

Cosmic particle showers & thunderstorms

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cosmic lightning project:

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LOFAR

Radboud Universiteit Nijmegen



university of
 groningen



LOFAR

Radio detection of cosmic rays



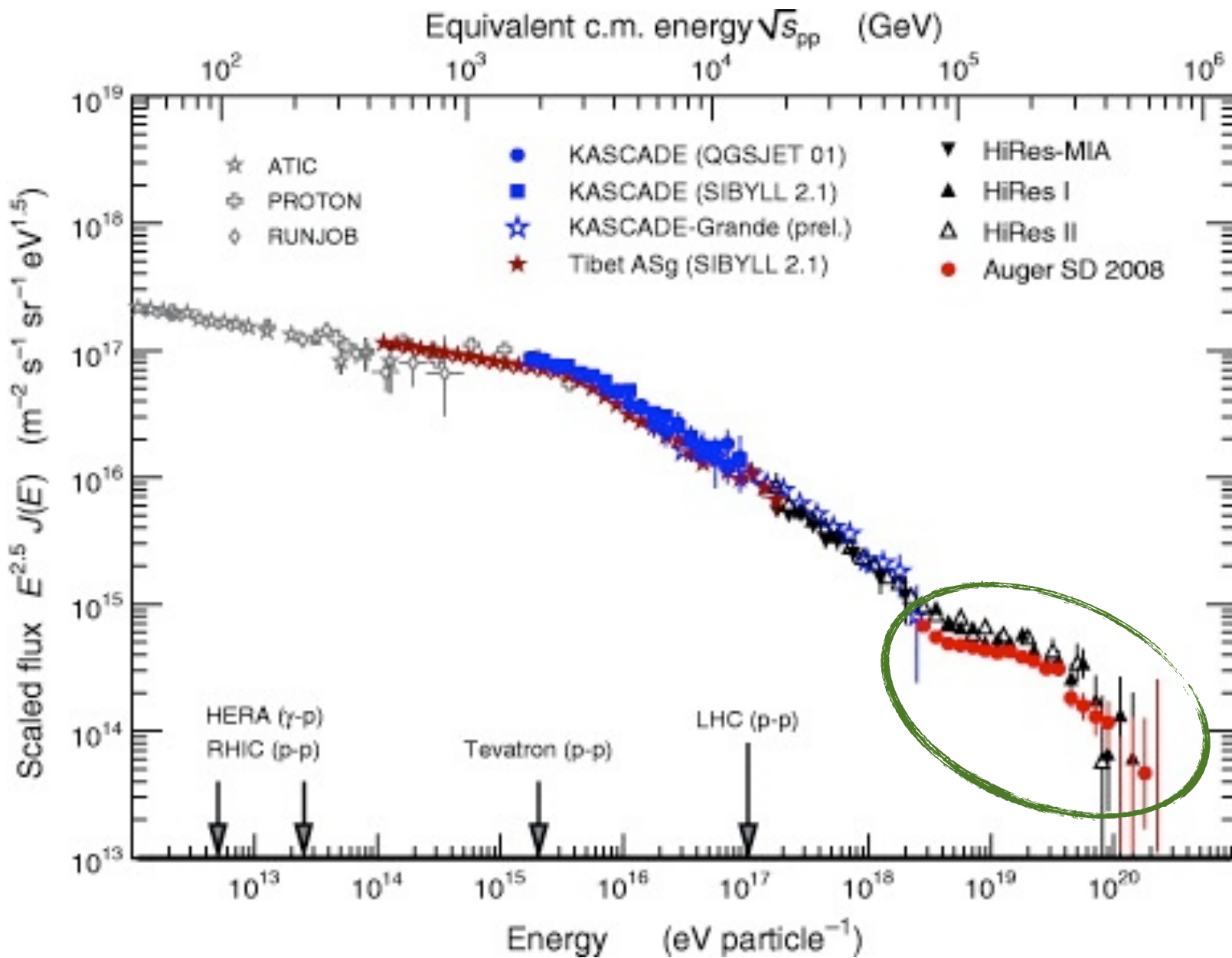
detection of
discharges

- localization & imaging of lightning
- high altitude discharges?

CR - thunderstorm
interaction

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

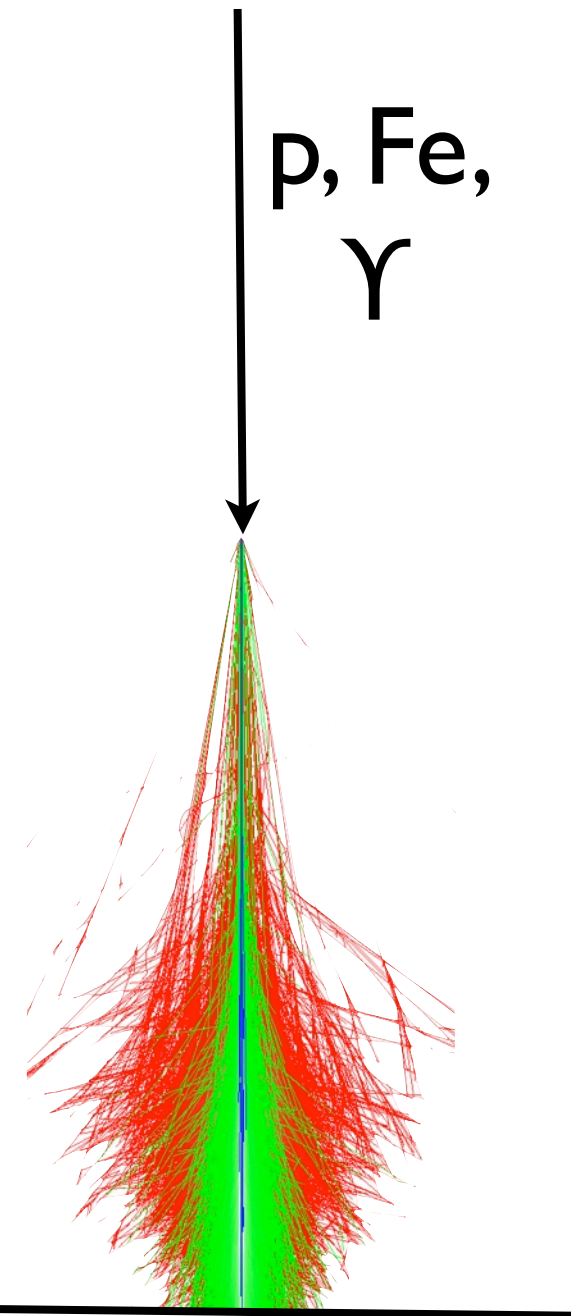
Cosmic Rays



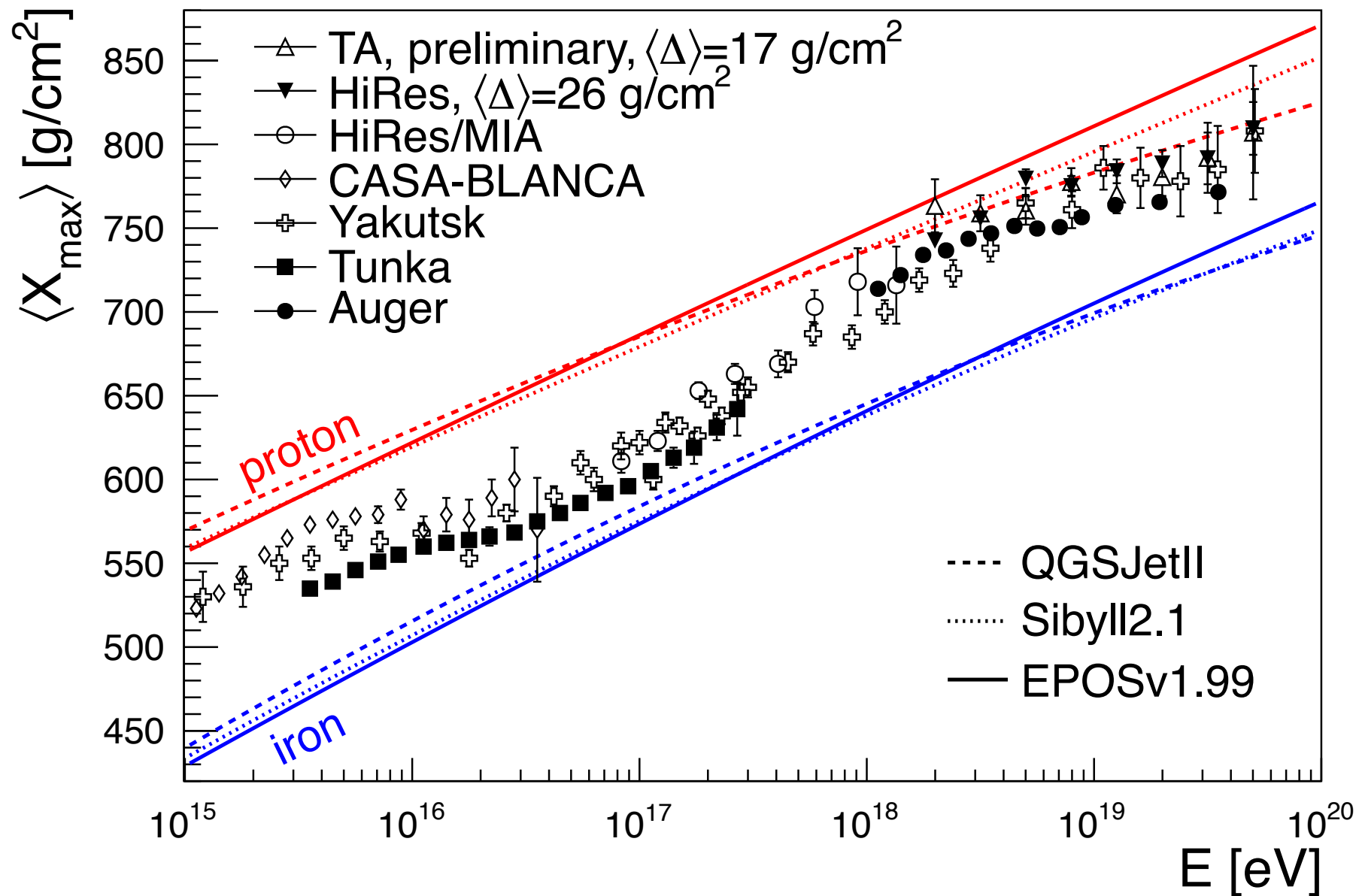
What are the sources?
What energy do they reach?

Measure:

- direction
- energy
- mass

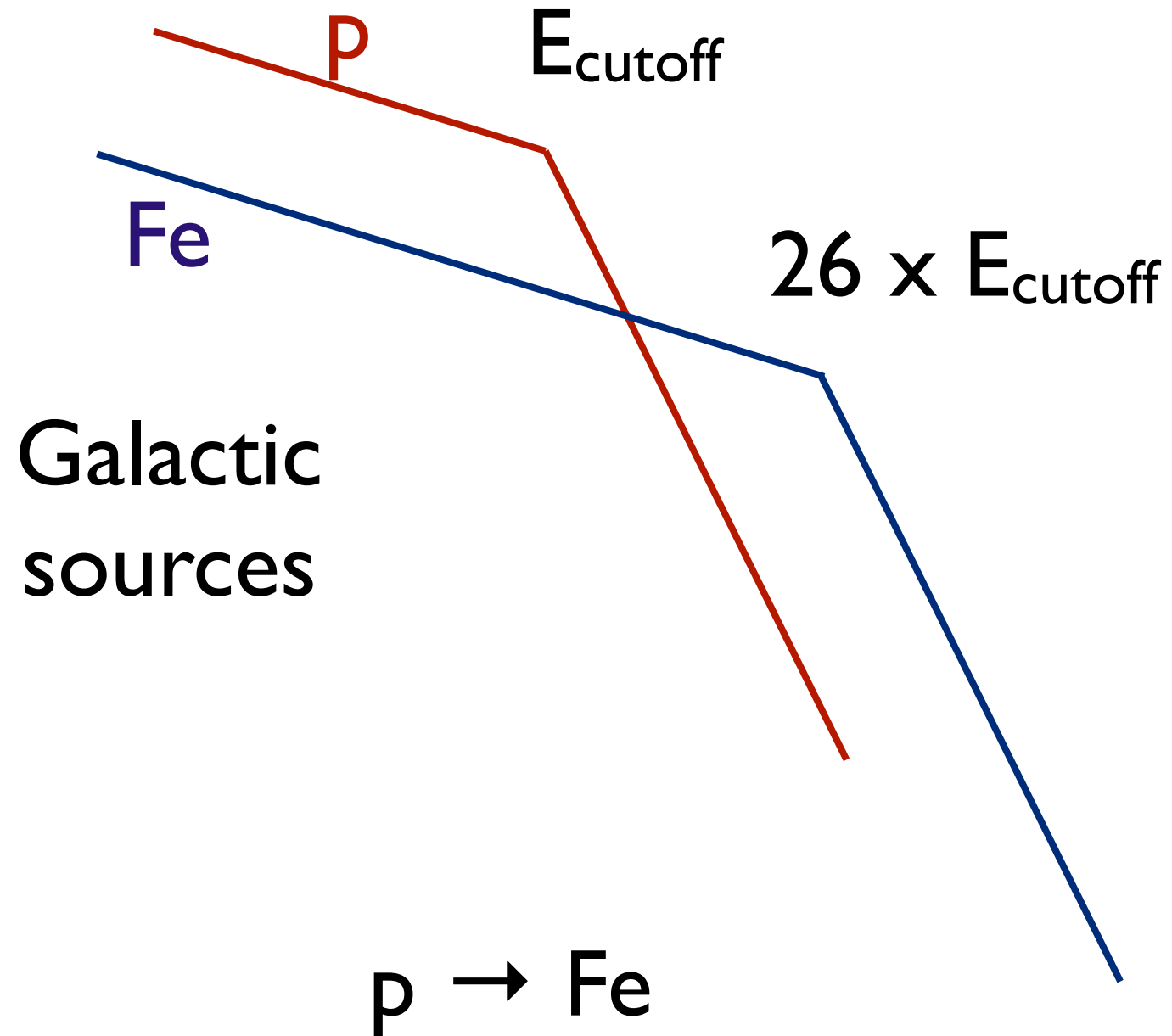


Xmax : atmospheric depth of shower maximum depends on Energy & Mass

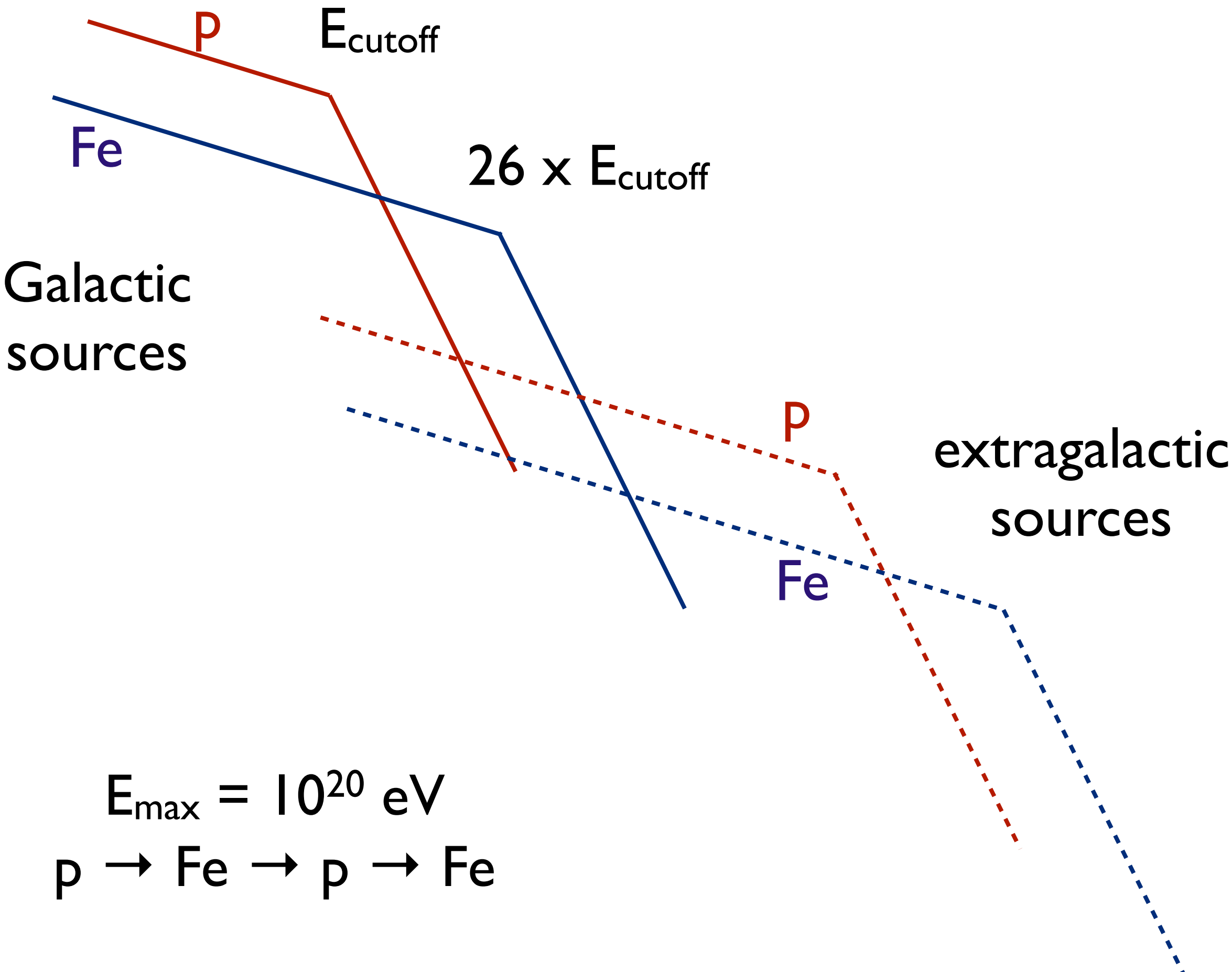


p → Fe → p → ?

