Ultraviolet SN observations with *Swift*

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Why Study SNe in *Ultraviolet*

✓ ***Metallicity***: for the higher sensitivity to the ejecta metal content UV is a powerful probe of the progenitor structure and explosion mechanism;

✓ ***CSM interaction***: SN environment structure through UV excess and spectral features (accompanied by X-ray emission);

✓ ***High-z Ia SN survey***: local UV template light curve to compare against higher redshift SNe;

✓ ***SN Spectral Energy Distribution***: UV combined with optical and IR data will improve actual knowledge about it;

✓…

UV is a powerful tool to improve our knowledge on SNe!!

Why Study SNe with *Swift*

For details see P. Roming talk

Swift has imaging and spectral capabilities perfectly suited to study SNe:

- Extended λ coverage from Opt to X-rays:
  UVOT telescope :
  wavelength range 1700 -- 6000 Å,
  3 optical UBV + 3 UV (W1,M2,W2) filters
  2 grism (UV,V)
  XRT telescope (0.3 -- 10 KeV);

- Rapid response and flexible scheduling: observations can be scheduled within less than one day from SN discovery mapping the rising phase of the supernova light curve;

- Ability to revised targets frequently: more detailed light curves and great spectroscopic follow-up (spectral time evolution).

Selection Criteria

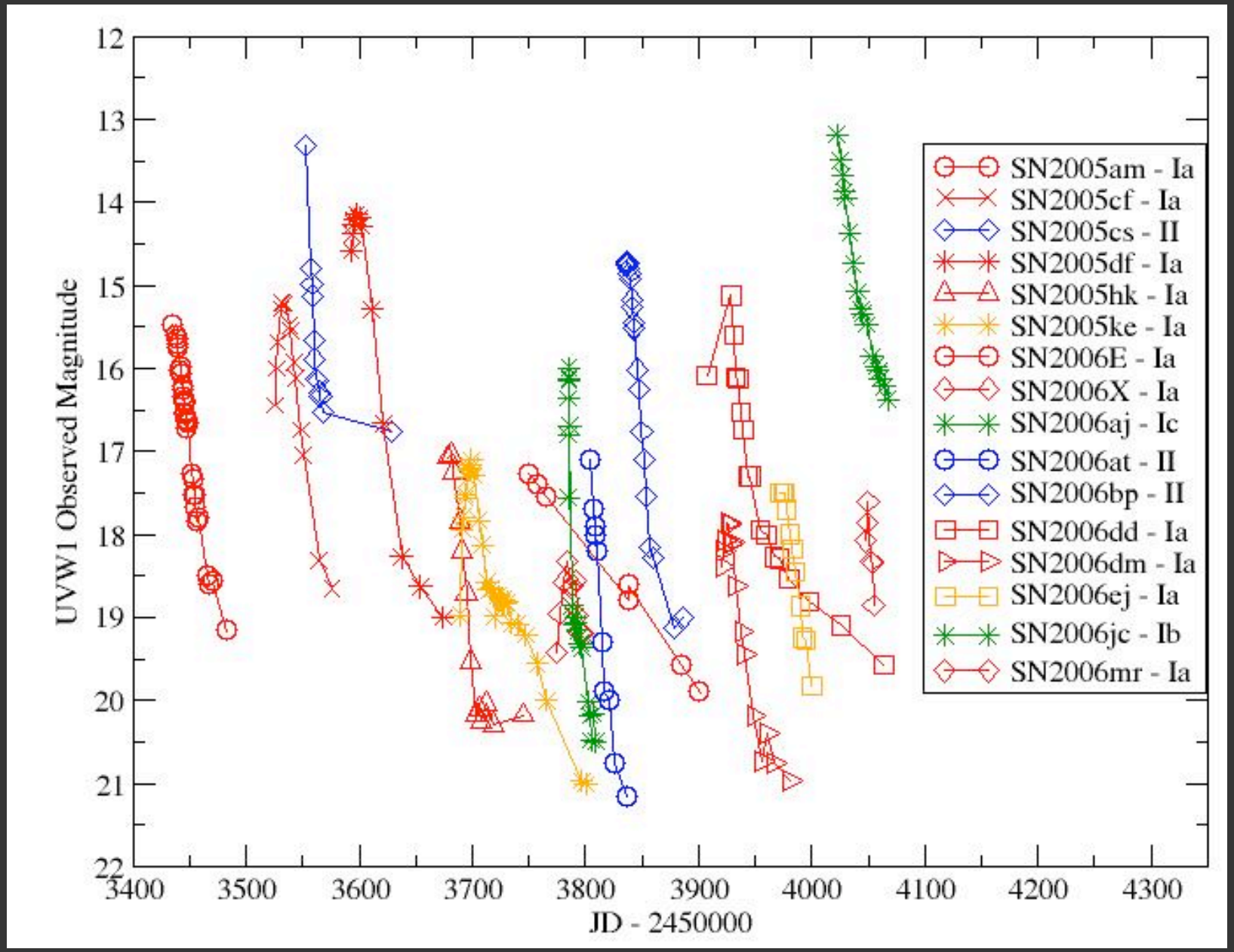
- ***Young*** : several days before maximum in optical wavelengths;
- ***Nearby***: only local events at z < 0.01 (≈< 50 Mpc), to enable X-ray detections;
- ***Low extinction***: Av < 0.5 mag;
- ***Good location***: distant >8” from the host galaxy nucleus or bright field star;
- ***SN brightness for Grism observations***: V < ≈ 16 mag.

Swift Observations of Supernovae

SN	Type	SN	Type	SN	Type
2005am	Ia	2006E	Ia	2006gy	IIn
2005bc	Ia	2006T	IIb	2006lt	Ib
2005bf	Ib/c	2006X	Ia	2006mr	Ia
2005cf	Ia	2006aj	Ic	2007C	Ib/c
2005cs	II	2006at	II	2007D	Ic
2005da	Ic	2006bc	II	2007I	Ic
2005df	Ia	2006bp	IIP	2007S	Ia
2005ek	Ic	2006bv	IIn	2007Y	Ia ?
2005gj	Ia	2006dd	Ia	2007aa	II
2005hk	Ia	2006dm	Ia	2007af	Ia
2005ip	IIn	2006dn	Ic	2007ax	Ia
2005ke	Ia	2006ej	Ia	2007bb	II
2005kd	IIn	2006jc	Ib	2007bg	Ic
2005mz	Ia	2006lc	Ib/c	2007bm	Ia
				2007ch	IIP

