星系宇宙学重点实验室系列讲座

超大质量黑洞撕裂恒星事件

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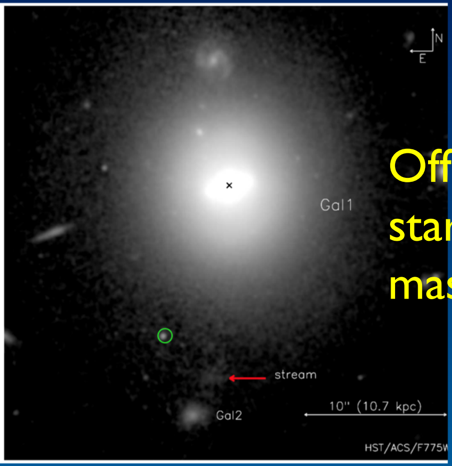
DIVERSITY OR IMPOSERS ?

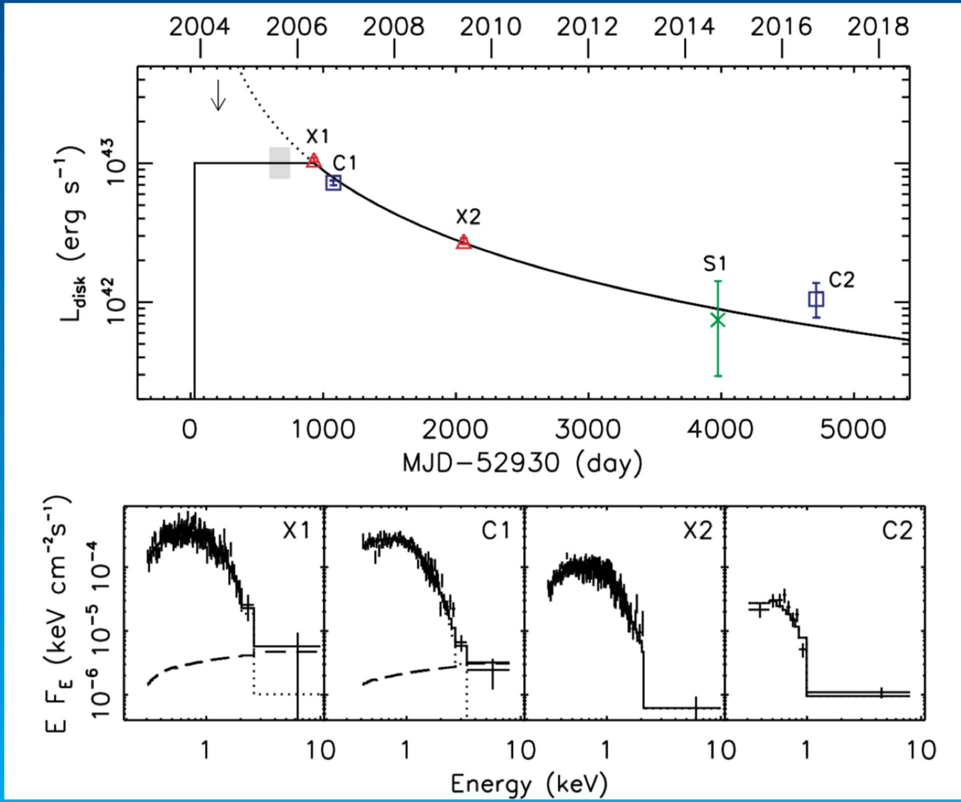
A LUMINOUS X-RAY OUTBURST FROM AN INTERMEDIATE-MASS BLACK HOLE IN AN OFF-CENTRE STAR CLUSTER

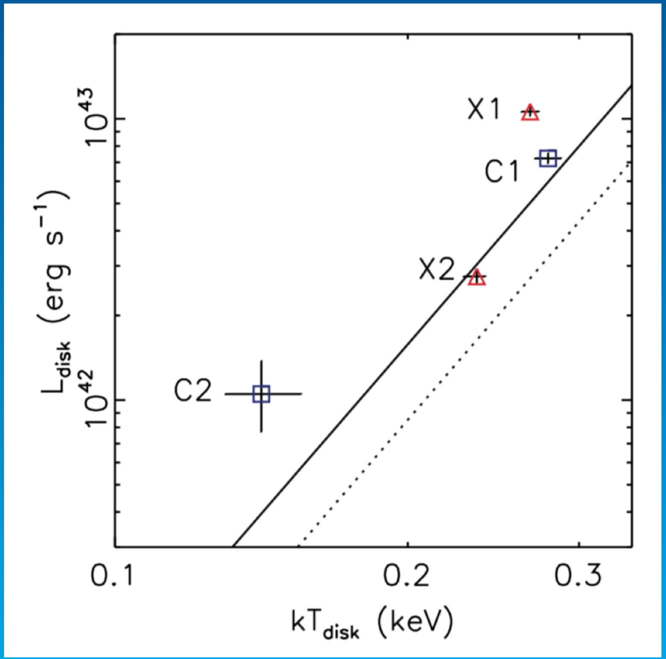
Dacheng Lin et al. 2018

6dFGS gJ215022.2-055059



Off nuclear star cluster of mass ~$10^7 M_\odot$



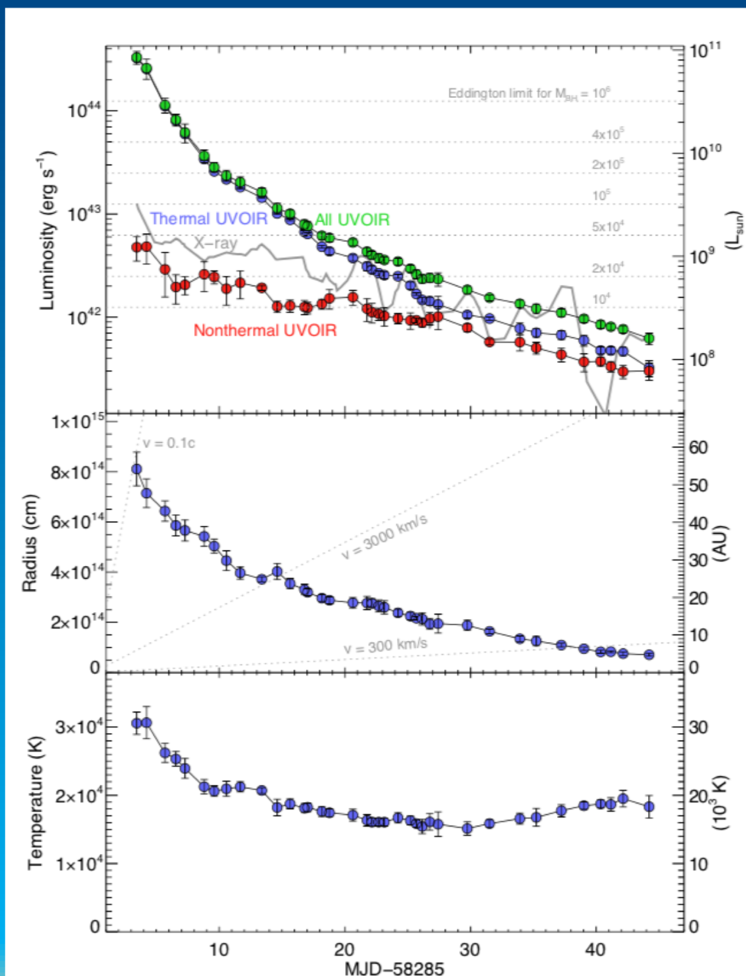


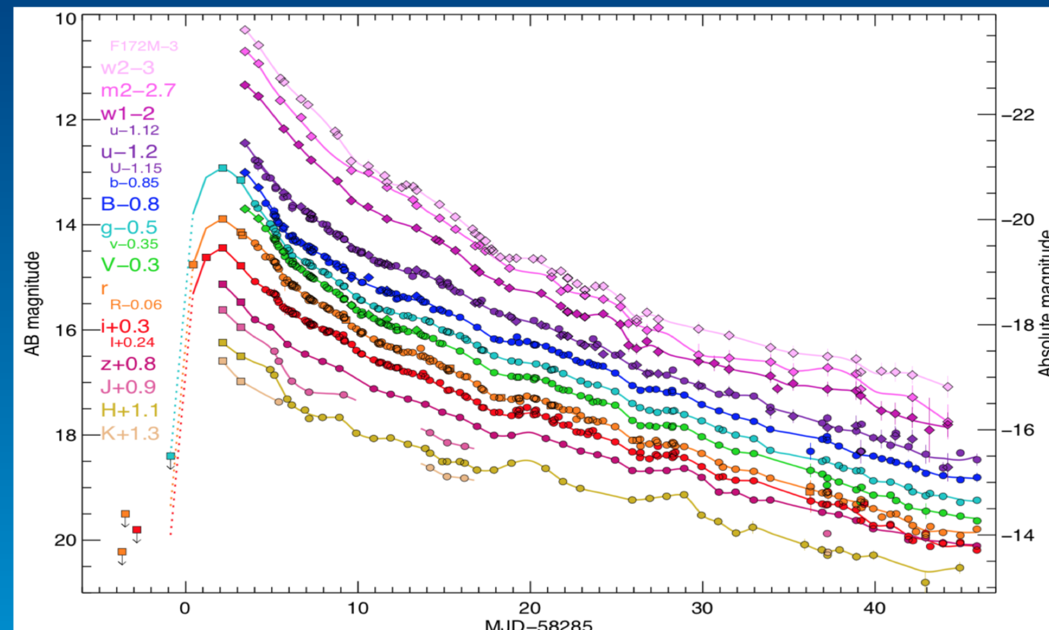
Decade long X-ray flares, black body disk emission

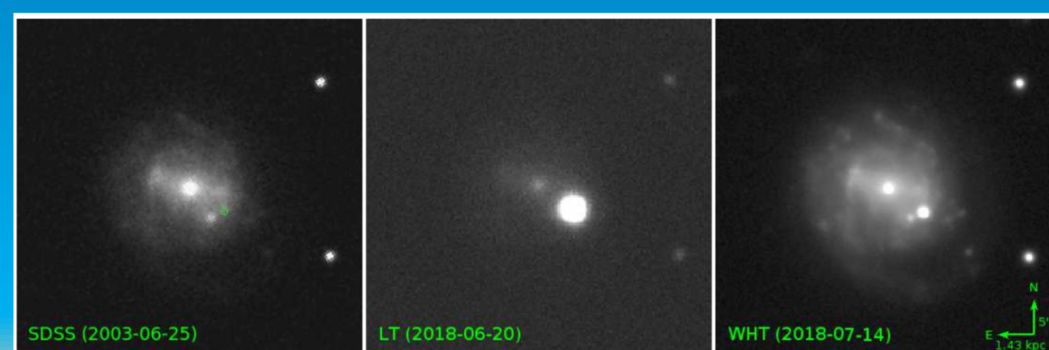
AT2018COW: WD DISRUPTED BY IMBH?

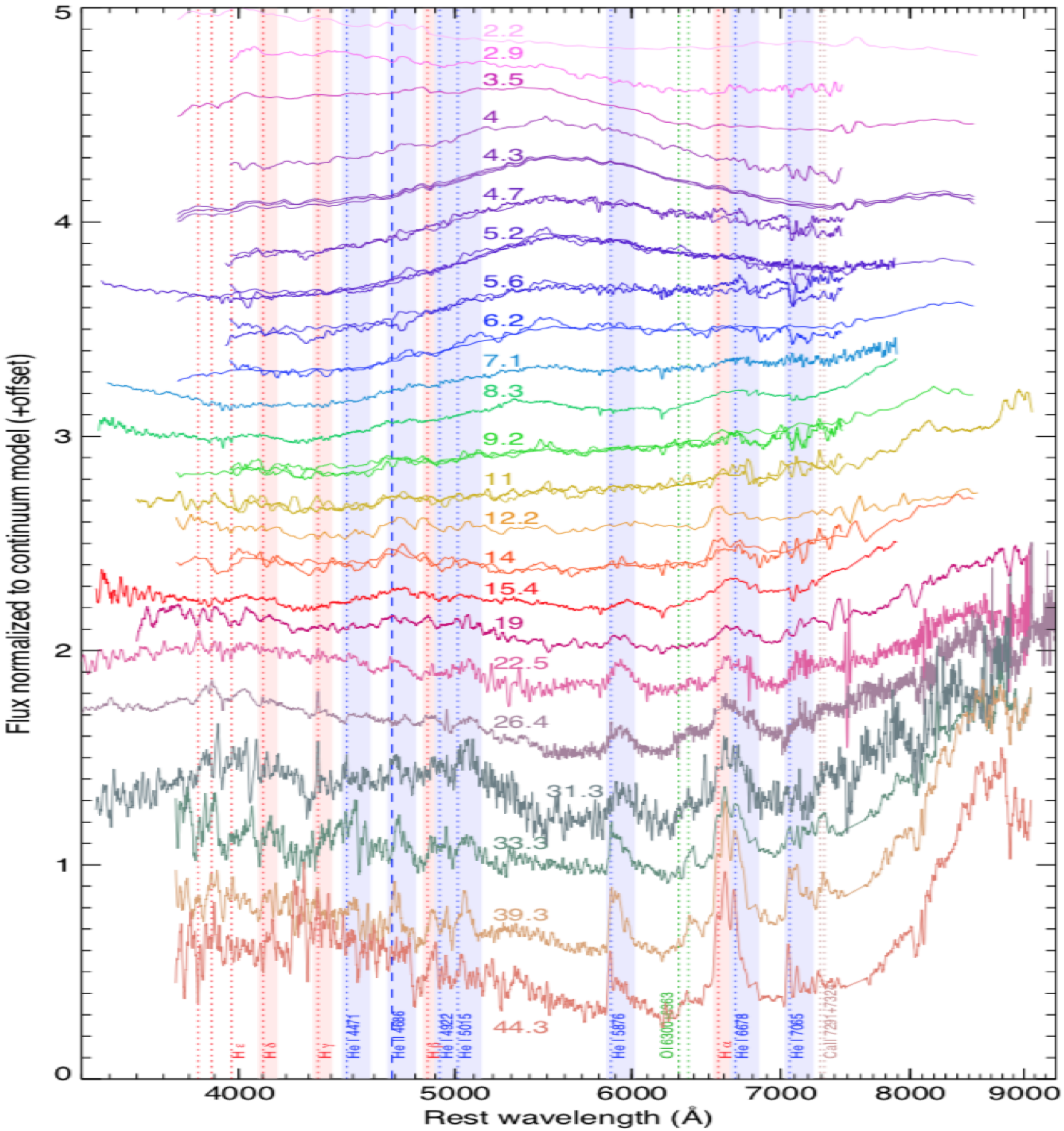
Perley+18;Prentice+ ‘18;Kuin+ ‘18; Rivera Sandoval+18

Short duration ~ week in optical
~ a month in X-ray
Louv~10^{44} erg/s; Lx~10^{43} erg/s
Strong He line but no CNO lines
off nucleus in galaxy Z 137-068. GC?