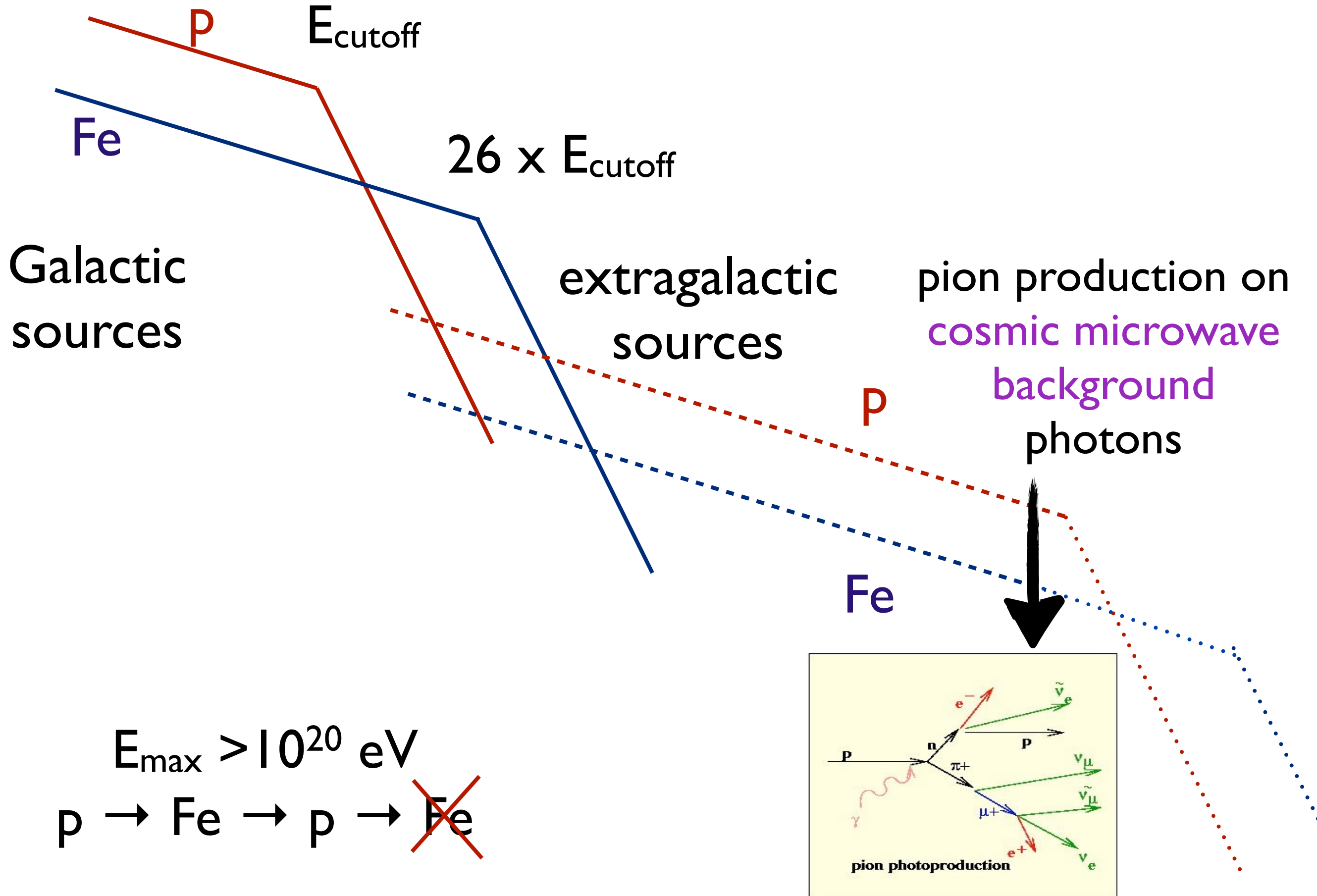
possible explanation



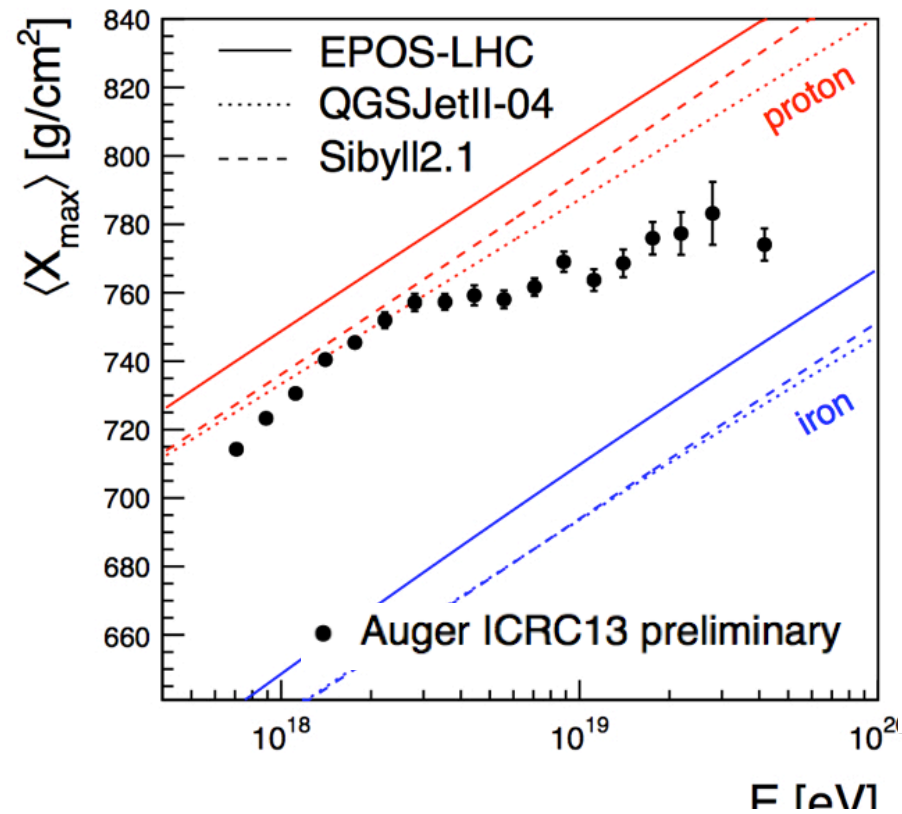
Scenario I



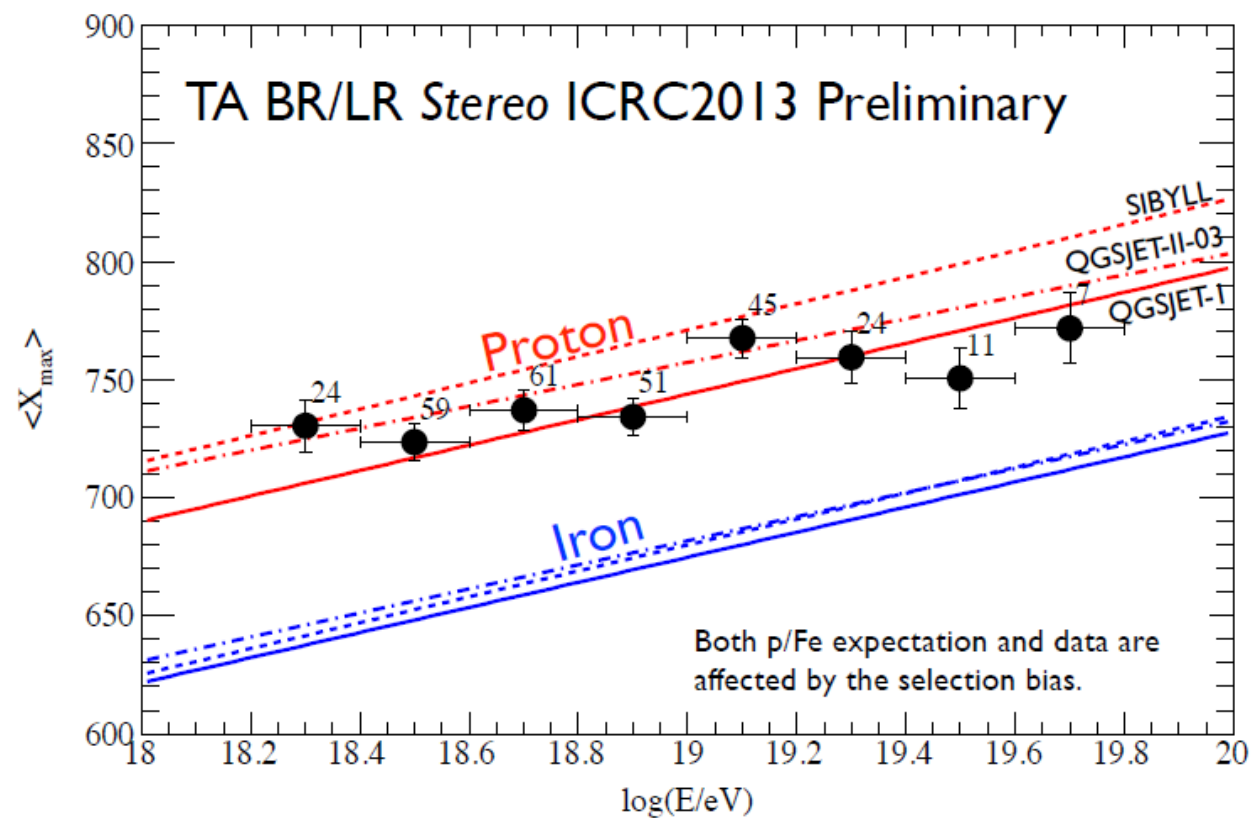
Scenario II



Inconclusive results so far..



Auger ICRC 2013 Rio de Janeiro

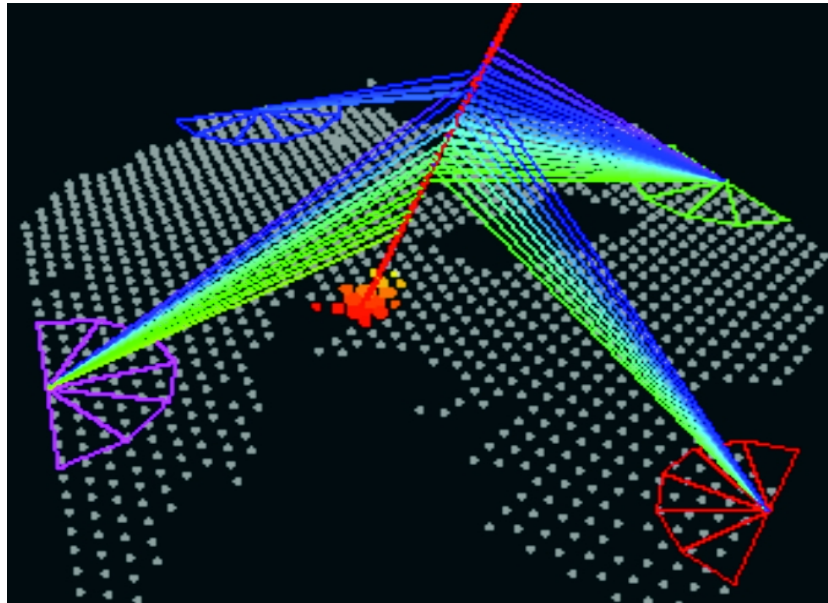


Telescope Array ICRC 2013 Rio de Janeiro

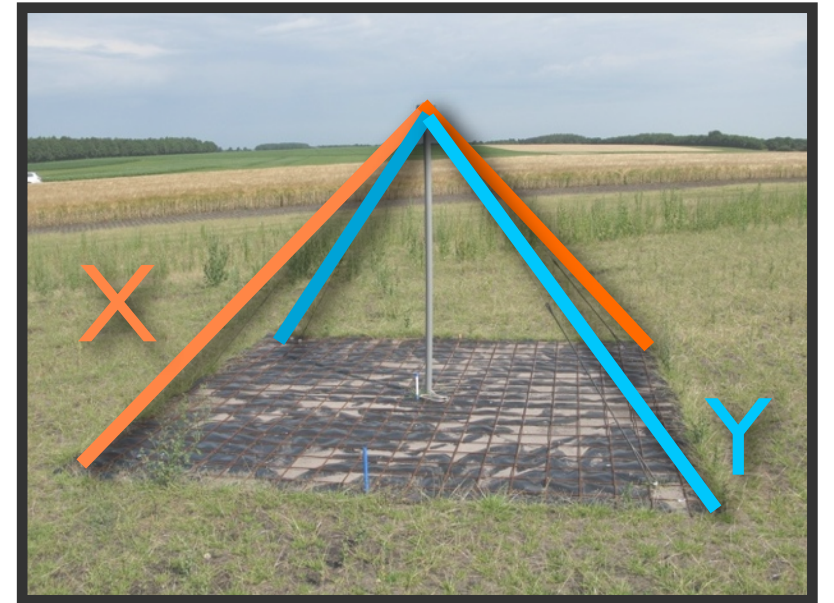
Radio: a new handle on CR Composition



auger surface detector



auger hybrid detection

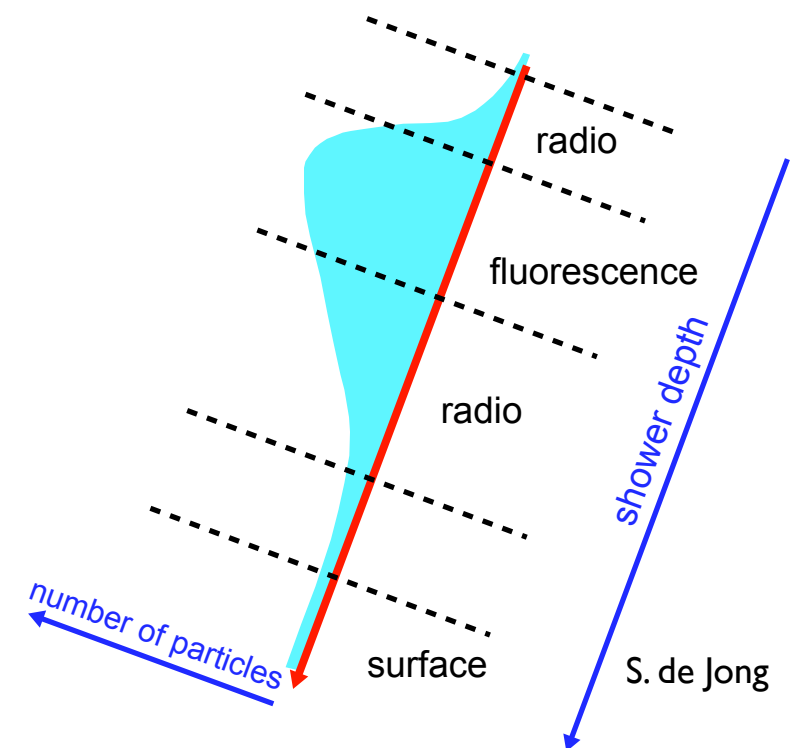


LOFAR radio antenna

Surface detection: muon component
- very sensitive to hadronic interaction models

