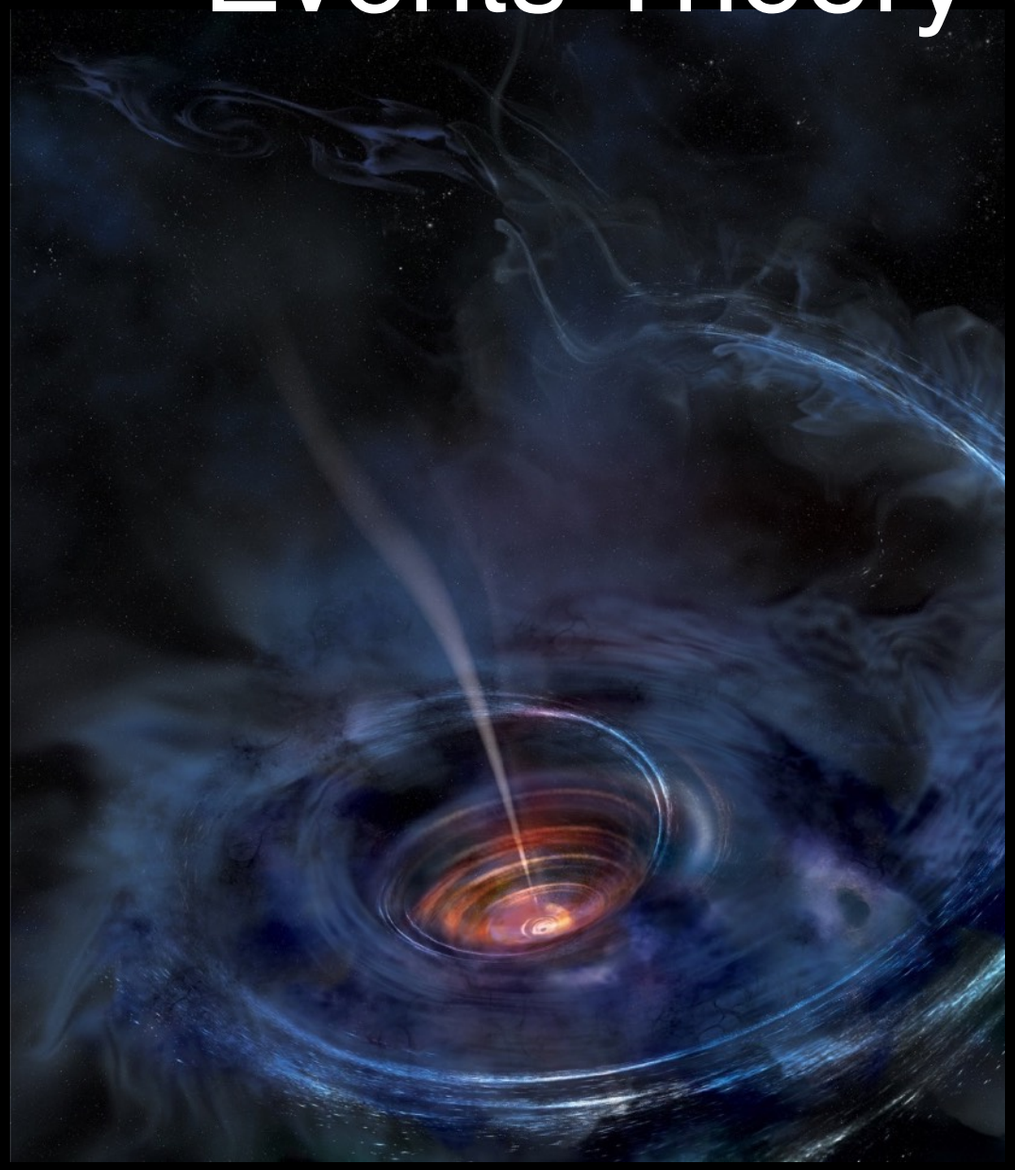
X射线天文学60周年及中国X射线天文研究
June 15-18 2022

Recent Developments in Tidal Disruption Events Theory (and Observations)



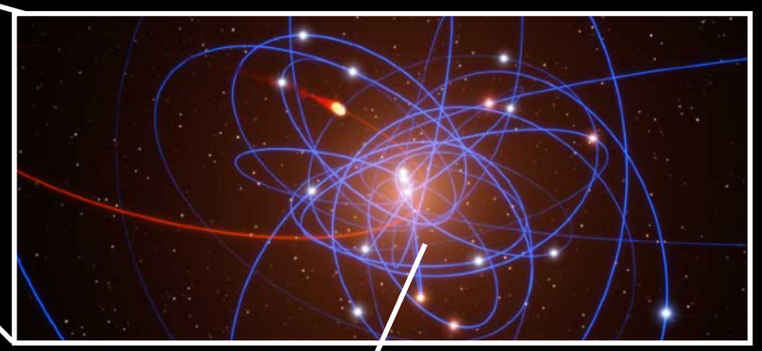
Lixin Dai
戴丽心

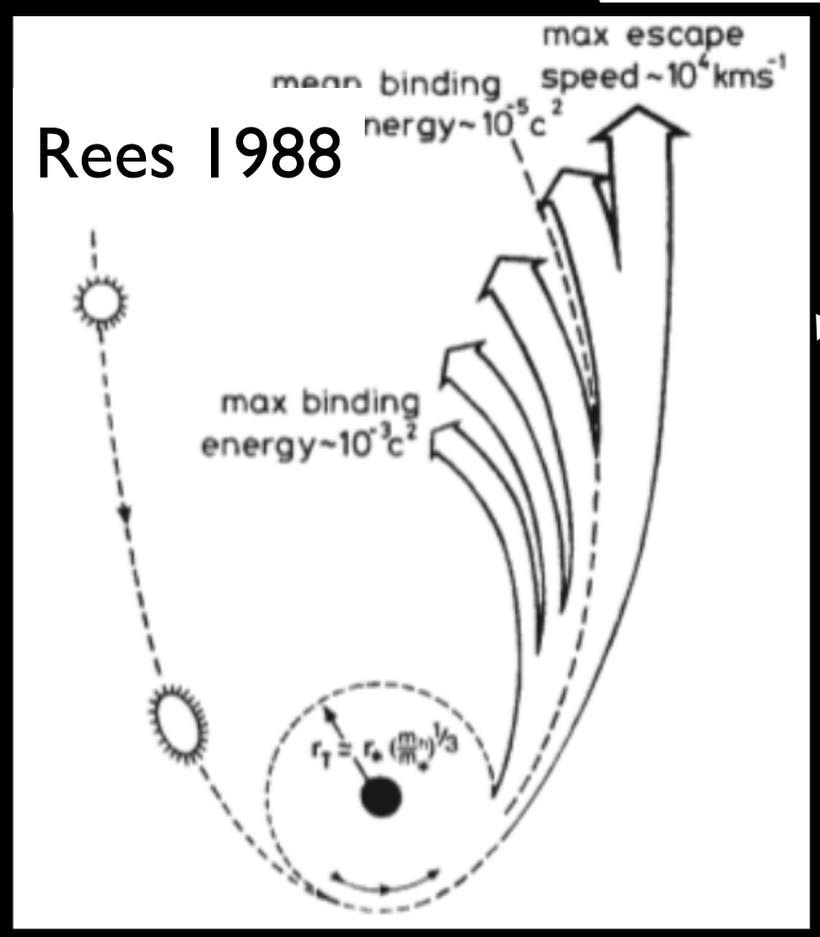
The University of Hong Kong

Tidal Disruption Events

10-100 kpc

1 parsec



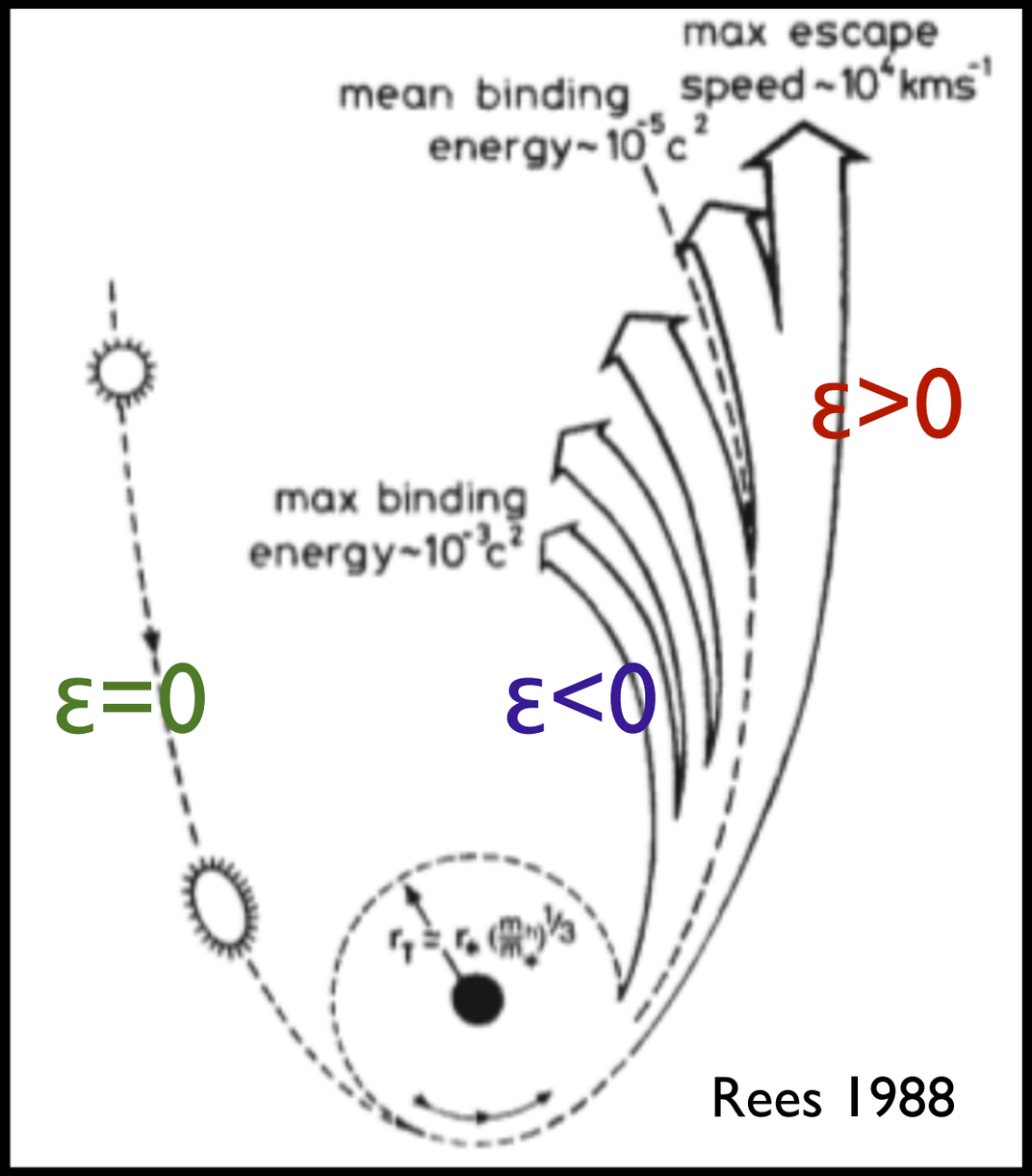


MBH tidal force > stellar self-gravity

$$GM_\star / R_\star^2 \approx GM_{BH}/R_T^2 \, (R_\star / R_T)$$

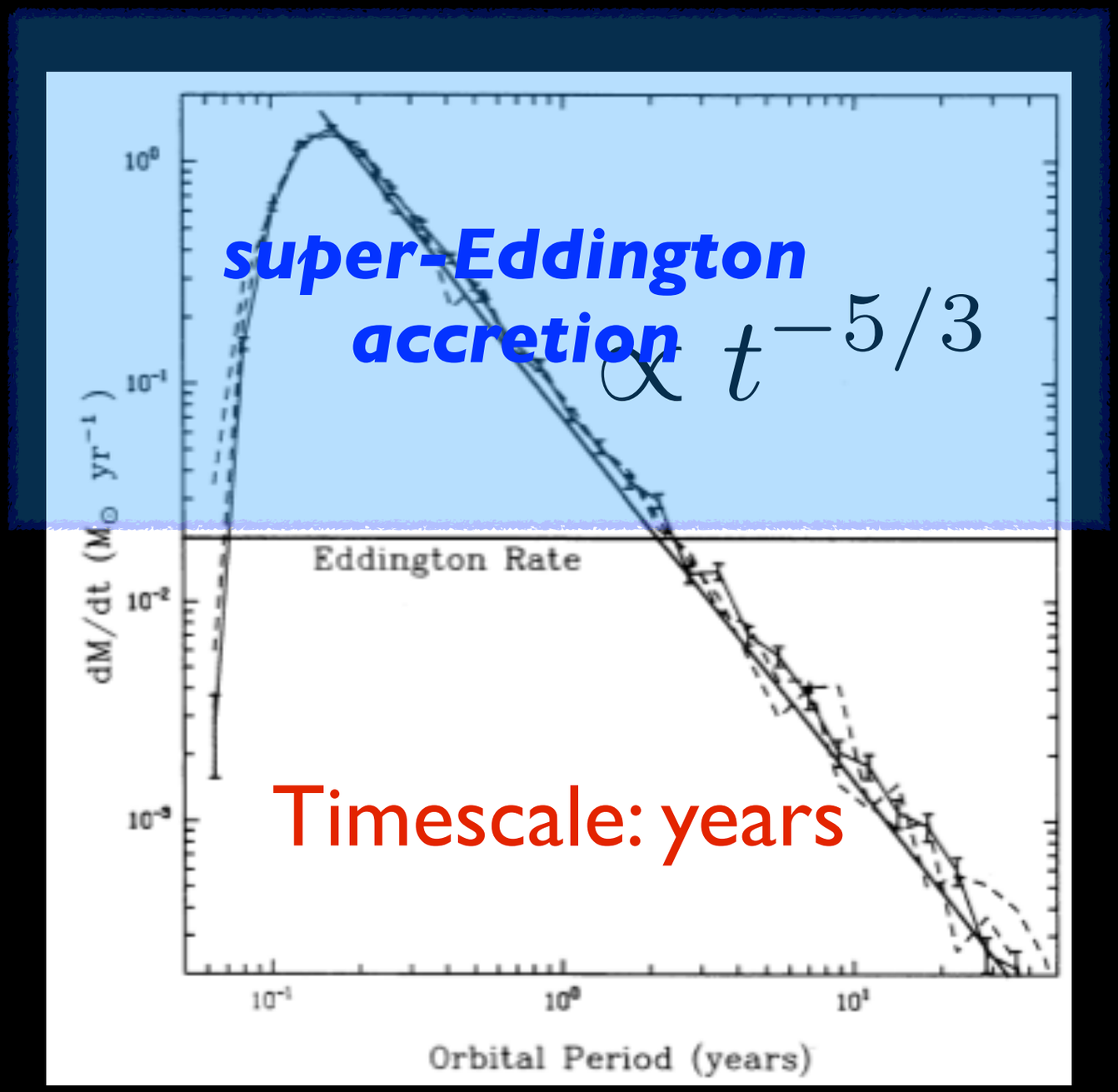
$$R_T \approx R_\star \, (M_{BH} / M_\star)^{1/3}$$

