Radio Observations of TDEs: Status and Prospects

Kate D. Alexander

Unveiling the Physics Behind Extreme AGN Variability

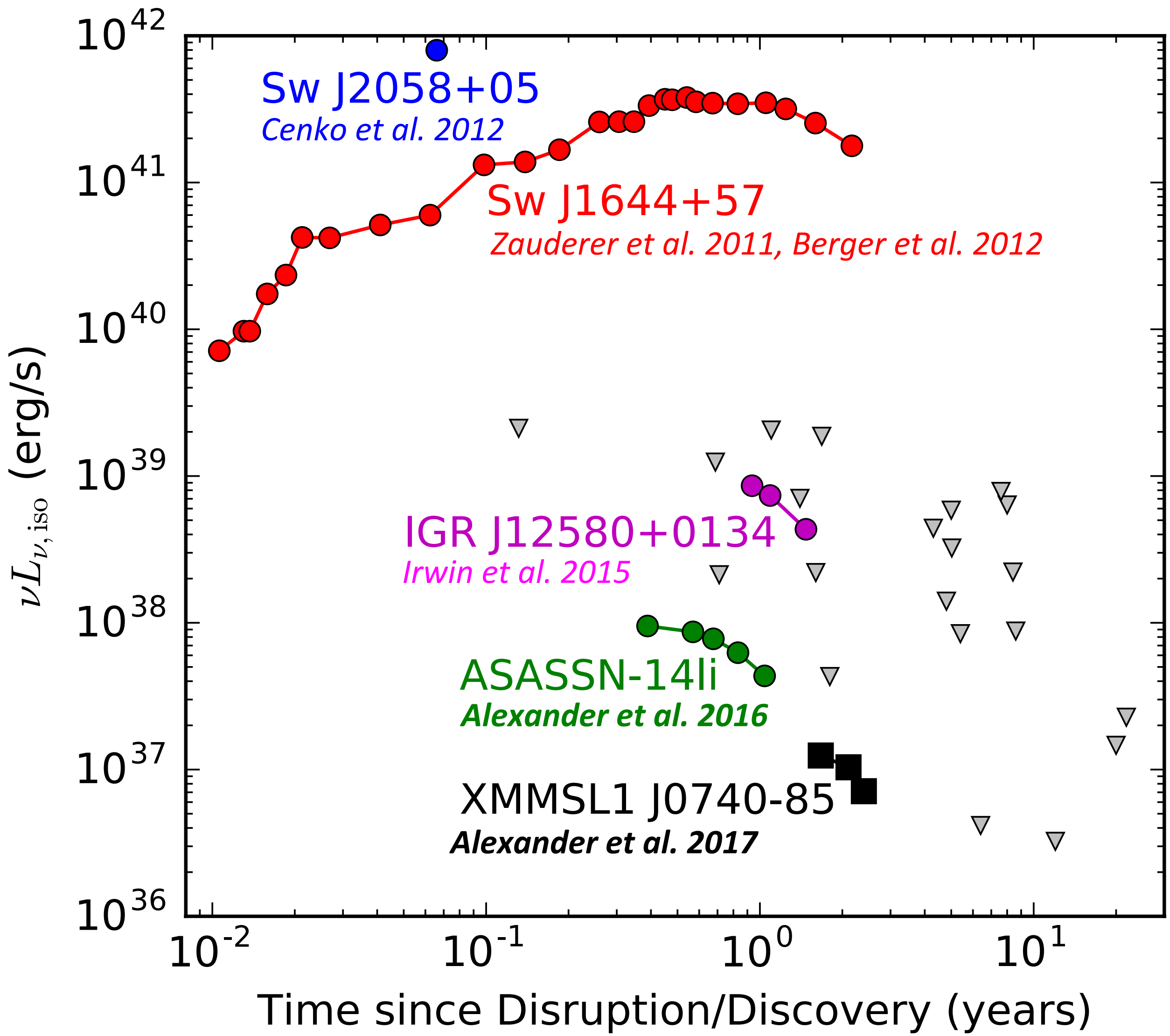
July 14, 2017

Part I: Current Status

Open Science Questions

- What process(es) produce radio emission in TDEs?
- How do relativistic jets form? What conditions are required?
- What do the environments around (recently) quiescent supermassive black holes look like?
- How can we optimize follow-up observations to maximize scientific return?

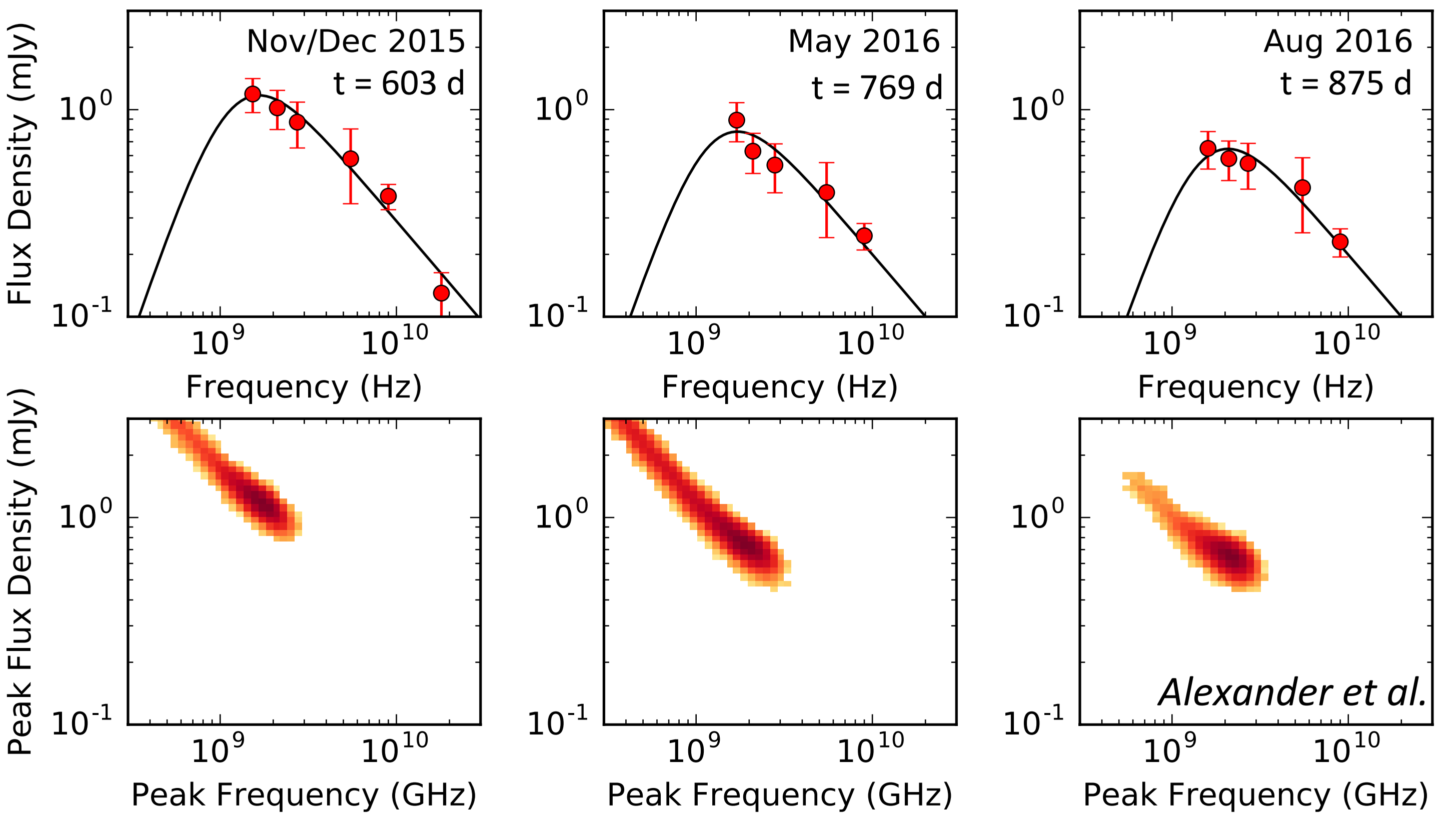
Current Radio TDE Sample



Alexander et al. (2017)

Synchrotron Model

- Fit each SED separately (no dynamical assumptions)
- SEDs transition from $\nu^{5/2}$ to ν^{-1} at $(\nu_p, F_{\nu,p})$



Alexander et al. (2017)