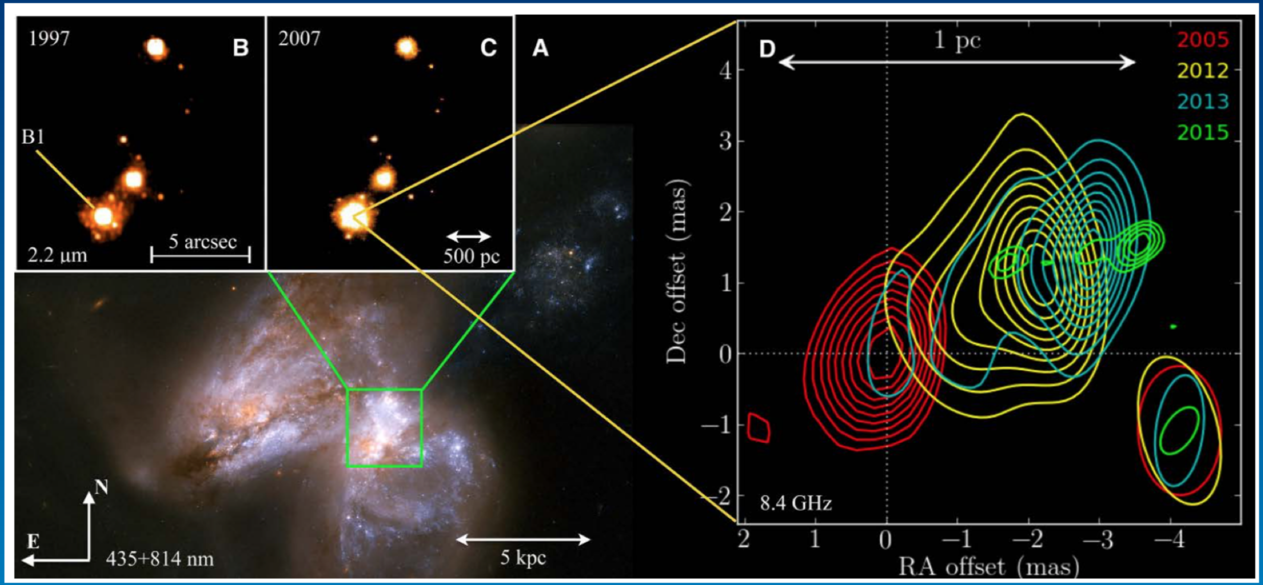


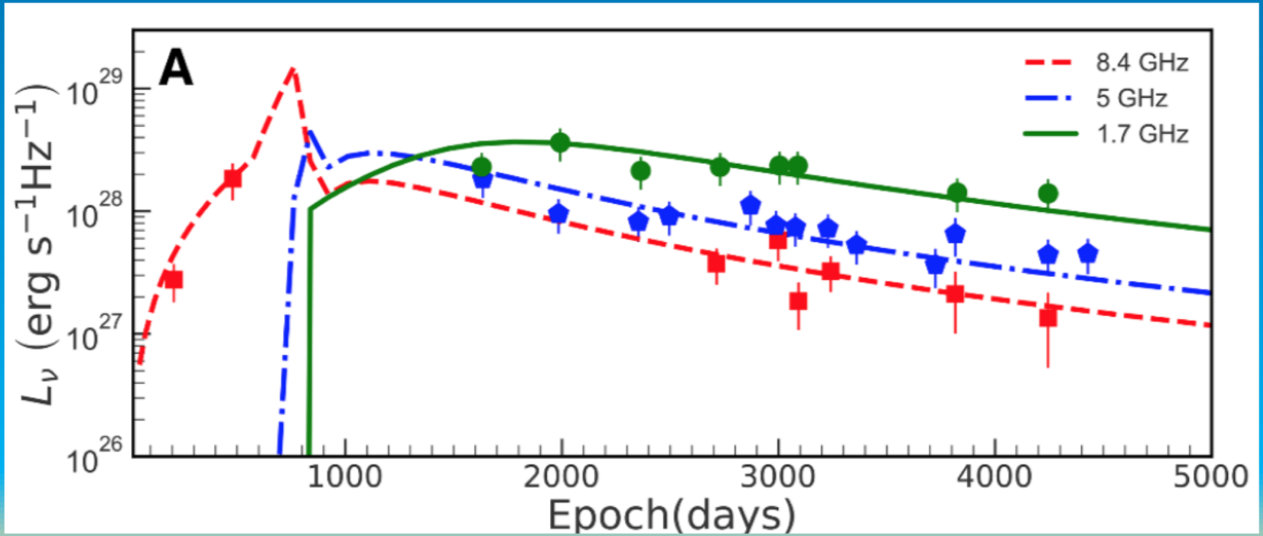




Flux normalized to continuum model (+offset)
Rest wavelength (Å)
2.2
2.9
3.5
4
4.3
4.7
5.2
5.6
6.2
7.1
8.3
9.2
11
12.2
14
15.4
19
22.5
26.4
31.3
33.3
39.3
44.3

A DUST-ENSHROUDED TIDAL DISRUPTION EVENT WITH A RESOLVED RADIO JET IN A GALAXY MERGER S. MATTILA+, *SCIENCE*





Arp 299-B AT1, 44.8 Mpc

NIR+radio flare

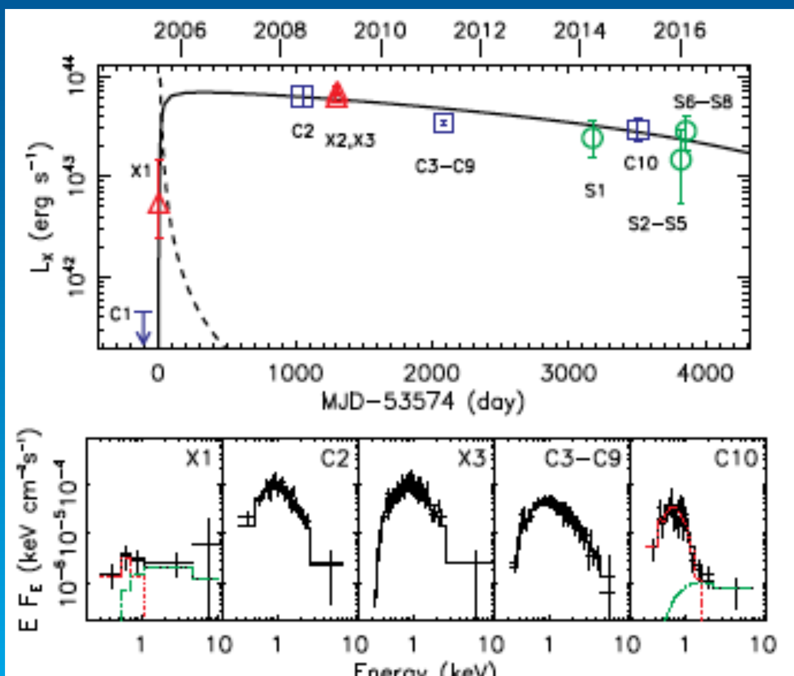
- >10 years
- >1.5 × 10^{52} erg

optical and X-ray weak

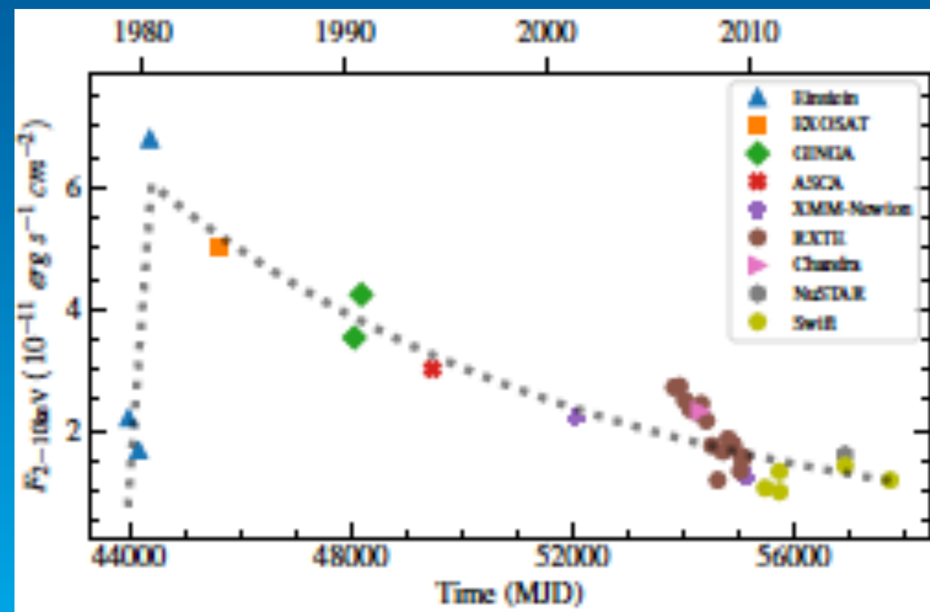
offset jet

DECADE LONG FLARES /SLOWED TDE/PARTIAL DISRUPTION?

XJ1500+0154, Lin et al. 2017

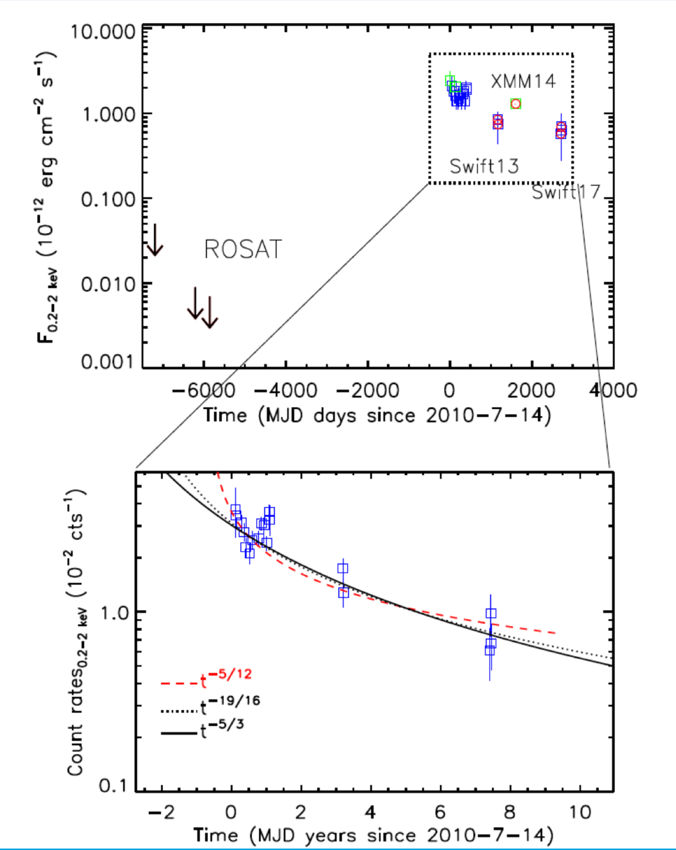


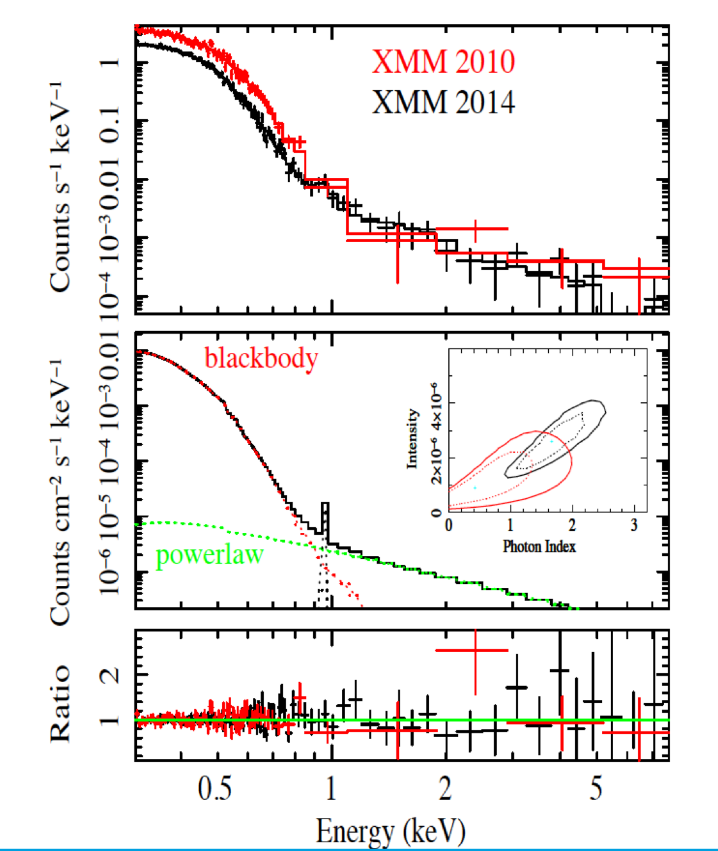
NGC 7213, Yan & Xie 2017



Motivated by partial disruption model of Guillochon+15

GSN 069: ANOTHER SLOWED TDE?



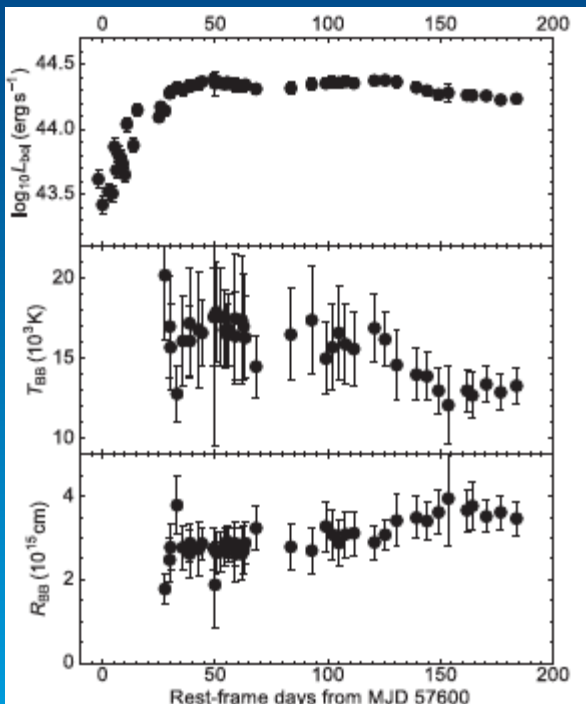


New Swift observation confirmed the long term decline after a factor of 300x brighten in X-rays.

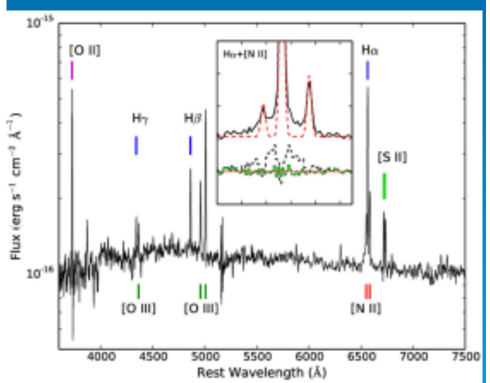
Shu et al. 2018 ApJL accepted

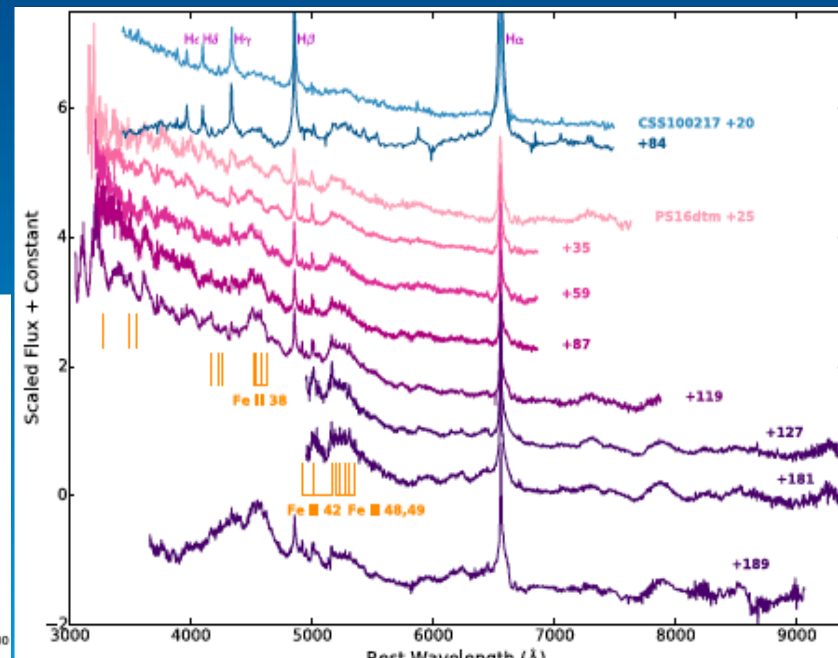
PS16DTM:A TIDAL DISRUPTION EVENT IN A NARROW-LINE SEYFERT 1 GALAXY ?

