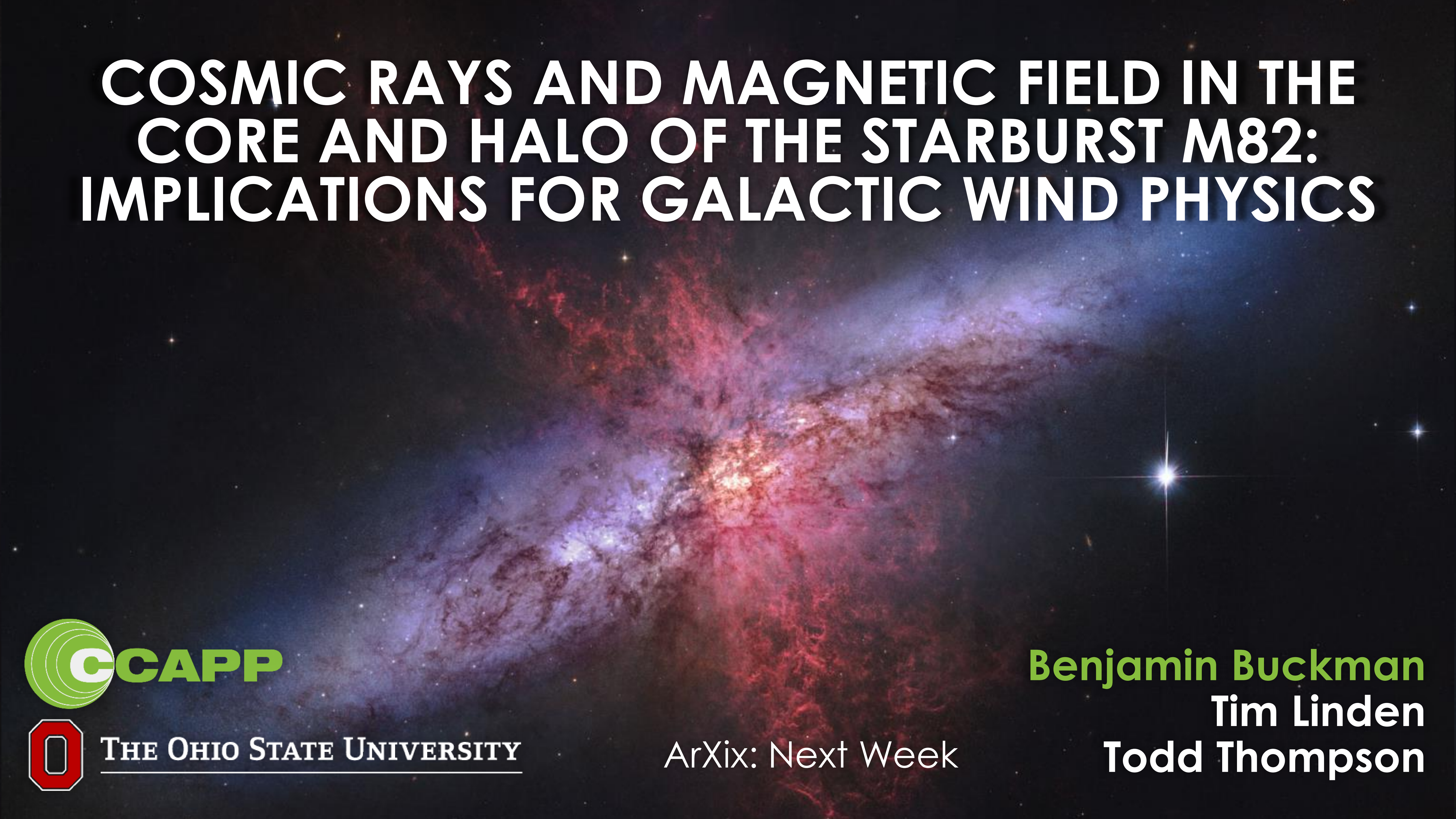
COSMIC RAYS AND MAGNETIC FIELD IN THE CORE AND HALO OF THE STARBURST M82: IMPLICATIONS FOR GALACTIC WIND PHYSICS



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The Ohio State University

ArXix: Next Week

QUESTION!

- Can cosmic rays propel a gas cloud?

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

QUESTION!

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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 mangetic field

