# Constraints on radio jets from known stellar tidal disruption events

*Do all TDFs launch jets?*

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Tidal Disruption events and AGN outbursts workshop
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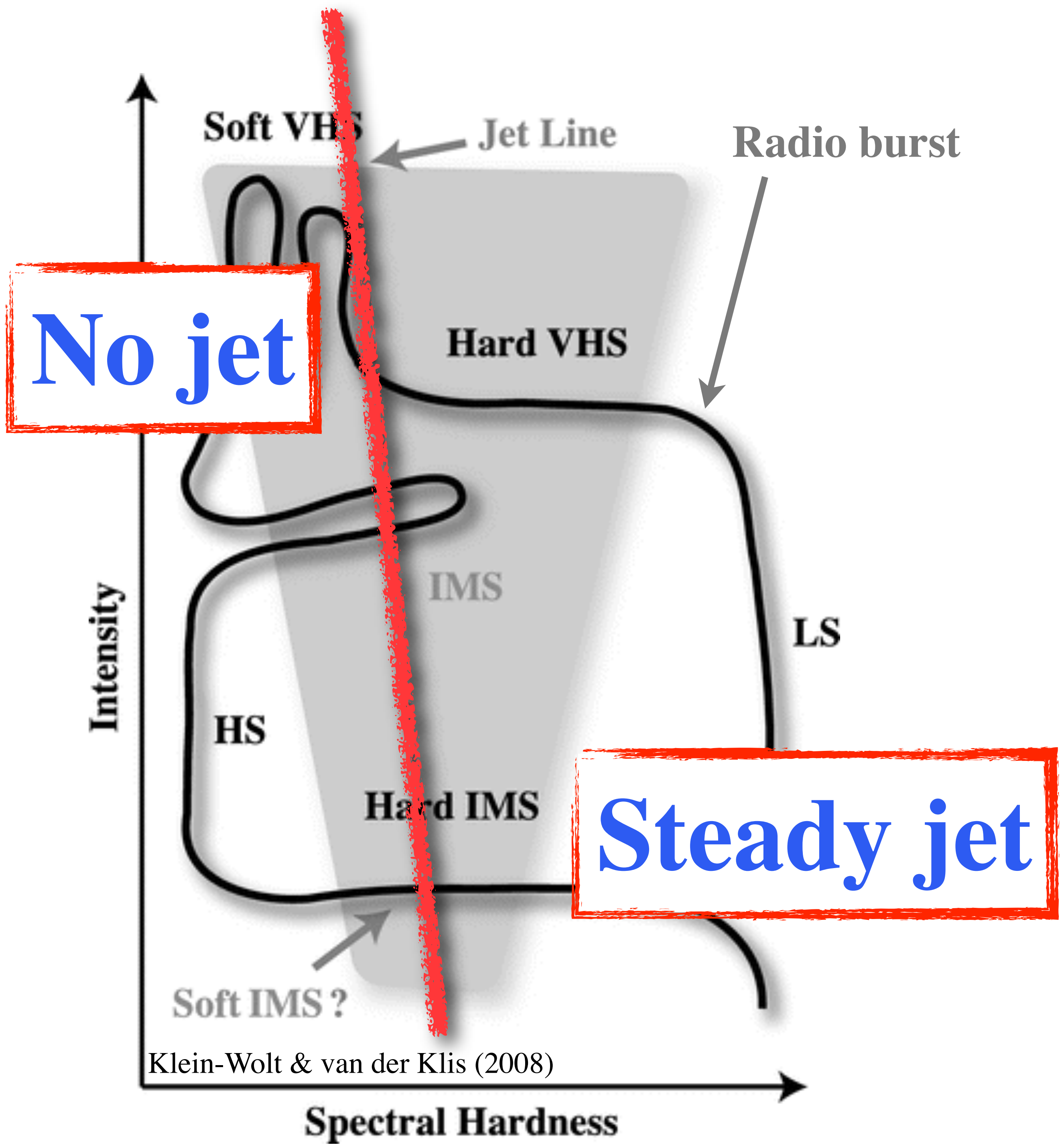
# Learn from tidal disruption jets

- For single events:
  - Disk + B-field
  - Calorimetry
- Discovery:
  - Radio not absorbed
  - Upcoming radio transient surveys
- Accretion states

# Black hole accretion modes

- Two accretion states, divided by Eddington rate
- Radio jets below ~2% $\dot{M}_{Edd}$
  - Observed for stellar mass accreting binaries (McClintock & Remillard 2004; Fender et al. 2004)
  - Also the case for SMBHs? (Körding et al. 2006; Best & Heckman 2012)
- With TDEs we probe these rates for a single SMBH



