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Investigating the contribution of high-energy precipitation during pulsating aurora: KAIRA and optical data comparison

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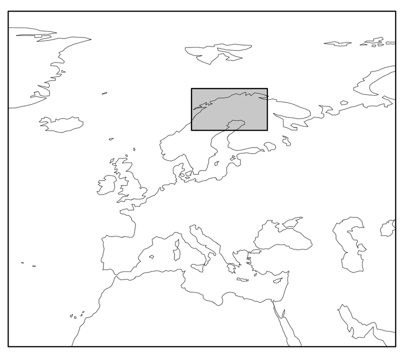
Introduction

Pulsating aurora is among the clearest examples of the high temporal and spatial variability of particle precipitation into the ionosphere. This work studies the possible contribution of **high-energy particle precipitation during a pulsating aurora event** over Kilpisjärvi ($L = 5.9$). It is based on the comparison of optical data and cosmic noise absorption (CNA) data. The optical data consists of all-sky camera images of the **auroral blue-line emission** (427.8 nm), and the CNA data at 30 MHz was obtained from an experiment of the **Kilpisjärvi Atmospheric Imaging Riometer Array** (**KAIRA**), used here as a multi-beam riometer.



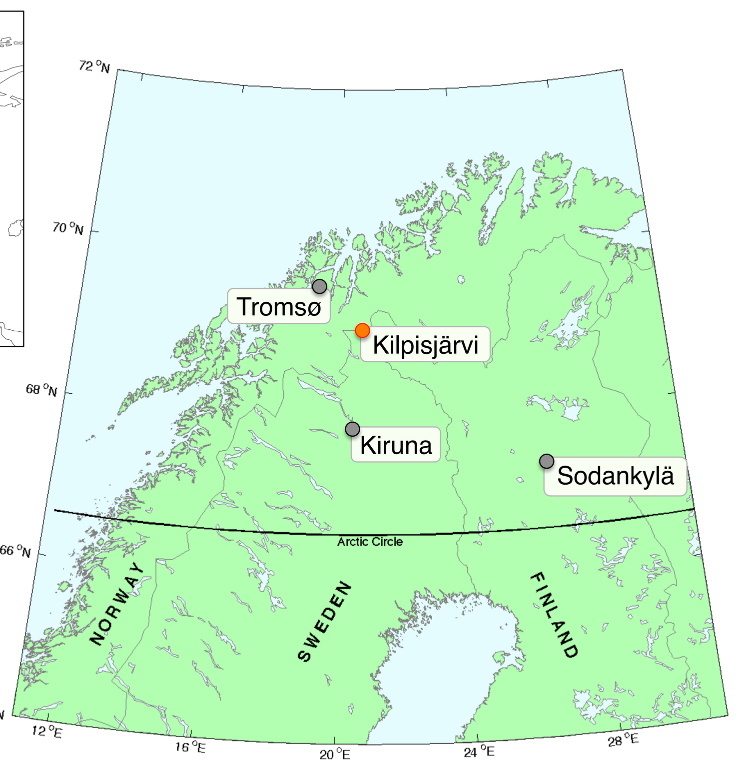


Figure 1 – Map of the area. The instruments used in this study are located in Kilpisjärvi, on Finnish territory, just next to the border with Norway.

The scientific observatory in Kilpisjärvi, with the dome containing the all-sky camera. The background features the Saana fell, sacred to the Sámi people. *Photo by T. Raita.*

Kilpisjärvi Atmospheric Imaging Riometer Array (KAIRA)

KAIRA consists of two arrays:

- High-band antenna (**HBA**) array
  110–270 MHz, 48 "tile" antennas
- Low-band antenna (**LBA**) array
  10–80 MHz, 48 "inverted-V" aerials

It is based on the **LOFAR** (Low-Frequency Array) International Telescope technology.

