Status of Shock Breakout Observations

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in collaboration with:

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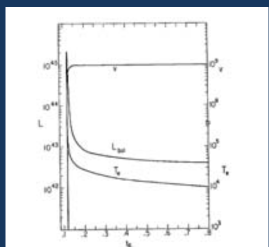
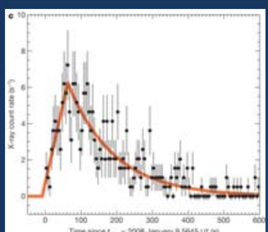
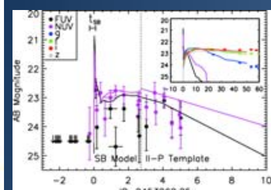
GALEX & Pan-STARRS

Outline



- Motivations for and challenges in observing shock breakout in core-collapse SNe

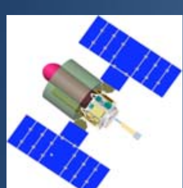




- Recent observational results in the X-rays and UV

+

- Detection capabilities of Pan-STARRS + GALEX TDS

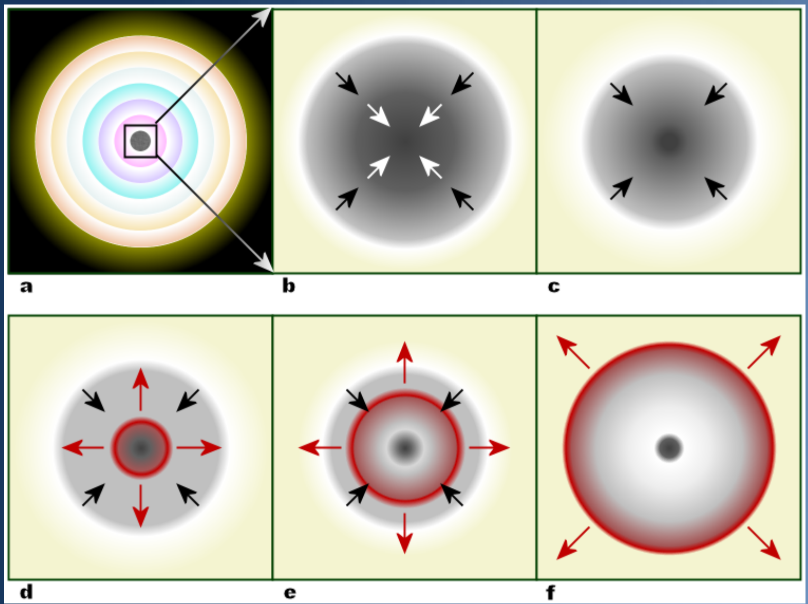


- Prospects for the future

Shock Breakout in Core Collapse SNe

- Expect a UV/X-ray burst when the shock that launches the SN ejecta emerges at the progenitor surface, and heats the outer layers (Colgate 1974) to T≈10^5 K.

- The SN ejecta cools through expansion and radiation, causing the peak of the emission to shift from X-ray to UV to optical.



wikipedia

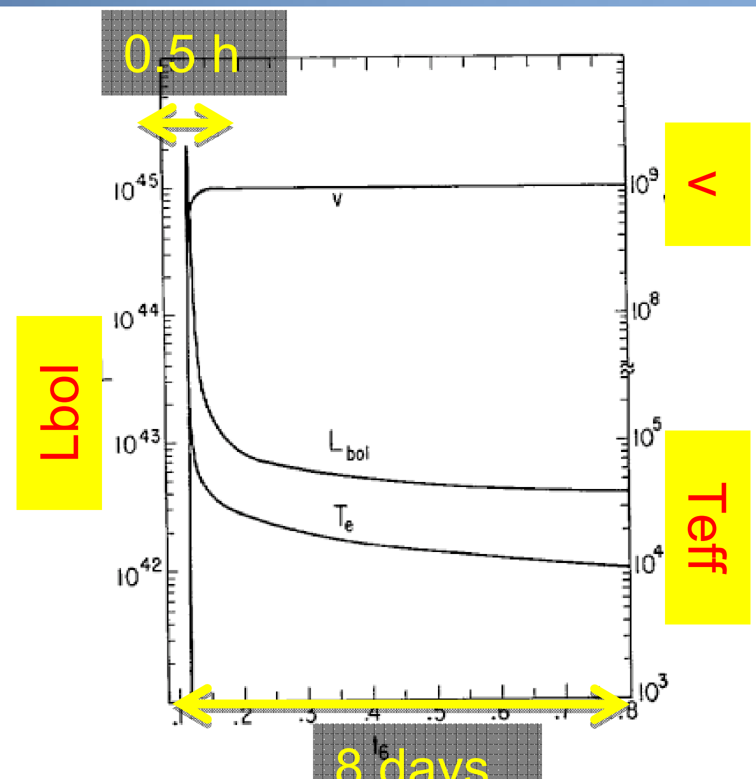


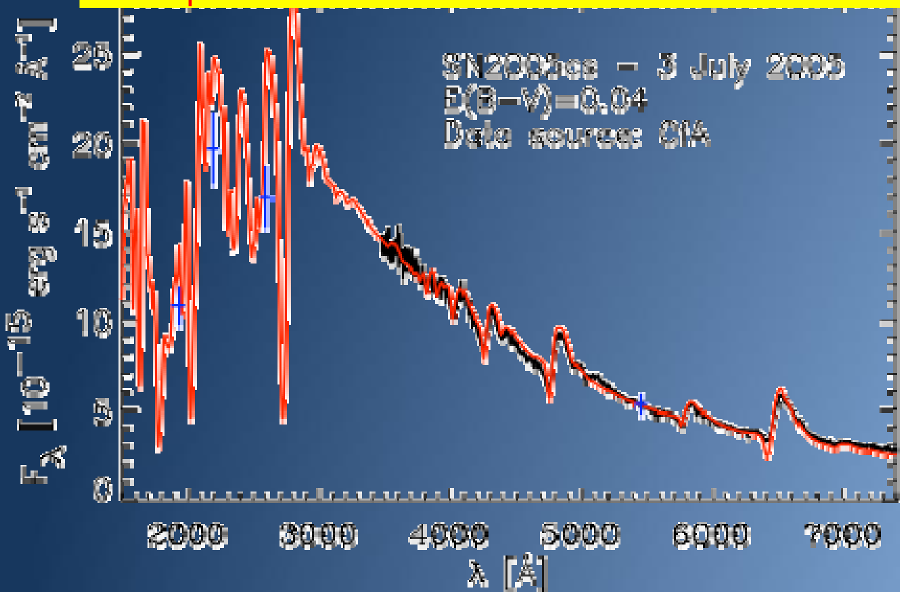
FIG. 2.—Luminosity, effective temperature, and photospheric material velocities at early times. The bolometric luminosity L_{bol} (ergs s^{-1}), effective temperature T_e, and velocity of matter in the outermost material layers (in the model, at the photosphere) in units of 10^8 cm s^{-1} = 10^3 km s^{-1} are plotted as functions of time for the thermal burst epoch. Time is given in units $t_6 = t/10^6$ s.

Falk (1978)

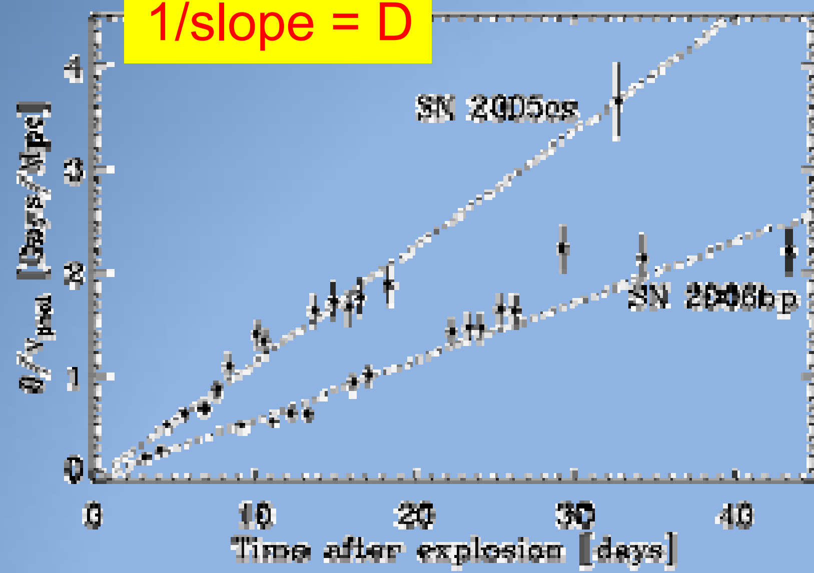
Distance Measurements

- Constrain the time of shock breakout (t_{sbo}).
- Can apply EPM distance measurement with fewer epochs of spectra.

θ, v_{phot} from synthetic spectrum



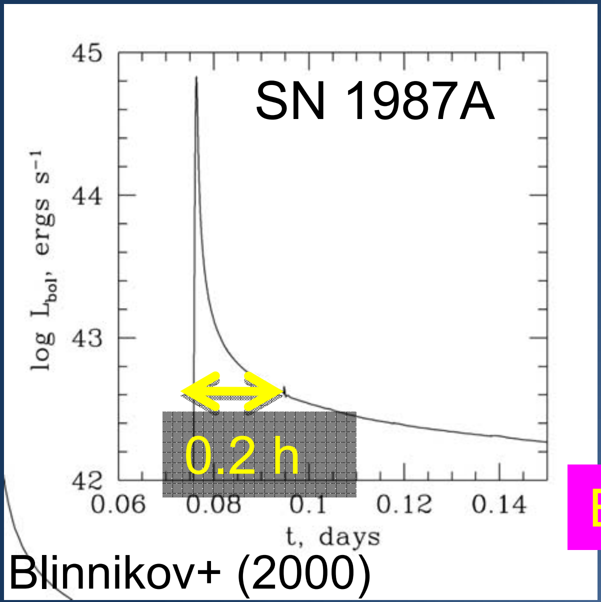
1/slope = D



Dessart+ (2008)

$\theta/v_{phot} = (t - t_{sbo})/D$
where $\theta = R_{phot}/D$

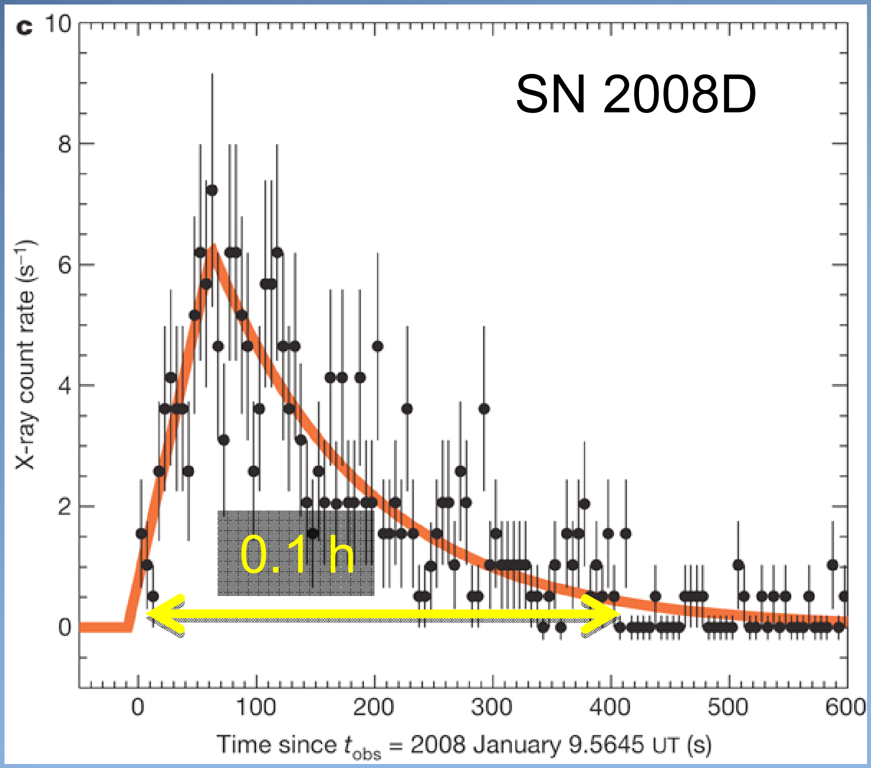
Sensitivity to Progenitor Radius



Blinnikov+ (2000)

