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Circular polarization of radio emission from air showers in thunderstorm conditions.

Gia Trinh

LOFAR Cosmic Ray KSP & Cosmic Lightning Project

O. Scholten, S. Buitink, A. M. van den Berg, A. Corstanje, U. Ebert,
 J.E. Enriquez, H. Falcke, J.R. Hörandel, A. Nelles, P. Schellart, J. P. Rachen,
 C. Rutjes, L. Rossetto, S. Thoudam, S. ter Veen

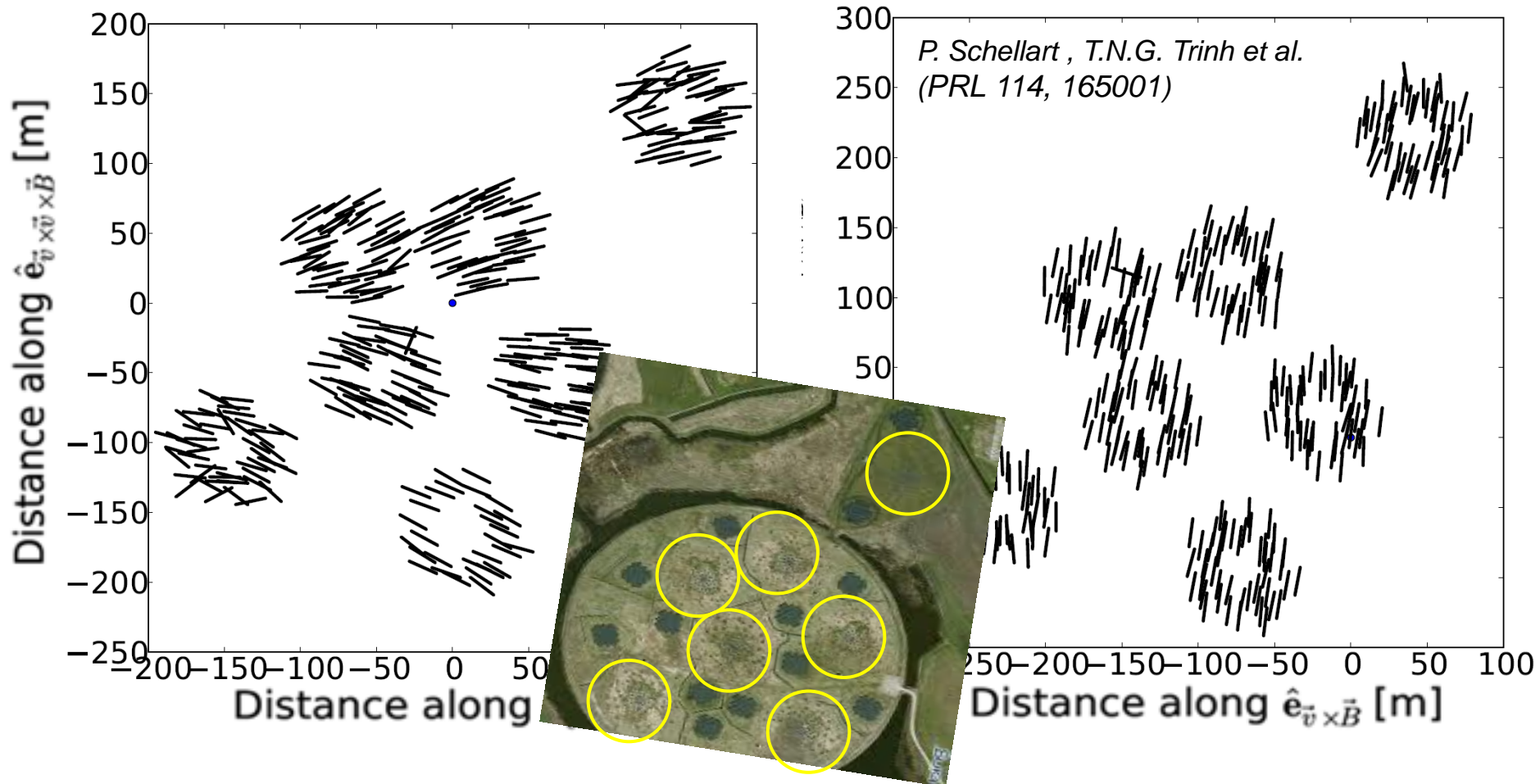
LOFAR Science Workshop

April 5th – 6th, 2016

P. Schellart



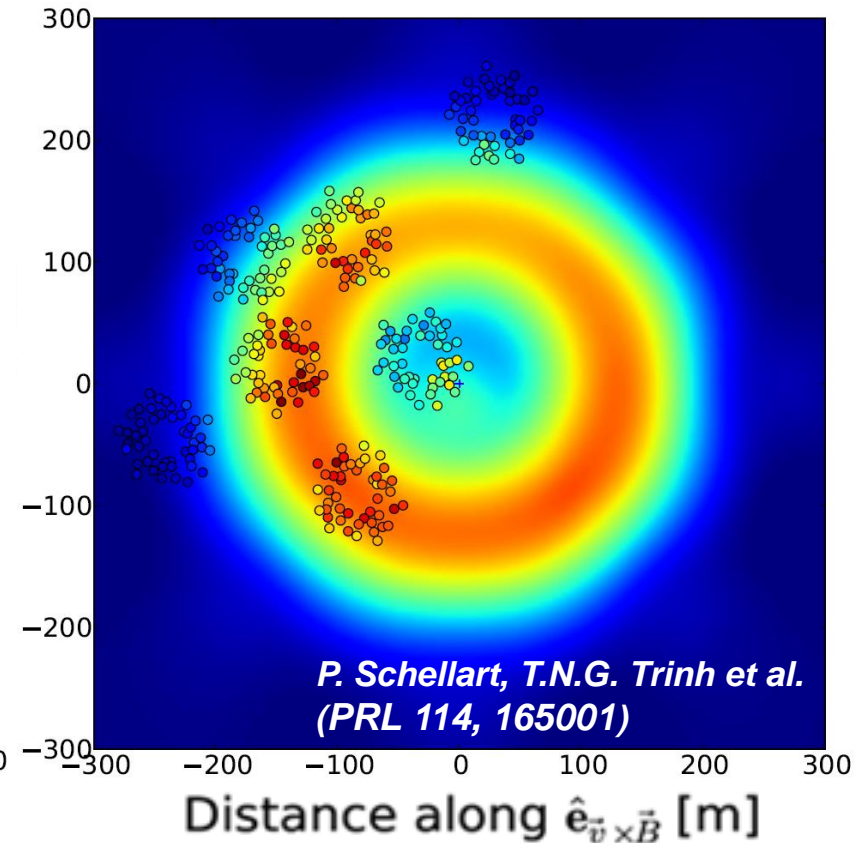
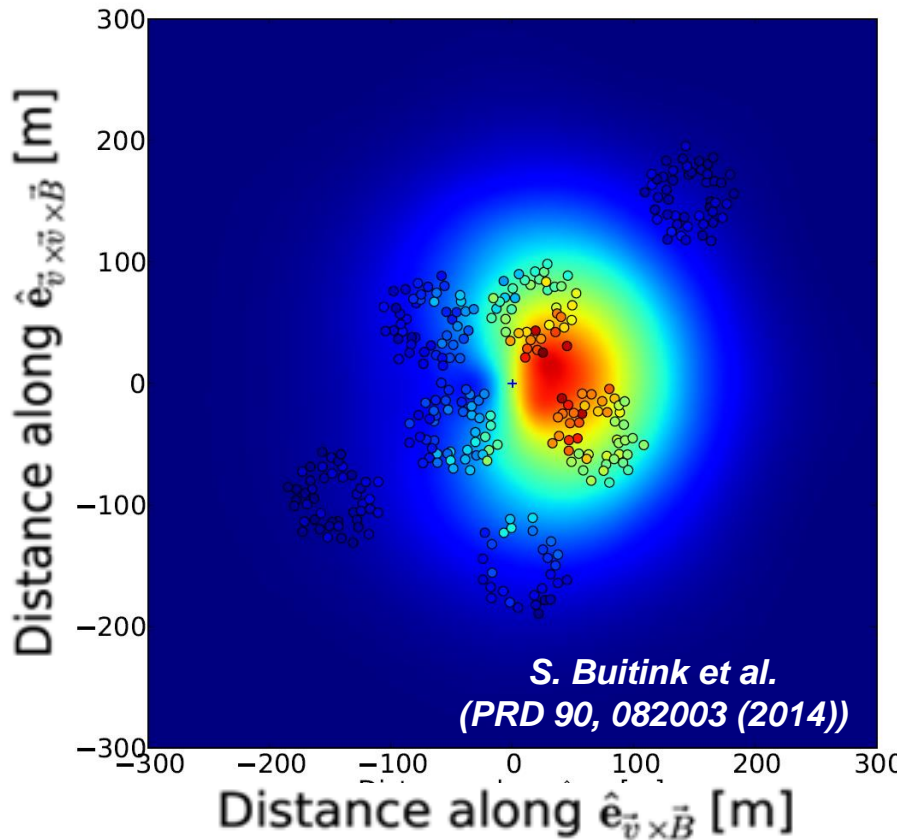
Fair weather vs thunderstorm



