Galactic Centre Dark Matter Constraints

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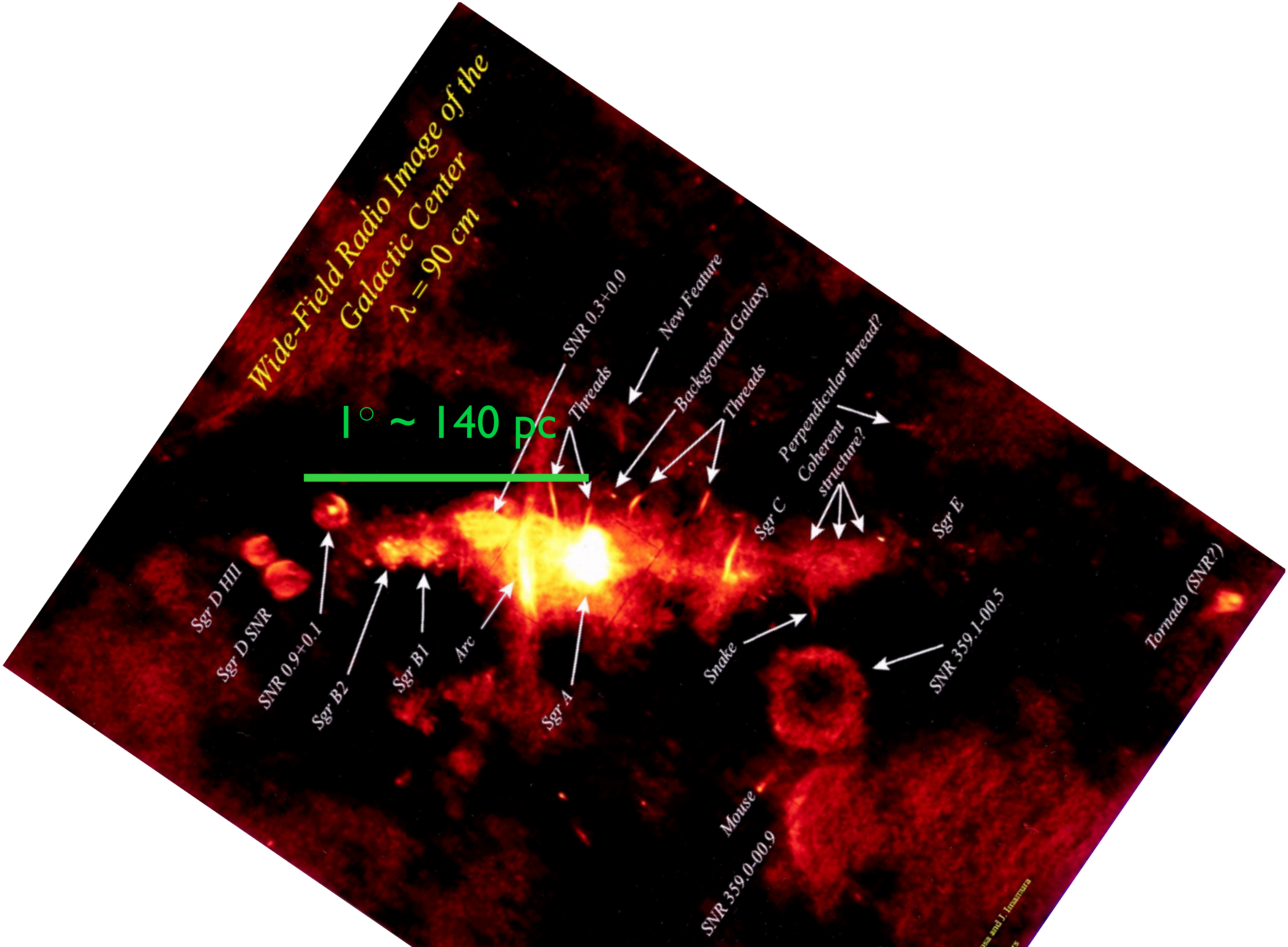
MARIE CURIE ACTIONS

Refs:

GC Magnetic field: Crocker, Jones, Melia, Ott, Protheroe, Nature 468:65 2010 (1001.1275)

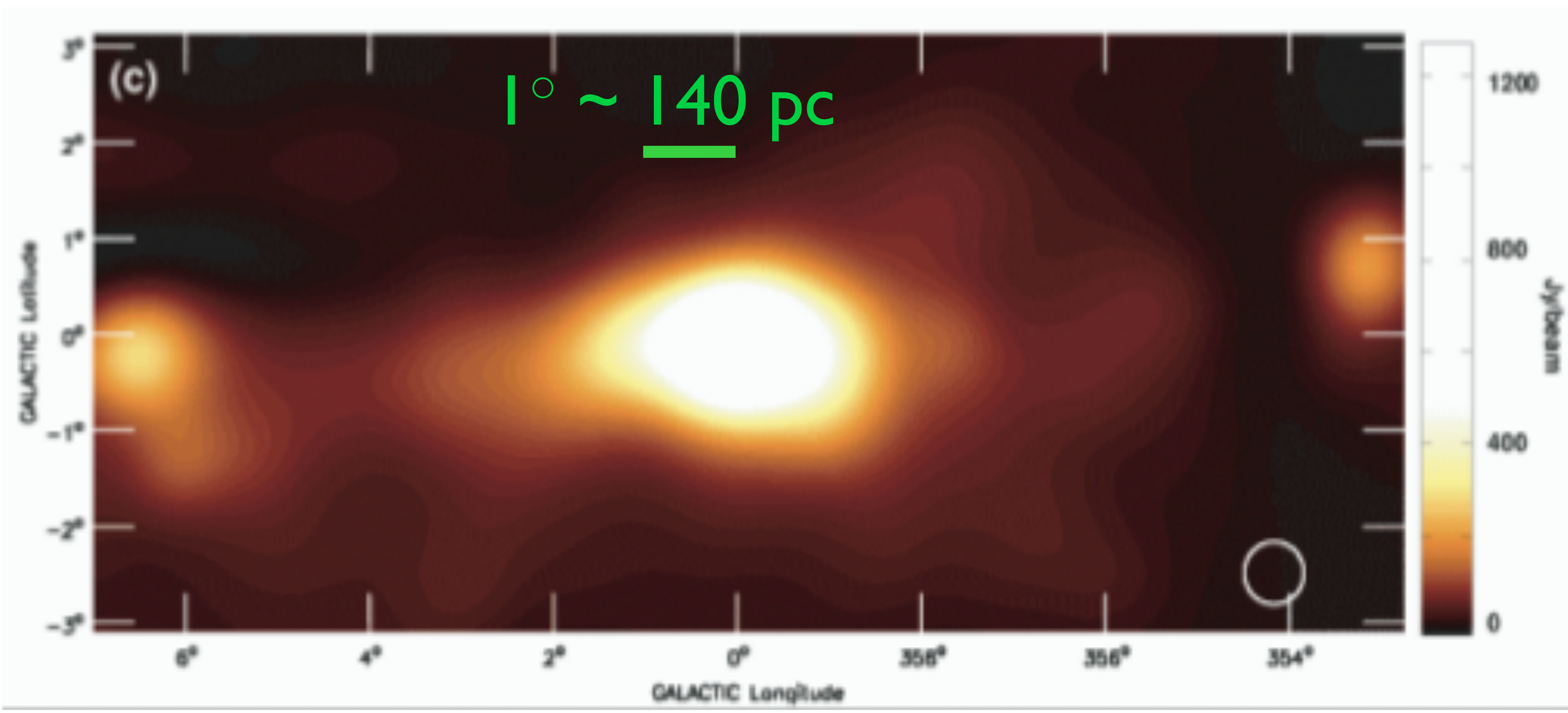
GC DM constraints: Crocker, Bell, Balazs, Jones, PRD 81:063516 2010 (1002.0229)



Wide-Field Radio Image of the Galactic Center
λ = 90 cm
1° ~ 140 pc
SNR 0.3+0.0
Threads
New Feature
Background Galaxy
Threads
Perpendicular thread?
Coherent structure?
Sgr C
Sgr E
Sgr D HII
Sgr D SNR
SNR 0.9+0.1
Sgr B2
Sgr B1
Arc
Sgr A
Snake
SNR 359.1-00.5
Tornado (SNR?)
Mouse
SNR 359.0-00.9