# Radio observations -- “Status of the field”

< 2011 No detections ≈3 events followed up

> 2011 Two detections (‘Swift events’), more followed up

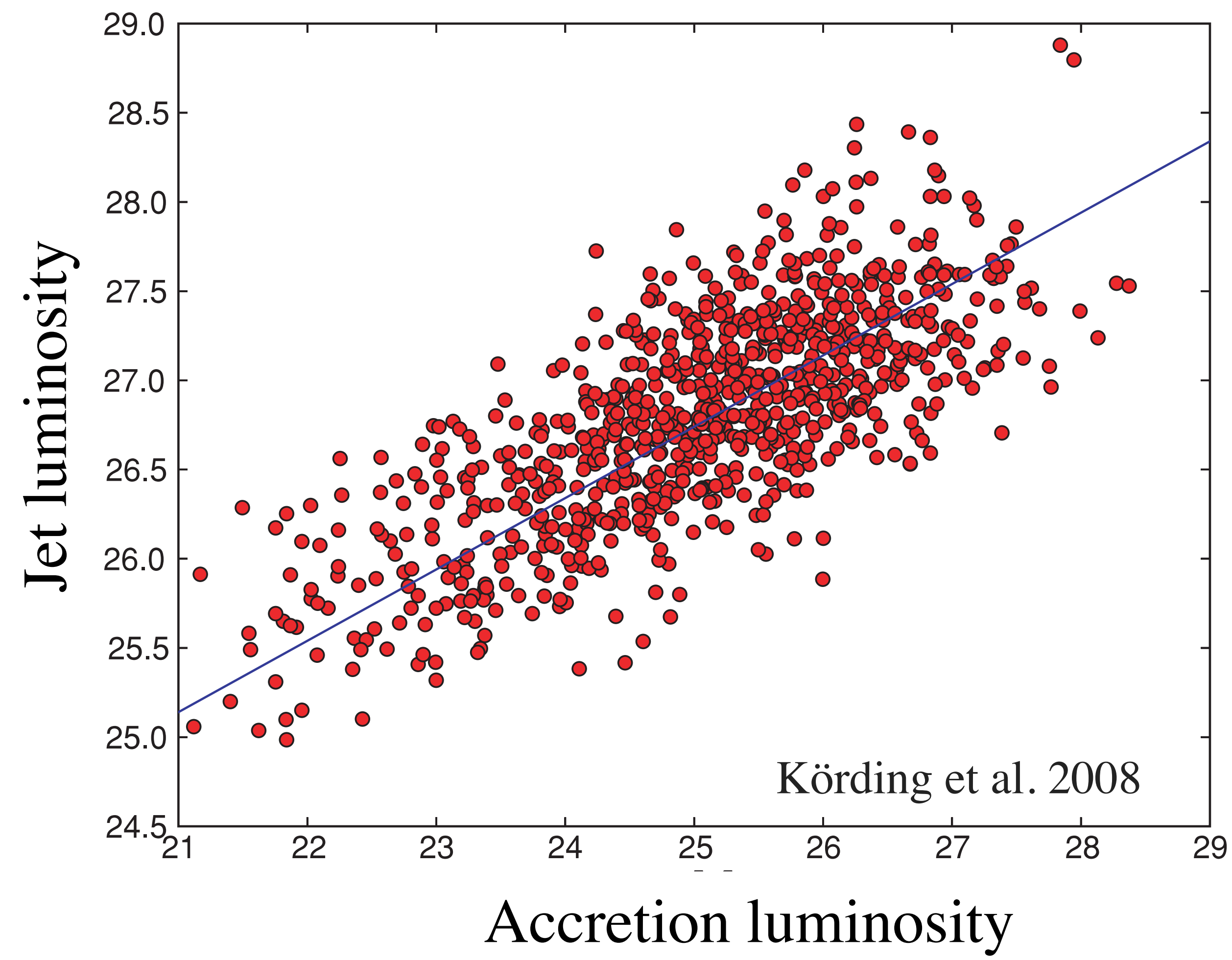
# Two models

- External model (Giannios & Metzger 2011; Metzger, Giannios, Mimica 2011)
  - Interaction of forward/backward shock with environment
  - On-axis (or isotropic)
  - Inspired by GRB afterglows

- Internal model (van Velzen, Falcke, Farrar 2010, van Velzen, Körding, Falcke 2011)
  - Emission from matter injected in the jet from the disk
  - Doppler boosting
  - Inspired by AGN jets

# Standard AGN jet model

- Conical jet model (Blandford & Königl 1979)
- Jet power is a linear function of disk luminosity (Rawlings & Saunders 1991; Falcke & Biermann 1995)
- Well constrained by observation




$$L_\nu = C_{\rm eq}\delta^2 \int_{z_{\rm ssa}}^{\infty} {\rm d}z\, z^2 \epsilon_{\rm syn}(z,\nu/\delta) \propto (q_j L_d)^{17/12}$$

