A high-resolution study of NGC 315

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Introduction

Nearby radio galaxies are ideal targets for investigating the physical phenomena regulating the formation and evolution of relativistic jets. These fundamental processes are expected to occur very close to the central supermassive black hole, on scales which can be only resolved through very-long-baseline interferometry (VLBI) observations. In this context, we present a study of the nearby (z = 0.0165), giant radio galaxy NGC 315 in which we analyzed multi-frequency (1 GHz, 5 GHz, 8 GHz, 12 GHz, 15 GHz, 22 GHz, 43 GHz), and multi-epoch VLBI observations. We assumed an inclination of the jet of $\theta = 38^\circ$ [1] and the mass of the central black hole of $M = 2.08 \times 10^9\, M_\odot$ [2].

Jet collimation and speed

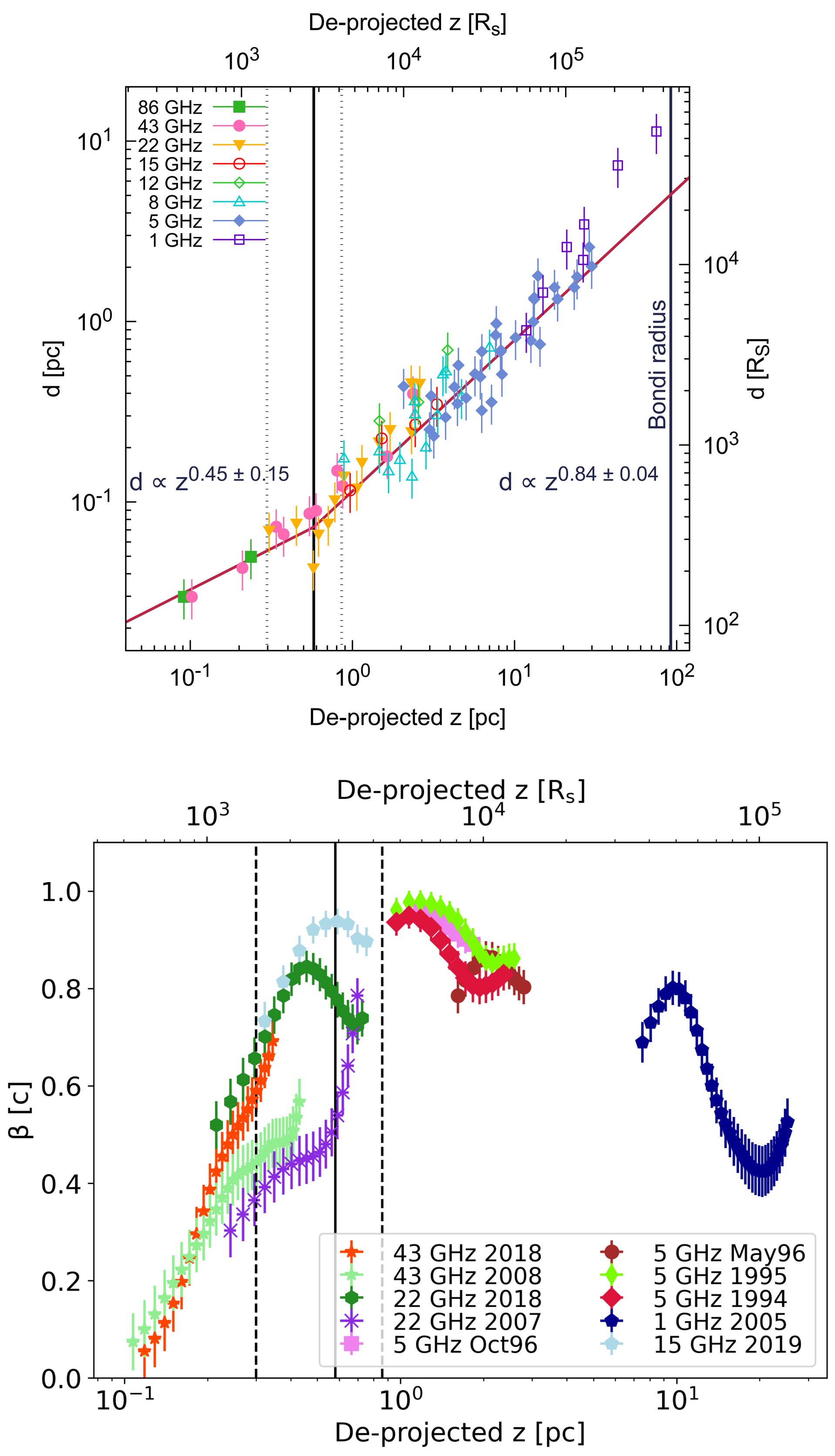

Fig. 1: Top panel: Jet collimation profile in NGC 315, based on a MODELFIT analysis of the VLBI data (adapted from [3] using a more recent estimate of the mass). Bottom panel: Jet intrinsic speed profile based on the analysis of the jet-to-counterjet intensity ratio. The speed profile is in agreement with the findings of [4]. The terminal velocity $\beta \sim 0.9$ is reached already on sub-pc scales. The transition distance from a parabolic to a conical jet shape ($z = 0.58 \pm 0.28$ pc) is highlighted by the black vertical lines. These results suggest a co-spatiality of the collimation and acceleration processes.

