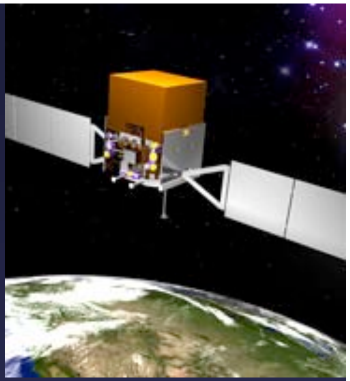
Future Opportunities for Joint *Swift* and GLAST Programs

Stefan Immler

Swift Science Center

CRESST NASA/GSFC

Outline



Swift:

- The instrument on board *Swift*
- Science I: Gamma-ray Bursts
- Science II: Supernovae
- Science III: Survey of Galaxies

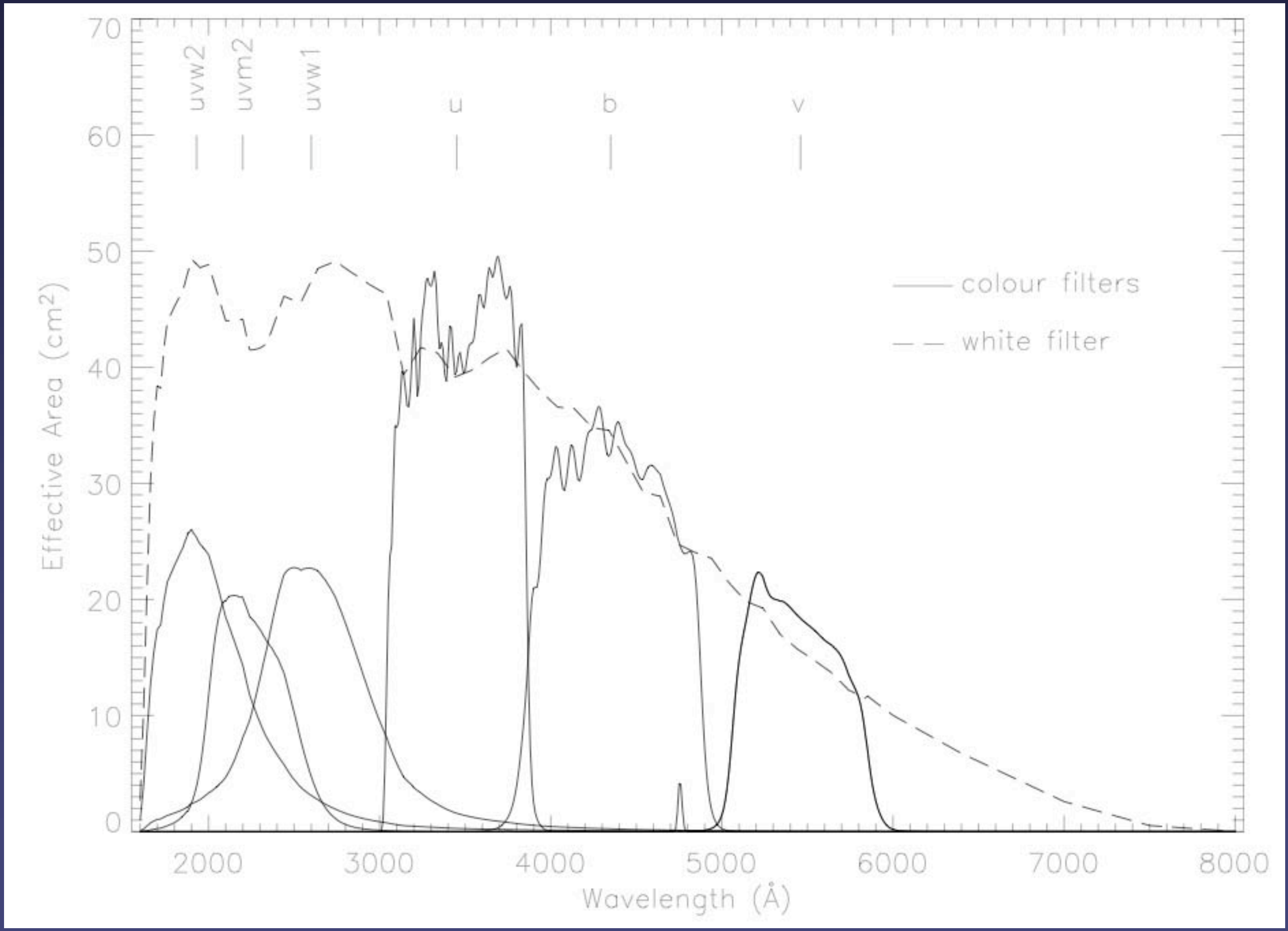
GLAST and _Swift_:

- *Swift* identification of GLAST sources
- GLAST observations of *Swift* GRBs
- Joint non-GRB science opportunities

The *Swift* Observatory

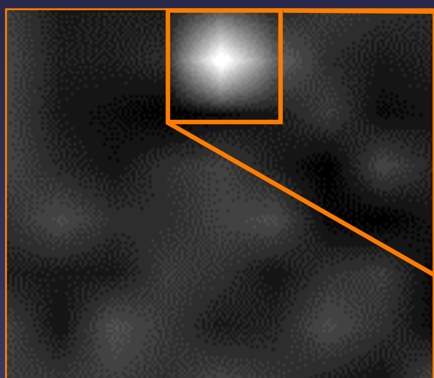
Burst Alert Telescope	
Detector	CdZnTe
Aperture	Coded Mask
Effective Area	5200 cm^2
Field of View	2.0 sr (partially coded)
Detection Elements	256 × 128 elements
Point Spread Function	20 arcmin
Location Accuracy	3 arcmin
Energy Range	15-150 keV
X-Ray Telescope	
Detector	XMM EPIC CCD
Effective Area	135 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

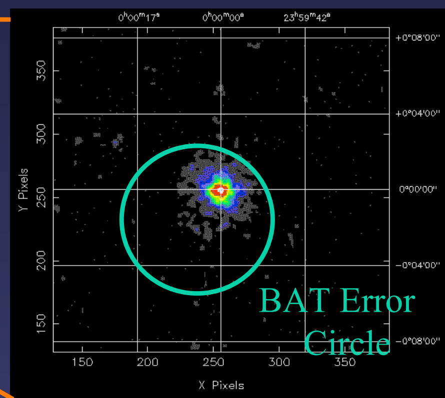


Swift GRBs

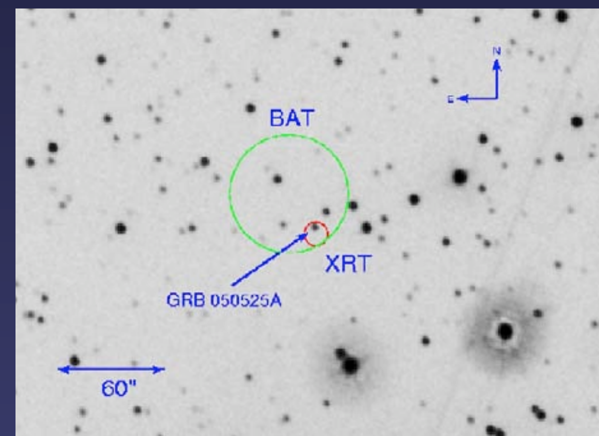
BAT Burst Image



XRT Image



UVOT Image



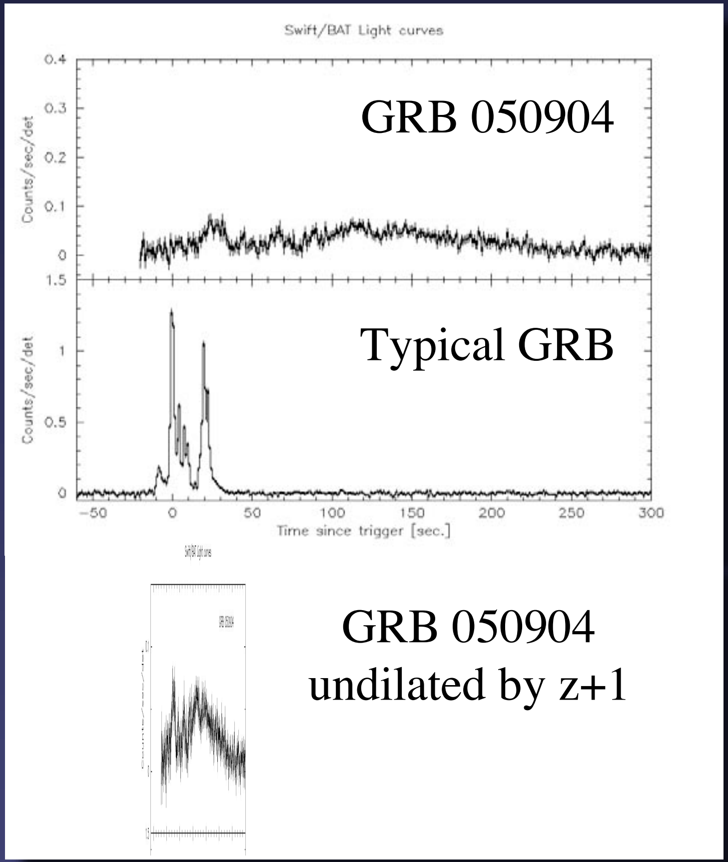
T < 10 sec
3 arcmin

T < 90 sec
3 arcsec

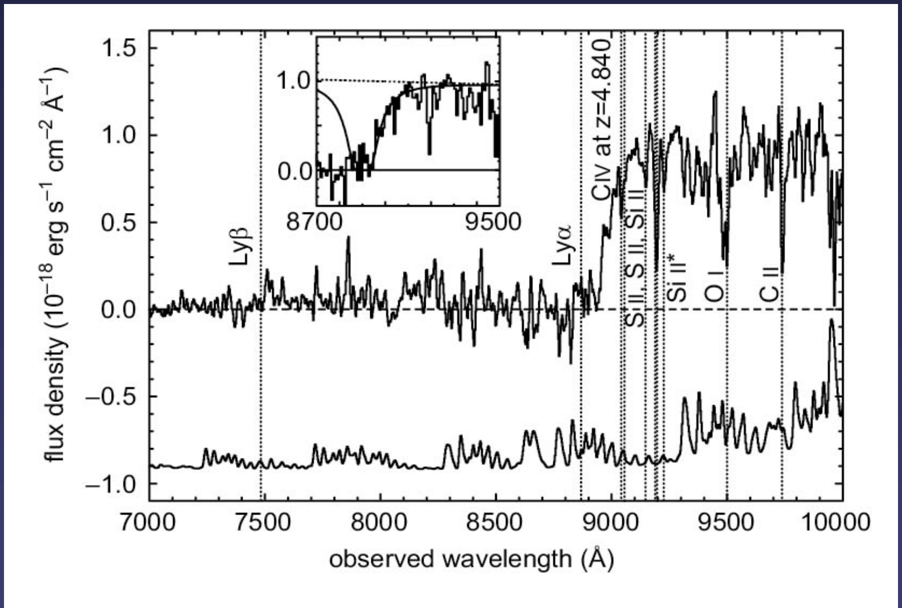
T < 2 min
0.5 arcsec

- Sensitive instruments on board Swift
- ~200 bursts
- Accurate positions
- Afterglow in X-rays (>90%) and opt/UV (~50%)
- Redshifts

GRB 050904



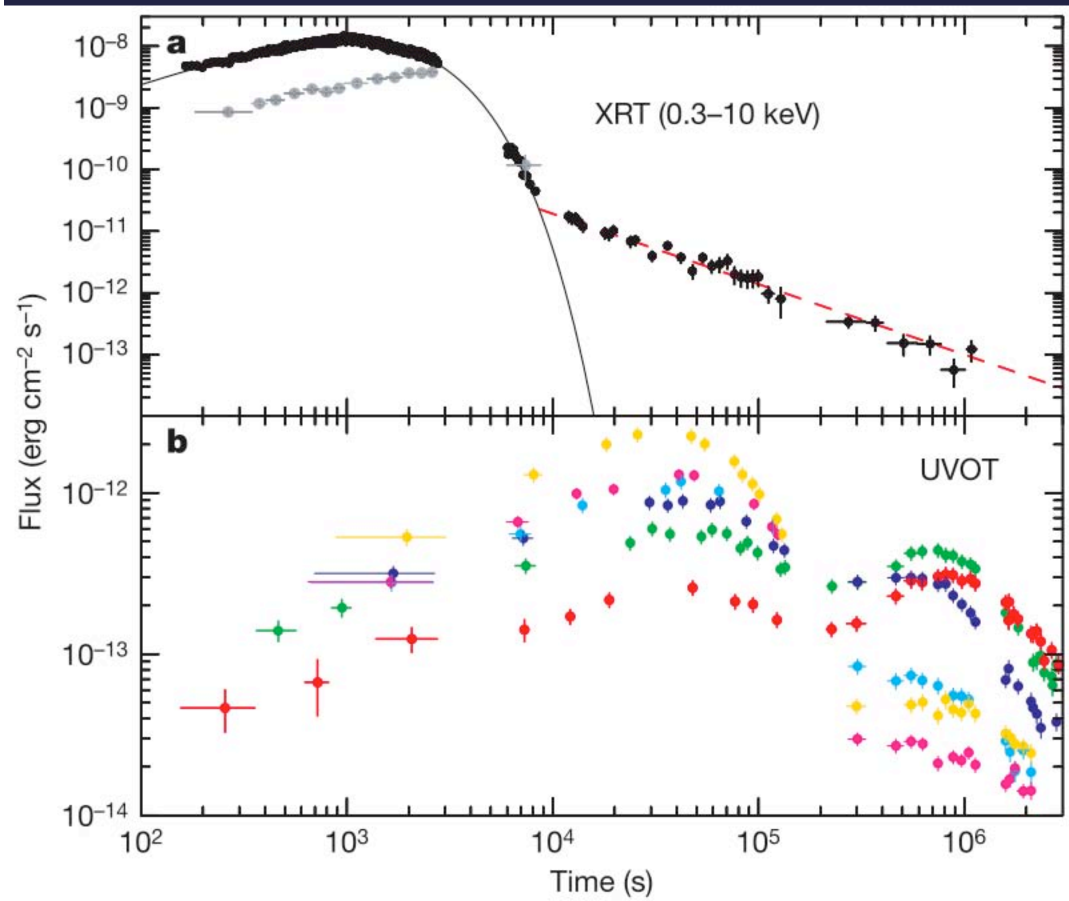
Subaru IR Spectroscopy

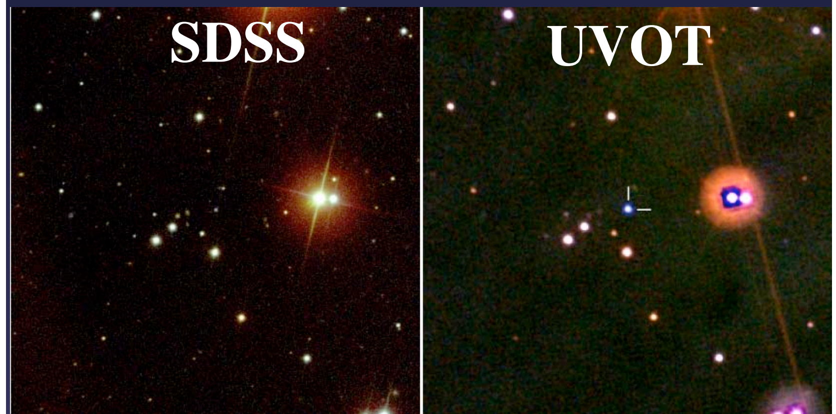


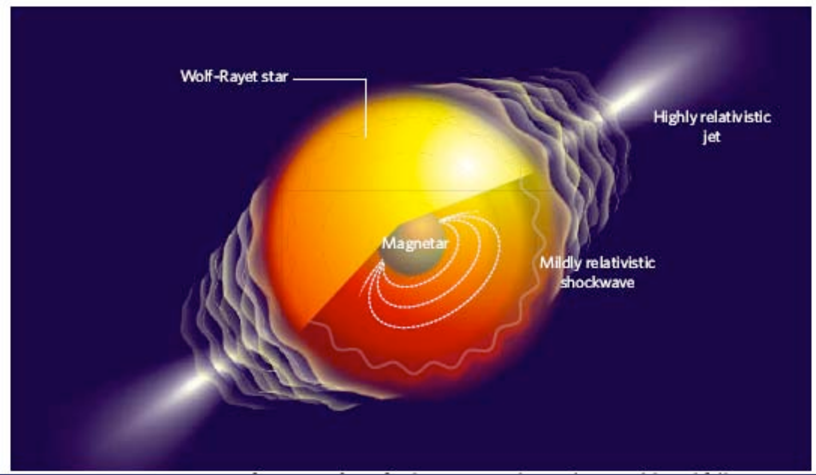
Kawai et al. 2006

- T_{90} = 225 sec (not corrected for time dilation)
- Redshift $z = 6.29$ (12.8 Gyrs)
- Most distant GRB at an age of the universe of ~1 Gyr
- S (15–150 keV) = 5.4×10^{-6} erg cm^{-2}

