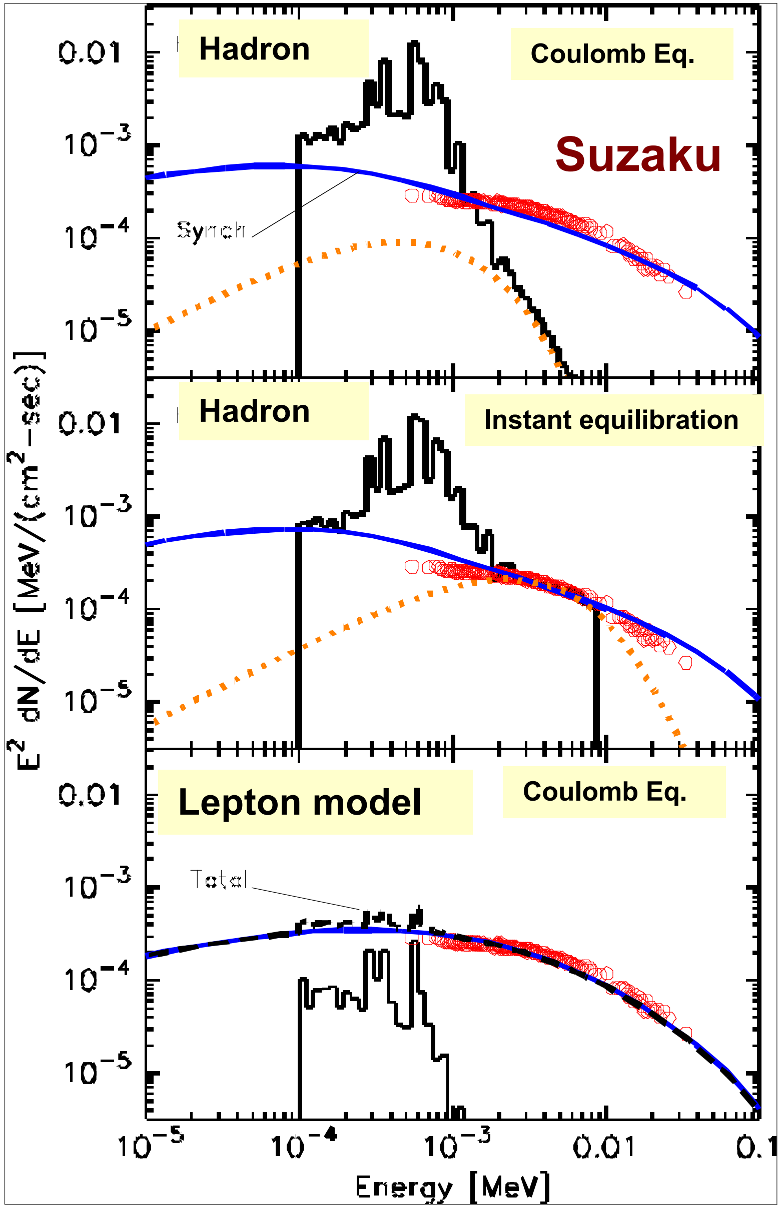


Models including Thermal X-ray lines:

