Summary

on Radio Detection of UHECR

Andreas Haungs

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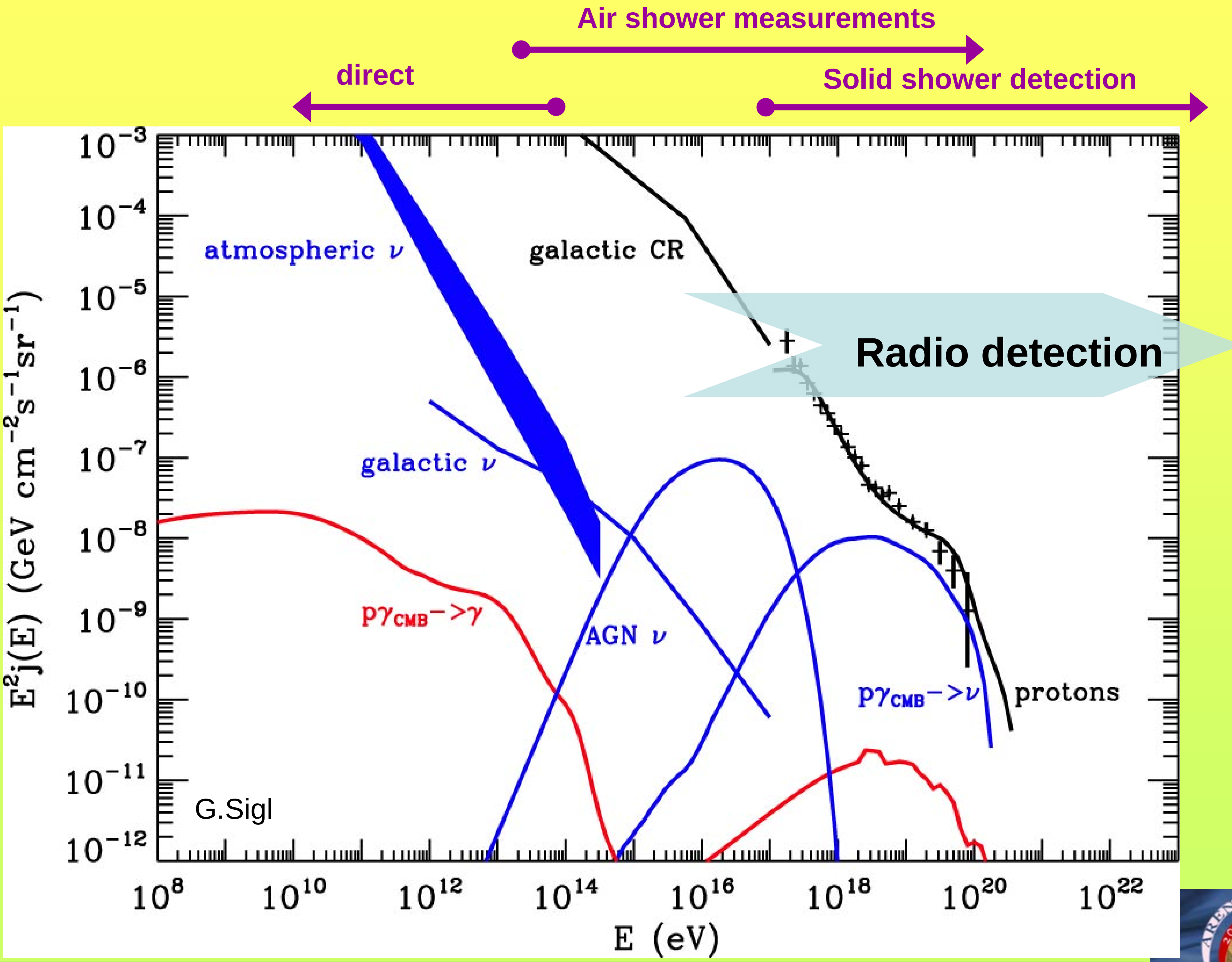
Apologize…..

ARENA 2008:
33 contributions related to Radio detection of UHECR
➔
- **personal selection of "highlights"!**
- **concentration on experimental results and concepts**
- **intro related to our " working frame"**

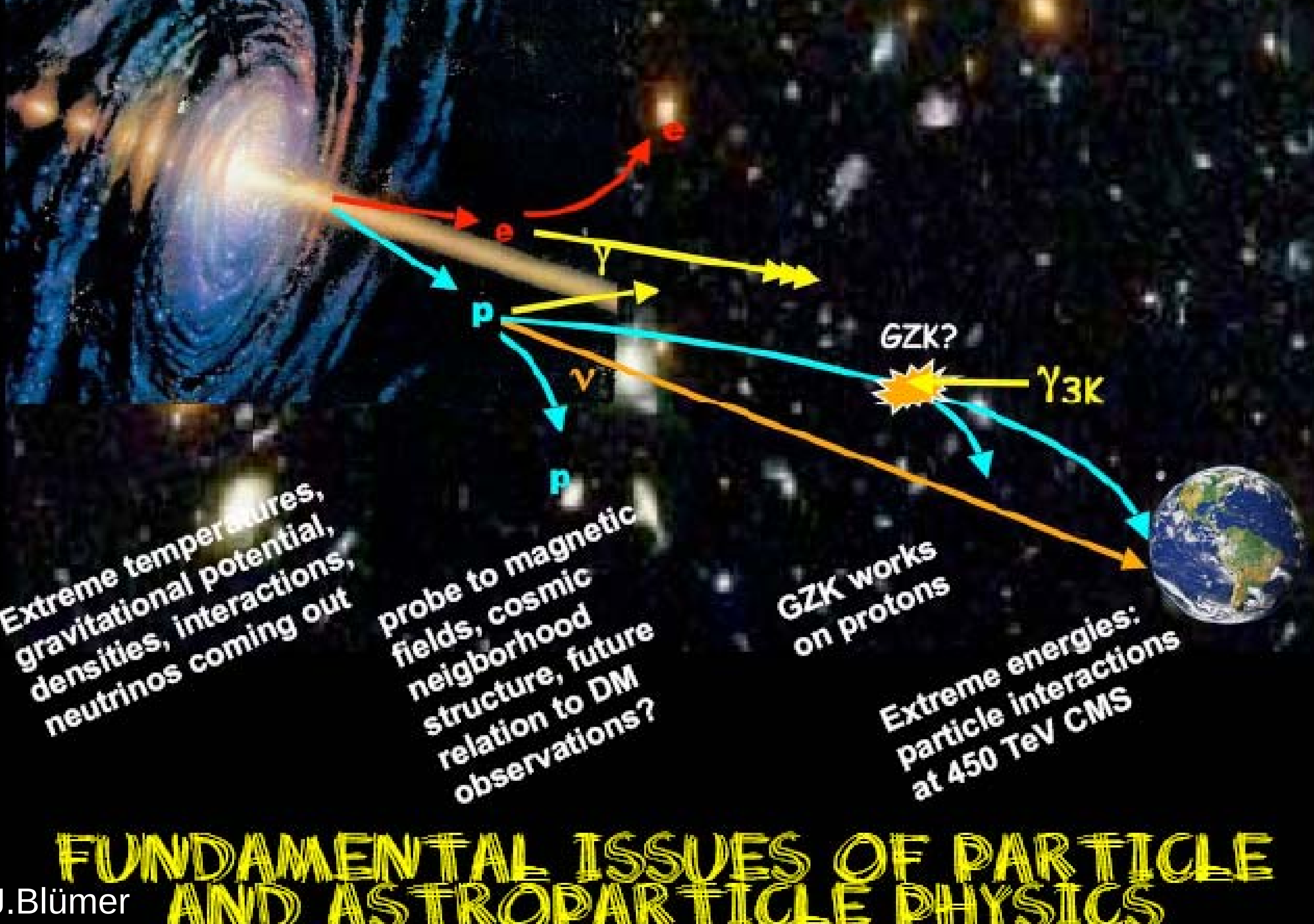
ARENA 2008:
food and conference dinner too good, Germany too successful in the European championship, and the discussions too productive to spend much time for the summary…..



The High Energy Universe

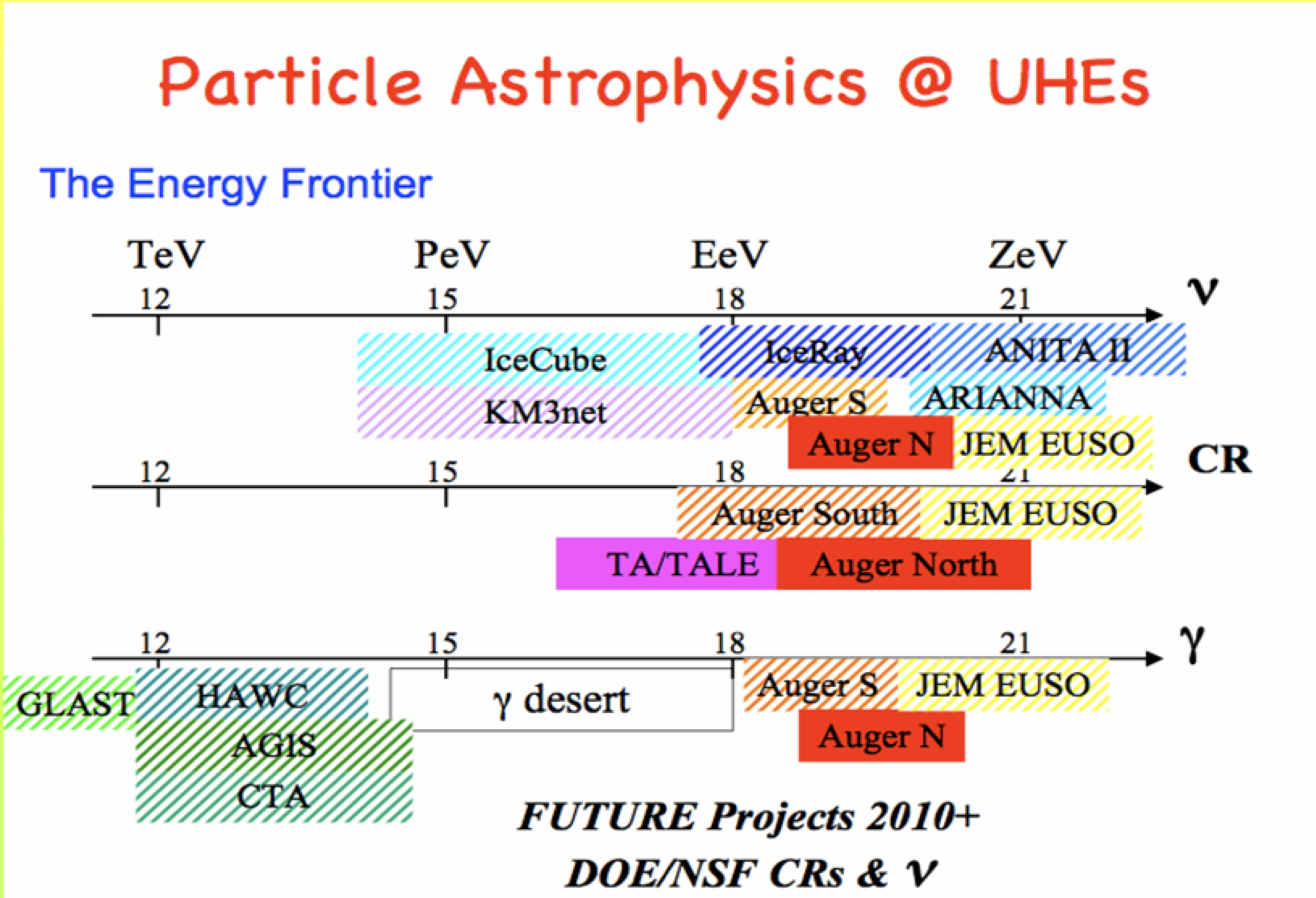


The High Energy Universe: Multi-Messenger Approach



J.Blümer

The High Energy Universe



Angela Olinto

The High Energy Universe: Future Projects in Europe

Three priorities:

Charged CR, neutrinos, TeV γ

Data taking:
Auger South
≥ 2010:
Auger North
≥ 2018: EUSO ?

under construction/ data taking:
IceCube
≥2011:
KM3NeT

Data taking/upgrade
H.E.S.S., Magic
2012: CTA

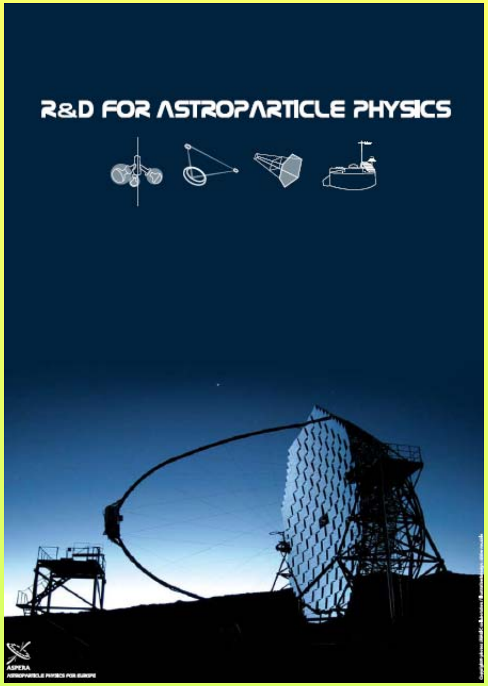
- **radio R&D embedded in large projects !!**
(also acoustic detection)

ASPERA
European strategy for astroparticle physics

Motivation

ASPERA R&D Recommendations:

An active and timely R&D effort is needed on a European scale to improve and further develop the radio detection technique to incorporate current detector stations into large detector arrays, specifically designed for ultra-high energy cosmic and neutrino astrophysics.

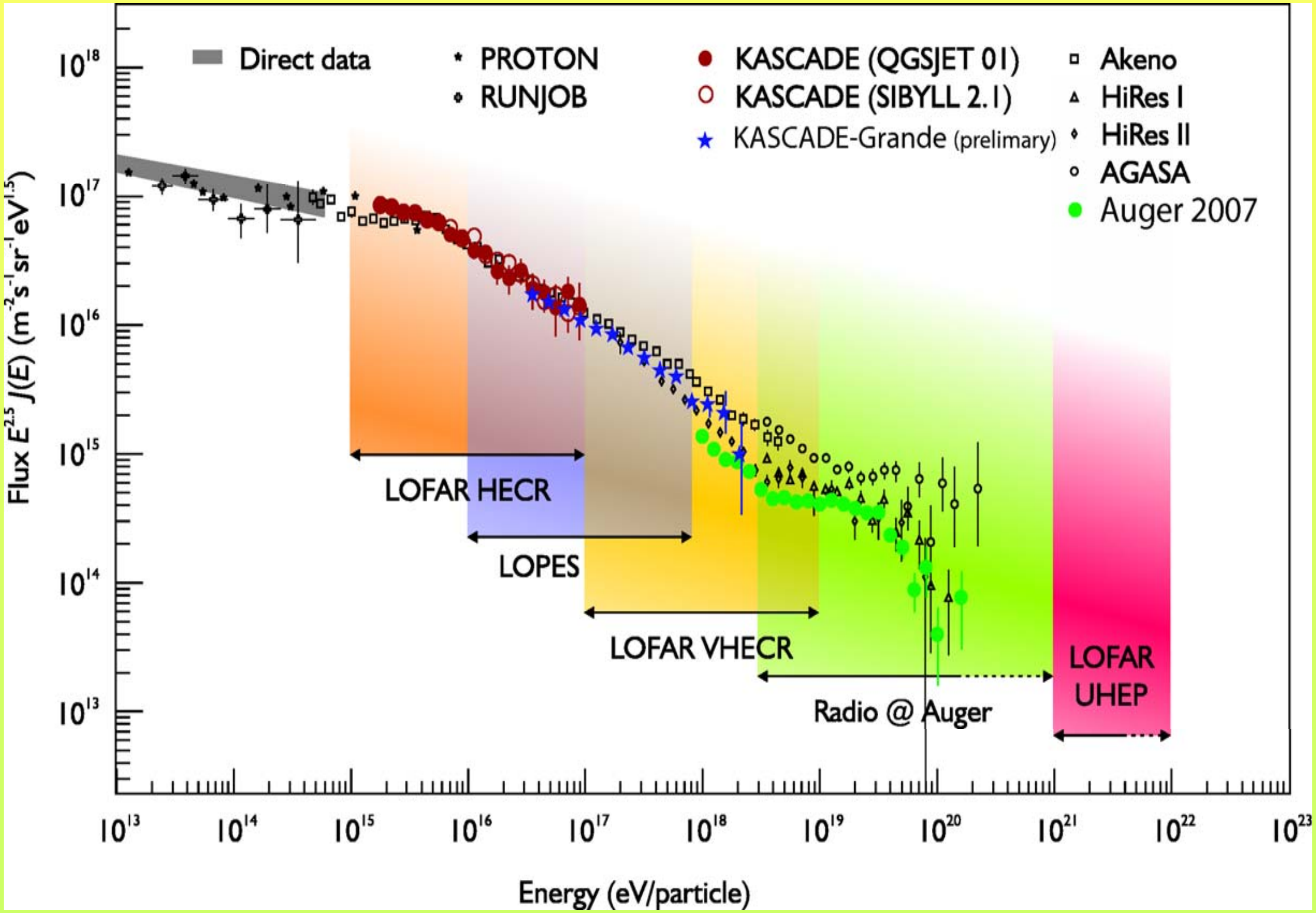


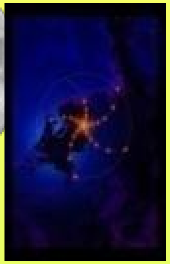
ASPERA - European strategy for astroparticle physics
Roadmap Phase III - will be submitted to European funding agencies

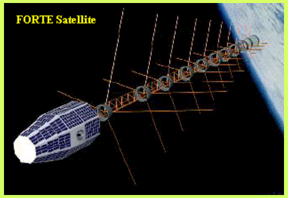
Cosmic Rays (+ Gamma Rays)