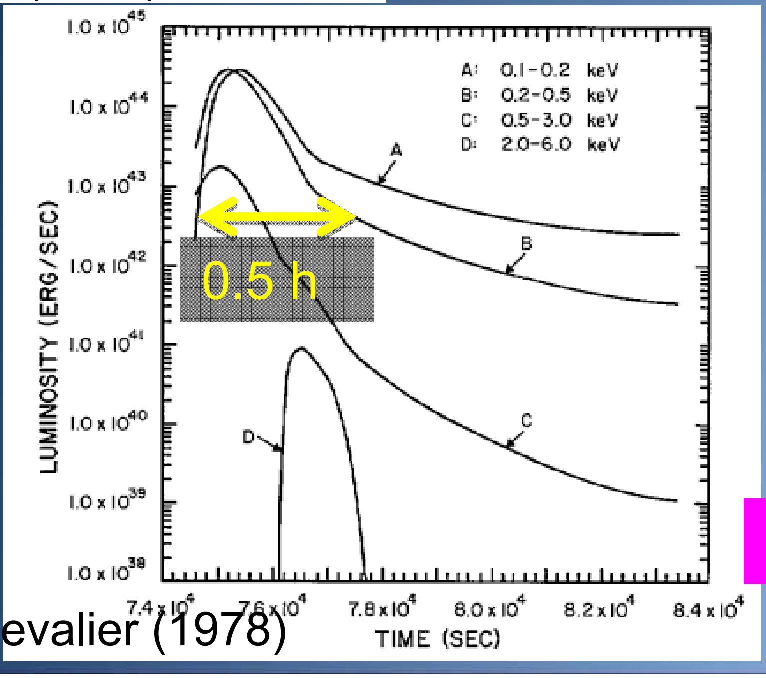
Duration of the burst expected to be on the order of the light-crossing time (t=R/c).

BSG (R≈10^{12} cm)



Soderberg+ (2008)

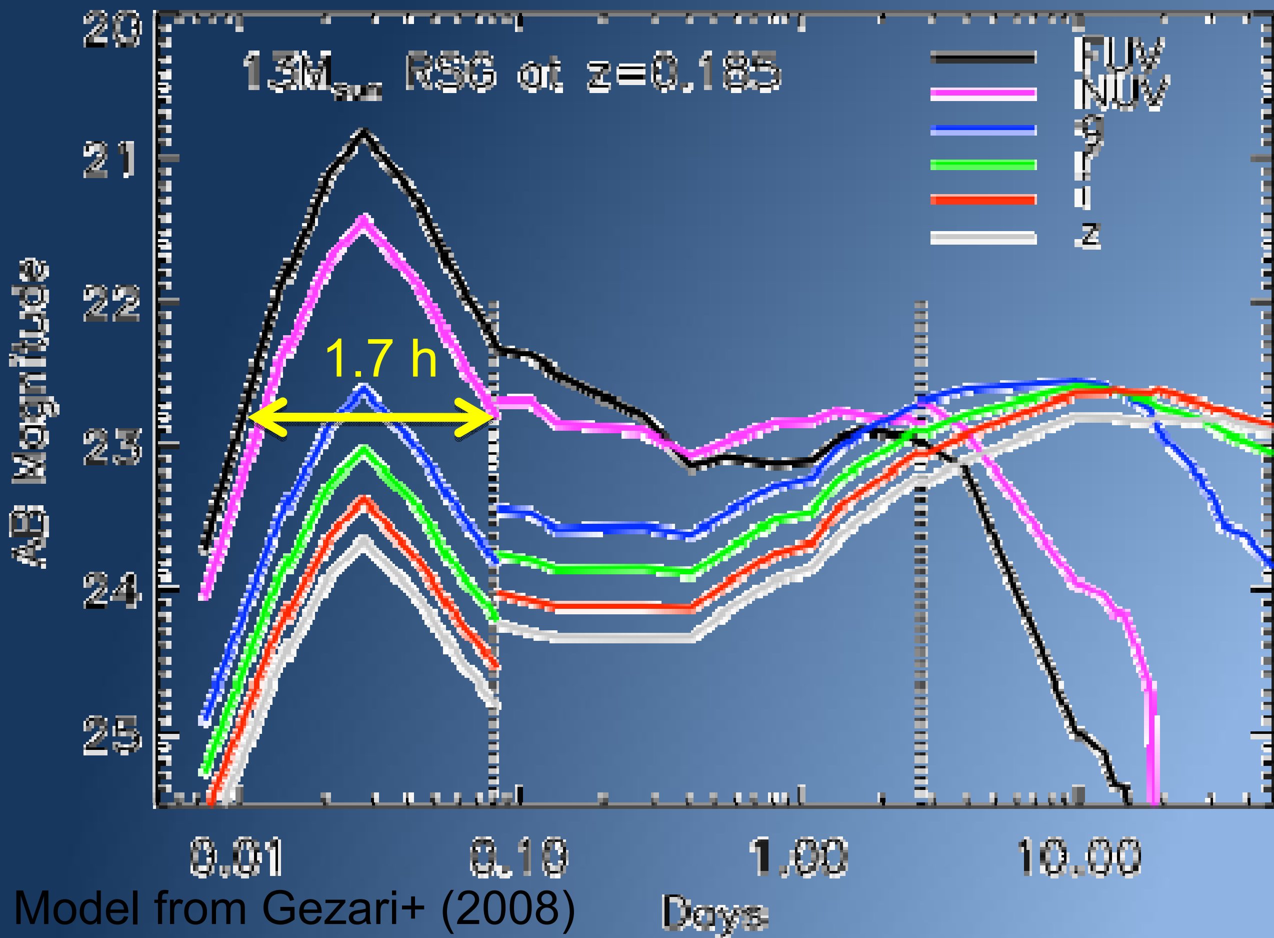
WR (R≈10^{11} cm) with dense wind



Klein & Chevalier (1978)

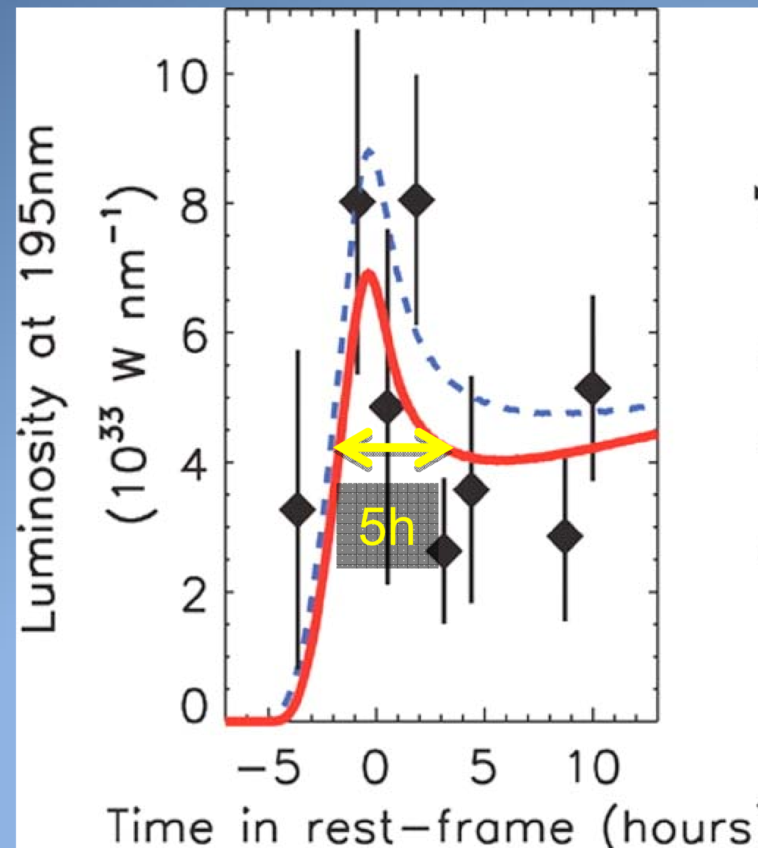
RSG (R≈10^{13} cm)

Sensitivity to Envelope Structure



Model from Gezari+ (2008)

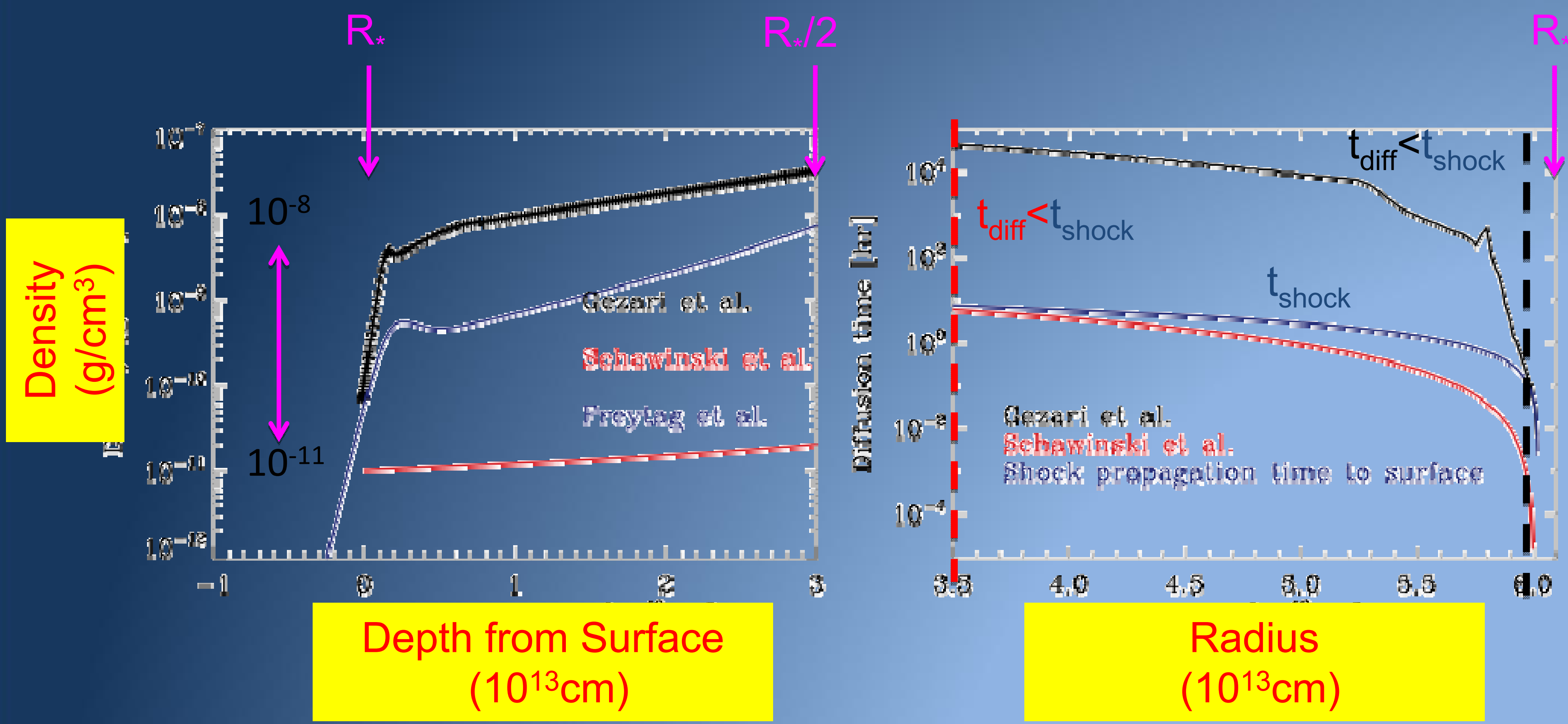
Standard RSG



Schawinski+ (2008)

