Prompt radio-emitting outflows in tidal disruption events from accretion disk winds

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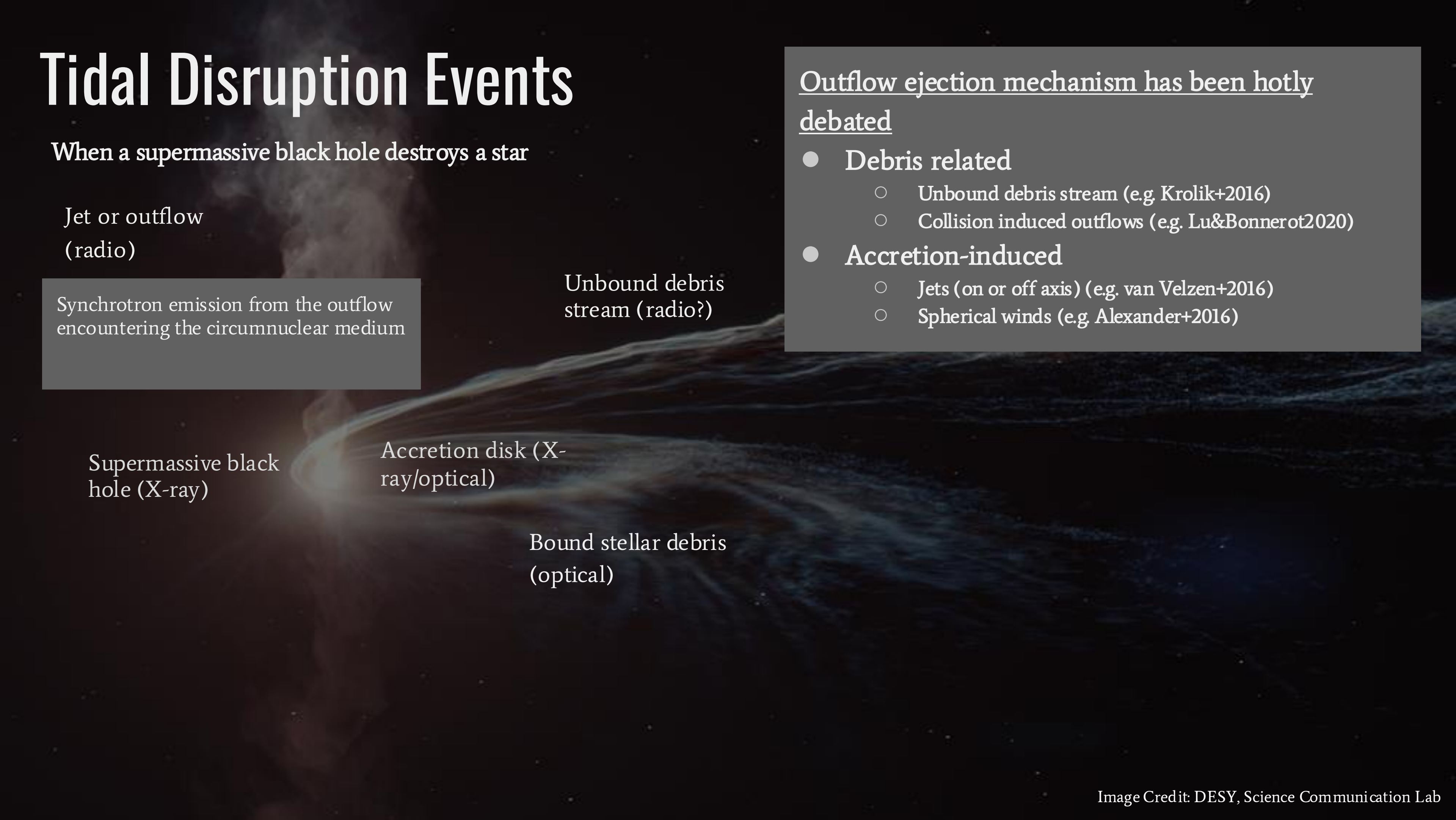
Tidal Disruption Events

When a supermassive black hole destroys a star



Jet or outflow
(radio)

Synchrotron emission from the outflow encountering the circumnuclear medium

Unbound debris stream (radio?)

Supermassive black hole (X-ray)

Accretion disk (X-ray/optical)

Bound stellar debris (optical)

Outflow ejection mechanism has been hotly debated

- Debris related
    - Unbound debris stream (e.g. Krolik+2016)
    - Collision induced outflows (e.g. Lu&Bonnerot2020)
- Accretion-induced
    - Jets (on or off axis) (e.g. van Velzen+2016)
    - Spherical winds (e.g. Alexander+2016)

Image Credit: DESY, Science Communication Lab

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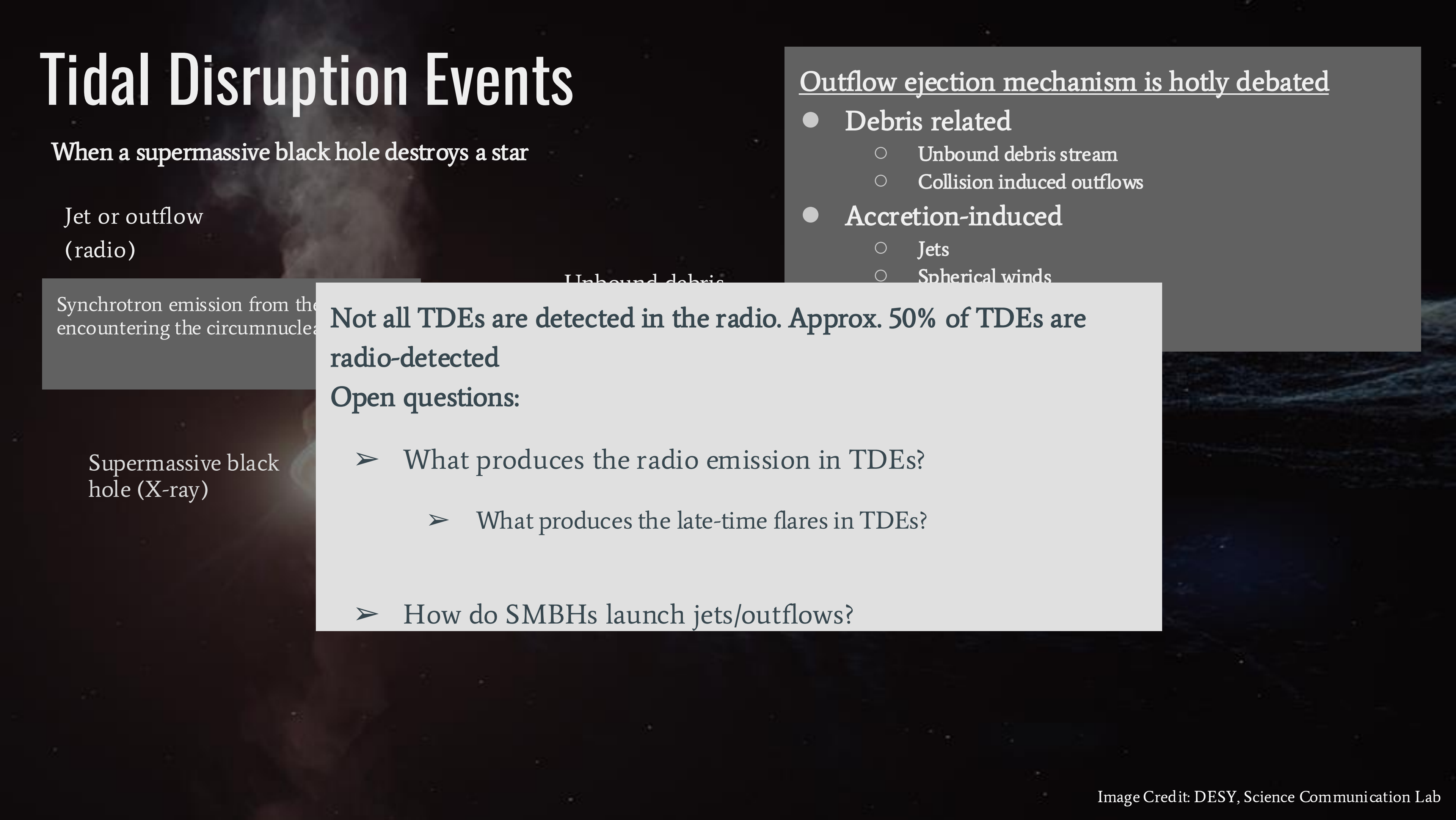

