Investigating Type Ia Supernova progenitors using spectropolarimetry

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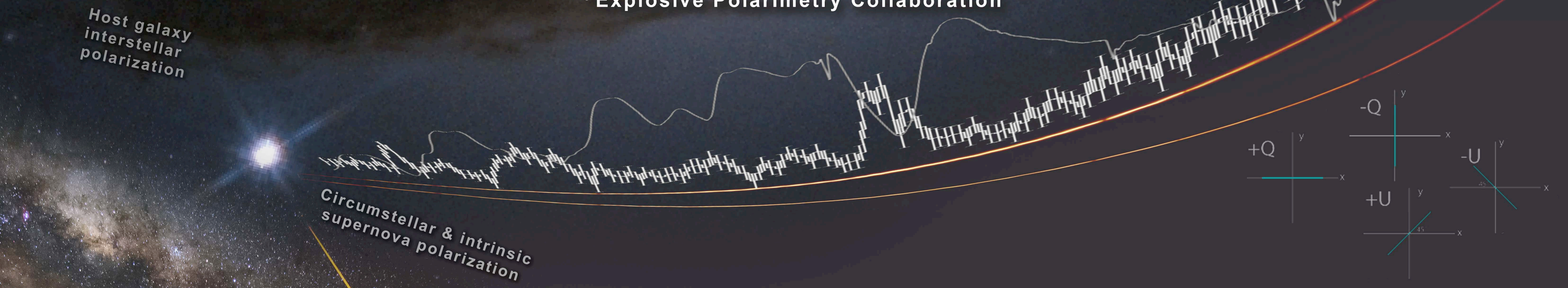
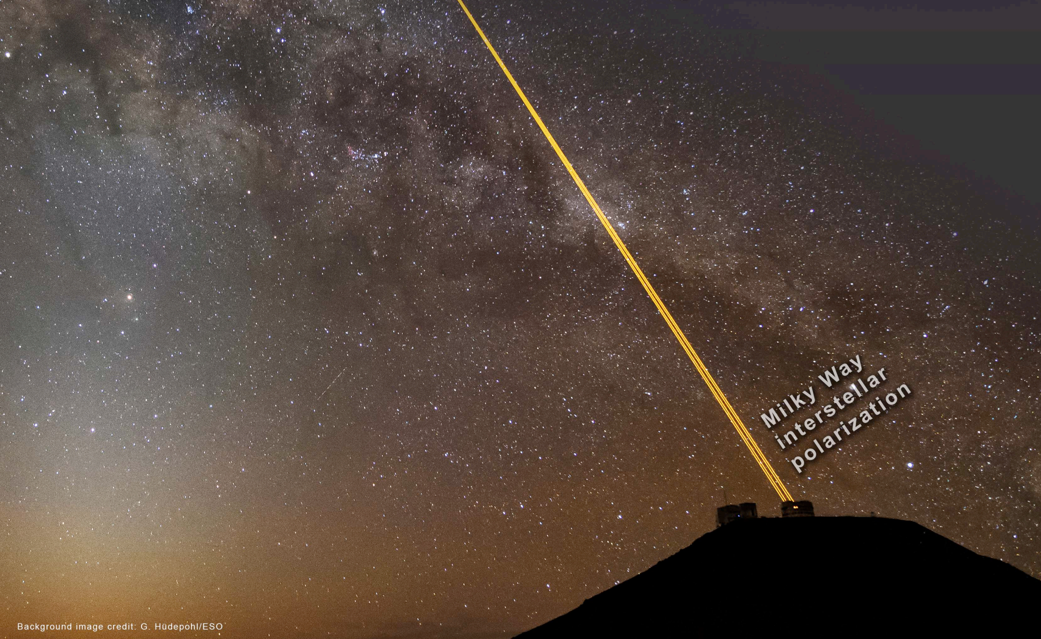
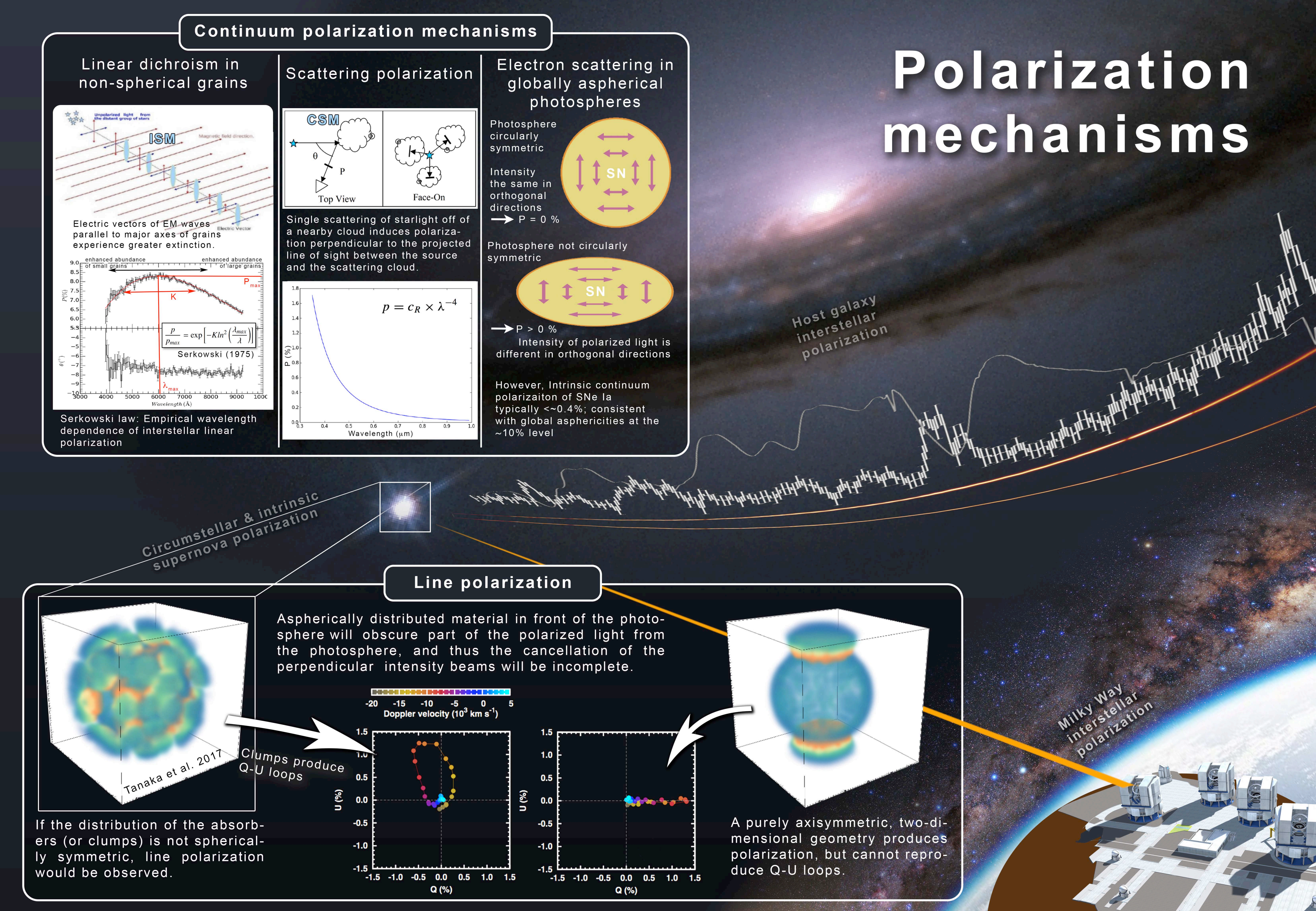


