X-Ray Observations of Supernovae as Probes of Stellar Environments

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X-Ray Supernovae

- 32 SNe have been detected in X-rays over the past 27 years In the near aftermath (days to years) after their explosions.

- X-ray luminosities range from 10^{34} erg/s (SN 1987A) to some 10^{41} erg/s (e.g., SNe 1988Z, 1995N, 2002hi) up to >10^{43} erg/s for GRB/SN (e.g., SN 2006aj/GRB060218).

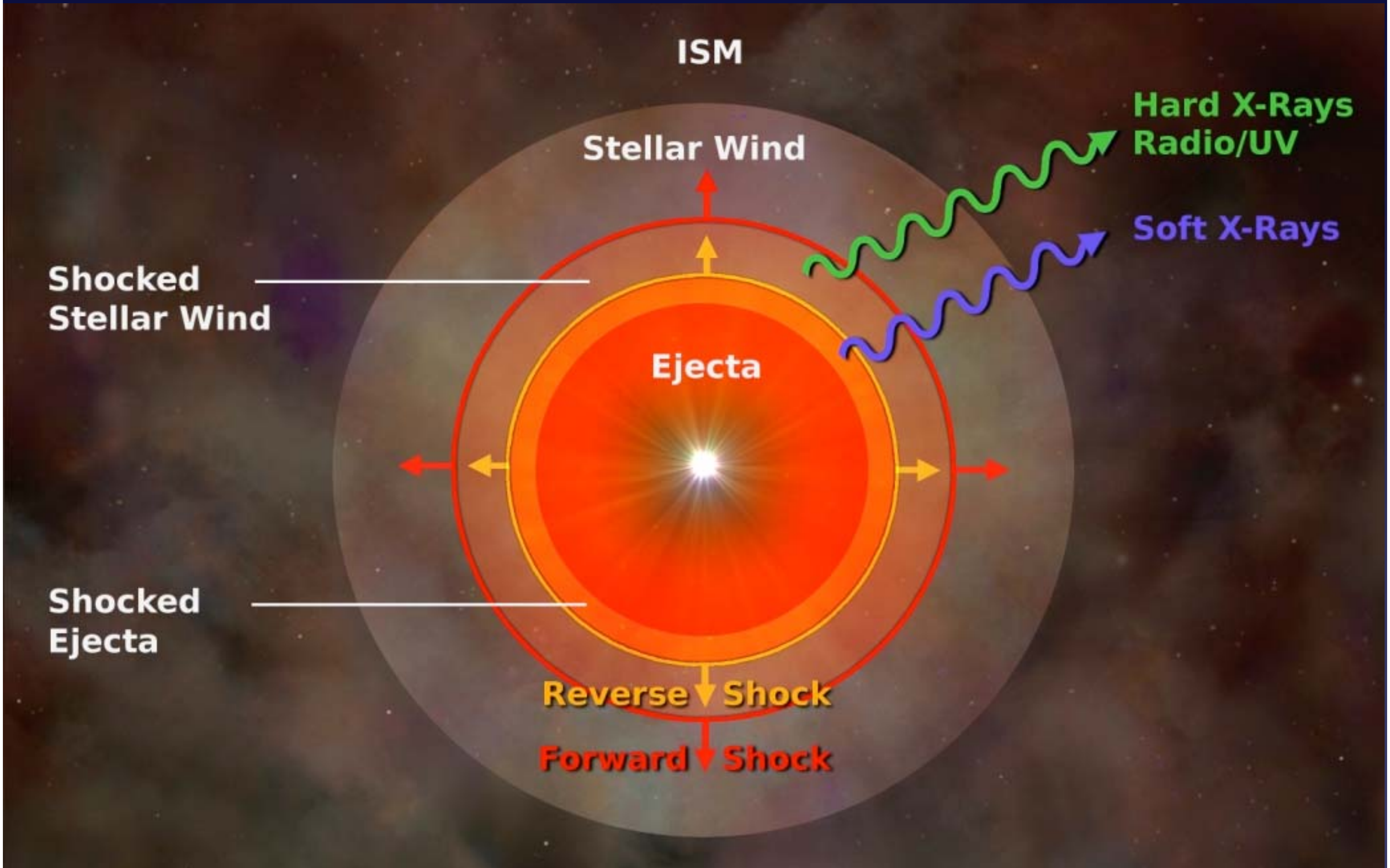
- Approx. half of all detections are from *Chandra*.

- *XMM-Newton* is very successful in follow-up observations to monitor the long-term X-ray evolution of SNe (see this talk) and to get high quality X-ray spectra.

- Due to its rapid response (hrs), flexible scheduling capabilies and multi-wavelength coverage, *Swift* is playing an increasingly important role in probing CSM interaction with UV and X-ray observations of young SNe.

Golden Age of X-Ray SN Research

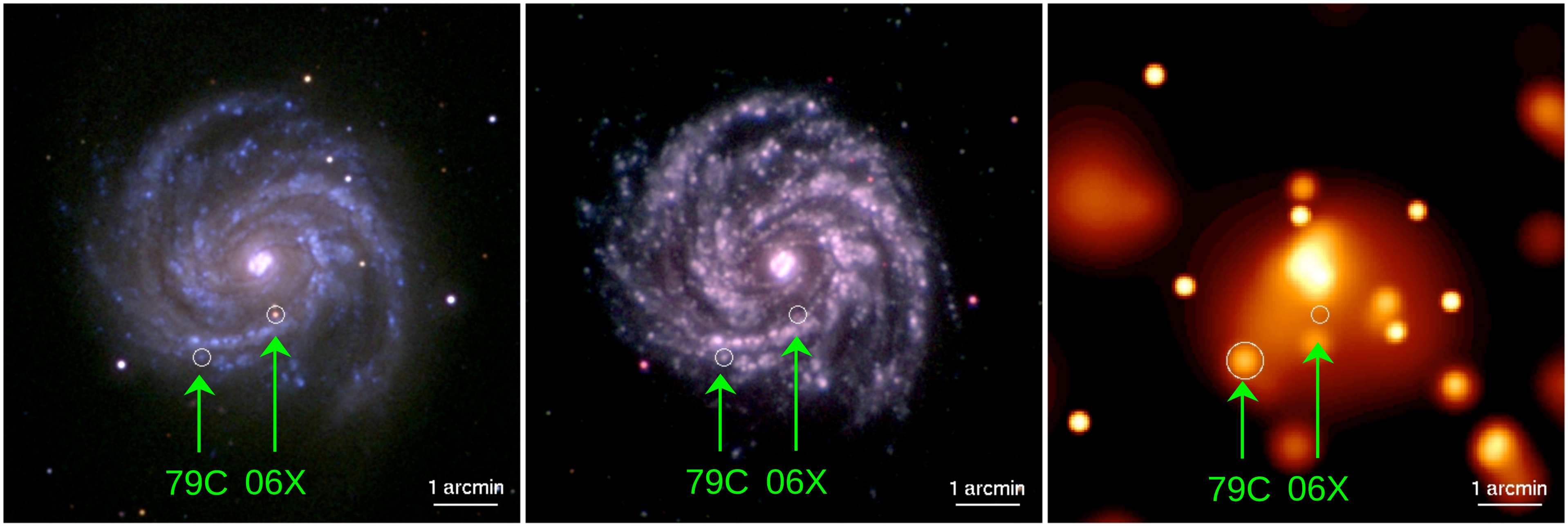
Circumstellar Interaction



Radio, Ultraviolet and X-rays emission

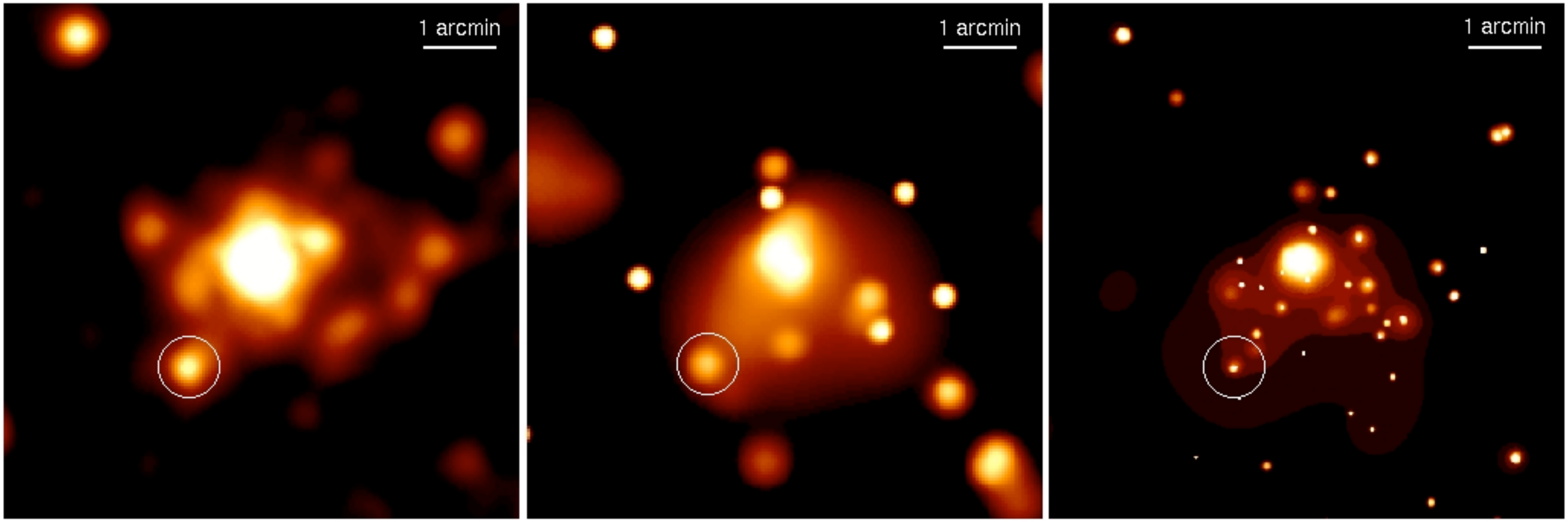
SN 2006X and SN 1979C in M100

Swift UVOT *V, B, U* | UVOT *UVW1, UVW2, UVM2* | *Swift* 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

