A Multi-Wavelength Study of Nonthermal Radio Filaments (NTFS)

First Direct Evidence for Interstellar Magnetic Reconnection

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MeerKAT 1.3 GHz band spectral index image, Heywood+ (2020)


1-2.5 keV
2.5-4 keV
4-9 keV
Chandra ACIS-I image
(Wang+2002, 2021)

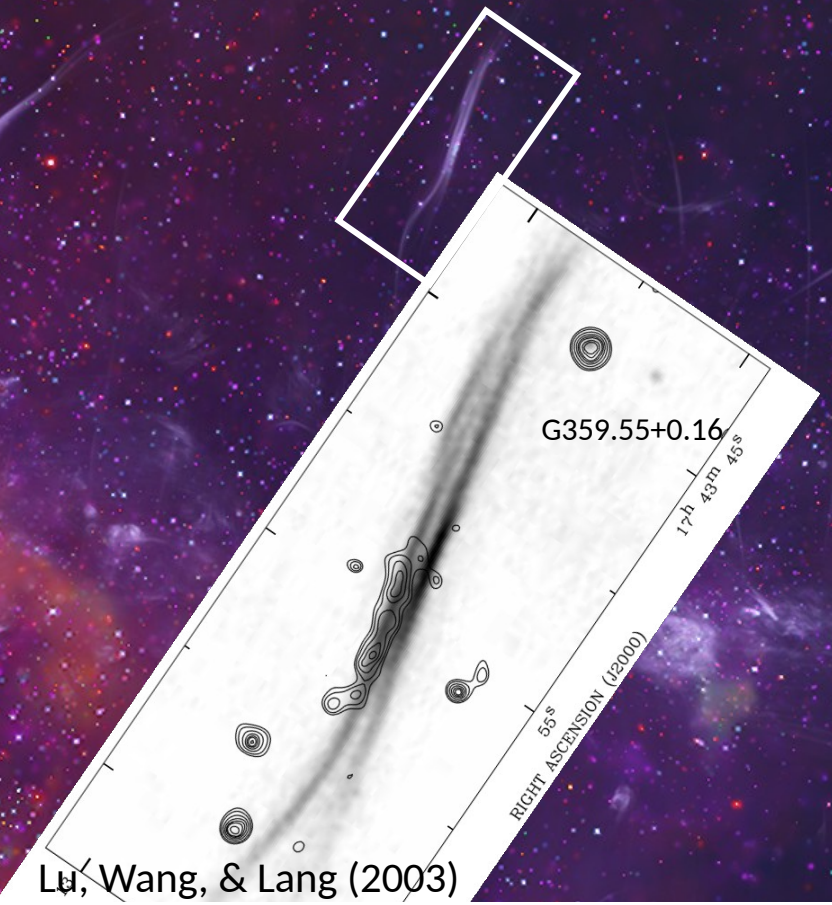
Meerkat 1.3 GHz
1-4 keV
4-9 keV

Wang 2021

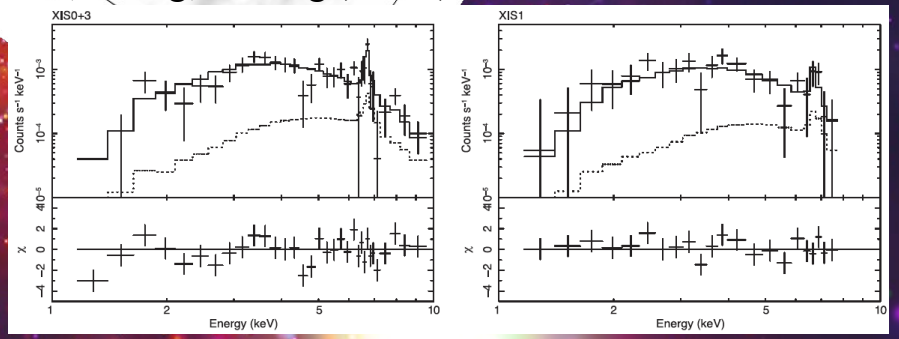
Arches Cluster

Quintuplet Cluster

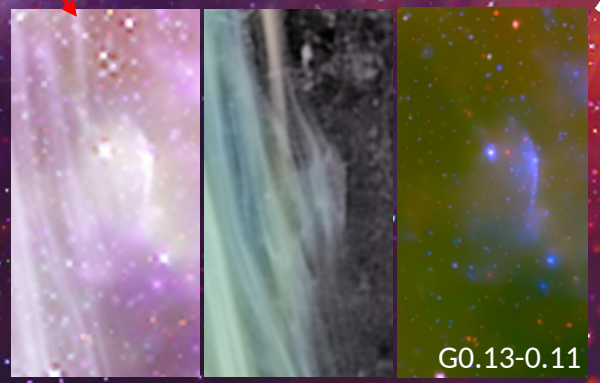
Central Cluster



Lu, Wang, & Lang (2003)



