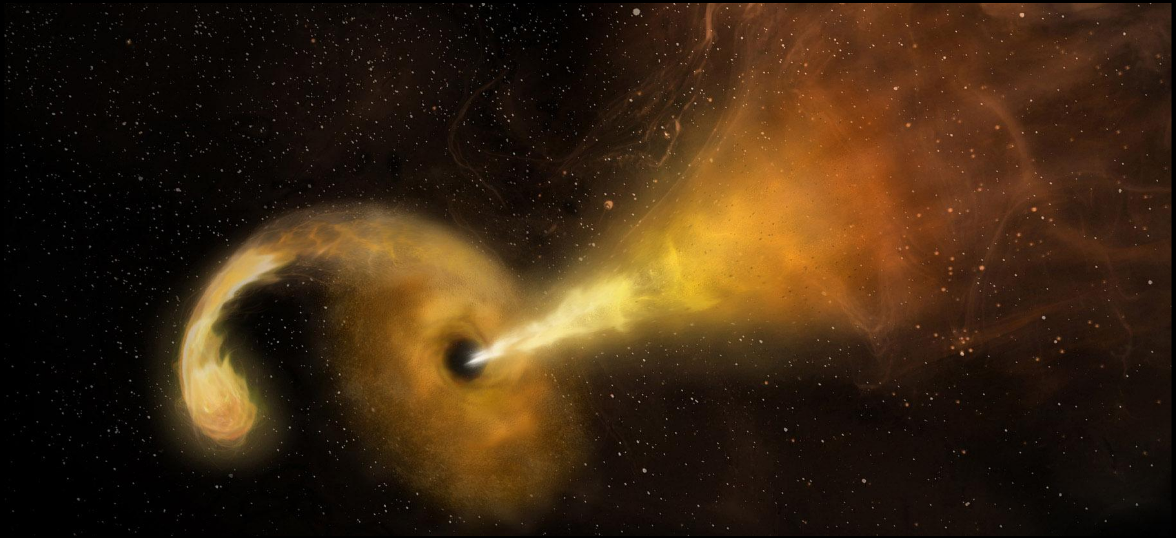
Tidal Disruption Events: Unique probes of outflows and accretion in supermassive black holes

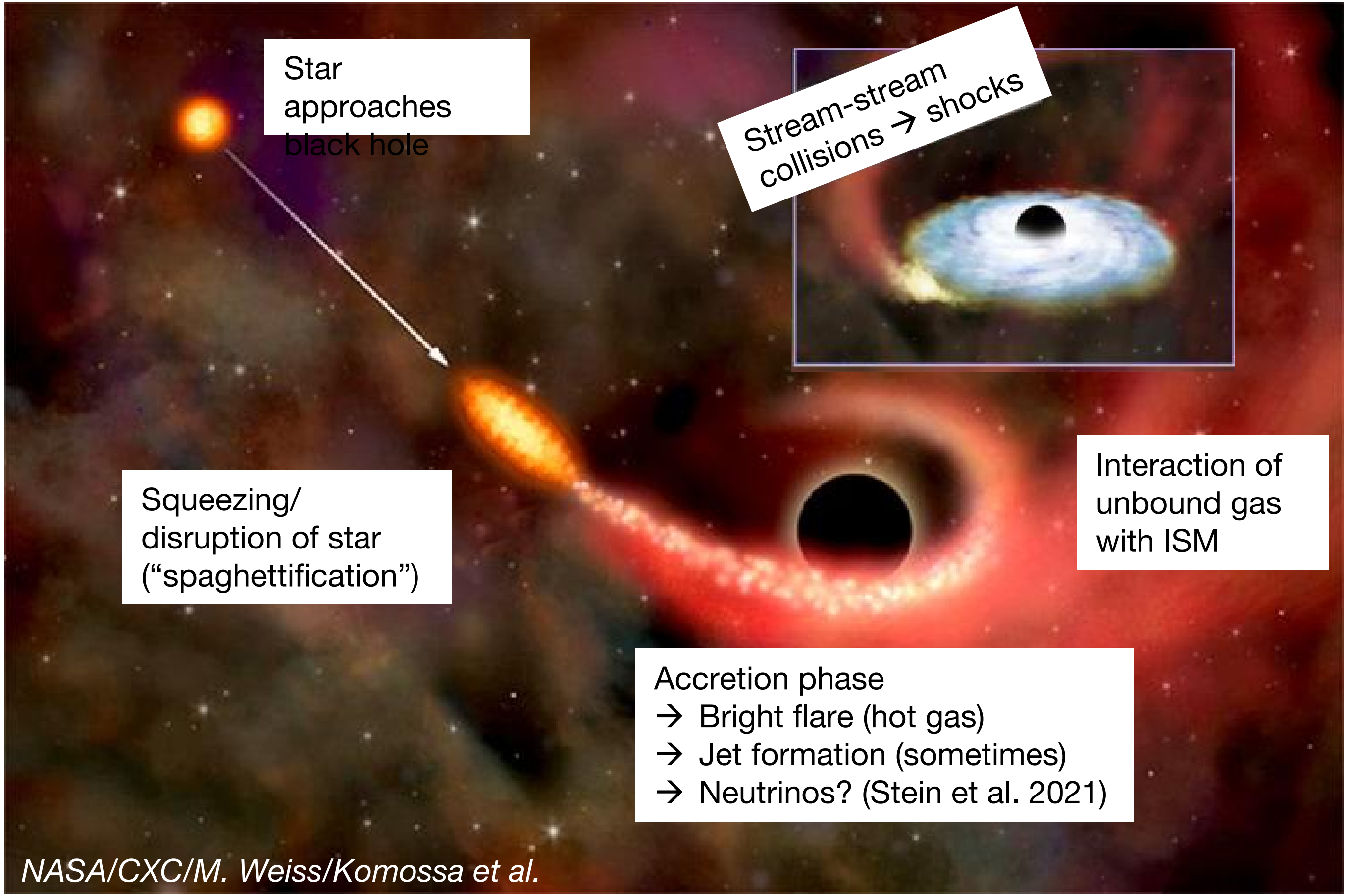


NRAO/AUI/NSF/NASA

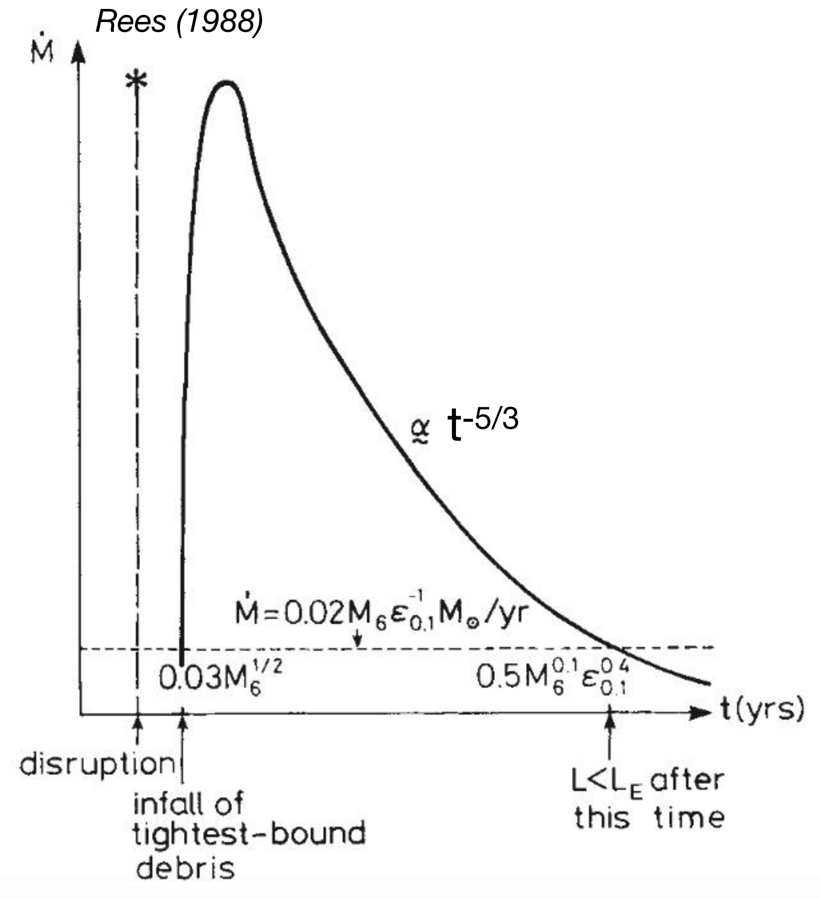
Kate D. Alexander
University of Arizona

Texas Symposium on Relativistic Astrophysics, December 13, 2023

Tidal Disruption Events (TDEs)



