Tidal Disruption Events followed-up with milli-arcsec resolution

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IGRJ12580+0134 team: Jay Blanchard (JIVE), Zsolt Paragi (JIVE), Bob Campbell (JIVE), Minnie Mao (Univ. Manchester)

Outline

- Why Tidal Disruption Events are important, and why do very long baseline interferometry (VLBI)?

- European VLBI Network (EVN) results:

  - "No apparent superluminal motion in the first-known jetted tidal disruption event Swift J1644+5734", *Yang et al. 2016, MNRAS 462, L66*

  - "The TDE ASASSN-14li and Its Host Resolved at Parsec Scales with the EVN", *Romero-Cañizales et al. 2016, ApJ 832, 10*

  - "The case of IGRJ12580+0134" – new results by *Blanchard et al.*

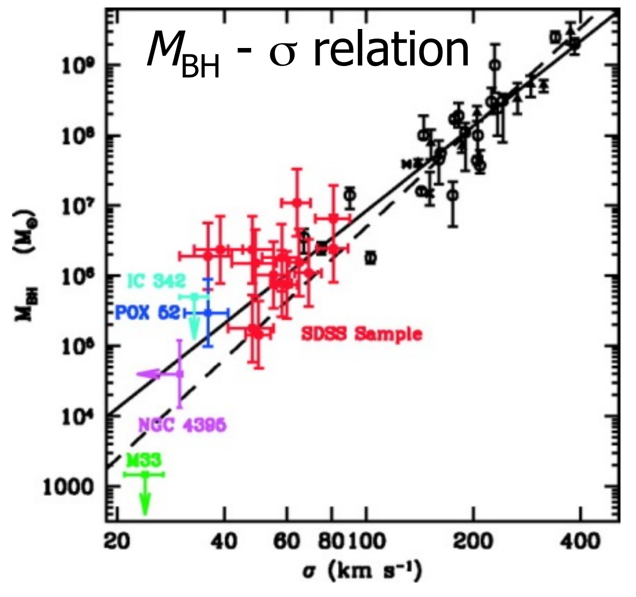
- Further thoughts / Conclusions

Why TDE are important?

- **They may give a clue on the massive BH population (M_{BH}<10^6 $M_\odot$)**

  To understand supermassive BH formation we must now the BH demographics – but massive BH below ~10^6 $M_\odot$ are hard to find.

  Where are the left-over seed BH required by structure formation models? How do they grow?

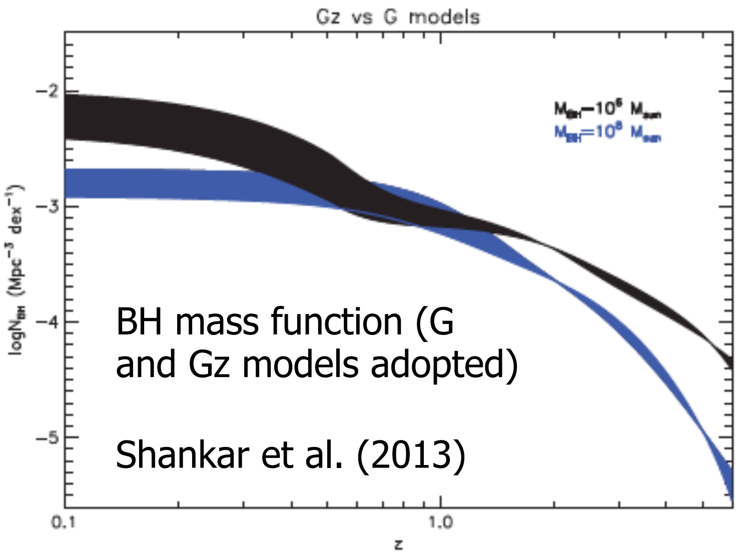


Barth, Greene & Ho (2005)

- **We can study jet formation in a pristine environment**

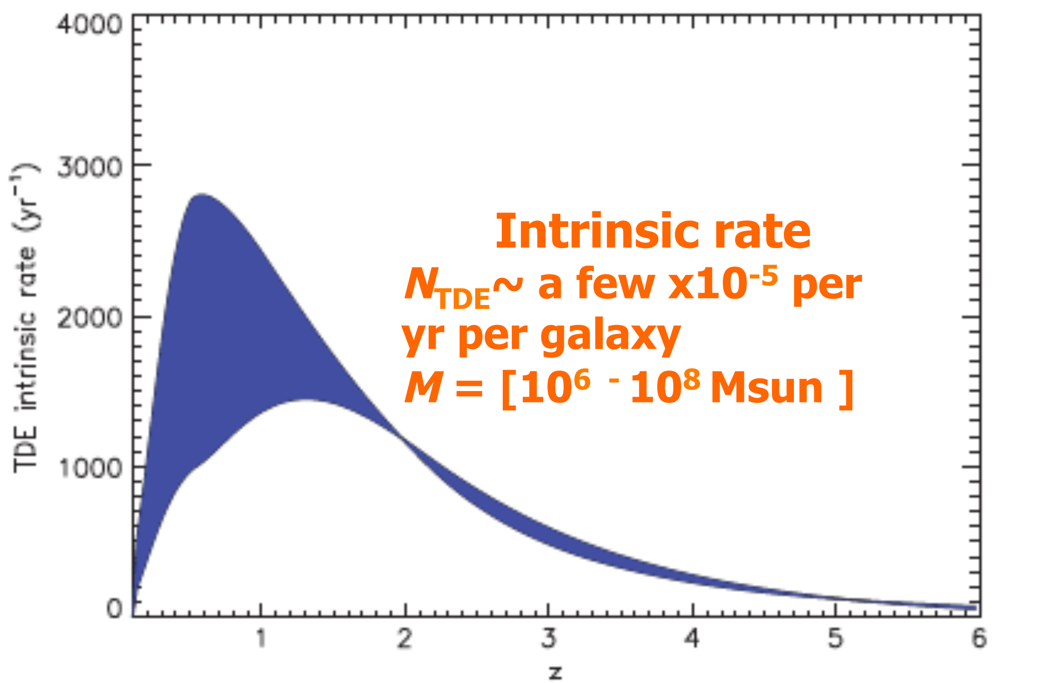
  Also relevant for AGN feedback. VLBI will have a crucial role in this, since milliarcsecond resolution is needed.

What is the expected TDE rate?



