Polarization Diagnostics for Supernova Circumstellar Material

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Motivation

What are we studying?

Many supernovae (SNe), particularly those of Type IIn, show signatures of interaction with circumstellar material (CSM). We want to understand what these signatures can tell us about supernovae and their progenitor stars through unpolarized and polarized light.

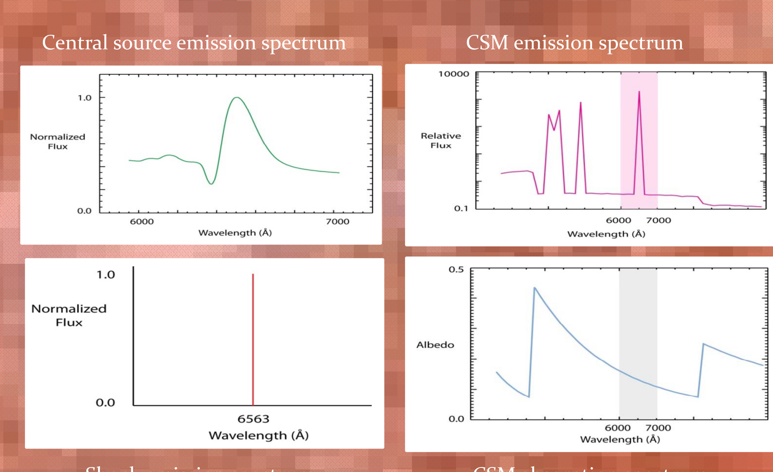
Why are we doing this?

We hope to be able to use numerical models to help interpret observations and constrain CSM geometries and other stellar parameters. This should help astronomers better understand the characteristics of supernova explosions and progenitor stars.

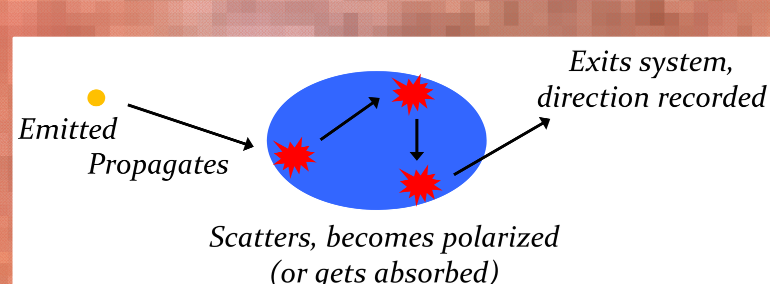
Methods

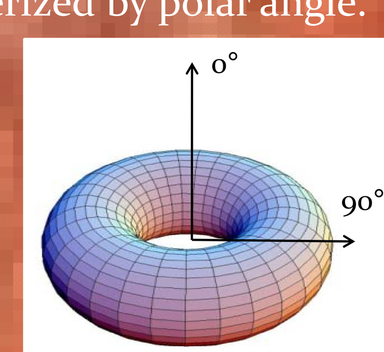
We are using three dimensional radiative transfer computer models to investigate how polarized Hα emission line shapes correlate with various characteristics of the CSM, including geometry, optical depth, temperature, and brightness.

Our code, called *SLIP*, emits virtual, unpolarized "photons" from a central supernova source with a P Cygni profile in the Hα line; from a surrounding, stationary CSM composed of hydrogen; and from an ionized "shock" region interior to the CSM. The CSM emits and absorbs photons according to its temperature.



Once emitted from any source, photons become polarized via coherent electron scattering in the CSM. Outgoing photons are binned by viewing angle; each model contains data for all viewing angles. Here we present axisymmetric models characterized by polar angle.



