

On the Relationship Between Type Ia Supernovae and their Host Galaxies

Rebecka Mähring
`rebecka.mahring@gmail.com`

under the guidance of
Seméli Papadogiannakis
Oskar Klein Center
Stockholm University

April 14, 2019

Abstract

Using data from the Palomar Transient Factory (2009-2012) and Intermediate Palomar Transient Factory (2013-2017) surveys, it was investigated whether two characteristics – metallicity and total stellar mass – of host galaxies affected the luminosity of type Ia supernovae (SNe Ia). A total of 79 SNe were used to investigate the impact of metallicity, and 238 for stellar mass, with linear regression analyses being performed in both instances. Results indicated a lack of statistically significant correlations, and thereby lack of host bias with respect to these properties, in accordance with the results of, e.g., S. Papadogiannakis et al. (2018) and Scolnic et al. (2017). However, these results also contradicted those of, among others., Kelly et al. (2009), Sullivan et al. (2010), and Wolf et al. (2016), who found correlations between SNe brightness and the relevant host properties. These discrepancies were discussed, and possible explanations presented.

Contents

| | | |
|----------|--|-----------|
| 1 | Introduction | 1 |
| 1.1 | Previous Research | 1 |
| 1.2 | Aim of Study | 2 |
| 2 | Theoretical Background | 2 |
| 2.1 | Stars | 2 |
| 2.1.1 | Stellar Nucleosynthesis | 3 |
| 2.1.2 | Death of Stars | 3 |
| 2.2 | Supernova Explosions | 4 |
| 2.2.1 | Thermonuclear Supernovae | 4 |
| 2.2.2 | Standardized Candles & Host Bias | 6 |
| 2.3 | Galaxies | 6 |
| 2.3.1 | Metallicity | 7 |
| 2.3.2 | Measuring Stellar Mass | 7 |
| 2.3.3 | Classification | 8 |
| 2.4 | The PTF and iPTF Surveys | 9 |
| 3 | Method | 9 |
| 4 | Results | 9 |
| 5 | Discussion | 12 |
| 5.1 | Origins of Dichotomy | 12 |
| 5.2 | Conclusions | 13 |
| 5.3 | Proposals for Future Research | 13 |
| 6 | Acknowledgements | 14 |
| | References | 15 |

1 Introduction

Supernovae are some of the most violent phenomena in the universe. They are also crucial for the emergence of carbon-based lifeforms, since it is through them that the interstellar medium is enriched with elements heavier than He and H. Type Ia supernovae (SNe Ia) are especially relevant for research, since they – through their role as standardized candles in observational cosmology – have become central to our understanding of the large-scale evolution of the universe. However, the progenitors, and environmental determinants of SNe Ia and their characteristics are largely unknown, leading to uncertainties in how to wield them as tools in cosmology.

1.1 Previous Research

Much research has been done on type Ia supernovae since Tycho Brahe first aimed his telescope at SN 1572, and core characteristics of their spectra and light curves identified (1; 2). The differences between type Ia supernovae, and type II, Ib, and Ic supernovae (collectively CC SNe) led Hoyle et al. (1960) to propose that they have fundamentally different progenitors (3); while CC SNe are the result the gravitational collapses of massive stars, SNe Ia are theorized to represent the thermonuclear disruption of a degenerate star in a binary system. Two main hypotheses for the specific creation of SNe Ia now exist: the single degenerate progenitor scenario (4), and the double degenerate progenitor scenario (5).

Already in the 1930’s, Zwicky and Baade realized that the brightness, and uniformity of spectra and light curves of SNe Ia make them ideal to measure distances in time and space. Since then, they have been used in the discovery of the universe’s accelerated expansion (6; 7). However, recent studies have raised the concern of a ‘host bias’, allegedly resulting in systematic errors of cosmological parameters extracted using SNe Ia (8; 9; 10; 11).

Some studies – e.g., those by Kelly et al. (2009), Sullivan et al. (2010), and Wolf et al. (2016) – have identified a positive correlation between absolute magnitude of SN, and the mass of host galaxies. Furthermore, Wolf et al. (2016), D’Andrea et al. (2011), and Pan et al. (2013) identified a correlation between host metallicity and SN brightness. Hamuy et al. (2016) also found that brighter SN generally occurred in spiral galaxies (9; 10; 8; 12; 11; 13). It has therefore been suggested that host galaxy mass should be introduced as a third parameter when calibrating SNe Ia light-curves for cosmology (10).

However, a non-dependence of SNe Ia properties on their environments has also been demonstrated; Anderson et al (2014) identified a lack of correlation between SN stretch (i.e, light curves) and environmental properties, and Scolnic et al. (2018) found no correlations between luminosity of SNe and color, stretch, or mass of hosts. Thus, there is an apparent dichotomy in the literature. Further studies are needed in order to clarify SNe’s dependence on host galaxies, both in order to improve their usage in observational cosmology, and gain vital clues about their progenitors.

