STRONTIUM-84 ANOMALIES IN THE EARLY SOLAR SYSTEM REVISITED. Jonas M. Schneider[1]*, Christoph Burkhardt[1], and Thorsten Kleine[1,2]. *jonas.m.schneider@uni-muenster.de, [1]Institut für Planetologie, University of Münster, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany, [2]Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany.

Introduction: Nucleosynthetic isotope anomalies in meteorites and their components may be used to trace the transport of solid material in the early solar system and to assess genetic relationships among and between meteorites and planets. For many elements the isotope anomalies among bulk meteorites allow differentiating between carbonaceous (CC) and non-carbonaceous meteorites (NC), which has led to the proposal that the solar accretion disk was subdivided into two co-existing but spatially separated reservoirs [1,2]. The isotope anomalies often also reveal characteristic trends among the individual meteorite groups within each reservoir, which provides critical information on the nature and origin of the NC-CC reservoir separation, and the compositional evolution within the NC and CC reservoirs.

Strontium is a promising target to identify nucleosynthetic isotope anomalies, because it has several isotopes that were produced by different stellar nucleosynthetic processes. Of the four stable Sr isotopes (^{84}Sr, ^{86}Sr, ^{87}Sr, ^{88}Sr), ^{87}Sr is the decay product of ^{87}Rb, which leaves the remaining three Sr isotopes for the identification of nucleosynthetic isotope anomalies. These are therefore typically expressed as variations in the ^{84}Sr/^{86}Sr ratio after internal normalization to ^{88}Sr/^{86}Sr. Prior studies have shown that nucleosynthetic Sr isotope anomalies exist in Ca, Al-rich inclusions (CAIs) and some bulk meteorites [3,4], but overall Sr shows less systematic isotope variations than almost all other elements and it is unclear as to whether there is a systematic offset in Sr isotope anomalies between NC and CC meteorites that goes beyond the effect of variable CAI addition, and whether or not there is a resolvable trend in Sr isotope anomalies within the NC reservoir. For example, while some [3] reported homogeneous ^{84}Sr isotope compositions for several NC meteorites (angrites and eucrites) and terrestrial rocks, others [5] reported resolved variations among NC meteorites and between some NC meteorites and terrestrial samples. Furthermore, whereas acid leachates of primitive chondrites seem to indicate that Sr isotope anomalies are related to variability in *s*-process Sr [6], it was recently shown that Sr isotope anomalies in CAIs rather seem to be caused by variations in the *p*-process isotope ^{84}Sr itself [7]. The Sr isotope variations among bulk meteorites may, therefore, reflect complex mixtures of isotopically distinct Sr from different nucleosynthetic sources and carriers.

To better constrain the origin of Sr isotope variations among meteorites, and to assess whether or not NC and CC meteorites have systematically different Sr isotope compositions, we obtained new high-precision Sr isotopic data for a comprehensive set of NC and CC meteorites, as well as several samples from Earth, Mars, and the Moon.

Materials and Methods: As terrestrial weathering can significantly alter the Sr isotopic composition of meteorite finds [4], we mostly selected meteorite falls and avoided meteorite finds from hot deserts whenever possible. Of the 35 meteorite samples analyzed in this study, only one is a desert find (NWA 4590), while seven are meteorite finds from Antarctica. The remaining 27 meteorite samples are all observed falls. In addition to these meteorites, ten terrestrial rocks and five lunar Apollo Samples were analyzed. The carbonaceous chondrites of this study were digested in Parr bombs using 1:1 HF-HNO_3, whereas all other samples were digested in 3:1 HF-HNO_3 on a hotplate. Strontium was separated from the sample matrix using established ion exchange procedures [e.g., 3]. The Sr isotope measurements were performed using the Triton Plus TIMS at the Institut für Planetologie in Münster, using a two-line dynamic acquisition method following the procedure described in [3]. The results are given in μ^{84}Sr values as the parts-per-million deviations of the ^{84}Sr/^{86}Sr ratio of a sample relative to that of the standard after internal normalization to a fixed ^{88}Sr/^{86}Sr. The reproducibility of the method was assessed by repeated measurements of the NIST SRM987 standard and is ±34ppm (2s.d.).

Results: Different samples of a given group or meteorite type have indistinguishable Sr isotope compositions, allowing the calculation of group means (Fig. 1). All NC meteorites of this study, including angrites, eucrites as well as enstatite and ordinary chondrites, display indistinguishable μ^{84}Sr values averaging at 5±5 ppm (2 s.d.). The terrestrial and lunar samples, and the martian meteorites all have μ^{84}Sr values that are indistinguishable from those of the NC meteorites (Fig. 1), and all samples together define mean μ^{84}Sr = 5±9 ppm (2s.d.). By contrast, the carbonaceous chondrites of this study, including CV, CM, CR, and CI chondrites as well as the ungrouped chondrites Tagish Lake (TL) and Tarda, have more variable μ^{84}Sr values, which range from the characteristic NC composition up to μ^{84}Sr anomalies of ~80 ppm (Fig. 1).

