Black Hole Mass Estimation: How good is the virial estimate?

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Abstract

The current 'standard quasar model' consists of a central engine, accretion disk, and sometimes a jet. However, these components cannot entirely explain some quasar spectral features, specifically, the presence of broad emission lines (BELs), which are assumed to originate from high velocity gas in the broad line region (BLR). The addition of a wind to the standard model provides a mechanism to drive the outflowing gas emanating from the accretion disk.

We test the impact on the virial black hole mass calculation due to the quasar's orientation to the observer. The geometry of the BLR is modelled by implementing the wind component or the disk wind model. While the models are dependent on the specified parameters, they are able to qualitatively reproduce the predicted features of the emission lines.

Introduction

The mass of the central black hole can be estimated using the virial relation, assuming that the gas in the BLR is in Keplerian motion. The virial black hole mass with emitting region of radius r is approximated as $M_{BH} \approx \Delta v^2 r/G$. The velocity dispersion, Δv, is determined from the width of an individual line by measuring the full width at half maximum (FWHM) or the line dispersion.

Cylindrical Disk Wind Model

The kinematics of the wind in the BLR is modelled using the cylindrical disk wind model introduced by Shlosman & Vitello (1993), illustrated in Fig. 1. In this model, the outflowing wind is launched from the base of the accretion disk at radii between r_{min} and r_{max} along the streamlines. The wind spirals upward in a helical motion with opening angle constrained within θ_{min} and θ_{max}. The velocity components consist of the poloidal and rotational velocities.

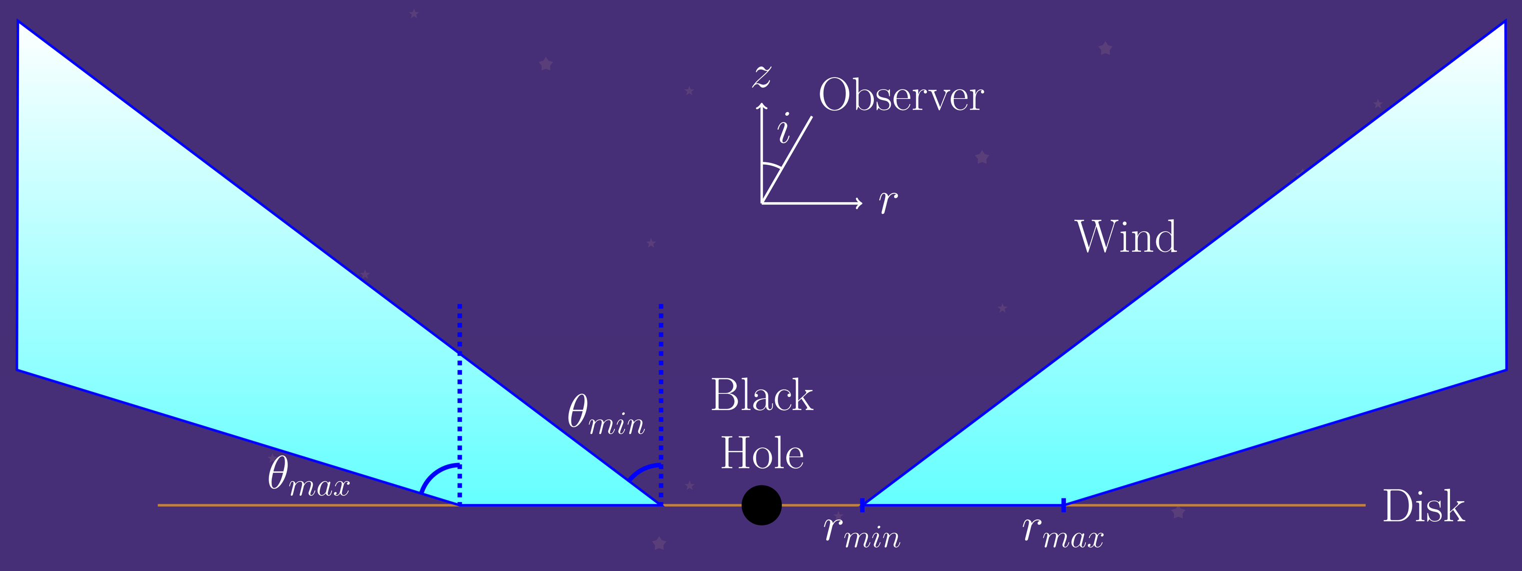
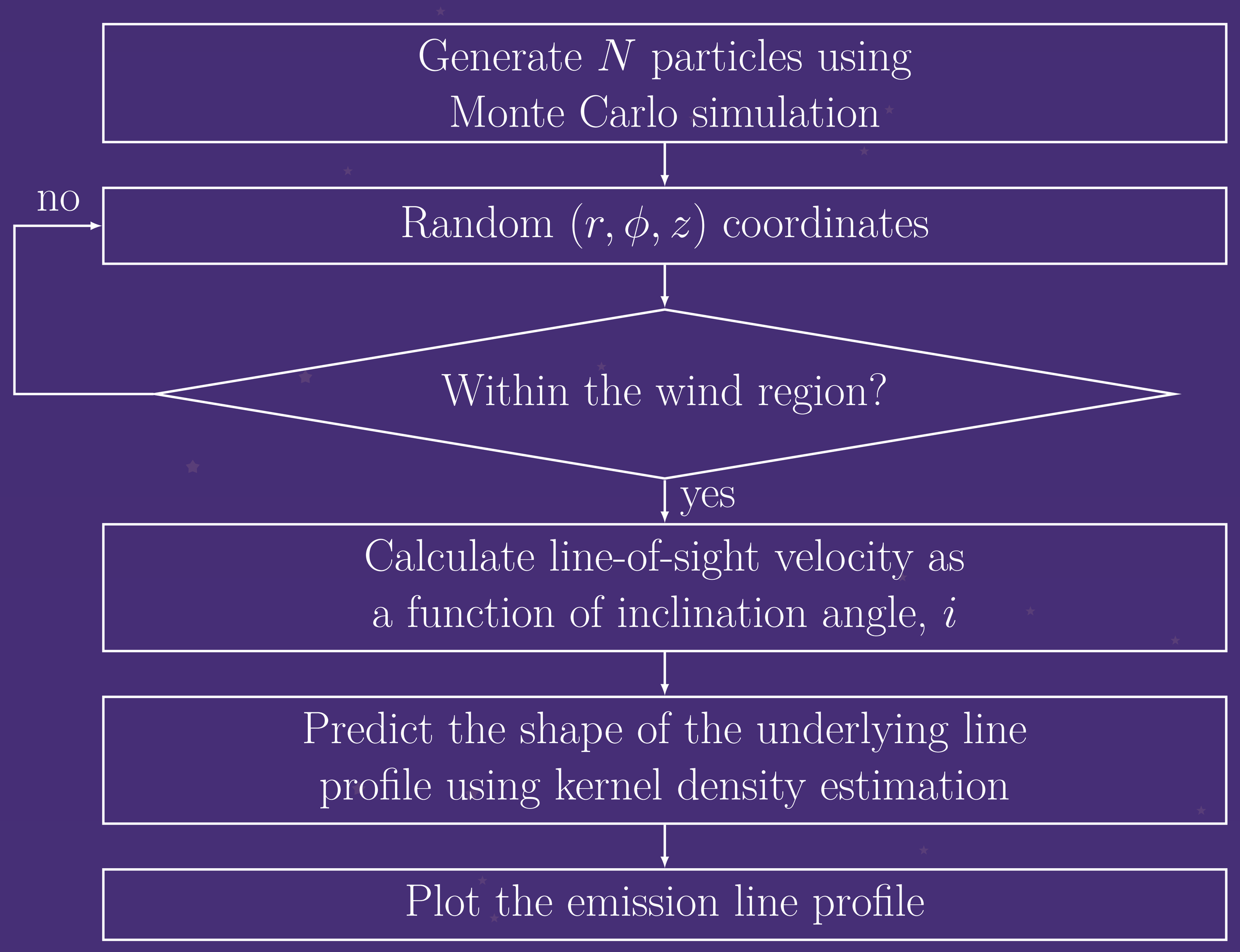


