An accretion disc-irradiation hybrid model for the optical/UV variability in radio-quiet quasars (2016, MNRAS, 462, L56)

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OUTLINE

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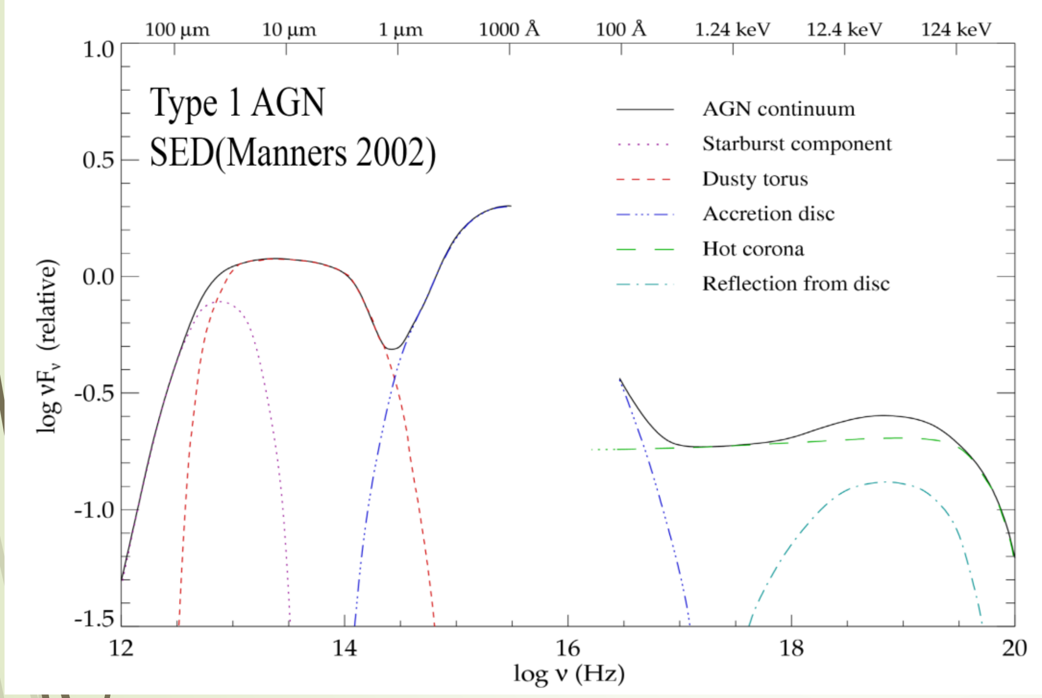
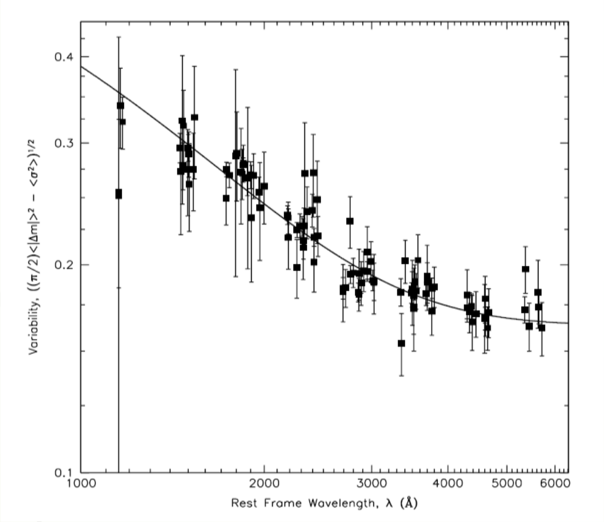
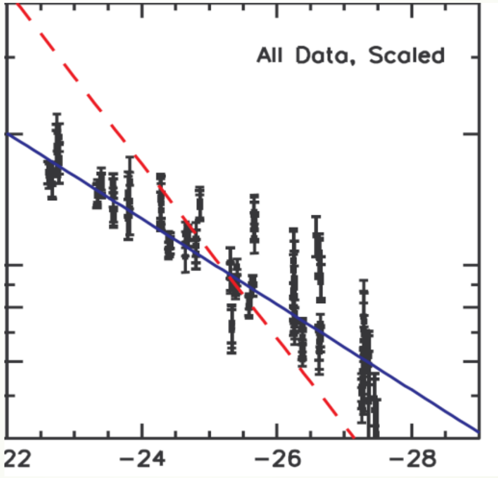
INTRODUCTION