GRB 060218 / SN 2006aj



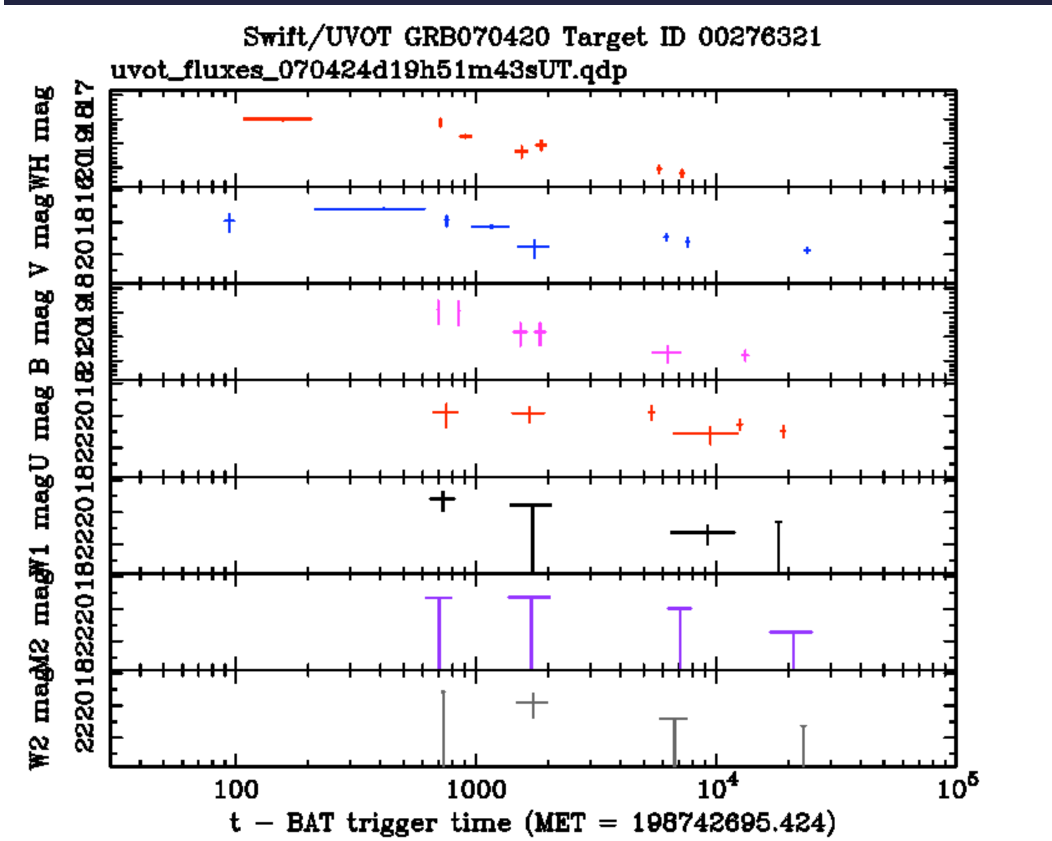


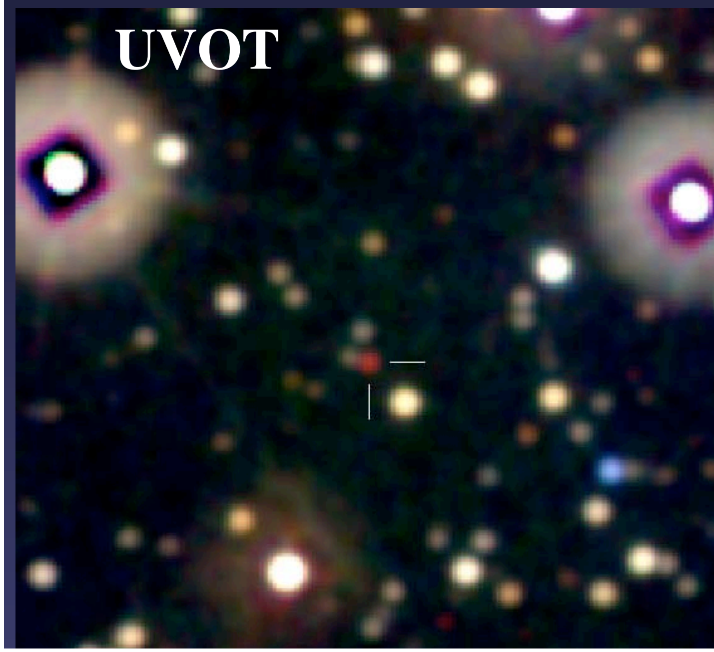


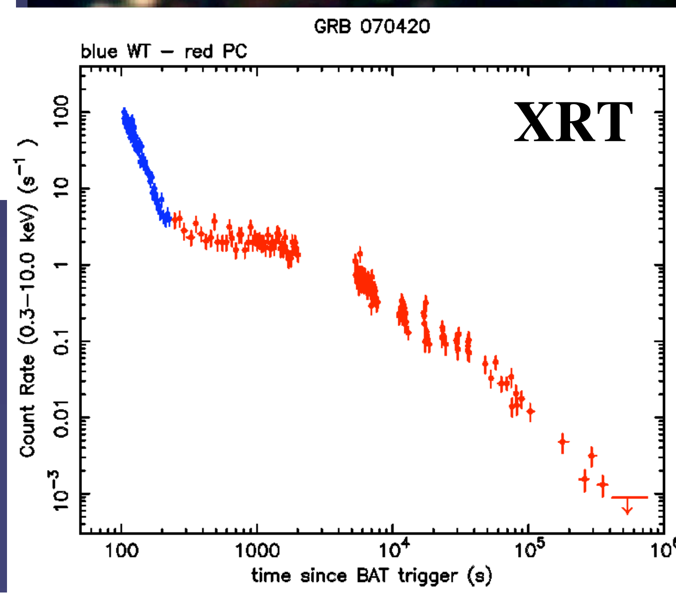
- Extremely long GRB, ~35 min
- In field of view of BAT, XRT, UVOT during outburst
- Nearby: z = 0.033, d = 145 Mpc

Campana et al. 200

GRB 070420







- Long-duration GRB without SN
- UVOT afterglow and light curve

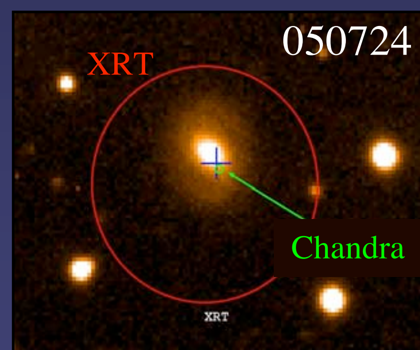
Afterglow Positions

Long GRBs

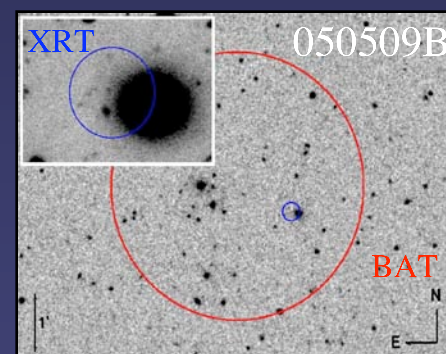
SF
irregulars

Short GRBs

Offset SF galaxy



elliptical



cD elliptical

- Accurate afterglow positions are important to study
  the birthplaces and environment of long/short

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

Swift Observations of Supernovae

SN	Type
2005am	Ia
2005bc	Ia
2005bf	Ib/c
2005cf	Ia
2005cs	II
2005da	Ic
2005df	Ia
2005ek	Ic
2005gj	Ia
2005hk	Ia
2005ip	IIn
2005ke	Ia
2005kd	IIn
2005mz	Ia

SN	Type
2006E	Ia
2006T	IIb
2006X	Ia
2006aj	Ic
2006at	II
2006bc	II
2006bp	IIP
2006bv	IIn
2006dd	Ia
2006dm	Ia
2006dn	Ic
2006ej	Ia
2006jc	Ib
2006lc	Ib/c

SN	Type
2006gy	IIn
2006lt	Ib
2006mr	Ia
2007C	Ib/c
2007D	Ic
2007I	Ic
2007S	Ia
2007Y	Ia ?
2007aa	II
2007af	Ia
2007ax	Ia
2007bb	II
2007bg	Ic
2007bm	Ia
2007ch	IIP

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

Swift Observations of Supernovae

SN	Type
2005am	Ia
2005bc	Ia
2005bf	Ib/c
2005cf	Ia
2005cs	II
2005da	Ic
2005df	Ia
2005ek	Ic
2005gj	Ia
2005hk	Ia
2005ip	IIn
2005ke	Ia
2005kd	IIn
2005mz	Ia

SN	Type
2006E	Ia
2006T	IIb
2006X	Ia
2006aj	Ic
2006at	II
2006bc	II
2006bp	IIP
2006bv	IIn
2006dd	Ia
2006dm	Ia
2006dn	Ic
2006ej	Ia
2006jc	Ib
2006lc	Ib/c

SN	Type
2006gy	IIn
2006lt	Ib
2006mr	Ia
2007C	Ib/c
2007D	Ic
2007I	Ic
2007S	Ia
2007Y	Ia ?
2007aa	II
2007af	Ia
2007ax	Ia
2007bb	II
2007bg	Ic
2007bm	Ia
2007ch	IIP

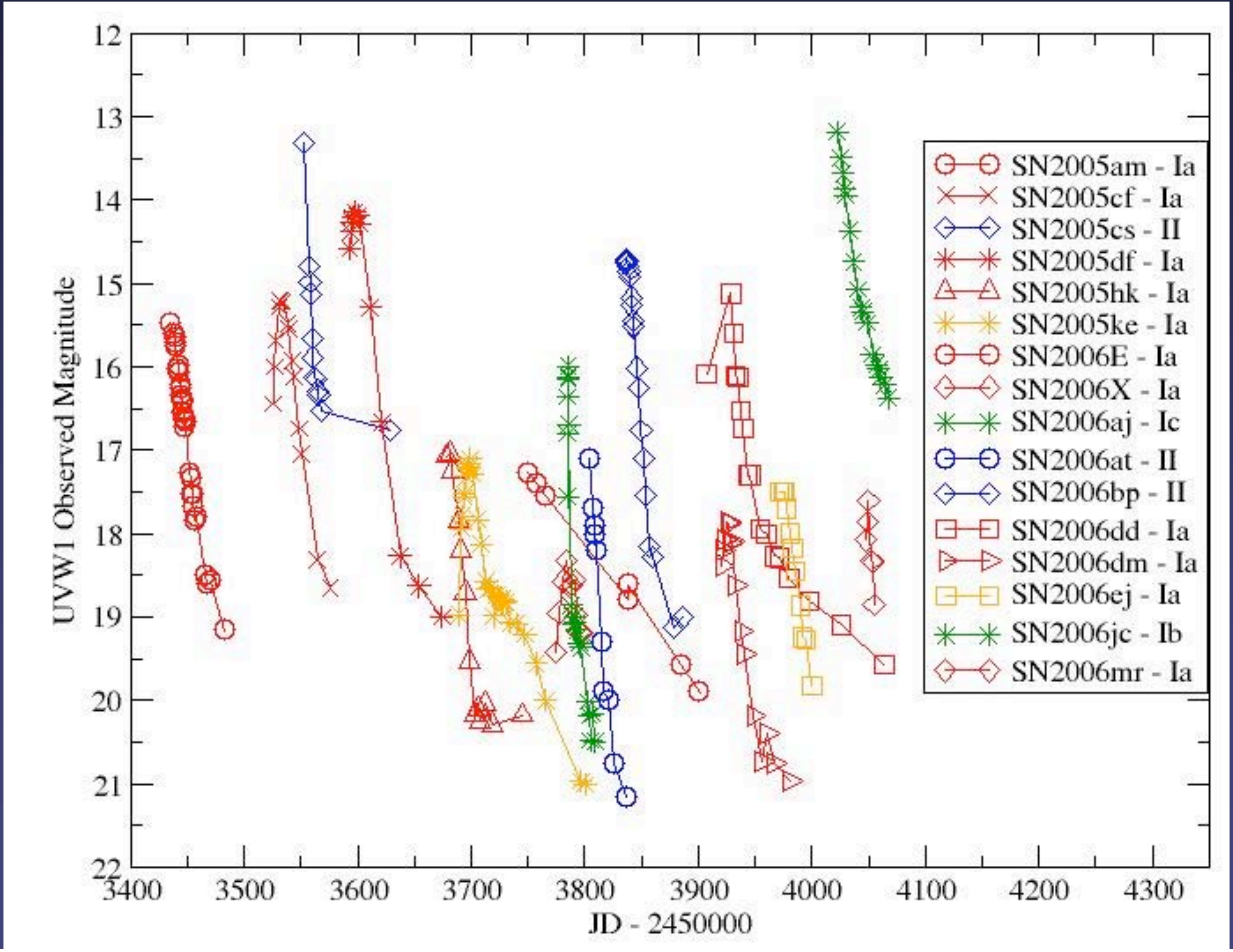
43 total — 19 (12) type Ia — 12 (2) type Ib/c — 12 (3) type II

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

UVOT Lightcurves of SNe



Primary Objectives

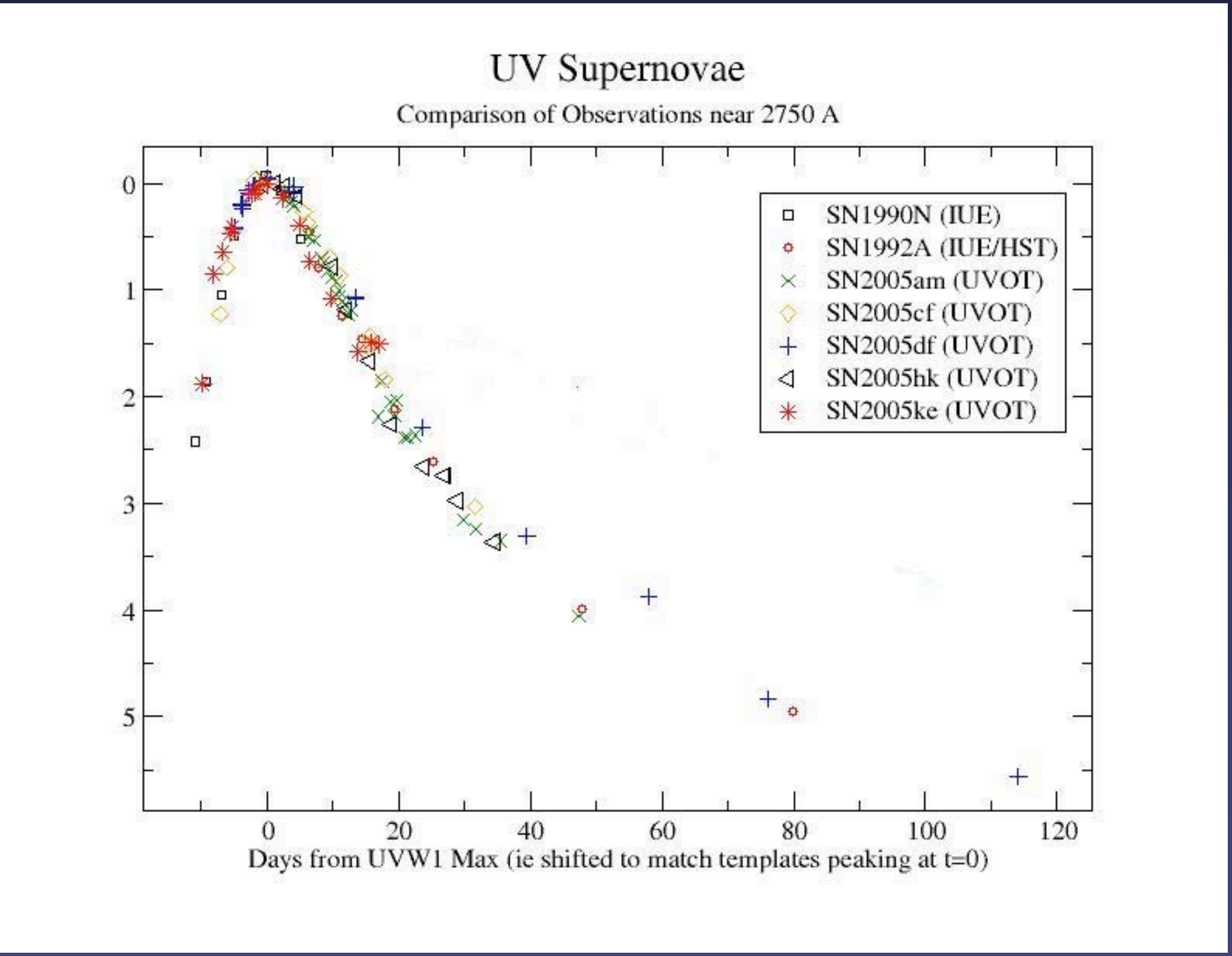
1) Thermonuclear SNe:

- 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.

