FERMI-LAT OBSERVATIONS OF SUPERNova REMNANT KES 79

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Connecting Cosmic Rays & SNRs

- Below $E_{\text{knee}}$, CRs are thought to be Galactic in origin:
  - Supernova remnants (SNRs)
  - Colliding stellar winds.

- Evidence in favour of SNRs:
  1. CR energy density $\approx 1 \text{ eV cm}^{-3}$.
     - SNRs can naturally explain this.
  2. Spectral index of CR spectrum at Earth $\approx 2$.
     - Consistent with spectral index of derived by DSA.
**Diffusive Shock Acceleration**

- **Forward shock** (& reverse shock??) of a SNR can accelerate particles
  - e.g. SN1006

- Shock-wave propagates & particles scatter off MHD waves giving:
  \[
  \frac{dN}{dE} \propto E^{-2}
  \]

- Lagage & Cesarsky (1983) applied DSA to shell-type SNRs
  
  - Particles in SNRs can be accelerated up to 10 - 100 TeV.

- **SNRs can be** CR accelerators!

*Chandra X-ray image (NASA/CXC/Middlebury College/F.Winkler)*
Particles lose energy via...

• **Leptonic emission:**
  – Inverse Compton (IC):
    • electron transfers energy to a low energy photon
  – Non thermal Bremsstrahlung.

• **Hadronic emission:**
  – Pion decay:
    \[ p + p \rightarrow \pi^0 + X \rightarrow \gamma + \gamma + X \]
    • consequence of SNRs interacting with dense material

...producing GeV/TeV gamma-rays
How can we distinguish?

• Leptonic emission:
  – Inverse Compton (IC):
    • electron transfers energy to a low energy photon
  – Non thermal Bremsstrahlung.

• Hadronic emission:
  – Pion decay:
    \[ p + p \rightarrow \pi^0 + X \rightarrow \gamma + \gamma + X \]
    • consequence of SNRs interacting with dense material

γ-ray, X-ray & radio data can help!
Kesteven 79

- Poorly defined “shell” type remnant.
- Distance: \(~7.1 \, \text{kpc}\)
- Radio emission seen towards the NE and SW.
- Broad 1667 MHz OH absorption feature found at \(~105 \, \text{km \, s}^{-1}\).
- CO survey reveals large elongated molecular cloud toward the east, at similar velocity.
- Has an X-ray pulsar CXOU J185238.6+004020
Counts map of Kes 79

- 52 Months of Fermi-LAT data
- 0.2 – 200 GeV
- 1 deg x 1 deg region centered on Kes 79
- Detection significance: ~ 7 \( \sigma \)
- 1667 MHz OH absorption feature
- 2FGL J1852.7-0047c
- Extent of Kes 79
- VLA Galactic plane survey contours
Gamma-ray spectrum of Kes 79

Statistical errors

Power law fit
\[ \Gamma = 2.62 \pm 0.12 \]

Systematic errors
- Fermi syst + Galactic diffuse bkg syst

Pion decay model
\[ \Gamma = 2.90 \]
\[ E_{\text{cutoff}} = 20 \text{ GeV} \]
\[ n_0 = 16 \text{ cm}^{-3} \]

Exponential Cut-off
\[ \Gamma = 2 \pm 0.40 \]
\[ E_{\text{cutoff}} = 2.71 \pm 4.18 \text{ GeV} \]

Upper limits
Gamma-ray spectrum of Kes 79

Pion decay model

- $\Gamma = 2.90$
- $E_{\text{cutoff}} = 20 \text{ GeV}$
- $n_0 = 16 \text{ cm}^{-3}$

IC model required $E_{\text{ELEC}} > 10^{51} \text{ erg}$

- Energetically unfavourable

Non-thermal Bremsstrahlung required $K_{\text{ep}} > 0.3$ for reasonable $E_{\text{ELEC}}$
X-ray analysis of Kes 79

• Spectral analysis of 14 regions.
• 21 archival XMM obs.
  – Total time ~450 ks.
• Model using two component NEI model (vpshock+pshock)
• Derive ambient density
Inferred ambient density

- Inferred:
  \[ n_0 = 1.61^{+0.55}_{-0.78} - 3.49^{+1.41}_{-1.31} f^{1/2} d^{5/2}_{7.1} \text{ cm}^{-3} \]

- **Smaller** than \( n_0 \) derived using \( \gamma \)-ray analysis!
  - Dense material does not radiate significantly in X-rays.
  - Escaped particles interact with upstream material, enhancing \( \gamma \)-rays.

- MC found towards E/SE of Kes 79
  - MCs are clumpy & have \( n_0 \) similar to above (Chevalier 1999)

\[ \Longrightarrow \text{Kes 79 likely to be interacting with MC} \]
Conclusion

• **SNRs can accelerate CRs!**

• **Accelerated particles emit γ-rays via leptonic & hadronic emission**
  
  – SNRs interacting with dense material (MCs) are strong candidates for γ-ray emission.

• **Using ~52 months of Fermi-LAT data we detected γ-rays from Kes 79.**

• **Assuming pion-decay model, we inferred \( n_0 \) larger than \( n_0 \) derived from thermal X-rays.**
  
  – Kes 79 is interacting with a dense clumpy material which do not radiate significantly in X-rays.
Test Statistic (TS) Map

- $L_{ps} =$ Likelihood of a point source being found at a given position.
- $L_{null} =$ Likelihood of the model without the additional source
- Assuming a background set of sources, it models the residual $\gamma$-rays that are not accommodated in the background model

$$TS = 2 \log \left( \frac{L_{ps}}{L_{null}} \right)$$