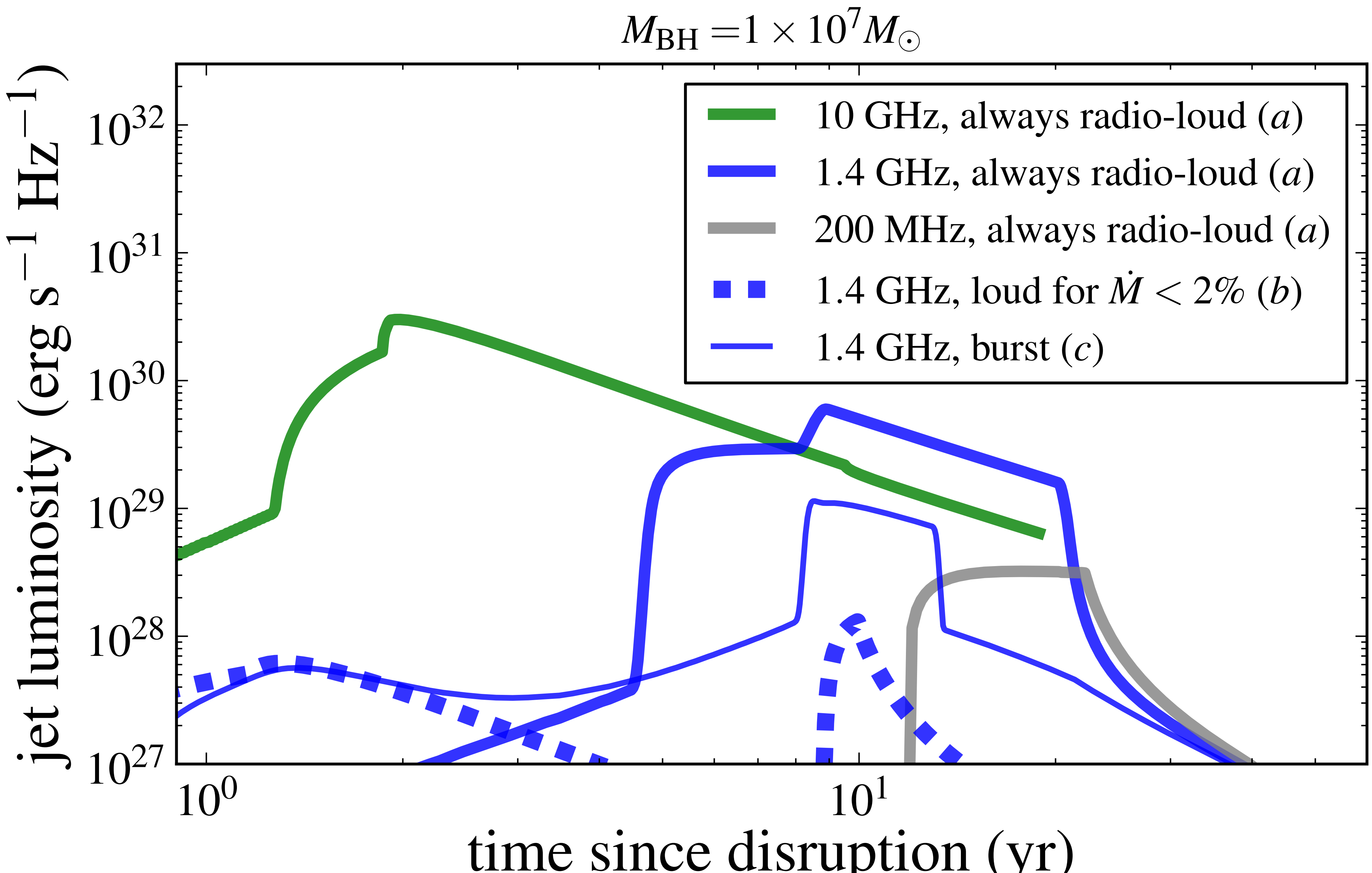
# Add time dependence

- Disk luminosity given by fallback rate
- Self-absorption radius sets the emission timescale
- Three scenarios for order of accretion modes

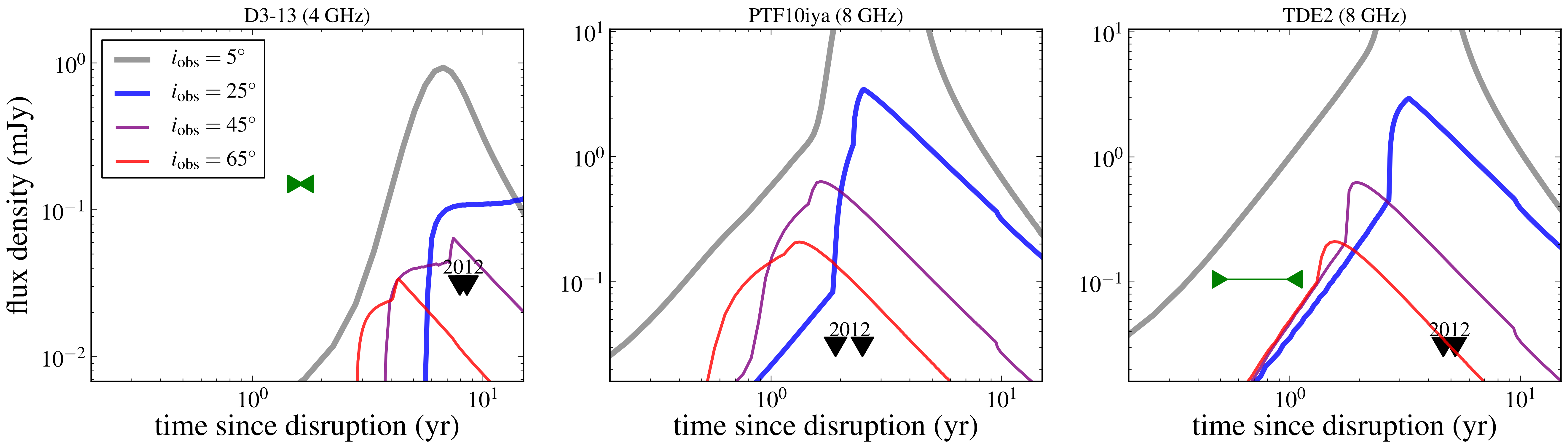
$$q_j = \begin{cases} 0.2 & \text{all times} \\ 0.002 & \dot{M}(t) > 2\%\dot{M}_{\rm Edd} \\ 0.2 & t < t_{\rm fallback} \end{cases}$$

Radio-loud
Eddington trigger
Radio burst

# Model light curves



# Delay could explain existing non-detections



# Jansky VLA observations at 5 GHz

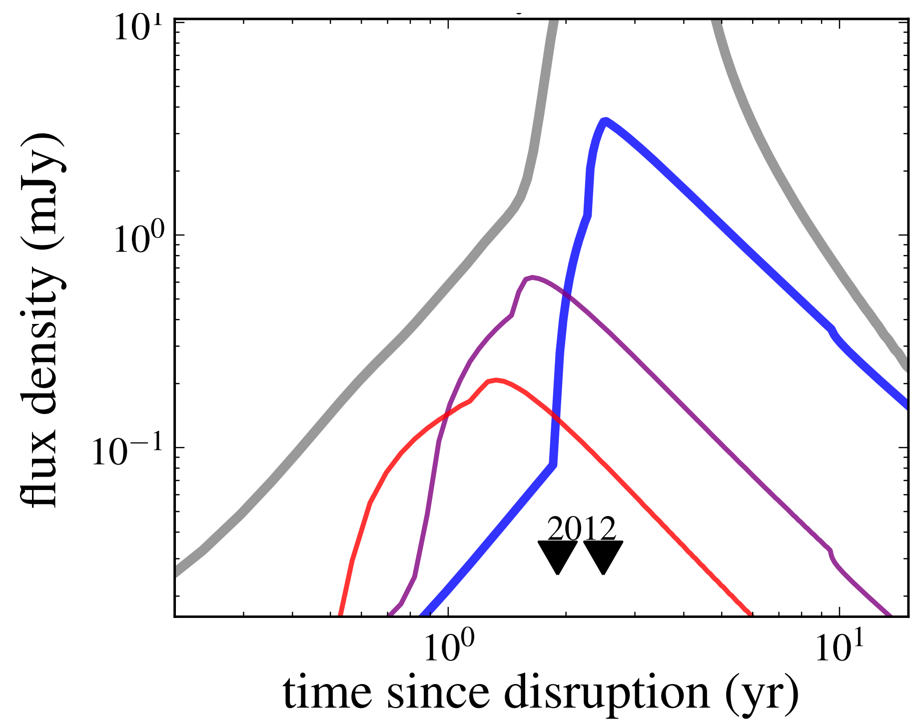
| name | integration time (min) | $\sigma(F_\nu)$ $\mu$Jy | $\Delta t$ (yr) |
|---|---|---|---|
| TD 04A | 30 | 9 | 8.0 |
| TD 04B | 18 | 8 | 7.6 |
| VV-1? | 28 | 10 | 5.4 |
| SG-2? | 28 | 8 | 4.8 |
| TDE2 ... | 25 | 12 | 4.3 |
| PTF10iya ... | 18 | 8 | 1.6 |

