Pan-STARRS1 Observations of TDEs

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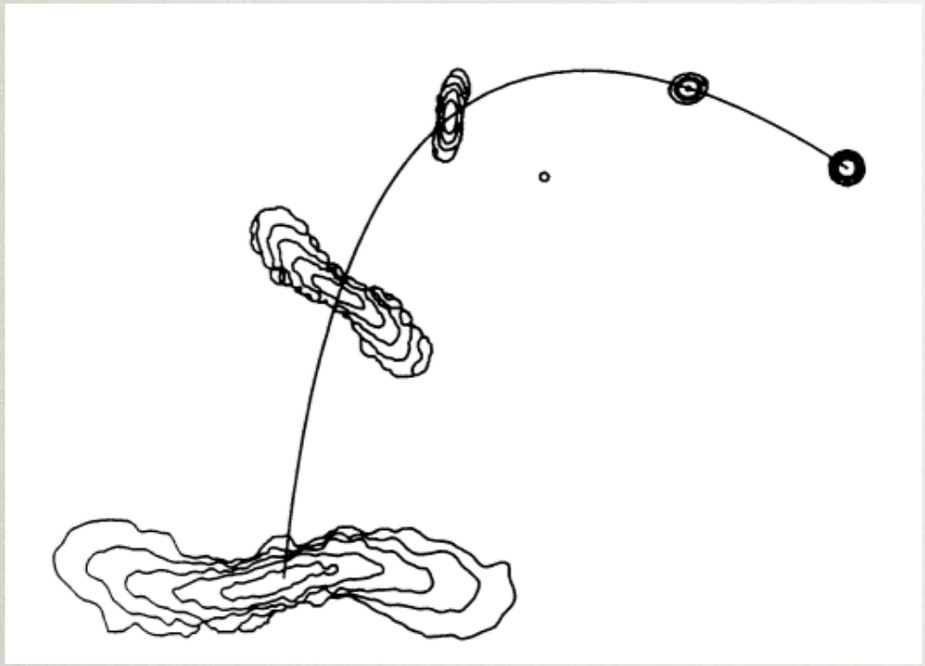
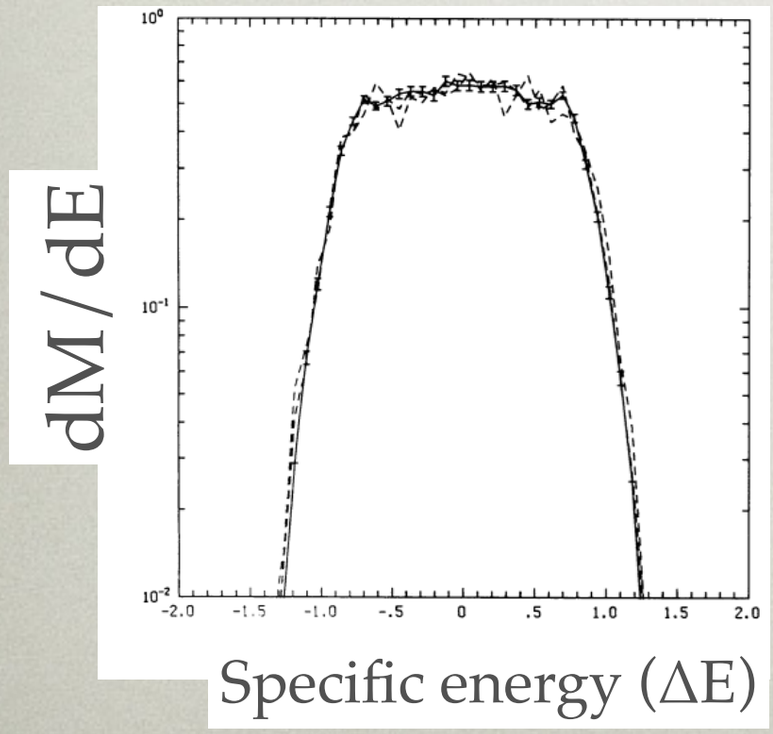
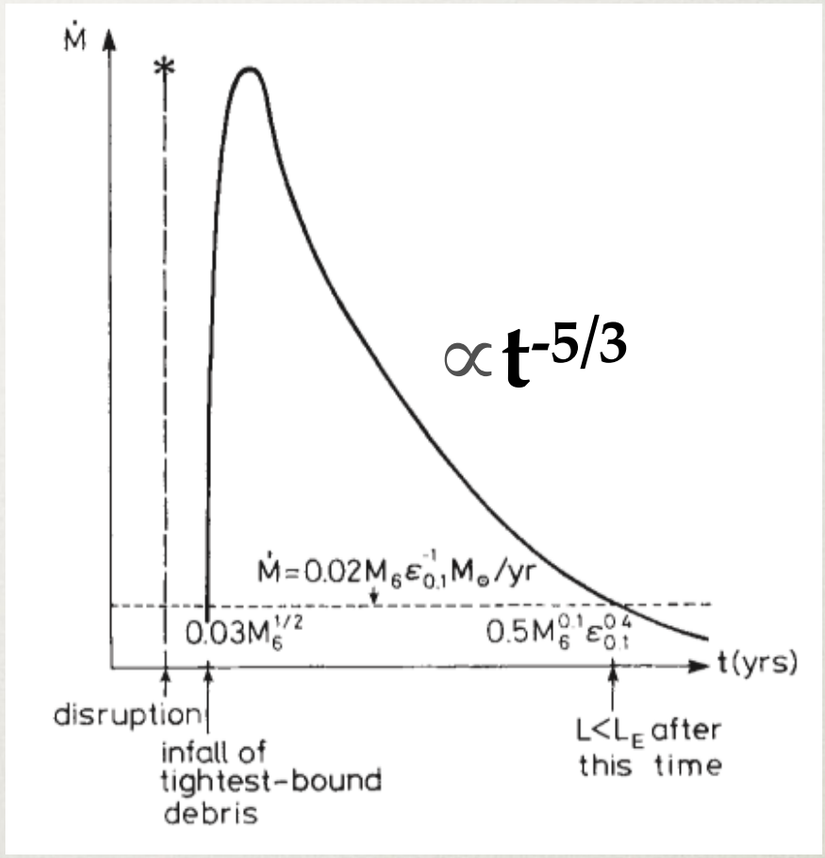
Tidal Disruption Events





Evans & Kochanek 1989



Rees 1988

- Bright in UV / soft X-rays
- $T_{BB} > 2\times10^5$ K, so optical is far down Rayleigh-Jeans tail of BB
- Rates per galaxy ~ 0.1% of SN rate

Pan-STARRS1 Medium Deep Survey

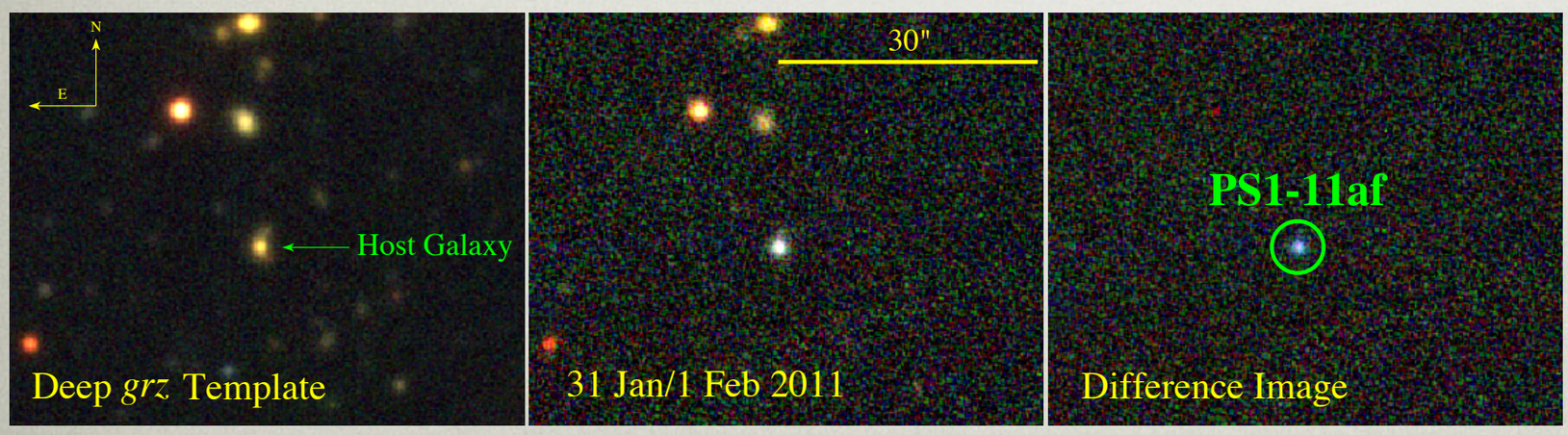
- 1.8m telescope on Maui
- 10 fields across sky (each 7.2 sq. deg.)
- ~4 observed nightly
- 3 day cadence for each filter
- Limiting mag ~23.5 in griz
- 120-150 transients/month
- 6/10 fields chosen for GALEX observations (PI: S. Gezari)

Depth/cadence of MDS similar to LSST!

See review talk by Will Burgett Thursday 4pm

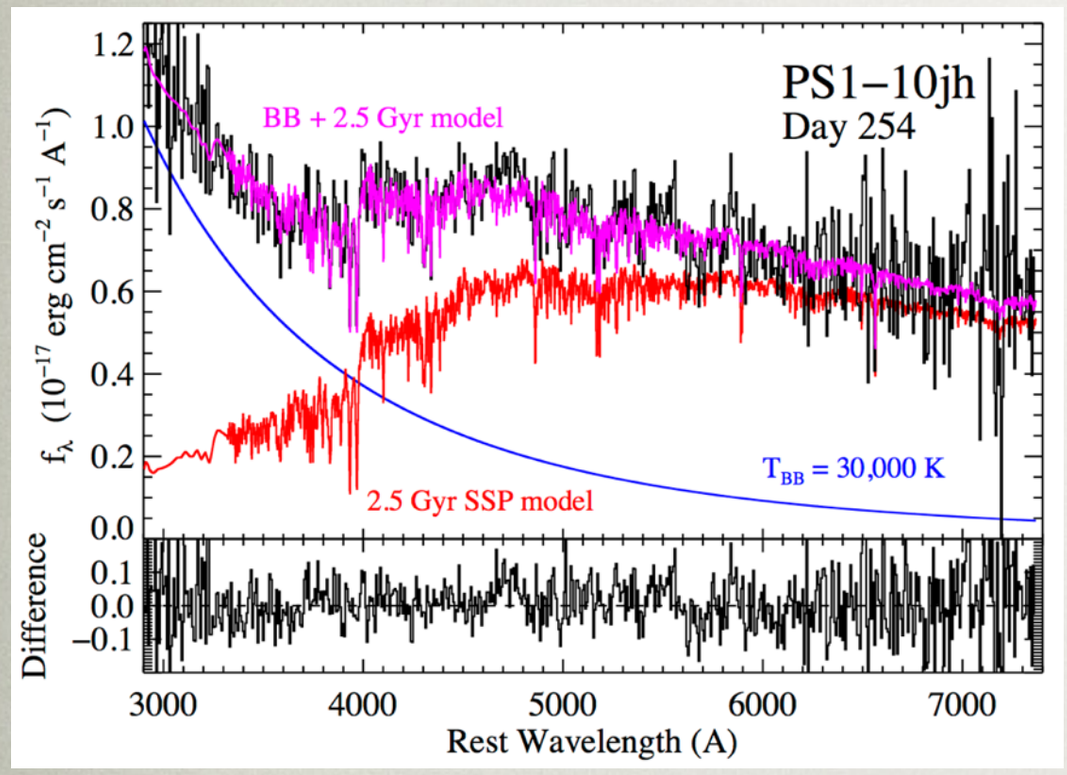
Two TDEs So Far:

