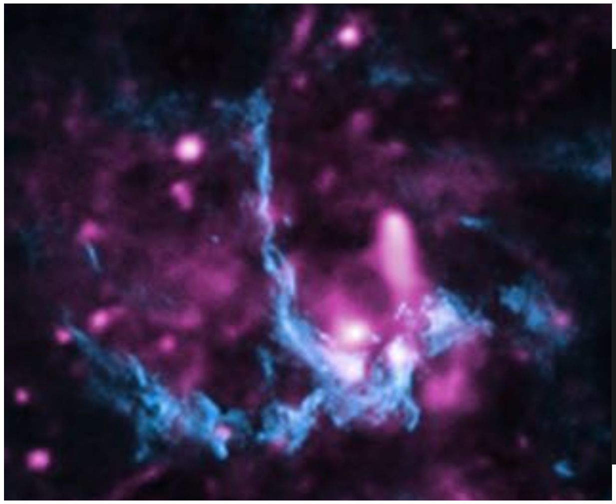
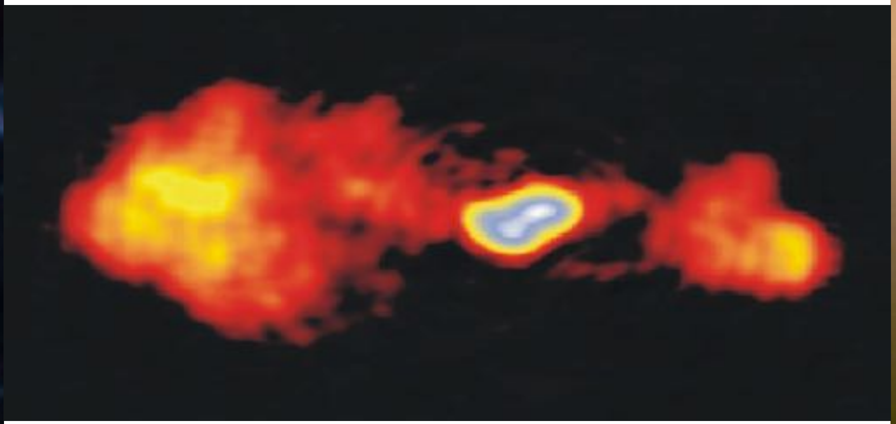
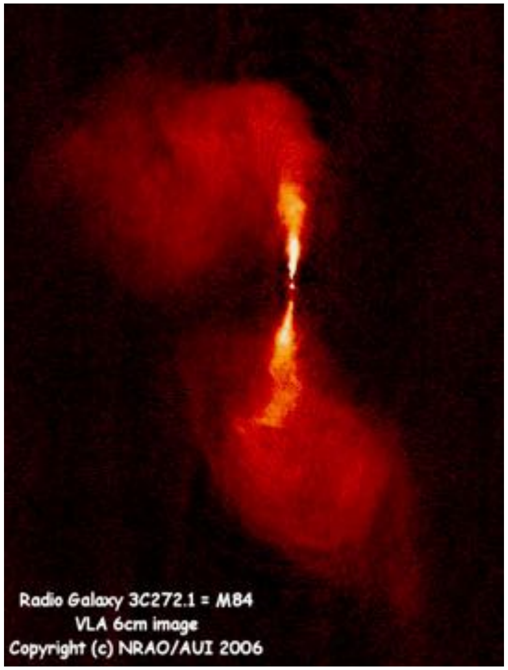
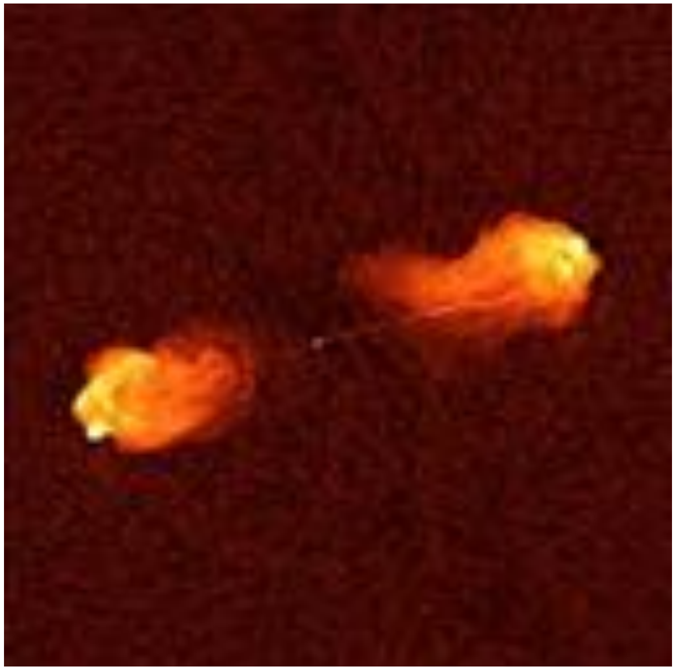




Setting the Boundary Conditions for Imaging: Polarimetric and Temporal Probes of Accretion Flows

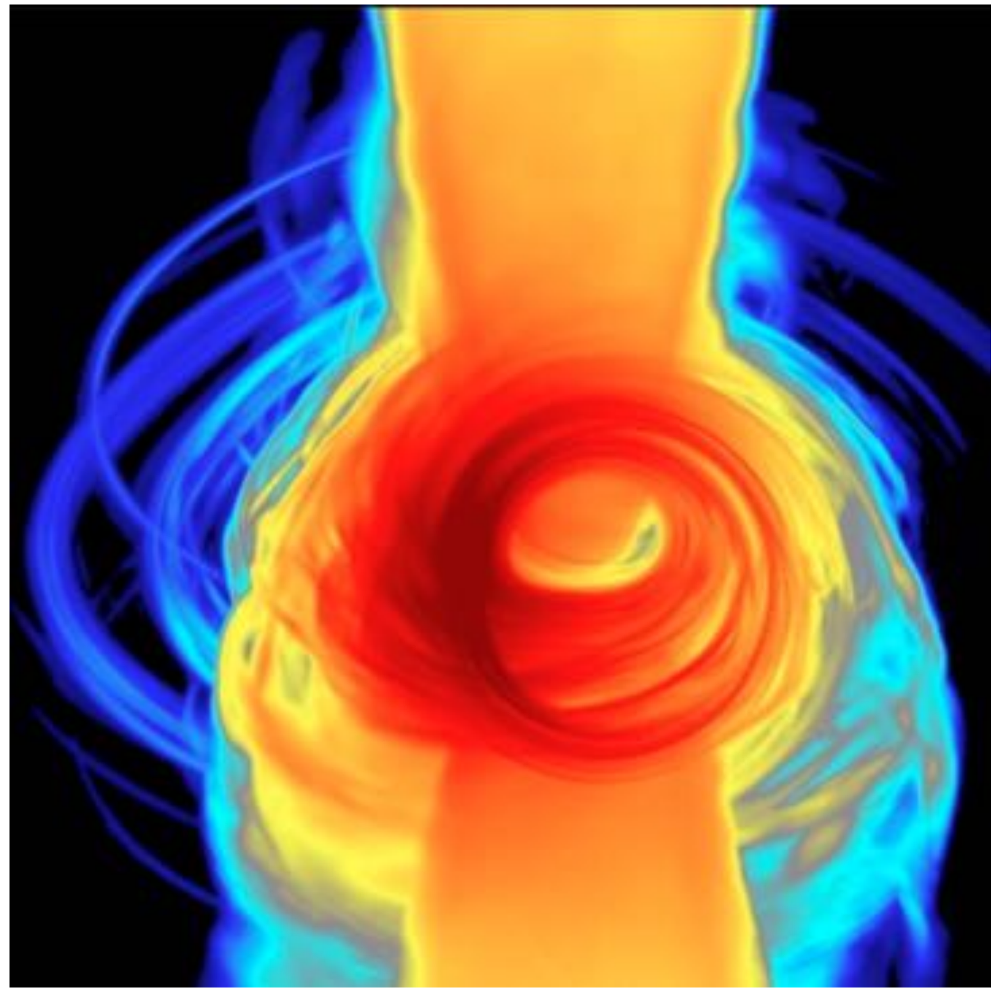


Geoffrey C. Bower
(ASIAA, Hilo)



Advancing the Astrophysical Model

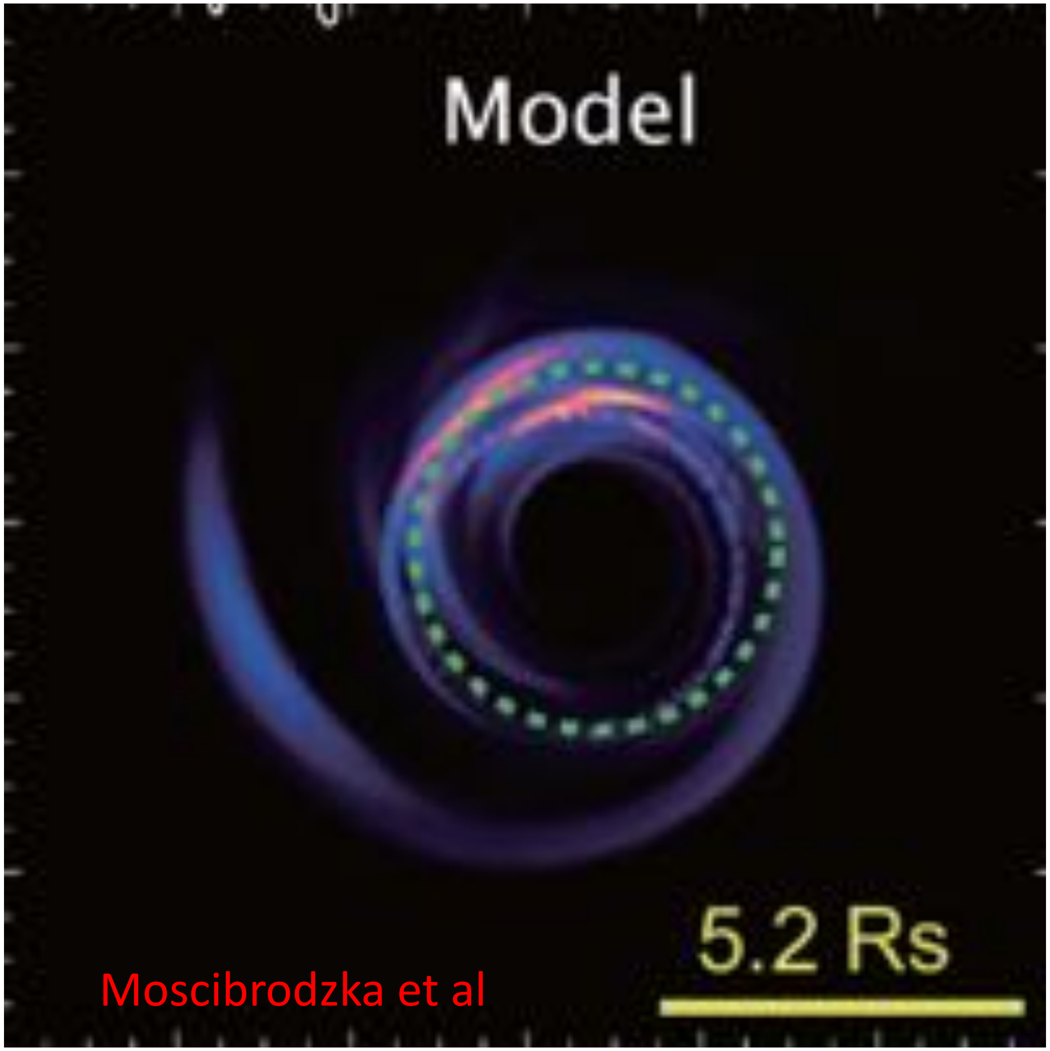
- Mode of accretion: Bondi, ADAF, CDAF, RIAF
- 3D Magnetohydrodynamics
- General Relativity Inflow: Accretion Outflow: Jets BH – MHD interface (ISCO)
- Microphysics: Heating & cooling of particles
- Radiation Transport
- Can we reproduce basic parameters, spectrum, size, and variability of Sgr A*?



