Stellar tidal disruption flares

new probes of black hole astrophysics

Sjoert van Velzen

Hubble Postdoctoral Fellow

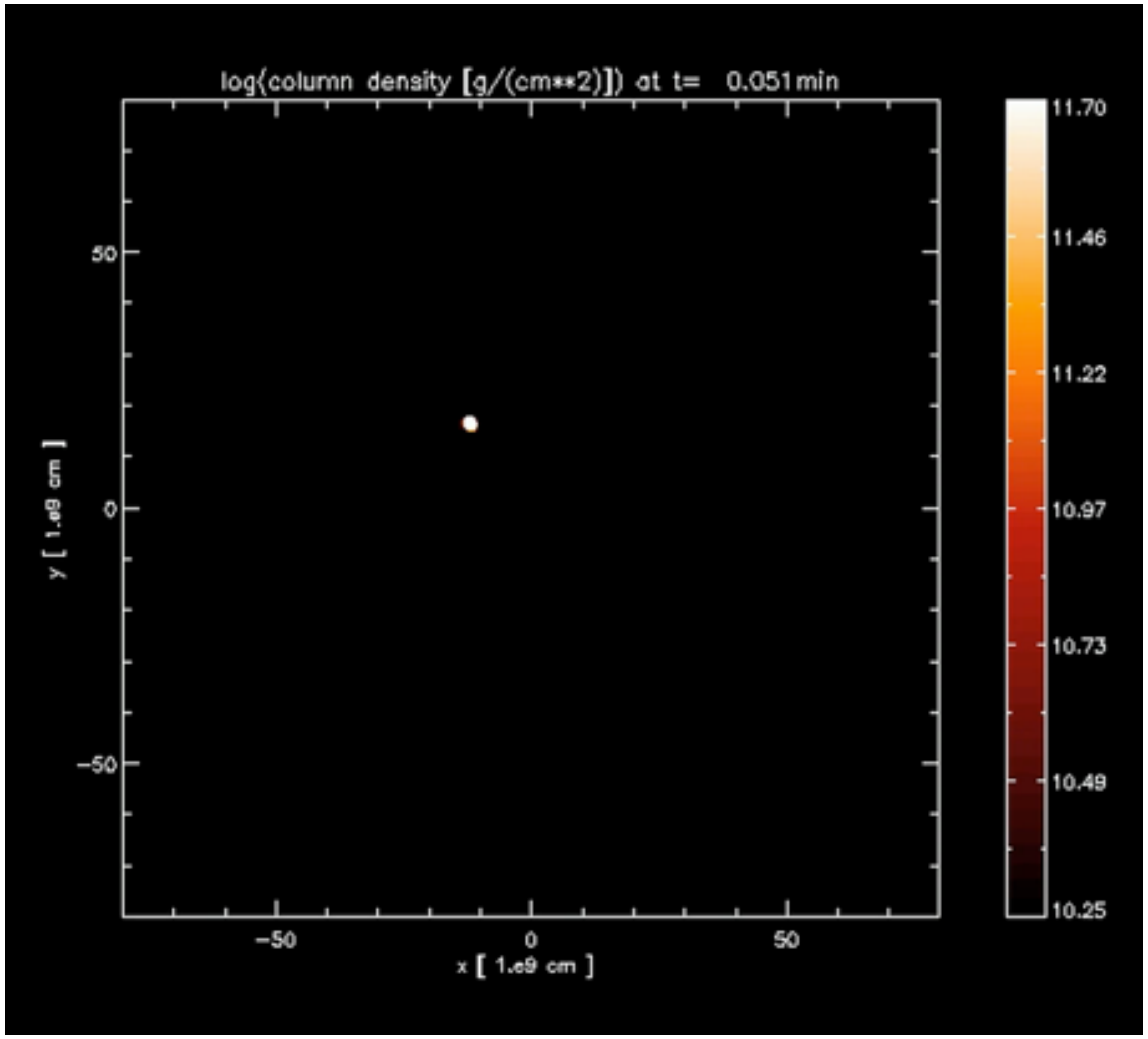
Johns Hopkins University

Glennys Farrar, Heino Falcke, Rob Feder,
Nick Stone, Peter Jonker, Thomas Wever,
Nadia Blagorodnova, Elmar Körding,
Suvi Gezari, Gemma Anderson, Dale Frail

Gaia Science Alerts Workshop, Nov 12, 2015

Stellar tidal disruption events

- Unlucky star
- ~50% of debris falls back onto BH (Evans & Kochanek 1989)
  - Fallback rate ~ $t^{-5/3}$
  - Fallback rate ≫ Eddington rate
- Accretion flare, peaked at EUV (Rees 1988)
- Max mass for visible flare ~10^8 $M_\odot$ (Hills 1975)
- Rare events: ~10^4 yr wait time (Magorrian & Tremaine 1999)



Roswogg et al. (2009)

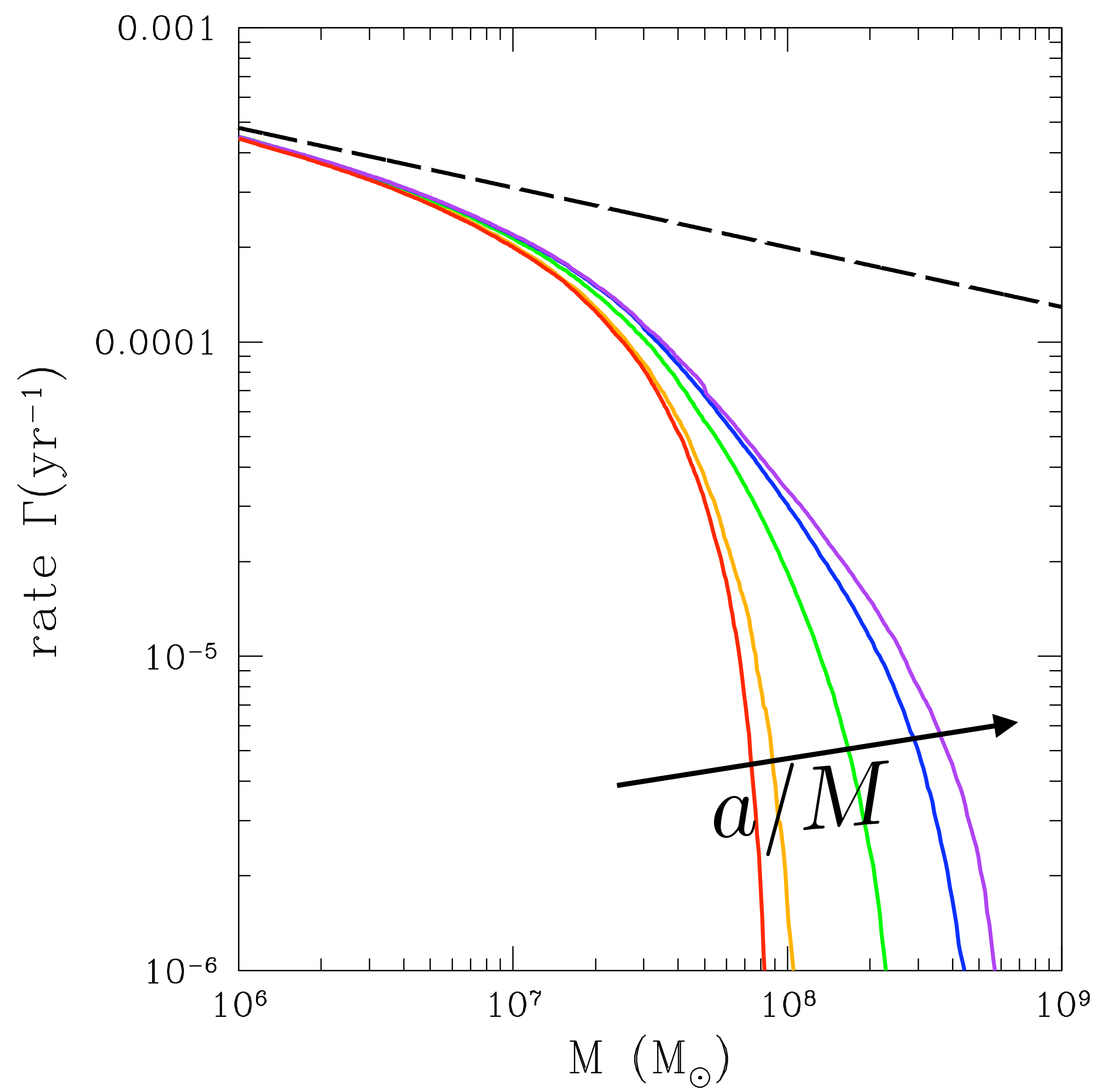
Interesting for many reasons

- Accretion physics (thermal emission)
- Jet physics (non-thermal emission)

- Probe dormant black holes (measure BH mass?)
- Stellar dynamics
- SMBH mergers

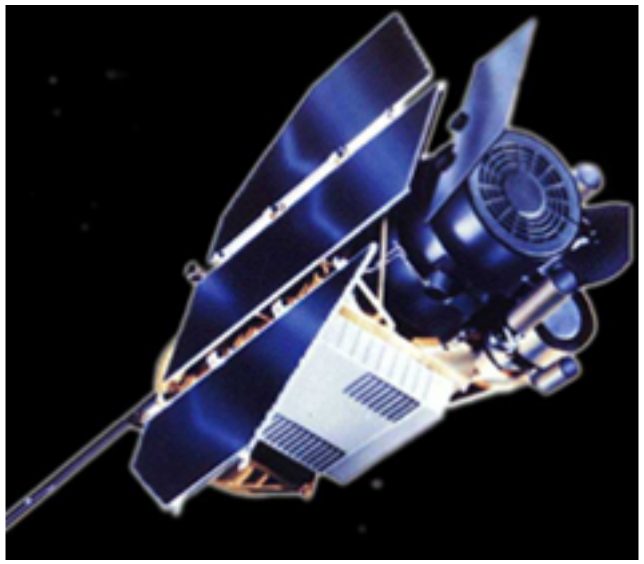
- Intermediate-mass BHs

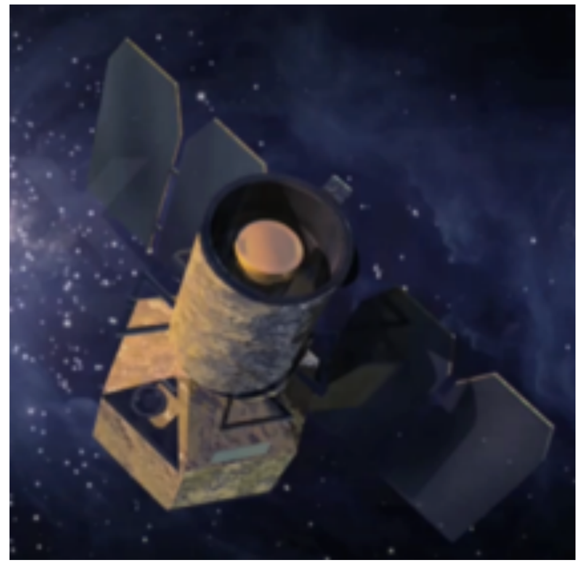
- General relativity

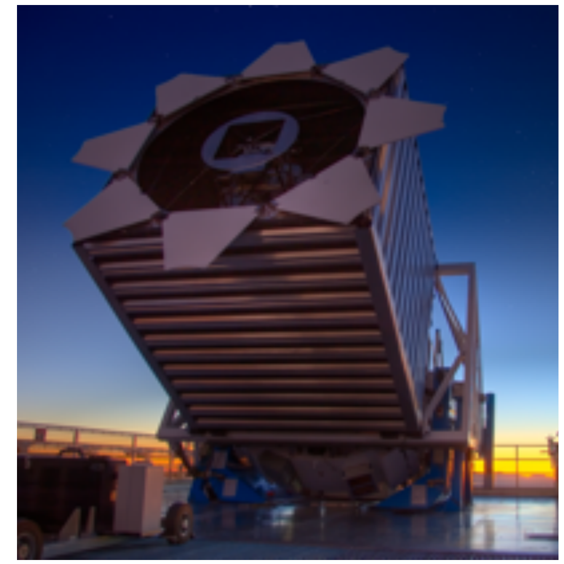


(Kesden 2011)

Timeline of TDE (thermal emission)