Linear polarization



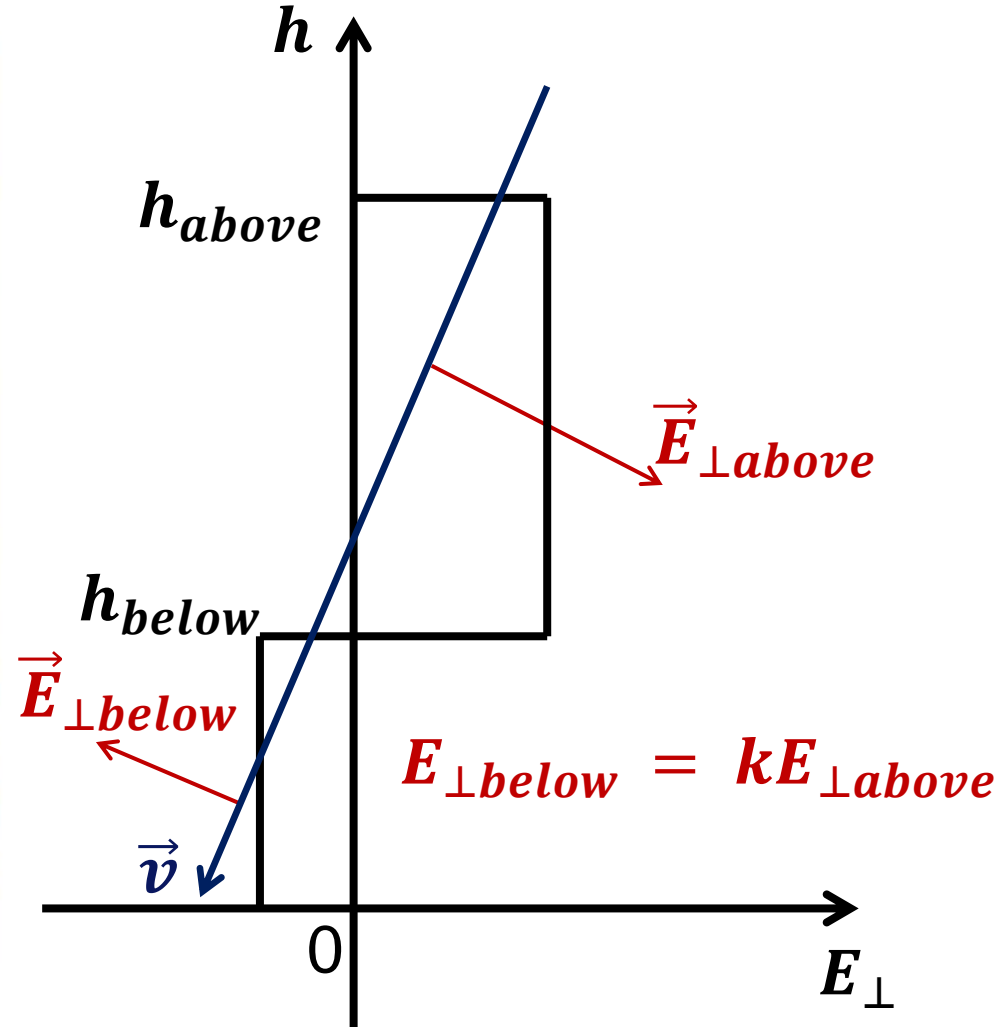
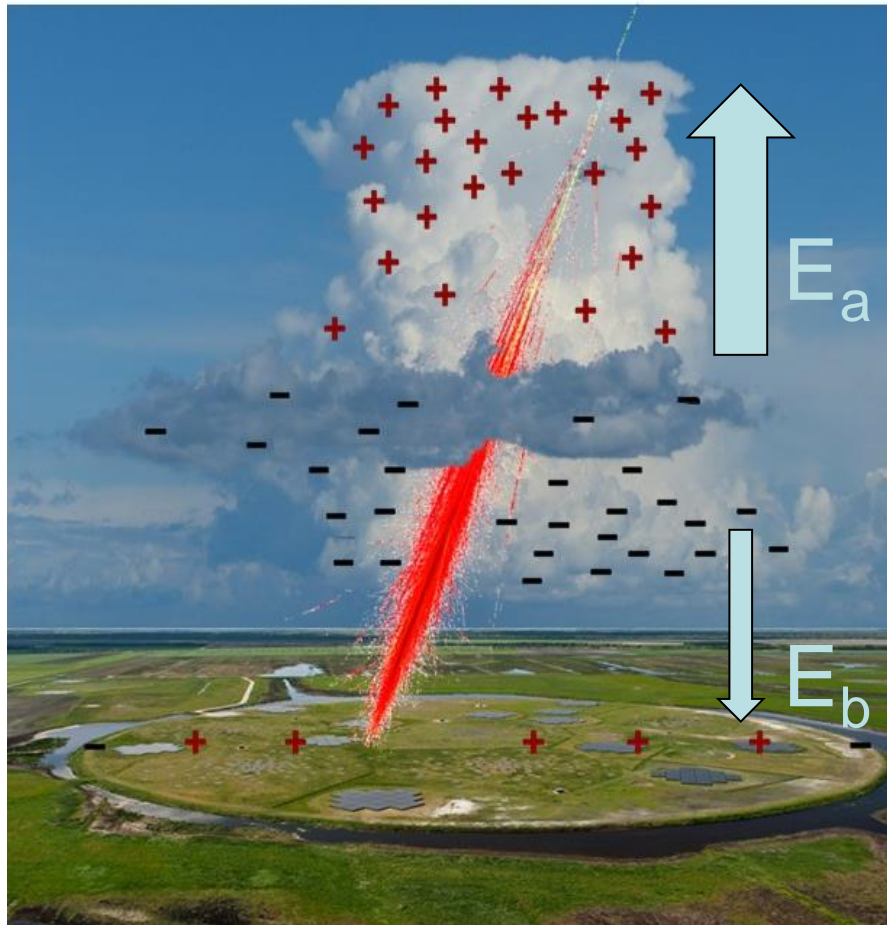
Fair weather vs thunderstorm



