Characteristics of Millimeter Variability of Sgr A*

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Introduction

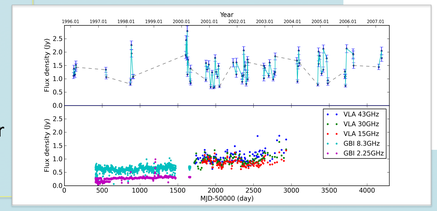
We present the analysis of flux variations of Sgr A* at millimeter wavelengths based on the long-term monitoring project spanning over a decade (1996-2008) using the Nobeyama Millimeter Array. We investigate basic characteristics of the flux variability using some standard parameterizations of the data. Such basic properties of the flux variations in the mm-regime can provide valuable information not only for its underlying mechanisms in general but also for understanding observed radio/mm flux measurements during an accretion event.

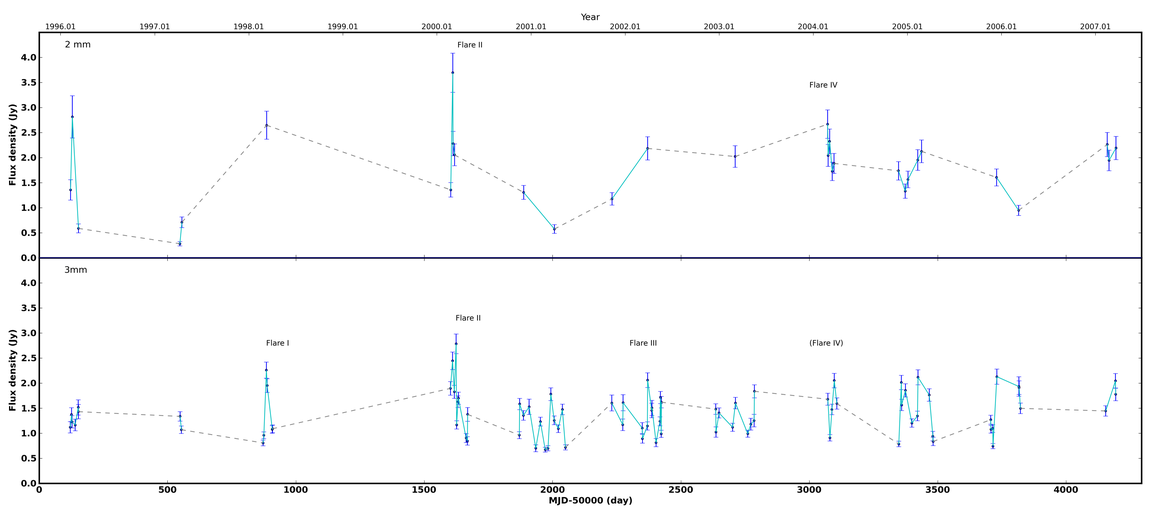
Data

- Using Nobeyama Millimeter Array between 1996 – 2007
  (Note: 2008 data is excluded for this analysis) at 2-and 3-mm bands
- Each epoch of the observations separated by ~1-10 days, each observing run lasted ~4hrs(centered around +/- a few hrs of hour angle)
- Bandwidth: 1GHz*per sideband LSB and USB data (90, 102, 134, 146 GHz)
  *Except for 1996 : 320MHz at 102 and 146GHz
- Each sideband data was independently calibrated and peak flux densities were measured on CLEANed images (-> daily averaged flux densities for this analysis)
- Restricted uv distances were used (<25 kλ) – taking advantage of the interferometer to filter out extended emission

Light Curves

For comparison at lower radio frequencies , we used VLA data from Herrnstein el al. (2005 AJ 127) and Green Bank Interferometer (GBI) data as these data have some overwraps with our observation date ranges as shown below.





General Variability Characteristics

Table 1 shows measures of variability at each band (2mm and 3mm). The data at 90 and 102 GHz, and at 134 and 146 GHz were averaged together for 3mm and 2mm band, respectively. The (robust) sigma and fractional variability (V=standard deviation/mean) indicate tendency of larger fluctuations as observing frequency increases. (V~0.3 at 3mm ~0.4 at 2mm)

Band	N_data	mean	median	sigma	V
2mm	30	1.78	1.92	0.76	0.41
3mm	86	1.40	1.32	0.45	0.31

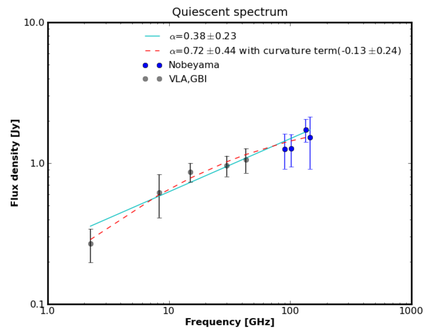
Table 1.