(Gammie et al.)

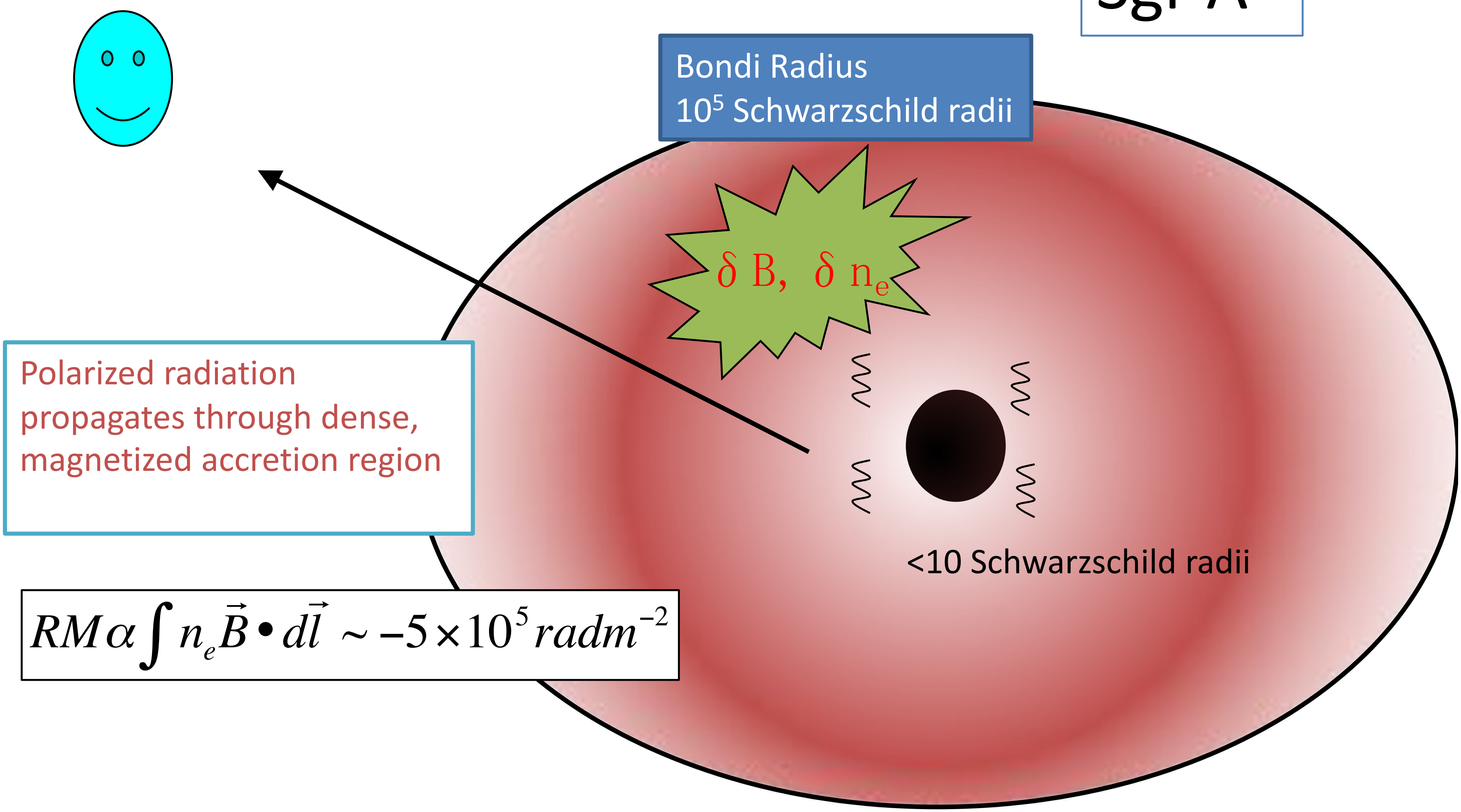
Accretion Flow Models

- Thin-disk accretion
  - $M_{dot} > 10^{-2} M_{dot}^{Edd}$
- Advection dominated accretion flow (ADAF)
  - Two temperature solution
  - Steep accretion profile
- Convection dominated accretion flow (CDAF)
- Radiatively inefficient accretion flow (RIAF)
  - Two temperature solution
  - Stalled accretion flows + outflows
  - Flat accretion profile
- Magnetically Arrested Disk (MAD)
- …



RM Originates in the Accretion Flow

Sgr A*



$$RM \,\alpha \int n_e \vec{B} \bullet d\vec{l} \sim -5\times10^5\, rad\, m^{-2}$$

RM Constrains Accretion Rate → $M_{dot} \sim 10^{-8\ +/-\ 1}\ M_{sun}\ y^{-1}$

Bower et al 2003, Marrone et al 2006

Time-Dependent Accretion Simulations Predict RM Changes

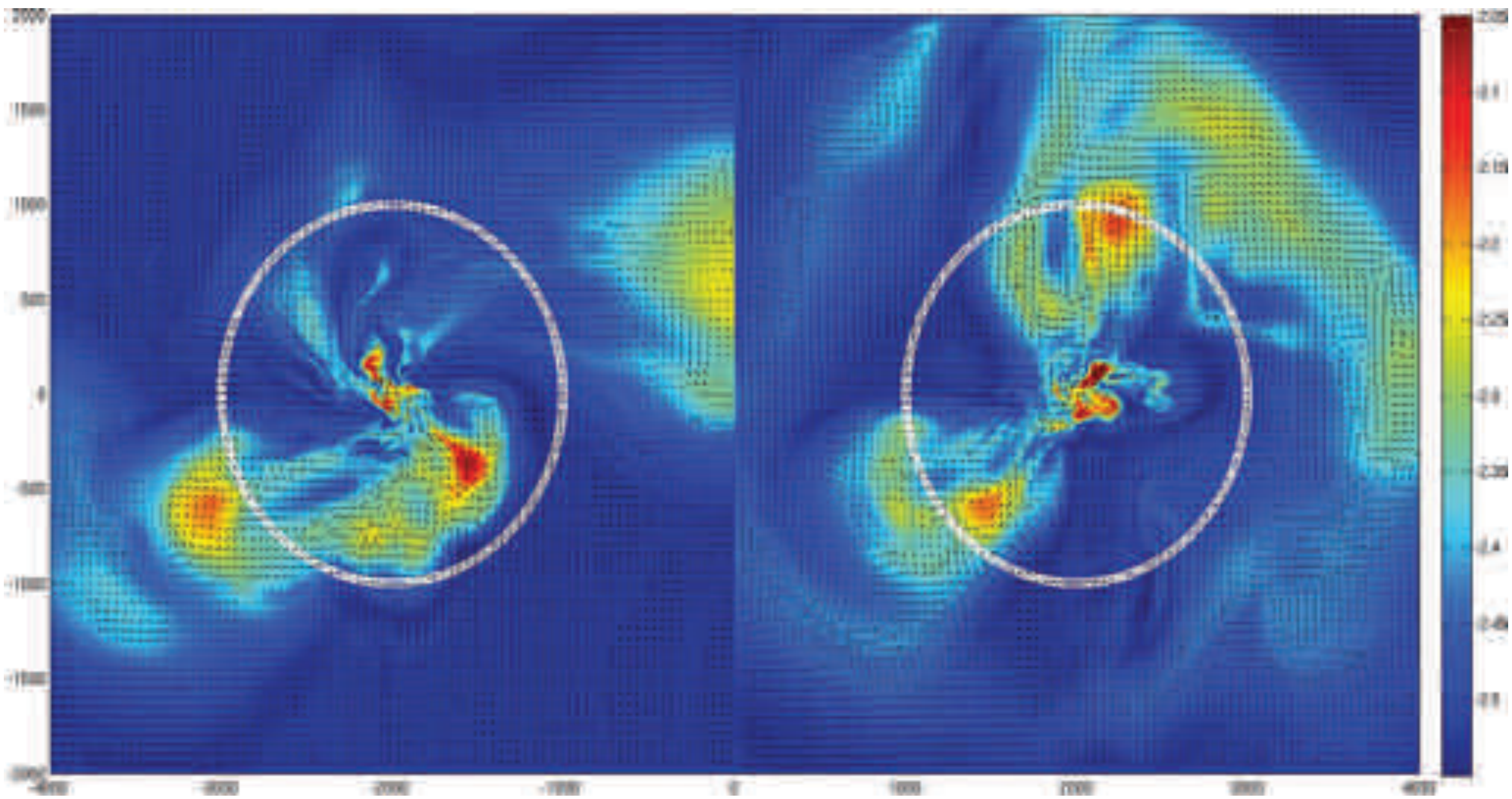
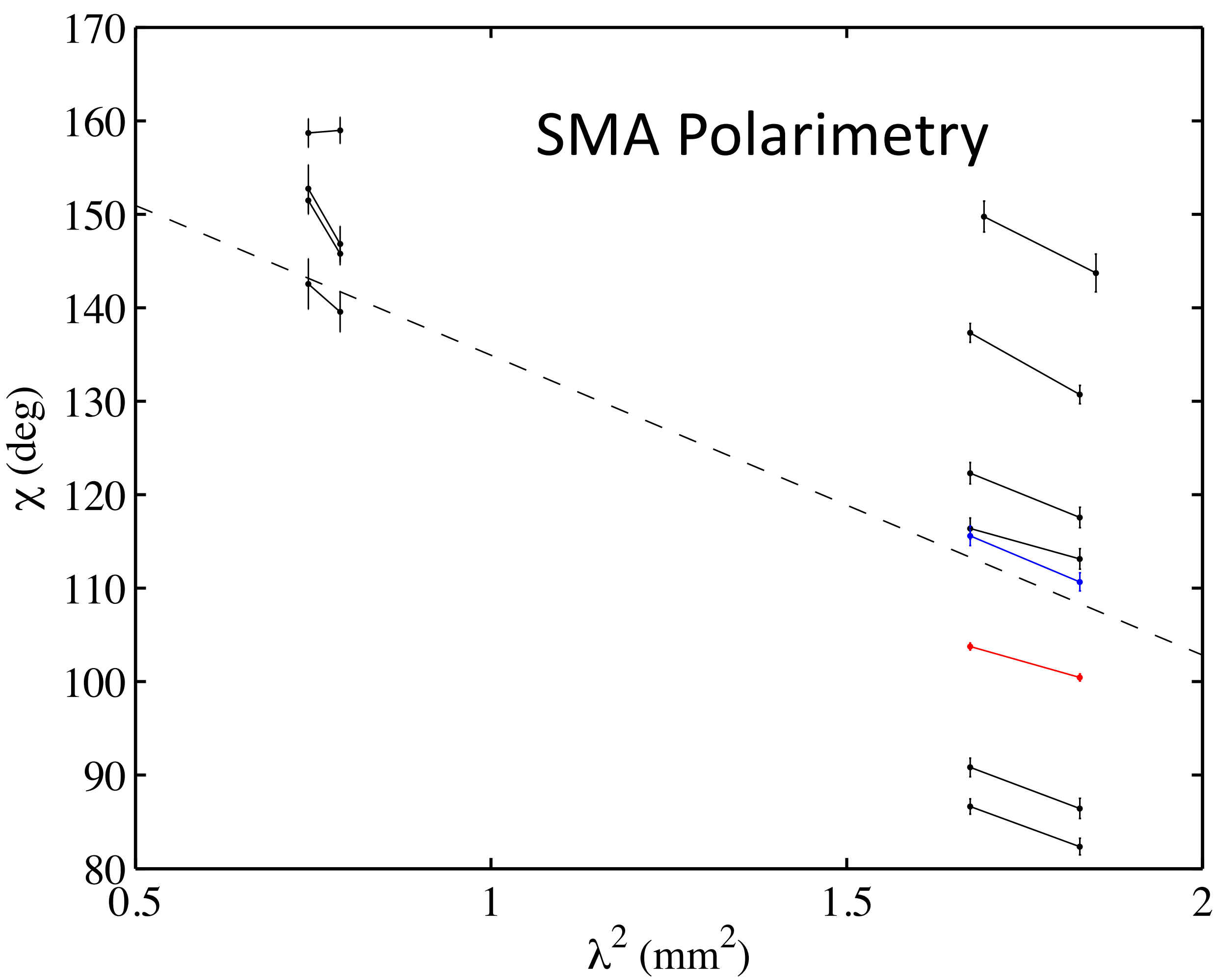