1.2 Aim of Study

The aim of this study is to use additional data to investigate whether luminosity of type Ia supernovae is affected by the metallicity or stellar mass of their resident galaxies, and then compare results with those of previous studies.

2 Theoretical Background

Because of the great distances in space, astrophysics as a science has historically been wholly dependent on the light radiated from objects. This property is quantified as luminosity, which is the amount of radiant energy given off per unit of time. However, luminosity has certain limitations; it is hard to know whether an object is near and faint, or distant and bright, making comparisons between objects difficult. Thus, absolute magnitude is often considered instead. It is expressed in terms of the apparent magnitude – the brightness of the object as perceived by an observer on Earth – which is in turn defined as

$$m_x = -2.5 \times \log_{10} \left(\frac{F_x}{F_{x_0}} \right), \quad (1)$$

where F_x is the flux density of the spectral band x , and F_{x_0} is the corresponding reference flux. Absolute magnitude is the apparent magnitude the object would have if it were situated exactly 10 parsecs from the viewer with no dimming of light. This is expressed as

$$M_x = m_x - 2.5 \times \log_{10} \left(\frac{d}{10} \right)^2, \quad (2)$$

where m_x is the object's apparent magnitude, and d is the actual distance to the object. (14)

2.1 Stars

One of the types of objects most studied by astronomers are stars: large and compact spheres of gas formed when molecular clouds in the interstellar medium collapse. Normally, interstellar clouds are in a state of hydrostatic equilibrium, with their outward forces – created by temperature and density of particles, and more complicated factors such as rotation, turbulence, and magnetic field lines – balancing the inward force of gravity. If this balance is disturbed (e.g., by the cloud being slightly compressed by an outside influence) the interstellar cloud will collapse. Since they are not perfectly symmetrical, they will fragment, with different points in which mass congregates. If the mass of these points grow to at least $0.08M_{\odot}$ (where M_{\odot} is the Sun's mass), they become capable of fusing hydrogen into helium, thereby counteracting the force of gravity and creating a star¹. (15)

¹Points accumulating $0.02 - 0.08M_{\odot}$ instead form faint objects called 'brown dwarfs', and those with less than $0.02M_{\odot}$ are classified as planets.

2.1.1 Stellar Nucleosynthesis

In the core of stars, stellar nucleosynthesis takes place. Nucleosynthesis is a form of nuclear fusion, which combines atoms with low atomic number to form heavier elements, releasing energy in the process, as well as enriching the interstellar medium with new elements. (14) For main-sequence stars², this means fusing hydrogen with helium. Lower mass stars such as our Sun have the proton-proton chain reaction (turning two hydrogen atoms into helium and a neutron), while in more massive stars, the carbon-nitrogen-oxygen (CNO) cycle takes place instead. The main difference is that the CNO cycle uses carbon, nitrogen, and oxygen as catalysts throughout the reaction. Both, however, use up hydrogen³, and have helium as their primary product. (14)

As the amount of hydrogen in the cores of stars decreases and starts to run out, the temperature gradually increases due to gravitational contraction. When the core reaches 1×10^8 K, helium nuclei gain enough thermal energy to overcome their mutual repulsion and fuse. Thus, a new process called 'helium burning' takes over the role of counteracting gravity, producing carbon, oxygen, and gamma rays. (14)

When the core has no more helium to burn, gravitational contraction raises core temperatures enough for it to burn carbon, producing magnesium, helium, and oxygen. If the core temperature rises to roughly 1.5×10^9 K, oxygen burning can take place, producing various elements and types of radiation. Lastly, at temperatures greater than 3×10^9 K, silicon burning can begin, and produces stable iron atom, $^{56}_{26}\text{Fe}$. Since iron has the highest energy per nucleon, this is the last stage of thermonuclear burning. (14)

In general, more massive stars go through these processes faster, despite the fact that they initially have more hydrogen to burn. Namely, due to their increased mass, pressure and temperature at their core are also more extreme, leading to faster burning. This difference in temperature and pressure is also the reason for why the CNO cycle, instead of 'regular' hydrogen burning, takes place in more massive stars. (14)

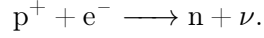
2.1.2 Death of Stars

Eventually, stars run out completely of nuclear fuel, and therefore no outward pressure to counteract gravity. Stars of mass below the Chandrasekhar limit of $1.4M_{\odot}$ collapse until the electron shells of atoms begin to overlap, and electron degeneracy pressure (a force due to particles not being able to inhabit the same space simultaneously, as dictated by the Pauli exclusion principle) thereby grows large enough to counteract gravity. The resulting objects are referred to as 'white dwarfs' or 'degenerates', and are faint, very dense, and made mainly of carbon and oxygen. (15; 14)

²These are stars that appear as a distinctive, continuous band in a Hertzsprung-Russell diagram, which shows stellar color against brightness.