Fluorescence Detection to measure X_{\max}
- duty cycle $\sim 10\%$, $\sigma \sim 20 \text{ g/cm}^2$

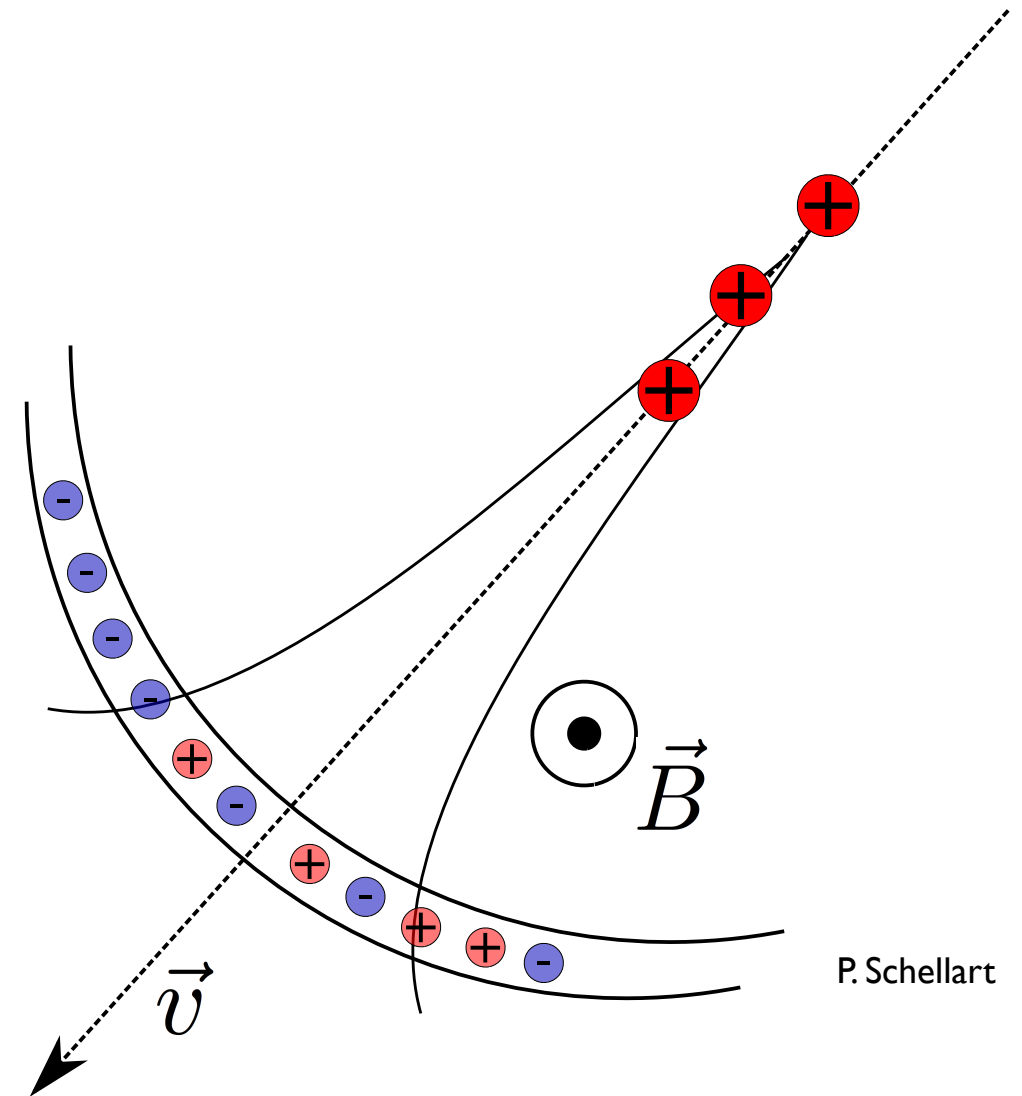
Radio Detection to measure X_{\max} :
- cheap detectors, duty cycle $\sim 100\%$
- high angular resolution ($< 0.5^\circ$)
- attractive method to increase statistics at ultra-high energy!



Does it work? Is the precision good enough?

What drives the radio emission?

- Earth magnetic field
electrons/positrons deflected
 $E \sim dn_{\text{ch}}/dt$
- Charge excess
negative charge due to electron knockouts
 $E \sim d(n_e - n_p)/dt$
- Non-unity index of refraction
Cherenkov-like effects
ring structure possible

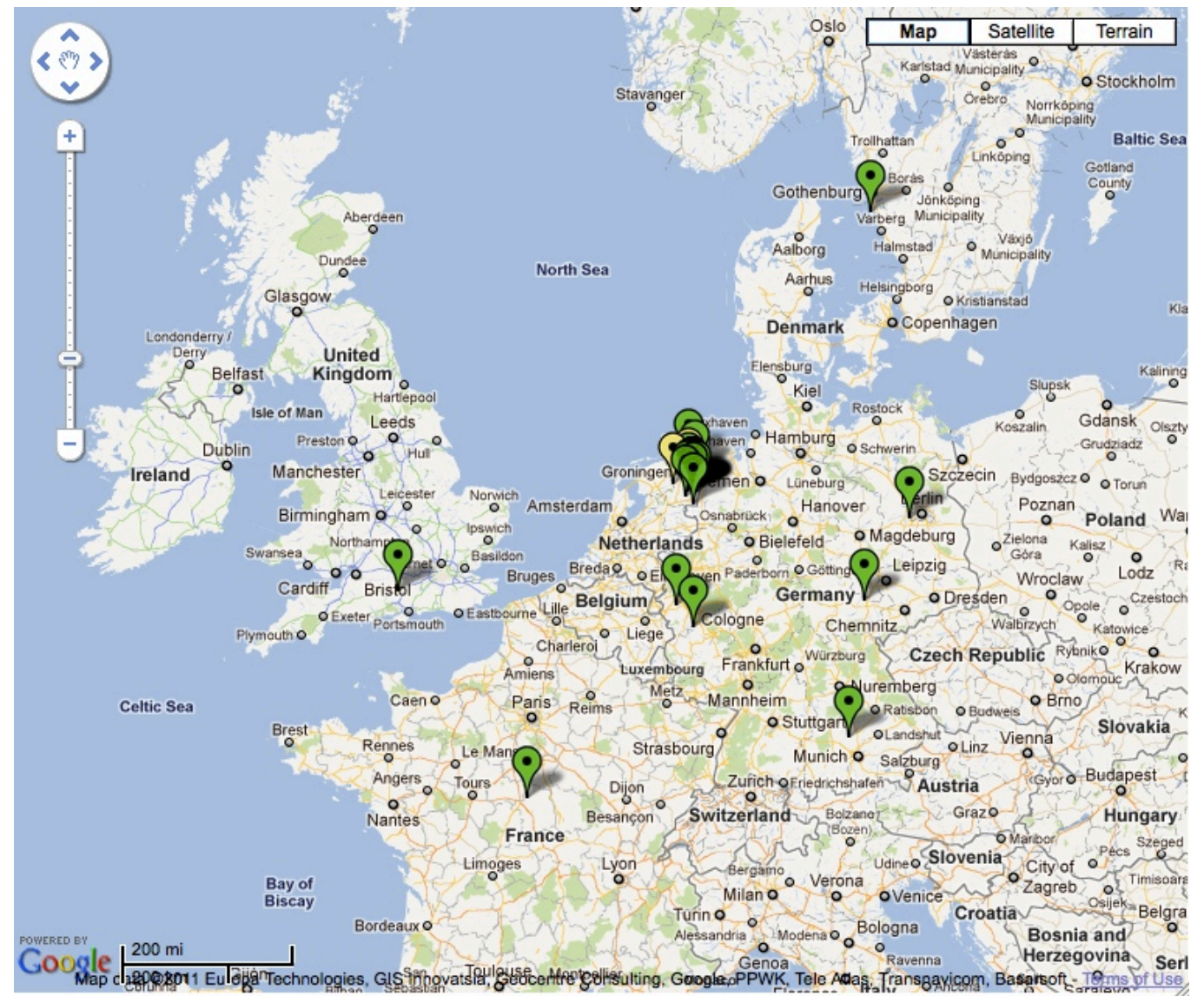


Coherent at 100 MHz
wavelength $>$ shower front size
 $P \sim n^2$

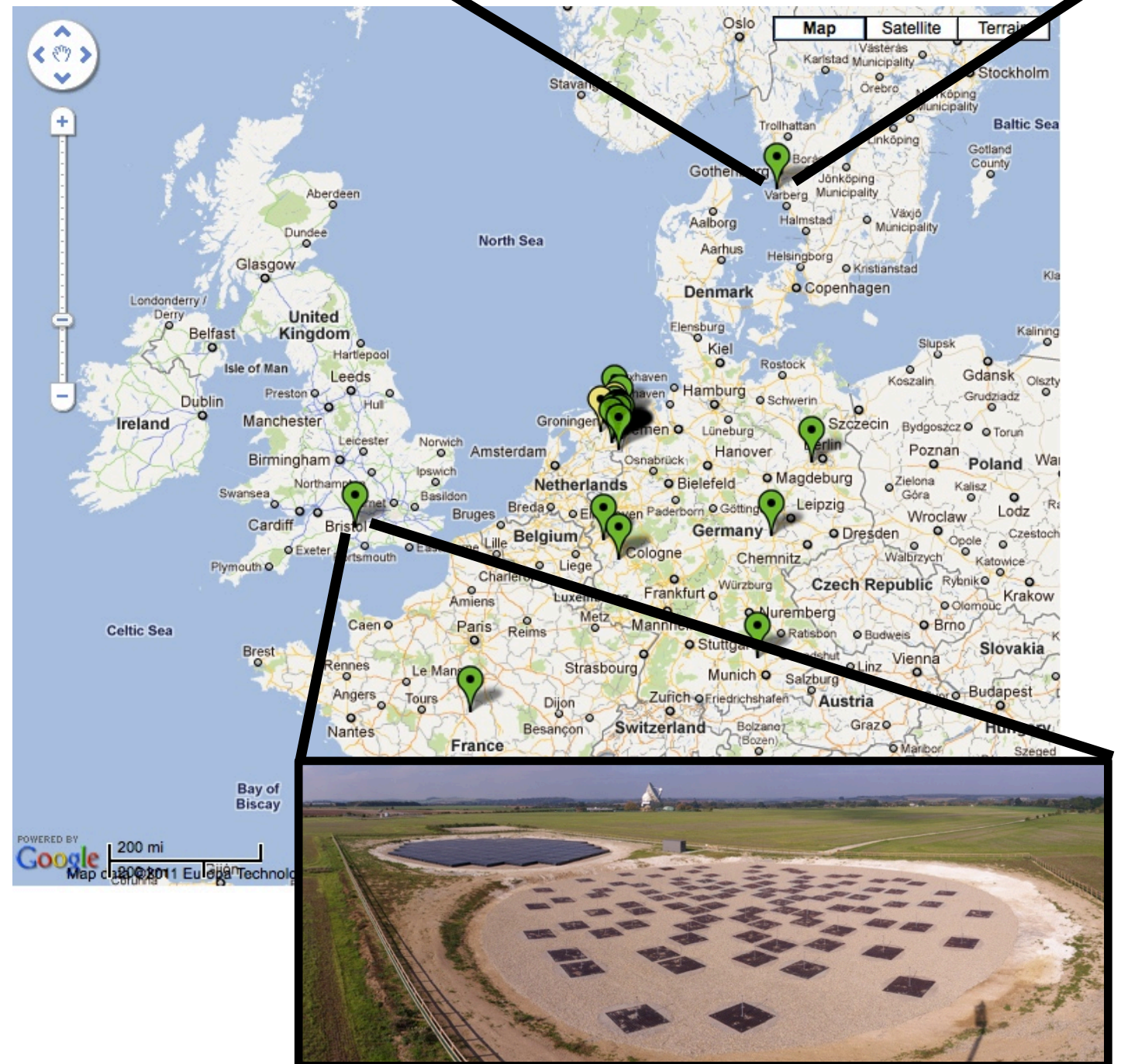
LOFAR

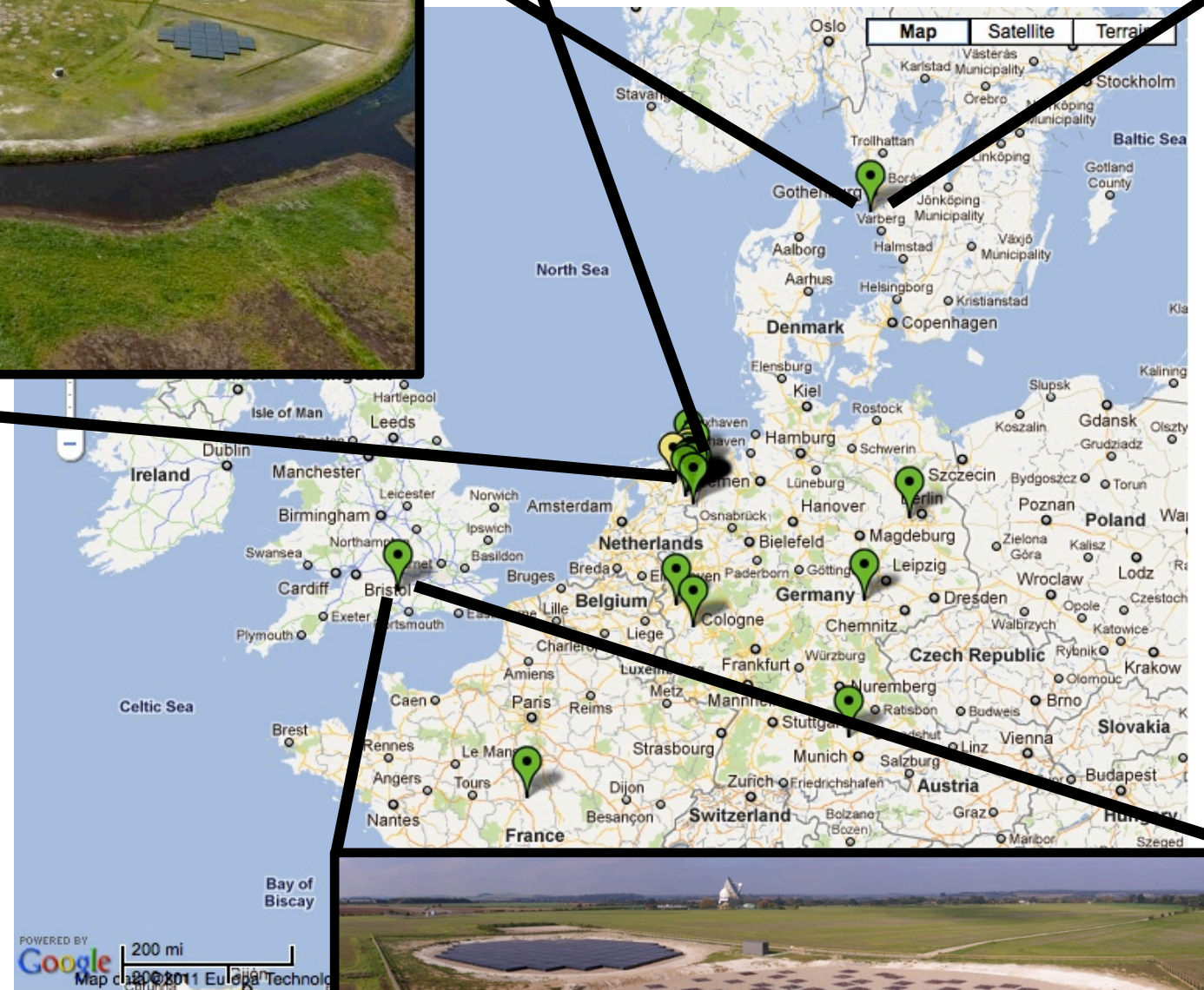
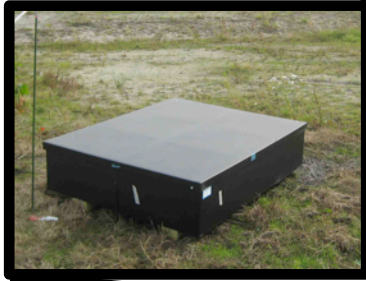
low frequency array
10 - 250 MHz