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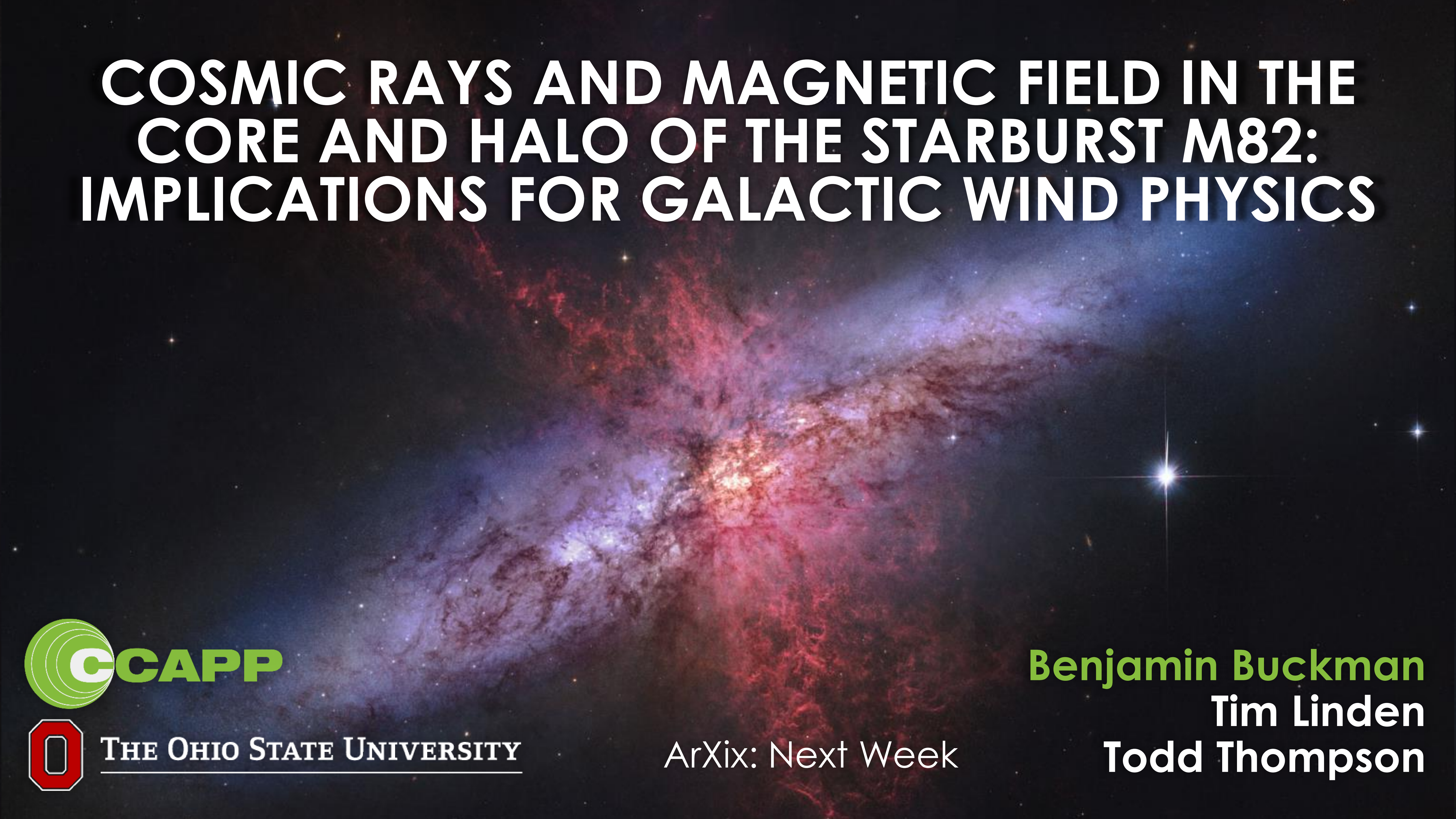

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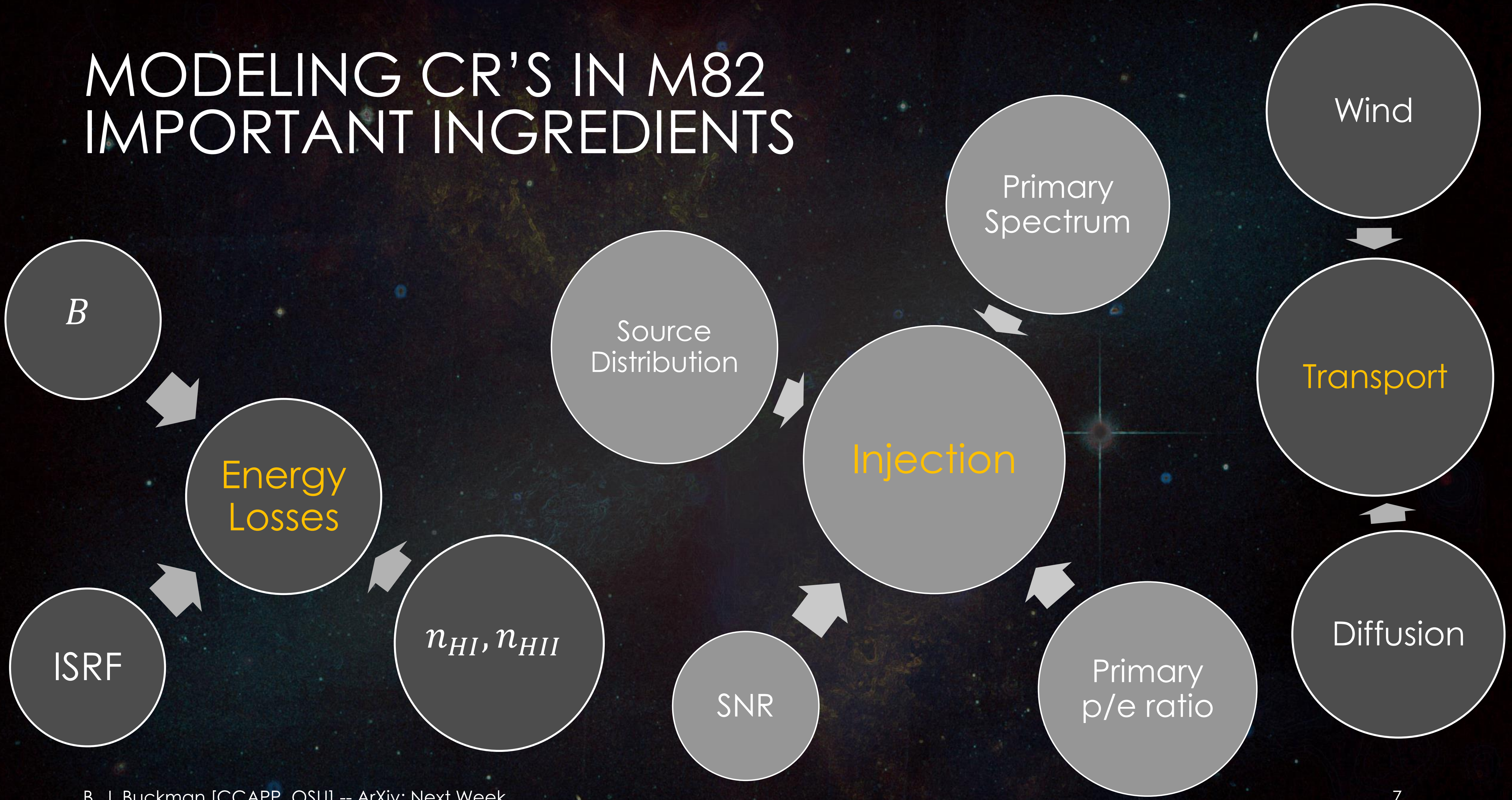
STARBURST GALAXY M82