Intensity footprint

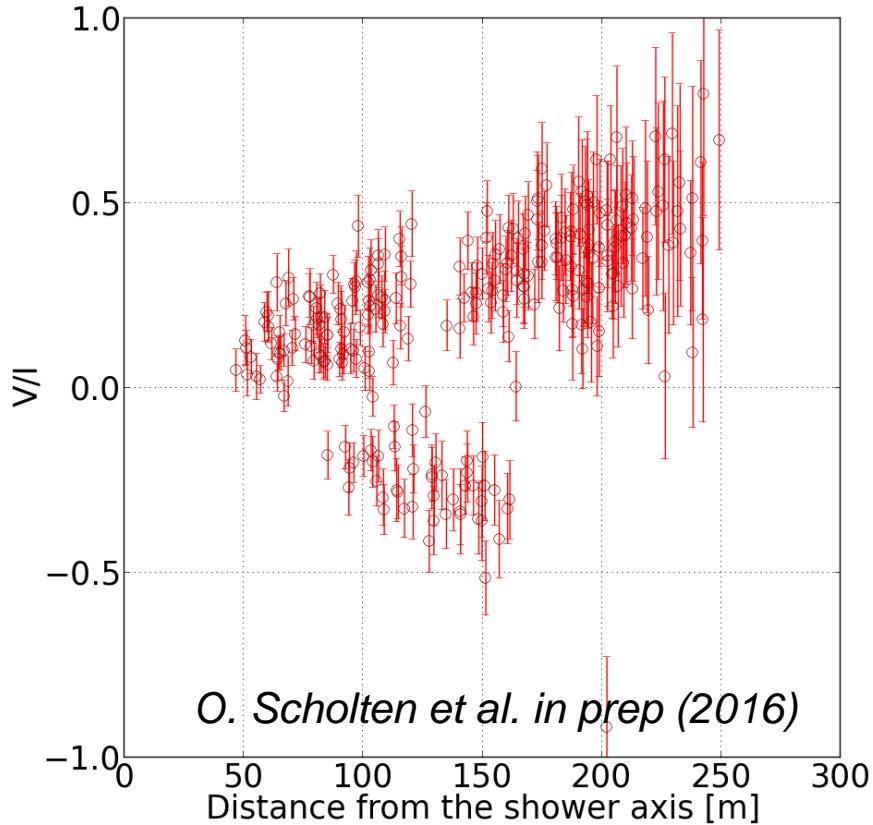


Structure of E-fields

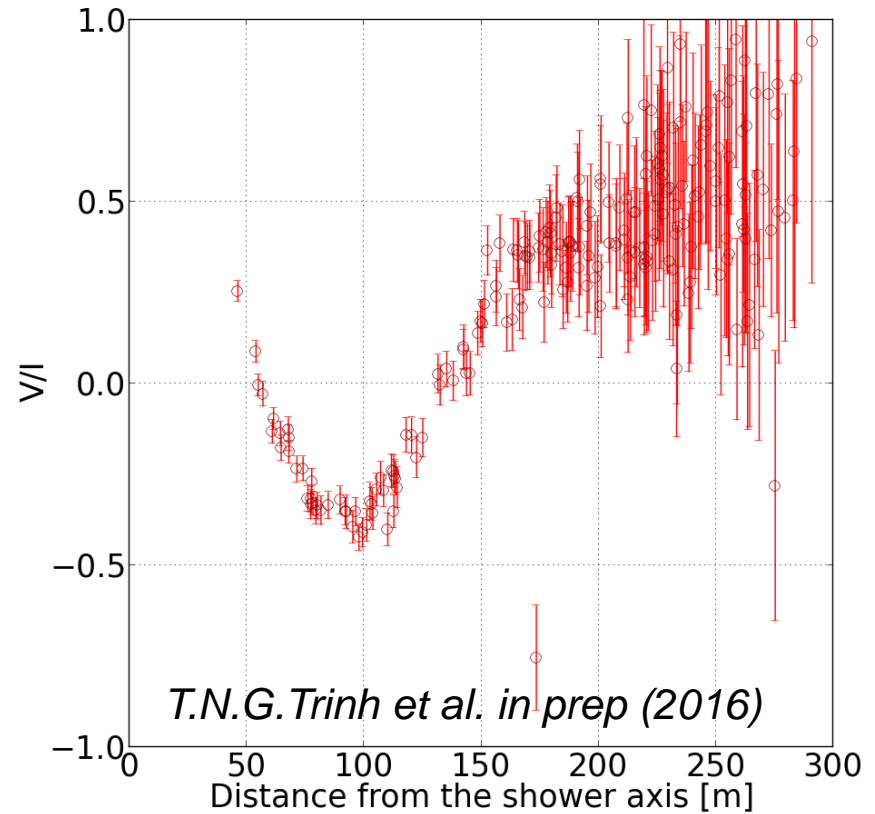




Fair weather vs thunderstorm



Small, vanish at the core
(Charge excess)

