THE INITIAL ABUNDANCE OF ^{60}Fe IN THE INNER SOLAR SYSTEM: EVIDENCE FROM CHONDRULES. M. Telus[1], G. R. Huss[1], S. Tachibana[2], and J. Goswami[3] [1]HIGP, Univ. of Hawai‘i at Mānoa, Honolulu, HI 96822 telus@higp.hawaii.edu, [2]Department of Earth & Planetary Science, University of Tokyo, 7-3-1 Hongo, Tokyo 113-0033, [3]Physical Research Laboratory, Ahmedabad-380009, India.

Introduction: Iron-60 is considered key for understanding the birth environment of the solar system. It can only be produced in significant quantities in stars, and a high initial $^{60}Fe/^{56}Fe$ in the solar system (5-10×10^{-7}) would point strongly toward a supernova source. Evidence from chondrites has pointed to a relatively high initial ratio [e.g., 1-4]. However, evidence from differentiated meteorites suggests a low initial ratio [see Wadhwa et al, this volume].

Recently, Ogliore et al. (2011) [5] demonstrated that the way much of the ^{60}Fe data collected by ion microprobe have been reduced results in a positive statistical bias that overestimates the $(^{60}Fe/^{56}Fe)_0$ ratio [e.g., 6]. This statistical bias also affects other isotopic systems measured by ion microprobe [6], and it potentially also affects other mass spectrometry data. In short, data collected with low count rates and reduced as the mean of the ratios measured in individual cycles is likely to be affected by this statistical bias. The University of Hawai‘i group is currently revisiting the ion probe data to which we have access to eliminate this statistical bias and determine which of the published data are reliable. A paper summarizing the results of this review will be submitted shortly, and the main findings will be presented at this workshop.

Partial review of previously published data: The discovery paper for ^{60}Fe in chondritic materials was Tachibana and Huss (2003) [1]. Re-analysis of these data showed that they were significantly affected by the positive statistical bias. When the data are re-reduced in a way that eliminates that bias, all of the reported excesses disappear (e.g., Fig. 1).

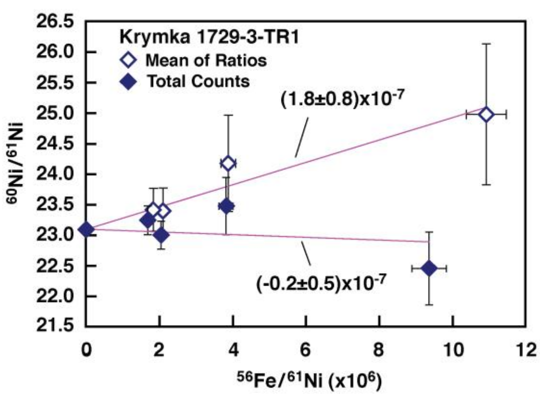

Fig. 1. Data for Krymka troilite TR1. Open symbols show data as reported in [1]. Filled symbols show the data reduced correctly using total counts. Error bars and uncertainties on initial ratios are 2σ.

Much of the previously reported chondrule data was also affected by positive bias [6]. For instance, Semarkona chondrule CH1-4, the discovery chondrule, was previously reported to have an initial ratio of (2.7±0.8)×10^{-7} [3]. However, using total counts, we do not find evidence of ^{60}Fe using ASU data (Fig. 2).

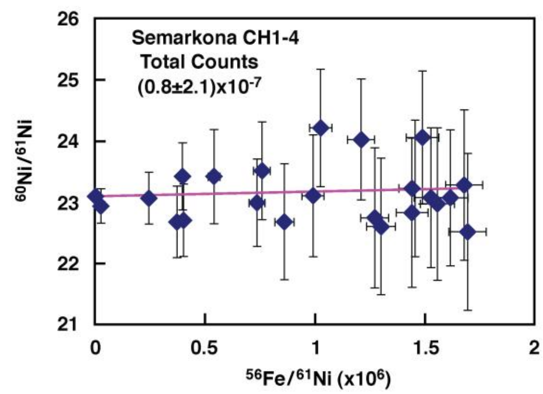

Fig. 2. Data for Semarkona CH1-4 obtained at ASU and reduced correctly using total counts does not show clear evidence of ^{60}Fe.