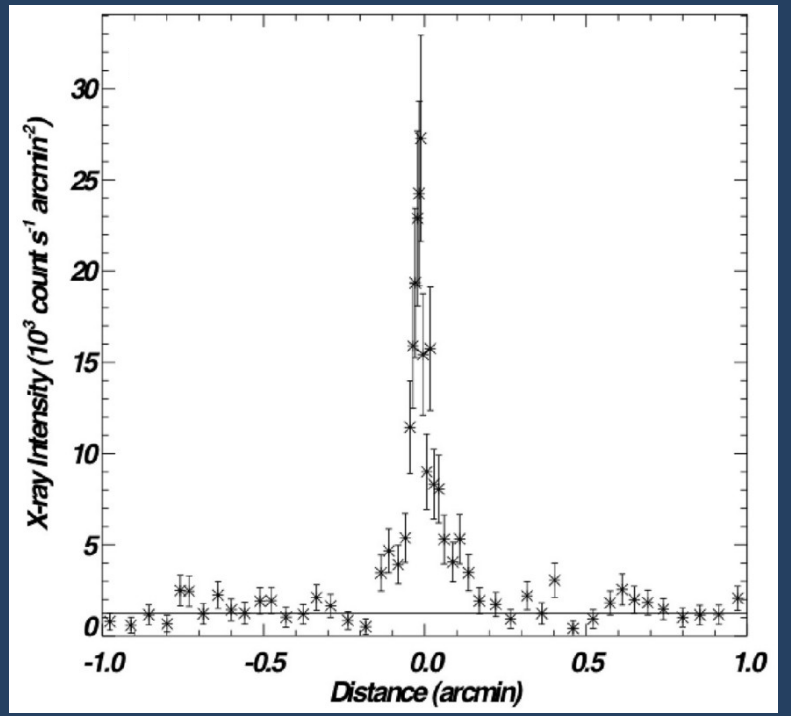
(Yamauchi+2014)



Wang+ (2002)

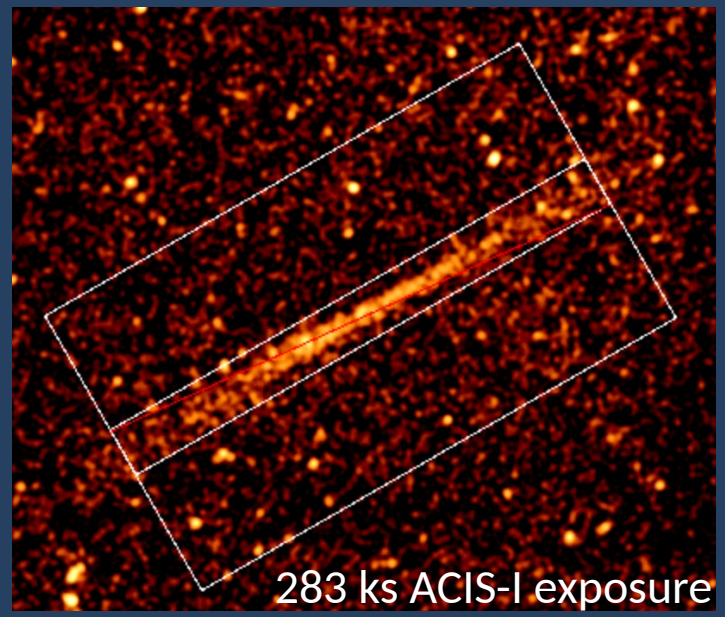
G0.17-0.41
Wang+(2022)

G0.17-0.41: Spatial properties of the X-ray/radio association



- The X-ray-emitting region is very narrow (δx<6”) and confined within a strand of magnetic tubes, probably in field-confined plasmoids.
- Apparent substructures are individually detected at ~2σ significance.

