Multiple Tidal Disruptions As An Indicator Of Binary Supermassive Black Holes

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Chris Wegg and Nate Bode

wegg@caltech.edu

Advisor: Sterl Phinney

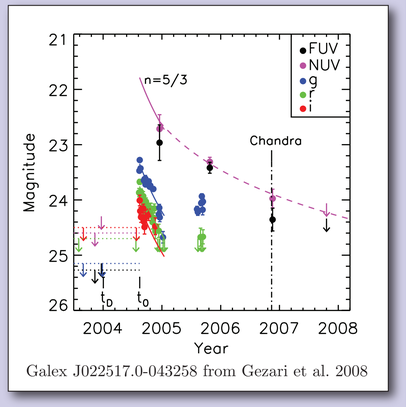
Caltech

0 Abstract

We find that the majority of systems hosting multiple tidal disruptions (TDs) are likely to contain hard binary supermassive black hole (SMBH) systems, and also show that the rates of these repeated events are high enough to be detected by the Large Synoptic Survey Telescope (LSST) over its lifetime. Therefore, these multiple TD events provide a novel method for identifying SMBH binary systems with parsec to subparsec separations. The rates of TDs are investigated using simulations of non-interacting stars initially orbiting a primary SMBH and the potential of the model stellar cusp. The stars are then evolved forward in time and perturbed by a secondary SMBH inspiraling from the edge of the cusp to its stalling radius. We find with conservative magnitude estimates that the next-generation transient survey LSST should detect multiple TDs in approximately three galaxies over five years of observation, though less conservative estimates could increase this rate by an order of magnitude.

1 What is a Tidal Disruption?

- Stars that pass within $r_t \sim r_\star \left(\frac{M_{\rm BH}}{M_\star}\right)^{1/3}$ of a SMBH get torn apart by tidal forces
- Half the star is unbound
- Half falls back at a rate (for late times) $dm/dt \propto t^{-5/3}$
- Modeling as a disk extending to r_t emitting at $L_{\rm edd}$ spectrum peaks in EUV/X-ray



Galex J022517.0-043258 from Gezari et al. 2008

But many, many, complications and uncertainties, e.g.
See Sw 1644+57 for situation analagous to Blazar

2 Idea

- The canonical TD rate is $\Gamma = \gamma 10^{-5}$ yr^{-1} with $\gamma \sim 1-10$ (Wang & Merritt, 2004)
- It has been suggested that merging SMBH binaries greatly enhance TD rate by up to $\Gamma = 1$ yr^{-1} (Chen et al., 2009; Ivanov et al. 2005)
- Probability of observing two TDs from the same galaxy $\propto \Gamma^2$ → systems with multiple TDs in $\sim$ 5–10 yrs must have high rate → Binary SMBH

3 Simulations of Stars around SMBH Binary

Need to calculate rate of disruptions that includes:

- Non-Keplarian Stellar potential
- Evolution of SMBH binary

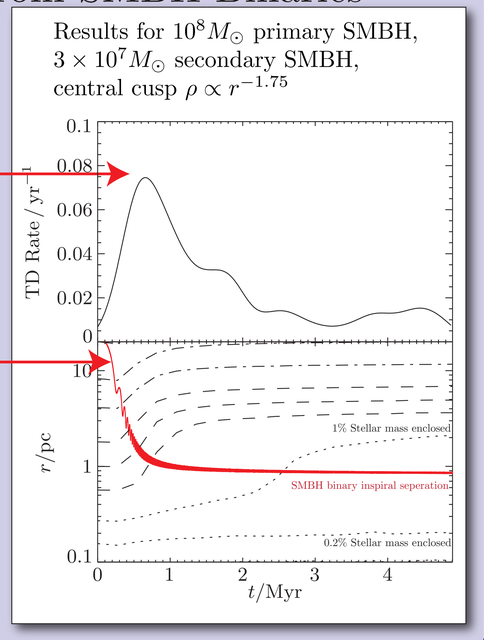
Simulations evolve a star under the influence of three components:

1. Primary SMBH
2. Primary surrounded by η-model cusp $\rho(r) = \frac{GM_1\eta}{2\pi r_c^3}\frac{1}{(r/r_c)^{3-\eta}(1+r/r_c)^{1+\eta}}$
   Source of initial conditions of star
   Source of non-Keplerian potential
3. Secondary SMBH spirals in.
   Inspiral path fitted to dynamical friction, stellar ejection and stalling

4 TD Rate From SMBH Binaries

TD rate greatly increased over isolated SMBH rate of 10^{-4}–10^{-5} yr^{-1}

Binary inspiral: Shows peak in TD rate occurs as SMBH binary stalls



5 Scaling to the Universe

Rate of TDs from single SMBHs

We calculate rates for high cadence optical surveys LSST, PTF and Pan-STARRS. Gezari et al. (2008) TDs have a mean abs g mag of -18.3 (see plot in panel 1)

⇒ Redshift limit of 0.35 , 0.06 , 0.35

⇒ We can observe TDs from $(30, 1, 1) \times 10^6$ galaxies which have black holes of mass 10^6–10^8 $M_\odot$

⇒ Assuming a rate of TDs of $\gamma \times 10^{-5}$ yr^{-1} we will observe TDs at a rate of $\sim 300\gamma$, 0.7γ, 0.7γ yr^{-1}

Number of multiple TDs from single SMBHs

Observing for 5 years the expected number of systems hosting a single SMBH exhibiting multiple tidal disruptions is $0.03\gamma^2$, $8\times10^{-4}\gamma^2$, $8\times10^{-4}\gamma^2$.

Rate of TDs from binary SMBHs

Using the results of our simulations and a local SMBH merger rate of 0.02 Gyr^{-1} Galaxy^{-1} we find overall rates from close SMBH binaries of 8 , 0.02 , 0.02 yr^{-1}.

Number of multiple TDs from binary SMBHs

Using the results of our simulations, we find during 5 years of observation we expect to observe 3 , 0.07 , 0.07 galaxies hosting binary SMBHs displaying multiple tidal disruptions.

In our fiducial model systems displaying multiple TDs are 100 times more likely to host a close SMBH binary than an isolated SMBH

6 Discussion and Caveats

- Monitoring systems that have already displayed a TD is a good strategy for finding more TDs and locating SMBH binaries.
- Once a double TD is detected these galaxies would be expected to have a steady TD rate, with further events on a human timescale.
- All rates/numbers scale with the redshift limits, ours are conservative - if the TD candidate of van Velzen (2010) with abs mag -20.3 was typical all numbers would increase by an order of magnitude.
- We have chosen a steep cusp - centrally $\rho \propto r^{-1.75}$. Rates of tidal disruptions from close binaries could potentially also probe cusp densities.
- A much higher γ, or other transient increases in the TD rate could cause contamination, but other signatures will likely identify TDs that occurred in SMBH binaries. These include possible spectroscopic signatures, morphology or kinematics indicating a recent major merger, or interruption of the TD flare (Liu, 2009).