Other Key Science Projects:

Transients, EoR & Cosmic Rays

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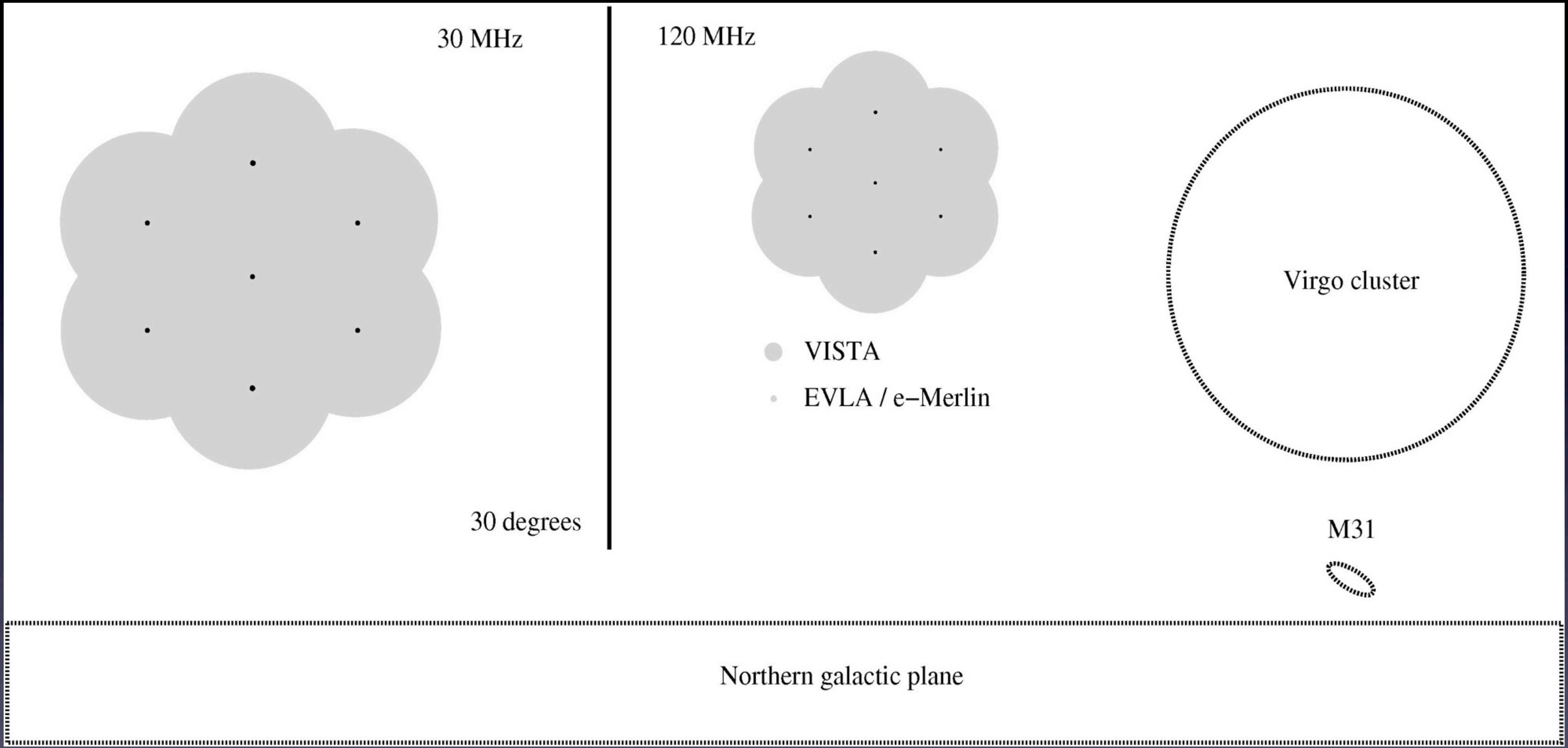
The Transients KSP

PIs: Ralph Wijers, Rob Fender, Ben Stappers

Aim: identify, monitor and study all transient and variable radio phenomena

- Accreting black holes / neutron stars
- GRB afterglows
- Pulsars
- Extrasolar planets
- Active flare stars
- Counterparts to gravitational wave sources
- Serendipity
- SETI
- ......

LOFAR as a transient monitor



LOFAR's large collecting area, vast field-of-view and multiple beams give it an unprecedented ability to monitor the sky for transient phenomena

LOFAR Transients 'Modes'

1. Radio Sky Monitor
   - Monitoring of a large fraction of the sky ~daily
2. Targetted surveys
   - e.g. for pulsars, nearby star systems, known active/ interesting systems, monitoring of Virgo cluster, follow-up of newly discovered transients
3. Piggybacking
   - Search all LOFAR observations with automated transient-finding tools