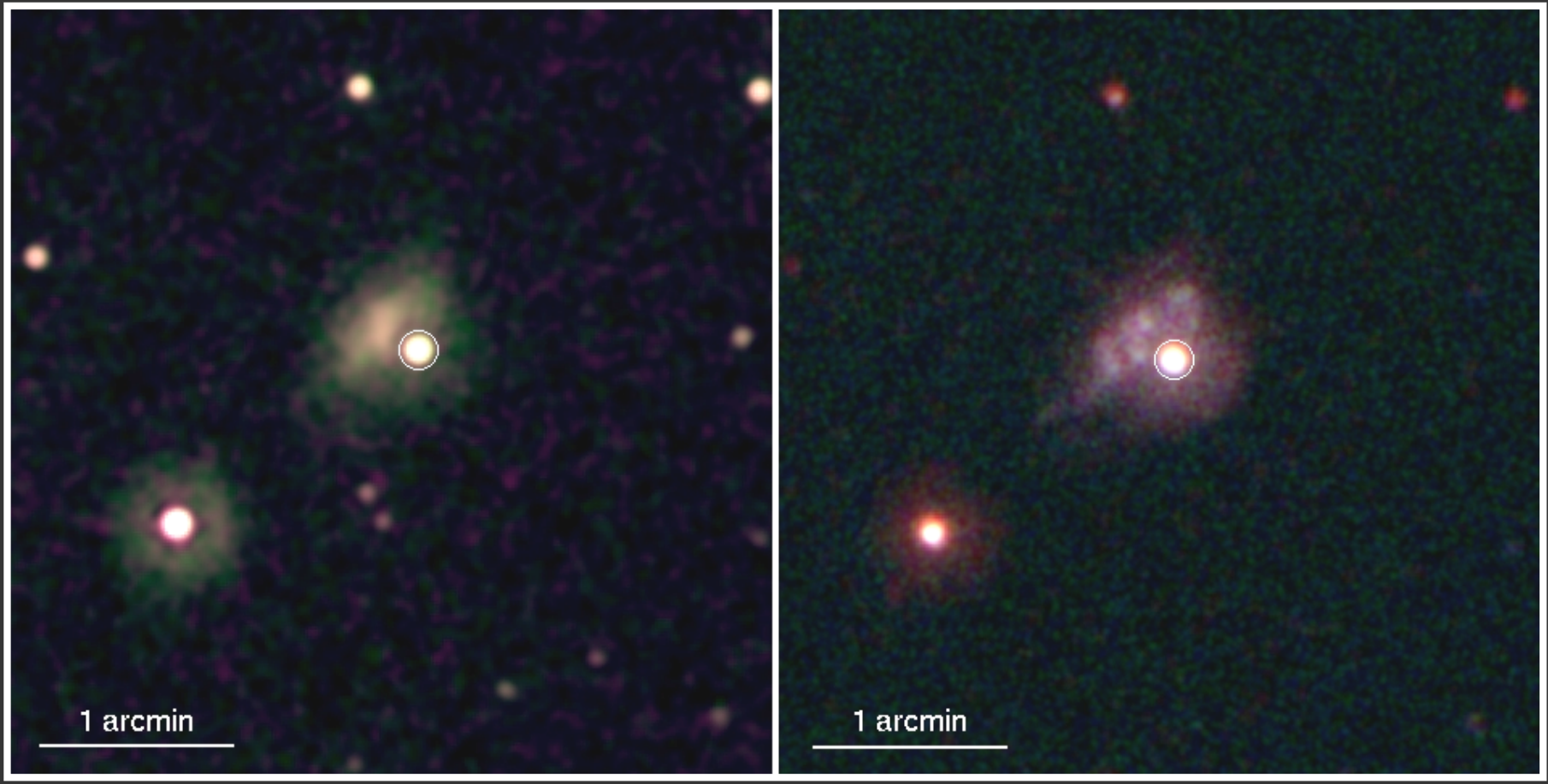
43 SNe total — 19 (12) type Ia — 12 (2) type Ib/c — 12 (3) type II

UVOT Lightcurves of SNe



Brown et al.

