Received ______________________; accepted ______________________

1. Introduction

2. Spectroscopic Observations

These spectra were taken during two observing runs at the 10-meter telescope at Keck Observatory in December of 1997, and a run at both the Keck 10-meter and the ESO 3.6-meter in March of 1998. At Keck, we used the LRIS (Low-Resolution Imaging Spectrometer) instrument, while at ESO, FORSII (FOcal Reducer/low dispersion Spectrograph II) was employed. At Keck, two gratings were used, the 300/mm grating with a dispersion of 2.55 Å per pixel and a wavelength coverage of 5220 Å, and the 400/mm grating with a dispersion of 1.86 Å per pixel and a wavelength coverage of 3810 Å. At ESO, both 1.5" and 2" slits were used for the targets, while the 1" slit was used for the standard star. Exposure times ranged from 10 minutes to 90 minutes. Observations were also made of the standard stars BD332642, HD84937, and HD19445 (at Keck) and LTT 7379 (at ESO) for the purpose of flux calibration of the supernovae spectrum.

3. Data Reduction

The IRAF spectral reduction package was used to reduce these spectra. First, the overscan was subtracted by passing all the images through the *ccdproc* task. Bias frames were then combined using the *zerocombine* command, averaging them together and rejecting the highest pixel values and those above 3σ of the average pixel value. The resulting bias frames were then used to correct the images. Dome flats for each telescope position had been taken on the night of the observations, and these were combined with the *flatcombine* task, creating a separate flat for each object observed. A second pass through *ccdproc* was then used to flat-field the images. After removing cosmic rays with *cosmicrays*, *apall* was used to extract the 1-D spectrum. Samples for sky subtraction were taken on either side of the galaxy/supernova light, at a distance that attempted to minimize light contamination from either the target or other light sources while being close enough to the target to remain valid. When possible, supernovae spectra were extracted separately from galactic spectra, sometimes using a "shoulder-extraction" technique wherein the galaxy light was traced but the aperture offset to cover just the off-center supernova light. On the observing nights, images of the HeXeArNe arc light were taken for each telescope position; these lines were first identified with *identify*, then the wavelength dispersion was calculated, and applied to the spectrum with *dispcor*. Finally, the standard star spectra were combined into a single sensitivity function by running the *standard* and *sensfunc* tasks. Flux calibration was then obtained by applying this sensitivity function to each supernova spectum with *calibrate*.

4. Spectral Matching Technique

The spectral matching program Superfit, developed by Howell & Wang, was used to both subtract the galactic spectra from the raw spectra and to find the best-fit template match, as well as lightly smooth the final spectra. Out of a database of template spectra for all varieties of supernovae, which can be restricted to certain subsets should the researcher desire, the program computes the χ^2 deviation of each template spectrum from the object spectrum, using the formula:

$$\chi^2 = \frac{\omega(O(\lambda) - \alpha T(\lambda) 10^{cA_\lambda} - bG(\lambda))^2}{\sigma(\lambda)^2} \tag{1}$$

where ω is a weighting function, O is the observed spectrum, T is the supernova template spectrum, G is the galaxy template spectrum, A_λ is the reddening law, σ is the error on the spectrum, and a, b, and c are constants that are varied to obtain the best fit. The reddening law for these spectra was given a value of $R_V = 3.1$, while the weighting function was set equal to one everywhere except at the location of telluric atmosphere lines, where it was set equal to zero. In cases where supernovae type was already firmly established as

Type Ia through other criteria, only Type Ia template spectra were used. All data spectra were rebinned with a bin size of 5Å, to speed up the matching process as well to as produce slightly less noisy spectra. Redshift, when known from spectral features or galaxy lines, was also constrained in the matching process.

In some cases, the best fit match did not agree with the light curve epoch of the supernova; in such a case, the best fit match within two days of the known epoch was used. Usually, the χ^2 difference between these matches was very small, and the final selected match could be seen an equally-valid choice.

This procedure provides a verification of the spectral type, which can be often well-established but rarely completely certain, based not only on a few distinguishing features but on the characteristics of the entire observed spectrum. It also gives a verification of the supernova epoch, which is particularly useful when light curve data is not available, and is still valuable as a check on the light curve fit when it has already been determined.

5. Results

5.1. Identification Criteria

The "by-the-book" criterion for classifying a supernova as Type Ia is the existence of the Si II λ6150 line; however, in many high-redshift supernovae, this line is moved outside of the optical range, and other methods must be used for identification. These include:

- The S II "W", formed by closely-placed S II lines around λ5500.

- The double-peak created by Ca II λ3945, Si II λ4130, and Mg II λ4481.

The presence of any of these features is strong evidence that the spectrum in question is a Type Ia, since they do not occur in any other supernova type. Probably the “best” criterion to reference in these spectra is the double-peak; unlike the Si II line, it exists within the wavelength range of nearly all the observed SNe, and unlike the S II W, it is a strong enough feature to be visible even in spectra with a low signal-to-noise ratio.

