Self-consistent modeling of Sgr A* quiescent emission

Roman Shcherbakov (Harvard),
rshcherb@cfa.harvard.edu ; http://www.cfa.harvard.edu/~rshcherb/
Frederick K. Baganoff (MIT), Robert Penna (Harvard)
Thanks Ramesh Narayan, Charles Gammie
Prague, 17 Feb 2010

Multitude of observational data

inefficient accretion onto supermassive black hole

X-Rays

1Ms of Chandra obs.

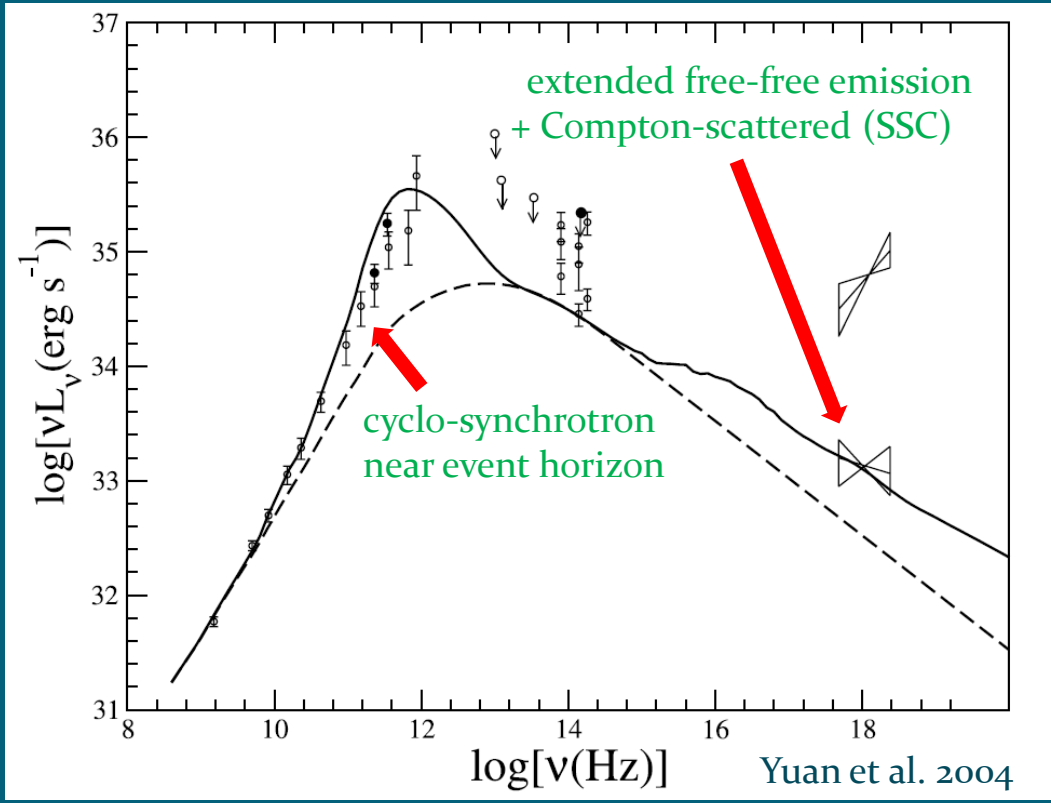
IR

sub-mm + radio

VLBI, SMA; polarization data

spatially resolved X-Rays & sub-mm

quiescent=median of all observations (incl. flares)



Idea of the model

Goal:

1. explain X-Ray surface brightness within 5”
2. fit sub-mm SED + linear/circular polarization fractions, RM

↓

Minimum set of effects (reduce free parameters)

- ✓ feeding by stellar winds (arcsec scales)
- ✓ conduction/outflows for BH feedback
- ✓ entropy production (viscosity)
- ✓ electron heating mechanism
- ✓ GR dynamics near Kerr BH (μas scales)