SN 2006jc - Type I b/c

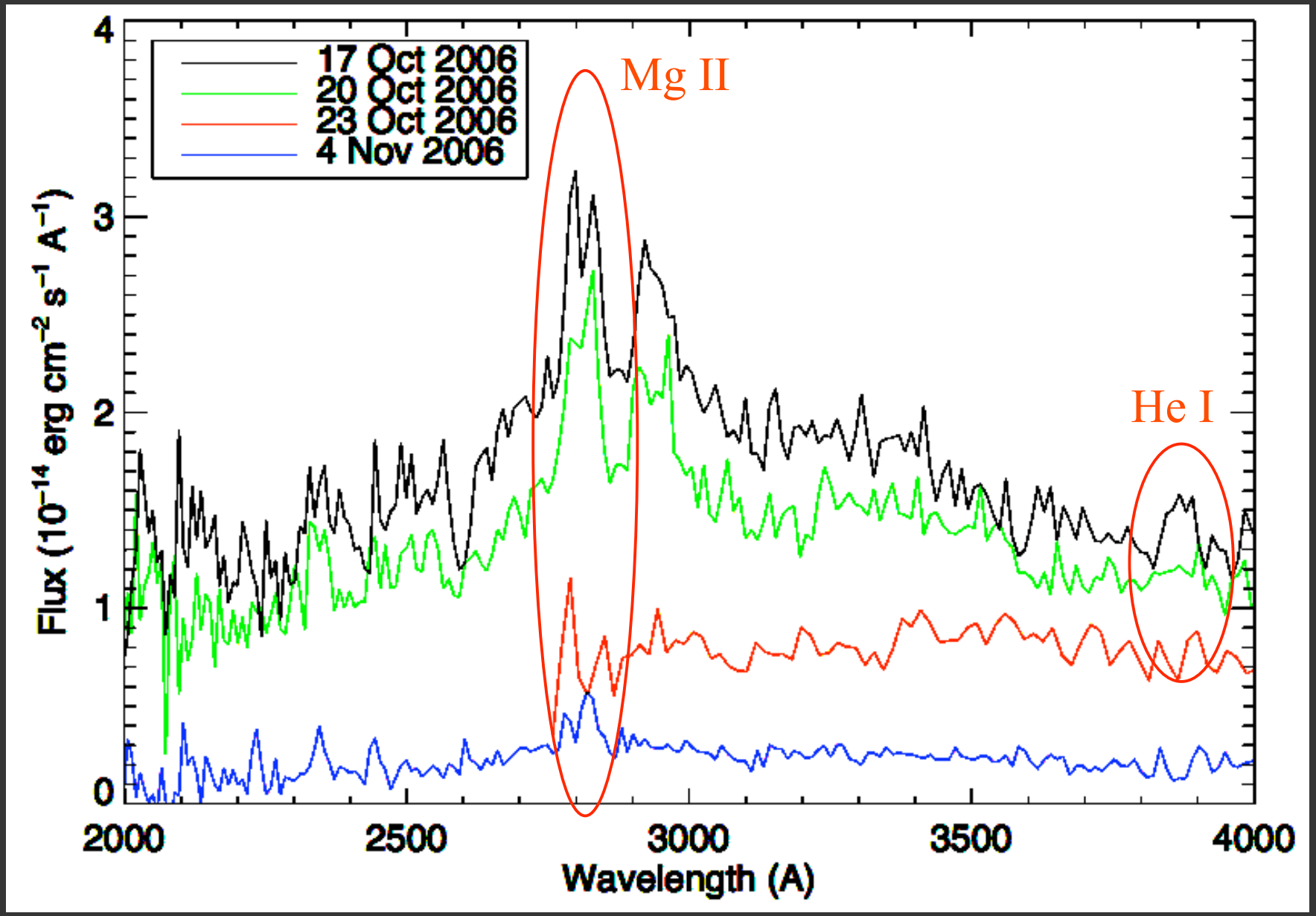


Swift optical

Swift UV

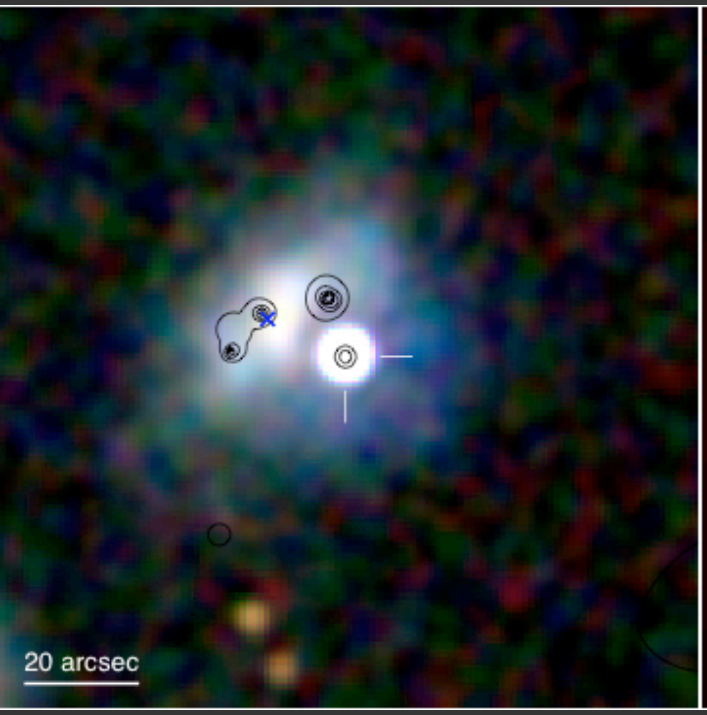
13.8 mag in unfiltered image at the discovery epoch (Nakano et al, CBET 666)
23.6 Mpc (z=0.00557, H_0=71 km $s^{-1}Mpc^{-1}$)
48 epochs with Swift+UVOT (photometry both in Optical and UV filters)
3 UV grism + 3 V grism spectra