RSG with low-density envelope

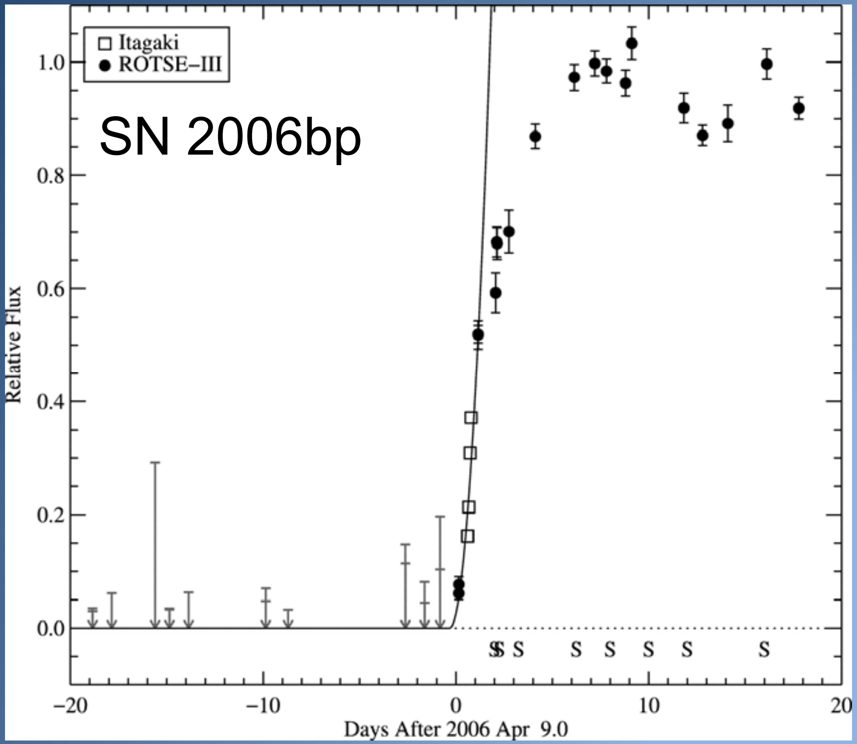
Sensitivity to Envelope Structure



Radiative precursor starts when $t_{diff}<t_{shock}$,
where $t_{diff} = 3\tau H/c$,
and H is the atmospheric scale height.

Challenges in Observing Shock Breakout

- Optical surveys are not sensitive to the **short burst** of **high energy** emission at the time of shock breakout.

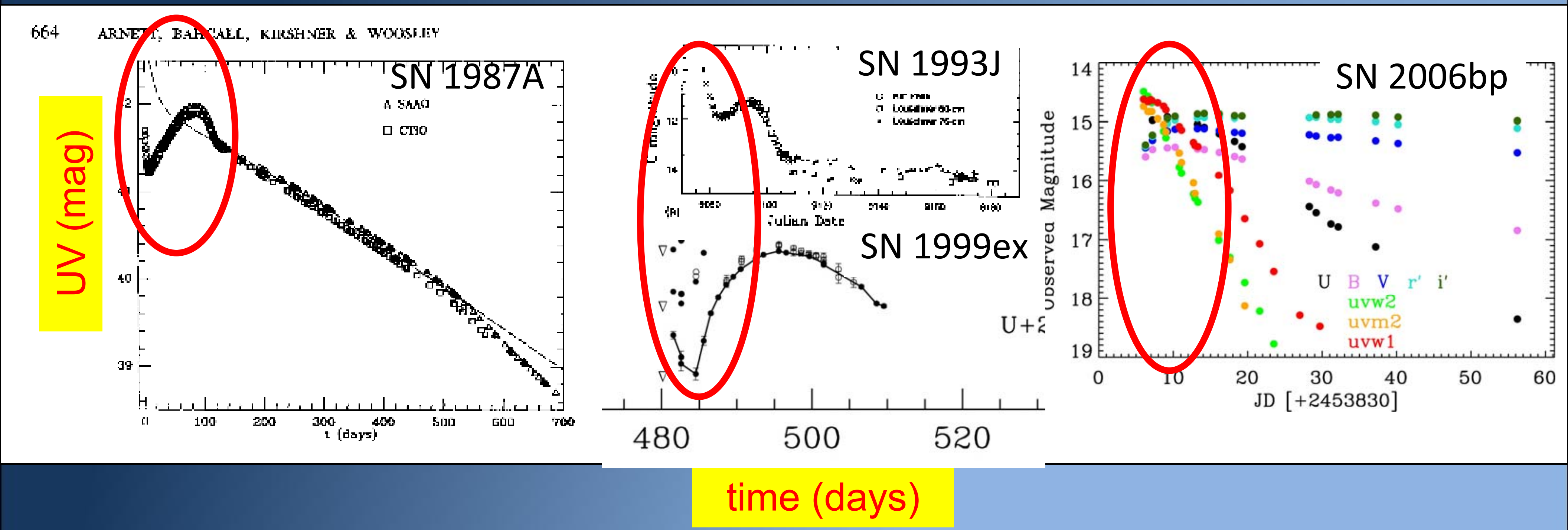


Quimby+ (2007)

UV/X-ray observations are more sensitive to shock breakout.

Challenges in Observing Shock Breakout

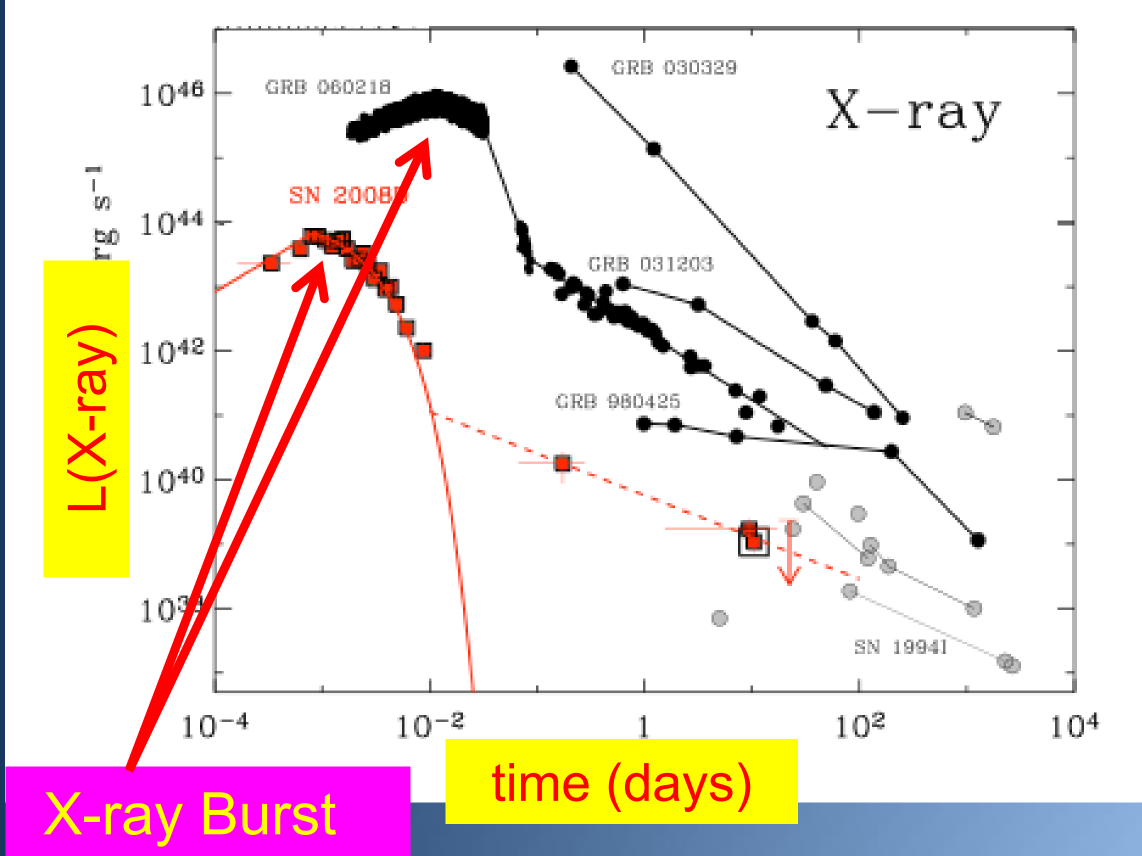
- SNe discovered in optical surveys are observed once they are already **fading** in the UV.



The UV/X-ray burst from shock breakout happens weeks before the optical peak, and thus is missed by follow-up observations of optical discoveries.

Serendipitous Discoveries in the X-rays

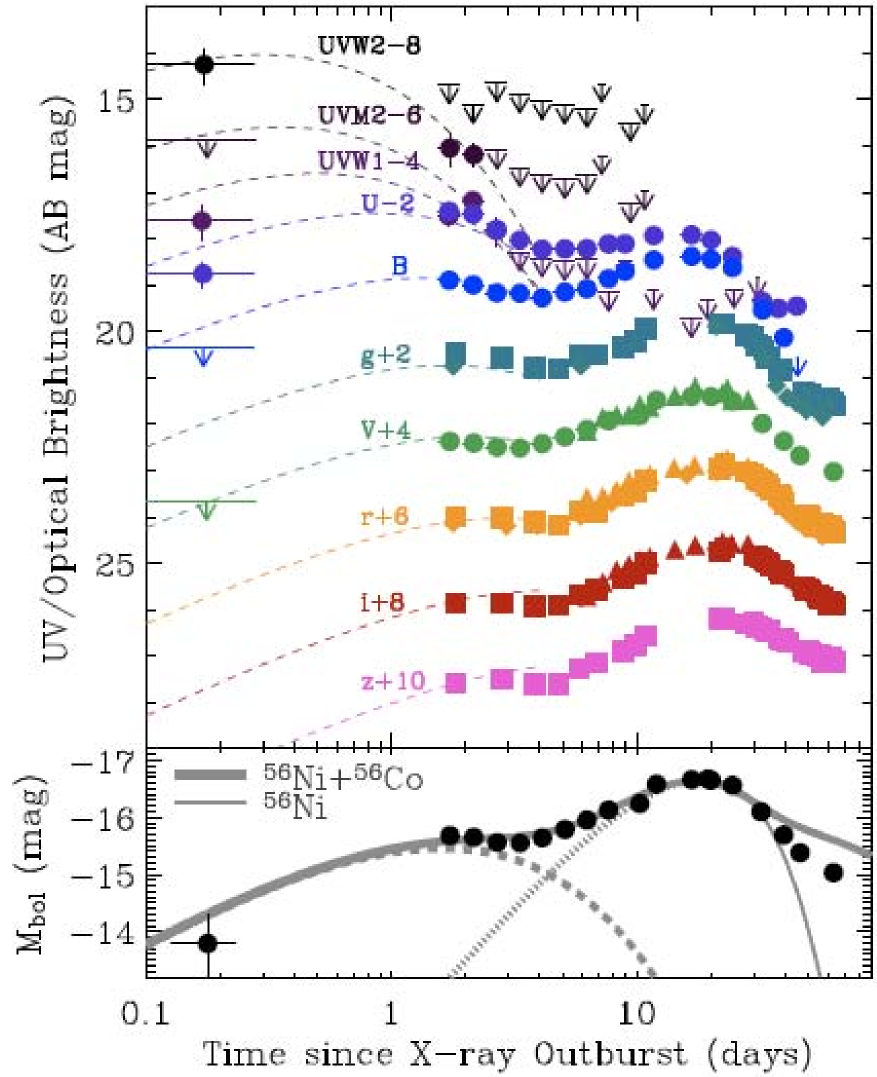
Soderberget al. 2008



- Only 2 SNe have been observed at the time of shock breakout in the X-rays.
- SN 2006aj (Type Ic) was associated with a GRB (Campana+ 2006).
- SN 2008D (Type Ib) was serendipitously discovered in the field of view of a Swift X-ray observation (Soderberg+ 2008; Modjaz+ 2008).