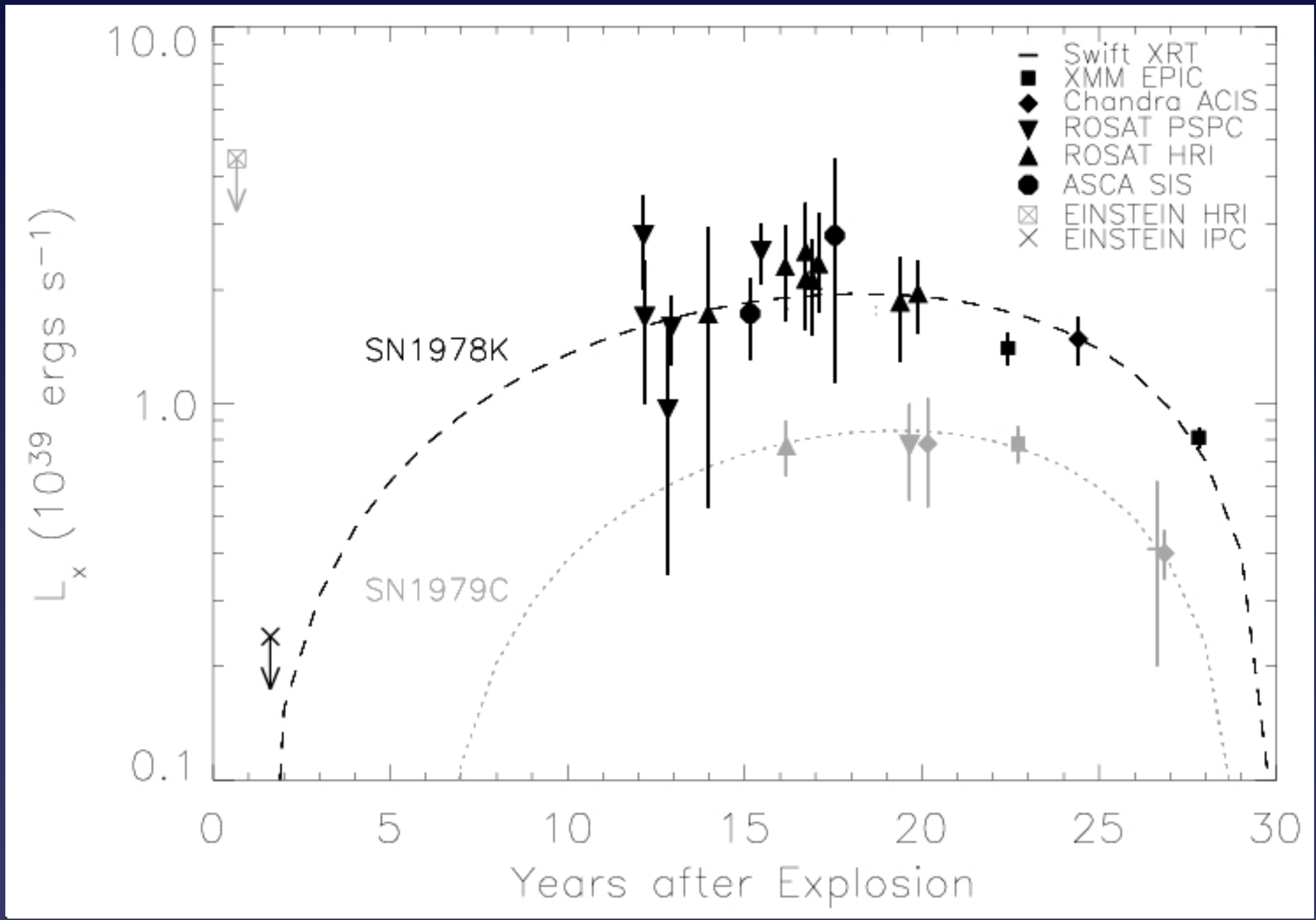
SN 1979C in M100



XMM-Newton *Swift* XRT *Chandra* ACIS

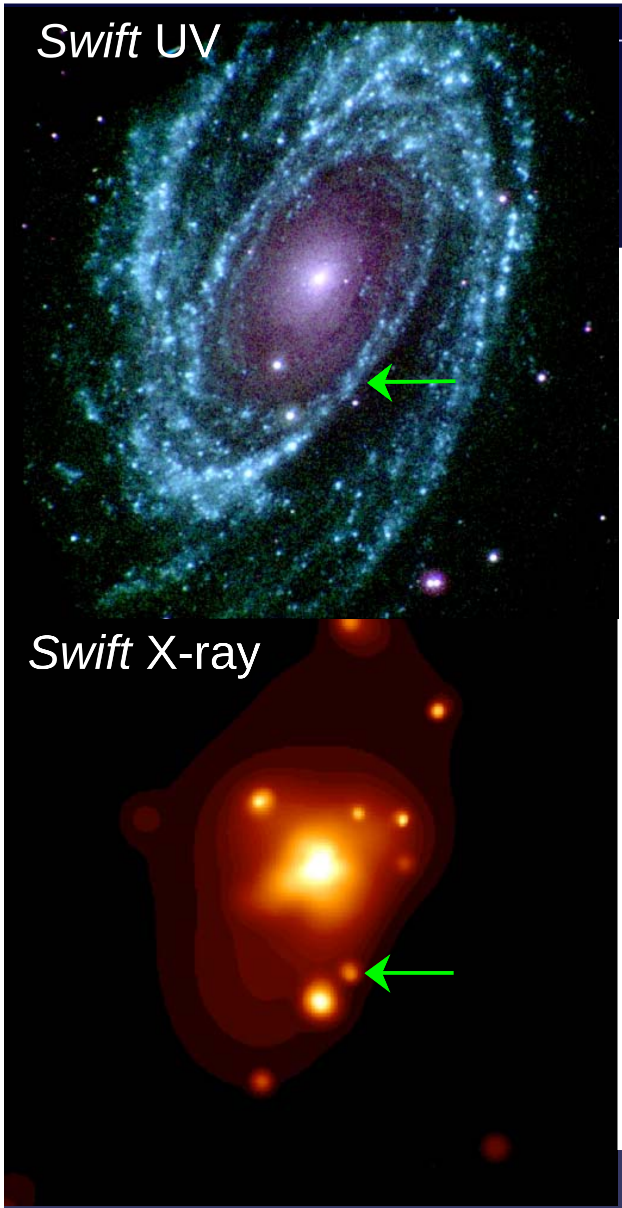
- High X-ray luminosity, $L_x = 8 \times 10^{38}$ erg/s (0.3–2 keV) at $t = 27$ years
- High and constant mass-loss rate of $1.5 \times 10^{-4}\ M_{\odot}\ yr^{-1}$ over >20,000 yrs in the history of the progenitor

