Pan-STARRS
PS1 Science Consortium

GALEX Galaxy Evolution Explorer

The Transient UV/Optical Universe

Suvi Gezari

University of Maryland

Research Class – October 15, 2012

The **Transient** UV/Optical Universe

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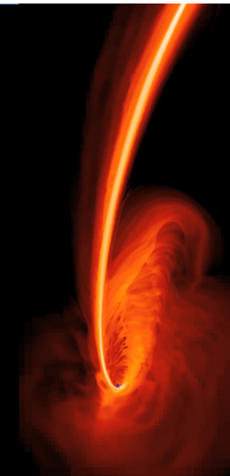
Science Drivers

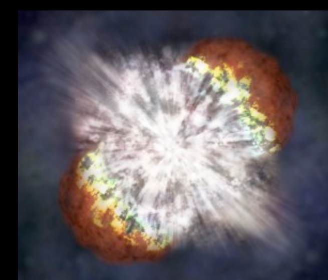
<u>Tidal Disruption Events</u>

- UV bright for months to years.



<u>Supernova Shock Breakout</u>

- UV bright for hours to days depending on the radius of the progenitor star.



<u>Active Galactic Nuclei</u>

- UV bright, and amplitude of variability increases with shorter wavelength.

<u>Variable Stars</u>

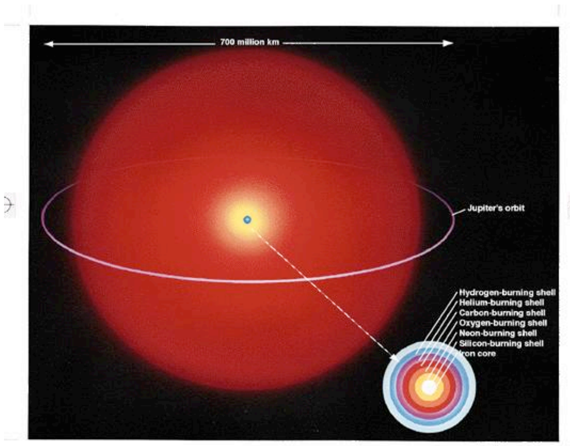
- M-dwarf stars flare in UV for $\Delta t \approx 100$ sec.
- RR Lyrae have periodic fluctuations on the timescale of 0.5 d.

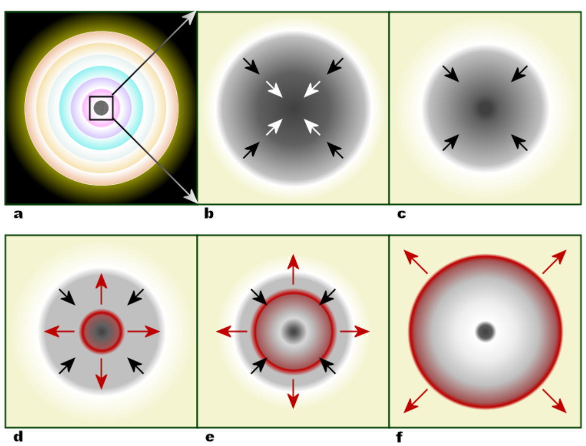
Outline

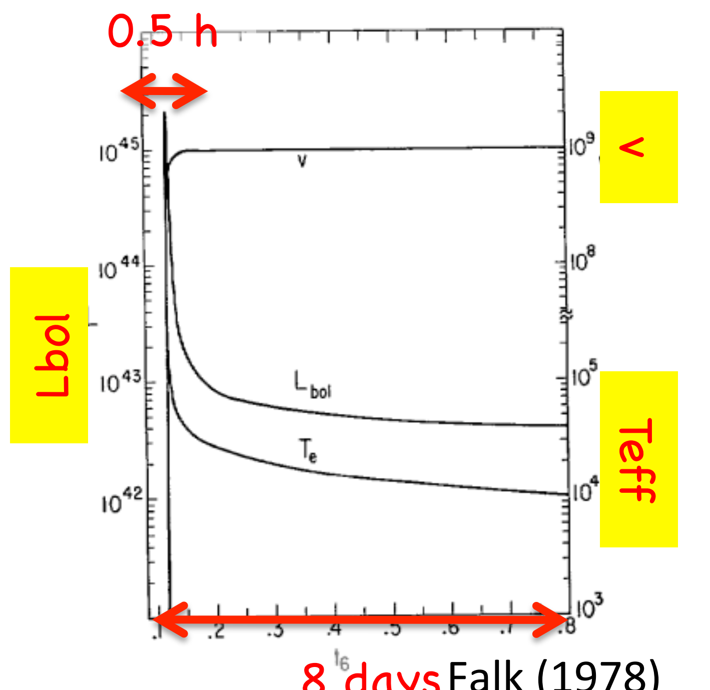
- Why study transients in the UV?
- GALEX Time Domain Survey + Pan-STARRS1.
- Selection and characterization of UV variables.
- GALEX TDS transient discoveries.
- Potential projects for grad students.

Supernova Shock Breakout

- Most luminous phase of a core-collapse explosion.
- UV/X-ray burst of radiation when shock emerges at the surface of the star.





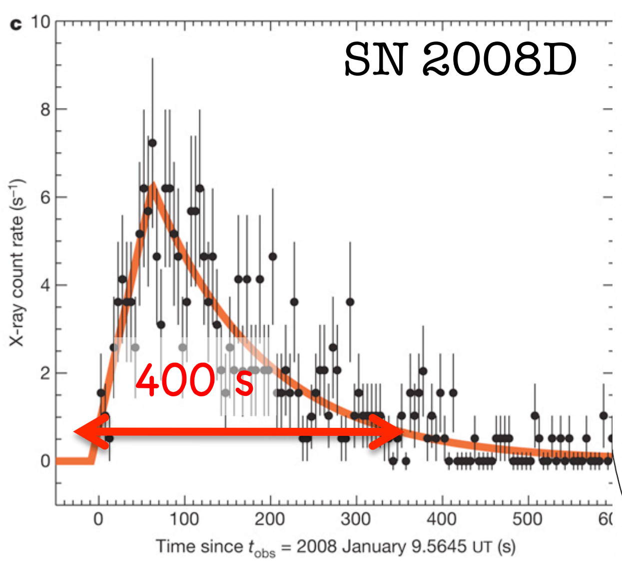


Falk (1978)

FIG. 2.—Luminosity, effective temperature, and photospheric

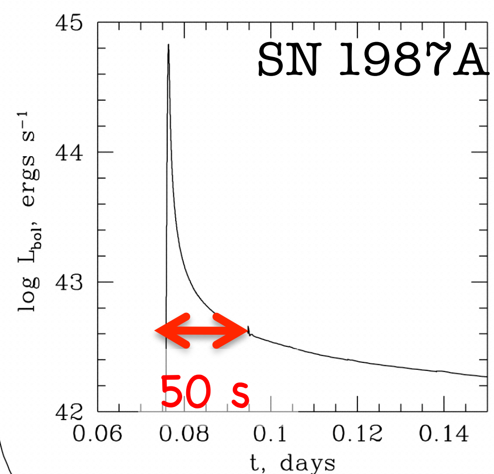
Supernova Shock Breakout

The duration of shock breakout signal is sensitive to the radius of the progenitor ($\tau \sim R_\star/c$) and the presence of a wind.



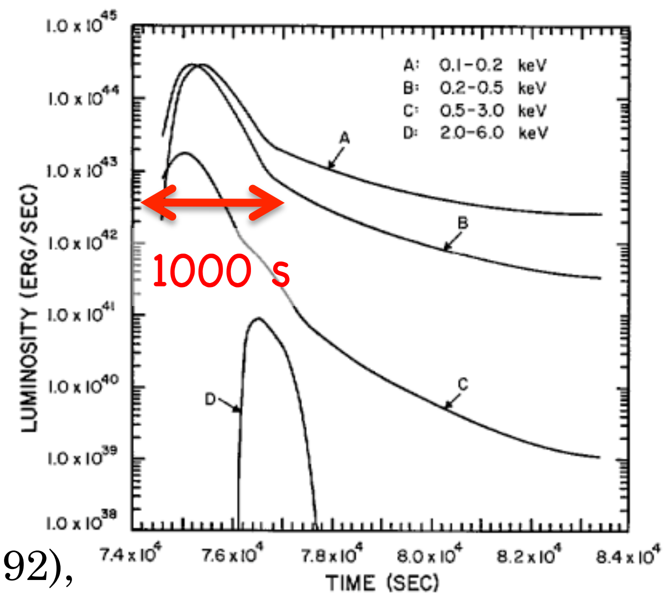
Soderberg+ (2008)

WR star ($R_\star \approx R_{sun}$) with dense wind



Ensman & Burrows (1992), Blinnikov+ (2000)

BSG ($R_\star \approx 50 R_{sun}$)

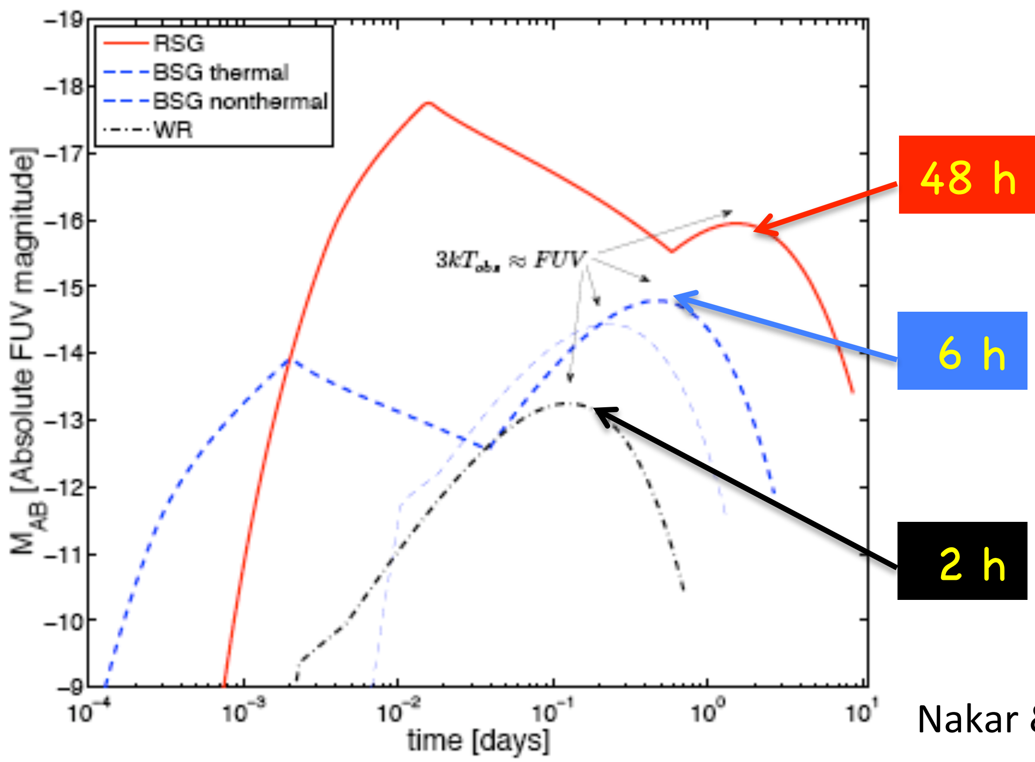


Klein & Chevalier (1978)

RSG ($R_\star \approx 500 R_{sun}$)

Expanding Cooling Ejecta

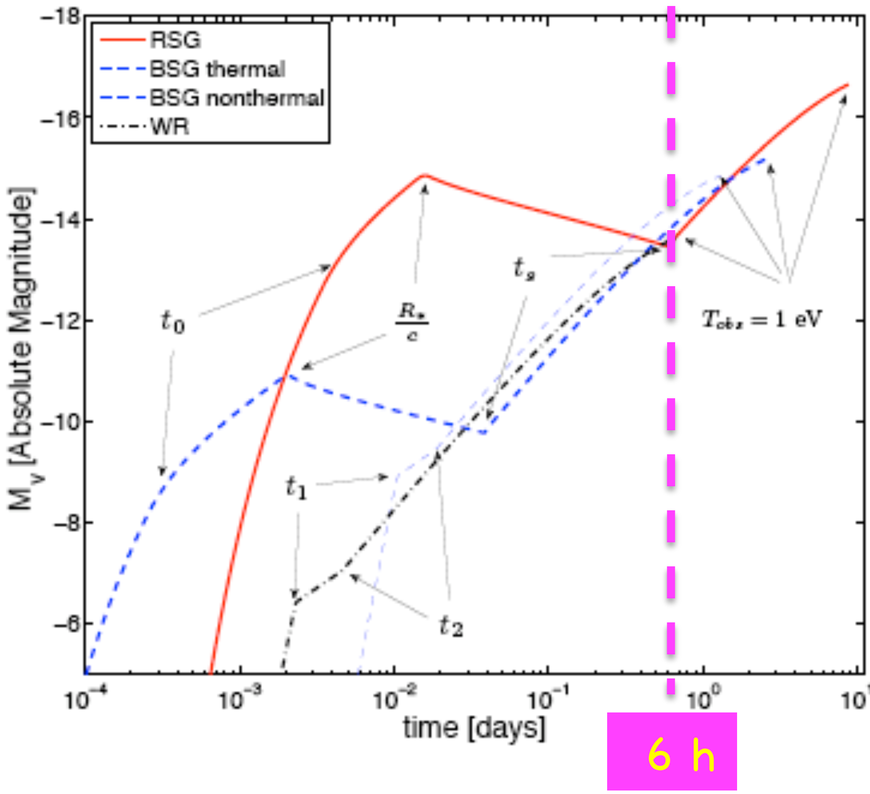
The early evolution of the UV light curve from the expanding, cooling ejecta is determined by $R_\star$ and E/M_{ej}.



Nakar & Sari (2010)

Expanding Cooling Ejecta

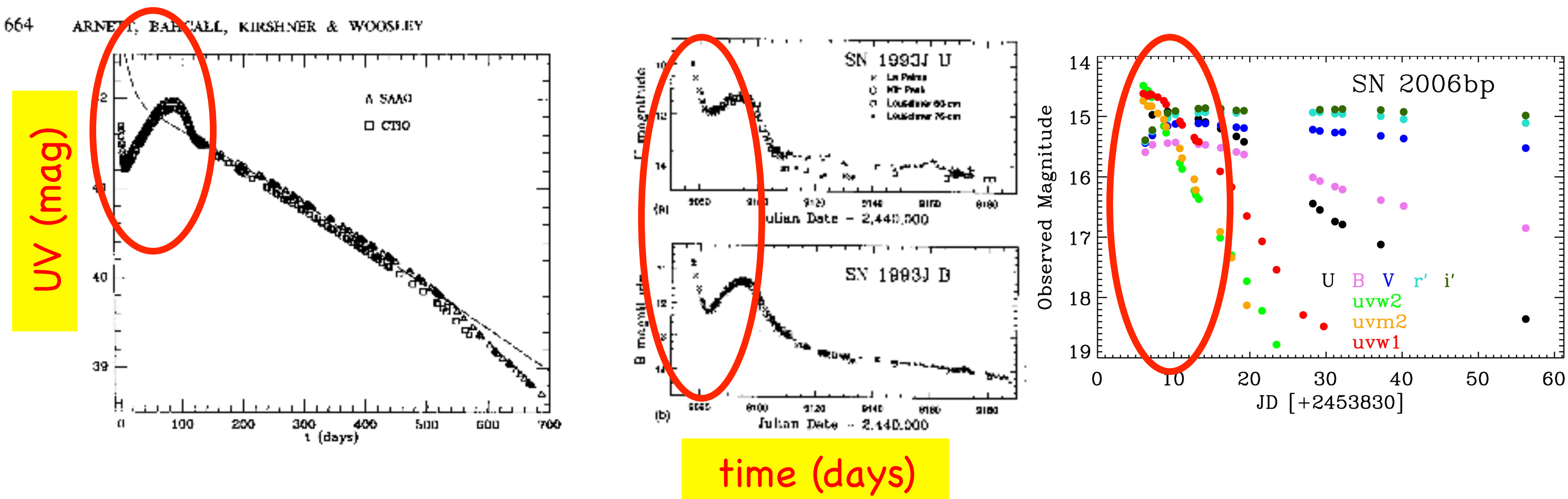
In the optical, the shock breakout peak is 3 mag fainter, and there is no distinction between progenitors for t > 6 h.



Nakar & Sari (2010)

Opportunity for GALEX

- SNe discovered in optical surveys are caught too late, when the UV emission is already fading rapidly.
- Parallel wide-field monitoring in the UV can catch SNe early, when the hot, thermal emission from the ejecta is bright in the UV.