Figure 1. 2D slice of the simulation for 600^3 box at 15 Bondi times. Colour represents the entropy, and arrows represent the magnetic field vector. The right-hand panel is the equatorial plane (yz), while the left-hand panel a perpendicular slice (xy). White circles represent the Bondi radius ($r_B = 1000$). The fluid is slowly moving, in a state of magnetically frustrated convection. A movie of this flow is available as Supporting Information with electronic version of this article (see Appendix C for a description).

Pang, Pen, et al 2011

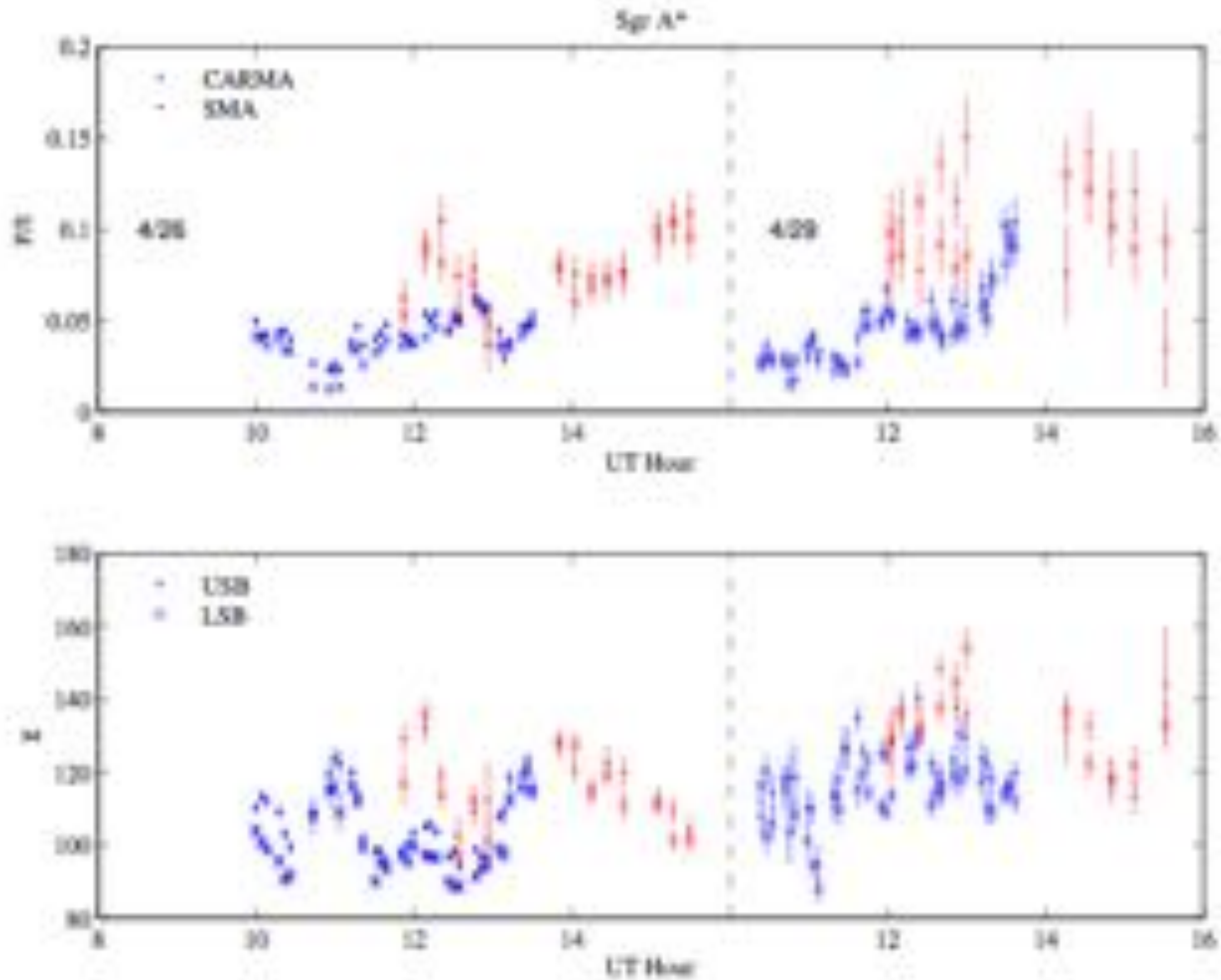
State of the Art circa 2011



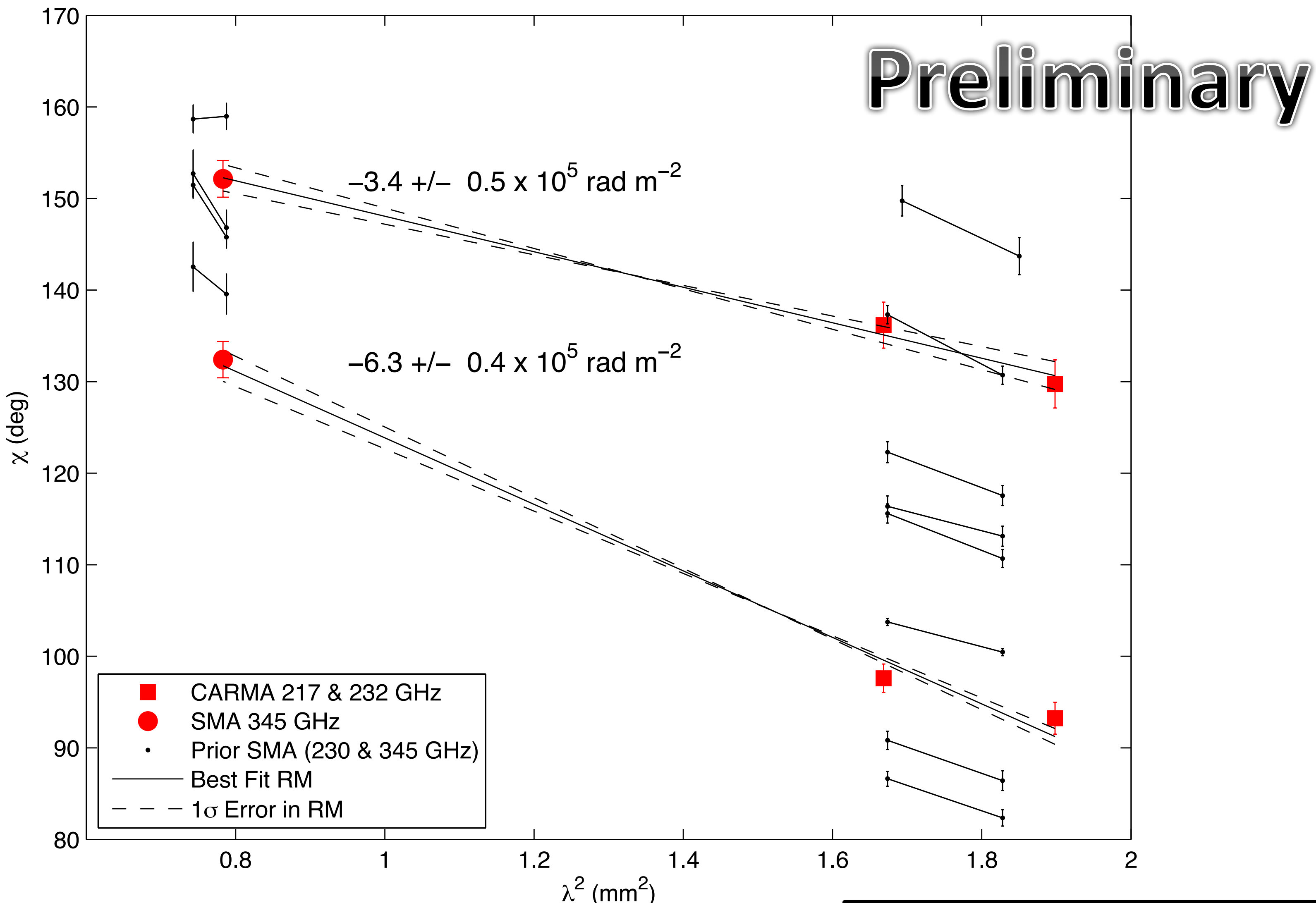
Marrone et al

- What causes the stability of the RM?
- How variable and on what timescale is the RM?
- Are there non-λ^2 effects?
- Is there a relationship between LP, CP, and RM variability?

