Reply on RC2
Daniel K. Whiter et al.


We thank the reviewer for their careful reading of the manuscript and useful comments. We have copied the review below and inserted our responses to each point in bold text.

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This paper provides additional observations and analysis of an optical phenomenon that has been identified close to auroral structures at high latitudes: the 'Fragmented Aurora-like Emission'. The authors have identified two cases that on the face of it look somewhat different but use the fine-scale capabilities of ASK to show that these are actually similar. The paper is well written, with good explanations and makes a commendable effort to constrain the causes of these FAE based on the available observations.

I recommend that the manuscript be accepted for publication after some minor revisions and after the authors have considered a couple of minor points.

- line 13: '...electrostatic ion cyclotron (EIC) waves and...'  
  Thank you, fixed.

- line 109: you mention that they share the same internal structuring and dynamics. Although you go on to explain this in a later section at this position in the manuscript it comes across as quite a bold statement of fact. It just feels a little jarring at this point.
  We have softened this sentence to make it more a description of the FAEs' appearance: “The FAEs in event 2 are larger and brighter than the FAEs in event 1, and they are not north-south aligned, although their internal structuring and dynamics look similar.”

Figures 1 & 3: although you do it for figure 4 I feel it would have been helpful to have the ASK fov shown on figures 1 & 3 where you are inviting the reader to compare the two observations from different instruments.

We have added the ASK FOV to the all-sky images from event 2 in Figure 3.

Unfortunately the focus of the all-sky camera images during event 1 is not sufficient to resolve stars and therefore they cannot be accurately geometrically
calibrated, and so it is not possible to mark on the position of the ASK field-of-view in Figure 1. We have added a sentence to the manuscript to explain this limitation.

-line 95: you mention that the FAE are not visible in the all sky camera as they are small and quite fast moving, yet they are visible in the camera during the second event, and you go on to show that the phase and group speeds are comparable. So they cannot be invisible in the first due to being fast moving, if they are moving at the same speed as the structures in example 2. Or am I missing something about the instrument cadence? I suspect it is a matter of size (as you mention) and perhaps brightness.

Yes it is correct that size is important, but mainly through the combination of size and speed. Even though the FAEs in the two events move at similar speeds, because they are so much smaller in event 1 the motion blur makes them impossible to detect. However, in event 2 they are large enough that they are visible despite the blur. We have amended the sentence on line 110 to make this point clearer.

-Figure 5: the ESR data is quite noisy, though the bulk structures do stand out. I am not totally familiar with all of the properties of sporadic E, so I wonder is it normal for enhancements in electron density during sporadic E to be associated with a bite out in ion temperature localised at the same altitude? If I saw this in the data it would give me a little cause for concern that there is something going wrong in the ISR fitting process, which would make me a little nervous, particularly as it accompanies peaks in electron temperature that might suggest a problem with the temperature ratio fitting. Have the authors considered this? Although not a massive part of the paper, the supposed sporadic E layer is the strongest evidence of high electric field at this time, so it is worth making doubly sure that it is not an instrument artefact.

This is a good point. If the mean ion mass inside a sporadic E is significantly elevated above normal the ISR fitting process may produce incorrect temperature estimates. We therefore have low confidence in the temperature measurements at 110-116 km altitude. However, in our calculations we have only used temperature measurements from lower altitudes, at 100 km. We have added a sentence to the manuscript explaining that the temperature measurements inside the sporadic E are not reliable: “If the mean ion mass is significantly increased inside the E_S layer (due to the presence of metallic ions) the incoherent scatter spectrum fitting process may produce incorrect temperature estimates, and therefore electron and ion temperatures in the altitude range 110-116 km are not reliable at these times.”

You say that the FAE never fill the radar beam, yet the period when the FAE are in nearest the magnetic zenith of ASK, there is an enhancement in Te and Ti. I would suggest that there are two other occasions that look similar in the data – after 19:02 and 19:05:30. Have the authors looked at what is happening around those times in the optics? I note that these are outside of the images presented in figure 1. If there are data available and it shows no FAE then it might seem very likely that the coincident Te and TI enhancements are unrelated. I note that you are rightly cautious in your description of a possible link already.

