^{26}Al-^{26}Mg SYSTEMATICS IN THE UNUSUAL UNGROUPED ACHONDRITE NWA 7325 AND THE EUCRITE JUVINAS.

D.R. Dunlap[1], M. Wadhwa[1], S.R. Romaneillo[1], [1]Center for Meteorite Studies, School of Earth and Space Exploration, Arizona State University Tempe, AZ 85287 (drdunlap@asu.edu)

Introduction: The use of short-lived radionuclides as chronometers can provide high-resolution constraints on the relative timing of events in the early Solar System [1]. In particular, ^{26}Al ($t_{1/2}$ ~7.05×10^5 yrs) may have been an important heat source for early planetesimal melting and differentiation and the ^{26}Al-^{26}Mg system has been applied extensively in recent years for dating such events (e.g., [2-6]).

In this work, high precision ^{26}Al/^{26}Mg systematics are reported for NWA 7325, a recently recovered ungrouped mafic achondrite, and Juvinas, a basaltic eucrite. NWA 7325 is a reduced, Fe-poor, Mg-Ca rich cumulate olivine gabbro that was suggested to be of possible Mercurian origin based on its petrographic and geochemical characteristics [7]. Recently, an ancient absolute Pb-Pb age of 4562.5±4.4 Ma was reported for this achondrite [8]. Here, we report high precision ^{26}Al-^{26}Mg systematics for whole rock and mineral separates of NWA 7325 to determine its origin and chronology, and to ascertain whether there is concordance between the Al-Mg and the Pb-Pb chronometers in this sample.

An internal ^{26}Al-^{26}Mg isochron was previously reported for the Juvinas eucrite [6]. Moreover, a high precision Mg isotope composition for the Juvinas whole rock was reported by [9]. Here we report a new internal Al-Mg isochron for Juvinas to place better constraints on its chronological and petrogenetic history.

Analytical Methods: All chemistry and mineral separations were performed under clean laboratory conditions in the Isotope Cosmochemistry and Geochronology Lab (ICGL) at Arizona State University (ASU). Interior pieces, free of any fusion crust, of NWA 7325 (~500 mg) and Juvinas (~293 mg) were obtained from the meteorite collection in the Center for Meteorite Studies at ASU. Fragments of each of these pieces (47.4 mg for Juvinas and 85.4 mg for NWA 7325) were kept for whole rock analyses. The remaining portions were crushed and sieved prior to mineral separation. Procedures and protocols for mineral separation, dissolution and purification of Mg were similar to those described previously [3, 4], with only minor modifications. Prior to any chemical separations, a ~5% aliquot of each sample solution was reserved for the determination of Al/Mg ratios.

	^{27}Al/^{24}Mg (±5%)	δ^{26}Mg* (±2SD)	# of analyses (n)
NWA7325 Ol1	0.17 (0.01)	0.08 (0.03)	4
NWA7325 Ol2	0.20 (0.01)	0.09 (0.05)	4
NWA7325 WR1	0.63 (0.03)	0.10 (0.03)	4
NWA7325 Px1	5.13 (0.26)	0.11 (0.02)	4
NWA7325 Plag1	46.00 (2.30)	0.19 (0.01)	4
NWA7325 Plag2	76.87 (3.84)	0.25 (0.02)	4
Juvinas Px2	0.10 (0.01)	0.04 (0.02)	4
Juvinas Px1	0.25 (0.01)	0.03 (0.03)	4
Juvinas WR1	2.00 (0.10)	0.02 (0.02)	4
Juvinas Plag1	75.00 (3.75)	0.03 (0.04)	3
Juvinas Plag2	114.86 (5.74)	0.03 (0.02)	4
Juvinas Plag3	131.30 (6.56)	0.01 (0.03)	3

Table 1. The ^{27}Al/^{24}Mg ratios and radiogenic ^{26}Mg excesses (δ^{26}Mg*) in whole rocks and mineral separates of NWA 7325 and Juvinas. Errors on the Mg isotope composition are ±2SD.