³In the case of the CNO cycle, it is rather protons that are used. However, since hydrogen atoms are ionized in the cores of stars, this amounts to the same thing as using hydrogen.

In the case of stars who at the end are of their thermonuclear burning phase are more than $1.4M_{\odot}$, however, electron degeneracy pressure is not enough to halt implosion. Instead, gravitational contraction is enough to push protons into electrons, triggering beta decay:



As a result, the amount of neutrons in the core, as well as its density, gradually increases. Neutrons, however, do not create new particles when pushed together, as do electrons and protons. Thus, the neutron degeneracy pressure (also due to the Pauli exclusion principle) eventually grows large enough to stop the star's implosion. A rigid core known as a neutron star is thus formed, and the collapsing outer layers of the star bounce against it, reversing direction and travelling outwards in the form of a supernova explosion. (15; 14)

2.2 Supernova Explosions

Historically, supernovae have been divided into two groups – type I (which includes Ia, Ib, and Ic) and type II – based on visual properties such as their light curves (absolute magnitude against time) and absorption spectra. In the case of light curves, type Ia generally have a maximum brightness of $10^{10}L_{\odot}$ that decreases gradually over time, whereas type II supernovae are characterized by lower peak luminosity at 10^9L_{\odot} that decline more rapidly. Using absorption spectra, type I and II can be differentiated by whether there is hydrogen in the ejected material. (2; 16)

However, more recently it has been shown that they can instead be divided into the categories 'core-collapse supernovae' and 'thermonuclear supernovae' based on the events preceding the explosion. Core-collapse (CC) supernovae include type II, type Ib, and type Ic supernovae, and are created in the gravitational collapse of a massive star (as described in Section 2.1.2). Thermonuclear supernovae include only type Ia. (2; 16)

2.2.1 Thermonuclear Supernovae

Two main things led Hoyle et al. (1960) to theorize about the origins of SNe Ia: the lack of hydrogen and helium in their spectra, and their presence in old as well as new stellar populations (3). This suggests that at least one degenerate – probably a white dwarf – must be involved in their creation. Although research has since narrowed it down into two two main scenarios – the single degenerate (SD) scenario, and the double degenerate (DD) scenario – there is great diversity and uncertainty within these two.

In the case of SD, the binary pair consists of a white dwarf orbiting a common center of mass with a massive star (17). The nature of the massive star is unknown; it has been suggested that it could be a main sequence star (e.g. van den Heuvel et al. 1992), a red giant (e.g. Patat et al. 2011), a subgiant (e.g. Han & Podsiadlowski 2004), or a helium star (Tutukov & Yungelson 1996) (17). The white dwarf gradually accrues gas from the massive companion, thereby exceeding the

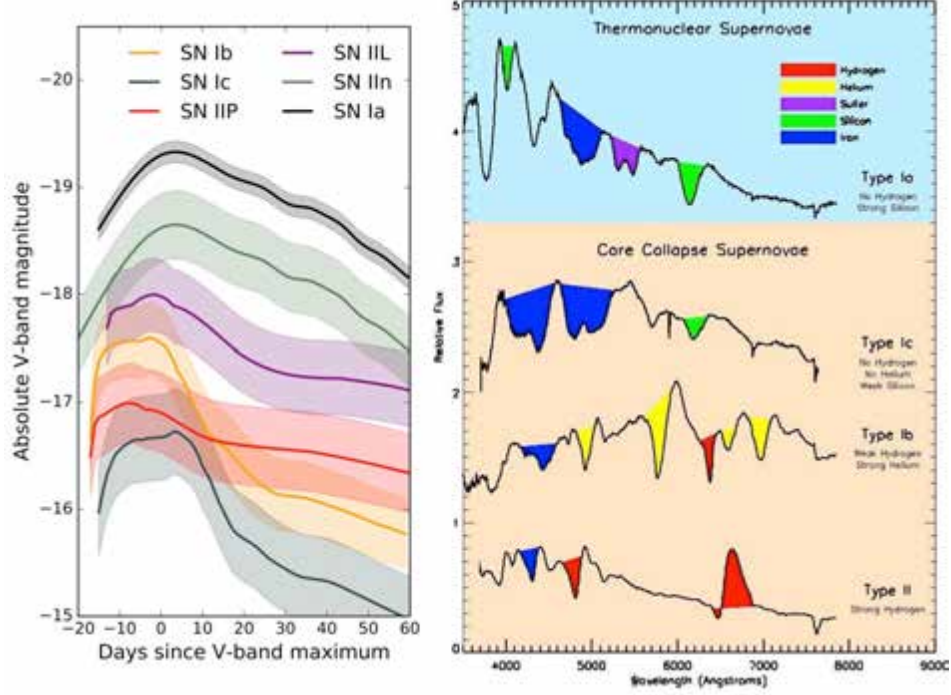


Figure 1: Differences in light curves (left), and spectroscopic signatures (right) for different supernova types. Source: (2)

Chandrasekhar limit of $1.4M_{\odot}$ and entering into the process described in Section 2.1.2 (17). Besides the nature of the companion star, the specific process of mass transfer is also disputed, with the two main candidates being Roche-lobe overflow⁴, or a strong wind from the companion (17).

