THE BIRTH OF A RELATIVISTIC JET FROM A TIDAL DISRUPTION EVENT

B. Ashley Zauderer

The Birth of a Relativistic Outflow from Transient Accretion onto an SMBH (Nature 2011)

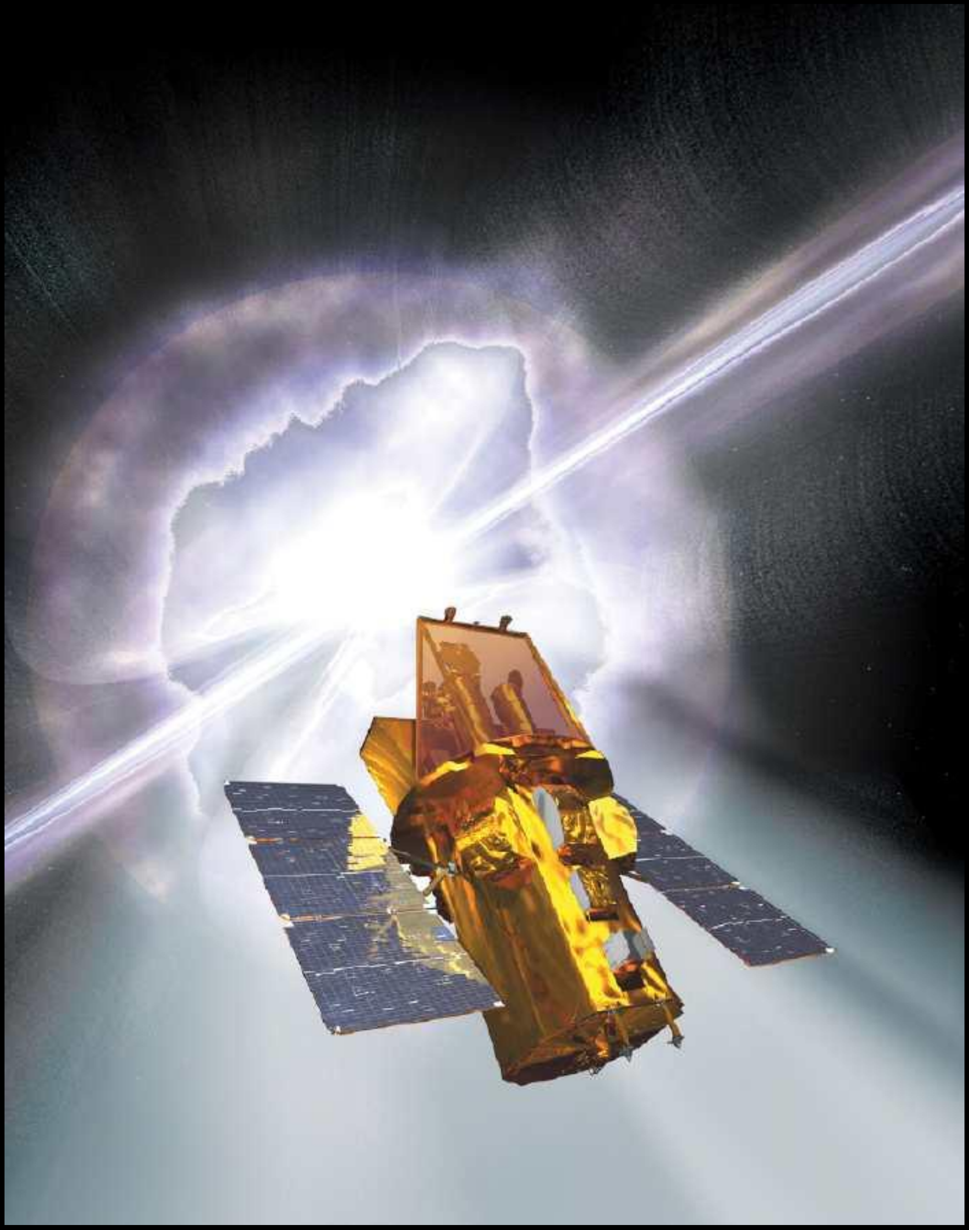
A. Zauderer, E. Berger, A. Soderberg, A. Loeb, R. Narayan, D. Frail, G. Petitpas, A. Brunthaler, R. Chornock, J. Carpenter, G. Pooley, K. Mooley, S. Kulkarni, R. Margutti, D. Fox, E. Nakar, N. Patel, N. Volgenau, T. Culverhouse, M. Bietenholz, M. Rupen, W. Max-Moerbeck, A. Readhead, J. Richards, M. Shepherd, S. Storm, C. Hull

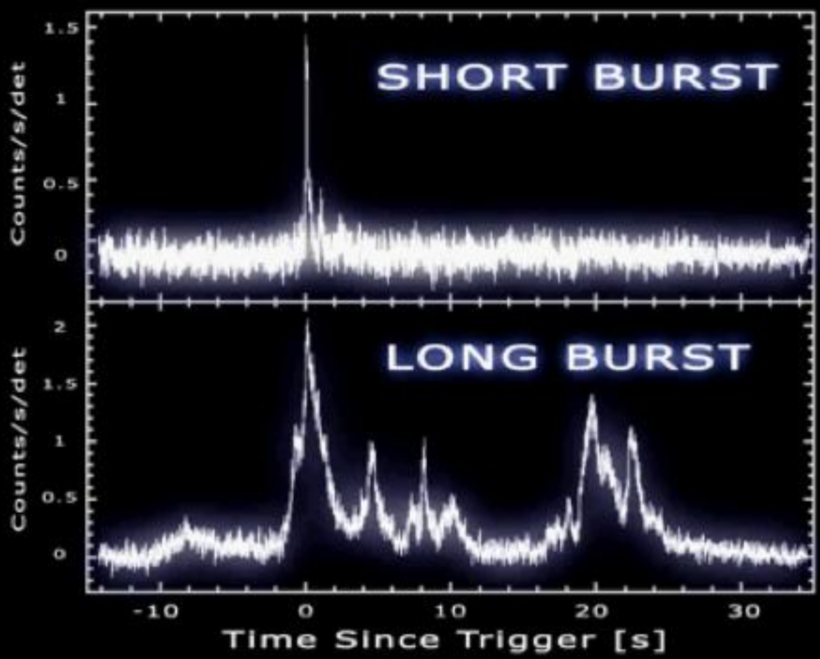
Radio Monitoring of the Tidal Disruption Event Swift J164449.3+573451.
I. Jet Energetics and the Pristine Parsec-Scale Environment of an SMBH (ApJ 2012)

E. Berger, A. Zauderer, G. Pooley, A. Soderberg, R. Sari, A. Brunthaler, M. Bietenholz


Image Credit: NASA/CXC/M

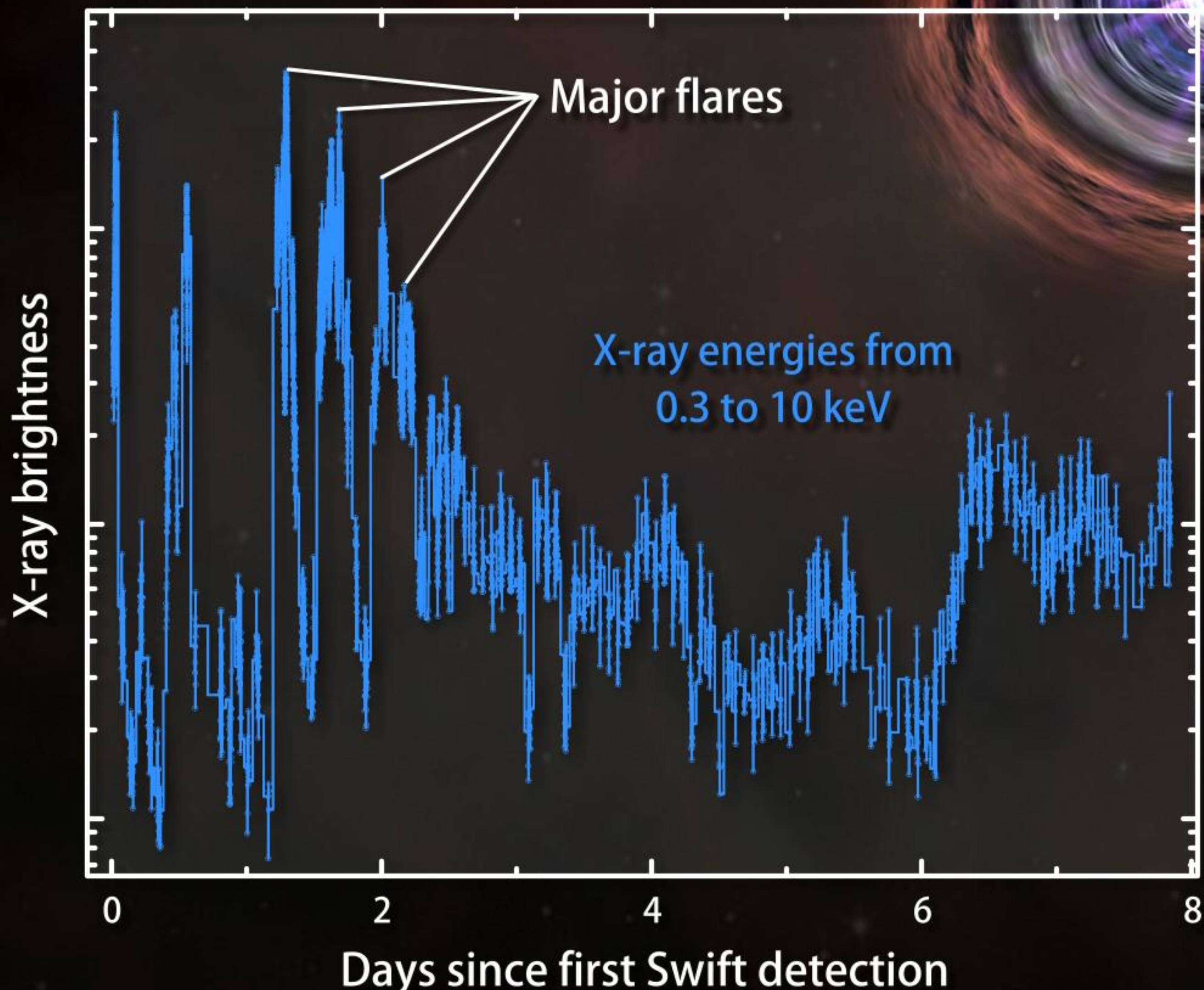
Video credit: NASA/Goddard Space Flight Center/CI Lab





Swift Telescope (Credit: NASA)

GRB 110328 / Swift J164449.3+573451



Initial trigger:

2011 March 28.54 UT

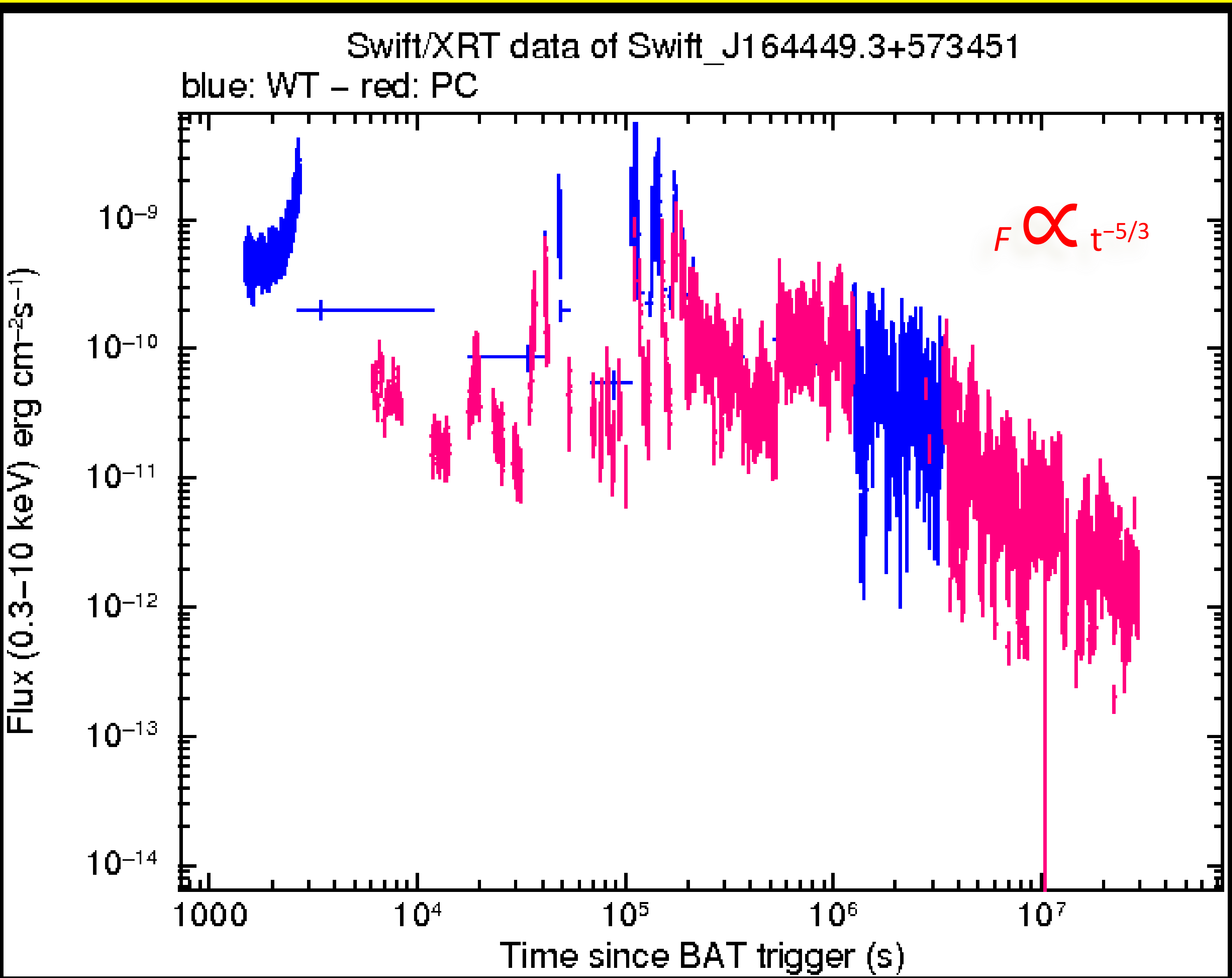
followed by five additional triggers

γ-ray emission detected starting 2011 March 25 UT

Burrows et al. Nature (2011)

NASA/CXC/Warwick/A.Levan et al.

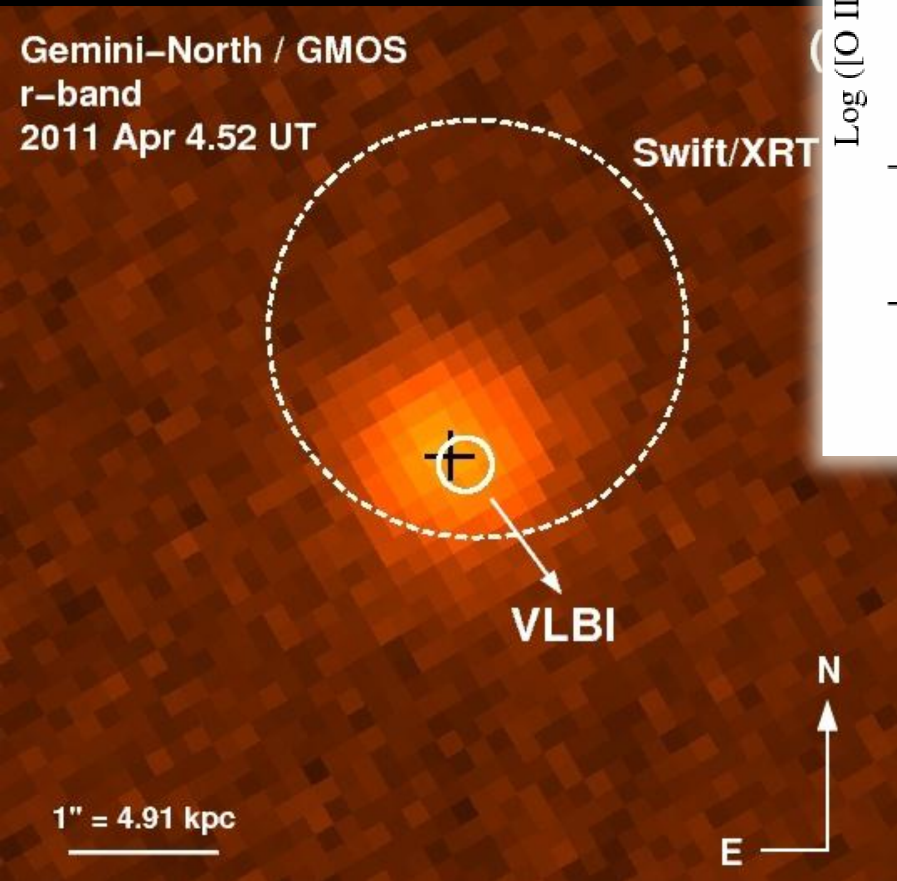
GRB 110328 / Swift J164449.3+573451

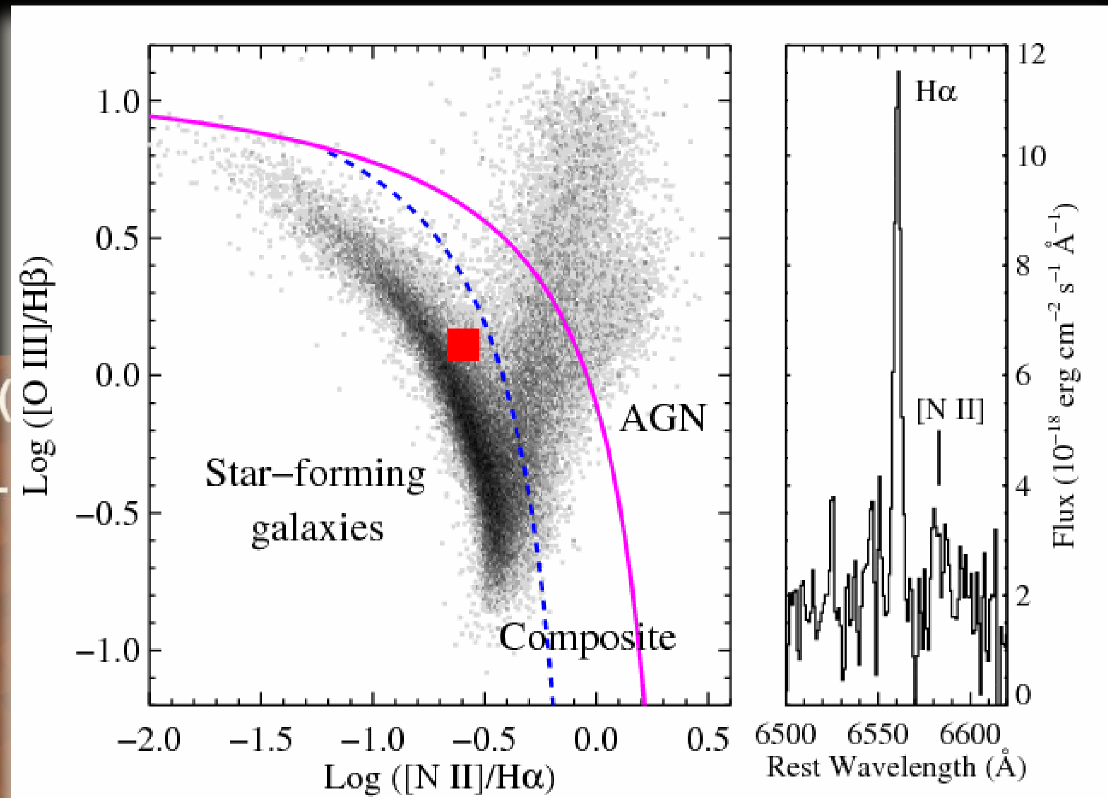


Host Galaxy

Galaxy at z = 0.354 located inside *Swift*/XRT error circle

Radio emission localizes the transient to the nucleus



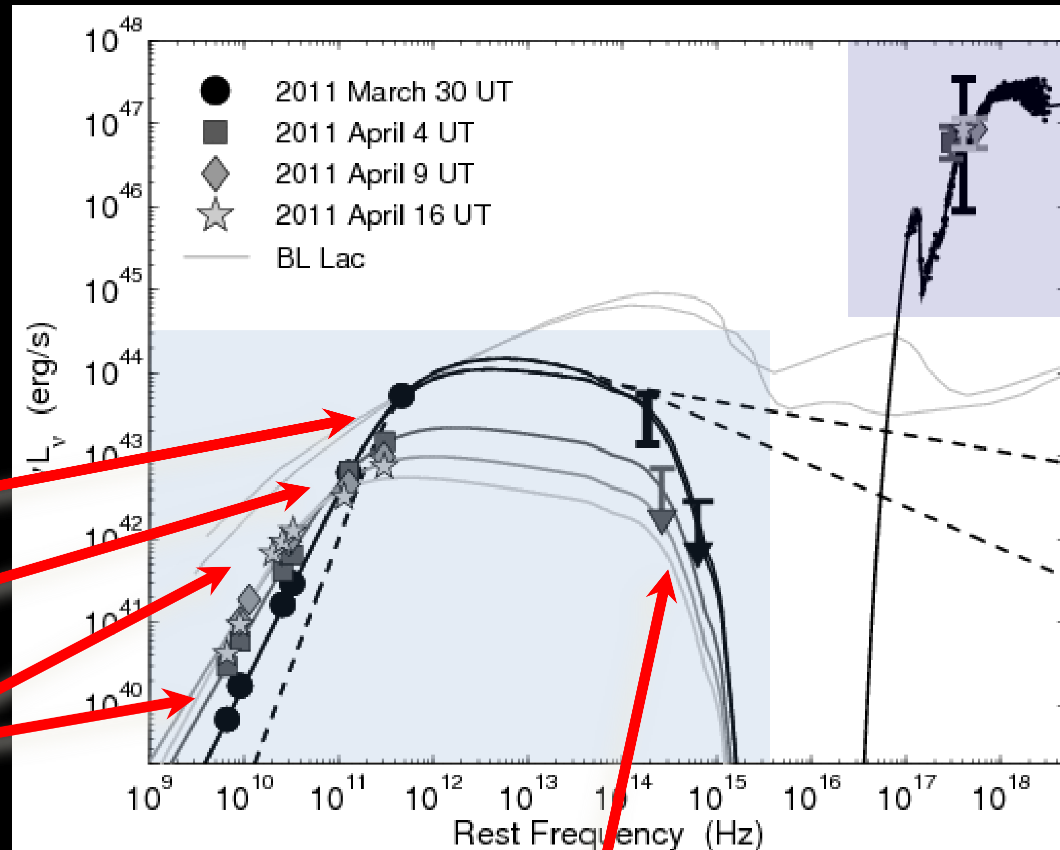


Zauderer et al. 2011

No evidence for AGN activity (line ratios, widths, lack of previous radio/X-ray emission)