- 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



GALPROP

Energy Losses

Transport

Injection

GALPROP

- ►injection
- ►propagation
- ►energy losses
- ►secondaries

Cosmic ray Distribution

Radio Emission

- Synchrotron
- Free-Free

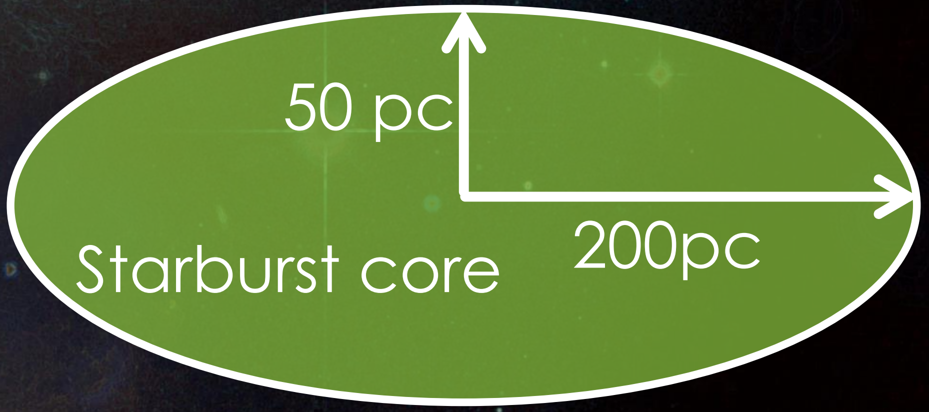
Gamma-ray Emission

- Bremsstrahlung
- Inverse Compton
- Pion-decay Emission

Simulation box size:
$R \in [0,5]$ kpc, $z \in [-4,4]$ kpc

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



CONSTRAINING PARAMETERS

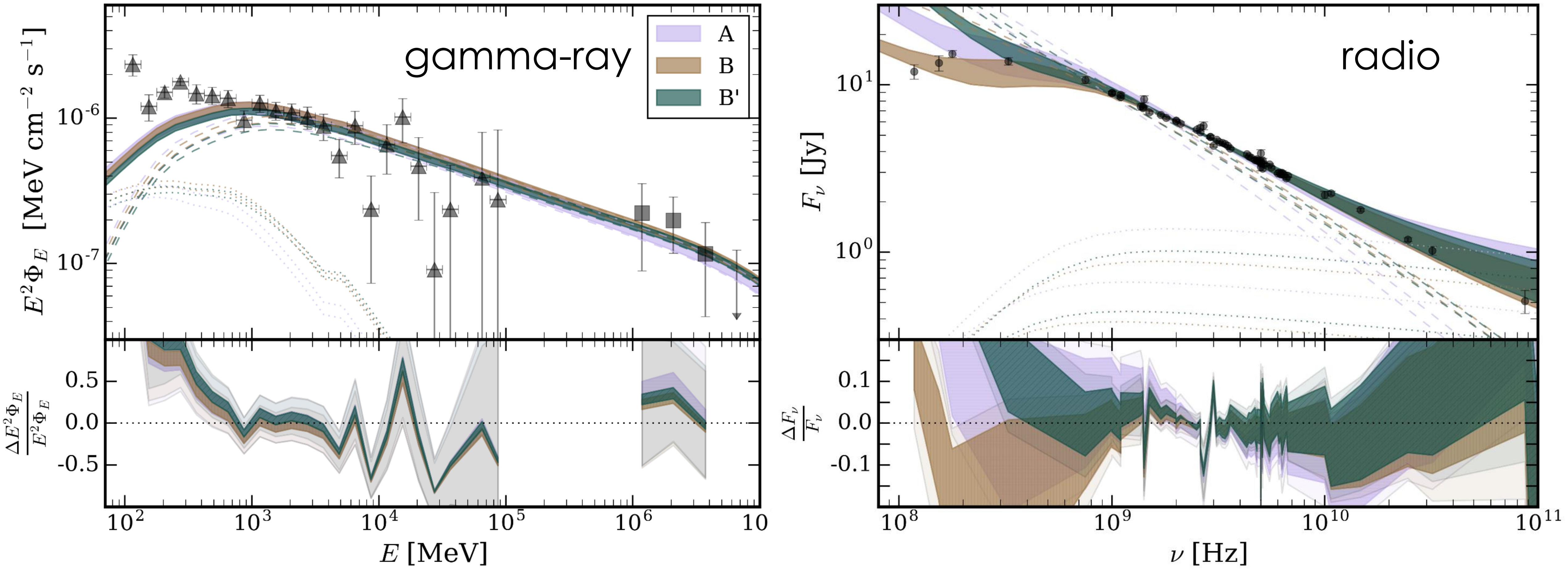
- Use integrated radio and gamma-ray emission to constrain properties in starburst core:
  - Magnetic Field
  - Gas Density
- Use extended radio halo to constrain halo properties:
  - Magnetic field, $B \propto r^{-\beta}$
  - Gas density
  - CR advection velocity