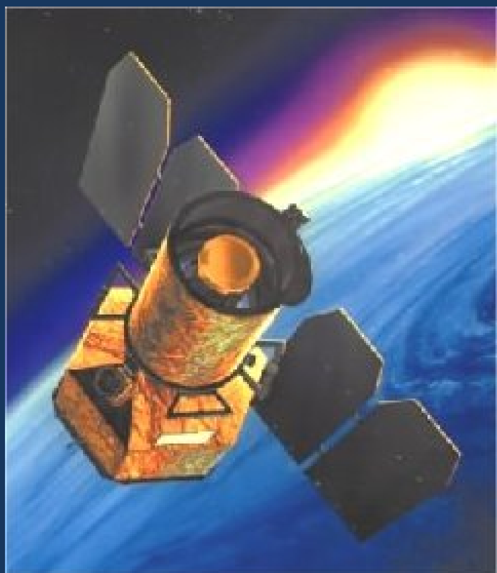
Serendipitous Discoveries in the X-rays

Soderberget al. 2008



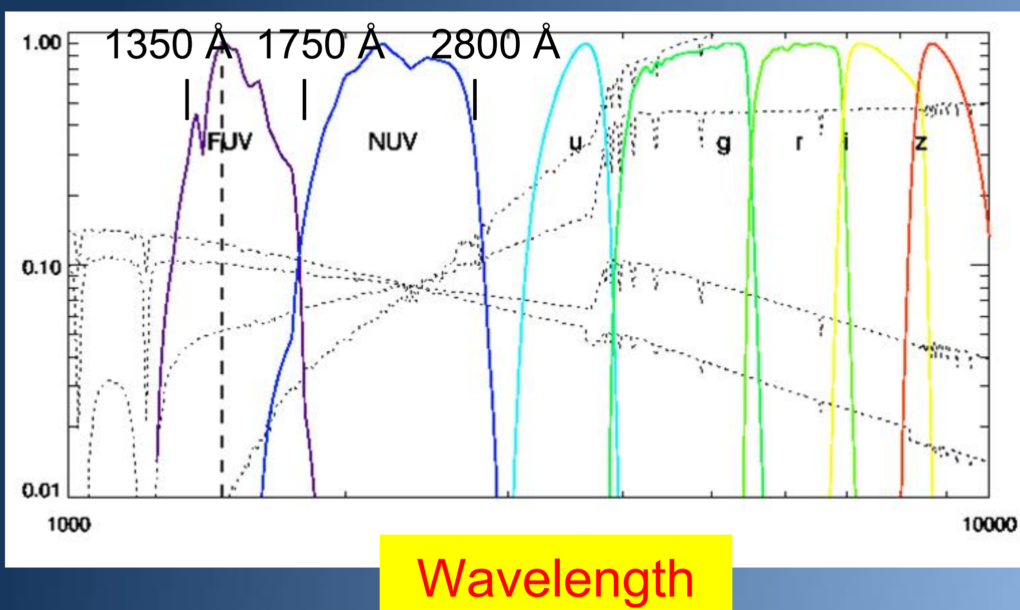
- X-ray and UV/optical properties of SN 2008D consistent with shock breakout of a:
- $R=7x10^{10}$ cm WR star (Soderberg+ 2008)
- $R=6x10^{11}$ cm He star (Chevalier &Fransson 2008).
- Duration of the burst (≈100 sec) requires the presence of a dense wind to delay the shock breakout OR asphericity (**see poster by Couch**).

GALEX Galaxy Evolution Explorer



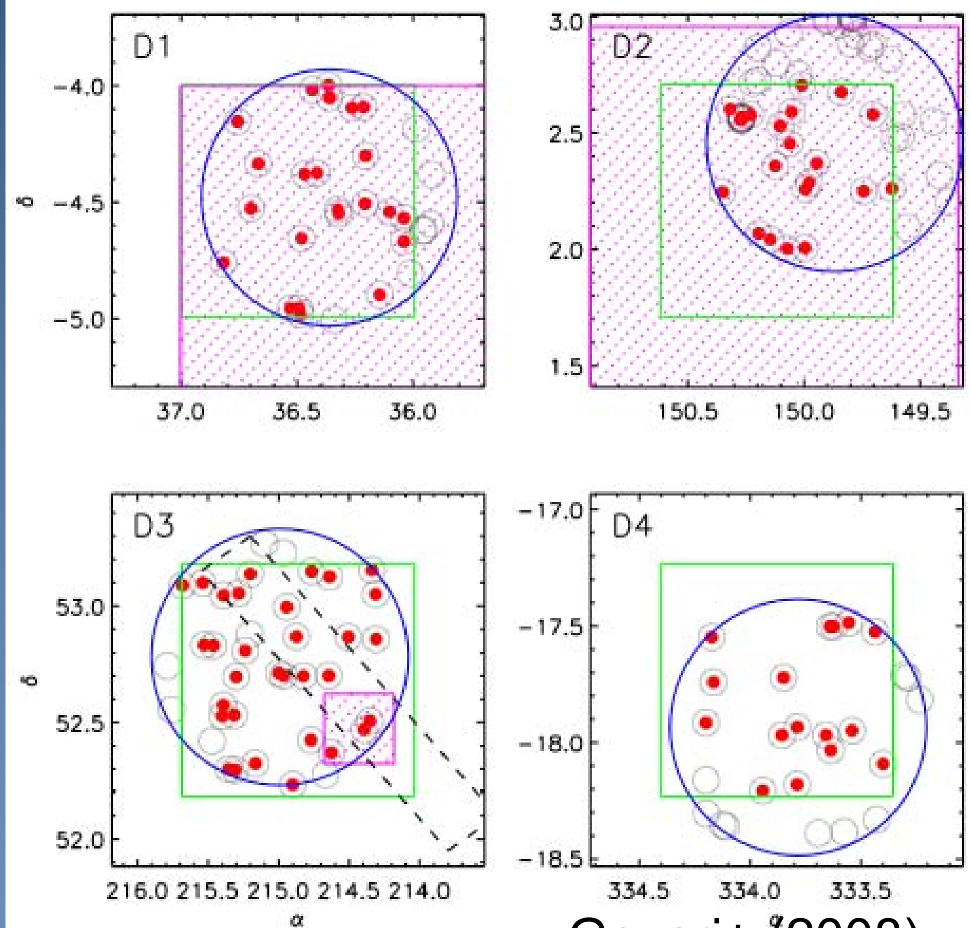
Early UV detections of SNe identified in optical surveys not a problem with parallel wide-field GALEX observations.

- NASA Small Explorer mission launched on April 28, 2003.
- 50 cm telescope with a 1.2 deg^2 field of view.
- 1.5''/pixel, 6''/8'' resolution FUV/NUV
- Some deep fields are revisited over a baseline of 2-4 years to complete deep observations.



Synergy Between GALEX and SNLS

- 3 deg^2 of overlap between CFHTLS SNLS and GALEX DIS fields with multiple observations.

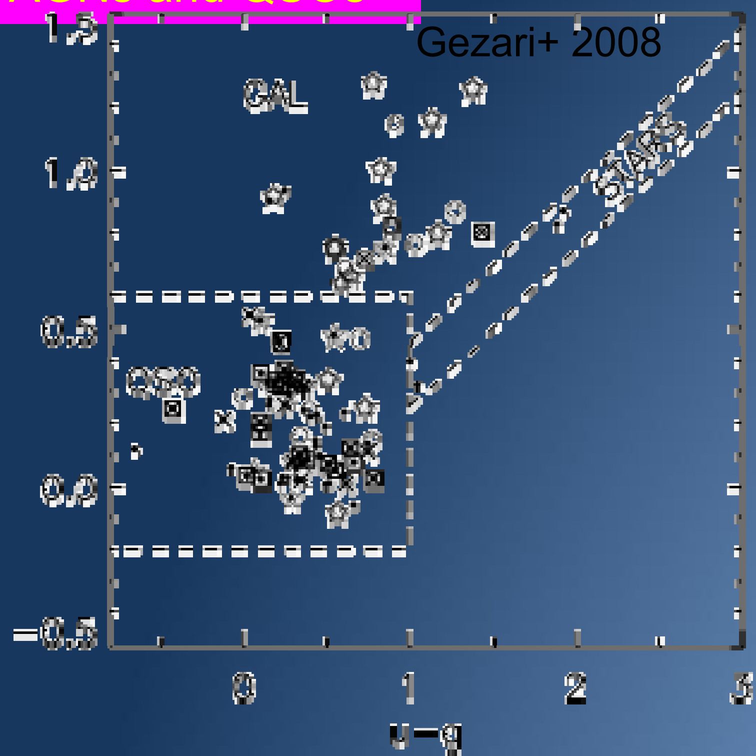


Gezari+ (2008)

