Swift Observations of Supernovae

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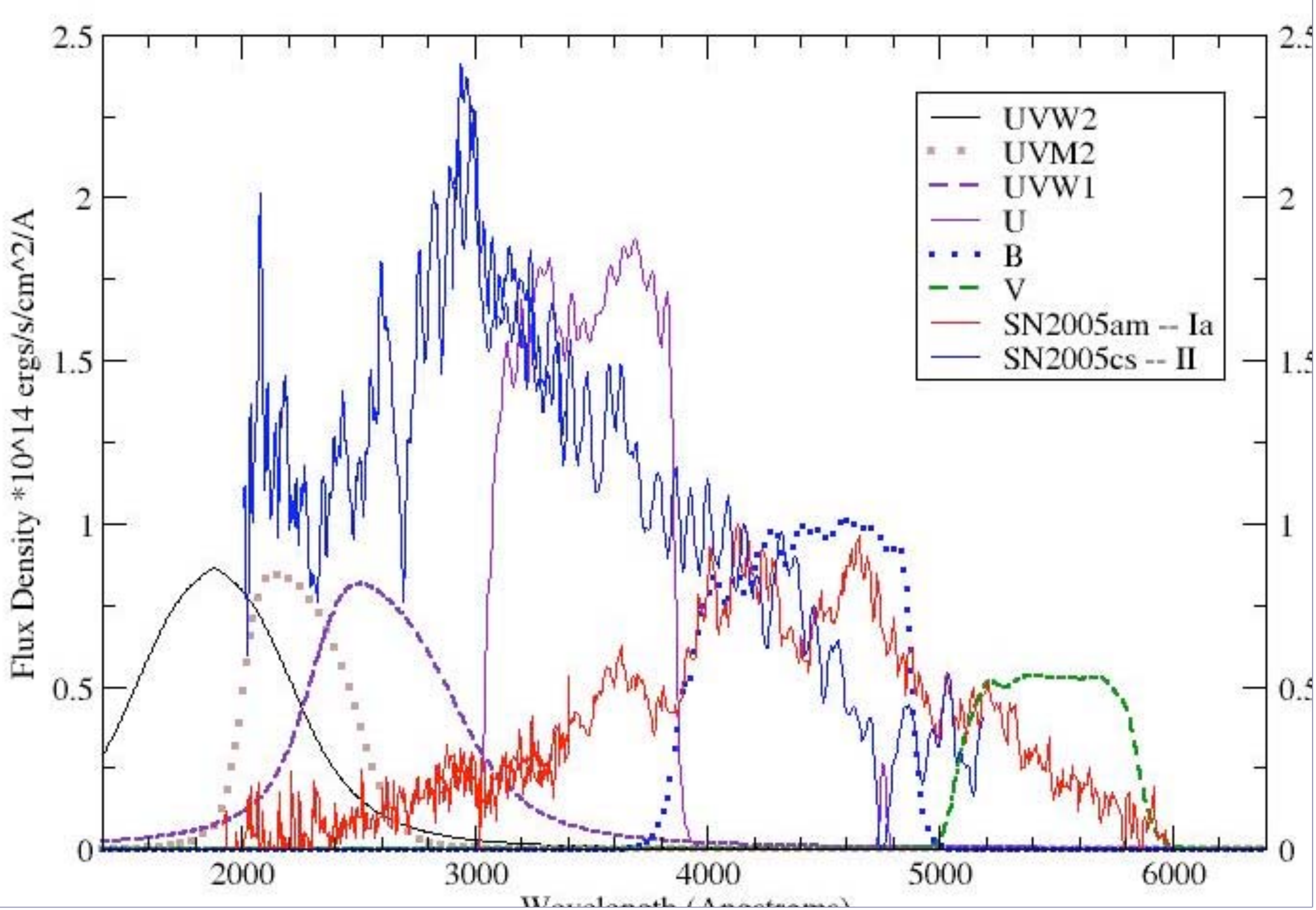
and the *Swift* Supernova Team

The *Swift* Observatory

Burst Alert Telescope	
Detector	CdZnTe
Aperture	Coded Mask
Effective Area	5200 cm^2
Field of View	2.0 sr (partially coded)
Detection Elements	256 × 128 elements
Point Spread Function	20 arcmin
Location Accuracy	3 arcmin
Energy Range	15-150 keV
X-Ray Telescope	
Detector	XMM EPIC CCD
Effective Area	135 cm^2 at 1.5 keV
Field of View	23.6 × 23.6 $arcmin^2$
Detection Elements	600 × 600 pixel
Point Spread Function	18 arcsec HPD at 1.5 keV
Location Accuracy	3 arcsec
Energy Range	0.2-10 keV
UV/Optical Telescope	
Aperture	30 cm Ritchey-Chrétien
Detector	Intensified CCD
Detector Operation	Photon Counting
Field of View	17 × 17 $arcmin^2$
Point Spread Function	1.9 arcsec at 350 nm
Location Accuracy	0.3 arcsec
Wavelength Range	170 nm - 650 nm
Spectral Resolution	200 at 400 nm
Filters/Grisms	7/2

The *Swift* UVOT Filters



Swift Observations of Supernovae

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

38 total — 17 (12) type Ia — 11 (2) type Ib/c — 10 (3) type II

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2005ek	Ic	2006jc	Ib
2005gj	Ia	2006lc	Ib/c
2005hk	Ia	2006gy	IIn
2005ip	IIn	2006lt	Ib
2005ke	Ia	2006mr	Ia
2005kd	IIn	2007C	Ib/c
2005mz	Ia	2007D	Ic
2006E	Ia	2007I	Ic
2006T	IIb	2007S	Ia
2006X	Ia	2007Y	Ia ?
2006aj	Ic	2007aa	II
2006at	II	2007af	Ia

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Primary Objectives

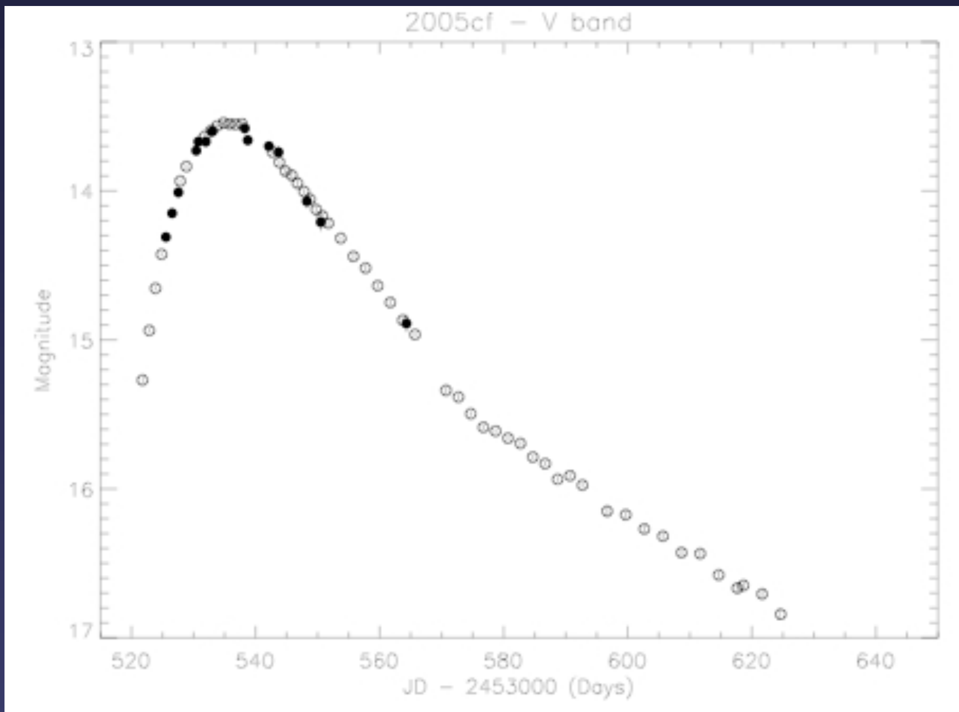
Thermonuclear SNe:

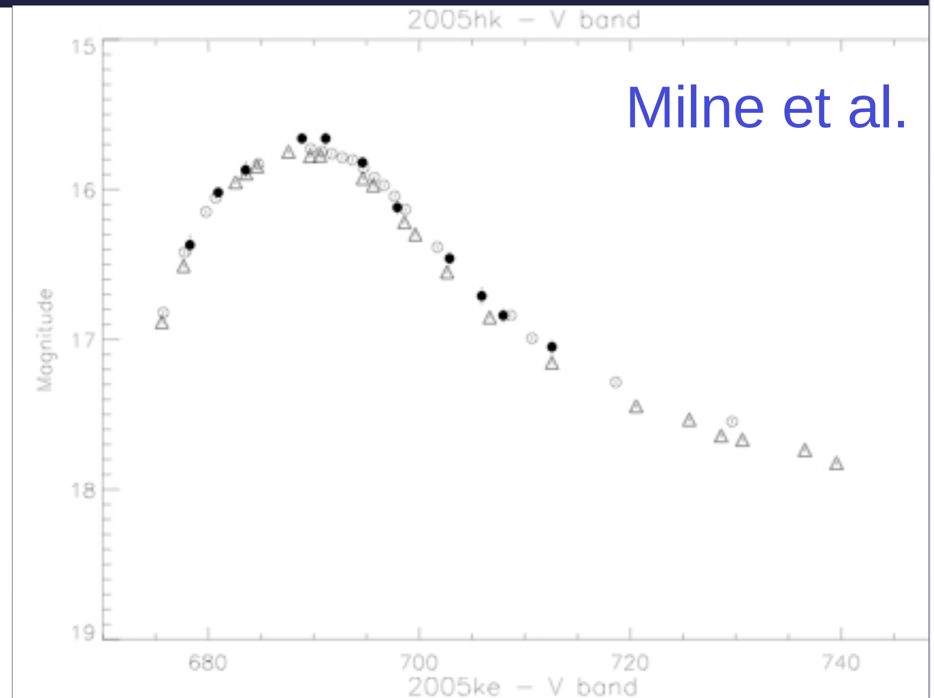
- UV as another window to probe of the explosion physics:
  Iron-peak line blanketing occurs in the UV. Early epochs probe the iron near the surface. Absorption of UV leads to more opt emission.

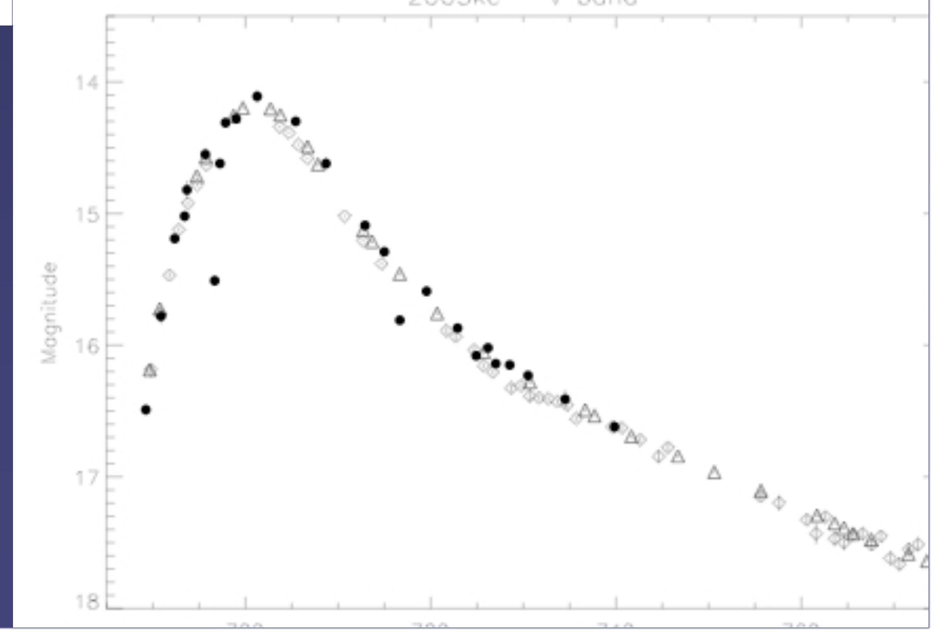
- Create template lightcurves and explore their use as UV standard can
  With increasing redshift, rest-frame UV emission is shifted into the opt/NIR. Thus, UV observations of local SNe Ia permit the creation of UV templates against which high-*z* SNe can be compared.

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

Swift vs Ground-Based Photometry





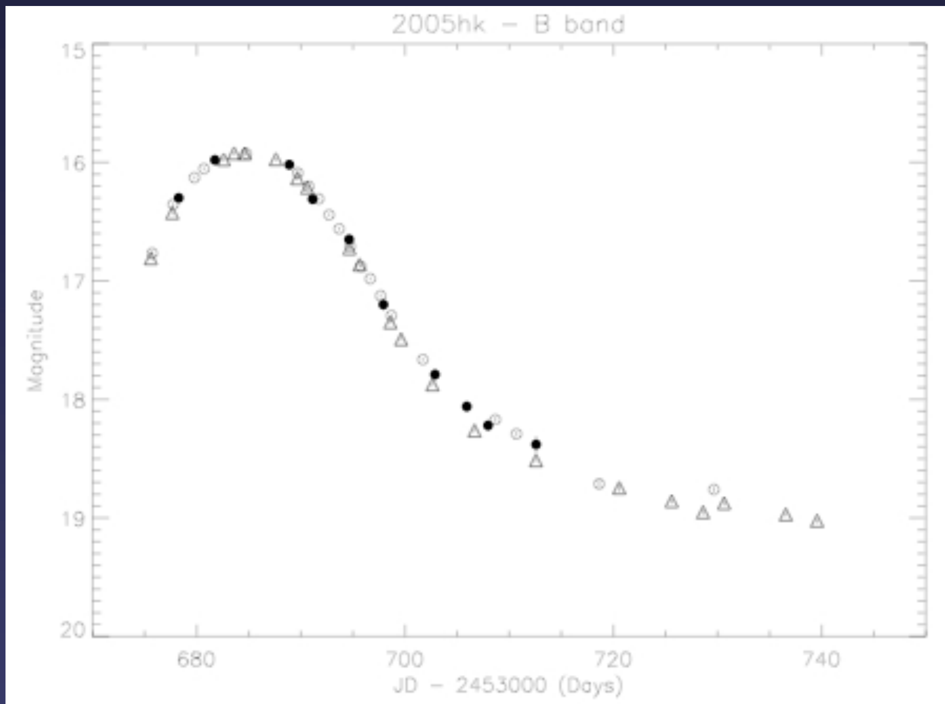


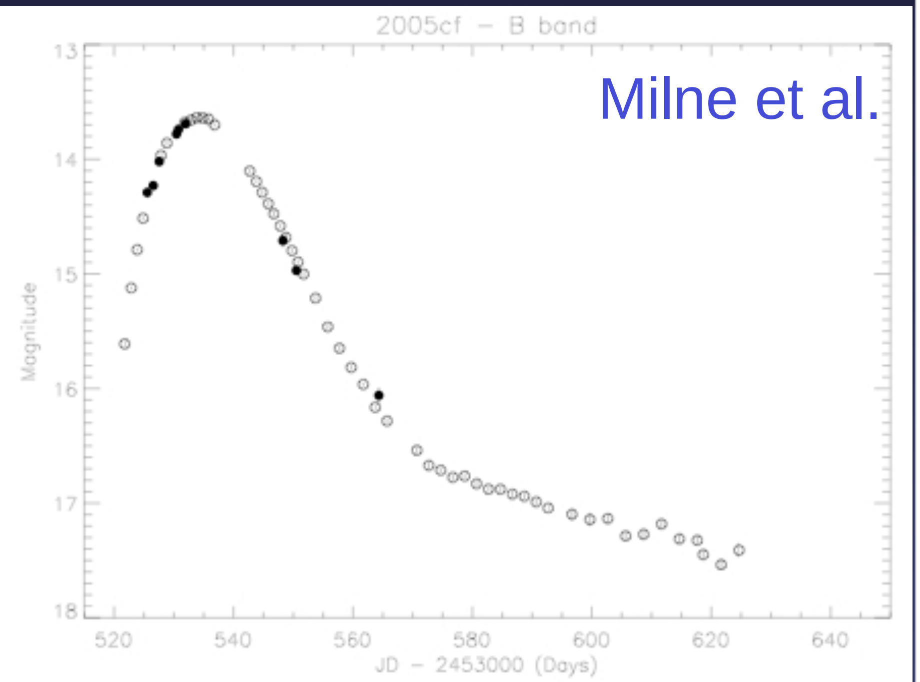
V-band

High level of agreement between Ground-based and *Swift* V, B, U Photometry

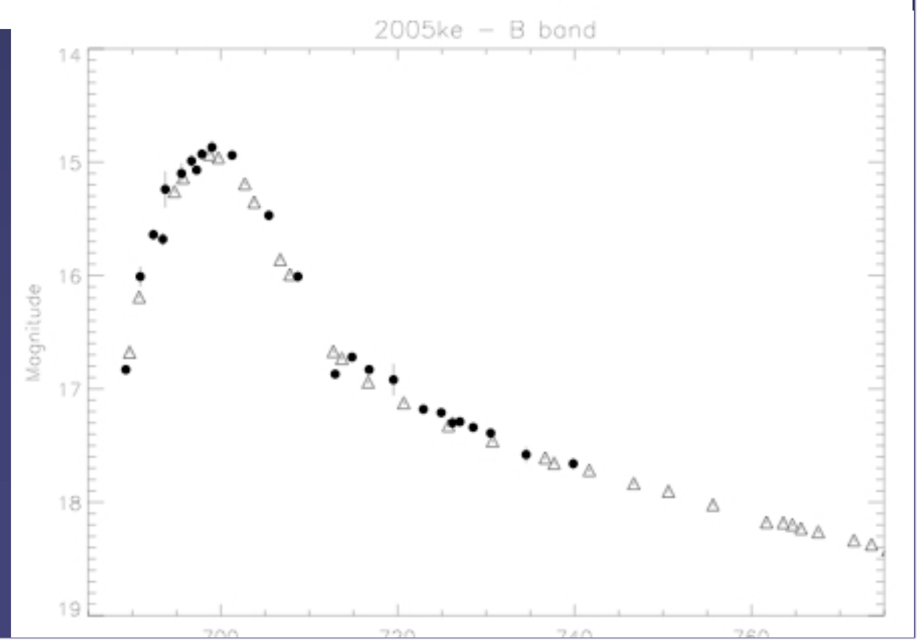
Rogue points being investigated

Swift vs Ground-Based Photometry





Milne et al.