1999 ROSAT

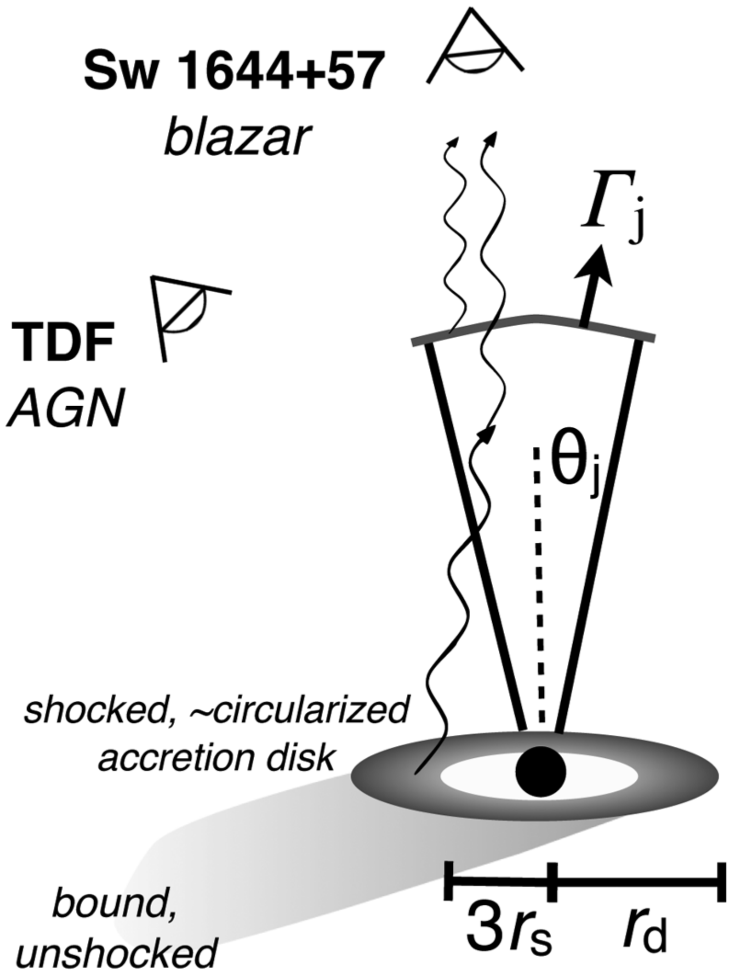
2006 GALEX

2010 SDSS

PS1, PTF, CRTS, ASAS-SN, ... Gaia

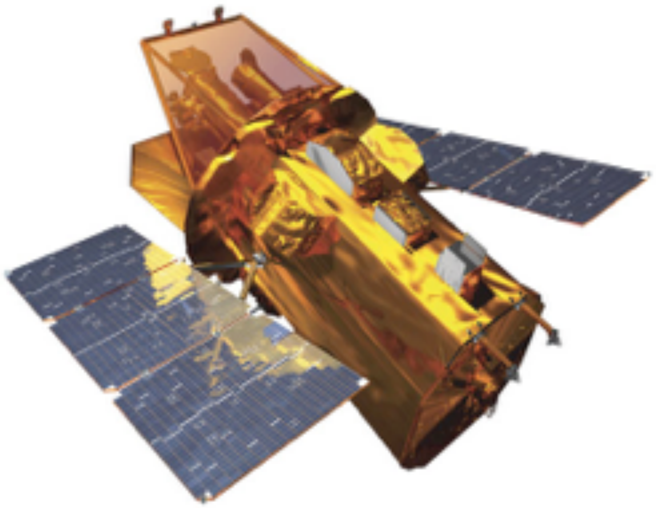
Non-thermal emission: tidal disruptions with jets

Credit: Marscher et al., Wolfgang Steffen, Cosmovision, NRAO/AUI/NSF



Bloom et al. (2011)

Timeline of TDE observations



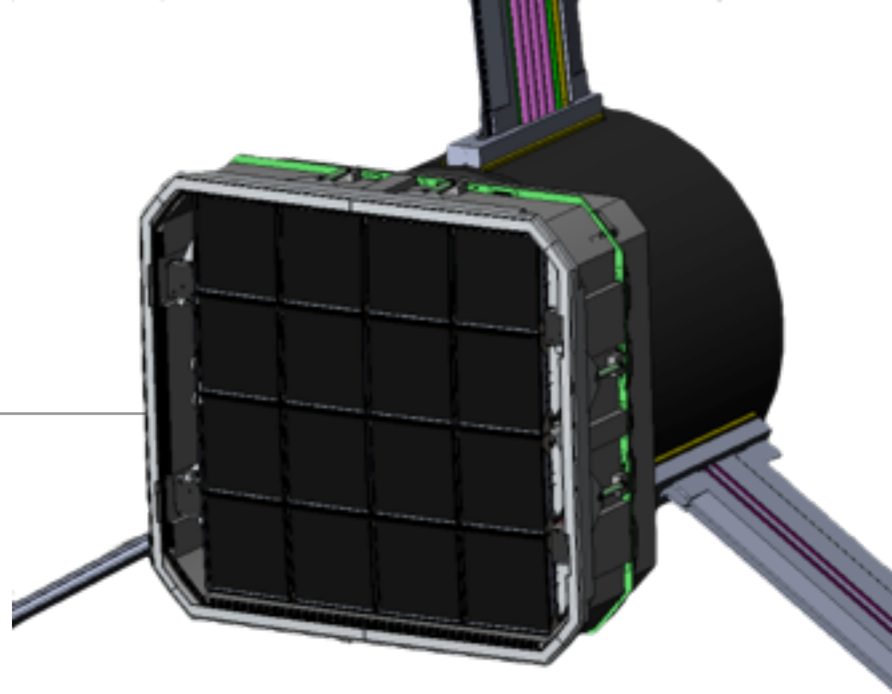
1999 **2011** **2015**

First TDF jets (non-thermal)