Epoch of Reionization
Radio Transients
Astroparticle Physics
Cosmic Magnetism
Surveys
Solar Physics

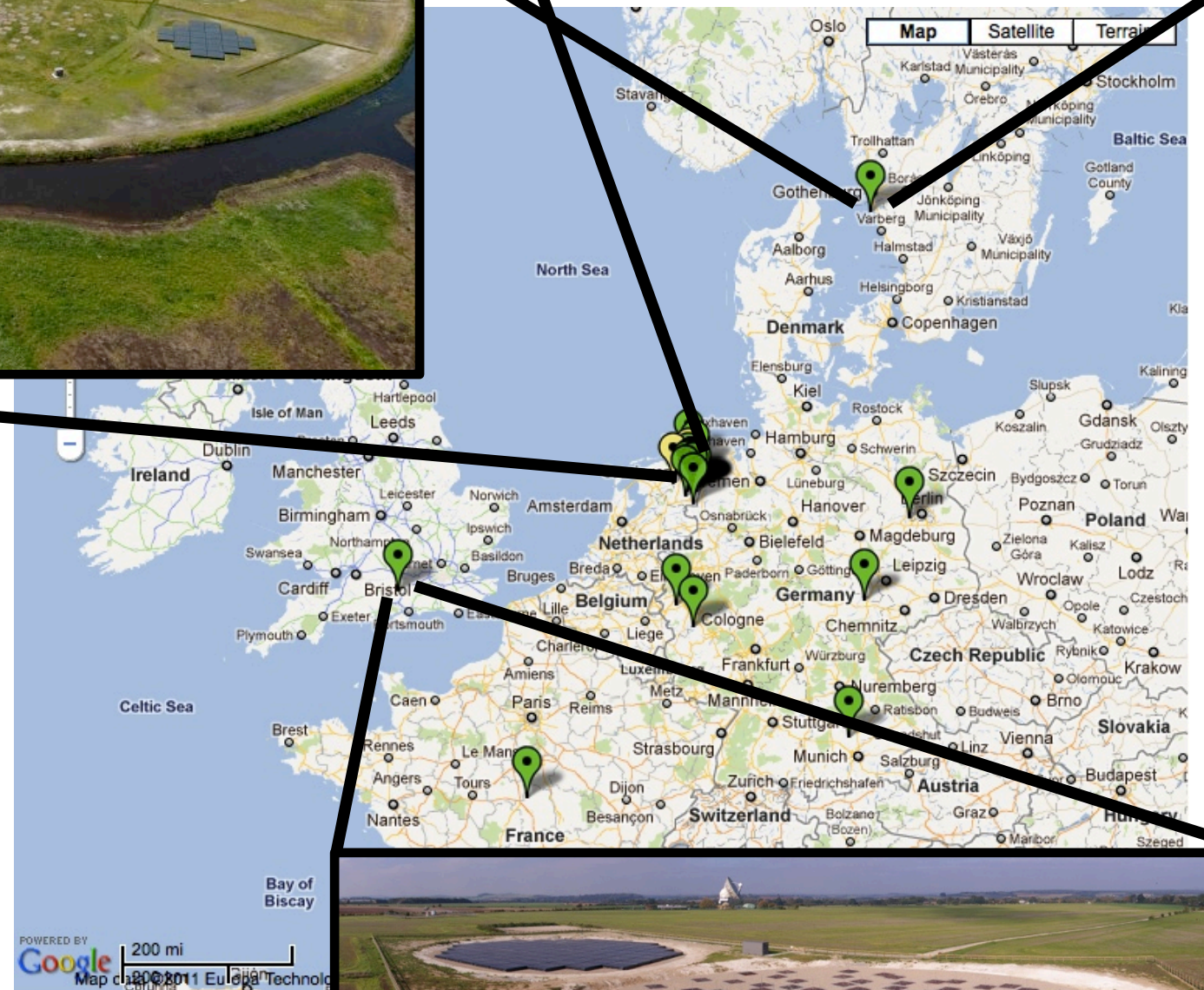
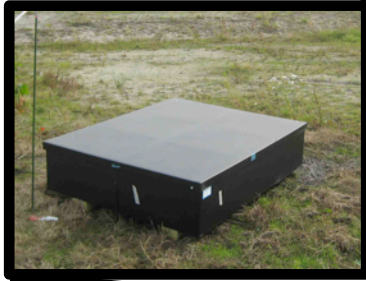


LOFAR
24 core stations
9 remote stations
8 international stations

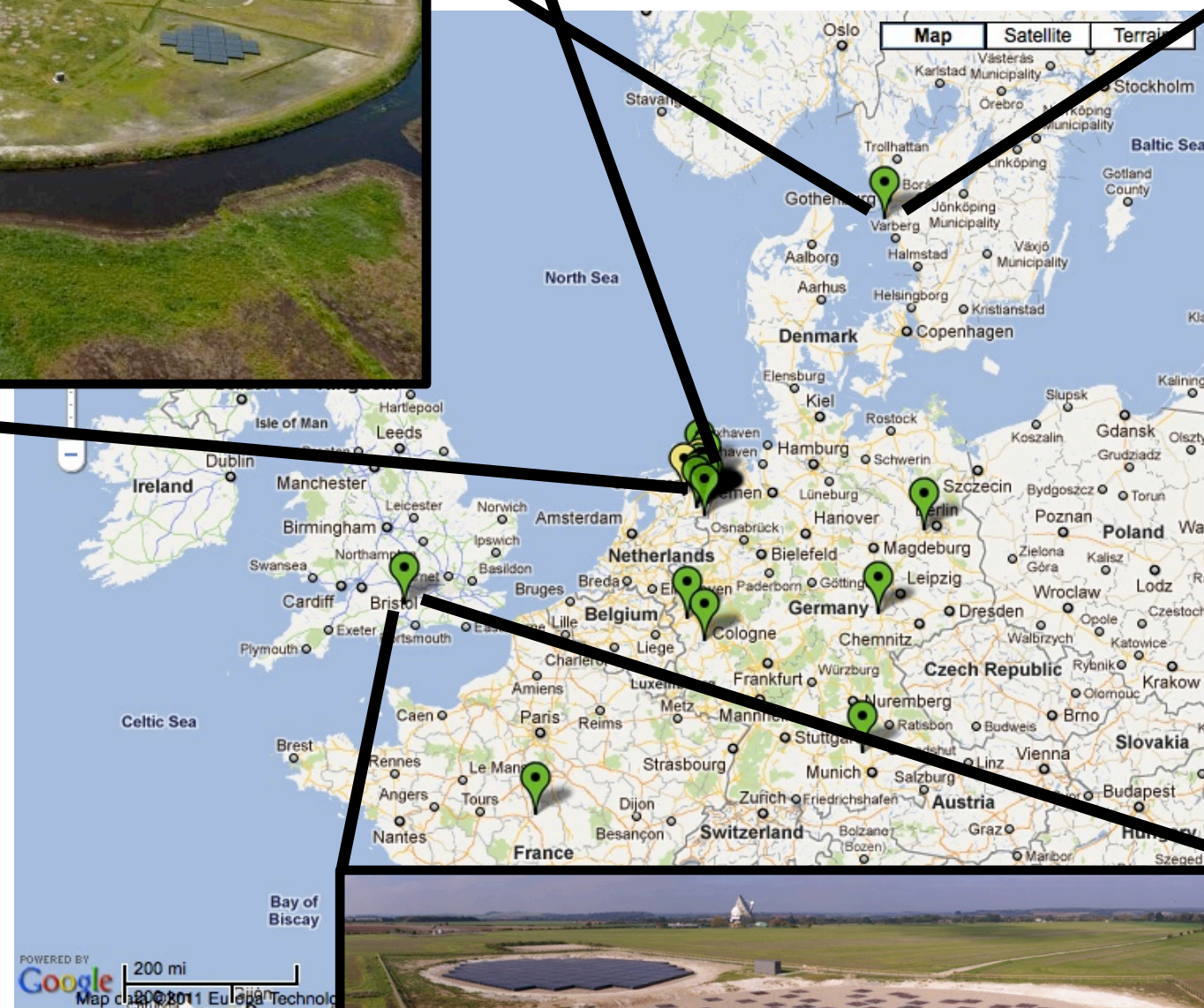
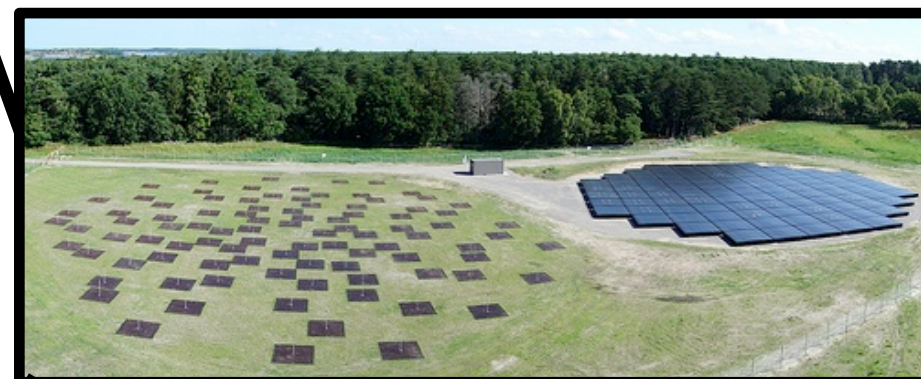




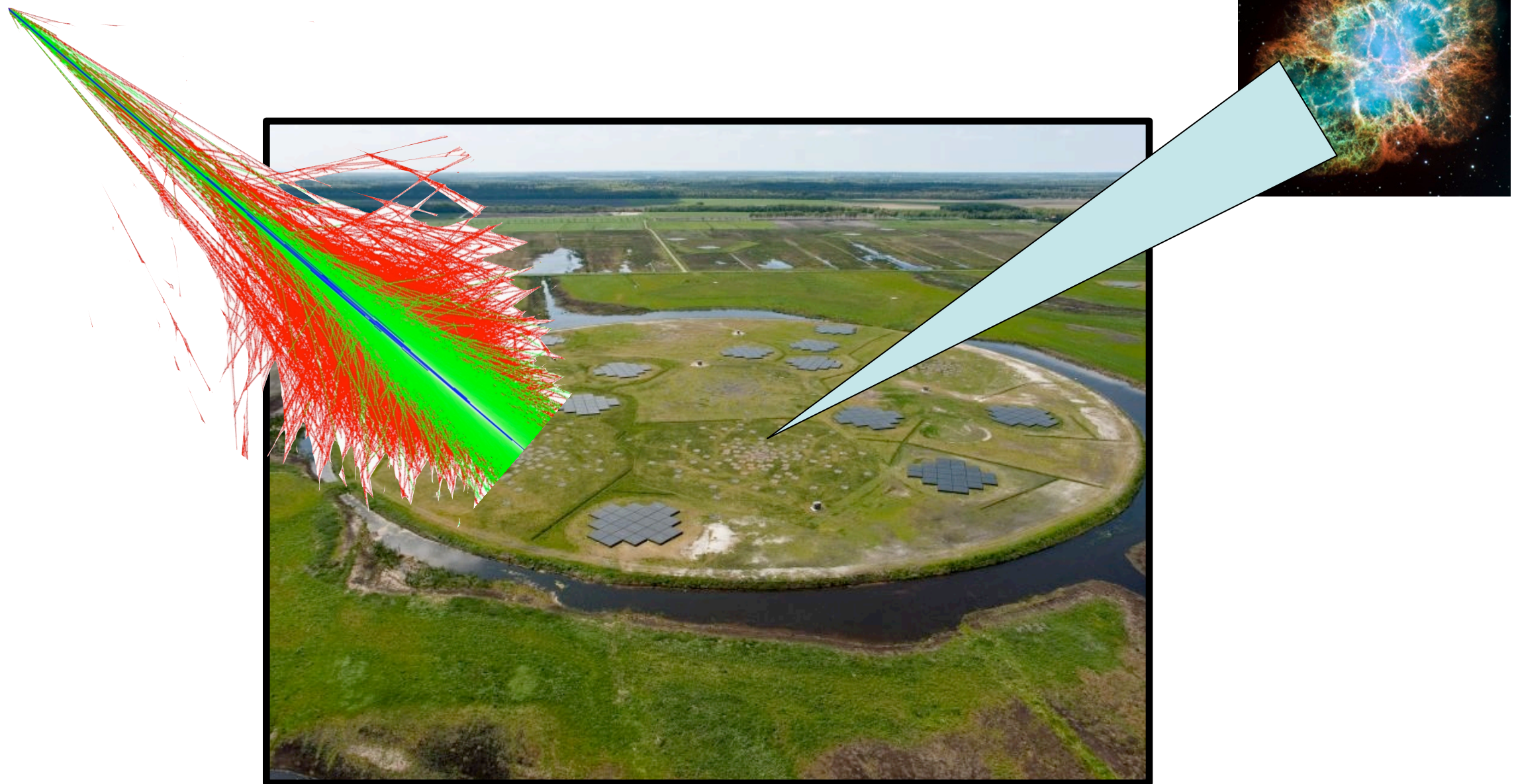
SUPERTERP
6 core stations
+
LORA
LOFAR Radboud air
shower array



LBA:
96 / station
10 - 80 MHz
5 ns time resolution
> GB buffer/antenna



HBA: 48 / station 110 - 250 MHz



LOFAR is designed to support many different observation strategies

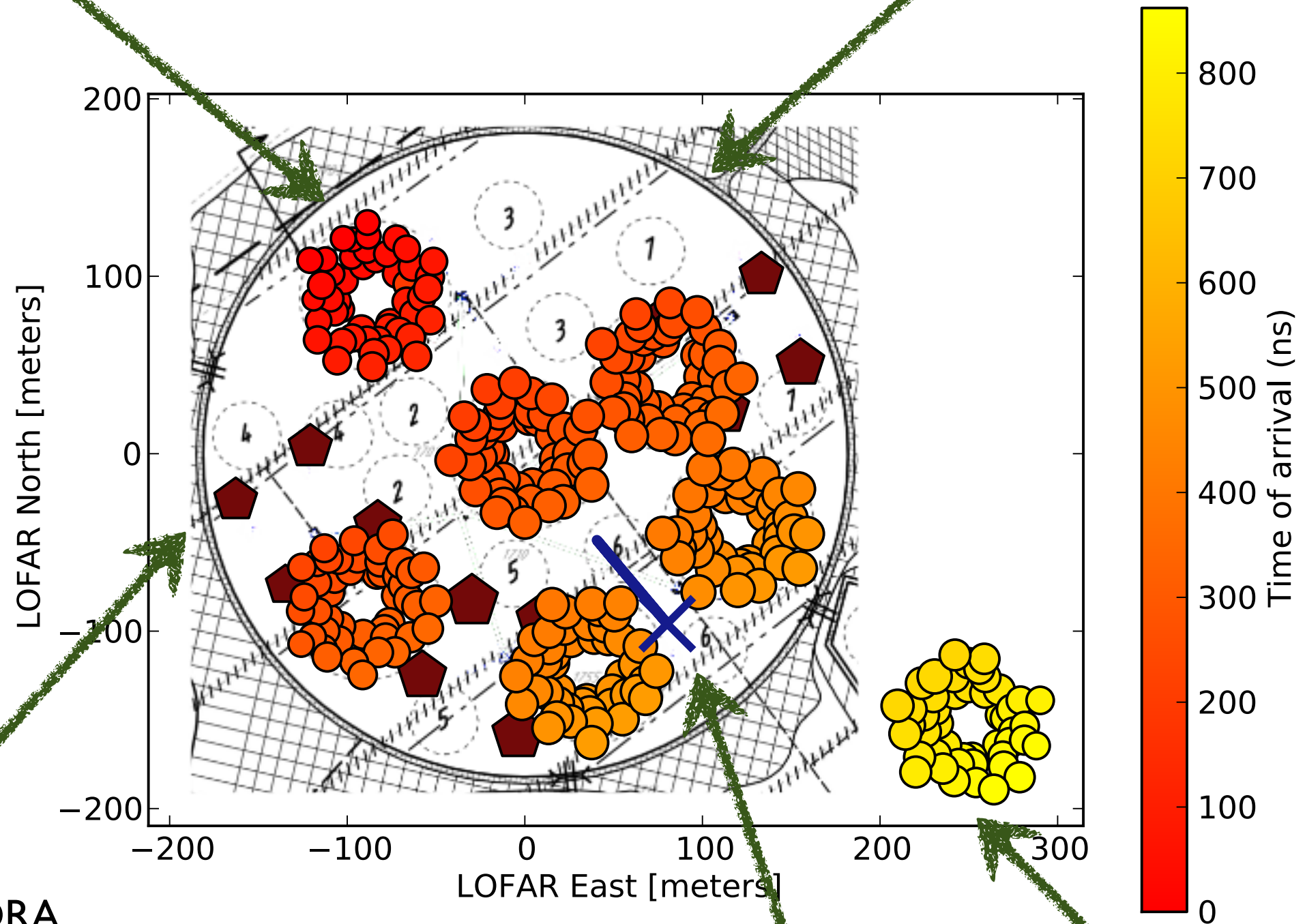
CR detection runs in the background during other observations