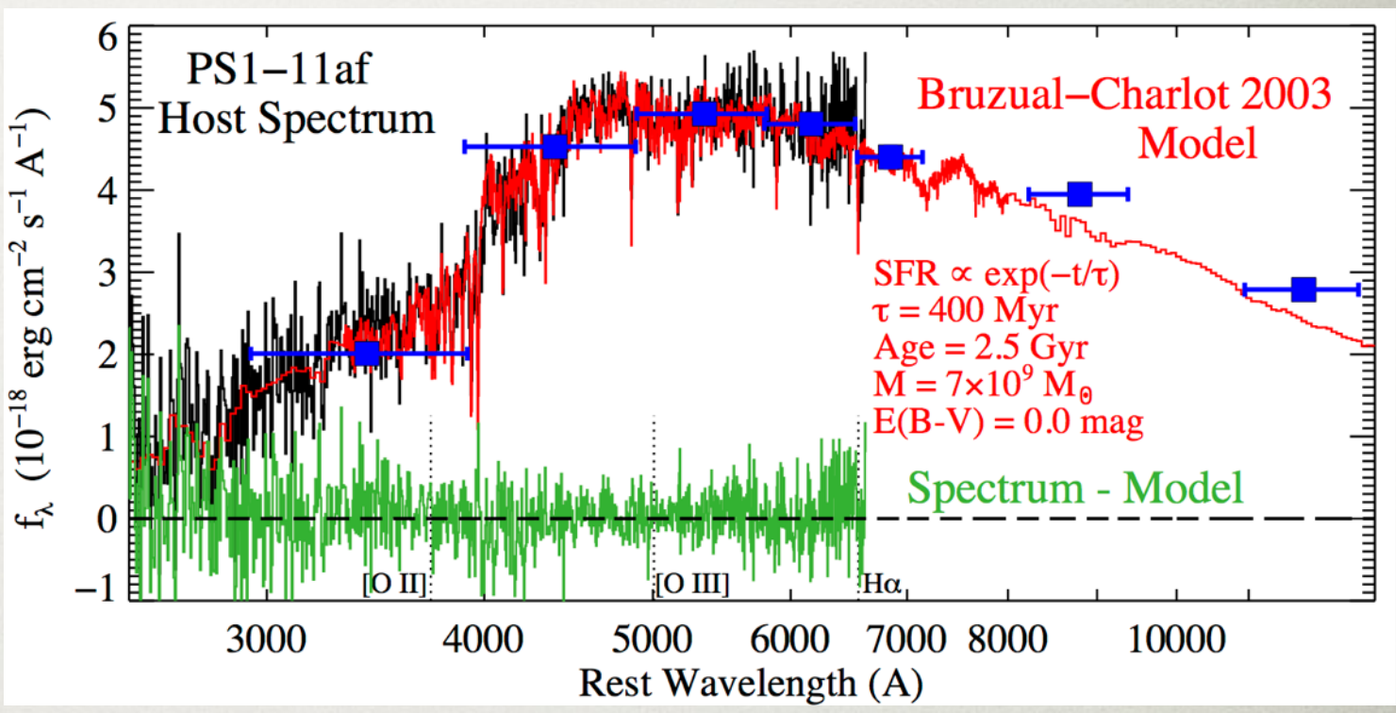
PS1-10jh at z=0.1696 (Gezari, RC, et al. 2012)



PS1-11af at z=0.4046 (RC et al. 2013)

Both in Early-type Hosts

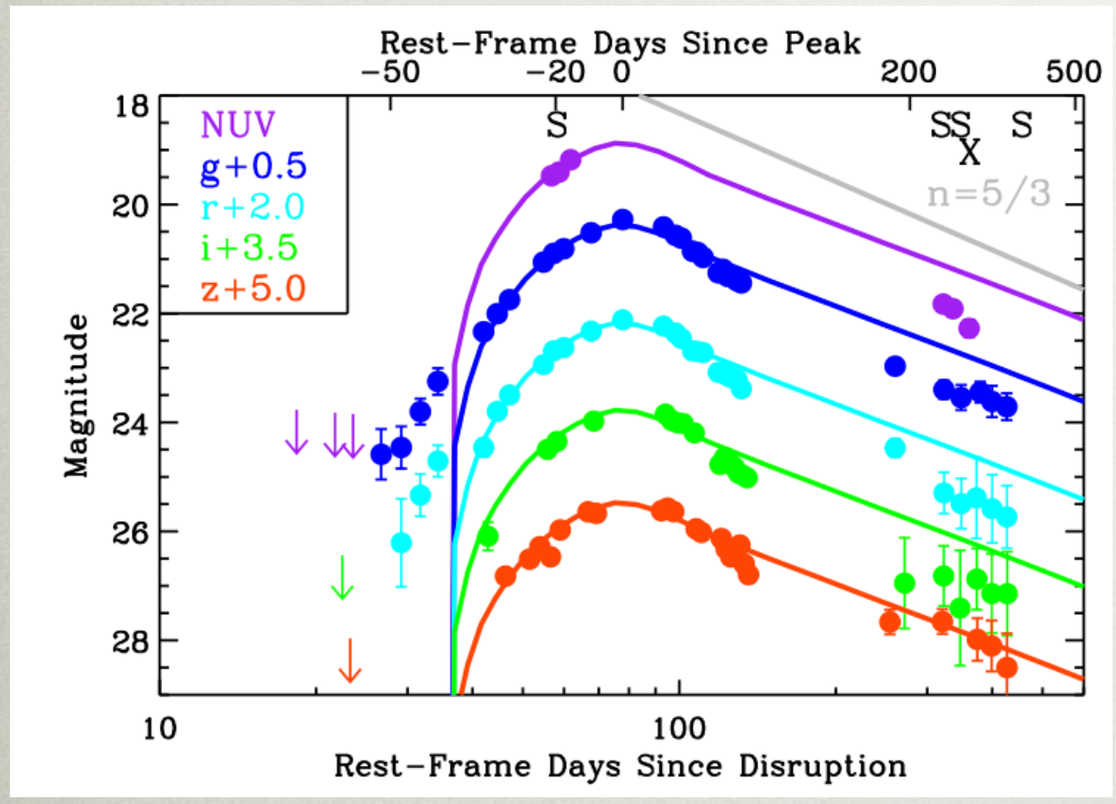


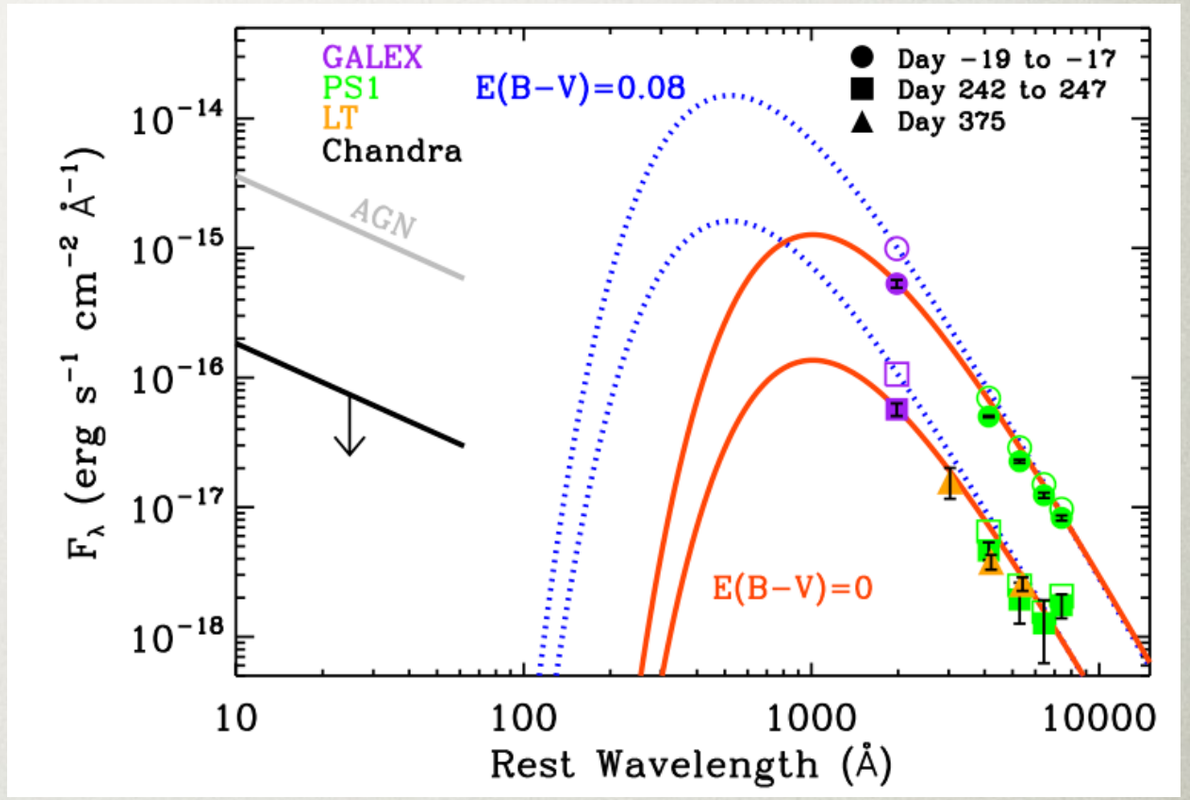


- Host M_r = -18.7 mag
- NUV > 25.6 mag, FUV > 25.1 mag (SFR < 0.02 $M_\odot$/yr)
- $M_\star = (3.6 \pm 0.2) \times 10^9\ M_\odot$
- expect $M_{BH} = 4^{+4}_{-2} \times 10^6\ M_\odot$

- Host M_r ~ -20 mag
- SFR < 0.02 $M_\odot$/yr from lack of Hα
- $M_\star = 7 \times 10^9\ M_\odot$
- expect $M_{BH} = 8 \times 10^6\ M_\odot$ (Häring & Rix 2004)