Blanchard et al. 2017;
IR echo Jiang et al. 2017

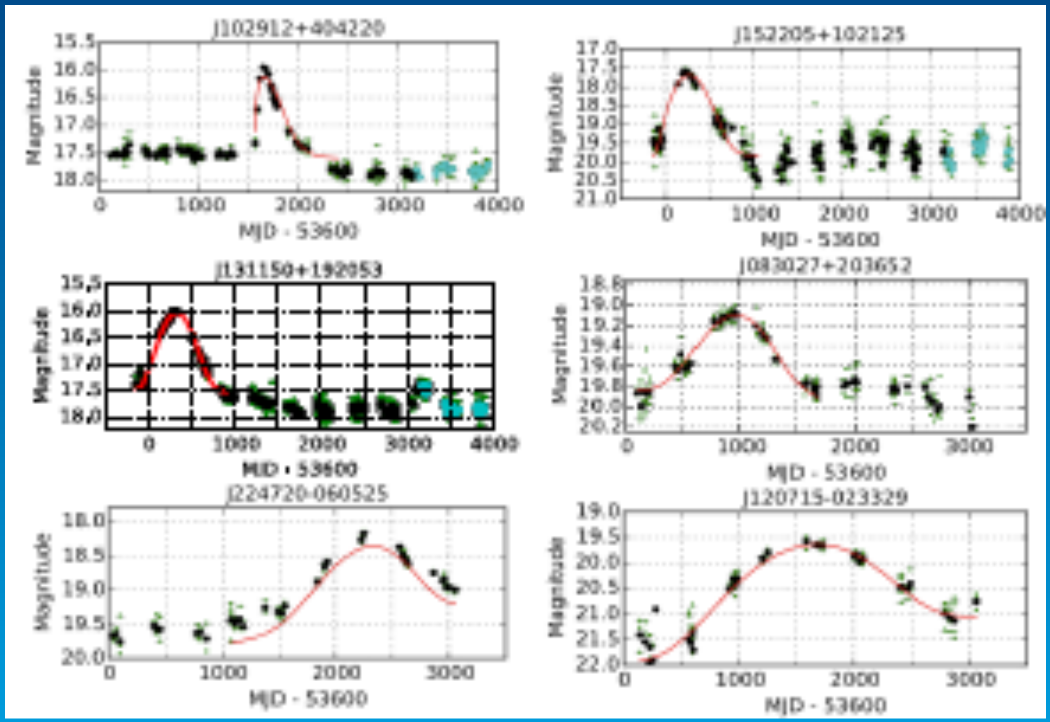


Blanchard





AGNS WITH MAJOR FLARES: TDE OR DISK INSTABILITY



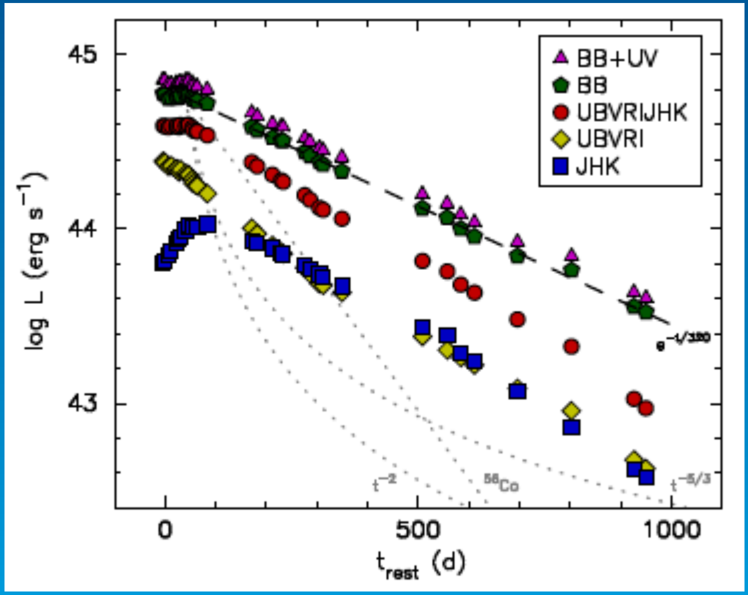
Graham et al. 2017

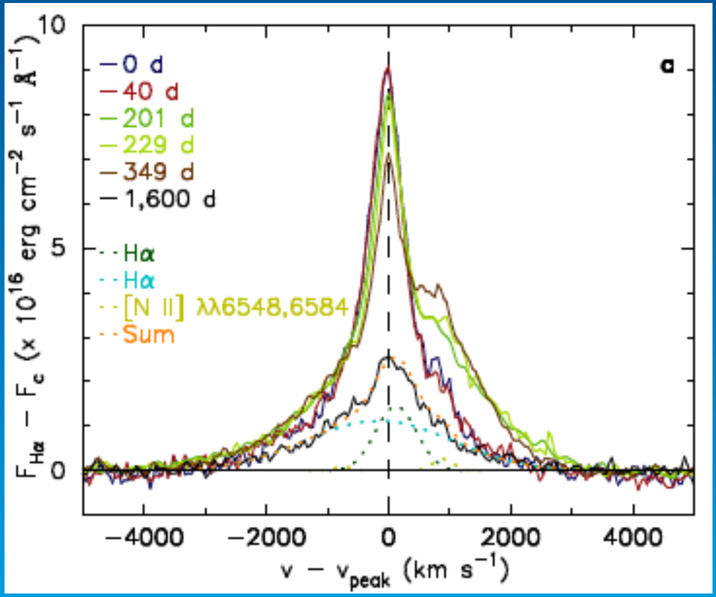
- Time scales: inner region radiation pressure instability?
- Changing look AGN/turn-on (off) AGNs
- TDE?

A POPULATION OF HIGHLY ENERGETIC TRANSIENT EVENTS IN THE CENTRES OF ACTIVE GALAXIES

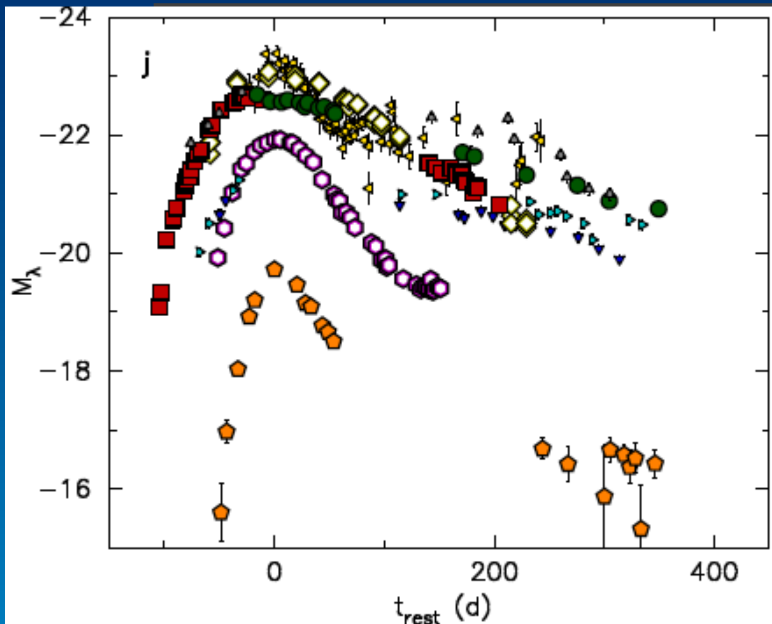
Kankare et al. 2017

- Eint= 2.3×10^{52} erg; strong FeII emission during the flares

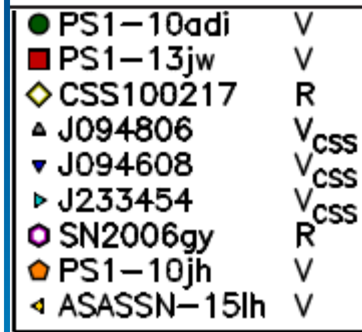




Kankare et al. 2017



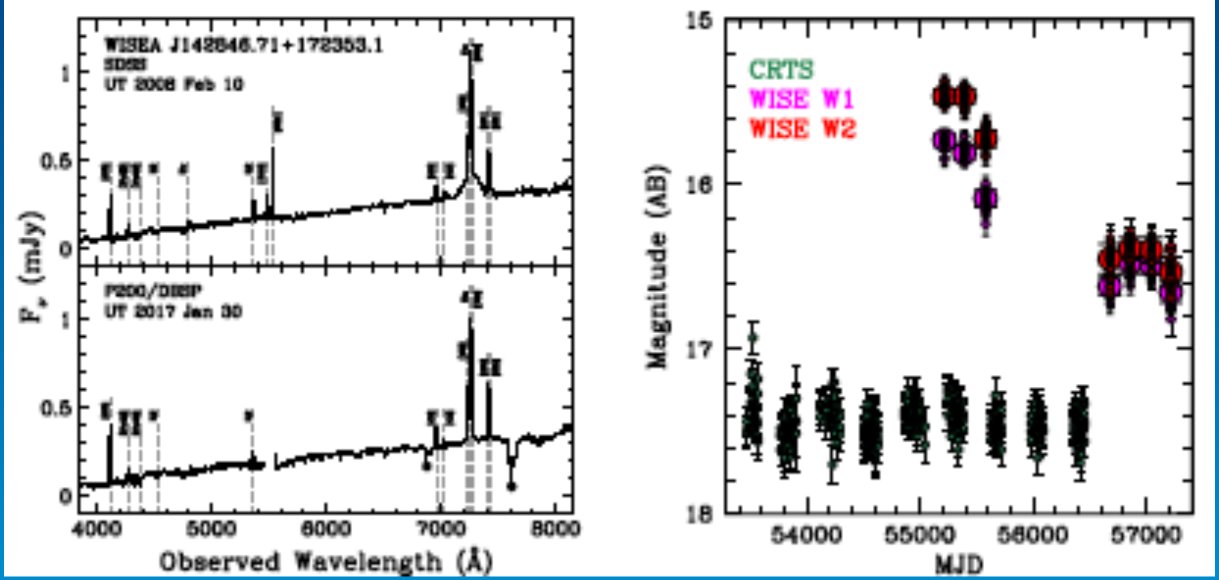
Transient	Host	Type[1]	ROSAT[2]	z^2
PS1-10adi	SDSS J204244.74+153032.1	-	N	0.203
PS1-13jw	SDSS J084453.56+425744.8	S1n	Y	0.345
CSS100217	SDSS J102912.58+404219.7	S1	N	0.147
J094806	SDSS J094806.55+031801.9	AGN	N	0.207
J094608	SDSS J094608.49+351222.4	S1n	Y	0.119
J233454	SDSS J233454.07+145712.8	S1	N	0.107



Kankare et al. 2017

- Be more luminous and lasts longer than previous known TDEs and SLSNs, but comparable to ASASSN-15lh
- They found 5 other similar transient events, all are AGNs.

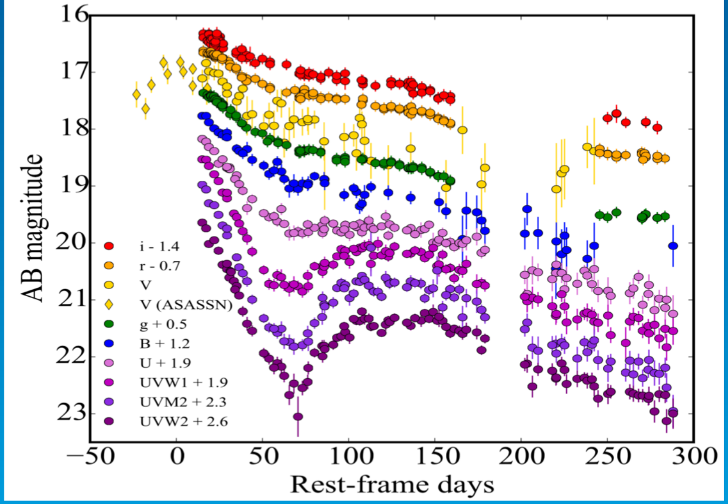
CHANGING LOOK/TURN ON(OFF) AGNS

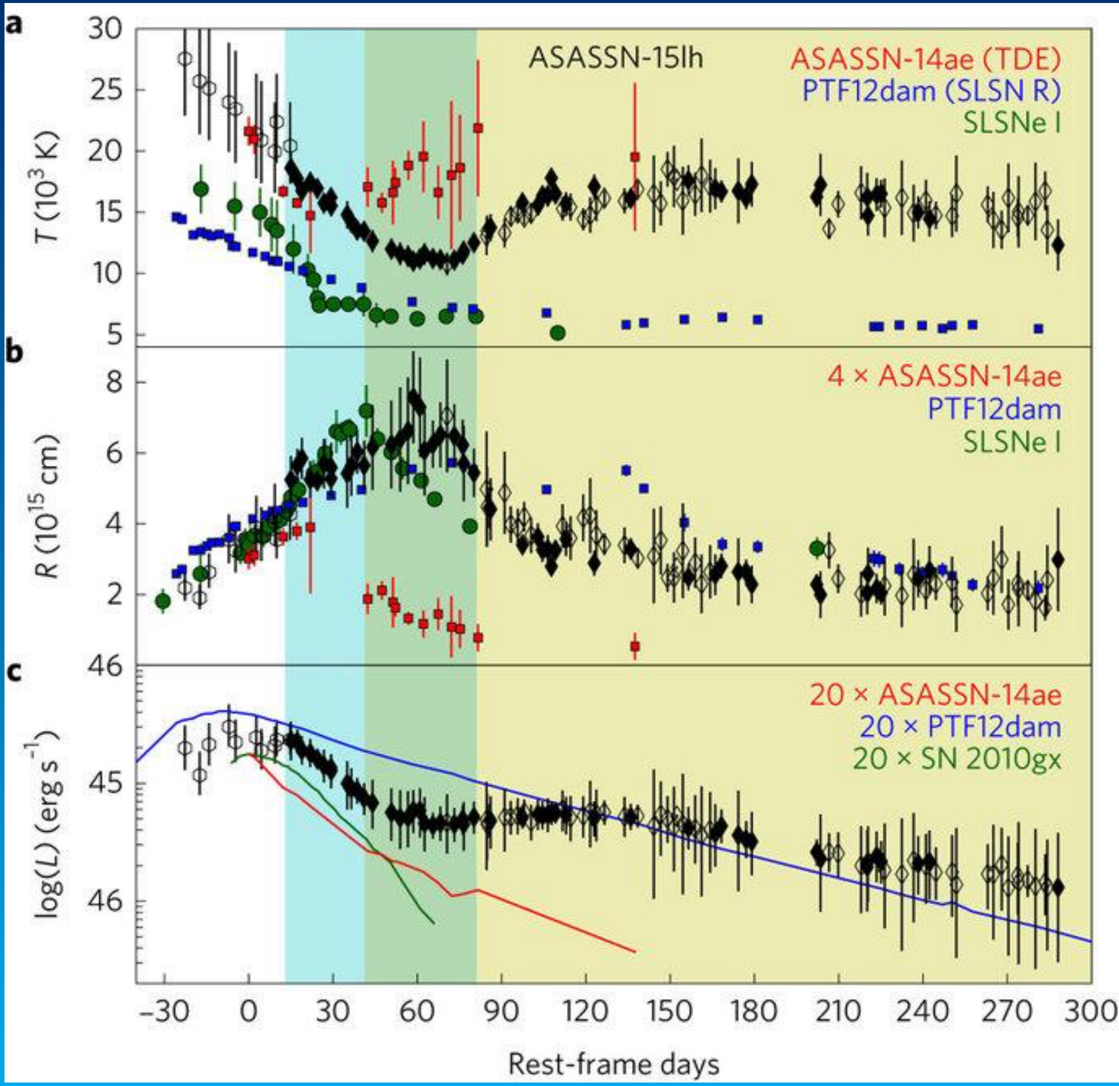


- Gezari et al. 2017
- Sheng et al. 2017
- Assef et al. 2017
- Wu et al. 2017

ASASSN-15LH: MOST LUMINOUS SN OR TDE IN MASSIVE GALAXIES

$M_{\bullet} \sim 10^{8.6} M_{\odot}$

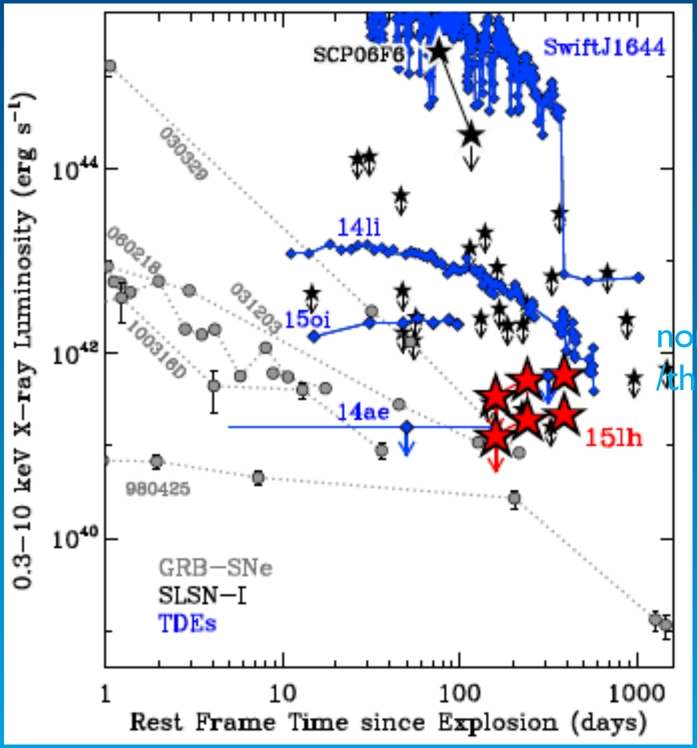




Dong et al. 2015,
Leloudas et al. 2016;

ASASSN-15LH

- *Detection of soft X-ray:* $L_x \sim 10^{41}$–10^{42} erg s^{-1} during UV rebrigtening



nonther
/themal

Margutti et al. 2017

Opacity change due to gas being ionized --> gas become transparent to soft X-rays

X-ray rebrightening is observed in other objects as well.

