The Circular Polarization of Sgr A* at Submillimeter Wavelengths

Diego Muñoz
Harvard University

Some observational facts about Sgr A*:

- Underluminous ($L \sim L^{-9}_{\text{Edd}}$) SMBH of $4.5 \pm 0.4 \times 10^6 M_\odot$ (Ghez et al '08)
- At a distance of $8.4 \pm 0.4$ kpc (Ghez et al '08)
- Size-frequency relation: $\theta_{\text{diam}} \sim \nu^{-1.3}$ (e.g. Falcke et al '09)
- Flat-to-inverted radio spectrum
- Submillimeter excess above 50-100 GHz

![Graph showing spectral index variations with frequency]
Some more…

• Linear Polarization (LP) undetected (<0.1%) at radio wavelengths
• Circular Polarization (CP) at the 0.5% level at radio wavelengths

On the other hand…

• Linear Polarization ~7% at submm wavelengths
• Circular Polarization undetected above 43 GHz at the 1% level.

• Submm flares ~daily.
• Permanent variability in LP position angle.
• Faraday rotation measure (RM) to be fairly constant among epochs.
The Circular Polarization of Sgr A*
Our results

Previous observations (Marrone 06) were focused on LP measurements and RM. CP considered limited by calibration.
The Circular Polarization of Sgr A*
Maps (230 GHz, 230 GHz VEX, 345 GHz)

SMA Compact North configuration

At 230 GHz. March 31st, 2007

Blue Contours: CLEANed Stokes I
Red Contours: CLEANed Stokes V
-8,-5,-3,-2,2 x σ
The Circular Polarization of Sgr A* Maps (230 GHz, 230 GHz VEX, 345 GHz)

SMA Very Extended configuration At 230 GHz.

SMA Compact-north configuration At 345 GHz.
The Circular Polarization of Sgr A*

Maps of 1924-292

Blue Contours: CLEANed Stokes I
Red Contours: Stokes V
-5, -3, 3 x $\sigma$

CP<0.2%

SMA Compact North configuration
At 230 GHz. May 30th, 2008
Polarization Tests

• Gain Calibration: R,L separate gains
• CP in quasars
• Time Variability (flux and offsets)
• Spectral Variability (flux and offsets)
• Role of the Leakages
• What causes the position offsets?
• Unexpected instrumental pol. (Beam squints?)
• Polarimetric tests on 1924-292

The CP flux of Sgr A* is real
Stratified/Multilayered synchrotron sources
(de Bruyn '76, Blandford & Konigl 79, also Loeb & Waxman '07)

Synchrotron-emitting Uniform plasma shell

\[ \log F_\nu \sim \nu^{5/2} \]

\[ \sim \nu^{-(p-1)/2} \]

\[ \nu_m \]
Separate component?
(eg. Ozel et al ‘00, Melia & Falcke ‘01, Melia ‘01, Falcke & Markoff 00)
Do we care about the outer layers at submm λ?

**Stokes I**: outer layers irrelevant to observed submm emission from central source

**Stokes I,Q,U,V**: Outer layers essential to observed emission.

We need **polarized radiative transfer**

Submm radiation travels through a birefringent magnetized plasma. State of polarization changes.

**Faraday Rotation**: Rotates the planes of LP. i.e. changes $Q \leftrightarrow U$  

**Faraday Conversion**: Changes $Q, U \leftrightarrow V$ i.e. converts LP to CP

$\propto \lambda^2$  

$\propto \lambda^3$
Optically thin Faraday “Screen”

Too optically thin (i.e. $\tau \sim 10^{-2}$) is unlikely to produce 1% CP

“Source”

submm/mm emission

CP here?

... or CP here?

radio emission
The Circular Polarization of Sgr A* 

Turbulent jet model

Beckert (2003).
Summary:

- Sgr A* is circularly polarized at a 1.5% level
- Calibration uncertainties create no significant instrumental CP flux
- Unlikely that the origin of observed CP and Faraday rotation take place in the same region
- If – at summ/mm wavelengths -- the total flux, as well as LP and CP come from the same compact region, the inclusion of GR optical effects might be necessary.