Future Opportunities for Supernova Studies

Stefan Immler

(CRESST NASA/GSFC)

on behalf of the *Swift* Supernova Team

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

42 total — 19 (12) type Ia — 12 (2) type Ib/c — 11 (3) type II

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2005hk	Ia	2006dm	Ia	2007af	Ia
2005ip	IIn	2006dn	Ic	2007ax	Ia
2005ke	Ia	2006ej	Ia	2007bb	II
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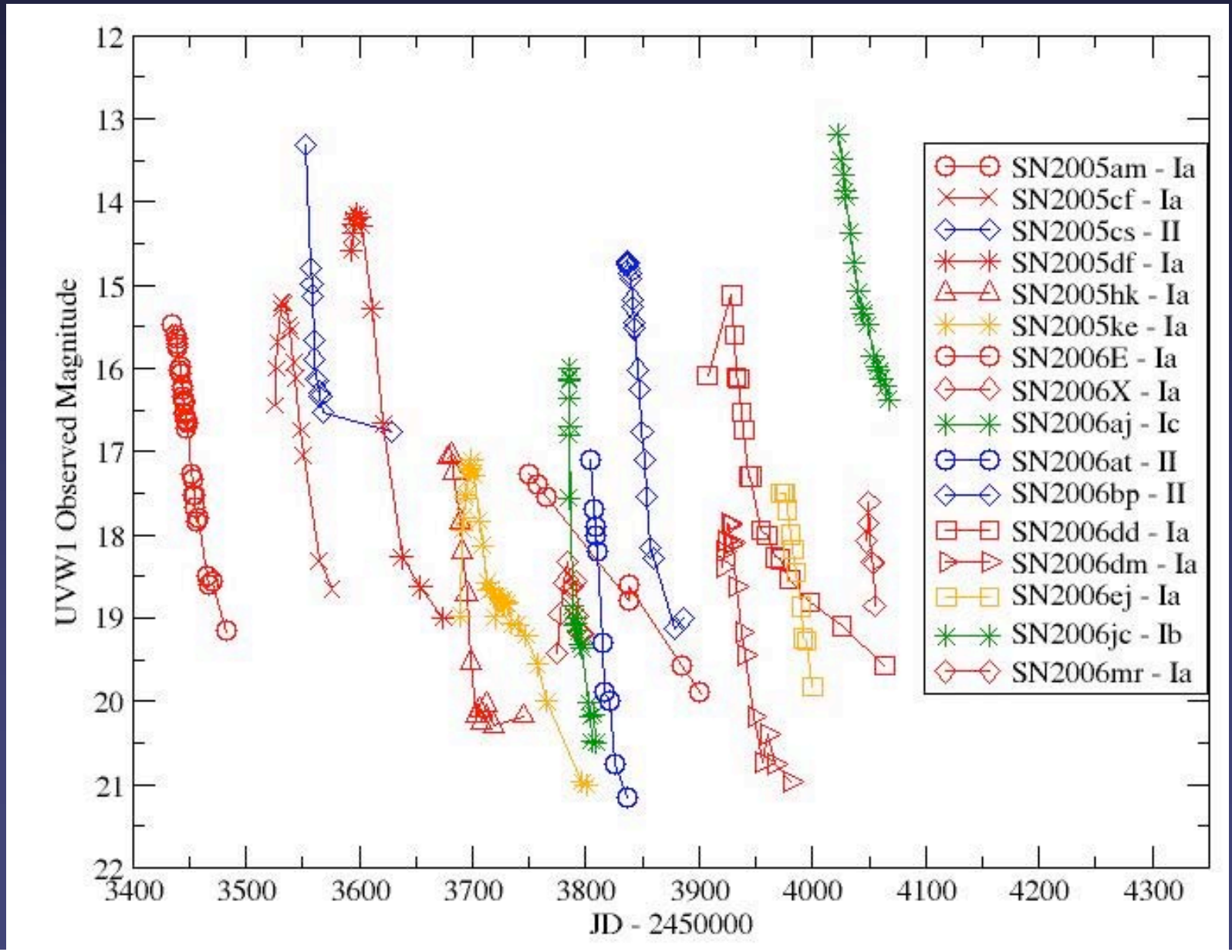
UVOT Lightcurves of SNe



Primary Objectives

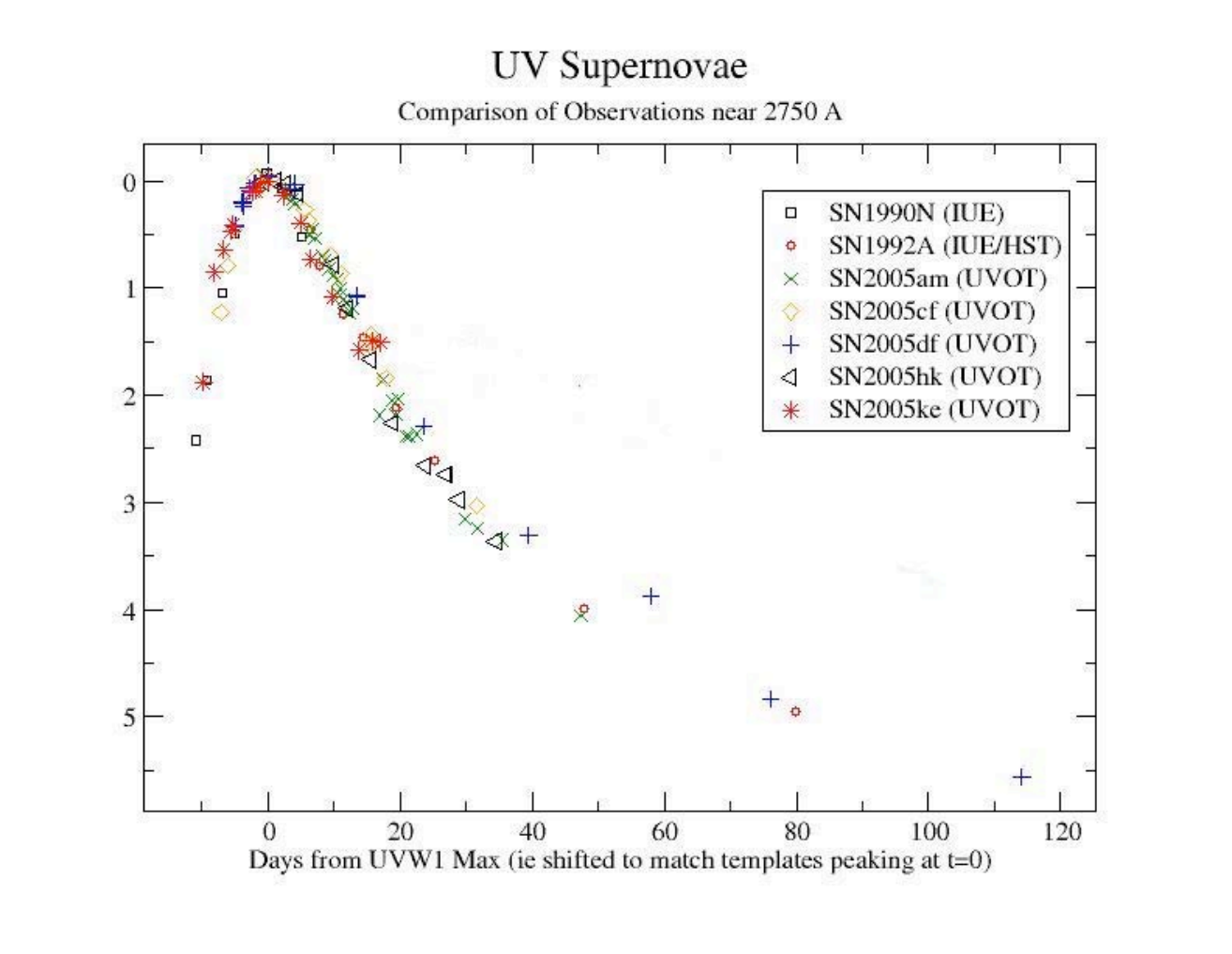
1) Thermonuclear SNe:

- UV as another window to probe of the explosion physics:
  Iron-peak line blanketing occurs in the UV. Early epochs probe the
  iron near the surface. Absorption of UV leads to more opt emission.

- Create template lightcurves and explore their use as UV standard candles.
  With increasing redshift, rest-frame UV emission is shifted into the
  opt/NIR. Thus, UV observations of local SNe Ia permit the creation of
  UV templates against which high-*z* SNe can be compared.

- Search for CSM interaction in the UV (excess, spectra) and in X-rays

UV Light Curves

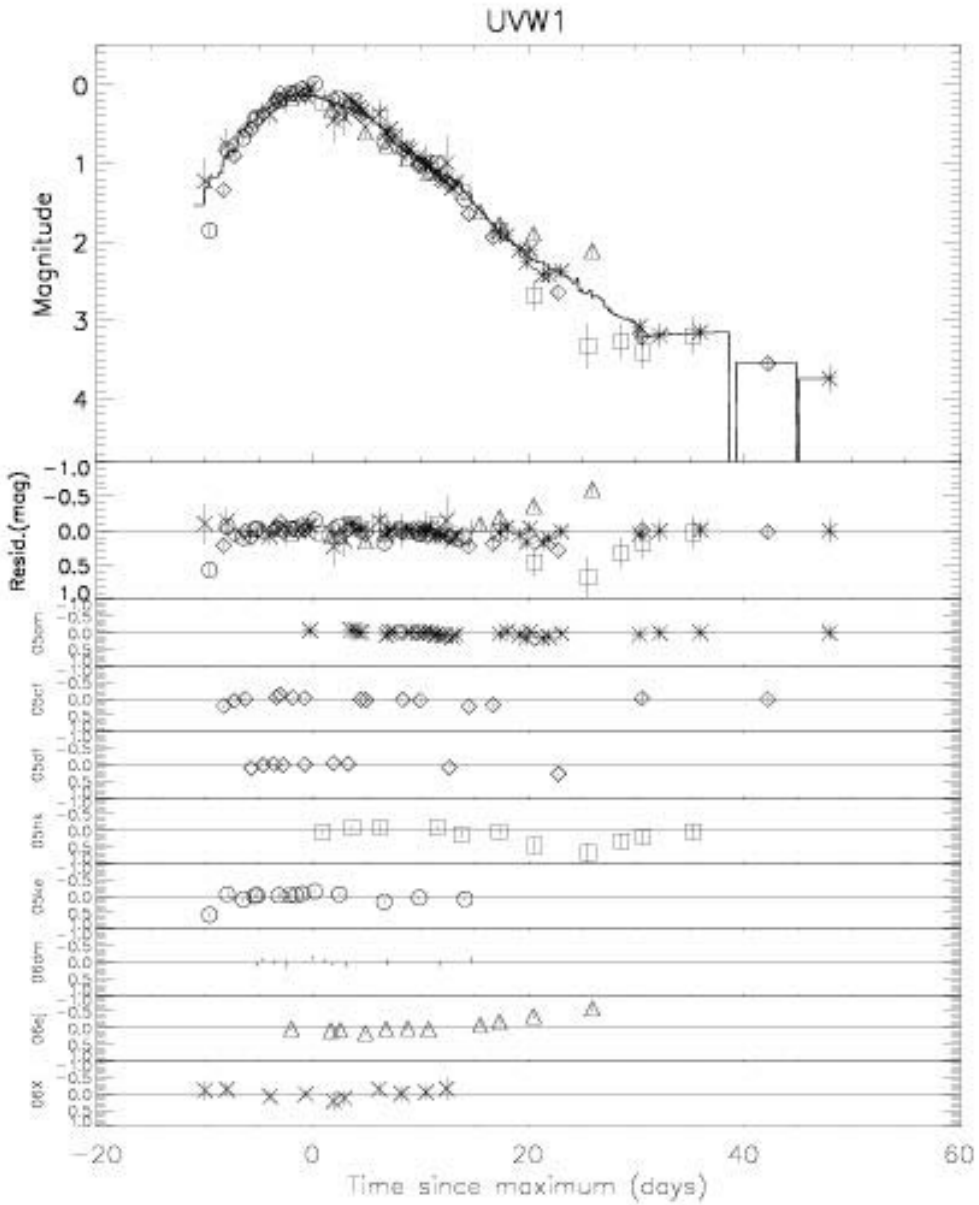


- The UV light curves have similar shapes.
- The UV light curves appear more homogenous than the opt light curves.

