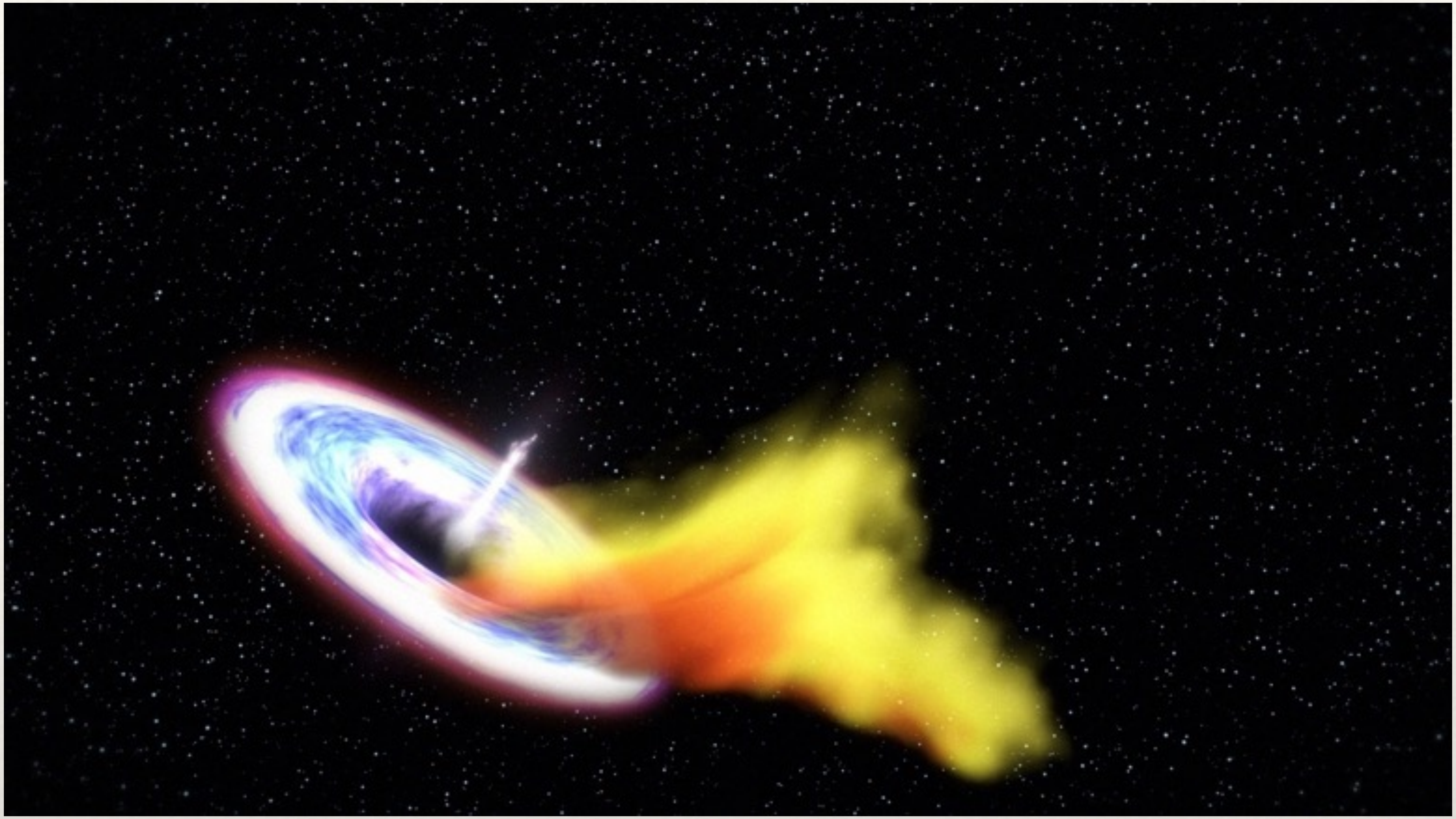
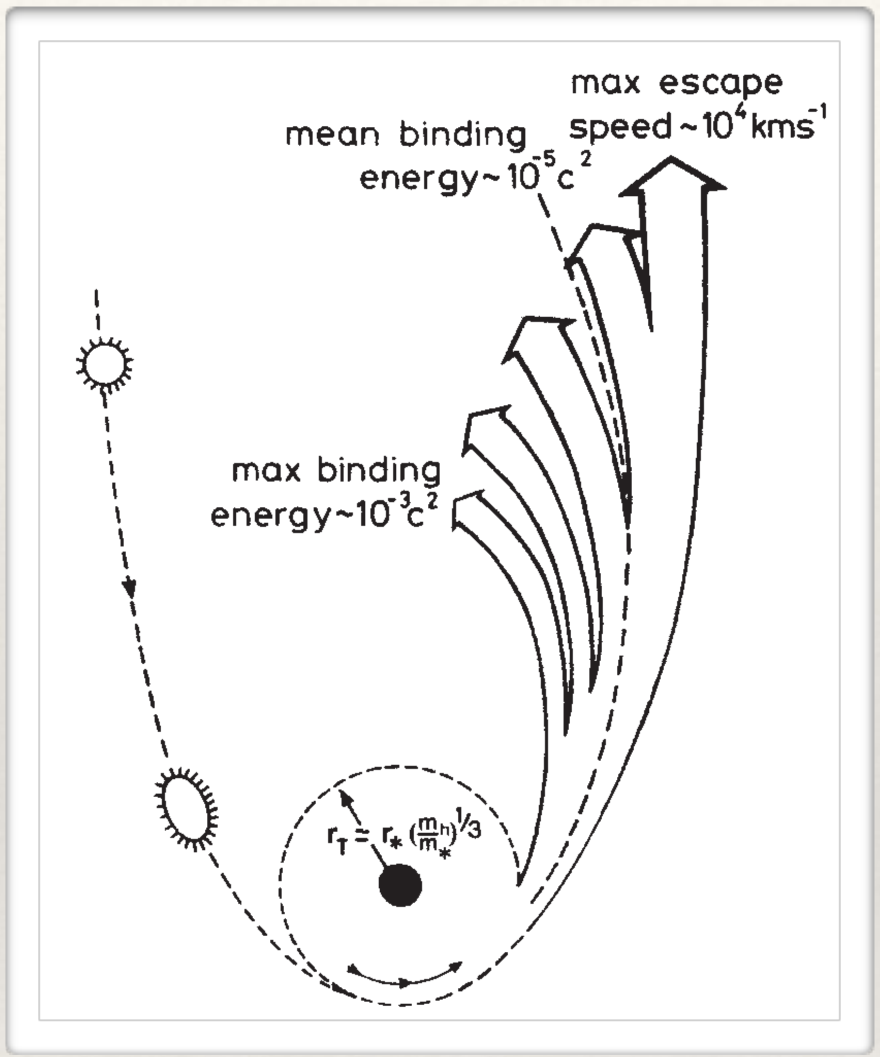


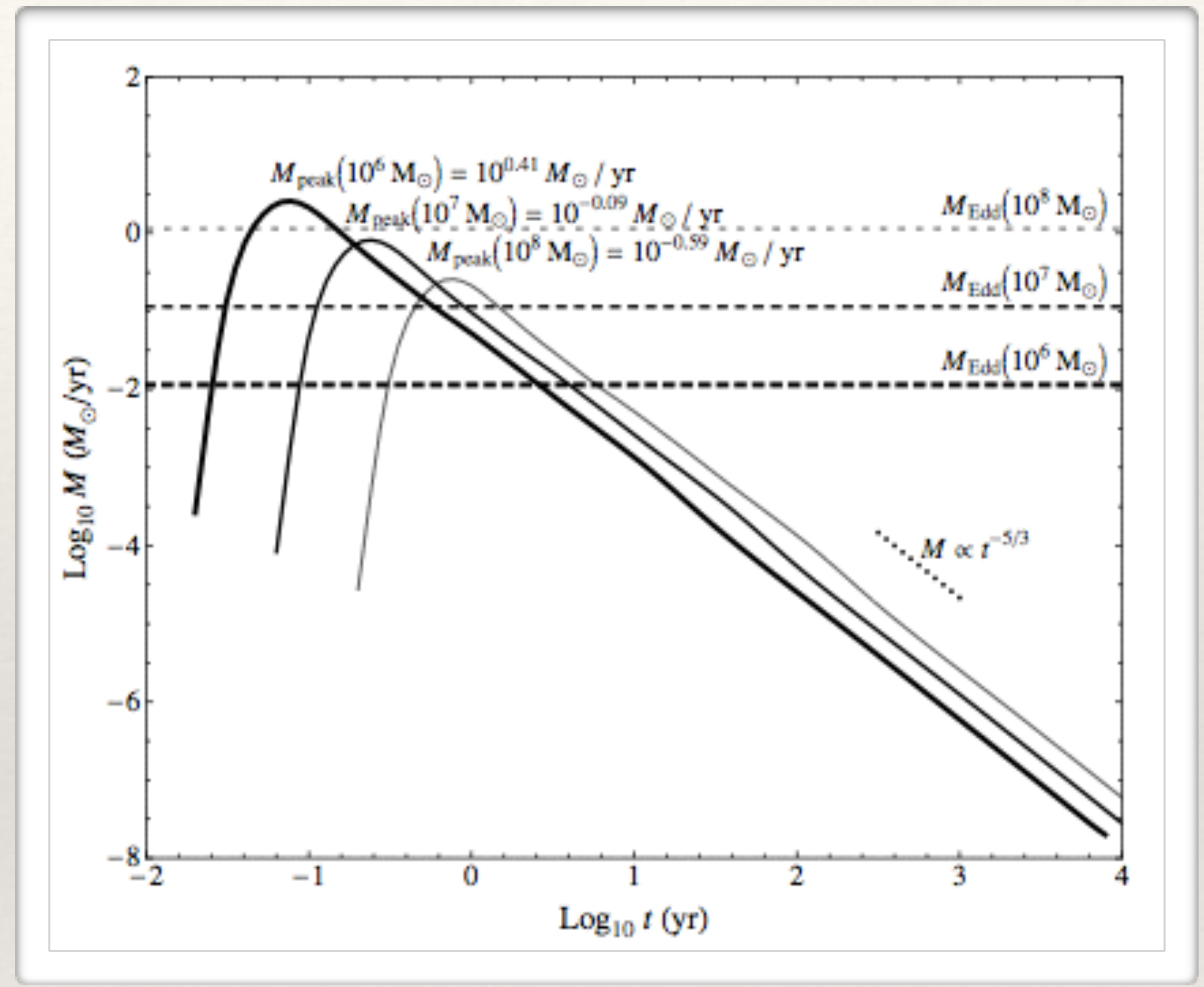
Observational Progress in Identifying and Characterizing Tidal Disruption Flares

