Exploring the Geometry of the Brightest SUPERNOVAE

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The huge luminosities and complex polarization spectra of Type IIn supernovae arise from interaction between the SN ejecta and dense circumstellar material.

The most luminous supernova explosions, sometimes reaching Mv ~ -21, belong to the subclass known as Type IIn. Spectra of these objects consistently reveal intense interaction between the supernova ejecta and dense circumstellar matter configurations. The enormous optical output of the brightest Type IIn supernovae is powered by this interaction rather than by a process intrinsic to the explosion mechanism.

To better understand the interactions that drive Type IIn's, and to investigate the relation between Type IIn's and other, non-shell supernovae, we would like to know more about the geometry of the circumstellar material that surrounds these objects. Polarimetry provides our only source of information about the geometry of an unresolved supernova. The observed continuum polarization of most core-collapse supernovae likely arises from electron scattering in highly aspherical envelopes, perhaps formed by bipolar jets during the core collapse process (Howell et al. 2001; Höflich 1991). In the case of Type IIn's, additional polarization effects can arise from light scattering through the circumstellar shell.

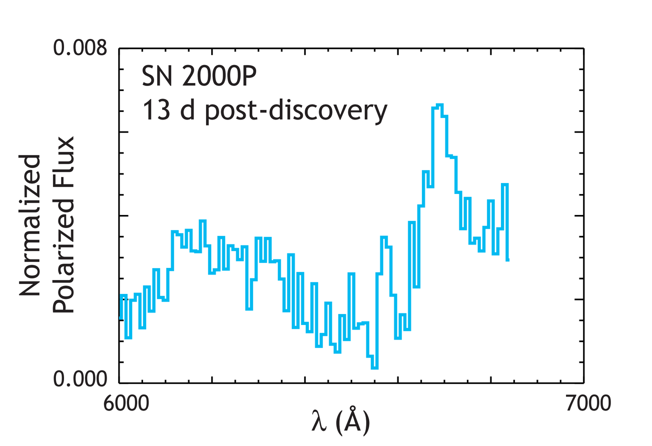
As a first step toward understanding emission line polarization in Type IIn's, we have constructed simple models of an electron-scattered Hα line.

Although strong polarization has been observed in the emission lines of supernovae of all types, models of supernova polarization have generally assumed line-scattered photons to be unpolarized. Emission lines probably become polarized via a combination of phenomena, including originating and scattering within inhomogeneous ejecta and complex non-homologous wind velocity structures such as jets, "fingers", and convective overturns. In Type IIn's, clumpy or asymmetric circumstellar material provides another potential source of line polarization.

We have begun to model line polarization in Type IIn supernovae by quantifying the simplest of these multiple contributions, that of electron scattering in aspherical circumstellar matter configurations. These results should provide a baseline or underlying polarization signal to more complex polarization spectra, and serve as our first step toward constructing more sophisticated line polarization models.

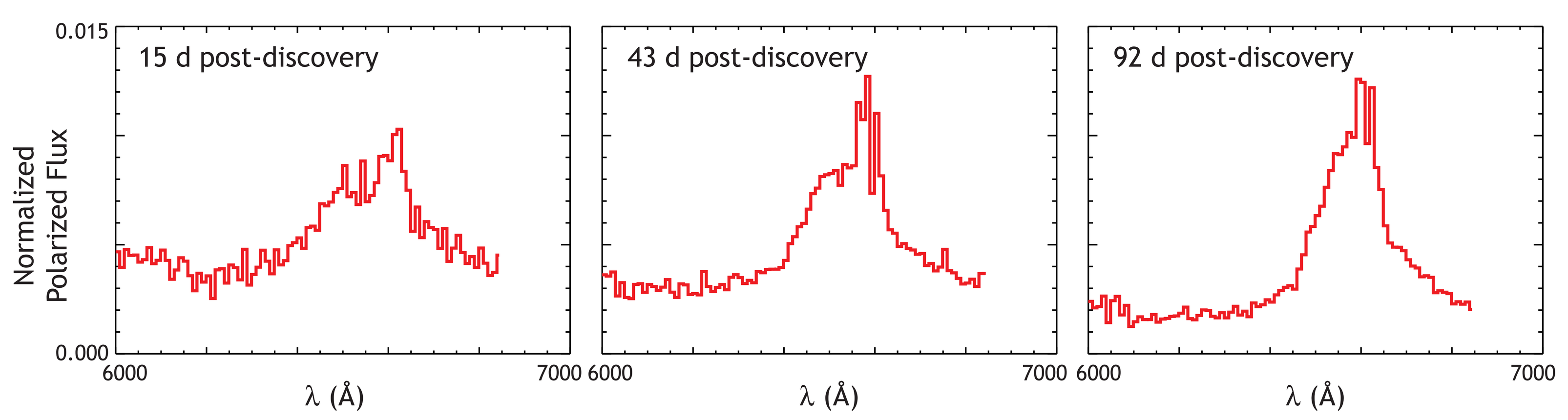
We use a Monte Carlo radiative transfer code (called SLIP for Supernova LIne Polarization) that tracks a spectrum of virtual "photons" as they radiate from a central source and scatter through a stationary circumstellar shell. As our input spectrum, we take the results of a PHOENIX spectrum synthesis simulation of SN 1999em, a supernova of a possibly related type (Type IIP; Baron et al. 2004). The radius of each envelope is 10 times that of the interior source, so these models simulate a Type IIn supernova very early in its evolution, before the ejecta begin to interact with the shell. Each envelope has a physical thickness of 1/20 its radius; we varied the optical depth between 1 and 10.