Explanation is not unique, lack of good spectrum cannot rule other possibility such as interaction of unbound debris with torus.

MISSED PHYSICS IN THE CLASSICAL MODEL

FALL BACK RATE

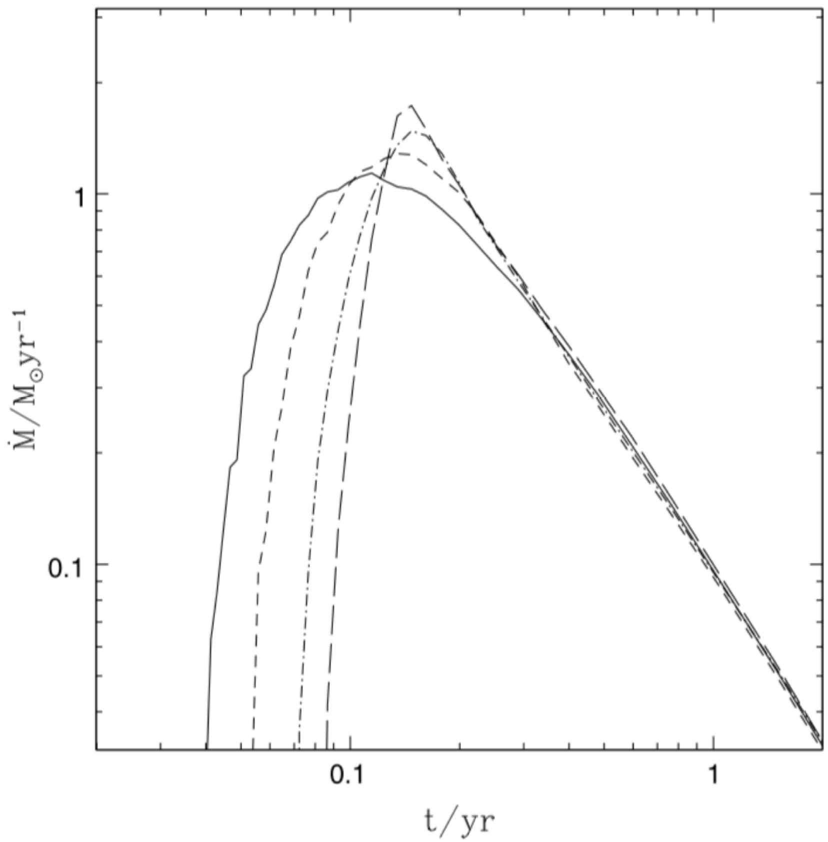


Fig. 1. Evolution of the accretion rate onto a $10^6 M_\odot$ SMBH following the disruption of stars with different internal structure, parameterized as polytropes with different indices γ. From left to right: $\gamma = 1.4, 1.5, 5/3, 1.8$.
From Lodato et al. (2009).

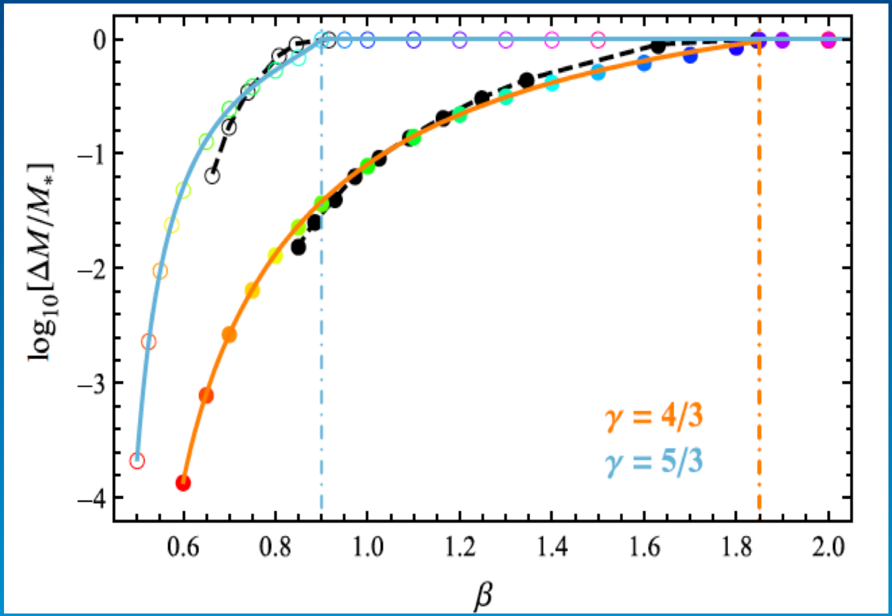
The fall back at the rising phase depends on the structure of the star.

