Title: Polarized emission from Black Hole Accretion Disks and Jets

Date: Nov 10, 2014 09:50 AM

URL: http://pirsa.org/14110064

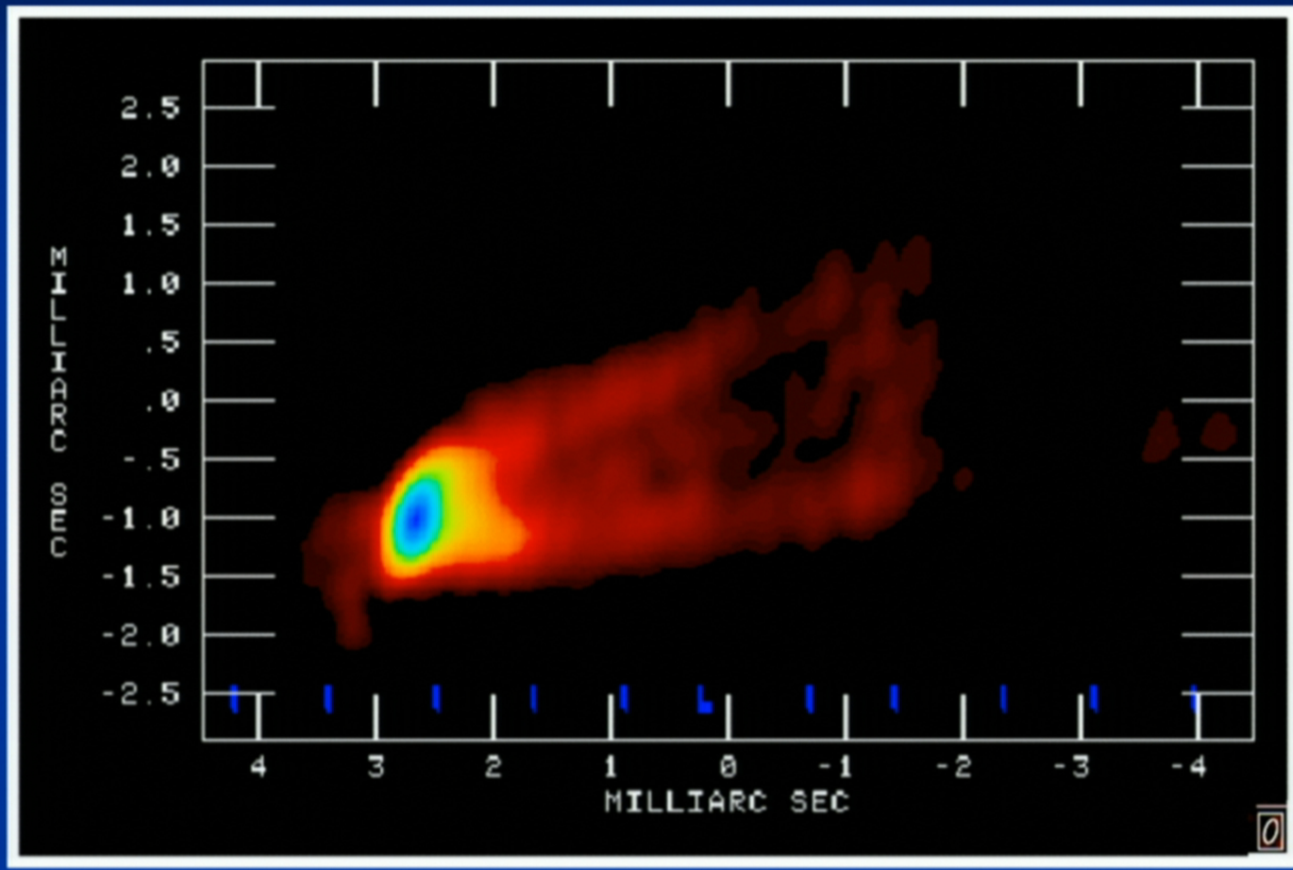
Abstract: We discuss how polarized emission can place constraints on the properties of accretion flows and jets in the strong gravity regime for systems like SgrA* and M87 being observed by the Event Horizon Telescope.

"Doubt is an uncomfortable condition, but certainty is a ridiculous one."
– Voltaire

"Doubt is an uncomfortable condition, but certainty is a ridiculous one."
– Voltaire

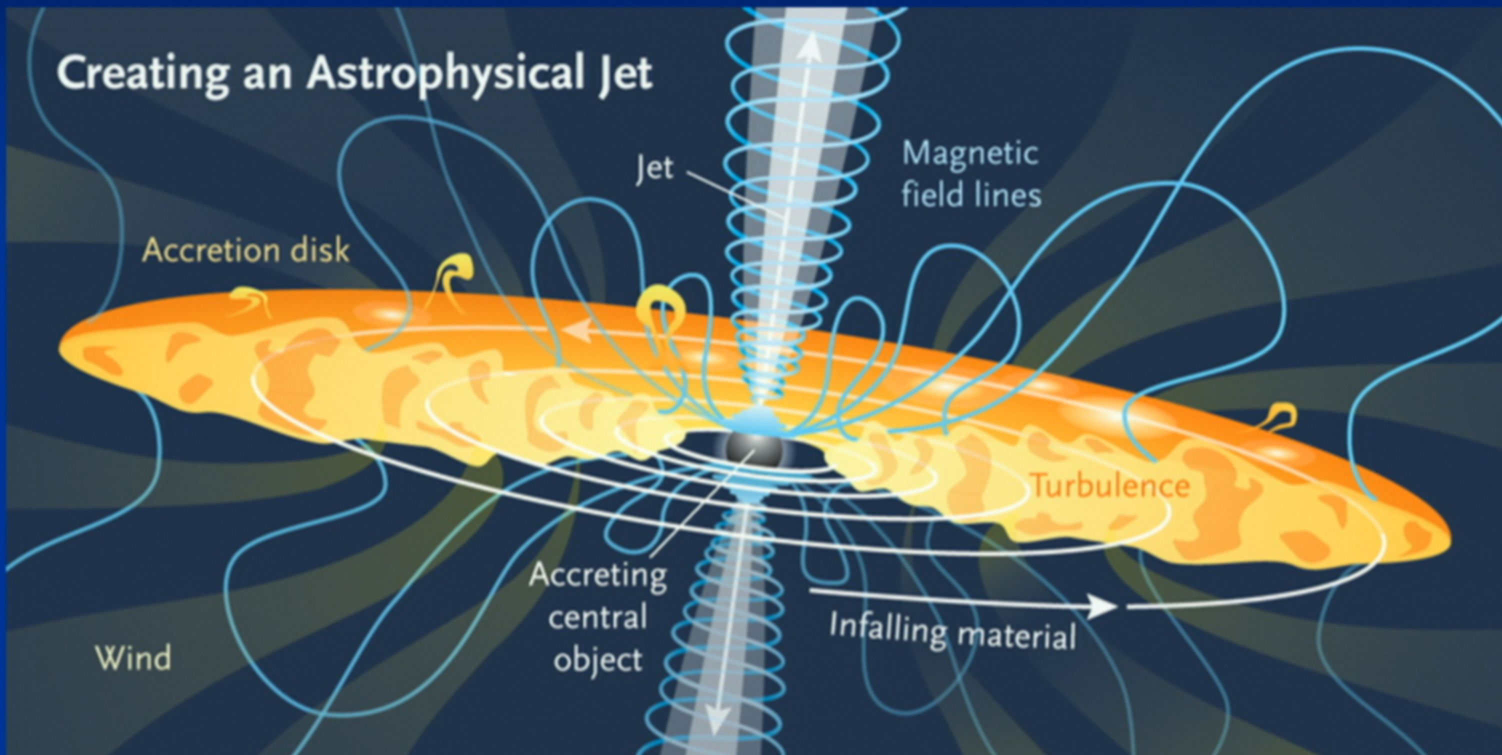
"Our doubts are traitors,
and make us lose the good we oft might win,
by fearing to attempt."
– William Shakespeare, *Measure for Measure*

