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Multi-Messenger Signal From Tidal Disruption Events

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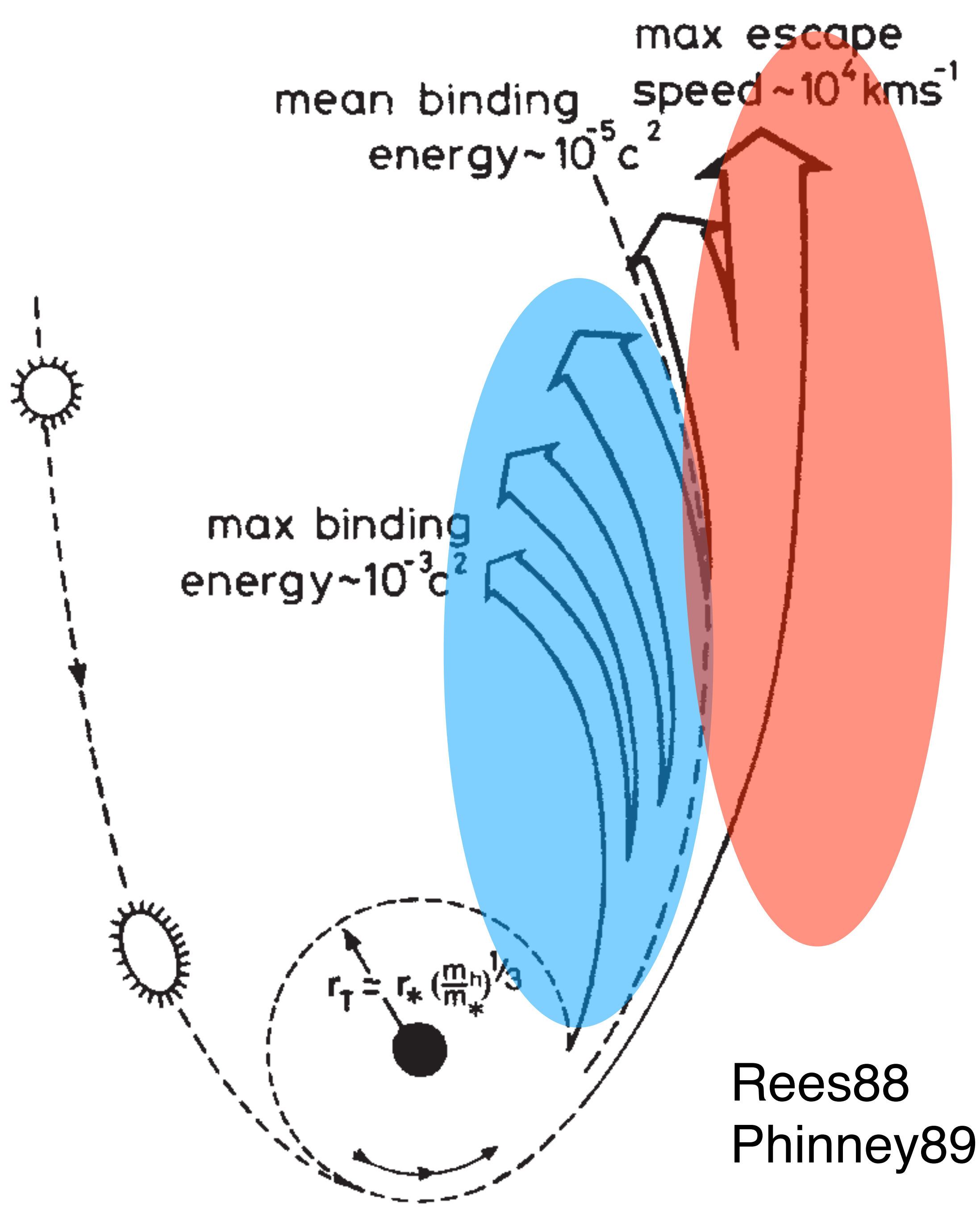
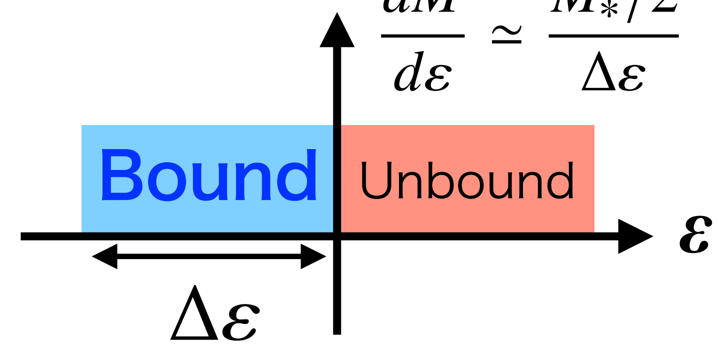
Tidal Disruption Events: Basics



Rees88
Phinney89

$$\frac{dM}{d\varepsilon} \simeq \frac{M_*/2}{\Delta\varepsilon}$$



$$\Delta\varepsilon = \left(-\frac{GM_{\rm BH}}{R_{\rm T}}\right) - \left(-\frac{GM_{\rm BH}}{R_{\rm T} \pm R_*}\right) \simeq \pm\frac{GM_{\rm BH}}{R_{\rm T}^2} R_*$$

$$t = \frac{2\pi G M_{\rm BH}}{(-2\varepsilon)^{3/2}}$$

$$\dot{M}_{\rm fb} = \frac{dM}{d\varepsilon}\frac{d\varepsilon}{dt} = \dot{M}_{\rm peak}\left(\frac{t}{t_{\rm fb}}\right)^{-5/3}$$

$$t_{\rm fb} \simeq 40{\rm day}\ R_{*,0}^{3/2} M_{*,0}^{-1} M_{\rm BH,6}^{1/2}$$

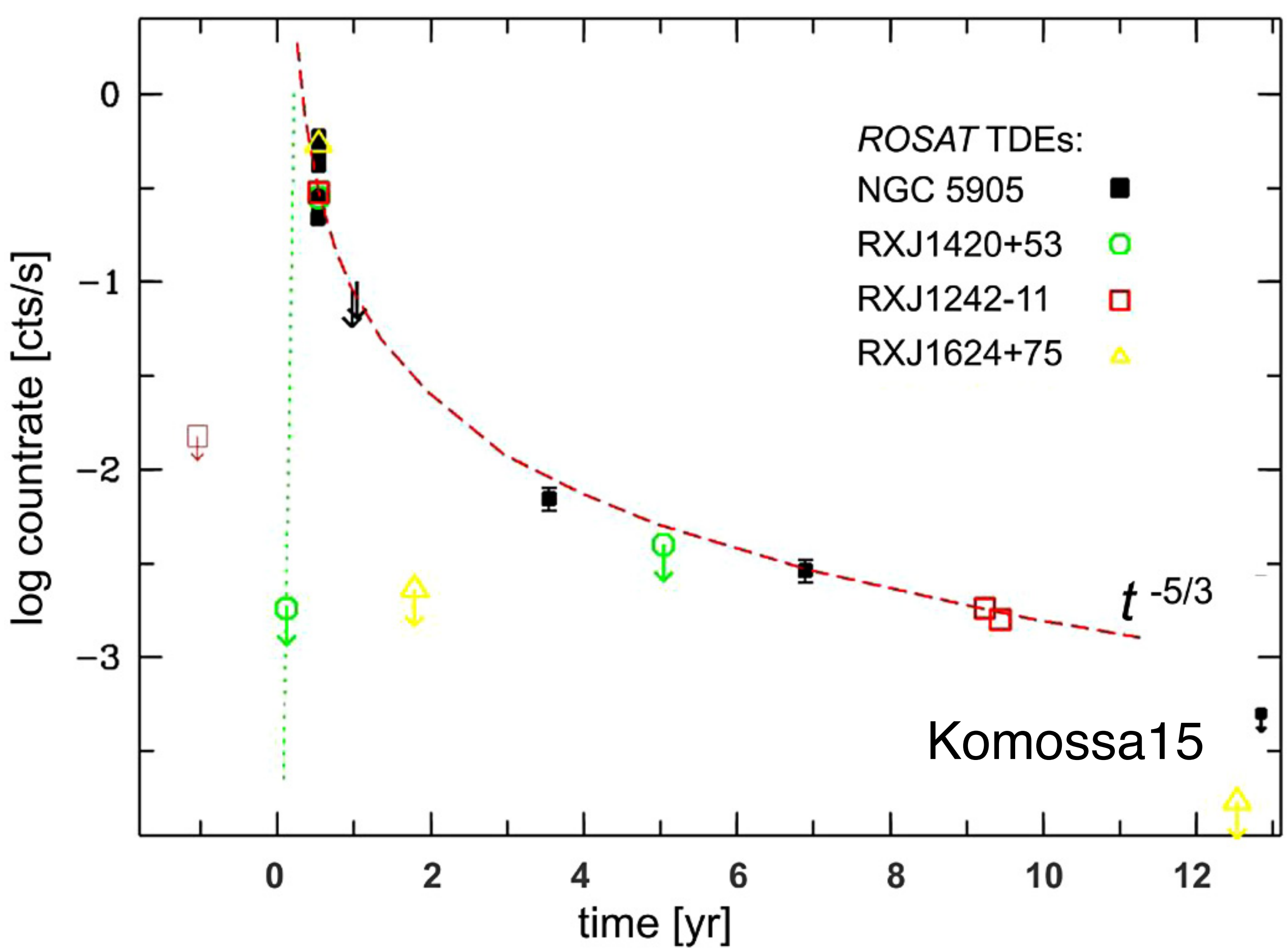
$$\dot{M}_{\rm Edd} = \frac{L_{\rm Edd}}{\eta c^2}$$

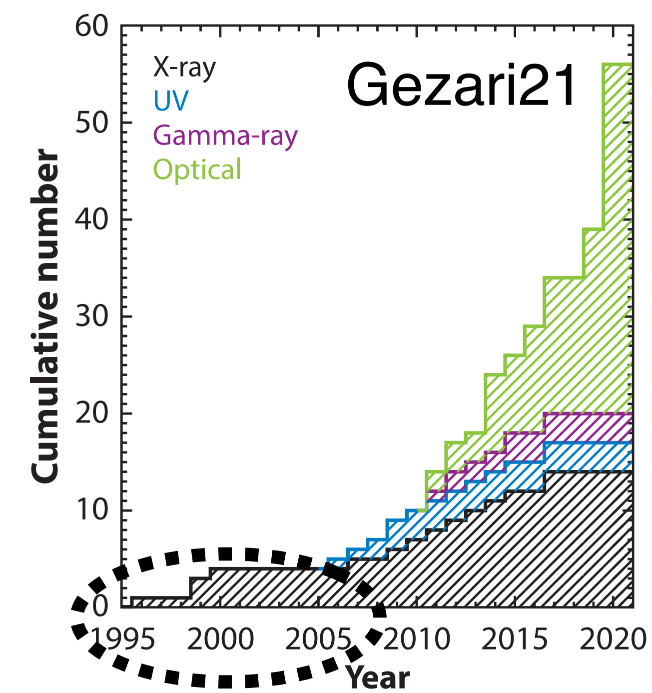
$$\dot{M}_{\rm peak} = \frac{M_*}{3t_{\rm fb}} \simeq 100\dot{M}_{\rm Edd}\ \eta_{-1} R_{*,0}^{-3/2} M_{*,0}^{2} M_{\rm BH,6}^{-3/2}$$

Expectation: soft X-rays flares
in galactic center with $\sim L_{\rm Edd}$ lasting $\sim$yr

