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The chemical signature of SNIax in the stars of Ursa minor?

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Abstract. Recently, a new class of supernovae Ia was discovered: the supernovae Iax. The increasing sample of these objects share common features as lower maximum-light velocities and typically lower peak magnitudes. In our scenario, the progenitors of the SNe Iax are very massive white dwarfs, possibly hybrid C+O+Ne white dwarfs; due to the accretion from a binary companion, they reach the Chandrasekhar mass and undergo a central carbon deflagration, but the deflagration is quenched when it reaches the outer O +Ne layer. This class of SNe Ia are expected to be rarer than standard SNe Ia and do not affect the chemical evolution in the solar neighbourhood; however, they have a short delay time and they could influence the evolution of metal-poor systems. Therefore, we have included in a stochastic chemical evolution model for the dwarf spheroidal galaxy Ursa minor the contribution of SNe Iax. The model predicts a spread in [Mn/Fe] in the ISM medium at low metallicity and - at the same time - a decrease of the [alpha/Fe] elements, as in the classical time delay model. This is in surprising agreement with the observed abundances in stars of Ursa minor and provide a strong indication to the origin of this new classes of SNIa.

1. Introduction

The scenario leading to a supernova type Ia (SN Ia) explosion is still under debate. The two most common progenitor scenarios are: the single degenerate scenario, in which a white dwarf of a mass close to the Chandrasekhar (Ch) mass accrete mass from a companion - a red giant or a main sequence star, and the double degenerate scenario, in which two white dwarfs merge due to the loss of angular momentum. Both scenarios present pro and contros, but at the present none of them is able to explain all observational constraints of SNe Ia (e.g. Maoz et al., 2014). Thanks to the observational surveys, a large number of SNe Ia are observed as a luminous and (almost) standard candle, and the SNIa explosions are fundamental to understand the expansion rate of the Universe bringing up the existence of a dark energy, after the dismiss by Albert Einstein several decades ago. On the other hand, the surveys have revealed a small variation of the standard candle such as superluminous or faint called Type Iax (e.g. Foley et al., 2013).

In general, it is not easy to constrain SN Ia scenarios because the chemical outcomes are similar. However, the chemical signature is relatively clear in the case of Mn, which is one of the few chemical elements with just a single stable isotope (^{55}Mn). Recently, this chemical element has been investigated in Kobayashi et al. (2015), where it has been shown how the presence of three channels for the production will promote a different trend in the chemical evolution for dwarf galaxies, keeping unchanged the trend in the case of the solar vicinity model. A similar analyses was performed, but only for the solar vicinity, in Seitenzahl et al. (2013), and the final results was in favor of the presence of two scenarios for SNe Ia. Regarding the results for dwarf galaxies, a flat and under solar trend for Sagittarius was obtained by Cescutti et al. (2008), by means of a strong dependence to the metallicity of the SN Ia yields, keeping again a good agreement for the solar neighbourhood; the same observational results were obtained for Sculptor, Fornax, Carina and Sextans in North et al. (2012). Note that, however, such a metallicity effect is not expected for the majority of SNe Ia where Mn is synthesised in nuclear statistical equilibrium (Kobayashi et al., 2006, 2015).

In this work we will use the stochastic and inhomogeneous chemical evolution models, to study the pollution due to SNe Ia in the later stage of a dwarf spheroidal galaxy (dSph), satellite of our Galaxy. At present, not many measurements of Mn are present in literature for stars in dSph galaxies. We decide to compare our results with Ursa minor because it is one of the dwarf spheroidal with the larger number of stars for which Mn is measured (Ural et al., 2015), and therefore we decide to apply our modelling to this case.

2. SN Ia scenarios and nucleosynthesis

In this paper, we consider the same assumptions for sub-luminous (such as SNe Iax), sub-Ch, and Ch-mass SNe Ia in terms of nucleosynthesis and rate of the events as in Kobayashi et al. (2015). For comparison, we present also results based on the SN Ia prescriptions used in previous papers as Cescutti et al. (2008); Spitoni et al. (2010), based on the original work presented in Matteucci & Greggio (1986). We decide to call the former prescriptions "Herts" model, whereas the second is called "Trieste" model, from the location of the groups that have developed them. More details can be found in the papers mentioned above, or in the more recent paper by Cescutti & Kobayashi (2017).

3. Chemical evolution models for Ursa minor

We start our analysis on the dSph Ursa minor from the standard chemical evolution model described in Ural et al. (2015), in particular their model C, which takes into account a star formation history based on the observational constrained by Carrera et al. (2002) and infall and winds from the system able to reproduce the metallicity distribution function obtained by Kirby et al. (2011) (for details, see Sect. 3 Ural et al., 2015). The target of this contribution is however, to investigate the possible spread produced by a double channel of production of Mn from two different sources. Therefore, we have developed a stochastic chemical evolution model in the same fashion as those implemented in Cescutti (2008); Cescutti & Chiappini (2010); Cescutti et al. (2013) for the Galactic halo, but with the specific chemical evolutions of Ursa minor, described above. As we will see, also in this model we predict a dispersion in the first enrichment by SNe II, but later in the evolution also the differential production of Mn by the different channel.

4. Abundances measured in in Ursa minor stars

We compare our results with the same set of stars shown in Ural et al. (2015). In this work, the abundance of three stars have been measured and compared to the abundances collected from other authors (Shetrone et al., 2001; Sadakane et al., 2004; Cohen & Huang, 2010; Kirby & Cohen, 2012). We decide to compare our results also with the data coming from other two dSphs similar to Ursa minor, Sextans and Carina, using the data available in North et al. (2012).