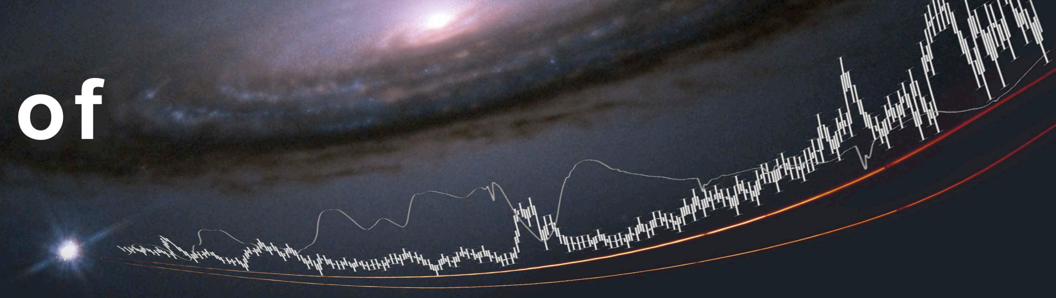
Spectropolarimetry is a powerful technique that enables us to study interstellar and circumstellar dust along lines of sight to Type Ia Supernovae (by measuring the continuum polarization), and the supernova Ia (SNe Ia) ejecta asymmetry (by measuring polarization of absorption lines). This provides insights on global and local asymmetries of SN explosions. These aspects are fundamental for our understanding of the phenomenon and are hardly approachable by any other observational technique.





