**Fe-Ni AND Al-Mg ISOTOPE SYSTEMATICS IN CHONDRULES FROM UNEQUILIBRATED ORDINARY CHONDRITES:** R. K. Mishra[1], J. N. Goswami[1], S. Tachibana[2], G. R. Huss[3] and N. G. Rudraswami[1], [1] Physical Research Laboratory, Ahmedabad -38009, India, [2] Department of Earth and Planetary Science, University of Tokyo, 7-3-1 Hongo, Tokyo, Japan, [3]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, HI, 96822, USA.
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**Introduction:** The former presence of short lived now-extinct nuclide $^{60}Fe$, that decays to $^{60}Ni$ with a half life of 1.49 Ma, in early solar system solids has been well established [1-3]. Since $^{60}Fe$ is produced only by stellar nucleosynthesis, a precise initial solar system $^{60}Fe/^{56}Fe$ value will allow identification of the stellar source of this nuclide and its contribution to the inventory of the other short lived now-extinct nuclides present in the early solar system. At present, the solar system initial $^{60}Fe/^{56}Fe$ values inferred from studies of sulfide phases and chondrules in UOCs range from 3-10 x $10^{-7}$ [1-3]. This range of values was inferred with the assumption that chondrules in UOCs, Semarkona and Bishunpur, formed 1-2 Ma after the formation of CAIs and sulfide phases in UOCs were formed ~ 1Ma after CAIs. This range of values do not allow to choose between the various proposed stellar sources of $^{60}Fe$, namely Wolf Rayet star (WR star), thermally pulsating asymptotic giant branch star ( TP-AGB) and various stellar mass supernova. The time of formation for a set of semarkona chondrules has been reported based on Al-Mg isotope data [4-6]. We have conducted a combined study of Fe-Ni and Al-Mg isotope systematics in Fe-rich and Al-rich phases respectively, in chondrules from UOCs to address this issue.

**Sample Details and Analytical procedure:**
Chondrules from UOCs, Semarkona (LL3.0), LEW 86134 (L3.0) and Bishunpur ( LL3.1) were selected for this study. Fe-Ni isotope study was performed in Fe-rich phases (olivine, pyroxene) while Al-Mg isotope study was carried out on Al-rich glassy phases and occasional plagioclase phases found in chondrules. The isotopic analyses were done using a Cameca ims-4f ion microprobe at Physical Research Laboratory (PRL), Ahmedabad, and using a using Cameca ims-1280 ion microprobe at the University of Hawai'i (UH), Manoa.

For Fe-Ni isotope study, intensities of $^{57}Fe$,$^{60}Ni$ and $^{62}Ni$ ions were measured using the Cameca ims-4f at PRL. A 8nA $O^-$ primary beam was used and the measurements were made in peak jumping, pulse counting mode and at a mass resolution of ~ 4000, to avoid all major interferences apart from unresolved hydrides. Hydride contribution was found to be at less than per mil level. The count rates in $^{57}Fe^+$, $^{60}Ni^+$ and $^{62}Ni^+$ were ~$10^4$, ~20 and ~2 respectively. A typical analysis time lasted for a couple of hours. Dynamic background was monitored at 56.5 during the analyses. Measurements were repeated on the same spot as long as Fe/Ni ratio remain nearly the same to improve analytical precision. The instrumental mass fractionation was inferred by measuring low Fe/Ni phases within the chondrule and suitable terrestrial analogue. A plot of Fe-Ni isotope systematics in a Semarkona chondrule is shown in Fig. 1. The Fe-Ni isotopic study was carried out at the University of Hawai'i using a Cameca ims-1280. A focused, 15-30μm, 3-5nA, primary $O^-$ beam was rastered over a 20×20 μm squares on samples and standards. The secondary ions were accelerated to 10kV and passed through a 50eV energy window and the instrument was operated at a mass resolving power of ~5000. Secondary ions ($^{57}Fe^+$, $^{60}Ni^+$, $^{61}Ni^+$, and $^{62}Ni^+$) were counted on a monocollector electron multiplier. Each spot was measured for about 2 hours. Contributions due to molecular interferences of hydrides and molecular ions of oxides were found to be less than permil level. The instrument mass fractionation was based on measured $^{61}Ni/^{62}Ni$ ratio.

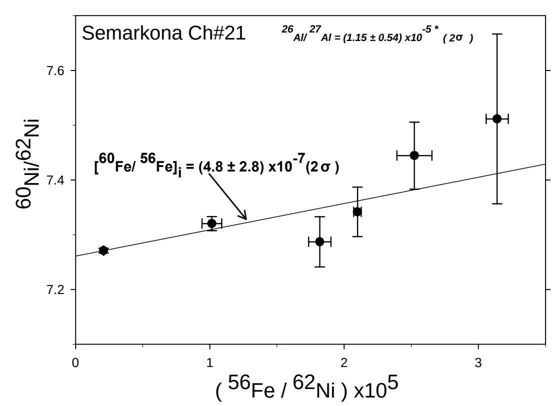


*Fig. 1. Fe-Ni isotope plot for a Semarkona chondrule (errors are 2σ)*

**Result and Discussion:**
Some of the preliminary result obtained at PRL and Hawaii have been reported earlier[7-10].The results obtained for UOC chondrules from the present study are shown in Table 1.