No detections

# Exclusion for the external model

- Find largest jet angle consistent with non-detection

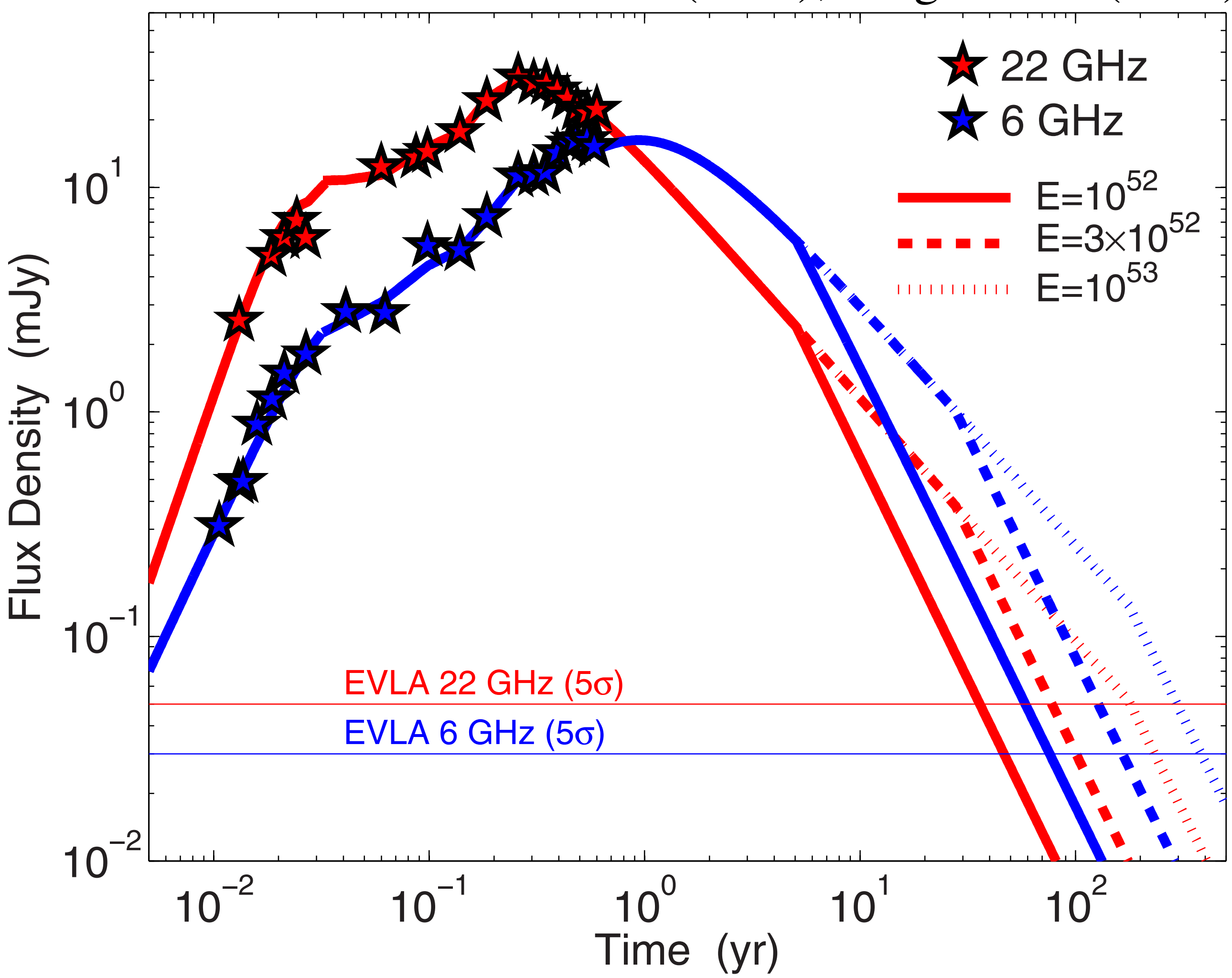
- Probability for *at least one* detection:
  - Always radio loud: 99.992%
  - Radio flare: 50%
  - Only below 2% Eddington: 33%