Tidal disruption of a star



- Demographics of dormant massive black holes
- Stellar dynamics in galaxy center

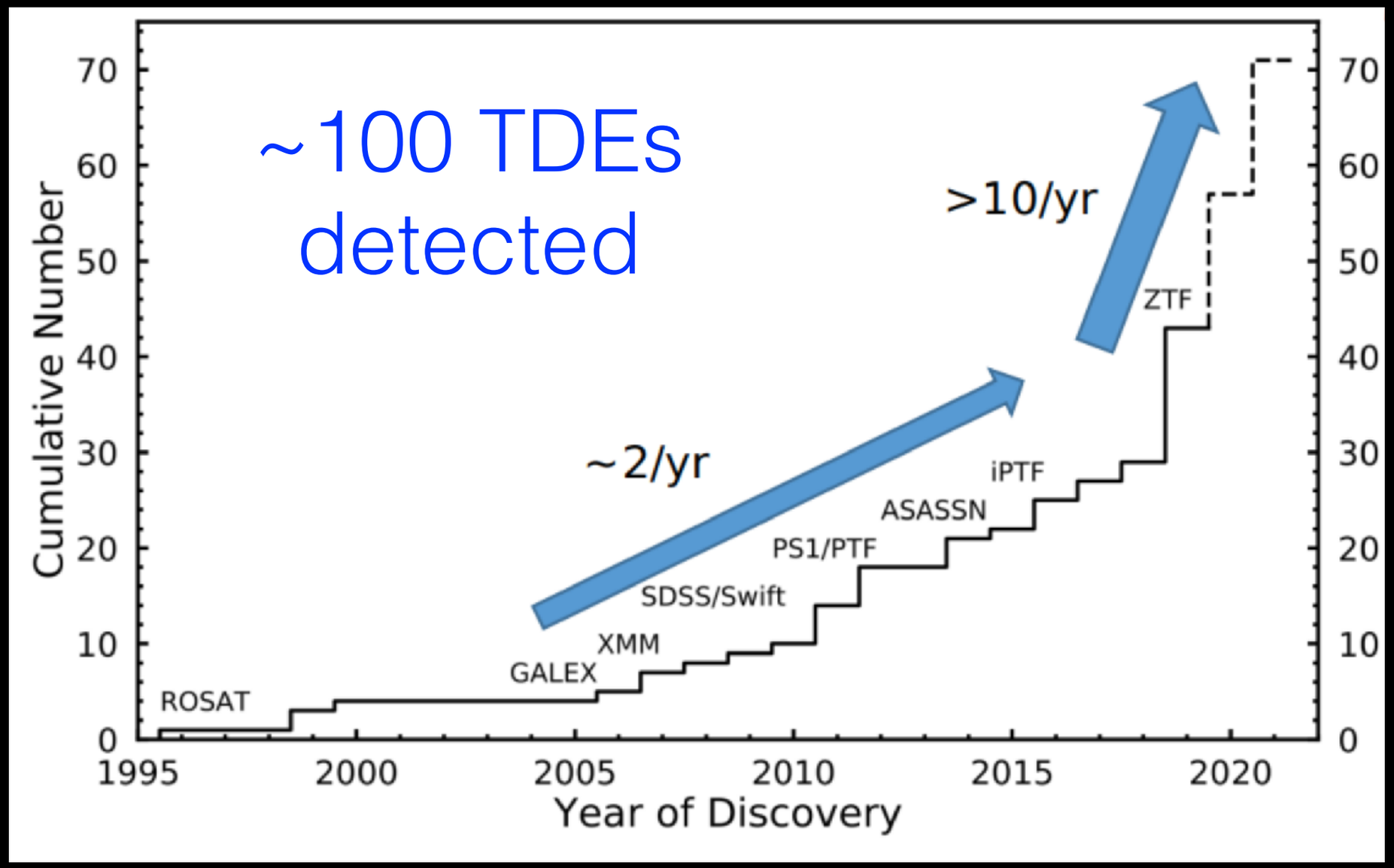
Debris fallback



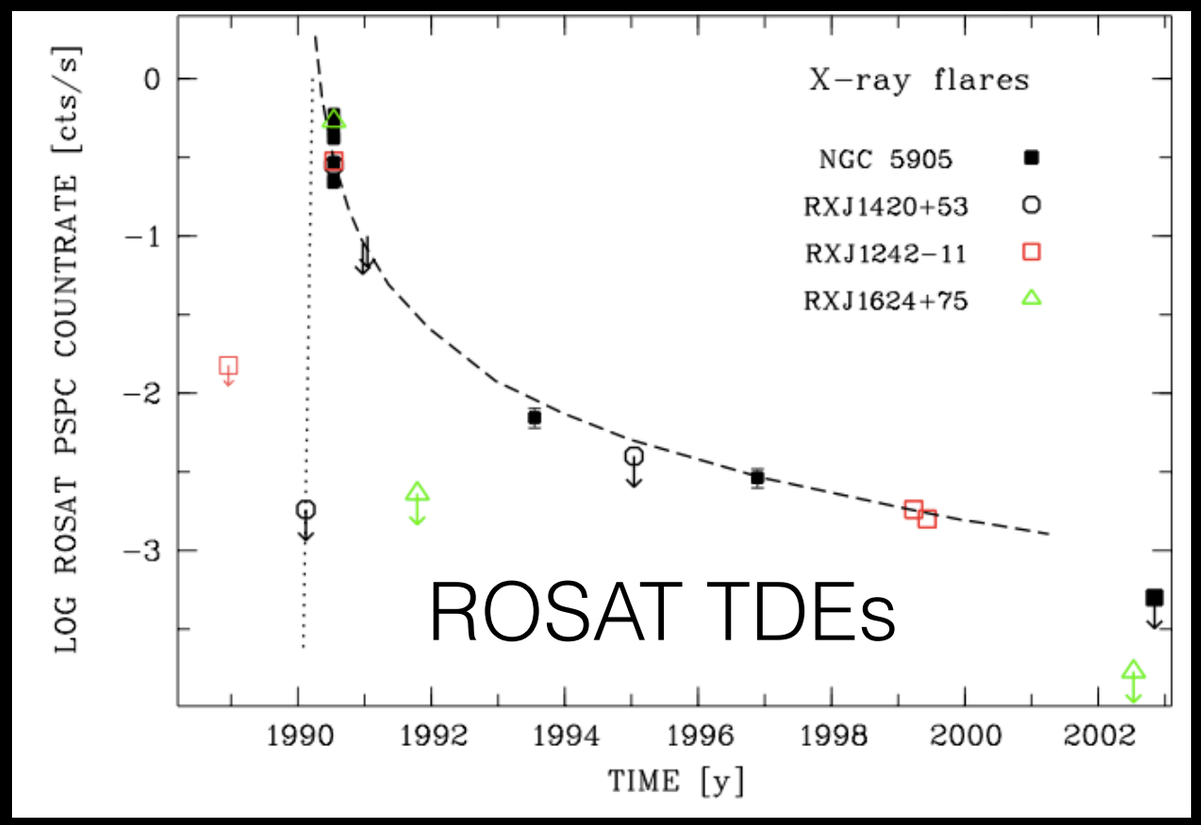
- Physics of black hole accretion disks & jet

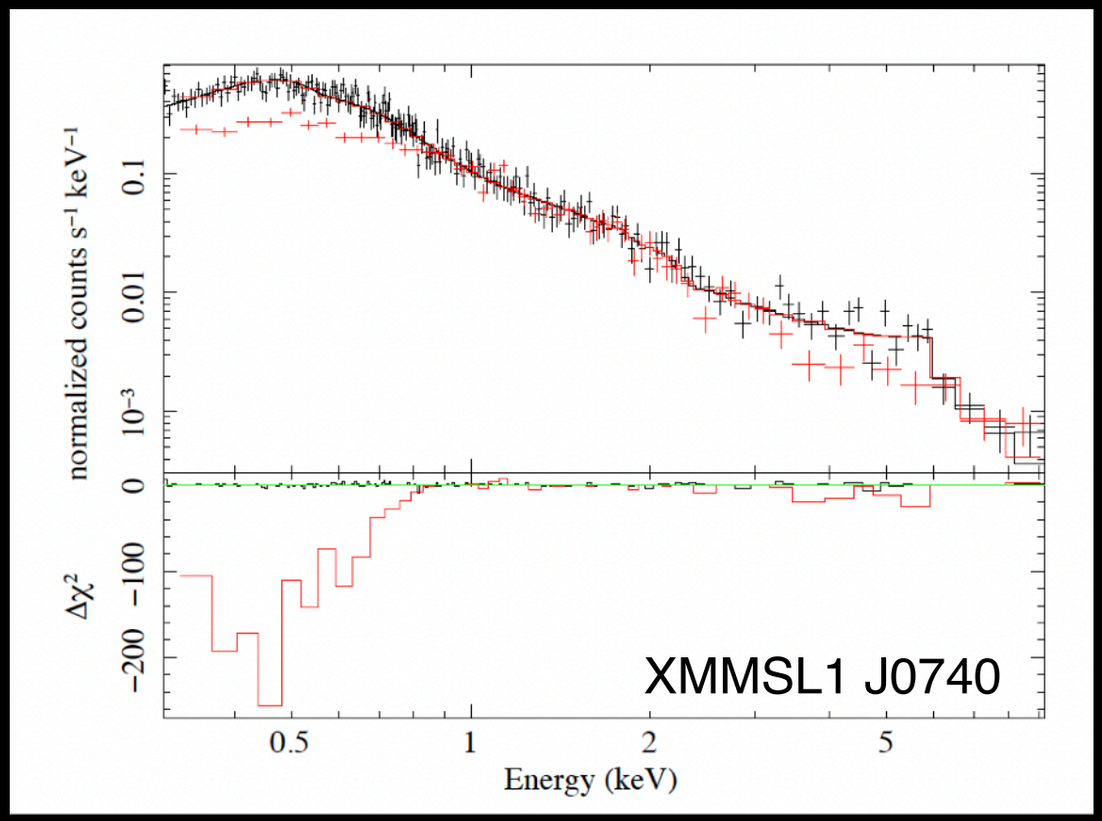
Evans & Kochanek 1989; Phinney 1989; Lodato et al. 2009; Guillochon & Ramirez-Ruiz 2013; Tejeda et al. 2017; Golightly et al. 2019; Gafton & Rosswog 2019; Ryu et al. 2020

Overview of TDE Observations
(+ questions posed by observations)



