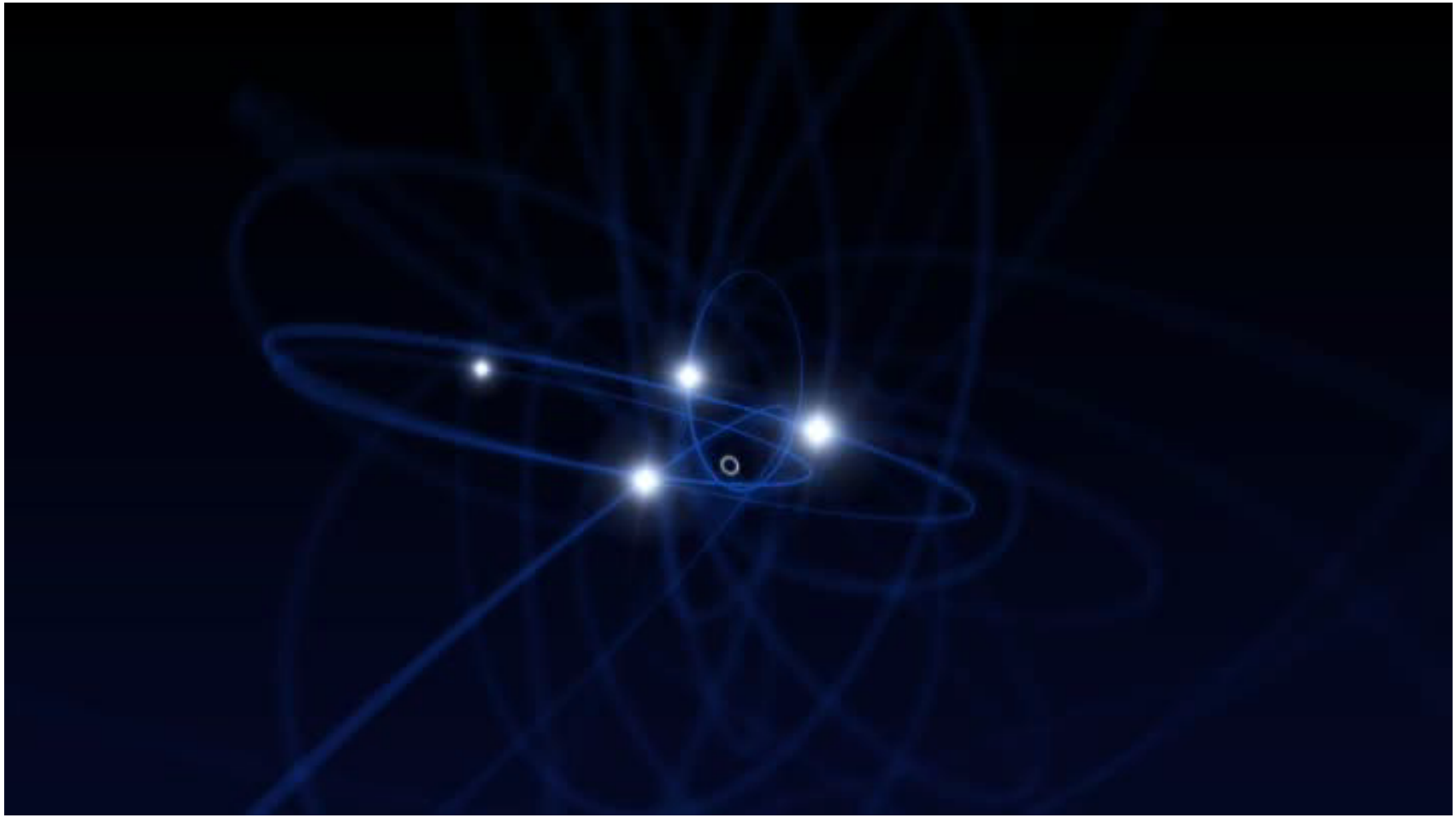
From the Bondi Radius to the Event Horizon:

Accretion and Outflow in Sagittarius A*

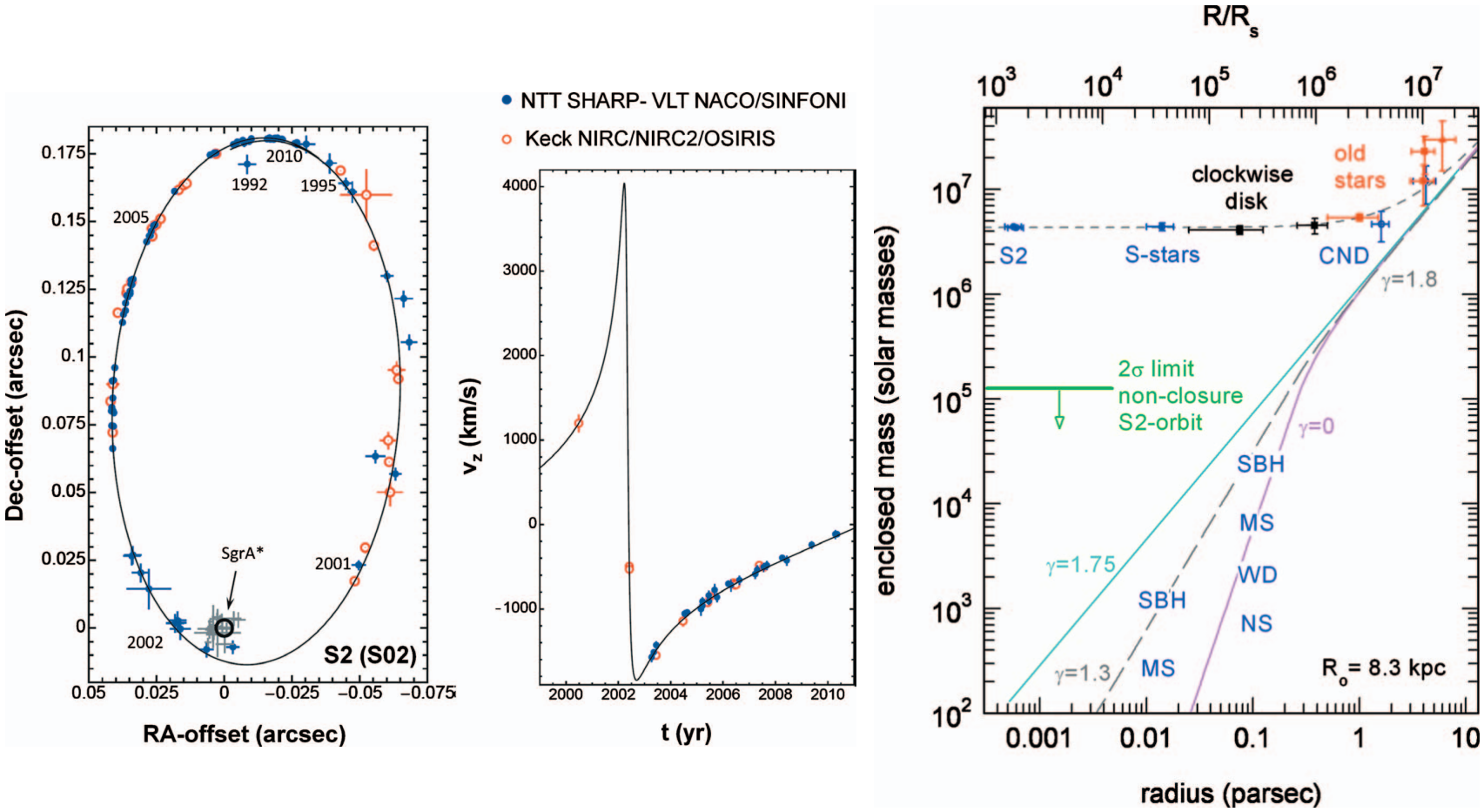
Geoffrey C. Bower, Dick Plambeck, Chat Hull
(UC Berkeley)
Dan Marrone
(Arizona)