↓

Radial model at large radius
with GRMHD simulations at small radius

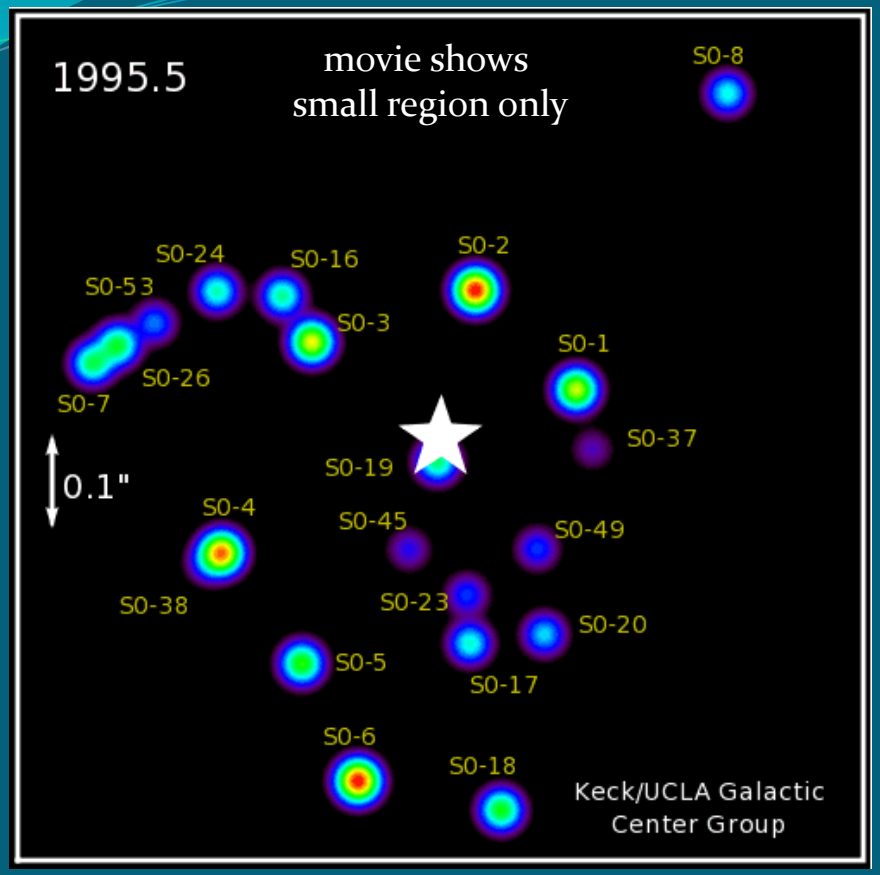
↓

- ✓ precise bremsstrahlung & cyclo-synchrotron emissivities
- ✓ GR polarized radiative transfer

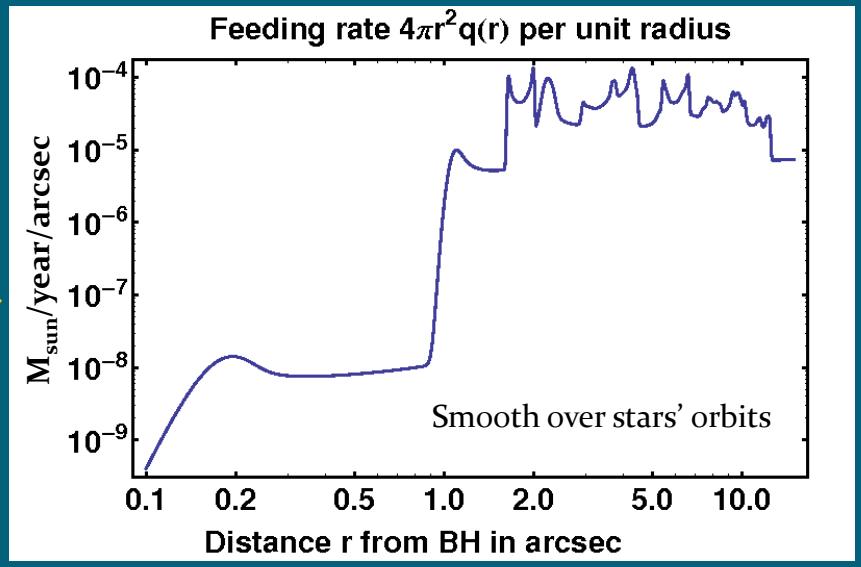
I. Radial model at large radius

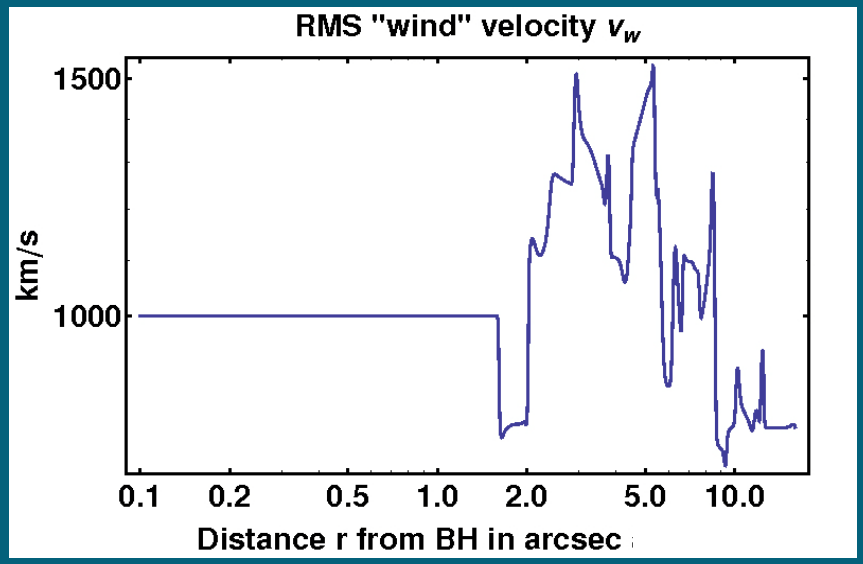
Shcherbakov, Baganoff 2009, ApJL, submitted