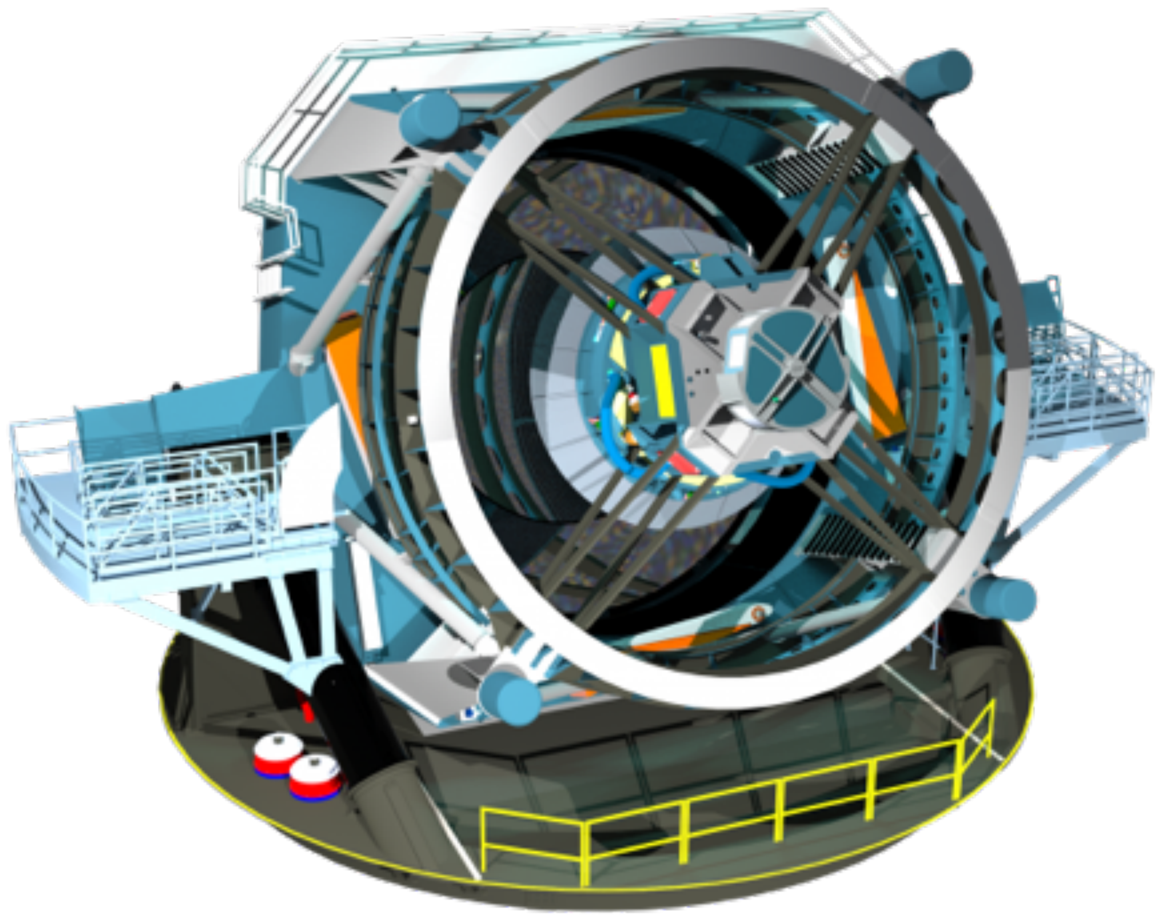
First jet from thermal TDF

~100 TDF jets from SKA radio transient survey

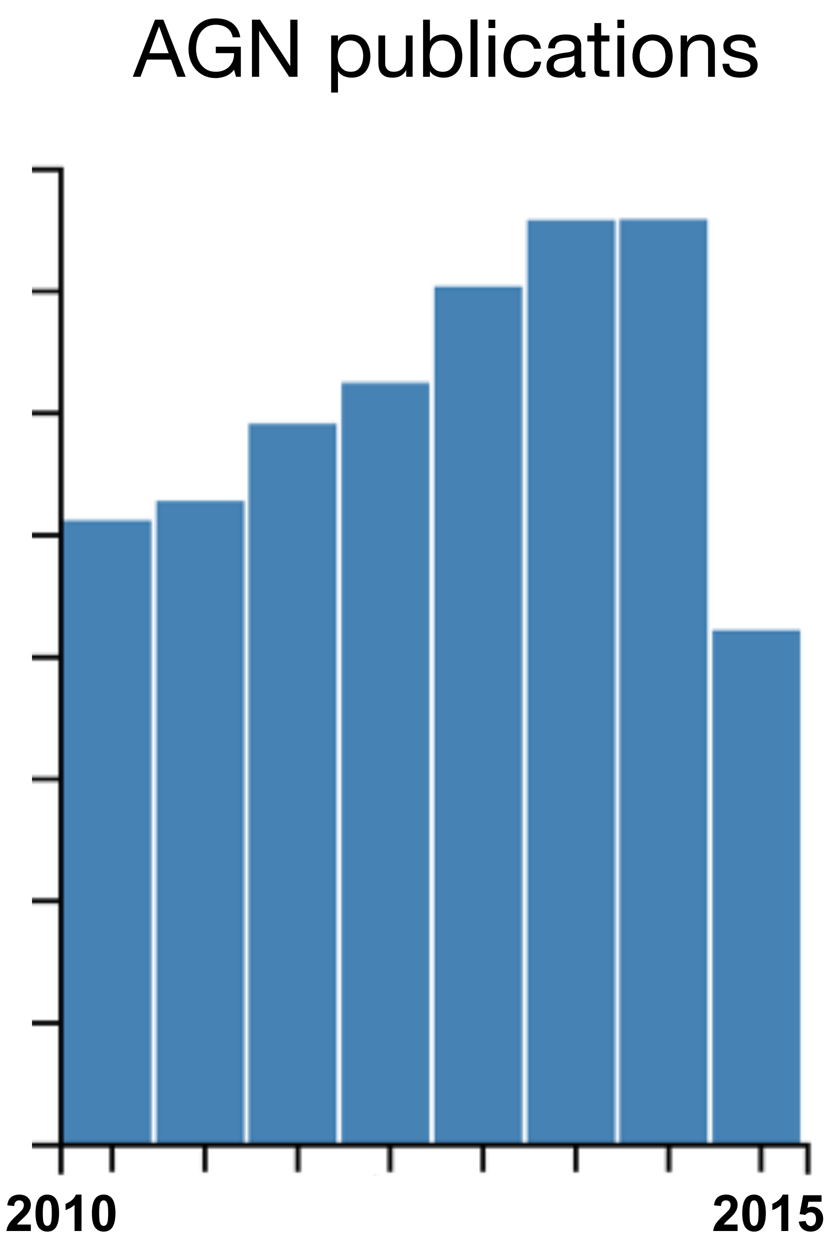
The time-domain revolution

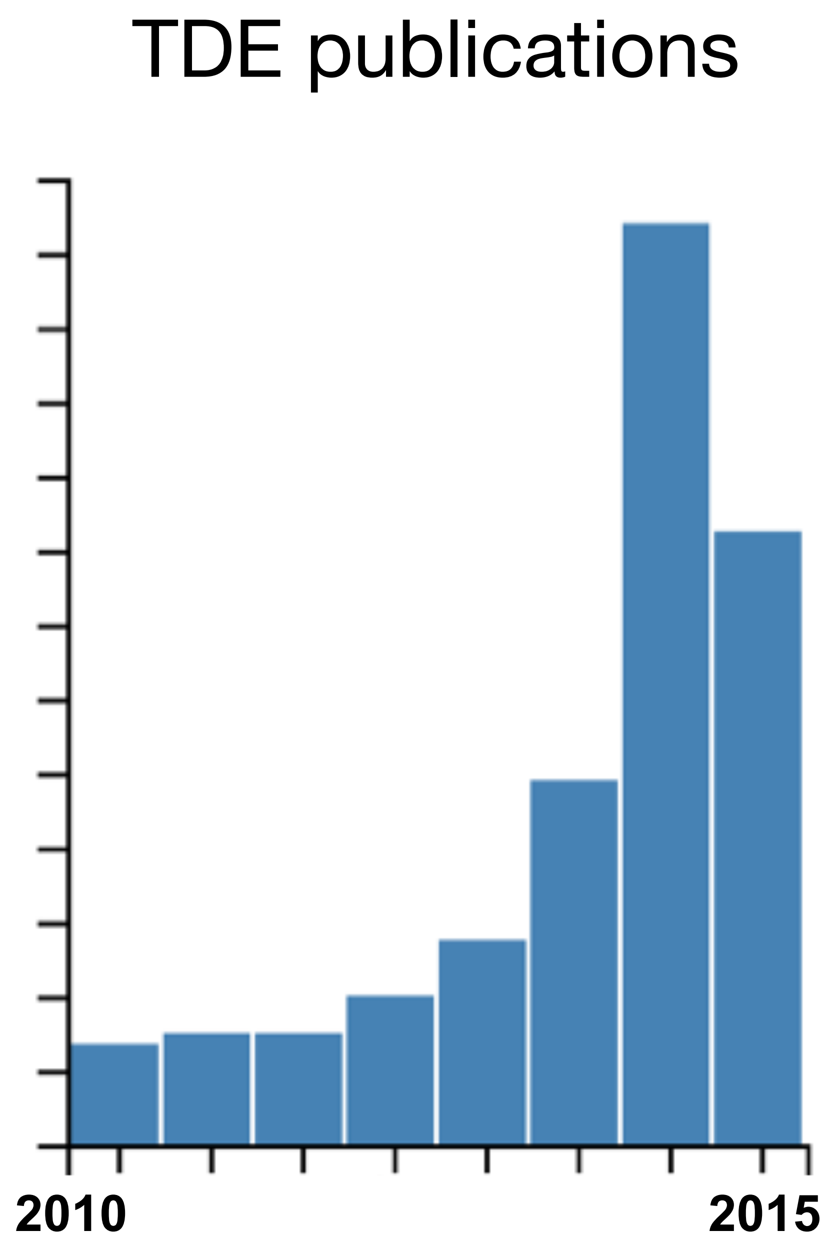


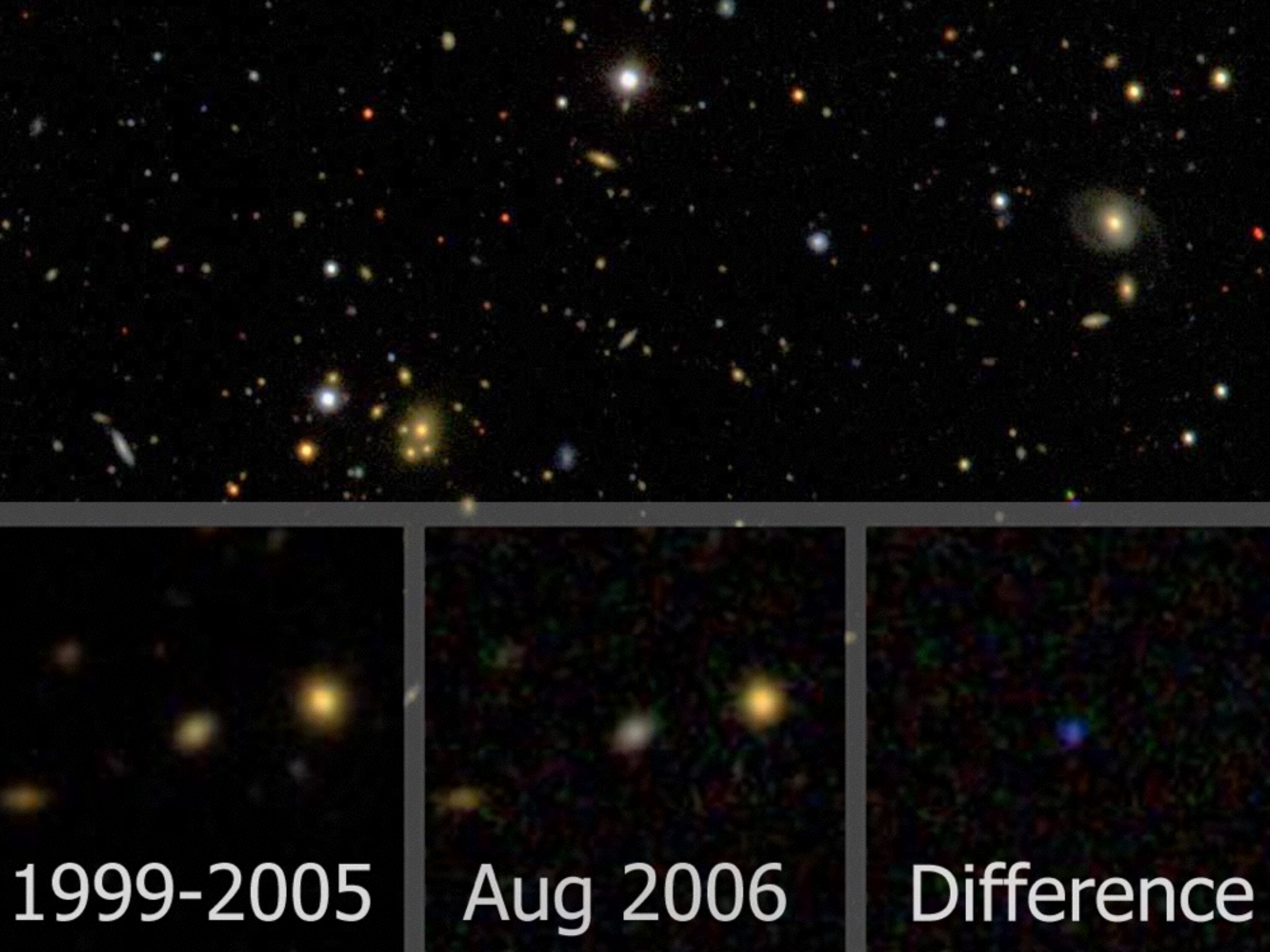
- Completed surveys:
  - ROSAT (3)
  - GALEX (3)
  - SDSS Stripe 82 (2)
- Ongoing:
  - XMM (≈6); Swift (2)
  - PTF (3); Pan-STARRS (2); ASAS-SN (3); CRTS (0?); Gaia(0)
- (Near)-future:
  - eROSITA; ZTF; BlackGEM; ATLAS; LSST, TESS, …



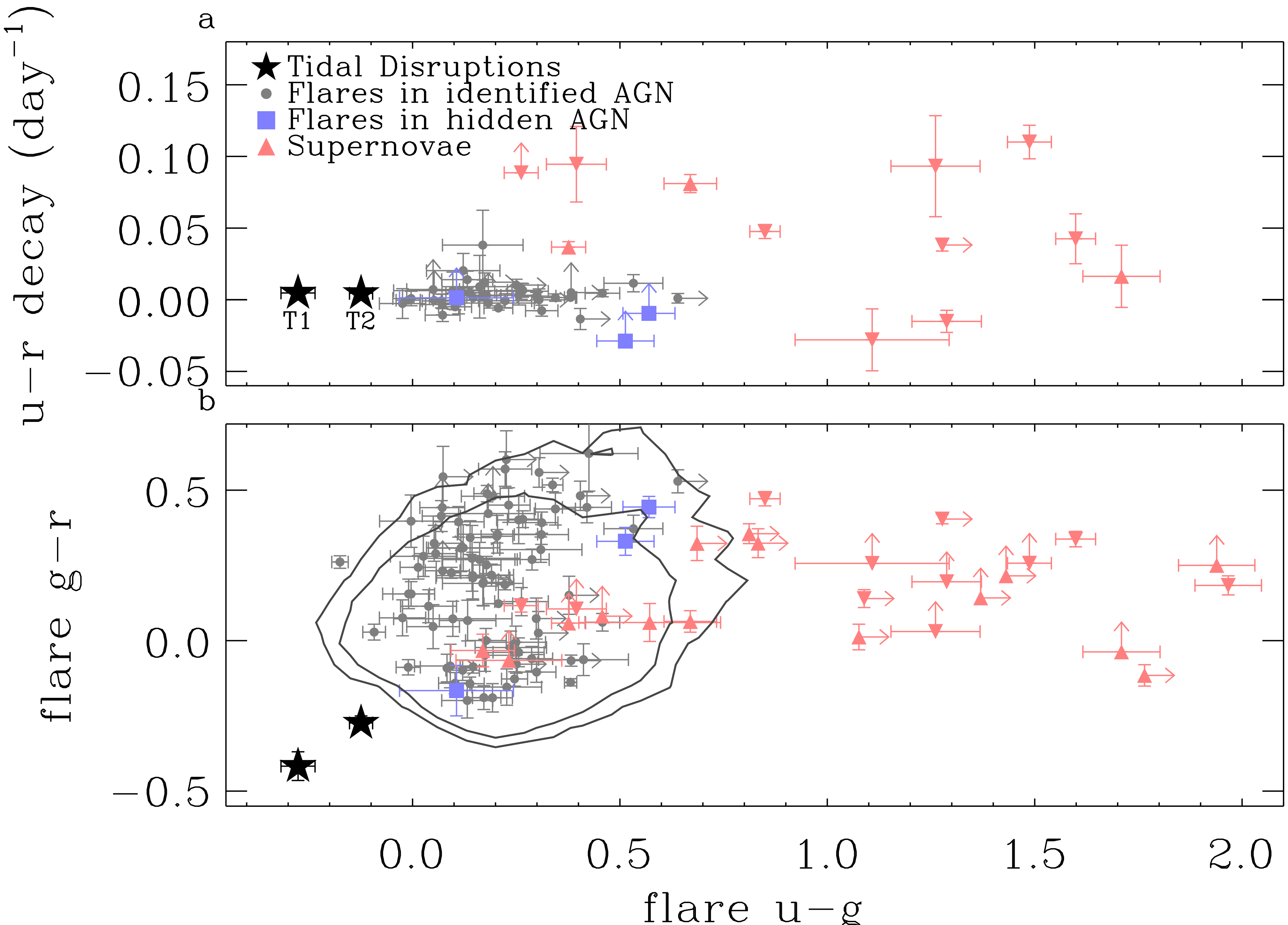
The time-domain revolution (😱)