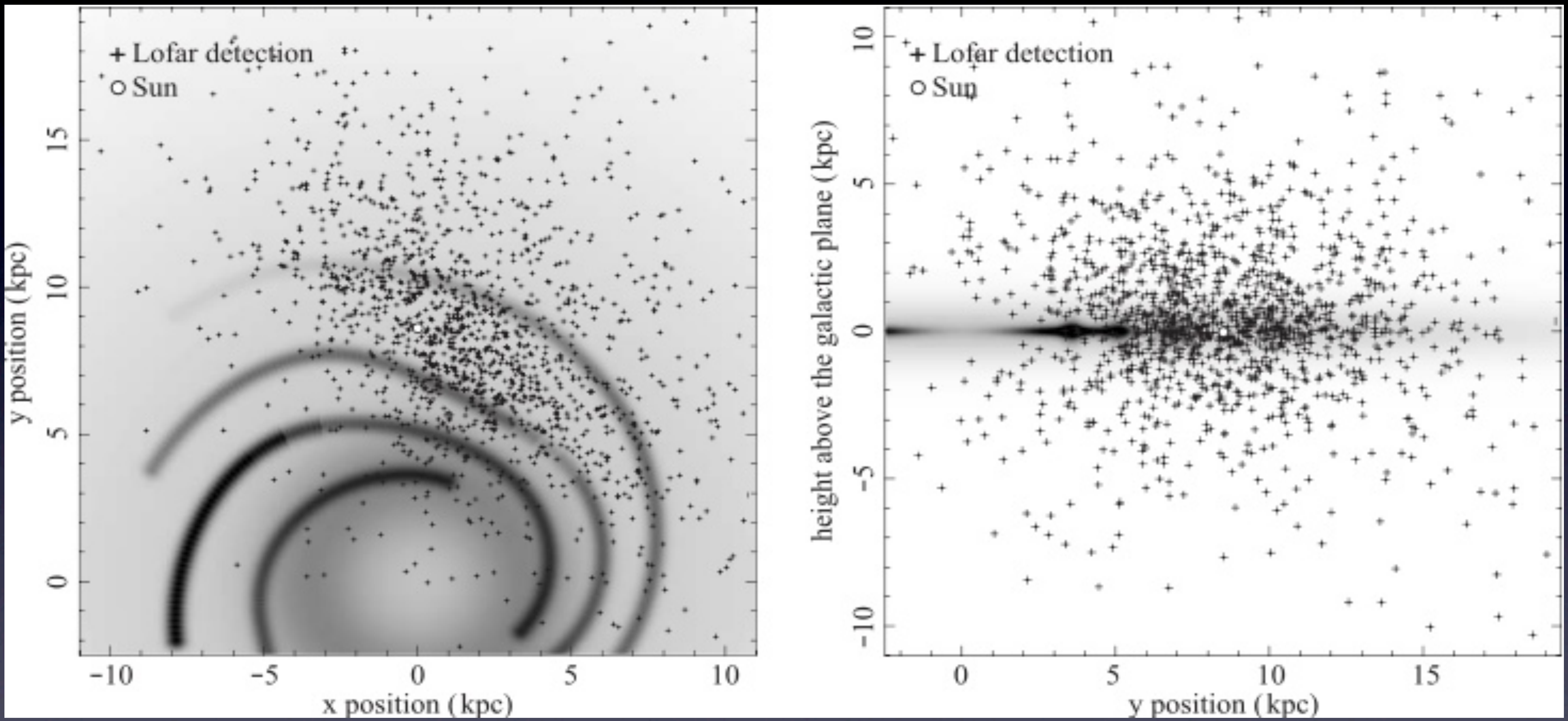
Mode 3 will clearly have a large overlap with Surveys

The transient buffer boards

"What was going on 20 seconds ago?"

- Raw data recorded in RAM buffers
- Possible to reform images in any direction on the sky using the RAM data, in response to both internal or external triggers
- Data period that can be stored in RAM buffers depends on bandwidth and number of antennae/beams stored, but is typically a few seconds
- Tool for searching for very rapid, coherent events

