The Origin of Diffuse Radio, X-ray and γ-ray Emission from the Galactic Center.

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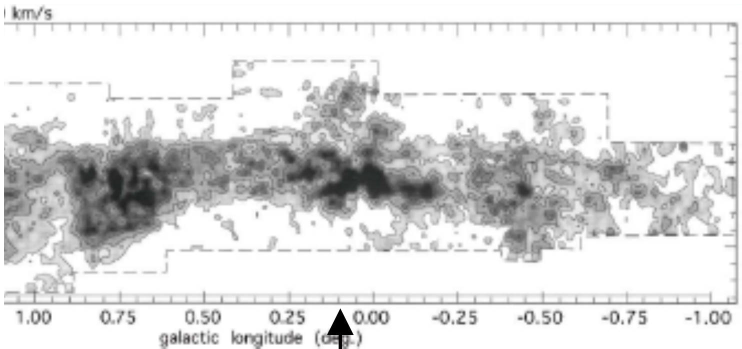
I. Nonthermal Brehmsstruhlung

A. Diffuse γ−ray Emission
B. High cosmic ray ionization rate: High xe
C. Cosmic ray heating rate: High T
D. Fluorescent 6.4 keV line emission

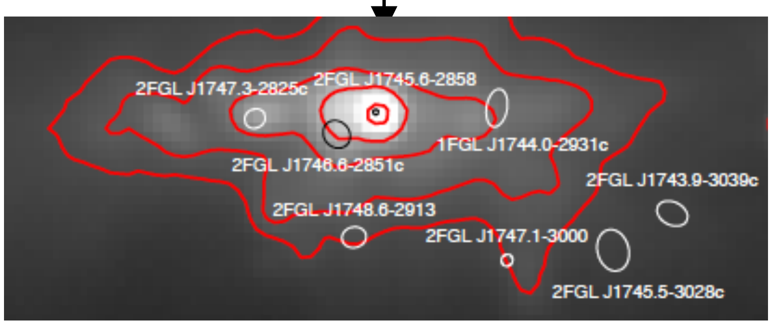
J.W. Hewitt, M. Wardle, V. Tatischeff, D. A. Roberts, W. Cotton,
H. Uchiyama, M. Nobukawa, T. G. Tsuru, C. Heinke & M. Royster

FYZ+2012 (arXiv:1206.6882)

