^{53}MN-^{53}CR SYSTEMATICS OF BRACHINA REVISTED IN HIGH PRECISION. D. R. Dunlap[1], M. Wadhwa, and S. J. Romaniello, [1]Center for Meteorite Studies, School of Earth and Space Exploration, Arizona State University Tempe, AZ 85287. (drdunlap@asu.edu)

Introduction: The short-lived chronometer based on the decay of ^{53}Mn to ^{53}Cr ($t_{1/2}$= 3.7 Ma) has been applied extensively in recent years for determining the high resolution timescales of planetesimal accretion and differentiation (e.g., [1-5]). In addition, the mass independent anomalies in ^{54}Cr can serve as a powerful genetic tracer of meteorite parent bodies (e.g., [6-8] and references therein).

Brachina is an enigmatic meteorite that is the type specimen for the Brachinite class of primitive achondrites. It has a fine-grained, equigranular, unshocked texture dominated by honey-brown olivine (80 vol%) with prevalent 120° triple junctions indicative of a high degree of equilibration [9]. Besides olivine, the other phases that are present in this meteorite include plagioclase, clinopyroxene, and chromite. The petrogenesis of this achondrite has long been a matter of debate. It was initially suggested to form as a residue from partial melting of a chondritic precursor [9], but was subsequently suggested to be an igneous cumulate [10]. More recently, [11] performed a detailed petrologic, thermodynamic, and experimental study and hypothesized that Brachinites formed as partial melt residues of a relatively FeO-rich, R chondrite-like starting material.

High resolution chronology of Brachina using short-lived chronometry was previously attempted by [12,13]. The ^{53}Mn-^{53}Cr systematics reported by [12] yielded a ^{53}Mn/^{55}Mn ratio of $(3.8 \pm 0.4) \times 10^{-6}$. Relative to the the D'Orbigny age anchor [14-16], this ^{53}Mn/^{55}Mn ratio corresponds to an ancient age of 4564.2 ± 0.6 Ma In this study, we investigate the Mn-Cr isotope systematics in the achondrite Brachina with high precision techniques with the goal of refining the petrogenesis and chronology of this unique meteorite.

Methods: All sample handling, mineral separation and ion exchange chromatography procedures were performed under clean laboratory conditions in the Isotope Cosmochemistry and Geochronology Lab (ICGL) at Arizona State University (ASU). An interior fragment, free of any fusion crust, was selected from a piece of Brachina that was obtained from the South Australian Museum. The fragment was ultrasonicated in methanol before any further processing. A single large chromite grain (Chr-1) was handpicked from small fragment that was crushed. A small chip (~30 mg) was broken off and digested using HNO_3:HF treatment, followed by dissolution of residual chromites in a Parr bomb, to obtain a dissolved whole rock (WR) sample. Another larger chip (~101 mg) was also broken off the main piece and was processed through a differential dissolution protocol that resulted in an olivine-rich fraction (Ol), a pyroxene- and plagioclase-rich silicate fraction (Sil) and a second chromite fraction (Chr-2).

The chemical separation procedures and mass spectrometrtic methods for Cr isotope analyses have been described previously [18]. The Cr isotopic ratios were analyzed using ICGL's Thermo Finnigan *Neptune* multicollector ICPMS. Chromium isotopes were measured in high-resolution mode. The intensities of ^{50}Cr, ^{52}Cr, ^{53}Cr, and ^{54}Cr were measured, along with ^{49}Ti, ^{51}V, and ^{56}Fe to monitor and correct for isobaric interferences. The Cr isotopic data are reported relative to the NBS 979 standard after internal normalization to ^{50}Cr/^{52}Cr (=0.051859; [13]). Our external reproducibility is ±0.04 and ±0.08 (2SD) for ε^{53}Cr and ε^{54}Cr, respectively, based on repeat measurements of terrestrial rock standards over the course of this study. The Mn/Cr ratios were measured using a Thermo iCAP-Q quadrupole inductively coupled plasma mass spectrometer (ICPMS) in the Keck Laboratory at ASU.

Results and Discussion: The results of our high precision investigation of the ^{53}Mn-^{53}Cr systematics of Brachina are shown in Fig. 1. The slope of the internal isochron for Brachina corresponds to a ^{53}Mn/^{55}Mn ratio of $(4.27\pm0.32) \times 10^{-6}$ with the initial $\varepsilon^{53}Cr_i$ of -0.071 ± 0.047 (where $\varepsilon^{53}Cr = ((^{53}Cr/^{52}Cr_{sample}/^{53}Cr/^{52}Cr_{standard}) - 1) \times 10^4]$ (MSWD = 2.0). The ^{53}Mn/^{55}Mn ratio determined here for this achondrite agrees well with the value that was previously determined by [12]. The initial $\varepsilon^{53}Cr_i$ value, however is distinct from that reported by [12]; this is because a second order fractionation correction was being applied to the data reported by [12]. Therefore, we believe that the initial Cr isotope composition reported here is robust.

