# VLBA PROPOSAL COVERSHEET

rcvd:

DEADLINES: 1st of Feb., June, Oct.

**(1)** Date Prepared: October 10, 2004

**(2)** Title of Proposal: **An X-ray/Radio Transient 2.5″ from Sgr A***



| **(3)** AUTHORS (Add * for new location) | INSTITUTION | E-mail | Grad Students Only: For Ph.D. Thesis? | Grad Students Only: Anticipated Ph.D. Year |
|---|---|---|---|---|
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**(4)** Related previous or current VLBI proposal(s): BB183, BB206 ⊗ Resubmission


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**(7)** Scientific Category: ⊗ astrometry & geodesy ⊗ galactic ○ extragalactic ○ other:

**(8)** Wavelength(s) requested (those not available on the global network are indicated with a small circle):
○ 90cm ○ 50cm ∘ 30cm ○ 21cm ○ 18cm ○ 13cm ○ 6cm ∘ 5cm ⊗ 3.6cm ○ 3.6/13cm
○ 2cm ⊗ 1.3cm ○ 7mm ∘ 3mm
⊗ Global Network standard bands ○ Special frequencies:__________

**(9)** Recording format: ⊗ Default continuum setup (VLBA only), ○ VLBA/MkIV, ○ MkIII: Mode______
Bandwidth per BaseBand channel: ______
Aggregate bit rate:_____ ( _____ BB channels at _____ Samples/sec of ○ 1 bit, ○ 2 bit )

**(10)** ⊗ Multi-epoch observation: 2 epochs of 4 hours each, separated by 10 days

| **(11)** Network | Requested antennas | Total time requested |
|---|---|---|
| EVN & MERLIN | | |
| VLBA | ALL but HN, SC and MK | 2 x 4 hours |
| other NRAO | | |
| | | |
| Non-VLBI Intruments | | |

**(12)** ABSTRACT (Do not write outside this space. Please type)


We have detected a transient radio source within 2.5 arcsec of Sgr A*. VLBA observations can determine the scattering properties of this object, determine its morphology, and determine its proper motion. This source has the potential for major advances in Galacter Center science related to stellar remnants, interaction of nonthermal and thermal matter, and scattering.


Scheduler use only
(12/02)

**(13)** Observation type: ⊗ Interferometry, ◯ Spectroscopy, ◯ Pulsar, ⊗ Phase referencing

**(14)** Proposal is ◯ Suitable ⊗ Unsuitable for dynamic scheduling.

**(15)** Polarization: ◯ Single Polarization ⊗ Dual Circular Polarization
Global network standard for single polarization is LCP for all $\lambda$s except 13cm (RCP) and 3.6cm (RCP).

**(16)** Tape usage (Show <recording time>/<total time>): ______

**(17)** Assistance required:
Observation Setup: ◯ Consultation, ◯ Extensive help, ◯ Observe file preparation
Postprocessing: ◯ Consultation, ◯ Extensive help, ◯ Calibration service

**(18)** Processor: ⊗ Socorro, ◯ JIVE, ◯ Haystack, ◯ Bonn, ◯ Washington, ◯ Other____________
Special processing: ◯ XPol, ◯ Pulsar gate, ◯ Multiple Fields: ______
Averaging time: ______ Spectral channels per baseband channel: ______
◯ Other special processing: ______________________________

**(19)** Postprocessing Location: UC Berkeley

**(20)** Source list: ⊗ J2000 ◯ B1950
If more than 4 sources, please attach list. If more than 30, give only selection criteria and GST range(s)

| | Source 1 | Source 2 | Source 3 | Source 4 |
|---|---|---|---|---|
| Name(s) | CXO J174540.0-290031 | | | |
| RA (hh mm) | 17 45 | | | |
| Dec (dd.d) | -29.0 | | | |
| GST range (Europe) | | | | |
| GST range (US) | | | | |
| GST range (Other) | | | | |
| Band(s) | 3.6,1.3 | | | |
| Flux density (Total, Jy) | 0.001 - 0.030 | | | |
| Flux density (correlated, mJy) | 1 - 30 | | | |
| RMS needed (mJy/beam) | 0.3 - 1 | | | |
| Peak/RMS needed | 10 | | | |

**(21)** Preferred VLBI session or range of dates for scheduling, and why:

**(22)** Dates which are NOT acceptable, and why:

**(22)** Attach a self-contained scientific justification, not in excess of 1000 words.
Preprints or reprints will not be forwarded to the referees.

