Flux Limits for Ultra-High Energy Neutrinos

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High E neutrino Physics $E_\nu > 10^{22}$ eV

NuMoon@WSRT, results

NuMoon@LOFAR, status

Combination of exp. & modeling

Physics of Cosmic rays

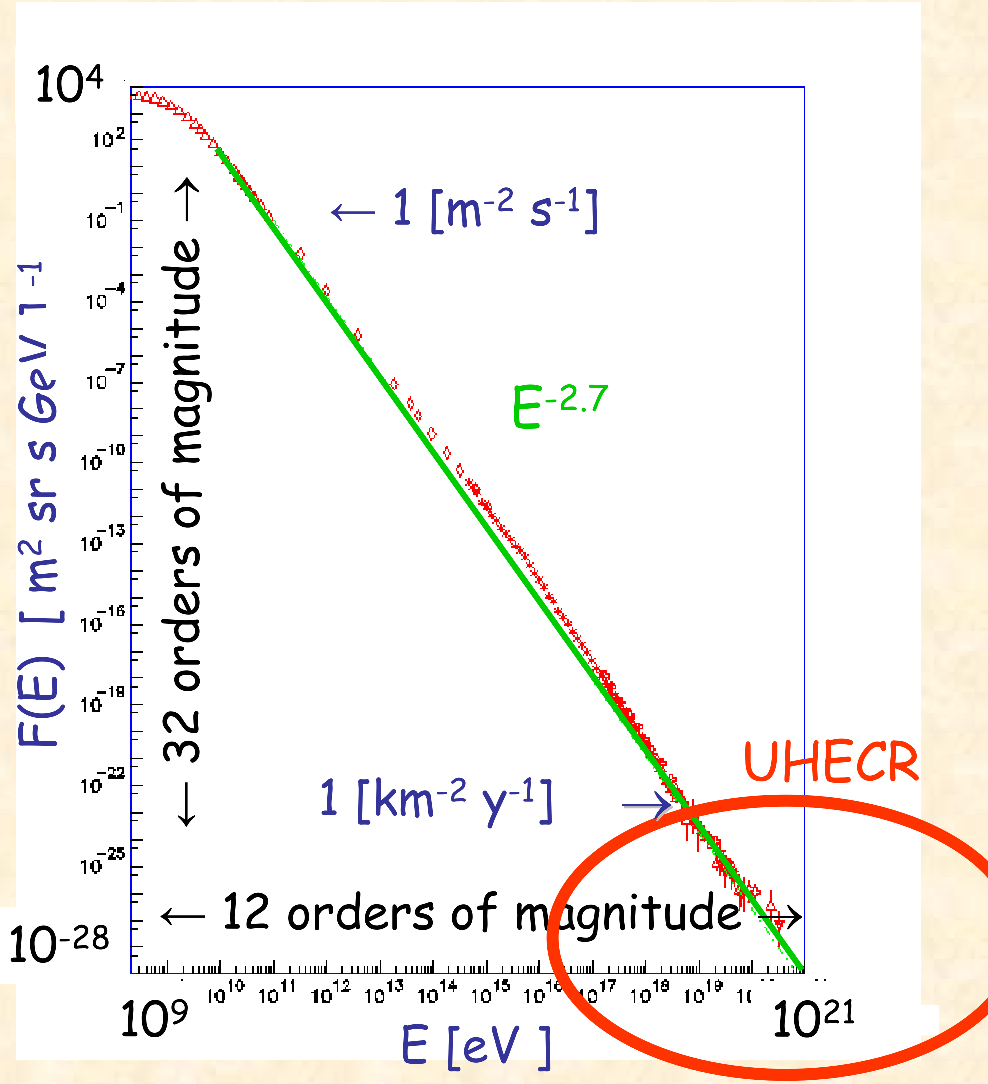
Spectrum is power law
Flux ~ E^{-3}
Non thermal spectrum!

There must be sources!

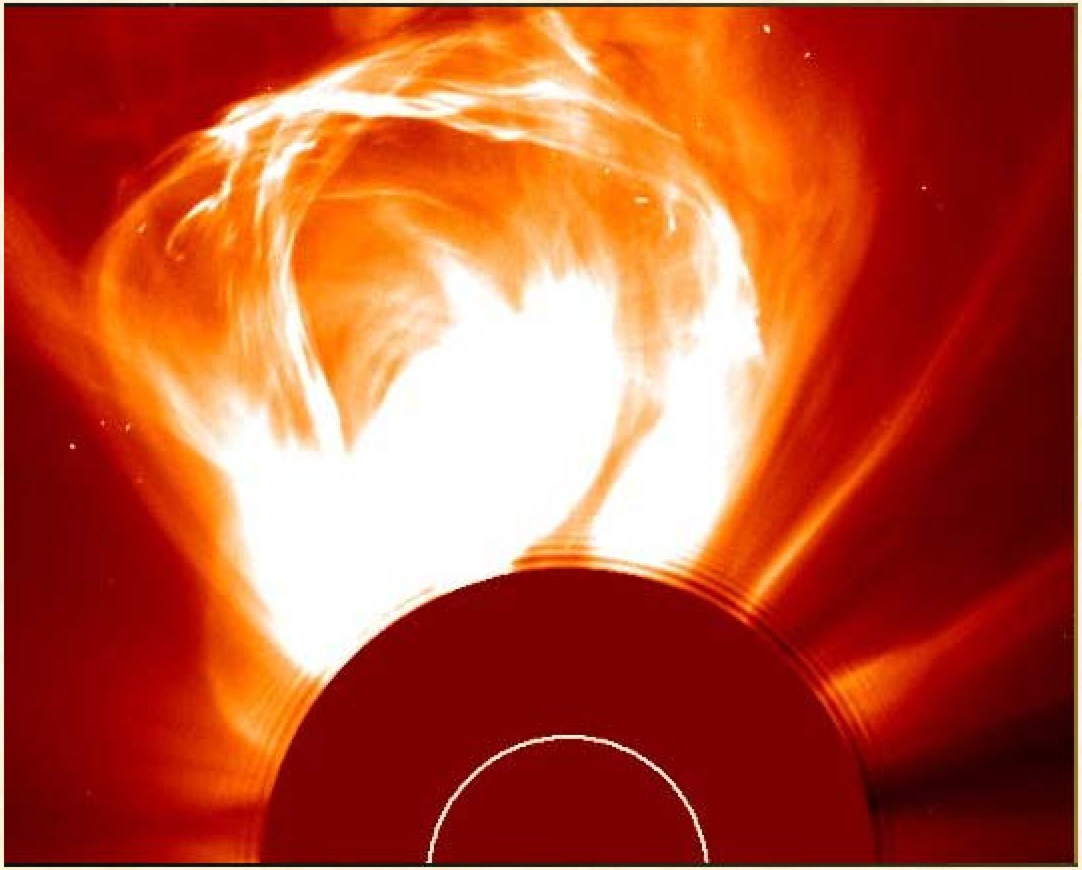
Where? What?
End point?

