

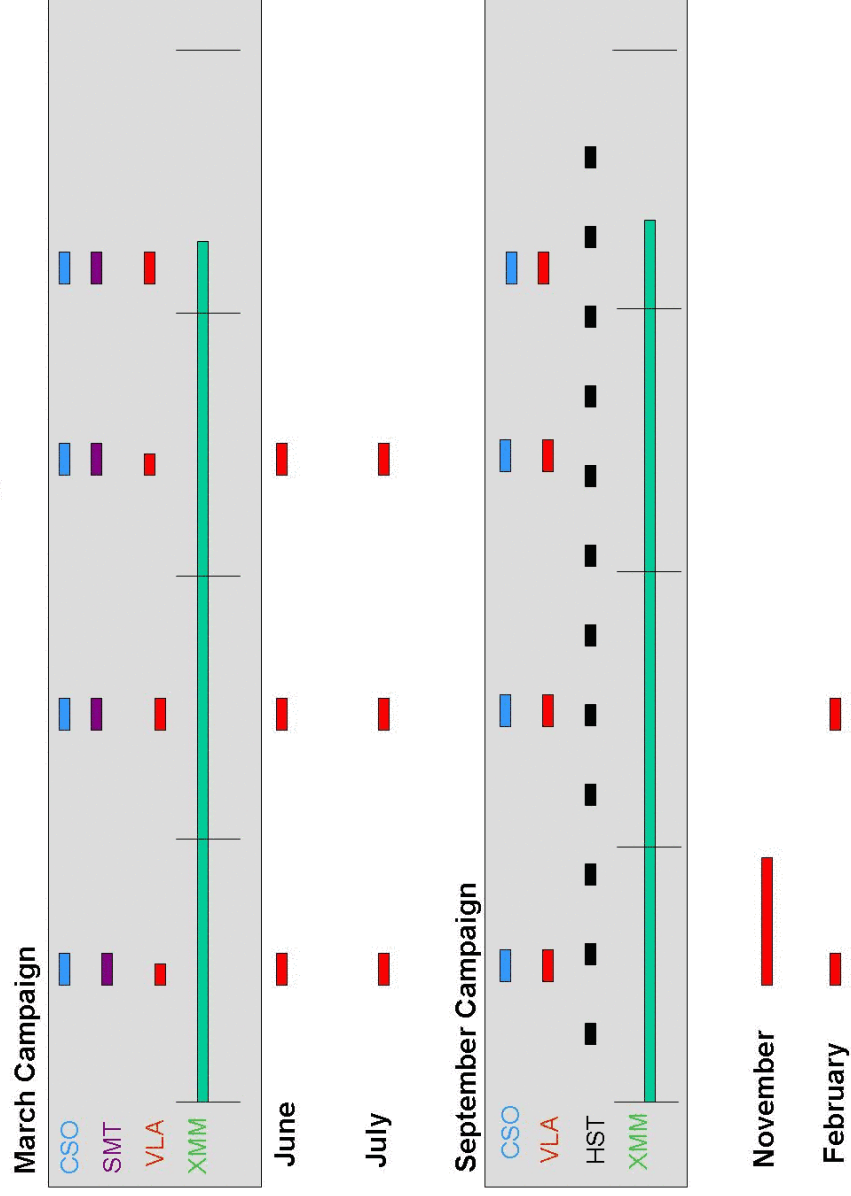
## A Coordinated Multi-wavelength Experiment to Observe the Variability of Sgr A\*

- Radio Observations (VLA)
  - Observing technique
  - Light curves at 7mm, 1.2cm and 6cm
  - Evidence for quasi-periodic hourly variability
  - Time delay between the 7mm and 1.2cm peaks
  - Outflow from SgrA\*?
- Near-IR Observations (NICMOS/HST)
  - Observing technique
  - Photometry of SgrA\*, S2, background and IRS16SW
  - Light curves at 1.6, 1.87 and 1.9microns
  - Evidence for low-level flare activity with quasi-periodic variability
  - Accreting material orbiting at 3Rsch?
- Cross correlation between radio, X-ray and near-IR wavelengths
- SSC to explain the X-ray correlation?
- SMT and CSO Observations (870 and 450 microns)
- SgrA\* peaks near 1mm?
- Conclusions: Low-level activity in almost all wavelengths

## Collaborators

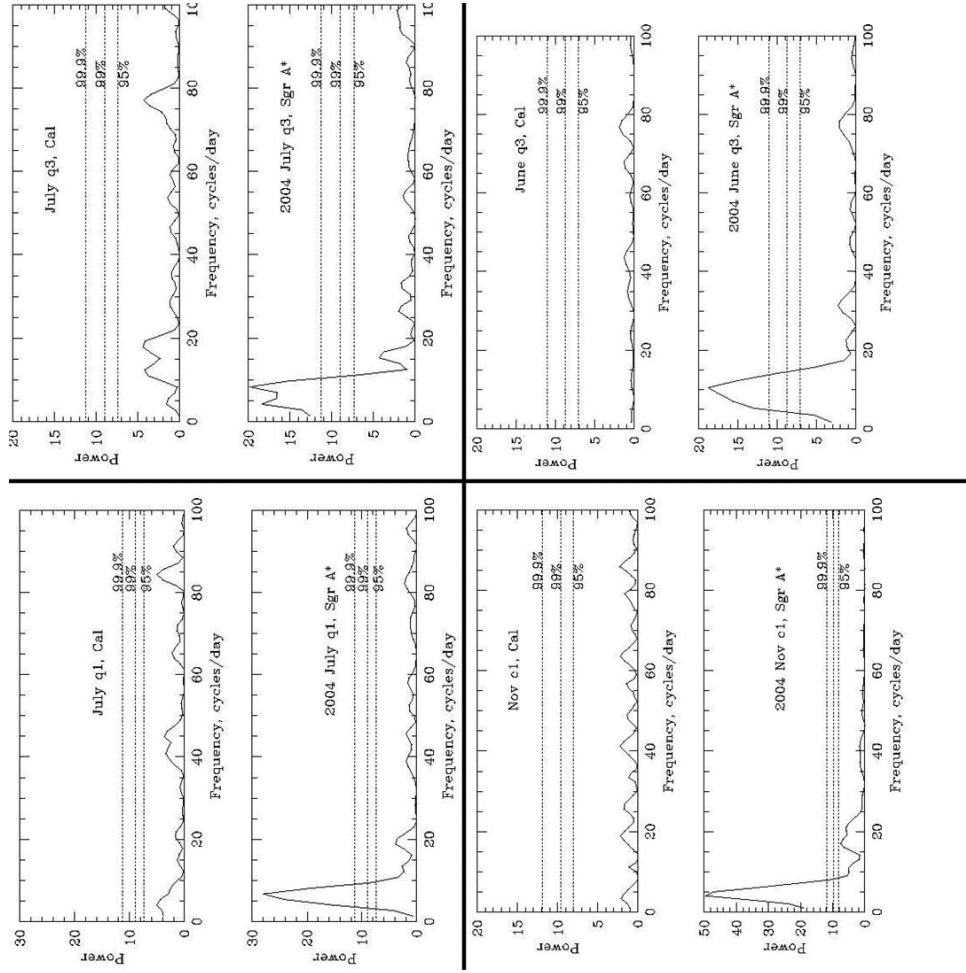
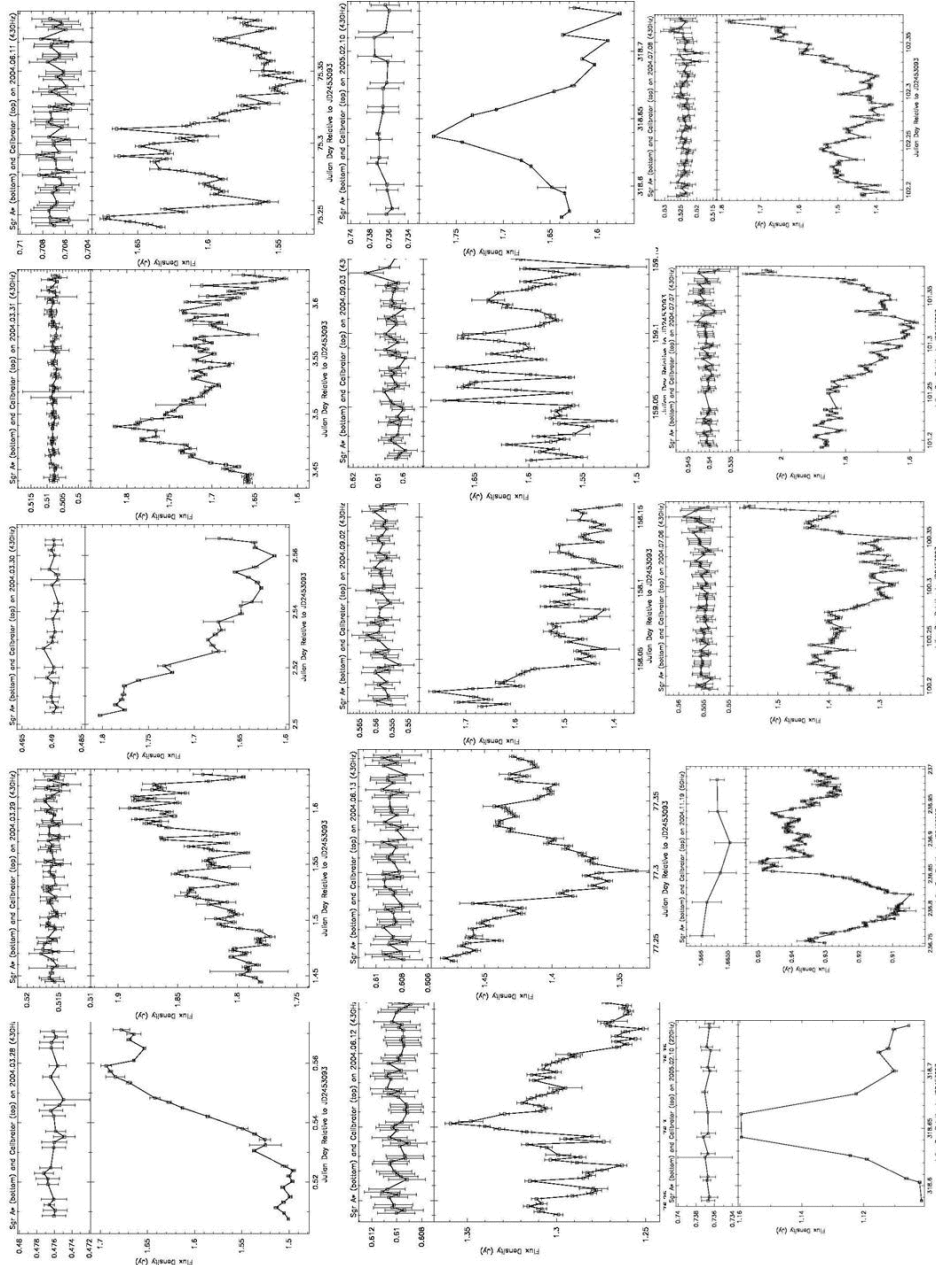
Radio (VLA)	Near-IR (HST)	X-Ray (XMM)	Sub-millimeter (CSO, SMT)
• D. Roberts	• H. Bushhouse	• A. Goldwurm	•D. Dowel
• G. Bower	• S. Shapiro	• G. Belanger	•B. Vila Vilaro
• C. Hencke		• D. Porquet	•L. Kirby
			•C. Walker
			•G. Novak

