Spectra and light curves of the radiative reprocessing in an outflow

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Abstract

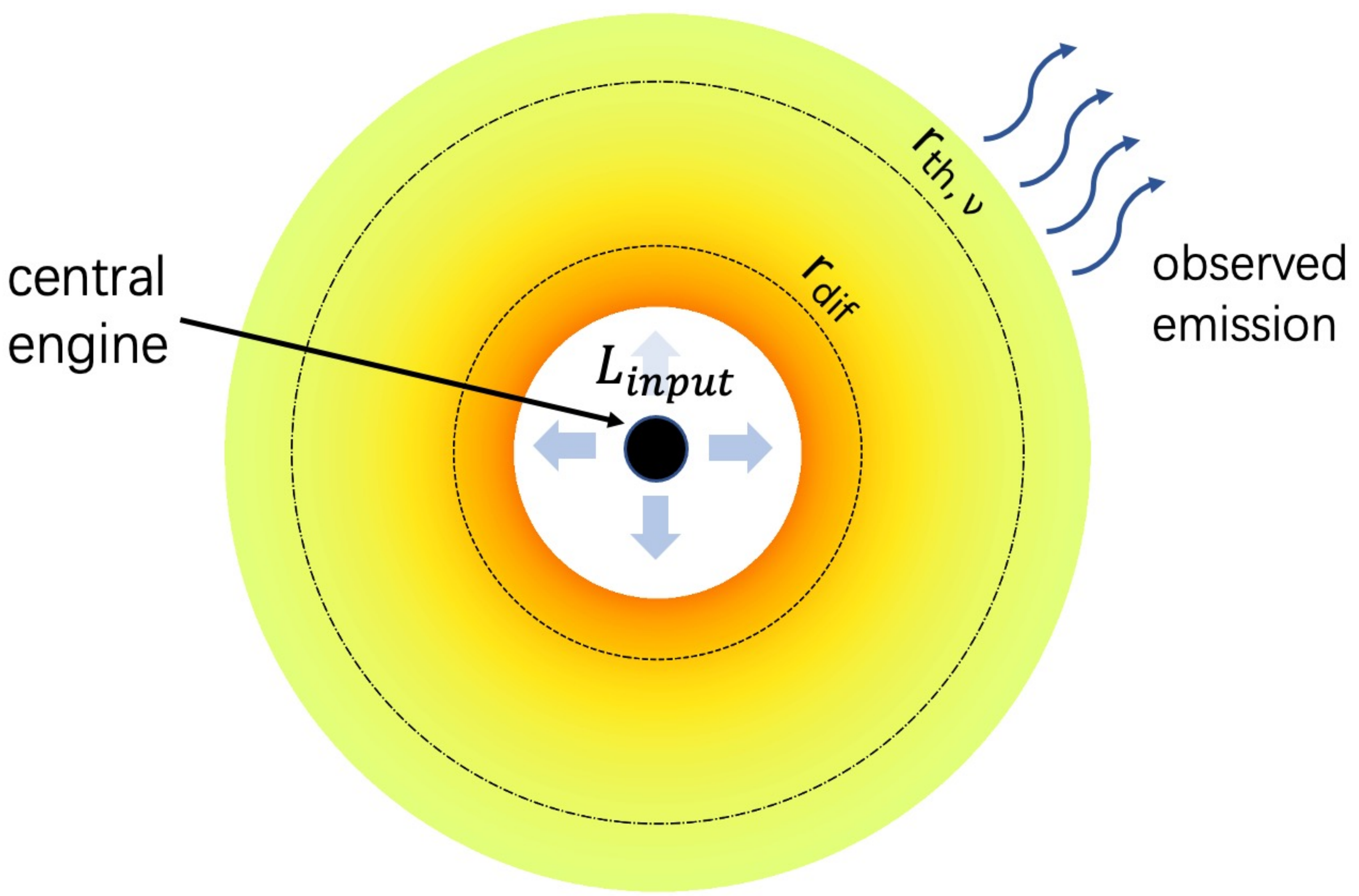
The radiation reprocessing model, in which an optically-thick layer or outflow absorbs the high-energy emission from a central source and re-emits in longer wavelengths, has been frequently invoked to explain some optically bright transients such as tidal disruption events (TDEs) and fast blue optical transients (FBOTs). Previous studies on this model did not take into account either the time evolution of the radiation signature or the frequency-dependent opacity. We study the radiative reprocessing in a time-dependent and spherical outflow composed of pure hydrogen gas. Frequency-dependent bound-free, free-free, bound-bound and electron scattering opacities are considered. We present the analytical and numerical results of the emitted spectrum and the light curve. The results show that although the outflow is highly ionized, the bound-free transition in the outflow cannot be neglected due to its large cross-section. The results also show that the emitted spectrum has a significant extension in the NIR band, and evolves as $L_\upsilon \propto \upsilon^{0.5}$. The model predicts light curves at different wavelengths.