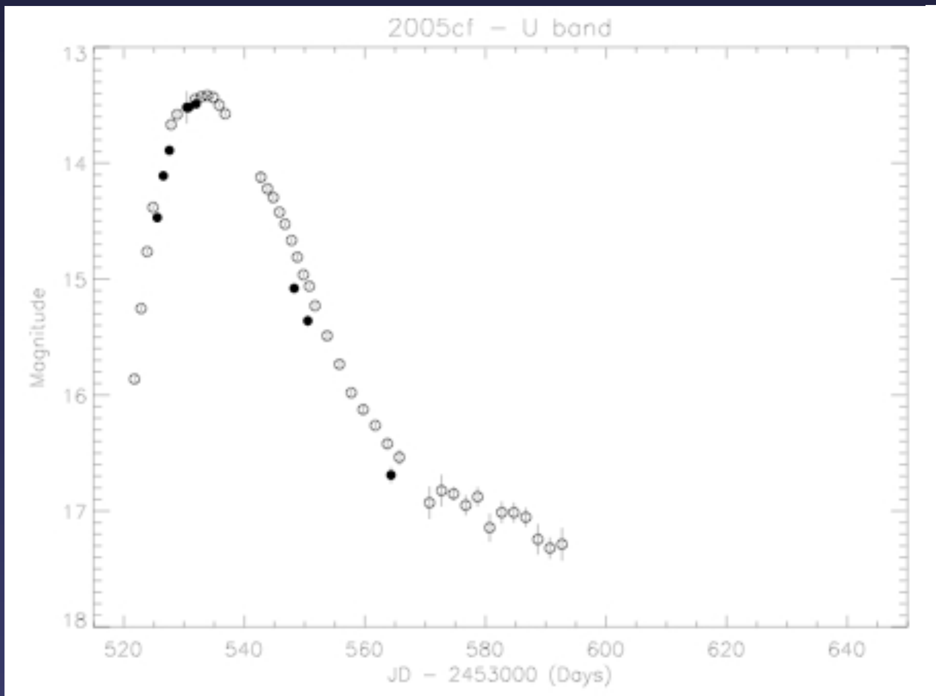


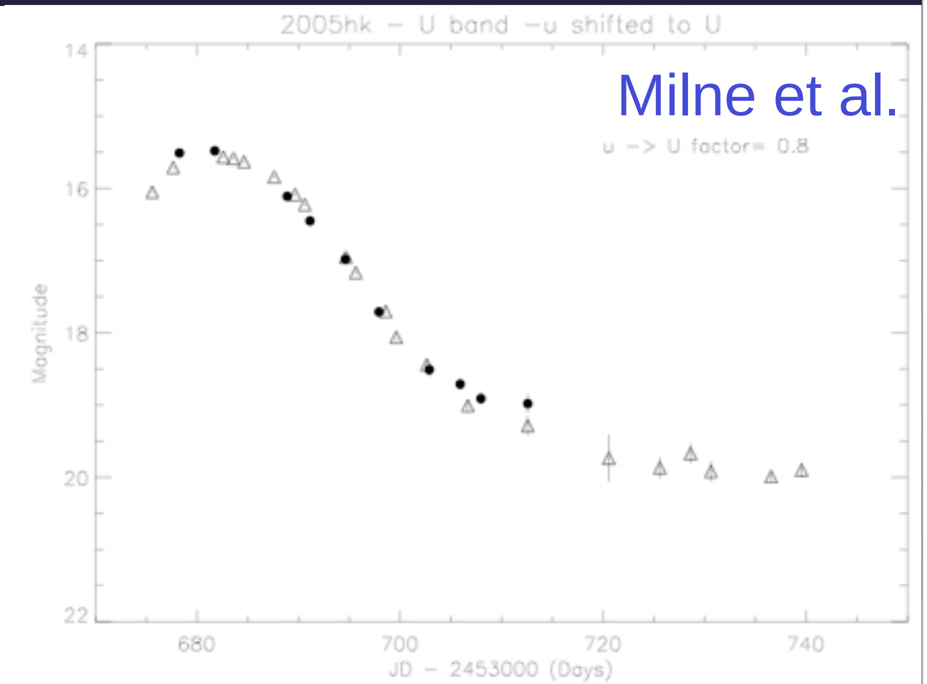
B-band

High level of agreement between Ground-based and *Swift* V, B, U Photometry

Rogue points being investigated

Swift vs Ground-Based Photometry





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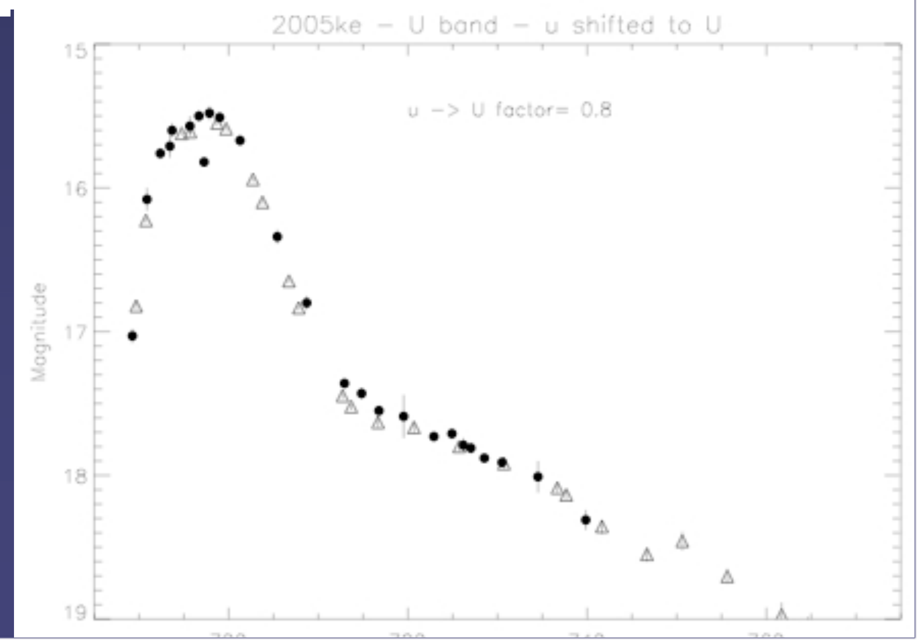
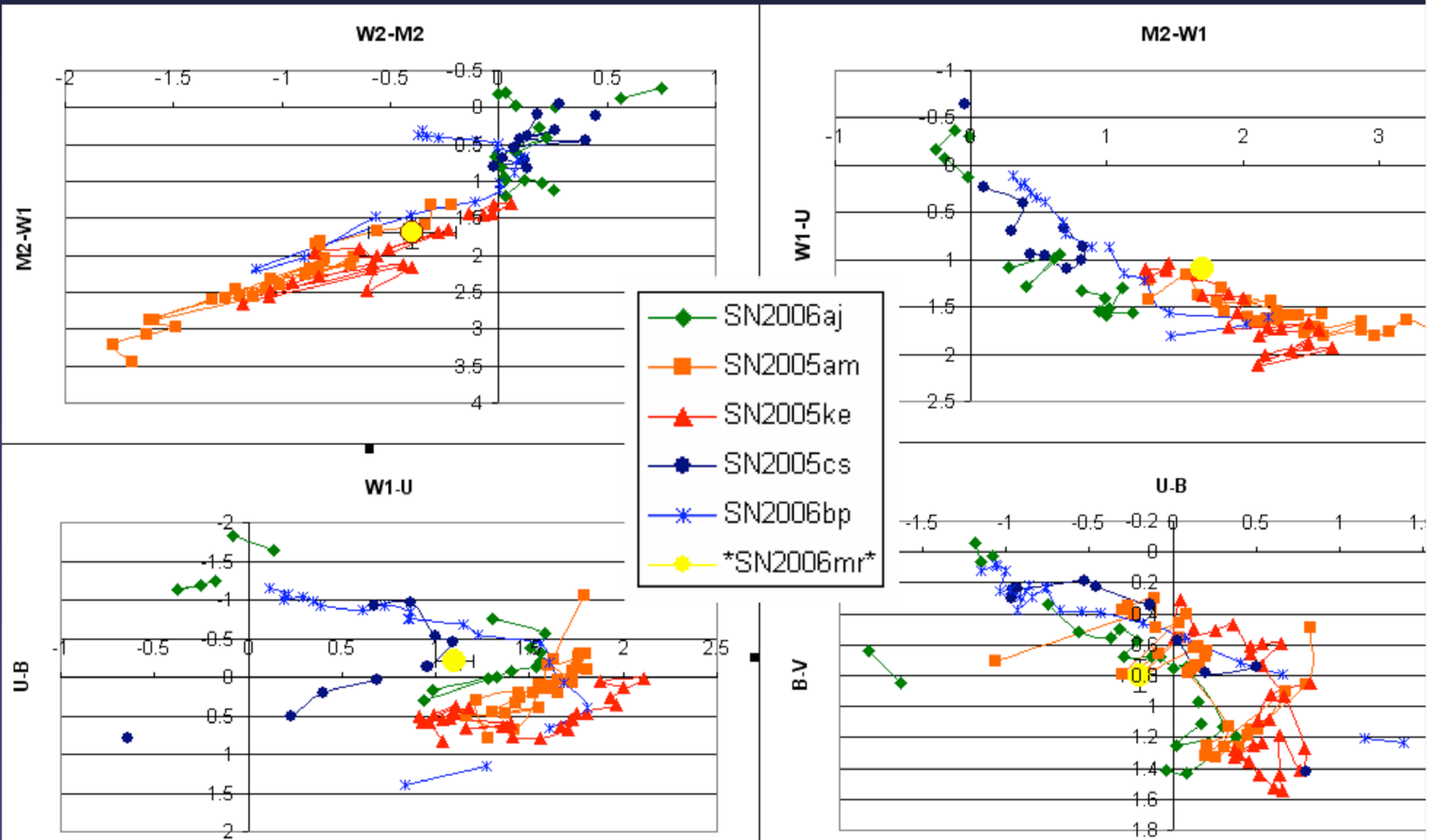


U-band

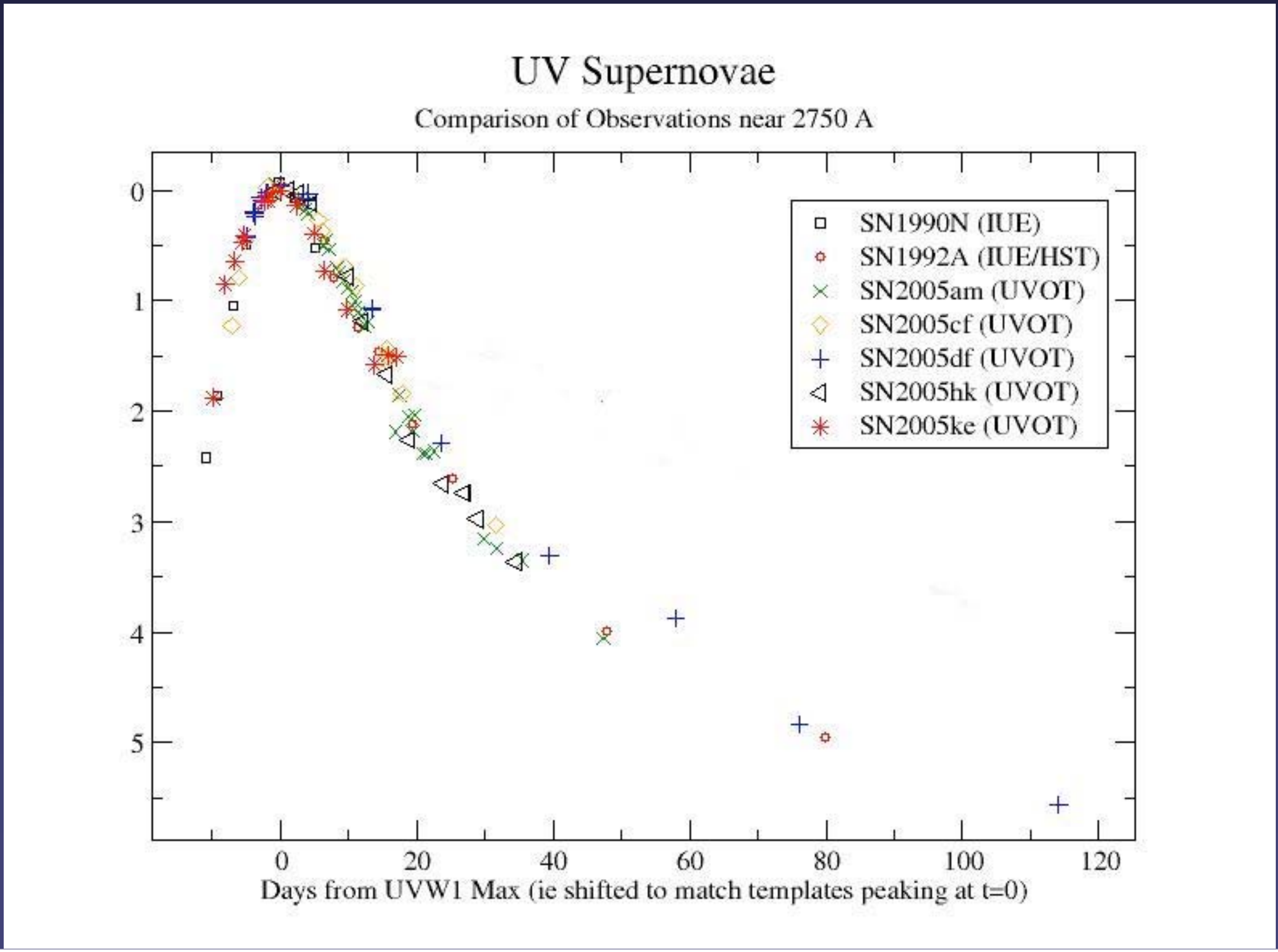
High level of agreement between Ground-based and *Swift* V, B, U Photometry