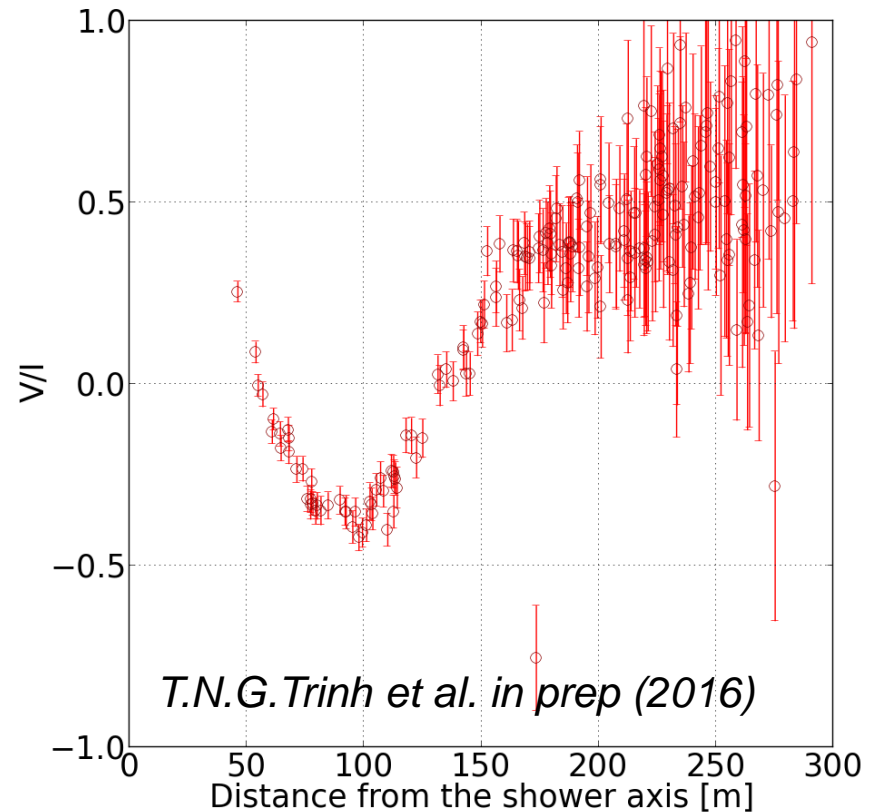
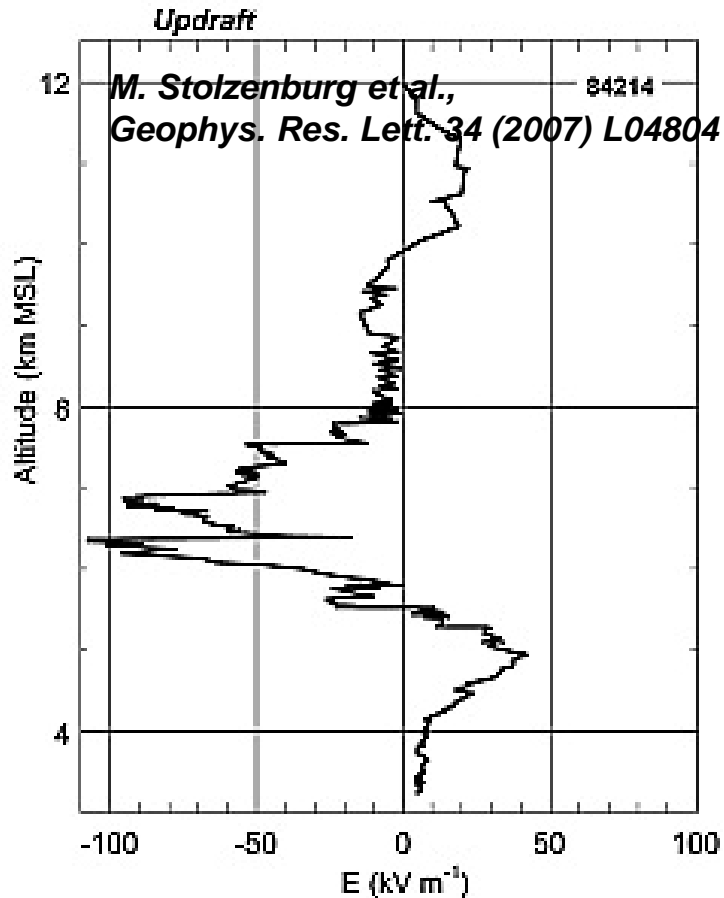


Large, finite at the core, change sign
(Change in the current's direction)

Circular polarization



Circular polarization in thunderstorm conditions





Full polarization – Stokes parameters

$$I = \frac{1}{n} \sum_{i=0}^{n-1} (E_{i,\vec{v} \times \vec{B}}^2 + \hat{E}_{i,\vec{v} \times \vec{B}}^2 + E_{i,\vec{v} \times \vec{v} \times \vec{B}}^2 + \hat{E}_{i,\vec{v} \times \vec{v} \times \vec{B}}^2),$$
$$Q = \frac{1}{n} \sum_{i=0}^{n-1} (E_{i,\vec{v} \times \vec{B}}^2 + \hat{E}_{i,\vec{v} \times \vec{B}}^2 - E_{i,\vec{v} \times \vec{v} \times \vec{B}}^2 - \hat{E}_{i,\vec{v} \times \vec{v} \times \vec{B}}^2),$$
$$U = \frac{2}{n} \sum_{i=0}^{n-1} (E_{i,\vec{v} \times \vec{B}} E_{i,\vec{v} \times \vec{v} \times \vec{B}} + \hat{E}_{i,\vec{v} \times \vec{B}} \hat{E}_{i,\vec{v} \times \vec{v} \times \vec{B}}),$$
$$V = \frac{2}{n} \sum_{i=0}^{n-1} (\hat{E}_{i,\vec{v} \times \vec{B}} E_{i,\vec{v} \times \vec{v} \times \vec{B}} - E_{i,\vec{v} \times \vec{B}} \hat{E}_{i,\vec{v} \times \vec{v} \times \vec{B}}).$$

