Supergiant halos as an integral record of natural pionic radioactivity

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Abstract

In this paper an unified interpretation of the supergiant halos (SGH), discovered by Grady, Walker and Laemmlein, is discussed. So, it is proved that SGH’s can be considered as integral records of the nuclear pionic radioactivity.

The radioactive halos (see Ref. \cite{1}) were first reported between 1880 and 1890 and their origin was a mystery until the discovery of radioactivity and its power of coloration. The radioactive halos are spherical, microscopic-sized discolorations in crystals. In cross sections on a microscope slide, they appear as a series of tiny concentric rings, usually surrounding a central core (see Fig. 1). This central core is (or at least initially was) an radioactive inclusion in crystal. The $\alpha$-particles, emitted from the radioactive inclusion during radioactive decay, damage the mineral and discolor it, with most of the damage occurring where the particle stop. How far this $\alpha$-particle travels depend on its energy. Since all the $\alpha$-particles from a particular parent nucleus have the same energy and the particles are fired in all directions, a spherical shell of discoloration will produced, appearing circular in cross-section. Radioactive uranium $^{238}\text{U}$ from inclusions generates multi-ringed halo (see Fig. 1) because its radioactive decay series:

\begin{equation}
^{238}\text{U} (\alpha) \rightarrow^{234} \text{Th} (\beta) \rightarrow^{234} \text{Pa} (\beta) \rightarrow^{234} \text{U} (\alpha) \rightarrow^{230} \text{Th} (\alpha) \rightarrow^{226} \text{Ra} (\alpha) \rightarrow^{222} \text{Rn} (\alpha) \rightarrow^{218} \text{Po} (\alpha) \rightarrow^{214} \text{Pb} (\beta) \rightarrow^{214} \text{Bi} (\beta) \rightarrow^{210} \text{Po} (\alpha) \rightarrow^{206} \text{Pb} (stable)
\end{equation}

Hence, of the 15 parent nuclei in this $^{238}\text{U}$-decay chain, eight emit alpha particles when they decay forming eight rings. However, due to overlap, only five of eight rings of a $^{238}\text{U}$ halo are normally visible. If, instead of radioactive uranium $^{238}\text{U}$, the inclusion was composed of an radioactive isotope along the decay chain, there would be only fewer rings. So, omitting the first few isotopes in the decay series it is quite simple to work out which isotope was originally in the inclusion by counting the rings. Hence, $^{218}\text{Po}$ forms three rings, $^{214}\text{Po}$ form two rings while $^{210}\text{Po}$ forms only one.
Therefore, aside from their interest as attractive mineralogical oddities, the halos are of great interest for the nuclear physics because they are an integral record of radioactive nuclear decay in minerals. This integral record is detailed enough to allow estimation of the energy involved in the decay process and to identify the decaying nuclide through genetic decay chain. This latter possibility is particularly exciting because there exist certain classes of halos, such as [1]: dwarf halos, X-halos, giant halos and the supergiant halos [3-4], which cannot be identified with the ring structure of the known alpha-emitters. Hence, barring the possibility of a non radioactive origin, these new variants of halos can be interpreted as evidences for hitherto undiscovered alpha-radionuclide, as well as, signals for the existence of new types of radioactivities.

Therefore we must underline that in addition to the Laemmlein discovery [4], who found halos of rather diffuse boundaries with radii up to several thousand micrometers surrounding Thorium-containing monazite inclusions in quartz, Grady and Walker [3] found twenty-five extremely large halos called supergiant halos (SGH).

The SGH have the following essential characteristic features:
1. The SGH radii are between 50\( \mu m \) and 410\( \mu m \). They have large oval to circular inclusions with radii of 20-52 \( \mu m \).
2. SGH do not have sharp edges.
3. In thick sections ( >30\( \mu m \) ) SGH are surrounded by approximately circular brown regions having the same color in unpolarized light as the normal halos and exhibiting the same colors of pleochroism.
4. The coloration of SGH gradually fades as they move away from inclusion.
5. The SGH, with inclusions removed and etched with HF, show an abundance of fossil fission tracks in immediate proximity to the inclusion.
6. Three-dimensional etching of the SGH revealed a complex pattern of extended fossil fission tracks distribution throughout the halo.
7. The SGH inclusions were found to be alpha-active.