Rogue points being investigated

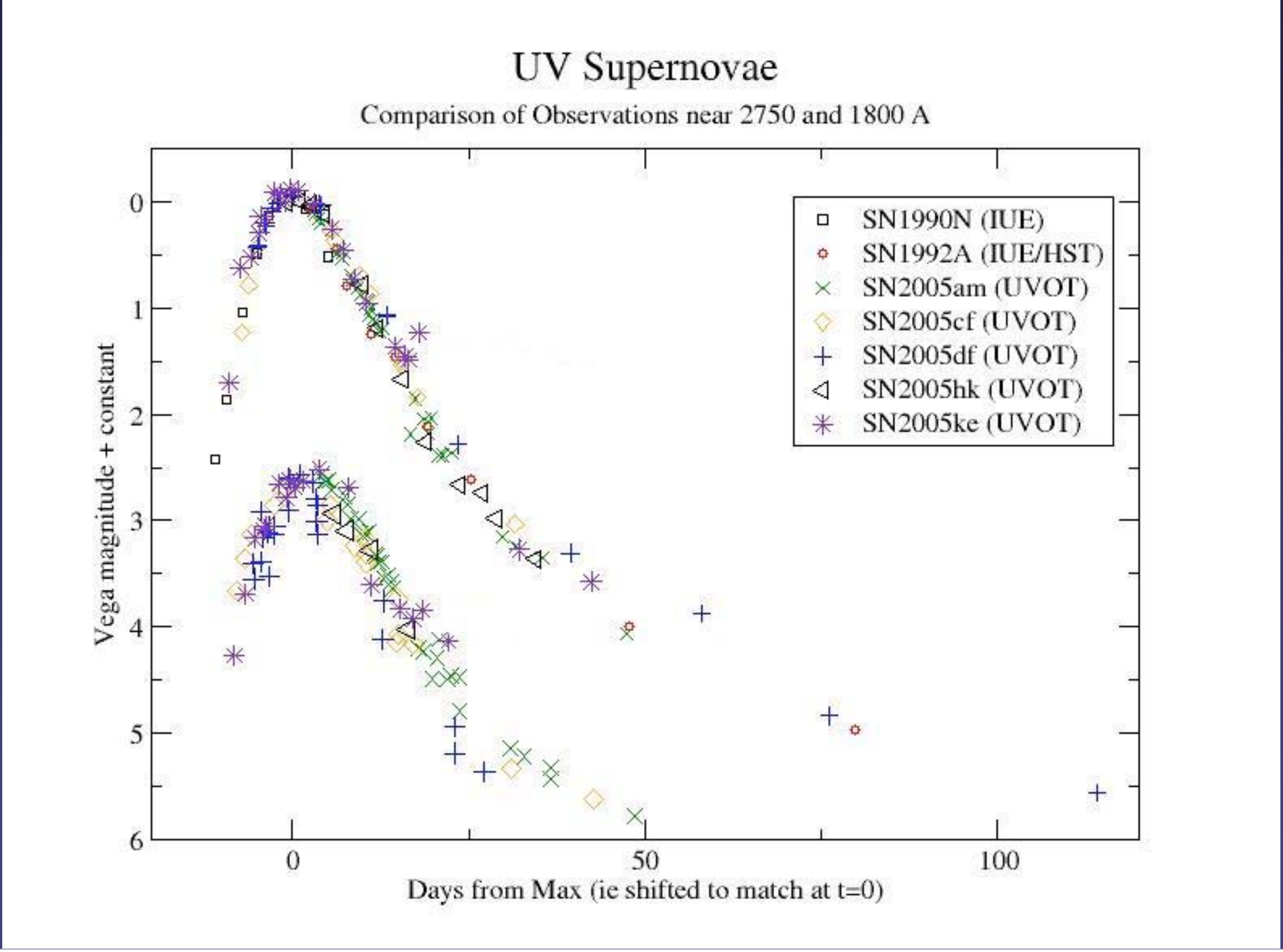
SN Phototyping with UV Colors



UV Light Curves



UV Light Curves

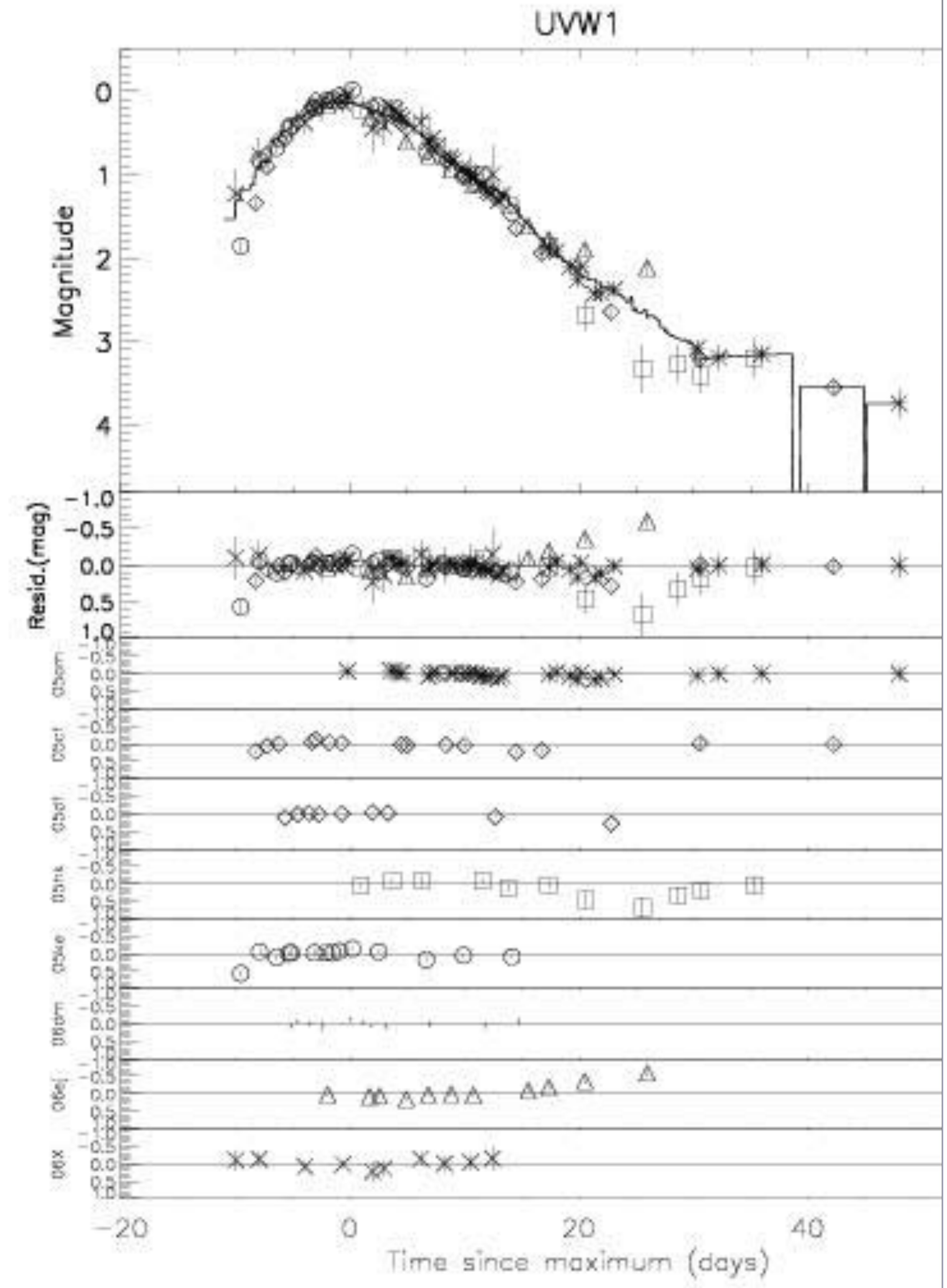


UV Light Curves

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

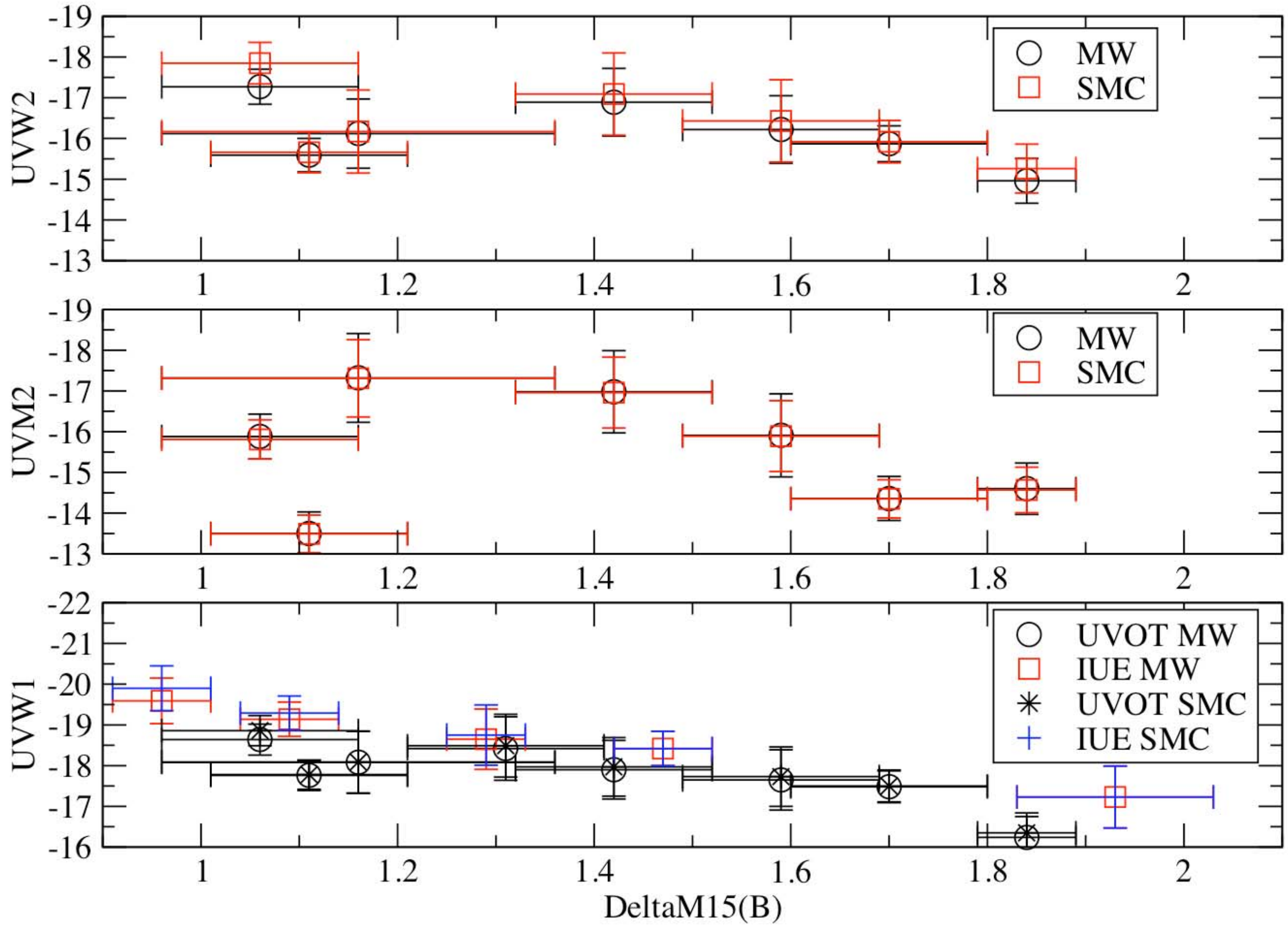
UV Template

- 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.

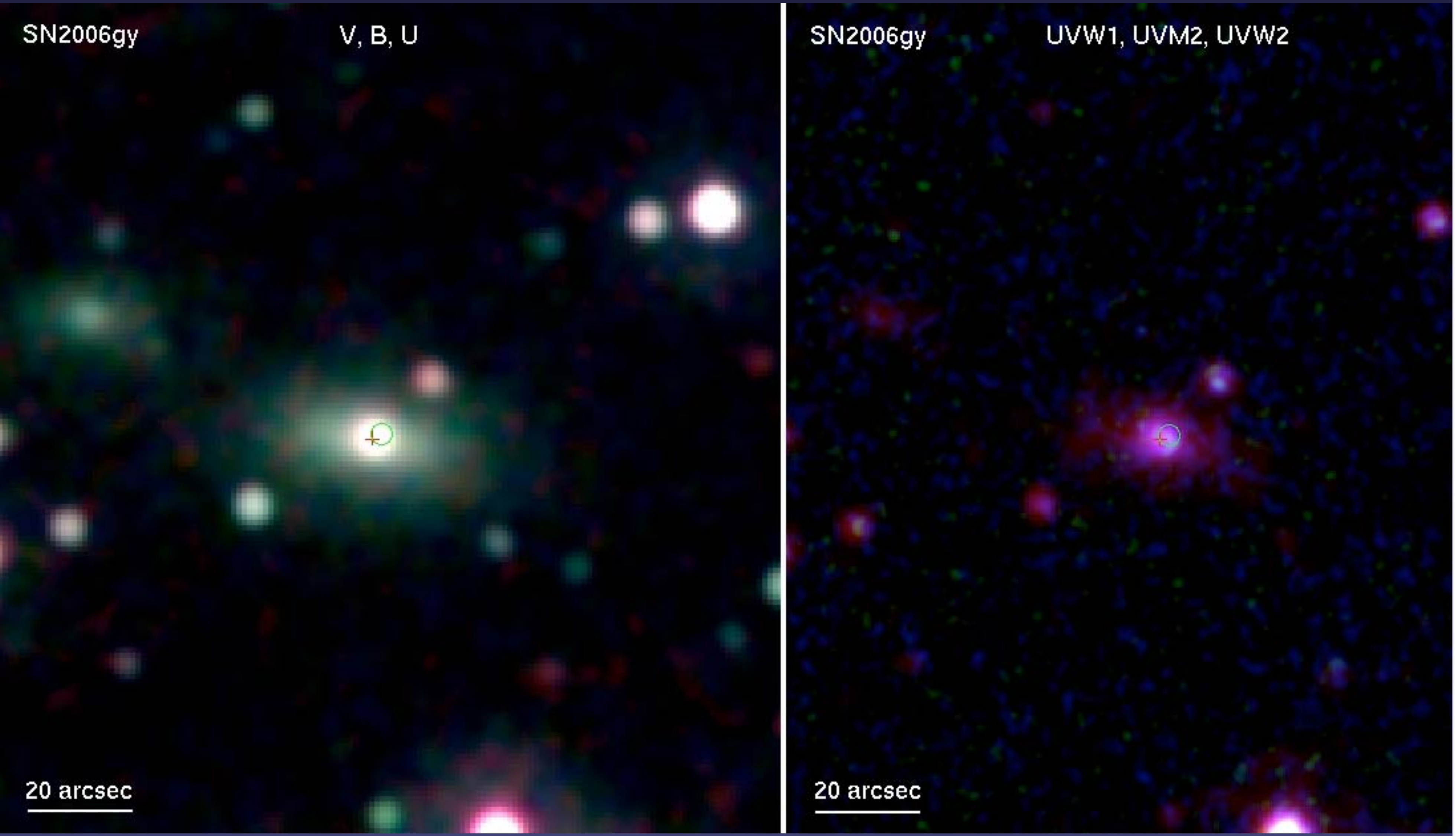
UV Standard Candles



- SNe that are opt bright are also bright in the UV

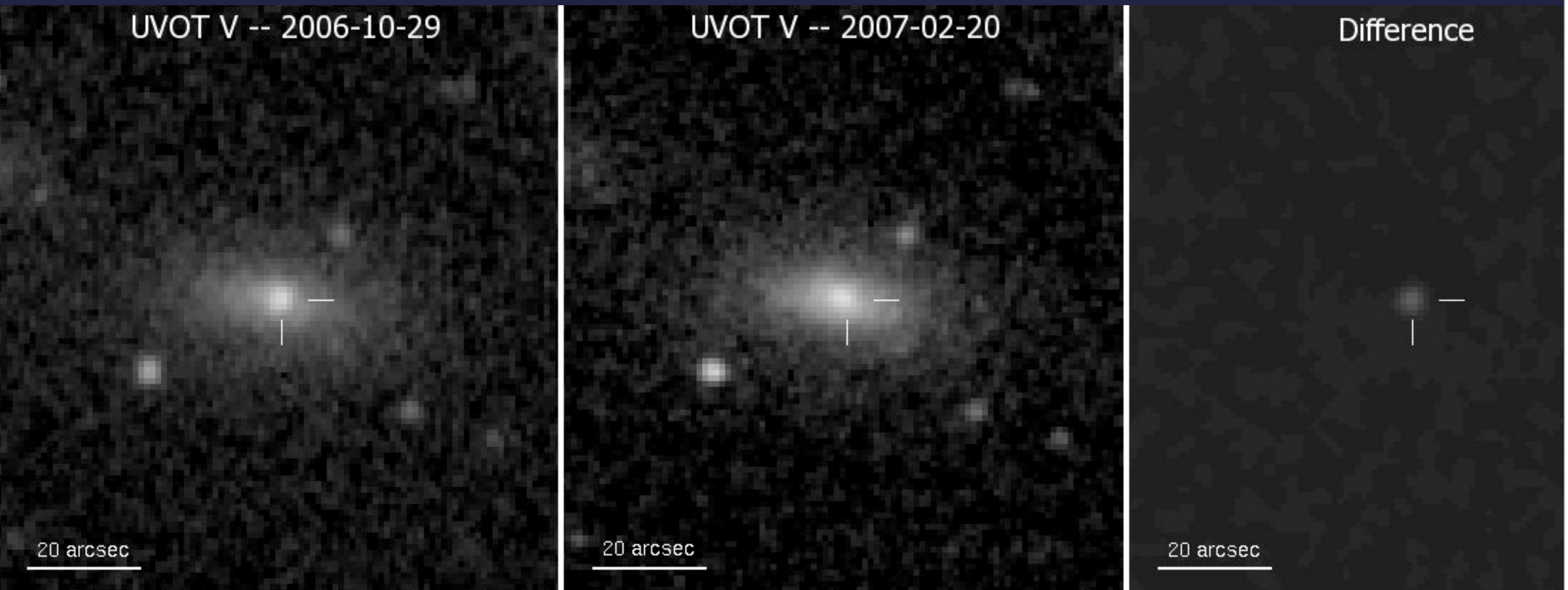
SNe 2006dd and 2006mr in NGC 1316

SN 2006gy



The most luminous SN ever? M_V = –22, rise time >50 days
See papers by Smith et al. 2007 and Ofek et al. 2007