Synchrotron emission from the
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<u>Outflow ejection mechanism is hotly debated</u>

- Debris related
    - Unbound debris stream
    - Collision induced outflows
- Accretion-induced
    - Jets
    - Spherical winds

Not all TDEs are detected in the radio. Approx. 50% of TDEs are radio-detected

Open questions:

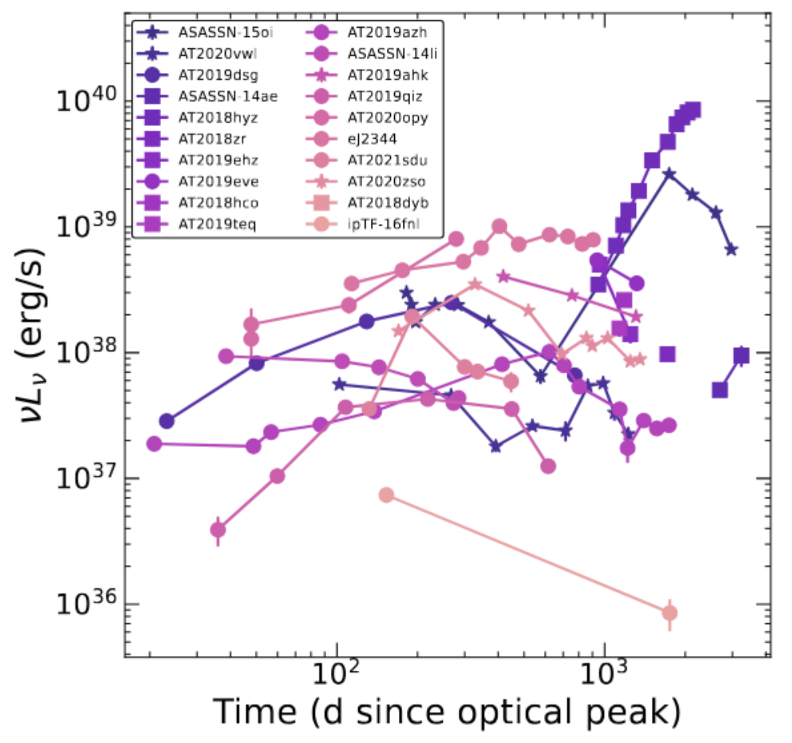
- ➢ What produces the radio emission in TDEs?
    - ➢ What produces the late-time flares in TDEs?
- ➢ How do SMBHs launch jets/outflows?

Image Credit: DESY, Science Communication Lab

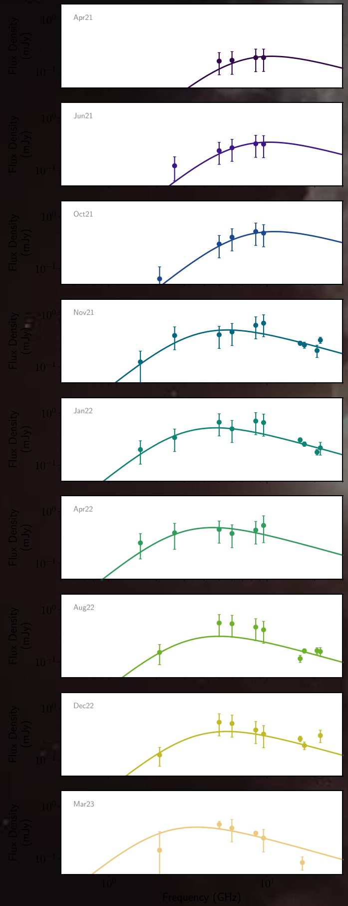
Radio emission from TDEs

Extremely diverse properties (as we heard from Kate!):

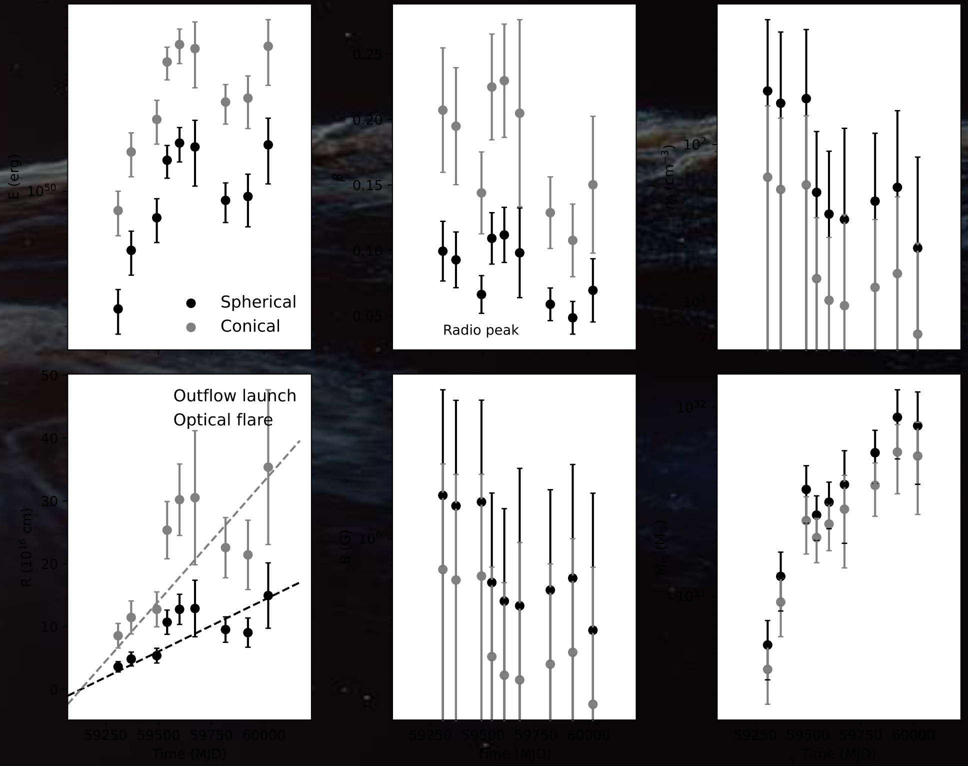
- Double flares
- Rising radio emission >1000s days
- Very early radio emission in some