Stellar Orbits Around Sgr A* Show 4 x 10^6 M_{sun} Black Hole



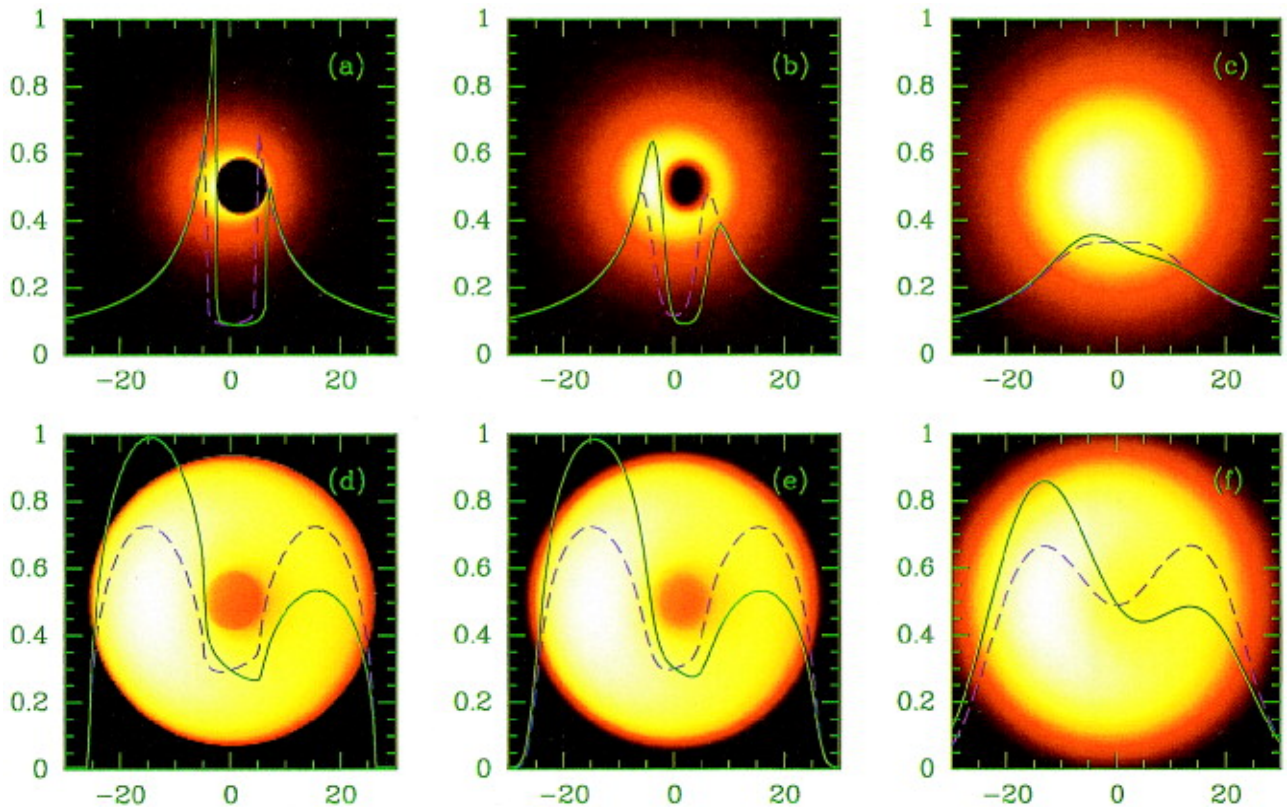
Genzel, Gillessen et al

Strong Evidence for a Black Hole



Genzel et al 2010

The Black Hole Shadow

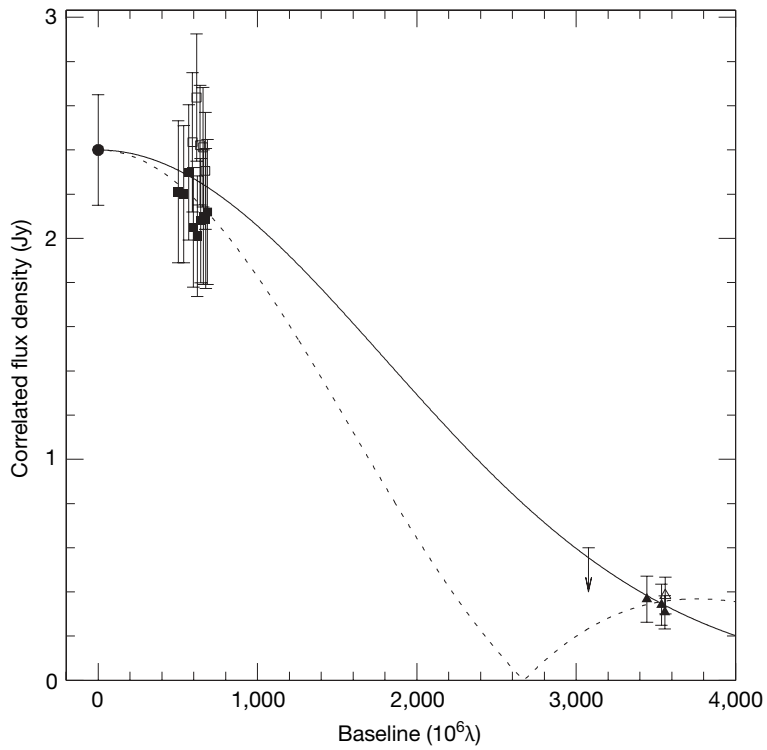


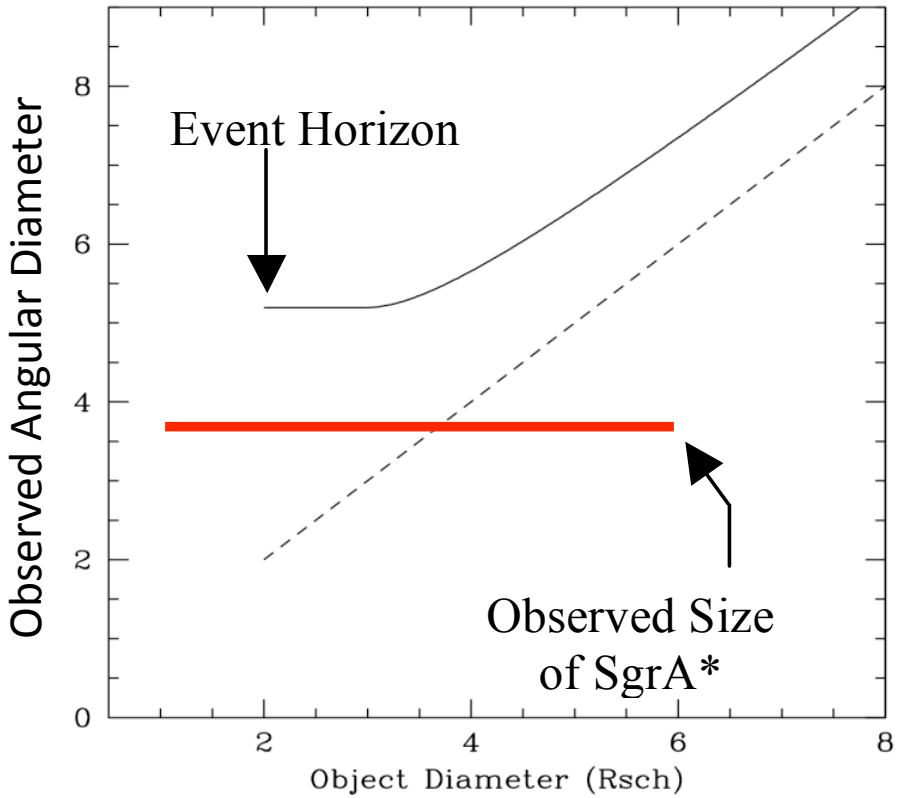
Falcke, Melia & Agol 2000

Bardeen 1973

$R_s/D \sim 10$ *microarcsec*

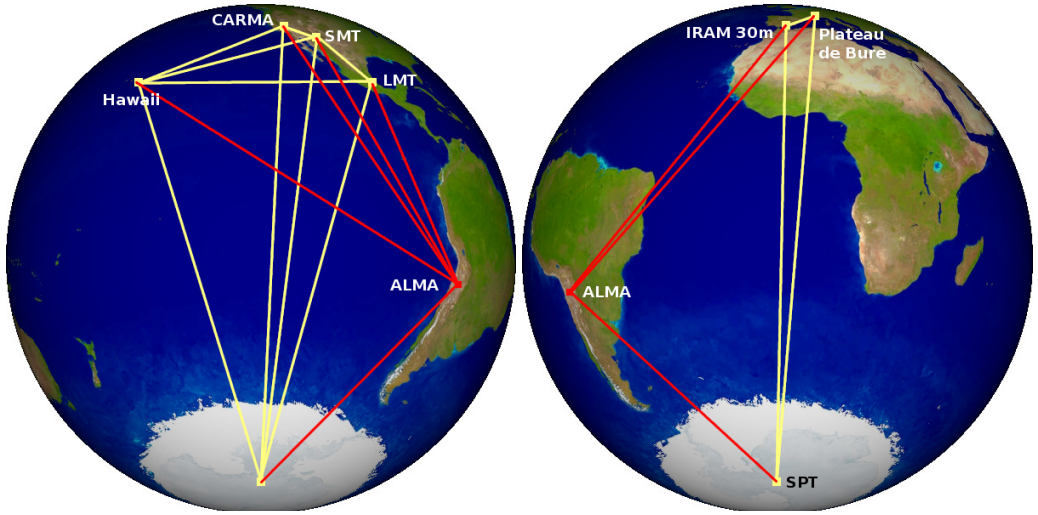
MM VLBI Imaging of Sgr A*

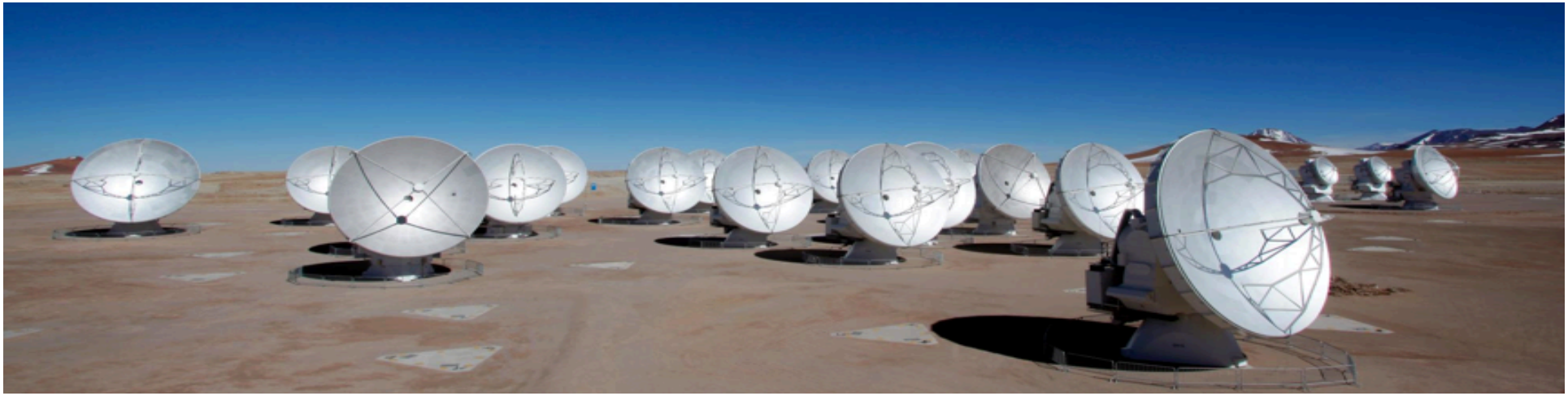




Doeleman et al 2008

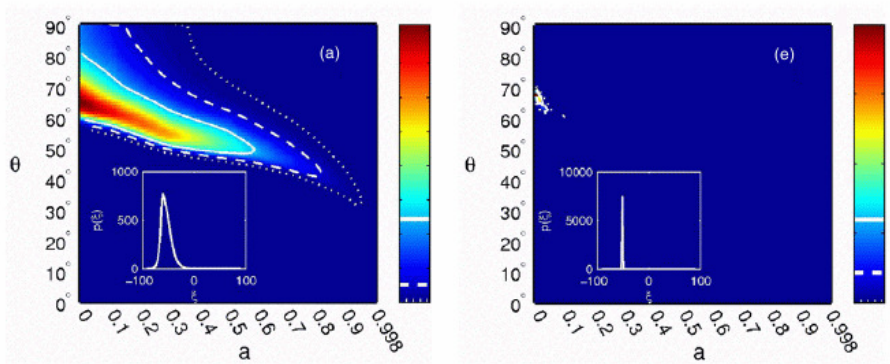
