^{26}Al-^{26}Mg and ^{207}Pb-^{206}Pb SYSTEMATICS OF ALLENDE CAIs: REINSTATED CANONICAL SOLAR INITIAL ^{26}Al/^{27}Al RATIO, VARIABLE κ-VALUES (^{232}Th/^{238}U) AND THE AGE OF THE GALAXY.

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Introduction: Ca-, Al-rich inclusions (CAIs) in primitive meteorites (chondrites) play a pivotal role in the high-resolution chronology of the early Solar System. They are the oldest solids formed within the Solar System and thus mark the beginning of Solar System evolution 4567.2±0.6 million years (Myr) ago [1]. Over three decades of research using ^{26}Al-^{26}Mg chronometry (^{26}Al decays to ^{26}Mg with $t_{1/2}$ = 0.73 Myr) has revealed that most CAIs contain excess radiogenic ^{26}Mg* from the decay of ^{26}Al and define an initial ^{26}Al/^{27}Al ratio of ~5×10^{-5}, commonly referred to as the solar system "canonical" value [2, 3]. The "canonical" ^{26}Al/^{27}Al ratio has recently been revised upwards to a "supra-canonical" value of (5.8-7.0)×10^{-5} [4-9] The precise knowledge of the initial (^{26}Al/^{27}Al)$_0$ is crucial if we are to use CAIs as the "time zero" age-anchor and guide future work with other short-lived radio-chronometers in the early Solar System.

^{26}Al-^{26}Mg Systematics: Here we report new high precision ^{26}Al-^{26}Mg isotopic analyses of several coarse-grained, igneous CAIs (fragments as well as micro-drilled) and the mineral separates from CAI from the Allende (CV) chondrite using multicollector inductively-coupled plasma mass-spectrometry (MC-ICP-MS). We show that our new results for both bulk CAIs (Fig 1) and mineral separates (Fig. 2) are in excellent agreement with the data originally reported by [4] (Fig. 1a), but disagree with both the revised data presented in a corrigendum [5] as well as recent new data [6] (Fig. 1b). Our results do not support the supra-canonical ^{26}Al/^{27}Al ratio [4-9]; instead, they are consistent with the canonical value of 5×10^{-5} [2, 3].

Discrepancy between "canonical" and "supra-canonical" (^{26}Al/^{27}Al)$_0$ ratio: The discrepancy can easily be resolved, in good faith and integrity for the betterment of our science, through bilateral sample exchange and careful calibration against standards. We note that all our bulk CAI samples (supplied to Martin Bizzarro) were reproduced [10]. However, none of the "supracanonical" samples have been available for us to reproduce. We thus face an odd situation where every single CAIs examined by [4-6] from all four CV chondrites (Allende, Vigarano, NWA 779, and SAH 98044) plot precisely on the slope of (^{26}Al/^{27}Al)$_0$ = (5.85±0.05) × 10^{-5}, without a single exception of deviation from this line outside the very small error of <1% of the slope. Whereas such data were not to be seen again in any new CAI samples examined by us and many new attempts by other laboratories [10-15], and all plots to the right of [6] by ~10% or more. It would be a mistake to interpret both sets of data as being correct (Fig. 1b) prematurely, and start to assign astrophysical meandings to it.