SN 2006jc - Early UV Spectra

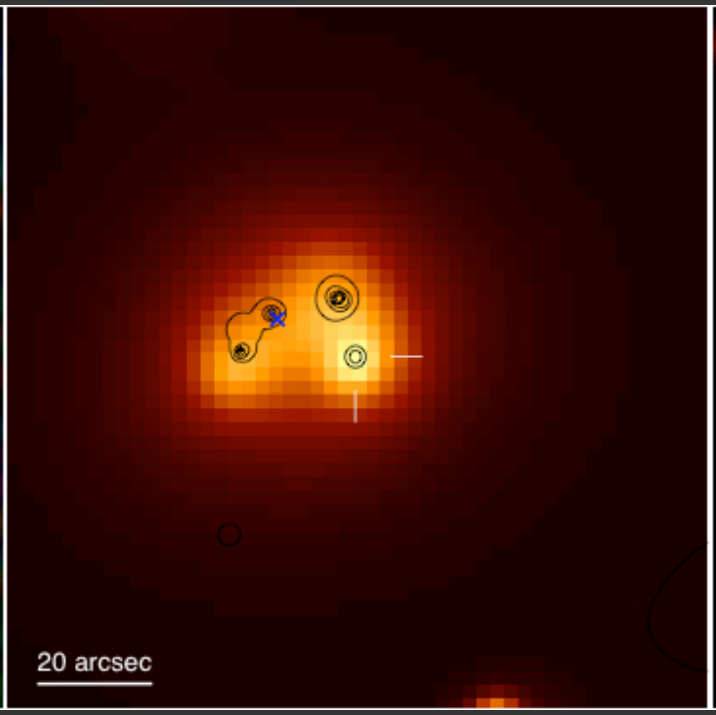


SN 2006jc is the result of LBV, whose outburst was observed two years before SN

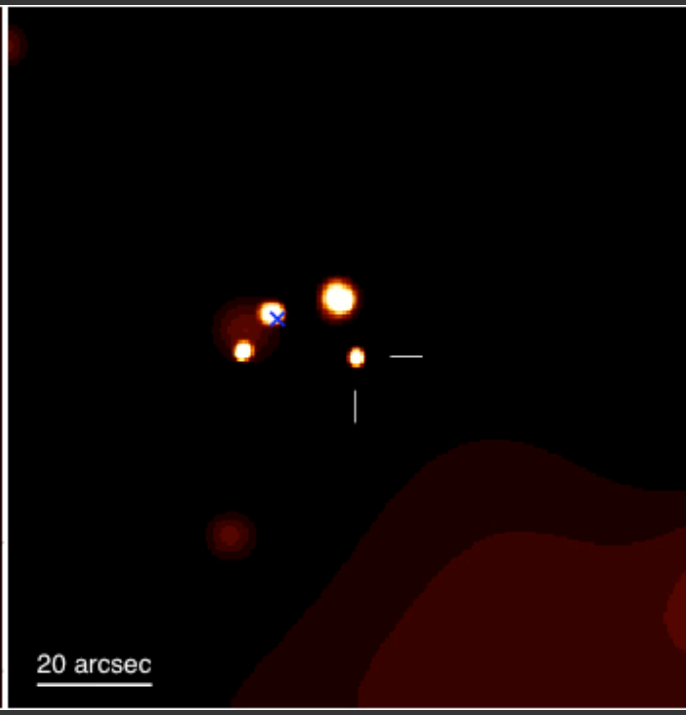
SN 2006jc



Swift optical



Swift X-ray

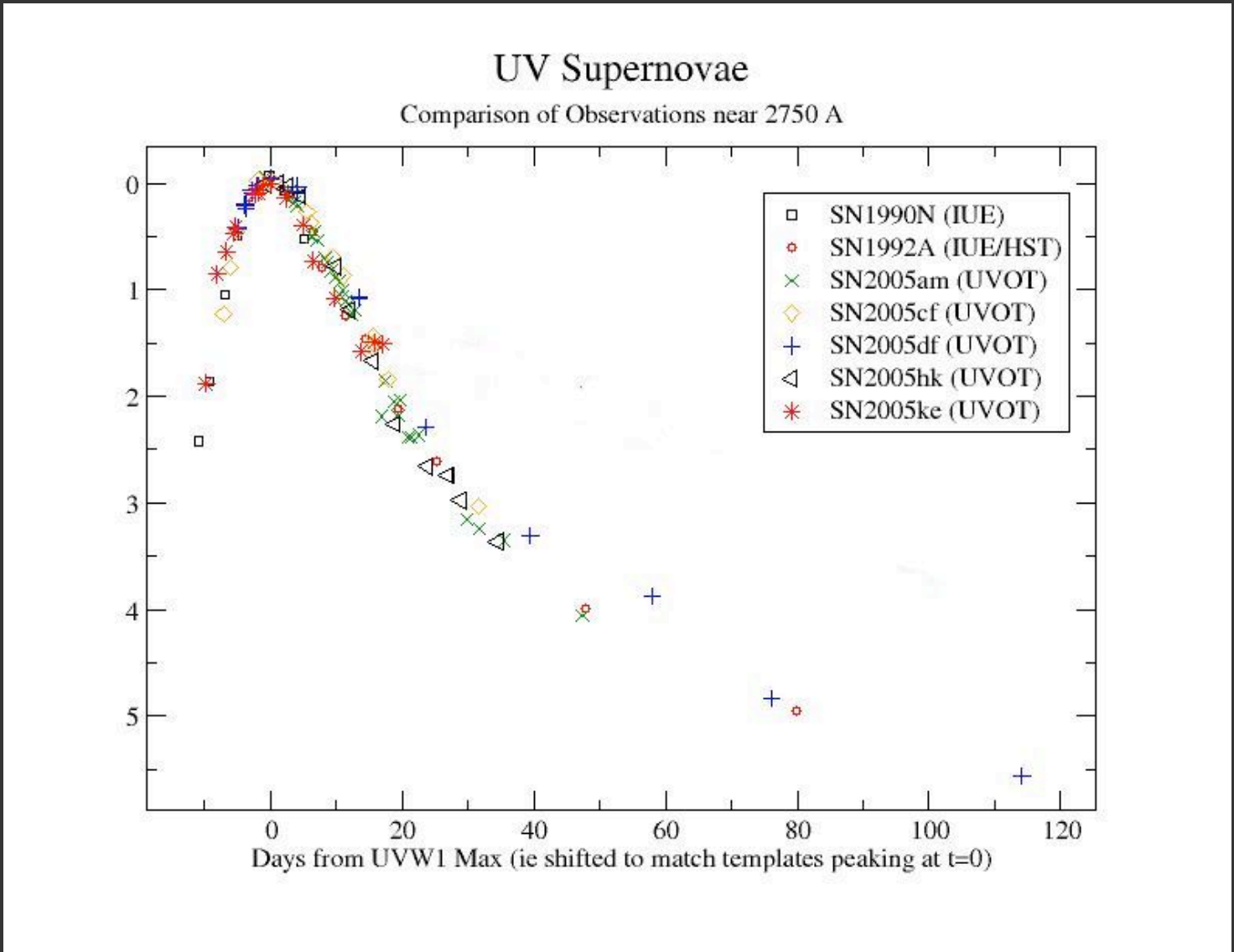


Chandra X-ray

Independent evidence of interaction: SN 2006jc detections in X-rays with Chandra and XRT (Immler et al. 2007,in prep).

In Optical strong HeI emission lines with a narrow P-Cygni profile and a very blue continuum confirm dense CSM.(Foley et al. 2007, Pastorello et al. 2007)

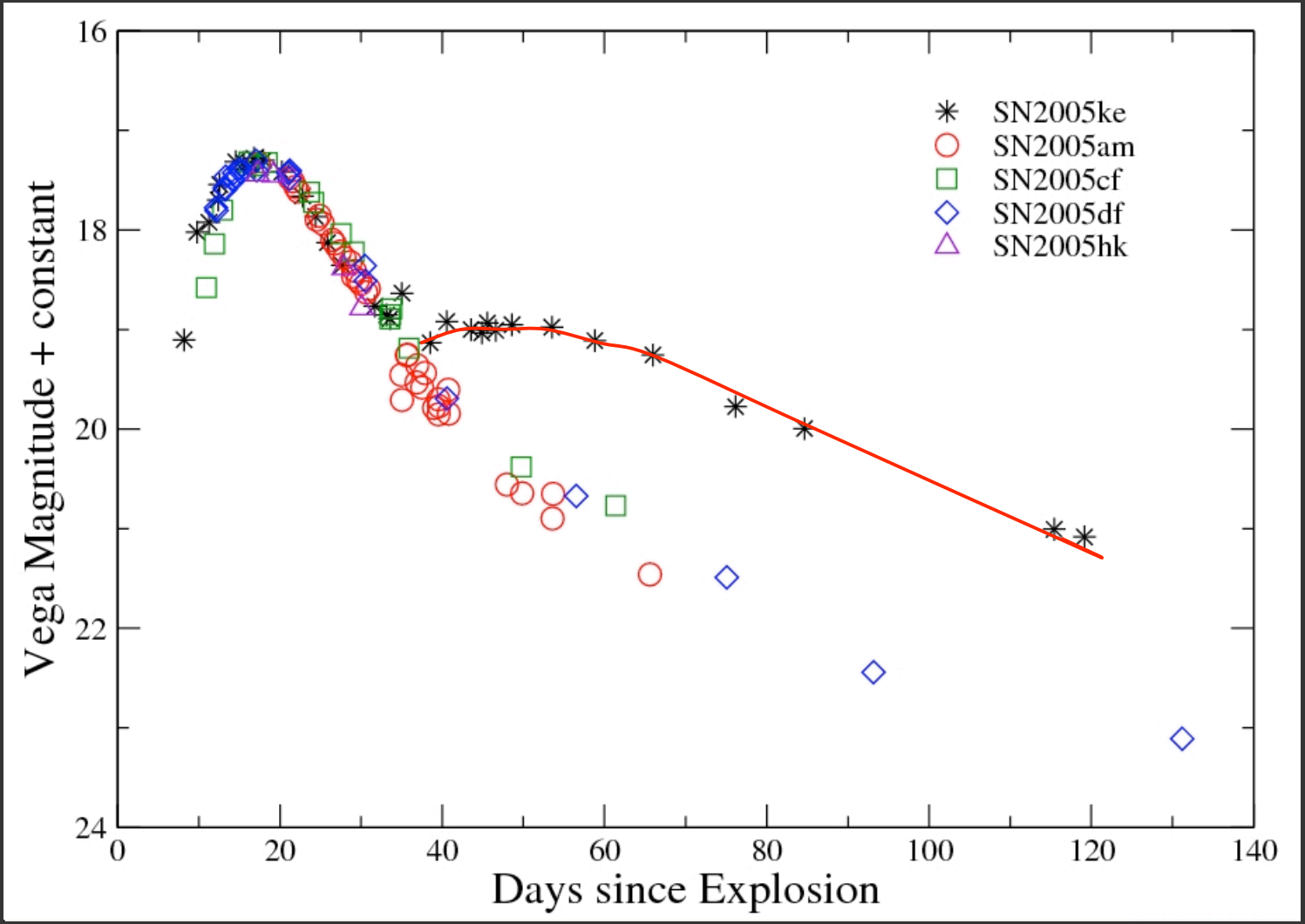
UV Light Curves of SNe Type Ia



Brown et al.