Other chondrules still show clear evidence of ^{60}Fe. For example, using total counts, the lower Fe/Ni-ratio spots of radiating pyroxene chondrule Semarkona DAP-1 give a $(^{60}Fe/^{56}Fe)_0$ ratio of (3.2±1.5)×10^{-7} (Fig. 3), compared to (4.2±2.0)×10^{-7} obtained from individual ratios. Using all points, $(^{60}Fe/^{56}Fe)_0$ from the errorchron is still resolved. Recalculations of Krymka chondrules reported in [7] still show evidence for ^{60}Fe, with initial ratios ranging from (1.0-2.7)×10^{-7}.

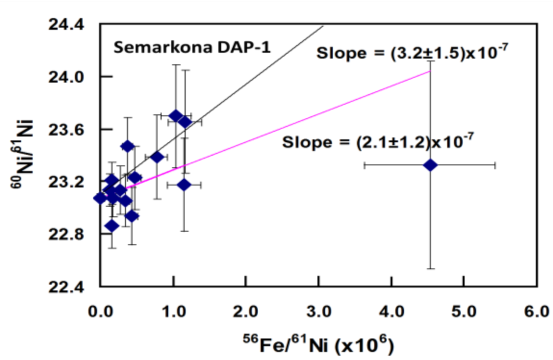

Fig. 3. Semarkona chondrule DAP-1 still shows evidence of ^{60}Fe after proper data reduction using total counts. The high Fe/Ni spot may be disturbed.

Recently measured chondrules: We have measured several additional radiating and porphyritic chondrules from ordinary chondrites Semarkona (LL3.0), Krymka (LL3.1), Bishunpur (LL3.1) and QUE97008 (L3.05) at the University of Hawai'i [8, 9]. Most chondrules have (^{60}Fe/^{56}Fe)$_0$ ratios that are unresolved from zero (Fig. 5). However, there are a few chondrules that seem to show resolved initial ratios. For example, radiating pyroxene chondrule, Krymka Ch11, gives a (^{60}Fe/^{56}Fe)$_0$ ratio of (2.7±0.5)×10^{-7} (Fig. 4).

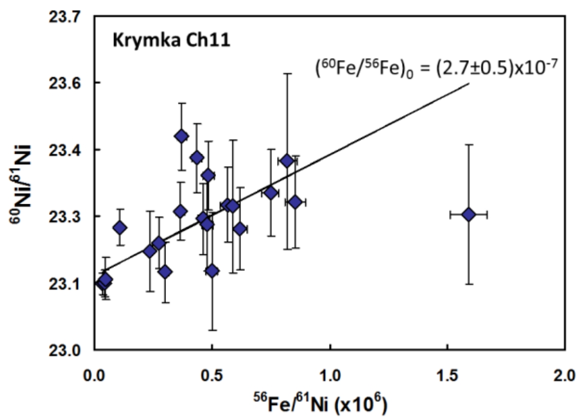

Fig. 4. Data for Krymka CH11 collected at UH and reduced correctly using total counts.

Discussion: Our most reliable chondrule data now shows indications of a spread in the (^{60}Fe/^{56}Fe)$_0$ among chondrules outside of experimental errors (Fig. 5). In particular, three QUE97008 chondrules have upper limits that are lower than the lower error bars of two Krymka chondrules (Fig. 5). The Krymka chondrules also show a resolved spread in initial ratios.

