THE INITIAL $^{87}Sr/^{86}Sr$ OF THE SOLAR SYSTEM. Y. Di[1] and Y. Amelin[1], [1]Research School of Earth Sciences, Australian National University, Acton, ACT 2601, Australia (yankun.di@anu.edu.au; yuri.amelin@anu.edu.au).

Introduction: It has been shown that the initial $^{87}Sr/^{86}Sr$ of low Rb/Sr early Solar System materials (chondrite phosphates, igneous achondrites, CAIs, lunar basalts, etc.) can be used to construct a high resolution relative chronology [1-3]. When applied to differentiated planetary bodies, the initial Sr model age provides a time estimation of the volatile depletion events related to partial condensation of the precursor materials [4], evaporation during chondrule formation [5] and accretional collision [6], and magma ocean degassing [7]. This chronometer is useful for constraining the time of planetesimal accretion [8], estimating the life span of the protoplanetary disk [9, 10], and identifying the volatile depletion mechanisms of planetary bodies [11, 12].

Application of the initial $^{87}Sr/^{86}Sr$ chronometer requires accurate Solar System initial $^{87}Sr/^{86}Sr$ value as a reference point, which may be represented by the initial $^{87}Sr/^{86}Sr$ of CAIs from CV chondrites. This value, however, is currently not well constrained. Measurements of initial $^{87}Sr/^{86}Sr$ of CAIs in [2, 9, 12, 13] have yielded variable results. For example, ALL [2], the lowest CAI $^{87}Sr/^{86}Sr$ discovered so far, was never reproduced by later studies. The progress towards a consistent Solar System initial $^{87}Sr/^{86}Sr$ is partly limited by the fact that the Rb–Sr systems of Allende CAIs were disturbed after the primary formation, possibly due to the alteration and metamorphism on the CV parent body [2, 9, 14-16]. Because the time of the disturbance and the Rb/Sr evolution history are uncertain, extrapolation or regression using disturbed CAIs can result in an erroneous initial $^{87}Sr/^{86}Sr$. It is therefore important to search for CAIs with sufficiently low Rb/Sr (so that the radioactive accumulation of ^{87}Sr is negligible), or CAIs with undisturbed Rb–Sr system to determine a reliable Solar System initial $^{87}Sr/^{86}Sr$.

In this work, we study the Rb/Sr systems in a collection of CAIs from the Allende meteorite, with the aim of searching the best CAIs to define the primitive $^{87}Sr/^{86}Sr$ ratios of the Solar System.

Samples and methods: Samples studied here include 16 USNM CAIs processed by Mason and Taylor [17], the CAI USNM 3529–49 (not studied before), and the CAI SJ101 [18]. Twenty-three fractions, including powders prepared by [17] were cleaned ultrasonically but processed without acid leaching. Another three fractions (two from 3529–49 and one from SJ101) were leached in cold 0.5M HNO_3 (L1), hot 6M HNO_3 + HCl (L2), and hot 1M HF (L3) before dissolution. The dissolution and conversion procedures are after [8].

Sr was separated using cation exchange chromatography chemistry, and purified twice using Eichrom Sr Spec resin. $^{87}Sr/^{86}Sr$ and $^{84}Sr/^{86}Sr$ ratios were measured on the Triton *Plus* at RSES, ANU, using a 3-line multidynamic method [19]. Measured isotopic ratios were normalized to $^{88}Sr/^{86}Sr = 8.375209$ using the exponential fractionation law. The long-term precision (2 relative standard deviations) of SRM987 measurements were 32 ppm for $^{84}Sr/^{86}Sr$ and 5 ppm for $^{87}Sr/^{86}Sr$.

$^{87}Rb/^{86}Sr$ ratios were determined using isotope dilution TIMS method, following [8].

Results: *Reference materials* We report $^{87}Sr/^{86}Sr$ measurement results of SRM987 and seawater so that our CAI results are directly comparable to all published data. The SRM987 and seawater measurements yielded 0.7102514 ± 0.0000037 (2SD, N = 43) and 0.7091771 ± 0.0000032 (2SD, N = 6) respectively.