5.2. Supernovae

SN 1997ek This supernova was observed all three nights of the December observing run; the third night had the best signal-to-noise ratio, and the results are pictured here. It was observed for 50 minutes through the 400/8500 grating. Redshift was found to be $z = 0.863$, determined through galaxy lines. After subtraction of a galaxy template, it was matched with a template spectrum (SN 1999aa) at an epoch of -1 days, which fits with lightcurve data. Note that this template comes from a peculiar supernova, indicating the possibility that 1997ek is a peculiar of this type.

SN 1997el This supernova was observed for 30 minutes through the 300/5000 grating. Galaxy [O II] and [O III] lines yield a redshift of $z = 0.636$.

SN 1997em This supernova was observed for 40 minutes through the 300/5000 grating.

SN 1997ep This supernova was observed for 20 minutes through the 300/5000 grating. Measurements of galaxy lines give(Ca II H & K) a redshift of $z = 0.462$.

SN 1997eq This supernova was observed for 30 minutes through the 400/8500 grating, on the third night of the December run. The redshift of $z = 0.538$ was determined through galaxy lines. It matches very well with the template spectrum of SN 1990N at an epoch of +3 days, which conforms to lightcurve data, leaving little doubt that this is a Ia.

Table 1. Supernova Observation Data

IAU name	Day of Obs.	Scope	Exp. Time (sec)	Grating	Redshift	Spec. Match	Epoch	Peculiar	Host Galaxy
sn1997ek	12/31/97	Keck	3000	300/5000	0.863	sn1999aa	-1	y	···
sn1997el	12/29/97	Keck	1800	300/5000	0.636	···	+3	···	···
sn1997em	12/30/97	Keck	2400	300/5000	0.462	sn1989B	-4	n	···
sn1997ep	12/30/97	Keck	1200	300/5000	0.462	sn1992A	+5	n	···
sn1997eq	12/31/97	Keck	1800	400/8500	0.538	sn1990N	3	n	···
sn1997er	12/30/97	Keck	900	300/5000	0.466	sn1990N	-7	n	···
sn1997eu	12/31/97	Keck	900	400/8500	0.592	sn1999aa	+5	y	Sc
sn1997ex	12/30/97	Keck	···	···	0.361	···	···	···	···
sn1997ey	12/29/97	Keck	1800	300/5000	0.575	···	···	···	···
sn1997ez	12/31/97	Keck	3900	400/8500	0.778	sn1999bn	2	n	···
sn1997fa	12/30/97	Keck	900	400/8500	0.498	sn1992A	+9	n	···
sn1998as	···	ESO	···	···	0.355	···	···	···	···
sn1998aw	03/31/98	Keck	1200	400/8500	0.44	sn1994D	-5	n	···
sn1998ax	···	ESO	···	···	0.497	···	···	···	···
sn1998az	03/29/98	Keck	1200	400/8500	0.459	···	···	···	···
sn1998ba	···	ESO	···	···	0.43	···	···	···	···
sn1998bc	···	ESO	···	···	0.399	···	···	···	···
sn1998bd	···	ESO	···	···	0.254	···	···	···	···
sn1998bi	03/29/98	Keck	1500	400/8500	0.74	sn1994D	-4	n	···

SN 1997er This supernova was observed for 15 minutes through the 300/5000 grating. Redshift was determined to be $z = 0.466$ through the galaxy lines [O III] and Hβ.

SN 1997eu This supernova was observed for 15 minutes through the 400/8500 grating.

SN 1997ex

SN 1997ey This supernova was observed for 30 minutes through the 300/5000 grating. Ca II H & K lines yield $z = 0.575$.

SN 1997ez This supernova was observed for 65 minutes through the 400/8500 grating, on the third night of the December run. Redshift was determined to be $z = 0.778$ through galaxy lines. After subtraction of a galaxy spectrum, it matched with the template spectrum of SN 1999bn, at an epoch of +2 days.

SN 1997fa This supernova was observed for 15 minutes through the 400/8500 grating.

SN 1998aw This supernova was observed for 20 minutes through the 400/8500 grating. Redshift was determined through spectral template matching after subtraction of a galaxy template, and was found to be $z = 0.44$; finding a redshift through spectral features instead of galaxy lines yields a less-precise result. The supernova matches well with the spectrum of SN 1994D at an epoch of −5 days.

SN 1998az This supernova was observed for 20 minutes through the 400/8500 grating. Redshift was determined through galaxy lines ([O III], Hβ) to be $z = 0.459$.

SN 1998bi This supernova was observed for 25 minutes through the 400/8500 grating. Reshift was determined through spectral template matching after subtraction of a galaxy template, and was found to be $z = 0.74$. The spectrum, after galaxy subtraction, is a good match with that of SN 1994D at an epoch of -4 days, which fits closely with lightcurve data.