GALEX
CFHTLS
X-ray
DEEP2

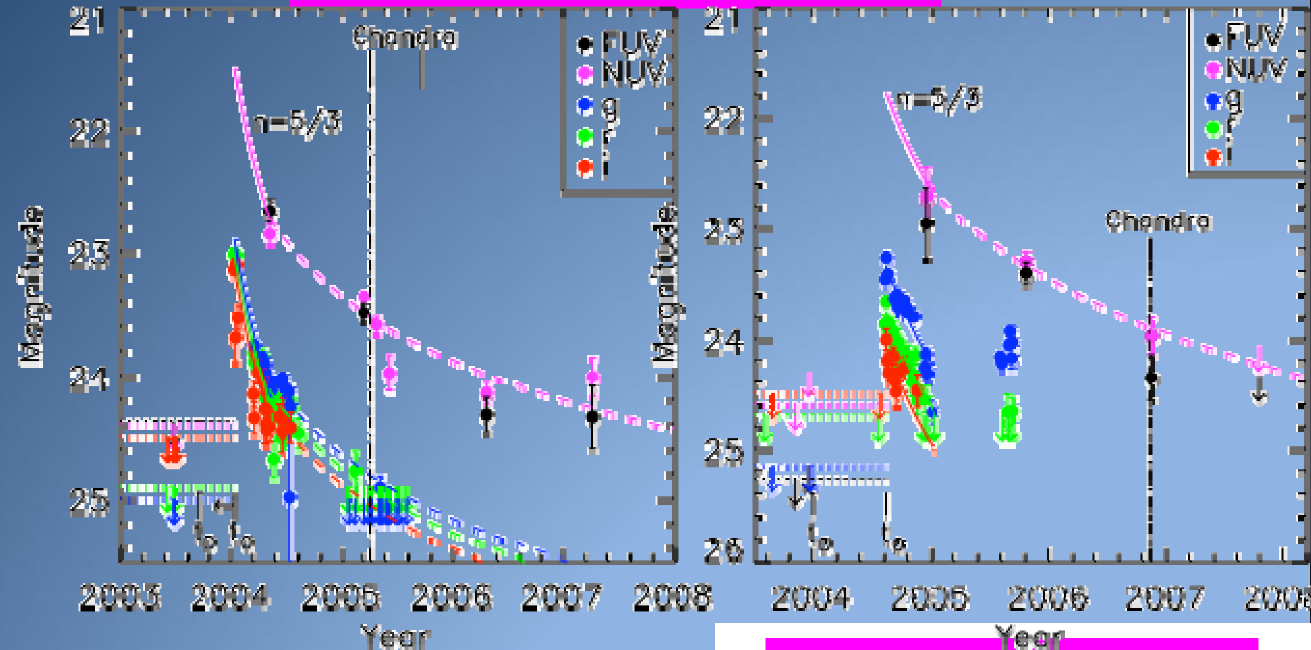
Synergy Between GALEX and SNLS

AGNs and QSOs

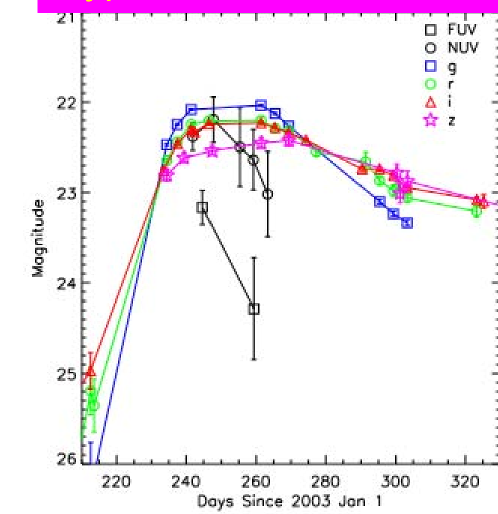


Tidal Disruption Flares

Gezari+ 2008

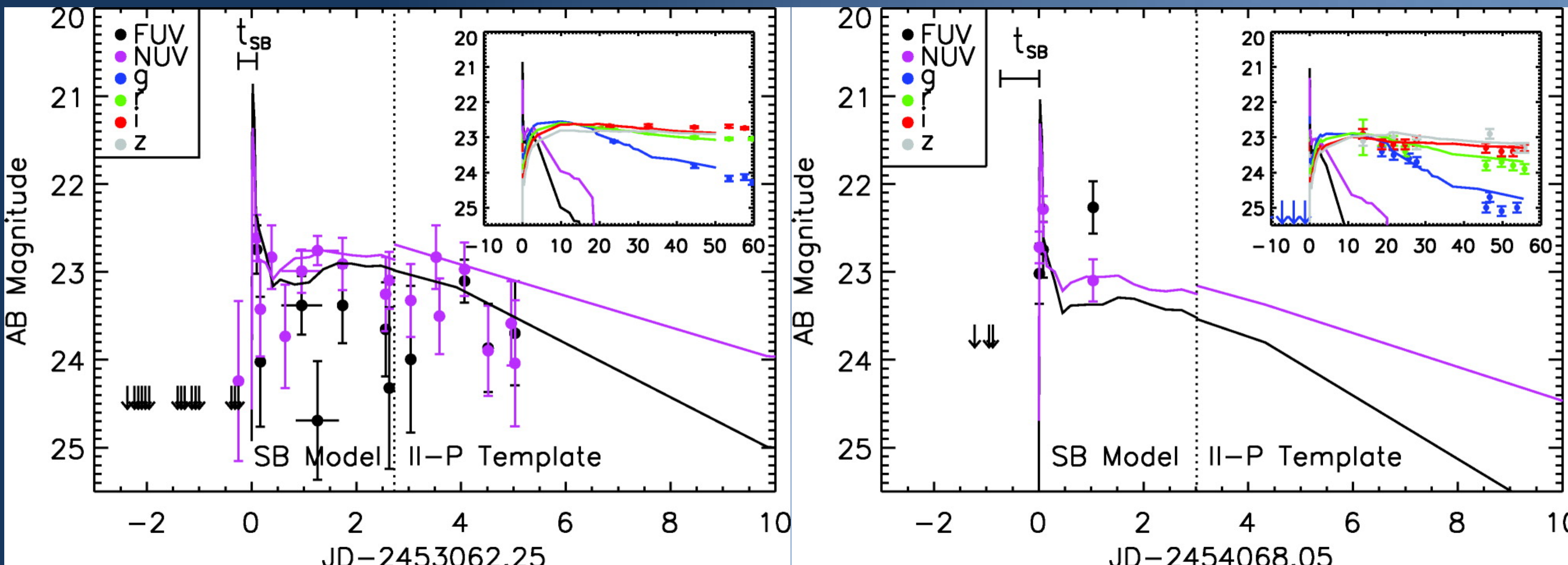


Type IIn SN at z=0.189



Searched for SNLS SN candidates with GALEX DIS observations within 30 days before the optical discovery.

Synergy Between GALEX and SNLS



z=0.185

z=0.324

Gezari+ (2008)

- Detected early **rising** UV emission from two Type II-P supernovae discovered in the optical by SNLS two weeks later.

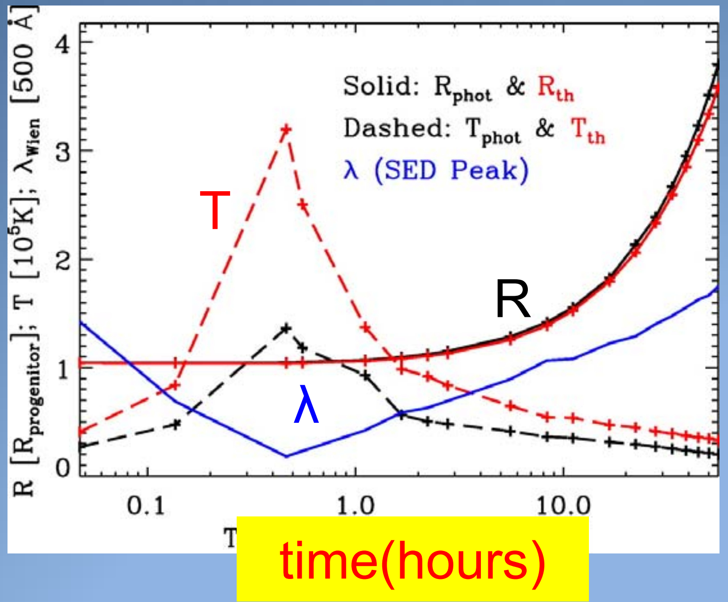
- Compare the UV and optical light curves to models for the shock breakout and its immediate aftermath.

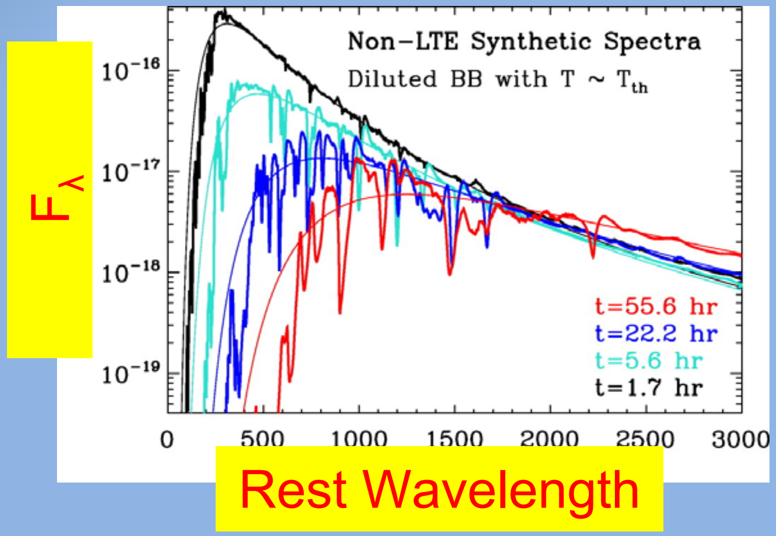
Modeling Shock Breakout in a RSG

I. The evolution of a RSG until core collapse, and the first 55 hr after shock breakout are modeled with a one-temperature Lagrangian radiation hydrodynamics code (KEPLER).

II. Post-process the KEPLER models with a non-LTE radiative transfer code (CMFGEN) and calculate synthetic spectra and corresponding UV and optical light curves.

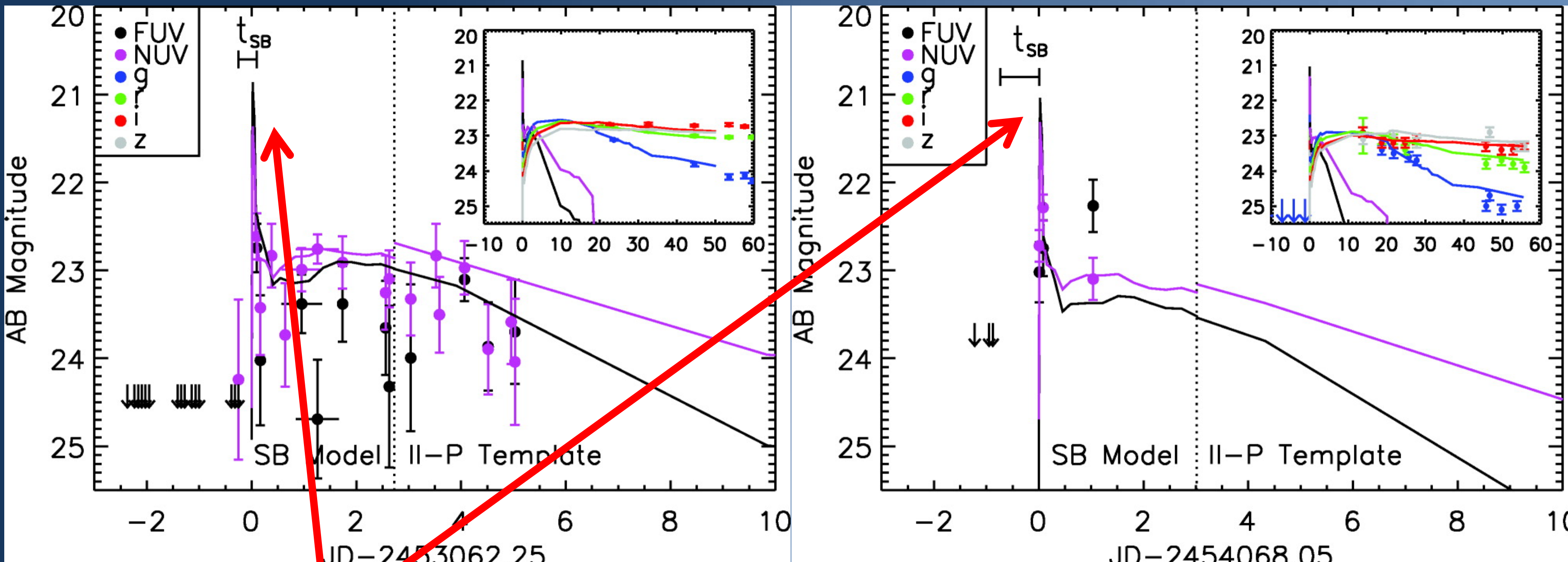
III. Model the late-time (t> 2 days) UV and optical light curves using multiepoch synthetic non-LTE spectra computed for SN II-P 2006bp (Dessart+ 2008).