Thermal X-Ray TDEs





$kT_{BB} \sim 0.04 - 0.1$ keV

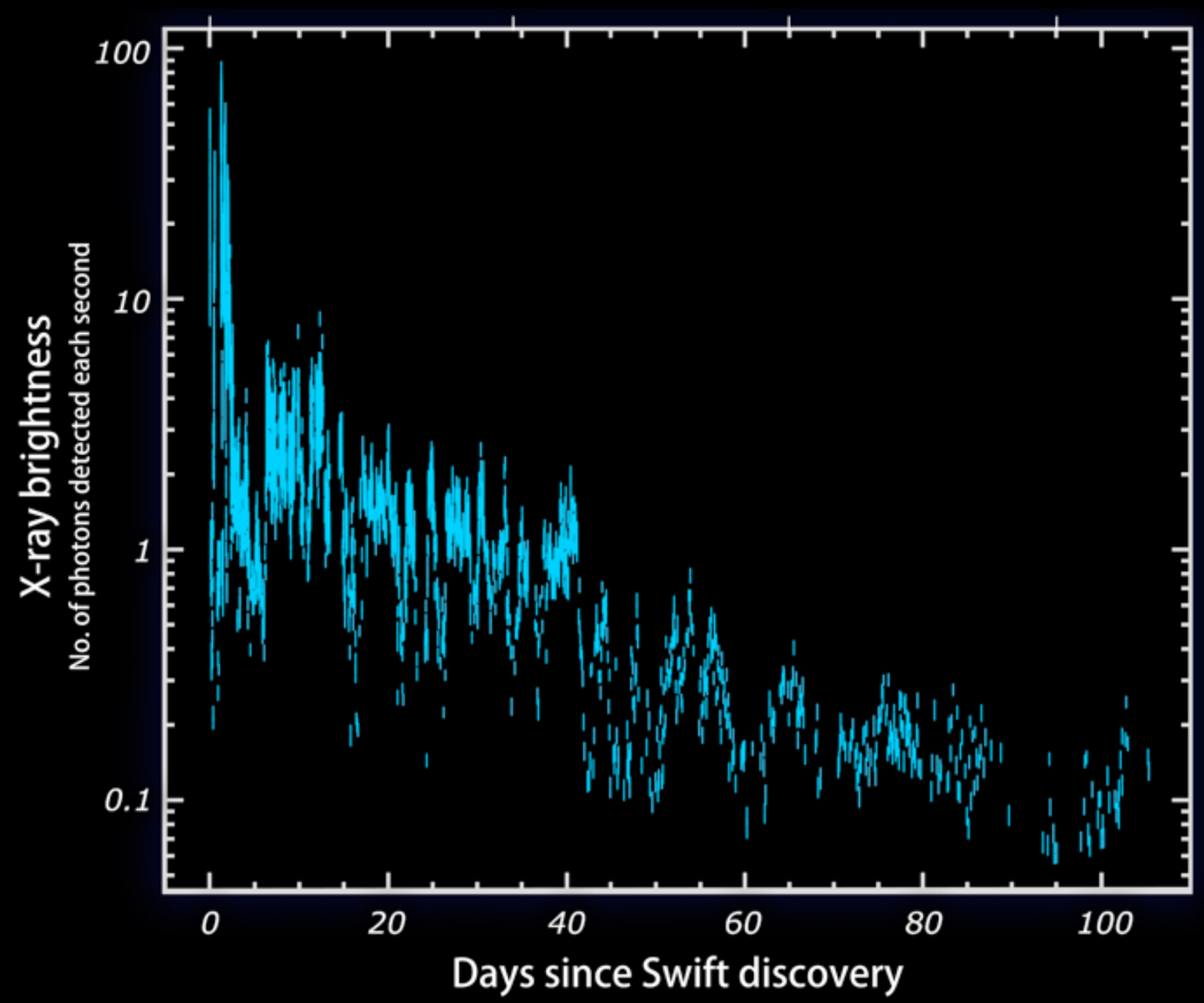
$T_{BB} \sim 10^5$ K

Komossa & Bade 1999
Komossa & Greiner 1999

Saxton et al. 2016

Jetted X-Ray TDEs: Swift J1644+57

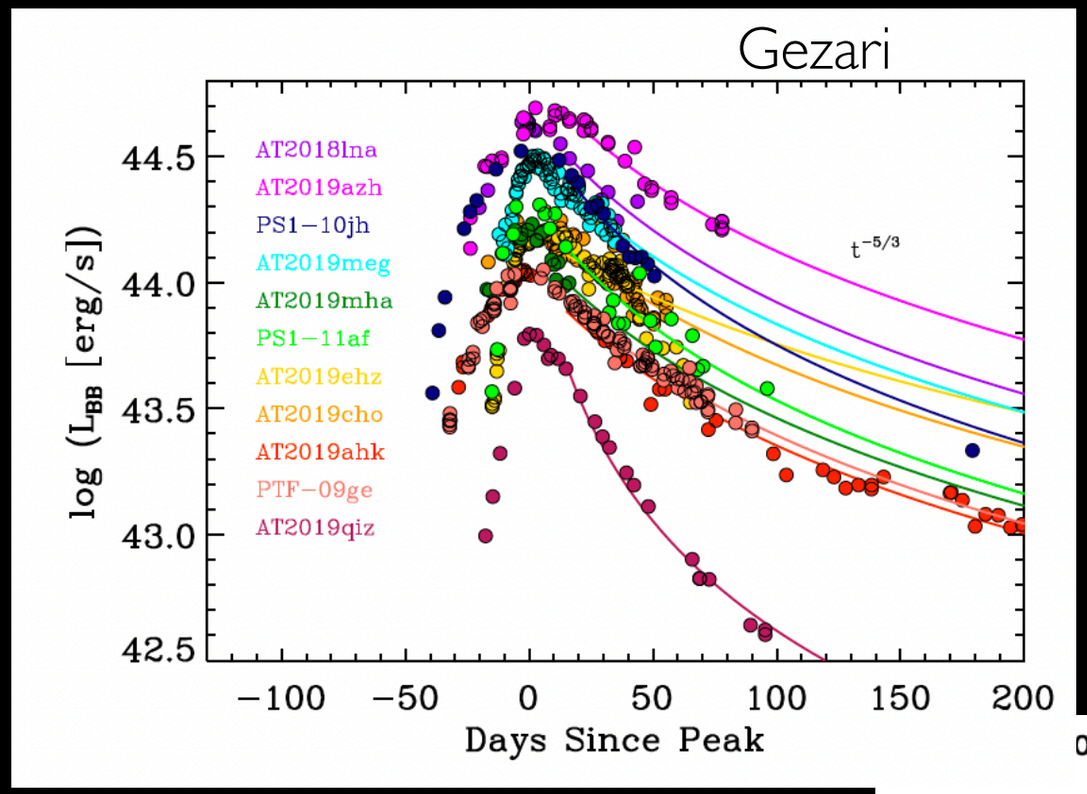
Non-thermal $L_{x,\,iso} \sim 10^{47\text{-}48}$ erg/s

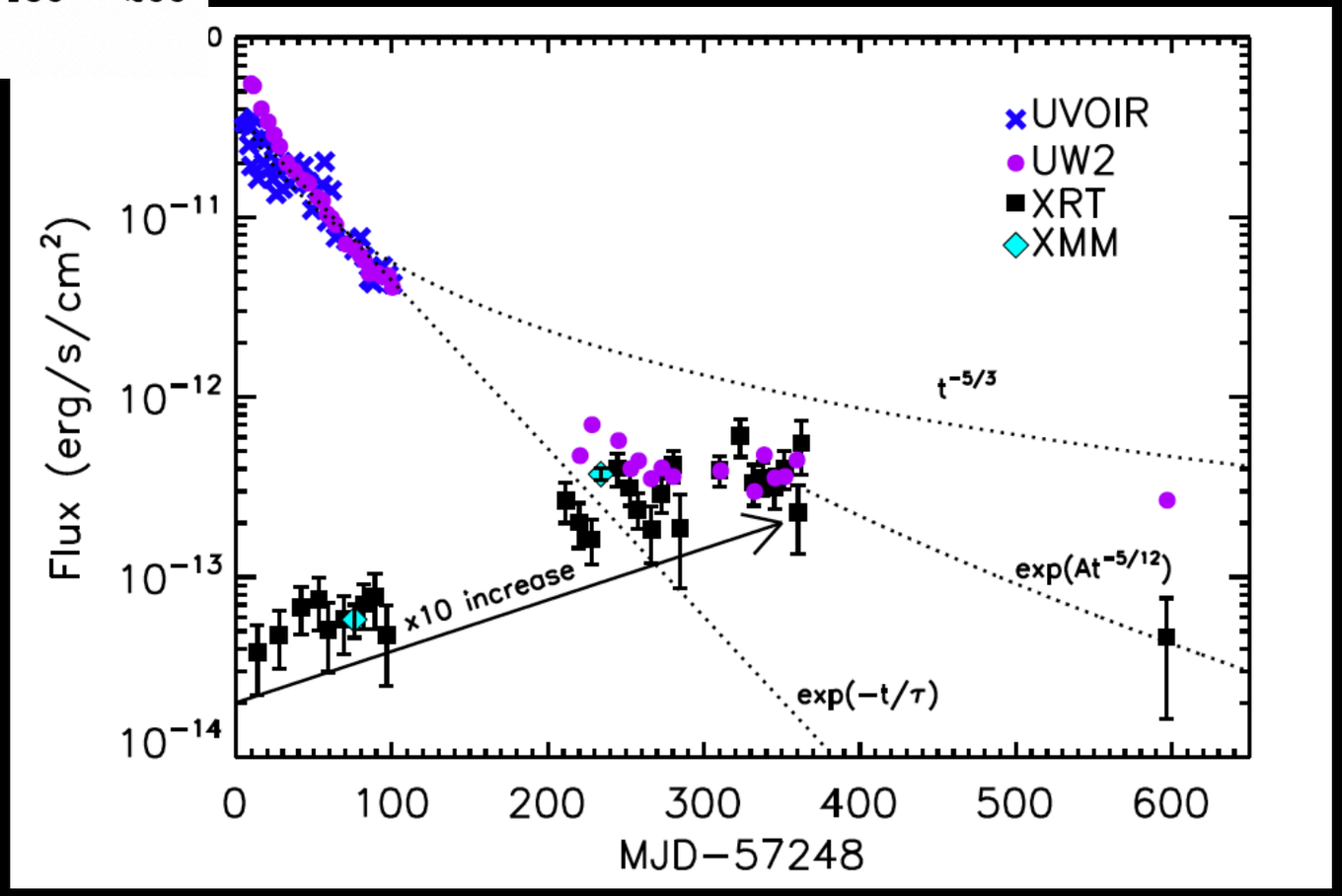


Burrows et al 2011, Bloom et al 2011, Levan et al 2011, Zauderer et al 2011

Optical TDEs

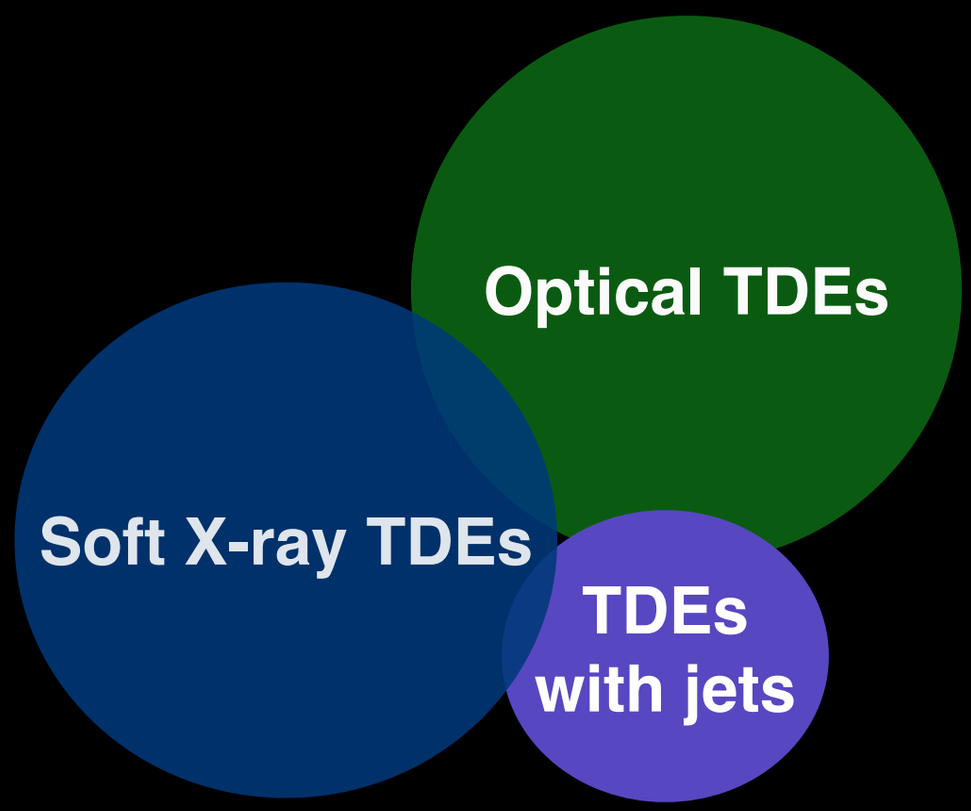
- Cannot be explained by standard thin disks, $T_{BB} \sim 10^4$ K
- Rebrighten in X-rays at late time