SN 2006gy

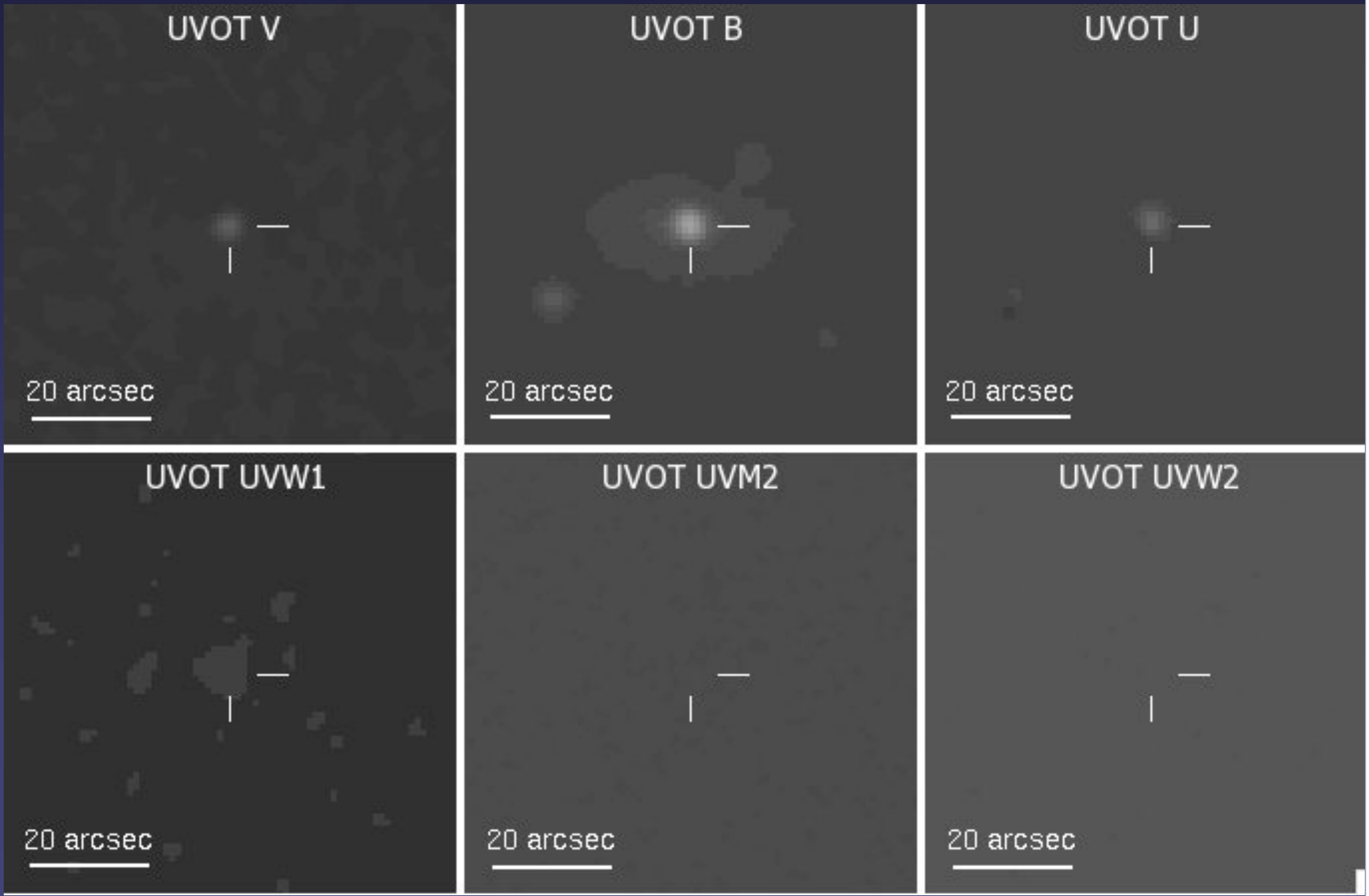


Two Swift UVOT and XRT observations.

SN 2006gy recovered in the optical with UVOT using image subtraction.

The non-detection with Swift XRT places tight upper limits on the mass-loss rate of the progenitor, $\dot{M} < 10^{-4} M_{\odot}$ yr^{-1}

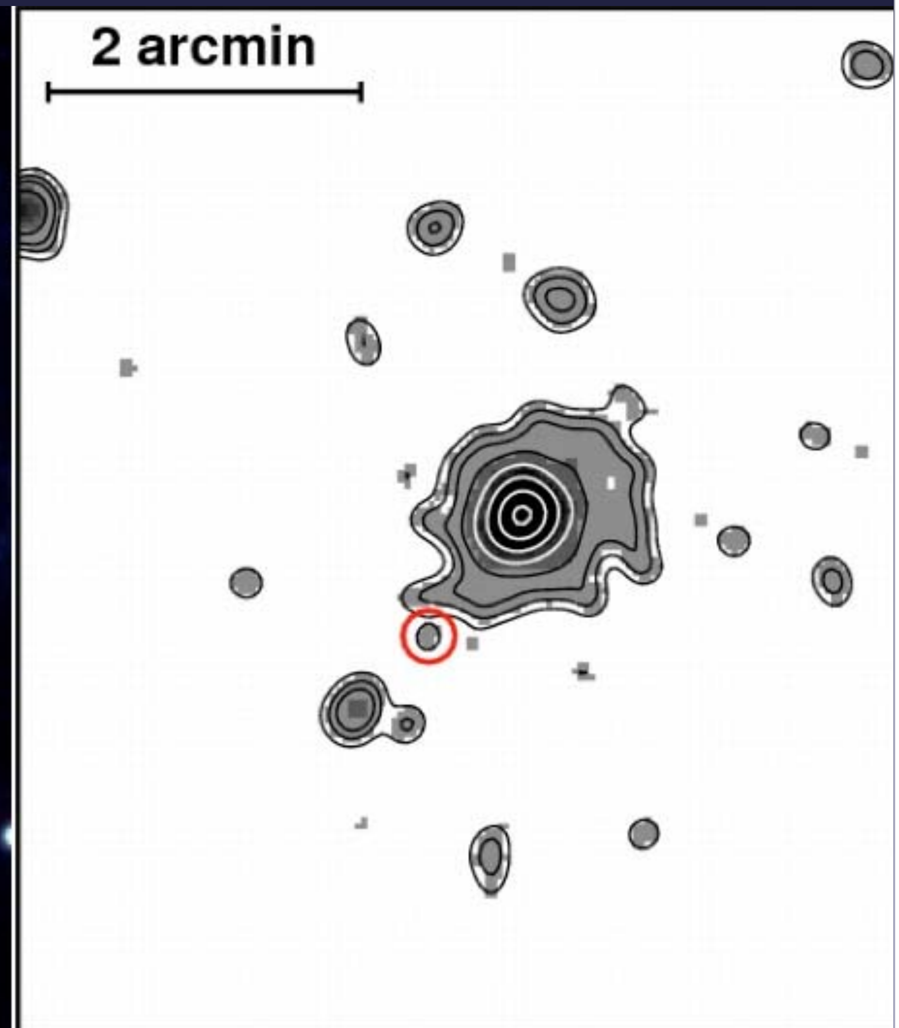
SN 2006gy



Optical, but no UV emission detected from SN 2006gy

SN 2005ke in NGC 1371

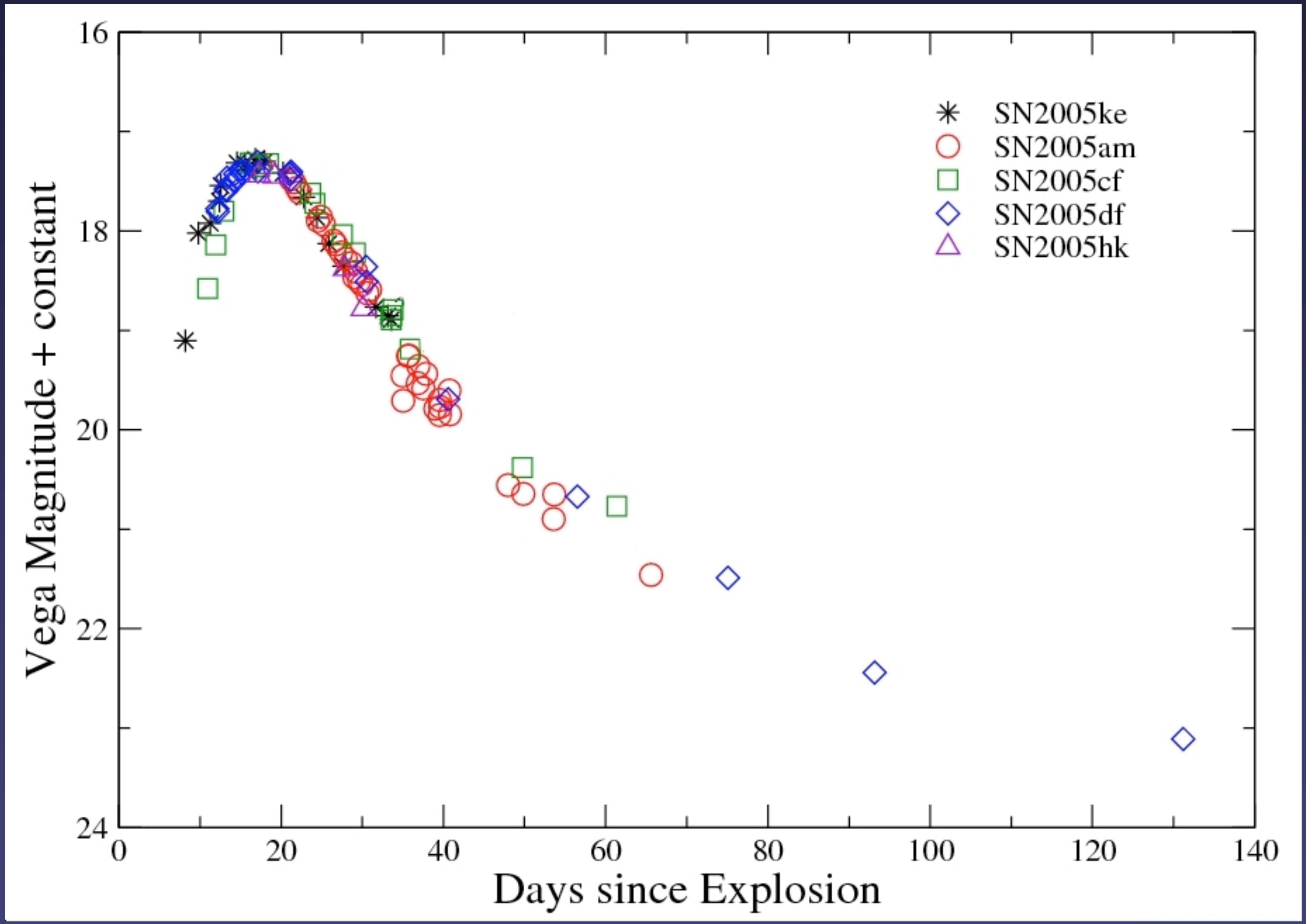
UVOT ultraviolet



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 $3 \times 10^{-6}\ M_\odot\ yr^{-1}$
- CSM density $4 \times 10^{7}\ cm^{-3}$ at a distance of 2×10^{15} cm

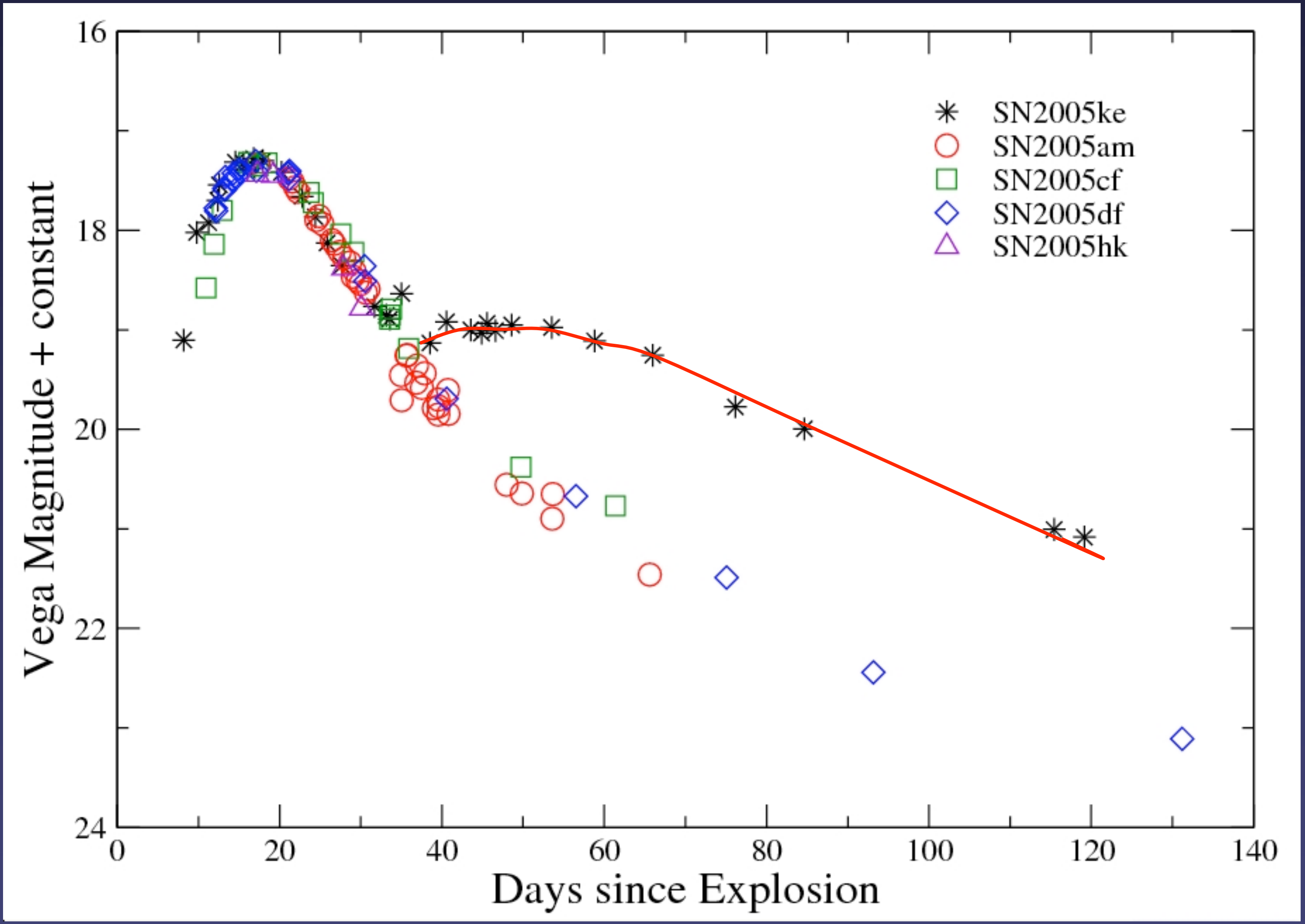
SN 2005ke in NGC 1371



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?

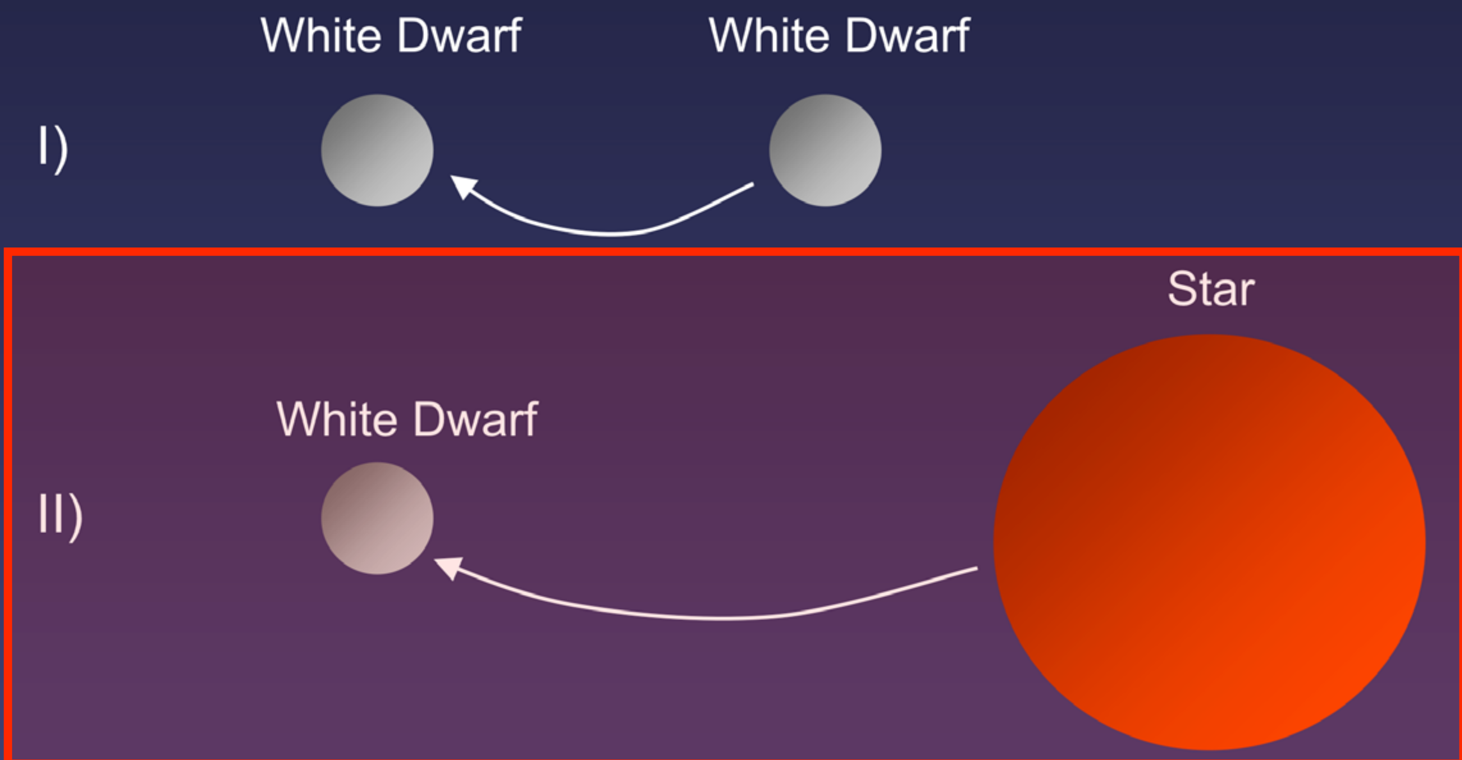
SN 2005ke in NGC 1371

- First tentative detection of CSM interaction for a SN Ia in X-rays
- UV excess independently confirms CSM interaction
- Direct obs. evidence for a companion star in a SN Ia system?
- Companion's mass-loss rate and CSM matter density can be measured for the first time for a SN Ia:

$\dot{M} = 3 \times 10^{-6}\ M_{\odot}\ \mathrm{yr}^{-1}$

$\rho_{\mathrm{CSM}} = 4 \times 10^{7}\ \mathrm{cm}^{-3}$ at a distance of $r = 3 \times 10^{15}$ cm

SN Ia Systems



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

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

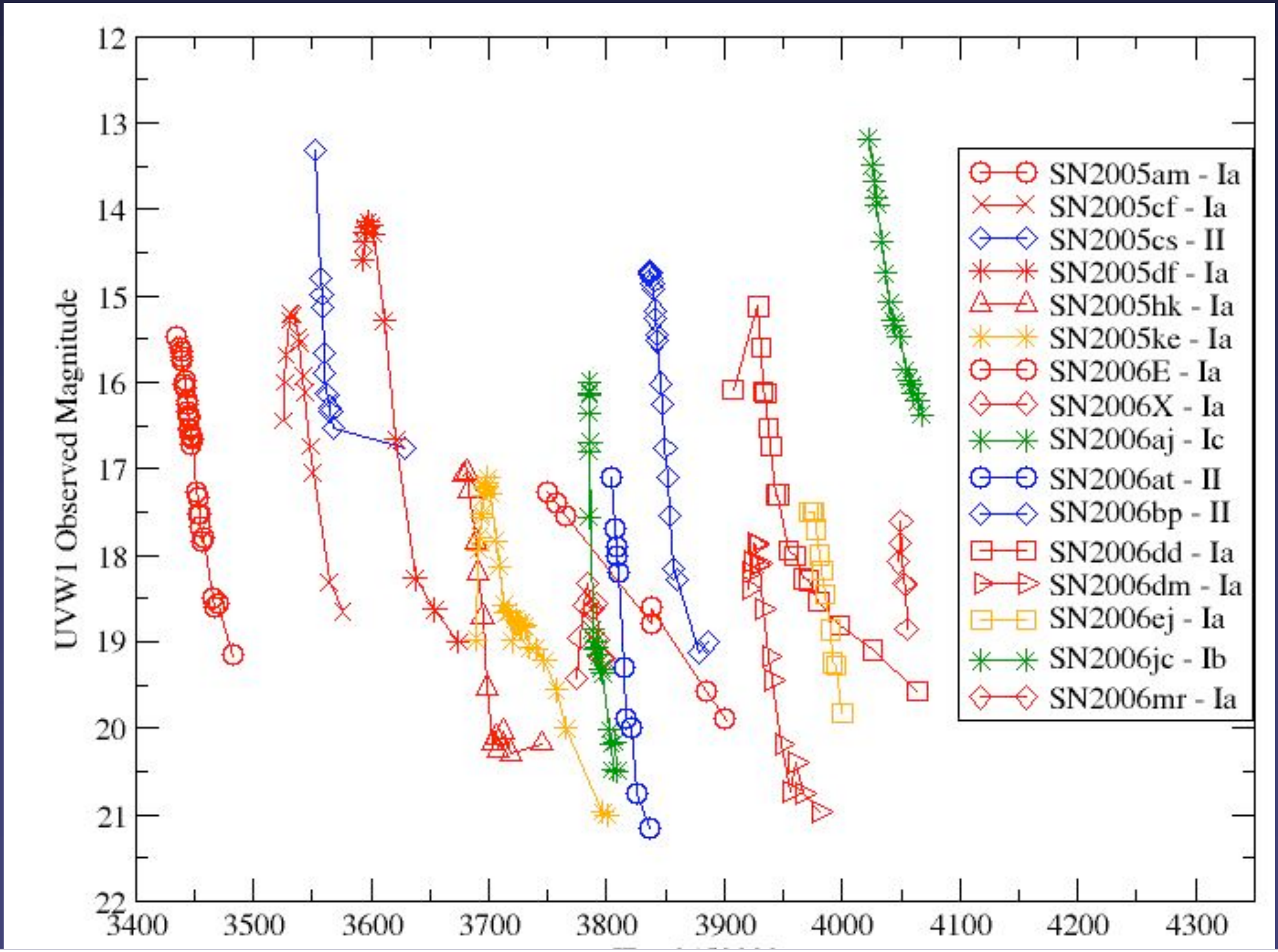
Two scenarios how thermonuclear SN (Type Ia) systems could look like

Primary Objectives

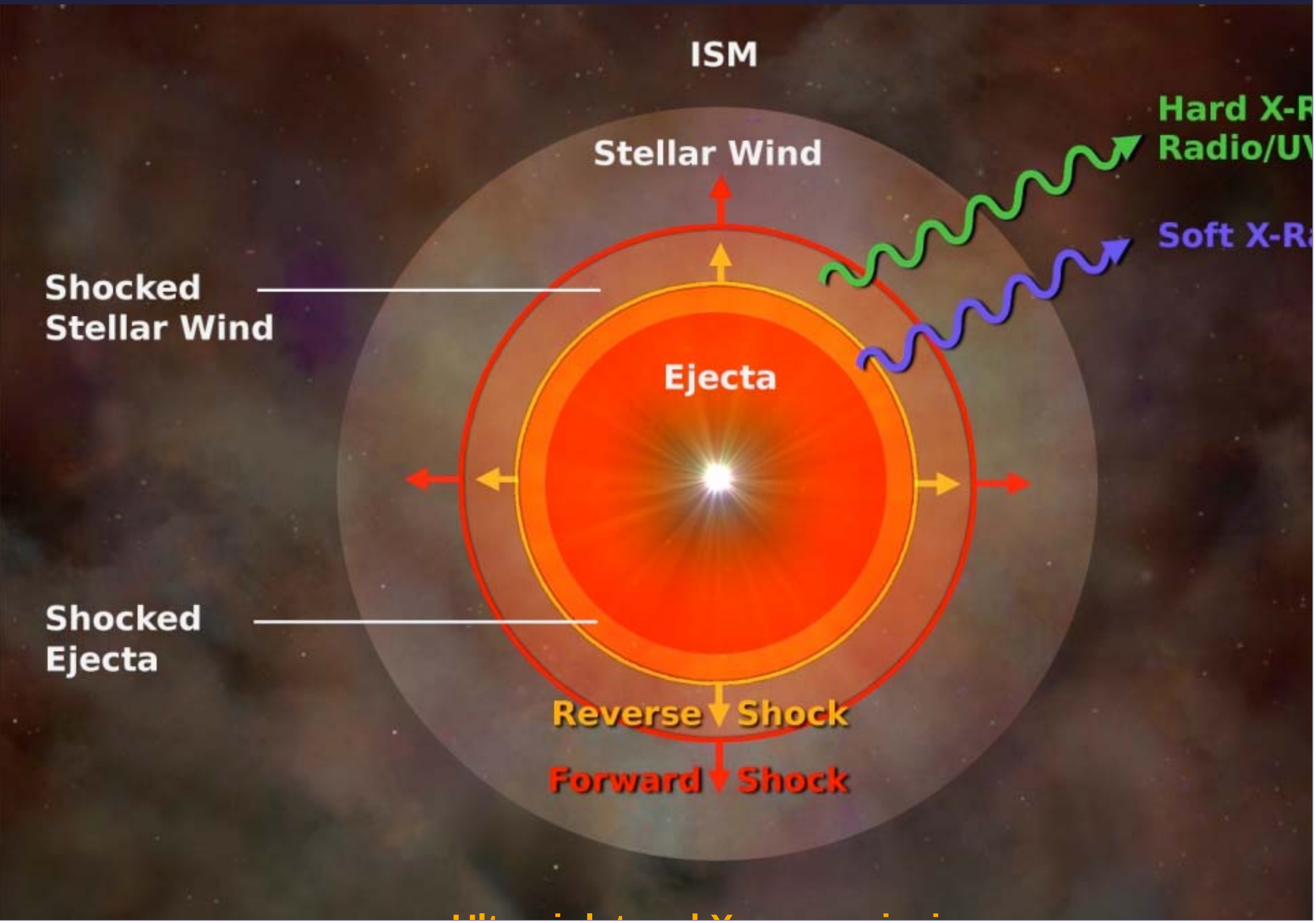
Core-Collapse SNe:

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

UVOT Lightcurves of SNe



Circumstellar Interaction

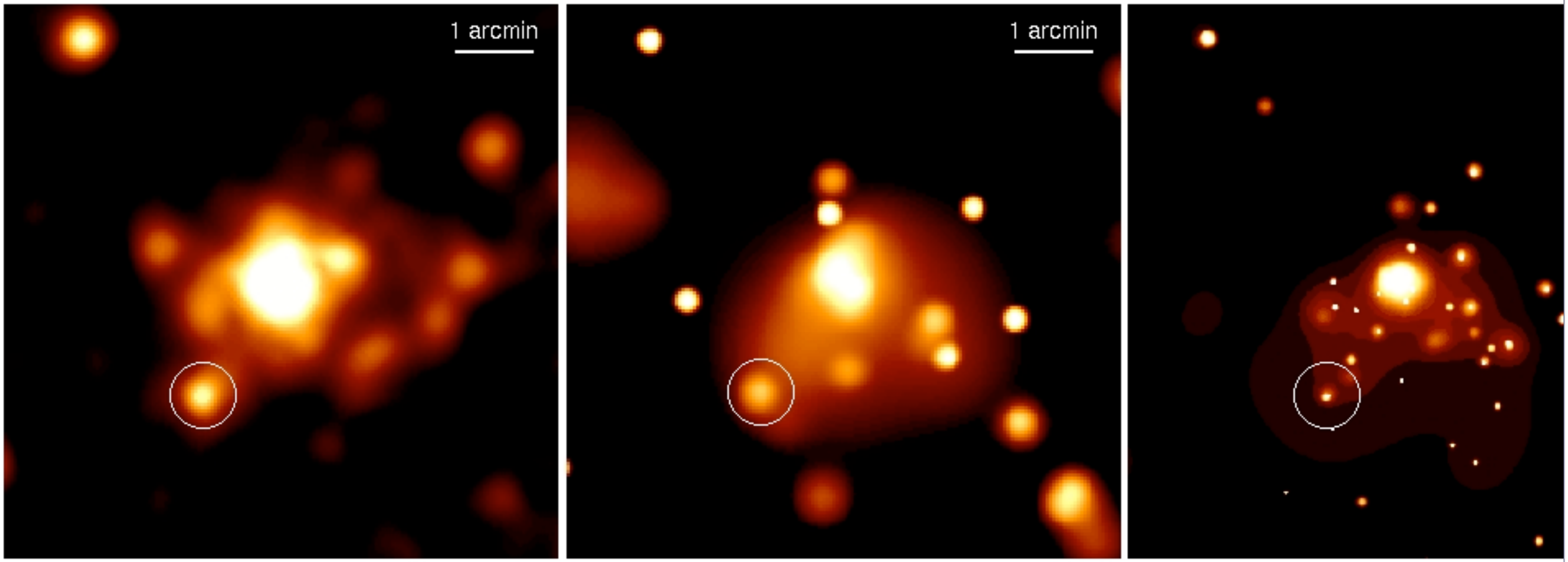


SN 2006X and SN 1979C in M100

UVOT *V, B, U* UVOT *UVW1, UVW2, UVM2* XRT 0.2–10 keV

- SN 2006X (young type Ia) not detected in the UV and in X-rays
- SN 1979C (type II) is one of the oldest SN still visible in UV and X-rays

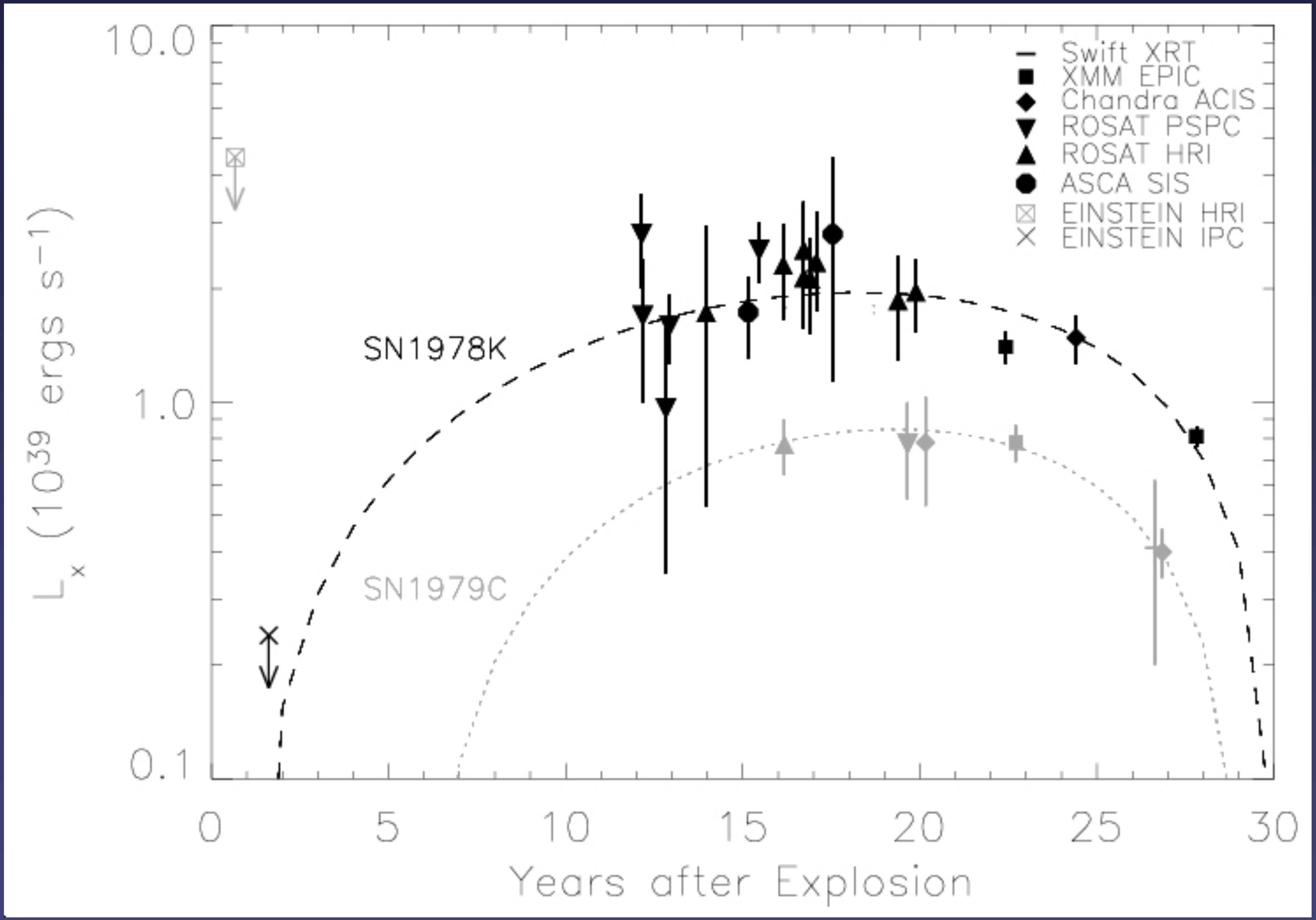
SN 1979C in M100



XMM-Newton Swift XRT Chandra ACIS

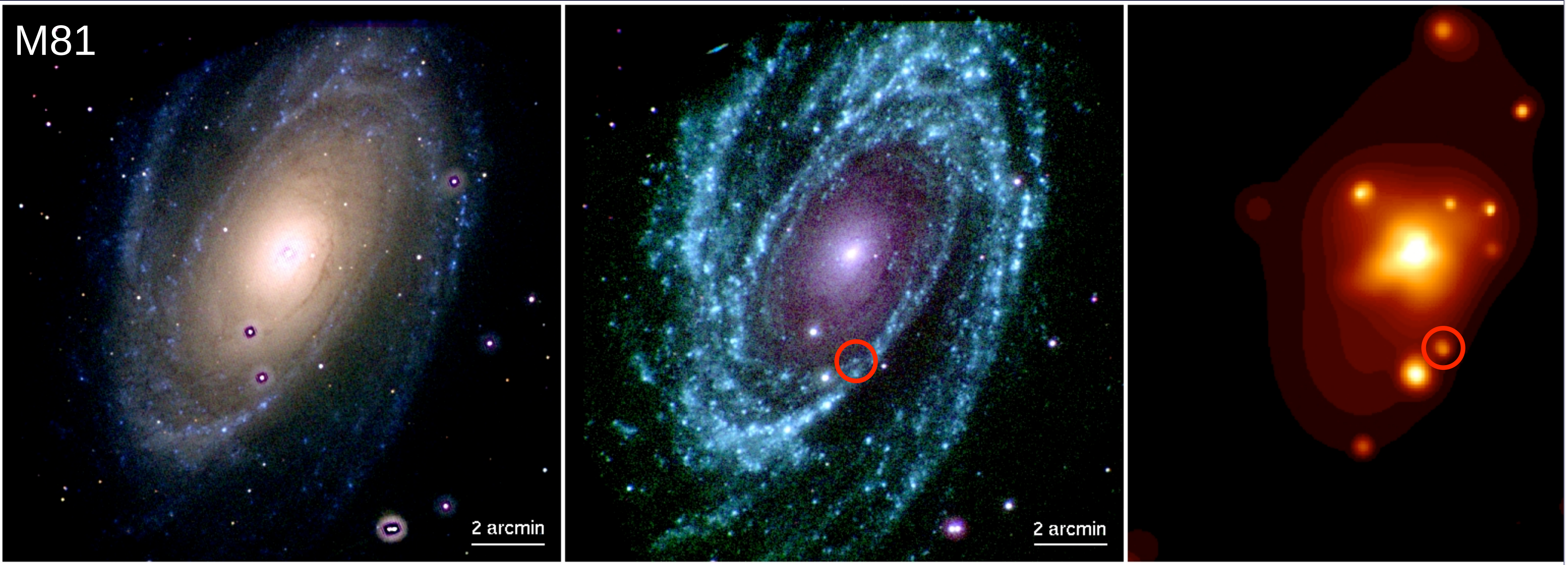
- High X-ray luminosity, $L_x = 8 \times 10^{38}$ ergs/s (0.3–2 keV) at t = 26 years
- High and constant mass-loss rate of $1.5 \times 10^{-4}\ M_{\odot}\ yr^{-1}$ over >20,000 yrs in the history of the progenitor

