Spectra of the radiative reprocessing in an outflow

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Abstract

The radiation reprocessing model, in which an optically-thick 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 fast blue optical transients (FBOTs). Previous studies on this model did not take into account 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 and electron scattering opacities are considered. We present the analytical and numerical results of the emitted spectrum. The results also show that the emitted spectrum has a significant extension in the NIR band, and evolves as $L_\nu \propto \nu^{0.5}$. We apply the model to the typical FBOT: AT2018cow. The modeling finds the total mass of the outflow ~ 3 $M_\odot$, leading us to speculate that the residual compact object may be a stellar-mass black hole.

Introduction

Many studies have shown that the reprocessing model could explain 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

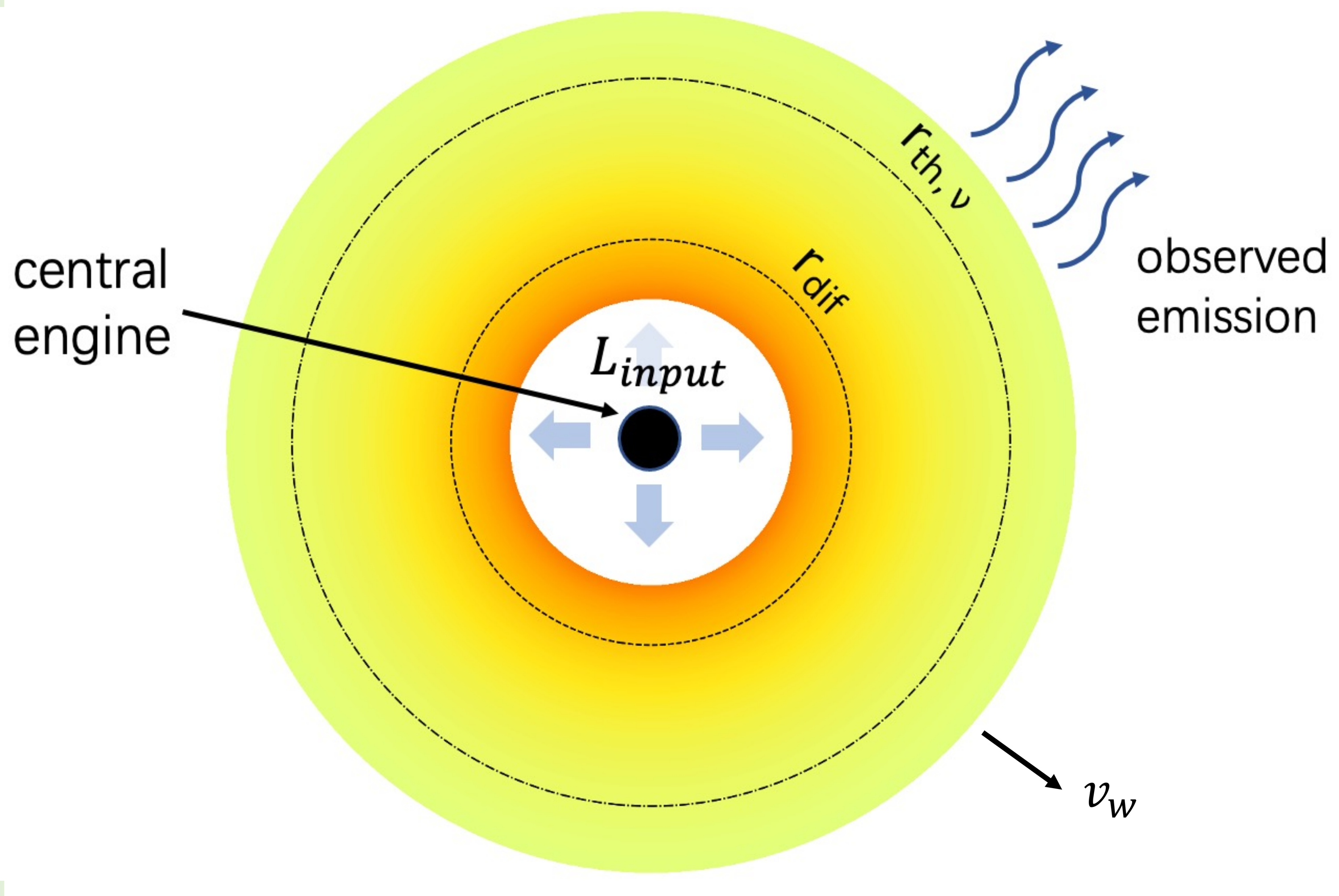

Fig1. Schematic.

