Jets from stellar tidal disruptions by supermassive black holes

Dimitrios Giannios
Princeton University

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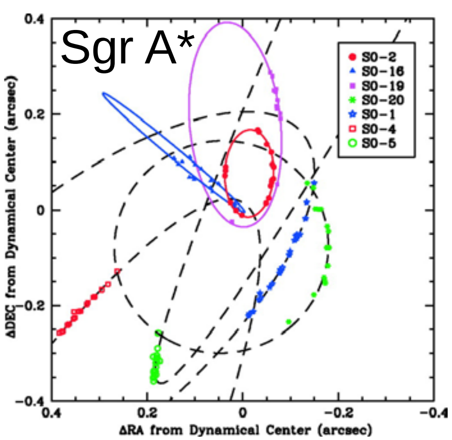
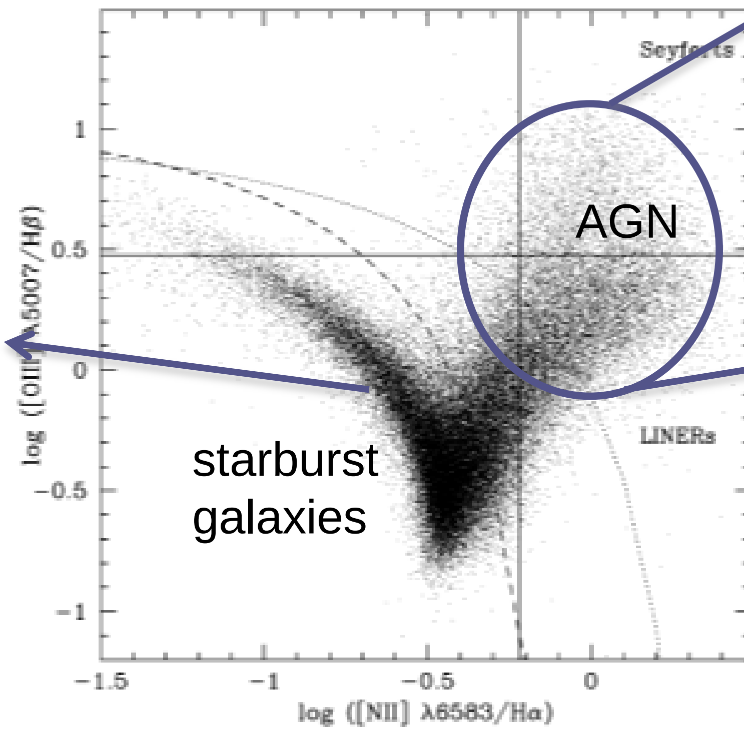
Galactic centers: some are active, most are dormant



Ghez et al. 2005



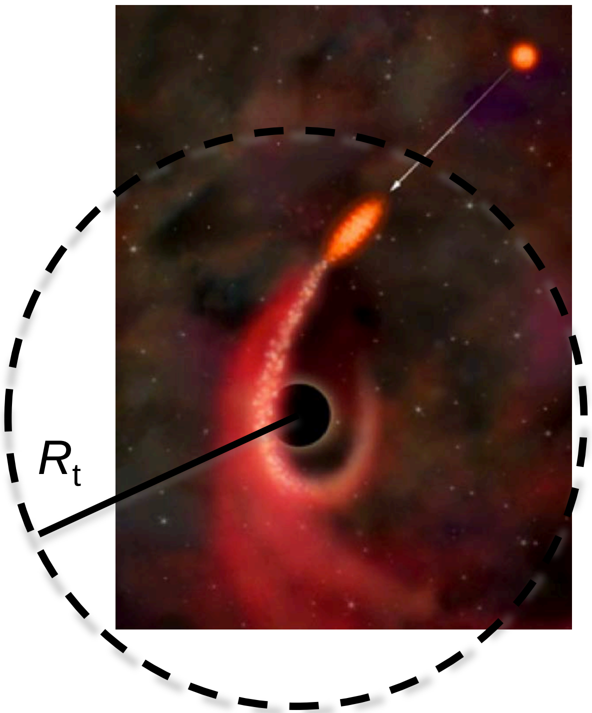
Baldwin, Phillips & Terlevich 1981
Kormendy & Richstone 1995; Kauffmann et al. 2003

Waking up SMBHs with stellar tidal disruptions

When a wandering star finds itself within

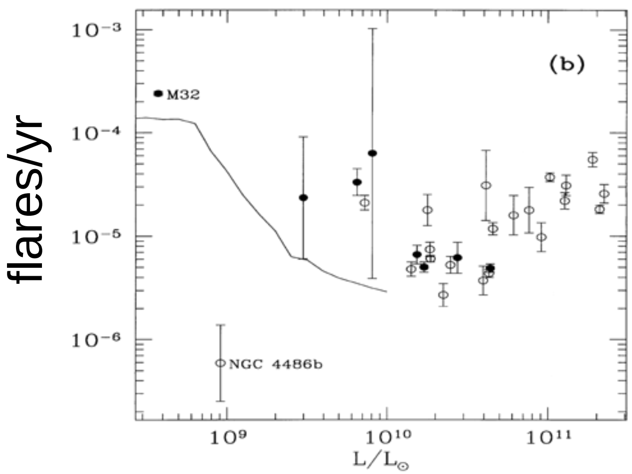
$$R_p \le R_t \sim \left(\frac{M_{\rm BH}}{{\rm M}_*}\right)^{1/3} R_*$$