## A week in the life of SgrA\*

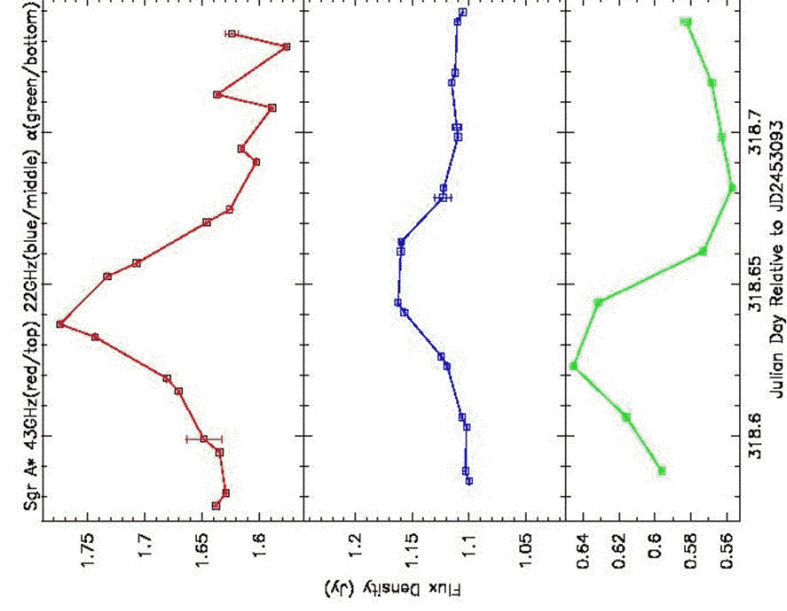


## Radio Continuum Variability (VLA)

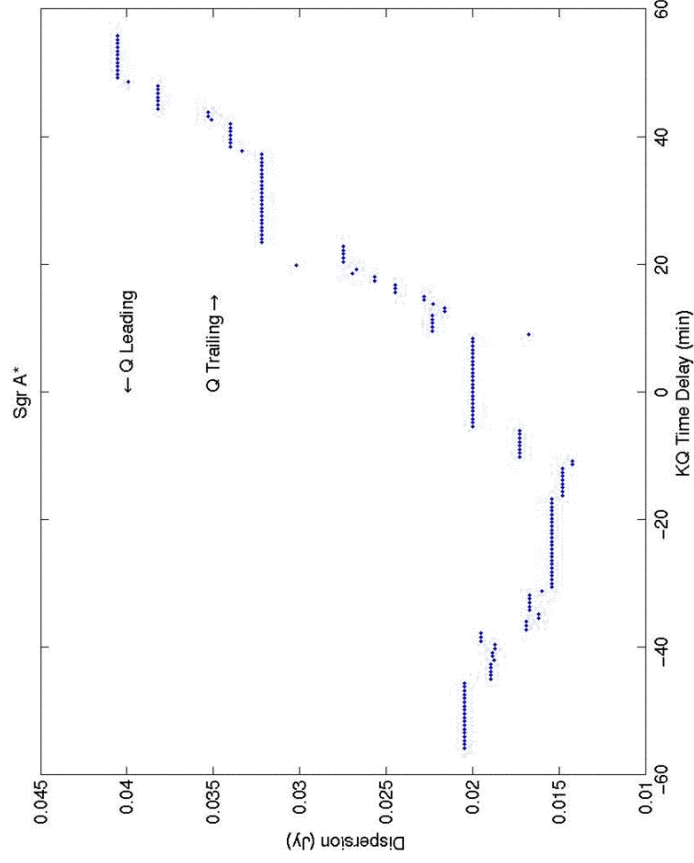
- **Motivation:**
  - Long term variability (Zhao et al 2001; Herrnstein et al. 2004)
  - Hourly variability
- **Observations:**
  - 19 sets of observations (none were snapshots) in one year
  - Mainly at 7mm and some at 1.2cm and 6cm (sub-arcs resolution)
    - Using the same calibrators (3C286, NRAO 530 and 1820-254)
    - Fast switching mode with high time resolution
    - Alternating SgrA\* (90sec) and the calibrator (30sec)
    - Sky tipping every 30min to account for the atmosphere opacity
    - Pointing to NRAO 530
    - High frequency calibration
    - The flux of SgrA\* was fitted in the UV plane (>100 kλ)
    - Similar variability in the image plane



- ~10% variability at 7mm, 5% at 1.3 and 6cm
- Lomb-Scargle periodogram searches for periodicity
- Significant quasi-periodic behavior with a period of ~2-2.5h
- The emission region is about  $300R_{sch}$
- Consistent with the 3mm variability on the same time scale (Mauerhan et al. 2005)

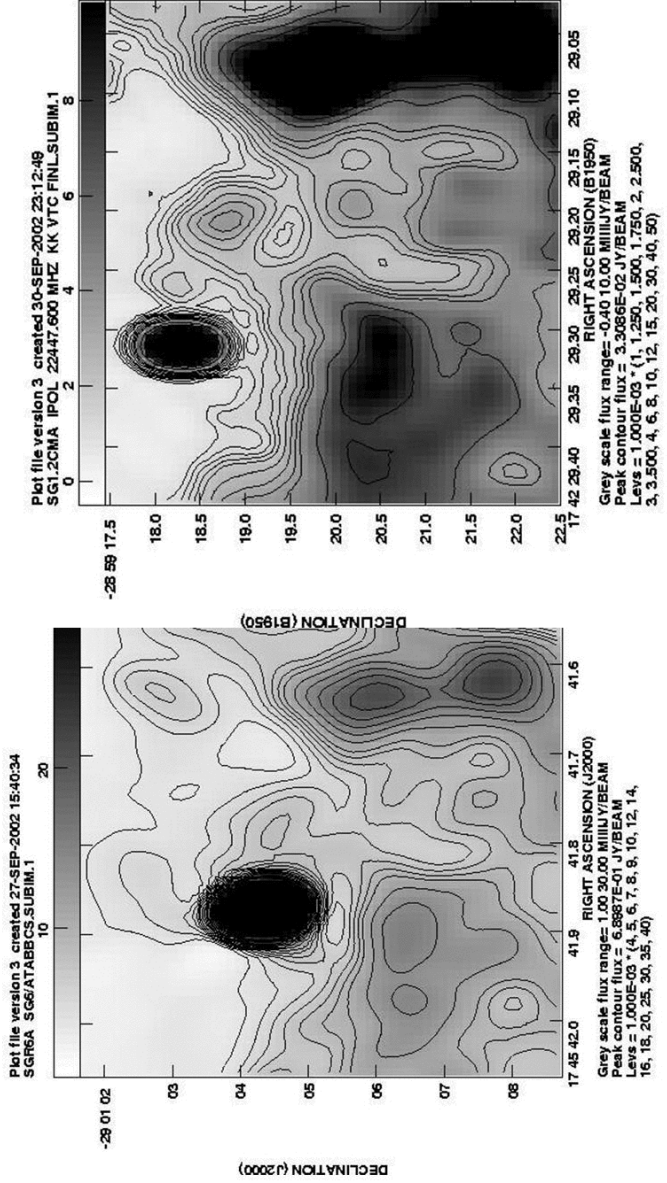


- Light curves of SgrA\* observed simultaneously at 7mm and 1.2cm
- The spectral index steeper at higher frequencies and during flares consistent with Herrnstein et al. (2004)
- The 7mm peak is leading the 1.2cm peak



