Accretion Flow in M87: SANE or MAD?

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Abstract

Theoretical analysis and numerical simulations indicate that, depending on the magnetization, black hole hot accretion flow is divided into two modes, SANE (standard and normal evolution) and MAD (magnetically arrested disk). **It has long been a question whether the accretion flow in reality should be described by SANE or MAD**. Here in this paper, by using the measured rotation measure(**RM**) value in the prototype low-luminosity AGN M87 at 2,5 and 8 GHz along the jet at various distances from the black hole, combined with our three dimensional general relativity magnetohydrodynamical(GRMHD) numerical simulations of black hole hot accretion flows for SANE and MAD, **we find that only MAD can explain the measured rotation measure, SANE overestimate the rotation measure by two orders of magnitude**.

Introduction

Event Horizon Telescope Collaboration in 2019 has successfully captured the first picture of supermassive black hole in the center of M87. By comparing the resolved polarization structure with GRMHD simulations, all viable models are found to be MAD. However, such a result is subject to some model limitations, and a phenomenological approach is adopted to mimic such uncertainties. Given these uncertainties, it is important to examine the conclusion with new additional constraints. Here we present a new method calculating RM predicted by SANE and MAD respectively and find the same conclusion.

Method

GRMHD simulation: We employ two sets of 3D GRMHD simulations assuming different accretion mode(SANE/MAD), with a central black hole having spin a=0.98. Details can be found in[1].

Normalization: We use the accretion rate presented in[2] to normalize the simulated density and magnetic field strength, where accretion rate:

$$\dot{M} = -\int_0^{2\pi}\int_0^{\pi} \rho u^r \sqrt{-g}\, d\theta d\varphi$$

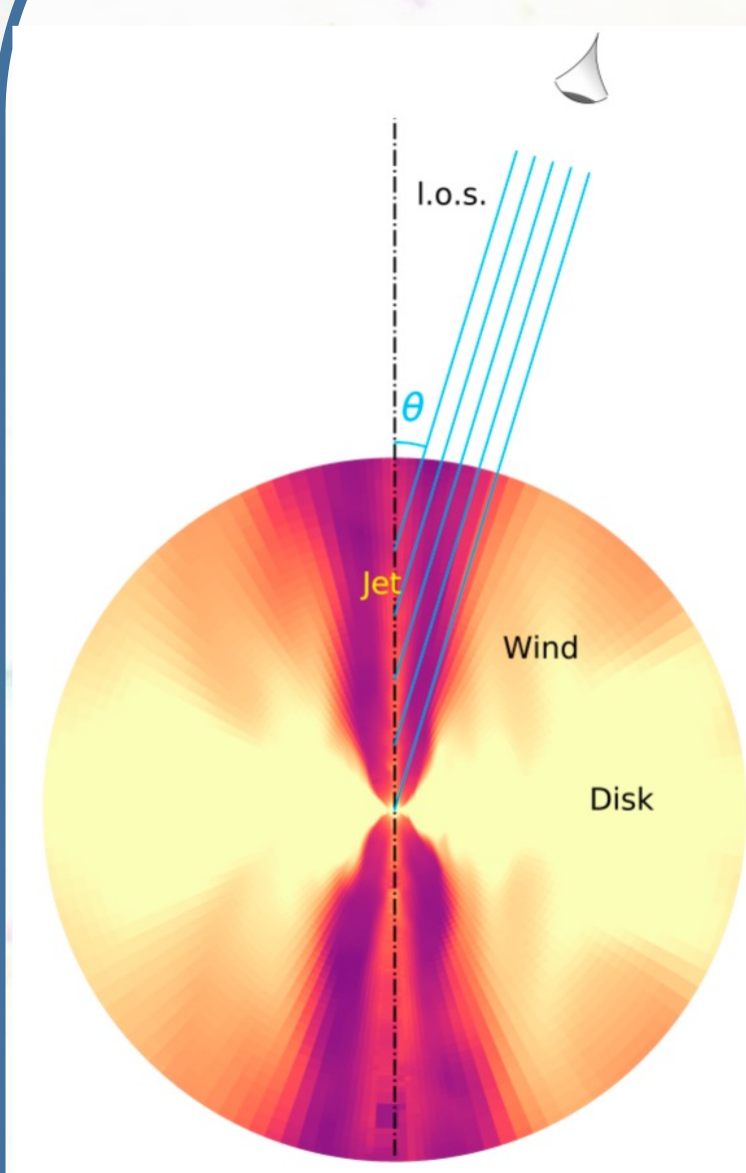

Fig1. One snapshot in GRMHD simulation. RM is calculated along line of sight, from the observer to the central axis of the relativistic jet.