Brad Cenko
NASA Goddard Space Flight Center
IAU 324: New Frontiers
September 13, 2016

Tidal Disruption Flares (TDFs)



Rees 1988

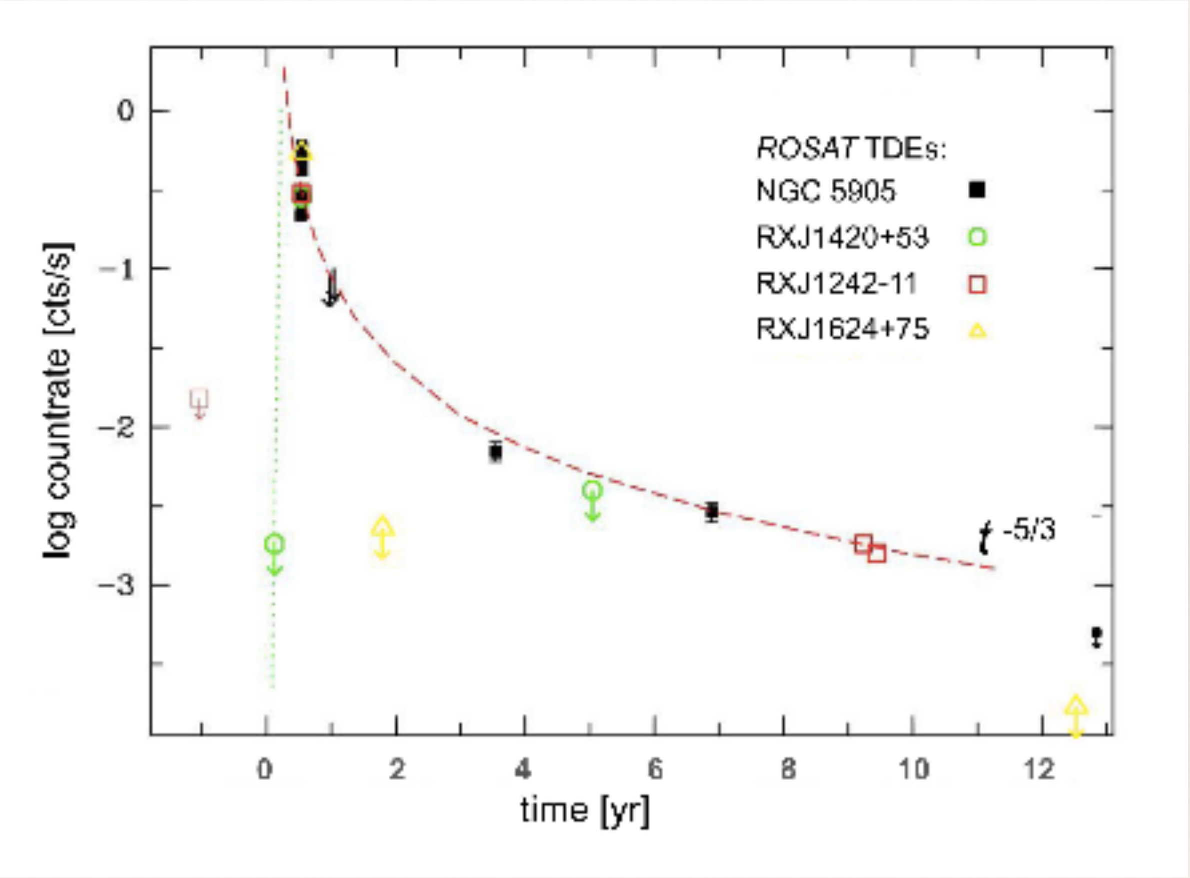


De Colle+ 2012

Luminous (10^{44} erg s^{-1}), long-lived (> months), thermal (10^5 K) flares from nuclei of otherwise quiescent galaxies

Early TDF Discoveries: X-Ray Selected

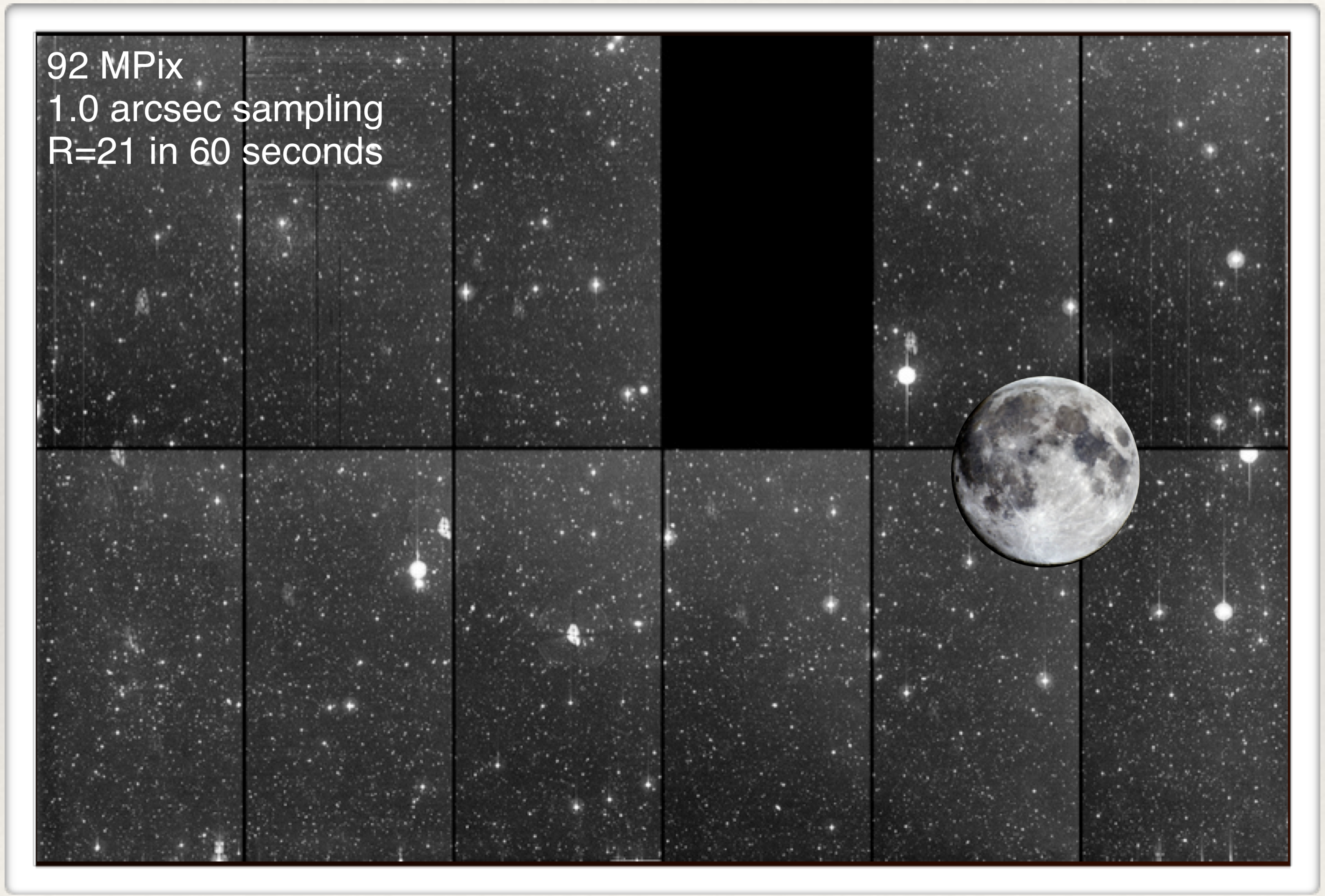
- Earliest events identified largely by ROSAT
- Agreed reasonably well with simple analytical models (kT <~ 100 eV, blackbody radius ~ tidal radius, $t^{-5/3}$ decay (though sparsely sampled)
- Subsequent X-ray discoveries have indicated additional diversity (see upcoming talk by Richard Saxton)



Komossa, 2015

Rise of Optical Time-Domain Surveys

7.1 deg camera on Palomar 48 inch Oschin Schmidt telescope



Wide-field, high cadence optical transient surveys (Pan-STARRS, PTF, ASAS-SN) have revolutionized the search for TDFs

Rise of Optical Time-Domain Surveys

Summit of Palomar Mountain

P48 = discovery

P200 (Keck, Gemini) = Spectroscopy

P60 = Multi-color Imaging

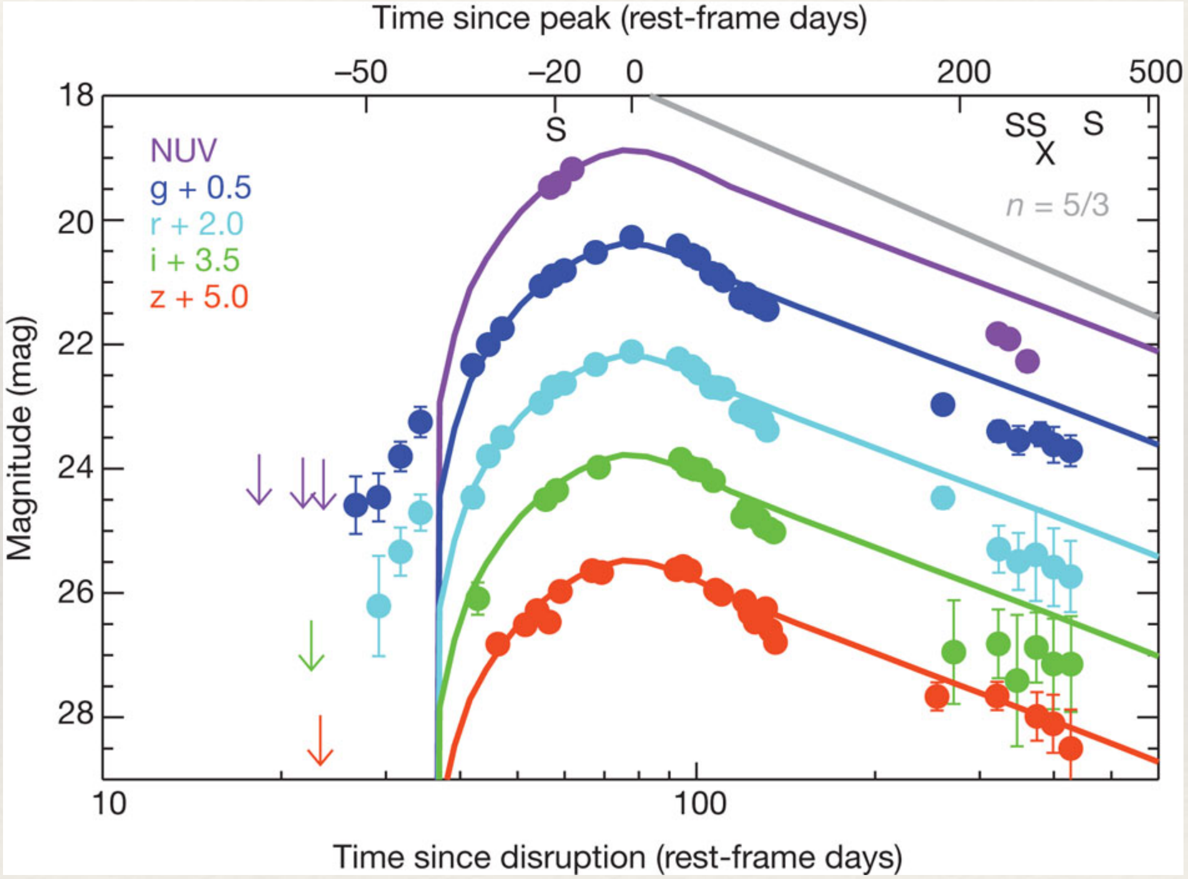
Factory = fully automated, end-to-end discovery and follow-up