From left to right central concentration increases

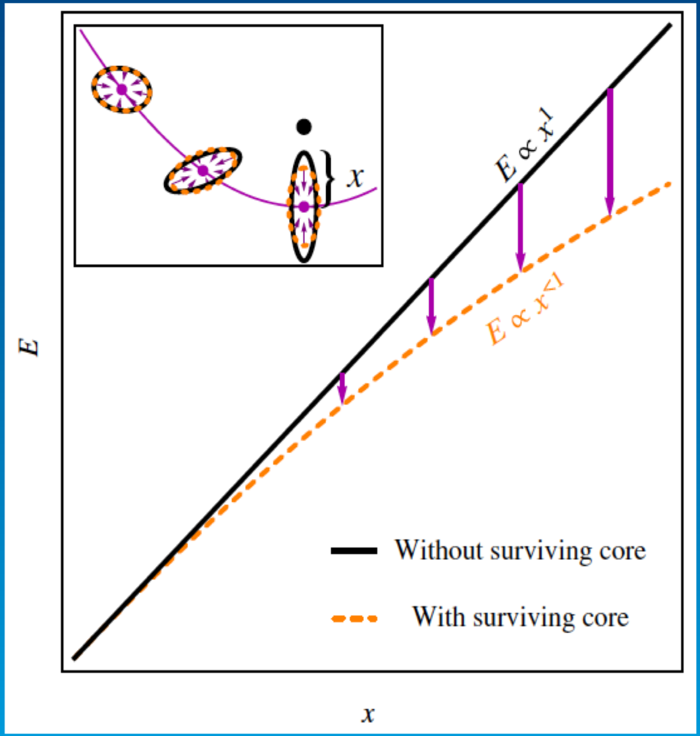
PARTIAL DISRUPTION

$\beta \equiv r_p/r_t < 1,$

Guillochon & Ramirez-Ruiz 13

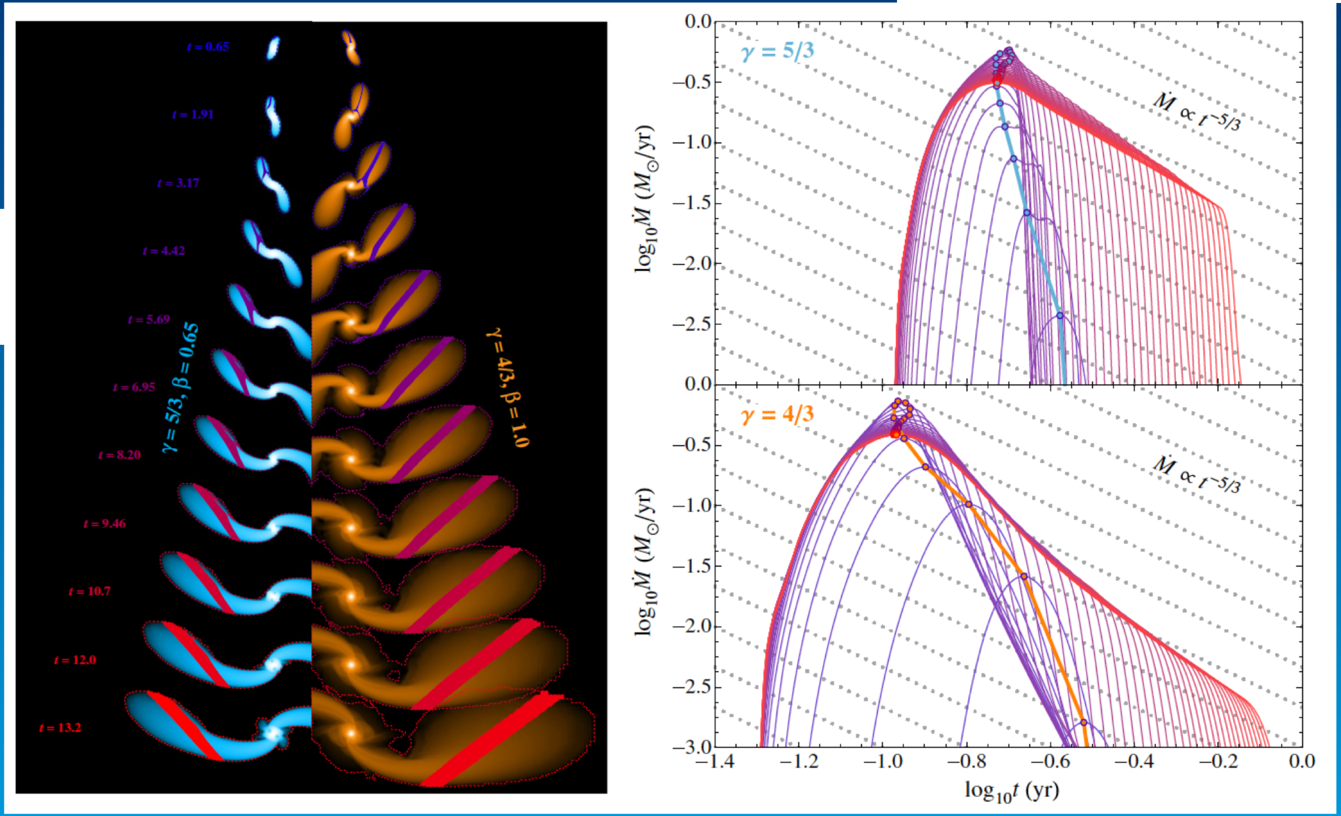


fraction of stripped mass



Guillochon & Ramirez-Ruiz, 13

filled region
– peak rate

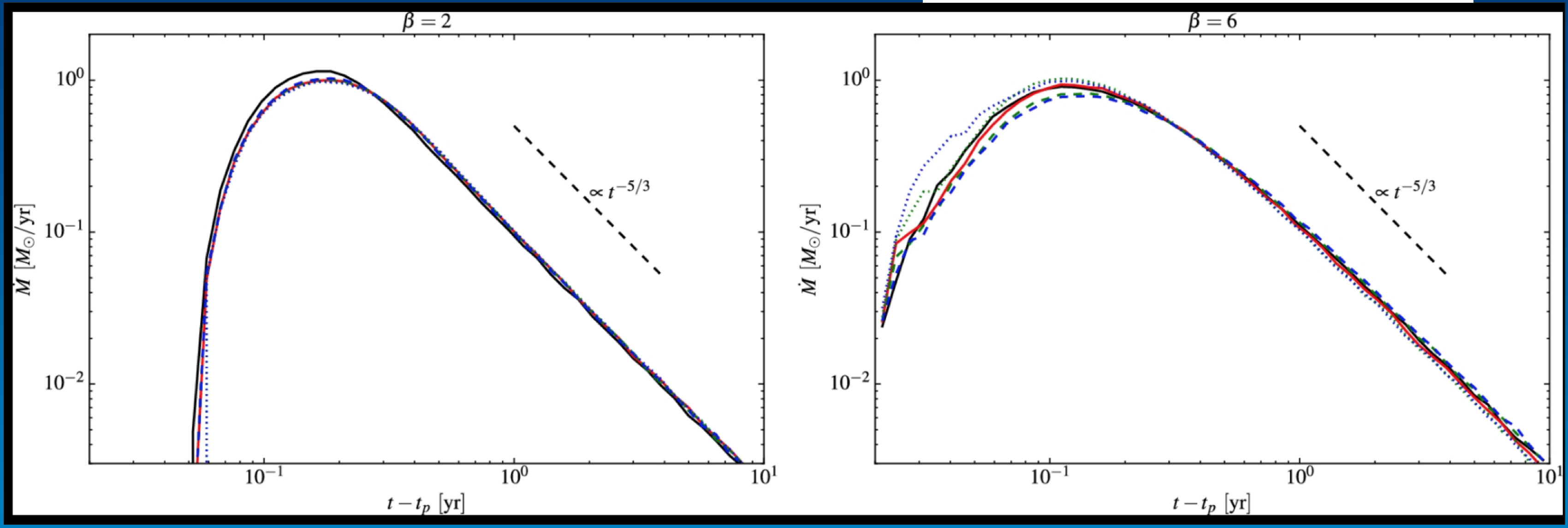


similar values of ΔM
$M_* = M_\odot$; $M_h = 10^6\ M_\odot$

fallback rate deviates from $t^{-5/3}$
The same E from a range of stellar radius

BLACK HOLE SPIN DOES NOT AFFECT MUCH THE FALLBACK RATE

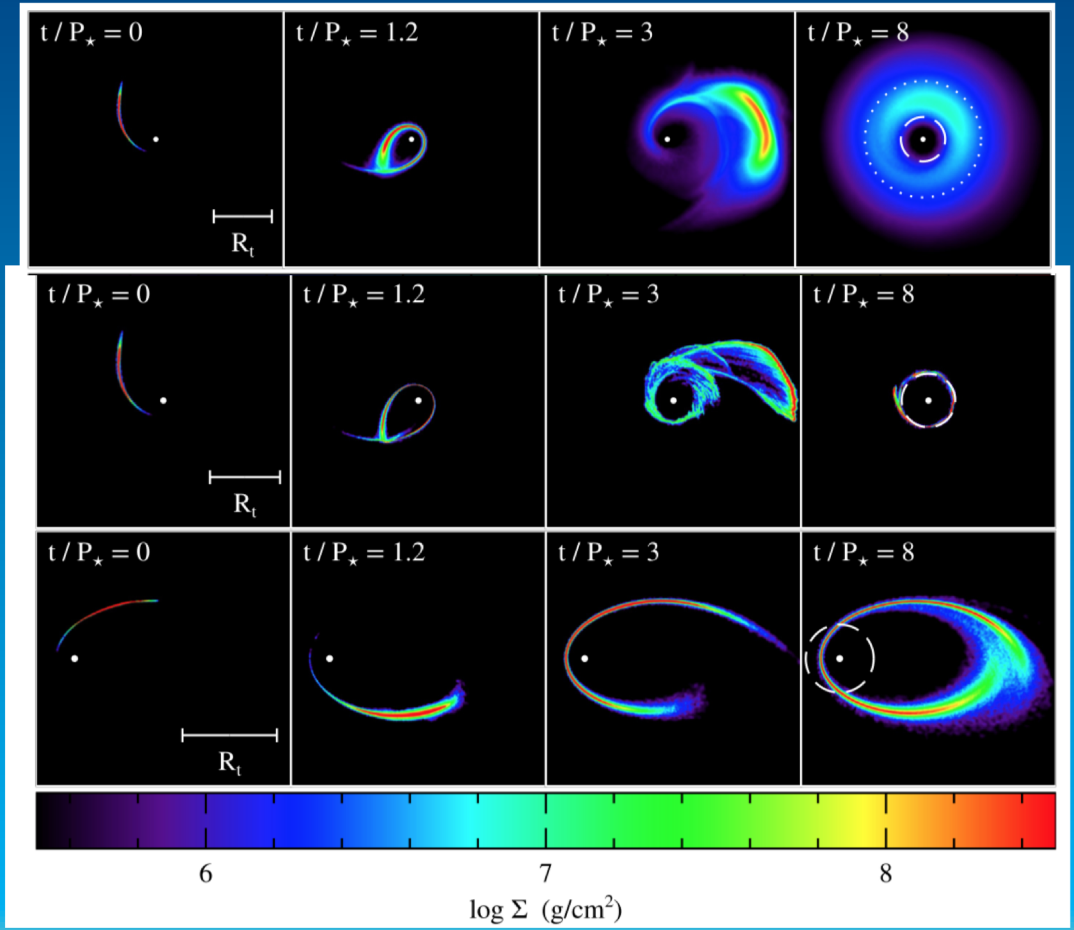
Tejeda et al. 2017 MNRAS



Mass fallback rates $\dot{M}$ of the debris after the first periapsis passage for the canonical TDEs with β = 2 (left-hand panel) and β = 6 (right-hand panel) discussed in Section 5.1. The solid black curve represents the Newtonian simulation; the solid red curve represents the disruption by a non-rotating ($a^* = 0$) BH; the dashed (dotted) curves represent the trajectories of stars on prograde (retrograde) orbits around BHs with spin parameters 0.5 (green) and 0.99 (blue). $M=10^6 M_\odot$, $M_* = M_\odot$, $R_* = R_\odot$

EFFICIENCY OF CIRCULIZATION

Streams loss kinetic energy through self crossing, then settle on a circular (low energy) orbits



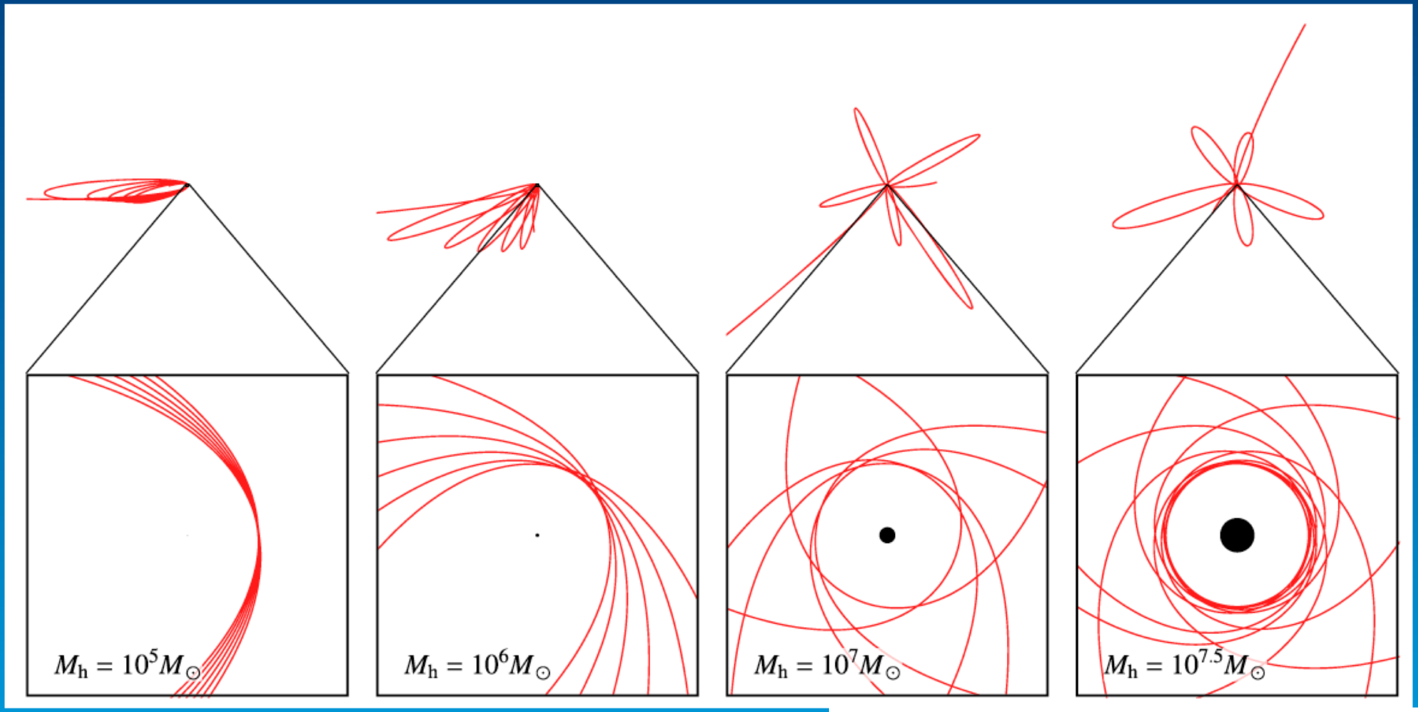
adiabatic , Schwarzschild disk puffs up due to shock heating; $10^6 M_{\odot}$

Isothermal, Schwarzschild precession causes orbit crossing and helps gas settling down in circ orbit

Isothermal, Newtonian

Bonnerot et al. 2015

BLACK HOLE DEPENDENCE



Guillochon & Ramirez-Ruiz 15

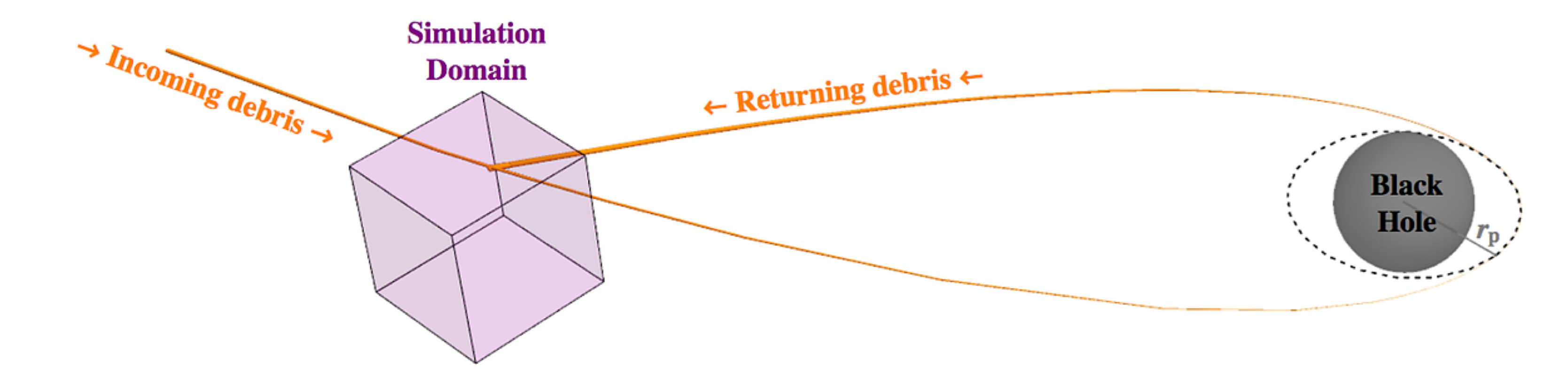
Circularization is much more effective for large holes because of relativistic effect is stronger in the late, causing instantly accretion in the latter. Accretion onto small holes is delayed.

EFFICIENCY OF CIRCULIZATION

- Relativistic effect helps the circularization of debris
- Frame dragging effect of spin hole will lead debris to miss crossing lowering the efficiency
- If debris cannot cool down, if forms a thick torus rather than a thin ring
- periapse precession is larger for more massive hole, causing instantaneous accretion

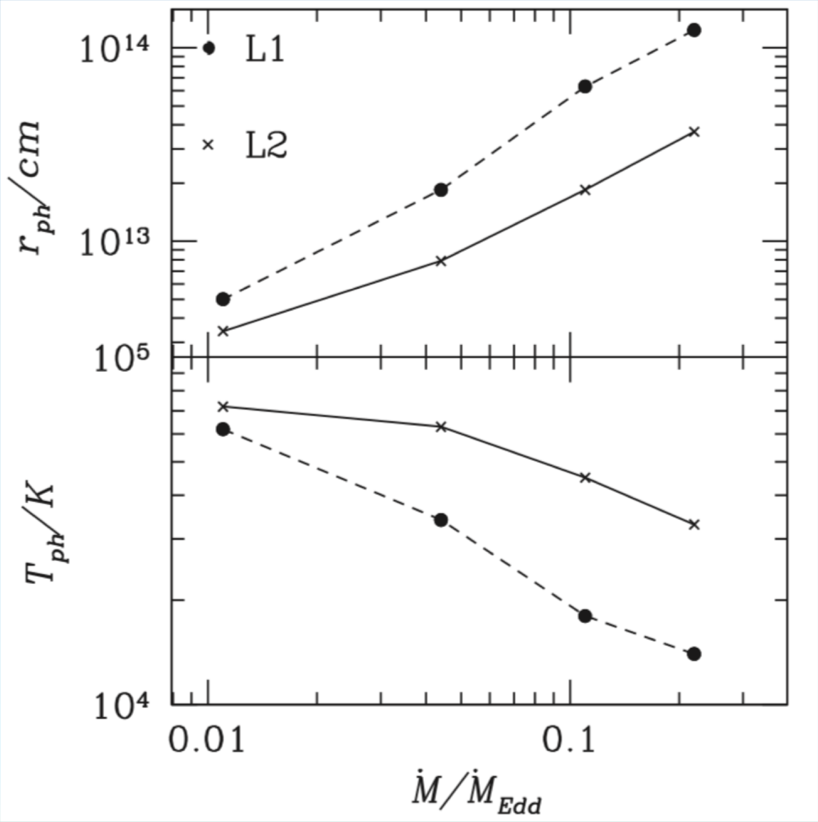
SIMULATION: STREAM COLLISIONS

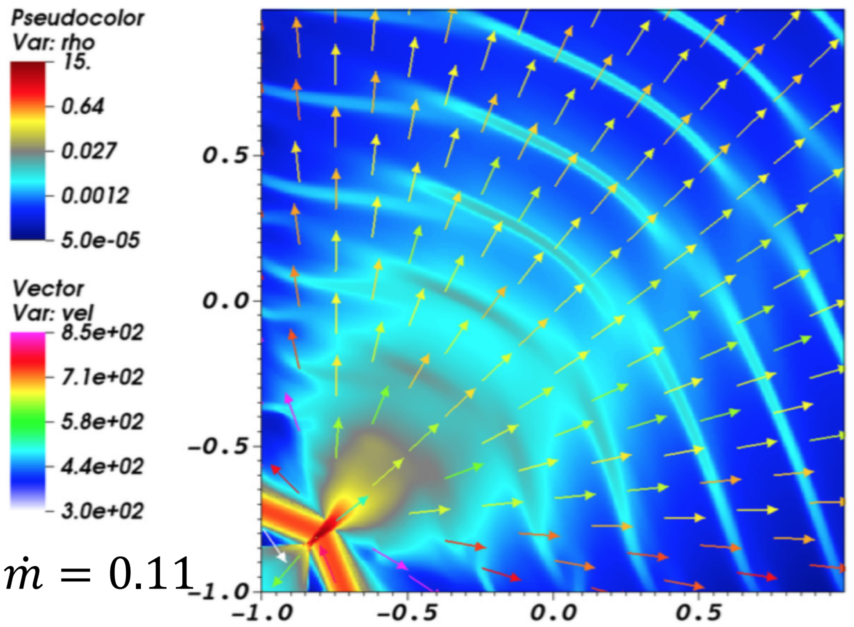
Jiang et al., 2016



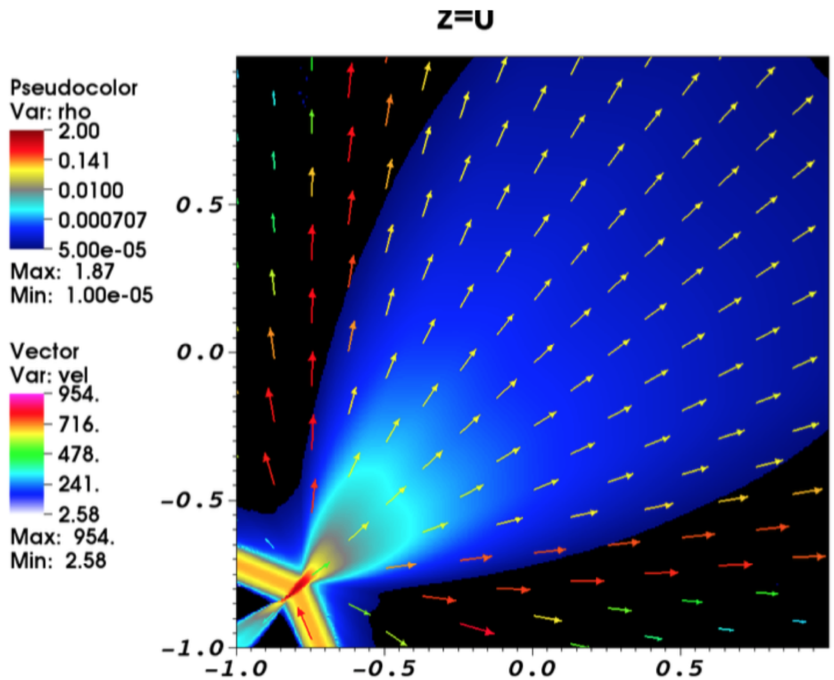
High mass flow rate: 2% of the initial kinetic energy is converted to radiation directly; more than 16% of the mass can become unbound;
Low mass flow rate: radiative efficiency increases slightly to 8%, no unbound gas being produced when the mass flow rate drops to 1% of Eddington

photosphere size (10^{14} cm) is directly proportional to the mass flow rate: temperature a few times 10^4 K