it is tidally disrupted
e.g. Rees 1988



For *solar* type star

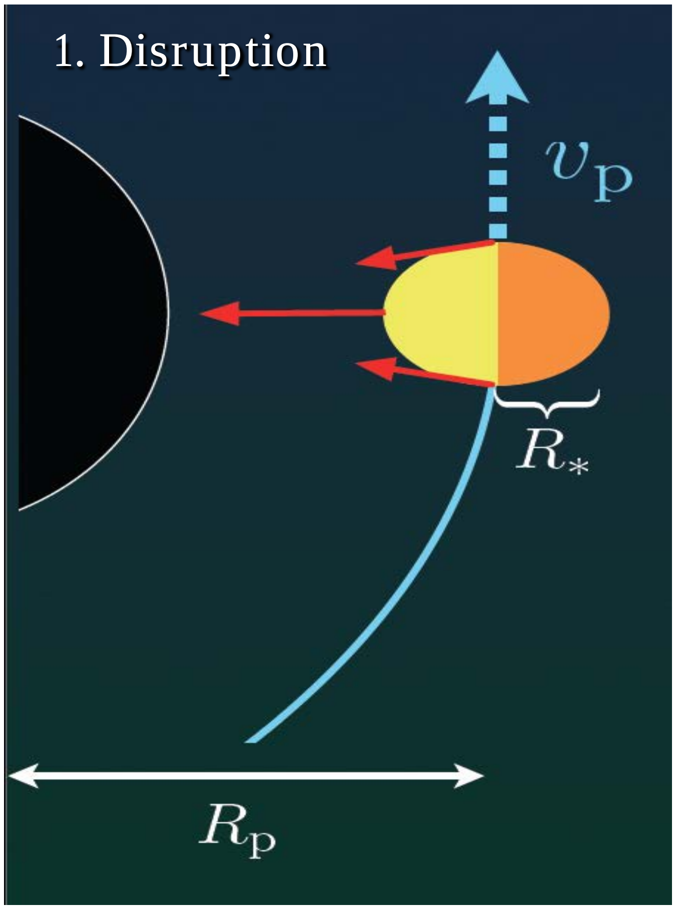
$$R_t \ge R_s = \frac{2GM_{\rm BH}}{c^2}, \;\; \text{for } M_{\rm BH} \le 10^8 M_\odot$$

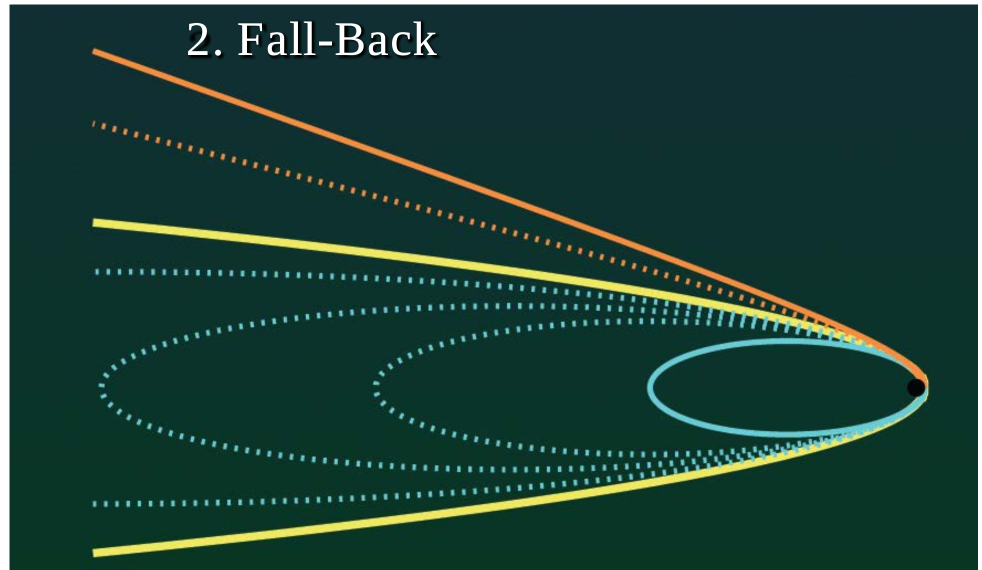


Rate of TDEs~10^{-4}-10^{-5} $\mathrm{yr}^{-1}\mathrm{gal}^{-1}$
(e.g. Magorrian & Tremaine 1999)

Tidal Disruption of a Star by a Supermassive Black Hole

(Rees 1988; Phinney 1989; Evans & Kochanek 1989)





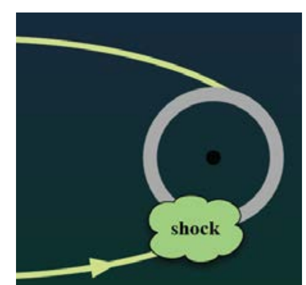
~half has $\epsilon > 0$ unbound: hyperbolic trajectories

~half has $\epsilon < 0$ bound: elliptical orbits

3. Circularization and Accretion

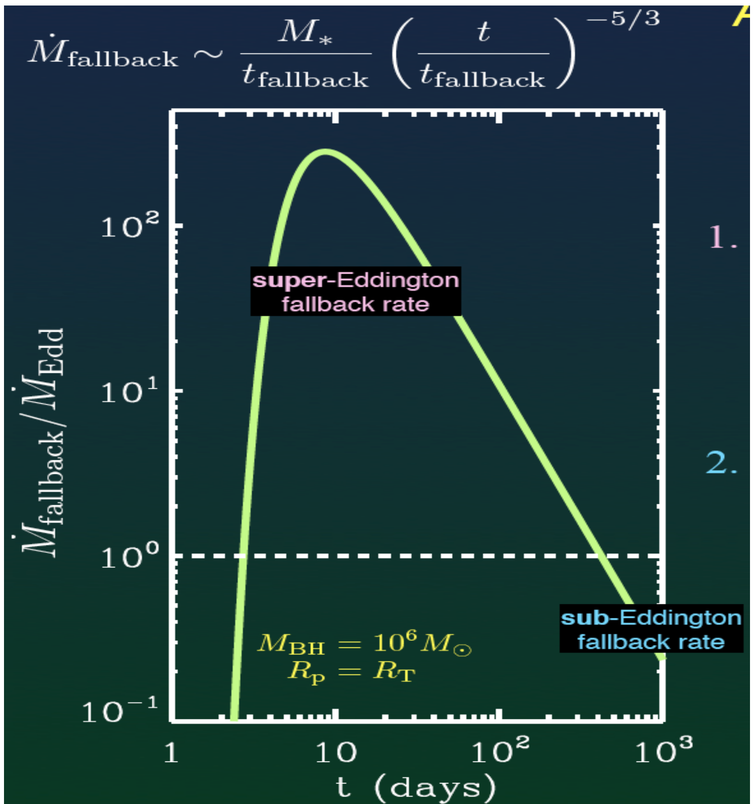
$$\dot{M}_{\rm fallback} \sim \frac{M_*}{t_{\rm fallback}}\left(\frac{t}{t_{\rm fallback}}\right)^{-5/3}$$