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Energy Equipartition

$$R_{\rm eq} \;=\; (3.4\times10^{15}\,{\rm cm})\,F_{\nu,p,mJy}^{\frac{9}{19}}\,d_{L,26}^{\frac{18}{19}}\,\nu_{p,10}^{-1}(1+z)^{-\frac{10}{19}}\,f_A^{-\frac{8}{19}}\,f_V^{-\frac{1}{19}}$$

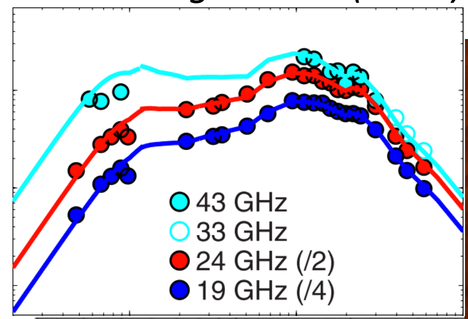
$$E_{\rm eq} \;=\; (4.3\times10^{46}\,{\rm erg})\,F_{\nu,p,mJy}^{\frac{23}{19}}\,d_{L,26}^{\frac{46}{19}}\,\nu_{p,10}^{-1}(1+z)^{-\frac{42}{19}}\,f_A^{-\frac{12}{19}}\,f_V^{\frac{8}{19}}$$

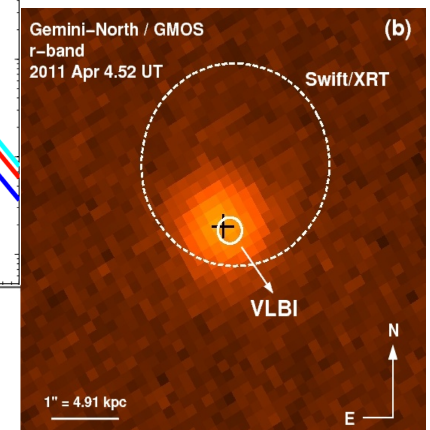
and other quantities (N_e, B, etc.)

Case Study I: Sw J1644+57

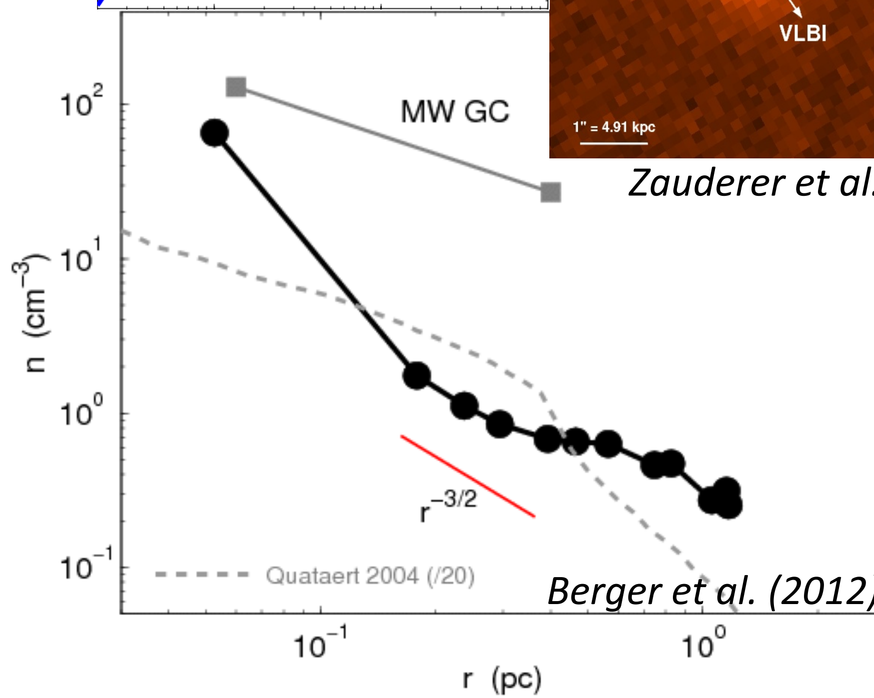
- Radio localization to the core of a *z = 0.354* galaxy
- On-axis **relativistic jet**
- Circumnuclear density
  - Better spatial resolution than Galactic center observations!
- An unusually energetic event (E ~ 10^{52} erg)
  - similar jets **ruled out** for bulk of TDEs by radio detections/limits

Berger et al. (2012)





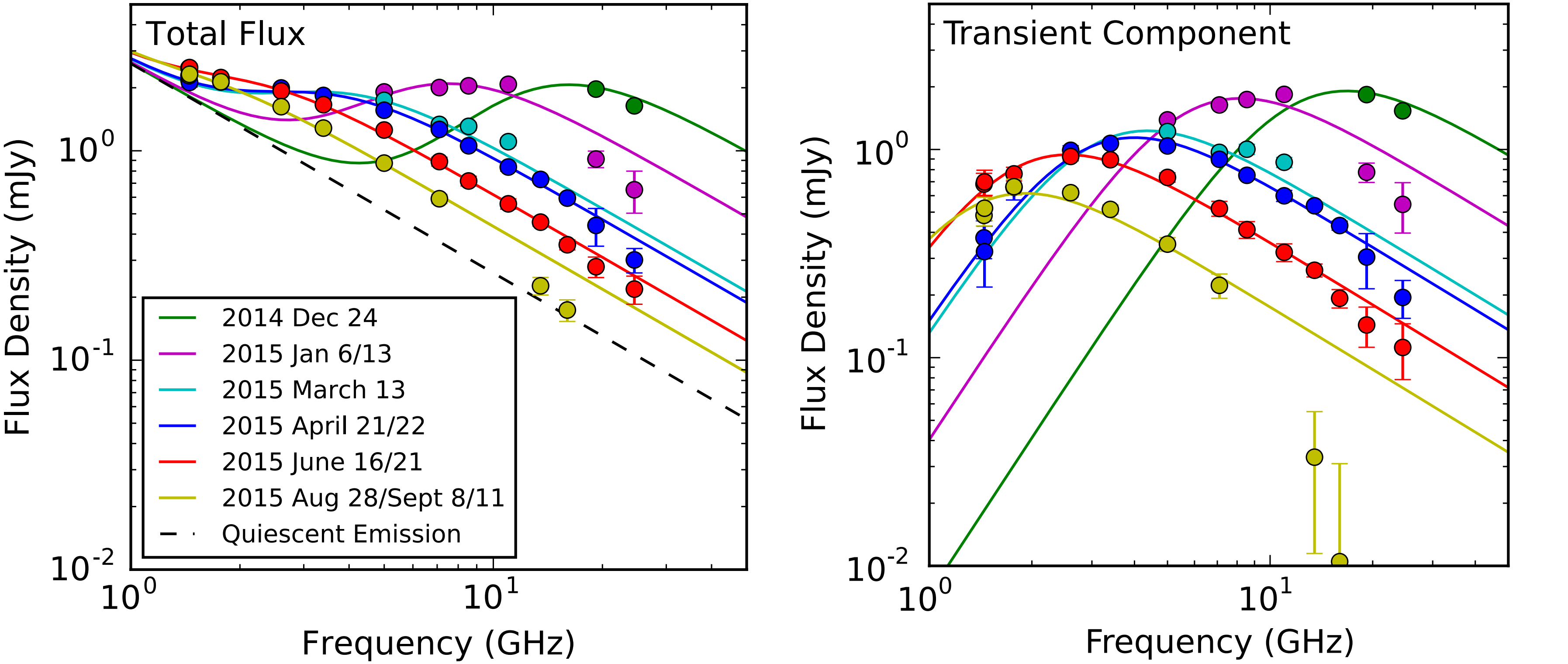
Zauderer et al. (2011)



Berger et al. (2012)

