Response to reviewer #2

Dear Anonymous Reviewer,

We very much appreciate your supportive and thorough feedback. Please find our answers to your enclosed below.

Responses to major comments

> It should be emphasised that the paper does not deal with all the issues necessary for age determination, it is focused on the reliable determination of De values by IR-RF on a set of single K-feldspar grains.

We agree. Strictly speaking, we focus only on the D_e determination. So perhaps the title of our manuscript is a bit misleading. On the other hand, for all the different luminescence-dating methods at hand (for instance, SAR OSL, pIRIR, TT-OSL, VSL etc.), it appears that the approach to determine D_e, sets the name of the dating method. It somewhat makes sense because the dose rate determination is relatively independent for all the different approaches to determine a D_e. Hence, we termed it 'dating', for which the reasons is perhaps now more understandable.

> the bright spots were associated by the authors with bremsstrahlung photons from the beta source. To my knowledge, M.Krbetschek correlated this effect with energy deposition from cosmic radiation (muon component). Was this idea checked? Are there arguments against this idea?

Interesting point, worth its own study. We are sure that the speckle noise is caused almost entirely by bremsstrahlung. We know from radiation protection measurements, that the radiation level directly above the β-source shielding is at least 10 µSv / h (sorry, we have no particular numbers available and none of us has direct access to a lexsyg research device in the moment. Instead, we refer to Liritzis & Galloway (1990) who measured similar radiation levels for Risö and Daybreak TL readers). The CCD of the camera is located about 85 mm above the β-source ring. Therefore, we can assume that the radiation level at the camera is by far larger than the usual background radiation of about 0.1 µSv / h (which includes cosmic rays). Liritzis & Galloway (1990) explained in a conclusive way, supported by gamma spectroscopic measurements, that these radiation levels are caused by bremsstrahlung produced on the impact of β-particles into the shielding material. In addition, in camera tests without a nearby β-source we observed very few bright spots: Mostly zero or one spot per 5 sec exposure, seldom two spots. During RF measurements, we observe about 150 bright spots per 5 sec exposure. Thus, we conclude that the main part of the speckle noise must be caused by bremsstrahlung originating from the β-source module. From a data processing point of view, the cause does not matter much.

Our manuscript contained a short explanation and the reference to Liritzis & Galloway (1990) in Line 186 of the pre-print. To clarify the dominating cause of speckle noise, we moved this text fragment to section 2.1 "Equipment".

> Figure 3: the before/after picture for step 2 (image alignment) requires some explanation. A blurry picture is presented as an improvement, this is not understandable at first glance.

We agree and added the following to figure caption:

Note: The grey step 2 images show the signal value differences between the median signal values of the natural dose RF images and the median signal values of the regenerated dose RF images. A homogeneous color means that the images are aligned.

> Concerning the discussion about the De distribution of BDX16651: Dosimetric aspects should be more discussed. The existence of a broad De distribution does not necessarily result in a broad age distribution, if the K content varies from grain to grain. Here spectrometric methods for the K determination of single grains could help, e.g. far-red radiophosphorescence (Dütsch, C., Krbetschek, M.R., 1997. New methods for a better K-40 internal dose rate determination. Radiation Measurements 27, 377-381. and Krbetschek, M.R., Goetze. J, Irmer, G., Rieser, U. and Trautmann, T., 2002. The red luminescence emission of feldspar and its wavelength dependence on K, Na, Ca-composition. Mineralogy and Petrology 76, 167-177.)

We agree that grain-to-grain variations in the K-concentration might contribute to the scatter, and we now rephrase the paragraph and cite the study by Dütch and Krbetschek (1997). However, we should mention that Dütch and Krbetschek (1997) target the internal ^{40}K dose rate contribution of feldspars, not specifically K-feldspar. IR-RF relies on the hypothesis that Pb replaces K; the defect responsible for IR-RF. Highest IR-RF intensities are expected from grains with higher K concentration (not necessarily but as a rule of thumb). Besides, we can try to estimate the impact of different K concentration using a simple thought experiment based on the dose data from sample BDX16651. Suppose the internal K-concentration varies between 8% and 14% and other dose rate component amounts to 2 Gy ka^{-1}. Now we can expose the grains to such a setting for about 40 ka.

```
K_concentration <- seq(8,14,0.1)

theta_K <- 0.0565 ##Brennan 2003; for spherical grains self-absorption
dr_conv <- 0.7982 + 0.0185 ## Guérin et al., 2011, dose rate conversion factor

DR <- 2 + K_concentration * theta_K * dr_conv
De <- DR * 40
```

In this case the expected range of the D_e would be around 94.8 Gy to 105.8 Gy. Admittedly, this is a simplified scenario but should show that the large scatter we observed for our sample is unlikely to be caused dominantly by the internal K concentration.