1999-2005
Aug 2006
Difference

Results from an unbiased pipeline



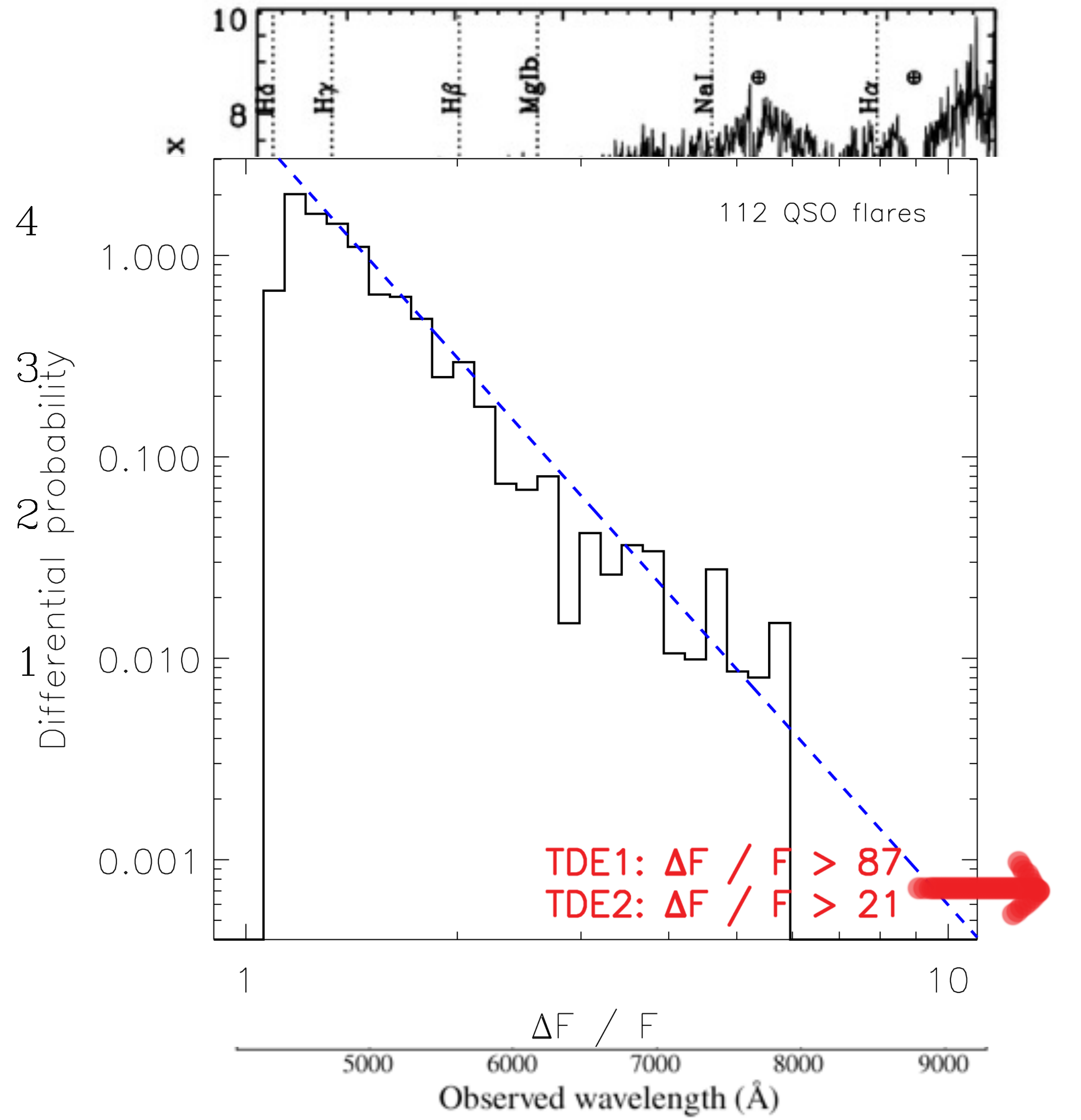
Cooling

Spectral energy distribution

van Velzen et al. (2011)

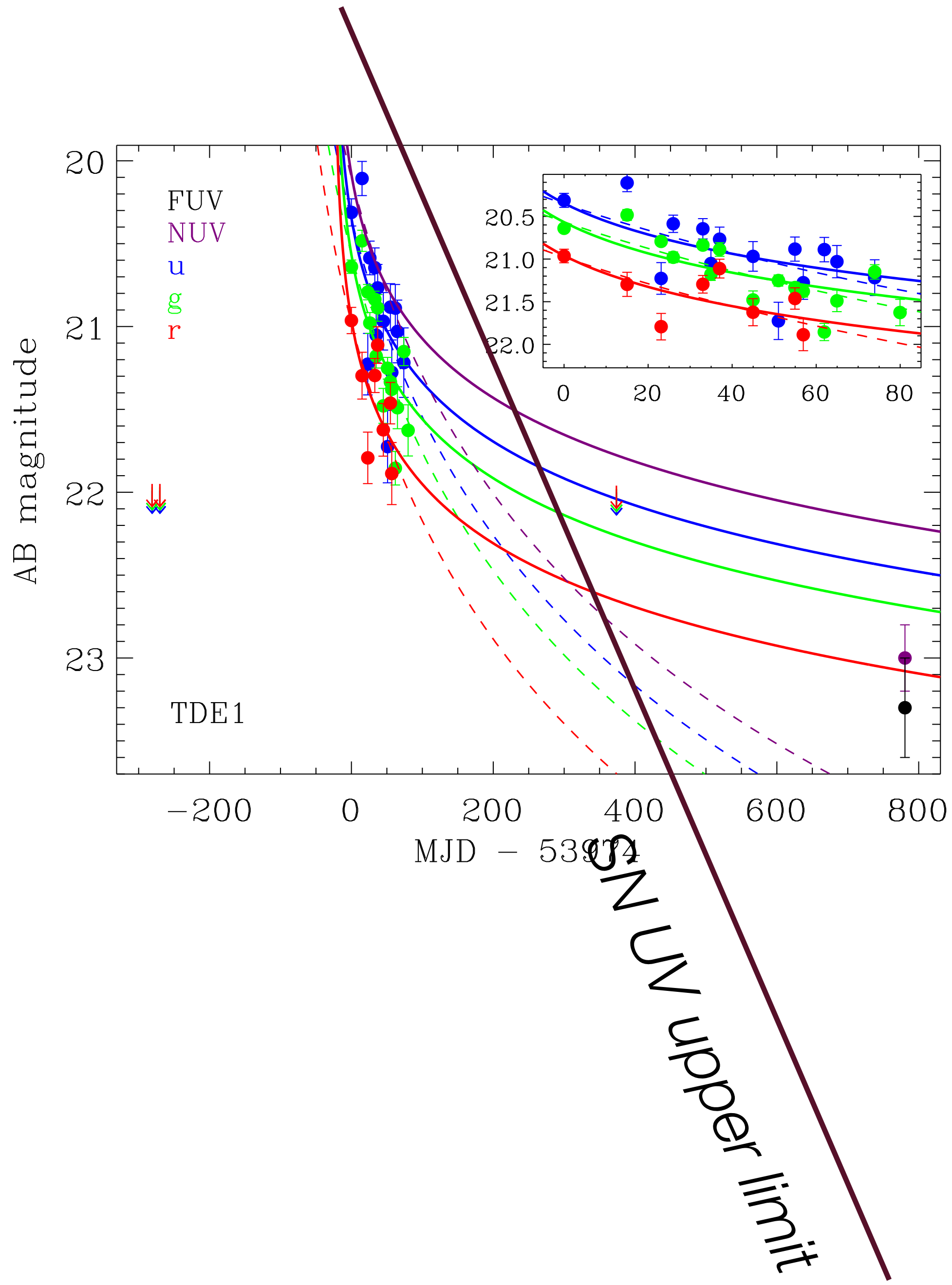
Could these flares originate from AGN?

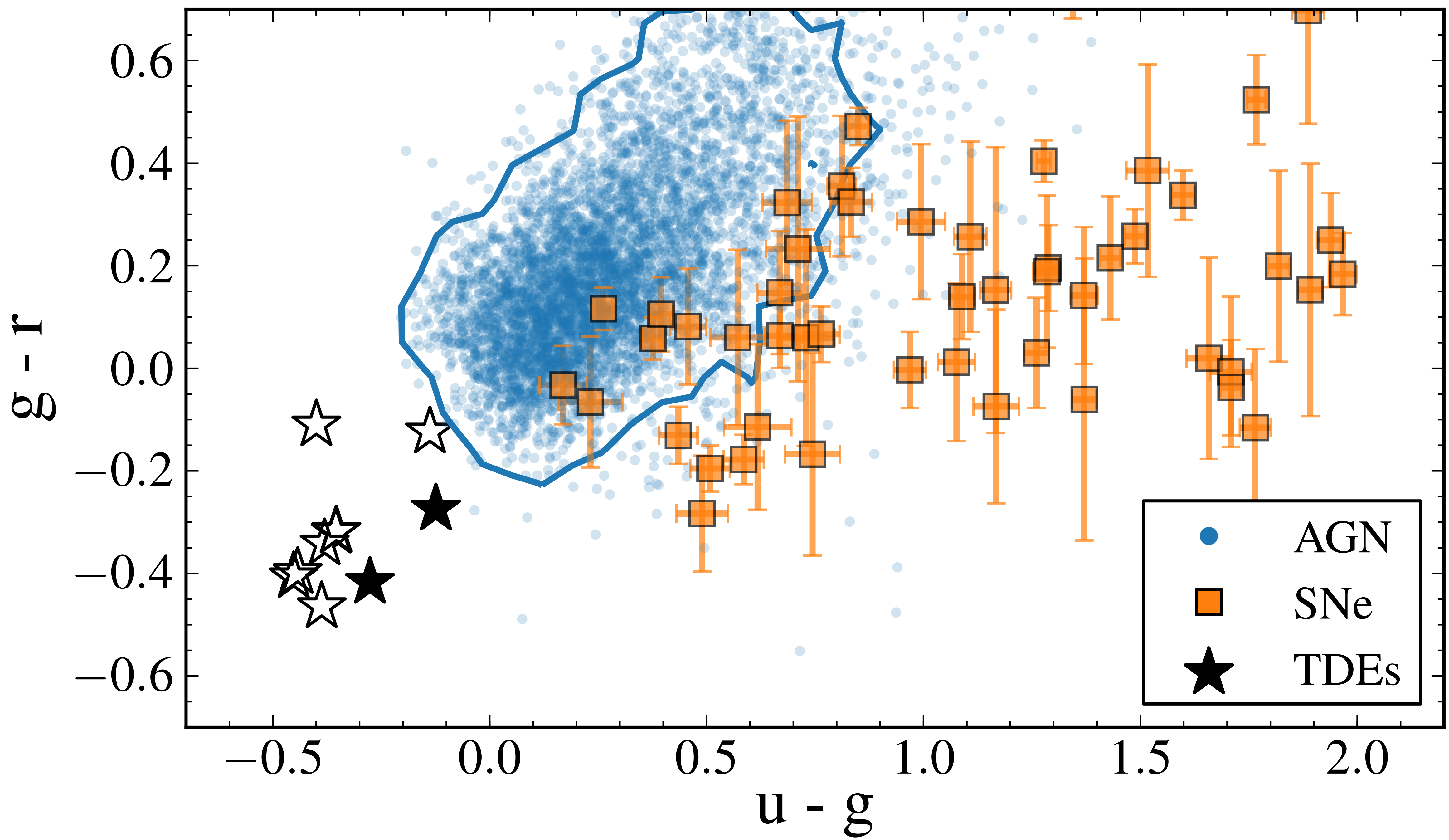
- Flares are more blue than QSO (in their high-state)
- Host spectra show no sign of active black hole
- Flux increases very large: P(AGN)~10^{-7},10^{-5}
- No additional variability: P(AGN)~10^{-6},10^{-5}
- Radio non-detection: F < 20 μJy; L < 10^{37} erg s^{-1}



Could there flares be supernovae?