Gezari+ (2008)

Synergy Between GALEX and SNLS



z=0.185

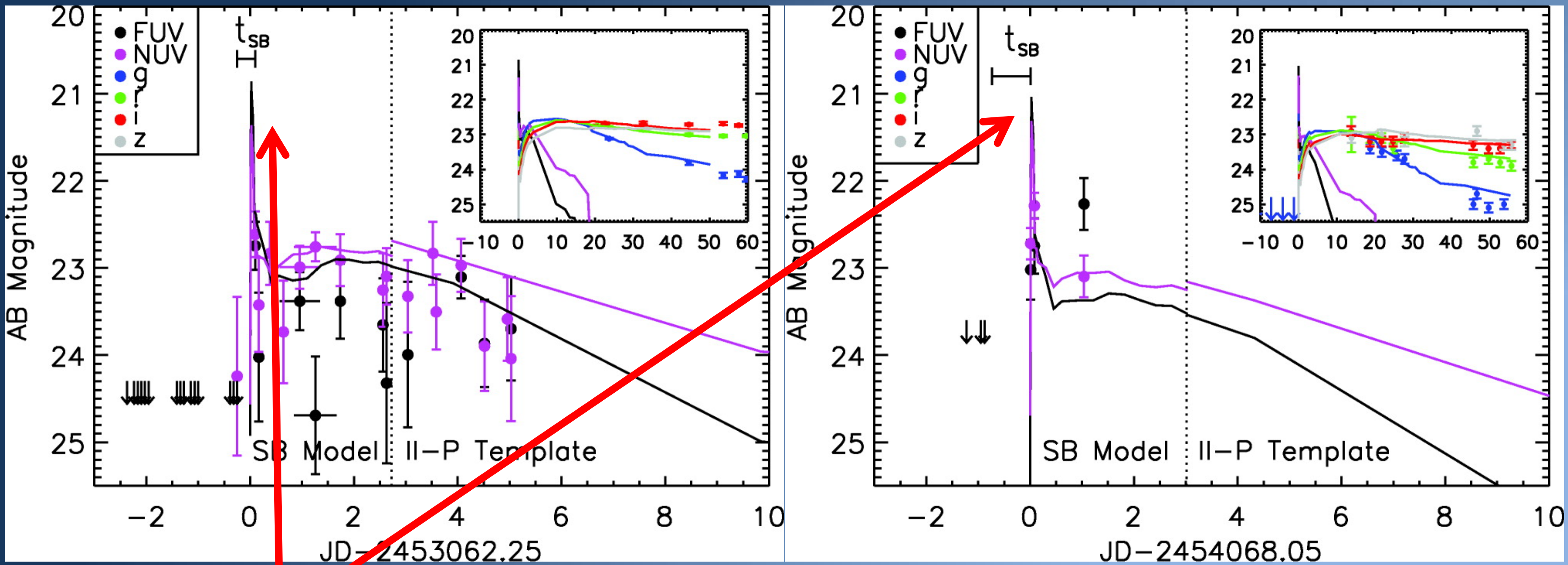
z=0.324

Gezari+ (2008)

Constrain the time of shock breakout to within hours.

- The onset of UV emission marks the time of shock breakout.
- The duration of the UV burst is 1000 sec, and the observed signal is smeared out to 2000 sec due to light-travel time effects.

Synergy Between GALEX and SNLS



z=0.185

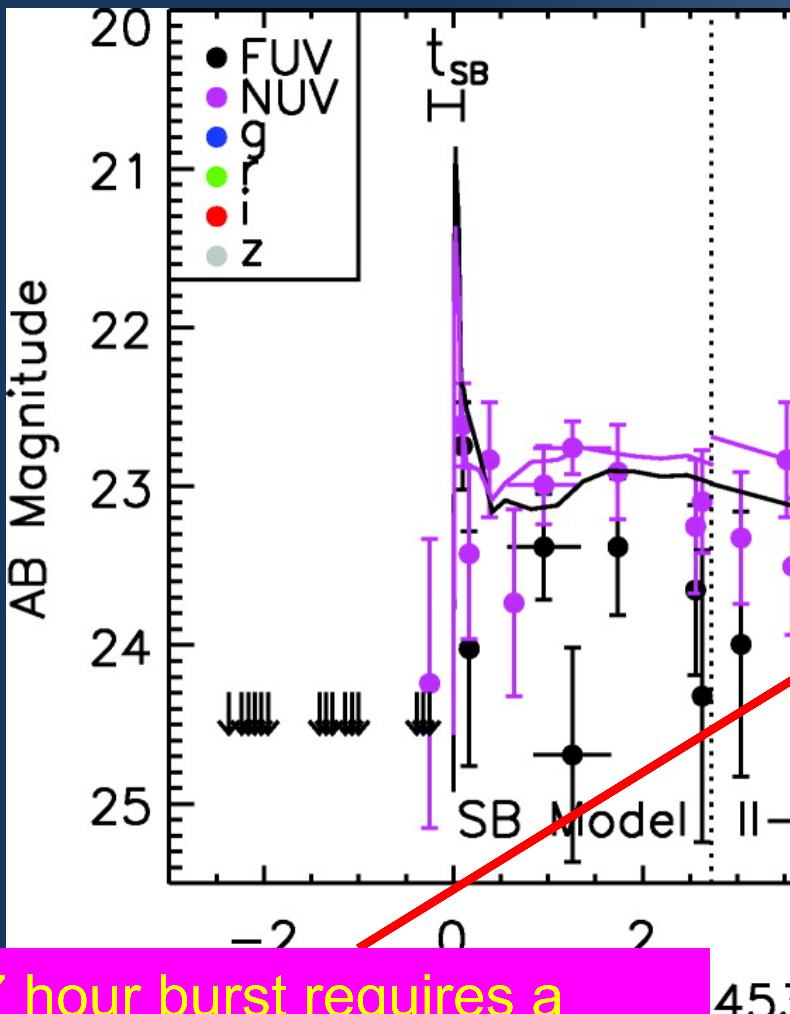
z=0.324

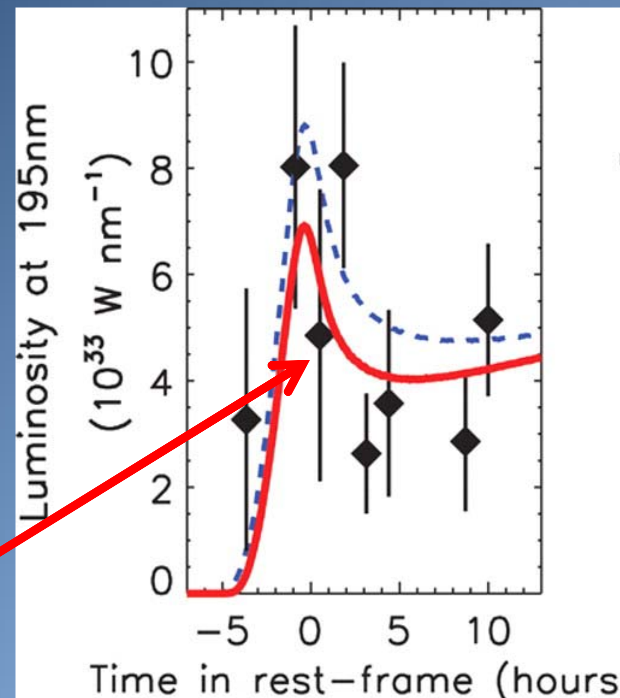
Gezari+ (2008)

The GALEX observations (separated by hours) must not coincide with the peak of the <30 min UV burst predicted by our models.

- The onset of UV emission marks the time of shock breakout.
- The duration of the UV burst is 1000 sec, and the observed signal is smeared out to 2000 sec due to light-travel time effects.

Synergy Between GALEX and SNLS





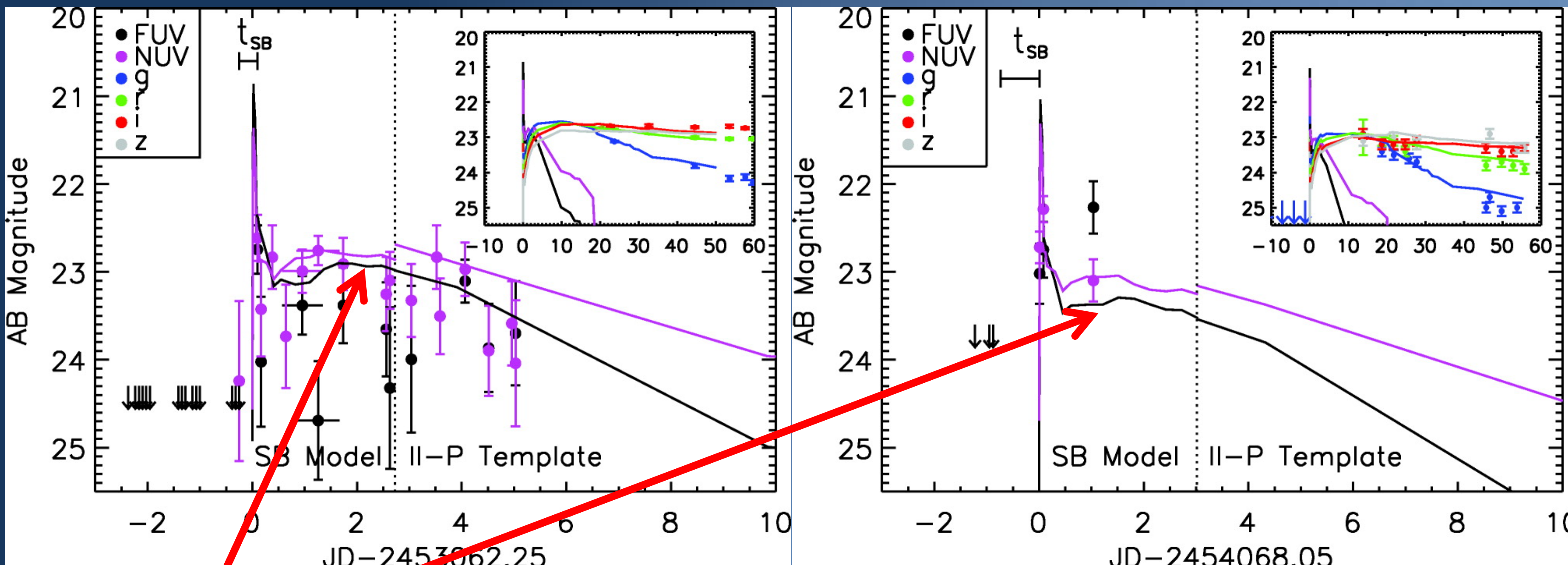
Schawinski+ (2008)

7 hour burst requires a non-standard red supergiant envelope or an unusually dense wind.