References

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Spectral analysis

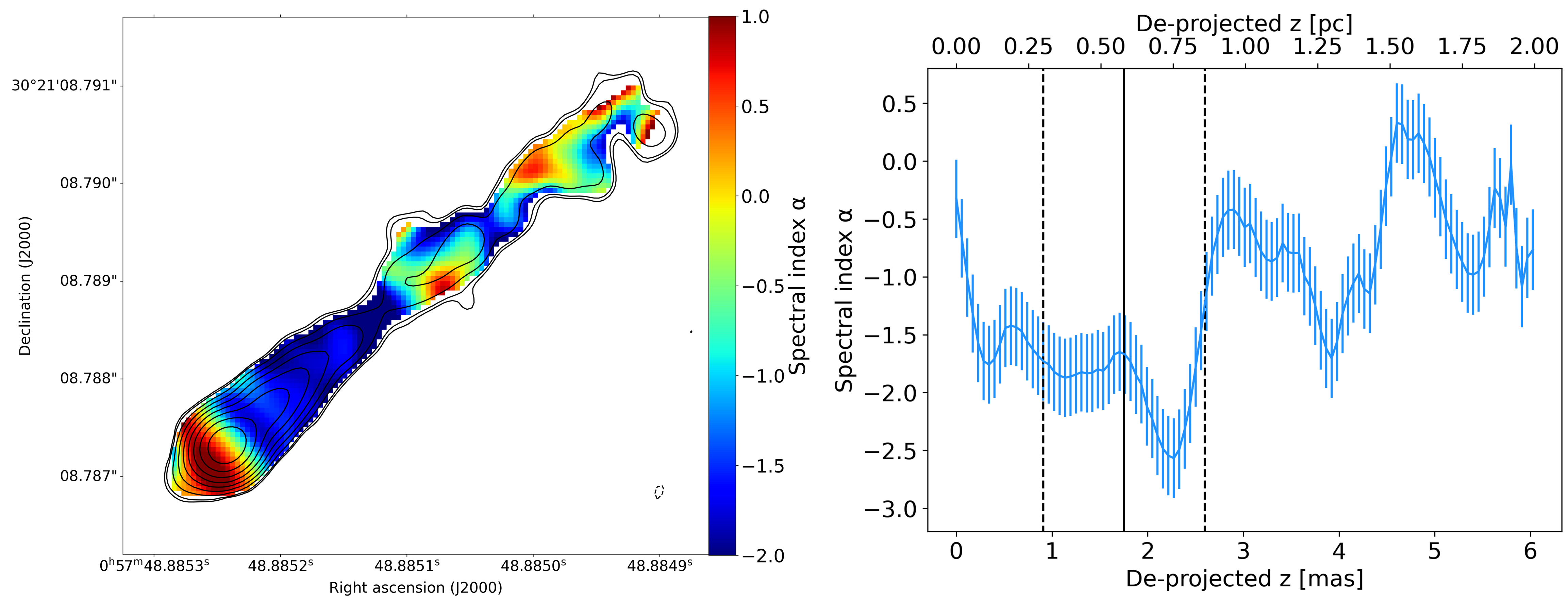

Fig. 2: Left panel: spectral index map ($S_\nu \propto \nu^\alpha$) between the frequencies 22 GHz and 43 GHz. The contours describe 43 GHz continuum emission. Right panel: spectral index evolution as a function of distance from the core along the ridgeline. The black vertical lines are indicative of the shape transition distance. Within the collimation region, the