BH Jet in M87



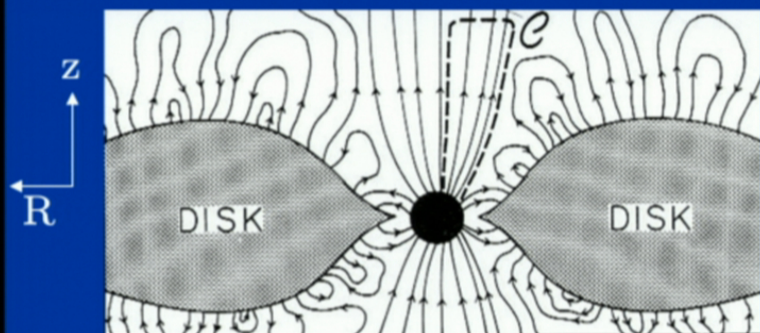
VLBA Radio: 0.1pc – 0.01pc : Walker et al. (2008)

Magnetized Accretion



Role of Magnetic Field / Flux

Weak Field MRI Disk
+
Blandford-Znajek Jet
= Flux is Fine-Tuned



SANE = Standard And Normal Evolution

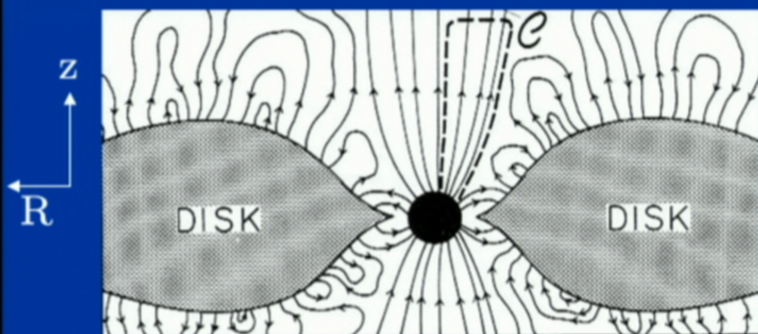
MRI = Magneto-Rotational Instability

Lense Thirring : Bardeen-Petterson Alignment

Blandford & Znajek (77) MacDonald & Thorne (82),
Balbus & Hawley (1991,1998)

Role of Magnetic Field / Flux

Weak Field MRI Disk
+
Blandford-Znajek Jet
= Flux is Fine-Tuned



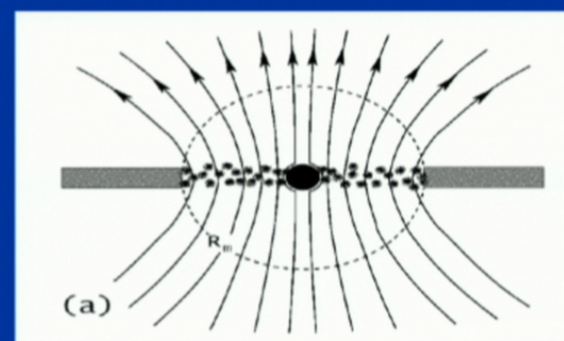
SANE = Standard And Normal Evolution

MRI = Magneto-Rotational Instability

Lense Thirring : Bardeen-Petterson Alignment

Blandford & Znajek (77) MacDonald & Thorne (82), Balbus & Hawley (1991,1998)