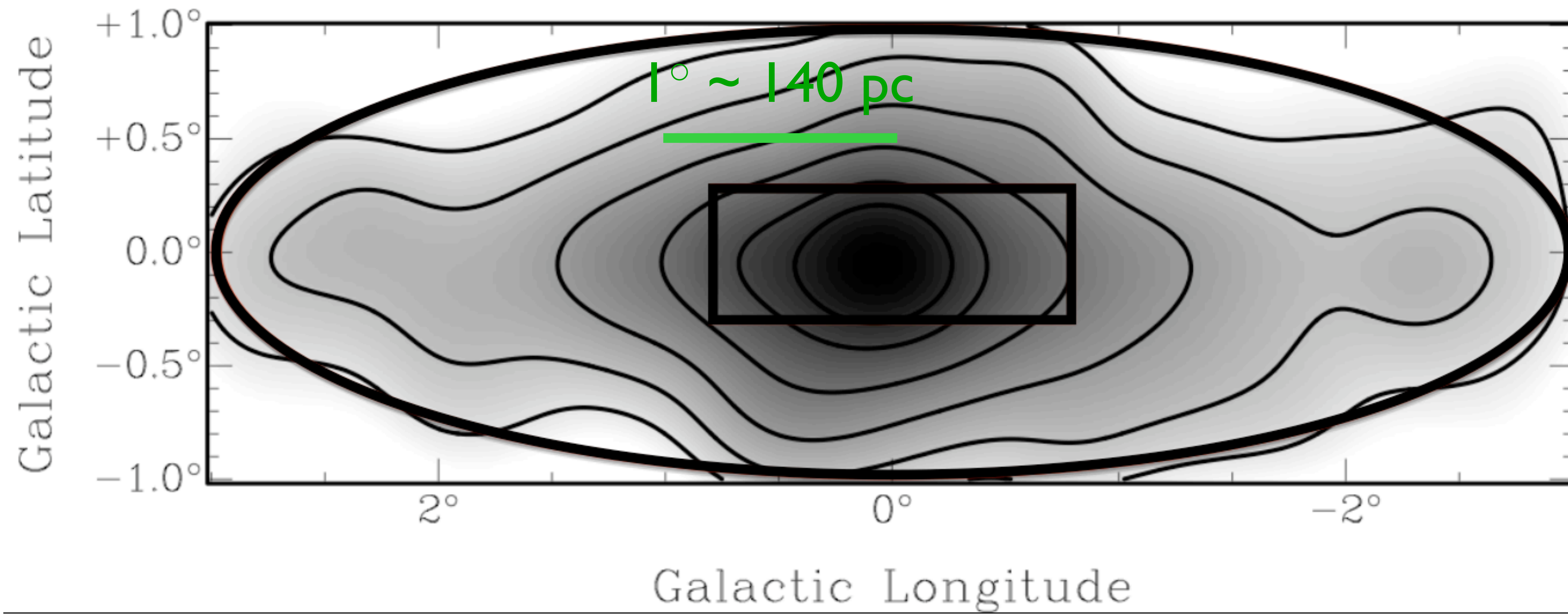
GC: Diffuse, Non-thermal Source on ~6° scales

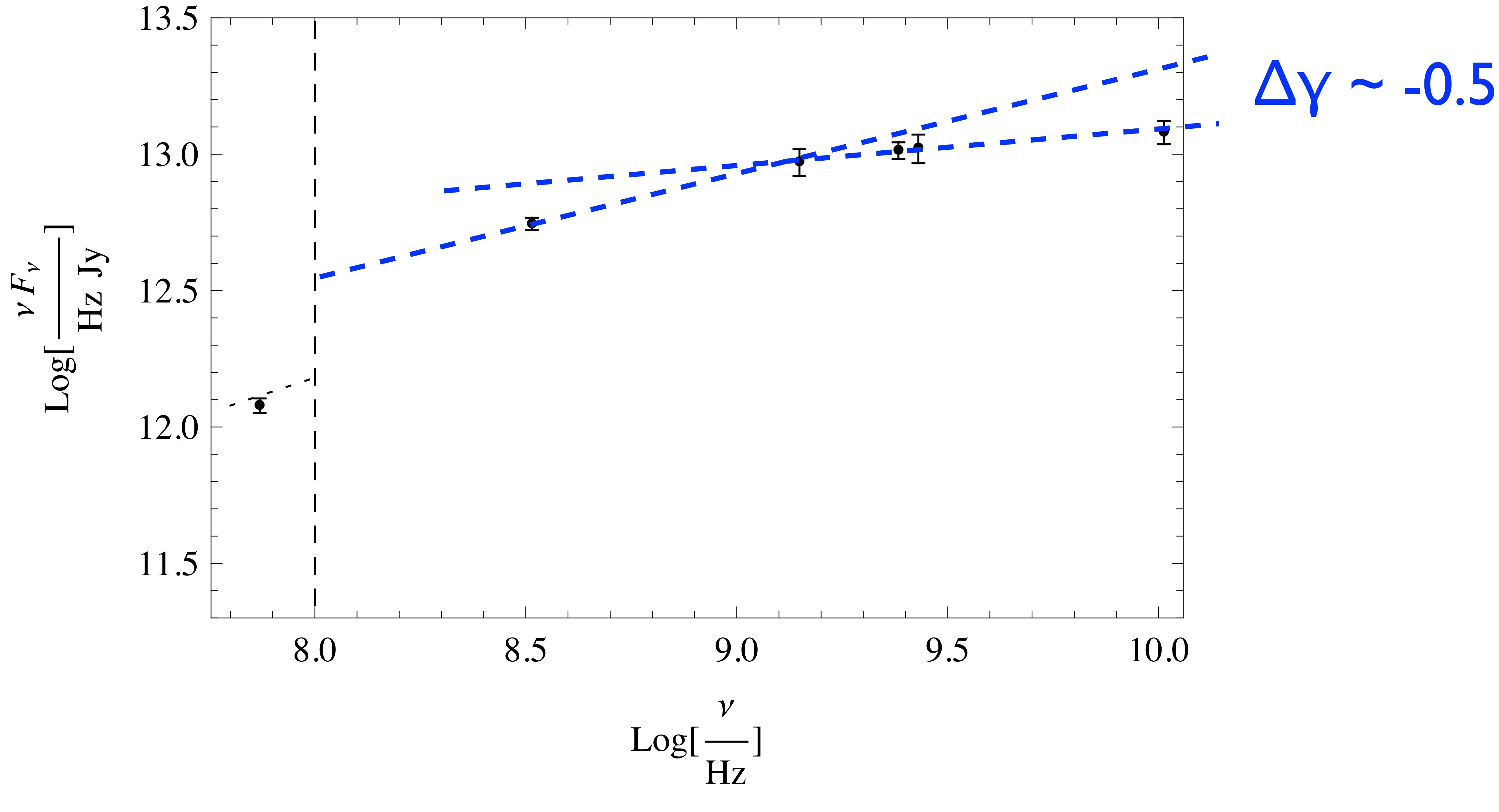
330 MHz (GBT, LaRosa et al 2005)



GC: Diffuse, Non-thermal Source on ~6° scales

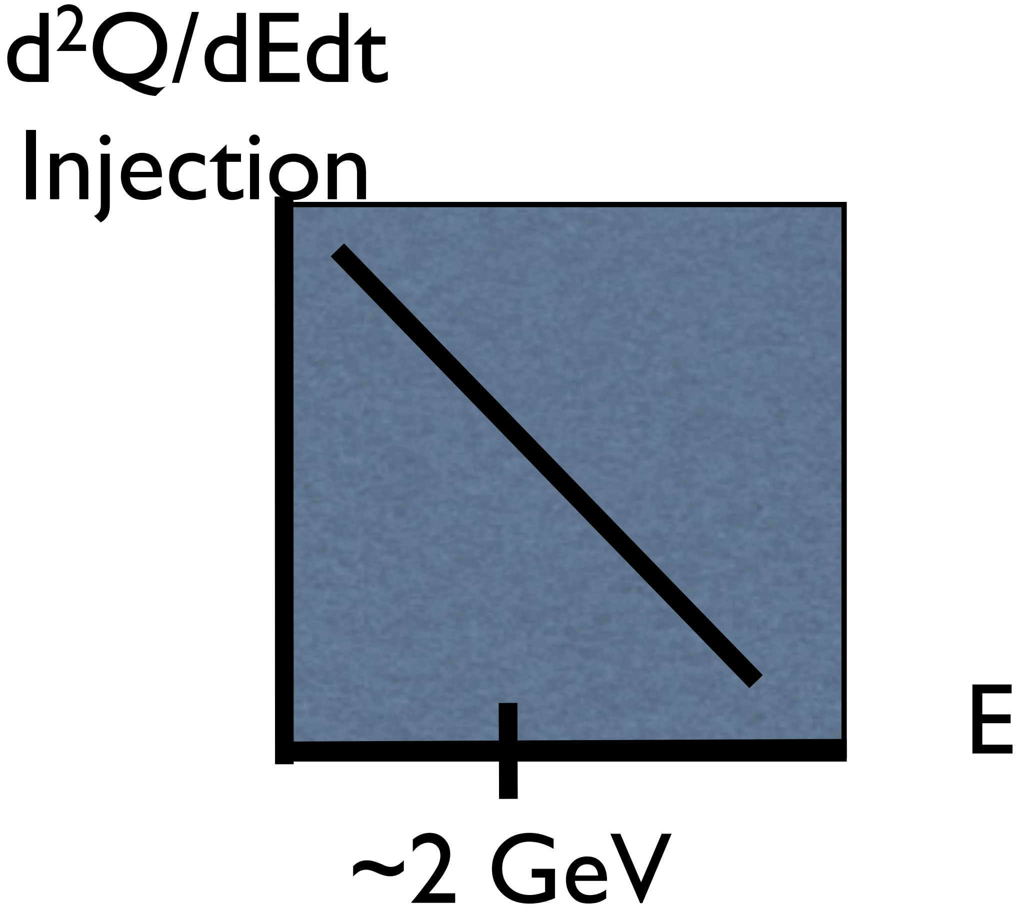
10 GHz (Nobeyama, Handa et al 1987)