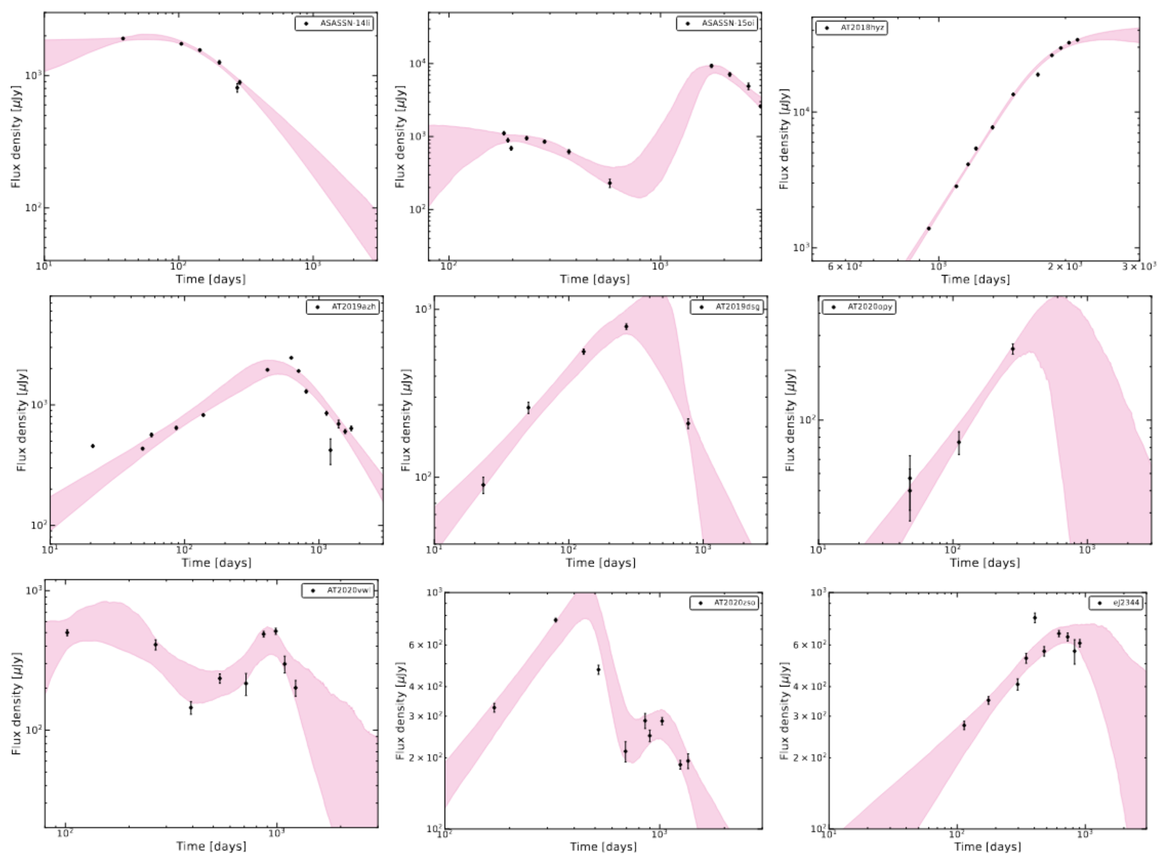
Broadband spectral monitoring constrains physical outflow properties



ATCA observations of eJ2344 (Goodwin+2024)



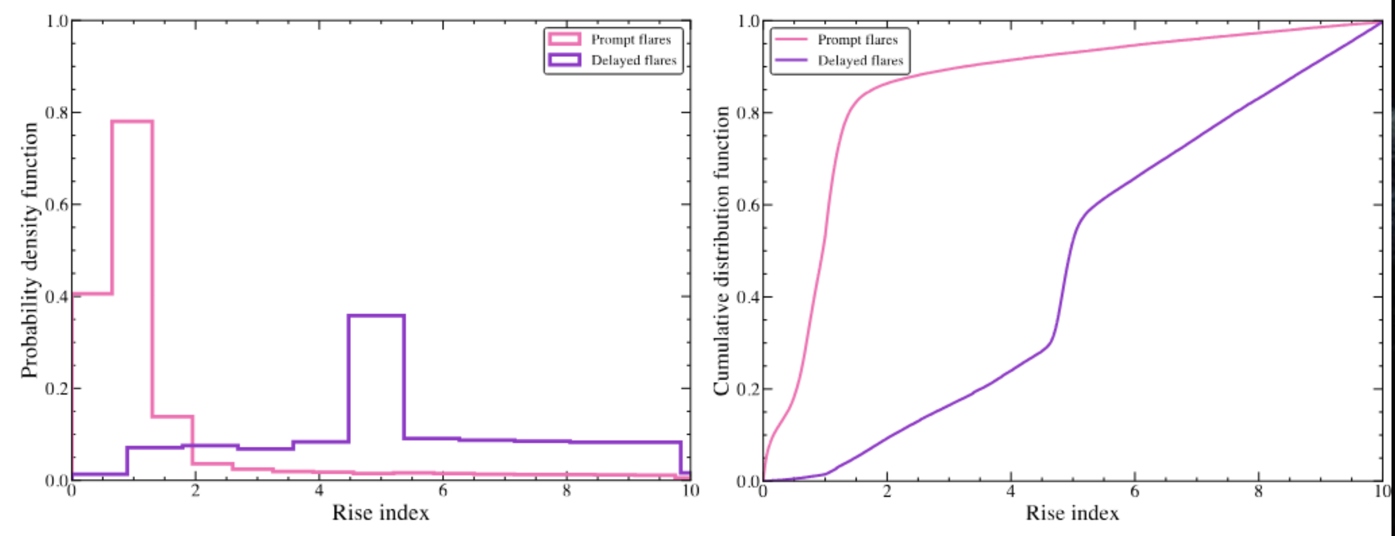
Lightcurve fitting reveals very different behaviour for prompt vs delayed flares



Lightcurve fitting reveals very different behaviour

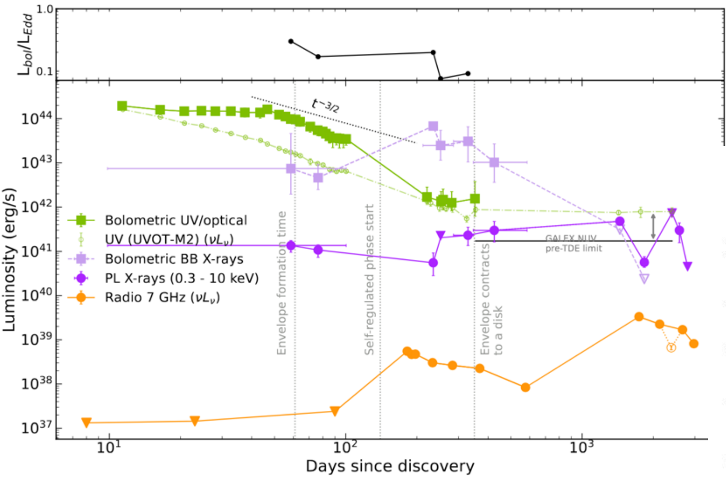
Prompt radio emission rises with index 1-2

Delayed flares typically rise much more steeply

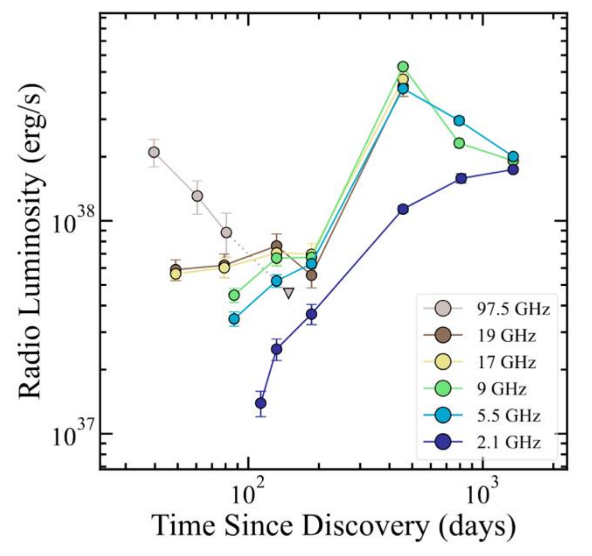


The case for multiple ejection mechanisms

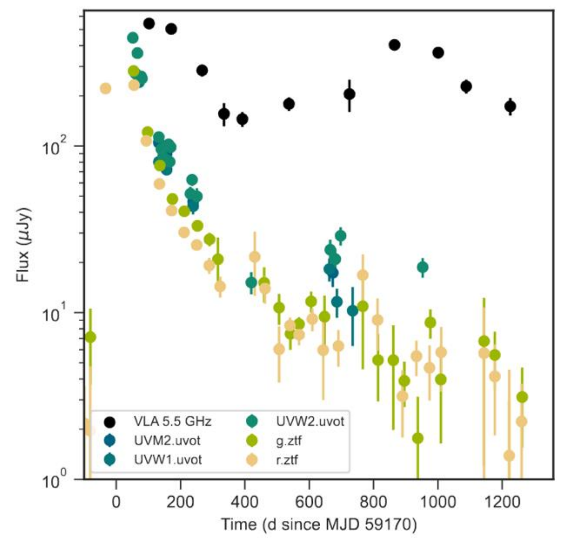
ASASSN-15oi (Hajela+2025)



ASASSN-19bt (Christy+2024)



AT2020vwl (Goodwin+2025)