The ε^{54}Cr value calculated from the average of measurements on the WR, Chr-1, Chr-2, Sil and Ol fractions (n=20) is -0.74 ± 0.08 ε units. This value is similar to that of other basaltic achondrites as well as the acapulcoite primitive achondrites [6-8] and references therein).

Relative to the D'Orbigny angrite age anchor [14-16], a ^{53}Mn-^{53}Cr age of 4564.8 ± 0.5 Ma is calculated for Brachina. As discussed earlier, Brachina's formation history is debated, with possible petrogenetic scenarios including formation as an igneous cumulate or perhaps as a partial melt residue from an R chondrite-like starting material [9-11]. In either of these scenarios, what is evident from the ^{53}Mn-^{53}Cr systematics is its formation occurred early on the Brachinite parent body, well within ~3-4 Ma of CAI formation [18,19]. Given the data presented here, it seems likely that Brachina represents one of the earliest generations of achondrites produced in the early Solar System and can provide unique insights into earliest phases of igneous activity in the Solar System.

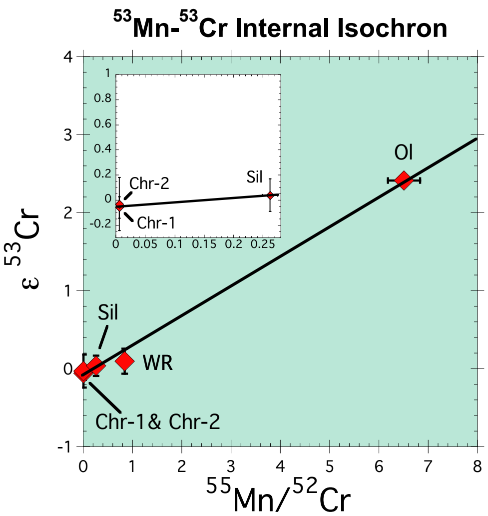

Figure 1: In this figure the ^{53}Mn-^{53}Cr internal isochron for Brachina is shown. The symbols refer to the average of 5 repeat analyses plotted as follows: olivine (Ol), whole rock (WR), silicates (Sil), Chromite (Chr 1 & 2). Chr-1 was hand picked while the Chr-2, Sil, and Ol were collected through careful differential dissolution. The initial $\varepsilon^{53}Cr_i = -0.071 \pm 0.047$ and a ^{53}Mn/^{55}Mn ratio of $(4.27\pm0.32) \times 10^{-6}$, taken relative to the D'Orbigny angrite age anchor [4,12], gives a ^{53}Mn-^{53}Cr age of 4564.8 ± 0.5 Ma. The ^{55}Mn/^{52}Cr errors are 2sigma are ±5% while the errors on the ε^{53}Cr representing 2 standard error is 2SE.

References: [1] Lugmair and Shukolyukov (1998) GCA. [2] Glavin D. P. et al. (2004) *MAPS, 39,* 693-700. [3] Shukolyukov and Lugmair (2006) EPSL. [4] Moynier et al. (2007) ApJ. [5] Trinquier A. et al. (2008) *GCA, 72,* 5146-5163. [6] Trinquier et al. (2007) ApJ. [7] Sanborn et al. (2015) LPSC. [8] Suguira and Fujiya (2014) MAPS. [9] Nehru C. E. et al. (1983) *JGR, 88,* B237-B244. [10] Mittlefehldt D. W. et al. (2003) *MAPS, 38,* 1601-1625. [11] Gardner-Vandy K. G. et al. (2013) *GCA, 122,* 36-57. [12] Wadhwa M. et al. (1998) *LPSC XXIX,* Abstract #1480. [13] Spivak-Birndorf L. J. andWadhwa M. (2009) *LPSC XXXX,* Abstract #2131. [14] Spivak-Birndorf L. et al. (2009) *GCA, 73,* 5202-5211. [15] Amelin Y. (2008), *GCA, 72,* 221-232. [16] Brennecka G. A. and Wadhwa M. (2012) *PNAS, 106,* 9299-9303. [17] Mercer C. M. et al. (2015) *LPSC, XXXXVI*, Abstract#2920. [18] Bouvier A. and Wadhwa M. (2010) *Nature Geocscience*, *3*, 637-641 [19] Connelly J. N. et al. (2008), *Astrophys. Journ.*, *675*, L121-124.