Tidal Disruption of a Star

Probe for M_{BH}

Tidal Disruption Radius

- $R_p < R_T \approx R_\star \, (M_{BH}/M_\star)^{1/3}$

Characteristic Timescale

- $t_{min} = 0.11 \text{ yr } (M_{BH}/10^6\, M_\odot)^{1/2} (M_\star/M_\odot)^{-1} (R_\star/R_\odot)^{3/2}$

Critical Black Hole Mass

- $M_{crit} = 10^8\, M_\odot (M_\star/M_\odot)^{-1/2} (R_\star/R_\odot)^{3/2}$

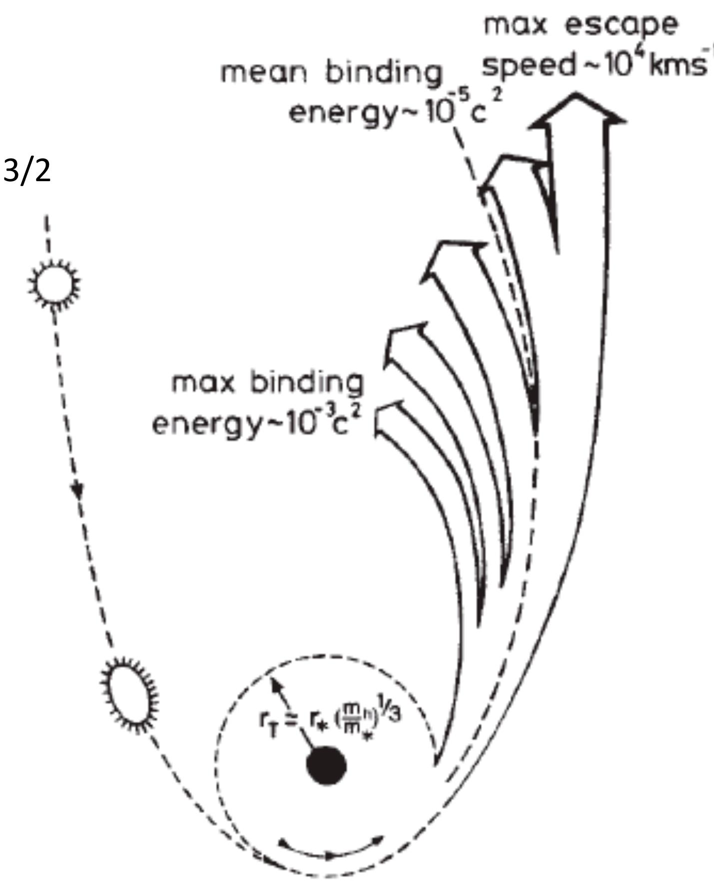
Bolometric Luminosity

- $L_{bol} \approx L_{Edd} = 1.3\text{x}10^{44} \text{ ergs s}^{-1} (M_{BH}/10^6\, M_\odot)$

Characteristic Temperature

- $T_{eff} \approx [L_{Edd}/(\sigma 4\pi R_T^2)]^{1/4}$

  $= 2.5\text{x}10^5 \text{ K } M_6^{1/12} (R_\star/R_\odot)^{-1/2} (M_\star/M_\odot)^{-1/6}$



Rees (1988)

Probe for M_{BH}

Tidal Disruption Radius

- $R_p < R_T \approx R_\star (M_{BH}/M_\star)^{1/3}$

Characteristic Timescale

- $t_{min} = 0.11 \text{ yr } (M_{BH}/10^6 M_\odot)^{1/2} (M_\star/M_\odot)^{-1} (R_\star/R_\odot)^{3/2}$

Critical Black Hole Mass

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Bolometric Luminosity

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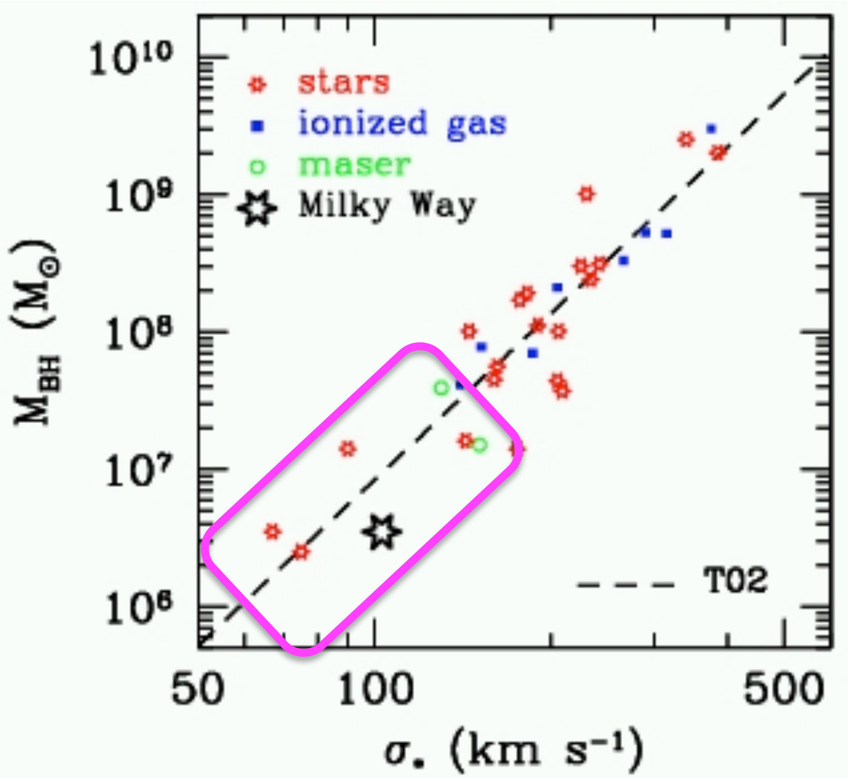
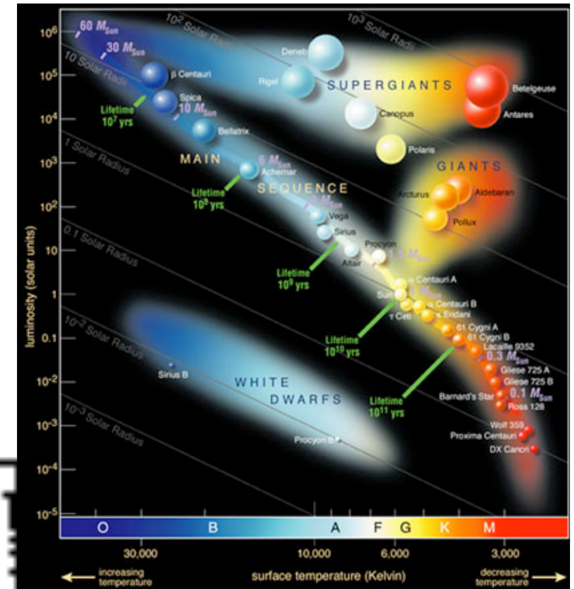
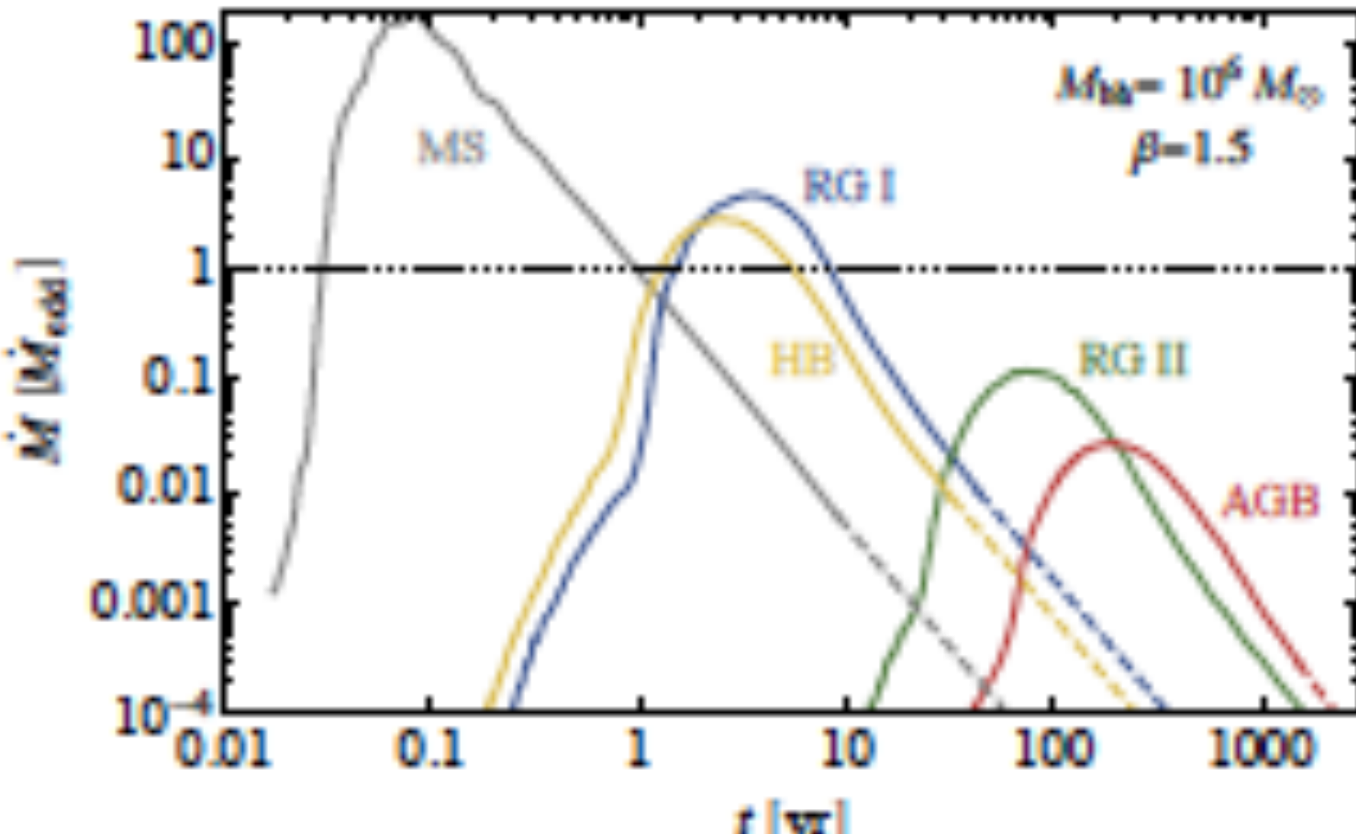


Sensitive probe of the lower mass range of SMBHs where the M_{BH}-σ relation is poorly constrained.

Type of Star Disrupted

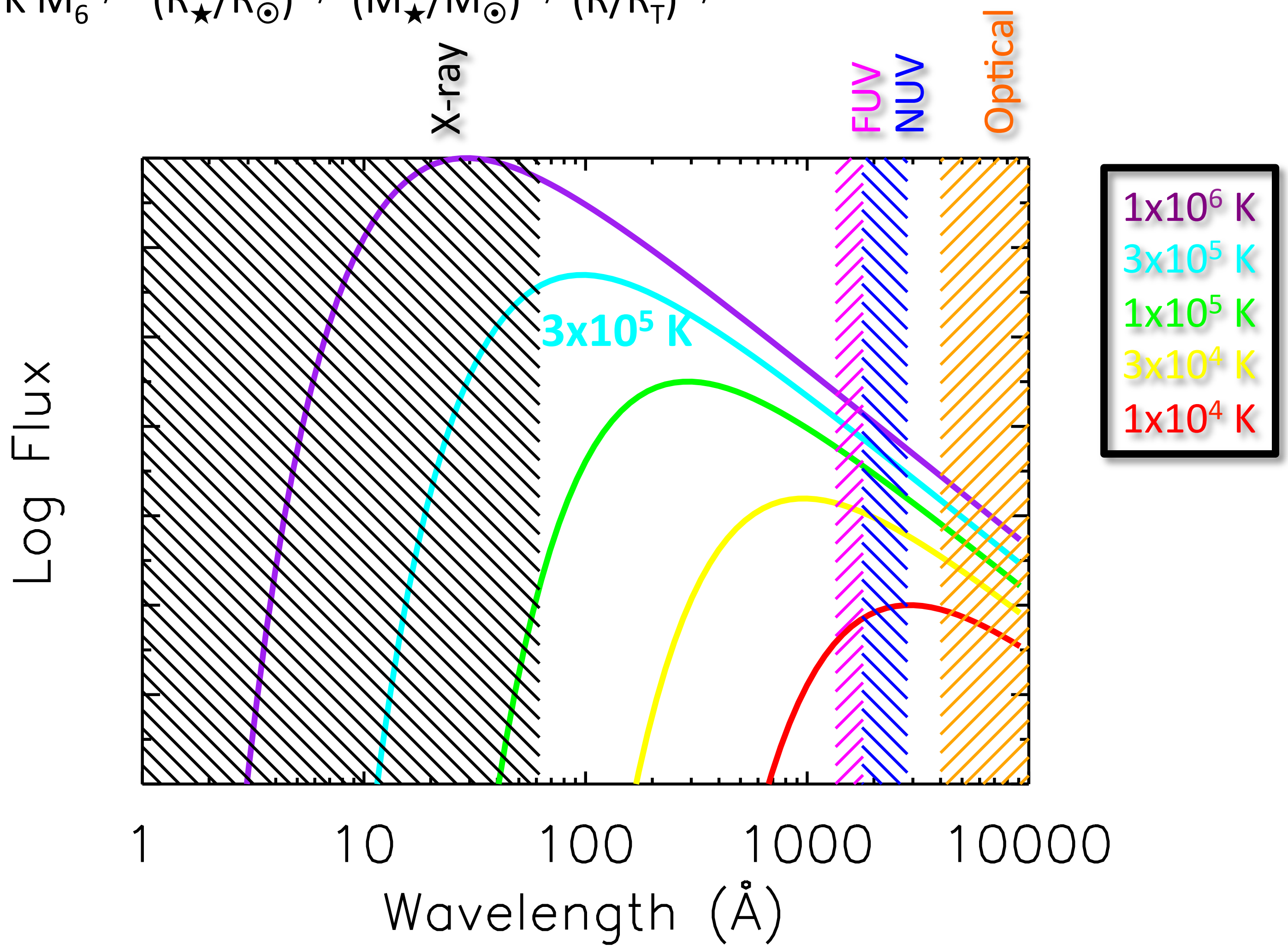




MacLeod, Guillochon, & Ramirez-Ruiz 2012

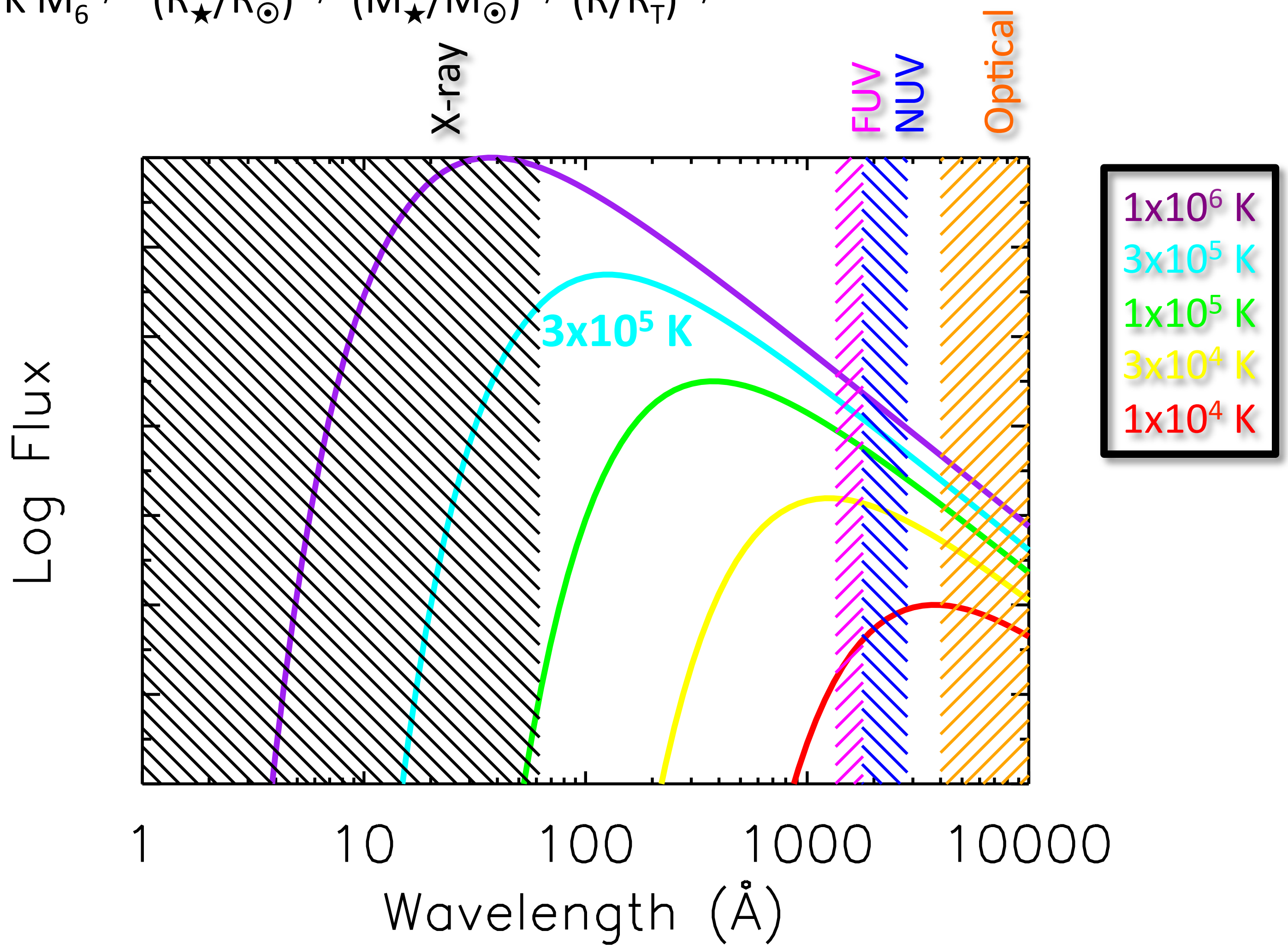
Opportunity for GALEX

$T_{eff} \approx [L_{Edd}/(\sigma 4\pi R^2)]^{1/4}$
$= 2.5\text{x}10^5 \text{ K } M_6^{1/12} (R_\star/R_\odot)^{-1/2} (M_\star/M_\odot)^{-1/6} (R/R_T)^{-1/2}$