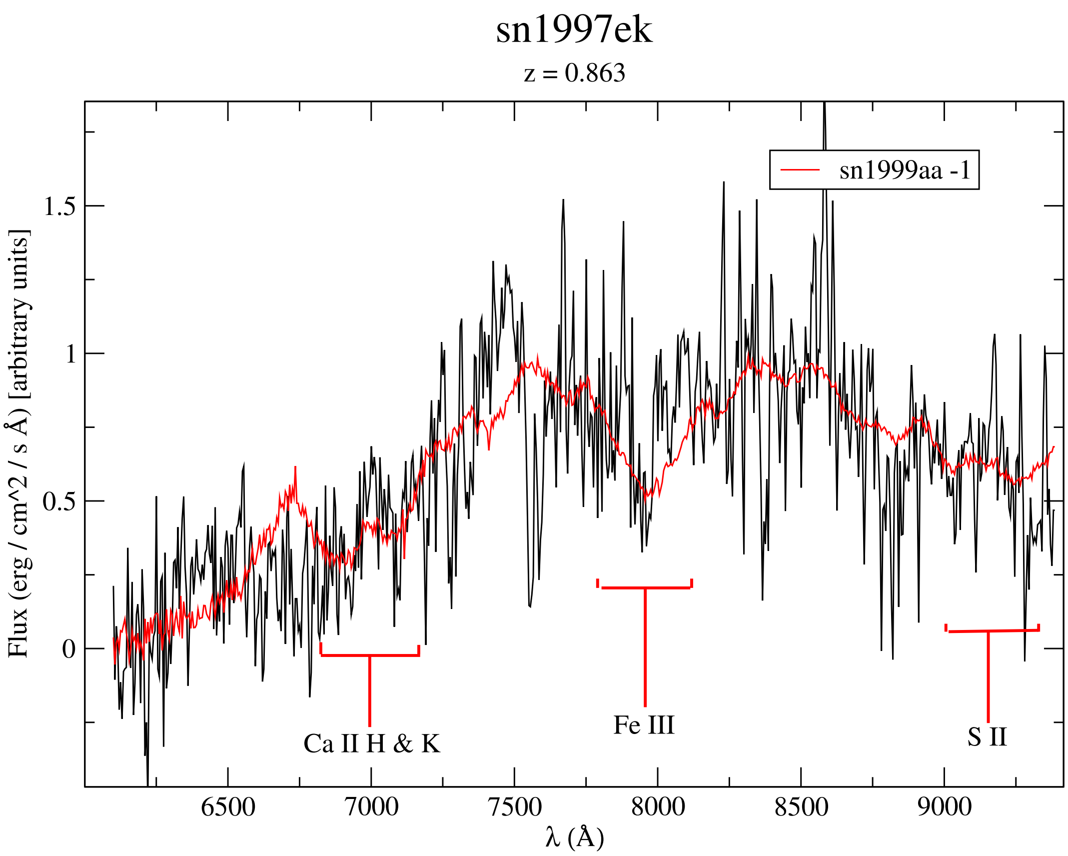

Fig. 1.— Slightly smoothed spectrum of sn1997ek, compared with the template spectrum of sn1999aa at a similar epoch. Note that sn1999aa is a peculiar supernova, indicating that sn1998be might also be a peculiar of this type.

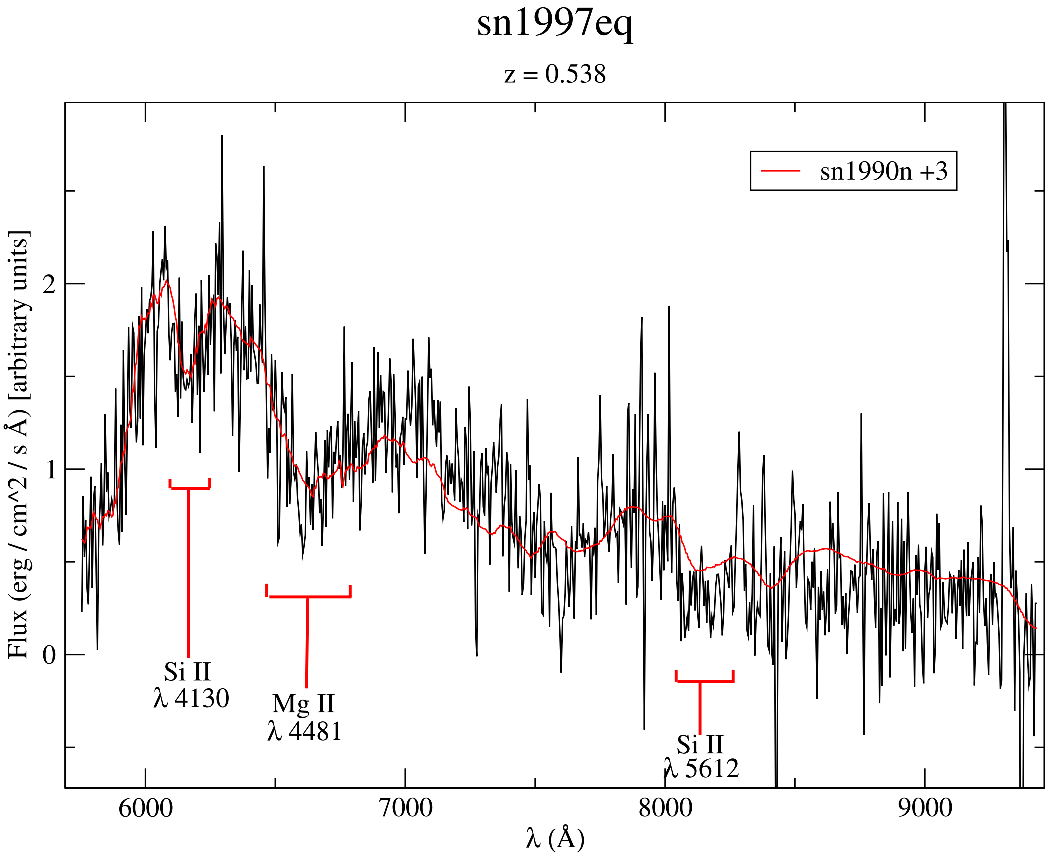

Fig. 2.— Slightly smoothed spectrum of sn1997eq, compared with the template spectrum of sn1990N at a similar epoch