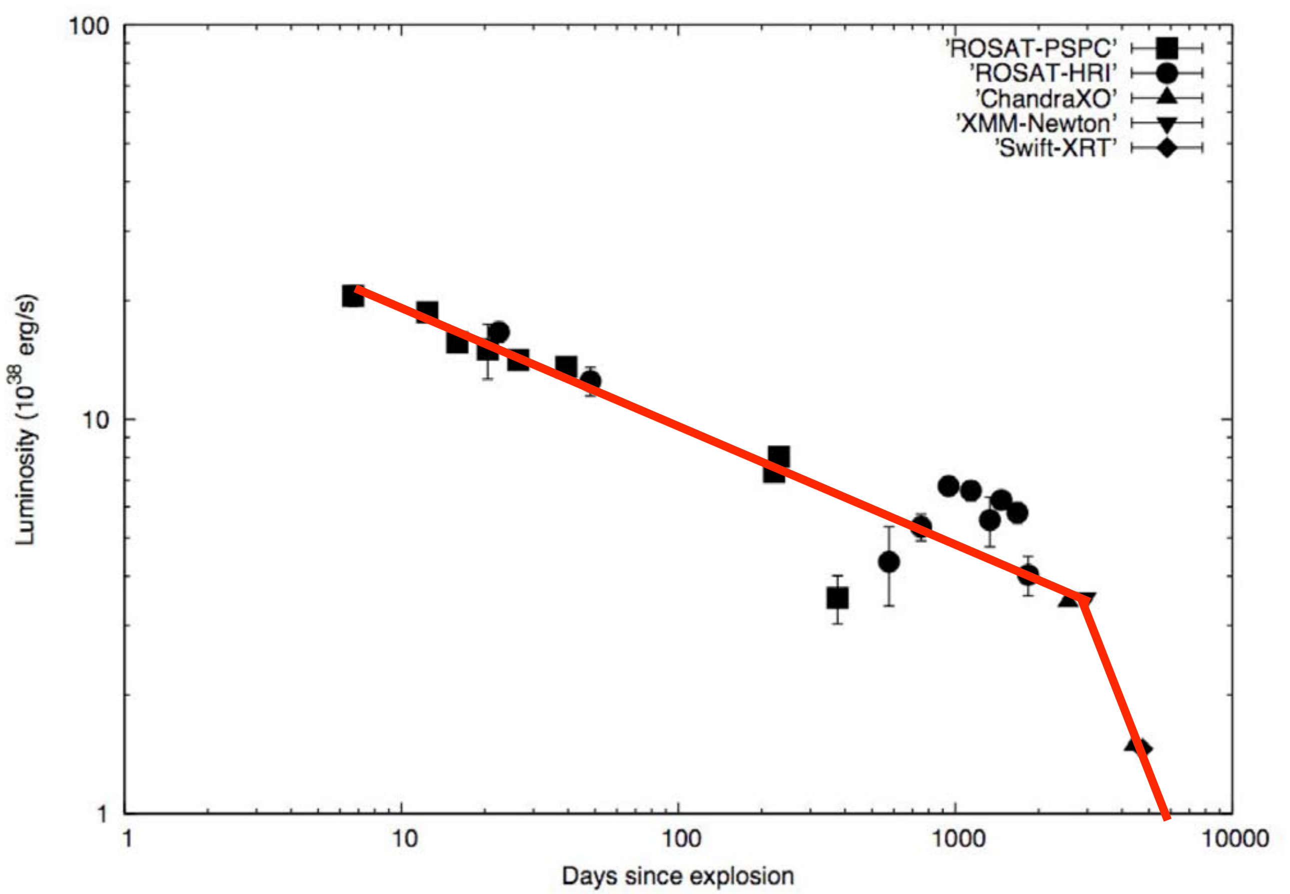
SNe 1978K and 1979C



- SNe 1978K and 1979C 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 in M81

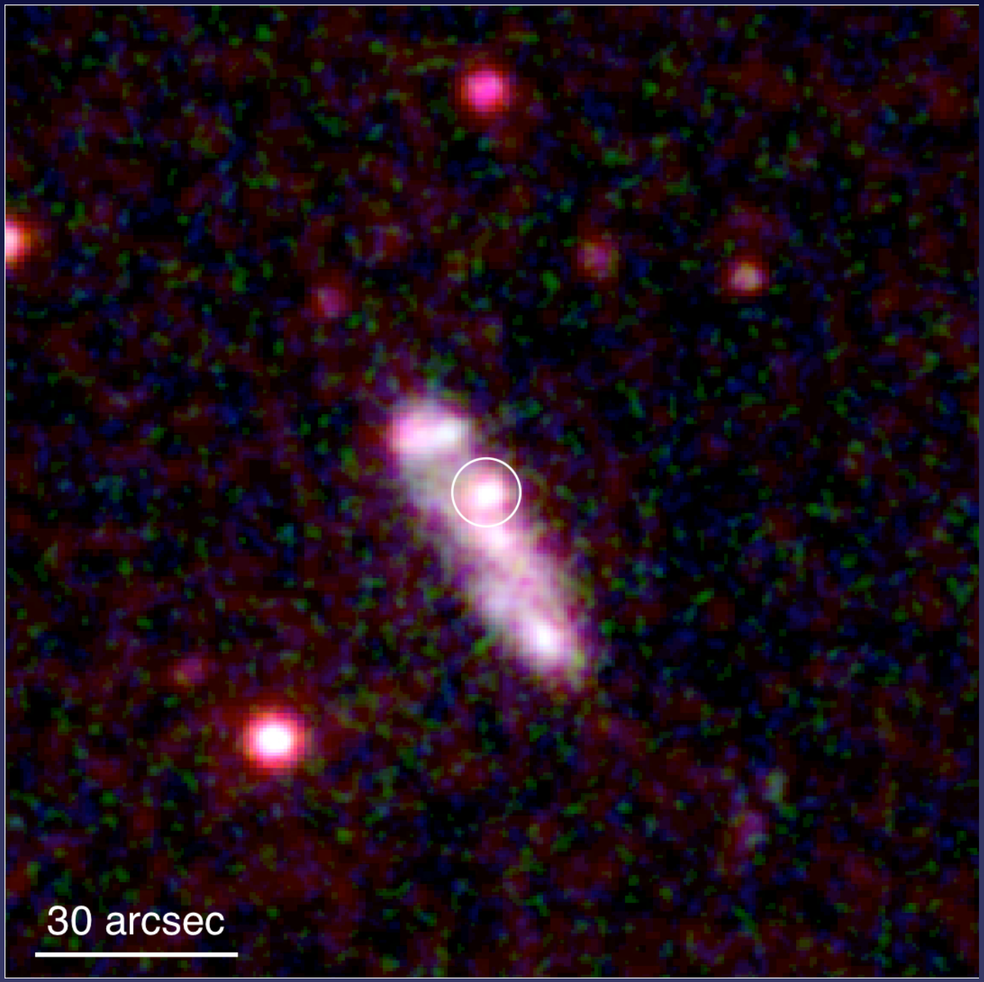




- SN 1993J shows a flat evolution over ~8 years, followed by a steep decline.
- Has the shock left the CSM and is entering the ISM?
- Is the shock slowing down and coming to a standstill?

P. Chandra & Immler 2007

SN 2005kd

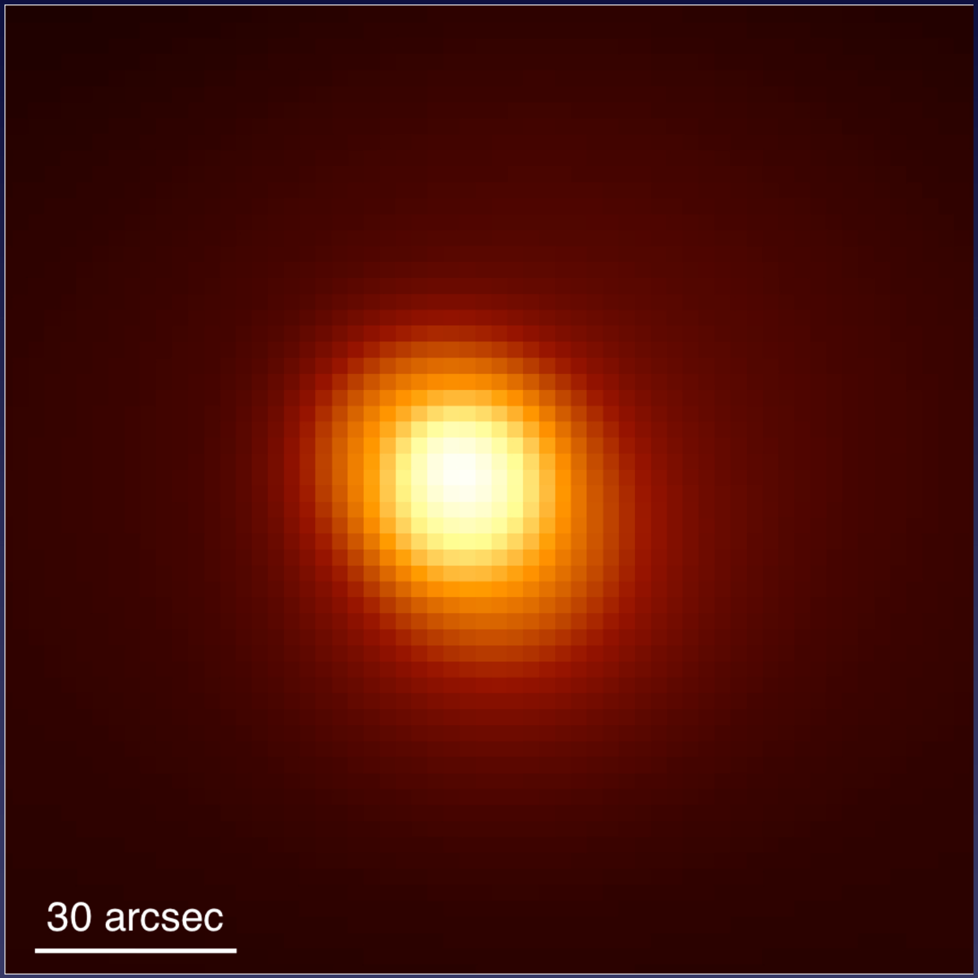


Swift ultraviolet

- Type IIn SN, distance 65 Mpc
- Visible in the ultraviolet with *Swift*, even 2 years after its explosion

Immler & Pooley 2007

SN 2005kd



Swift X-ray

- Brightest X-ray emitting SN ever, $L_x = 2.5 \times 10^{41}$ erg/s (0.2–10 keV)
- High mass-loss rate of some 10^{-4} $M_{\odot}$ yr^{-1}
- But is the X-ray source due to the SN itself?

