Novae And Supernovae

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Novae

Novae are interacting binaries with an accreting white dwarf and a mass losing secondary on the main sequence

Nova outburst is caused by thermonuclear runaway reaction in the accreted material and accompanied by the ejection of the accreted material with velocities > 300 km/s

UV and X-ray studies of novae in outburst provide an understanding of the physics of the nova phenomenon and the nature of the underlying white dwarf

The presence of many emission lines in different ionization stages help in determining the chemical abundances of the ejecta with high accuracy and refine our knowledge on the nucleosynthesis taking place during the outburst.

The properties and duration of the soft X-ray emission are direct indicators of the hot nuclear burning shell on the white dwarf envelope, while the hard X-ray emission provides a diagnostic of the conditions in the nova shell and the possible resumption of accretion

Novae during outburst - UV

- Fireball phase: rise to optical maximum – strong emission lines all over the UV range
- Dip in UV flux – iron curtain – featureless spectrum
- UV maximum – lifting of iron curtain – emission lines with P-Cygni profiles
- Nebular phase – faint continuum with typical nebular emission lines superimposed
- Max UV luminosity – close to Eddington limit for 1 solar mass WD

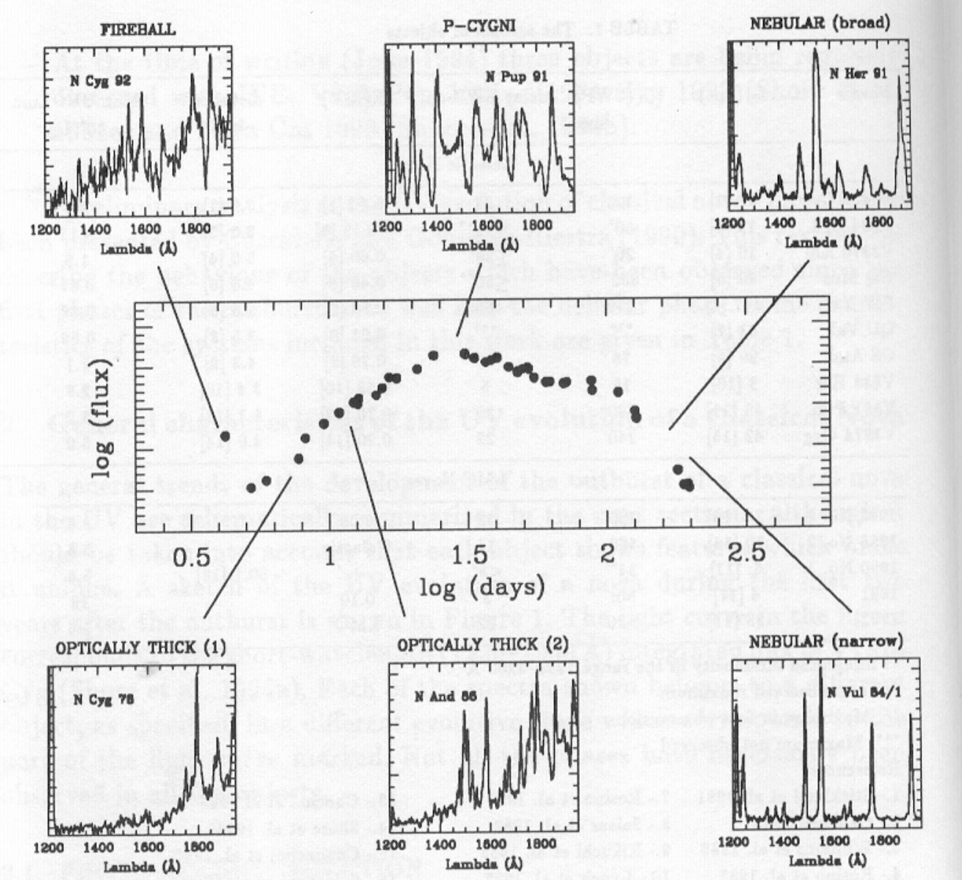
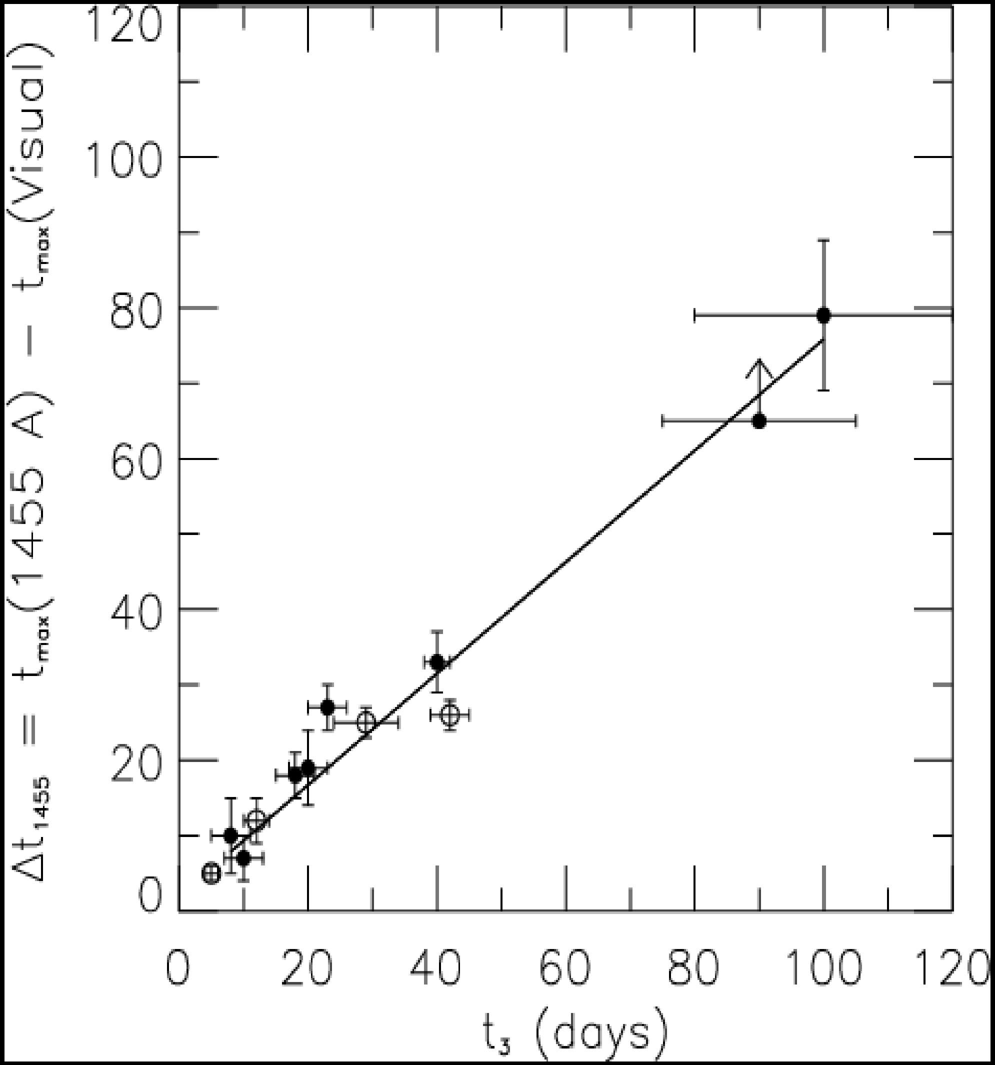


Figure 1. Schematic evolution of a classical nova in the UV during the first two years after the outburst. The light curve is that of V1974 Cyg and the spectra correspond to different objects chosen as representative examples, as labeled.

