# Cosmic particle showers & thunderstorms

Stijn Buitink - R.U. Nijmegen

cosmic lightning project:

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### **LOFAR**

Radio detection of cosmic rays



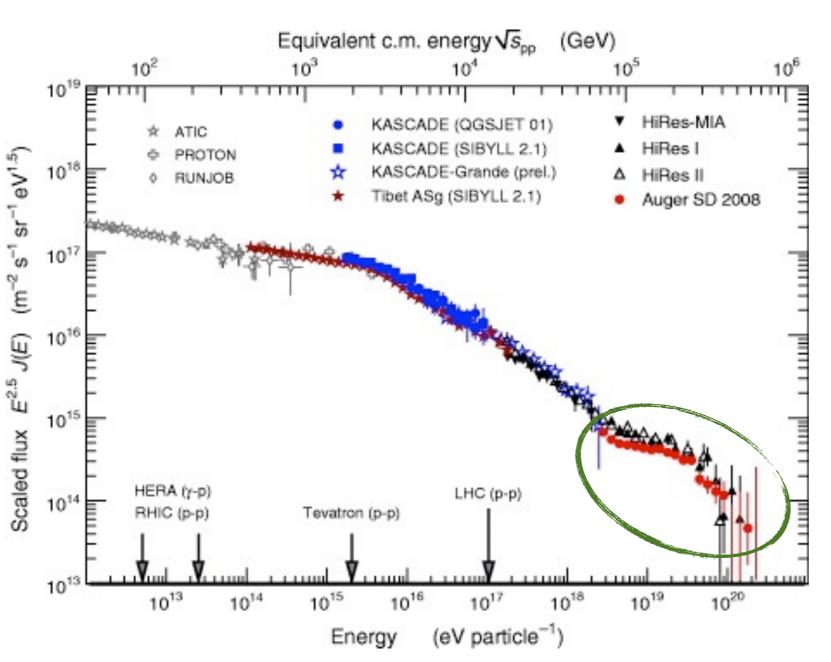
detection of discharges

CR - thunderstorm interaction

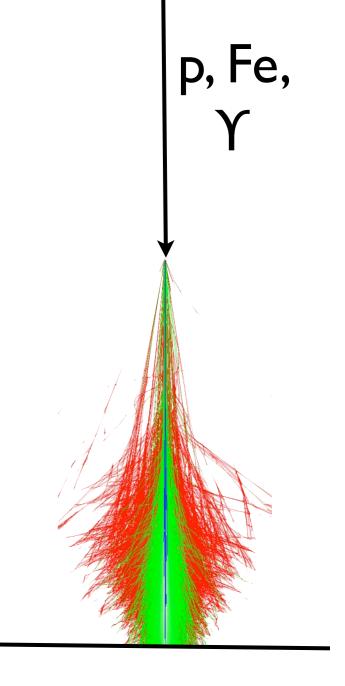
- localization & imaging of lightning
- high altitude discharges?

- lightning triggering
- ionization
- influence of E-field on CR radio emission
  - → measure E?

## Cosmic Rays



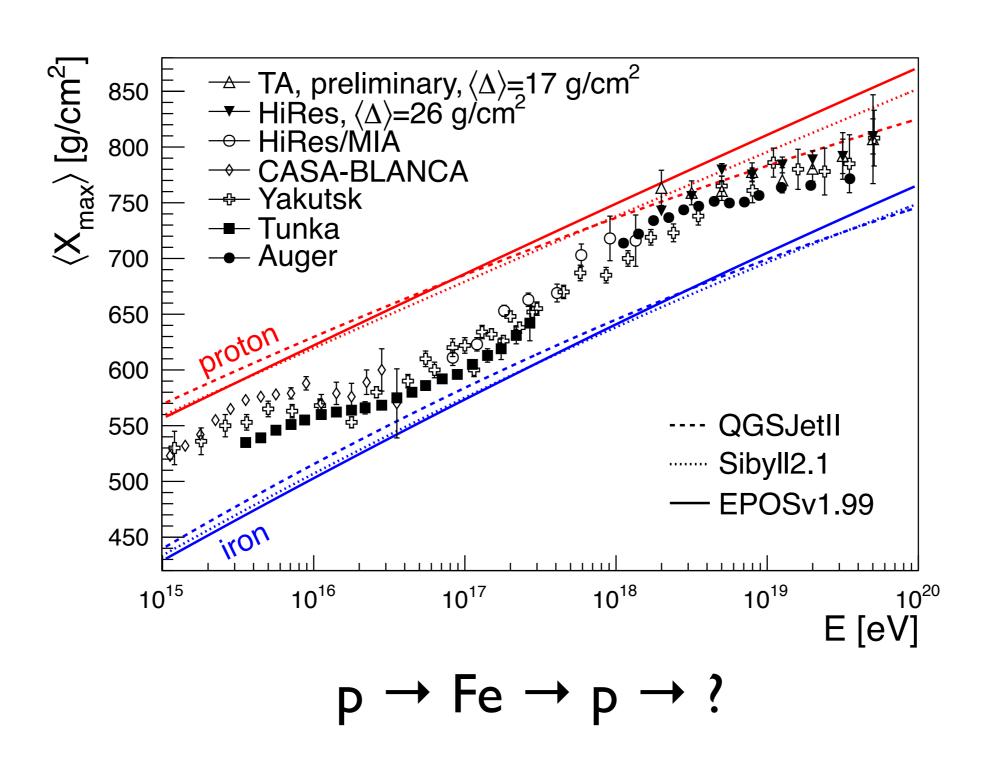




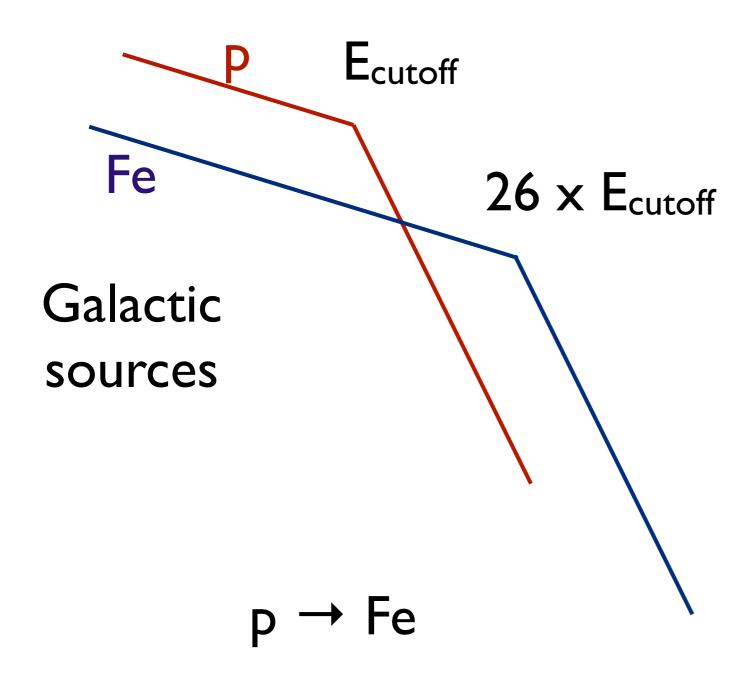
#### Measure:

- direction
- energy
- mass

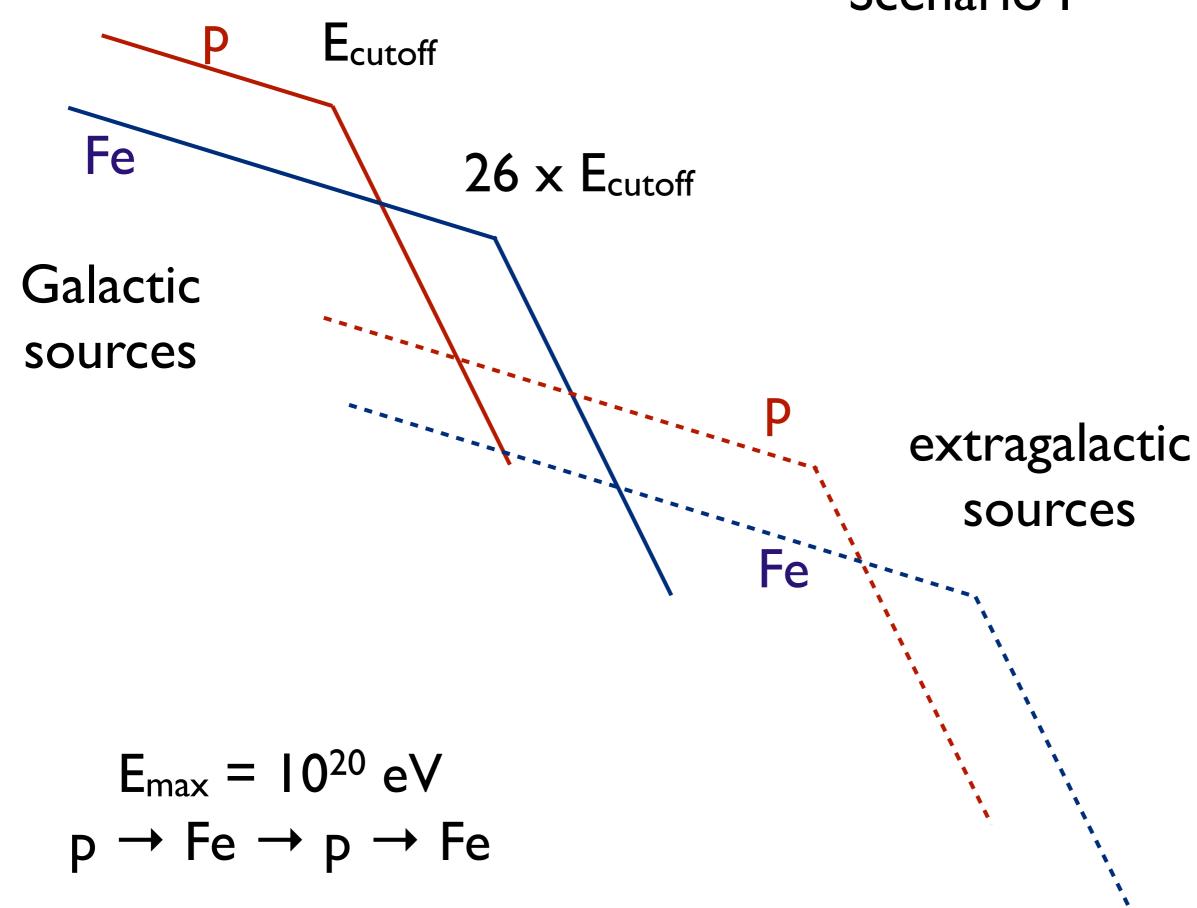
## Xmax: atmospheric depth of shower maximum depends on Energy & Mass