GC ISM: Low and High Energy Emission

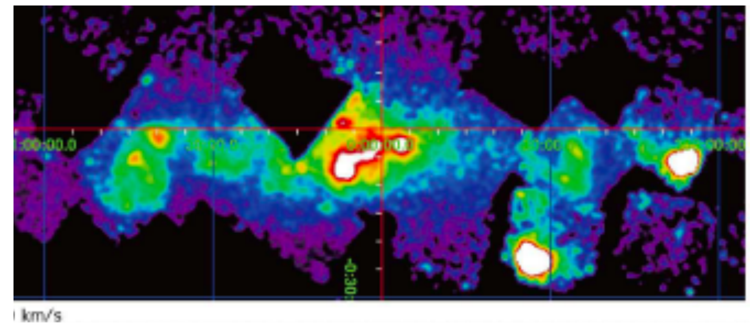


CO

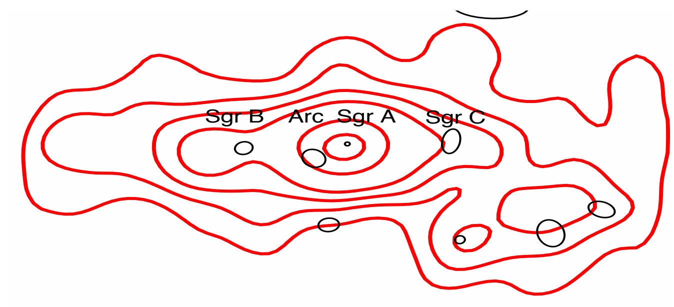


1.4 GHz

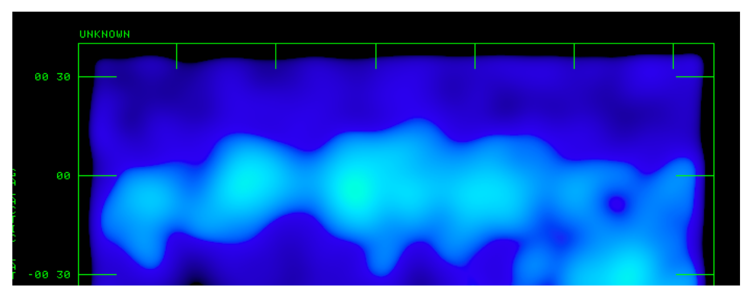
Sgr B2 B1 Arc Sgr A* Sgr C



FeI 6.4 keV



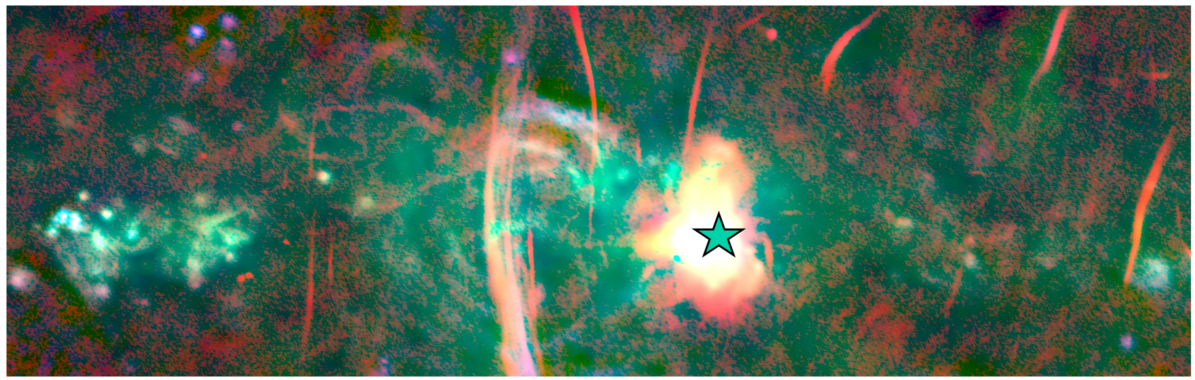
GeV/Fermi



TeV/HESS

I. GC ISM: Radio Continuum

- Mixture of thermal and nonthermal emission
- Thermal Emission
  - Compact HII regions
  - Evolved HII regions
- Nonthermal Emission
  - SNRs
  - Nonthermal filaments
  - Diffuse background
  - Colliding winds

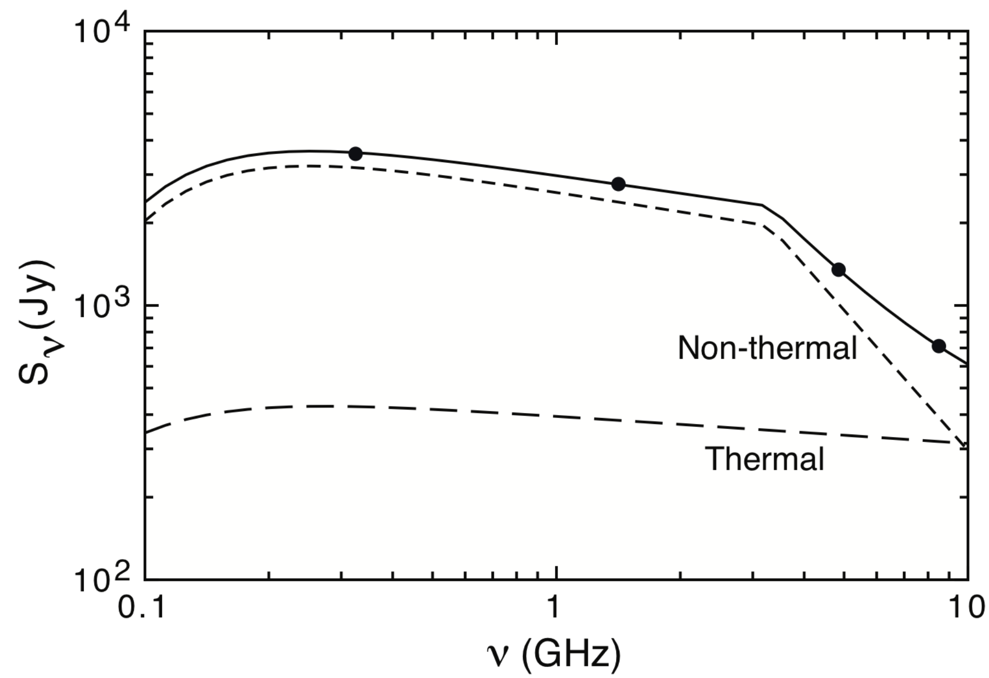


Sgr B2 Sgr B1 Arc Sgr A* Sgr C

$$S_\nu = \Omega(S_{NT0}\exp(-\tau_\nu + B_\nu(T)) \times (1 - \exp(-\tau_\nu))$$