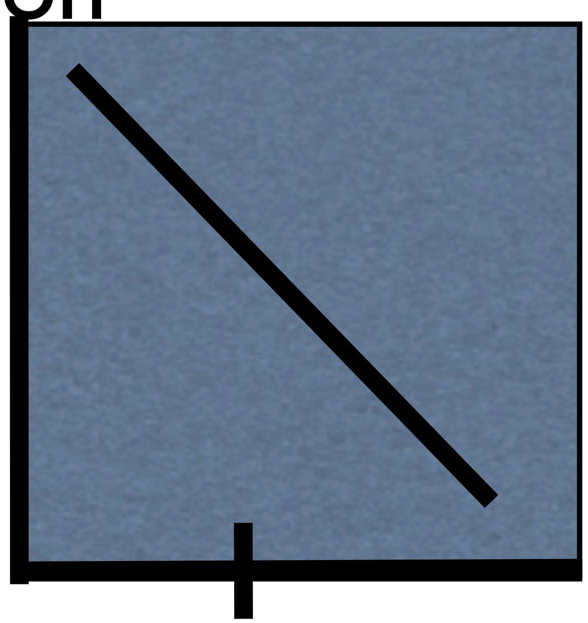


13.5
13.0
12.5
12.0
11.5
8.0
8.5
9.0
9.5
10.0
$\mathrm{Log}[\frac{\nu F_\nu}{\mathrm{Hz\ Jy}}]$
$\mathrm{Log}[\frac{\nu}{\mathrm{Hz}}]$
Δγ ~ -0.5

Electron Cooling



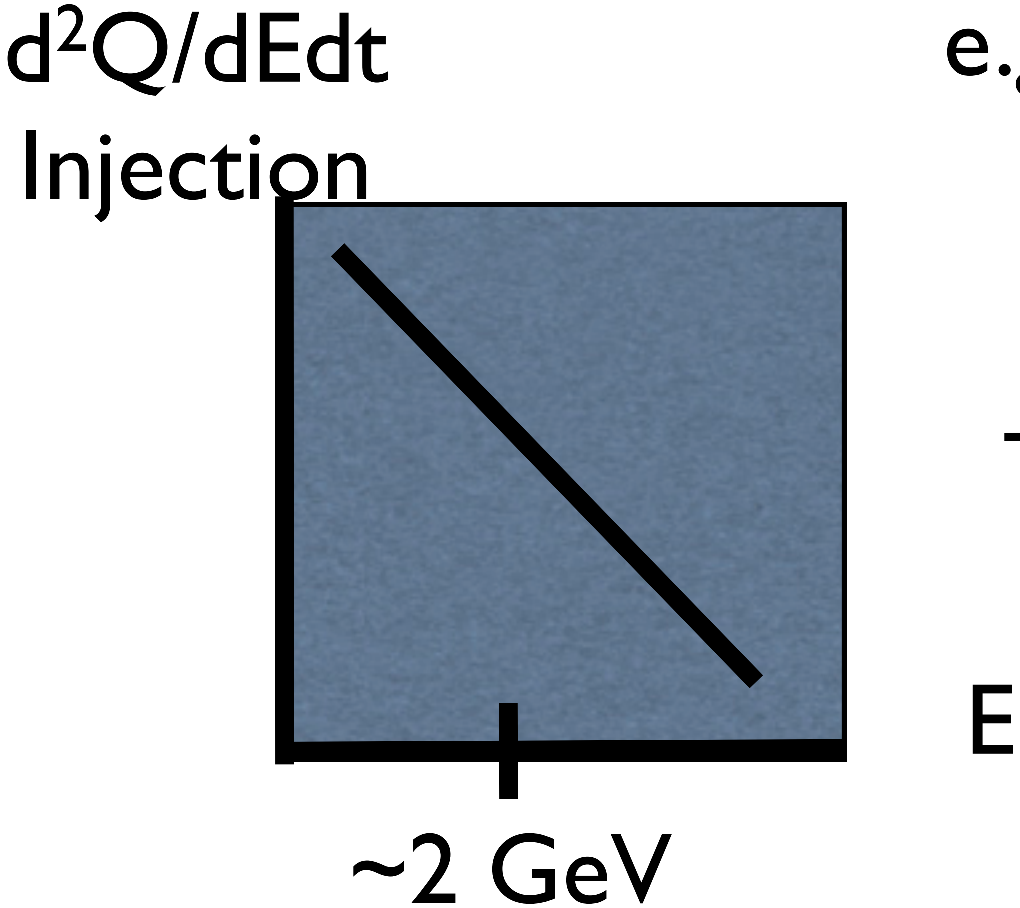
Electron Cooling



e.g. **B**=0.1 mG

$n_{H2} \sim 30\ cm^{-3}$

Electron Cooling



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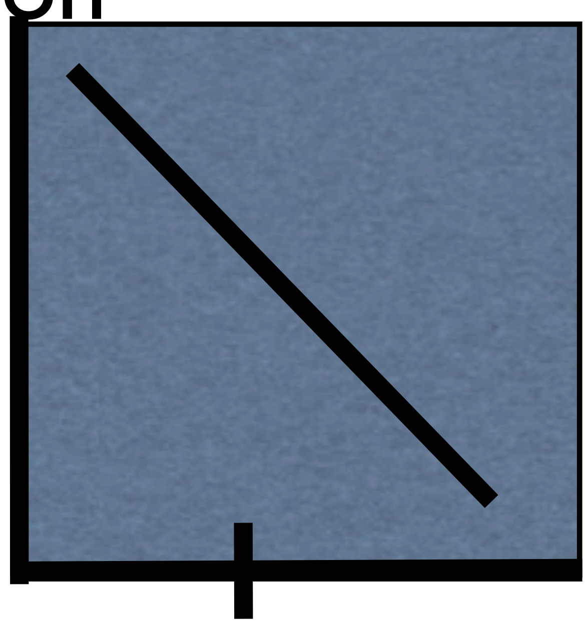
Cooling

Electron Cooling



e.g. $\mathbf{B}$=0.1 mG

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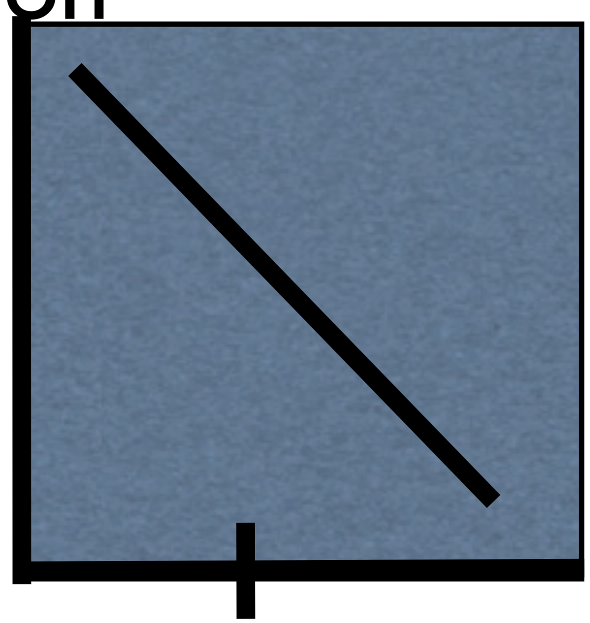
Cooling

$$E_{bk} = E_{bk}[n_H, \mathbf{B}]$$

Electron Cooling



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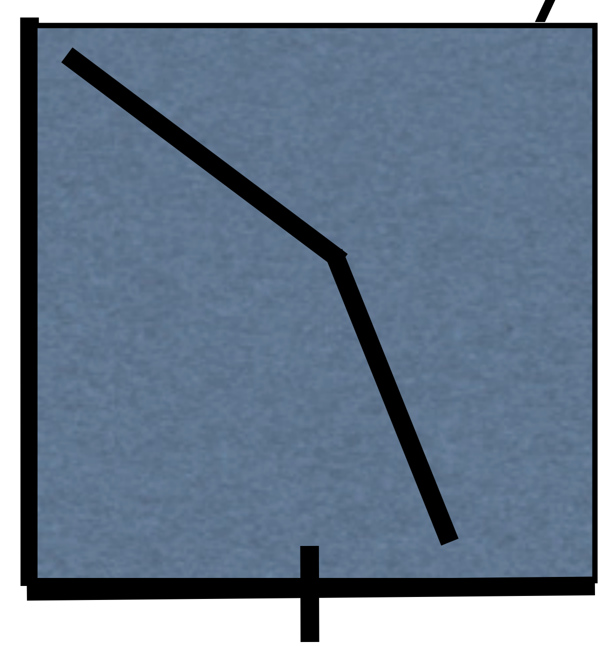
Cooling