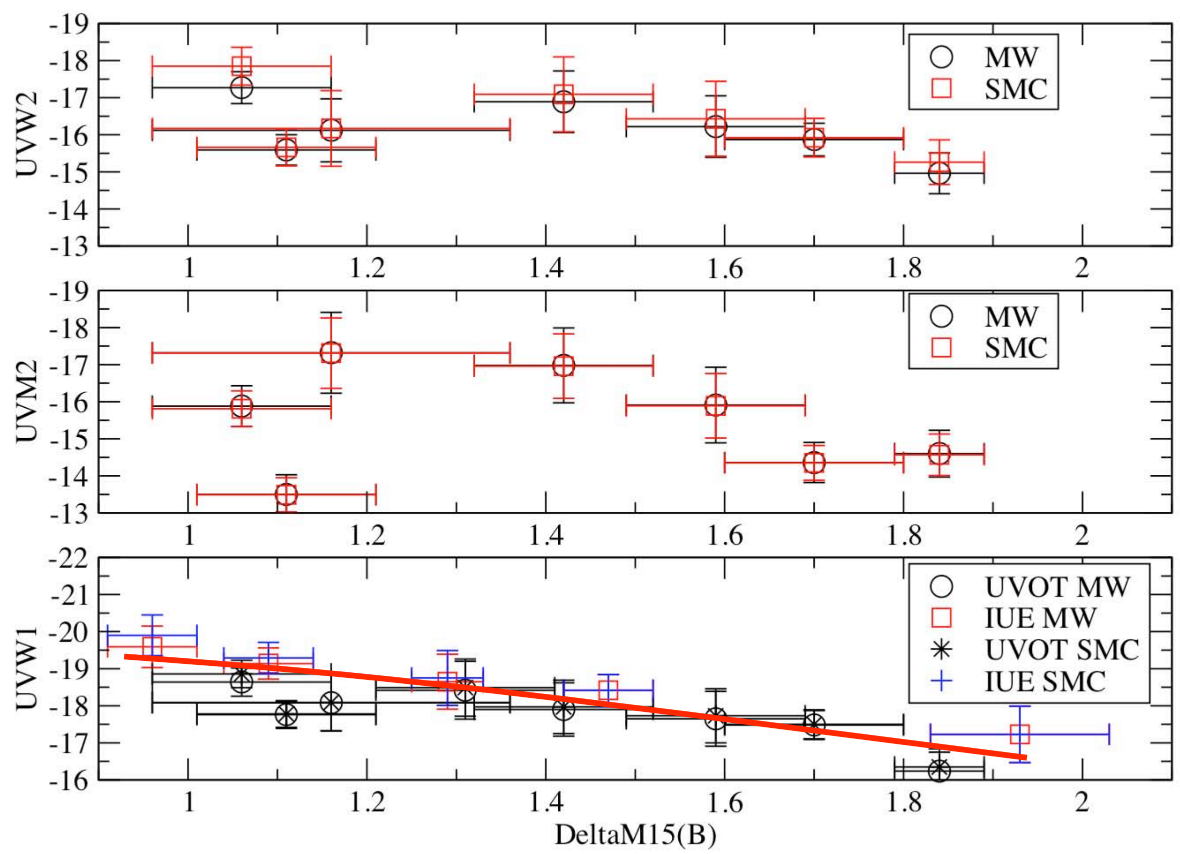
- Search for CSM interaction in the UV (excess, spectra) and in X-rays

UV Light Curves



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

UV Standard Candles



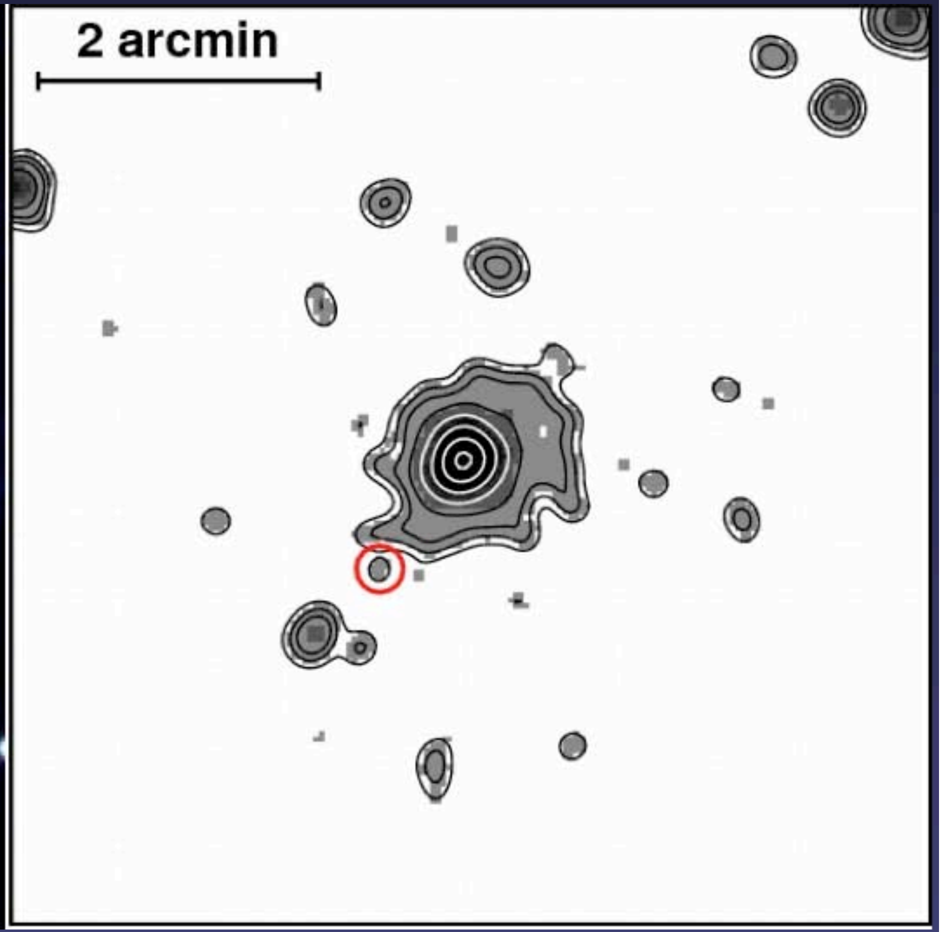
- SNe that are opt bright are also bright in the UV
- Correlation between peak brightness and Δm_{B15}

SNe 2006dd and 2006mr in NGC 1316

- 4 Type Ia SNe within 26 years
- NGC 1316: the most productive SN factory in the local universe?

SN 2005ke in NGC 1371

UVOT ultraviolet

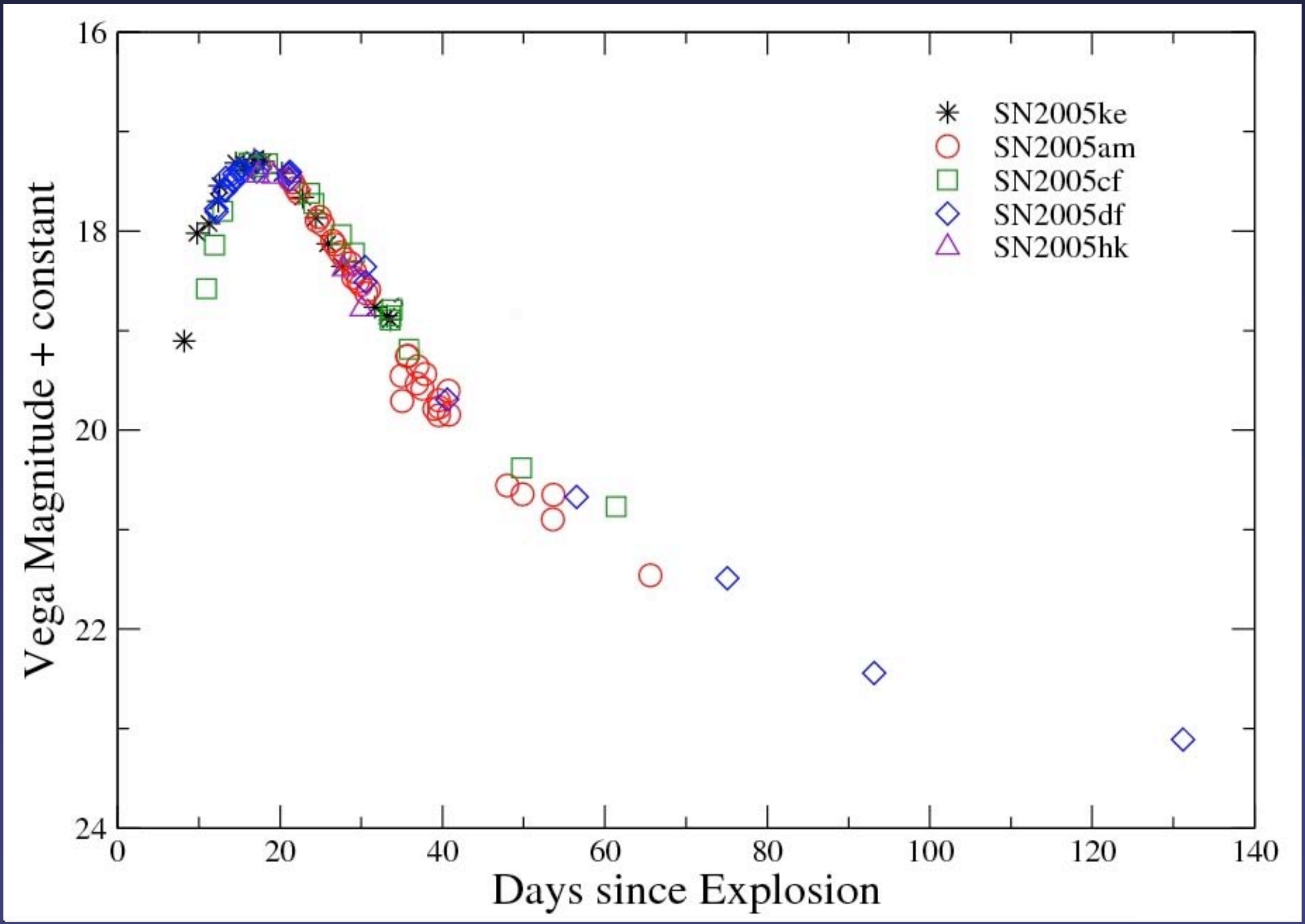


XRT X-rays (258 ks)

- 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

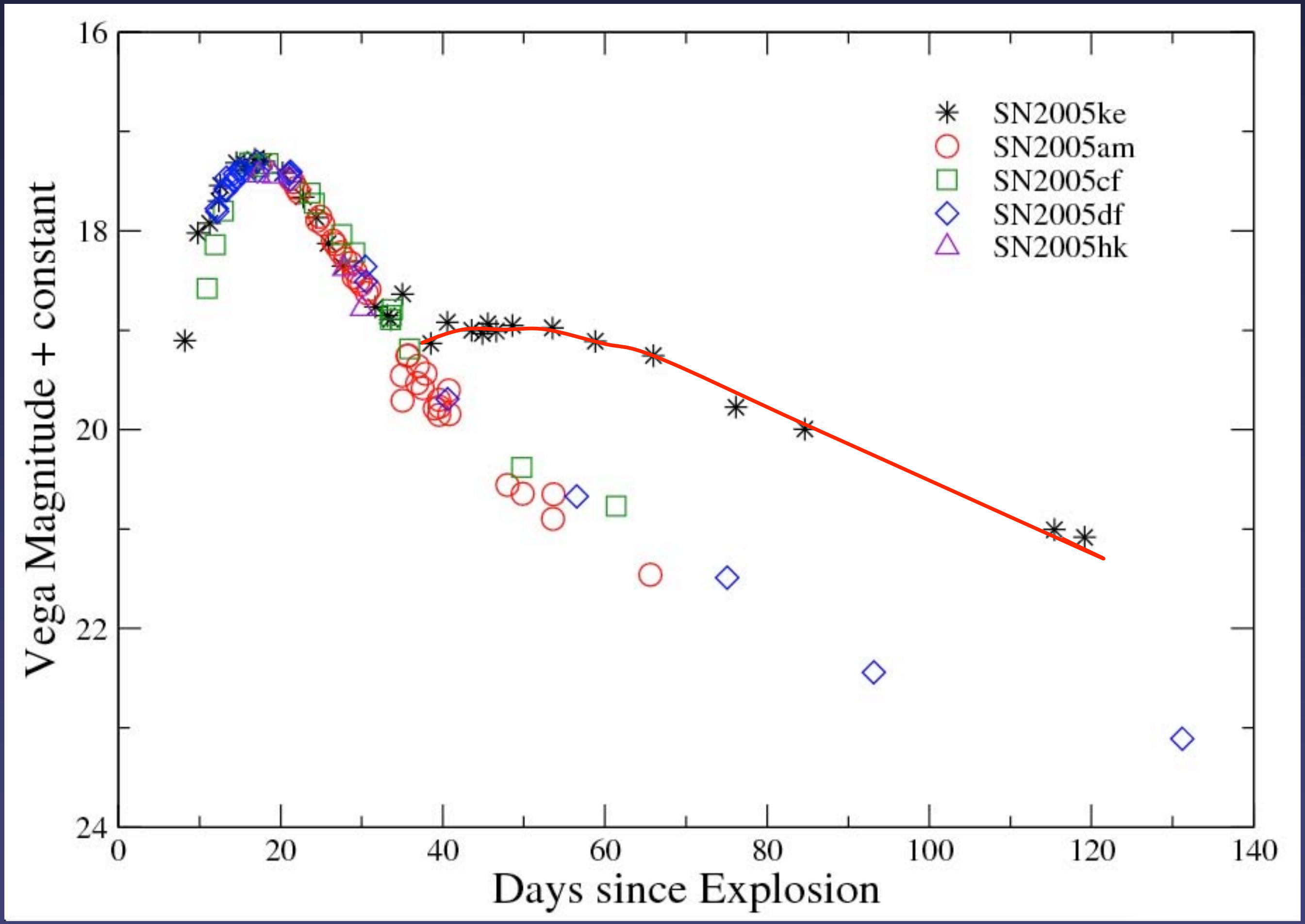


Swift UV lightcurves of type Ia supernovae

UV lightcurve shapes of Type Ia supernovae are surprisingly similar

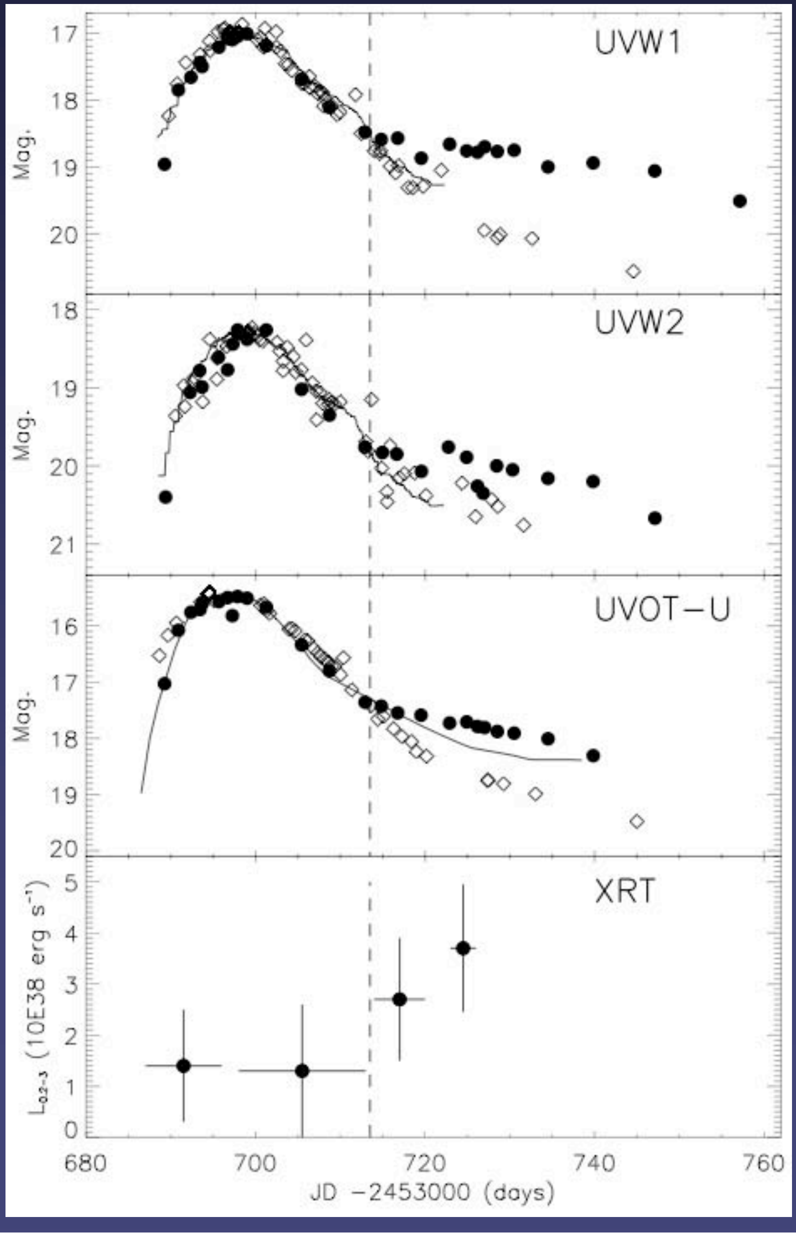
except:

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?