- 2450 Jy at 325 MHzz (90cm)
- Radio spectrum: broken power law

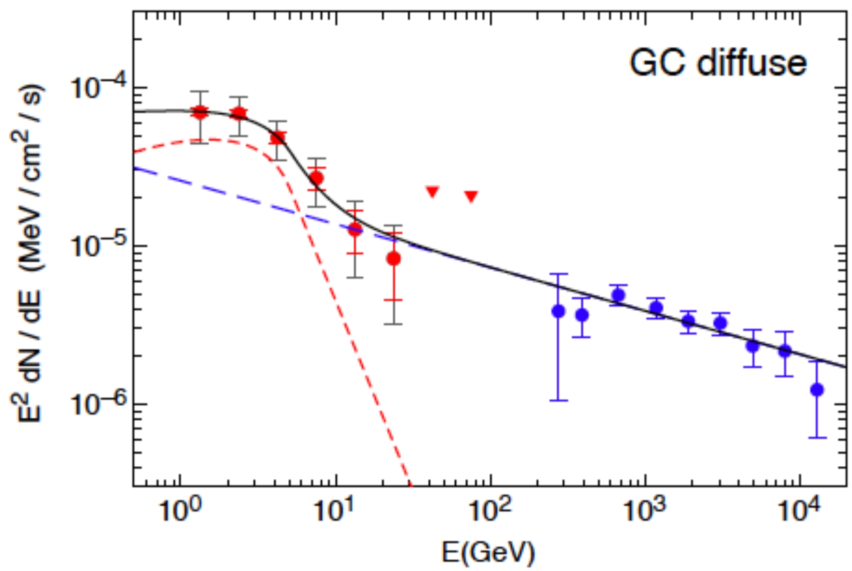
$\nu^{-0.25}$ below 3.3 GHz and $\nu^{-1.7}$ above 3.3 GHz.



I. Nonthermal Brehmsstruhlung

A. Cosmic rays & γ-ray Emission

- Fermi data
- The photon spectrum of diffuse γ−ray
- Predicted model from radio spectrum
- A break in radio and γ−ray spectrum
- Rapid cooling at high energies
- HESS data
- Younger population of electrons



bremsstrahlung photon flux is

$$F_\gamma = \frac{10^{-14} \times E_\gamma^{-p} \times f(p) \times \nu^{(p-1/2)} \times S_\nu \times n_H}{B^{(p+1)/2)}} \text{ ph cm}^{-2} \text{ s}^{-1} \text{ GeV}^{-1}$$

Table 4. Parameters of the fit to γ-ray sources using *Fermi* and H.E.S.S. data

Source	B (μG)	n_H (cm^{-3})	F_{325MHz} (Jy)	p1	p2	ν_{break} (GHz)	Flux(H.E.S.S.) (MeV cm^{-2} s^{-1})	Γ(H.E.S.S.)
GC diffuse	8	12.5	508	1.5	4.4	3.3	$(2.58\pm1.39) \times 10^{-5}$	2.27±0.07