INTEGRATED EMISSION

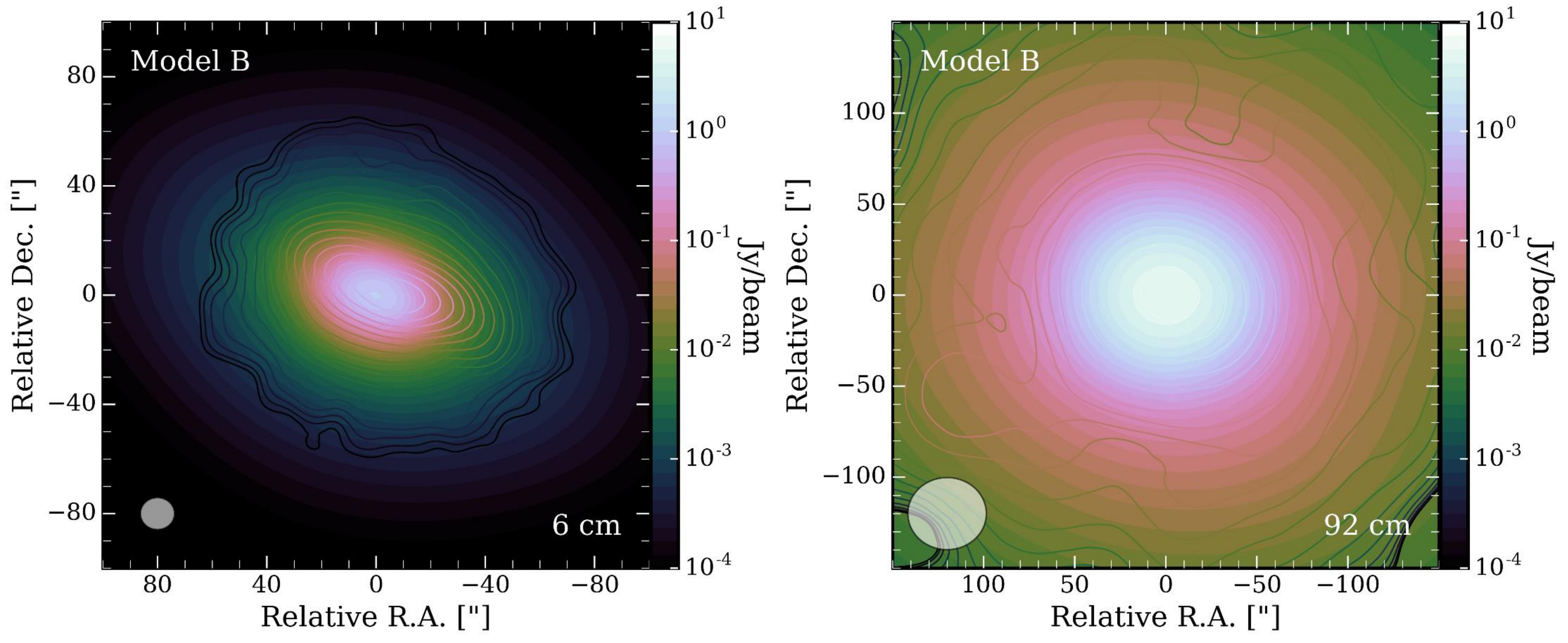
We replicated emission with our models

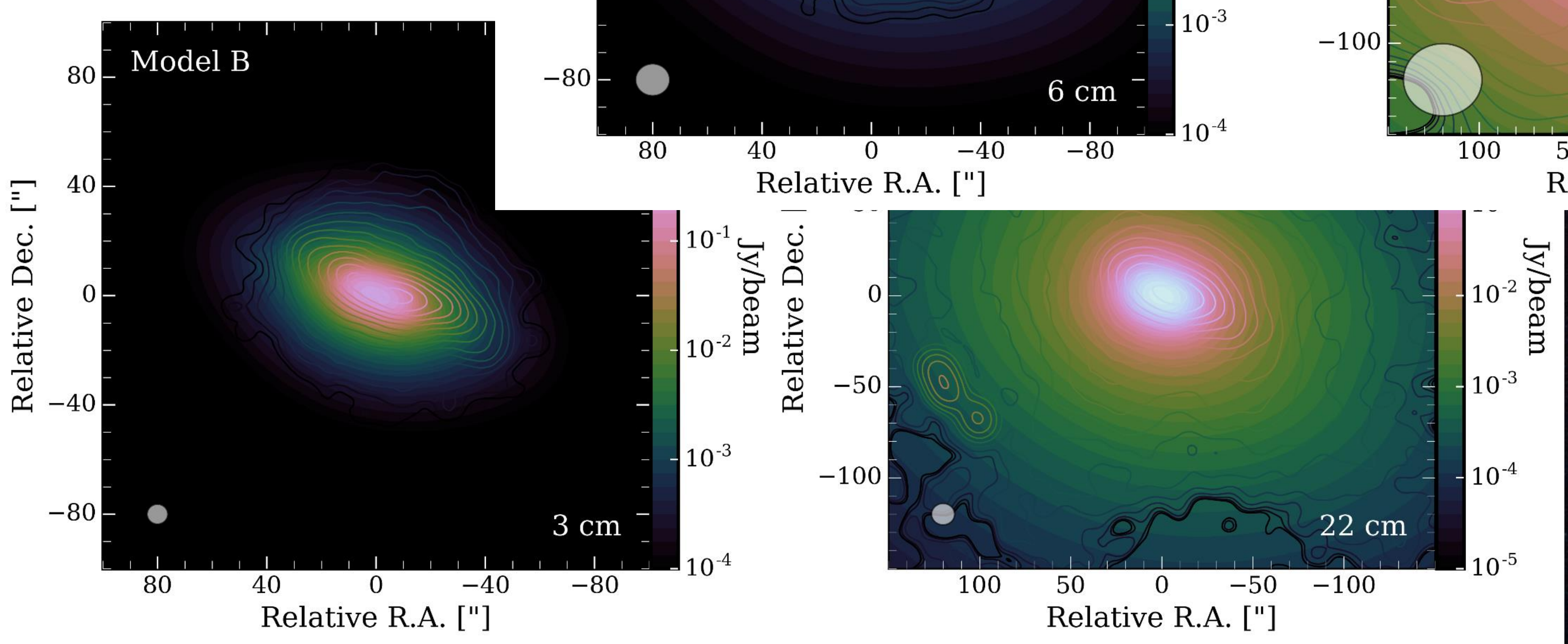
We constrain magnetic field and gas density

