Introduction: It is generally believed that chondrules lost virtually all their trapped noble gases upon their formation at high temperatures [1, 2]. However, it is not clear whether earlier reported small trapped noble gas concentrations were real or stemmed from contamination with clastic rim or matrix material that often surrounds chondrules.

In contrast, Okazaki et al. [3] recently found large concentrations of noble gases with a subsolar element pattern in chondrules of an enstatite chondrite (EH4), which are embedded in matrix with a normal Q-pattern. Relative to solar abundance subsolar noble gases are depleted in the light elements, but the depletion is less than for the Q-component [4]. The preferred explanation by Okazaki and co-workers [3] is an irradiation of the chondrule precursor material with solar wind ions (SW) near the sun. The subsolar element pattern was then established by strong fractionation of the SW noble gases during chondrule formation. The chondrules were transported to colder regions of the disk by the X-wind, where they accreted with low-temperature dusty material. This scenario leads to the expectation that other primitive meteorites contain such noble gas rich chondrules as well.

We measured Ne and Ar in 27 chondrules of the primitive chondrites Allende (CV3red), Leoville (CV3red), Krymka (LL3.1), Bishunpur (LL3.1), and Semarkona (LL3.0) to determine their trapped noble gas composition. The low temperature fine-grained material surrounding chondrules may be similar to the chondrule precursor dust [5]. Therefore, we also measured noble gases in fine-grained rim- and matrix-material („fine-grained samples“). This also served to check for contamination of our chondrule samples with fine-grained material.

Experimental: Small amounts (~20–900 µg) of chondrules and fine-grained material were separated under a binocular microscope from polished sample slices that had previously been investigated by SEM. Special attention was paid to avoid cross-contamination, since the fine-grained material may contain much higher noble gas concentrations than the chondrules themselves. After a 24 hour bakeout in vacuum at ~100 °C to remove atmospheric gases, the noble gases were extracted by melting the samples with an IR laser in CW-mode. This provides very low blanks of 7±4x10⁻¹⁵ and 2±4x10⁻¹³ cm³STP for ²⁰Ne and ³⁶Ar, respectively, which corresponds in most cases to less than a few % of the measured gas concentrations. However, the major part of the measured ²⁰Ne and ³⁶Ar in the chondrules is of cosmogenic origin, and their trapped noble gas concentrations (²⁰Neₜ, ³⁶Arₜ) that were calculated via the cosmogenic ²¹Ne and ³⁸Ar, respectively, may in some cases be comparably low as the blank values. Only chondrules where the blank correction amounted to less than 20% of their inferred ²⁰Neₜ and ³⁶Arₜ concentrations are considered here (for one exception see caption of Fig. 1).

Results: The major part of the chondrules shows no measurable ²⁰Neₜ but small concentrations (< 2x10⁻⁸ cm³STP/g) of ³⁶Arₜ. Only two chondrules revealed neither ²⁰Neₜ nor ³⁶Arₜ. In 9 chondrules both ²⁰Neₜ (up to 2x10⁻⁸ cm³STP/g) and ³⁶Arₜ (up to 7x10⁻⁷ cm³STP/g) were detected, with element ratios (³⁶Ar/²⁰Ne)ₜ ranging from <0.1 to 28 (Fig. 1).

In contrast, the fine-grained samples generally show much higher noble gas concentrations of up to ~4x10⁻⁷ and ~7x10⁻⁶ cm³STP/g for ²⁰Neₜ and ³⁶Arₜ, respectively. Their Ne isotopic composition is mostly HL-like, indicating the presence of presolar diamonds that carry mainly He and Ne but are depleted in heavier...
noble gases [8], whereas the Ar-isotopic composition points to phase Q [10] as the main carrier phase for heavy noble gases. The ratios \((^{36}\text{Ar}/^{20}\text{Ne})_{\text{tr}}\) of \(\sim 10-40\) in fine-grained samples of Leoville, Krymka, Bishunpur and Semarkona all lie in the range of Q-ratios (Fig. 1). Only Allende with \((^{36}\text{Ar}/^{20}\text{Ne})_{\text{tr}}\) ratios of \(\sim 3-6\) displays a slightly higher portion of the HL- relative to the Q-component.