CAI 3529–Z: the lowest measured $^{87}Sr/^{86}Sr$ We analyzed a bulk fraction of CAI 3529–Z, the one from which [9] derived their lowest measured $^{87}Sr/^{86}Sr$ and defined the CAI initial value. This fraction indeed has the lowest $^{87}Sr/^{86}Sr$ measured in our entire sample set, 0.699065 ± 0.000004 (normalized to SRM987 $^{87}Sr/^{86}Sr$ = 0.710250 [12]) or 0.698981 ± 0.000004 (normalized to seawater $^{87}Sr/^{86}Sr$ = 0.709090 [2]). The $^{87}Rb/^{86}Sr$ is 0.00156 ± 0.00007, also the lowest among all analyzed samples. Our $^{87}Sr/^{86}Sr$ value is higher than the lowest measured $^{87}Sr/^{86}Sr$ of [9] (a leached residue of 3529–Z) by 1.8 ± 0.3 ε-unit (1 ε-unit = 1 part per 10^4) (SRM987-normalized), and higher than ALL [2] by 3.0 ± 0.6 ε-unit (seawater-normalized). Correction for in situ ^{87}Sr growth (using t = 4567.30 Ma [20]) gives an initial $^{87}Sr/^{86}Sr$ of 0.698962 ± 0.000006 (SRM987-normalized) or 0.698878 ± 0.000006 (seawater-normalized) for this CAI, which is 1.47 ± 0.07 ε-unit lower than the measured value, but is still significantly higher than the residue measured by [9] and ALL.

CAI 3529–49: undisturbed Rb–Sr system The CAI 3529–49 exhibits an undisturbed Rb–Sr system. Eight bulk, leachate, and residue analyses from this CAI define a statistically significant isochron (Fig. 1; the analyses of L3s failed due to the too low Rb and Sr contents in leachates). For both melilite (Me) and pyroxene (Pyx) fractions, early leachates have higher Rb, Sr contents and Rb/Sr ratio than later leachates and residues. The regressed isochron age (4492 ± 99 Ma) is identical to the formation age of CV CAIs [20], suggesting that the Rb/Sr fractionation in this CAI has a primary condensation/crystallization origin. The regressed CAI initial $^{87}Sr/^{86}Sr$ is 0.698689 ± 0.000055 (normalized to seawater $^{87}Sr/^{86}Sr$ = 0.709090 [2]). This

value is the lowest initial $^{87}Sr/^{86}Sr$ found in CV CAIs so far, lower than ALL by 1.2 ± 1.0 ε-unit. When regressed together, our 3529–49 data and ALL plot on a common isochron (MSWD = 1.6) with initial $^{87}Sr/^{86}Sr$ = 0.698736 ± 0.000032, identical to the 3529–49 initial value.

The SRM987-normalized equivalent of the initial $^{87}Sr/^{86}Sr$ of the CAI 3529–49 is 0.698773 ± 0.000055.

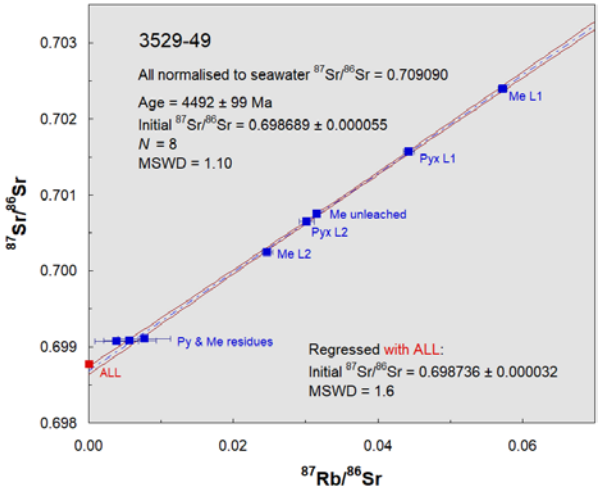

Fig. 1. Rb–Sr isochron of the CAI 3529–49.