- The UV light curves have similar shapes.
- The UV light curves appear more homogenous than the opt light curves.
- Light curves were shifted in time and magnitude to fit template.

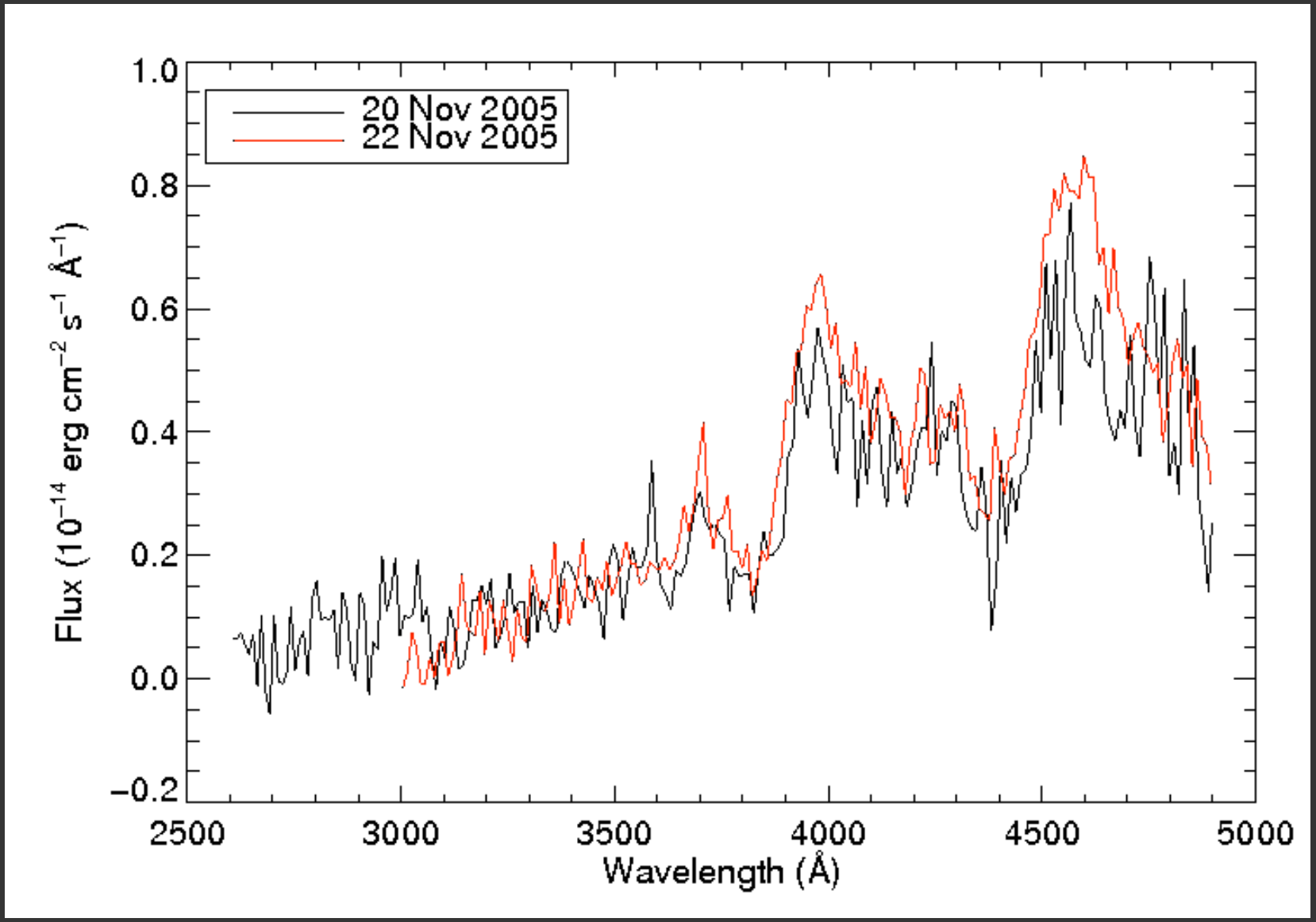
SN 2005ke



Immler et al.

- Excess ultraviolet emission detected for SN 2005ke
- Caused by the interaction of the supernova shock with dense CSM?
- Evidence for a single degenerate binary system?