- Not normal SNe: more blue, little cooling
- UV detection > 2 yr after the flare
- Based on geometry:
  - *P*(SN) < 2%
- New kind of "nuclear" core collapse SN?
  - Never observed before (?)
  - Would require factor 1000 suppression outside nucleus

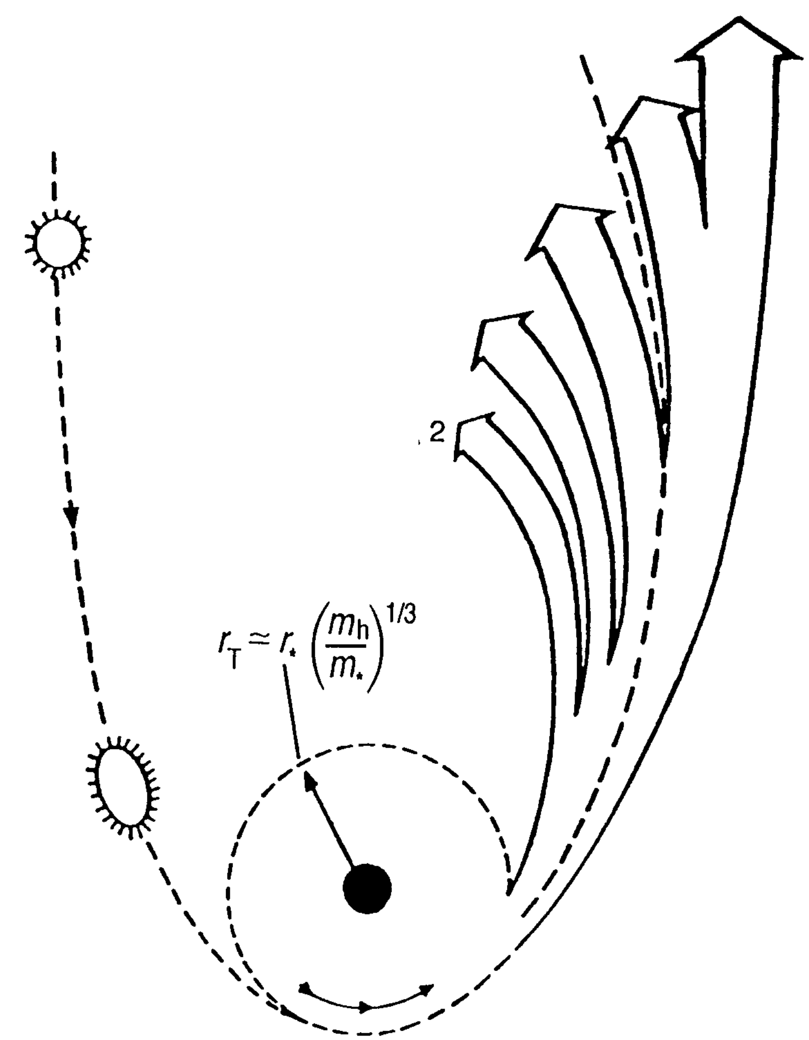



0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
g - r
−0.5
0.0
0.5
1.0
1.5
2.0
u - g
AGN
SNe
TDEs

Most pressing open questions

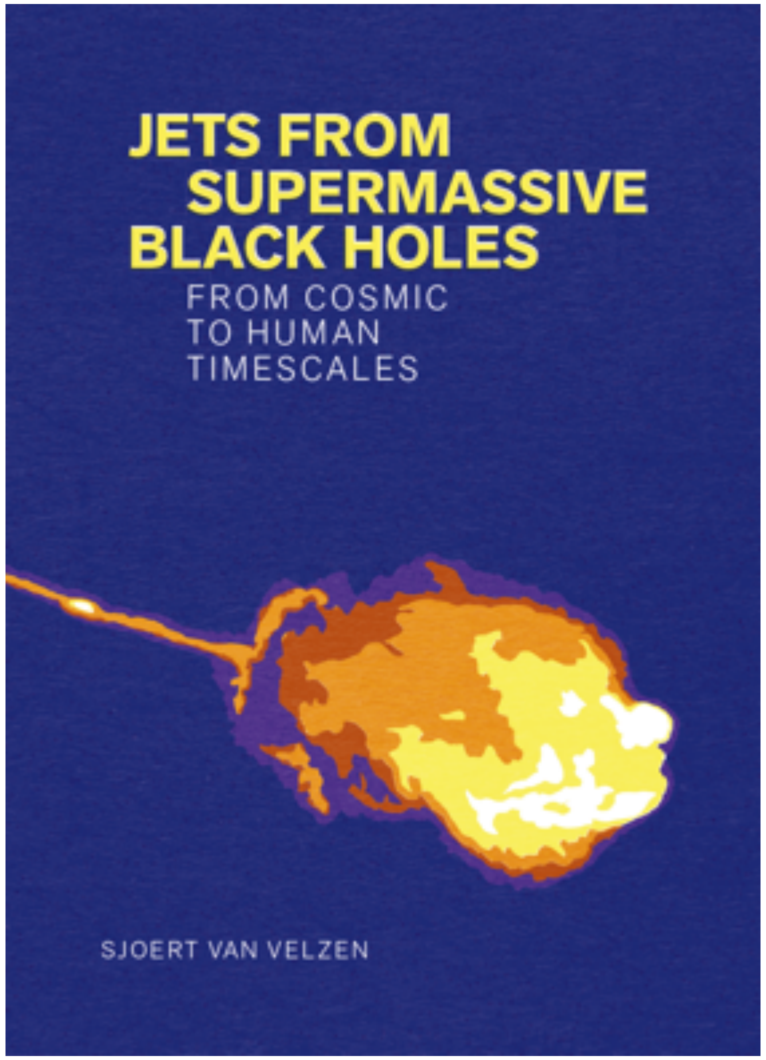
- Evolution of stellar debris streams:
  Efficiency of disk formation

- **Origin** of optical photons?
  - ~~Small disk~~
  - Wind (eg, Strubbe & Quataert 2011; Miller 2015)
  - Reprocessing (Loeb & Ulmer 1997; Guillochon et al. 2014; Metzger & Stone 2015)
  - Shocks (Piran et al. 2015)



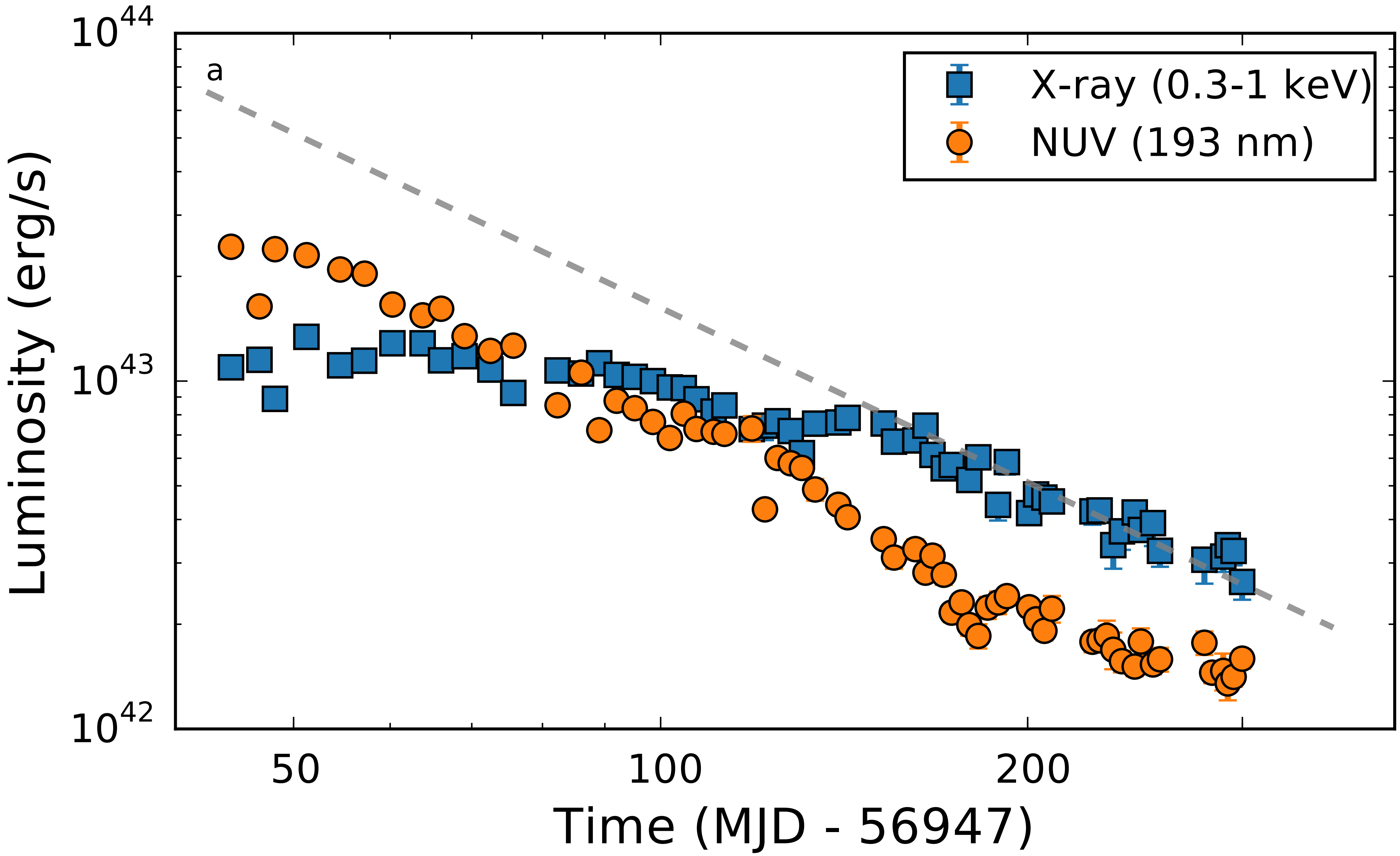
Rees (1988)

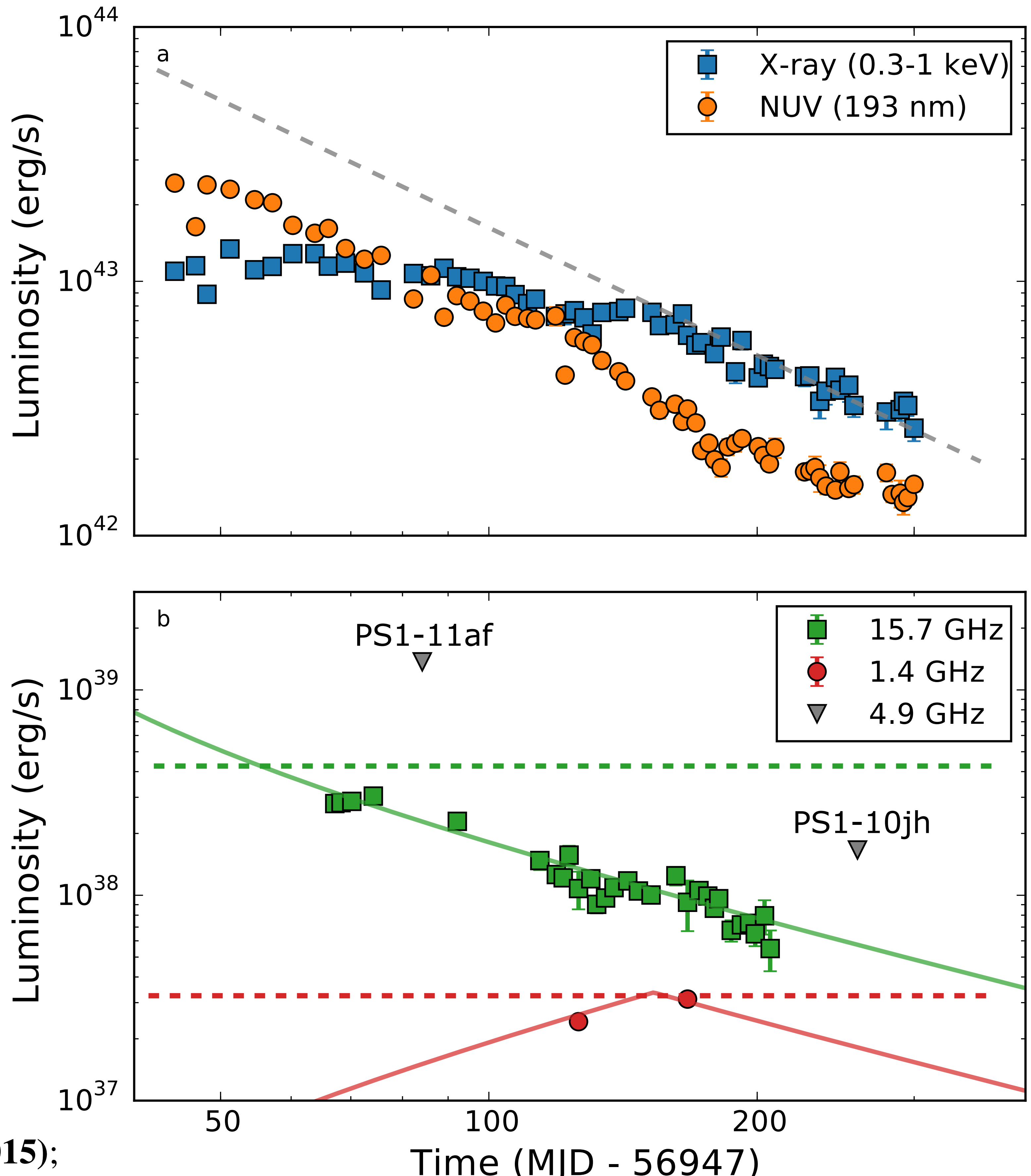
A prediction from Spring 2014



To solve this problem we have to discover TDFs with detected emission from *both* the jet and the disk. I predict that these events will be discovered within the next four years and will open up a new avenue of research, leading to a better understanding of jet formation in supermassive black holes.