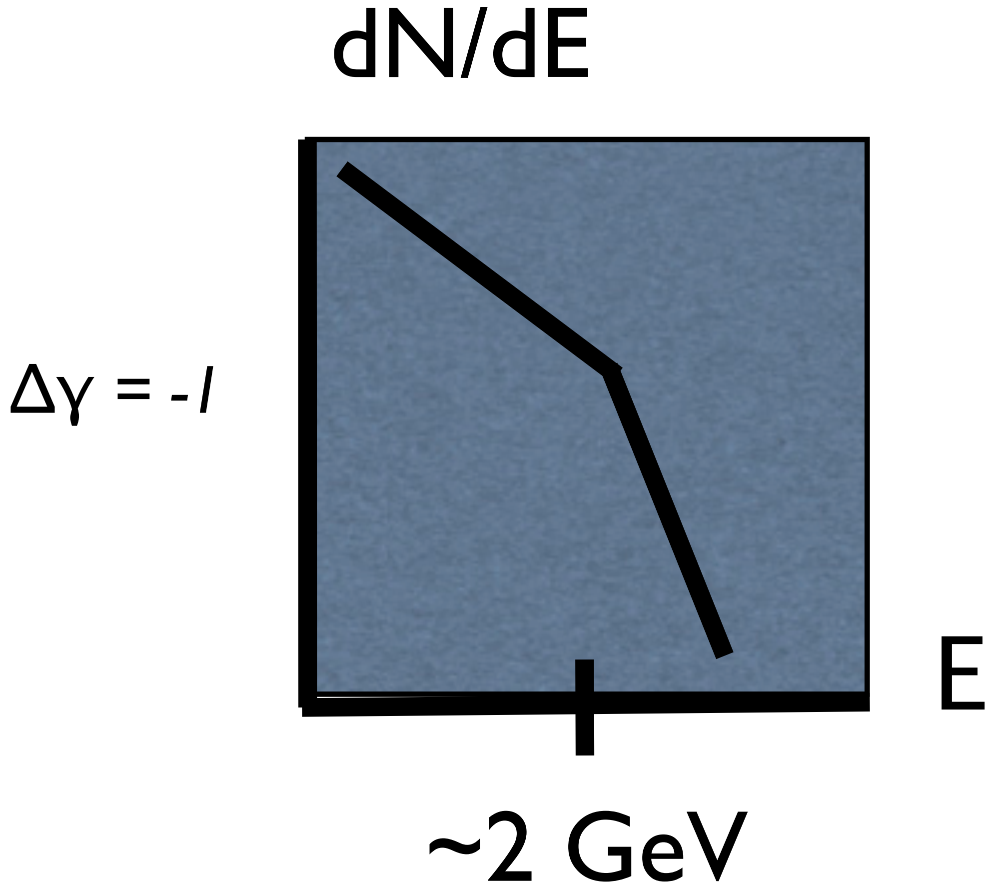


$\Delta\gamma = -1$

$E_{bk} = E_{bk}[n_H, \mathbf{B}]$

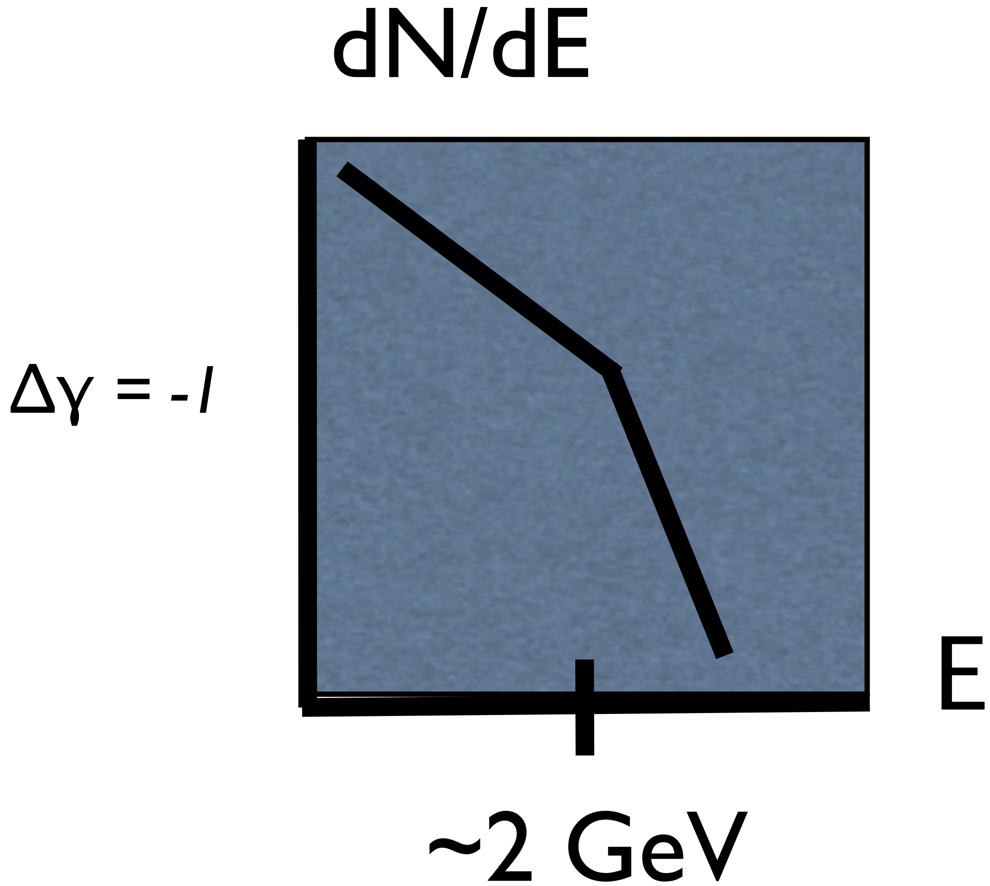
Synchrotron Spectrum of Cooled Electrons