The LBA array (foreground) and the HBA array (background) on a sunny winter day. *Photo by D. McKay.*

KAIRA is a **multi-purpose** radar, applicable to:

- multi-beam, multi-frequency riometry;
- bistatic incoherent scatter radar observations (with Tromsø VHF);
- interplanetary scintillation;
- all-sky interferometric riometry;
- radio astronomy;
- solar radio emission studies...

More details on KAIRA in *McKay-Bukowski et al.* [2015] (open access)

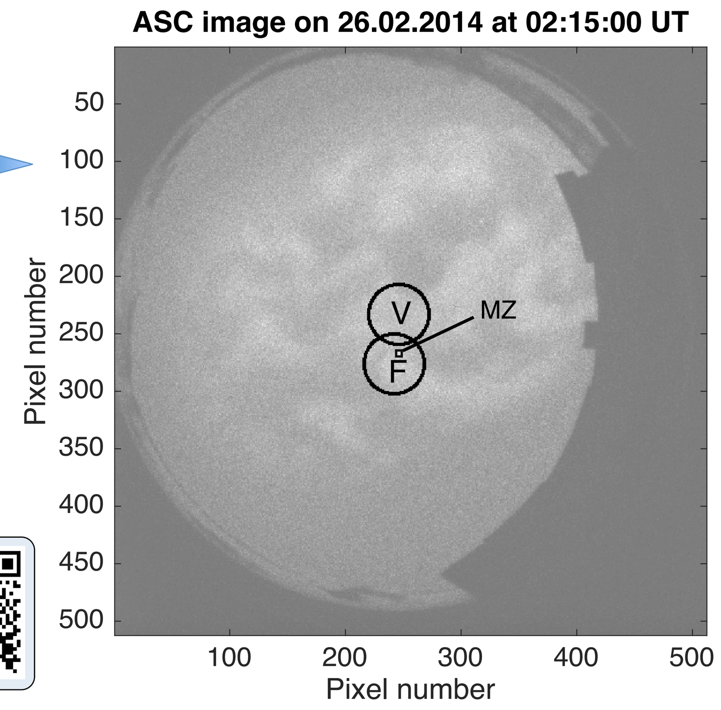


Figure 2 – Two KAIRA beams mapped on an all-sky camera image. Beams are noted V (vertical) and F (field-aligned); MZ indicates the magnetic zenith.

CNA and Optical Data Correlation

Optical data: weighted average of pixel values within KAIRA beam.
Time resolution: 2 s for optical data; 1 s for KAIRA data.
Event date: 26 February 2014, 02:00 UT (~05:00 magnetic local time).