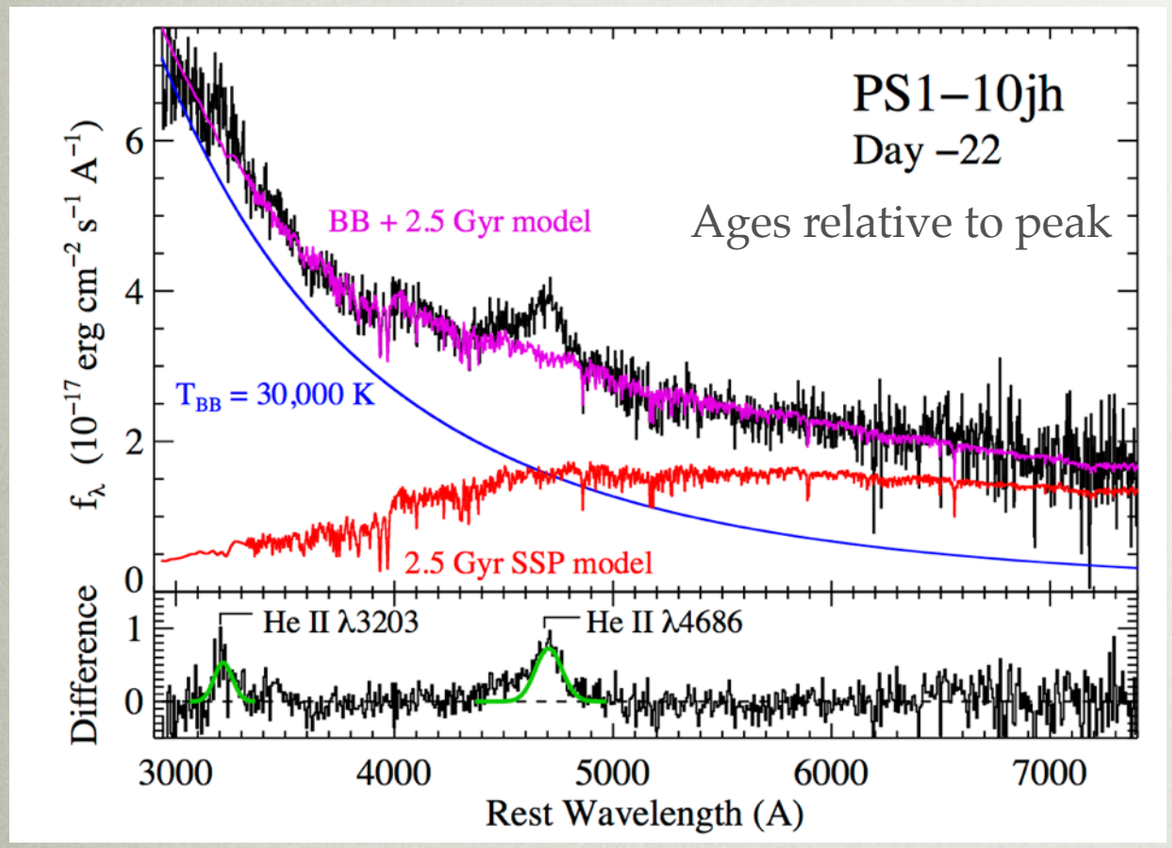
PS1-10jh: Slow Color Evolution

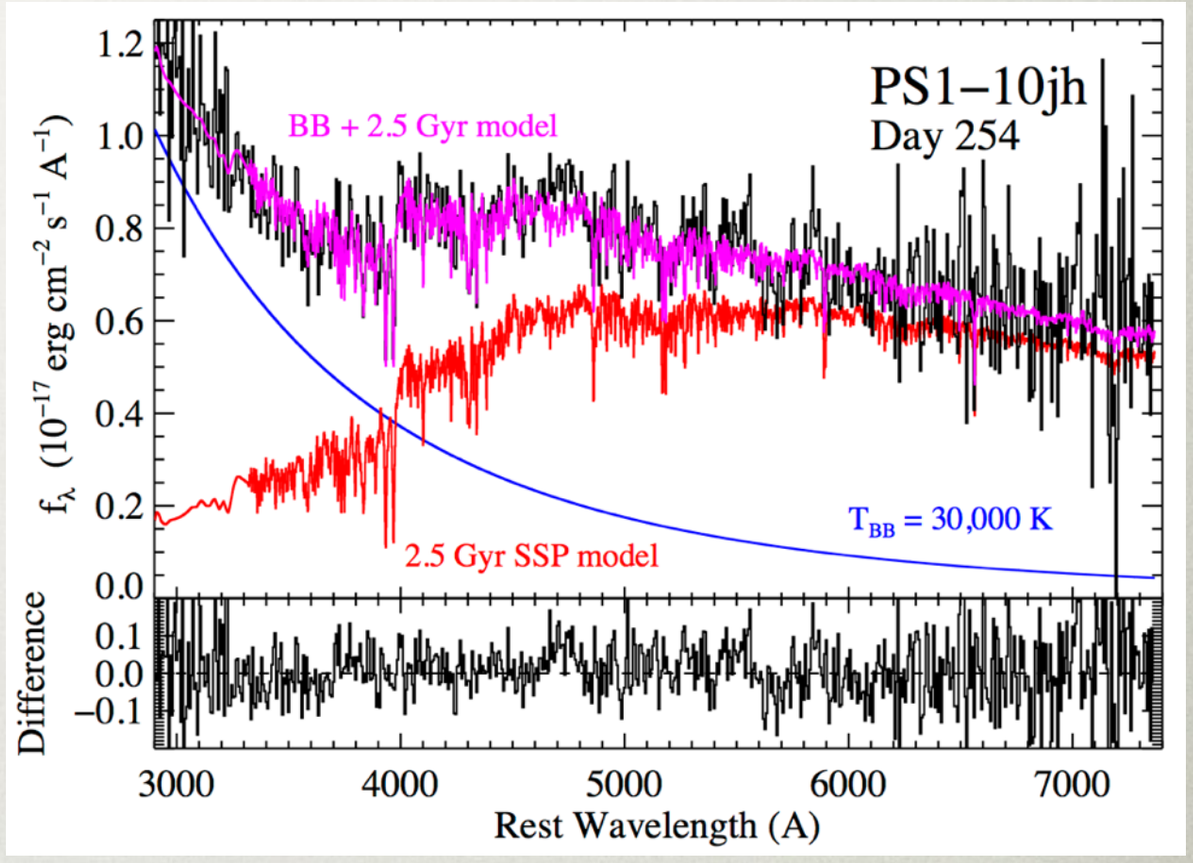




- $T_{BB} \sim (2.9 \pm 0.2) \times 10^4$ K for 1 year
- Non-detection with Chandra in 10ks at t=+272 days ($L_X < 4.8 \times 10^{41}$ erg/s)

PS1-10jh Spectroscopy





Persistent, broad (FWHM~9000 km/s)

He II emission lines

But no Balmer lines...

Not a SN

- $T_{BB} \gtrsim 30{,}000$K (too hot)
- for 1 year (too long)
- Host not star forming

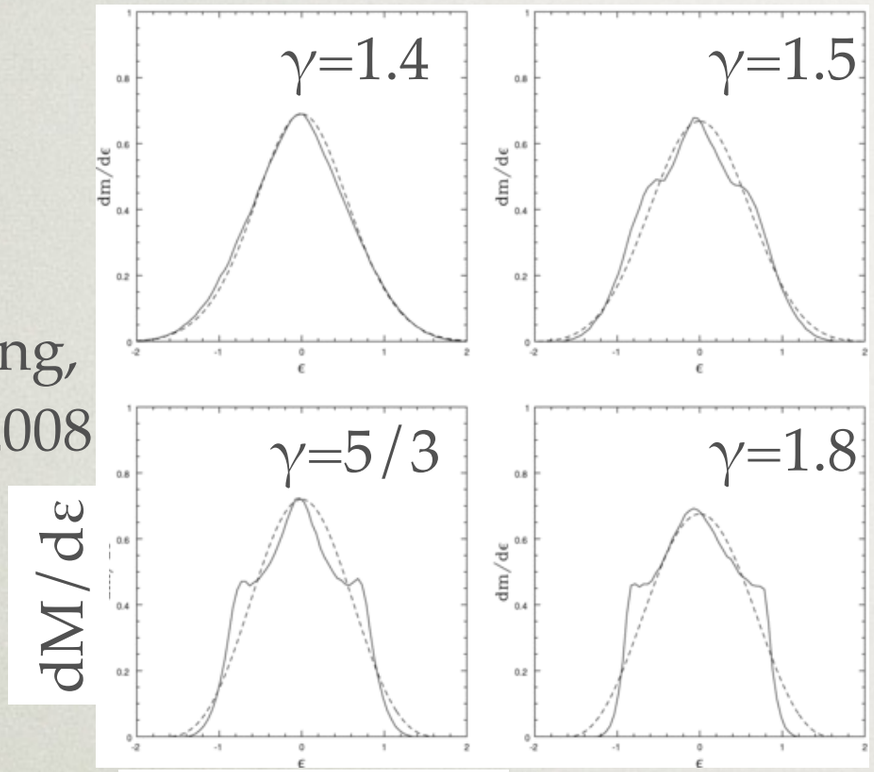
Not An AGN

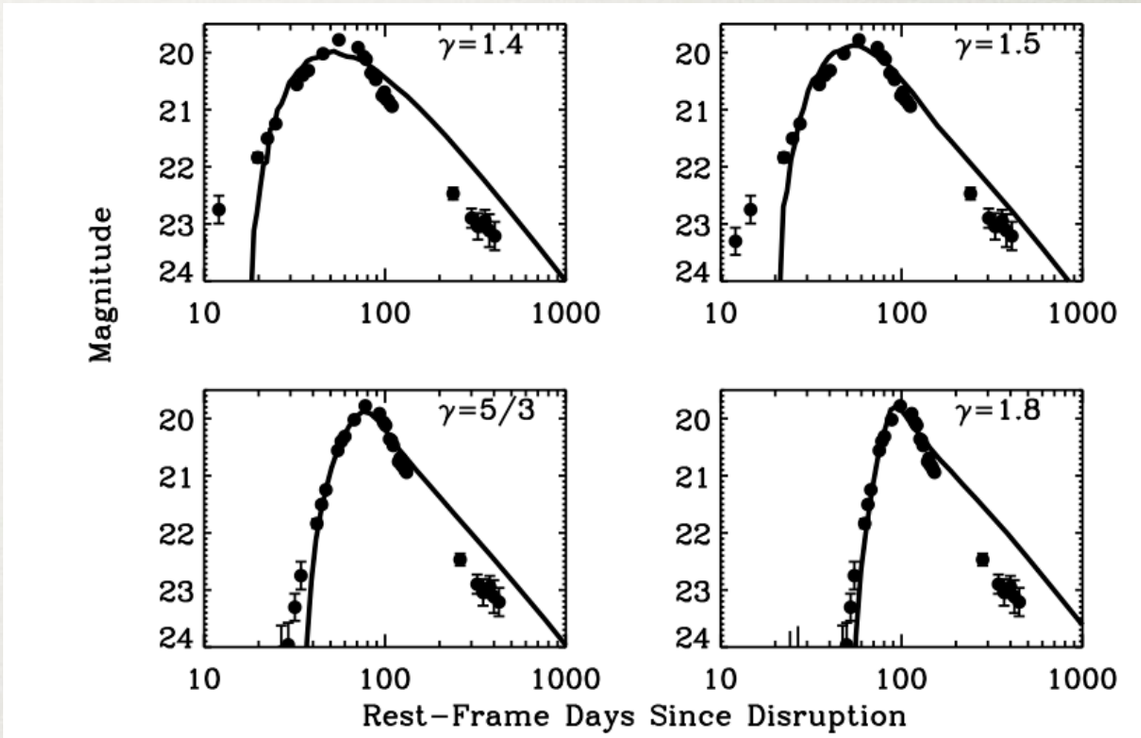
- FUV > 25.1 mag before event ($M_{1500} > -14.2$ mag)
- Extreme variability outlier ($\Delta M_{NUV} > 6.4$ mag)
- SED during event wrong (X-rays are a factor of >20 too low)
- Broad He II lines, no Balmer lines (low H mass fraction of accreted gas? BLR too small?)