DEGENERACY in the core



EXTENDED EMISSION





Wavelength increases

Halo size increases

TIMESCALES

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

- Electron Cooling Timescales
  - $\tau_{ionization} \sim 10^6 \left(\frac{\nu_{crit}}{1\ GHz}\right)^{\frac{1}{2}} \left(\frac{B}{100\ \mu G}\right)^{-\frac{1}{2}} \left(\frac{n}{100\ cm^{-3}}\right)^{-1}$ yr
  - $\tau_{bremss} \sim 3 \times 10^5 \left(\frac{n}{100\ cm^{-3}}\right)^{-1}$ yr
  - $\tau_{IC} \sim 3 \times 10^5 \left(\frac{\nu_{crit}}{1\ GHz}\right)^{-\frac{1}{2}} \left(\frac{B}{100\ \mu G}\right)^{\frac{1}{2}} \left(\frac{U_{rad}}{1000\ eV\ cm^{-3}}\right)^{-1}$ yr
  - $\tau_{synch} \sim 10^6 \left(\frac{\nu_{crit}}{1\ GHz}\right)^{-\frac{1}{2}} \left(\frac{B}{100\ \mu G}\right)^{-\frac{3}{2}}$ yr

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

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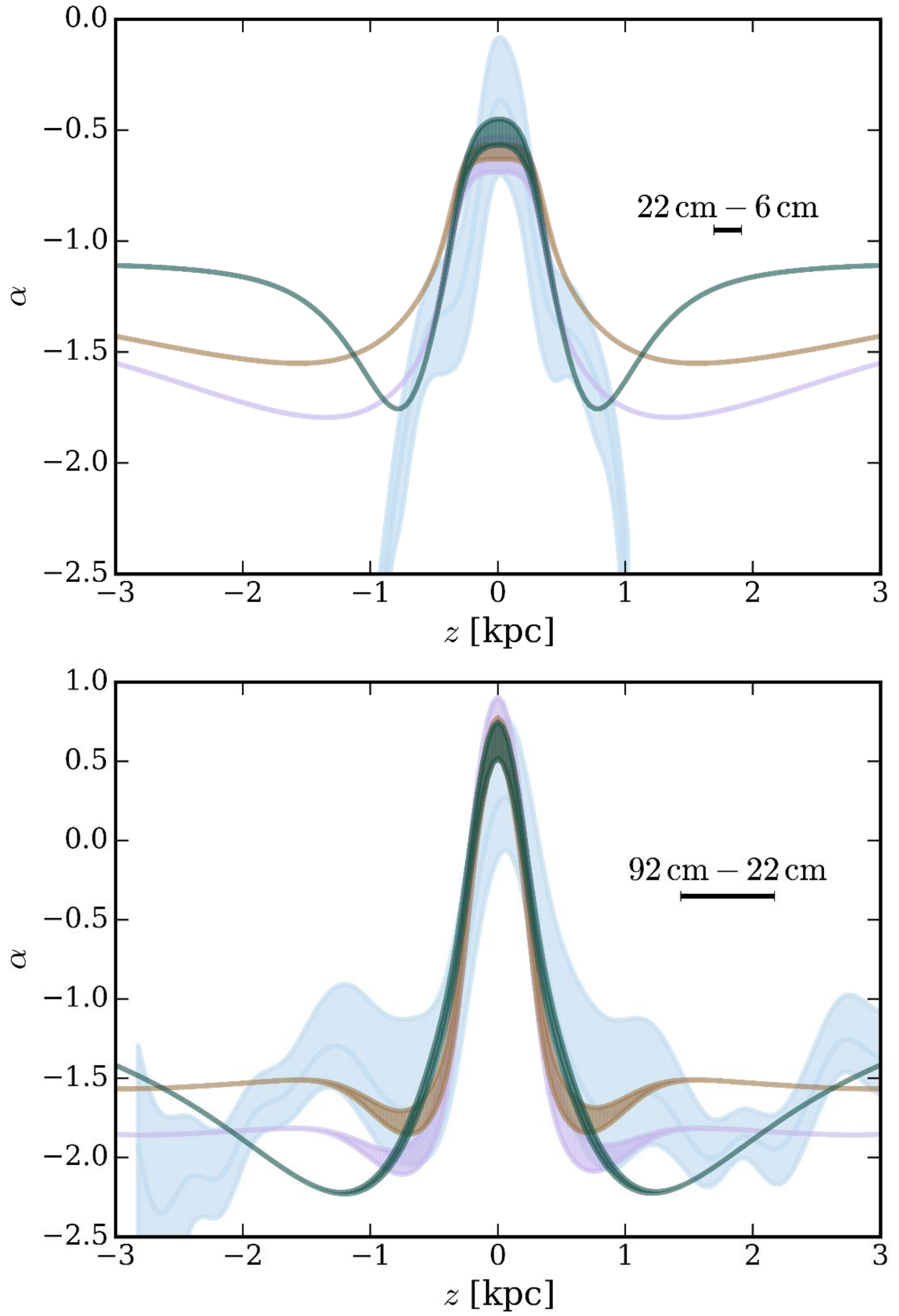