Nevertheless, we rephrase the part a little bit to make sure that the reader does not get the impression we may have overlooked this aspect.

Furthermore, we realised that this section header was poorly chosen, making a distinction between a "technical" and a "scientific" dimension, while both have a scientific dimension. Hence, we renamed the section from "scientific dimension" to "application dimension".

> In Sec. 4.1 the proposed mirror is called in the text "parabolic" but in the picture "spherical". What is correct? And - would it be beneficial to use an elliptical mirror with camera and sample in the focuses?

Thank you for spotting this discrepancy. We realised that regardless of the different labelling of the mirror in the figure and the main text, the best term would be the more general 'concave mirror system' because the actual setup might be more complicated. We changed the label in the figure to 'concave mirror' and rephrased line 372 - 376 to:

A system of one or two concave mirrors would allow to relocate the camera and the filters further away from the β-source and thus minimise bremsstrahlung effects and potential filter degradation. Such a mirror *optic would also eliminate chromatic aberration and thus enable the ability to take RF images at different wavelengths without refocusing. A dedicated RF optic would also adress further optical aberrations and thus reduce signal cross-talk.*

Concerning your second question: We assume you refer to an elliptically 'cutted' mirror to perform the 90° reflection (and not a mirror with elliptical surface). In this case, a lens optics to focus the light to the CCD would still be needed. In fact, M. Krbetschek and D. Degering used such an optic in their experimental setup. Applying a lens optic would mean that the user either has to deal with chromatic aberration, and thus refocusing the camera each time the detection wavelength is changed (something we recommend for future research), or the user has to use an achromatic lens optic. Achromatic optics have usually weak transmission properties below 400 nm and would have trouble to detect the 300 nm peak of K-feldspar (see Murari et al., in press). An all-mirror optic has the advantage that one could measure RF emissions over the whole UV-to-NIR wavelength range without refocusing. A camera with UV-coating, like the camera we used, is sensitive from around 200 nm to about 1000 nm. After reconsidering our proposal, we guess that a system of two parabolic off-axis mirrors might give the best results while keeping the complexity and costs of the system within reasonable limits. But one large concave mirror like sketched in the figure might also work. However, this is an issue which should be calculated or simulated proberly during the actual development of a dedicated RF reader.

> Although the main goal of the paper are technical aspects, in Sec. 4.2 the authors should give a list of problems to be solved before the method can be used for "real" dating purposes.

It is unfortunate (and it is still very frustrating for us) that after we solved all the tiny technical issues along the way, we could not show more dating results because of the degenerated cooling system. However, this should not leave the reader with the impression that SR IR-RF cannot be used for "real" dating purposes because our technical problem is limited to a particular system. We strongly believe that our method can be used for actual dating applications as it is. However, we are aware that further application tests are necessary and that future research will add improvements and refinements, like we stated in section 4.1.

When it comes down to IR-RF dating in general, we feel that our manuscript might not be the right place to discuss cause and implication of IR-RF related issues that may need additional research. Here we may refer to the manuscript by Murari et al. (in press), which we already cited in our manuscript. However, we believe that our method is a valuable tool to investigate some of these issues, like we stated in section 4.2.

Please let us know if this is what you had in mind. If not, of course, we are happy to add additional information to the manuscript if needed.

Responses to remarks in the PDF

Thank you very much for spotting all these minor mistakes we did not spot ourselves during the last check before the manuscript submission. We corrected all flagged issues where possible. Below our feedback to three of them because we felt that we better elaborate on it. > Table should be shifted before the statements.

To produce the PDF, we used the Copernicus LaTeXtemplate, which places the tables automatically. However, we will keep an eye on it to make sure that it is set correctly in the final published version; if accepted for publication.

> too long for the line

This comment refers to a monospace-typed function call on page 12 that exceeds the column width. We acknowledged the problem and found it also at other pages. However, we found no easy fix for it and believe that this is a problem to be solved by the journal production office's final typesetting.

Dirk Mittelstrass, Freiberg and Sebastian Kreutzer, Aberystwyth, March 15, 2021

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