GRB 110328 / Swift J164449.3+573451

- Radio spectrum ⇒ synchrotron
- No optical ⇒ $A_V > 3$ mag
- L_X exceeds L_{syn} by ~10^3
- L_X does not evolve / L_{syn} does



SMA

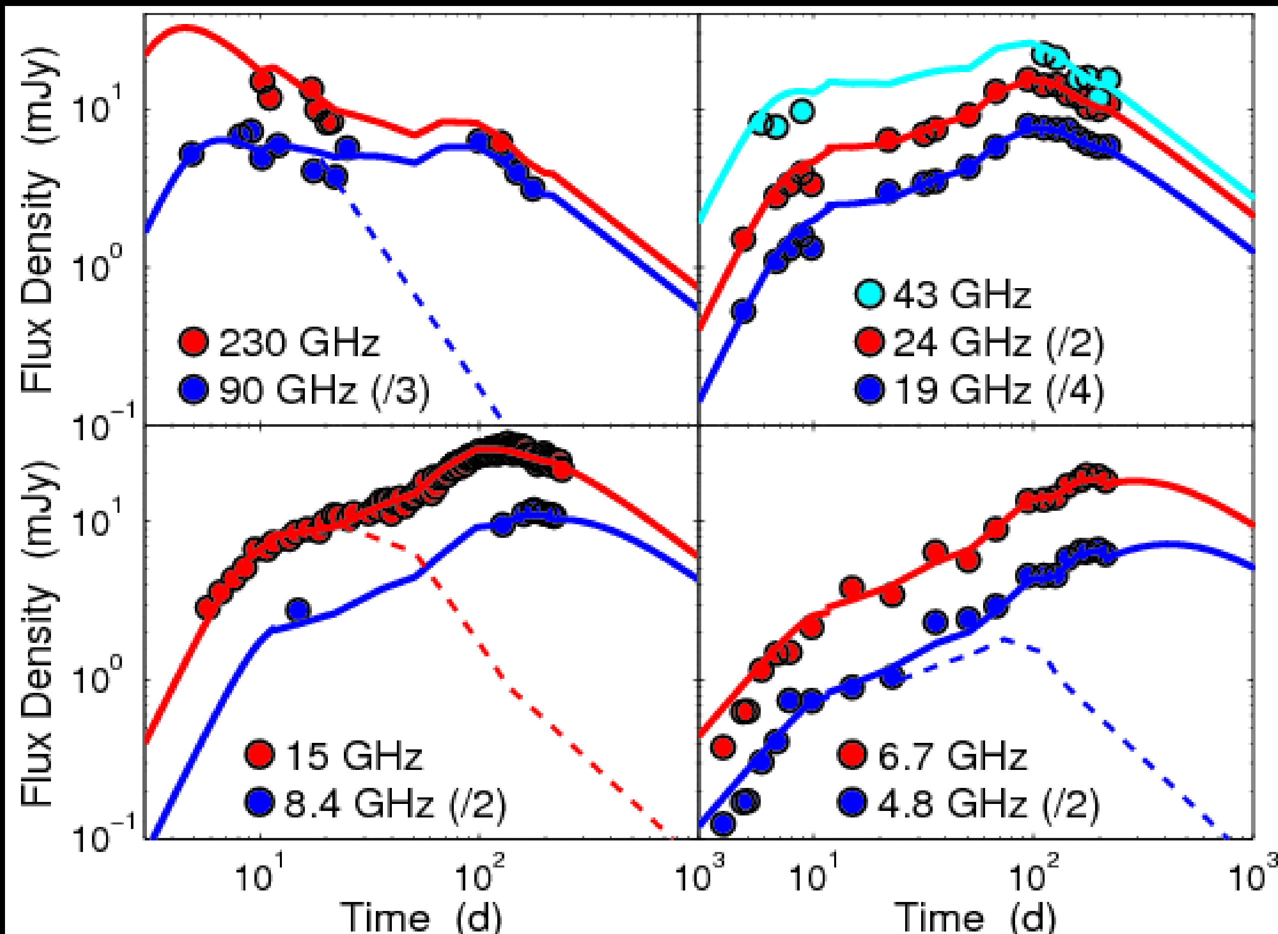
CARMA

EVLA, Ryle,
OVRO 40-m

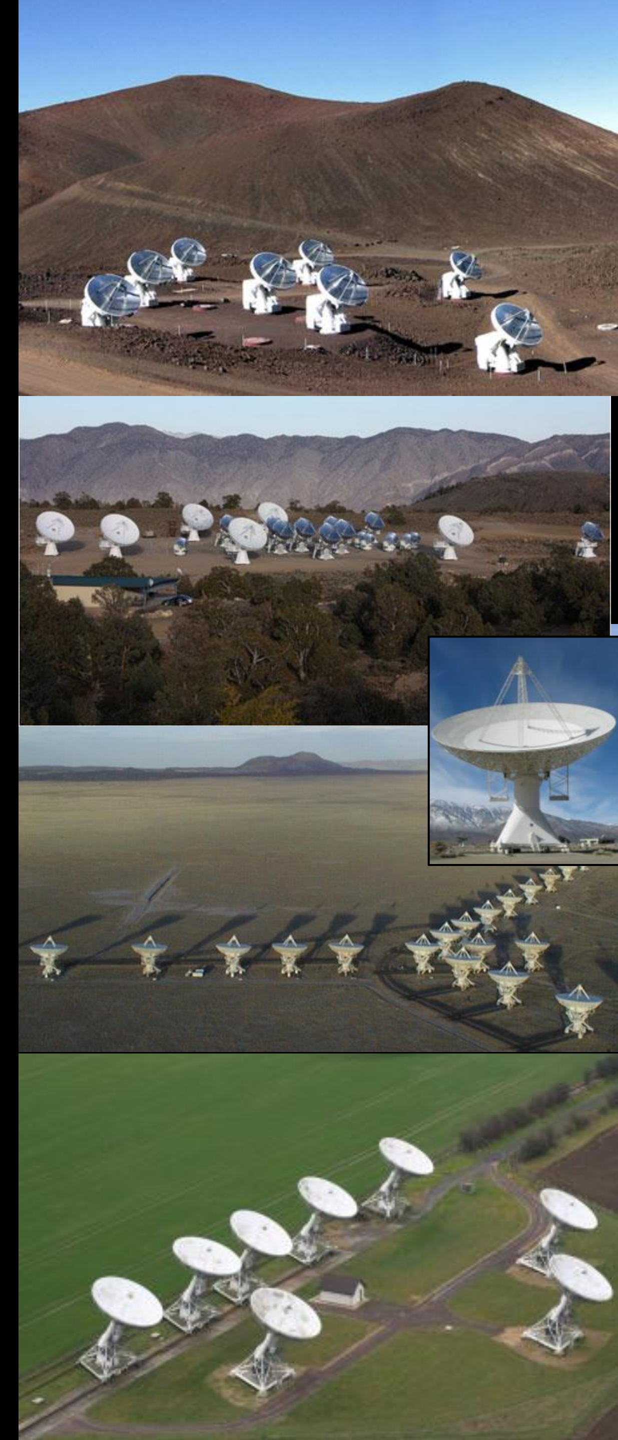
Zauderer et al. 2011

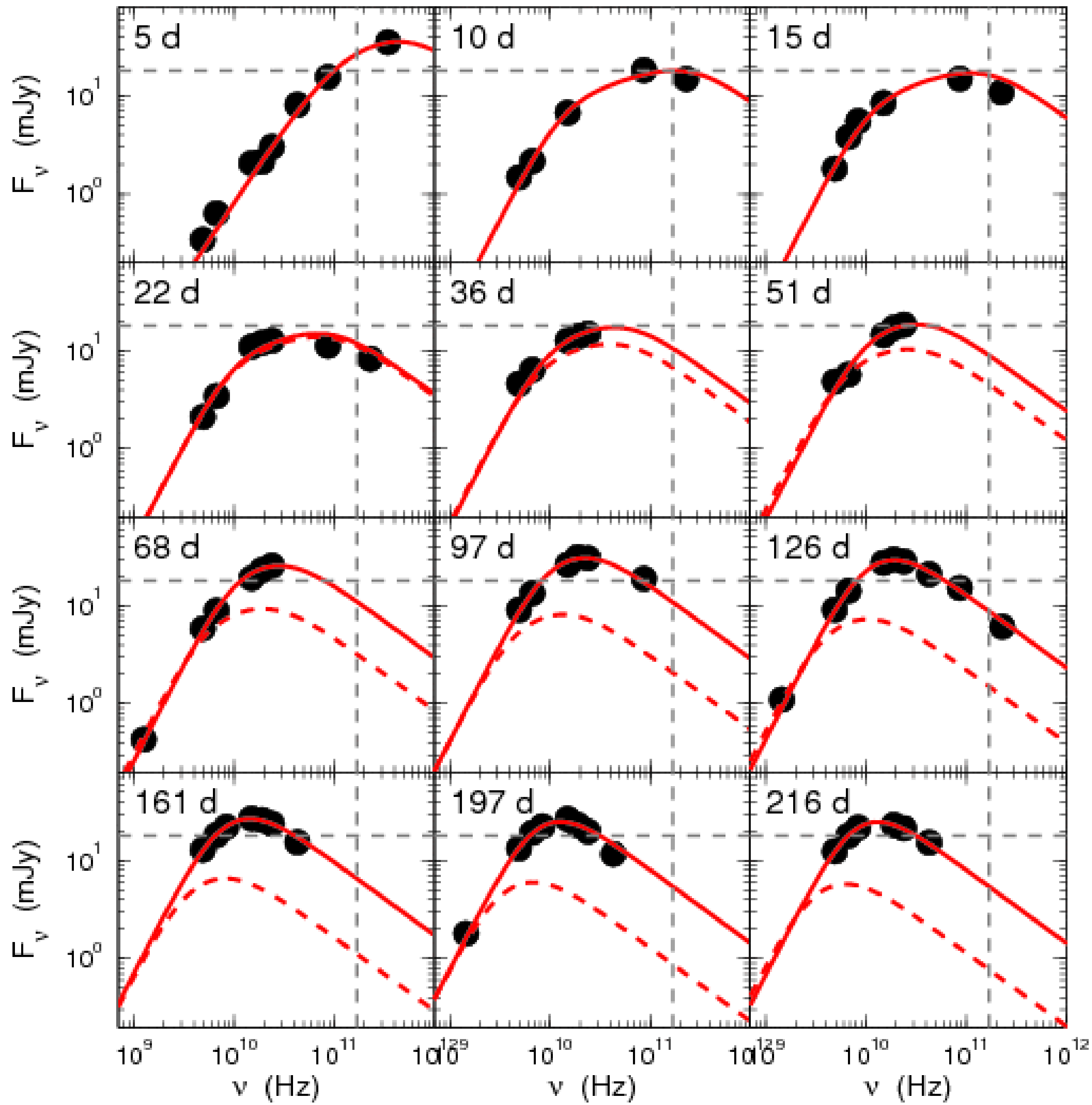
no optical / weak NIR

SMA
CARMA
EVLA
AMI-LA



Berger et al. 2012

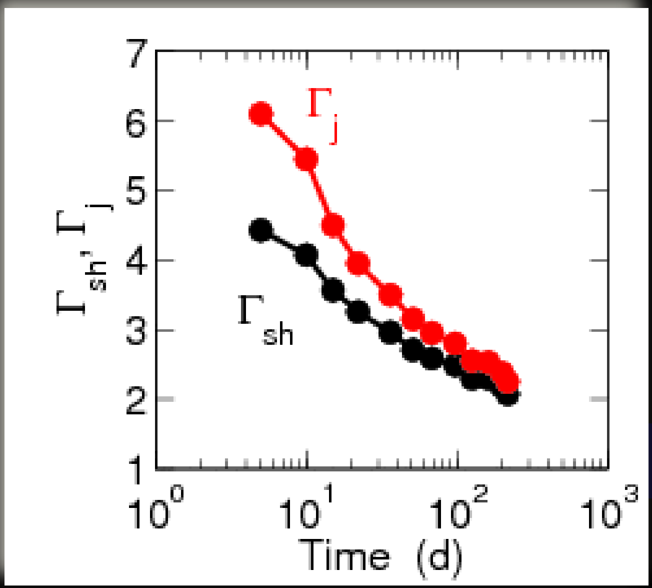




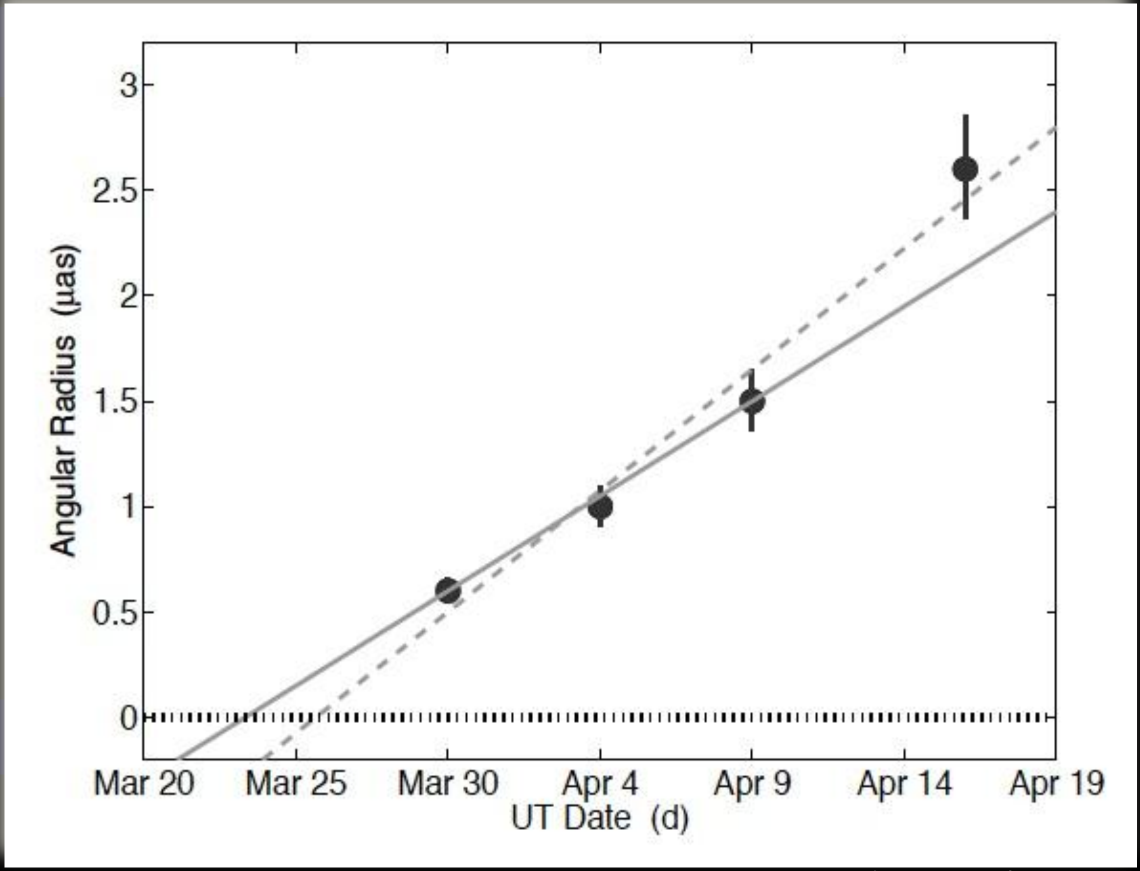
Berger et al. 2012

Relativistic Expansion

1. Synchrotron Modeling
2. Interstellar Scintillation



