Are optical TDEs really TDEs? 
Stellar dynamics constraints

Micro-TDEs predict ultra-long (likely faint) GRBs

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Optical TDEs could naturally explain nuclear transients in apparently non-AGN galaxies
TDE interpretation has several potential problems

- Surprises/problems
  - Peculiar spectra (?)
  - E+A host galaxies: enhanced rate X50
  - TDE rate problem: taking out the E+A →
    → rate problem for the rest → too low ?
  - TDE hosts MBH mass distribution
  - Potentially too small inferred mass/energy (?)
  - Light curves issues, lack of delay (?)
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The peculiar spectra raise constrains on the transient source/structure

- Surprises/problems
  - Peculiar spectra (?) - line ratios, equivalent width
  - Not necessarily a problem, but introduces on constraints on any successful model (whether TDE or otherwise)

Saxton, Perets & Baskin (2016) pointed out the difficulty with getting both the line ratios and equivalent width → suggested a solution very similar to what discussed already in Roth and Kocahnek talks
Several models for rate enhancement exist

- Non-spherical potentials (Vasiliev & Merritt → not a very significant enhancement)
- Radial anisotropy → Nick’s talk
- Massive perturbers
- Steep dense nuclear cusp
- Eccentric disk
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- Non-spherical potentials (Vasiliev & Merritt → not a very significant enhancement)
- Radial anisotropy → Nick’s talk
- Massive perturbers:
  - GMCs and nuclear spiral arms:
    factor 2 enhancement; larger for binary disruption and evolved stars (Perets et al. 2007, Hamers & Perets 2017)
  - Infall of newly formed massive IMBH hosting clusters → $10^{-3}$ yr$^{-1}$ (Mastrobuonno-Battisti, Perets & Loeb 2014)
    > both increased following mergers and may operate over long timescales
  - Binary MBHs → discussed → likely too long inspiral times to explain E+A result
TDE interpretation: rate enhancement

• Compact, steep cusp
  – Requires significant fraction of the of the nuclear cluster mass to form on short time scales
  – Can one form so many stars and so close to the MBH ?
  – Need to get read of the nuclear gas mass on short timescales (otherwise $\rightarrow$ AGN)
  – Too steep MBH mass dependence
  – Mass segregation will shorten the timescale for making cusp shallower
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Aharon, Mastrobuonno-Battisti & Perets
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What is the expected dependence on MBH mass?

- Theoretical considerations of the loss-cone dynamics suggest (Merritt & Wang 2005)
  \[ \dot{N} \propto M_{BH}^{\delta}, \quad \delta = \frac{27 - 19\gamma}{6(4 - \gamma)} \]

- Where \( \gamma \) is the density profile
  - e.g. BW \( \rightarrow \gamma = 7/4 \ (3/2) \rightarrow \delta = -0.46 \ (-0.1) \)
  - Steep \( \gamma = 2.5 \ (2.75) \rightarrow \delta = -2.3 \ (-3.7) \)

- This dependence needs to be convoluted with the MBH mass function
• Mass distribution of E+A galaxies and their MBHs

![Histogram of TDEs](#)

![Graph of SFR vs. Star Formation Rate](#)

Law-Smith et al. 2017

Wevers et al. 2017
E+A MBH mass function
The diagram shows a cumulative distribution function (CDF) plot with the following key features:

- **Log10(M_\text{BH})** on the x-axis.
- **Cumulative Fraction** on the y-axis.

The lines represent different mass functions:

- Red line: Optical TDEs
- Blue line: E+A (below 7.4)
- Green line: M^{-0.3} E+A
- Purple line: M^{-1.2} E+A
- Gray line: M^{-1} E+A

A label for **M^{-0.3}** is also present on the plot.
E+A MBH mass function

\[ M^{-1.2} \]

\[ M^{-1} \]

Cumulative Fraction

Log10(M_{BH})
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E+A MBH mass function

$M^{-2.3}$

$M^{-3.6}$

Cumulative Fraction vs. Log10($M_{BH}$)

- Red: Optical TDEs
- Blue: E+A (below 7.4)
- Magenta: $M^{-2.3}$ E+A
- Black: $M^{-3.67}$ E+A
Selection effects do not solve the discrepancy
Where are the TDEs in regular galaxies?

