Testing EMDA gravity with observed shadows of M87* and Sgr A*

Siddharth Kumar Sahoo, Neeraj Yadav, Indrani Banerjee

Department of Physics and Astronomy, National Institute of Technology, Rourkela, Odisha-769008 India

ABSTRACT

Einstein-Maxwell-dilaton-axion (EMDA) gravity provides a simple framework to investigate the signatures of string theory. The axion and the dilaton fields arising in EMDA gravity have important implications in inflationary cosmology and in addressing the late time acceleration of the Universe. It is therefore instructive to explore the implications of such a model in explaining the astrophysical observations. The Kerr-Sen metric represents the exact, stationary, and axisymmetric black hole solution of EMDA gravity. Such a black hole is characterized by the angular momentum □ acquired from the axionic field and the dilatonic charge □2 arising from string compactifications. We study the role of spin and the dilaton parameter in modifying the shape and size of the black hole critical curve, which is associated with the projection of the spherical null geodesics on the sky. We compare the theoretically derived critical curve with the Event Horizion Telescope results related to the images of M87* and Sgr A* to obtain constraints on the dilaton parameter □2. We take into account the errors in mass and distance of M87* and Sgr A* while deriving their theoretical critical curve. Our analysis reveals that the image of M87* exhibits a preference toward the Kerr scenario when the critical curve angular diameter is calculated with the central value of mass and distance. When errors in mass and distance are taken into account the allowed range of □2 turns out to be 0≲□2≲1. For Sgr A*, the preferred range of □2 is 0.1≲□2≲0.4 when central values of mass and distance are used to calculate the theoretical critical curve. When error bars in mass and distance are used to calculate the theoretical critical curve of Sgr A*, the preferred range of □2 turns out to be 0≲□2≲0.5. Thus the image of M87* favors the Kerr scenario and allows the Kerr-Sen scenario only when errors in the mass and distance are taken into consideration while the image of Sgr A* favors the Kerr-Sen scenario and allows general relativity when errors in the mass and distance are taken into account.

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Department of Physics and Astronomy, National Institute of Technology, Rourkela, Odisha-769008 India
521ph1007@nitrkl.ac.in, 418ph5062@nitrkl.ac.in, banerjeein@nitrkl.ac.in

Introduction

- Black hole shadow is a dark region observed in the celestial sphere of a distant black hole observer. It is formed because of light rays trapped by the strong gravity of the black hole, hence do not reach the observer. This makes it suitable to test alternative gravity theories and general relativity in strong gravity regions.
- Einstein Maxwell dilaton axion gravity (EMDA) arises in the low-energy effective action of superstring theories.
- The Kerr-Sen metric is a charged, stationary, axisymmetric rotating black hole solution of the field equations in EMDA gravity. It has three parameters, mass (M), spin parameter (a), dilaton charge parameter (r_2).
- We constrain the dilaton parameter r_2(related to the charge of the Kerr Sen black hole) by using the vertical angular diameter of the shadow of M87* and Sgr A* as reported by the EHT Collaboration. We also consider the effect of error bars in mass and distance of the black hole on constraints of r_2.

Methodology

- We assume space time is described by Kerr-Sen metric
- Fix the value of r_2 and vary the spin (a) of the black hole in a suitable range such that the event horizon radius is real and positive.
- For each combination of (r_2, a), we calculate the values of vertical angular diameter $\Delta\Theta$.
- In these calculations we use values of mass M, distance D, and inclination angle θ from previous measurements.
- We plot contour plots for the angular diameter $\Delta\Theta$ with r_2 along y-axis and spin (a) along x-axis.
- The values of r_2 which are able to reproduce the EHT estimated $\Delta\Theta$ for the black hole shadow give us the allowed values of r_2 based on the EHT data.
- We also consider the effect of error bars of mass and distance on constraints r_2.