Novae during outburst - UV

- The maximum in the UV continuum (1455 A) lags systematically after the visual maximum - a linear function of t_3
- The ultraviolet outburst duration increases linearly with increasing t_3



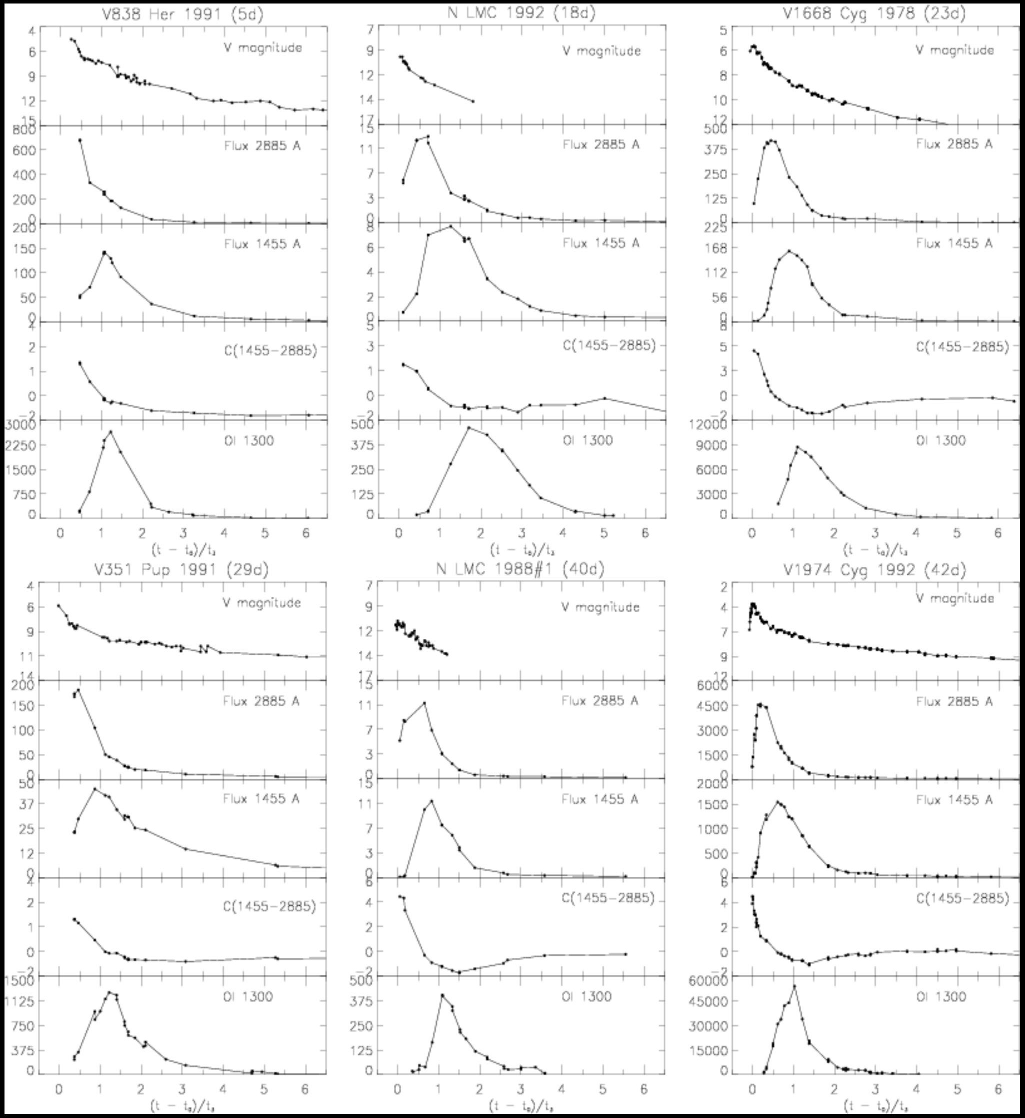
Novae during outburst - UV

- Colour index of the UV continuum

C(1455-2885)=

-2.5Log(F_1455)/F_2885)

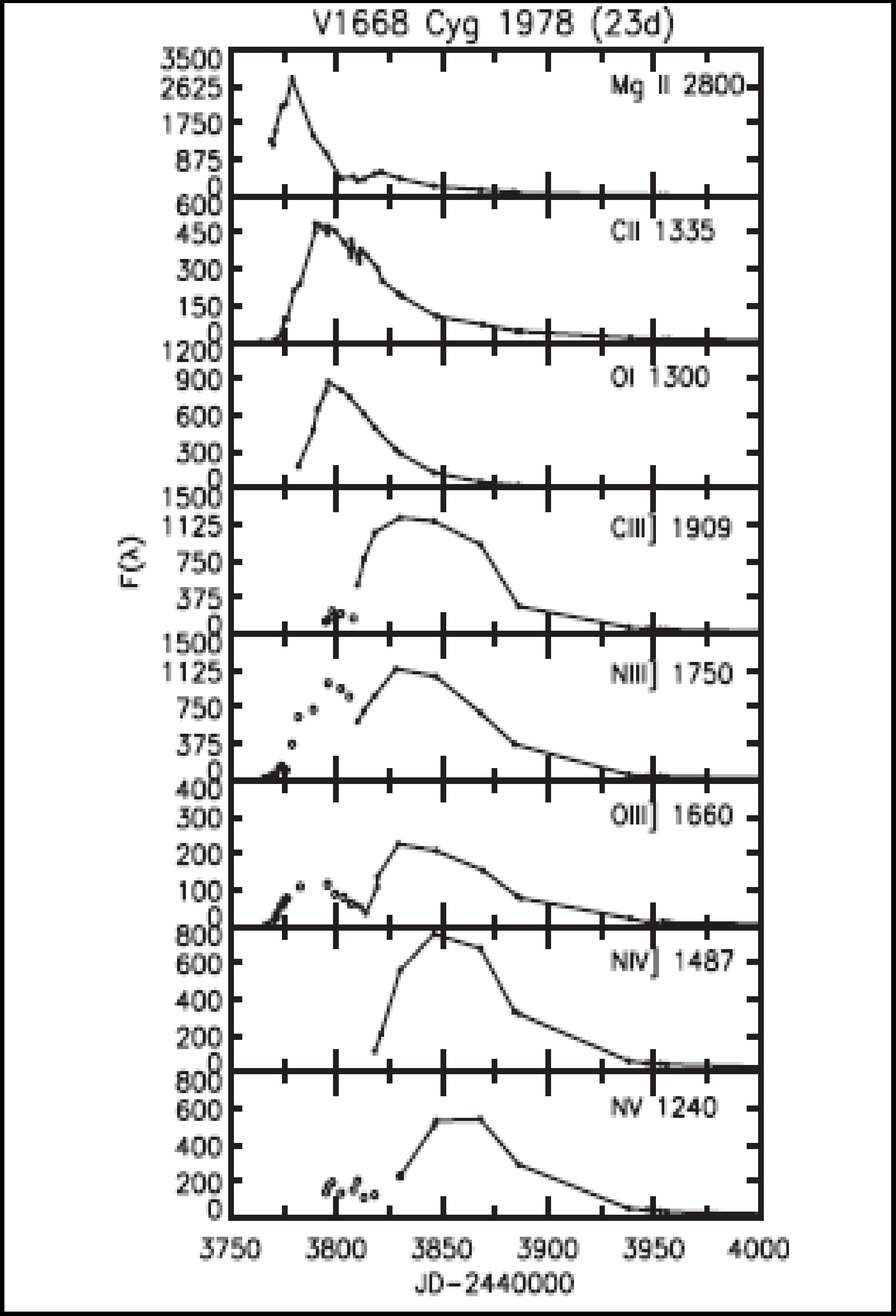
Nova appears as a red object in the earliest phases, gets rapidly hotter, reaches a local minimum, followed by an upturn to redder colours or a plateau



