Homework 5

Introduction to Black Hole Astrophysics (PHYS480)

(Due at the start of class on May 11, 2021)

Exercise 1

[Reverberation mapping (2 pt)] Reverberation mapping is one of the methods for measuring masses of supermassive black holes (SMBHs) in distant galaxies. In this exercise, we will use real observational data of the SMBH at the center of galaxy NGC 4593 and estimate its mass.

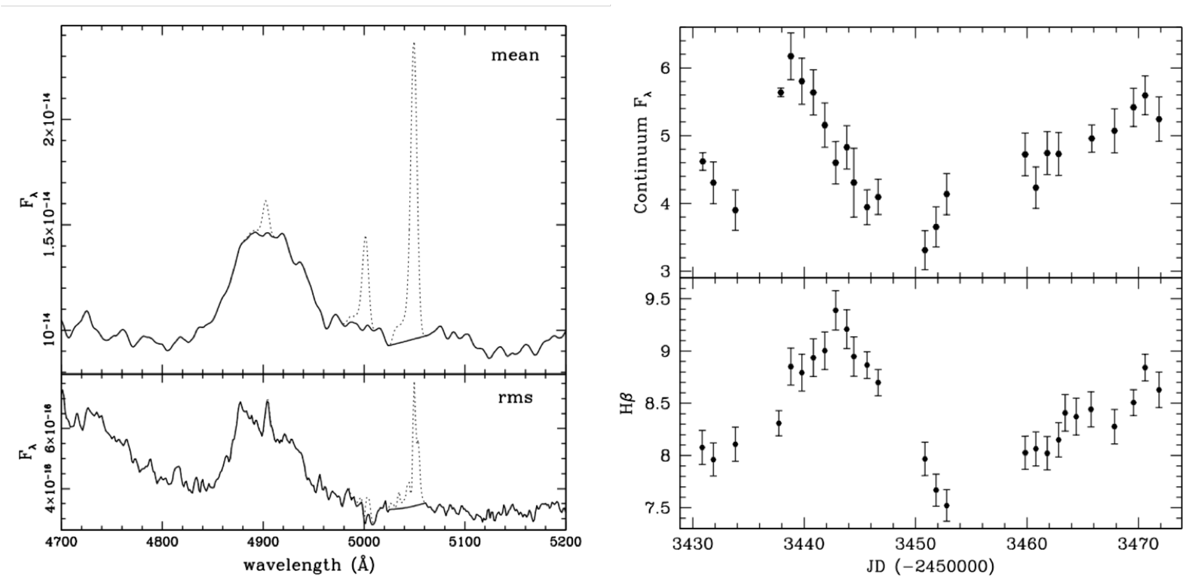

Figure 1: *Left:* A portion of the optical spectrum of an accreting SMBH. *Right:* The top panel shows the observed variation of light coming from near the black hole over a period of 40 days (the x-axis is marked in days). The lower panel shows the observed variation of light emitted by the gas clouds orbiting the black hole.

(1) Figure 1 (left) shows a portion of the optical spectrum of this SMBH. The broad peak centered at $\lambda_0 \sim 4900$Å (1Å is 10^{-10} m) shows emission from gas clouds surrounding the SMBH. The emission line is broad because the clouds are moving with a range of velocities and thus have a range of Doppler shifts. From this figure, measure the width of the line halfway down from its top and call it $\Delta\lambda$. What is the value of $\Delta\lambda$ in Å? Convert $\Delta\lambda$ to a characteristic velocity v of the gas clouds using the Doppler formula

$$v = \frac{\Delta\lambda}{\lambda_0} \times c.$$

(2) In Figure 1 (right), the top panel shows the variation of light coming from near the SMBH. The lower panel shows the variation of light emitted by the gas clouds orbiting the SMBH. Their patterns look similar but the latter is delayed in time. Please briefly explain why it is the case.

(3) From this figure, measure the time delay Δt between the variation of light from the SMBH and that of the gas clouds (e.g., by measuring the time shift between the peaks of the emission). What is Δt in days? What is the approximate distance between the SMBH and the gas clouds in units of light-days?

(4) Using the values obtained in (1) and (2), esimate the mass of the SMBH using

$$M = \frac{v^2 r}{G}.$$

Exercise 2

[Changing-look AGNs (1.5 pt)] In class we discussed different types of active galactic nuclei (AGNs) categorized by different features seen in their observed electromagnetic spectra. Although most AGNs vary on timescales longer than human lifetimes, a small number of AGNs are observed to "change their looks." Please read the following two articles about these "changing-look AGNs" and answer the questions below.

The links to the articles can be found here:
– Exploring the host galaxies of changing-look AGNs (`https://astrobites.org/2020/11/24/exploring-the-host-galaxies-of-changing-look-gn/`).
– A new kind of changing-look AGN (`https://astrobites.org/2021/04/03/a-new-kind-of-changing-look-agn/`).

(1) What are changing-look AGNs? How are they identified observationally?

(2) Please briefly summarize the main results of these two articles.

(3) What are the open questions astrophysicists try to answer regarding changing-look AGNs?

Exercise 3

[Tidal disruption events (1 pt)] A tidal disruption event (TDE) occurs when a star is ripped apart when tidal forces from a supermassive black hole (SMBH) overcome the self gravity of the star. This can only happen when the tidal disruption radius, $R_T \approx R_\star (M_{BH}/m_\star)^{1/3}$, is greater than the event horizon of the SMBH. Otherwise the star would be swallowed into the event horizon without being disrupted. In this exercise, let us assume that the SMBH is non-spinning.

(1) For a Sun-like star, please derive the critical mass of the SMBH above which the TDEs would not occur.

(2) Similarly, please derive the critical mass of the SMBH in the case when a white dwarf passes by the SMBH, assuming its mass is comparable to the Sun and radius is comparable to the Earth. Please comment on the implication of your answer if astrophysicists discover a TDE of a white dwarf some day in the future.

Exercise 4

[Fermi bubbles (0.5 pt)] Watch a video about the *Fermi* bubbles (`https://www.youtube.com/watch?v=t8o5W425uhw`; the first 13:15 minutes) and write down one thing you have learned or one question you have.