Immler & Pooley 2007

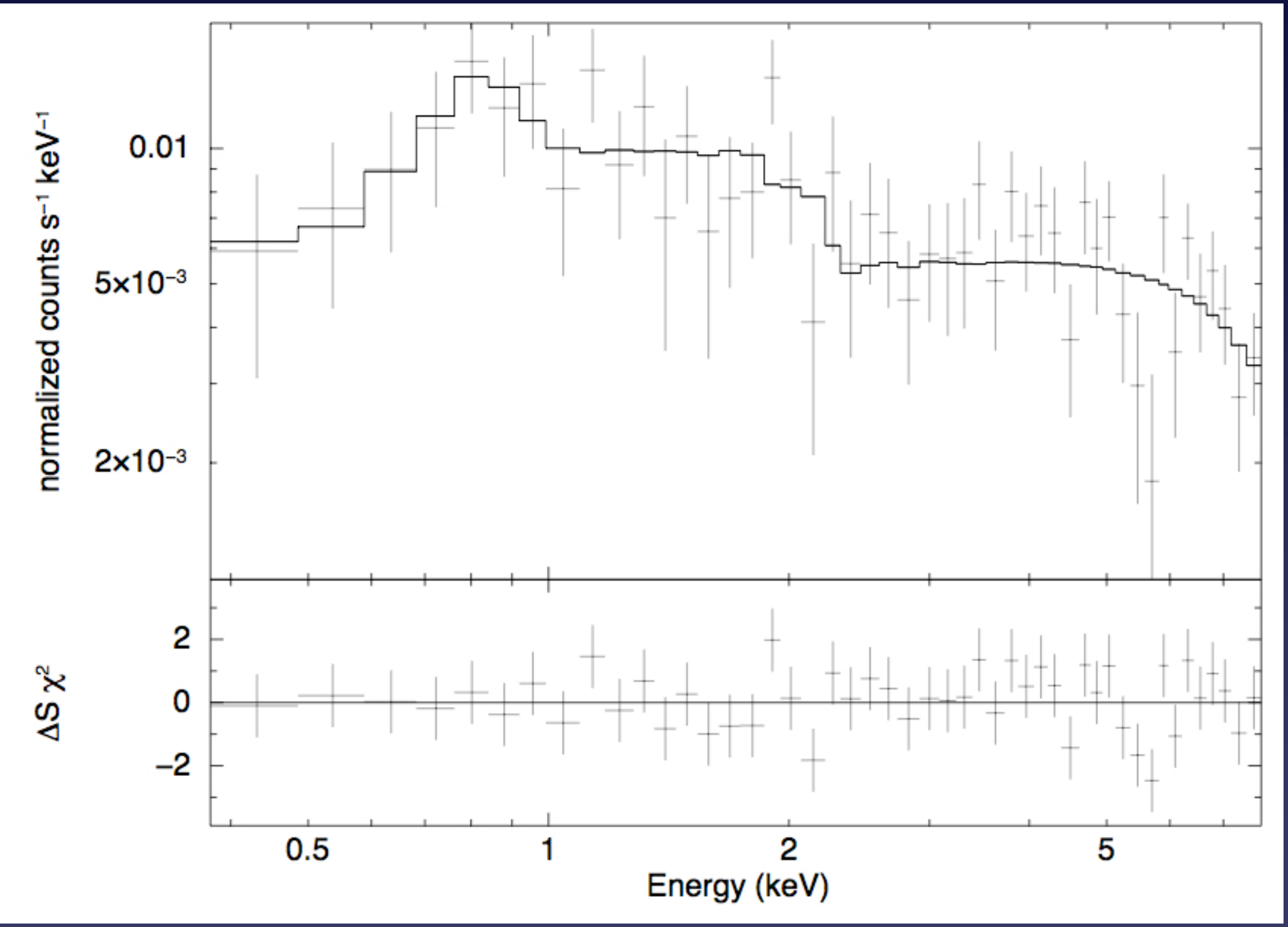
SN 2005kd

Chandra X-ray

- But is the X-ray source due to the SN itself?
- Yes!

Immler & Pooley 2007

SN 2005kd

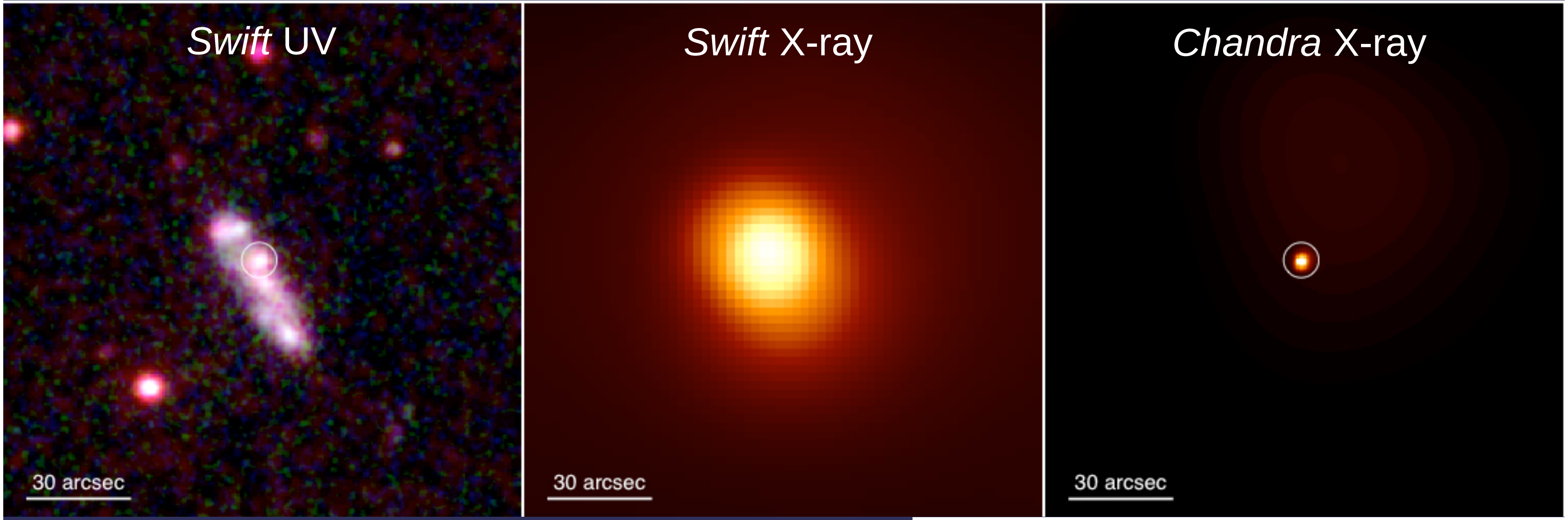


XMM-Newton
EPIC spectrum

- X-ray spectrum with XMM-Newton (55 ks) is best fit by a 2-temp thermal plasma:
- kT_{low} = 0.7±0.2 keV, kT_{high} ≈ 70 keV (χ_r ≈ 1), with no intrinsic absorption.