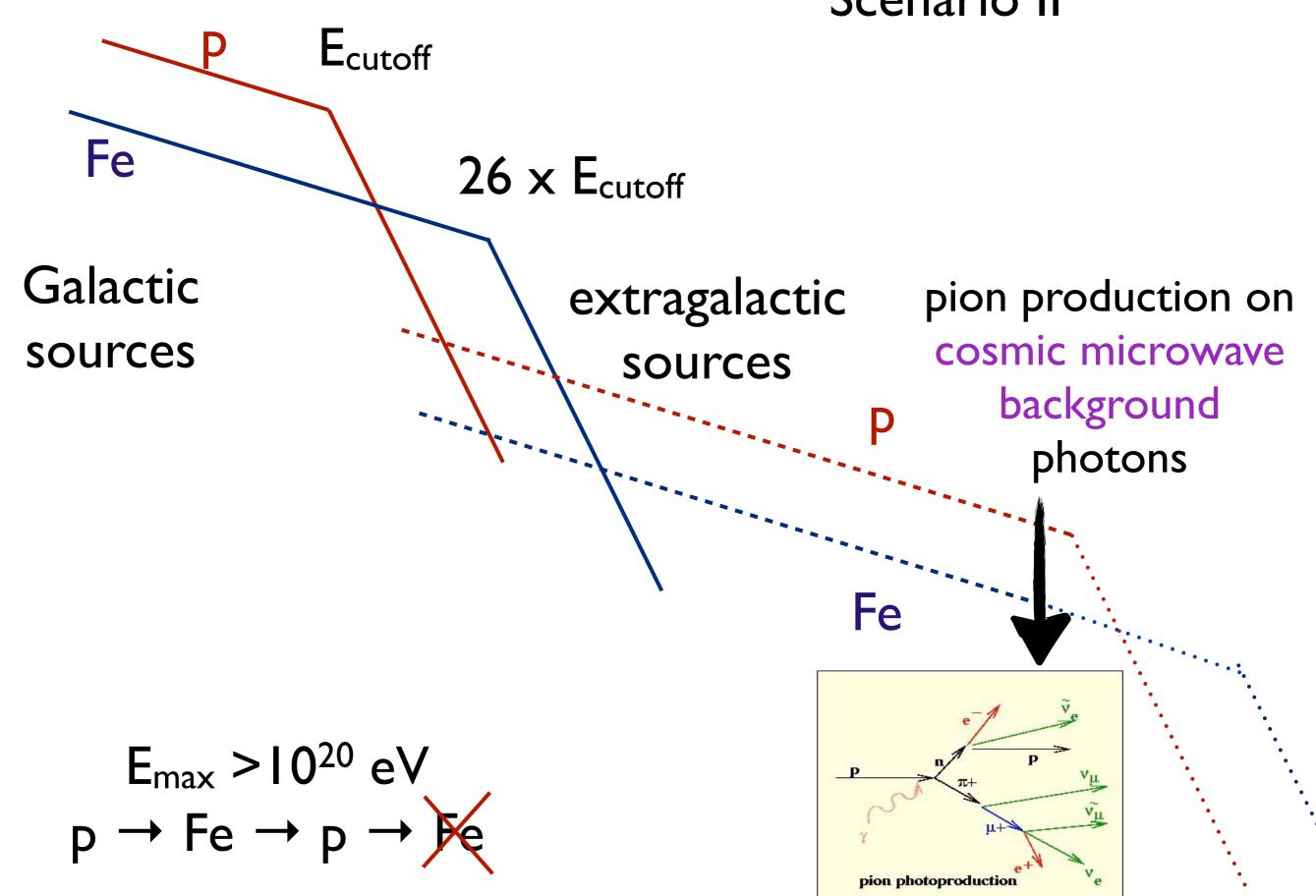
## possible explanation



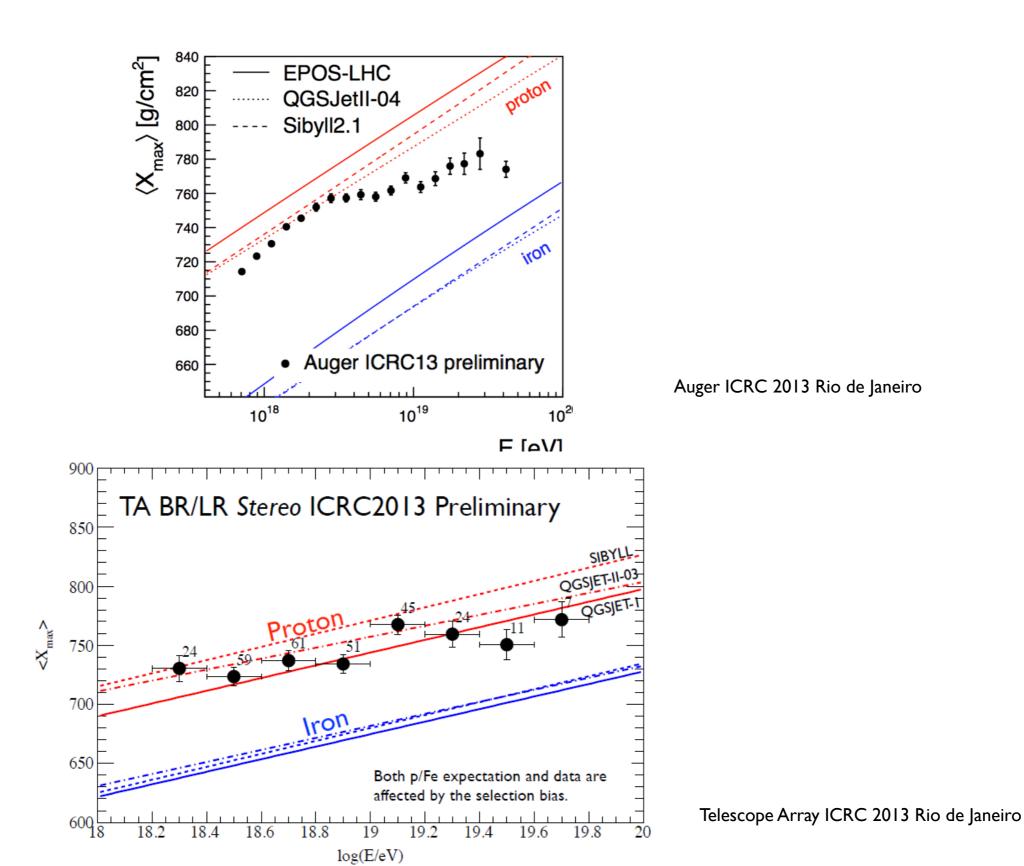
## Scenario I



## Scenario II

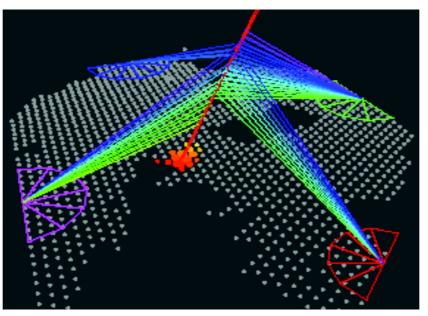


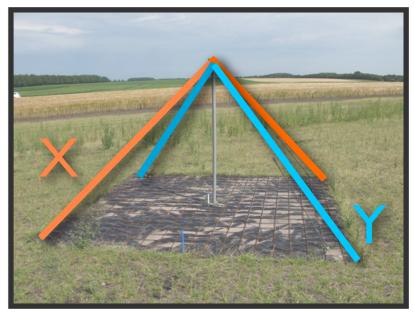
## Inconclusive results so far...