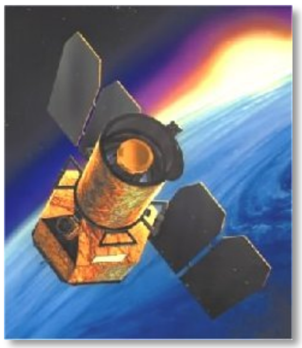
Opportunity for GALEX

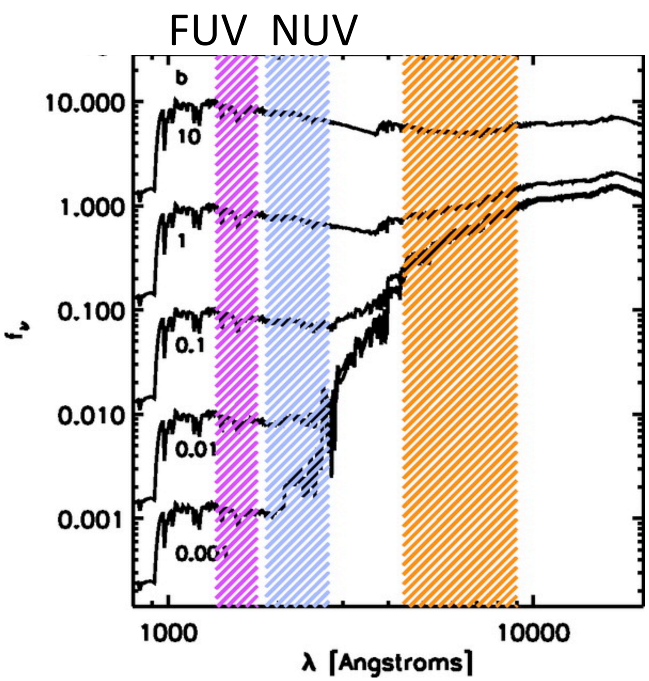
$T_{eff} \approx [L_{Edd}/(\sigma 4\pi R^2)]^{1/4}$
$= 2.5\times10^5\ K\ M_6^{1/12}\ (R_\star/R_\odot)^{-1/2}\ (M_\star/M_\odot)^{-1/6} (R/R_T)^{-1/2}$

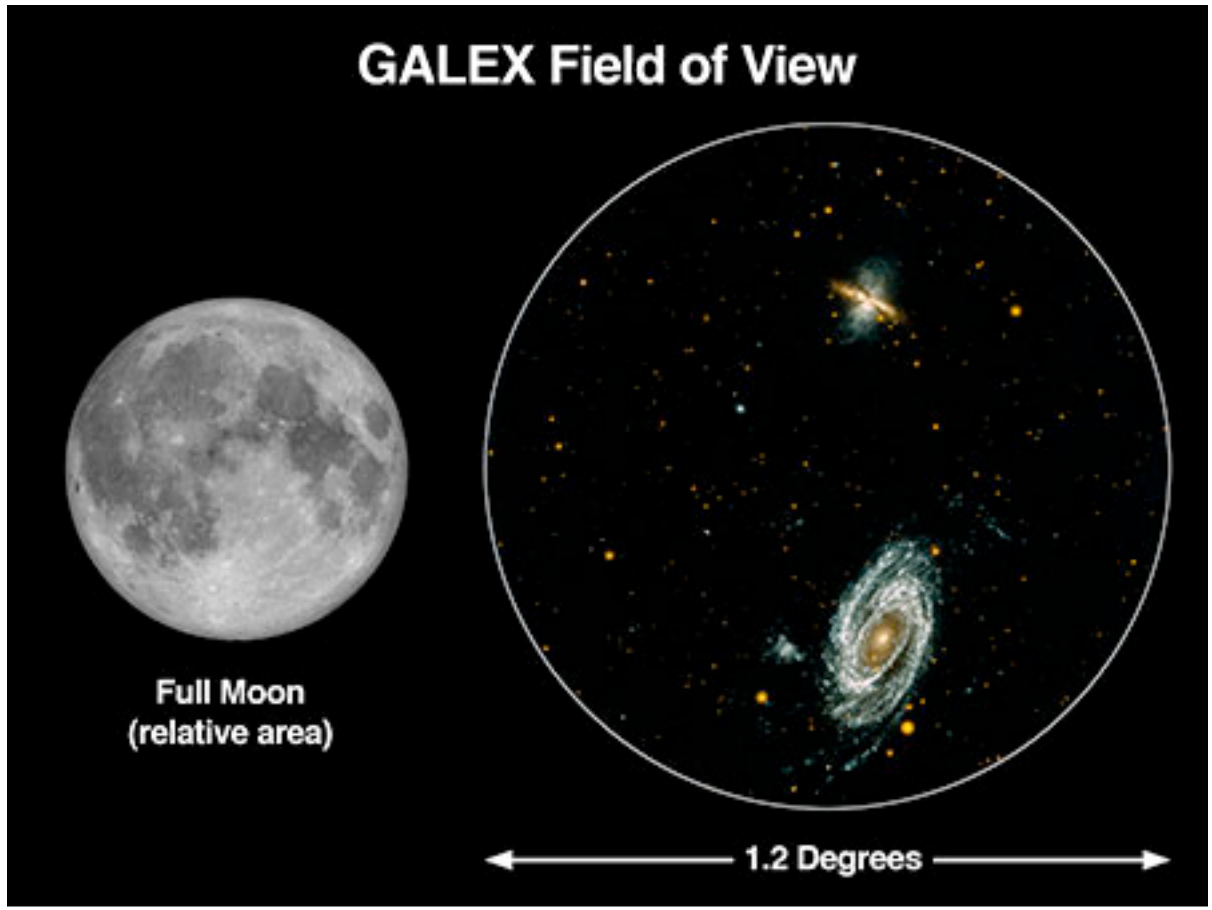


Benefit from the K correction at higher redshifts!

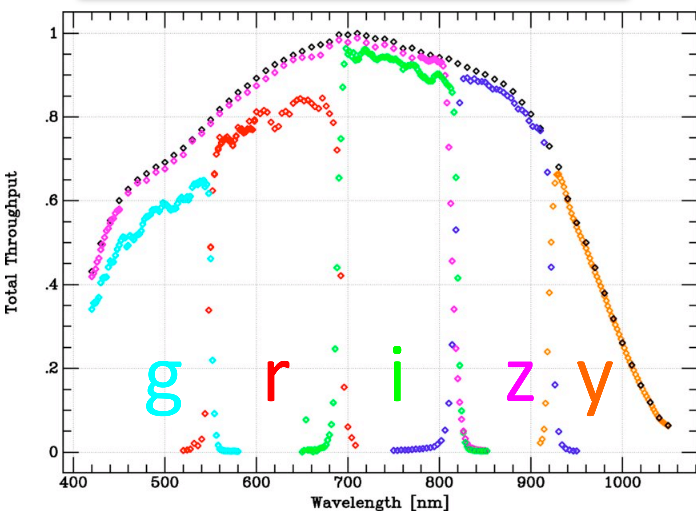
GALEX

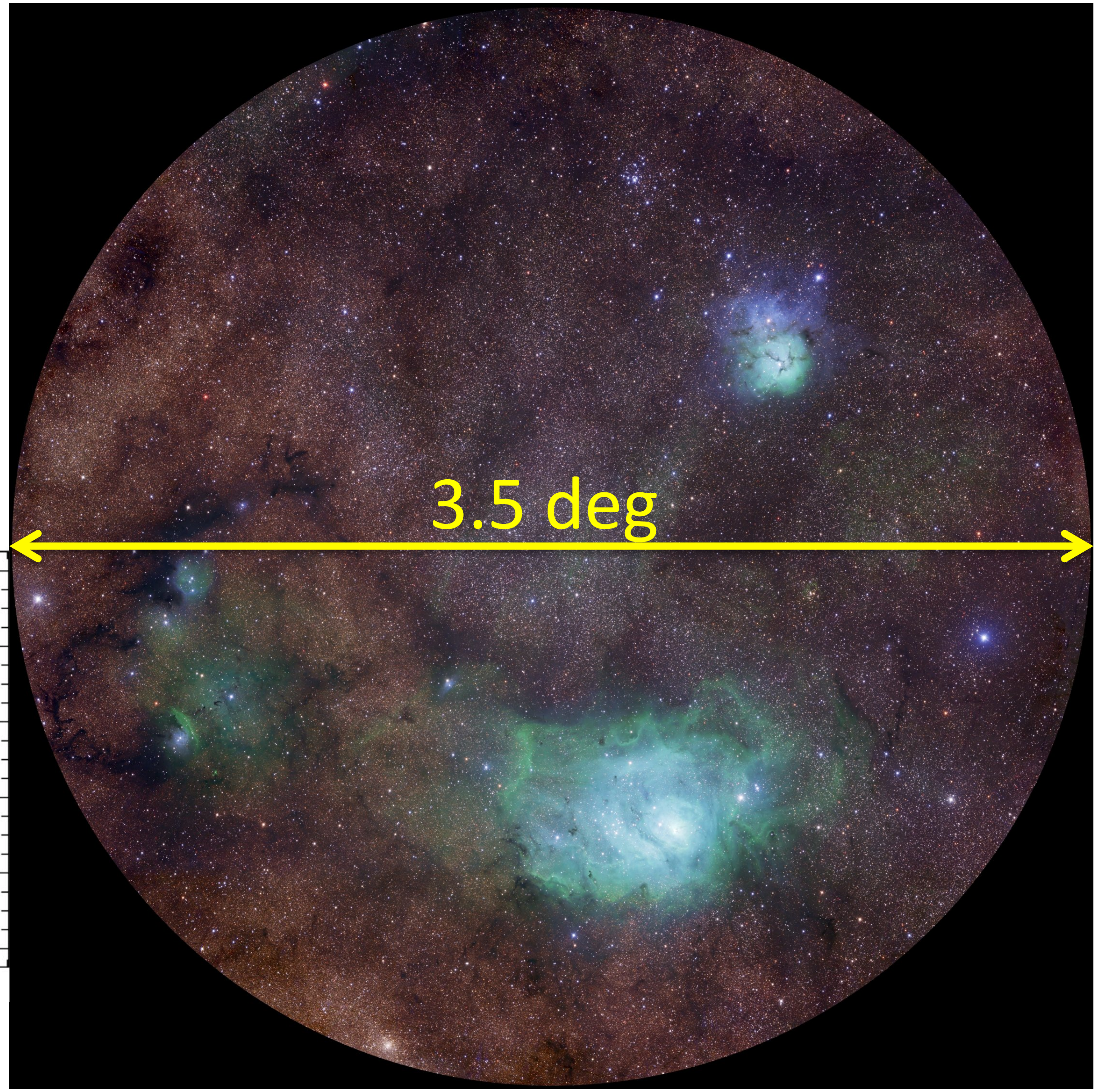



FUV NUV
b
10.000
1.000
0.100
0.010
0.001
10
1
0.1
0.01
0.001
f_ν
1000
10000
λ [Angstroms]

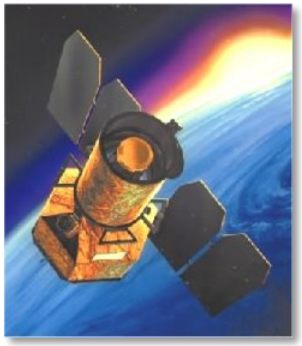

GALEX Field of View
Full Moon
(relative area)
1.2 Degrees

Pan-STARRS1





GALEX TDS + PS1 MDS



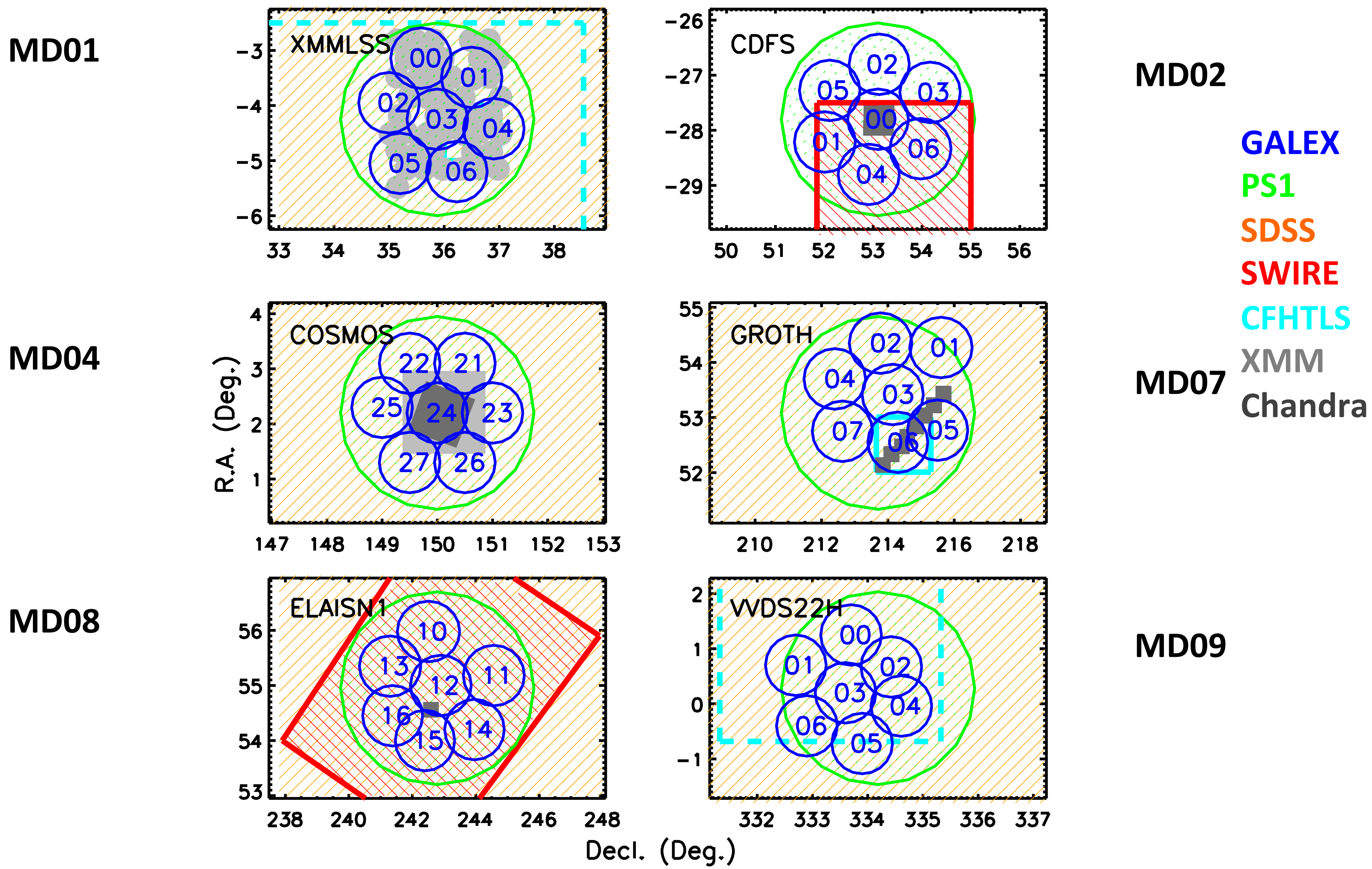
	Band	FOV	Depth	FWHM	Cadence	Stack
GALEX	NUV	1.1 deg	23.3 mag	5.4”	2 d	24.8 mag
PS1	g,r,I,z,y	3.3 deg	23.0 mag	1.0”	3 d	24.3 mag

GALEX TDS and PS1 MDS well-matched in area, depth, and cadence.