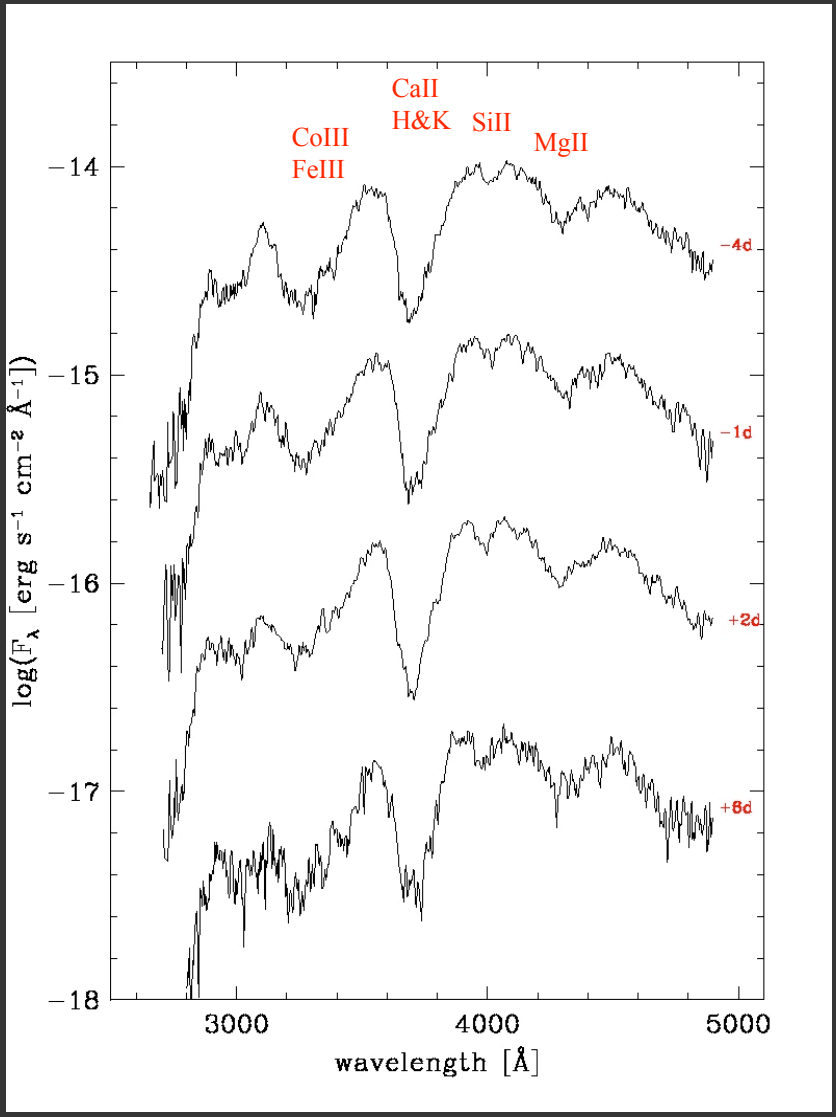
SN 2005ke

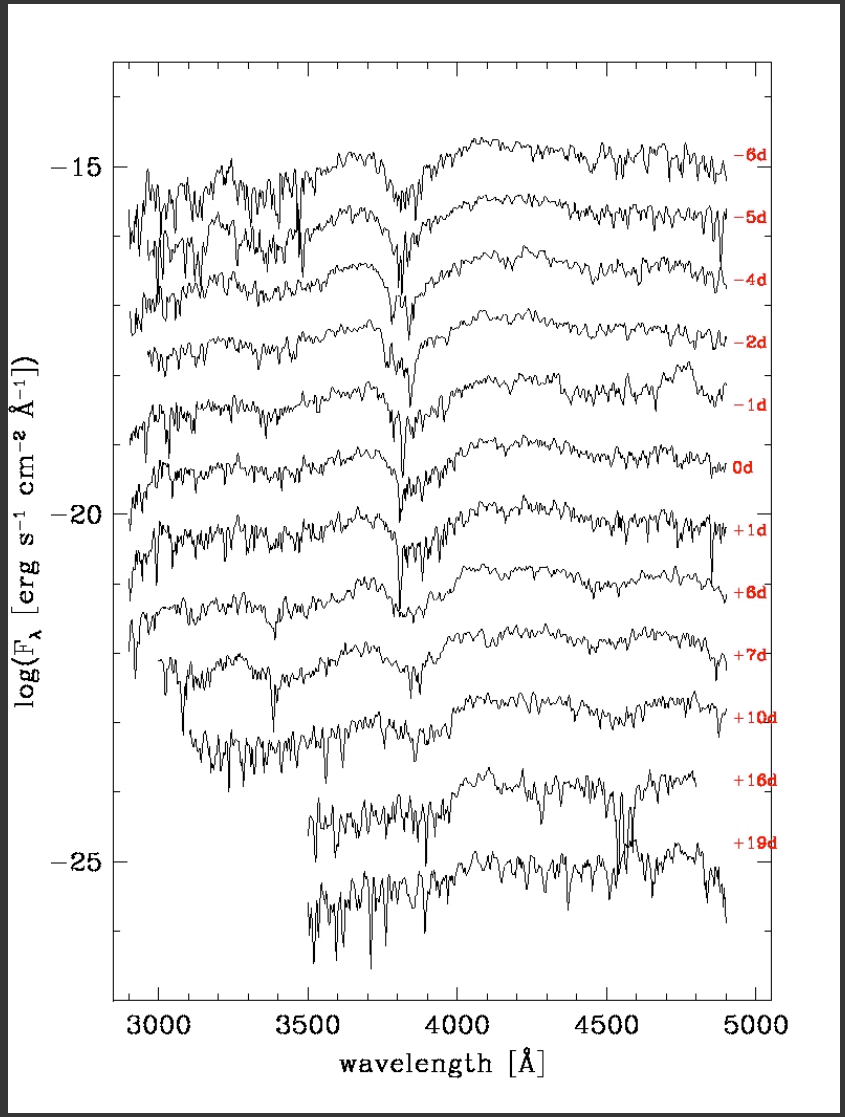


No Spectral Evidence: Only pre-maximum Spectra

SN 2005ke is a sub-luminous Type Ia

SNe Type Ia UV spectra





SN2005df
Line blanketing

SN2005cf
Detailed Spectral Follow-up

Future SN Observations with Swift

- Due to the fast response, flexible scheduling and multi-λ coverage (opt+UV+X-rays, both photometry and spectroscopy), *Swift* is perfectly suited to study SNe.

- Results obtained so far demonstrate the high potential of *Swift*:

  - UV and X-rays as probes for CSM interaction and SN progenitor (UV excess, UV grism, early X-ray detections, etc);

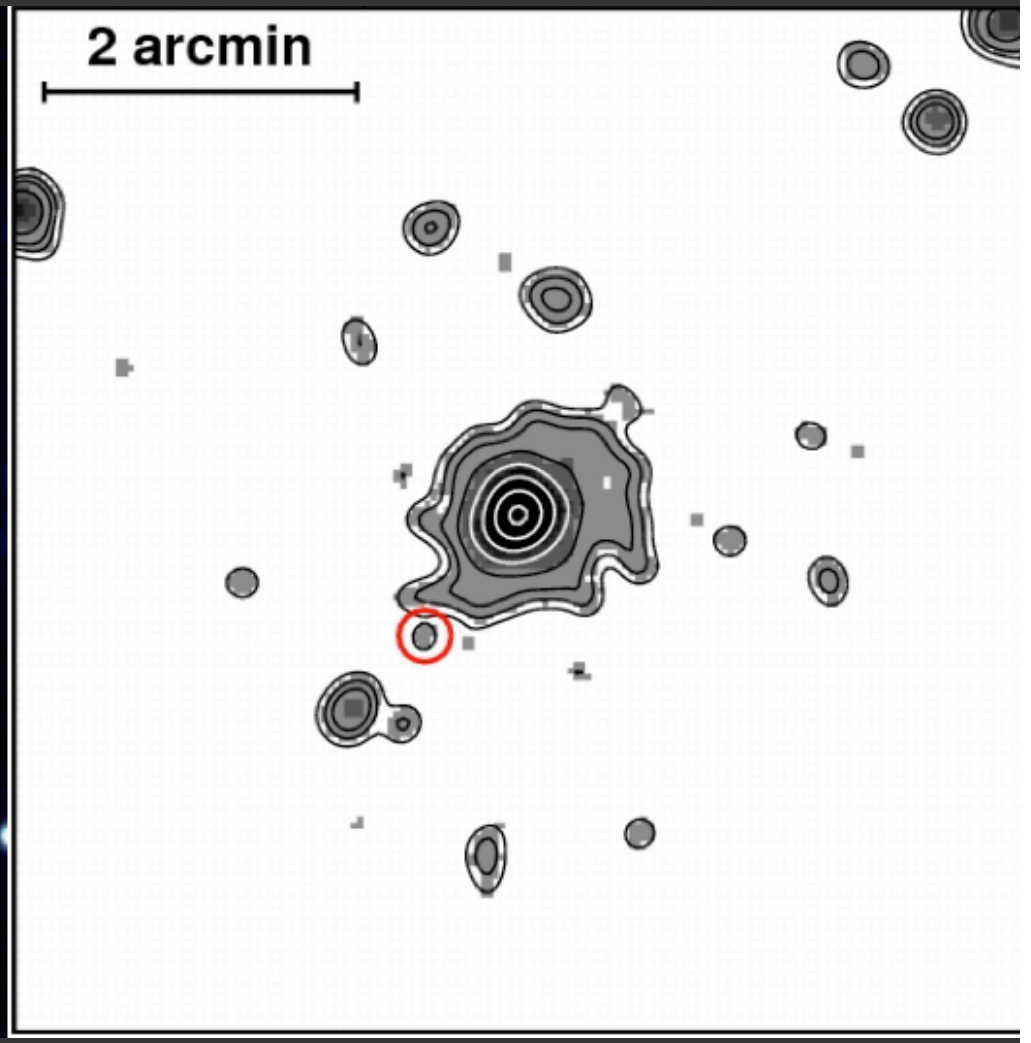
  - SNe Ia UV light curve templates are being created and efforts are being made to establish SNe Ia as UV standard candles with large implications for cosmology and future missions.

