The interstellar magnetic field near the Galactic center

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Magnetic fields on scales from kilometres to kiloparsecs: properties and origin

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Outline

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The old picture

Non-thermal radio filaments (NRFs) $\perp$ GP

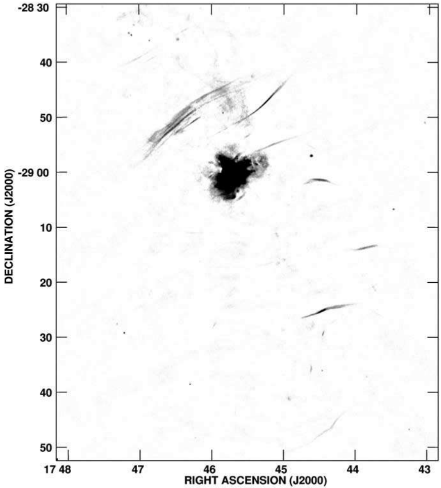
* Morphology & radio polarization measurements
  $\vec{B} \parallel$ filaments $\Rightarrow$ $\vec{B} \perp$ GP at low $|z|$
  $\Rightarrow$ $\vec{B}$ poloidal in general

* Dynamical argument
  No/little bending of NRFs $\Rightarrow$ $P_{\rm mag} > P_{\rm ram}$
  $\Rightarrow$ $B \gtrsim 1$ mG inside NRFs

* Pressure balance argument
  Confinement of NRFs $\Rightarrow$ $B_{\rm out} \sim B_{\rm in}$
  $\Rightarrow$ $B \gtrsim 1$ mG everywhere

☞ *Pervasive strong ($\gtrsim 1$ mG) & poloidal $\vec{B}$*

Non-thermal radio filaments



(Nord et al., AJ, 128, 1646, 2004)

Problems in derivation of mG field

- Dynamical argument

  No/little bending of NRFs $\Rightarrow$ $P_{\rm mag} > P_{\rm ram}$ $\Rightarrow$ $B \gtrsim 1$ mG inside NRFs

  Potential problems :

  - Some NRFs are significantly distorted
  - Only a fraction of the NRFs are actually colliding with clouds
  - Condition $P_{\rm mag} \gtrsim P_{\rm ram}$ probably too stringent

    More adequate condition : $V_{\rm A} \gg v_{\rm cloud}$ $\Rightarrow$ $B \gg 10\ \mu$G inside NRFs

- Pressure balance argument

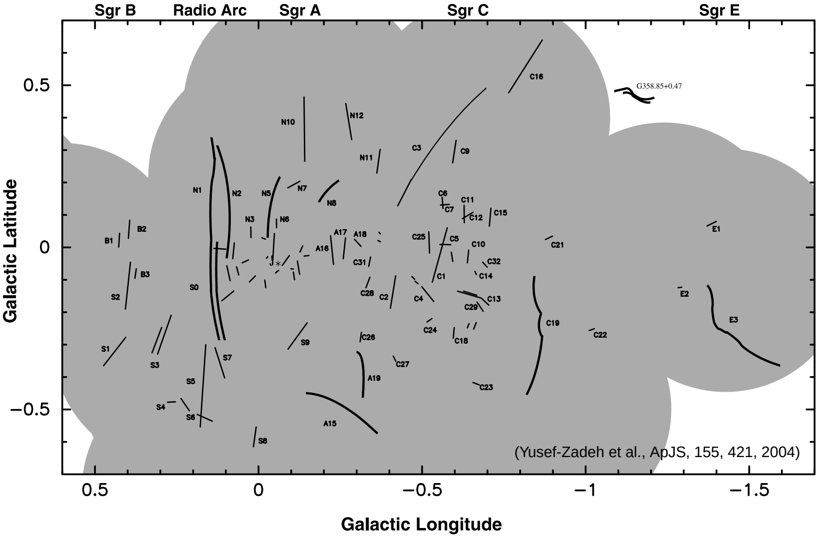
  Confinement of NRFs $\Rightarrow$ $B_{\rm out} \sim B_{\rm in}$ $\Rightarrow$ $B \gtrsim 1$ mG everywhere

  Other possibilities :

  - Confinement by thermal pressure of very hot gas
  - Confinement by magnetic tension
  - No confinement at all : NRFs are transient or dynamic structures

    (e.g., turbulent enhancements in B, magnetic wakes behind clouds ...)