• The rate estimates of $10^{-4}$ per yr were not derived from rare steep galaxies, but from typical local neighborhood galaxies.
Quenching of secular processes

- Secular processes are highly sensitive to additional sources or precession (see also Chang 2008; Haas & Subr 2016 for stellar disks for disk-induced Kozai)

- In M31 the nuclear cluster may still contain 1/10-1/8 of the eccentric disk mass

  The model neglects the gravitational influence of the nuclear disk on the bulge, since its mass is only 16% of the BH mass in the best-fit model; the model also neglects the influence of the bulge on the nuclear disk, since its mass interior to 1" is only 2% of the BH mass.

  Tremaine 1995

- More generally one requires to scour the NSC very significantly when the disk forms
Scouring of a nucleus can happen through inefficient cluster build-up

- Infalling clusters are disrupted beyond the radius of influence

Stars at $R_c$ from the infalling cluster center are stripped by MBH and the NSC at $R_s$, defined as the tidal radius for stars at that position:

$$R_s = \left( \frac{M_{BH} + M_{NSC(< R_t)}}{M(< R_c)} \right)^{1/3} R_c$$
Scouring of a nucleus can happen through inefficient cluster build-up

- Low mass nuclear cluster form only for MBHs more massive than $10^{8.5}$ Msun

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$$R_s = \left( \frac{M_{BH} + M_{NSC}(\leq R_t)}{M(\leq R_c)} \right)^{1/3} R_c$$

Antonini et al. 2015
Scouring of a nucleus can happen through binary MBH merger

- Binary MBH merger
But scoured nucleus can regenerate.
It takes them a relaxation time or so
Can eccentric disks or AGN disk instabilities solve the problems?

- Still await more quantitative models...
- Mass dependence:
  - eccentric disks → too high
  - Steep cusps → too low
  - Starved-disk instability → ? preference for low mass… (Phinney’s talk)
- Rates:
  - High rates in E+A galaxies and even higher for star-forming galaxies could be natural for both the starved-AGNs disk instability (Saxton, HP+16; Phinney’s talk) and the eccentric disk (Madigan+17)
  - Low rates for other galaxies – problem for any TDE model

- Observed jetted TDEs; X-rays:
  - Starved AGN → preference for face-on galaxies
  - Eccentric disk → Kozai-Lidov like behavior (Haas & Subr 2016) would suggest preference for more edge-on galaxies
Summary

• The rates of optical TDE-candidates are too high for E+A galaxies
• The rates of optical TDE-candidates elsewhere are too low
• The host MBH mass distribution inconsistent with TDE models expectation; highly inconsistent with enhanced-rates models (too high or too low) – sit in the TDE anti-Goldilocks region
• Can starved-AGN disk instability explain these?
• Are optical TDEs really TDEs?
Tidal disruptions occur on many scales

Shoemaker-Levi comet
We focus on “Micro-TDEs”: disruption of stars/planets by stellar compact objects $\sim 10^{-6}$ MBH mass (standard TDEs)

- Most of tidal disruption by stellar compact objects focused on disruption of other compact objects (e.g. Ruffert 1992)
- We try to characterize micro-TDEs; tidal disruptions by stellar BHs and neutron stars
The evolution and properties of μ-TDEs differ from TDEs

Partial disruption of a solar mass star by 10 solar mass BH Rp=2.15 Rsun

Simulations by J. Lombardi, using the SmashStar SPH hydro code (high-res 350K and low-res 50K particles)
The fall-back timescales for μ-TDEs are of the order of a few 1000 s

\[ t_{\text{min}} = \frac{2\pi R_p^3}{(GM_\odot)^{1/2}(2R_\star)^{3/2}} \approx 2469 \left( \frac{R_p}{1.3R_\odot} \right)^3 \left( \frac{R_\star}{0.6R_\odot} \right)^{3/2} \left( \frac{M_\bullet}{10M_\odot} \right)^{-1/2} \] s
The fraction and infall rate of fall-back material depends on the closest approach.

