Noble gases and nitrogen confirm that Hypatia, a diamond-rich pebble from SW Egypt, is a new type of extraterrestrial material

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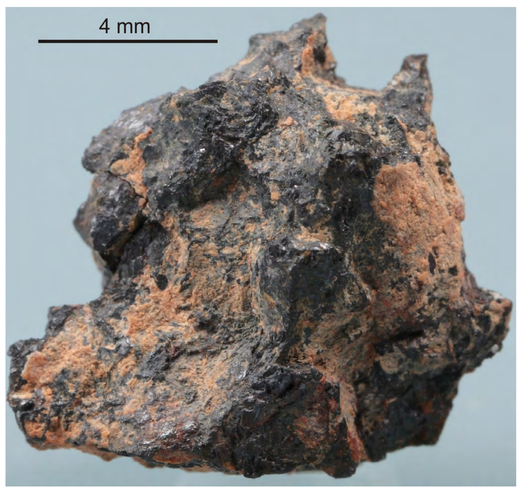

Figure 1: Photography of Hypatia [2].

Introduction

Hypatia is a diamond-rich pebble found in 1996 in the Libyan Desert Glass strewnfield [1]. This dark stone (figure 1) consists of ca. 70 wt. % of carbon and is very hard and riched in diamonds (figure 2). A preliminary study has already been conducted by Kramers et al. [2] and these authors have shown, based on Ar and $\delta^{13}C$ data, that Hypatia is extraterrestrial. Furthermore they reported that trapped Ne, Kr and Xe consist of the components P3 and G known in meteorites [3] but that components such as Q and HL ubiquitous in chondrites are absent. Based on these results, they have suggested that the parent body of Hypatia originates from an external region of the solar system such as the Kuiper Belt and that this stone may thus be related to a comet-like object.

We present here results from an extended study of Hypatia. We analysed noble gases and nitrogen in several mg-sized fragments of Hypatia in two different laboratories (CRPG Nancy and ETH Zürich) and performed X-ray and TEM observations (University of Jena).

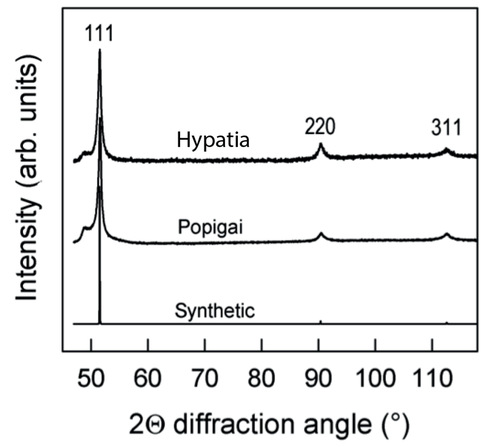

Figure 2: X-ray diffraction pattern of Hypatia in comparison to synthetic diamonds and impact diamonds from the Popigai structure.

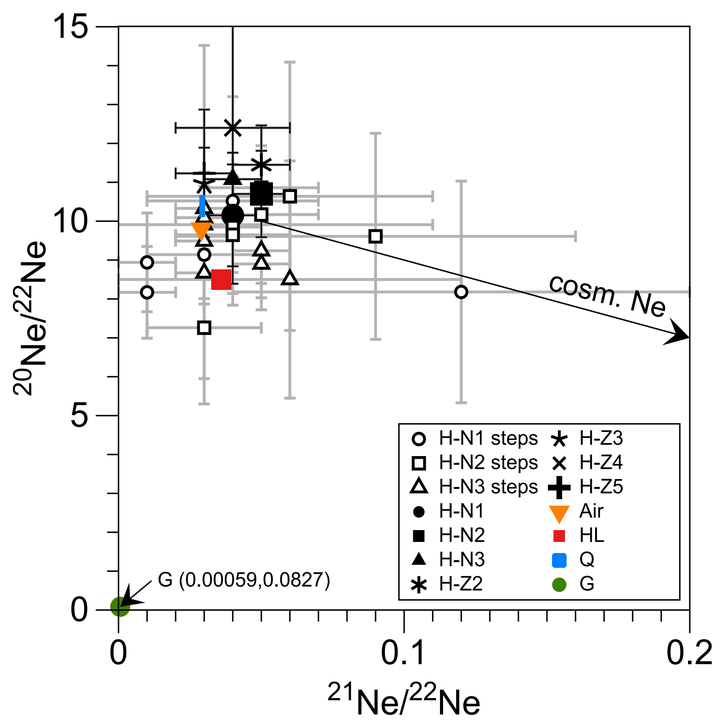

Figure 3: Three isotope plot of Ne showing individual heating steps and bulk results. The arrow points toward the cosmogenic component [5]. Bulk results plot close to the Q component. Reference values are from [3]. Error bars are 1σ.