Tidal Disruption Events: Observation

X-ray TDEs (1990s~)



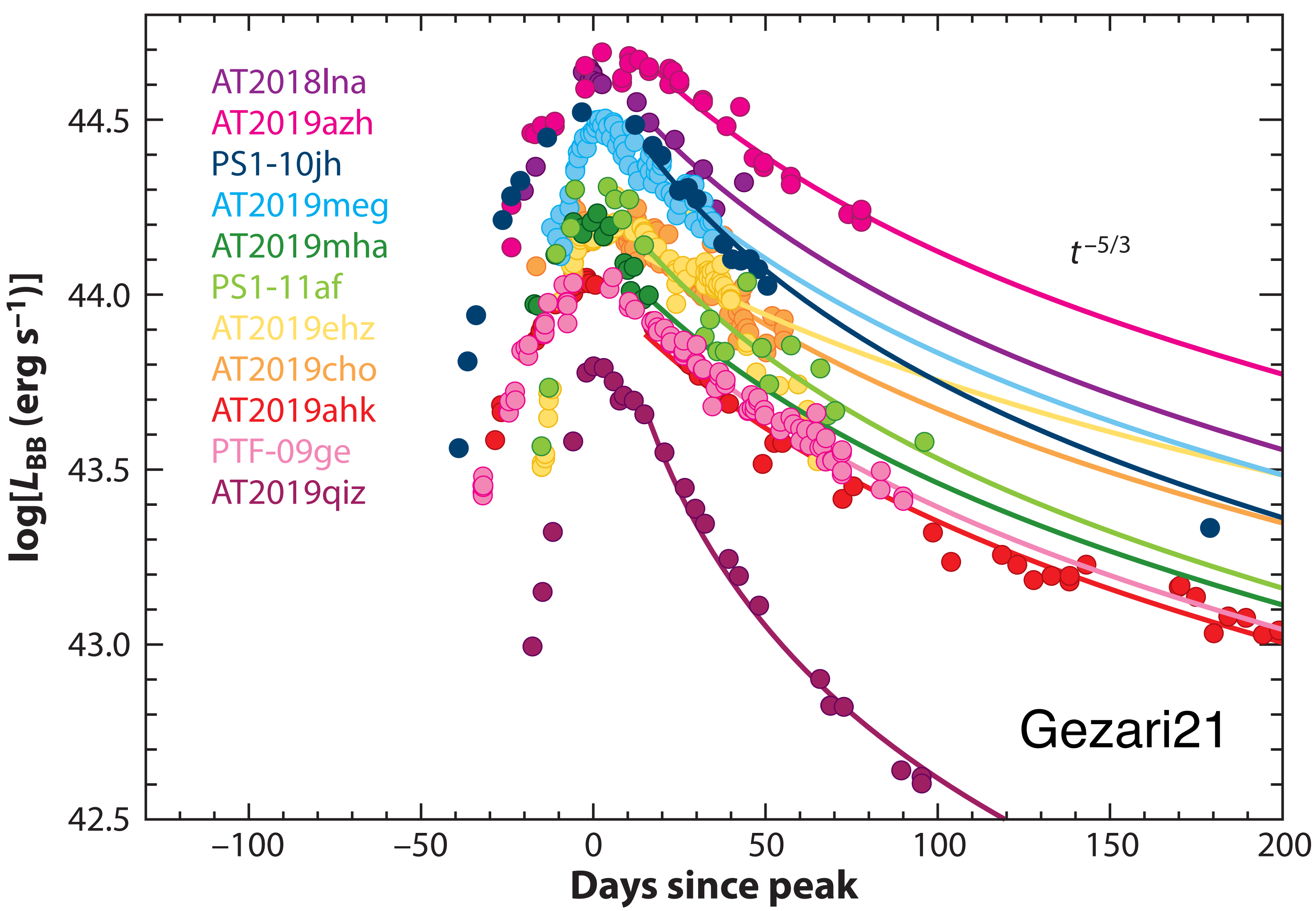


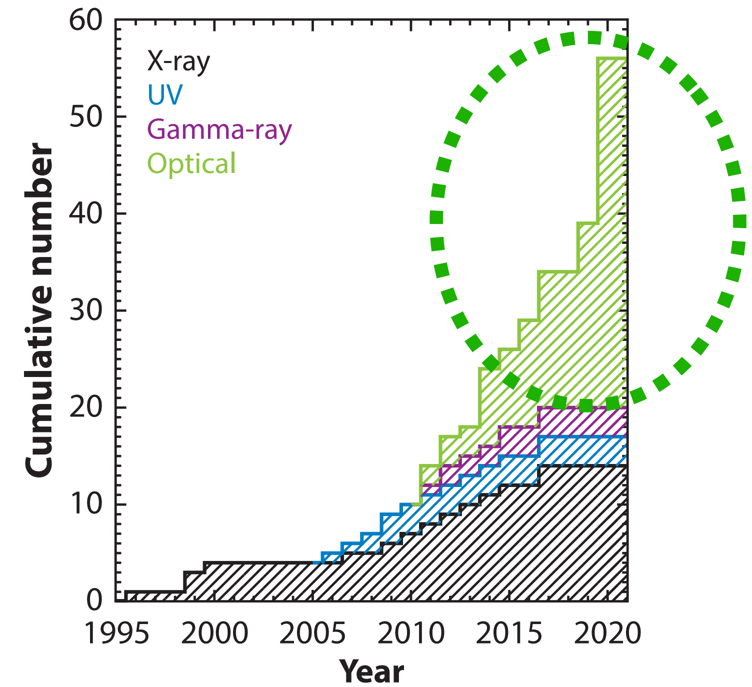
ROSAT all sky survey: 1990-91
20% of sky @0.1-2.4 keV
(Low-cadence…)

✓In galactic nuclear region (not AGN)
✓Lx~1e+44erg/s(~L_{Edd})
✓kT~0.1keV
✓L ~ $t^{-5/3}$

Tidal Disruption Events: Observation

Optical TDEs (2010s~)

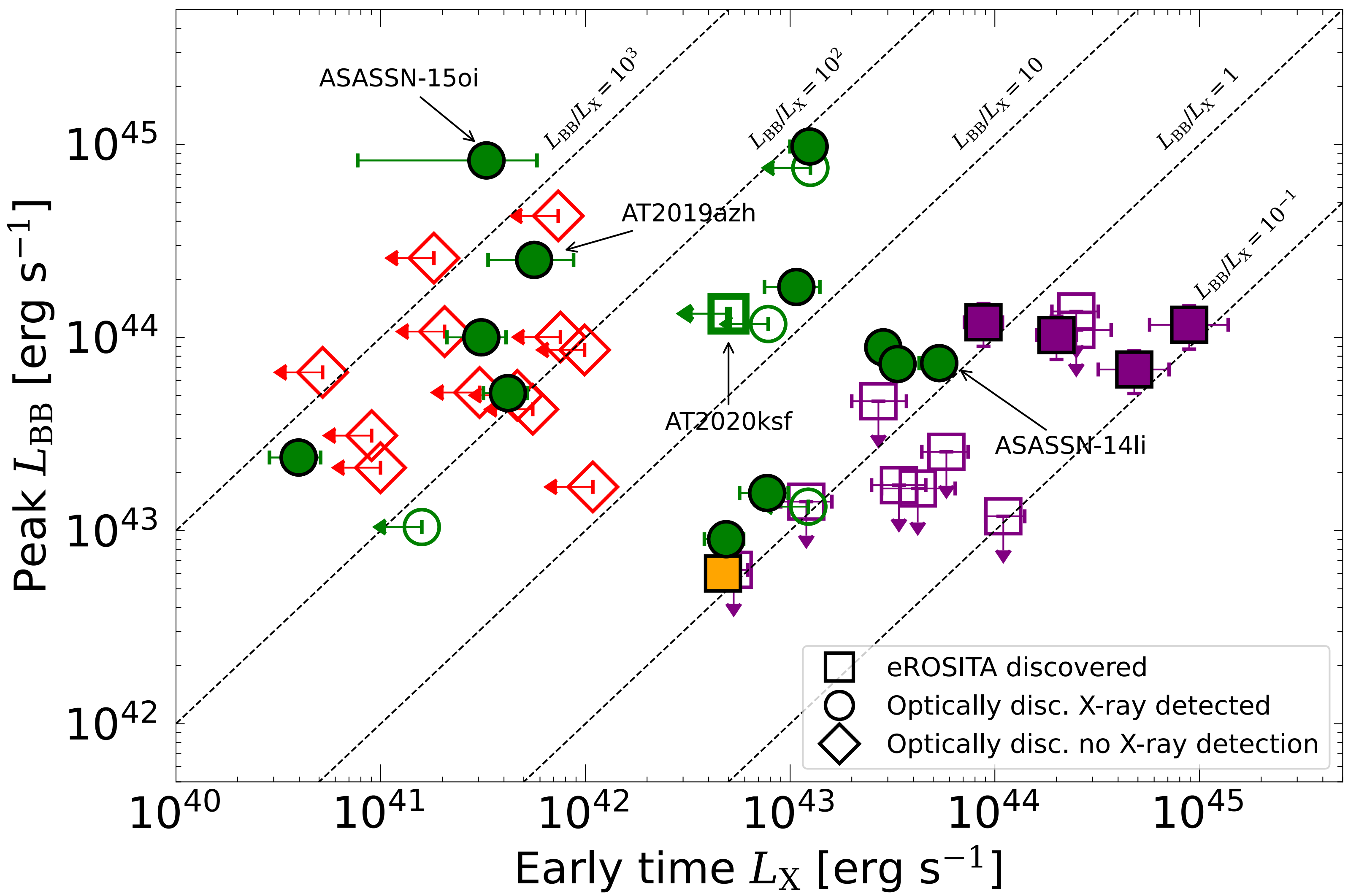




✓ In galactic nuclear region (not AGN)
✓ Lopt~1e+44erg/s(~L_{Edd})
✓ T~30000K, Rbb~1e+15cm
✓ L ~ $t^{-5/3}$

Emission mechanism: Reprocessing disk emission? Shock interaction? Cooling envelope?