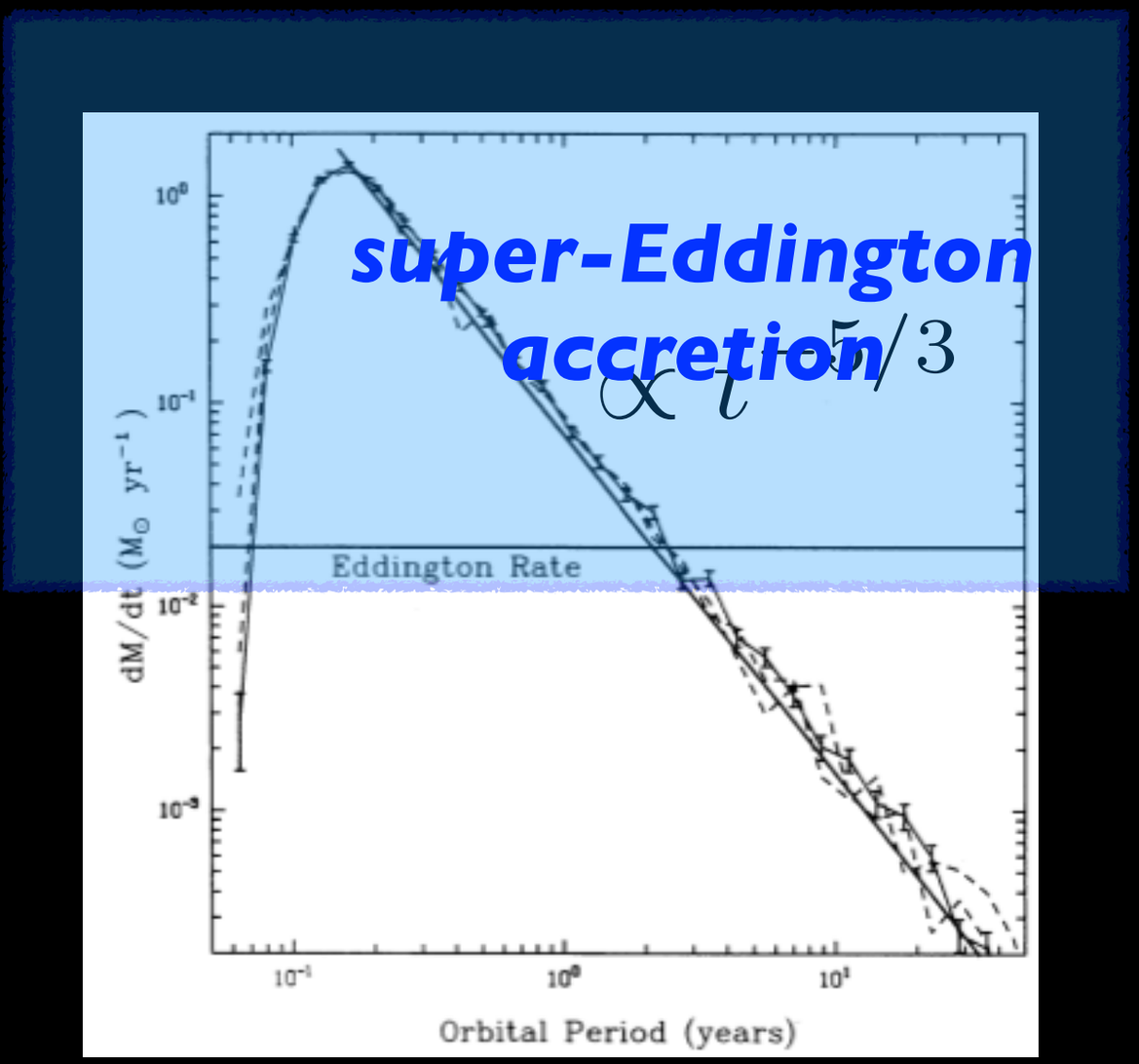
Gezari et al. 2017, Holoien et al. 2018, Wevers et al. 2019, Hinkle et al. 2021, Liu et al. 2022

Overview of TDE Observations (+ questions posed by observations)

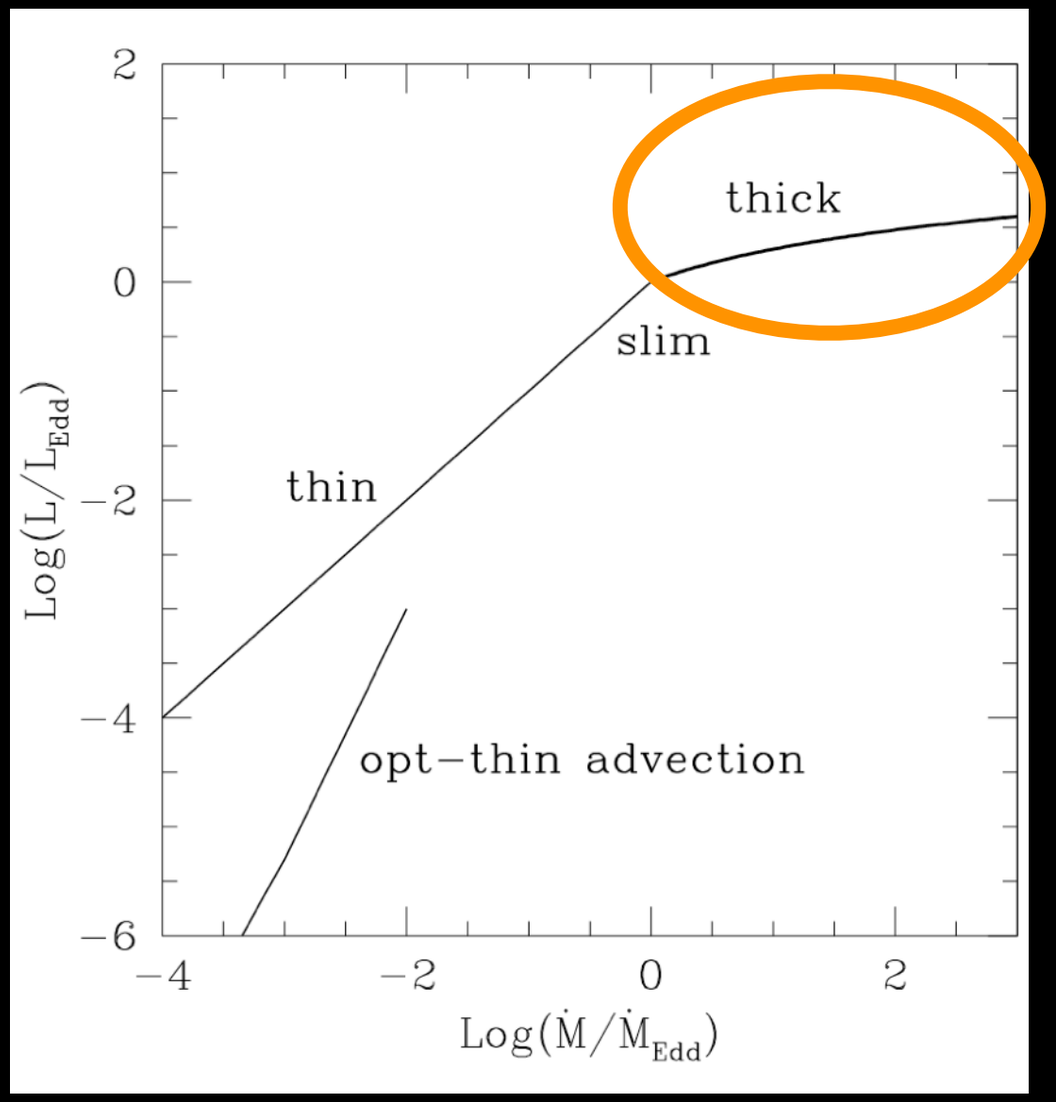


- Why are some TDEs X-ray strong and others optically strong?
- Why do some optical TDEs rebrighten in X-rays?
- Why do a small fraction of TDEs produce jets?

Super-Eddington Accretion in TDEs

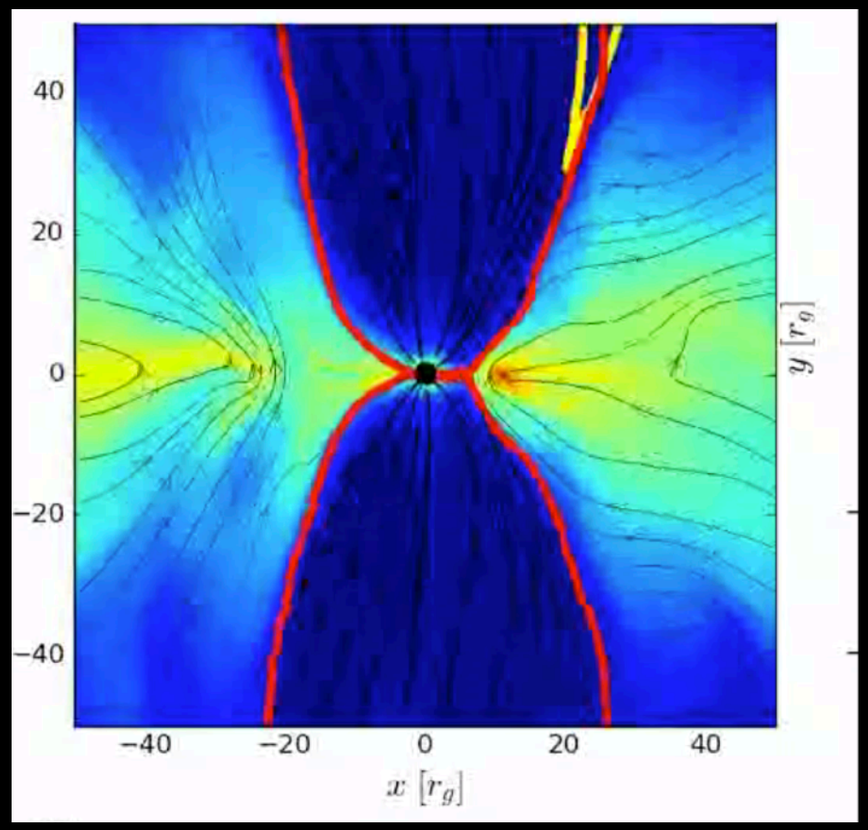


Shakura & Sunyaev 1973, Begelman 1978, Abramowicz et al. 1988, Ulmer 1999



- Large radiation pressure
- Geometrically thick disk, radiation-driven winds
- Photons coupled to gas, photon trapping in the inner disk

Simulating TDE super-Eddington Disks & Emissions

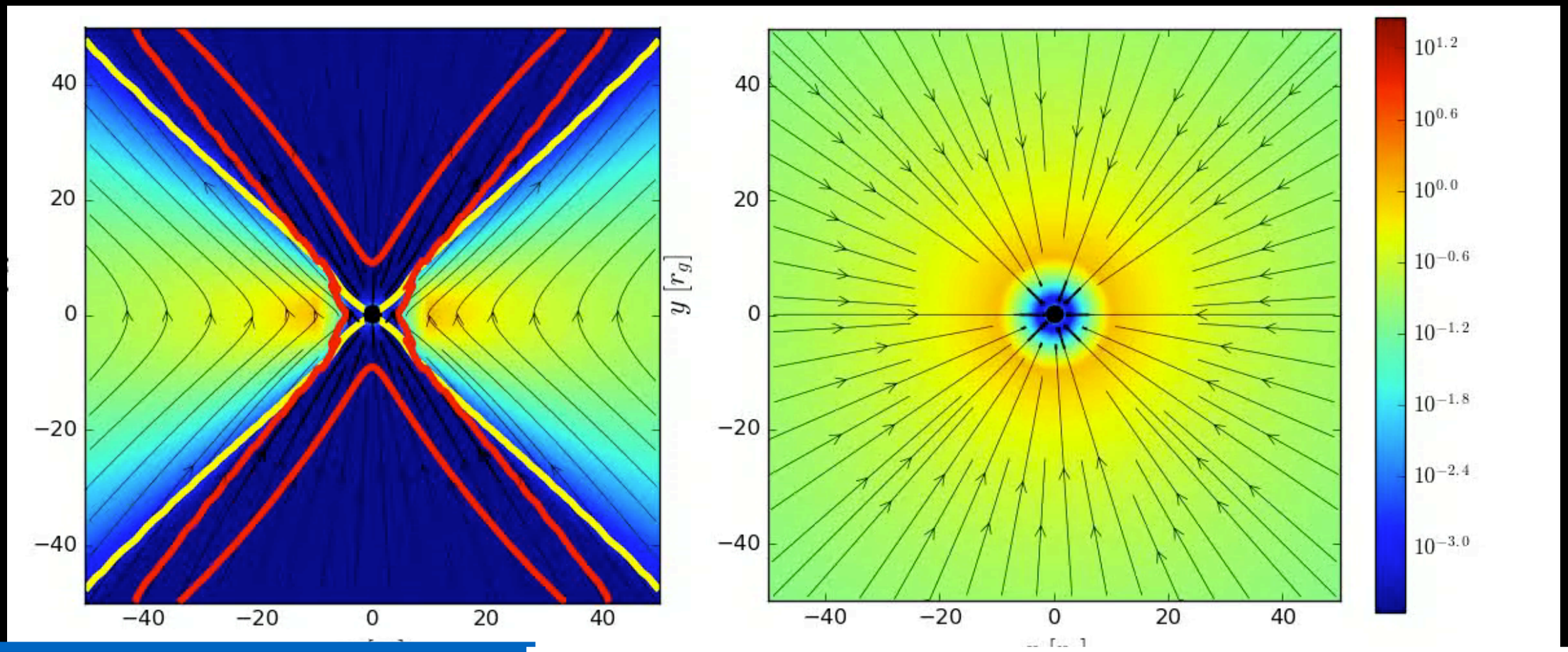


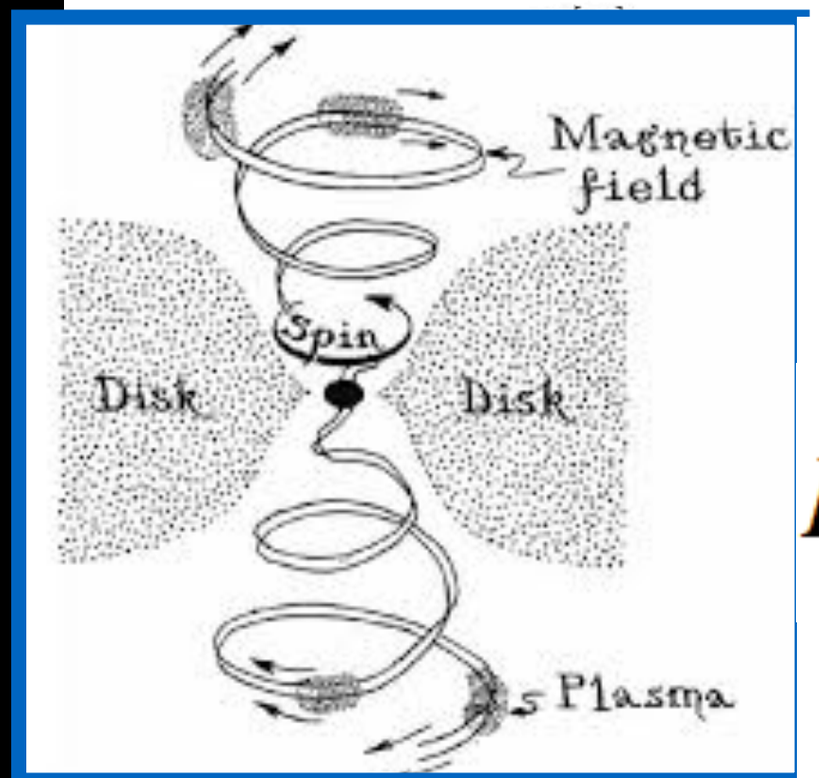
LD, McKinney, Roth et al. 2018

Thomsen, Kwan, **LD**, et al, 2022
arXiv: 2206.02804

- Disk simulation: 3D full GR-Radiation-MHD code HARMRAD (Gammie+ 03, McKinney+ 12,14)

Why do a small fraction of TDEs produce jets?