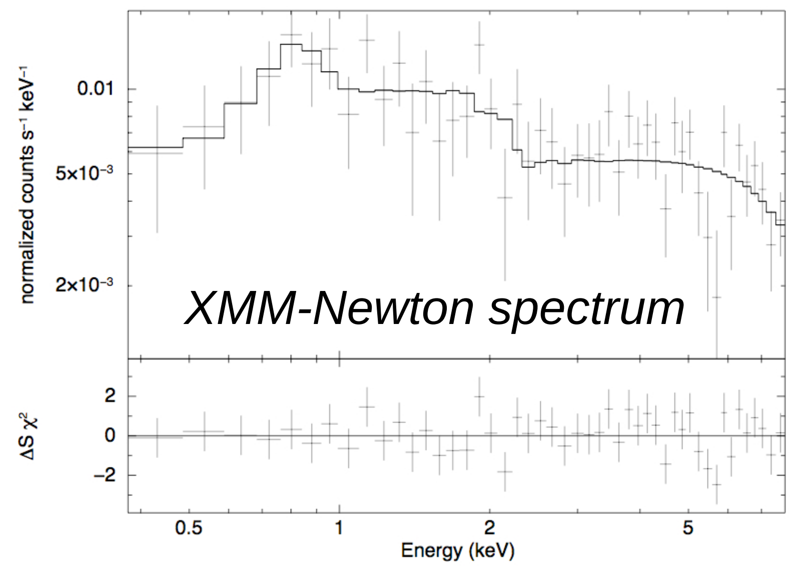
Immler & Pooley 2007

SN 2005kd

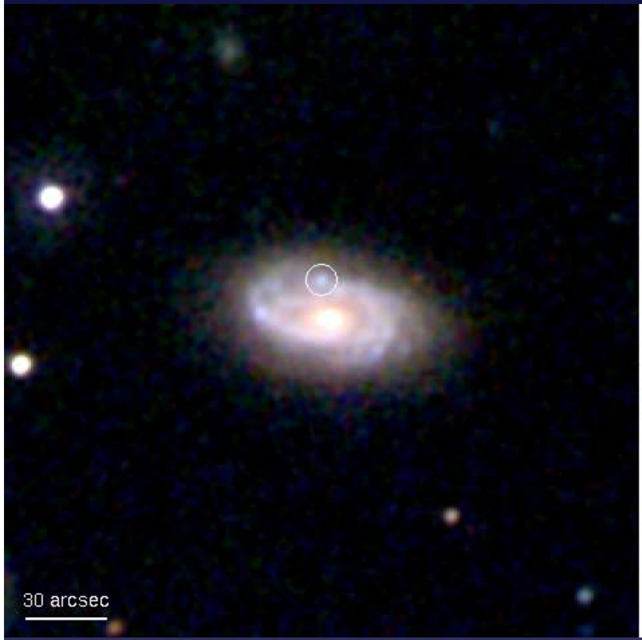


Great use of three space-based observatories:

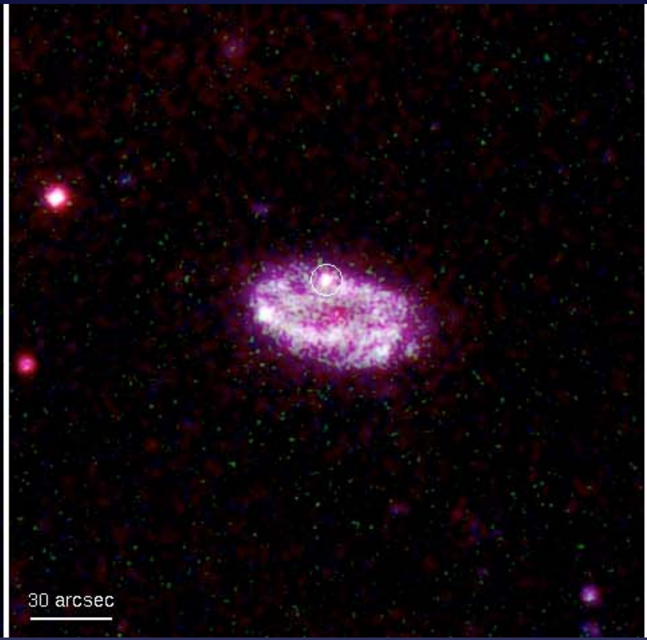
- *Swift* as a “scouting mission”
- *Chandra* snapshot gives position
- *XMM-Newton* gives high-quality spectrum