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In the papers [5] we discussed a completely new possibility for an unified interpretation of the supergiant halos (SGH), namely, that SGH’s are the integral records of the nuclear pionic radioactivity [5-7]. Indeed, the nuclear pionic radioactivity of a parent nucleus \((A,Z)\) can be considered as an inclusive reaction of form:

\[
(A, Z) \rightarrow \pi + X
\]  

where \(X\) denotes any configuration of final particles (fragments, light neutral and charged particles, etc.) which accompany emission process. The inclusive NPIR (Nuclear Pionic Radioactivity) is in fact a sum of all exclusive nuclear reactions allowed by the conservation laws in which a pion can be emitted by a nucleus from its ground state. The most important exclusive reactions which give the essential contribution to the inclusive NPIR (1) are the spontaneous pion emission accompanied by two body fission:

\[
\frac{A}{Z}X \rightarrow \pi + \frac{A_1}{Z_1}X + \frac{A_2}{Z_2}X
\]  

where \(X\) denotes any configuration of final particles (fragments, light neutral and charged particles, etc.) which accompany emission process.
Charged pions $\pi^\pm$ as well as neutral pions $\pi^0$ can be emitted during two-body or many body fission of parent nucleus. Therefore, we must show that a nuclear reaction (2) is able to produce the supergiant halos discovered by Grady and Walker [3] and Laemmlein [4].

Now, we remember that in order for a "discolored" region in a transparent mineral truly to be a radioactive halo (RH), it must satisfy the following rules:

R1: It must have an inclusion that is, or at one time was, radioactive. The dimension of the pionic radiohalo (PIRH) inclusion must be sufficiently large in order to satisfy the dose rule R2.

R2: The dimension of a radioactive halo is given by that particle emission process with largest range with the condition that its dose satisfy the coloration threshold condition.

R3: In the nuclear reactions (1) from the PIRH-inclusions, the $\pi^-$ yields should be about two orders of magnitude larger than the $\pi^+$ yields (see Ref. [5]).

A radioactive halo is called pionic radiohalo (PIRH) if its inclusion (R1) contains, or at one time has contained, a parent pionic radioactive (1) nuclide in such a concentration that produced a pionic dose satisfying the coloration threshold condition (R2). The PIRH by definition must be the integral record in time of the nuclear pionic radioactivity in some minerals such as biotite, fluorite, cordierite, etc. According to R3-rule (see Ref. [5]), we expect that, two types of PIRH are possible to be observed in nature. These will be the following:

- **PIRH(-)**, when only $\pi^-$ satisfy the dose rule R2 [5];
- **SPIRH**, which is defined just as a superposition of PIRH(-) and PIRH(+), when both $\pi^+$ and $\pi^-$ satisfy the dose rule R2.

PIRH(-) and SPIRH have the same signatures excepting a big difference (about 700-800 $\mu m$ in radius, in favor of SPIRH) in dimensions. This difference is given by the fact that $\pi^+ - \mu^+$ meson are mainly decaying via $\pi^+ \rightarrow \mu^+ + \nu_{\mu}$, while the $\pi^-$ are stopped in mineral producing the fission of the mineral nuclei in two or more fragments.

The PIRH signatures are as follows [5]:

- **PIRH** is a pionic radiohalo of supergiant dimensions which possess a large inclusion, sufficient to satisfy the rule R2. The supergiant PIRH dimension is essentially determined by the high ranges of $\pi-$mesons as well as of their product of decay $\mu$-mesons (see Fig. 2);
- **The PIRH** do not have sharps edges and their coloration gradually fades as moves away from inclusion;
- **The PIRH**, must show an abundance of fossil fission tracks in the immediate proximity to the inclusion. This signature is given just by the fission fragments of the pionic emitters (see reaction (1)) from the PIRH-inclusion.
- **The PIRH** inclusions, by definition, can be $\alpha$-active. As a consequence of the alpha-activity of the nuclei from the PIRH inclusions they must be surrounded by approximately circular regions having the same color as normal halos and exhibiting the same colors of pleochroism;
Extended fossil fission tracks distribution through the PIRH must be also present as a consequence of the fission of the mineral nuclei produced by the stopping $\pi^-$ mesons in mineral.

Next, comparing the PIRH signatures with the above essential characteristic features (1-7) of the SGH, it is easy to see that the PIRH(-) can be identified, with a surprising high accuracy, as being the SGH discovered by Grady and Walker [3] in biotite.

We note that a special investigation of the discovery of the Laemmlein-like [4] halos are necessary, since these SGH with dimensions around 1-1.5 mm can be identified as being the SPIRH produced by emission of $\pi^+$-mesons during fission of the parent nuclei from the halos inclusions.

References

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Fig. 1: Examples of uranium radiohalos [2]. (a) A fully-developed uranium radiohalo (dark mica). A uranium radiohalo comprises eight rings, but some rings are of similar size and cannot easily be distinguished. (b) A uranium radiohalos in which all four isotopes are from the $^{238}$U decay series.
**Fig. 2:** (a) A photomosaic of a part of one supergiant halo (SGH) F-12 discovered by Grady and Walker [3]. The essential characteristic features of this SGH are well reproduced by those of PIRH(-) supergiant halos (see the text); (b) A photo image of the mica surface showing fossil tracks next to inclusion pit.