- A continuation of this program (with slight adjustments as needed, e.g., more use of grism) will have strong positive impact on the general field of SN research.

Thank you for your attention..!

SN 2005ke

UVOT ultraviolet



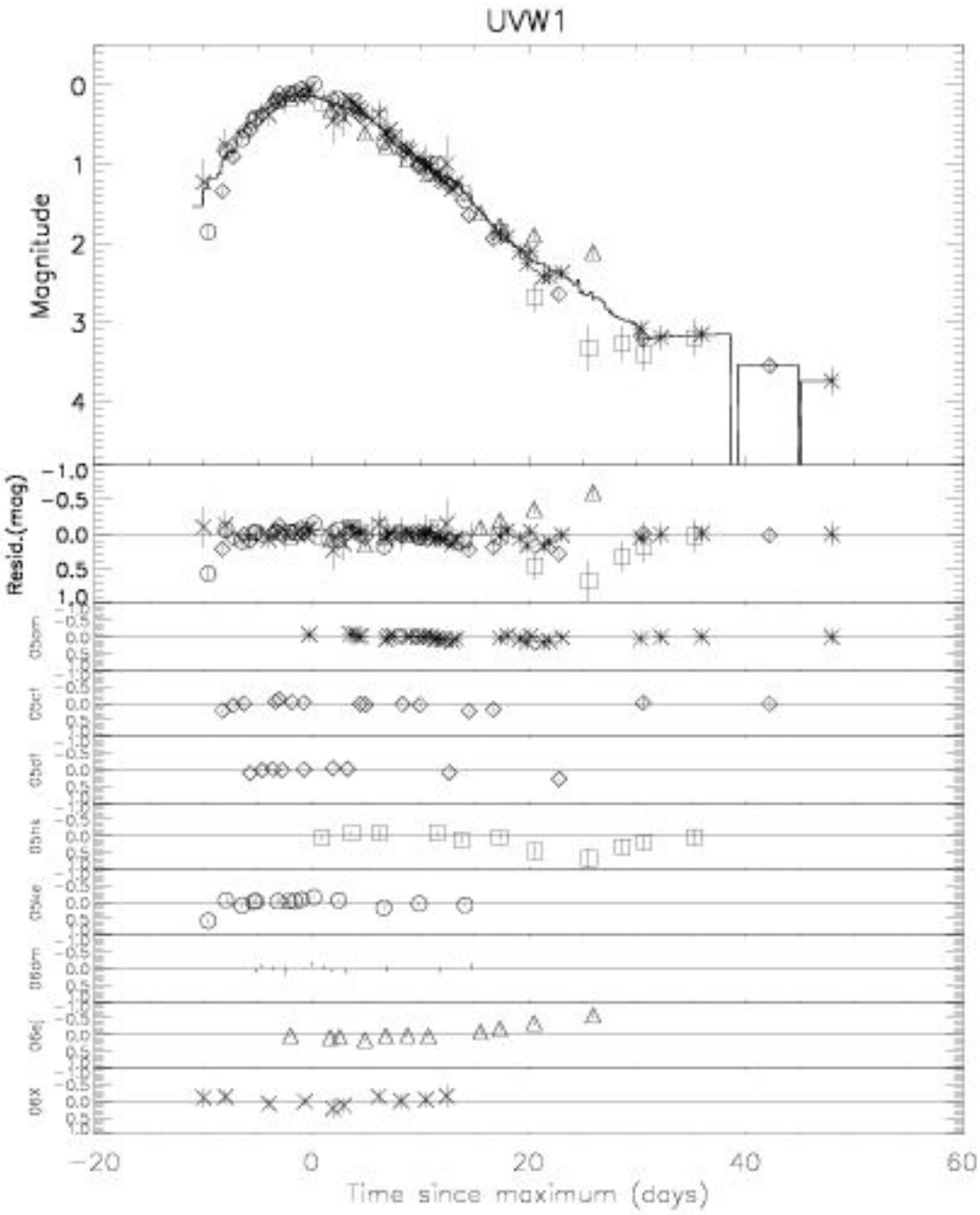
XRT X-rays

- First detection of a type Ia SN in X-rays from CSM interaction?
- Mass-loss rate of the progenitor's companion $3 \times 10^{-6}\ M_{\odot}\ \mathrm{yr}^{-1}$
- CSM density $4 \times 10^{7}\ \mathrm{cm}^{-3}$ at a distance of 3×10^{15} cm

