COSMIC-RAY-PRODUCED HELIUM AND NEON IN CHONDRULES IN ALLENDE AND MURCHISON. A. S. G. Roth, H. Baur, V. S. Heber, E. Reusser and R. Wieler. ETH Zurich, Department of Earth Sciences, Institute of Isotope Geochemistry and Mineral Resources, NW D84, CH-8092 Zurich, Switzerland. antoine.roth@erdw.ethz.ch

Introduction: Finding evidence for an irradiation of chondrules by energetic particles in the solar nebula prior to their incorporation into meteoritic matter (precompaction exposure) might yield information about the early solar energetic particle environment and also constrain the lifespan of chondrules as freely floating objects in the nebula. In a pioneering study, [1] searched for unusual differences in the densities of nuclear tracks among chondrules from ordinary chondrites. However, all observed track densities were entirely explained by exposure to galactic cosmic rays (GCR) during the journey of the meteoroid from its parent body to Earth. In contrast, Hohenberg and coworkers [2] reported large excesses of cosmogenic Ne in olivine grains with solar flare tracks in CM chondrites compared to track-free grains. If caused by GCR only, some of the gas-rich olivines would have suffered a precompaction exposure in a parent body regolith of several hundred million years. As this seemed excessively long, Hohenberg and coworkers suggested instead an irradiation by energetic particles from an early active sun. Smaller excesses of cosmogenic He, Ne and Ar relative to matrix samples were also reported for chondrules from some equilibrated chondrites [3], whereas a similar study did not find unambiguous differences [4]. This study reports concentrations of cosmogenic ^{3}He and ^{21}Ne and corresponding nominal GCR exposure ages of 23 chondrules from Allende (CV3) and 35 chondrules from Murchison (CM2) with individually determined major element concentrations. The low metamorphic grade as well as the short meteoroid exposure ages of these meteorites (Allende ~4 Ma and Murchison ~1 Ma) allow a relatively easy recognition of possible precompaction exposure records.

Results: Small meteorite chips were disaggregated by repeated freeze-thaw cycling. Unbroken chondrules were handpicked under a stereomicroscope and individually abraded using a corundum abrasion cell to remove matrix materials and potential solar gas-rich rims. Abraded chondrules were cleaned in an ultrasonic bath by acetone. Chondrules were then split under a stereomicroscope with a razor blade. The largest fragment was weighed and used for the mass spectrometric measurement of He and Ne concentrations and isotopic compositions by IR-laser gas extraction. Up to three remaining fragments per chondrule were measured for major element concentrations by electron probe microanalysis (on average 24 broad spot analyses per fragment). Mg and Si concentrations in a given chondrule were reproducible to within 18% and 12%, respectively. Production rates of ^{3}He and ^{21}Ne where determined with elemental production rates from a purely physical model [5], assuming present-day galactic cosmic ray flux and (somewhat arbitrarily) meteoroid radii of 32 cm and shielding depths of 4-6 cm.

All chondrules in Allende have noble gas concentrations (1σ) of 7.4±0.8 10^{-8}cm^{3}STP/g ($^3He_{cos}$) and 2.3±0.3 10^{-8}cm^{3}STP/g ($^{21}Ne_{cos}$). They thus exhibit very similar nominal ages of 4.1±0.4 Ma (^{3}He) and 3.2±0.4 Ma (^{21}Ne) (Fig. 1). Most chondrules in Murchison have noble gas concentrations of 2.6±0.8 10^{-8}cm^{3}STP/g ($^3He_{cos}$) and 0.8±0.3 10^{-8}cm^{3}STP/g ($^{21}Ne_{cos}$). Their corresponding ages range between 1.4±0.2 Ma (^{3}He) and 0.9±0.1 Ma (^{21}Ne). For Murchison, the age spreads are ~2 times lower than the spreads in $^3He_{cos}$ and $^{21}Ne_{cos}$ concentrations, proving the reliability of the production rate determination for each chondrule. The difference between nominal ^{3}He- and ^{21}Ne-based exposure age ranges may be due to the rather arbitrary assumption on shielding. Two chondrules with low nominal ages of ~0.4 Ma (^{3}He) and ~0.6 Ma (^{21}Ne) may have lost noble gases. However, six Murchison chondrules contain much more cosmogenic He and Ne than the majority, with concentrations up to 41.9±0.3 10^{-8}cm^{3}STP/g ($^3He_{cos}$) and 15.3±0.3 10^{-8}cm^{3}STP/g ($^{21}Ne_{cos}$). The highest nominal (GCR-only) ages are 24±1 Ma (^{3}He) and 22±2 Ma (^{21}Ne), respectively.

Discussion: All 23 chondrules from Allende and, with six exceptions, all 35 chondrules from Murchison show a remarkably narrow range of cosmic ray exposure ages. Their cosmic ray record is thus plausibly explained by their recent meteoroid exposure alone. This is supported by the basic agreement of noble gas ages given here with reported exposure ages of bulk Allende and Murchison [6-9]. Any precompaction exposure of chondrules would correspond to less than a few hundred thousand years of irradiation at present day GCR flux.