Observational Puzzles

- Low (and slowly evolving) temperature in optical/UV discovered TDFs
- Ubiquity of outflows (variety of velocities)
- Peculiar abundance patterns in optical (and particularly UV) spectroscopy
- Preferentially observed in "post-starburst" host galaxies

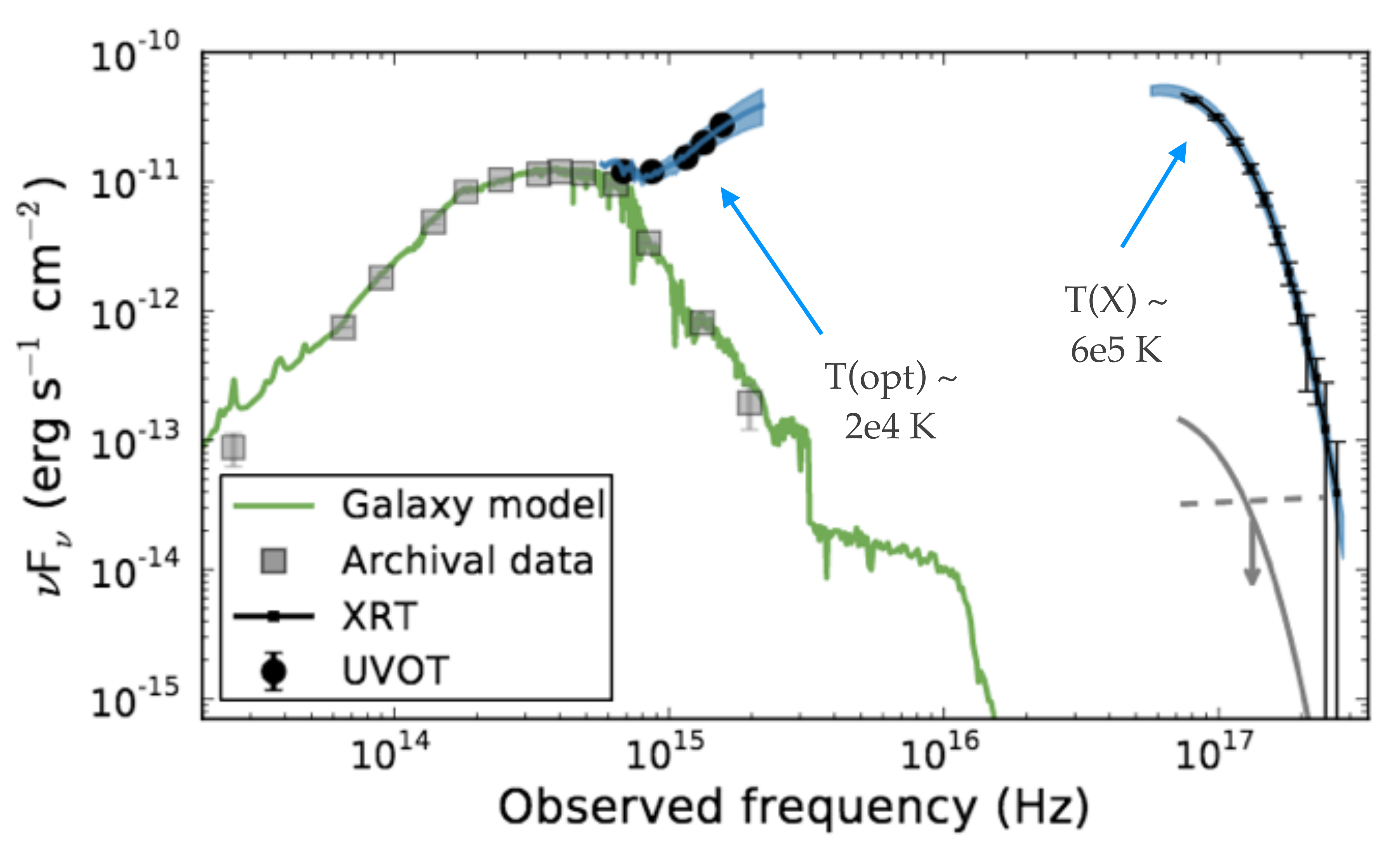
PS1-10jh: Cool, Constant Temperature

- PS1-10jh: Nucleus of non star-forming galaxy
- After removing host galaxy, blackbody continuum with T ~ 2 x 10^4 K (factor of > 5 lower than ROSAT events)
- No sign of color evolution for > 100 (rest-frame) d
- Corresponding blackbody radius ~ 10^{15} cm - **a factor of 10-100 larger than the tidal radius!**