The Rosetta Stone TDE: ASASSN-14li

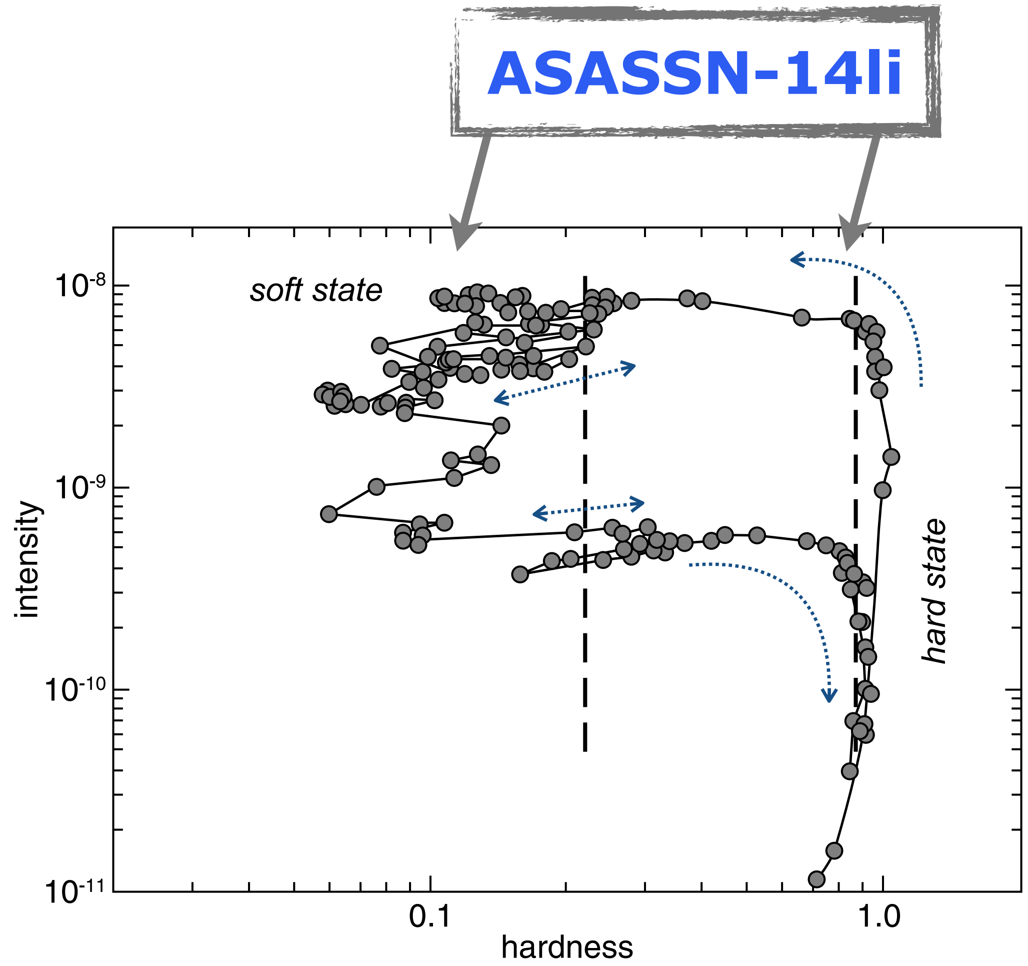




van Velzen et al. (2015);
(see also Alexander et al. (2015)

The first thermal TDF with variable radio emission

- Pre-flare accretion flow collapsed
- New jet launched, E~10^{48} erg, Γ≈2
  - Observe deceleration phase, n~1000 cm^{-3} (à la Nakar and Piran 2011)
- Natural analogy with stellar mass BHs
- All thermal TDF produce such jets!?



Tidal flares with Gaia

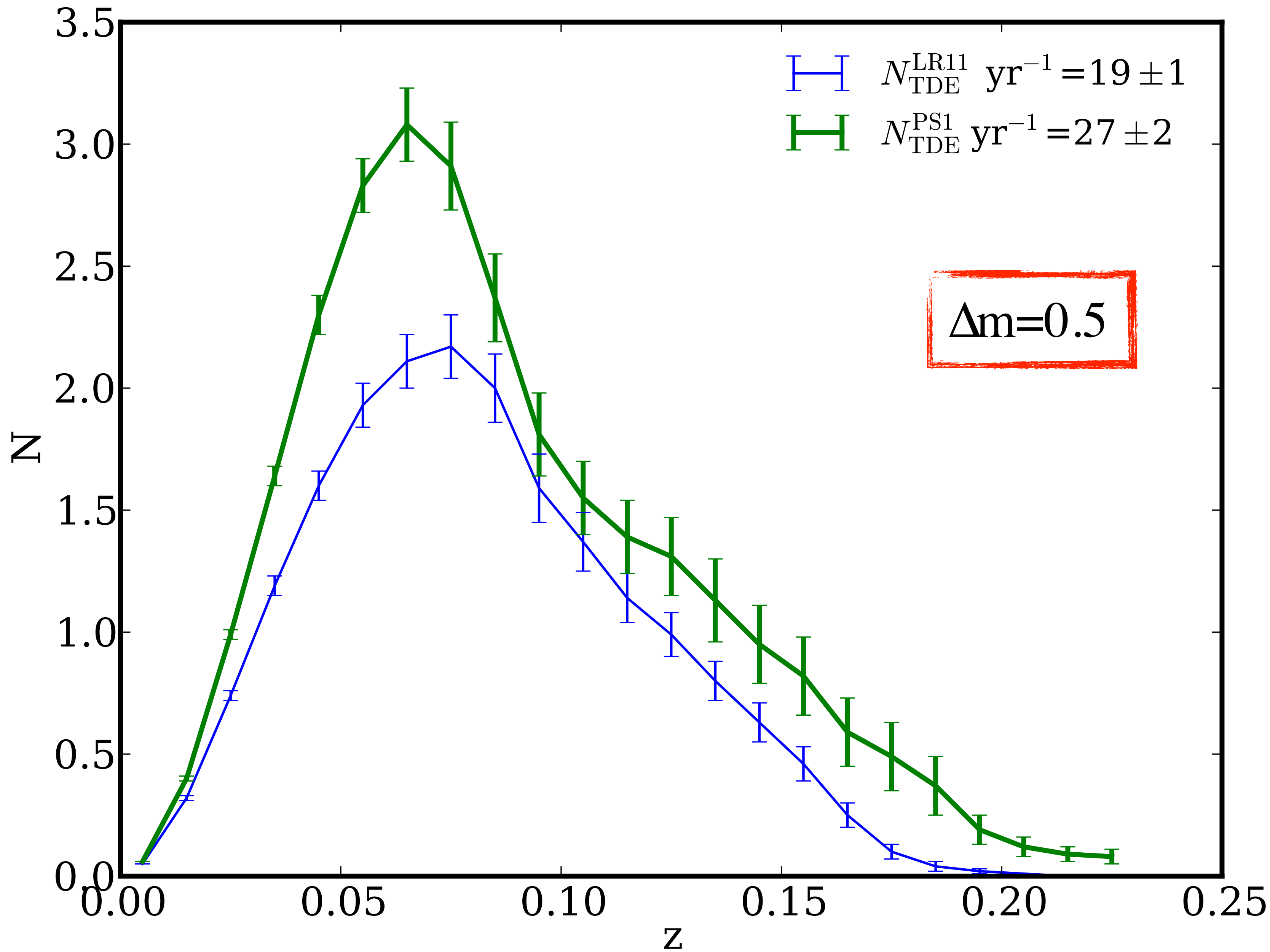
Advantages:

- High angular resolution
- All sky, unbiased
- Cadence
- Color / low-res spectrum

Challenges:

- Galaxy photometry
- Galaxy astrometry
- Galaxy not detected
- ~20 mas precision needed

We should find a few per year



Blagorodnova, van Velzen, et al. (2015)

General plan and dreams

- Follow-up every nuclear flare from Gaia:
  - Detected galaxy: no centroid shift
  - Not detected: *relative* astrometry to ground-based observations
- Gaia Alerts TDE/AGN Working Group
- First step: less stringent cuts for known galaxies
- Dream: monitor all galaxies

Conclusions & Outlook

- Dozen optical/UV TDE found.
- Thermal emission:
  - Reprocessing or shocks
- Perhaps all TDEs launch jets.
- We will find them with Gaia.