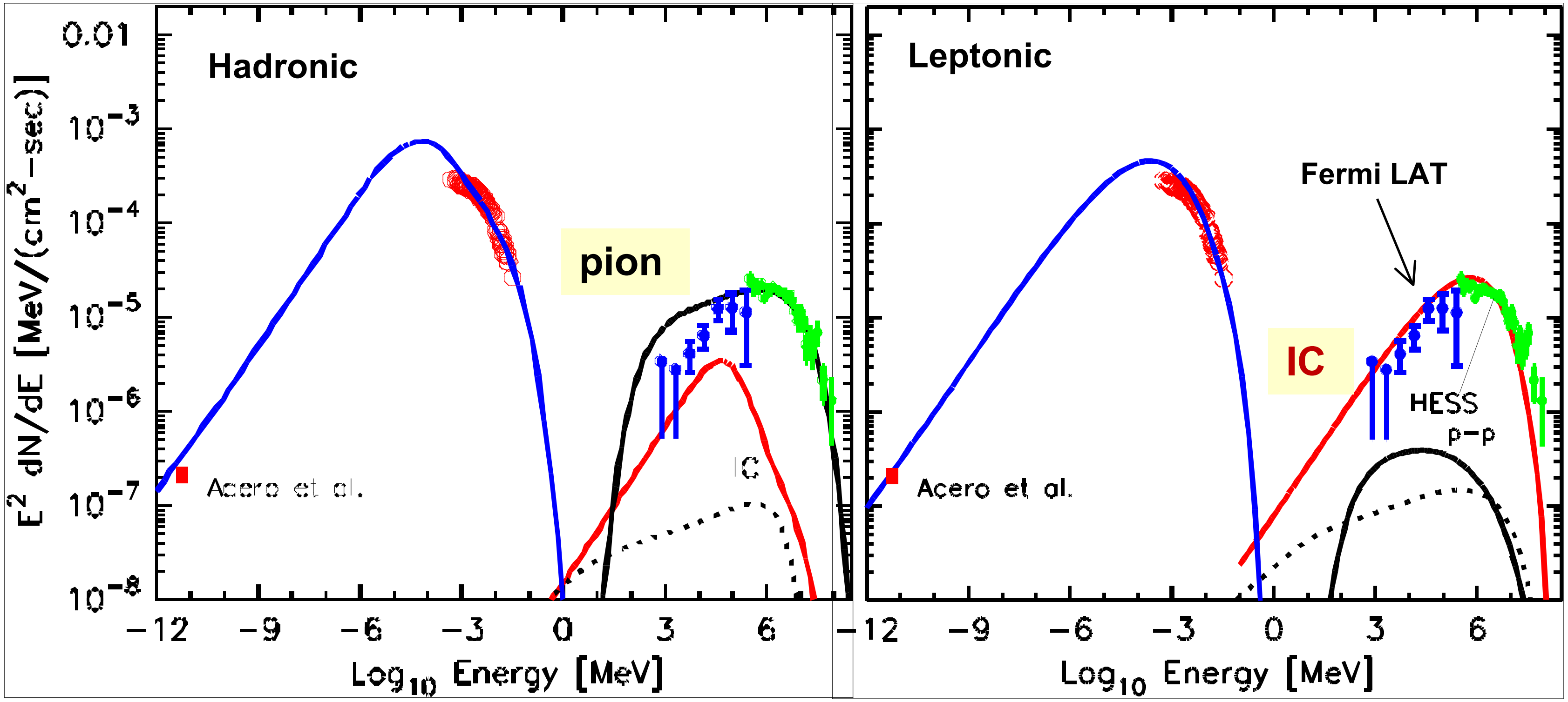
- **Non-equilibrium ionization calculation of heavy element ionization and X-ray line emission**
- **Compare Hadronic & Leptonic fits**
- **Range of electron temperature equilibration models**
- **Find: The high ambient densities needed for pion-decay to dominate at TeV energies result in strong X-ray lines**
- **Suzaku would have seen these lines**

→ Hadronic models excluded, <u>at least for uniform ISM environments</u>

With or without pre-SN wind if no external mass concentrations

Ellison, Patnaude, Slane & Raymond ApJ (2007, 2010)

For J1713, reasonable fits possible to continuum only with either pion-decay or inverse-Compton dominating GeV-TeV emission