Trigger from scintillators → read out buffer boards @ antennas

5. event display

antennas grouped
in rings

superterp

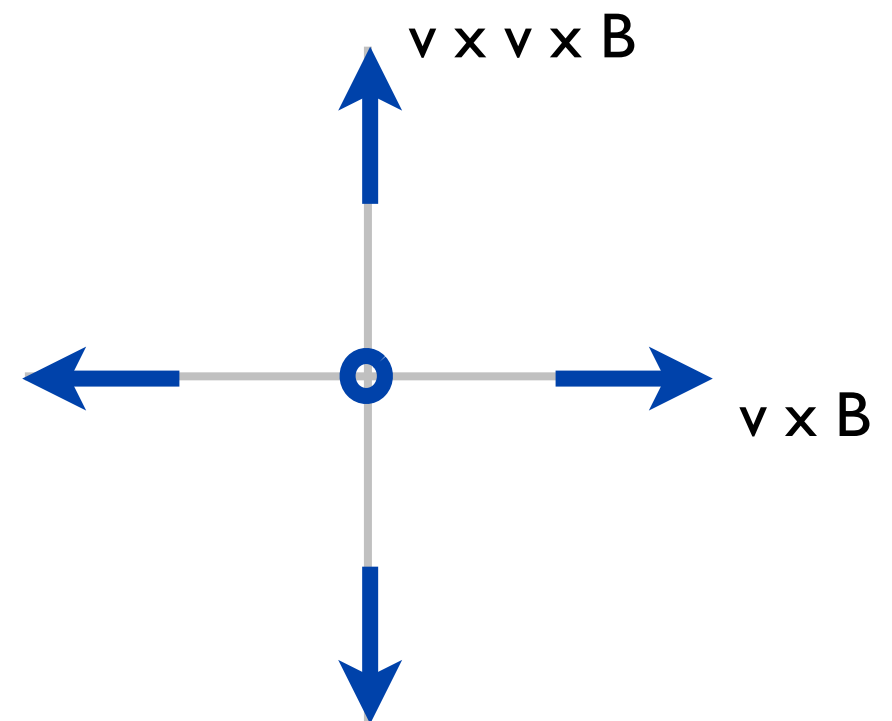
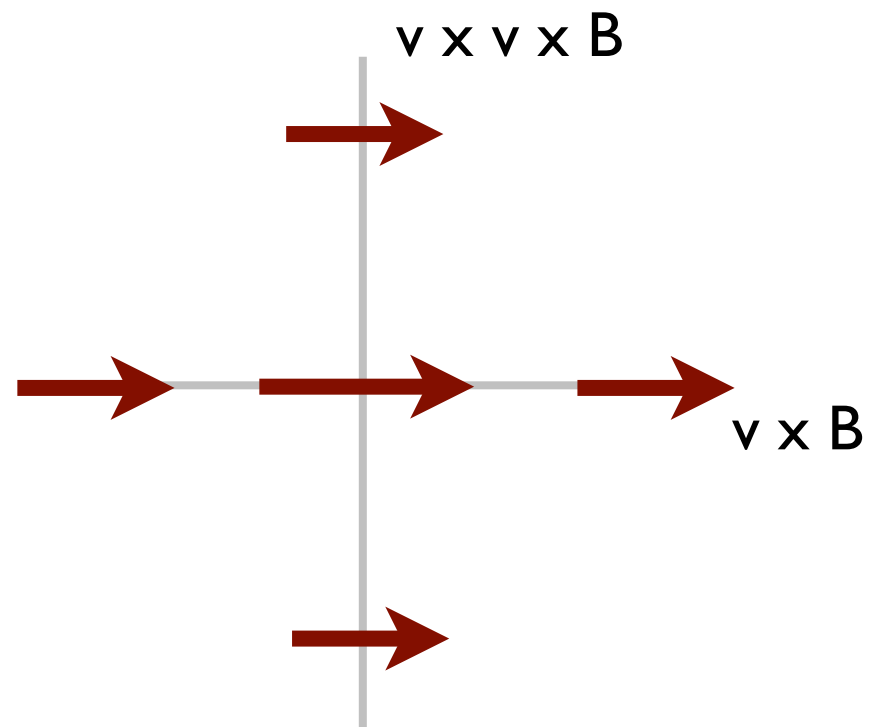


pentagons: LORA
scintillators

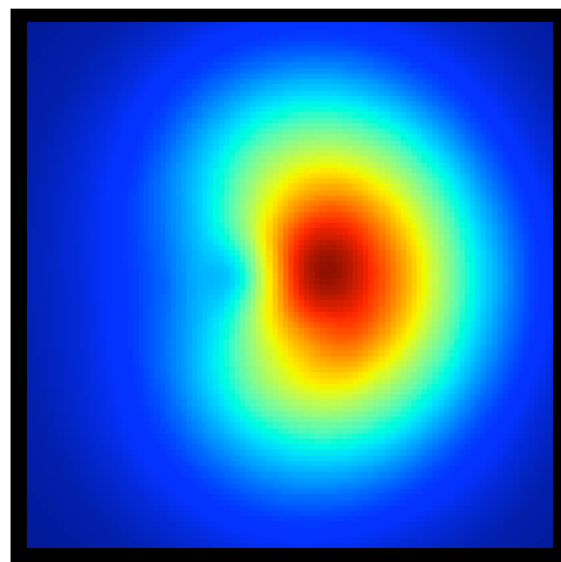
reconstructed
core & direction

station outside
superterp

radio pattern



vector sum of **geomagnetic** and **charge excess** component
relativistic beaming
distortion by Cherenkov-like effects ($n \neq 1$)

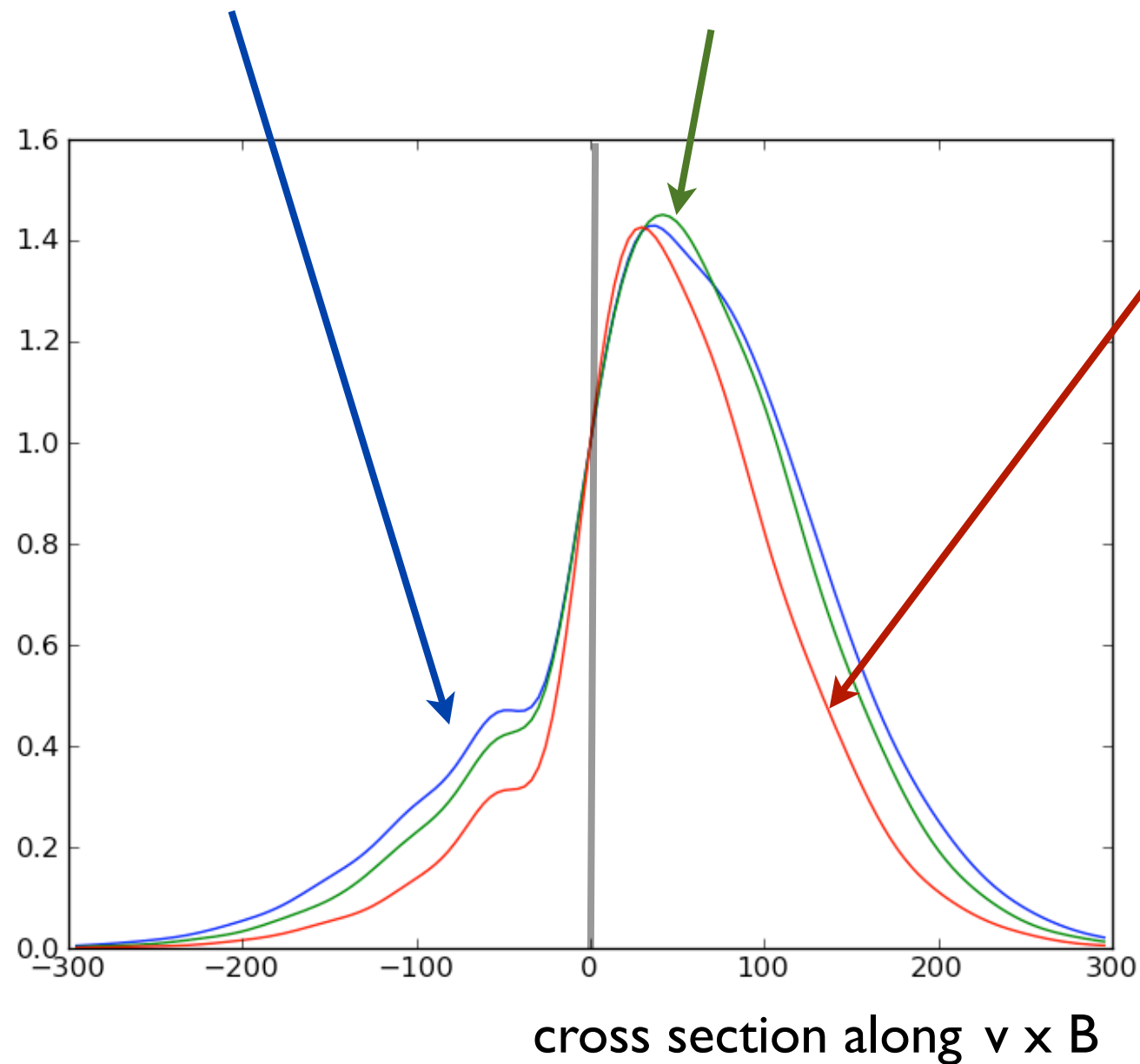
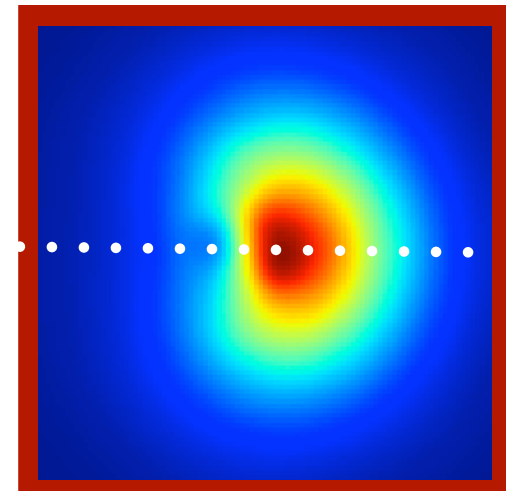
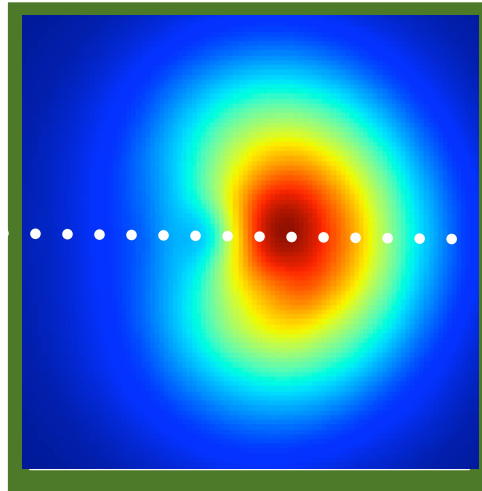
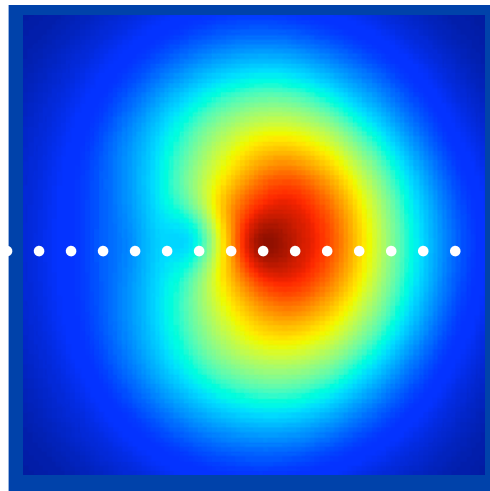


CoREAS simulation

$X_{\text{max}} \sim 600 \text{ g/cm}^2$

$X_{\text{max}} \sim 650 \text{ g/cm}^2$

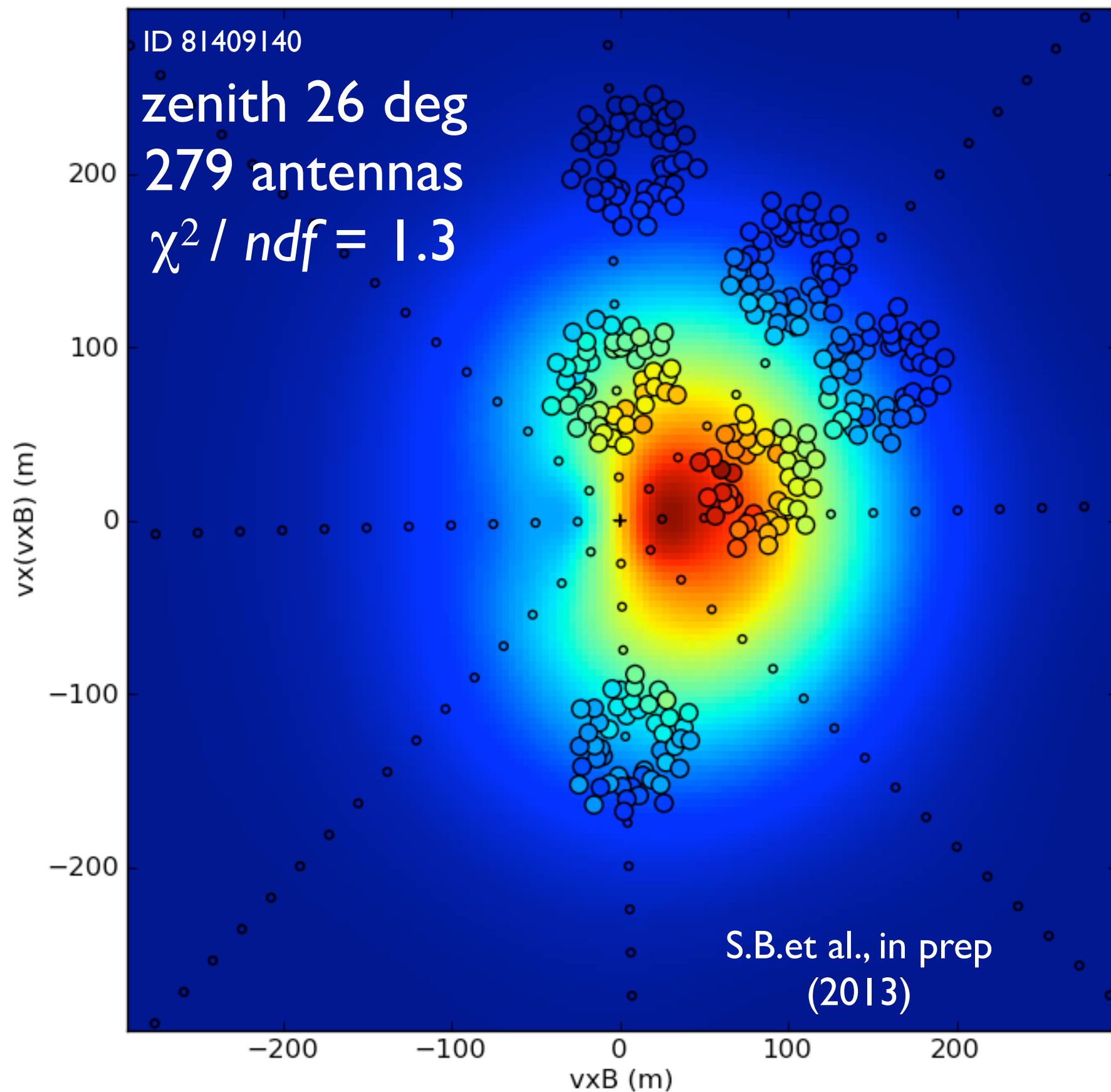
$X_{\text{max}} \sim 700 \text{ g/cm}^2$