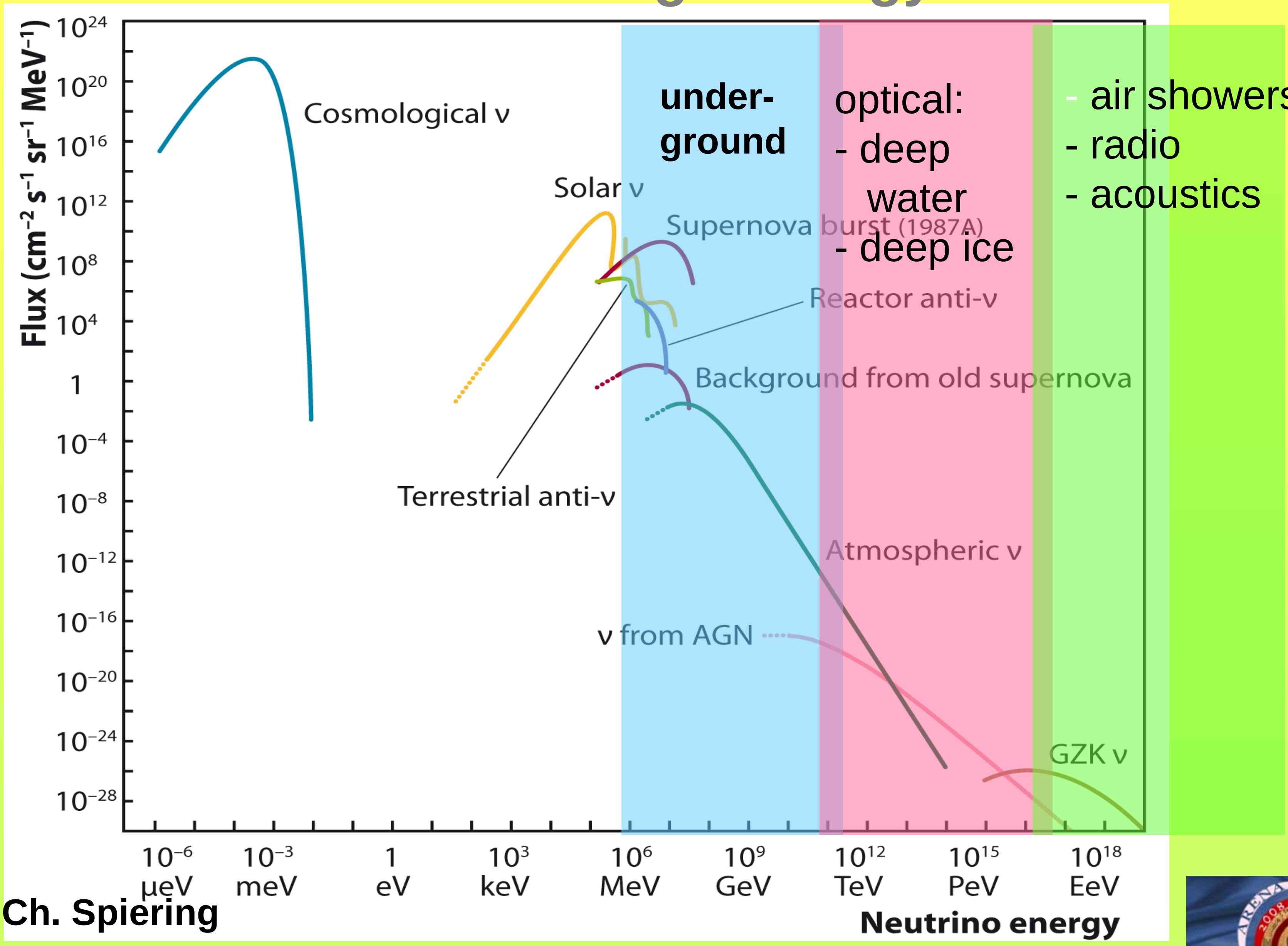




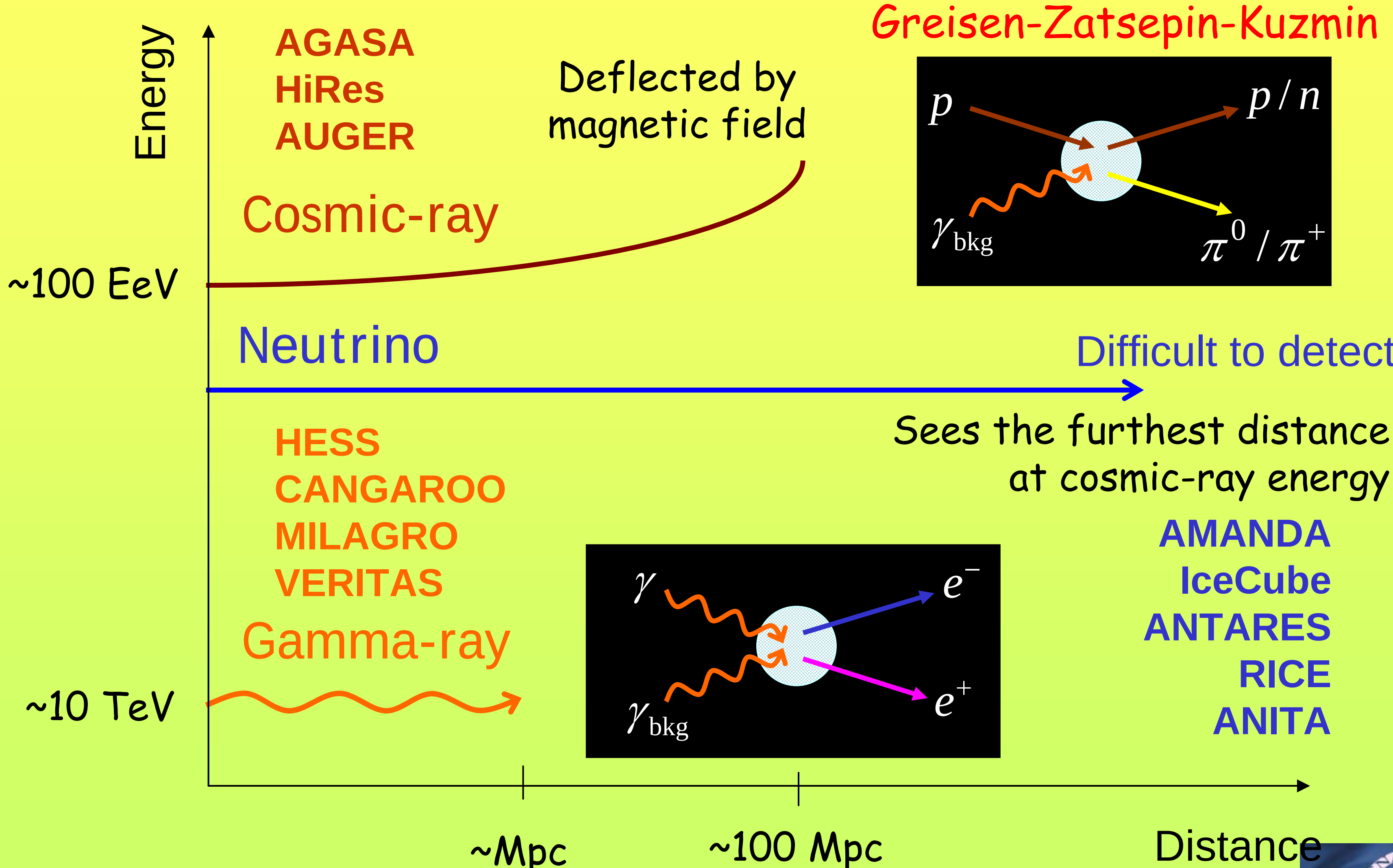


Neutrinos: the High Energy Frontier



Ch. Spiering

Probing Very High Energy Distant Universe



D. Besson

The High Energy Universe observed with Radio

UHECR

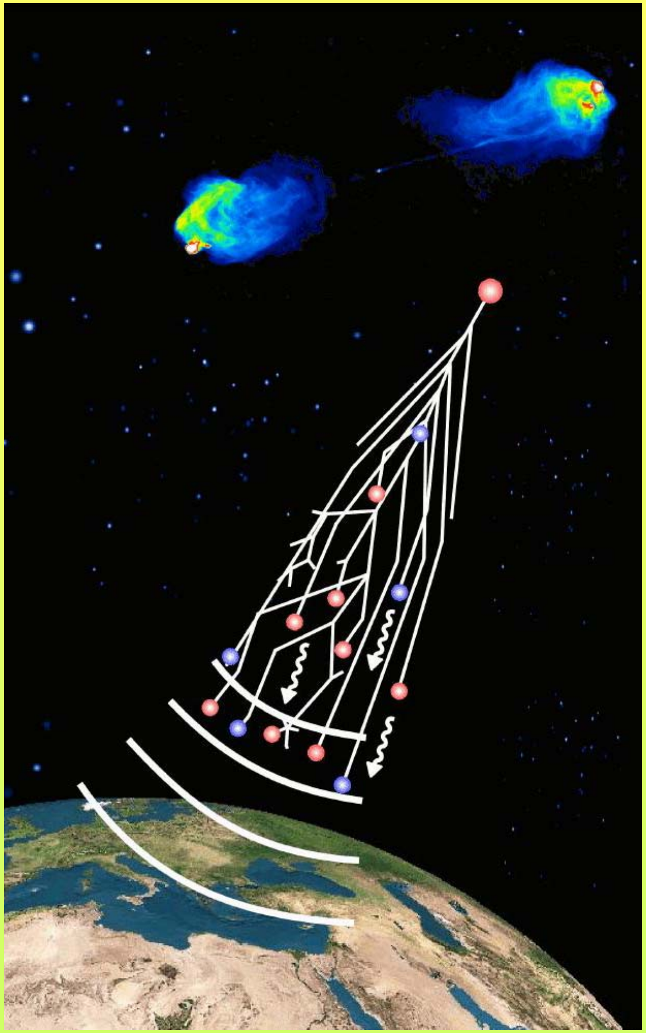
Particles:	Charged CR	Gamma Rays	Neutrinos
Targets:	Air	Solids	Moon
Experiments:	LOPES CODALEMA R-Auger LOFAR R-ICETOP 21CMA	ICERAY AURA ANITA RICE ARIANNA RAMAND SALSA	LUNASKA NuMoon (WRST/LOFAR/SKA) LORD ASTROPEILER GLINT RAMHAND
Theorie:	Geo-synchrotron		Askaryan

Radio from Air Showers

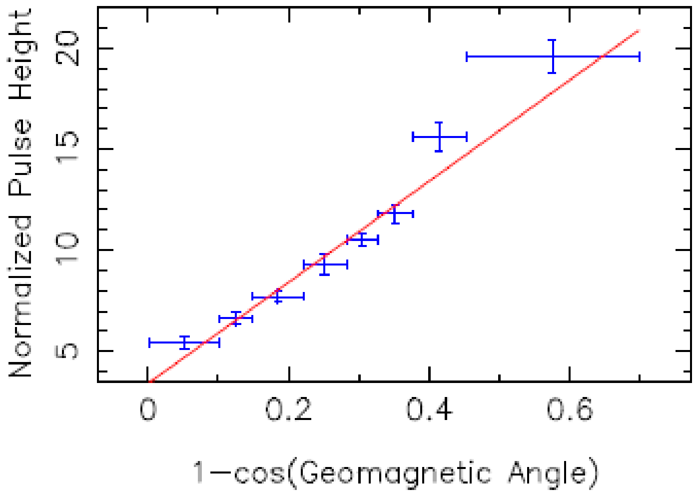
Detection principle:

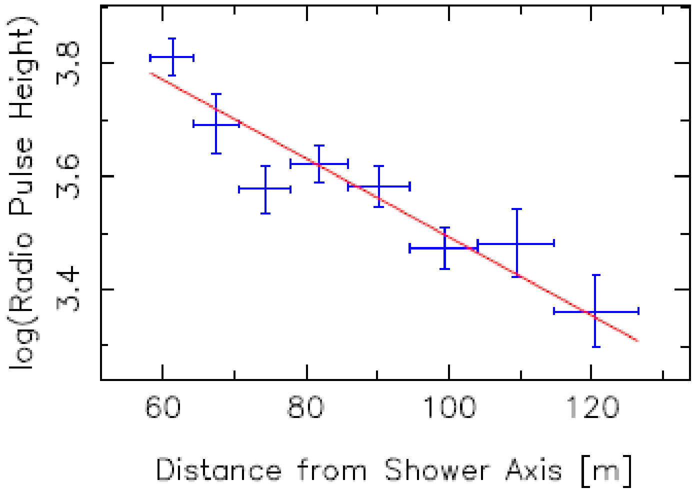
Geomagnetic field lead to coherent emission in air showers in the MHz frequency range !

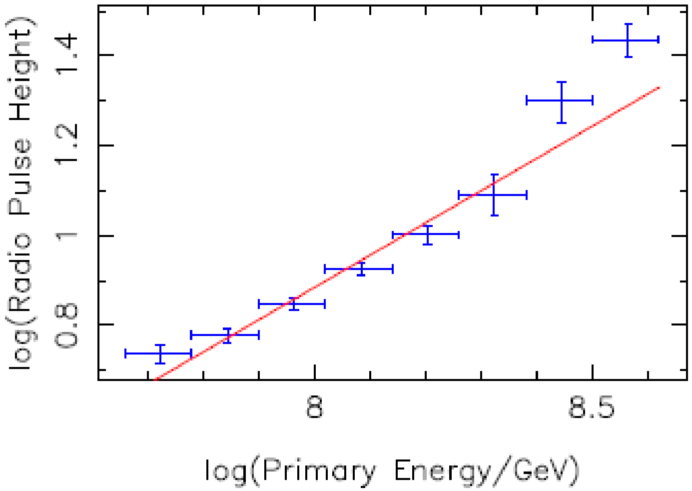
~1000 events detected!
➔ Now: do we understand the signals?



LOPES 30 results (parameterization):







$$\varepsilon_{est\text{-}EW} = A \cdot (1 + B - \cos\alpha) \cdot \cos\theta \cdot \exp(-R/R_0) \cdot (E/\ 10^{17}\mathrm{eV})^{\gamma}$$

[μV / m MHz]

$A = 10.9 \pm 1.1$

$B = 1.16 \pm 0.02$

$R_o = 202 \pm 64$ m

$\gamma = 0.94 \pm 0.03$

A.Horneffer, LOPES coll, ICRC 2007

A. Haungs / LOPES

LOPES, CODALEMA, Radio-AUGER agree on general results but questions:

- lateral distribution of signal
- polarization effects
- influence of frequency band
- efficiencies
- geomagnetic effects?
- thresholds?
- structure of wave front?
- composition sensitivity?
- .....

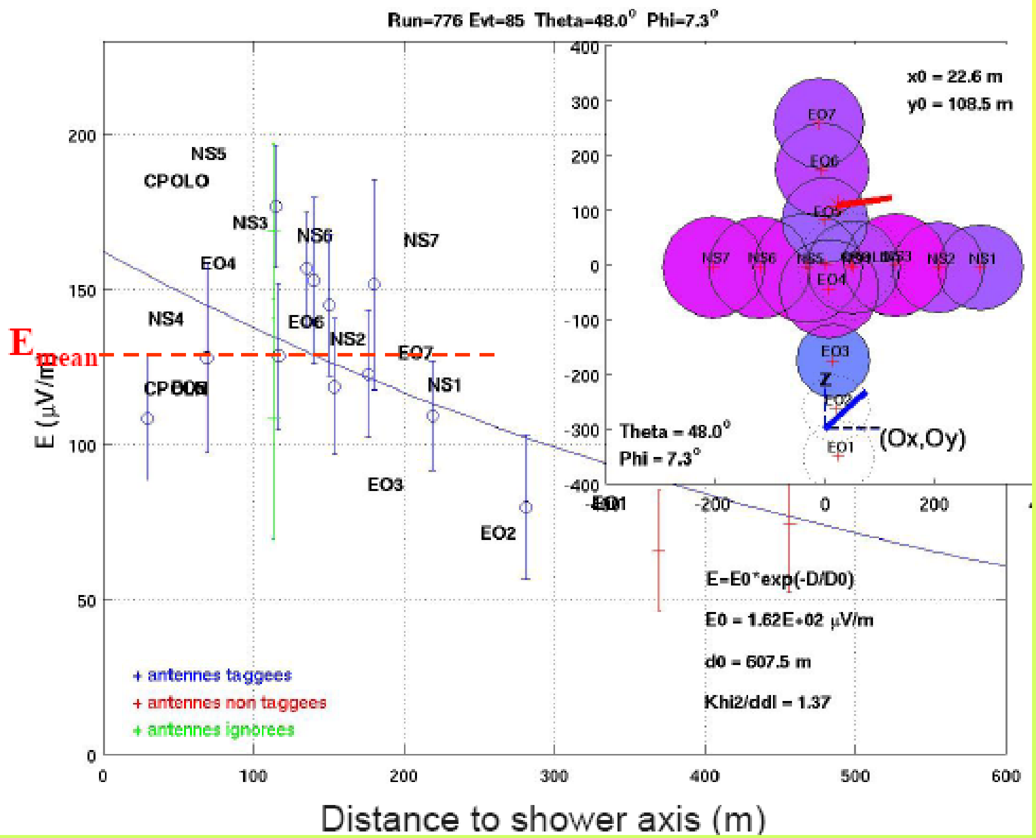
➔ continuation of precisison measurements will help to find answers!!

But around 50% of internal events (especially when Siqnal/Noise declines) don't exhibit clean exponential dependances at small impact parameters…

- Polarization effect ?
- Intrinsic to the electric field ?

=>Try a « minimum » estimator E_{mean}

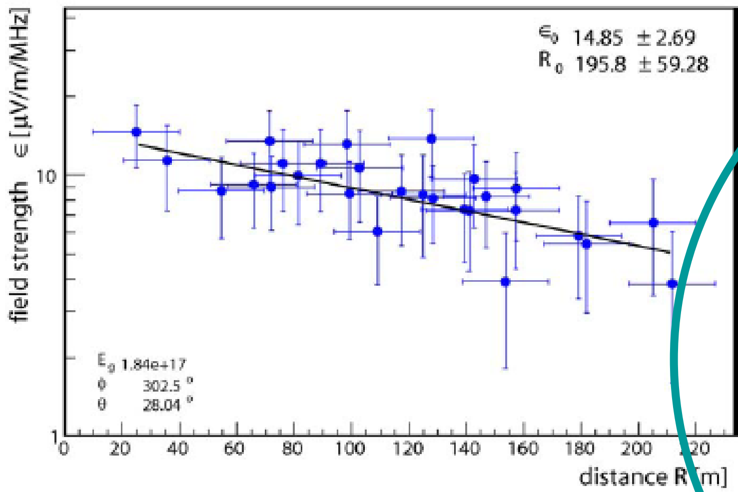
(but no explicit concept of distance for this observable!)

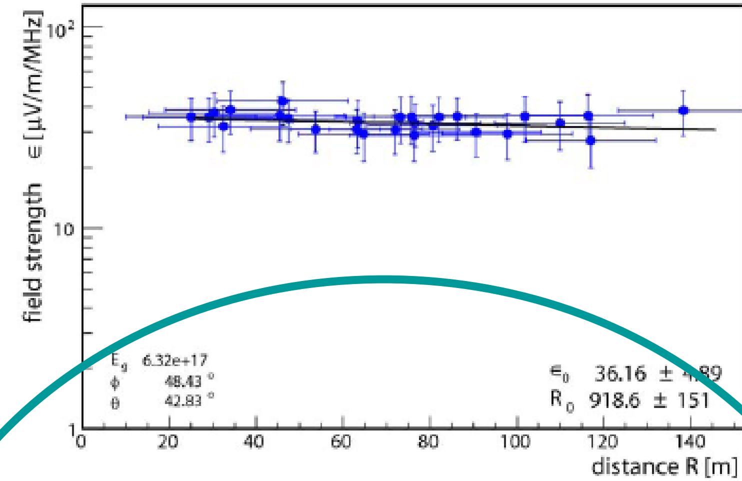


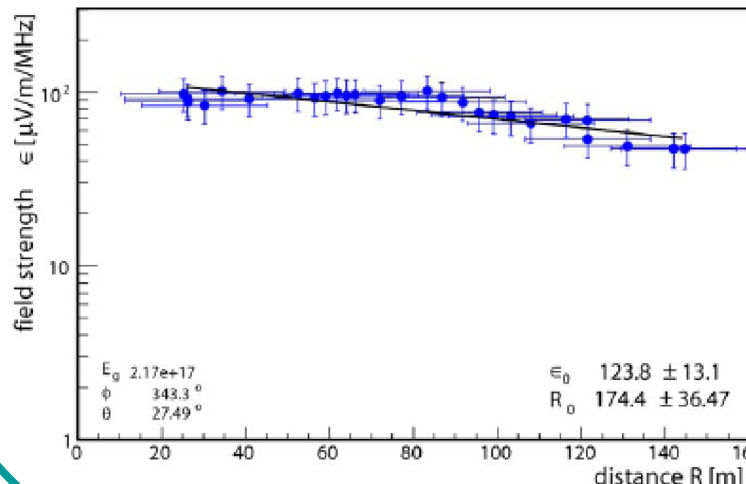
Pascal Lautridou / CODALEMA

LOPES 30: lateral distribution

-some more examples
(remember: all measurements with east-west oriented antennas only)



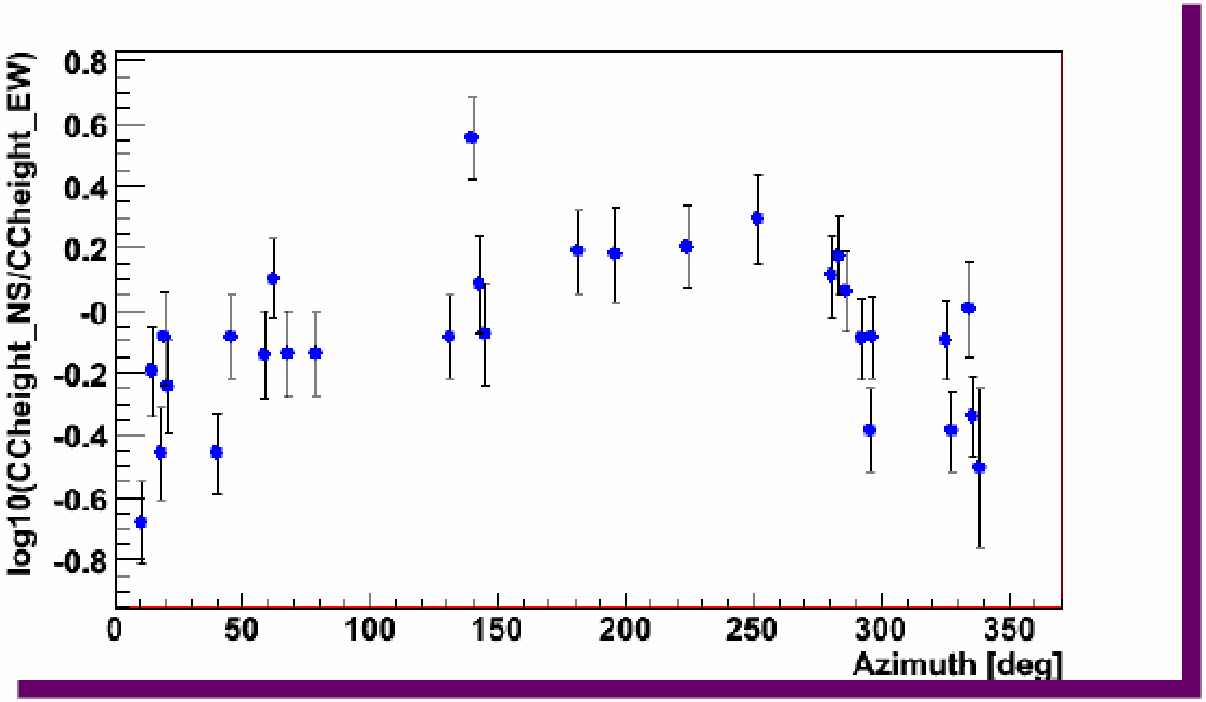




S. Nehls et al. – LOPES collaboration, PhD-thesis 2008 next week!

A. Haungs / LOPES

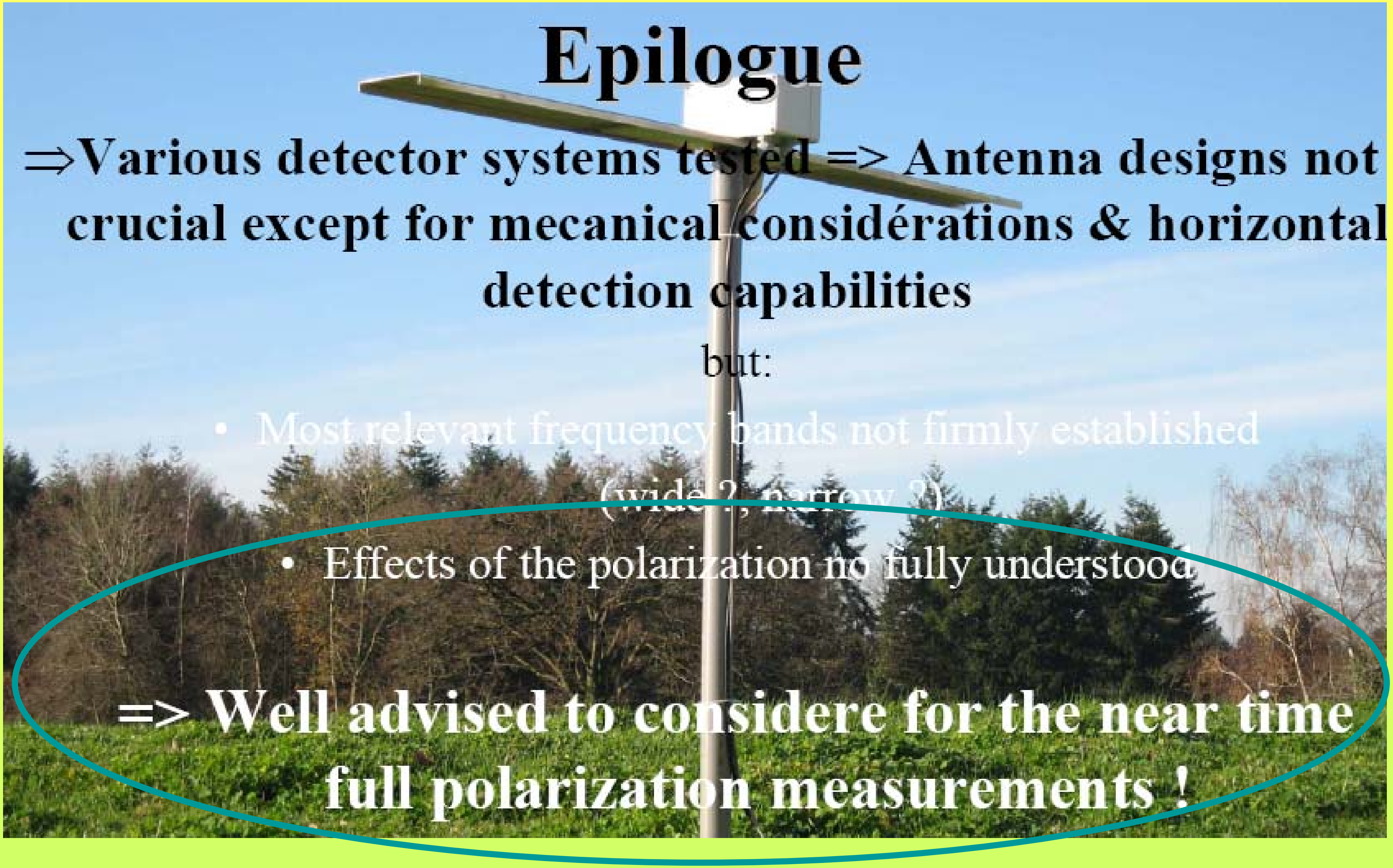
III. Dual-Polarization



-> Azimuth dependence of the pulse height ratio!

