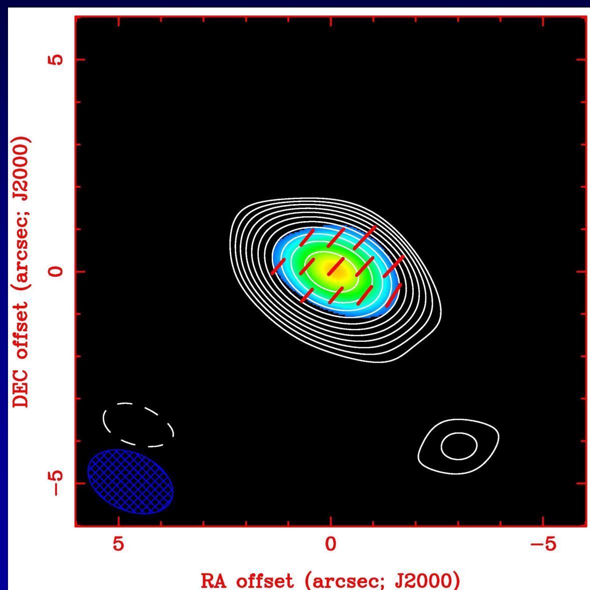
SMA Observations of Sgr A*

Dan P. Marrone, Ram Rao, Jim Moran, Jun-Hui Zhao
Harvard-Smithsonian Center for Astrophysics



Sgr A* at 337 GHz
2004 May 25

Outline

- Introduction to Sgr A*, submm perspective
- SMA Capabilities
- Observations of Sgr A*
  - 2004: Polarimetry at 880μm (340 GHz)
  - 2005: Photometry and polarimetry from 1.3mm to 450μm

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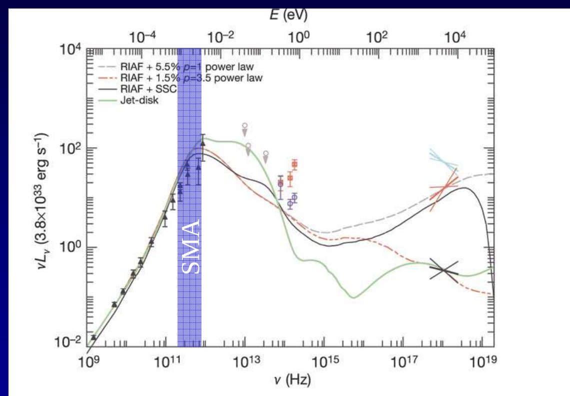
What is known about Sgr A*?

- Mass: 4×10^{6} $M_\odot$
  - From IR stellar orbits, VLBI proper motion monitoring
- Luminosity:

  $\sim10^{36}$ ergs/s $\approx 250L_\odot \approx 10^{-8}L_{Edd}$
  - Spectrum well measured from 90cm to 450μm, NIR, X-ray
  - Peak in submillimeter, variable at all(?) wavelengths

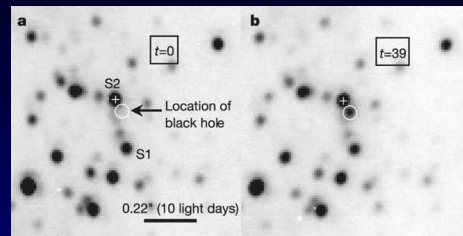


Sgr A* SED (Genzel et al. 2004)

What isn't known?

- Why is the luminosity so low?
- Inefficient radiation and accretion – which model?
  - Jets and/or winds and/or convection and/or advection
  - Spectrum alone is insufficient to separate accretion models
- Origin of the flares?
- Connections to other sources: typical LLAGN?

New Tools - Variability



1.65μm (H-band) flare (Genzel et al. 2004)

- Multi-wavelength monitoring
  - Rapid changes require small radius
    - → Direct connection to inner flow
  - Flare spectrum in submm/IR/X-ray should constrain mechanism(s) (e.g. Liu, Petrosian & Melia 2004)
  - Recent results:
    - IR flares may show short periodicity, polarization (Genzel et al. 2003)
    - Coincident X-ray/IR/mm flares (Eckart et al. 2004, Zhao et al. 2004)
- Need submm time resolution on timescales of flares (minutes)
- Polarization information useful

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New Tools - Linear Polarization