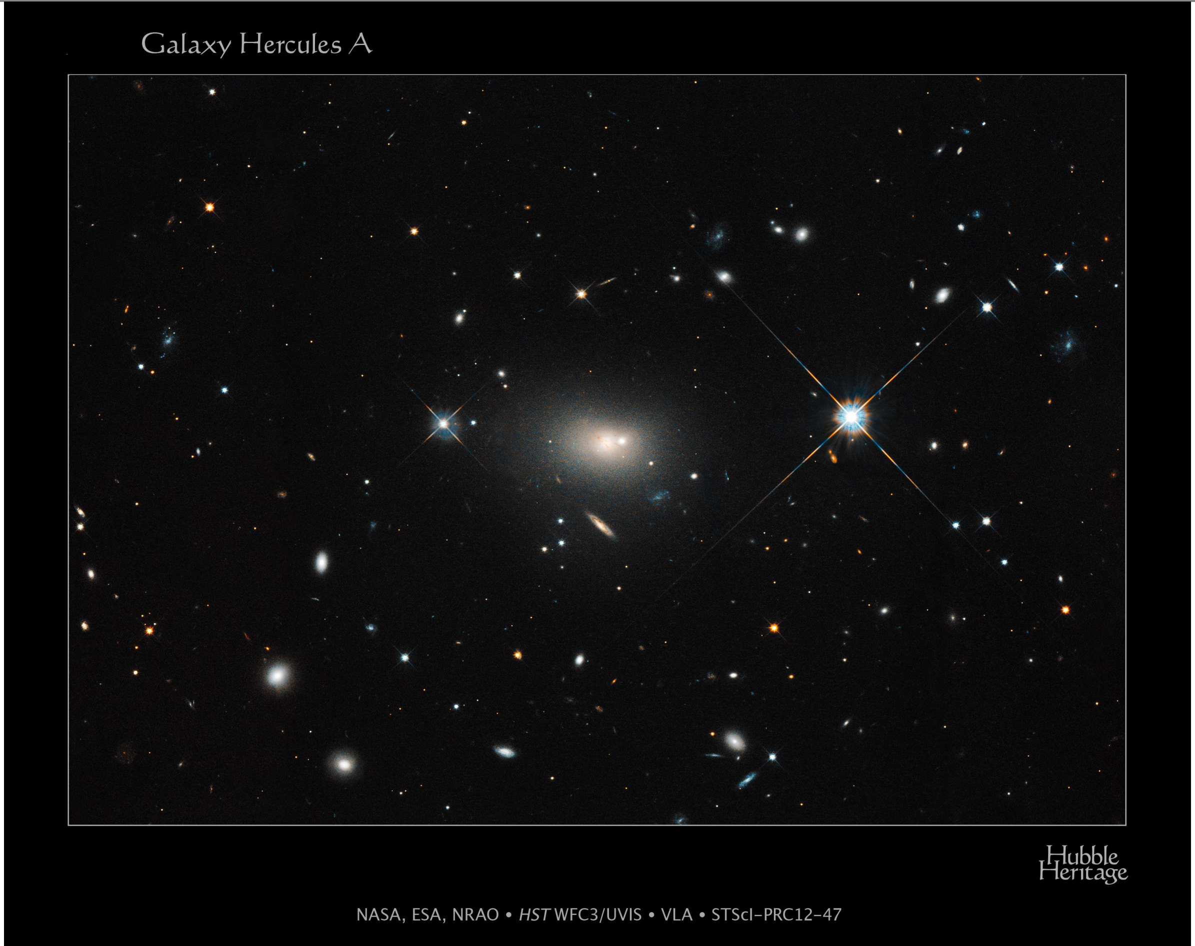
TDEs are unique probes of accretion



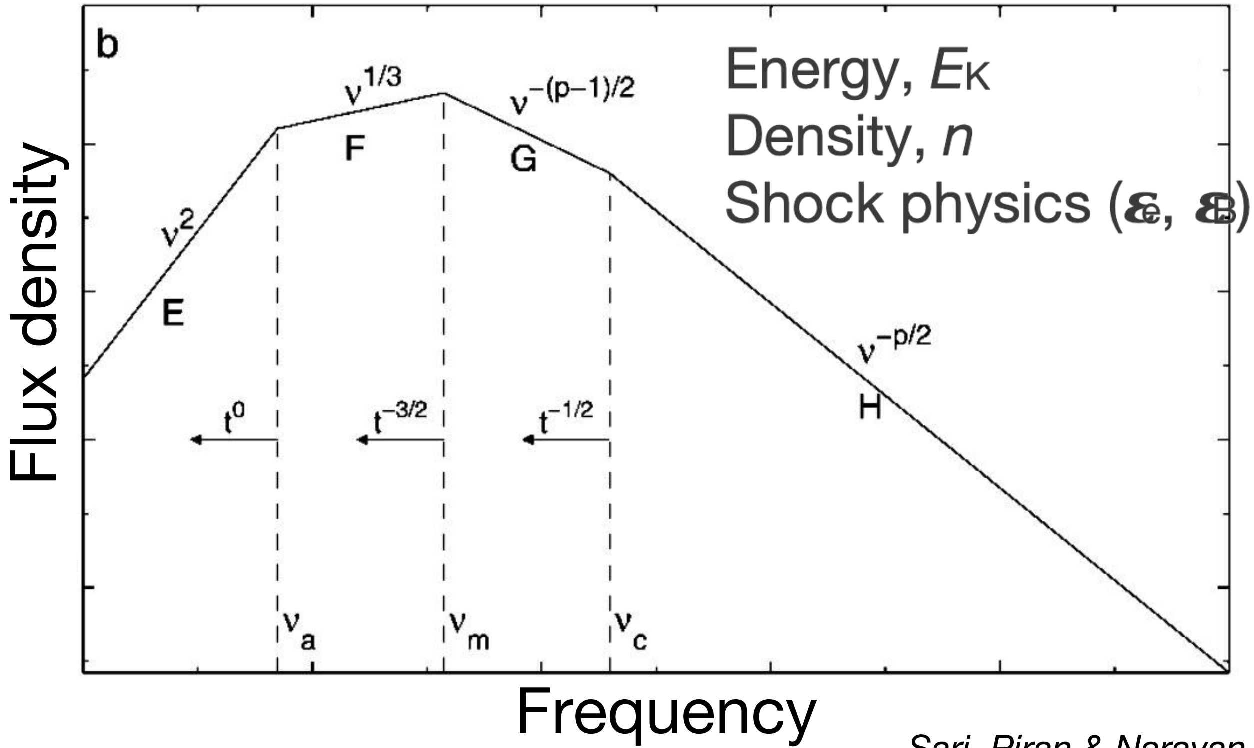
Key Questions:

- How efficiently can the stellar debris form an accretion disk?
- How do TDEs launch relativistic jets and/or non-rel. outflows?
  - Why are powerful relativistic jets so rare?
- What do the environments around (recently) quiescent supermassive black holes look like?