## Radio: a new handle on CR Composition







LOFAR radio antenna

auger surface detector

auger hybrid detection

#### Surface detection: muon component

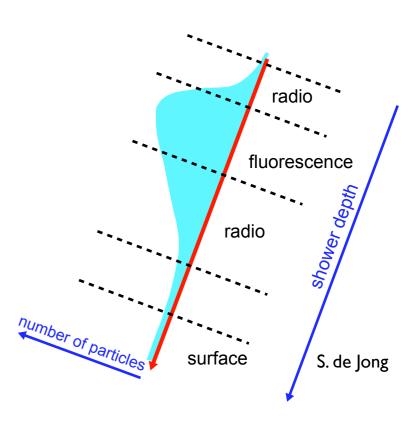
- very sensitive to hadronic interaction models

#### Fluorescence Detection to measure Xmax

- duty cycle ~10%,  $\sigma$  ~ 20 g/cm<sup>2</sup>

#### Radio Detection to measure Xmax:

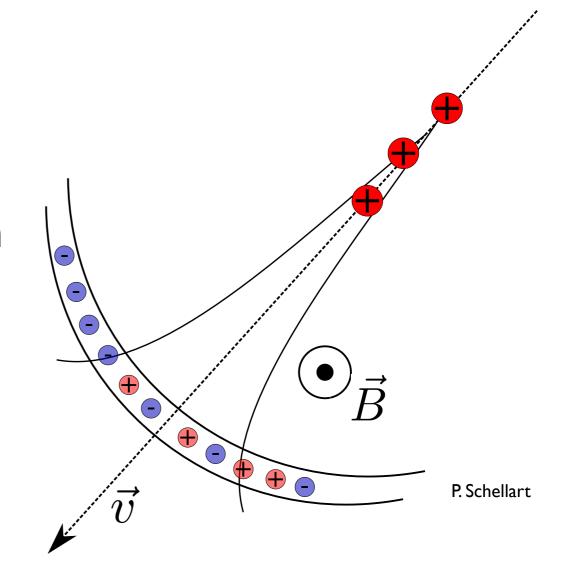
- cheap detectors, duty cycle ~100%
- high angular resolution (< 0.5°)
- attractive method to increase statistics at ultra-high energy!



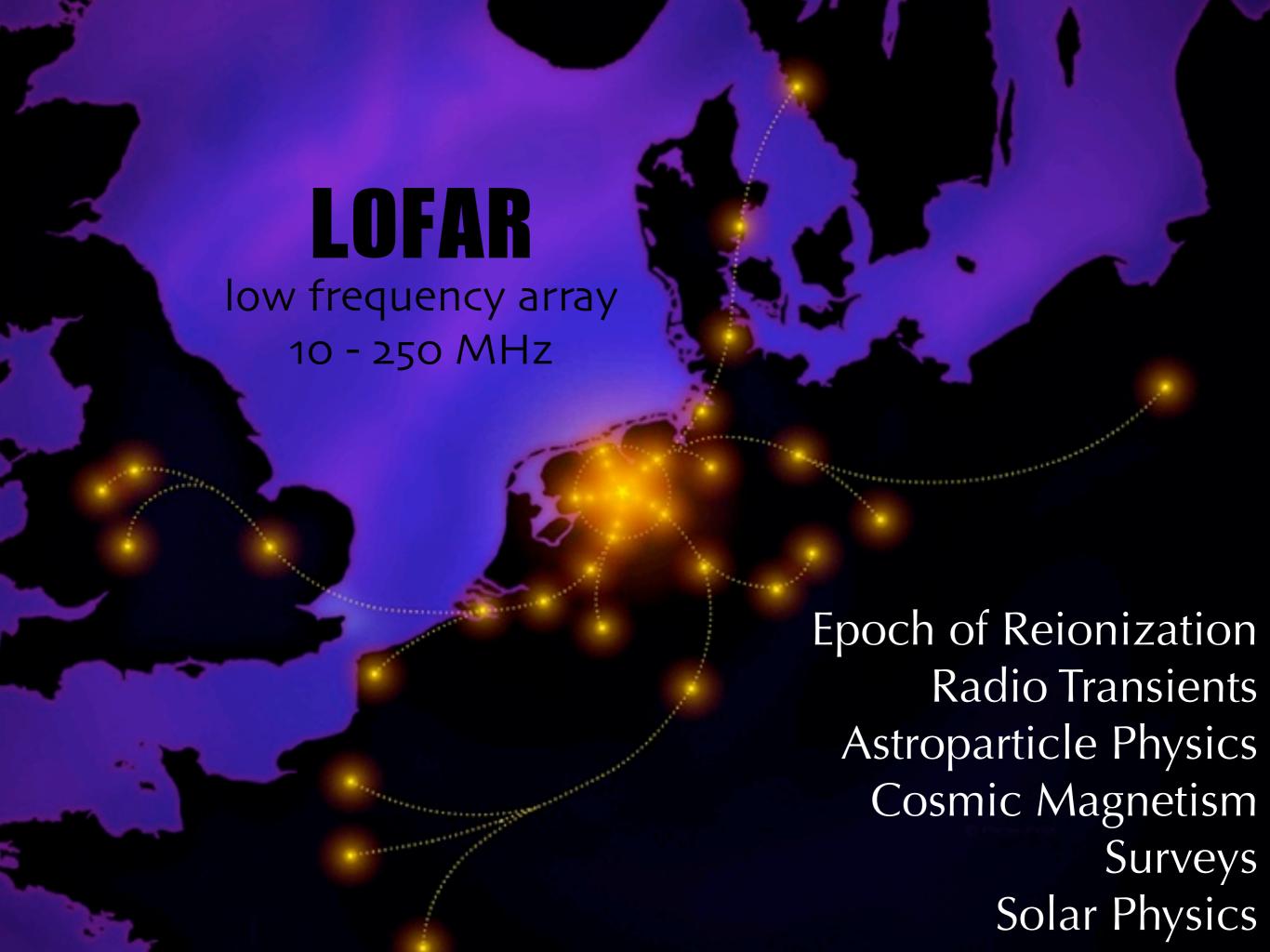
Does it work? Is the precision good enough?

## What drives the radio emission?

- <u>Earth magnetic field</u>
   electrons/positrons deflected
   E ~ dn<sub>ch</sub>/dt
- Charge excess
   negative charge due to electron
   knockouts
   E ~ d(n<sub>e</sub>-n<sub>p</sub>)/dt
- Non-unity index of refraction
   Cherenkov-like effects
   ring structure possible

