

## Shadow of black holes at cosmological distances

Oleg Yu. Tsupko

*Space Research Institute of Russian Academy of Sciences,  
Profsoyuznaya 84/32, Moscow 117997, Russia  
tsupko@iki.rssi.ru, tsupkooleg@gmail.com*

Gennady S. Bisnovatyi-Kogan

*Space Research Institute of Russian Academy of Sciences,  
Profsoyuznaya 84/32, Moscow 117997, Russia*

Volker Perlick

*ZARM, University of Bremen, 28359 Bremen, Germany*

It is expected that a distant observer should see a black hole as a dark spot in the sky on the background of other bright sources; this dark spot is referred to as a 'black hole shadow'. Attempts to actually observing the shadow of the supermassive black hole at the center of our Galaxy and at the center of M87 are under way.

Since we live in the expanding universe, this expansion should influence the size of a distant black hole shadow. We analytically investigate the influence of a cosmic expansion on the angular size of black hole shadow observed by a comoving observer. We have found: 1) exact solution for the shadow size in case when expansion is driven by cosmological constant only (Schwarzschild-de Sitter); 2) approximate solution for general case of multi-component universe (with matter, radiation, and dark energy) obtained by using of angular size redshift relation with effective linear size of the shadow; 3) numerical solution for general case obtained by numerical integration of geodesics in McVittie spacetime. Remarkably, it is shown that supermassive black holes at large cosmological distances in the Universe with matter may give a shadow size approaching the shadow size of the black hole in the center of our Galaxy, and present sensitivity limits.

Talk is mainly based on the following papers:

1. V. Perlick, O.Yu. Tsupko, and G.S. Bisnovatyi-Kogan, Black hole shadow in an expanding universe with a cosmological constant, Physical Review D 97, 104062 (2018)
2. G.S. Bisnovatyi-Kogan and O.Yu. Tsupko, Shadow of a black hole at cosmological distances, Physical Review D 98, 084020 (2018)