THE OXYGEN ISOTOPIC COMPOSITION OF THE SUN AS A TEST OF THE SUPERNOVA ORIGIN OF ^{26}Al AND ^{41}Ca IN THE EARLY SOLAR SYSTEM. M. Gounelle[1] and A. Meibom[1], [1]Laboratoire d'Étude de la Matière Extraterrestre, Muséum National d'Histoire Naturelle, 57 rue Cuvier, France (gounelle@mnhn.fr).

Introduction: Refractory silicates and oxides formed in the protoplanetary disk around the nascent Sun and have been preserved intact in primitive chondritic meteorites [1]. These minerals contain isotopic signatures of now extinct, short-lived radionuclides that were present in the disk in abundances much higher than in the ambient interstellar medium [2]. The origin of short-lived radionuclides in the early Solar System remains one of the most intensely debated questions in cosmochemistry because it bears on fundamental problems such as early solar system chronology, thermal evolution of planetesimals and the astrophysical environment in which our Solar System was born [2, 3]. The short-lived radionuclides ^{26}Al ($T_{1/2}$=0.73 Myr) and ^{41}Ca ($T_{1/2}$=0.1 Myr) are especially interesting since they share a common origin [4, 5]. It is usually assumed that these isotopes were delivered to the protoplanetary disk from a nearby type-II supernova [6, 7]. The goal of the present paper is to test the supernova origin of these short-lived radionuclides, exploring the collateral injection of oxygen isotopes into the protoplanetary disk.

Mixing a supernova ejecta with a protoplanetary disk: Analyses of refractory components in primitive chondrites have established the initial Solar System abundances of ^{26}Al and ^{41}Ca to be ^{26}Al/^{27}Al = 5 x 10^{-5} and ^{41}Ca/^{40}Ca = 1.5 x 10^{-8}, respectively [2]. The planetary system around the Sun is generally assumed to have formed from a disk of ~0.013 solar mass [8]. From these numbers, it is calculated that the protoplanetary disk contained 4.1 x 10^{-11} solar masses of ^{26}Al and 1.4 x 10^{-14} solar masses of ^{41}Ca, using an hydrogen mass fraction of 0.711 and the solar abundances of Lodders [9].

For any isotope i, the mass $M_{SN}(i)$ delivered from a supernova to the protoplanetary disk (in solar masses) is given by the equation $M_{SN}(i) = Y_{SN}(i) \times \exp(-\Delta/\tau_i) \times f$, where $Y_{SN}(i)$ is the total yield of isotope i from the supernova, τ_i is the mean life (for stable isotopes $\tau_i = \infty$), Δ is the time interval between nucleosynthesis in the supernova and incorporation into refractory meteorite components, and f is the mixing fraction, i.e. the fraction of the total supernova ejecta mixed into the protoplanetary disk.

For a supernova with known total yields of ^{26}Al and ^{41}Ca, f and Δ can be calculated assuming that ^{26}Al and ^{41}Ca have a supernova origin. State-of-the-art models of type-II supernovae of 15, 19, 20, 21 and 25 solar masses, respectively, provide yields of ^{26}Al and ^{41}Ca [10]. For these supernovae models, we calculate mixing fractions in the range f = 1.9 x 10^{-6} to 7.6 x 10^{-6} and Δ values from 1.0 to 1.8 Myr, consistent with previous estimates [7].

The oxygen isotopic composition of the disk before injection: The mixing factors, combined with the model supernova yields of ^{16}O, ^{17}O and ^{18}O [10] and the post-injection oxygen isotopic composition of the disk allow the *pre-injection* oxygen isotopic composition of the disk to be calculated by simple mass-balance. The post-injection masses of the three oxygen isotopes in a 0.013 solar masses disk are calculated assuming an hydrogen mass fraction of 0.711, a solar abundance of ^{16}O [9] and a SMOW isotopic composition for ^{17}O and ^{18}O.