Pulsars with LOFAR

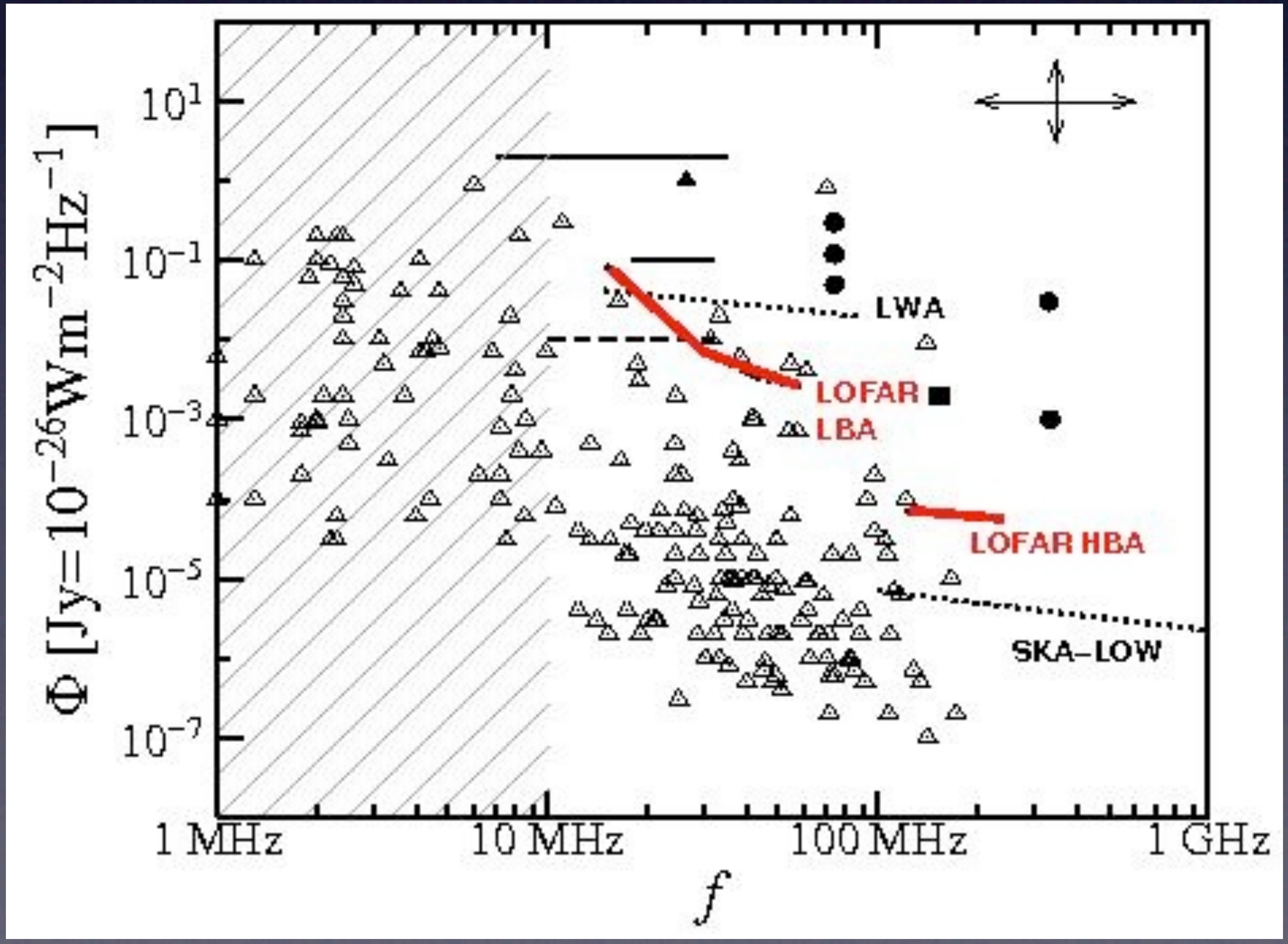


- Complete survey of pulsars in the northern sky
- Sources for the pulsar timing array (-> grav. waves)
- Find rare pulsars (e.g. RRAT; BH/NS binary); probe ISM

Extrasolar planets

Scaling Jupiter's radio emission to account for much stronger stellar winds from hot Jupiters, we could see radio bursts to 10s of parsec

- inclination-independent method of finding new planets?
- provides unique new info, rotation rate
- requires low frequencies



Epoch of Reionisation KSP

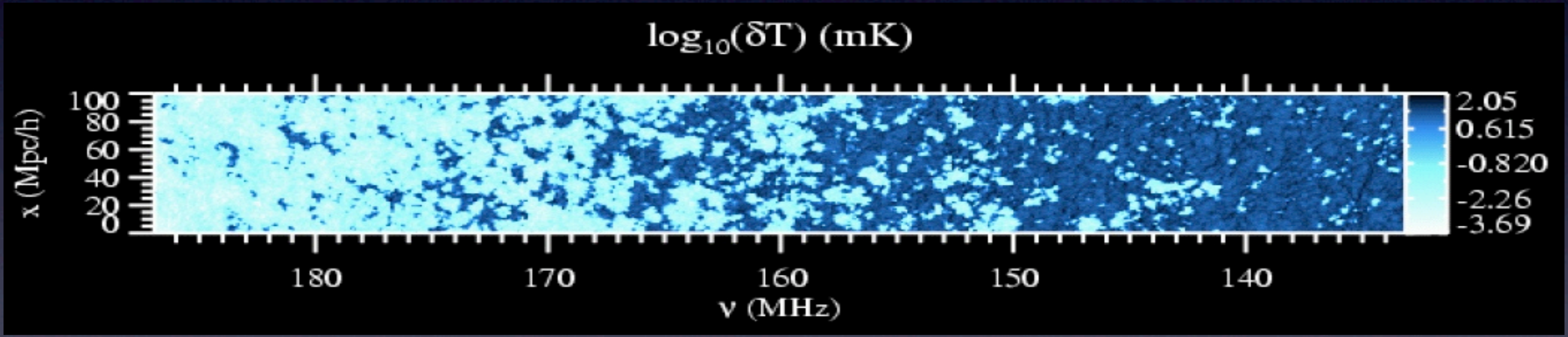
PI: Ger de Bruyn,
Michiel Brentjens, Leon Koopmans, Saleem Zaroubi

Aim: To detect the Epoch of Reionisation through the redshifted 21cm hyperfine transition of neutral hydrogen

- The “Epoch of Re-ionisation” occurred when the first astrophysical ionising sources turned on in the Universe.
- Lyman-a photons from these sources decouple the spin temperature of neutral hydrogen from the CMB temperature, resulting in a signal in the 21cm line.
- The EoR is believed to occur at z=7-11, placing the redshifted 21cm line within the LOFAR high band.

LOFAR EoR Signal

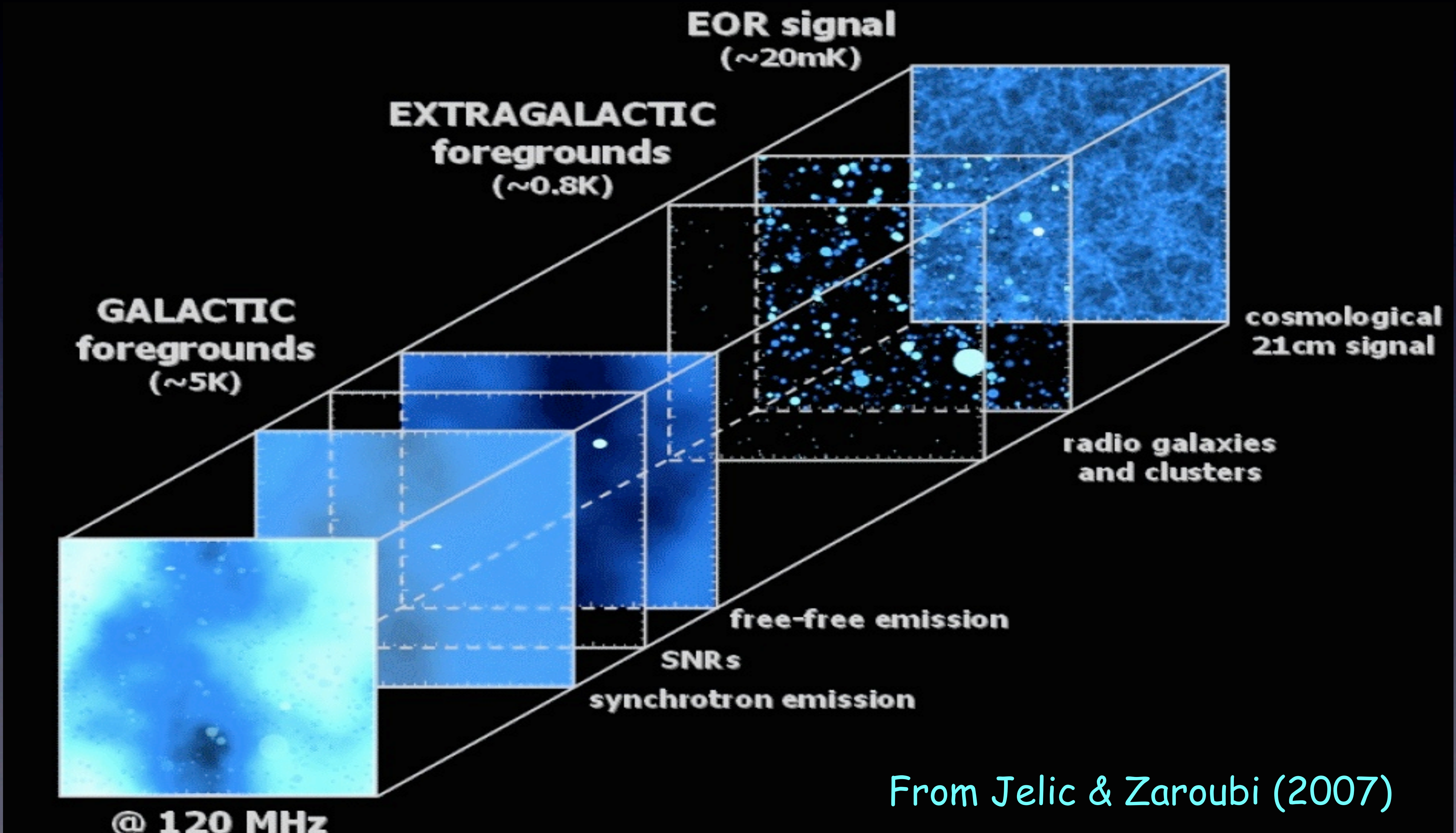
For $T_s \gg T_{CMB}$ the brightness temperature differential depends only on the overdensity and neutral fraction, so can be reconstructed from simulations.