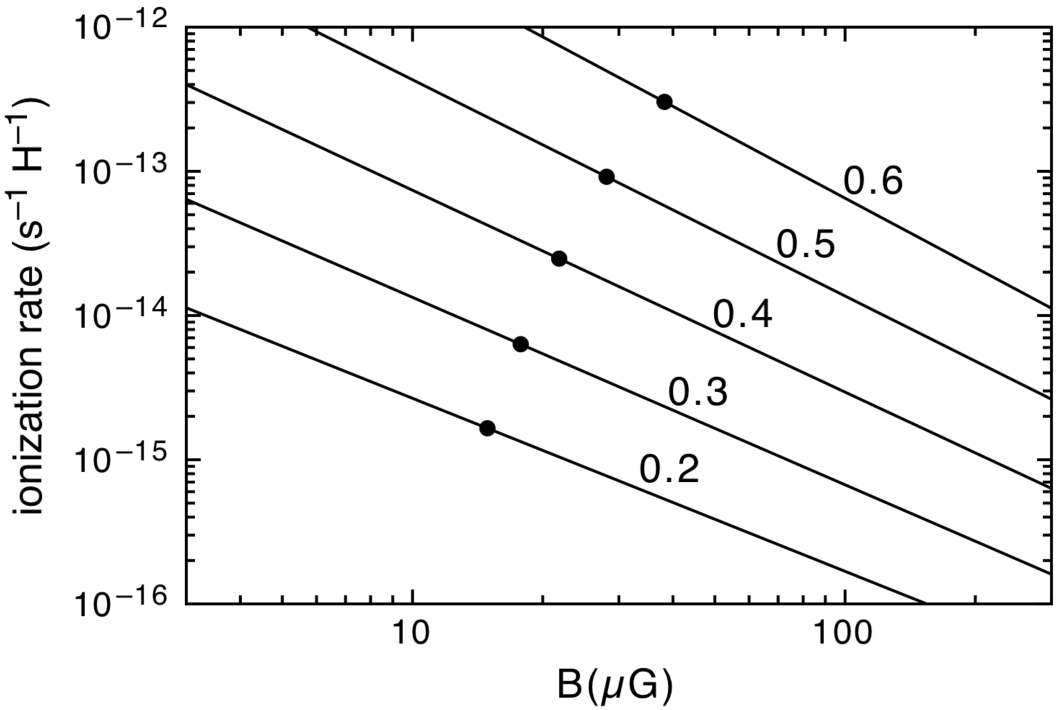
I. Nonthermal Brehmsstruhlung
B: Cosmic Ray Ionization Rate

- Power law distribution of electrons
- N(E) α E^{-p}; E_1=1MeV; E_2= 1GeV
- Flux=2450 Jy at 325 MHz

$$\zeta = \frac{1.6 \times 10^{-13}\, \mathrm{I}_\nu\, \nu^{(\mathrm{p}-1)/2}}{(p-1)\, L\, \mathrm{B}^{(\mathrm{p}+1)/2}}\, \mathrm{s}^{-1}\, \mathrm{H}^{-1}$$

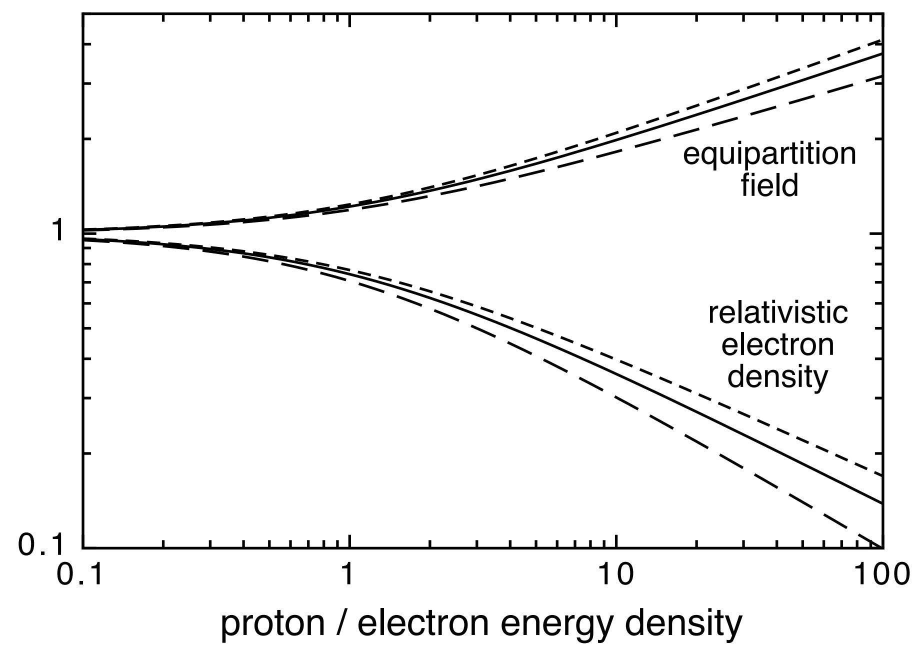
- $\zeta = 10^{-15}$ s^{-1}
- 280x70pc, L=280pc,
- B=16μG