The Event Horizon Telescope



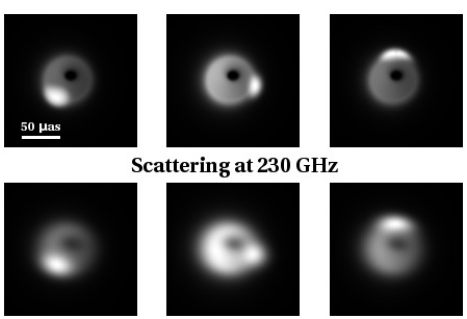


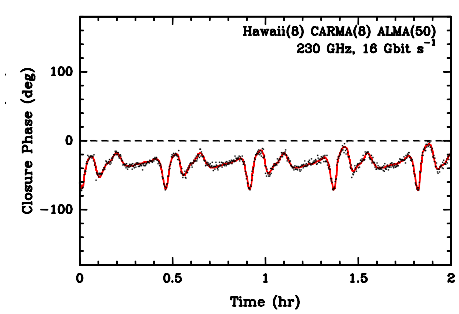
Fundamental Physics with Sgr A*

Constraints on Black Hole Spin from images
Broderick et al 2011

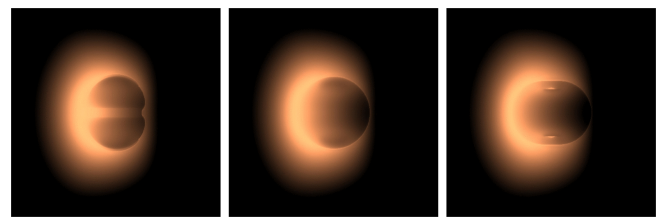


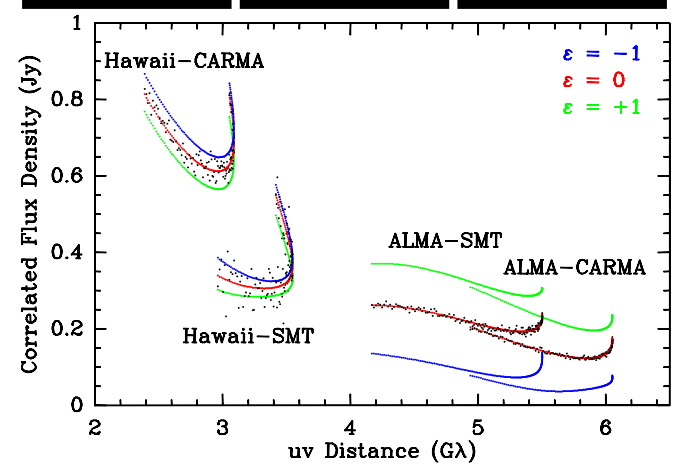
Constraints on Geometry/Mass from Orbiting Hot Spots
Doeleman et al 2009



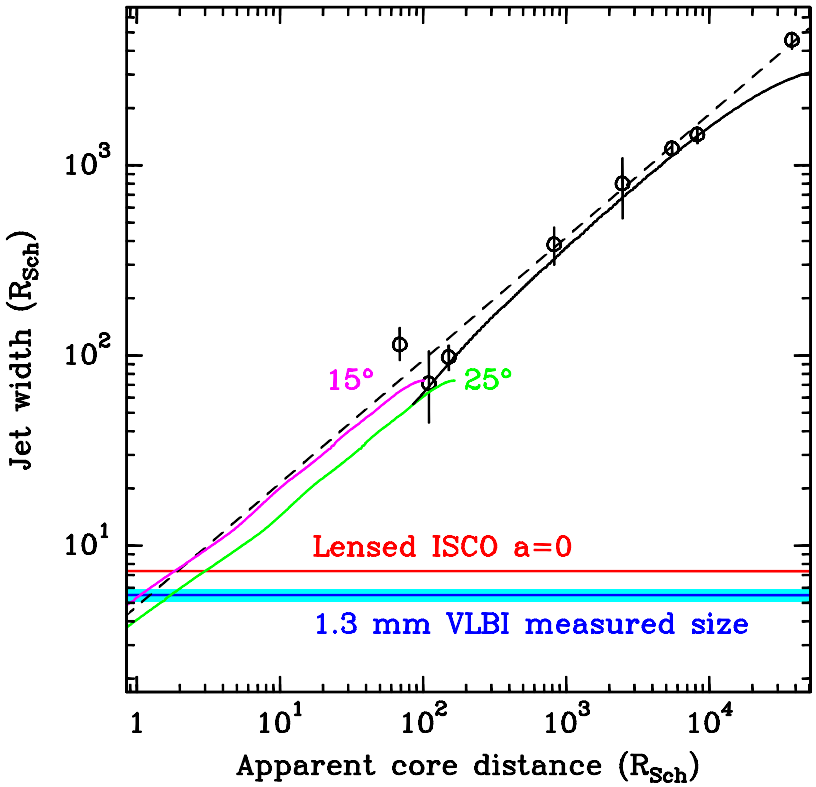


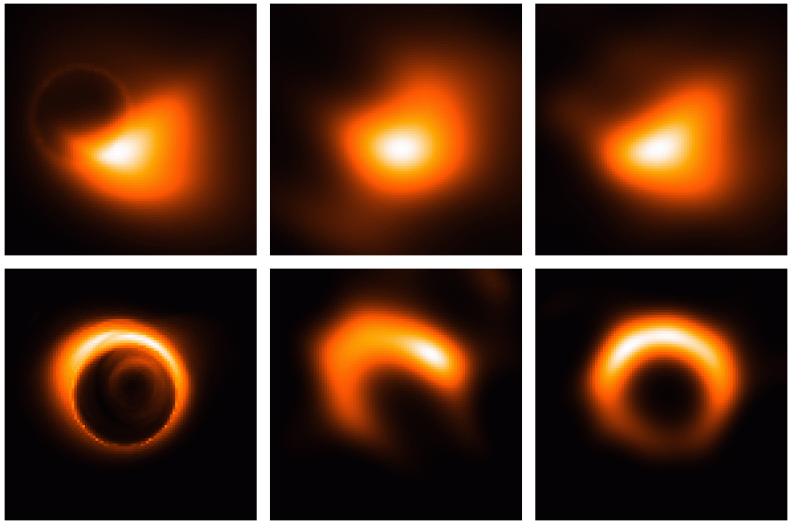
Violations of the No-Hair Theorem
Introduction of Quadrupole Moment
Psaltis and Broderick