In the DD scenario, on the other hand, the binary pair instead consists of two white dwarfs (WDs), one of which is slightly more massive. The more massive WD is then thought to disrupt the smaller one in its orbit, and accrete it. If their combined mass exceeds the Chandrasekhar limit, a supernovae is created. (17) The feasibility of this scenario has been much debated, and some (Nomoto & Iben 1985, Saio & Nomoto 1998, Shen et al. 2012) argue that the accretion is so slow that the collapse will instead manifest itself as some kind of non-SN Ia, low-luminosity, hydrogen-free, transient.

SNe Ia progenitors have never been directly observed; this is one reason for the uncertainties involved in modelling the explosion. Instead, indirect evidence has been used. Below is listed a few such methods (17), with method V. being the one utilized in this study.

- I. Studying existing populations of potential progenitors.
- II. Using pre-explosion data at the sites of nearby events to try to identify the progenitors.
- III. Attempting to use observed properties of the SNe themselves to give clues about the

⁴This is a region around the star in which orbiting material is bound gravitationally to it.

progenitors.

IV. Searching remnants of presumed SNe Ia for remaining traces of the progenitor systems.

V. Studying SNe explosions as a function of time and environment.



Figure 2: Artist's rendition of the SD (left) and DD (right) scenarios. Source: (2)

2.2.2 Standardized Candles & Host Bias

In space, distances to objects are judged using their luminosity. Since SNe Ia both have brighter peaks than CC SNe, and more uniform light curves and spectra, they have become widely used as 'standardized candles' in observational cosmology – namely, the luminous object by which distance is judged. (14)

Precision of distance indicators – such as SNe Ia – is dependent on the ability to calibrate them by establishing empirical relations between their absolute magnitude and light-curve shape. Host bias – namely, that luminosity of SNe Ia is significantly impacted by properties of host galaxies – complicates this. This is mainly due to the dynamic nature of a galaxy's properties, which are dependent on cosmic time. As a result, this could give rise to systematic bias in the distances deduced based on calibrations of SNe Ia. These apparent differences could, in turn, impact the measurements of cosmological parameters derived using SNe Ia light curves, as low-mass and low-metallicity galaxies dominate the production of SNe Ia at progressively higher redshifts. (17)

2.3 Galaxies

On a larger scale, stars – together with dust, gas, stellar remnants, and dark matter – congregate to form flat disks rotating around their own center of mass. These formations are known as galaxies. (18) In this study, two characteristics of galaxies are considered: mass and metallicity. These characteristics, the observational methods used to measure them, and how they relate to types of galaxies, will be outlined below.

2.3.1 Metallicity

Of all the elements in the universe, only hydrogen and helium were created in the Big Bang. The rest are produced through stellar nucleosynthesis, and are expelled into the interstellar medium through stellar winds, and supernovae explosions. Therefore, the amount of heavier elements as opposed to hydrogen or helium is an estimate of the time stars have been active in that area, and, therefore, of the galaxy's chemical evolution. This is quantified through the notion of metallicity, $[\text{Fe}/\text{H}]$, which is defined as

$$[\text{Fe}/\text{H}] = \log_{10} \left(\frac{N_{\text{Fe}}}{N_{\text{H}}} \right), \quad (3)$$

with N_{Fe} being the estimated number of iron atoms in the galaxy, and N_{H} the number of hydrogen atoms. (18)

The emissions of gaseous nebulae – namely, optically visible gas clouds – situated in the galaxy is one popular tool used to measure metallicity. When parts of these clouds collapse to form stars, the remainder of the gas is ionized by the radiation emitted during the star formation process. As a result, the gas emits photons from which emission spectra can be produced, thereby yielding information about the properties of the chemical composition of the galaxy. (19)

2.3.2 Measuring Stellar Mass

There are various methods for measuring the mass of a galaxy. One of these takes advantage of the fact that baryonic matter⁵ generally have a luminosity, either because the objects themselves give off light or, as is the case for gas clouds, glow due to radiation from other objects. Thus, by comparing the measured light wavelengths of the relevant galaxy with model spectra of galaxies of different masses, the mass can be defined that associated with the best fit model spectra. Concretely, the 'best fit' is defined as the fit for which the χ^2 value is minimized, as defined by

$$\chi^2 = \sum_{i=1}^k \left(\frac{X_i - \mu_i}{\sigma_i} \right)^2, \quad (4)$$

where X is the data point, σ is the error, and μ is the mean value. Since the uncertainty of a data point is in the denominator, this formula ensures that data points with larger uncertainties affect the χ^2 value less. As a result, the estimation of the certainty of the best fit is not disproportionately affected by uncertainty in data points. (20)

⁵This is all matter composed of baryons (a composite subatomic particle) – essentially, all 'ordinary' matter. Dark matter, for example, is presumably not made of baryons.