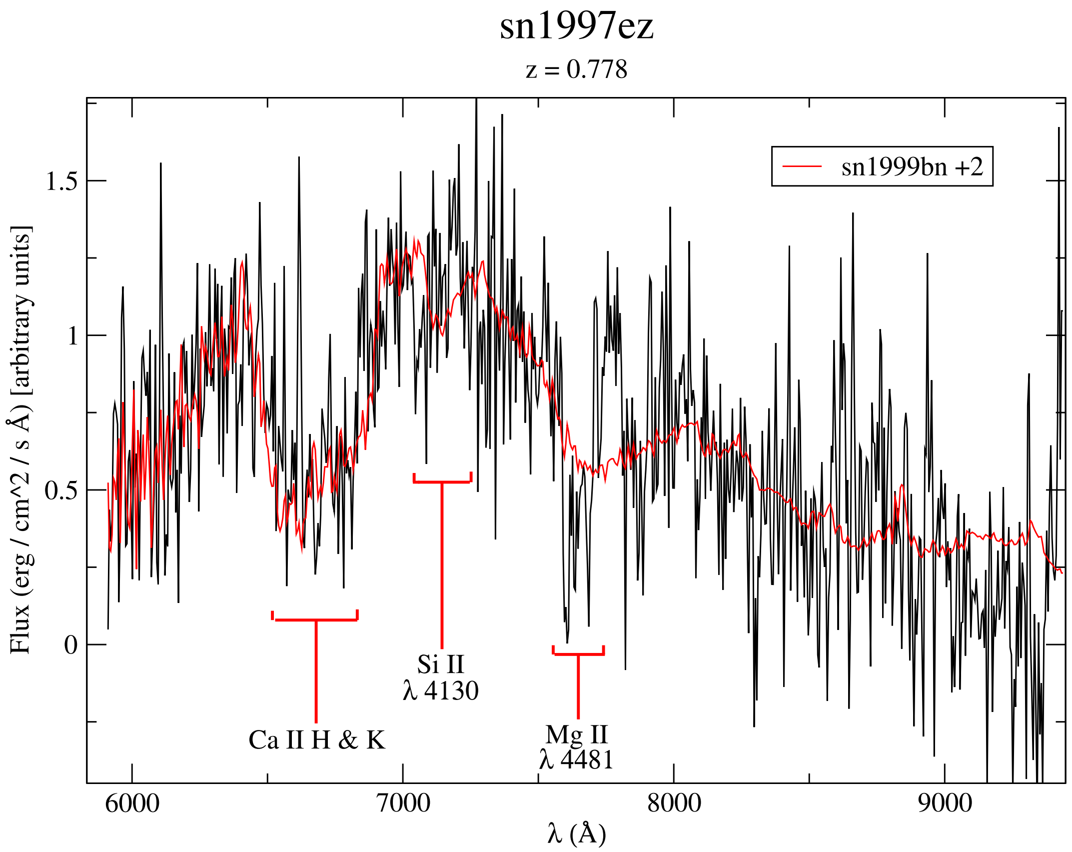

Fig. 3.— Slightly smoothed spectrum of sn1997ez, compared with the template spectrum of sn1999bn at a similar epoch