Information about the capabilities of the VLBA may be found on the World Wide Web by starting at the NRAO home page, http://www.nrao.edu, and selecting the VLBA from "Sites and Telescopes."

A brief summary of the capabilities of the EVN antennas is given in the EVN STATUS TABLE in the EVN USER GUIDE, which may be found at http://www.evlbi.org/user_guide/user_guide.html.

Please include the full postal addresses for first-time users or for those that have moved (if not contact author).

# An X-ray/Radio Transient 2.5$''$ from Sgr A*

Bower et al.

## 1. Transient Discovery

In observations on 1 and 4 October 2004, we detected a radio transient in the Galactic Center (GC) at L-band with the VLA. Observations at 1515 MHz and 1715 MHz on 1 October 2004 and 1365 MHz on 4 October 2004 show a $\sim 30$ mJy source 2.5$''$ south of Sgr A* (Figure 1). This source is not present in archival (24 June 1999) L-band observations of Sgr A* (Figure 2).

Follow-up observations on 7 October 2004 show that the source continues to be present at L band as well as appearing at 8.4 GHz and 22 GHz (Figure 3). We measure flux densities of $30 \pm 5$ mJy, $10 \pm 2$ mJy, and $4 \pm 1$ mJy at 1.4, 8.4 and 22 GHz, respectively. Imaging of this source is particularly difficult because it lies very close to the bright point source Sgr A* and it lies within a region dominated by diffuse flux. We achieve a position with an accuracy of 0.02 arcsec with the 8.4 GHz observations.

The radio source is positionally coincident with an X-ray transient (CXO J174540.0-290031; Figure 4). The best fit radio position is 17:45:40.063, -29:00:30.622, in agreement at $< 0.4$ arcsec with the X-ray position, which has an accuracy of $\sim 0.5$ arcsec. The X-ray transient was bright during XMM observations in April, and Chandra observations in July and at the end of August. It brightened by a factor of 2 between July-September. The source started out hard in July, with a spectrum that could be described as a power-law with photon index $\Gamma = 0$. By September, the source had softened to a $\Gamma = 1.0$ power law, which is still hard, but more typical of an accreting neutron star or black hole. Its luminosity of $> 10^{34}$ erg/s indicates that it is an accreting black hole or neutron star.

The X-ray luminosity is quite low, $\sim 10^{-5}$ to $10^{-4} L_{Edd}$, however, for a compact object with strong radio emission. The ratio of peak X-ray to peak radio emission is $\sim 2 \times 10^5$ mJy/crab, which is rivaled only by Cyg X-3 (Fender & Kuulkers 2001) with a ratio of $2 \times 10^4$. Typical values of this ratio are in the range 100 to 1000. RXTE ASM observations would have caught a recent X-ray burst as faint as $10^{-2} L_{Edd}$.

The precise VLA position for the radio source permits us to determine that there is no infrared counterpart at a limit of $K = 16.5$ (Lu & Ghez, private communication). This indicates that the companion of the transient source is fainter than a B-star.

The diffuse X-ray emission within 3" of the transient has brightened by a factor of 2 over previous observations. This may be reflected X-ray emission, but it could also be energy input from the action of a jet.

**This source offers an exciting and rare opportunity to study a compact object in the GC**. This one of only a handful of GC transient radio sources and it is by far the closest to Sgr A* (e.g., Davies et al. 1976; Zhao et al. 1986; Hyman et al. 2002). We know very little about the compact object population of the GC, its relationship to massive star formation, and bulge formation (Miralde-Escude & Gould 2000; Hansen & Milosavljevic 2003). Potential science includes:

- A study of the radio/X-ray luminosity. The quite large radio to X-ray luminosity ratio indicates that this object may be quite unususal. A better characterization of the radio spectrum and its evolution will help us to compare this source to other galactic X-ray sources (e.g., Fender, Belloni & Gallo 2004) and extragalactic sources (Falcke, Körding & Markoff 2004).

- A high resolution radio image of the X-ray transient source. Detection of a jet may resolve the question of the nature of this object and the diffuse X-ray emission.

- Proper motion with respect to Sgr A*. A small PM with respect to Sgr A* will confirm that the source is galactic; an extragalactic background source would show a PM of 6 mas/y. Additionally, we can ask: Is it in a bound orbit? Does it share a similar velocity with the high mass stars in the neighborhood? Typical stellar velocity dispersion at this radius from Sgr A* is $150 \pm 50$ km/s (Ghez et al. 1998) or 10 microarcsec/day. Compact objects such as pulsars often have proper motions of $\sim 300$ km/s, much higher than field stars (Brisken et al. 2003). If this object persists for a month or more, we can measure its proper motion with multiple VLBA observations. The transient studied by Zhao et al. (1986) persisted for $\sim 6$ months before fading away.