Evolution of emission lines indicates a growth in the degree of ionization of novae.

The time **D**(t) needed for a given line to reach flux maximum is (a) increasing function of the ionization and (b) proportional to t_3

Emission lines are good tracers of the temperature and luminosity changes of the postnova. The nuclear turnoff is proportional to t_3 and emission line light curve can be used as a measure of the nuclear turnoff time. This has implications for the white dwarf properties, TNR model etc.



Novae during outburst - X-Ray

Soft X-rays: (a) during very early phases, the fireball phase; soft X-ray with SED of hot stellar atmosphere; duration ~ hours (b) later phases of outburst, soft X-rays due to remnant hydrogen shell burning on WD surface – cessation of this phase indicator of the turn-off time

Hard X-rays: from hot circumstellar material due to shocks in the nova outflow. Bremsstrahlung SED (a) shocks from interaction of the expanding envelope with circumstellar material (e.g. RS Oph) (b) shocks from density inhomogeneities within the expanding envelope (c) shocks from the collision of a fast wind with preexisting slow wind material from the WD remnant

Non-radial oscillations of the WD detected in the X-ray light curves (e.g. V1494 Aql, V4743 Sgr) – an additional and important way to derive WD parameters (Orio 2004 and references therein)

Nova V832 Vel 1999 (Ness et al 2005)

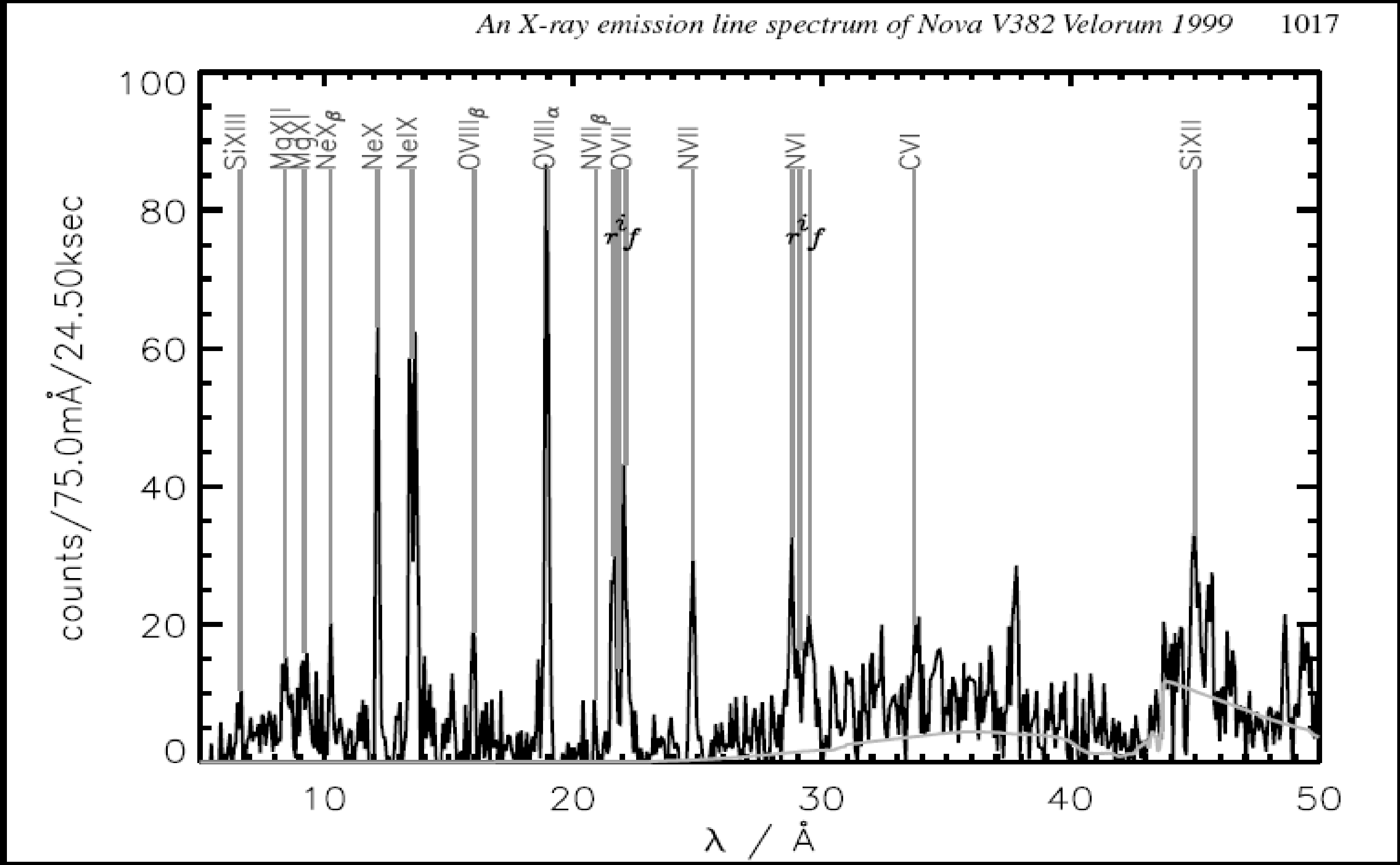
Outburst – 22 May 1999

UV spectral evolution followed the fireball, iron curtain, P-Cyg etc phases

Lines profiles structured indicative of structure (fragmentation) in the shell. Abundance estimates indicated underabundance of C and Si and overabundance of O, Ne, Al (relative to Solar).