The Al and Mg concentrations were determined on a Thermo ICAP-Q mass spectrometer in the Keck Laboratory at ASU. The Mg isotopic ratios were analyzed using a Neptune multicollector inductively coupled plasma mass spectrometer (MC-ICPMS) in the ICGL at ASU using protocols similar to those described earlier [3, 4]. Instrumental mass fractionation was corrected using a sample-standard bracketing technique. Radiogenic excesses in ^{26}Mg from the decay of ^{26}Al (δ^{26}Mg*) were calculated using sample-standard bracketing and internal normalization of the samples and bracketing standards (using the exponential fractionation law) to a ^{25}Mg/^{24}Mg ratio of 0.12663 [10]. The slopes and intercepts of the internal isochrons for both NWA 7325 and Juvinas were calculated using the ISOPLOT software [11].

Results and Discussion: The results of our Al-Mg analyses of NWA 7325 and Juvinas whole rocks and mineral separates are shown in Table 1. The internal isochrons for each of these samples are shown in Fig.1.

NWA 7325: The internal isochron for NWA 7325 corresponds to a ($^{26}Al/^{27}Al$) = (2.87±0.26)×10^{-7} and an initial $\delta^{26}Mg^*_0$ = 0.095±0.011‰ (Fig. 1). Relative to the D'Orbigny angrite age anchor ($^{26}Al/^{27}Al$) ~5.06±0.92×10^{-7} [3] at 4563.4±0.3 Ma [12]), we calculate an Al-Mg age for NWA 7325 of 4562.8±0.3 Ma. This age is in agreement with the Pb-Pb age reported by [8], but is an order of magnitude more precise.

A noteworthy aspect of the Al-Mg internal isochron for NWA 7325 is that it lies well above the bulk chondritic value (Al/Mg ~0.1 and $\delta^{26}Mg^*$ ~0; e.g., [5, 13]) and has a well-resolved positive intercept of 0.095±0.011‰. Such a high initial ratio has not been previously reported for any other achondrites with the exception of the ungrouped achondrite GRA 06129, which is characterized by a $\delta^{26}Mg_0^*$ = 0.08±0.01‰ [14]. In contrast to NWA 7325, however, GRA 06129 does not show any evidence of live ^{26}Al at the time of its last Al-Mg equilibration. As such, the high positive initial $\delta^{26}Mg_0^*$ for NWA 7325 could imply a distinct, non-chondritic initial Mg isotope composition for its parent body (implying gross heterogeneities in the initial Mg isotope composition in the early Solar System). Alternatively, the source reservoir for this achondrite may have evolved with a highly superchondritic Al/Mg ratio early in the history of the Solar System prior to the partial melting event that formed the NWA 7325 parent melt. In either case, the Al-Mg systematics imply that this meteorite originated on a parent body distinct from that of other known achondrites. The precise, ancient ^{26}Al-^{26}Mg age of ~4563 Ma (within only a few million years of Solar System formation and contemporaneous with the formation of the oldest angrites; [1, 18] and references therein), however, makes it unlikely that this sample originated in the evolved crust of a differentiated planetary-sized body. In light of this, a Hermean origin for this achondrite seems doubtful.

Juvinas: An ^{26}Al-^{26}Mg internal isochron for Juvinas was previously reported by [6]. Consistent with these previous results, we did not observe any evidence for live ^{26}Al in Juvinas at the time of last Al-Mg equilibration of this sample (Fig. 1). Nevertheless, the data reported here provide a slope for the Al-Mg isochron corresponding to a $^{26}Al/^{27}Al$ ratio of (-0.5±1.3)×10^{-8}, which yields a more stringent upperlimit on the $^{26}Al/^{27}Al$ ratio of ≤7.9×10^{-9} (an order of magnitude lower than that previously reported by [6]). Relative to the D'Orbigny angrite age anchor [12], we estimate an upper limit on the $^{26}Al/^{26}Mg$ age for Juvinas of <4559.1 Ma, which most likely defines the time of later metamorphic equilibration during which the Pb-Pb systematics were also reset [15].