Synchrotron Spectrum of Cooled Electrons



Synchrotron Spectrum of Cooled Electrons

e.g. **B**=0.1 mG

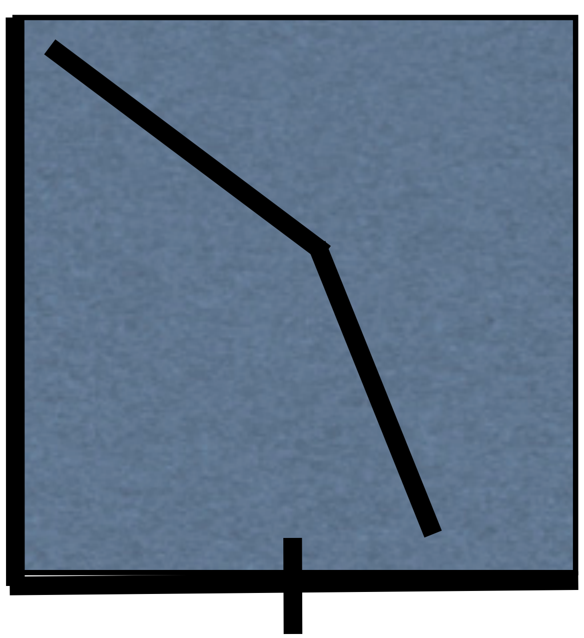


Synchrotron Spectrum of Cooled Electrons

e.g. **B**=0.1 mG

dN/dE

Δγ = -*1*



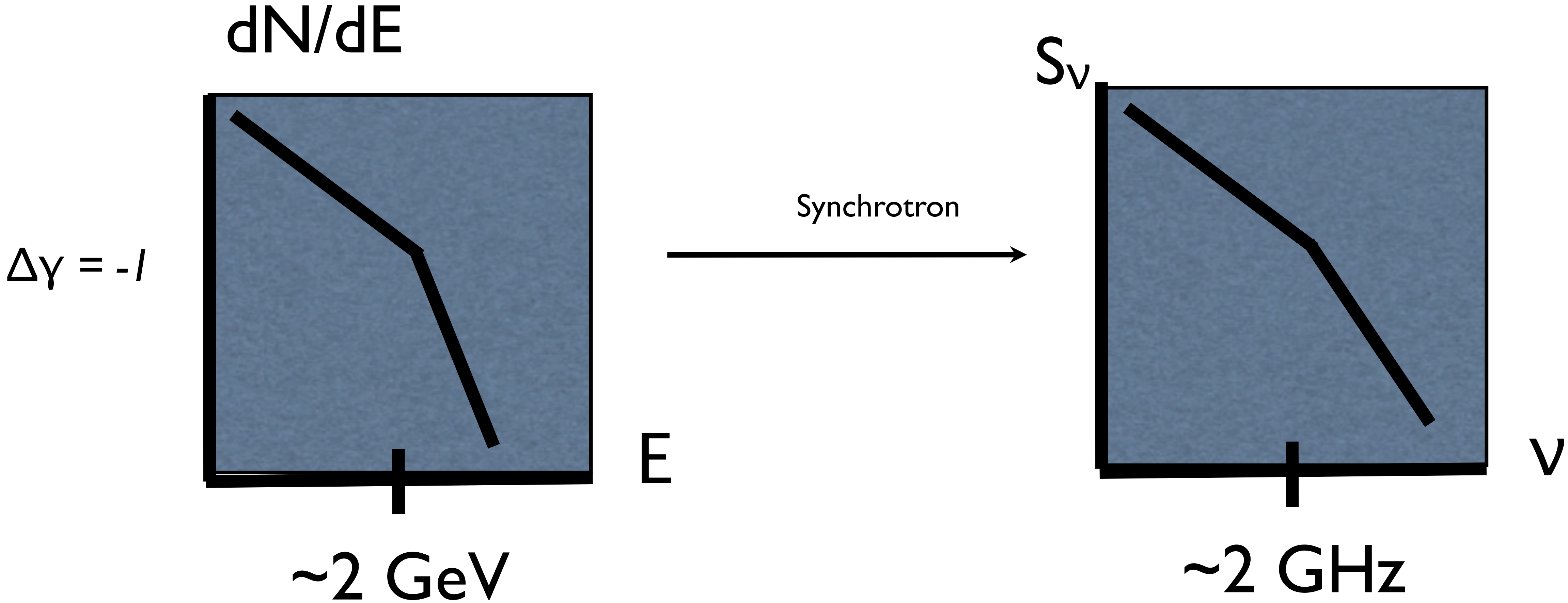
E

~2 GeV

Synchrotron →

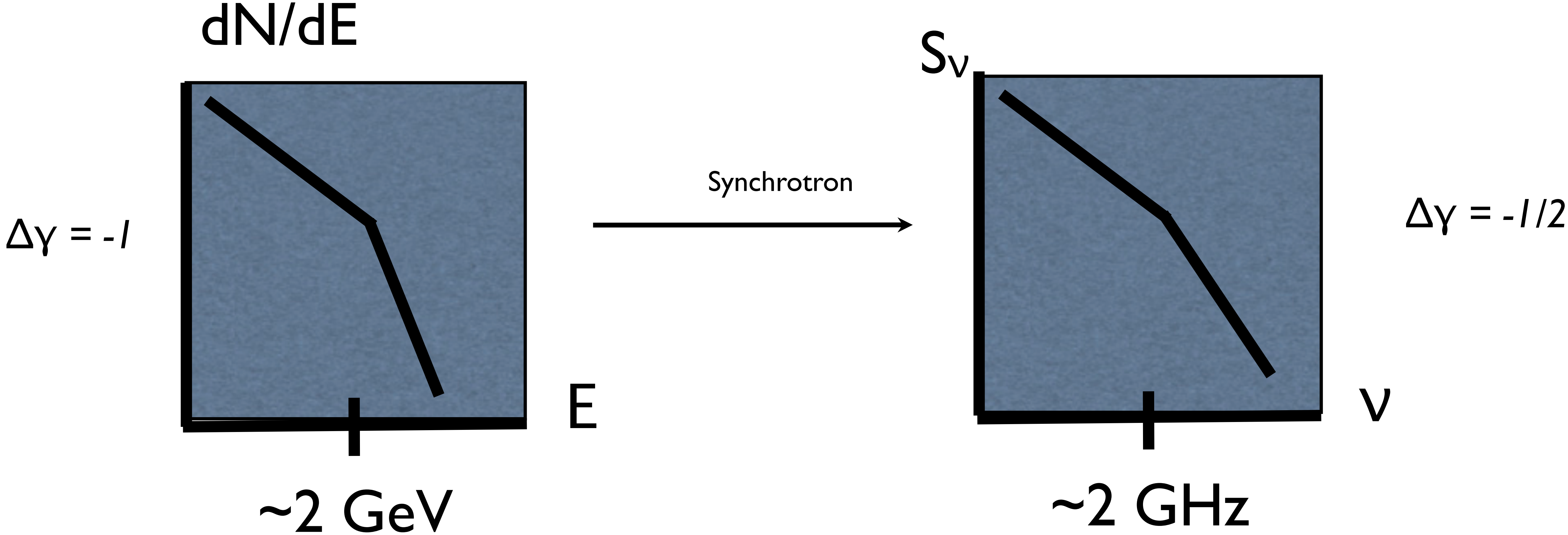
Synchrotron Spectrum of Cooled Electrons

e.g. **B**=0.1 mG



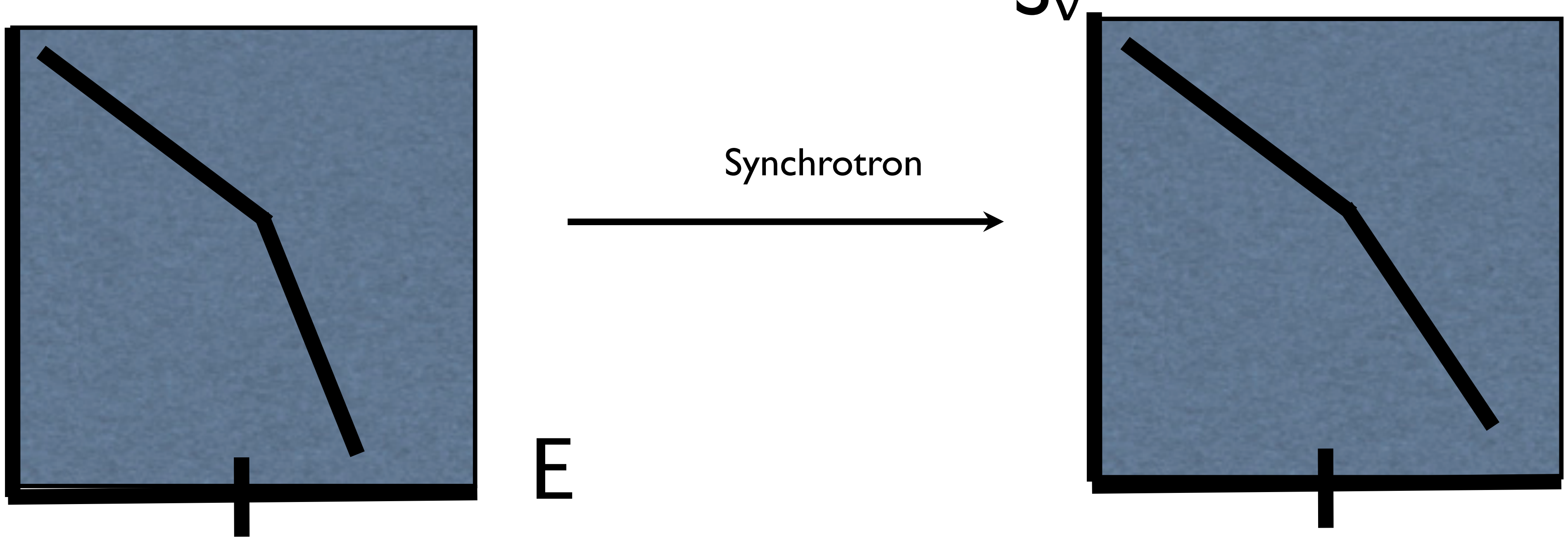
Synchrotron Spectrum of Cooled Electrons

e.g. **B**=0.1 mG



Synchrotron Spectrum of Cooled Electrons

e.g. $\mathbf{B}$=0.1 mG

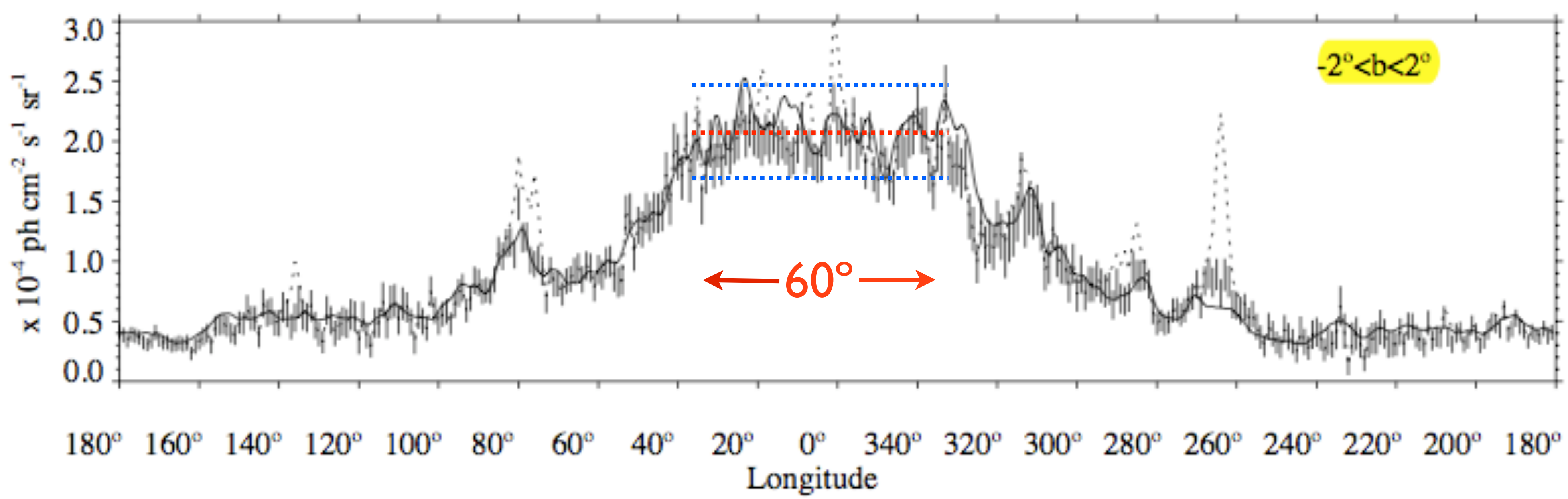


$$\nu_{bk} = \nu_{bk}[n_H, \mathbf{B}]$$

- know n_H
- know steady-state (cooled) electron population
- ➟can predict bremsstrahlung emission by same electron population
- electrons synchrotron radiating at ~GHz frequencies are bremsstrahlung radiating at ~GeV energies

