**Introduction:** Chondrules are variable in composition [1-4] and in texture and the proportions of different types vary in different chondrite types. The variety of bulk, mineral and isotopic compositions, and textures, form a basis for interpreting chondrule formation processes. Many chondrules have textures indicating rapid growth at near-liquidus temperatures [5]. This is generally accepted, but the nature of chondrule precursor material and its interaction with its environment during heating and cooling is still debated.

**Precursors:** Chondrules might have formed by the heating of primitive solar system dust, with evaporation and reduction forming the dispersion of chondrule compositions [6-8]. Alternately, they were derived from nebular condensates, and processed added lower temperature components. Both presolar material and nebular condensates are expected to be very fine-grained and such materials fail as precursors of typical porphyritic chondrules, which require a coarser-grained material supplying fewer nuclei to the melt [9].

More processed precursors such as annealed or melted refractory inclusions, granular olivine aggregates (GOA) and chondrule material are possible. The observations of Krot [in 10] document cases of RI material incorporated into chondrules especially in CC, and thoroughly melted Al-rich chondrules may have arisen in this way. GOA have been identified in Type I chondrules in CC [11]. GOA represent either protoplanetary material formed before most chondrules [11], or annealed condensate material [12].

The most popular concept for a chondrule precursor is the dustball [13] containing both fine and coarse material. For CC IA chondrules, both coarse-grained (GOA, RI) and dustball precursors are required to explain the textures [14]. In some OC Type IA chondrules, textures can be explained by the disruption of GOA during melting. Relic grains in both Types I and II in OC suggest that the precursors included chondrule debris. Thorough melting of many PO and all BO removes evidence of the precursors, and in OC the melting events may be multiple. Indeed, [15] suggested that in OC, chondrules were their own immediate precursors.

**Open systems:** Chondrule-gas interaction and volatiles in chondrules are a key to nebular conditions. We showed that Type II chondrules were chondritic in alkalis [16], and [17] showed that even at 1 atm, Na could not be retained at cooling rates required for chondrule textures.

Evaporation experiments in low pressure hydrogen reproduce some aspects of Type I chondrule properties by Fe loss, including the high Ca concentrations of forsteritic olivine [8] and the loss of S and Fe from different type I chondrules [18,19]. However, the features they document are not fully compatible with natural chondrules. S is rapidly lost from chondritic melts, yet Type II chondrules retain some troilite. K isotopes are fractionated in experiments, but not in chondrules [20]. Chondrules should be devoid of alkalis, as well as of metal, if they experienced any evaporation of FeO [8, 20, 21], yet even Type I chondrules contain moderate concentrations of Na. Enrichments towards the edge of Type Is [22] is consistent with Na condensation from the ambient gas. Metallic Fe evaporates faster than silicate Fe in a canonical gas [21], yet metal is common in magnesian Type I chondrules and [19] reported partial loss of Fe both from metal and from silicates. Oxygen evaporates and mass fractionates in experiments [23], yet the isotopic signature in chondrules is mixing or mass-independent effects.

It is now well documented that, for chondrules in OCs, the ambient gas had high partial pressures of Na and other lithophile elements, produced by evaporation from chondrules or accompanying fine dust, and (re-)condensation during chondrule formation would have been normal. Type II chondrules have chondritic Na [16] and Type I mesostasis contained enough Na to crystallize Na-bearing augite [3]. [24] showed that if molten chondrules interacted with solar to non-solar gases, Na contents were likely to change very little, though IA chondrules could have gained Na.

These considerations have lead to a series of melting experiments under high partial pressures of lithophile elements. SiO condensation experiments have duplicated textures of Type IA chondrules with pyroxene near the rims, suggesting that IAB chondrules would be the end result of this process [25]. Condensation experiments involving Na in the vapor are relevant to many aspects of chondrules [26-28].

Unlike alkalis, metals cannot dissolve in chondrule melts and therefore build opaque veneers when condensing onto chondrules: [19, 29-30] demonstrated condensation of volatile siderophile elements on CR2 chondrules, and sulfide veneers around Semarkona chondrules are ubiquitous [31].

**Na in olivine and melt:** The concentration of Na in minerals such as olivine can potentially indicate if they were in equilibrium with the chondrule melt, in turn giving an idea of pNa when the chondrules melted and cooled. Alexander et al. [32] recognized this and estimated very high pNa, leading to high solid densities in clumps heated to form chondrules. Since their work, there have been three experimental studies on the partitioning of Na between olivine and melt [26-28]. [26] used ferroan compositions, but [27-28] used Fe-free melts, with Na-rich vapor. [26] reported Na loss with time, but [28] used closed capsules, ensuring that olivine cores remained in equilibrium with melt at the end of the experiments. The value determined by [27, 28] for the FeO-free DO_d(O/Liq) are similar. The dependence of DO_d on FeO in olivine [27-28] is not well constrained, being based only on experiments by [26] and natural chondrules.
Fractional crystallization of a liquid changes its structure, and increases its Na solubility [28]. Based on the experiments of [28], fractionation can lead to condensation of Na into the melt from a gas with a high pNa. Glass inclusions in olivine in Semarkona Type II chondrules have lower Na than expected for fractional crystallization from the present bulk composition. This could be explained by condensation of Na to the melt after the inclusions were trapped, which would mean that Na in the bulk composition after the chondrule forming event was higher than its initial value.

Core Na concentrations Semarkona Type II chondrule olivine correlate with CaO and Fa. Based on the dependence of DNAs on olivine FeO [28], olivine rims [our data and 32] are in equilibrium with the glass in the pyroxene-bearing mesostasis. Some olivine cores also appear to be in equilibrium with melt taken as the bulk chondrule composition. Other olivine cores, particularly in IIA chondrules, have very high DNAs [this work and 32], which is incompatible with coexistence of olivine cores and the bulk liquid. Condensation, proposed above, would lead to low apparent DNAs, not high ones. Evaporation during crystallization would yield bulk compositions lower in Na than the initial, and thus explain high apparent DNAs. However some IIA olivine cores have extremely high Na and DNAs varies because of olivine Na, not melt Na. This suggests olivine formed from an Na-rich boundary liquid or Na diffused into olivine during crystallization (such that the cores are in equilibrium with late liquid). Examination of Fe-Mg zoning for these chondrules could confirm this if low cooling rates were indicated.

Chondrule relationships: Nebular turbulence tends to concentrate chondrule-sized objects into cluster [33] and chondrule properties can be explained in shock wave models if chondrule formation involved clumps of chondrule-sized precursors [34]. pSiO, Fe,K,Na,S were high as (some) chondrules may have been derived from a different source region than the Type Is. Clusters are absent from CCs whose chondrules were less processed and had precursors devoid of S [36].

Conclusions: Chondrules have experienced some volatile loss (Fe from type Is in CRs, S from type Is in OCs) followed by re-condensation on their surface for the elements of opake minerals. Type II chondrule melts acquired Na while cooling in ambient gas, and equilibrium Na partitioning exists between olivine rims and interstitial glass. The high pNa requires high concentration of chondrules for OC which indeed contain clusters. However, variations in chondrule compositions do not result exclusively from evaporation/condensation processes, as precursor composition effects clearly exist as well. For example, chondrule precursors for type Is in CCs contained no S unlike those in OCs.