The Interplay among Black Holes, Stars and ISM in Galactic Nuclei
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Black hole shadows in accretion disks and spin parameters of black holes:
Massive black holes and stellar mass black holes

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Abstract. Can we determine spin parameters of black holes by observations of black hole shadows in accretion disks? In order to answer this question, we have investigated shapes and positions of black hole shadows in optically thick accretion disks around Kerr black holes. In conclusion, in order to measure black hole spin parameters from shapes and positions of black hole shadows, it is crucially important to determine a position of a mass centers of a black hole in a region of a black hole shadow.

Determination of a spin parameter of a black hole is one of the greatest challenges in astrophysics in this century. Observation of a black hole shadow is one of the possible methods to determine a spin parameter of a rotating black hole in future.

We have found black hole shadows with quite similar sizes and shapes for largely different spin parameters of black holes and same masses of black holes. Thus, it is practically difficult to determine spin parameters of black holes from sizes and shapes of black hole shadows in accretion disks. In figure 1, we show examples of such black hole shadows with nearly same maximum widths of black hole shadows and nearly same ratios of minimum widths to maximum widths of black hole shadows. On the other hand, a vertical shift of a black hole shadow from a rotation axis of a black hole largely depend on a spin parameter of a black hole even if sizes and shapes of black hole shadows are quite similar. However, it is difficult to determine positions of rotation axes of black holes. So, we can not measure spin parameters of black holes from the vertical shifts.

We newly introduce *a shadow axis* of a black hole shadow. We define this shadow axis of a black hole shadow as a bisector perpendicular to a line segment of a maximum width of a black hole shadow. We can determine positions of shadow axis of black hole shadows by observations of black hole shadows. For non-rotating black holes, minimum intervals between mass centers and shadow axes of black hole shadows are null. On the other hand, for rotating black holes shapes and positions of black hole shadows are not symmetric with respect to a rotation axis of a black hole shadow. So, in these cases these minimum intervals between mass centers and shadow axes of black hole shadows are finite. Extents of these minimum intervals are quite roughly proportional to spin parameters of black holes for fixed inclination angles. *In order to measure spin parameters of black holes from shapes and positions of black hole shadows, it is crucially important to determine a position of a mass centers of a black hole in a region of a black hole shadow.*

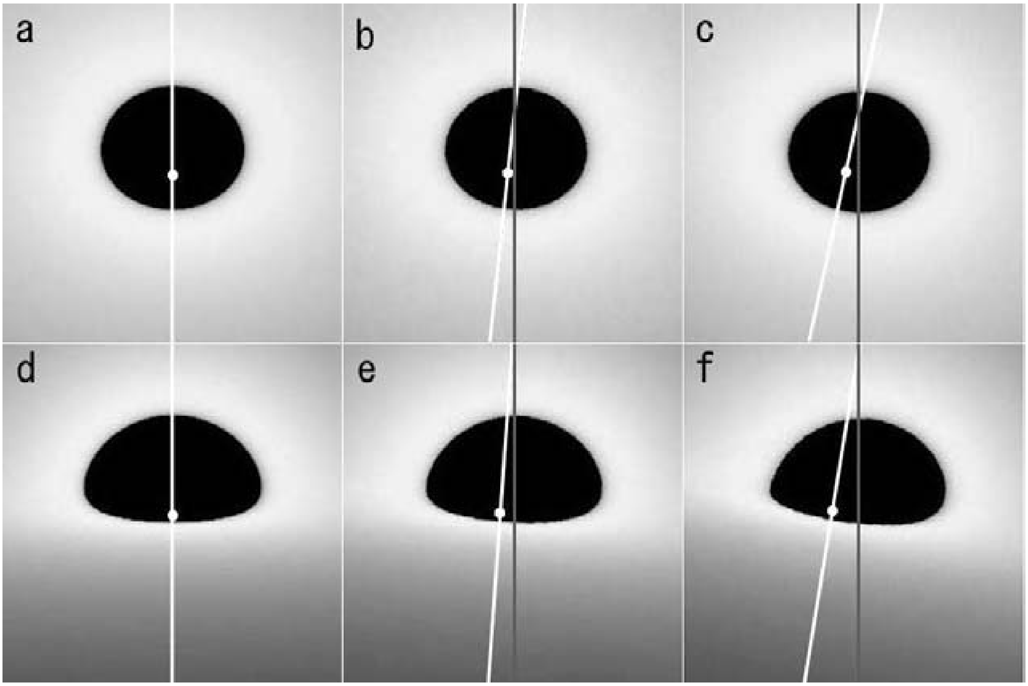

Figure 1. Black hole shadows with quite similar shapes and sizes for largely different spin parameters of black holes. Maximum widths of black hole shadows are ~ 6.2 $[r_g]$ for black hole shadows in panels of (a), (b) and (c), and ~ 7.7 $[r_g]$ for black hole shadows in panels of (d), (e) and (f), respectively. Here, r_g is a gravitational radius defined as $r_g = Gm/c^2$ where G, m and c are the gravitational constant, a mass of a black hole and the speed of light, respectively. Ratios of a minimum width of black hole shadows to a maximum width of a black hole shadow are ~ 0.86 for black hole shadows in panels of (a), (b) and (c), and ~ 0.60 for black hole shadows in panels of (d), (e) and (f), respectively. Adapted parameters are (a) $a/m = 0$, $i = 45°$ and $r_{\rm in} = r_{\rm h+}$, (b) $a/m = 0.5$, $i = 45°$ and $r_{\rm in} = 1.05r_{\rm h+}$, (c) $a/m = 0.958$, $i = 45°$ and $r_{\rm in} = r_{\rm ms}$, (d) $a/m = 0$, $i = 80°$ and $r_{\rm in} = r_{\rm h+}$, (e) $a/m = 0.5$, $i = 80°$ and $r_{\rm in} = 1.05r_{\rm h+}$ and (f) $a/m = 0.955$, $i = 80°$ and $r_{\rm in} = r_{\rm ms}$. where a, i and $r_{\rm in}$ are an angular momentum per unit mass of a black hole, an inclination angle between observer and the rotation axis of black holes, and an inner edge of an accretion disk, respectively. $r_{\rm ms}$ and $r_{\rm h+}$ is a marginally stable orbit of an accretion disk and an event horizon of a black hole, respectively. Positions of black holes are plotted by white dots. Rotation axes of accretion disks are plotted by white lines. In the case of finite spin parameters of black holes, black hole shadows are non-axisymmetric with respect to rotation axes of black holes. Note that in this case directions of maximum widths of black holes are slightly inclined. Thus, as panels of (b), (c), (e) and (f) shows, rotation axes of black holes are inclined from vertical directions. Shadow axes of black hole shadows whose definition is in the contents are plotted by gray lines in panels of (b), (c), (e) and (f). Minimum intervals between mass centers and shadow axes are (b) 0.32 $[r_g]$, (c) 0.58 $[r_g]$, (e) 0.59 $[r_g]$ and (f) 1.1 $[r_g]$, respectively. These intervals are roughly proportional to spin parameters of black holes.