> 0: N-S component dominant
< 0: E-W component dominant

G. Isar / LOPES



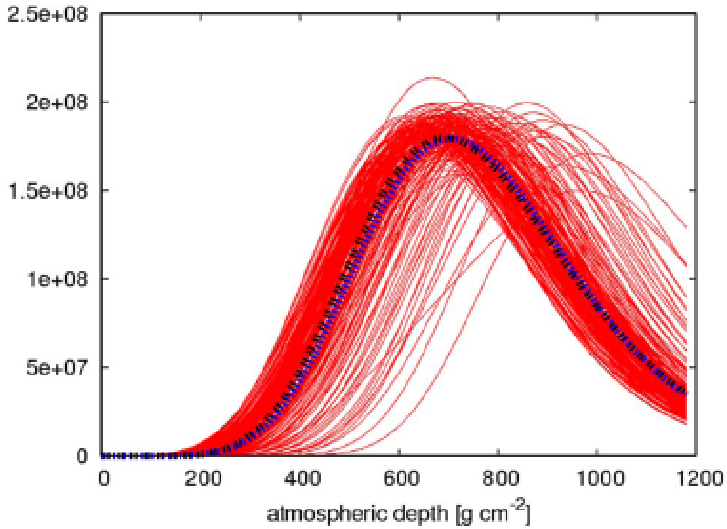
Pascal Lautridou / CODALEMA

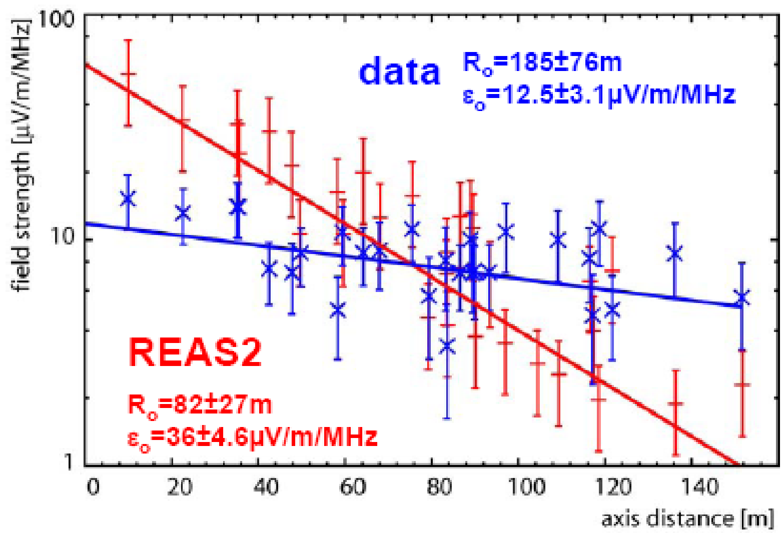
Radio in Air: new: direct comparisons data vs. sims

lateral distributions vs. simulations

- REAS2: CORSIKA based Monte Carlo simulations of radio emission
- performed for individual shower by using KASCADE parameters
- 250 CONEX shower ➔ for one „typical“ full REAS2 simulation

➔ Expected field strength per antenna position of LOPES30



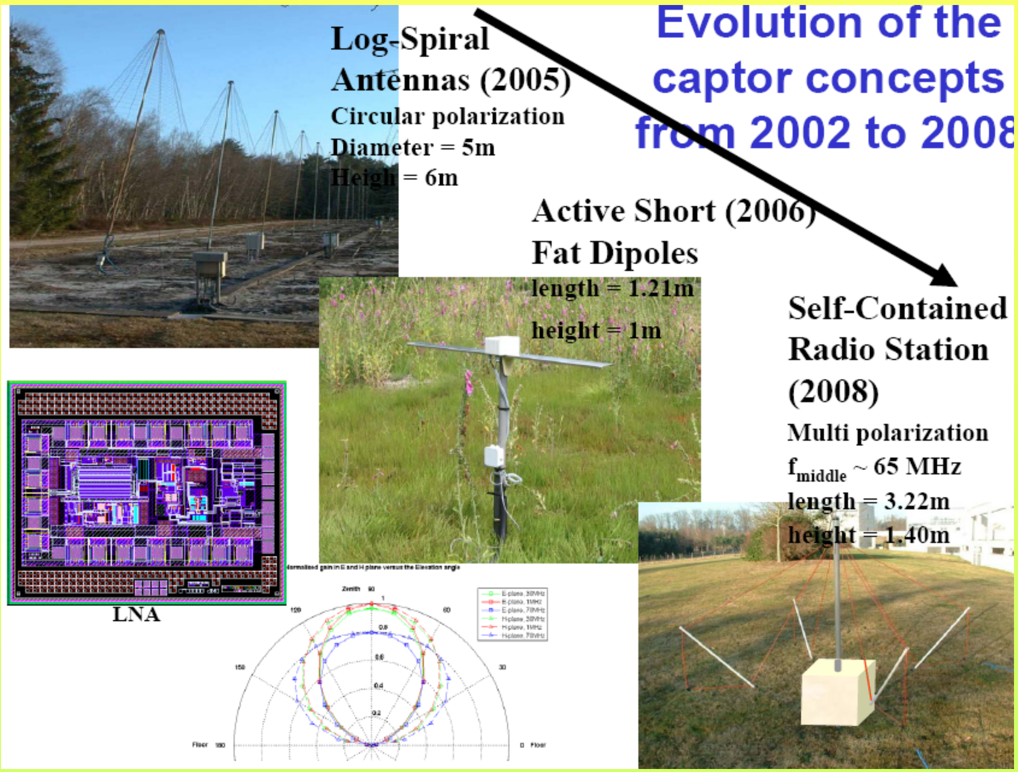


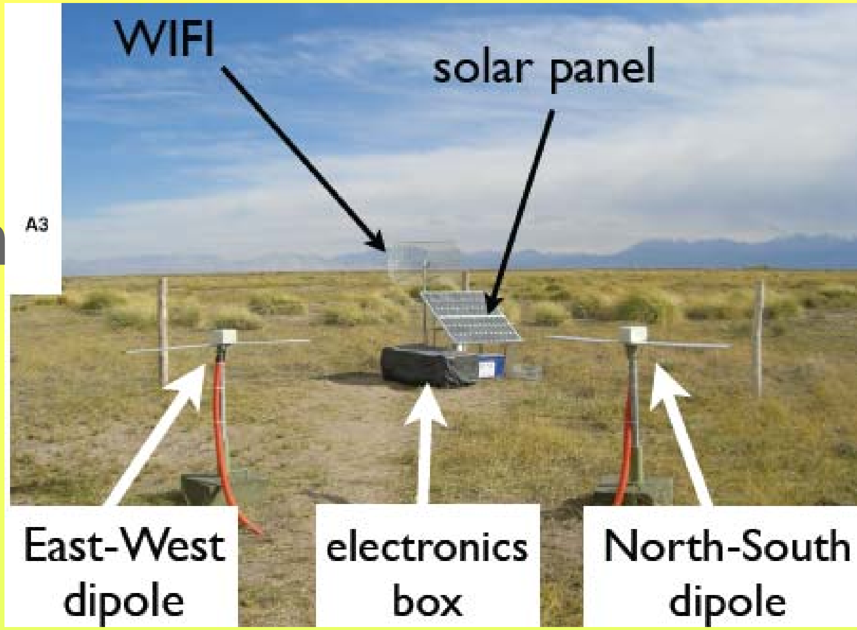
ev# 1143070602 x_c = -44.3m y_c= -22m E_0 = 2.3 10^{17} eV ϕ=19.3° θ= 5.9°

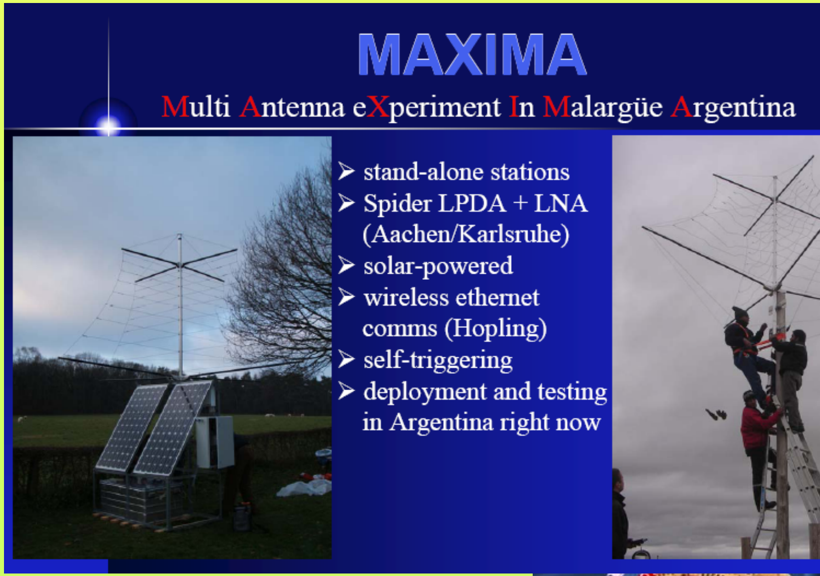
S. Nehls et al. – LOPES collaboration, PhD-thesis 2008 next week!

A. Haungs / LOPES

Radio in Air
further „hot topics“: self-contained radio-station







Pascal Lautridou / CODALEMA

Jose Coppens / Radio-Auger

Benoit Revenue / Radio-Auger

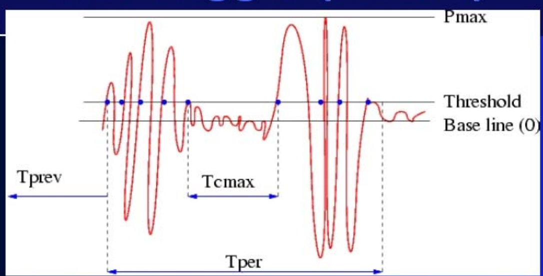
Radio in Air, further „hot topics": self-triggering

Conclusion

- for the first time, an autonomous radio detector is able to trigger on EAS

Benoit Revenue / Radio-Auger

Self-Trigger (level 1)

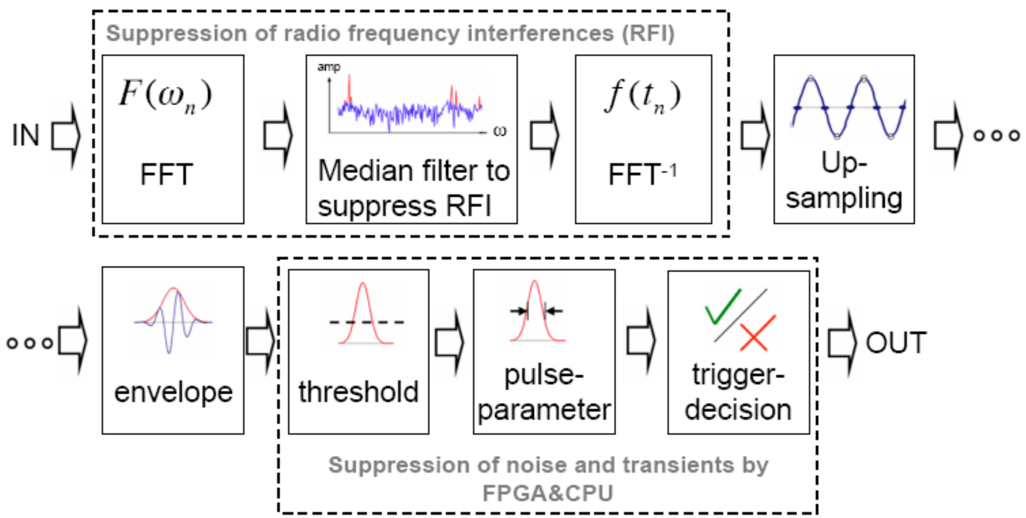


Trigger implemented in FPGA, parameters can be set by user:
- Threshold
- Tprev: time to previous threshold crossing
- Number of threshold crossings (blue dots) in a time window Tper
- Tcmax: maximum time between threshold crossings
- Pulseheight (Pmax) and pulseheight/pulsewidth

12

Jose Coppens / Radio-Auger

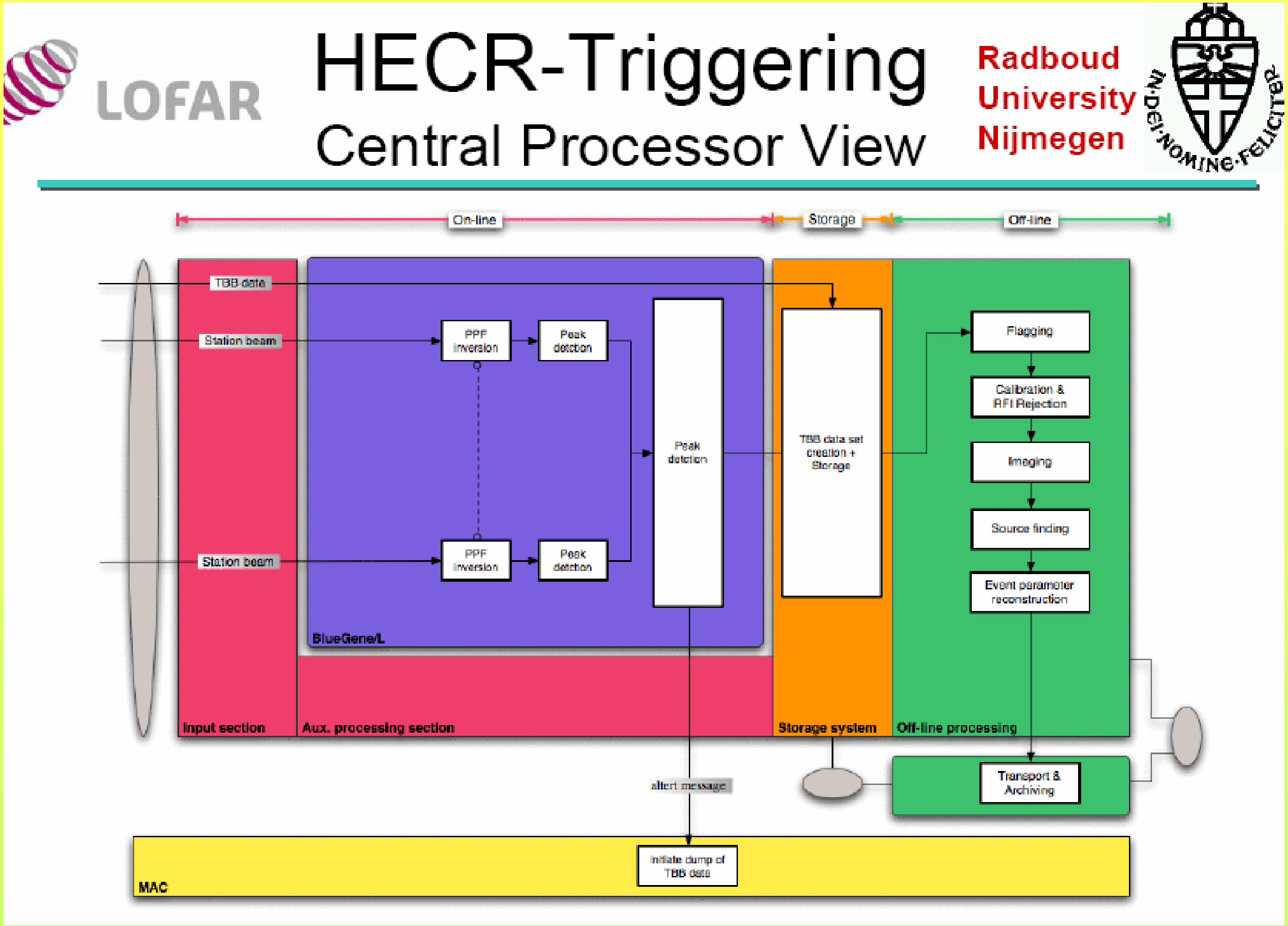
Schematic of Trigger in FPGA



First version of a complex trigger for radio trigger

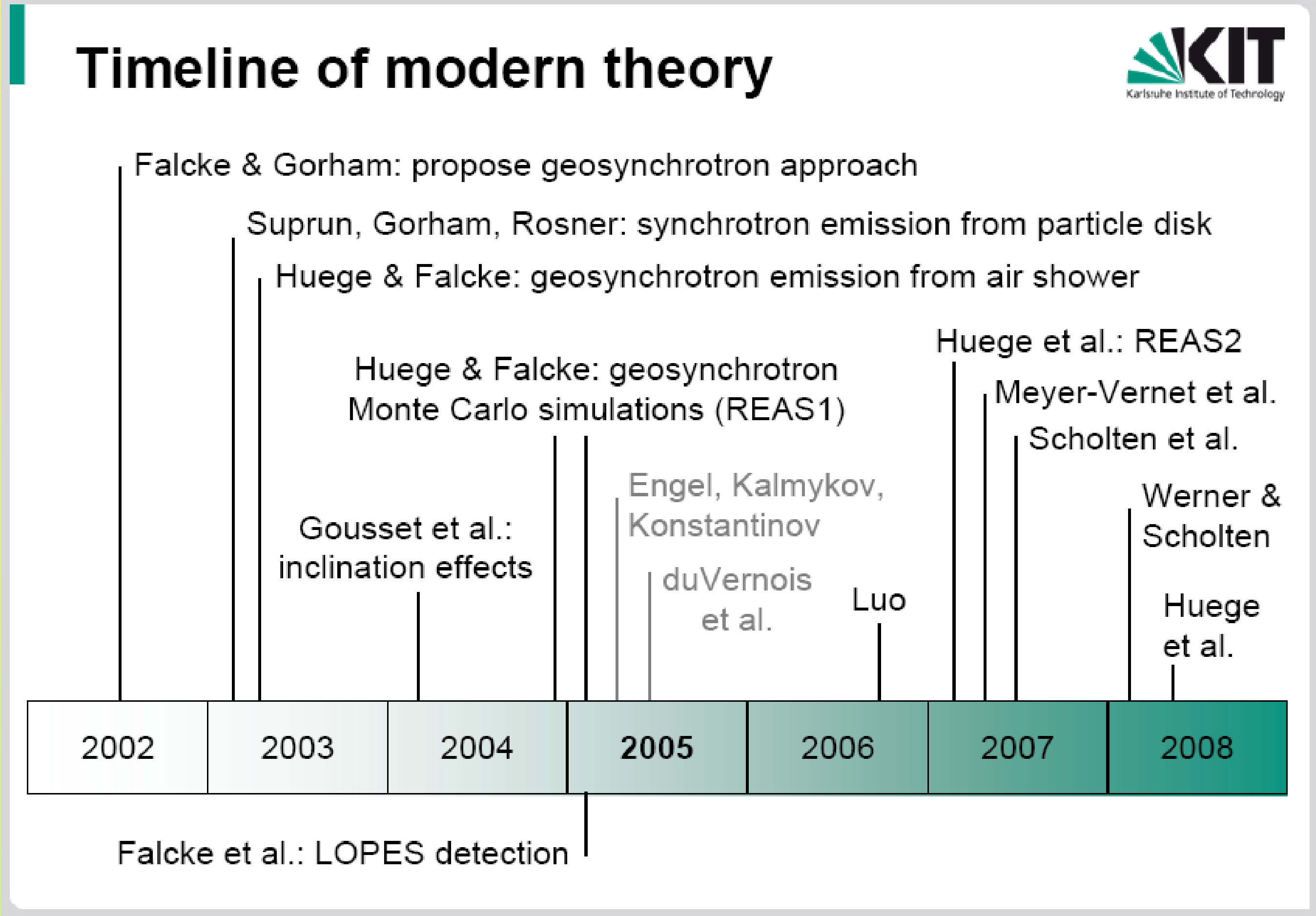
H.Gemmeke / LOPES + Radio-Auger

Radio in Air, further „hot topics“: self-triggering



Andreas Horneffer / LOFAR

Radio in Air, further „hot topics“: simulations!