Short Timescale Variability

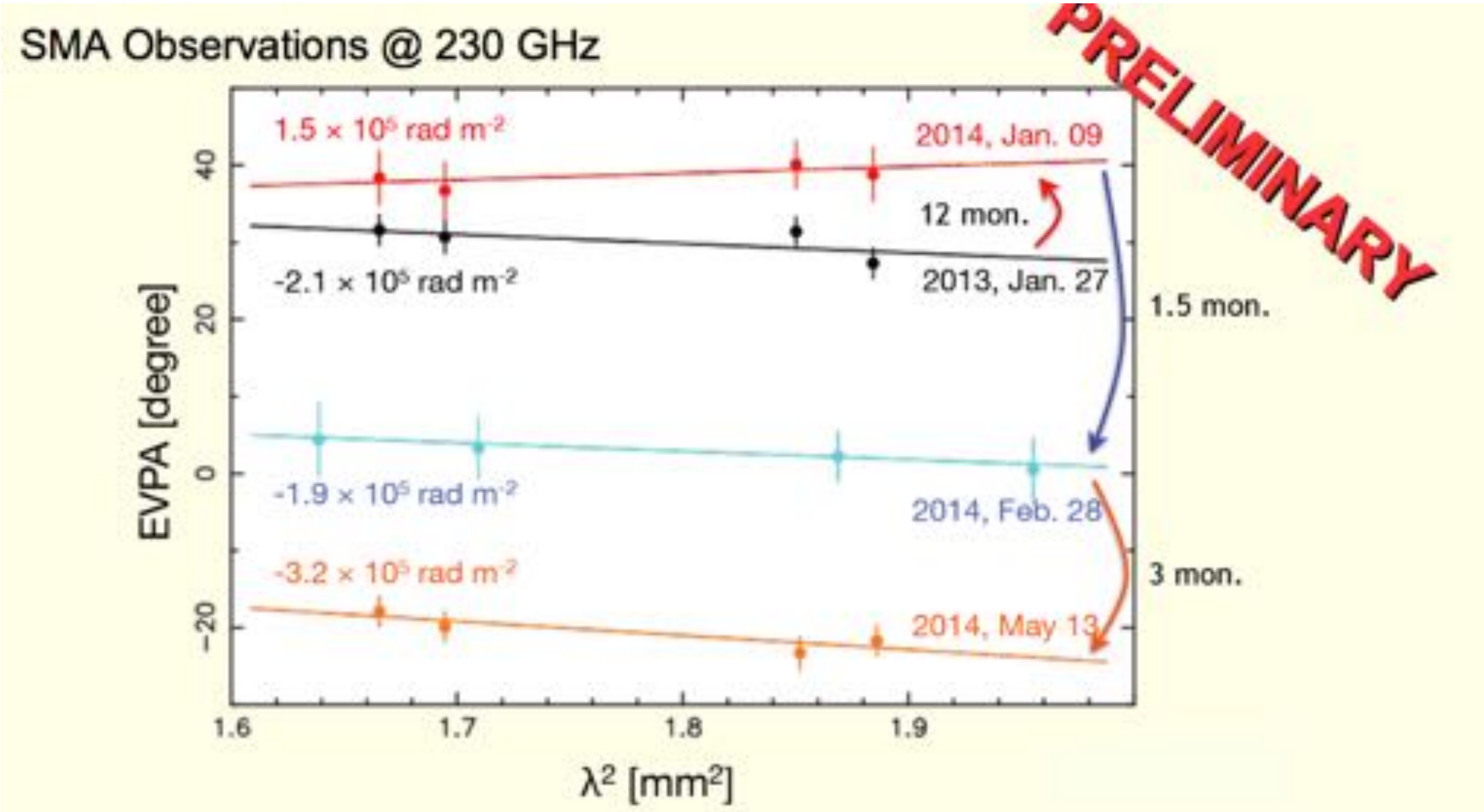


Variable RM from Simultaneous SMA/CARMA Observations



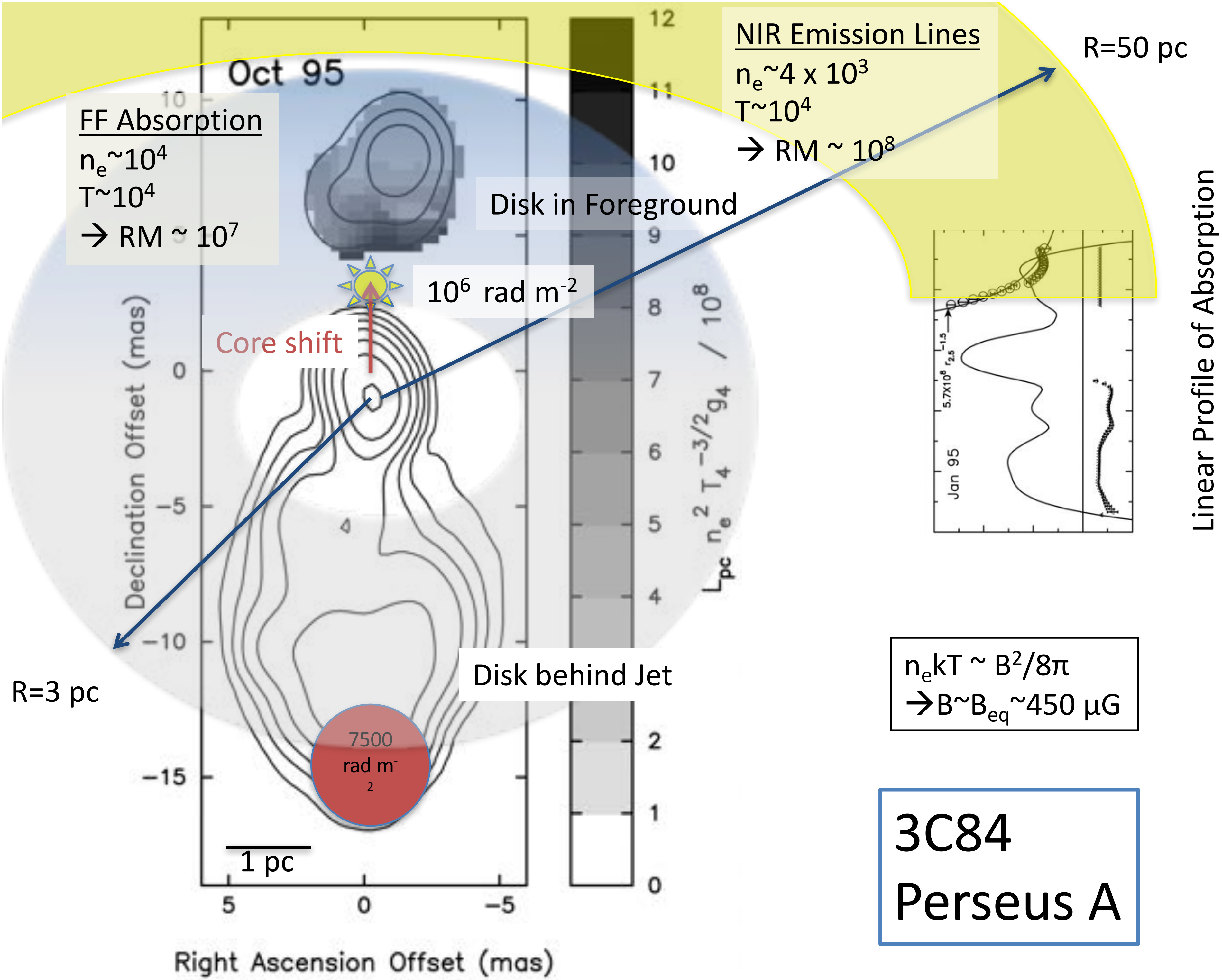
Bower, Plambeck, Marrone

M87



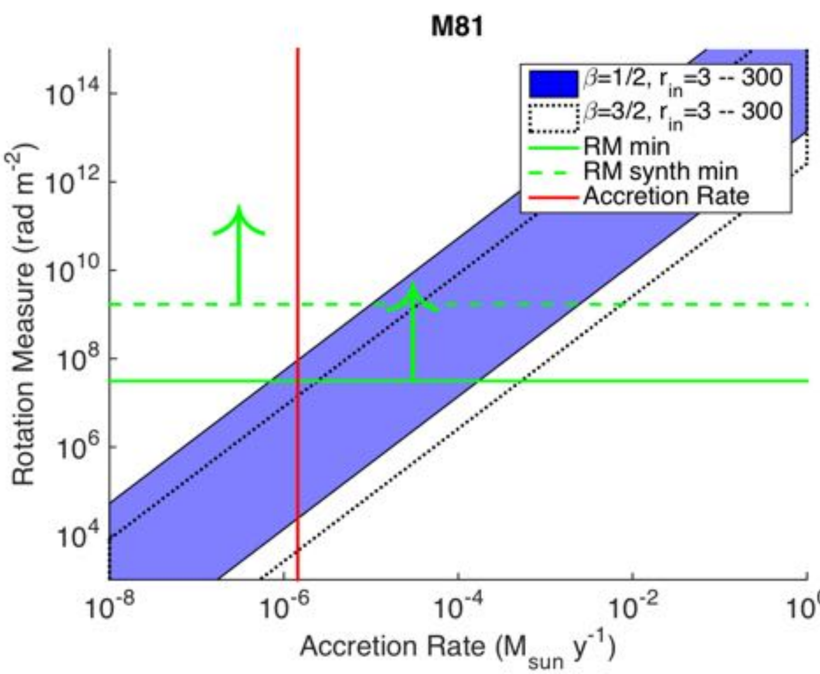
SMA Observations @ 230 GHz
PRELIMINARY
1.5 × 10^5 rad m^-2
2014, Jan. 09
12 mon.
-2.1 × 10^5 rad m^-2
2013, Jan. 27
1.5 mon.
-1.9 × 10^5 rad m^-2
2014, Feb. 28
-3.2 × 10^5 rad m^-2
3 mon.
2014, May 13
EVPA [degree]
λ² [mm²]

Algaba

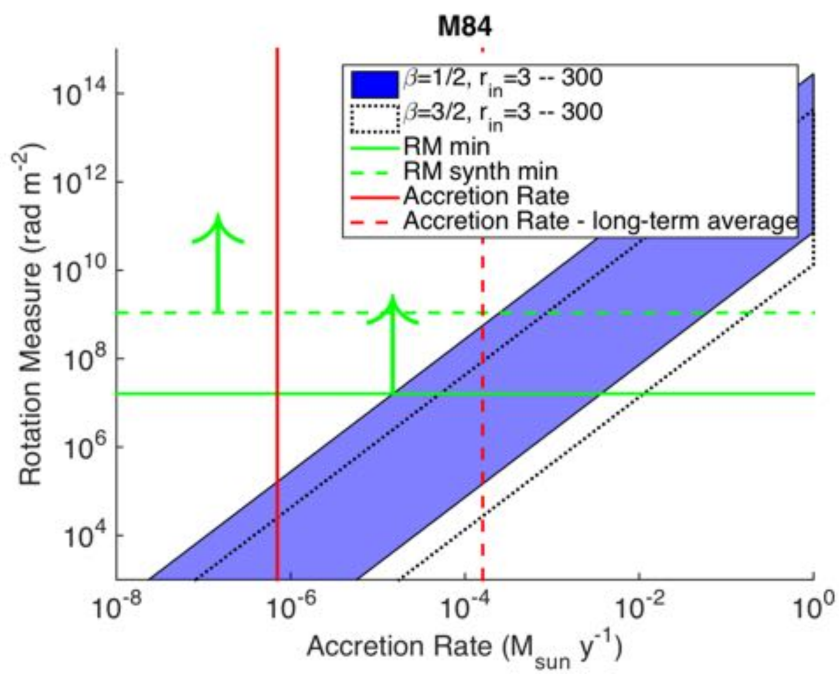


NIR Emission Lines
n_e~4 x 10^3
T~10^4
→ RM ~ 10^8
R=50 pc
FF Absorption
n_e~10^4
T~10^4
→ RM ~ 10^7
Oct 95
Disk in Foreground
10^6 rad m^-2
Core shift
Linear Profile of Absorption
Jan 95
Declination Offset (mas)
Right Ascension Offset (mas)
R=3 pc
Disk behind Jet
7500 rad m^-2
1 pc
n_ekT ~ B^2/8π
→B~B_eq~450 μG
3C84
Perseus A