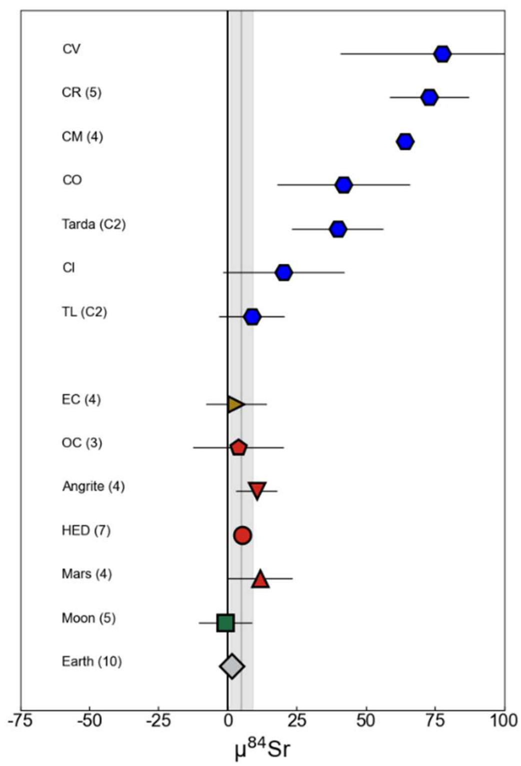

Fig. 1: New μ^{84}Sr data for meteorites and terrestrial samples of this study. Shown are meteorite group means with their associated uncertainties (95%c.i. for n≥4 and 2s.d. for n≤4).

Discussion: Unlike in some previous studies [5,8], we find no resolvable μ^{84}Sr variation between NC meteorites, Mars, and the Earth and Moon. This contrasts with the well-resolved and correlated isotope anomalies observed among NC meteorites for many other elements [6], including the Fe-group elements Cr and Ti, and the heavier elements Zr, Mo and Ru whose isotope anomalies are predominantly governed by variations in the abundance of *s*-process nuclides. The origin of this disparate behavior of Sr is unclear, but it may reflect either that the isotopically distinct carrier(s) responsible for the isotope variations among NC meteorites did not contain sufficient Sr, or that two competing processes (i.e., coupled *s*- and *p*-process variations) resulted in a net zero change of the Sr isotope compositions of NC meteorites. Either way, the μ^{84}Sr homogeneity among NC meteorites is inconsistent with an origin of nucleosynthetic isotope variability by thermal processing of SiC grains (e.g. [8]). When compared with other elements, this process would imply μ^{84}Sr variations among NC meteorites of at least 20-30 ppm, which is well outside the observed range for inner solar system materials.

The μ^{84}Sr variability among CC meteorites is largely controlled by their variable CAI contents. This is illustrated in Fig. 2, where the Ti and Sr isotopic composition of CC chondrites fall on mixing trajectories between an CI-like starting composition (essentially CAI-free) and CAIs. Thus, the entire μ^{84}Sr variability among meteorites is governed solely by the heterogeneous distribution of CAI. A possible origin of this apparent homogeneity among bulk materials other than CAI might be the early homogenization of a *p*-process carrier, which only survived in refractory inclusions like CAIs – as such leaving CAIs the only ^{84}Sr-anomalous components [7].

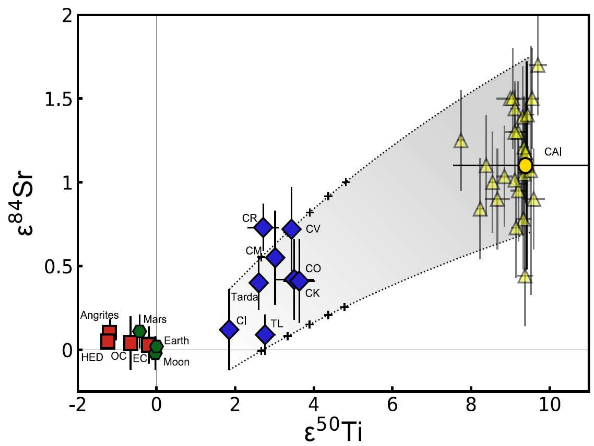

Fig. 2 The offset of carbonaceous meteorites can be explained by CAI admixture to CI-like material. Crosses on mixing lines denote 1% steps. Data for all CC chondrites (blue) are compiled from this study and [4]. Data for CAI are from [9], and ε^{50}Ti data are taken from compiled literature data [6].

References: [1] Warren, P. H. (2011), *Earth Planet Sci Lett*, *311,* 93. [2] Kleine, T. et al., (2020), *Space Sci Rev*, *216*. [3] Hans, U. et al., (2013), *Earth Planet. Sci. Lett. 374*, 204–214. [4] Fukai, R., Yokoyama, T., (2019), *Astrophys. J. 879*, 79. [5] Moynier, F. et al., (2012), *Astrophys. J*. 758:45. [6] Burkhardt, C. et al., (2019), *Geochim. Cosmochim. Acta 261*, 145–170. [7] Charlier, B.L.A., et al., (2021), *Sci. Adv. 7*. 28. [8] Paton, C. et al., (2013), *Astrophys. J. Lett. 763*, 2 [9] Brennecka, G.A. et al., (2020), *Science 370*, 837–840.