Metallicity Effect on Type Ia Supernovae and Galactic and Cosmic Chemical Evolution

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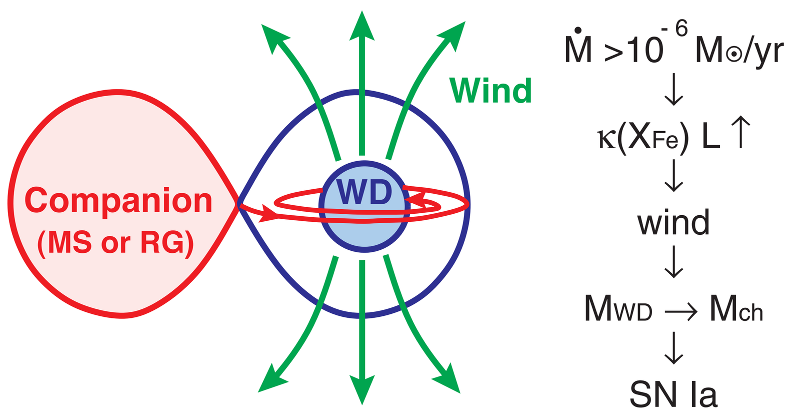
SN Ia Progenitor Scenario

Two types of supernovae explosions :

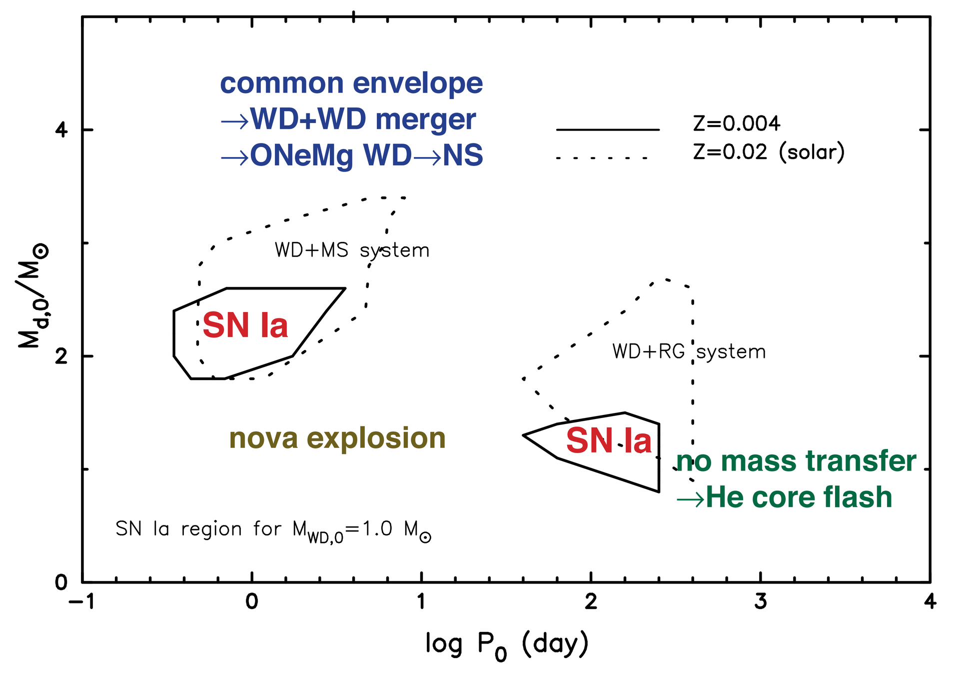
Type II supernovae (SNe II)
Core collapse induced explosions of short-lived ($10^{6\text{-}7}$ yr) massive star (> 8 $M_\odot$) which produce more O and Mg relative to Fe.

Type Ia supernovae (SNe Ia)
Thermonuclear explosions of accreting white dwarfs (WDs) in close binaries which produce mostly Fe and little O.
The companion stars of the WDs have not been identified but must be relatively long-lived (~Gyr) low-mass stars.

