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Dust grain properties in extragalactic environment through supernovae dust polarisation observations

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ABSTRACT

Dust polarisation observations of starlight at multi-wavelengths helps us to find maximum polarisation, P_{max} and the corresponding wavelength, λ_{max}. This λ_{max} is approximately proportional to average grain size, thereby helping to reveal grain sizes in the intervening medium. We study the average grain sizes in different host galaxies of 4 Type Ia and 10 Type II supernovae through spectropolarimetric observations at multi-wavelengths and compare with the average grain sizes in the diffused interstellar medium of our galaxy. We use archival P_{max}, λ_{max} and width of peak of polarisation curve (K) values from the literature. We plot P_{max} versus λ_{max} in color scale that represents K and find that grain sizes of some of the galaxies are smaller, some nearly comparable and some larger than typical grain size ($\approx$ 5500Å) of our galaxy. This gives us an insight into the different grain properties especially their sizes in external galaxies compared to our galaxy.

Keywords: dust–polarisation–spectropolarimetry

1. INTRODUCTION

Cosmic dust is crucial to study different astrophysical processes. Since the discovery of polarisation of starlight by Hall (1949) and Hiltner (1949) due to differential extinction by asymmetric dust grains aligned with the ambient Galactic magnetic field, dust polarisation technique becomes an important tool to study magnetic field morphology in molecular clouds and dust grain properties. This technique can be used to study the dust properties in the interstellar medium (ISM) of host galaxies by observing the intrinsic polarisation of supernovae (SN) light due to the asymmetric aligned dust grains in the ISM of the host galaxies.

The degree of polarisation depends on wavelength of light as given in Serkowski law (Serkowski et al. 1975). So, by observing the dust polarisation at different wavelengths the maximum polarisation (P_{max}), the wavelength of maximum polarisation (λ_{max}) and the width of the peak of the polarisation curve (K) can be determined. The value of λ_{max} provides information on the average grain size (Whittet 2022). Multi-band dust polarisation measurements help us to get an insight into the grain sizes in molecular clouds in our galaxy or other galaxies and can compare with the general diffuse ISM of our galaxy having typical grain size of $\approx$ 5500Å. The grain size acts as an important parameter in the study of polarisation and grain alignment mechanism.

Supernovae typically possess some intrinsic polarisation $\leq 1\%$ (e.g, Wang & Wheeler (2008)). So, the study of dust properties in ISM of external galaxies through SN polarisation is limited to mainly highly reddened SN so that the ISM dust polarisation of their host galaxies dominate the polarisation signal. In this work, we study the grain sizes in the ISM of host external galaxies of four reddened Type Ia supernovae SN1986G, SN2006X, SN2008fp, SN2014J and 10 Type II supernovae SN2017gmr, SN2017ahn, SN2013ej, SN2012ec, SN2012dh, SN2012aw, SN2010co, SN2008bk, SN2001du and SN2001dh through spectropolarimetric observations. The details about these supernovae can be found in Nagao et al. (2023) (for Type II SN) and Patat et al. (2015) (for Type Ia SN).

2. DATA

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We have used archival data for this investigation. For the details on spectropolarimetric observations and data reduction to determine P_{max}, λ_{max} and K values for each of the supernovae, please refer to Nagao et al. (2023) for Type II SN and Patat et al. (2015) for Type Ia SN.

3. RESULTS AND DISCUSSION

To study the variation in dust grain size properties in the ISM of external galaxies and then compare with our galaxy, we plot P_{max} with λ_{max} for each of the Type Ia and Type II SN as shown in Figure 1. The colorbars in Figure 1 represent the K parameter values which signify the width of peak of polarisation curve. The wavelength of maximum polarisation λ_{max} is an important quantity which can give information on the average size of the dust grains. For dielectric cylinders of radius r and refractive index n, to produce polarisation more efficiently it must follow the relation $\lambda_{max} = 2\pi r(n-1)$ (Whittet 2022). From Figure 1, **we see that the ISM of the host galaxies of three Type II SN (SN2001dh, SN2017ahn, SN2017gmr) have λ_{max} nearly comparable to the Milky Way value of 5500Å, derived from polarization studies of our own galaxy. This indicates that the average grain sizes in the ISM of these host galaxies are similar to those in the ISM of the Milky Way. Four Type II SN (SN2013ej, SN2012aw, SN2012dh and SN2008bk) have host galaxies with λ_{max} much less than 5500Å, and hence dust grains which are causing polarization in these systems are smaller than those in the Milky Way ISM. Three type II SN (SN2010co, SN2001du and SN2012ec) have hosts with λ_{max} greater than 5500Å, and so the dust grains causing polarization in these systems are larger than that in the Milky Way ISM.**

For the host galaxies of two type Ia SN, SN1986G and SN2006X, dust grain sizes are similar to those in our ISM. The hosts of SN2008fp and SN2014J, however, have smaller dust grain sizes than our ISM. There is therefore a diversity of average dust grain sizes in the ISM of external galaxies compared to our galaxy. The study of the grain size distributions is important in investigating the grain alignment mechanism.

