EARLY SOLAR IRRADIATION AS A SOURCE OF THE INNER SOLAR SYSTEM ISOTOPIC HETEROGENEITY. Y. Kadlag[1,2], J. Hirtz[2], H. Becker[1], I. Leya[2], K. Mezger[3], [1]Freie Universität Berlin, Institut für Geologische Wissenschaften, Malteserstrasse 74-100, Berlin, Germany, [2]Universität Bern, Physikalisches Institut, Sidlerstrasse 5, 3012, Bern, Switzerland, [2]Universität Bern, Institut für Geologie, Baltzerstrasse 1+3, 3012 Bern, Switzerland (yogita.kadlag@space.unibe.ch)

Introduction: Variations in neutron-rich isotopes of medium-mass elements such as ^{50}Ti, ^{54}Cr or ^{62}Ni in solar system objects are mainly attributed to heterogeneous infall of presolar dust with characteristic nucleosynthetic isotope compositions in different domains of the solar system at different times during the evolution of the solar nebula [e.g., 1,2]. Because nebular dust and pebbles resided in the solar nebula for at least 3 Ma (based on ^{26}Al-^{26}Mg ages of chondrules [3]) after the formation of the solar system, the contribution of a possible early solar irradiation of nebular dust and pebbles must be evaluated to fully understand mass-independent isotopic variations in solar system objects.

The depletion of ^{54}Cr in non-carbonaceous meteorites compared to carbonaceous meteorites has been attributed to the partially blocked flux of late-injected supernova remnant material into the inner solar system, possibly by growing proto-planetary embryos and destruction of ^{54}Cr-rich carriers by thermal processing in the inner solar system [4]. However, if the flux of freshly-injected supernova material was directed from the outer to the inner solar system and was partially blocked by proto-Jupiter [5], then ε^{54}Cr within the inner solar system should decrease towards the Sun, which does not appear to be the case. Enstatite chondrites, which presumably formed closer to the Sun than other meteorites have higher ε^{54}Cr than ordinary chondrites and HED meteorites. In this study, we have analyzed mass-independent Cr isotope variations in physically separated components from the unequilibrated enstatite chondrites, Sahara 97072 (EH3) and Kota Kota (EH3) to reveal the processes and time scales that affected neutron-rich isotopes in inner solar system objects.

Material and Method: Physically separated components from two unequilibrated enstatite chondrites, Kota Kota (EH3) and Sahara 97072 (EH3) were analyzed together with the reference materials BHVO-2, UBN, and the Allende Smithsonian standard powder.

Approximately 1 g chips of Kota Kota and Sahara 97072 were broken into pieces. Components such as chondrules, white mineral phases, and metal-troilite spherules were separated from the pieces. The remaining material was gently crushed and separated into different size fractions (< 80 µm, 80-150 µm, 150-200 µm 200-250 µm and > 250 µm) using nylon sieves and finally separated into magnetic, slightly magnetic, and non-magnetic fractions. All samples were dissolved in reverse aqua-regia in a high-pressure asher at 320°C. Mn/Cr and Fe/Cr ratios of the sample solutions were analysed in medium resolution on an Element XR™ ICP-MS. Powder of bulk Kota Kota (60 mg) was sequentially dissolved to obtain different fractions. Six different aliquots were prepared by progressive dissolution with weak (acetic acid) to strong ($HF+HNO_3$) acids. All samples were separated by a two-step column separation procedure [6] and Cr isotopes were analysed on a Triton TIMS following the method described in [4, 6].

Results: The ε^{53}Cr of UBN, BHVO-2, and Allende are 0.00 ± 0.08, 0.05 ± 0.08, and 0.05 ± 0.14, respectively. The values for ε^{54}Cr are 0.01 ± 0.08, 0.05 ± 0.14, and 0.85 ± 0.14, respectively. All values are in agreement with literature data [6, 7]. The ε^{54}Cr and ε^{53}Cr values of all samples analyzed in this study were corrected for spallogenic Cr using the equation described in [4] and exposure ages from [8]. The variations of ε^{53}Cr and ε^{54}Cr in the mechanically separated components of Sahara 97072 and Kota Kota range from -0.06 ± 0.07 to 0.39 ± 0.08 and -0.20 ± 0.15 to 0.59 ± 0.12, respectively. The variations of ε^{53}Cr and ε^{54}Cr in the differentially dissolved fractions of Kota Kota range from 0.02 ± 0.08 to 1.33 ± 0.08 and -0.15 ± 0.14 to 0.62 ± 0.26, respectively. The Fe/Cr ratio of mechanically separated components varies from 17 to 245, and in the differentially dissolved leachates of Kota Kota from 10 to 726. The ^{55}Mn/^{52}Cr ratio in mechanically separated components varies from 0.54 ± 0.05 (2SD) to 1.33 ± 0.09 and in differentially dissolved chemical leachates from 0.19 ± 0.01 to 22.0 ± 0.9.