Radial model: Feeding Mechanism



Realistic feeding:
sum over 31 main emitters



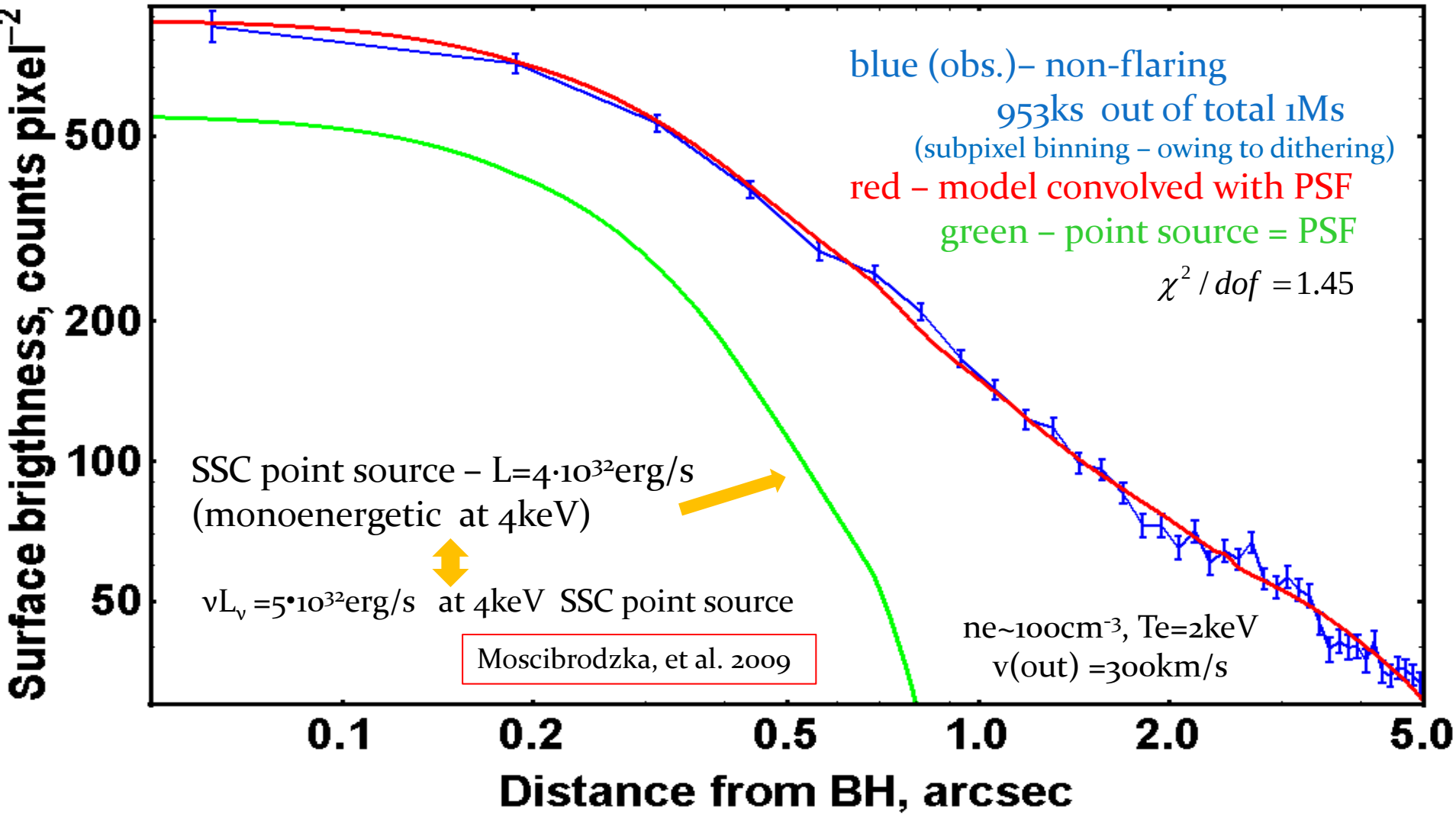


Stars emit wind at 300÷1200km/s
ejection rate $\sim 10^{-3} M_{Sun} / year$

Winds collide, heat the gas,
provide seed magnetic field

Most of gas flows out, some accretes

Results for X-Rays (model w/ conduction)