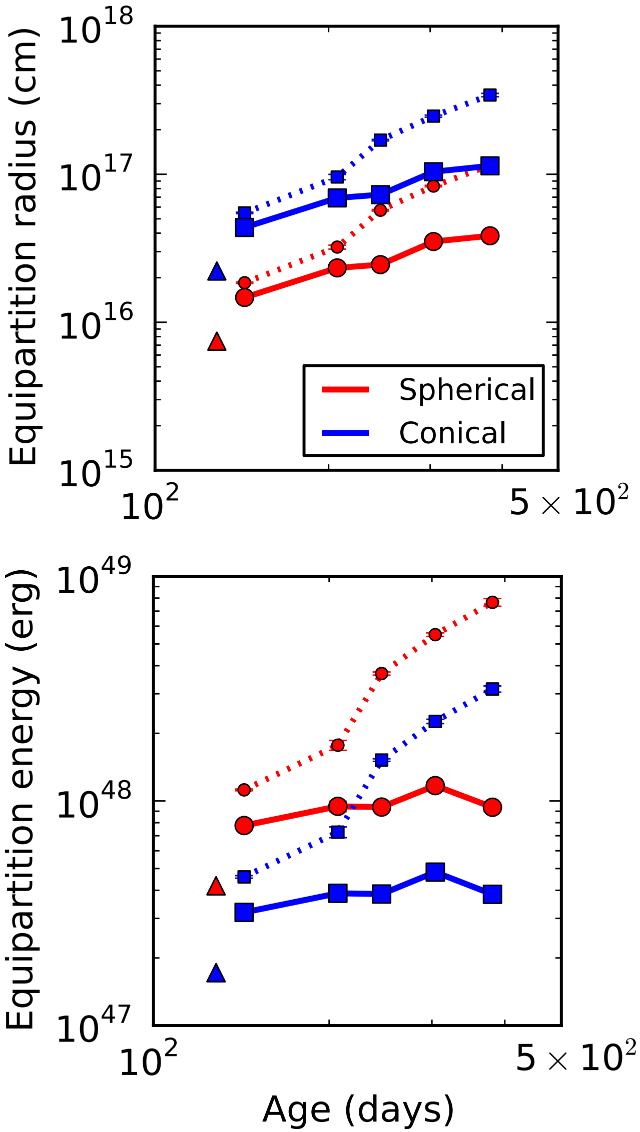
Case Study II: ASASSN-14li

adapted from Alexander et al. (2016)



- The emission is best modeled as the sum of a steady source with $F \propto \nu^{-1}$ (dashed line) and a transient component (right panel)
- Steady component is consistent with archival 1.4 GHz detections.

A Non-Relativistic Outflow



Fitting each SED independently, we find:

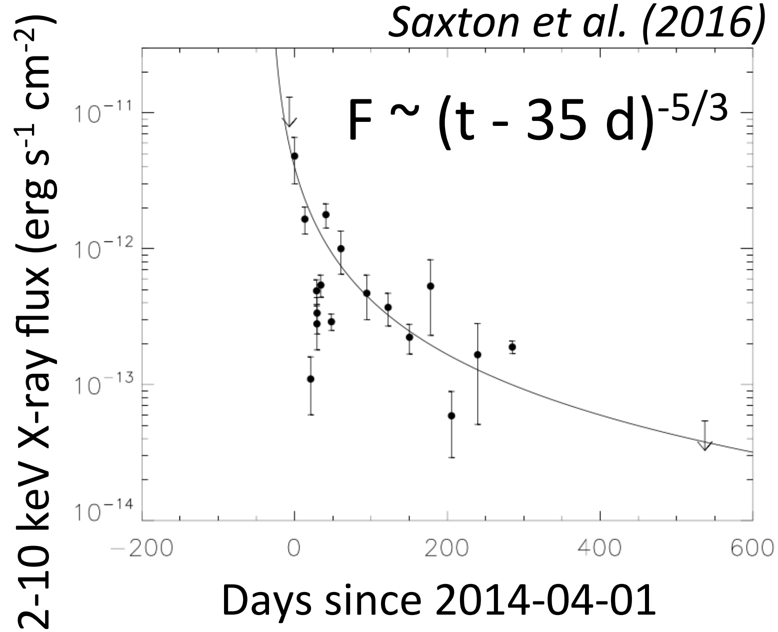
- The emitting region is expanding at a constant velocity of ≈12,000 – 36,000 km s^{-1}
- The outflow energy is roughly constant in time, E ≈ (4-10) × 10^{47} erg
- See also: van Velzen poster

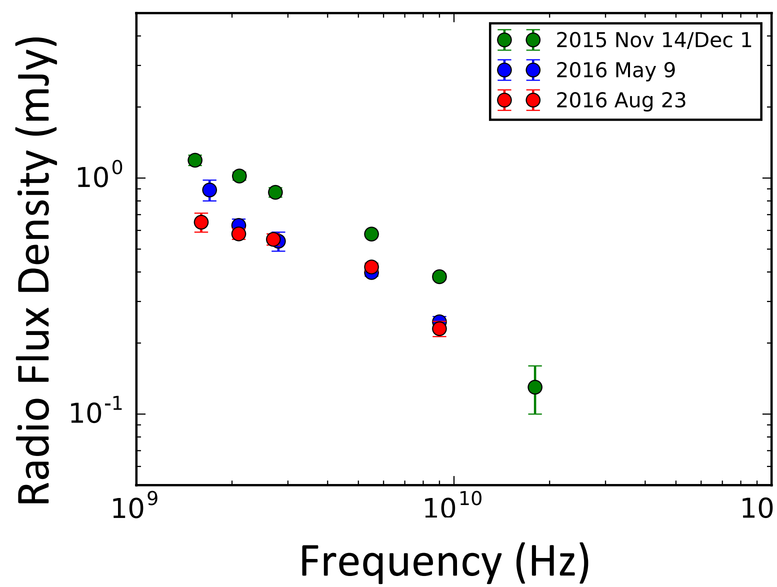
Alexander et al. (2016)

Case Study III: XMMSL1 J0740-85

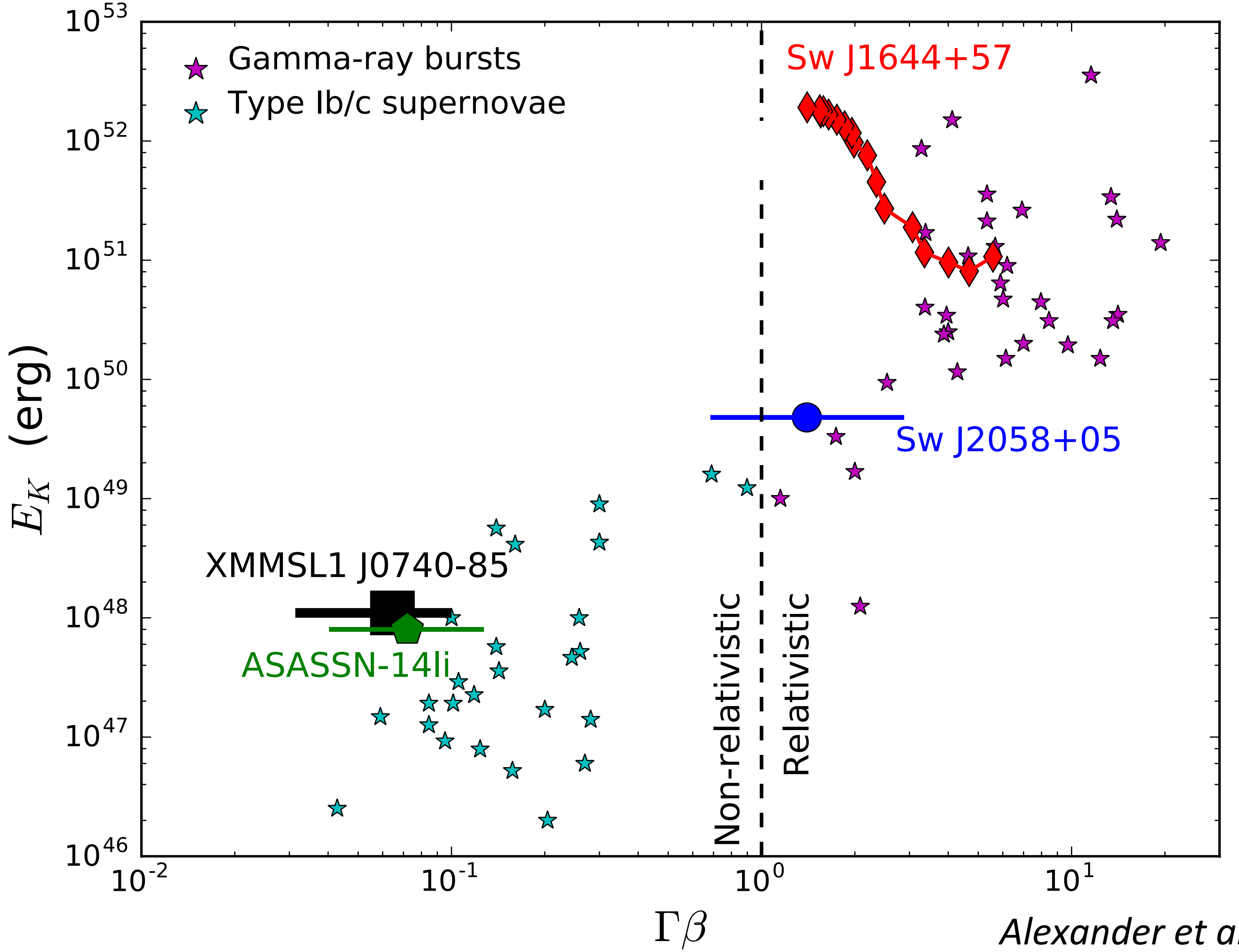
- Nearby TDE discovered in the XMM-Newton Slew Survey
  - X-ray emission shows both thermal and nonthermal components
  - Peak accretion rate is sub-Eddington
- Fading radio emission detected 19-28 months after discovery
  - Either a weak decelerated relativistic jet or a non-relativistic outflow match the observations
  - Earlier radio observations needed to break modeling degeneracies