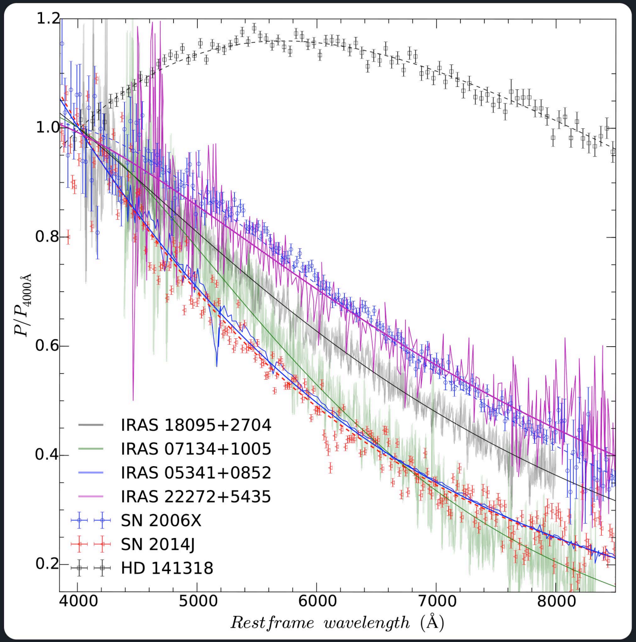
Polarization mechanisms
Continuum polarization mechanisms
Linear dichroism in non-spherical grains
Unpolarized light from the distant group of stars
ISM
Magnetic field direction
Electric Vector
Electric vectors of EM waves parallel to major axes of grains experience greater extinction.
enhanced abundance of small grains
enhanced abundance of large grains
P_{max}
K
$\frac{P}{P_{max}} = \exp\left[-K \ln^2\left(\frac{\lambda_{max}}{\lambda}\right)\right]$
Serkowski (1975)
λ_{max}
Wavelength (Å)
Serkowski law: Empirical wavelength dependence of interstellar linear polarization
Scattering polarization
CSM
θ
P
Top View
Face-On
Single scattering of starlight off of a nearby cloud induces polarization perpendicular to the projected line of sight between the source and the scattering cloud.
$p = c_R \times \lambda^{-4}$
P (%)
Wavelength (μm)
Electron scattering in globally aspherical photospheres
Photosphere circularly symmetric
Intensity the same in orthogonal directions
P = 0 %
SN
Photosphere not circularly symmetric
P > 0 %
Intensity of polarized light is different in orthogonal directions
However, Intrinsic continuum polarizaiton of SNe Ia typically <~0.4%; consistent with global asphericities at the ~10% level
Host galaxy interstellar polarization
Circumstellar & intrinsic supernova polarization
Milky Way interstellar polarization
Line polarization
Aspherically distributed material in front of the photosphere will obscure part of the polarized light from the photosphere, and thus the cancellation of the perpendicular intensity beams will be incomplete.
Tanaka et al. 2017
Clumps produce Q-U loops
Doppler velocity (10^3 km s^{-1})
U (%)
Q (%)
If the distribution of the absorbers (or clumps) is not spherically symmetric, line polarization would be observed.
A purely axisymmetric, two-dimensional geometry produces polarization, but cannot reproduce Q-U loops.