GALEX: m_{lim} (per epoch) = 23.3 mag, m_{lim} (stack) = 24.8 mag

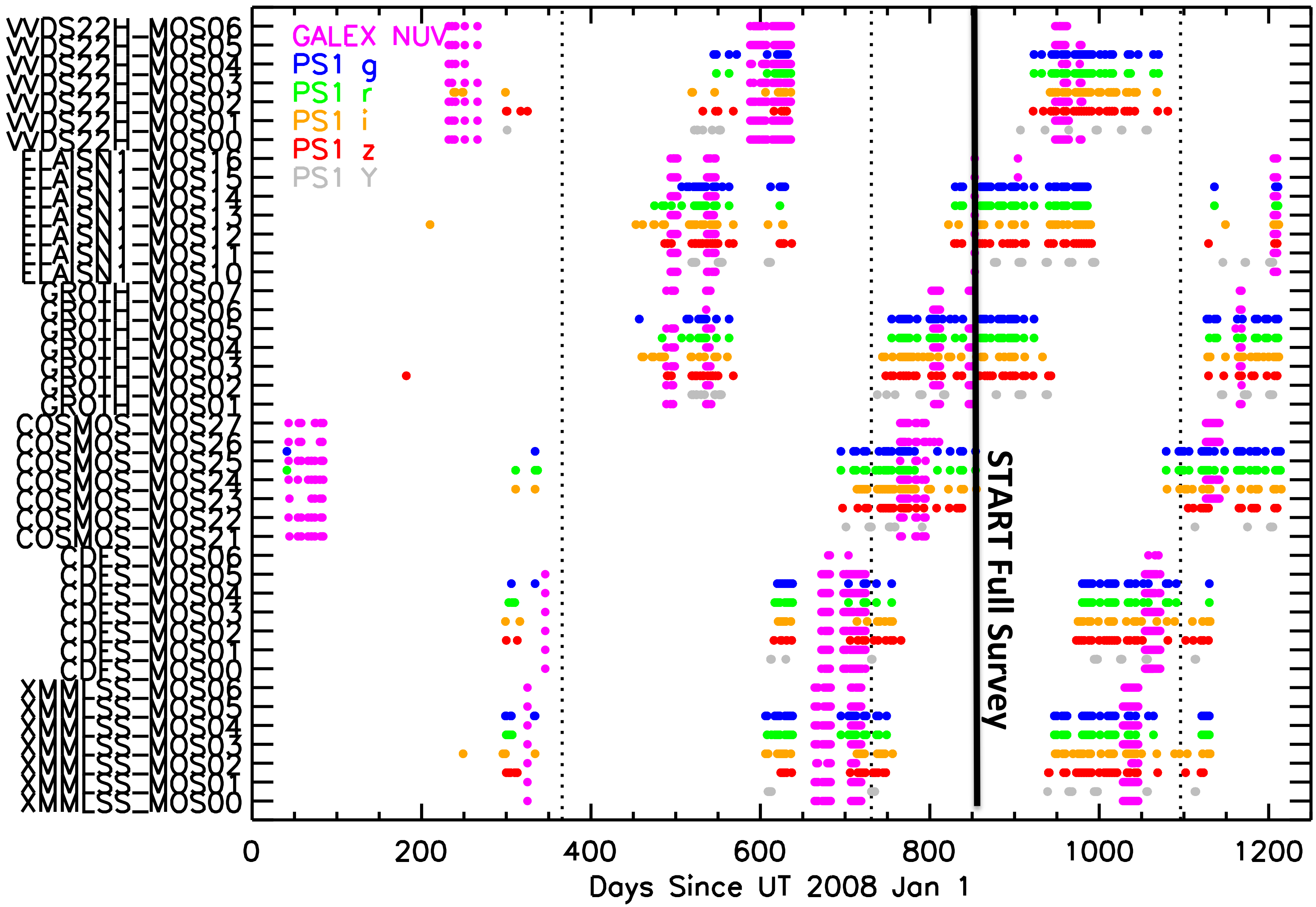
PS1: m_{lim} (per epoch) = 23.0 mag, m_{lim} (stack) = 24.3 mag