Guolo+23



Dai+18

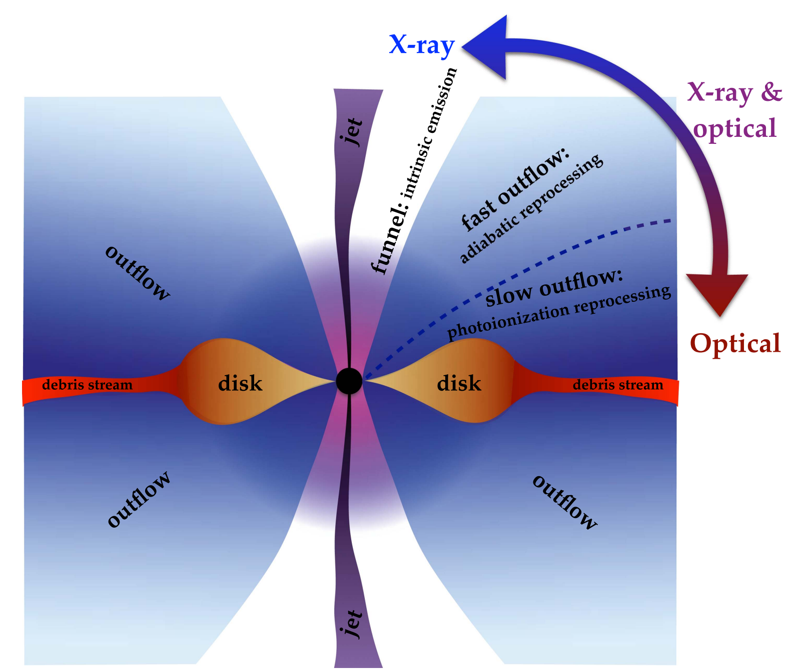
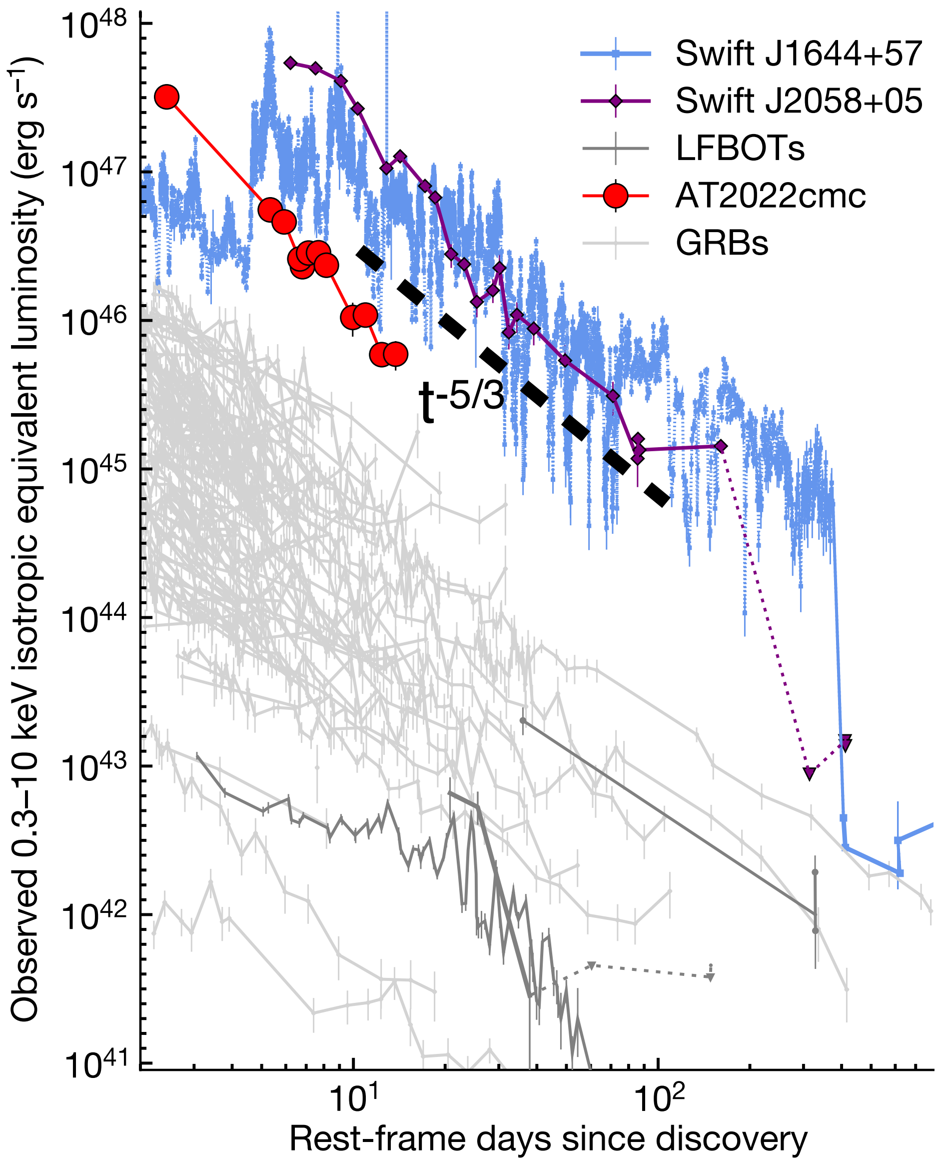
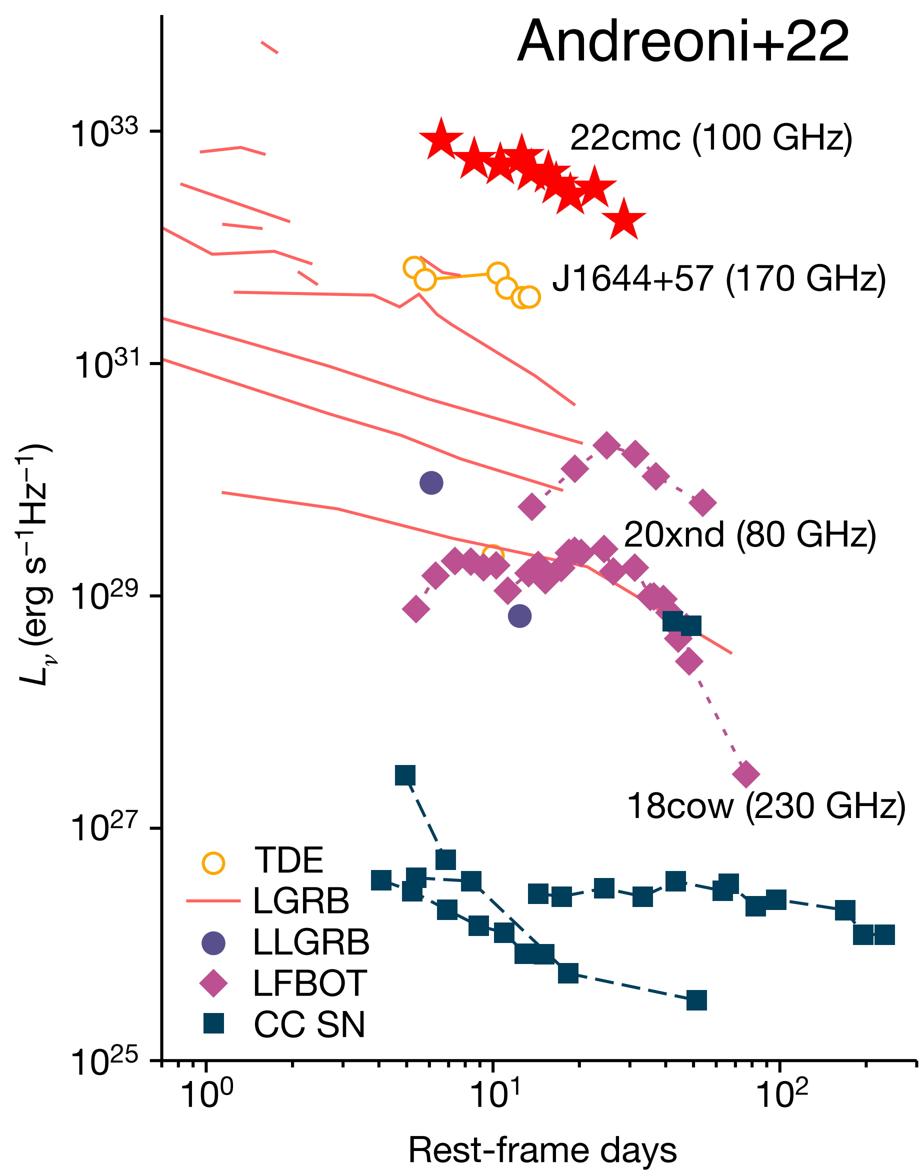


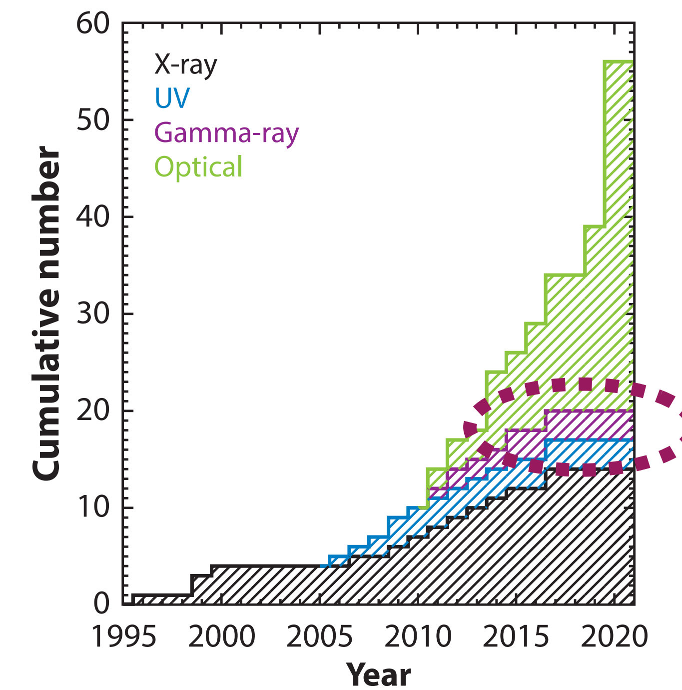
Figure 20. Distribution of peak L_{BB} × early time L_X for different TDE populations. Squares show *SRG*/eROSITA (X-ray) discovered sources, circles show optically discovered X-ray detected, while diamonds show optically discovered with no X-ray detection. Filled markers represent detections in both UV/optical and X-rays (early times), while hollow symbols represent upper limits in one of the two wavelength bands, where the arrows represent their 3σ upper limit. The colors are the same as in Fig. 19.