2.3.3 Classification

Galaxies are often categorized based on their visual morphology, and fall into one of three main groups: elliptical and spiral galaxies. Sometimes, lenticular (intermediates between elliptical and spiral galaxies), barred-spiral (spiral galaxies with a distinct bar-shaped structure), and irregular (galaxies with no clear structure; often the result of violent collisions) galaxies are also included as separate categories, but will not be explicitly discussed here. (18)

Elliptical galaxies (see Figure 3b for an example) are believed to have formed when several smaller galaxies merged, as supported by observational evidence showing an abundance of red stars. Since the universe was initially smaller, collisions between galaxies were more frequent then. As a result, elliptical galaxies are generally older than spiral galaxies. (18)

Since elliptical galaxies have had more time to accrue mass, and are created through collisions of galaxies, they are generally the most massive. In addition, they also display higher metallicity, and low density of gas in the interstellar medium (with the result being low star formation). These characteristics are due to elliptical galaxies having gone through more generations of stars, leading both to a high Fe/H ratio, and to matter becoming trapped in dead stars. (18)

Spiral galaxies are distinguished by several characteristics, with two central ones being spiral arms, and a central stellar bulge consisting of mostly older stars. The spiral arms are initially formed when the almost uniform distribution of stars in a rotating galaxy is disturbed, and are then most likely maintained by 'density waves'⁶ (21; 22). Spiral galaxies generally have varying metallicity and star-formation, with higher metallicity towards their center, and younger stars and more active star formation in their spiral arms. (14) An example of a spiral galaxy can be found in Figure 3a.



(a) The spiral galaxy NGC 1084.
Source: ESO/Hubble



(b) The elliptical galaxy ESO 325-G004. Source: ESO/Hubble

Figure 3: The two main types of galaxies.

⁶These are propagating differences in density, or compression waves, which keeps the galaxy's spiral arms from collapsing.

2.4 The PTF and iPTF Surveys

The Palomar Transient Factory (PTF) and Intermediate Palomar Transient Factory (iPTF) were two surveys whose main goals were to identify transient events⁷ such as supernovae, asteroids, comets, and variable stars. Both utilized the 1.2 meter Oschin Schmidt Telescope at Palomar Mountain, California, and were led by the California Institute of Technology. (1)

The survey strategy of both the PTF and iPTF was to perform an untargeted search 1-5 times per night, and then compare data to reference images (from 2009 in the case of PTF, and 2012 for iPTF). The same spot on the sky was usually observed again within 1-5 days. In this way, new transient events could be discovered and studied. (1)

The PTF survey ran 2009-2012, and the iPTF survey 2013-2017. In March of 2018, the Zwicky Transient Facility became the successor of the two surveys. (1)

3 Method

Data from the PTF and iPTF was used, with absolute magnitude of SNe as well as metallicity and total stellar mass of host galaxies having already been extracted (see the work of S. Papadogiannakis et al. (16; 1) for details). All best fits for mass with $\chi^2 > 2$ or $\chi^2 = 0$ were then excluded from the data sample, since these were unlikely to be good estimates of the actual mass of the galaxies.

The statistical uncertainty had been computed for stellar mass and absolute magnitude (based on uncertainties in both measurements and calibration), and were visualized as error bars for one standard deviation. In the case of metallicity, there was no existing measure of statistical uncertainty. Therefore, the error was determined by finding the SNe that had more than one value for metallicity⁸, computing the differences between these values, and defining the uncertainty as the mean of these differences.

In order to investigate the dependence of SNe Ia on their host environments, two linear regression analyses were performed, with the corresponding residual and p-values being computed. All management, visualization, and analysis of data was done using the Python libraries Numpy and Matplotlib.

4 Results

The results regarding metallicity of resident galaxies can be seen in Figure 4 for 79 data points. The linear regression has a slope around -0.1397 , with a residual of approximately 0.3168 . In addition, the linear regression for mass of resident galaxies against absolute magnitude of

⁷These are events that appear on the night sky for a limited amount of time.

⁸Different values were due to there being several spectra of the same galaxy.

supernovae is presented in Figure 5 for 238 data points, with a slope of 0.0029, and residual of around 0.3378.