X-rays first detected ~15 days after outburst by BeppoSAX (0.1-300keV). Hard X-ray component between 2-10keV (Orio et al 2001). No soft component. Emission due to shocks internal to the nova ejecta

Spectrum softened with time, and six months later hard X-ray component decreased by a factor 40 and had an extremely bright super soft component



By Feb 2000, Chandra observations indicated strong emission lines due to Si, Mg, Ne, O, N, C, but no Fe. A weak continuum was present due to the WD, consistent with a BB temperature of $3X10^5$. Emission lines faded subsequently.

Nuclear burning turned off by Feb 2000 indicative of a massive WD, consistent with its being an ONeMg WD as indicated by the UV, optical and X-ray observations

Recurrent nova RS Oph

6 recorded outbursts. 1985 and 2006 well studied in all wavelengths (X-ray to radio)

UV spectra during 1985 outburst – emission lines narrowing with time, ionization levels increasing

1985 data in all wavelengths indicate shock interaction of nova ejecta with circumstellar material from redgiant wind

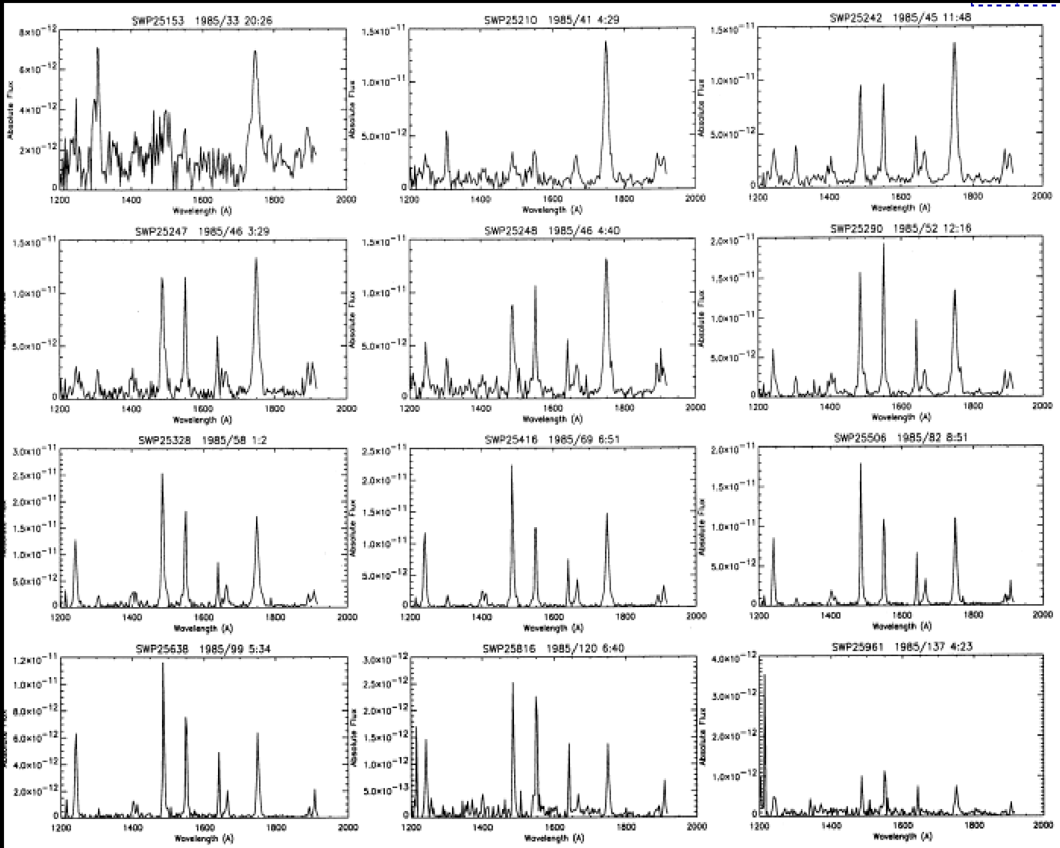


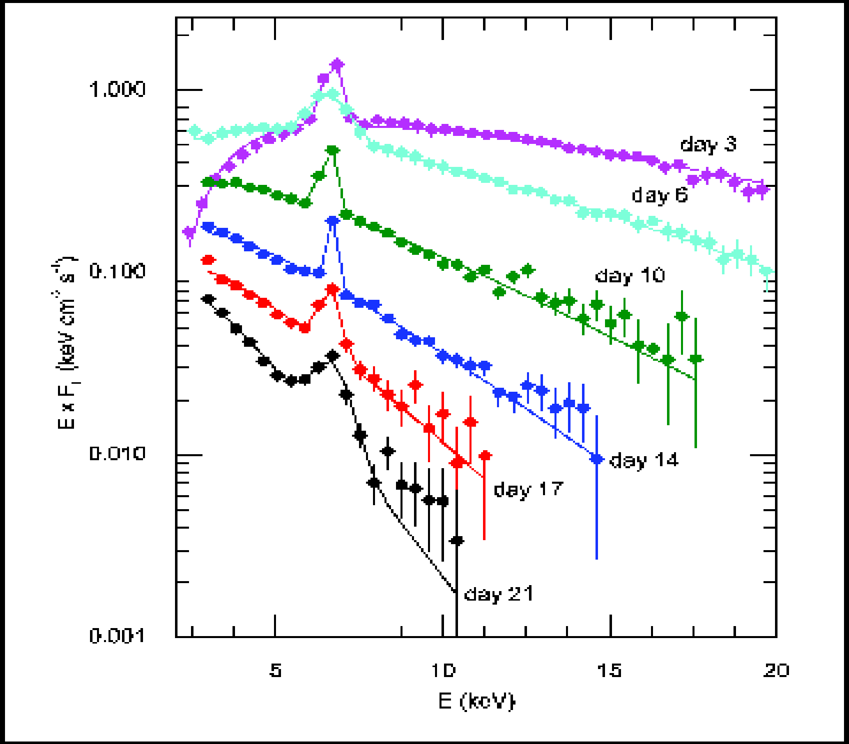
FIG. 3.—Atlas of high-resolution 1200–3300 Å *IUE* spectra binned to 0.5 Å resolution showing the development of the emission lines throughout the outburst. Units are ergs s^{-1} cm^{-2} $Å^{-1}$