$$t_{\rm fallback} \sim days$$

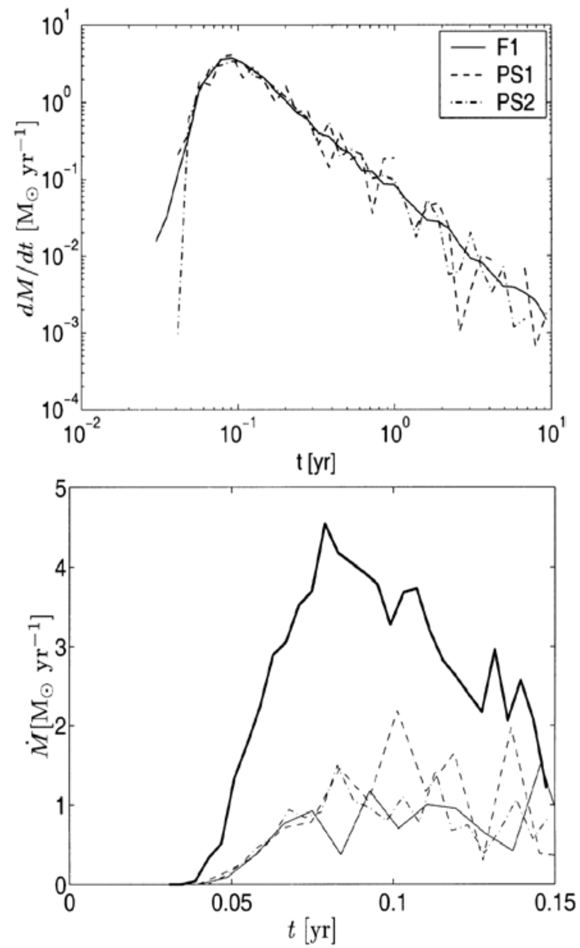


Thermal "Flares" from Accretion Disk (Optical, UV, X-ray)

(e.g. Rees 1988; Ulmer 1997; Ayal et al. 2000; Strubbe & Quataert 2009, 2010)



Ayal et al. 2000

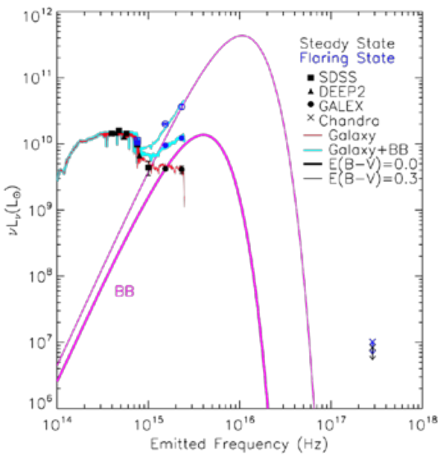


fallback rate

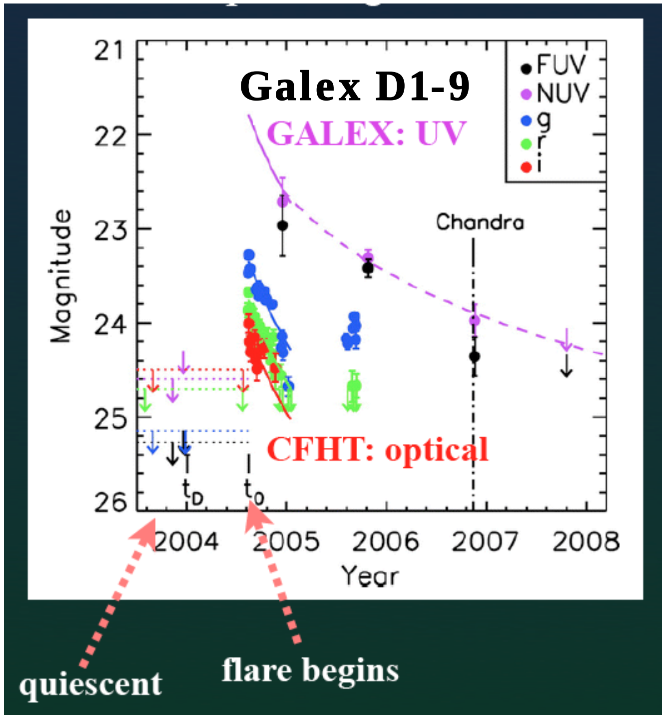
accretion rate

Tidal Disruption Candidates

Spectra



Light curves



Gezari et al. 2008

~10 Candidate Detections So Far by

- **ROSAT All-Sky Survey (Komossa 2002)**
- **XMM Slew Survey (Esquej et al. 2007)**
- **Galex Deep Imaging (Gezari et al. 2009)**
- **SDSS Stripe 82 (van Velzen et al. 2010)**
- **PTF (Cenko et al. 2010)**

Caution required to exclude alternatives (supernovae, “normal” AGN activity etc)

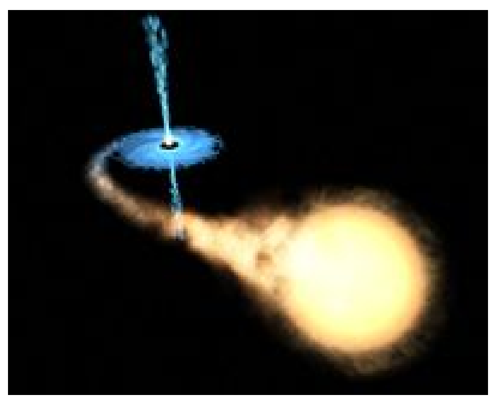
Where there is accretion to BH, there are jets!

