GENESIS SW-Oxygen corrected for SW/SUN isotopic fractionation is closer to Earth Oxygen than to CAI.

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Introduction: The latest report of GENESIS project [1,2] gave a convincing isotopic composition of oxygen in bulk solar wind (SW) sample collected on a concentrator, but correction for putative isotopic fractionation between SW and the Sun is still needed to conclude the solar oxygen isotopic composition. Here, we studied noble gas isotopic fractionation between SW and the Sun, and conclude that the isotopic fractionations is almost two times larger than that assumed in the GENESIS oxygen isotopic data reduction, and indicates that indigenous solar oxygen isotopic composition must be much closer to the terrestrial oxygen composition, contradicting the earlier suggestion on solar-CAI identical oxygen [3].

Primordial noble gas isotopic composition: Two major noble gas components are widely recognized in the early solar system, namely SW noble gas and Q noble gas in primitive meteorites. They are characterized by ubiquitous occurrence and by very uniform isotopic composition. The current Solar He consists of the primordial ^{3}He and of D-converted ^{3}He ($D + p \rightarrow {}^{3}He$; post D-burning He) [4]. Since Q-noble gas has much smaller $^{3}He/^{4}He$, which is characteristic to pre-D burning He in the solar system, we conclude that Q-noble gas must predate SW noble gas. The difference between the post D-He and GENESIS SW-He then corresponds to isotopic fractionation between the Solar- and SW-He. Figure 1 shows a schematic view of He isotopic evolution in the early solar system.

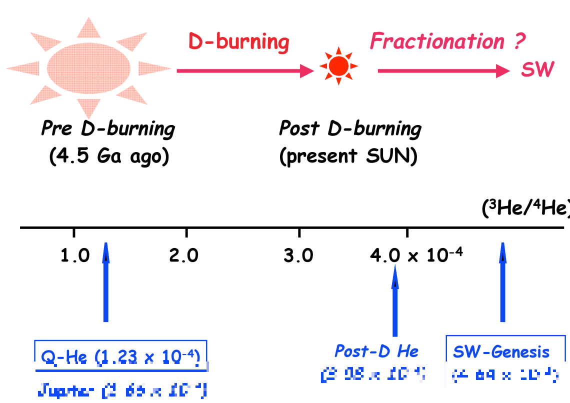

Figure 1. Helium isotopic evolution in the early solar system.

Noble gases isotopic fractionation in SW: In Figure 2, we plotted SW-noble gas isotopic ratios relative to Q-noble gas (SW/Q) against $(m_j/m_i)^{1/2}$, where m_j, m_i are mass of isotope i, j. The approximate linear array of data points shows that the isotopic compositions of Q- and SW-noble gases are related to each other by a mass dependent fractionation factor $(m_j/m_i)^{1/2}$, commonly observed in a process such as Rayleigh distillation. Therefore, from this fractionation relation and from the seniority of Q-noble gas to SW noble gas, we conclude that SW noble gas was fractionated from Q noble gas. Next we discuss the process of this fractionation.

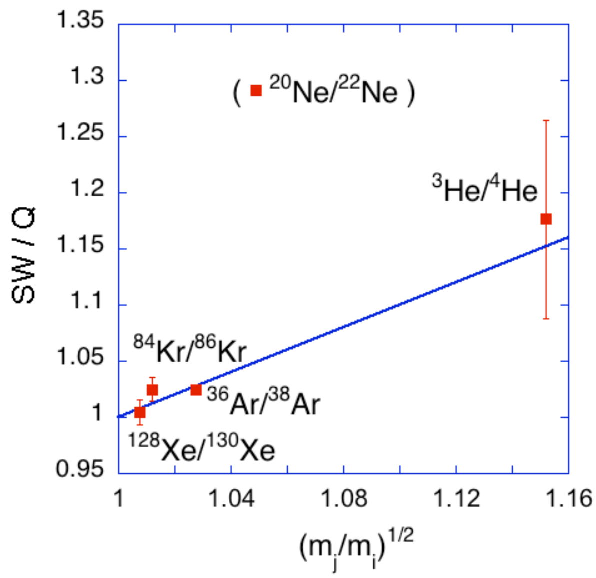

Figure 2. Noble gas isotopic ratios of SW relative to Q-noble gas (He : post D-burning He) is plotted against the square root of mass ratio. The clear linear correlation line supports that SW-noble gases are fractionated from Q-noble gas with a fractionation factor proportional to $(m_j/m_i)^{1/2}$. Here, Ne ratio is discarded, because Q-Ne cannot be well defined [5].

From an assumption on the conservation of ions in a stationary flow of plasma (SW), a relation $n_i V r^2$ = constant (n_i : the number density of ion 'i', V : the bulk velocity of plasma, r : radial distance from the Sun) can be deduced [6]. On the basis of this relation, Bodemer and Bochsler [7] derived an expression for an isotopic fractionation of minor ions in SW,

$$\text{fractionation factor } (x, y) = v_x(r_b)/v_y(r_b) \qquad (1)$$

,where x, y stand for isotopes, and $v_x(r_b)$, $v_y(r_b)$ indicate radial velocity of ions at radial distance r_b from the Sun, and a suffix b indicates an arbitrarily chosen reference point in the lower solar atmosphere.