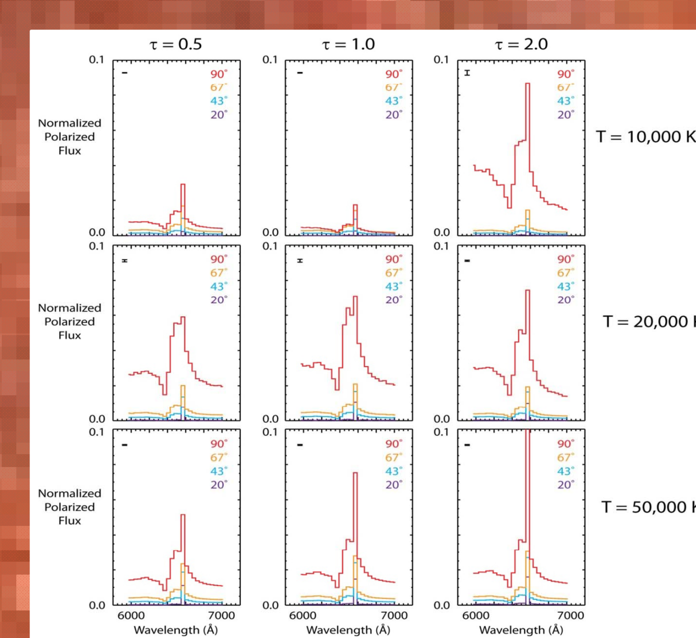


We used DU's high-performance computer cluster to run models with about 2 x 10^9 photons each (about 30 minutes of CPU time on 64 processors).

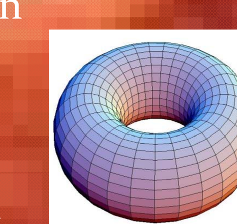
We created a grid of numerical models simulating polarized Hα line profiles for different combinations of parameters. We then compared the results of different models to see how the input parameters affected the polarized line shapes. Finally, we qualitatively compared our results with observations of the Hα line in supernovae from the Keck telescope .

Results

In each set of nine plots below, CSM optical depth runs from 0.5 to 2 (left to right) and CSM temperature runs from 10,000 K to 50,000 K (top to bottom). To calculate normalized polarized flux," we normalized each line profile in total flux to its peak value, then multiplied by percent polarization. Using this measure, we can quantitatively compare the amount of polarization produced between different models, but comparisons with observed polarized line profiles from SNe IIn are as yet only qualitative. Degrees indicate the viewing angle, with 0 representing a pole-on view and 90 representing an edge-on view. Typical error bars are shown for each plot. All models shown have a ratio of 10:1:2 for photons emitted from the central SN source, the CSM, and the interior shock region. A "spike" at the rest wavelength and a blueward "shoulder" from the SN's P Cygni profile are common features of these polarized line profiles.

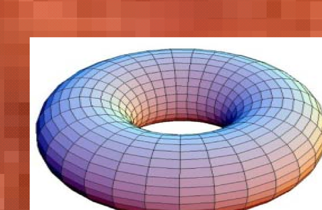


Disk models produce the highest polarization overall, particularly for edge-on viewing angles at which exiting photons have scattered many times within the disk.