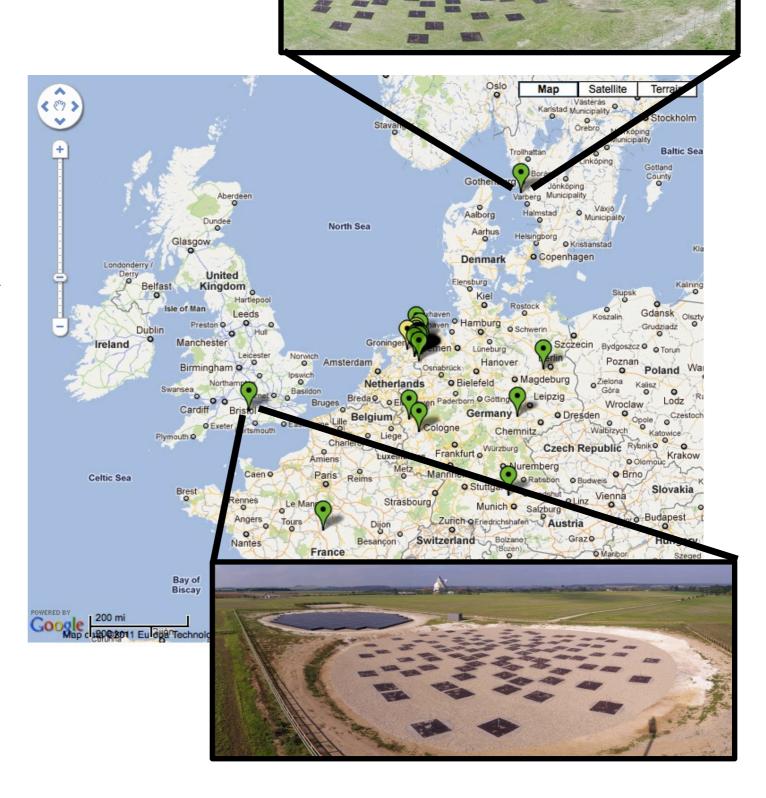


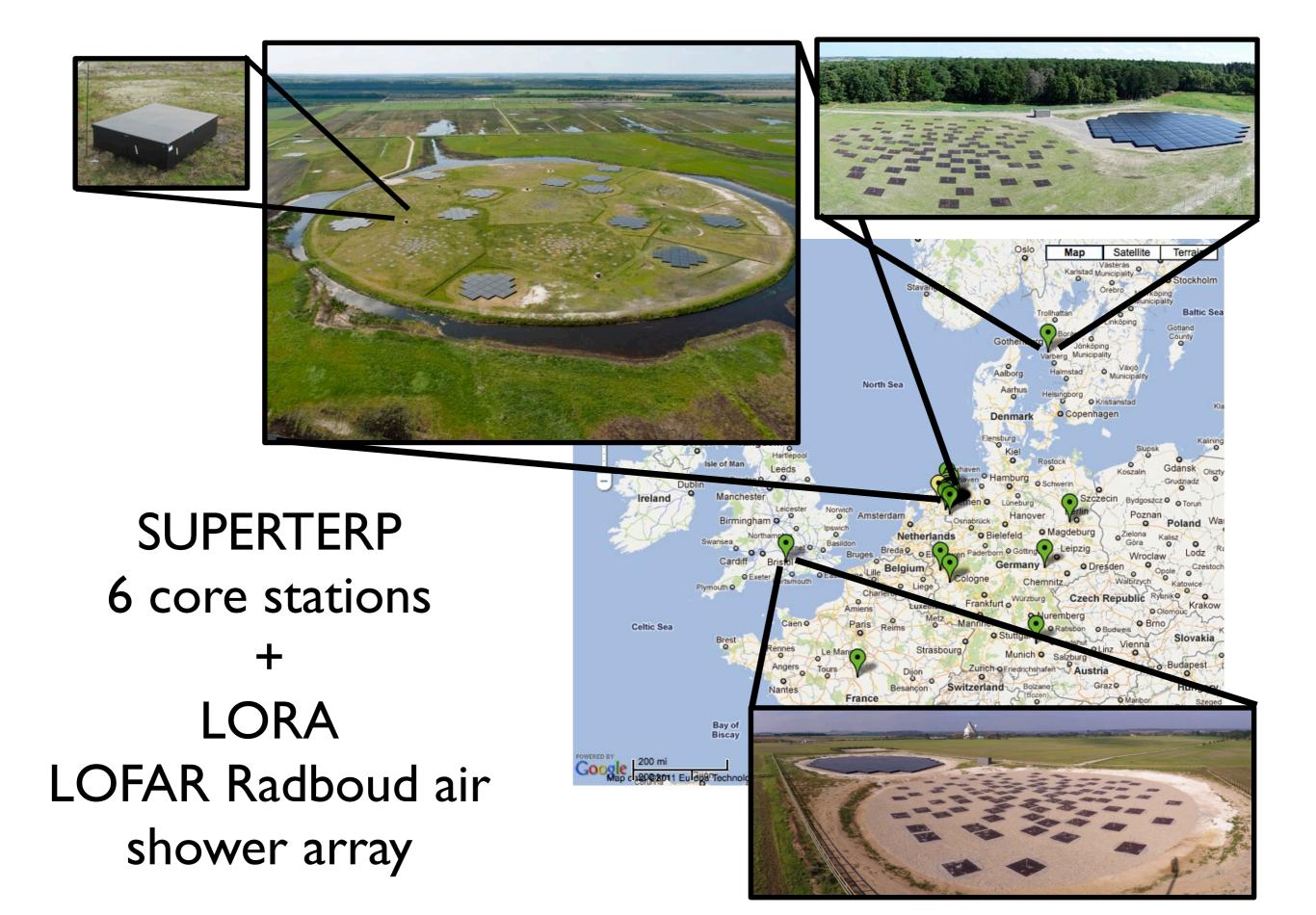
Coherent at 100 MHz wavelength > shower front size  $P \sim n^2$ 

