THE INTRINSIC VARIABILITY OF SGR A* AT RADIO WAVELENGTHS

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ABSTRACT

We have observed Sgr A* at 2.0, 1.3 and 0.7 cm with the Very Large Array (VLA) in order to constrain the variability in the flux density of Sgr A* and search for periodicities. The data consist of 70 epochs spread over ~550 days. Variabilities in the flux density of ~30% are observed at both 2.0 and 1.3 cm and are consistent with the typical variability observed by Zhao et al. (2001). Following a flare in the x-ray emission from Sgr A* on 27 October 2000, we observe an increase in the flux density of Sgr A* peaking on 05 November 2000. Preliminary analysis of the data shows periodicities at all three wavelengths of 100-150 days with wide profiles. This is consistent with the periodicity of 106+/-6 days reported by Zhao et al. (2001).

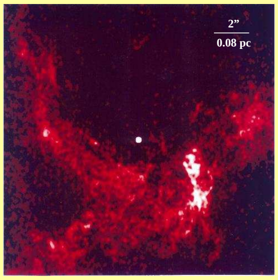


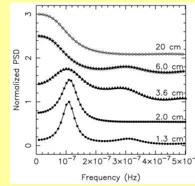
Figure 1: High resolution (0”.1) image of the central 0.6 pc of the Galaxy at 1.3 cm (Zhao & Goss 1998). Sgr A* is the bright point-source in the center of the image. Surrounding HII emission shows a spiral structure.

BACKGROUND

Accurate measurements of the proper motions of stars within 1 parsec of the Galactic Center indicate that a 2.6x10^6 M_{sun} black hole is located at the dynamical center of the Milky Way (Eckart & Genzel (1997) and Ghez et al. (1998)). In the radio, the position of the black hole is marked by a strong (~1Jy) point source called Sgr A* (see Figure 1).

Sgr A* has long been observed to be variable in its flux density at radio and millimeter wavelengths. Analysis of 20 years of VLA archival data by Zhao, Bower, & Goss (1998) shows that the flux density of Sgr A* appears to vary with a period of about 106 days (ν=1.1x10^{-7} Hz, see Figure 2). The pulse profile is very broad and it is likely that Sgr A* is a quasi-periodic source (see Figure 3). As observed in Figure 2, the amplitude of variability tends to increase towards shorter wavelengths. This observation is consistent with the idea that the emission comes from the region just outside the black hole. Shorter wavelengths will trace hotter gas which is closer to the black hole and therefore expected to show stronger variations.

The irregular sampling of the VLA archive data made it difficult to test for periods shorter than 50 days and a new monitoring program was begun to regularly sample the flux density of Sgr A*. These data will allow us to determine the exact nature (periodic, quasi-periodic or stochastic) of the variability of Sgr A*. A description of our monitoring and data reduction techniques as well as our results to date are presented below.



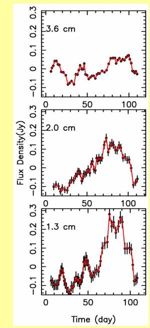


Figure 2: (a) PSD of VLA archive data from Zhao et al. (2001) showing a periodicity at short wavelengths of ~1.1x10^{-7} Hz (or ~100 days). (b) Pulse profile for 3.6, 2.0, and 1.3 cm showing that the profile is quite wide and best detected at 1.3 cm.

THE SGR A* FLUX DENSITY MONITORING PROJECT AT THE VLA

Data and Calibrations

Beginning in June 2000, we have observed Sgr A* at 2.0, 1.3 and 0.7 cm roughly once a week with the Very Large Array (VLA) in New Mexico. We observe at the shortest wavelengths possible at the VLA in order to observe the greatest amplitude variability. The data are sensitive to periods from ~20 to 500 days. In addition to Sgr A*, we observe the flux calibrator, 3C286, and two phase calibrators, 1741-312 and 1817-254. Any intrinsic variations in the phase calibrators will be uncorrelated while systematic offsets will be correlated. These correlated offsets are removed from the data as described below:

Figure 3 shows the flux density of the two phase calibrators after the initial AIPS calibrations. The offsets from day to day are due to errors in the absolute flux calibration, long term drifts in flux, and the intrinsic variability of the calibrators.

A constant slope is fit to each calibrator to estimate the long-term drift in flux. After the slope is removed, we are left with the daily offsets for each calibrator. The two phase calibrators track each other indicating that the offsets are due to systematic errors.

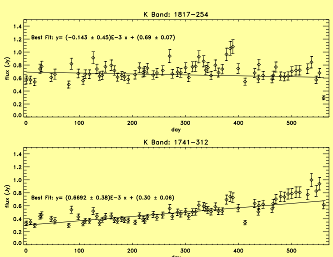


Figure 3: Flux density of the phase calibrators at 1.3 cm after AIPS calibration *only.*

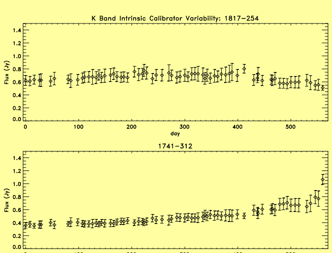


Figure 4: Flux density of the phase calibrators at 1.3 cm after correction for SDOs. This is the intrinsic variability of the two phase calibrators.