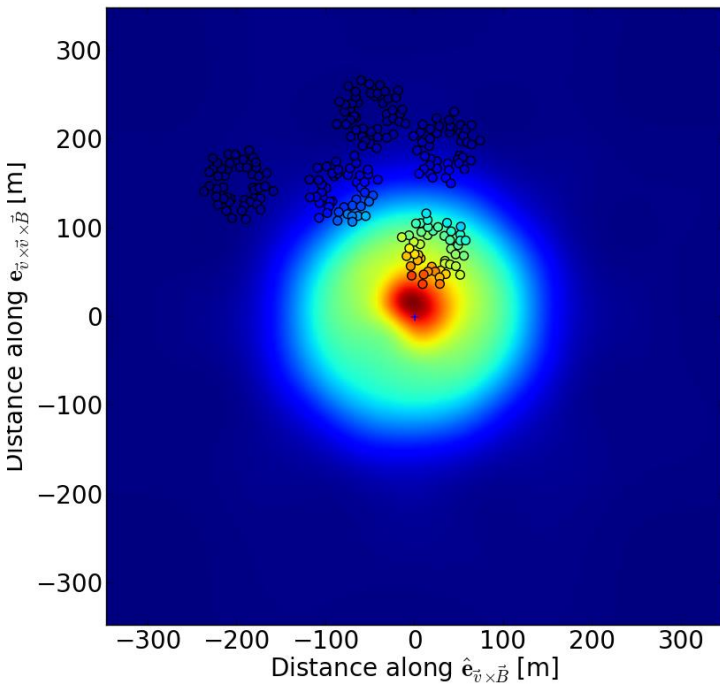
Intensity: I

Linear polarization angle: $2 \varphi = \text{atan}(U/Q)$

NEW: Circular polarization = V/I



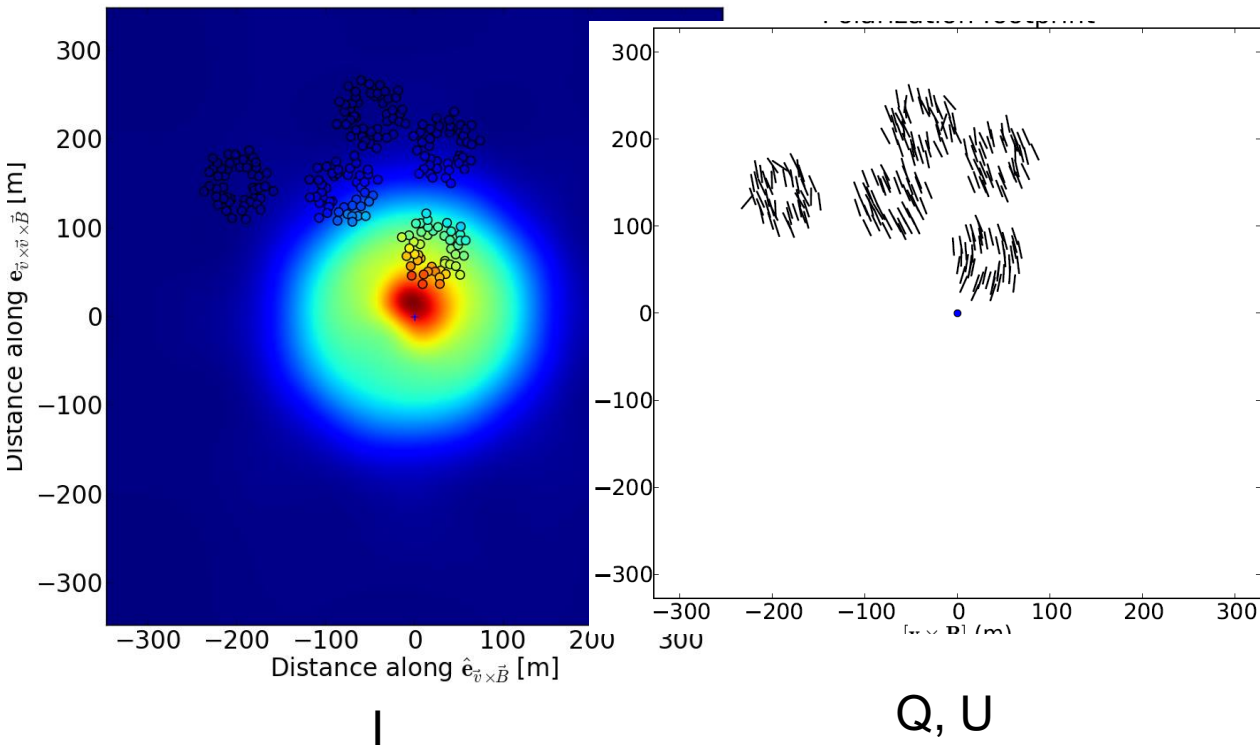
Evidence for more details



|

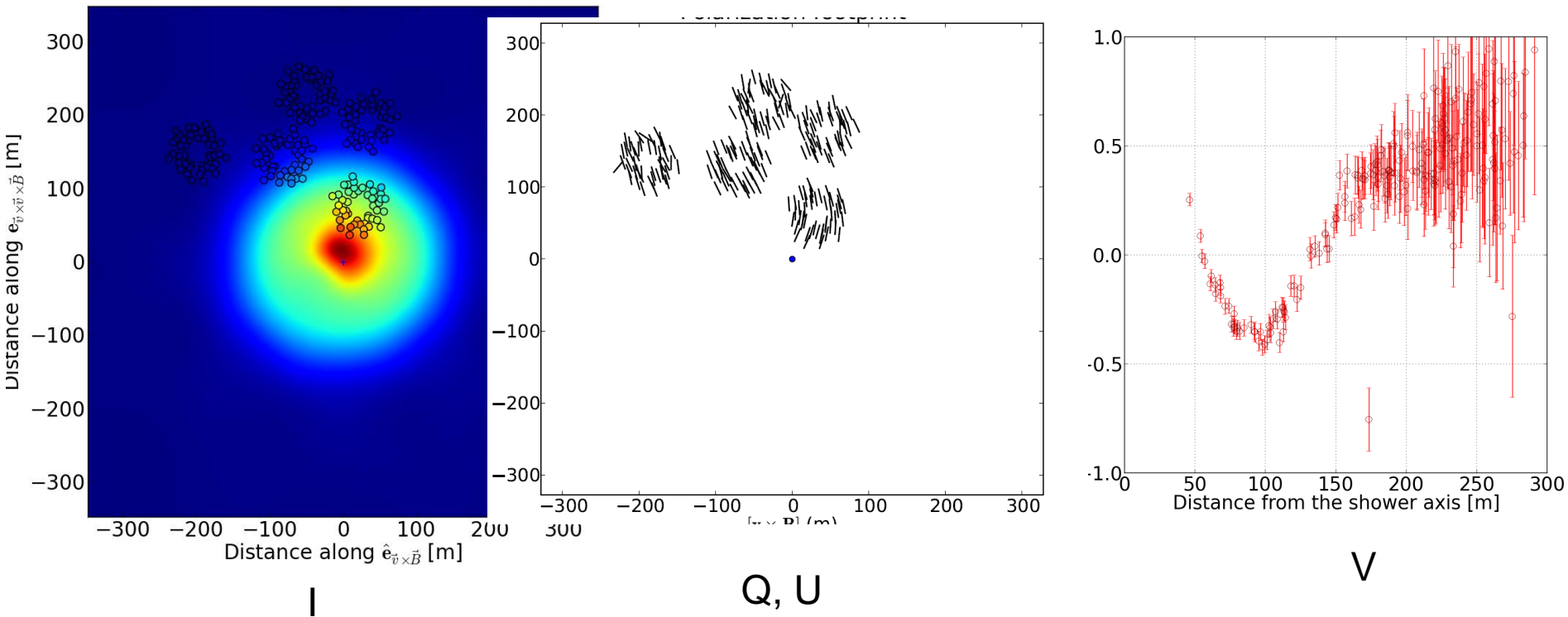


Evidence for more details