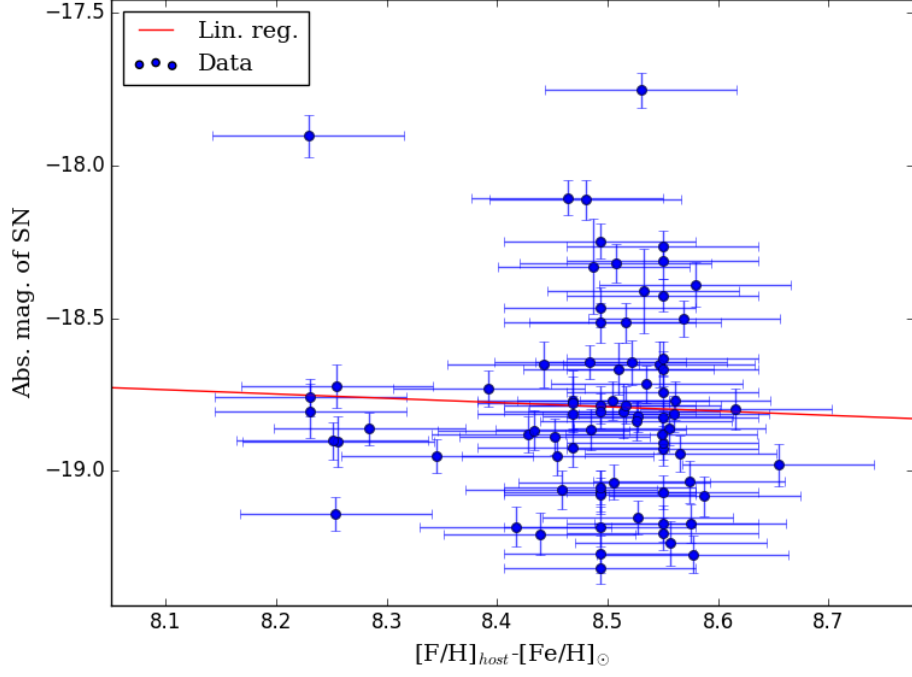


Figure 4: The relationship between absolute magnitude of SNe Ia, and the average metallicity of their resident galaxies

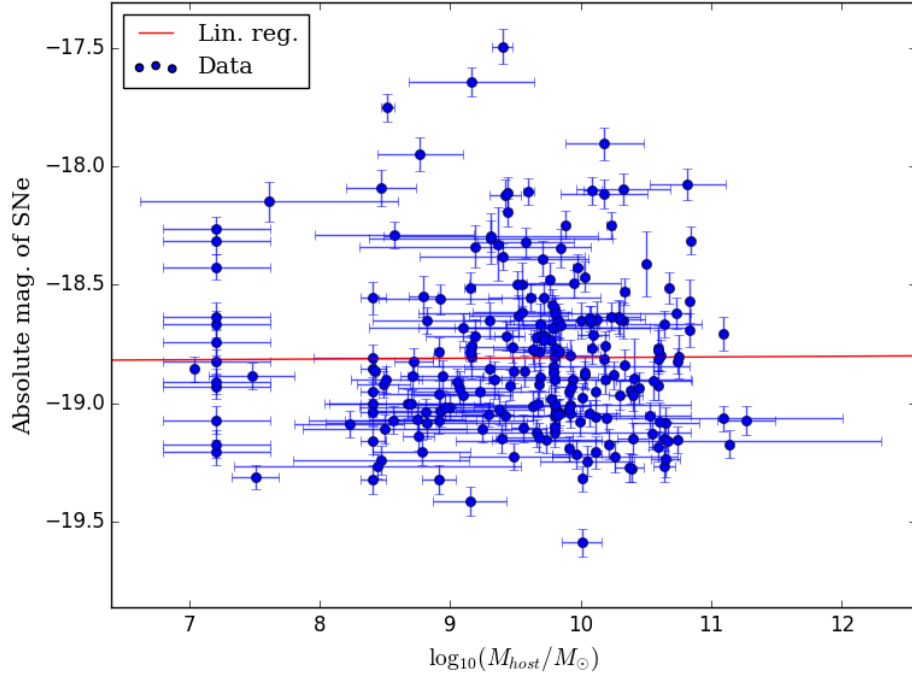


Figure 5: The relationship between absolute magnitude of SNe Ia, and the mass of their resident galaxies.

5 Discussion

For both Figure 4 and Figure 5, the value of residuals is close to zero, meaning that even the best fit line does not accurately predict actual data. Additionally, the error bars show that even if the linear regression were to be adjusted within one standard deviation, a significant correlation could not be attained. Therefore, it can reasonably be concluded that, for the analyzed data sample, no correlation was found between absolute magnitude of SNe Ia and either the mass or metallicity of their host galaxies.

This result would suggest that no significant insight can be gained into the mechanics of SNe Ia explosions by categorizing and comparing them based on their resident galaxies. Furthermore, results did not indicate the presence of a significant host bias, thereby indicating that it is not necessary to calibrate SNe light curves with respect to host mass or metallicity in order to extract reliable cosmological parameters.

These results are in agreement with, e.g., those of Papadogiannakis et al. (2018), and Scolninc et al. (2017). However, they contradict, among others, Kelly et al. (2009), Sullivan et al. (2010), and Wolf et al. (2016). It is therefore worth discussing what might have given rise not only to the differences between the results of this study and others, but the dichotomy in the research field at large.