Also, on comparing the values of P_{max} among all the SN of our study, it is found that P_{max} value is larger for the Type Ia SN namely SN2006X, SN2014J and SN1986G going upto nearly 8 % than the other SN which may imply that the alignment of grains are better in the ISM of the host galaxies of the above 3 Type Ia SN compared to other SN host galaxies of our study. In future, we will work on investigating the grain alignment efficiency in the ISM of external galaxies.

From this study, we come to the conclusion that there are diversities in the average grain size distributions in the ISM of external galaxies on comparison with our galaxy and in future we will go on testing grain alignment theories, which are at present mostly done in the ISM of our galaxy, by extending to other galaxies which will help us to further increase the present knowledge of grain alignment.

Software/Packages: Matplotlib

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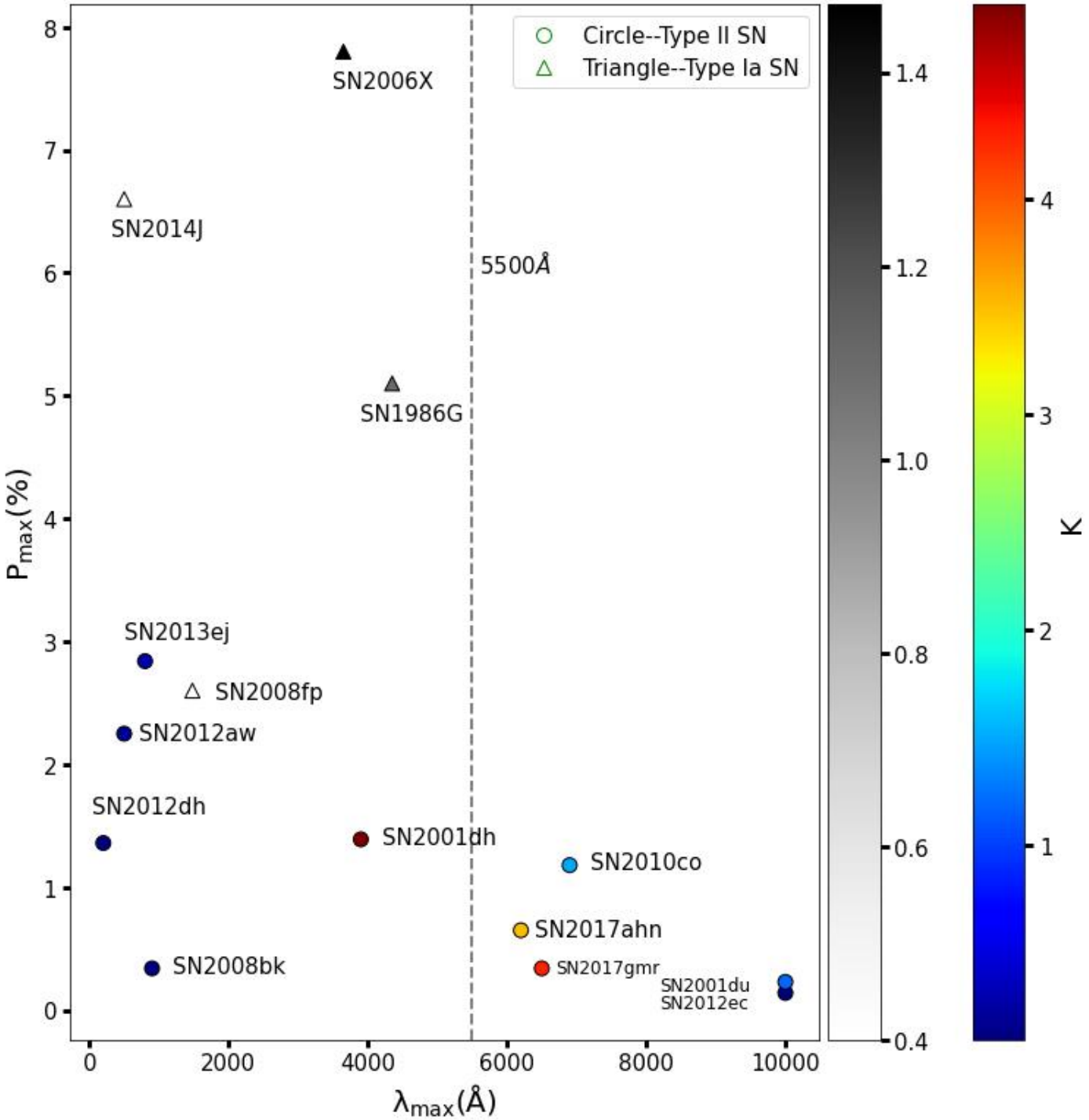

Figure 1. The Figure provides the P_{max} versus λ_{max} plot. The color bars denote the values of the width of peak of polarisation curve, K. A vertical dotted line is drawn at $\lambda_{max} = 5500\mathring{A}$ to indicate the λ_{max} value of the general diffuse interstellar medium of Milky Way galaxy. The circle symbols denote Type II SN and triangle symbols denote Type Ia SN.