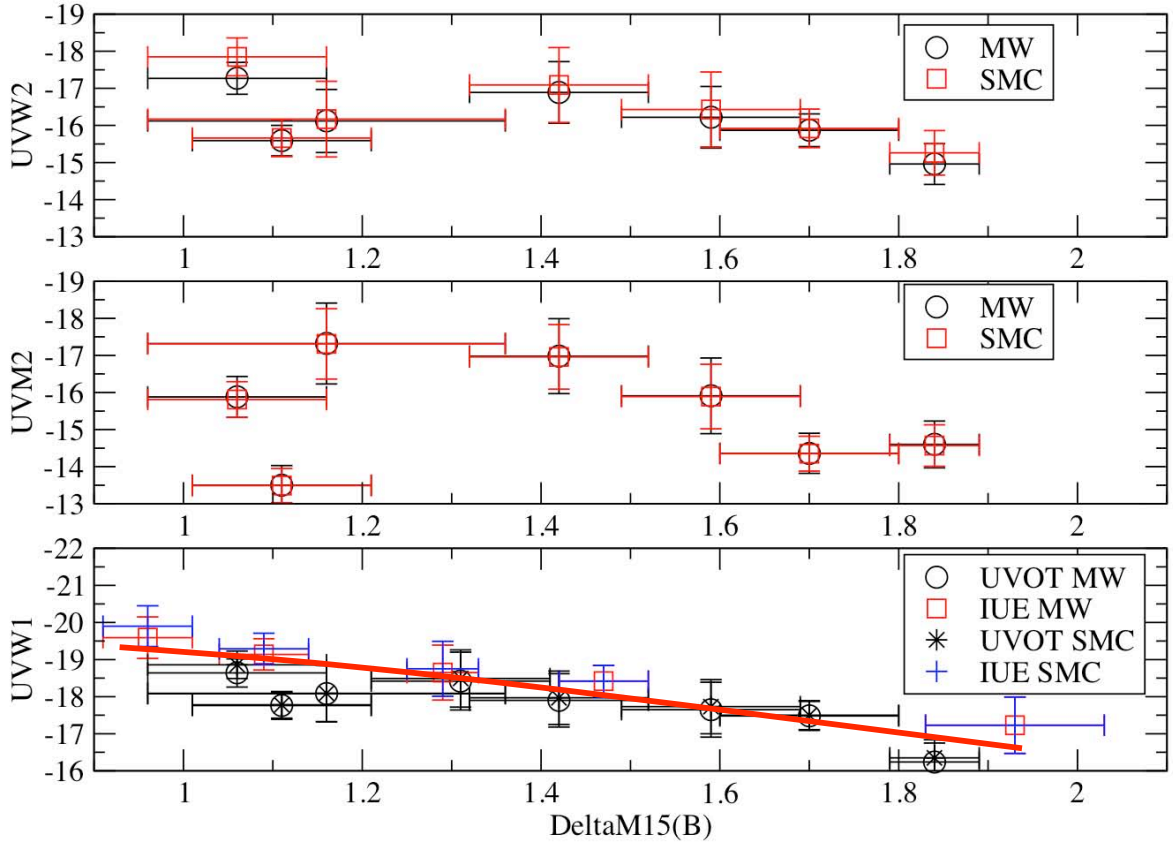
UV Template

- Lightcurves 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.