Take Swift J1644+5734 as prototype for predictions in the X-ray and radio bands: Donnarumma et al. (2015)

$$R(z) = \int_{M_{\min}}^{M_{\max}} \phi(M, z) V(z) N_{\rm tde} dM,$$

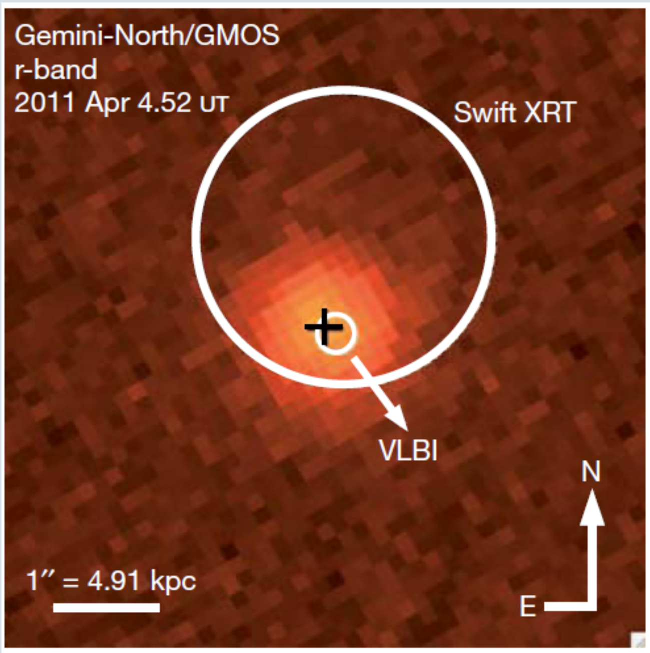


From intrinsic to jetted TDE rate: rescaling R(z) by a factor $(2\,\Gamma)^{-2}$

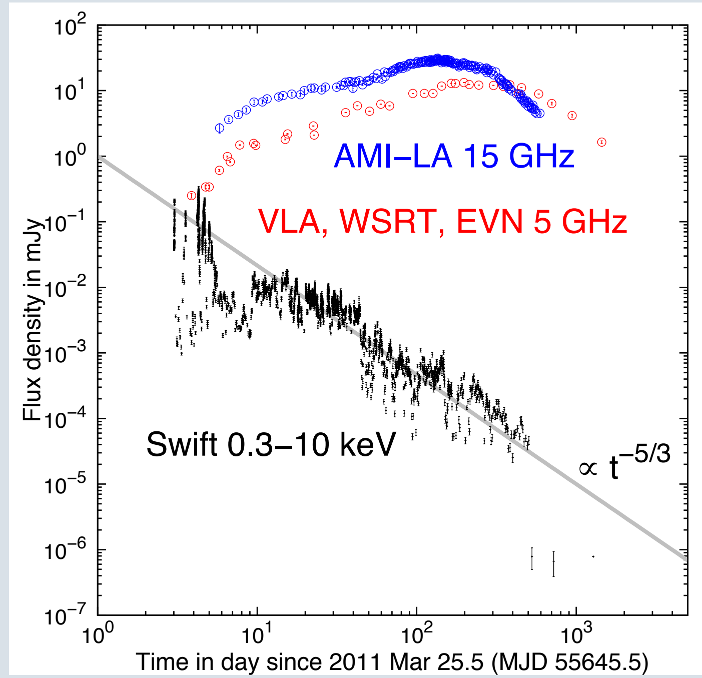
Must understand jet efficiency and measure Lorentz factors in TDE

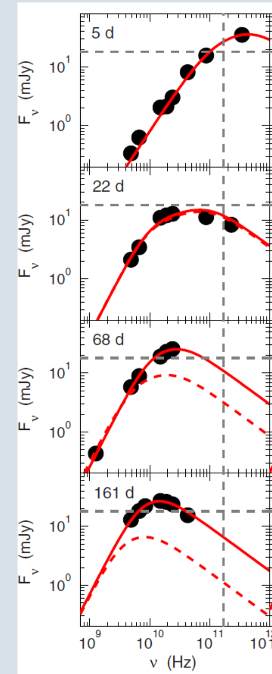
Swift J1644+5734: the first jetted TDE

Zauderer et al (2011, 2013)



Berger et al. (2012), Wiersema et al. (2012)



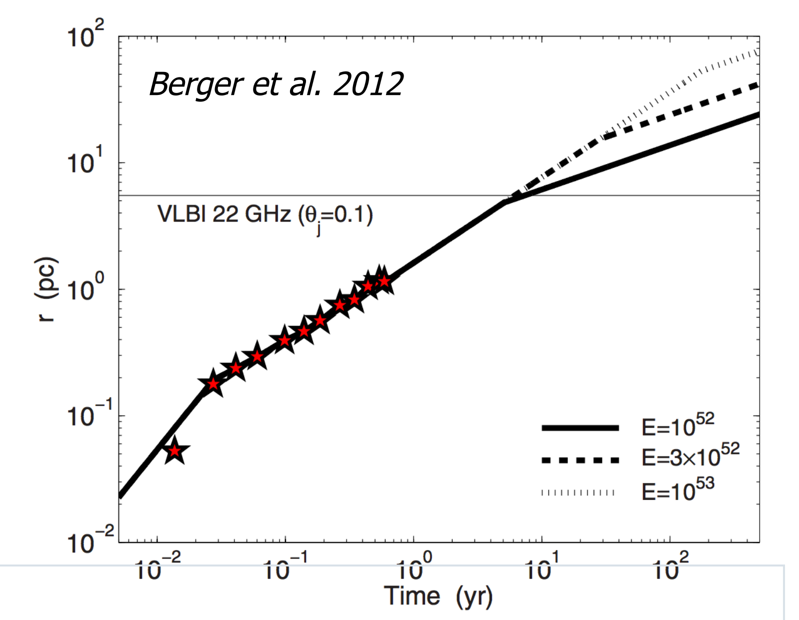


- Within 0.2 kpc of the host galaxy nucleus
- X-ray lightcurve follows $t^{-5/3}$
- Total X-ray energy $\sim 10^{53}\, f_{beam}$ erg

- X-rays: rapid variability (100s), non-thermal spectrum, high Eddington luminosity => inner jet close to the BH
- Radio: non-thermal, no rapid variability => shock interaction with ISM?

Swift J1644+5734: the first jetted TDE

- Estimate from interstellar scintillation: $\Gamma_{jet} \sim 5$ (multi-frequency radio monitoring; Zauderer et al. 2011).
- $\Gamma_{jet} \sim 7 - 2$, i.e. decreasing with the time in a collimated jet by analogy to GRB afterglows. The jet will be resolved (~0.2 mas) with VLBI at 22 GHz in 6 years assuming a jet opening angle ~5 deg (Berger et al. 2012).