In practice, however, there are many complications:

- signal very weak requiring very long exposure times
- foreground signals much larger, and variable

Challenge: removing foregrounds



From Jelic & Zaroubi (2007)

EoR observing plan

- 5 blank fields with low galactic foreground
- 6-point tile of observations in each field
- Full 48MHz frequency coverage, repeated twice to cover whole of 110-190 MHz range
- About 300 hours on-sky per pointing, using only core and short-baseline stations
- Total requirement of ~150 days with full LOFAR
- Signal ~0.2σ / beam - but statistically detectable
  - depth similar to deepest fields of Surveys, but not clear if same fields can be used (EoR need for low galactic background vs Surveys need for multi-wavelength data)

Alternative: 21cm forest

If sufficiently bright radio sources can be found within the EoR, then the EoR can be studied in <u>absorption</u> towards these sources through the 21cm forest.

A major goal of the Surveys KSP is to find such sources.

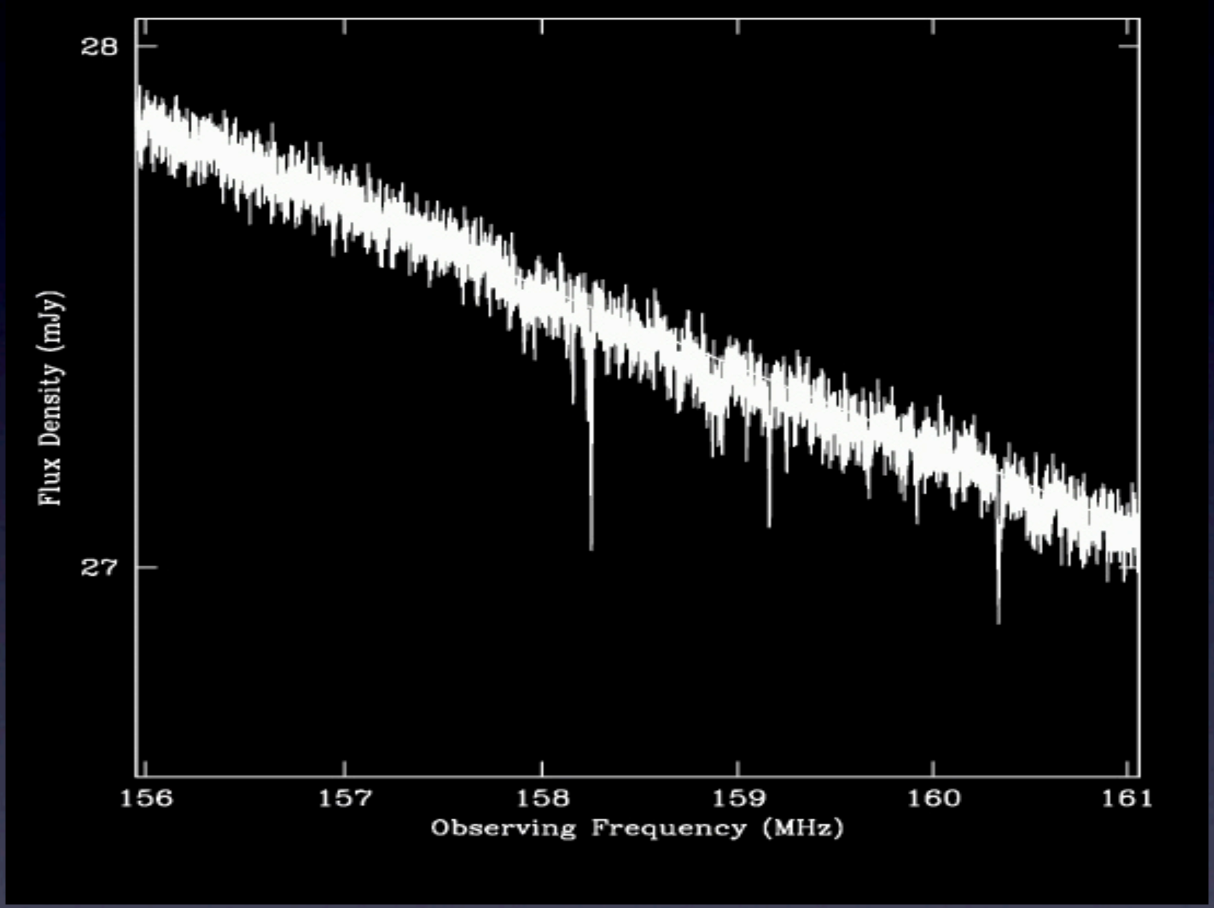


Figure: EoR absorption features seen towards an 18mJy z=8 radio galaxy by the Square Kilometer Array (from Carilli 2005)