Radio observations probe mass ejection



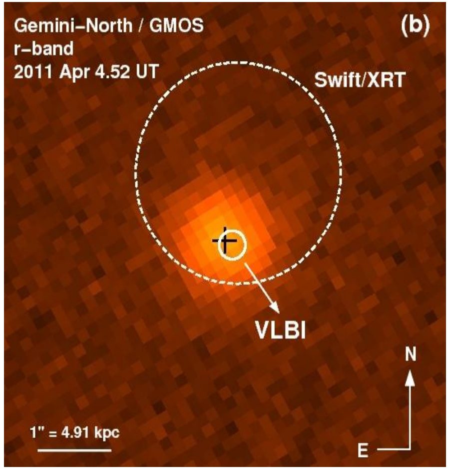
Shocks Generate Synchrotron Emission



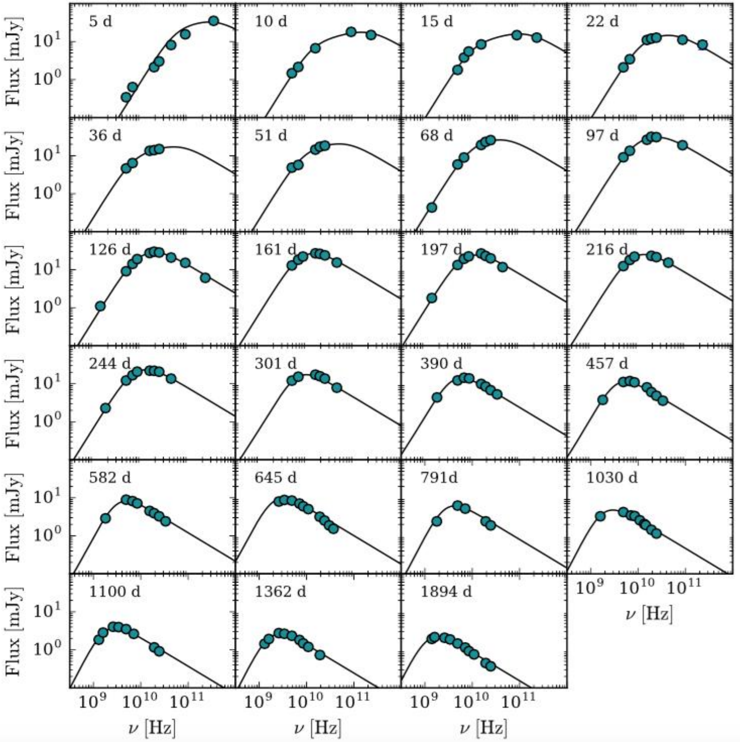
Sari, Piran & Narayan (1998)
Slide courtesy T. Laskar

Synchrotron emission from a relativistic jet

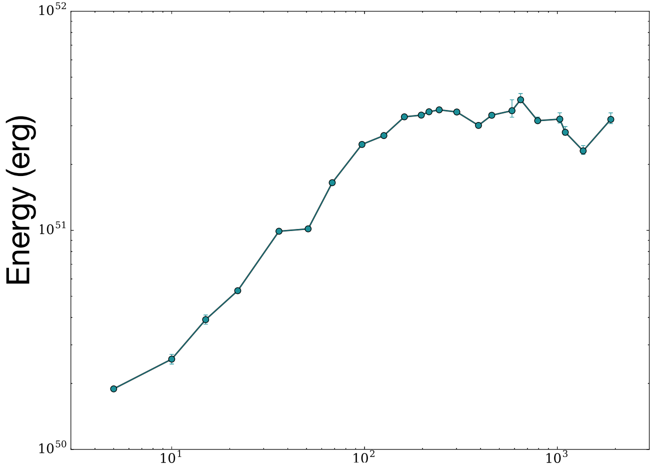
TDE Swift J1644+57



Zauderer et al. (2011)

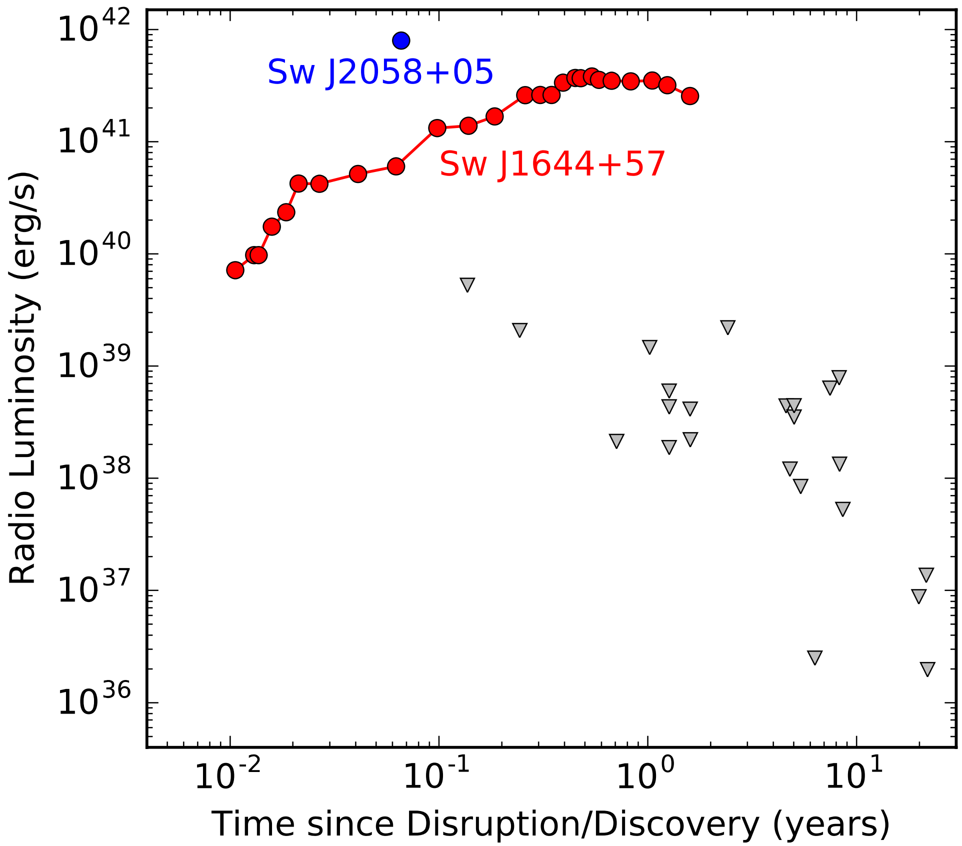


Eftekhari et al. (2018)



Eftekhari et al. (2018)

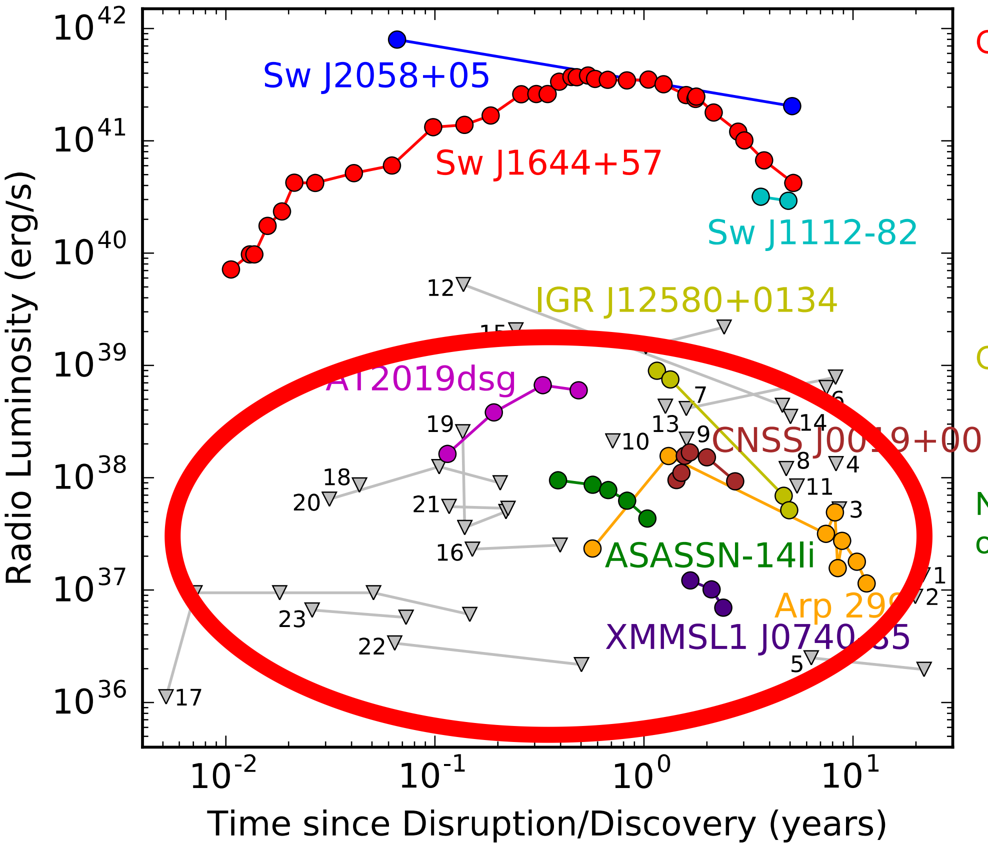
TDE Radio Observations (2014)