GALEX TDS Fields



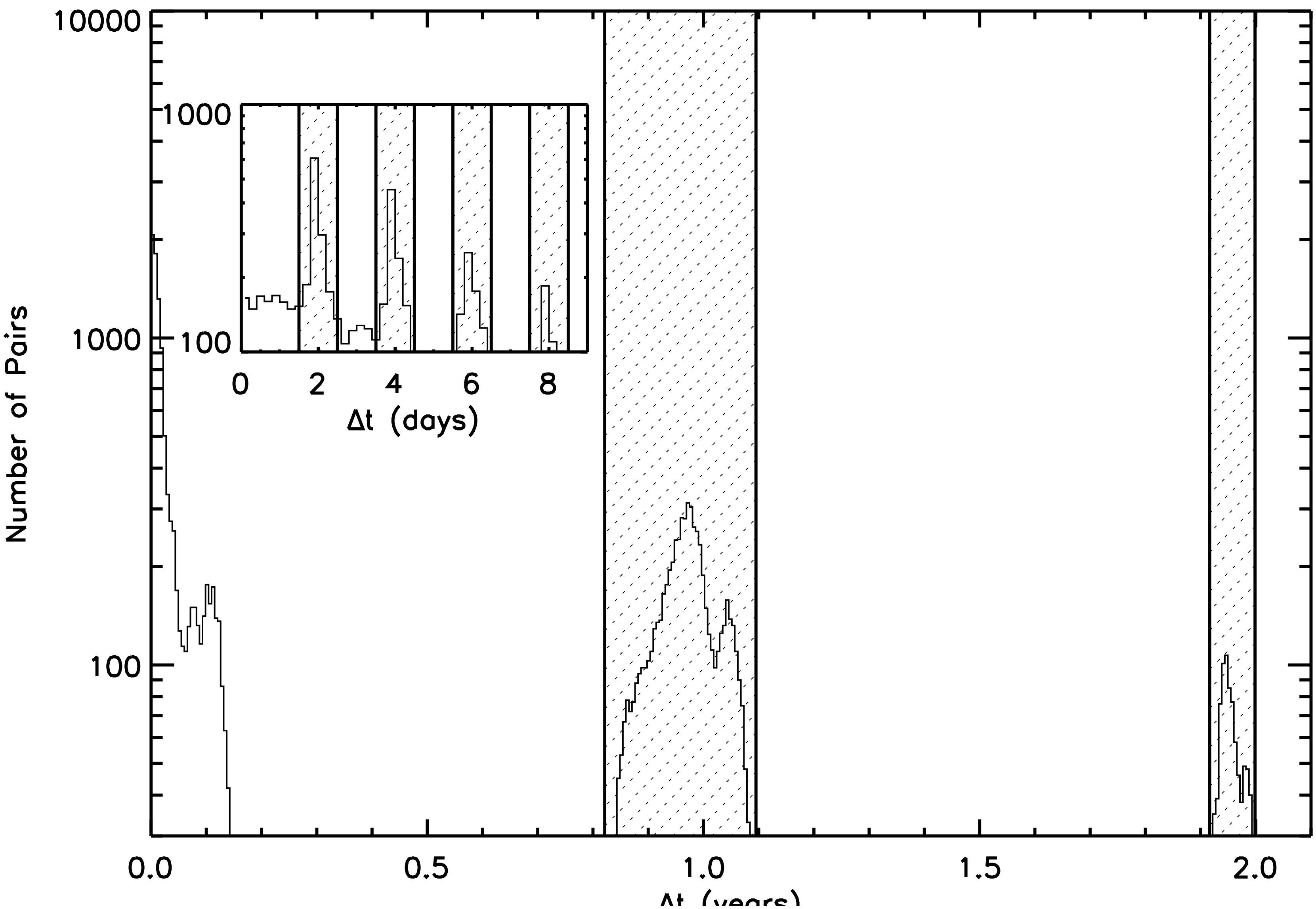
GALEX TDS Cadence

Δt (GALEX) = 2 days
Δt (PS1) = 3 days

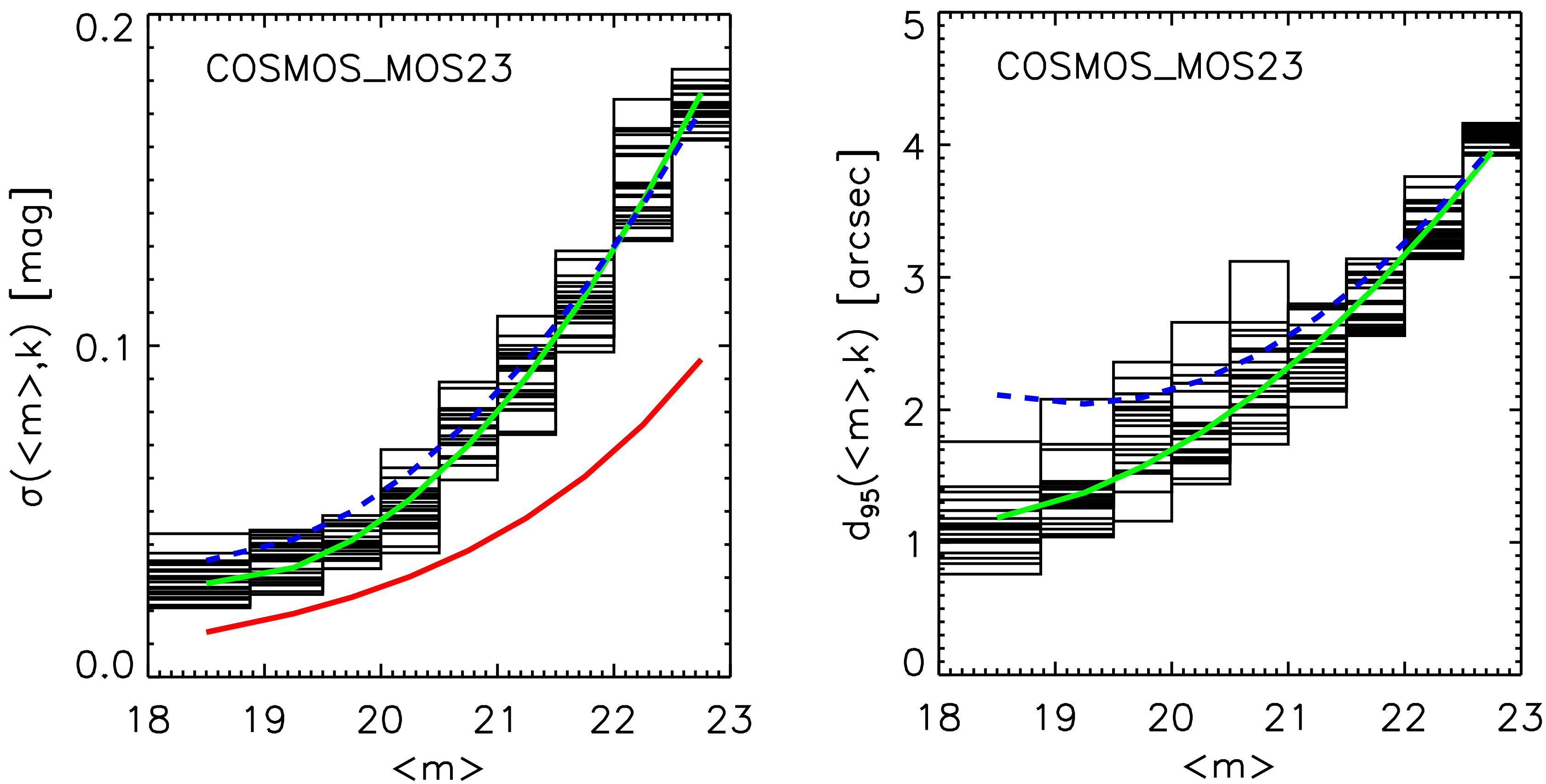


Characteristic timescales:
2d, 4d, 6d, 8d, 1y, 2y

GALEX TDS Timescales



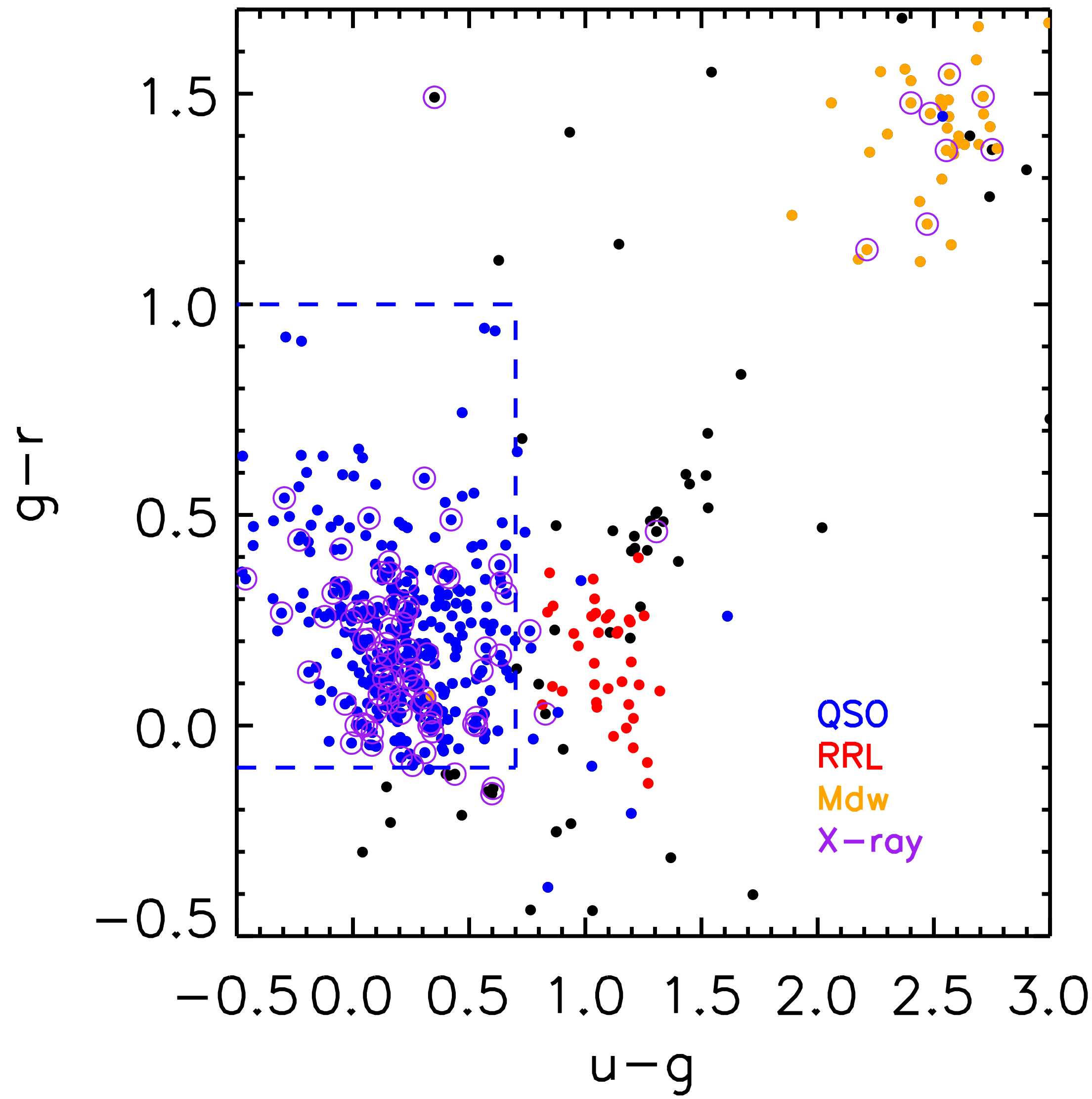
GALEX TDS 5σ Selection



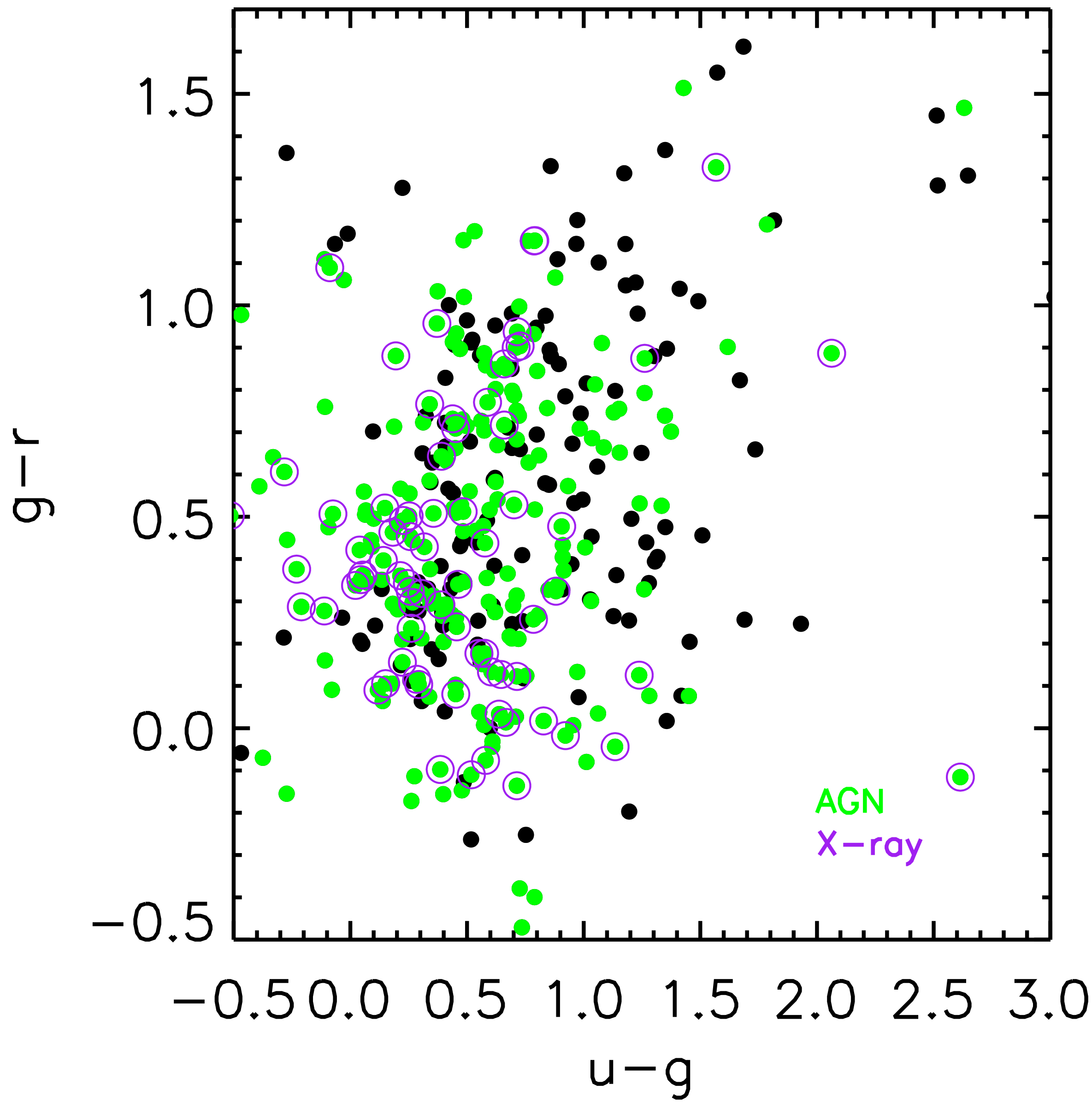
Magnitude-dependent photometric error

Magnitude-dependent association radius

Point Sources

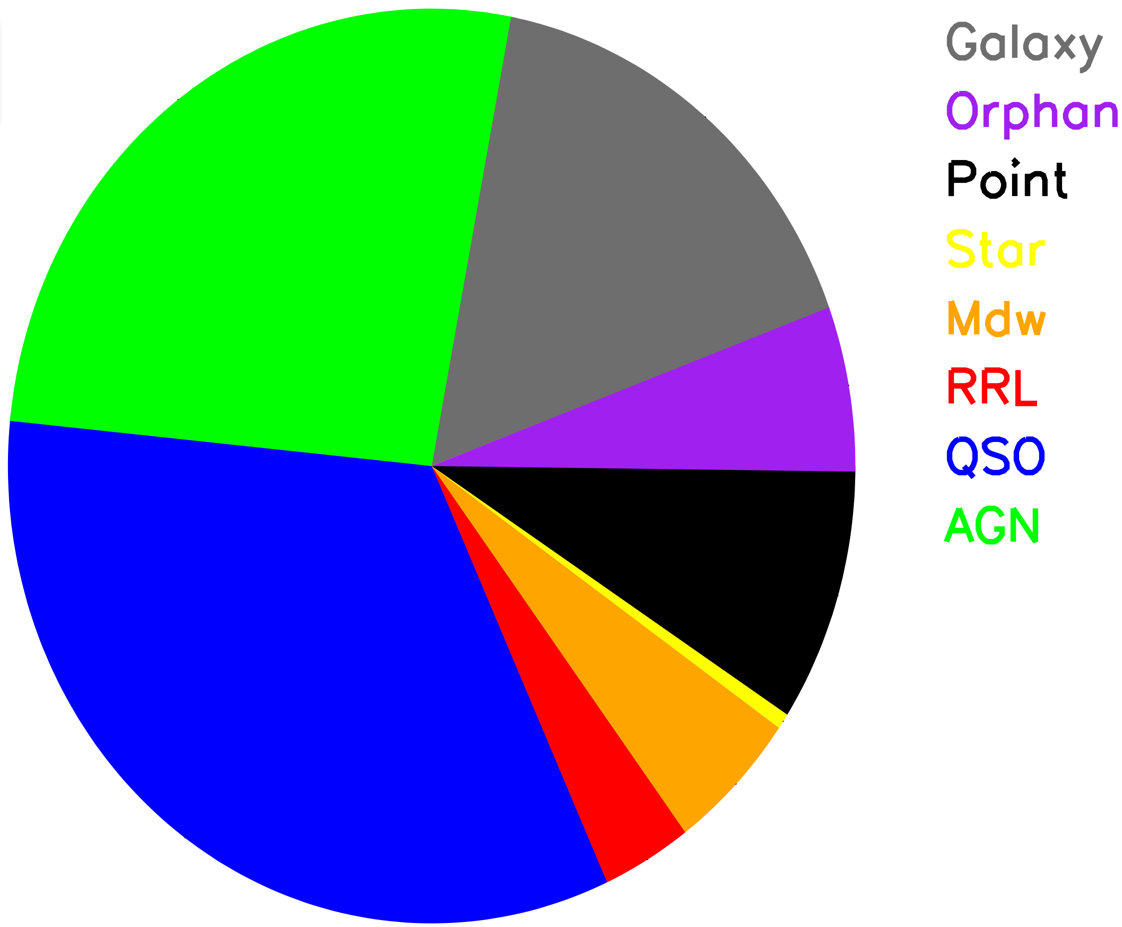


Extended Sources



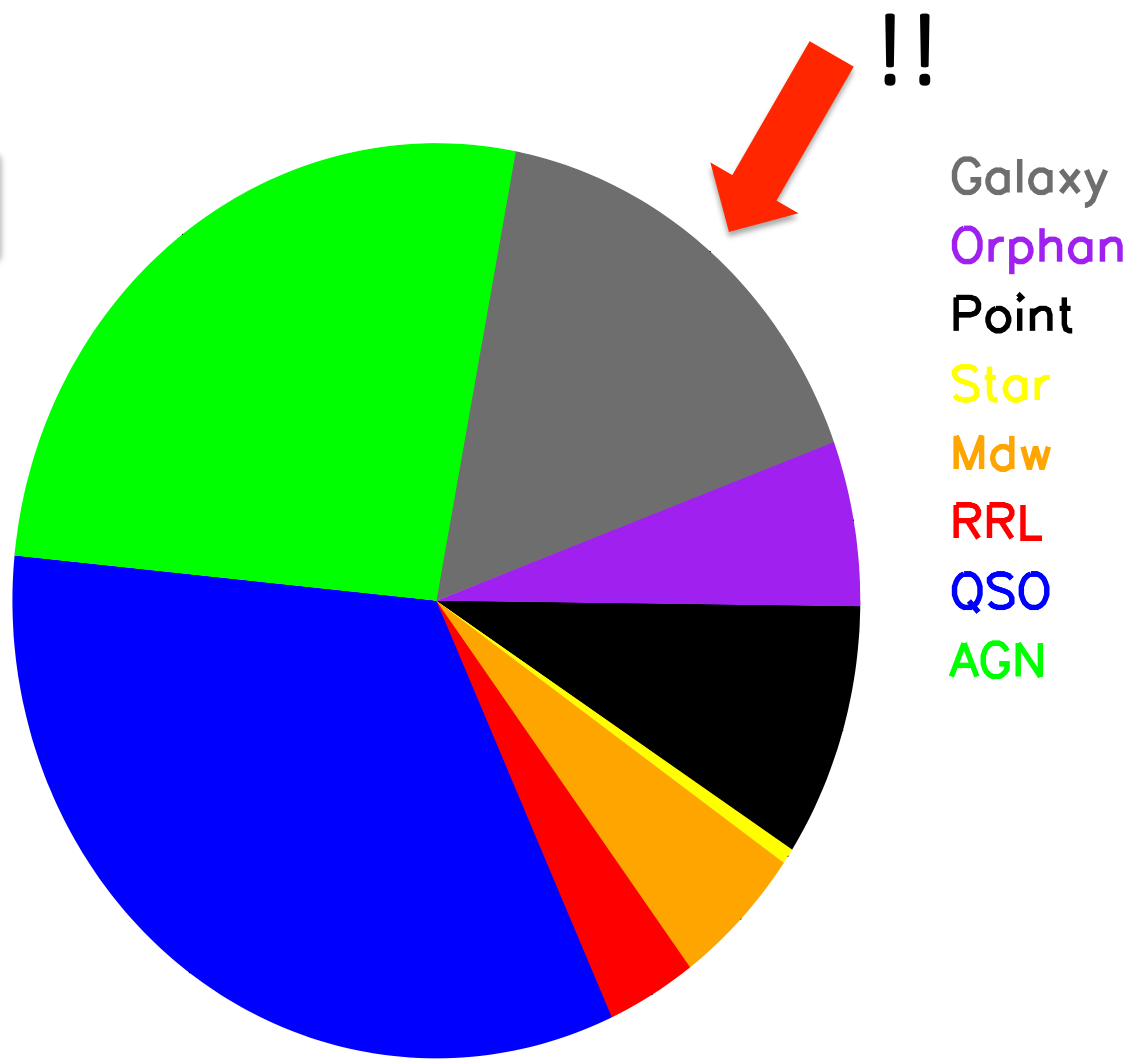
GALEX TDS Classifications

1078 Sources

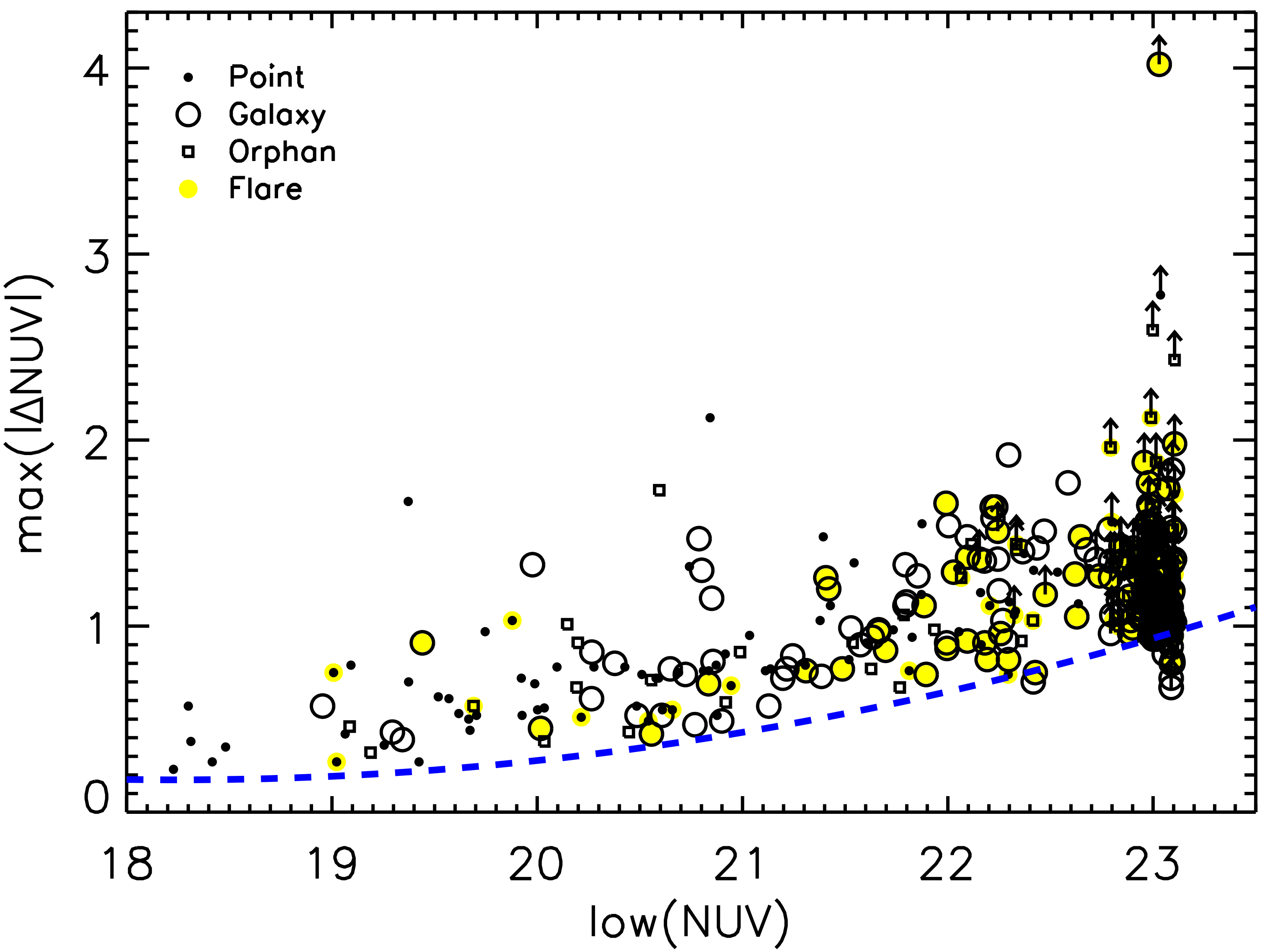


GALEX TDS Classifications

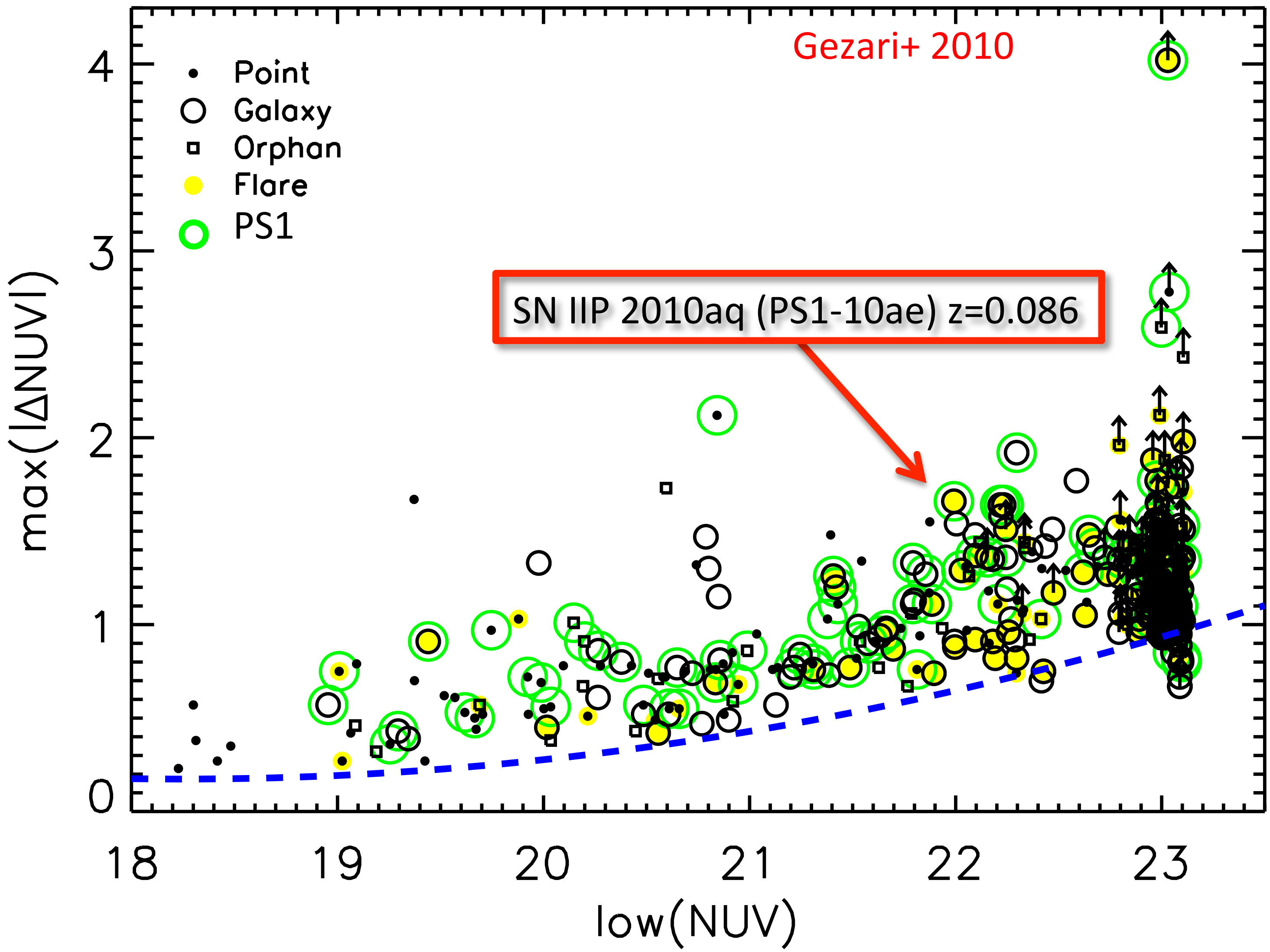