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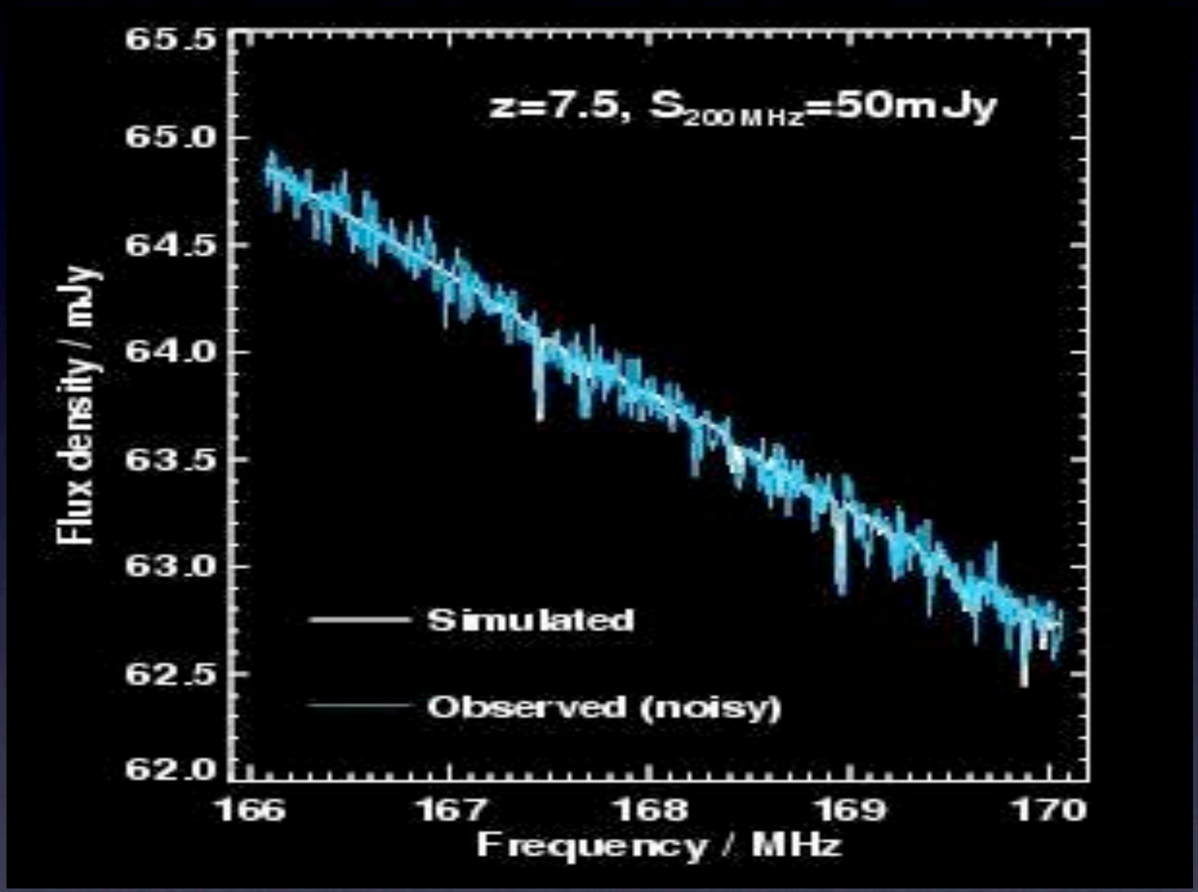

Figure: true (white) and observed (blue) radio spectrum of a 50mJy radio source at z=7.5, in a 1500 hr (1 beam) LOFAR integration; 21cm absorption visible above 167MHz.

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Cosmic Rays KSP

PIs: Heino Falcke, Jörg Hörandel

Aims: to detect and study ultra-high energy particles

- where are ultra-high energy cosmic rays produced?
- how are they produced?
- what are they made of?
- what is the exact shape of their energy distribution?
- can high energy neutrinos be detected?