Figure 1 is a three-oxygen isotope diagram showing the calculated *pre-injection* oxygen isotopic compositions of the protoplanetary disk for the various supernovae models [10]. For all supernovae models, the calculated pre-injection oxygen isotopic composition of the protoplanetary disk falls distinctly above the slope-1 line defined by refractory minerals in chondritic meteorites [11]. This is primarily because the type-II supernova ejecta is systematically depleted in ^{17}O relative to typical Solar System compositions [10, 12]. These results are robust to rational changes in the model input parameters such as the consideration of a super-canonical abundance of ^{26}Al [13], or variations of a few % of the disk post-injection oxygen isotopic composition spanning the whole interval of meteoritic measurements [14]. Isotopic anomalies of similar magnitude are not expected for other major elements in the protoplanetary disk, such as C and N, because type-II supernova do not produce these isotopes in highly anomalous ratios relative to the terrestrial values [10].

The predicted oxygen isotopic composition of the Sun: An important aspect of the calculations presented here is that supernova injection does not change the oxygen isotopic composition of the Sun. The Sun is roughly a factor of 100 times more massive than the protoplanetary disk and remains extremely well mixed by convection until a core in radiative equilibrium is established and gradually grows to near its main-sequence size, a process which takes about 10 million years [15]. Therefore, the Sun maintains an

oxygen isotopic composition similar to the pre-injection composition of the protoplanetary disk (Figure 1). Thus, if the protoplanetary disk was modified by injection of supernova material that co-delivered ^{26}Al and ^{41}Ca, then the oxygen isotopic composition of the Sun must be radically different from any composition recorded in terrestrial and meteoritic components which formed from the protoplanetary disk.

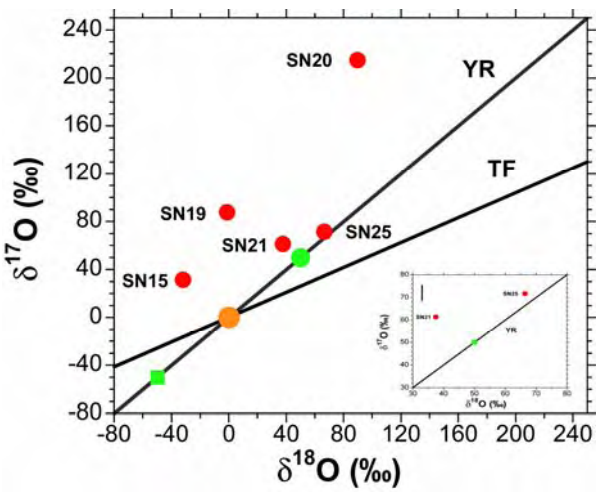

Figure 1. The red circles represent the calculated *pre-injection* oxygen isotopic composition of the disk for the different supernovae models. The label (e.g. SN25) indicates the original mass of the star going supernova. The orange circle along the YR line indicate the Earth composition, taken as the post-injection composition of the protoplanetary disk used in the calculations. The green square and circle are the oxygen isotopic composition of the Sun inferred from lunar soils measurements [16, 17]. The inset is a blow up around the Sun isotopic oxygen composition estimate of [17].

Discussion: The oxygen isotopic composition of the Sun has been recently estimated from Secondary Ion Mass Spectrometry (SIMS) measurements of lunar soils [16, 17]. Both estimates, though different, fall on the slope 1 line in the three oxygen isotope plot (Figure 1), significantly away from our calculated values (Figure 1, inset). If either of these estimates for the Sun are correct, it would rule out supernova injection of aluminium-26 and calcium-41 into the protoplanetary disk. This would mean aluminium-26 and calcium-41 were injected by a supernova during the molecular cloud core stage [18], or originated from an AGB star [19]. Both of these possibilities are astrophysically very unlikely [7, 20]. Alternatively, aluminium-26 and calcium-41 have a local irradiation origin [21].

Given the discrepancies between the two measurements [16, 17], it is also possible that the oxygen isotopic of the Sun is totally different from the present estimates, and is closer to values predicted by our calculations. The anticipated measurement of the Solar Wind oxygen isotopic composition from the Genesis sample return mission is expected to have a precision better than 5‰ (2σ), i.e. error bars much smaller than the smallest symbols in Figure 1 [22]. Thus, the Genesis measurement will reveal if a major shift in the proto-planetary disk oxygen isotopic composition took place during the earliest phases of the Solar System evolution, due to contamination of the protoplanetary disk by ejecta from a type II supernova.

References:

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