Gezari et al., 2012

ASASSN-14li: At Least 2 BB Components

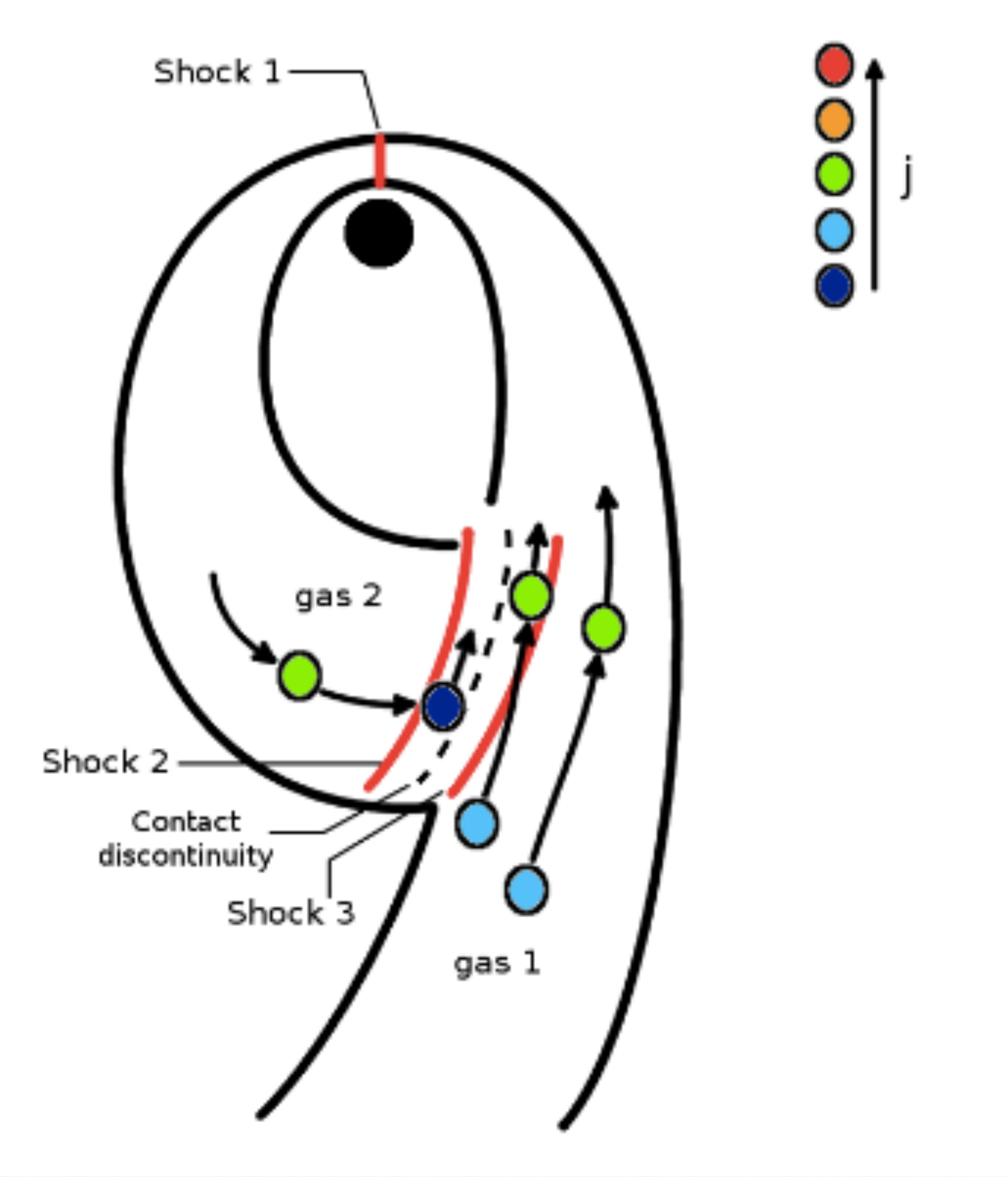


Van Velzen
et al., 2016

Comparable luminosity but varying temperature ⇒ **distinct emitting regions!**

Possible Explanations: Circularization and Reprocessing

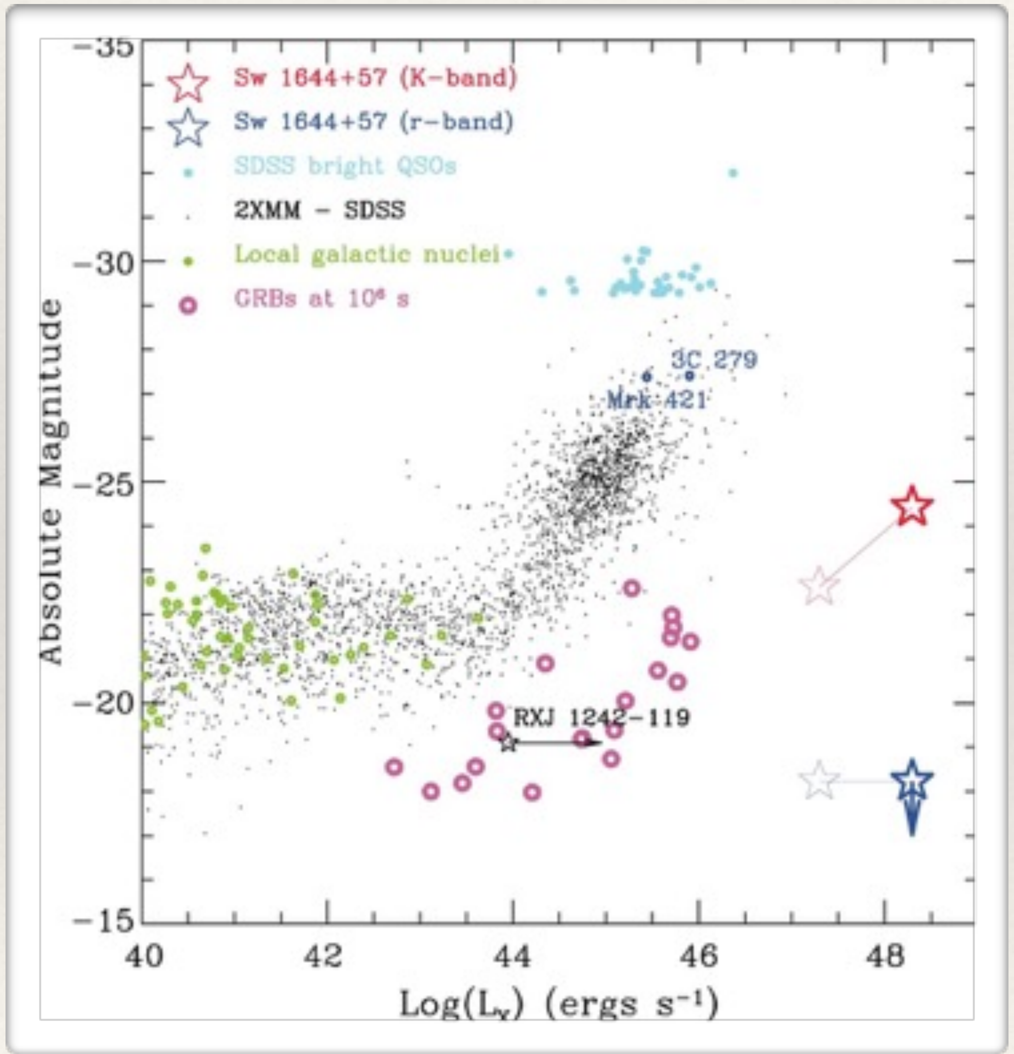
- 1. Efficient circularization at large radii (due to relativistic precession) leads directly to emission at these distances (e.g., Shiokawa et al., 2015)
- 2. Reprocessing of inner accretion disk by outer layer of material yields large photosphere (e.g., Roth et al. 2015)