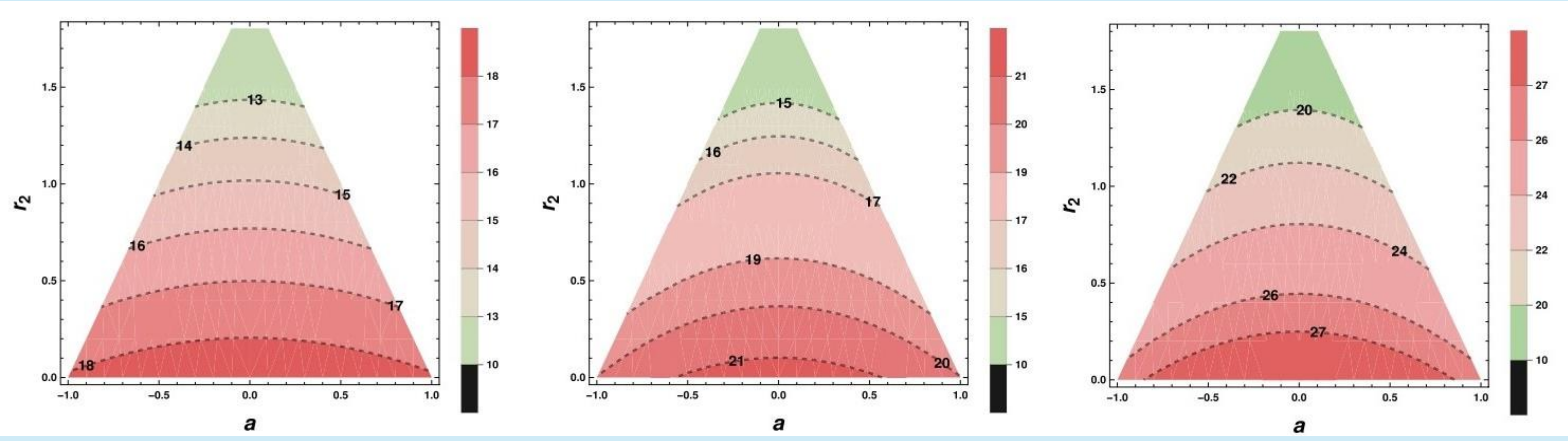
Conclusion

- We analyze the black hole shadow (critical curve) derived from theory and compare them with Event Horizon Telescope (EHT) results for the black holes M87* and Sgr A*.
- M87*: When we consider the central value of mass and distance, it favors the Kerr scenario ($r_2 \approx 0$). When we consider error bars in mass and distance, the allowed range for r_2 is $0 \lesssim r_2 \lesssim 1$.
- Sgr A*: When we consider the central value of mass and distance, it prefers the Kerr-Sen scenario. The preferred range for r_2 is $0.1 \lesssim r_2 \lesssim 0.4$. When we consider error bars in mass and distance, it allows general relativity within $0 \lesssim r_2 \lesssim 1.1$.

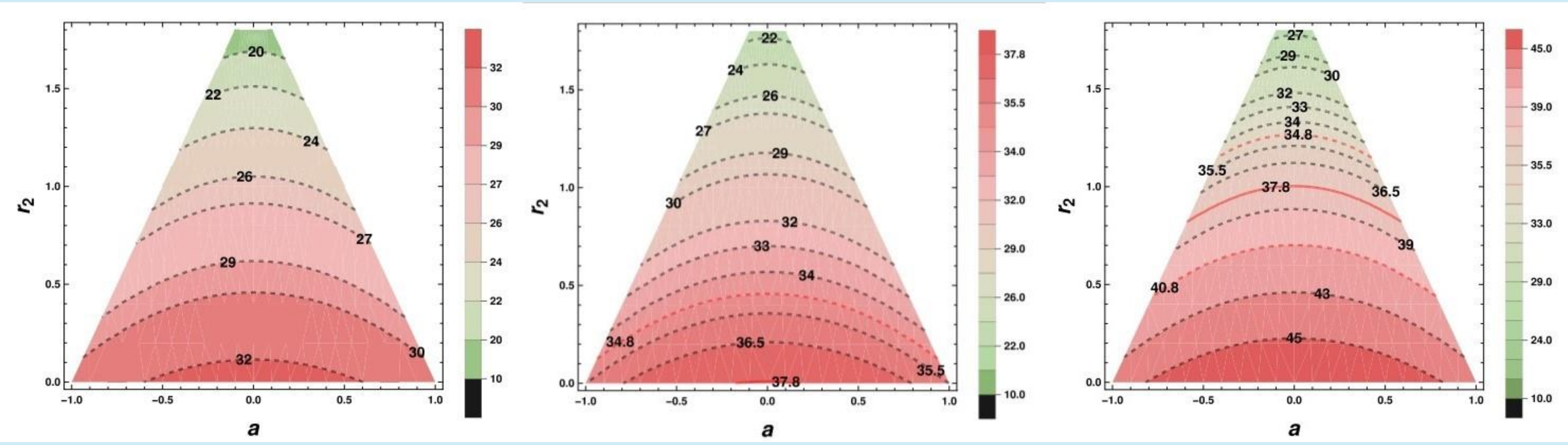
Measurements used in our work

- Shadow angular diameter with maximum offset for M87*: (37.8±3) μas
- Distance measurement for M87*: D = (16.8 ± 0.8) Mpc
- Mass from gas dynamics measurements for M87*: M= $3.5^{+0.9}_{-0.3} \times 10^9 M_\odot$
- Mass from stellar dynamics measurements for M87*: M= $6.2^{+1.1}_{-0.6} \times 10^9 M_\odot$
- Shadow angular diameter for SgrA*: (48.7±7) μas
- Mass and distance from Keck team measurements for SgrA*: M = (3.951±0.047) $\times 10^6 M_\odot$ and=(7935 ± 50)pc.
- Mass and distance from GRAVITY collaboration measurements for SgrA*: M = (4.297±0.012±0.040) $\times 10^6 M_\odot$ and D=(8246.7± 9.3)pc.