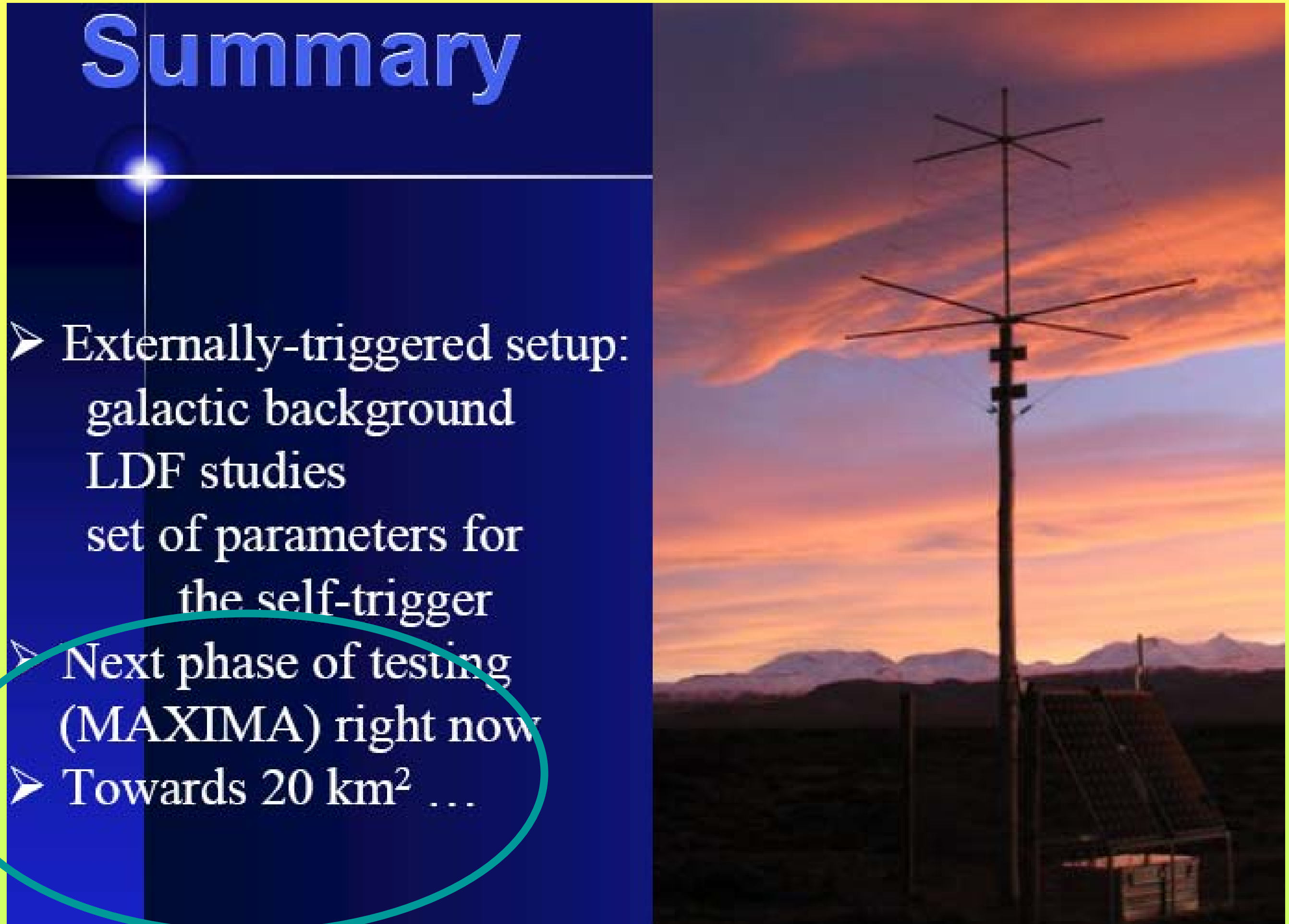
.. A lot of progress, triggered by the measurements….

➔ important: detector simulations!

Tim Huege

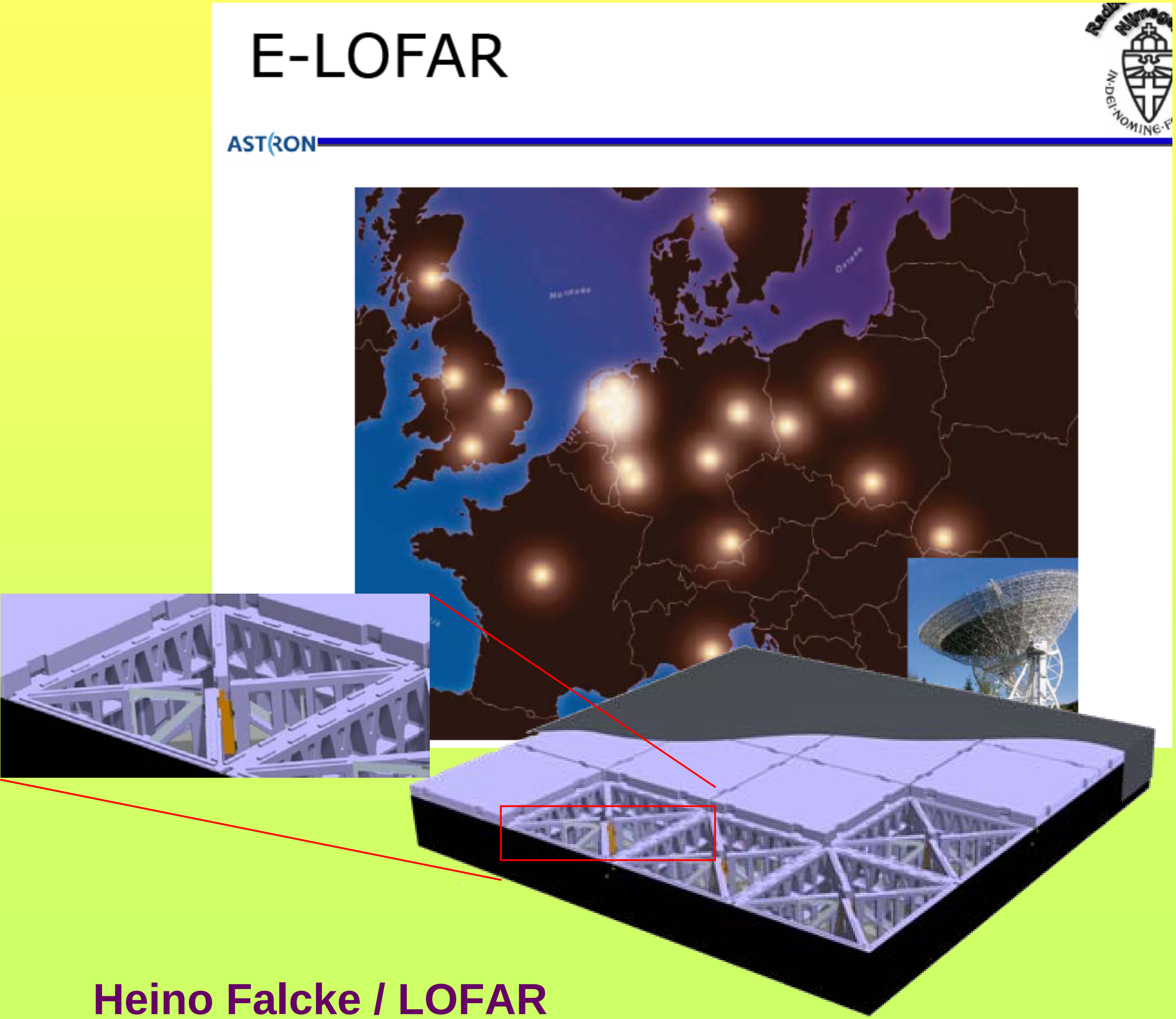
Olaf Scholten, Stefan Fliescher / R-Auger

Radio in Air, new arrays…



Jose Coppens / Radio-Auger

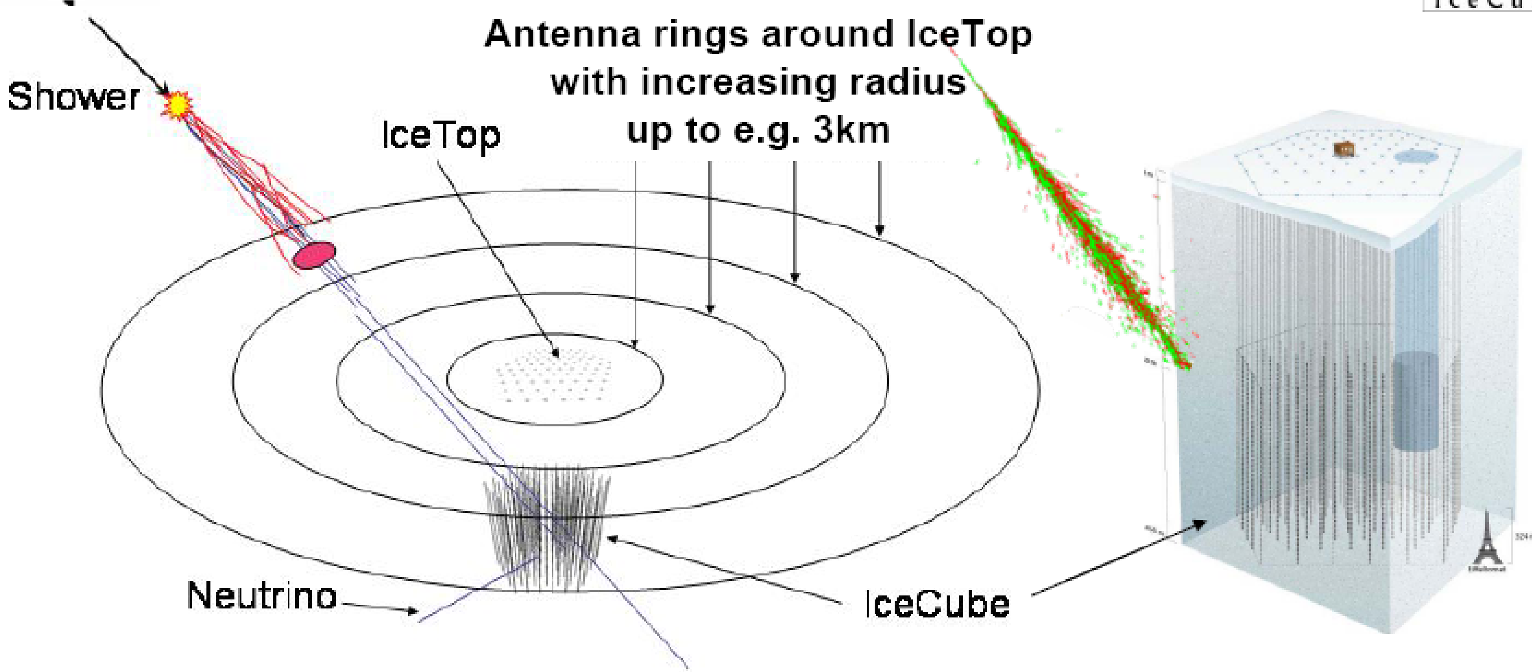
Radio in Air, new arrays…



Heino Falcke / LOFAR

Radio in Air, new arrays…

A large area radio air shower detector



Is the detector working as a background veto for EHE ν analysis?
What is the energy threshold to detect air showers with radio?

Jan Auffenberg / R-ICETOP

Radio in Air: Other techniques

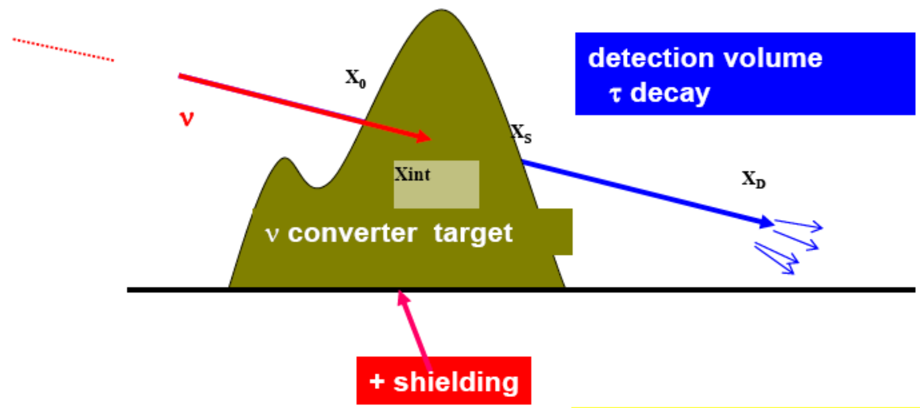
- **Bremsstrahlung (not discussed here)**
  molecular Bremsstrahlung; AMBER

- **Active and Passive Radar (not discussed here)**
  tested at various places

- **looking to a mountain for ν_τ-showers**
  e.g. 21CMA

- 2 constraints above PeV energies : limited medium thickness and large detection area to follow-up lepton-decay

=> Earth skimming or through-mountains neutrino trajectories
(cf *D Fargion- F Vannucci)*



Conditions met at 21CMA combined with radio-technique characterisation of air -showers

Daniel Ardouin / 21CMA

The High Energy Universe observed with Radio

UHECR

Particles: Charged CR — Gamma Rays — Neutrinos

Targets: Air — Solids — Moon

Experiments:

Air	Solids	Moon
LOPES	ICERAY	LUNASKA
CODALEMA	AURA	NuMoon (WRST/LOFAR/SKA)
R-Auger	ANITA	LORD
LOFAR	RICE	ASTROPEILER
R-ICETOP	ARIANNA	GLINT
21CMA	RAMAND	RAMHAND
	SALSA	

Theorie: Geo-synchrotron — Askaryan

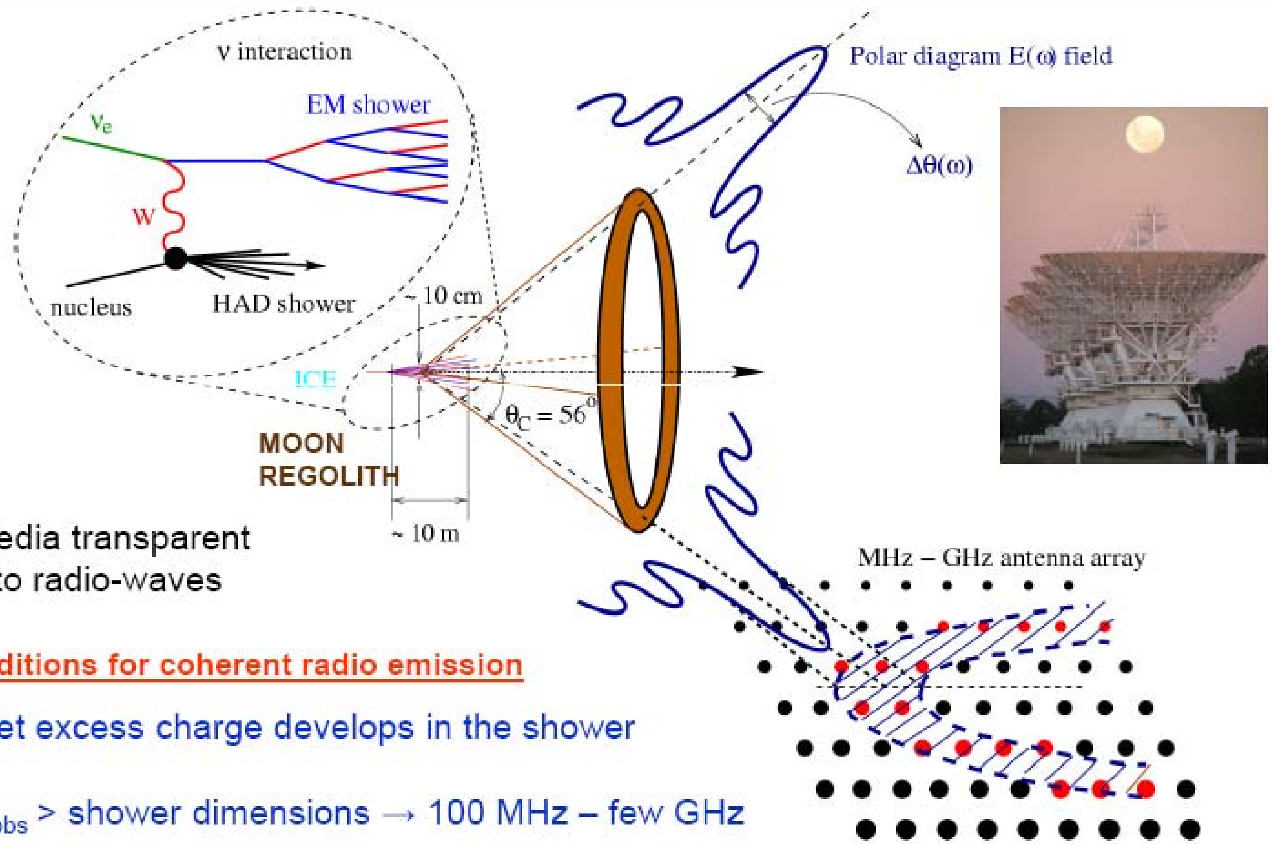
Radio in Solids and Moon

- **Strong emission process given in nature by the so-called Askaryan-effect**
- **Large attenuation lengths (up to ~km) for radio emission in different dense media like Antarctic ice or salt in salt domes**
- **Large detector volumes can be equipped with relatively small detector sampling**
- **Different concepts for the detection of high-energetic neutrinos by their radio emission in dense media**

➔ But, no positive detection yet!

Radio in Solids - Simulations

The radio technique in dense media



Conditions for coherent radio emission

1. Net excess charge develops in the shower
2. λ_{obs} > shower dimensions → 100 MHz – few GHz

Simulations with thinning options
➔ Saving considerably CPU-time!

Jaime Alvarez-Muniz

Radio in Solids – Target Characteristics

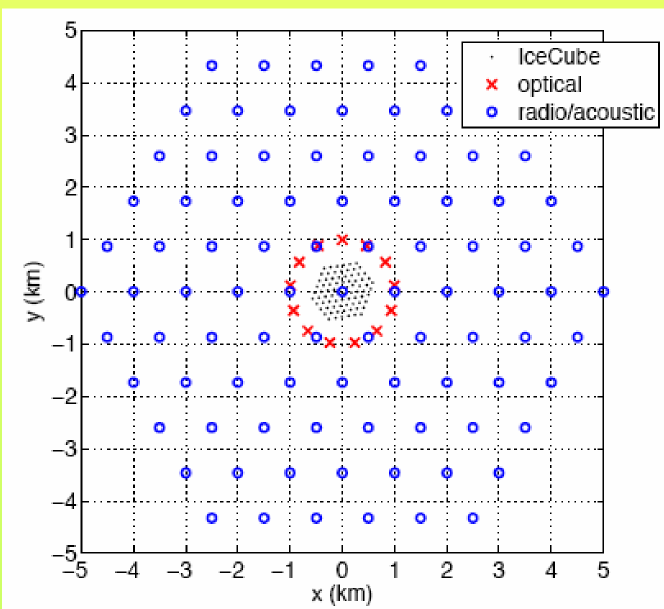
Material	 Ice	 Rock Salt	 Lunar Regolith
Density (g/cm^3)	0.92	2.2	1.8
Radiation Length (cm)	39	10	13
Cherenkov Angle (^{o})	56	66	55
Attenuation Length (m) at 250 MHz	~1000	~250 ?	~10

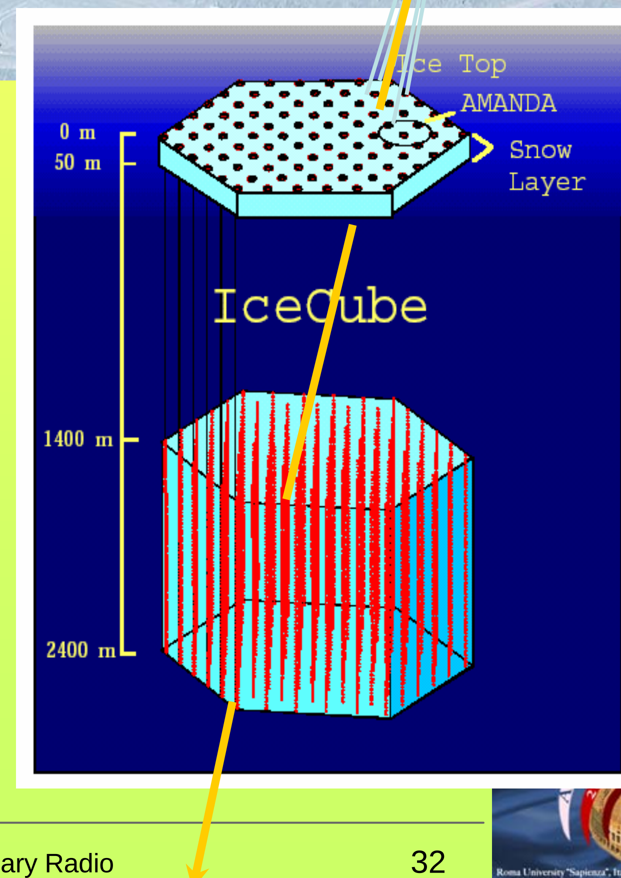
Radio in Ice

Detection principle:

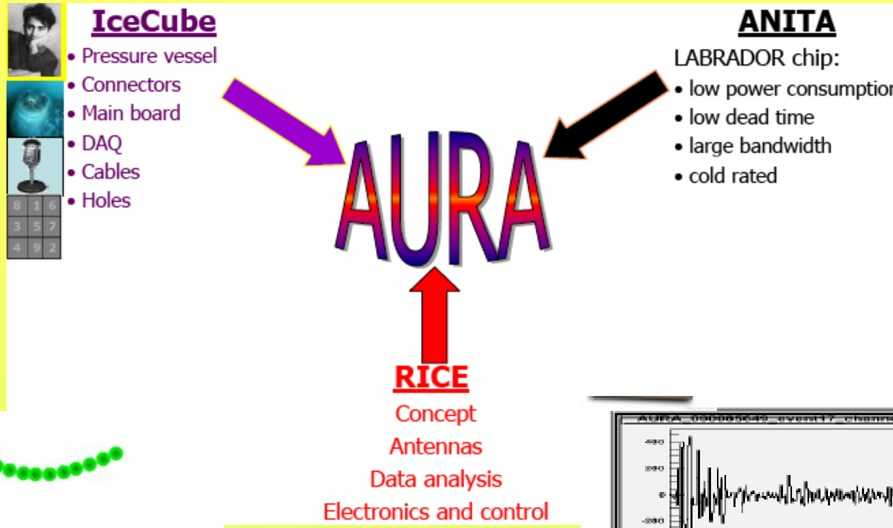
Askaryan-(Cherenkov) emission of radio in MHz-GHz frequency range by ν-interactions in ice

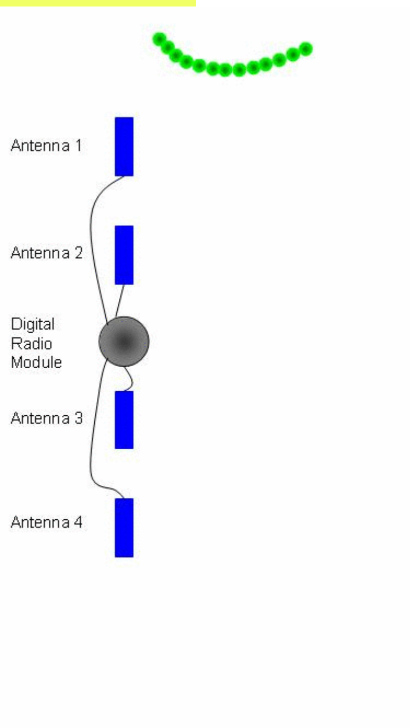
Aim: with radio to higher energies?