EHT Imaging of M87

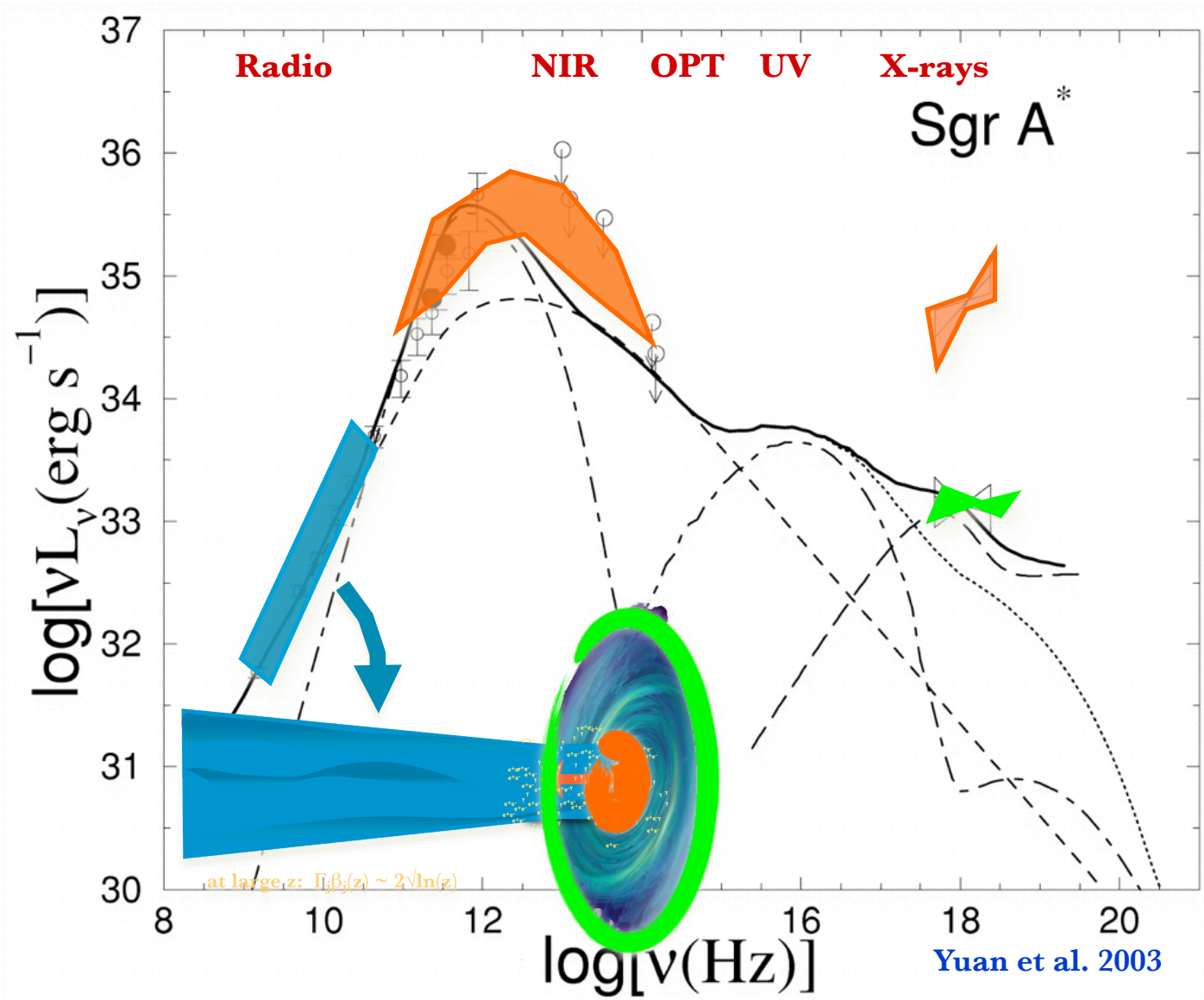




$R_S/D \sim 8$ *microarcsec*

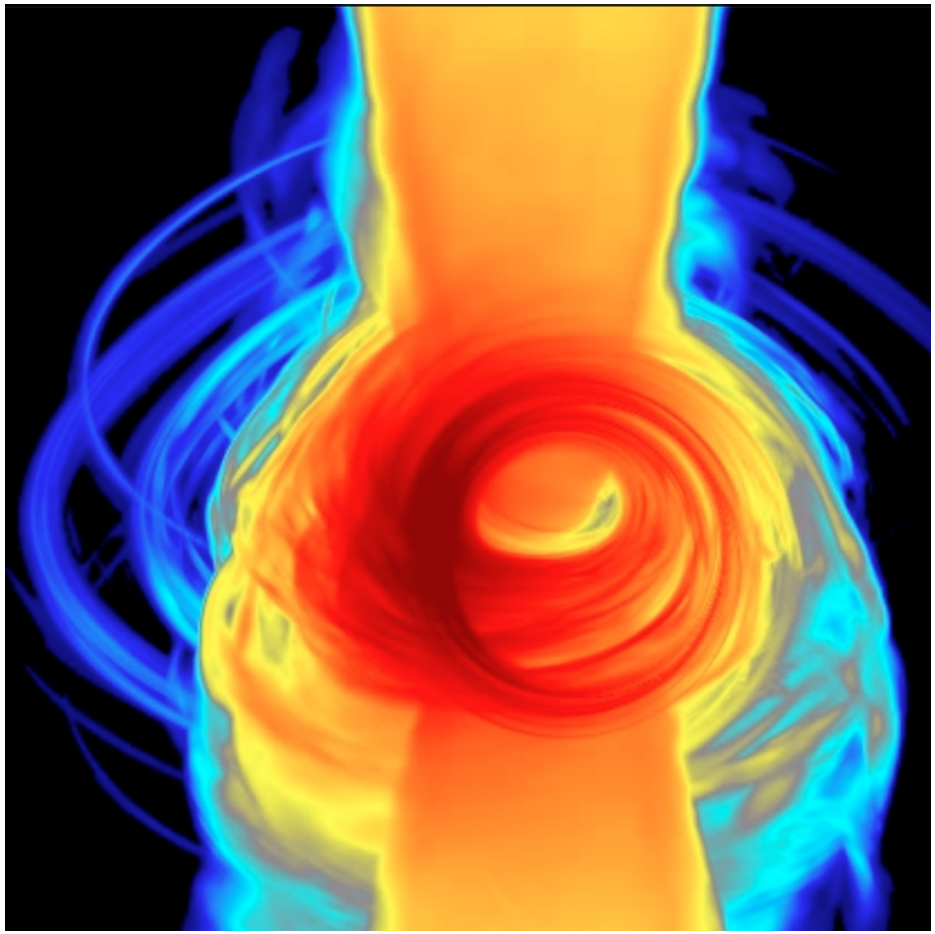
Doeleman et al 2012

Rich Phenomenology --- Jets and Disks



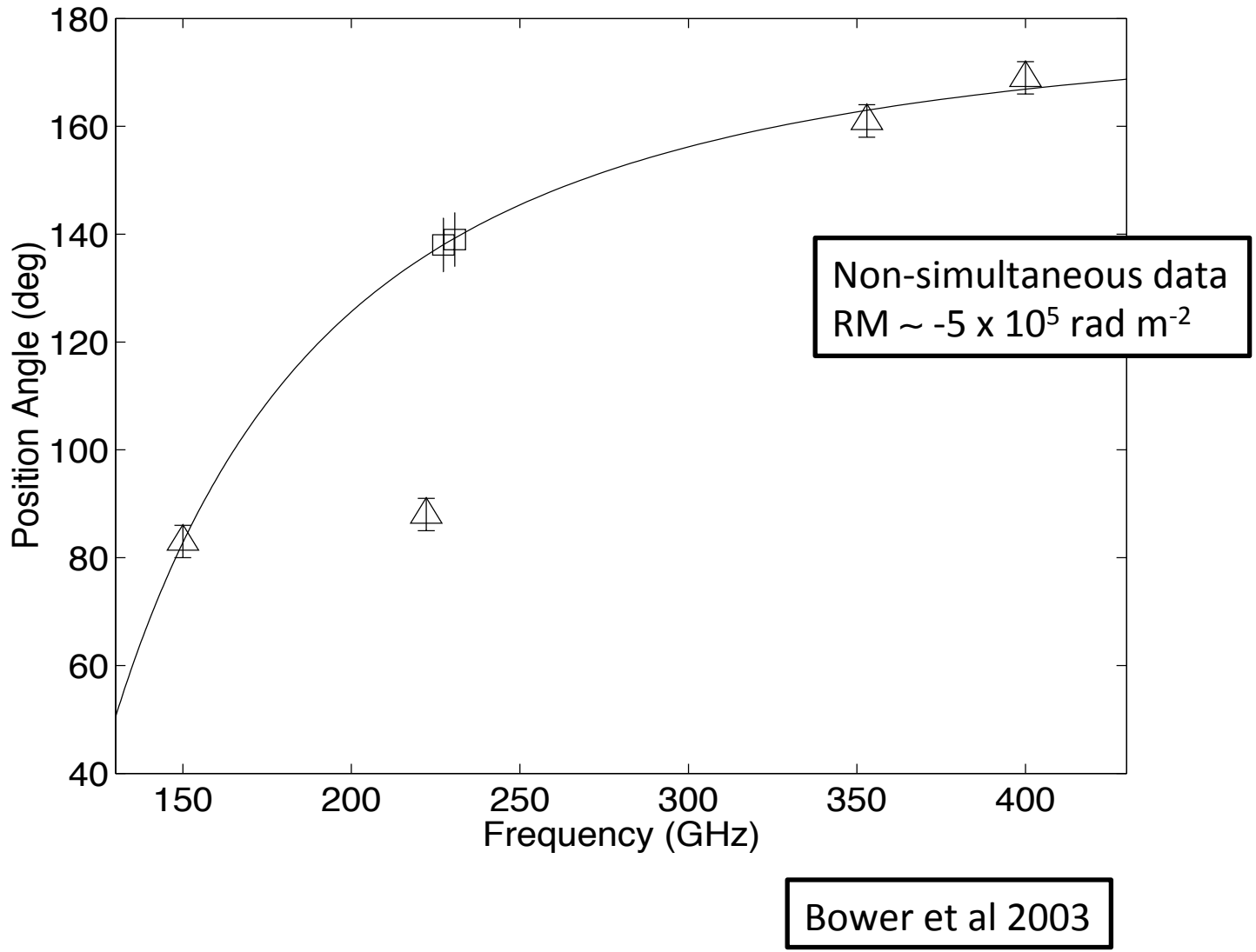
Advancing the Astrophysical Model

- **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*?**

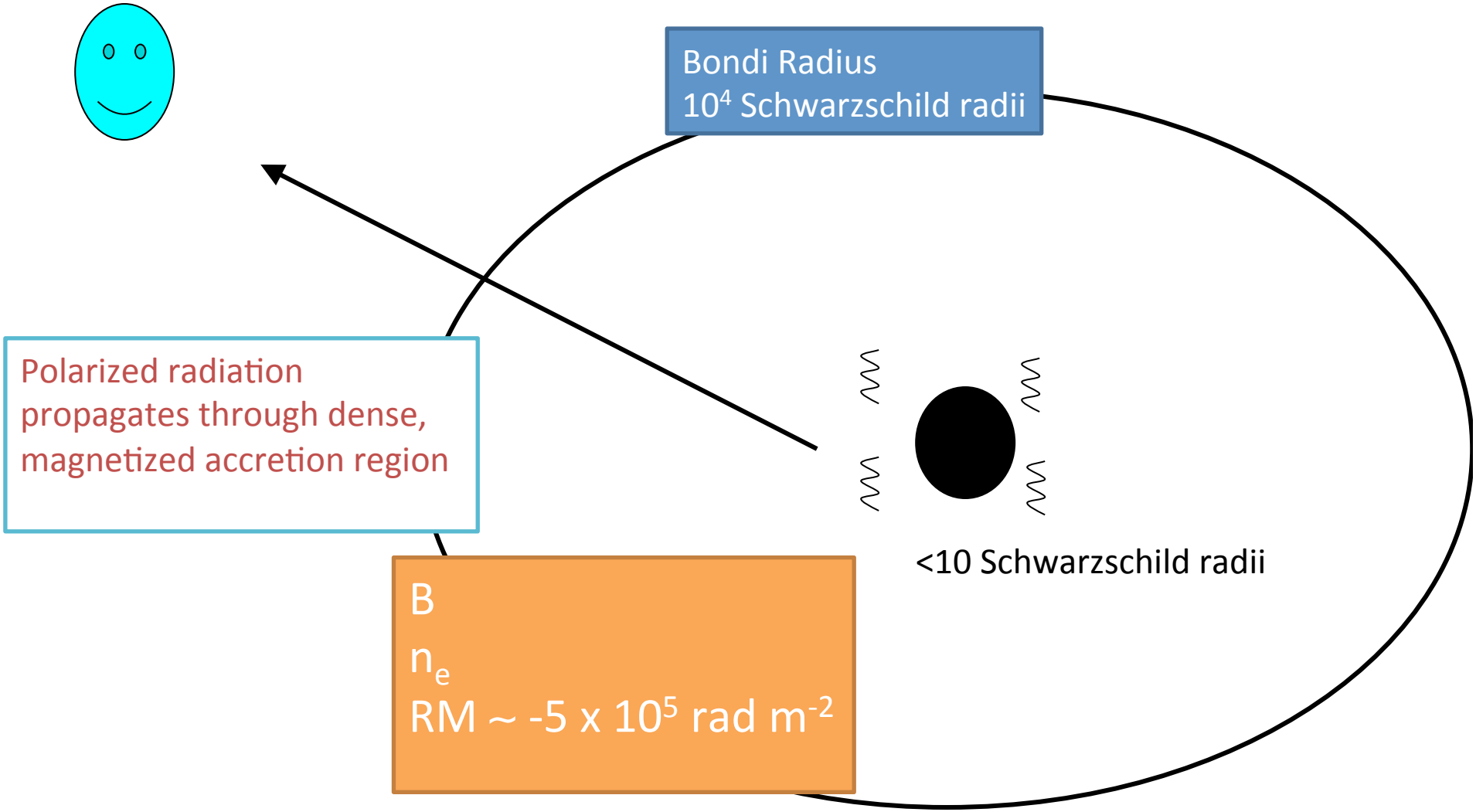


(Gammie et al.)