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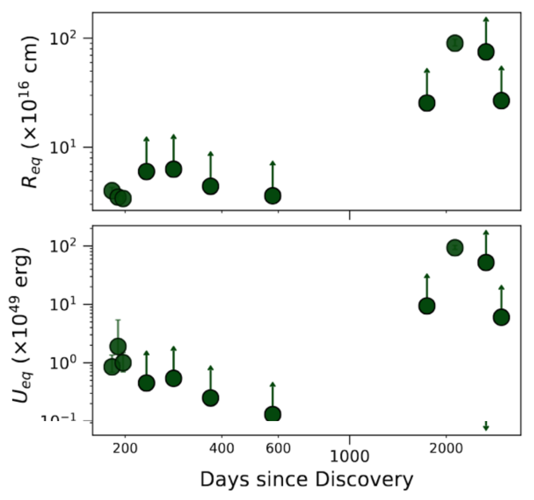
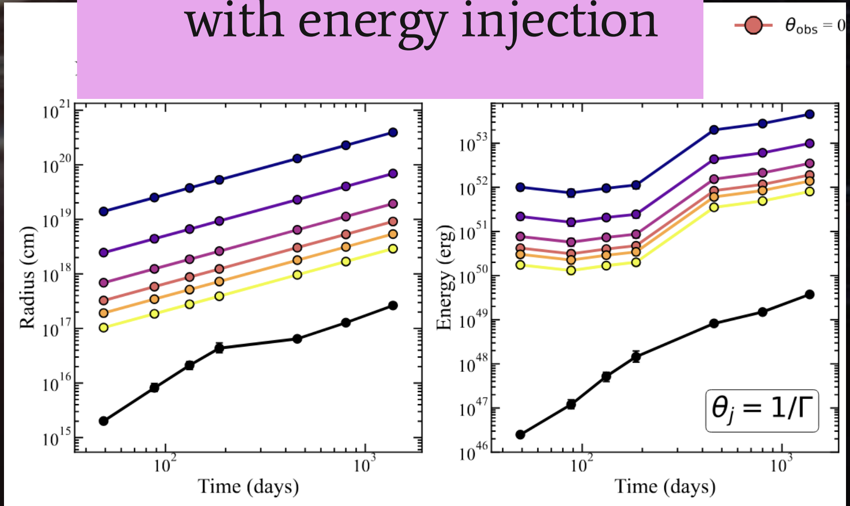


- Second flare associated with energy injection



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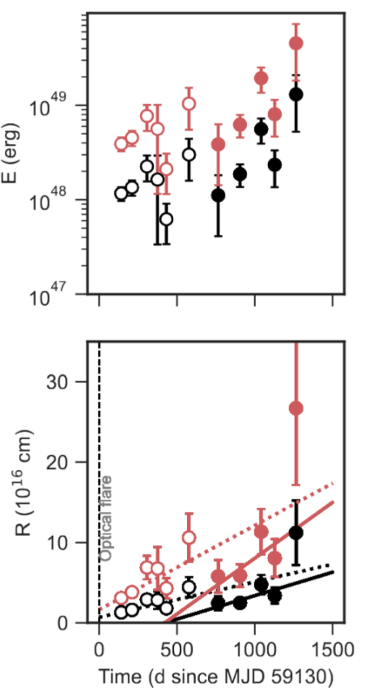
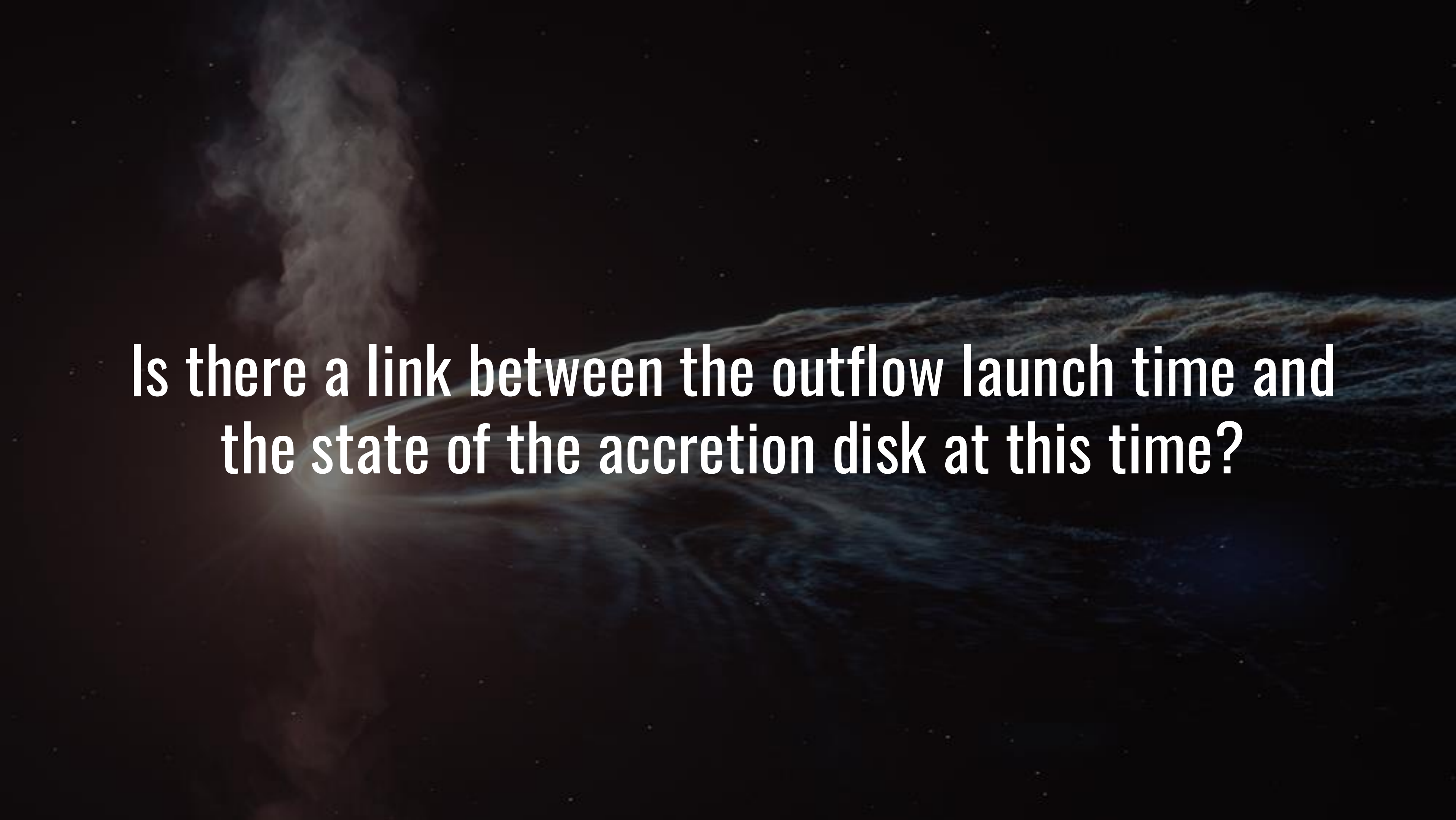
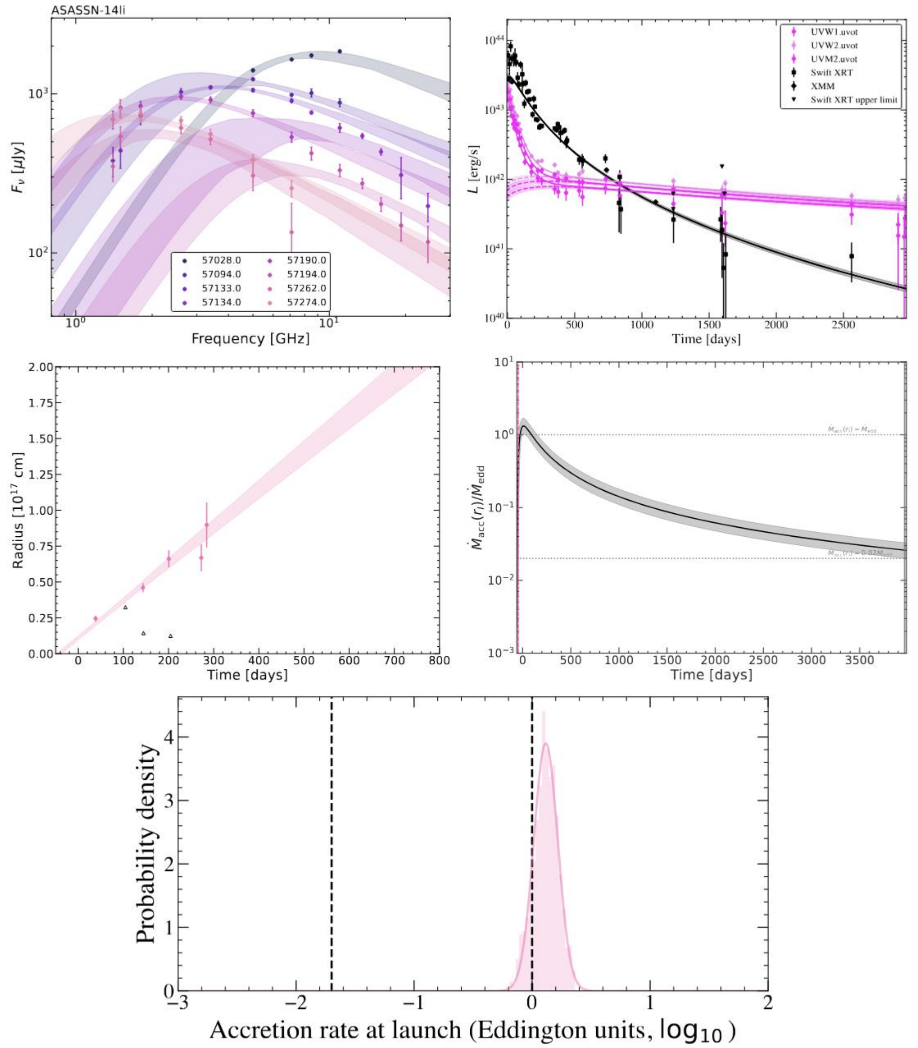