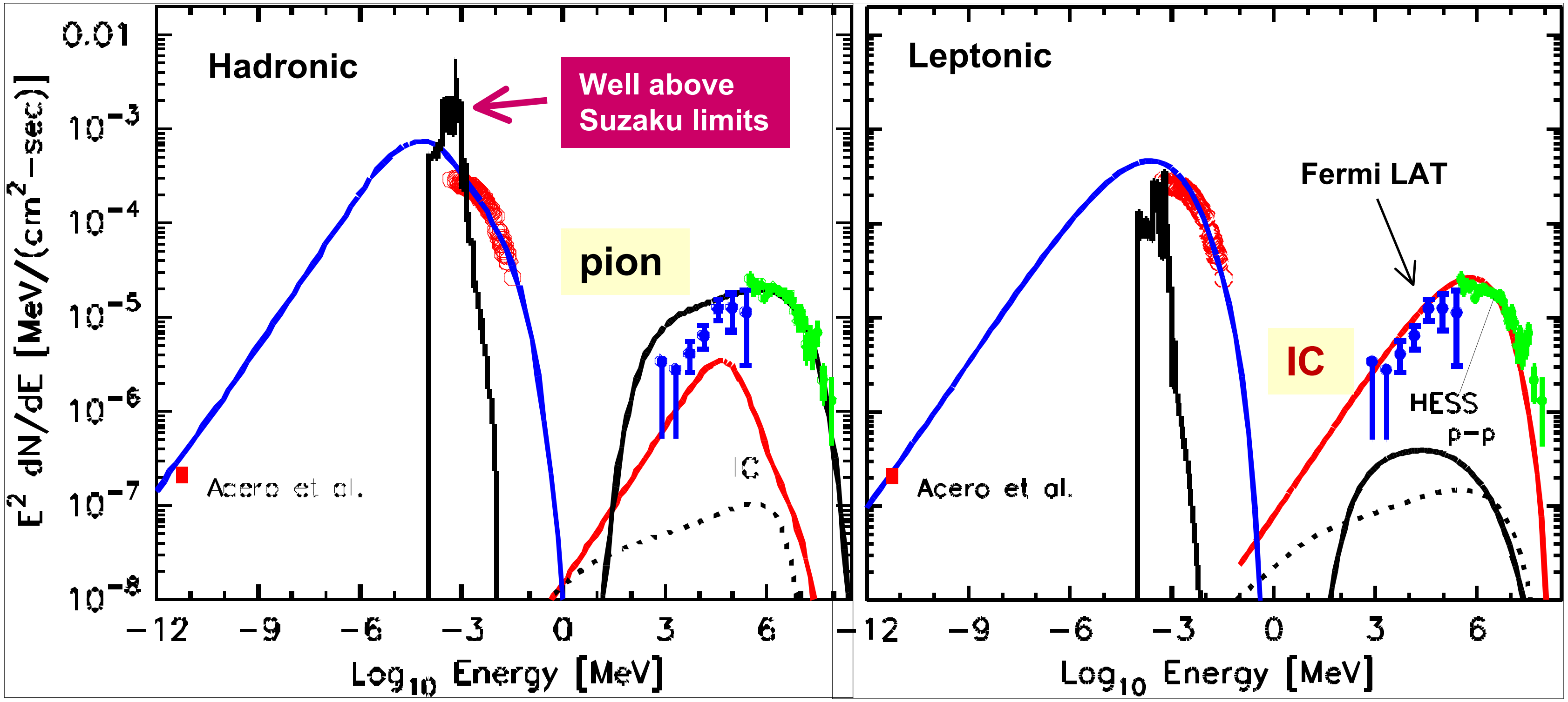


Hadron model parameters:
n_p = 0.2 cm^{-3}
e/p = K_{ep} = 5 10^{-4}
B_2 = 45 μG

Lepton model parameters:
n_p = 0.05 cm^{-3}
e/p = K_{ep} = 0.02
B_2 = 10 μG

Ellison, Patnaude, Slane & Raymond ApJ 2010

When X-rays are calculated self-consistently, force lower density and higher K_{ep} = 0.02, eliminates pion-decay fit



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Here, use only CMB photons for IC emission