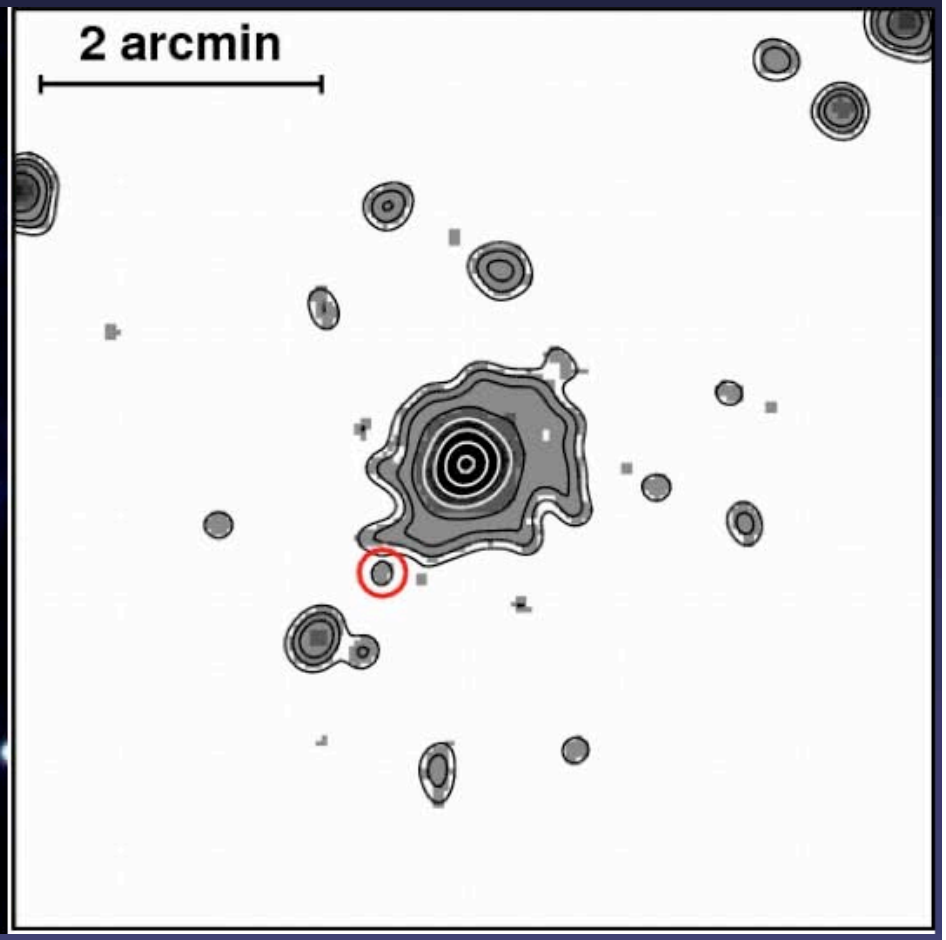


UV Standard Candles



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

SN 2005ke in NGC 1371



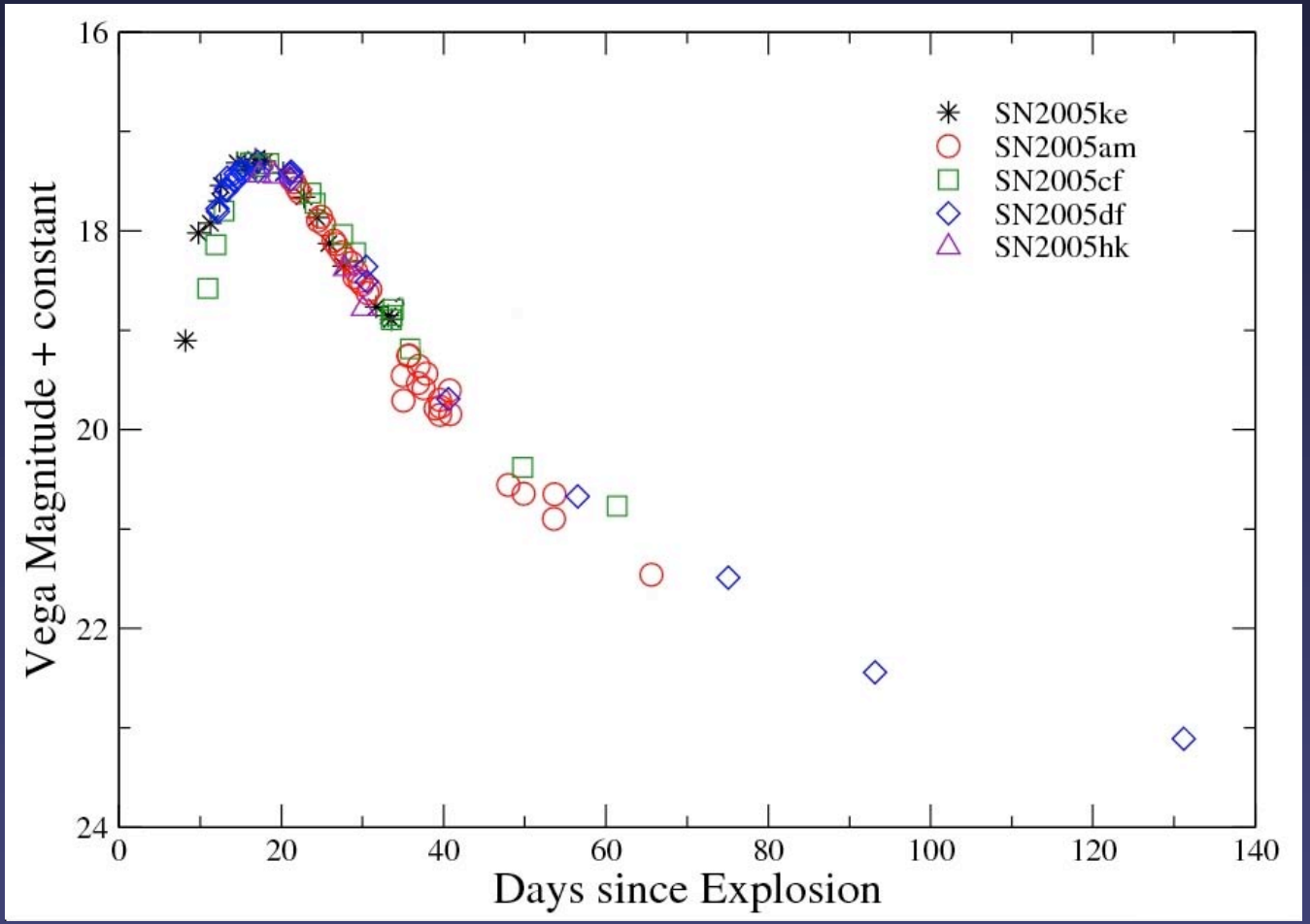
UVOT ultraviolet

XRT X-rays (258 ks)

- 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. 200

SN 2005ke in NGC 1371

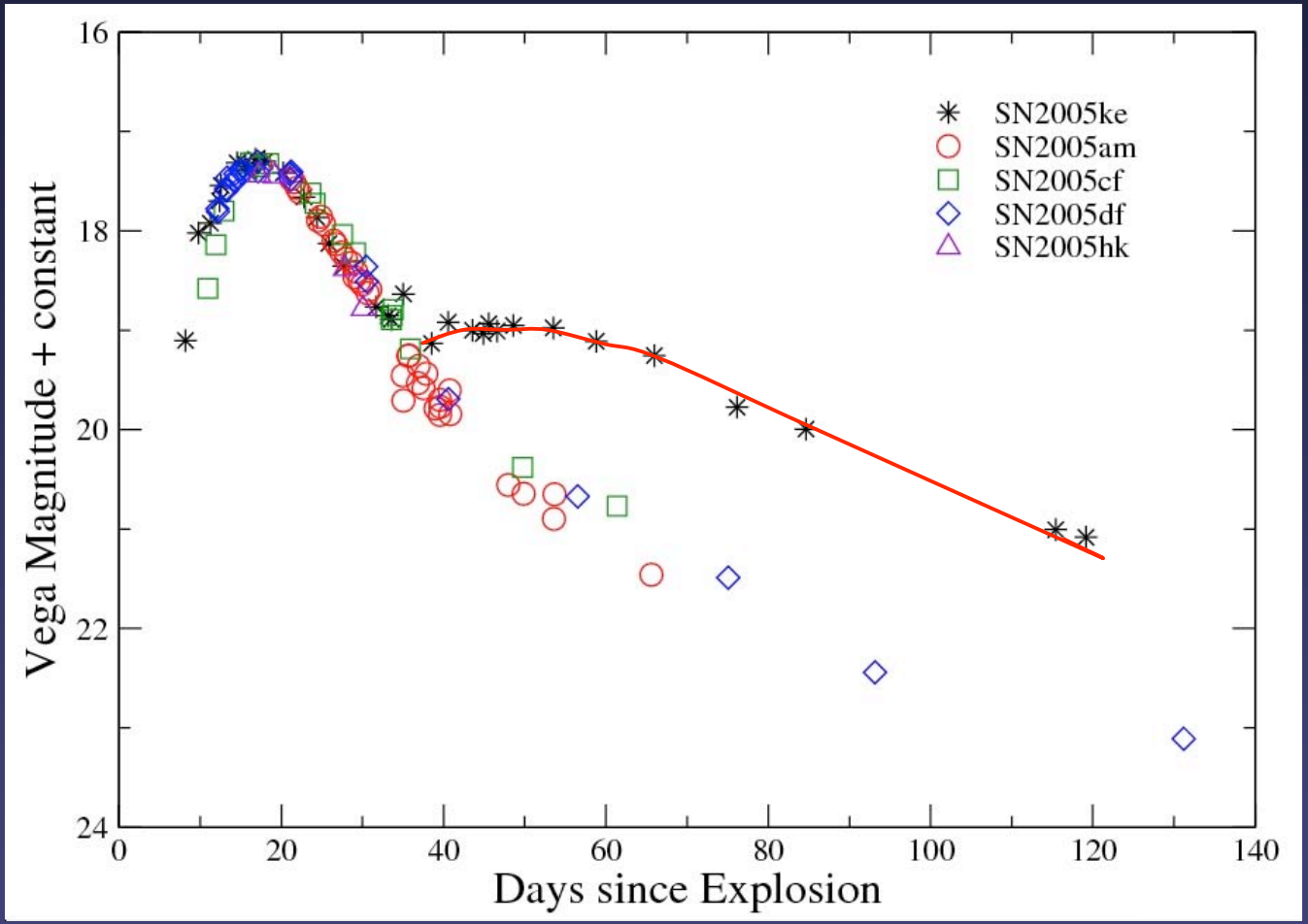


Swift UV lightcurves of type Ia supernovae

UV lightcurve shapes of Type Ia supernovae are surprisingly similar

except:

SN 2005ke in NGC 1371



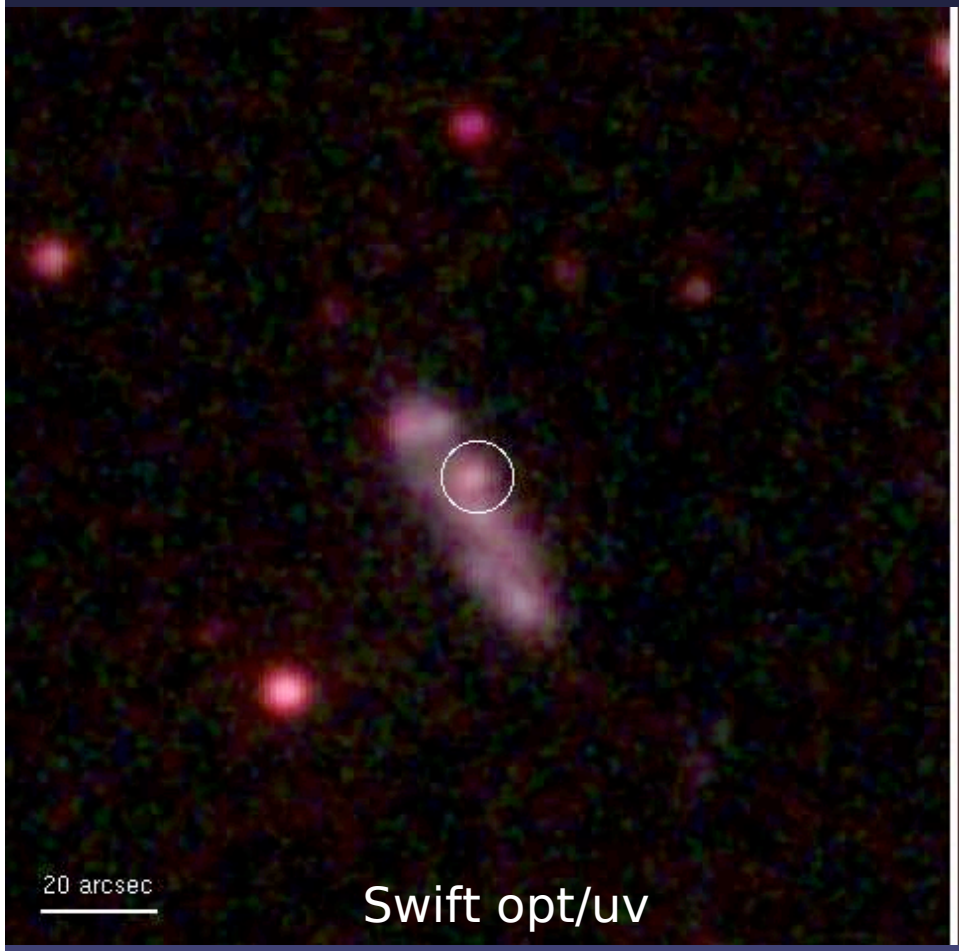
- Excess ultraviolet emission detected for SN 2005ke
- Caused by the interaction of the supernova shock with dense CSM?
- Evidence for a companion star?

Primary Objectives

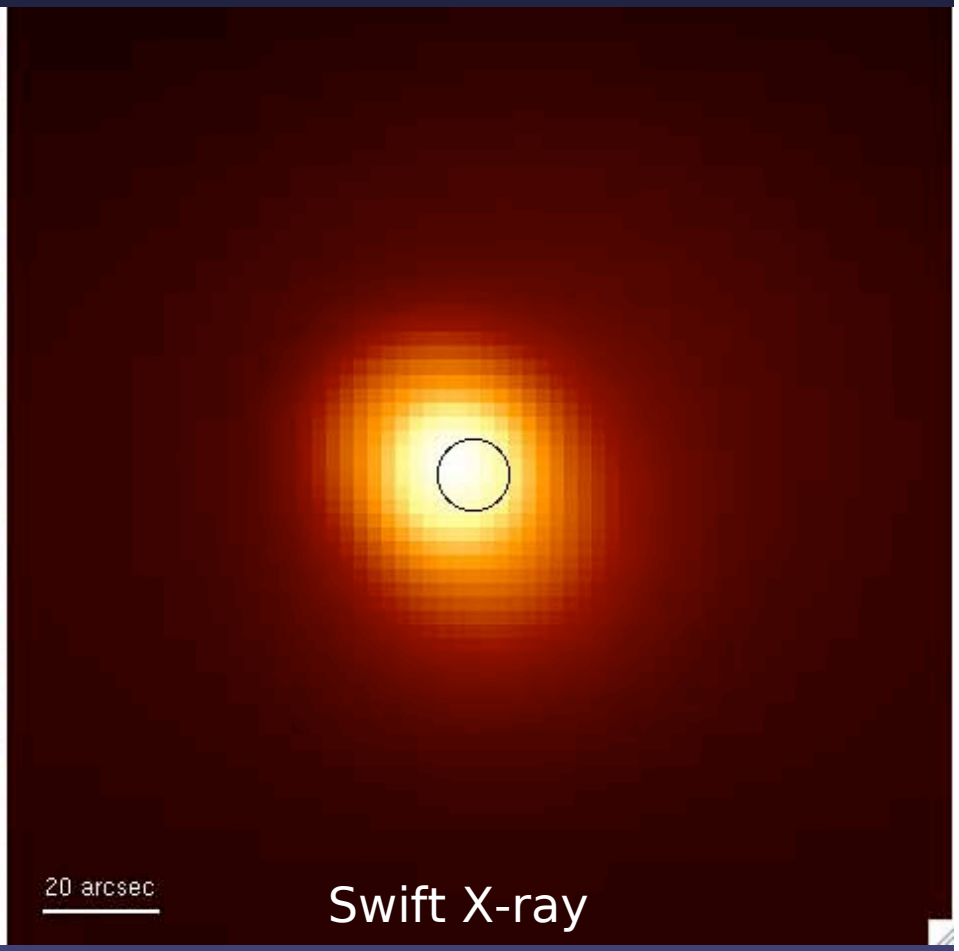
2) Core-Collapse SNe:

- Search for signatures of CSM interaction using XRT and UVOT.
- Exploring the general UV properties with photometry and spectra.

SN 2005kd



Swift opt/uv

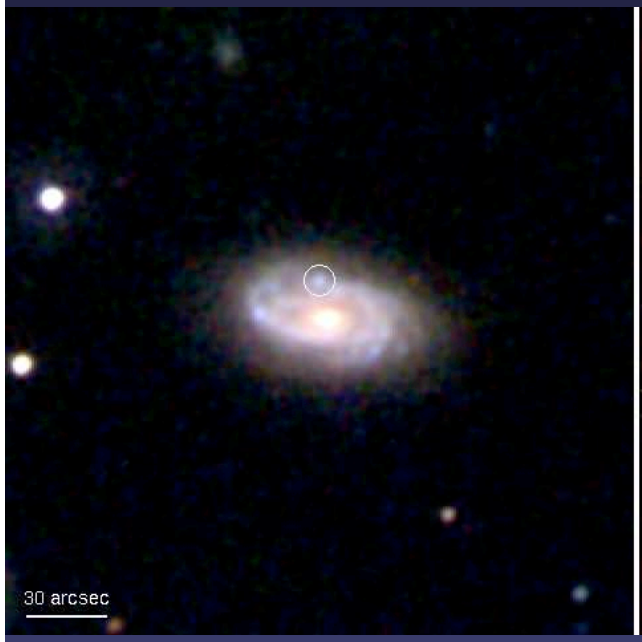


Swift X-ray

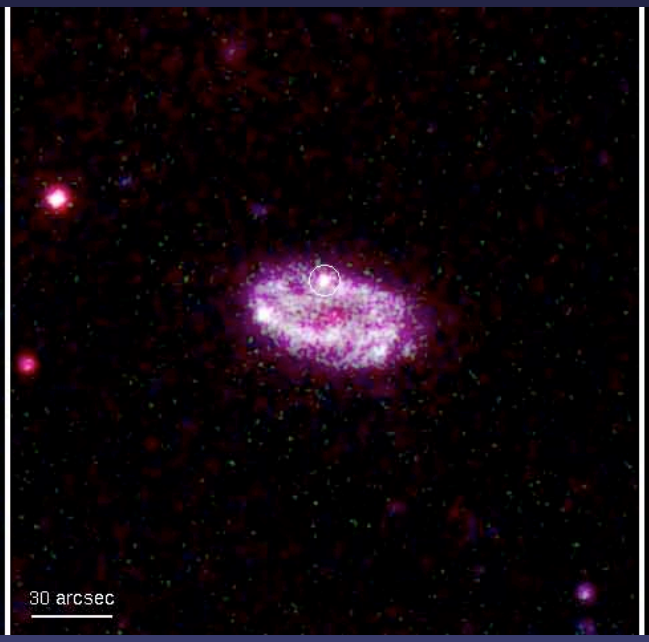
- Type IIn SN
- High X-ray luminosity, $L_x = 1.5 \times 10^{41}$ ergs/s (0.2–10 keV)
- High mass-loss rate of some 10^{-4} $M_\odot$ yr^{-1}