Saturated Field MAD Disk
+
Blandford-Znajek Jet
= Flux in Force Balance

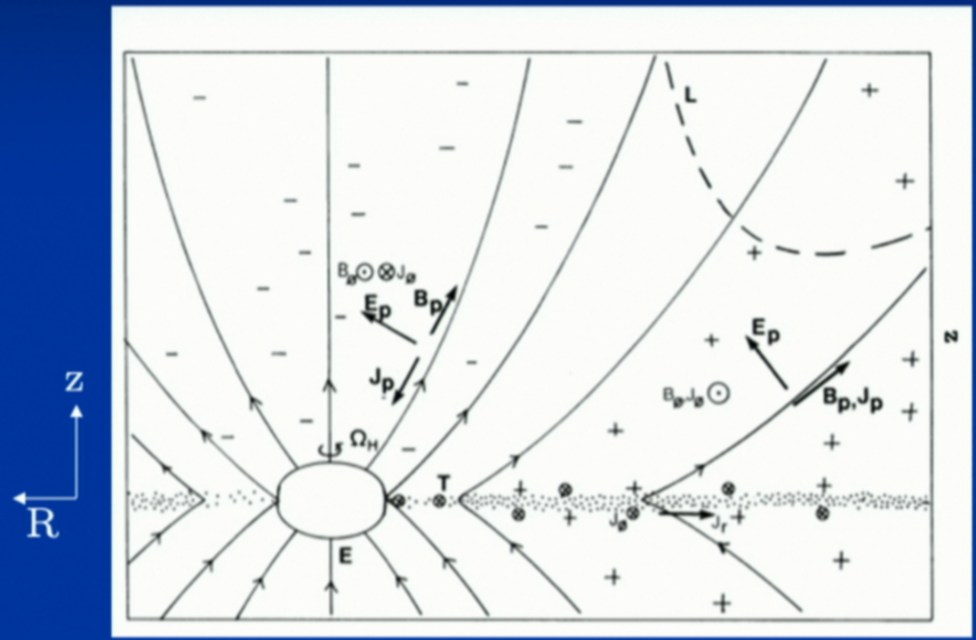


MAD = Magnetically Arrested Disk

Znajek (76), Bisnovatyi-Kogan & Ruzmaikin (74,76), Narayan et al. (03), Reynolds et al. (06), Igumenshchev et al. (03), ˜Komissarov (09)

Role of Magnetic Field / Flux

Blandford-Znajek 77 Jet

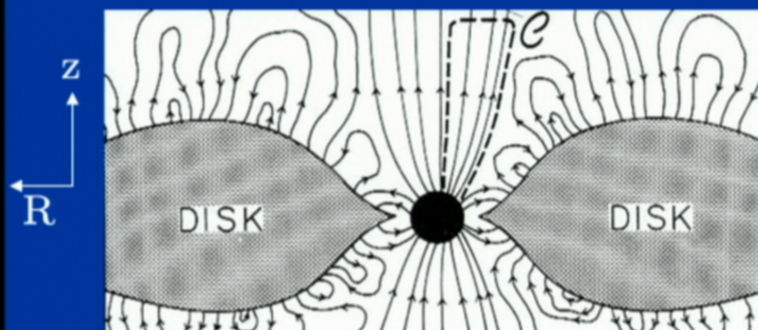


BZ Power P $\propto$ Psi^2 $\Omega^2_{\mathrm{Hparallel}}$

BZ Torque G = dJ/dt $\propto$ Psi^2 $\Omega_{\mathrm{Hparallel}}$

Role of Magnetic Field / Flux

Weak Field MRI Disk
+
Blandford-Znajek Jet
= Flux is Fine-Tuned



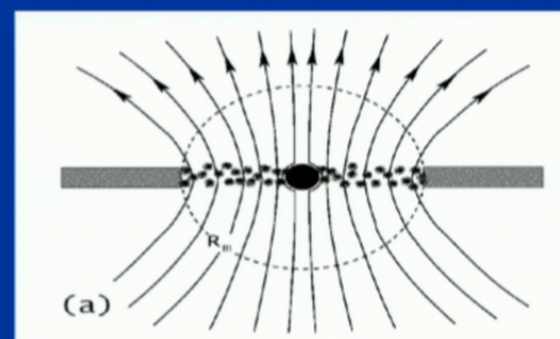
SANE = Standard And Normal Evolution

MRI = Magneto-Rotational Instability

Lense Thirring : Bardeen-Petterson Alignment

Blandford & Znajek (77) MacDonald & Thorne (82), Balbus & Hawley (1991,1998)

Saturated Field MAD Disk
+
Blandford-Znajek Jet
= Flux in Force Balance

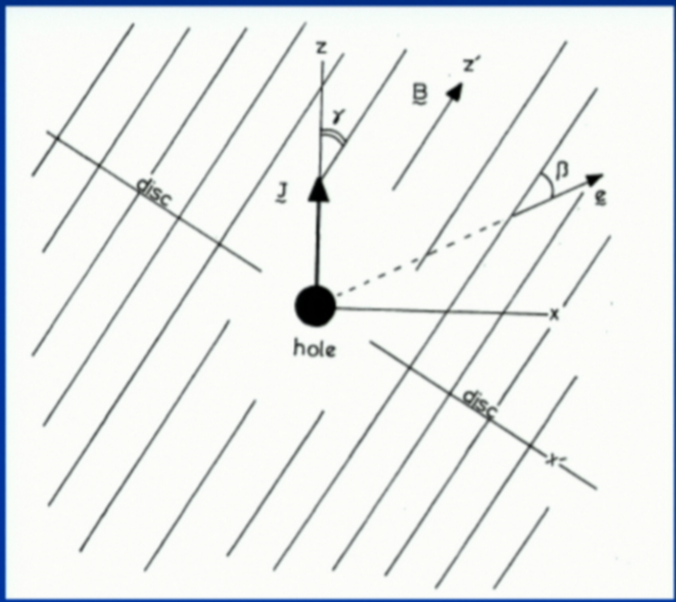


MAD = Magnetically Arrested Disk

Znajek (76), Bisnovatyi-Kogan & Ruzmaikin (74,76), Narayan et al. (03), Reynolds et al. (06), Igumenshchev et al. (03), ˜Komissarov (09)