EGRET (GeV) Data

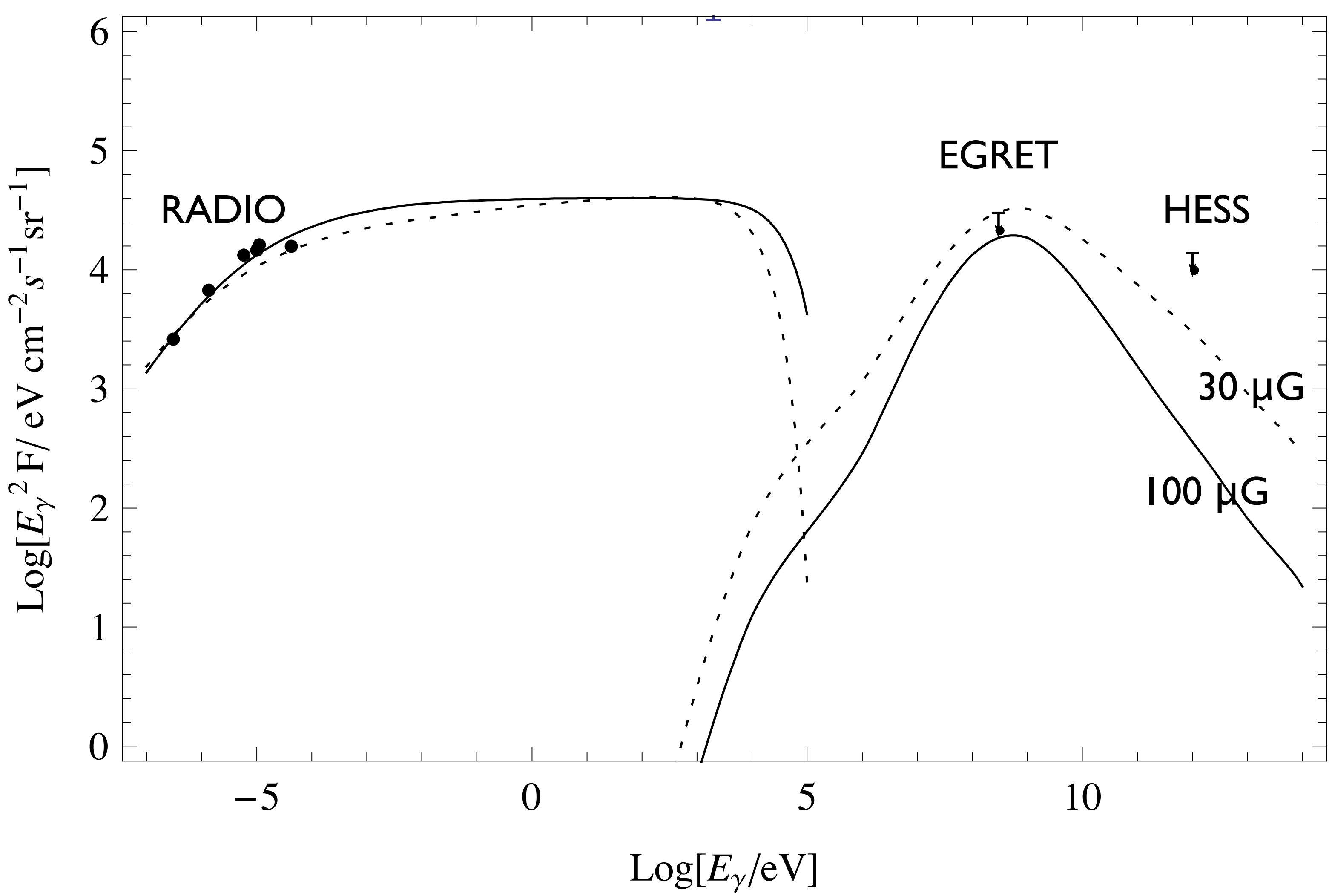
imply upper limit on the integral γ-ray intensity of
E > 300 MeV, | l | < 30.0° and | b | < 2.0° of 1 x 10^4 cm^{-2} s^{-1} sr^{-1}



300 MeV - GeV

Hunter et al. 1997

Modelled Broadband Spectrum



GC magnetic field is > 50 μG at 2σ confidence

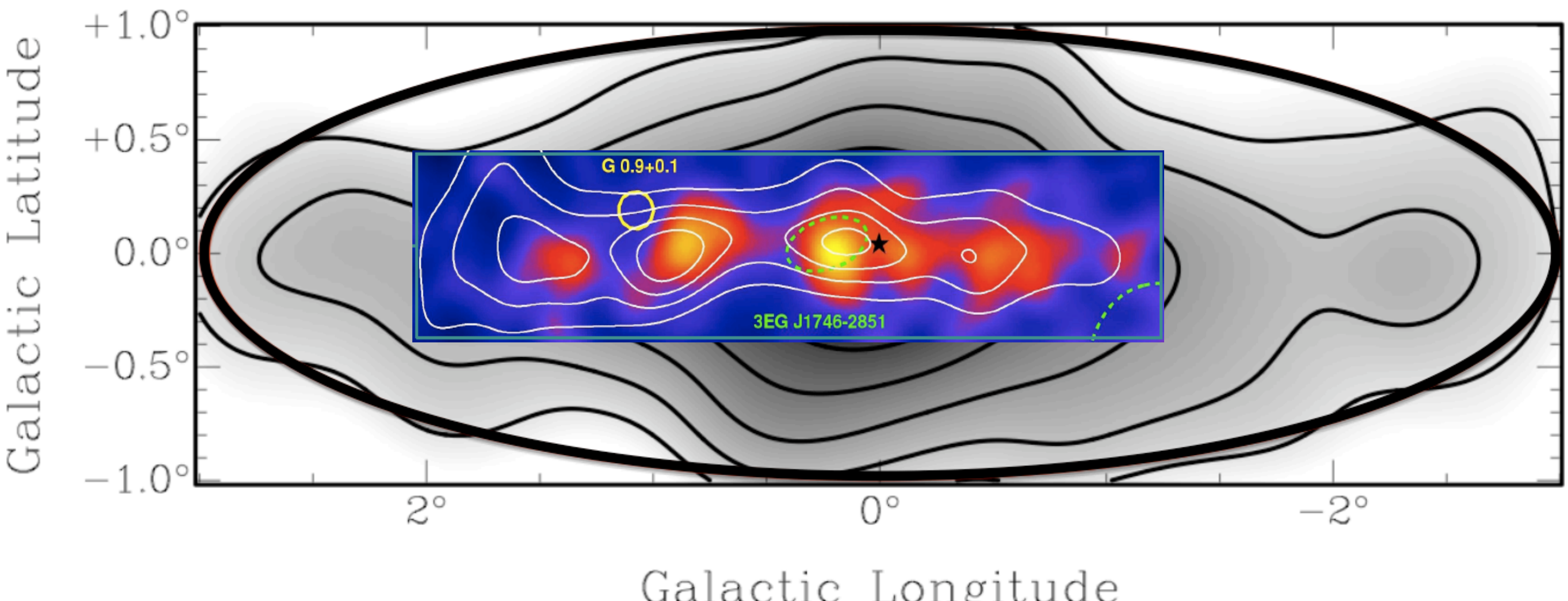
Possible Application to DM Constraints?

Radio Data

- Diffuse, non-thermal radio signal over freq range:
  - 74 MHz & 330 MHz (LaRosa et al. 2005)
  - 1.4 GHz → 10 GHz (assembled by us)
- 2 regions:
  - ellipse around the Galactic center (DNS) 3° semi-major axis & 1° semi-minor axis
  - smaller region around the Galactic center measured by HESS $|l| < 0.8°$ and $|b| < 0.3°$

HESS (TeV) Data

HESS data: $|\, l \,| < 0.8°$ and $|\, b \,| < 0.3°$
imply limit on the differential γ-ray intensity at 1 TeV of
$1.4 \times 10^{-20}\ cm^{-2}\ eV^{-2}\ s^{-1}\ sr^{-1}$
(Aharonian et al., Nature 439, 695, 2006)



DM Constraints: Strategy

- DM annihilation produces e^- e^+ pairs in the GC
- e^-s & e^+s cool by
  - ionization
  - bremsstrahlung
  - synchrotron
  - inverse Compton scattering
- radio and γ-ray data from the GC should constrain $<\sigma_{ann} v>$ and M_{DM}

Dark matter annihilation and primary e^+e^- spectrum

- Free parameters: $<\sigma_{ann}\, v>$ and M_{DM}
- Assume two annihilation processes:
  - $\chi\chi \longrightarrow e^+e^-$ $\longrightarrow$ monochromatic
  - $\chi\chi \longrightarrow$ qbar q $\longrightarrow \ldots \longrightarrow e^+e^-$

$\longrightarrow$polynomial in (E_e/m_χ) a la Borriello et al. 2008

- annihilation channels $\chi\chi \longrightarrow$ ZZ, WW lead to very similar e^+e^- spectrum as the $\chi\chi \longrightarrow$ qq channel