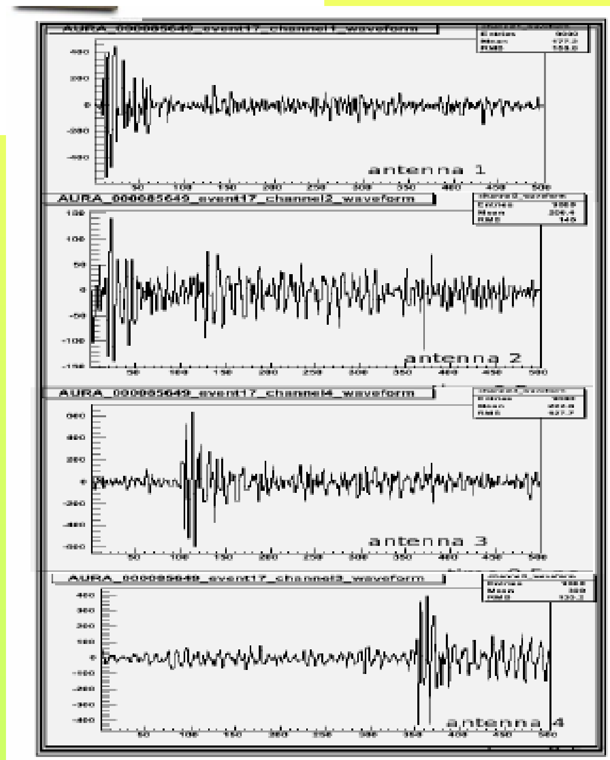


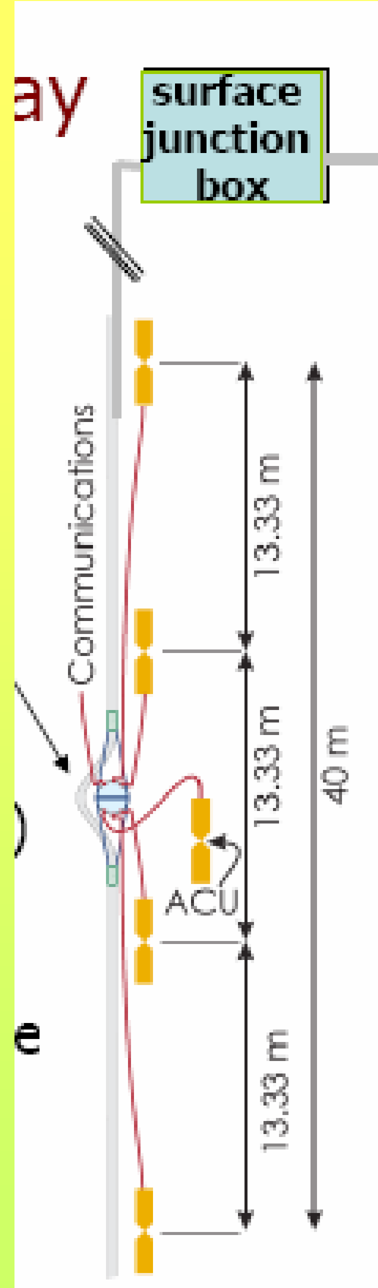
Radio in Ice: AURA





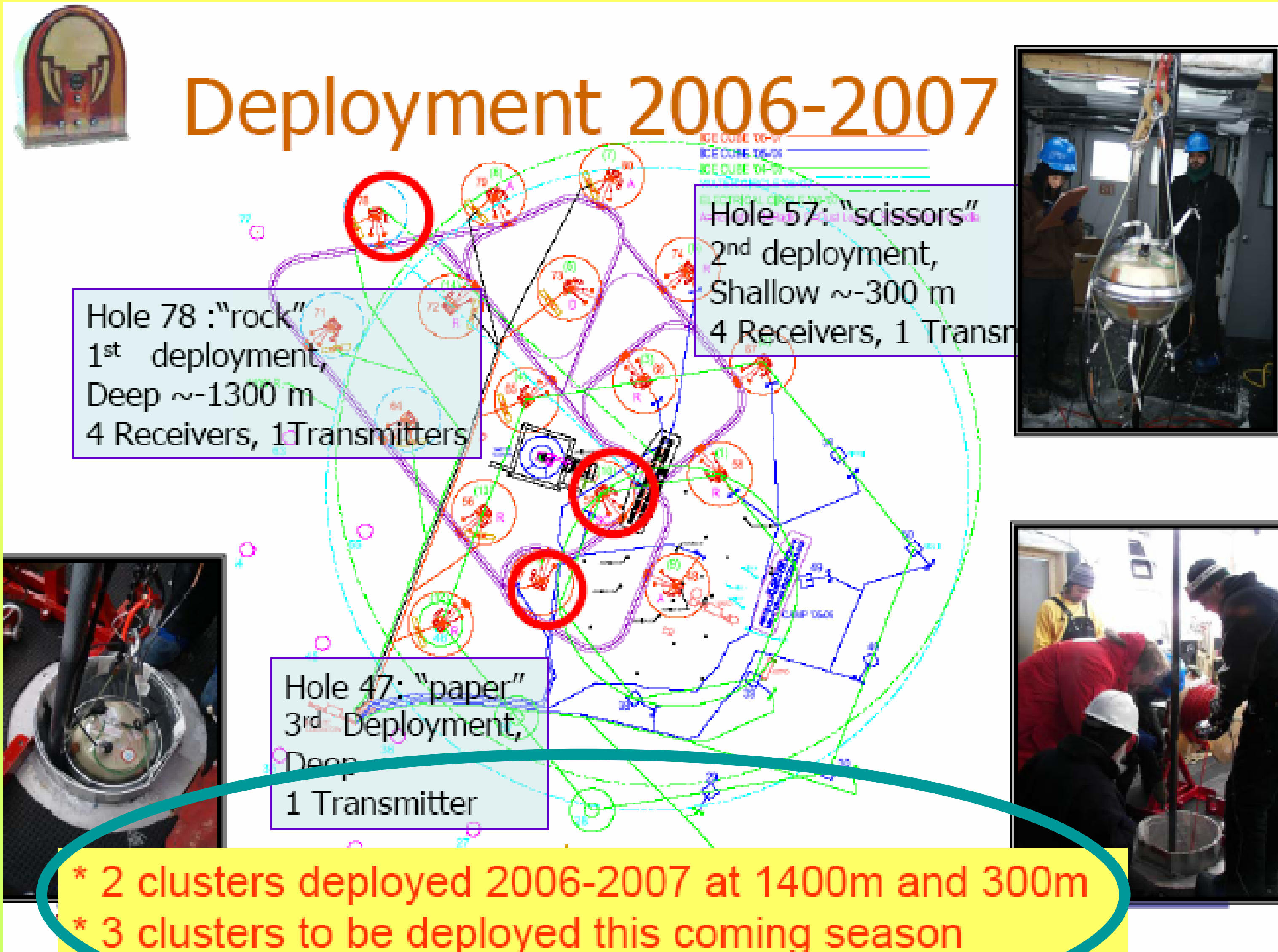
400MHz





Hagar Landsman / AURA

Radio in Ice: AURA



Hagar Landsman / AURA

Optimal depth?

Radio in Ice: ICERAY

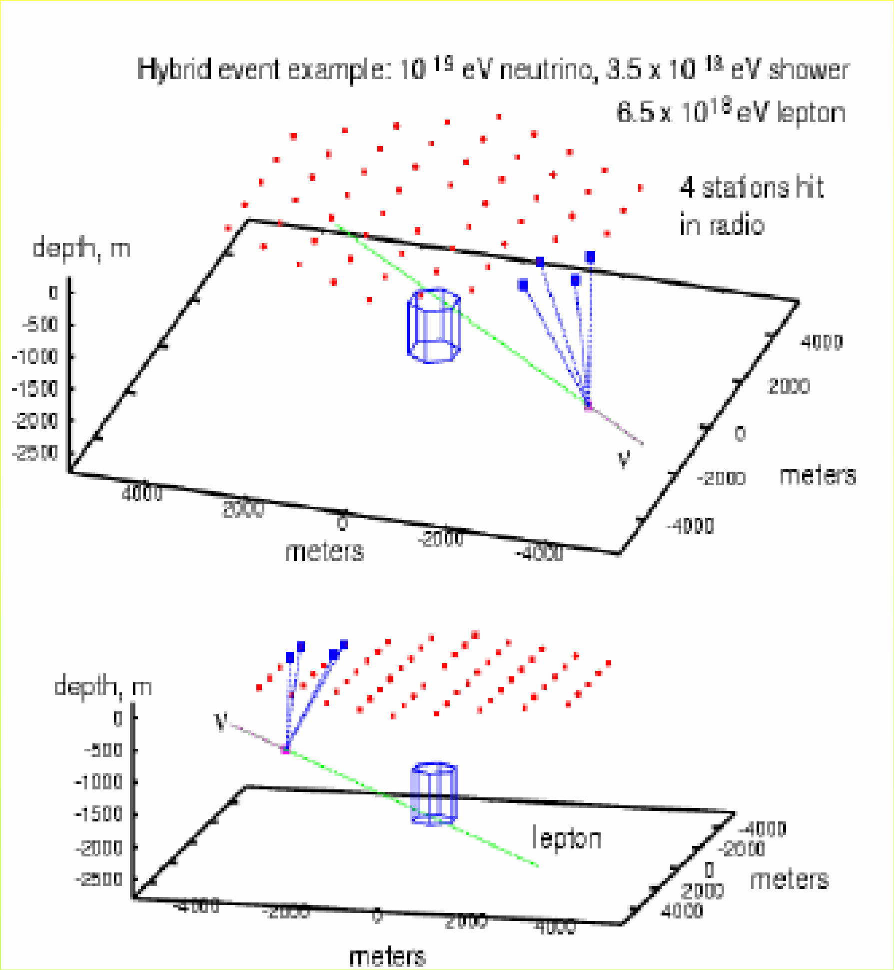
Goals

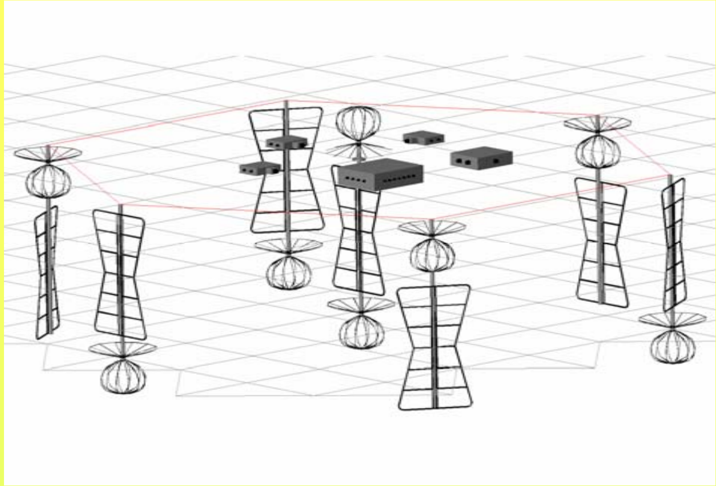
- Extend IceCube into the EeV range via a radio array (detecting Askaryan emission)
  - 50 km^2 (initial phase) to 300-1000 km^2 (final target)
  - substantial rates of GZK ν / year
- O(1^o) angular resolution
- Subset of events which trigger both radio and optical arrays
  - Allows calorimetry of both shower and outgoing lepton
  - Invaluable for cross-calibration / unambiguous GZK identification

John Kelley / ICERAY

Radio in Ice: ICERAY

"Golden" Hybrid Events





Attenuation length of ice is better at low frequency (< 500 MHz)

Drilling: **Optimal depth?**

Realistic goal: 200m

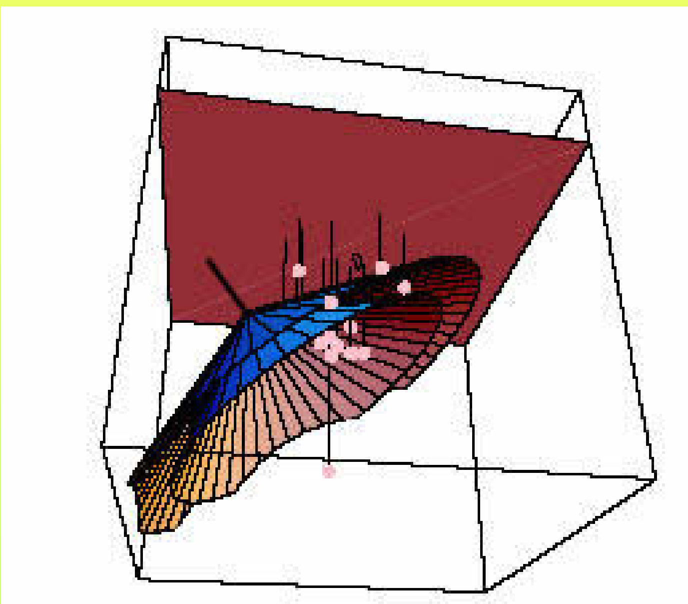
Triggering both IceRay and IceCube: rates are low, but extremely valuable for calibration

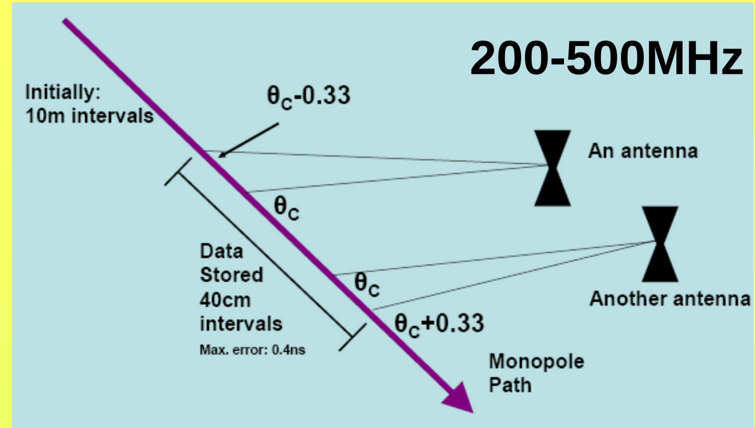
John Kelley / ICERAY

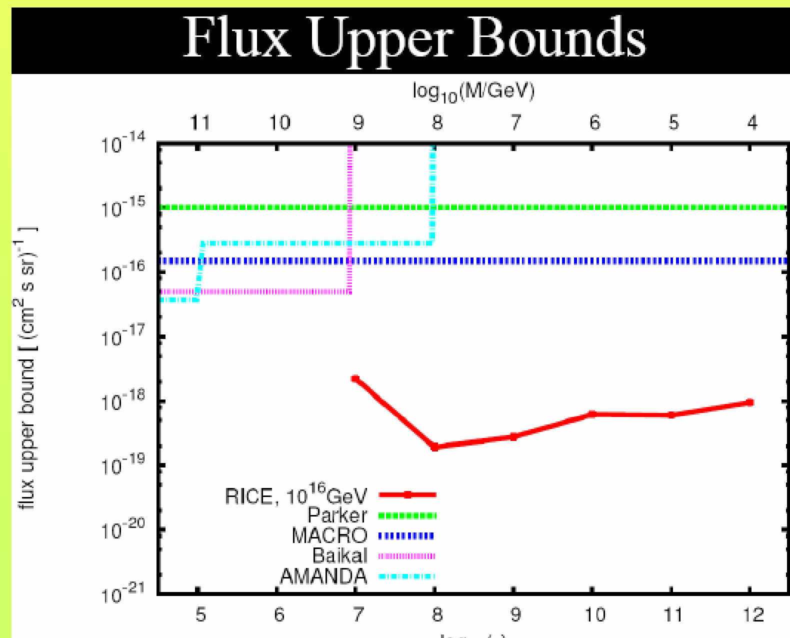
Radio in Ice: RICE

- Radio experiments at the Soutpole profit from RICE experience!
- RICE is stopped, but data are still useful!