LOFAR:
200 - 400 antennas/event

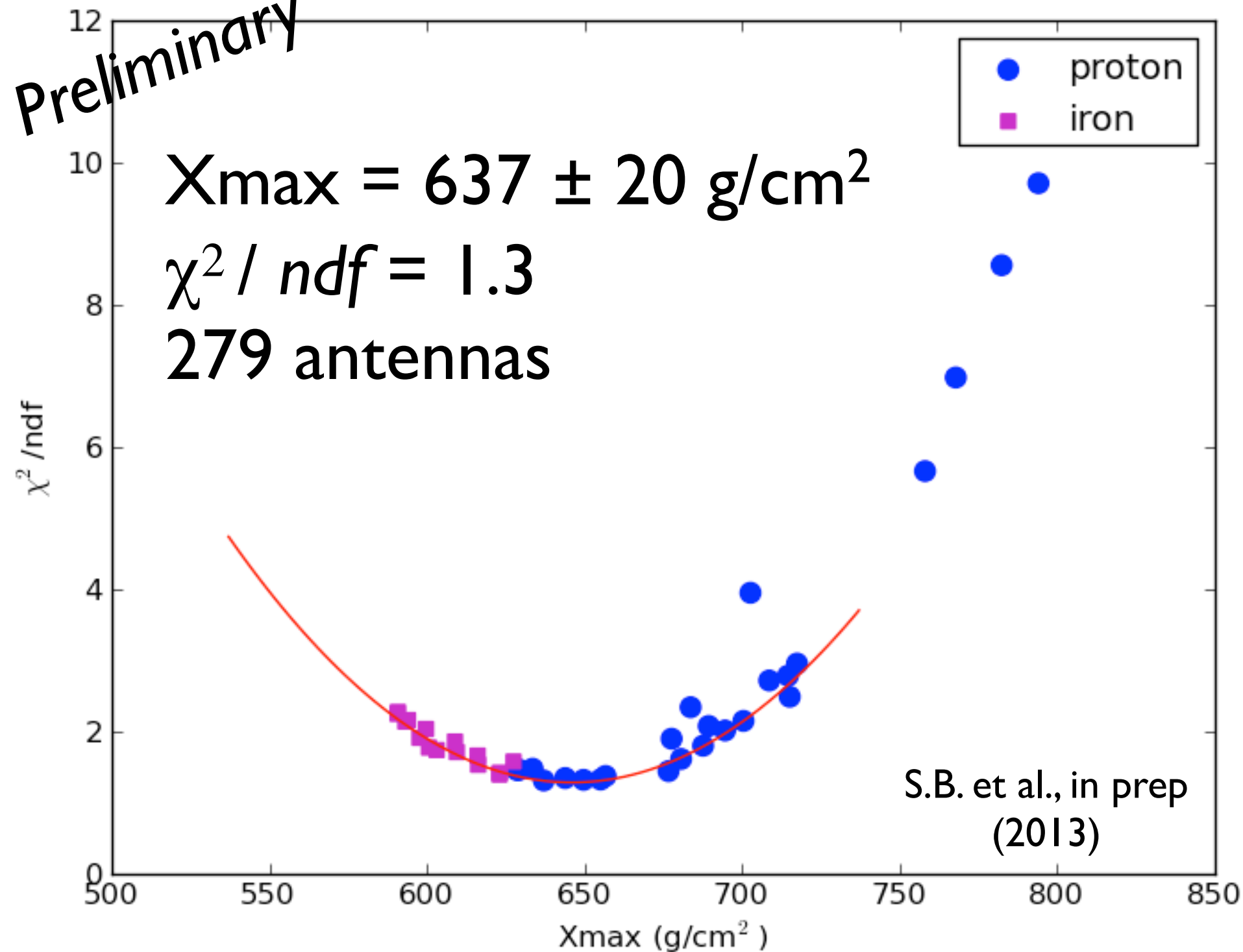
→ *fit full 2D pattern !*

best fit out of 40 simulations



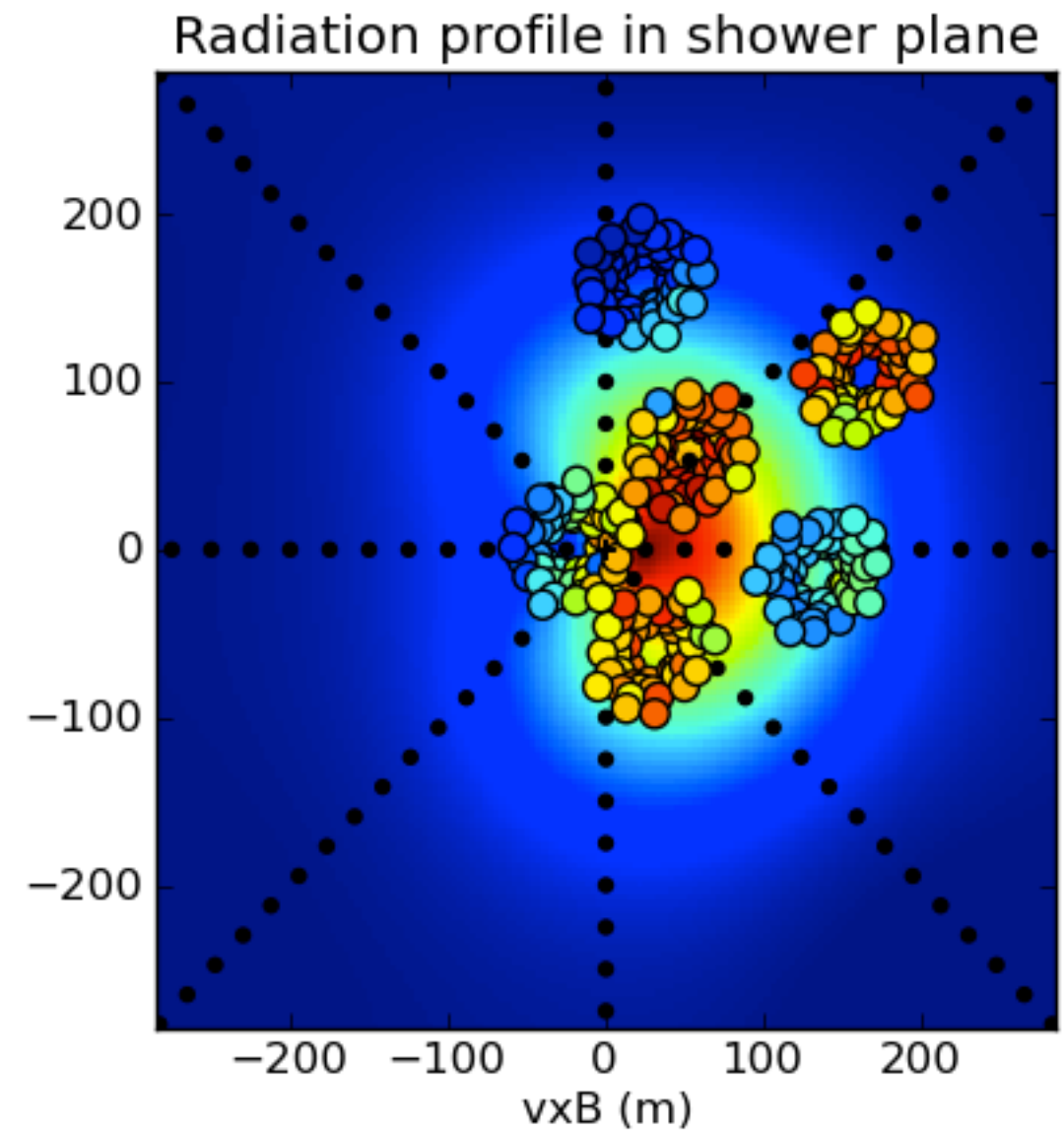
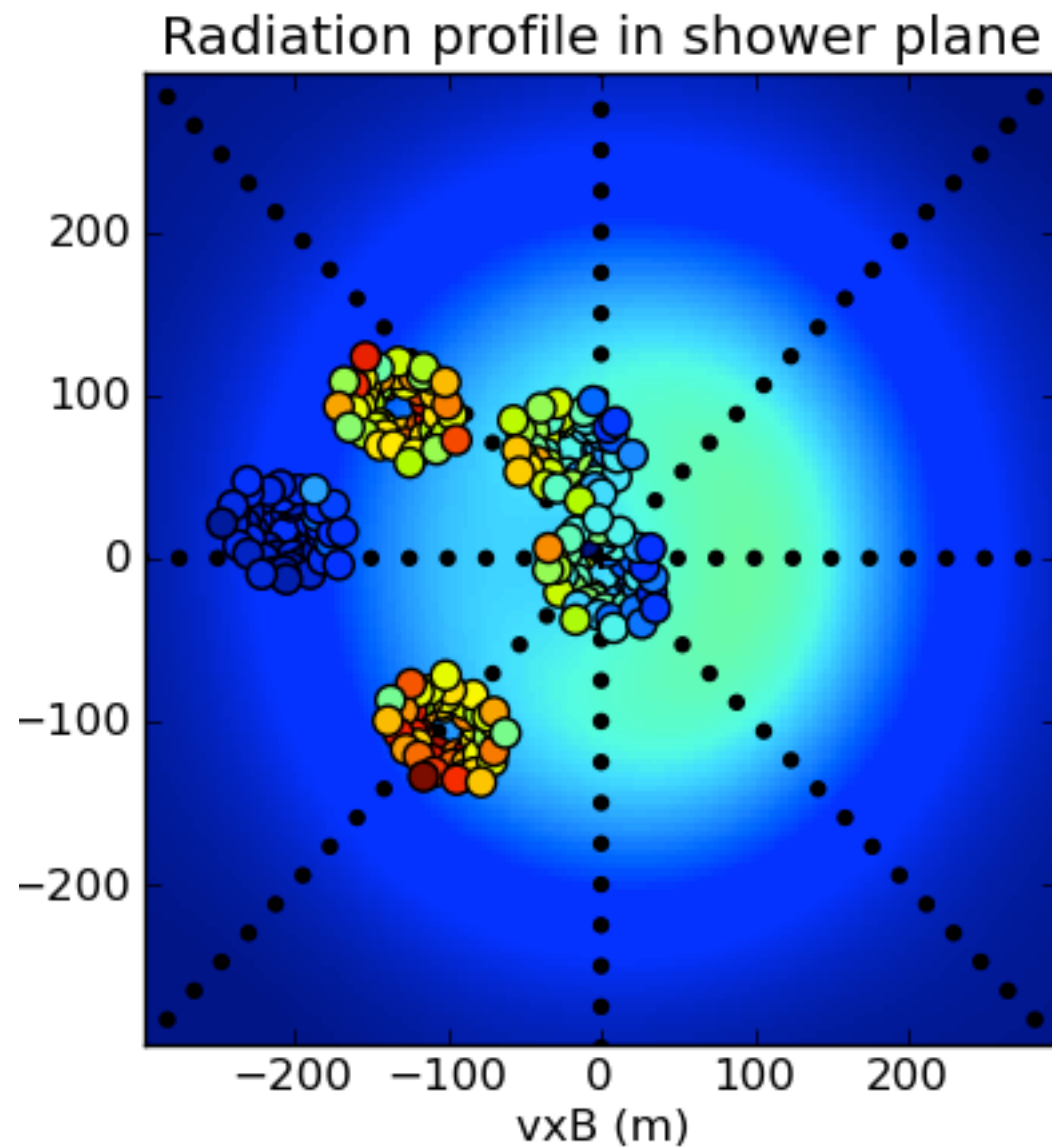
Fit Quality after core optimization