SN 2005ke in NGC 1371



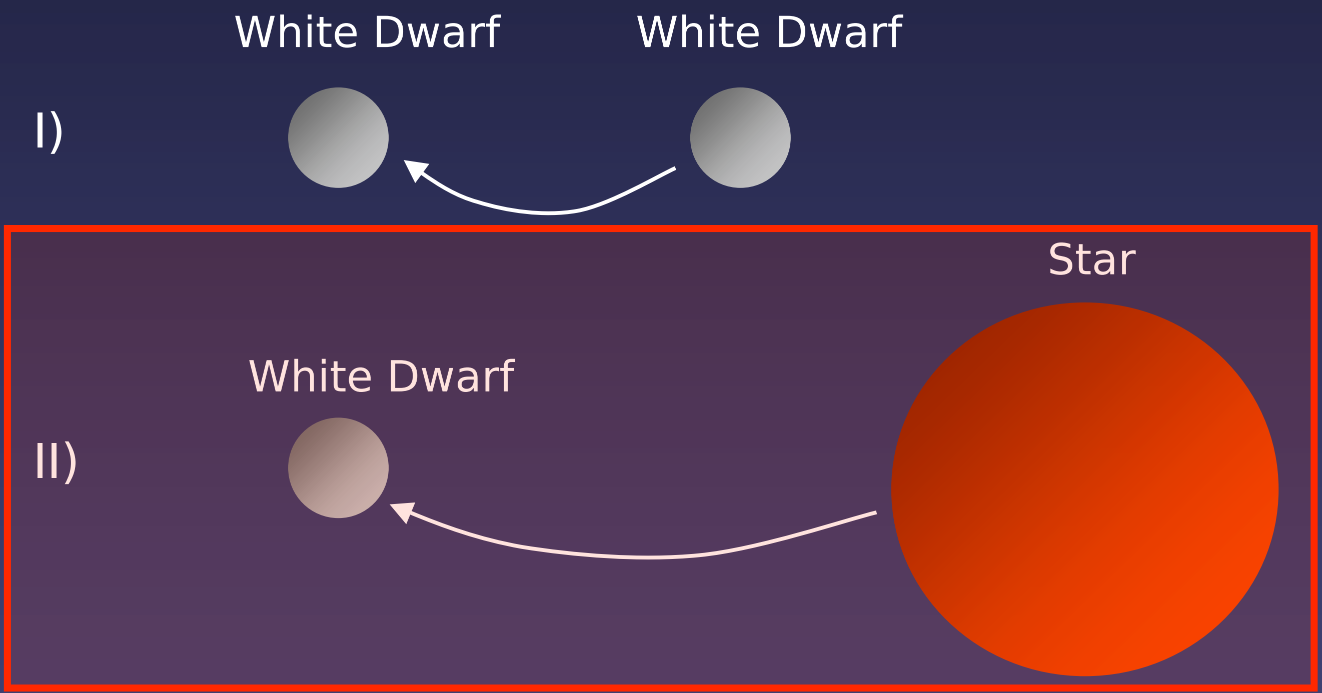
SN 2005ke in NGC 1371

- 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 from a companion star and explodes as it reaches the Chandrasekhar mass (1.4x Sun).

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

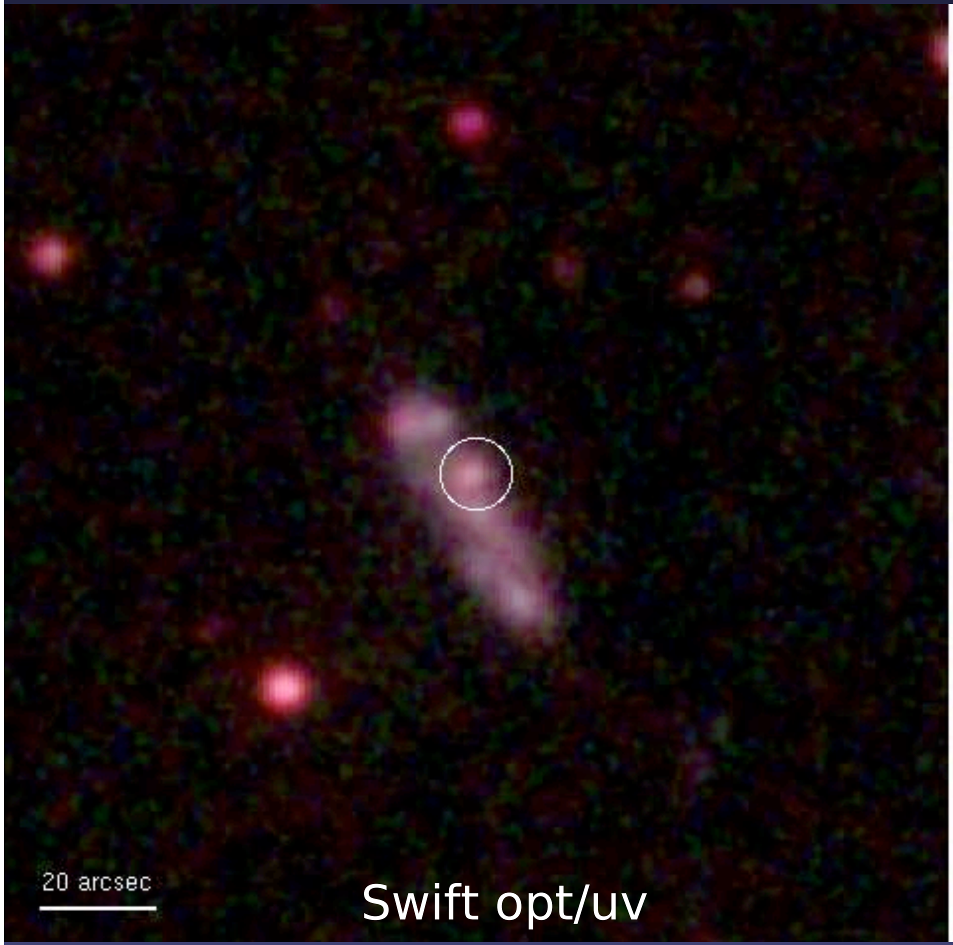
Primary Objectives

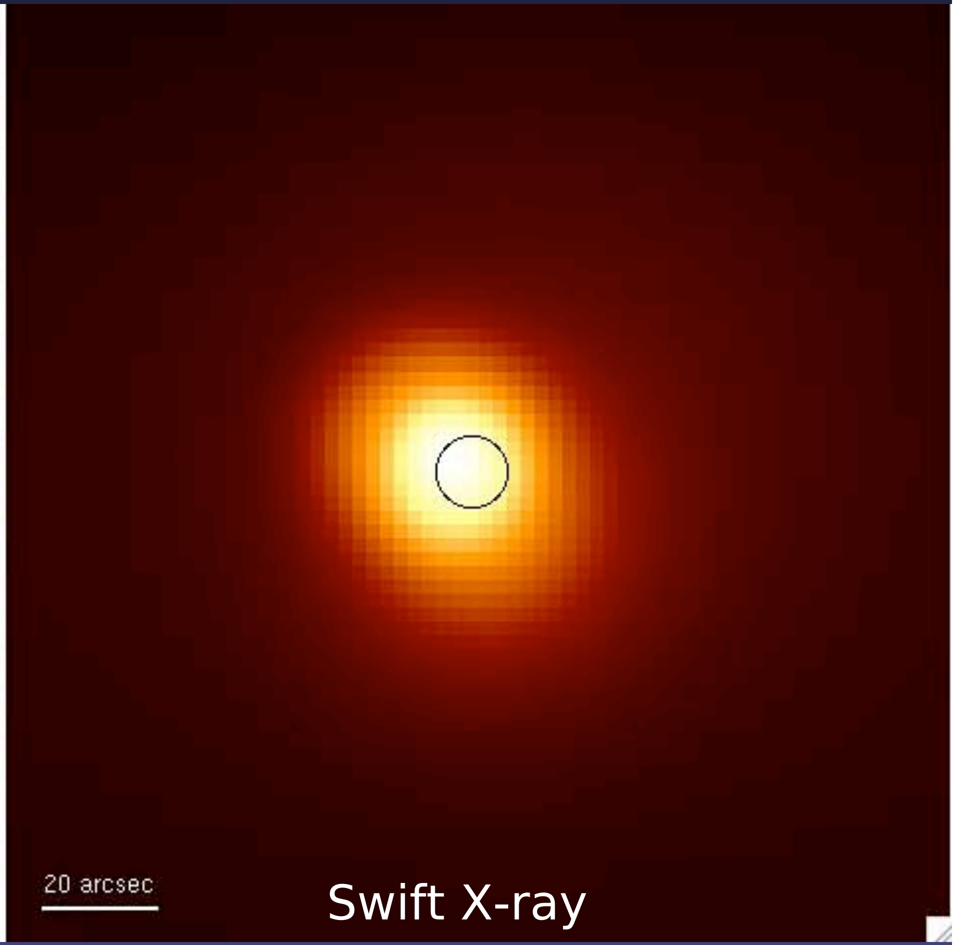
2) Core-Collapse SNe:

- Search for signatures of CSM interaction using XRT and UVOT.

- Exploring the general UV properties with photometry and spectra.

SN 2005kd

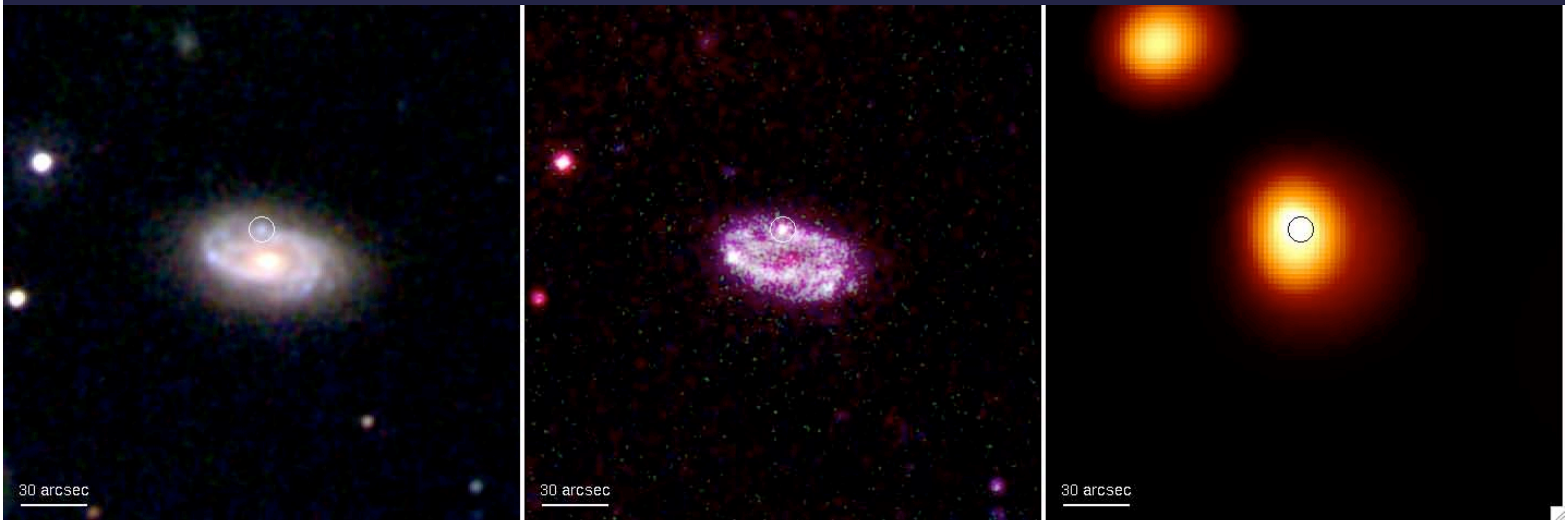




- Type IIn SN
- High X-ray luminosity, $L_x = 1.5 \times 10^{41}$ ergs/s (0.2–10 keV)
- High mass-loss rate of some $10^{-4}\ M_\odot\ \mathrm{yr}^{-1}$