➔ **Monopol search**

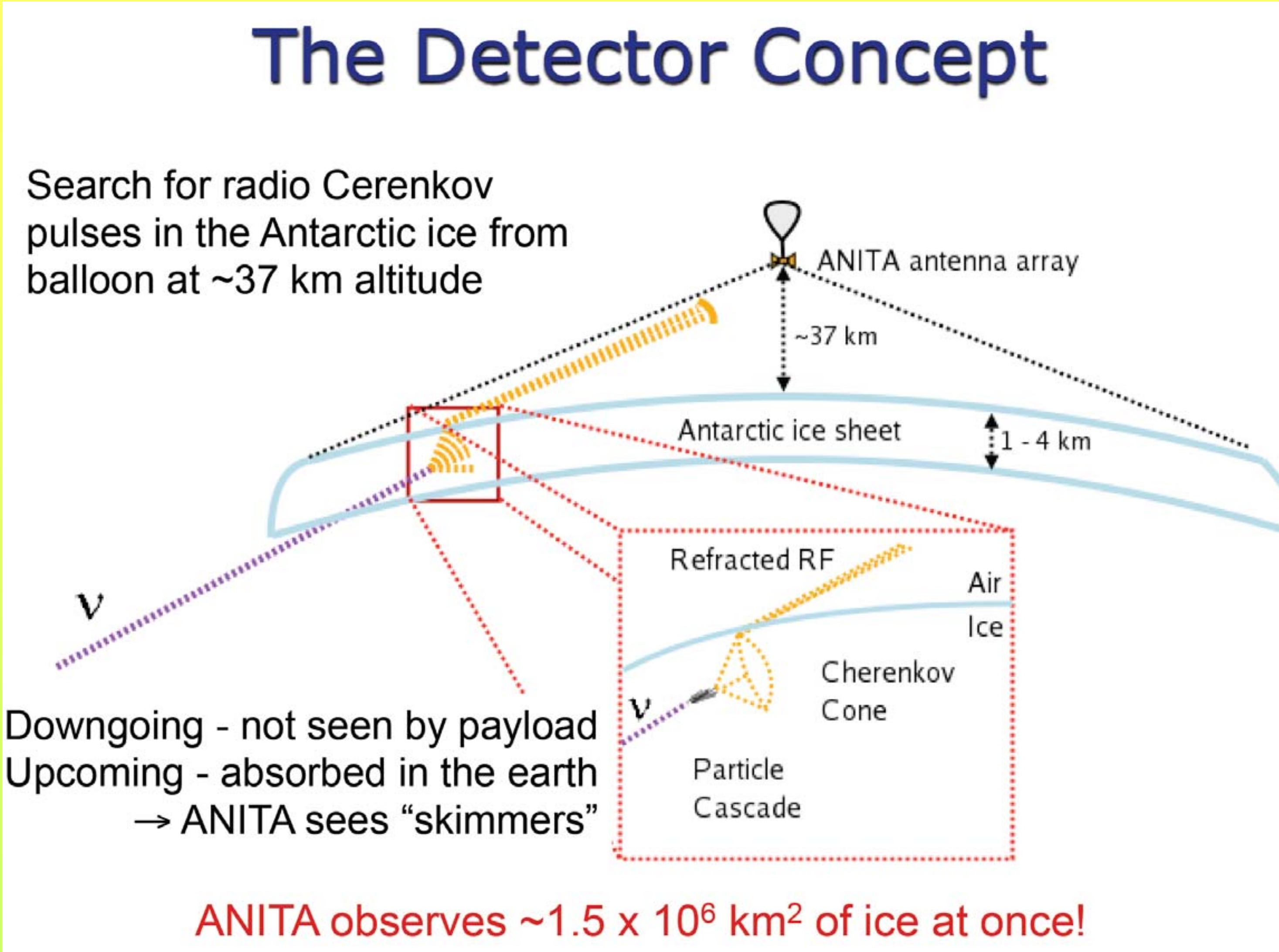






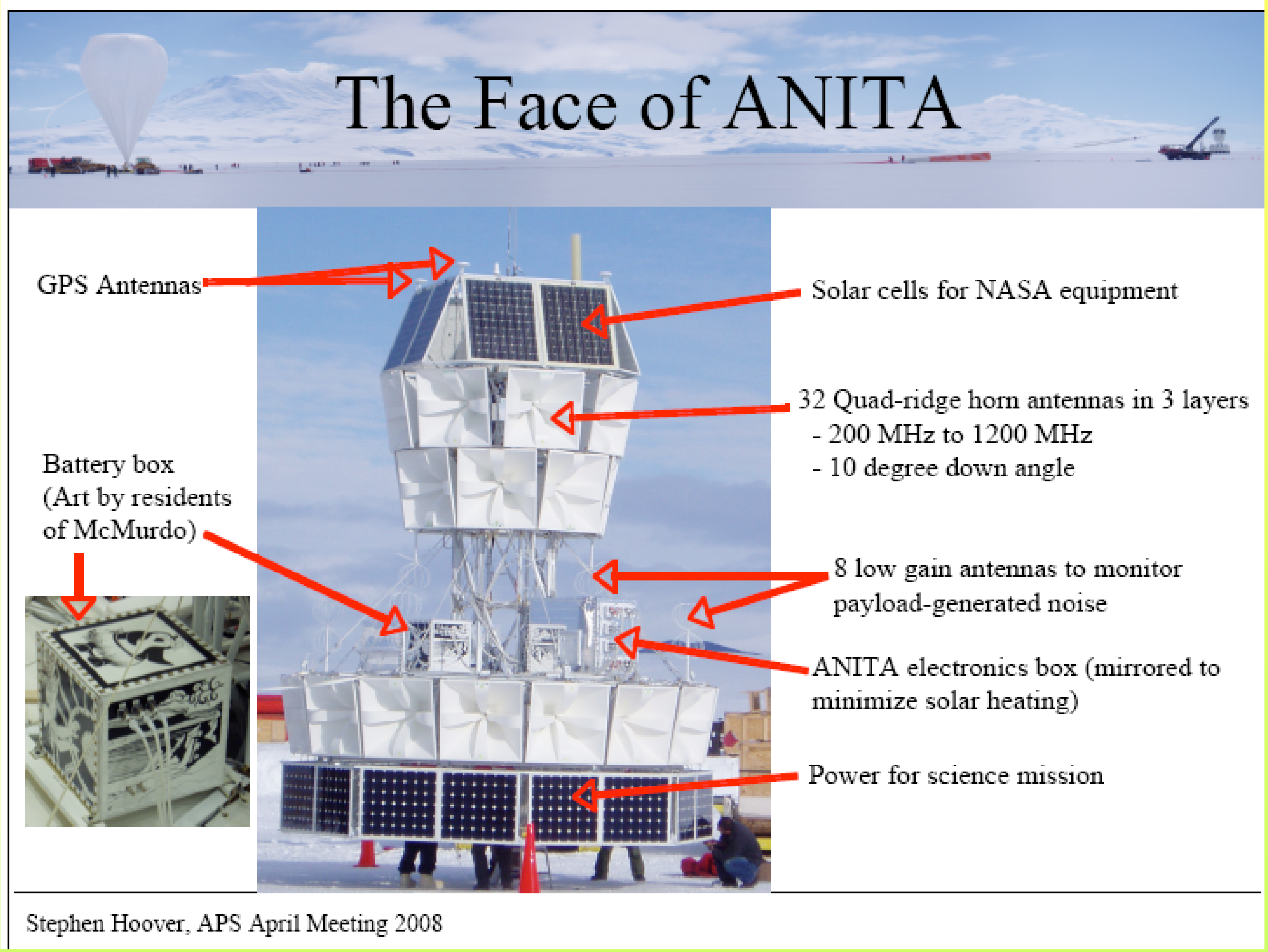
Daniel Hogan / RICE

Radio in Ice: ANITA



Amy Connolly / ANITA

Radio in Ice: ANITA

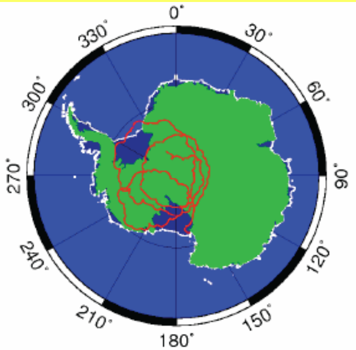


Amy Connolly / ANITA

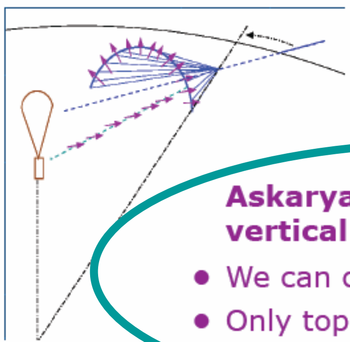
Radio in Ice: ANITA

The Flight

- Dec. 15th 2006 - Jan 18th 2007
- 3.5 trips around Antarctica
- Further "west" than average
- In view of radio noise (S. Pole and McM) 50% of time
- 18 days good livetime
- 1.2 km average depth



Horizontal Polarization?



Cerenkov radiation is:

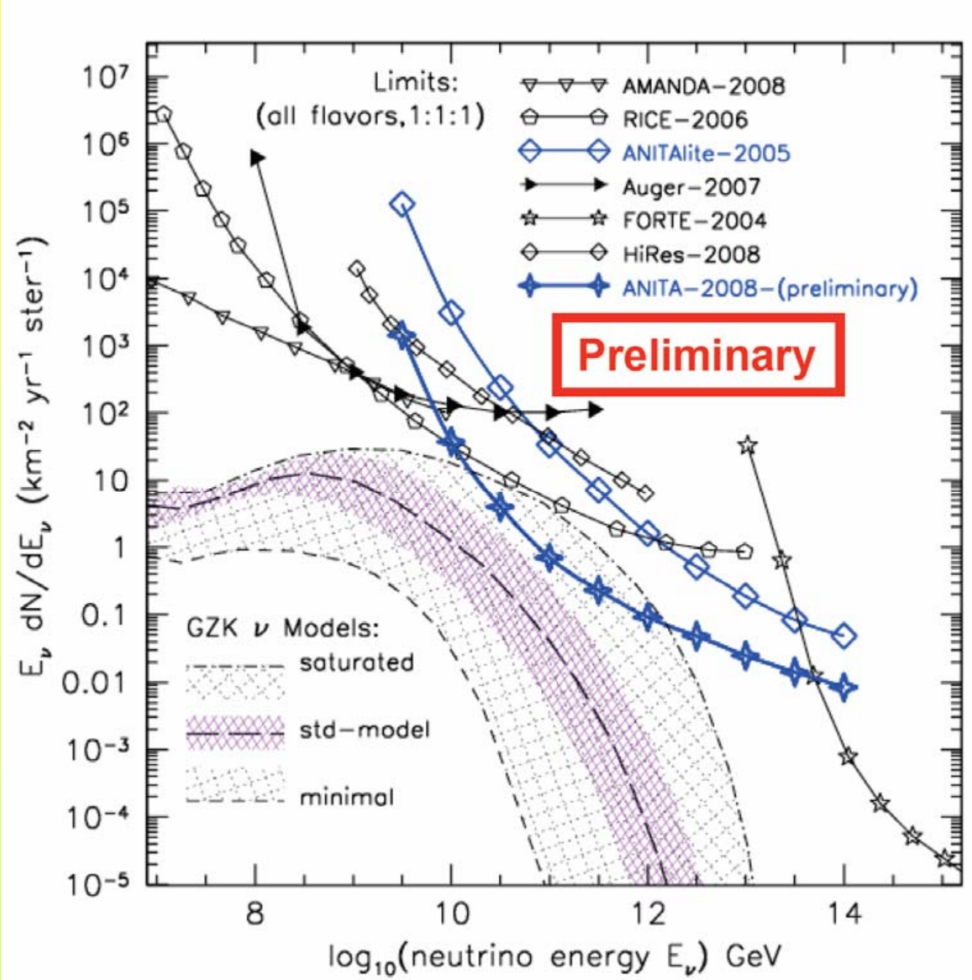
- Linearly polarized
- In the plane containing particle cascade momentum and Poynting vector

Askaryan signals strongly favor vertical polarization

- We can only see "skimmers"
- Only top of the cone escapes total internal reflection

Fresnel coefficients: Reflections from above strongly favor horizontal polarization (3:1) Could be:

- Air shower radio (geo-synchrotron)
- Solid state relays on satellites

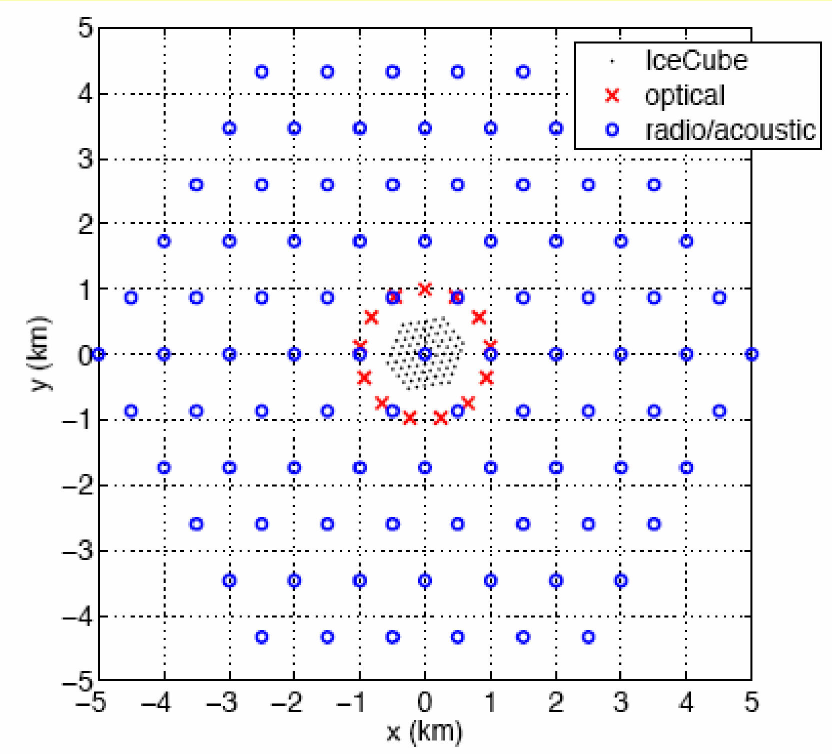


No signal detected! (fortunately?)

Amy Connolly / ANITA

Icecube as Hybrid Detector: Simulations

Delia Tosi / ICECUBE



Detection option	GZK events/year*)
IceCube	0.7
Optical	1.2
Radio	12.3
Acoustic	16.0
Optical+Radio	0.2
Optical+Acoustic	0.3
Radio+Acoustic	8.0 !!!
Opt.+Rad.+Acou.	0.1
TOTAL	21.1

Icecube as Hybrid Detector: Simulations

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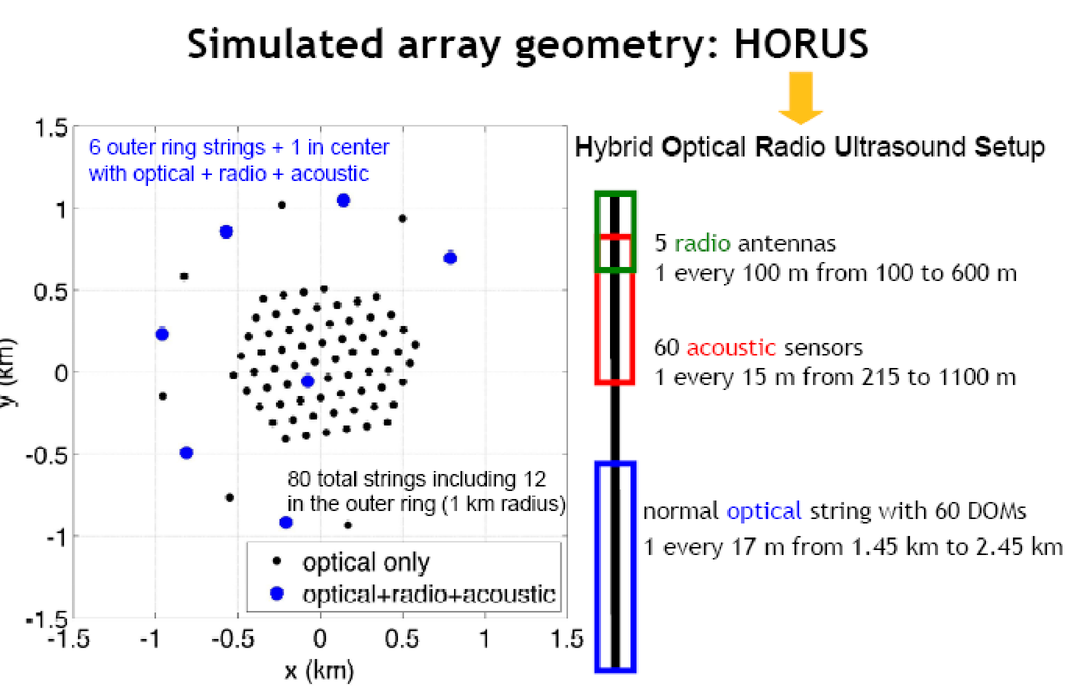
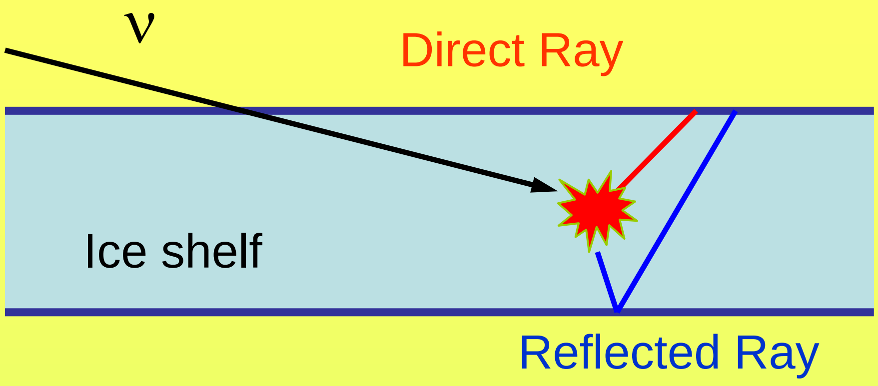


Detection option	GZK events/year*)
IceCube	2.39
Optical	3.99
Radio	1.68
Acoustic	0.43
Optical+Radio	0.098
Optical+Acoustic	0.043
Radio+Acoustic	0.089
Opt.+Rad.+Acou.	0.012
TOTAL	5.568

Preliminary!

Radio in ICE: Other techniques

- **ARIANNA**
  (not discussed ARENA08)



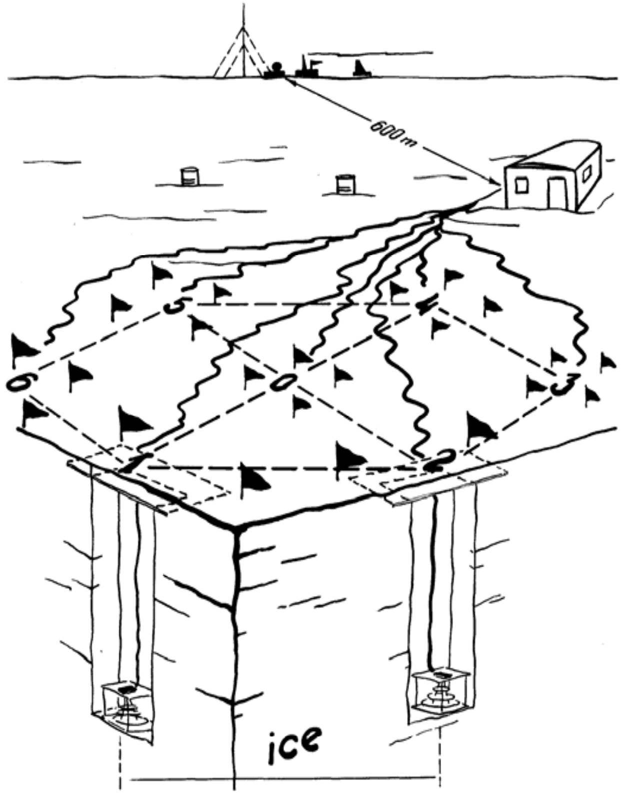


FIGURE 6

- **RAMAND**
  Radio Antarctic Muon And Neutrino Detection
  Historic idea (1980ies)

Igor Zheleznykh

Radio in ICE: further ideas

- **Permafrost**

Radio Signal Detection in Permafrost

G. A. Askaryan JETP (48)988 (1965)

"… possible working layers are: for internal radio detection – substances which absorb or scatter radio waves weakly (an ice layer, permafrost, very dry rock etc)…"

Permafrost covers ~20% of land on earth

There are regions with > 500 m thick layers

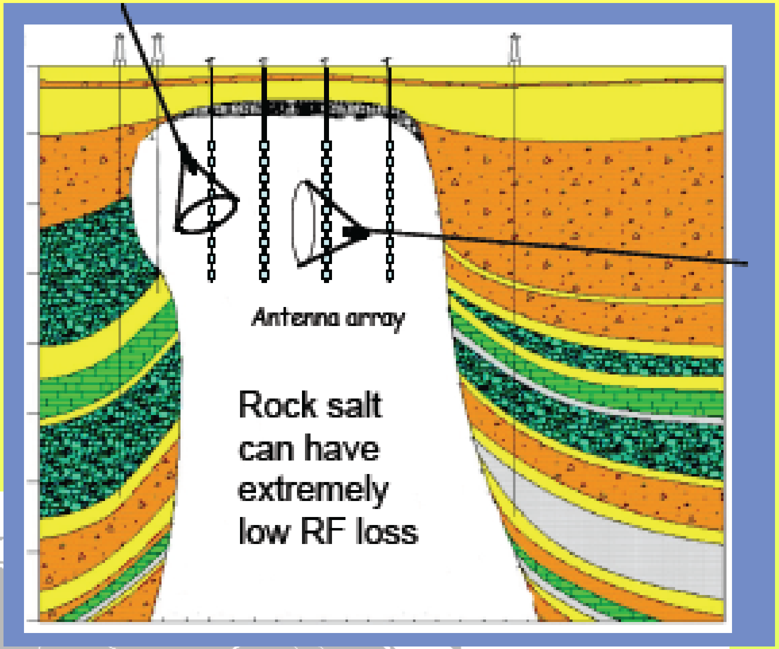
→→→ go for a ←←←

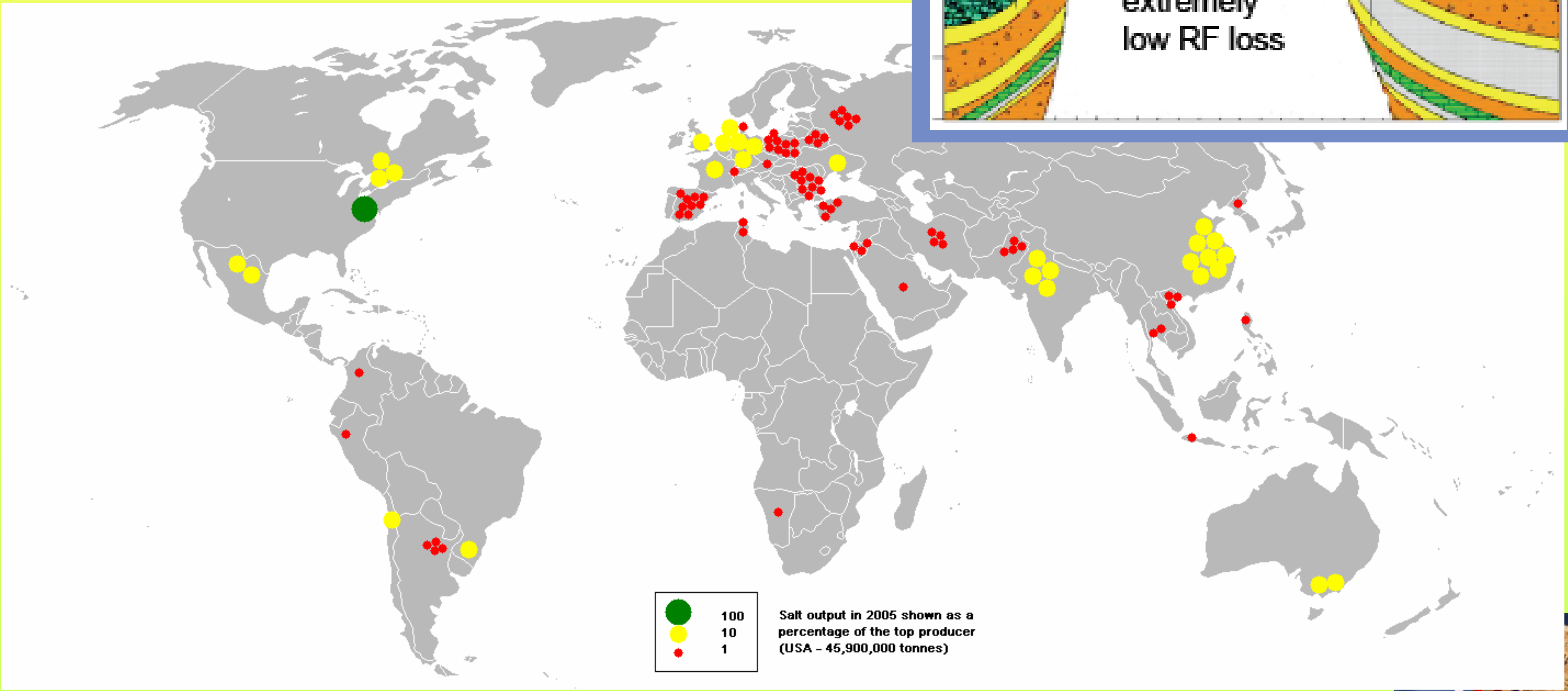
Test **A**skaryan **I**nstallation for **G**eology and **A**strophysics

Rolf Nahnhauer / TAIGA

Radio in Salt

- **Salt domes are extremely transparent for radio waves (as well as Antarctic ice)**
- **Factor ~2,4 more dense than ice**
- **Simpler environment conditions**





Radio in Salt: Salsa

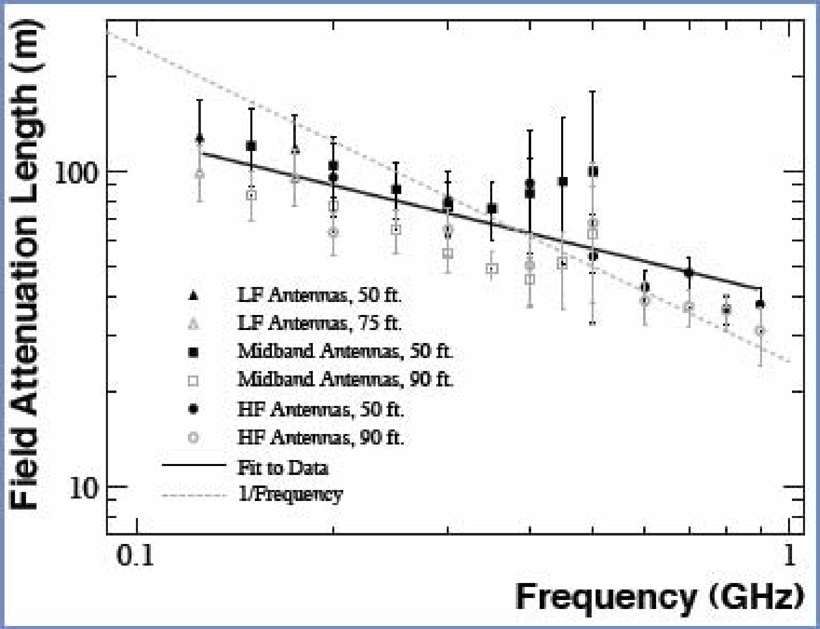
Attenuation Lengths

Fit to $$L_\alpha(\nu) = a \cdot \left(\frac{\nu}{1\ \text{GHz}}\right)^b$$

$b = -0.57 \pm 0.06$

$\chi^2 / \text{dof} = 25.6 / 36$

- 150 MHz: 93 ± 7 m
- 300 MHz: 63 ± 3 m
- 800 MHz: 36 ± 2 m



Recall: We estimate from Cote Blanche GPR result L_α >139 m @ 440 MHz have been observed