Role of Magnetic Field / Flux

King Lasota 76 Vacuum Torques

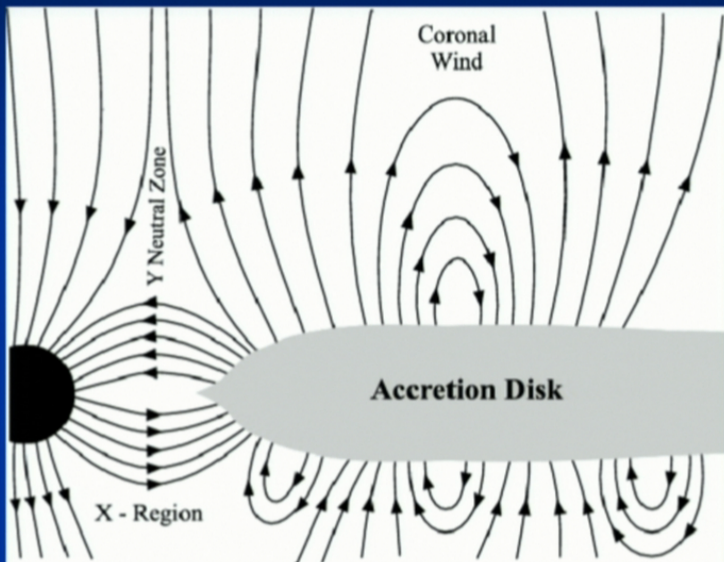


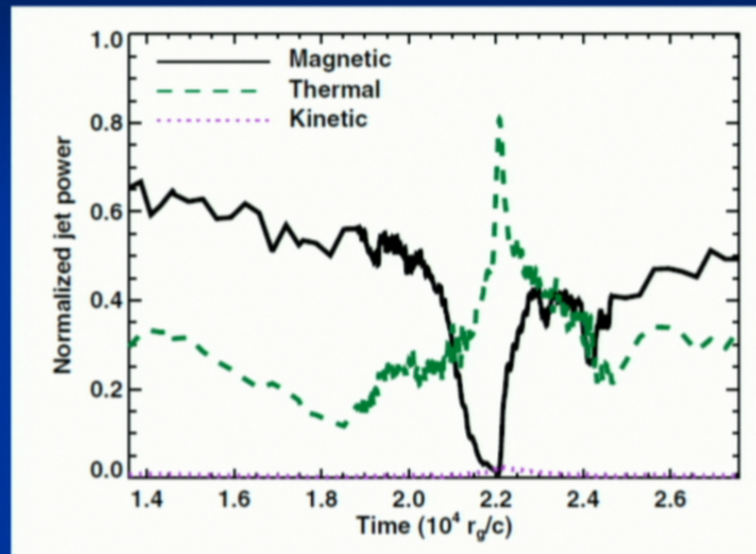
KL Power P $\propto$ Psi^2 $\Omega^2_{\mathrm{Hperp}}$

BZ+KL in Force-Free:
Palenzuela et al. (2010)

KL Torque G $\propto$ Psi^2 Ω_{Hperp}

Magnetospheric Reconnection





MR Power P $\propto$ Psi^2 v_r

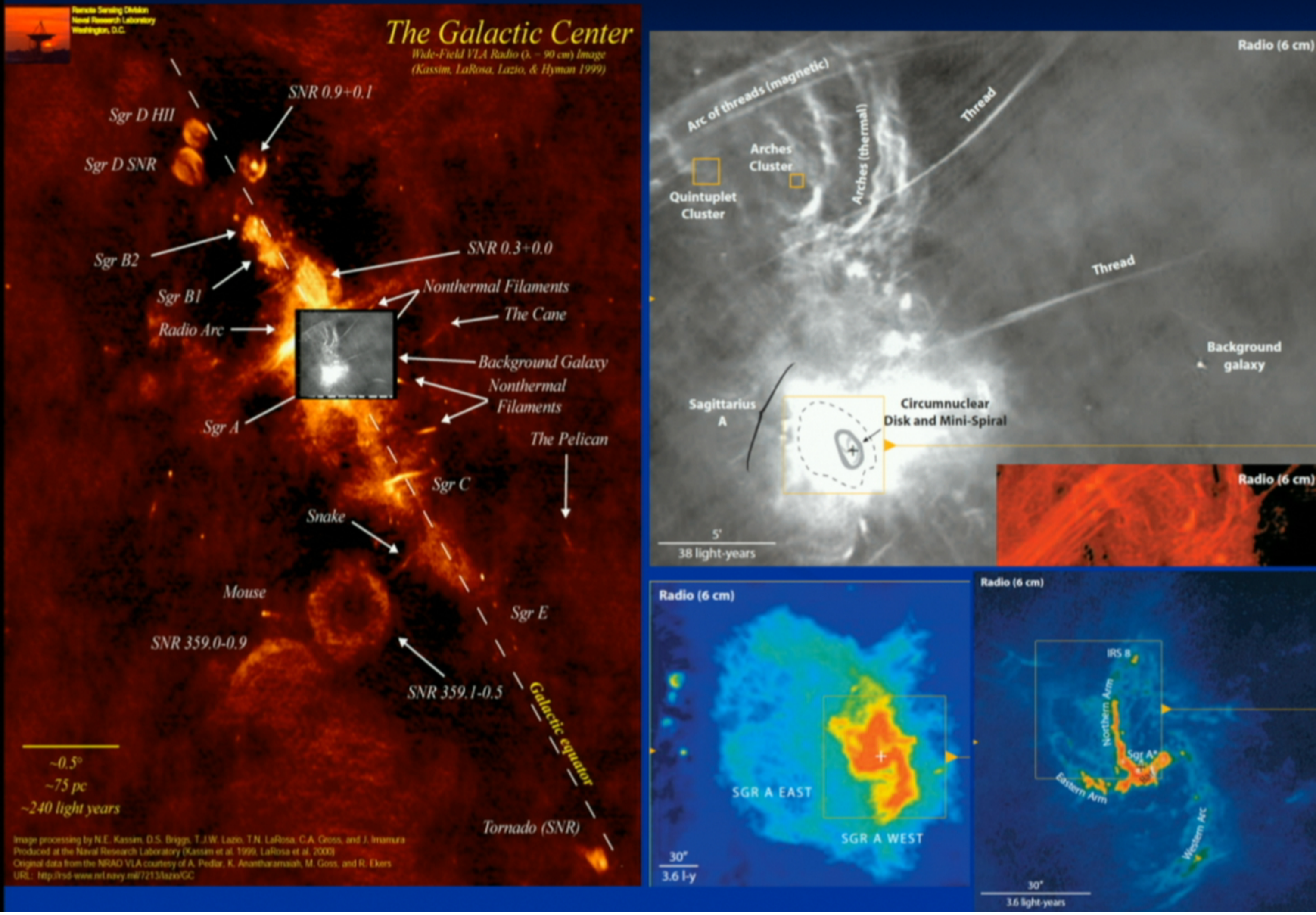
Dexter, McKinney, Markoff, Tchekhovskoy (2014)
Lovelace, Newman, Romanova (1997)
de Gouveia dal Pino, Lazarian (2005,2010)
Igumenshchev (2009)
Tagger & Pellat (99), Livio et al. (03), King et al. (04), Begelman & Armitage (14)

MAD vs. SANE vs. ZEN

- MAD: Aligned Ordered Poloidal Field (Subset: MCAF)
- SANE: Weak Aligned 1-Loop, Weak N-Loops
- SANEST: Aligned Ordered Toroidal Field
- SAME: Same but Mis-aligned Versions
- ZEN: Gaussian Random Field Spectra for Vector Potential, Densities, and Velocity Field consistent with means at large radii.