G0.17-0.41: X-ray Spectral Properties

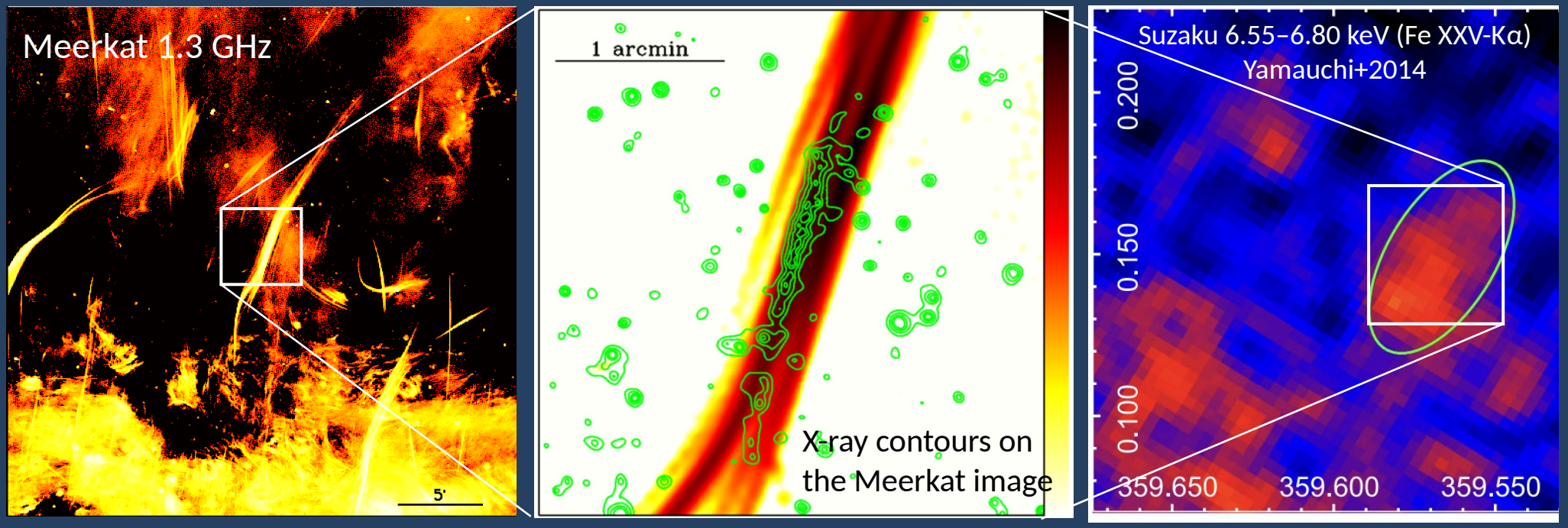


Parameter	APEC	Power Law
$N_H(10^{22}\ \mathrm{cm}^{-2})$	5.9 (4.5-7.5)	6.3 (4.6-8.6)
kT(keV) or Γ^a	17 (6.0-)	1.63 (1.15-2.19)
Z (solar)	0.15 (0-3.3)	-
f_X^b	1.2	1.2
$\mathrm{Log}(L_x)^c$	0.20 (0.15-0.30)	0.21 (0.15-0.30)
$\chi^2/d.o.f.$	43.3/46	43.7/47

[a] - Photon index.
[b]/[c] - The best-fit observed flux/absorption-corrected luminosity (assuming $D = 8.4$ kpc) in the 2-8 keV band and in units of 10^{-13} erg s^{-1} cm^{-2}/10^{33} erg s^{-1}.

- A new 210 ks ACIS-I observation was obtained.
- Unfortunately, the instrument's spectral resolution and sensitivity had degraded substantially. The measurement of metal abundance or proof of thermal emission remains inclusive for this X-ray thread.