5.1 Origins of Dichotomy

One thing that is worth noting is that this study did not account for color bias (namely, the fact that some wavelengths of light from the supernovae may have been absorbed by interstellar gas clouds before reaching Earth (1)). As a result, the observed supernova will have slightly lower observed than actual luminosity. In addition, this effect will vary for different supernovae, and will therefore have an impact on the distribution of data points relative to each other in Figures 5 and 4. This might result in a slightly different best fit regression line. As a result, the possibility that color bias was significant enough to hide a correlation (positive or negative) in the diagrams cannot be entirely ruled out.

Since metallicity and mass or galaxies are strongly related (2), however, it is to be expected for both diagrams to show the same relationship. The SNe samples used in Figure 4 and Figure 5 do not overlap completely, meaning that if color bias does significantly impact the distribution of, it must have distorted the two diagrams in a very similar way to produce a similar trend. This is not especially likely, suggesting that color bias might not have been significant enough to produce an entirely different result. Still, it is worth noting that it is not entirely statistically impossible.

Although sources of error might have resulted in a different trend line, a positive or negative correlation would have had the same problems – namely, that the results of this study are in accordance with some previous studies, and contradict others. The origin of this must have its

an explanation beyond the specifics of this study.

One possibility is that calibration of data has an inordinate impact, making comparisons between studies – which have calibrated data in different ways – nearly impossible, and giving rise to contradictory results. One further possibility is that there is selection bias of supernovae, differing for surveys and telescopes and resulting in different data samples.

A further possibility is that the variables – the absolute magnitude of the supernova, and properties of its host galaxy at the time of the explosion – being studied simply are not dependent on each other. The characteristics of a type Ia supernova are determined by its progenitors (1; 2; 3; 17). Although the progenitors are dependent on the host galaxy – stars are created from gas in the interstellar medium, and their chemical composition is thereby impacted by their galaxy’s (see Section 2.1) – they become less so after they enter the white dwarf stage (14; 15). Furthermore, the characteristics of the resident galaxies do not develop in a linear manner (18). E.g., a galaxy might collide with another galaxy, thereby increasing its mass, and triggering star formation (with the result being a significant increase in metallicity). As a result, the characteristics of the different galaxies studied have most probably evolved in different ways and to different degrees. Taken together, it would be plausible that the metallicity or mass of the host galaxy at the time of the explosion are not correlated with the supernova.

This would explain why different studies have found different trends; if the two are entirely unrelated, some data samples will display a correlation, and some will not. The lack or presence of a correlation does, in that case, not hold any deeper meaning. It is probable that in order to investigate how type Ia supernovae depend on their environment, properties of the supernova would have to be compared with, e.g., host metallicity and mass at the time the progenitors formed.

5.2 Conclusions

The analyzed data sample did not display any correlation between the luminosity of type Ia supernovae, and the stellar mass or metallicity of their host galaxies at the time of the explosion, thereby suggesting a lack of correlation. However, it cannot be concluded that luminosity of SNe Ia are not dependent on these factors based on these results. In order to clarify results, host properties at the time of SN progenitor formation would most likely need to be analyzed instead.

5.3 Proposals for Future Research

In the future, the color bias in this study could be adjusted for by comparing the observed wavelength spectra to spectra that are known to lack dust absorption. Using a similar method as that employed to find the stellar mass of galaxies, the known spectras and their corresponding luminosity could be used to fill in the gaps in the colors and luminosity of observed supernovae.

Ideally, a study would be conducted comparing metallicity and stellar mass of host galaxies

at or close to the time the SN Ia progenitors formed. This might prove more physically sound, and not give the same contradictory results for different studies. This might be done by keeping a record of galaxy properties, and then matching them with luminosity of SNe Ia when they are observed. Observationally, however, it might prove challenging to obtain a statistically significant sample using this method, since it is both uncertain when a supernova will appear, and difficult to estimate the time between its and its progenitors birth.

One further research direction that might be pursued is to study the environment closer to the SN, rather than overarching properties of the whole galaxy.

6 Acknowledgements

I want to thank Seméli Papadogiannakis for providing the data used in this study, and for always taking the time to answer my questions. Furthermore, I am grateful to Magnus Mähring for his help with my report and application.