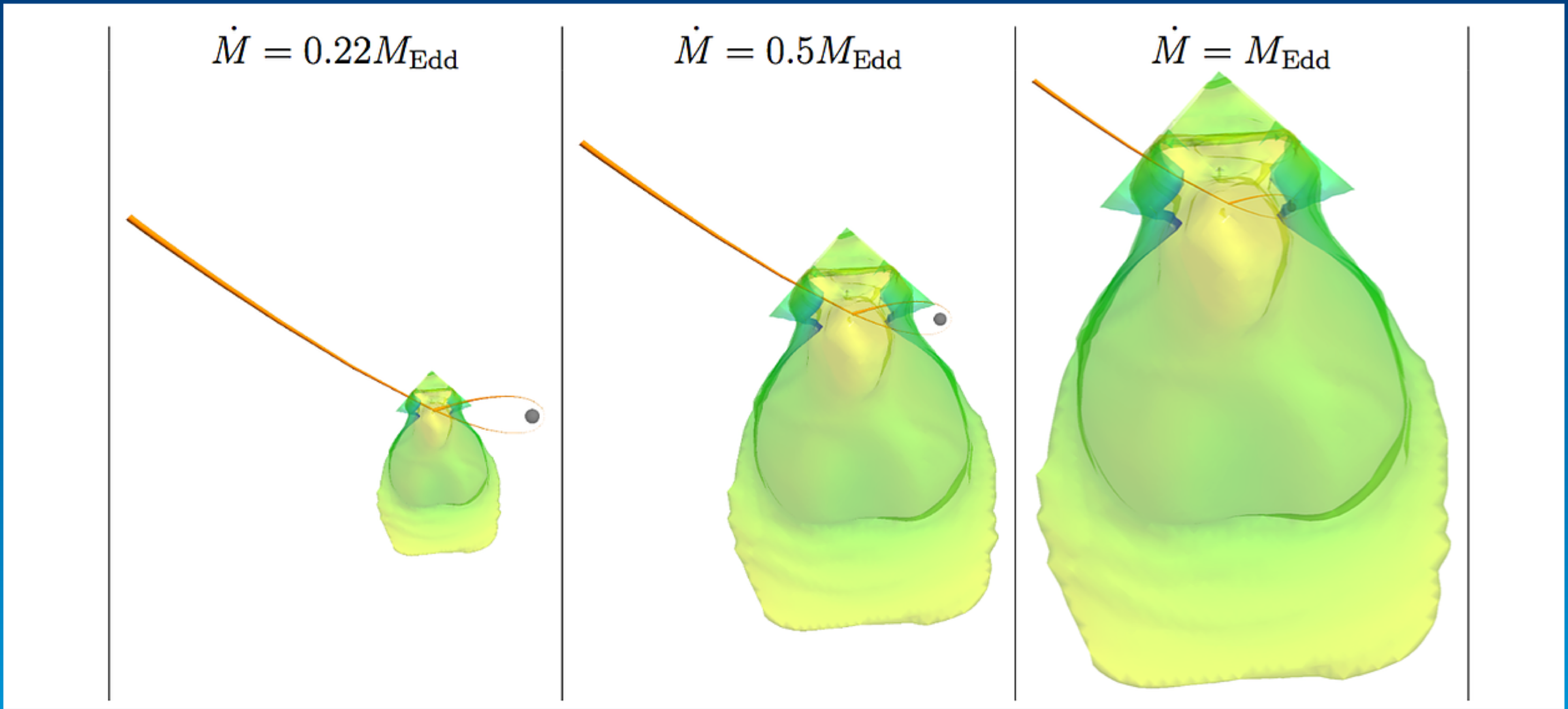


$\dot{m} = 0.11$



$\dot{m} = 0.011$

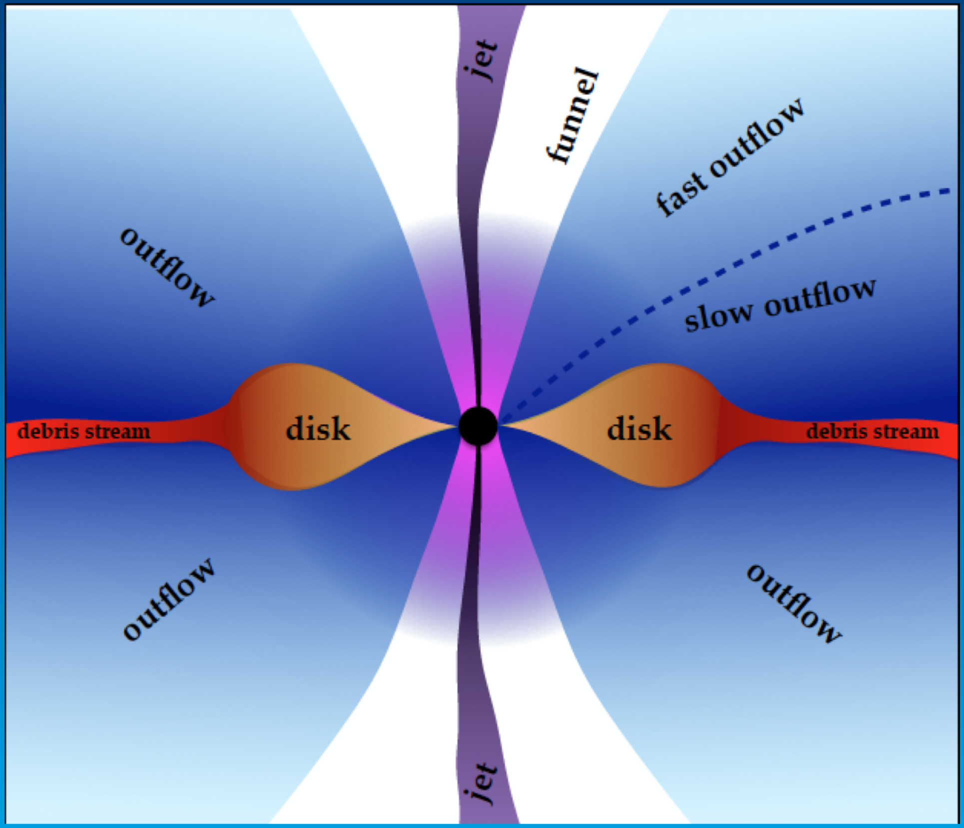
SCATTERING PHOTOSPHERE



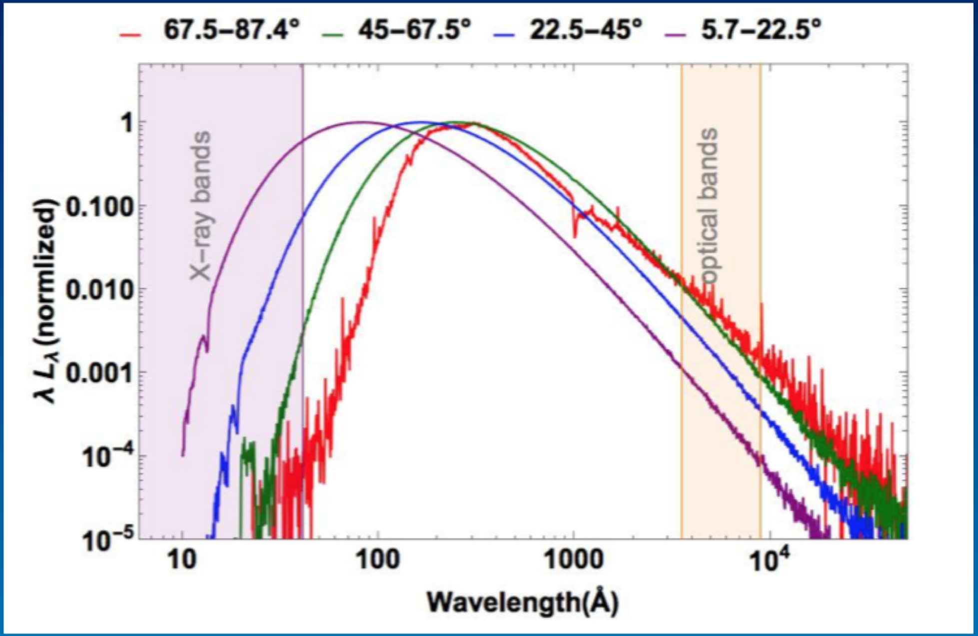
SUPERCRITICAL ACCRETION ONTO BLACK HOLE

Super-Eddington accretion

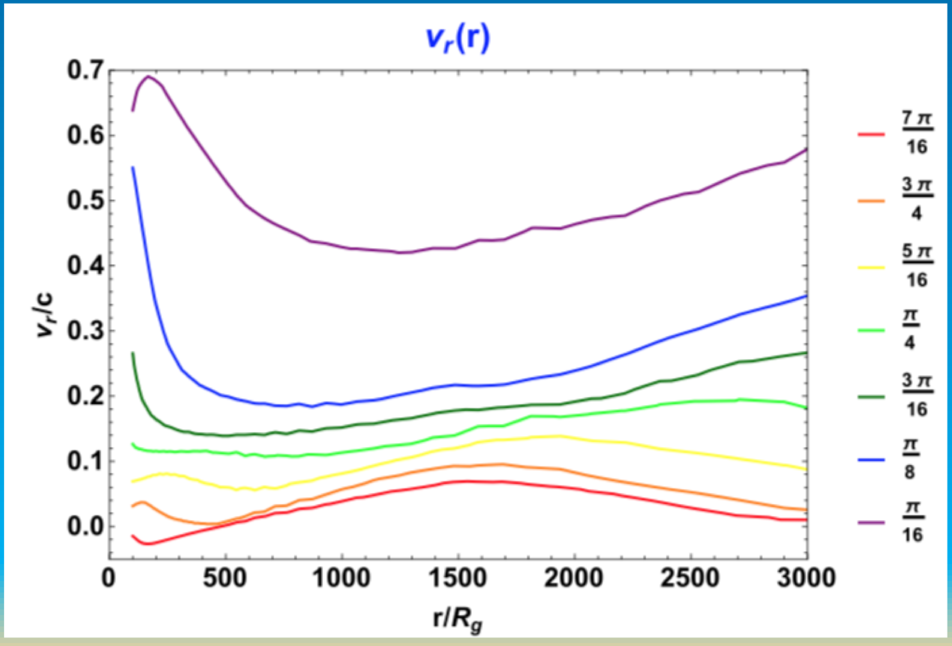
- thick disk and anisotropic radiation
- launching massive outflows
- Radiation efficiency is low and radiation luminosity is a few Ledd
- Jet?



Dai+ 18



67.5–87.4°
45–67.5°
22.5–45°
5.7–22.5°
X–ray bands
optical bands
λ L_λ (normlized)
Wavelength(Å)



v_r(r)
v_r/c
r/R_g
7π/16
3π/4
5π/16
π/4
3π/16
π/8
π/16

Dai+ 18

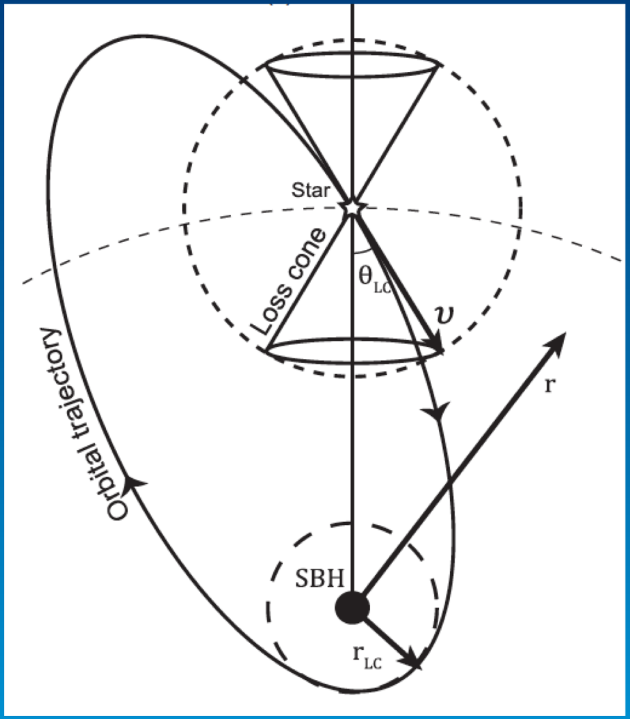
TIDAL DISRUPTION RATE

- Loss cone

$$J^2 \le J_{lc}^2(E) \equiv 2r_t^2[E - \Phi(r_t)] \approx 2GM_{BH}r_t$$

- stars in loss cone are depleted within one orbit
- In a spherical symmetric galaxies, loss cone is refilled by the diffuse of stars in phase space via gravitational encounter.
- Most disrupted stars are within the black hole gravitational influence radius

$$r_h \equiv \frac{GM_{bh}}{\sigma_*^2} \approx 10\left(\frac{M_{BH}}{10^8 M_\odot}\right)\left(\frac{\sigma}{200 km\ s^{-1}}\right)^{-2} pc$$

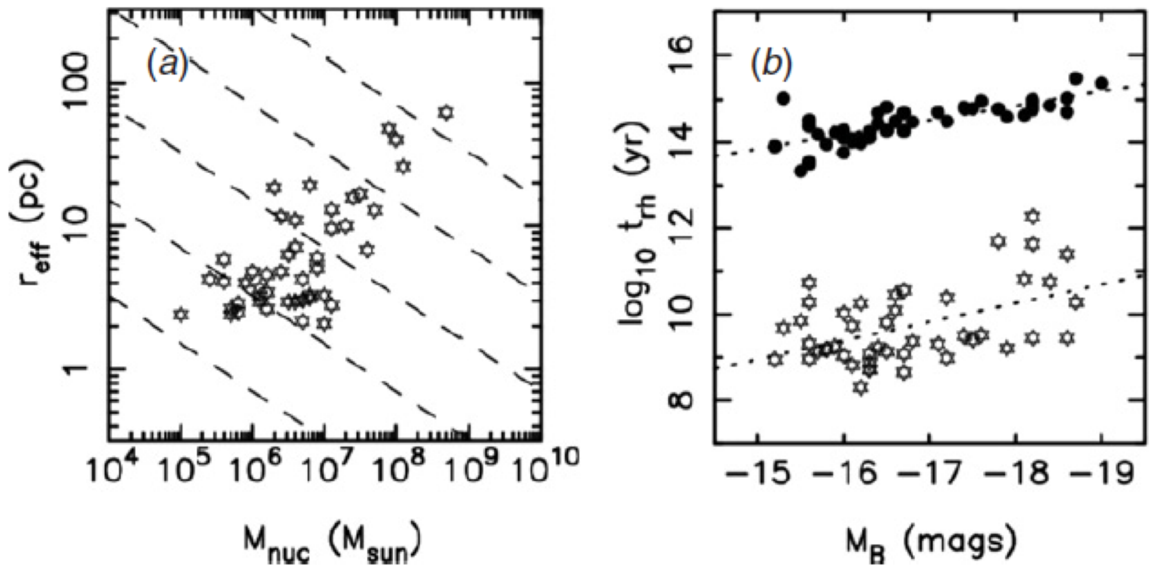


Loss cone can be viewed as a cone Toward the BH with half opening Angle of

$$\theta_{lc} \approx (r_{lc}/r)^{1/2}\ ,\ r \le r_h$$
$$\approx (r_{lc}r_h/r^2)^{1/2}, r \ge r_h$$

TIDAL DISRUPTION RATE

$$t_r = \frac{0.34\sigma^3}{G^2 m \rho \ln\Lambda} \approx 0.95 \times 10^{10} \left(\frac{\sigma}{200\,\mathrm{km\,s^{-1}}}\right)^3 \left(\frac{\rho}{10^6\,M_\odot\,\mathrm{pc}^{-3}}\right)^{-1} \left(\frac{m_\star}{M_\odot}\right)^{-1} \left(\frac{\ln\Lambda}{15}\right)^{-1} \mathrm{yr}.$$



Host

NSC

Bahcall–Wolf cusp

Figure 2. Properties of NSCs in galaxies belonging to the Virgo Galaxy Cluster [30]. The plotted points represent all Virgo galaxies, among the 100 brightest, that have compact nuclei [9]. *Left panel:* nuclear radii and masses; masses are from [54]. Dashed lines correspond to nuclear half-mass relaxation times of (10^8, 10^9, 10^{10}, 10^{11}, 10^{12}) years increasing up and to the right. *Right panel:* half-mass relaxation times of NSCs ($\star$) and their host galaxies ($\bullet$) plotted against absolute blue magnitude of the galaxy. Relaxation times were computed assuming $m_\star = M_\odot$. The lower dotted line is equation (11).