Extraterrestrial origin of Hypatia :

- $^{40}Ar/^{36}Ar$ ratios below the atmospheric value and down to **0.23±0.38** (figure 5)
- Q-Xe [4] is released at high temperature + ^{129}Xe(I) (figure 4)
- Neon isotopes close to the composition of phase Q with the addition of some cosmogenic Ne (figure 3)
- The isotopic composition of nitrogen is extremely negative ($\delta^{15}N$ = -110 ‰) compared to the Earth's atmosphere (figure 7)
- $^{3}He/^{4}He$ ratios compatible with phase Q ($1.6x10^{-4}$)

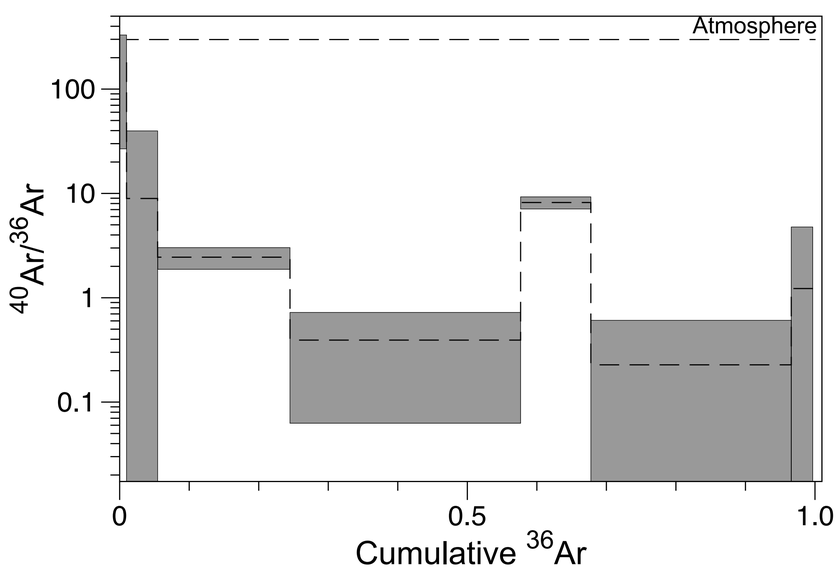

Figure 5: Isotopic composition of argon released during laser extractions. All values are well below the atmospheric value providing a new demonstration that Hypatia has an extraterrestrial origin. Ranges correspond to 2σ.

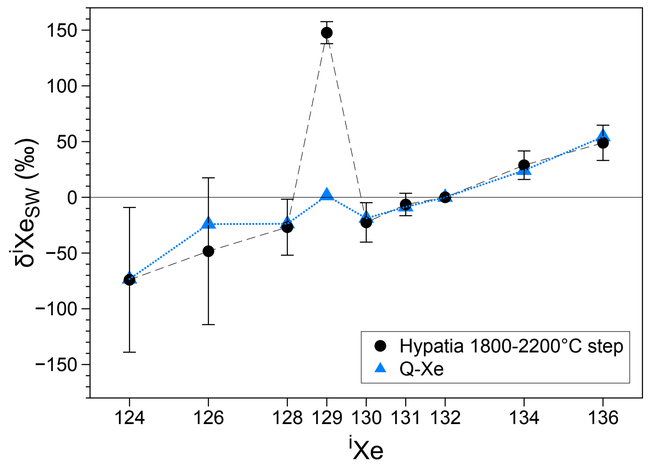

Figure 4: Isotopic composition of Xe released at high-temperature. The composition is expressed in permil deviation from the composition of Solar Wind (SW) [6]. The isotopic composition is almost identitical to Q-Xe except for a large excess of ^{129}Xe of unknown origin. Error bars are 2σ.

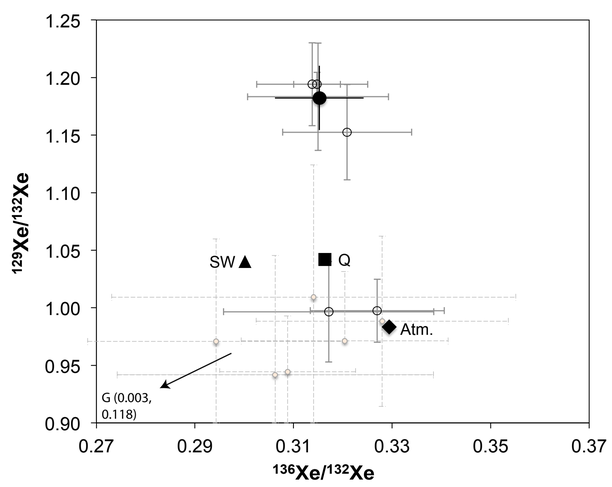

Figure 6: Three isotope plot of Xe. Some values from [2] are represented with small grey circles. Individual heating steps are shown with empty circles and bulk analysis with black circle. Arrow points toward the G component [3]. Error bars are 2σ.

Cosmic Ray Exposure ages

Excesses of $^{21, 22}Ne$ permit to compute a CRE age around **0.1 Myr** considering a m-sized body in space and following the method described in [5]. Such a low nominal age suggests that the parent-body of Hypatia might be a **larger body** (>1 m).