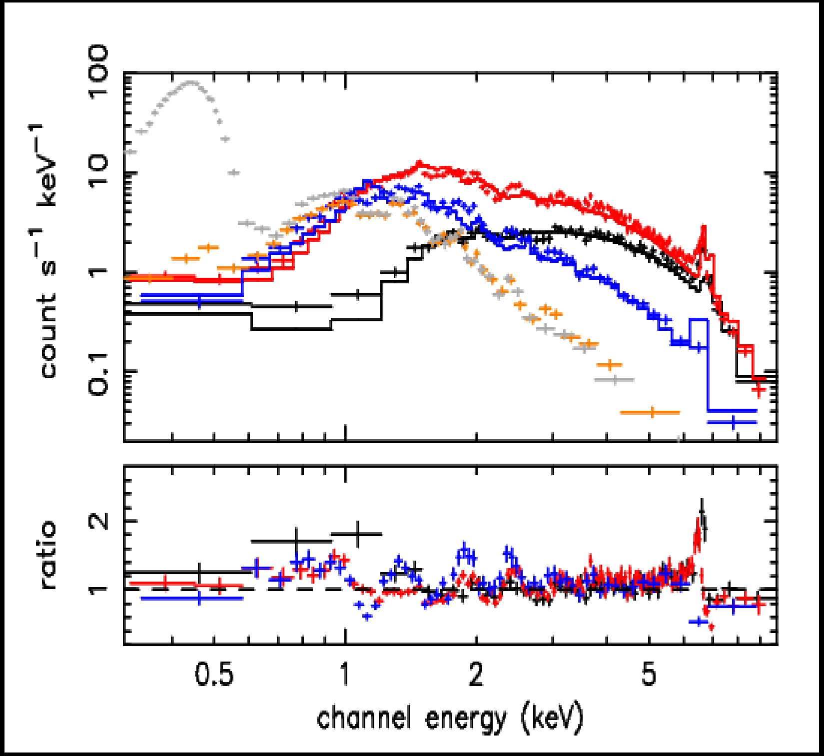
2006 outburst – Feb 12: Early X-ray observations by SWIFT and RXTE show both line and continuum. Thermal emission from hot gas (Bode et al. 2006, Sokolowski et al 2006). Development of soft component

Early onset of radio emission (Eyres et al 2006, Anupama et al 2006a). Evolution similar to SN 1993J (on faster timescales). VLBI observations show an extended, structured shell, elongated along the east-west direction (O'Brien et al 2006).

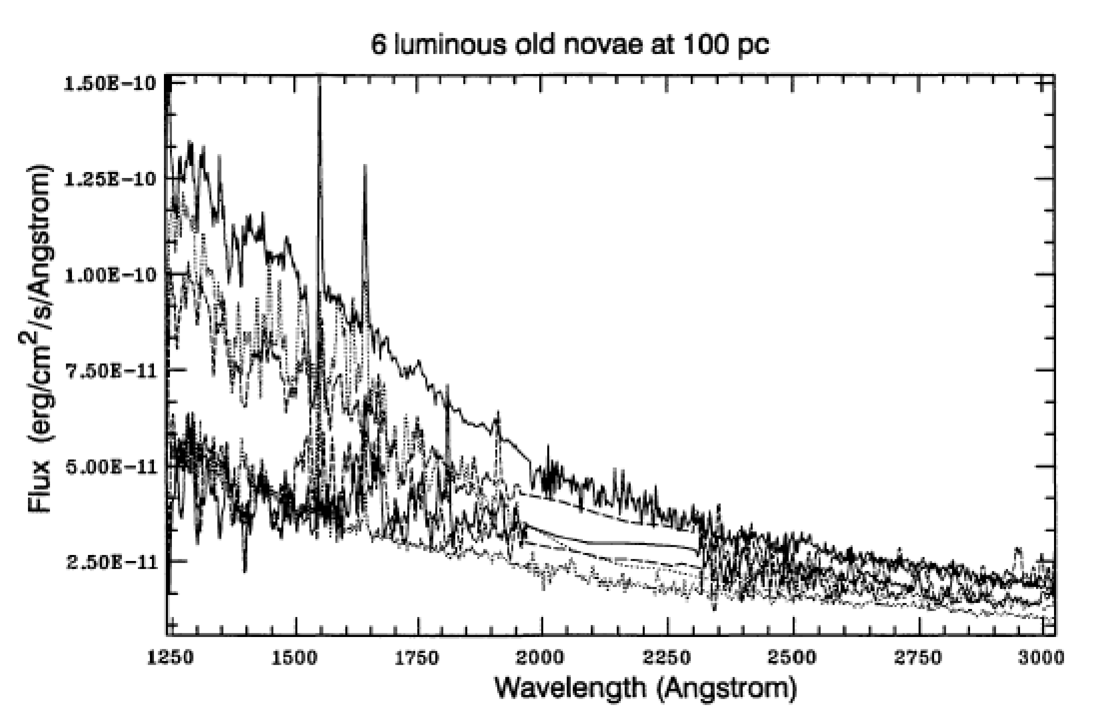
Evolution of optical (Anupama et al 2006b) and near-IR (Evans et al 2006) spectra very similar to 1985 outburst with presence of intense coronal lines peaking around 50-60 days.

All data consistent with shock interaction of nova shell with circumstellar material





Novae at Quiescence



- Novae with recent eruption expected to possess very hot primaries
- Spectrum of novae at quiescence very similar to other magnetic/non-magnetic CVs such as dwarf novae and nova-like variables
- Spectrum consists of a hot UV continuum with narrow emission lines superimposed
- Spectral index - 0.9 for high inclination to 2.8 for low inclination systems
- Total UV luminosity 20 L_sun

Novae - Quiescence

At quiescence the UV flux is dominated by the WD and the accretion disc, which gives rise to many emission lines

Diagnostic flux ratio diagrams – (Mauche at al 1997)