Introduction

Many studies have shown that the reprocessing model could explain the observed optical flux in the UV/optical TDEs orders of magnitudes higher than that predicted by a standard BH accretion disk model (Roth et al. 2016), and the NIR excess in some FBOTs (Margutti et al. 2021).

We invoke a time-dependent outflow surrounding the central engine. The origin of the outflow and the central engine is agnostic. We assume the outflow is spherically symmetric for simplicity. We also assume the outflow is composed by the pure hydrogen gas.

Model



r_{dif} - the diffusion radius

$r_{th,\upsilon}$ - the frequency-dependent thermalization radius

L_{input}- input luminosity

$\dot{M}(max)$ – maximum mass loss rate

t_*-specific timescale t – dynamical time

υ– velocity of the outflow r– radius

r_{in} - inner boundary of the outflow

r_{out} - outer boundary of the outflow

$T(r)$– gas temperature at radius r

The mass loss rate: $\dot{M} = \dot{M}(max)\,(1+\frac{t}{t_*})^{-5/3}$

The density profile of the outflow: $\rho(r,t) = \frac{\dot{M}}{4\,\pi\,r^2 \upsilon}$.

The temperature profile:

(1) For $r < r_{dif}$, $T(r) \propto r^{-2/3}$, since the gas temperature is determined by the adiabatically cooling.

(2) For $r_{dif} < r < r_{out}$, $T(r) \propto r^{-3/4}$, since the temperature profile is determined by the radiative transport.

Results

(1) Spectra

The monochromatic luminosity (Lu & Bonnerot 2019) could be roughly given by

$$L_\upsilon \approx \begin{cases} 4\,\pi r_{th,\upsilon}^2 \dfrac{4\,\pi\, B_\upsilon(r_{th,\upsilon})}{\tau_{es}(r_{th,\upsilon})}, & for\ r_{th,\upsilon} > r_{dif} \\ 4\,\pi r_{dif}^2 \dfrac{4\,\pi\, B_\upsilon(r_{dif})}{\tau_{es}(r_{dif})}, & for\ r_{th,\upsilon} < r_{dif} \end{cases}$$