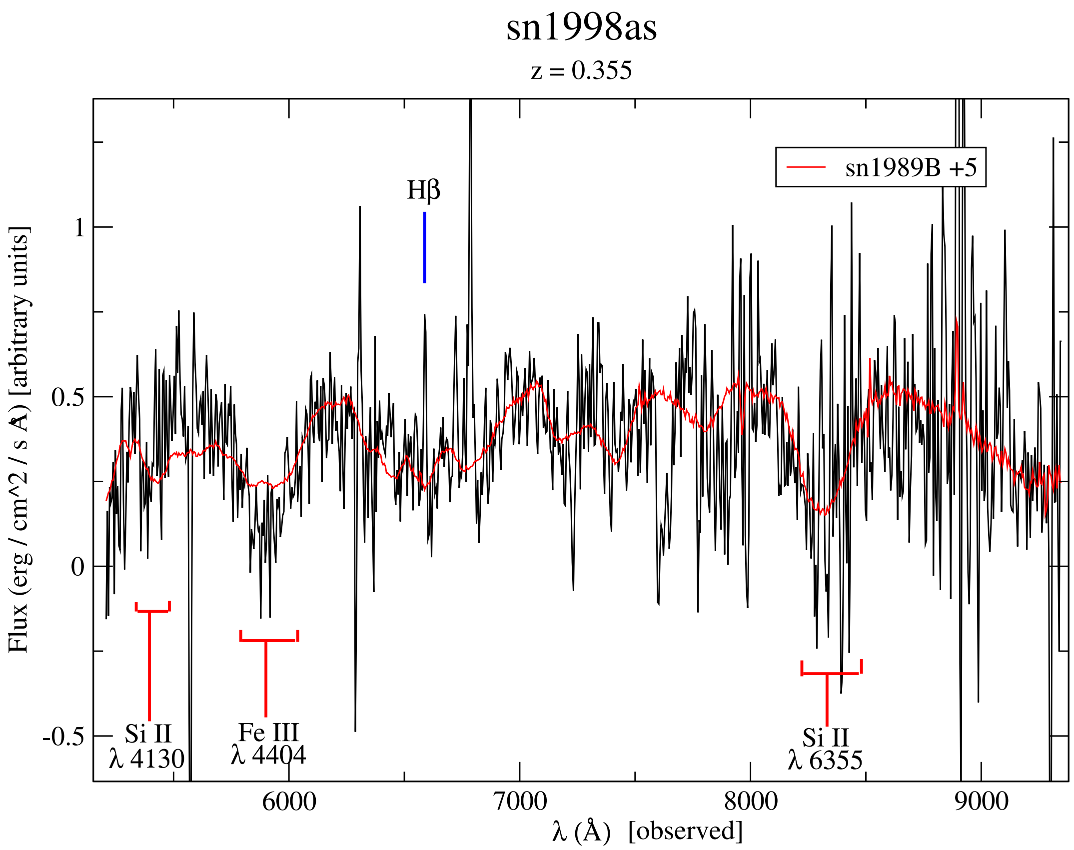

Fig. 4.— Slightly smoothed spectrum of sn1998as, compared with the template spectrum of sn1989B at a similar epoch

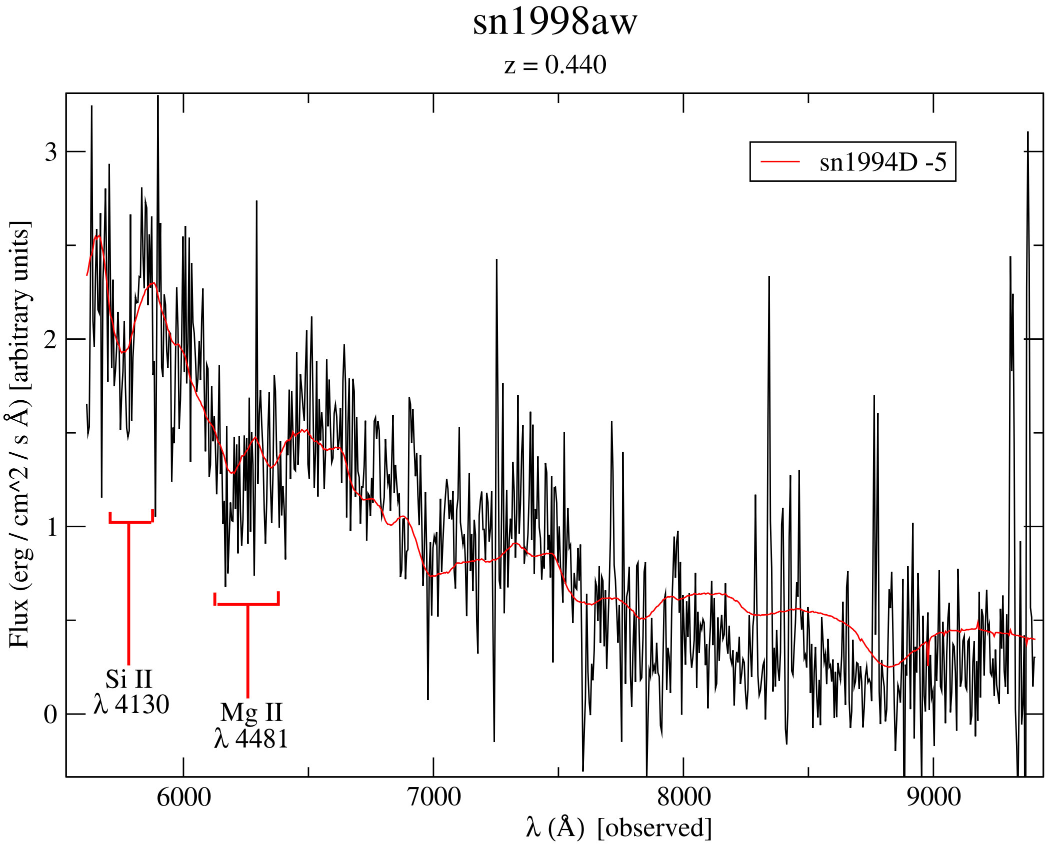

Fig. 5.— Slightly smoothed spectrum of sn1998aw, compared with the template spectrum of sn1994D at a similar epoch