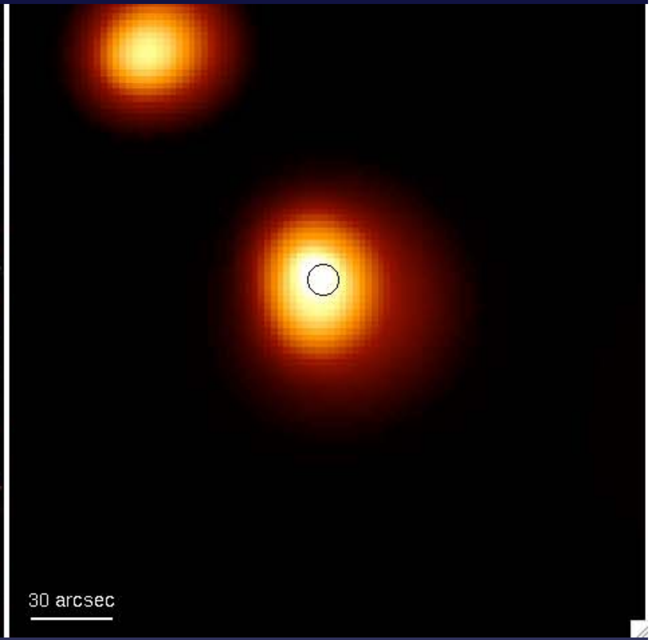
SN 2005ip



Swift optical



Swift UV

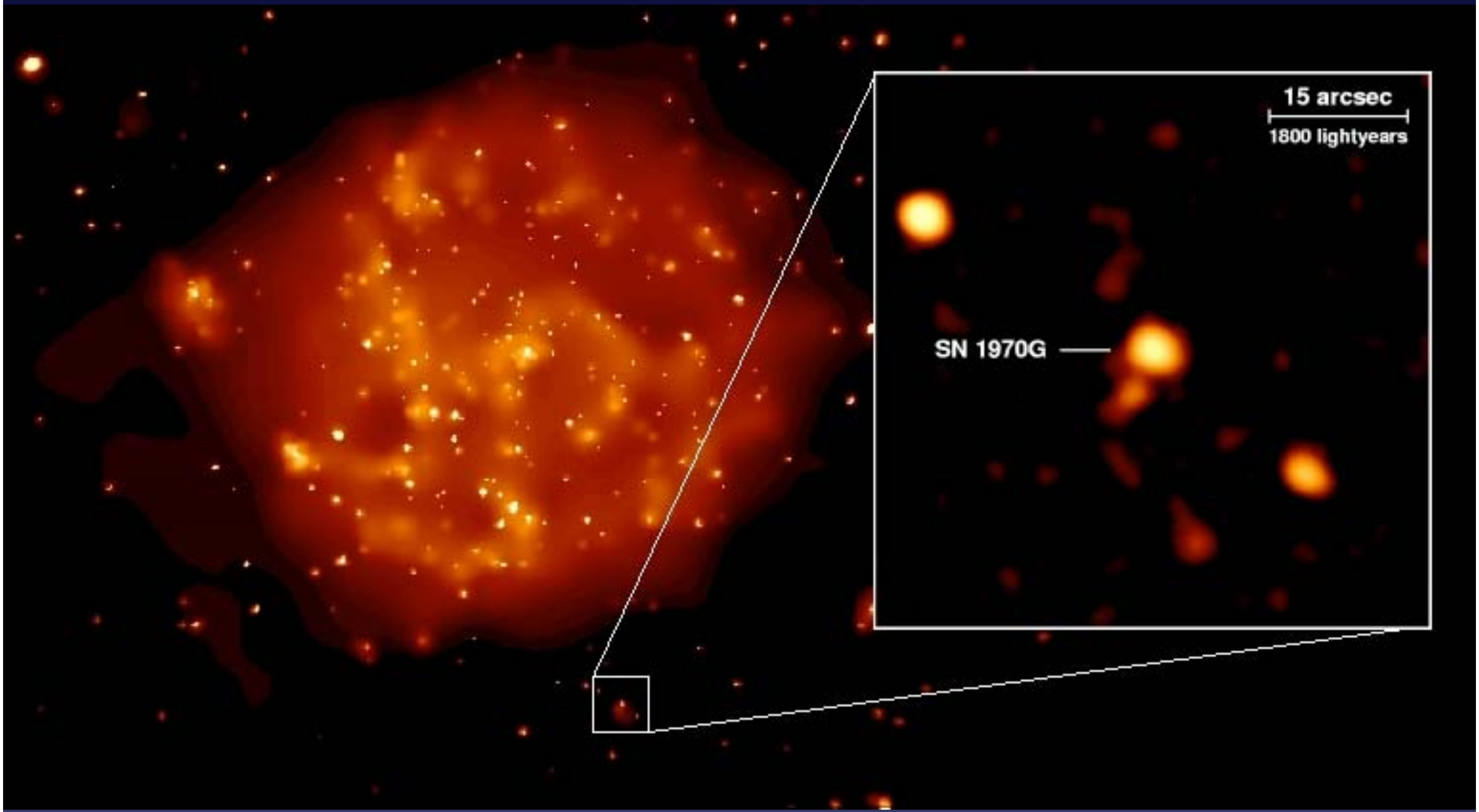


Swift X-ray

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

Immler & Pooley 2007

SN 1970G in M101

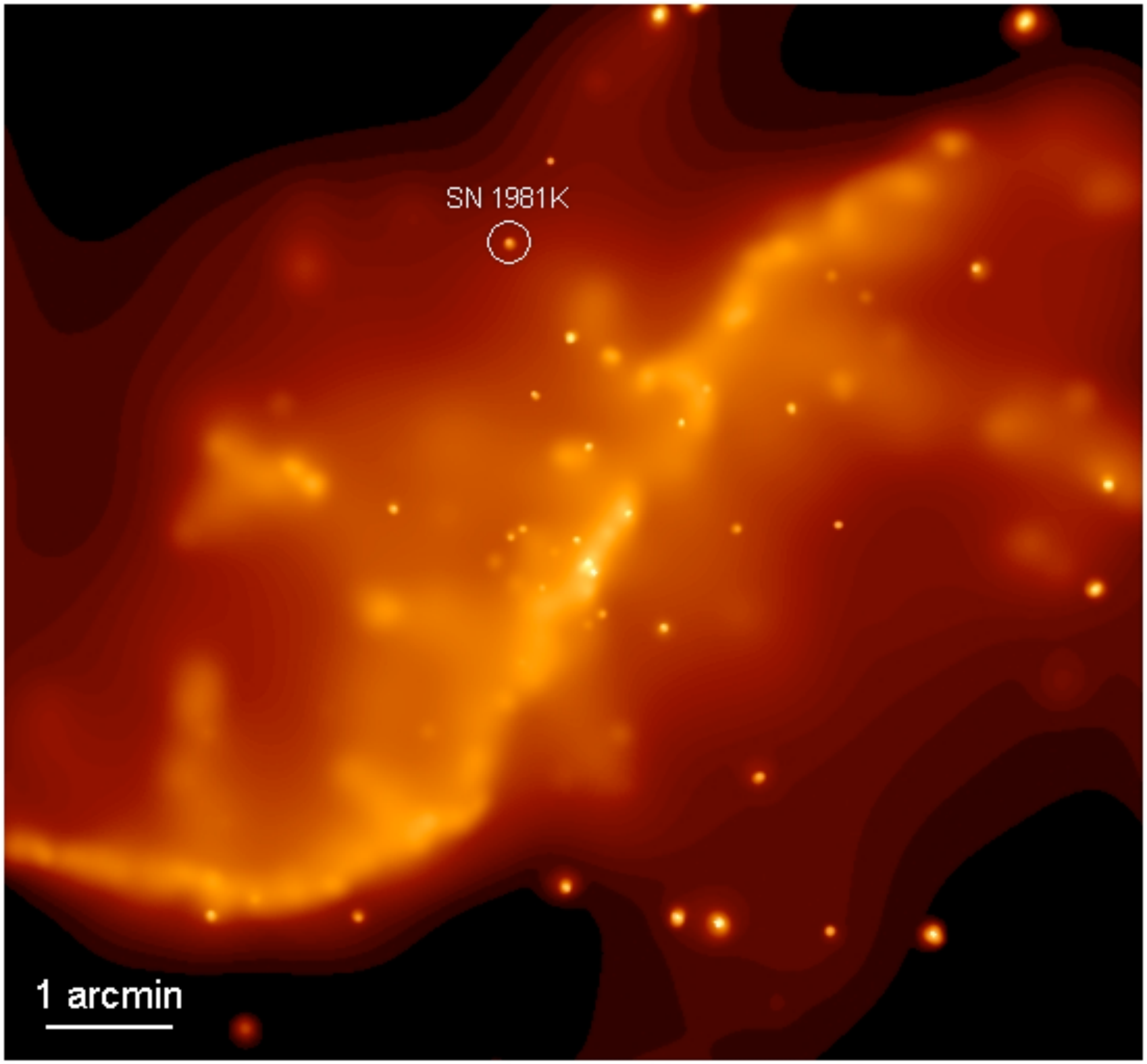


Chandra 1 Ms X-ray survey of M101

Detection of X-ray emission from SN 1970G 35 years after its explosion

Immler & Kuntz 2005

SN 1981K in NGC 4258

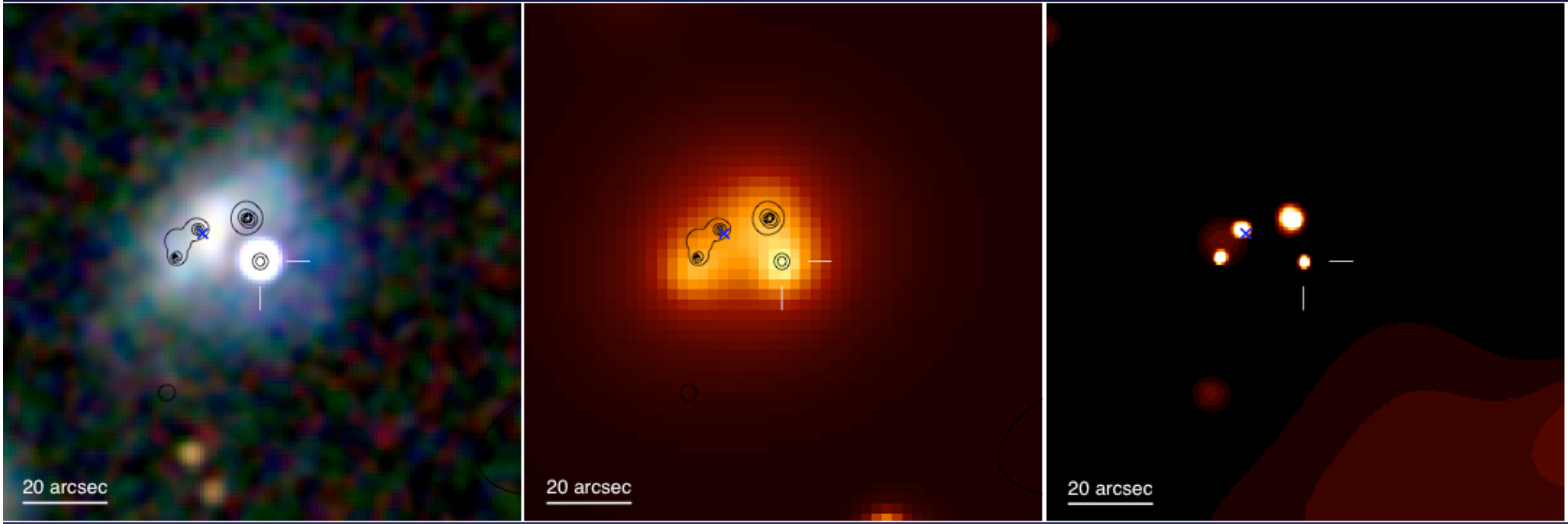


L_x = 1.2 x 10^{37} erg/s

20 years after the explosion.

Immler, Li, Yang & Wilson 2007

SN 2006jc in UGC 4904



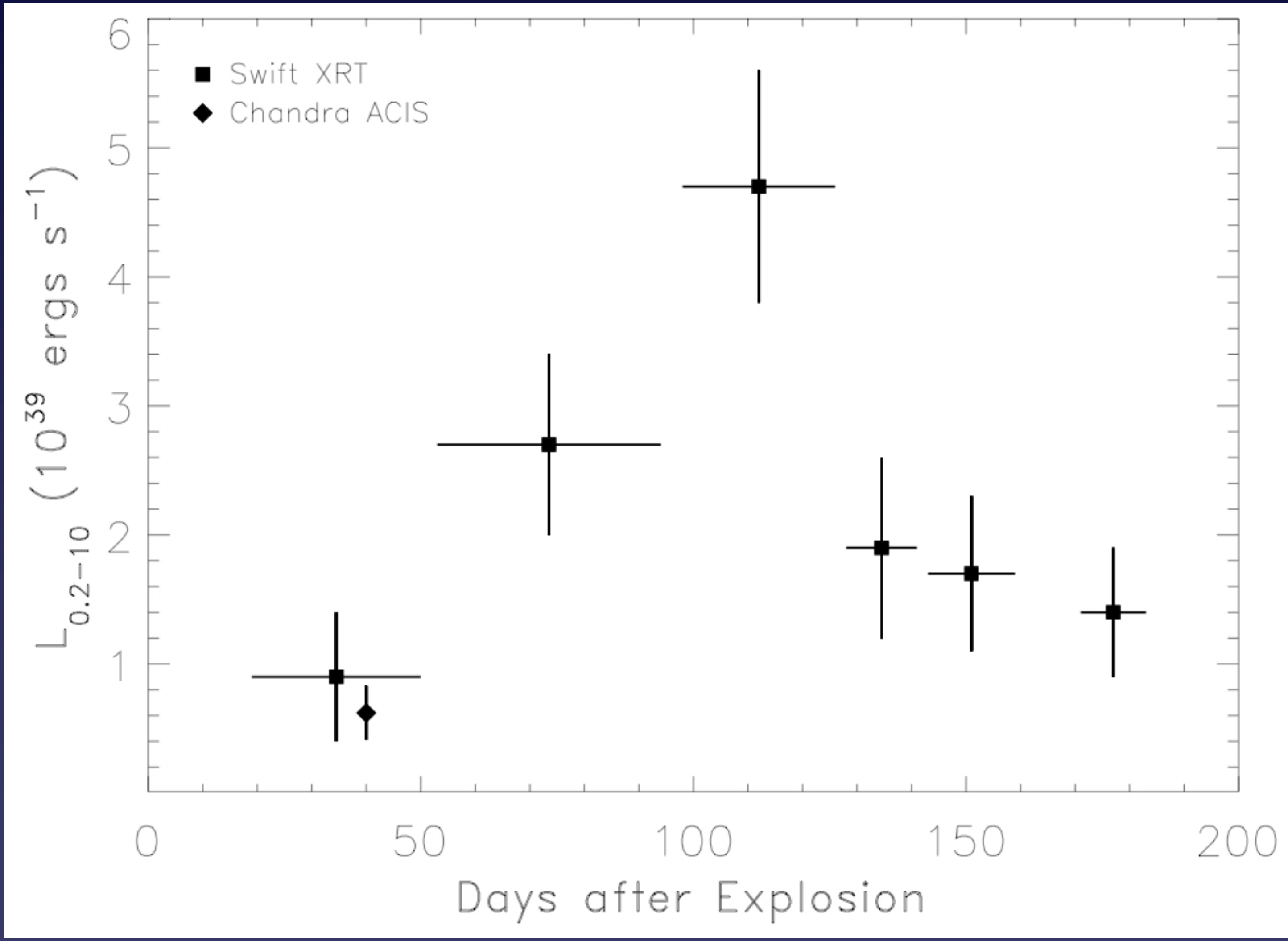
Swift optical | Swift X-ray | Chandra X-ray

