

ASTR 5110 Atomic and Molecular Processes Fall 2024. Problem Set 10. Due  
Wed 13 Nov.

1. An unusual N III fluorescence line from an accreting supermassive black hole

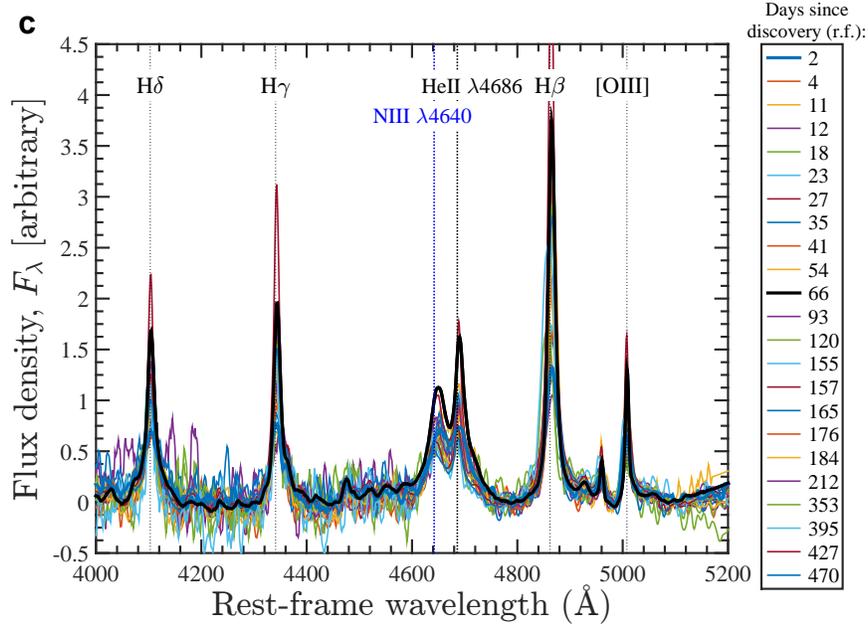


Figure 1: Optical spectrum of the accretion event AT 2017bgt on to a supermassive black hole over a period of 470 days (Trakhtenbrot et al. 2019 <https://arxiv.org/abs/1901.03731>).

Trakhtenbrot et al. (2019) <https://arxiv.org/abs/1901.03731> report that the All Sky Automated Survey for Supernovae observed the early-type galaxy 2MASX J16110570+0234002 at  $z = 0.064$  to brighten significantly over a two month period in 2017, an event they dubbed AT 2017bgt. The brightening did not match the lightcurve of a supernova, but was more similar to a TDE (Tidal Disruption Event), in which a supermassive black hole tidally disrupts a passing star, and proceeds to accrete the remains over a period of a year. Observations with the SWIFT, NuSTAR, and NICER satellites shortly after discovery established that AT 2017bgt had brightened in the ultra-violet by the exceptionally large factor of 75, and in x-rays by a factor of  $\sim 2$ –3. Optical spectroscopy, Figure 1, showed that, unusually for a TDE, the optical brightness remained roughly constant for more than a year. The spectrum also showed an unusual emission line which Trakhtenbrot et al. identify as N III  $2s^23p \ ^2P - 2s^23d \ ^2D$  464 nm, which they argue is a fluorescence line that results from a cascade of allowed lines after He II Ly $\alpha$  pumps N III in its ground state to a high lying level.

(a) (6 points) The resonance line (allowed line connecting to the ground state) that is pumped by He II Ly $\alpha$  30.3786 nm is N III  $2s^22p \ ^2P_{1/2} - 2s2p3p \ ^2S_{1/2}$  30.5756 nm. Would N III have to be redshifted or blueshifted, and by how much, in km/s, to make that resonance line coincident with the He II Ly $\alpha$  line? Is that velocity plausible, given the width of the allowed lines (e.g. H $\beta$ ) in the observed spectrum Figure 1?