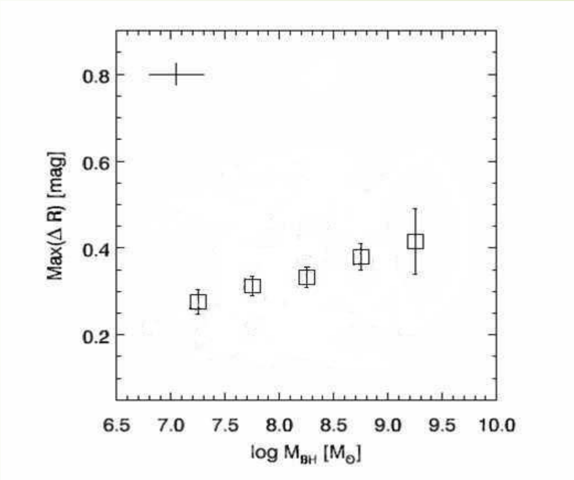
- Flux variability at all the bands is a well-known characteristic of active galactic nuclei (AGNs; Ulrich, Maraschi & Urry 1997).
- The optical/UV emission of quasars, varying at time-scales of hours to decades, is believed to come from an optically thick and geometrically thin accretion disc. Therefore, the study on quasar variability can help to understand the accretion process therein.

Quasar variability amplitude are found to be correlated with other properties, such as, black hole mass, luminosity, and wavelength.





Luminosity



Vanden Berk et al. (2004)

Wold et al. (2007)

Theoretical models

- The origin of quasar variability has remained unclear so far.
- Accretion disc with variable mass accretion rate (Pereyra et al. 2006; Li & Cao 2008; Gu & Li 2013)
- Inhomogeneous accretion disc (Kawaguchi et al. 1998; Dexter & Agol 2011)
- X-ray reprocessing/irradiation (Tomita et al. 2006; Cackett, Horne & Winkler 2007; Gil-Merino et al. 2012; Chelouche 2013), and etc.

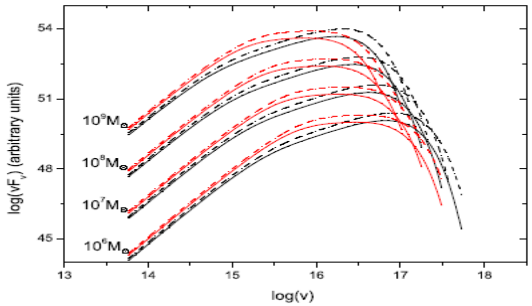
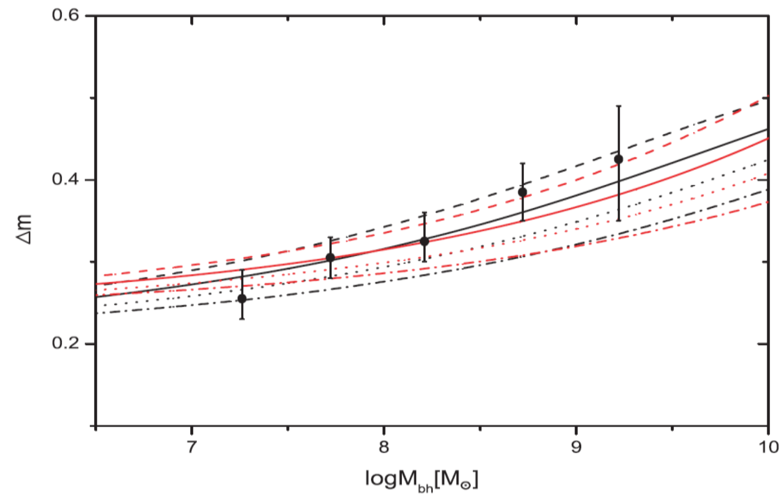


Figure 1. The spectra of standard thin discs/modified accretion discs for different black hole masses. The black and red lines correspond to standard thin disc model and modified disc model, respectively. The solid lines correspond to $\dot{m}_0 = 0.1$, while the dashed lines represent the cases with $\dot{m} = \dot{m}_0 \pm \delta\dot{m}$ ($\delta\dot{m} = 0.4\dot{m}_0$).