Immler, Pooley & Brown 20

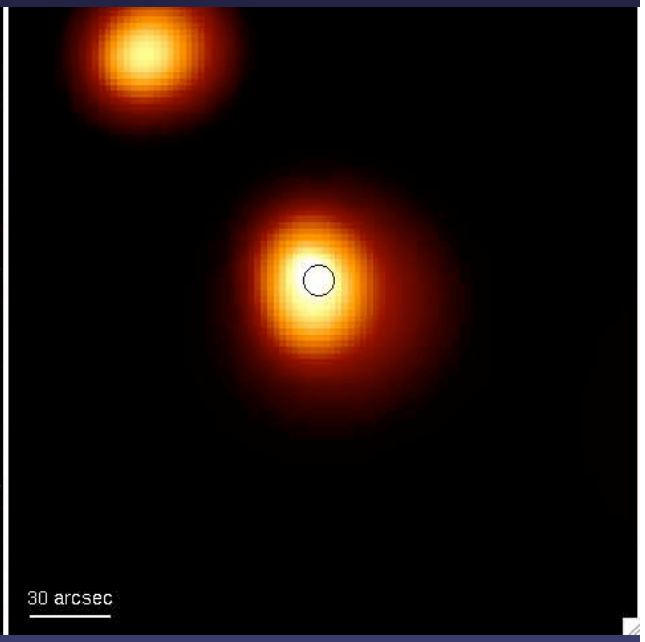
SN 2005ip



Swift optical



Swift UV

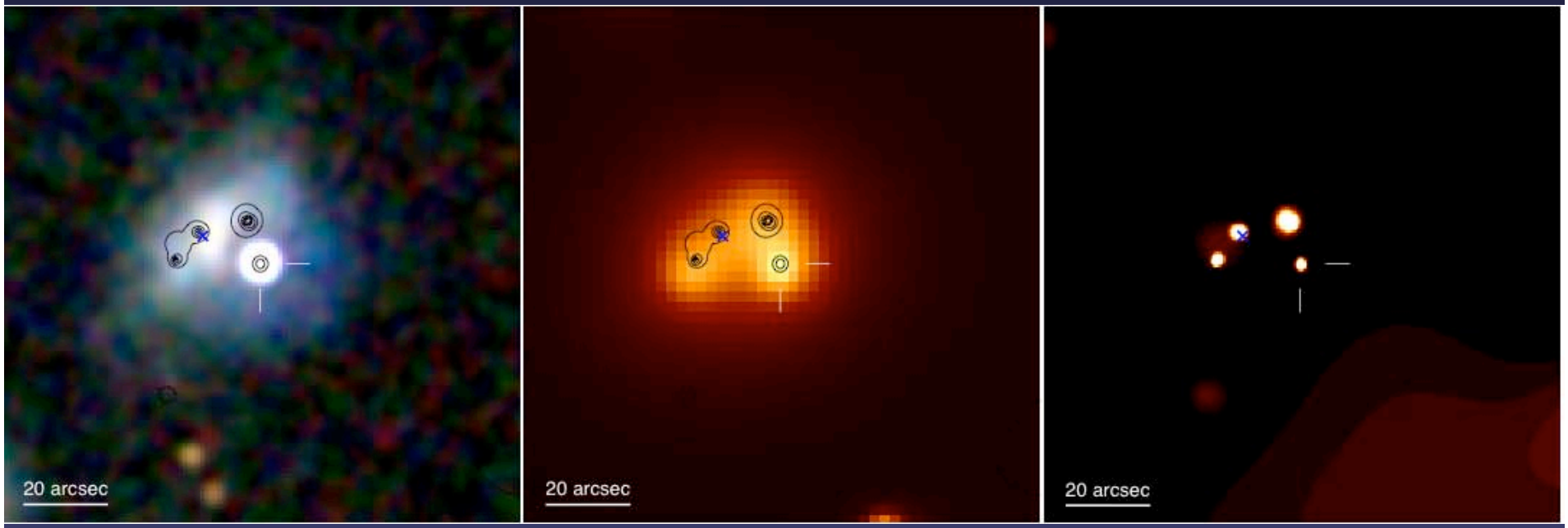


Swift X-ray

- Type IIn SN at 30 Mpc
- High X-ray luminosity, $L_x = 1.6 \times 10^{40}$ ergs/s (0.2–10 keV)
- High mass-loss rate of some 10^{-4} $M_\odot$ yr^{-1}