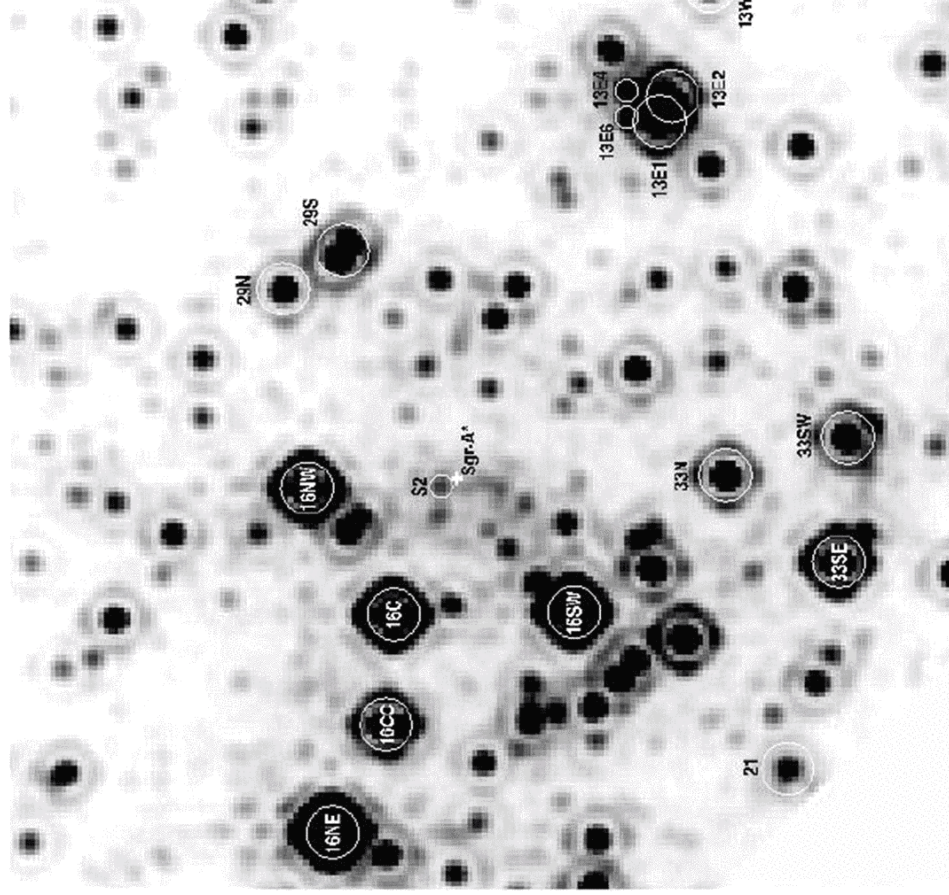
- The dispersion plot is minimum at ~20min
- An expanding self-absorbed synchrotron source with a delay of 20min implies plasma ejection took place 54min before the 7mm peak (van der Leen 1966).
- No near-IR or sub-millimeter data
- Continuous ejection

## 6 and 1.2cm VLA images of the Galactic Center



## Near-IR Line and Continuum (NICMOS /HST)

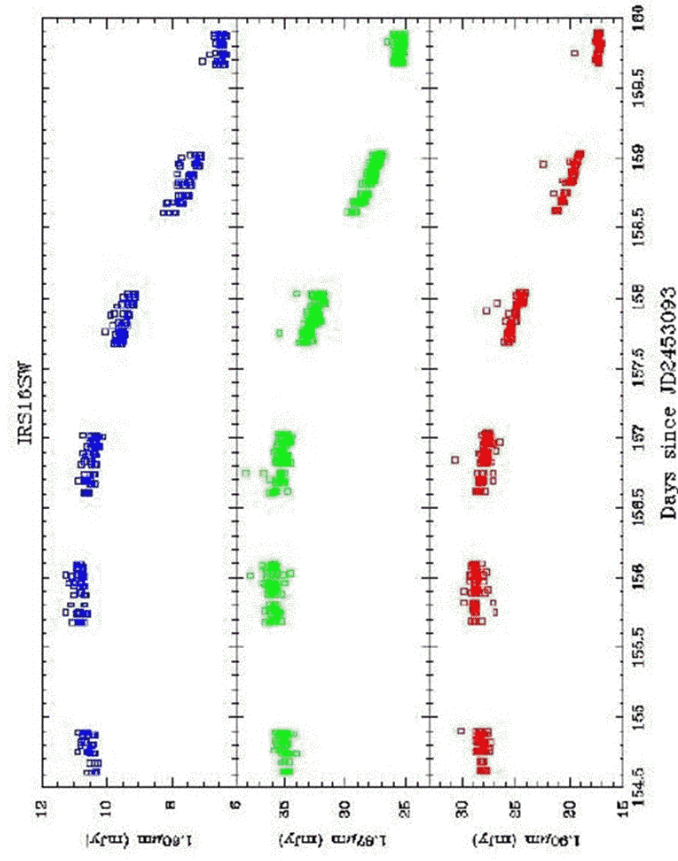
- **Motivation:**
  - To confirm the detection of 17min periodicity (Genzel et al. 2003)
- **Observations:**
  - 32 orbits of Camera 1 NICMOS in three bands:
    - F160W A broad band at 1.6 $\mu$ m (1.4-1.8 $\mu$ m)
    - F187N A narrow band at 1.87 $\mu$ m(1.865-1.885) (P $\alpha$  line)
    - F190N: A narrowband at 1.9 $\mu$ m (continuum)
  - Each cycle: Alternating between the three bands for about 7-8 min
  - Each orbit consists of two cycles



### 1.6 $\mu\text{m}$ image

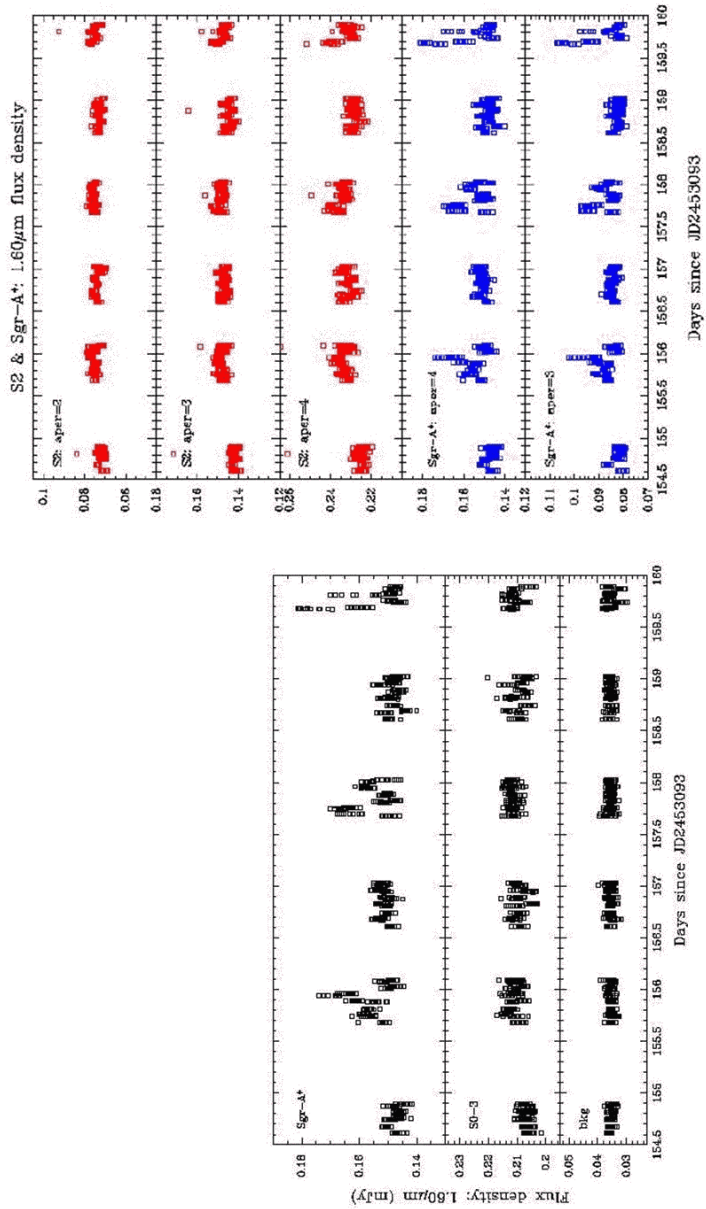
- Pixel size 0.043"
- Field of view 11"
- $\text{Sigma} = 0.002$  mJy after 30sec
- The position of S2 wrt SgrA\* estimated from orbit calculations (Ghez et al. 2003)
- S2 offset from SgrA\* is 0.13"N and 0.03"E
- PSF has a four pixel diameter

