COSMOGENIC NEON IN INDIVIDUAL CHONDRULE FRAGMENTS: RECORDS OF PRE-COMPACTION EXPOSURE. J. P. Das[1] , J. N. Goswami[2], O. V. Pravdivtseva[1], A. P. Meshik[1] and C. M. Hohenberg[1]. [1]Department of Physics, Campus Box 1105, Washington University, 1 Brookings Drive, Saint Louis, MO 63130, USA., jdas@physics.wustl.edu, [2]Physical Research Laboratory, Ahmedabad-380009, India.

Introduction: Studies of spallation-produced Ne in individual mineral grains from the matrix of CM chondrites provided records of pre-compaction exposure to energetic particles which, when coupled with parent body age constraints, yielded the first direct evidence of an active early (T-Tauri) Sun [1-3]. Young stars ~1 solar-mass are observed to go through an active (T-Tauri) phase as they contract toward the main sequence so this observation is not surprise. However, the "naked" T-Tauri phase is a more accurate description since most nebula gas must be dispersed in order to let solar energetic particles through [4].

Chondrules may provide similar records of pre-compaction exposure to energetic particles since they were clearly formed prior to incorporation in the parent meteorite. Based on absolute ages (e.g., Pb–Pb isochron, [5]) and constraints imposed by the extinct radionuclides ^{26}Al, ^{53}Mn and ^{129}I [6], chondrule formation is constrained to the several million years immediately after the formation of CAIs, the earliest solar system objects. Thus, chondrules too presumably formed during the active early stage of the Sun, and the presence of spallation-produced stable nuclides (e.g. noble gas isotopes, [1-3]), and solar flare particle tracks [7] should similarly document that exposure. In this work, we report spallation-produced ^{21}Ne in individual chondrule fragments.

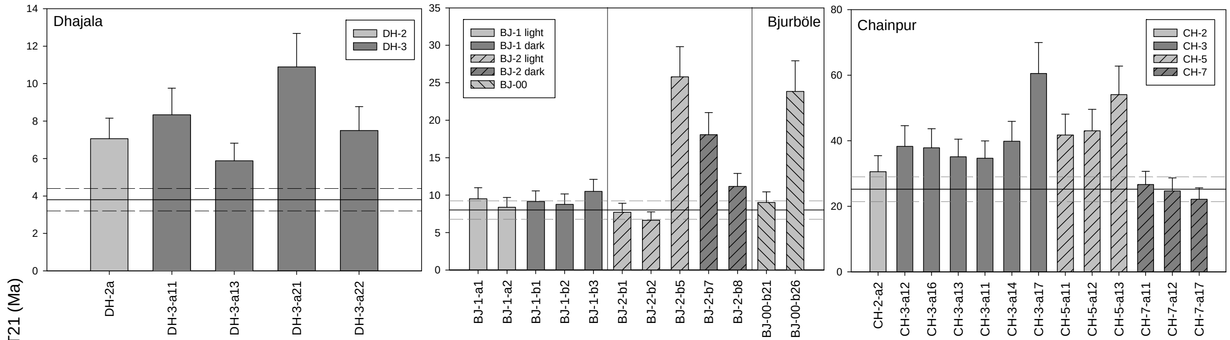
Laser extraction noble gas analysis: The samples of Murchison (CM2), Dhajala (H3.8), Chainpur (LL4), Bjurböle (L/LL4) and Parsa (EH3) meteorites were disaggregated by gentle crushing and high-powered ultrasonic agitation. The separated chondrules from disaggregated samples were then carefully broken into a few splits. The chemical compositions of these chondrule splits were determined by using the JEOL 540 SEM and the Tractor Northern 5400 X-ray system. The chemically characterized chondrule splits were then weighted by using a Mettler Toledo, model XP2U microbalance. The weight of chondrule splits was ranging from 2 to 230 μg. Gases from these splits were extracted by melting each fragment individually using the defocused beam of Nd-YAG laser in CW mode. Separated and purified helium and neon were then analyzed using the high sensitivity pulse-counting mass spectrometer system [8].

Results: 41 fragments from different chondrules were studied. For most samples, detectable amount of ^{21}Ne is found, whereas only few samples have detectable amount of ^{3}He. The Ne compositions of most chondrules are, as expected, mixtures of trapped and spallation components, with some suggestions of solar and Q-Ne. Resolution of the spallation contributions is largely independent of the trapped Ne details.

The amount of spallation-produced ^{21}Ne is dependent upon both the energetic particle exposure and the specific target chemistry. "Production" rates for ^{21}Ne were calculated based on the specific target chemistry of the respective grains using the formula suggested for diogenites (Table 6 of [9]). For shielding corrections, $(^{22}Ne/^{21}Ne)_c$ ratios of respective matrix/bulk were adopted for fragments of chondrules. The exposure "ages" shown in the figure are based upon the production rates for the current galactic cosmic ray (GCR) flux. Thus, CR "ages" those reflect only the production while part of the meteorite will be the conventional cosmic-ray exposure age (CRE) of the host, shown as the horizontal lines in the figure. However, it is found that some of the chondrule splits show higher apparent exposure "ages", indicating pre-compaction exposures to energetic particles.