Immler, Pooley & Brown 20

SN 2005ip

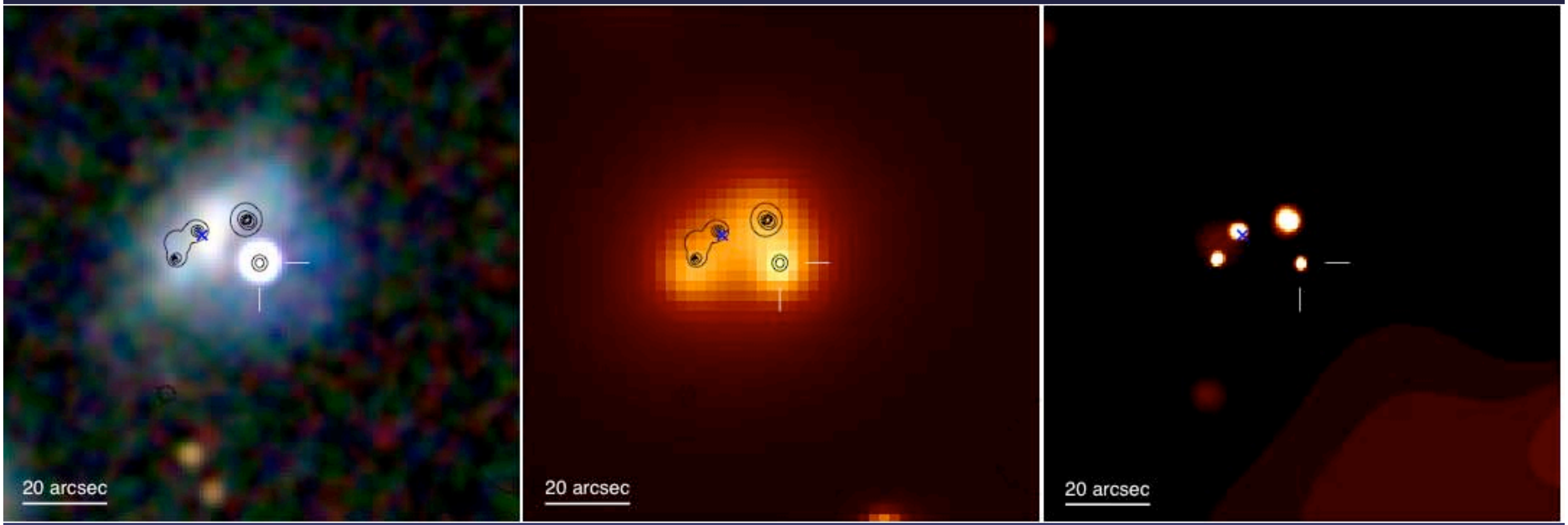


Swift optical　　Swift UV　　Swift X-ray

- 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

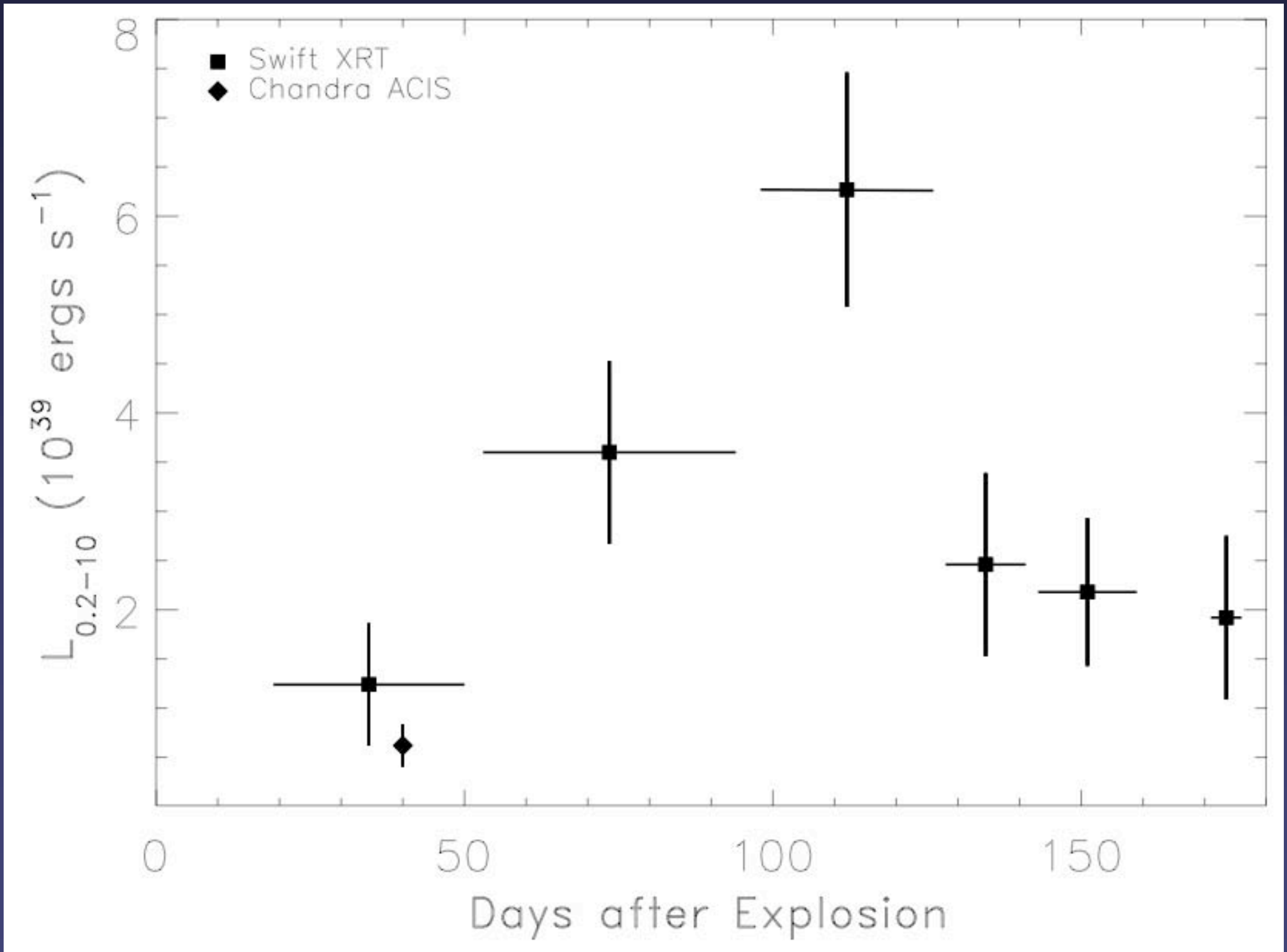


Swift optical　　Swift X-ray　　Chandra X-ray

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

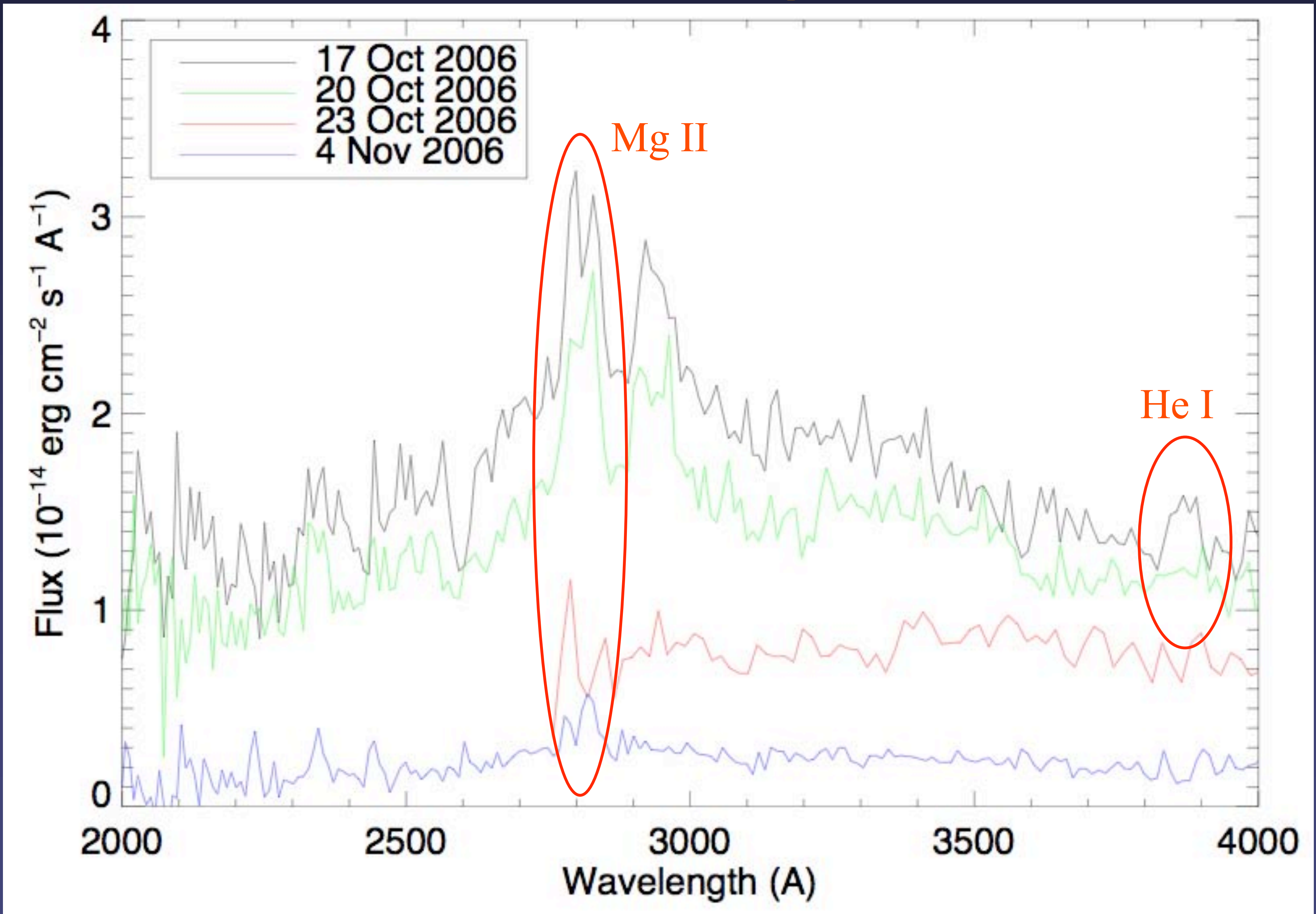
SN 2006jc is detected in X-rays with Chandra on day 40 after explosion and showed a brightening in X-rays with XRT, mass-loss rate $9 \times 10^{-5}\ M_{\odot}\ yr^{-1}$

SN 2006jc

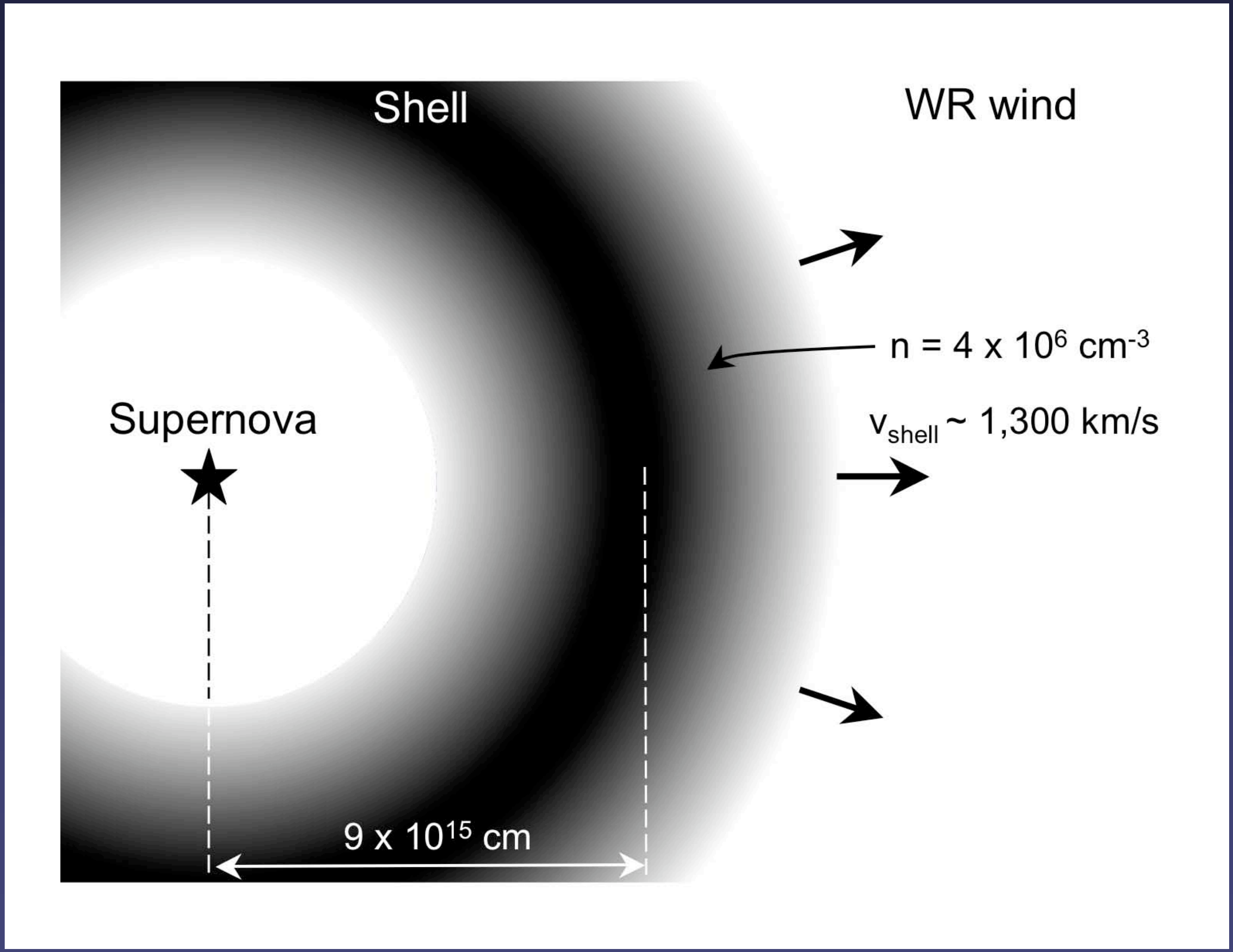


Brightening in X-rays: dense shell around the site of the explosion?
SN 2006jc is the result of LBV, whose outburst was observed two years befo

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})
0
1
2
3
4
2000
2500
3000
3500
4000
Wavelength (A)

SN 2006jc



Luminous Blue Variable - type outburst of WR progenitor, leading to ejection of shell

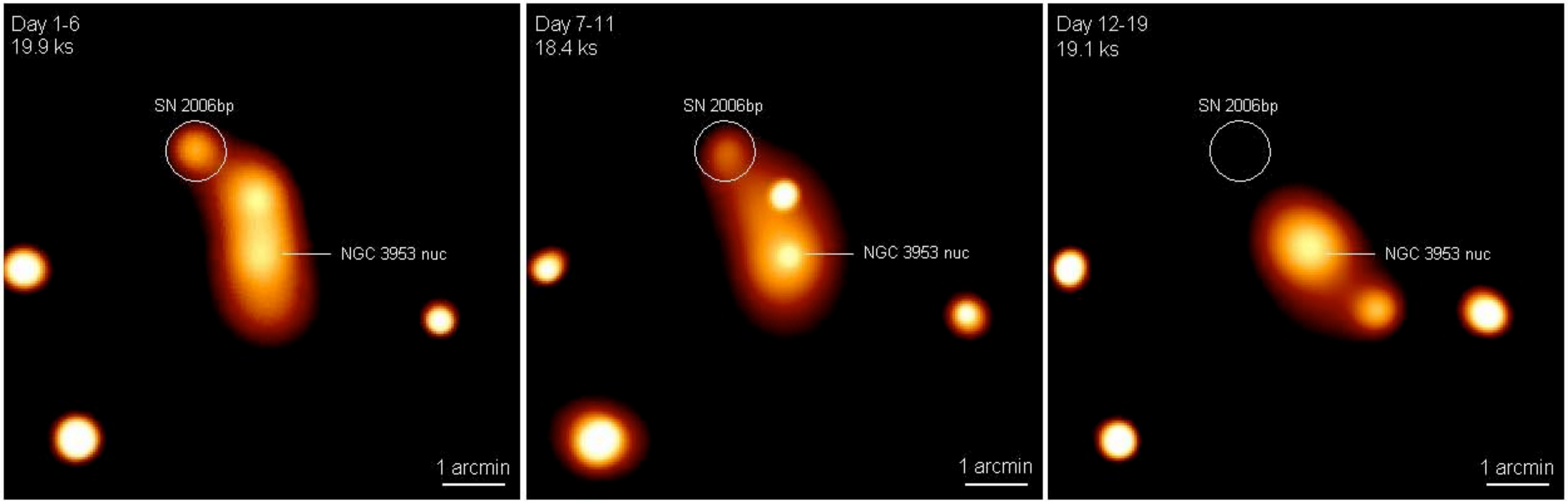
SN 2006bp in NGC 3953

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.

Swift Survey of Nearby Galaxies

Rationale: Use the multi-λ capabilities of Swift to perform a sensitive survey of nearby galaxies in the opt+UV+X-rays

Has been proposed and discussed during the Swift team meeting in 2006 as a suitable “fill-in” program

Galaxies selection criteria:

- Uniform distribution of galaxies across the sky
- Short exposure times of 1ks per UVOT filter
- No time constraints
- Minimal to zero impact on GRB science
- Nearby galaxies, *d* < 100 Mpc
- Extents of galaxies a few arcmin to fit into UVOT field-of-view
- All Hubble types, preference to those not obs by Chandra+XMM

Scientific Objective

A wide range of scientific topics can be addressed, such as:

- UV imaging and photometry as a probe of SFR processes (good spatial resolution and photometric accuracy, 6 filters)

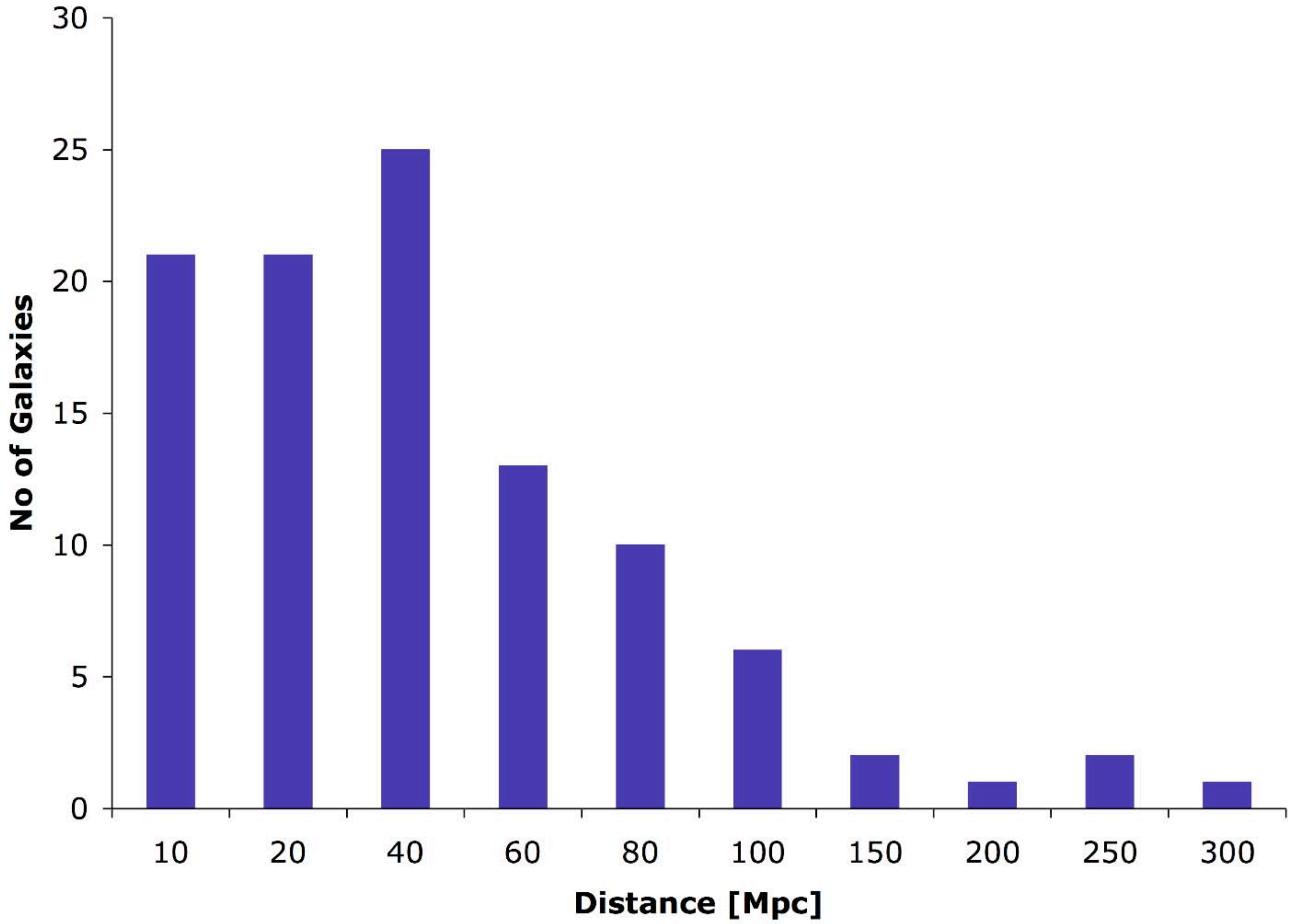
- Cooling flows and mass deposition rates for cluster galaxies

- Detection of previously unknown ULXs:
  Timing analysis on previously un-explored time domains of days
  Sensitive searches for optical+UV counterparts to study environs