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

SN 2006jc (24 Mpc) is detected in X-rays with *Swift* and *Chandra* *t* ~ 20–180 d and showed a unique brightening in X-rays

Immler et al. 2007a

SN 2006jc in UGC 4904

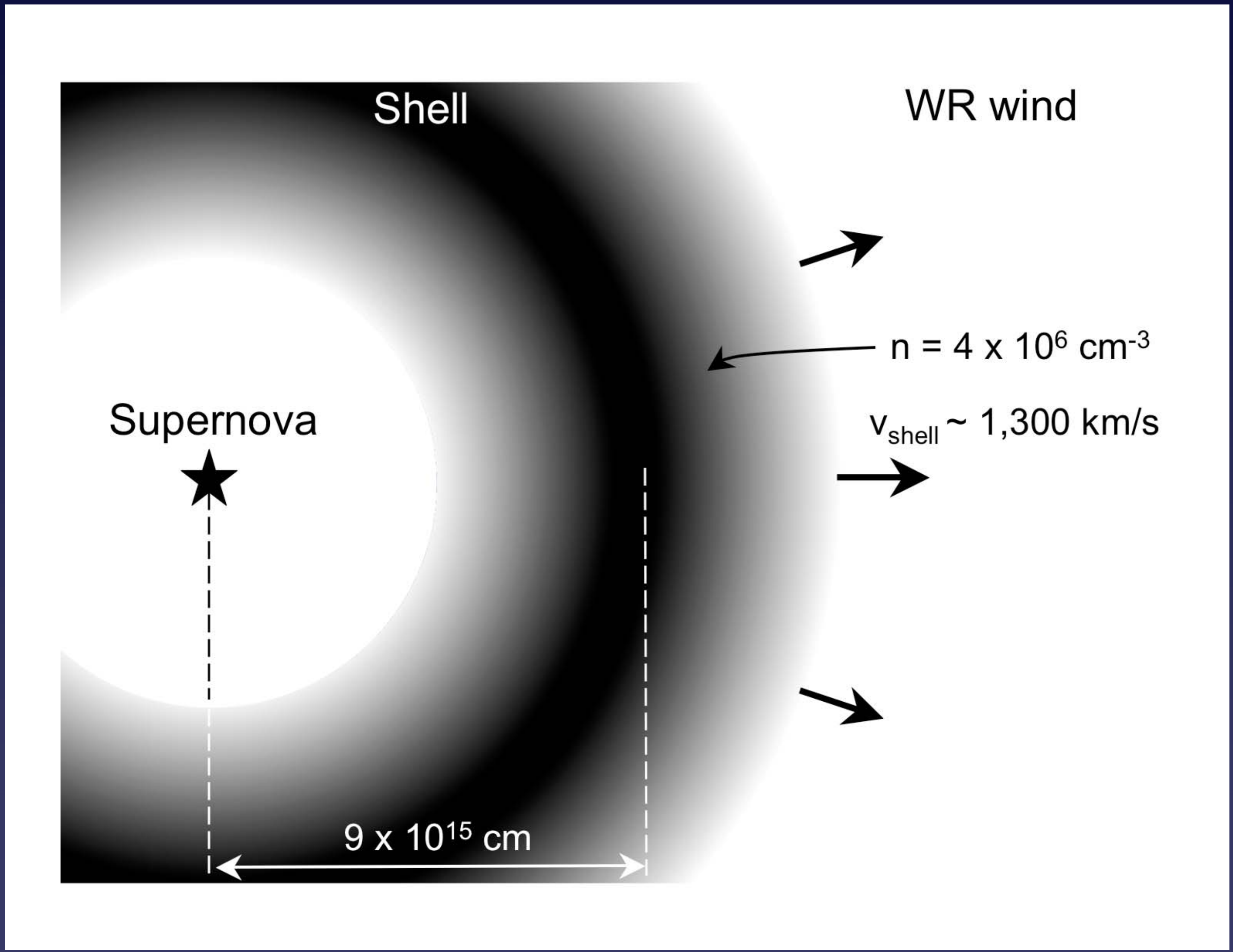


Brightening in X-rays: dense shell around the site of the explosion?

A luminous outburst was observed two years before SN

Immler et al. 2007a

SN 2006jc in UGC 4904



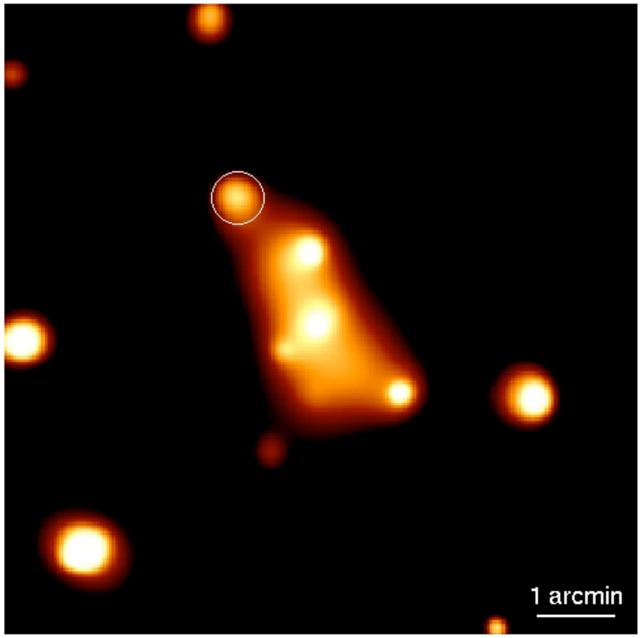
Outburst 2 years before the SN explosion, leading to ejection of a shell during an LBV-type outburst

