COSMIC RAYS AND MAGNETIC FIELD IN THE CORE AND HALO OF THE STARBURST M82: IMPLICATIONS FOR GALACTIC WIND PHYSICS

Benjamin Buckman
Tim Linden
Todd Thompson

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QUESTION!

- Can cosmic rays propel a gas cloud?

- If the answer to the previous question was yes, explain.
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• Can cosmic rays propel a gas cloud? **YES!**

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QUESTION!

- Can cosmic rays propel a gas cloud? **YES!**

- If the answer to the previous question was yes, explain.

\[ a_{gas} = -\frac{\nabla P_{CR}}{\rho_{gas}} \]

Acceleration of gas from CRs is due to the gradient of the CR pressure mediated by the magnetic field
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STARBURST GALAXY M82

- Gamma-ray detection – Not resolved
- Spatially resolved radio halo measurements @ multiple wavelengths
- Viewed from edge-on
- Well studied galactic wind
- Starburst core – known SNR and dimension
MODELING CR’S IN M82
IMPORTANT INGREDIENTS

- Transport
- Wind
- Injection
- Primary Spectrum
- Source Distribution
- Energy Losses
- $B$
- ISRF
- $n_{HI}, n_{HII}$
- SNR
- Primary p/e ratio

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GALPROP

- Injection
- Propagation
- Energy losses
- Secondaries

Energy Losses

Transport

Injection

Cosmic ray Distribution

Radio Emission
- Synchrotron
- Free-Free

Gamma-ray Emission
- Bremsstrahlung
- Inverse Compton
- Pion-decay Emission
INPUT DISTRIBUTIONS

• Magnetic Field ($B$) and Gas Density ($n$)
  - Constant inside ellipsoidal core
  - Outside core: $B \propto r^{-\beta}$, $n \propto r^{-2}$

• Interstellar Radiation Field
  - Determined from exponential disk of sources (dust+stars)

• Cosmic-ray Sources
  - Constant inside ellipsoidal core
  - No sources outside core

Simulation box size:
$R \in [0,5] \text{ kpc}, z \in [-4,4] \text{ kpc}$
CONSTRaining PARAMETERS

• Use **integrated radio and gamma-ray emission** to constrain properties in starburst core:
  - Magnetic Field
  - Gas Density

• Use **extended radio halo** to constrain halo properties:
  - Magnetic field, $B \propto r^{-\beta}$
  - Gas density
  - CR advection velocity
We replicated emission with our models
We constrain magnetic field and gas density
DEGENERACY in the core
EXTENDED EMISSION

- Wavelength increases
- Halo size increases

Model B

6 cm

3 cm

22 cm

92 cm
TIMESCALES

- Electron Cooling Timescales

\[
\tau_{\text{ionization}} \sim 10^6 \left( \frac{\nu_{\text{crit}}}{1 \text{ GHz}} \right)^{\frac{1}{2}} \left( \frac{B}{100 \mu \text{G}} \right)^{-\frac{1}{2}} \left( \frac{n}{100 \text{ cm}^{-3}} \right)^{-1} \text{ yr}
\]

\[
\tau_{\text{bremss}} \sim 3 \times 10^5 \left( \frac{n}{100 \text{ cm}^{-3}} \right)^{-1} \text{ yr}
\]

\[
\tau_{\text{IC}} \sim 3 \times 10^5 \left( \frac{\nu_{\text{crit}}}{1 \text{ GHz}} \right)^{\frac{1}{2}} \left( \frac{B}{100 \mu \text{G}} \right)^{\frac{1}{2}} \left( \frac{U_{\text{rad}}}{1000 \text{ eV cm}^{-3}} \right)^{-1} \text{ yr}
\]

\[
\tau_{\text{synch}} \sim 10^6 \left( \frac{\nu_{\text{crit}}}{1 \text{ GHz}} \right)^{\frac{1}{2}} \left( \frac{B}{100 \mu \text{G}} \right)^{-\frac{3}{2}} \text{ yr}
\]

\[
\left( \frac{E}{1 \text{ GeV}} \right) = \left( \frac{\nu_{\text{crit}}}{1 \text{ GHz}} \right)^{\frac{1}{2}} \left( \frac{B}{100 \mu \text{G}} \right)^{-\frac{1}{2}}
\]

Spectral index from competition of cooling timescales

steepen spectrum
RADIO SPECTRAL INDEX ALONG MINOR AXIS

- Spectral index changes by >1.5 along the minor axis of M82
- Changing of cooling mechanism can change spectral index by 1 at most
- Spectral steeping is due to the galactic wind and changing cooling mechanism
SPECTRAL STEEPENING CONSTRAINS:

- Cosmic ray population
- Magnetic field
- Gas density
- Wind velocity

All along the minor axis of M82
COSMIC RAY SPECTRA

Colors denote distance from core (0, 0.2, 0.5, 3.0) kpc

Protons

Electrons + Positrons

Radio emission spectral steepening
**GAS ACCELERATION**

\[ a_{\text{gas}} = -\frac{\nabla P_{\text{CR}}}{\rho_{\text{gas}}} \]

- Cosmic rays are subdominant to gravity
GAS ACCELERATION II

\[ a_{\text{gas}} = -\frac{\nabla U_B}{\rho_{\text{gas}}} \]

- Magnetic field is dynamically relevant!
- May effect galactic winds!
SUMMARY

• Using GALPROP:
  - Modeled integrated gamma-ray and radio data
  - Modeled radio halo and constrained magnetic field, gas density, and wind velocity

• Cosmic rays are not able to drive galactic winds in starburst galaxies

• Magnetic fields are dynamically relevant to galactic winds!
QUESTIONS?
MAGNETIC FIELD VS GAS DENSITY

- Degeneracy due to:
  - Relative gamma-ray/radio normalization
  - Radio spectral index

- We chose 3 models to exemplify behavior

- Magnetic Field must be >150 microG
EXTENDED EMISSION

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