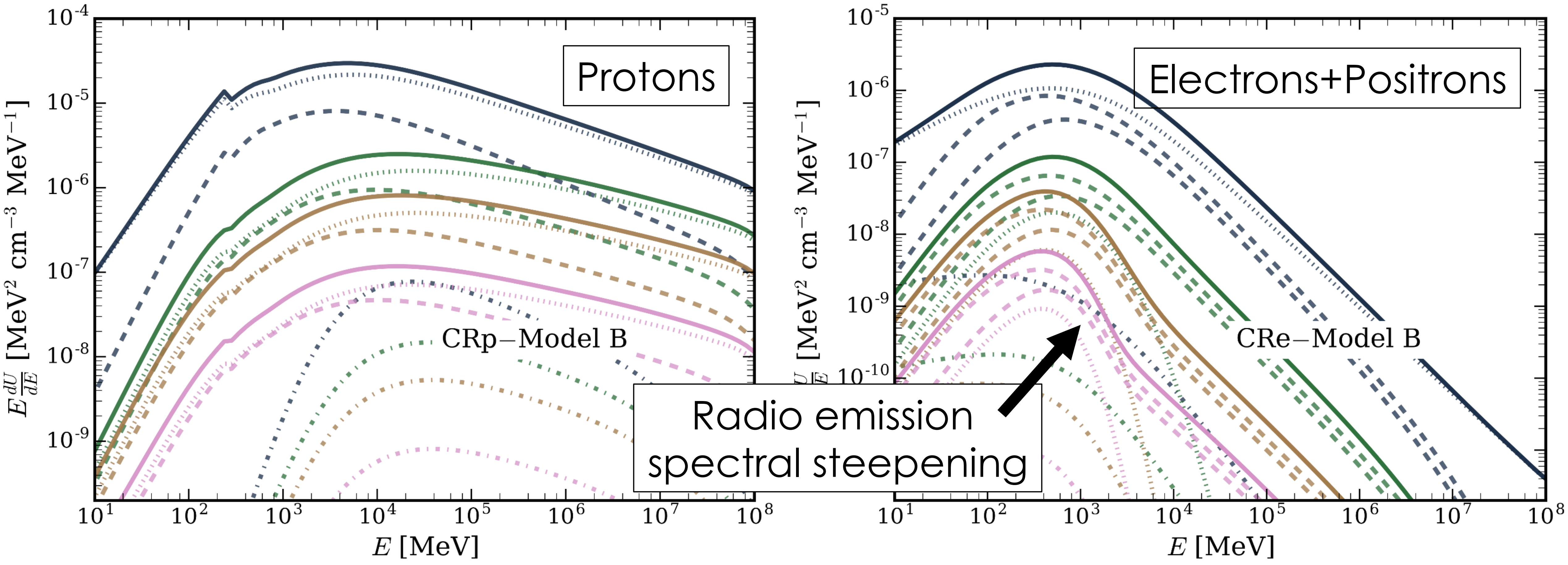
SPECTRAL STEEPENING CONSTRAINS:

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

All along the minor axis of M82

COSMIC RAY SPECTRA

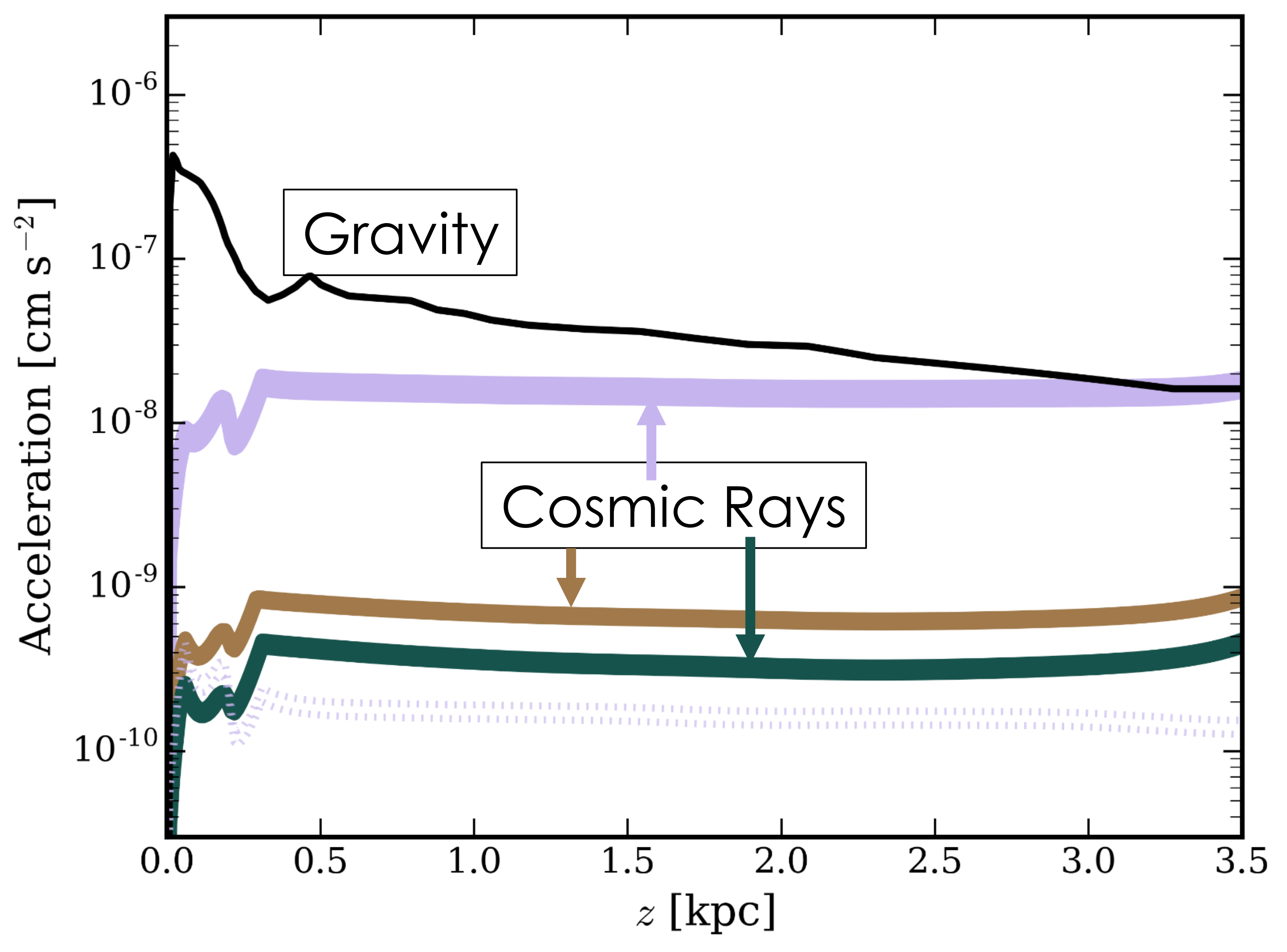
Colors denote distance from core (0, 0.2, 0.5, 3.0) kpc



