

Review report of 'Auroral spectral estimation with wide-band color mosaic CCDs', by Jackel et al.

General:

The paper describes color mosaic CCDs used in auroral imaging and the authors provide lengthy descriptions of a linear inversion technique to attempt to extract high resolution spectral information from these detectors. Especially two types of detectors, one RGB and one CYGM, are compared and discussed in detail. Such detectors are used today to give quantitative measurements of the colors of aurora in allsky imagers, and the authors claim to be able to provide qualitative estimates of the spectral response. It is found however that the inversion cannot lead to a sufficient spectral resolution of the measurements to be able to measure single auroral emissions. It is not clear exactly what the potential is of these detectors, nor if inversion technique is necessary at all if using these CCDs as RGB-detectors. It is of interest for the community to see what can and cannot be done with these detectors and I believe the paper is worth publishing, but the message must be made clearer and right now the reader is left wondering in what way the measurements can be used for qualitative auroral studies. I therefore suggest major revisions to the paper.

Major issues:

* The main problem I see with the paper is that it focusses very much on the inversion technique with the aim to be able to obtain 'good enough' spectral resolution to use one detector to do multispectral observations of aurora, and very little discussion is presented on exactly what kind of analysis the measurements would be used for and what resolution would be needed to reach this goal. To quote the Conclusions: 'Low-cost color mosaic imagers can effectively resolve 3 relatively wide-band channels that are well suited for auroral studies.' How are they well suited? What kind of analysis can you do? To be able to do qualitative emission ratio analysis to derive energies of the precipitation for example (which is the main method to use spectral ground-based information to learn about the precipitation that I am aware of) you need much better spectral resolution than these instruments can provide. But you do show that you are aware of this, in section 3.1, where you state that you need a spectral resolution of only a few nanometers to be able to do multispectral analysis, and that this is not possible with these kinds of detectors. Then at the same time you claim in the paper (page 779, line12) that with specially designed filters a spectral resolution of 40 nm can be achieved which is considered 'very good', but what kind of physics do you envisage to do with those kind of data? In what way can a spectral resolution of 40 nm be very good, for most measurements you will have severe background contamination that is probably varying with time in a non-predictable manner (e.g. molecular nitrogen band emissions due to high energy precipitation surrounding low energy atomic lines such as 630 nm)? Maybe you mean to use the color camera to separate nighttime green aurora from fainter dayside red aurora? Or perhaps to investigate SAR arcs, or search for precipitation within the polar cap? It would be very enlightening if you could include a qualitative discussion on what scientific investigations such low-cost allsky cameras can be used for. Of course, if you want to discuss using multi-spectral observations for energy ratios you also need to be aware of that you immediately run into the problem of perspective effects whenever you are looking anywhere else but in magnetic zenith (or a few degrees off magnetic zenith). So a multi-spectral ratio analysis of emissions in allsky data is only sensible in the few pixels around zenith anyway. This is also not discussed at all in the paper but would be nice to include, if you are

proposing to use these detectors (as single detector or in combination with a second) to measure two or several emissions to derive energies of the precipitation.

* Considering this, I think the abstract is a bit misleading. In the abstract you write 'In this study we use Backus-Gilbert linear inversion techniques to obtain quantitative measures of effective spectral resolution for multi-channel color mosaic CCDs.' I would rather say something along the line that you investigate how the spectral resolution of two specific color mosaic detectors can be improved by applying Backus-Gilbert linear inversion techniques, in hope to be able to distinguish between a number of common auroral emissions. The method does not succeed in isolating the narrow auroral features but three wide-band channels in red, green and blue can be resolved and so forth, and then mention how this can be used for scientific purposes, and that you look into chip combinations and filters to further improve the measurements. That way you are stating up front that you are analyzing how the spectral response can be improved by using inversion techniques, but that you cannot use this detector to obtain highly resolved spectral measurements to use for energy analysis. Although it seems that the bottom line of your research is that these detectors are not well suited for qualitative scientific spectral analysis of aurora, the discussion of the attempt to clean up the spectral information with inversion techniques is interesting and worth publishing anyway, since I am sure many people in our community have asked themselves if low-cost mosaic detectors can be used effectively for multi-spectral observations, without having to get several detectors or filters.