- Constrains density and B field through Rotation Measure:

$$\phi(\lambda) = \phi_0 + \lambda^2 RM \qquad RM \propto \int n_e(r) B(r) \cdot dr$$

  - RM can be used to infer inner $\dot{M}$
  - RM derived from PA measurement at multiple frequencies
- Polarization only available in mm/submm (≤ 3.5mm)
  - No LP detected 21cm – 7mm
- Polarization fraction measurements require high resolution
  - SCUBA detection contaminated by surrounding emission
- BIMA measurements …

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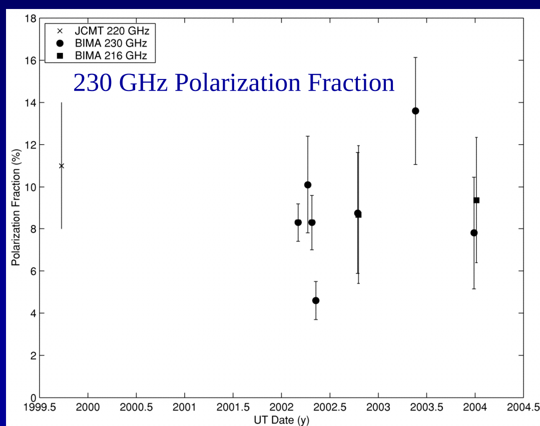
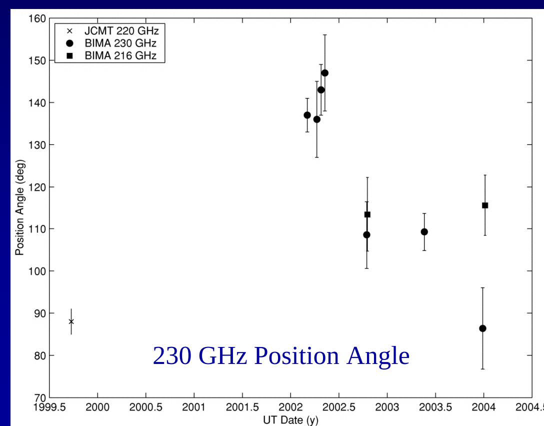
Linear Polarization of Sgr A*

- Confirmed interferometrically at 1.3mm (230 GHz) (Bower et al. 2003, 2005)
  - LP is variable → Need simultaneous data to infer RM
  - RM is low → Need widely separated frequencies





Bower et al. (2005)

SMA – A New Observing Tool

The Submillimeter Array (SMA)

- The first dedicated submillimeter interferometer
- 8 6-meter antennas on Mauna Kea
- Sub-arcsecond resolution in three bands:
  1.3mm, 850, and 450 μm (230, 345, 690 GHz)

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New Capabilities from the SMA

- High angular resolution eliminates JCMT confusion
- Better sensitivity than BIMA:
  - Larger continuum bandwidth (2 vs. 0.8 GHz)
  - Better site: atmosphere and latitude
  - Allows precision photometry (10’ sampling), polarization monitoring (sub-night sampling)
- Wider frequency separation
  - Greater sideband separation than BIMA (10 vs. 2.8 GHz)
  - Simultaneous observations at multiple frequencies
  - **Unprecedented sensitivity to RM**

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RM Sensitivity

Current Limit: ~10^6 rad/m^2

$$RM = \frac{\Delta\phi}{\lambda_L^{\ 2} - \lambda_U^{\ 2}}$$

SMA single band observations:

230 GHz RM = **1.1×10^5** rad/m^2/º
340 GHz RM = 3.7×10^5 rad/m^2/º
690 GHz RM = 3.1×10^6 rad/m^2/º
(BIMA at 230: 4.2×10^5 rad/m^2/º)

SMA dual band observations:

230/690 RM = **1.1×10^4** rad/m^2/º **→ RM detectible at < 10^5 rad/m^2**
(For one 180º wrap: RM > 2x10^6)

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SMA Polarimetry

- Measurement of LP best done with CP feeds
  - Linear feeds mix I, Q, U
  - Circular feeds mix I, V (likely small), Q, U uncontaminated
- SMA feeds are LP, single feed per band
- Need polarization conversion, multiplexing scheme