- $\zeta < 10^{-18}$ s^{-1}
- 280x70pc, L=280pc,
- B=1mG



Proton Contribution

The total cr electron density and B
for a given synchrotron emissivity

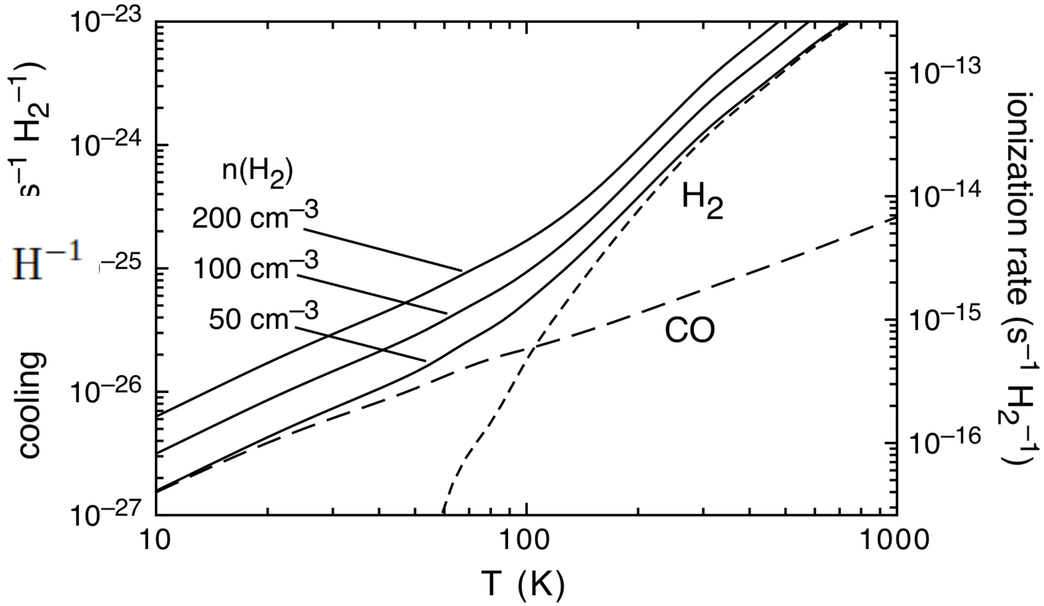


solid = $\nu^{-0.5}$ spectrum
long dash = ν^{-1}
short dash = $\nu^{-0.25}$

I. Nonthermal Brehmsstruhlung
C: Cosmic Ray Heating Rate

- High Temperature Molecular gas
  - Heating rate:

$$\frac{\Gamma}{n_{\rm H}} = 4.0 \times 10^{-26} \left(\frac{\zeta_{\rm H}}{10^{-15}\,{\rm s}^{-1}\,{\rm H}^{-1}} \right) \,{\rm erg\,s}^{-1}\,{\rm H}^{-1}$$



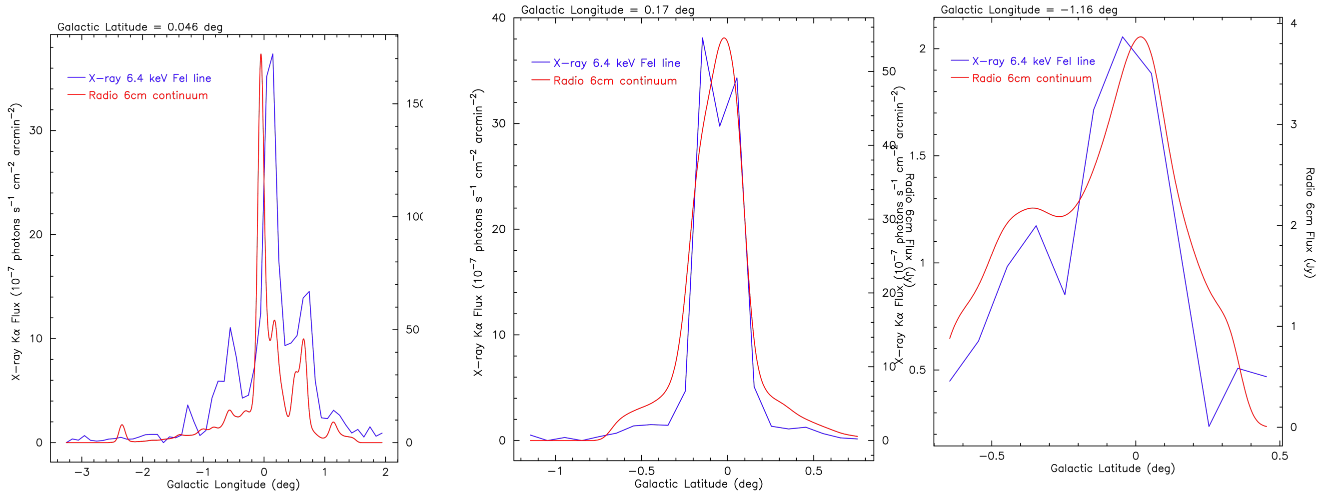
  - Heating rate needs to be resupplied by a SN every 7000 year

$$M_J \approx 0.53 \left(\frac{T}{10\,{\rm K}} \right)^{3/2} \left(\frac{n_{\rm H}}{10^6\,{\rm cm}^{-3}} \right)^{-1/2} M_\odot$$