### Aperature Photometry of IRS 16SW

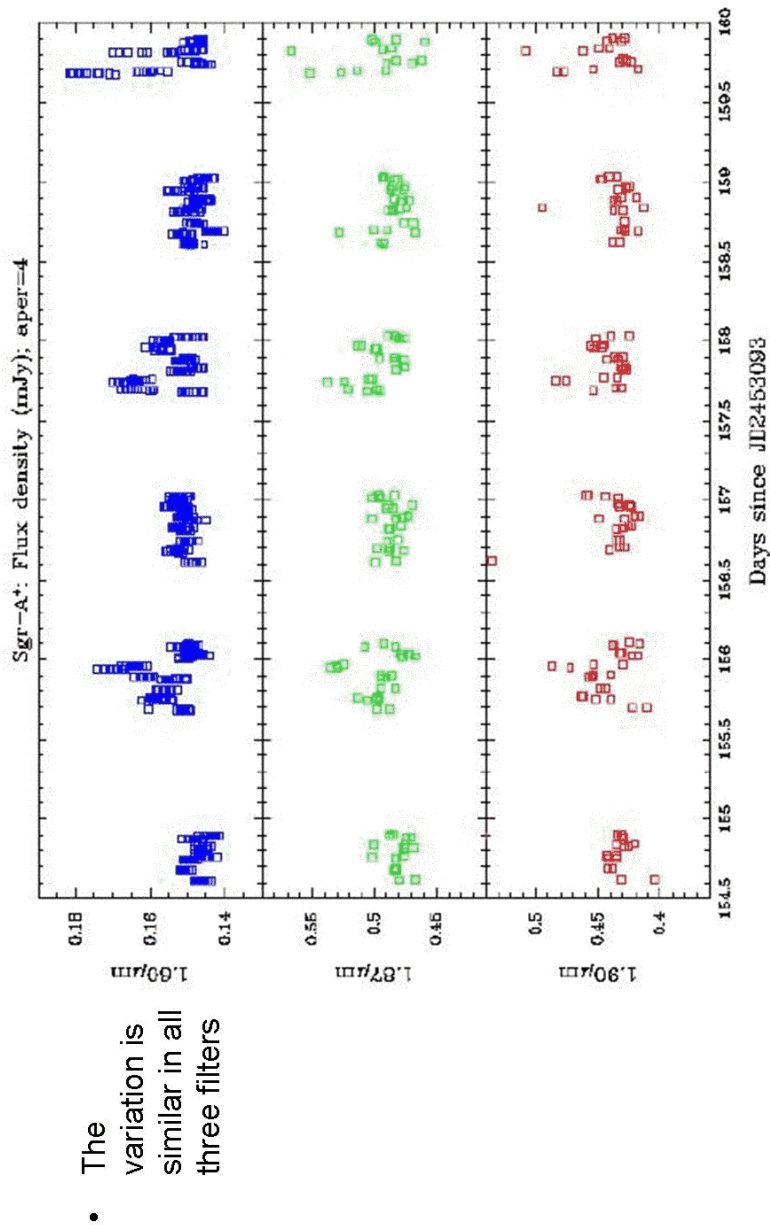


- IRS 16SW is known to vary with a period of 19.45 days
  - Ott et al. 1999;
  - Depoy et al. 2004

