A Deep, Archival Search for Tidal Disruption Events and Rate Constraints

SURF Project Proposal

Thuwaragesh Jayachandran

Caltech

Introduction

Tidal Disruption Events (TDEs) occur when a star's trajectory intersects the tidal radius of a supermassive black hole (SMBH). During a TDE, the star gets pulled apart and torn by the tidal forces exerted by the black hole, causing flares of multiwavelength radiation lasting for months-years [1]. These flares effectively shine a flashlight on otherwise quiescent black holes in distant galaxies, allowing us to study the black holes and the environments in which they reside. Although ~100 TDEs have been observed in the past decade, many open questions remain [1].

In particular, the rate of TDEs and the factors that drive the rate are not fully constrained. Low luminosity TDEs, in particular, are difficult to detect, and thus their contribution to the total TDE rate is unknown. Current constraints suggest, however, that these TDEs may be the most numerous [3, 4].

Moreover, the factors that drive the TDE rate are uncertain. TDEs are known to occur more frequently in host galaxies that underwent a burst of star formation in the last ~Gyr, but the origin of this effect is unknown. One possibility is that a galaxy merger can both drive stars towards the black hole and cause starbursts, but evidence for recent mergers in TDE hosts is limited [7].

In this project, we aim to set constraints on both the TDE rate and the factors that drive it by using re-processed, archival data from the Zwicky Transient Facility. Previous work has used primarily real-time data, which, while allowing for rapid follow-up of candidate events to remove contamination from TDE-like events (e.g., certain types of supernovae), does not provide the sensitivity of the re-processed data. We will use the archival data to assemble a sample of TDEs. We will then use this sample to study the rate as a function of host galaxy properties (at the minimum stellar mass; if time allows, star formation rate). By using archival, re-processed survey data, we will be able to include the faintest TDEs currently detectable in our analysis.

Objectives

This SURF project has two primary objectives: first, to assemble a sample of TDEs that includes low luminosity events; second, to use this sample to evaluate the TDE rate as a function of properties of the host galaxy (stellar mass, primarily). We address each of these goals in the following:

1. *Assemble a sample of TDE candidates, including faint events.*
    - We will assemble a sample of TDE candidates using reprocessed light curves from the Zwicky Transient Facility (ZTF). This database has been assembled by measuring the optical emission as a function of time for a large catalog of galaxies. This catalog of galaxies was assembled from the Pan-STARRS survey, which includes every galaxy brighter than a certain flux. The optical emission as a function of time in ZTF was measured at the center of each of these galaxies, enabling higher sensitivity than analyses that, e.g., blindly search for varying optical emission at any location in the sky. We will identify the TDEs by requiring their lightcurves satisfy certain criteria (rise time, fade time, color evolution) that is motivated by the results from previous optical TDE searches (in particular, [3]). This search will suffer from unavoidable uncertainty because TDEs are difficult to distinguish from certain other nuclear flaring events (e.g., supernova in galactic centers). We will adopt a few methods of correcting for the contribution of these events, as described below, including simply treating the measured TDE rates as an upper limit. The presence of these interlopers, however, is the most uncertain, but unavoidable, part of our analysis.

2. *Measure the rate of TDEs as a function of host galaxy properties.*
    - With our TDE sample from aim (1), we can contribute significantly to multiple questions about TDE physics by using the sample to measure the rate of TDEs as a function of various TDE and host galaxy properties. Given the limited time frame of this project, our primary goal will be to measure the TDE rate as a function of host galaxy stellar mass. Host galaxy stellar mass can be easily extrapolated from the brightness of the host galaxy, as provided by the Pan-STARRS survey. We will compare the TDE rate as a function of stellar mass to the results from [3], who performed an analogous analysis using the real-time, shallower ZTF data, and to theoretical models. If time permits, we will also measure the TDE rate as a function of TDE properties and host star formation rate.

Approach

We will complete our objective using the following procedure:

Specific Aim 1: The first step is to develop an algorithm that can filter out TDE flares from the ZTF dataset. The algorithm will select TDE candidates in steps, based on a number of parameters that have been previously used to detect TDEs [3]. These parameters are:

1. The number of flares detected (TDEs are generally expected to only occur once, so we expect a single brightening event)
2. The time it takes for the emission to rise from half-peak to peak
3. The time it takes for the emission to fade from peak to half-peak
4. The color of the emission (i.e., the ratio of the brightness of the emission at two different optical wavelengths)
5. The evolution of the color of the emission (supernova show significant evolution in this color, while TDEs do not)

We will develop a computer program to fit all the lightcurves in the ZTF database to standard TDE evolution models in order to measure these parameters. Final list of TDE candidates retrieved will be cataloged along with the TDE characteristics (i.e., the parameters listed above).

Specific Aim 2: The next steps are to (1) prepare a catalog of host galaxies of the observed TDEs, including physical properties and (2) measure the TDE rate as a function of the host galaxy properties. In the interest of time, we will focus on the host galaxy stellar masses, which can be easily measured from Pan-STARRS data using the galaxy distances measured by [5] and following the methods of [6]. We will measure the TDE rate by following the same methods used in [3], which were developed for a very similar analysis but using real-time ZTF data. We will then generate plots of the TDE rate as a function of stellar mass and overlay the results from [3] and theoretical simulations of the TDE rate. We will identify any interesting differences and interpret the results.

Workplan

Pre-SURF – basic reading about astronomical concepts, include measures of distance, galaxy evolution, and black hole physics

Week 1: further, more detailed reading about tidal disruption events and the current state of measurements of the TDE rate and its driving factors

Week 2-3: development of a code that can take a lightcurve from ZTF and fit it with a standard TDE flaring model

Week 4-5: extension of this code to enable fits to a large sample of ZTF lightcurves

Week 6: creating a catalog of host galaxy stellar masses

Week 7: development of a code to measure the TDE rate given the selection criteria applied to find the TDEs, following [3]

Week 8-9: Comparing the measured TDE rate as a function of galaxy stellar mass to previous work and theoretical predictions and interpretation of results.

Week 10: Final write-up

References

[1] Gezari et al., (https://ui.adsabs.harvard.edu/abs/2021ARA%26A..59...21G/abstract)

[2] Charalampopoulos et al., A detailed spectroscopic study of tidal disruption events. A&A 659 (A34) (2022)

[3] Yao et al., Tidal Disruption Event Demographics with the Zwicky Transient Facility: Volumetric Rates, Luminosity Function, and Implications for the Local Black Hole Mass Function (https://arxiv.org/pdf/2303.06523.pdf)

[4] Charalampopoulos et al., AT 2020wey and the class of faint and fast tidal disruption events. (https://ui.adsabs.harvard.edu/abs/2023A%26A...673A..95C/abstract) (2023)

[5] Beck et al., PS1-STRM: neural network source classification and photometric redshift catalogue for PS1 3π DR1. (https://ui.adsabs.harvard.edu/abs/2021MNRAS.500.1633B/abstract) (2021)

[6] Bell et al., The Optical and Near-Infrared Properties of Galaxies. I. Luminosity and Stellar Mass Functions (https://ui.adsabs.harvard.edu/abs/2003ApJS..149..289B/abstract) (2003)

[7] French et al., The Structure of Tidal Disruption Event Host Galaxies on Scales of Tens to Thousands of Parsecs (https://ui.adsabs.harvard.edu/abs/2020ApJ...891...93F/abstract) (2020)