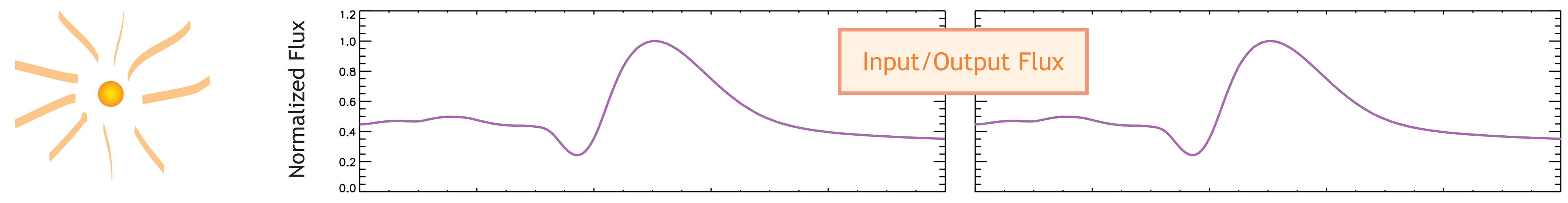
Results for the Hα line scattered through three representative geometries are shown at right. Each output polarization spectrum has been created by multiplying the fractional polarization by the normalized line shape emerging at each polar viewing angle *i*. Because electron scattering is wavelength-independent, each output line shape is the same as that of the input spectrum (though the absolute magnitude of the flux varies with *i*), and therefore the shape of the line in polarized flux is constant with *i*. However, the magnitude of polarization, which can be read off the *y*-axis at the peak of each curve, varies widely with viewing angle, optical depth, and geometry. Combined with other information about a supernova, this simple model could help constrain its geometrical properties.



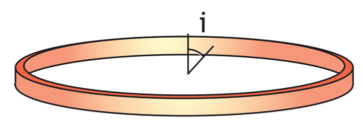
Polarization signatures similar to those of our models have been observed in some Type IIn supernovae, such as the two shown here. If due to electron scattering, these broad features imply disk-like or toroidal geometries at intermediate optical depths, or oblate ellipsoids viewed at nearly pole-on inclinations. The increase in polarization of SN 1997eg with time suggests a change in the optical depth or geometry of the scattering region.