r_{dif} - the diffusion radius
$r_{th,\nu}$ - the frequency-dependent thermalization radius
L_{input}- input luminosity
$\dot{M}$ – mass loss rate
t – dynamical time
v_w – velocity of the outflow
R_{in} - inner boundary of the outflow

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

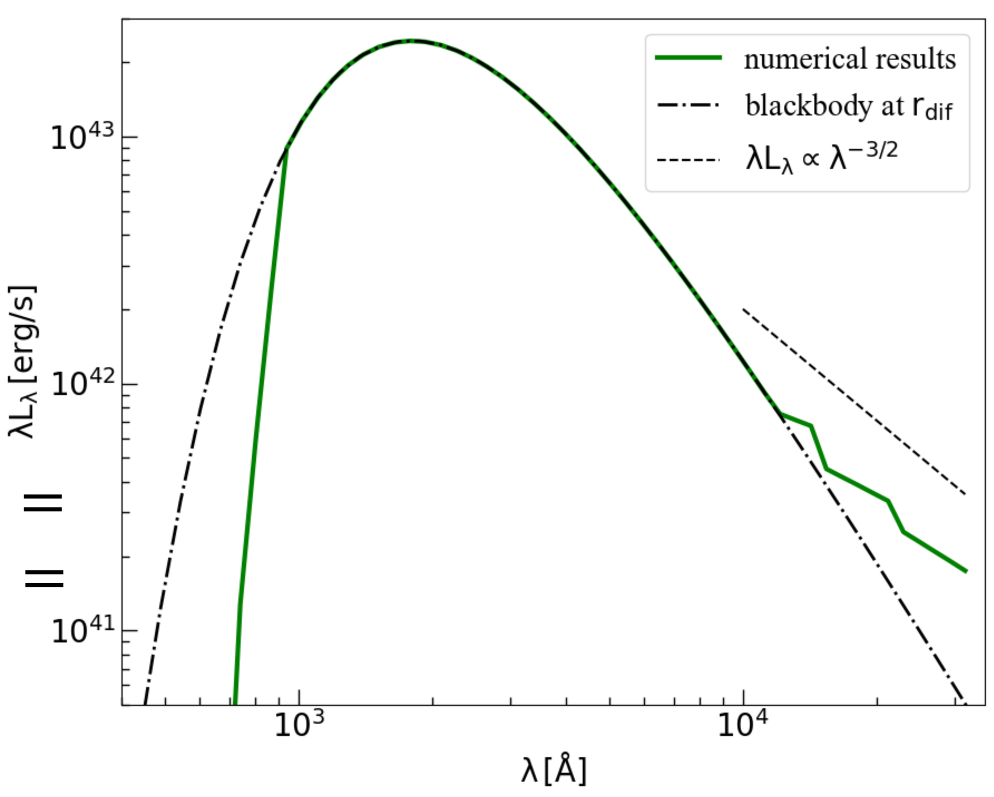

Fig 2. Emitted spectrum. Model parameters are set as: $L_{input} = 10^{44}\ erg\ s^{-1}$; $\dot{M} = 10^{-6}\ M_\odot\ s^{-1}$; $v_w = 3\times 10^9\ cm\ s^{-1}$.