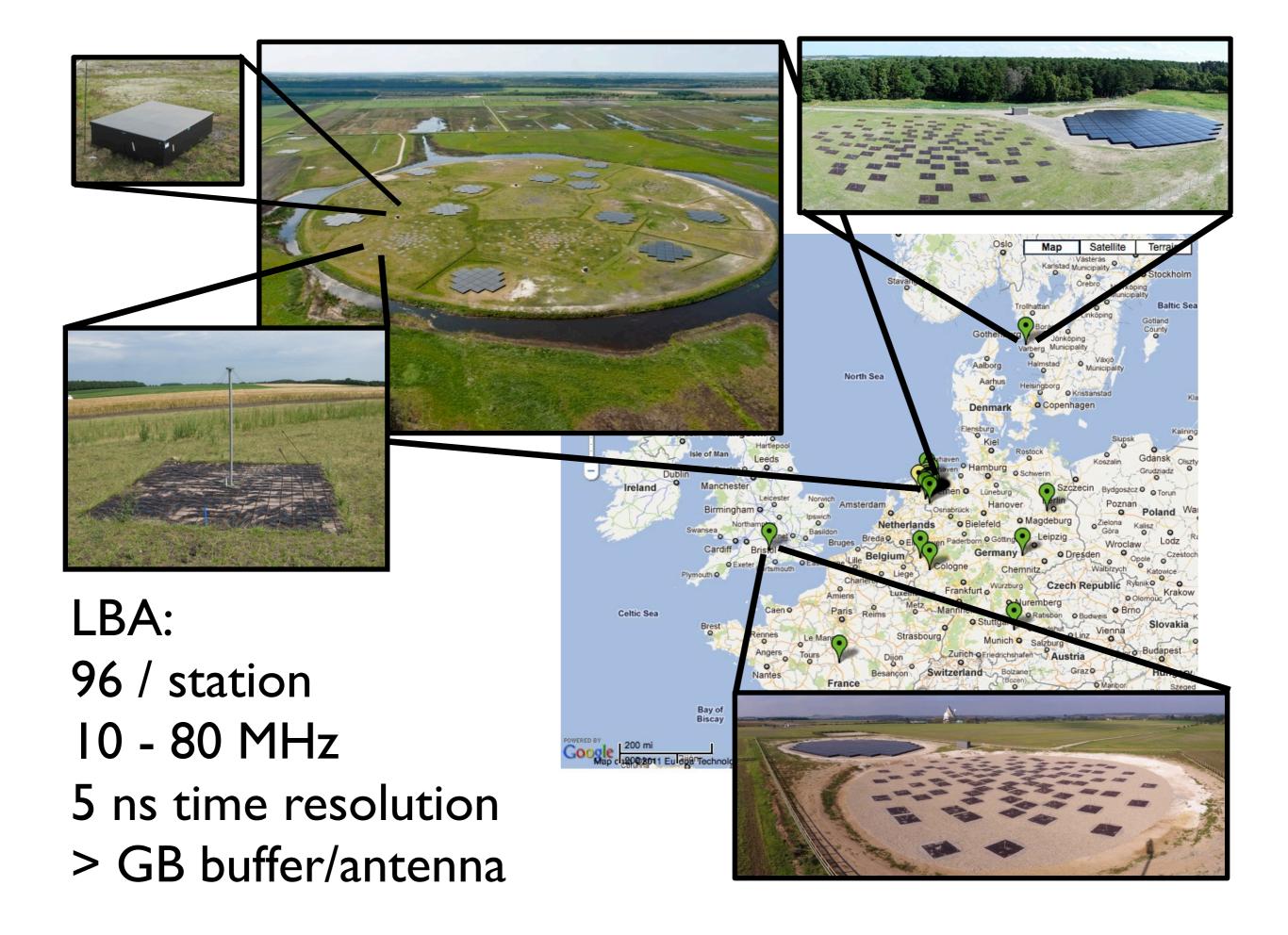


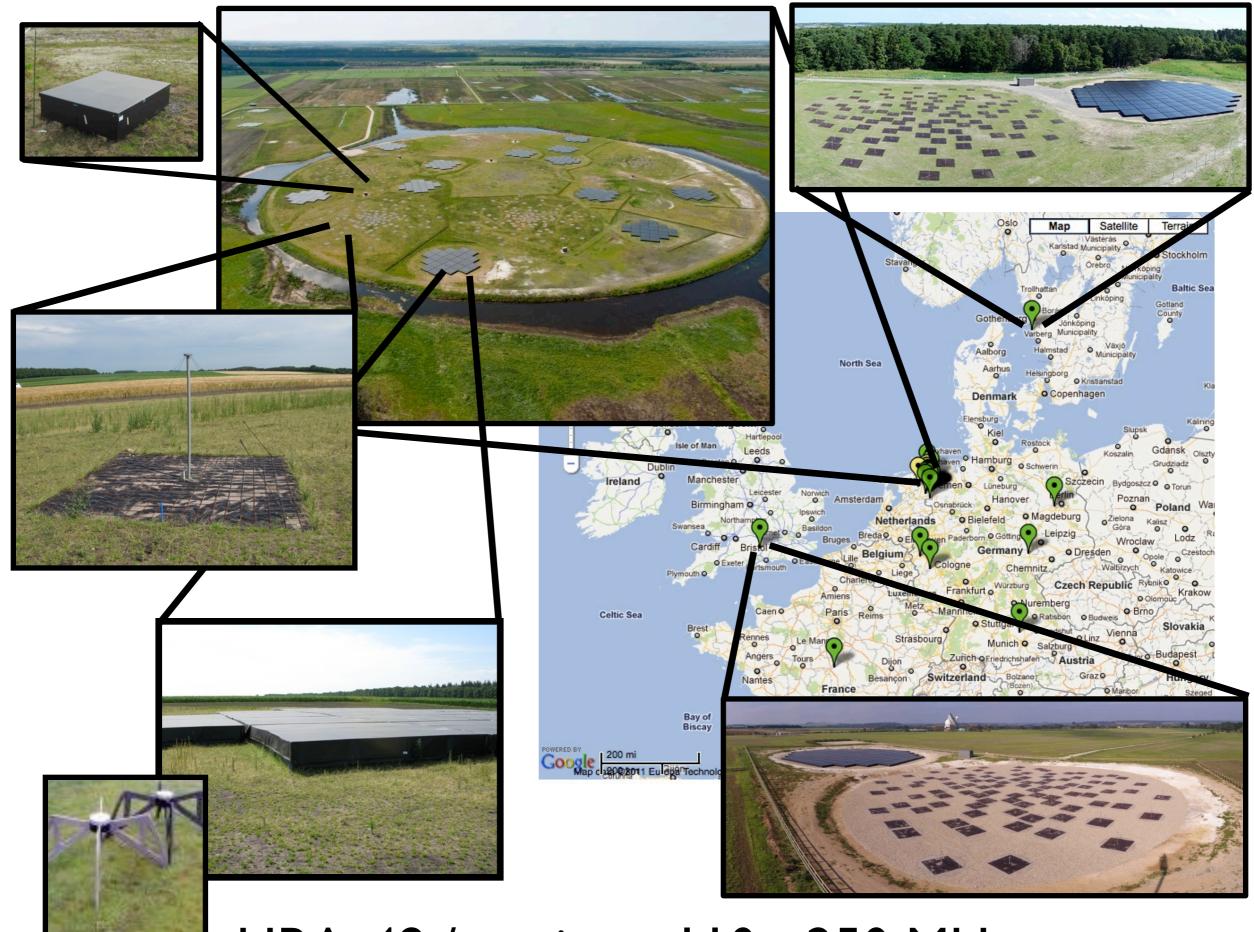
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24 core stations
9 remote stations
8 international stations

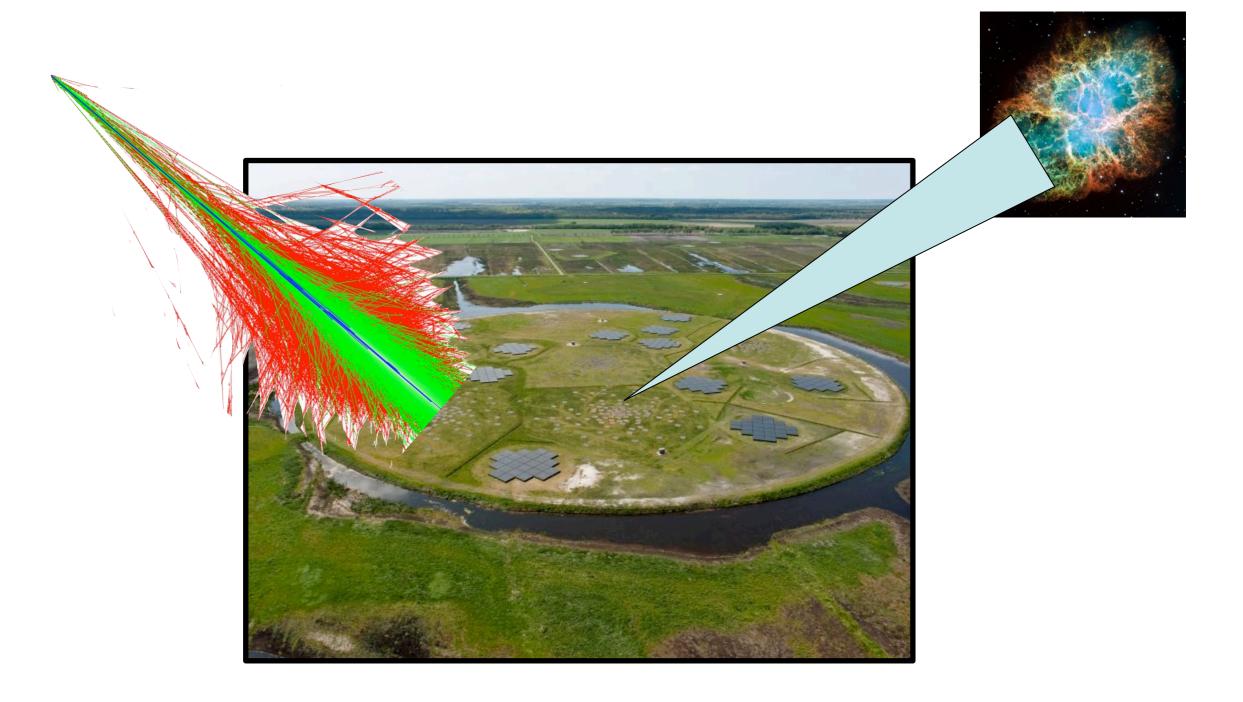








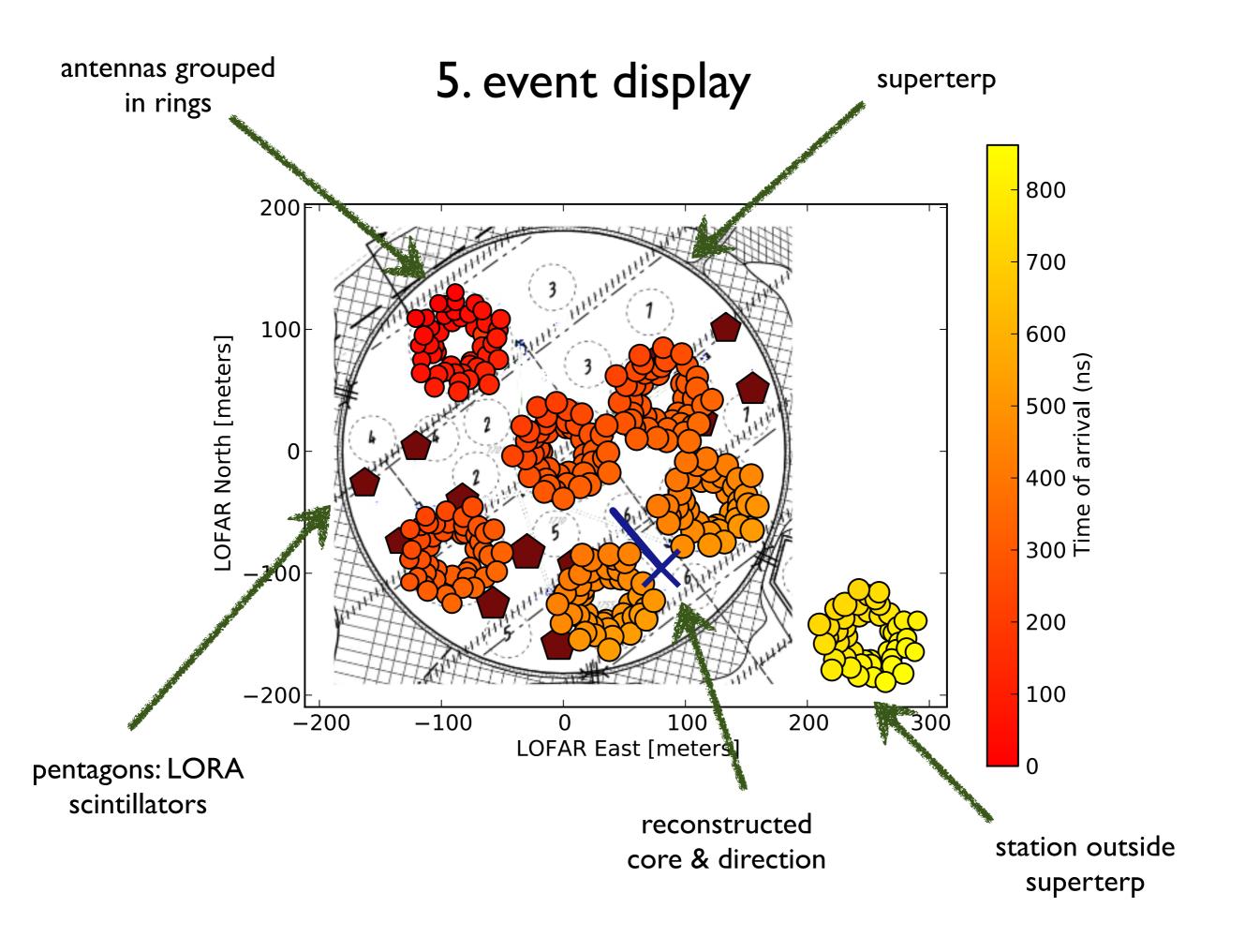
HBA: 48 / station 110 - 250 MHz



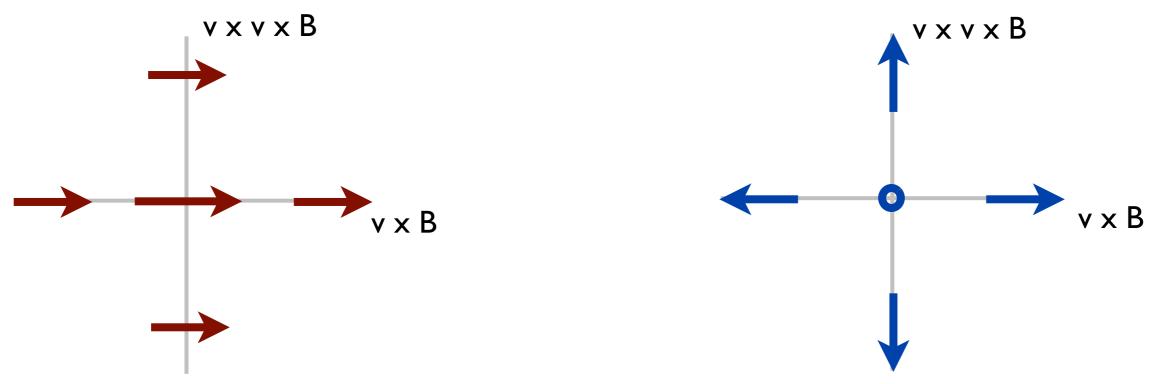
LOFAR is designed to support many different observation strategies