Evidence for more details



Full set of Stokes parameters \rightarrow more details about the structure of E-fields



3 layered E-fields

$$h_1 = 8 \text{ km}$$

$$h_2 = 5 \text{ km}$$

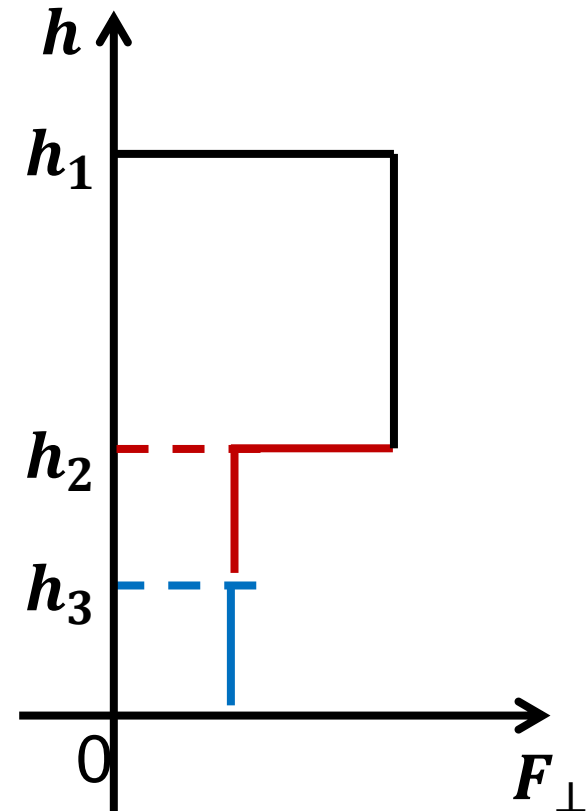
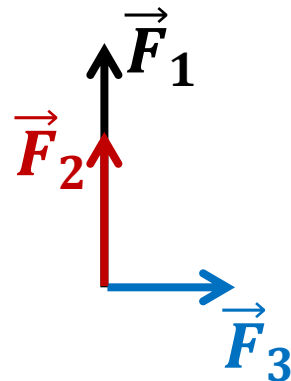
$$h_3 = 2 \text{ km}$$