Discussion: The observed heterogeneity of ε^{54}Cr and especially the enrichment in ^{54}Cr combined with high Fe/Cr in the metal-rich fractions of Sahara 97072 and Kota Kota compared to other components cannot be attributed to variable abundances of presolar grains in these fractions. Because of the extremely low abundance of presolar grains in chondrites, nucleosynthetic isotope variations caused by admixture of such grains should be independent of major element compositions. Cosmogenic contributions to Cr isotopes due to irradiation of meteoroid surfaces are relatively easy to constrain using exposure ages, Fe/Cr ratios, and physical models established in previous studies [4]. Because of the typically low exposure ages of the EH chondrites [8], subtraction of contributions from late irradiation results only in negligible changes in ε^{53}Cr and ε^{54}Cr. The slope of the ε^{54}Cr-ε^{53}Cr correlation in the magnetic fractions from Sahara 97072 and Kota Kota are ~ 3.3 ± 0.7 and 3.9 ± 0.1 (Fig. 1), respectively, which is similar within uncertainties to the theoretical slope of 3.6 ± 0.2 produced by irradiation of pure Fe [9]. Therefore, the correlation between ε^{54}Cr, ε^{53}Cr, and Fe/Cr in magnetic separates of EH3 chondrites suggests that variations in ε^{54}Cr and ε^{53}Cr in these materials could result from the irradiation of metal grains. Since the metal grains formed and accreted within the first few Ma after CAIs in a region close to the Sun, irradiation by solar energetic particles (SEP) could have been a potential source of cosmogenic ^{53}Cr and ^{54}Cr. Modeling of the irradiation of 1 mm to 50 cm sized CI chondrite-like dust and pebbles by galactic cosmic rays and solar energetic particles suggest that the observed isotope variations in the physically separated components of EH3 chondrites and in inner solar system planetary objects (such as Earth, Mars, Vesta and the ureilite and angrite parent bodies) can be generated by a 300 y to 0.3 My long irradiation of mm to cm sized dust and pebbles with average solar energetic particle fluxes of ~10^5 to 10^2 times the current SEP value, respectively.

The correlation of ε^{53}Cr with Mn/Cr observed in inner solar system objects [11] suggests that Mn and Cr-Fe rich phases were separated during high temperature processing of dust and gas. Elements more volatile than Cr were likely in the gas phase and were homogenized in the inner solar nebula. Thus, the near homogeneity of ^{53}Cr/^{52}Cr in inner solar system objects can also be attributed to early irradiation of dust, followed by the homogenization of volatile-rich gas in the inner solar system within the first few million years. In contrast, the record of ^{54}Cr may reflect spatial, compositional (and temporal) variations of refractory elements and Fe-bearing dust grains. This scenario best explains correlation of ^{53}Cr with Mn/Cr and ^{54}Cr with Fe/Cr and Fe/Cr in inner solar system objects including enstatite chondrites, ordinary chondrites, Mars, Vesta, ureilites, and other objects. The ε^{54}Cr of the modern silicate Earth is consistent with the accretion of 85% variably irradiated material (ε^{54}Cr of irradiated dust at 1 AU = -0.3) and final accretion of ~15% CI chondrite-like material (ε^{54}Cr of CI chondrites = 1.65).

Isotope variations of Cr in inner solar system objects, and presumably other some elements such as Ti and Ca indicate that the contributions from early irradiation of dust and pebbles in the inner solar system could have been significant. The elements more volatile than Cr (such as Mn, K) remain in gas phase during the period of irradiation and likely homogenized by diffusion of gas.

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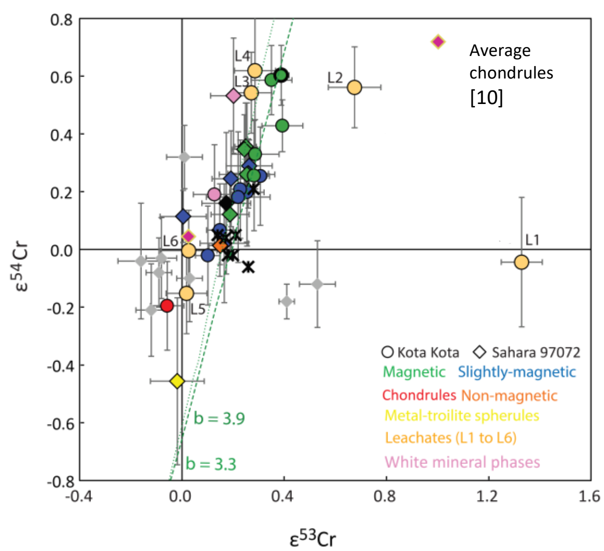

Fig. 1: ε^{54}Cr-ε^{53}Cr variation in physically separated components of the EH3 chondrites Kota Kota and Sahara 97072 and in chemical leachates of Kota Kota. Individual chondrule data from [9] of Sahara 97096 (paired to Sahara 97072) shown by gray symbols. Black crosses are whole rock data of enstatite chondrites from [5, 6]. The slopes of metal rich, magnetic fractions in Kota Kota (b = 3.3 ± 0.7) and Sahara 97072 (b = 3.9 ± 0.1) are indicated. Metal-rich leachate fractions of Kota Kota show higher and correlated ε^{54}Cr-ε^{53}Cr. The lowest ε^{54}Cr-ε^{53}Cr values are reported in the metal-troilite spherules, suggesting that their processing is different than matrix metal.