Possible VLBI strategies for Swift J1644+5734

Choice 1: wait for 6 years, measure size (if source still bright) with VLBI at high frequency

Choice 2: probe superluminal jet via proper motion β_{app} with VLBI (not necessarily highest frequency)

Constraints on Lorentz factor $\Gamma_{jet} = (1 - \beta^2_{int})^{-1/2}$ and viewing angle Θ will be:

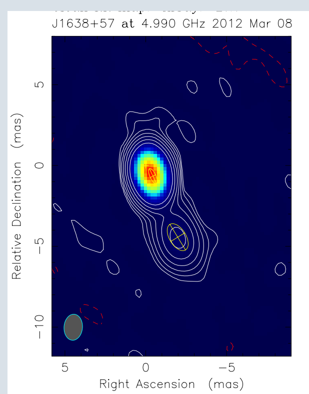
$$\Gamma_{min} = (\beta^2_{app} + 1)^{1/2}$$
$$\cos\ \theta_{max} = (\beta^2_{app} - 1) / (\beta^2_{app} + 1)$$

European VLBI Network (EVN) observations

- Initial real-time e-VLBI observations to establish strategy
- Deep follow-up observations at 5 epochs within three years
- Choose 5 GHz for excellent astrometry, great sensitivity and longer source detectability (as opposed to high frequencies)

- The main reference source source was ICRF J1638+5720, 55 arcmin away

Bright blazars often vary and have unstable cores – must be careful!