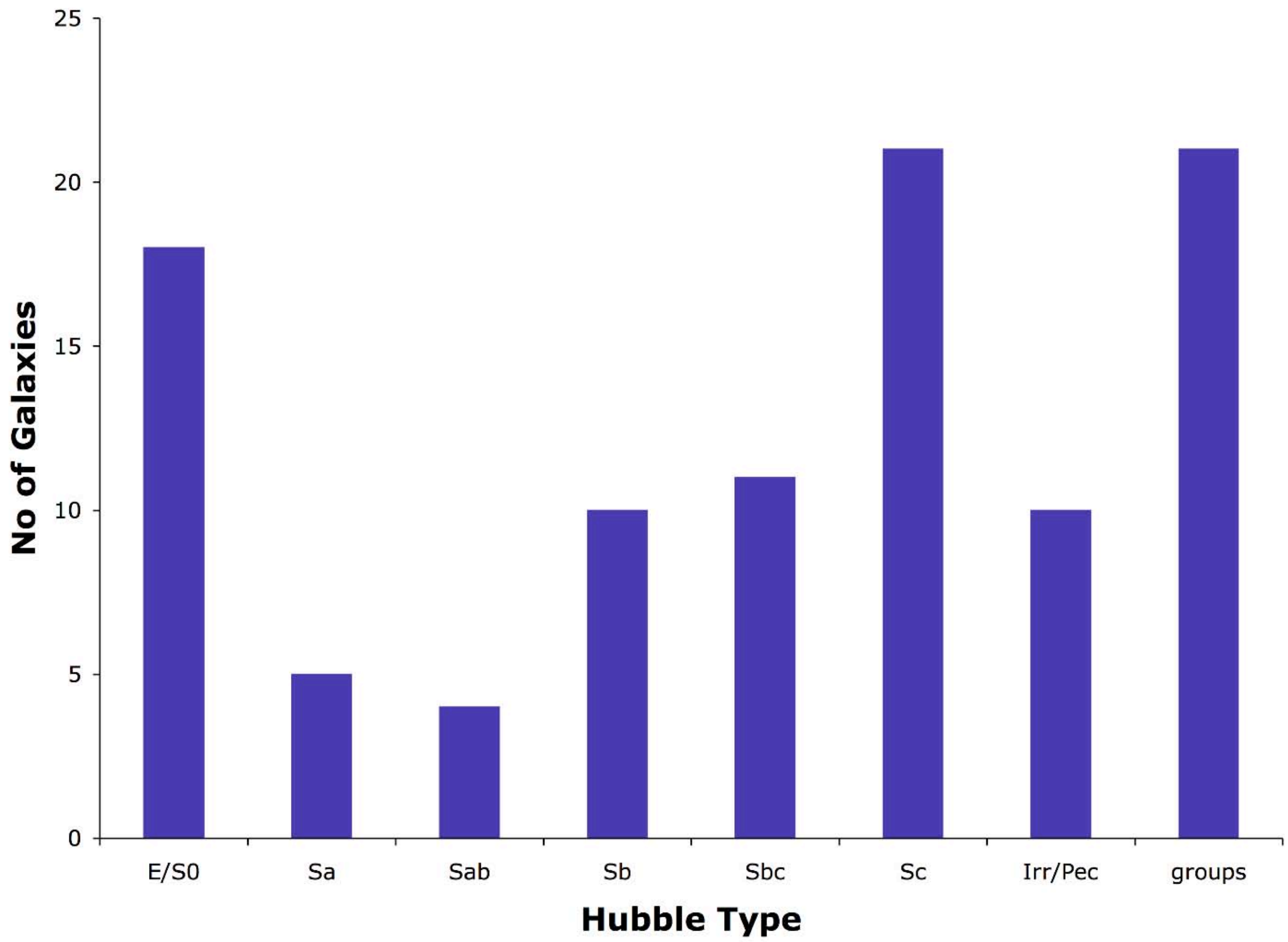
- Construction of SED of galaxies (calibration of Lα galaxies)