This talk:

Physics case UHEν
Measurement at highest E
(NuMoon & others)



Source – Solar Flare

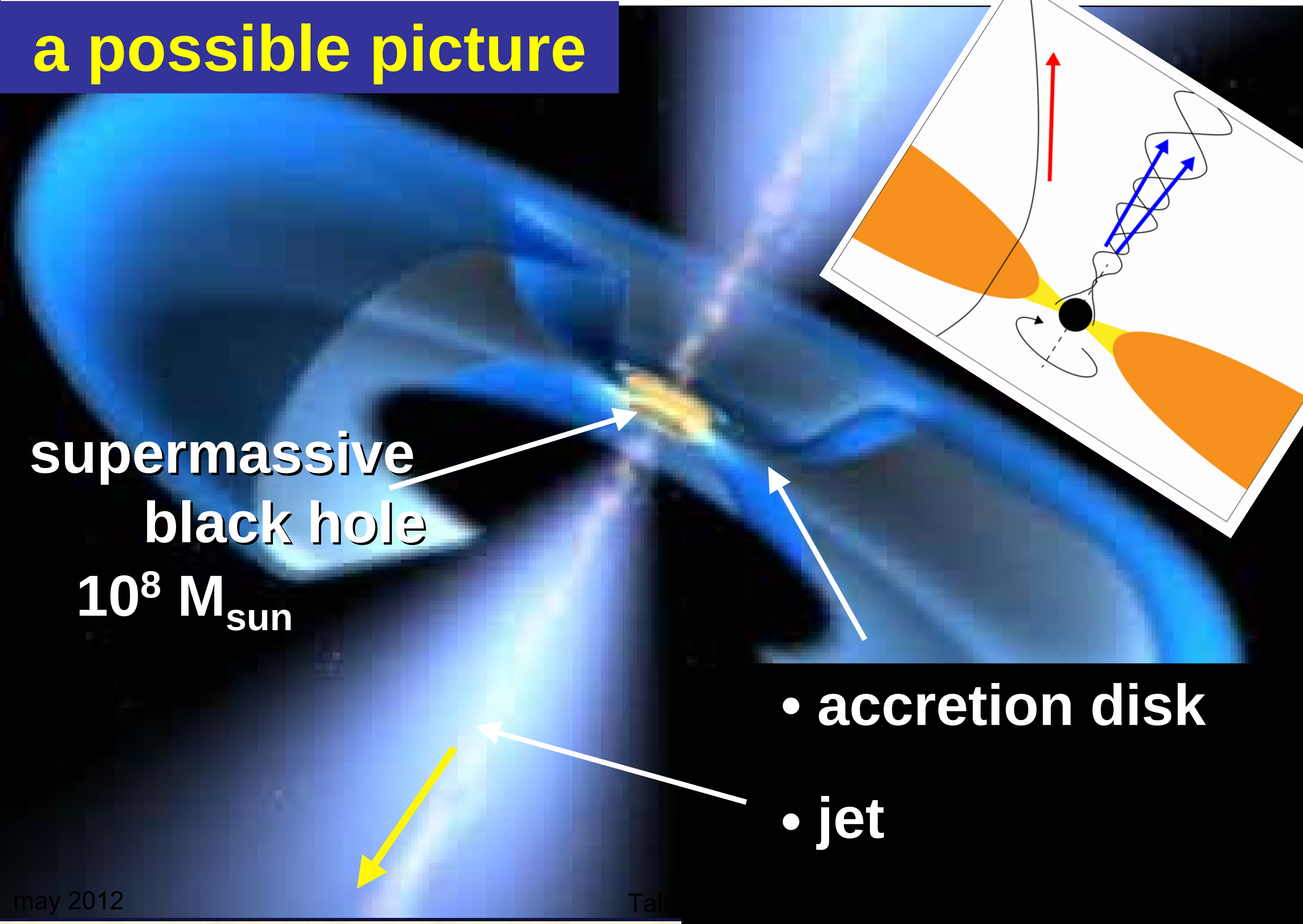


solar coronal mass ejection
→
10 GeV particles

flows of charged particles (plasmas) result in large B-fields

Source – Active Galactic Nucleus

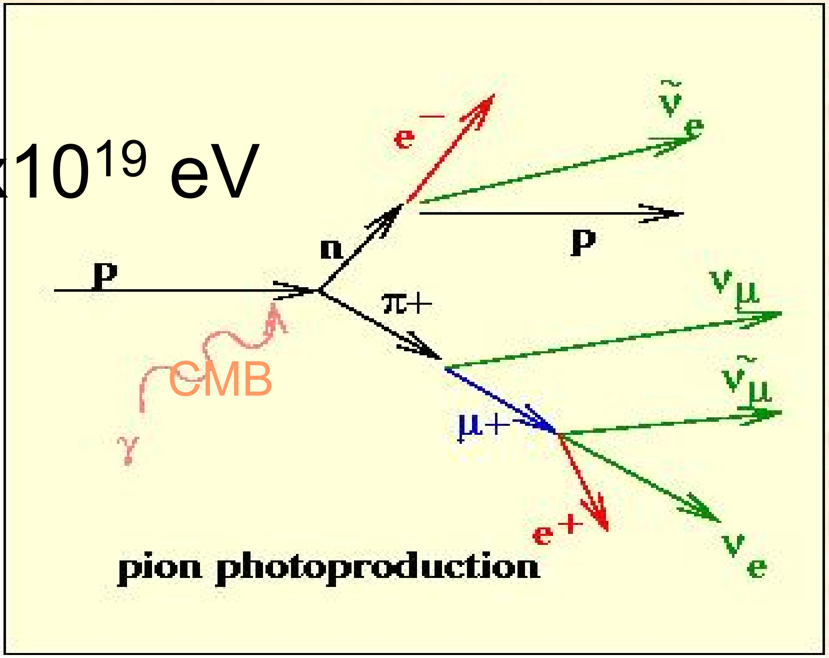
a possible picture



Transport:
Cosmic Microwave Background

Energetic protons loose energy through Interactions with the cosmic microwave background

E> $6x10^{19}$ eV

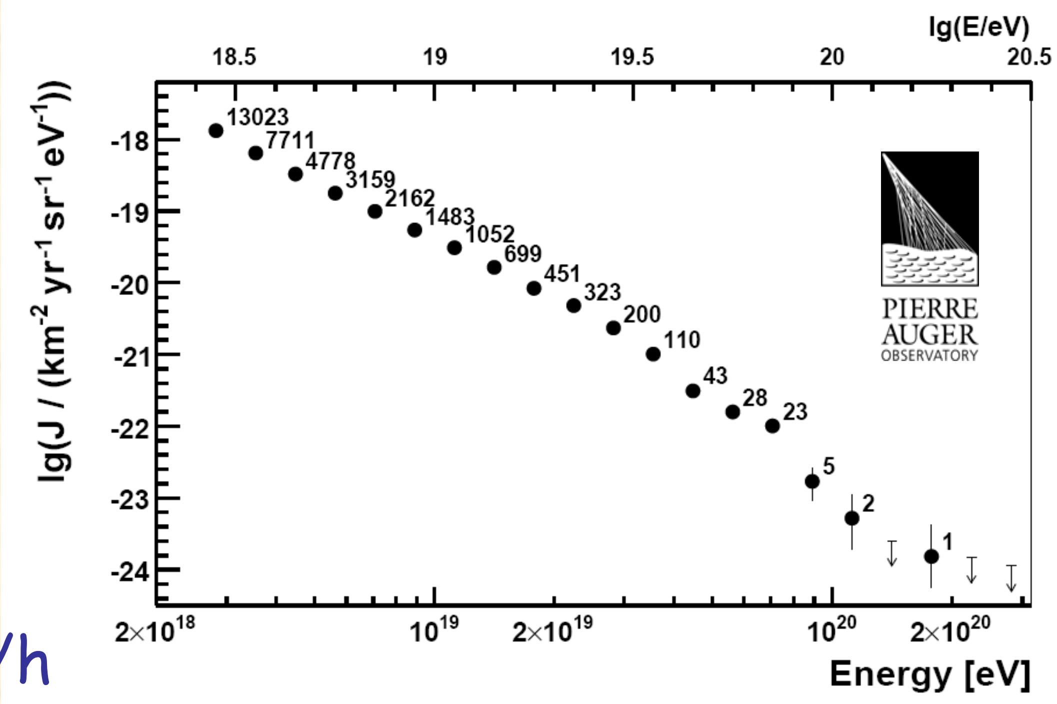


Based on Lorentz Invariance, What if …?

Production of Energetic Neutrinos

Greisen – Zatsepin – K'uzmin (GZK)

The Physics Case
Ultra-High Energy Cosmic Rays



- Production-acceleration mechanisms?