Spectropolarimetry of Type Ia Supernovae



Continuum polarization

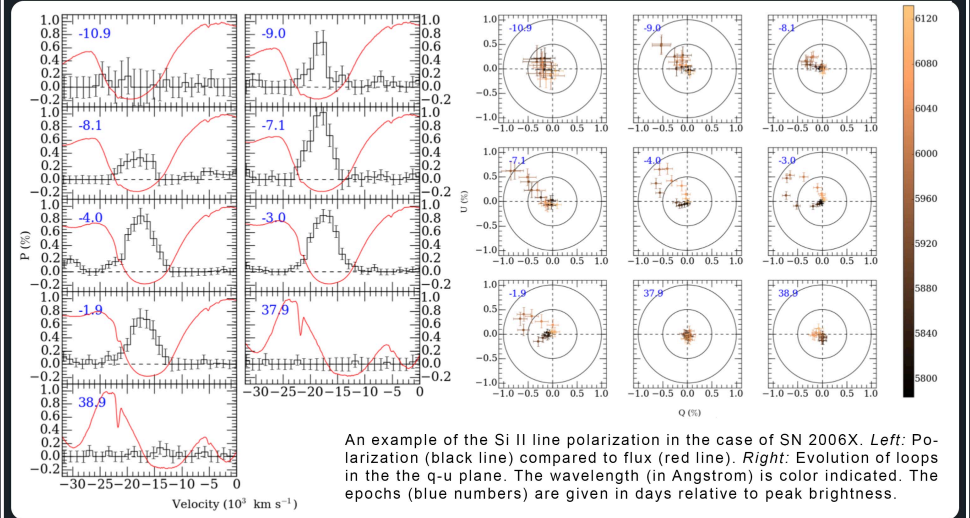
HD 141318 is a Galactic star with a normal polarization curve (with a wavelength of peak polarization, λ_{max}, at ~ 0.55 μm) produced due to linear dichroism of non-spherical grains aligned with the magnetic field. In contrast, SNe Ia have steeply rising polarization curves towards blue wavelengths with $\lambda_{max} \lesssim$ 0.4 μm, which may be produced due to scattering from nearby dust clouds. We noticed that some post-AGB stars (protoplanetary nebulae, PPNe), which also may play an important vague role on the evolutionary path of some SNe Ia (*Jones & Boffin 2017*), have remarkably similar polarization curves to those observed towards highly reddened SNe Ia. These polarization curves in PPNe are produced by CSM scattering (*Oppenheimer et al. 2005*). Thus, we suggest that also some SNe Ia polarization curves might be produced by CSM dust scattering (*Cikota et al. 2017c*). Furthermore, we speculate that those SNe Ia might have exploded within a PPN, and be observational evidence for the core-degenerate progenitor scenario (*Kashi & Soker 2011*), in which a white dwarf merges with the core of a companion AGB star.



Learn more about SN Ia continuum polarization and possible implications on the SN Ia progenitor systems:

- *Patat et al. (2015)*
- *Cikota et al. (2017c)*

Line polarization



An example of the Si II line polarization in the case of SN 2006X. *Left:* Polarization (black line) compared to flux (red line). *Right:* Evolution of loops in the the q-u plane. The wavelength (in Angstrom) is color indicated. The epochs (blue numbers) are given in days relative to peak brightness.

We examined the polarization of the Si II λ6355 Å line ($p_{Si\,II}$) as a function of time, which is seen to peak at a range of various polarization degrees and epochs relative to maximum brightness. We reproduced the Δm_{15}-$p_{Si\,II}$ relationship identified in a previous study, and show that subluminous and transitional objects display polarization values below the Δm_{15}-$p_{Si\,II}$ relationship for normal SNe Ia. We found a statistically significant linear relationship between the polarization of the Si II λ6355 Å line before maximum brightness and the Si II line velocity and suggest that this, along with the Δm_{15}-$p_{Si\,II}$ relationship, may be explained in the context of a delayed-detonation model. In contrast, we compared our observations to numerical predictions in the Δm_{15}-$v_{Si\,II}$ plane and found a dichotomy in the polarization properties between Chandrasekhar and sub-Chandrasekhar mass explosions, which supports the possibility of two distinct explosion mechanisms. A subsample of SNe displays evolution of loops in the q-u plane that suggests a more complex Si structure with depth. This insight, which could not be gleaned from total flux spectra, presents a new constraint on explosion models.

Learn more about linear spectropolarimetry of 35 Type Ia supernovae with ESO's VLT/FORS in *Cikota et al. (2019)*.