MAD vs. SANE vs. ZEN

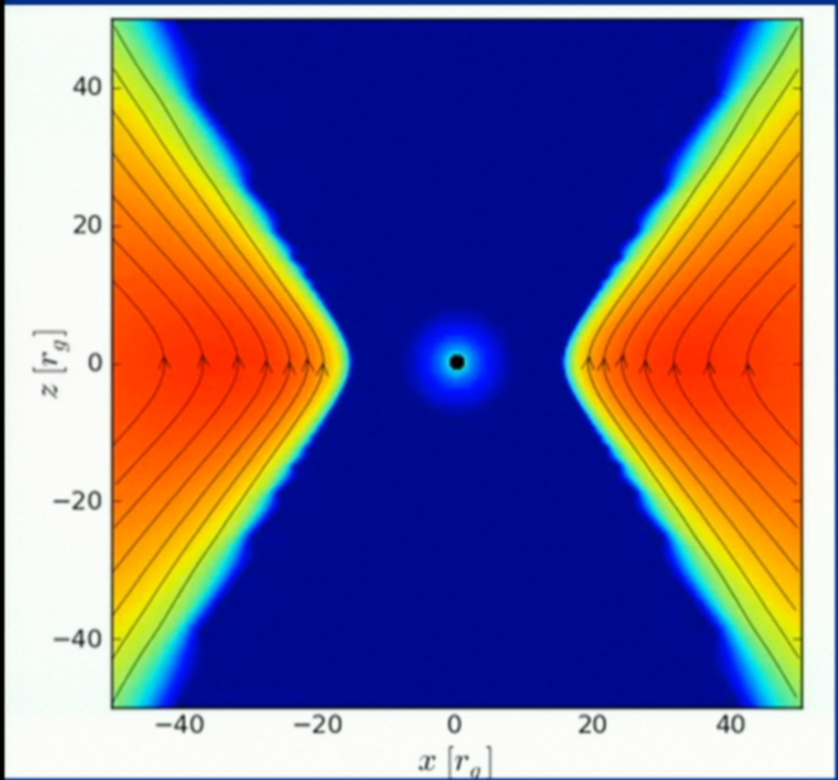
- MAD: Aligned Ordered Poloidal Field (Subset: MCAF)
- SANE: Weak Aligned 1-Loop, Weak N-Loops
- SANEST: Aligned Ordered Toroidal Field
- SAME: Same but Mis-aligned Versions
- ZEN: Gaussian Random Field Spectra for Vector Potential, Densities, and Velocity Field consistent with means at large radii.



The Galactic Center
Wide-Field VLA Radio (λ ~ 90 cm) Image
(Kassim, LaRosa, Lazio, & Hyman 1999)
SNR 0.9+0.1
Sgr D HII
Sgr D SNR
Sgr B2
SNR 0.3+0.0
Sgr B1
Nonthermal Filaments
The Cane
Radio Arc
Background Galaxy
Nonthermal Filaments
Sgr A
The Pelican
Sgr C
Snake
Mouse
Sgr E
SNR 359.0-0.9
SNR 359.1-0.5
Galactic equator
~0.5°
~75 pc
~240 light years
Tornado (SNR)
Radio (6 cm)
Arc of threads (magnetic)
Arches Cluster
Arches (thermal)
Thread
Quintuplet Cluster
Thread
Background galaxy
Sagittarius A
Circumnuclear Disk and Mini-Spiral
5'
38 light-years
Radio (6 cm)
Radio (6 cm)
SGR A EAST
SGR A WEST
30"
3.6 l-y
Radio (6 cm)
IRS 8
Northern Arm
Sgr A*
Eastern Arm
Western Arc
30"
3.6 light-years

Going MAD

Dim.less Flux: Psi/Mdot^{1/2}



Physical Setup:

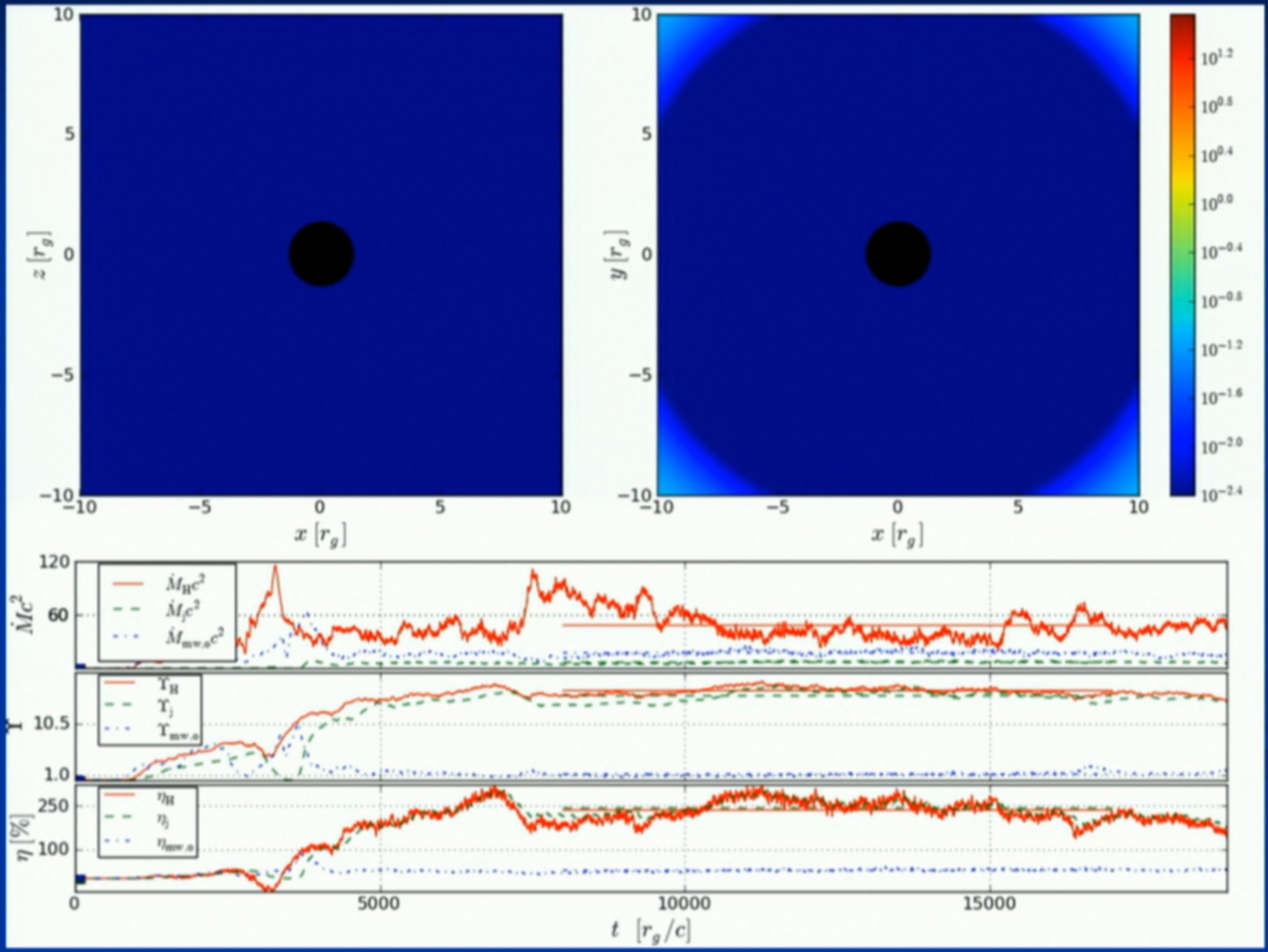
GRMHD + rho,u floor
Spin: a=0.99 (+-0.9,0.5,0.2,0.1,0)
Radiatively Inefficient
Run: ~30,000M to ~100kM