E=10^{19} eV ~ 50g@100km/h

- Intergalactic Transport (GZK) & Source produces neutrinos

Events have been seen above 10^{20} eV

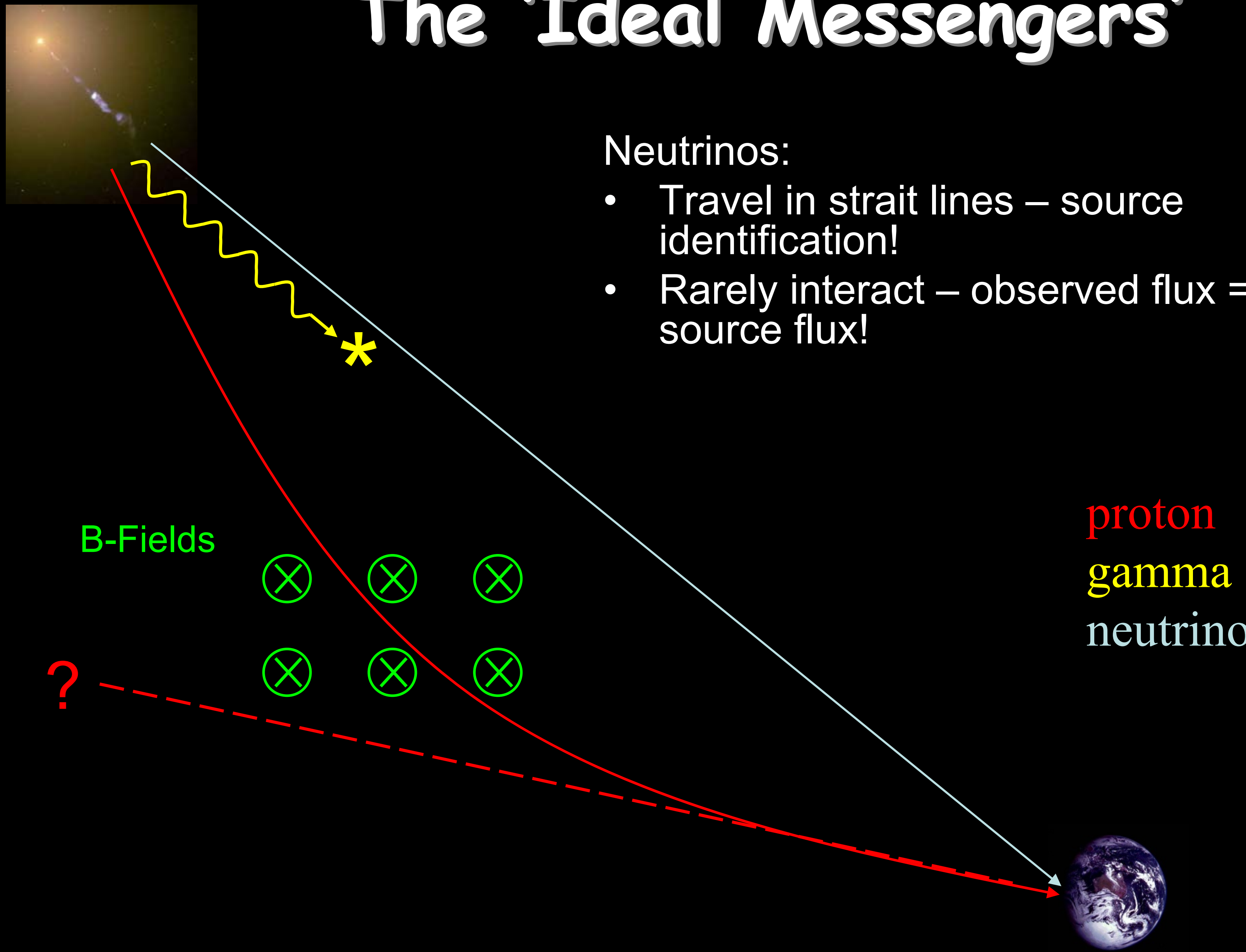
- Challenging rate: $\approx$ 1 / km^2 / sr / century above 10^{20} eV!

Go for neutrino detection

The 'Ideal Messengers'

Neutrinos:

- Travel in strait lines – source identification!
- Rarely interact – observed flux = source flux!



Cosmic ray & Neutrino Detection

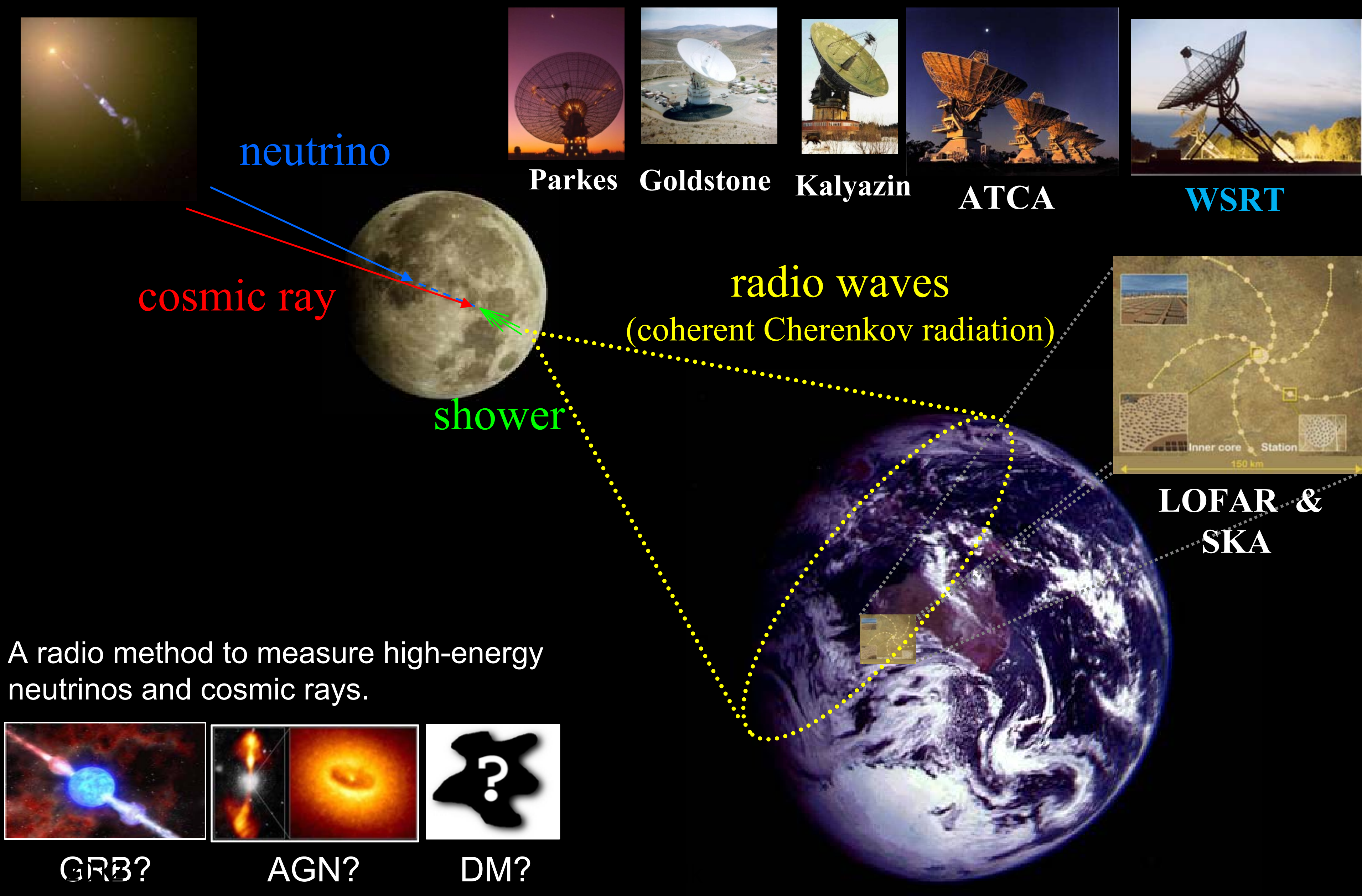
≈ 1 / km^2 / sr / century
above 10^{20} eV!