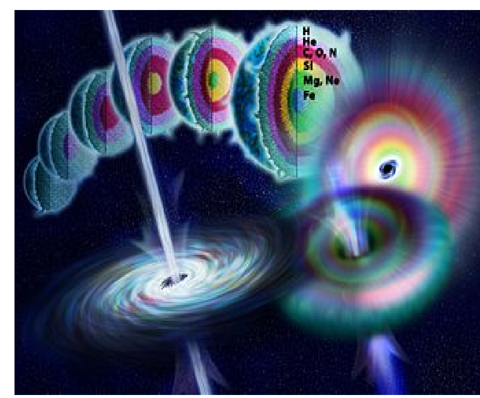
A substantial fraction of gravitational energy may be channeled into relativistic jets

$\Rightarrow$ *Non-thermal signatures from TDEs*


M87; NASA/Hubble

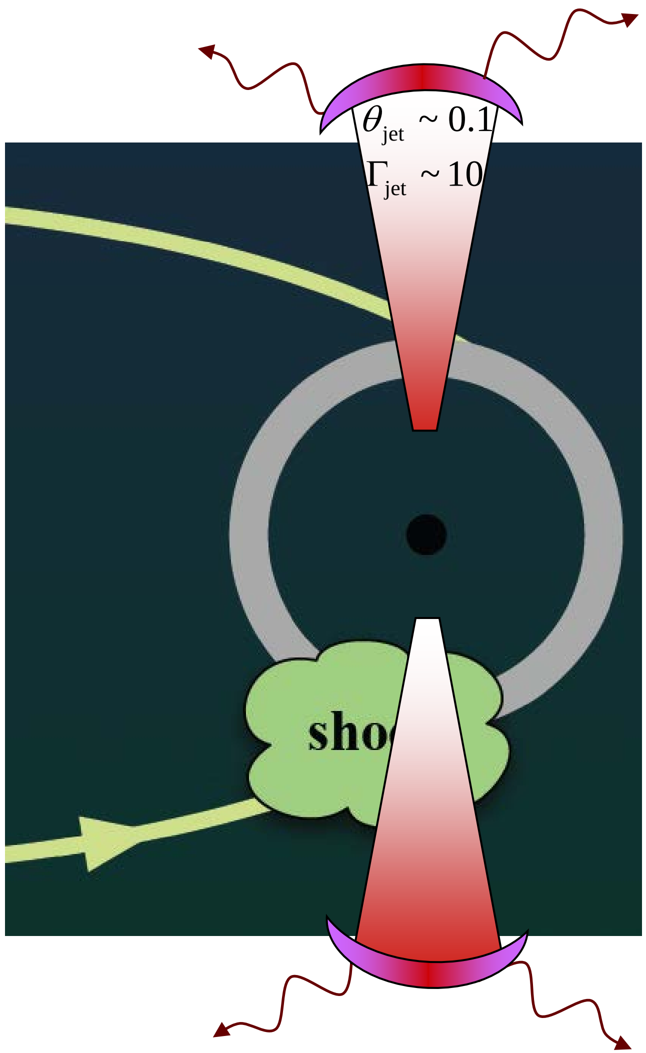
jets in galactic centers

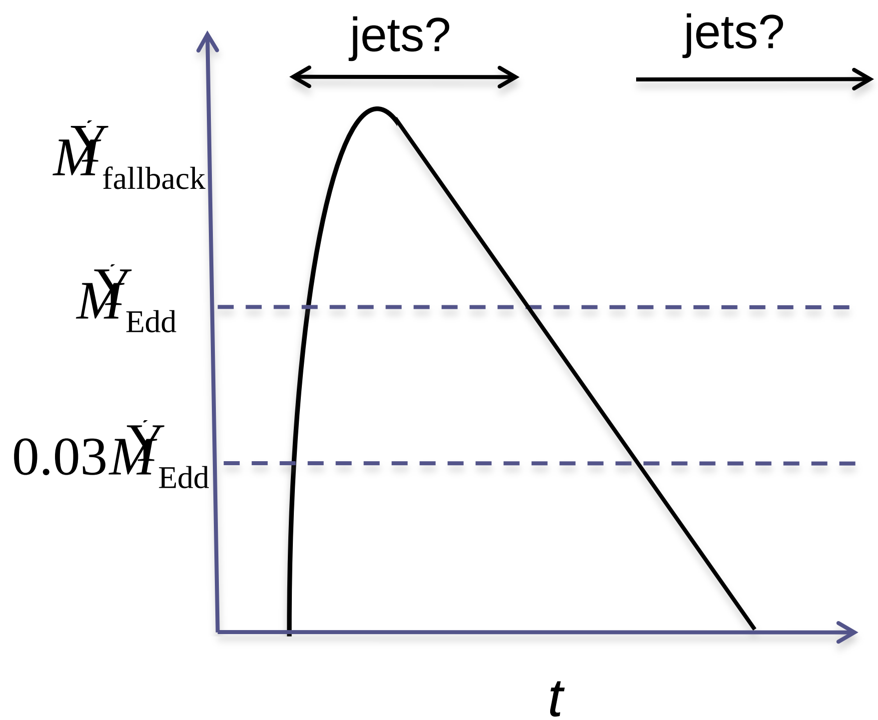

stellar binaries



gamma-ray bursts

"Radio transients from Stellar Tidal Disruptions by Massive Black Holes" Giannios & Metzger 2011





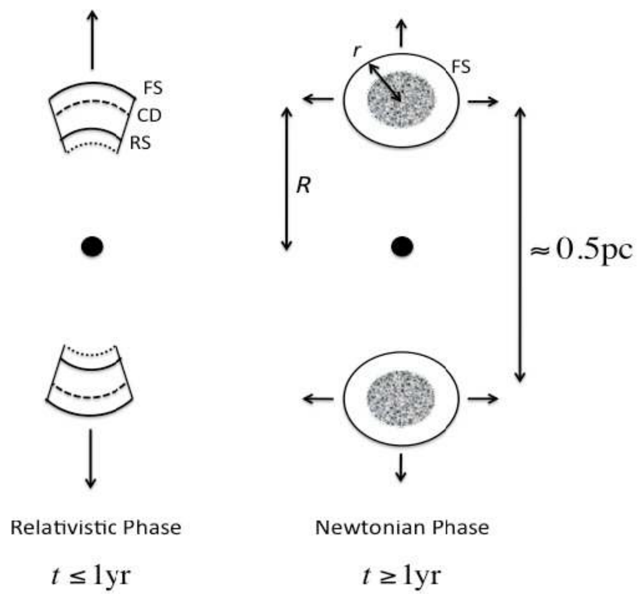
energy released $E_{rel} \sim 0.1 M_{acc} c^2 \sim 10^{53}$ erg

energy in jets $E_{jet} \sim \varepsilon_{jet} E_{rel} \sim 10^{51} \frac{\varepsilon_{jet}}{0.01}$ erg