spectral index rapidly decreases down to values of $\alpha \sim -1.7$, while it rises to typical values of $\alpha \sim -0.7$ beyond the shape transition distance.

Jet opening angle

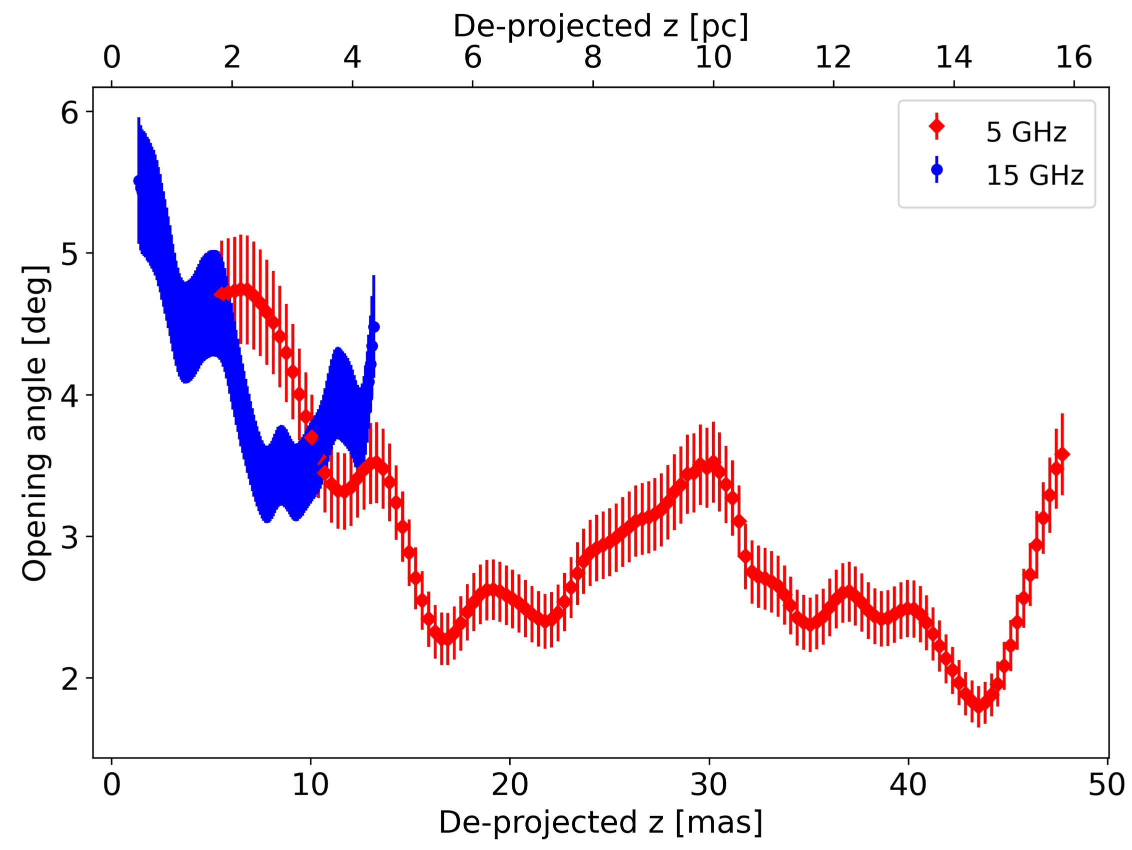

Fig. 3: Intrinsic opening angle as a function of distance, derived from the analysis of stacked images at 5 GHz (red points) and 15 GHz (blue points). Beyond the transition distance the jet shape is not perfectly conical, and a residual collimation is observed.