I. Nonthermal Brehmsstruhlung

D. Cosmic Ray Irradiation of Molecular Gas: FeI 6.4 KeV

- Fe Kα intensity vs. Synchrotron flux



$$I_{K\alpha} = \frac{40.1\mathrm{eV} \times \zeta \times \mathrm{N_H} \times \mathrm{q}}{4\pi} \ \mathrm{ph\ s^{-1}\ cm^{-2}\ sr^{-1}}$$

- Requires that
- N_H=3x10^{23} cm^{-2}

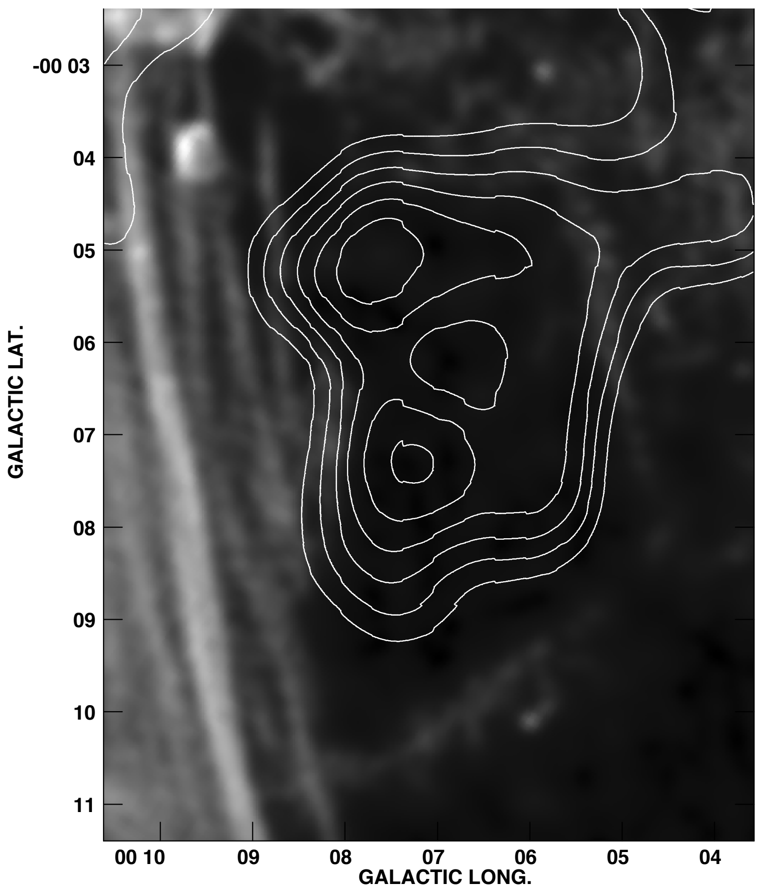
ζ =3x10^{-15} s^{-1}

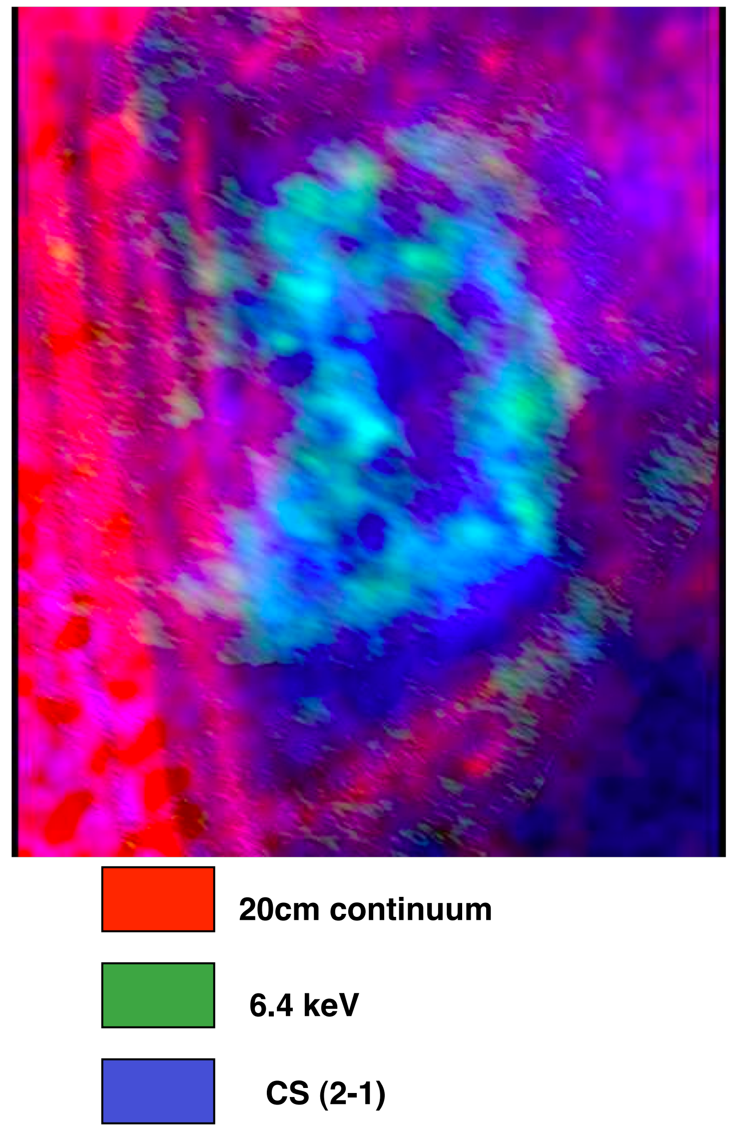
- Or

ζ N_H > 10^{9} s^{-1} cm^{-2}

D. Cosmic Ray Irradiation of Molecular Gas: FeI 6.4 KeV