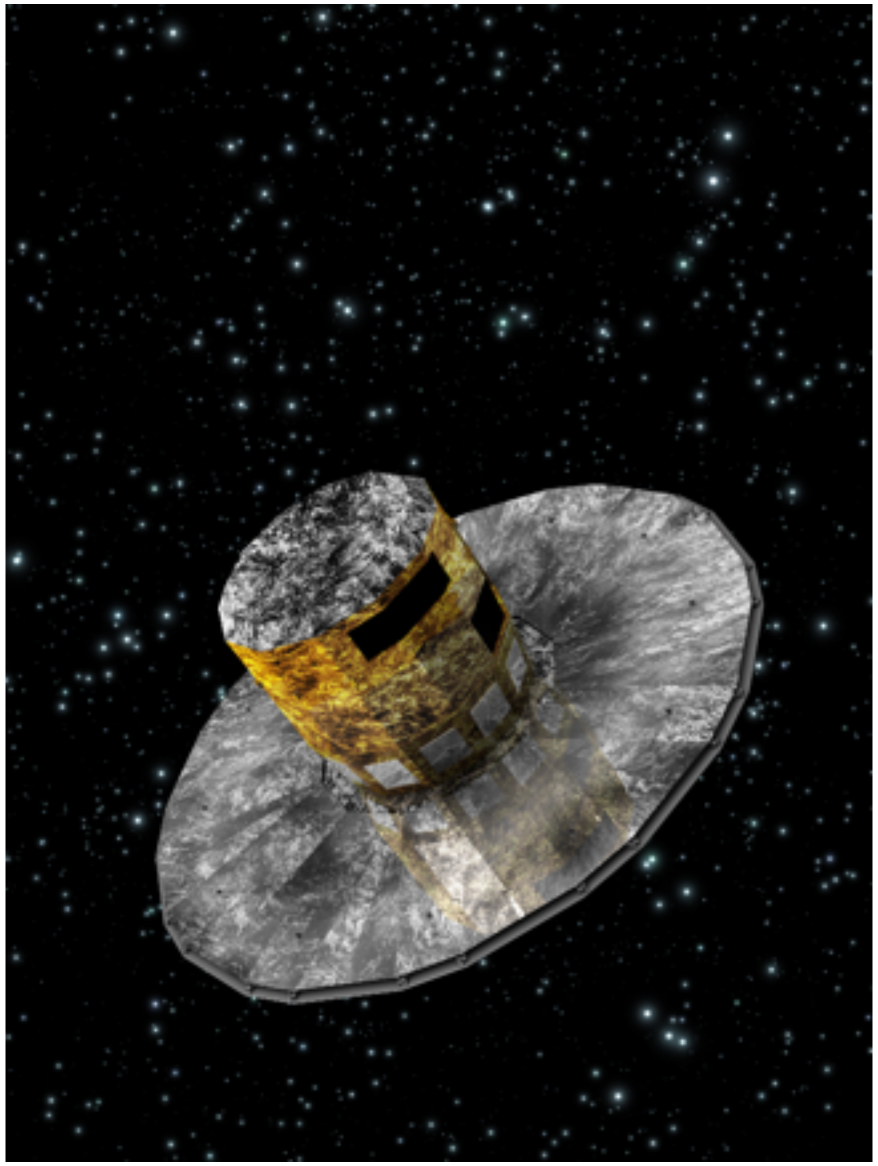
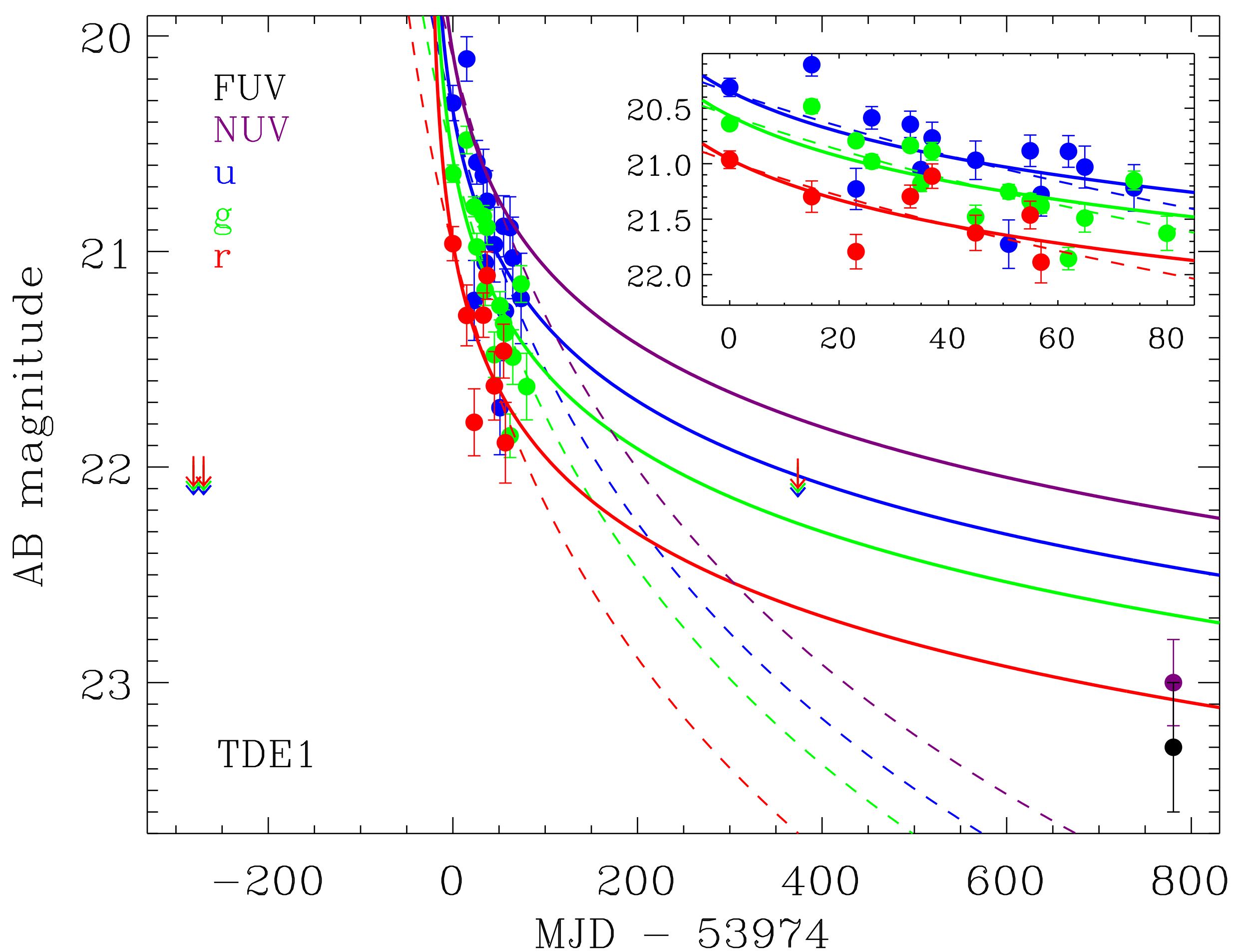


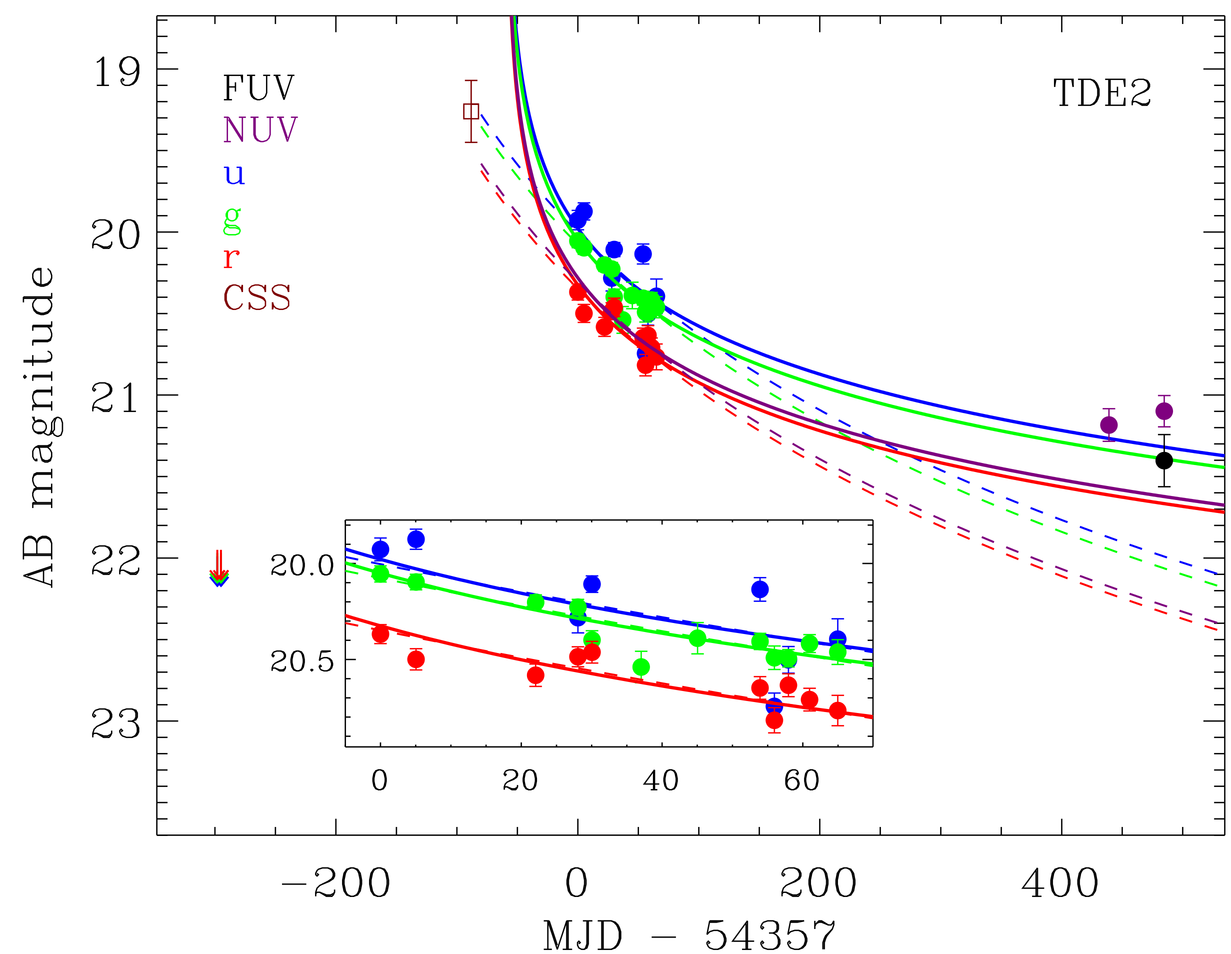
TABLE 1

Light curve model efficiencies & resulting optical TDF rates.

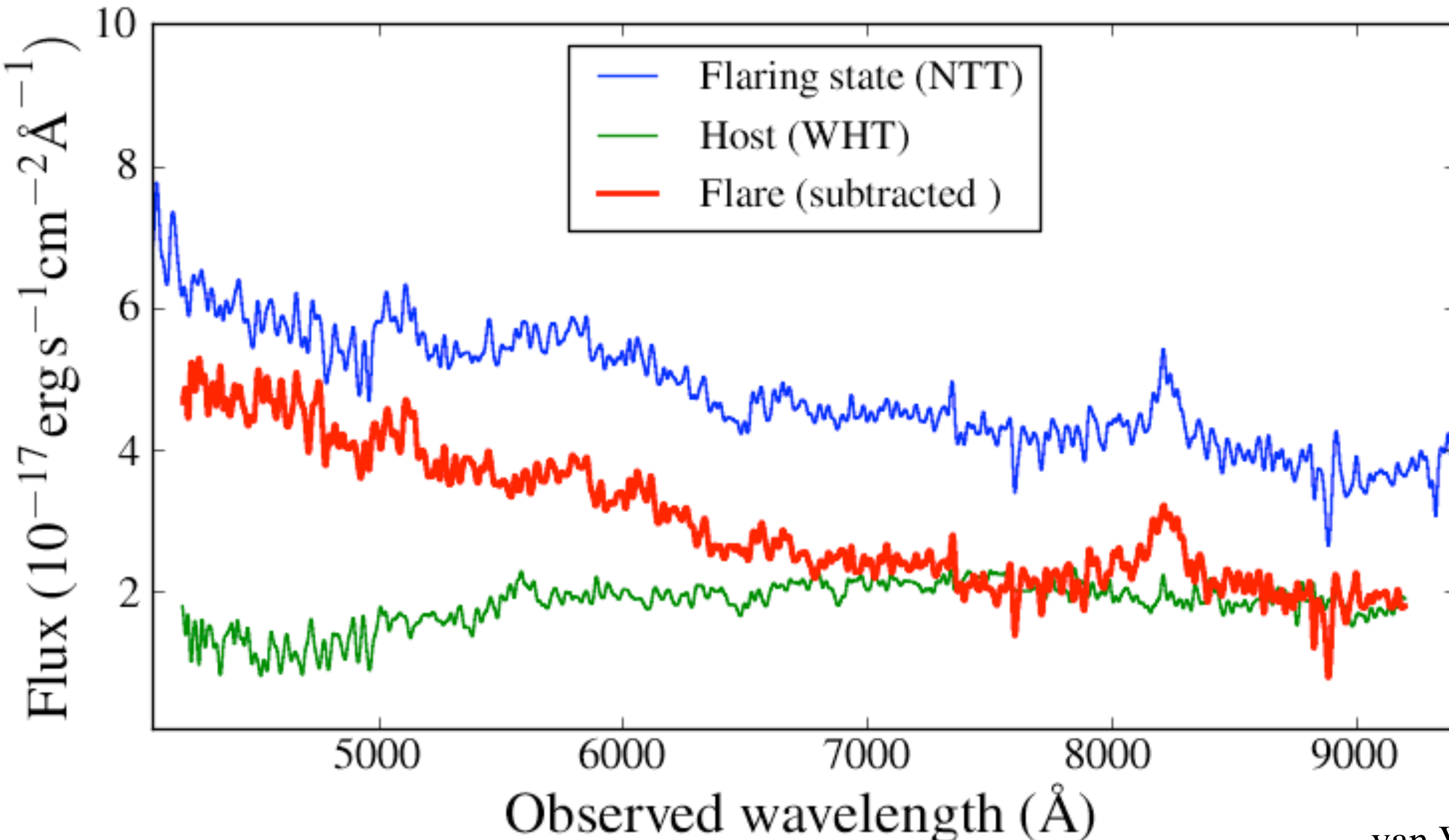
Name	Mean efficiency (%)	TDF Rate ($\mathrm{yr^{-1} galaxy^{-1}}$)	
SDSS-only	0.13, 0.62	$< 1.5 \times 10^{-4}$	
PS1 events (10jh, 11af)	1.0	2.0×10^{-5}	
Phenomenological	1.4	1.5×10^{-5}	
$M_{\rm BH}$ scaling: Häring & Rix (2004)		Correction for captures: Step-function	Exponential
Disk+Wind	0.83, 3.3	1.2×10^{-5}	1.7×10^{-5}
GMR14	1.2	1.8×10^{-5}	1.9×10^{-5}
$M_{\rm BH}$ scaling: Graham (2012)		Correction for captures: Step-function	Exponential
Disk+Wind	0.22, 1.5	2.1×10^{-5}	3.2×10^{-5}
GMR14	1.6	1.2×10^{-5}	1.3×10^{-5}