CR detection runs in the background during other observations

Trigger from scintillators → read out buffer boards @ antennas

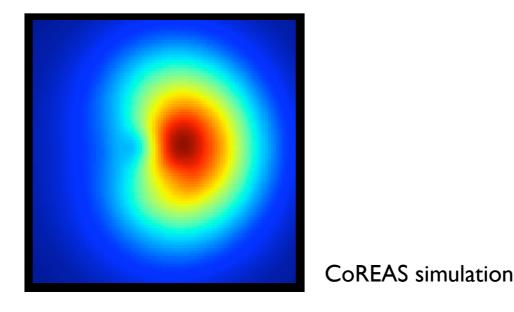


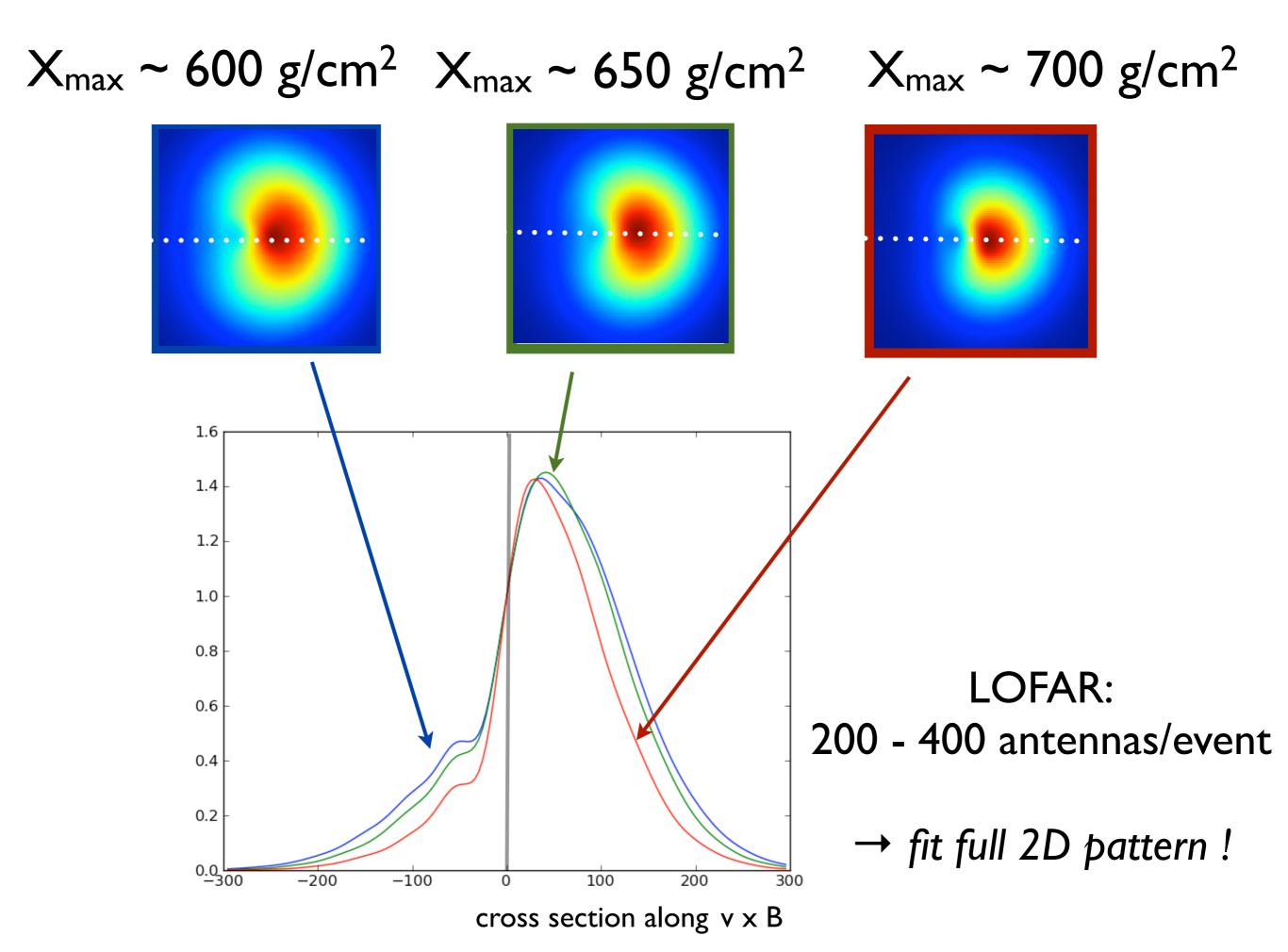
## radio pattern



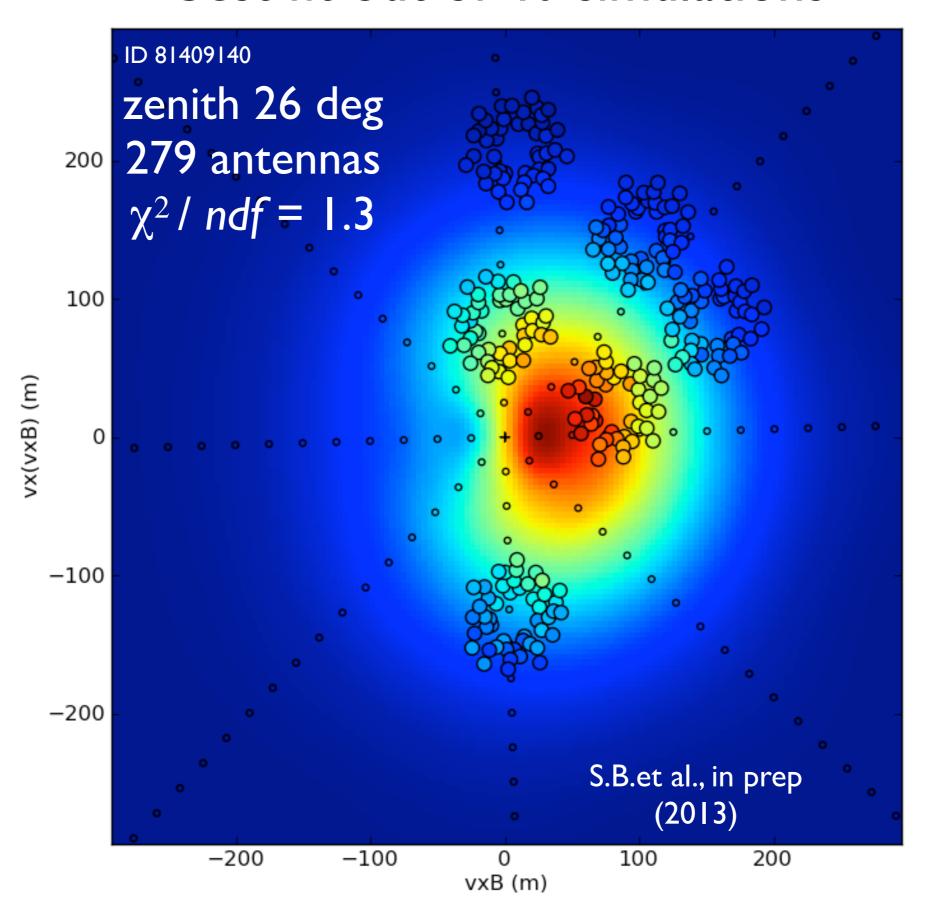
vector sum of geomagnetic and charge excess component relativistic beaming