accretion rate = $6 \cdot 10^{-8} M_{Sun}$/yr – <1% of the naïve model estimate

gives density normalization for GRMHD simulation

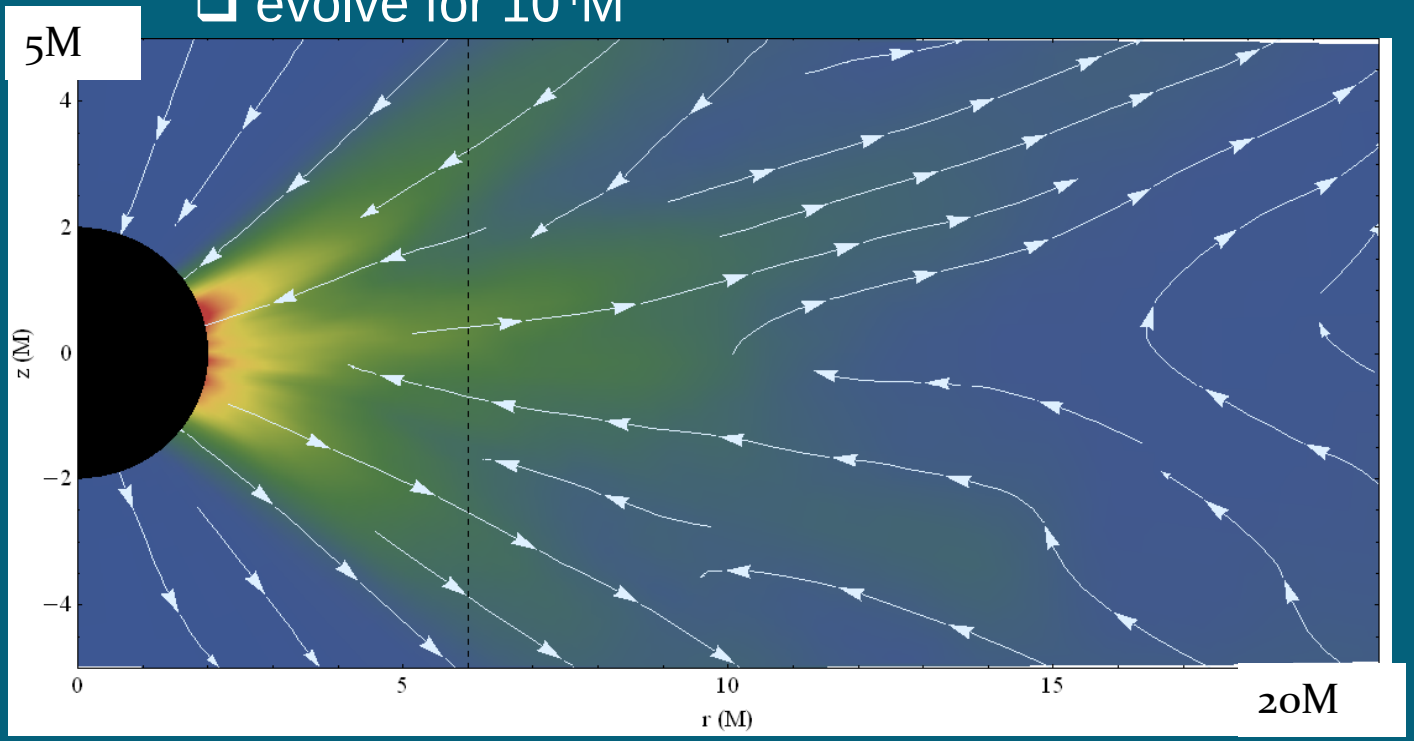
II. 3D GRMHD simulations close to the BH

Shcherbakov, Penna 2010, in preparation

GRMHD simulations

Initial setup and features

- ❑ start from torus w/ inner edge at 20M
- ❑ spins 0; 0.7; 0.9; 0.98
- ❑ no cooling
- ❑ evolve for 10^4M