Think !

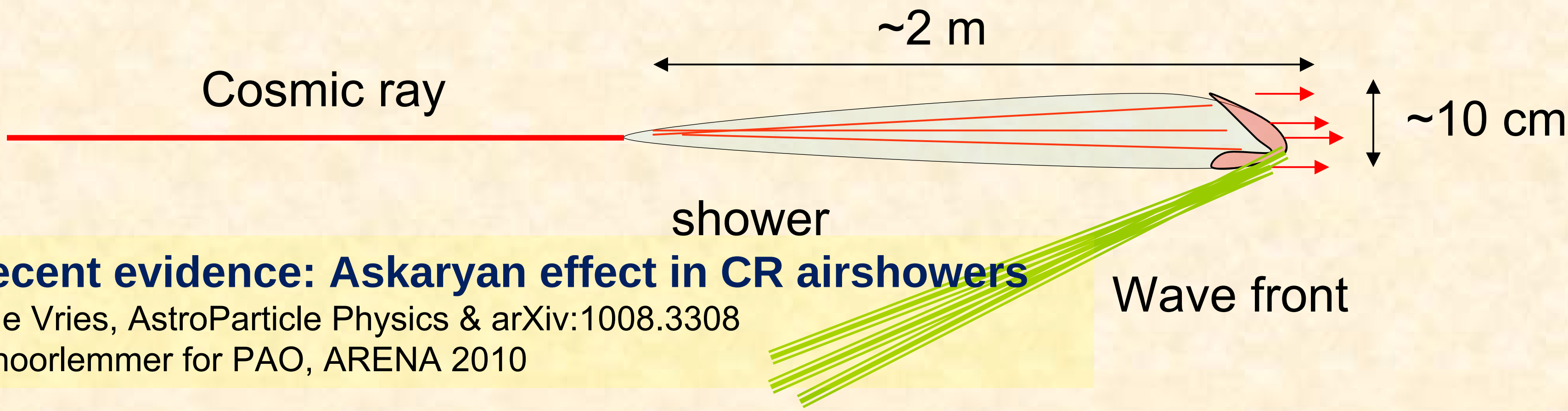
Not big enough for well beyond GZK !!

- **Icecube** **(Neutrinos)**
  – Ice Cherenkov, 1 k…
- **Antares**, KM3ne… …trinos)
  – Water Ch… …kov, 1 km^3
- **Pierr… …r Observatory** **(Cosmic rays)**
  – … showers, 3000 km^2

The Lunar Cherenkov Technique



Askaryan effect -2: Coherent Cherenkov emission



Recent evidence: Askaryan effect in CR airshowers

K.D. de Vries, AstroParticle Physics & arXiv:1008.3308

H. Schoorlemmer for PAO, ARENA 2010

Important magnitudes:

- Leading cloud of electrons, $v \approx c$

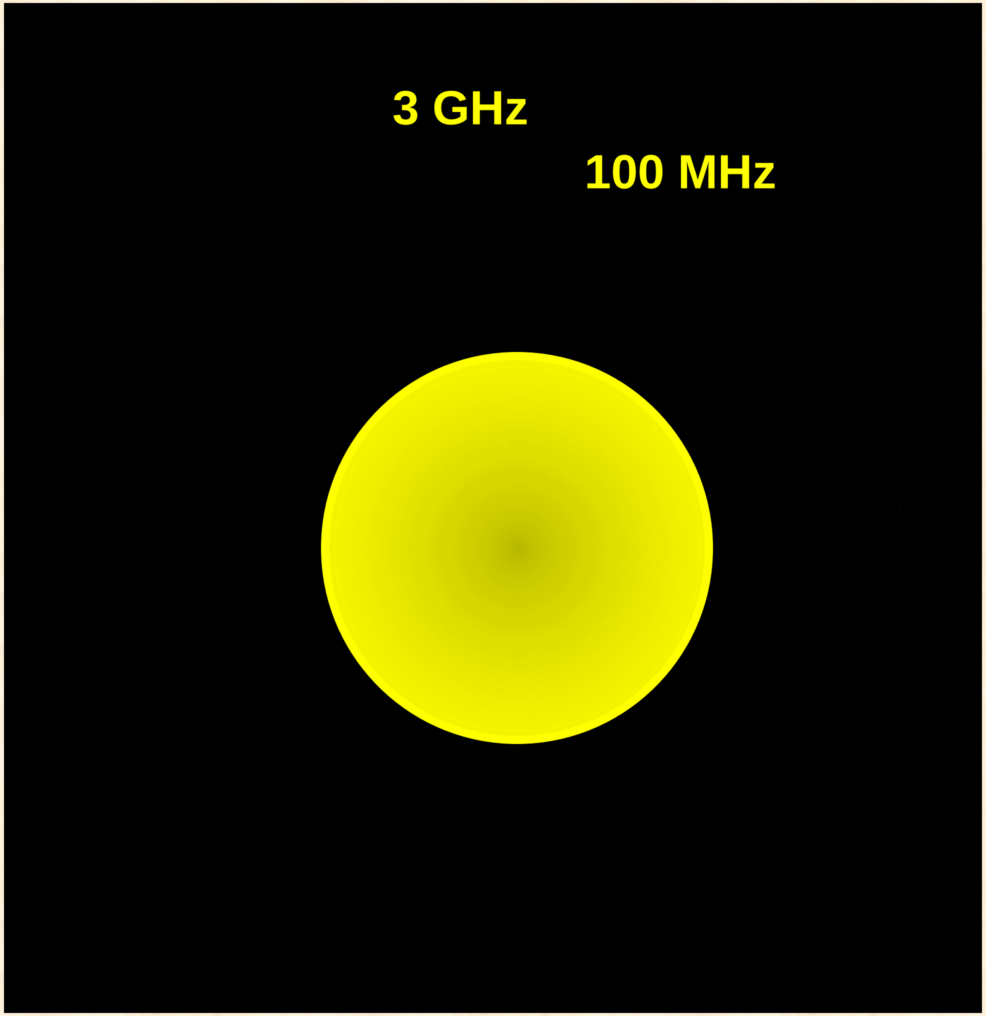
  Typical size of order 10cm

  Coherent Čerenkov for $\nu \leq$ 2-5 GHz

  $\cos\theta_c = 1/n$, $\theta_c = 56^o$ for ∞ shower length
- Length of shower, $L \approx$ 2-3 m

  strong angular spreading for $\nu \approx$ 100 MHz

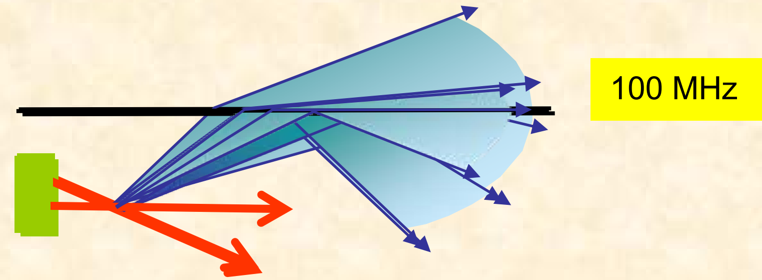
Cosmic rays, Position on Moon



O.S. et al, Astropart.Phys. 26 (2006) 219

Calculations for

E_{cr}=4 10^{21} eV



With decreasing ν

rim **inside**

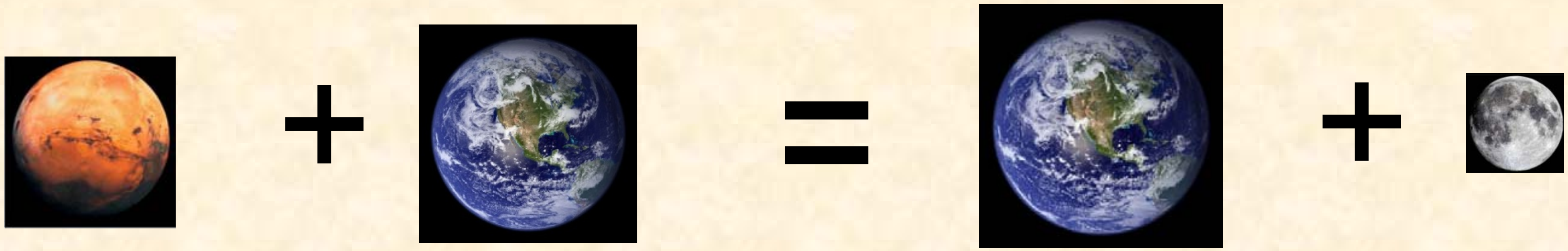
increasing probability:

$\int$ over surface Moon

Detection probability $\propto \nu^{-3}$

Lunar History

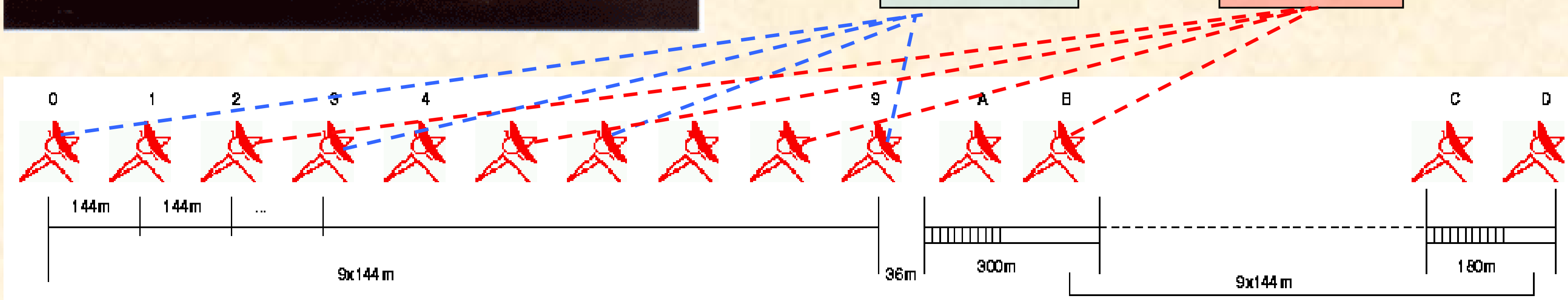
- Probably formed from Mars-sized impact on the Earth.



- Lunar ‘magma ocean’ gradually cooled to produce an extremely uniform, differentiated crust (>20km depth).
- The solid crust is subjected to a late, heavy bombardment, forming huge impact basins.
- Nearside basins fill with lava to form mare.
- Local surface pulverised to form regolith…