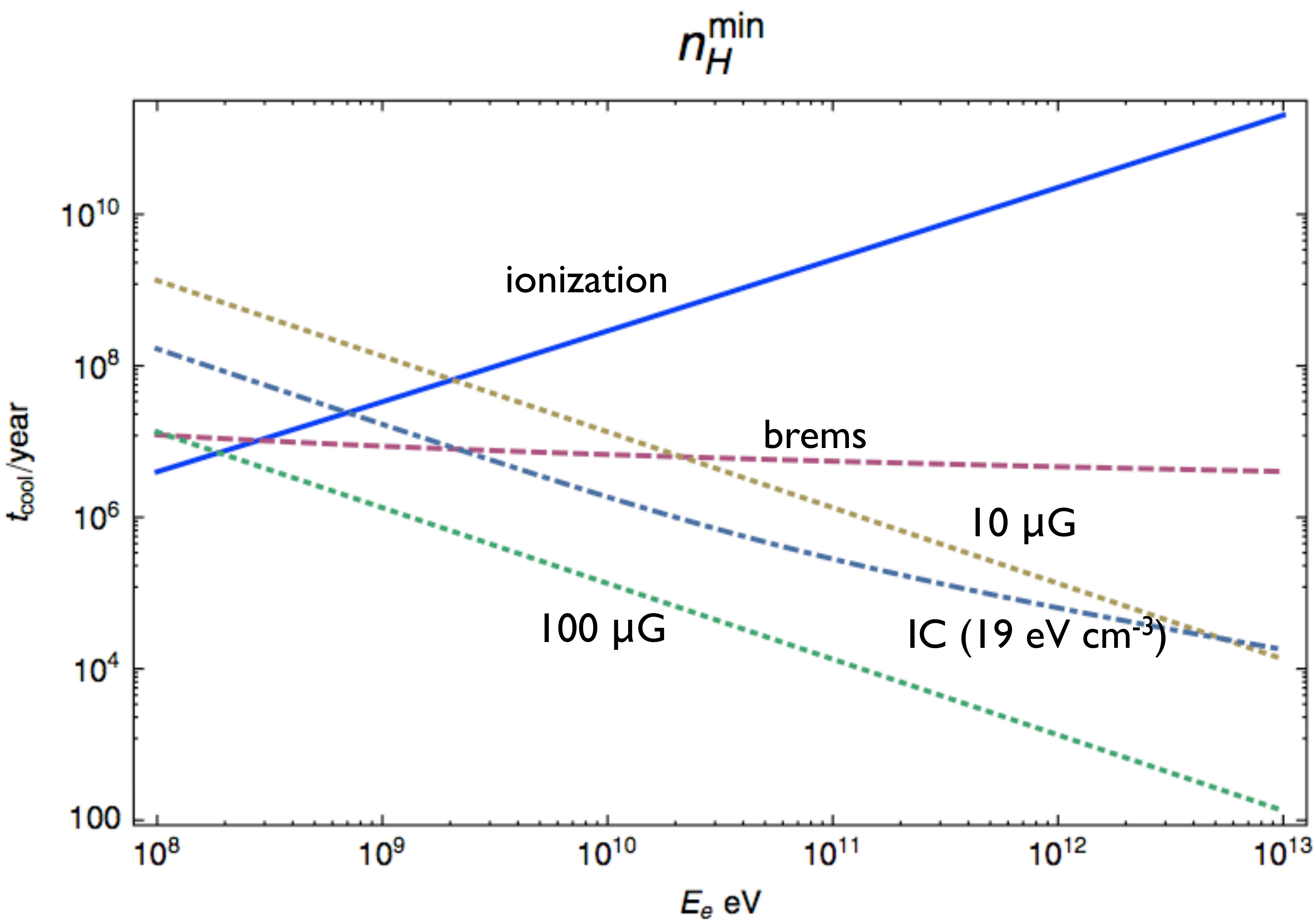
DM constraint

- use radio and gamma-ray observations already described
- BUT cannot self-consistently employ derived magnetic field constraint...have to use previously determined reasonable ranges of 10-100 μG for DNS and 10-1000 for HESS regions

Gas environment

- $\langle n_H \rangle_{vol}$ = 13 cm^{-3} for DNS and $\langle n_H \rangle_{vol}$ = 120 cm^{-3}
- minimum (path averaged, excluding material in dense molecular cloud cores)
    - $n_H \sim 3$ cm^{-3} for DNS
    - $n_H \sim 20$ cm^{-3} for HESS region

Cooling Timescales



Steady-State Electron Population

Injection spectrum from DM annihilation:

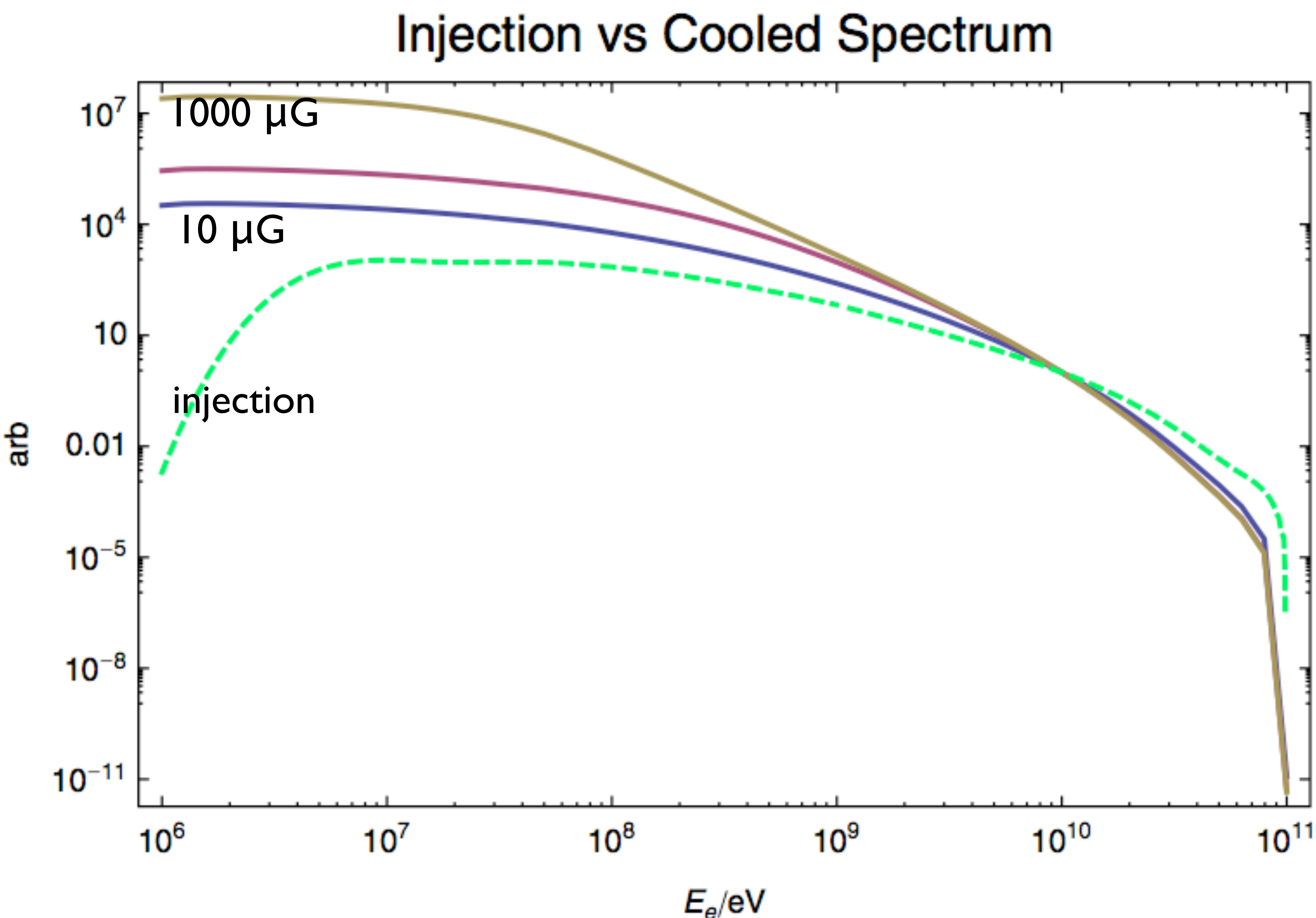
$$Q(E_e, r) = \frac{1}{2}\left(\frac{\rho(r)}{m_\chi}\right)^2 \langle\sigma_A v\rangle \frac{dN_e}{dE_e}$$

Cooled spectrum from DM annihilation:

$$\frac{dn_e}{dE_e}(E_e, \vec{r}) = \frac{\int_{E_e}^{m_\chi c^2} dE'_e Q(E'_e, \vec{r})}{-dE_e(E_e)/dt}$$

“thick target”

