THE INITIAL ^{87}Sr/^{86}Sr OF THE SOLAR SYSTEM AND THE AGE OF THE MOON.

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Introduction: The long-lived ^{87}Rb-^{87}Sr system provides a powerful chronometer for early Solar System events. Due to differences in the volatility of Rb and Sr, ^{87}Sr/^{86}Sr ratios record information about condensation and volatile depletion in the early Solar System. For Rb-poor Solar System materials such as Moore Co. plagioclase, Angra dos Reis, Juvinas and the lunar anorthosite 60025, corrections for radiogenic ingrowth of ^{87}Sr are small, and variations in resulting initial ^{87}Sr/^{86}Sr may be interpreted to reflect differences in the timing of separation from an evolving solar nebula [e.g., 1-3]. Thus, a chronology may be constructed based on relative variations in initial ^{87}Sr/^{86}Sr in planetary materials, rather than absolute ages derived by the internal ^{87}Rb-^{87}Sr isochron method.

Based on a re-normalized compilation of literature Rb-Sr data measured in various laboratories over the course of decades, Halliday and Porcelli [4] argued for a young lunar formation age of 90±20 Myr after the formation of CAIs. In order to improve on the normalization, we have measured Sr isotopic data for two Sr standards used in the literature: NBS 987 and Pacific seawater. Here we undertake a comprehensive set of Sr isotopic measurements in eucrites, angrites, lunar samples and CAIs in order to shed light on the early history of the Solar System.

Methods: Purified Sr was loaded onto Ta single filaments with phosphoric acid and run on the GV Isoprobe-T TIMS at Harvard using a multidynamic collection method and new Xact amplifier boards, generously provided by Isotopx. A 5V ^{88}Sr signal was typically maintained for 20-100 blocks of 10 cycles each (20 seconds integration time per cycle). Corrections for instrumental fractionation were made to a common ^{86}Sr/^{88}Sr value (0.1194) using the exponential law.

Results: Measured ^{87}Sr/^{86}Sr and 2σ errors for 9 NBS 987 runs (Fig. 1), 8 Pacific seawater runs (Fig. 2) and 4 Juvinas runs (Fig. 3) are shown with sample grand means and 2 standard error intervals. ^{87}Rb/^{86}Sr for the Juvinas sample was measured by isotope dilution to be 0.00256±5, yielding an initial ^{87}Sr/^{86}Sr of 0.699057 ± 8. We measure an offset of 0.001074 ± 5 between NBS 987 and Pacific seawater. Precise determination of the ^{87}Sr/^{86}Sr in these standard materials allows us to correct for interlab biases in literature data and to thereby construct an internally consistent compilation that includes our own new high-precision Sr data for early Solar System materials.

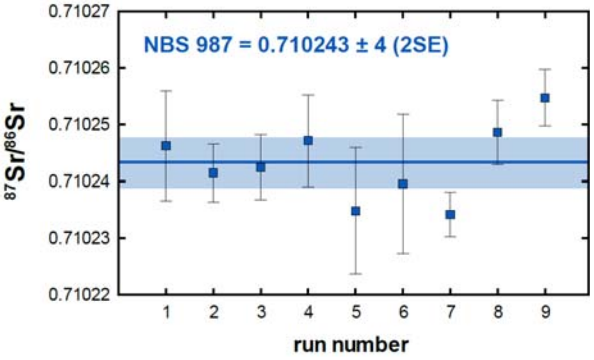

Fig. 1 Sr isotopic data for 9 individual filaments each loaded with 500 ng NBS 987 Sr. The grand mean and 2SE interval are indicated by the blue line and shaded band.

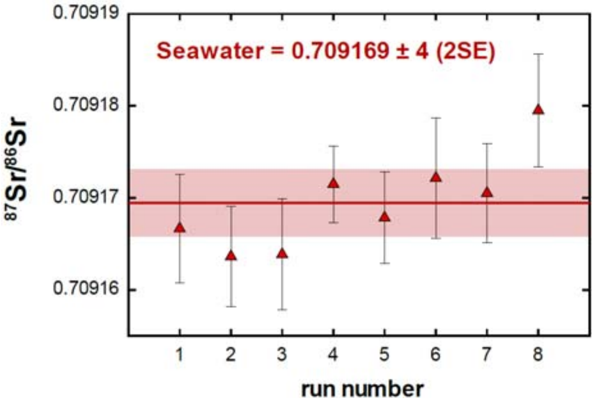

Fig. 2 Sr isotopic data for 8 individual filaments each loaded with 300 ng Sr purified from Pacific Seawater TP24N. The grand mean and 2SE interval are indicated by the red line and shaded band.

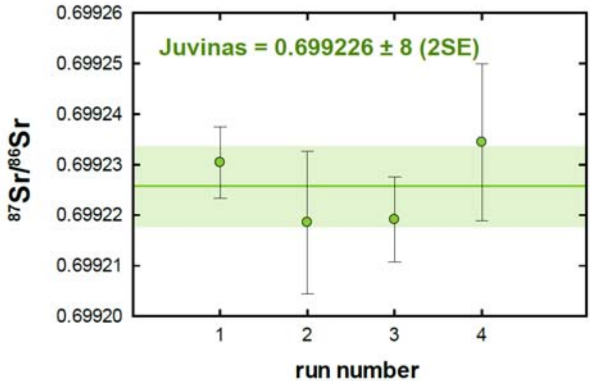

Fig. 3 Sr isotopic data for 4 individual filaments each loaded with 200 ng Sr purified from Juvinas. The grand mean and 2SE interval are indicated by the green line and shaded band.