SNe 1978K and 1979C



- SNe 1979C and 1978K are the oldest known X-ray emitting SNe
- Surprisingly similar evolution
- Evolution is best described by a t^2 rise followed by a t^{-3} decline

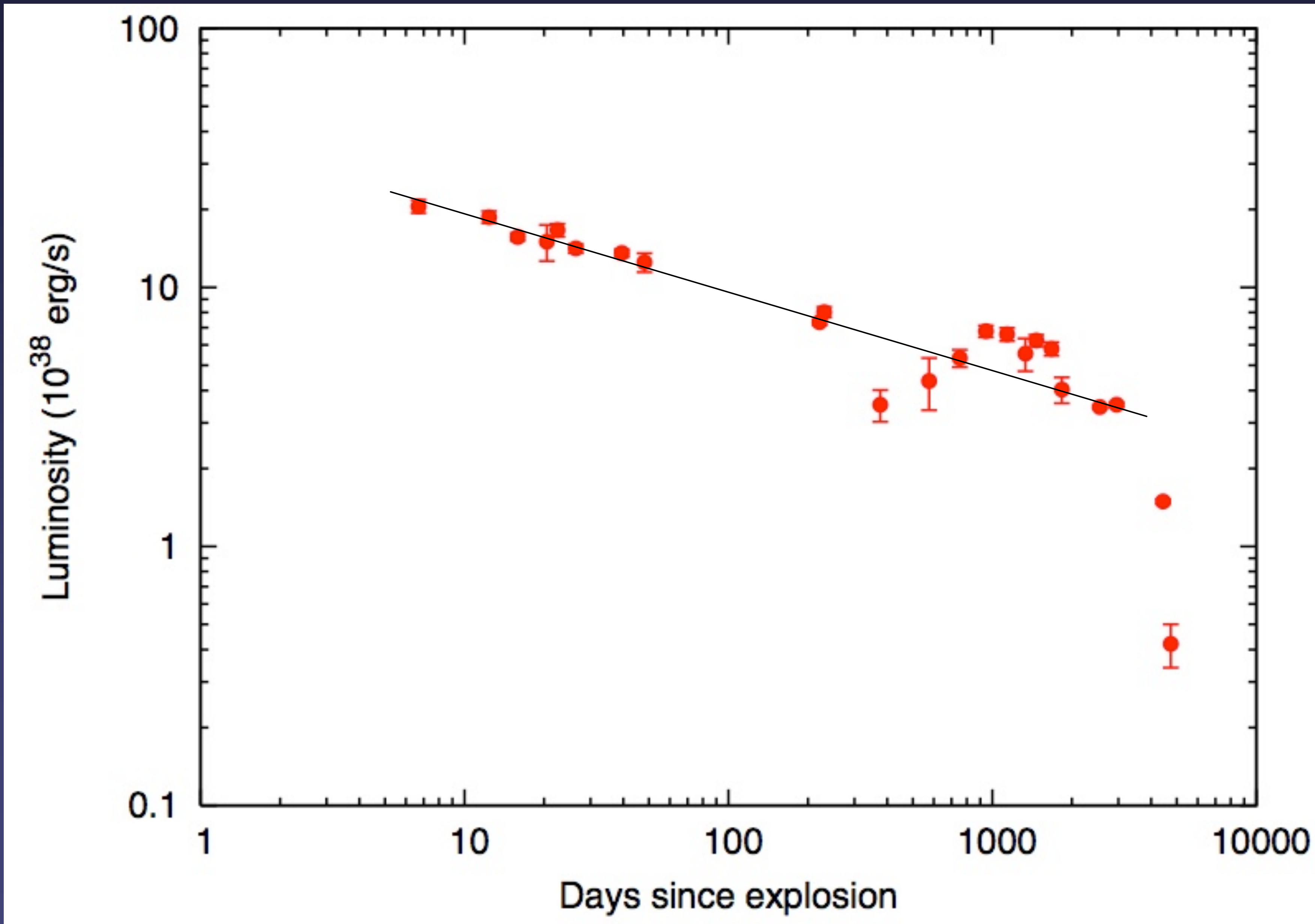
SN 1993J



Swift optical Swift UV Swift X-rays

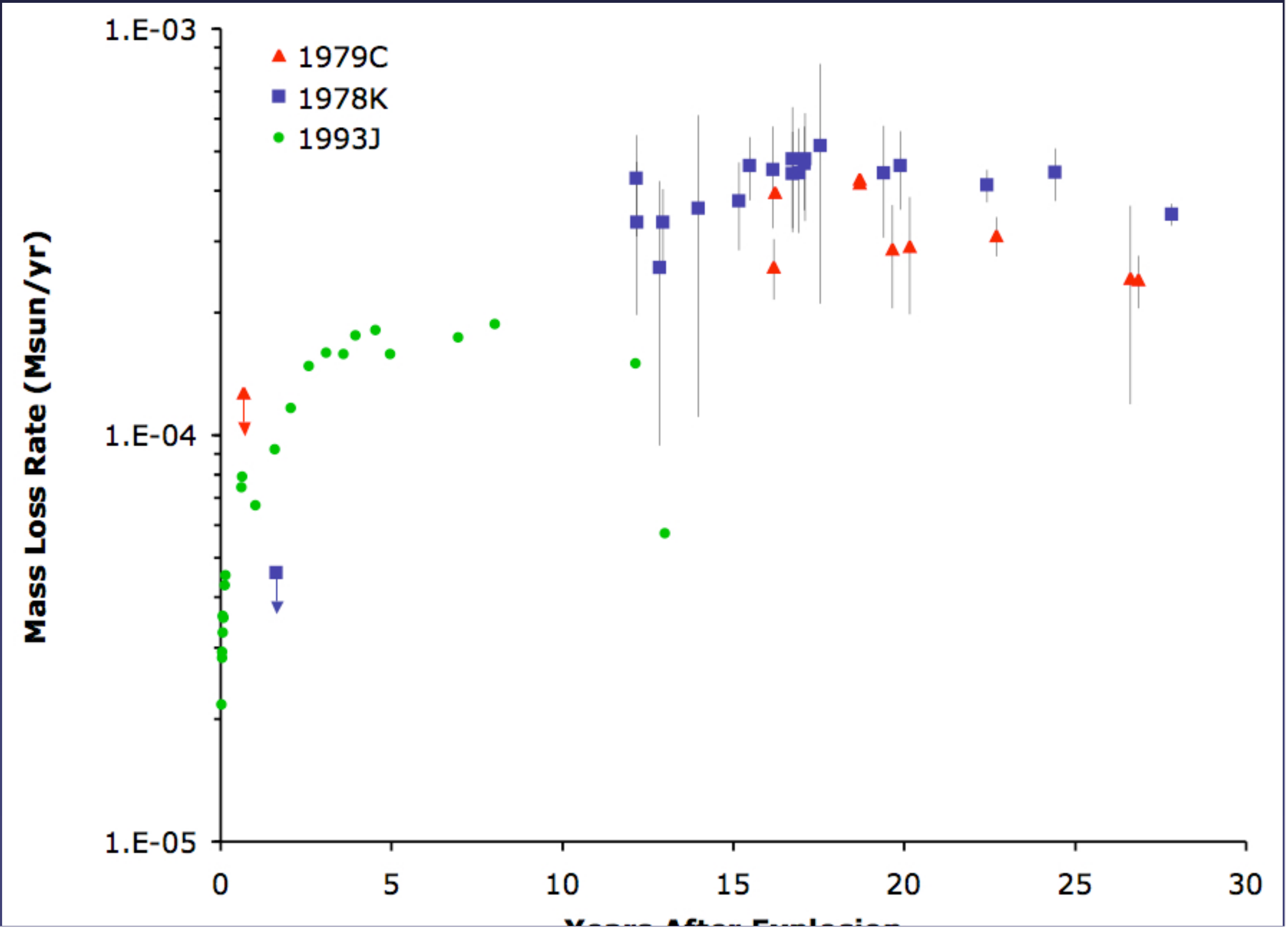
Late-time X-ray observations with *Rosat*, *XMM-Newton*, *Chandra*, and *Swift* allowed to construct the long-term X-ray light curve over a >12 year period.

SN 1993J

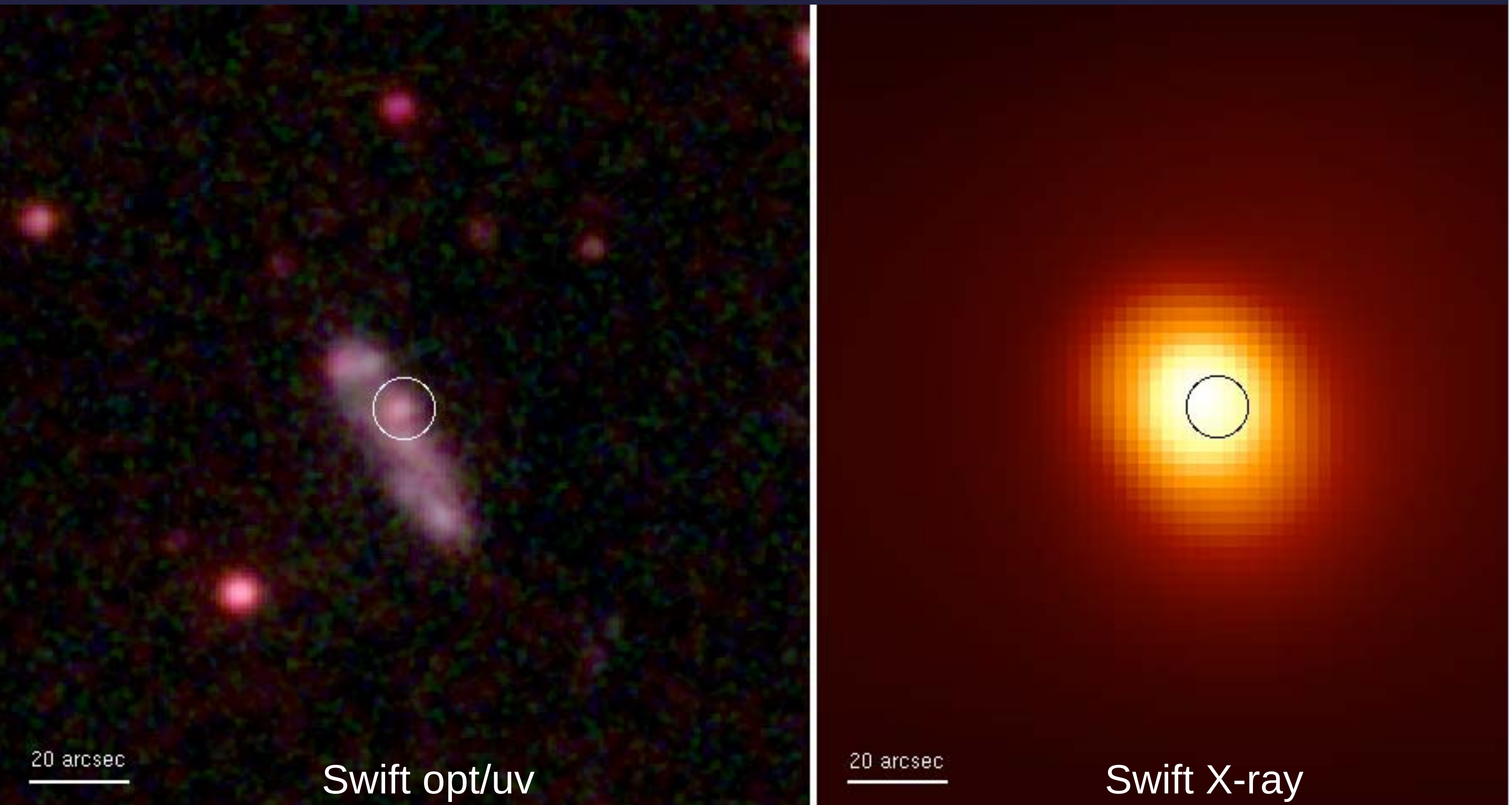


Multi-mission X-ray light curve shows an overall (slow) $t^{-0.3}$ rate of decline

Mass-Loss Rates of SNe 93J, 78K and 79

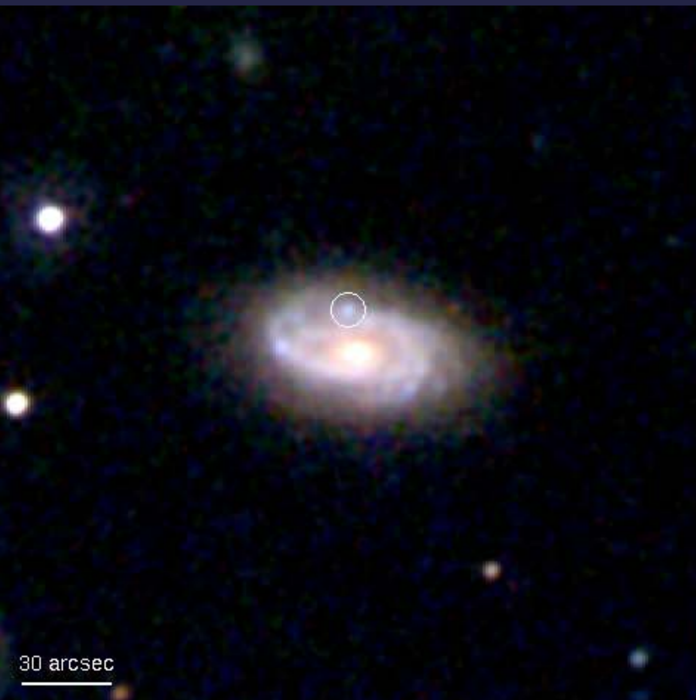


SN 2005kd

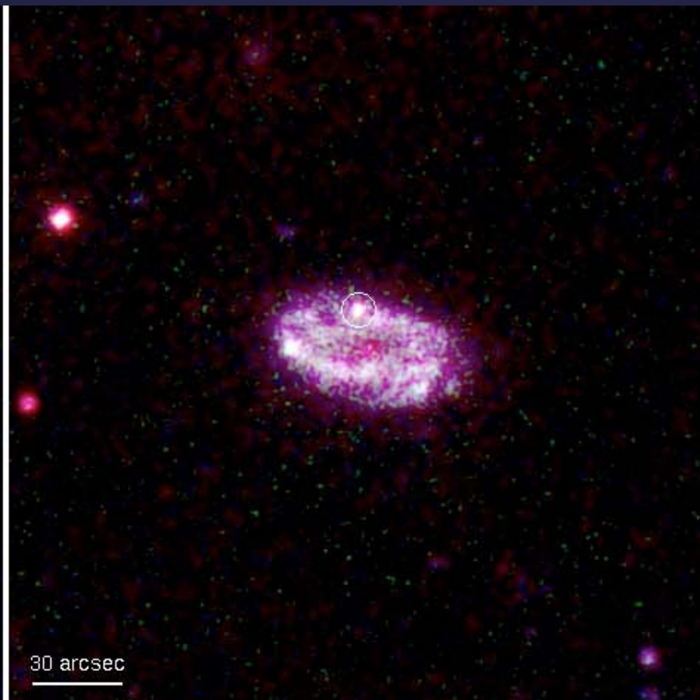


- Type IIn SN
- High X-ray luminosity, $L_x = 1.5 \times 10^{41}$ ergs/s (0.2–10 keV)
- High mass-loss rate of some $10^{-4}\ M_\odot\ yr^{-1}$