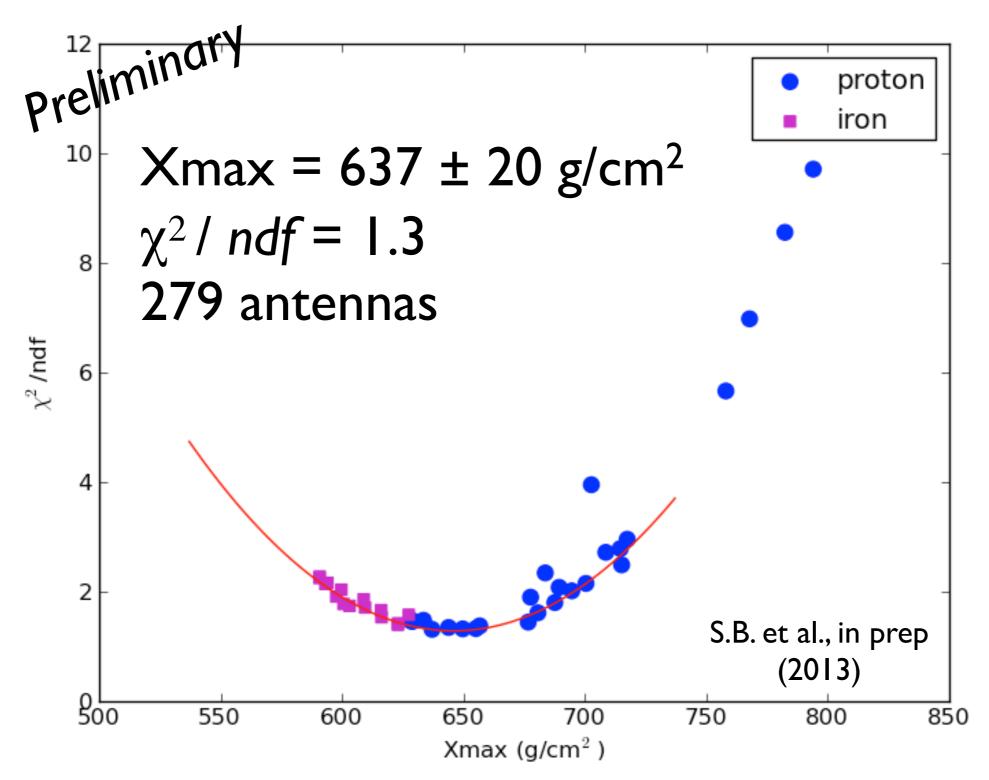
distortion by Cherenkov-like effects  $(n \neq 1)$ 





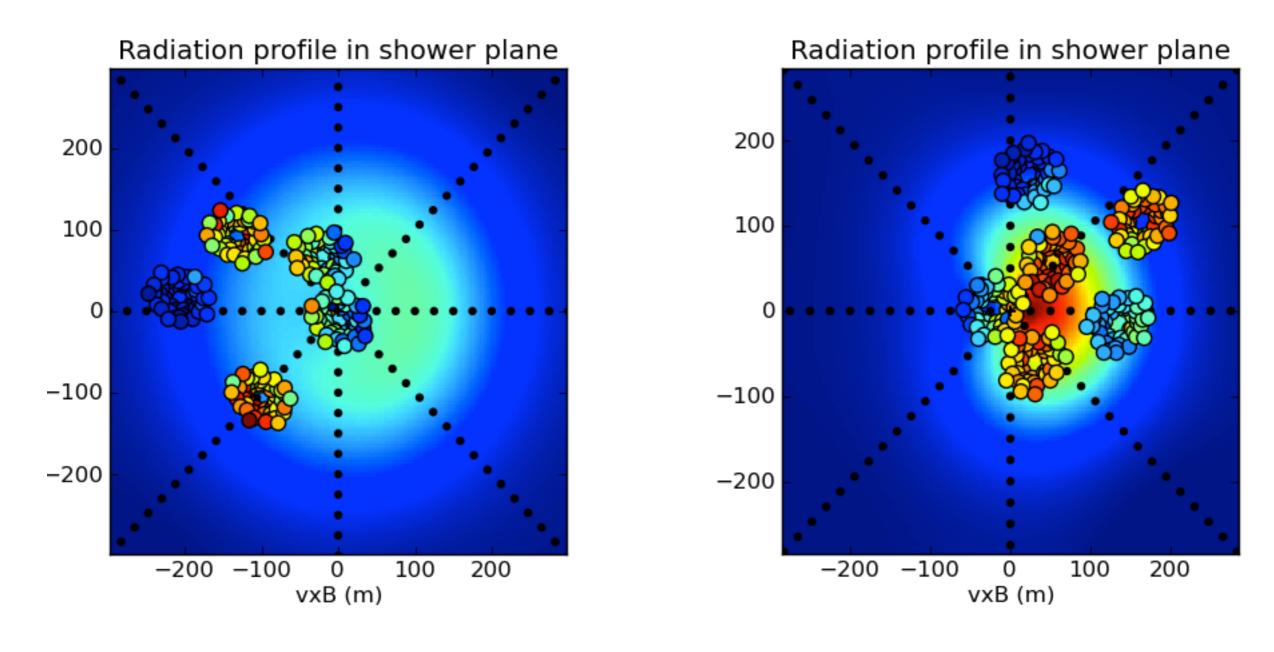
## best fit out of 40 simulations





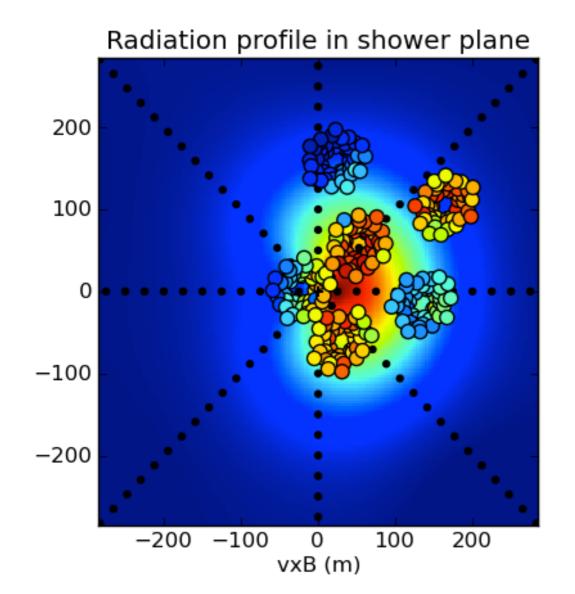
same precision as existing techniques with 10 x duty cycle!

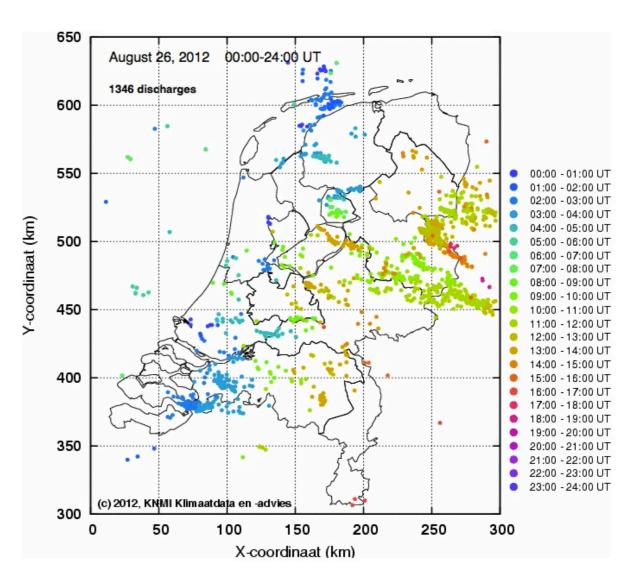
### however...



...sometimes events are very weird!

## cosmic lightning project: Gia Thi Ngoc Trinh





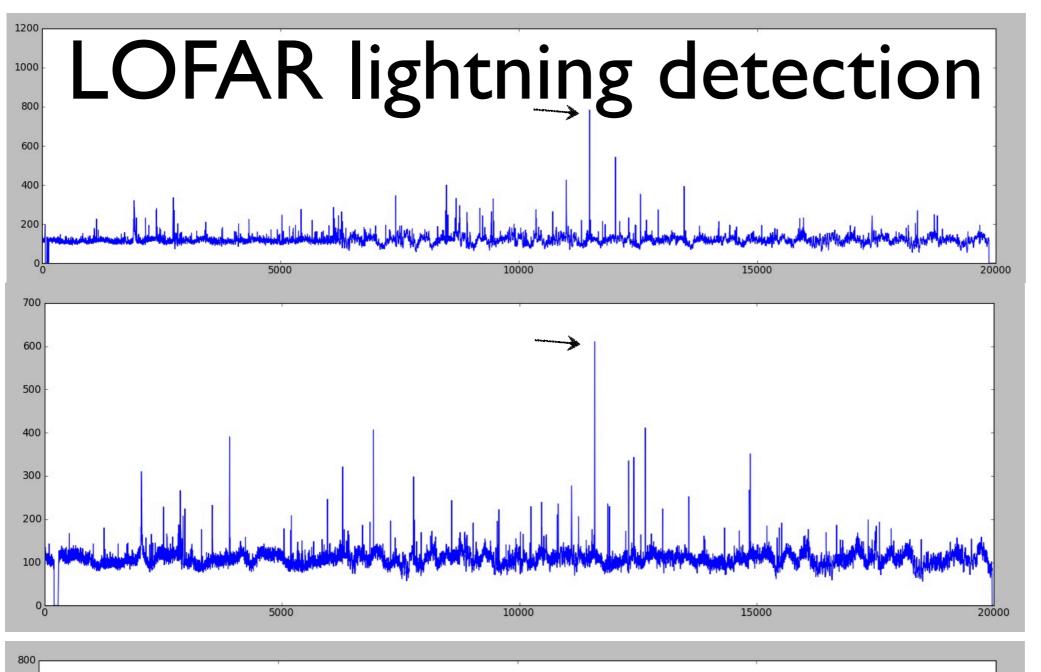
## Atmospheric electric fields!