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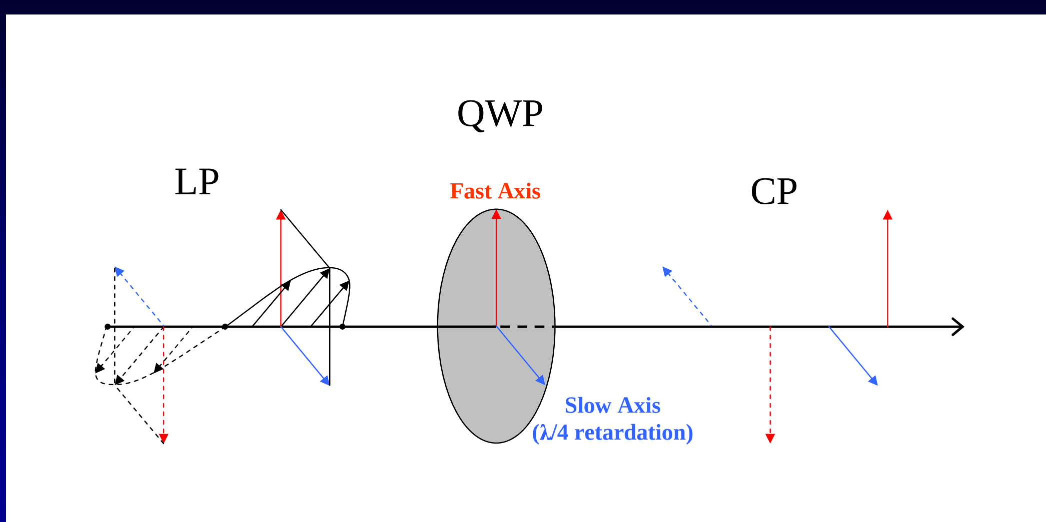
LP to CP Conversion: Quarter-wave plates



Simple "Broadband" QWP:
λ/4 at 3λ_0 3**λ/4** at λ_0,
Perfect for 230/690 GHz

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SMA Polarization Hardware

- Same observing technique as BIMA
- Polarimetry at 230, 340, 690 GHz this year

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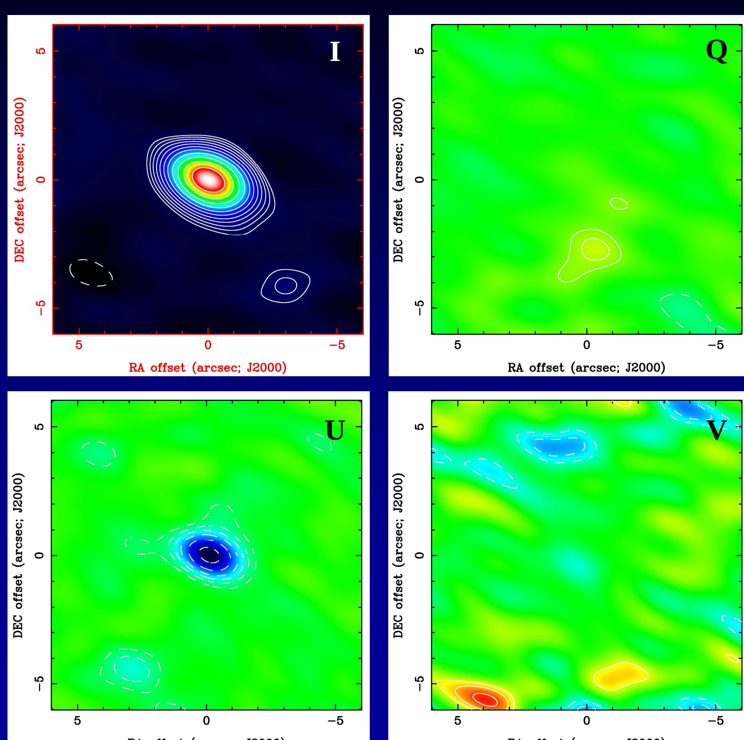
Sgr A* Polarization at 340 GHz