Fig. 1: Cylindrical disk wind model.

Method



Parameters

Table 1: Adopted fiducial values for 2 wind models.

Parameter	Notation	Murray et al. (1995)	Elvis (2004)
Black hole mass	M_{BH} ($10^8\ M_\odot$)	1.0	1.0
Wind radius	r_{min}; r_{max} (10^{16} cm)	1.0; 10.0	1.0; 2.0
Wind angle	θ_{min}; θ_{max}	69.0°; 89.0°	50.0°; 70.0°

Results

The relevant parameters presented in Table 1 are selected to resemble the BLR disk wind models of Murray et al. (1995) and Elvis (2004). In order to assess the orientation impact, the differential probability for inclination angle between 5° and 85° is plotted against the FWHM of the simulated emission line profile and the calculated black hole mass, $M_{BH,cal}$, as displayed in Fig. 2 and Fig. 3 (*left*) respectively. The calculated black hole mass as a function of inclination angle is shown in Fig. 3 (*right*). As demonstrated in Fig. 3, the systematic errors on the virial black hole mass measurement can be approximately three to four times larger than the input black hole mass of $10^8\ M_\odot$.

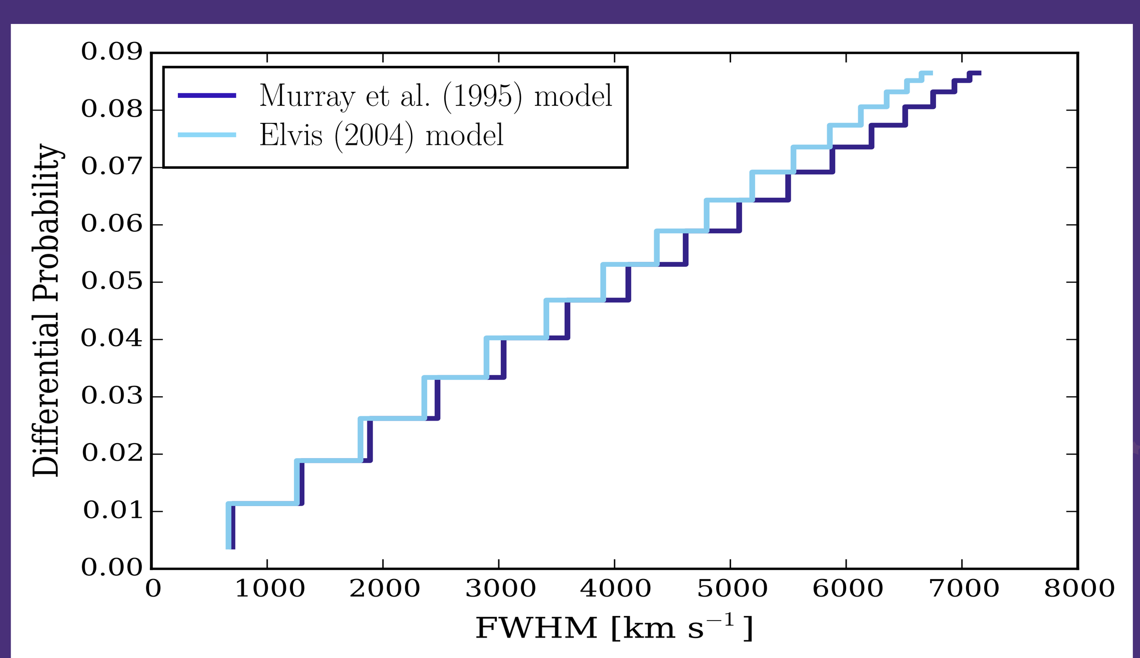


Fig. 2: Differential probability against FWHM.

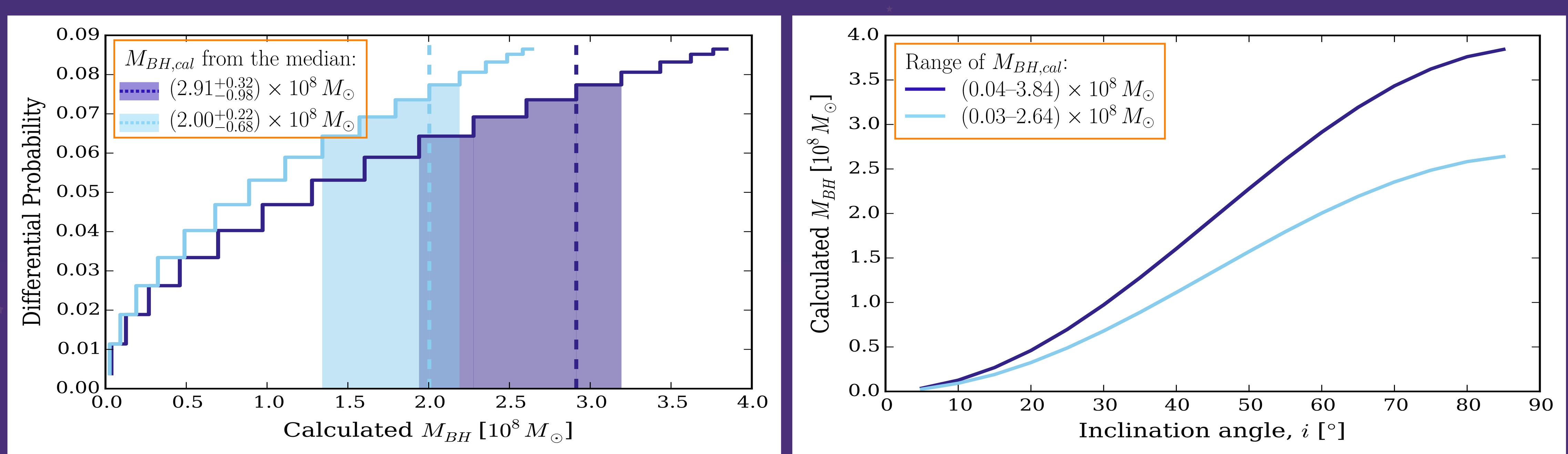


Fig. 3: Calculated virial black hole mass distribution. The shaded region represents the $M_{BH,cal}$ within one sigma range of the median (dashed).

Conclusions

- ⋆ There is a strong observational evidence of a disk wind model.
- ⋆ The systematic errors on the black hole mass estimation are $(2.91^{+0.32}_{-0.98}) \times 10^8\ M_\odot$ for the Murray et al. (1995) model and $(2.00^{+0.22}_{-0.68}) \times 10^8\ M_\odot$ for the Elvis (2004) model.
- ⋆ The disk wind model is dependent on the geometry of the model, position of the wind, and angle of inclination.

References

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