

**Q in Saratov (L4).** Sachiko Amari<sup>1</sup>, Scott Messenger<sup>2</sup>, Simon J. Clemett<sup>3</sup>, and Alexander Meshik<sup>1</sup>, <sup>1</sup>Physics Department and The McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130, USA. E-mail: sa@physics.wustl.edu. <sup>2</sup>Robert M Walker Laboratory for Space Science, EISD, ARES, NASA Johnson Space Center, Houston, TX 77058, USA. <sup>3</sup>ERC, Inc. / JACOBS, 2224 Bay Area Boulevard, Houston, TX 77023, USA.

## Introduction:

It has been known that the majority of heavy noble gases in chondrites are contained in a very small portion of meteorites, named Q for quintessence [1]. Subsequent studies indicate that Q is present in various chemical and petrologic types of chondrites [2-6]. The noble gas elemental abundance pattern is characterized by high enrichment of the heavy noble gases. Isotopic ratios of the Q-gases are fairly uniform except for Ne [5]. In contrast, the nature of Q remains elusive. Q is most likely carbonaceous matter [7] although Marrocchi et al. [8] have recently proposed sulfides are also Q along with carbonaceous phases.

## Experimental:

In an ongoing effort to identify and isolate Q from Saratov (L4) [9, 10], we carried out separation of the HF-HCl residue produced previously [11]. After 4 successive cycles of colloidal separation, density separation was carried out, yielding 7 density fractions with the density ranging from 1.26 to > 2.5 g/cm<sup>3</sup> (Fig. 1). Noble gases in the 7 fractions were analyzed in two temperature steps, 800°C and 1600°C, with a high-sensitivity noble gas mass spectrometer SuperGnome at Washington University in St. Louis.

We analyzed organic species with two-step laser mass spectrometry at Johnson Space Center. Two ionization lasers were applied: the 266 nm laser was used to analyze aromatic and conjugated organic species, and the 118 nm was later used to detect any organic species. We also carried out C and N isotopic imaging using the NanoSIMS 50L at Johnson Space Center.

## Results and discussion:

Most of the Xe ( $\geq 90\%$ ) in all fractions was released at 1600°C. Fractions AO and AP show the highest <sup>132</sup>Xe concentrations among the 7 fractions,  $6.95 \times 10^{-7}$  cm<sup>3</sup>STP/g and  $6.98 \times 10^{-7}$  cm<sup>3</sup>STP/g, respectively. The <sup>132</sup>Xe concentrations of the other fractions range from  $1.6 \times 10^{-7}$  cm<sup>3</sup>STP/g to  $5.2 \times 10^{-7}$  cm<sup>3</sup>STP/g. Consequently, subsequent analyses were carried out for AO and AP.

Although the densities of AO (2.11 – 2.16 g/cm<sup>3</sup>) and AP (2.16 – 2.23 g/cm<sup>3</sup>) are lower than those of oxides, which contain main target elements to produce cosmogenic Ne, the Ne isotopic compositions of AO and AP indicate that there are still oxide grains in these fractions [<sup>20</sup>Ne/<sup>22</sup>Ne, <sup>21</sup>Ne/<sup>22</sup>Ne] ( $9.33 \pm 0.49$ ,  $0.49 \pm 0.14$ ), ( $10.1 \pm 0.94$ ,  $0.0888 \pm 0.0092$ ) for AO and AP, respectively].

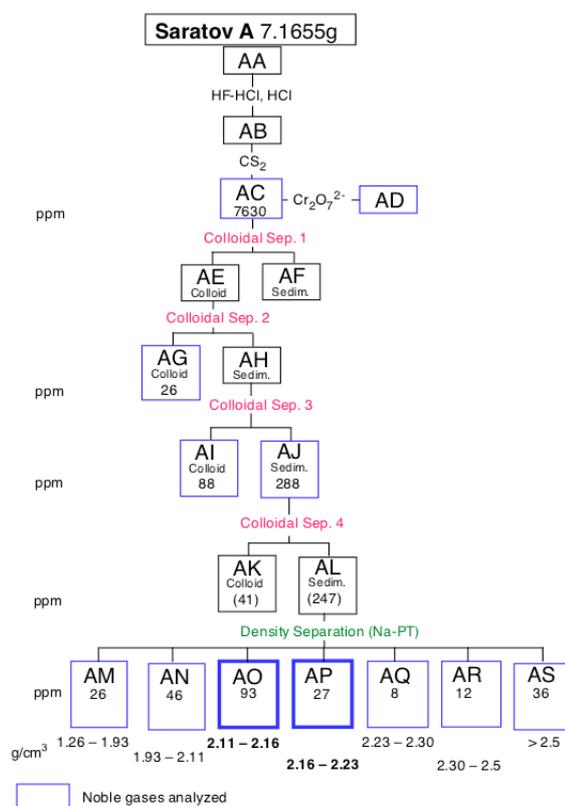


Fig. 1. Separation of Saratov

Organic analysis indicates that ammonia (NH<sub>3</sub>) is present in both AO and AP (NH<sub>4</sub>OH was never used during the separation), and that the organic matter in AO and AP consists of a mix of aromatic and waxy hydrocarbons. Although kinds of organic species are similar in AO and AP, the amount of organic species in AO is 4 ~ 5 times higher than that in AP.