Also, no narrow emission lines from host

The Star

Lodato, King, & Pringle 2008

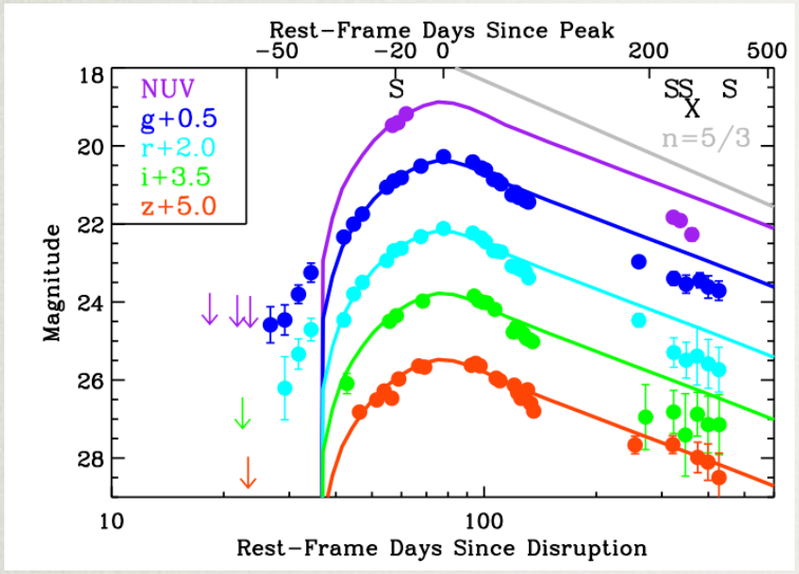


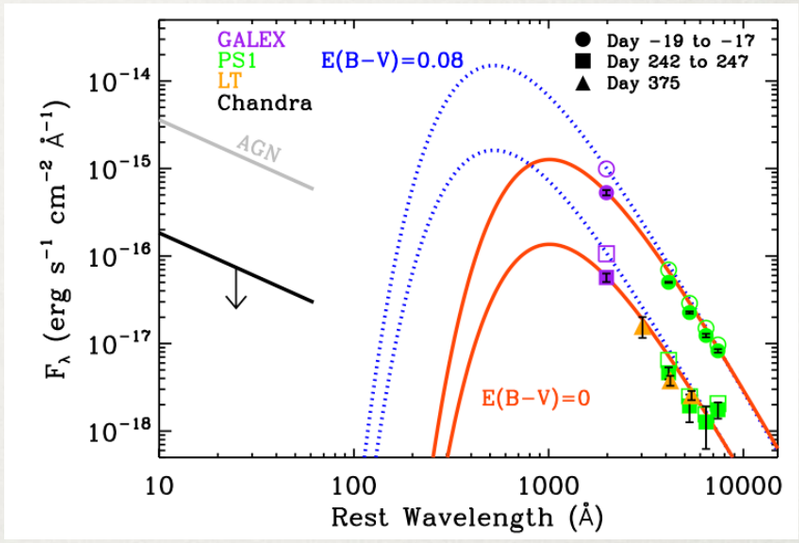


Fits to PS1-10jh g_{P1} light curve

- $P \propto \rho^{\gamma}$ with $\gamma=5/3$ is best fit (fully convective star or degenerate core)
- He-rich: H mass fraction $X < 0.2$ (He-rich core: Gezari et al. 2012; Bogdanovic et al. 2013)? Or is the BLR too small for Balmer lines (Guillochon et al. 2013)?

The Accretion Event

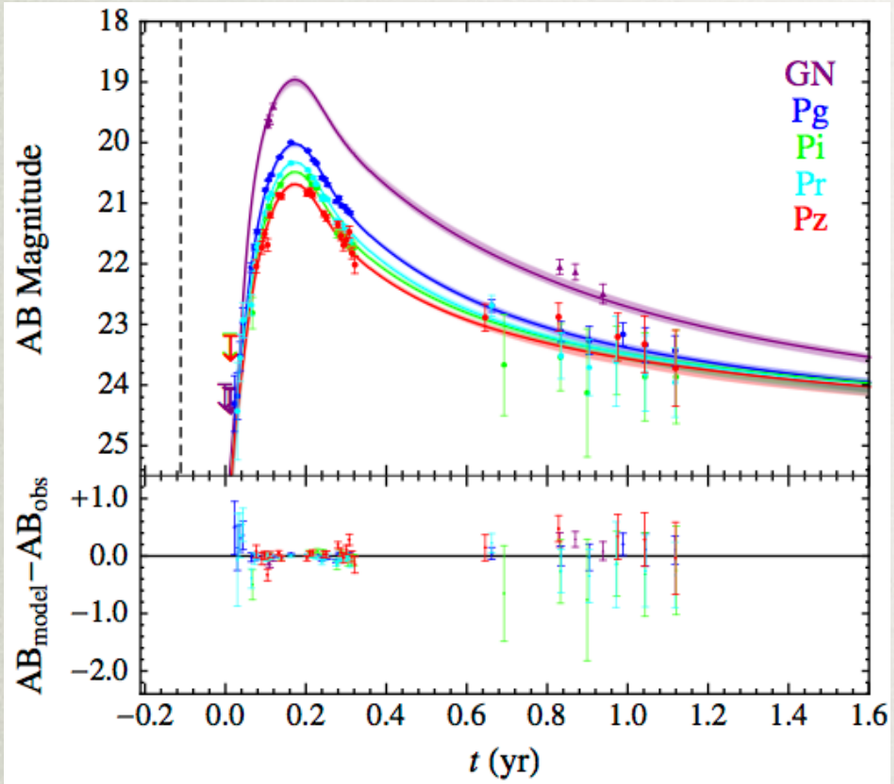


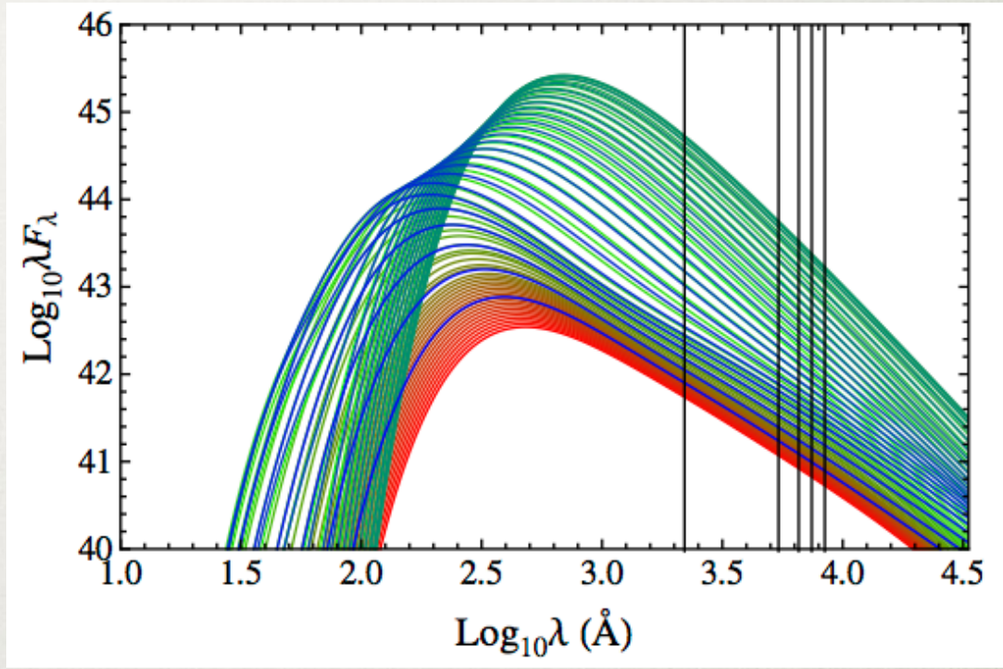


For fiducial $m_\star$=0.23 $M_\odot$ and $r_\star$=0.33 $R_\odot$

- $M_{BH} = (1.9 \pm 0.1) \times 10^6 \, m_\star^{\,2} \, r_\star^{\,-3} \, M_\odot$ ($M_{BH} = 2.8 \times 10^6 \, M_\odot$)
- $T_{BB} \gtrsim 3 \times 10^4$ K
- $L_{peak} \gtrsim 2.2 \times 10^{44}$ erg/s ($L_{peak} \gtrsim 0.6 \, L_{Edd}$)
- $E > 2.1 \times 10^{51}$ ergs
- $M_{acc} > 0.012 \, (\eta/0.1)^{-1} \, M_\odot$ ($M_{acc} \gtrsim 0.058 \, M_\star$)

