Stellar-Mass Black-Hole Models at Eddington Luminosity

Toru Okuda

Hakodate College, Hokkaido University of Education, Hakodate 040-8567, Japan

Black-hole accretion disk models with 3 and 15 Eddington critical accretion rates are examined by two-dimensional radiation hydrodynamic calculations. The numerical results show that the super-Eddington model with 15 Eddington critical rate can explain well the small collimation degree of the jets and the high mass-outflow rate estimated for SS 433.

§1. Introduction

We have examined super-Eddington black-hole models for SS 433 based on two-dimensional hydrodynamical calculations coupled with radiation transport. Although, in these models, a high-velocity jet of 0.2–0.4c is formed along the rotational axis, we cannot obtain a small collimation degree of \( \sim 0.1 \) radian of the jets and a sufficient mass-outflow rate comparable to \( \sim 10^{20} \) g s\(^{-1}\), as is expected for SS 433. For these open problems, we examine here further investigations of the super-Eddington models with other model parameters and over a wider range of the computational domain than the previous one.

§2. Model parameters

We consider a Schwarzschild black hole with mass \( M_\ast = 10M_\odot \) and take the inner-boundary radius of the computational domain as \( R_{\text{in}} = 2R_\ast \), where \( R_\ast \) is the Schwarzschild radius. The model parameters used are listed in Table I, where \( \dot{m} \) is the input accretion rate normalized to the Eddington critical accretion rate \( \dot{M}_E \) given by \( 16L_E/c^2 \) and \( R_{\text{max}} \) is the outer-boundary radius. The viscosity parameter \( \alpha \) used is \( 10^{-3} \).

Table I. Model parameters.

<table>
<thead>
<tr>
<th>Model</th>
<th>( \dot{m} )</th>
<th>( M ) (g s(^{-1}))</th>
<th>( R_{\text{max}}/R_\ast )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>( 8 \times 10^{19} )</td>
<td>450</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>( 4 \times 10^{20} )</td>
<td>( 10^5 )</td>
</tr>
</tbody>
</table>

§3. Numerical results

Figures 1 and 2 show the time evolutions of the luminosity (lines) and the mass outflow-rate (dotted lines) from the system for models 1 and 2, respectively. In model 1, after the luminosity decreases accompanying large fluctuations, it increases abruptly to the high luminosity at \( t \sim 9 \times 10^4 R_\ast/c \) and after then maintains its high value. During the decreasing luminosity phases, the high velocity jets appear intermittently and the mass outflow-rate is also very variable. In the later high state,

\(^1\) E-mail: okuda@cc.hokkyodai.ac.jp
the mass outflow-rate is steadily high. Model 2 never shows such decreasing feature of the luminosity as is found in model 1 and the luminosity attains to a constant value after \( t \sim 10^5 R_*/c \), which is comparable to the arrival time \( R_{\text{max}}/0.4c \) of the high velocity jets to the outer boundary. The mass outflow rates \( \dot{M} \) are high as \( \sim 10^{19} \text{ g s}^{-1} \) which is comparable to that expected for SS 433.\(^2\) In both models, the structures of the inner disk are similar to the previous ones, that is, the disk is geometrically thick and convection is dominant in the innermost region. Figure 3 shows the temperature contours and velocity vectors at the final phase for model 2. The high velocity jets elongate roughly vertically to the disk plane and we expect the collimation angle of the jets to be very small.

From the above results, model 2 is promising for the explanation of SS 433 from viewpoints of the jets formation, the expected small collimation degree, and the large mass outflow-rate. The detailed results will be presented elsewhere in near future.

References