TIDAL DISRUPTION RATE

- Wang & Merritt (2004) derived for an isothermal model

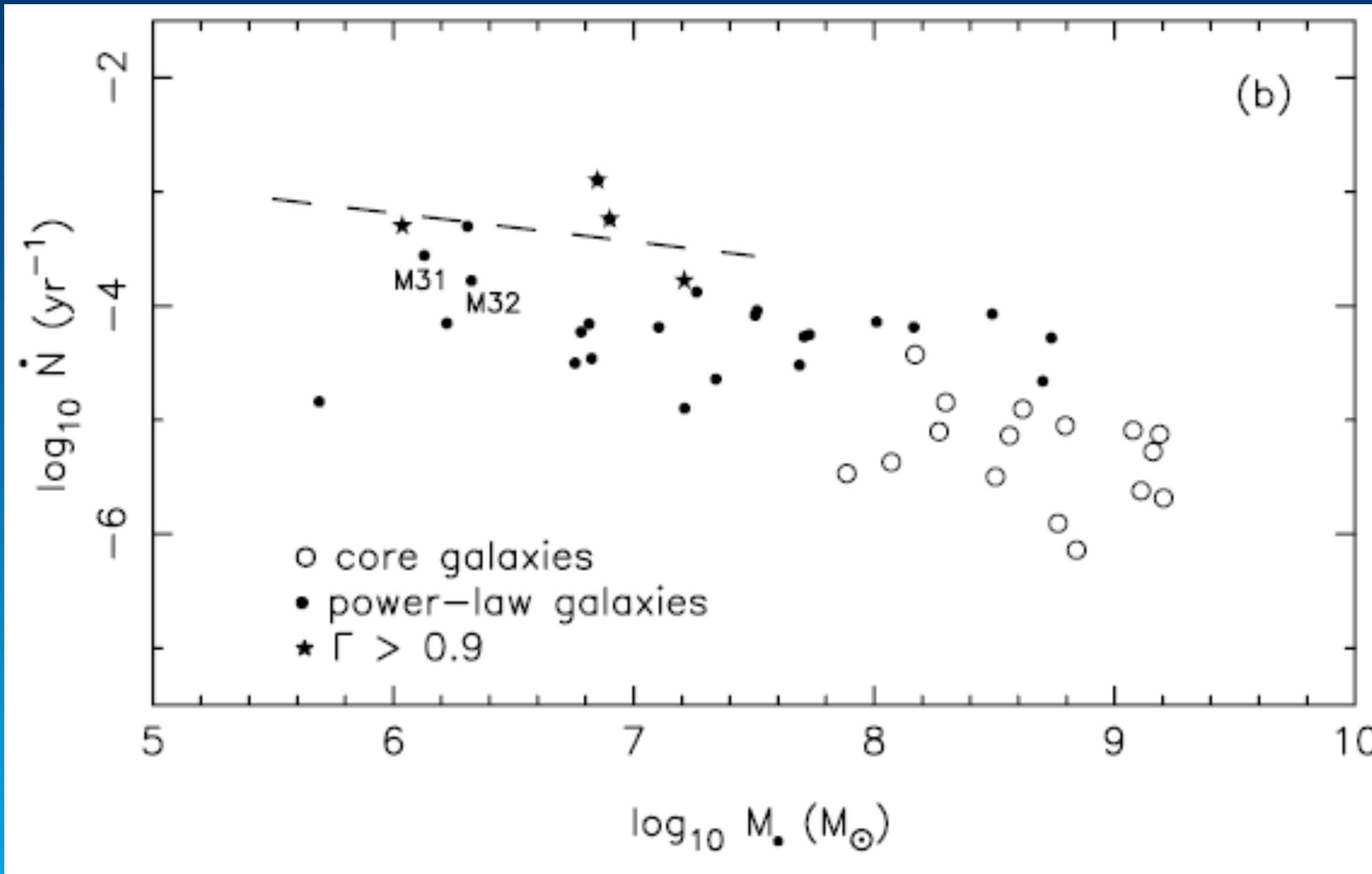
$$\dot{N} \approx 4.3 \times 10^{-4} \left(\frac{\sigma}{90\,\mathrm{km\,s^{-1}}} \right)^{7/2} \left(\frac{M_\bullet}{4 \times 10^6\, M_\odot} \right)^{-1} \mathrm{yr}^{-1}$$

Combine with $M_{BH} - \sigma$ relation (Savorgnan, et al. 2016)

$$M_\bullet \approx 3.2{\times}10^6 M_\odot \left(\frac{\sigma}{90\ km\ s^{-1}} \right)^{5.1}$$

Tidal disruption rate is about 10^{-4} gal^{-1} yr^{1} for a $10^6 M_\odot$ BH, and scales with black hole mass as $M_\bullet^{-0.31}$.
This gives for 10^6 events in 10 Gyr, so it is important for growth of black hole with mass less than $10^6 M_\odot$.

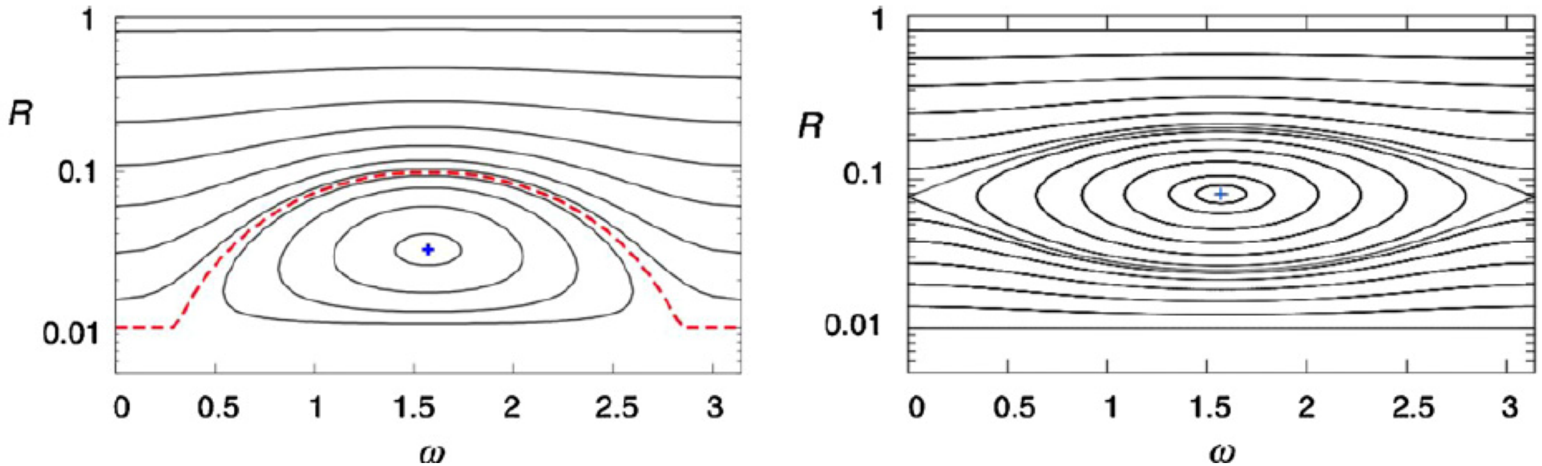
TIDAL DISRUPTION RATE



Magorrian & Tremaine 1999; Wang & Merritt 2004; Brockamp et al. 2011

TIDAL DISRUPTION RATE

- In massive non-spherical bulge, the refilling is not dominated by diffusive process due to its long time scale



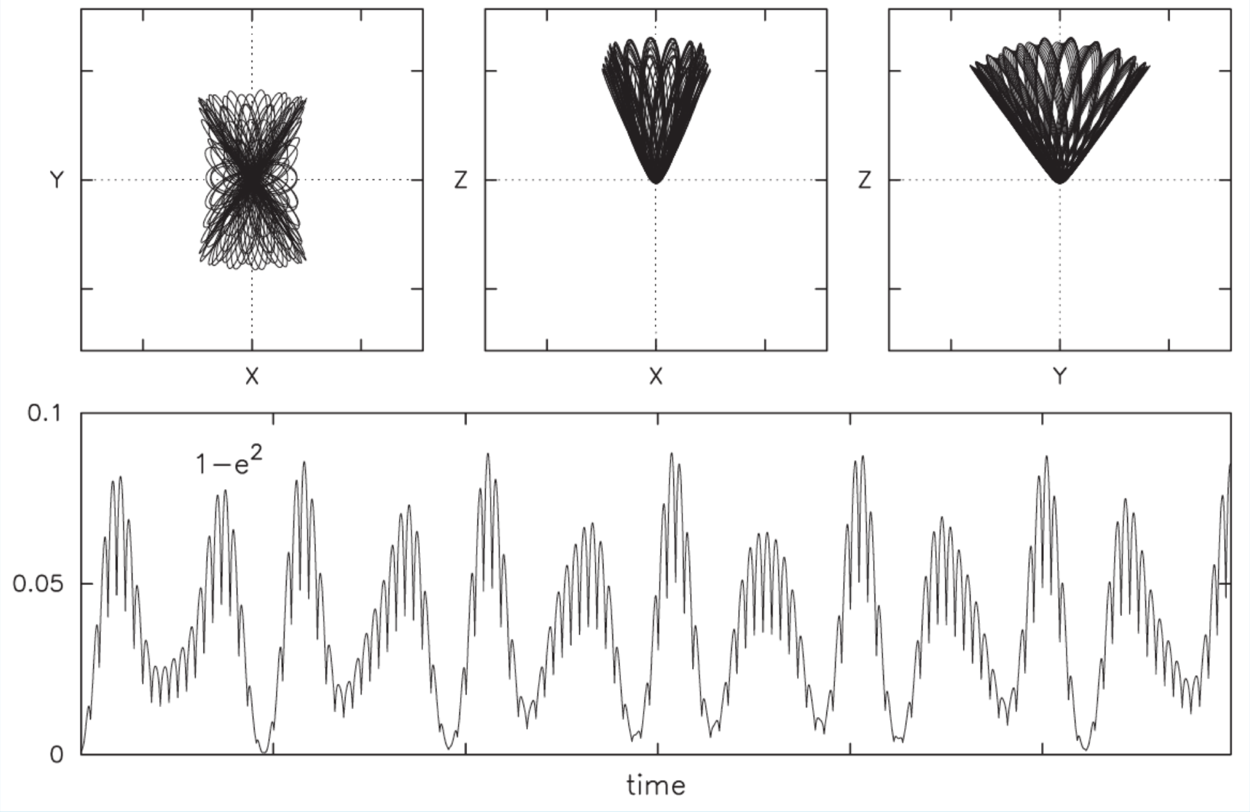
phase diagrams for orbits near MBH with the same E and Lz but different values of the 'third integral'

$R = l^2/l_c^2,\ l_c$ is the circular angular momentum

ω -- argument of periapsis

There is a family of Saucer-like orbits, in which angular momentum *vary* with a period of t_{prec}

TRIAXIAL GALAXIES

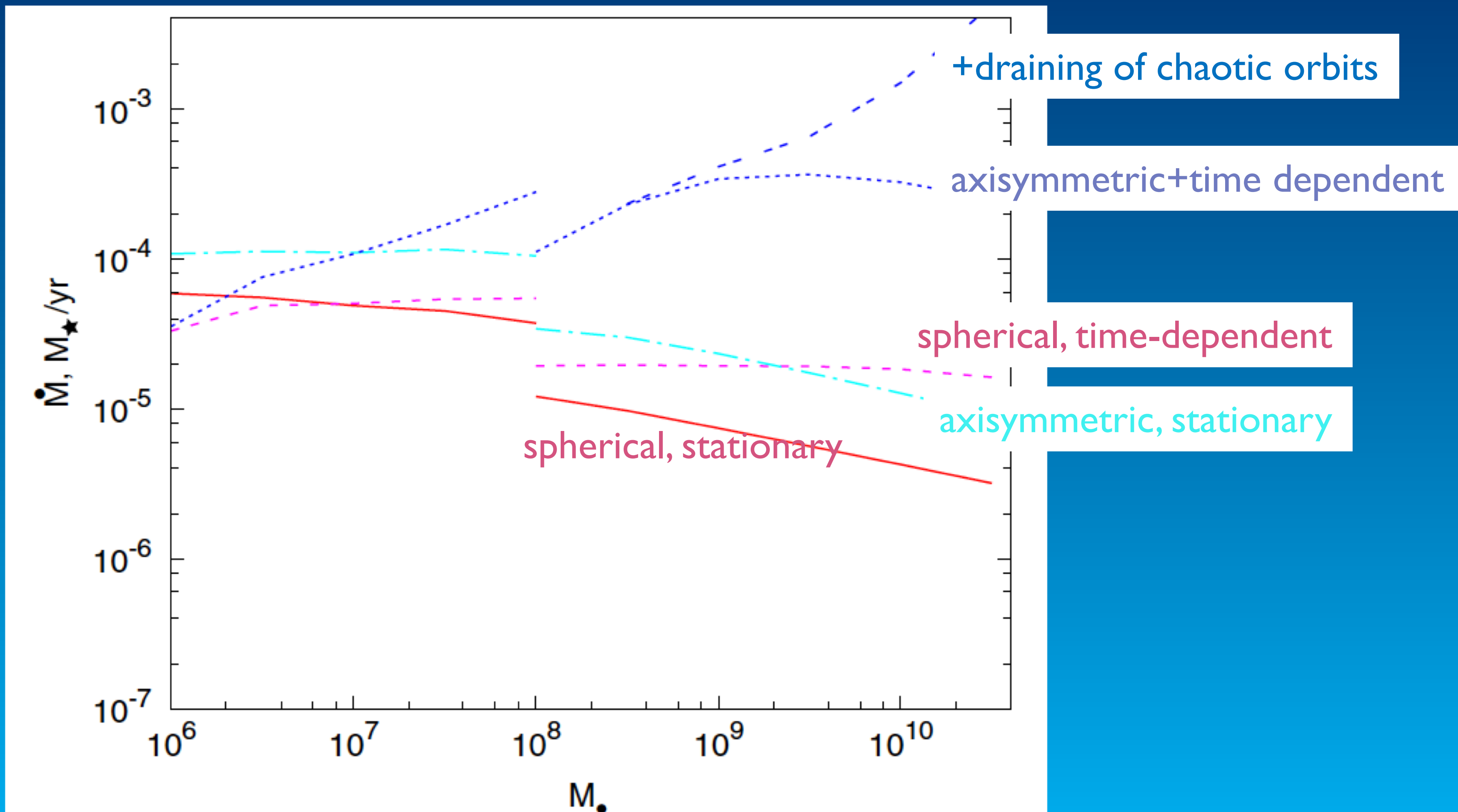


the angular momentum of a pyramid orbit reaches zero at the corners of the 'pyramid'.

$$\epsilon \approx \frac{1}{2}(1-q), \;\; q = \frac{b}{a} \qquad t_{prec} \approx \epsilon^{-1/2} P \frac{M_\bullet}{M_*}$$

$$P = \frac{\pi}{\sqrt{2}} \frac{GM_\bullet}{\mathcal{E}^{3/2}} = \frac{2\pi a^{3/2}}{\sqrt{GM_\bullet}} \approx 1.48 \left(\frac{M_\bullet}{4 \times 10^6 M_\odot}\right)^{-1/2} \left(\frac{a}{\mathrm{mpc}}\right)^{3/2} \mathrm{yr}$$

