CONDENSATION OF CHONDRULES: CONDITIONS FOR "FIERY RAIN".

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Introduction: Ebel and Grossman [1] computed stability fields of ferromagnesian liquids at canonical nebular total pressures, P^{tot}, 10^{-3} to 10^{-6} bar, in systems enriched up to 1000x in CI dust that are otherwise solar in composition. They concluded that most chondrules cannot be made in this way because very little Na condenses above the solidus, and Na_2O contents of most chondrules plot above Na_2O-FeO trajectories of calculated condensates. A much more difficult constraint to satisfy comes from recent work on the distribution of Na between olivine and chondrule glass, that indicates that ≥90% [2] or ~50% [3] of the Na was condensed at near-*liquidus* temperatures. In the context of melting chondrule precursors, we showed that Na retention at chondrule liquidus temperatures requires dust enrichments $>10^4$x even at total hydrogen pressures of 10^{-1} bar, and suggested that the appropriate conditions may be found in liquid+solid+vapor plumes generated by impacts on icy planetesimals [4]. Because that result is based on an equilibrium condition, it implies that chondrule-like assemblages may be able to condense from cosmic gases at much more extreme conditions than explored by [1]. Therefore, in the present work, we investigate compositions of condensate assemblages computed to form at combinations of very high dust enrichment and P^{tot}.

Results: In a system enriched in CI dust by a factor of 1000 relative to its complementary solar gas, a ferromagnesian silicate-liquid and a liquid NiFe alloy are stable at T>>2000K at P^{tot}=1 bar. Olivine, X_{Fa}=0.08, becomes stable at 1900K, where log f_{O2}=IW-1.4, 61% of the Na is condensed into the liquid and X_{Ni} of coexisting metal is 0.11. S condenses at T>1670K, forming an Fe-S liquid. X_{Fa} of olivine reaches 0.28 by 1320K, so spans the range found in many Type II chondrules. The proportion of Na condensed at the temperature of olivine appearance increases at even higher total pressure, *e.g*., to 75% at 2 bars, but increasing Na by raising dust enrichment increases the f_{O2}. If instead the system is enriched in completely dehydrated CI dust by a factor of 1000, a ferromagnesian liquid and a liquid NiFe alloy are still stable at T>>2000K at 1 bar P^{tot} but, in this case, olivine, X_{Fa}=0.028, becomes stable at 1960K, where log f_{O2}=IW-2.5, only 43% of the Na is condensed into the liquid and X_{Ni} of coexisting metal is 0.06. In this case, X_{Fa} reaches only 0.07 by 1260K, so spans the range of many Type I chondrules. If the dust enrichment is increased to 2300 in this case, 74% of the Na is condensed when olivine becomes stable at 1930K, and X_{Fa} ranges from 0.05 to 0.15.

Conclusions: At $P^{tot} \geq 1$ bar, equilibrium condensate assemblages in systems enriched by a factor of 1000 in CI dust contain olivine with the X_{Fa} of chondrules at 2000-1300K, and ferromagnesian silicate liquid that has Na_2O contents ≥0.75 wt% at the appearance temperature of olivine. If impacts on CI parent bodies can generate plumes with cooling rates of chondrules, as well as dust enrichments and P^{tot} like those explored here, chondrules are likely products.

References: [1] Ebel D. S. and Grossman L. 2000. *Geochimica Cosmochimica Acta* 64:339–366. [2] Alexander C. M. O'D. *et al*. 2008. *Science* 320:1617-1619. [3] Hewins R. H. *et al*. 2012. *Geochimica Cosmochimica Acta* 78:1-17. [4] Fedkin A. V. *et al*. 2012. Abstr. #2565. 43rd Lunar & Planetary Science Conf.