VectorPlot of <B> and DensityPlot of <B^2>

Azimuthal and t average
in "quasi-steady" accretion for each of 4 spins

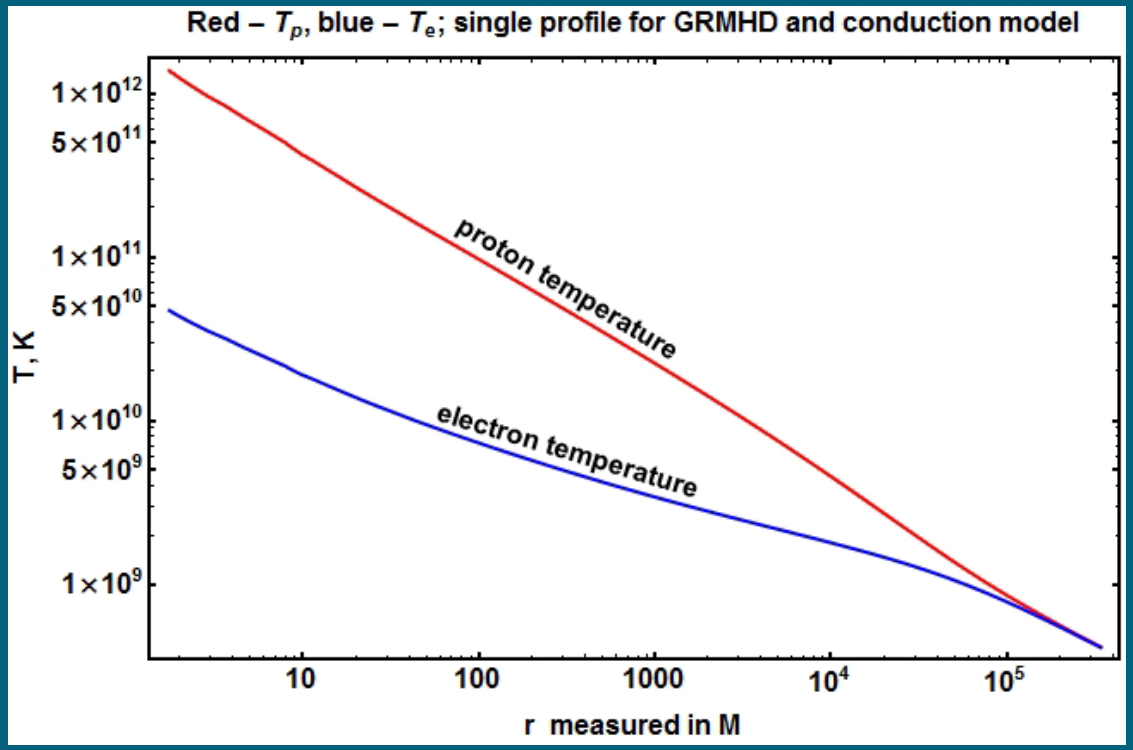
Matching T_e and n_e to large scales

Splitting of internal energy U into Tp and Te

1. Relativistic heat capacity of e-
2. Direct heating mechanism
   => Tp/Te ≠const

$$f_e / f_p = \frac{1}{3}\sqrt{T_e / T_p}$$

Sharma et al. 2007



Tp/Te≈18 at 6M

$n_e=4\cdot10^5 cm^{-3}$ at 24M

– at outer boundary for GRMHD

Emissivities/Faraday rotation + conversion

Observed circular polarization (V): >1% at 230GHz

V emissivity (j_V)

absent in synchrotron approx.

