

INITIAL $^{87}\text{Sr}/^{86}\text{Sr}$ CHRONOLOGY IN THE SOLAR SYSTEM. D. A. Papanastassiou^{1,2} and J. H. Chen²,

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With the introduction of high precision mass spectrometry through the introduction of programmable magnetic field control and digital data acquisition and processing [1], it was recognized that small variations in initial $^{87}\text{Sr}/^{86}\text{Sr}$, could define a high resolution relative chronology for the chemical fractionation and separation of low Rb/Sr materials from parent reservoirs with high Rb/Sr, such as the solar nebula and chondrites [2,3]. For the determination of a primitive $^{87}\text{Sr}/^{86}\text{Sr}$ chronology, it is important to search for samples with extremely low Rb/Sr for which the correction for in situ ^{87}Rb decay is extremely small and essentially independent of the age of the sample or the age of its disturbance. For primitive initial $^{87}\text{Sr}/^{86}\text{Sr}$, the ultimate goal is extremely low measured values of $^{87}\text{Sr}/^{86}\text{Sr}$, below the reference value BABI [2].

The purpose of this work is to determine with current state-of-the-art precision, the $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{84}\text{Sr}/^{88}\text{Sr}$ ratios in the Allende D7 CAI (USNM 3898) and in Angra dos Reis. This CAI yielded the most primitive *measured* value of $^{87}\text{Sr}/^{86}\text{Sr}$ and was defined as ALL = -3.0 ± 0.3 eu [4], below the BABI value [2].

It is important to recognize that all isotope ratio mass spectrometers, under the best conditions (e. g., in the absence of mass interferences) can determine high precision isotope ratios but not absolute ratios. An illuminating anecdote (until now): when we were to receive the Finnigan 262, at Caltech, we received a call from Dr. Habfast: this is a very well behaved, high precision instrument but it yields, for the NIST 987 SRM (Standard Reference Material) 0.71028, not 0.71025; do you want us to fix? The “fix” would have consisted of taking apart the collectors (and electron repellers), reassembling, and testing. Dismantling and reassembling, in the hope of obtaining the “correct” ratio did not appear useful. We accepted the instrument and it operated extremely well, for the express purpose of obtaining very precise data. We note that the Lunatic I had a Faraday cup which was completely shielded from stray secondary electrons. The improved precision was due to a fast electrometer (Applied Physics, Cary 36), larger duty cycle by fast B-field switching and digitization of the electrometer output. Multiple cup mass spectrometers permit a much higher duty cycle and eliminate the uncertainties from any instabilities in the ion beams. Still, the only way to compare data between different laboratories and instruments is through the use of standard solutions such as the NIST 987 SRM.

Hans et al. [5] obtained high precision measurements for ^{84}Sr in Allende inclusions. They found es-

sentially a uniform excess in CAI of the p-process ^{84}Sr , at the level of 1.2 eu, based on normalization for mass dependent fractionation to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$. These workers also considered the case that the effects in $^{84}\text{Sr}/^{88}\text{Sr}$ might be due to the process of normalization for isotope fractionation, whereby, samples with an excess of ^{88}Sr , would appear to have an excess in ^{84}Sr . Such an excess in ^{88}Sr would have the same magnitude and sign as the ^{84}Sr effects. A sample with an *excess* in ^{88}Sr of 1.2 eu, normalized to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$, would also result in an apparent *deficit* in $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.6 eu. It was hypothesized [5] that the primitive measured $^{87}\text{Sr}/^{86}\text{Sr}$ in CAI USNM 3898 (labelled ALL [4]) may not have been an indicator of primitive ^{87}Sr , but an artifact from an ^{88}Sr excess. To “erase” the difference between the $^{87}\text{Sr}/^{86}\text{Sr}$ BABI and ALL values of 3.0 ± 0.3 eu, one would need a heretofore unseen ^{84}Sr excess, even in FUN inclusions [6] (translatable to an ^{88}Sr excess) of 6 eu. Hans et al. [5] allowed for such a high ^{84}Sr excess in USNM 3898, by claiming that “no precise ^{84}Sr data are available for this CAI”. For this claim, they missed a publication [6] on FUN ^{84}Sr , which provided a measurement of $^{84}\text{Sr}/^{88}\text{Sr}$ in USNM 3898 of -4 ± 2 eu. The *hypothesized* value for an excess in ^{84}Sr of $+6.0$ eu is not supported, by the data in [6]. The interlaboratory calibration for $^{87}\text{Sr}/^{86}\text{Sr}$ was discussed in detail in last year’s abstract [7].