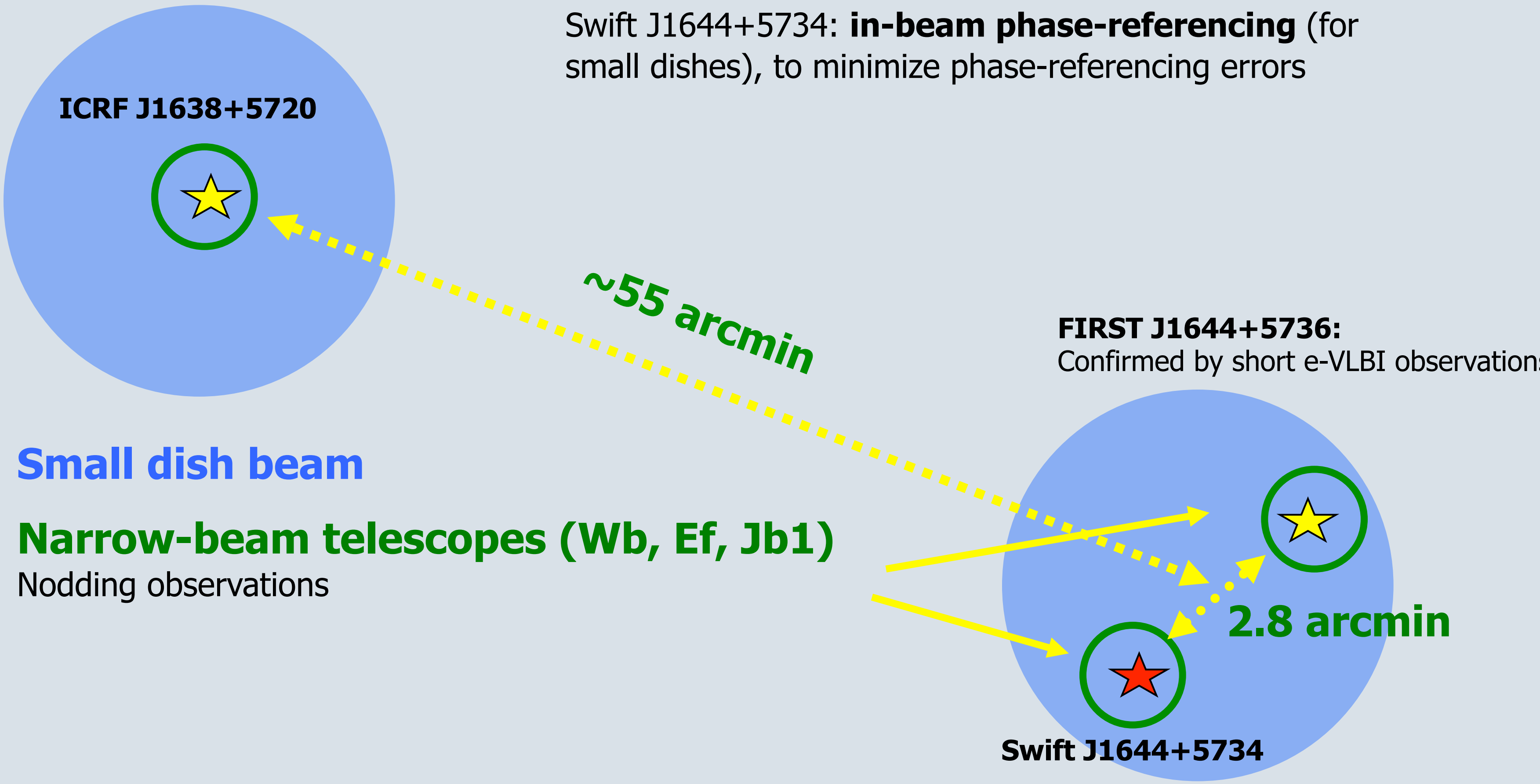


- Central Processor: JIVE, Dwingeloo, NL

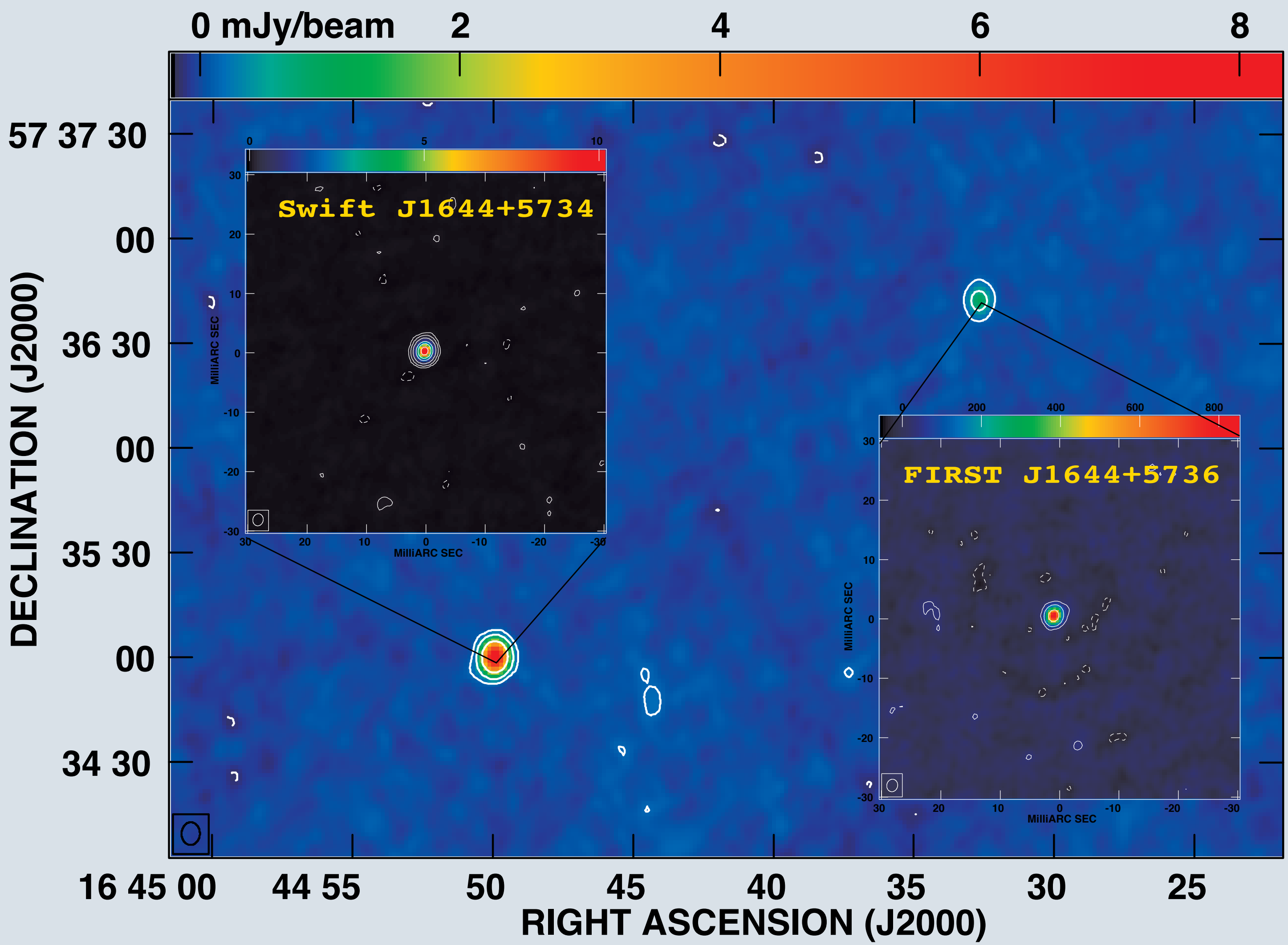
Observational strategy

Calibration of faint sources in VLBI: **phase-referencing**

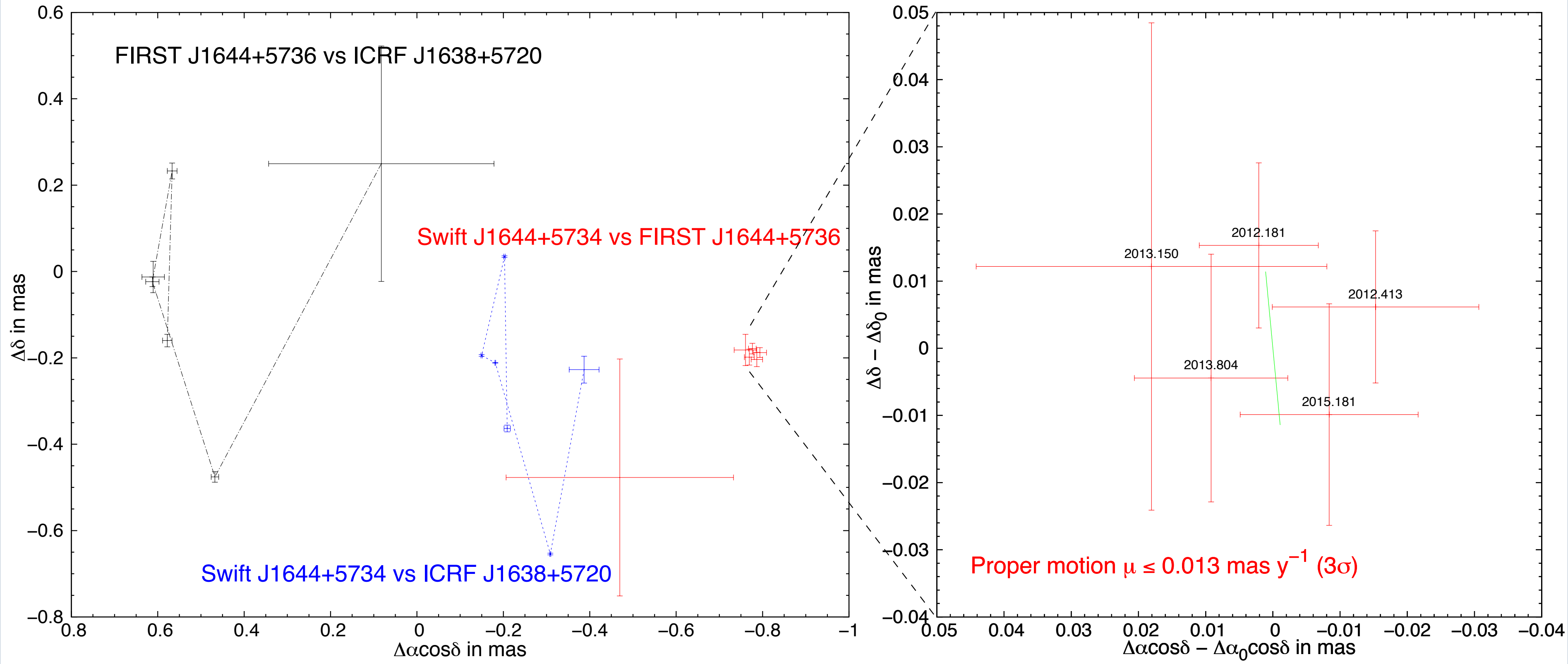
Swift J1644+5734: **in-beam phase-referencing** (for small dishes), to minimize phase-referencing errors



