REFRACTORY PHASES OF MICROMETEORITES AND THE PRIMITIVITY OF COMETARY NUCLEI. M.Gounelle[1,4], M.Maurette[1], C.Engrand[1], G.Kurat[2], F.Shu[3]. [1]CSNSM, Bât.104, 91405 Orsay Campus, France. [2]Naturhistorisches Museum, Postfach 317, Wien, Austria. [3]Dept. Astronomy, University of California, Berkeley, CA 94720. [4]Department of Mineralogy, The Natural History Museum, Cromwell Road, London SW7 5BD, UK (mattg@nhm.ac.uk

Introduction:

We justify elsewhere [1] the assumption that large (≥100µm) Antarctic micrometeorites (AMMs) are cometary dust particles, and that their present characteristics can be extended to "early" micrometeorites released through the sublimation of dirty cometary ices during the period of heavy bombardment prior to 3.9 Ga ago. We use below some of the common characteristics of modern and early micrometeorites to both further constrain the scenarios proposed for the origin of the solar system and confirm that cometary nuclei are not as primitive as previously thought.

Refractory phases in carbonaceous chondrites and micrometeorites:

Chondrites represent ≈85 % of the meteorites falls on Earth. The primitive carbonaceous chondrites are a rare, primitive sub-type of chondrites that amount to ~5 % of the falls. Refractory phases in carbonaceous chondrites include calcium-aluminium-rich inclusions (CAIs) and chondrules. CAIs formed at high temperatures (~1600 K) in the solar nebula and are the oldest solid phases known at this date. Chondrules are igneous objects composed of olivine and pyroxene set in glassy mesostasis and varying amounts of minor minerals. They have formed at a slightly lower temperature than CAIs, but suffered subsequently a brief heating episode a higher temperatures (~2000 °K).

Large AMMs represent the dominant extraterrestrial material captured by the Earth today [2 and references herein]. Their chemistry, mineralogy and isotopic composition relate them to the CM2 hydrous-carbonaceous meteorites [3, 4]. AMMs also contain CAIs and chondrules that exhibit both similarities and differences with regard to the refractory phases observed in CM2 carbonaceous chondrites. These differences for micrometeorites include: - smaller sizes by a factor of 5-10 (see Fig.1 and Fig.2, respectively, in ref. 2); - a strong depletion of chondrules, which are at least 20 times less abundant than in CM2 chondrites, where this abundance (~5%) is already the smallest value observed among the chondrites.

However, in spite of these large differences in sizes CAIs show striking similarities in micrometeorites and CM2 chondrites [3,5], including: - their mineralogical composition; their relative modal abundance of about 1%; - the isotopic composition of their constituent oxygen. This suggests that both the small and large CAIs were made through similar processes in the early solar system. How can we explain their large size differences?

Micrometeorites and the x-wind model:

The presence of tiny CAIs observed in Antarctic micrometeorites that originate from comets [1] can only be interpreted within the model of solar system formation proposed by Frank Shu and collaborators [6,7,8], where the the "x-wind" plays an important role.

Other scenarios have difficulties in explaining the formation of refractory phases in the distant zone of coldness and ices where comets formed. Indeed, the age of the refractory inclusions found in carbonaceous chondrites correspond to the date of formation of the solar system and not to that of much older interstellar phases that would predate the formation of the solar system. They cannot be interstellar dust grains and they formed at the highest temperatures very near the early Sun.

The x-wind model allows a considerable transport of matter from the inner to the outer part of the nebular disk. The disk material is attracted by the young Sun, which captures about 2/3 of it during its growth, and rejects the remaining 1/3 as an x-wind [6]. A fraction of the material accreted by the star transits through a peculiar zone called the reconnection ring, which spread up to 0.06 AU from the Sun. In this ring, fluctuating impulsive magnetic eruptions occur [7]. They trigger fluctuations of the temperature experienced by the ring material which generate a succession of cycles of vaporisation/condensation leading to the formation of CAIs [8]. Chondrules form in a transition zone between the reconnection ring and the edge of the nebular disk [8].

After their formation, a fraction of these phases are ejected on ballistic trajectories by the x-wind generated at the boundary between the reconnection ring and the nebular disk. They are thus redistributed over the entire nebular disk including the formation zone of comets between Neptune and Uranus. These ballistic flights induce a severe size sorting effect [6]. The largest refractory phases are poorly coupled to the wind and fall in the inner solar system peppering the building material of asteroids with large CAIs and chondrules. But the much smaller phases found in micrometeorites are much better coupled to the wind and are carried much further away, in the formation zone of comets at heliocentric distances ≥ 20 AU units.

One could then explain the similar mineralogical and oxygen isotopic composition of CAIs in micrometeorites and CM2 chondrites (since their common fabric is the reconnection ring), and their much smaller sizes in micrometeorites.

Current tests of the x-wind model:

An additional test of the x-wind scenario is the prediction a third kind of strong similarity between the CAIs of micrometeorites and carbonaceous chondrites [9]. As the two types of CAIs with such very different sizes were both formed in the reconnection ring, they have been exposed to similar fluences of protons and ^{3}He particles generated during the impulsive eruptive events. Such irradiations produce short-lived isotopes and well as stable nuclei. One expects to observe the same concentrations of extinct isotopes (^{10}Be, ^{26}Al, ^{41}Ca, ^{53}Mn) and stable isotopes (such as ^{138}La et ^{50}V) in CAIs found in meteorites and micrometeorites. Indeed, computations [9] show that their concentration is independent on their size, *as a first approximation*.

The concentration of the 4 extinct isotopes have been measured in the large CAIs of meteorites and their concentrations are quite compatible with the predictions of the Shu’s scenario [9] at the condition to consider that all CAIs were initially coated with a mantle of Ca-poor material that get subsequently evaporated from the inclusions. The other scenarios, such as those invoking the explosion of a nearby supernova to trigger the gravitational collapse of the initial solar nebula [10] cannot account for the high concentrations of ^{10}Be. The only feature that we still don’t understand is the strong depletion of small chondrules in the formation zones of comets. It might be that they are not formed in the reconnection ring or that they evaporate away when they are exposed for a long time in the Sun luminosity.

The most performing ion microprobes as well as new instruments such as the multicollection ICP-MS should allow in a few years from now to make the appropriate measurement on the very small-sized CAIs of micrometeorites. We intend to investigate the Mg-Al systematics of micrometeorites to search for the presence of live ^{26}Al in micrometeorite CAIs, at concentration level similar to that observed in the much larger CAIs of CM2 carbonaceous chondrites. We’ll also measure the isotopic composition of vanadium in meteorites and micrometeorites. This measurement would constitute a severe test on the validity of the x-wind model [9].

The primitivity of comets:

In the conventional model of cometary nuclei the primitive dust grains trapped in dirty cometary ices are considered as interstellar dust grains of the "Greenberg" type that were kept frozen in the formation zone of cometary ices. They never got near the Sun as to be strongly remobilised by both strong heating and heavy irradiations. This model does not look valid anymore. Our findings comfort earlier suggestions of Mc Sween and Weismann [11], which have been pretty ignored at that time. This new model of non-primitive cometary nuclei should be taken into consideration in the preparation of space missions to comets such as Rosetta. Could COSIMA, the ion microprobe of the mission, detect CAIs and refractory hydrous silicates with low iron contents in cometary dust?

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