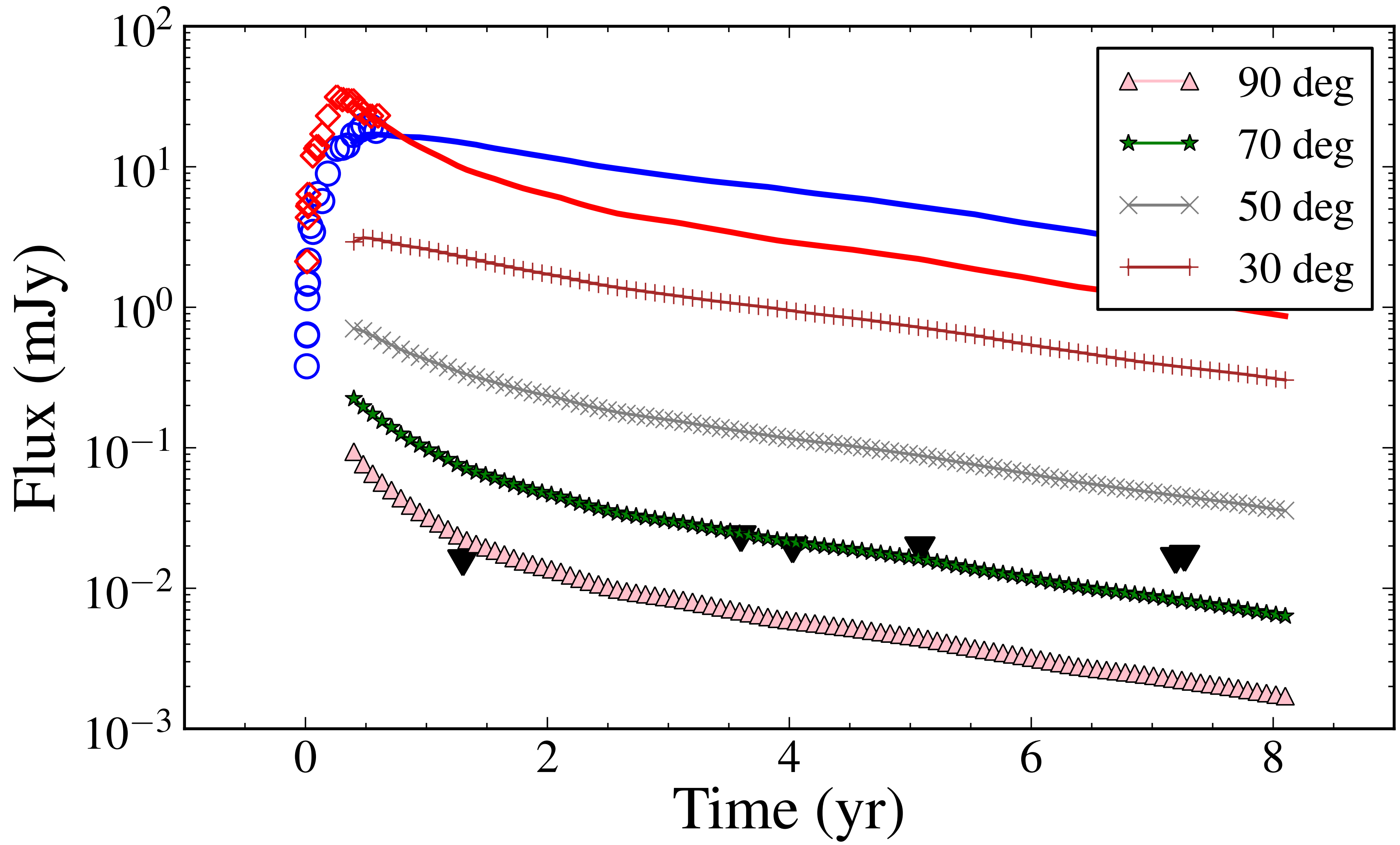
# Sw 1644+57 late-time light curve

- few mJy after 10 yr! (if $\Gamma>1$)
- Scale to off-axis observers
  - Knowledge of frequency structure required
  - Assume 'blob'

Zauderer et al. (2011); Berger et al. (2012)