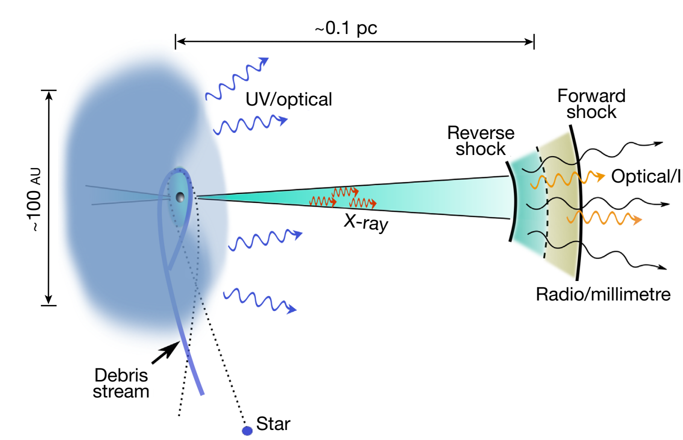
Tidal Disruption Events: Observation

Jetted TDEs: Hard X-ray + Bright Radio







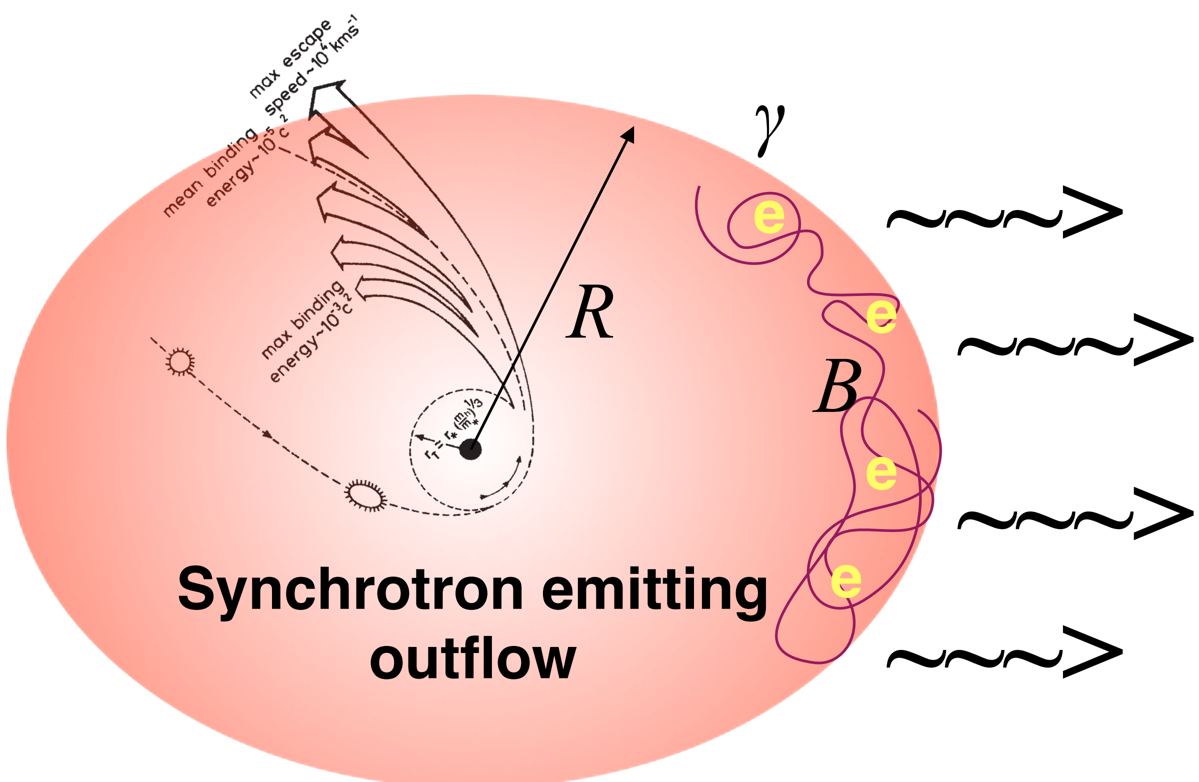


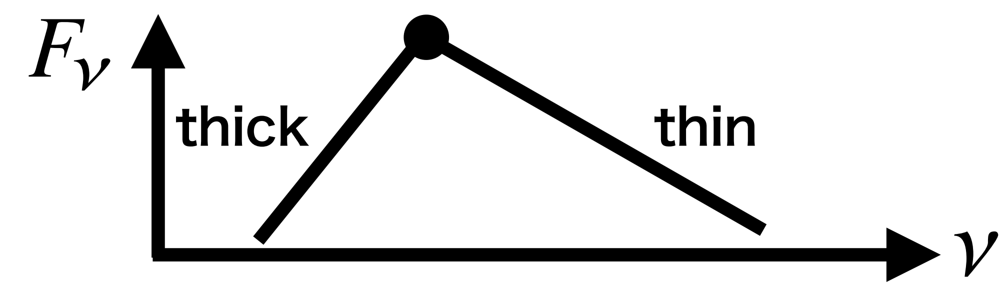
Ex,iso > 1e+53 erg

What can we learn?

Chevalier98,Barniol-Duran+13

Radio in TDEs: Equipartition analysis



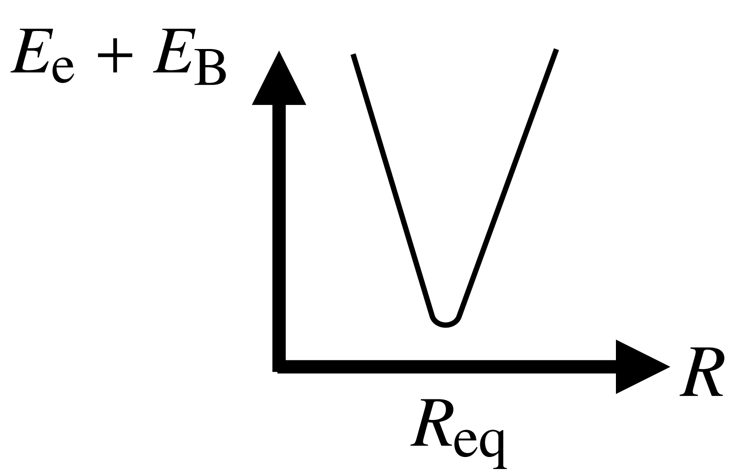


$$\nu_p \sim \gamma^2 \frac{eB}{m_e c} \propto \gamma^2 B$$

$$F_\nu \sim N \frac{\sigma_T c \gamma^2 B^2}{\nu_p d^2} \propto NB$$

$$F_\nu \sim \frac{m_e c^2 \gamma}{c^2} \frac{R^2}{d^2} \propto \gamma R^2$$

=> Total Energy: $E_{\rm tot} \sim B^2 R^3 + N m_e c^2 \gamma \sim R^{11} + R^{-6}$



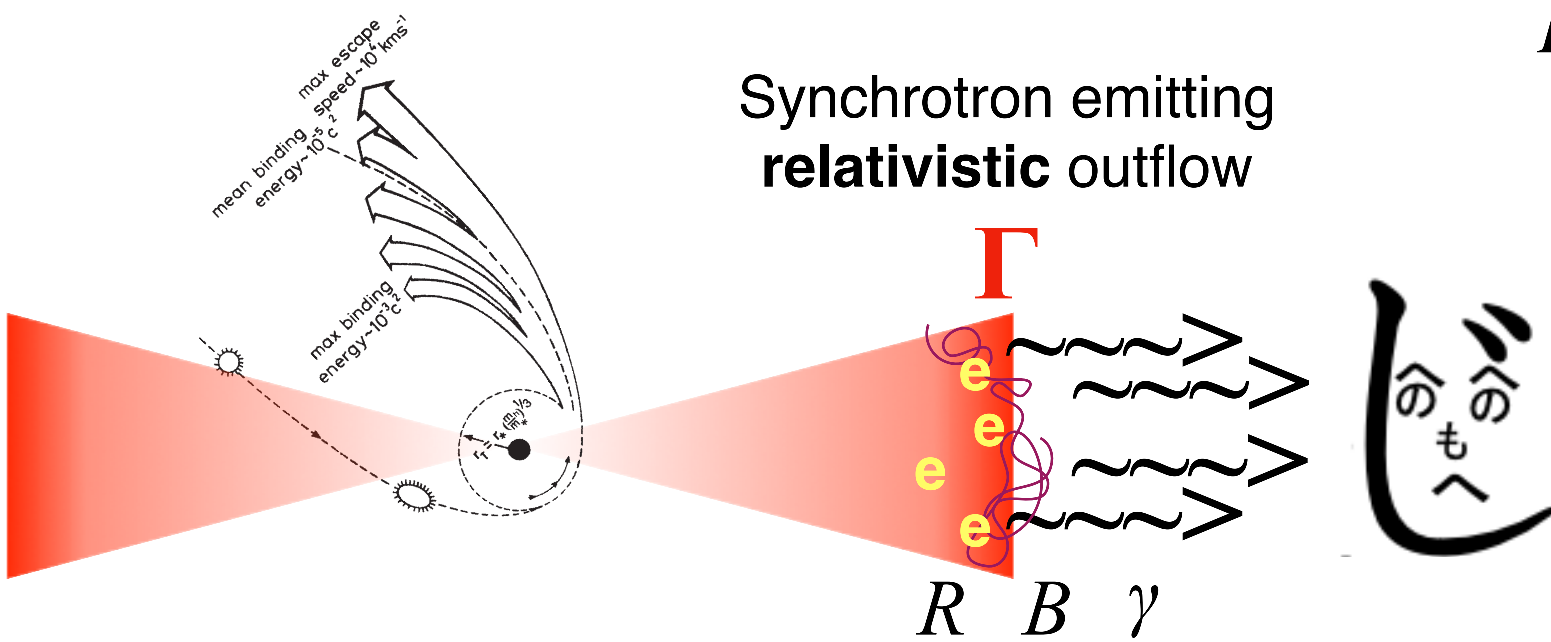
R should be $\sim R_{\rm eq}$

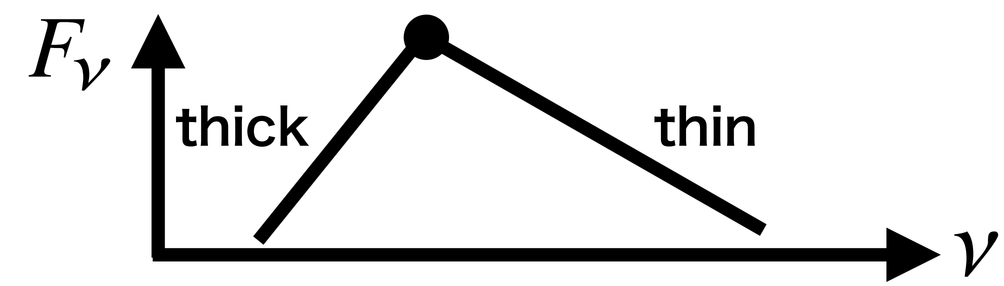
=> Estimation of other quantities

Chevalier98,Barniol-Duran+13

Radio in TDEs: Equipartition analysis

Synchrotron emitting **relativistic** outflow





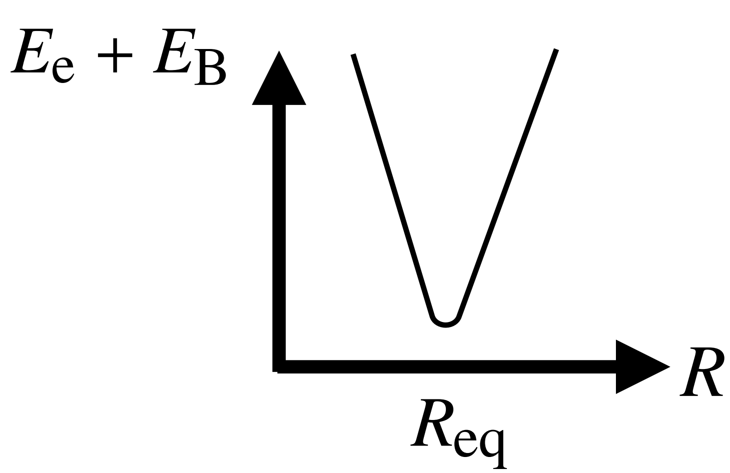
$$\nu_p \sim \gamma^2 \frac{eB}{m_e c} \propto \gamma^2 B \,\Gamma$$

$$F_\nu \sim N \frac{\sigma_T c \gamma^2 B^2}{\nu_p d^2} \propto N B \,\Gamma^3$$

$$F_\nu \sim \frac{m_e c^2 \gamma}{c^2} \frac{R^2}{d^2} \propto \gamma R^2 \,\Gamma$$