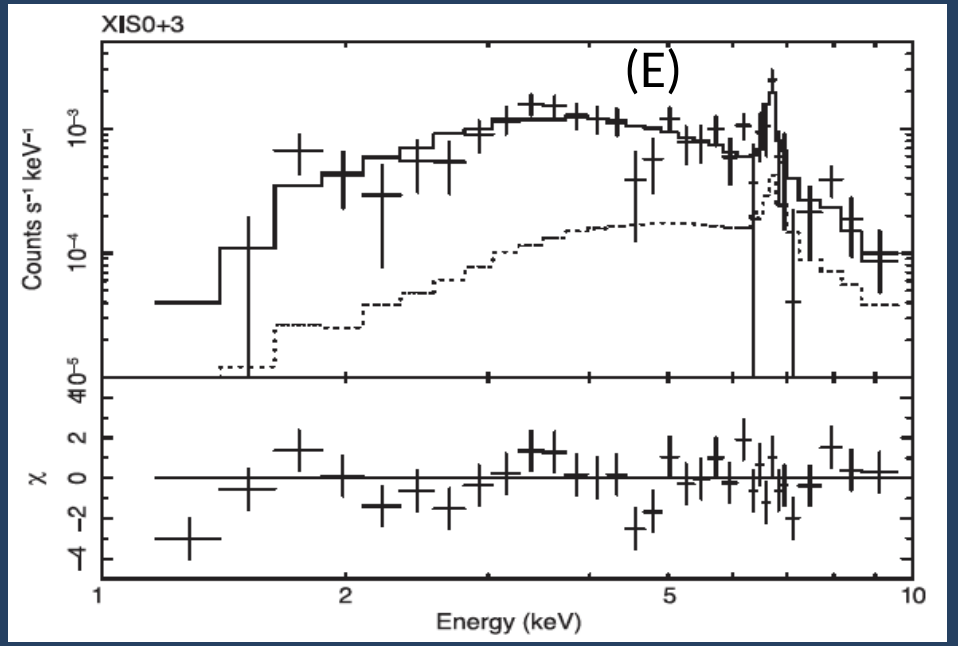
G359.55+0.16



Wang+(2026)

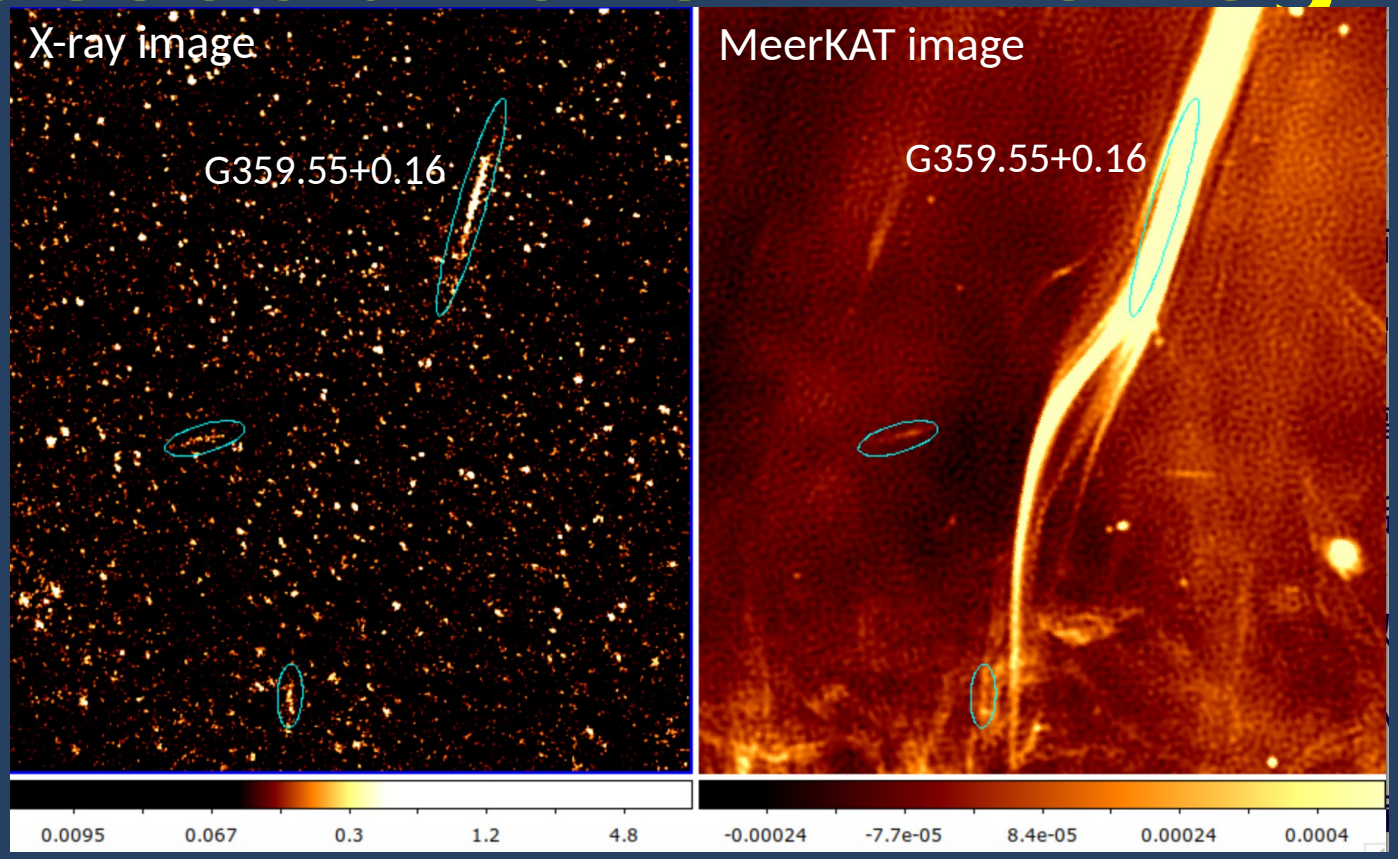
(F)