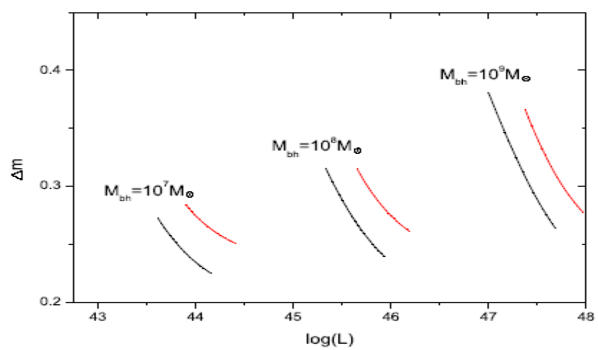


Figure 3. The variability amplitude as functions of luminosity for different black hole masses. The black lines and red lines are for standard thin disc model and the modified disc model, respectively, which are the same as in Fig. 1.

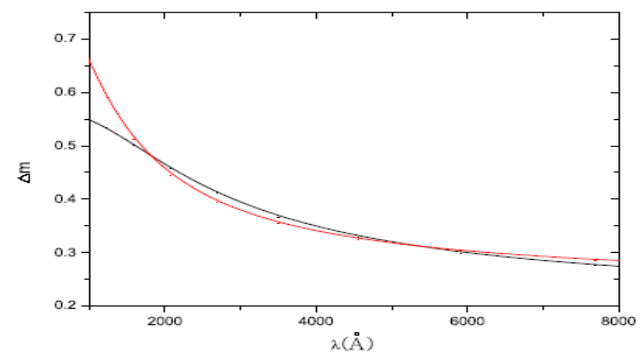


Figure 4. The variability amplitude of different accretion rate changes as a function of rest-frame wavelength. The arrangement of black line, red line, accretion rate and variation of accretion rate are the same with Fig. 1.

Li & Cao (2008)

Motivation

- Two problems of accretion disc model:
- At first, the viscous time-scale of an accretion disc (~10^3 yr at $R = 10^3 R_g$ for a 10^8 M black hole) is much longer than the quasar variability time-scale observed (days ~ decades).
- Secondly, the accretion disc model can not fit the observed difference spectrum well.

- Two improvements:
- 1. We constrain the accretion disc size to make sure that the viscous time-scale at outer radius of disc is consistent with the observed variability time-scale;
- 2. We consider the effect of irradiation from an X-ray point source above the inner disc, which can help to increase the flux variation in UV bands and make the spectrum become bluer.

MODEL

Viscous time-scale at R_* is equal to quasar variability time-scale observed.