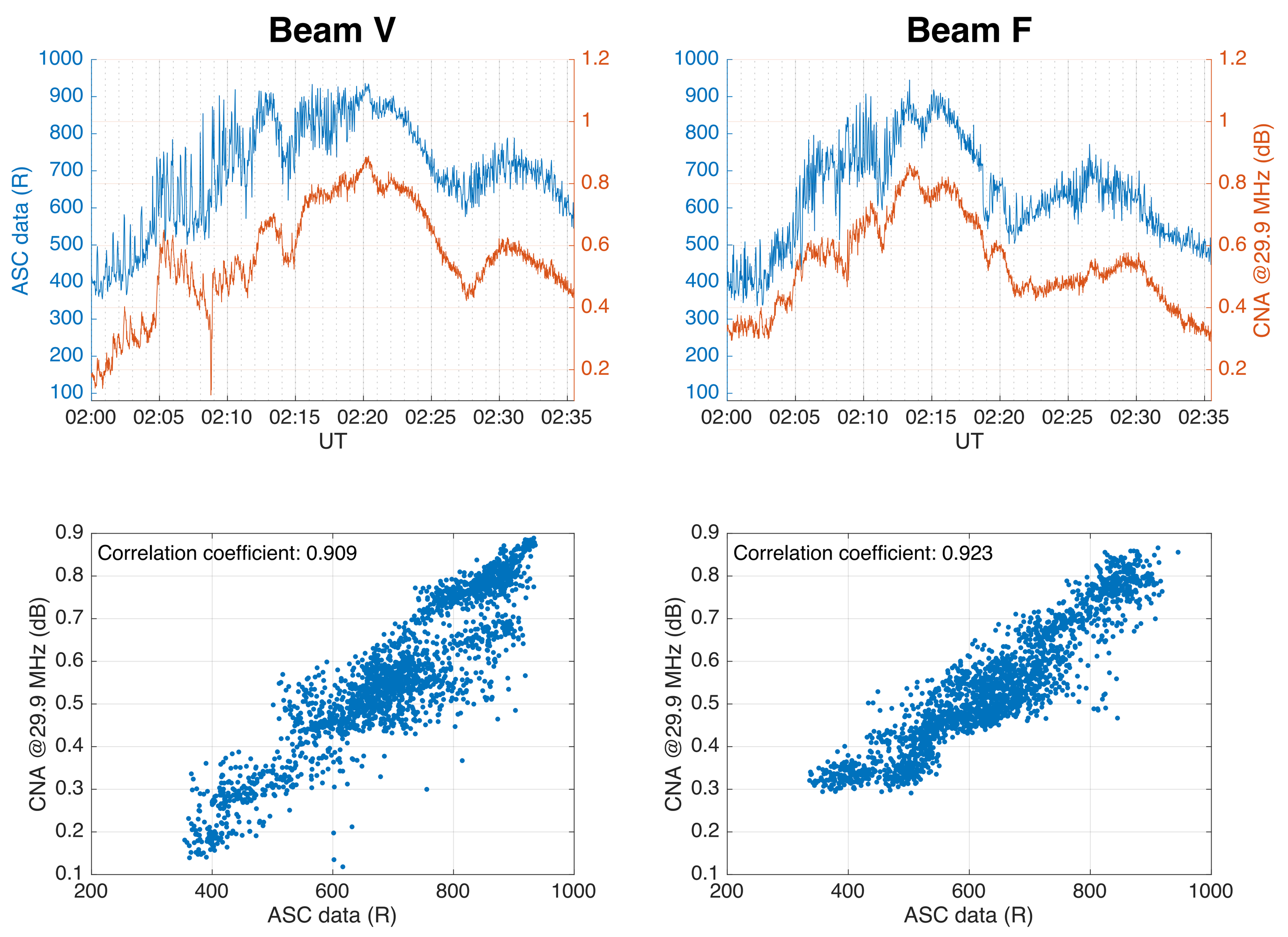


Figure 3 – (top) Time series of the optical and CNA data during the 26 February 2014 pulsating aurora event. (bottom) Correlation between CNA and optical data sets.

Pulsations in CNA?

For each beam, a data subset exhibiting **clear optical pulsations** was chosen (Figure 4, top). **Pulsations are also clearly visible in the CNA data, following the optical ones!**