Another Model



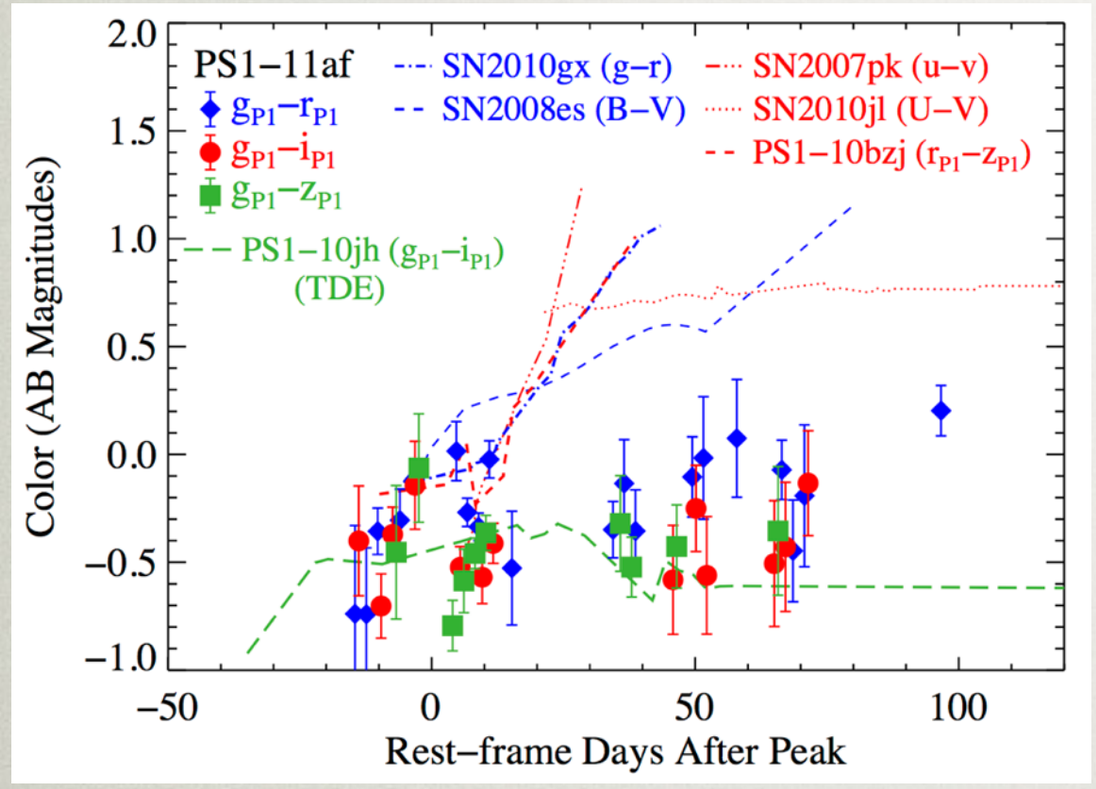


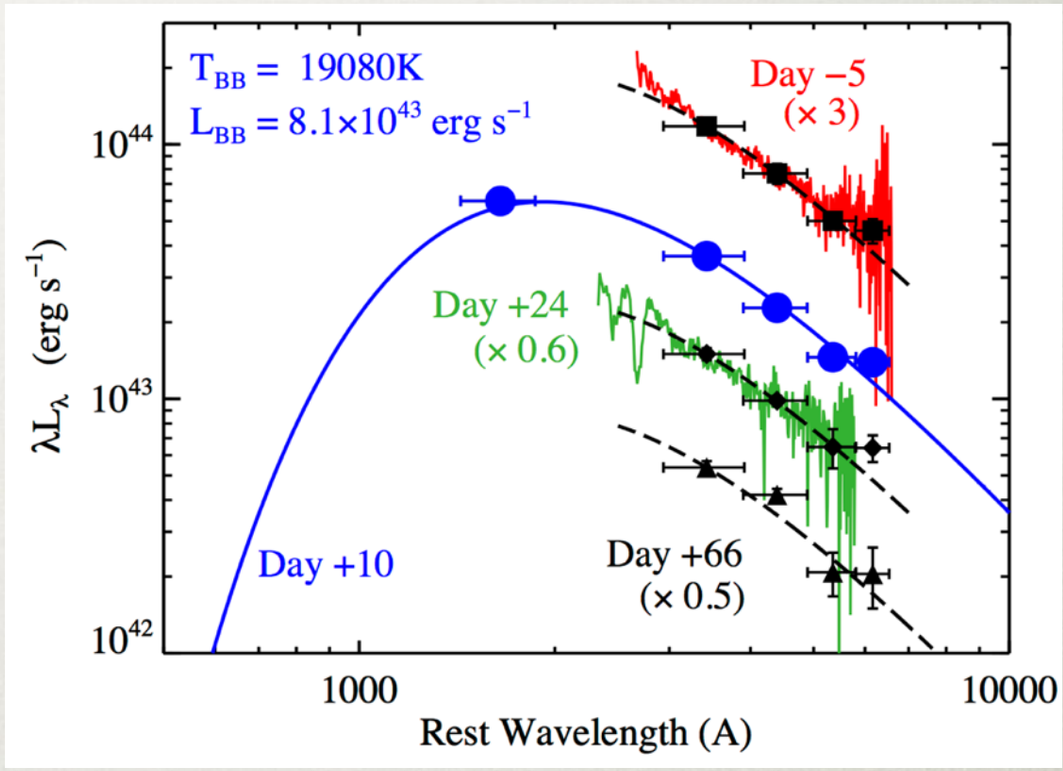
Guillochon et al. 2013

- Why does L_ν follow $\dot{M}_{acc}$?
- Partial disruption ($\beta = r_{tidal} / r_{pericenter} = 0.87$)
- $M_{BH} \sim 10^7\ M_\odot$
- $M_\star = 0.23\ M_\odot$

See James Guillochon's talk

PS1-11af: Another PS1 TDE

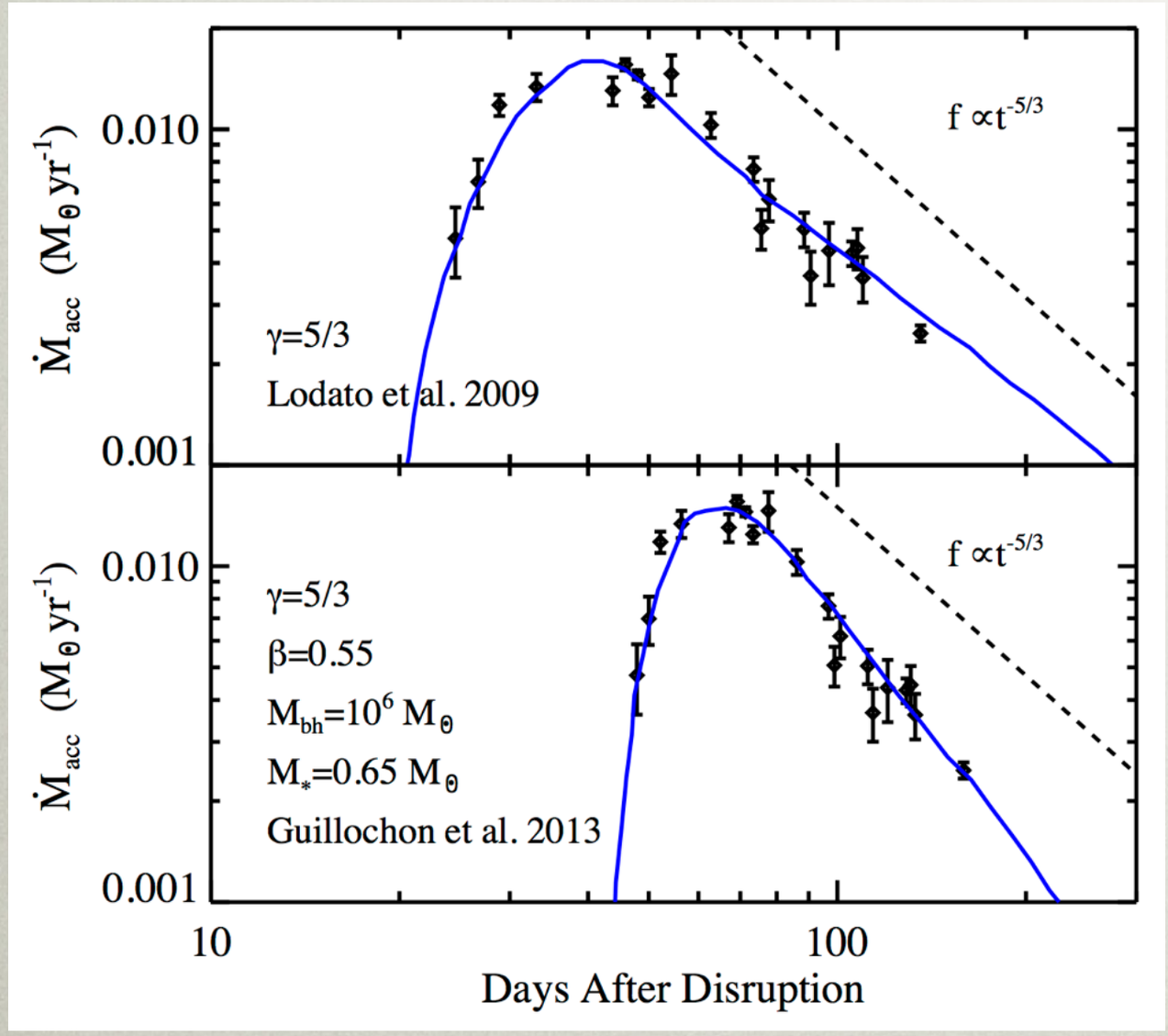




Does not cool like SNe!

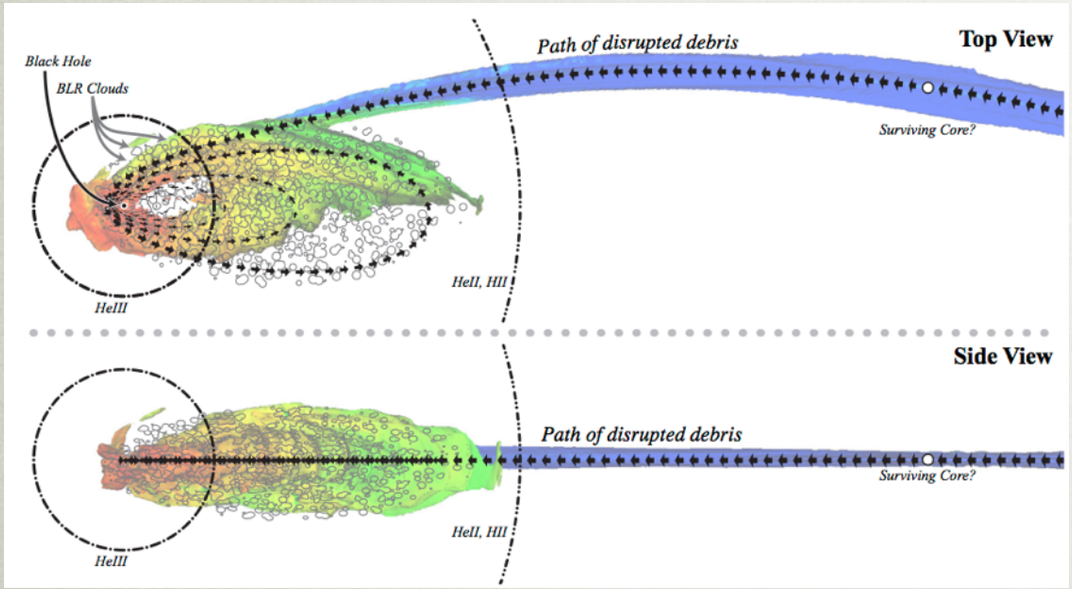
- $f_\nu \sim \nu^{0.73}$
- $T_{BB} \sim 19{,}000K$
- $R_{BB} \sim (0.6\text{-}1.2)\ x10^{15}$ cm

A Partial Disruption Event?