Emission lines – NV 1240, SiIV 1400, CIV 1550, HeII 1640

Diagnostic diagrams

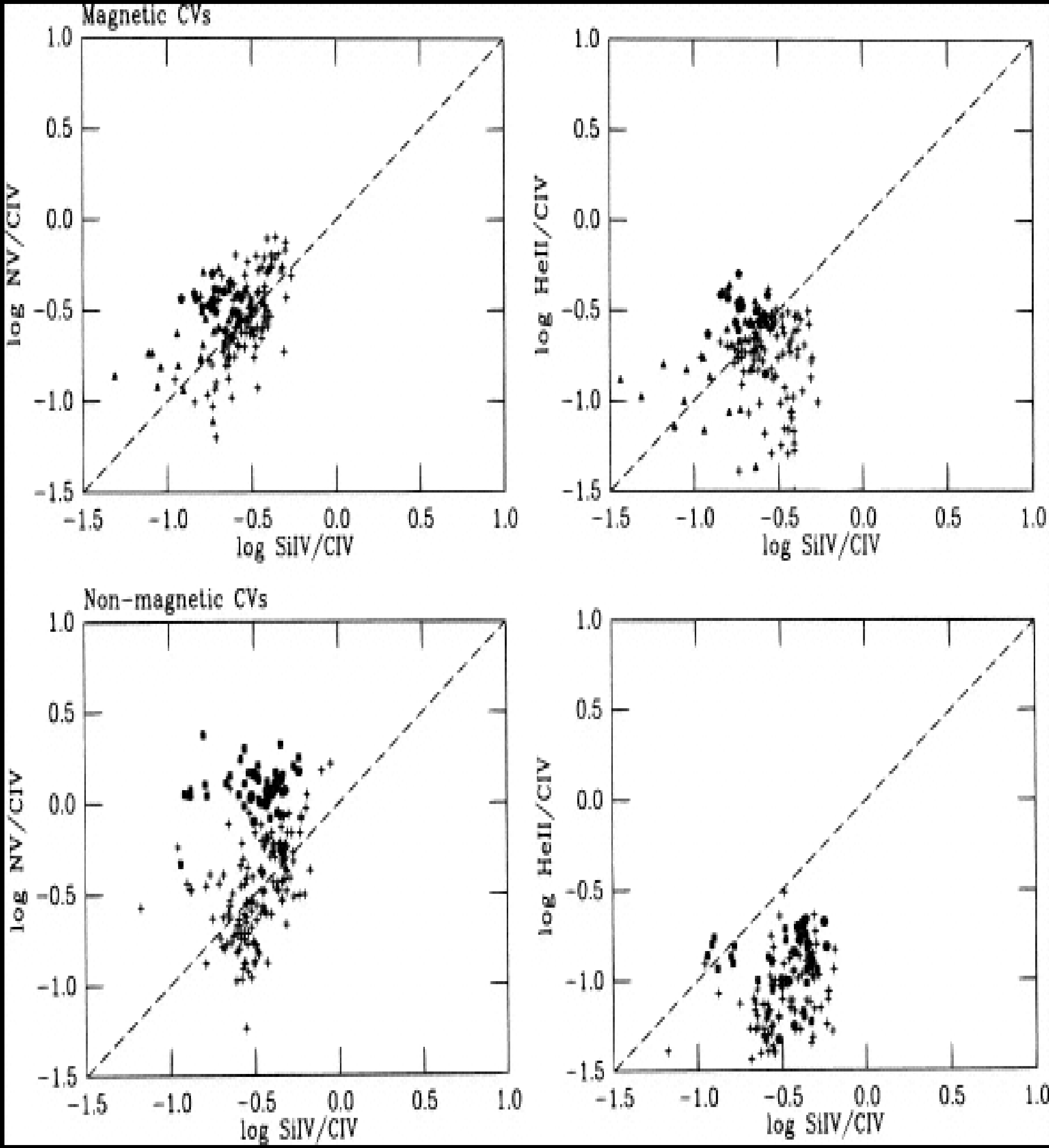
NV/CIV and HeII/CIV versus SiIV/CIV

Ratios clustered within a range of

~1 decade for log(SiIV/CIV)

~-0.5~1 decade for log(HeII/CIV)

~-1.0 and ~1.5 decades for log(NV/CIV)~-0.25

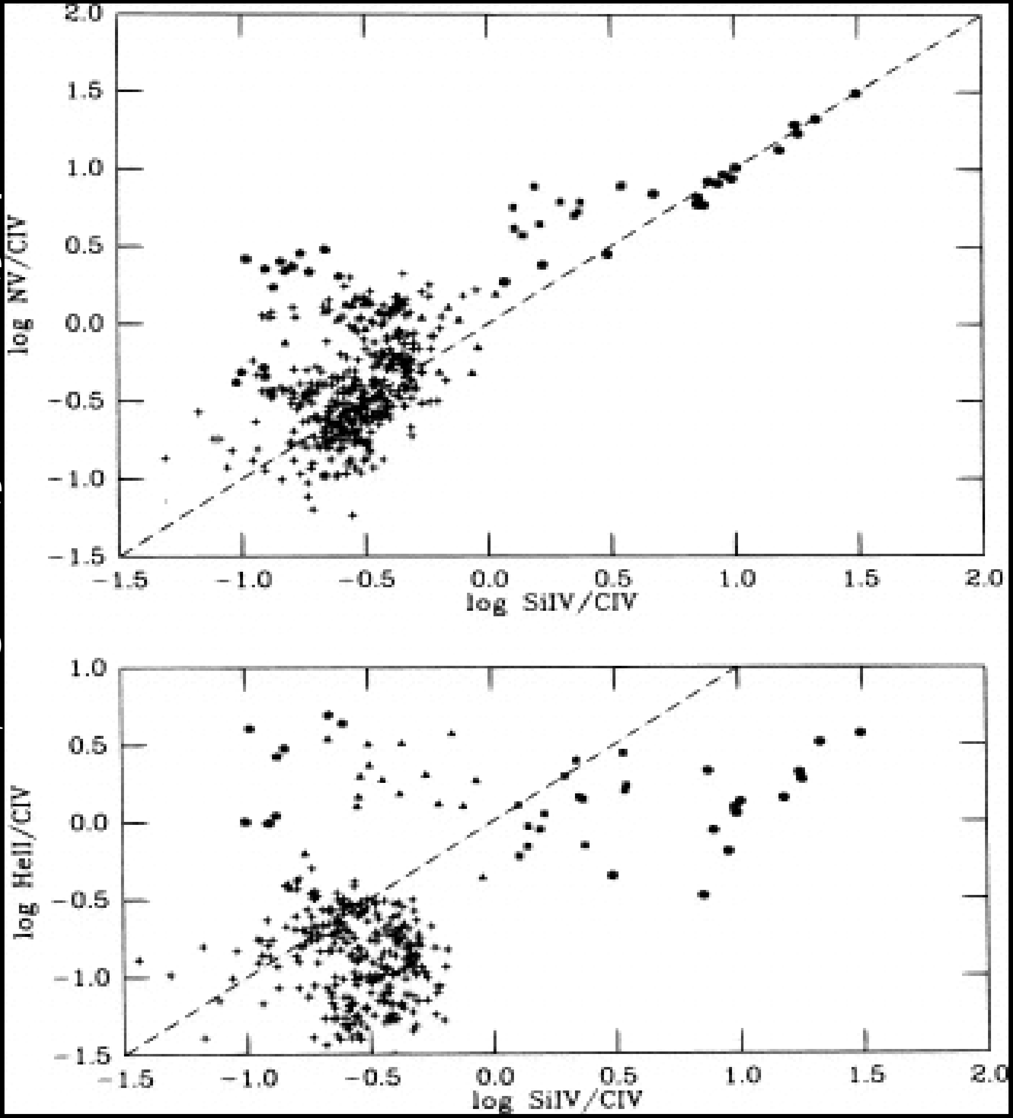


Novae - Quiescence

No major difference between the non-magnetic and magnetic systems in the NV/CIV ratio

Clear difference in the HeII/CIV ratio, which is ~0.25 decades larger in the magnetic systems

These line ratios can be used to constrain the models on the excitation mechanisms



Supernovae

UV observations important for understanding the behaviour of SNe.