The target field with VLBI resolution



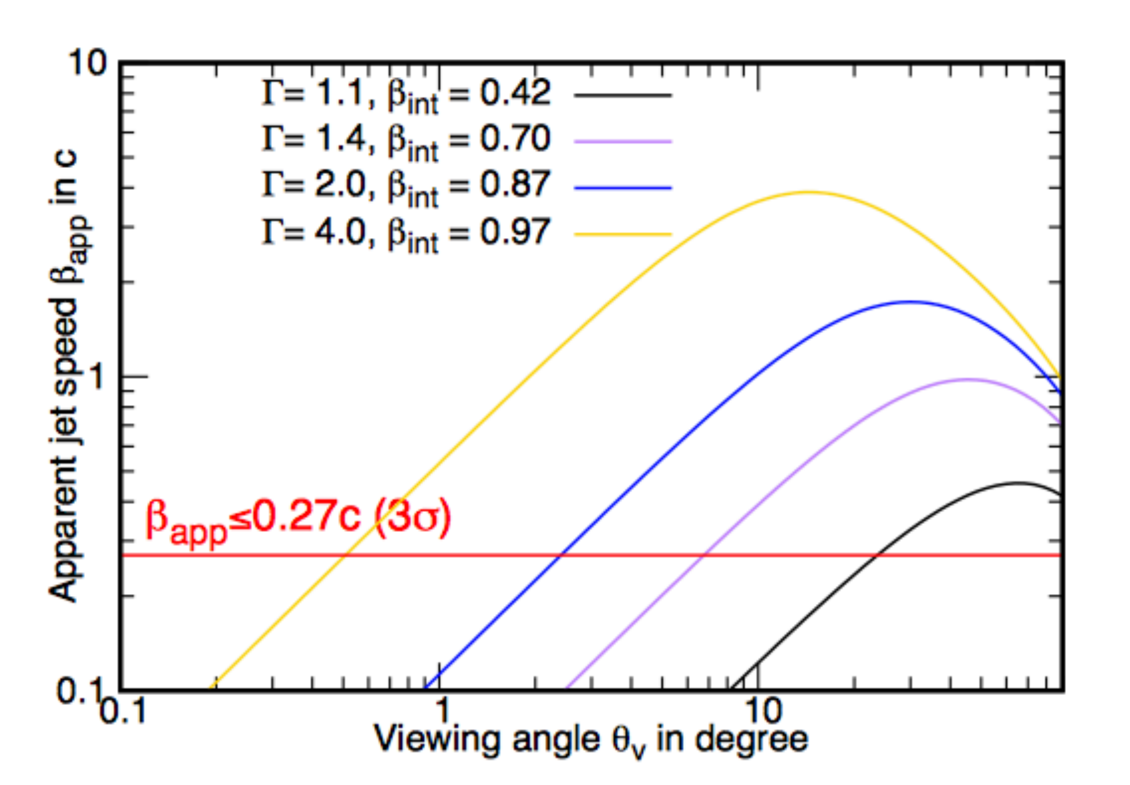
Ultra-high precision astrometry



ICRF frame: standard deviation is 50 μas in RA and 260 μas in DEC; similar to Berger et al. (2012)

TDE-FIRST source relative astrometry: 13 μas in RA and 11 μas in DEC – best ever achieved with the EVN for a continuum source

Strong constraint on proper motion



=> Small viewing angle

If Γ_{jet} = 2 (Zauderer et al. 2013) , then Θ_v< 3°

("Tip of the iceberg", or "cosmic conspiracy"?)

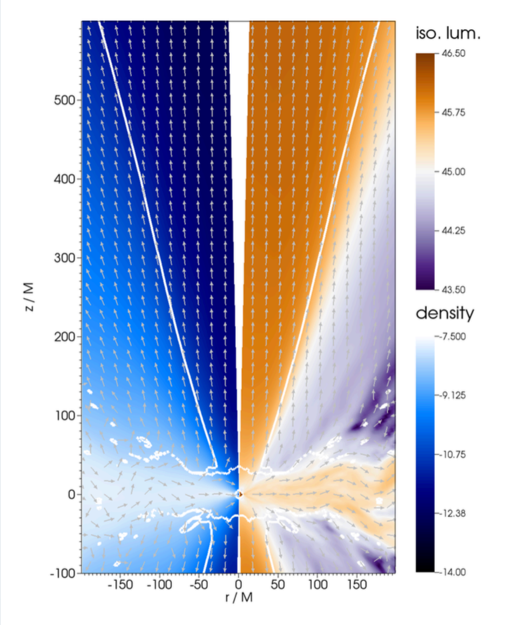
=> Or strong deceleration

Γ_{jet} ≤ 2, due to dense circum-nuclear medium / no constraint on viewing angle.

$n_{cnm} \geq 5\ E_{iso,54}\ cm^{-1}$ at radius ~1pc

Supporting alternative views? -unlikely

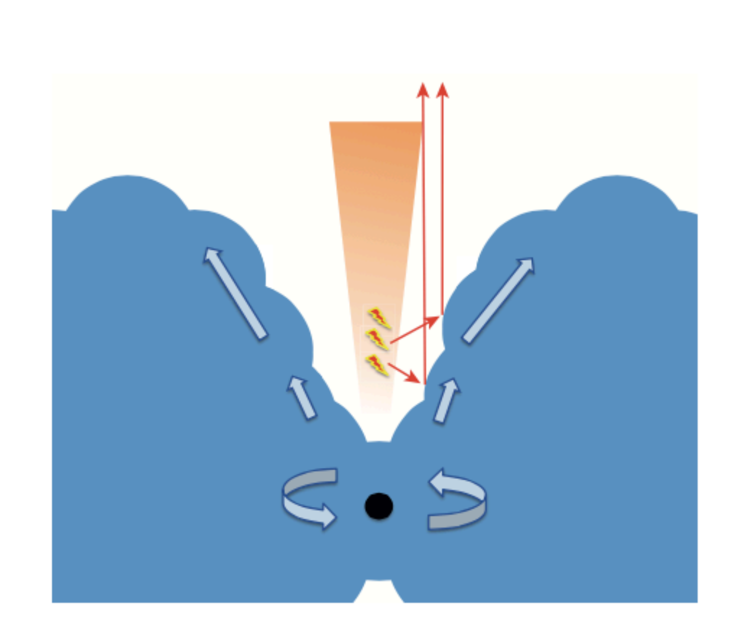
Sadowski & Natarayan (2015)



Highly super-Eddington, fully radiative pressure driven jets can explain the high luminosity jets in (most) TDE and ULXs