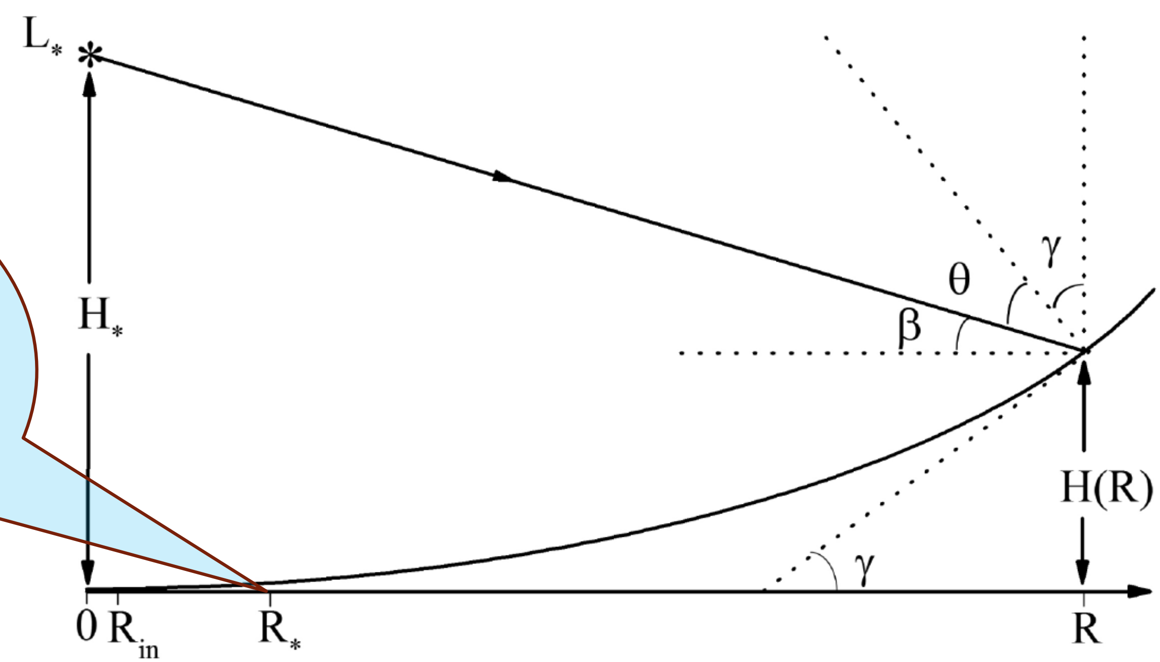


Figure 1. Schematic diagram for the accretion disc-irradiation hybrid model. The X-ray point source locates on the rational axis above the disc.

typical quasar variability time-scale observed). For an initial mass accretion rate $\dot{M}_1$, the total energy flux radiated from an accretion disc and X-ray point source is

$$F_1 = \sigma T_{\rm eff,1}^4 = F_{\rm disc,1} + F_{\rm irr,1}$$
$$= \frac{3GM\dot{M}_1}{8\pi R^3}\left(1 - \sqrt{\frac{R_{\rm in}}{R}}\right) + \frac{L_{*,1}(1-a)\cos\theta}{4\pi R^2}. \quad (4)$$

Assuming that the global mass accretion rate varies from $\dot{M}_1$ to $\dot{M}_2$ and the luminosity of X-ray point source varies from $L_{*,1}$ to $L_{*,2}$, the energy flux can be calculated with

$$F_2 = \sigma T_{\rm eff,2}^4 = F_{\rm disc,2} + F_{\rm irr,2}$$
$$= \frac{3GM\dot{M}_2}{8\pi R^3}\left(1 - \sqrt{\frac{R_{\rm in}}{R}}\right) + \frac{L_{*,2}(1-a)\cos\theta}{4\pi R^2} \quad (5)$$

when $R_{\rm in} < R < R_*$. For $R_* < R < R_{\rm out}$, however, we maintain the mass accretion rate on to $\dot{M}_1$ due to its large viscous time-scale. Thus the energy flux is given by

$$F_2 = \sigma T_{\rm eff,2}^4 = F_{\rm disc,1} + F_{\rm irr,2}$$
$$= \frac{3GM\dot{M}_1}{8\pi R^3}\left(1 - \sqrt{\frac{R_{\rm in}}{R}}\right) + \frac{L_{*,2}(1-a)\cos\theta}{4\pi R^2}. \quad (6)$$

With equations (4)–(6), the spectrum of the accretion disc can be calculated with

$$f_\nu = \frac{4\pi\cos i\,\nu^3}{c^2 D^2}\int_{R_{\rm in}}^{R_{\rm out}} \frac{R\,{\rm d}R}{e^{h\nu/kT_{\rm eff}} - 1}, \quad (7)$$

RESULTS

Observed composite relative variability spectrum given by Ruan et al. (2014).