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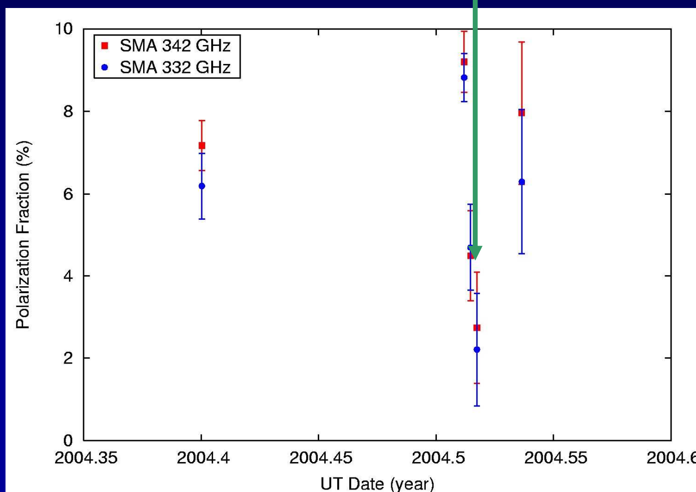
Polarization Fraction

• P lower at 340 than 230 GHz

• P varies significantly, unlike Bower et al. results at 230 GHz

X-ray/IR Flare



Data from:
Aitken et al. (2000)
Bower et al. (2003)
Bower et al. (2005)
Marrone et al. (2005, in prep)

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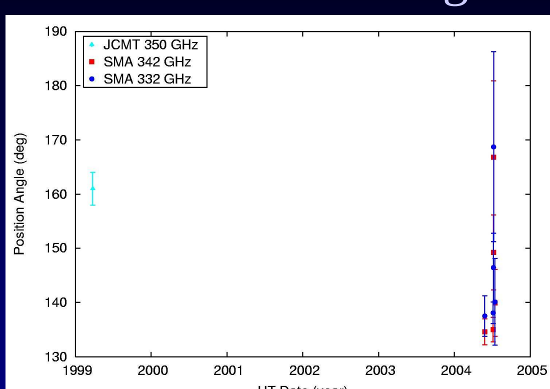
Position Angle – Rotation Measure



All PA Data

If the 7/7 point is excluded (low S/N)

• 20º PA shift from 1999

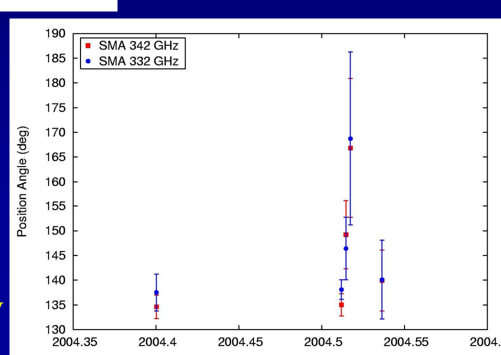
→ **ΔRM = 4×10⁵ rad/m²**

Matches changes seen at 230GHz

• Consistent PA between sidebands (10 GHz separation)