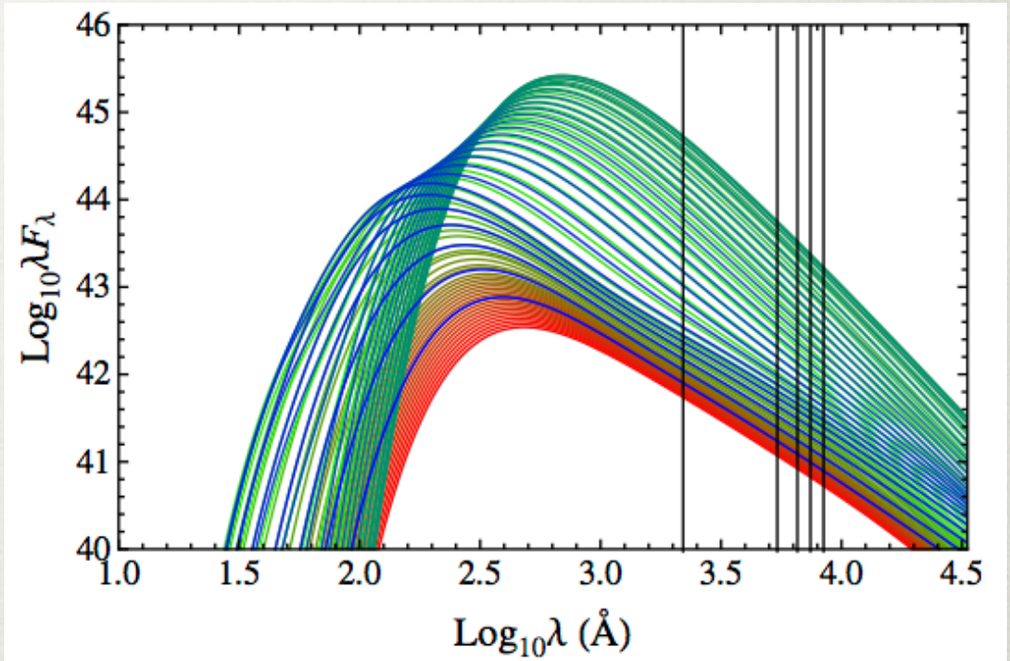


- $M_{acc} \sim 0.003\ M_\odot$ (Assuming radiative efficiency η=0.1)
- Using γ=5/3 models of Lodato et al. $M_{BH} \sim 1.8 \times 10^6\ M_\odot$
- But $M_\star >> M_{acc}$

So What is The Source of Optical Light?

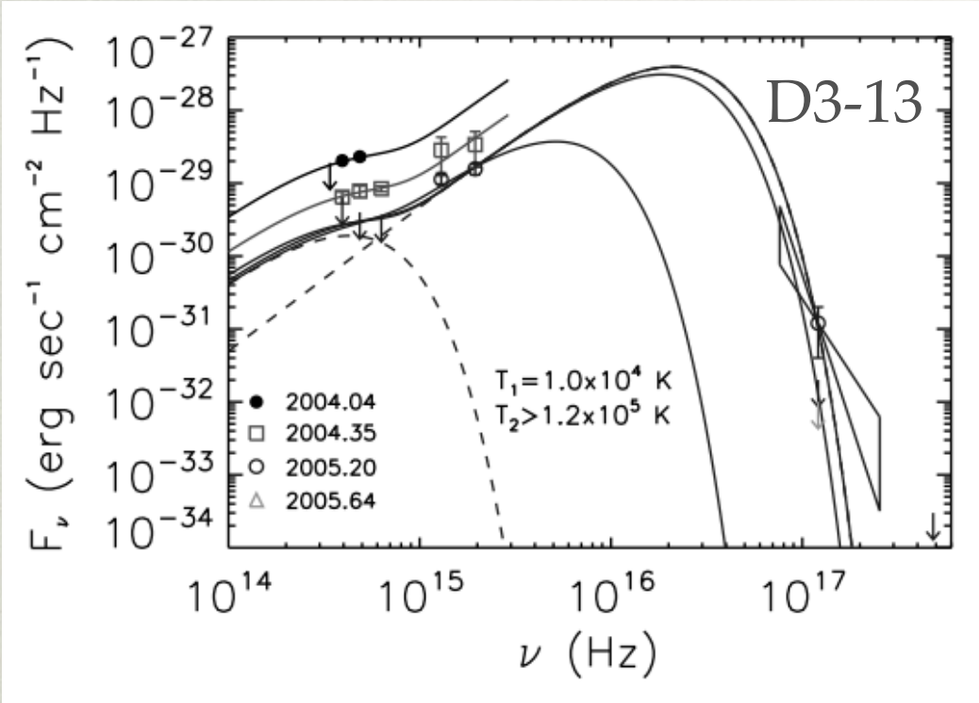


Guillochon et al. 2013

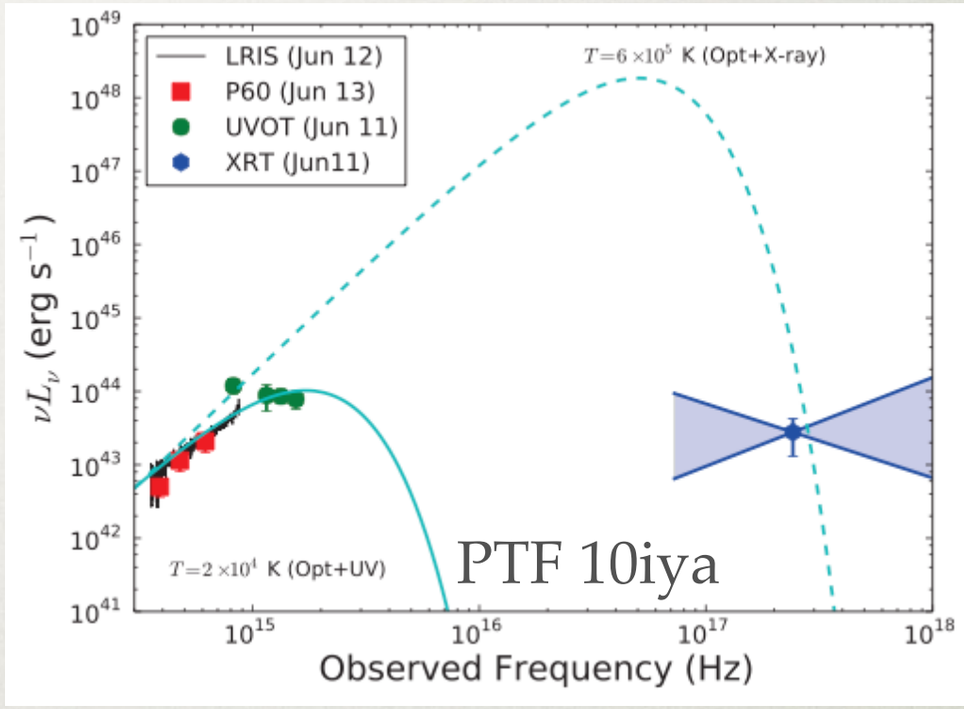


- T_{BB} is too low, R_{BB} is too high for standard thin disk models at tidal radius
- So optical emission is higher than expected

Relevant Precedents?



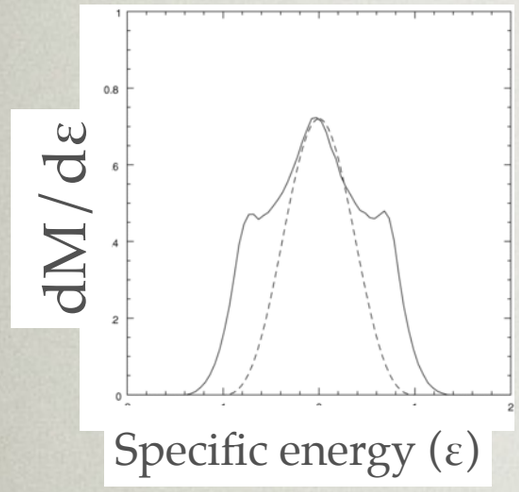
Gezari et al. 2008

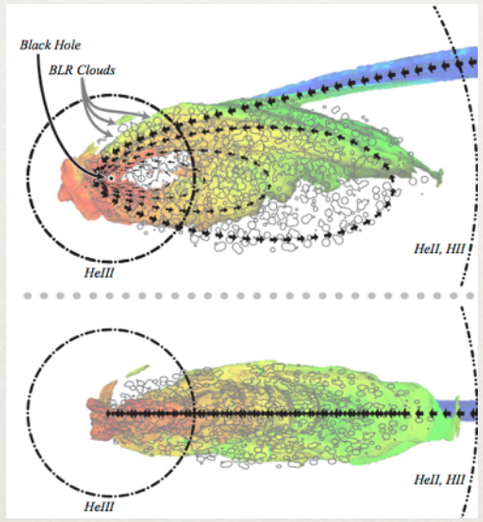


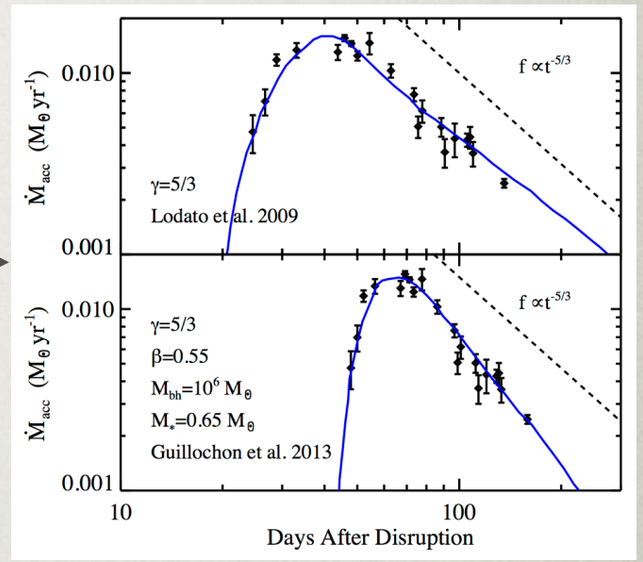
Cenko et al. 2012

- In each case, X-rays do not fall on extrapolation of low-energy SEDs
- Separate components (disk + wind?)

How to Interpret Observed Light Curves?