Rotation Measure for Sgr A*

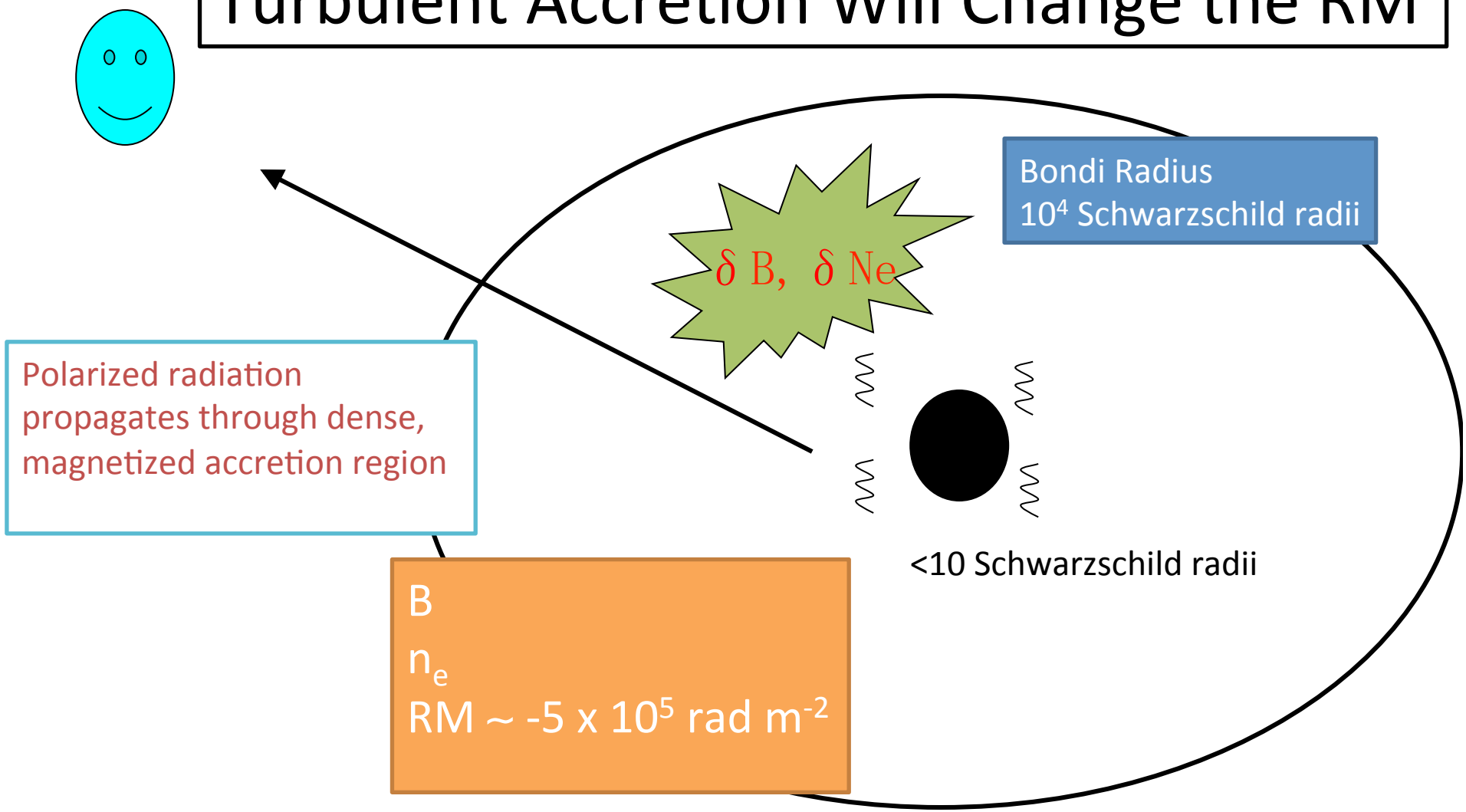


RM Originates in the Accretion Flow



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

Turbulent Accretion Will Change the RM



Time-Dependent Accretion Simulations Predict RM Changes

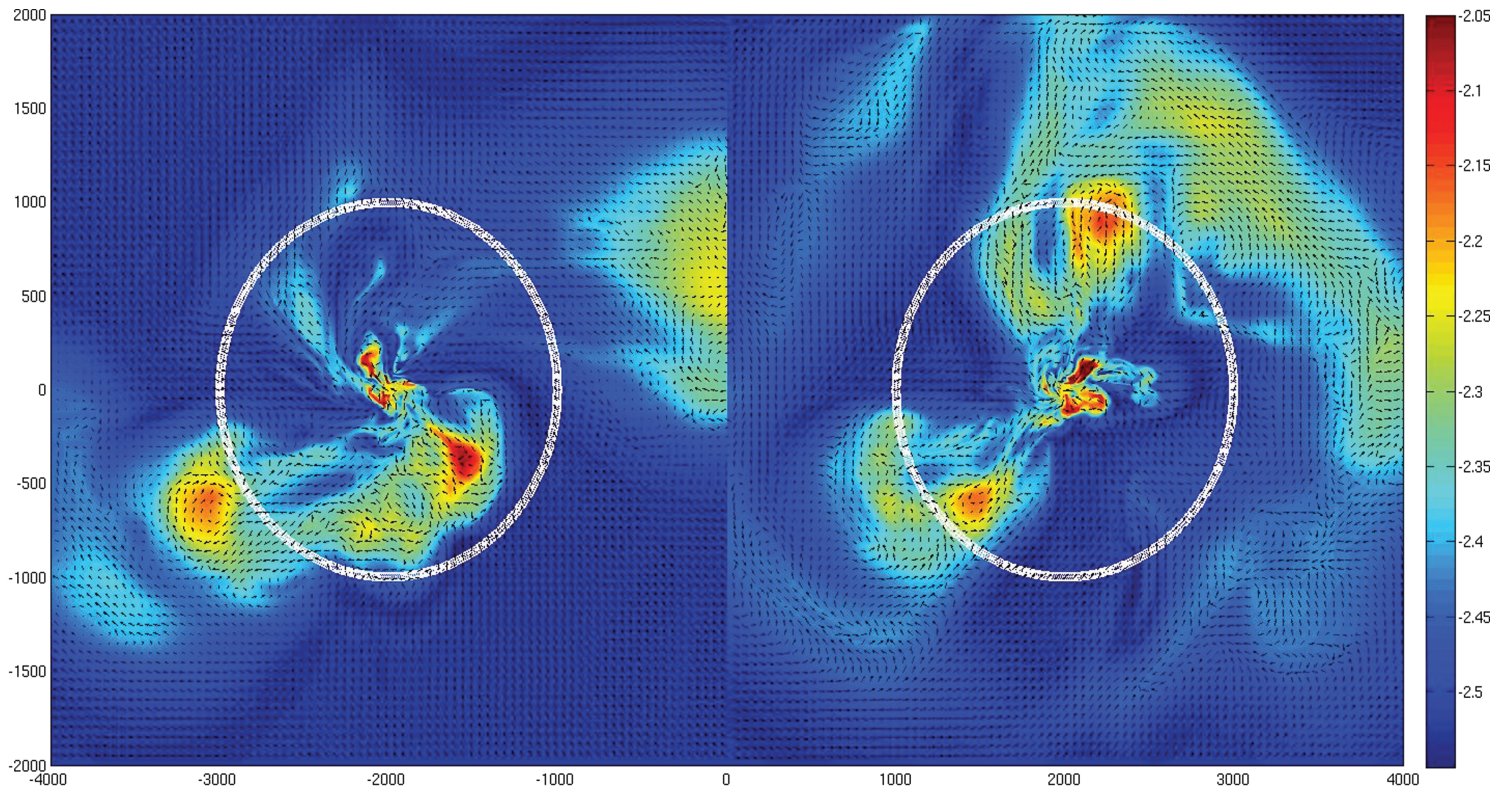
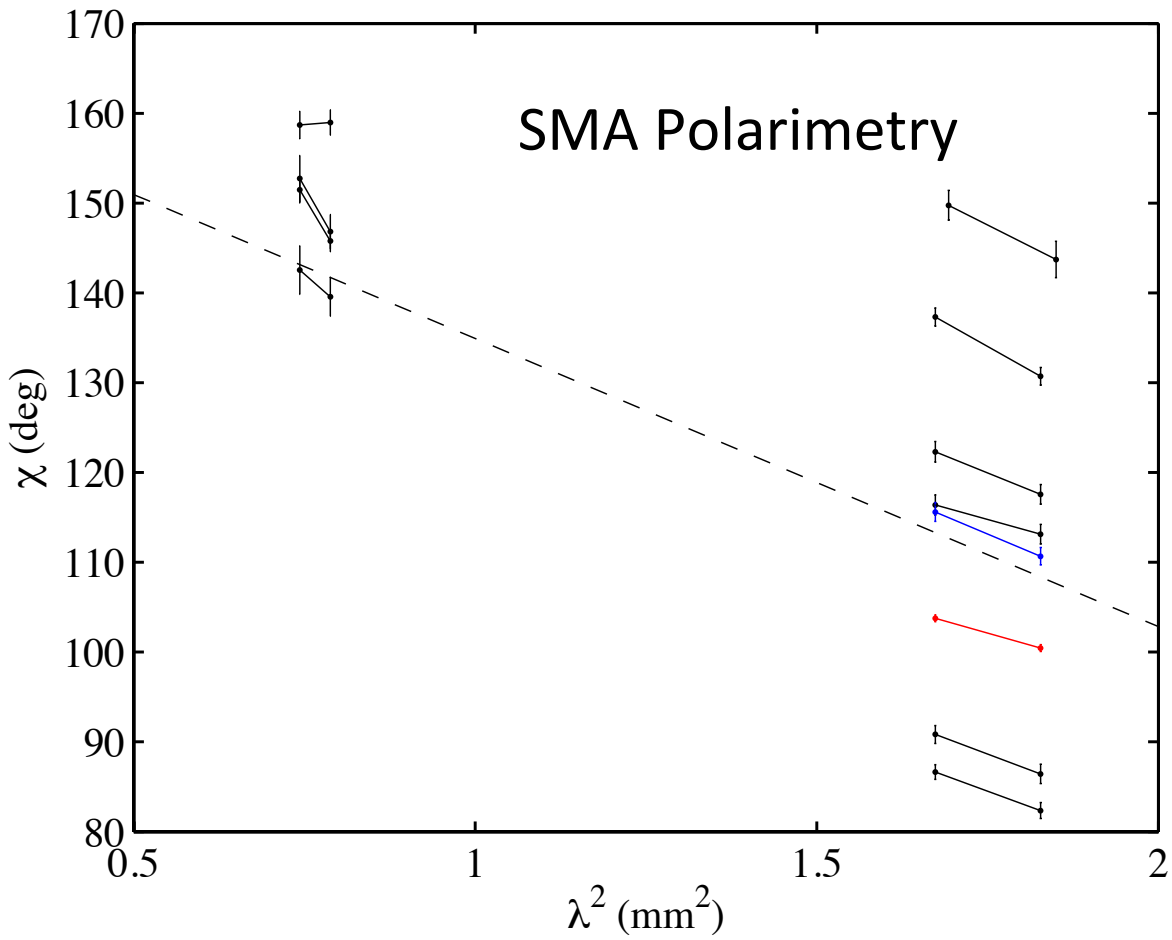