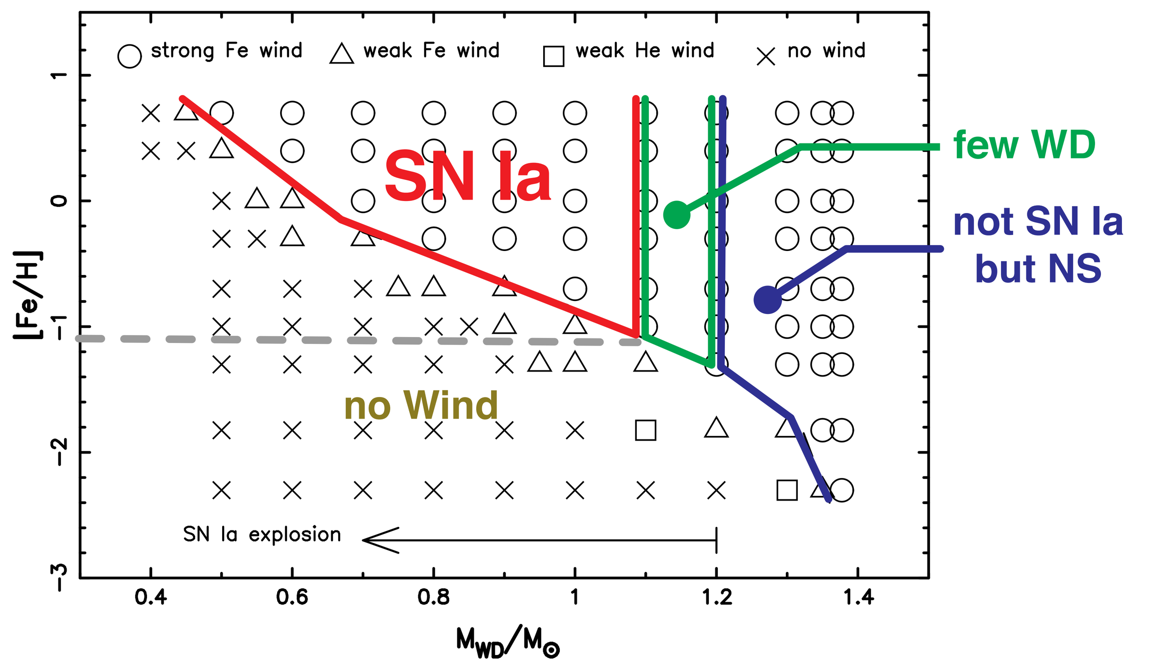
In our SN Ia progenitor scenario, the accreting WD blows a strong wind to reach the Chandrasekhar mass limit.



SN Ia regions in the diagram of the initial orbital period vs. the initial mass of the companion star for the initial WD mass of 1.0 $M_\odot$. In these regions, the accretion from the companion star increases the WD mass successfully through the occurrence of SN Ia. The left and the right regions correspond to the WD+MS and the WD+RG systems, respectively. The dashed line shows the case of solar abundance (Z=0.02), while the solid line shows the much lower metallicity case of Z=0.004. The size of these regions clearly demonstrate the metallicity effect, i.e., SN Ia regions are much smaller for smaller metallicity.



Metallicity dependence of the optically thick winds in WD mass vs. metallicity diagram. The strong winds are possible only for the region above the dashed line. The term "weak" implies that the wind velocity at the photosphere does not exceed the escape velocity there, that is, it cannot blow the accreted matter off the WD. For the metallicity as small as Z=0.001, the opacity peak at log T(K) ~ 5.2 is very weak, being smaller than the peak of helium lines at log T(K) ~ 4.6. Then, the wind is driven by the helium line peak rather than the iron line peak, which we call "He wind" instead of "Fe wind". Since only the initial WD mass of < 1.2 $M_\odot$ can produce an SN Ia and there is few WDs with the initial mass of > 1.1 $M_\odot$, SN Ia events occur only for the progenitors with [Fe/H] < -1.1.