Is there a link between the outflow launch time and the state of the accretion disk at this time?

Accretion disk / outflow connections

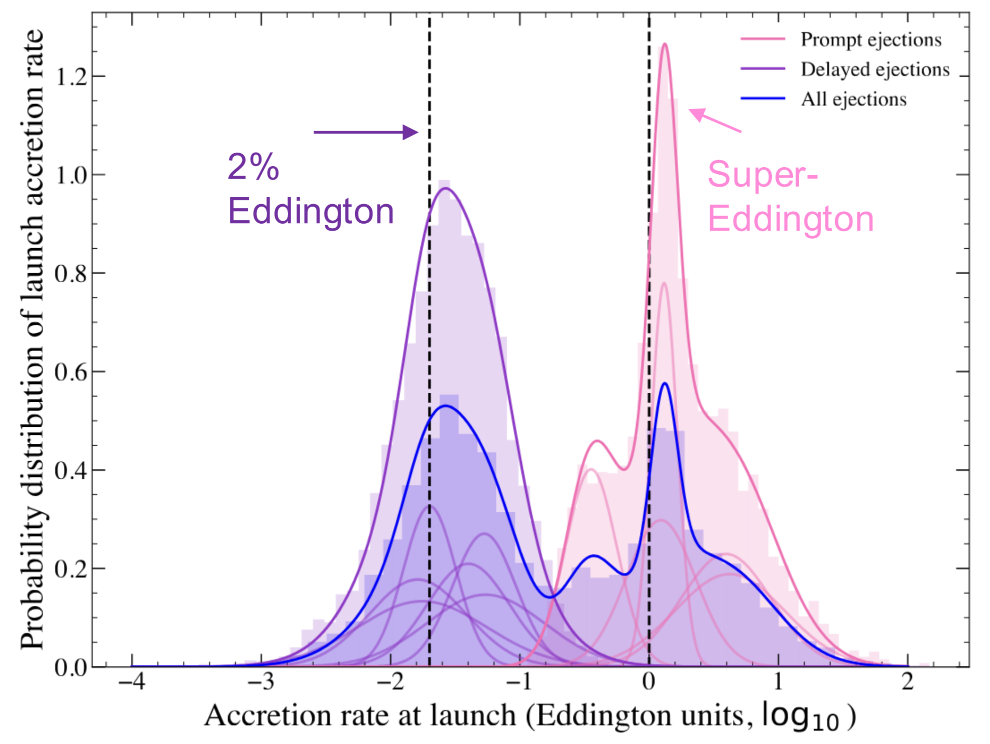


Model a sample of TDEs to extract the disk accretion rate at the time of outflow launch

Goodwin & Mummery (2026)

Accretion rate at outflow launch is a bimodal distribution

Goodwin & Mummery (2026)



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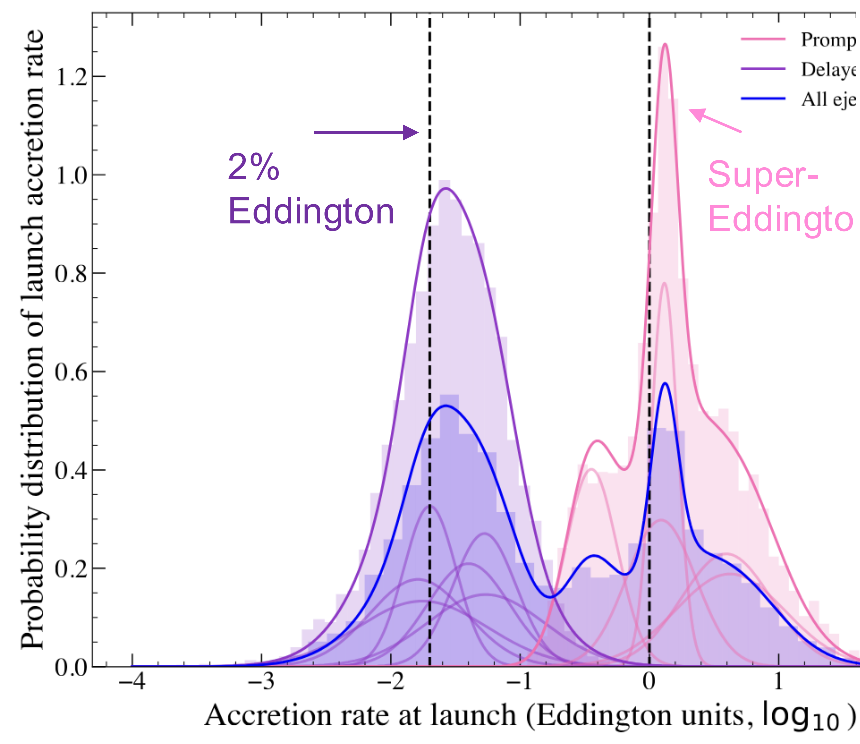
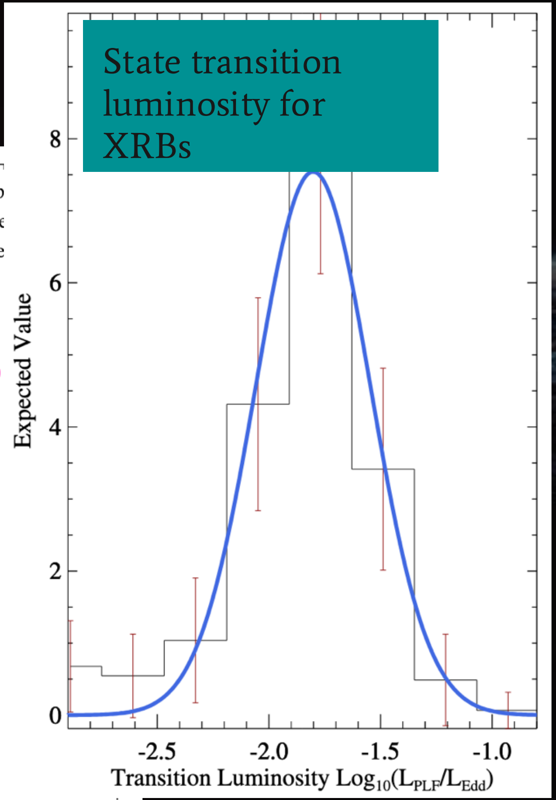
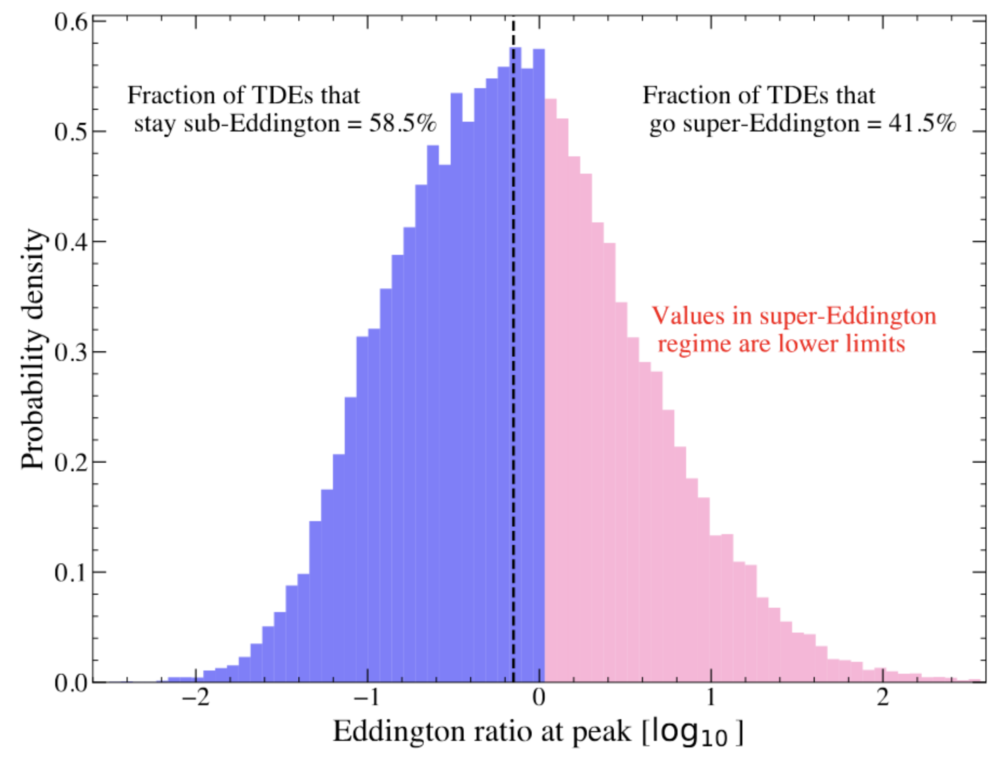