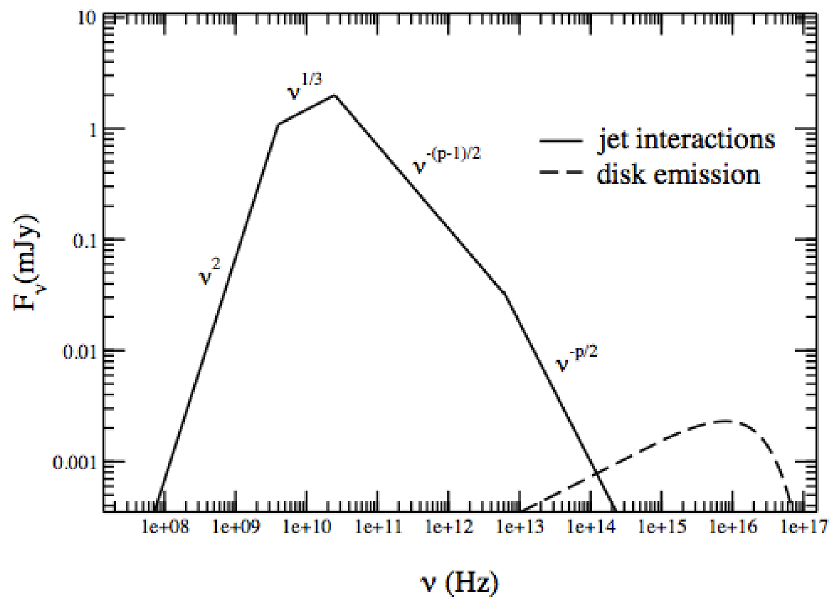
Supernova or GRB!

The jet powers pc-scale radio lobes → Radio Transients

Jet Interaction with ISM



Prediction: radio synchrotron emission peaking at $t_{\rm peak}$ ~ a few years:



$$F_{\nu_{syn}} \sim 2\left(\frac{\varepsilon_j}{0.01}\right)\left(\frac{\varepsilon_B}{0.01}\right)^{1/2}\left(\frac{\Gamma_{\rm jet}}{10}\right)^{-1}\left(\frac{D}{1Gpc}\right)^{-2} mJy$$

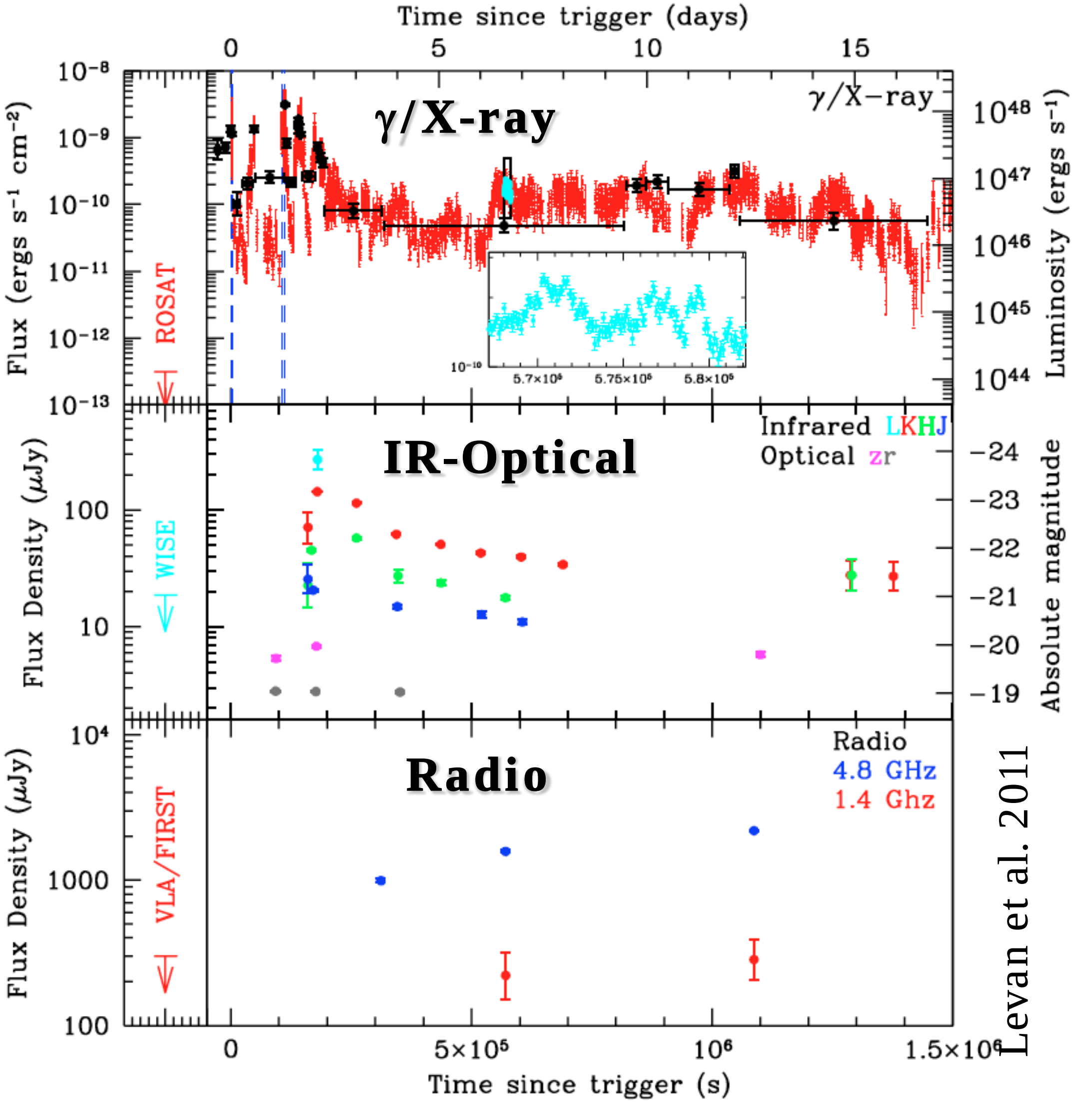
Blind radio surveys may detect tens of TDEs per year Giannios & Metzger 2011