Ellison, Patnaude, Slane & Raymond ApJ 2010

Recent Fermi LAT data consistent with leptonic model

So far, include only

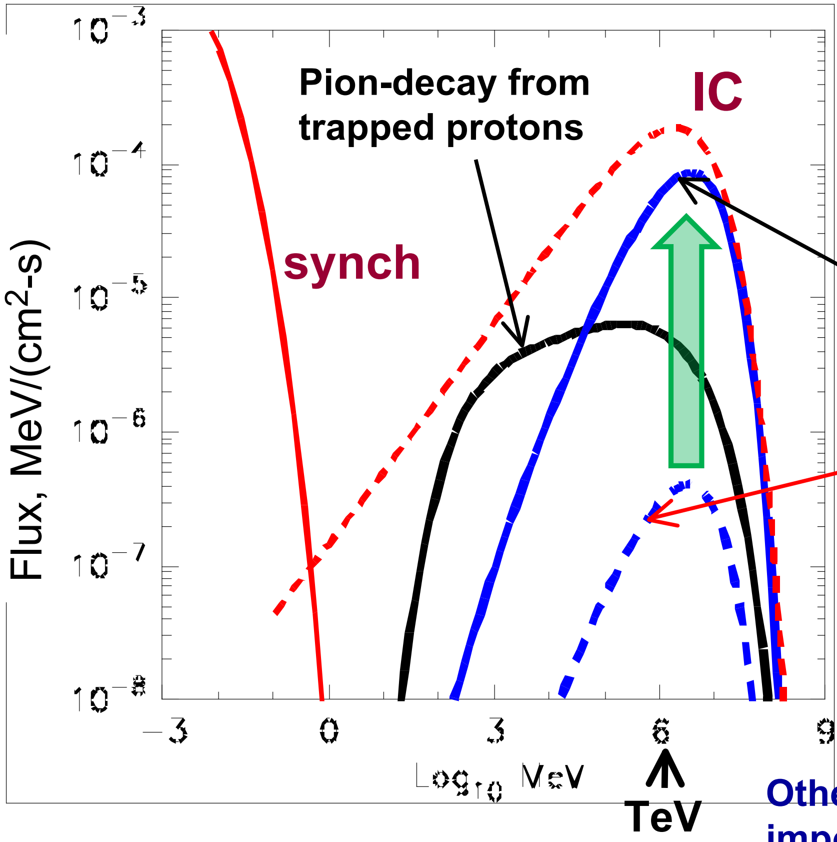
➔ Trapped CRs

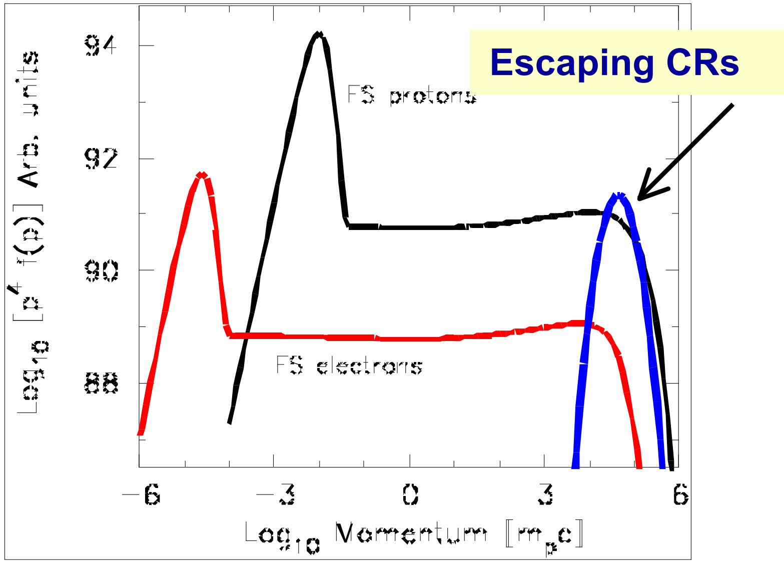
➔ SNR in uniform environment

What happens if escaping CRs are interacting with dense external material ?