On-axis jet

TDE Radio Observations (2020)

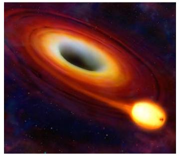
Alexander et al. (2020)



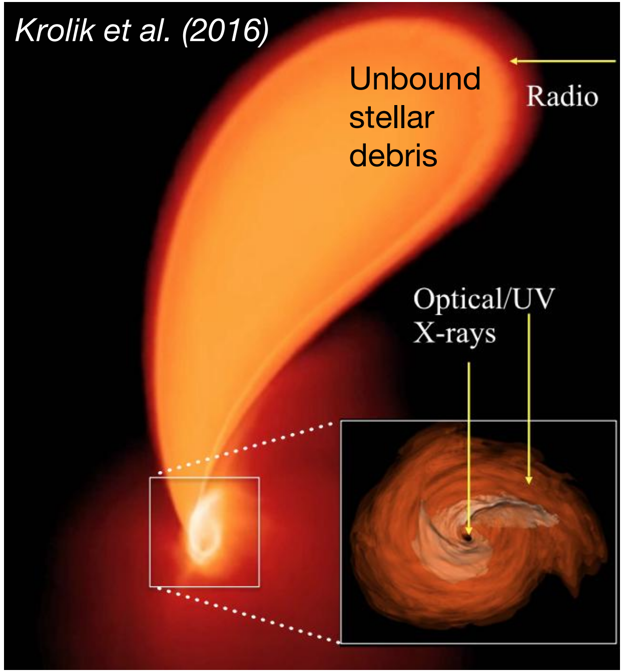
On-axis jet

Off-axis jet

Non-relativistic outflow

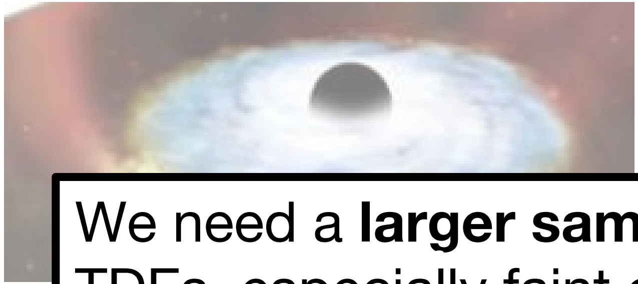


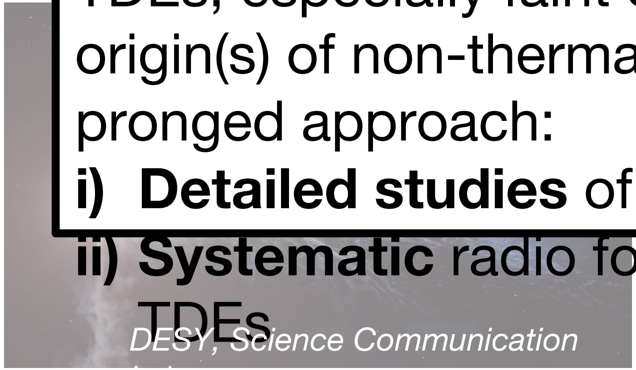
What powers faint radio TDEs?

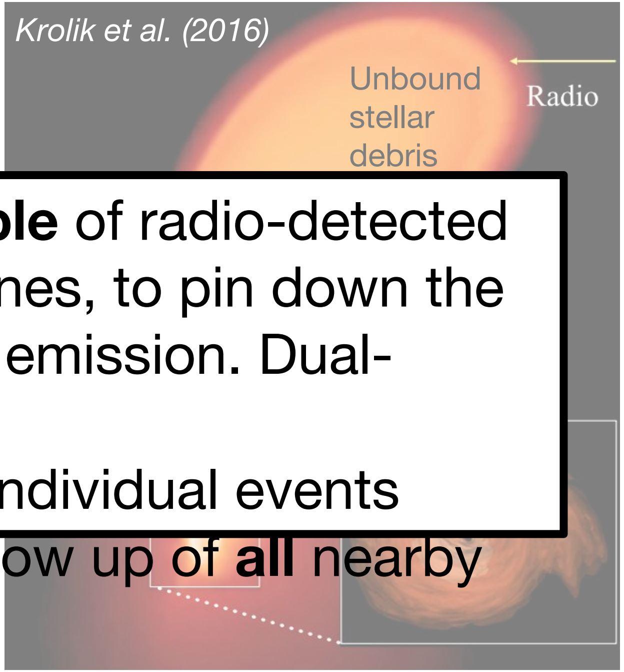


Stream-stream collisions? Winds or weak jets launched during a super-Eddington accretion phase? Shocks from the unbound stellar debris stream?

What powers faint radio TDEs?







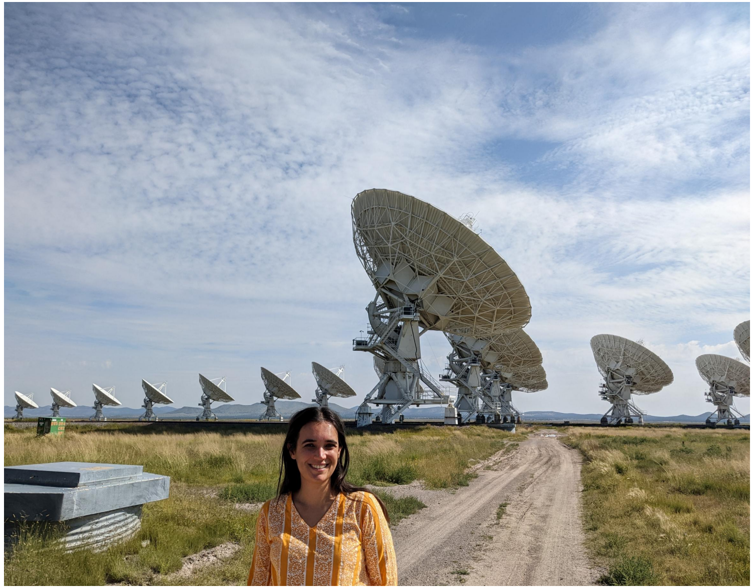
We need a **larger sample** of radio-detected TDEs, especially faint ones, to pin down the origin(s) of non-thermal emission. Dual-pronged approach:

i) **Detailed studies** of individual events
ii) **Systematic** radio follow up of **all** nearby TDEs

Stream-stream collisions? Winds or weak jets launched during a super-Eddington accretion phase? Shocks from the unbound stellar debris stream?