Preliminary



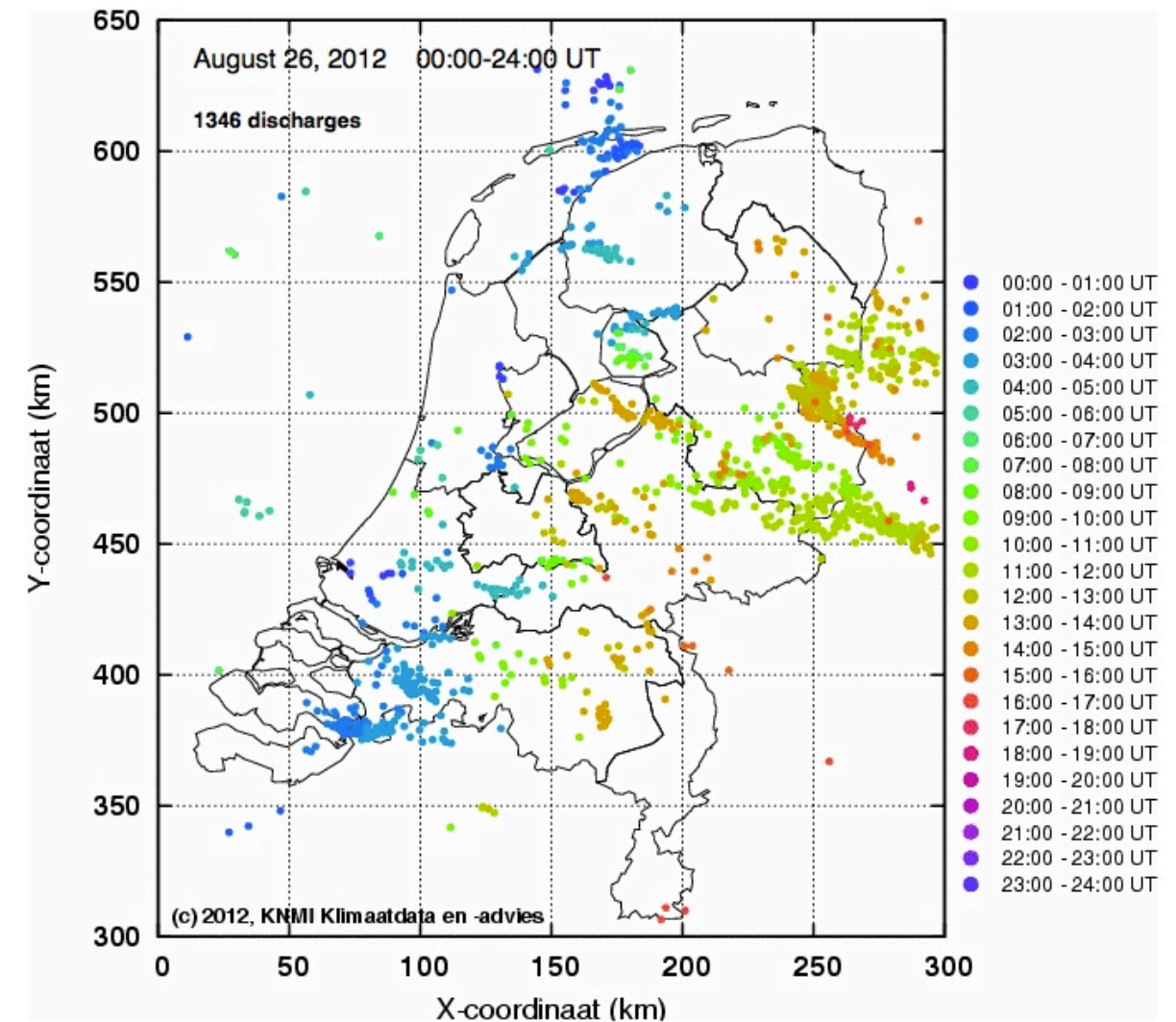
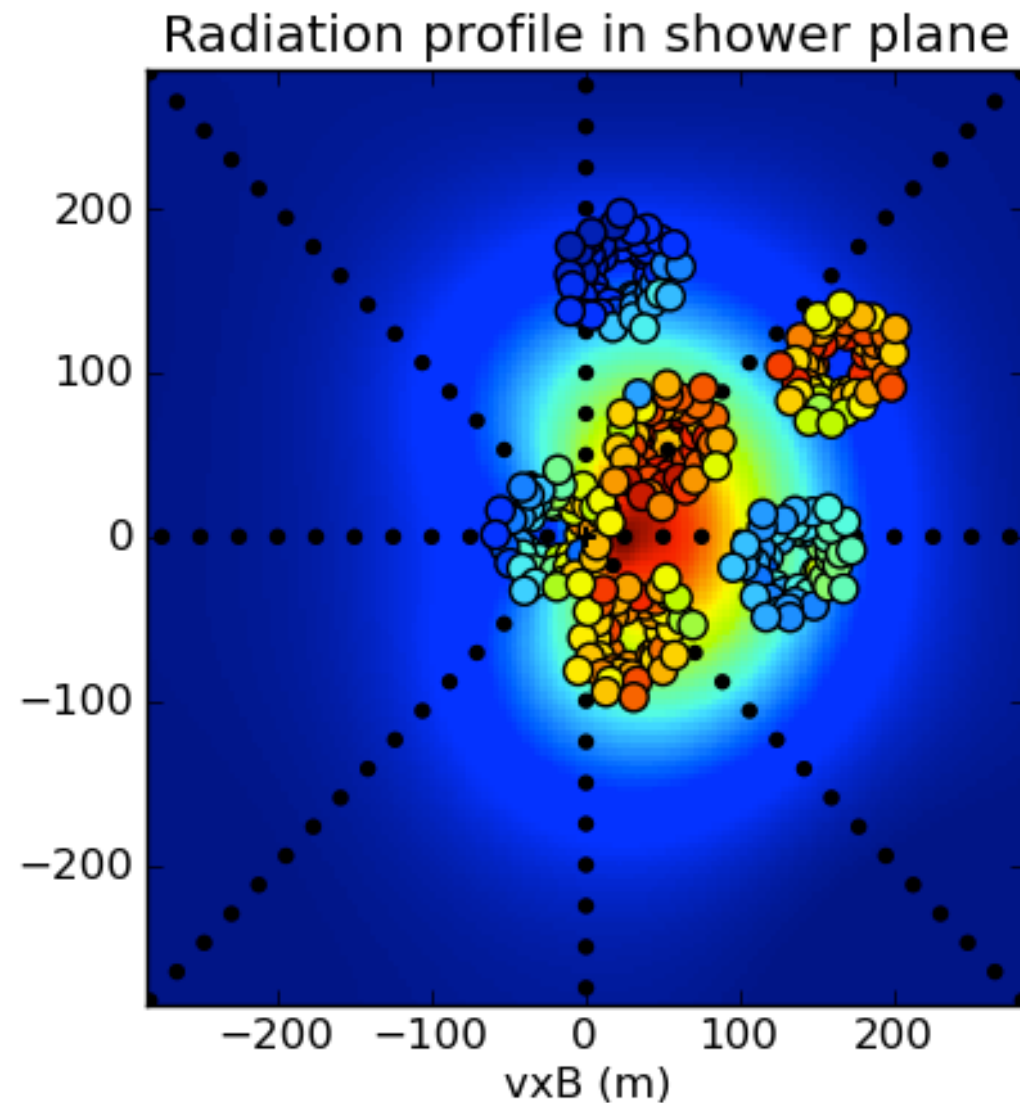
same precision as existing techniques
with 10 x duty cycle !

however...



...sometimes events are very weird!

cosmic lightning project: Gia Thi Ngoc Trinh



Atmospheric electric fields !

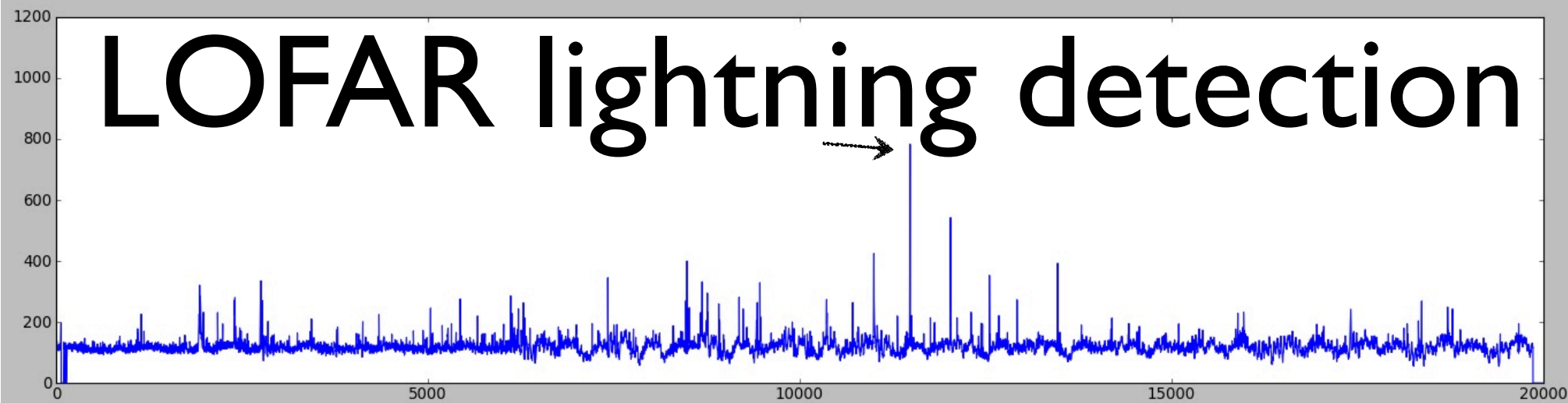
- acceleration shower particles

measure E ?

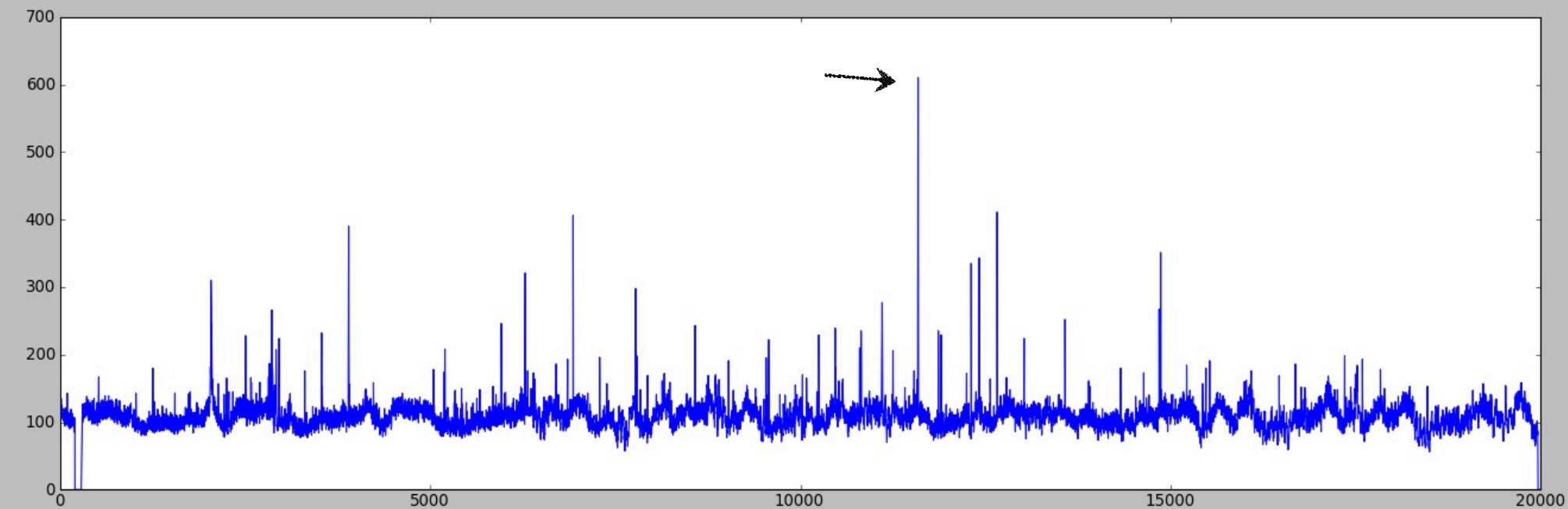
- ionization electron avalanches ?

detect CR - TS interaction ?