- UV surface brightness of ellipticals as a probe of

Distance Distribution

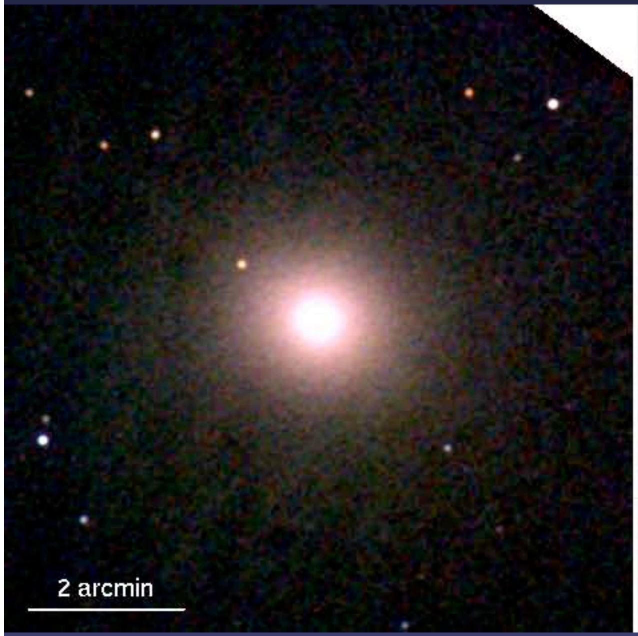


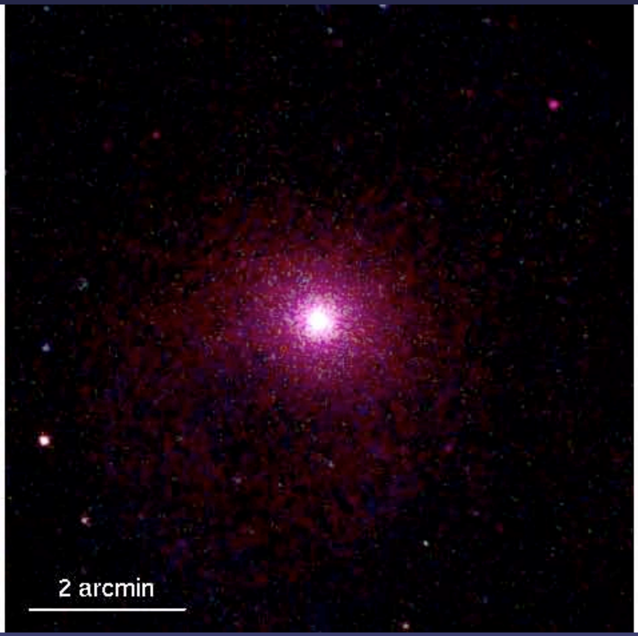
Hubble Types

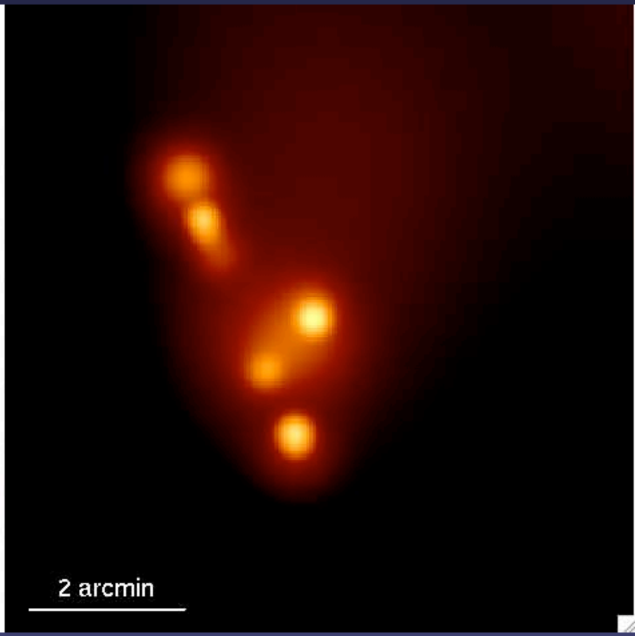


Elliptical Galaxies

NGC 3953







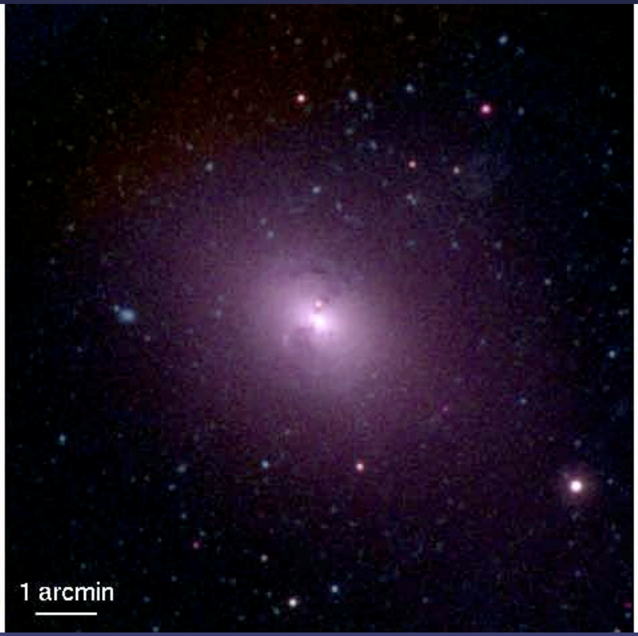
V, B, U

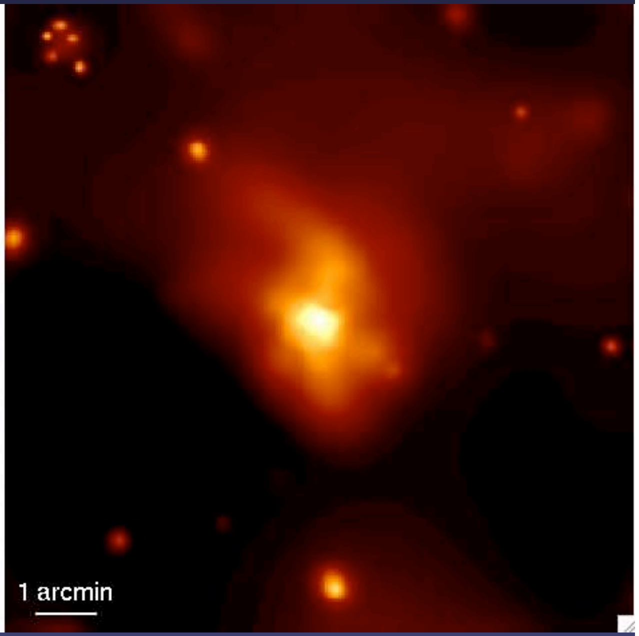
W1, M2, W2

X-ray

Elliptical Galaxies

NGC 1316





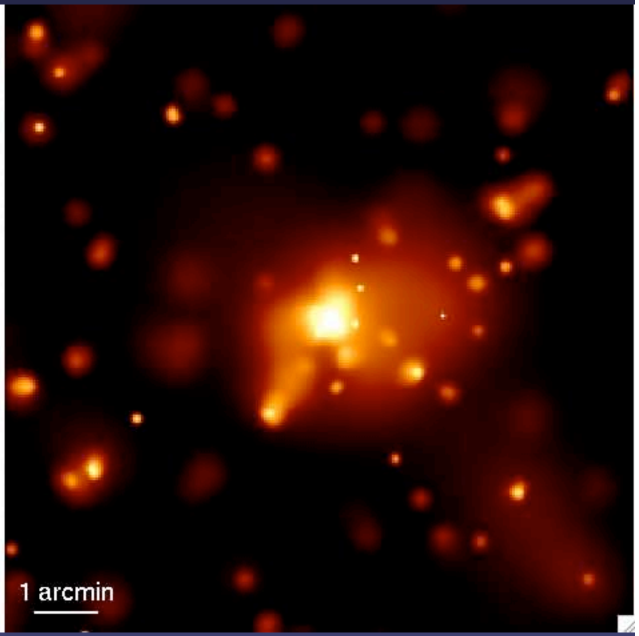
V, B, U

W1, M2, W2

X-ray

Spiral Galaxies

NGC 4321



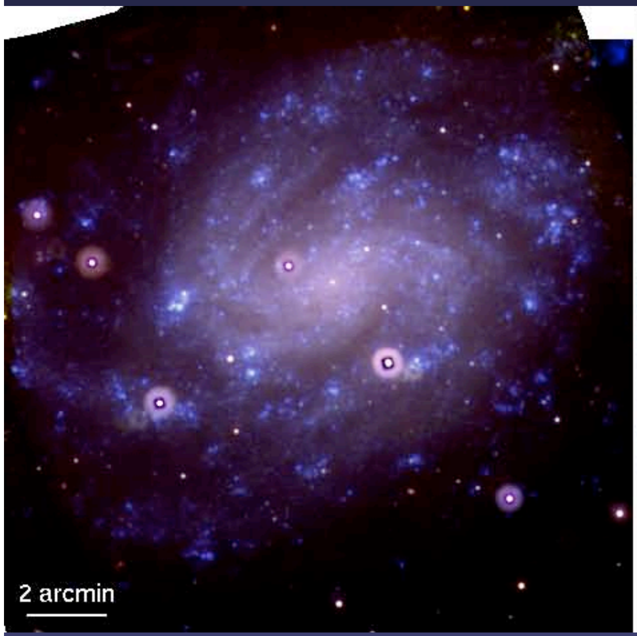
V, B, U

W1, M2, W2

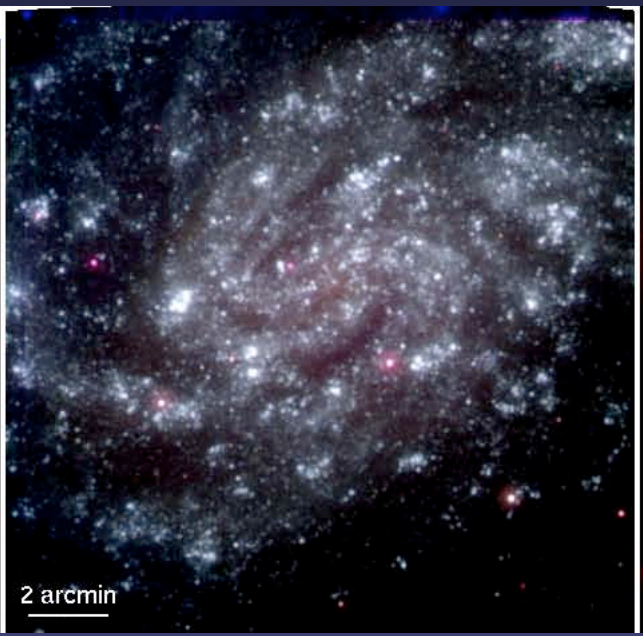
X-ray

Spiral Galaxies

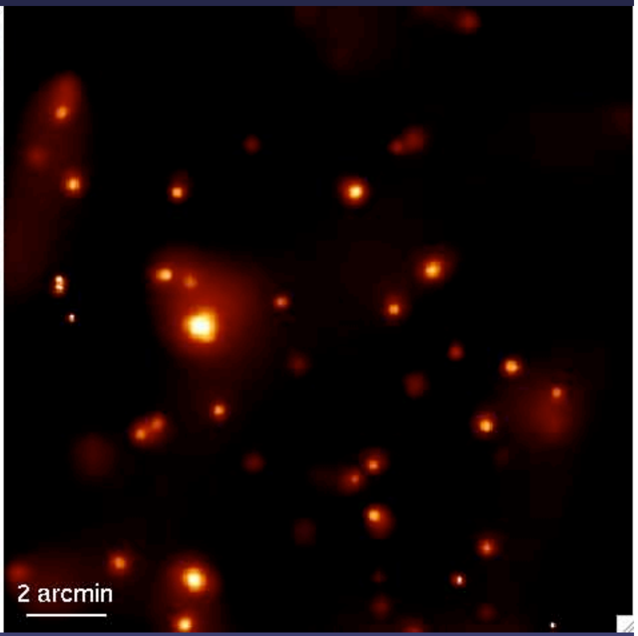
NGC 300



V, B, U



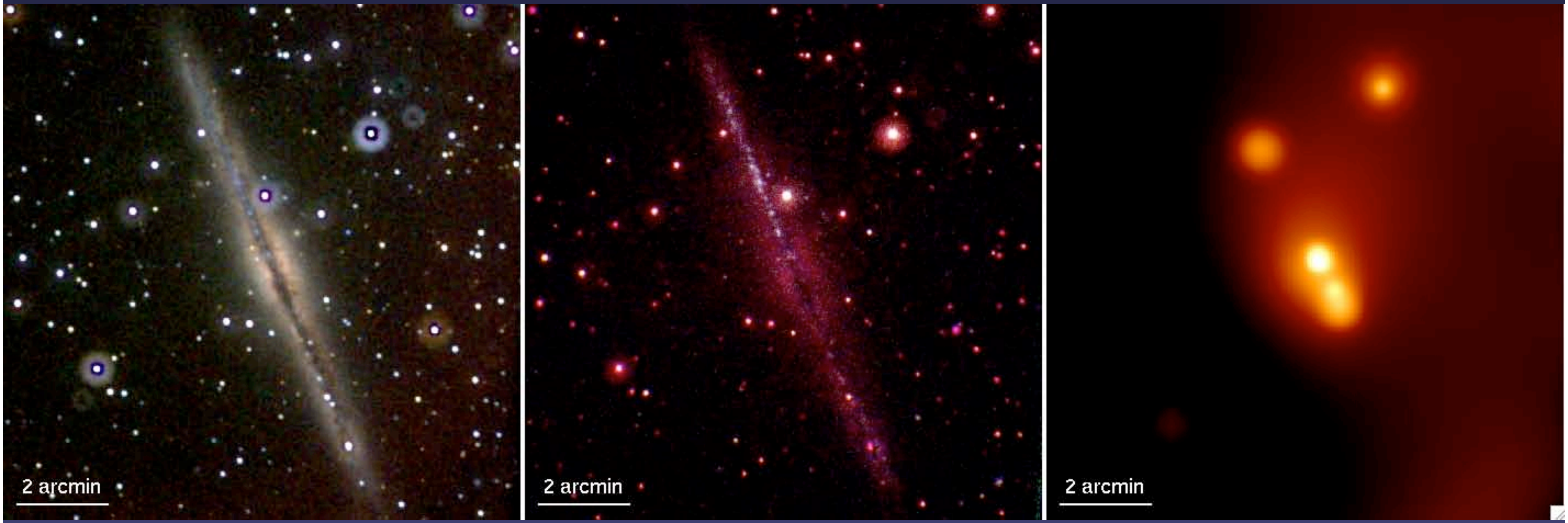
W1, M2, W2



X-ray

Spiral Galaxies

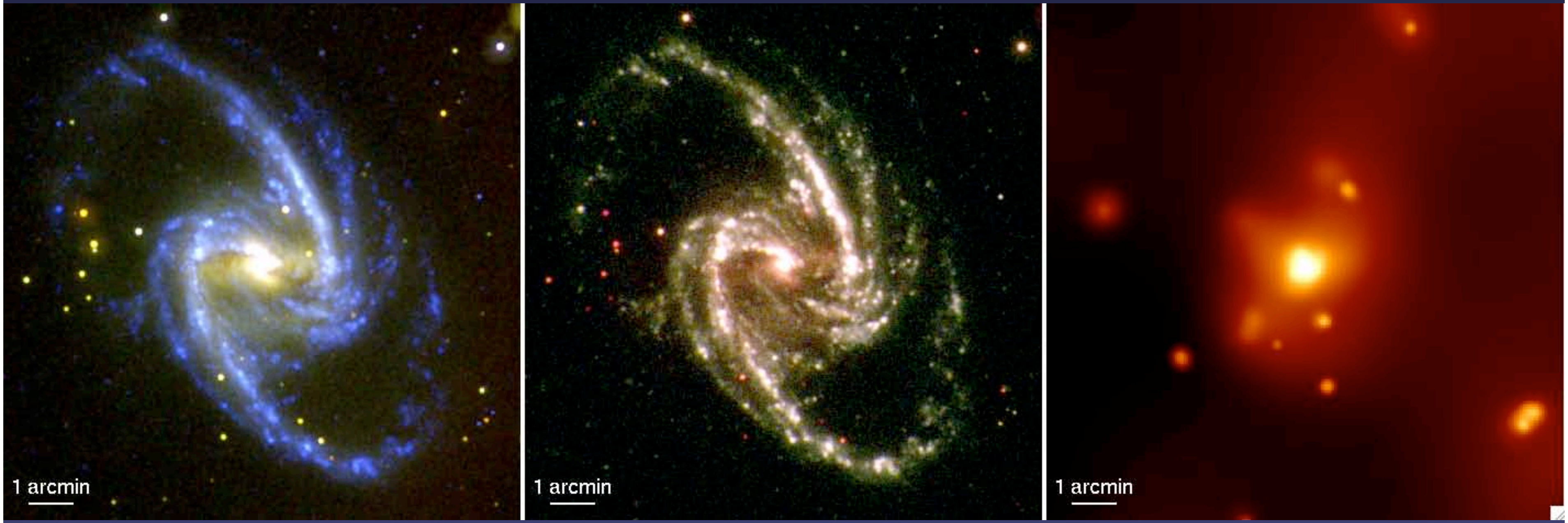
NGC 891



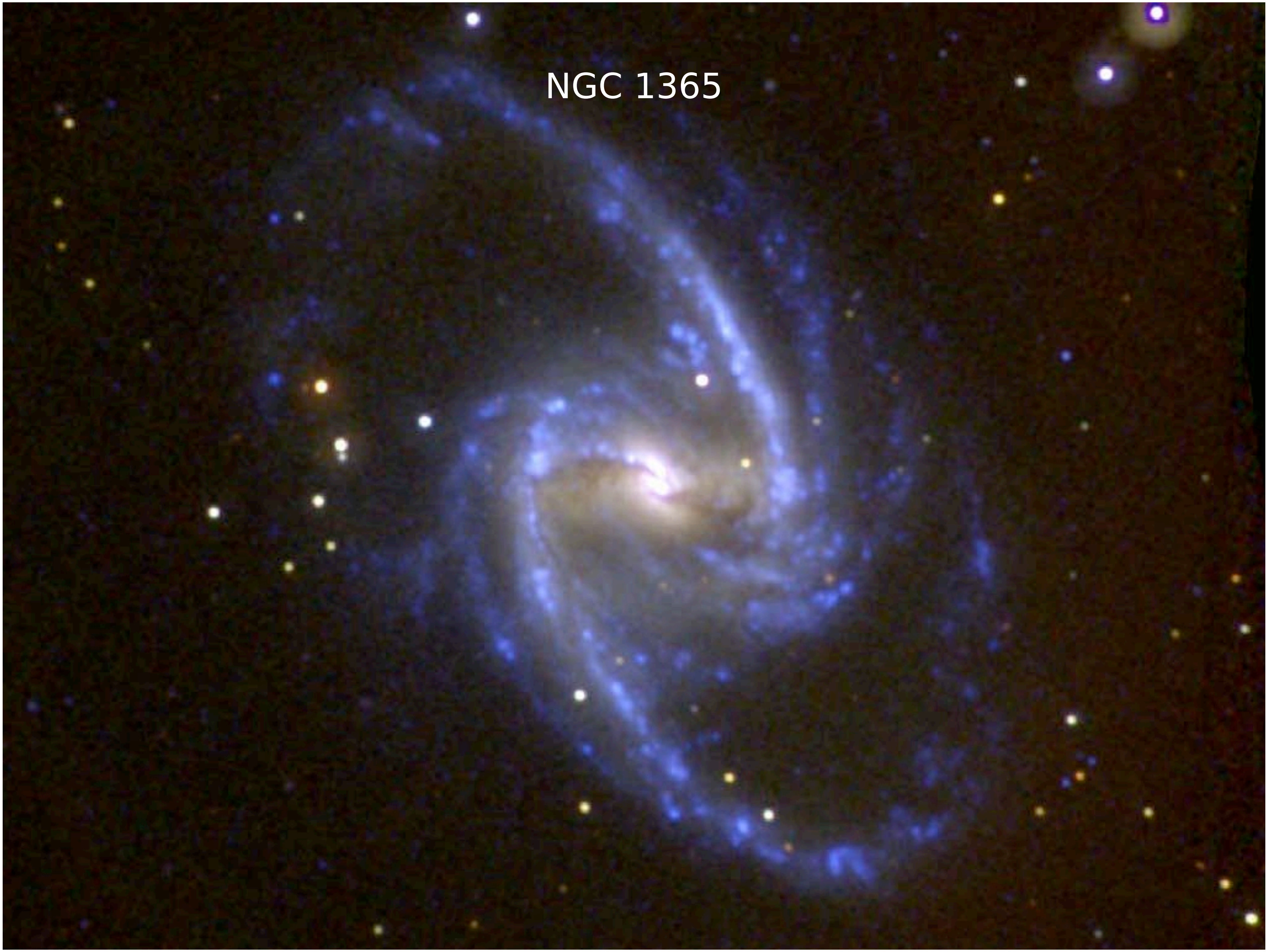
V, B, U   W1, M2, W2   X-ray

Spiral Galaxies

NGC 1365

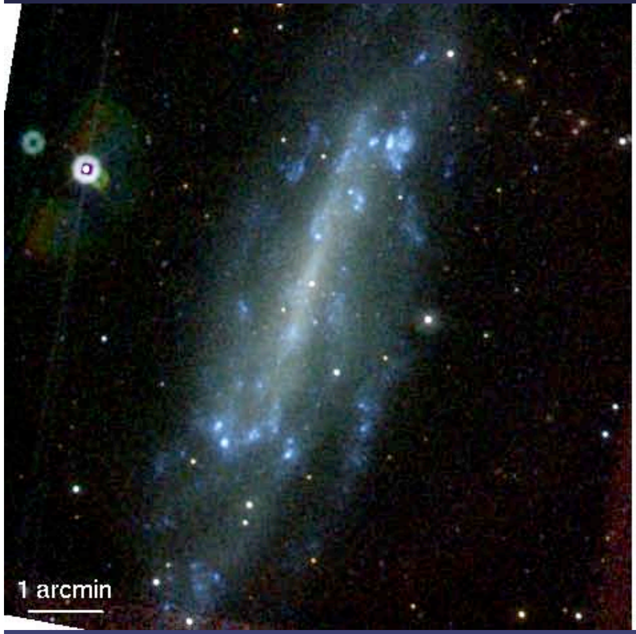


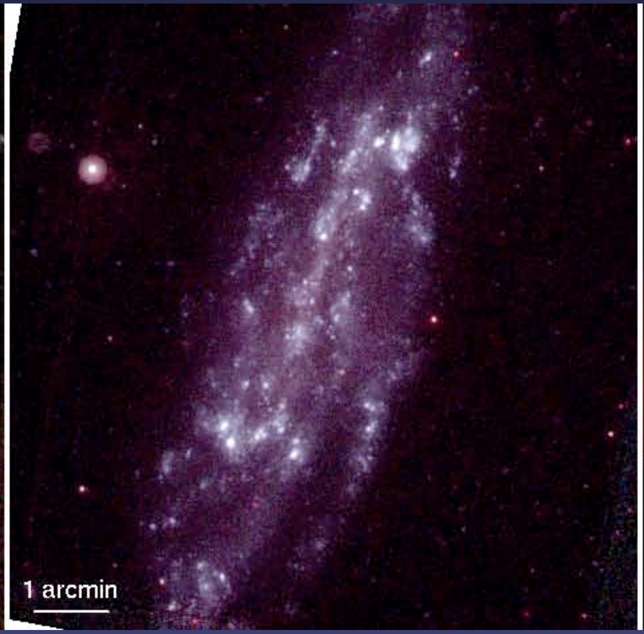
V, B, U | W1, M2, W2 | X-ray

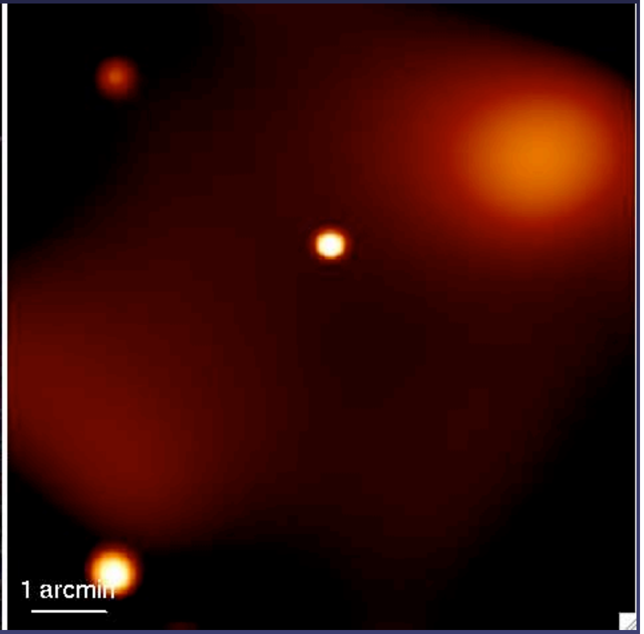

NGC 1365

Spiral Galaxies

NGC 4236







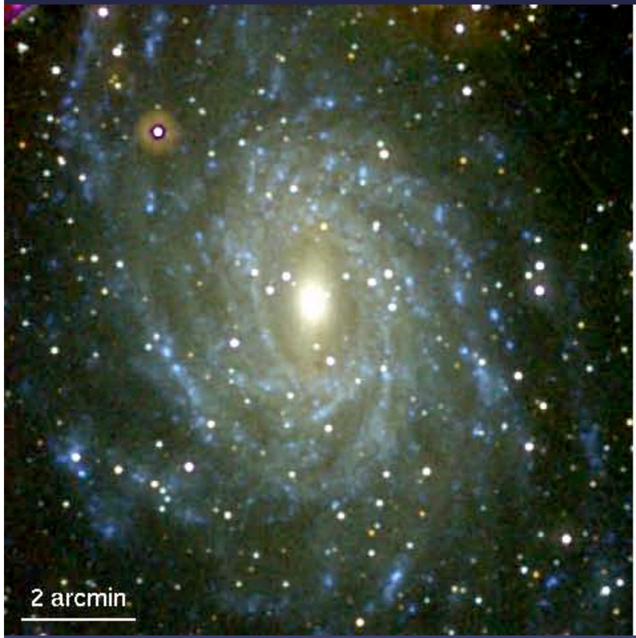
V, B, U

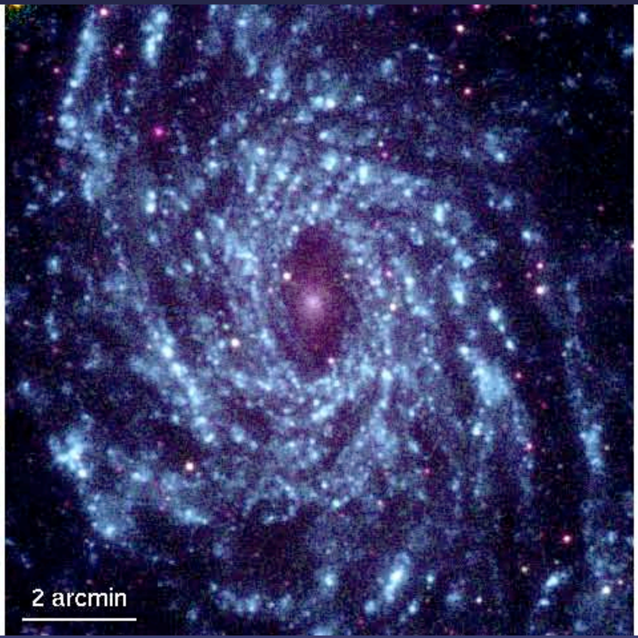
W1, M2, W2

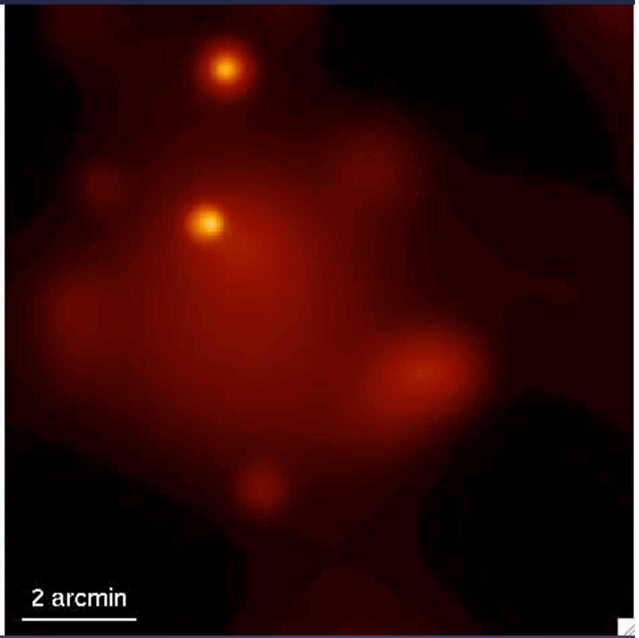
X-ray

Spiral Galaxies

NGC 6744







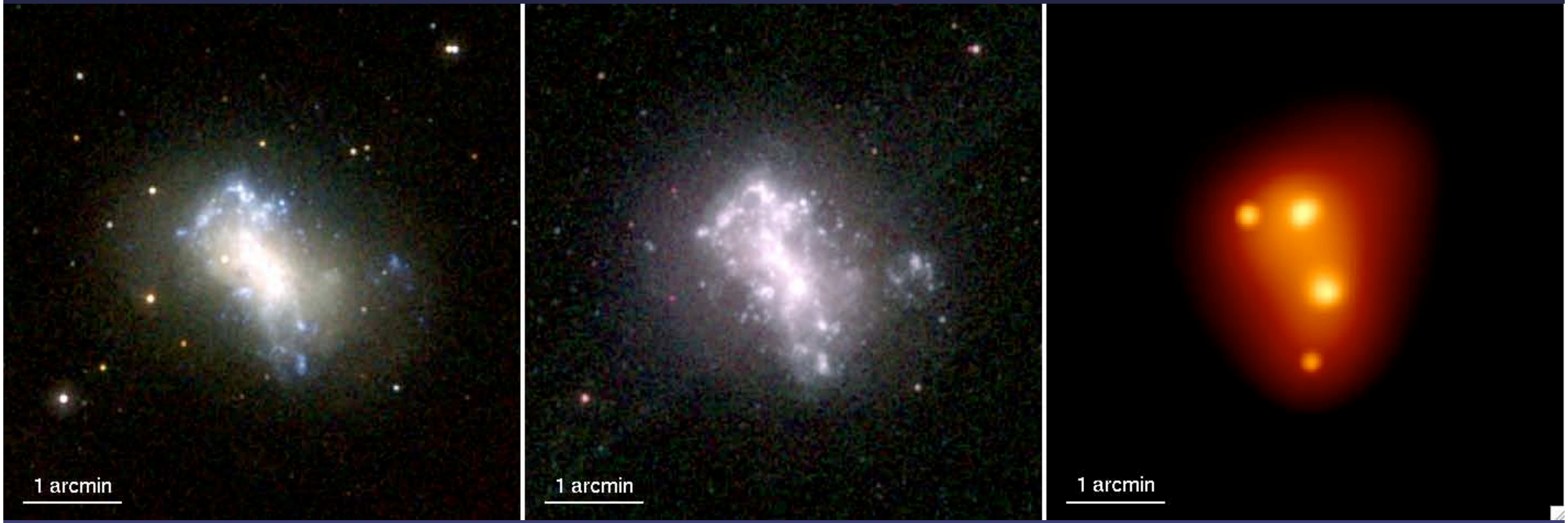
V, B, U

W1, M2, W2

X-ray

Irregular Galaxies

NGC 4449



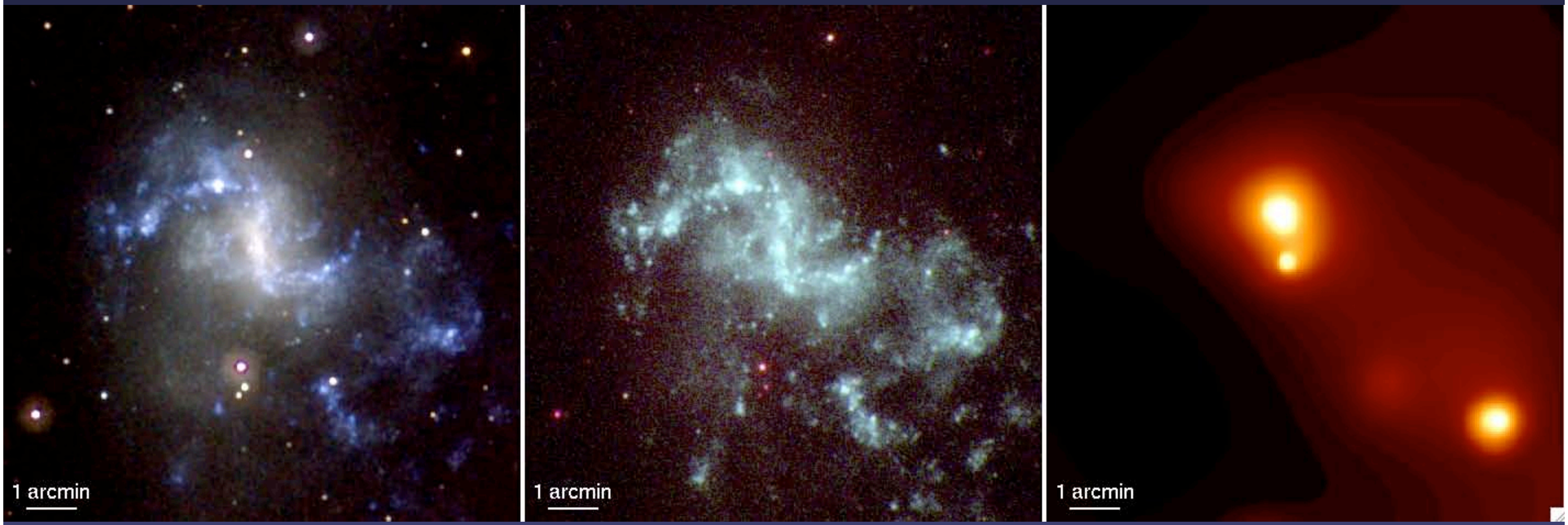
V, B, U

W1, M2, W2

X-ray

Irregular Galaxies

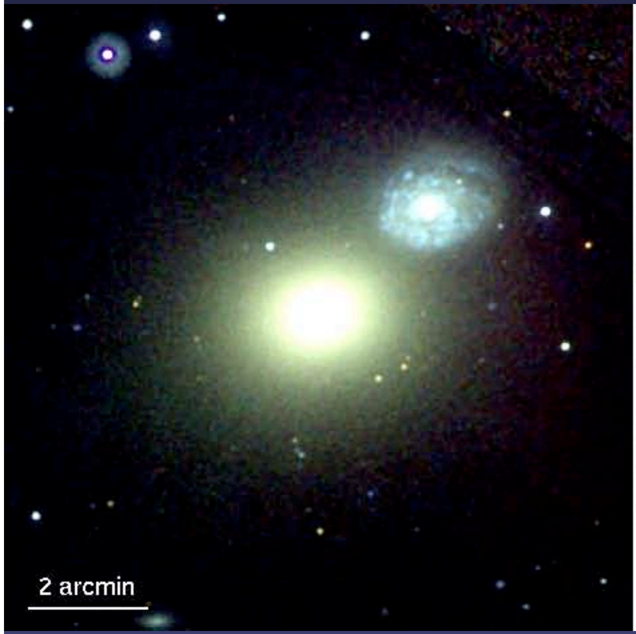
NGC 1313



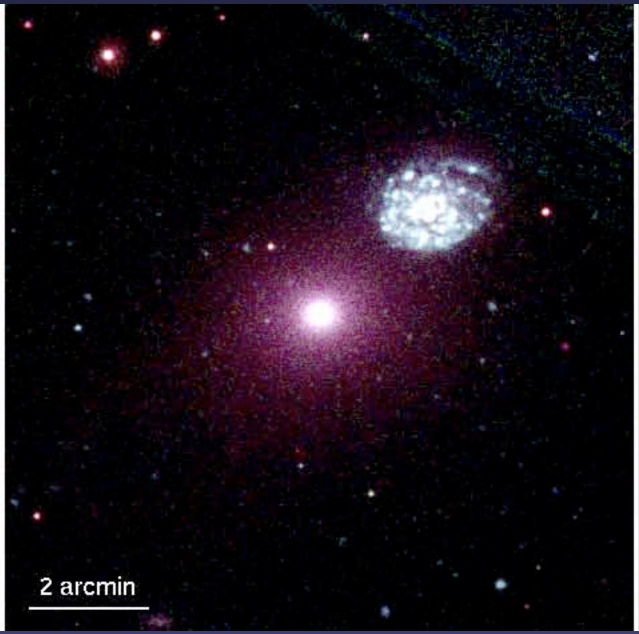
V, B, U | W1, M2, W2 | X-ray

Peculiar Galaxies

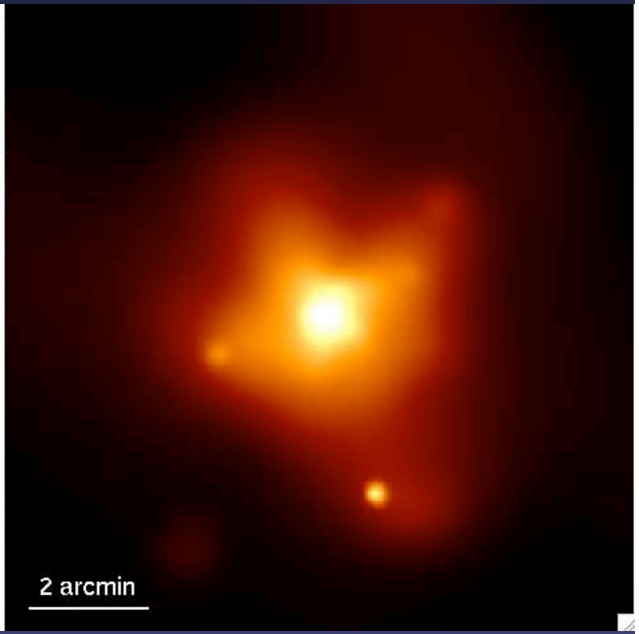
NGC 4649



V, B, U



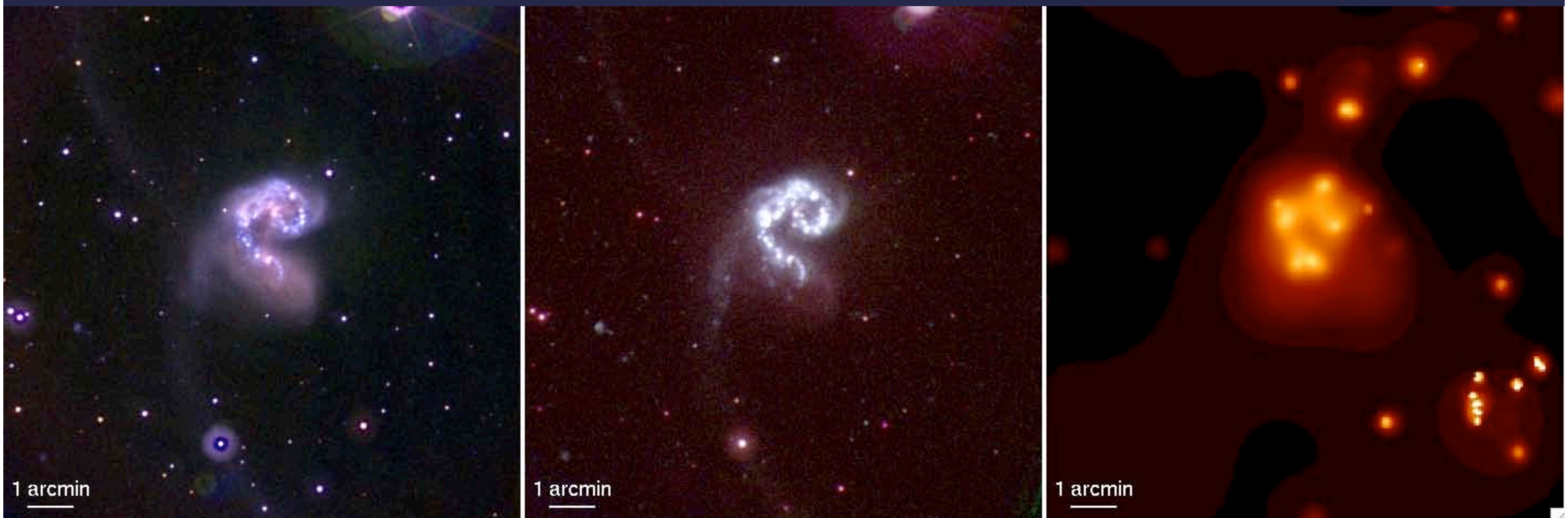
W1, M2, W2



X-ray

Groups of Galaxies

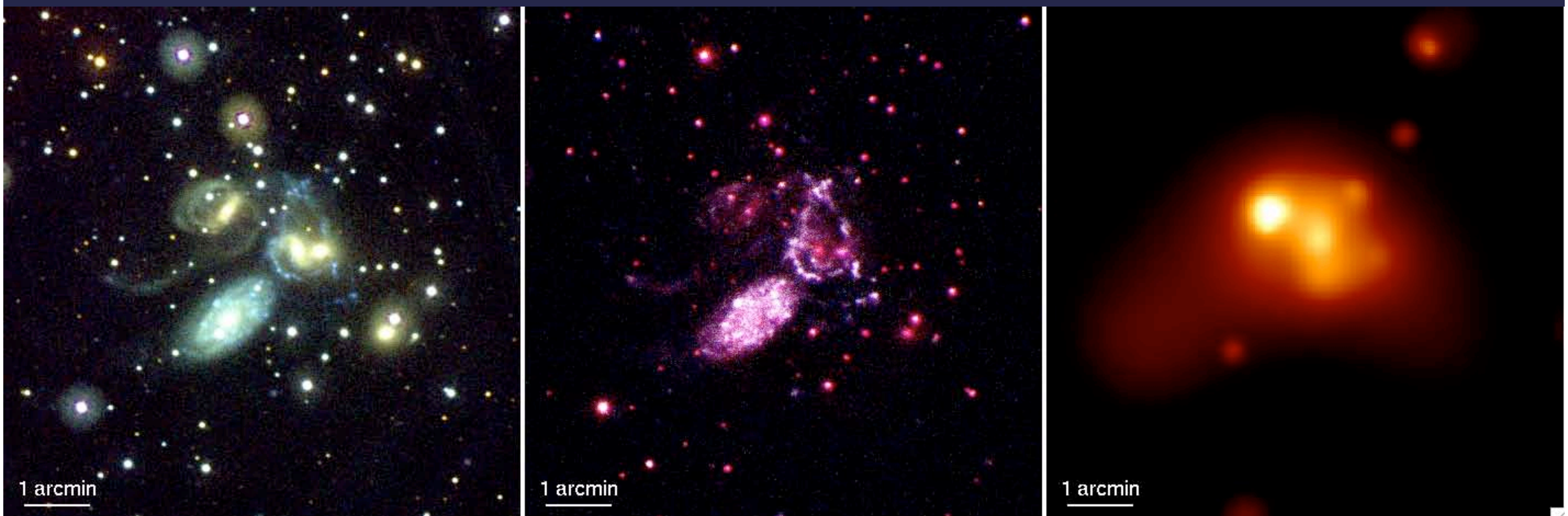
Arp 224



V, B, U   W1, M2, W2   X-ray

Groups of Galaxies

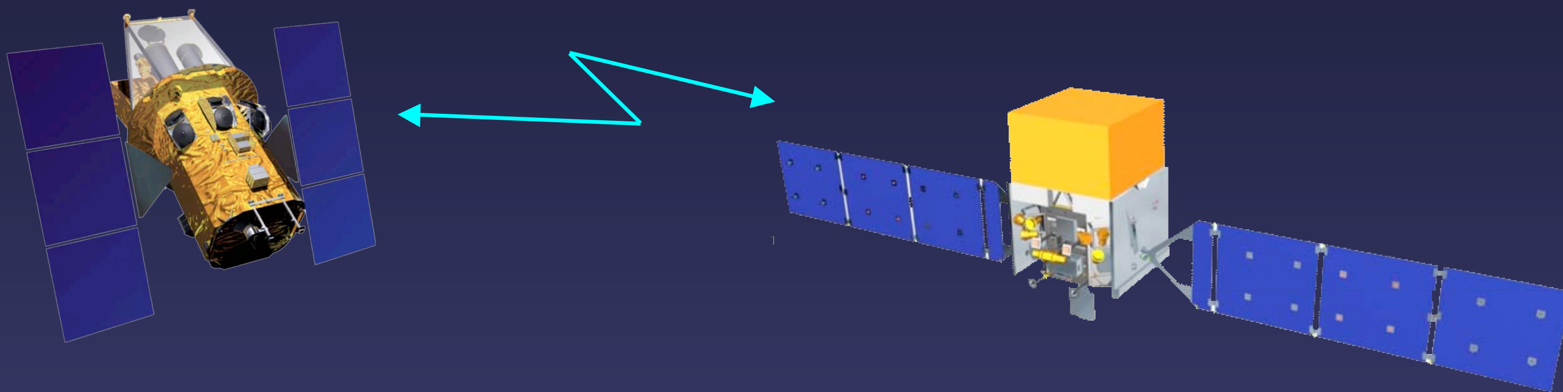