$$R \sim c\Gamma^2 t$$

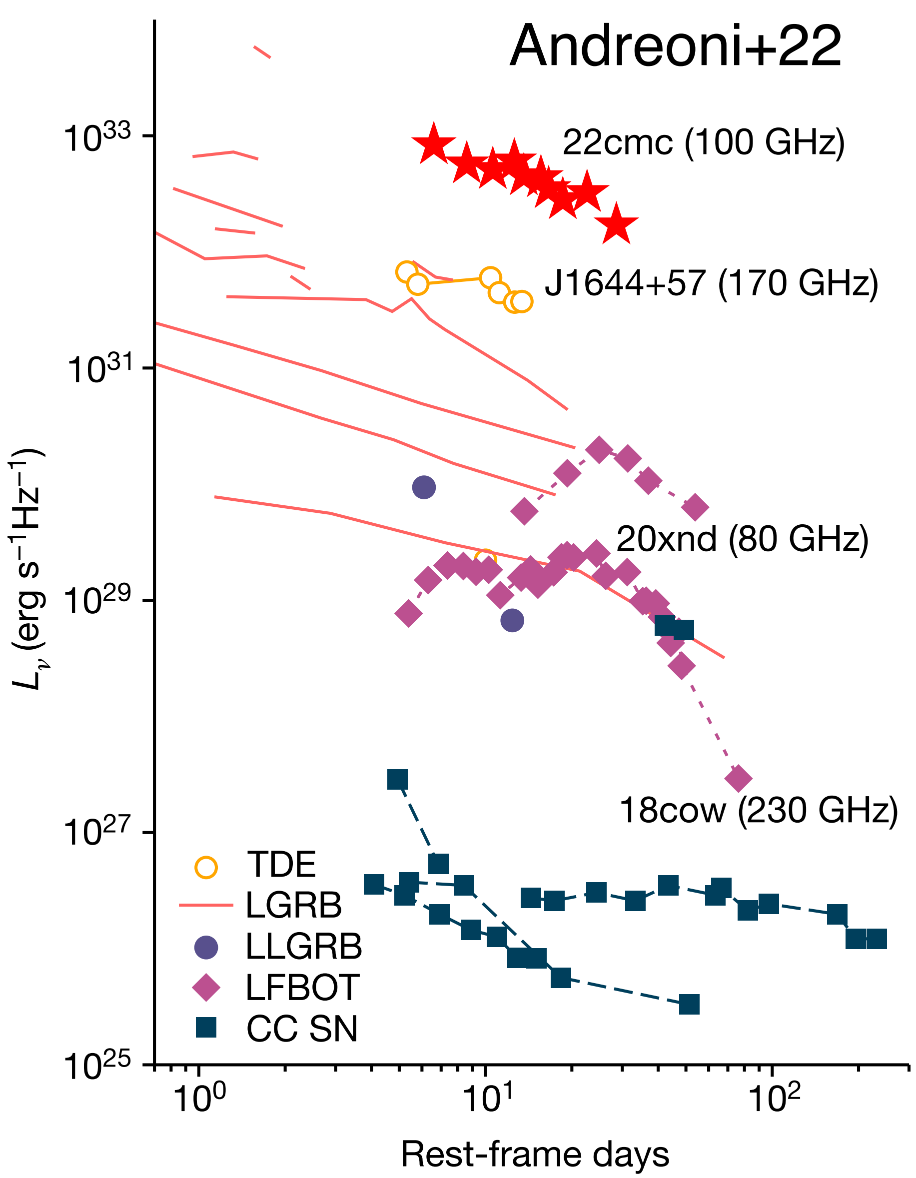
=> Total Energy: $E_{\rm tot} \sim B^2 R^3 + N m_e c^2 \gamma \sim R^{11} + R^{-6}$



R should be $\sim R_{\rm eq}$

=> Estimation of other quantities

Jetted TDEs: Radio analysis



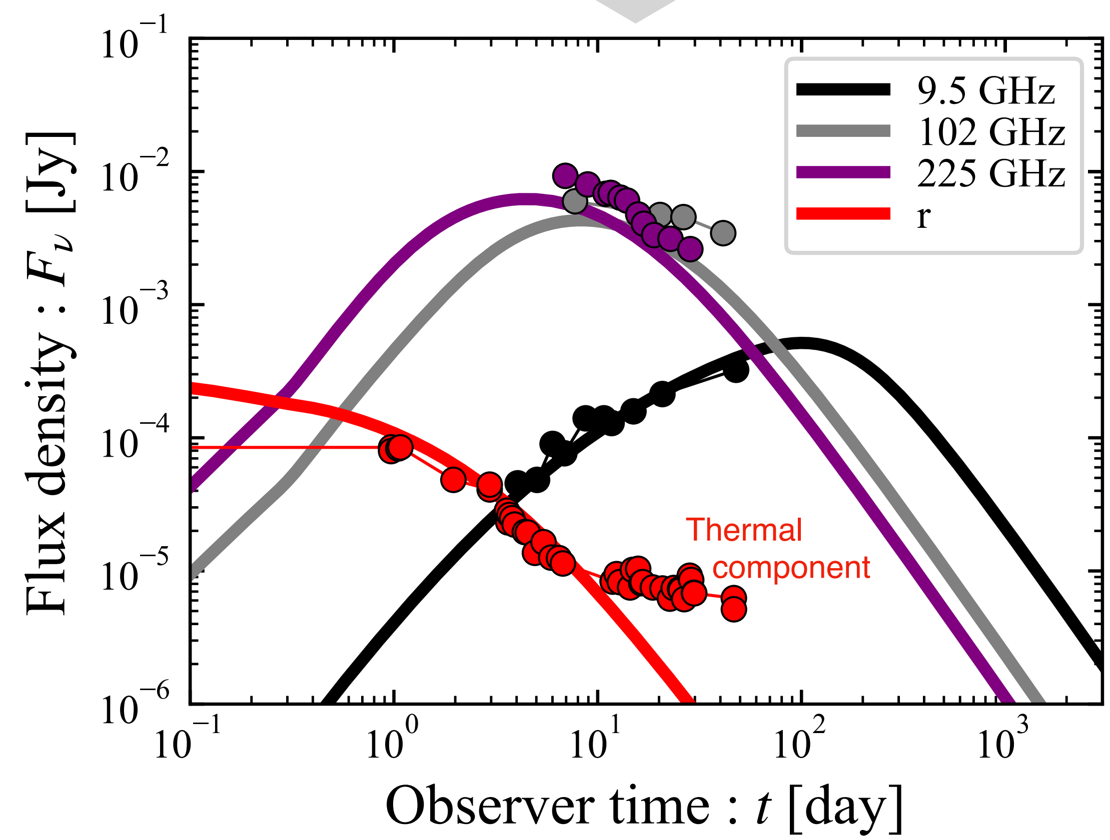
What can we learn?

Equipartition analysis

Γ~2-3 (Relativistic source!)

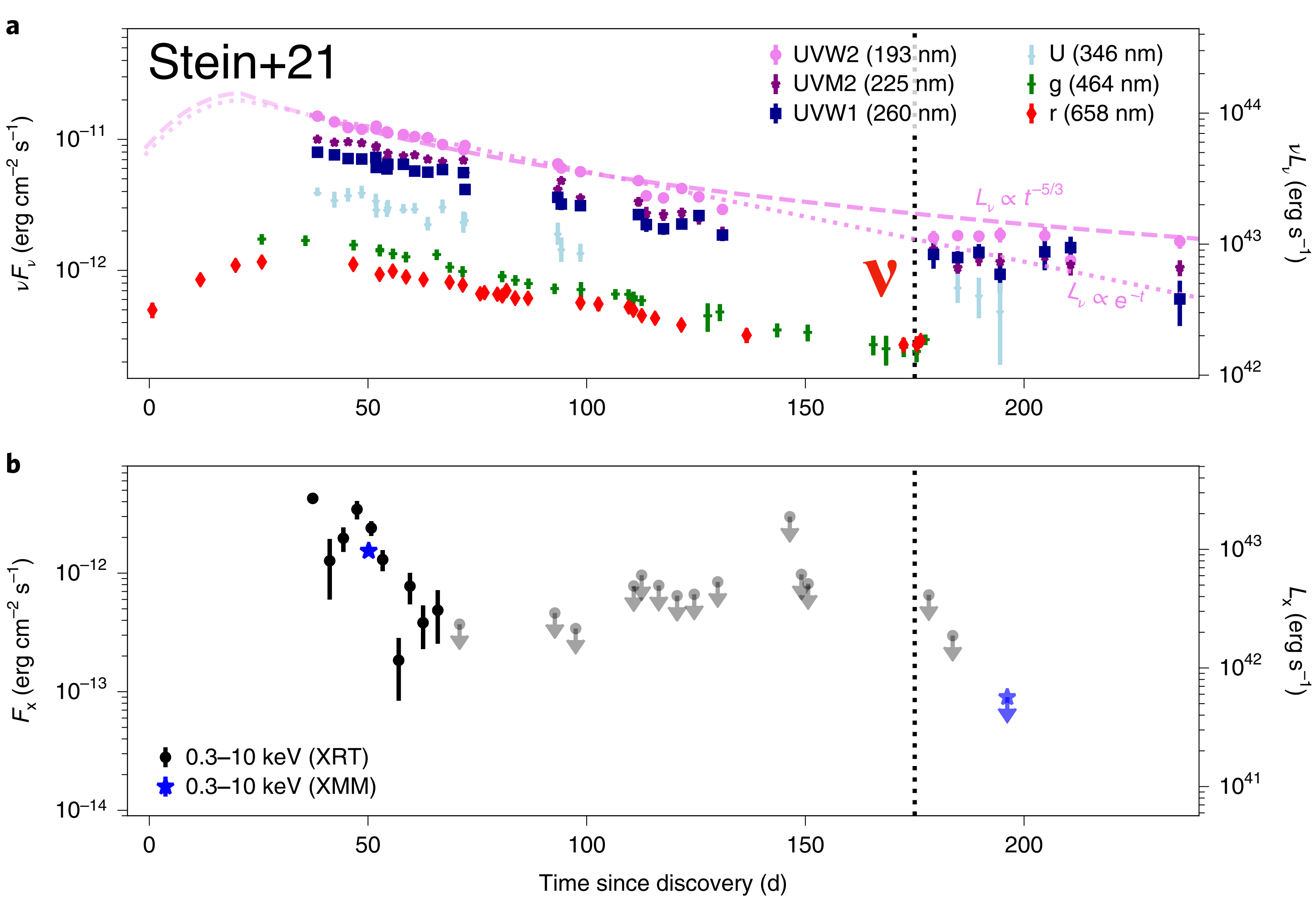
$E_{\rm j,iso}$~1e+53 erg

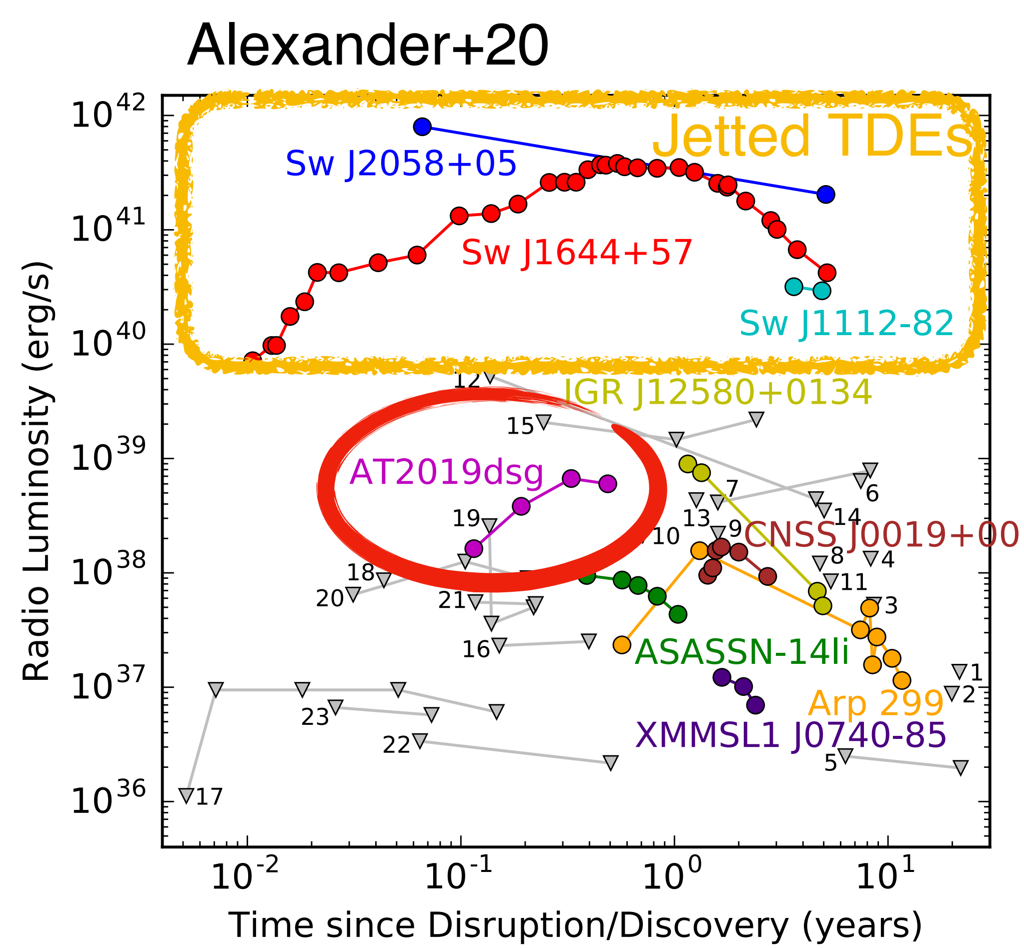
Detailed modeling (as GRB afterglow)