Immler & Pooley 200

SN 2006jc

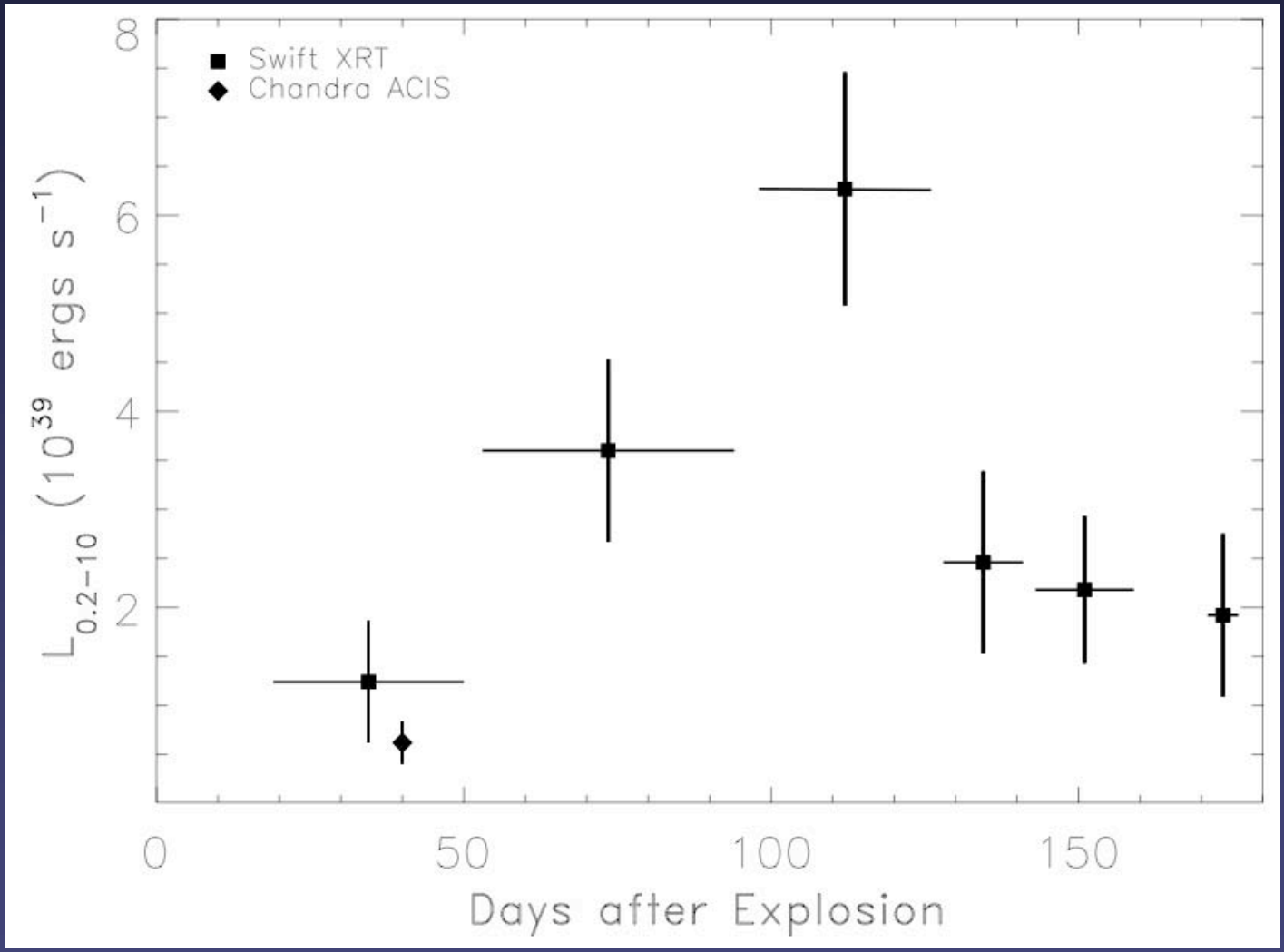


Swift optical | Swift X-ray | Chandra X-ray

SN 2006jc (Type Ib) is the brightest SN observed by Swift (13 mag) to date.

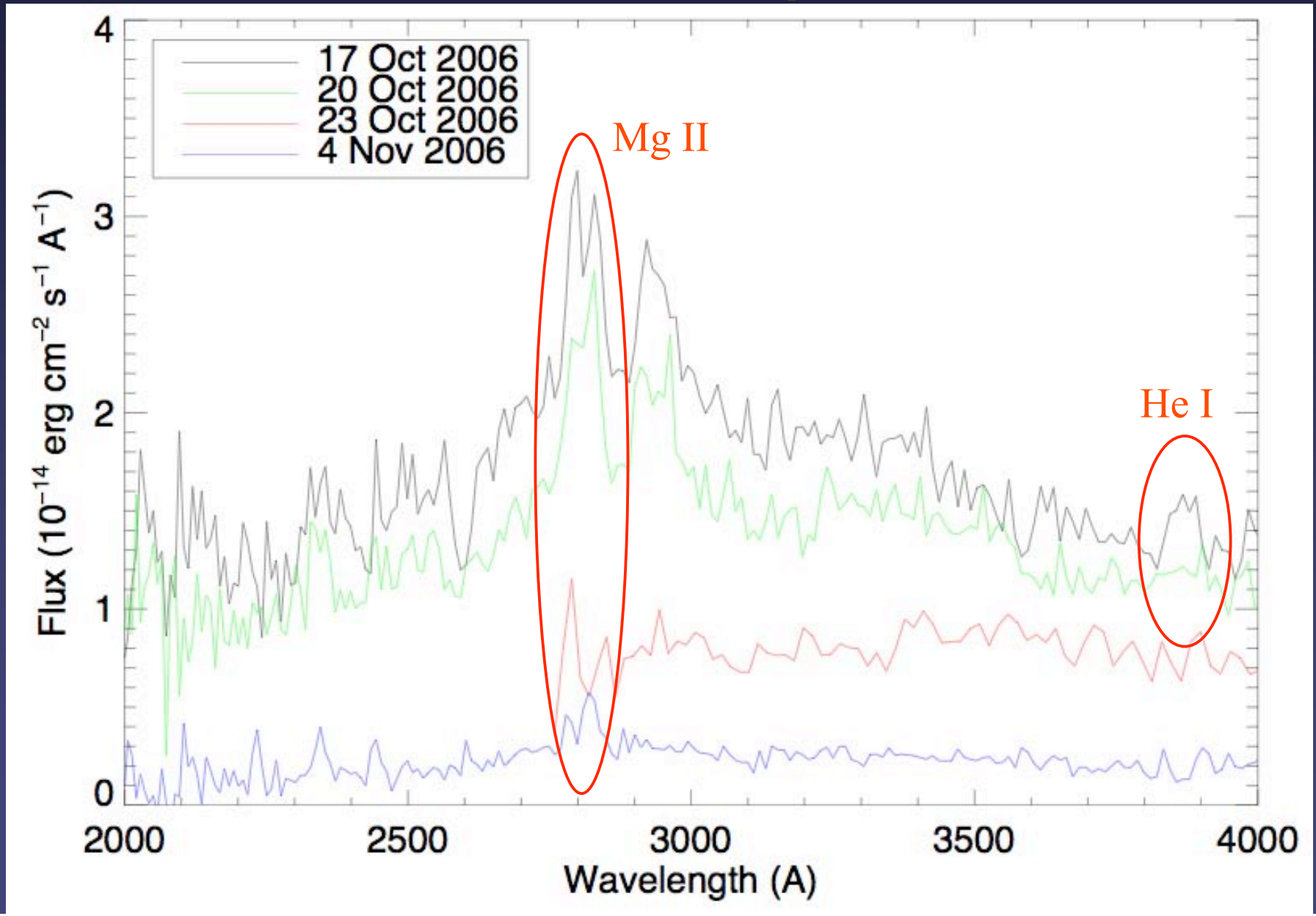
SN 2006jc is detected in X-rays with Chandra on day 40 after explosion and showed a brightening in X-rays with XRT, mass-loss rate 9×10^{-5} $M_{\odot}$ yr^{-1}