Thank you for pointing out these times. There are FAEs visible at 19:05:20UT-19:05:40UT, with similar sizes and motion to the FAEs already presented in event 1. However, the FAEs at this later time are dimmer than the main event 1 or event 2 FAEs. Dim but fairly dynamic aurora passes through the ASK field of view from about 19:01:50UT until the brighter aurora enters at 19:02:40UT (coincident with the electron density enhancement), but no FAEs are
visible in this earlier period. We note that intense electron and ion temperature enhancements are present at ~100 km altitude during the FAEs already presented in event 1 and at the later time, but a temperature enhancement at that altitude is not as clearly present between 19:02UT and 19:03UT, when the weaker enhancement is at a slightly higher altitude.

We have added a paragraph to the manuscript in section 2.1 discussing the FAEs at around 19:05:30UT: “Electron and ion temperature enhancements are also present at 100 km altitude just before 19:05:30 UT. FAEs are again visible in the ASK images at this time, for about 20 s from 19:05:20 UT, although they are dimmer than the FAEs during the main part of the event, and fade in and out of visibility, making their sizes and speeds difficult to determine accurately. Again they are poleward of an auroral arc and drift eastward approximately parallel to the arc. FAEs are not present prior to 19:04 UT; they are only visible when the electron and ion temperatures are significantly enhanced at 100 km altitude, providing some evidence that the FAEs themselves occur at this altitude.”

-line 169: you assume an emission height of 112.5 km but I don’t think you justify/explain that anywhere. I assume that is because of the sporadic E peak in figure 5, yet in describing that feature you focus on temperature enhancements closer to 100km. This is confusing.

Especially as later you switch from 112.5 km to 100 km. I think you should be consistent in your altitude choice or explain why you use different altitudes.

The apparent discrepancy is because we had assumed an emission altitude of 112.5 km for the auroral arc but 100 km for the FAEs, although we agree this is confusing. The 112.5 km estimate was only used to convert the speed of the arc from degrees/s (directly related to pixels/frame in the camera FOV) to m/s, but this conversion is irrelevant for the analysis of the FAEs, for which pixels/frame is the important number. We have therefore removed the arc speeds in m/s from the manuscript to avoid confusion.

Line 200 onwards: I am not as convinced as the authors that lack of apparent field-aligned component to the shape is indicative of a non-precipitation mechanism. At higher energies structures can diverge significantly from the field aligned structure – pulsating aurora for example. Plus, how are you defining field aligned at these scales? Analysis of optics is not my strongpoints and I recognise that there are significant experts in the author list, but I wonder if the emission difference could be due to the spectrum of precipitation rather than evidence of no precipitation?

A lack of field-aligned extent has been used as evidence against a precipitation mechanism for other emission features such as the streaks discussed by Semeter et al. (2020) – we wish to point out that the same argument could apply to FAEs, although we agree that alone this is not sufficient evidence against a precipitation mechanism; the lack of OI 777.4 nm is much stronger evidence. We have amended the sentence on lines 202-204 to emphasise the comparison with other unusual emission features, and added a sentence to concede that high energy precipitation can produce structures with little field-aligned extent: “It should be noted that high energy precipitation can result in thin emission layers barely exhibiting any perspective effect (e.g. Ivchenko at al., 2005); however, even in the case of monoenergetic high energy precipitation, locally excited atomic oxygen emissions are observed co-located with the molecular emissions in the thin layer (Dahlgren et al., 2012), which is not the case for the FAEs.”

I would like to emphasize that I am not advocating that this is a precipitation mechanism,
rather that I do not feel the authors make the case strongly enough to completely dismiss it.

To us the lack of significant OI 777.4 nm emission during comparatively bright N2 1PG emission is very strong evidence against a precipitation mechanism, but we accept that the strength of this evidence may not be apparent to readers less familiar with ASK observations. We have therefore calculated the OI/N2 (ASK3/ASK1) brightness ratio in a selected FAE and compared this with model results to show that the observations are not consistent with a precipitation mechanism. Two additional figures have been added to the manuscript: model results showing the relationship between the OI/N2 brightness ratio and the electron precipitation energy, and ASK images showing the selected FAE.