exact cyclo-synchrotron emissivities;
so far – Melrose, 1971 approx for j_V

Faraday conversion: LP to V

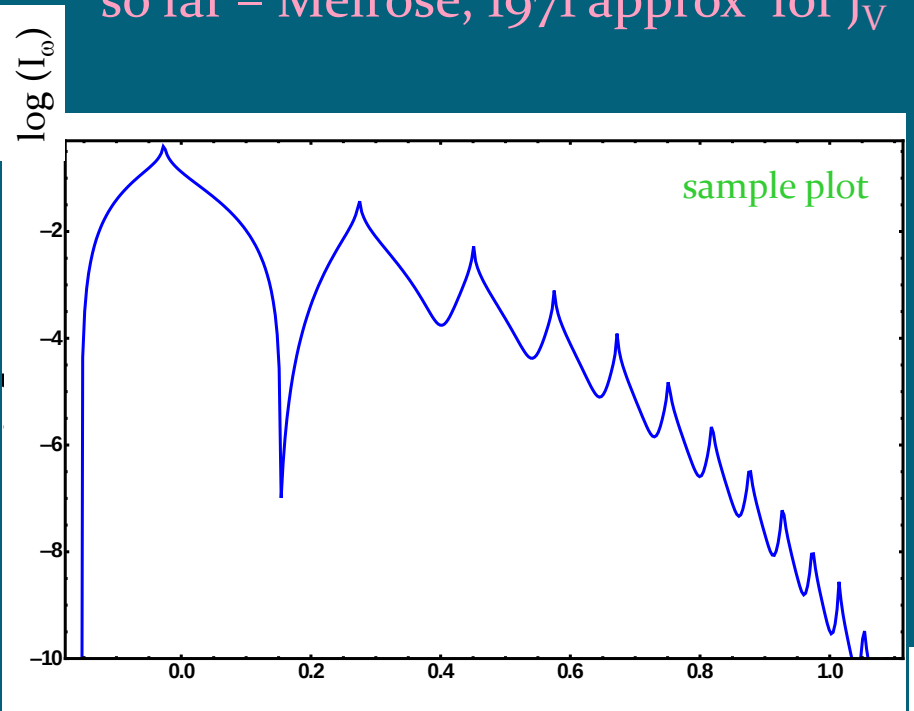
Known only in asympt. regime

Computed for relevant T_e and ω/Ω_c
Shcherbakov, 2008, ApJ for thermal plasma

Conversion rate large for intermediate $T_e \sim 5m_e$
very different from previous calculations!