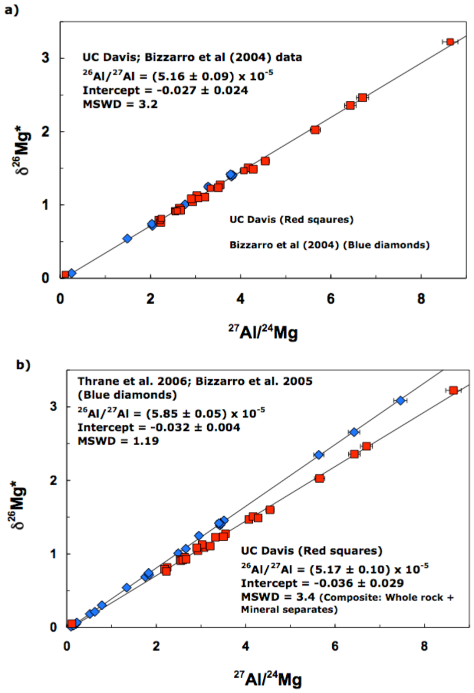

Fig. 1. ^{26}Al-^{26}Mg systematics in CAIs from the Allende CV3 carbonaceous chondrite. a) Summary of data from [4] and this study. The red squares are from this study, which includes CAI whole rock fragments, mineral separates, and micro-drilled inclusions. The blue dots are from [4]. The precision for both ^{27}Al/^{24}Mg and δ^{26}Mg* (*denotes the radiogenic ^{26}Mg component, as deviations in parts per 1000 from a terrestrial standard) is comparable in both studies. The plot shows excellent agreement between this study and the original data of [4]. b) Summary of data from as reported in their corrigendum [5], and [6] and the current study. In contrast to Fig. 1a, the systematic difference in the slope is apparent.

Pb-Pb Ages: Pb isotopic data from two Allende CAIs (AJEF and A43) are plotted in a ^{207}Pb/^{206}Pb vs. ^{204}Pb/^{206}Pb isochron diagram in Fig. 3a. Acid-washed fractions from both CAIs and the pyroxene second wash from AJEF plot on a single isochron, corresponding to the age of 4567.44 ± 0.34 Myr. These dates also agree, within error, with the ages of the recently dated CAIs from Efremovka [1].

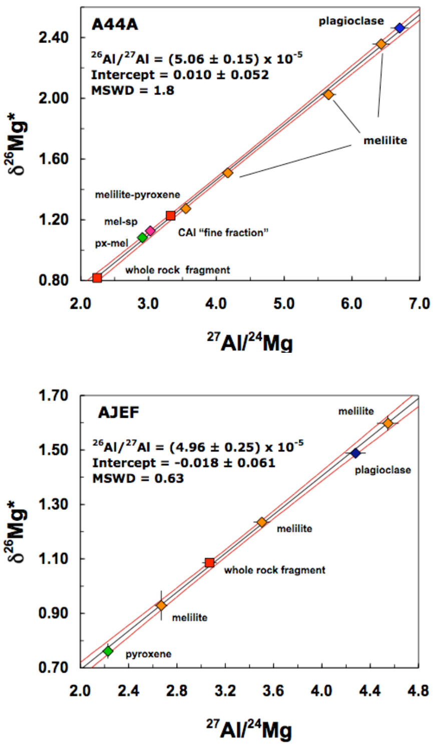

Fig. 2. Internal isochrons of mineral separates and whole rock fragments from Allende CAIs A44A and AJEF, with the canonical ^{26}Al/^{27}Al ratio. It shows that minerals on bulk scale are not affected by secondary disturbance in the CAIs.

Anchoring (^{26}Al/^{27}Al)$_0$ onto an absolute timescale: Combining our Mg and Pb isotope results from the same suite of CAI samples allow us to anchor the precisely determined (^{26}Al/^{27}Al)$_0$ = (5.17±0.10)×10^{-5} to an absolute ^{207}Pb-^{206}Pb age of 4567.4±0.34 Myr at the very beginning of the Solar System. It is a step forward over the earlier less precise results of (^{26}Al/^{27}Al)$_0$ = (4.63±0.44)×10^{-5} and 4567.2±0.6 Myr obtained for Efremovka CAIs [1].