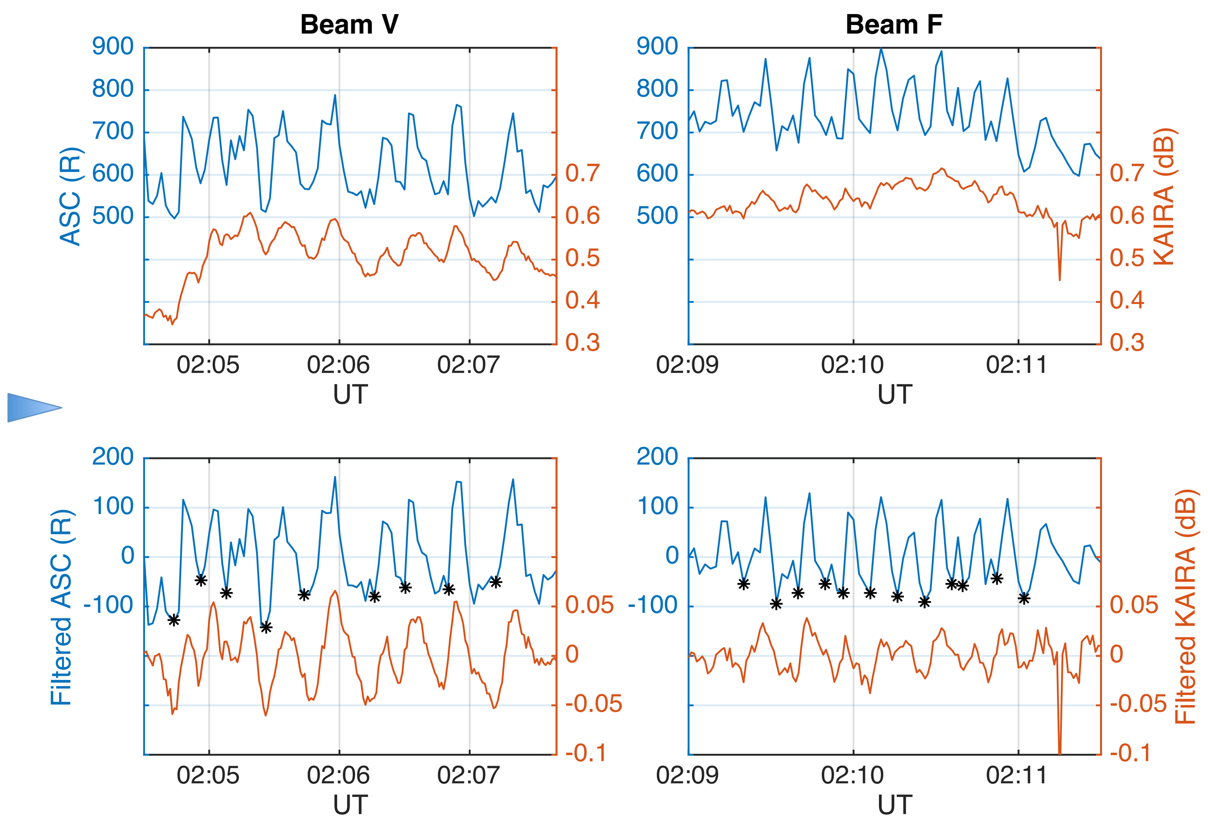


Figure 4 – Time series of the data during pulsation time intervals. (top) Original optical data and original KAIRA data. (bottom) High-pass-filtered optical and KAIRA data. Black stars indicate the chosen zero epochs for the superposed epoch analysis (see Figure 5).

Can we trust that the fluctuations in CNA indeed match the optical pulsations?

Superposed Epoch Analysis

Optical and CNA data were **high-pass filtered**, to remove background value and fluctuations with periods longer than 30 s.

The **zero epochs** were defined as the local minima before optical pulsations (stars in Fig. 4).