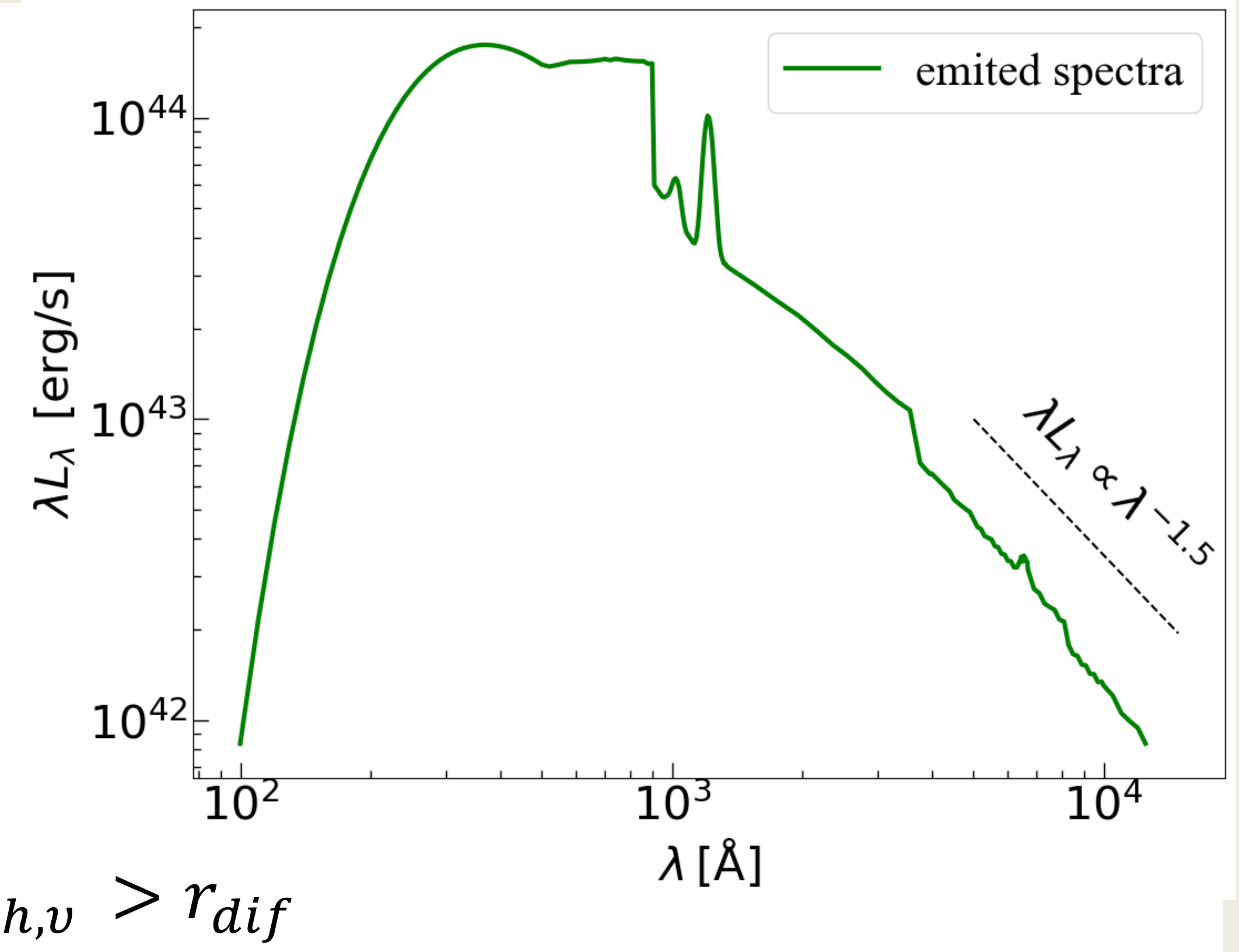


Fig. 1 Emitted spectrum. Model parameters are set as: $\dot{M}(max) = 10^{-5}\ M_{sun}\ s^{-1}$; $r_{in} = 10^{14}\ cm$; $v = 10^9\ cm\ s^{-1}$; $t_* = 1\ day$