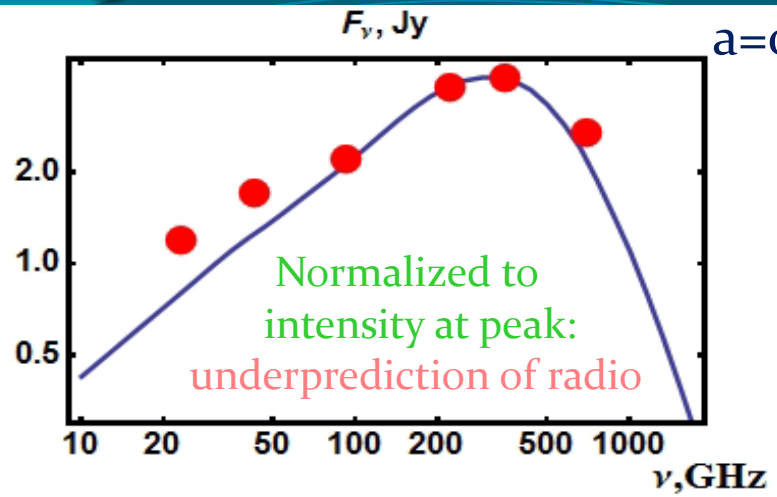
original code is developed

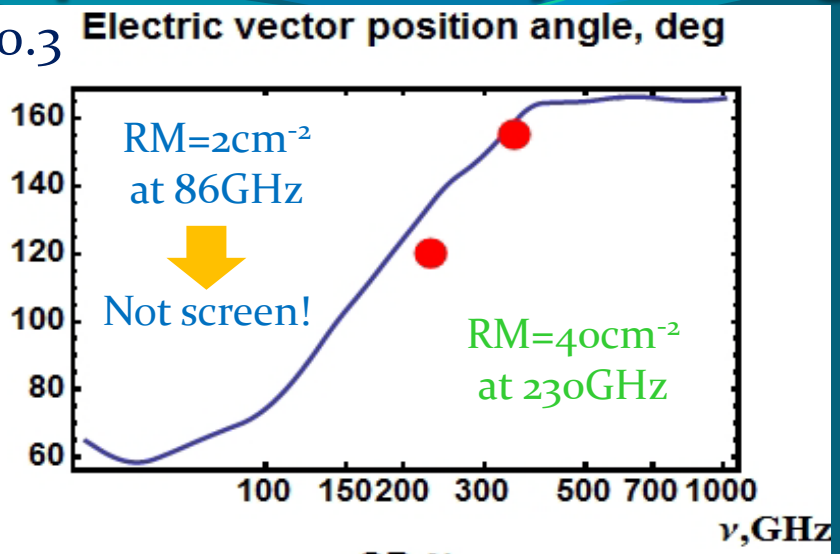
for arbitrary particle distributions

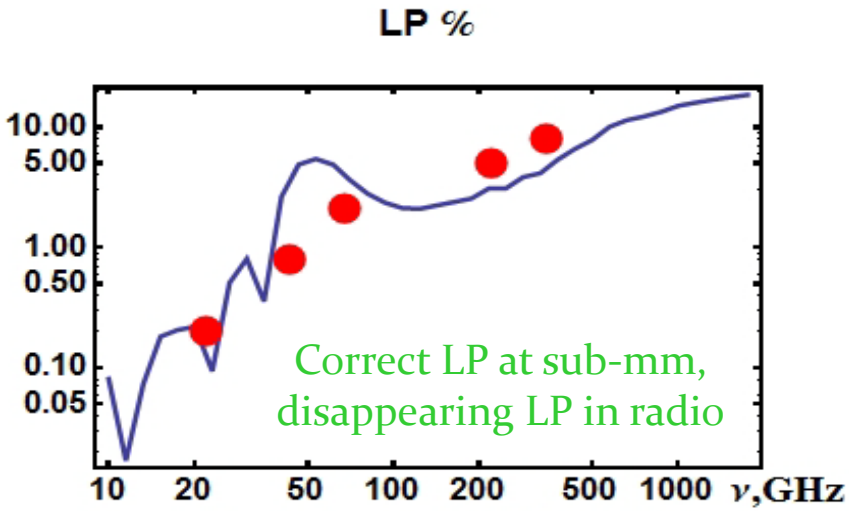


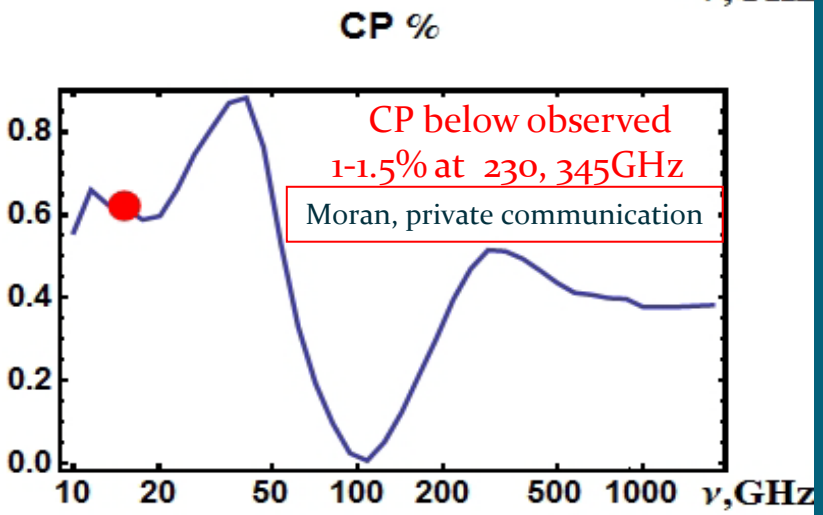
Fitting sub-mm data w/ GR polarized ray tracing

a=0.7; θ=0.3









obs: Bower et al. 2002,Yuan,2004 Macquart et al. 2006; Marrone et al. 2007, Yusef-Zadeh et al. 2007

Conclusions

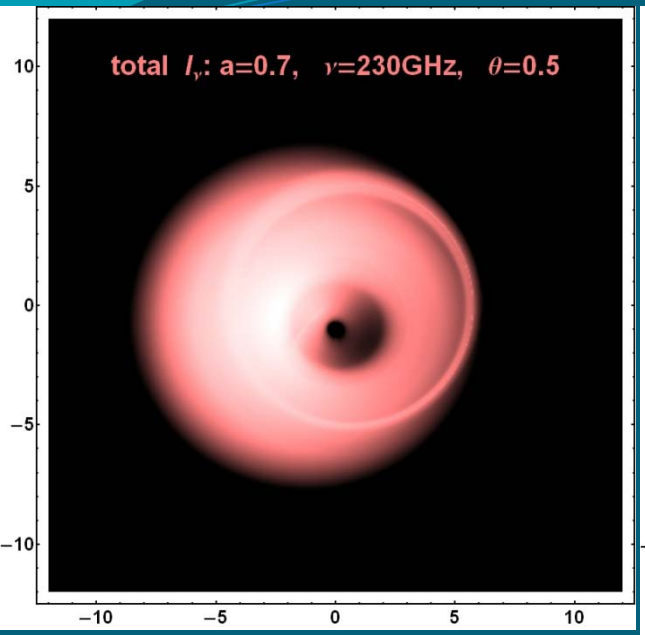
I. High a>0.7, θ>0.6 bad: lower density => weak beam depolarization and high LP at lower ν

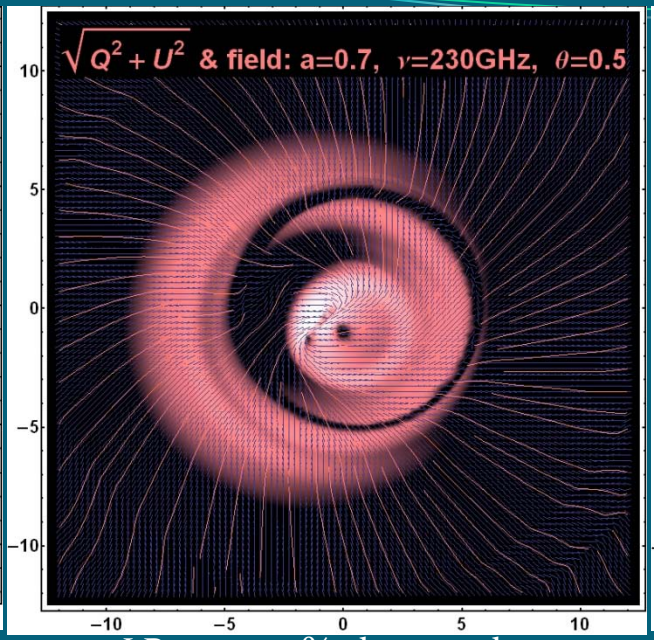
II. CP<1%, less radio – need more mildly relativistic e^-?