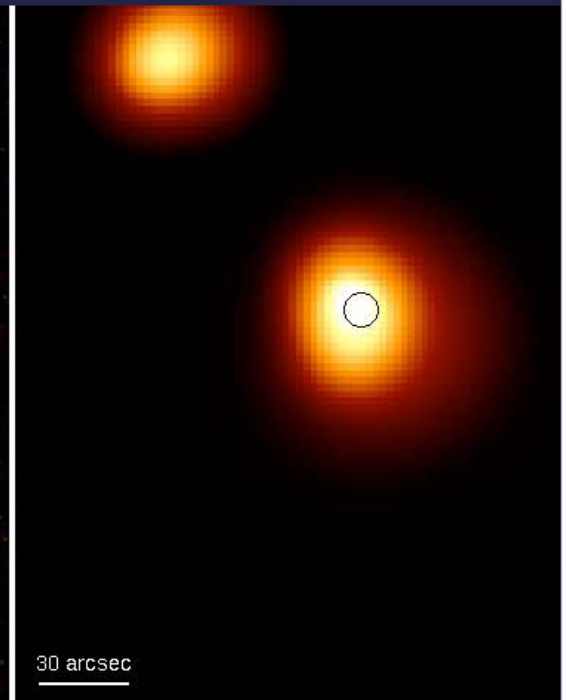
SN 2005ip



Swift optical



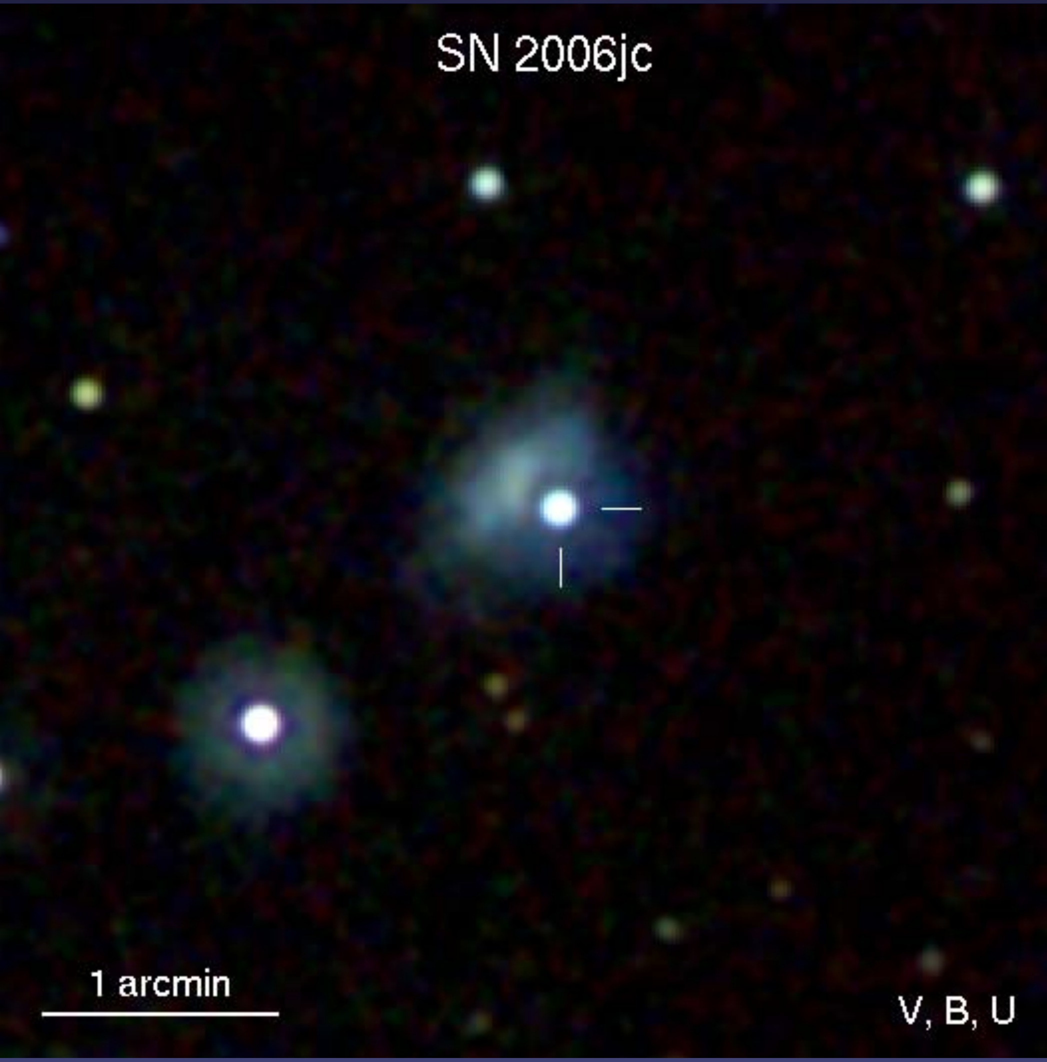
Swift UV



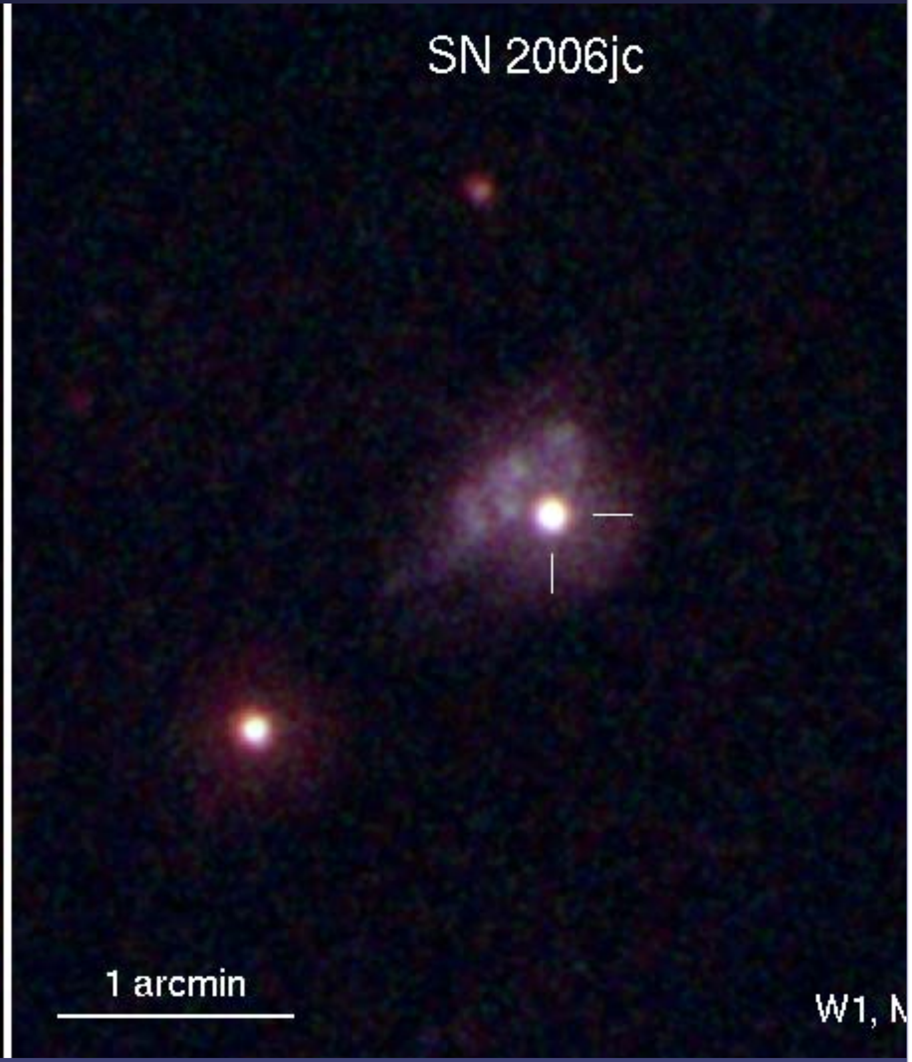
Swift X-ray

- 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 $10^{-4}\ M_{\odot}\ yr^{-1}$

SN 2006jc



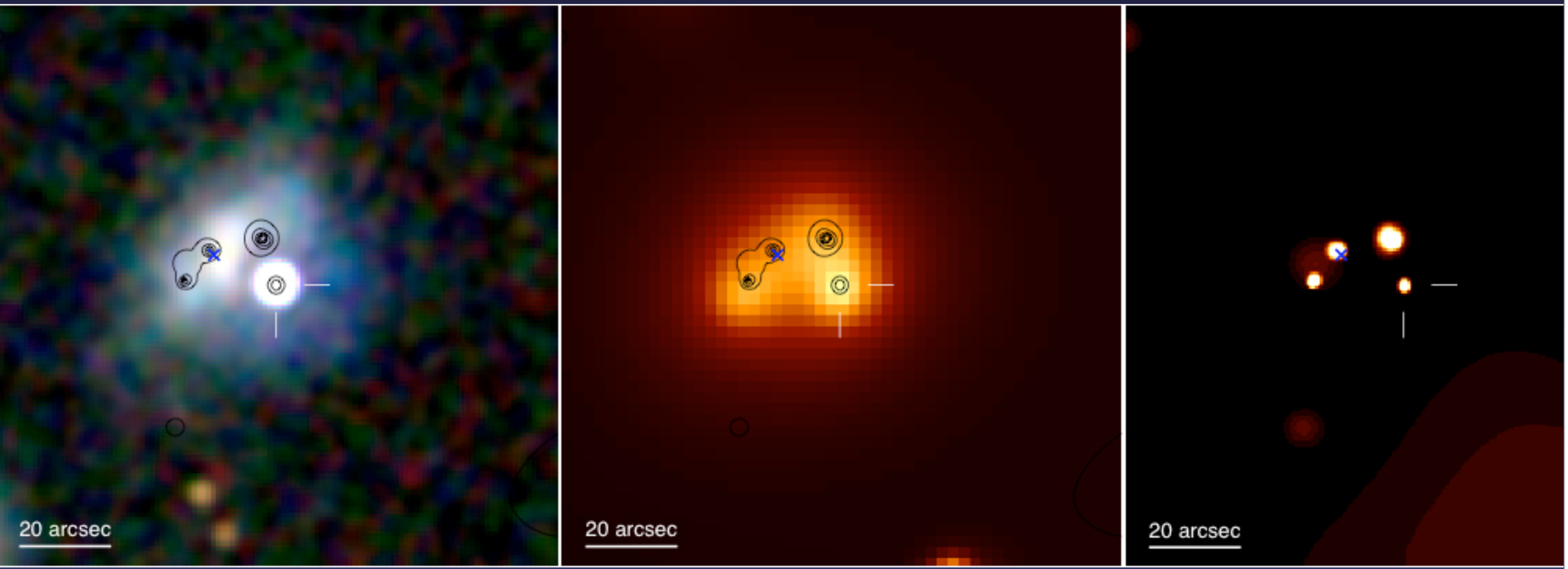
Swift optical



Swift ultraviolet

The brightest SN observed by Swift (13 mag)