Once minor ions are entrained into SW, they are practically conserved within a SW magnetic flux [6]. Since the GENESIS bulk SW samples (noble gases, oxygen and others) were collected in a concentrator over more than one year period irrespective of their mode such as fast, slow or corona mass ejection, we assume that isotopic fractionation which took place within SW was homogenized to yield only an average SW composition at the Earth orbit. This inference is sup ported by the observation that the isotopic composition of the GENESIS bulk SW-noble gas is almost identical with the average isotopic composition of noble gases implanted in Apollo lunar soil samples at different epochs over a billion of year period. Therefore, the difference in the isotopic compo sition between the GENESIS bulk SW sample and the Sun must be attributed to isotopic fractionation between SW and the Sun.

As illustrated in Figure 2, the isotopic fractionation factor of noble gas between SW and the Sun is proportional to $1/(m_i/m_j)^{1/2}$. Such fractionation trend is very common in nature known as Rayleigh distillation fractionation. The key underlying process is the equi-partition of energy between thermal and kinetic energies under thermal equilibrium condition, namely, $kT = 1/2mv^2$. The isotopic fractionation factor in proportional to $1/(m_i/m_j)^{1/2}$ shown in Figure 2 implies that a process similar to the Rayleigh distillation fractionation takes place from the Sun to SW.

Discussions : Geiss and Reeves [4] first pointed out that the much larger $^3He/^4He$ in the SW than cosmic $^3He/^4He$ ratio inferred from primitive meteorites was due to the addition of the D-converted ^3He within the Sun, and they suggested the following relation

$$(^3He/^4He)_{post\text{-}D} = (^3He/^4He)_{protosolar} + D/^4He$$
$$= (^3He/^4He)_{protosolar} + (D/H)_{protosolar} \times (H/^4He)_{post\text{-}D} \qquad (1)$$

, where ^4He and ^3He were attributed to the big bang. Putting currently available empirical data of D/H [8] and H/He [9] in equation (1), we can estimate the magnitude of noble gas isotopic fractionation between the SW and the Sun (Table 1). In Table 1, we also compare the magnitude of noble gas isotopic fractionation, which was used as a reference parameter to correct the experimentally determined GENESIS SW oxygen isotopic composition [1, 2].

	Rayleigh	This work	GENESIS
$^3He/^4He$	~ 15 %	~ 16 %	
$^{20}Ne/^{22}Ne$	~ 5.0	na	~ 3.0 %
$^{36}Ar/^{38}Ar$	~ 2.7	~ 3.0	~ 1.6
$^{84}Kr/^{86}Kr$	~ 1.2	~ 2.3	
$^{128}Xe/^{130}Xe$	~ 0.8	~ 0.6	

Table 1 Isotopic fractionation of noble gases relative to the solar ratios. Rayleigh: A theoretical isotopic fractionation factor, which is proportional to $1/(m_i/m_j)^{1/2}$, GENESIS: Estimated on the basis of imperfect Coulomb drag isotopic fractionation in a magnetic flux of SW [1].

If fractionation factors for noble gases between SW and the Sun (*cf.* this work in Table 1) were applied to the GENESIS bulk SW oxygen isotope, oxygen isotopic compositions in the Sun would be further shifted to heavier isotopes along a terrestrial fractionation line well beyond the CAI point in an oxygen three isotope plot (e.g. Figure 4 in [2]), but they would come closer to the Earth composition, although we still may need some mass-independent isotopic fractionation in order to make the GENESIS SW-oxygen precisely match with the terrestrial oxygen.

So far our argument concerned with mass-dependent type isotopic fractionation. This is reasonable in the case of noble gas, since the isotopic fractionation occurs on a atom, which is dependent on mass only. However, since the solar chromosphere is known to contain a substantial amount of CO molecule as identified in IR absorption line of the solar radiation (CO/C ~ 0.2-0.3 [10]), mass-independent isotopic fractionation may also need to be considered in correcting oxygen isotopic fractionation between SW and the Sun. The photo-dissociation of CO [11, 12] or the self-shielding of CO may be viable possibility.

Conclusions:

1. The average noble gas isotopic composition in the early solar system is represented by Q-noble gases, from which SW-noble gas was fractionated.
2. Noble gas isotopes in SW is mass-dependently fractionated from Q-noble gas with a fractionation factor inversely proportional to a square root of mass ratio of isotope. We suggest the characteristic fractionation factor is attributable to the Rayleigh distillation type fractionation.
3. If the noble gas isotopic fractionation factor concluded in this work were applied to the GENESIS SW-oxygen data, the corrected oxygen isotopic composition becomes much closer to the terrestrial oxygen than to that suggested in the latest GENESIS report [1, 2], and thus contradicts a widely held view [3] that the solar oxygen isotopic ratio is the same as CAI oxygen, but differs from the terrestrial oxygen.

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