Non-thermal radio filaments



Other problems with pervasive mG field

- Magnetic energy

  If $B \simeq 1$ mG throughout volume $\sim (300 \text{ pc})^2 \times 150$ pc $\Rightarrow$ $E_{\rm mag} \sim 10^{55}$ ergs

  ☞ $\sim$ energy released by 10^4 supernova explosions
  $\sim$ rotational kinetic energy in CMZ
  $\gg$ turbulent kinetic energy in CMZ
  $\gtrsim$ thermal energy of very hot gas

- Synchrotron lifetimes

  If $B \simeq 1$ mG

  $*$ $t_{\rm syn} \sim 3 \times 10^4$ yrs at $\nu \sim 1.5$ GHz
  ☞ CR e^- cannot travel entire length of longest NRFs

  $*$ $t_{\rm syn} \sim 1.2 \times 10^5$ yrs at $\nu \sim 74$ MHz
  ☞ CR e^- need to be injected/re-accelerated at implausibly high rate

Outline

Recent radio observations

- Radio continuum (synchrotron) emission

  $*$ Inside NRFs : $B_{\rm equip} \sim (50 - 200)\ \mu$G

  $*$ In large-scale diffuse ISM : $B_{\rm equip} \sim (6\ \mu{\rm G})\ (k/f)^{2/7} \quad \to (6 - 80)\ \mu$G

- Radio (synchrotron) + X-ray / γ-ray (Inverse-Compton / bremsstrahlung)

  $*$ In X-ray filament : $B \sim (30 - 130)\ \mu$G

  $*$ In large-scale diffuse ISM :
  Downward break in radio spectrum at ~ 1.7 GHz $\Rightarrow$ $B \gtrsim 50\ \mu$G

Other recent observations

- FIR/submm (dust thermal emission) polarization

  $\ast$ In dense molecular clouds : $\vec{B} \sim\parallel$ GP

- Faraday rotation

  $\ast$ In diffuse ionized medium : $|B_\parallel| \sim 10\ \mu$G

  If $\vec{B} \sim\perp$ GP $\Rightarrow$ $B \gg 10\ \mu$G

- Zeeman splitting

  $\ast$ In dense neutral clouds : $|B_\parallel| \lesssim (0.1 - 1)$ mG

  If $\vec{B} \sim\parallel$ GP $\Rightarrow$ consistent with $B \sim 1$ mG

Problems with equipartition field

- Equipartition assumption

  No theoretical justification

  ∗ In GD & in external galaxies (at large scales)

  $\vec{B} \parallel$ GP $\Rightarrow$ - CRs injected into ISM tend to be magnetically confined
  - When $P_{\rm CR} \gtrsim P_{\rm mag}$ $\Rightarrow$ Parker instability $\Rightarrow$ CRs escape

  ☞ Self-regulating mechanism

  ∗ In GC

  $\vec{B} \perp$ GP $\Rightarrow$ CRs injected into ISM directly escape along field lines

  ☞ No self-regulating mechanism, like Parker instability

- Proton-to-electron energy ratio

  Very uncertain value

  ∗ In GD & in external galaxies : $k \simeq 100$

  ∗ In GC, in extragalactic jets & in galaxy clusters : $k \simeq 1$

Other theoretical considerations

- **Inside NRFs**

  Apparent rigidity & organized structure
  $\Rightarrow$ NRFs are magnetically dominated
  $\Rightarrow$ $B > B_{\rm equip} \sim 100\ \mu$G

- **Dynamo scenario**

  If dynamo amplification & saturation
  $\Rightarrow$ $P_{\rm mag} \sim P_{\rm turb}$
  $\Rightarrow$ $B \sim 200\ \mu$G
  (everywhere or in localized filaments only)

Outline

1. The old picture
2. New ingredients
3. Conclusions

Conclusions

- In large-scale diffuse intercloud medium
  - $\ast$ $\vec{B} \sim$ poloidal
    - ☞ *inward advection from GD, outflows from GC, local dynamo*
  - $\ast$ $B \gtrsim 50\ \mu$G (??)
- Filamentary structures (NRFs)
  - $\ast$ $\vec{B} \sim$ poloidal
  - $\ast$ $B > 100\ \mu$G $\longrightarrow$ $B \gtrsim 1$ mG in some NRFs
    - ☞ *turbulent enhancements in B, magnetic wakes behind clouds*
- In dense molecular clouds
  - $\ast$ $\vec{B} \sim$ horizontal
    - ☞ *shearing of initially poloidal $\vec{B}$ by cloud motions or tidal forces, decoupling from intercloud $\vec{B}$ due to cloud rotation*
  - $\ast$ $B \sim 1$ mG