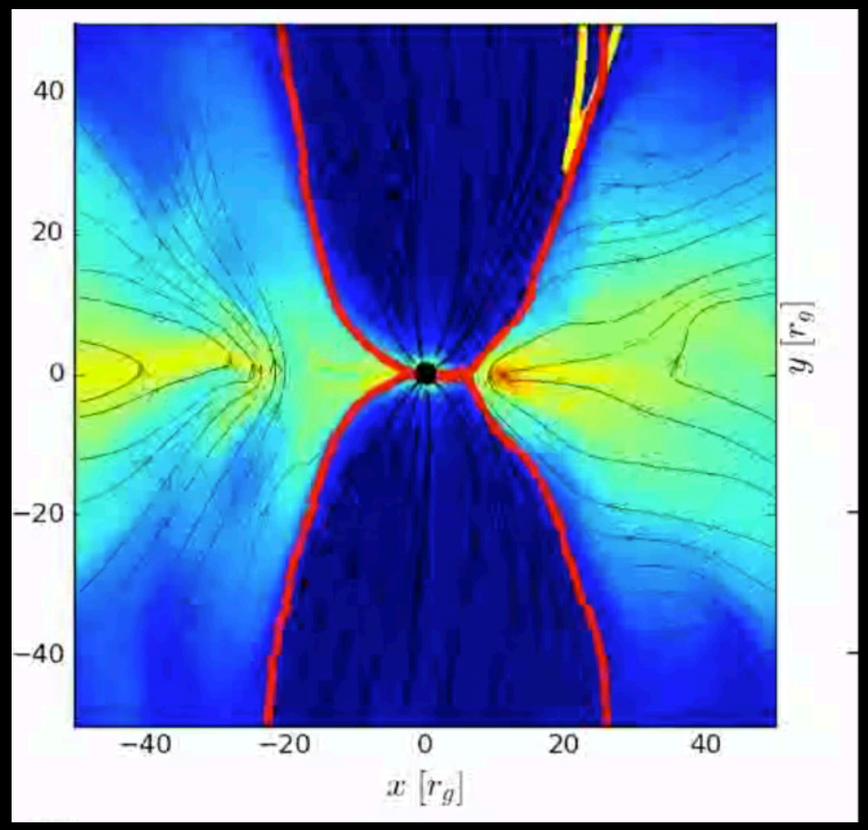


Relativistic Jet:
spinning black hole + magnetic flux

$$P_{BZ,old} \approx P_0 \left(B^r[\mathrm{G}]\right)^2 \left(\Omega_H^2/c\right) r_g^4$$

Blandford & Znajek 1977

Simulating TDE super-Eddington Disks & Emissions



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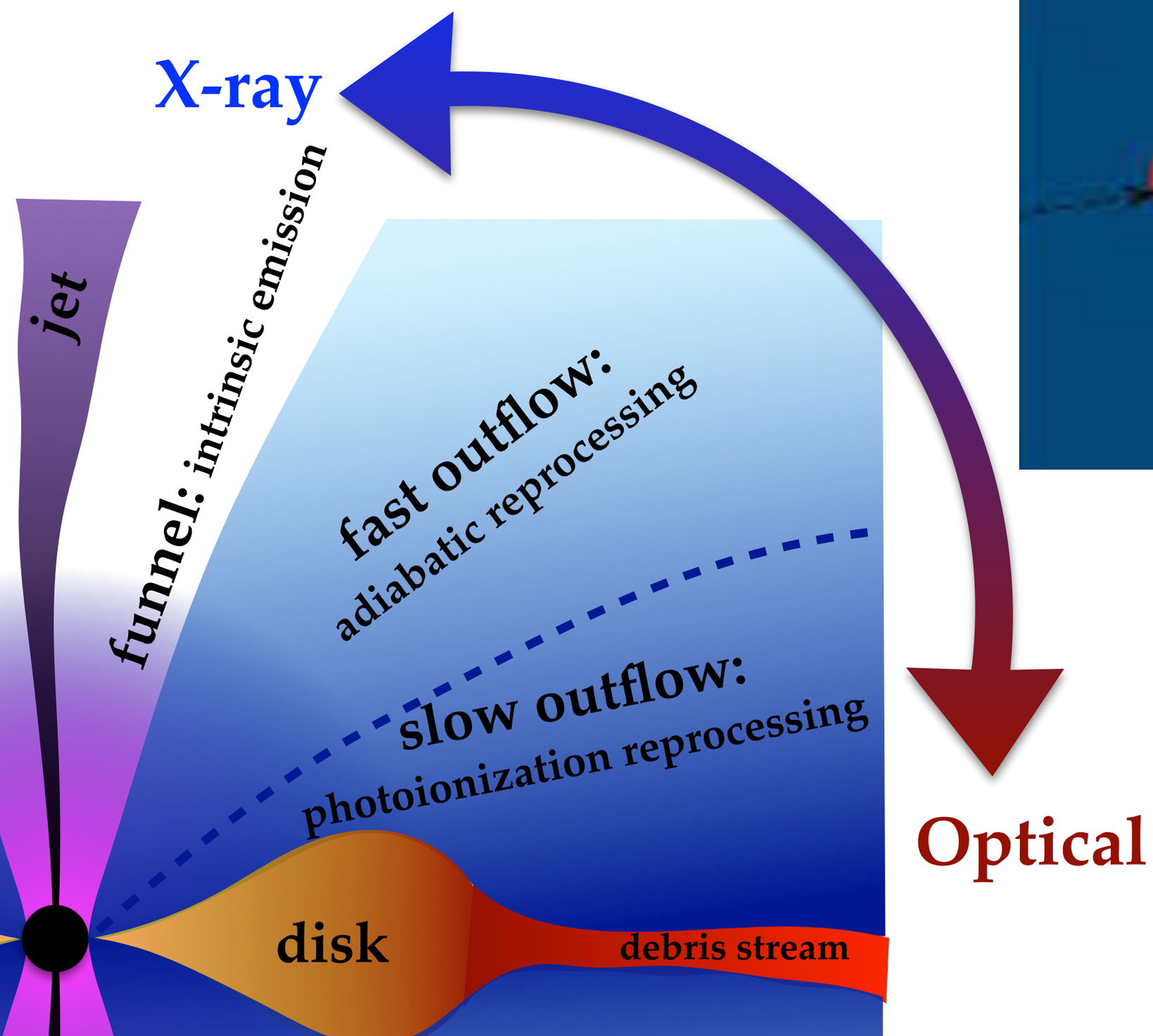
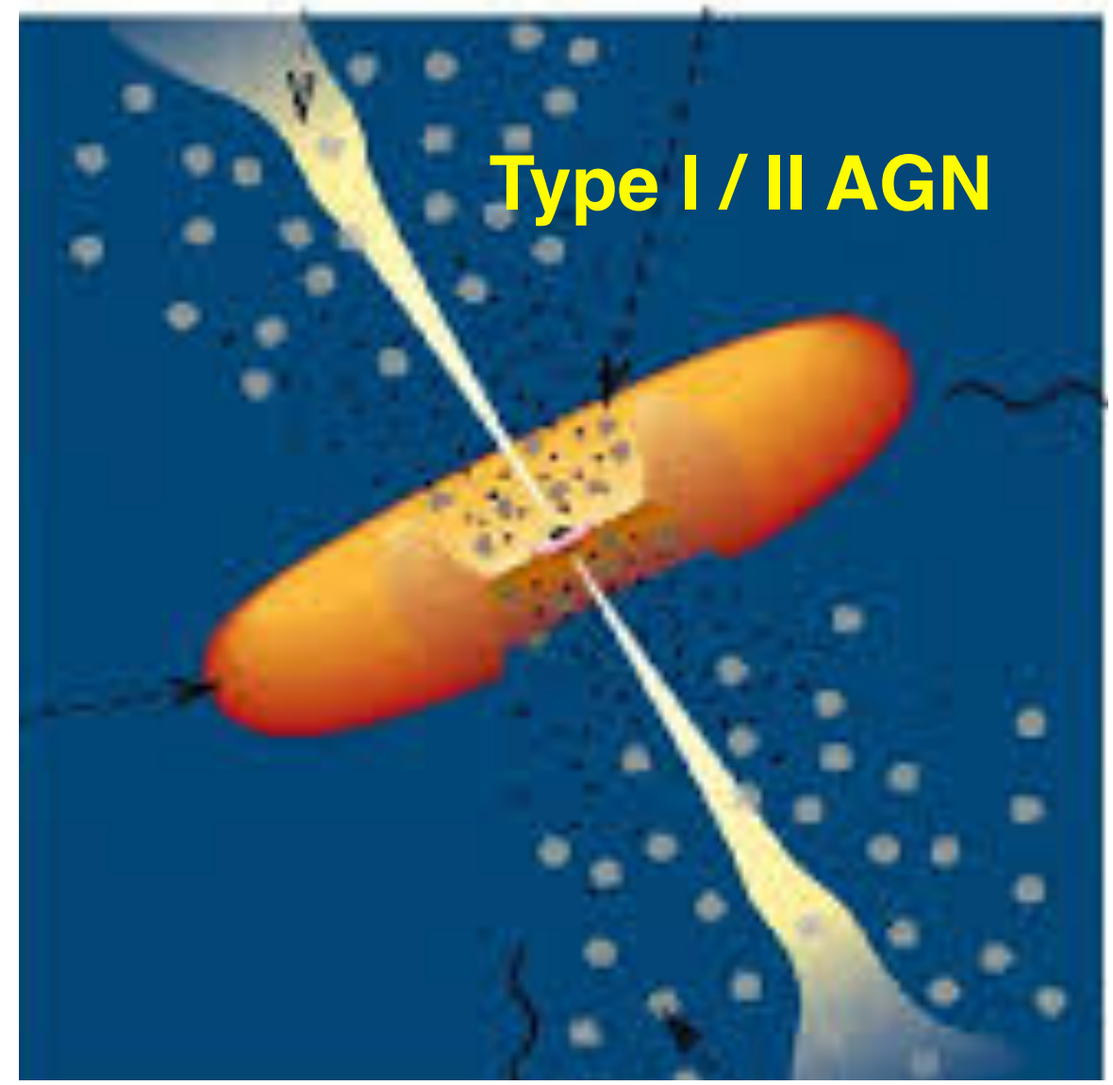
- Disk simulation: 3D full GR-Radiation-MHD code HARMRAD (Gammie+ 03, McKinney+ 12,14)
- Spectra: Monte-Carlo Radiative Transfer Code SEDONA (non-LTE, scattering, Comptonization, ff/bf/bb) (Kasen+06, Roth+16)