Solar Neighborhood

SN Ia model

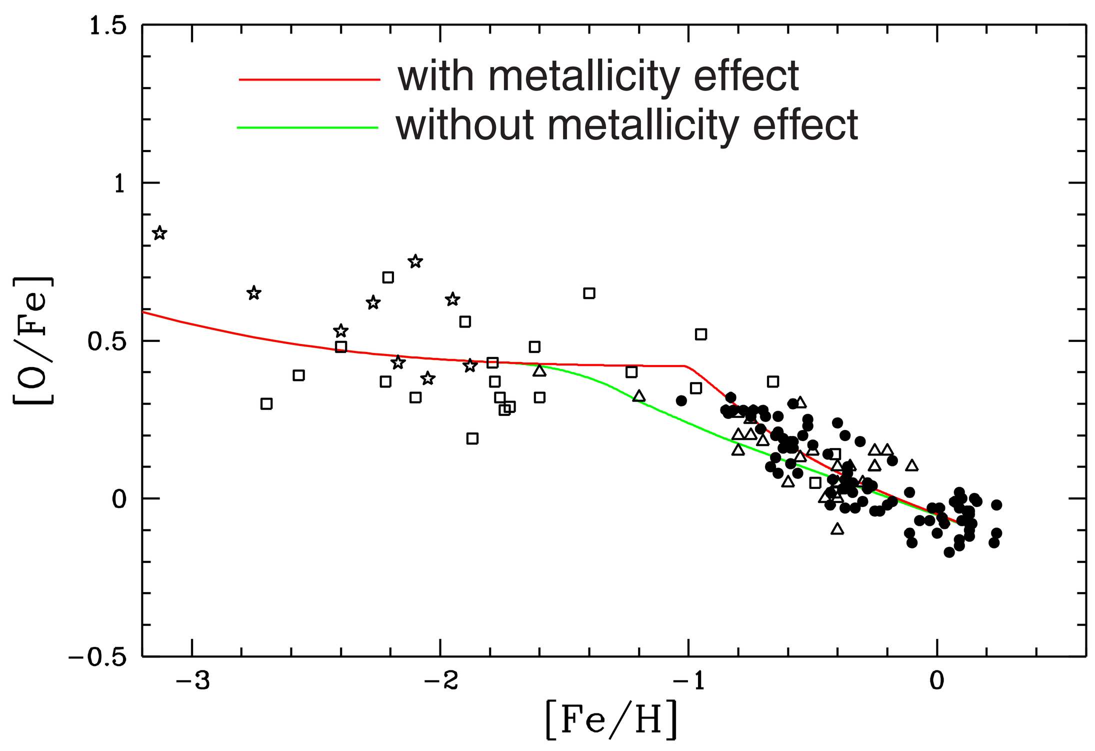
SN Ia lifetime ~ companion lifetime = 0.6-15 Gyr
companion mass : MS 1.8-2.6 $M_\odot$, RG 0.9-1.5 $M_\odot$
companion mass distribution : power law, slope=0.35

SN Ia metallicity effect → [Fe/H] > -1.1

Early time or [Fe/H] < -1.1 : only SN II
Later time and [Fe/H] > -1.1 : SN II & Ia

Star formation history in the solar neighborhood

infall, Schmidt SFR, Salpeter IMF, age=15 Gyr



The left figure shows the Evolutionary change in [O/Fe] against [Fe/H] in the solar neighborhood. Observational data sources are in Kobayashi et al. (1998, ApJ, 503, L155).

★Our scenario without the metallicity effect (green line) : The companion star with M ~ 2.6 $M_\odot$ evolves off the main-sequence to give rise to SNe Ia at the age of ~ 0.6 Gyr. The resultant decrease in [O/Fe] starts too early to be compatible with the observations.

★Our scenario with the metallicity effect (red line) : SNe Ia occur at [Fe/H] > -1, which naturally reproduce the observed break in [O/Fe] at [Fe/H] ~ -1.