- The duration of the UV burst depends on the structure of the RSG progenitor envelope or possibly its asphericity (Couch, Wheeler, &Milosavljevic 2008).

- GALEX photon data can be used to probe the <2000 sec burst.

Synergy Between GALEX and SNLS



z=0.185

z=0.324

Gezari+ (2008)

2-day plateau in UV predicted by our models following shock breakout for a RSG progenitor.

- The UV initially plateaus because the shift of the peak of the SED to longer λ and the ejecta expansion both counteract the decrease in L_{bol}.

- The UV subsequently drops as the ejecta continue to cool.

See also poster by Tominaga.

Detection Capability of PS1 MDS+GALEX TDS

- 10 footprints spaced uniformly around the sky

- On a given night, 7 fields will be observable (~50 deg^2)

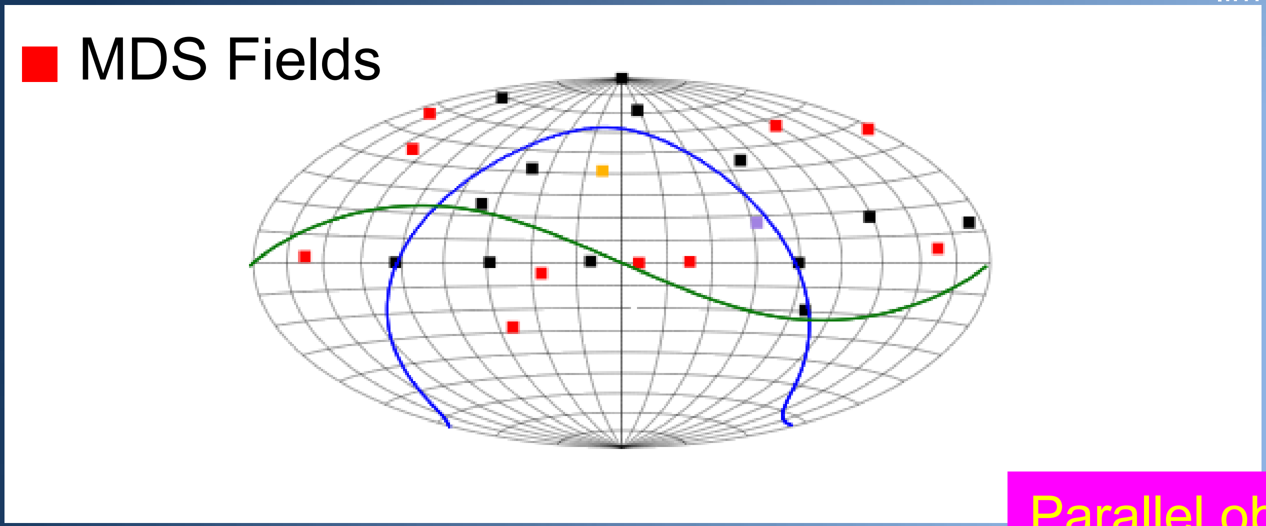
- Cycle through 5 filters every 4 days:

day	1	2	3	4
filter	g,rizy			

+ GALEX Time Domain Survey

- Monitor 1-2 fields every 2 days
- m_{lim} = 23.5

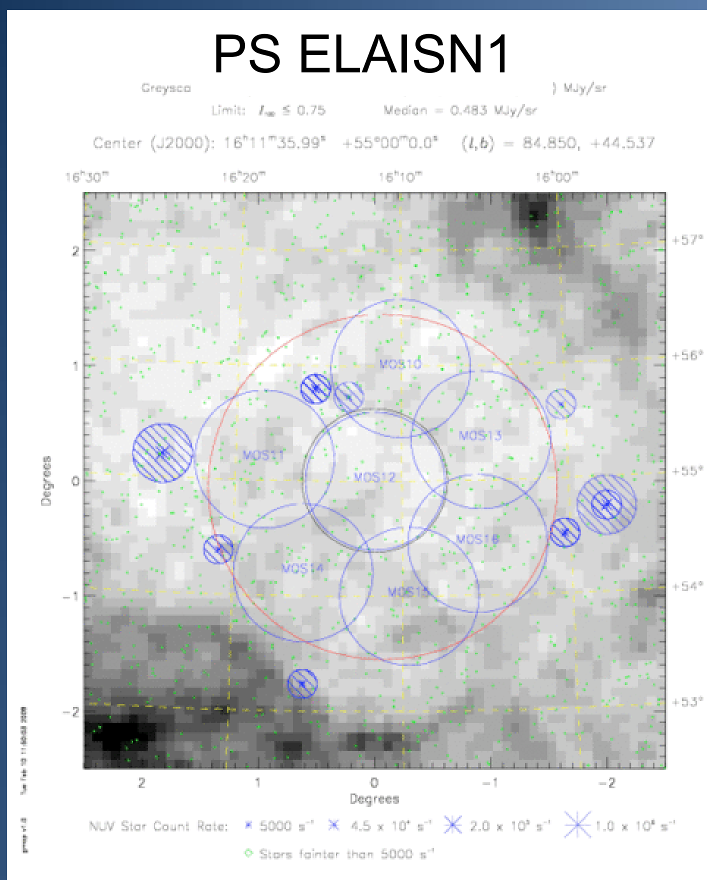
- Sensitivities chosen to detect SNeIa out to z=0.5 (m_{lim}>24 in most bands)

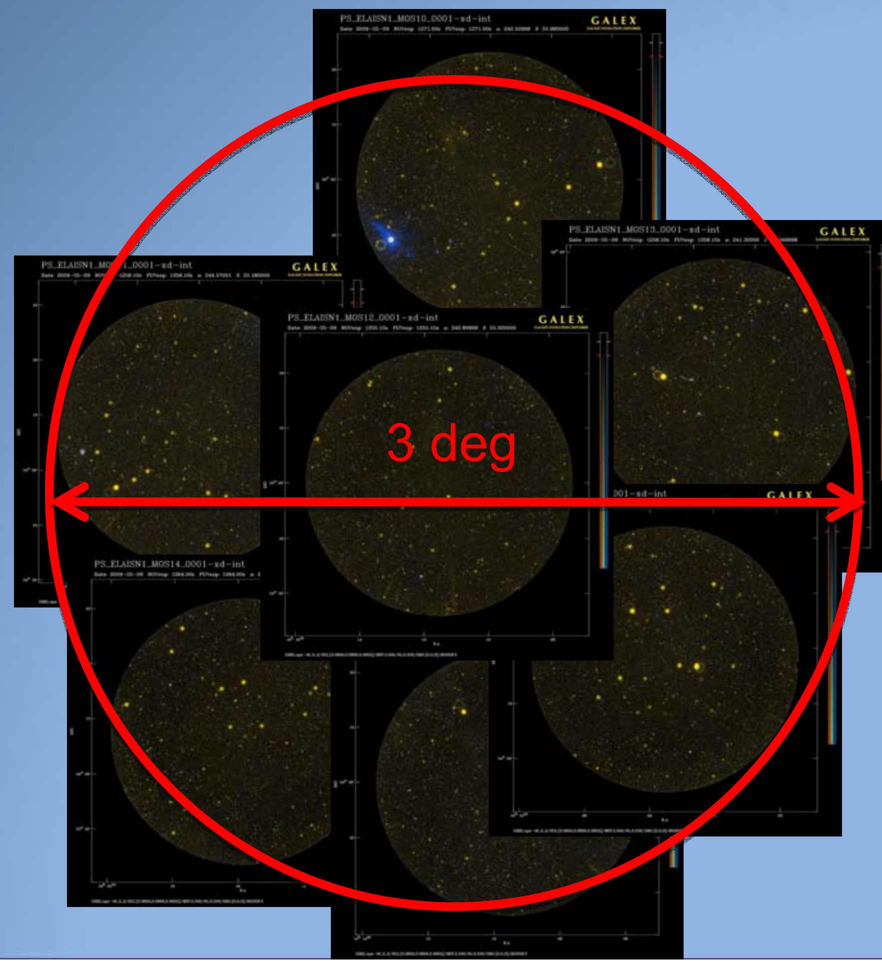


Parallel observations with GALEX will provide simultaneous UV/optical light curves of AGNs and SNe.

Detection Capability of PS1 MDS+GALEX TDS

- Pan-STARRS MDS monitors 50 deg^2 with m_{lim}=25.
- The GALEX TDS is monitoring 7deg^{2}of the Pan-STARRS MDS with cadences ranging from 98.6 min (2 consecutive orbits) to days.





Detection Capability of PS1 MDS+GALEX TDS

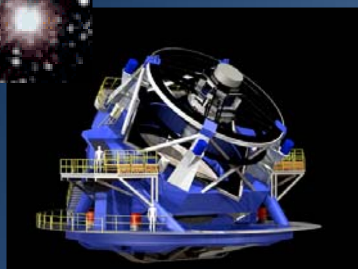
- Pan-STARRS MDS monitors 50 deg^2 with m_{lim}=25.
- The GALEX TDS is monitoring 7deg^2 of the Pan-STARRS MDS with cadences ranging from 98.6 min (2 consecutive orbits) to days.
- The calculated detection efficiency of our GALEX survey for the 2-day UV plateau from the total number of SNe II-P observed is 7%.
- Expect Pan-STARRS MDS Type II-P detection rate of 23 $month^{-1}$ per 7deg^2

Pan-STARRS and GALEX TDS have the potential to detect early UV emission from shock breakout from ≈10 Type II SNe per year.

GALEX+PTF?

SNIa collision emission? (talk by Kasen+ 2009)

Prospects for the Future



LSST will have a similar depth and cadence to PS1 MDS, but with a factor of 400 increase in area, yielding tens of thousands of SNe per month!