Matsumoto&Metzger23

Detection(?) of high-energy neutrino





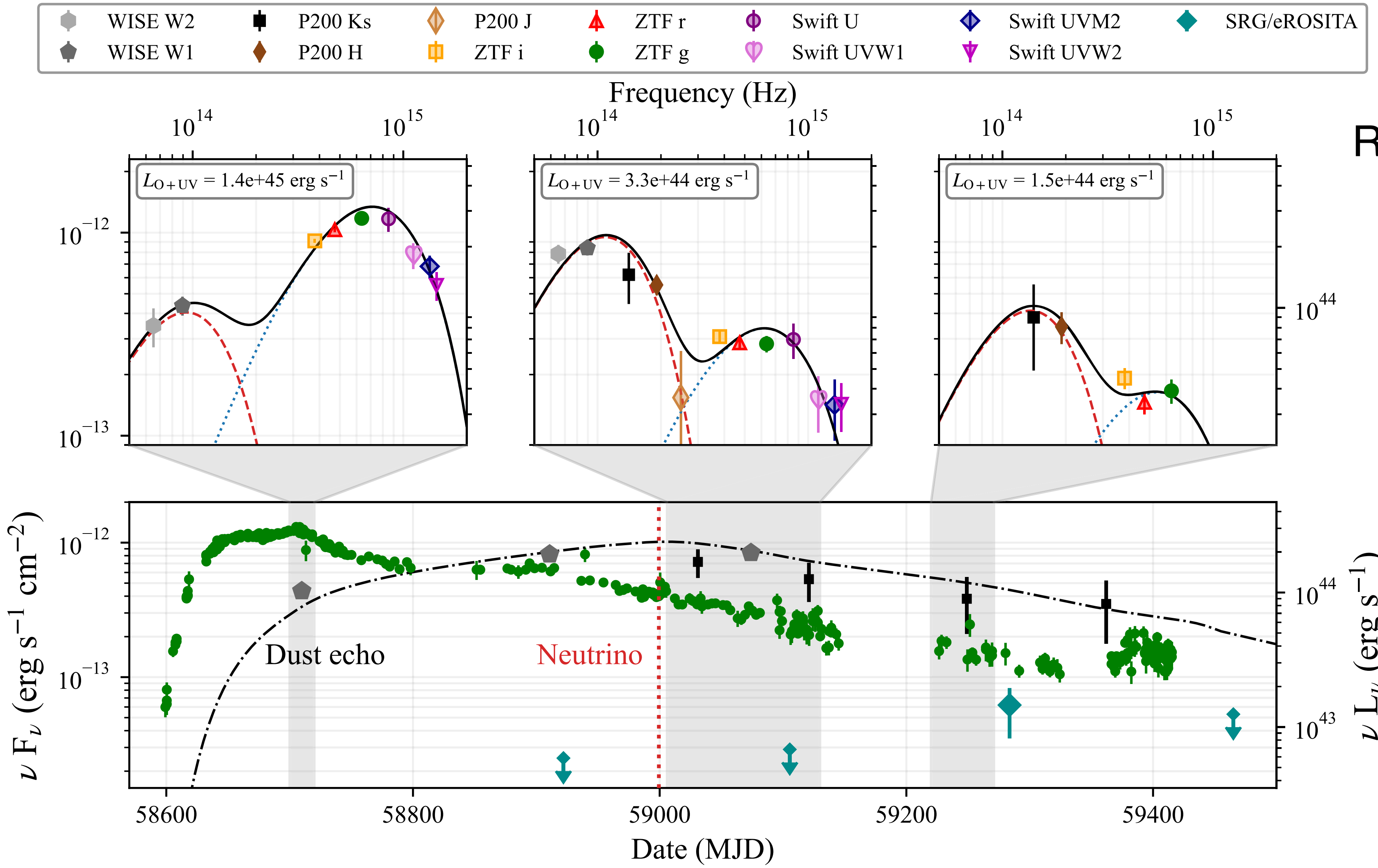
AT 2019dsg: Optical + <u>weak radio</u>

Neutrino association @ **~150days** after opt. peak

No jet signature in radio (~0.05c, ~1e+48erg)

Cendes+21,
Matsumoto+22

Detection(?) of high-energy neutrino



Reusch+21

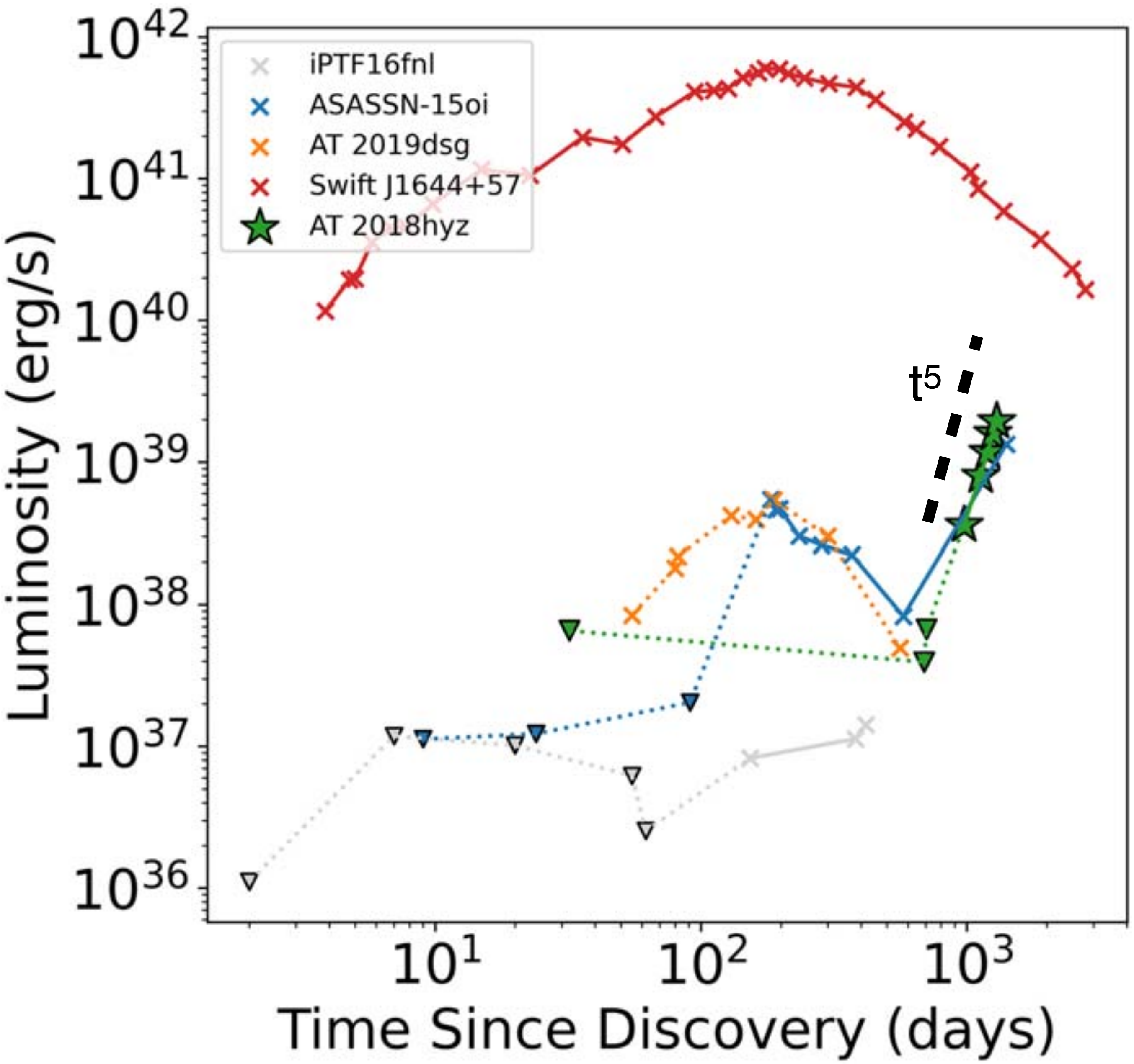
AT 2019fdr: Optical TDE

Neutrino association @ **~150days** after opt. peak

=> Late time (>100days) observation can be a key

Recent observation: Late radio flare

Cendes+22,Horesh+21

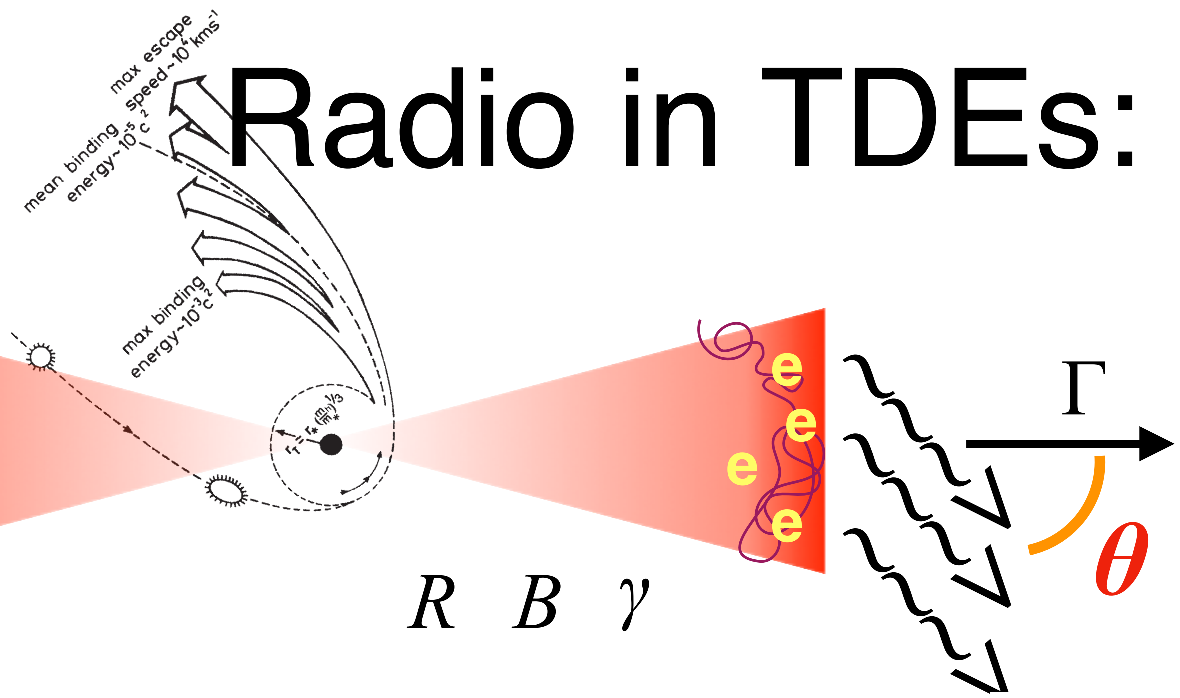


- Radio flare ~ 1000days after optical discovery
- Flux increases as t^5
- Origin?