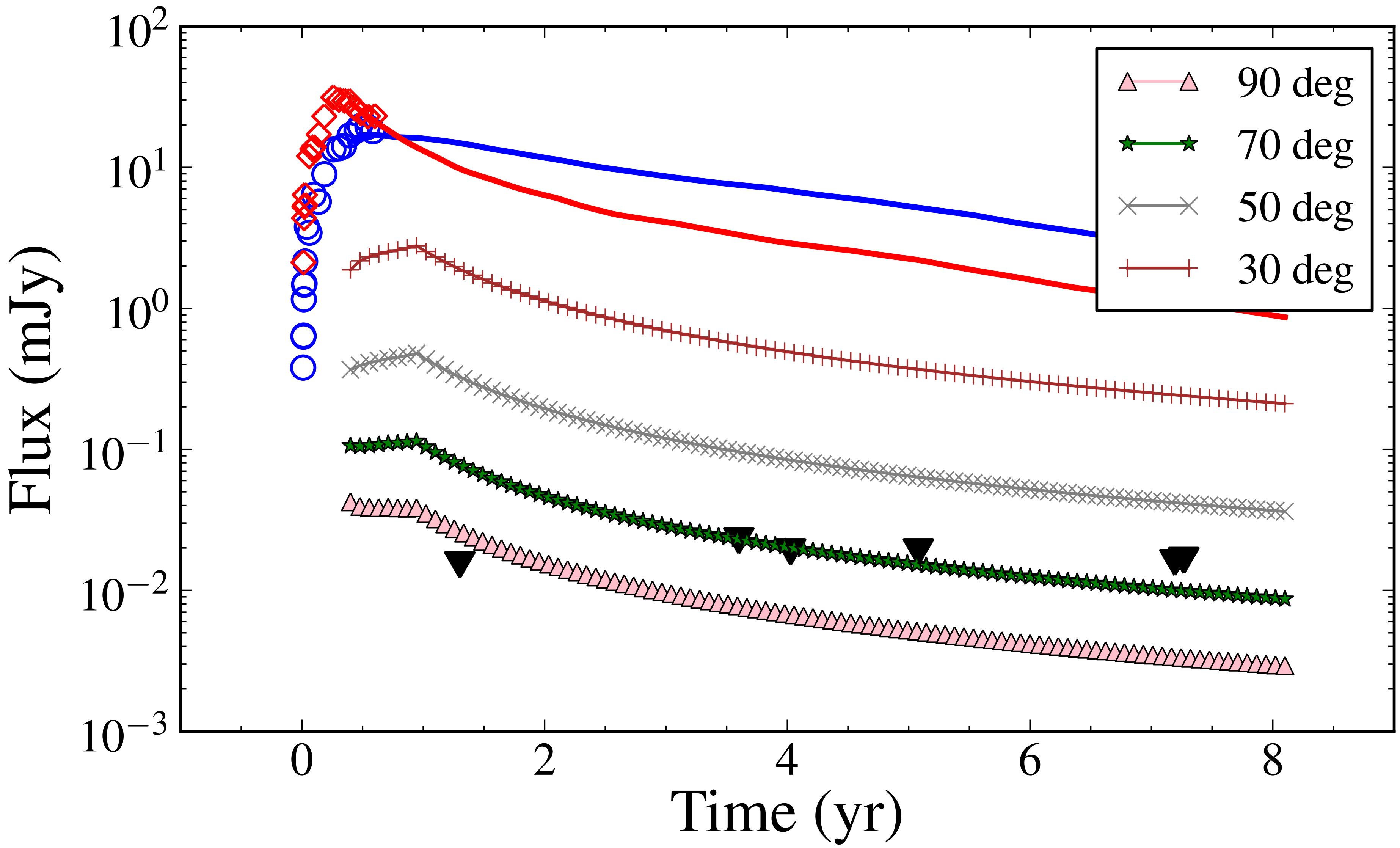


# Sw 1644+57 off-axis: Γ(t>1yr) = 2




Probability zero detections = 0.1%

# $\Gamma(t) = \sim t^{-0.2}$ ; Sedov-Taylor if $\Gamma<2$




Probability zero detections = 0.1%

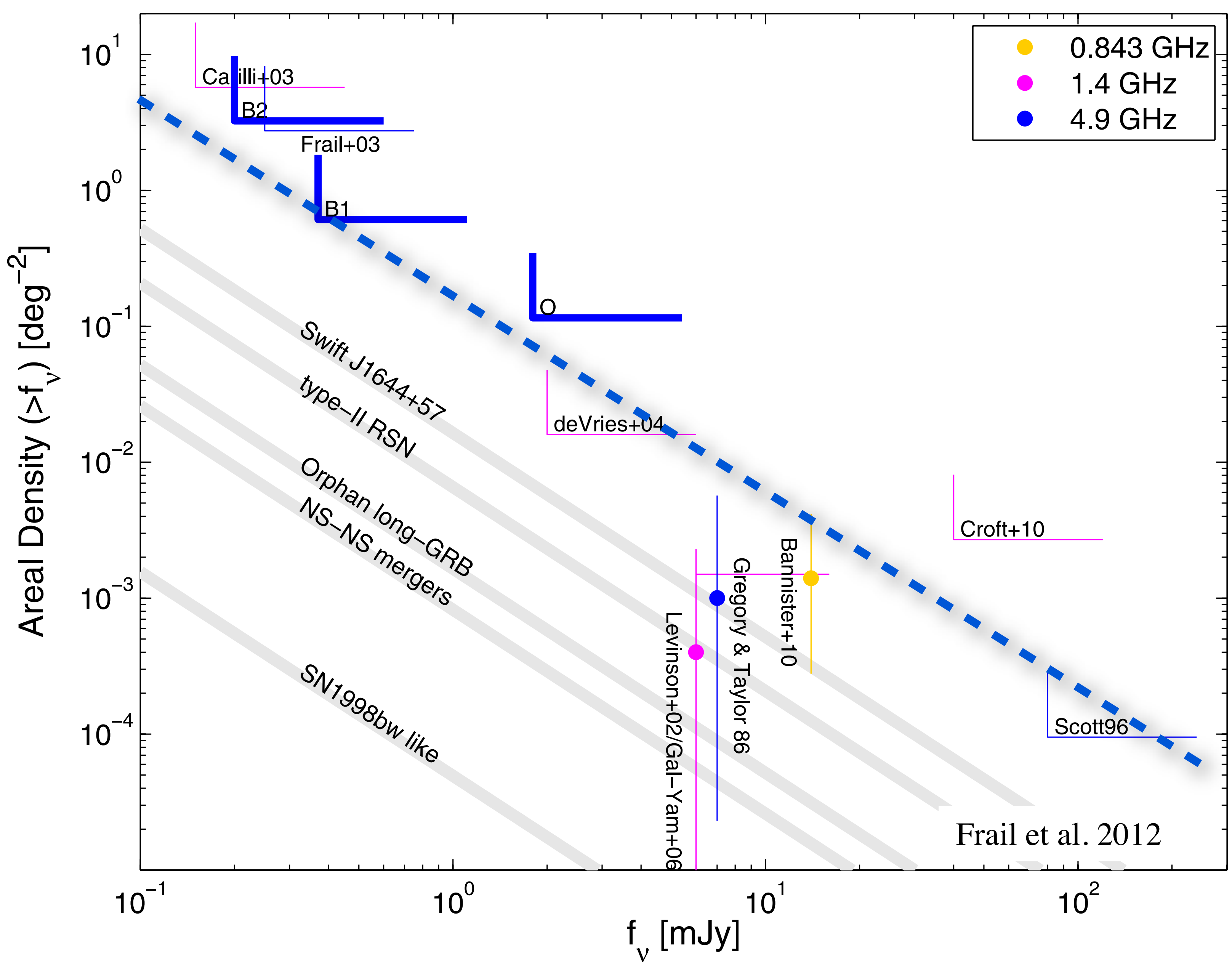
# Not all TDF launch jets?

- Radio upper limits for optically discovered TDF inconsistent with current jet models

- But optical TDF (may) have different:
    - Environment
    - Black hole mass; accreted matter
    - Delay with respect to time of disruption

# Good news: areal rate of Sw 1644+57

$$R(F_\nu) \sim 10^{-3} \left(\frac{20\ \mathrm{mJy}}{F_\nu}\right)^{3/2} \frac{\dot{N}_{\mathrm{TDE}}}{10^{-5}\ \mathrm{yr}^{-1}} (1/\Gamma)^2\ \mathrm{deg}^{-2}$$



# Outlook

- Wait for Sedov phase of Sw 1644+57
- Analyze Sw 2058+05
- Include other non-detections
- Keep observing!