Numerical Setup:

Fully 3D (no syms), large Rout
Kerr-Schild Coords
288x128x128 – 272x128x256
Explicit Res+Conv Tests

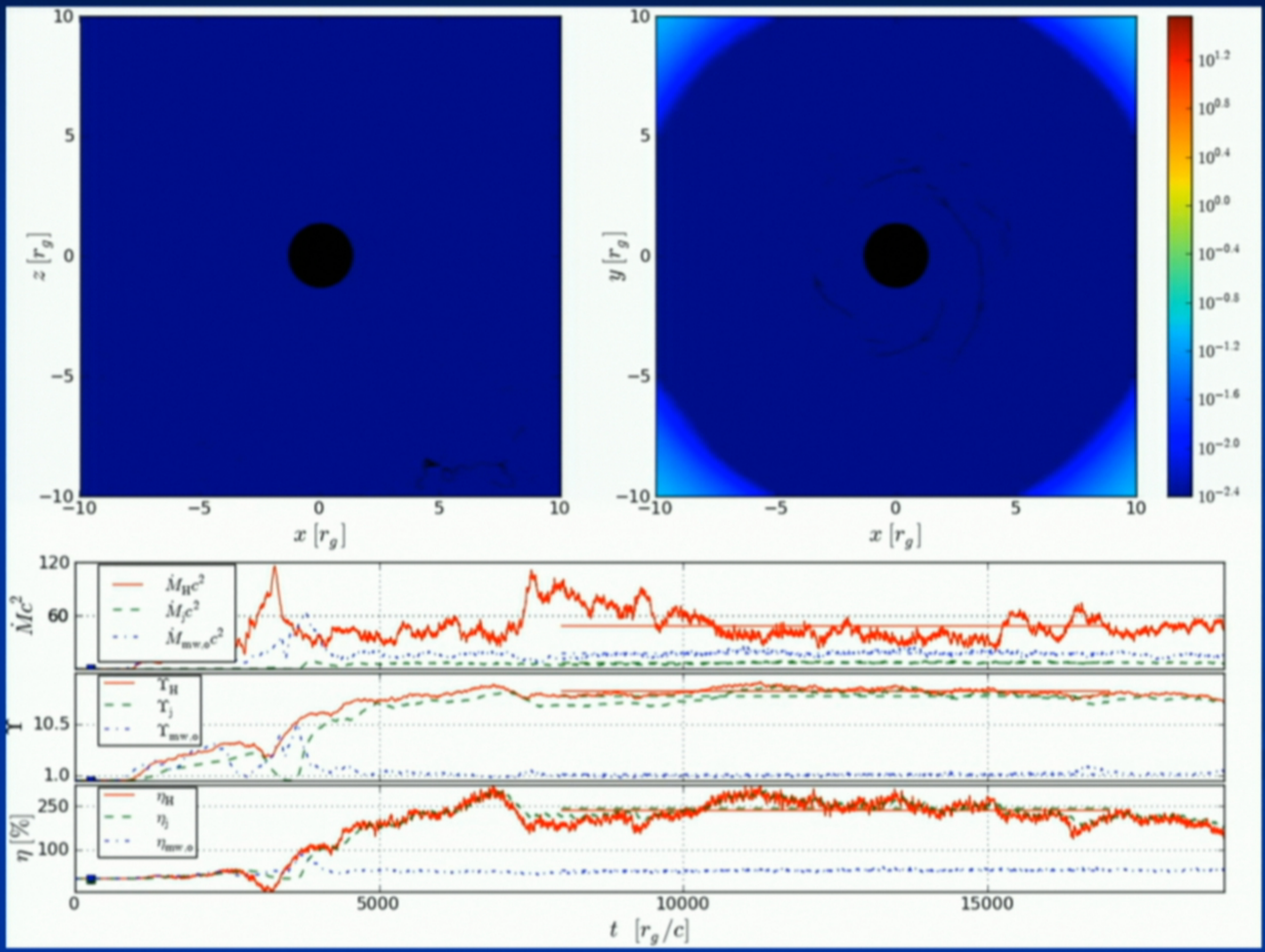
Tchekhovskoy, Narayan, McKinney (2011)
McKinney, Tchekhovskoy, Blandford (2012)
Narayan et al. (2012)