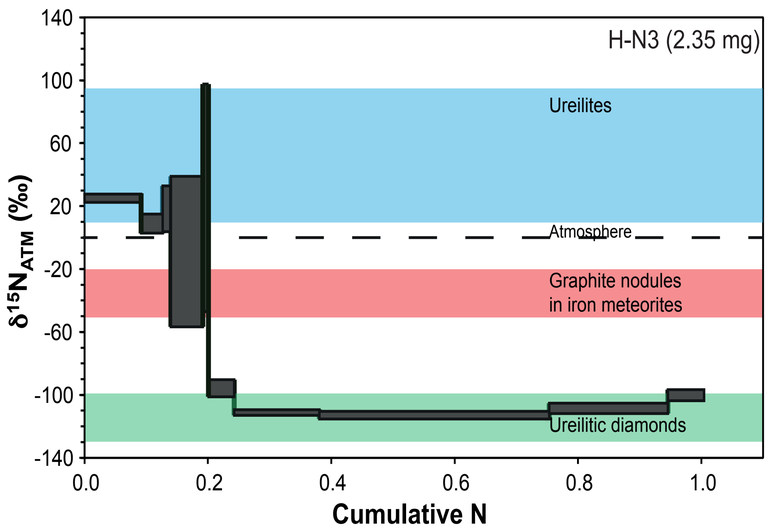

Figure 7: Isotopic composition of nitrogen released during one laser extraction. Results for other samples are similar. Note that the main release of nitrogen has an isotopic composition of -110 ‰ similar to nitrogen found in ureilites [7].

A new type of extraterrestrial material

While Hypatia is extraterrestrial, we have not been able to find a known extraterrestrial material that shares all of its properties, and we thus conclude that Hypatia is a new, unique type of extraterrestrial material. However, a few extraterrestrial materials seem to be related to Hypatia.

An example of the isotopic composition of nitrogen released during laser extraction is shown in figure 6. In all samples the major part of nitrogen is released at mid-high temperature with a $\delta^{15}N$ around -110 ‰. This major release is reminiscent from ureilites that systematically show a similar component presumably sited in carbonaceous matter. Furthermore elementary abundances of volatile elements (figure 7) are similar to those measured in bulk ureilites [8] but also to those found in a graphite inclusion of the iron meteorite Canyon Diablo [9].

These results suggest that Hypatia may be related to ureilites and especially to the carbon-rich part of ureilites but we cannot exclude an origin related to graphite nodules found in iron meteorites. A comprehensive study of nitrogen isotopes in these objects would probably permit to determine firmly what is the origin of Hypatia.

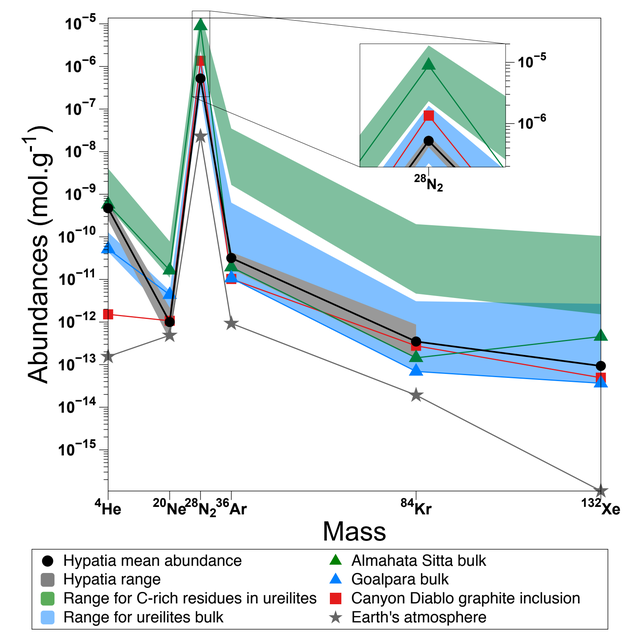

Figure 8: Elementary abundances of noble gases and nitrogen in Hypatia compared to those measured in ureilites [8] and in a graphite inclusion of Canyon Diablo [9,10].

Conclusions

We first confirmed firmly the extraterrestrial origin of this unusual stone. In contrast to the previous exploratory work [2] we found noble gases with isotopic signatures closely resembling the Q component and did not find any indication for a G component. We have attempted to put constraints on the origin of Hypatia. Isotopes of nitrogen match the composition of N_2 in ureilites but elementary abundances closely resemble those found in graphite inclusions in iron meteorites.

References

[1] Barakat (2012) *The Precious Gift of Meteorites and Meteorite Impact Processes, Nova Sci. Pub, ISBN: 1621009394.* [2] Kramers et. al (2013) *EPSL, 382,* 21-31. [3] Ott (2014) *Chem. der Erd., 74(4),* 519-544. [4] Busemann et al. (2000) *MAPS, 35,* 949-973. [5] Leya & Masarik (2009) *MAPS, 44(7),* 1061-1086. [6] Meshik et al. (2014) *GCA, 127,* 326-347. [7] Rai et al. (2003) *GCA, 67(12),* 2213-2237. [8] Göbel et al. (1978) *JGR, 83(B2),* 855-867. [9] Matsuda et al. (2005) *MAPS, 40(3),* 431-443. [10] Prombo & Clayton (1983) *LPSC XIV,* 620-621.