Quiescent spectrum

The quiescent spectrum excluding the prominent flares from our data and averages of all the VLA, GBI data at each frequencies is constructed. Fitting to the data with a power law ($S \propto \nu^{\alpha}$) gives ~0.38+/-0.23. If a 'curvature' term of spectral index is included, a better fit is obtained with α=0.72, curvature=-0.13.

Flares

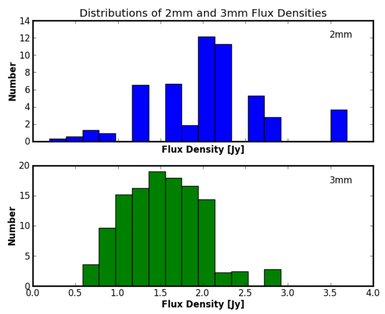
The light curves show at least four flares as they were marked in the plot above. The analyses of these flares including intra-day variability were reported else where (e.g. Miyazaki et al 2004, ApJ 611).

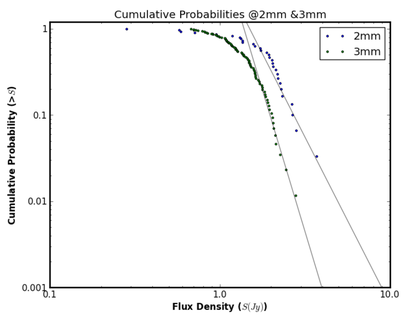


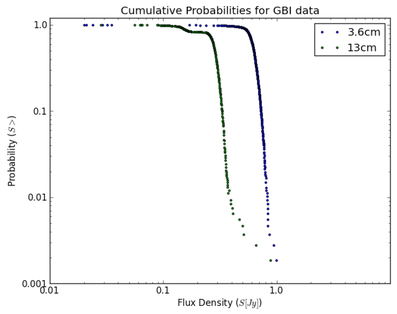
Flux Density Distributions

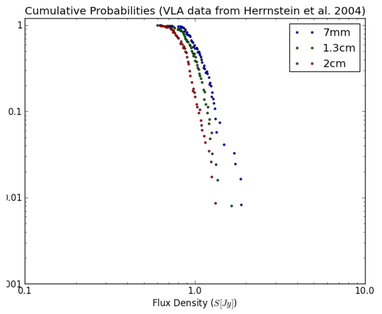
The distributions of flux density measurements indicate the flaring and low activity states and the deviation from the normal distribution is higher at 2mm as compared to 3mm.

The figure below shows the cumulative probabilities of the 2-and 3-mm fluxes indicating deviations from the smooth curve and at higher flux density end can be fitted by a power law (with slope of -3.9 and -6.6 at 2mm and 3mm, respectively.)



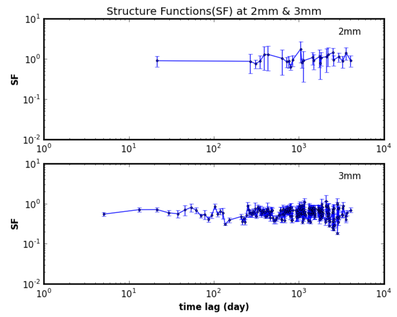


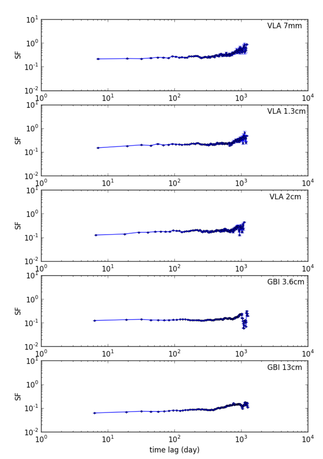




Structure Functions

$$SF(\tau) = < [S(t) - S(t+\tau)]^2 >$$





- The structure functions (SF) for the 2mm- and 3mm-data appear to be consistent with stochastic variations (slope~0)
- For the 3mm data, there are dips at ~87d and 136d that seem to be related flaring activities (bin width~8d for the 3mm data)
- As a comparison, the SFs from the VLA and GBI data is shown on left (more detailed analysis has been done by Macquart & Bower 2006, ApJ 641)

Summary

- 10+ years of the monitoring data at mm-waves shows flares and less active states
- While data sampling at 2mm is poor, tendency of higher variability at the higher frequencies was seen
- Averaged spectrum excluding flares gives the spectral index, $\alpha \sim +0.38$
- The cumulative probability distributions clearly show multiple components
- The structure functions for the time lag ~ a few days to a few 1000 days do not show significant structure change except for some dips which are likely related to flares