Going MAD



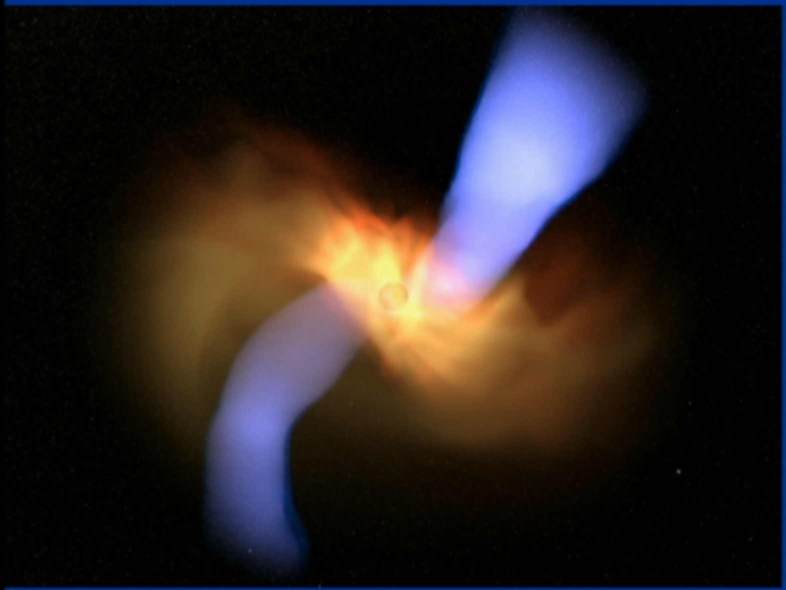
$z\,[r_g]$
$y\,[r_g]$
$x\,[r_g]$
$\dot{M}c^2$
$\dot{M}_H c^2$
$\dot{M}_j c^2$
Υ
Υ_H
Υ_j
$\eta\,[\%]$
η_H
η_j
$t\ [r_g/c]$

Going MAD



$z\ [r_g]$
$y\ [r_g]$
$x\ [r_g]$
$\dot{M}c^2$
$\dot{M}_H c^2$
$\dot{M}_j c^2$
$\dot{M}_{mw,o} c^2$
Υ
Υ_H
Υ_j
$\Upsilon_{mw,o}$
$\eta\ [\%]$
η_H
η_j
$\eta_{mw,o}$
$t\ [r_g/c]$

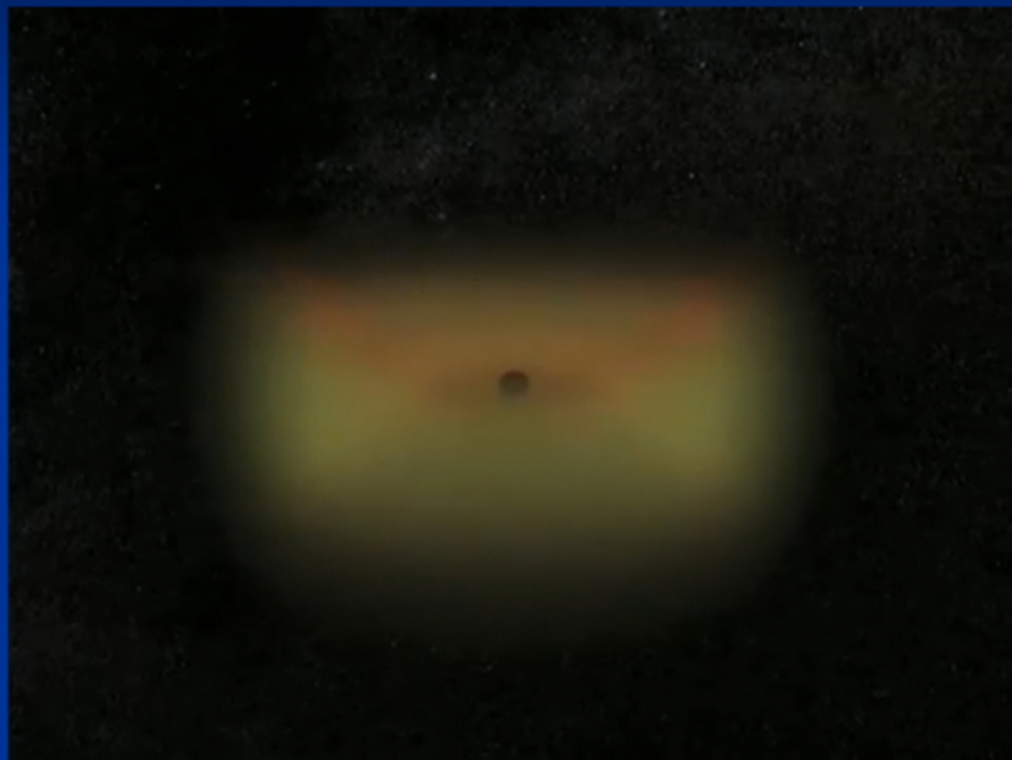
GRMHD with Tilt and Jet



Physical Setup:
Spin: a=0.99 (+-0.94,0.9,0)
Tilt: 0.1,0.3,0.6,0.7rad, 90deg
(Tilt turned on mid-way)