Results

For low frequency:

$$\nu L_\nu \approx 1.21\times 10^{42}\ erg\ s^{-1} \left(\frac{\dot{M}}{10^{-6}\ M_\odot\ s^{-1}}\right)^{\frac{5}{4}} \left(\frac{v_w}{3\times 10^9\ cm\ s^{-1}}\right)^{-\frac{5}{4}} \left(\frac{\nu}{3\times 10^{14}\ Hz}\right)^{\frac{3}{2}}.$$

Apply to AT2018cow

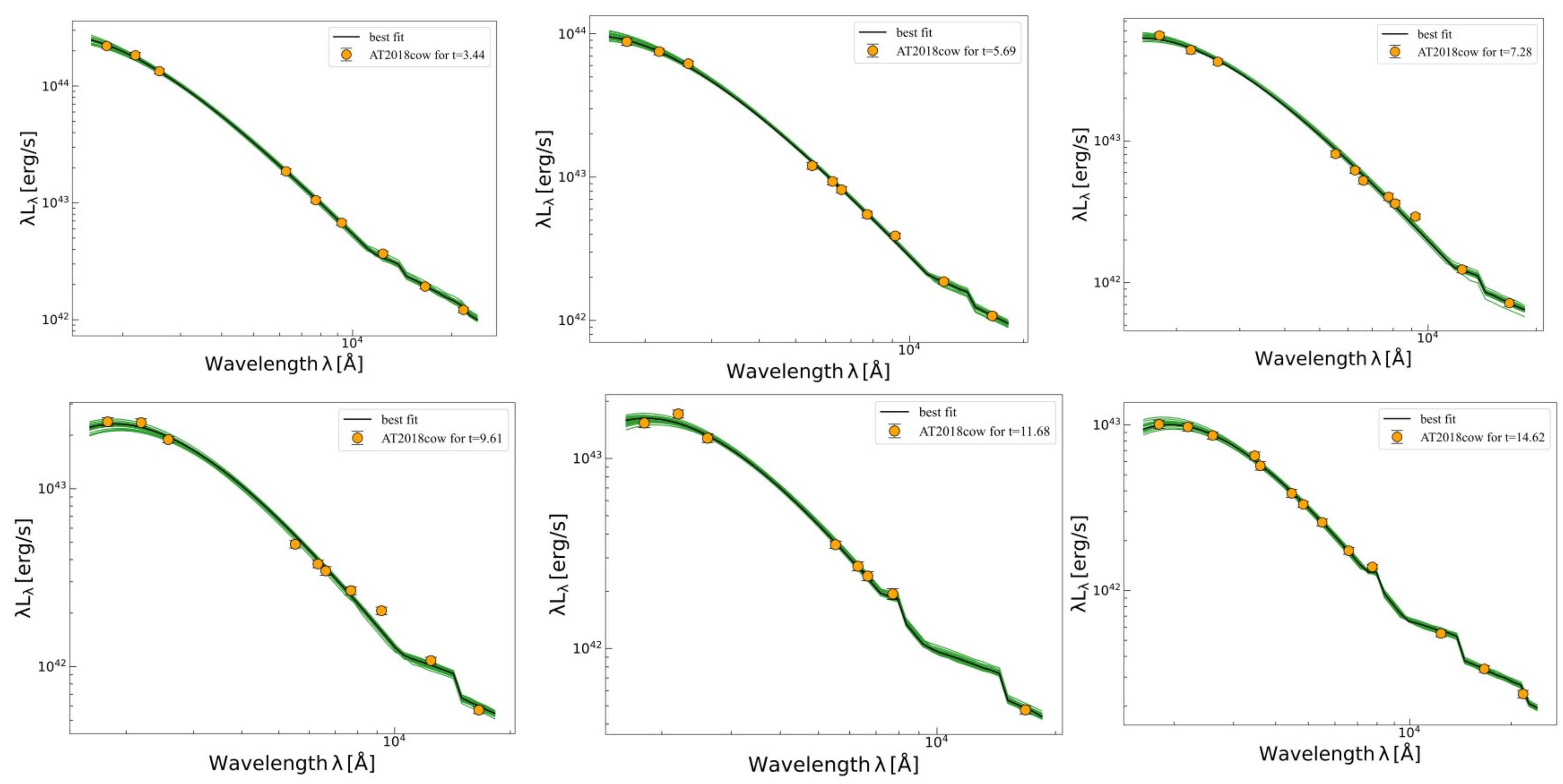

Fig3. Fitting of AT2018cow SED data.