GAS ACCELERATION

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

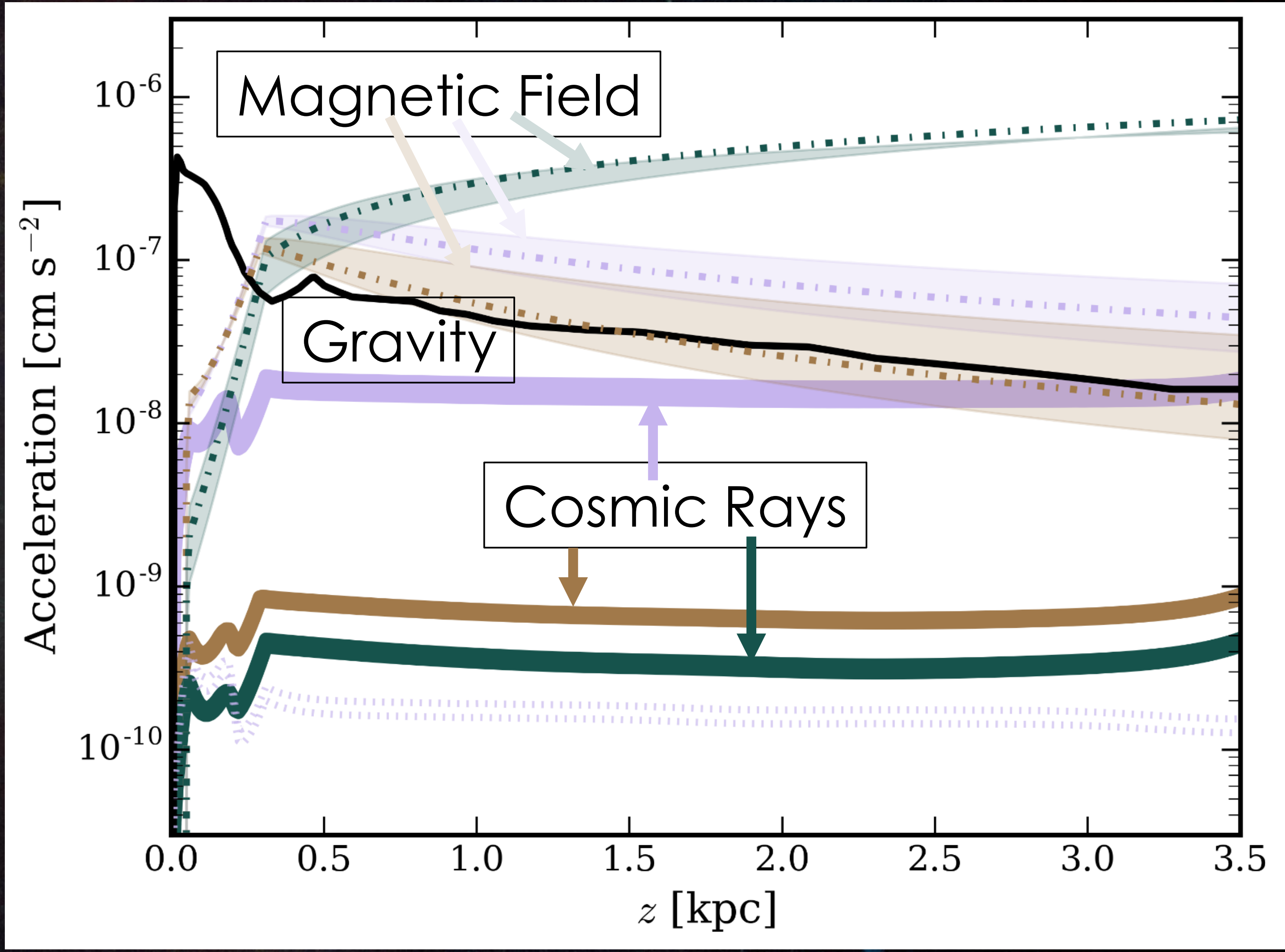
- Cosmic rays are subdominant to gravity