Predicted rates for different processes



Merritt 2013, Class Quant Grav

RELATIVITY EFFECT:
转动黑洞附近的恒星轨道

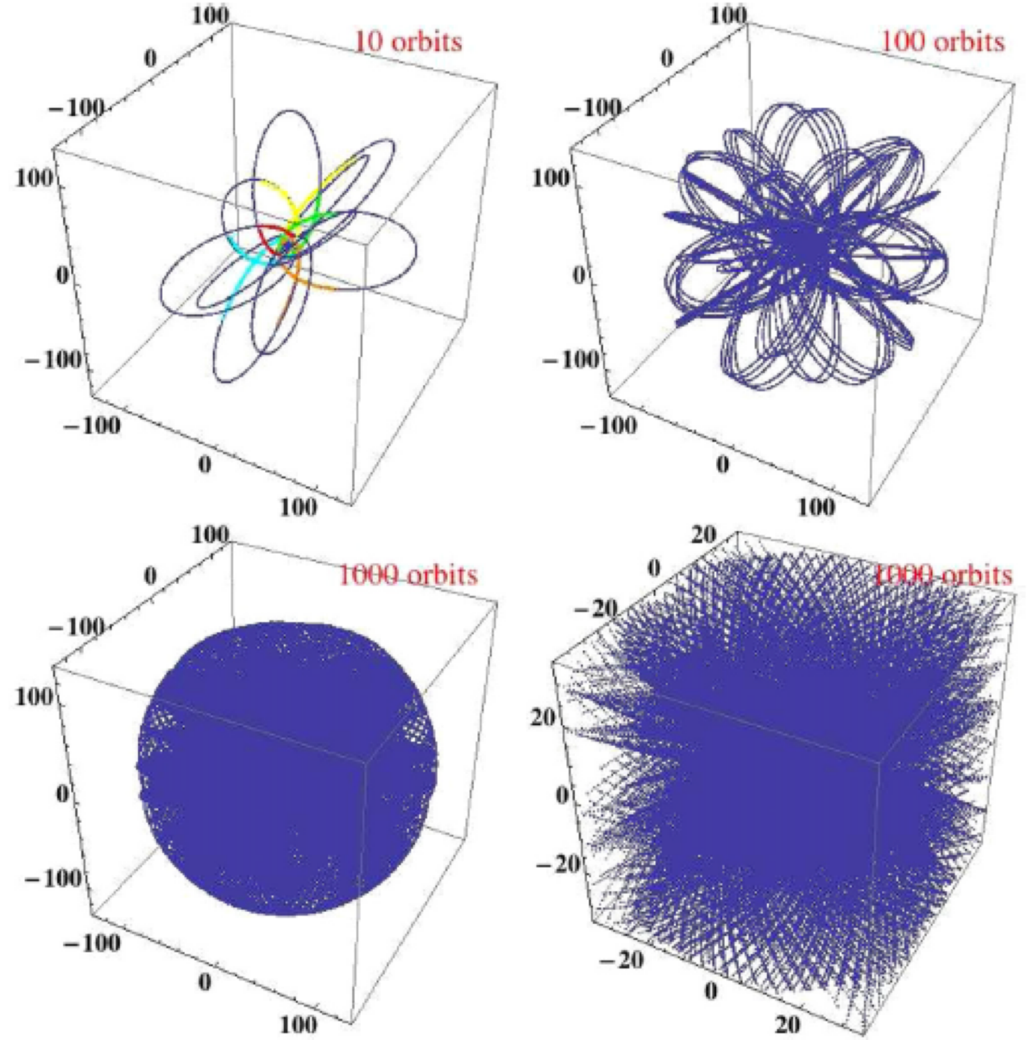
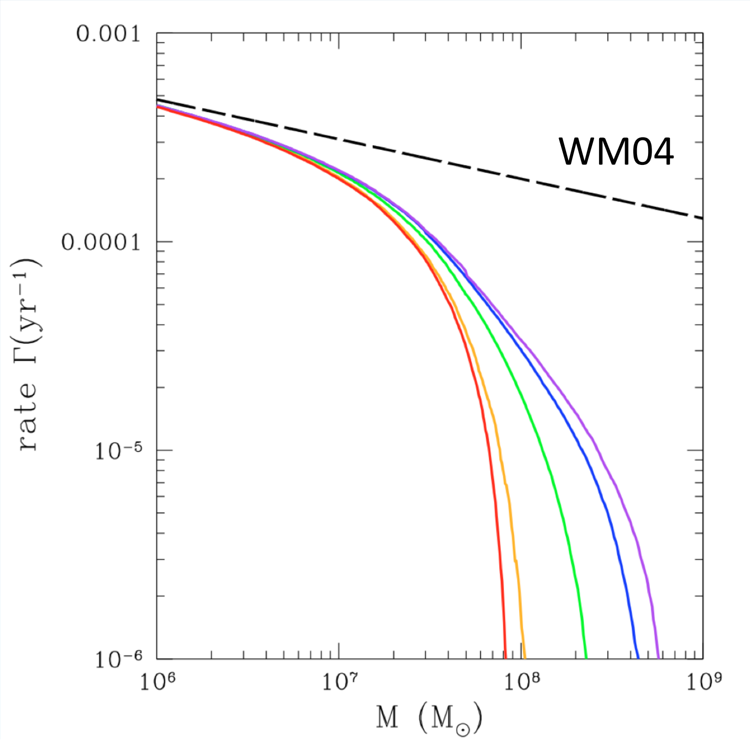


Figure 5. The geodesic for the center of a star in an eccentric orbit with $e = 0.9$, $i = 45°$ around a Kerr black hole with $M = 10^7 M_\odot$ and $\tilde{S} = 0.5$. $R_p \sim 7.1\ R_g$ and $R_a \sim 134.3\ R_g$. We show the first 10, 100, 1000 orbits and a zoomed-in of the 1000 orbits case. For the panel showing 10 orbits, we also overplot the locations of the tidal streams at $t = T$ (red), $t = 2T$ (green), $t = 3T$ (orange), $t = 4T$ (cyan), and $t = 5T$ (yellow). All tidal streams tend to align with the geodesic curve.

Dai, Escala, Coppi 2013

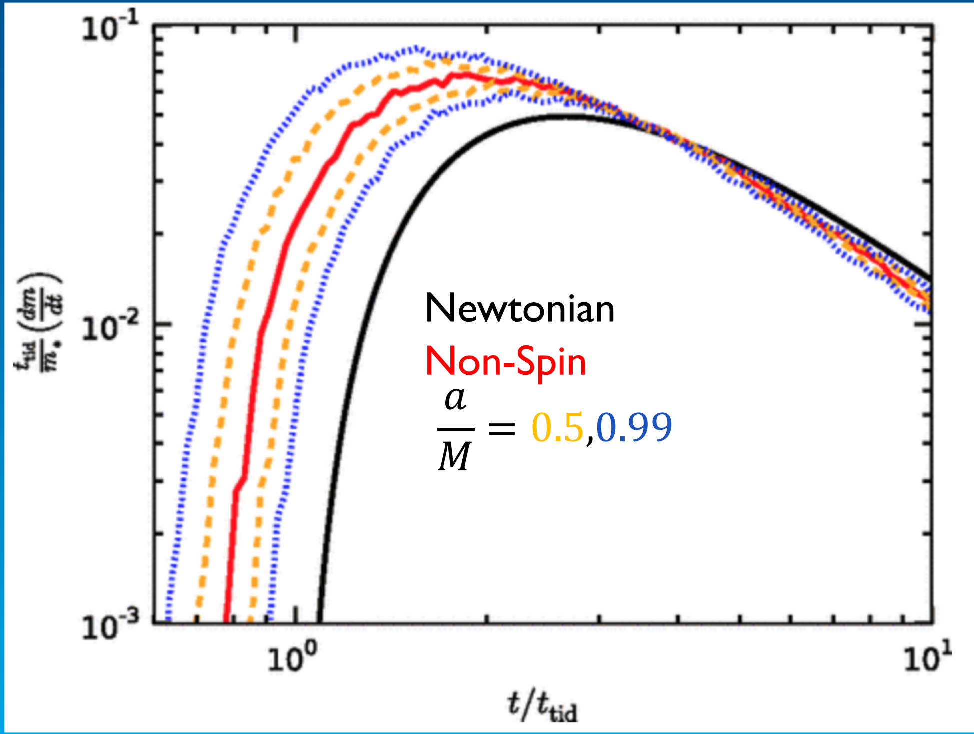
BLACK HOLE SPIN AND TDE

- Spin can significantly increase the tidal disruption rate for black hole mass >$10^8 M_\odot$.



TDE rate increases with SBH spin, a/M= 0, 0.5,0.9 , 0.99, and 0.999.

Kesden'12A PRD



Fall-back rate for $M_\bullet = 10^8 M_\odot, R_p = 6M_\bullet$ and $l = 0^\circ$

Kesden'12B PRD

TDE RATE: OTHER EFFECTS

- In black hole binary, the rate may be boosted up to 0.1 gal-1 yr-1 (Chen et al.), but strong dependent on the evolution stages
- Binary stars + binary black hole (袁业飞小组)
- Massive disturbers around the black holes: GMC, star cluster, spiral arm (Hamers & Perets 17;)
- Kicked off black hole (Komossa & Merritt 2008)

BROAD EMISSION LINE REGION

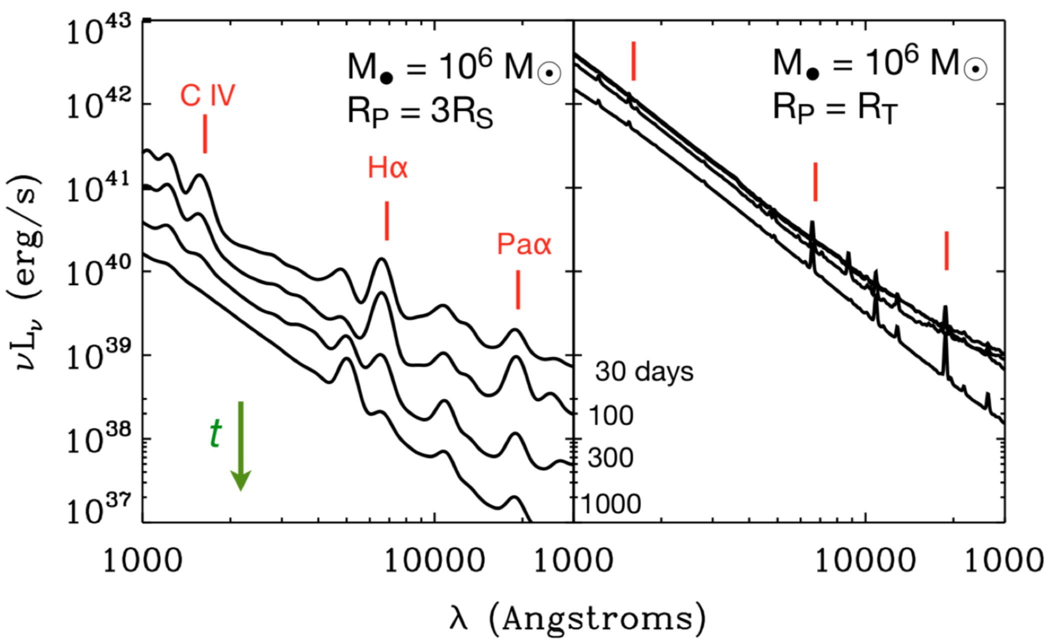
unbound debris: too small solid angle Kochanek'94, Guillochon+14

bound stream/disk (Eracleous+

massive super-Eddington disk wind (Strubbe & Quataert 10;Guillochon+14; Liu+17)

Outflows (radiation transfer, Roth+15, Roth & Kasen 18)

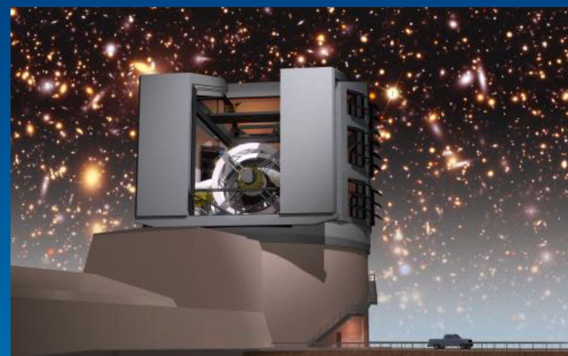
from Strubbe & Quataert (2010)



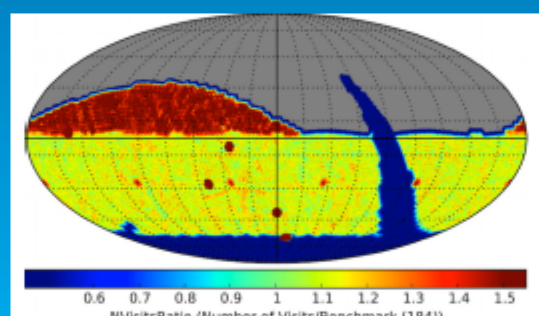
Future optical surveys

zPTF

FOV: 47 square degree depth: single visit r=20.7
a photometric variability catalog with nearly 300 observations each year， for northern sky

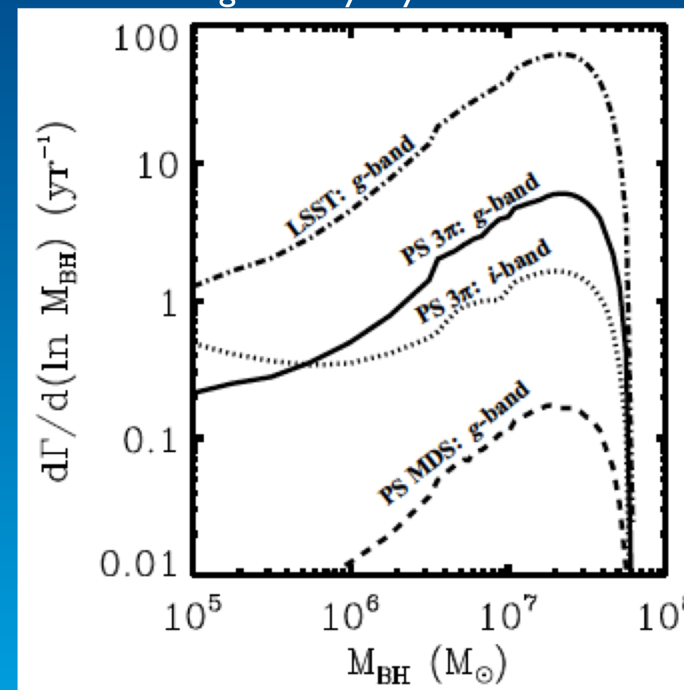


LSST
FOV: 9.6 sq deg
Depth: 23.9, 25.0, 24.7, 24.0, 23.3, 22.1 (ugrizy)



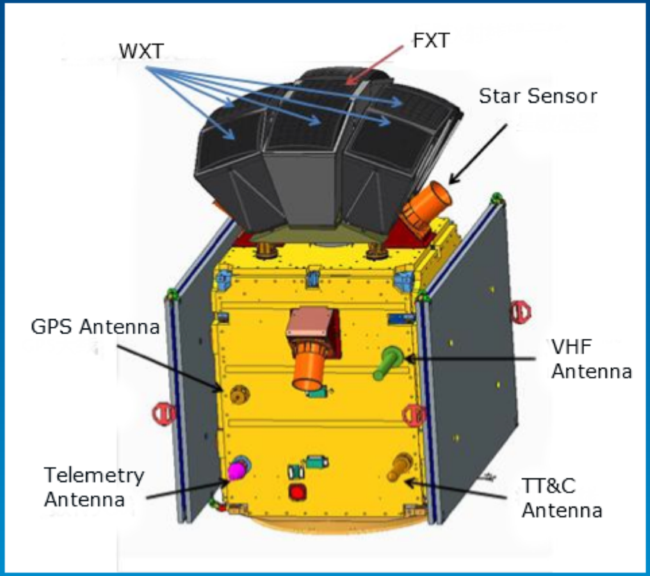
WFST/Mephisto telescope

Near simultaneous 3-band
300 deg^2 every day

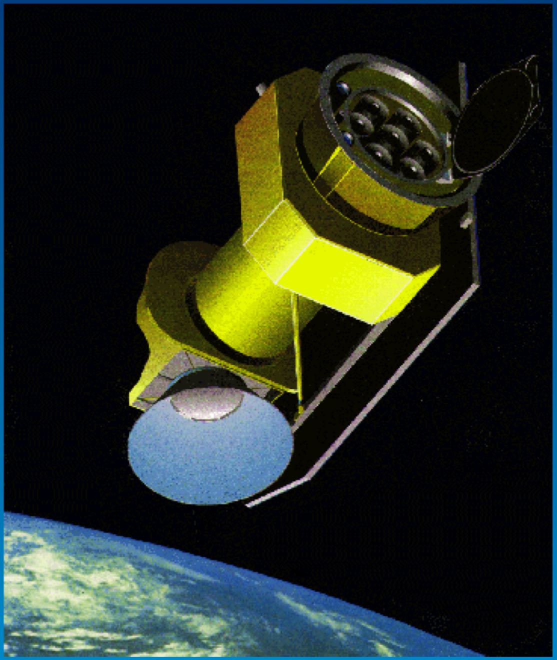


Follow-up 成千上万目标是巨大挑战

X射线巡天



Einstein Probe (China)
Lanch: 2018?



eROSITA

Germany/Russia
Launch 2017

每年探测到几百个TDE，获得一些源很好X射线光变曲线