Immler et al. 2006

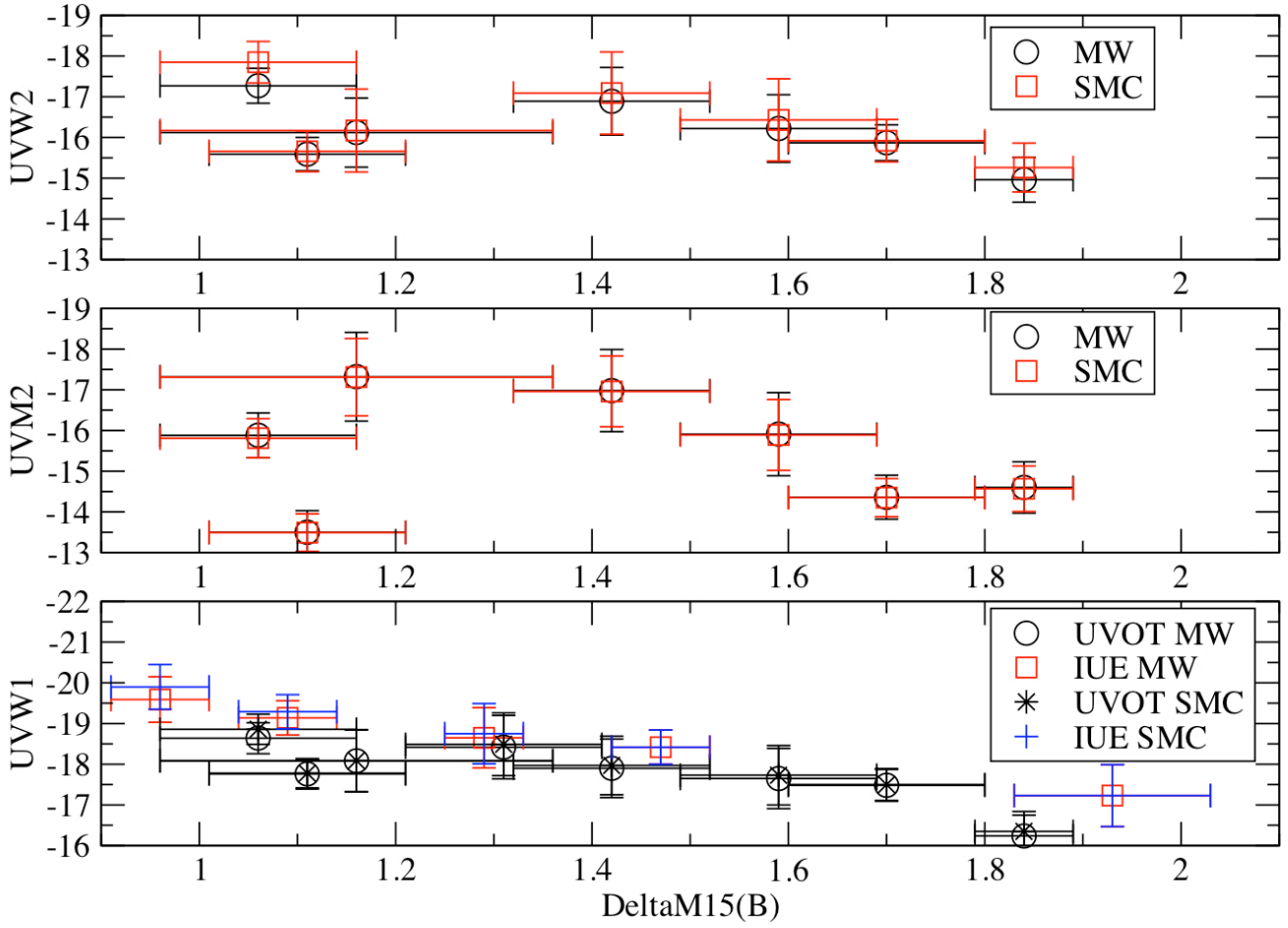
UV Template

- Light curves are fitted to the UVW1 template.
- This improves the peak date and magnitude determination.
- The UV template rises quicker and fades slightly slower than the U-band template.



Milne et al, 2007 (in preparation)

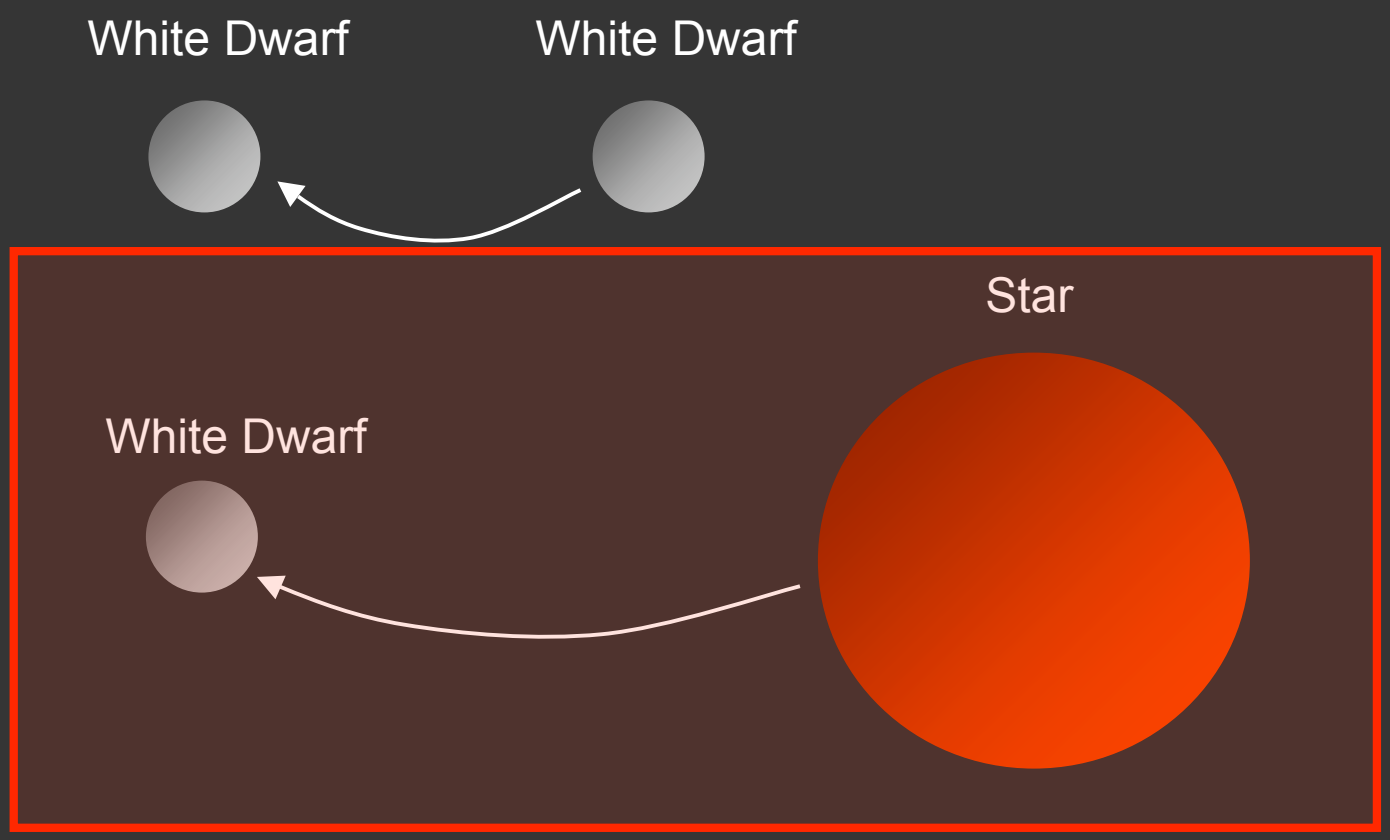
UV Standard Candles



- SNe that are opt bright are also bright in the UV
- Correlation between peak brightness and Δm_{B15}

Brown et al.

SN Ia Systems



Double Degenerate Model

Single Degenerate Model

A **thermonuclear (Type Ia) supernova** is a white dwarf that accretes matter from a companion star and explodes as it reaches the Chandrasekhar mass (1.4x Sun).

Unsolved question: **What is the companion star?**

Two scenarios how thermonuclear SN (Type Ia) systems could look like