Berger et al. 2012

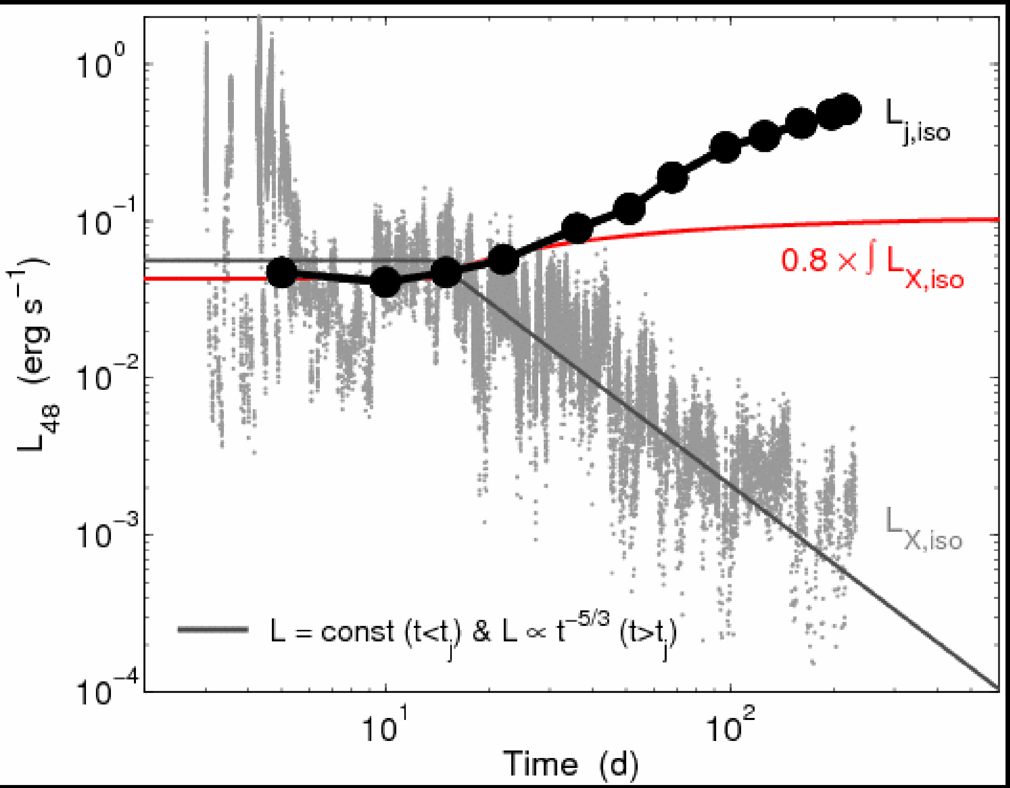


Zauderer et al. 2011

Formation epoch: March 23-26

$$\theta_{\rm eq} \approx 110\, d_{\rm L,Mpc}^{-1/19}\, F_{\nu,\rm p,mJy}^{9/19}\, \nu_{\rm p,GHz}^{-1} \;\; \mu as$$

Jet Energetics



$$\begin{aligned} E_{\rm j,iso} &= \Delta t_j \times L_{\rm j,iso} \\ &\approx 10^6\,{\rm s} \times L_{\rm j,iso} \\ &\approx 5 \times 10^{53}\,{\rm erg\ at\ 200\,d} \end{aligned}$$

The increase in jet energy cannot be explained by on-going injection from the accreting SMBH

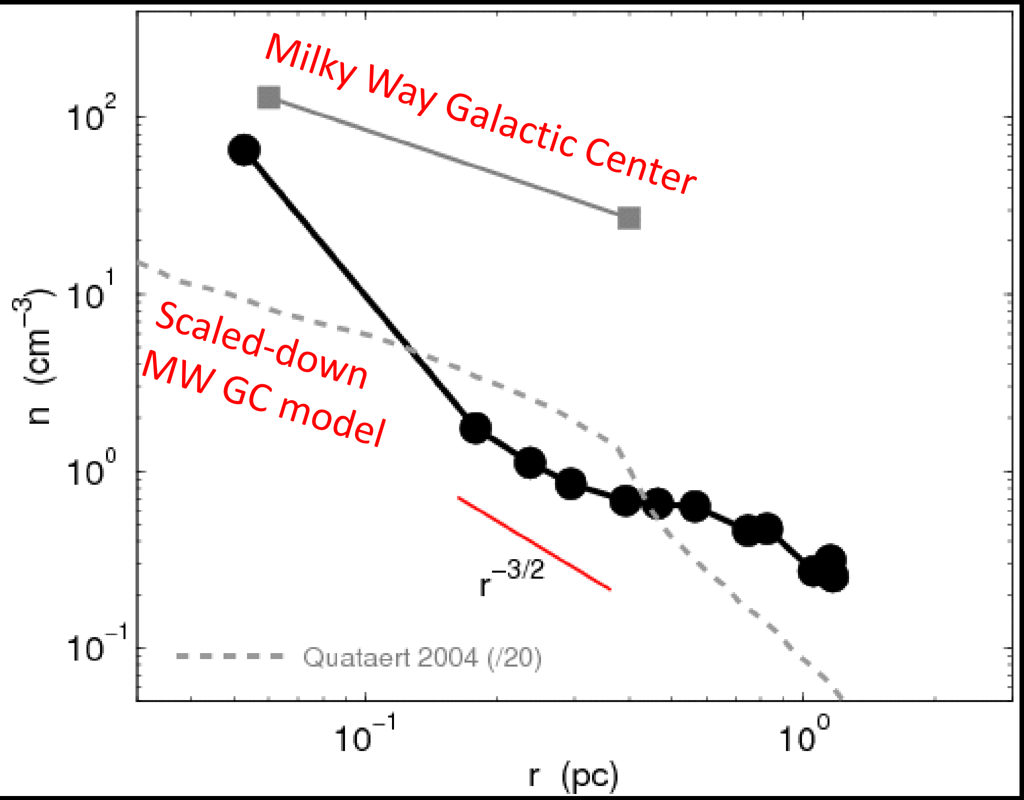
(as seen in X-rays w/ $L \propto t^{-5/3}$).