*Table 1. Initial* $^{60}Fe/^{56}Fe$ and $^{26}Al/^{27}Al$ values *in UOC chondrules**

| Sample | Initial ($^{60}Fe/^{56}Fe$) | Initial $^{26}Al/^{27}Al$ | Source |
|---|---|---|---|
| Semarkona (LL 3.0) | | | |
| SEM #2 | $< 2.9\text{x}\ 10^{-7}$ | $(5.5\pm 0.17)\times10^{-6}$ | PRL |
| SEM# 21 | $(4.8\pm 1.4)\times10^{-7}$ | $(1.15\pm 0.27)\times10^{-5}$ | PRL |
| SEM #39 | $(4.3\pm 1.2)\times10^{-7}$ | $<1.35\times10^{-5}$ | PRL |
| SMK3-6 | $(1.7\pm 0.6)\times10^{-7}$ | $(7.2\pm 1.4)\times10^{-6}$ | UH |
| SMK1-5 | $(3.2\pm 0.8)\times10^{-7}$ | $<6.7\times10^{-6}$ | UH |
| SMK1-6 | $<4.9\times10^{-7}$ | $(6.6\pm 1.0)\times10^{-6}$ | UH |
| Bishunpur (LL 3.1) | | | |
| BIS32 | $(1.9\pm 0.55)\times10^{-7}$ | $<3.5\times10^{-6}$ | UH |
| LEW 86134 (L3.0) | | | |
| LEW#36 | $(4.1\pm 1.3)\times10^{-7}$ | $(1.63\pm 0.6)\times10^{-5}$ | PRL |
| LEW#37 | $(4.9\pm 1.9)\times10^{-7}$ | ----- | PRL |

*Errors reported in Table-1 & shown in fig. 2 are 1σ.

Fig. 2 is a plot of $(^{60}Fe/^{56}Fe)_0$ vs. $(^{26}Al/^{27}Al)_0$ in the analyzed chondrules along with the expected trends, assuming co-injection of $^{26}Al$ and $^{60}Fe$, for three different values for solar system initial $^{60}Fe/^{56}Fe$ and using $^{26}Al$ as the time marker. In spite of the relatively

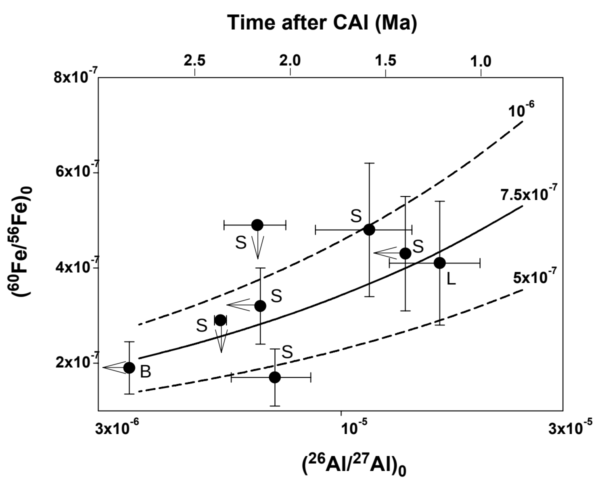


*Fig. 2.*$(^{60}Fe/^{56}Fe)_0$ *vs* $(^{26}Al/^{27}Al)_0$ *plot for chondrules from Semarkona, Bishunpur and LEW 86134*

large errors, resulting primarily due to low counting statistics, and upper limit values in several cases, a correlation between $(^{60}Fe/^{56}Fe)_0$ and $(^{26}Al/^{27}Al)_0$ can be discerned. The data lie in a band running from the lower left to upper right of Fig. 2. The three lines that bracket the data are model calculations of the change in $(^{60}Fe/^{56}Fe)_0$ and $(^{26}Al/^{27}Al)_0$ as a function of time starting from the generally accepted initial $^{26}Al/^{27}Al$ value for the solar system of $5\times10^{-5}$ and three different initial $^{60}Fe/^{56}Fe$ values as indicated on the plot. If $^{26}Al$ and $^{60}Fe$ were co-injected into the nascent solar system and distributed uniformly in the solar nebula at the time of CAI formation, the chondrule precursor solids that formed from solar nebula material and the chondrules themselves should fall along a trend such as those shown in Fig. 2. Our data do not support the suggestion [9] of a late injection of $^{60}Fe$, relative to $^{26}Al$, from the same stellar source. Previous studies of the short-lived nuclides $^{41}Ca$ and $^{26}Al$ in refractory phases in carbonaceous chondrites have shown that their presence and initial abundances are correlated indicating that they were injected together into the solar system from a stellar source [8]. Based on the results obtained in this study we can now include $^{60}Fe$ to the list of short-lived nuclides of stellar origin that were injected contemporaneously into the solar system.The results obtained in this study suggest an initial solar system $^{60}Fe/^{56}Fe$ value of $\geq 5\times10^{-7}$. This will suggest a high mass ( $>30M_\Theta$ ) supernova as the most plausible stellar source for $^{60}Fe$ as well as the other two nuclides (see, eg.,13].

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