Figure 1. 2D slice of the simulation for 600^3 box at 15 Bondi times. Colour represents the entropy, and arrows represent the magnetic field vector. The right-hand panel is the equatorial plane (yz), while the left-hand panel a perpendicular slice (xy). White circles represent the Bondi radius ($r_B = 1000$). 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

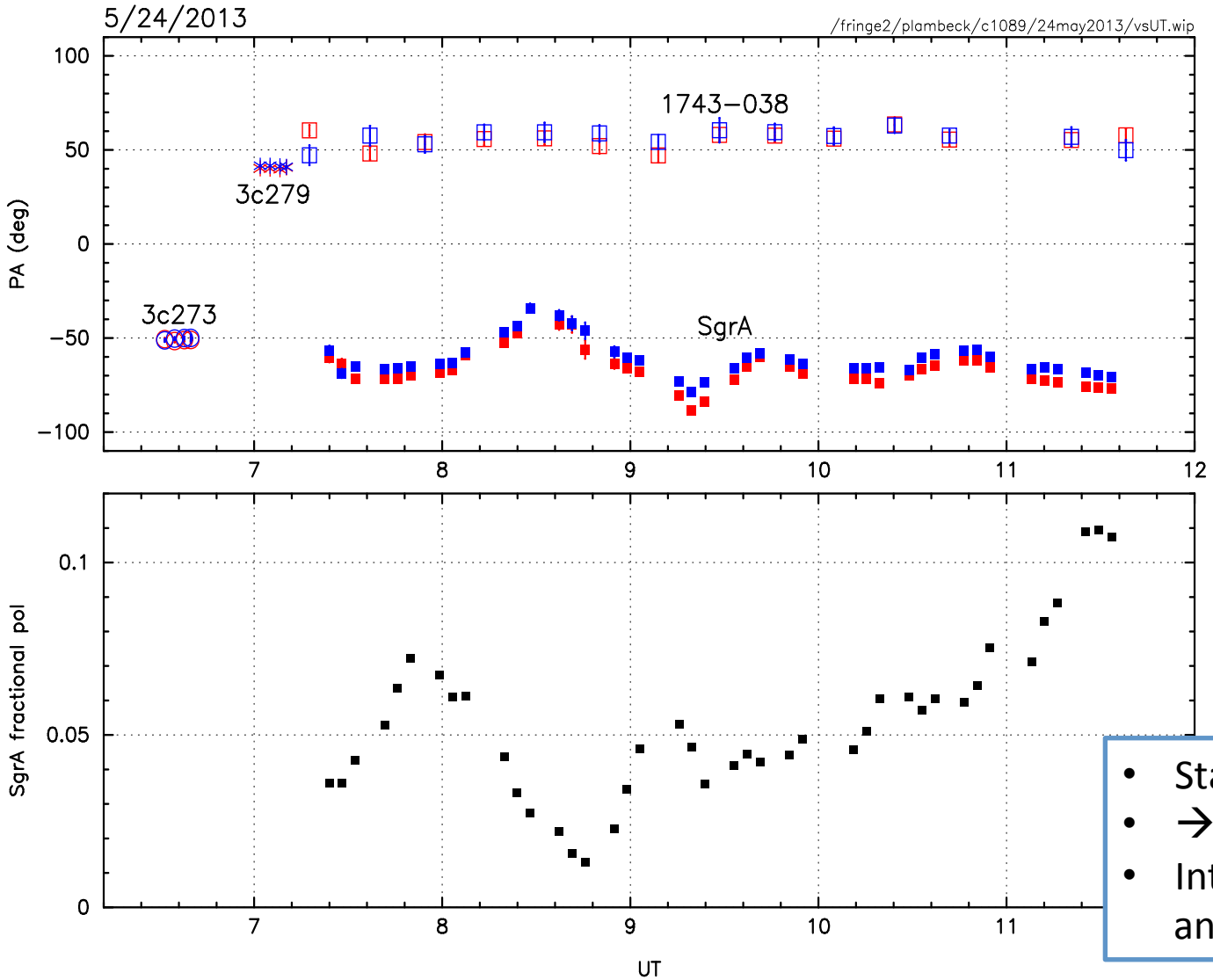
State of the Art circa 2011



Marrone et al

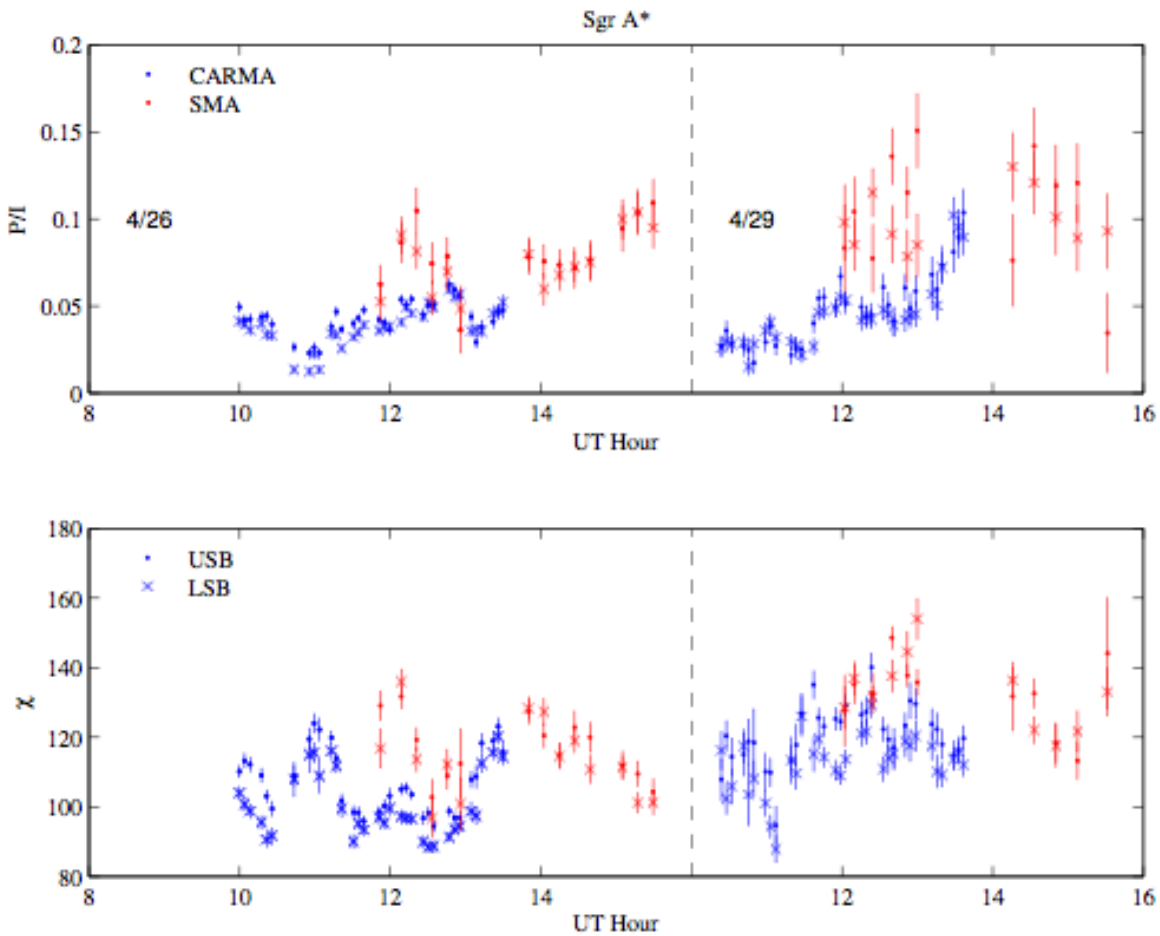
- What causes the stability of the RM?
- How variable and on what timescale is the RM?
- Are there non-λ^2 effects?
- Is there a relationship between LP, CP, and RM variability?