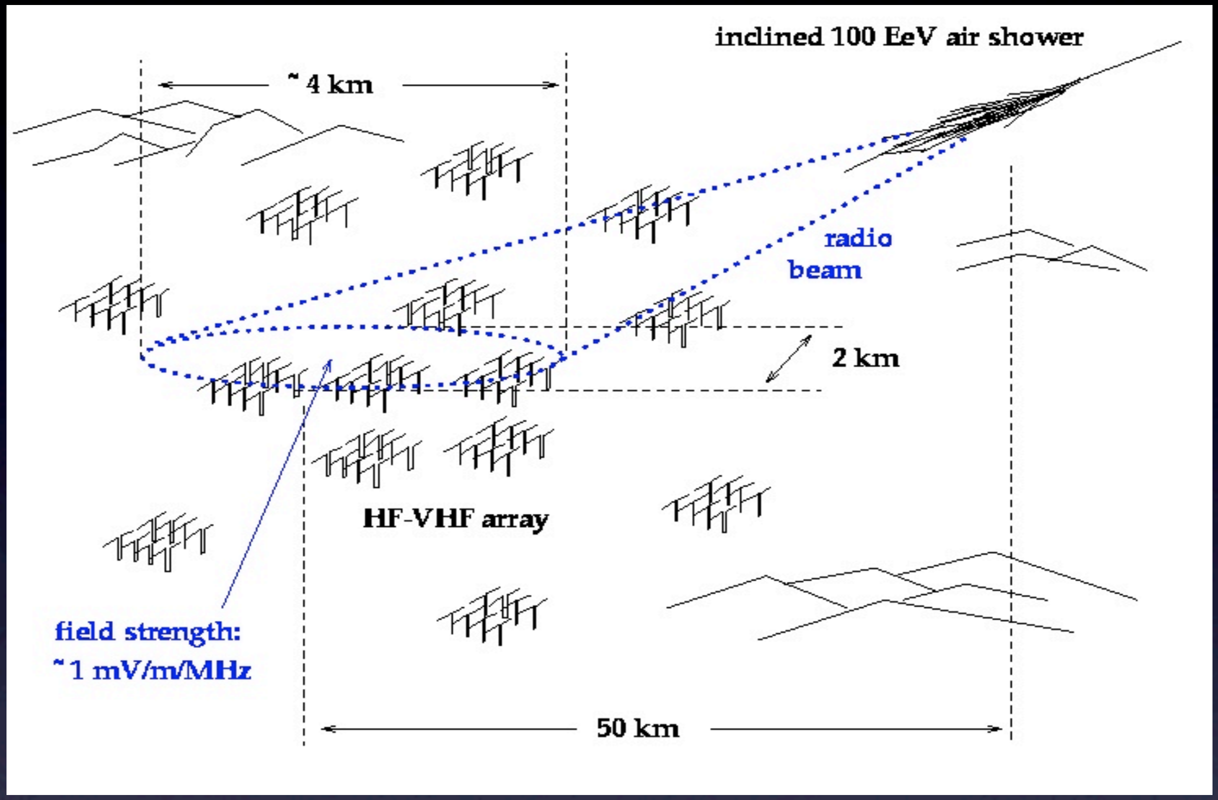
Data can be reconstructed from transient buffer boards.

Many observations can piggyback on other telescope uses.

Radio detection of Cosmic Rays

Ultra-high energy cosmic ray (UHECR) produces particle shower in atmosphere

Electrons & positrons emit synchrotron radiation which adds coherently at low freq.



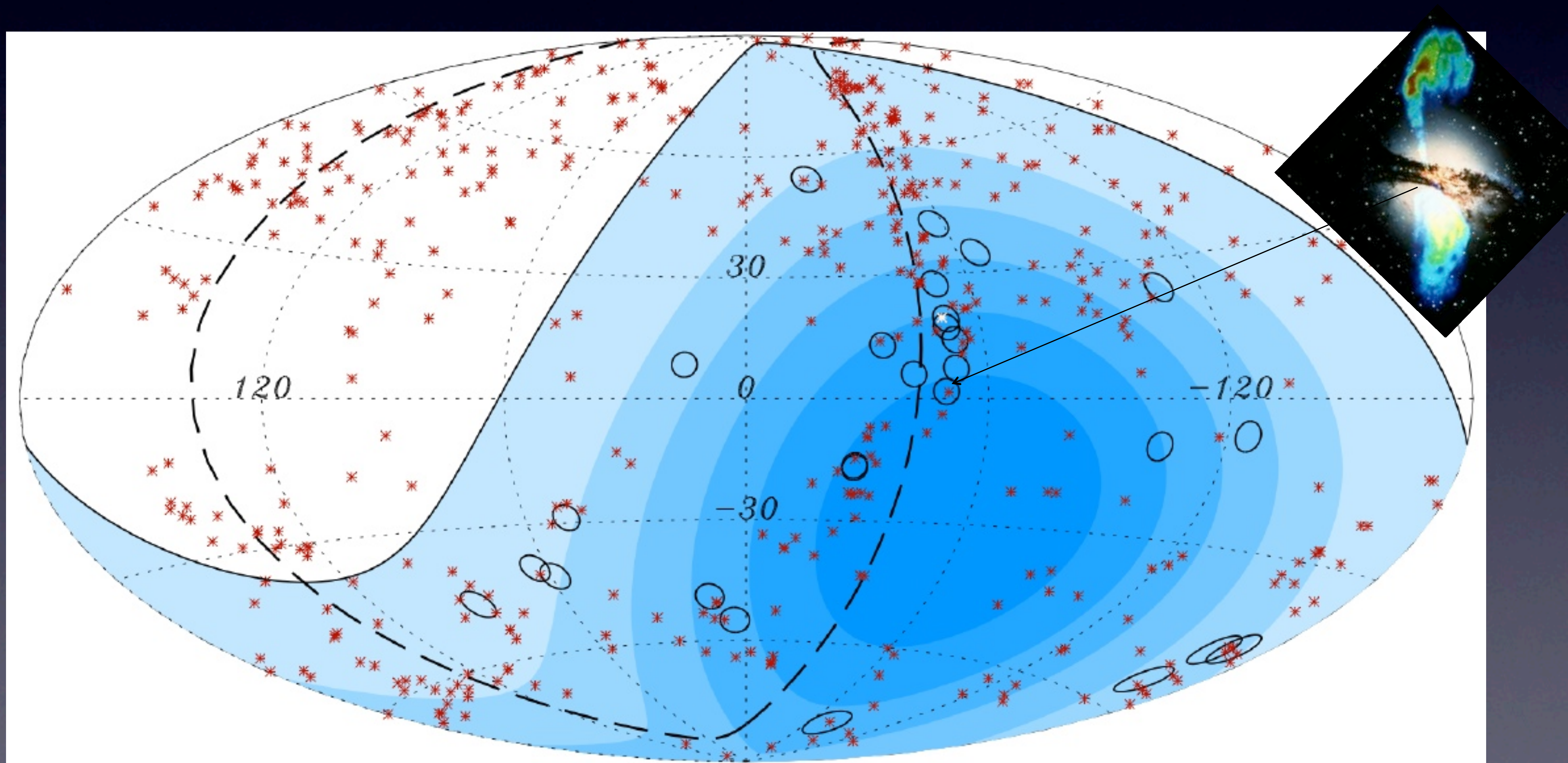
Can cause GJy flames on tens of nano-second timescales

Depending on cosmic ray energy, detection can be triggered at antenna, station or full array level