Saxton et al. (2016)



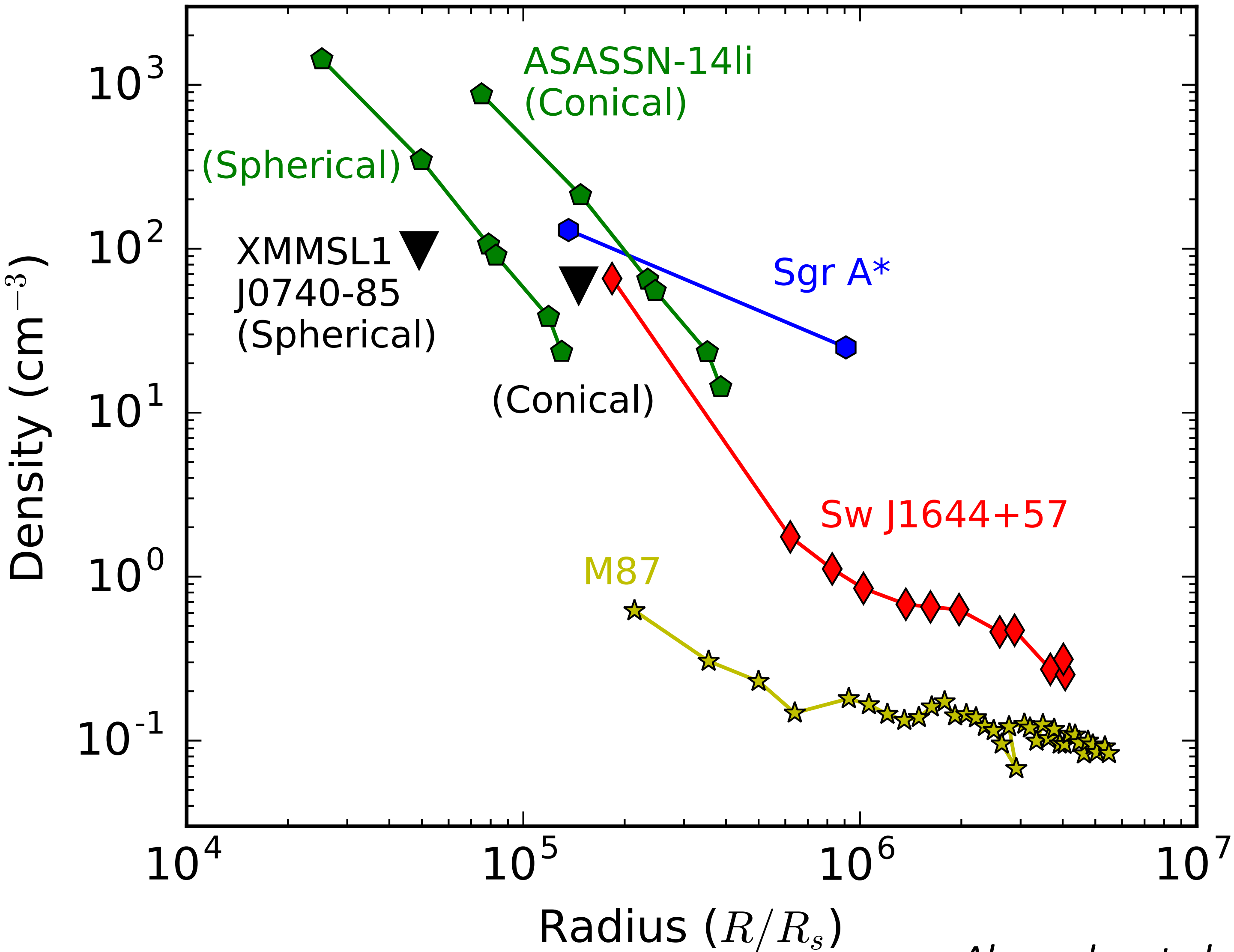


TDE Populations: Energetics



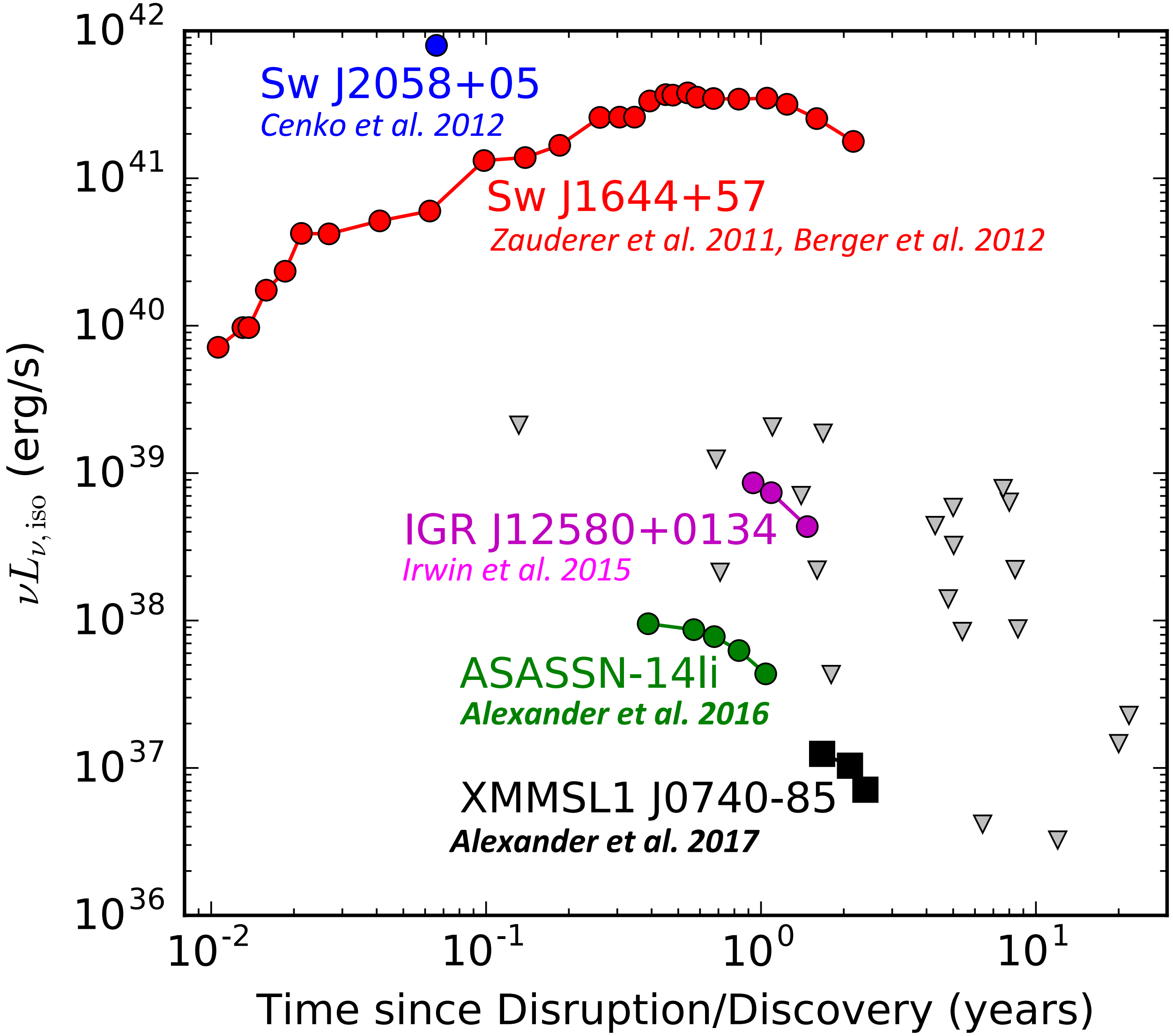
Alexander et al. (2017)