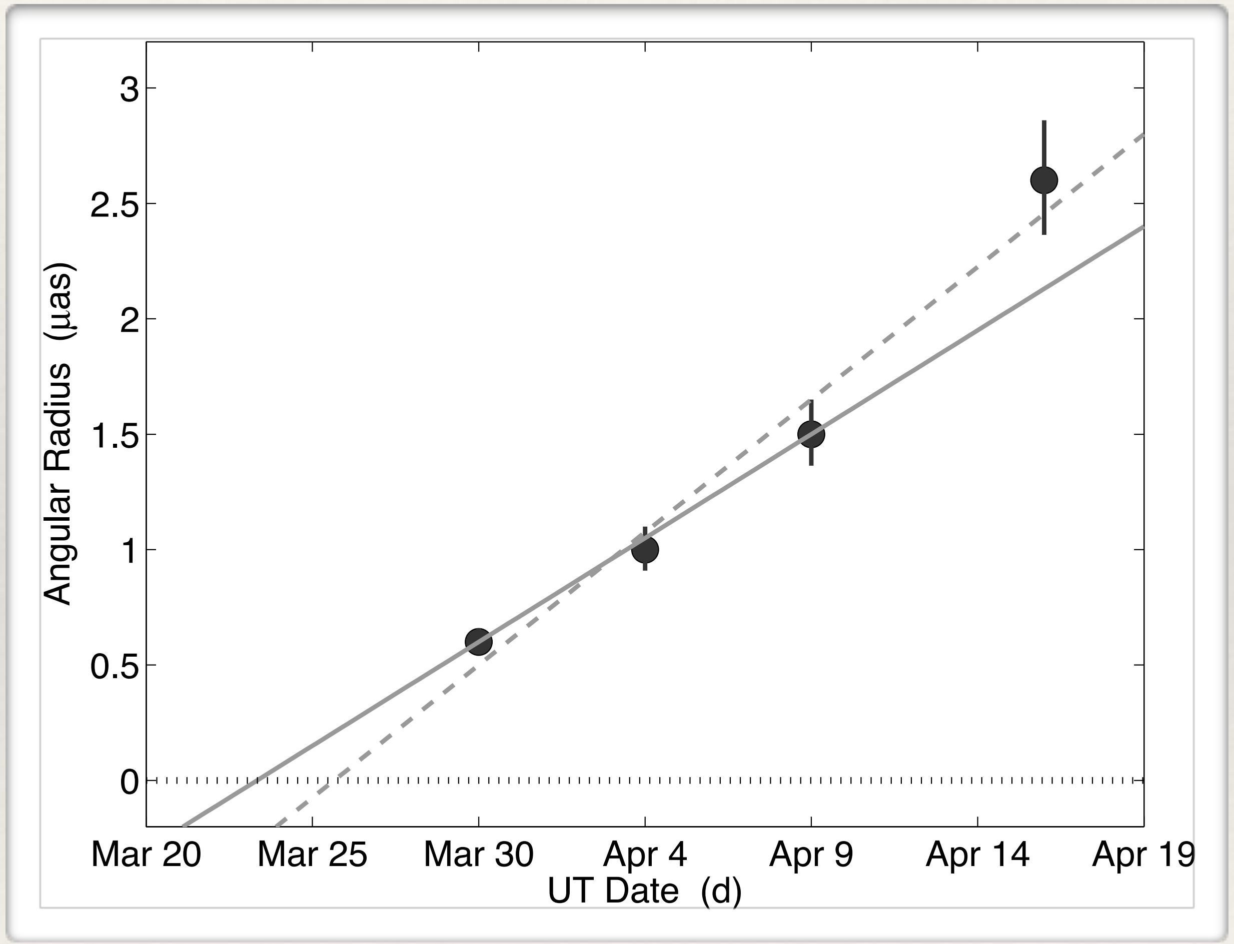
Shiokawa et al., 2015

Outflows I: Relativistic TDFs

Sw J1644+57: A remarkable high-energy transient



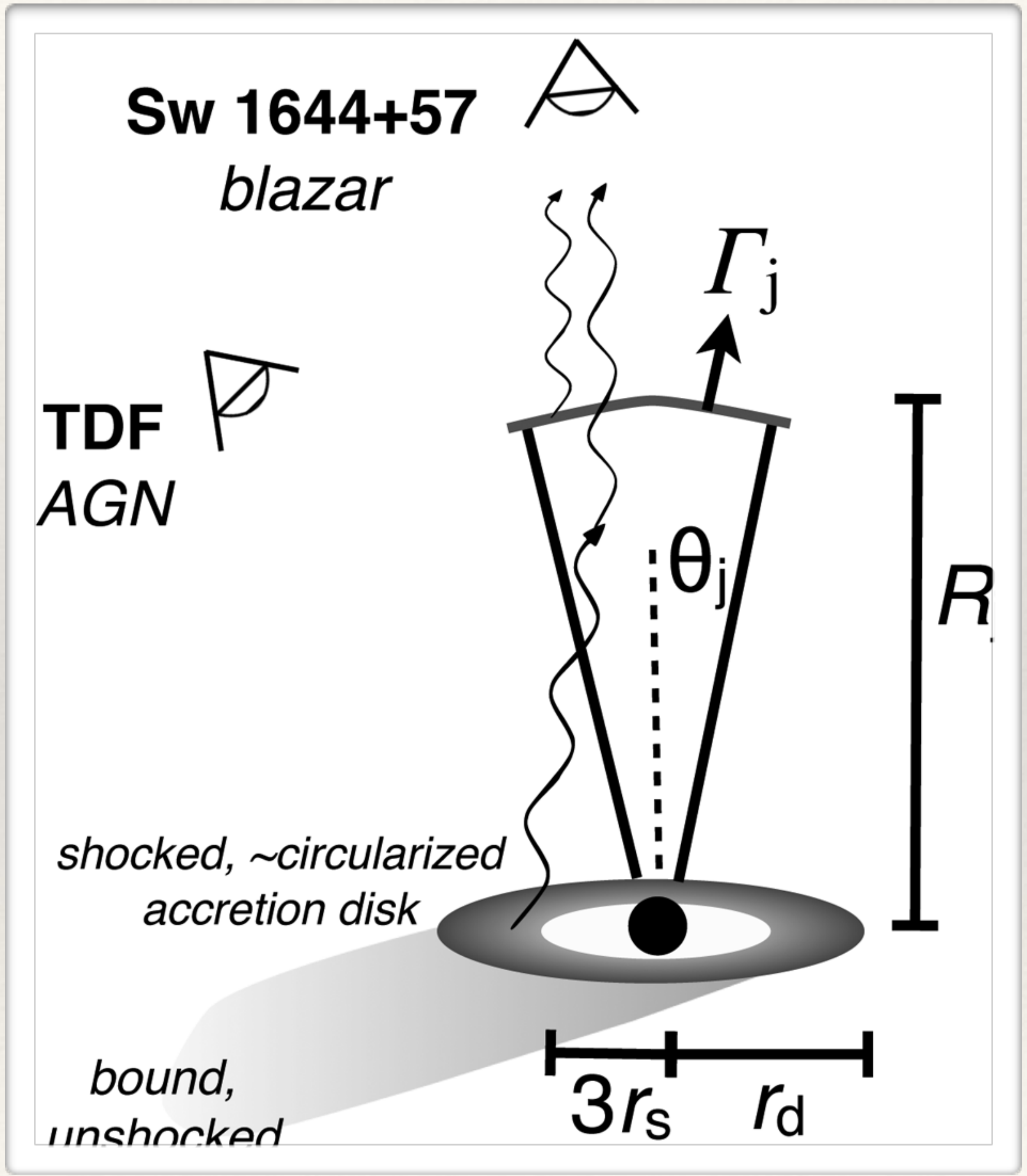
Levan et al., 2011



Zauderer et al., 2011

Outflows I: Relativistic TDFs

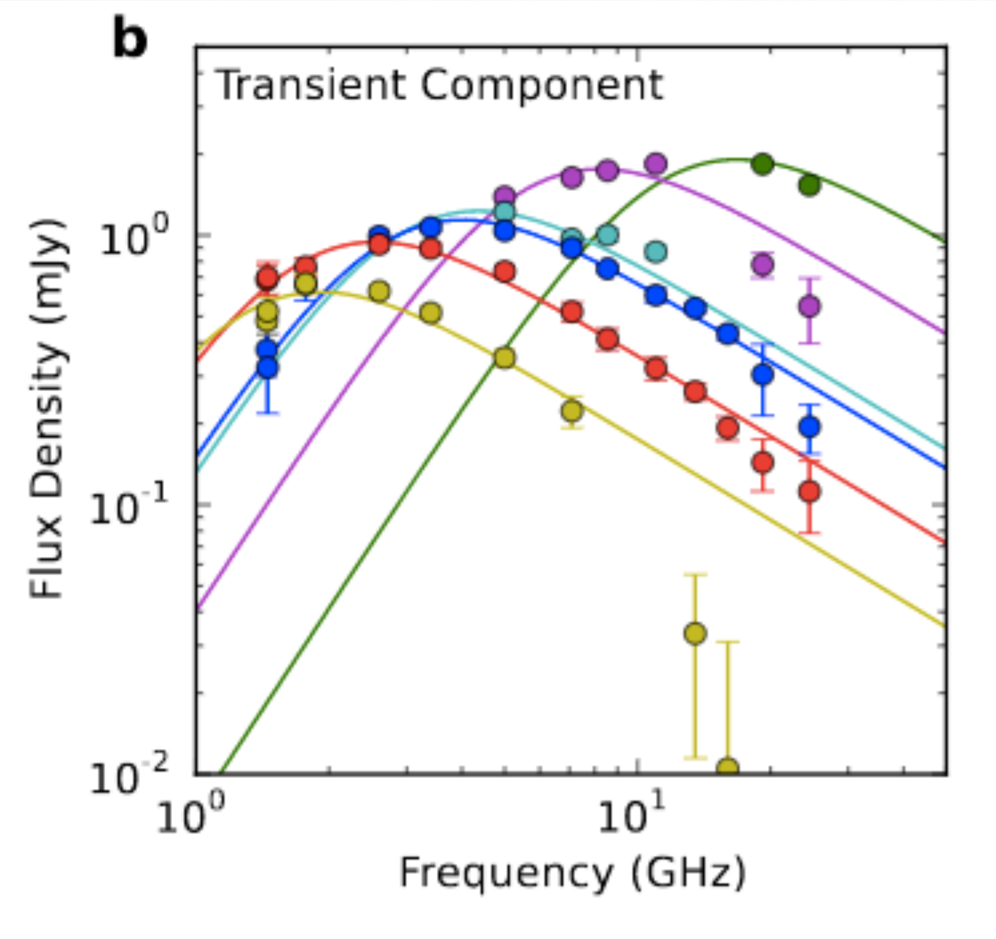
- Star tidally disrupted by SMBH
- Resulting shocked, circularized accretion disk gives rise to thermal emission
- Launches collimated, relativistic jet powering non-thermal radio and (likely X-ray)
- In analogy with AGN, non-thermal component only visible for preferential viewing angles

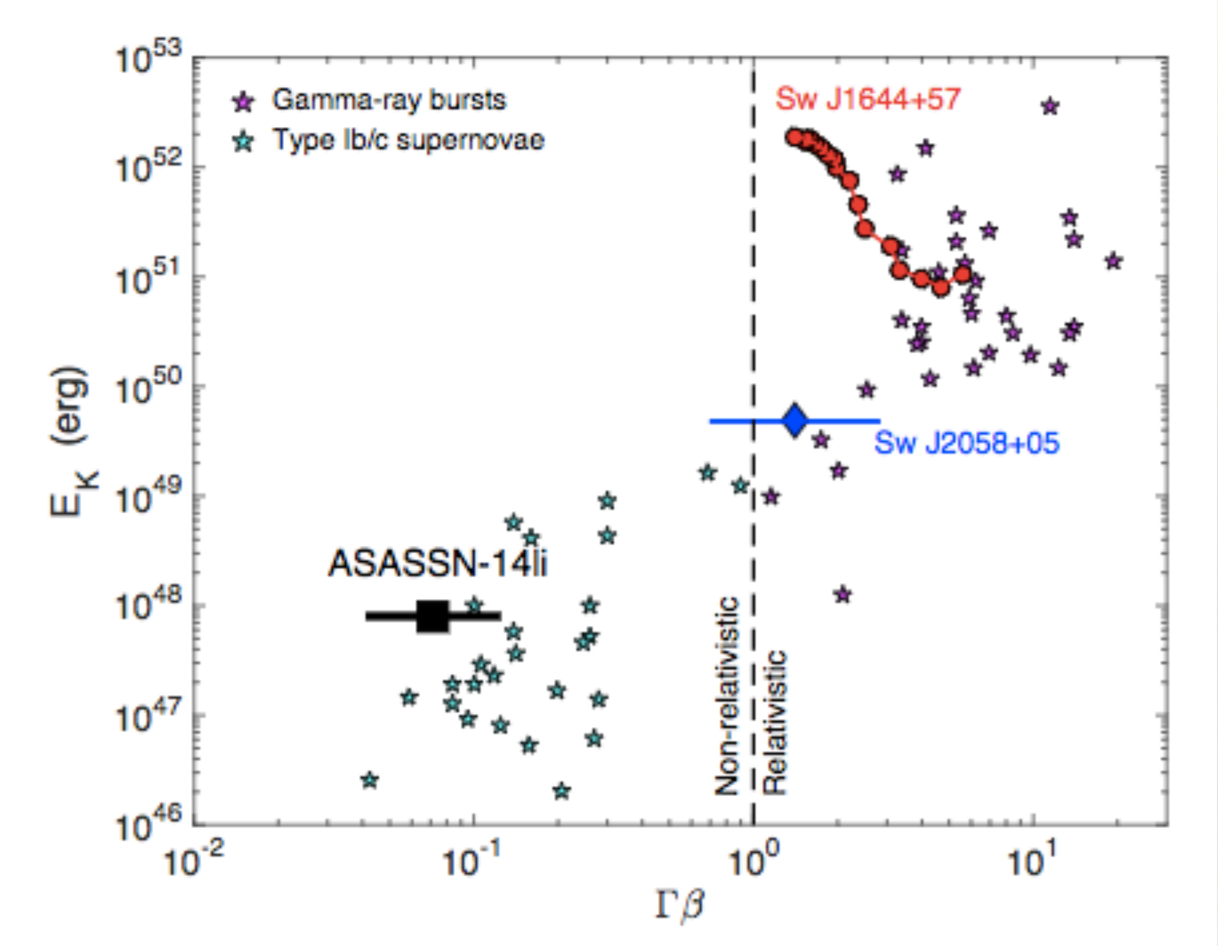


Zauderer et al., 2011

Outflows II: Fast (but not relativistic)

ASASSN-14li: Radio



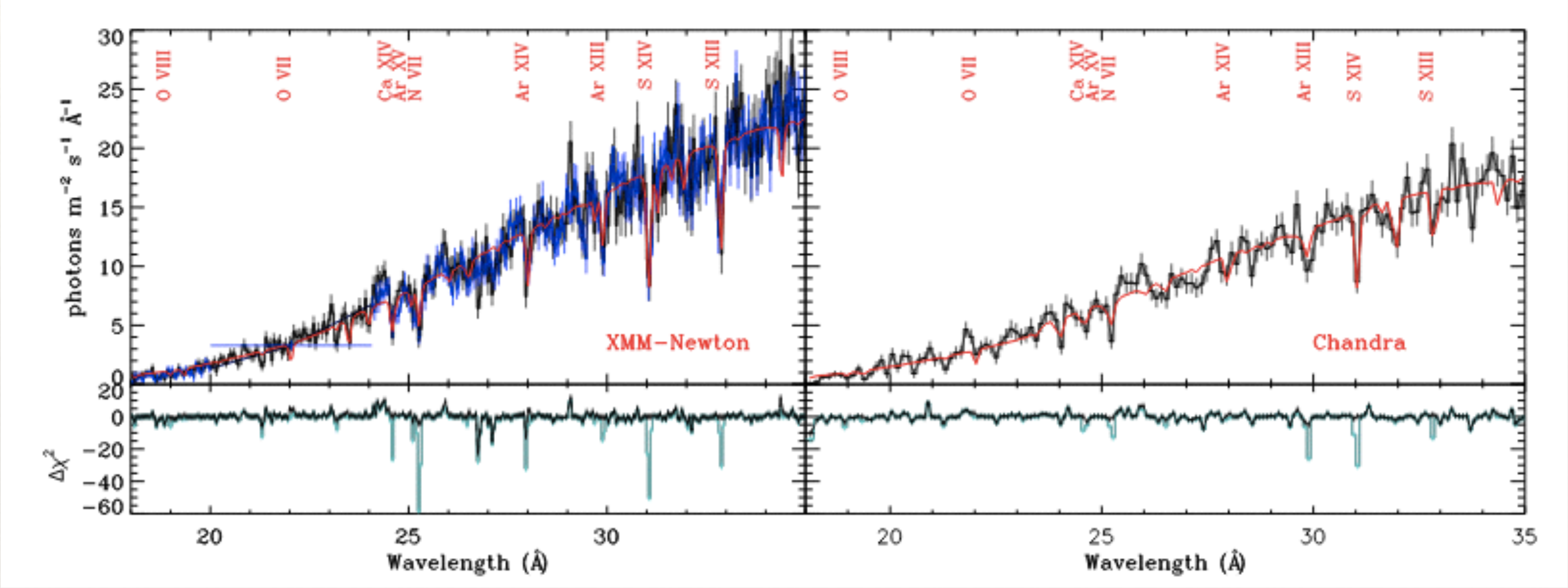


Alexander et al., 2016

From broadband radio observations, measure outflow velocity of ~ 20,000 km s^{-1} and E ~ 10^{48} erg