Dynamical Unified TDE Model

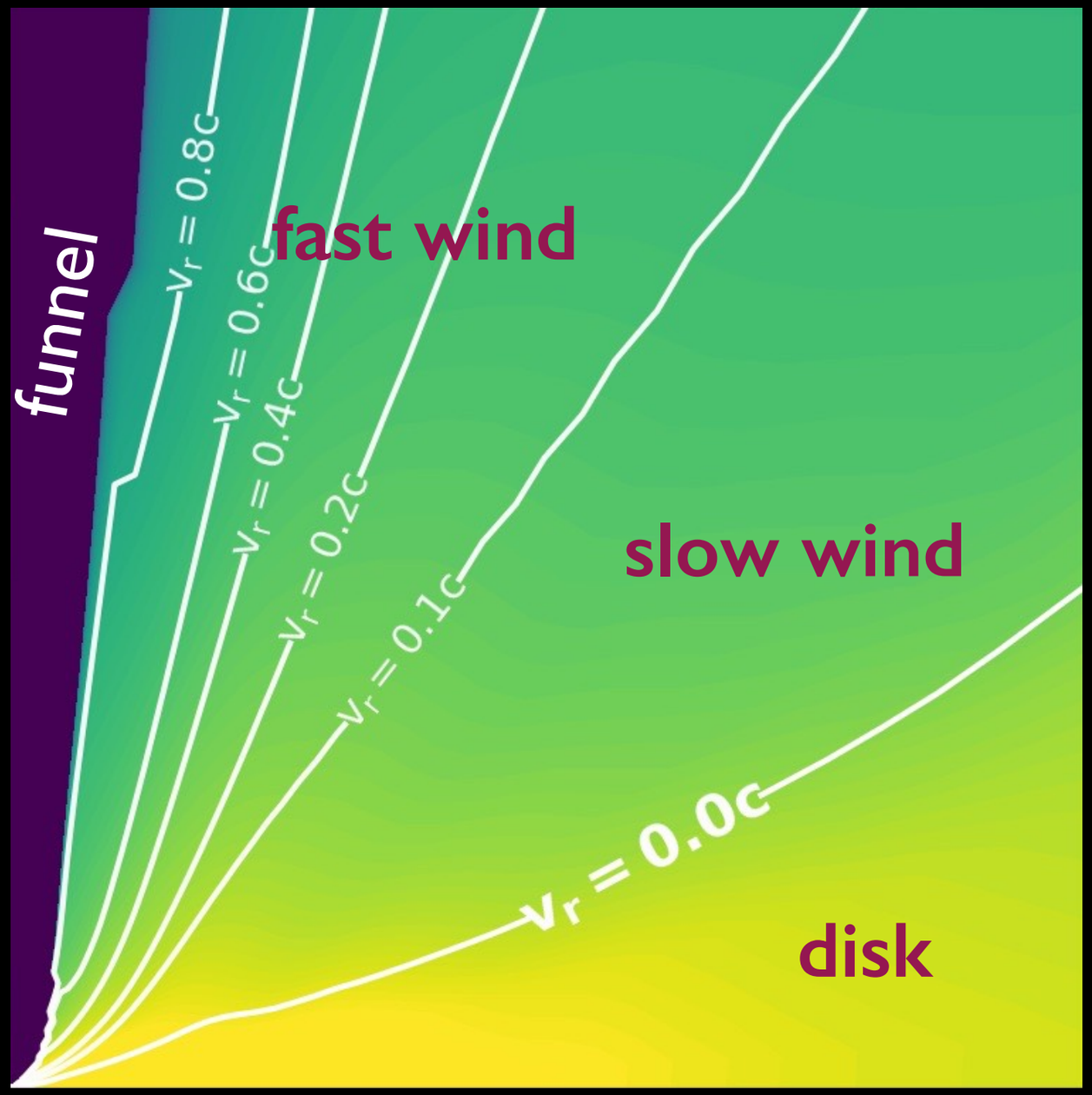




LD, McKinney, Roth et al. 2018

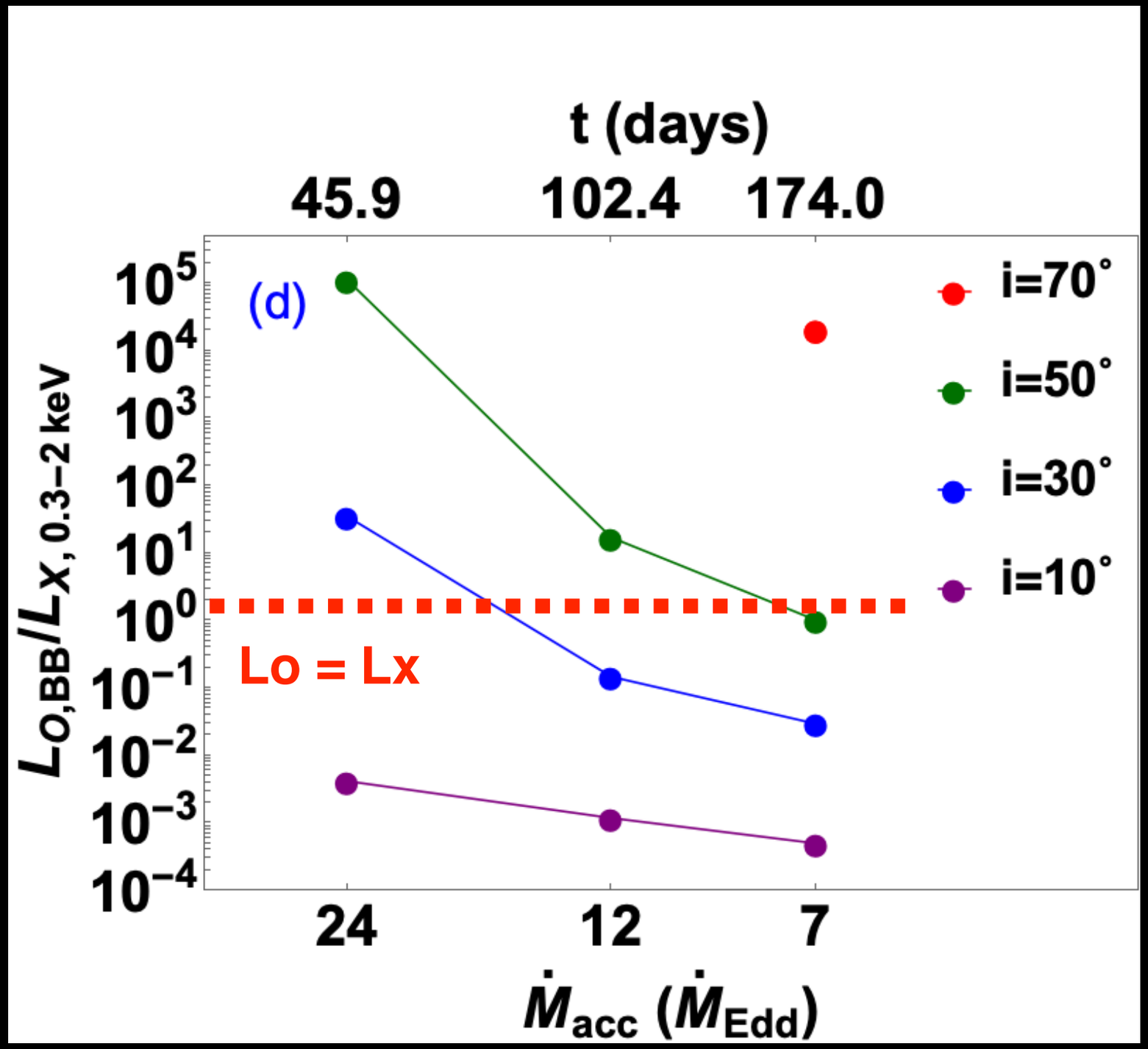
Thomsen, Kwan, LD et al. 2022

Why are some TDEs X-ray or optically strong?



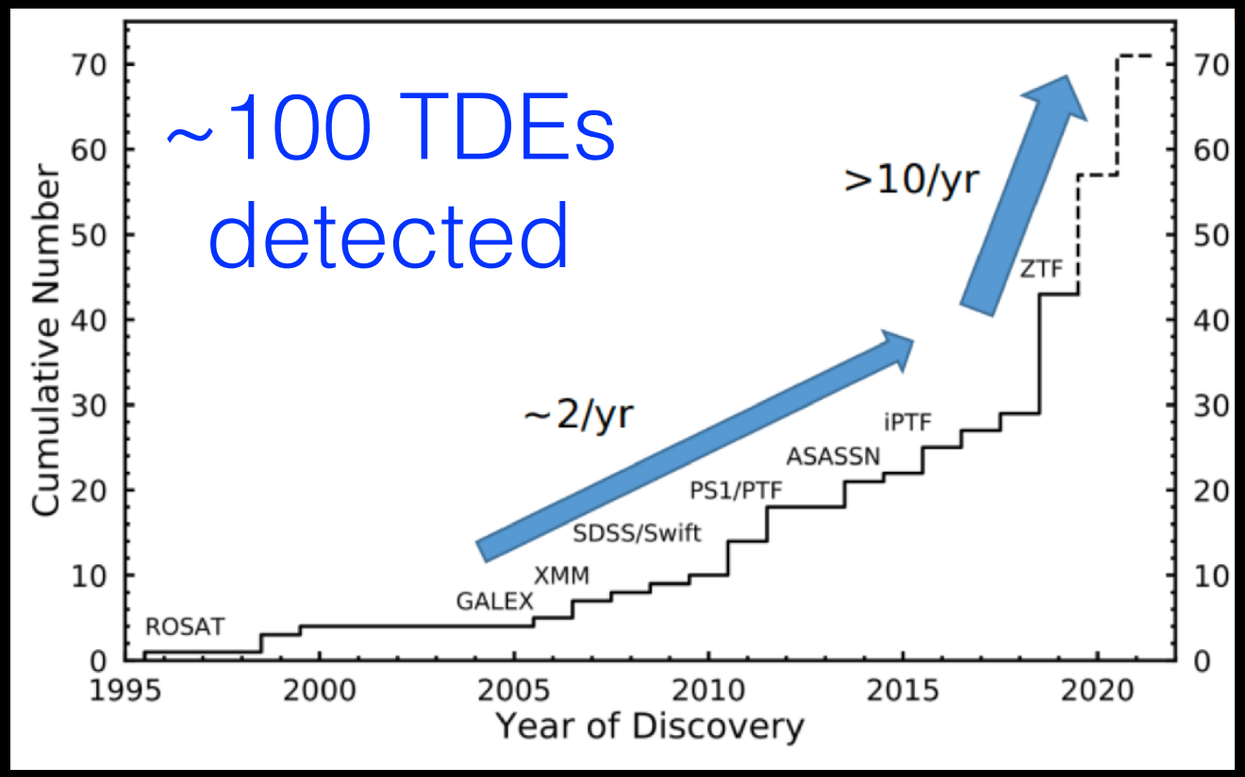
viewing angle
(+ accretion rates)

Why do optical TDEs rebrighten in X-rays?



Thomsen, Kwan, **LD**, et al, 2022

TDE/Transient surveys in the next decade



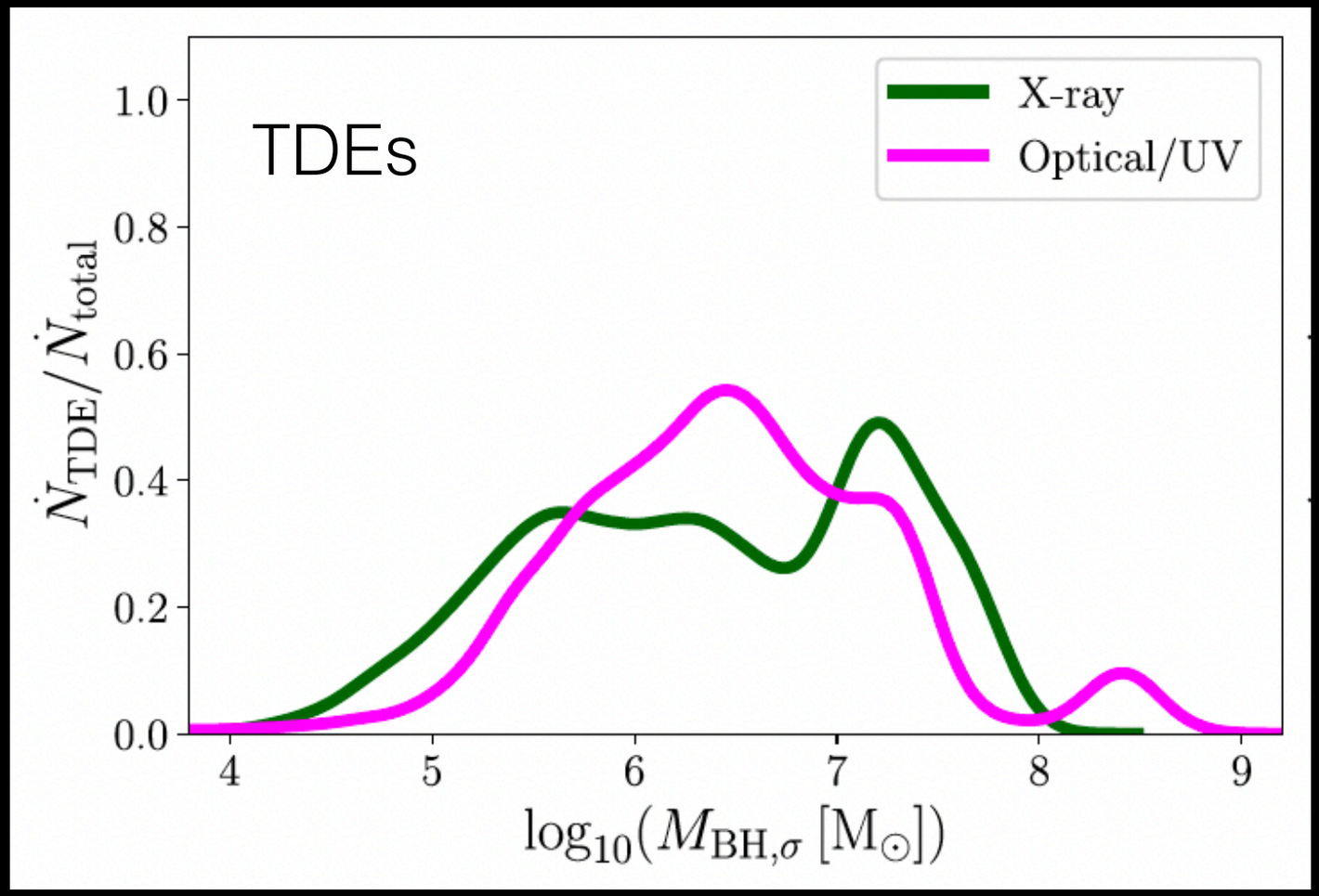
Einstein Probe

Vera Rubin Observatory

eROSITA

What can we learn from X-ray TDEs?