Discussion: Using a new normalization based on our measurements of NBS 987 and Pacific seawater (Fig. 4), we find that some samples with discrepant reported initial ^{87}Sr/^{86}Sr values agree within error when properly normalized: Allende CAI D7 from [5,6]; Moore Co. plagioclase from [7,8]; LEW86010 from [8,9]; and Juvinas from [1,10 and this study] all agree within error. We note that after proper normalization, our Juvinas measurements result in a value for the basaltic eucrites' initial ^{87}Sr/^{86}Sr that is within 10 ppm of the original value (BABI) determined by [1]. Thus, a careful normalization resolves some standing issues in the literature. However, normalized initial ^{87}Sr/^{86}Sr data for Angra dos Reis [2,8,9] and lunar anorthosite 60025 [7,11] do not all agree within error. In particular, significant differences in the initial ^{87}Sr/^{86}Sr for lunar anorthosite 60025 persist after correcting for inter-laboratory bias. Therefore, there is a clear need to make new high-precision measurements of Sr in 60025 and Angra dos Reis in order to further our understanding of early Solar System chronology.

A precise determination of the lunar initial ^{87}Sr/^{86}Sr is particularly important to our understanding of the processes that shaped the early Earth-Moon system and the early Solar System. The timing of the Moon-forming giant impact has important implications for the timescale of Earth's accretion and the segregation of the iron core: Yu and Jacobsen [12] showed that a late Moon-forming giant impact (at ~100 Myr) requires extremely short timescales of accretion (mean age of accretion < 1 Myr) based on Hf-W systematics. A strict constraint on the timing of the Moon-forming giant impact is thus critical to our understanding of Earth's growth and metal-silicate differentiation as well as our broader understanding of Solar System history.

The very low initial ^{87}Sr/^{86}Sr of 60025 strongly supports formation of the Moon within the first 30 Myr of Solar System history rather than 100 Myr later.

References: [1] Papanastassiou D. A. and Wasserburg G. J. (1969) *EPSL, 5,* 361-376. [2] Wasserburg G. J. et al. (1977) *EPSL, 35,* 294-316. [3] Brannon J. C. et al. (1988) *Proc 18th LPSC* 555-564. [4] Halliday A. N. and Porcelli D. (2001) *EPSL, 192,* 545-559. [5] Gray C. et al. (1973) *Icarus, 20*, 213-239. [6] Podosek F. et al. (1991) *GCA, 55*, 1083-1110. [7] Papanastassiou D. A. and Wasserburg G. J. (1976) *Proc 7th LPSC,* 665. [8] Lugmair G. W. and Galer S. J. (1992) *GCA, 56*, 1673-1694. [9] Nyquist L. E. et al. (1994) *Meteoritics, 29*, 872-885; [10] Allegre C. J. et al. (1975) *Science*, 187, 436-438. [11] Carlson R. W. and Lugmair G. W. (1988) *EPSL, 90*, 119-130. [12] Yu G. and Jacobsen S. B. (2011) *PNAS 108*, 43; [13] Tonui E. K. et al. (2003) *LPSC XXXIV,* Abstract #1812.

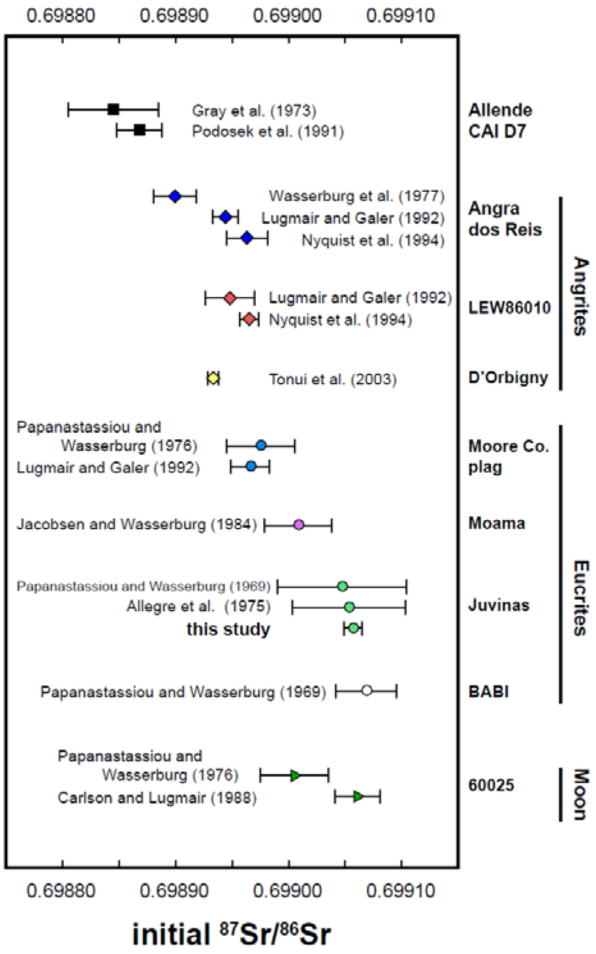

Fig. 4 Variation in initial ^{87}Sr/^{86}Sr in a suite of Solar System materials [1,2,5-11,13; this study], re-normalized based on our measurements of NBS 987 and Pacific seawater.