Circumnuclear Density Profiles

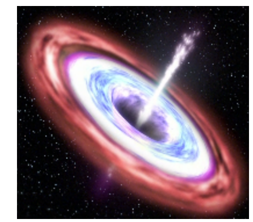


Alexander et al. (2017)

Expanding the Radio TDE Sample

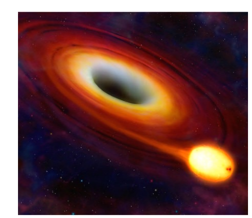


On-axis jet



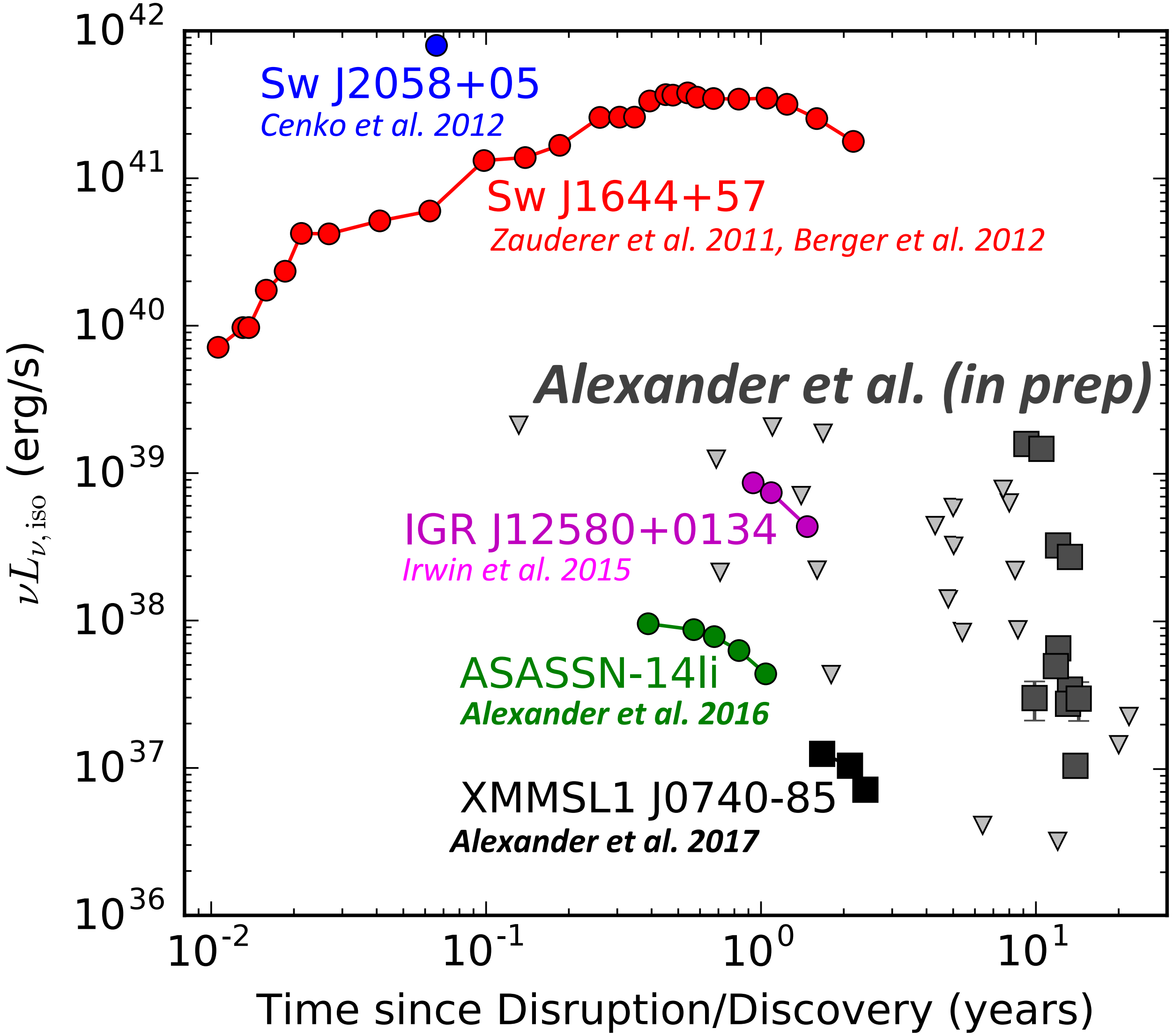
Off-axis jet

Non-relativistic outflow



Alexander et al. (2017)

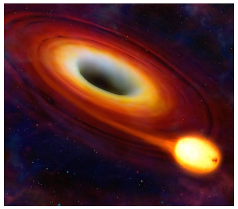
Expanding the Radio TDE Sample



On-axis jet

Off-axis jet

Non-relativistic outflow

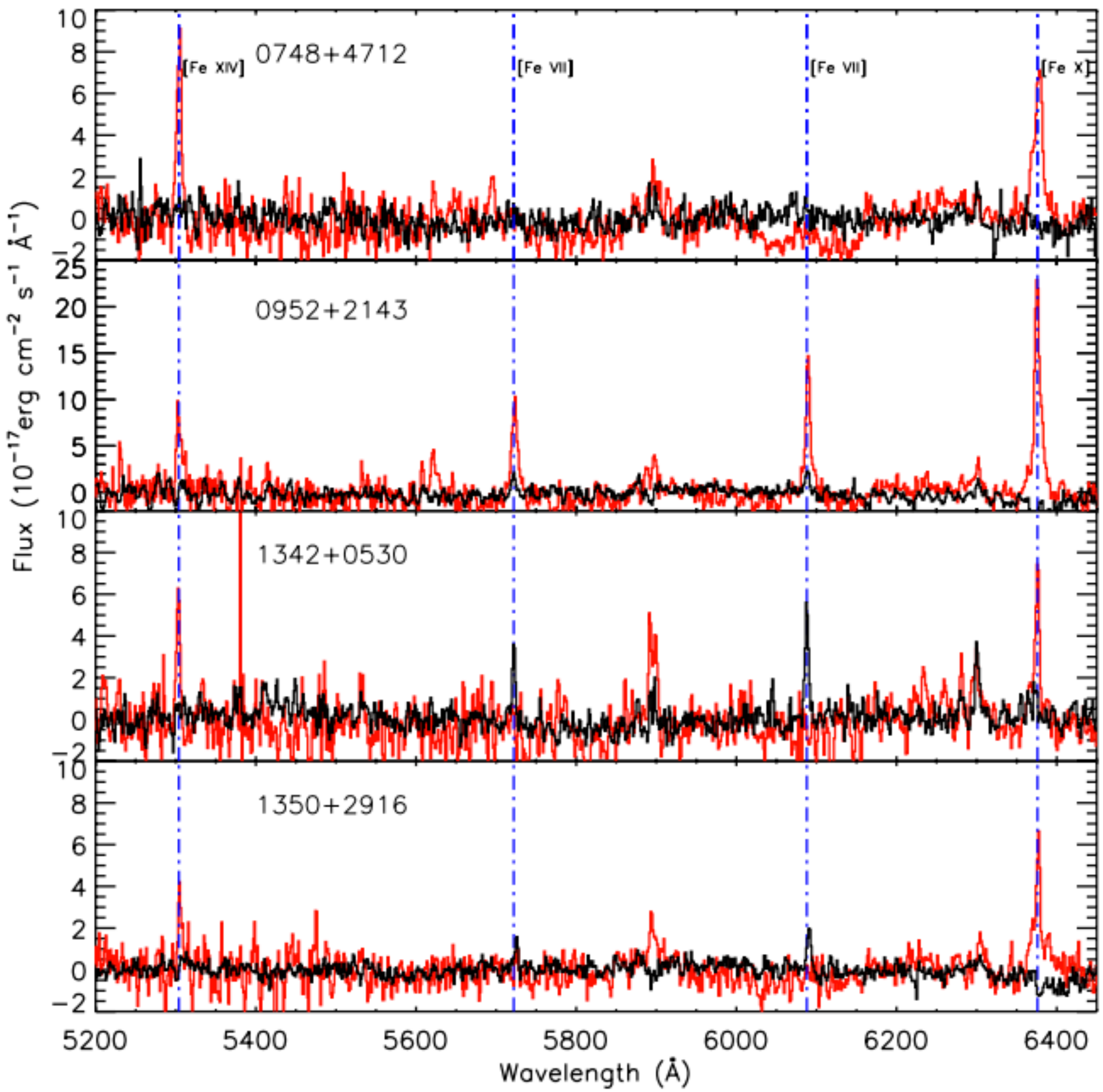


Alexander et al. (2017)