- A new probe of scattering very close to Sgr A*. Does it have the same scattering properties as Sgr A*? This is the closest compact radio source to Sgr A*. The Zhao et al. transient at a distance of $\sim 36$ arcsec showed a similarity with Sgr A* in scattering properties, although the inclination of the scattering disk and its axial ratio were not determined. Variations in these parameters has implications for the magnetic field structure and the distribution of ionized gas in the GC.

## 2. Requested Observations

### 2.1. VLA

Continued radio monitoring of this object is essential for determining the suitability of VLBA measurements as well as for characterizing the radio/X-ray luminosity correlation. We are pursuing further X-ray observations. We request three observations over the next two weeks. We will measure the spectrum at 1.4, 5.0, 8.4 and 22 GHz. We require 60 minutes per epoch to give us a range in (u,v) coverage at each frequency that will permit us to resolve out the diffuse structure.

### 2.2. VLBA

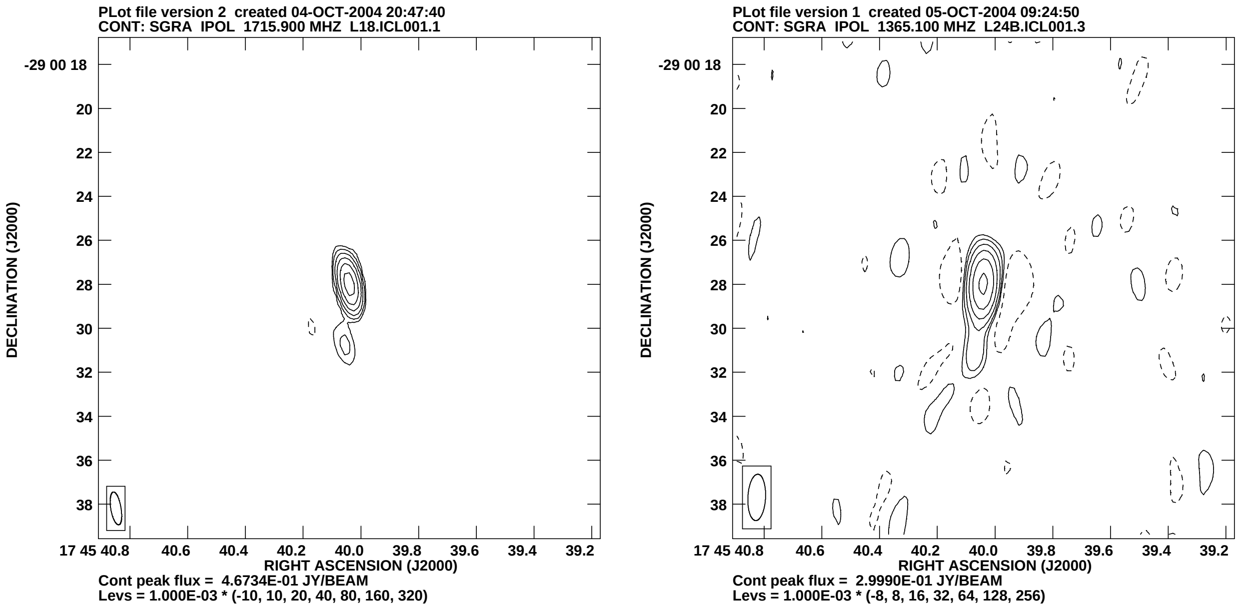
We request two VLBA observations, spaced by $\sim 10$ days, as soon as possible. A proper motion a few times in excess of the stellar velocity dispersion will be detectable over this span.

While the L-band flux density appears to be stable over the past 10 days, the flux density at higher frequencies may fall off more rapidly with time. The steep spectral index of this source suggests that it may be fading. Observations will be performed at 8.4 GHz and 22 GHz. The two frequencies will allow us to characterize the angular size as a function of wavelength, which is important for scattering studies and for determining the intrinsic structure.

Because of the extreme scattering environment, we will not need HN, SC or MK. Baselines to these stations are resolved out. With 1 hour of observation at 8.4 GHz and 3 hours of observation at 22 GHz, we can achieve an image rms of 200 $\mu$Jy and 320 $\mu$Jy and resolution (set by Sgr A* scattering size) at 17 mas and 2.4 mas at the two frequencies, respectively. This will enable us to achieve $> 10\sigma$ detections and source positions to an accuracy of $\sim 1$ mas and $\sim 0.1$ mas, respectively.