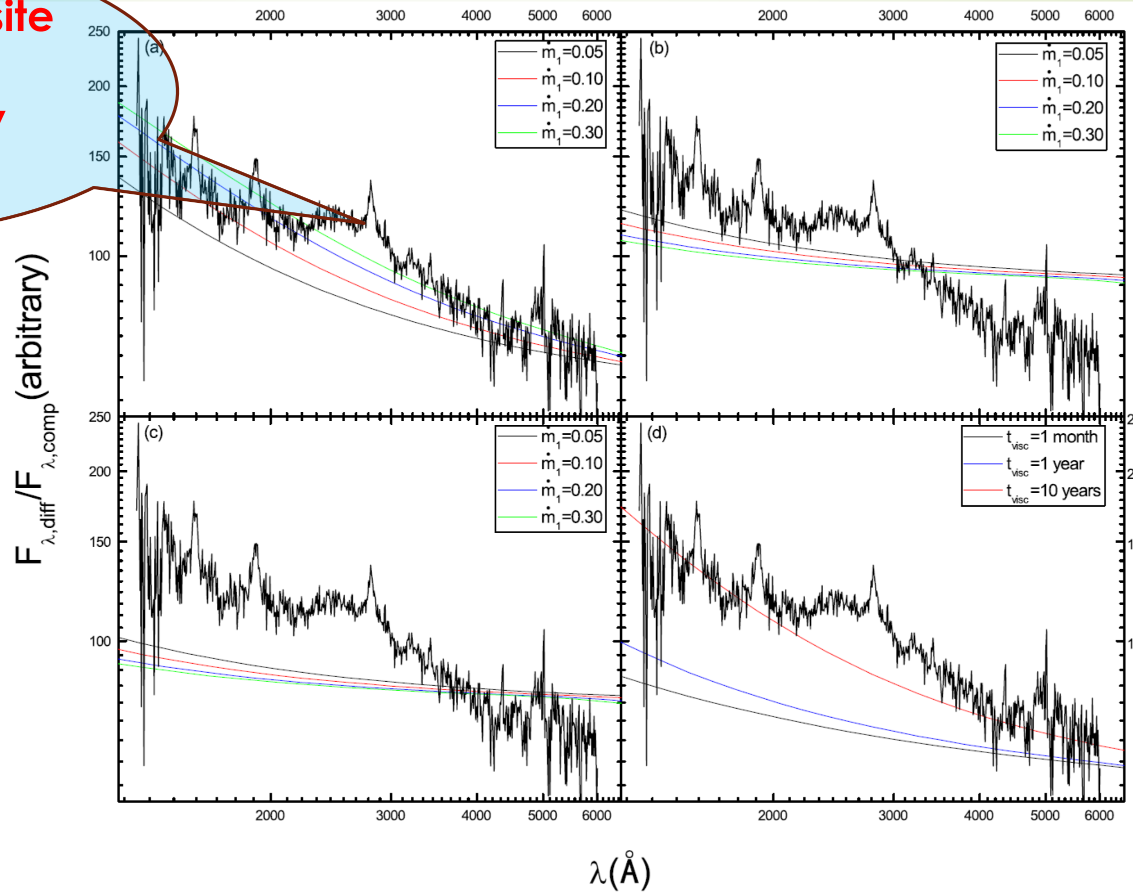


Figure 2. The relative variability spectrum as functions of rest-frame wavelength for different initial mass accretion rate $\dot{m}_1$ and different viscous time-scale. The black curve represents the observed composite relative variability spectrum given in fig. 6 of Ruan et al. (2014). Panel (a) represents our new model in this work, where the parameters $\alpha = 0.1$, $a = 0.4$, $L_* = 0.3L_{\rm bol}$ ($L_{\rm bol} = GM\dot{M}/2R_{\rm in}$), and $\delta\dot{m} = 100$ per cent $\dot{m}_1$ are adopted. Here $\dot{m} = \dot{M}/\dot{M}_{\rm Edd}$, $\dot{M}_{\rm Edd} = 1.5 \times 10^{18} m\,{\rm g\,s^{-1}}$, $m = M/{\rm M}_\odot$. Panel (b) represents the standard accretion disc model (no limiting the disc size), where all the parameters are the same as panel (a) except that $\delta\dot{m} = 30$ per cent $\dot{m}_1$. Panel (c) represents the standard accretion disc model plus irradiation, where all the parameters are the same as panel (b). Panel (d) also represent our model but for different viscous time-scale, where all the parameters are the same as panel (a) except that $\dot{m} = 0.1$.