*If I want to single out one emission, you are suggesting to add narrow-band filters on top of the detector, or a multi-notch filter. This is interesting, and I'm then immediately wondering if this could be a cheaper way to do spectral analysis of aurora, but the paper lacks a clear discussion on what the sensitivity would be for such an instrument. For how long would I have to integrate the data to get an adequate signal-to-noise ratio for observations of the individual 7 auroral emissions that you have listed in Table 1? Is it feasible at all to use one of these color CCDs together with a narrow-band filter for auroral measurements? You are discussing this solution at length and I suggest that you either include a discussion on the sensitivity and integration times needed for your combinations to make the discussion complete, or if not possible, you should shorten the discussion of notch-filters etc. significantly and just mention it as a possibility that needs to be further looked into.

* I am then left wondering, if I want to do the kind of qualitative auroral analysis that you will describe as possible with these detectors, do I still need to do the Backus-Gilbert inversion of the measurements, or can I get the same physics results by simply installing a color mosaic detector with suitable optics in the field and then directly analyse the data in the RGB or CYGM pixels of the detector? How much are my results further improved by using inversion techniques? Obviously this would depend on what it is I am observing, which is why I am asking for a more detailed description of what kind of physics can be done with an RGB detector, and how sensitive it would be to variations in the spectral response. It would then also be of great interest to include a discussion on the importance (qualitatively, not quantitatively) of cleaning up the RGB spectra with inversion techniques.

Minor issues:

1) Introduction, line 21: spectroscopically -> spectrally?

- 2) Figure 1: I suggest changing the y limits to go up to perhaps 600 R/nm instead to better show the details of the auroral spectrum.
- 3) Figure 2: I don't see what important information this figure adds to the paper, I suggest removing the figure and lines 12 – 14 on page 762.
- 4) Figure 3 and 4 contain pretty much the same information. I suggest you remove figure 3 with the reference diode power level, it is enough to just discuss it in the text.
- 5) Page 765, line 11: ‘..with column pairs subsequently binned..’, do you mean to say column and row pairs? You bin in both directions (columns and rows) here, right?
- 6) Page 766, lines 21 – 23: ‘..consistent with an increase in characteristic precipitation energy..’. The variation could also be due to a change in energy flux (which is for example linearly related to the brightness of the 427.8 nm N₂⁺ emission).
- 7) Page 772, line 17: It seems the wavelength where equal amounts of blue and green channels are needed is 520 nm rather than 510 nm.
- 8) You may want to reconsider the title of the y-axis in figure 12 (and the following similar contour plots of resolution function)? It is not strictly resolution on the y-axis (the resolution doesn't continuously increase for longer wavelengths), would it be more appropriate to call this synthetic bandwidth, or resolution at specific wavelength, or something similar?
- 9) I don't see the purpose of figure 17, perhaps I don't understand exactly what it is meant to show but it seems to me that you have already shown the overall spectral response for the different detectors in figures 4,5 and 7, and this figure can be omitted.
- 10) You seem to have mixed up D and d in some of your equations, and dropped indices? In equation (13) you have stated a capital D, which I assume should be the weighing coefficients d_{ij} as introduced in equation (4), and not D which is the matrix notation? Then in equation (21) you give the error estimate again, but this time the d has dropped one of its indices?
- 11) Page 780, lines 24 – 26. You say that only H9C/MX7C and 3 x MX7C provide equally good results for all wavelengths above 400 nm in figure 22, but what about Mx7C raw (dotted line)? That one seems to be as good as the other two?
- 12) Table 5 is not mentioned in the text at all as far as I can see, it just appears as a table (and it is not clear what is meant by the first column, also, in the legend it says spread, error and noise, but it seems to be listing spread, error and bias).
- 13) Page 785, lines 23 – 25 (Conclusions): You say: ‘Multiple low-cost devices can also be operated at numerous locations to study spatial scales that are inaccessible to a single camera.’ What do you mean by this, are you sure you mean spatial scales? Don't you mean dimensions? One imager can only observe in the 2D plane, but with an additional imager looking from the side you can get information on the height distribution, so I believe this is what you mean?
- 14) Page 788, line1 (appendix B): The bracket seems to be in the wrong place for the reference. ‘..definitions from (International...’.