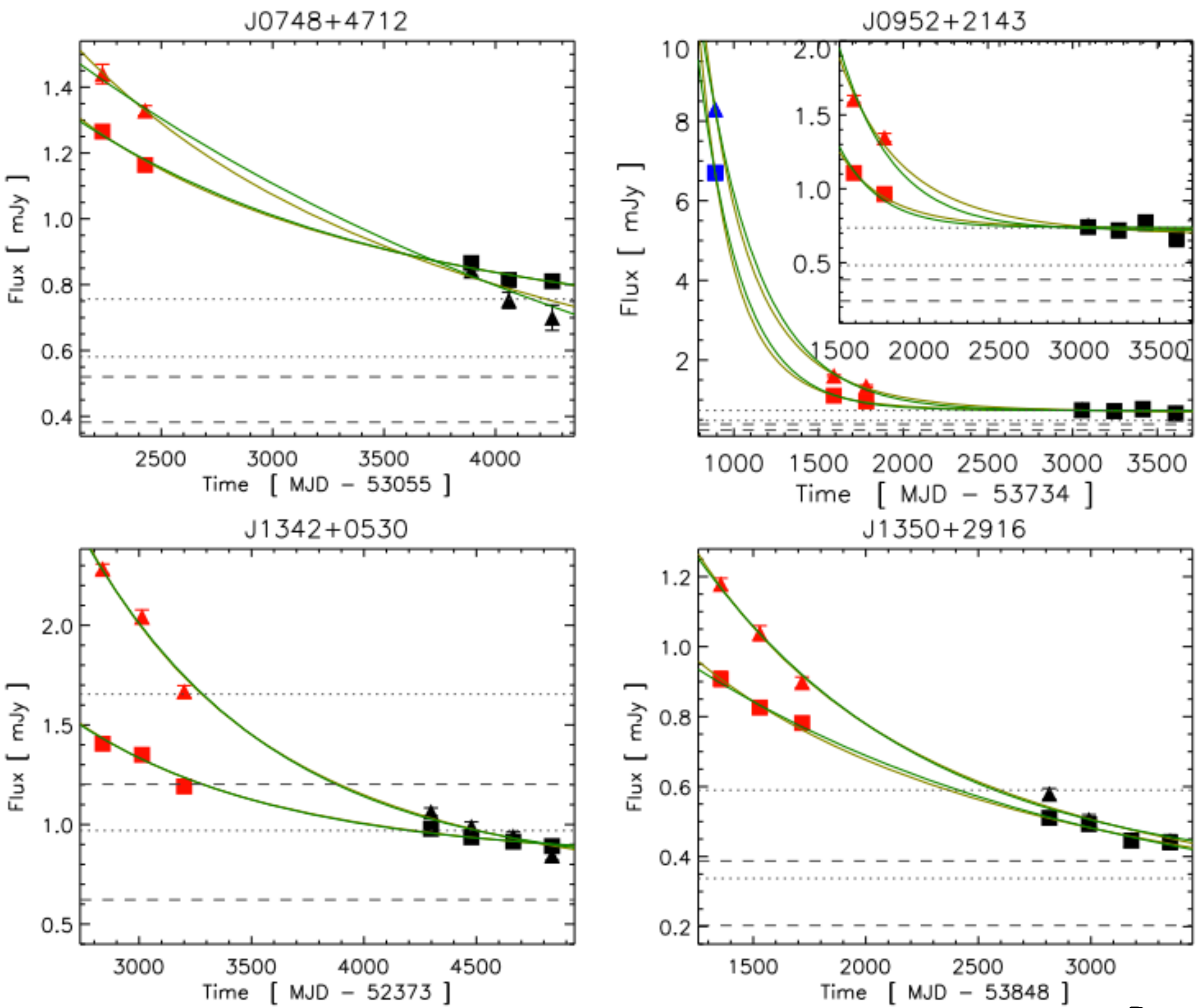
Extreme Coronal Line Emitters

Yang et al. (2013)

- Evidence of highly ionizing radiation
- Lines faded over 5-10 yr in 4 of 7 SDSS ECLE galaxies selected by Wang et al. (2012)



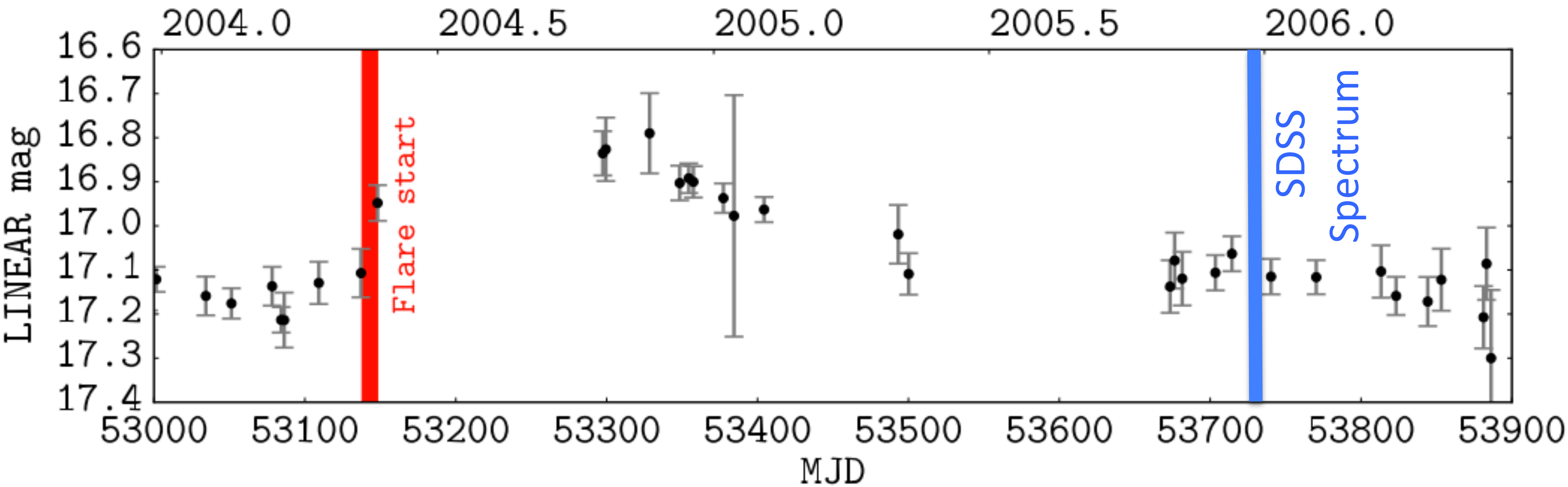
Mid-IR Echos in WISE data



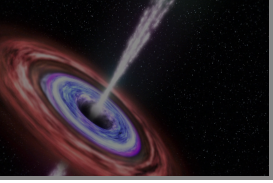
Dou et al. (2016)

SDSS J0952+2143: Optical Flare

Palaversa et al. (2016)