Characterizing local TDEs

- New **VLA Large Program** (PI: Alexander, in collaboration with: James Miller-Jones, Sjoert van Velzen)
  - 300 hours over 3 yr to observe **all** new TDEs at z<0.1, new jetted TDEs at all redshifts
  - The first **systematic** radio program to study TDEs in the local Universe

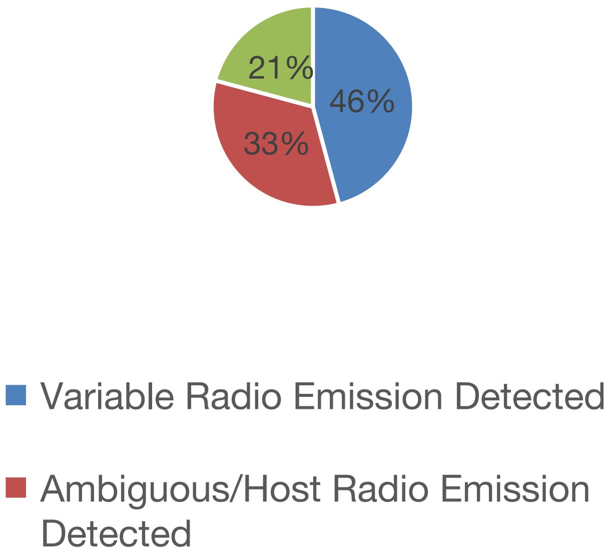


Observations started Nov 2020, follow up continues through mid-2024. See https://as.arizona.edu/radiotdes/

Characterizing local TDEs

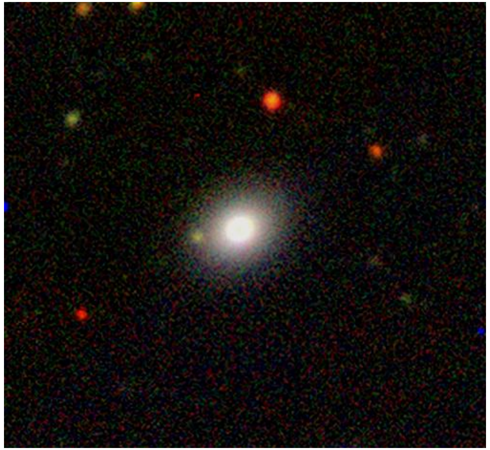
- 24 TDEs observed
  - Preliminary results announced by ATel, AstroNote
  - Full list on our website: https://as.arizona.edu/radiotdes/
- 3 papers including our data already published (Goodwin et al 2023, Pasham et al 2023, Yao et al 2 ... m to come!
  - Student projects

Fraction of TDEs with Radio Detections

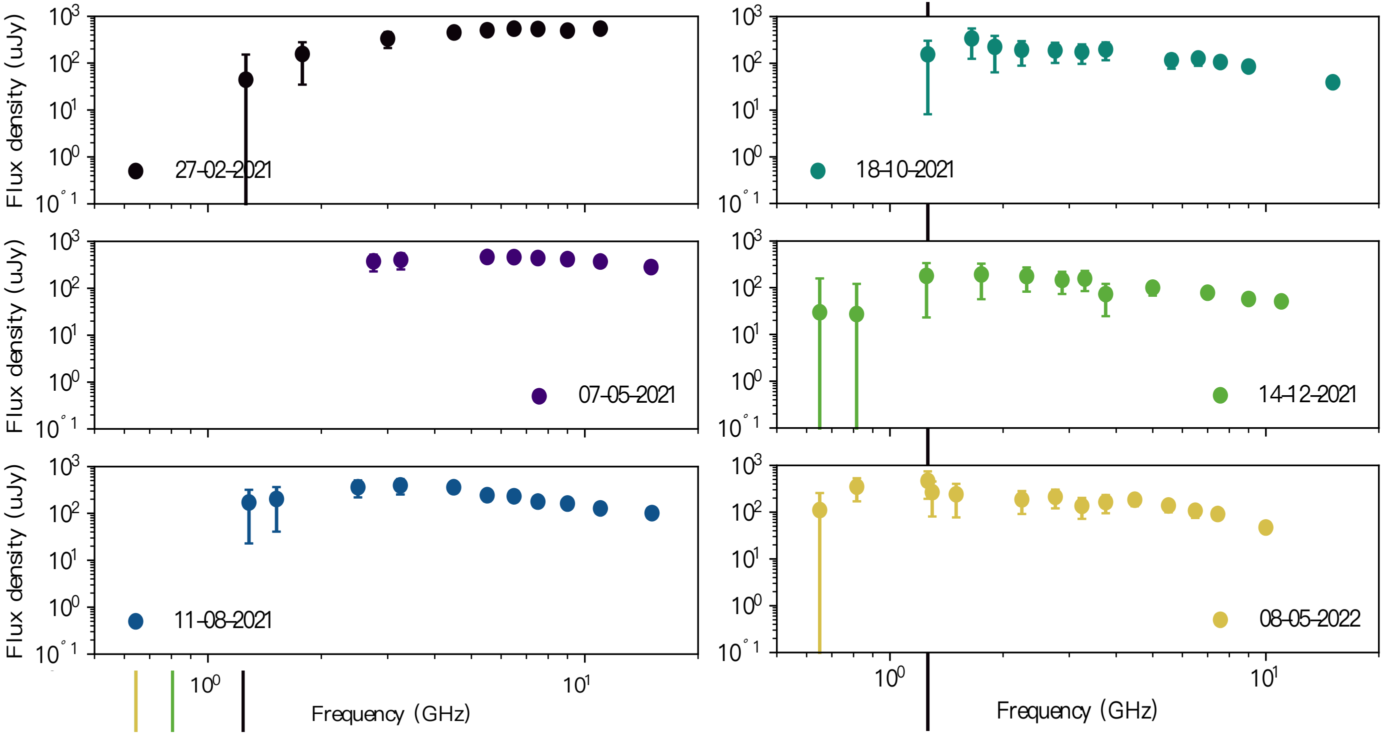


Radio monitoring of “typical” TDE AT2020vwl

Goodwin, Alexander et al. (2023)



Goodwin, Alexander et al. (2023)

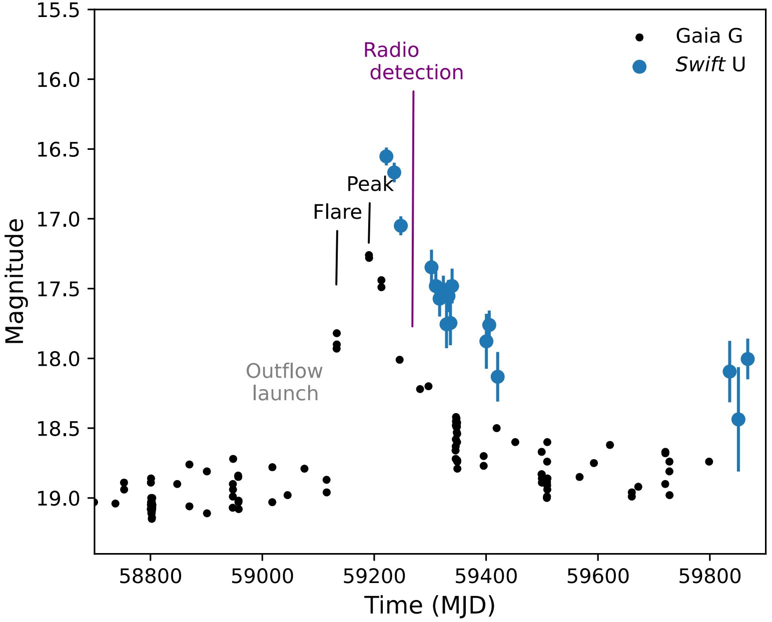


Radio observations reveal a non-relativistic outflow (v ~ 0.03c).

What powered the outflow?