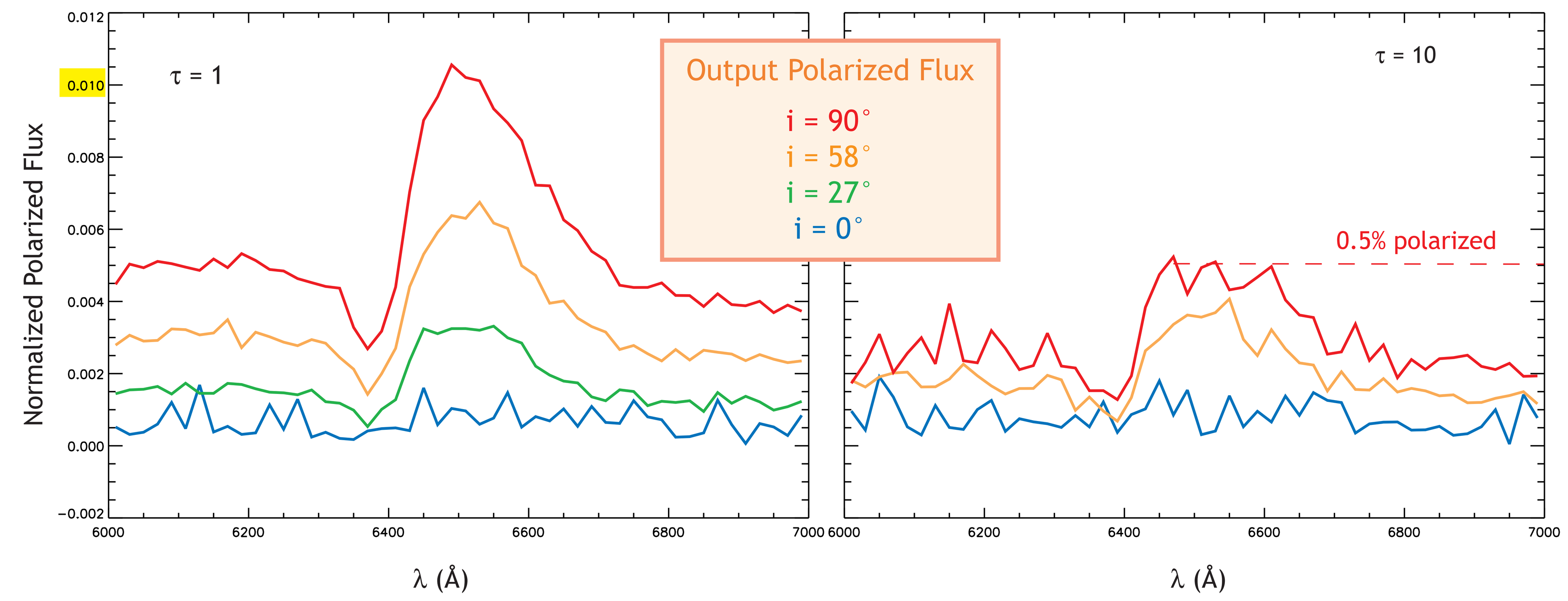
SN 1997eg (see Leonard et al. 2000, Filippenko & Leonard 2003)



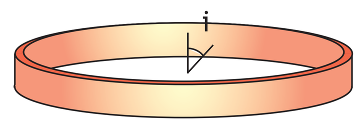


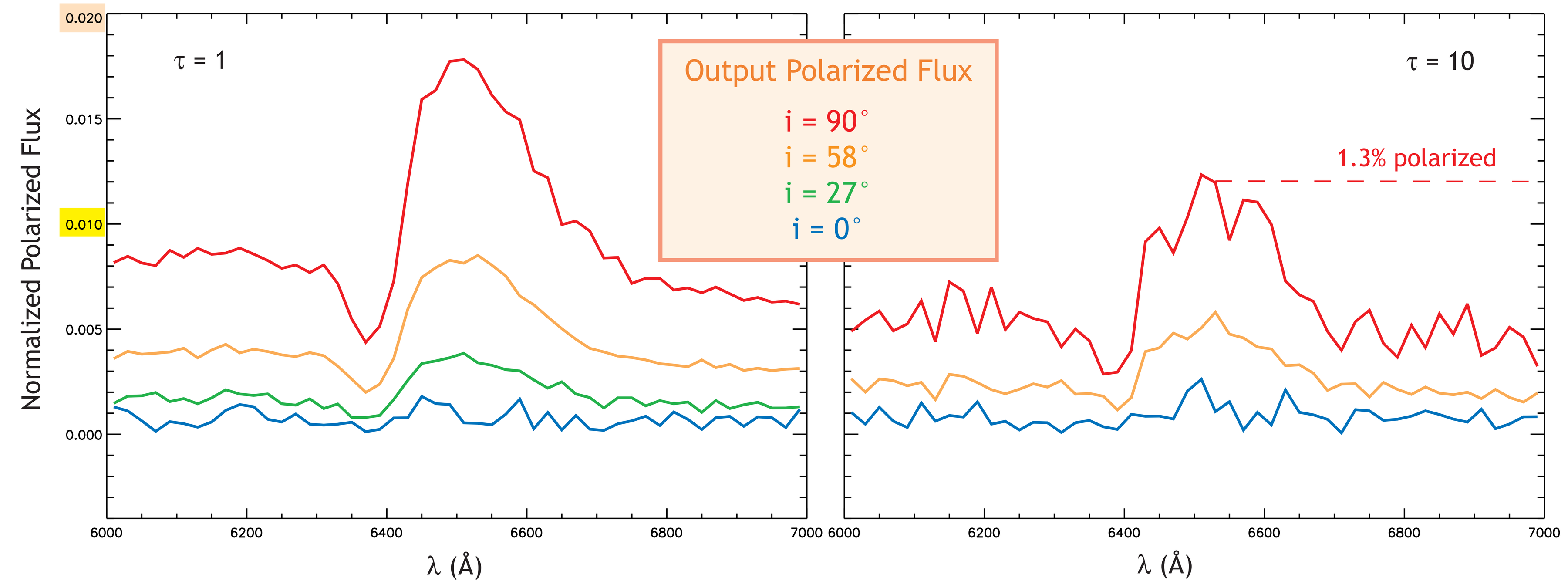
Disk-like Shell
(z/r = 0.005)