Outflows III: Very low Velocity

ASASSN-14li: X-ray

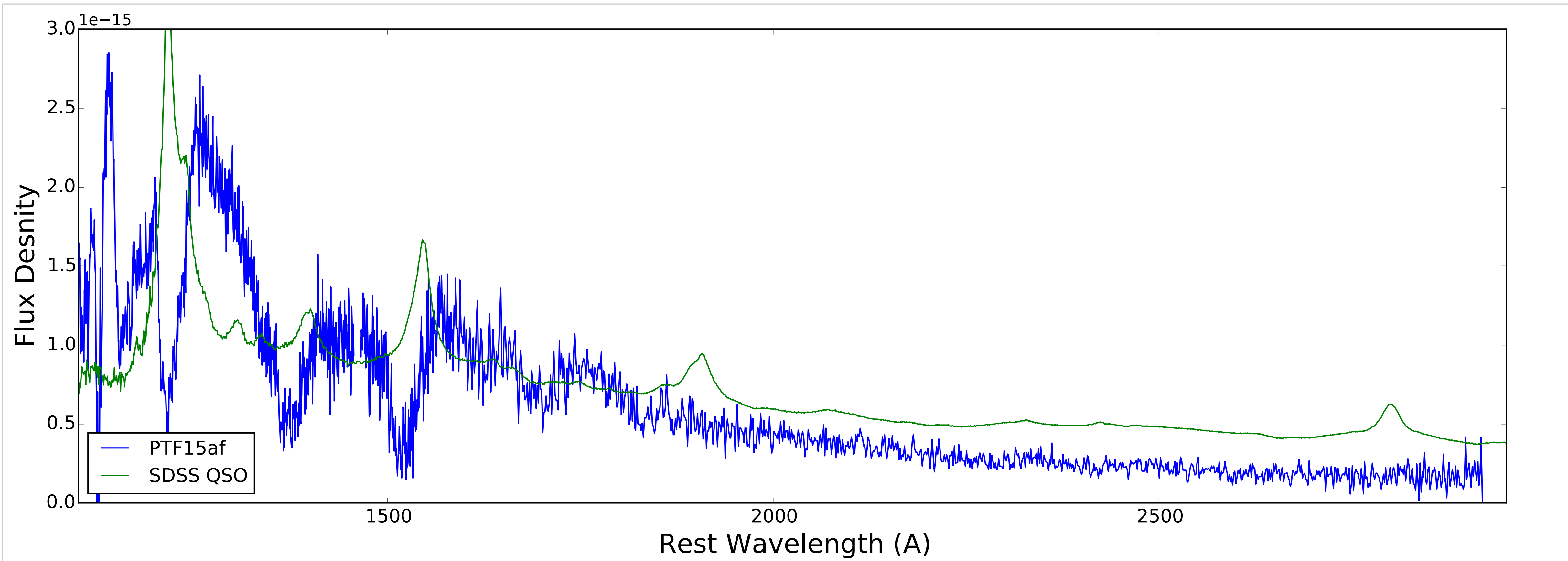


Miller et al. 2015

Highly ionized gas, close to black hole (varies on few day time scales), velocities of few **hundred** km s^{-1}

Outflows IV: P Cygni profiles

iPTF15af UV Spectra

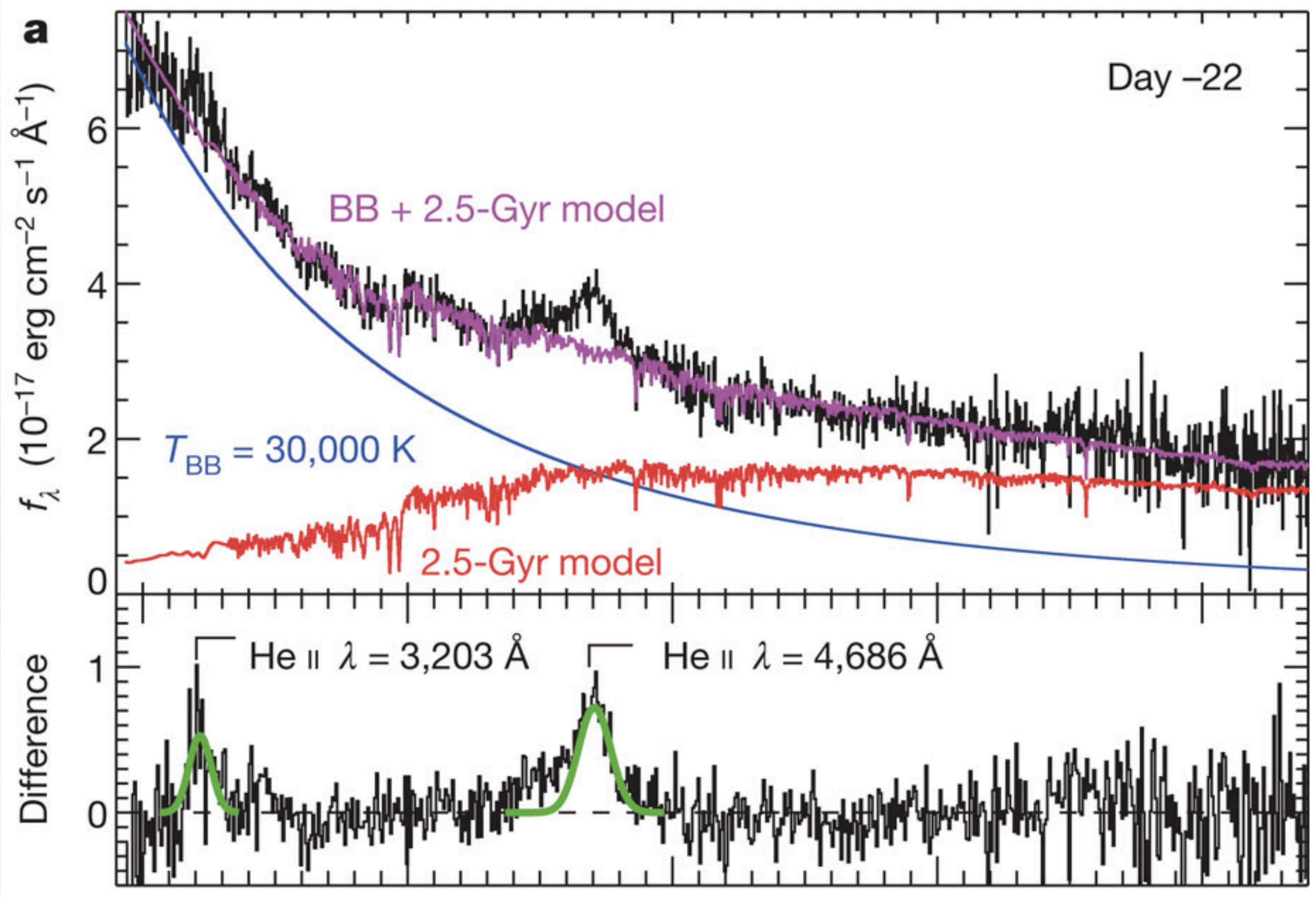


Cenko et al. in prep.

Broad (~ 10000 km s), blue-shifted absorption of C IV, Si IV, Lyα (?); P Cygni like?

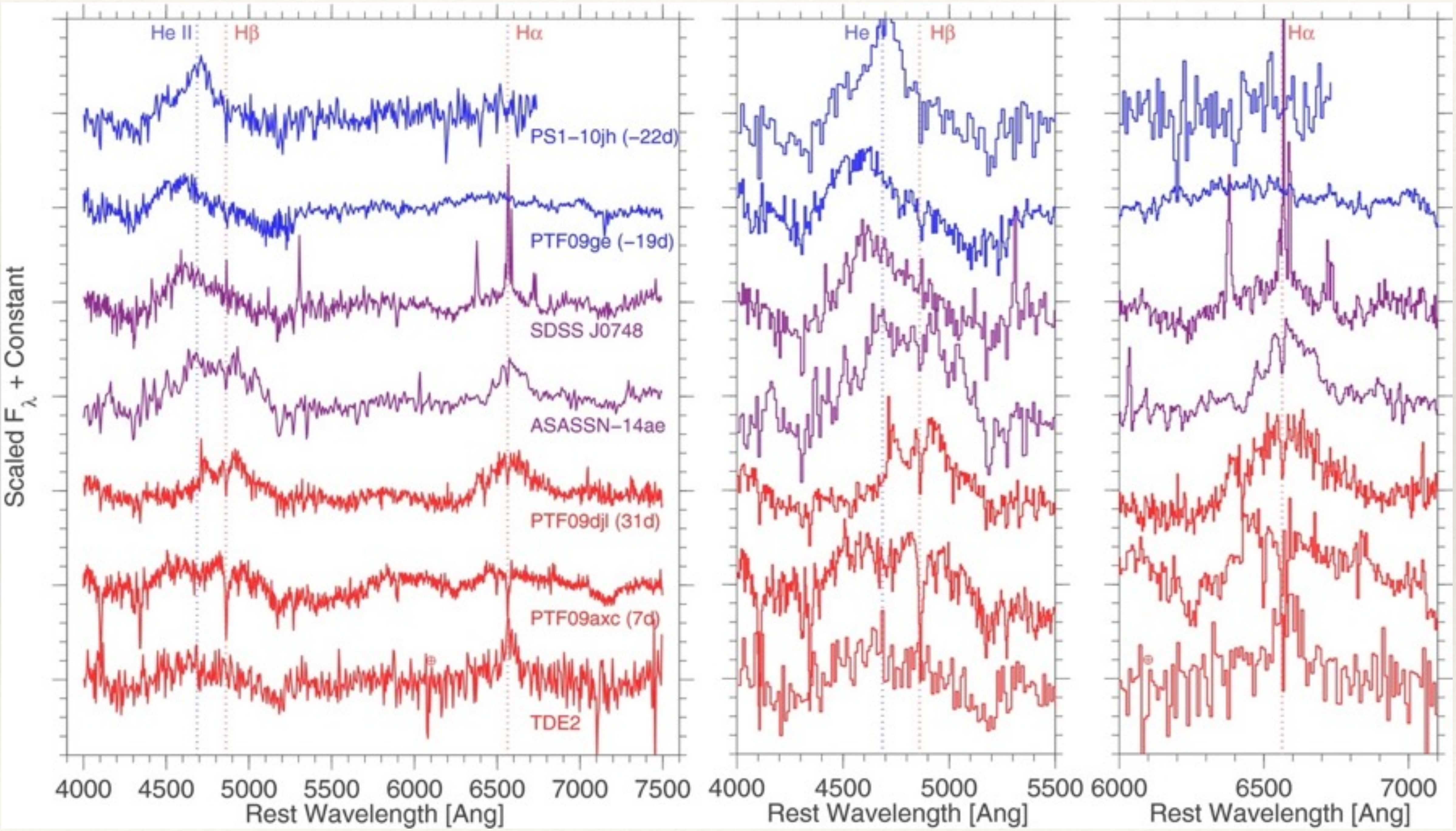
Abundance Patterns: PS1-10jh

- Strong, broad He II emission lines, but no corresponding Balmer H lines
- H-poor star disrupted?
- Complex photoionization conditions in emitting gas?