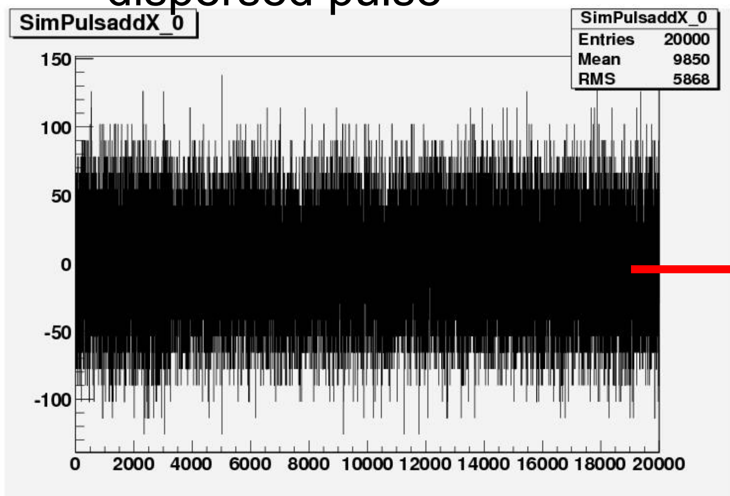
NuMoon Experiment @ WSRT

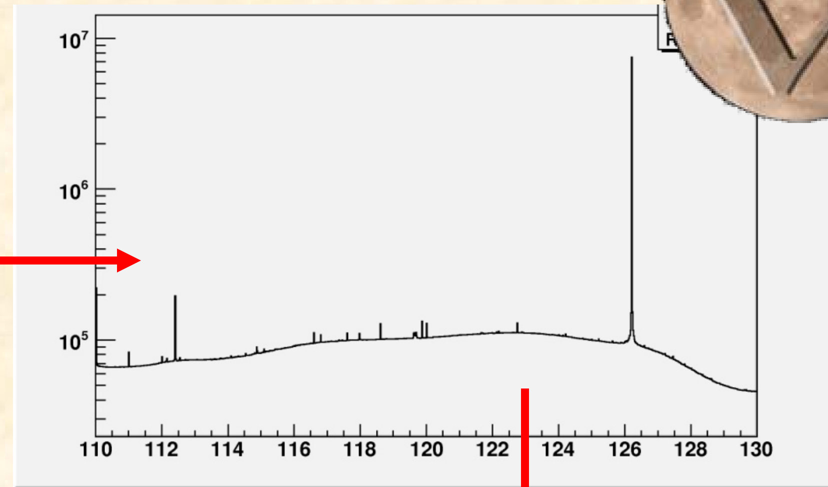
Use Westerbork radio observatory



11 dishes of 25 m diameter, 110-175 MHz band

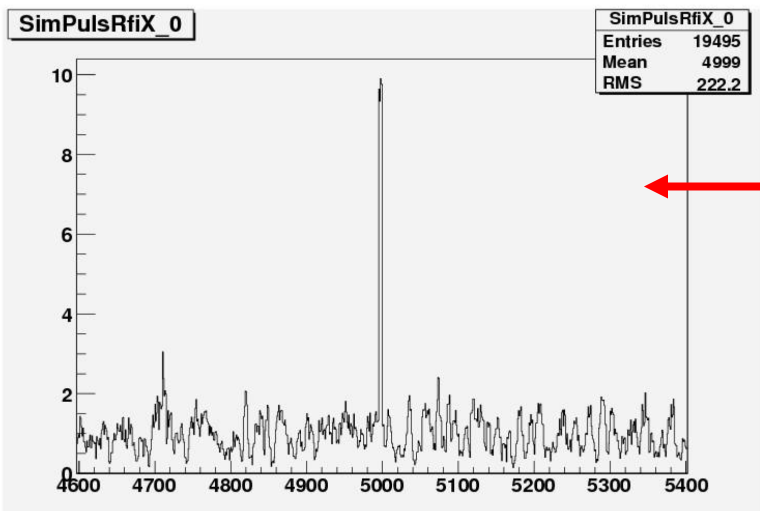
dispersed pulse

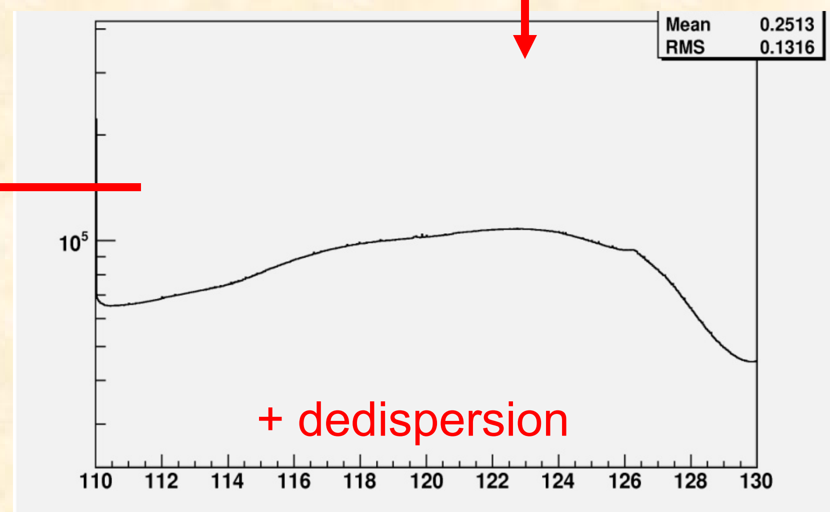




time →

frequency →

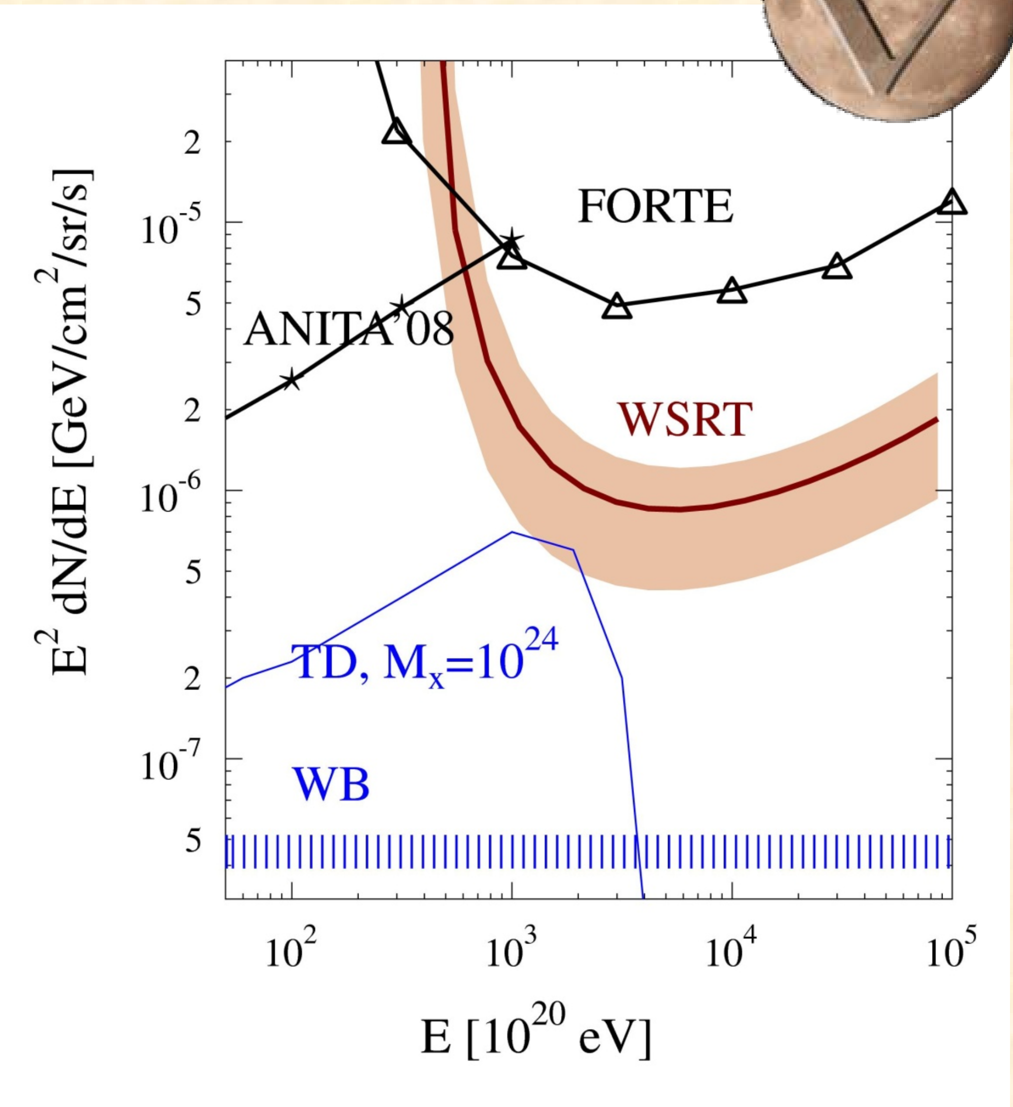




pulse visible after dedispersion

Trigger: 4σ pulse in all four frequency bands

Results WSRT observations



No pulse of 240kJy seen in 46.7 h data

→

90% confidence limit on neutrino flux

O.S. et al, PRL 103 (2009) 191301

Buitink, et al, A&A 521, A47 (2010).