However, six out of the 35 Murchison chondrules show unequivocal precompaction exposure records, corresponding to up to 22 Ma irradiation at present-day GCR intensity in a 4π geometry. These He and Ne excesses may be related to (1) the inheritance of cosmogenic noble gases from chondrule precursors, (2) the irradiation of chondrules in the solar nebula by galactic and/or solar cosmic rays, or (3) the differential exposure of chondrules on the surface of the Murchison parent body.

It seems unlikely that the gas-rich Murchison chondrules inherited excess gases from relict olivine grains being originally as gas-rich as grains found by Hohenberg and coworkers. None of the studied gas-rich chondrules shows a He-Ne elemental fractionation as would be expected to have happened during the high temperature chondrule formation.

Whether the six Murchison chondrules were actually irradiated by galactic and/or solar cosmic rays as single objects free-floating in the solar nebula, or whether they may have been exposed on the surface of the Murchison parent body needs further study. CM chondrites are regolith breccias composed of lithic clasts (i.e. primary rocks) embedded in a fine-grained clastic matrix. Solar-flare track-rich olivines in Murchison are restricted to the clastic matrix [10]. Fragments of primary rocks are free of track-rich grains and solar noble gases and must therefore have formed in an environment shielded by cosmic rays. Because several analysed matrix fragments contained traces of solar Ne, it is reasonable to conclude that the six pre-exposed chondrules were originally from a matrix portion and hence were irradiated on the surface of the Murchison parent body. This is also in agreement with the absence of pre-exposed chondrules in our solar-gas-free chip of Allende. We thus prefer a scenario where some Murchison chondrules were exposed in a 2π geometry for up to about 50 million years prior to compaction of the meteorite. On the other hand, since 22 Ma seems excessive for the free-floating time of a chondrule in the nebula, in this case the noble gas excesses would certainly have been produced by a high fluence of energetic solar particles.

The 29 chondrules in Murchison that do not record precompaction exposure were probably not embedded in primary rock fragments because the studied chips of Murchison were mostly composed of fine-grained clastic matrix. Therefore shielded chondrules from immature regolith portions likely were freshly admixed to more mature regolith on the Murchison parent body.

Conclusions: Most of the 58 studied chondrules in Allende and Murchison contain very similar concentrations of cosmogenic He and Ne, limiting a potential pre-exposure in the Solar Nebula to a present-day GCR flux to less than a few hundred thousand years. This suggests an effective shielding of chondrules from energetic particles in the solar nebula and possibly a very short lifespan of chondrules in the nebula. Both implications are in agreement with the formation of chondrules in high-density and self-gravitating regions [11]. Six chondrules in Murchison unequivocally contain cosmogenic He and Ne from a pre-compaction exposure. Our preferred interpretation is a pre-exposure in the regolith of the Murchison parent body for up to several ten million years.

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References: [1] Allen J. S. et al. (1980) *Geochim. Cosmochim. Acta*, 44, 1161-1175. [2] Hohenberg C. M. et al. (1990) *Geochim. Cosmochim. Acta*, 54, 2133-2140. [3] Eugster O. et al. (*2007) Meteoritics & Planetary Science*, 42, 1351-1371. [4] Das J. P. and Murty S. V. S. (2005) In *International Cosmic Ray Conference*, 101-104. [5] Leya I. et al. (2000) *Meteoritics & Planetary Science*, 35, 259-286. [6] Rancitelli L. A. et al. (1969) *Science*, 166, 1269-1272. [7] Scherer P. and Schultz L. (2000) *Meteoritics & Planetary Science,* 35, 145-153. [8] Herzog G. F. et al. (1997) *Meteoritics & Planetary Science*, 32, 413-422. [9] Eugster O. et al. (1998) *Geochim. Cosmochim. Acta*, 62, 2573-2582. [10] Metzler, K. (2004) *Meteoritics & Planetary Science*, 39, 1307-1319. [11] Alexander C. M. O. et al. (2008) *Science*, 320, 1617-1619.

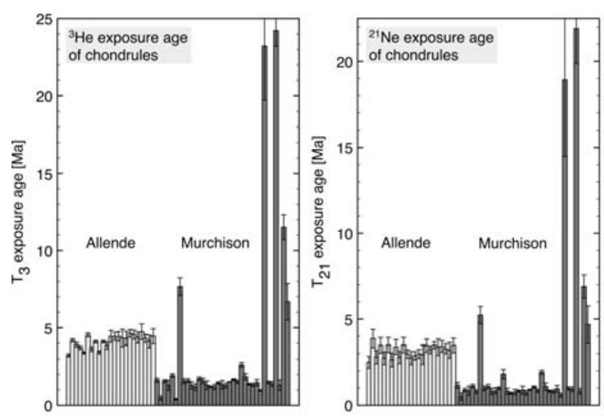

Figure 1: Bar charts of ^{3}He exposure age (left panel) and ^{21}Ne exposure age (right panel) for chondrules in Allende (light grey) and Murchison (dark grey).