t_{obs}	$\dot{M}$ ($M_\odot$/s)	v_w (cm/s)	L_{input} (erg/s)
3.44	$1.02^{+0.04}_{-0.04}\times 10^{-5}$	$7.21^{+0.16}_{-0.16}\times 10^{9}$	$9.92^{+0.53}_{-0.51}\times 10^{44}$
5.69	$3.44^{+0.12}_{-0.12}\times 10^{-6}$	$4.40^{+0.09}_{-0.08}\times 10^{9}$	$3.66^{+0.18}_{-0.17}\times 10^{44}$
7.28	$1.99^{+0.07}_{-0.07}\times 10^{-6}$	$3.63^{+0.07}_{-0.07}\times 10^{9}$	$2.08^{+0.09}_{-0.09}\times 10^{44}$
9.61	$1.50^{+0.04}_{-0.04}\times 10^{-6}$	$2.97^{+0.06}_{-0.06}\times 10^{9}$	$9.40^{+0.30}_{-0.30}\times 10^{43}$
11.68	$9.54^{+0.34}_{-0.33}\times 10^{-7}$	$2.39^{+0.06}_{-0.06}\times 10^{9}$	$6.35^{+0.21}_{-0.20}\times 10^{43}$
14.62	$6.32^{+0.15}_{-0.15}\times 10^{-7}$	$2.16^{+0.05}_{-0.05}\times 10^{9}$	$3.96^{+0.12}_{-0.12}\times 10^{43}$

Table 1. Best-fit parameters.

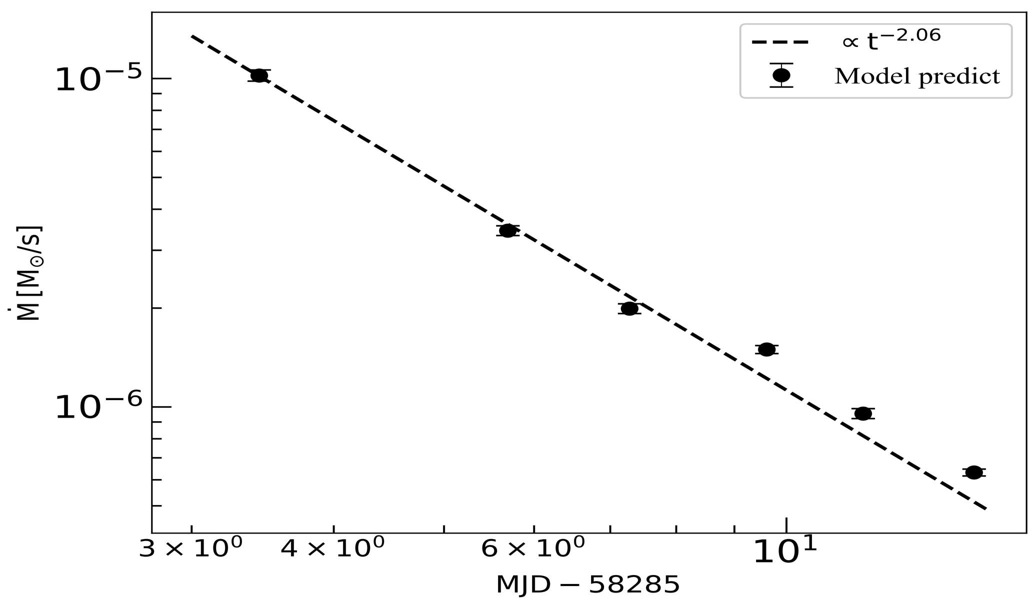

Fig 4. Best-fit parameters of $\dot{M}$.

Conclusion

For AT2018cow, a supermassive star explosion event, the pre-SN mass $\gtrsim 8\ M_\odot$. The total mass of the outflow ~ 3 $M_\odot$, thus the residual compact object mass: $M_{obj} \gtrsim 8 - 3.046\ M_\odot \sim 5 M_\odot$.

➡ The compact object might be a stellar-mass BH.