And then came the … Event

GRB 110328A/Swift 1644+57

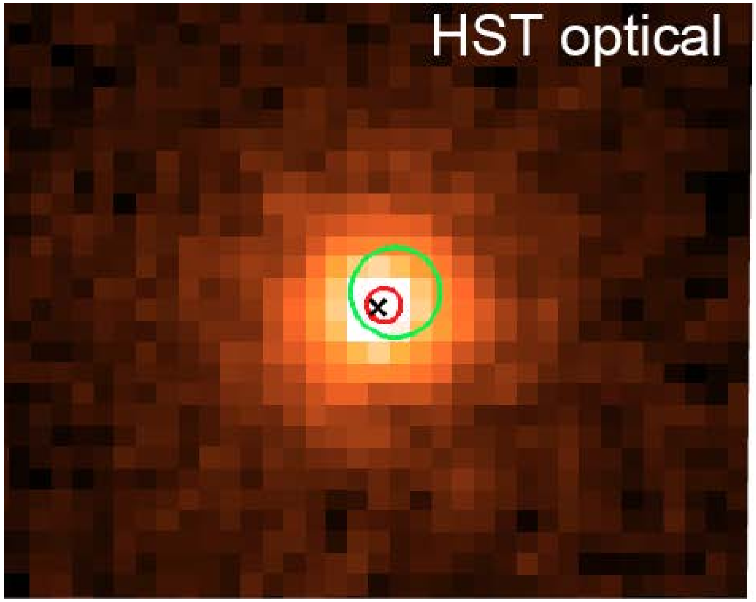
(Levan et al. 2011; Bloom, Giannios et al. 2011; Burrows et al. 2011)

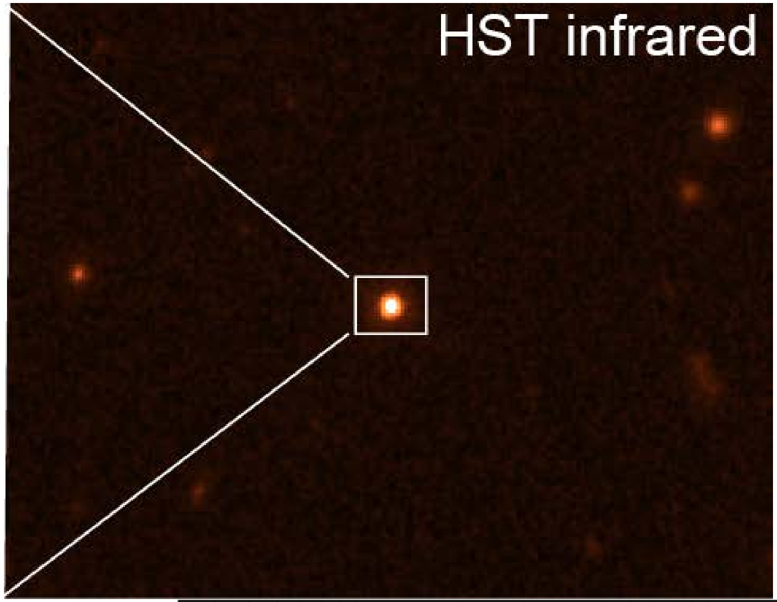
- Triggered *Swift* BAT on March 28, 2011
- Triggered BAT 3 more times over next few days
- Still bright in X-rays
- New IR and Radio source
- Host galaxy at z = 0.35
- *NOT a (normal) GRB*
    - low luminosity
    - duration ~ months
- *NOT a normal AGN*
    - no evidence for AGN or past activity



Levan et al. 2011

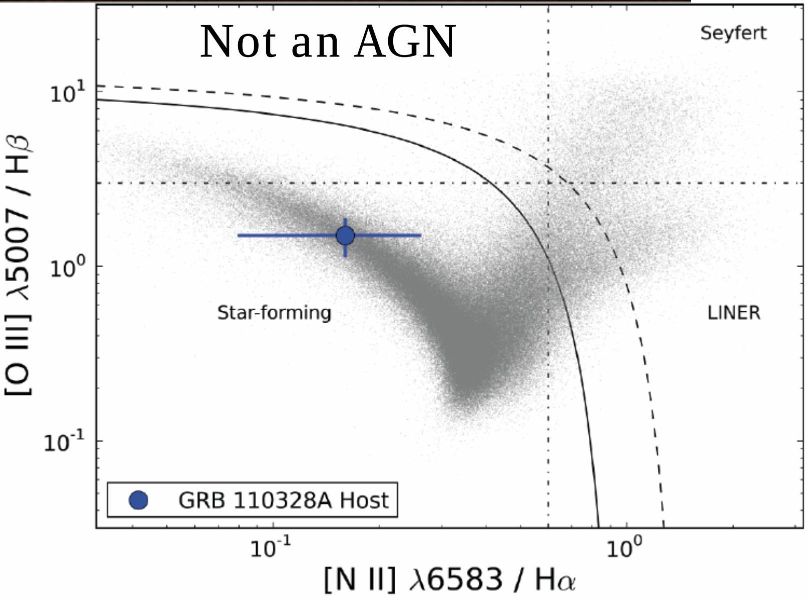
Compact Host Galaxy at z = 0.35





Levan et al. 2011

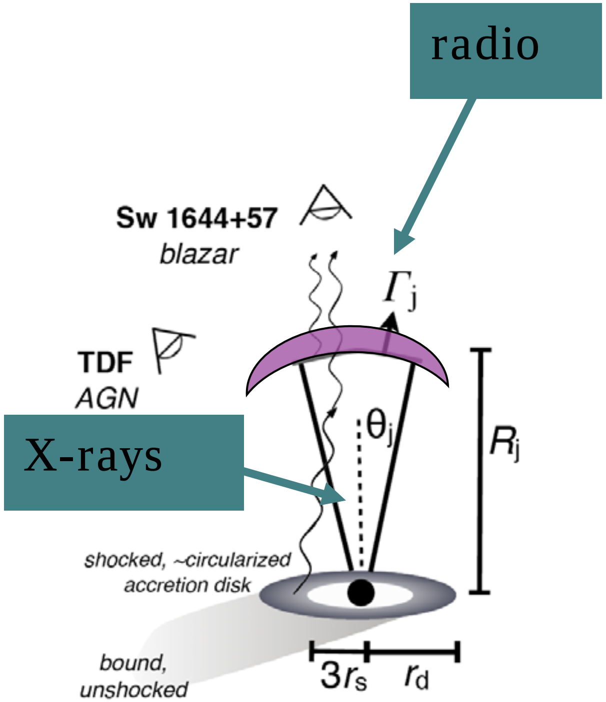
- Within < 150 pc of galactic center
  $\Rightarrow$ SMBH origin
- ~100 s variability and bulge mass $M_b < 10^{10}\ M_\odot \Rightarrow M_{BH} < 10^7\ M_\odot$
- $L_X > 10^{47}$ erg s$^{-1} > 100\ L_{Edd} \Rightarrow$ super-Edd accretion and/or beaming