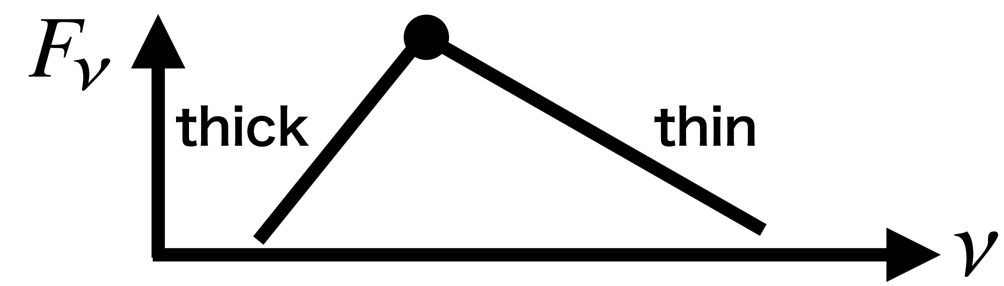
Delayed disk formation?

Off-axis jet?

Radio in TDEs: Equipartition analysis



Γ=> $\delta = \dfrac{1}{\Gamma(1-\beta\cos\theta)}$



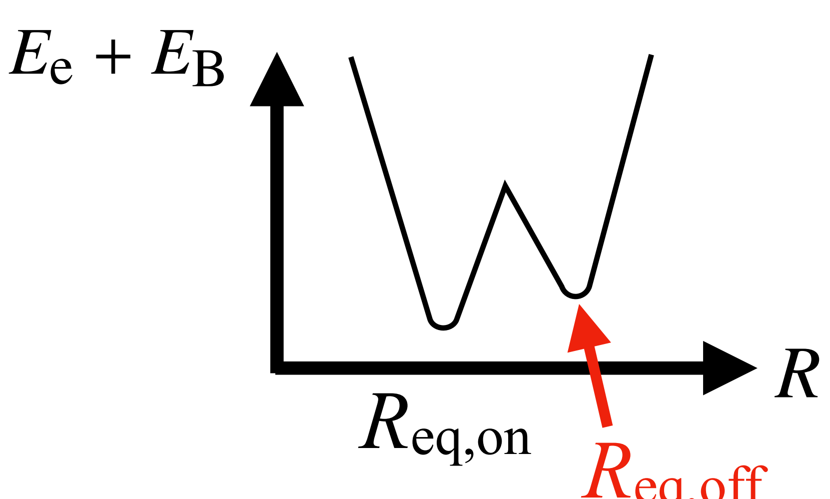
$$\nu_p \sim \gamma^2 \frac{eB}{m_e c} \propto \gamma^2 B\, \delta$$

$$F_\nu \sim N \frac{\sigma_T c \gamma^2 B^2}{\nu_p d^2} \propto NB\, \delta^3$$

$$F_\nu \sim \frac{m_e c^2 \gamma}{c^2} \frac{R^2}{d^2} \propto \gamma R^2\, \delta$$

$$R \sim c\delta^2 t$$

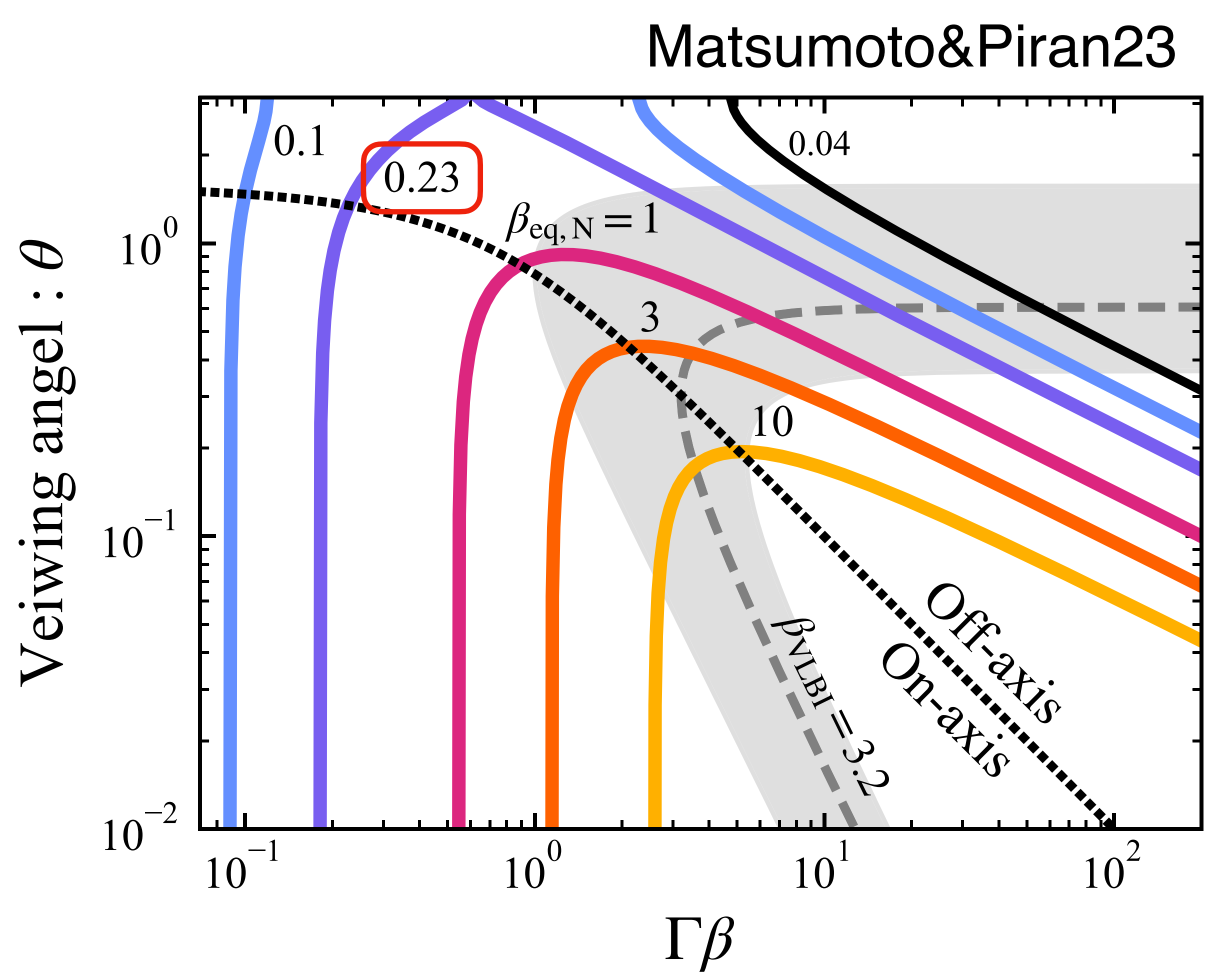
=> Total Energy: $E_{\rm tot} \sim B^2 R^3 + N m_e c^2 \gamma \sim R^{11} + R^{-6}$