State transition luminosity for XRBs

Vahdat Motlagh+2018

How many TDEs go super-Eddington?

Goodwin & Mummery (2026)



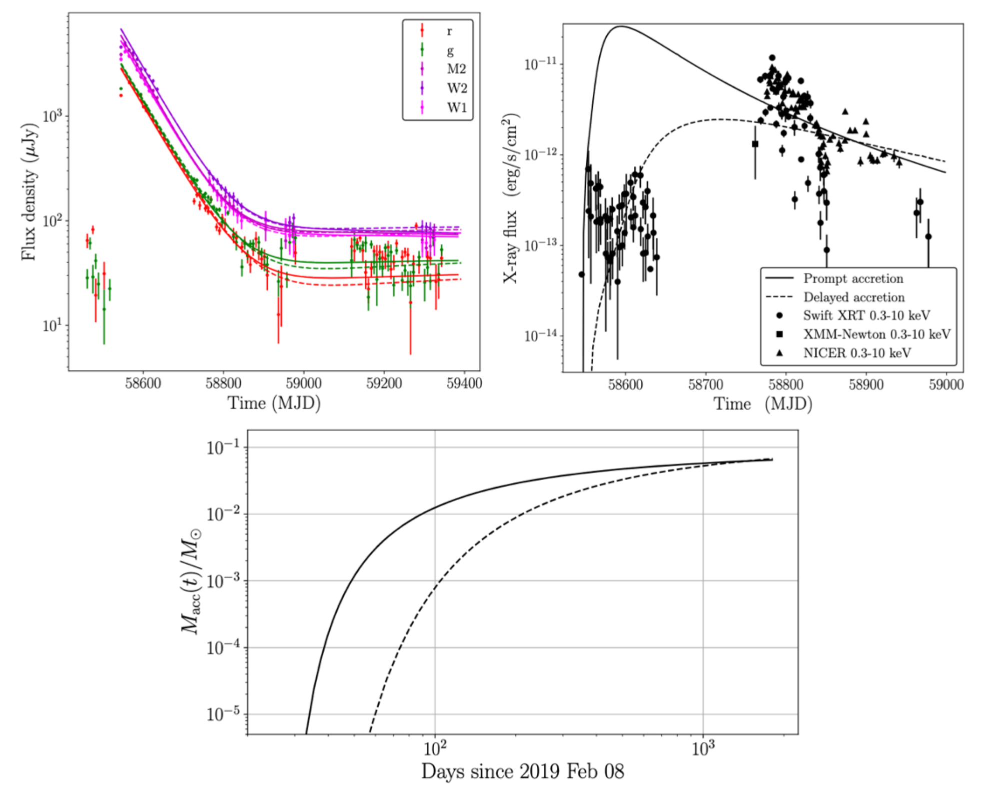
Peak accretion rate depends on:

- Stellar mass
- Viscous time

Whether super-Eddington depends on:

- Black hole mass

What about X-rays?

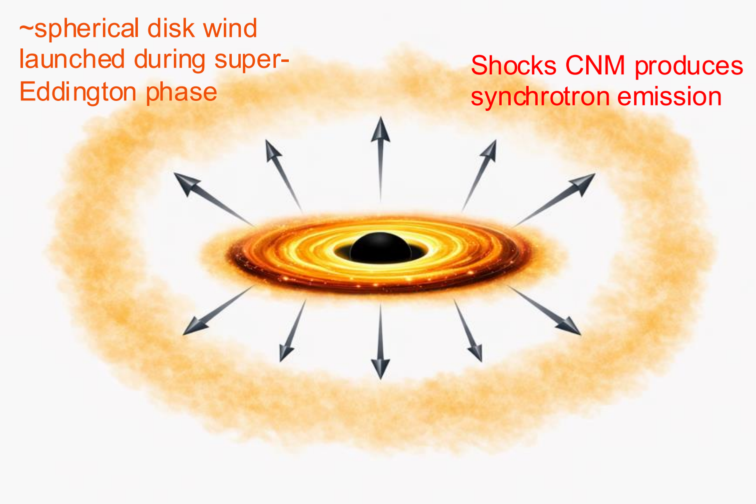


AT2019azh
(Goodwin+2022)

X-ray emission alone is a poor tracer of the accretion rate in the disk due to obscuration