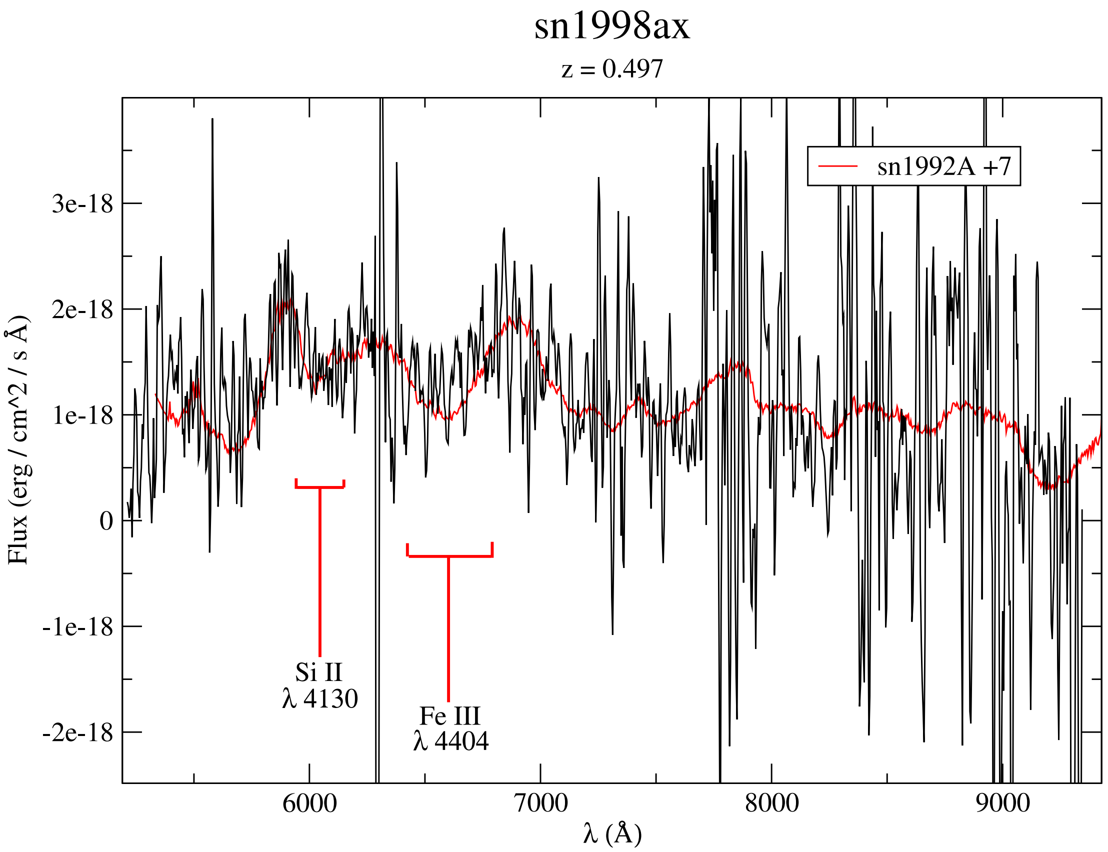

Fig. 6.— Slightly smoothed spectrum of sn1998ax, compared with the template spectrum of sn1992A at a similar epoch

