Tidal Disruption Events
Relativistic spectral line reverberation

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Supermassive Black Holes in the Universe

BHs and Galaxies co-evolution
Growth of BHs
SMBH mass ?
SMBH spin ?

TDEs: Critical probe of more than 90% SMBHs in the Universe

SMBHs in Normal Galaxies
Tidal Disruption Events (TDEs): Theory

When a star is passing too close to a SMBH, it can be shredded by strong tidal forces partially or entirely, producing optical, UV, and X-ray flares due to accretion of the debris of the star.

Some pioneer works:

Hills, 1975, Nautre, 254, 295:
“Possible power source of Seyfert galaxies and QSOs’

Carter & Luminet, 1982, Nature, 296, 211:
“Pancake detonation of stars by black holes in galactic nuclei”

Rees, 1988, Nature, 333, 523:
“Tidal disruption of stars by black holes of $10^6 - 10^8$ solar masses in nearby galaxies

Rees, 1990, Science, 247, 817:
“Dead Quasars” in Nearby Galaxies?

TDEs were initially associated with bright SMBHs...

But they are different from flares in AGNs!
Tidal Disruption Events (TDEs): Theory

A star will be disrupted by a central supermassive black hole when $R_p < R_T = R_\star (M_\bullet / M_\star)^{1/3}$.

A fraction of the stellar debris falls back onto the black hole and is accreted, resulting in a luminous flare.

For $M_\bullet > 10^8 M_\odot$, $R_T < R_{Sch}$, and the star is swallowed whole.

Predictions for the disruption of normal stars like our Sun by SMBHs of $\sim M=10^7$ solar masses (Based on fall-back mass rate only):

Luminosity: $L \sim L_{Edd} = 1.3 \times 10^{45} M_7$ erg s$^{-1}$
Temperature: $T_{eff} \sim 3 \times 10^{5} M_7^{-1/12}$
Light curve: $L(t) \sim (t-t_0)^{-5/3}$
Tidal Disruption Flares: the Rise

The rise is not well known but can be fast - a few weeks or less!!

TDE flares seen with the ROSAT  (Kommosa et al. 2002)
Observations of X-ray Flares of Three Relativistic TDEs

Swift J1644+57, Swift J2058+05, and Swift J1112-8238

Brown et al. MNRAS 2015;452:4297-4306
X-ray Flares of TDEs: Relativistic Events and Classical TDE

From Brown et al. MNRAS 2015;452:4297-4306
Tidal Disruption Flares: the Rise

The rise is not well known but can be fast - a few weeks or less!!

RISE: corresponds to an extremely large range of mass accretion rate:
- observed luminosity range: $10^{35}$ ergs/s – $10^{47}$ ergs/s

RISE: barely known (in both theory and observation aspects)
- the start of the flare would occur weeks before its peak
Observations of X-ray Flares of Three Relativistic TDEs

Swift J1644+57, Swift J2058+05, and Swift J1112-8238
Iron Line Reverberation in AGN Cases
Reverberation mapping with the iron lines due to illuminating X-ray flares

- proposed for the study of the iron line response to the illuminating flares in AGNs (before the Chandra era)
- model based on hard X-ray irradiation of cold, dense matter in the innermost disk inside $\sim 100$ Rg
- broad, relativistic iron lines to probe black hole mass and spin

Young & Reynolds 2000
The idea: a $\delta$-function illumination flare generating an expanding ionization circle

- A circle of illumination in the rest frame
- Expanding with light speed

region passed by ionization circle
Reverberation mapping: Schwarzschild BHs

Young & Reynolds 2000

part of the ionization circle is seen because of significant light travel effect

Separation between the double line peaks become narrower with time due to
1) reduced gravitational redshift  2) reduced Doppler effect
Reverberation mapping: case of Kerr BHs

different from the Schwartzchild BH case:
A “red-ward moving bump” - signature of a Kerr SMBH

Young & Reynolds 2000
Iron line reverberation mapping of the innermost disks
AGNs vs. Previously dormant SMBHs (TD flares)

**AGN**
- Coupling between the iron line and the ionization flux
- Illuminations by both persistent flux and flares exist!
- Only recently results are achieved from averaging flares

**TD flares**
- A newly formed disk has not been ionized
- X-ray flare illuminates and ionized the fresh disk
- Rising edge of the luminous TD (X-ray) flare serves as the “δ-function” illumination

TD flares from previously dormant SMBHs are perfect targets

Potential application in the spectral lines in the UV band
Prediction of Line Reverberation in TDEs


ionization circle
Prediction of Line Reverberation in TDEs


ionization circle
Predictions of Line Profiles in the TDE cases


Loop feature

Redward tail

Loop feature

Schwarzschild BH Case

Kerr BH case
The Maximum Mass of SMBHs in TDEs: Kerr BHs

For Kerr SMBHs, the ISCO radius is much smaller than that of Schwartzchild SMBHs:

- The disruption radius can be:
  \[ \sim 5 \text{ time smaller} \]

- For the disruption of sun-like stars, the maximum mass of the SMBHs can be:
  \[ \sim 7 \times 10^8 \text{ solar masses} \]

Cases of the disruption of giant stars or stars less compact, or cases of partial disruptions would point to more massive SMBHs in TDEs.

Kesden 2012, PhRvD, 85, 4037
The Maximum Mass of SMBHs in TDEs

“An ultraluminous quasar with a twelve-billion solar mass black hole at redshift 6.30”

M = 1.2 x 10^{10} solar masses


Wu et al. 2015, Nature 518, 512
General conclusion:

- Peak mass accretion rate is about 10% of the classical expectation
- The mass accretion rate peaks 3-8 times later
Early Detection of Tidal Disruption Events in Radio
Multi-wavelength survey and future early alerts from SKA

SMBH fundamental plane for AGNs (Merloni et al. 2005)

SKA Science White book
Chapter (Yu et al. 2015):

Due to its large FOV and high sensitivity, SKA has the potential to lead next generation X-ray monitoring of black hole transients

Towards lower accretion rate regimes the radio luminosity decreases slower than the X-ray luminosity

SKA’s detection sensitivity corresponds to 1-2 orders of magnitude lower than next generation X-ray all sky monitors = sending out alerts about 1-2 weeks earlier
Summary

1. X-ray flares of TDEs provide us the opportunity to measure dormant SMBH mass and spin through spectral reverberation, as well as.

2. The early rising phase of the TDE outburst, if our current understanding of black hole accretion applies to TDEs, would be accompanied by radio emission well above the sensitivity of the Square Kilometer Array (SKA) - the future radio wide field telescope.