(b) (6 points) As a simplified model of fluorescence, consider a 3-level atom (of N III). Assume that the 3 levels are populated by radiative pumping by He II Ly $\alpha$  at rate  $W_{13}$  and stimulated emission at rate  $W_{31}$ , and by allowed radiative decays, so

$$\dot{n}_1 = -n_1 W_{13} + n_2 A_{21} + n_3 (A_{31} + W_{31}) , \quad (1a)$$

$$\dot{n}_2 = -n_2 A_{21} + n_3 A_{32} , \quad (1b)$$

$$\dot{n}_3 = -n_3 (A_{31} + W_{31} + A_{32}) + n_1 W_{13} . \quad (1c)$$

Show that in steady state

$$n_1 : n_2 : n_3 = 1 : \frac{W_{13} A_{32}}{A_{21} (A_{31} + W_{31} + A_{32})} : \frac{W_{13}}{A_{31} + W_{31} + A_{32}} . \quad (2)$$

(c) (6 points) Use detailed balance to argue that in thermodynamic equilibrium at temperature  $T_{13}$ , the rates of radiative decay  $A_{31}$ , excitation  $W_{13}$ , and stimulated decay  $W_{31}$  are related by

$$\frac{g_3 A_{31}}{e^{h\nu_{13}/kT_{13}} - 1} = g_1 W_{13} = g_3 W_{31} . \quad (3)$$

The temperature  $T_{13}$  is called the excitation temperature of the line.

(d) (6 points) What is the energy  $h\nu_{13}/k$  of the He II Ly $\alpha$  line in Kelvin? Argue that the excitation temperature  $T_{13}$  of the 1 and 3 levels of N III cannot exceed the temperature of a hypothetical blackbody source centered on the supermassive black hole.

(e) (6 points) The condition for a laser is that there be a population inversion  $n_U/n_L > g_U/g_L$ . Could the  $1 \leftrightarrow 3$  transition develop a laser? Could the  $2 \leftrightarrow 3$  or  $2 \leftrightarrow 1$  transitions perhaps develop a laser?

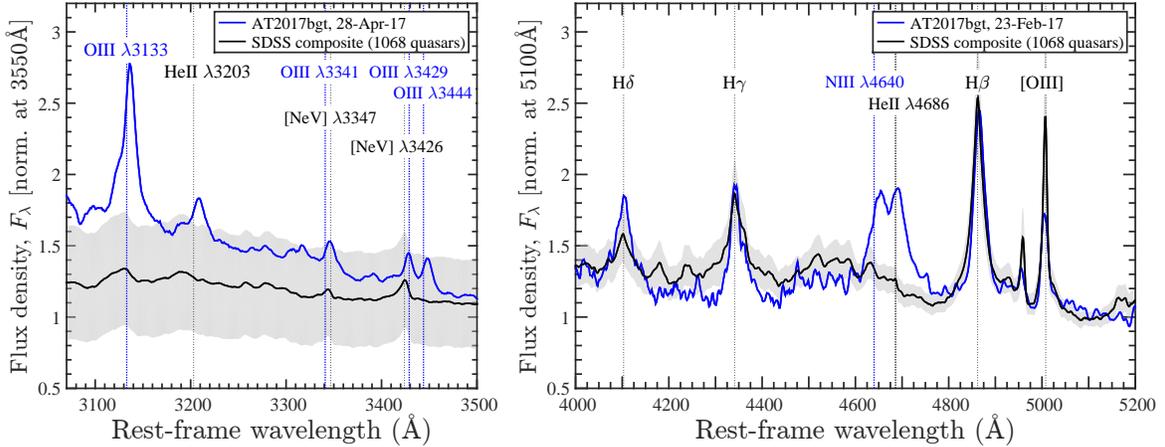


Figure 2: Near UV and optical spectrum of AT 2017bgt two days after discovery, compared to a composite of SDSS quasars. The spectrum of AT 2017bgt shows fluorescence lines, notably O III 313 nm and N III 464 nm, that are atypical of quasars.