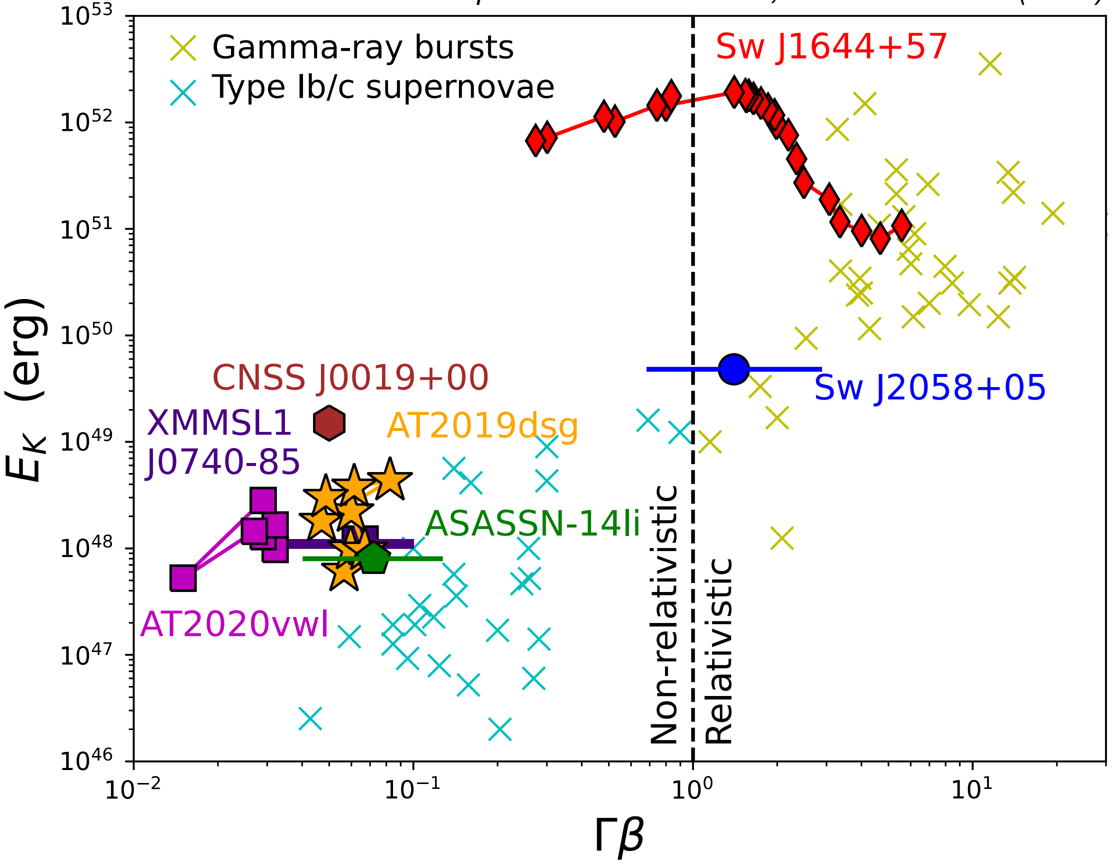
- Weak jets?
- Winds launched during a super-Eddington accretion phase?
- Shocks from the unbound stellar debris stream?
- **Stream-stream collisions?**

Goodwin, Alexander et al. (2023)



Population studies: TDE Energetics

updated from Cendes, Alexander et al. (2021)



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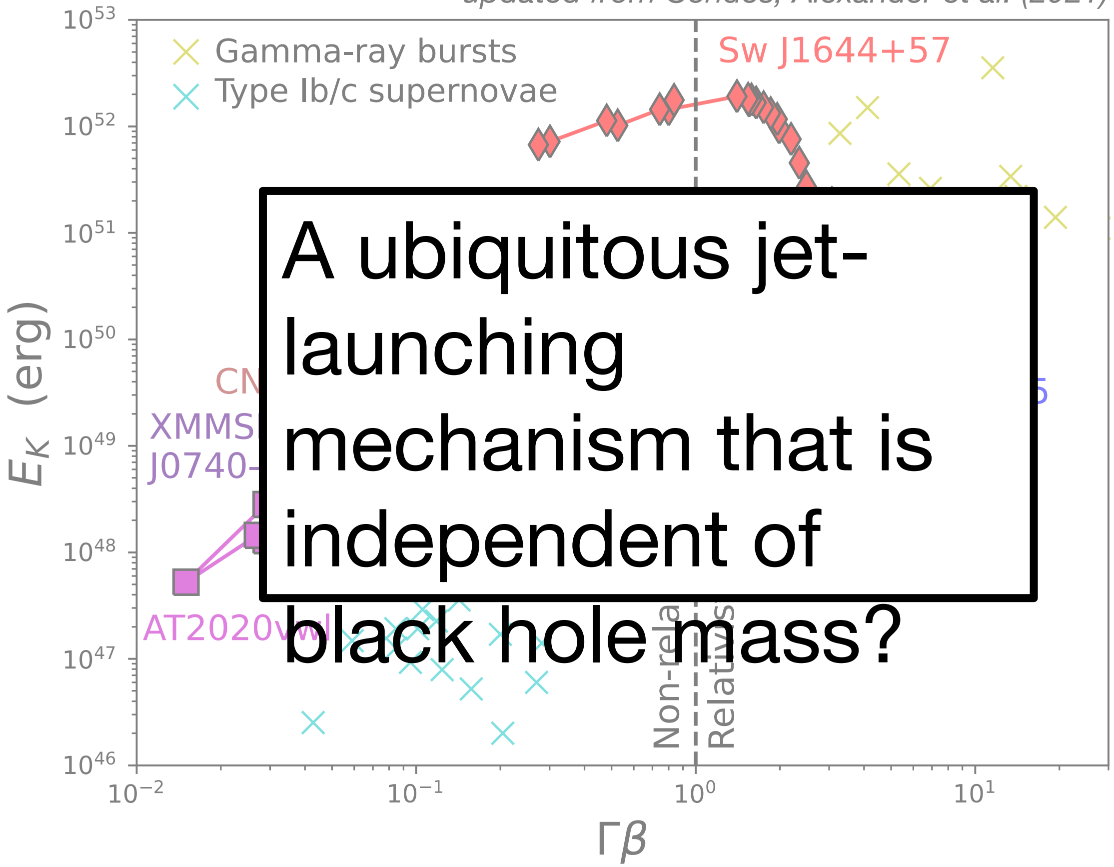
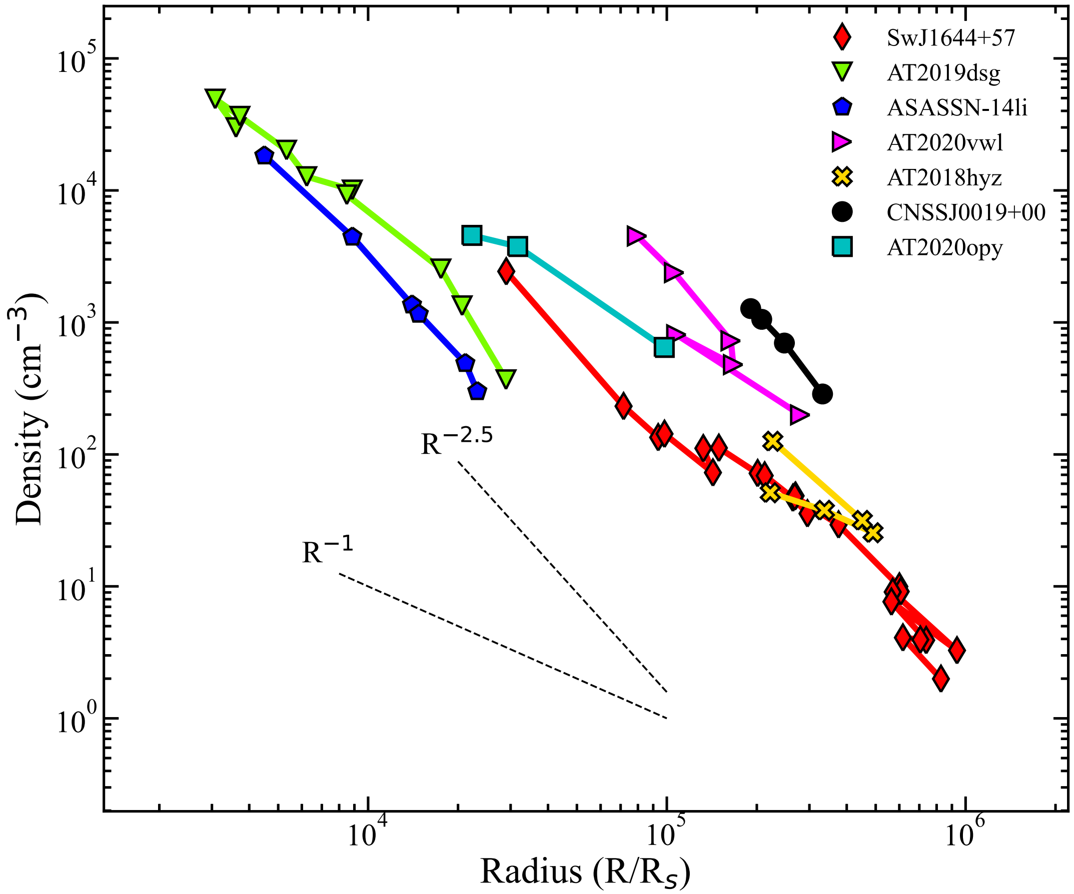