Trapped CRs interact with compressed ISM within SNR

Escaping CRs may interact with dense external material: molecular cloud, shell from pre-SN wind





Pion-decay from escaping protons:

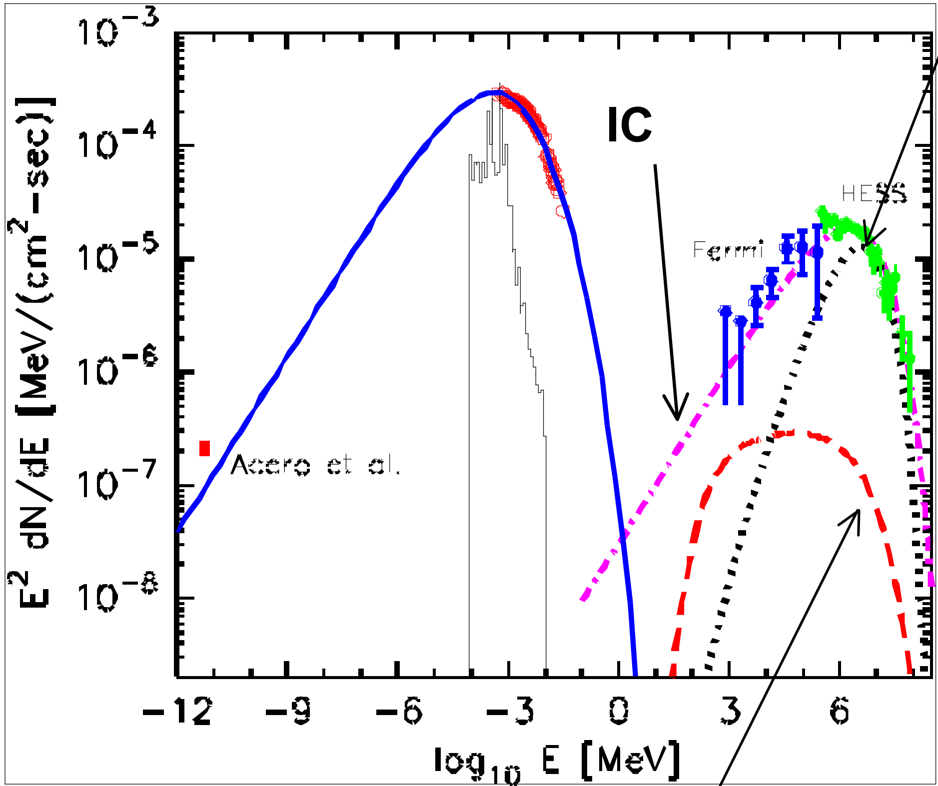
From dense, massive external shell

From low-density, uniform ISM

Escaping vs. trapped CRs:
1. Different spectral shape
2. Strong variation with environment

Other parameters: B, K_{ep}, n_p determine relative importance of Synch & IC (electrons) vs. pion-decay (protons)