Instead, relativistic jet launched w/ a distribution of Lorentz factors explains the increase in *E* and evolution of *R*

$$E_{\rm j}(>\Gamma_{\rm j}) \propto \Gamma_{\rm j}^{-2.5}$$

Is this ubiquitous for relativistic jets, Blandford-Znajek mechanism, GRBs?

Parsec-Scale Environment

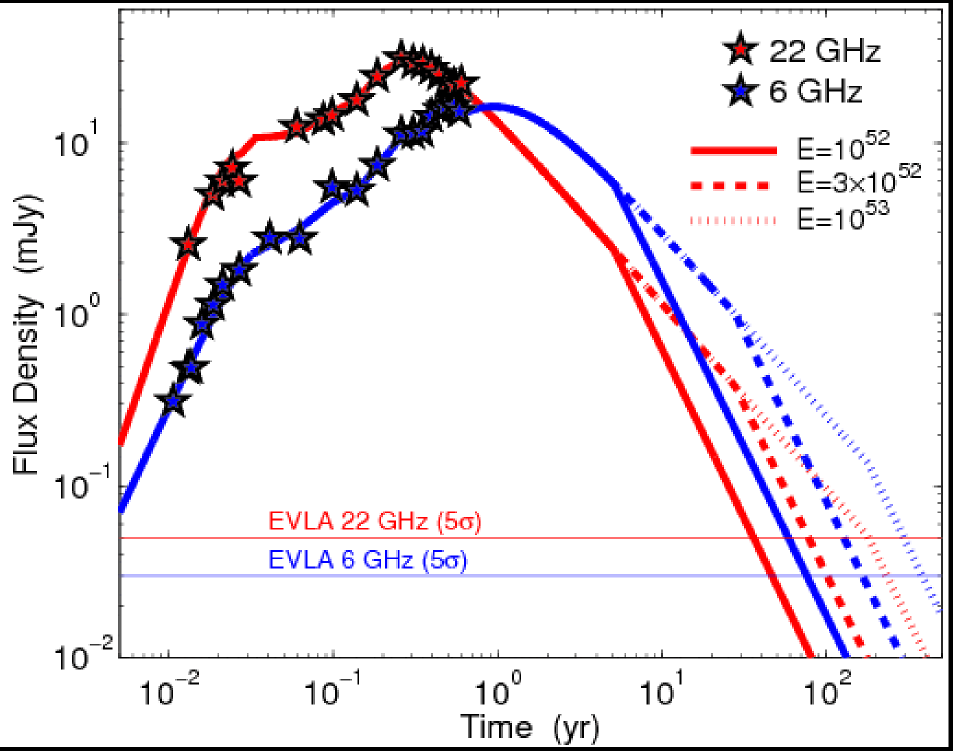


Radial profile is roughly $\rho \propto R^{-3/2}$ w/ flattening at ~0.5 pc (Bondi?)

Lower density relative to Galactic Center indicative of lower SFR?

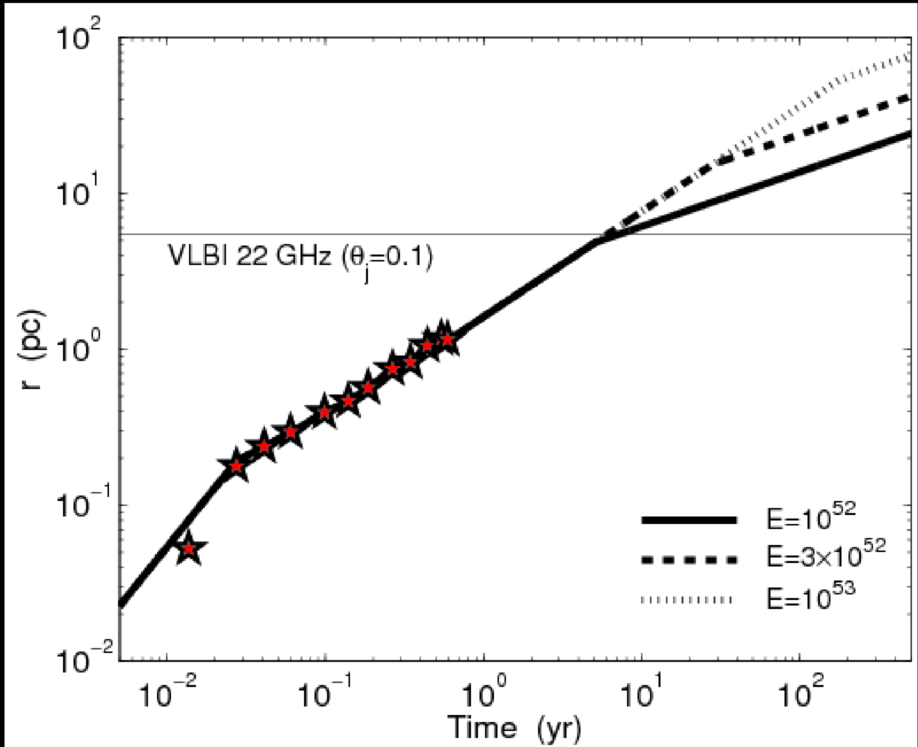
The density profile around a dormant SMBH at z = 0.354 measured with better spatial resolution than for the Milky Way Galactic Center

Future Evolution



Radio source will be resolvable with VLBI in ~3-5 years if stays collimated; ~1-2 years if it spreads

Depending on total E_j, the radio emission will remain detectable with EVLA for ~100-500 years



Future Work

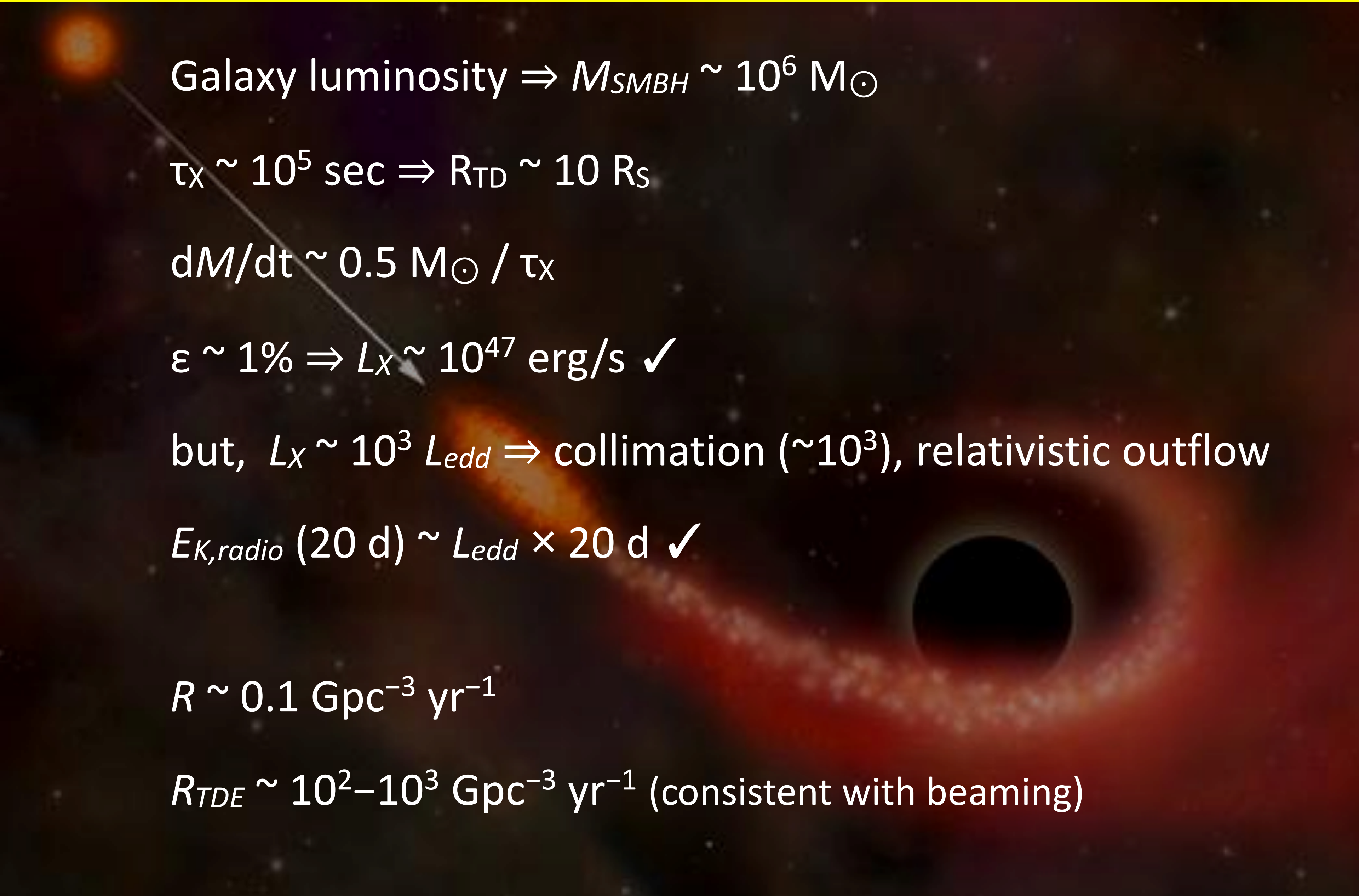
- Continued monitoring to track the energy scale and density profile

- Polarization at 5-45 GHz (detected...) and implications for the jet geometry.

- VLBI monitoring to resolve the outflow and/or measure proper motion.

- The long-term appearance of off-axis events; predictions for future radio searches.

Tidal Disruption Event?