Upper Limits on Polarization
→ Challenging Accretion Models

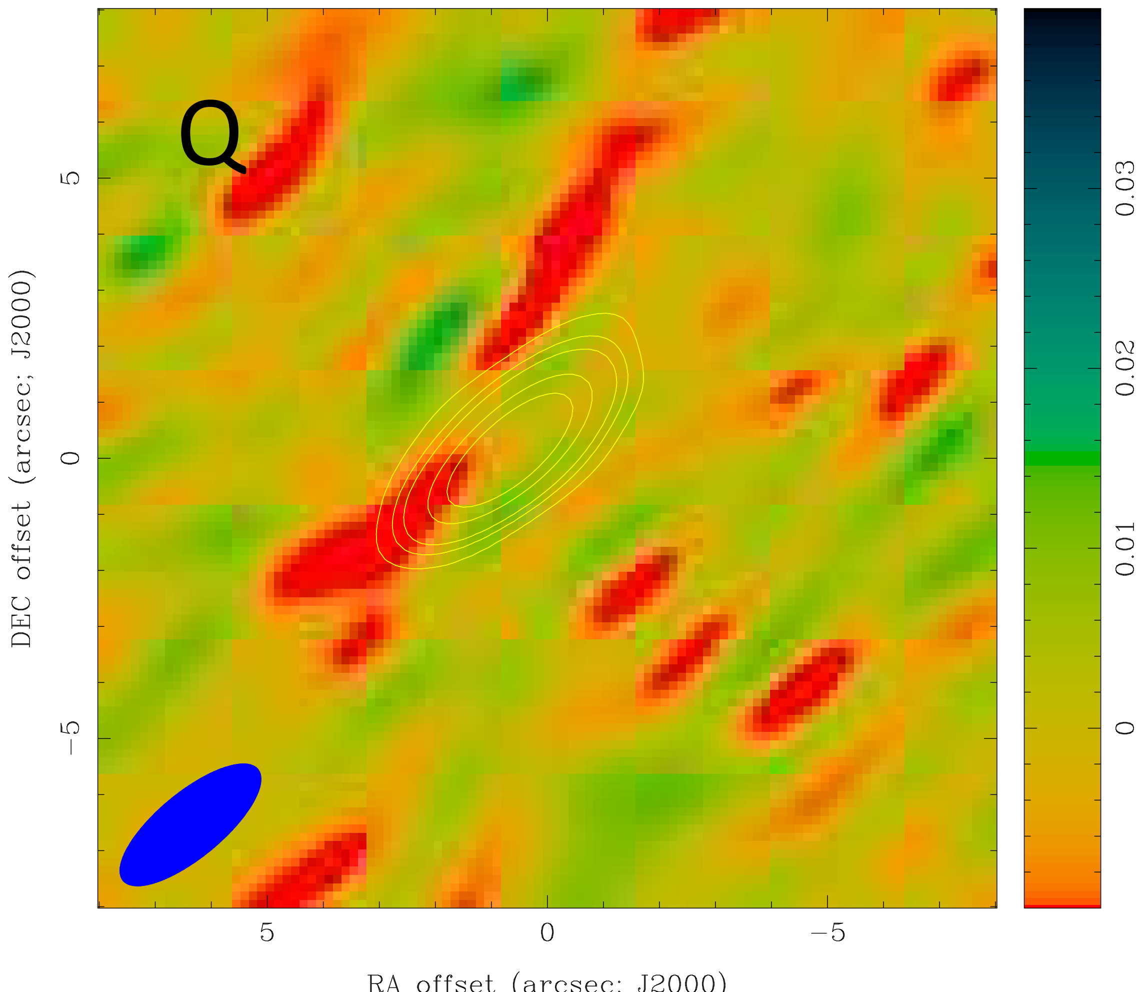


CARMA



SMA

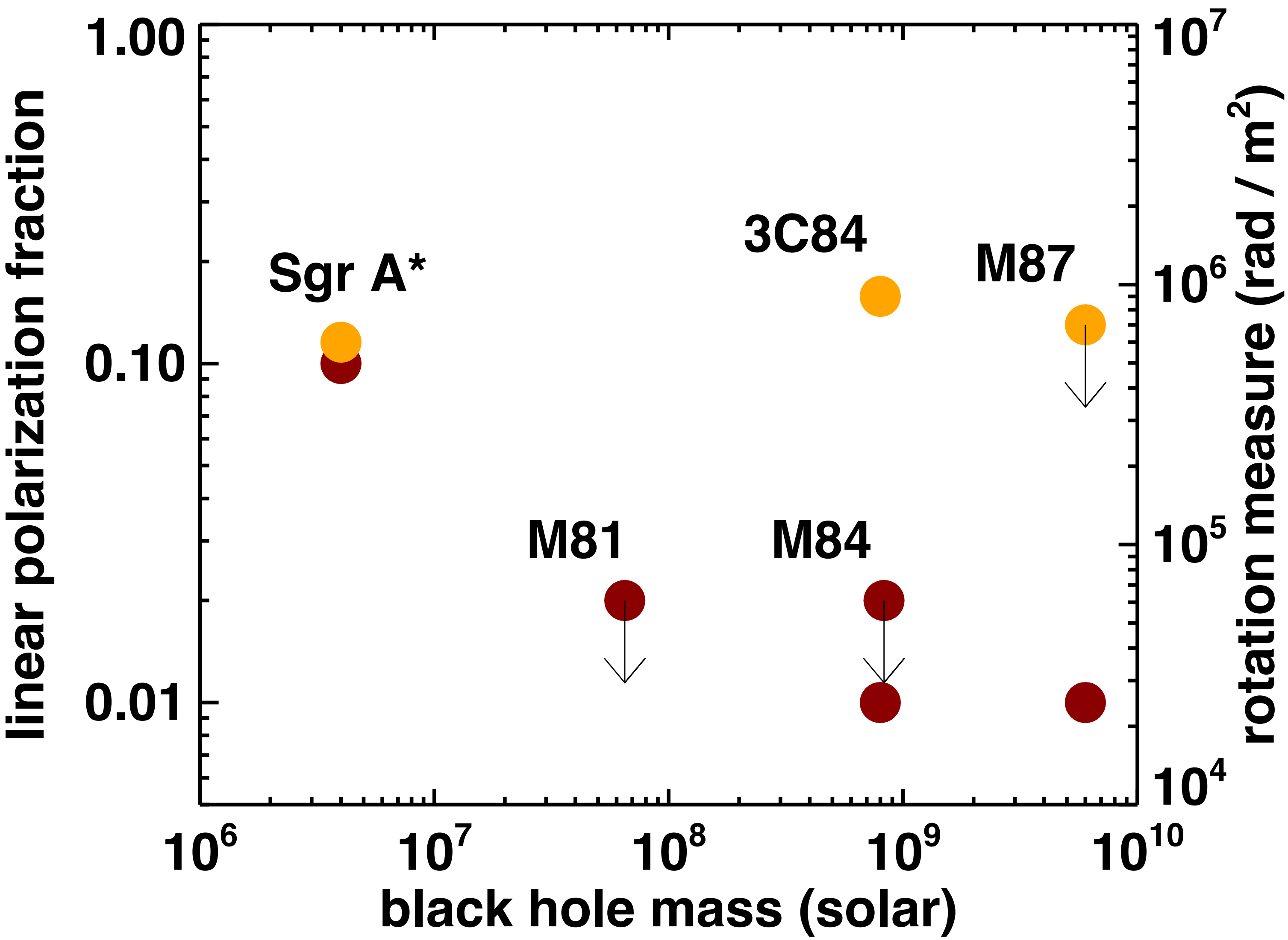
Cygnus A Upper Limits from SMA



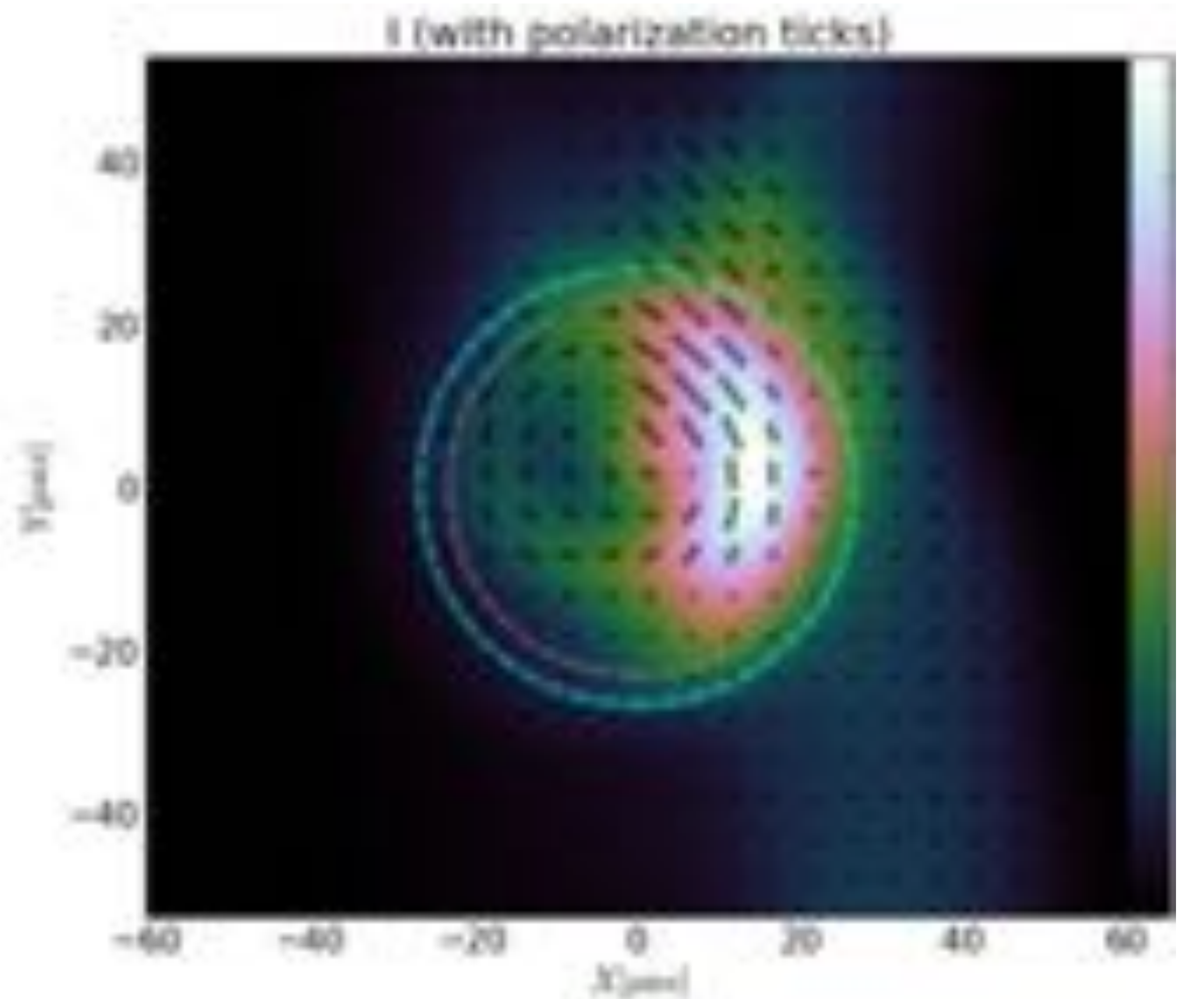
P < 0.5%

See Talk by Lo Wen-Ping

LLAGN Polarization Summary

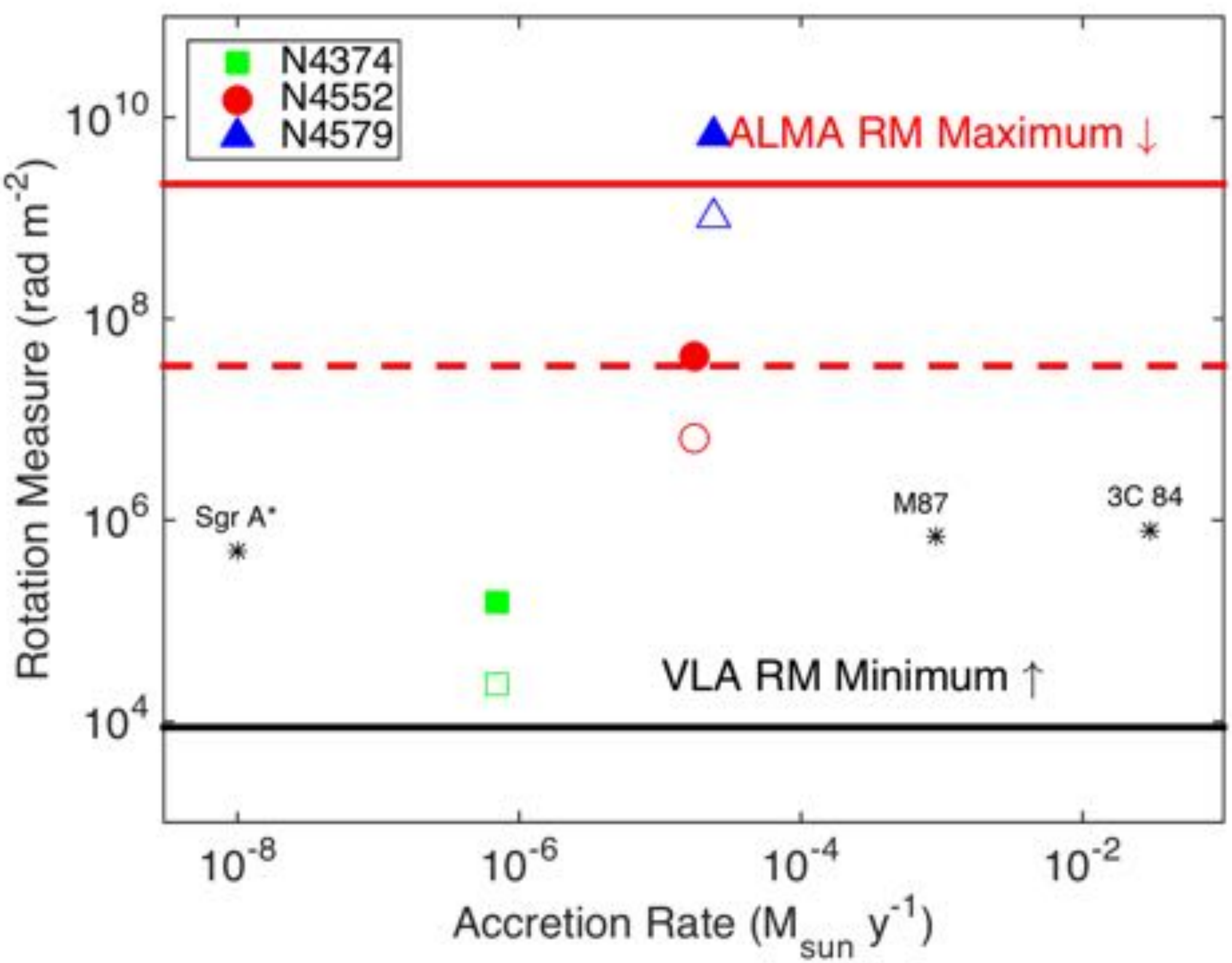


Intrinsic Polarization Suppressed?



Gold et al 2016