SN 2006jc

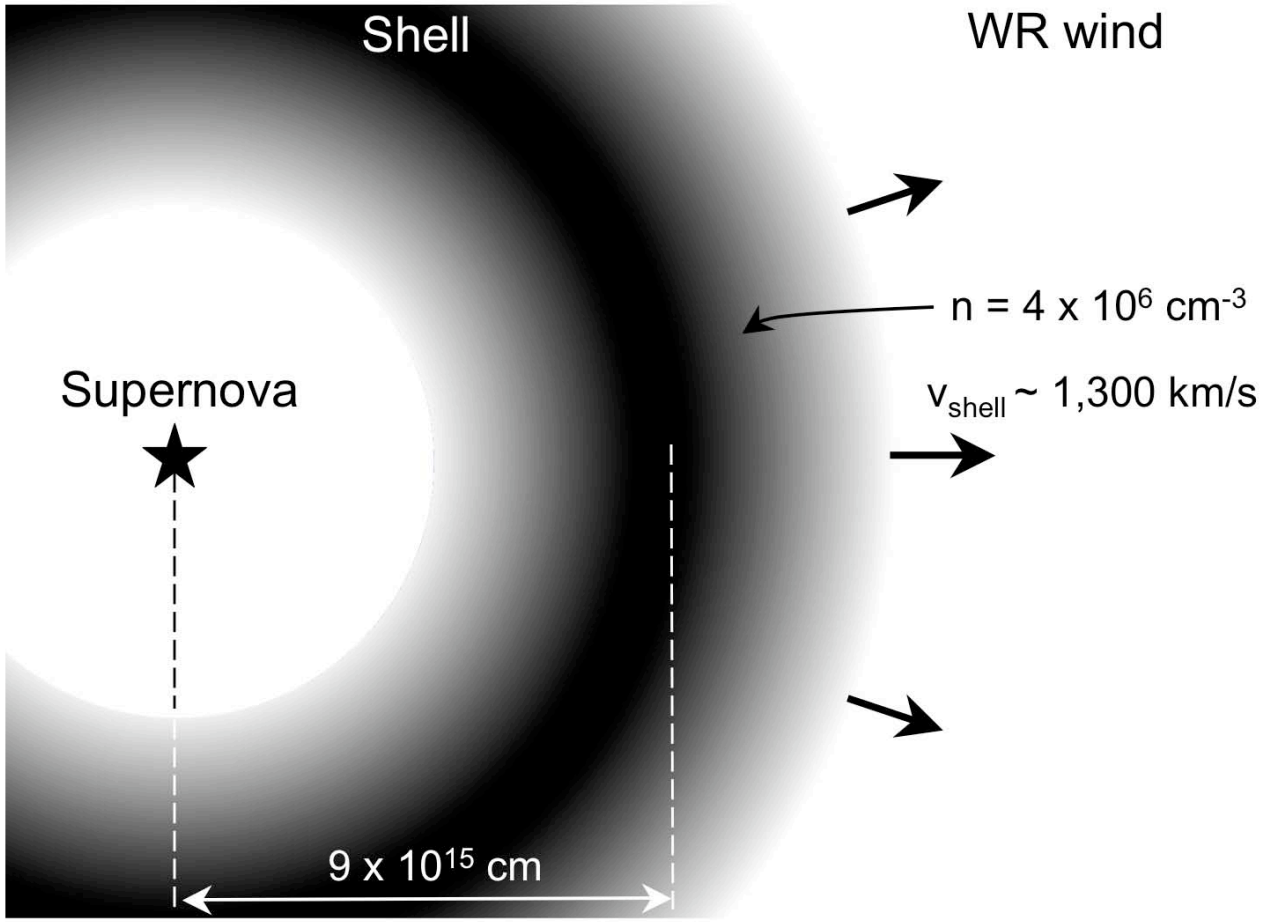


Brightening in X-rays: dense shell around the site of the explosion?
SN 2006jc is the result of LBV, whose outburst was observed two years befo

SN 2006jc


17 Oct 2006
20 Oct 2006
23 Oct 2006
4 Nov 2006
Mg II
He I
Flux (10^{-14} erg cm^{-2} s^{-1} A^{-1})
Wavelength (A)
0
1
2
3
4
2000
2500
3000
3500
4000

SN 2006jc



Transition of Luminous Blue Variable to WR progenitor, leading to ejection of shell

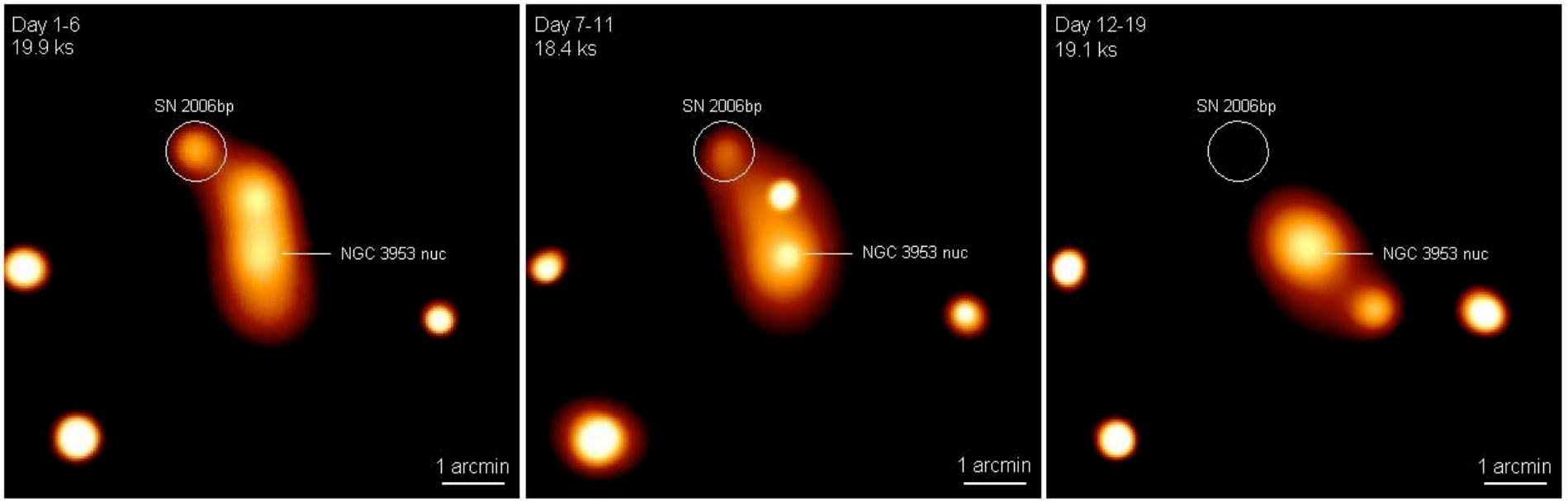
SN 2006bp in NGC 3953

Swift optical Swift UV Swift X-ray

- Type IIP ('plateau') SN at d = 14.9 Mpc
- Observed with Swift <1 day after the explosion
- Detection of X-ray emission < 1 day after the explosion
- Earliest detection of a SN in X-rays (minus GRB/SN), $L_x = 2 \times 10^{39}$ ergs/s

Immler et al.

SN 2006bp in NGC 3953



- Daily *Swift* observations allow timing analysis of X-ray flux
- SN would have been missed with any other observatory (XMM, Chandra)
- With *Swift* we are probing a previously unexplored time domain for SNe
- The SN is fading below the detection threshold within 10 days
- Detection of previously unknown, variable ULX in the host galaxy

Immler et al.

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 a perfectly suited to study SNe.
- Results obtained so far demonstrate the high potential of *Swift*:
  - SNe Ia UV light curve templates are being created,
  - Efforts are being made to establish SNe Ia as UV standard candle with large implications for cosmology and future missions (SNAP,
  - UV and X-rays as probes for CSM interaction (UV excess, UV grism early X-ray detections, densely sampled X-ray light curves, etc). X-ray detection detection rate dramatically increased from <2% pre-Swift to >20%.
- 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.