Galaxy luminosity ⇒ M_{SMBH} ~ 10^6 $M_\odot$

τ_X ~ 10^5 sec ⇒ R_{TD} ~ 10 R_S

dM/dt ~ 0.5 $M_\odot$ / τ_X

ε ~ 1% ⇒ L_X ~ 10^{47} erg/s ✓

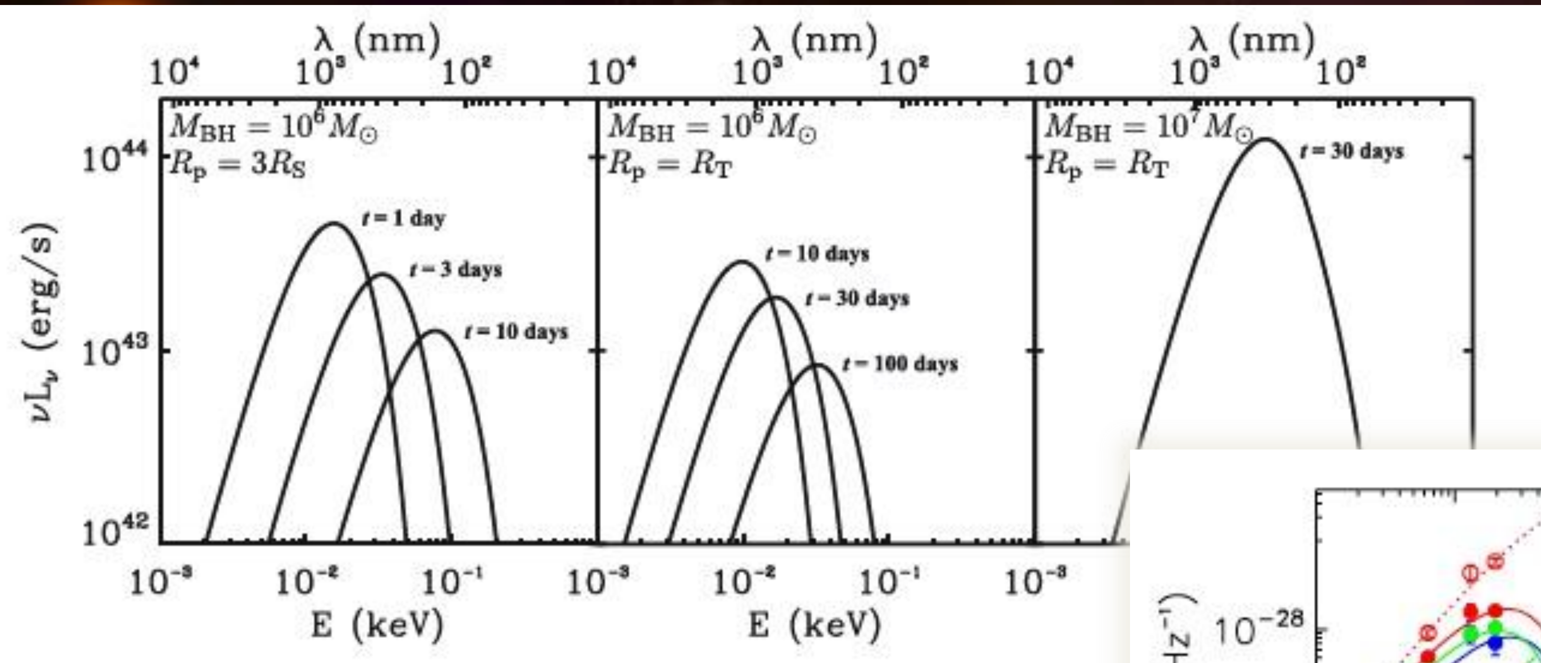
but, L_X ~ 10^3 L_{edd} ⇒ collimation (~10^3), relativistic outflow

$E_{K,radio}$ (20 d) ~ L_{edd} × 20 d ✓

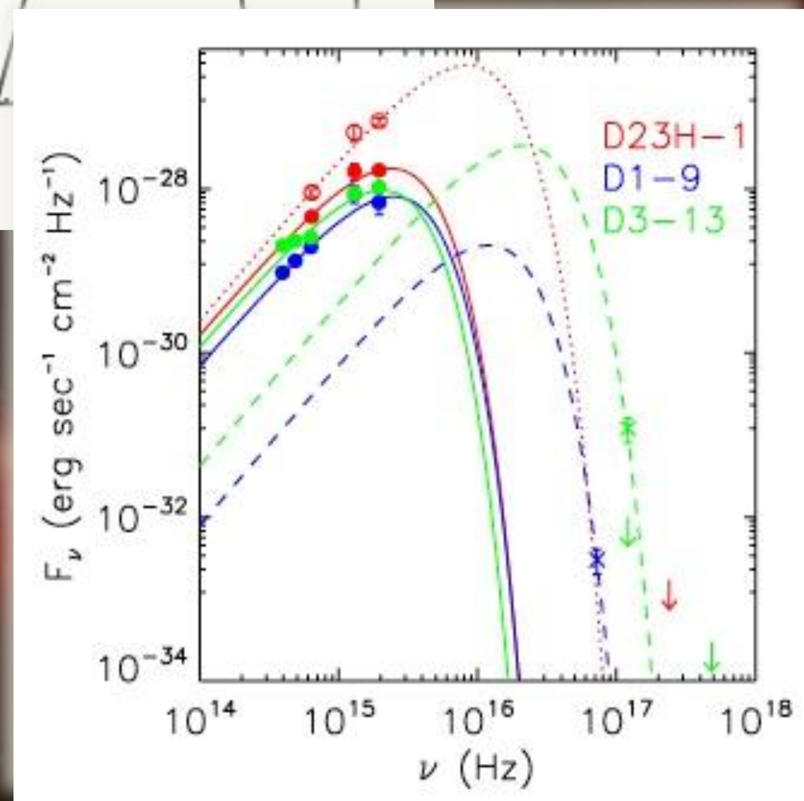
R ~ 0.1 Gpc^{-3} yr^{-1}

R_{TDE} ~ 10^2–10^3 Gpc^{-3} yr^{-1} (consistent with beaming)

Tidal Disruption Event?



Strubbe & Quataert; Giannios & Metzger

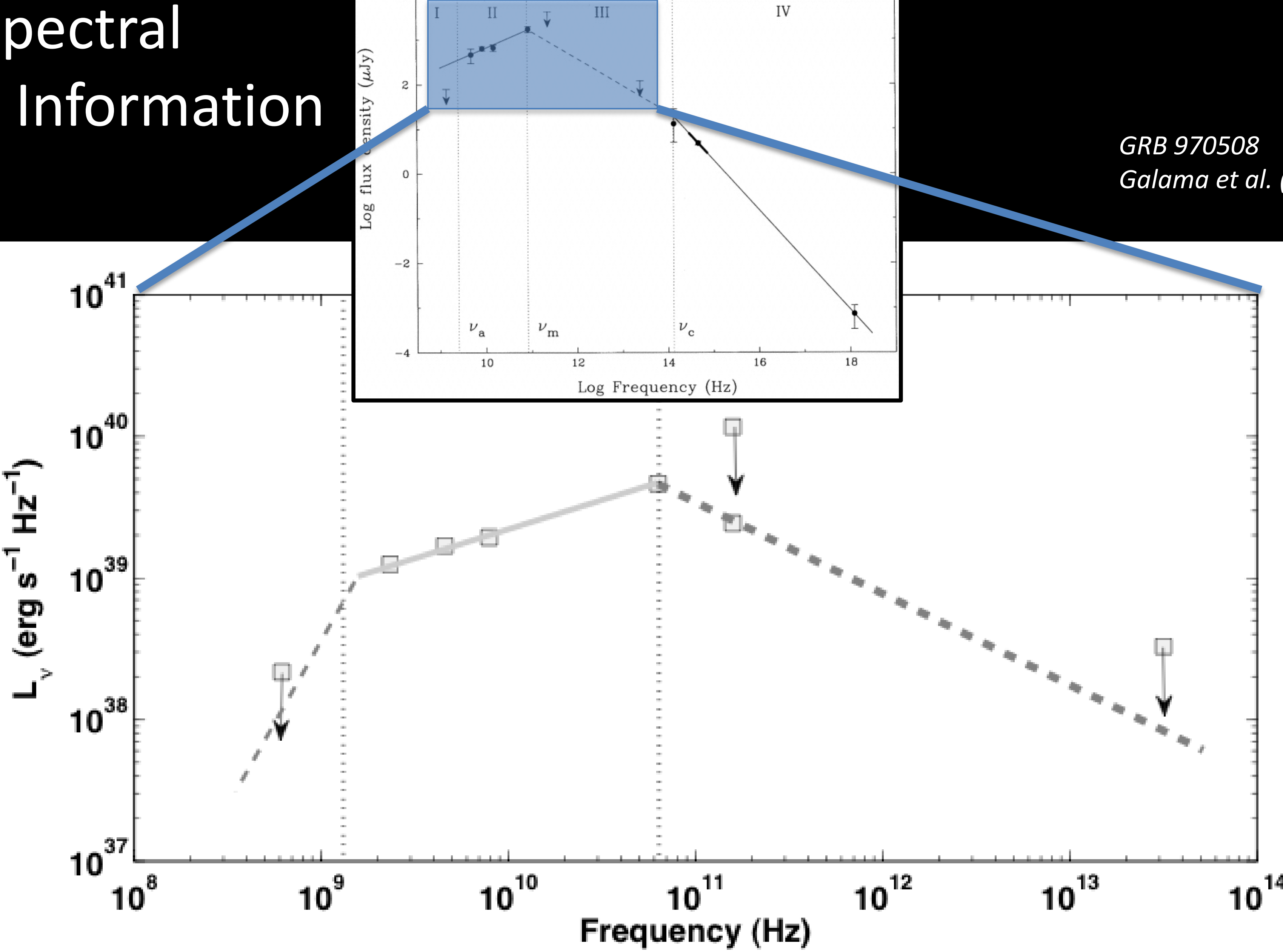


Gezari et al.