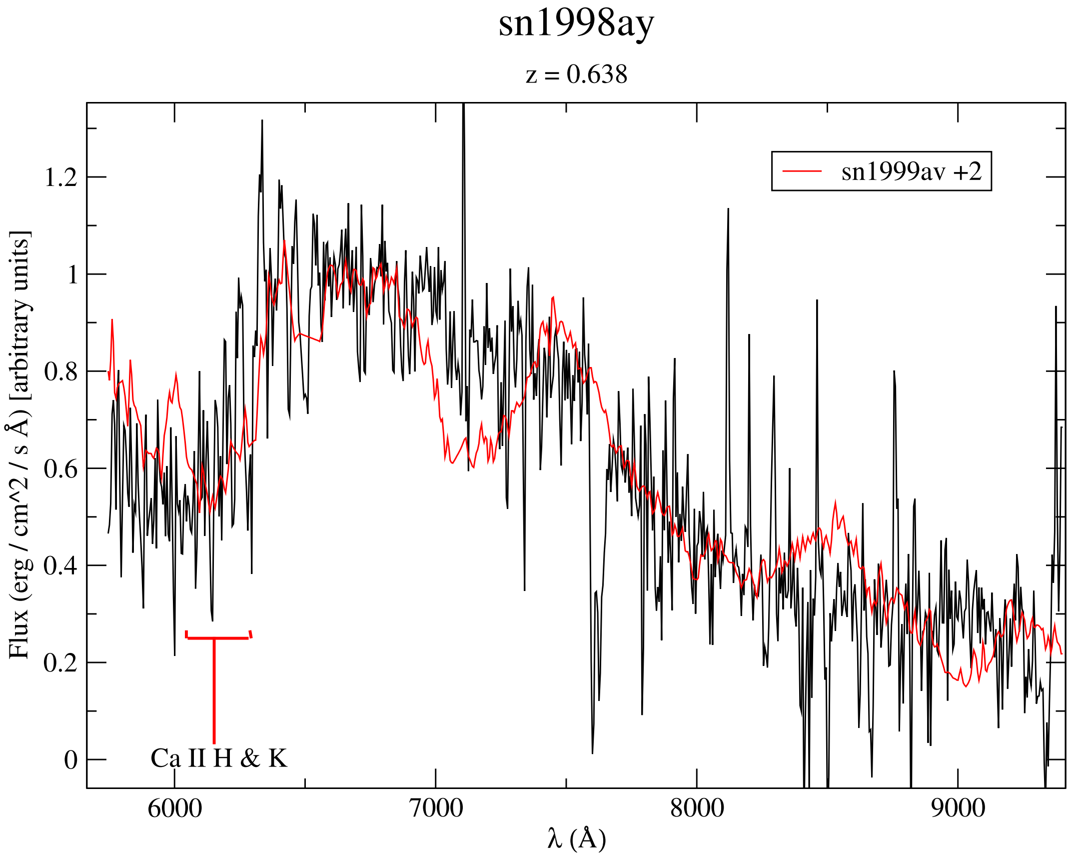

Fig. 7.— Slightly smoothed spectrum of sn1998ay, compared with the template spectrum of sn1999av at a similar epoch

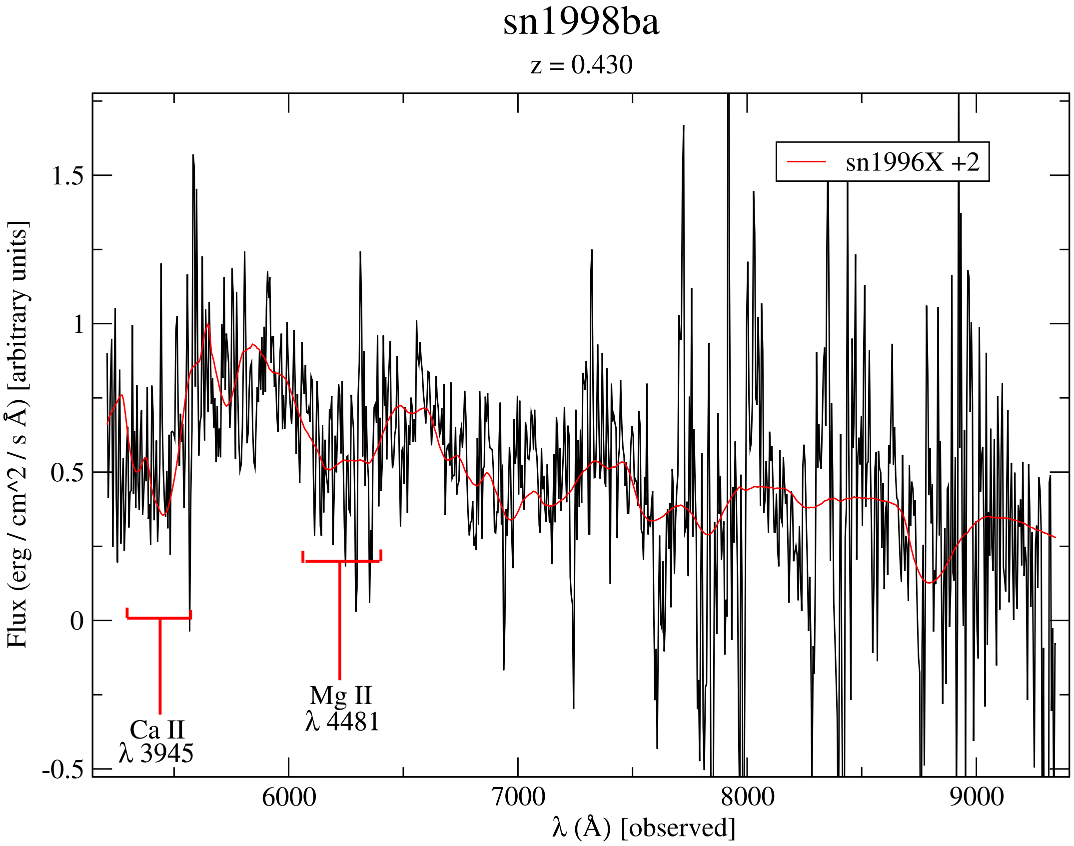

Fig. 8.— Slightly smoothed spectrum of sn1998ba, compared with the template spectrum of sn1996X at a similar epoch