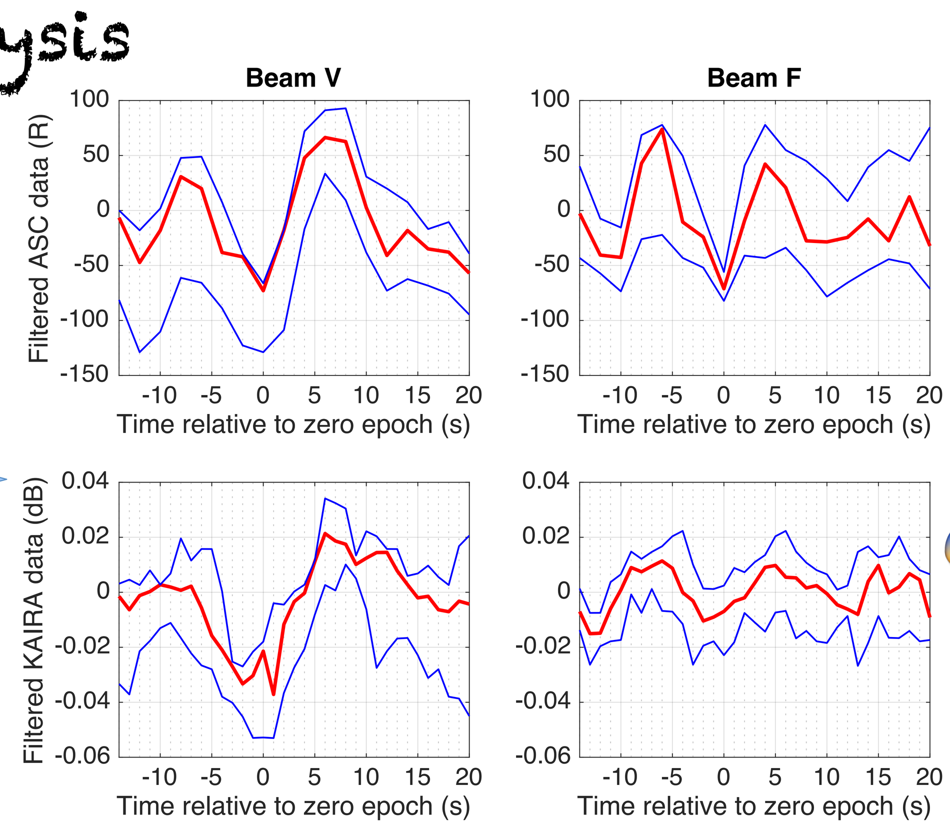


Figure 5 – Superposed epoch analysis of the filtered ASC and CNA data during pulsations. (median values; upper and lower quartiles).

Pulsation periods:
~12+ s (beam V)
~10 s (beam F)

Spread suggests **irregular** periods

Pulsations with similar periods in CNA, even in beam F!

Discussion

CNA at frequency ω is given in dB by $A_{dB} = 4.6 \times 10^{-5} \int \frac{N_e \nu_{en} \mathrm{d}l}{\nu_{en}^2 + (\omega \pm \omega_L)^2}$

In practice, A_{dB} is proportional to the total electron density in the D region.

SIC model simulations estimated the recombination time at 60–90 km altitude to be of the order of 40–60 s. Approximating the N_e decay as exponential, during a ~8 s pulsation "off" time, the CNA decrease is expected to be of about 15%, which is consistent with observations (Fig. 4, beam V).

More detailed simulations with the SIC model reproduced ~0.1 dB oscillations in CNA by modulating with 10 s period the precipitation flux estimated based on incoherent scatter radar (EISCAT) measurements during the event. It was in addition found that modulating only the low-energy part of the flux (ionizing down to ~100 km) only creates ~0.01 dB oscillations in CNA.

The Sodankylä Ion-Neutral Chemistry (SIC) Model

The SIC model is a **middle atmosphere and *D*-region** 1-dimensional model, which resolves the concentrations of:

- 36 positive ions;
- 27 negative ions;
- 13 neutral species.

More details on the SIC model in *Verronen et al.* [2005]

It considers more than 400 chemical reactions, and ionization sources include solar UV, X-rays, electron and proton precipitation, and galactic cosmic rays. Vertical transport is included, and SIC can be run either in static or dynamic mode.

Conclusion

The main findings from this comparison between CNA data from KAIRA and optical data are:

- CNA and optical data show a **very high** (>0.9) **correlation**;
- **Pulsation signatures can be seen in CNA**;
- Pulsation periods are **irregular**, even within a same patch.

References

McKay-Bukowski, D., J. Vierinen, I. I. Virtanen, R. Fallows, M. Postila, et al. (2015), *IEEE Trans. Geosci. Remote Sens.*, *53*(3), 1440–1451, doi:10.1109/TGRS.2014.2342252.

Verronen, P. T., A. Seppälä, M. A. Clilverd, C. J. Rodger, E. Kyrölä, et al. (2005), *J. Geophys. Res. Space Physics*, *110*(9), A09S32, doi:10.1029/2004JA010932.

... and, (hopefully) Grandin, M., A. Kero, N. Partamies, D. McKay, A. Kozlovsky, and D. Whiter (2017), Observation of pulsating aurora signatures in cosmic noise absorption data (submitted).

Acknowledgements

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