Amy Connolly / Salsa

Radio in Salt: Salsa

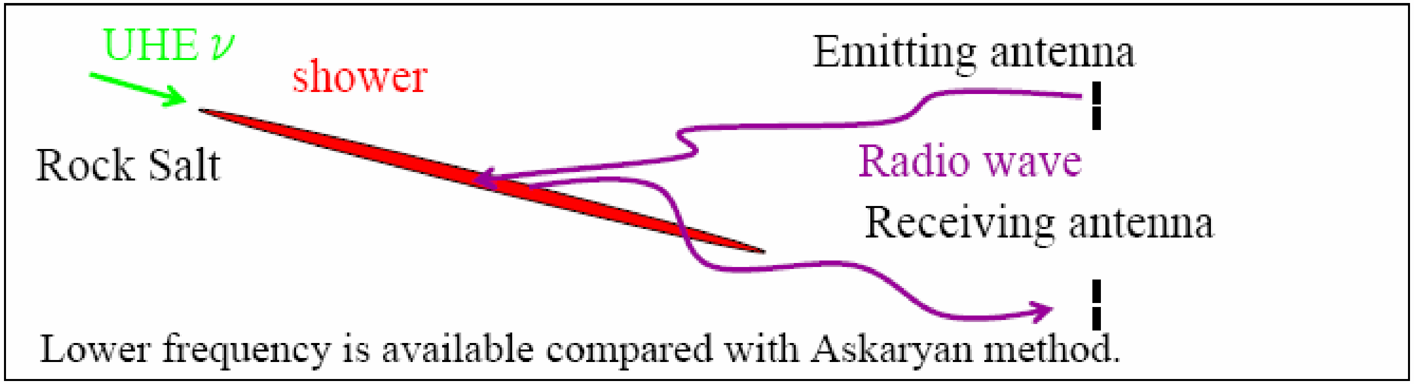
Future / Conclusions

- Before a SalSA can proceed, affordability aside, we need to definitively measure long attenuation lengths in salt (> ≈250 m)
- Borehole method works well, but only allows to sample limited region of salt per mine visit
- Would like to construct a GPR system to sample salt more efficiently
- Currently it looks difficult for salt to compete in sensitivity with any future detector in ice, but
  - It is important to explore new media
  - Salt could complement ice (Northern sky, accessibility)

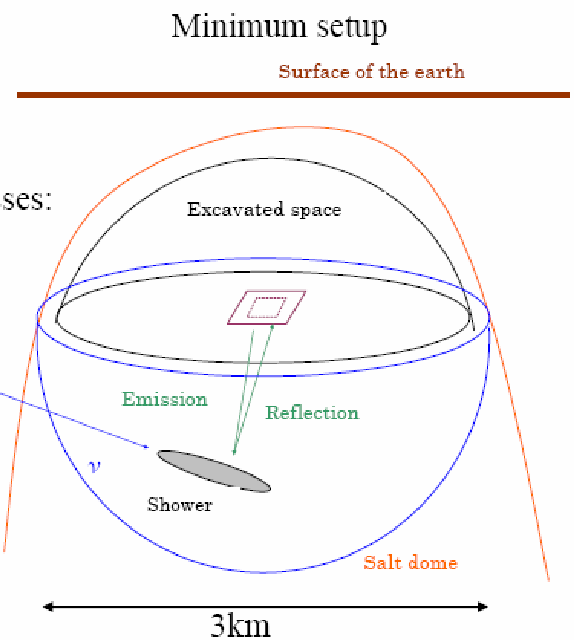
Amy Connolly / Salsa

Radio in Salt (maybe also Ice): by Radar technique

Radar method: microwave reflection experiment



- Radar method does not require expensive boreholes.
- # of GZK neutrinos/year is estimated by a simulation.
[W exchange] + [W-Gluon fusion] processes:
6～18 GZK neutrinos/year > 10^{17}eV
- Minimum setup:
# of GZK neutrinos could be counted.
High peak power radar of 1GW,
otherwise array antennas of lower power are needed.
- If the reflection is due to local thermal blobs,
Antarctic ice would be utilized.
Acoustic wave would be reflected in a similar way .



Masami Chiba

The High Energy Universe observed with Radio

UHECR

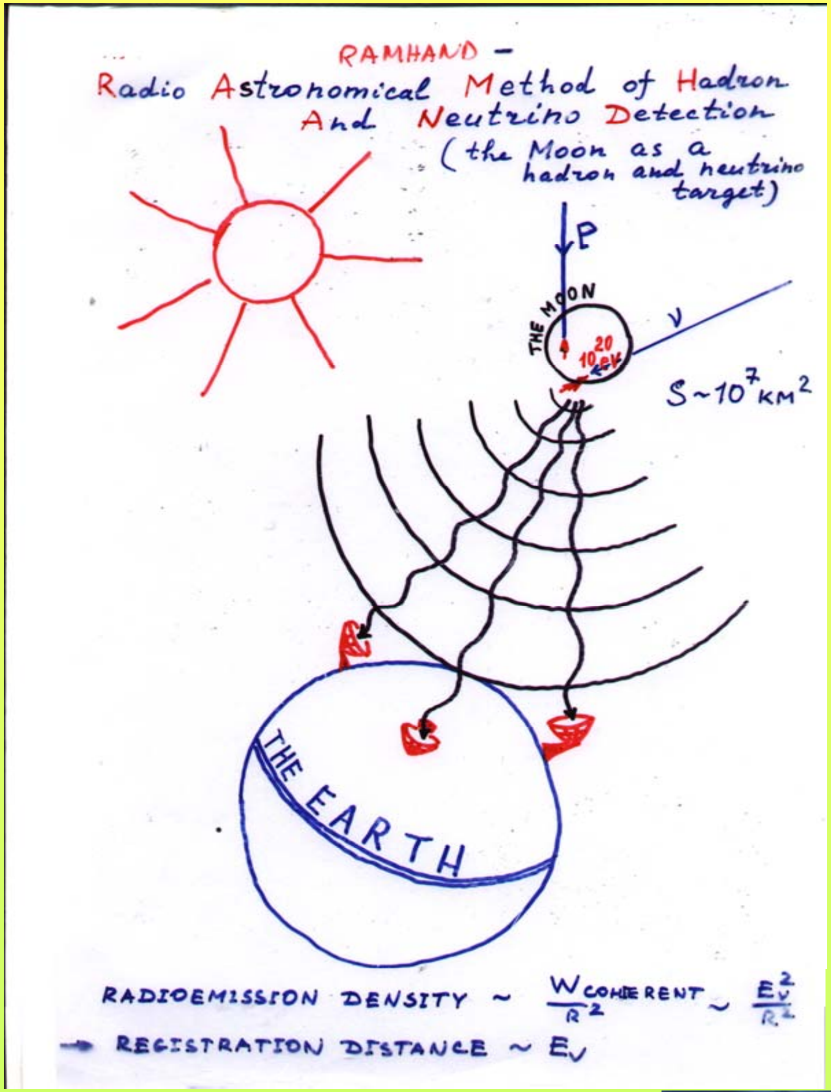
Particles:	Charged CR	Gamma Rays	Neutrinos
Targets:	Air	Solids	Moon
Experiments:	LOPES CODALEMA R-Auger LOFAR R-ICETOP 21CMA	ICERAY AURA ANITA RICE ARIANNA RAMAND SALSA	LUNASKA NuMoon (WRST/LOFAR/SKA) LORD ASTROPEILER GLINT RAMHAND
Theorie:	Geo-synchrotron		Askaryan

Radio at the moon

Detection principle:

Askaryan-emission from the regolith of the moon by ν AND cosmic rays interactions!

Strategy is to use or optimize existing infrastructures



Igor Zheleznykh / RAMHAND

Radio at the moon

IRO

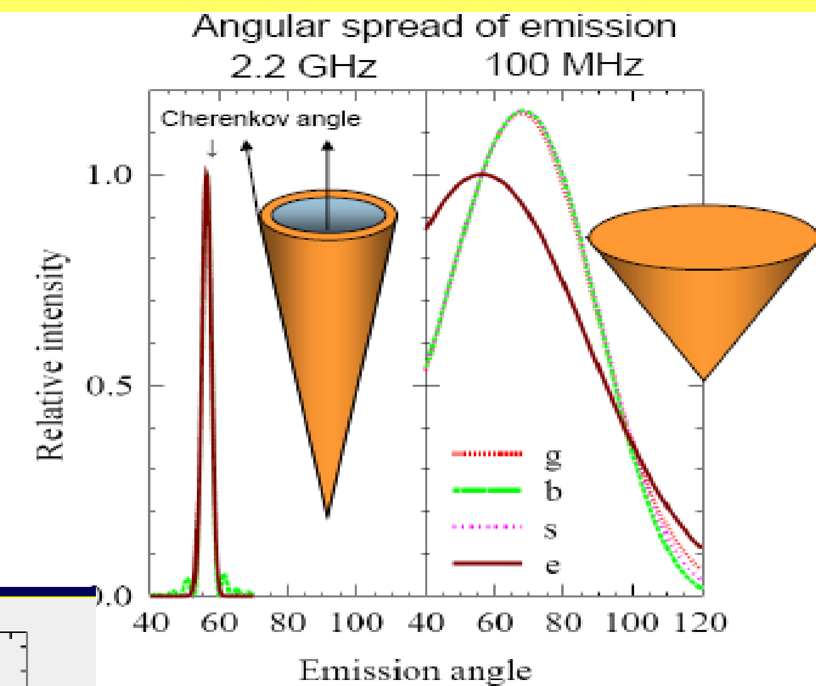
Conclusions

- Fruitful interaction between radio astronomy and high energy particle communities
  - Some culture differences
- Big improvements in signal processing technology
- Significant sensitivity improvements since 1995
  - Sensitivity estimates have been improved
  - Sensitivity estimates don't all agree (many assumptions)
  - High v low frequency?
- Future sensitivity improvements will need antenna arrays or focal plane arrays
- Proposed future radio facilities will probe all UHE models
- Strategy for targeted experiments is different

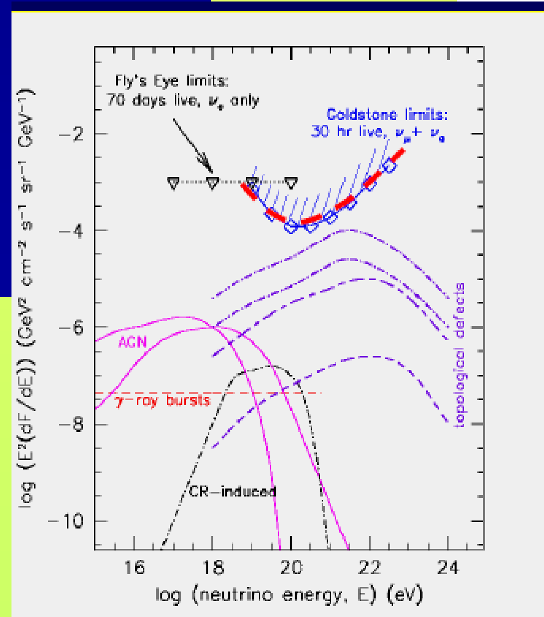
Ron Ekers

Radio at the moon: which frequency?

- Minimum neutrino energy
  - Determined by pulse detection threshold, hence radio telescope sensitivity
  - GHz frequencies better
  - Moves curve to left
- Neutrino flux limit determined
  - Volume of neutrino detector
  - Acceptance solid angle
    - » Lower frequency better
  - Observing time
  - Moves curve down



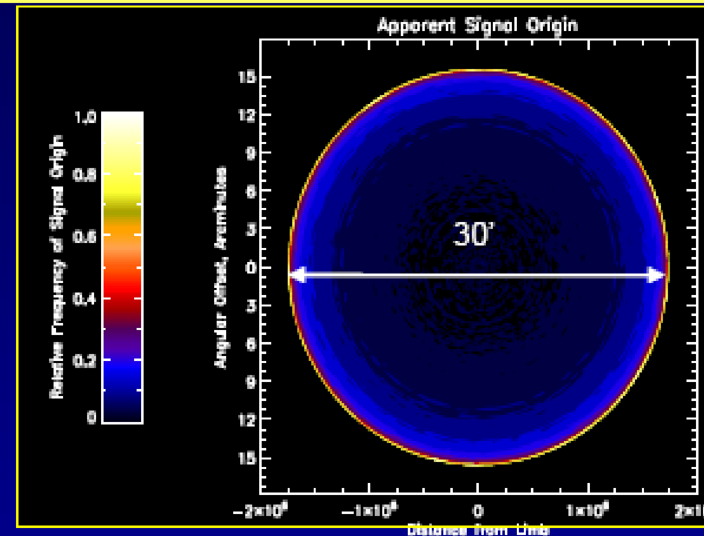
Scholten, et al. (2006, in press)



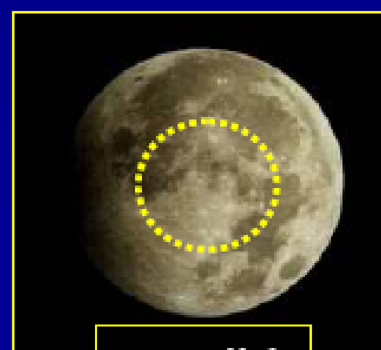
Ron Ekers

Radio at the moon: zoom to the limb?

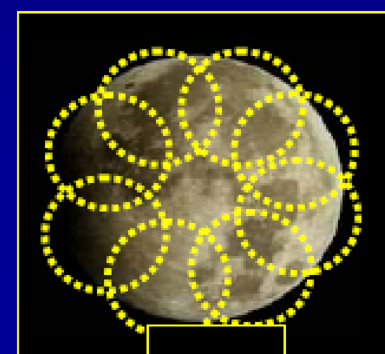
- Event rates highest at the limb
- Noise contribution from all moon
- We want to observe the entire lunar limb



20m dish



64m dish

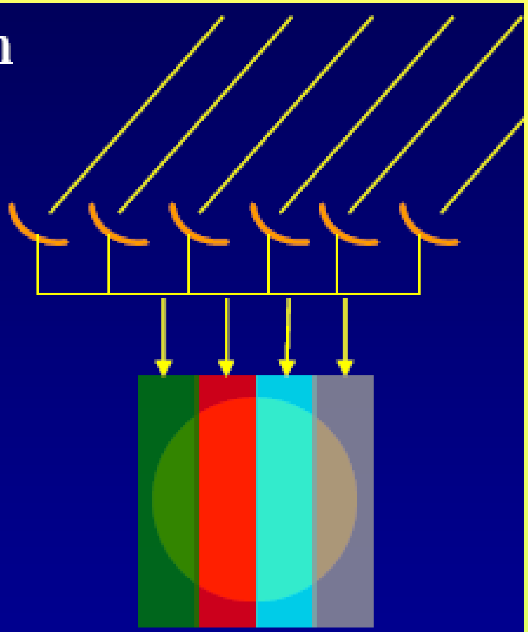


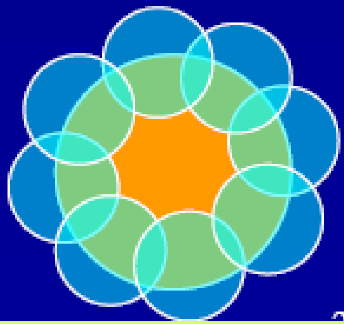
array

Ron Ekers

Radio at the moon: Imaging and beamforming array!

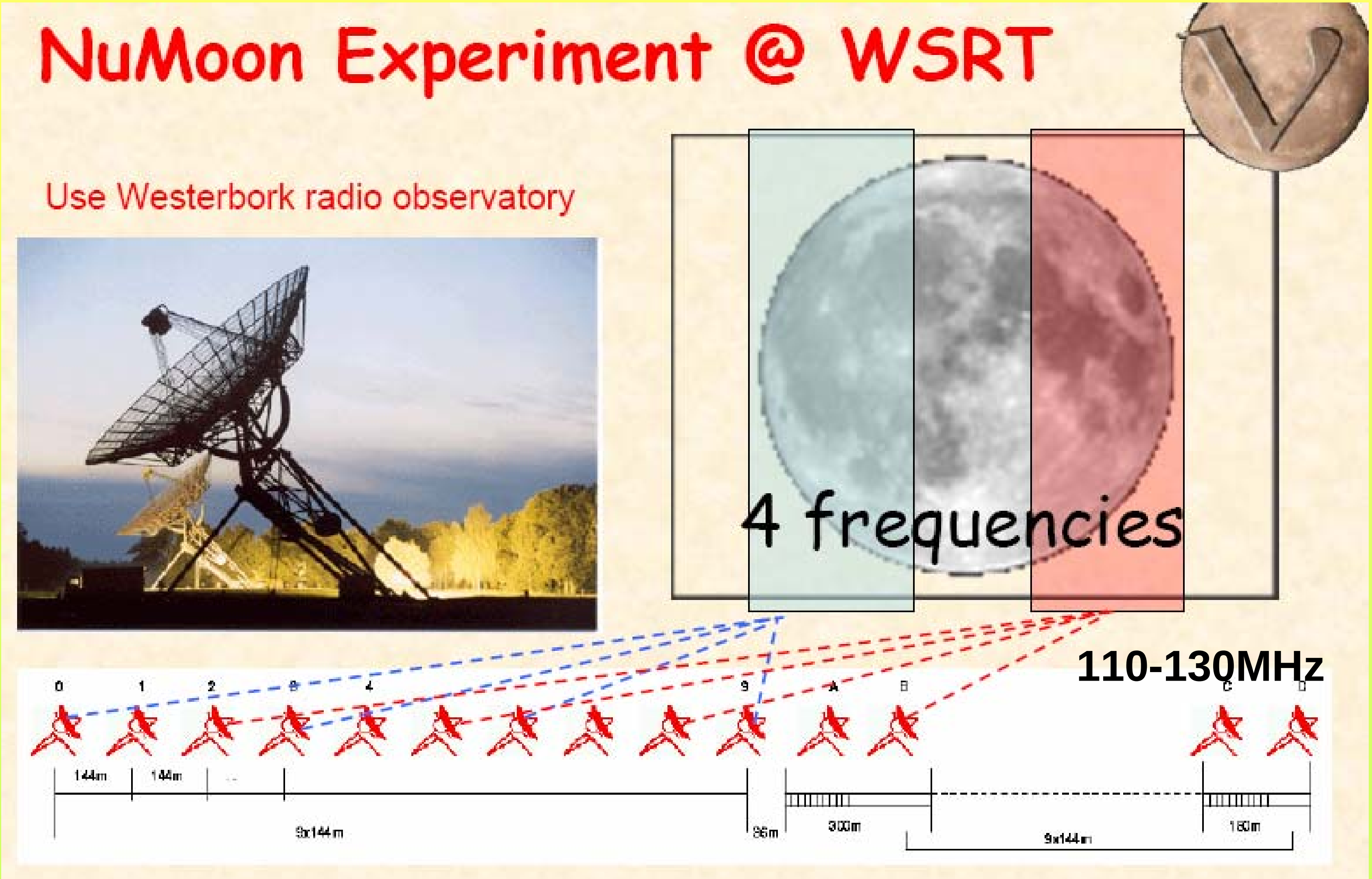
- Noise dominated by thermal emission from moon
  - Increasing antenna size doesn't help
- Aperture plane or Focal plane
- Arrays of small antenna (eg ATCA-SKA)
  - Form multiple beams from multiple antennas
  - Coherent addition of signals
  - Enough beams to cover all moon
- Multiple beams in a large dish
  - Eg Parkes + focal plane array
  - Max signal from limb of moon
  - Needs fully sample focal plane array
  - Beam former to illuminate whole limb