- acceleration shower particles

measure E?

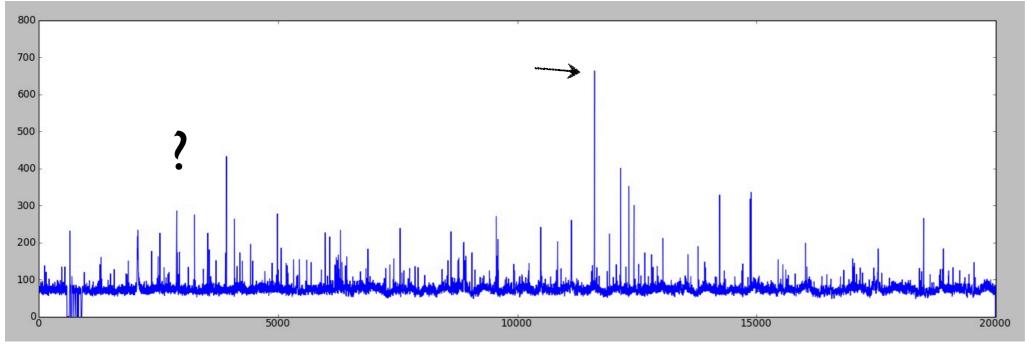
- ionization electron avalanches?

detect CR - TS interaction?

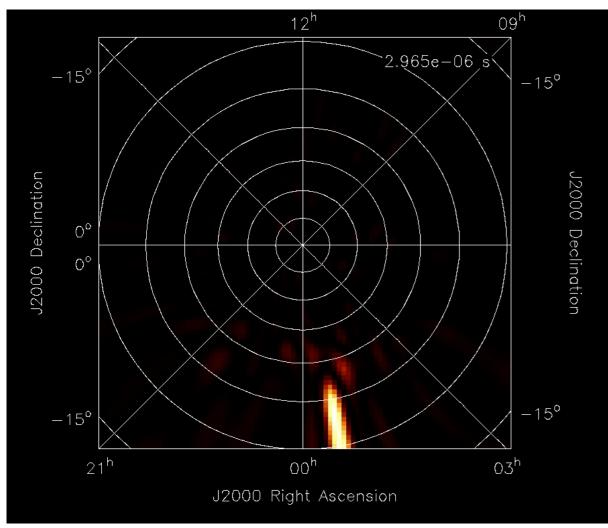


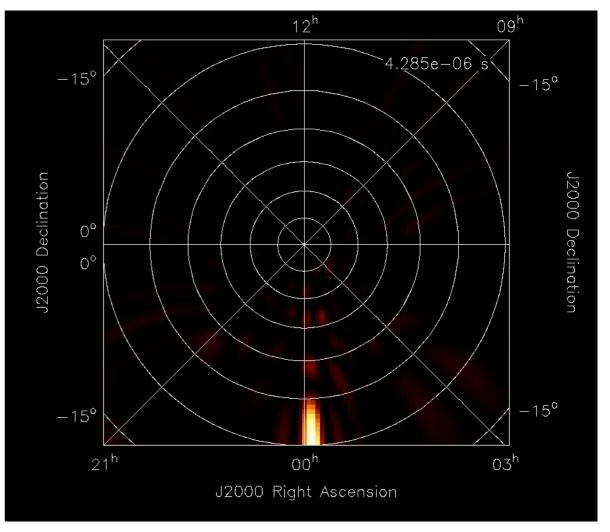
**RS503** 

**RS106** 



**CS002** 



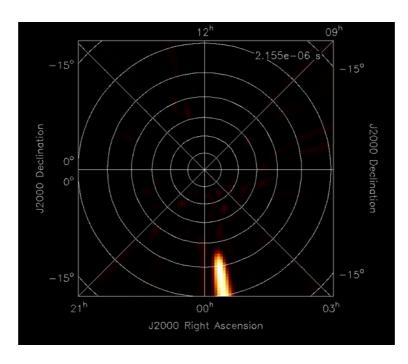


**RS503** 

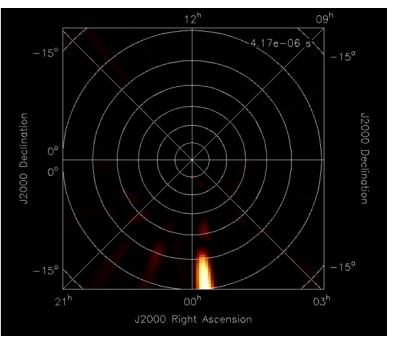
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22000 Declination
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J2000 Right Ascension

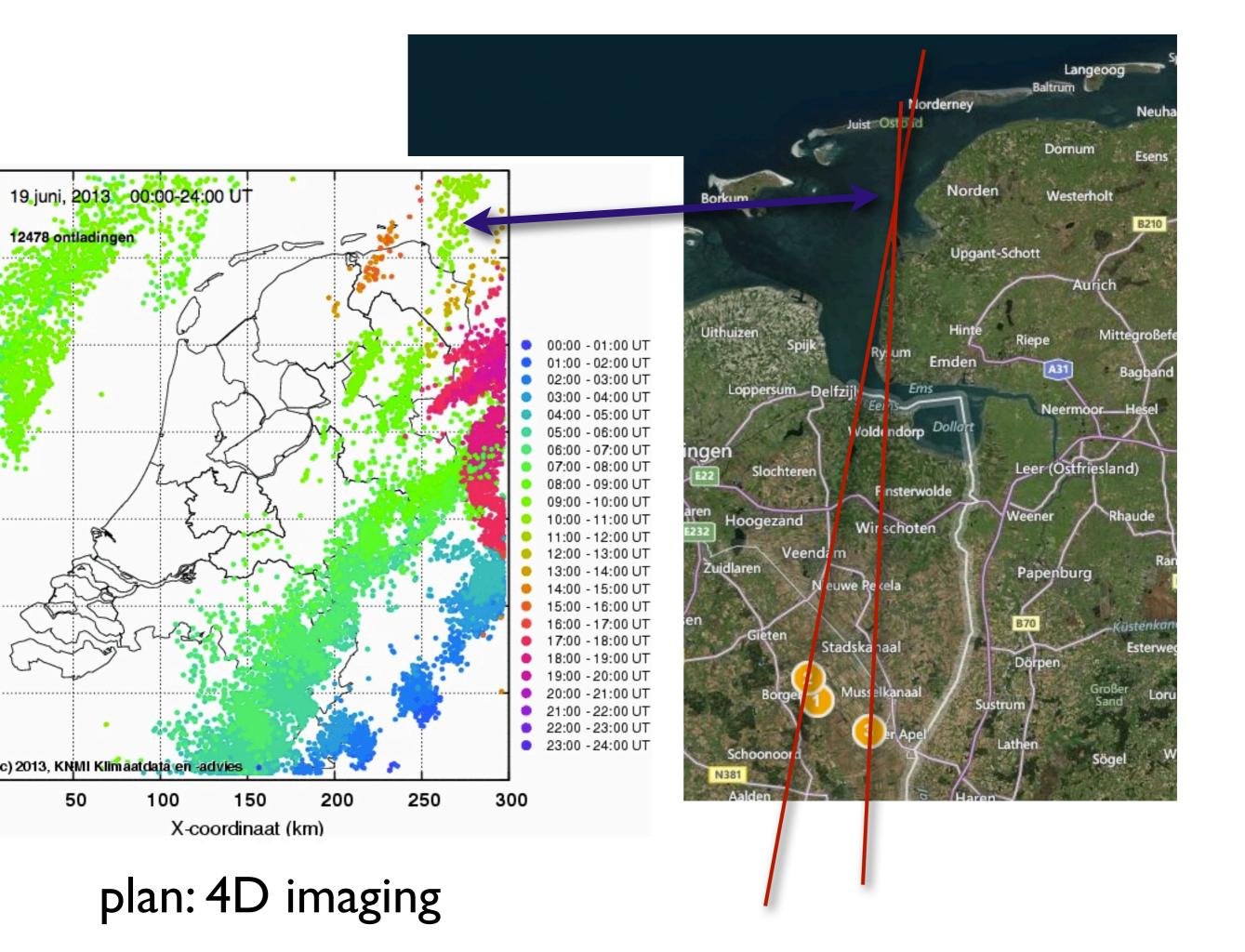


**RS106** 



CS002 RS205

**RS208** 



### **LOFAR**

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detection of discharges

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CR - thunderstorm interaction

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  - → measure E?

Thanks!