Polarimetric Imaging

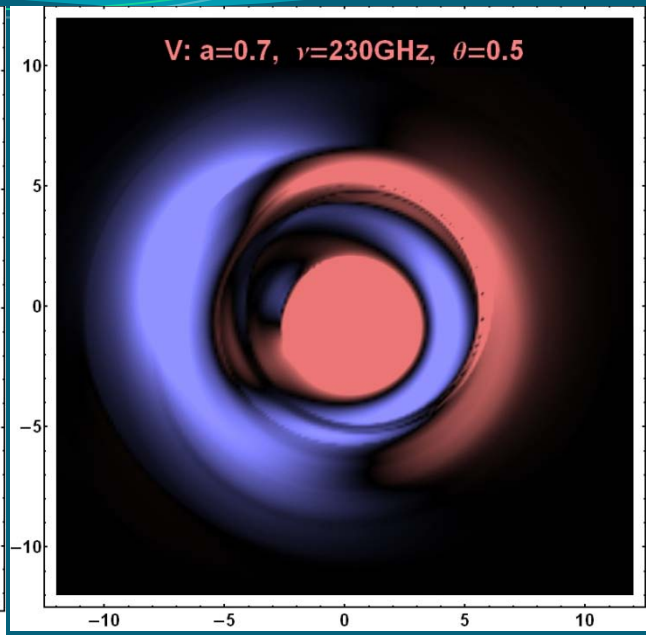
Distances measured in M

White to darkest red – factor of 8

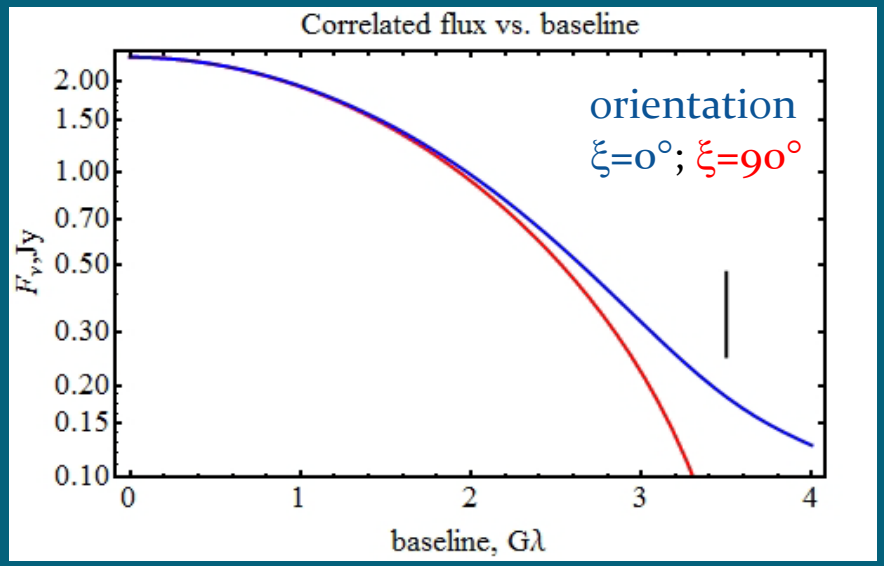




LP up to 70% along each ray
Cancellations lead to LP~5%



CP up to 4% along each ray
Cancellations lead to CP~0.5%



Size at 230GHz is above observed 37μas

Doeleman, et al. 2008

But

- obs. at lower F_ν
- used early simulation times
- very sensitive to T

Conclusions

Emphasis on self-consistency

- ✓ Main physical effects captured within arcsec model
- ✓ Realistic 3D GRMHD simulations of rg scales matched to arcsec model

- ✓ Fit to extended X-Ray emission
- ✓ X-Ray point source $L \approx 4 \cdot 10^{32}$ erg/s
- ✓ Fits to sub-mm total intensity
- ✓ Fits LP fraction, CP fraction(?), rotation measure

Future work

- ✓ Use X-Ray spectrum & include ang. momentum into large scale model
- ✓ Employ correct cyclo-synchrotron (original calculations done)
- ✓ Do proper averaging, analyze variability
- ✓ Etc… (seen flare in a simulation!)