5. Results

Both scenarios are able to reproduce the main observed trends within the uncertainties for [Ca/Fe] vs [Fe/H] and [Mn/Fe] vs [Fe/H] (e.g. Cescutti et al., 2008; Kobayashi et al., 2015; Ural et al., 2015) Therefore, at least in first approximation - the two models are compatible and by means of an homogenous model, it was not possible to distinguish between them. Therefore, in this work we use a stochastic model to outline a different conclusion, for the Mn case.

In the Trieste model (Fig. 1, the contour plot) the strong dependence of the [Mn/Fe] to the stellar mass in massive stars, produce a large spread for [Fe/H]< -2. On the other side, at [Fe/H]> -2, when the SNe Ia start to play an important role, the spread for the Trieste model in the [Mn/Fe] vs [Fe/H] space is decreased, due to the approximately constant enrichment of Mn and Fe from the SNe Ia. In this region, the model does not agree with any of the abundances measured in the 4 stars of Ursa minor (black symbols).

The Herts model with its stochastic results shown in Fig.1 displays a butterfly shape distribution with remarkable differences compared to the Trieste model. Again the bulk of the data at [Fe/H]~ -2 are within the prediction of the model; moreover at lower metallicities most of the measured stars are in good agreement with the model, and in this case the three stars at [Fe/H]< -2.5 and [Mn/Fe]< -0.5 are better within the limits of the probability predicted by the model. The most striking difference is on the high metallicity tail. In this region, at [Fe/H]> -2, the model produces again a spread (the right wing of the butterfly!). This is due to the onset of the two SN Ia channels that start to enrich the ISM. Producing a difference [Mn/Fe] ratio, they create a spread in the model results: regions polluted by the SNe Iax tend toward solar [Mn/Fe] ratios, the contrary for the sub-Ch SNe Ia.

Comparing the data we have for this galaxy, it clearly appears that the Herts model is the one that more closely approximates what is displayed by the stars of Ursa minor. In fact three stars have a [Mn/Fe]> -0.5 and one instead have a lower value, presenting therefore a spread. At this stage, the number of data are not yet statistically enough to ensure that our prediction is firm, and future observational campaign to measure more spectra of stars in Ursa minor is encouraged. Moreover, we underline that it will be vital for this project to measure not the most extreme metal poor tail, as commonly happens, but the opposite, the metal rich end, in order to disentangle this problem. As mentioned in the introduction, not many measurements of Mn are present in literature for stars in dSph galaxies. In this respect a significant work has been carried out by North et al. (2012), where the measurement of four dSph galaxies are presented: Sculptor, Fornax, Carina and Sextans. For this reason, we include also the stars measured for Carina and Sextans, two dSphs with stellar mass similar to Ursa minor, in total 13 more data points in the plot. Moreover eight of these data sit at [Fe/H]> -1.8, increasing significantly the only 4 data available for Ursa minor in this metallicity range, where the new Herts model predicts a spread in [Mn/Fe]. Although the data belong

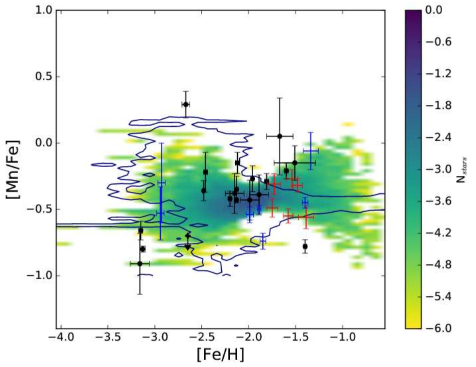

Fig. 1. [Mn/Fe] vs [Fe/H], the data in black represent the abundances measured in stars belonging to the dSph Ursa minor presented in Ural et al. (2015); in red we present the data for the dSph Carina from North et al. (2012) and in blue those for the dSph Sextans again from from North et al. (2012) and Tafelmeyer et al. (2010). The colour-coded surface density plot presents the density of long living stars for the Herts model, the contour line the same results for the Trieste model.

to two different dSphs, it is still encouraging to see that the model is in excellent agreement with them; in fact the data for Sextans for example show a remarkable spread of more than 0.5 dex. Therefore, we encourage more investigations to establish the presence of this spread in the [Mn/Fe] vs [Fe/H] space in other satellites of the Milky Way, in particular in the faint classical dSphs as Ursa minor, Sextans, Carina and Draco.

6. Conclusions

We present new results for the chemical evolution of the [Mn/Fe] in the dwarf spheroidal galaxy Ursa minor with two different prescriptions for the SNe Ia. These two prescriptions that we call Herts and Trieste, present these differences: in the Trieste model we allow to explode only a single channel of SNe Ia, the single degenerate with a deflagration; in the Herts model we have two different channels, one is a sub-Ch channel, with a double detonation, the other is a special case of single degenerate, originated from a relatively massive primary star, producing a relatively weak deflagration (SN Iax channel). These two channels produce on the average the same amount of Mn as the the single channel in the Trieste model. We show that in the framework of an homogenous chemical evolution model, both Herts and Trieste prescriptions are compatible with the data available for Mn in this dSph. On the other hand, in the stochastic framework, the results are quite different and the data seem to favour the Herts model, and therefore, the presence of two channels for SNe Ia at low metallicity, in addition to normal SNe Ia at higher metallicities. Clearly, also more data are important to raise firmer conclusions, and we encourage to test our thesis by analysing the stars belonging to the tail at higher metallicities for this class of dSphs, rather than focusing on the most extreme metal-poor component.

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