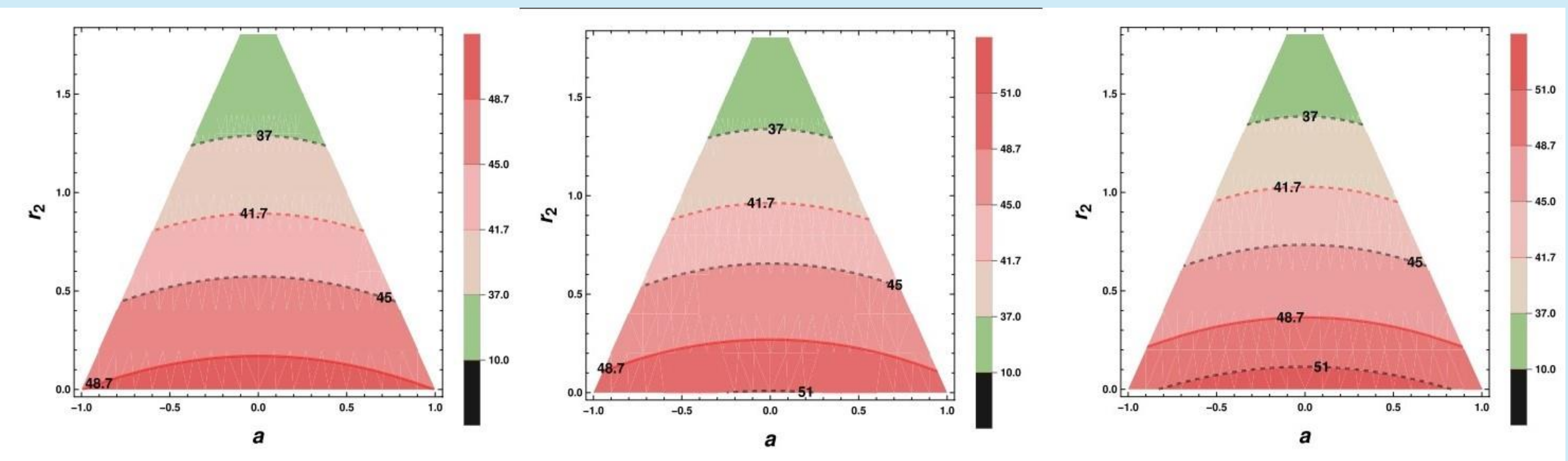
M87*(Contour Plots using gas dynamics measurement)



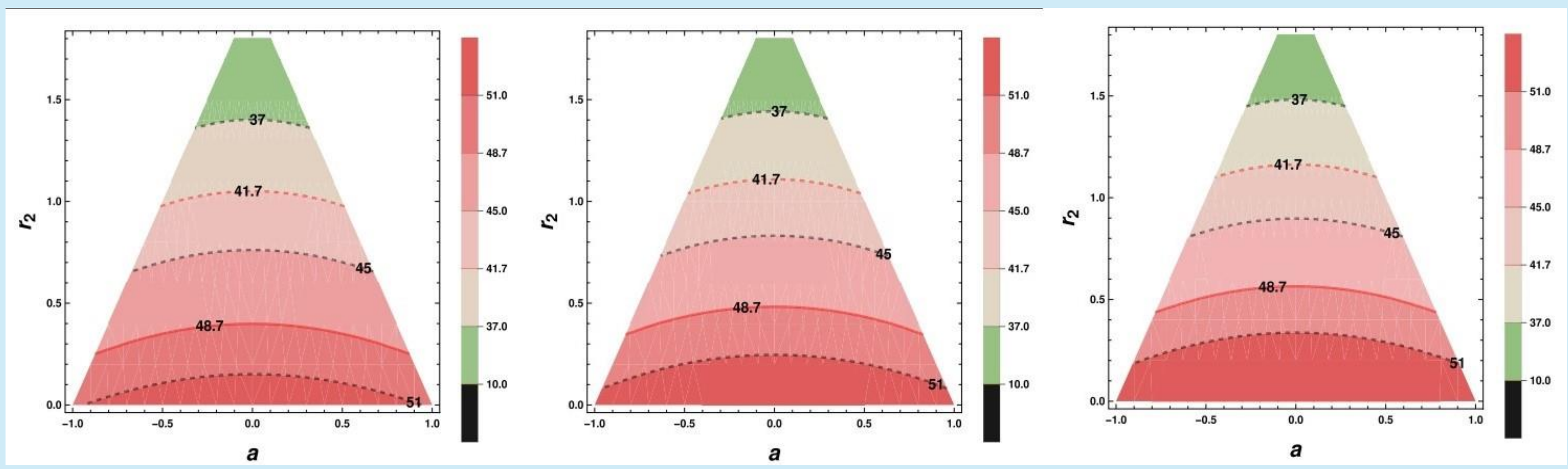
M87*(Contour Plots using stellar dynamics measurement)



Sgr A* (Contour Plots using Keck team measurement)



Sgr A* (Contour Plots using GRAVITY collab. measurement)



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