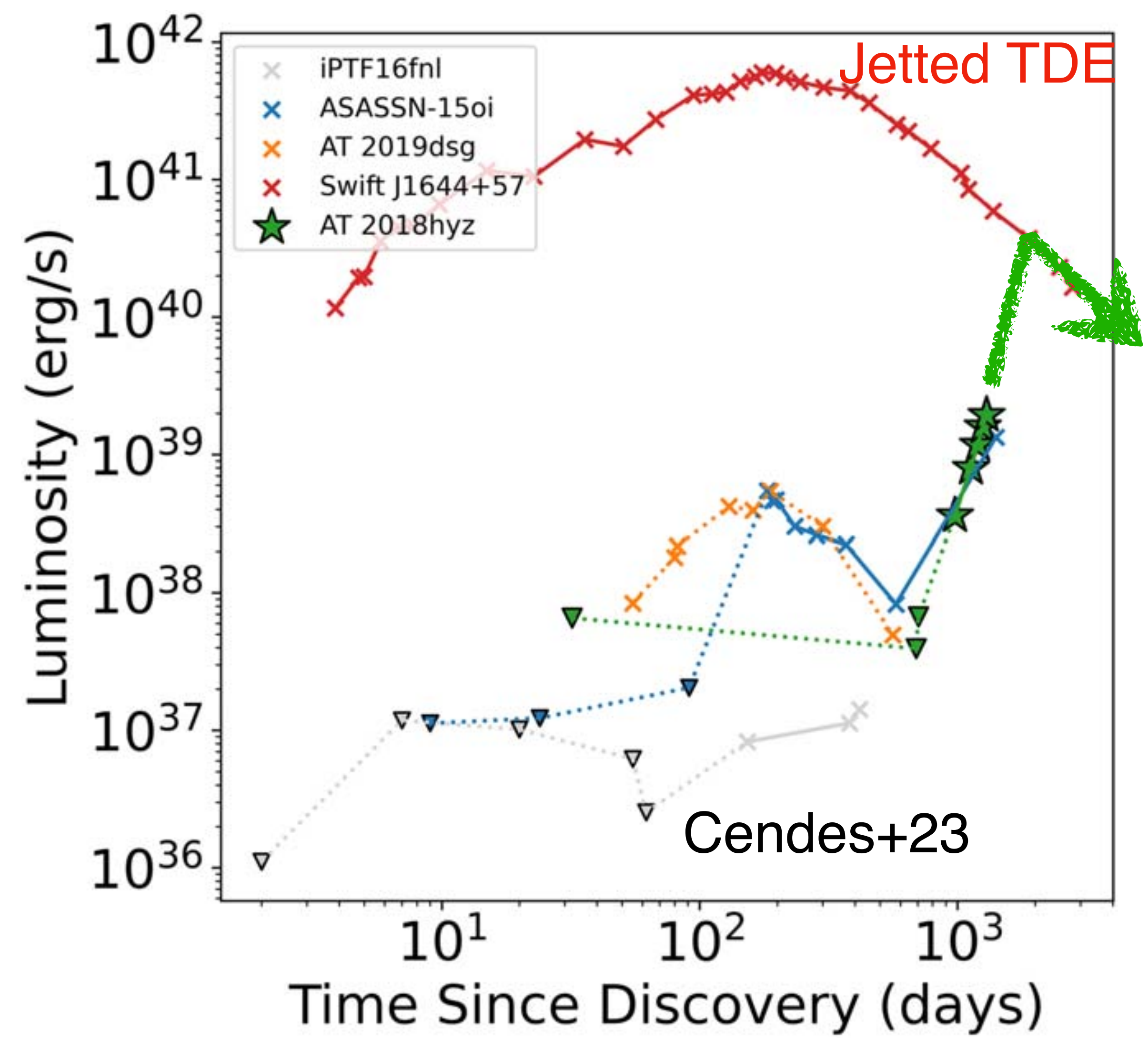


Two minimizing radii corresponding to on/off-axis

Late radio flare as off-axis jet

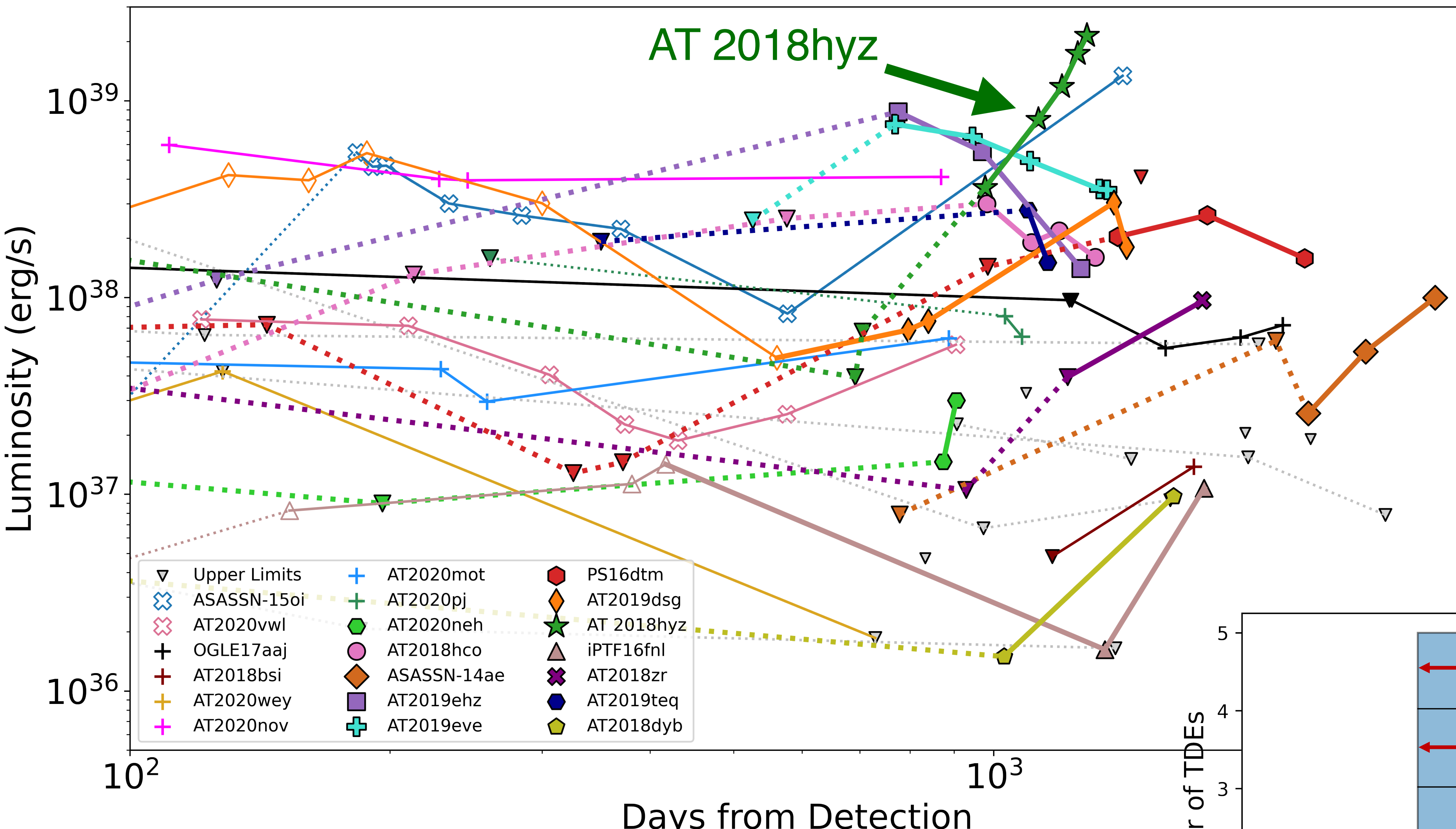
Apparent velocity is increasing $\beta_{\rm eq,N}=R_{\rm eq}/t\sim0.1c(t/1000{\rm day})$



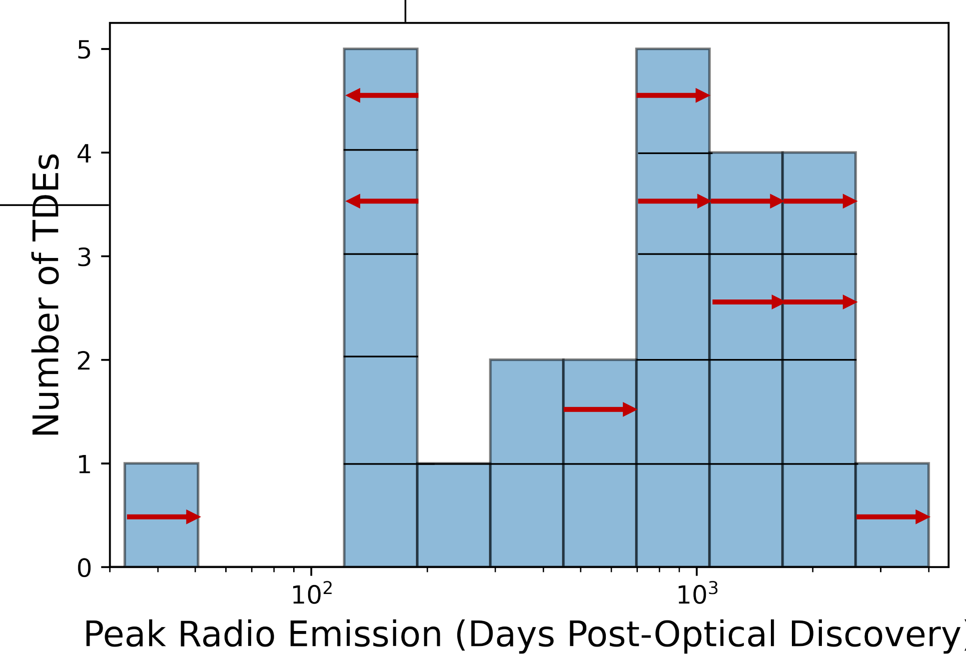


Future VLBI obs. will confirm or reject off-axis scenario

Ubiquitous late radio flare



Cendes+23
Somalwar+23



~40-50% of optical TDEs show late (~>1000days) radio flares!

Most of them are not bright (≠off axis jet)

Event rate

Sazonov+21, Yao+23

Andreoni+22

$\mathcal{R}_{\rm opt} \sim \mathcal{R}_{\rm x} \sim 1000\ /{\rm Gpc}^3/{\rm yr}\ (\sim 10^{-4}\ /{\rm galaxy/yr})$

$\mathcal{R}_{\rm on\text{-}jet} \sim 0.01\text{-}0.1\ /{\rm Gpc}^3/{\rm yr}$

Beaming: $f_{\rm b} \sim \theta^2 \sim 0.01$

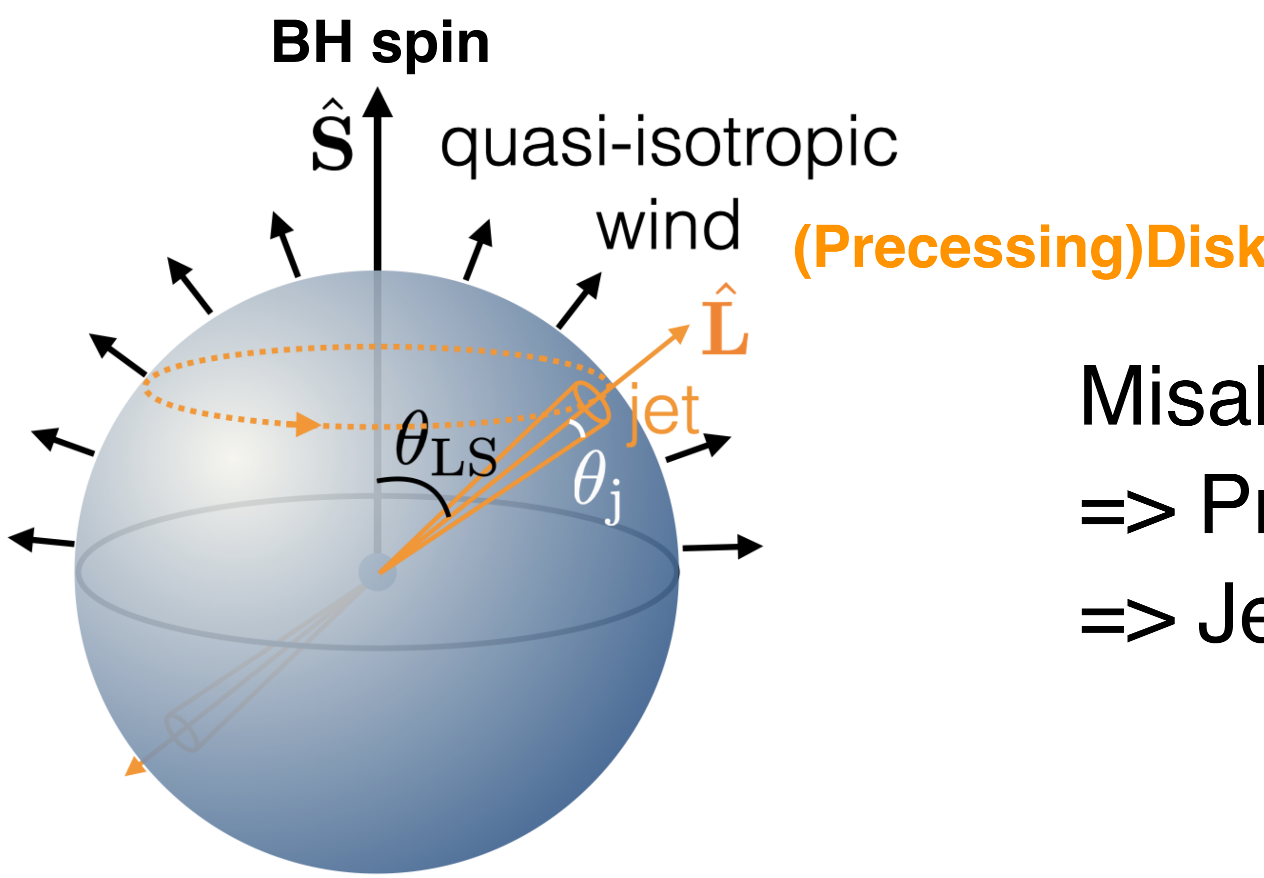
$\mathcal{R}_{\rm \mathbf{off}\text{-}jet} \sim 1\text{-}10\ /{\rm Gpc}^3/{\rm yr}$

At most **a few %** of TDEs can have off-axis jet

Why jetted TDEs are so rare?
(<1% <=> AGN:10%)

Lu, Matsumoto, Matzner 23

Jet Breakout = Double alignment?



Misalignment
=> Precessing Disk&Jet (e.g., Liska+18)
=> Jet is easily choked
within disk wind

1. Observer's line of sight = jet axis : $f_{\rm b} \sim \theta_{\rm j}^2$
2. Stellar ang. mom. = BH spin : $f_{\rm LS} \sim \theta_{\rm LS}^2 \sim \theta_{\rm j}^2$

On-axis Successful Jet: $\mathcal{R}_{\text{on-jet}}/\mathcal{R}_{\rm TDE} \sim \theta_{\rm j}^4 \sim 10^{-4}\,(\theta_{\rm j}/0.1)^4$

Summary

- Tidal Disruption Events: Optical/X-ray flares
  in galactic nuclear regions.
- Only 4 jetted TDEs have been discovered.
- Radio emission: Powerful probe of outflows.
- High-energy neutrinos association(?)
  with optical (not jetted) TDEs at >~100 days.
- Late-time radio flares (>1000days):
  - ~1% of them are potentially off-axis jetted event
  - Most of them are delayed outflow?
- Rarity of jetted TDEs = "Double-alignment"?