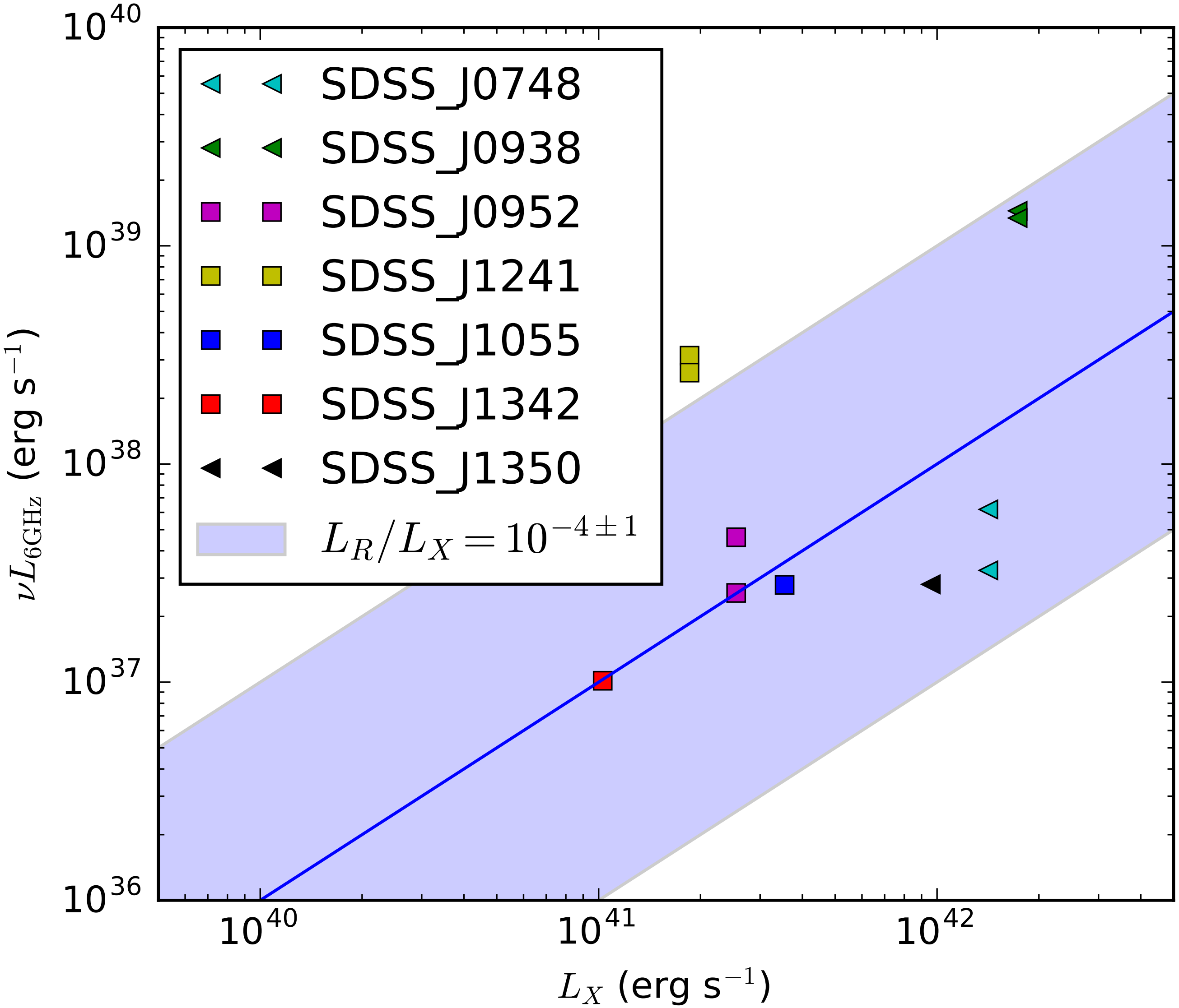
- LINEAR optical survey serendipitously detected an optical flare ~1.6 yr before SDSS spectrum
- 10 year light curve shows optical variability of σ < 0.08 mag outside of flare interval



Radio Observations

Initial Detections at 5.0 and 7.1 GHz (March 2016):

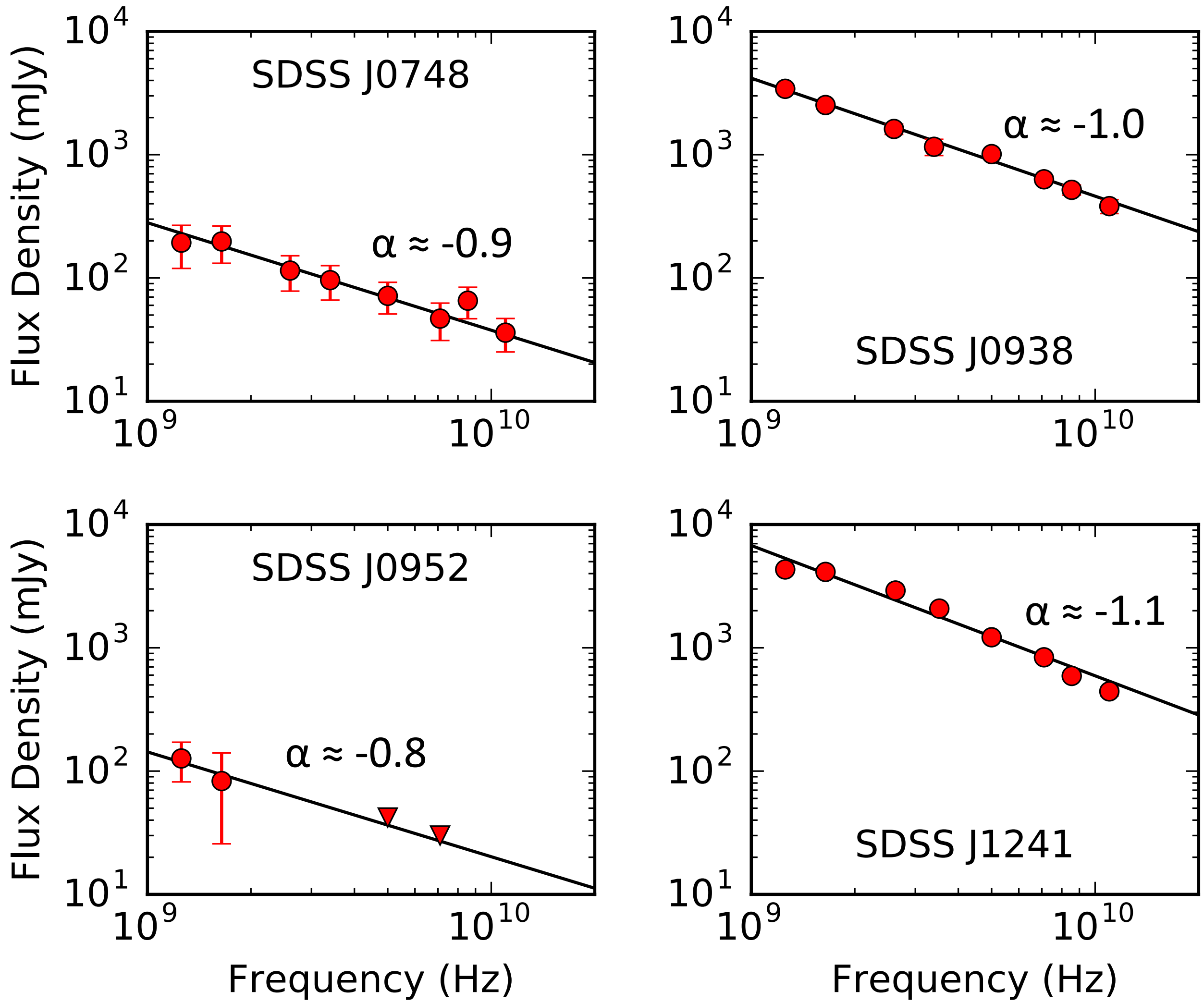
- All 7 Wang et al. sources detected (flux densities 0.03 – 1.2 mJy)
- Steep spectral indices (α = -0.6 – -1.6)
- X-ray coverage is poor, but L_R/L_X similar to radio-quiet AGN
-



Alexander et al. (in prep)

Radio Observations

- Four brightest sources reobserved (June 2017)
- SDSS J0748 fades faster than expected for a TDE ($F_\nu \propto t^{-7\pm3}$), others also fade.
- SDSS J0938: 1.4 GHz flux density is comparable to 1999 FIRST detection
- SDSS J1241: factor of 5 brighter than FIRST upper limit



Alexander et al. (in prep)

TDEs? AGN flares?