<table>
<thead>
<tr>
<th>$R_p , (R_\odot)$</th>
<th>Fraction of bound material</th>
<th>Return rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.29</td>
<td>0.35</td>
<td>$t \propto t^{-2.7}$</td>
</tr>
<tr>
<td>1.94</td>
<td>0.09</td>
<td>$t \propto t^{-3.6}$</td>
</tr>
<tr>
<td>2.15</td>
<td>0.05</td>
<td>$t \propto t^{-3.6}$</td>
</tr>
</tbody>
</table>
The fall-back material accretes on the compact-object on the viscous timescale - $10^4$-10$^6$ s

- Accretion flare timescale
  - For a MS star/planet $\sim 10^4$ s
  - For a red giant $\sim 10^6$ s

$$t_{\text{acc}} \approx \frac{t_{\text{kep}}(2R_p)}{\alpha 2\pi h^2} \approx 3.6 \times 10^4 h^{-2} \left(\frac{\alpha}{0.1}\right)^{-1} \left(\frac{R_p}{1.3R_\odot}\right)^{3/2} \left(\frac{M_\bullet}{10M_\odot}\right)^{-1/2} \text{ s}$$
The accretion flare energy depends on the accretion scenario

- The radiated energy: 
  
  \[ E_f = \eta f_{acc} M_\star c^2 \]

  - \( \eta \) is the rest-mass to radiation efficiency
  - \( f_{acc} \) is the fraction of the mass accreted on the BH

- In the naïve case of complete accretion

  \[ E_f = 1.2 \times 10^{52} \left( \frac{f_{fall}}{0.1} \left( \frac{\zeta}{1} \right) \left( \frac{\eta}{0.1} \right) \left( \frac{M_\star}{0.6 M_\odot} \right) \right) \text{ ergs} \]

  - \( f_{acc} = \zeta f_{fall} \); \( \zeta \) is the fraction of the fallback debris accreted onto the BH
Outflows can significantly reduce the fraction of accreted material

- The radiated energy:
  \[ E_f = \eta f_{\text{acc}} M_\times c^2 \]
  - \( \eta \) is the rest-mass to radiation efficiency
  - \( f_{\text{acc}} \) is the fraction of the mass accreted on the BH
- In a convection dominated accretion flow outflows eject most of the material

\[ f_{\text{acc}} \sim 8.3 \times 10^{-5} f_{\text{fall}} \left( \frac{\alpha}{0.1} \right) \left( \frac{R_p/1.3R_\odot}{r_s} \right)^{-1} \]

and so we get only \(~10^{-4}\) of the energy
The rates of \( \mu \)-TDEs could be high and arise from various channels

- **Close encounters in dense clusters:**
  - Old environment: In globular clusters: \(~10^{-7}\) (NS \( \mu \)-TDEs) and \(~10^{-6}\) (BH \( \mu \)-TDEs) yr\(^{-1}\) per MW galaxy
  - Young environments: Young superclusters in star-forming galaxies

- **Natal kicks** can kick NS/BHs onto their companions and disrupt them (rates depend on the binary properties and evolution – pop-syn calculations in progress)
  - Young environments
  - Would be associated with a SN – typically a few days after collapse

- **Perturbations of wide (>10^3 AU) binaries in the field**
  - Could reach rates of \( 10^{-7}\) per MW galaxy (for BHs from direct collapse)
Post natal-kick $\mu$-TDEs may naturally produce eccentric $\mu$-TDEs with multiple periodic flarings.

Eccentricity 0.9; $R_p=4.2$ Rsun
Summary:
μ-TDEs may produce long, faint GRBs/XRFs and could be important targets for transient surveys

- They might be related to the new subclass of ultra-long GRBs (see Levan 2015 for an overview)
- Could be associated with CC SNe
- Maybe explain the late flare in (short) GRB 050709 (16 days after the GRB !)
- Environment and host galaxies depend on dominant formation channel