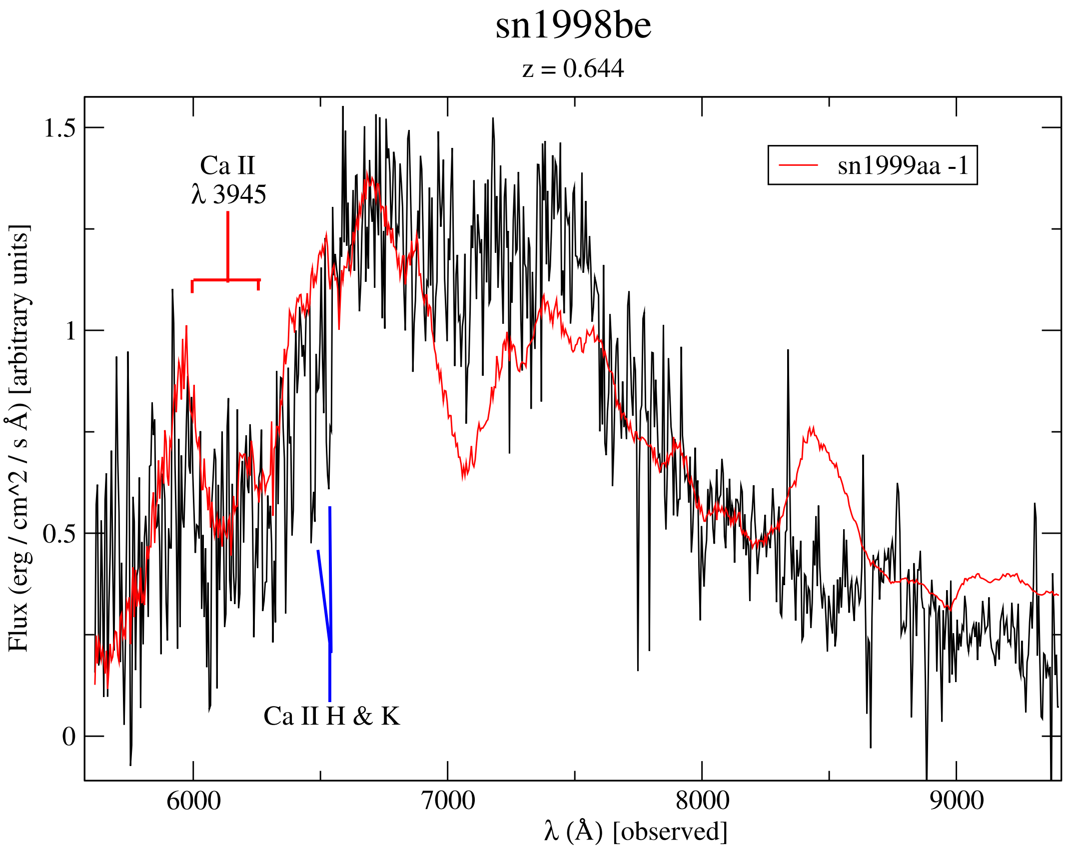

Fig. 9.— Slightly smoothed spectrum of sn1998be, compared with the template spectrum of sn1999aa at a similar epoch. Note that sn1999aa is a peculiar supernova, indicating that sn1998be might also be a peculiar of this type.

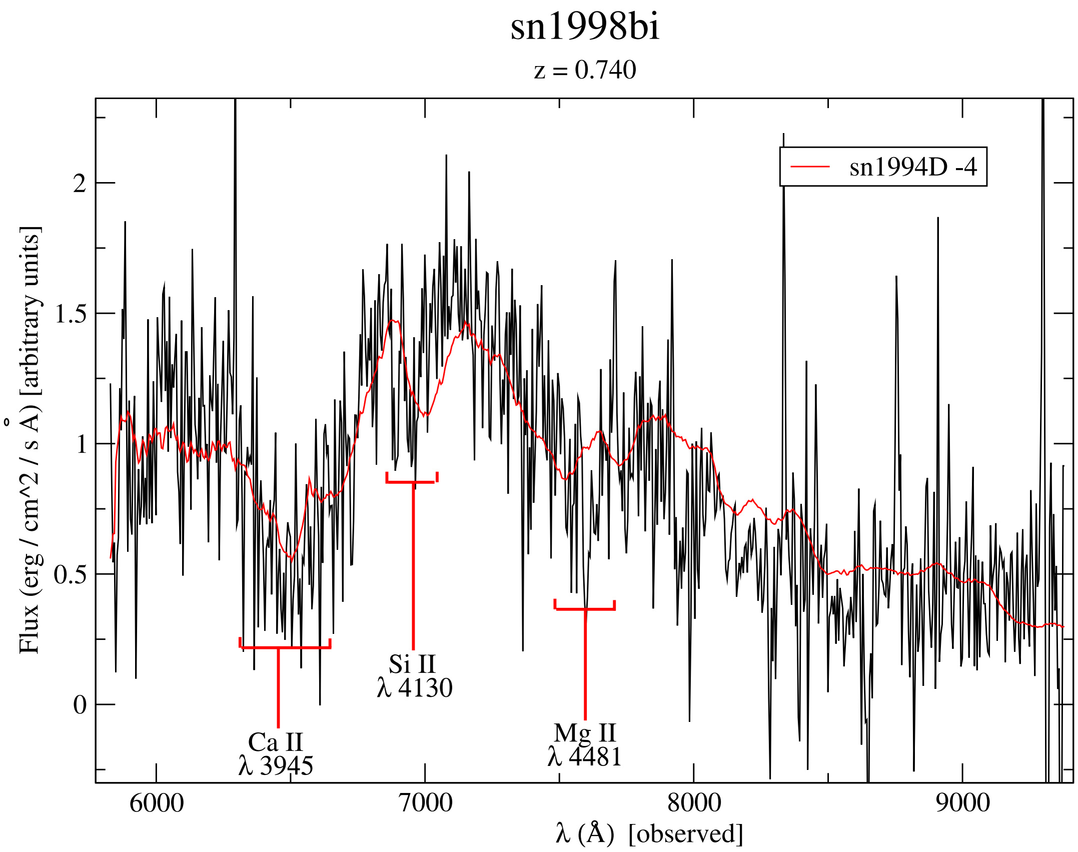

Fig. 10.— Slightly smoothed spectrum of sn1998bi, compared with the template spectrum of sn1994D at a similar epoch