# Aperature Photometry of SgrA\*, S02, S03 and the Background

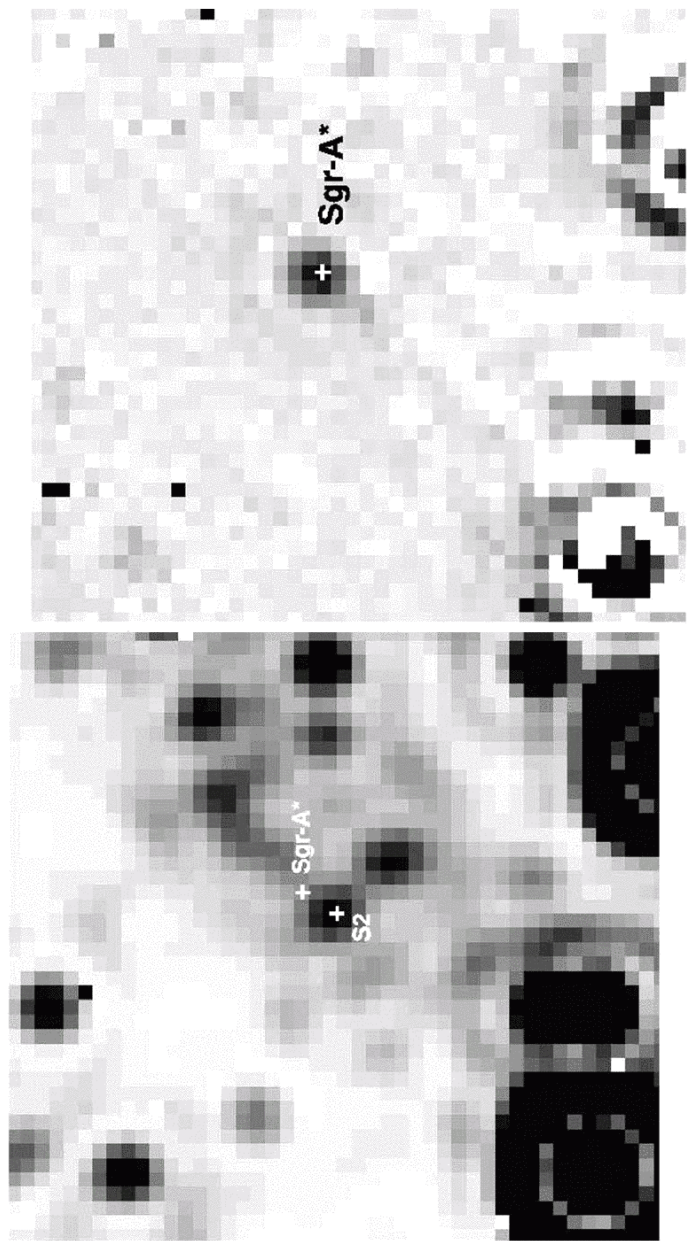


# Light Curve of SgrA\* at 1.6, 1.87 and 1.90 microns

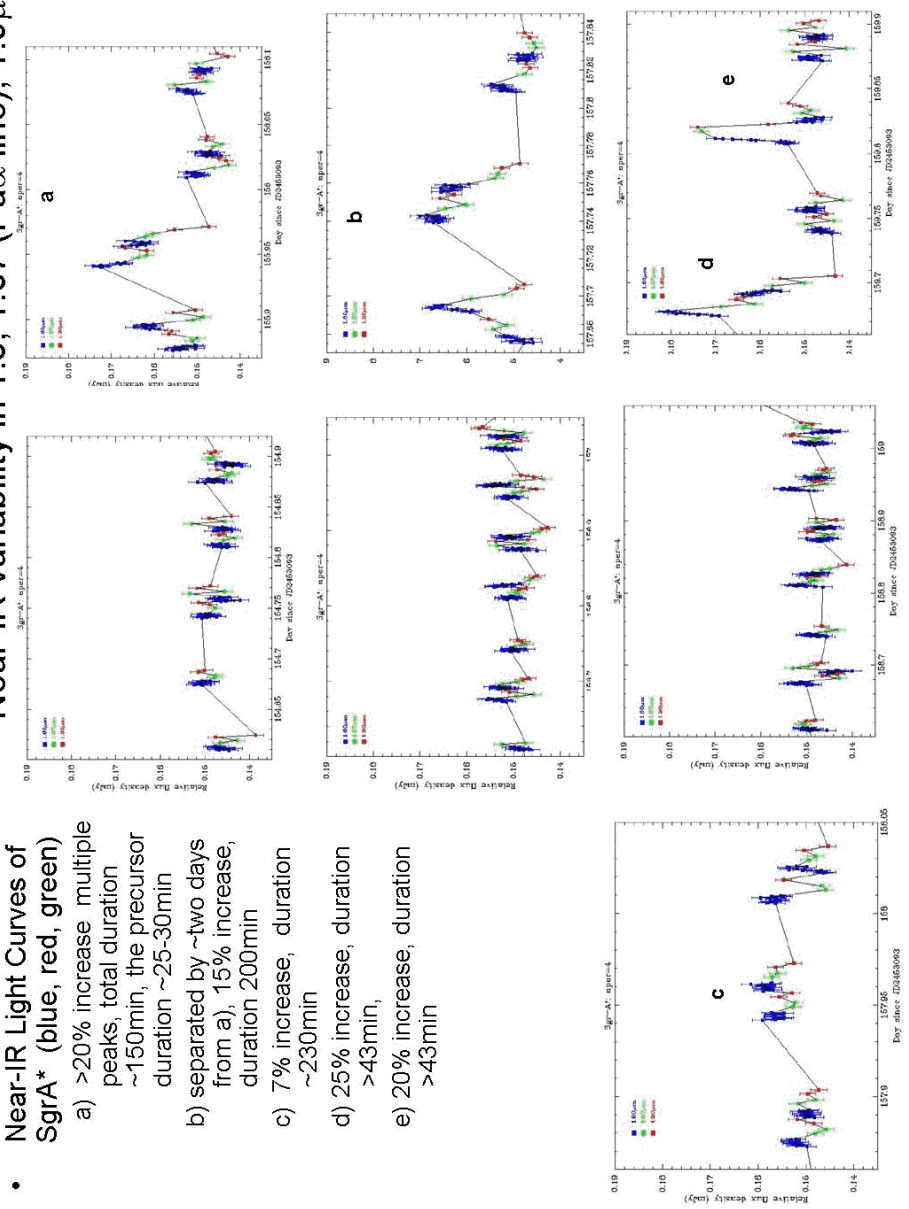


- The variation is similar in all three filters

1.6 micron Emission from SgrA\*



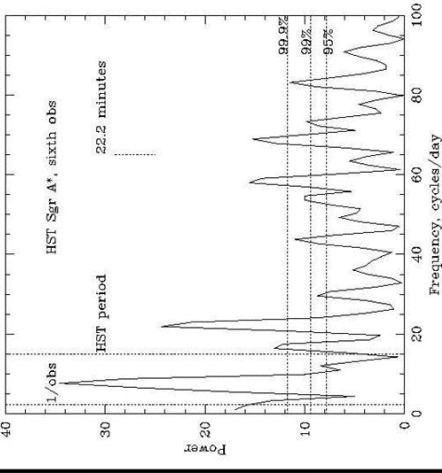
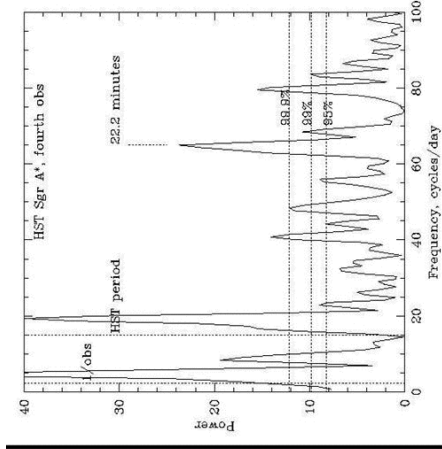
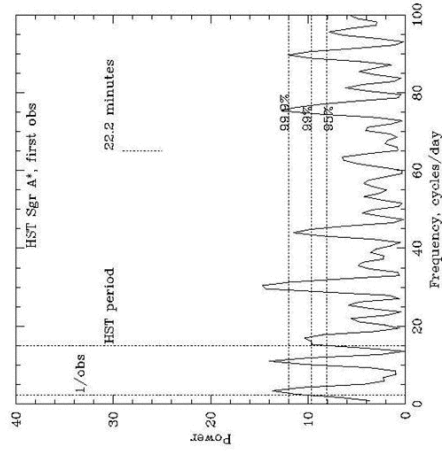
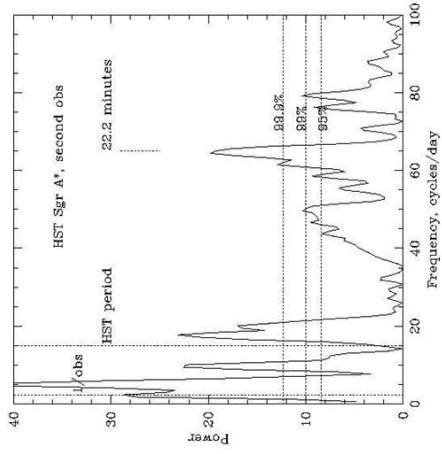
Near-IR variability in 1.6, 1.87 (Pa $\alpha$  line), 1.9 $\mu$ m



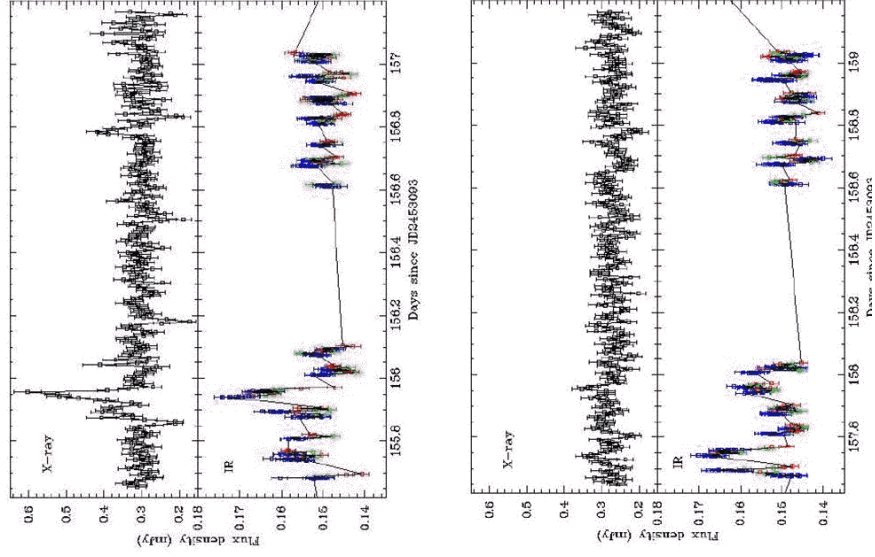
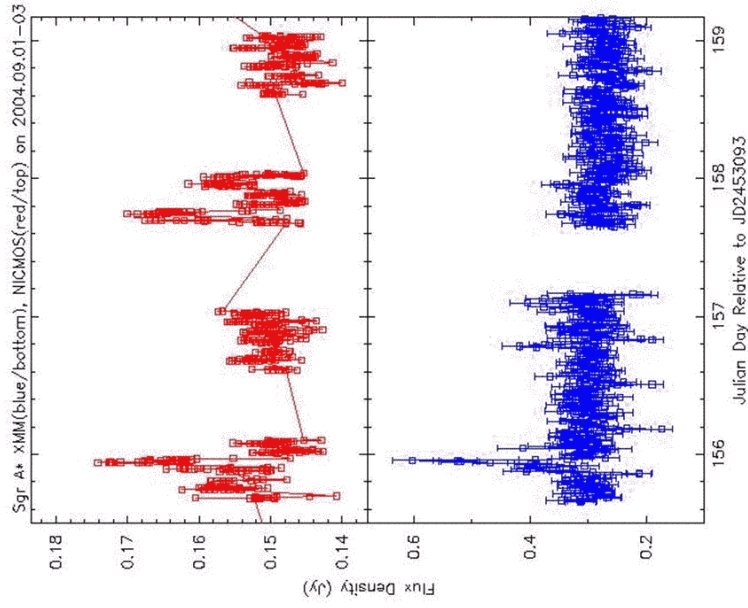
- Near-IR Light Curves of SgrA\* (blue, red, green)
  - a) >20% increase multiple peaks, total duration ~150min, the precursor duration ~25-30min
  - b) separated by ~two days from a), 15% increase, duration 200min
  - c) 7% increase, duration ~230min
  - d) 25% increase, duration >43min,
  - e) 20% increase, duration >43min



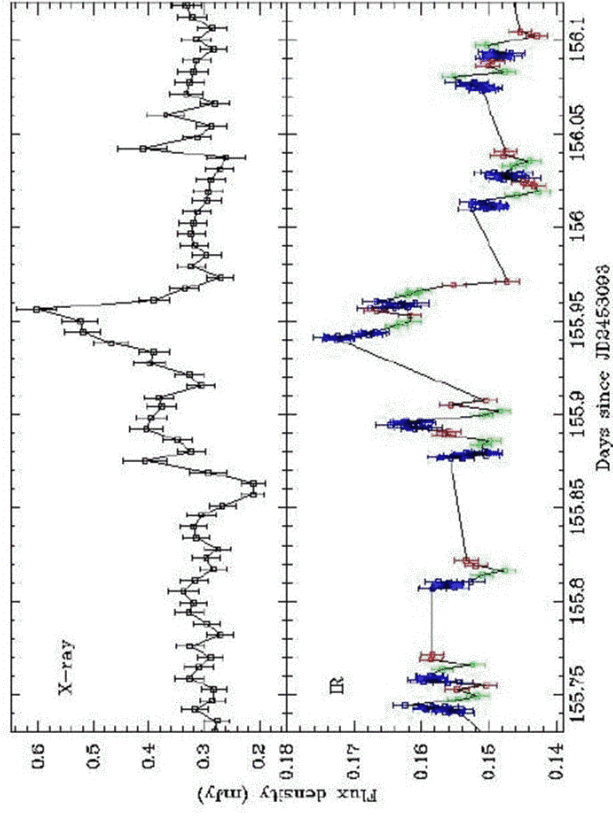
- Lomb-Scargle periodogram searches for periodicity
- Significant quasi-periodic behavior with a period of ~22min during the flares