We have verified the methods of this observation through use of a March 2004 VLBA 43 GHz observation of Sgr A* (BB183). We attain an rms of 800 $\mu$Jy at the location of the transient, which is close to the expected noise for these observations.

Fig. 1.— *(left)* 1715 MHz image obtained on 1 October 2004. Sgr A* is the bright source and the transient is due south of it. Beam size is 1.5 x 0.5 arcsec in p.a. 10 deg. *(right)* 1365 MHz image obtained on 4 October 2004. Images were made with inner (u,v) cutoff of 50 kilo$\lambda$. Beam size is 2.1 x 0.8 arcsec in p.a. -3 deg. 1715 MHz image included PT data.




## 3. References

Brisken, W., et al., 2003, AJ, 126, 3090
Davies, R.D., et al., 1976, Nature, 261, 476
Falcke, H., Körding, E., & Markoff, S., 2004, A&A, 414, 895
Fender, R.P. & Kuulkers, E., 2001, MNRAS, 324, 923
Fender,R.P., Belloni, T.M., & Gallo, E., 2004, A&A, submitted, astro-ph/0409360
Ghez, A.M., et al., 1998, ApJ, 509, 678
Hansen, B.M.S. & Milosavljevic, M., 2003, ApJL, 593, L77
Hyman, S.D., et al., 2002, AJ, 123, 1497
Miralde-Escude, J. & Gould, A., 2000, ApJ, 545, 847
Zhao, J.-H., et al., 1992, Science, 255, 1538

Fig. 2.— 1365 MHz observation of Sgr A* from 24 June 1999, showing no transient source. Beam size is 2.3 x 0.9 arcsec in p.a. 6 deg.

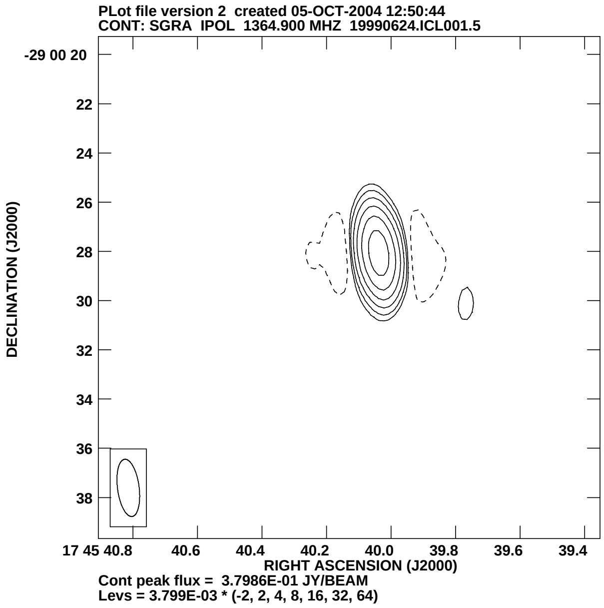



Fig. 3.— 8.4 GHz observation of Sgr A*, showing the transient source. Beam size is 0.44 x 0.16 arcsec in p.a. 12 deg.

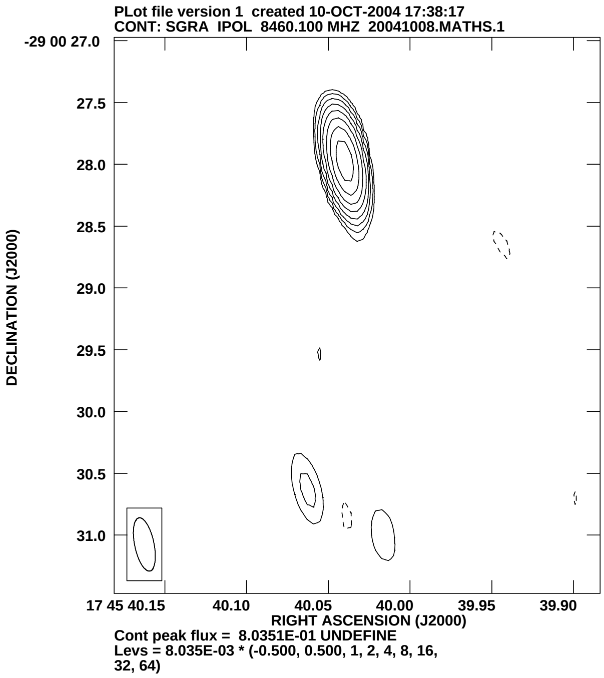


Fig. 4.— CXO X-ray image before and after appearance of the transient.