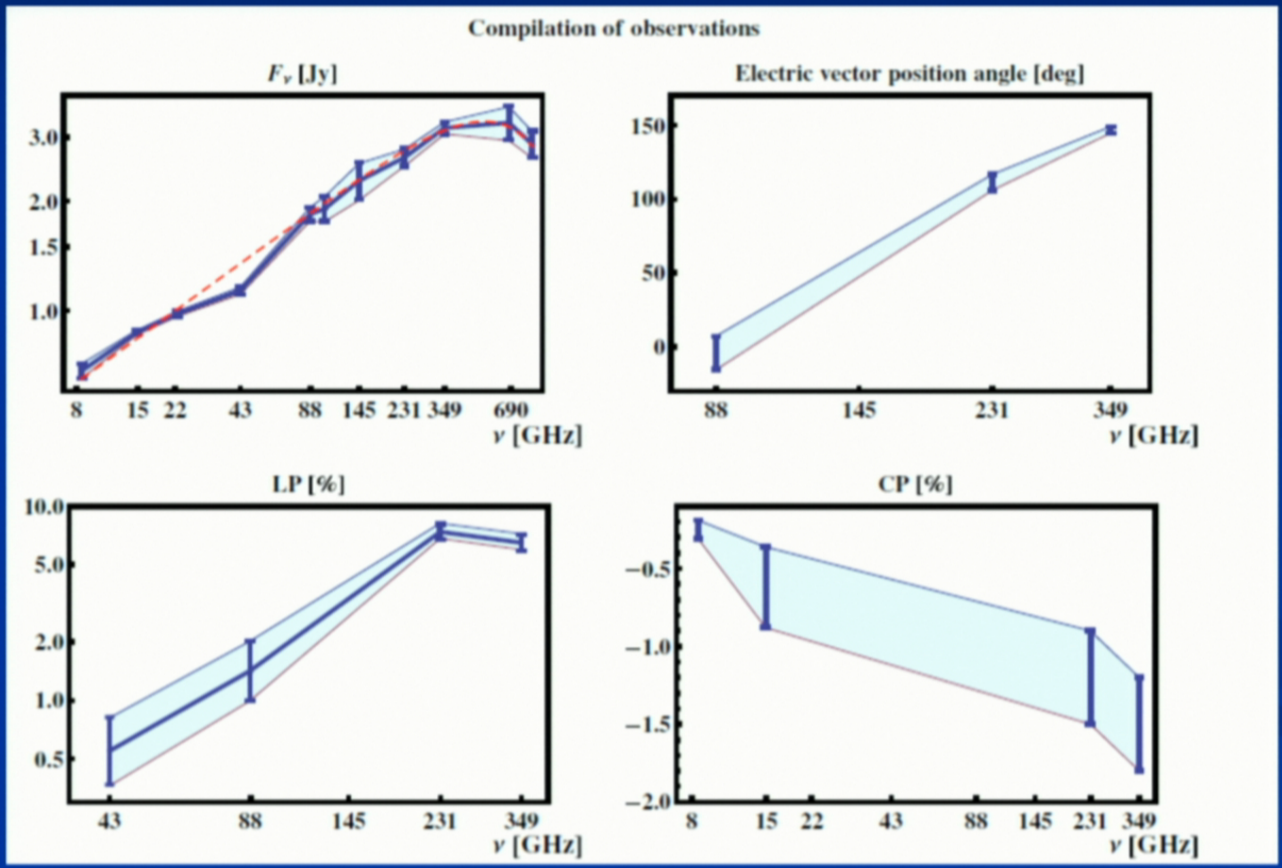
McKinney, Tchekhovskoy, Blandford (2013)

Black Hole Tilt [0deg -> 90deg]



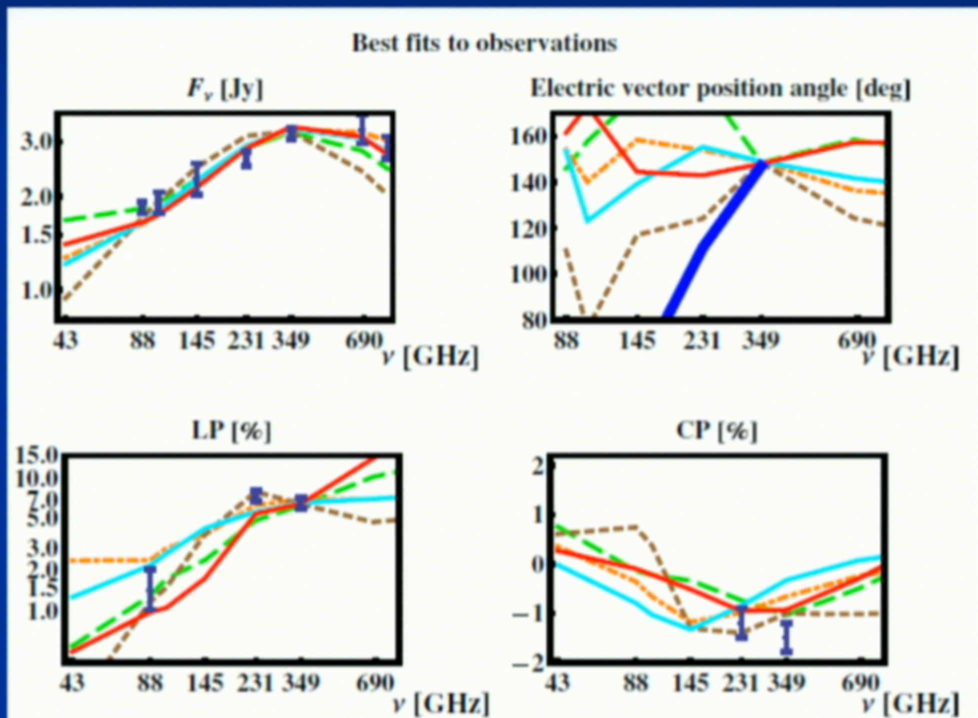
Naturally Saturated Magnetic Field Strength
Jet Controls Disk

Polarization for SgrA*



Shcherbakov, Penna, McKinney (2012)

Best Fits for SANE models



a=0 (brown) ; a=0.5 (red) ; a=0.7 (green) ; a=0.9 (cyan) ; a=0.98 (orange)

Shcherbakov, Penna, McKinney (2012)

See also Dolence et al., Dexter et al., Broderick et al., CK et al. (2014)

- Spins: a=0,.5,.7,.9,.98
- State: SANE RIAF
- Thermal electrons
- Te/Tp set from Coulomb collisions, heating rates (Sharma et al. 2007), and heat capacities.

Electron Temperature at 6M: Te~3E10K

Inclination Angle: ~75deg

Mass Accretion Rate: Mdot~5E-8Msun/yr

\chi^2/dof\sim 2

Questions/Issues

- Anything Really **Constrained**? (Polarization helps?)
- What **Magnetic Field?**
- Does the disk or jet Warp/Bend near the BH**?**
- Need **Larger Radial** Ranges and better **BCs.**
- Seeing **Disk** or **Jet?**
- **Non-Thermal** electrons crucial?
- **Comptonization** and **Pair** Production crucial?
- **Non-Ideal** MHD (e.g. thermal conduction) crucial?