Cosmic SN Ia rate

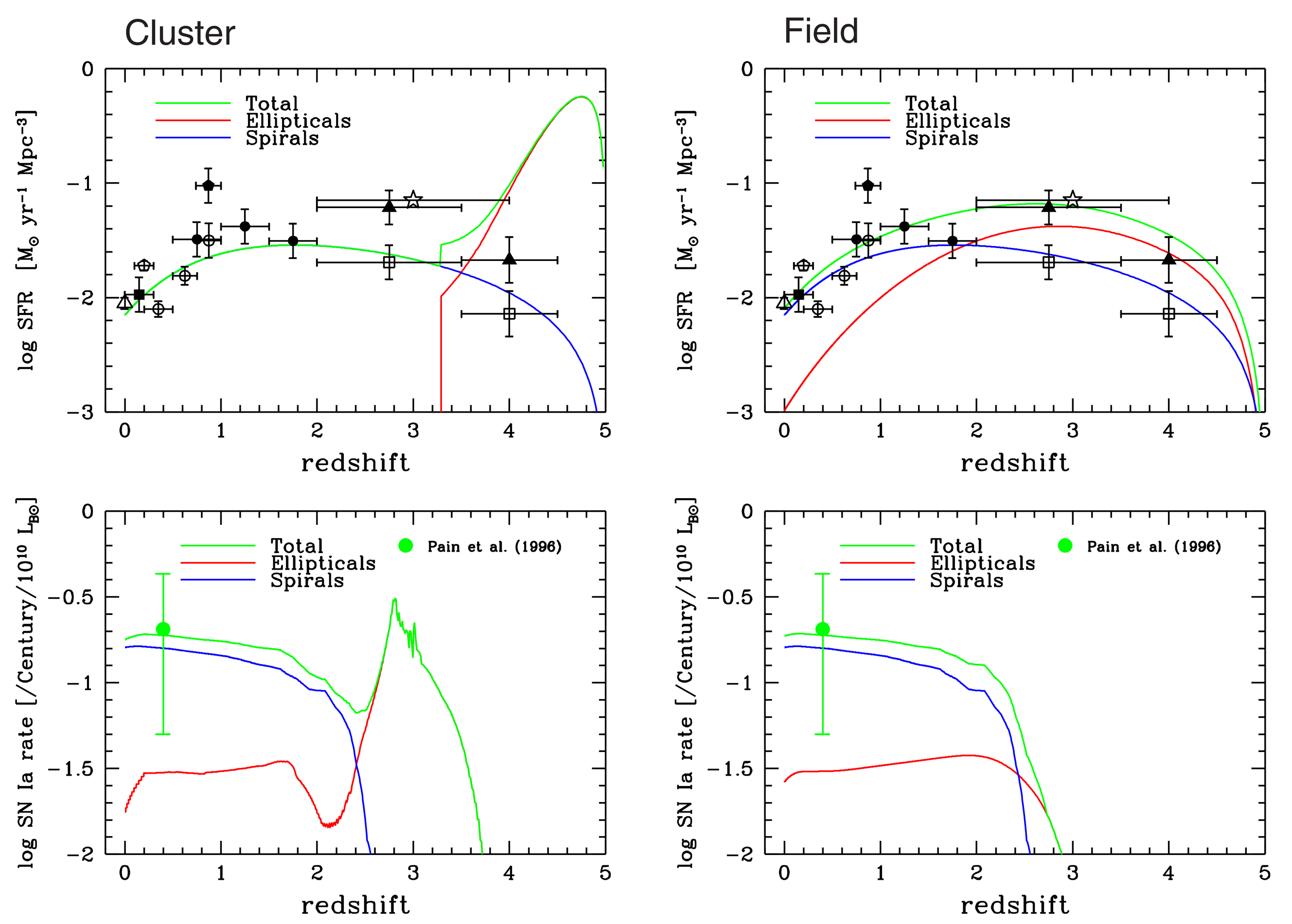
We make a prediction of the cosmic SN Ia rate as a composite of ellipticals and spirals.
We use h=0.5, Ω_0=0.2, λ_0=0, and z_F=5.

cluster galaxies
spirals : continuous infall and star formation
ellipticals : star burst and stop the star formation at t > 1 Gyr
field galaxies
formation epochs of ellipticals span over 0 < z < 5.

Results are in the right figure. The upper and lower panels show the cosmic SFR and SN Ia rate, respectively.

★The SN Ia rate in spirals drops at z ~ 2.5 due to the low-iron abundance, while SNe Ia can be found at z > 3 in cluster ellipticals, where the timescale of metal enrichment is sufficiently short.

★If the formation of field ellipticals is protracted to lower redshifts, the SNe Ia rate in the field ellipticals decreases from z ~ 2.



Conclusions

We introduce a metallicity dependence of the SN Ia rate in the Galactic and cosmic chemical evolution models.
In our SN Ia progenitor scenario, the accreting WD blows a strong wind to reach the Chandrasekhar mass limit.
If the iron abundance of the progenitors is as low as [Fe/H] < -1, then the wind is too weak for SNe Ia to occur.
Our model successfully reproduces the observed chemical evolution in the solar neighborhood. We then make a prediction of the cosmic supernova rates which can test this metallicity effect.