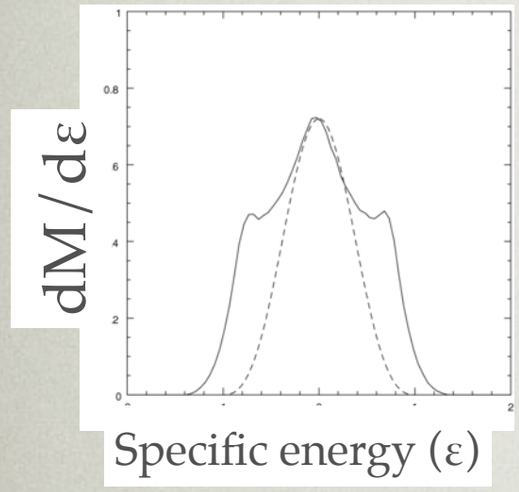


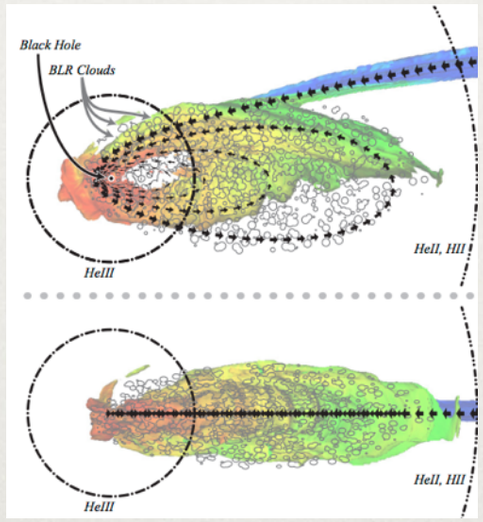


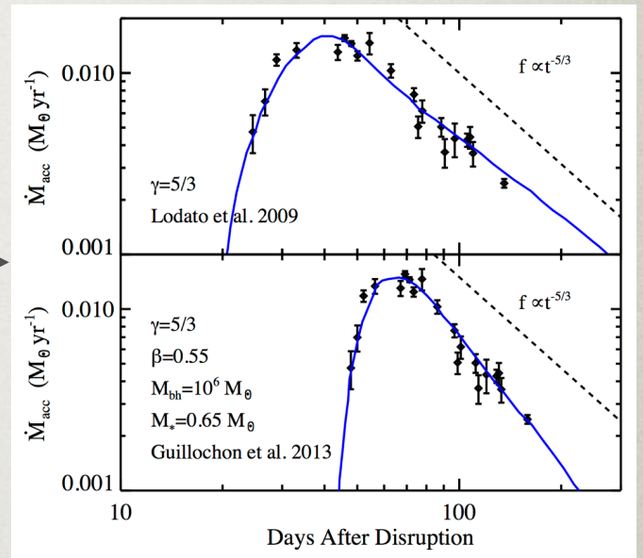
$$\mathrm{dm/d\varepsilon} \longrightarrow \dot{M}_p(t) \longrightarrow \dot{M}_{acc}(t) \longrightarrow L_{bol}(t)$$

$$L_\nu(\nu,t) \longrightarrow L_{bol}(t)$$

How to Interpret Observed Light Curves?



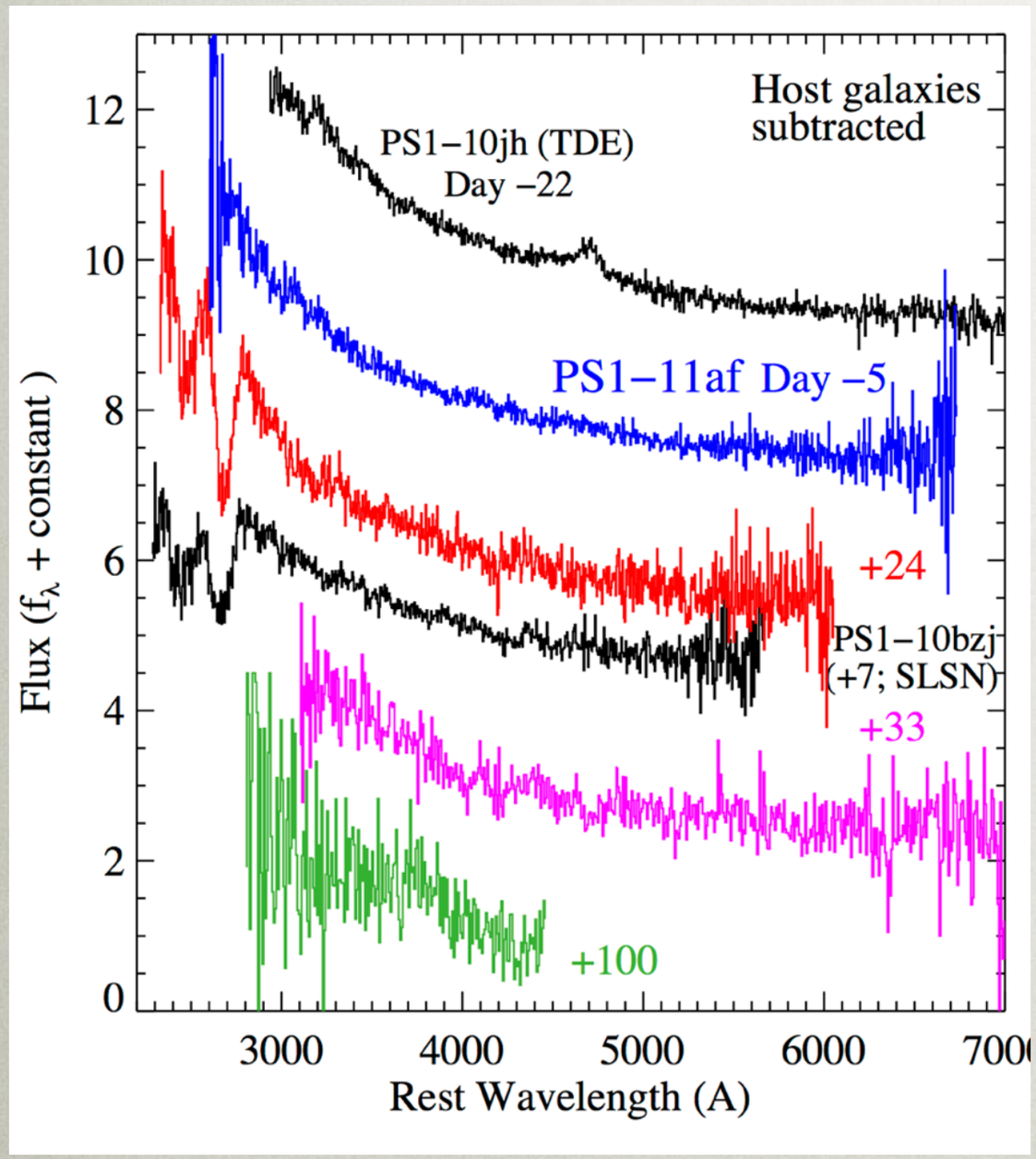


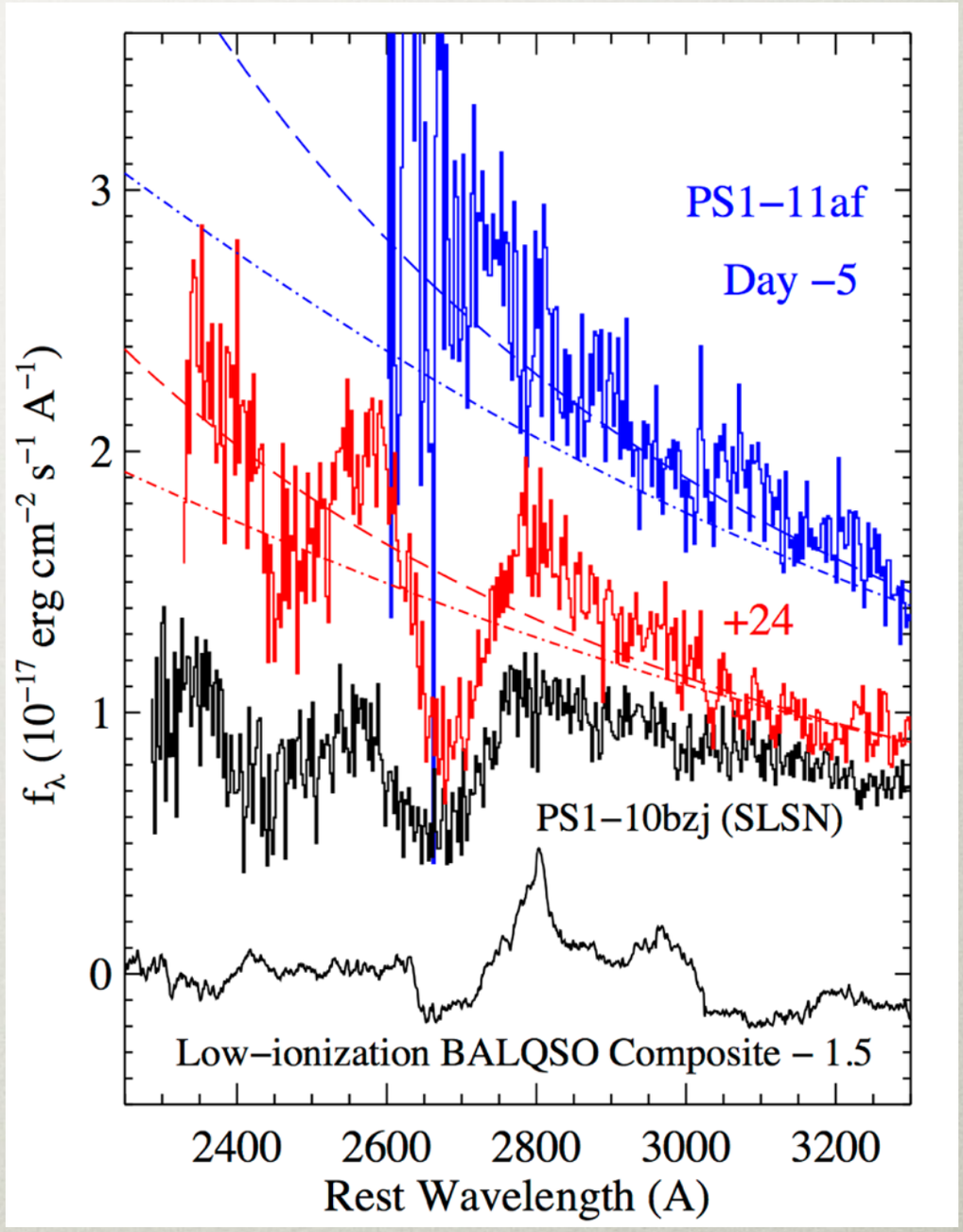


$$\mathbf{dm/d\varepsilon} \xrightarrow{\text{Kepler*}} \dot{\mathbf{M}}_{\mathbf{p}}(t) = \dot{\mathbf{M}}_{\mathbf{acc}}(t) \propto (1/\eta)\, \mathbf{L_{bol}}(t)$$