See Guolo+2024

Expectations of a disk wind



~spherical disk wind launched during super-Eddington phase

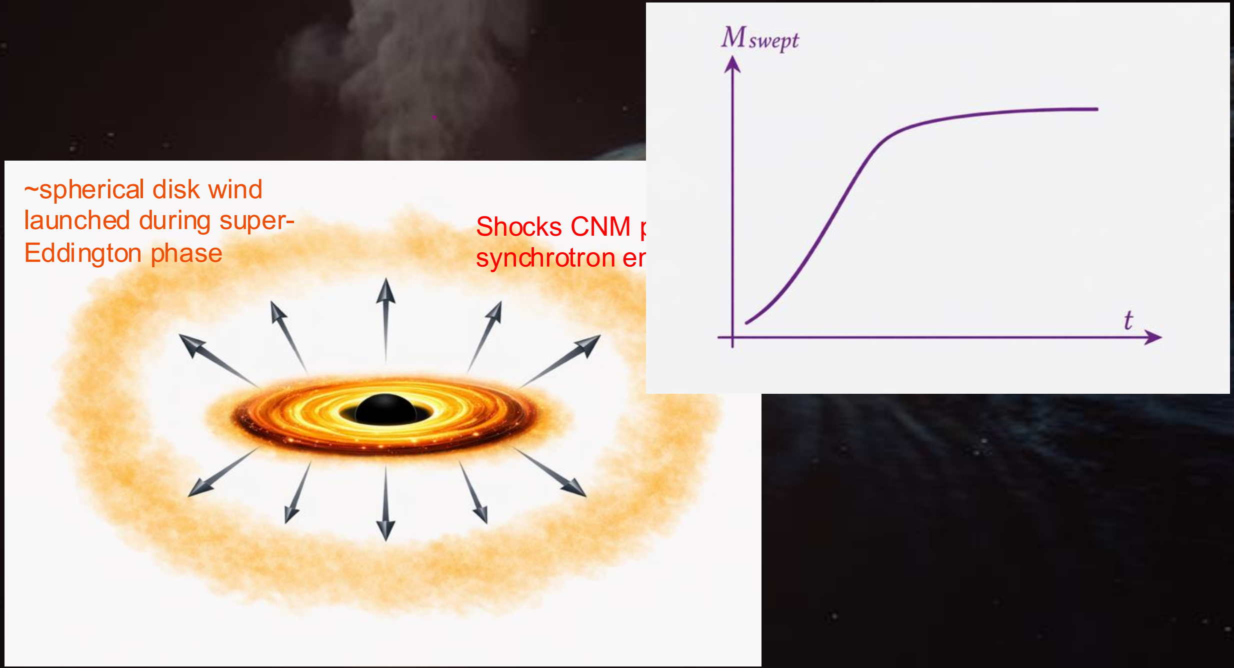
Shocks CNM produces synchrotron emission

Synchrotron emission depends on:

- Mass/energy in outflow
- Density of ambient environment

Goodwin & Mummery (in prep)

Expectations of a disk wind



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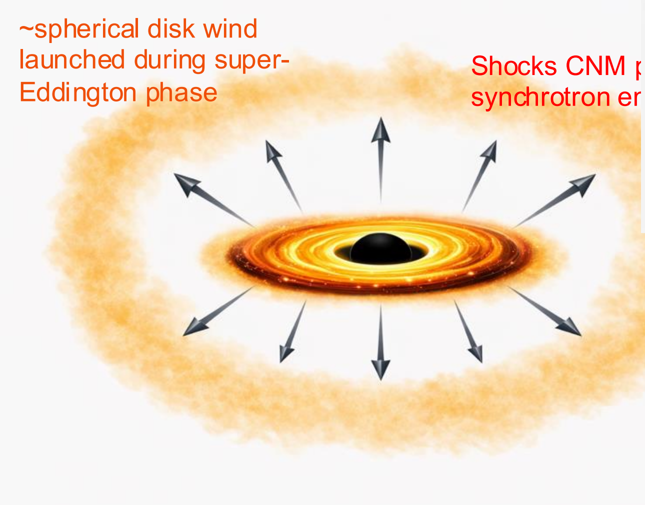

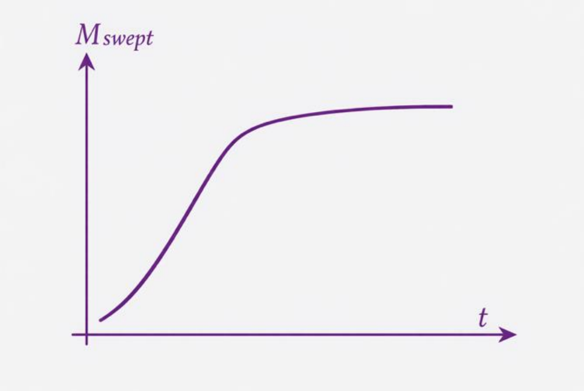

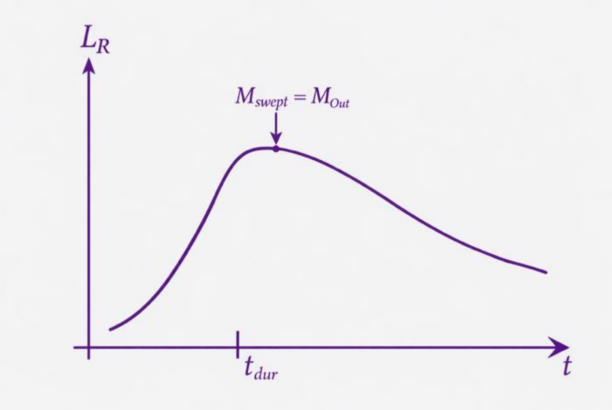

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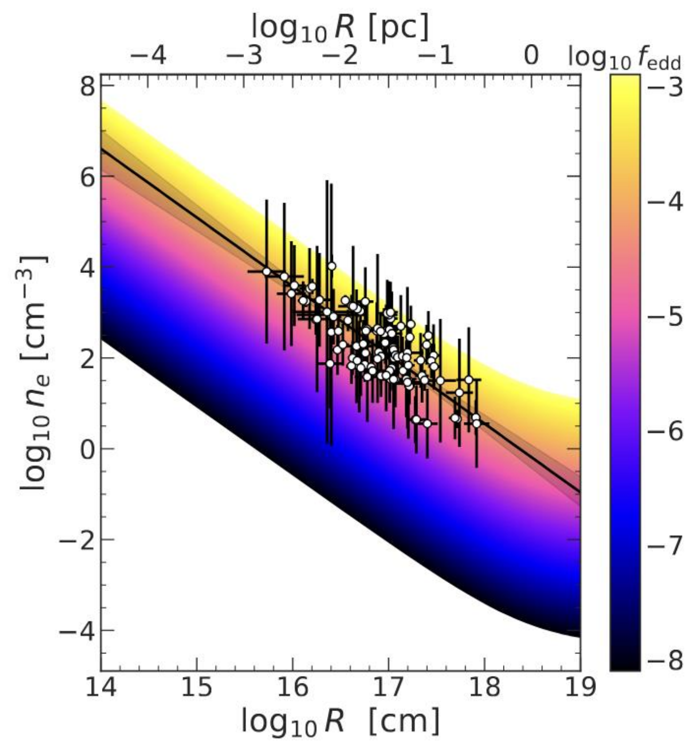
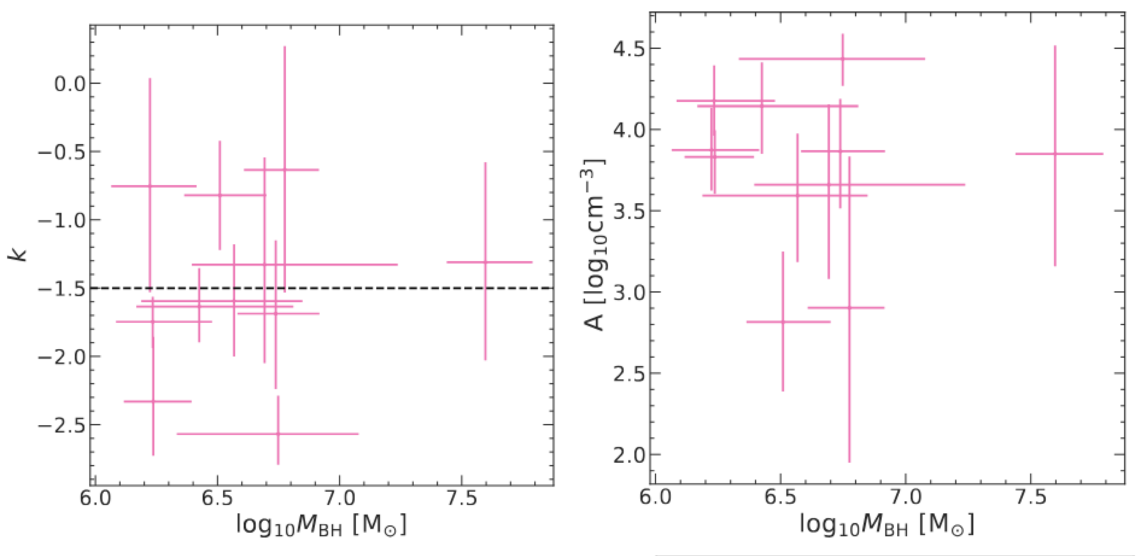
Goodwin & Mummery (in prep)