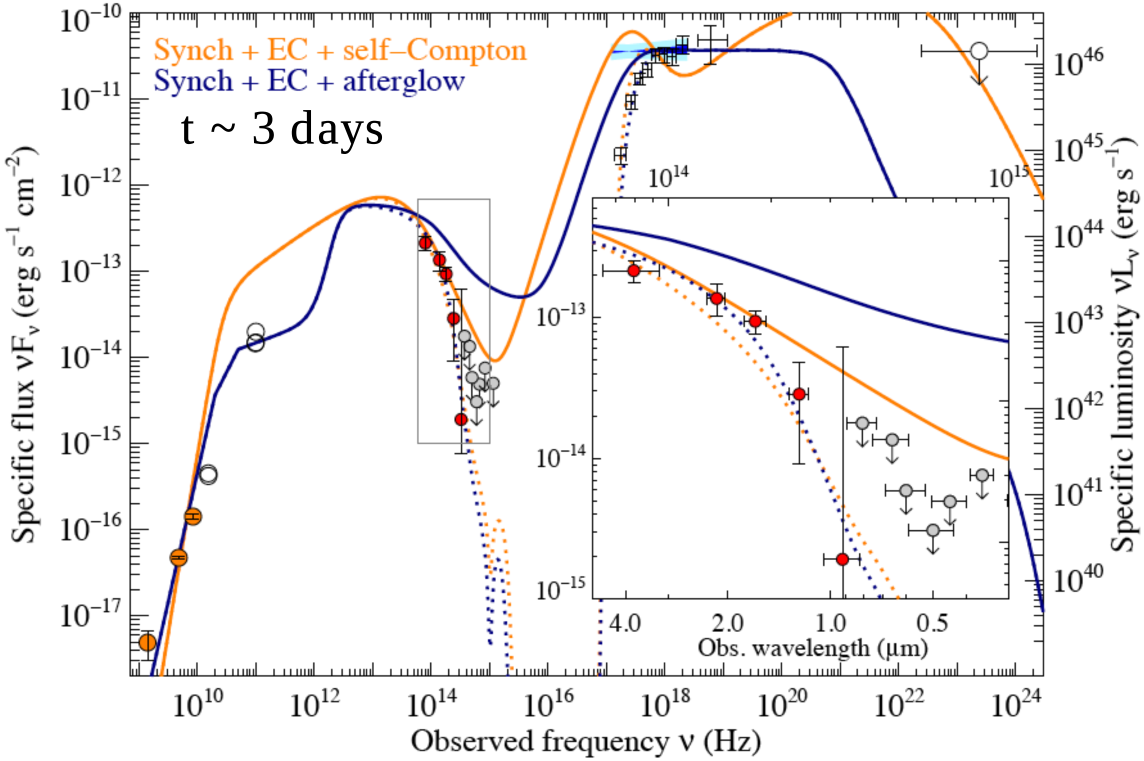


Levan et al. 2011

TD jet Hypothesis

Bloom, Giannios et al. 2011; see also Burrows et al. 2011, Zauderer et al. 2011; Krolik & Piran 2011 …

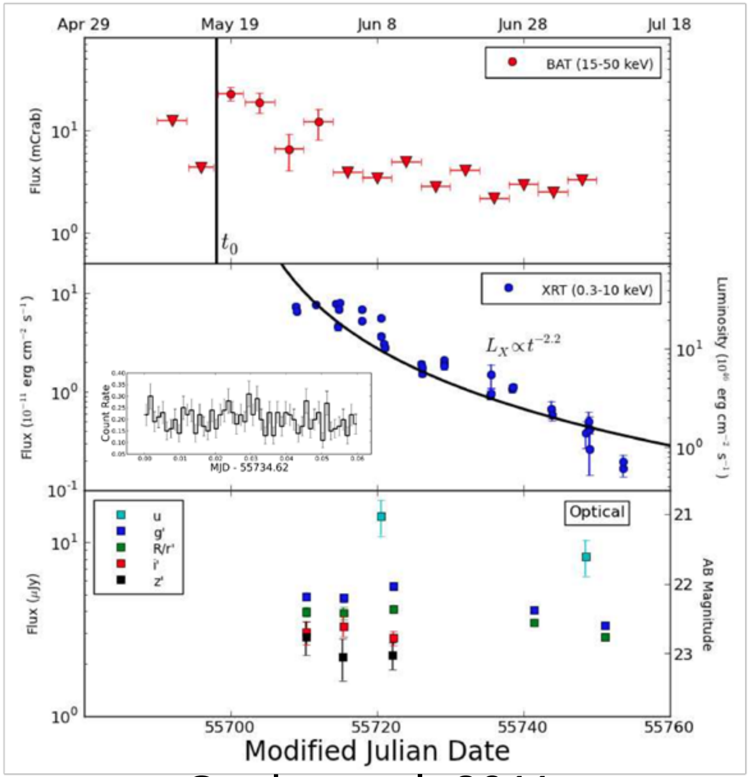




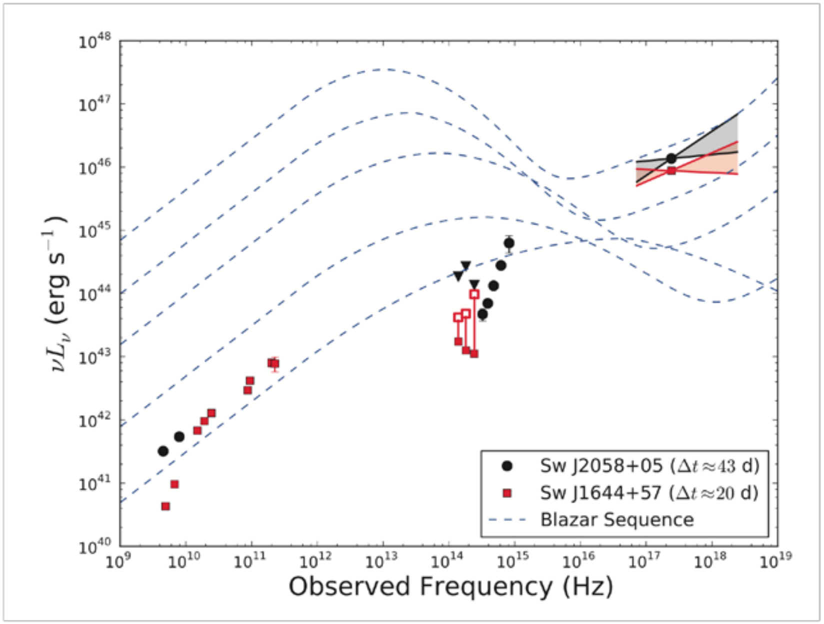
• synchrotron self-absorption ⇒ $R_{radio} > 10^{16}$ cm ⇒ $v_{ej} \sim c$ ⇒ external shock from ISM interaction (Giannios & Metzger 2011)