A ubiquitous jet-launching mechanism that is independent of black hole mass?

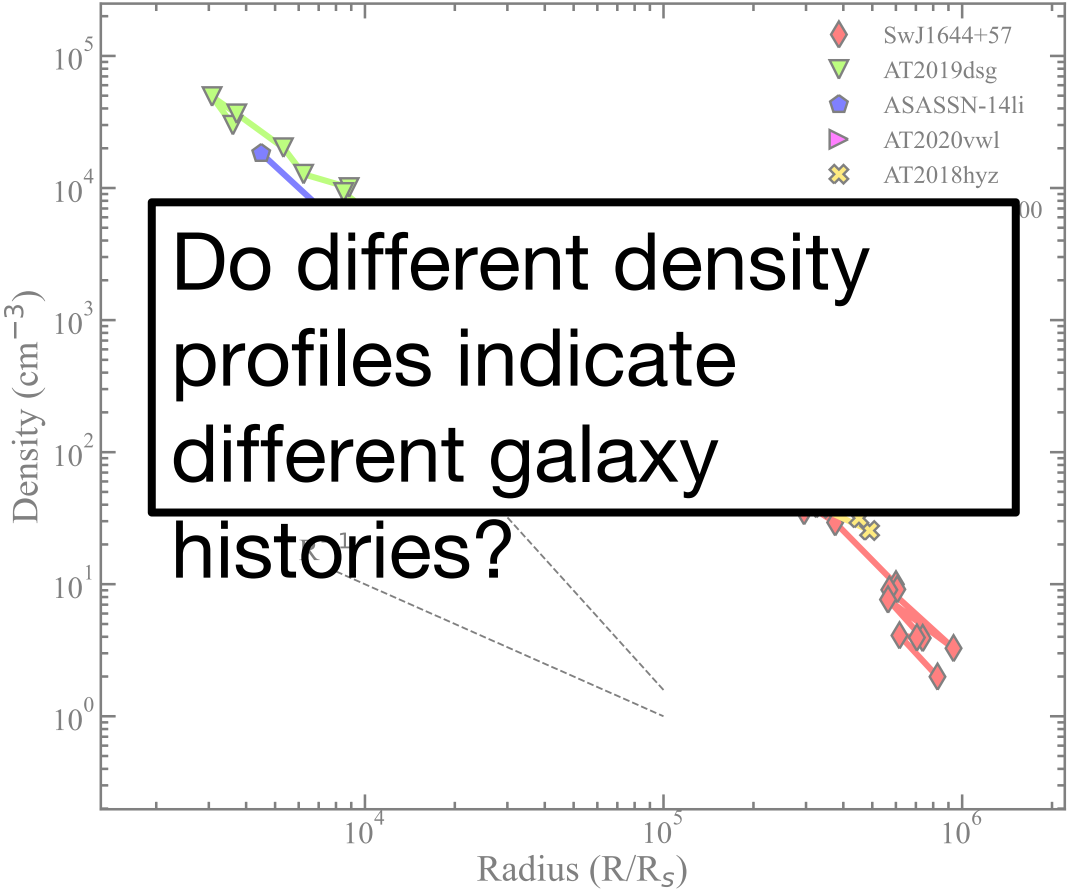
Circumnuclear Density Profiles

Christy, Alexander et al. (in prep)



Circumnuclear Density Profiles

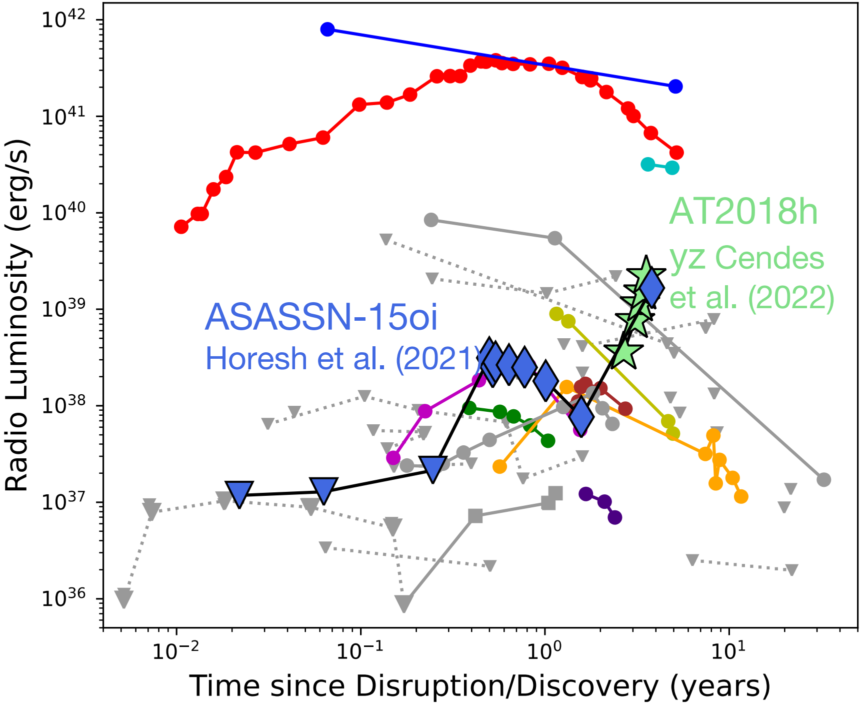
Christy, Alexander et al. (in prep)



Do different density profiles indicate different galaxy histories?

Other recent surprises: late-time flares

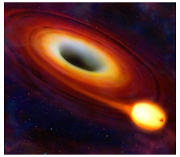
Updated from Alexander et al. (2020)



On-axis jet

Off-axis jet

Non-relativistic outflow

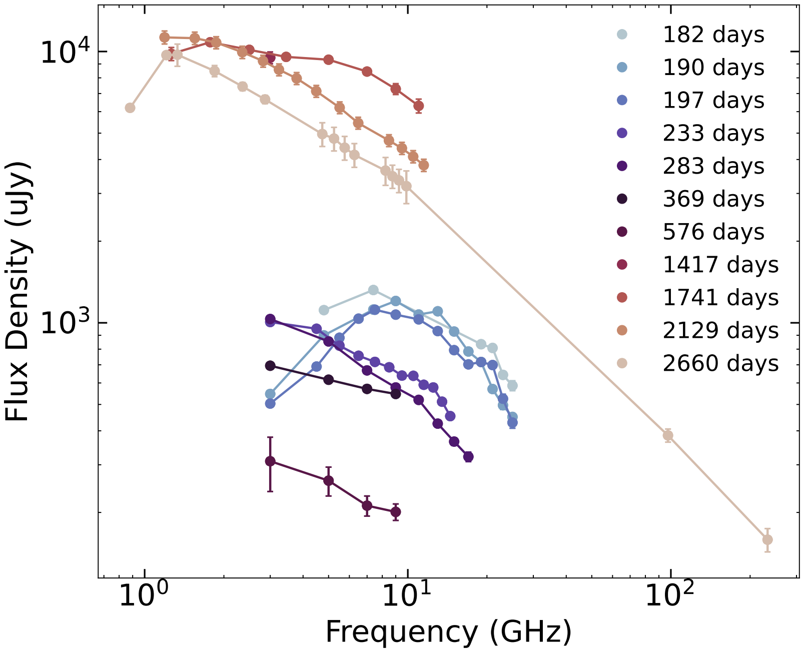


Up to **~40%** of TDEs show radio emission years post-disruption (Cendes et al. 2023; Alexander et al. in prep).

