First Results from the NuSTAR “Mini-survey” of the Galactic Center Region

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Topics for this talk

- Mini-survey overview
- PWN: Cannonball and North Filament (G359.97-0.038)
- Non-thermal filaments: Sgr A-E
- Point Source and Diffuse Emission in vicinity of Sgr A*
**NuSTAR Galactic Center mini-survey image (10-40 keV)**

- **Date**: 1E1743-2843
- **Molecular clouds**
- **Sgr A* complex**
- **Sgr A-E knot**

0.7 pc = angular resolution (FWHM) at GC; ~700 ksec
The Cannonball: a pulsar wind nebula

Likely a high-velocity neutron star breaking through its supernova remnant Sgr A East

X-ray image from Chandra
2-10 keV
Park et al. (2005)

X-ray image from NuSTAR
3-79 keV

5.5 GHz radio image
astro-ph arXiv:1309.7020

Cannonball image 10-30 keV
Cannonball is detected to $\sim 30$ keV

NuSTAR data jointly-fit with Chandra

Best-fit with a power law model

$\Gamma = 1.5 \pm 0.5$

Chandra imaging plus NuSTAR spectroscopy imply $\sim 300$-$500$ microGauss B-field, in agreement with lower limit of $\sim 300$ microGauss from radio equipartition arguments (Zhao et.al. 2013)
- G359.97-0.038 is a known X-ray filament detected by Chandra (Johnson et al. 2009)
- NuSTAR detected non-thermal emission above 10 keV.
- Fermi GeV source in the 2nd catalog is centered at G359.97-0.038.
G359.97-0.038 is a known X-ray filament detected by Chandra (Johnson et al. 2009)

NuSTAR detected non-thermal emission above 10 keV (Mori et al. in prep)

Fermi GeV source in the 2nd catalog is centered at G359.97-0.038.

Chandra image

NuSTAR 10-40 keV image
G 359.88-0.08 (Sgr A-E) looks like a classic PWN

- Brightest GC non-thermal filament (NTF) detected by NuSTAR up to ~ 50 keV.
- Spectra best fitted with a simple absorbed power-law with photon index of ~2.3 (+/- 0.2), confirming its non-thermal emission.
- Detected by NuSTAR as an extended source in both 3-10 keV and 10-50 keV bands (Zhang et al., in prep)
- The high energy (>10keV) centroid sits closer to the south-eastern end.
**But Sgr A-E is (k)not a PWN**

Rule out PWN on morphological grounds
What is it? Magnetic flux tube (Yusef-Zadeh et.al. 1984; Tsuboi et.al. 1986)

* B-field and ~50 keV X-rays imply short electron cooling time (~1 year): what is the source of the electrons?

*Chandra 2-8 keV image overlaid with VLA 20-cm contour.*
NuSTAR morphology of GC is similar to Chandra

Note: hard X-rays from Sgr A-East are purely thermal – they are the high-T component previously detected by XMM (Sakano et.al. 2004)
The Galactic Center drastically simplifies at > 40 keV

- One strong source dominates, consistent with both the Chandra Pulsar Wind Nebula G359.95-0.04 and the HESS TeV source J1745-290

- “northern filament” is alternate candidate for Fermi GeV emission

- The INTEGRAL >20 keV source IGR J17456-2901 is an imaging artifact

- A “protrusion” to the south-west extending beyond the CND but not associated with obvious radio features
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- A “protrusion” to the south-west extending beyond the CND but not associated with obvious radio features.
There is a pervasive, diffuse non-thermal >20 keV X-ray emission from the Galactic Center (Perez et.al., in prep)

Based on flux and/or spectrum and/or spatial extent:

• This is **not** the GRXE posited to be due to mCVs (Revnivtsev et.al., Nature, 2009)

• This is **not** the GRXE of INTEGRAL due to IC and bremsstrahlung (Porter et. al. ApJ, 2008)

• This is **not** the Suzaku GC emission (Koyama et.al., PASJ, 2008)
PWN Candidates and Non-thermal Filaments

- Cannonball is a PWN;
- Sgr A-E is a magnetic flux tube;
- NuSTAR hard X-ray filament north of Sgr A-East coincident with Fermi GeV source

Hard X-ray (8-79 keV) morphology of the Sgr A* region

- Chandra PWN dominates Sgr A* region;
- diffuse, non-thermal emission above 20 keV;
- evidence for outflow(?) to SW of Sgr A*
- Sgr A-East hard X-ray emission is thermal