We have initiated measurements of $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{84}\text{Sr}/^{86}\text{Sr}$, using the Triton, at JPL. We report data on NIST 987, on Moore Co. plagioclase, and on Angra dos Reis. Moore Co. plag was used as a standard (cf [8]. For Angra dos Reis cf [9]. An analysis of seawater Sr was obtained, because in the earlier work, in the Lunatic Asylum, seawater was used as the reproducibility standard. We have delayed measurements on USNM 3898, because of the very small amount of available material. We expect data on that CAI to be presented at the conference.

Sr measurements on the Lunatic I, on single, oxidized Ta filaments were routine. For well understood reasons (by us), the use of Ta single filaments is not optimal for the Triton, because the filaments are significantly shorter and they are heated by a DC current-regulated power supply, which would result in hot spots on Ta oxidized filaments as the Ta_2O_5 slowly decomposes at Sr-running, filament temperatures. The use of fine Ta_2O_5 powder, as we used for Ti measurements [10] has not been investigated carefully, for this work. The sample filaments in the Lunatic I were heated by a square-wave, voltage-regulated power supply, through an isolation transformer.

For the Triton, we used a dual configuration data collection scheme (Main Configuration: cups L1: ^{86}Sr , C: ^{87}Sr , H1: ^{88}Sr ; and Configuration 1: L1: ^{84}Sr , C: ^{85}Rb , H1: ^{86}Sr). Instrumental fractionation was determined from the Main Configuration steps, using $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$, and applied to $^{87}\text{Sr}/^{86}\text{Sr}$ and to $^{84}\text{Sr}/^{86}\text{Sr}$ (from Configuration 1). The data are presented in the Table. The data show excellent reproducibility for $^{87}\text{Sr}/^{86}\text{Sr}$ for NIST 987 and good precision for $^{84}\text{Sr}/^{86}\text{Sr}$, in part because not all data were obtained at high ion beam currents (for ^{84}Sr). The $^{87}\text{Sr}/^{86}\text{Sr}$ for seawater, using the Triton, is 199 ppm higher than for the Lunatic I. This difference is not unexpected, based on the NIST 987.

The measured value for $^{87}\text{Sr}/^{86}\text{Sr}$ for Angra dos Reis is lower by 1.65 ‰ than the measured value for Moore County plagioclase and for Angra dos Reis pyroxene. Given the very similar and very low values for $^{87}\text{Rb}/^{86}\text{Sr}$, for these samples, we confirm the more primitive $^{87}\text{Sr}/^{86}\text{Sr}$ of Angra dos Reis, relative to Moore Co. and BABI. The extrapolation to initial $^{87}\text{Sr}/^{86}\text{Sr}$ values is uncertain depending on potential disturbed systematics, as discussed earlier [11, 12]. However, we do not concur with the conclusion [5] that the difference between BABI and ADOR is close to zero.

The key measurement will be on CAI USNM 3898 (D7), which is in progress, very carefully, given the

very small amount of material tracing its heritage to the samples analyzed in 1973, by Gray et al. [4].

References: [1] Wasserburg G. J., Papanastassiou

- D. A., Nenow E. V., and Bauman C. A. (1969) *Rev. Sci. Instrum.* 40, 288. [2] Papanastassiou D. A. and Wasserburg G. J. (1969) *EPSL* 5, 361. [3] Wasserburg G. J., Papanastassiou D. A., and Sanz H. G. (1969) *EPSL* 7, 33. [4] Gray C. M., Papanastassiou D. A., and Wasserburg G. J. (1973) *Icarus* 20, 213. [5] Hans U., Kleine T., and Bourdon B. (2013) *EPSL* 374, 204. [6] Papanastassiou D. A. and Wasserburg G. J. (1978) *GRL* 5, 595. [7] Papanastassiou D. A. (2015) *46th LPSC*, abstract 2243. [8] Papanastassiou D. A. and Wasserburg G. J. (1972) *EPSL* 13, 368. [9] Wasserburg G. J., Tera F., Papanastassiou D. A., and Hunkele J. C. (1977) *EPSL* 35, 294. [10] Niederer F. R., Papanastassiou D. A., and Wasserburg G. J. (1980) *Ap. J. (Letters)* 240, L73. [11] Stewart B. W., Papanastassiou D. A., Capo R. C., and Wasserburg G. J. (1993) *24th LPSC*, abstract 1357. [11] Lugmair G. W. and Galer S. J. G. (1992) *GCA* 56, 1673.

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TABLE 1