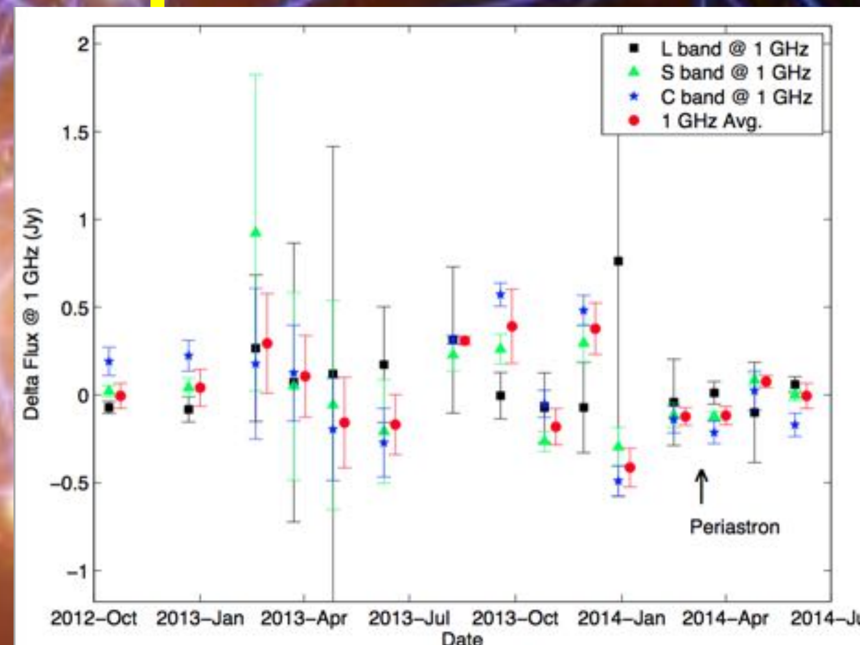
Pursuing Higher RMs with Spectropolarimetry

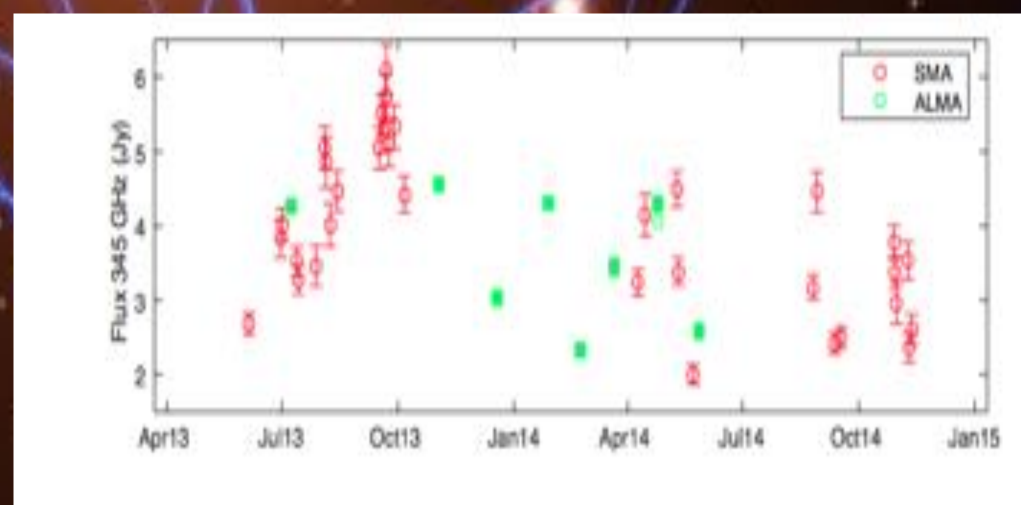


Temporal Probes

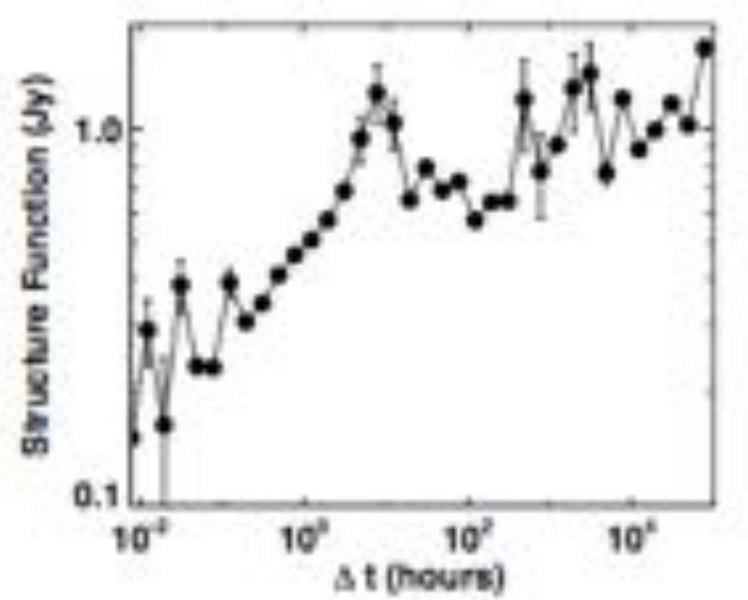
Searching for the G2 Impact

- VLA, SMA, and ALMA monitoring show no evidence for enhanced Sgr A* activity through G2 periastron between 1 and 350 GHz
- This supports the compact or bound cloud hypothesis
- Bower et al. 2015 ApJ