• X-ray variability ⇒ $R_X \sim c\, \delta t_X\, \Gamma^2 \sim 3 \times 10^{14} (\Gamma/10)^2$ cm ⇒ "internal" process (e.g. shocks, reconnection)

Swift J2058.4+0516: a *Second* Relativistic Tidal Disruption Flare within months?



Cenko et al. 2011



jets from TDEs: (Rough) energetics and rates

- *observed* (0.3-10) keV fluence $E_{x,iso}$~2x10^{53} erg
  - ~ x3 for likely bolometric correction
  - ~ x2 for radiative efficiency of flow

$\Rightarrow E_{k,iso} \sim 10^{54}$ erg

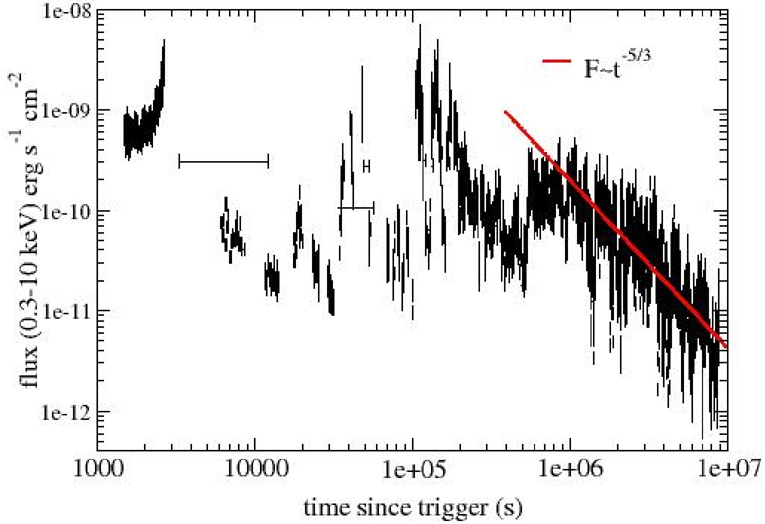
or $E_{k,true} \sim 10^{51}$ erg *depending on beaming*

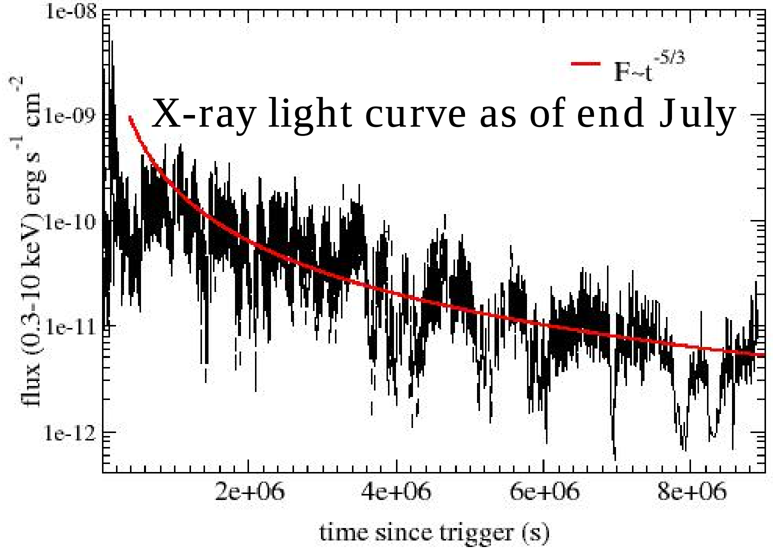
- Rates *very* uncertain: 1 (2) event(s) in 7 years of *Swift* operation (Ω_{fov}=4π/7 sr); observable out to z~0.8 (1.1)

$\Rightarrow R_{obs} \sim 10^{-9}$ gal^{-1}yr^{-1} or $R_{true} \sim 10^{-6}$ gal^{-1}yr^{-1}

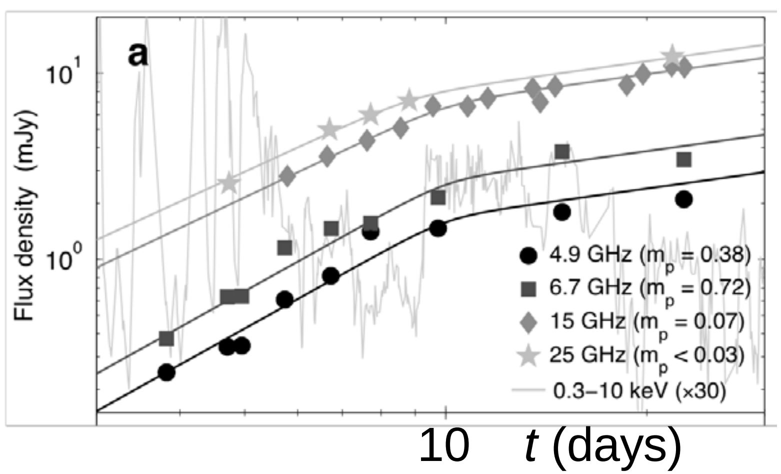
$\Rightarrow$*~3% of ALL TDEs accompanied by powerful jets?*

Predictions





- x-ray emission will continue to fade over the next few months (no major re-brightening/repetition expected)
- GHz Radio emission will remain detectable for ~ years
- relativistic motion observable with VLBI (?)



Zauderer et al. 2011

Implications

- **Detections:** Future TDE detections with blind *radio* surveys Giannios & Metzger 2011

- **Probe** of ISM density/profile at the galactic centers

- **Jet physics:** B fields responsible for accelerating AGN jets can be generated *in situ* (e.g. via disk dynamo)

- TDE jets may accelerate **UHECRs** (Farrar & Gruzinov 2009), but production rate may be insufficient