G359.55+0.16: X-ray Spectral Properties



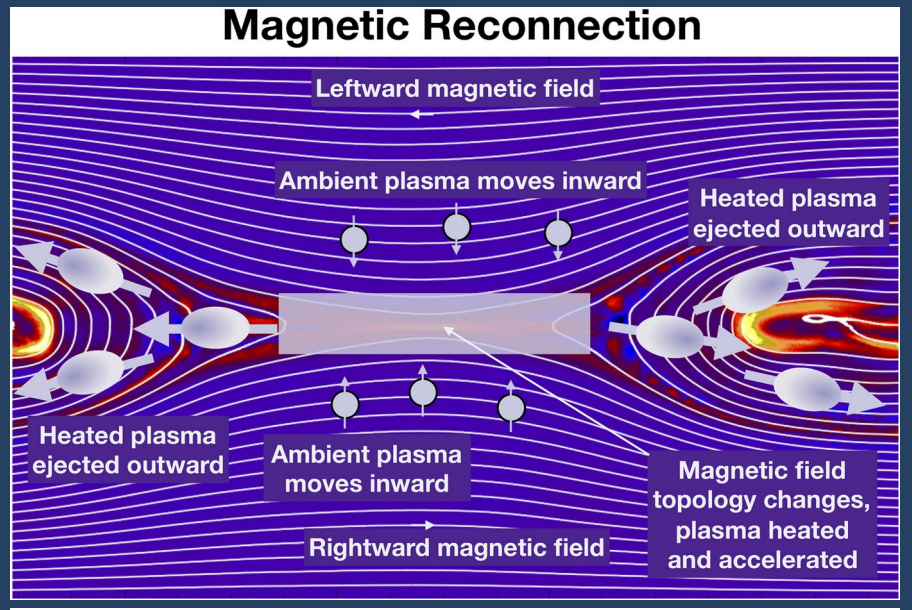
- A new 210 ks ACIS-I observation was also obtained.
- Both the Chandra and Suzaku spectra can be well fitted with a thermal plasma with kT=9.3 keV and Z=0.58 solar.