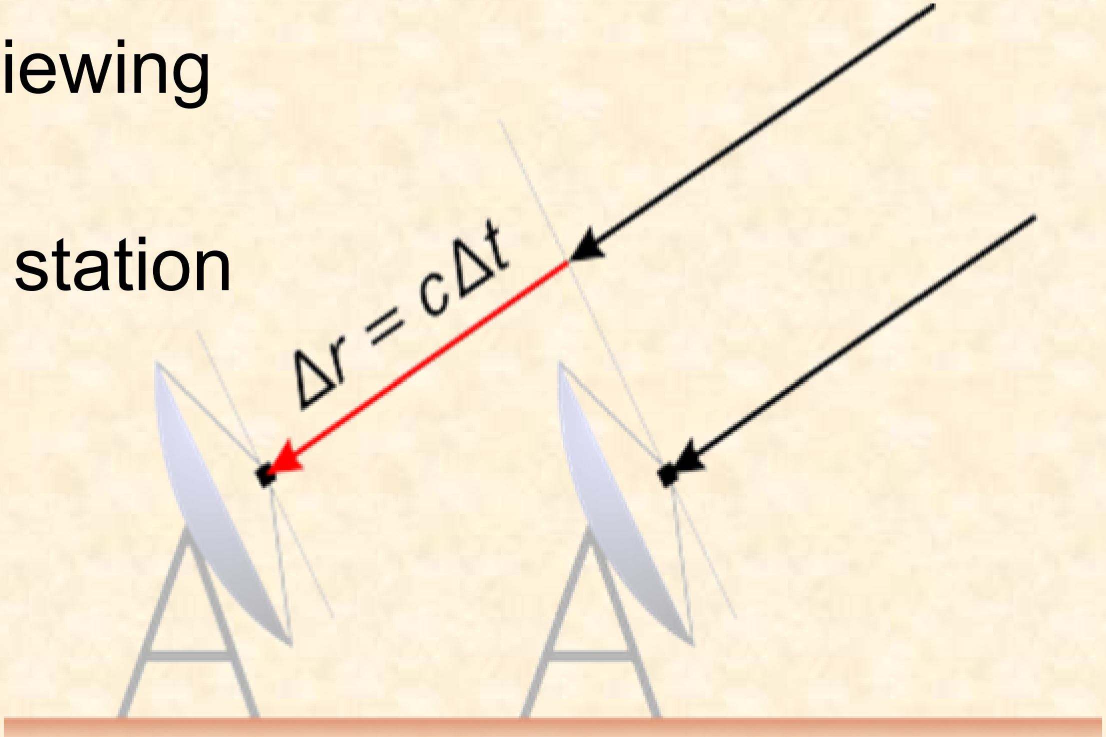
NuMoon Experiment @ LOFAR

New generation of radio-telescopes, many (3000) simple wire antennas

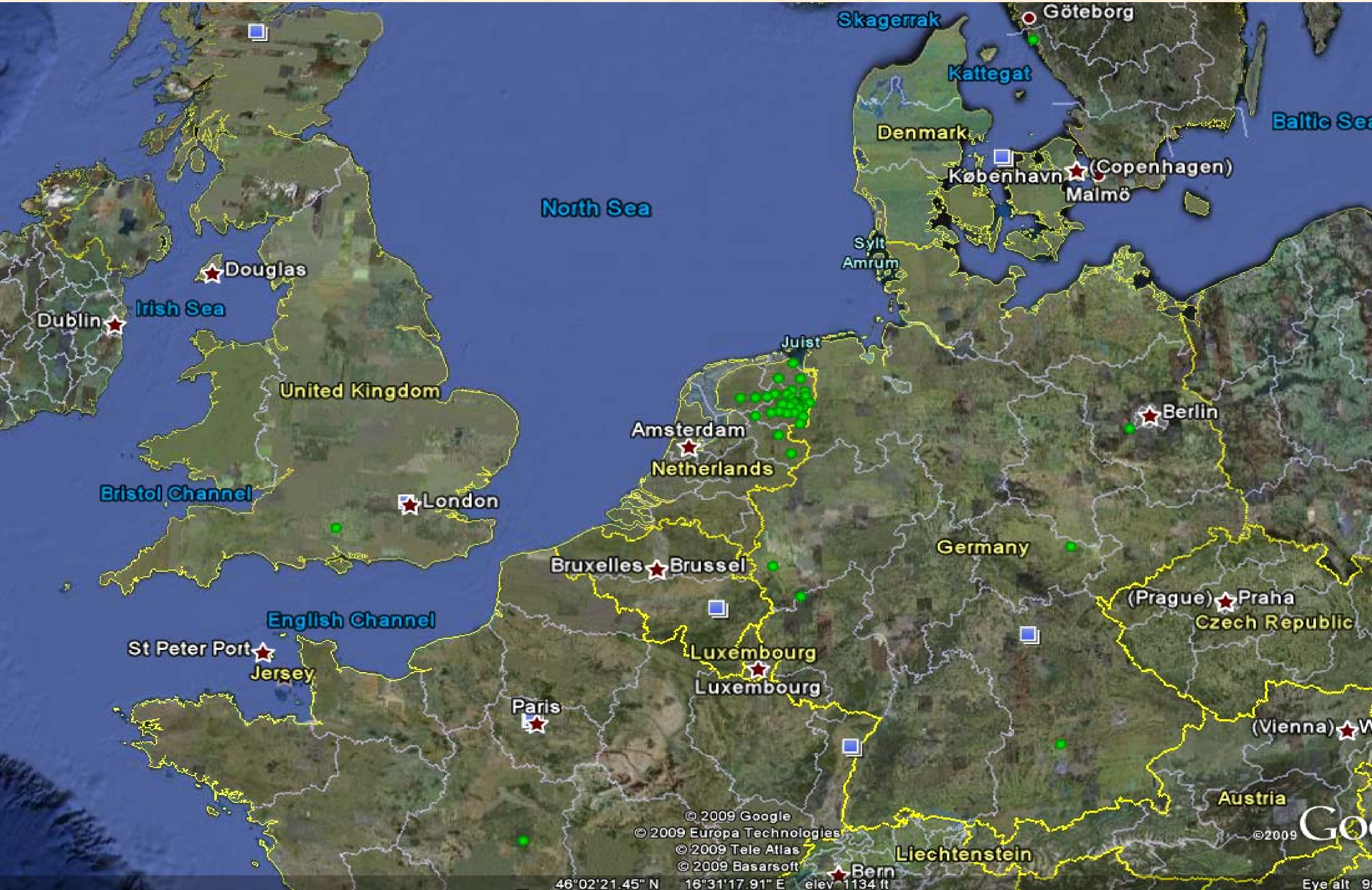
- Total collecting area ≈ 0.25 km^2
- Cover whole moon,
- Sensitivity 25 times better than WSRT.
- Band: 115-240 MHz
- Multiple tied-array beams

New generation telescopes: software beamforming

- Coherently add signal of antennas
- Delay determines viewing direction
- Multiple beams per station possible

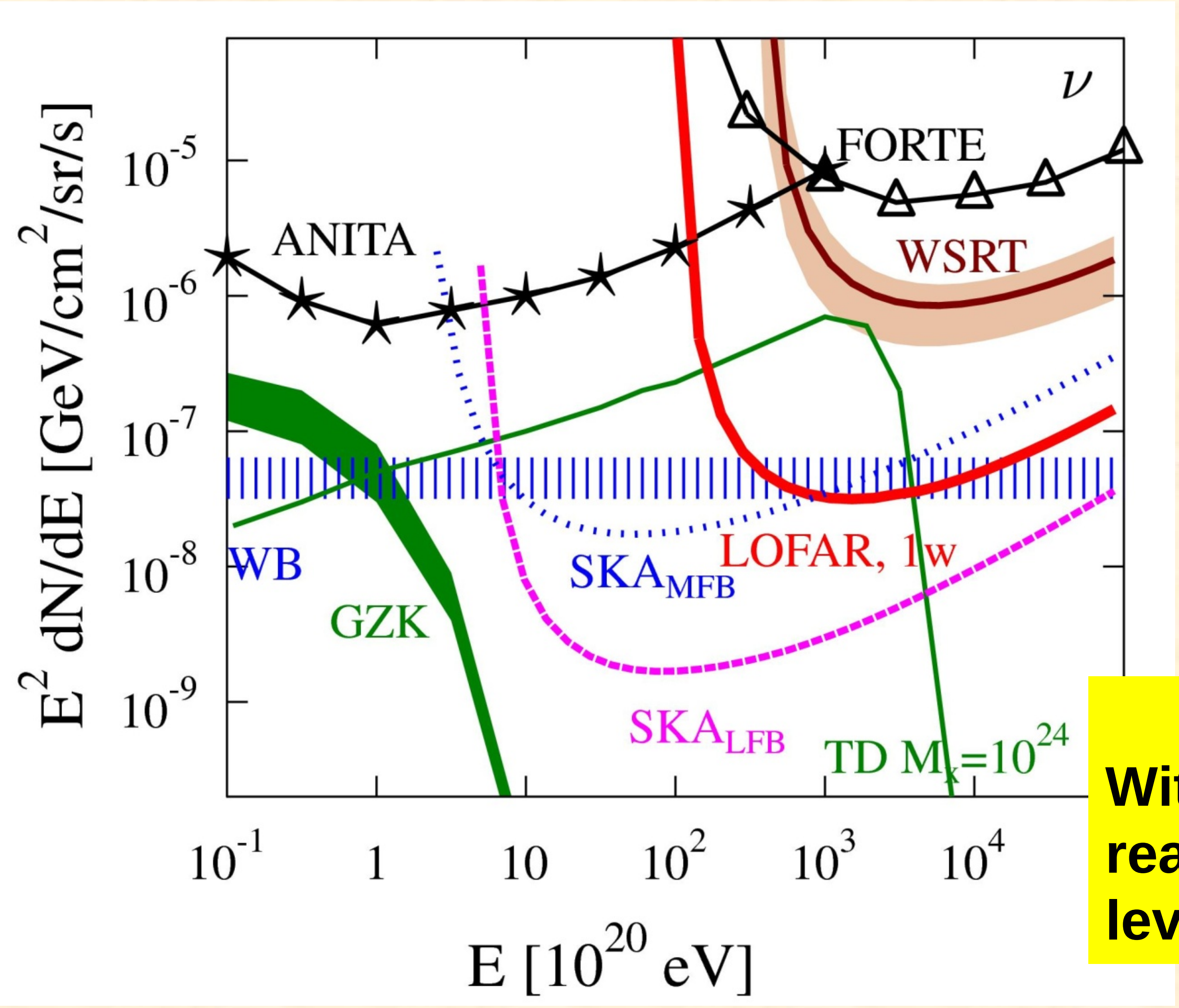


elofar



Skagerrak
Göteborg
Kattegat
Baltic Sea
Denmark
København
(Copenhagen)
Malmö
North Sea
Sylt
Amrum
Douglas
Irish Sea
Dublin
Juist
United Kingdom
Amsterdam
Berlin
Netherlands
Bristol Channel
London
Germany
Bruxelles
Brussel
(Prague)
Praha
Czech Republic
English Channel
St Peter Port
Jersey
Luxembourg
Luxembourg
Paris
(Vienna)
Austria
© 2009 Google
© 2009 Europa Technologies
© 2009 Tele Atlas
© 2009 Basarsoft
Liechtenstein
Bern
46°02'21.45" N
16°31'17.91" E
elev 1134 ft