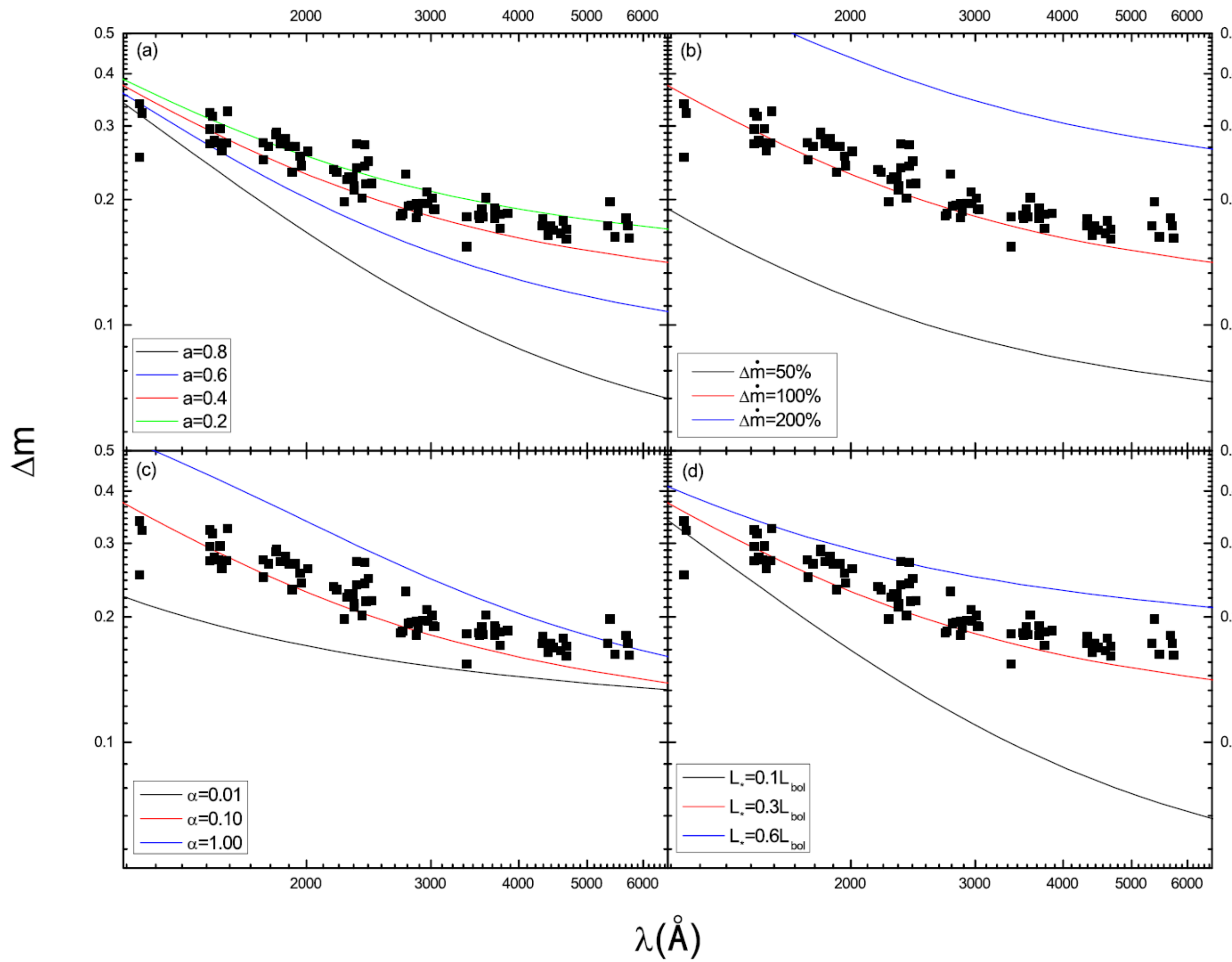


Figure 3. The variability amplitude as functions of rest-frame wavelength for different parameters, where $\delta\dot{m} = 100$ per cent $\dot{m}_1$ except for panel (b). The black squares are the statistical results given in fig. 13 of Vanden Berk et al. (2004).