Preliminary work: Spherically symmetric model



Pion-decay from escaping CRs with 10^4 M_0 of **external** material

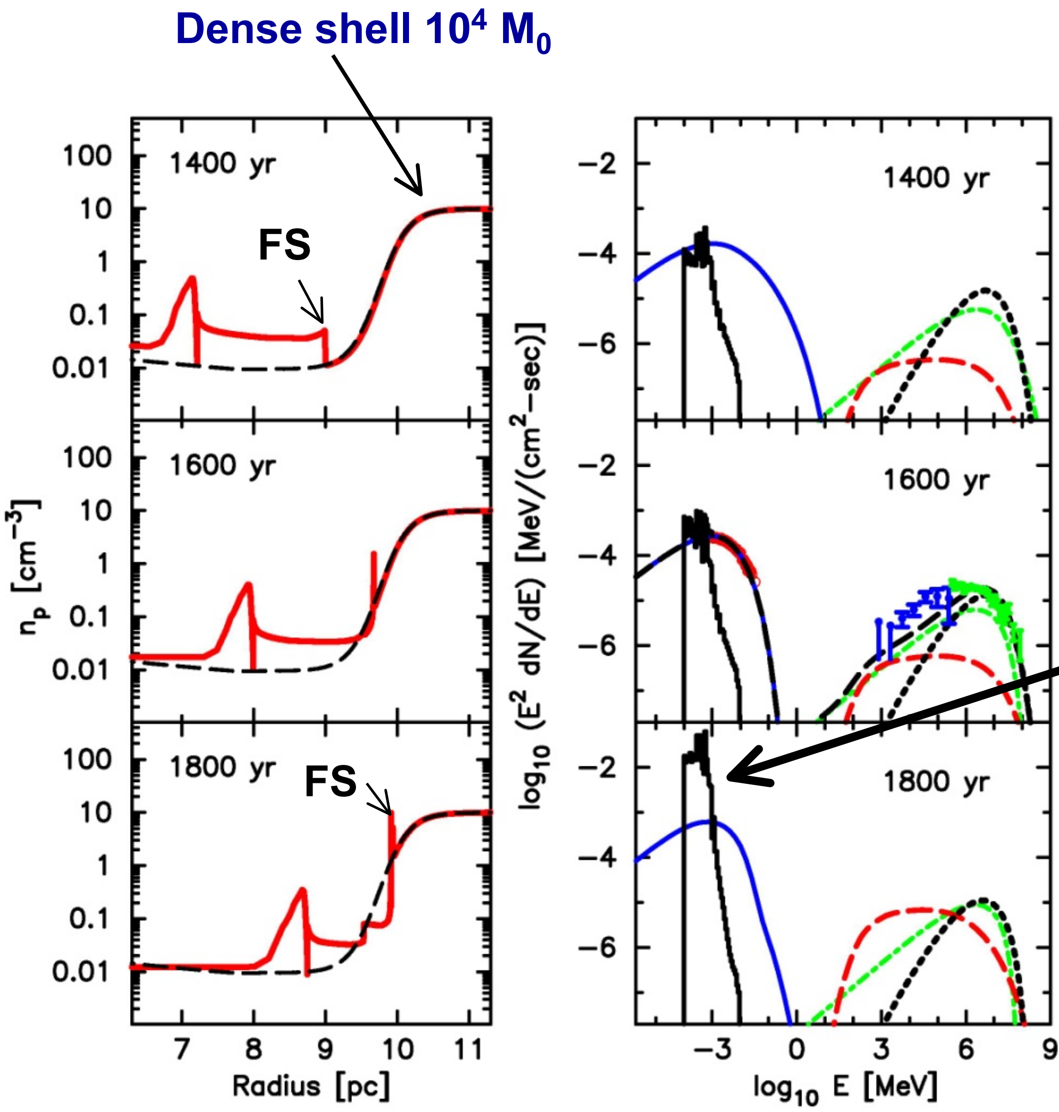
Pion-decay from trapped CRs

Pion-decay from escaping CRs can be important at TeV energies but this requires >> 100 M_0 of external material

Also, problems with still unknown shape of escaping CR distribution

All simple models for escaping CRs suggest the distribution will be narrow

What if forward shock is interacting with dense shell?



If blast-wave shock impacts dense material, strong lines will be produced

Rapid increase in line intensity as shock hits shell

External mass must be external for X-rays consistent with J1713 observations

Ellison, Slane, Patnaude Bykov work in progress

Warning: **many uncertainties in model, but**

For SNR Rx J1713:

Observations NOT consistent with pion-decay origin for GeV-TeV emission

Inverse-Compton is best explanation for GeV-TeV

Hadron model only possible if escaping CRs interact with >>100 M_0 of external material without producing X-ray lines. Not so easy to arrange this

Note, most CR energy is still in ions even with IC dominating the radiation ➔ SNRs produce CR ions!

(Detailed model of escaping CRs interacting with external material in progress)