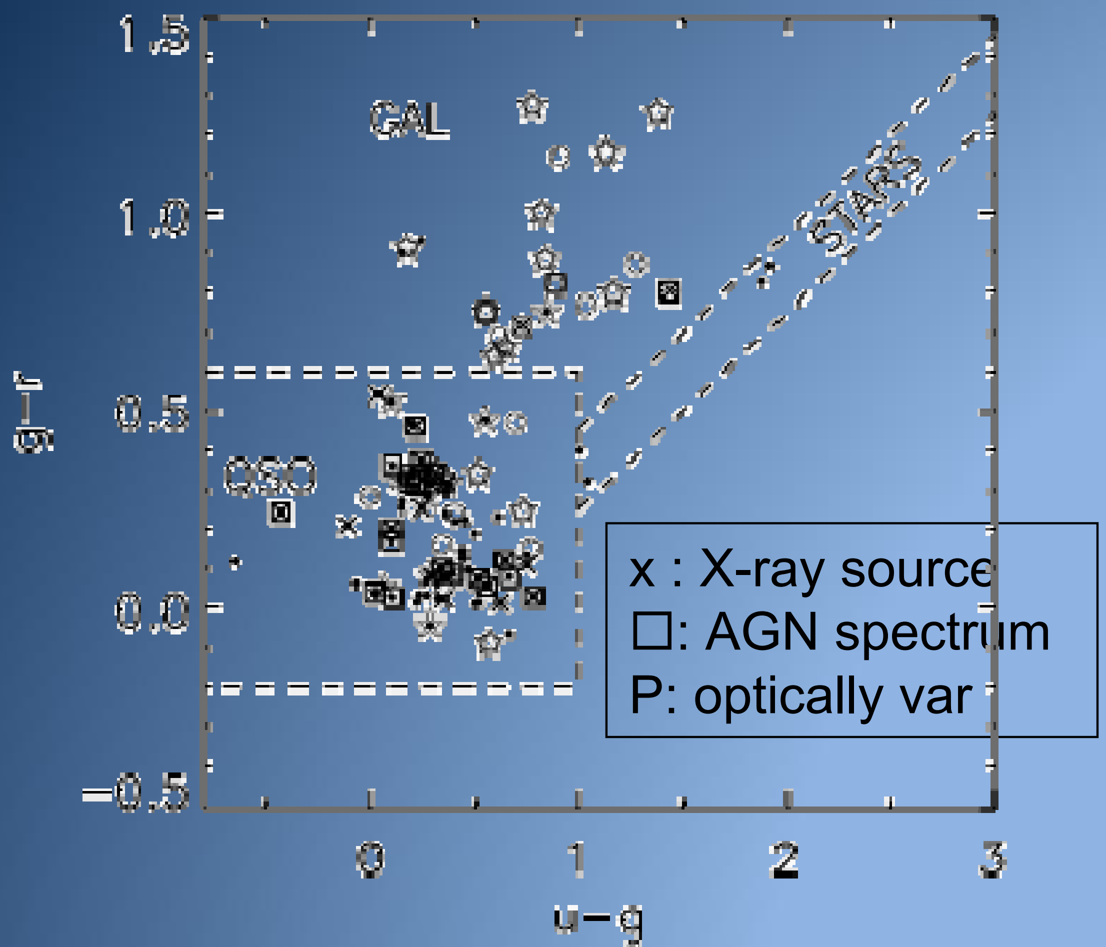
+

EXIST will survey the whole sky every two 95-minute orbits from 5-600 keV. Prompt follow-up capabilities on board in the soft X-ray (0.1-10 keV) and UV/optical/NIR (0.3-2 μm).

The wide-field sensitivity and fast triggering capability of EXIST has the potential to detect tens of shock breakout events per year from core-collapse SNe within 200Mpc.

UV Variable Sky

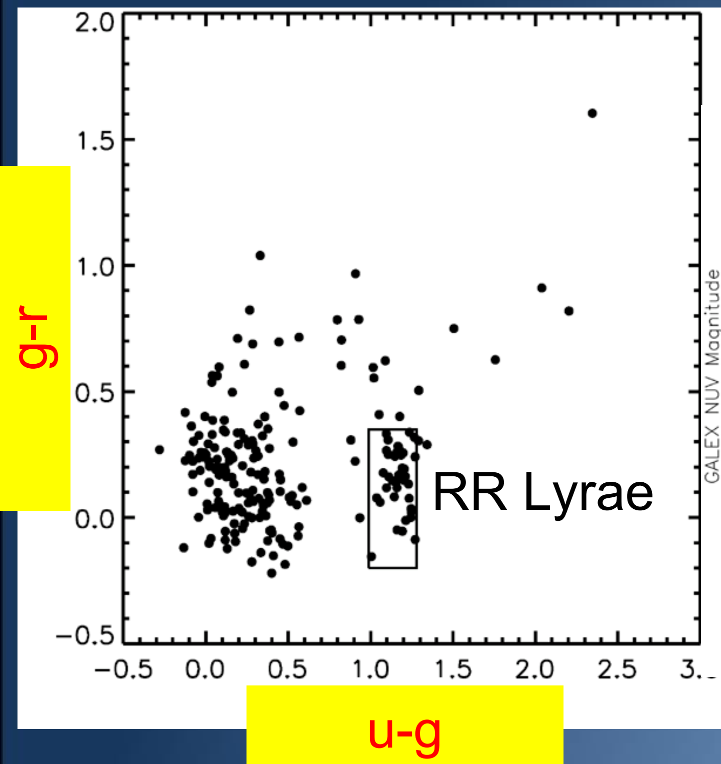
- Variability studies of deep (m_{lim}=24), yearly epochs of GALEX data mainly detect QSOs and AGNs.

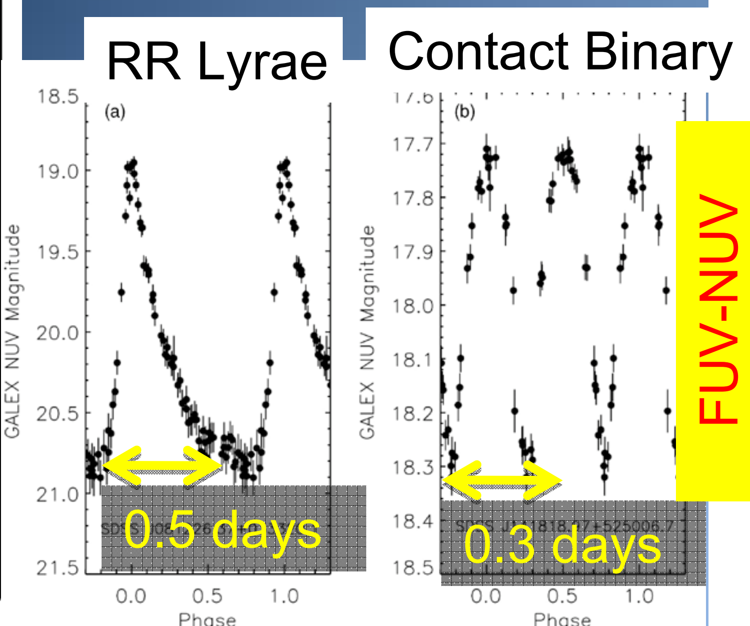


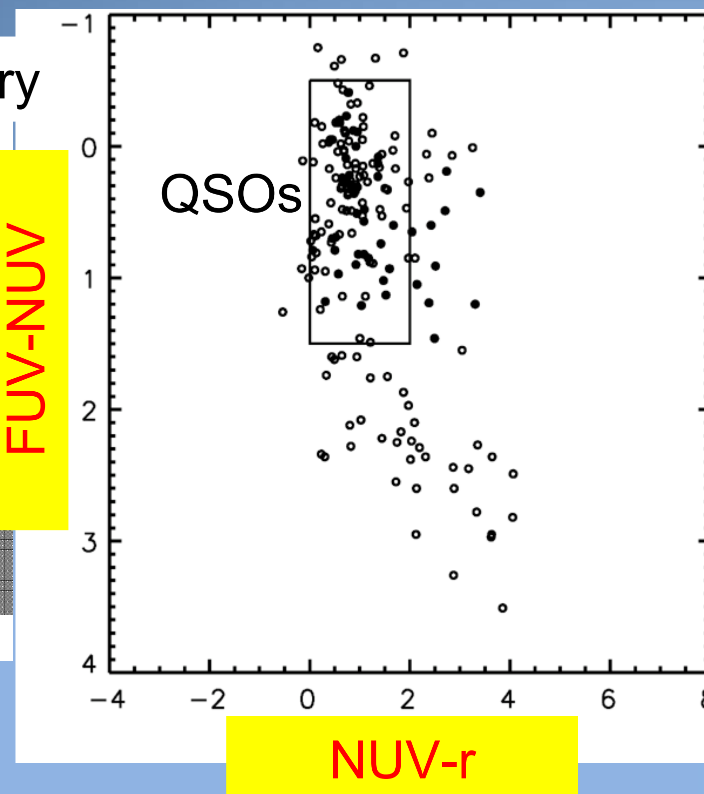
Gezari+ (2008)

UV Variable Sky

- Visit-to-visit variability studies (m_{lim} = 21) detect RR Lyrae, short periodic variable stars, and QSOs.



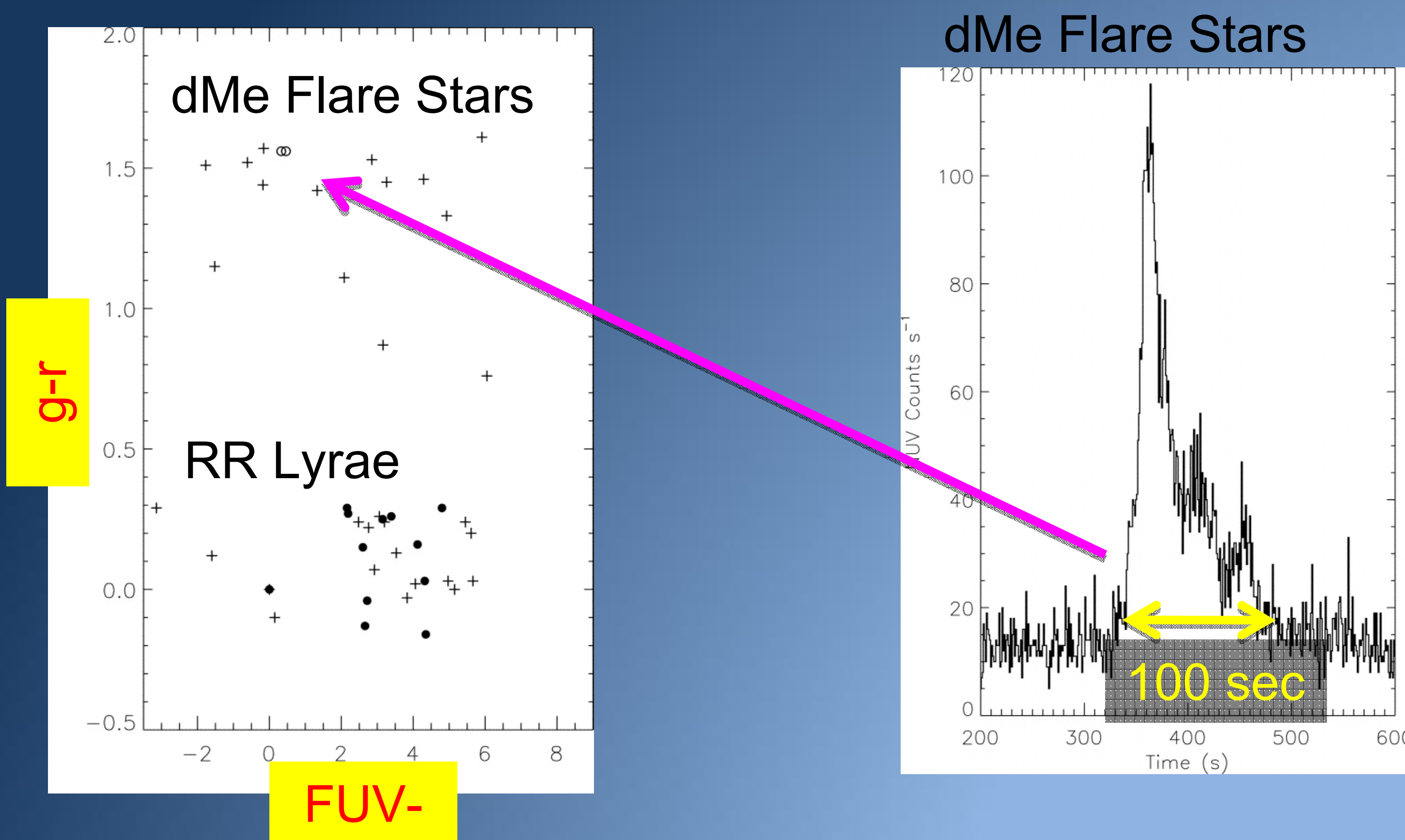




Welsh+ (2005), Wheatley+ (2008)

UV Variable Sky

- Intra-visit variability studies reveal dMe Flare stars.



Welsh+ (2005)g

Can robustly distinguish UV flashes associated with SNe from stellar and quasar variability using host galaxy optical colors and morphology and simultaneous optical light curves from PS1.