(2) Monochromatic Light Curves

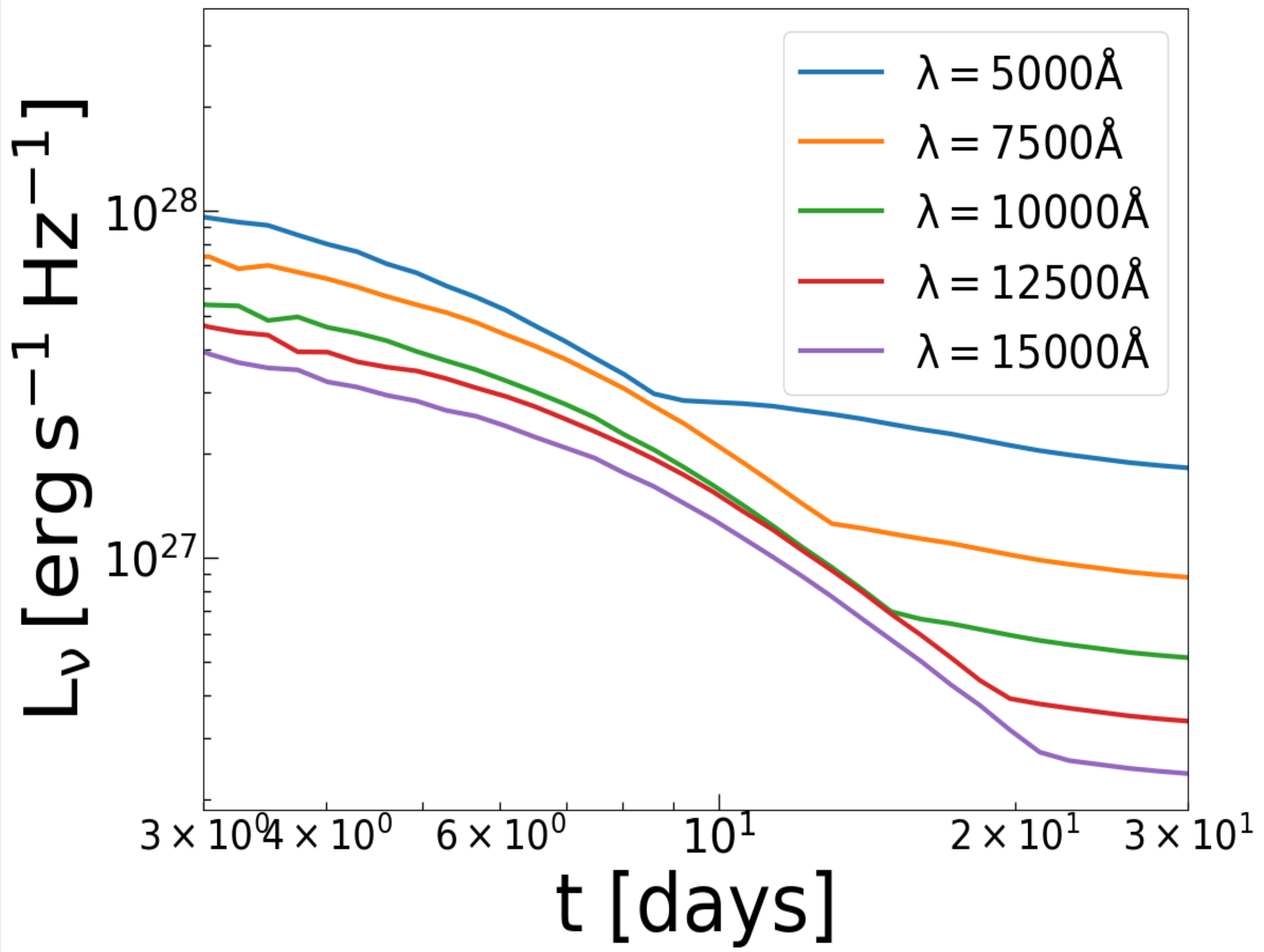


Fig. 2 Monochromatic light curves. Model parameters are set as:. The inconsistency in the evolution of the light curves is due to the evolution of $(r_{dif}, r_{th,\upsilon})$.

Conclusion

(1) As shown in Fig. 1, the emitted spectrum show the significant NIR excess, and evolves as $L_\upsilon \propto \upsilon^{0.5}$;

(2) There are differences between the light curves with different wavelengths (see Fig.2).