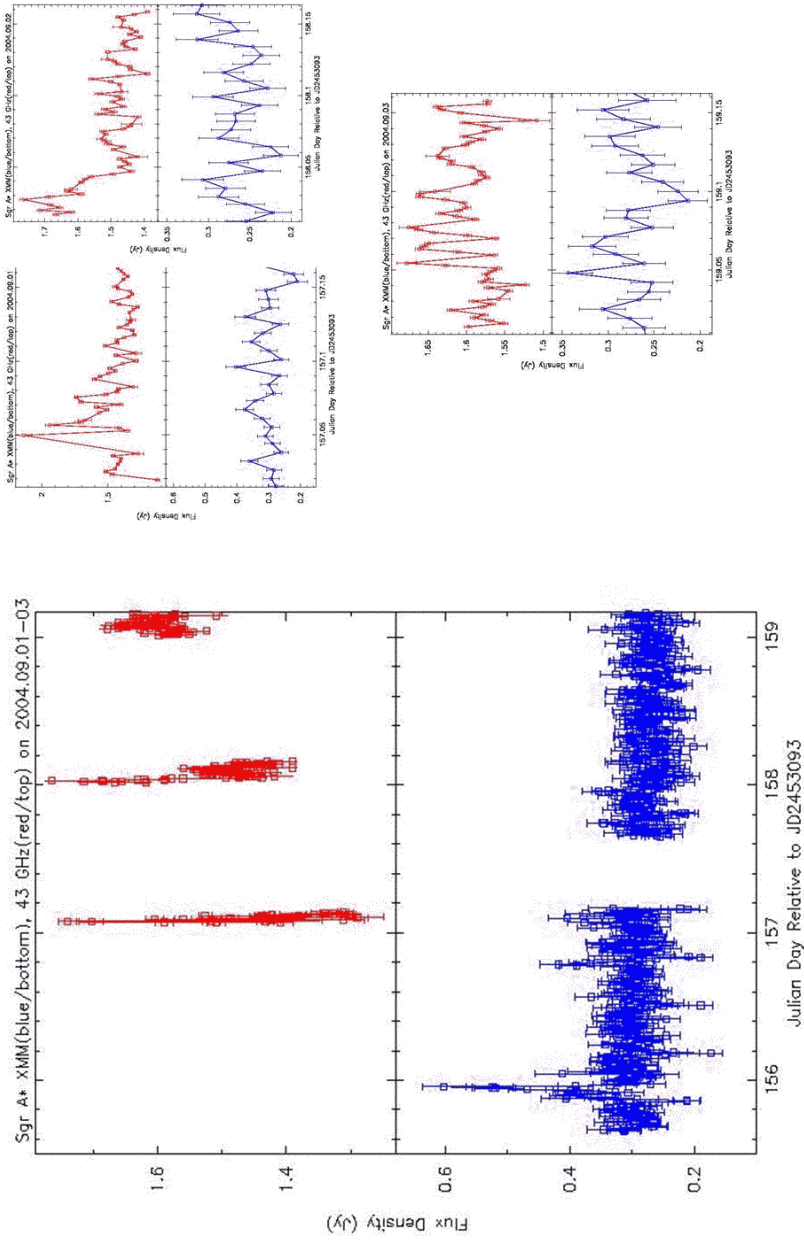
### IR (1.6-1.9 $\mu$ m) vs. X-Ray (September Campaign)



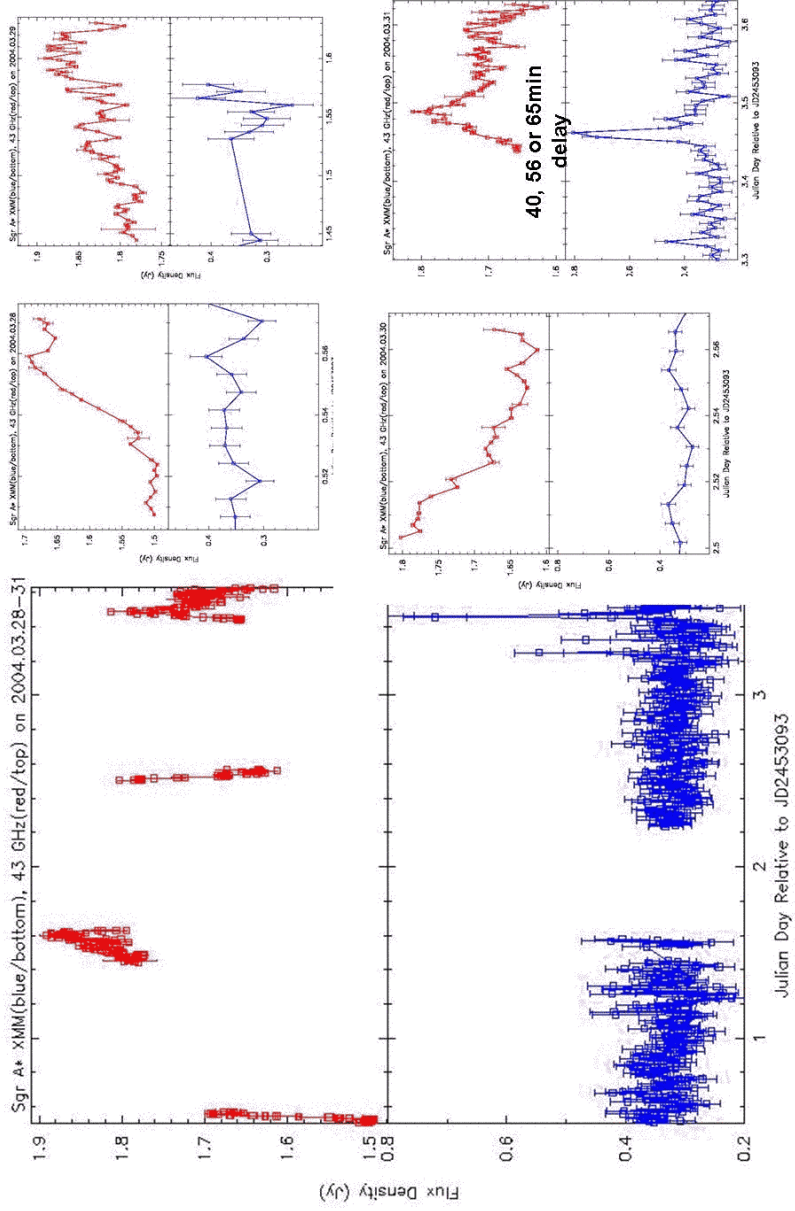
- X-ray flare, duration 5000sec,  $L_x \sim 7.7 \times 10^{34}$  erg/s with a soft spectrum (Belanger et al. 2005)
- IR-flare with  $L_x \sim 1.8 \times 10^{35}$  erg/s
- #ph/s (near-IR)  $> 30 \times$  #ph/s
- Synchrotron self-Compton (first flare) but not the second flare



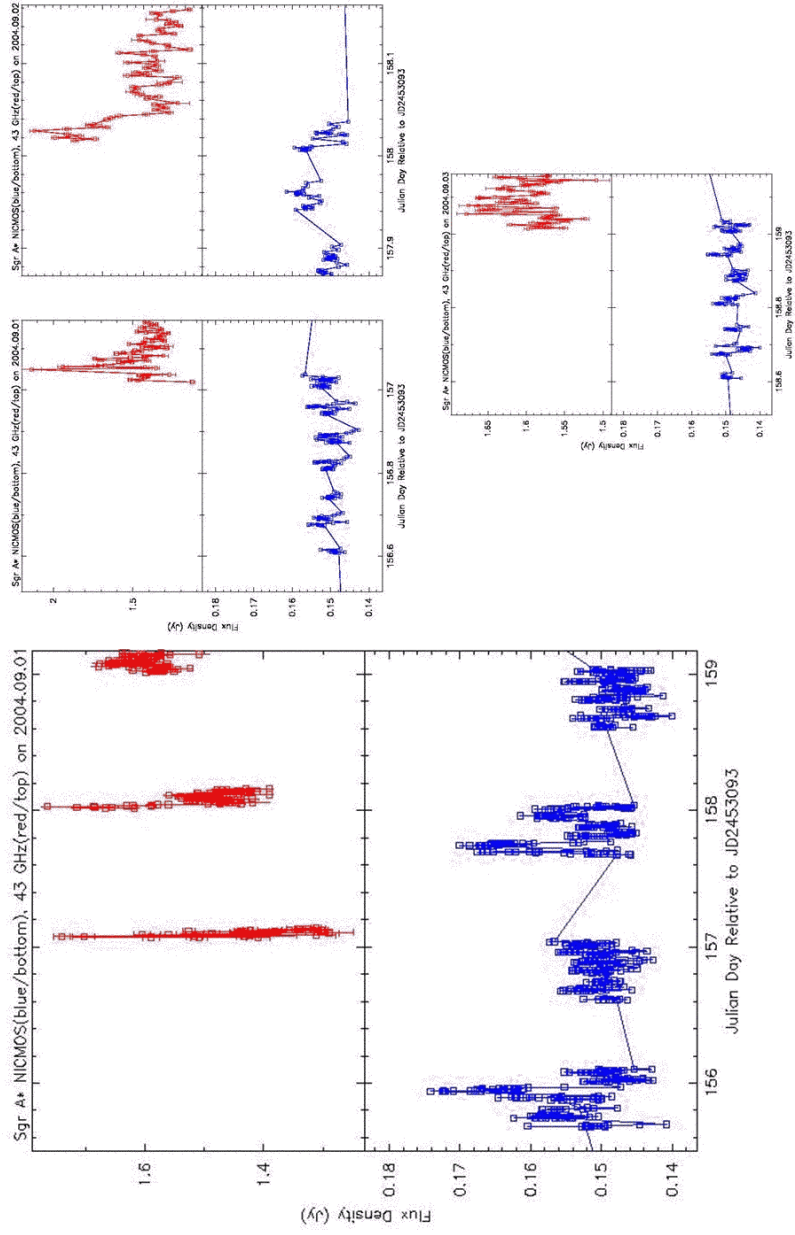
### Radio (7mm) vs X-ray (September Campaign)