As shown in the figure, 11 splits; DH-2a, DH-3-a21(Dhajala), BJ-2-b5, BJ-2-b7, BJ-00-b26 (Bjurböle), CH-3-a12, CH-3-a17, CH-5-a13 (Chainpur), Mur-sph, Mur-ch1(Murchison) and Par-1-a3 (Parsa) show evidence of higher apparent "ages" when compared with that of their respective host matrix, the conventional CRE age. In addition, in this first ever study on different fragments of single chondrules, it is observed that fragments from the same chondrules show different CRE ages (Figure)

Discussion: The excess apparent CRE "ages" in fragments of chondrules ranges from 5 to 35 Ma (Figure), such large excesses, up to 35 Ma, are observed first time in this study. Since, from the short-lived nuclides, chondrule formation must have been completed within a few million years after formation of CAIs [5, 6], if due to GCR irradiation, the energetic particle flux must have been greater than that of the current GCR secondary cascade, responsible for the nominal CRE of these meteorites. Neither the energy nor the flux of present solar energetic particles is sufficient to account for the effect within that constraint. This suggests that either the duration of the chondrule-forming events is underestimated or the pre-compaction setting of chondrules included exposure to a flux of energetic particles greater than the contemporary particle environment. Since earlier studies of grains from the matrix of



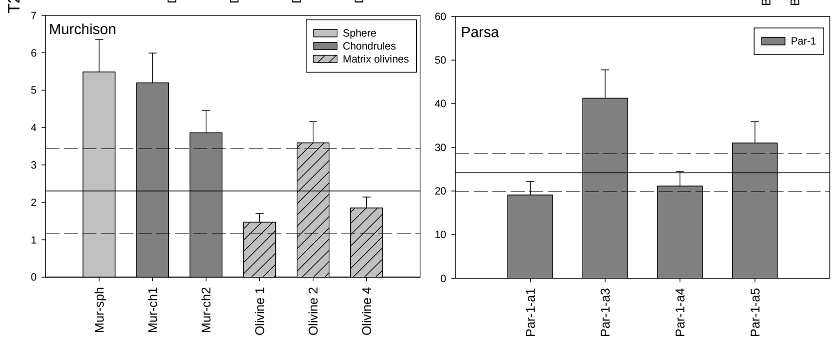


Fig. ^{21}Ne galactic cosmic ray (GCR) exposures ages for fragments of single chondrules from Dhajala, Chainpur, Bjurböle, Murchison and Parsa chondrites. Horizontal line in each panel represents ^{21}Ne GCR ages for matrix of respective meteorites except Parsa for which, ^{21}Ne age of bulk is used as reference.

gas-rich meteorites have provided evidence for exposure to an early more-energetic Sun [1-3], it is more likely that these chondrules experienced a similar exposure.

Additionally, it is observed that fragments from the same chondrules show different energetic particle doses, indicating an attenuation scale comparable with the chondrule size, and thus energies less than that of galactic cosmic rays. As for example, the fragments of chondrule BJ-2 show exposure ages ranging from 7 to 25 Ma. The radius of BJ-2 chondrule is estimated to be ~1.4 mm. In order for spallation to occur, energies of more than a few MeV are required. From SRIM software [10], the range of 10 MeV protons on the Mg-Al-Si targets with 3 g/cm^3 density is about 0.6 mm, thus it is possible that spallation production attenuates from surface to the interior of a chondrule provided the energy is a few tens of MeV. These criteria suggest that these chondrules were probably exposed to solar cosmic rays (SCR), perhaps more energetic and certainly more intense than the present SCR environment. The quantity of spallation-produced ^{21}Ne and the observed attenuation with position within the chondrules effectively argue against GCR irradiation. Thus, this study provides new evidence in favor of an enhanced solar energetic particle environment at the time shortly after chondrule formation, in agreement with the conclusions previously derived from the precompaction exposure of olivine grains in CM meteorites [1-3].

In summary, these results show that grains within chondrules were exposed to energetic particles prior to compaction and are often heterogeneous with respect to exposure doses. This suggests that chondrules were exposed to enhanced solar cosmic rays during or shortly after the chondrule formation process. In absence of known production rates for this enhanced flux, it is impossible to estimate the actual pre-compaction exposure times for the fragments. However, as in the case of individual olivine grains in the CM meteorites [1-3], the quantity of spallation ^{21}Ne indicates an enhanced (over the current particle environment) irradiation and the dose variability suggests a relatively low-energy irradiation. Both observations lead to the same conclusion derived from earlier single grain studies [1-3]: that pre-compaction irradiation of both chondrules and individual grains is due to an early active (T-Tauri) Sun [4].

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Additional Information: This work is supported by NASA grant NNX09AE83G.