1078 Sources



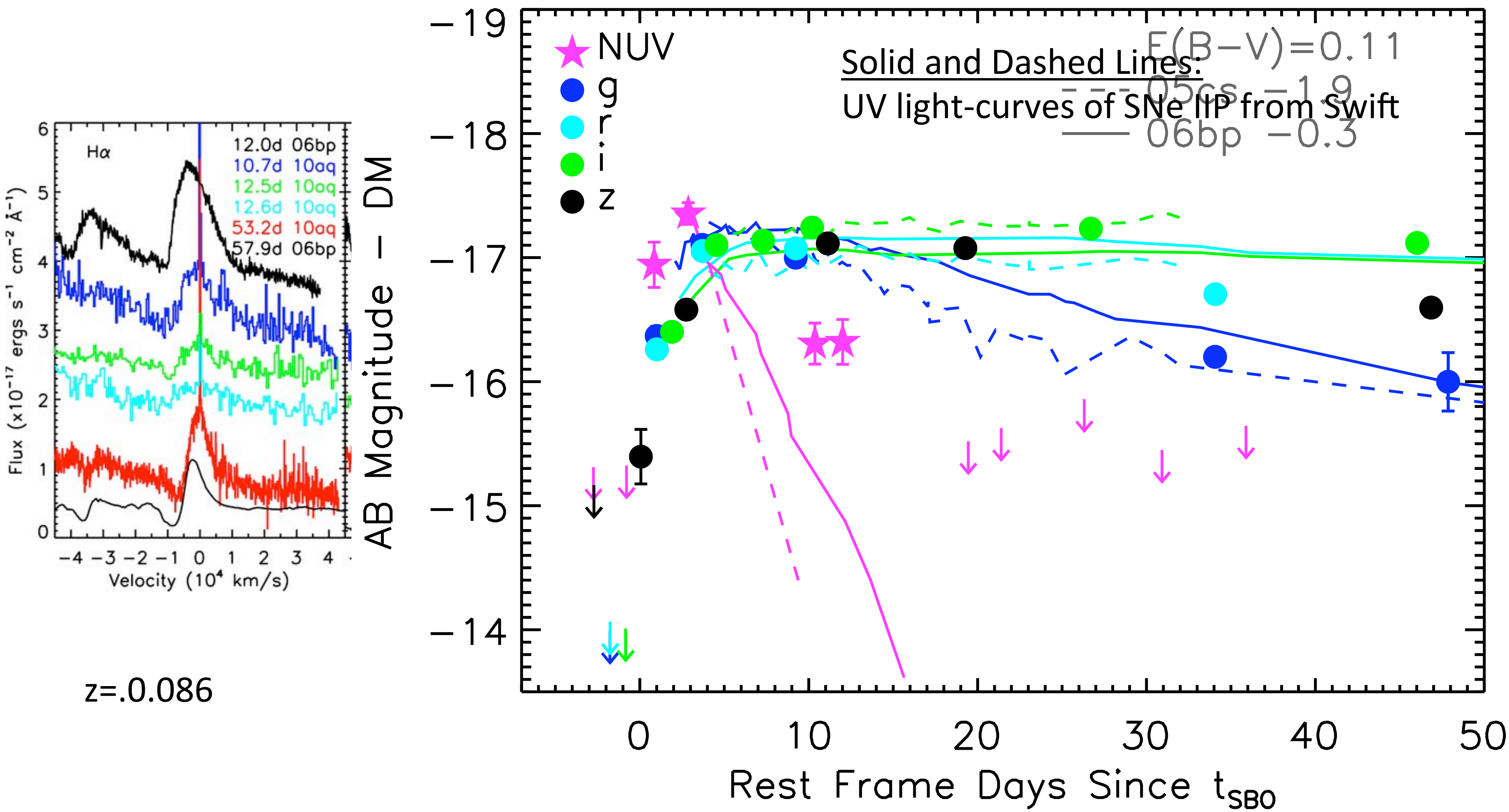
GALEX TDS Unclassified Sources



GALEX TDS Unclassified Sources



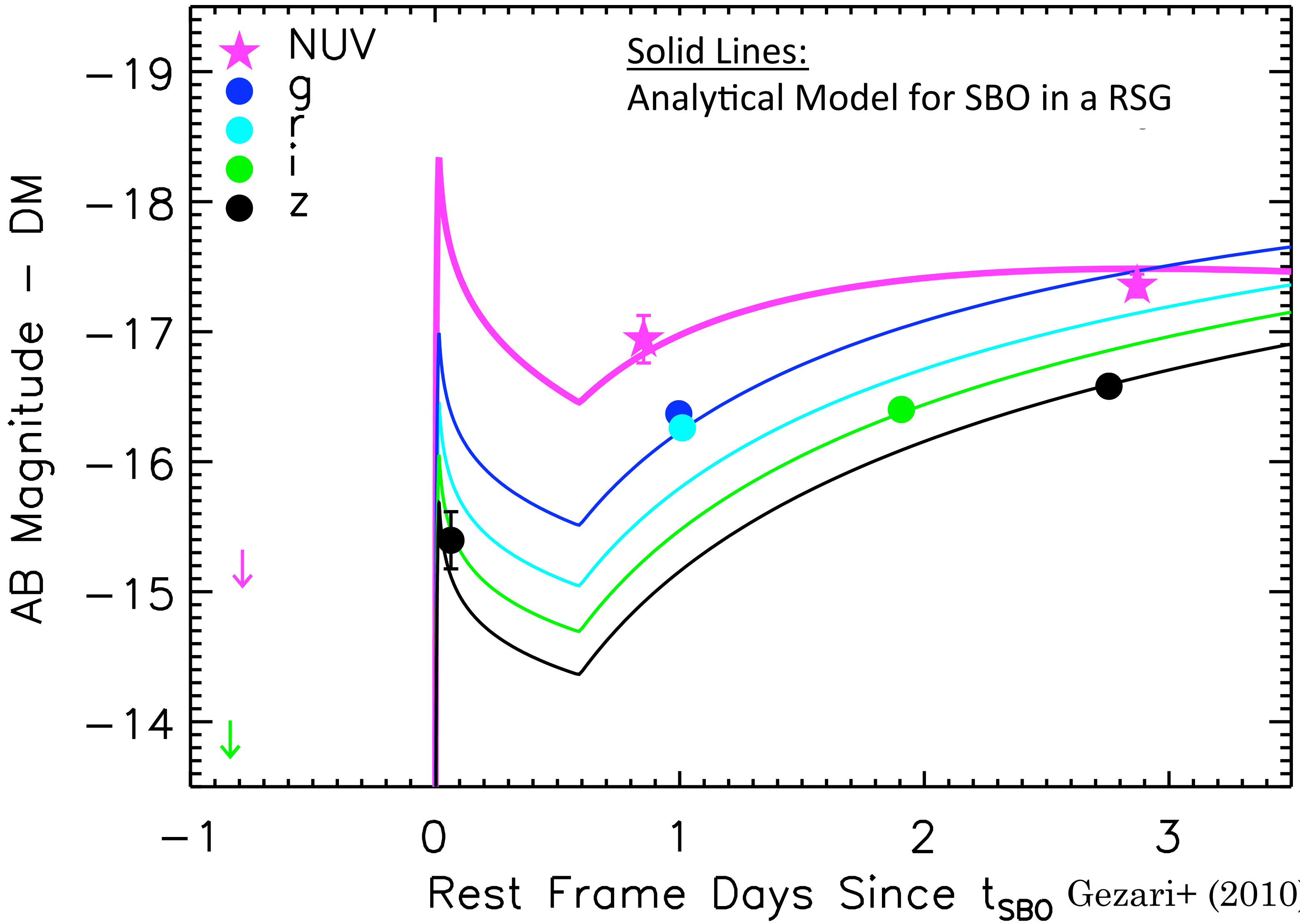
SN IIP 2010aq



z=.0.086

Gezari+ 2010

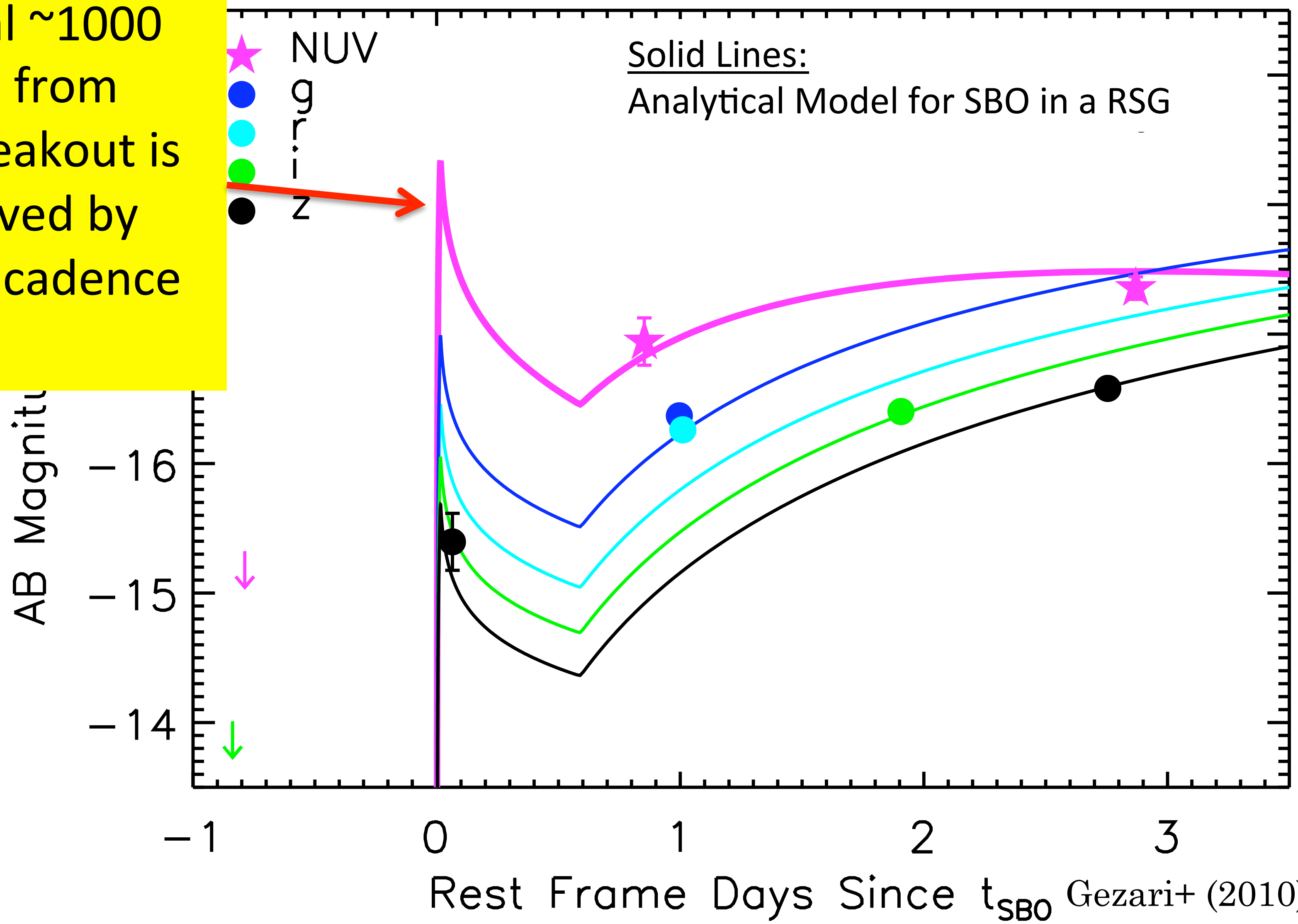
Measuring $R_\star$



Gezari+ (2010)

Measuring $R_\star$

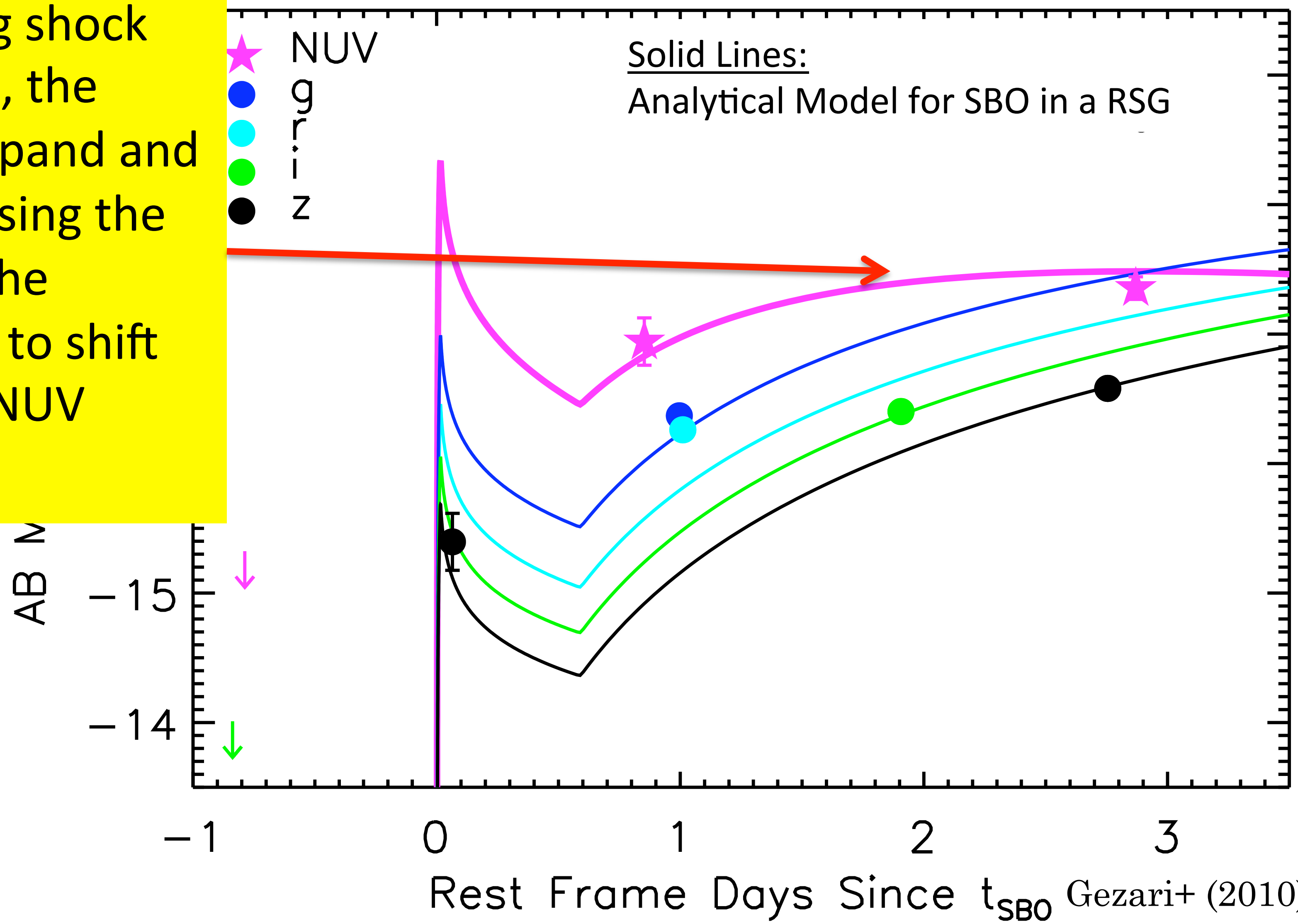
The initial ~1000 sec pulse from shock breakout is not resolved by the daily cadence imaging.



Gezari+ (2010)

Measuring $R_\star$

Following shock breakout, the ejecta expand and cool, causing the peak of the emission to shift into the NUV band.

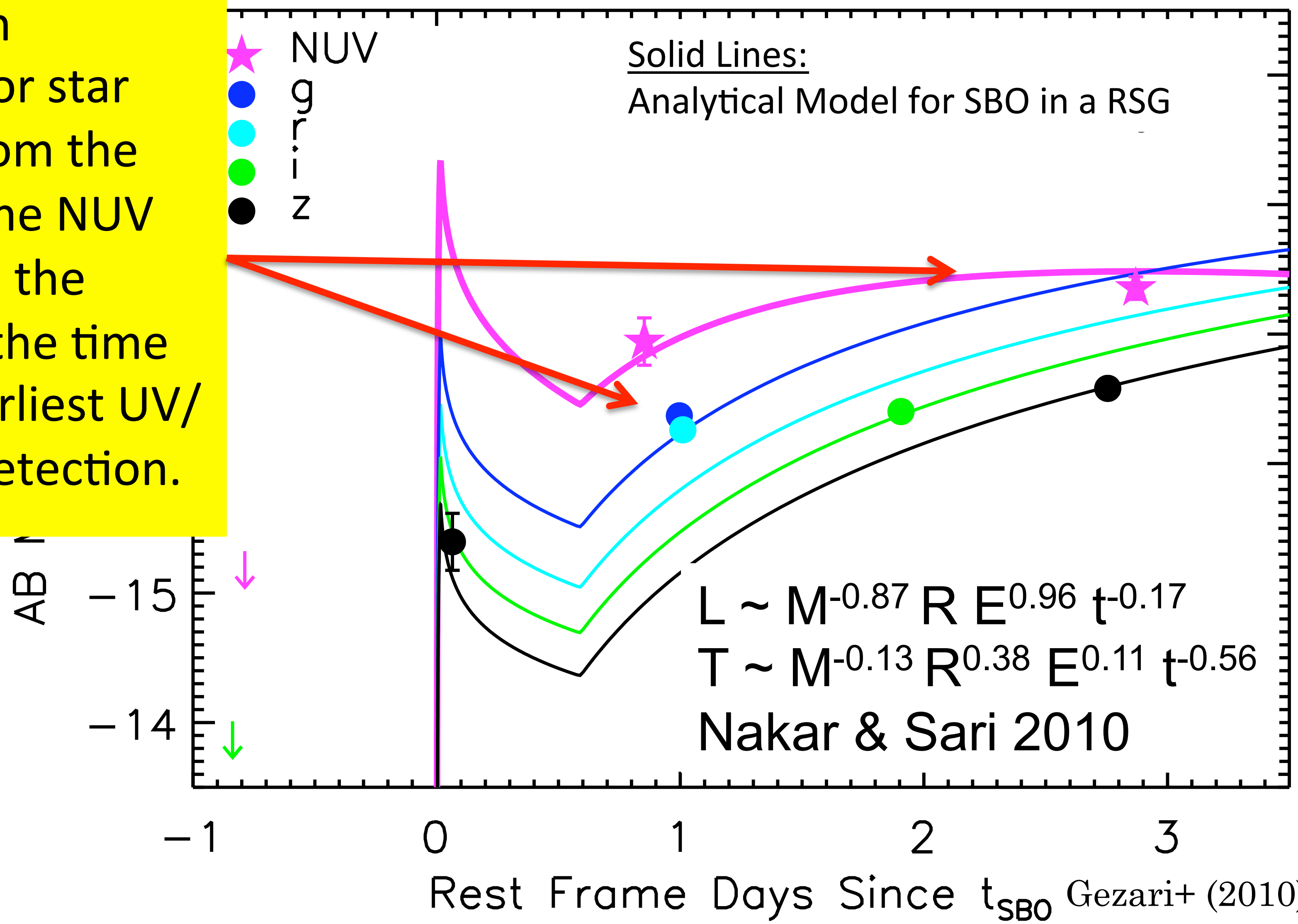


Gezari+ (2010)