More X-ray threads/NTF associations in the region



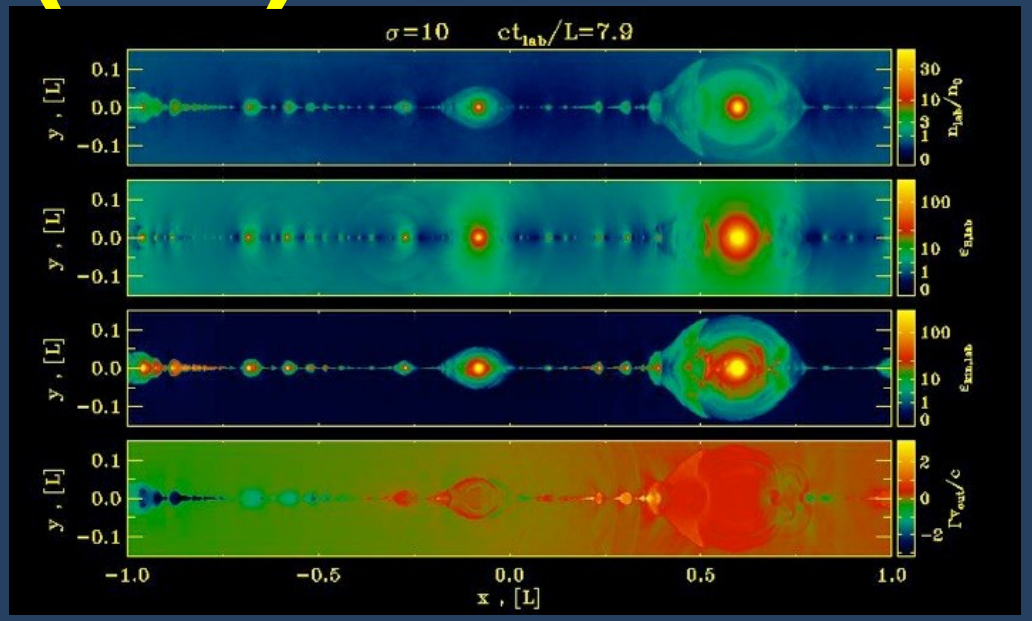
- All X-ray threads have associated NTFs, but not vice versa.
- They contain no apparent point-like X-ray or radio sources.

Interstellar Magnetic Reconnection (MR) Scenario



$$kT_{\rm rec} \approx \frac{m_i V_A^2}{2} \approx \frac{B^2}{8\pi n} \approx 10\, n_{\rm cm^{-3}}^{-1}\, B_{\rm mG}^2\ {\rm keV}$$

plasma heating rate of $\sim E_{\rm th}/t_{\rm d} \sim 2 \times 10^{36}$ erg s^{-1}

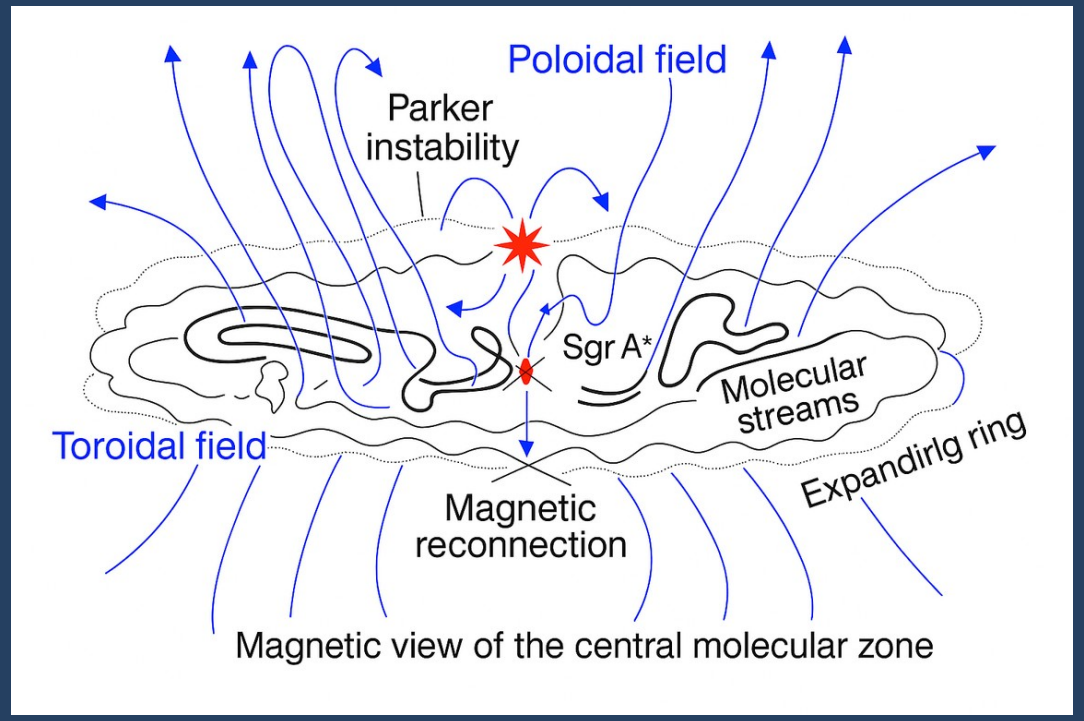


MHD particle-in-cell simulation (Sironi+)