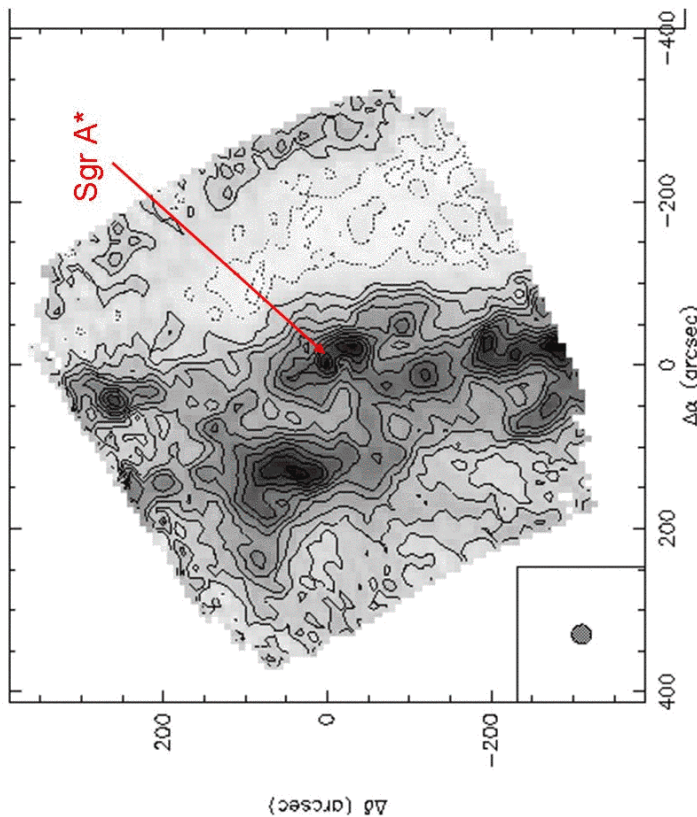
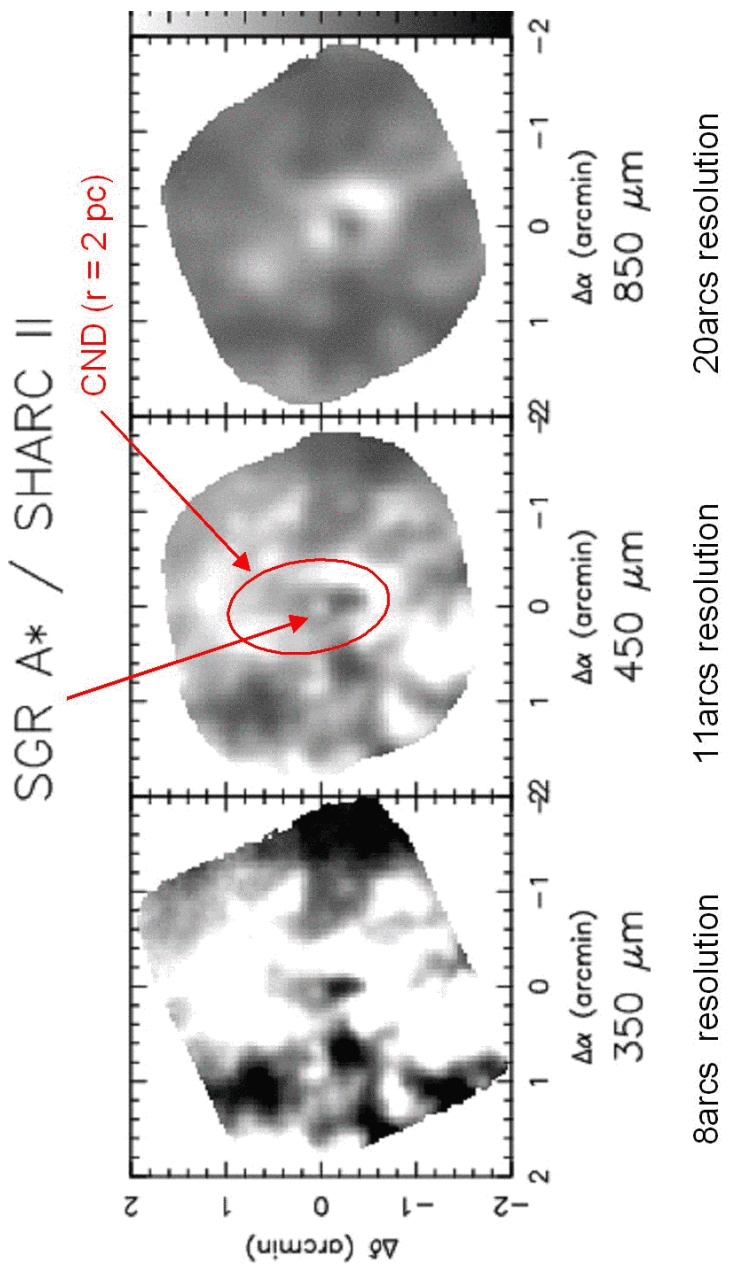
### Radio (7mm) vs X-ray (March Campaign)



### IR (1.6-1.9 $\mu$ m) vs. Radio (7mm) (September Campaign)

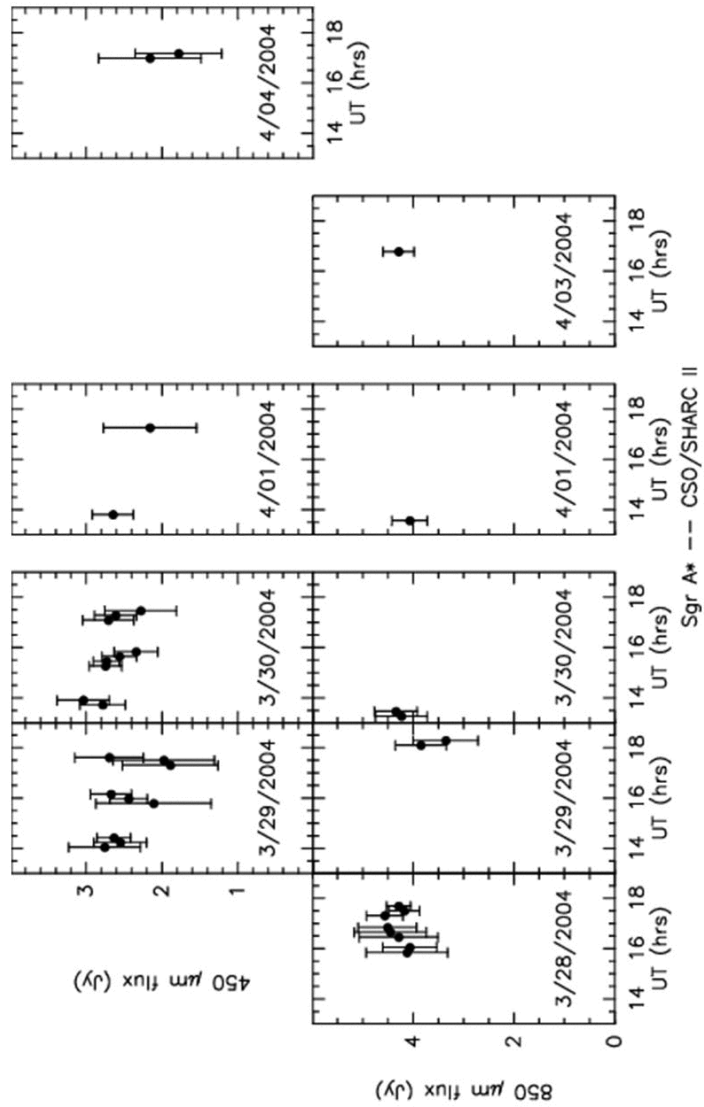


Sub-millimeter Images of Sgr A\*  
(March 2004, September 2004)