The Juvinas Al-Mg internal isochron reported here also yields a $\delta^{26}Mg^*_0$ of 0.029±0.007‰ (Fig. 1). Given that the Al-Mg system is completely equilibrated (the $\delta^{26}Mg^*$ values in the whole rock and other mineral separates agree within the errors with this value; Table 1), this slightly but resolvably positive initial can be combined with the $^{27}Al/^{24}Mg$ ratio of the Juvinas WR to calculate a model crystallization age for this eucrite. Such a calculation yields a model $^{26}Al/^{27}Al$ at the time of original crystallization for Juvinas of ~2×10^{-6}, yielding an ancient model crystallization age consistent with its ^{53}Mn-^{53}Cr age (relative the D'Orbigny angrite; [12,16,17,19]). This agrees with a similar model age calculation for Juvinas based on a small but resolvable excess $\delta^{26}Mg^*$ =(0.030±0.003) measured in its whole rock [9].

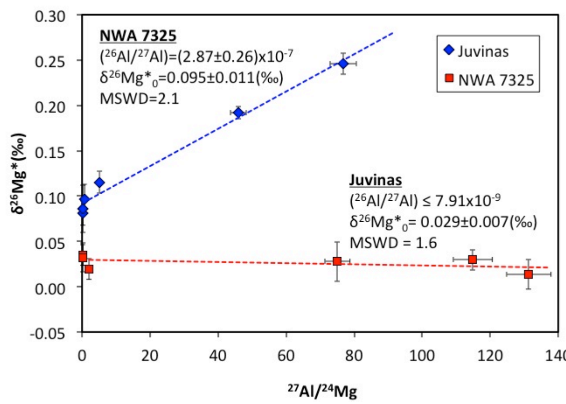

Figure 1. Mg isochron plot showing the data for NWA 7325 (blue diamonds) and Juvinas (red squares).

References: **[1]** Davis A. M. and McKeegan K. D. (2014) *Treatise on Geochem.* (2nd Ed.), *1,* 361-395. [2] Wadhwa M. et al. (2009) *GCA, 73,* 5189-5201. [3] Spivak-Birndorf L. et al. (2009) *GCA, 73,* 5202-5211. [4] Bouvier A. et al. (2011) *GCA, 75,* 5310-5323. [5] Schiller M. et al. (2010) *EPSL, 297,* 165-173. [6] Wadhwa M. et al. (2003) *LPS XXXIV*, Abstract #2055. [7] Irving A. J. et al. (2013) *LPS XLIV*, Abstract #2164. [8] Amelin Y. (2013) *MAPS*, Abstract #5165. [9] Schiller M. et al. (2010) GCA, 74, 4844-4864. [10] Catanzaro M. et al. (1966) *J. Res. Nat. Bur. Stand., 70a,* 453-458. [11] Ludwig K. R. (2003) *BGC SP, 4,* 1-71. [12] Brennecka G. A. and Wadhwa M. (2012) *PNAS, 106,* 9299-9303. [13] Thrane K. et al. (2006) *Ap. J.*, *646,* L159-L162. [14] Shearer C. K. et al. (2010) *GCA*, *74,* 1172-1199. [15] Galer S. J. and Lugmair G. W. (1996) *Meteoritics, 31,* A47-A48. [16] Lugmair G. W. and Shukolyukov A. (1998) *GCA, 62,* 2863-2886. [17] Nyquist L. E. et al. (2003) *EPSL, 214,* 11-25. [18] Wadhwa M. (2014) *Treatise on Geochem.* (2nd Ed.), *1,* 397-418. [19] Glavin D. P. et al. (2004) *MAPS, 39,* 693-700.