A Bridge from Sgr A* to LLAGN: A 300ks Simultaneous Multi-\(\lambda\) Campaign on M81* with the Chandra HETGS

Sera Markoff (MIT)
C. Canizares (MIT), G. Bower (UC Berkeley), P. Chandra (TIFR), T. Cheung (KIPAC), S. Gallagher (UCLA), S. Heinz (MIT), M. Jiminez-Garate (MIT), H. Marshall (MIT), M. Muno (UCLA), M. Nowak (MIT), A. Peck (CfA/SMA), G. Petitpa (CfA/SMA), A. Ray (TIFR), R. Schödel (U Köln), A. Young (MIT)
Motivation

1. Study accretion flow of a low-lum SMBH in detail
   - isolate accretion flow $\rightarrow$ Chandra (1’’), nearby source (selects low-luminosity)
   - obtain high-res lines from nuclear region $\rightarrow$ HETGS
   - nearby LLAGN are bright $\rightarrow$ HETGS (avoid pileup)

2. Useful comparison to Sgr A*
   - Sgr A* is weird, and we know a lot about how weird it is, but not why. Need a candidate LLAGN with enough similarities to make a useful comparison of: spectrum, variability, accretion processes
Why M81?

1. Nearest active nucleus in spiral (Sb) w/ reliable M & D, can resolve inner 17pc (~$5 \times 10^6$ R$_g$) with *Chandra*!

2. Classic LLAGN (LINER/Seyfert 1), no blue bump
M81* is a classic LLAGN

adapted from Ho (1999)
M81* vs. LLAGN

adapted from Ho (1999)
Why M81?

1. Nearest active nucleus also in spiral (Sb) w/ reliable M & D, can resolve inner 17pc (~5x10^6 R_g) with *Chandra*!

2. Classic LLAGN (LINER/Seyfert 1), no blue bump

3. X-ray bright (L~10^{41} erg/s), significant variability (30% intraday has been observed), flares?

4. *XMM-Newton* observed neutral/ionized Fe, possibly redshifted, *ASCA* & *BeppoSAX* saw highly ionized Fe

5. Most similar LLAGN to Sgr A* in the radio: spectrum and polarization (CP > LP in cm range)
Why GTO?

➡️ To get good statistics, needed ~300ks: expensive!

Soap Box: The following results would not have been achievable with less time.

They will also not be possible with upcoming X-ray missions...
M81* Campaign Overview

At best 6 instruments simultaneously!
M81* Campaign Overview

At best 6 instruments simultaneously!

- 235 MHz (GMRT)
- 610 MHz
- 1.4 GHz (GMRT/VLA)
- 8.4 GHz (VLA/VLBA)
- 22 GHz (VLA)
- 43 GHz
- 100 GHz (PdBI)
- 230 GHz (SMA)
- 345 GHz
- 2.2 μm (Lick)
- 2-10 keV (Chandra)

Dates:
- 2/23
- 2/24
- 7/11
- 7/13
- 7/15
- 7/17
- 7/19
- 7/26
- 8/14
M81* Campaign Overview

- 235 MHz
- 610 MHz
- 1.4 GHz
- 8.4 GHz
- 22 GHz
- 43 GHz
- 100 GHz
- 230 GHz
- 345 GHz
- 1.25 µm
- 1.65 µm
- 2.20 µm
- 2-10 keV

UT (Feb 22-25)

- GMRT
- GMRT/VLA
- VLA/VLBA
- VLA
- PdBI
- SMA
- Lick
- Chandra

- 235 MHz
- 610 MHz
- 1.4 GHz
- 8.4 GHz
- 22 GHz
- 43 GHz
- 100 GHz
- 230 GHz
- 345 GHz
- 1.65 µm
- 2.20 µm
- 2-10 keV

UT (Feb 23-25)

- 14:00 20:00 08:00 02:00
- 1.25 µm
- 2.20 µm
- 23 24 25
M81* Campaign Overview

At best 6 instruments simultaneously!

- 235 MHz: GMRT
- 610 MHz: GMRT
- 1.4 GHz: GMRT/VLA
- 8.4 GHz: VLA/VLBA
- 22 GHz: VLA
- 43 GHz: VLA
- 100 GHz: PdBI
- 230 GHz: SMA
- 345 GHz: SMA
- 2.2 μm: Lick
- 2-10 keV: Chandra

Survey dates:
- 2/23
- 2/24
- 7/11
- 7/13
- 7/15
- 7/17
- 7/19
- 7/26
- 8/14
M81* Campaign Overview

At best 6 instruments simultaneously!