$$F_1 = 20F_L$$

$$\sim 50 \text{ keV/m}$$

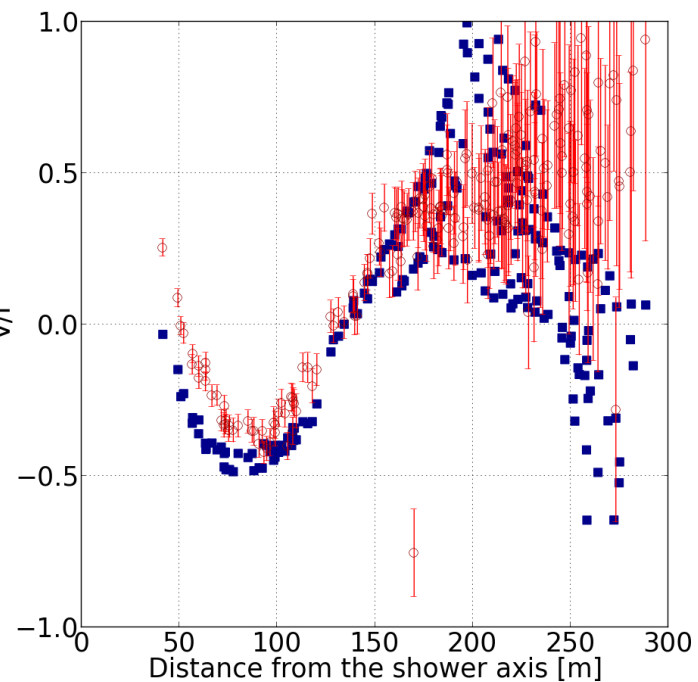
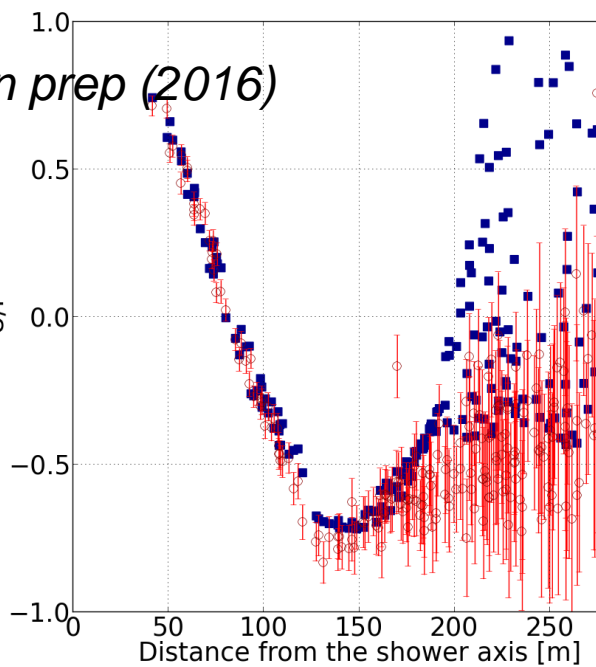
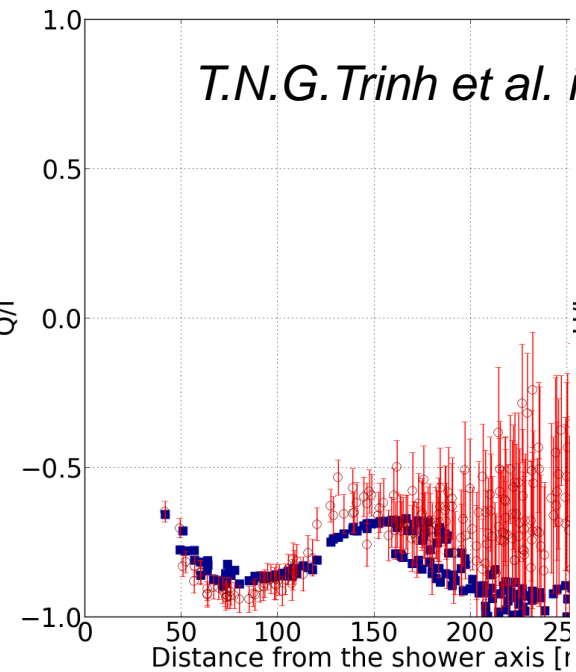
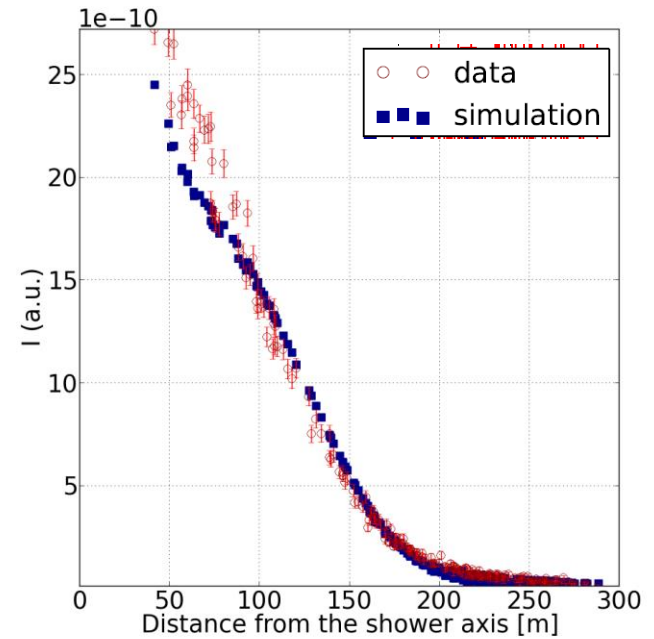
$$k = 0.3$$

$$X_{\text{max}} = 770 \text{ g/cm}^2$$





Fitting Q, U, V





Conclusion

- Observe large circular polarization in thunderstorm events.
- Related to the change in the transverse current.
- Get more details about E-fields when using full set of Stokes parameters.