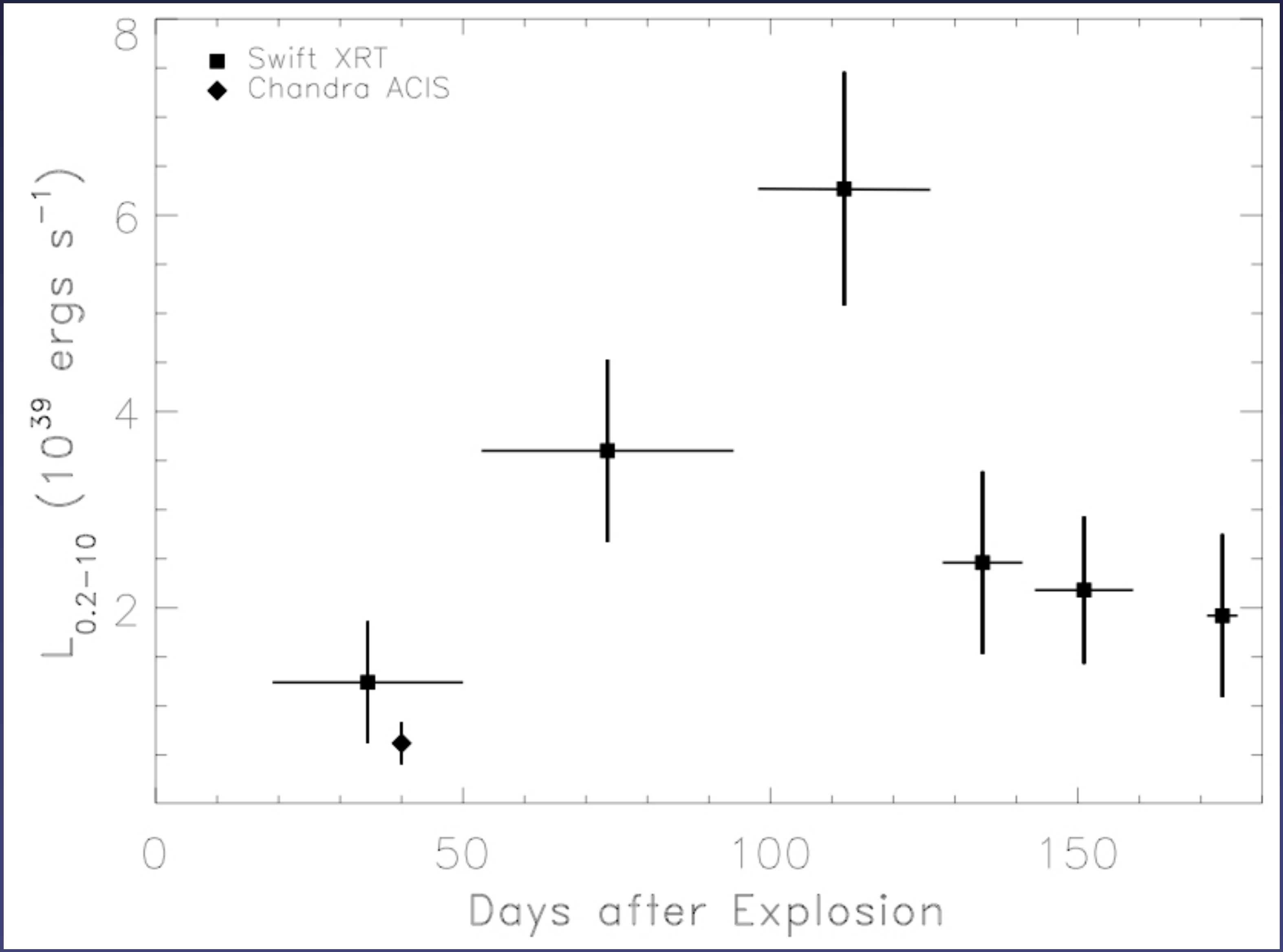
SN 2006jc



Swift optical　　Swift X-ray　　Chandra X-ray

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

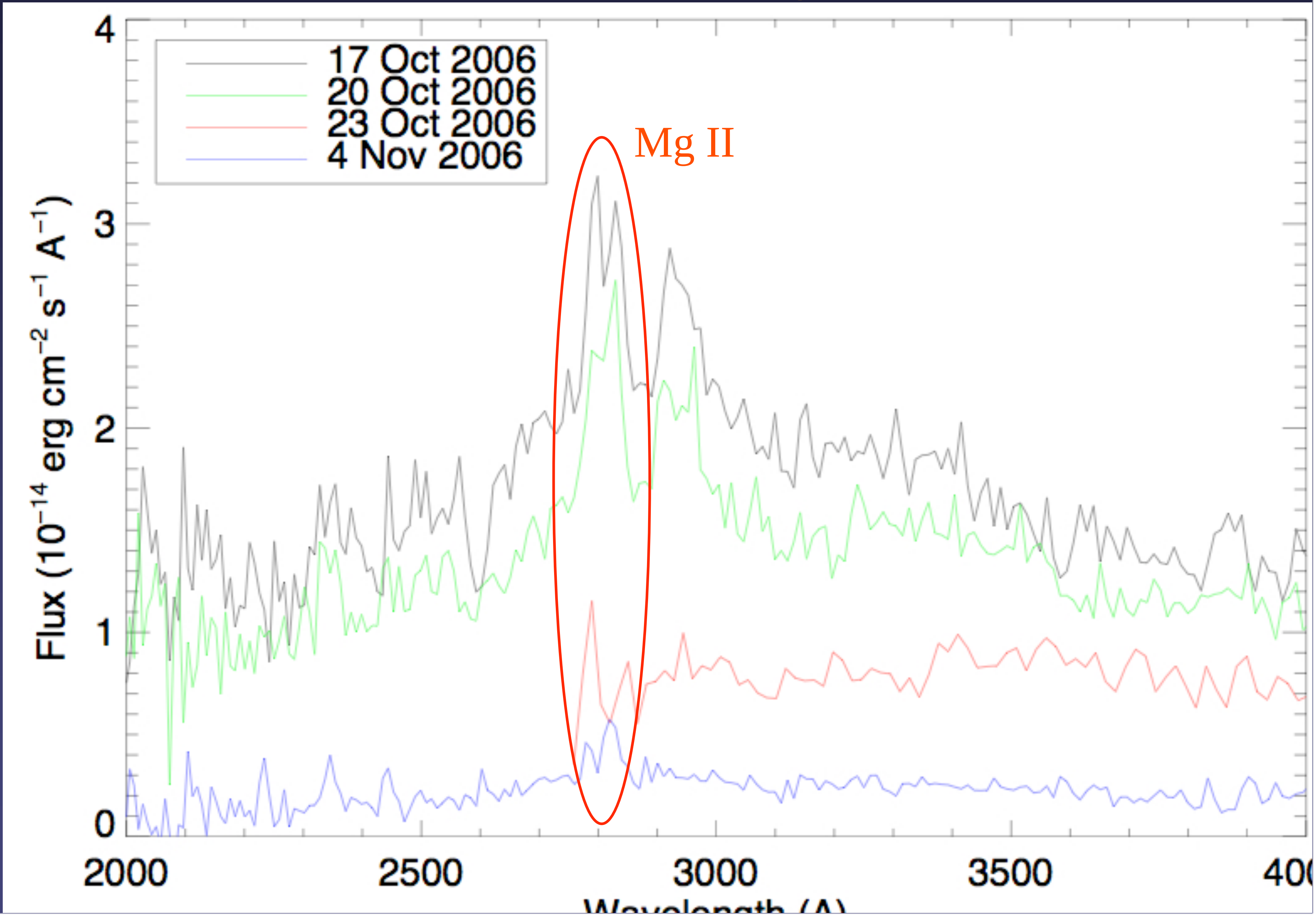
SN 2006jc



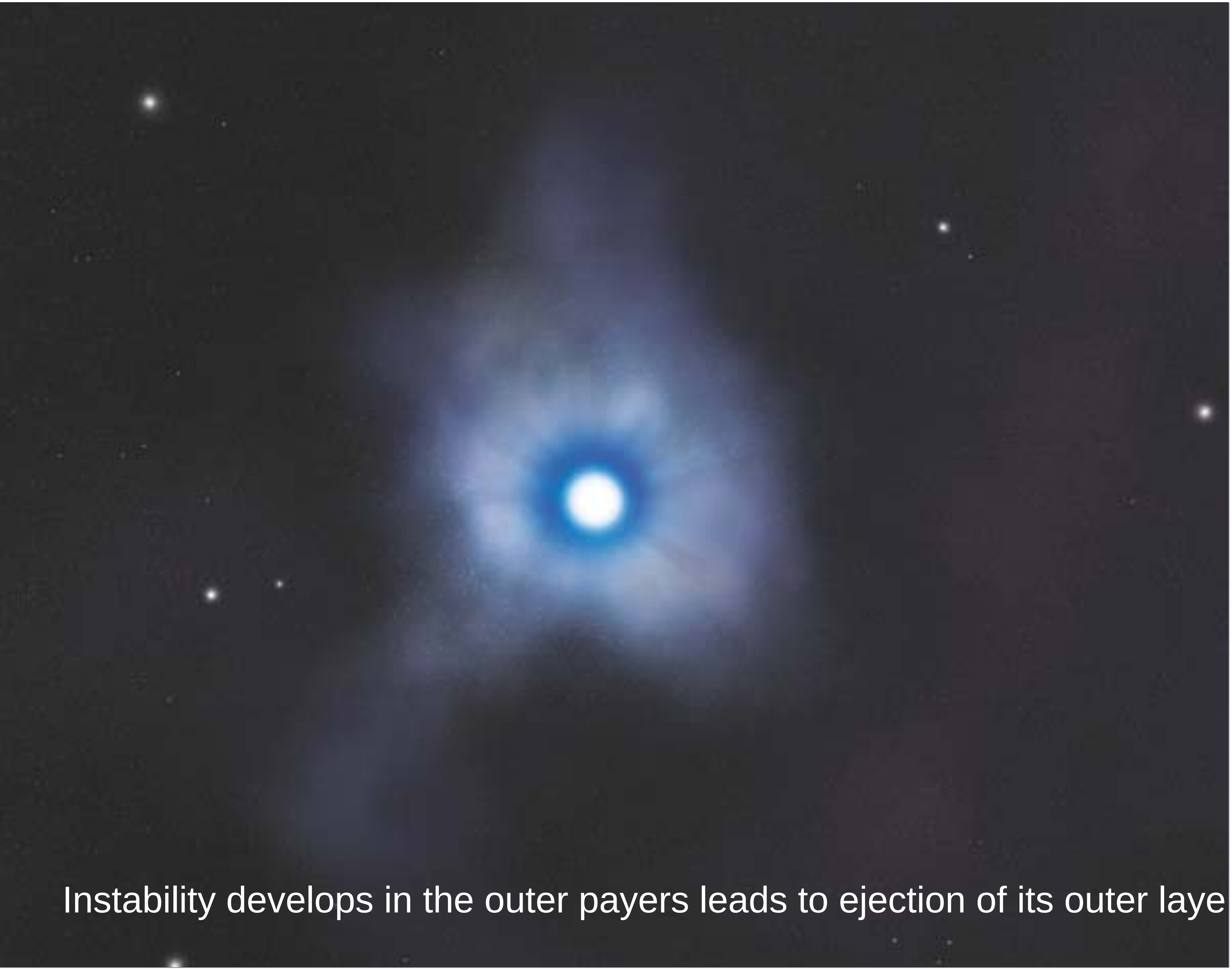
Brightening in X-rays: dense shell around the site of the explosion?

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

SN 2006jc


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

Blue supergiant at the end of its life.


Instability develops in the outer payers leads to ejection of its outer laye


Ejected material has formed a shell after 2 years.

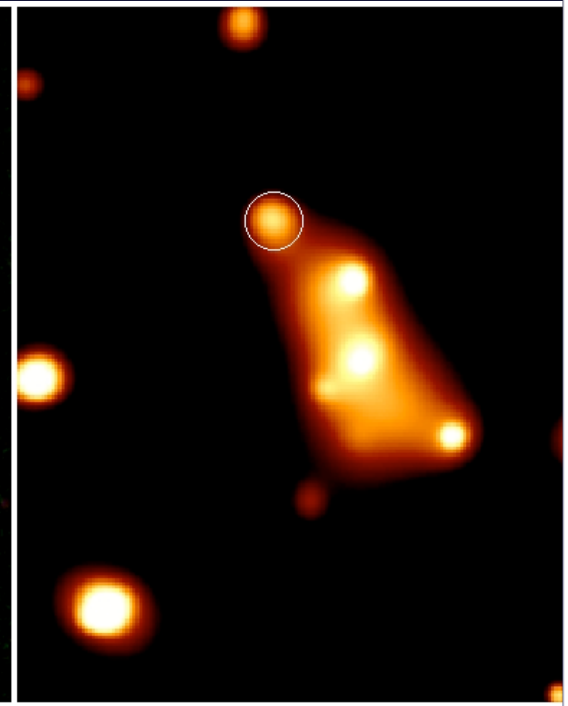
Core-collapse of star leads to formation of outgoing SN shock.


Shock hits the shell and heats to X-ray temperatures.

SN 2006bp in NGC 3953

Swift optical

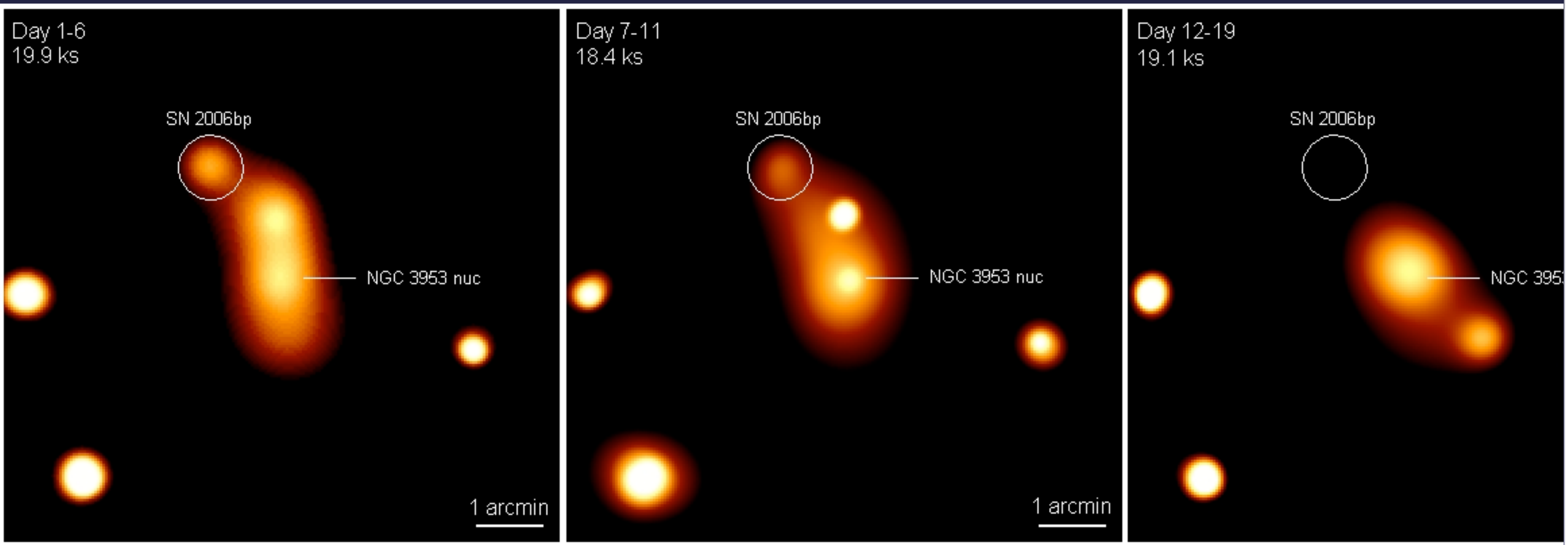
Swift UV



Swift X-ray

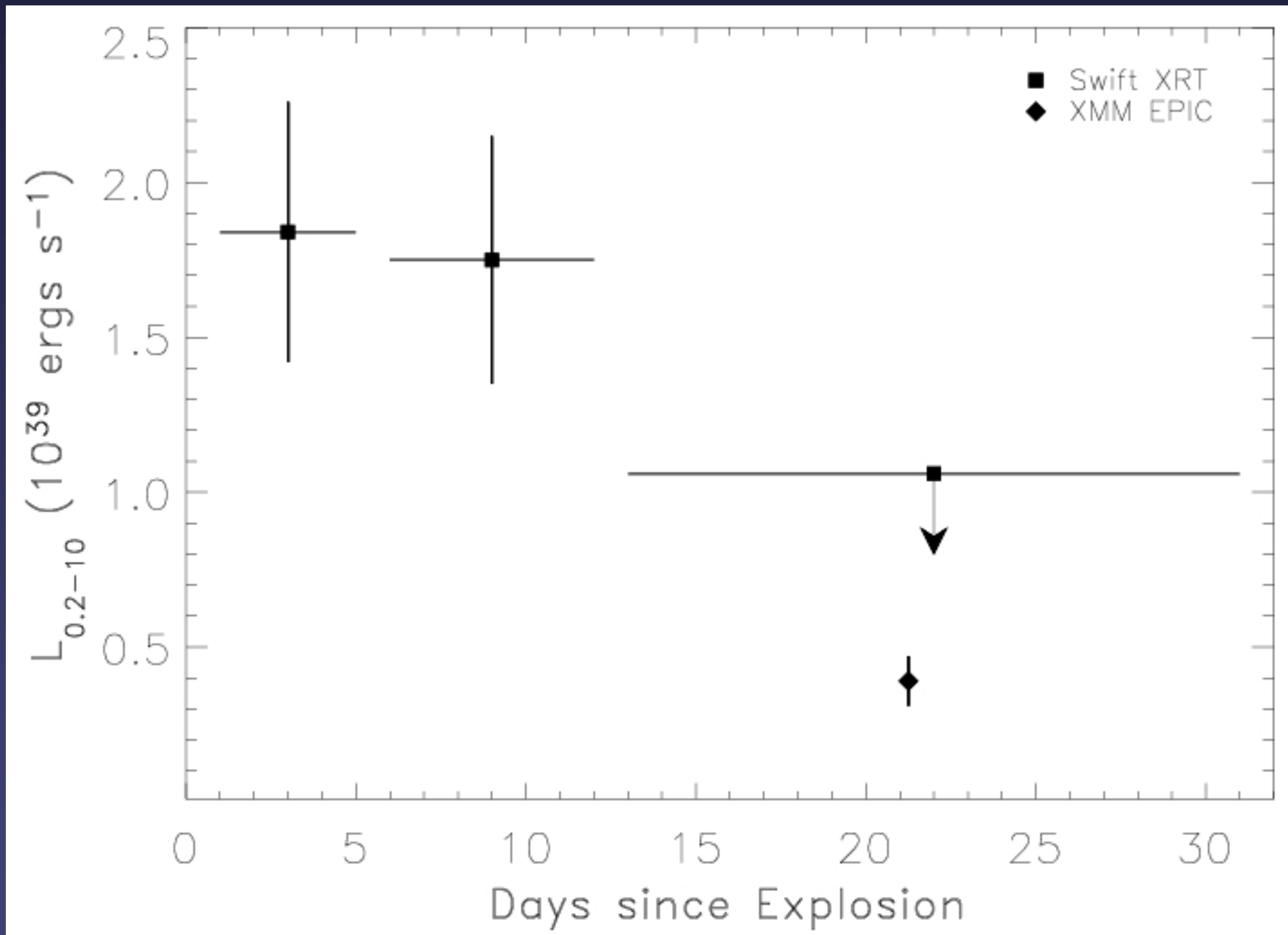
- Type IIP ('plateau') SN at d = 14.9 Mpc
- Observed with Swift <1 day after the explosion
- Detection of X-ray emission < 1 day after the explosion
- Earliest detection of a SN in X-rays (minus GRB/SN), $L_x = 2 \times 10^{39}$ ergs/s

SN 2006bp in NGC 3953



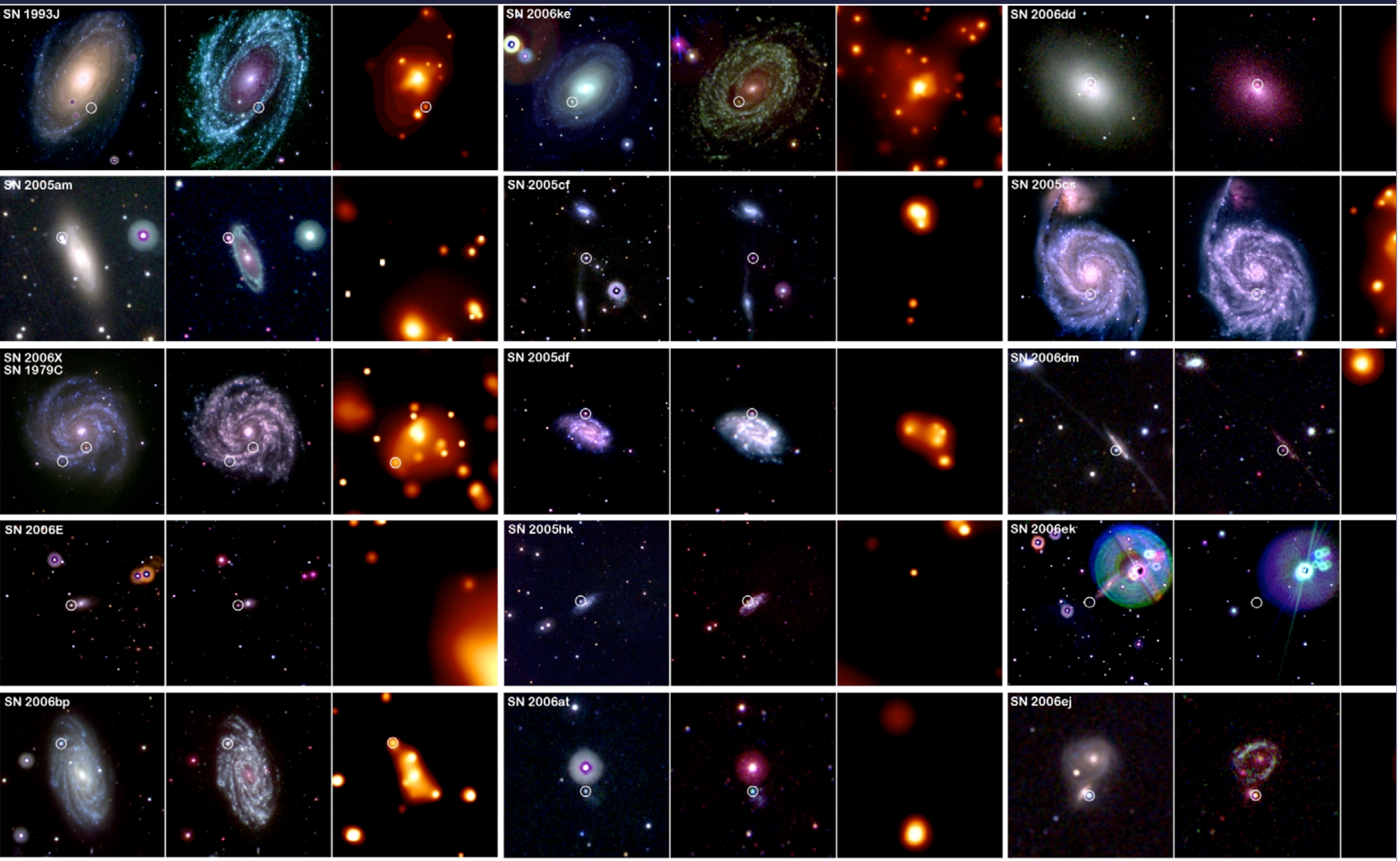
- Daily *Swift* observations allow timing analysis of X-ray flux
- SN would have been missed with any other observatory (XMM, Chandra)
- With *Swift* we are probing a previously unexplored time domain for SNe
- The SN is fading below the detection threshold within 10 days
- Detection of previously unknown,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

SN 2006bp in NGC 3953



- Recovered in an XMM-Newton DDT observation 21 days after outburst
- X-rays is inconsistent with inverse Compton scattered photospheric photons on relativistic electrons due to high required Lorentz factors (~10–100)

Swift Mugshots of Supernovae



38 SNe have been observed with *Swift* to date, from 1–200 days after the explos

Summary

- 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 candles with large implications for cosmology and future missions (SNAP, et
  - 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%.
- Your input is needed:
  The more interest of the community to use *Swift*, and the more Swift UVOT and XRT papers, the brighter is Swift's prospect in the future.