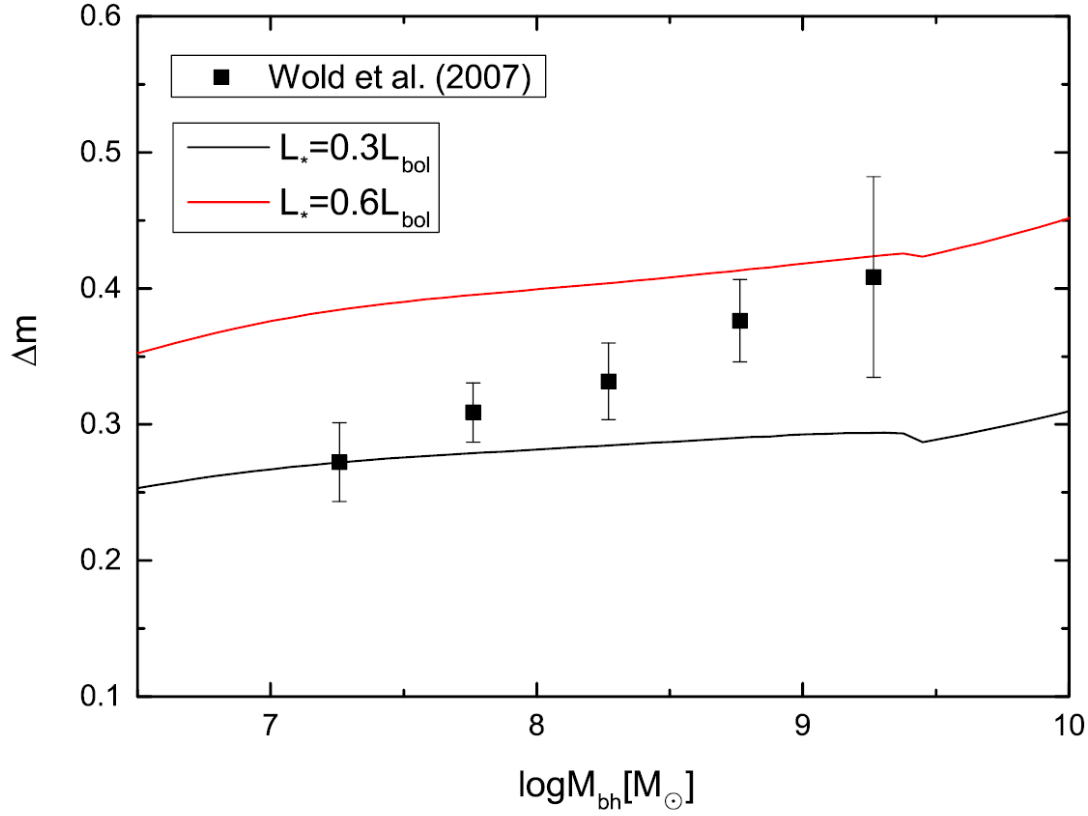


Figure 4. The variability amplitude in *R*-band as functions of black hole mass for different L_*, where all the parameters adopted are the same as Fig. 2 except that $\dot{m}_1 = 0.1$ and $\delta\dot{m} = 2\dot{m}_1$. The five black squares with error bars are the statistical results given in fig. 5 of Wold et al. (2007; see their paper for details.). The red and black lines are for $L_* = 0.3L_{\rm bol}$ and $0.6L_{\rm bol}$, respectively.

