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Supernovae in 3-D: Bridging the Gap Between Observations and Theory

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Abstract. Recent theoretical and observational advances promise to revolutionize the study of supernovae by allowing us to glimpse the three-dimensional structure of supernova ejecta. Increases in supercomputing capabilities have encouraged the development of three-dimensional hydrodynamical supernova explosion models, while spectropolarimetric observations with 8m-class telescopes now provide detailed information on the geometric characteristics of supernova ejecta. However, until a mechanism exists to communicate between these two lines of inquiry, our understanding of supernova explosions will remain incomplete. We introduce a new initiative to develop spectrum synthesis and radiative transfer codes that will calculate the spectropolarimetric consequences of hydrodynamical explosion models, thus bridging the gap between observations and theory.

Our group is a new collaboration between groups at UC Berkeley and Lawrence Berkeley National Laboratory that brings together a cutting-edge campaign of spectropolarimetric supernova (SN) observations and a suite of versatile modeling tools, including spectrum synthesis and Monte Carlo radiative transfer codes. Detailed modeling will allow us to predict observable features of explosion models and to analyze existing and future spectropolarimetry in the context of these models. This combined approach can lead to a new understanding of SN ejecta, including the mechanisms of core collapse, the nature of SN progenitor systems, the characteristics of SN environments, and the extent to which ejecta asphericity may affect the determination of cosmological parameters.

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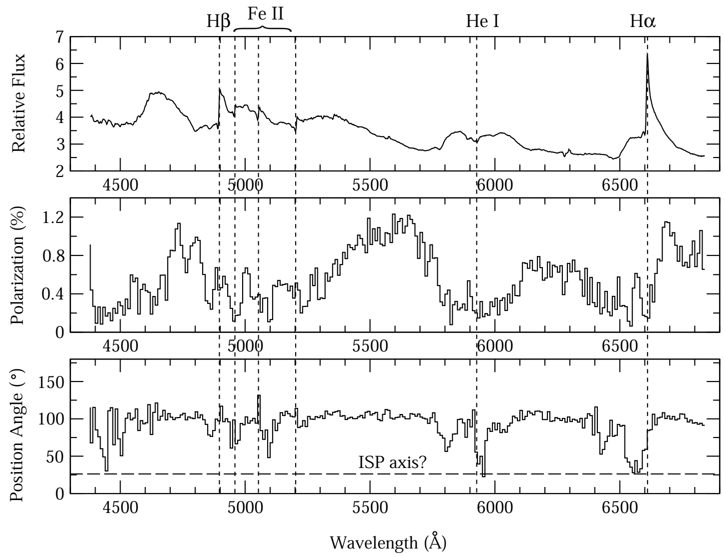

Figure 1. Flux and polarization spectra of SN 2000P taken with Keck-LRIS on 2000 March 25, 17 days after discovery. The spectra have not been deredshifted. Polarization data have been binned to 10 Å.

In a recent spectrum synthesis study, Thomas et al. (2004) found that both 1-D models with multiple shells and a 3-D model with a line-of-sight clump fit the complex high-velocity CaII infrared spectral features of SN 2000cx, an unusual Type Ia SN. Existing spectropolarimetric data can help break the degeneracy in these fits to the flux spectrum. Using a two-component radiative transfer model, Kasen et al. (2003) found that a clumped-shell geometry was more effective than either a spherical shell, an ellipsoidal shell, or a toroid in reproducing the flux and polarization profiles of the high-velocity CaII IR triplet in the normal Type Ia SN 2001el. Predicted spectra from this clumped-shell model suggest that large polarization features can exist for certain lines of sight even when the flux spectrum is relatively featureless. Results such as these show that the combination of spectropolarimetric observations and modeling with traditional spectroscopic analysis can lead to more detailed insight into the geometric characteristics of SN ejecta.

We are developing a combination spectrum synthesis and Monte Carlo radiative transfer code to model the flux and polarization spectra arising from complex SN geometries such as those of SNe Type IIn. Spectra of IIn's indicate intense interaction between the SN ejecta and a dense circumstellar medium (CSM). Modeling of this interaction can reveal the characteristics of the CSM and lead to insights into the progenitor's mass-loss history. SN 2000P (Figure 1) is an example with many intriguing features, including distinct line polarization effects (often offset from the lines in the flux spectrum), changes in polarization at constant position angle (PA), and a potential secondary axis, perhaps due to an interstellar polarization (ISP) contribution, indicated by the similar PA's of several different lines. Spectropolarimetric modeling can also help distinguish between ISP choices, as in the case of SN 1998S (Leonard et al. 2000).

Other projects planned for this collaboration include a SN polarization classification system, an atlas of polarization features of various SN ejecta models, and spectropolarimetric investigations of the properties of the ISM in other galaxies (Leonard et al. 2002). Our full poster is available online at http://grammai.org/jhoffman/pubs/pol04.pdf.

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