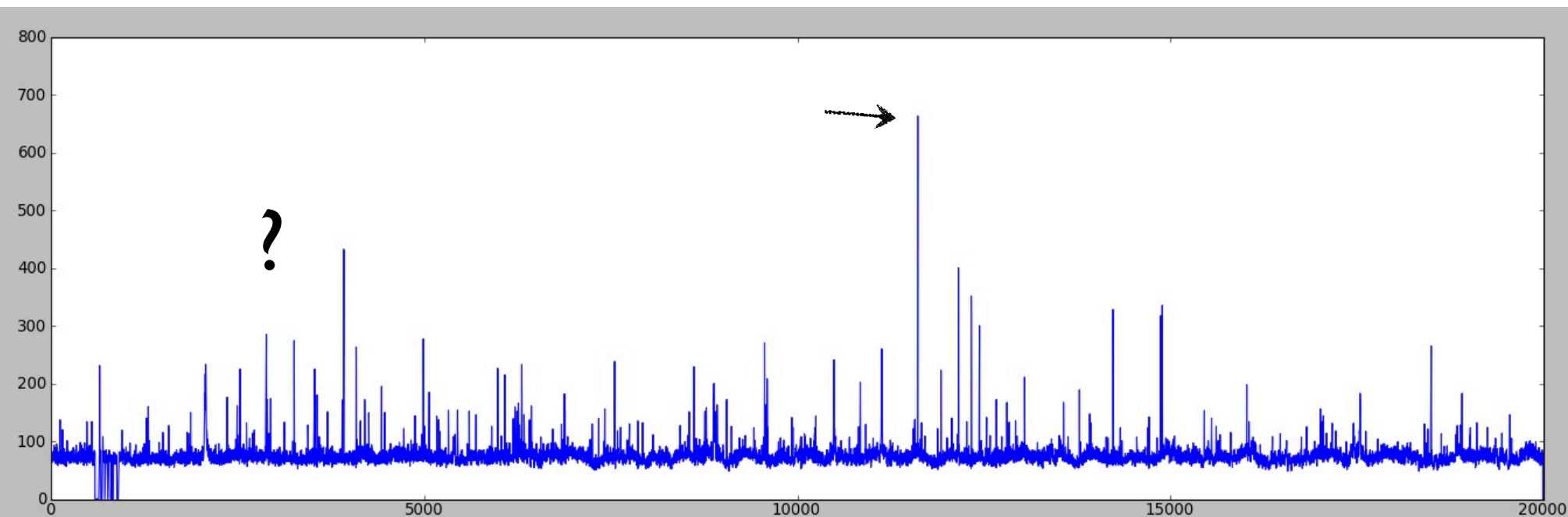
LOFAR lightning detection



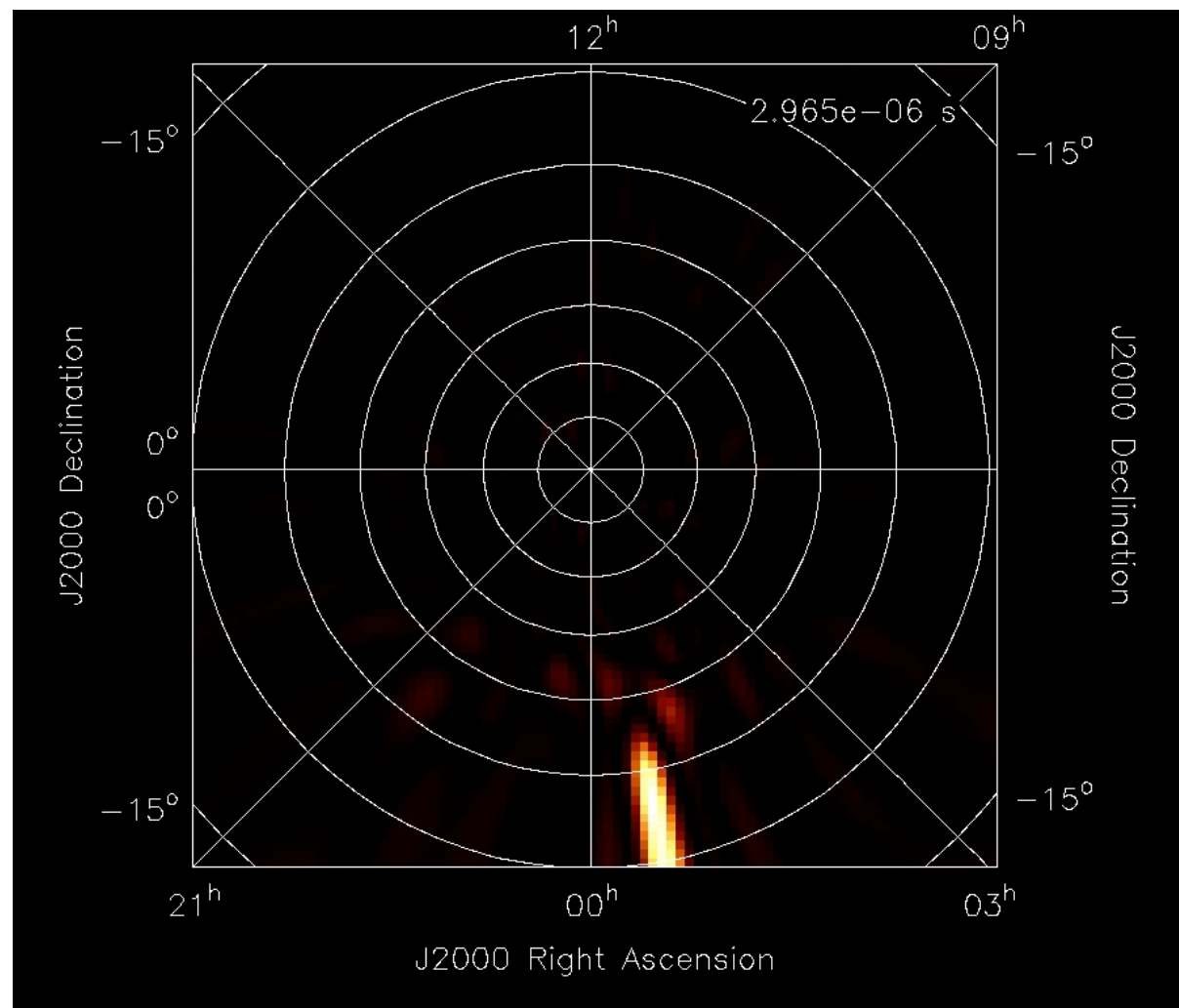
RS503



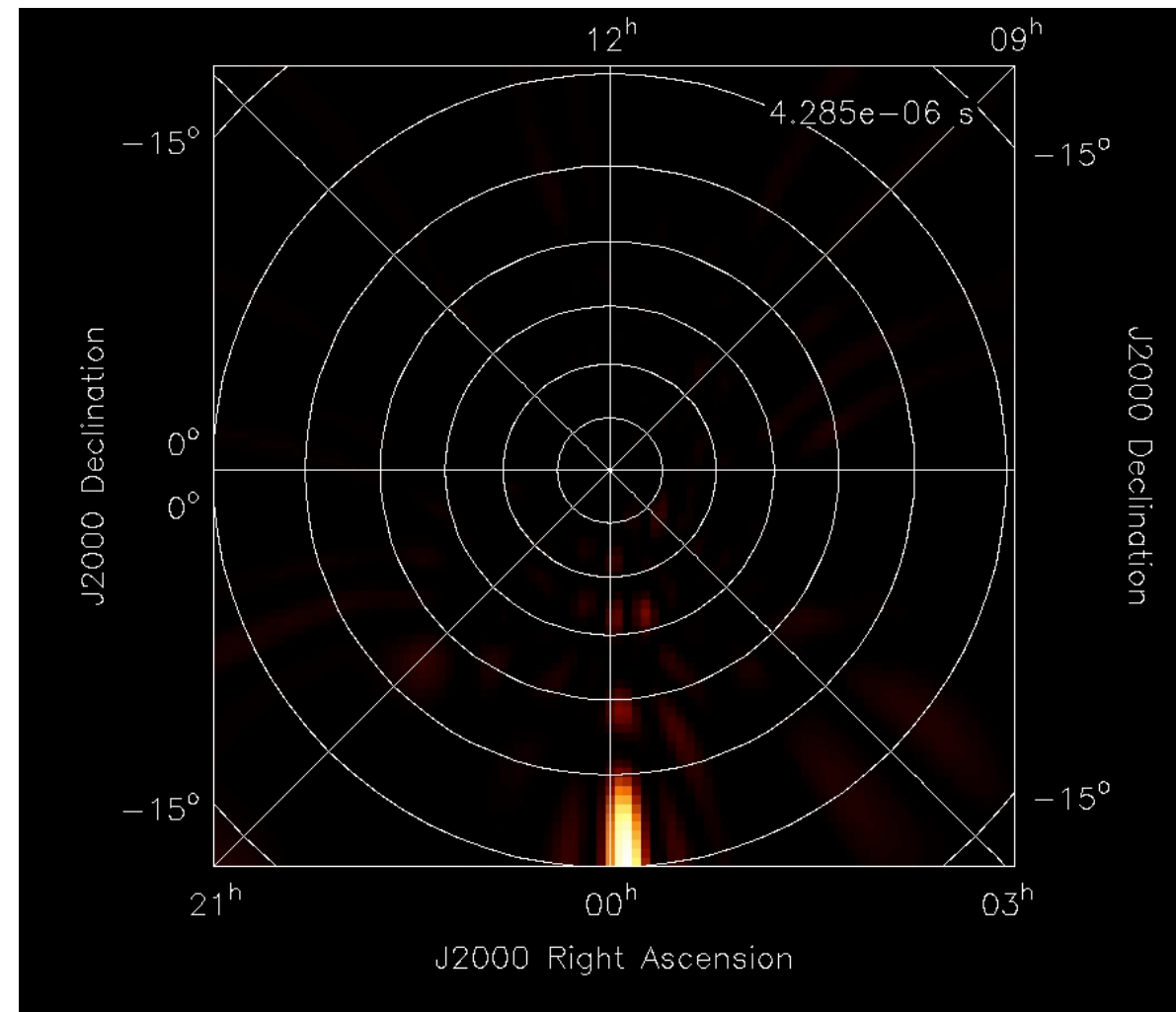
RSI06



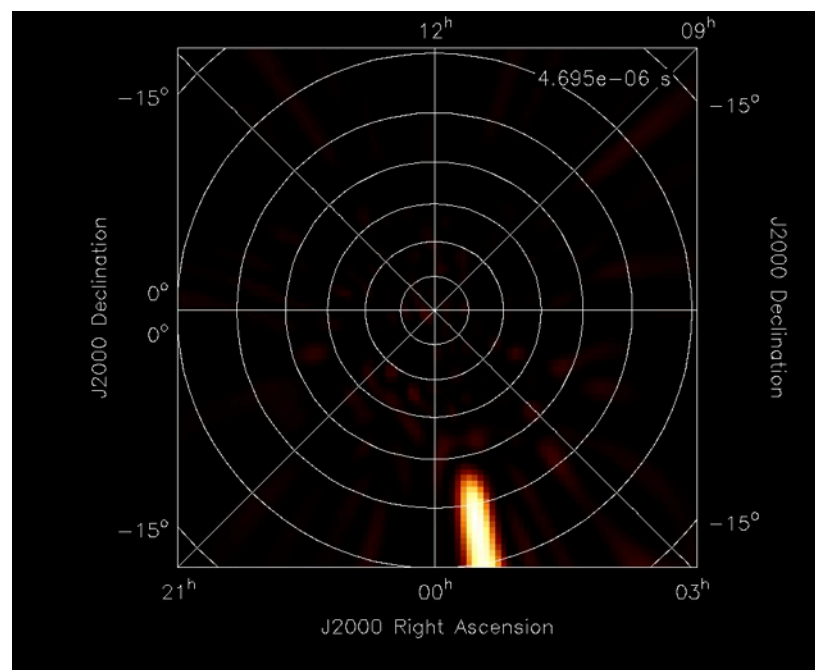
CS002



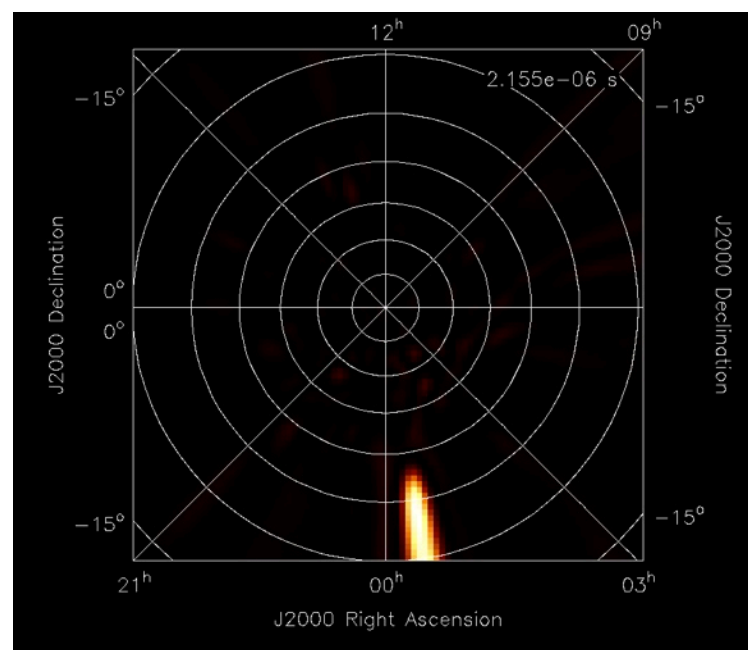
RS503



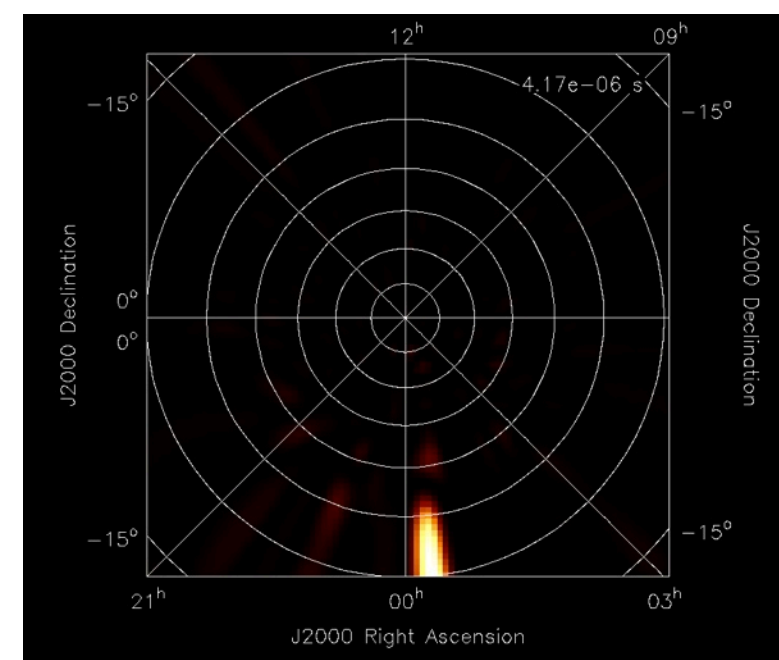
RSI06



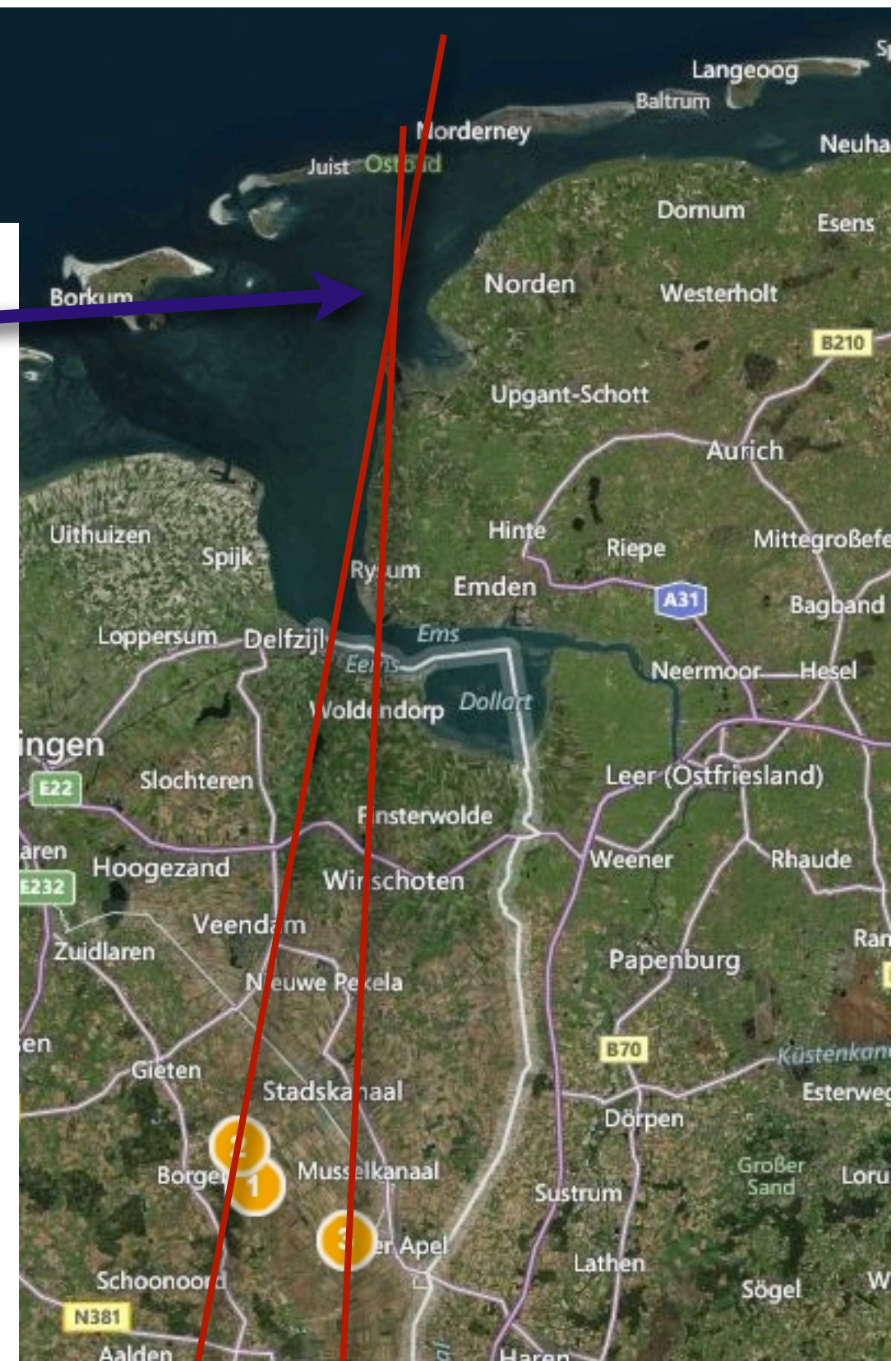
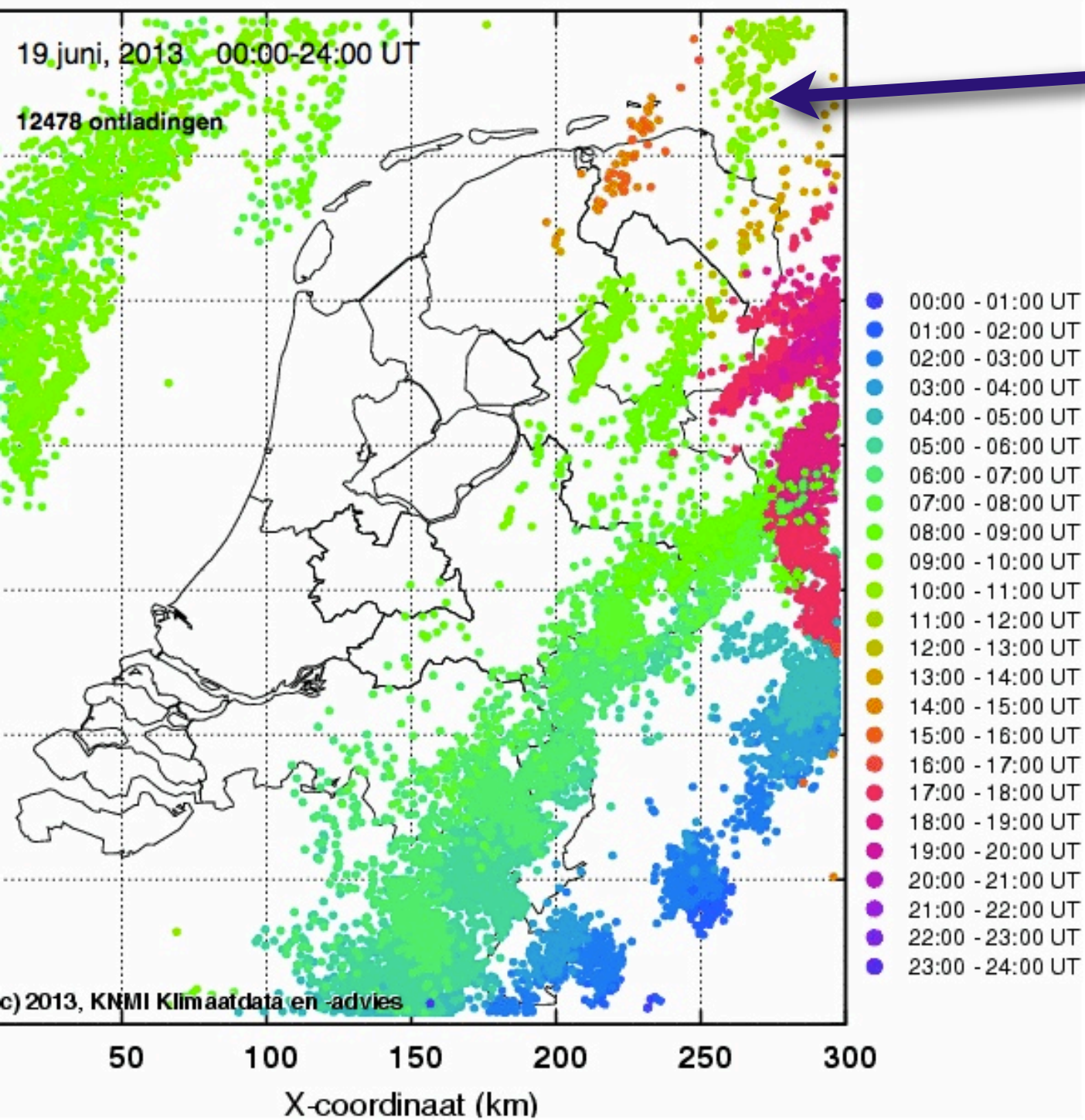
CS002



RS205



RS208



plan: 4D imaging

LOFAR

Radio detection of cosmic rays



detection of
discharges

- localization & imaging of lightning
- high altitude discharges?



CR - thunderstorm
interaction

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

Thanks!