Time-Resolved CARMA Polarimetry

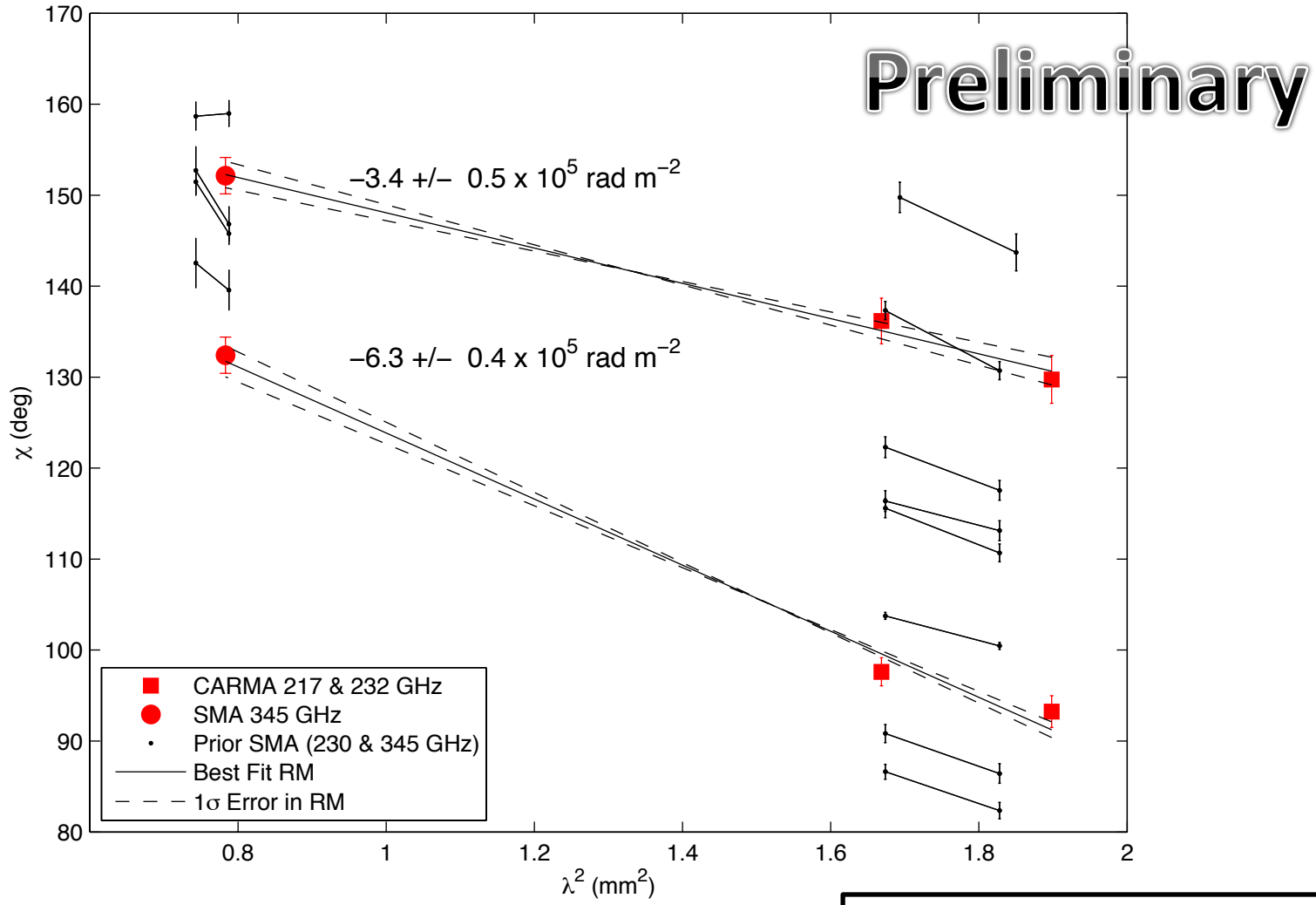


- Stable USB-LSB phase
- → RM=-3.8 x 10^5 rad m^{-2}
- Intrinsic variability in PA and fraction

Time Domain Comparisons to SMA



Variable RM from Simultaneous SMA/ CARMA Observations



Bower, Plambeck, Marrone

The G2 Gas Cloud Event

A gas cloud on its way into the super-massive black hole in the Galactic Centre

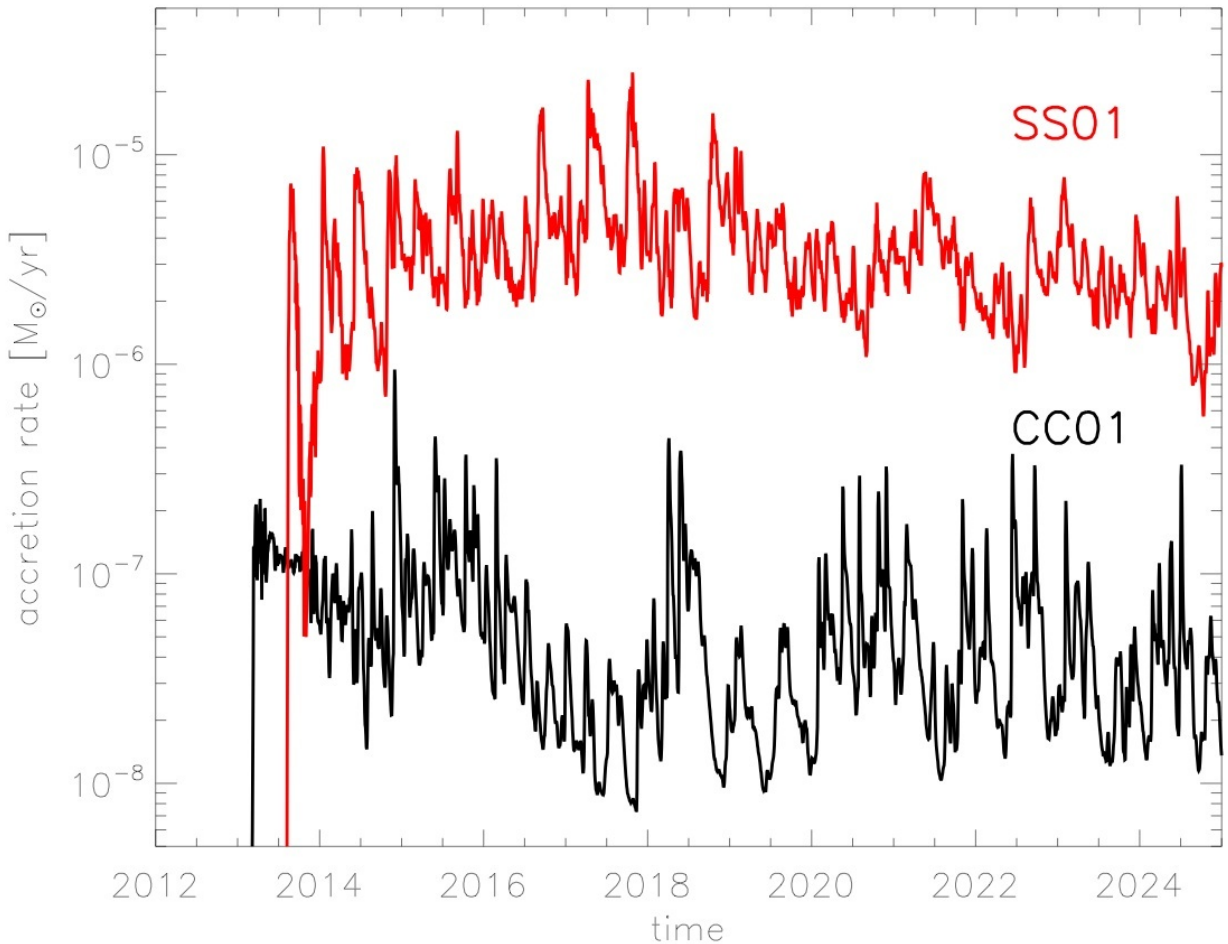
S. Gillessen, R. Genzel, T. Fritz, E. Quataert, C. Alig, A. Burkert, J. Cuadra, F. Eisenhauer, O. Pfuhl, K. Dodds-Eden, C. Gammie, T. Ott

Nature, Dec. 2011

MPE

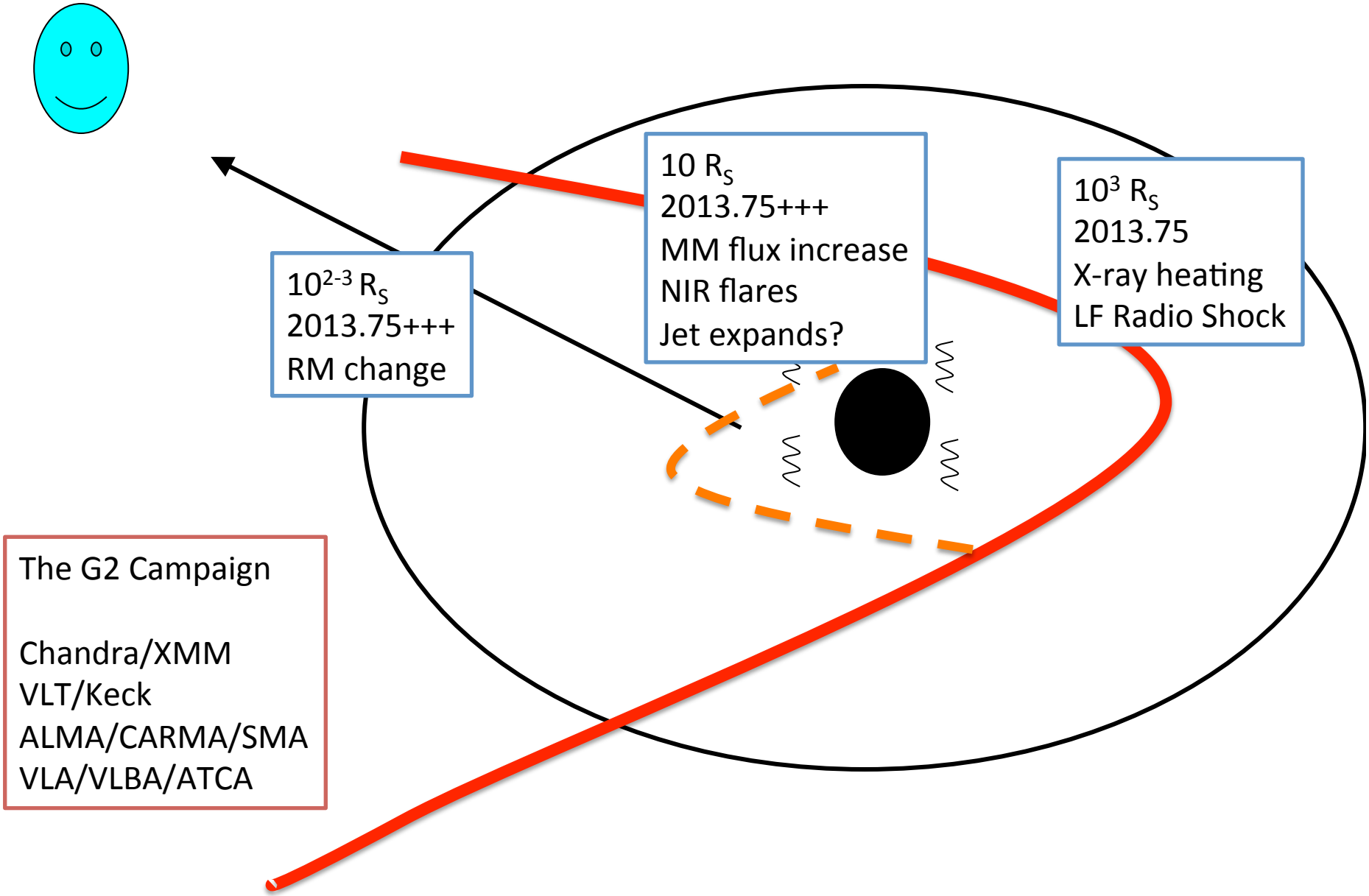
Simulation by: M. Schartmann, A. Burkert, C. Alig, S. Gillessen, R. Genzel using PLUTO 3.1.1 (Mignone et al. 2007)