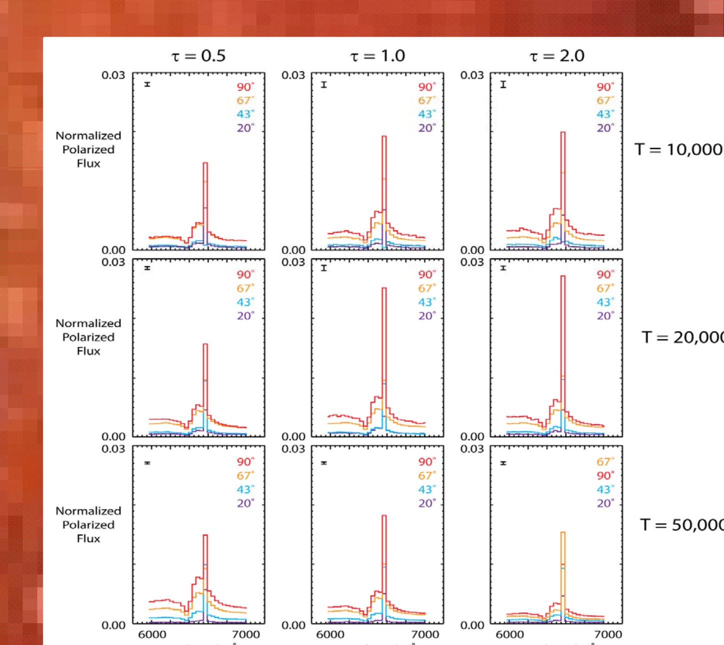
Disk

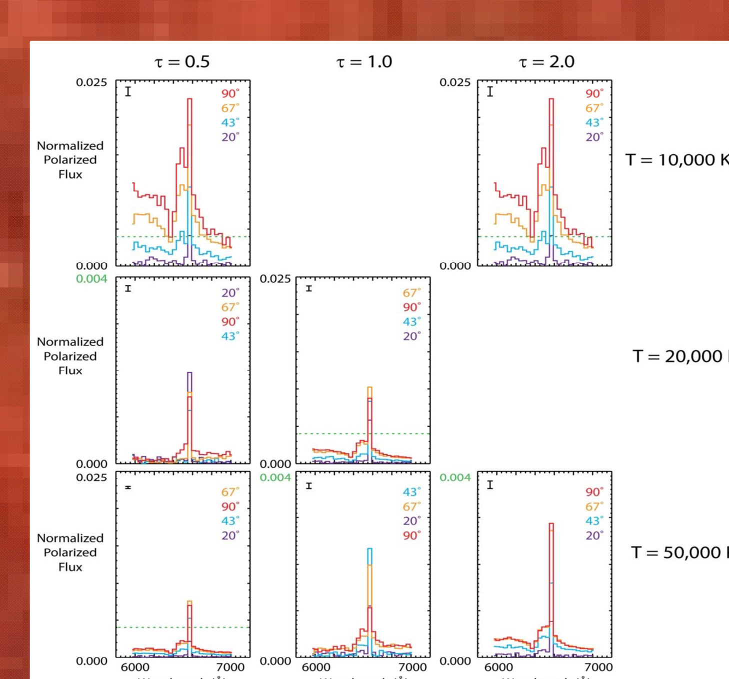
Variations in CSM temperature correspond to significant changes in the shapes of the polarized lines, suggesting these profiles could have diagnostic value.



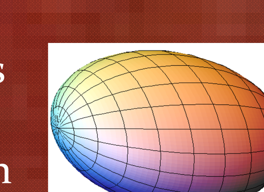
Toroid (a radially thinner version of the disk)

Toroidal models produce intermediate polarization, which is not very sensitive to CSM temperature except at edge-on inclinations. Varying CSM optical depth changes the ratio between the line peak and its "shoulder".





Increased CSM temperature tends to decrease the polarization for ellipsoidal models (note y-axis values). There is less distinction between viewing angles for this geometry, because it is more uniform in three dimensions than the disk or the toroid. Some ellipsoidal models with very low S/N are not shown.

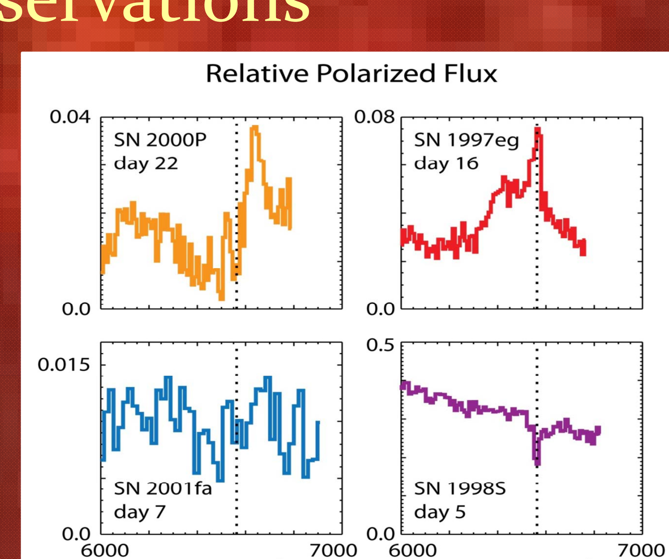


Ellipsoid

For all model geometries, higher optical depths generally produce more polarization. However, the specific behavior of this trend is sensitive to the CSM temperature, which affects the ionization balance of the scattering region.

Comparison with Observations

At right are observed polarized Hα lines from Type IIn supernovae at similar epochs of evolution. The Hα line varies strongly among objects and over time. However, the "spikes"and "shoulders" in the polarized Hα profiles of SN 2000P and SN 1997eg (top panels) qualitatively resemble some of the line profiles arising from our models. Future work comparing models with observations should reveal the changing characteristics of the CSM that may give rise to these variations.



Future Research

Our next step is to mathematically describe the properties of these polarized line shapes (e.g. "spike" to "shoulder" ratio) to better understand the relationship of the parameters to the resulting profiles.

We will then quantitatively compare our models with observed Hα polarized line profiles from SNe Type IIn to see if the models can explain the actual line shapes. One difficulty with doing this is that many of our models are degenerate in the polarized flux profiles, so we will investigate ways to distinguish them. Modeling other emission lines besides Hα may provide ways to break the degeneracies.

Finally, we hope to use our models to predict future observations of supernovae interacting with their CSM. This may have important implications for SN classification schemes and progenitor identification.

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Background image from www.astronomy-pictures.net .

Ellipsoid image from virtualmathmuseum.org . Toroid and disk images from www.math.havard.edu .

Keck SN data courtesy A. Filippenko, UC Berkeley .

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