→ **RM < 9×10⁵ rad/m²**

SMA Only



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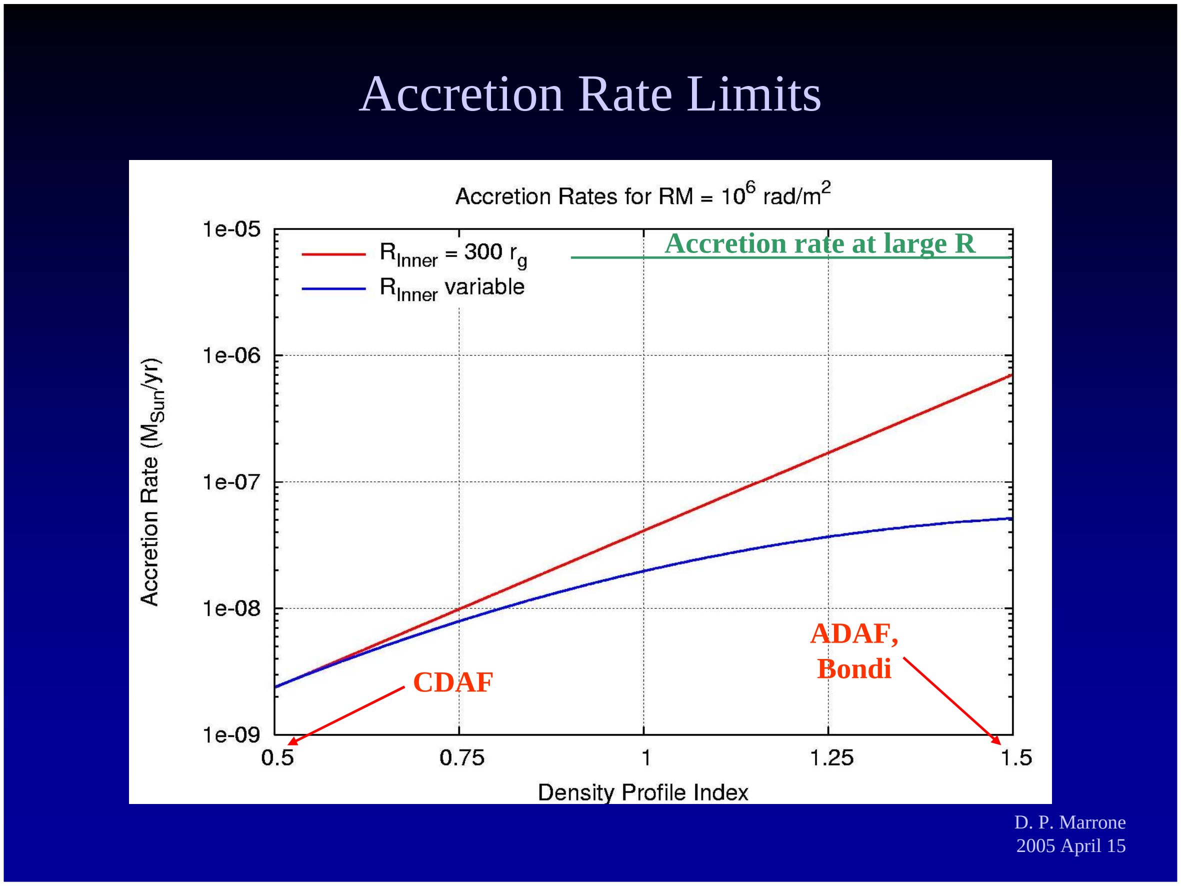
Accretion Rate Limits
Accretion Rates for RM = 10^6 rad/m^2
R_Inner = 300 r_g
R_Inner variable
Accretion rate at large R
Accretion Rate (M_Sun/yr)
1e-05
1e-06
1e-07
1e-08
1e-09
0.5
0.75
1
1.25
1.5
Density Profile Index
CDAF
ADAF,
Bondi
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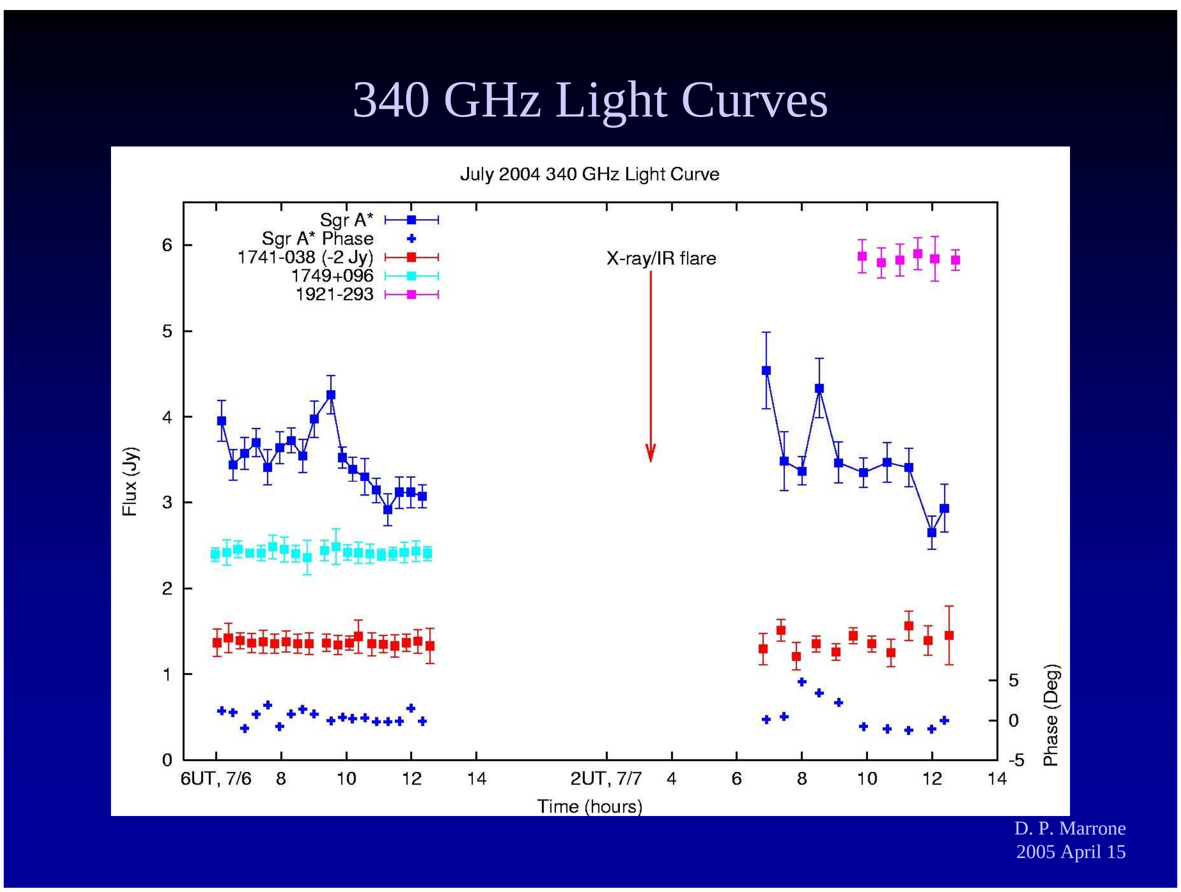
340 GHz Light Curves
July 2004 340 GHz Light Curve
Sgr A*
Sgr A* Phase
1741-038 (-2 Jy)
1749+096
1921-293
X-ray/IR flare
Flux (Jy)
Phase (Deg)
Time (hours)
6UT, 7/6