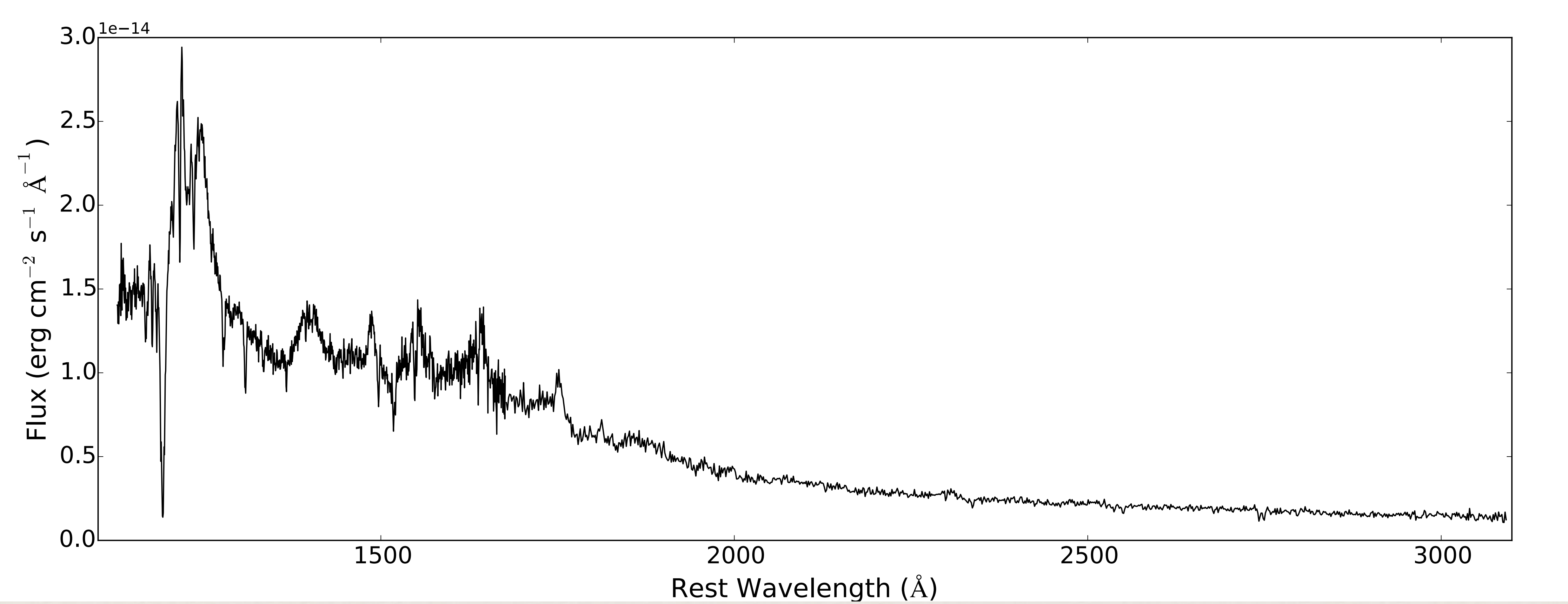
Gezari et al. 2012

Variable H-He Ratio in Optical Spectra



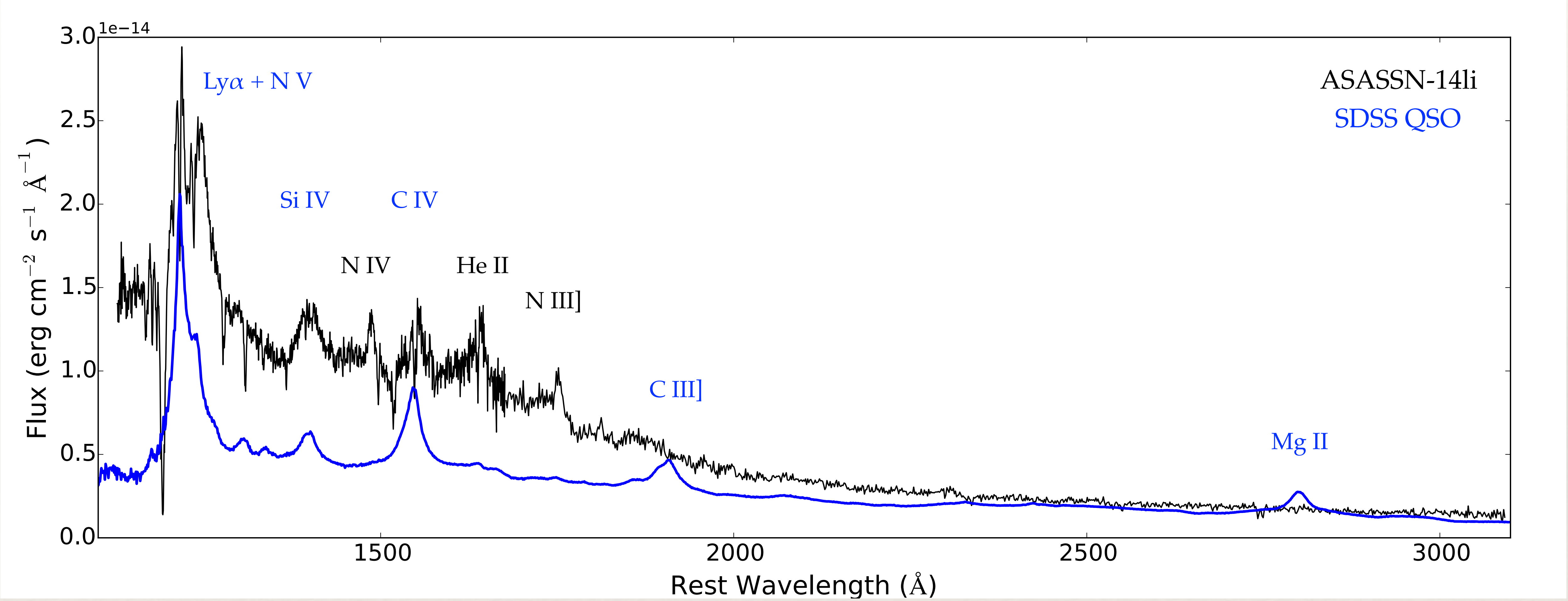
Arcavi+ 2014

Abundance Patterns: ASASSN-14li



First UV spectrum of a TDF (Cenko et al. 2016)

Abundance Patterns: ASASSN-14li



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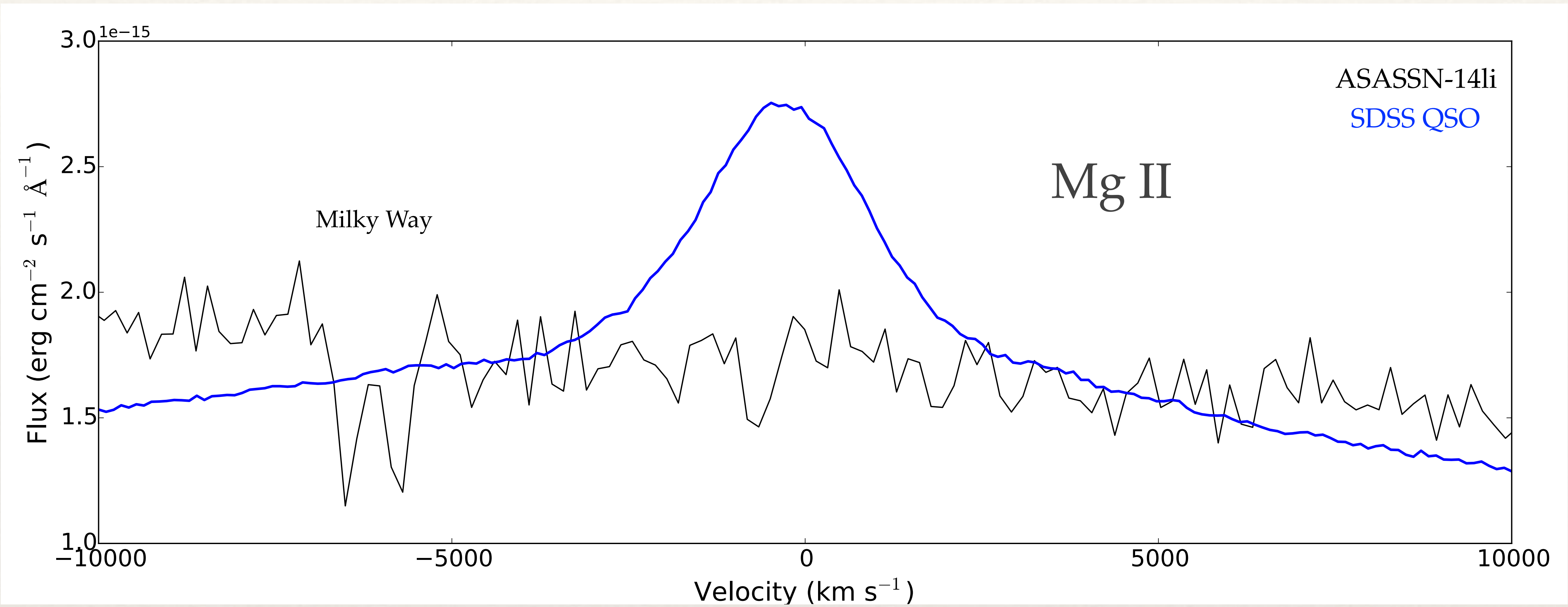
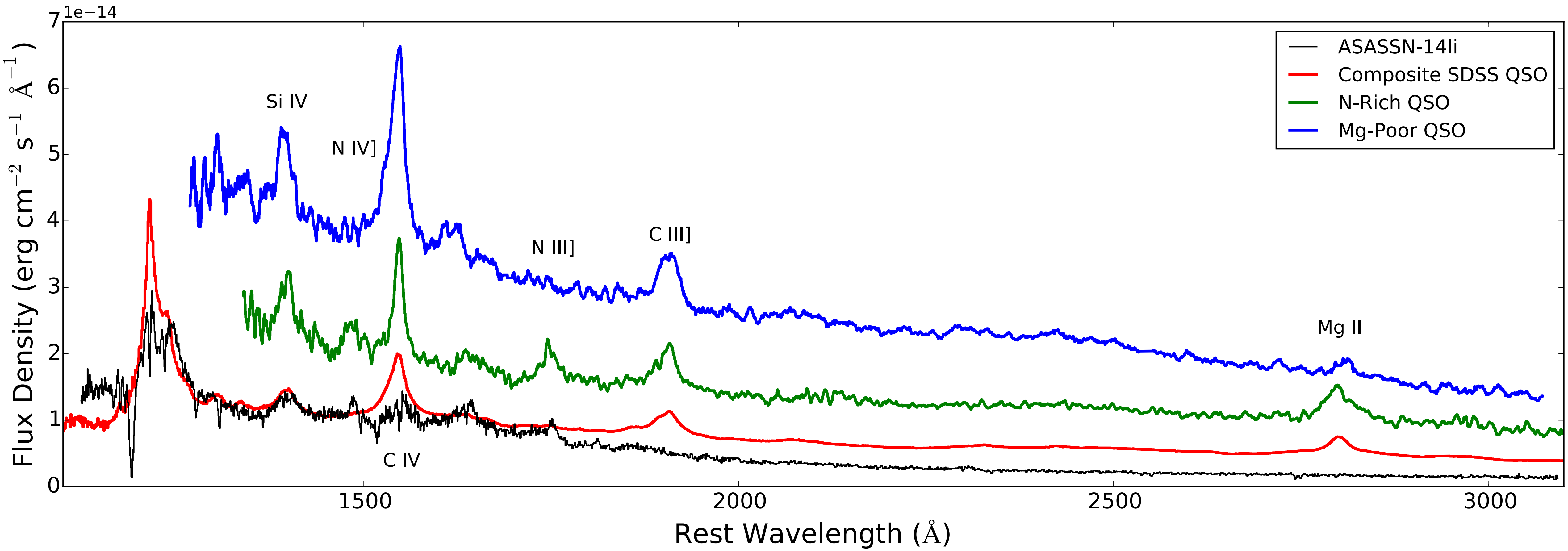