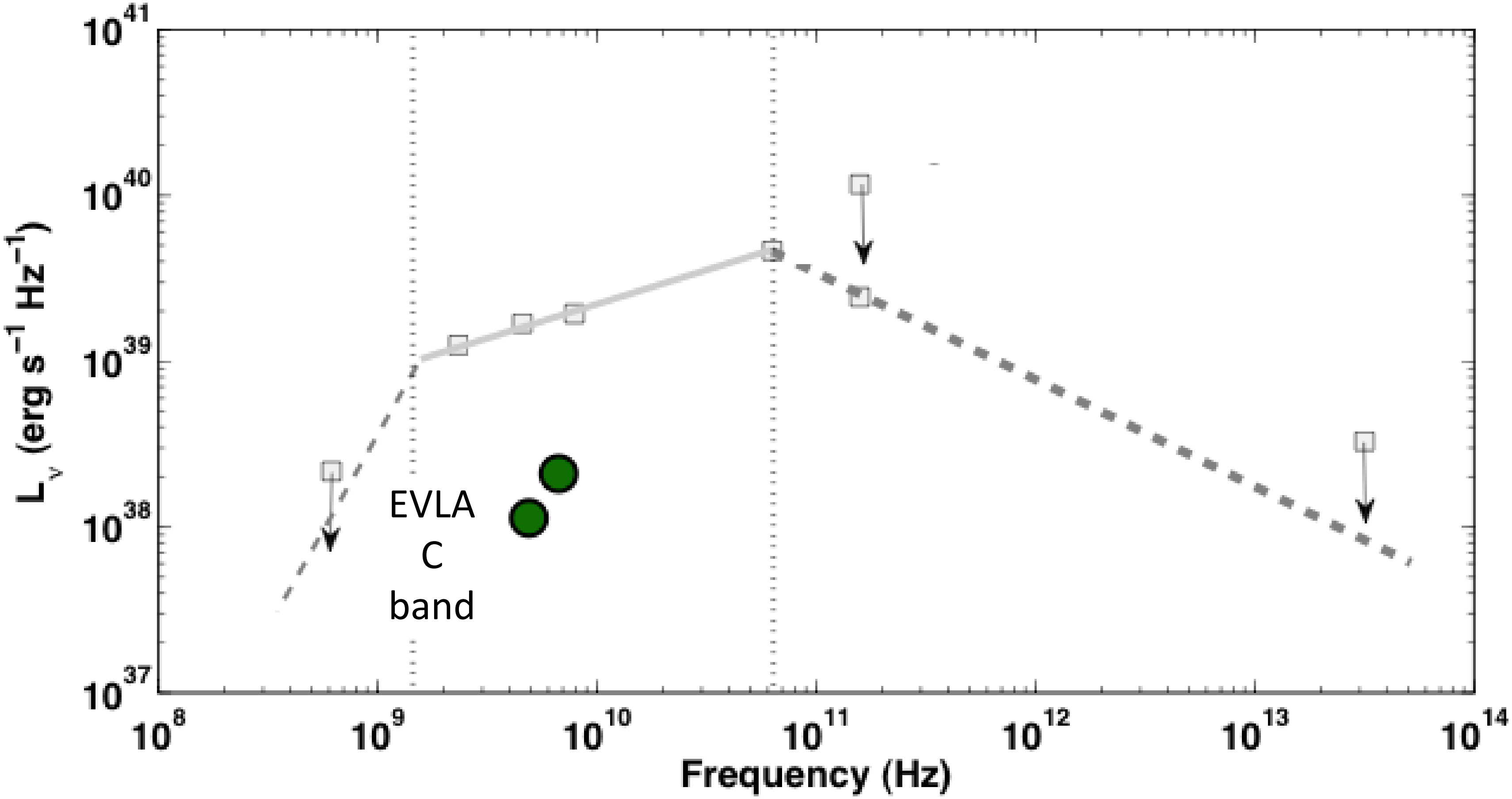
Theoretical Prediction:

- UV/optical/soft X-rays with $L \sim L_{edd}$
- Radio emission *posited*; peak at ~1 year

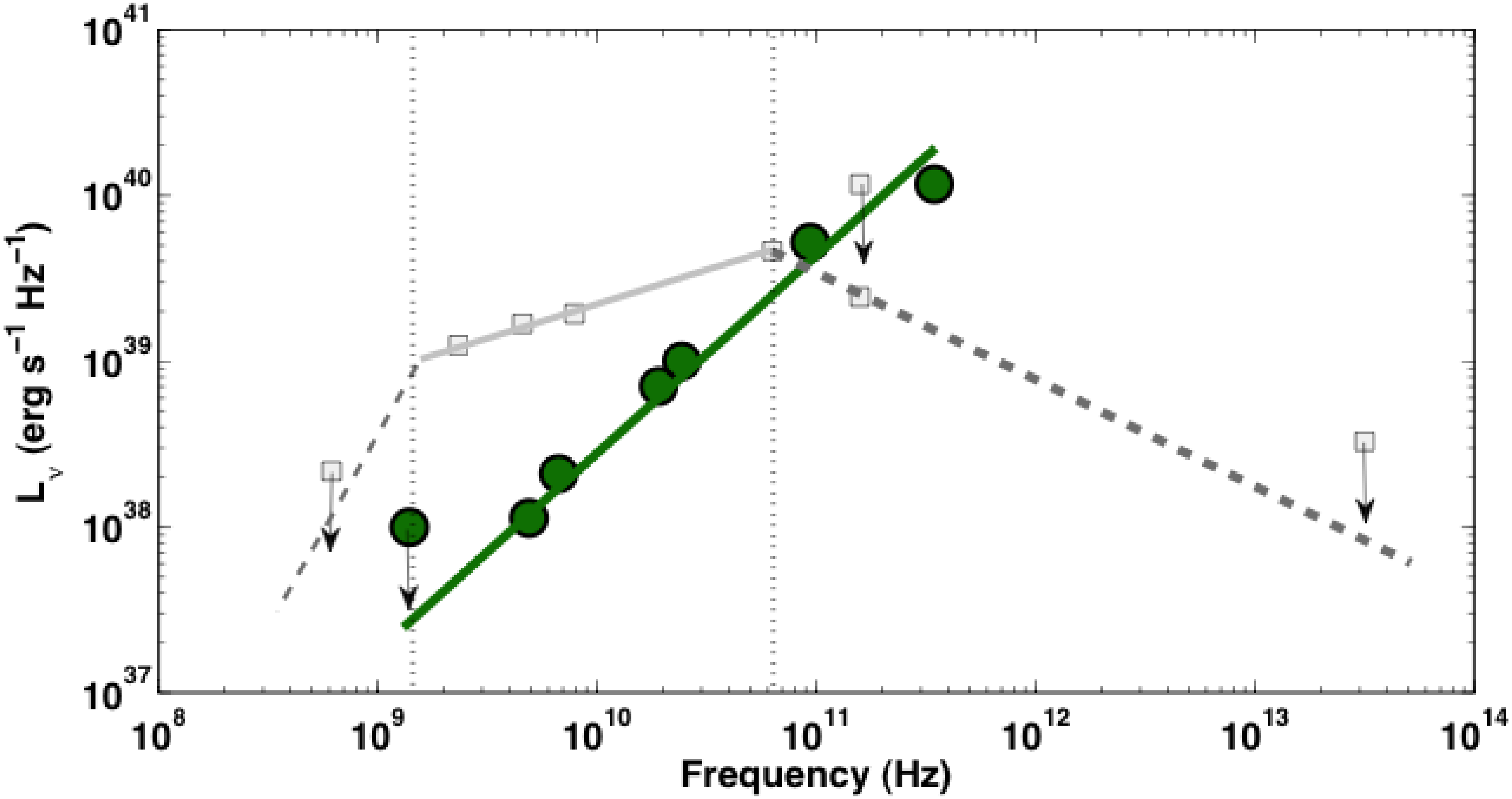
Spectral Information



GRB 970508
Galama et al. (1998)



L_ν (erg s^{-1} Hz^{-1})
10^{41}
10^{40}
10^{39}
10^{38}
10^{37}
EVLA
C
band
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
Frequency (Hz)



L_ν (erg s^{-1} Hz^{-1})
10^{37}
10^{38}
10^{39}
10^{40}
10^{41}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
Frequency (Hz)

Progenitor Possibilities

Non-TDE:

(1) Long GRB with Nuclear Origin ?

- spectral information unusual
- coincidence with nucleus of inactive galaxy
- x-ray data
- only mildly relativistic

(2) AGN / Blazar

- typical lifetimes of ~million years
- spectral diagnostics
- no prior signatures in X-ray or radio

TDE variations:

(1) million solar mass black hole disrupting a star

(2) Less massive BH disrupting a white dwarf (Piran)

(3) Variations in BH spin (M. Kesden, Gultekin) / precession of jet (N. Stone)

Radio Monitoring

Long-term radio study provides several unique opportunities:

- Structure and evolution of a relativistic jet* (flux, polarization, VLBI)
- Total energy output from the tidal disruption event
- Pristine environment of a previously-dormant SMBH

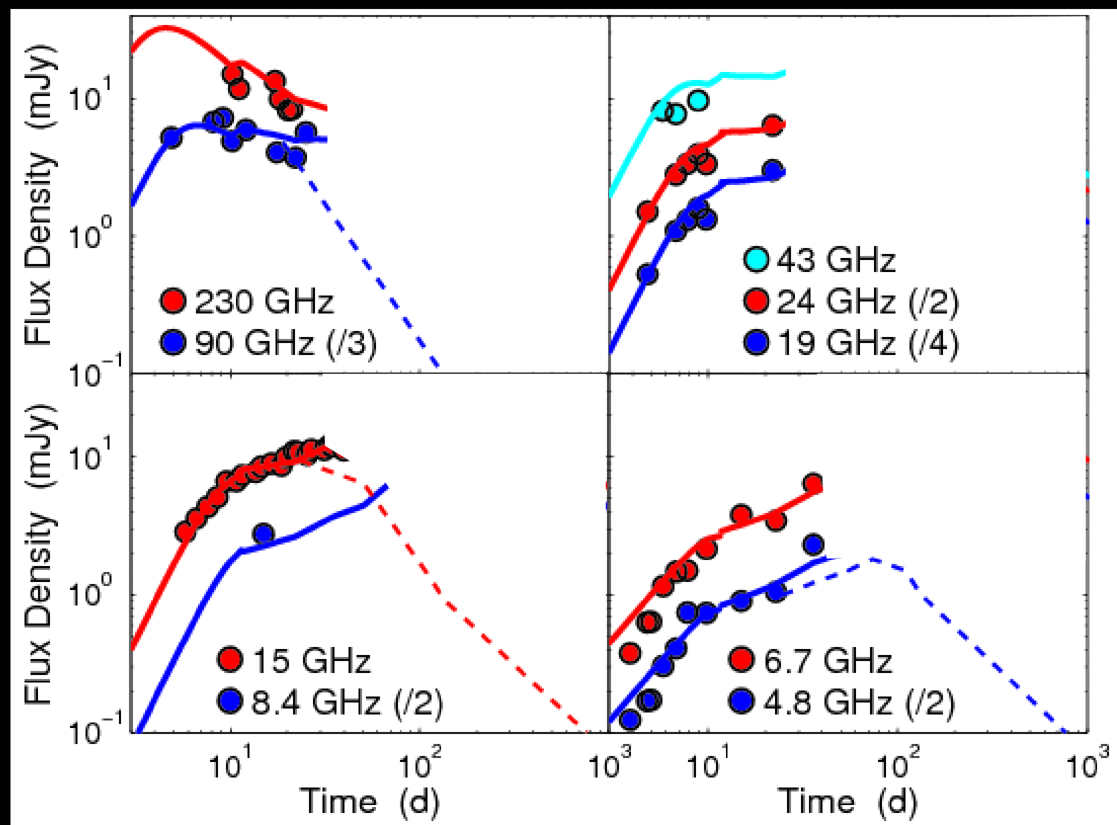
SMA
CARMA
EVLA
AMI-LA

Observed radio evolution reveals much longer rise time and brighter emission than expected