Variable κ and the age of the Galaxy: Time-integrated model ^{232}Th/^{238}U ratios (κ values) are calculated from radiogenic ^{208}Pb*/^{206}Pb* ratios and ^{207}Pb*/^{206}Pb* dates. The κ values are between 5.2-5.7 for the CAI AJEF, and between 7.6-8.1 for A43, compared to average solar κ value of 3.77 [16]. Variations in the κ values among the minerals, or between residues and washes, in a single CAI, are much smaller than the variations between the CAIs. This suggests that the most significant fractionation between Th and U occurred before formation of the CAIs. We fully acknowledge that fractination between Th and U may occur in the early solar nebula, but also note that the presence of isotopically distinct reservoirs in the early Solar System was eloquently argued for by [17]. If the Th/U variation reflects primordial chemical heterogeneity, we can use the above range of κ values to calculate the mean age of the interstellar dust reservoirs from which CAI AJEF and A43 condensed from, using the following equation [18]:

$$T_{galaxy}=21.8*[\log(U/Th)_0-\log(1/\kappa)] \qquad \text{Eq. (1)}$$

where T_{galaxy} is expressed in Gyr (billion years), and $(U/Th)_0$ is the production ratio (Cowan et al., 1999). Our calculated T_{galaxy} range from 10.0-10.9 and 13.6-14.2 Gyr, corresponding the two populations of the observed κ values, respectively. This is entirely consistent with the astronomical observation of U/Th ratio in extremely old metal poor stars and the derived age of the Galaxy of 10.3 and 14.0 Gyr [18]. The meteoritic κ values can be determined much more precisely typically by orders of magnitude than astronomical observation of $(U/Th)_{obs}$, which has a typical error margin of ~ 3 Gyr for the calculated T_{galaxy} [18].

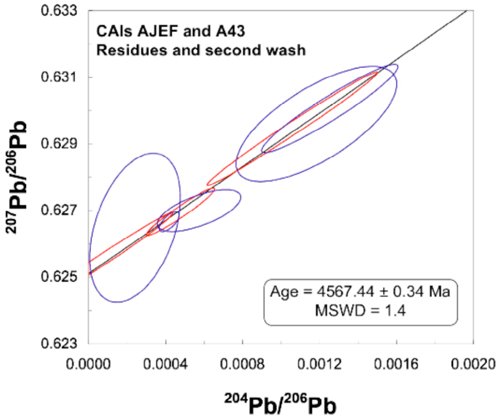

Fig. 3. ^{207}Pb/^{206}Pb vs. ^{204}Pb/^{206}Pb isochron diagram for acid-washed pyroxene, melilite and bulk rock fractions and a second (hot acid) wash of the pyroxene fraction from the CAIs AJEF (red) and A43 (blue). Data-point error ellipses are 2σ.

References: [1] Amelin Y. et al (2002) Science 297, 1678-1683. [2] Lee T. et al (1977) ApJL, 211, L107-L110. [3] MacPherson G.J. et al. (1995) Meteoritics 30, 365-386. [4] Bizzarro M. et al. (2004) Nature 431, 275-278. [5] Bizzarro M. et al. (2005) Corrigendum: Nature 435, 1280. [6] Thrane K et al. (2006) ApJL, 646, L159-L162. [7] Young E.D. et al. (2005) Science 308 (2005) 223-227. [8] Taylor D.J. et al. (2005) LPSC 36th, A2121. [9] Galy A. et al. (2004) LPSC 35th, A1790. [10] Town C.C. et al. (2007) Workshop on the Chronology of Meteorites and the Early Solar System, LPI Contri. No.1374, p.169-170. [11] Jacobsen B. et al. (2007a) LPSC 38th, A1491. [12] Jacobsen B. et al. (2007b) Workshop on the Chronology of Meteorites and the Early Solar System, LPI Contrib. No.1374, p.80-81. [13] Jacobsen S.B. et al. (2007) Workshop on the Chronology of Meteorites and the Early Solar System, LPI Contri. No.1374, p.82-83. [14] Teng F. Z. et al. (2007) LPSC 38th, A1837. [15] Kita N.T. et al. (2007) Workshop on the Chronology of Meteorites and the Early Solar System, LPI Contri. No.1374, p.92-93 and the oral presentation. [16] Lodders K. (2003) ApJ 591(2003) 1220-1247. [17] Loss R.D. et al. (1994) ApJL 436, L193-L196. [18] Cayrel R. et al. (2001) Nature 409, 691-692.