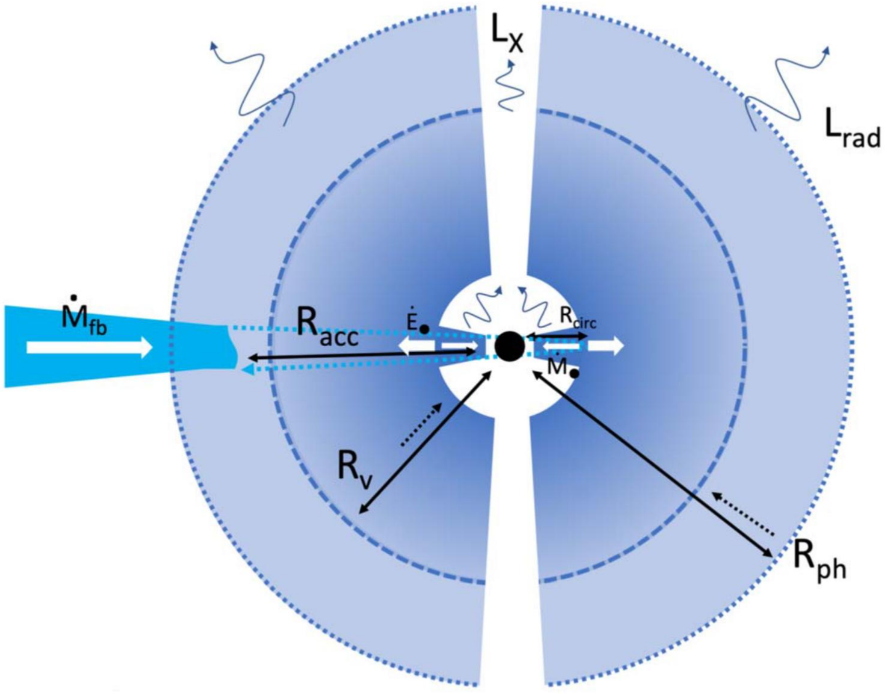
ASASSN-15oi: a tale of two outflows

- Multi-frequency radio observations show that the second flare is more energetic, possibly expanding faster!
- Can we link the launch times of these radio outflows to other physical processes occurring in the TDE?

Hajela et al. (in prep)



Cooling envelope model (Metzger 2022)

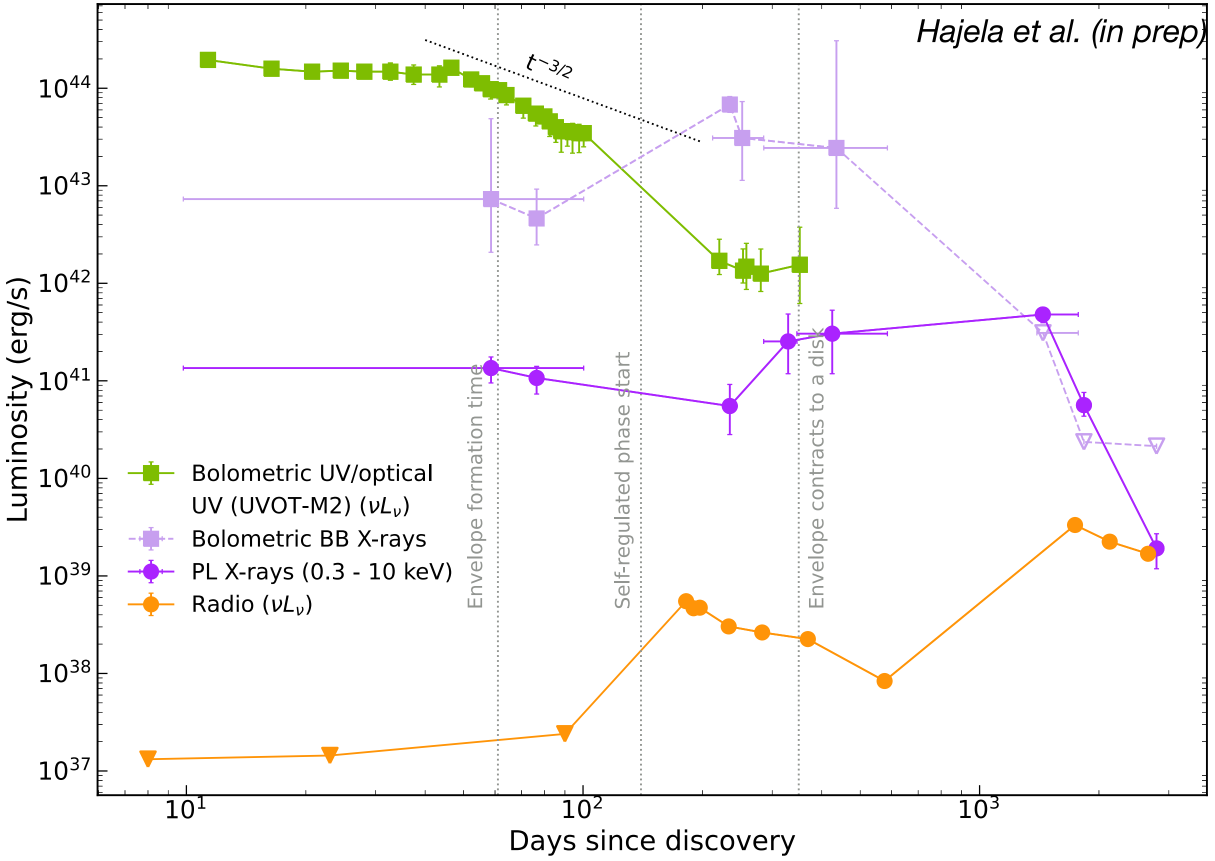


Metzger (2022)

- Stellar debris stream rapidly circularizes, but material is not able to accrete promptly
- Instead, a quasi-spherical pressure-supported debris envelope forms
- The envelope cools and shrinks as M_{fb}. drops, eventually allowing the accretion rate to rise (after ~several 100 days)
- High accretion rates may power outflows

15oi in the cooling envelope model

- Timescales for envelope formation, accretion from Metzger 2022 roughly match optical decline, (thermal) X-ray peak
- Envelope size ~ observed optical R_{BB}
- Second radio flare: decelerated outflow launched at peak accretion time?
- First radio flare: related to circularization?



Summary

- Radio observations probe mass ejection in TDEs.
  - Powerful relativistic jets are rare, non-relativistic outflows are more common. Open questions remain:
    - What powers late-time flares?
  - A range of density profiles probe accretion history
    - **Steep r $^{-2.5}$ profiles** around ASASSN-14li, CNSS J0019+00
- New data/technology is driving the field.
  - Optical wide-field surveys discovering 10s of TDEs per year, soon to be 100s or 1000s (Rubin Observatory)
  - **VLA Large Program**: characterize local X-ray and optically-selected TDEs. Complementary to blind searches in radio surveys.
- More surprises are inevitable! Stay tuned.