β_{int} **~ 0.3c**

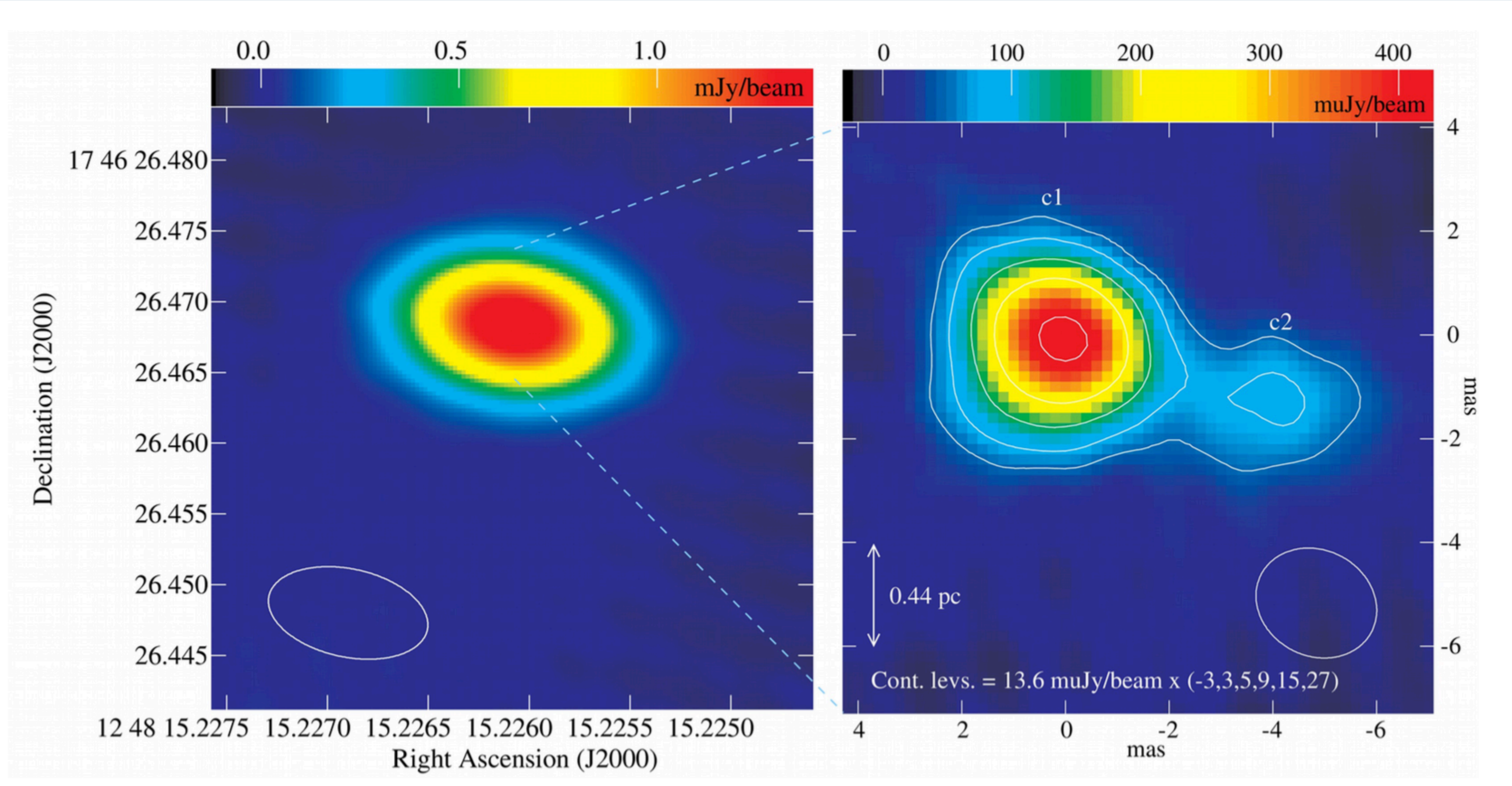
Kara et al. (2016)



X-rays may be a result of reverberation off a super-Eddington accretion flow, not dominated by a jet.

No relativistic jet is needed to explain X-rays
(but what about the transient radio emission?)