Observations: light curves





Observations: flaring state spectrum (TDE2)

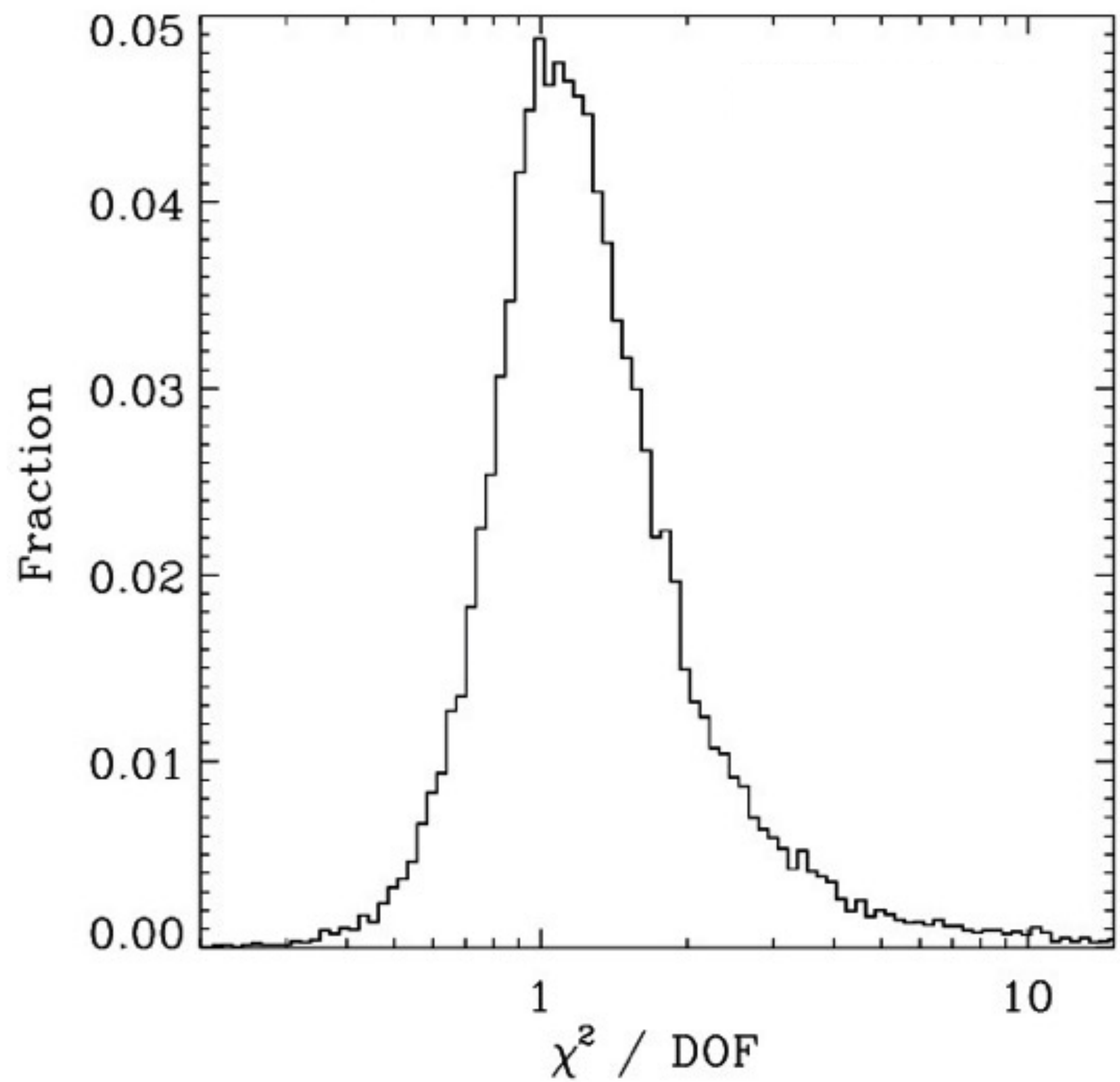


van Velzen+ 2011

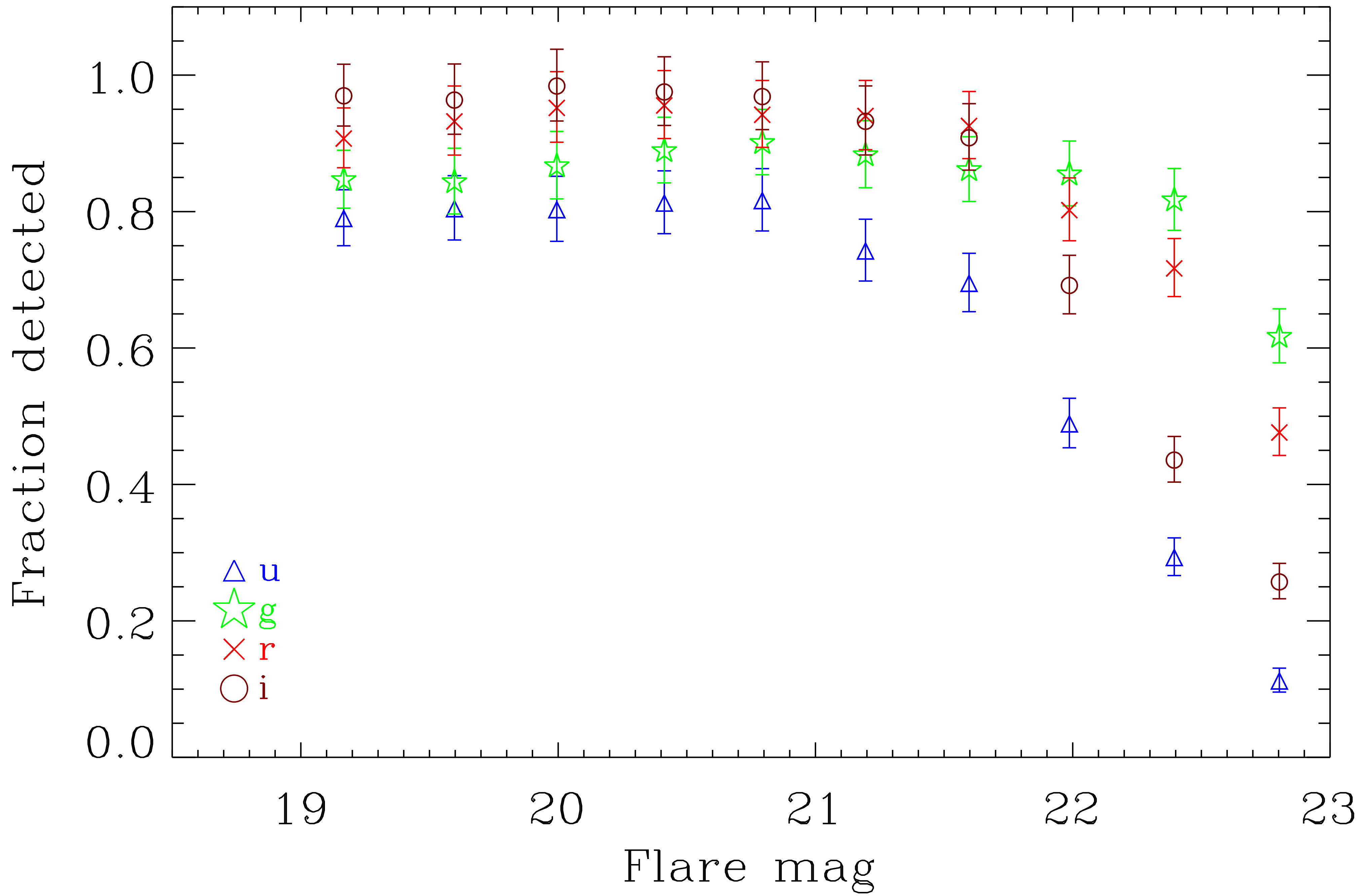
Flare selection: catalog cuts

$$\begin{aligned} \chi^2/\mathrm{DOF} &> 5 \\ \Delta F/F_{\mathrm{mean}} &> 0.1 \\ \Delta F/\sigma &> 7 \end{aligned}$$

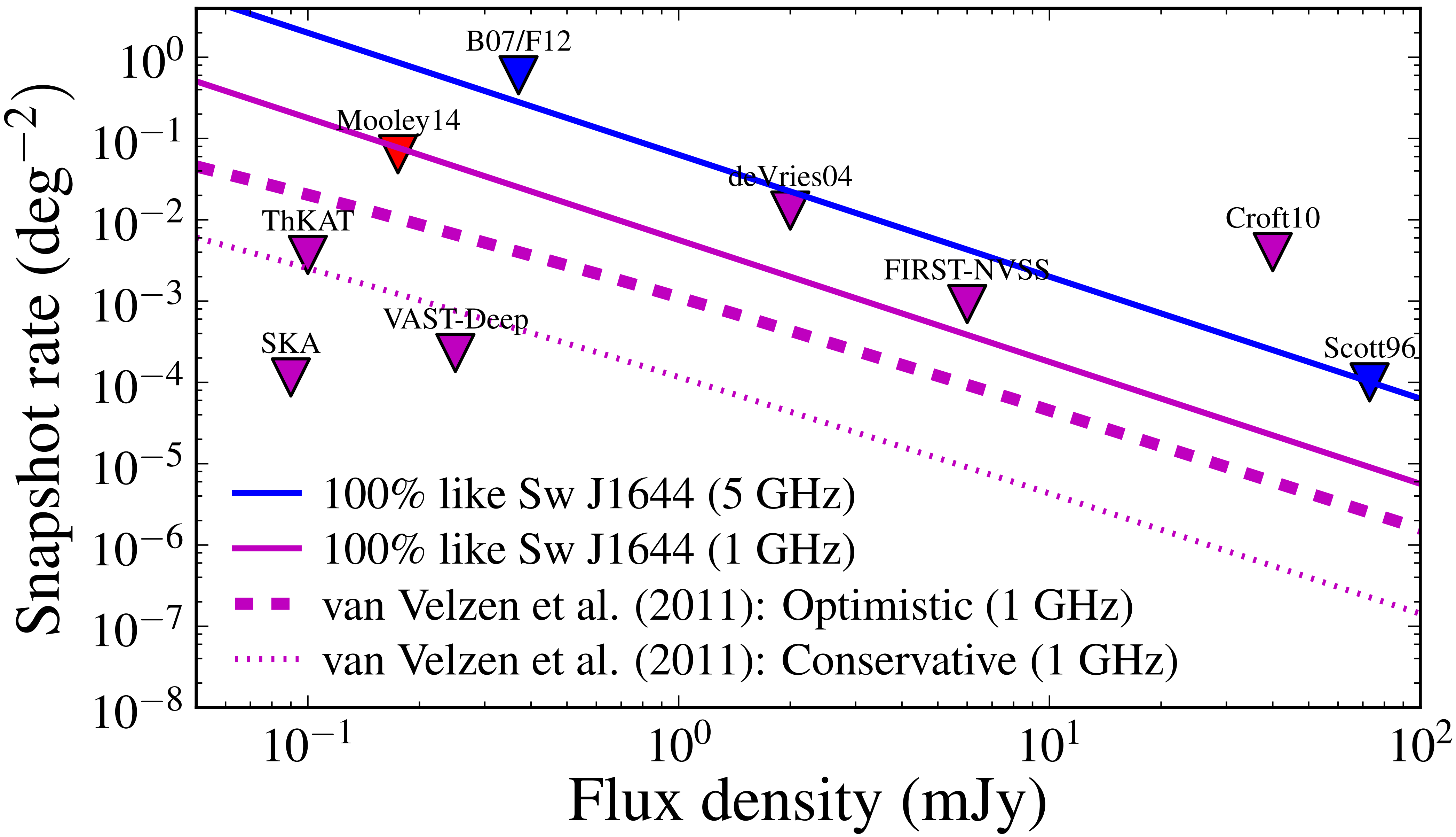
- Factor 100 reduction: 21,383 follow-up candidates



Efficiency: catalog selection + difference imaging



Snapshot rate



Donnarumma+ 2015