Magnetic field

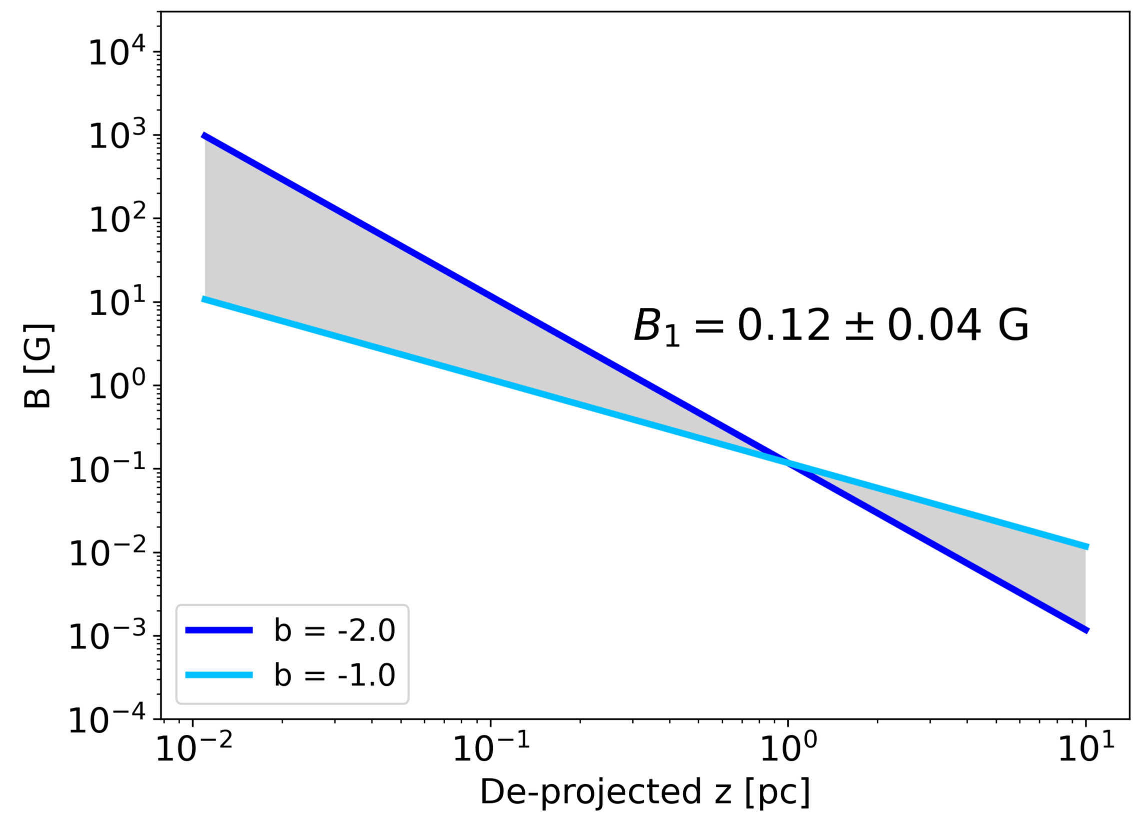

Fig. 4: Magnetic field strength as a function of distance, $B = B_1 z^b$. Here, $B_1 = 0.12 \pm 0.04$ G is the magnetic field at 1 pc computed based on the observed the core-shift under the assumption of energy equipartition, and b varies between -1 and -2.

Future prospects

Study the source on larger scales and attempt to reproduce the observed morphology by means of relativistic magneto-hydrodynamic simulations.