Measuring $R_\star$

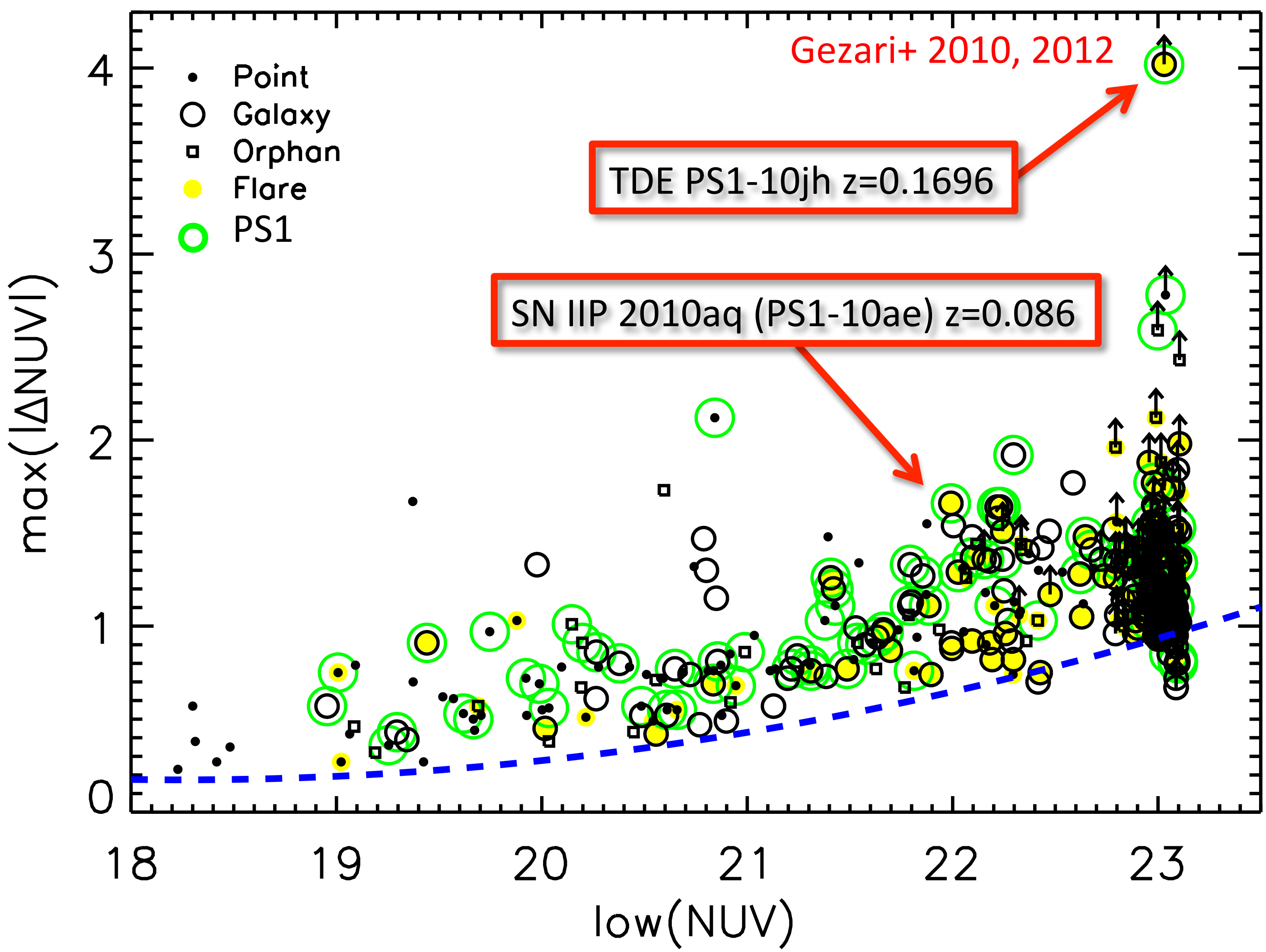
Constrain progenitor star radius from the time of the NUV peak and the temp at the time of the earliest UV/optical detection.

RSG, $R_\star \approx 700 \pm 200\ R_{sun}$



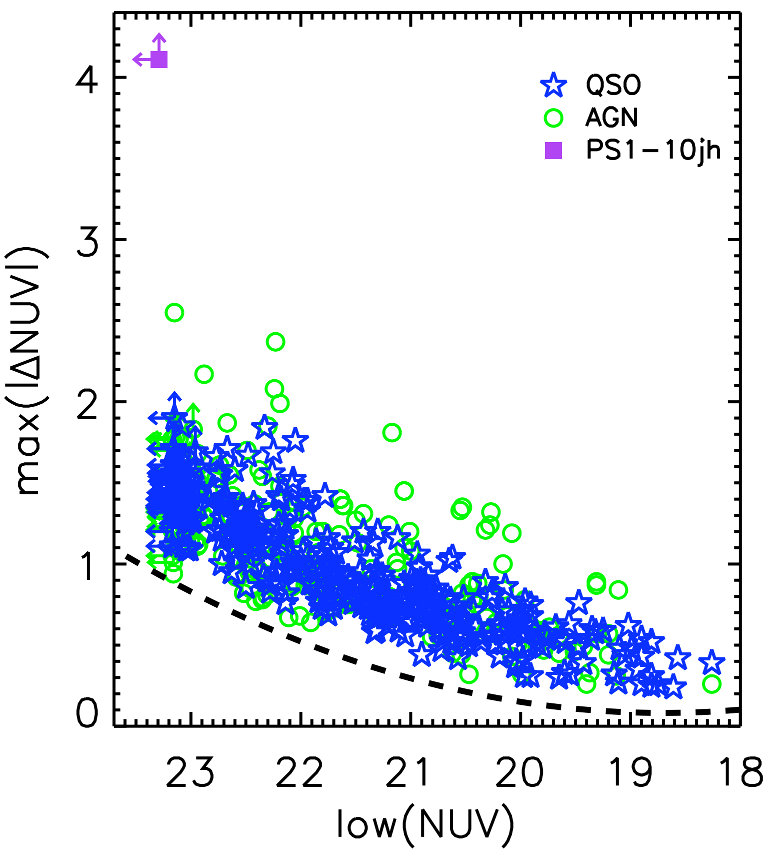
Gezari+ (2010)

GALEX TDS Unclassified Sources



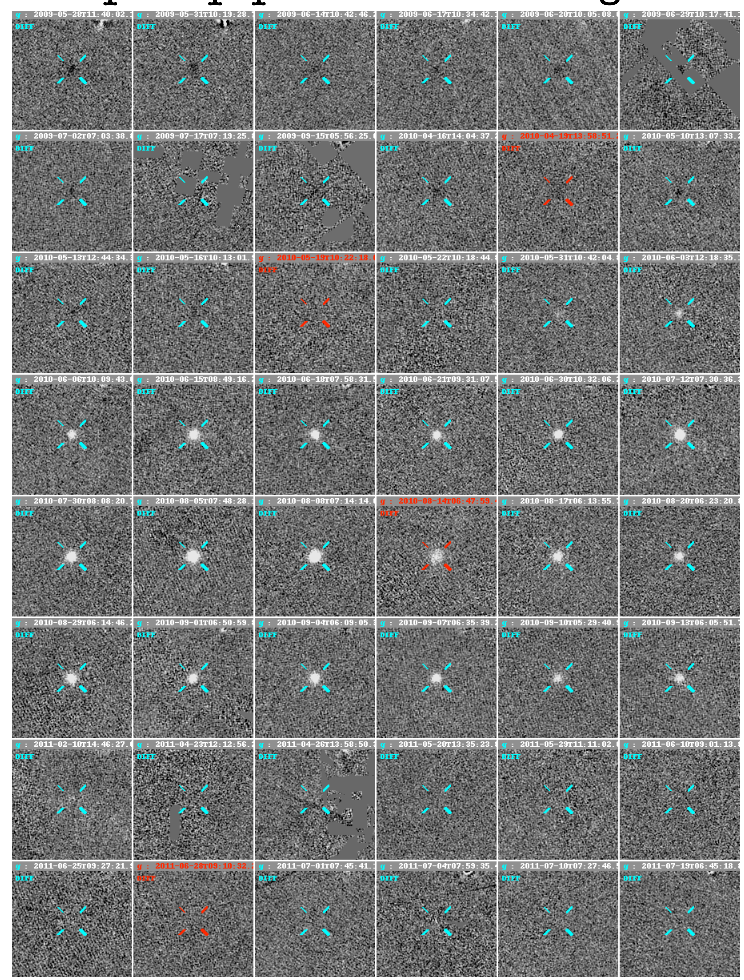
PS1-10jh

GALEX TDS



PS1 MDS

photpipe difference images

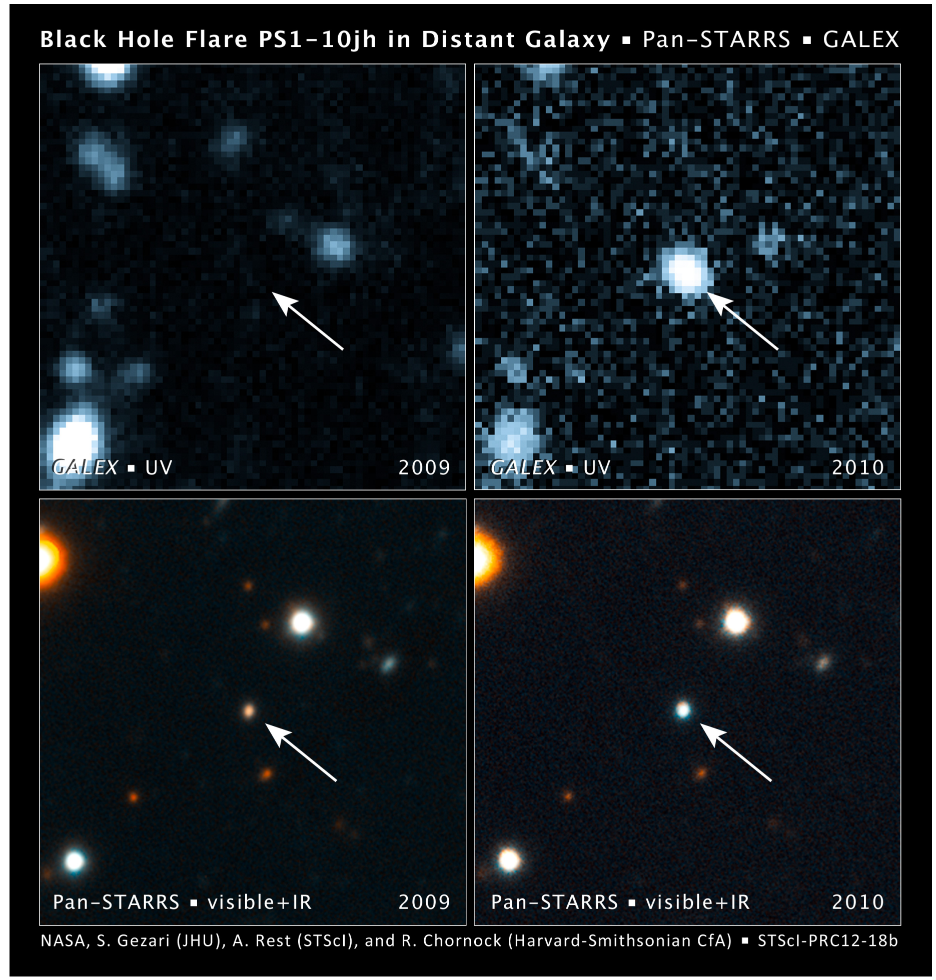


Transient discovered on 31 May 2010

PS1-10jh

- Flare coincident with inactive galaxy nucleus
- z=0.1696
- M_r = -18.7 mag
- $M_{gal} = 3.6 \times 10^9\ M_\odot$
- $M_{BH} = 4^{+4}_{-2} \times 10^6\ M_\odot$
- SFR < $0.022\ M_\odot\ yr^{-1}$