235 MHz
610 MHz
1.4 GHz
8.4 GHz
22 GHz
43 GHz
100 GHz
230 GHz
345 GHz
2.2 Mm
2-10 keV
GMRT
GMRT/VLAVLA
VLA/VLAVLAVLBA
VLA
PdBI
SMA
Lick
Chandra

UT (Jul 12-16) 06:00 18:00 18:00 06:00 18:00 06:00 18:00 06:00 18:00 06:00

1.25 Mm
1.65 Mm
2.20 Mm

2-10 keV
Chandra
Results I: Emission Lines from Accretion Flow
(See poster 1.24 by A. Young et al.)

🌟 Iron lines observed from w/in 17pc!
Results I: Emission Lines from Accretion Flow

- Iron lines observed from w/in 17pc! (>99%)  
  - Fe Kα fluorescent line ⇒ cooler material
  - Fe XXV, XXVI (He, H-like) ⇒ hotter material
  - Fe XXVI either double peaked or redshifted w/ velocity ~3000 km/s. *XMM lines were nuclear!*
    - heated atmosphere above disk or hot, inner (radiatively inefficient?) flow, R_k ~ 10^4 R_g  
      (consistent w/some scenarios)

- Broadened lines from low-Z elements: Mg, Si, S, O. A first for LLAGN!! Plasma diagnostics for accretion flow (T, density ⇒ η)
Results I: Long Integration Times

Fe band
Mg XII
Si XIV

300 ks
75 ks
19 ks
Results II: Continuum Emission

All observations from Feb-Aug '05
Results II: Continuum Emission

No Sgr A*-like flares!

![Graph showing results of continuum emission with no Sgr A*-like flares.](image-url)
M81* Jet w/VLBA

Plot file version 1 created 13-OCT-2005 17:21:02
CONT: M81 IPOL 8421.459 MHZ BB211.ICL001.8

Cont peak flux = 6.1858E-02 JY/BEAM
Levs = 1.000E-03 * (-0.500, 0.500, 1, 2, 4, 8, 16, 32, 64)

10^4 AU
Results II: Continuum Emission
Results II: Continuum Emission

![Graph showing continuum emission with data points for M81* and Sgr A*]
Results II: Continuum Emission

The graph shows the relationship between the logarithm of the frequency $\nu$ (Hz) and the logarithm of the flux density $L_\nu$ (mJy) for two different sources: M81* and Sgr A*. The graph plots the data points and includes two curves representing each source, with M81* in blue and Sgr A* in pink. The x-axis is labeled $\log_{10} \nu$ (Hz) and ranges from 10 to 20, while the y-axis is labeled $\log_{10} L_\nu$ (mJy) and ranges from -6 to 2.
Sgr A*/M81* in the fundamental plane

\[ \log_{10} L_x + 0.6934 \log_{10}(M/M_\odot) \text{ (erg/s)} \]

\[ \log_{10} L_R \text{ (erg/s)} \]

(Markoff 2005)
As above, so below...

Hard state XRB
(GX 339-4, M=6 \(M_\odot\))

Low-lum AGN
(M81*, M=7\(\times\)10\(^7\) \(M_\odot\))

Sgr A*
(M=4\(\times\)10\(^6\) \(M_\odot\))
As above, so below...

Hard state XRB
(GX 339-4, $M=6 \, M_\odot$)

Low-lum AGN
(M81*, $M=7 \times 10^7 \, M_\odot$)

Sgr A*
($M=4 \times 10^6 \, M_\odot$)
Summary/Outlook

- Many species of lines observed from near the nucleus, several with indications of high velocities
  - observing hot/cold phases of flow
  - 300ks was necessary to resolve most lines
  - detailed plasma diagnostics to come (Young et al. 2006)

- Radio to submm quite variable, hint of a submm bump similar to Sgr A*
  - modeling of broadband/comparison to come (Markoff et al. 2006)

- **Upcoming:** followup continuum monitoring with ACIS (PI: J. Miller), along with more simultaneous multiwavelength in radio/submm/IR/opt