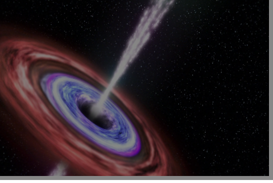
- Strong coronal line emission is NOT a simple TDE diagnostic in isolation
  - ECLE galaxies with fading coronal lines may have hosted TDEs, but some are likely AGN
  - Has this level of coronal line variability been seen in AGN before?
- Radio observations should be part of a multi-wavelength follow-up strategy
  - Early follow-up key for constraining emission models
  - In our ECLE sample, any TDE-caused radio emission is less energetic than Sw J1644+57 jet

Part II: The Survey Era

Radio Interferometers

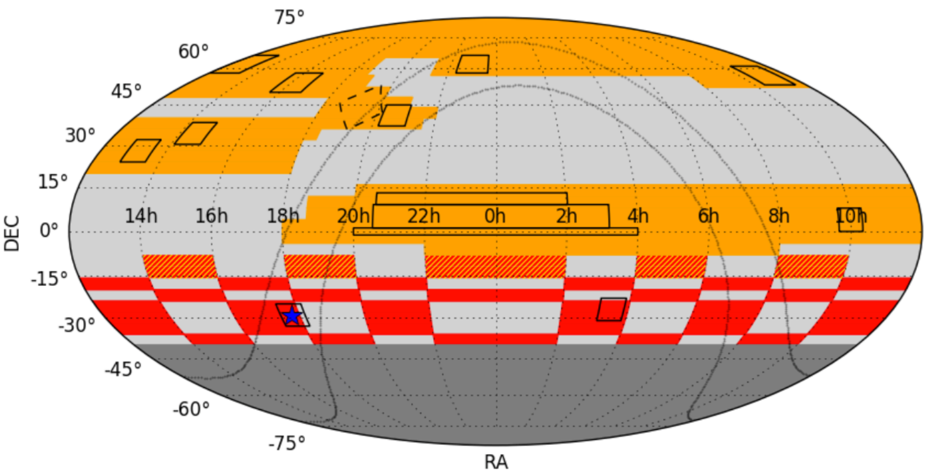
- VLA, ATCA, ALMA, LOFAR, MWA, ASKAP, MeerKAT, etc.
- To date: surveying large areas of the sky at high sensitivity and resolution is difficult, very time consuming
- Future: era of all-sky radio surveys, real-time transient searches (SKA, others)
- A better understanding of known radio transient populations will inform survey strategies

Image courtesy of NRAO/AUI



Looking Forward: VLA Sky Survey

- All sky coverage north of declination -40°
  - 5520 hr over ~7 yr (6 configuration cycles)
  - 3 epochs separated by 32 months
- Single frequency band (2-4 GHz), full polarization
- 2.5 arcsec resolution
- Survey rms ~69 μJy/beam
  - 9.7 million extragalactic source detections predicted
- Pilot survey completed last year; first epoch on schedule to begin fall 2017

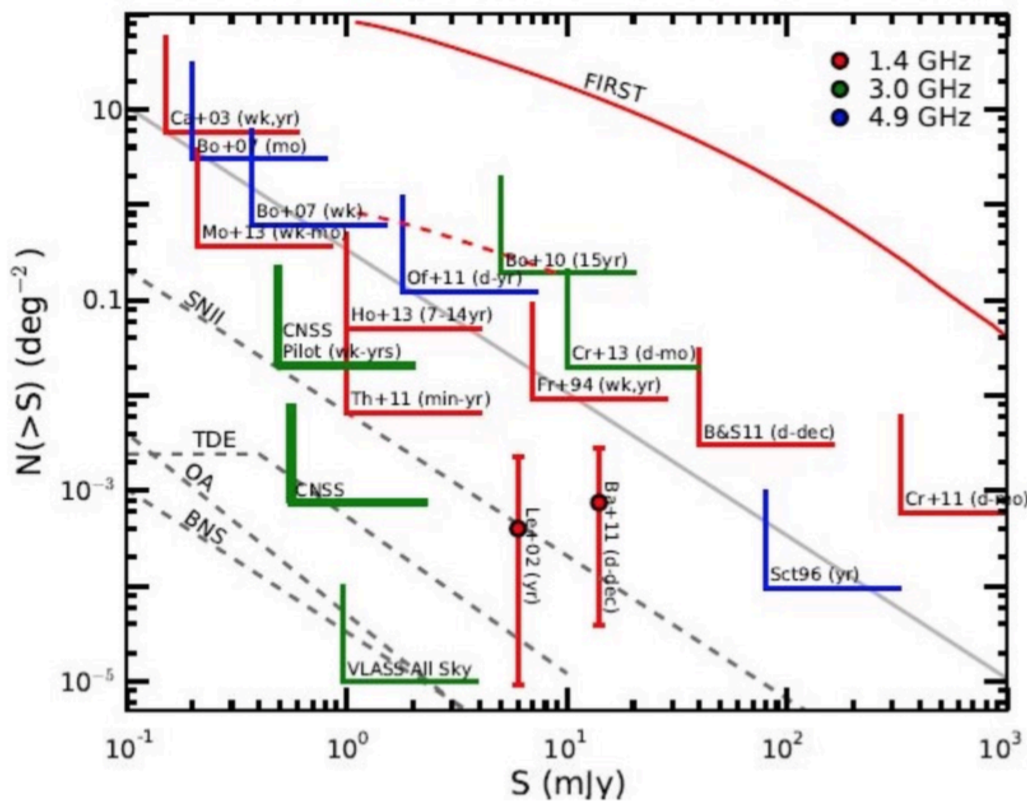


VLASS Memo 7

VLASS for transient discovery

- TDE radio emission evolves slowly at 3 GHz
  - New TDEs in survey data may be difficult to distinguish from other transients
  - In most cases, sources will be identified too late for rapid early follow-up
- Final source catalogs will be valuable reference to interpret future TDE candidates

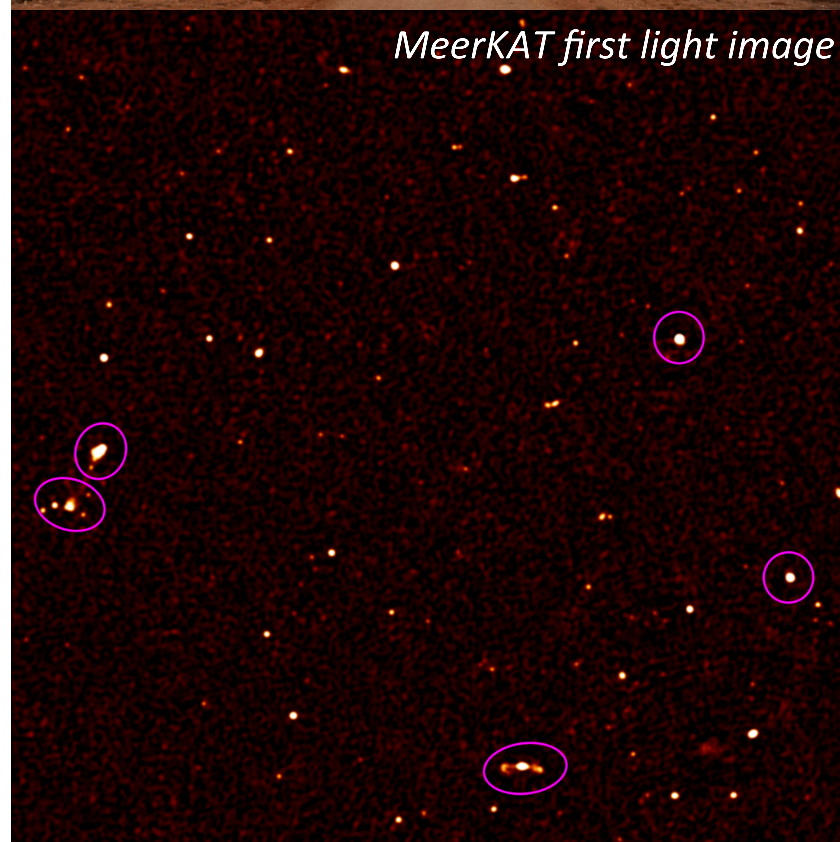
Instantaneous 3 GHz Source Counts of Radio Transients



VLASS Memo 3

Upcoming Surveys: Long Term

- Square Kilometer Array
  - TDE discovery rate poised to increase by orders of magnitude
  - ThunderKAT: SKA precursor radio transients survey
- How do we identify the most promising candidates for follow-up?
  - Large radio flares in galaxy centers with durations of months – years
  - Multiwavelength approach



Conclusions

- Progress on TDE open science questions:
  - What process(es) produce radio emission in TDEs?
    - *Relativistic jets (sometimes), non-relativistic winds*
  - What conditions are required to form relativistic jets?
    - *Highly super-Eddington accretion seen in extreme relativistic events (Sw J1644+57)*
  - What do the environments around (recently) quiescent supermassive black holes look like?
    - *Steep $r^{-2.5}$ profile in "gold standard" TDE ASASSN-14li*
- This is an exciting time for radio transient science!
  - Ongoing surveys will soon provide deep radio sky maps
  - Planned surveys will discover new transients in real-time, complementing follow-up of TDEs and AGN outbursts at other wavelengths.