GAS ACCELERATION II

$$a_{gas} = -\frac{\nabla U_B}{\rho_{gas}}$$

- 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

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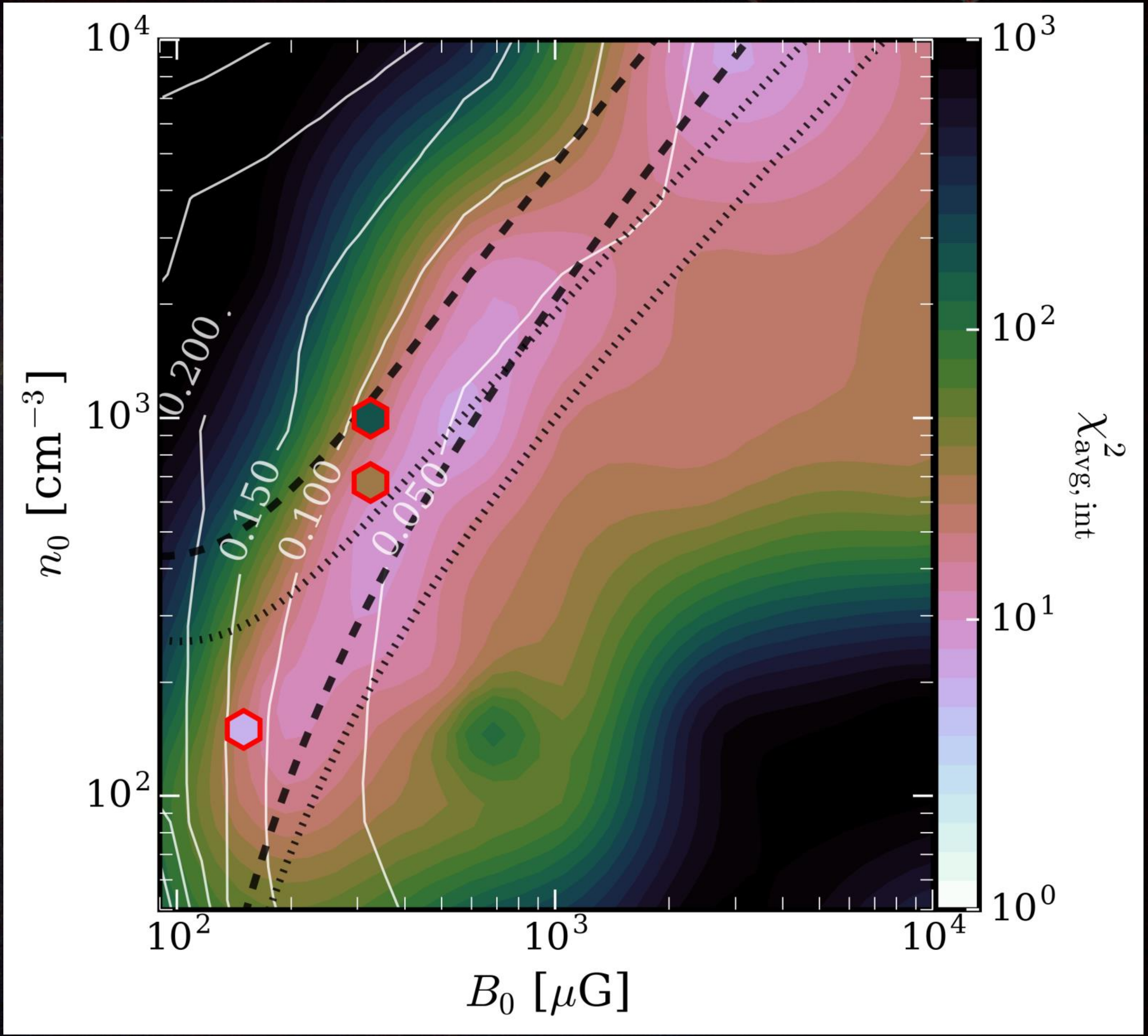
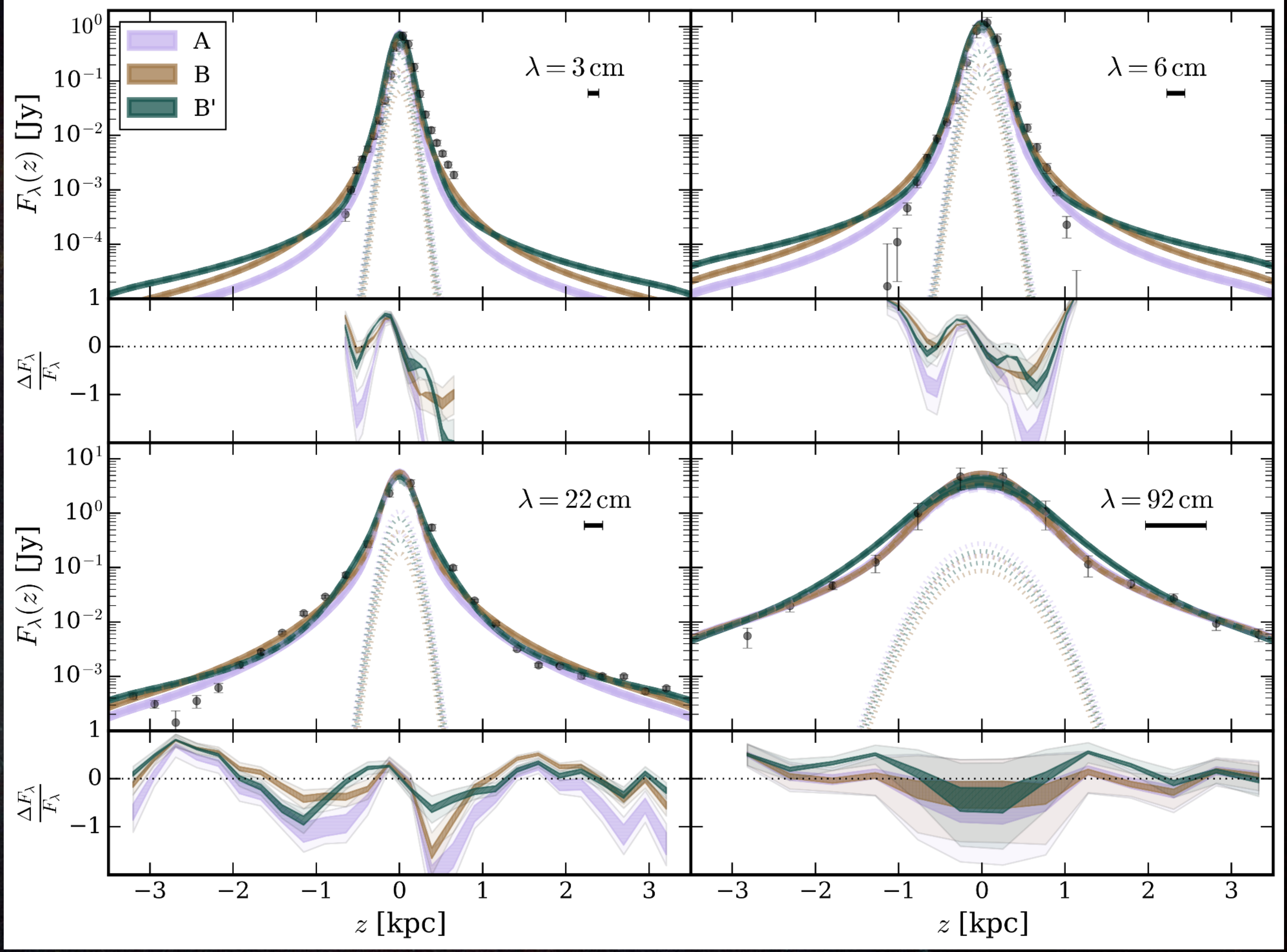


EXTENDED EMISSION



ENERGY DENSITY