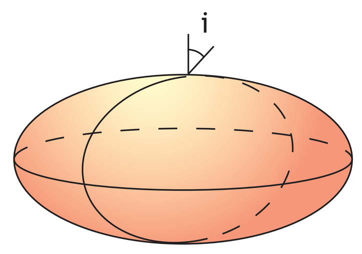


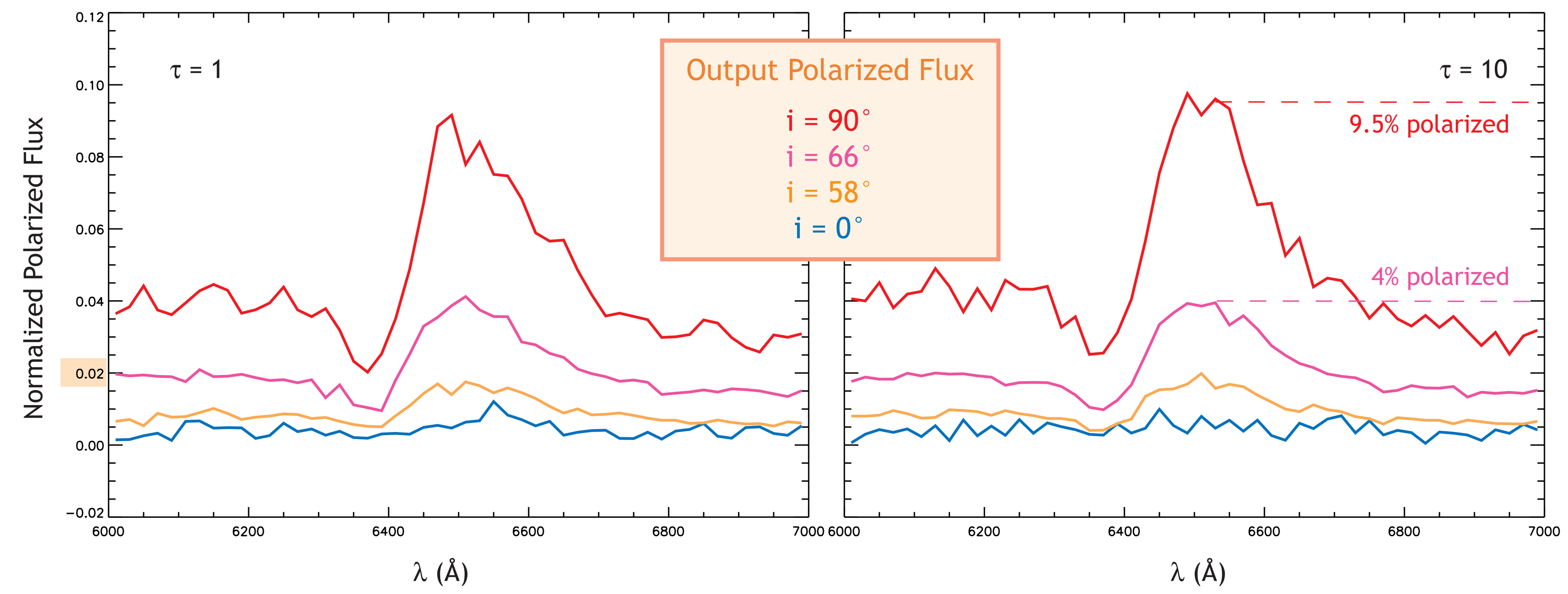
Toroidal Shell
(z/r = 0.1)





Oblate
Ellipsoidal Shell
(c/a = 0.5)





Some Type IIn's show polarization signatures similar to those of our early models. But there is lots more work to do! Our next step is to add hydrogen to the circumstellar shells to create absorption edges, smooth continua, and narrow emission lines.

The polarization spectra shown at left are from less strongly interacting supernovae than other Type IIn's, whose flux spectra show smooth black-body continua arising from the circumstellar material. Such signatures provide the direction for the next level of sophistication in our models; we have started to add hydrogen to the circumstellar material. The presence of hydrogen affects the outgoing spectrum by contributing 1) a wavelength-dependent absorptive opacity; 2) a source of continuum emission; and 3) a source of narrow-line emission. All the new "photons" thus produced can themselves scatter in the circumstellar material, so the resulting polarization signatures should be quite complex. We have also added a velocity grid and Doppler shifting capabilities to the code so that we can consider an expanding scattering region. Finally, with access to the NERSC 6000-processor Seaborg supercomputer, we expect to be able to construct full-spectrum models at spectral resolutions comparable to those of state-of-the-art spectropolarimeters.