References

- [1] S. Papadogiannakis, *Properties of Type Ia Supernovae from the (Intermediate) Palomar Transient Factory*. PhD thesis, Stockholm University, 04 2019. Thesis was undefended at the time this report was written.
- [2] T. Petrushevska, *Supernovae seen through gravitational telescopes*. PhD thesis, Stockholm University, 05 2017.
- [3] F. Hoyle and W. A. Fowler, “Nucleosynthesis in supernovae,” *The Astrophysical Journal*, vol. 132, p. 565, 1960.
- [4] J. Whelan and I. Icko, Jr, “Binaries and supernovae of type i,” *The Astrophysical Journal*, vol. 186, pp. 1007–1014, 11 1973.
- [5] I. I., Jr and A. V. Tutukov, “Supernovae of type i as end products of the evolution of binaries with components of moderate initial mass (m not greater than about 9 solar masses),” *The Astrophysical Journal Supplement Series*, vol. 54, pp. 335–372, 01 1984.
- [6] A. G. Riess et al., “Observational evidence from supernovae for an accelerating universe and a cosmological constant,” *The Astronomical Journal*, vol. 116, p. 1009, 12 1998.
- [7] S. Perlmutter et al., “Measurements of Ω and Λ from 42 High-Redshift Supernovae,” , vol. 517, pp. 565–586, June 1999.
- [8] R. C. Wolf *et al.*, “SDSS-II Supernova Survey: An Analysis of the Largest Sample of Type Ia Supernovae and Correlations with Host-Galaxy Spectral Properties,” *Astrophys. J.*, vol. 821, no. 2, p. 115, 2016.
- [9] P. L. Kelly, M. Hicken, D. L. Burke, K. S. Mandel, and R. Kirshner, “Hubble residuals of nearby type ia supernovae are correlated with host galaxy masses,” *The Astrophysical Journal*, vol. 715, 12 2009.
- [10] M. Sullivan, A. Conley, D. Howell, J. Neill, P. Astier, C. Balland, S. Basa, R. Carlberg, F. Dominique, J. Guy, D. Hardin, I. Hook, R. Pain, N. Palanque-Delabrouille, K. Perrett, C. Pritchett, N. Regnault, J. Rich, V. Ruhlmann-Kleider, and E. Walker, “The dependence of type ia supernovae luminosities on their host galaxies,” *Monthly Notices of the Royal Astronomical Society*, vol. 406, 08 2010.
- [11] M. Hamuy, M. M. Phillips, R. A. Schommer, N. Suntzeff, J. Maza, and R. Avilés, “The absolute luminosities of the calan/tololo type ia supernovae,” *Astronomical Journal*, vol. 112, 09 1996.

- [12] Y.-C. Pan, M. Sullivan, K. Maguire, A. Gal-Yam, I. Hook, D. A. Howell, P. E. Nugent, and P. A. Mazzali, “Type ia supernova spectral features in the context of their host galaxy properties,” *Monthly Notices of the Royal Astronomical Society*, vol. 446, 09 2014.
- [13] R. R. Gupta, C. D’Andrea, M. Sako, C. Conroy, M. Smith, B. Bassett, J. A. Frieman, P. M. Garnavich, S. Jha, R. Kessler, H. Lampeitl, J. Marriner, R. C. Nichol, and a. Donald P. Schneider, “Improved constraints on type ia supernova host galaxy properties using multi-wavelength photometry and their correlations with supernova properties,” *The Astrophysical Journal*, vol. 740, p. 92, 10 2011.
- [14] B. W. Carroll and D. A. Ostlie, *An Introduction to Modern Astrophysics*. 2nd (international) ed., 2007.
- [15] J. Lequeux, *Birth, Evolution and Death of Stars*. World Scientific Publishing Company, 2013.
- [16] S. Papadogiannakis, A. Goobar, R. Amanullah, M. Bulla, S. Dhawan, G. Doran, U. Feindt, R. Ferretti, L. Hangard, D. A. Howell, J. Johansson, M. M. Kasliwal, R. Laher, F. Masci, A. Nyholm, E. Ofek, J. Sollerman, and L. Yan, “R-band light-curve properties of type ia supernovae from the (intermediate) palomar transient factory,” *Monthly Notices of Royal Astronomical Society*, 11 2018.
- [17] D. Maoz, F. Mannucci, and G. Nelemans, “Observational clues to the progenitors of type ia supernovae,” *Annual Review of Astronomy and Astrophysics*, vol. 52, 12 2013.
- [18] L. S. Sparke and J. S. Gallagher, III, *Galaxies in the Universe: An Introduction*. Cambridge University Press, 2 ed., 2007.
- [19] T. Hughes, *A Phenomenological Study of Star Formation and Chemical Evolution in Nearby Galaxies*. PhD thesis, Cardiff University, 08 2010.
- [20] F. R. Chromey, *To Measure the Sky: An Introduction to Observational Astronomy*. Cambridge University Press, 2010.
- [21] C. C. Lin and F. H. Shu, “On the spiral structure of disk galaxies,” *The Astronomical Journal*, vol. 140, p. 646, 08 1964.
- [22] H. Pour-Imani, D. Kennefick, J. Kennefick, B. Davis, D. W. Shields, and M. Shameer Abdeen, “Strong evidence for the density-wave theory of spiral structure in disk galaxies,” *The Astrophysical Journal*, vol. 827, p. L2, 08 2016.