Effect of environment

TDE hosts have very similar environment profiles



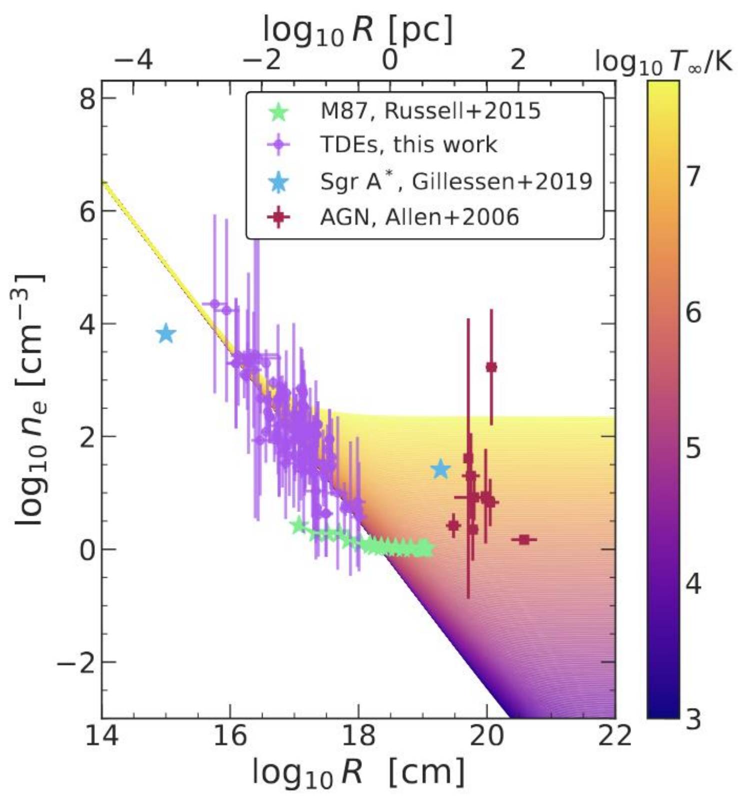
$$N_e = AR^k$$



Goodwin & Mummery (in prep)

Revealing the intra-Bondi density profile

TDEs are powerful probes of intra-Bondi radii in galaxies



Goodwin & Mummery (in prep)

Expectations of a disk wind

- In the viscous limited regime, Mdot_peak depends only on disk mass and viscous time (not BH mass)
- Mout depends on disk mass
- Velocities are roughly the same
- Rdec depends on Mout and ambient density (BH mass)
- Radio luminosity (at peak) depends on Mout and B field

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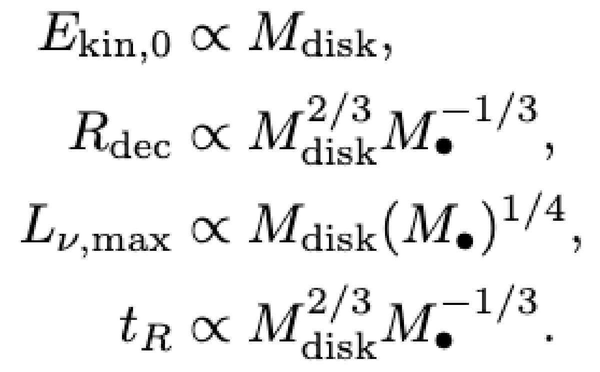
Therefore, we expect:



$$E_{\mathrm{kin},0} \propto M_{\mathrm{disk}},$$

$$R_{\mathrm{dec}} \propto M_{\mathrm{disk}}^{2/3} M_{\bullet}^{-1/3},$$

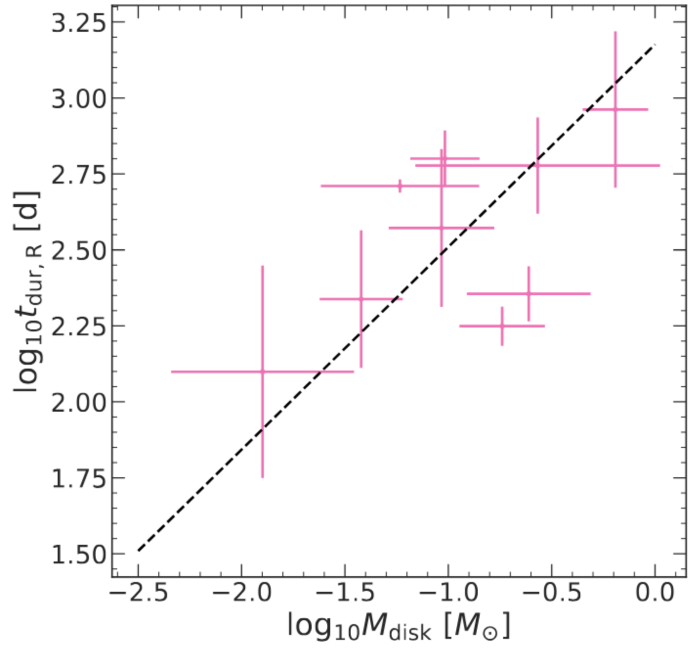
$$L_{\nu,\mathrm{max}} \propto M_{\mathrm{disk}} (M_{\bullet})^{1/4},$$

$$t_R \propto M_{\mathrm{disk}}^{2/3} M_{\bullet}^{-1/3}.$$

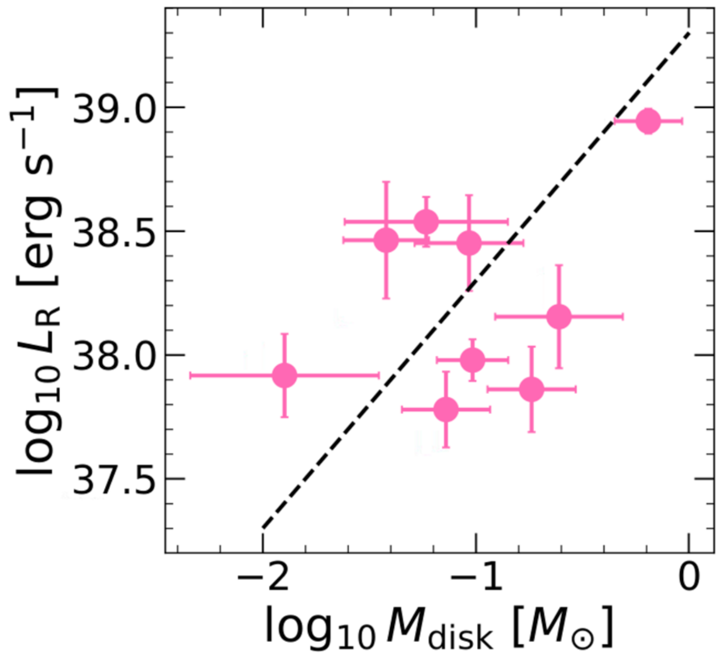
Goodwin & Mummery (in prep)

Expectations of a disk wind

$t_{dur} \sim M_{disk}^{2/3}$



$L_{R,pk} \sim M_{disk}$



Goodwin & Mummery (in prep)

Discussion points

- Prompt radio outflows launched by accretion disk winds requires efficient disk circularization
- Observed fraction of TDEs that exhibit prompt radio emission is ~consistent with theoretical prediction of 40%. Implies uncollimated outflows and efficient disk circularization in all events
- Presence of prompt radio emission governed by both disk (stellar) mass and black hole mass
    - Low mass black holes are more likely to go Super-Eddington but launch less luminous outflows

Summary

- ★ Combing radio and accretion disk modelling in TDEs reveals outflows are launched at two critical accretion rates: during a super-Eddington wind phase and at a critical accretion rate of 2% Eddington
- ★ Approximately ~40% of TDEs should launch a (prompt) super-Eddington disk wind
- ★ With the (small) sample publicly available, the duration and luminosity of prompt radio flares correlates as expected with a disk mass for a disk wind
- ★ Radio emission reveals that TDE hosts have very similar ambient density profiles that are consistent with the expectations of a Bondi sphere
- ★ This model requires that disk formation is prompt in majority of TDEs