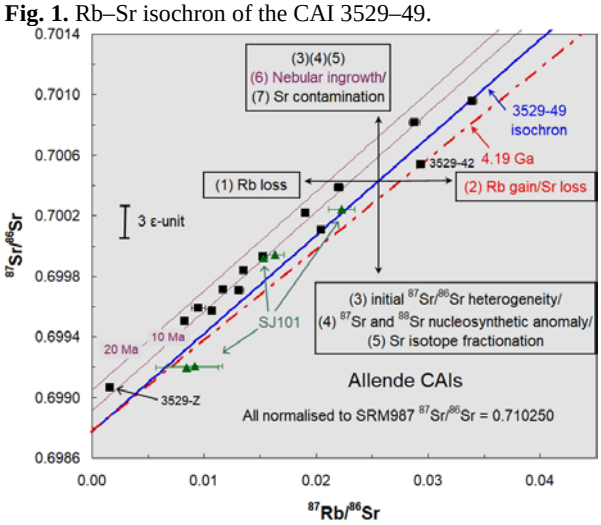

Fig. 2. Rb–Sr systems of Allende CAIs with $^{87}Rb/^{86}Sr < 0.05$.

Other CAIs Fig. 2 shows the $^{87}Rb/^{86}Sr$–$^{87}Sr/^{86}Sr$ diagram of other studied CAIs with $^{87}Rb/^{86}Sr < 0.05$. Most CAIs scatter above the 3529–49 isochron, with calculated model Rb loss ages (purple lines in Fig. 2) ranging from 6 to 15 Ma after the formation of 3529–49. Only one CAI (3529–42) plots below the isochron, with a maximal model Rb gain/Sr loss age of 4.19 Ga. Two CAIs (3529–41 and 3529–44) plot along the isochron, suggesting that they may have unmodified Rb–Sr systems and share a common initial $^{87}Sr/^{86}Sr$ with CAIs 3529–49 and 3898 (ALL).

The bulk, leachates, and residues of the CAI SJ101 failed to define an internally consistent isochron (Fig. 2), suggesting that Rb and Sr experienced redistribution between minerals, possibly on the parent body or during the acid leaching treatments.

$^{84}Sr/^{86}Sr$ results The CAI $\mu^{84}Sr$ values (defined as $10^6[(^{84}Sr/^{86}Sr_{sample})/(^{84}Sr/^{86}Sr_{SRM987}) - 1]$) range from –79 to 227 ppm. Consistent with [16] and references therein, we observed significant $\mu^{84}Sr$ heterogeneity both within and between individual CAIs. These data will be discussed in detail elsewhere.

Discussion and conclusion: By comparison via seawater, our Rb–Sr isochron of the CAI 3529–49 is in excellent agreement with ALL [2]. This agreement confirms that the initial $^{87}Sr/^{86}Sr$ of some CAIs can be as low as 0.698773. However, most other CAIs examined in this study and in other studies, including those with extremely low $^{87}Rb/^{86}Sr$ [9, 13], show deviations of up to +3 ε-unit from our primitive CAI isochron. This indicates that they may have different initial $^{87}Sr/^{86}Sr$ ratios (mechanisms #3, 4, 6 in Fig. 2) or their Rb–Sr systems experienced multi-stage, non-isochemical evolutions (#1, 2, 7 in Fig. 2). Moreover, the Sr isotope fractionation of Allende CAIs [16] before the closure of the Rb–Sr systems can also shift the measured $^{87}Sr/^{86}Sr$ and destroy the isochron relationship (#5 in Fig. 2). To recognize which mechanism(s) caused the observed deviations, more petrographic, elemental and isotopic information are needed. In the context of ^{87}Sr or ^{88}Sr nucleosynthetic heterogeneity, whether the "Solar System initial" $^{87}Sr/^{86}Sr$ chronologically meaningful need to be reconsidered.

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