

Interactive comment on “Auroral spectral estimation with wide-band color mosaic CCDs” by B. J. Jackel et al.

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Reviewer #2 correctly identifies some key results that should be more directly connected to practical applications, some assertions that need to be justified, and some deficiencies in the abstract. These are all valid criticisms. Trying to address them has significantly improved this paper; details are provided below. See also the supplemental "diff" change tracking PDF.

Major issues:

...very little discussion is presented on exactly what kind of analysis the mea-

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surements would be used for and what resolution would be needed to reach this goal... Yes, the underlying logic should have been more explicit. Additional text addresses this point: “For existing all-sky imagers, narrow-band systems can provide the most information about characteristic energy of precipitation and white-light observations provide virtually none. The question then becomes: how to quantitatively assess the utility of color ASIs relative to these limiting cases? Our response in this paper is to focus on optimizing spectral resolution. This approach is based on the assumption that a larger number of narrower pass-bands should lead to more accurate spectral observations and consequently to more accurate energy estimation. An alternate perspective involving direct inversion of precipitation energy is briefly considered in the Discussion, but is otherwise beyond the scope of this paper.”

...the abstract is a bit misleading... Yes, it was not a good summary of the final paper, changed: “Two spectrally calibrated commercial detectors (Sony ICX285AQ and ICX429AKL) with very different color mosaics (RGB vs. CYGM) were found to have very similar spectral resolution: 3 channels with FWHM ≈ 100 nm; a NIR blocking filter is important for stabilizing inversion of both 3-channel configurations. Operating the ICX429AKL in a non-interlaced mode would improve spectral resolution and provide an additional near infra-red channel. Transformations from arbitrary device channels to RGB are easily obtained through inversion. Simultaneous imaging of multiple auroral emissions may be achieved using a single color camera with a triple-pass filter. Combinations of multiple cameras with simple filters should provide ~ 50 nm resolution across most of the visible spectrum. Performance of other instrument designs could be explored and compared using the same quantitative framework.”

...For how long would I have to integrate the data to get an adequate signal-to-noise ratio...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... Good question. Text in

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§5 now reads: “Compared to a conventional system with a white-light CCD and a single narrow band filter, the 3×3 system will have moderately reduced sensitivity ($\sim 80\%$) due to the additional wideband filter losses, significantly reduced sensitivity (33%) since only $1/3$ of the pixels respond to each wavelength, and a similar factor of 3 reduction in spatial resolution. Each channel may also contain some leakage from the other two wavelengths, so inversion will be required for optimal signal separation.

For a fair comparison, the conventional system should also measure three different wavelengths, presumably with some kind of filter-wheel. This would reduce sensitivity by more than a factor of three, due to additional switching and read-out time required for each filter, and data from different filters would not be simultaneous. Overall, the 3×3 design will have comparable sensitivity and perfect simultaneity, but reduced spatial resolution and inferior out-of-band wavelength rejection.

Phenomena such as quiet auroral arcs, diffuse aurora, polar cap arcs, and patchy pulsating aurora are easily observed by existing Rainbow systems with 5 second exposures at a 6 second cadence. Moderate losses from a second filter would not drastically reduce the threshold of observable luminosity. A 3×3 device should thus be particularly useful during periods with bright dynamic aurora, although the lack of background estimates could be a concern during quiet times. ”

We also note later that the multi-camera systems considered in this paper will have increased sensitivity due simply to the additional detector area, with specific amounts depending on the filter combinations.

...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?

Good point. In general, Backus-Gilbert inversion provides a formalism to quantatively

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assess the performance of a multi-channel system. For a single RGB (Bayer) CCD we basically find that the instrument channels cannot be significantly improved upon. For a single CYGM device we can show that the optimal combinations are very similar to the RGB case. Once the transformation matrix is calculated, CYGM can be converted to RGB and then processed normally. Significant improvements over RGB require additional quasi-orthogonal channels, giving inversion something to work with.

Modified text in section 4.1: “These results indicate that the H9C can only usefully distinguish between three independent spectral ranges, each strongly resembling one of the measurement kernels. More precise wavelength discrimination, such as trying to separate N_2^+ (470.9 nm) and H_β (486.1 nm) emissions, is simply not possible given the measurement characteristics of this device. In the absence of other spectral information, linear inversion will not provide any advantage over working directly with the original RGB instrument channels.”

and new text in section 4.2: “Both modes of the ICX429AKL produce multiple channels each with a complicated spectral response. Linear inversion can determine how these channels should be combined in order to achieve the best possible wavelength resolution. The transformed channel combinations for this device are easier to work with than the original channels, as they can be used to construct RGB images for visual examination or compared with emission spectra to determine sensitivity.”

Minor issues:

- 1) **Introduction, line 21: spectroscopically – > spectrally?** Yes, changed.
- 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.** Yes, that is much better.
- 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.** Agreed, removed.

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.** Agreed, removed.

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?** The text was correct, but admittedly confusing: “that is read in fast mode with column pairs subsequently binned”. Reading in fast mode implicitly bins rows by 2, after which we explicitly bin by 2 over columns. This distinction is important to an instrument operator but less so to the typical reader of this paper. Changed to “ 2×2 binning”

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).** Increasing energy flux with the same characteristic energy (and assuming no feedback from increased heating) would increase all emission wavelengths by the same amount, leaving the Rainbow:THEMIS ratio unchanged. Observations show a change in ratio, so some change in spectral shape is required. The figure only shows total intensity; text added to indicate that ratio variation figure is “not shown”.

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.** Yes, fixed.

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?** Yes, synthetic bandwidth is more appropriate.

9) **I don’t see the purpose of figure 17, perhaps I don’t understand exactly what**

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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. The purpose was communicated poorly, changed: “The central theme of this study is examination of color mosaic CCD capabilities for spatial resolved multi-spectral analysis of the aurora. It is admittedly also important to be able to produce colorful images for scientific communication and public outreach. RGB data can often be displayed with minimal processing, but CYGM data must first be transformed into some other form. One approach suggested in the ICX429AKL data sheet is reviewed in Appendix ???. It relies on the combination of several color theory concepts, and when applied to auroral data the results are often not visually appealing.”

and “Figure ?? contains a summary of the RGB conversion matrices applied to the calibration scans. These results should be assessed in terms of their visual appearance, so they are displayed as color bars.”

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? Yes, fixed, sorry for the confusion.

11) Page 780, lines 24–26. You say that only H9C/MX7C and 3 x MX7C provide equally good result sfor 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? Yes, discussion has been improved.

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). Yes, text added.

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? This was poorly worded; the intended reference was to combining multiple fields of view eg. THEMIS mosaic. Text changed.

14) **Page 788, line1 (appendix B): The bracket seems to be in the wrong place for the reference. ‘..definitions from (International. . . Yes, the citation “(?)” should now behave correctly.**

Please also note the supplement to this comment:

<http://www.geosci-instrum-method-data-syst-discuss.net/3/C286/2014/gid-3-C286-2014-supplement.pdf>

Interactive comment on Geosci. Instrum. Method. Data Syst. Discuss., 3, 753, 2013.

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