# A LOW ABUNDANCE OF $^{135}$Cs IN THE EARLY SOLAR SYSTEM: BARIUM ISOTOPIC SIGNATURES OF VOLATILE-DEPLETED METEORITES

G. A. Brennecka[1*], T. Kleine[1]
[1]Institut für Planetologie, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (*brennecka@gmail.com)

**Introduction:** Precisely knowing the abundances of short-lived radionuclides at the start of the Solar System is fundamental for understanding the stellar environment of Solar System formation. Previous investigations of the short-lived $^{135}$Cs→$^{135}$Ba system ($t_{1/2}$ = 2.3 Ma) have resulted in a range of calculated initial amounts of $^{135}$Cs, with most estimates elevated to a level that requires extraneous input of material (*e.g.*, from a supernova) to the protoplanetary disk [1-4]. Such an array of proposed $^{135}$Cs/$^{133}$Cs initial Solar System values has severely restricted the system's use as both a possible chronometer and as an informant about supernovae input. However, if $^{135}$Cs was as abundant in the early Solar System as previously proposed, the resulting deficits in its daughter product $^{135}$Ba would be easily detectable in parent bodies from the very early Solar System with measured sub-chondritic Cs/Ba.

**Samples & Methods**: In this work, we investigate the Ba isotopic signatures of volatile-depleted samples (*i.e.*, sub-chondritic Cs/Ba) from the very early Solar System, including four angrites (Angra dos Reis, D'Orbigny, NWA 4801, and NWA 6291) and five eucrites (Stannern, Millbillillie, Bouvante, Petersburg, and Juvinas). Whereas both meteoritic groups are known for being volatile depleted, for angrites it is known from Rb-Sr systematics that the volatile-depletion event occurred within ∼1 million years of the start of the Solar System [5], making angrites in particular the ideal sample set to quantify initial $^{135}$Cs/$^{133}$Cs from Ba isotope signatures. To compare our findings with less volatile-depleted samples, we additionally measured the two unique achondrites (GRA 06129 and Bunburra Rockhole), the aubrite Shallowater, and multiple aliquots of the terrestrial rock standard BHVO-2.

Barium was separated from sample and standard matrices following the chemistry reported in [6]. Once chemically purified, the Ba isotopic compositions were measured on a Thermo Triton*Plus* instrument at the Institut für Planetologie at the University of Münster. All Ba isotopes are reported relative to $^{136}$Ba and are internally normalized to $^{134}$Ba/$^{136}$Ba=0.3078 [6]. Each sample was measured multiple times, and each run consisted of 300–600 ratios with 16-second integration times.

**Results & Observations**: No achondrite sample measured in this study, or those reported in previous works [7-10], has a $\varepsilon^{135}$Ba value resolved from terrestrial standards. In this study, the measured average of angrites and eucrites is $\varepsilon^{135}$Ba=0.04±0.06 (2SD, N=9). From this, and a known volatile-depletion age of ~1 Ma for angrites [5], we calculate an upper limit for the Solar System initial $^{135}$Cs/$^{133}$Cs of $2.8\times10^{-6}$, well below previous estimates reported in the literature. This significantly lower initial $^{135}$Cs/$^{133}$Cs ratio now suggests that all of the $^{135}$Cs present in the early Solar System was inherited simply from galactic chemical evolution and no longer requires addition from an external stellar source such as an asymptotic giant branch star or type II supernova.

As keenly pointed out by Young [11, 12], when corrected for input from Wolf–Rayet winds in the dense phases of star-forming regions, radionuclides of the early Solar System align along a single trend and are consistent with a residence time in the molecular cloud of 200±100 Ma, which is similar to the present-day rate of molecular cloud conversion into stars in the Milky Way. As this new data indicates that the initial $^{135}$Cs/$^{133}$Cs is approximately two orders of magnitude lower than previously thought, $^{135}$Cs now joins this list of radionuclides that are simply obtained from the existing molecular cloud, fitting along the previously established trend. Thus, $^{135}$Cs is no longer an outlier requiring a unique stellar source; it is simply another radionuclide present in the early Solar System that was inherited from the surrounding molecular cloud—the most likely statistical scenario of Solar System formation.

**References**: [1] Hidaka et al. (2001) *EPSL*, 193, 459. [2] Nichols et al. (2002) *LPSC* Abstract #1929. [3] Srinivasan et al. (2011) *LPSC* Abstract #1953. [4] Hidaka & Yoneda (2013) *NatSR*, 3, 1330. [5] Hans et al. (2013) *EPSL*, 374, 204. [6] Carlson et al. (2007) *Science*, 316, 1175. [7] Andreasen & Sharma (2007) *LPSC* Abstract #2242. [8] Bermingham et al. (2014) *GCA*, 133, 463. [9] Bermingham et al. (2016) *GCA*, 175, 282. [10] Srinivasan & Ali (2010) MetSoc Abstract #5344. [11] Young (2014) *EPSL*, 392, 16. [12] Young (2016) *ApJ*, 826, 129.