The case of ASASSN-14LI

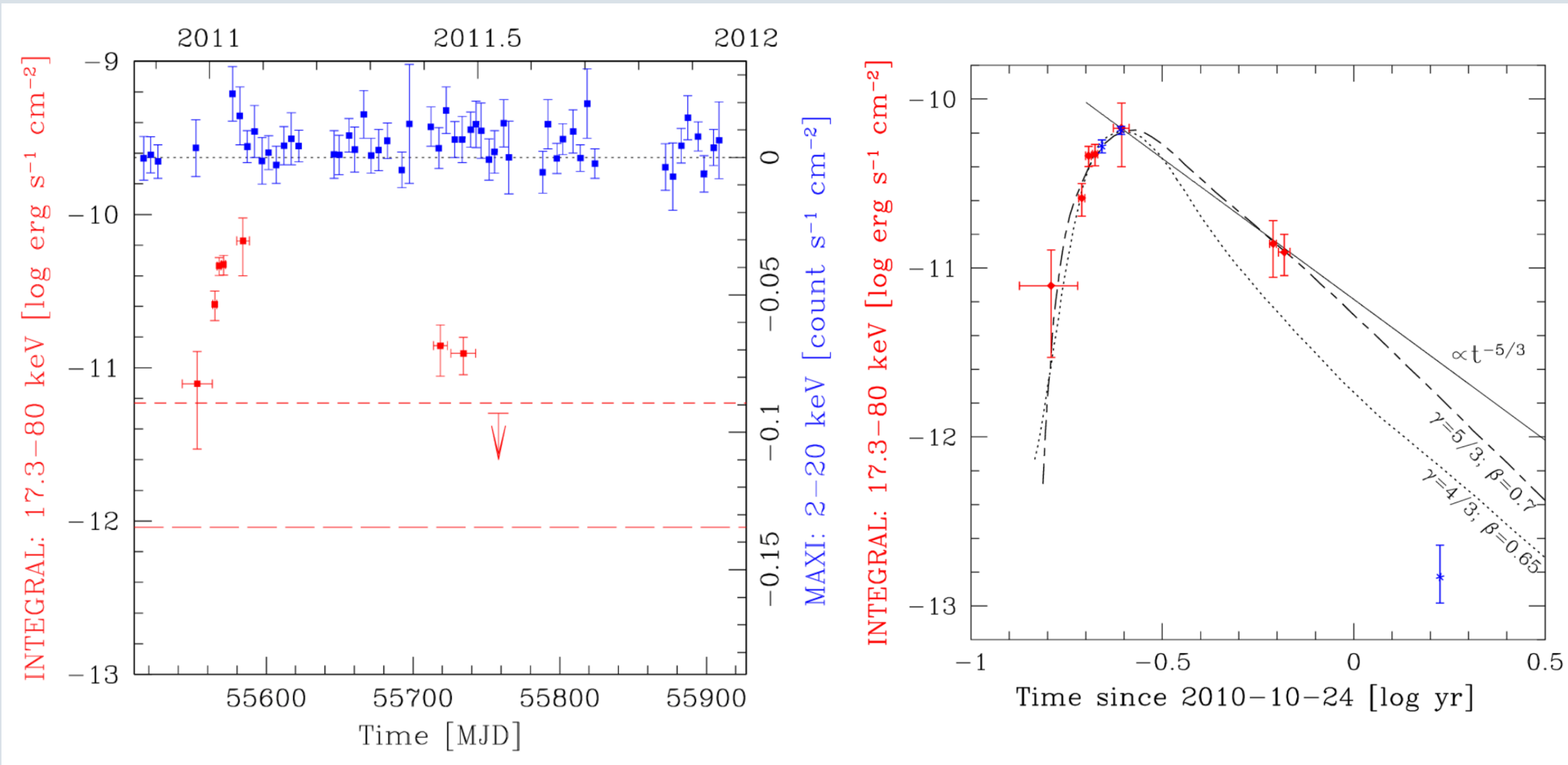


Relativistic jet from an off-axis **thermal TDE?**

- But note pre-existing AGN
- Image reliability issues: faint structure to be confirmed
- At odds with van Velzen+16 claim of jet deceleration within 0.1 pc?

Romero-Canizales et al. 2016
arXiv 1609.00010v1

The case of IGR J12580+0134



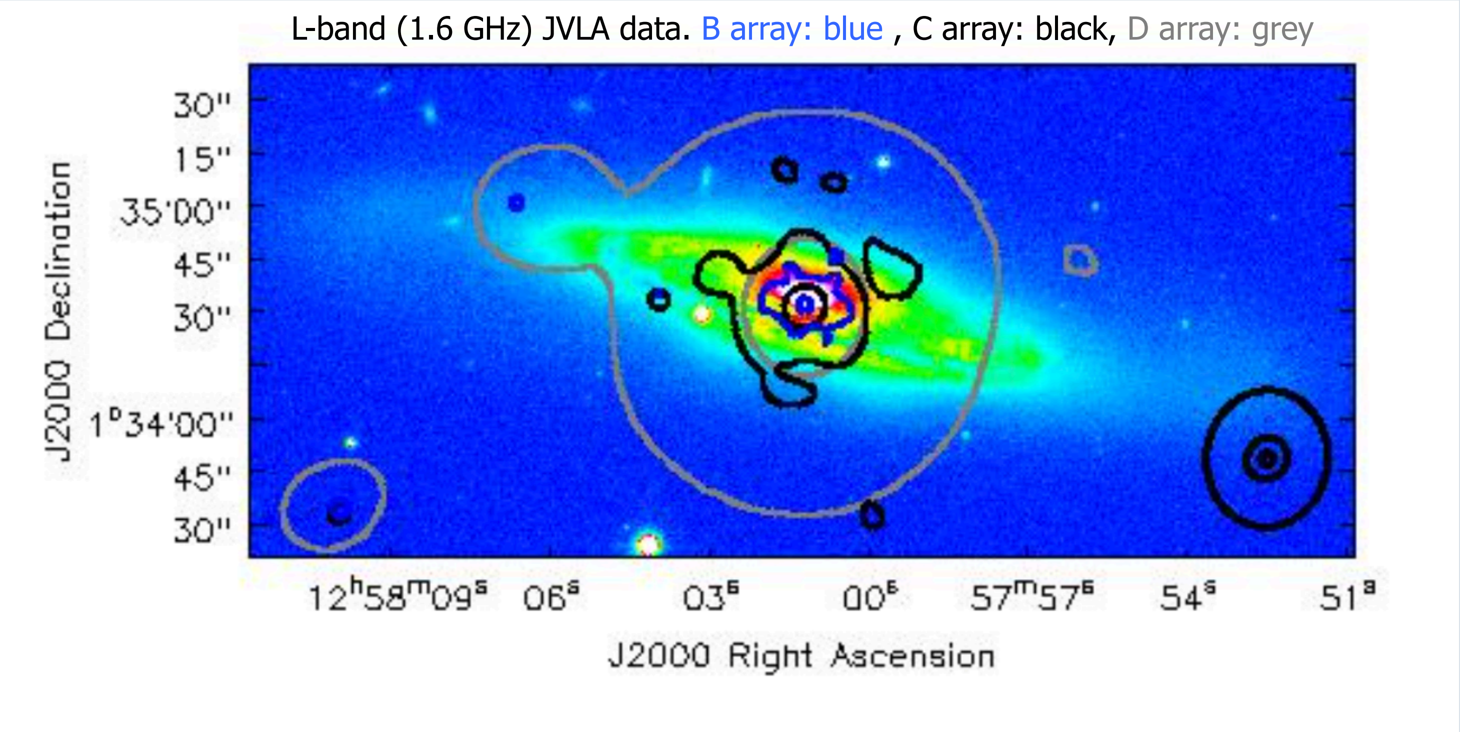
INTEGRAL hard X-ray transient detected in the core of the Seyfert 2 galaxy NGC 4845 in 2011 (**IGR J12580+0134**)

Nikołajuk & Walter 2013
A&A 552, A75

XMM-Newton, Swift, and MAXI follow-up: evolution as expected for a **TDE**

Variability: M_{BH}~3x10^5 $M_\odot$; <u>10% of a 14-30 Jupiter-mass object needed for the flare</u>