Arp 319



V, B, U W1, M2, W2 X-ray

- Status of the Swift Survey of Nearby Galaxies:
- 111 galaxies completed (2007 June 4), more to come
- Demonstrates the capabilities of the instruments on board Swif

Swift Identification of GLAST Sources



- *Swift* will be in orbit for >10 years

- Significant overlap with GLAST over the remaining *Swift* lifetime

- A lot of emphasis is being given in the *Swift* planning to joint observations with GLAST (joint working group organized by David Band and Jamie Kennea at the *Swift* MOC)

Swift Identification of GLAST Sources

- GLAST needs counterparts and redshifts to interpret GRB
- LAT GRBs can be followed up by *Swift* XRT & UVOT
  - <20 arcmin localizations needed (~20 per year, or 1 every 2 weeks)
  - ToO repointing of *Swift* within ~2 hrs
  - Most GRB will be detectable by *Swift* XRT at 2–3 hrs
  - Unique counterparts can be found with 3 arcsec source localizations
  - Redshifts and host galaxy information from optical follow-up
- *Swift* GRBs can be followed up by GLAST
  - LAT will scan GRB within following orbit
  - Searches performed for high energy afterglows (E_{peak}!)
  - Correlation studies of high energy signatures with low energy and afterglow properties
- Ideal case is BAT and LAT co-pointings: "Golden Bursts"
  Study over 10 orders of magnitude in the electromag. spectrum

Joint Non-GRB Science Opportunities

- BAT & LAT both monitors sky daily for blazar flares (15 blazars in BAT survey out to z = 3)
- Joint campaigns of active sources opt/UV + X-ray + BAT + LAT
- XRT & UVOT searches of un-identified LAT sources
- XRT & UVOT observations of LAT pulsars
- LAT observations of galactic transients found by BAT
- New sources found by LAT can be rapidly observed by *Swift* (~200 *Swift* ToO's performed to date)

The synergy between GLAST and *Swift* will lead to exciting new discoveries in GRB and non-GRB science