Local SNe – distinguish between different explosion models, UV probes the metallicity of the progenitor as well as the degree of mixing of the synthesized 56Ni (Blinnikov & Sorohina 2000)

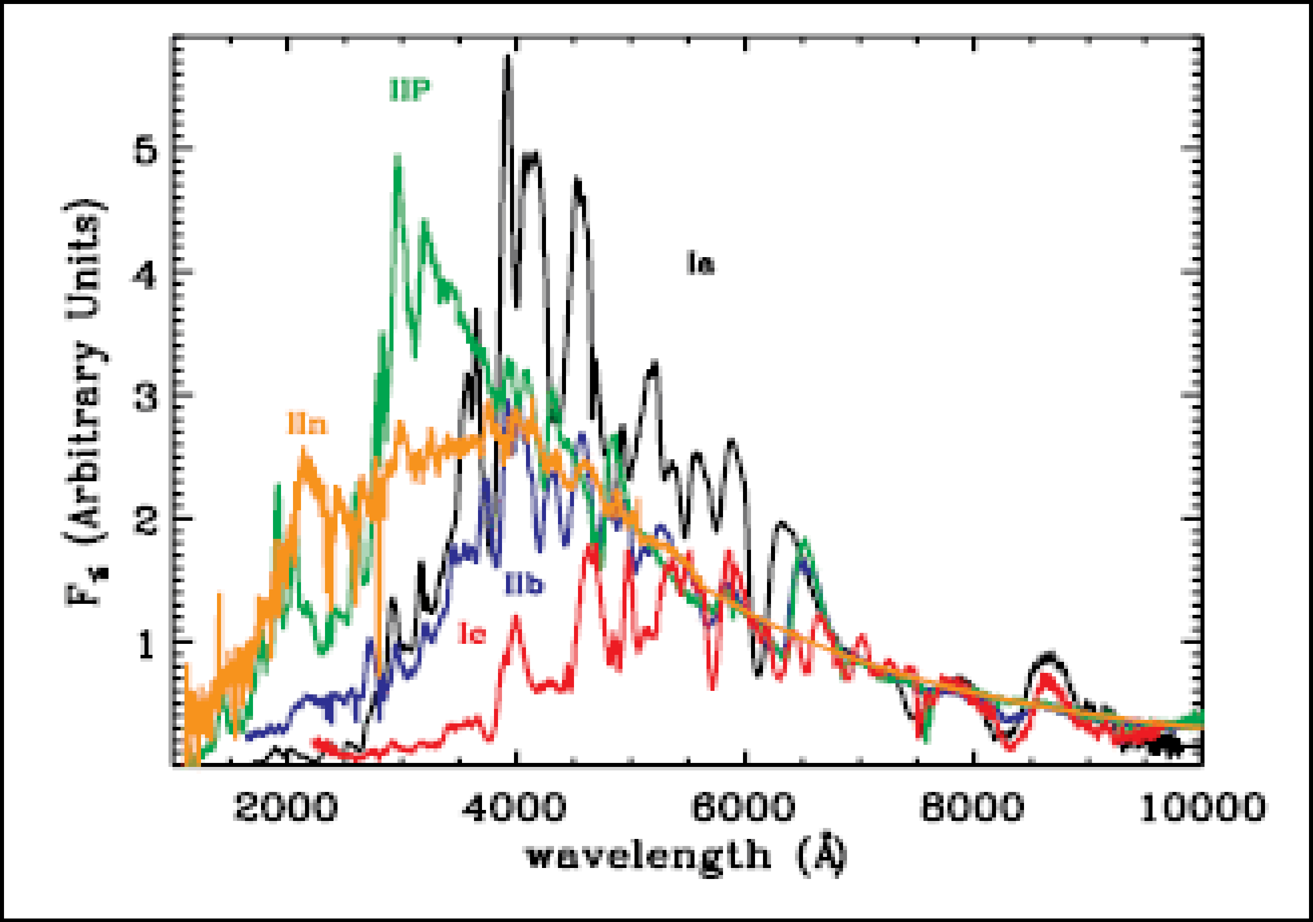
High redshift SNe – rest frame UV redshifted to optical bands – understanding the rest frame UV behaviour critical to understanding the nature of distant SNe

Supernovae

X-rays – (a) caused by shocks due to interaction of expanding SN shell with the nearby medium (interstellar/circumstellar)

(b) at early epochs (SNe Ia) by gamma-rays produced in the decays of 56Ni synthesized in the SN explosion. These gamma-rays scatter off of electrons in the ejecta via Compton scattering. Down scattered photons can escape the ejecta, be further down scattered, or be absorbed via bound free absorption. Energetic electrons created by the interaction of these gamma-ray photons slow in the ejecta, generating bremsstrahlung emission that produces photons in the 0.1-100 KeV range

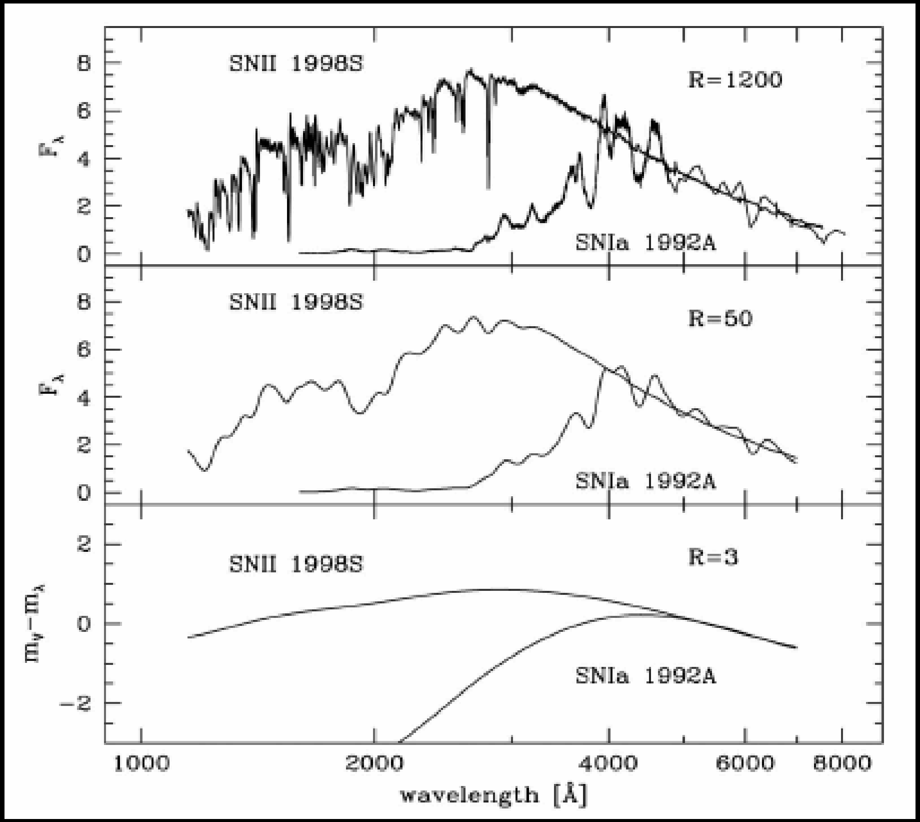
Supernovae – UV Spectra



(Johnson & Crotts 2006)