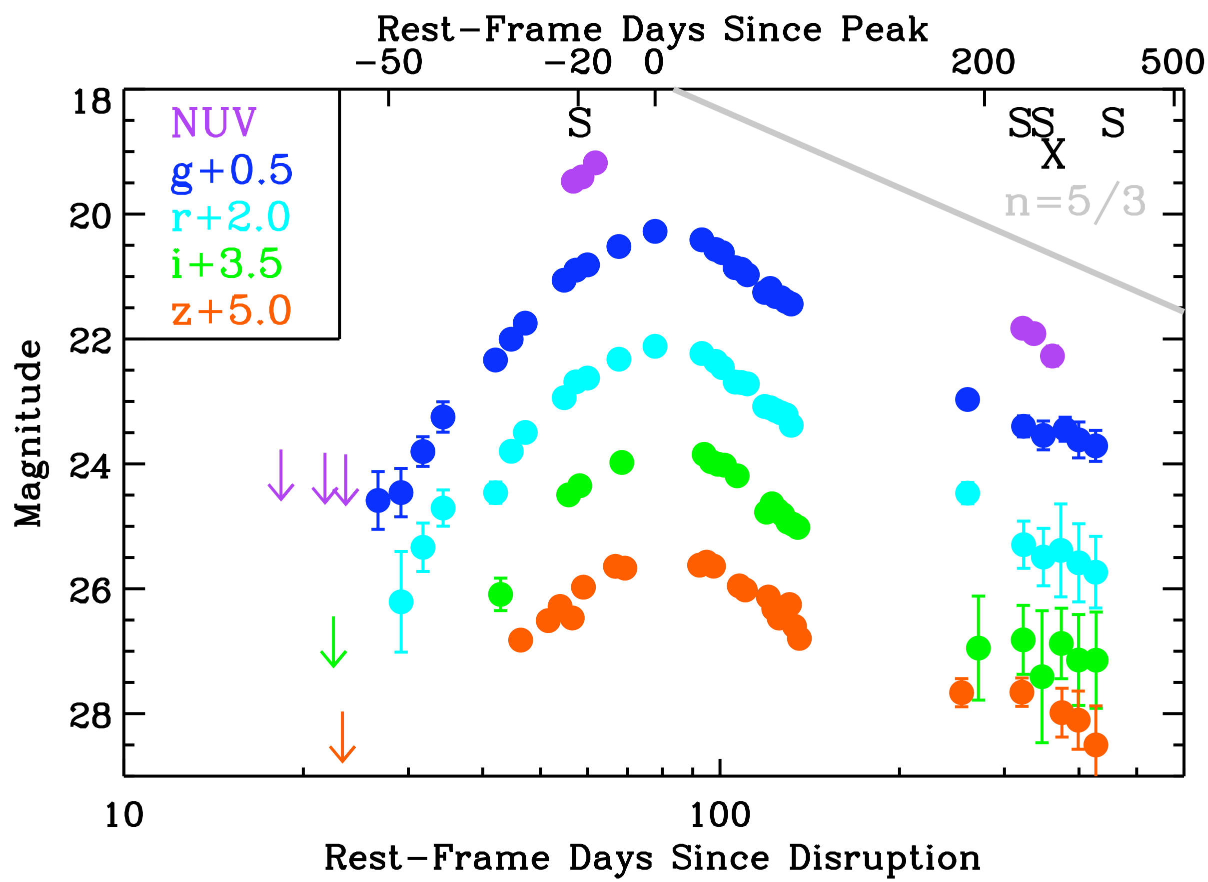
GALEX TDS



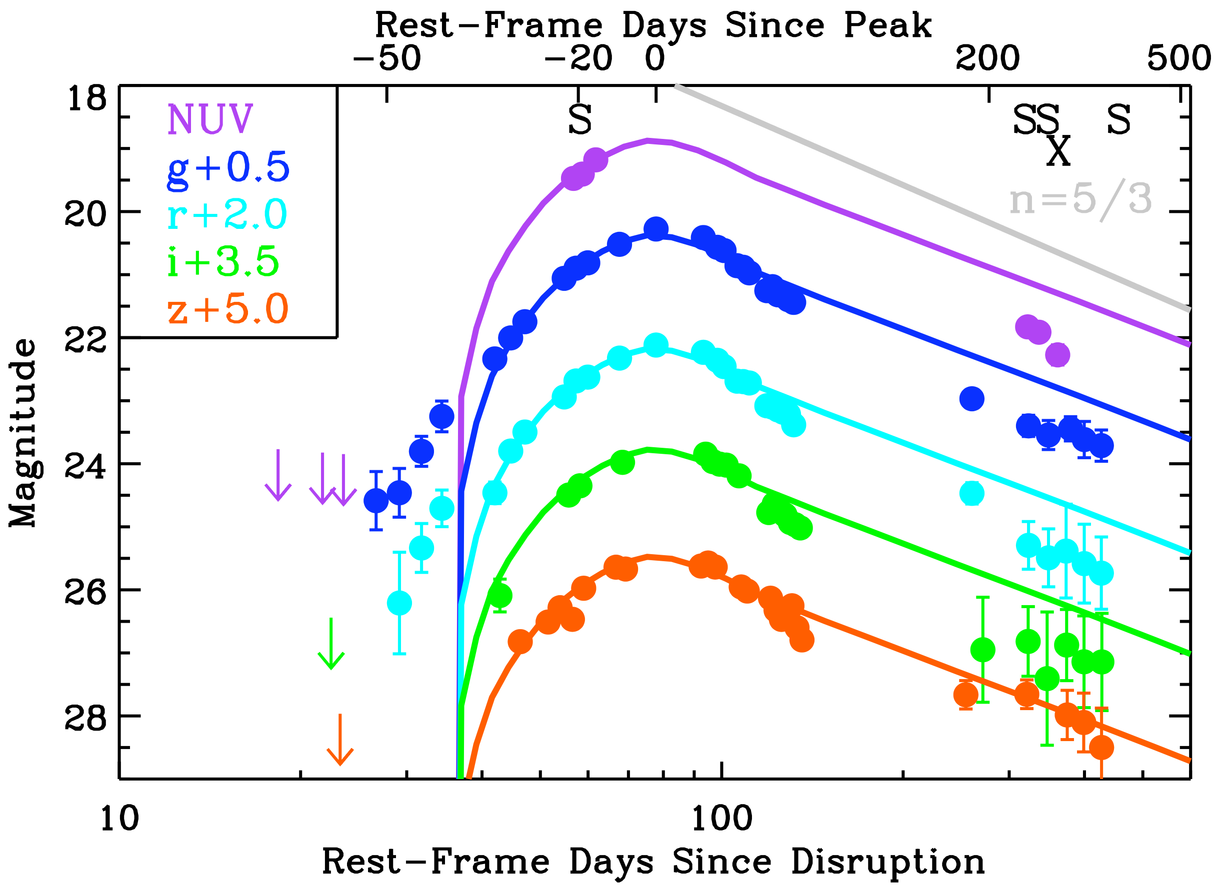
Gezari+ 2012

PS1 MDS

Slow Rise/Power-law Decay

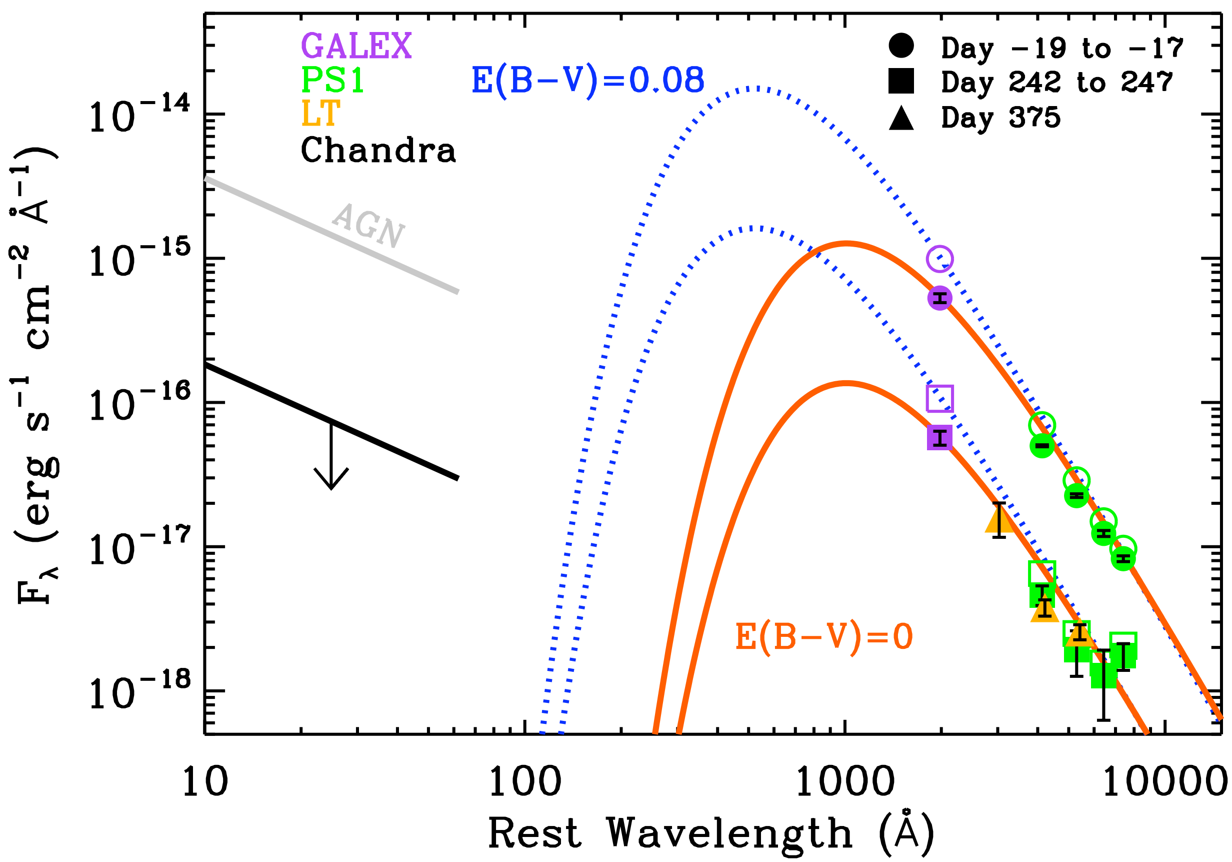


Fit to Mass Accretion Rate



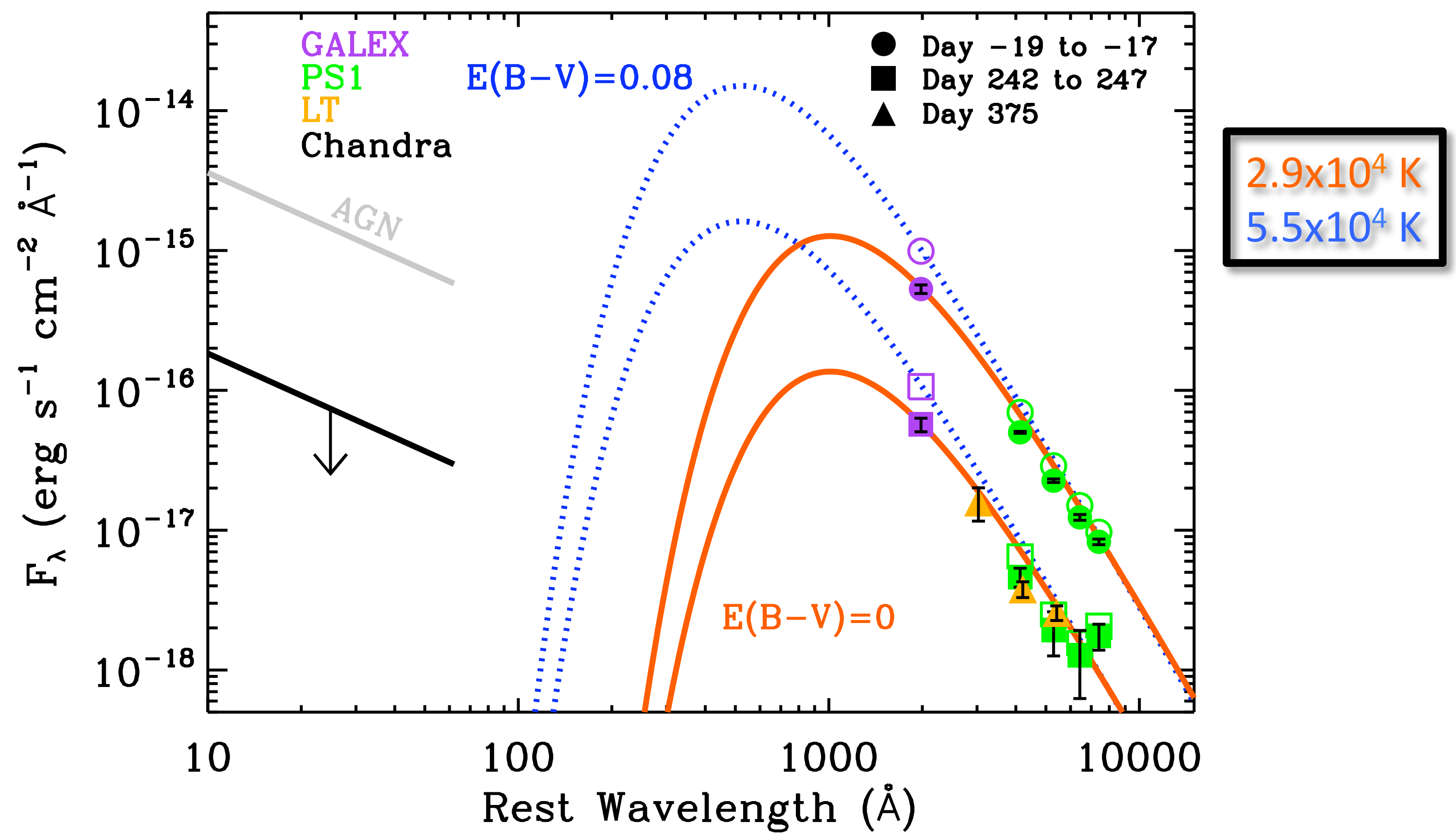
$M_{BH} = (1.9 \pm 0.1) \times 10^6\ M_\odot\ m_\star{}^2 r_\star{}^{-3}$

Hot Blackbody Emission



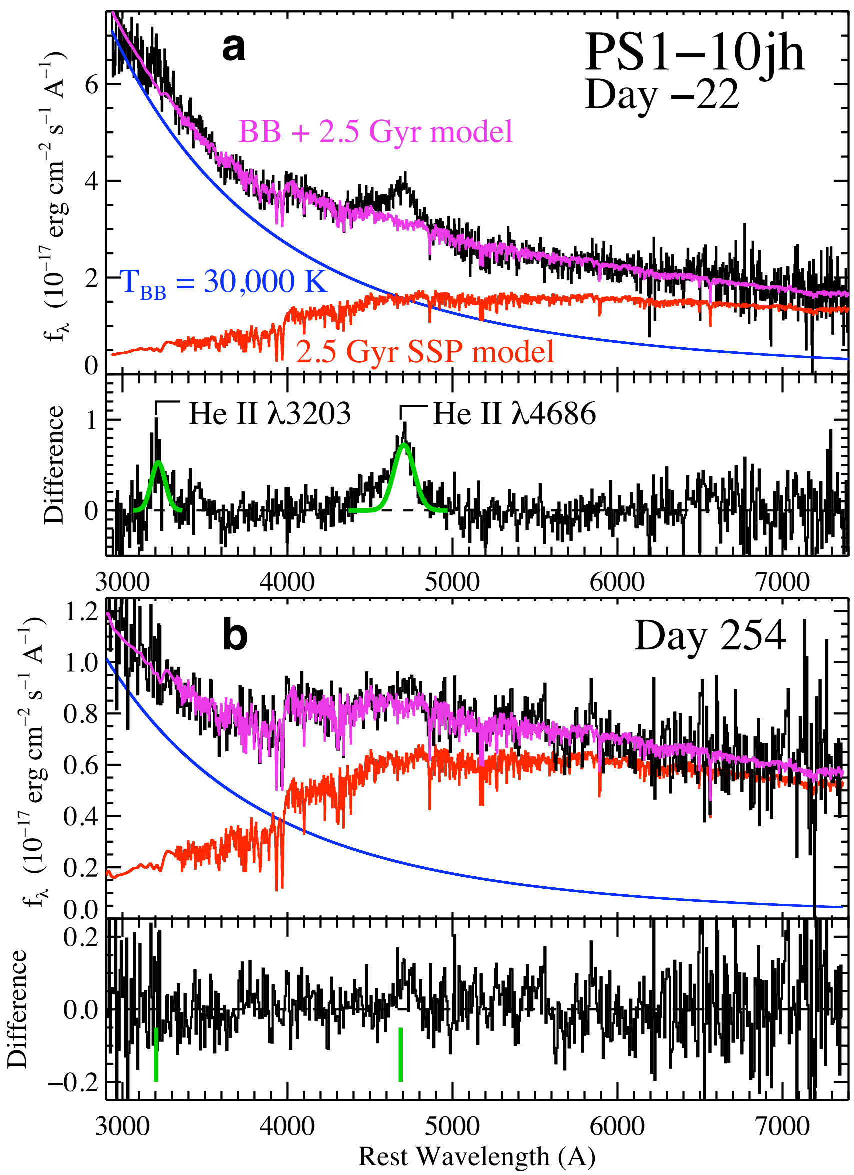
2.9×10^4 K
5.5×10^4 K

Hot Blackbody Emission



Long-lived hot blackbody emission and extreme UV to X-ray ratio rule out a SN and AGN origin, respectively.

Photoionized Stellar Debris



- Broad He II emission (FWHM = 9,000 km/s)
- He II 3203/4686→ E(B-V) < 0.08 mag
- He II 4686/ Hα → X < 0.2
- Tidal disruption debris expelled at high velocities (v_{max}~10^4 km/s)
- Expelled debris from a helium-rich stellar core!

LETTER

Gezari+ 2012, Nature

An ultraviolet–optical flare from the tidal disruption of a helium-rich stellar core

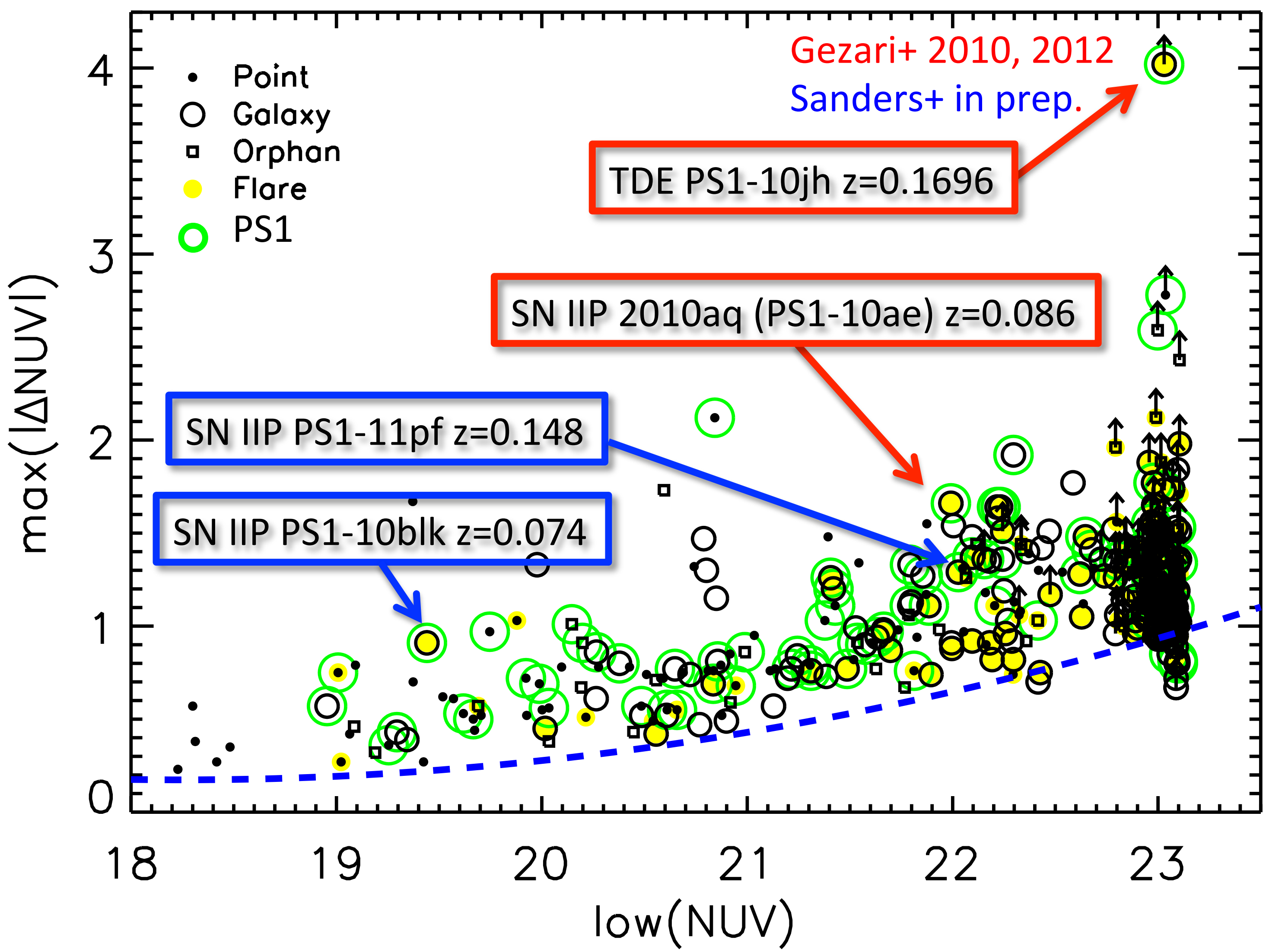
S. Gezari[1], R. Chornock[2], A. Rest[3], M. E. Huber[4], K. Forster[5], E. Berger[2], P. J. Challis[2], J. D. Neill[5], D. C. Martin[5], T. Heckman[1], A. Lawrence[6], C. Norman[1], G. Narayan[2], R. J. Foley[2], G. H. Marion[2], D. Scolnic[1], L. Chomiuk[2], A. Soderberg[2], K. Smith[7], R. P. Kirshner[2], A. G. Riess[1], S. J. Smartt[7], C. W. Stubbs[2], J. L. Tonry[4], W. M. Wood-Vasey[8], W. S. Burgett[4], K. C. Chambers[4], T. Grav[9], J. N. Heasley[4], N. Kaiser[4], R.-P. Kudritzki[4], E. A. Magnier[4], J. S. Morgan[4] & P. A. Price[10]

- $L_{bol} > 2.2 \times 10^{44}$ erg/s, $E_{tot} > 2.1 \times 10^{51}$ erg, $M_{acc} > 0.012\ M_{\odot}$
- Tidally stripped Red Giant (precursor to a helium white dwarf)
- For $M = 0.23\ M_{\odot}$, $R = 0.33\ R_{\odot}$:

$M_{acc}/M_{\star} > 0.058$ and $M_{BH} = 2.8 \times 10^{6}\ M_{\odot}$

- We can weigh black holes with tidal disruption events!

GALEX TDS Unclassified Sources



Potential Projects

Variable Stars: A Joint UV/Optical Perspective

- UV M dwarf flaring rate.
- UV/optical light curves of RR Lyrae stars.

Probing Accretion onto SMBHs via Variability

- UV/optical light curves of QSOs. λ-dependent variability.
- Spectroscopic properties of large-amplitude variable AGNs.

Time-domain Astronomy

- Light-curve classification in preparation for LSST.

Combining PS1 with Multi-Wavelength Wide-Field Surveys

- FERMI, Swift/BAT, UKIDSS, WISE, FIRST