# Lessons from multi-frequency radio data (Zauderer et al. 2011)

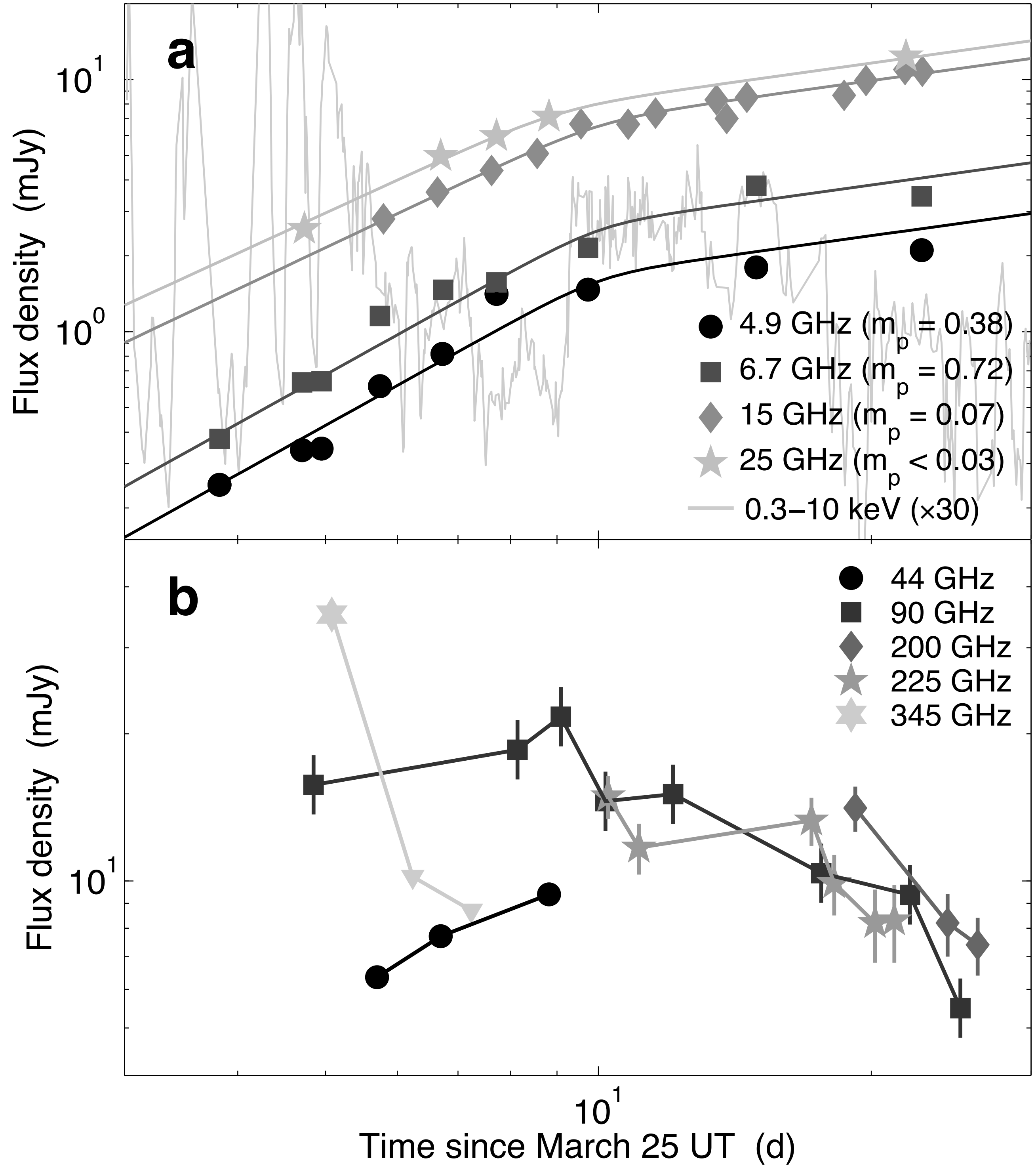
- ~days delay between 4.9 GHz and 6.7 GHz

- For conical jet:

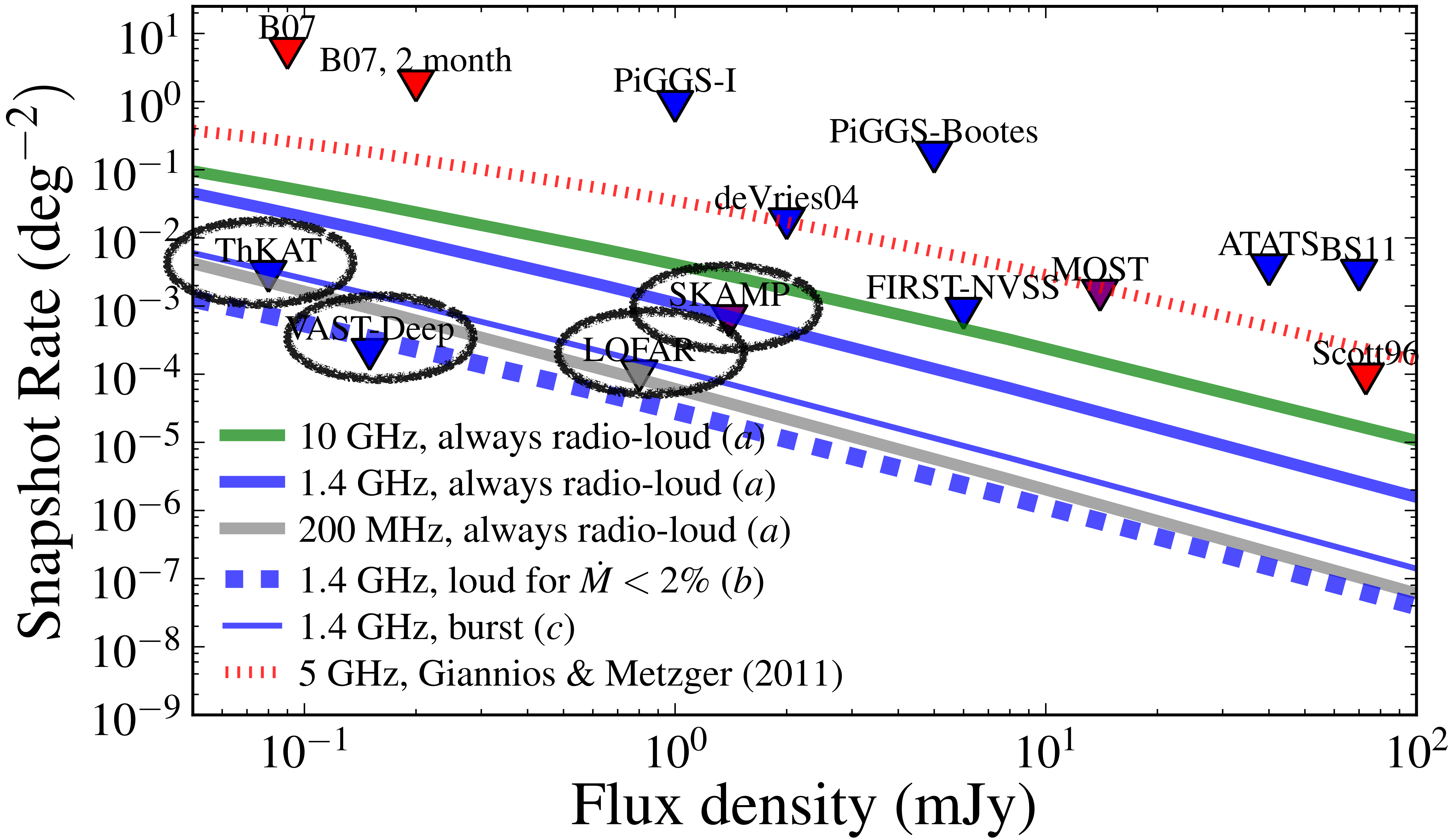
$$z_{\rm ssa} = z_0(\nu/\nu_0)^{-1}$$

$$z_0 \sim 10^{-3}\,{\rm pc}$$

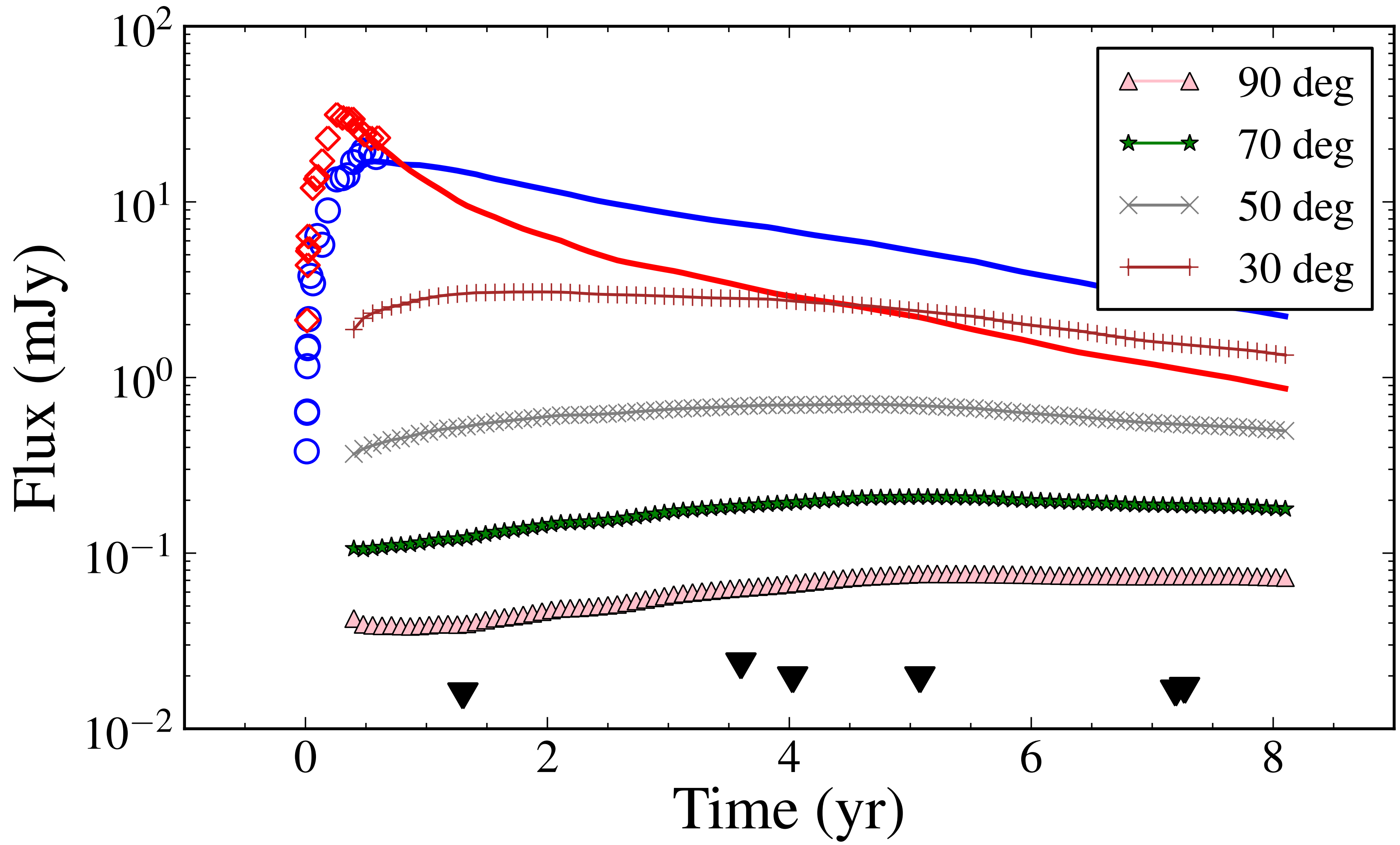
- Much smaller than equipartition for $q_j = 0.2$



# Predicted rate and observed upper limits



# Sw 1644+57 off-axis: $\Gamma(t) = \sim t^{-0.2}$




Probability zero detections = 0.00%