UV spectra of all type II at early phases are very blue, provide clear evidence for the presence of a dense CSM

UV spectra of all type I at early phases indicate suppression of continuum due to line blanketing by iron peak elements



(Panagia 2003)

SN I and SN II can be discerned based on their UV distribution

SN II are strong UV emitters

All SN I have steeply declining spectra at short wavelengths

Peak spectral emission is different

Simple photometry may be adequate to distinguish SN I from SN II

Type Ia SN – SN 2005am (Brown et al 2005)

SWIFT OBSERVATIONS OF SN 2005am 1195

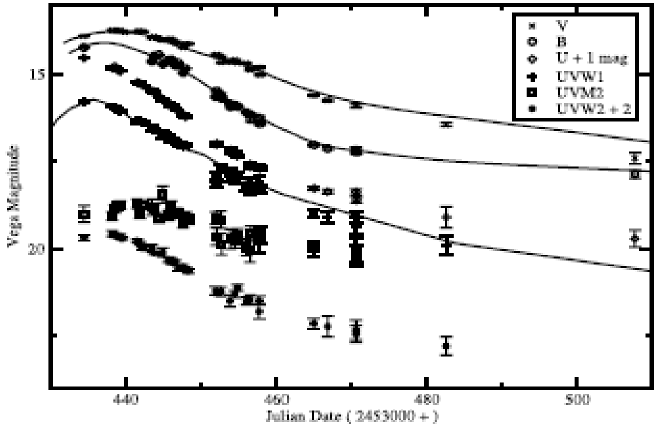


FIG. 2.—UV and optical light curves of SN 2005am obtained by UVOT. For visual clarity, the *U* curve has been shifted by +1 mag and the UVW2 curve by +2 mag. Overlaid are *B* and *V* templates of SN 1992A (Hamuy et al. 1996) and the *F275W template from SNe 1992A/1990N (for our UVW1 curve; Kirshner et al. 1993).

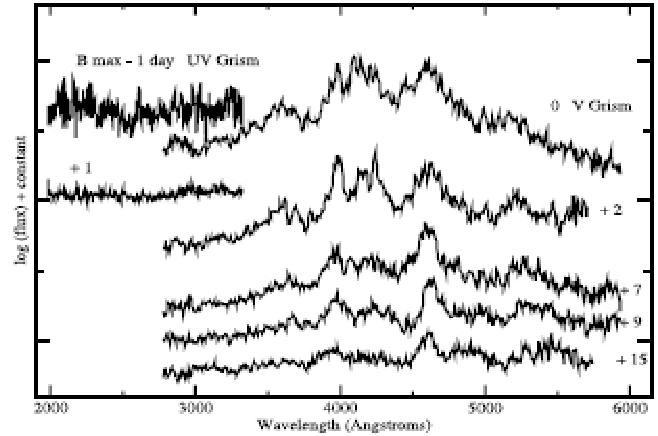


FIG. 3.—UVOT grism spectra of SN 2005am. Each spectrum is labeled with its epoch in days from B_{max}. The vertical scale is given in logarithmic units of ergs s^{-1} cm^{-2} $Å^{-1}$. The spectra have been trimmed from their full size to avoid contamination by other spectral orders.

SWIFT observations – UV & Optical photometry, grism spectroscopy and X-ray

UV light curve similar to other well studied SNe Ia SN1992a & SN 1990N

Decay rate in UV shallower than in the U and B bands.

UV spectrum – continuum suppressed by deep absorption from blends of iron peak elements

No X-ray flux detected

Normal SN Ia

Type Ia SN – SN 2005ke (Immler et al (2006)

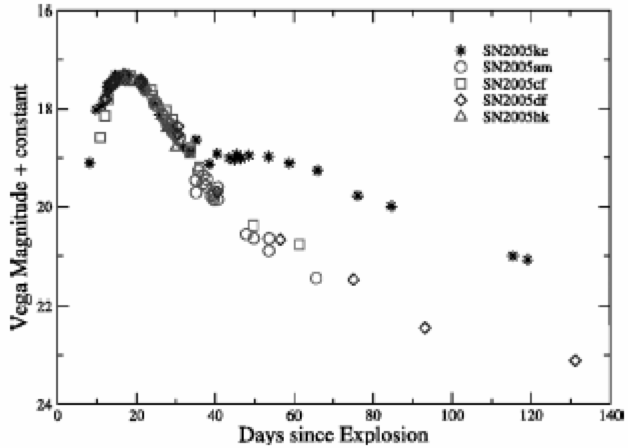


FIG. 1.—Comparison of the UVW1 magnitudes of SNe Ia observed with *Swift*. The light curves of SNe 2005am, 2005cf, 2005df, and 2005hk are shifted vertically to align them with the SN 2005ke template near maximum. The time is given in days after the outburst. The excess in the UV emission of SN 2005ke starting around day 35 after the outburst is likely caused by CSM interaction. [*See the electronic edition of the Journal for a color version of this figure.*]

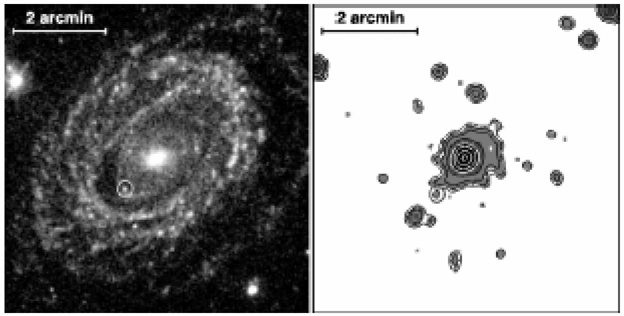


FIG. 2.—*Swift* UV and X-ray image of SN 2005ke and its host galaxy NGC 1371. *Left*: The UV image was constructed from the UVOT UVW1 (750 s exposure time), UVW2 (1966 s) and UVM2 (1123 s) filters obtained on 2005 November 14.67 UT and slightly smoothed with a gaussian filter of 1.5 pixel (FWHM). The position of SN 2005ke is indicated by a white circle of 10" radius. *Right*: The (0.2–10 keV) X-ray image was constructed from the merged 268 ks XRT data and is slightly smoothed with a gaussian filter of 1.5 pixels (FWHM). The position of SN 2005ke is indicated by a red circle of 10" radius. Contour levels are 0.3, 0.6, 0.9, 1.5, 3, 6, 12, and 20 counts pixel^{-1}. Same scale as the UV image. [*See the electronic edition of the Journal for a color version of this figure.*]

SWIFT observations

Early UV light curve similar to other SNe Ia

Show excess UV emission starting around 35 days after outburst

X-ray detected 1-54 days after outburst. Luminosity and decline consistent with interaction with CSM

UV excess may also be explained as an effect of CSM interaction