Ron Ekers

Radio at the moon: NuMoon



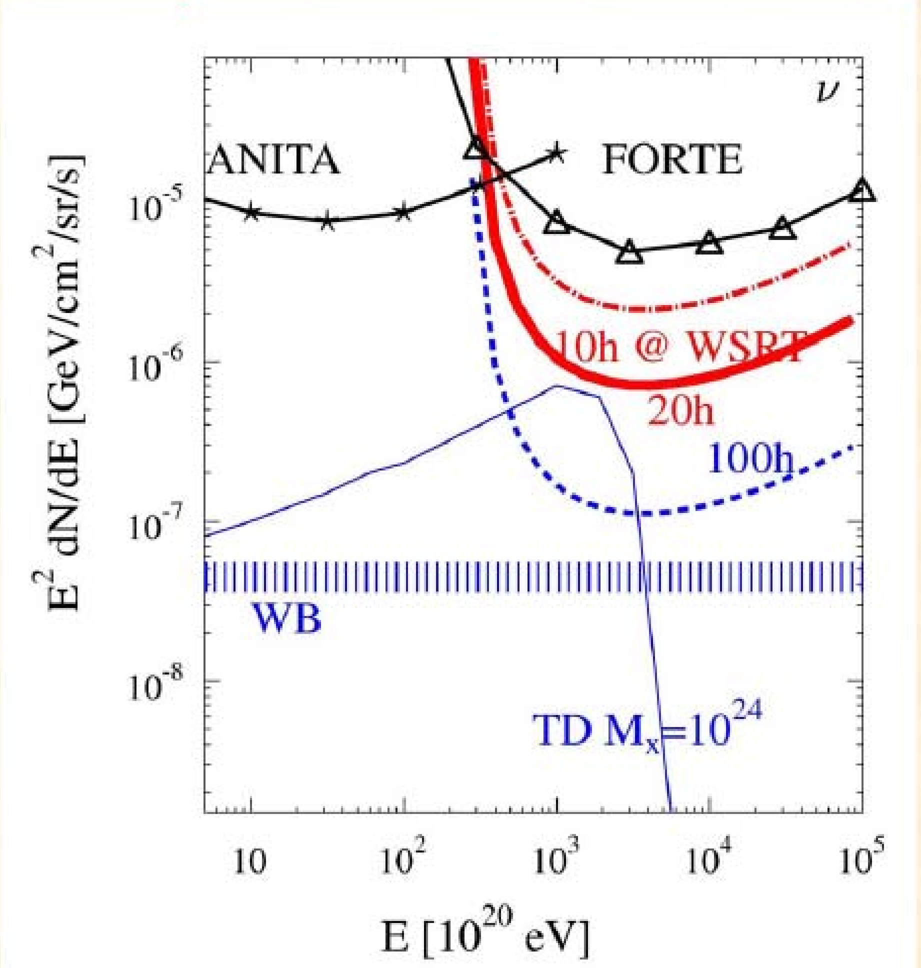
Olaf Scholten / NuMoon

Radio at the moon: NuMoon

Prelimenary Results

Analysis of
10 h 40 min data

Additional observation time: 7 June +10h



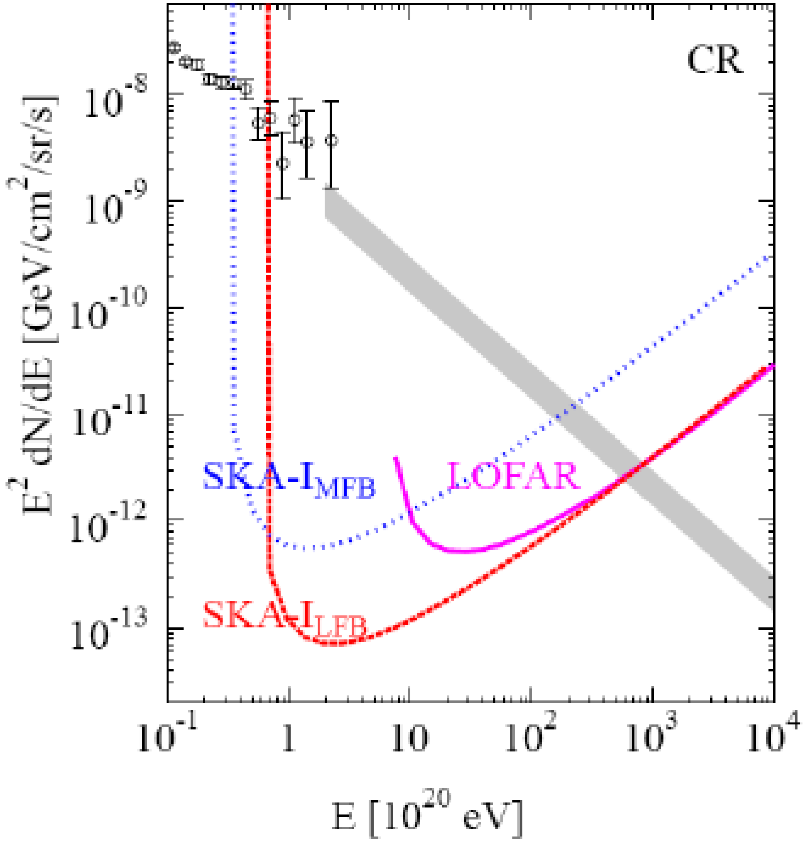
Olaf Scholten / NuMoon

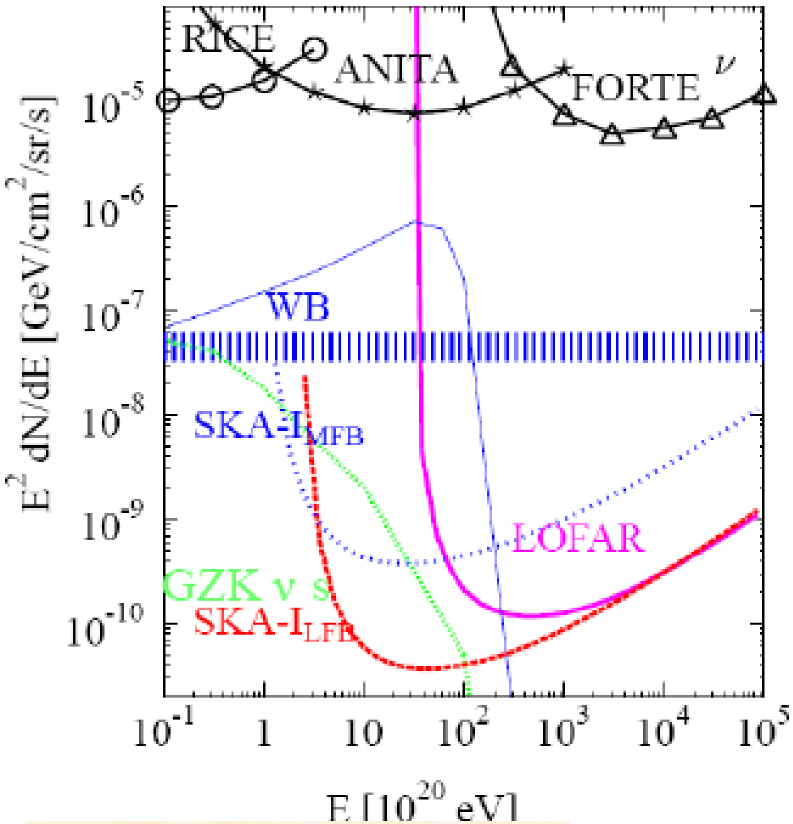
Radio at the moon: NuMoon

Olaf Scholten / NuMoon

Radio at the moon: NuMoon

1 year, 10% SKA





Olaf Scholten / NuMoon - SKA
Heino Falcke / LOFAR - SKA

SKA:

LFB: 100-300 MHz

MFB: 300-500 MHz

Radio at the moon: LUNASKA

ATCA

- 6x22m dishes in NSW, Australia
- Aperture synthesis antenna
- 6km E-W Baseline

- We are using this to develop methods and technology scaleable to the SKA

Development

- Dedispersion
- Triggering (fast logic)
- RFI discrimination
- Observations!

Clincy James / LUNASKA

Radio at the moon: LUNASKA

May 5th-7th 2007 (5 hr)

- 10pm-6am.
- Simultaneous baseband recording (64 Mhz at 1.2 GHz).
- Targeted Sag A region.
- Centre-pointing.
- Only ms timing available!

Feb 26th-28th 2008 (14 hr)

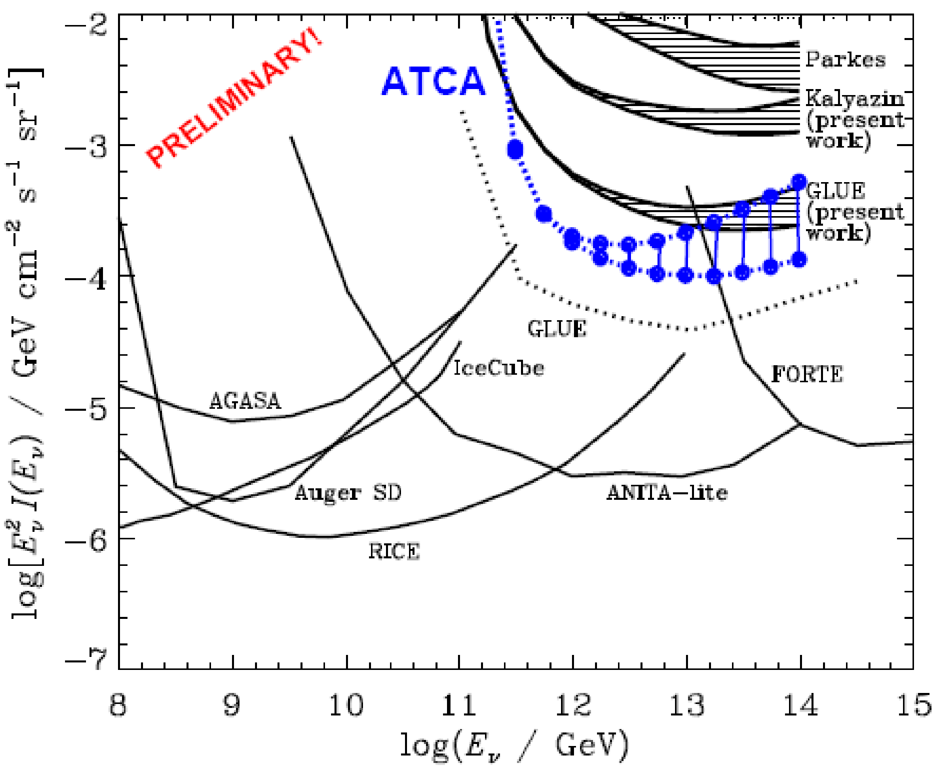
- Repeat of '07 set-up.
- 14 hrs stable configuration.

March 17th-19th 2008 (20 hr)

- Targeted Cen A.
- Pointed at limb to maximise Cen A sensitivity.

Expected ATCA Limit

- **We have not finished analysing 2008 data.**
- **Plot approximate limit on an isotropic flux assuming no detections.**
- **Range reflects the regolith depth (upper: 10m, lower: ~∞)**



Clincy James / LUNASKA

Radio at the moon: GLINT

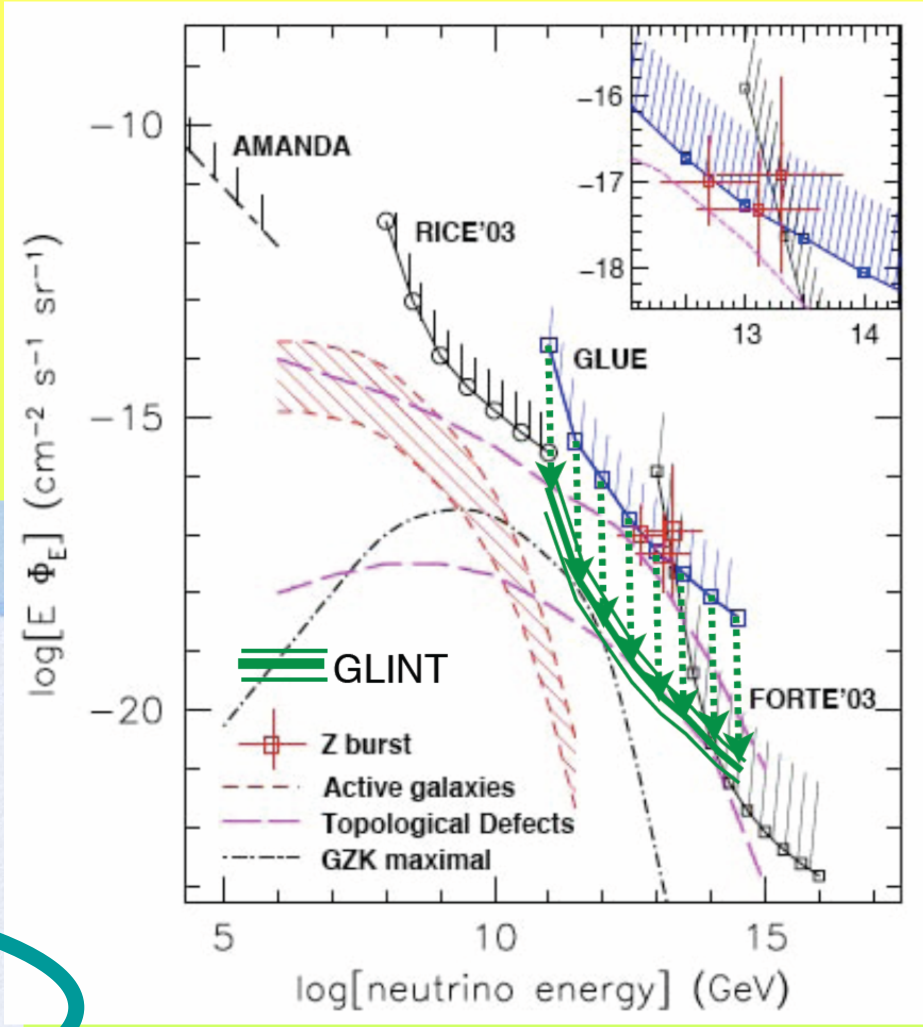
Green Bank LuNAr Interferometer for Neutrino Transients

Factor of 300 improvement in sensitivity over original experiment

Group	Freq. (MHz)	Band-Width (MHz)	Diam-eter (m)	System Temp (K)	Neutrino Beam (degree)	Relative System Sensitivity	Obs. Duration (hours)	Rel. Counts
Parkes	1400	200	64.0	100	3.1	131	10	1
GLUE	2200	70	48.1	110	2.0	33	120	3
Westerbork	140	20	93.5	200	30.9	40	200	6
							500	15
GLINT	1300	2000	53.6	110	3.3	337	2000	513
							4000	1025

The GLINT interferometer will have very wide frequency coverage and the ability to determine the point of origin of radio transients generated by neutrinos.

Our proposed system will operate for two or more years, in order to detect a statistically significant number of neutrino transients.



Glen Langston / GLINT

Radio at the moon: ASTROPEILER

Search for UHE neutrinos using a refurbished 25-m telescope

25 m diameter
Astropeiler Stockert
built 1956
operated by University of Bonn and MPIfR

shut down 1997
got private property
industrial monument 1999

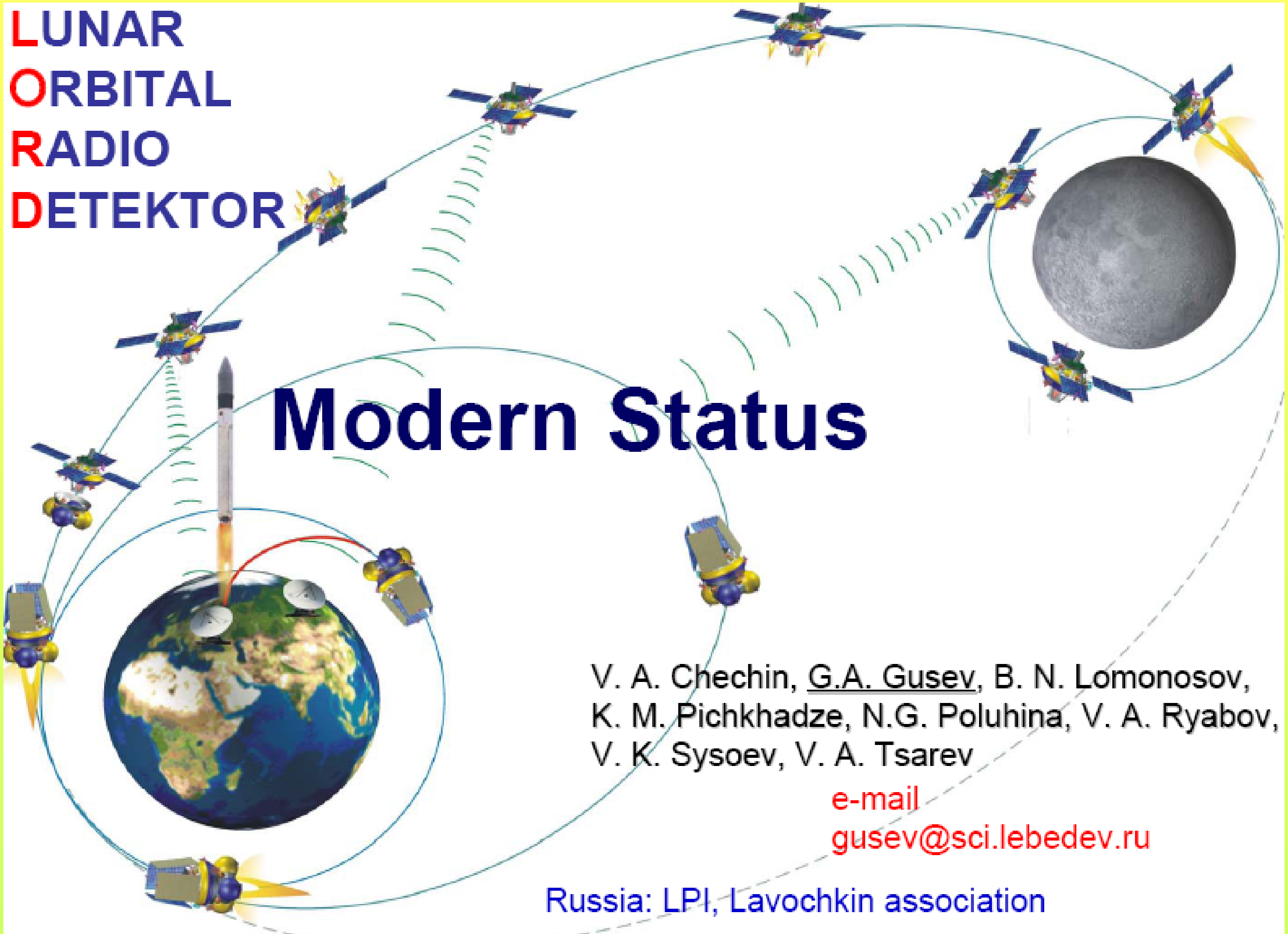
since 2005 owned by NRW foundation
At present in reconstruction!

1.4 GHz; 140MHz bandwidth

Perfect for outreach!
Main problem: sponsoring!

Peter Kalberla / Astropeiler

Radio at the moon: LORD



Gusev German / LORD

Radio at the moon: LORD

CONCLUSIONS

1. For CR spectrum E^{-3} statistics per year in the LORD experiment :

- for CR – one hundred events;
- for GZK neutrino (maximum flux model) – several units events.

2. Conception of radio detector (first generation) is developed and optimized.

3. There are principle possibilities for selection of the events from the radio pulse background and separation between CR and neutrino cascades.

4. The LORD experiment is included in LUNA-GLOB mission, to be launched at about 2012 year.

500 MHz Antenna

Gusev German / LORD

Conclusion of Summary…..

Radio in Air

- Air-shower observations are becoming “standard”
- coincidences with EAS arrays !!

Radio in Solids

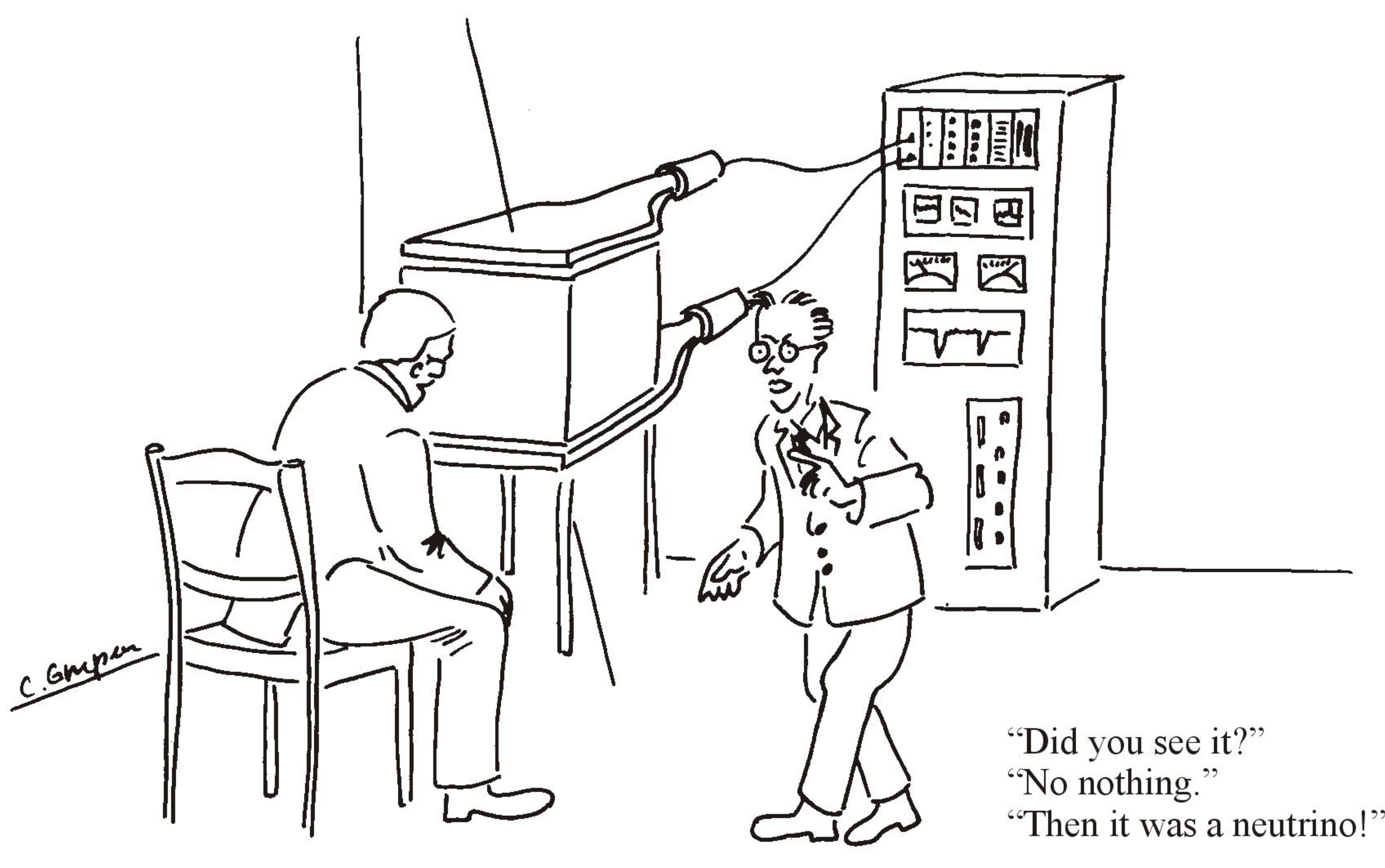
- Proof-of-Principle in the lab
- No correlation (yet) in hybrid detection
- Application to larger scales in work (engineering, physics)
- R&D on new and alternative targets

Radio in the Moon

- Boom in experiments (measurements and proposals)
- R&D for optimization

For all…

- Simulations are more and more important…
- The science is compelling for construction of a large-scale array
- Expect maturation of initial round of experiments (R-AUGER, ANITA, LOFAR, AURA, e.g.) in next few years, with possible first indications of UHE neutrinos



But we will hear it!!