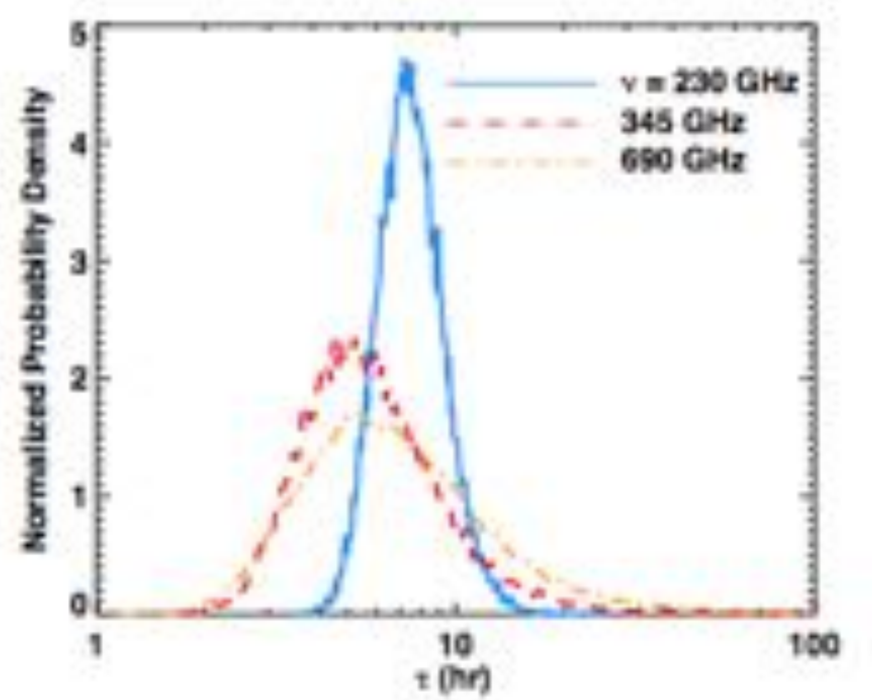




Sgr A* Variability

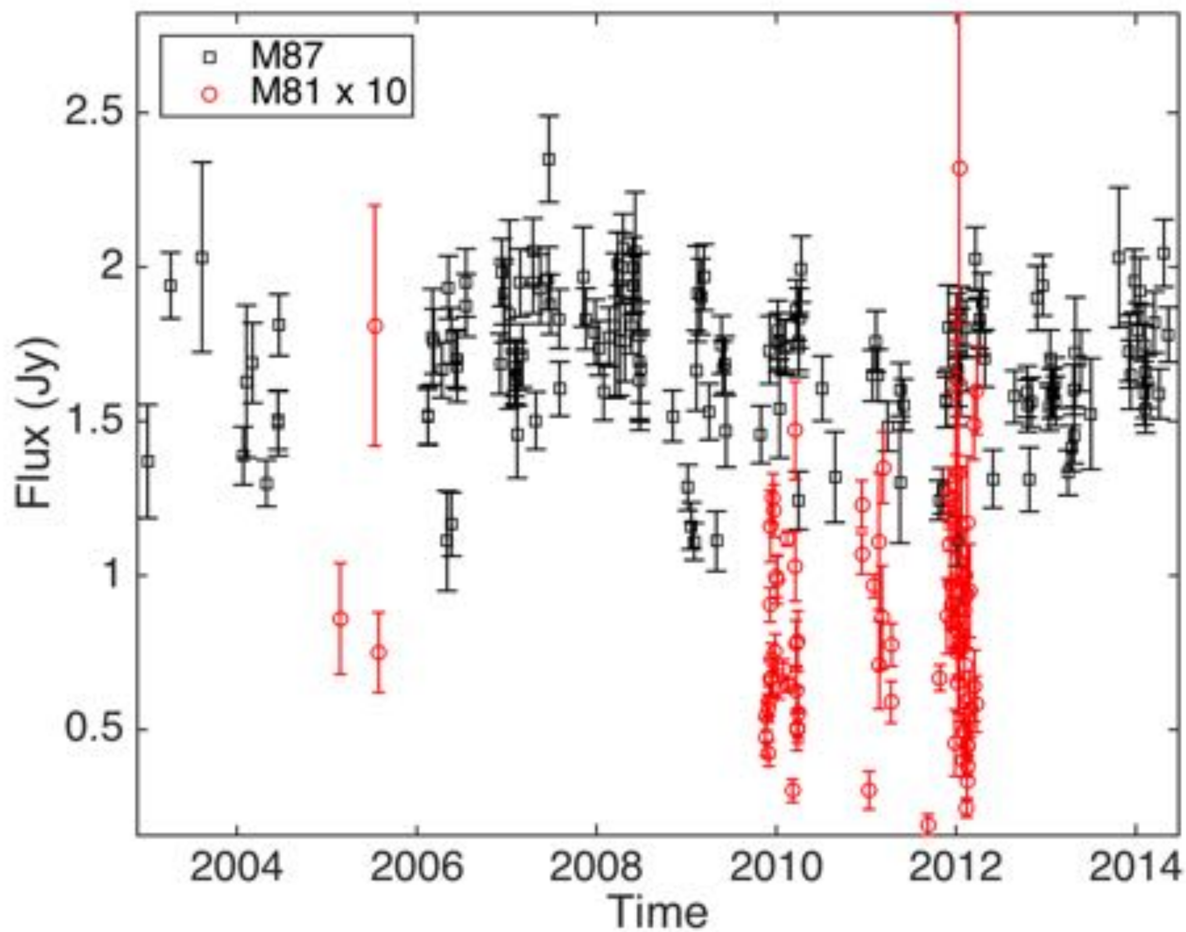


Damped Random Walk

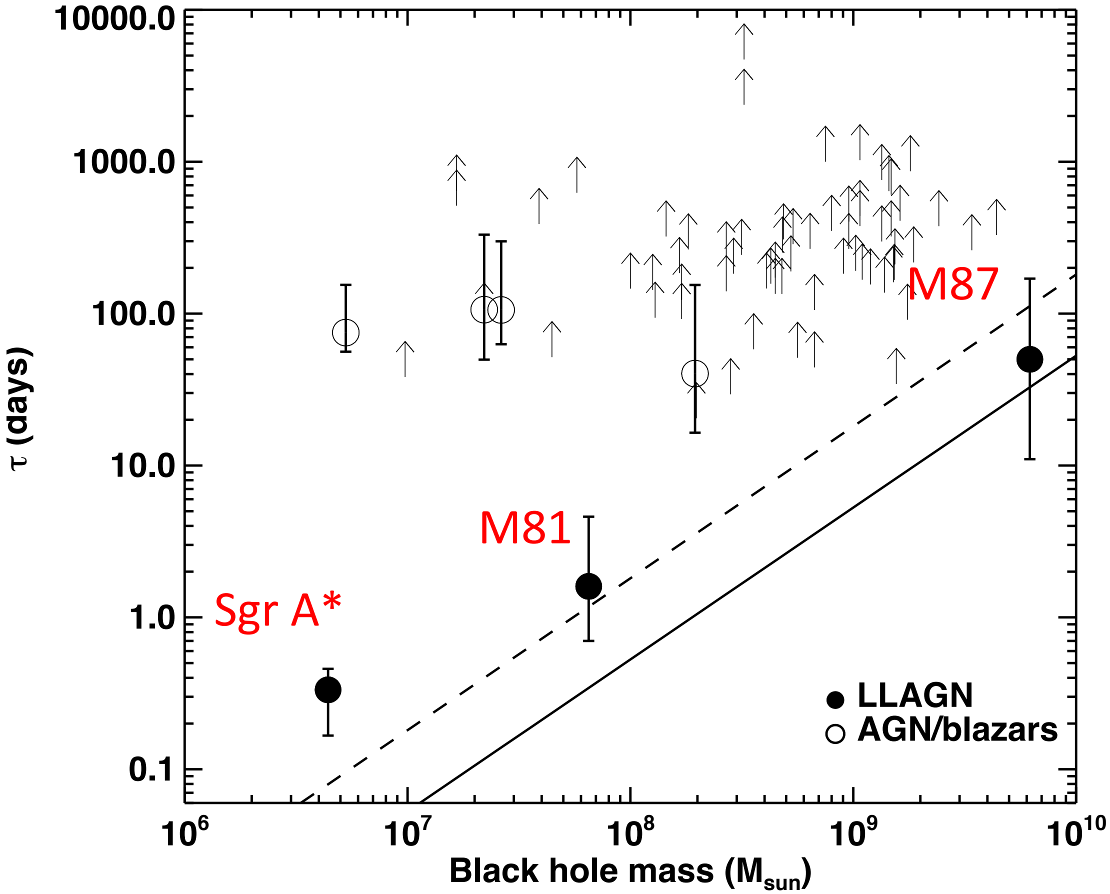


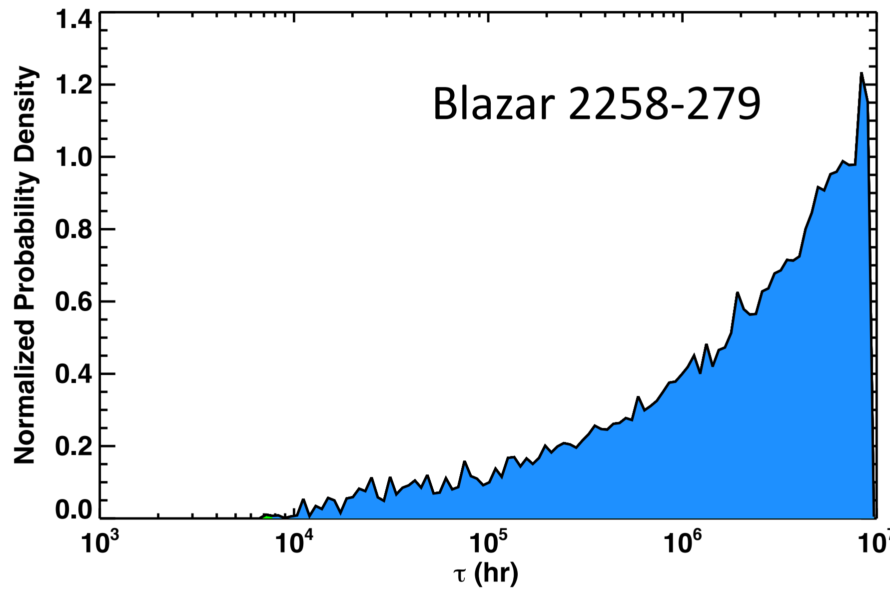
Dexter et al. 2014

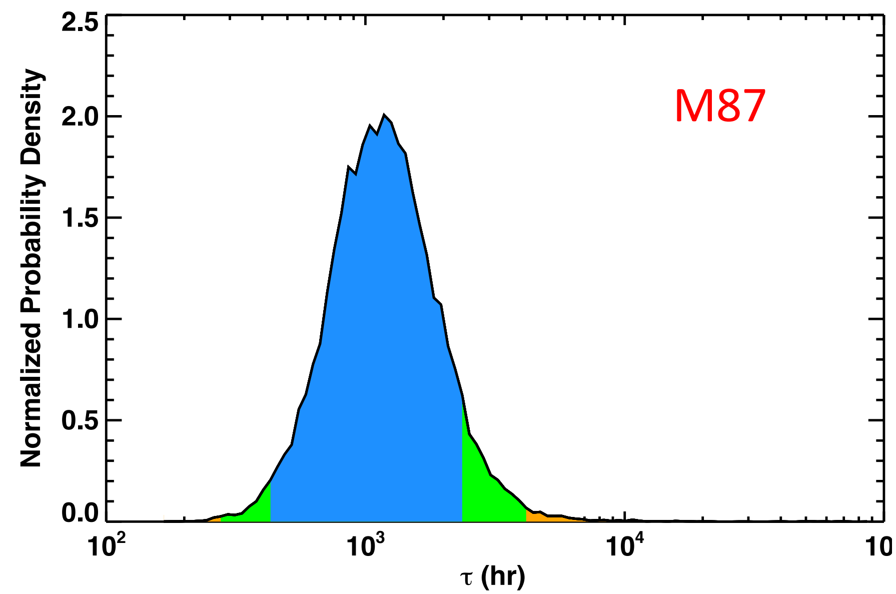
M87 & M81 Lightcurves



Black Hole Mass-Timescale Correlation

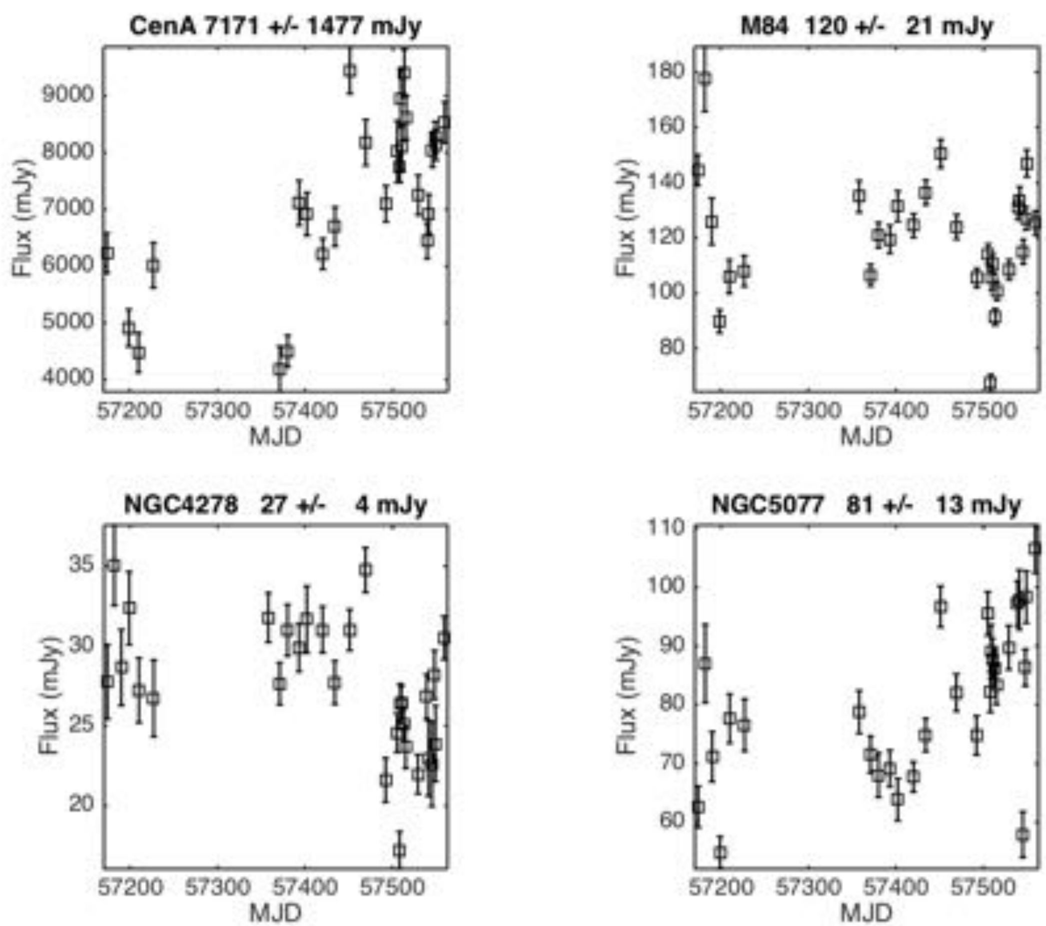




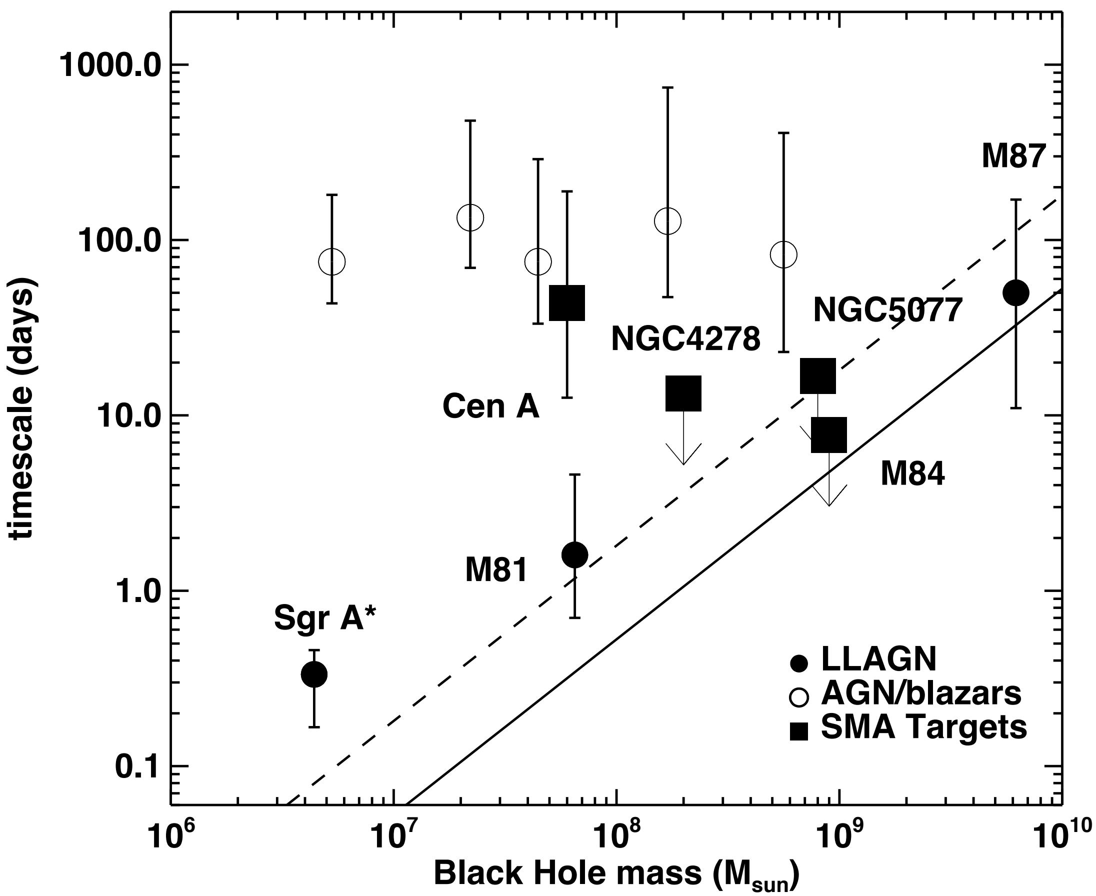


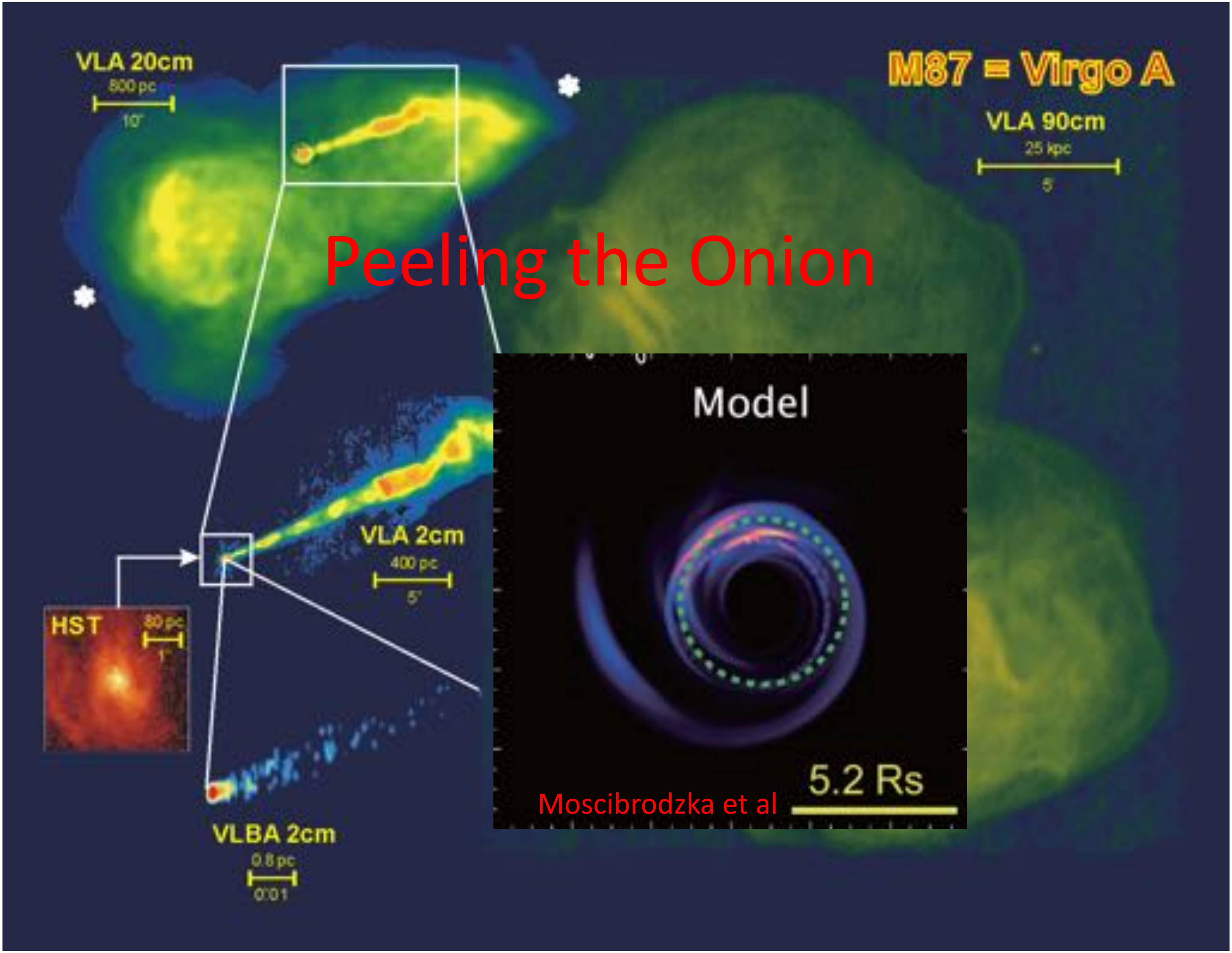
Bower et al 2015

SMA Monitoring of More LLAGN



Black Hole Mass-Timescale Correlation

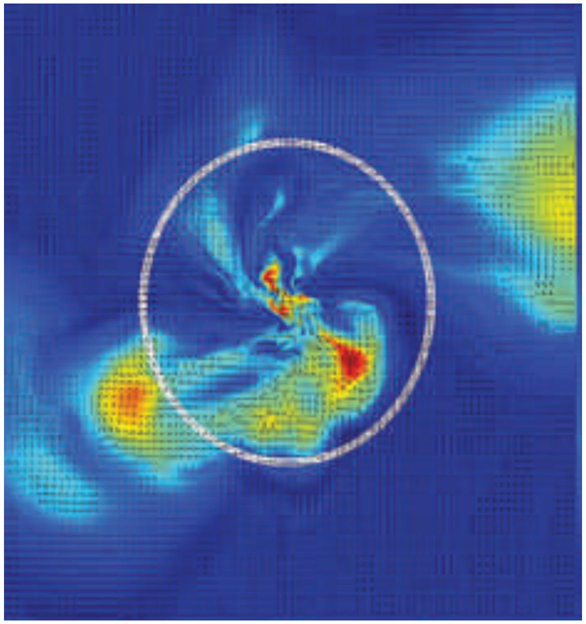




Peeling the Onion
M87 = Virgo A
VLA 20cm
800 pc
10"
VLA 90cm
25 kpc
5'
VLA 2cm
400 pc
5"
HST
80 pc
1"
VLBA 2cm
0.8 pc
0.01"
Model
5.2 Rs
Moscibrodzka et al

wSMA LLAGN Accretion FLows Campaign

- Goals
  - Size and structure of the inner accretion disk: Tau-MBH relation for large ensemble
  - Large-scale accretion flow structure: RM detection and variability
  - Extreme variability: accretion events, jet-launching → Triggering high resolution imaging
  - How unique is Sgr A*?
  - Continuum and Spectroscopic Survey: CO absorption, emission; continuum
- Methods
  - 100 sources x 100 observations
    - Delta T ~ 1 day – 2000 days
    - Log-periodic separation
  - 15 minutes/observation (including overhead) --> 1 mJy rms
  - 5 mJy threshold for detection, 20 mJy threshold for monitoring
  - Target bright subset for polarization monitoring
  - 5 year campaign → 1 hour/day



wSMA LLAGN Accretion Flows Campaign
Technical Requirements

- Sensitivity → Expand sample
  - Low Rx temperature
  - High bandwidth
- Dual frequency is valuable but not critical
  - Observing time will be dominated by higher frequency
  - Perhaps useful for ~20% brightest sources of sample
- Full Stokes
  - Useful for ~20% brightest sources of sample
  - Snapshot calibration
- Pipeline software processing

wSMA LLAGN Accretion Flows Campaign

Why won't ALMA do this?

- Calibration and scheduling overheads make sensitivity of SMA and ALMA comparable
- Long-term monitoring is hard to sell to short-term TAC

Summary

- Polarimetry
  - Accretion Rate Measure
  - Test of Accretion Mode
  - Probe of Turbulence, Inhomogeneity
  - Inner disk dynamics
- Time Domain
  - Secular Events
  - Separation of LLAGN from Blazars
  - Radius of Emission