If the trapped noble gases in the chondrules would stem from cross-contamination, their \((^{36}\text{Ar}/^{20}\text{Ne})_{\text{tr}}\) would be identical to those of the respective adjacent fine-grained material. This is the case for three chondrules (Fig. 1), which are thus excluded from further discussion. However, the ratios \((^{36}\text{Ar}/^{20}\text{Ne})_{\text{tr}}\) of the 6 remaining chondrules from Semarkona and Bishunpur with a maximum \(^{30}\text{Ar}_{\text{tr}}\) of \(\sim 5x10^{8}\) cm\(^3\)STP/g lie distinctly below those of the respective fine-grained samples. Three of these chondrules show \((^{36}\text{Ar}/^{20}\text{Ne})_{\text{tr}}\) values even lower than the air ratio of 1.9. This proves that the trapped noble gases of these 6 chondrules were not due to residual atmospheric contamination, as atmospheric Ar would have remained adsorbed more effectively than Ne. Therefore we conclude that 6 out of 27 chondrules contain measurable concentrations of \(^{20}\text{Ne}_{\text{tr}}\) and \(^{34}\text{Ar}_{\text{tr}}\) that were neither caused by atmospheric contamination, nor by contamination with fine-grained material or imprecise blank corrections.

**Discussion:** Although we still lack basic knowledge about the precursor material of chondrules, it must have been very primitive [11]. A promising candidate is the fine-grained matrix-like material in type 3 ordinary and carbonaceous chondrites [5]. Therefore the measured noble gas patterns in the fine-grained samples may serve as a proxy for noble gases in chondrule precursor material. Any high-temperature processing of such material would fractionate the noble gases towards higher \((^{36}\text{Ar}/^{20}\text{Ne})_{\text{tr}}\). On the one hand this is because the main Ne-carrier phase in primitive bulk meteorites (presolar diamonds) degasses at lower temperatures than phase Q [12, 13], which carries most of the trapped Ar, on the other hand Ne diffuses faster than Ar. Therefore the \((^{36}\text{Ar}/^{20}\text{Ne})_{\text{tr}}\) ratio of the precursor material of the obviously molten chondrules should have been lower than the measured values in the chondrules themselves, implying that the measured fine-grained material as it is present in the primitive chondrites today cannot explain the element ratios of the 6 chondrules under discussion.

A possible precursor may be an HL-rich material, but this is rather improbable, given its low resistance during thermal processing. Also chondrule formation in a strongly oxidising environment, which could possibly cause a preferential attack of the Q-carrier [7], is in contrast to the generally held view that the most reducing conditions existed closest to the sun. A more attractive explanation is that the chondrules obtained small concentrations of rather unfractionated solar noble gases via entrapping into melt during their formation near the young active sun.

These small amounts of solar gases may be recognisable in those chondrules which were most effectively molten, and thus contain the lowest Q-gas concentrations from their precursor material. Indeed, the chondrules with the lowest \(^{36}\text{Ar}_{\text{tr}}\) concentrations also display the lowest ratios \((^{36}\text{Ar}/^{20}\text{Ne})_{\text{tr}}\). The element ratios in our 6 chondrules under discussion could then be interpreted as mixtures of solar gases and remnants of Q-gases.

In contrast, Okazaki et al. [3] need to explain for their chondrules up to 2 orders of magnitude larger \(^{36}\text{Ar}_{\text{tr}}\) concentrations than the values found here. Such values would be too high to be accounted for by solution into melt. A second difference to our chondrules is their fractionated subsolar element pattern. Therefore Okazaki and co-workers [3] propose an irradiation of very fine-grained chondrule precursor material with large amounts of SW-noble gases, followed by subsequent melting and strong fractionation.

**Conclusion:** In contrast to results of Okazaki et al. [3] the chondrules of the 5 primitive carbonaceous and ordinary chondrites Allende, Leoville, Krymka, Bishunpur, and Semarkona do not contain subsolar noble gases. 6 out of 27 chondrules from Semarkona and Bishunpur contain measurable concentrations of trapped \(^{20}\text{Ne}_{\text{tr}}\) and \(^{36}\text{Ar}_{\text{tr}}\). Their element ratios either point to an HL-rich chondrule precursor material or, more probably, to a mixture of small amounts of solar gases and remnants of Q-gases from the chondrule precursor material. In the latter case, the solar gases may have been entrapped into the molten chondrules during their formation near the young sun.