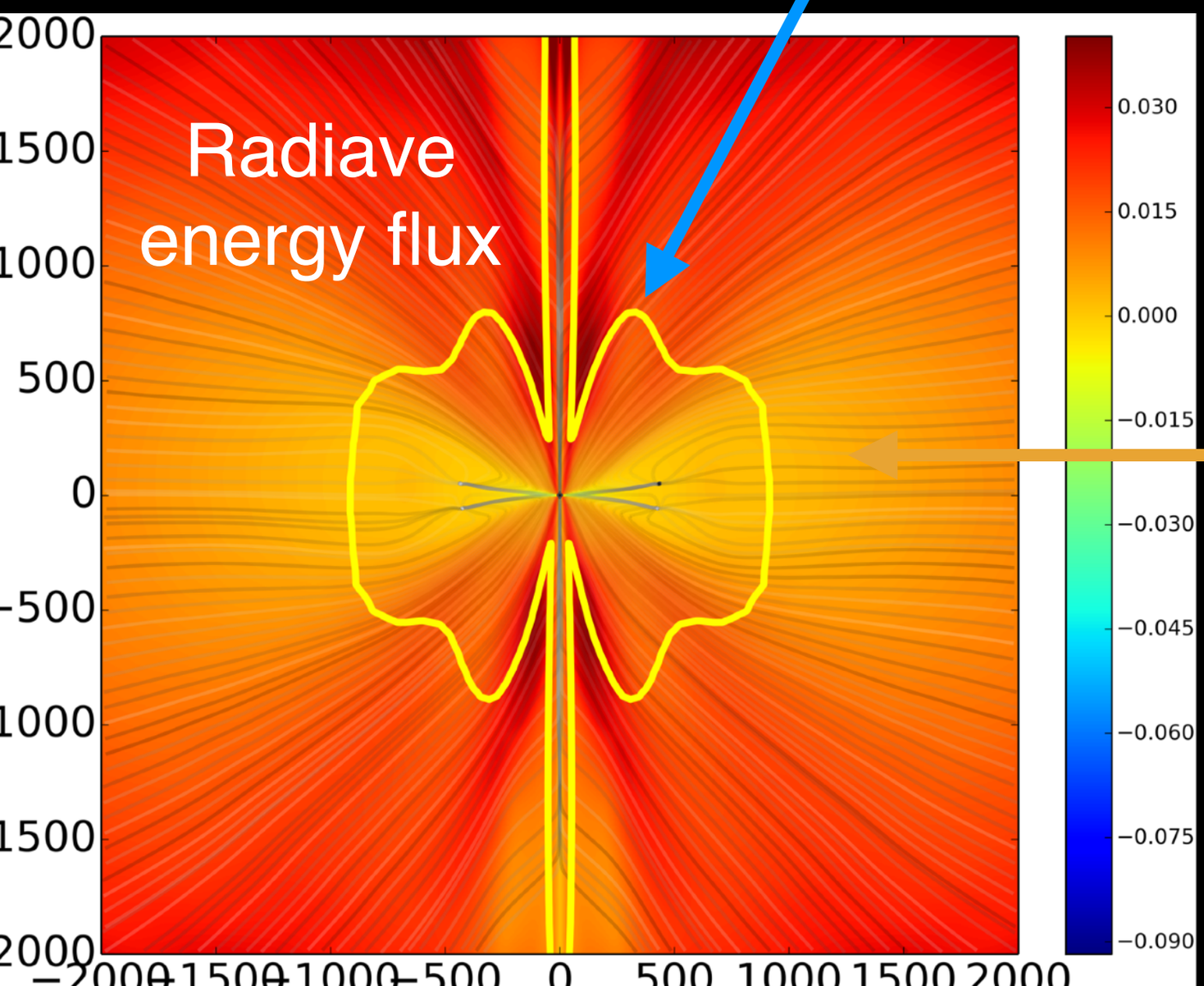
(Dormant) Massive Black Hole Demographics



Wong, Pfister, **LD**,2022

What can we learn from X-ray TDEs?

X-ray: beamed, super-Eddington



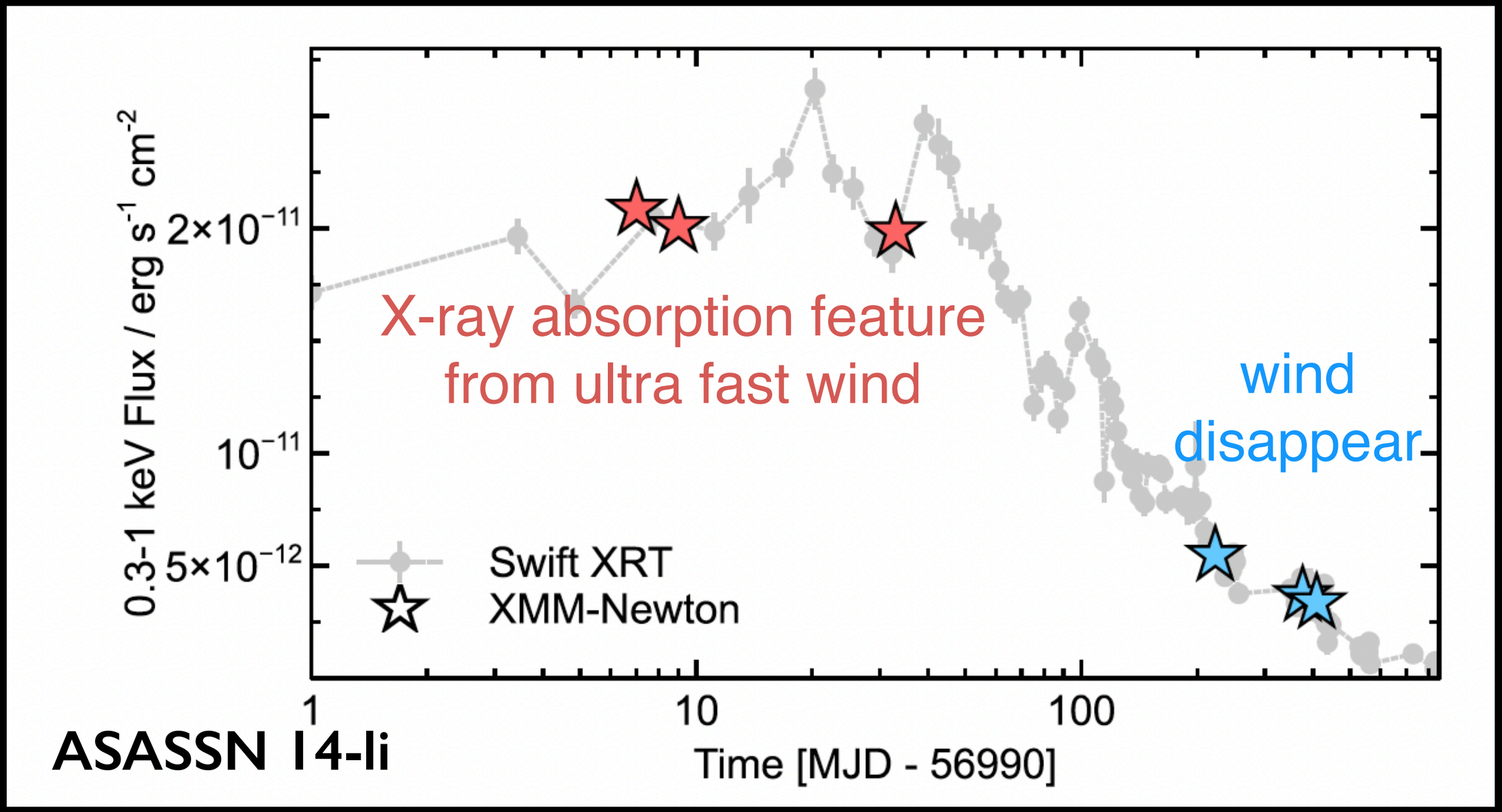
- Super-Eddington luminosity as NLS1s?
- Beaming effect similar to ULXs?

Optical: Eddington-regulated

LD, McKinney, Roth et al. 2018

What can we learn from X-ray TDEs?

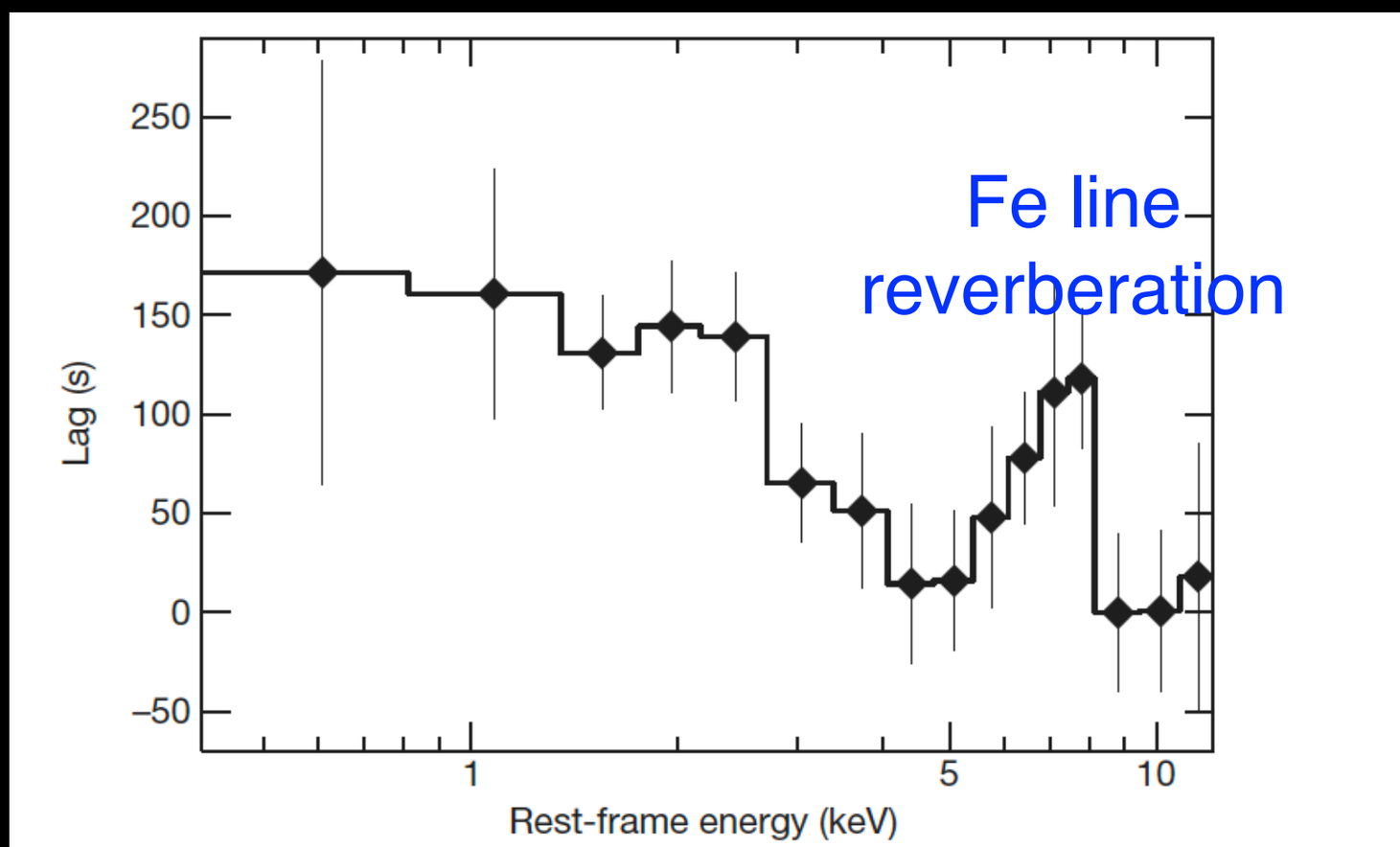
wind ↔ accretion

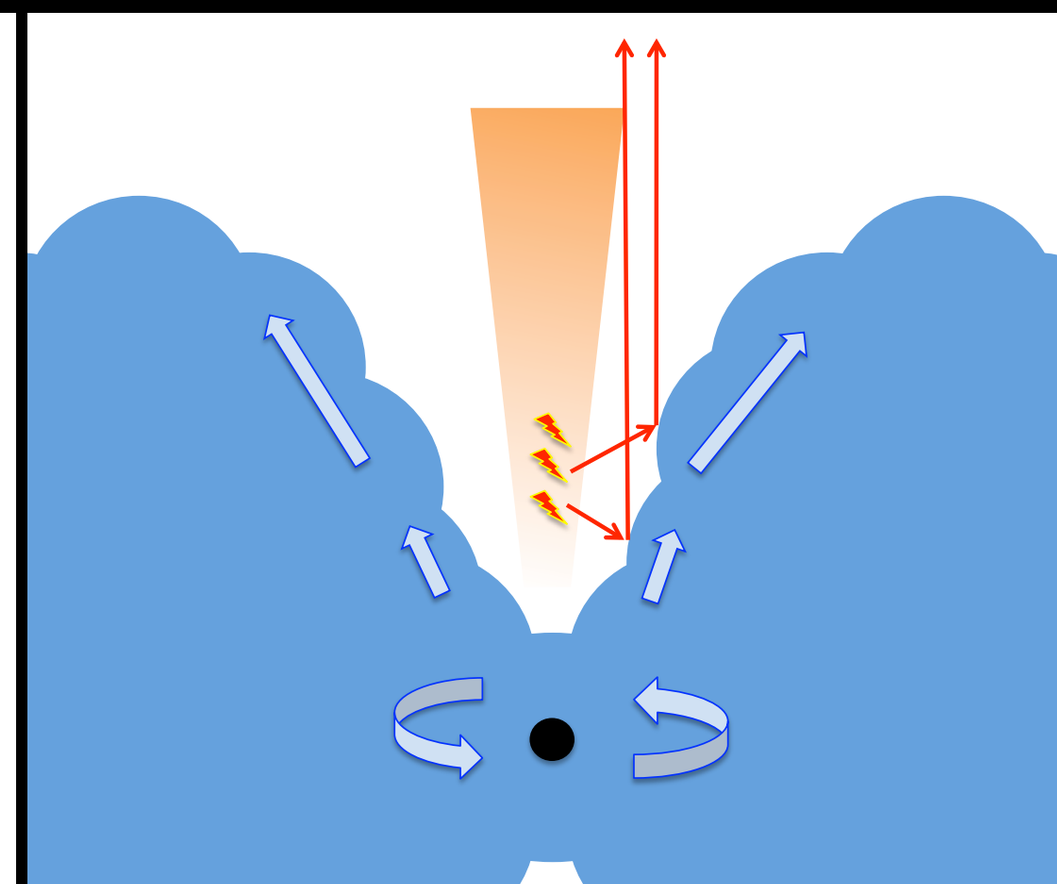


Kara, **LD,** Reynolds et al. 2018

What can we learn from X-ray TDEs?