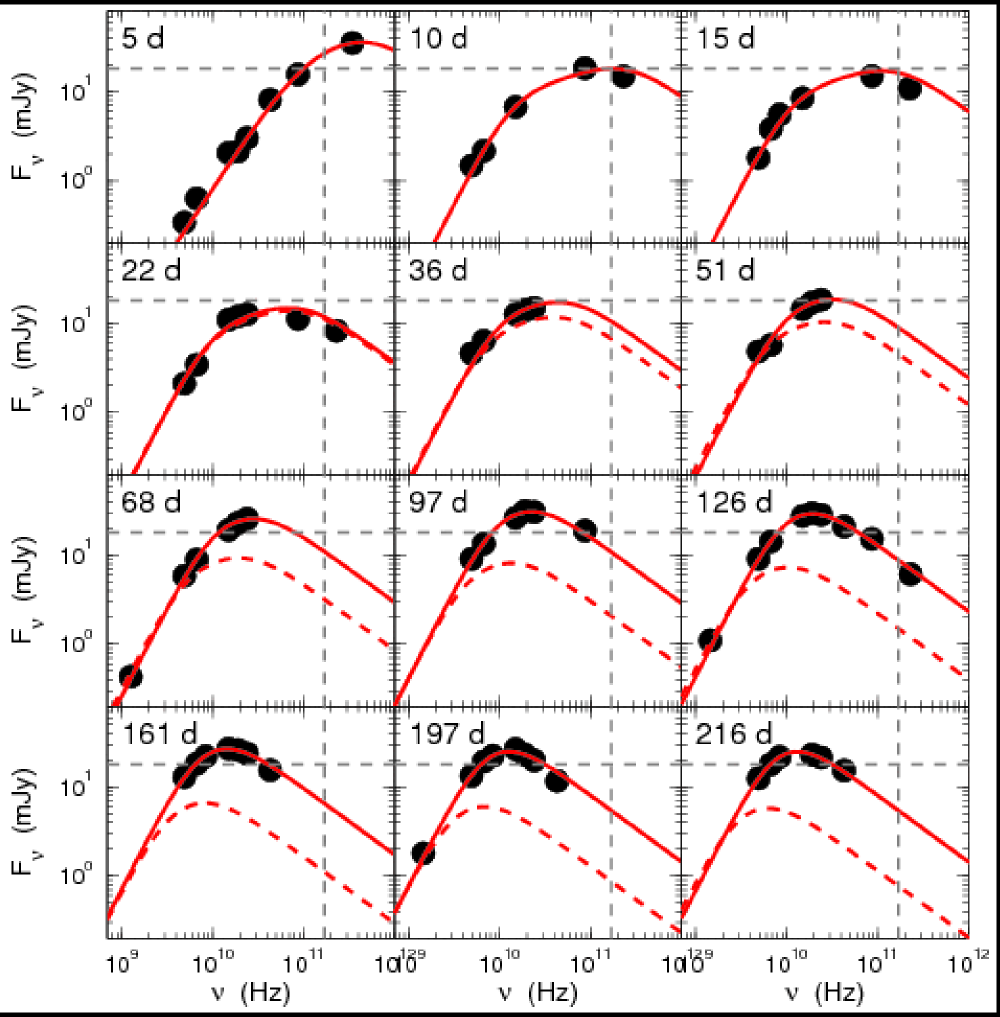
⇒ <u>increase in *E*, *ρ*, both?</u>

(lines are model fits, next...)

Potentially applicable to GRBs since $\Delta t/\tau_{dyn}$ is similar



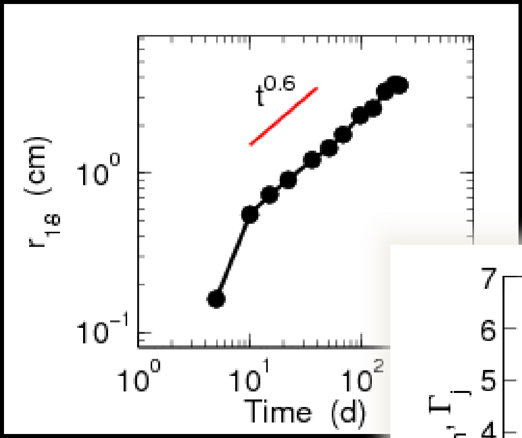
Radio Monitoring

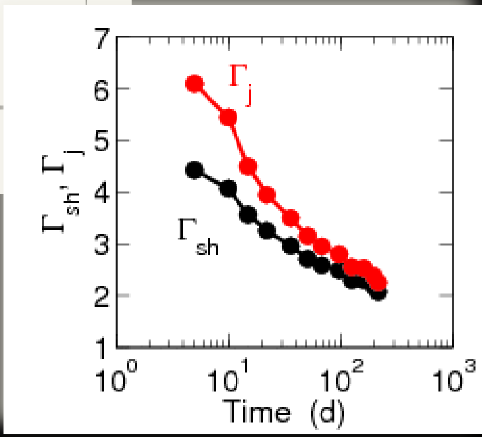


No assumptions about hydrodyn.

Model each "snapshot" spectral energy distribution with a synchrotron model (cf GRBs)

⇒ determine time evolution of *E, ρ, R, Γ*





no change in *E, ρ*

Relativistic Expansion III

$$\nu_o \approx 10 \text{ GHz}$$

$$\theta_{F,0} \approx 1 \ \mu\text{as}$$

for $\nu > \nu_0$

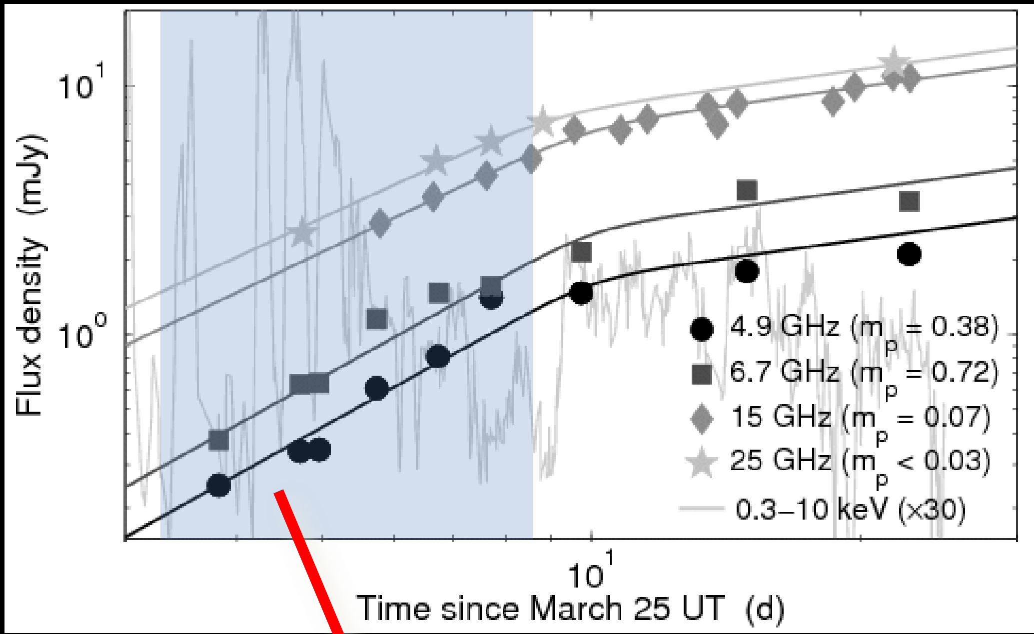
$$m_p \propto (\nu/\nu_0)^{-17/12} (\theta_s/\theta_{F,0})^{-7/6}$$

for $\nu < \nu_0$

$$m_p \propto (\nu/\nu_0)^{17/30} (\theta_s/\theta_r)^{-7/6}$$

$$\theta_s \approx 5 \ \mu\text{as}$$

$$\Gamma \approx \text{few}$$



Large variations in X-rays are not accompanied by variations in radio

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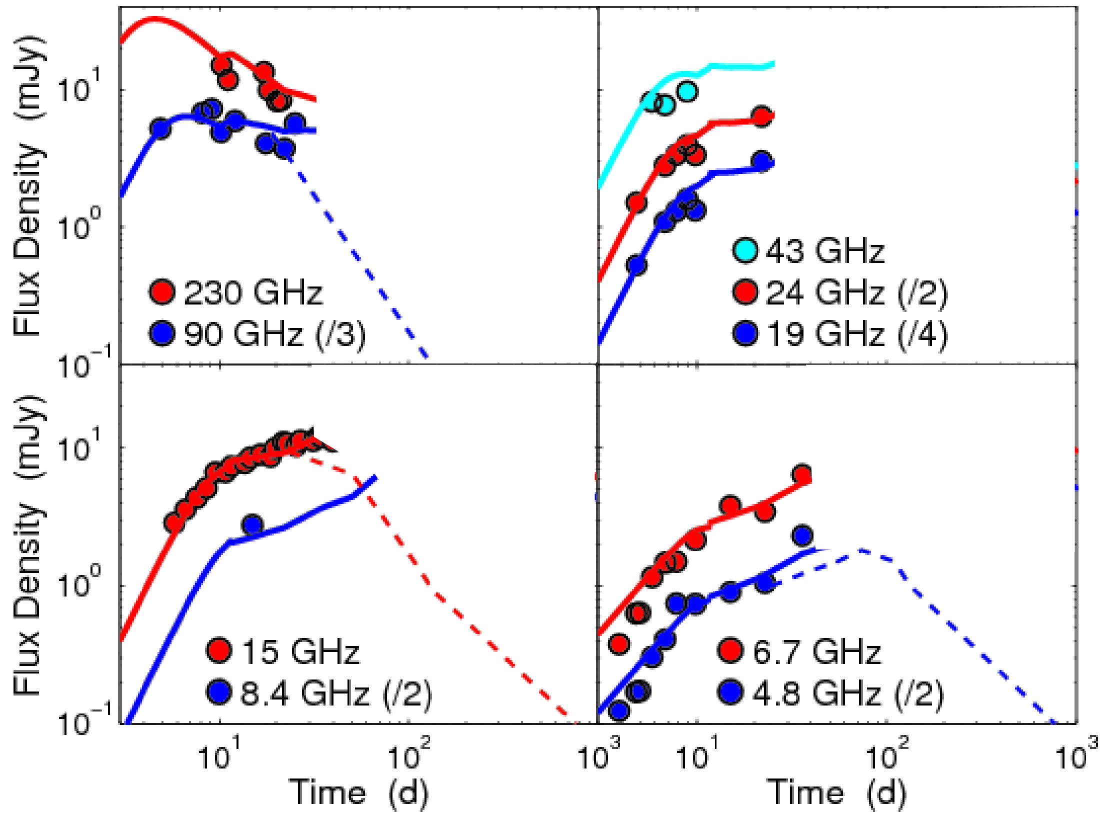

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