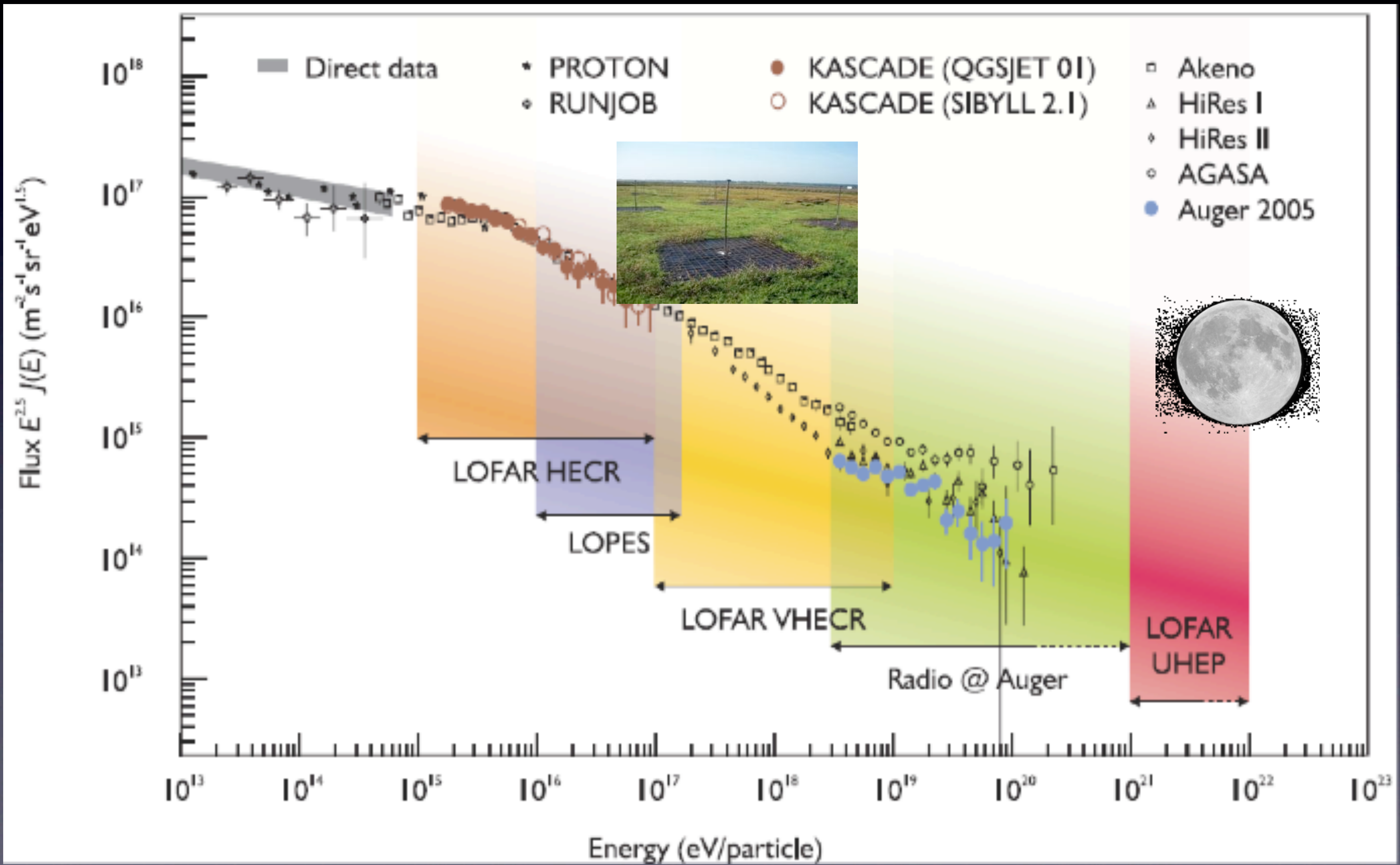
Time delays between different antenna give excellent shower front direction, composition & energy measurements

AUGER: UHECR & AGN

AUGER collaboration (Science, 2007) found UHECR directions correlated with locations of nearby AGN (probability ~ 2×10^{-3})