Expanding jet in IGR J126580+0134



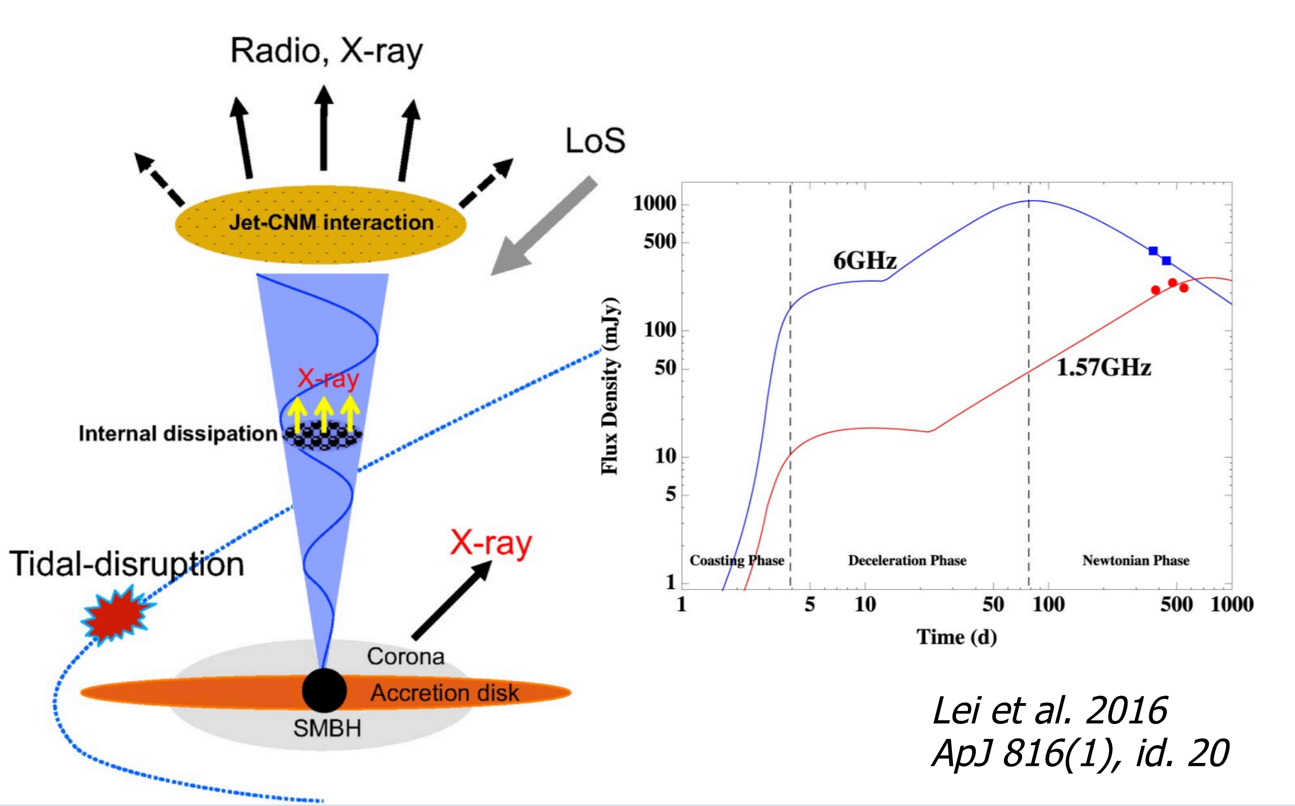
Irwin et al. 2015
ApJ 809(2), id. 172

1.4 GHz VLA surveys: 46 mJy (NVSS), 33.9 mJy (FIRST)

Within ~ a year after TDE: 230-260 mJy (1.6 GHz), 432-362 mJy (6 GHz)

SSA spectrum; spectral evolution consistent with adiabatic expansion, i.e. outflow that <u>should be resolvable with VLBI</u>

The first relativistic off-axis TDE



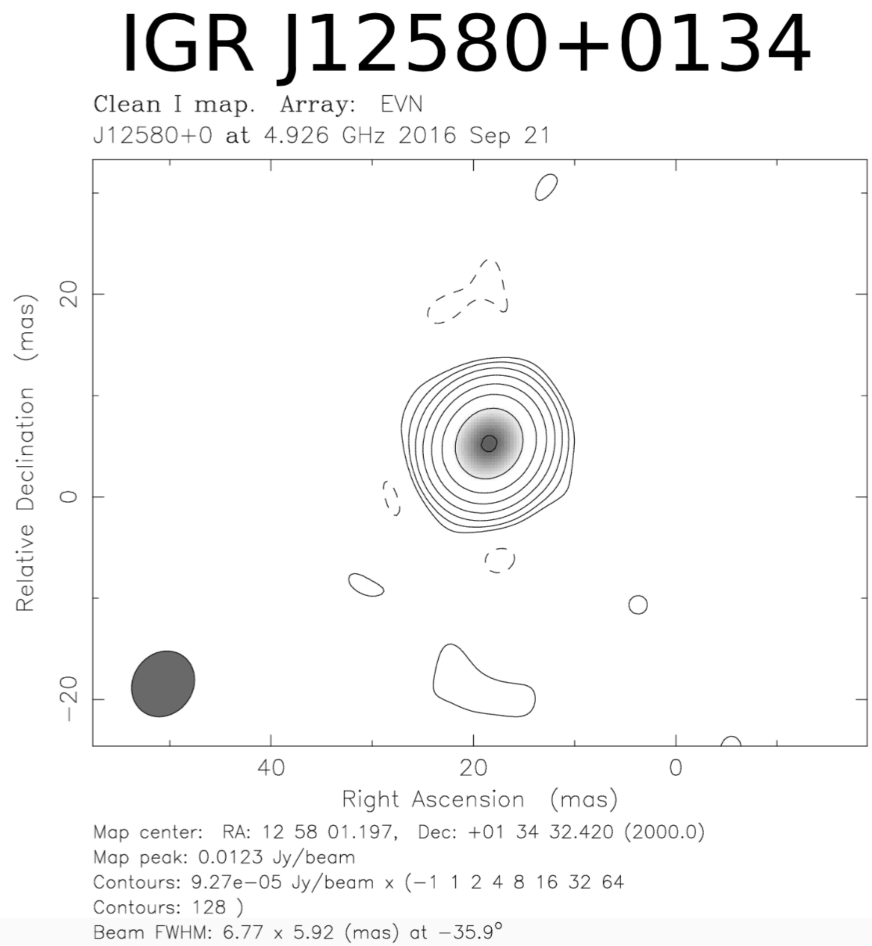
Lei et al. 2016
ApJ 816(1), id. 20

Lei et al. (2016) external forward shock model: expected 5 GHz flux is ~90 mJy now

Irwin et al. (2015) standard jet model: expected size is ~12 milliarcseconds now

=> The e-EVN should resolve IGR J12580+0134 at 5 GHz in 2016

The first relativistic off-axis TDE with the e-EVN



Blanchard et al. in prep.

=> No resolved jet; radio source is consistent with a faint Seyfert 2 core

Concluding remarks

- Knowledge of jet efficiency and typical Lorentz factor is important to be able to predict TDE rates
- Donnarumma et al. (2015) predicts TDE will be a unique probe of quiescent SMBH at high redshifts, especially in the **low-mass tail** of the SMBH mass function ($L_{\mathrm{TDE}} \propto M_{\mathrm{BH}}^{-1/2}$)!
- Future surveys in the optical (LSST), X-rays, radio (SKA) have great potential to detect a large number of events
- VLBI and especially when SKA1-MID added as a phased array will be a great tool to study jetted TDE
  (SKA-VLBI, Paragi et al. 2015)
- Currently no strong observational support for relativistic jets from VLBI yet; will keep trying… Gaia TDE candidates radio follow-up?