The “systematic daily offset” (SDO) for each day is taken as the weighted mean of the 2 calibrator offsets for that day. The SDOs are divided out of the data and errors are propagated through resulting in data that show the *intrinsic* variability of the 2 calibrators *(left)* and Sgr A* *(above right)*.

***Note:* An additional fractional error is added to the data in addition to the errors reported by AIPS so that the resulting fit of the SDOs to both calibrators has a reduced χ^2 of 1.0.**

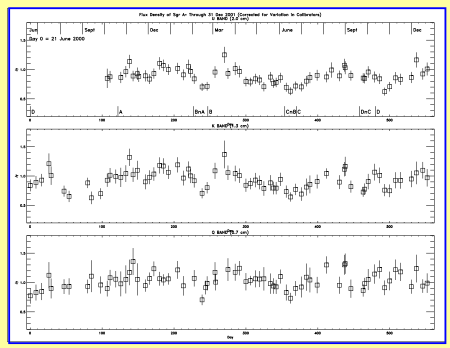


Figure 5: Intrinsic variability of Sgr A* from 21 June 2000 to 31 Dec 2001.

The Intrinsic Variability of Sgr A*

Figure 5 shows the intrinsic variability of Sgr A* from June 2000 to the present at 2.0 cm (U Band), 1.3 cm (K Band), and 0.7 cm. (Q Band).

The data cover more than 500 days with samplings about once a week making them an excellent tool for studying the nature of the variability of Sgr A*.

RESULTS

The flux density of Sgr A* at 2.0 and 1.3 cm show significant variability. The reduced χ^2 of a fit of the data to a constant flux density is 1.9 for U Band and 1.7 for K Band. We observe variations in the flux density of ~30% which is consistent with the typical amplitude observed by Zhao et al. (1998). Due to larger errors in Q Band, we are sensitive only to flares of more than ~50%. Although flares of up to 100% are observed in the archival data, we have not observed any of these large flares to date indicating that Sgr A* is relatively quiet at this time.

SEARCHING FOR PERIODICITIES:

We have recently begun to search our data for periodicities similar to the 106 day periodicity found in the archival data. The power spectral density is computed with a Lomb periodogram, which can identify periodicities in irregularly-spaced data. The significance of the PSD is estimated through Monte Carlo simulations. Each iteration of the simulations randomly reorders the flux densities over the same sampling function. The PSD at a given frequency is considered significant if it exceeds the 99th percentile of simulated results at that frequency. Frequencies higher than ~1x10^{-6} Hz and lower than ~4x10^{-8} Hz are not properly sampled by this data set.

In Figure 6, we present a *preliminary* PSD for our 2 cm data. There is a significant peak in the PSD of Sgr A* at 8.90x10^{-8} Hz (133 days). This peak well-exceeds the 99th percentile of the Monte Carlo simulations. In Table 1, we present our *preliminary* PSD results for all three bands. Our best estimate of the 3σ errors are ~7 days for periods and ~30 days for lags. Note that the lags are in order of wavelength indicating that short wavelengths tend to peak first.

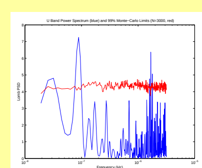


Figure 6: Lomb Periodogram of 2.0 cm Sgr A* data.

Table 1: Preliminary Results of PSD Analysis of Sgr A* Flux Density Data

Observing Band	Peak Frequency (Hz)	Associated Period (days)	Lag (days)
U BAND (2.0 cm)	8.90x10^{-8}	133 +/- 3	31 +/- 10
K BAND (1.3 cm)	8.75x10^{-8}	135 +/- 3	24 +/- 10
Q BAND (0.7 cm)	9.78x10^{-8}	121 +/- 3	14 +/- 10

MULTI-WAVELENGTH STUDIES:

Baganoff et al (2001) observed a strong flare of Sgr A* in the x-ray on 27 October 2000 (day 129). Following the x-ray flare, the radio flux density rises in all 3 bands and peaks about 1 week later on 05 November 2000. The correlation between the x-ray flare observed by Baganoff et al. (2001) and the following rise that we observed indicates the interesting results that can be obtained by observing Sgr A* simultaneously at a variety of wavelengths. We plan to observe Sgr A* in the spring of 2002 with the VLA coincident with new x-ray observations by Baganoff et al.

In addition, the Harvard-Smithsonian Sub-millimeter Array (SMA) is currently in testing phase and we have made preliminary observations of Sgr A* at 230 GHz *(see poster 103.09)*. Coincident observations at the SMA and VLA will allow us to track the variability in a wider range of wavelengths and determine whether the spectrum of Sgr A* changes during flares.

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