Extrapolation: Seeking the Faraday rotation on parsec scales,we first use broken powerlaw to fit electron density and magnetic field in radial direction, then extrapolate these quantities to parsec scales.

Rotation Measures Calulation: Linearly polarized radiation experiences Faraday rotation traveling through magnetized plasma. When the linearly polarized vectors are rotated because of surrounding plasma, the degree of rotation which depends on wavelength is known as rotation measures. RM could be expressed a composition of number density of electrons and magnetic field strength parallel to the line of sight

$$RM = \frac{e^3}{2\pi m_e^2 c^4}\int f_{rel} n_e B_{\parallel} dl \ [\mathrm{rad\ m^{-2}}]$$

We use this formula to calculate RM along the jet at different locations. Together with observation data, rotation measure calculation can then shred light on the actual accretion mode of M87.

Results and Conclusion

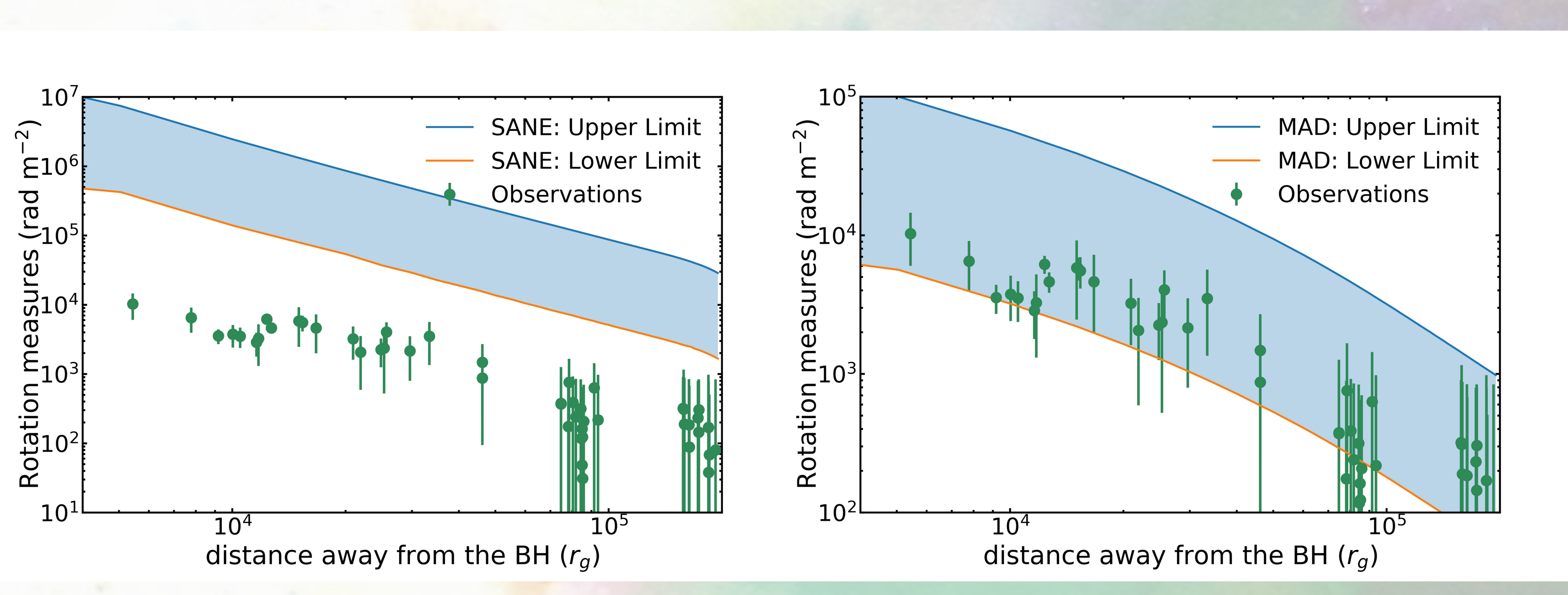

Fig2. Comparision: RM calculated from simulation(MAD/SANE) & Observed RM

Since the accretion rate[2] of M87 is $(3-20)\times 10^{-4} M_{\odot}/\mathrm{yr}$. The RM predicted from simulation are illustrated as the blue range. The observed RM[3] with uncertainy are shown as the green points.

It is clear that MAD(right) can explain the observed RM along the jet, SANE(left) overestimates the RM by two orders of magnitude.

References

1.Yang et al. arXiv:2102.03317 (2021).

2.Event Horizon Telescope Collaboration et al. The Astrophysical Journal, 910,L13 (2021).

3.Park et al. The Astrophysical Journal, 871,257 (2019).