Injection and Cooled Spectra



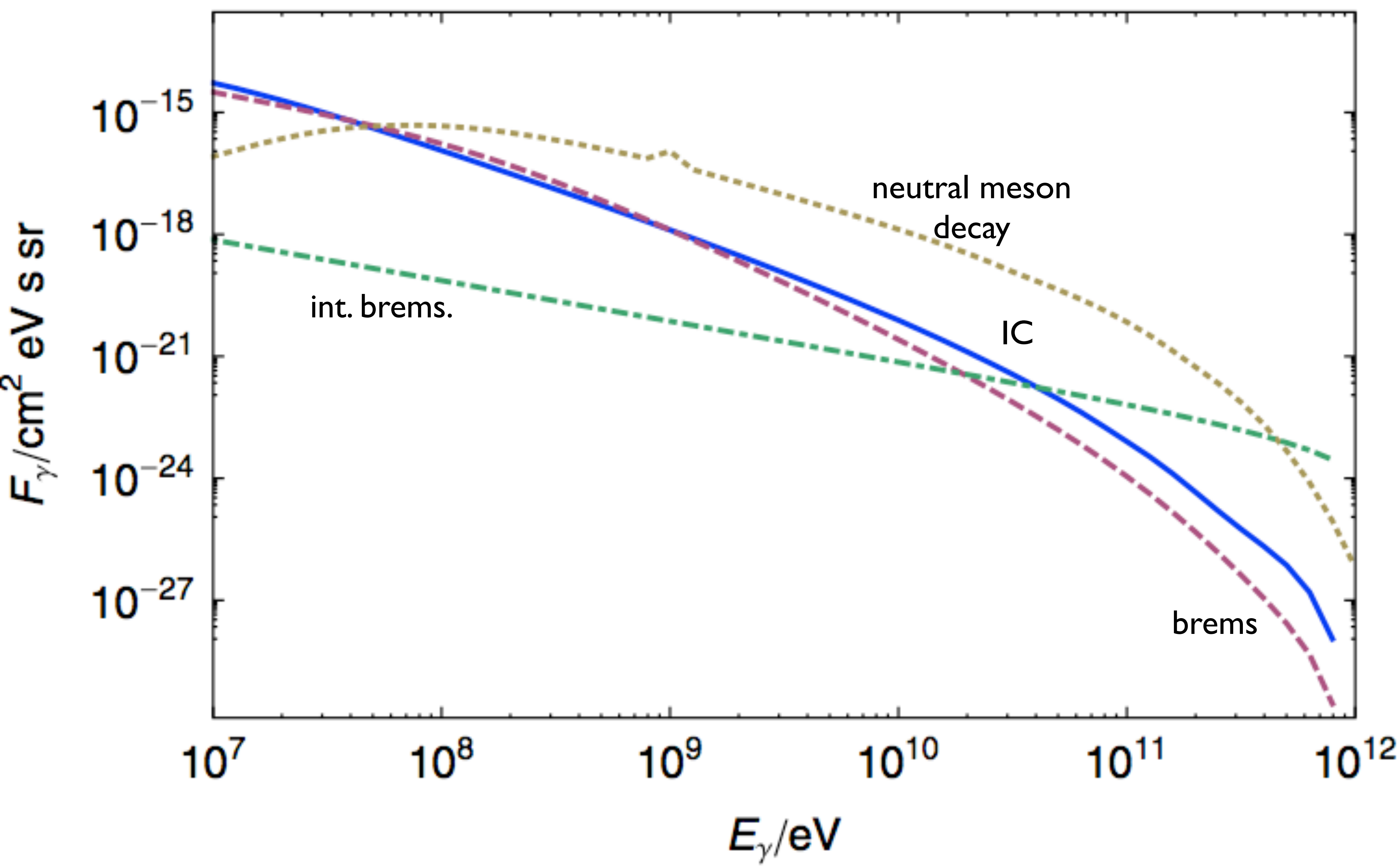
E.g.:

$XX \longrightarrow$ qbar q

m_X = 100 GeV

n_H = 3 cm^{-3}

Radiative Processes



E.g. Spectrum:

XX⟶qbar q

m_χ = 1 TeV

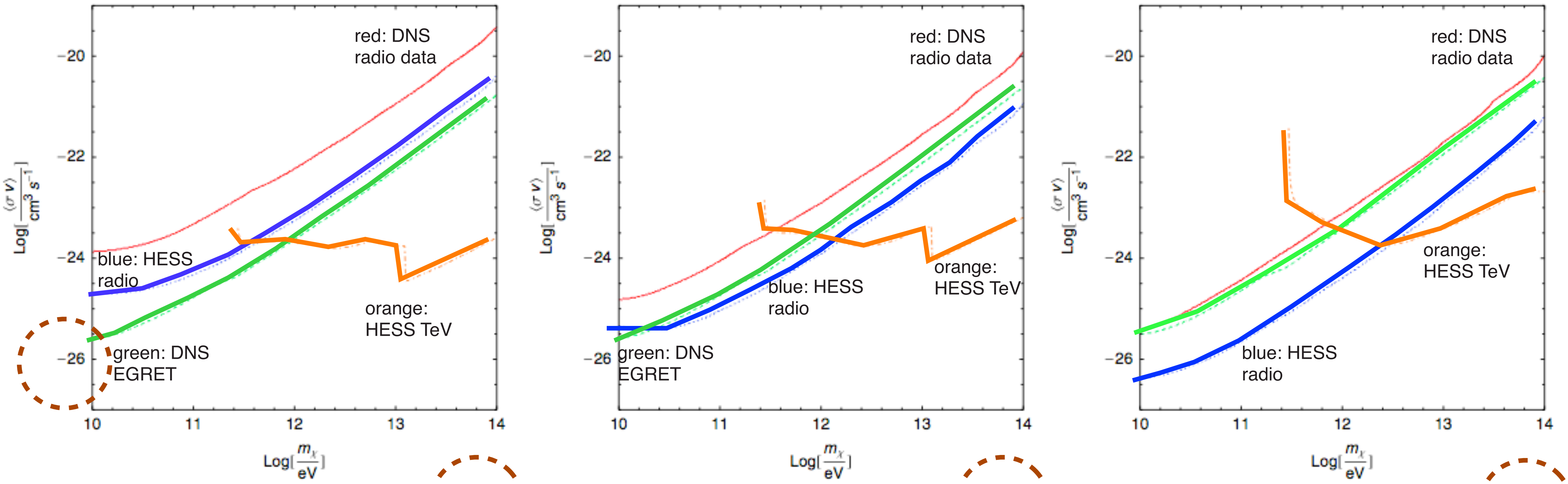
$\langle\sigma_{ann} v\rangle = 10^{-26}$ cm^3 s^{-1}

B = 100 μG

n_H = 3 cm^{-3}

DM Constraints

e.g. NFW & χχ→qbar q

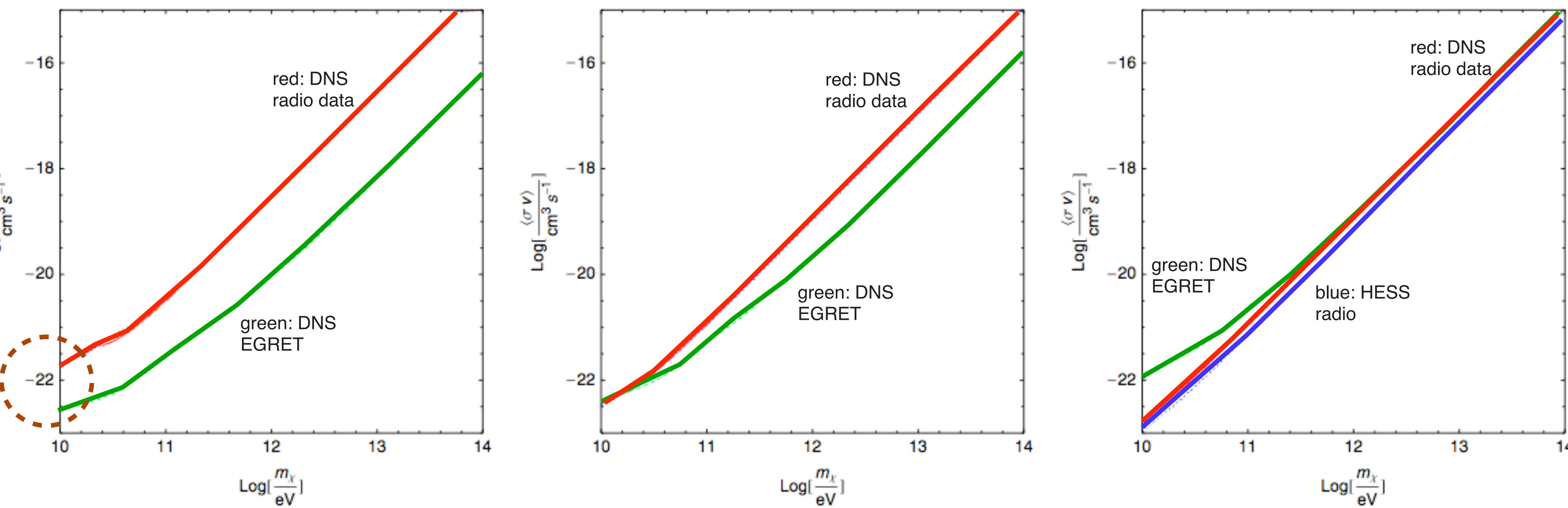


(a) $\chi\chi \rightarrow \bar{q}q$; NFW profile; $B = 10\mu$G. (b) $\chi\chi \rightarrow \bar{q}q$; NFW profile; $B = 30\mu$G. (c) $\chi\chi \rightarrow \bar{q}q$; NFW profile; $B = 100\mu$G.

...relative insensitivity to magnetic field

DM Constraints

e.g. ISO & $\chi\chi \rightarrow e^+e^-$



(a) $\chi\chi \rightarrow e^+e^-$; Isothermal profile; $B = 10\mu$G.

(b) $\chi\chi \rightarrow e^+e^-$; Isothermal profile; $B = 30\mu$G.

(c) $\chi\chi \rightarrow e^+e^-$; Isothermal profile; $B = 100\mu$G.

...relative insensitivity to magnetic field

N.B. no HESS TeV constraint for ISO

Conclusions

- Combination of gamma-ray and radio data is relatively insensitive to assumed magnetic field
- Our constraints conservative as we
  - do not remove astrophysical contributions to the radio data
  - ignore contribution to radio emission from DM annihilation e^+e^- along LOS but out of GC
- Get 1-2 orders of magnitude better constrains than previous, most comparable limits
- Constraints rule out sizeable portion of parameter space favoured to explain various positron anomalies
- For, e.g., NFW and qbar q annihilation we constrain the allowed boost factors to
  - $\lesssim 1$ at $M_X = 1$ GeV
  - < 1000 at $M_X = 1$ TeV

Comparison

XX⟶qbar q

NFW