Fe Kα reverberation observed from TDE Swift J1644 / super-Eddington disk for the first time

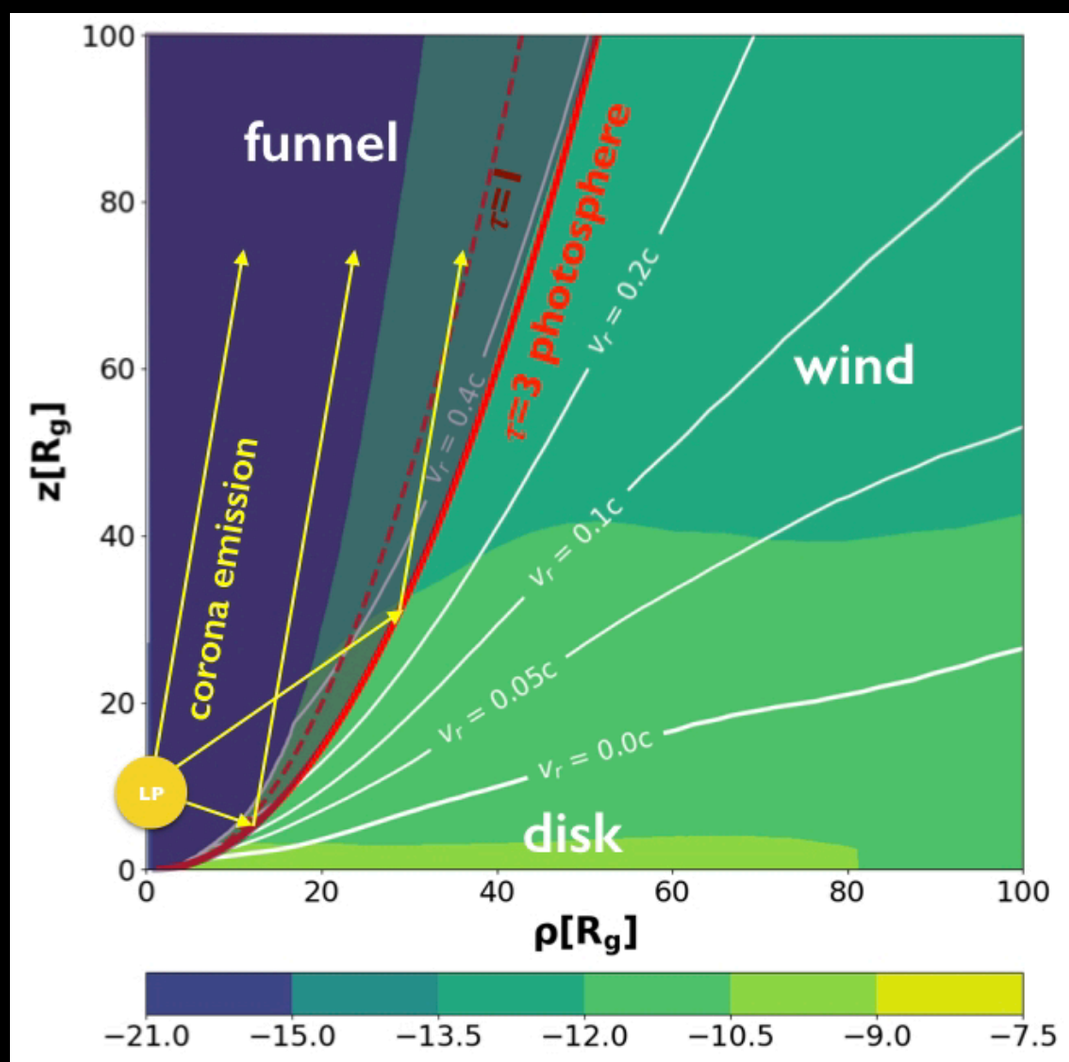




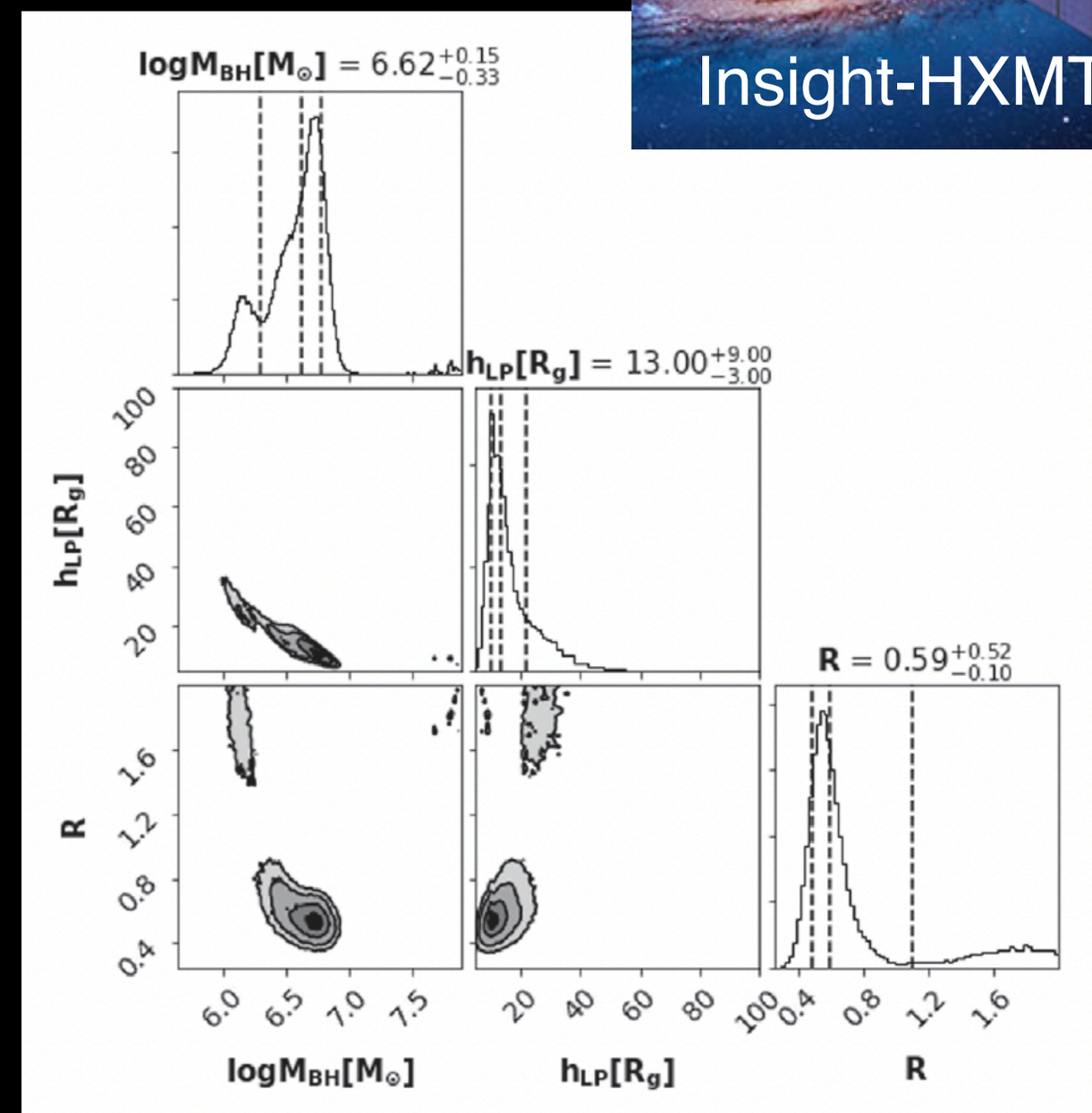
Kara, Miller, Reynolds & **LD,** 2016, Nature

What can we learn from X-ray TDEs?

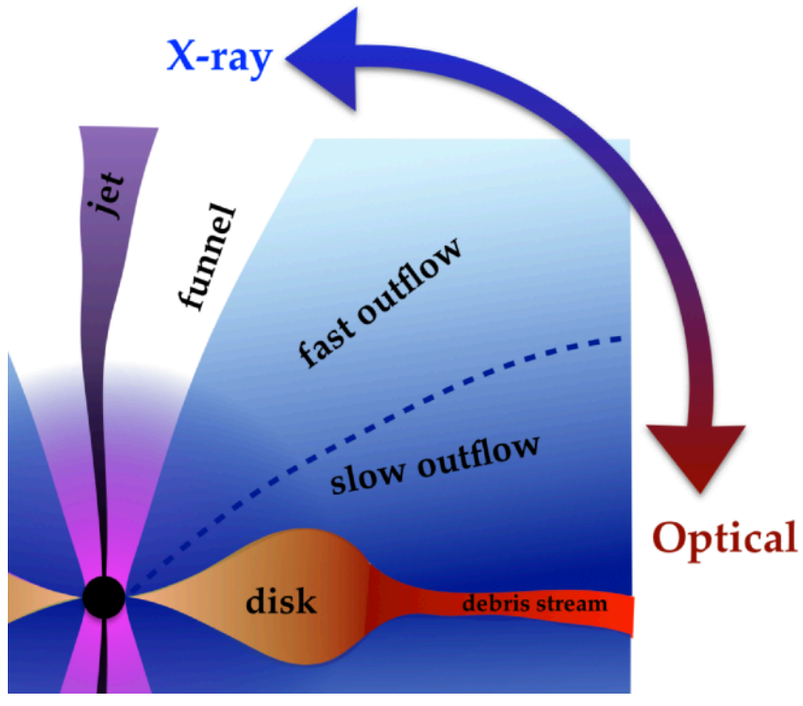
Constrain black hole mass, disk morphology, wind launching, coronal height & geometry…

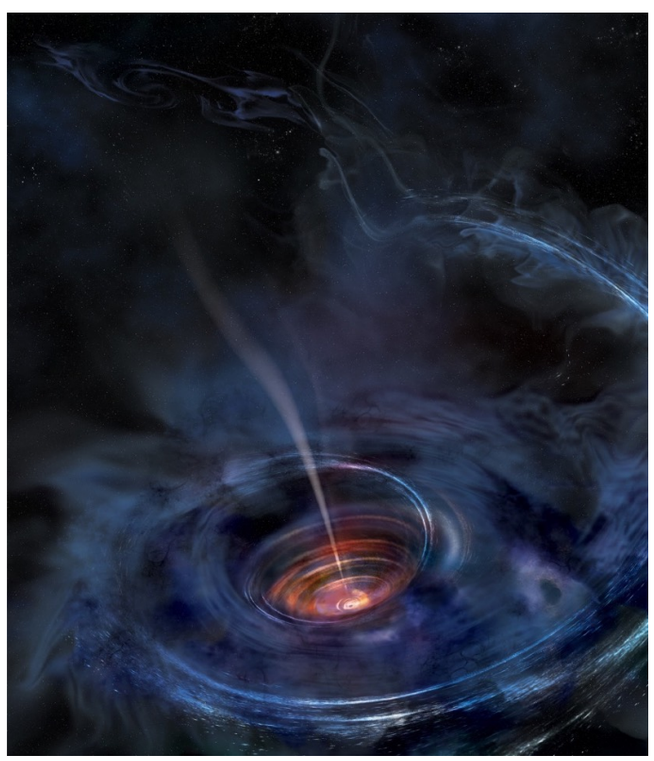


Thomsen, **LD** et al. 2019, 2022



Takeaways





Diversity of TDEs can be understood via a dynamical unification model.

X-ray observations + modelings of TDEs shed light on the physics of black hole accretion disk, wind, relativistic jet, radiation, and corona.

A lot of X-ray TDE science remains to be done!

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