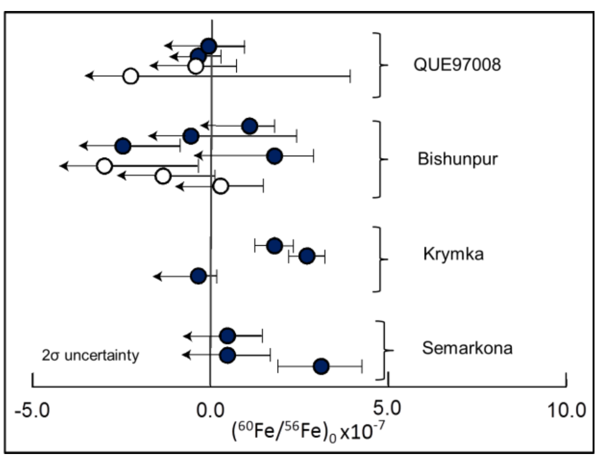

Fig. 5 (^{60}Fe/^{56}Fe)$_0$ for radiating chondrules (filled circles) and porphyritic chondrules (open circles) [8, 9].

Determining the initial abundance of ^{60}Fe in the solar system requires samples that formed rapidly and have remained undisturbed since formation. We have assumed that olivine and pyroxene in chondrules from type 3.0-3.2 chondrites are undisturbed. But only a few of the pyroxene-bearing chondrules that we have measured show clear evidence of ^{60}Fe. Before we can interpret our results in terms of chronology, isotopic heterogeneity in the solar system, or the solar system initial ^{60}Fe/^{56}Fe ratio, we must be sure that the scatter in the data is not due to isotopic disturbance or to residual experimental problems. Radiating pyroxene chondrules have high Fe/Ni ratios, but the pyroxene crystals are typically narrower than the ion probe beam, and the nickel is in part located in tiny metal or sulfide grains between the pyroxene crystals. These grains may be susceptible to aqueous alteration, so the very highest Fe/Ni points (e.g., Figs. 3, 4) may reflect secondary processing. In addition, a lack of Ni diffusion data for pyroxene makes the thermal stability of pyroxene difficult to assess.

Taking the data in Fig. 5 at face value, one might infer that the chondrules formed over a minimum time period of ~3 million years. In this case, the highest measured ratio of ~3×10^{-7} would be a lower limit on the initial ^{60}Fe/^{56}Fe ratio in the solar system. If this value is taken to represent the ratio when chondrules formed, assumed to be ~2 million years after CAIs based on ^{26}Al data, then the inferred initial ratio for the solar system is ~5×10^{-7}. This value is lower than we inferred previously [3, 4]. Alternatively, one might infer that a spatial heterogeneity in the distribution of ^{60}Fe existed in the early solar system. But these interpretations require that the data are reliable.

Conclusions: The recent discovery that much of the published ion probe data for the ^{60}Fe-^{60}Ni system was incorrect has been a serious setback to the attempts to infer the initial ^{60}Fe/^{56}Fe ratio for the solar system and to establish the ^{60}Fe-^{60}Ni system as a chronometer. However, after re-analyzing much of the published data and making a series of new measurements, we conclude that there is still solid evidence for ^{60}Fe in chondrules from primitive chondrites and that the initial ratio for the solar system is in the range of (3-5)×10^{-7}. This value is somewhat lower than earlier estimates, but it is significantly higher than is inferred from differentiated meteorites. Our next task as a community is to understand this difference.

References: [1] Tachibana S. and Huss G. R. (2003) *Astrophys. J.* **588**, L41-L44. [2] Mostefaoui S. et al. (2005) *Astrophys. J.* **625**, 271-277. [3] Tachibana S. et al. (2006) *Astrophys. J.* **639**, L87-L90. [4] Mishra R. K. et al. (2010) *Astrophys, J.* **714**, L217-L221. [5] Ogliore R. C. et al. 2011. *Nucl. Instrum. Methods. Phys. Res. B*, **269**, 1910-1918. [6] Huss G. R. et al. (2011) *Lunar & Planet. Sci.* **42**, #2608. [7] Tachibana S. et al. (2009) *Lunar & Planet. Sci.* **40**, #1808. [8] Telus M. et al. (2011) *Lunar & Planet. Sci.* **42**, #2559. [9] Telus M. et al. (2011) *MAPS* **46**, s1, A232 #5489.