

This cume is based on the paper **Dynamical Unification of Tidal Disruption Events**, by Thomsen *et al.* (2022, ApJL, 937, L28). The paper seems long, but the main body is 10 pages (i.e. you may ignore the appendices).

The exam contains 10 questions or subquestions, worth 58 total points. 40 points (70%) guarantees a pass.

Please make sure your writing is legible. I am not fluent in hieroglyphs and I cannot grade what I cannot read! Also, please show all work and do attempt each problem, showing your thought process even if you cannot solve it completely. If during the exam you have any question please email me (wlyra@nmsu.edu). I will also be accessible via zoom <https://nmsu.zoom.us/my/wlyra>.

At the end of the exam, put your responses in question order, scan or photograph them, and upload them to the canvas assignment.

1. Explain the observations that this letter attempts to explain, and the proposed solution. Keep your answer brief (≈ 5 sentences, 6 points).
2. Fig. 1 shows a cartoon of the unified model of Tidal Disruption Events (TDEs hereafter). Based on your reading of the text, label the following figure with the following labels: Slow Wind, X-ray emission, Fast Wind, Optical emission, Funnel. (5 points)

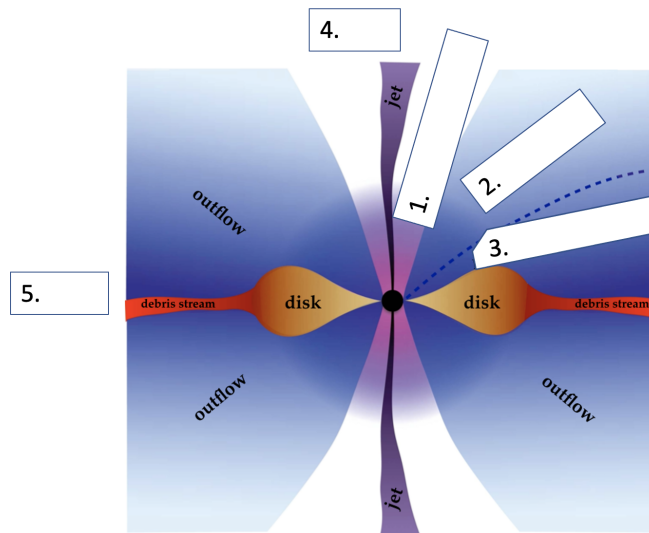


Figure 1. Sketch of the unified model of Tidal Disruption Events.

3. Based on Fig 1 and Fig 2 (panels f and g), explain how the proposed mechanism for X-ray re-brightening of the TDE spectrum works. Hint: Consider the behavior of the scattering photosphere at intermediate inclinations in Fig 1 as the mass accretion rate declines. (6 points)

4. Fig 3c notes that some X-ray TDEs have blackbody radius (derived from luminosity and temperature) smaller than the gravitational radius R_g . One of the proposed solutions (Sect 3.3) is that “the measured temperature [is] higher than the true temperature owing to Comptonization effects.” Clarify what the authors mean by this statement. (6 points)
5. The paper states that the spin parameter of the black hole they consider is $a = 0.8$. The spin parameter is defined as the ratio of the black hole angular momentum J to the critical angular momentum J_c , the maximum angular momentum a rotating (Kerr) black hole can have. Knowing that the event horizon of a Kerr black hole is

$$R_K = R_g \left(1 + \sqrt{1 - a^2} \right), \quad (1)$$

show that this critical angular momentum is (6 points)

$$J_c = \frac{GM^2}{c}, \quad (2)$$

where M is the mass of the black hole, G the gravitational constant and c the speed of light.

6. The existence of a critical angular momentum invites the question: what happens if you were to add angular momentum to a maximally spinning black hole? Show mathematically that the critical angular momentum constraint is not exceeded. For that, consider a maximally rotating Kerr black hole that accretes a gas parcel of mass δm traveling at speed $\approx c$ at the event horizon. Compare the initial and final angular momentum of the merged black hole. (8 points)
7. According to black hole thermodynamics, the entropy S of a black hole is proportional to its area A

$$S = \frac{c^3 k^2}{4G\hbar} A \quad (3)$$

where k is Boltzmann constant and $\hbar$ the reduced Planck constant. As the angular momentum increases, according to Eq. 1, the event horizon of a Kerr black hole decreases. Yet, according to Eq. 3 this implies that the entropy of the black hole decreases, violating the second law of thermodynamics. How to solve this apparent paradox? (6 points)

8. The paper works out a model for a TDE occurring in a gas-free environment, with the only gas provided by the disruption of the star. Consider, instead, that the TDE happens inside the pre-existing accretion disk of an active galactic nucleus (AGN).
 - (a) Name at least one extra hydrodynamical process that would be occurring due to interaction with the AGN gas, and a brief explanation (1-2 sentences) of why it should occur. (3 points)

- (b) How would this process affect the dynamics, and how would the conclusions of the paper about the emission properties of TDEs be changed, if at all? (6 points)
- (c) Suggest an observational test to measure the bolometric luminosity of a TDE, if it were to occur in an AGN. (6 points)