2UT, 7/7
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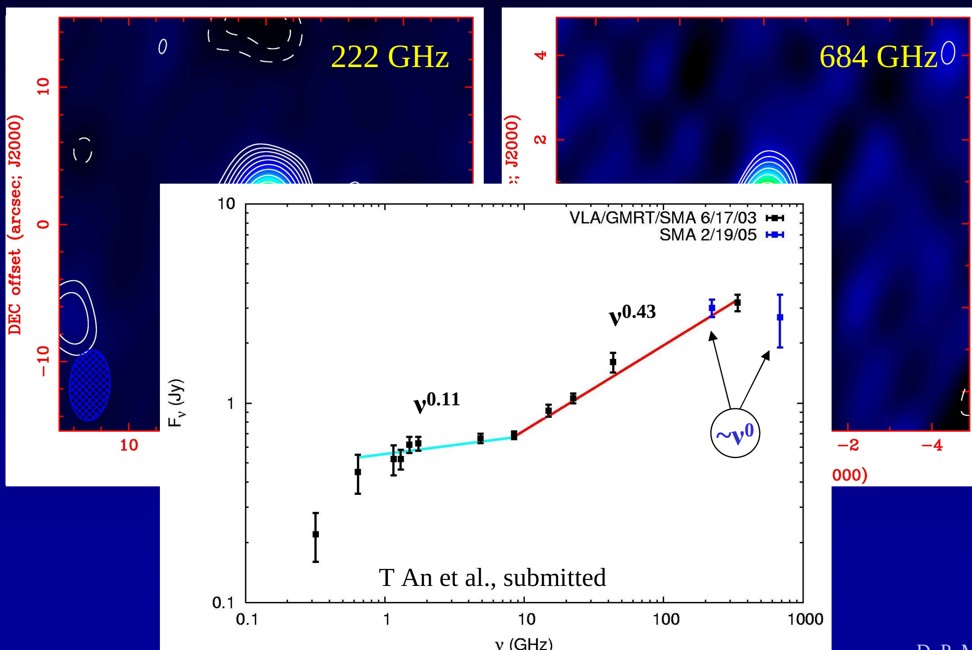
Sgr A* 230/690 GHz (continuum)



Upcoming Observations

- 2005 GC observations are SMA Legacy Science
- 3-band polarimetry (230/690 simultaneous)
  - First polarization measurement at 690 GHz (450µm)
  - **First detection of the RM**
- 5 coordinated monitoring nights
  - Chandra/VLT/Keck/SMA/VLA
  - Coordinated IR/submm polarization?
- Precision short-timescale photometry
  - CP feeds: no effects from LP changes
  - Power spectra for comparison with accretion simulations
  - Time-resolved polarization measurements