Carbon and N isotopic imaging was carried out for AO and AP. In one 20 × 20 μm<sup>2</sup> area of AO, we found three spots (~0.3 μm) with <sup>15</sup>N

depletions. The  $^{14}\text{N}/^{15}\text{N}$  ratios of these spots are  $424 \pm 62$ ,  $417 \pm 53$ ,  $423 \pm 65$ , and agree with those of the sun ( $442 \pm 6$ ) [12] and the Jupiter ( $435 \pm 57$ ) [13]. The  $^{12}\text{C}/^{13}\text{C}$  ratios of the spots are  $123 \pm 17$ ,  $104 \pm 6$ , and  $90 \pm 6$ , respectively. The  $\text{O}^-/\text{C}^-$  and  $\text{CN}^-/\text{C}^-$  ratios are high ( $1.48 \sim 3.99$ , and  $0.80 \sim 2.80$ , respectively).

It has been observed that Q and the Q-gases are closely related to the original composition of the solar system. The  $^3\text{He}/^4\text{He}$  ratio of He-Q is estimated to be  $(1.41 \sim 1.59) \times 10^{-4}$  [3, 5], and is very close to the ratio of Jupiter [ $(1.66 \pm 0.05) \times 10^{-4}$ ] [14]. A stepped combustion analysis of CR2 and CR3 chondrites indicated that the heavy noble gases were accompanied by isotopically light N, suggesting that Q might be related to solar N [15].

Since the three spots with the same  $^{14}\text{N}/^{15}\text{N}$  ratio as the original solar ratio are present in a Q-rich fraction, we have concluded that these spots represent Q. The high  $\text{O}^-/\text{C}^-$  and  $\text{CN}^-/\text{C}^-$  ratios indicate that Q in AO is most likely organic. We note that this does not exclude a possibility that other types of Q exist.

The C isotopic ratios of the spots show a slight enrichment in  $^{12}\text{C}$  relative to the solar ratio ( $^{12}\text{C}/^{13}\text{C}_{\text{solar}} = 89$ ). Hashizume et al. (2004) estimated that a lower limit of the  $^{12}\text{C}/^{13}\text{C}$  of the solar wind implanted in lunar regolith is  $99.4 \pm 2.2$ , suggesting that the original solar ratio might be higher than 89. More analysis is required to determine the  $^{12}\text{C}/^{13}\text{C}$  ratio of Q with better precision.

We estimated a Xe concentration of Q by first determining the areal fraction of AO represented by the three  $^{15}\text{N}$ -poor spots ( $\sim 0.08\%$ ). This leads to an estimated Xe concentration of Q of  $\sim 1 \times 10^{-3} \text{ cm}^3\text{STP/g}$ . Such a high Xe concentration of Q is seen in terrestrial samples: Xe concentrations of up to  $10^{-2} \text{ cm}^3\text{STP/g}$  are observed in samples from the natural nuclear reactor Okelobondo [16]. The estimated Xe concentration of Q is still one order of magnitude smaller than the Okelobondo samples.

## References:

[1] Lewis R. S. et al. (1975) *Science*, 190, 1251-1262. [2] Huss G. R. et al. (1996) *Geochim. Cosmochim. Acta*, 60, 3311-3340. [3] Wieler R. et al. (1991) *Geochim. Cosmochim. Acta*, 55, 1709-1722. [4] Wieler R. et al. (1992) *Geochim. Cosmochim. Acta*, 56, 2907-2921. [5] Busemann H. et al. (2000) *Meteorit. Planet. Sci.*, 35, 949-973. [6] Matsuda J. et al. (2010)

*Geochim. Cosmochim. Acta*, 74, 5398-5409. [7] Ott U. et al. (1981) *Geochim. Cosmochim. Acta*, 45, 1751-1788. [8] Marrocchi Y. et al. (2015) *Geophys. Res. Lett.*, 42, 2093-2099. [9] Matsuda J. et al. (2010) *Meteorit. Planet. Sci.*, 45, 361-372. [10] Amari S. et al. (2013) *Astrophys. J.*, 778, 37 (39pp). [11] Matsuda J. et al. (2008) *Meteorit. Planet. Sci.*, 43, A92. [12] Marty B. et al. (2011) *Science*, 332, 1533-1536. [13] Owen T. et al. (2001) *Astrophys. J.*, 553, L77-L79. [14] Mahaffy P. R. et al. (1998) *Space Sci. Rev.*, 84, 251-263. [15] Verchovsky A. B. et al. (2012) *Lunar & Planet. Sci.*, 43, #2645. [16] Meshik A. P. et al. (2000) *Geochim. Cosmochim. Acta*, 64, 1651-1661.