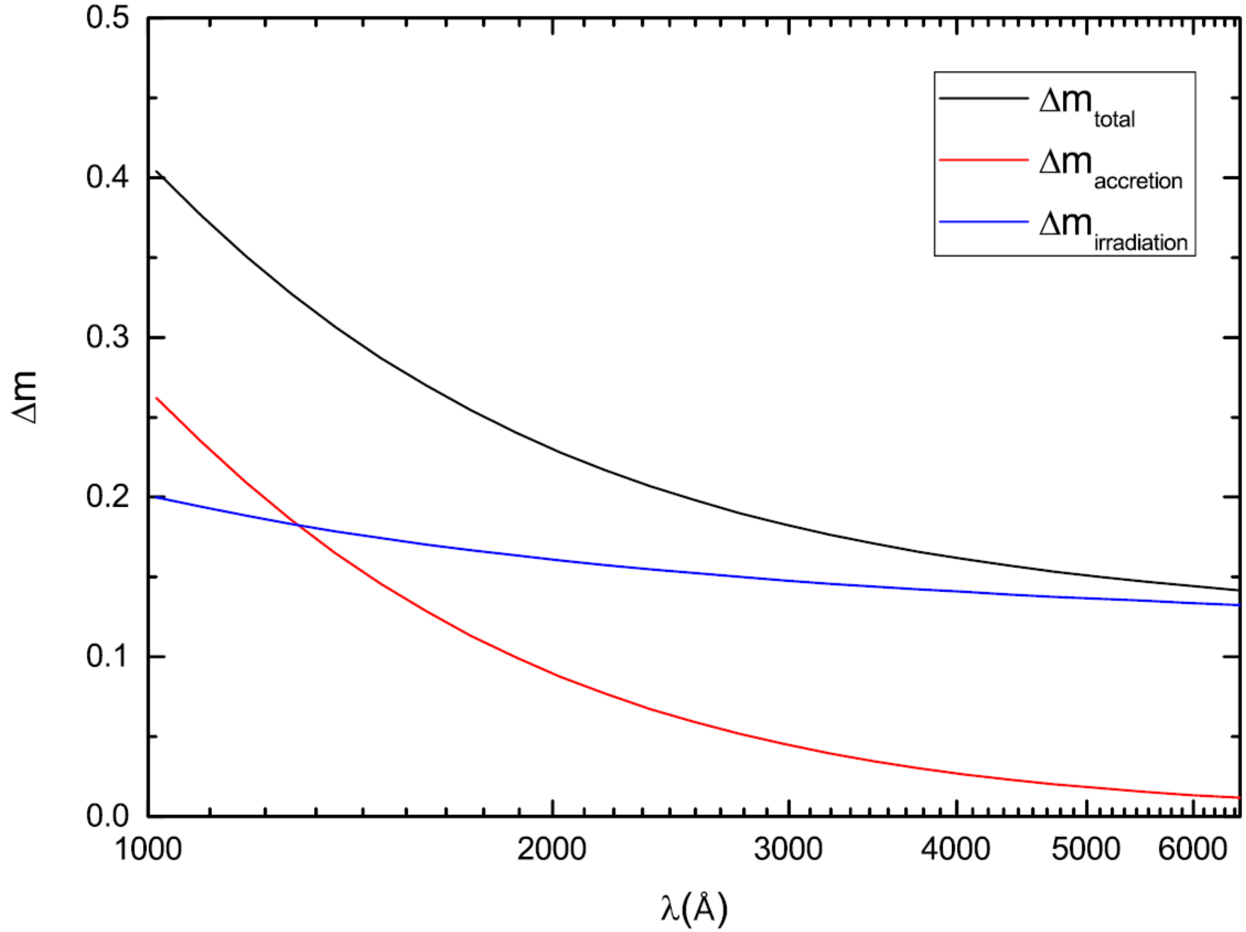


Figure 5. The variability amplitude as functions of rest-frame wavelength for the well-fitting parameters. The red and blue lines correspond to the variability from accretion disc and irradiation, respectively.

SUMMARY

- In this work, we upgrade the accretion disc model by constraining the disc size to match the viscous time-scale of accretion disc to the variability time-scale observed and by including the irradiation/X-ray reprocessing to make the emitted spectrum become steeper.
- We find this hybrid model can reproduce the observed bluer-when-brighter trend quite well, which is used to validate the theoretical model by several works recently.
- The traditional correlation between the variability amplitude and rest-frame wavelength can also be well fitted by our model.
- In addition, a weak positive correlation between variability amplitude and black hole mass is present, qualitatively consistent with recent observations.

THANKS!