Brightness temperature

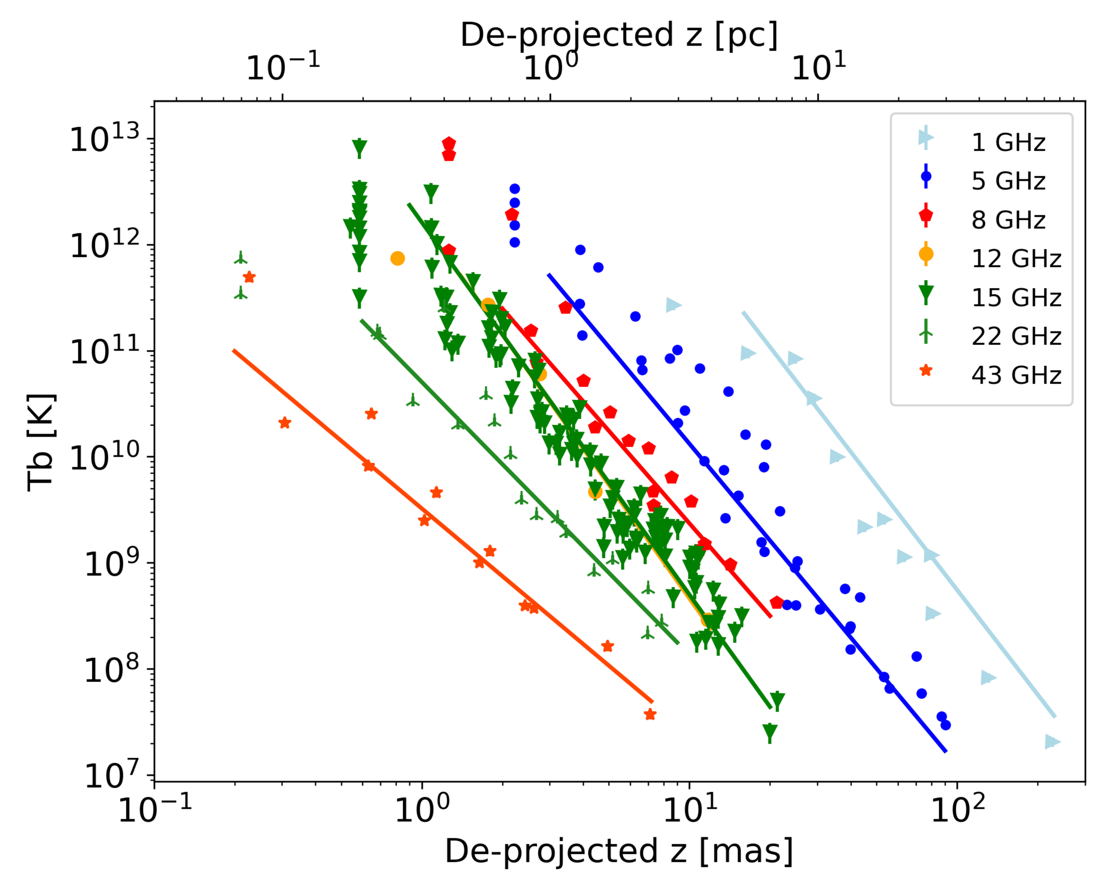

Fig. 5: Brightness temperature as a function of distance. At each frequency, a power law $T_B \propto z^\epsilon$ is fitted. Between 1 GHz and 15 GHz, $\epsilon \sim -3.50$, which is much steeper than found in blazars, and in agreement with estimates for other radio galaxies [5]. In the collimation region, partially described by data at 22 GHz and 43 GHz, flatter indices of -2.57 ± 0.15 and -2.12 ± 0.13 respectively are inferred.

Jet launching and evolution

Under the assumption of a jet launched through the Blandford–Znajek within a magnetically arrested disk [6], from our estimation of the magnetic field strength at 1 pc we predict an accretion luminosity of $L_{acc} \sim 10^{43}$ erg s^{-1}. This is in agreement with estimates of the bolometric luminosity obtained by [7] by integrating the spectral energy distribution of the nucleus.

We observe the bulk of the jet collimation and acceleration to take place on sub-pc scale (Fig. 1), $z \sim 0.6$ pc $\sim 10^3$ R_s, a distance much smaller than the Bondi radius ($\sim$ 92 pc). In this region, a very steep spectral index is measured (Fig. 2). Beyond it, a residual collimation is observed and the jet evolves with a quasi-conical shape highlighted both by the jet expansion index and by a mildly decreasing intrinsic opening angle on pc-scales (Fig. 3). We propose that the jet may be initially confined by a thick disk. The nuclear properties of NGC 315 are indeed consistent with the expectations for an advection-dominated accretion flow, whose outer radius is of the order of $\sim 10^3$ R_s [8].