$$\mathbf{L}_{\nu}(\nu,t) \times \mathrm{BC} = \mathbf{L_{bol}}(t)$$

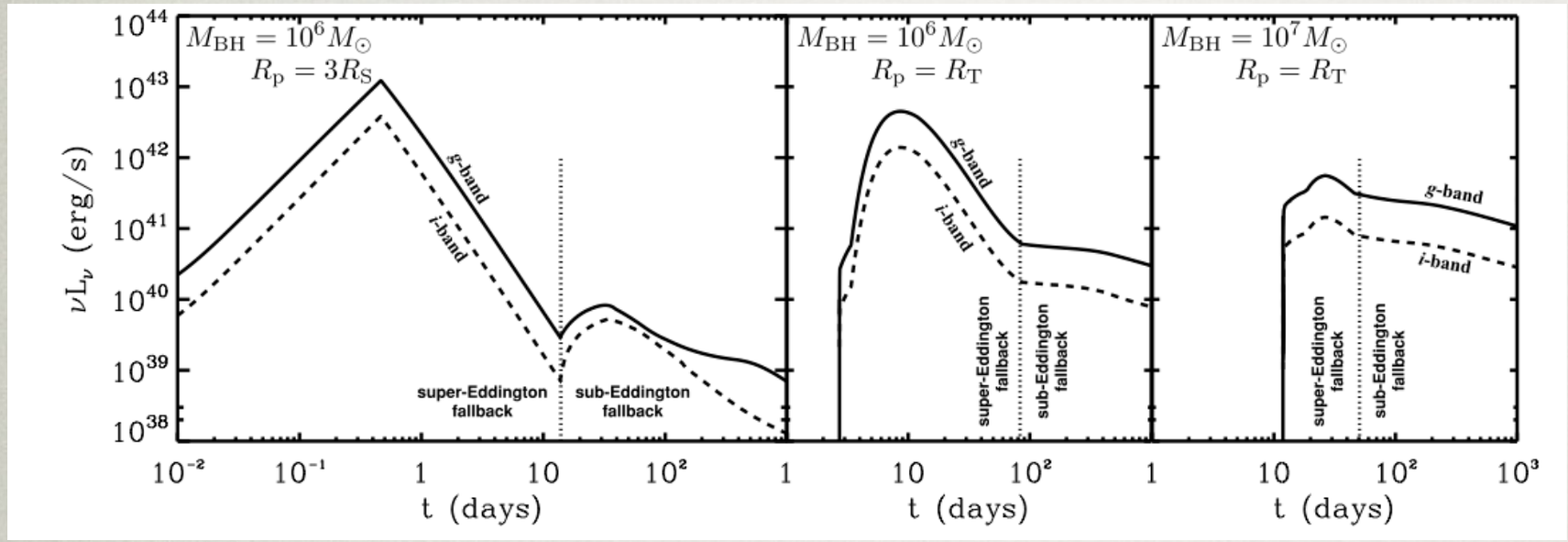
PS1-11af: Transient UV Absorption Features



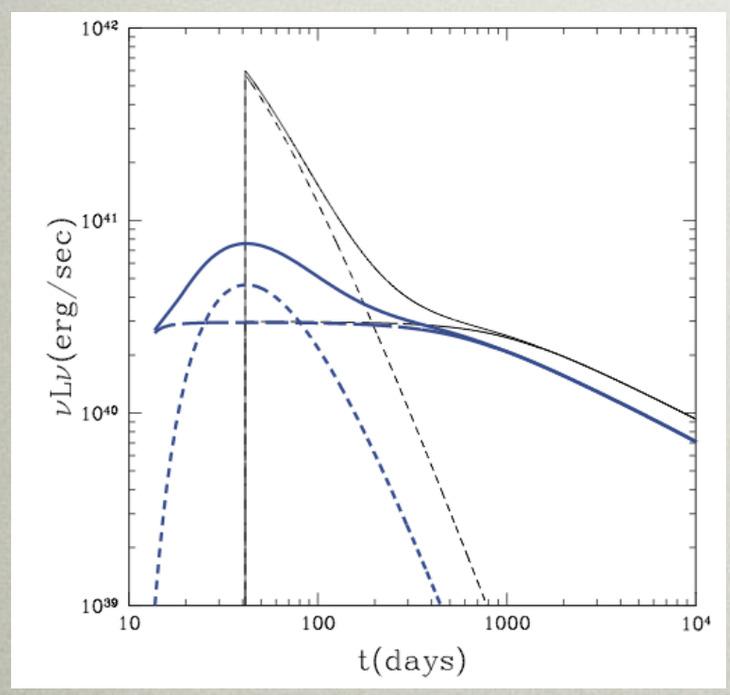


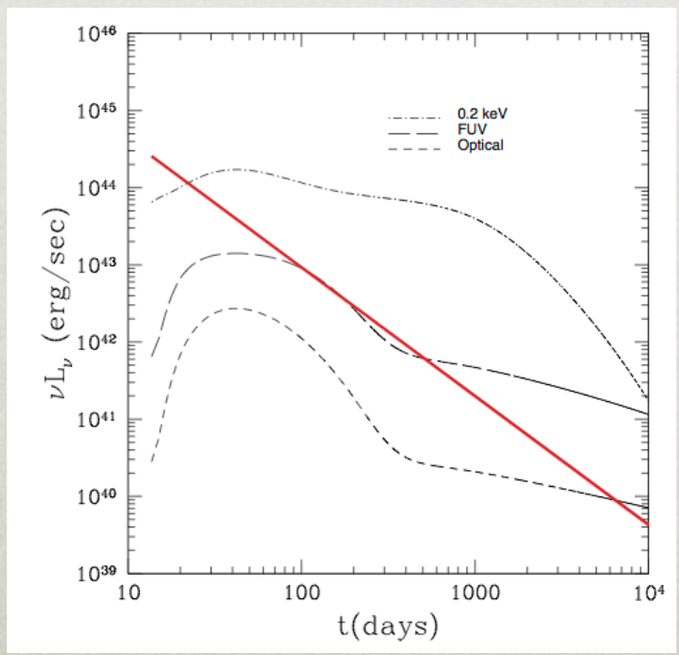
Mg II? Where are H/He lines?

When Does Outflow Form?



Strubbe & Quataert 2009

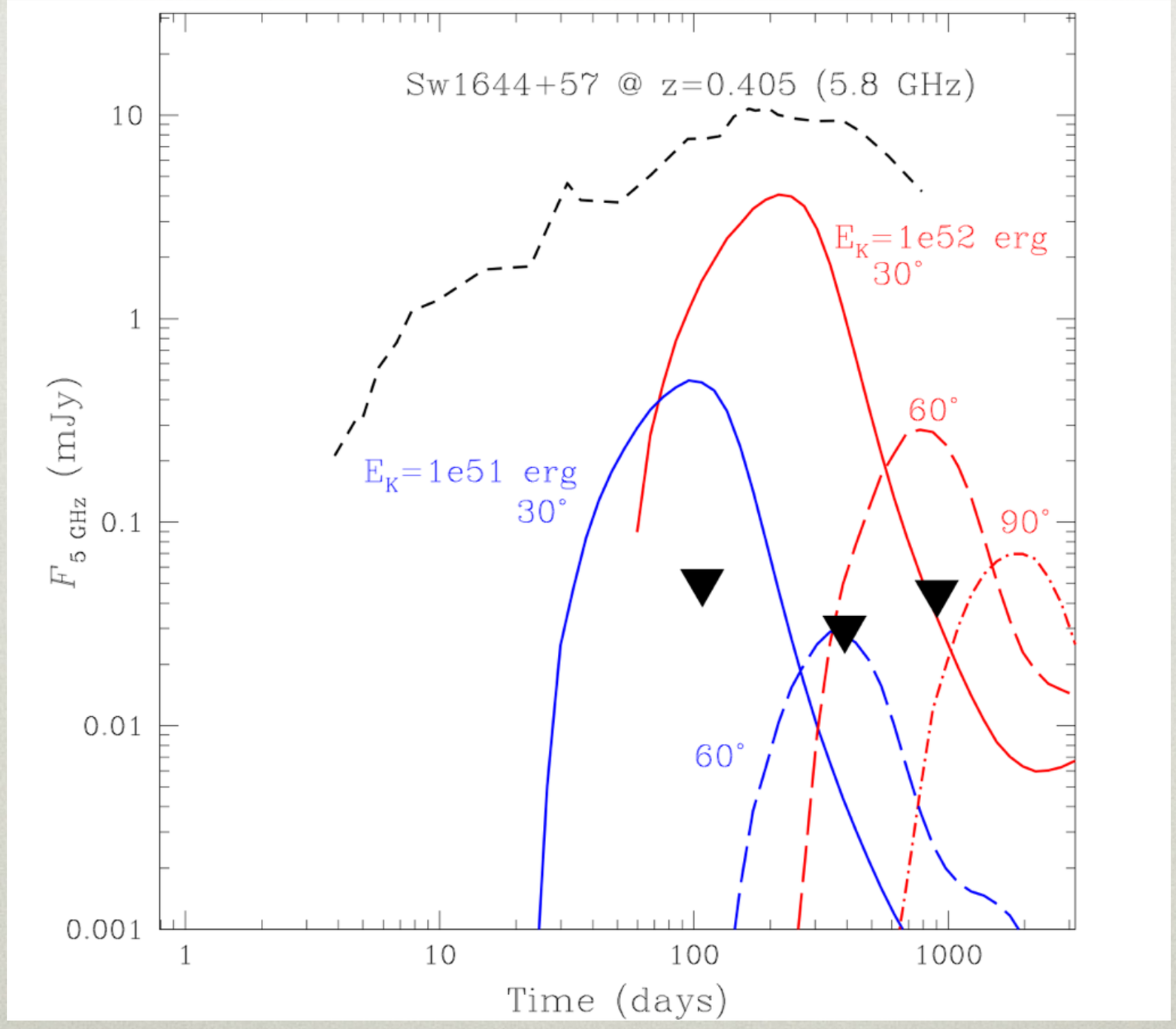




Lodato & Rossi 2011

- Is it an outflow?
- Hydrodynamically or radiatively driven?
- Is it tied to the Eddington ratio?
- Why no evolution?

No Jet Visible... yet...



Conclusions

- We have found two optically-selected TDEs in Pan-STARRS1 + GALEX data
- T_{BB} is too low (2-3×10^4 K), R_{BB} is too high (~10^{15} cm) for thin disk models —> reprocessing?
- How do these relate to the soft X-ray TDE candidates?
- More theoretical understanding of reprocessing/outflows and their effects on optical light curves needed
- Can we use TDE light curves to measure M_{BH}?