Radio Arc

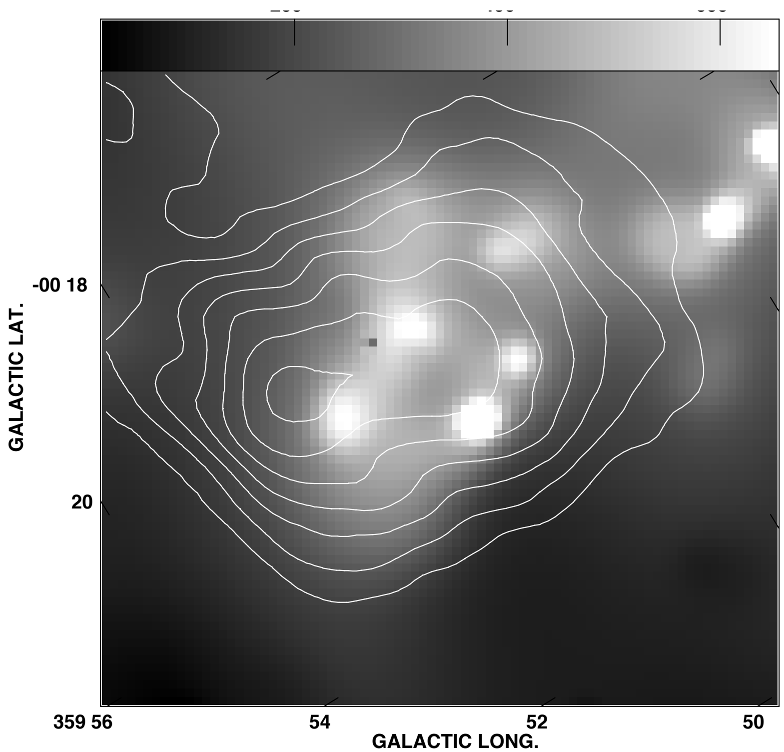


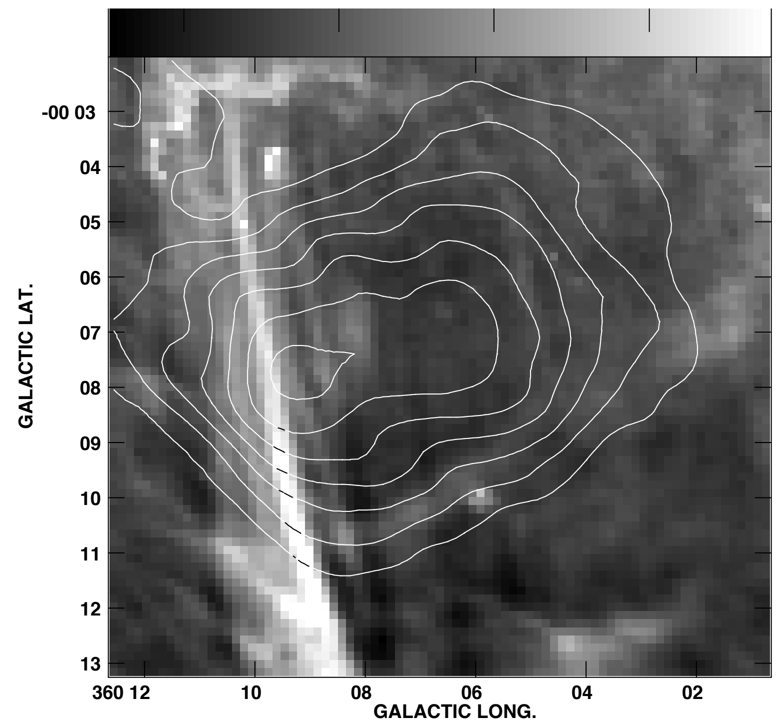


- Morphology
- An embedded cloud
- A bath of synchrotron radiation

D. Cosmic Ray Irradiation of Molecular Gas: FeI 6.4 KeV

Radio Arc



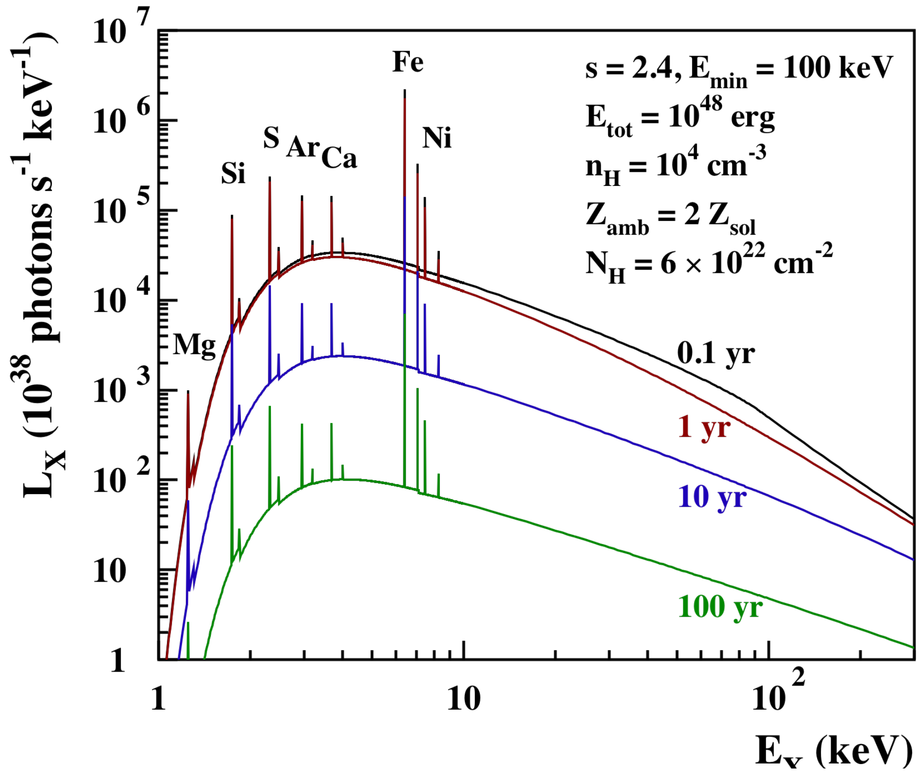


- Contours of 74 MHz emission
- 6.4 keV line emission

- Contours of 74 MHz emission
- 1.4 GHz Emission

D. Cosmic Ray Irradiation of Molecular Gas: CR Losses

- Time evolution of a power law distribution
- Rapid ionization losses at low energies
- Expected X-ray flux as a function of time
- Similar to observed time variability of 6.4 KeV line



Conclusions

- Interaction of Nonthermal Electrons + Molecular Gas

– LECR population
– ($\zeta \sim 10^{-15-14}$ s^{-1})
– Variable 6.4 keV line
– Heating of Molecular gas to high T

– HECR population
– GeV emission
– TeV Gamma-ray Emission

– Consequences: self-consistent check on the applicability of the model