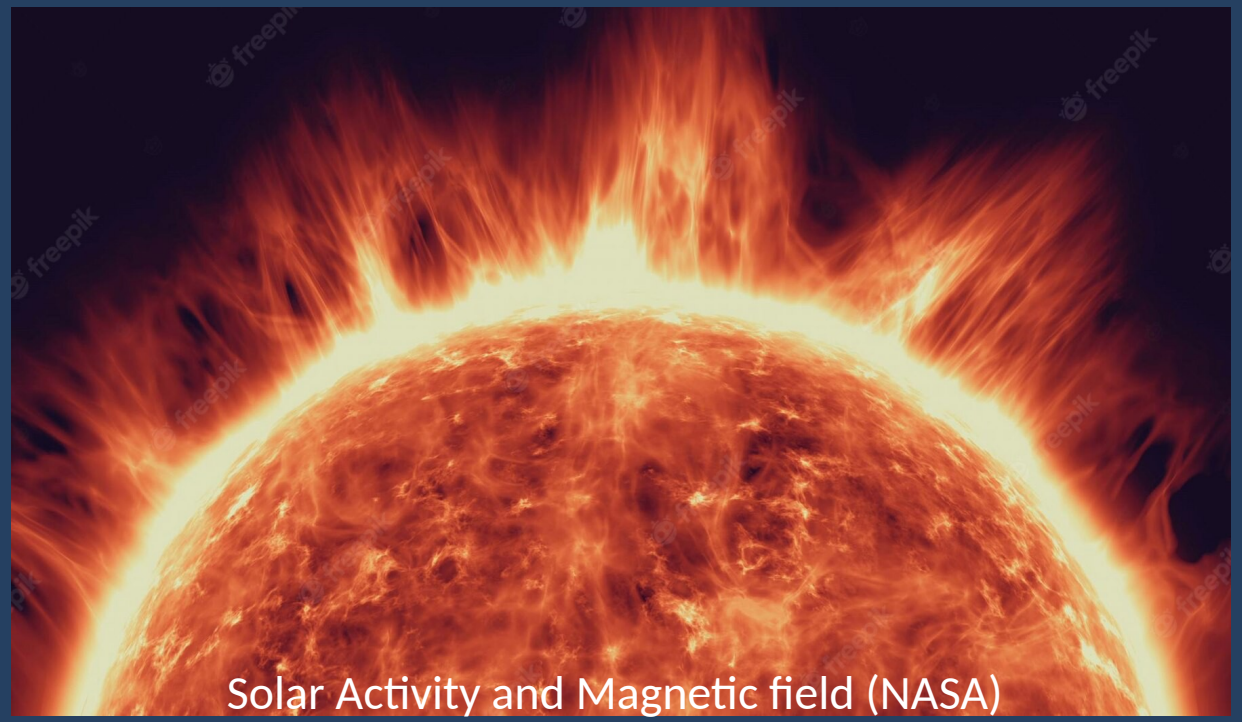
Tanuma et al. (2003)

- The total energy generation rate of the region should be higher, accounting for the energy in plasma motion and particle acceleration.
- Observed X-ray/NTF associations may represent only the tip of the interstellar reconnection.

Magnetic configuration in and around the Galactic center



Magnetic view of the central molecular zone


Solar Activity and Magnetic field (NASA)

- GC may be an excellent lab for studying MR physics in a spatially and time-resolved fashion.
- Interstellar MR may play a major role in heating plasma, accelerating cosmic rays, driving turbulence, and regulating global ISM structures.

Summary

- Multiple X-ray threads have been detected; all of them are associated with nonthermal radio filaments (NTFs), but not vice versa. At least some of the X-ray threads are thermal in origin.
- Magnetic reconnection (MR) provides the most natural explanation of such thermal X-ray thread/NTF associations and may represent a significant source of diffuse hot plasma, partly responsible for the diffuse X-ray background observed in the GC.
- Hot thermal electrons can also serve as seeds for reconnection-accelerated MeV-GeV cosmic rays, which are responsible for partial ionization of molecular clouds and synchrotron radio emission of NTFs.
- The magnetic field represents a major energy feedback source in the Galactic center, driving/shaping outflows and transporting/converting energy.