Mass Accretion Predictions



Schartmann et al 2012

G2 Cloud Effects

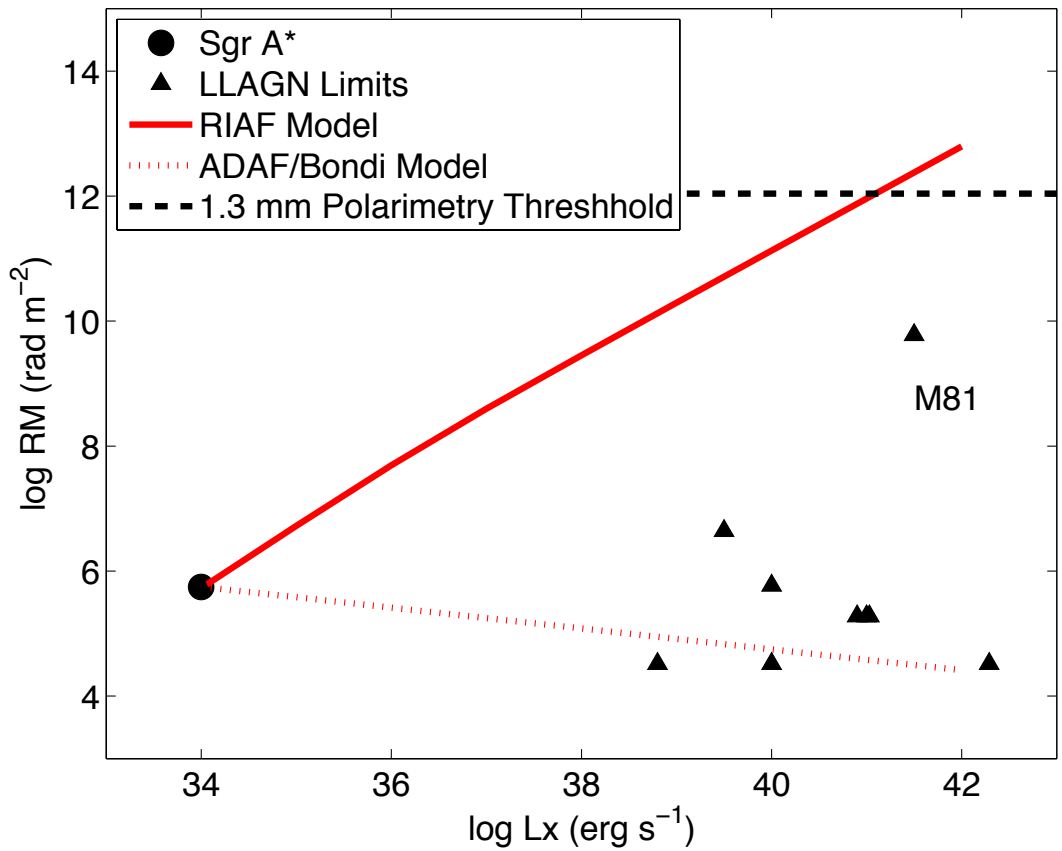


The G2 Campaign

Chandra/XMM
VLT/Keck
ALMA/CARMA/SMA
VLA/VLBA/ATCA

RM Limits for LLAGN

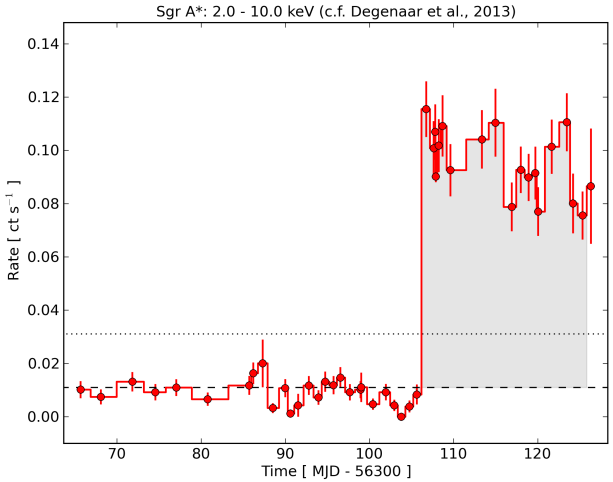
- High Frequency VLA Survey Finds no LP from LLAGN up to 43 GHz
- Clearly distinct from other AGN population
- Assuming bandwidth depolarization, allows us to set lower limits on RM



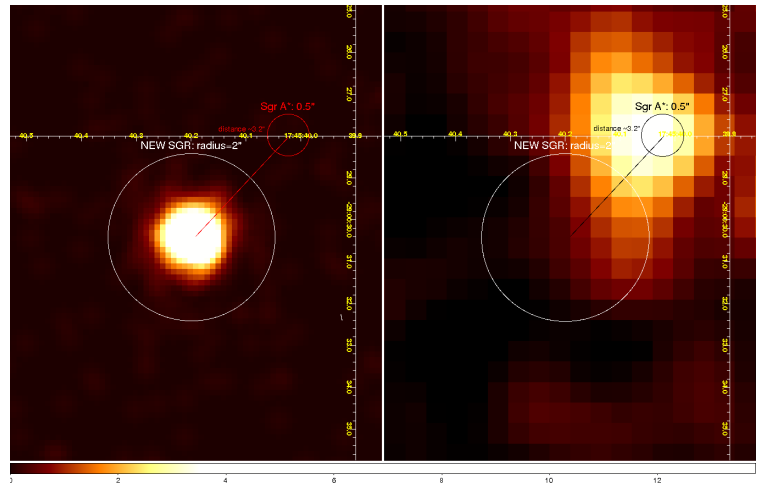
CARMA observations of M81, 3C84

Galactic Center Magnetar

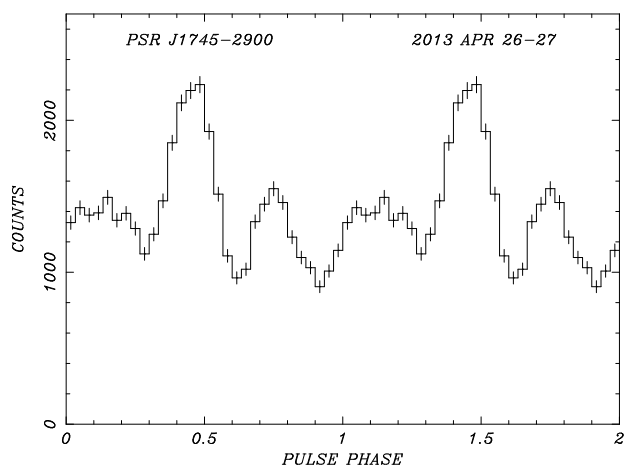
X-Ray Burst



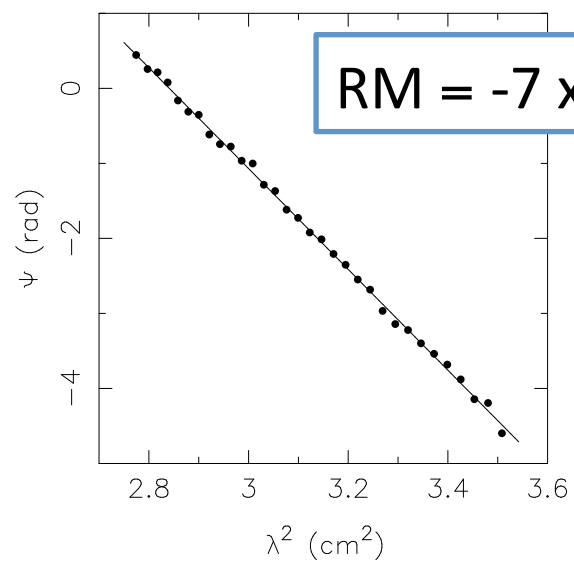
X-ray Localization: 3” to Sgr A*



X-ray Pulsations



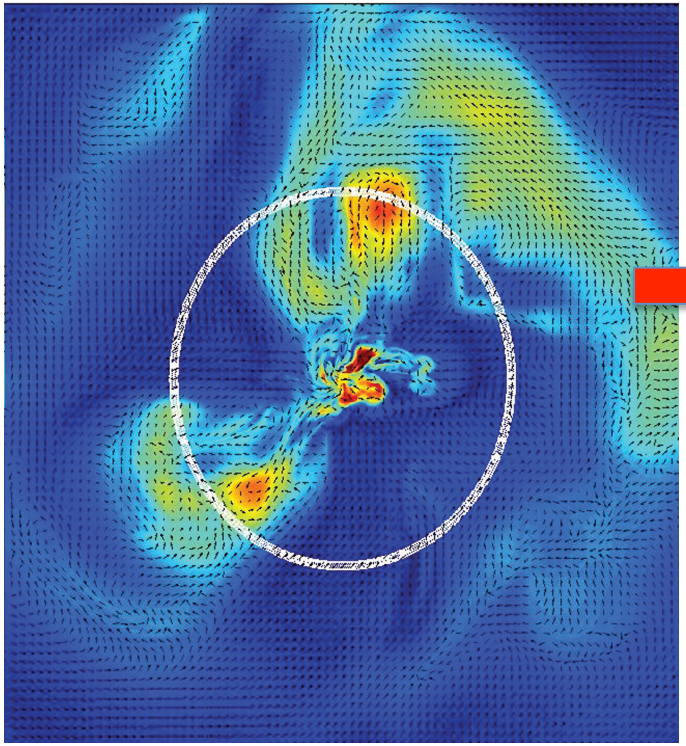
Radio Pulsations and Rotation Measure



RM = -7 x 10^4 rad m^{-2}

Summary

Astrophysics



Fundamental Physics