Cenko et al. 2016

No Mg II (and other low ionization lines)

in emission or absorption

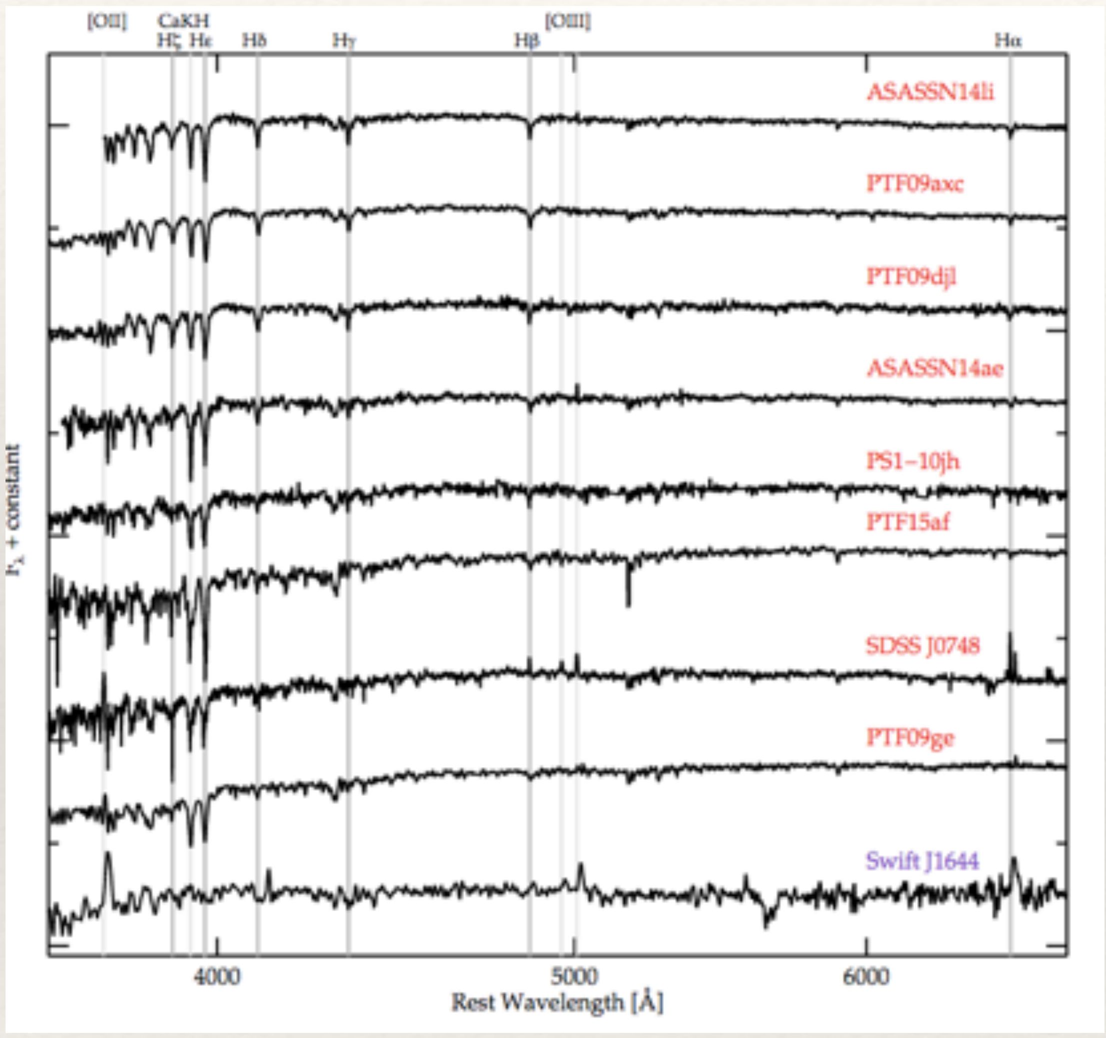
Abundance Patterns: ASASSN-14li

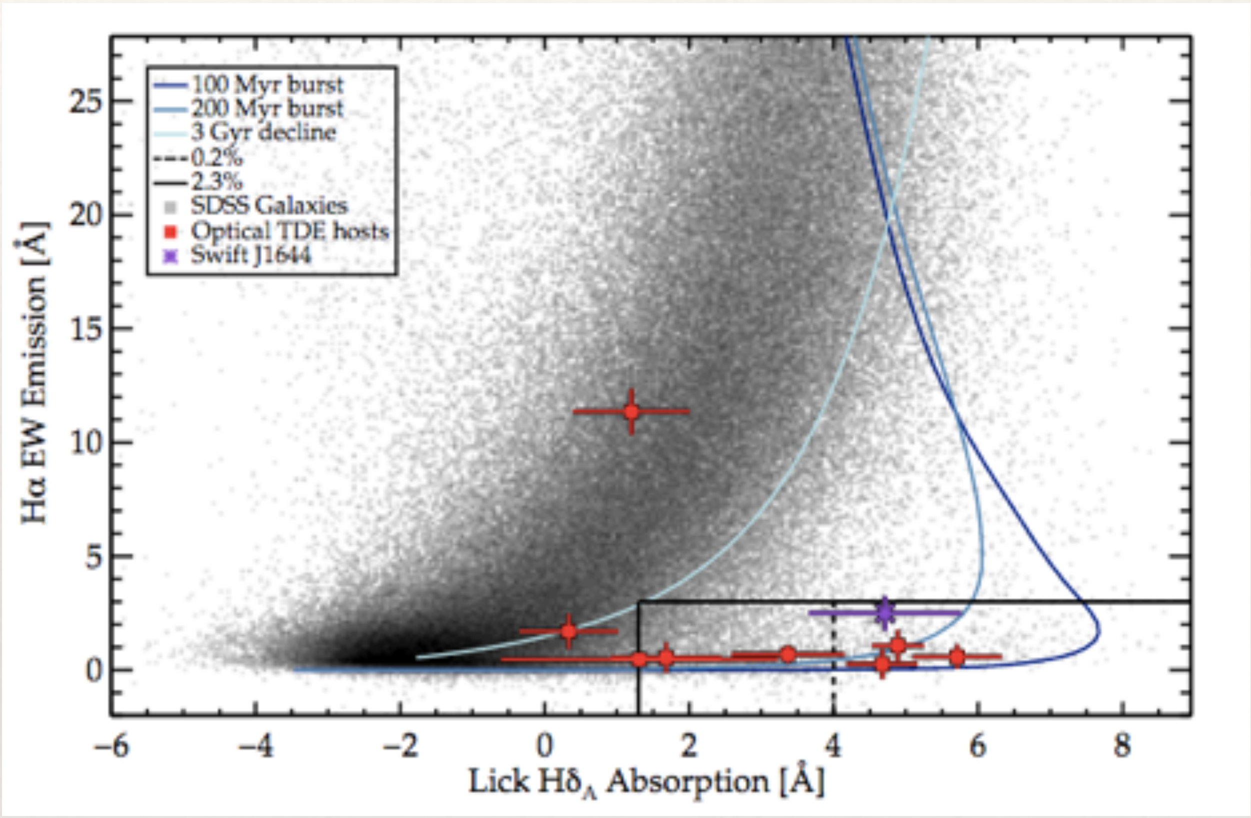


Cenko et al. 2016

N-rich Quasars: possible TDFs?? N over-abundance due to CNO processing in Sun-like star (Kochanek et al. 2016)

Host Galaxies: Preference for Post-Starbursts





French et al. 2016

Factor of tens to hundreds over-abundant in "post-starburst" galaxies - post mergers?

Conclusions / Remaining Puzzles

- Why is the UV/optical emission seen from TDFs coming from such a large radius?
- What dictates the presence / speed of outflowing material in TDFs?
- How does the observed abundance pattern relate to physical conditions in the emitting gas?
- Why do TDFs occur preferentially in post-starburst galaxies?