Immler et al. 2007a

SN 2006bp in NGC 3953

Swift optical

Swift UV

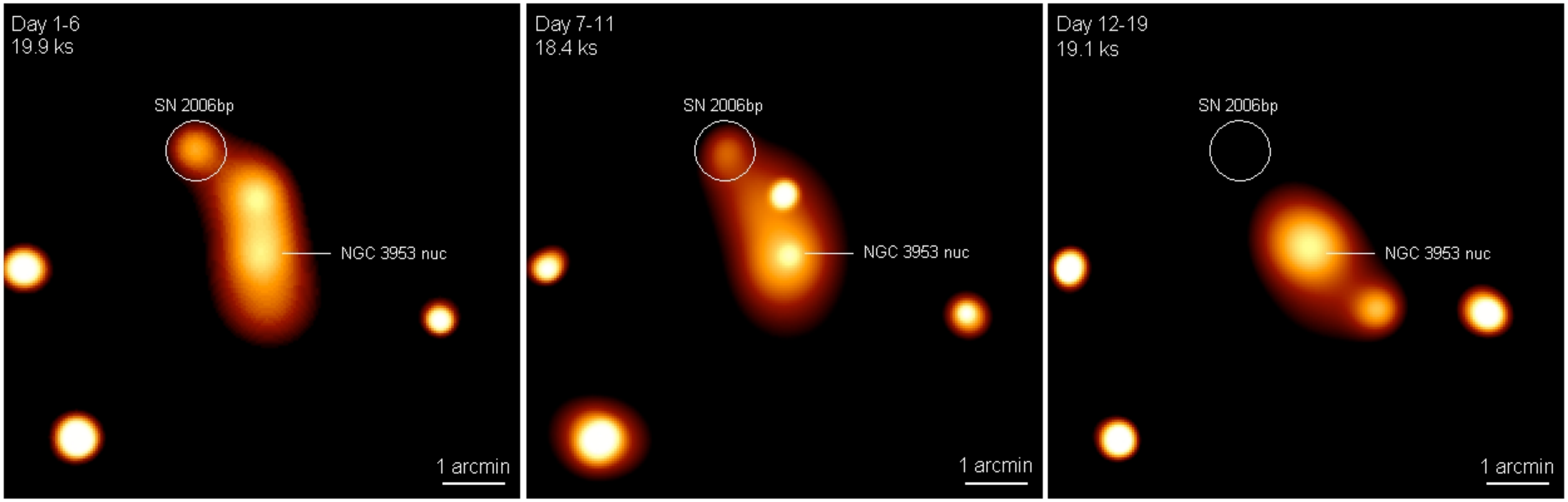


Swift X-ray

- 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. 2007b

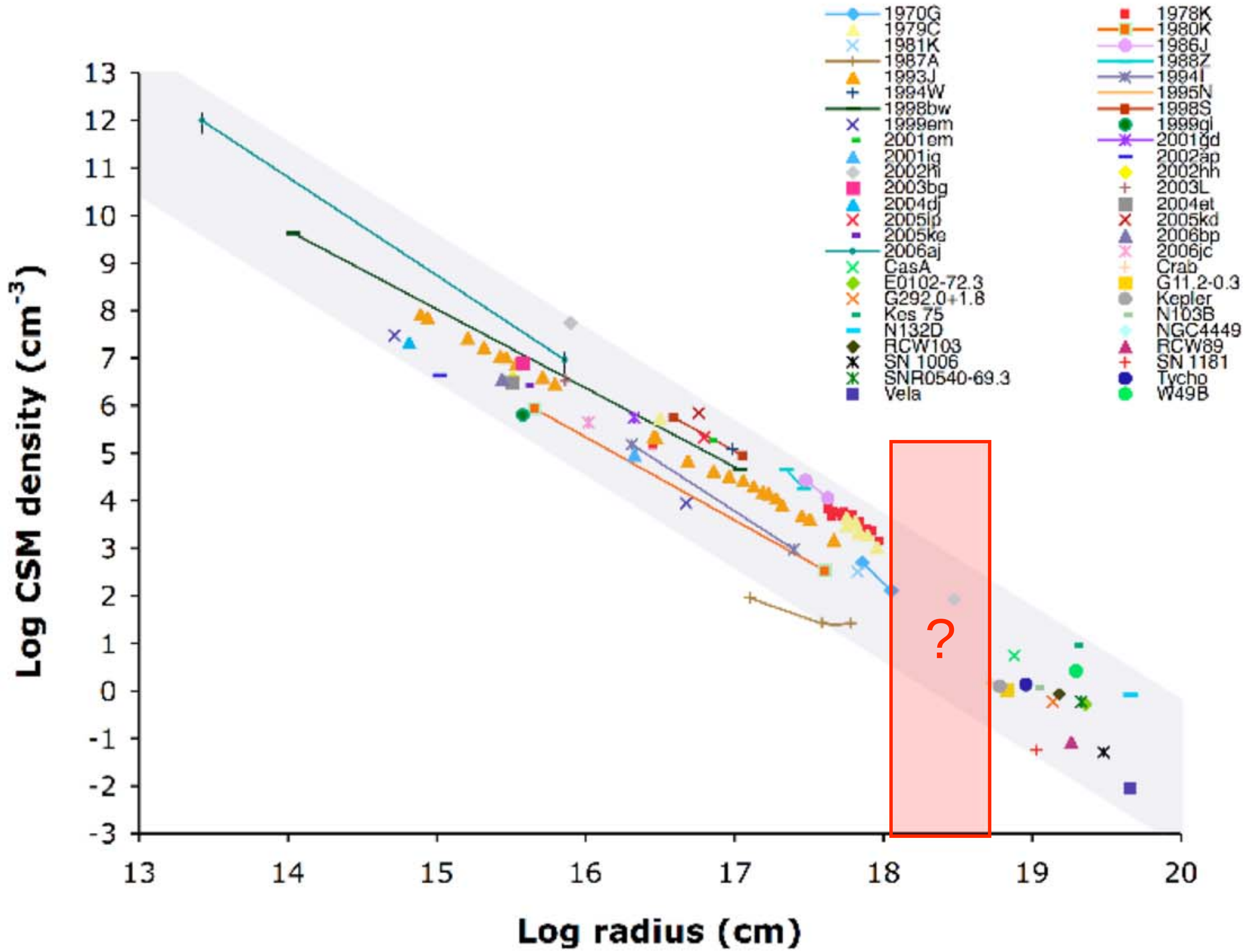
SN 2006bp in NGC 3953



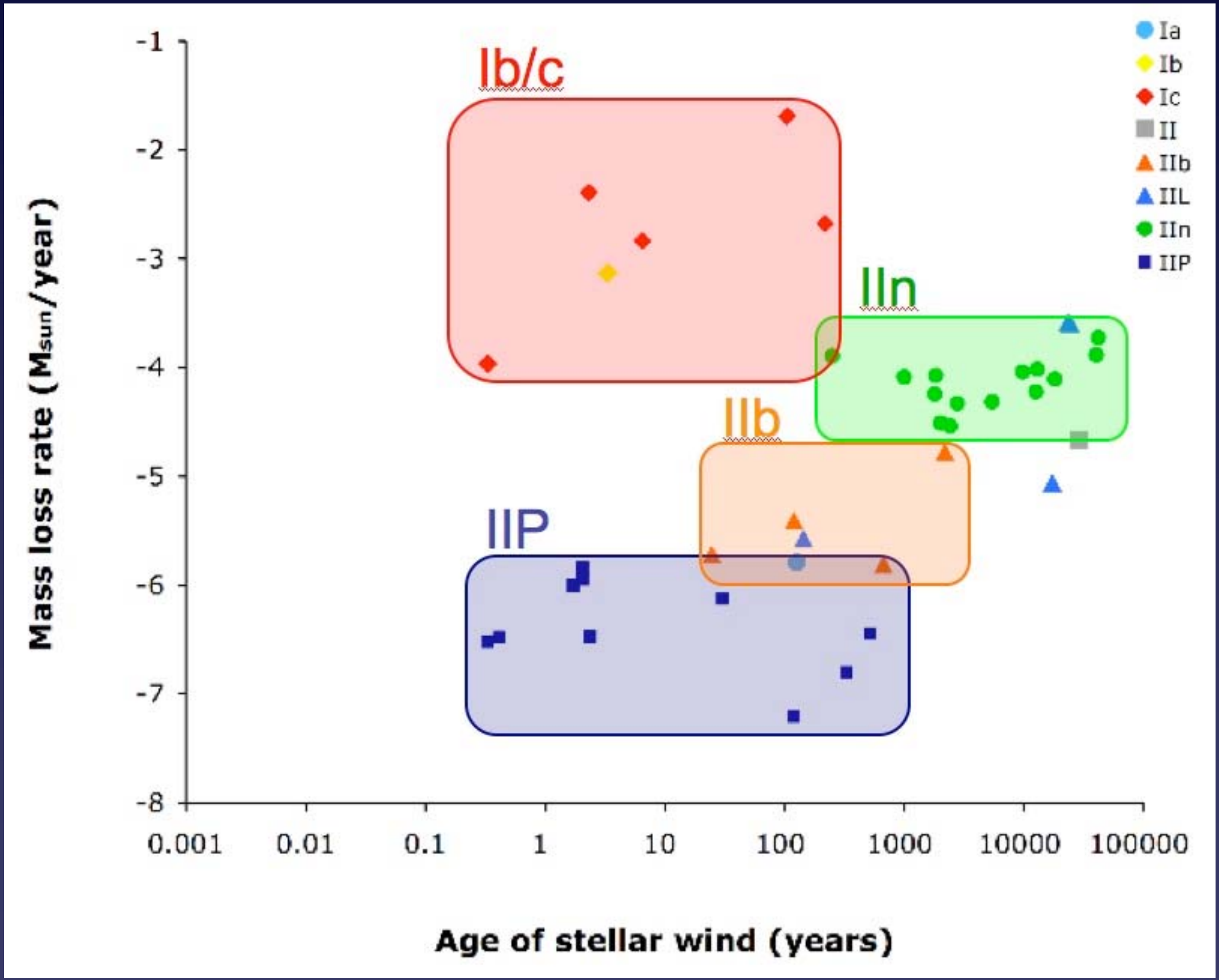
- Flexible scheduling with *Swift* observations allow X-ray timing analysis.
- SN would have been missed with any other observatory (*XMM*, *Chandra* …).
- With *Swift* we are probing a previously unexplored time domain for SNe.
- The SN is fading below the detection threshold within 10 days.
- Detection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

Immler et al. 2007b

Environments of SN



Mass-Loss Rates of SN Progenitors



Sequence RSG (IIP) - superwind/LBV (IIn) - post LBV (IIb)

Summary

X-ray observations of young SNe are uniquely suited to:

- Measure key physical parameters of CSM interaction, such as:

  Mass-loss rates of the progenitors over significant time-scales in the evolution of the progenitor as a function of SN type and progenitor,

  CSM densities in the environments of SNe out to large radii,

- Study the temporal evolution of the forward and reverse shock,

- New observations with *Swift* are used to probe the previously unexplored time domain of the early UV and X-ray emission (< days) and probe links between GRBs/SNe by observing SN related long-duration GRBs.

- *Chandra* is essential in getting high-accuracy position needed to ID SNe.

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SN X-Ray Light Curves