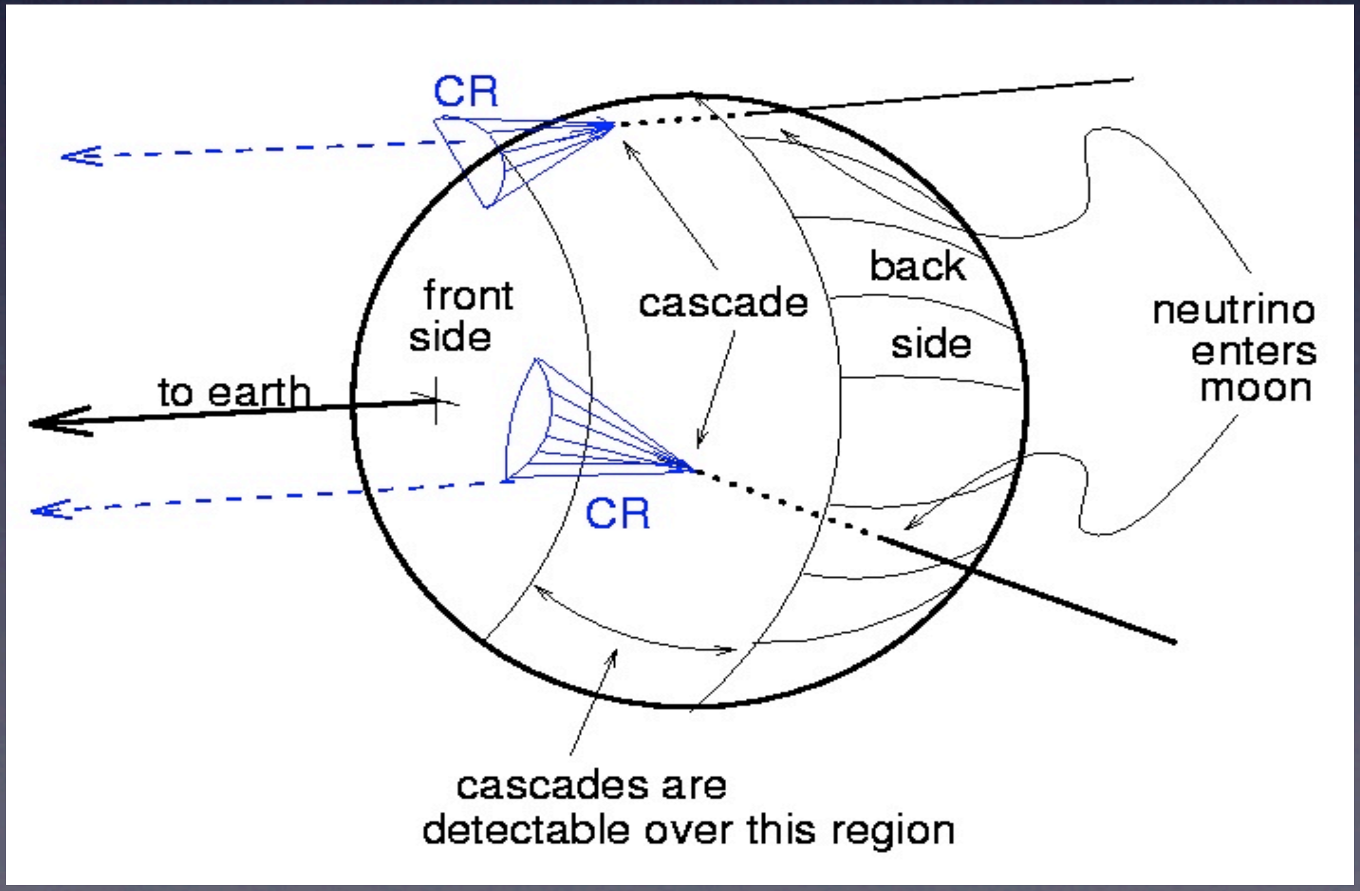


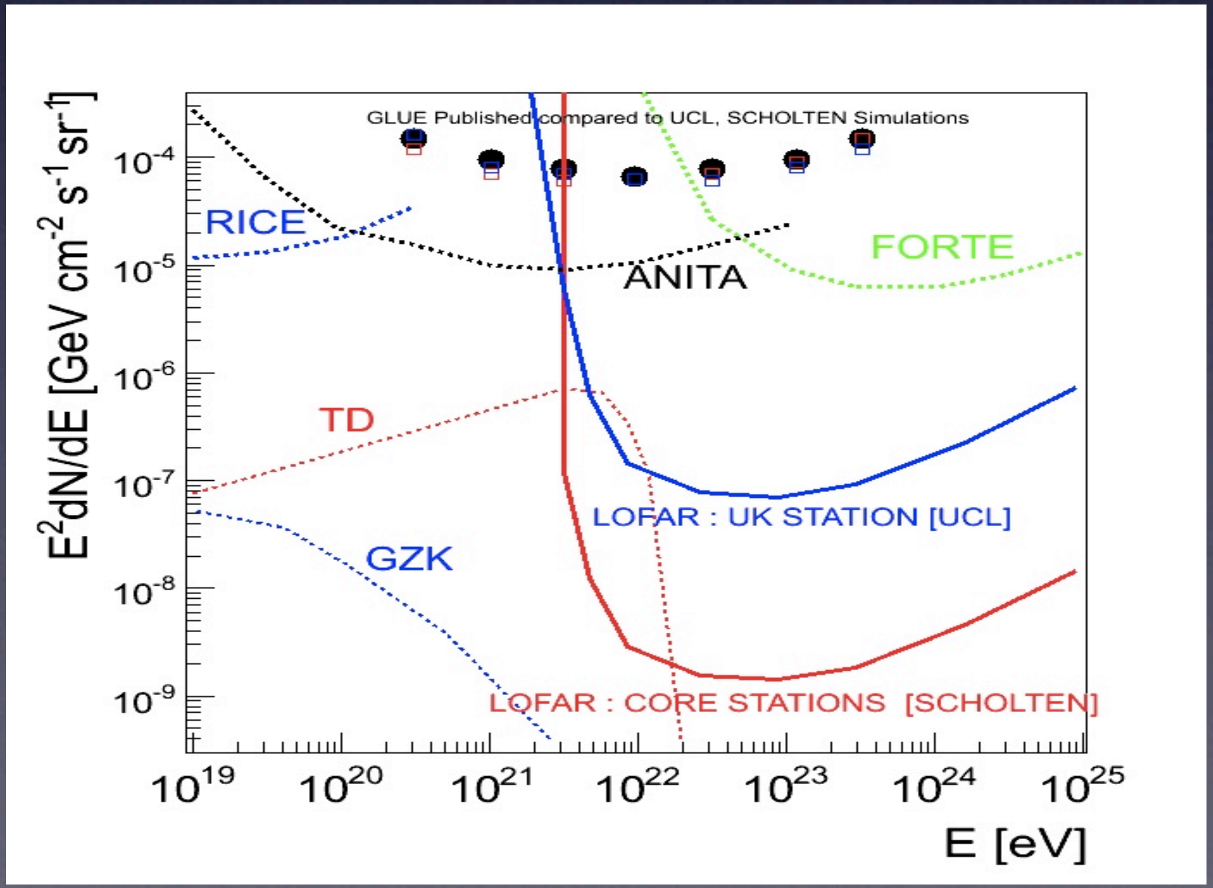
Cosmic Ray energy spectrum



Particle astrophysics & the moon

- High energy neutrinos can produce a coherent radio burst when interacting with the lunar regolith
- LOFAR could detect these, if pointed at the moon
- Probes new energy scales, above LHC energy range
- Any detection would imply new physics / local source





Conclusions

LOFAR will be tackling a very wide range of science goals

Many of the Key Science Projects have considerable scope for sharing observations (piggybacking etc), which will need detailed planning