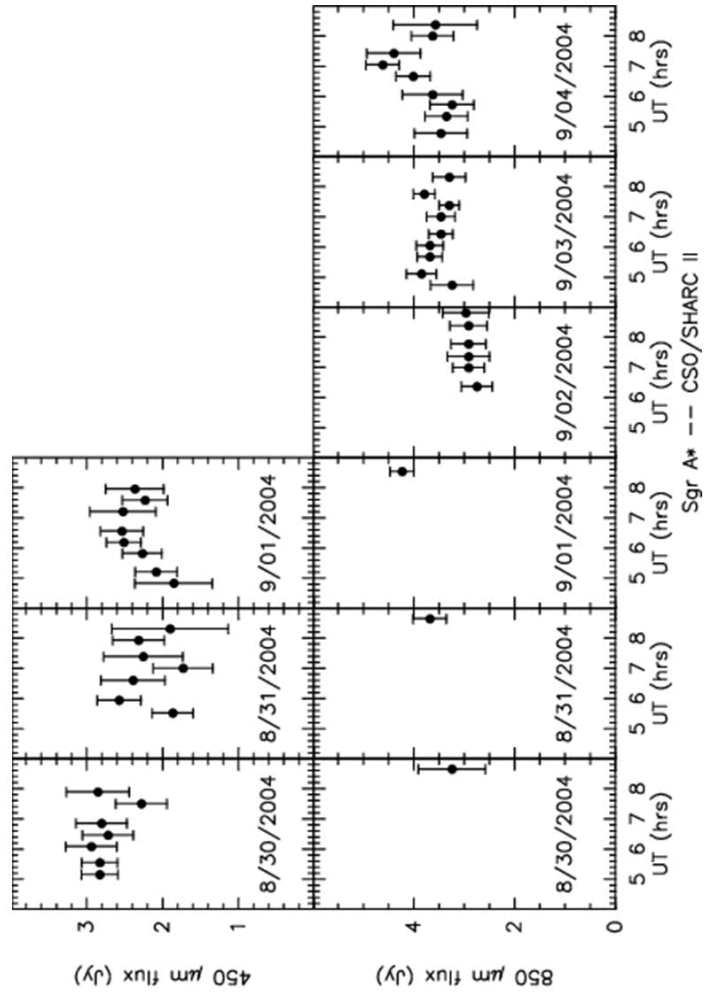


- 870 micron SMT image with 13arcsecond resolution

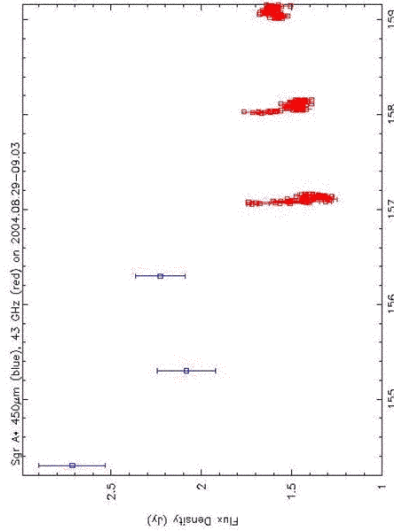
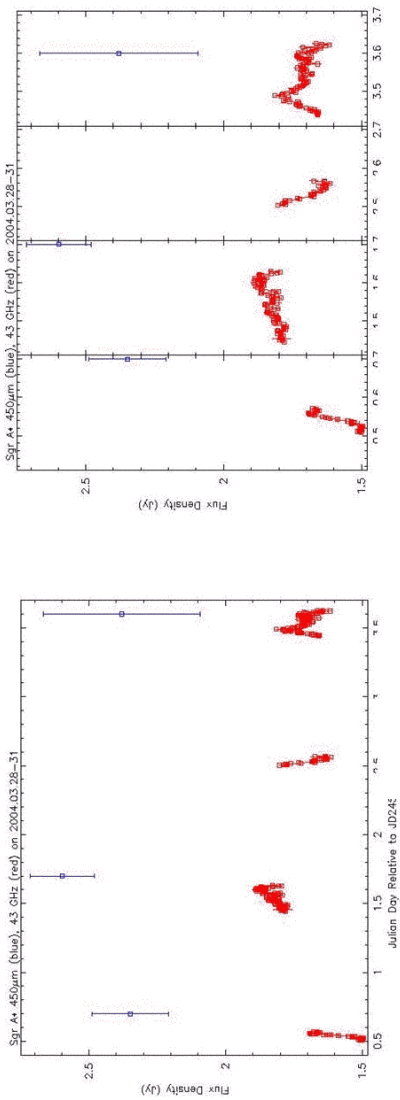
### Submillimeter 0.87mm and 0.45mm Emission (CSO) March Campaign



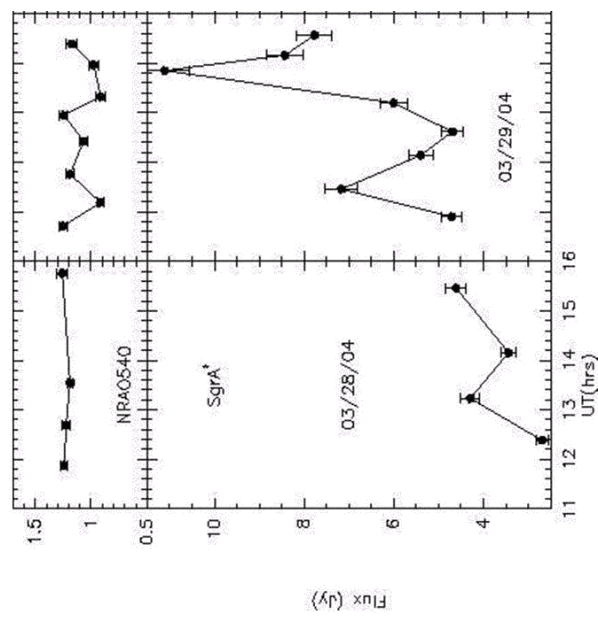
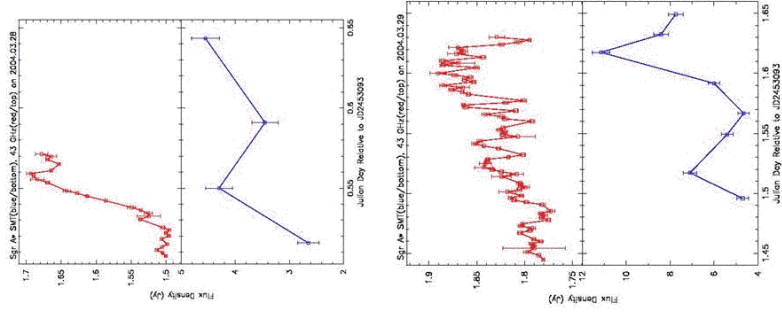
### Submillimeter 0.87mm and 0.45mm Emission (CSO) September Campaign



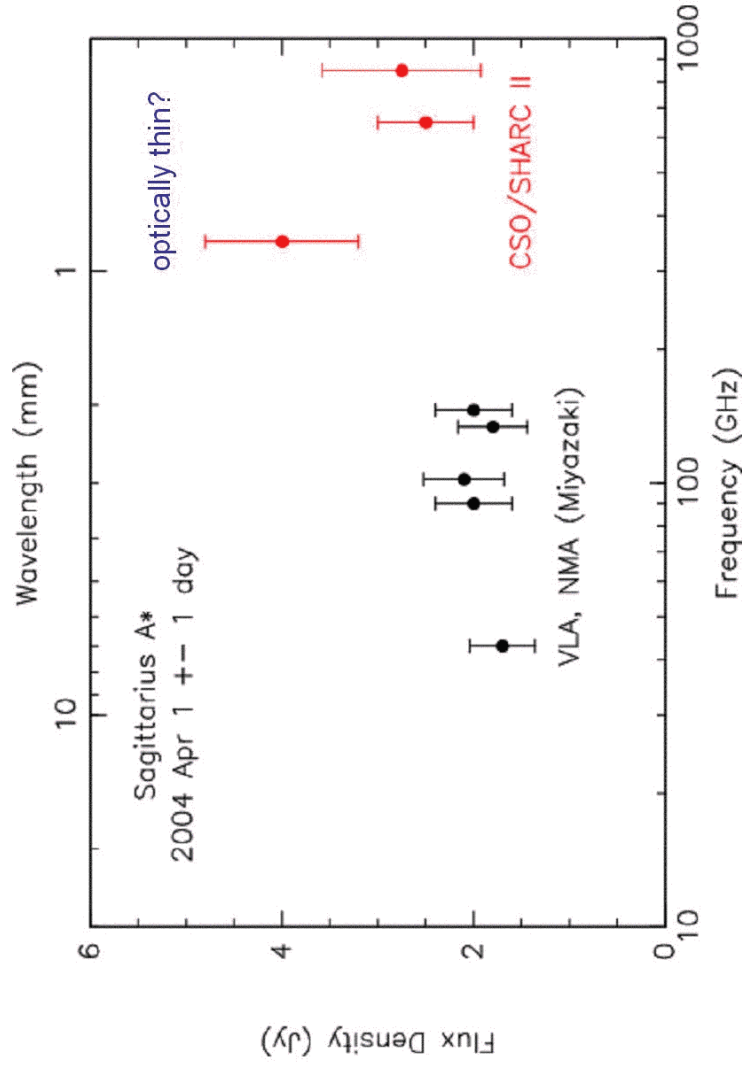
## Submillimeter 7mm and 0.45mm Emission (CSO) March Campaign



## SMT Observations (870microm) March Campaign



## Sub-millimeter Spectrum is Flat or Falling



## Conclusions

- Quasi periodic hourly time variability of 5-10% in radio wavelength
- Time delay Implies continuous ejection of plasma
- Low level near-IR variability (>10-40%) more than 1 flare per day
- Evidence for a near-IR flare with quasi-periodic 22min behavior
- Dynamical size corresponds to a radius of 3R<sub>Sch</sub> (no rotation)
- Correlation between a near-IR and X-ray flare: consistent with SSC
- No correlation between 7mm and near-IR or 7mm and X-ray
- A possible correlation between 7mm, 3mm, 0.87 and 0.45mm
- The turnover frequency is near 1mm
- The flow always fluctuates even in its quiescent phase