Neutrinos

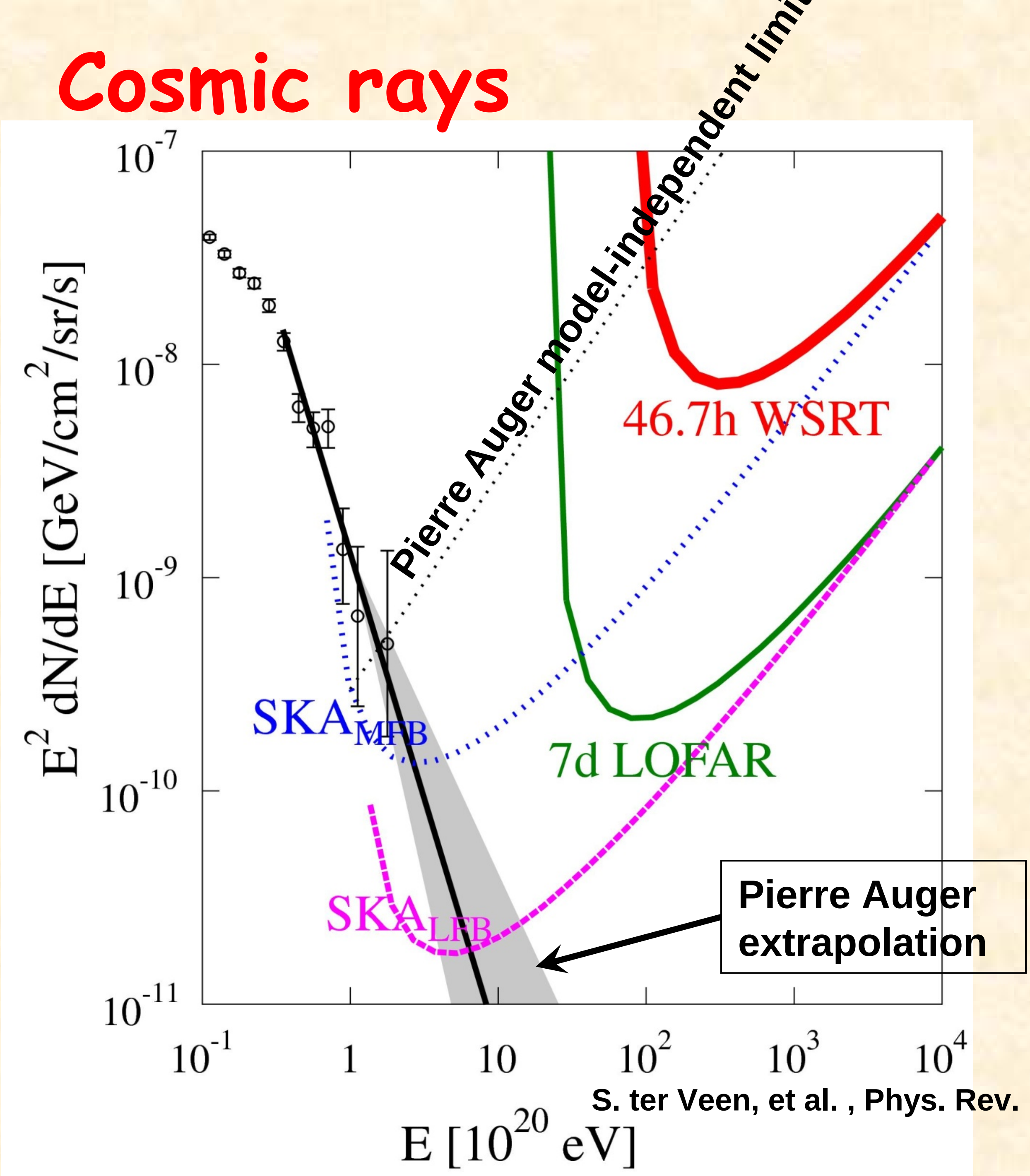


LOFAR, 1 week

Conclusion:

With LOFAR able to reach sensitivity level W-B estimate

Cosmic rays



S. ter Veen, et al. , Phys. Rev. D 82, 103014 (2010).

Conclusions

NuMoon @ WSRT: New limit for E > 10^{23} eV

NuMoon @ LOFAR: Sensitive to W-B flux

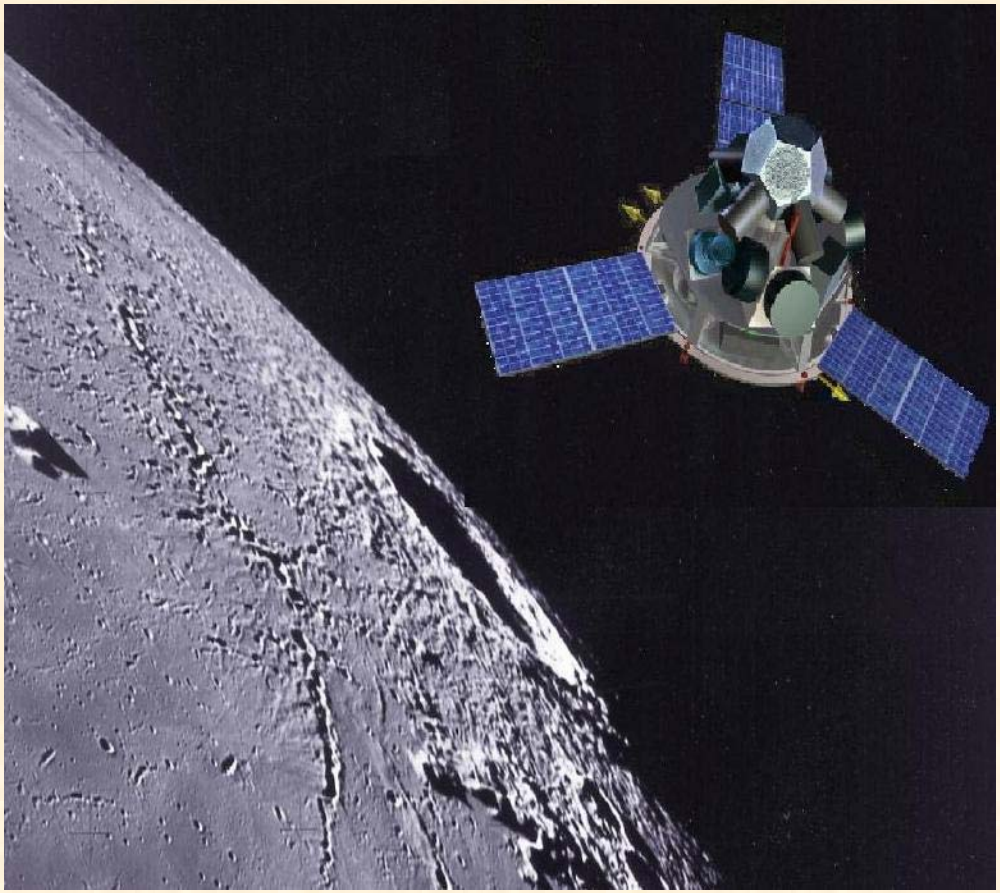
Thank you Franco,
for showing that beauty in physics
lies in its simplicity

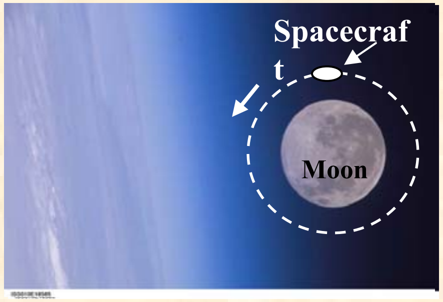
NuMoon collaboration:

O.S., Stijn Buitink, Heino Falcke , Clancy James, Maaijke Mevius, Ben Stappers, Kalpana Singh, Richard Strom , Sander ter Veen

LORD

Lunar Orbiter for Radio Detection

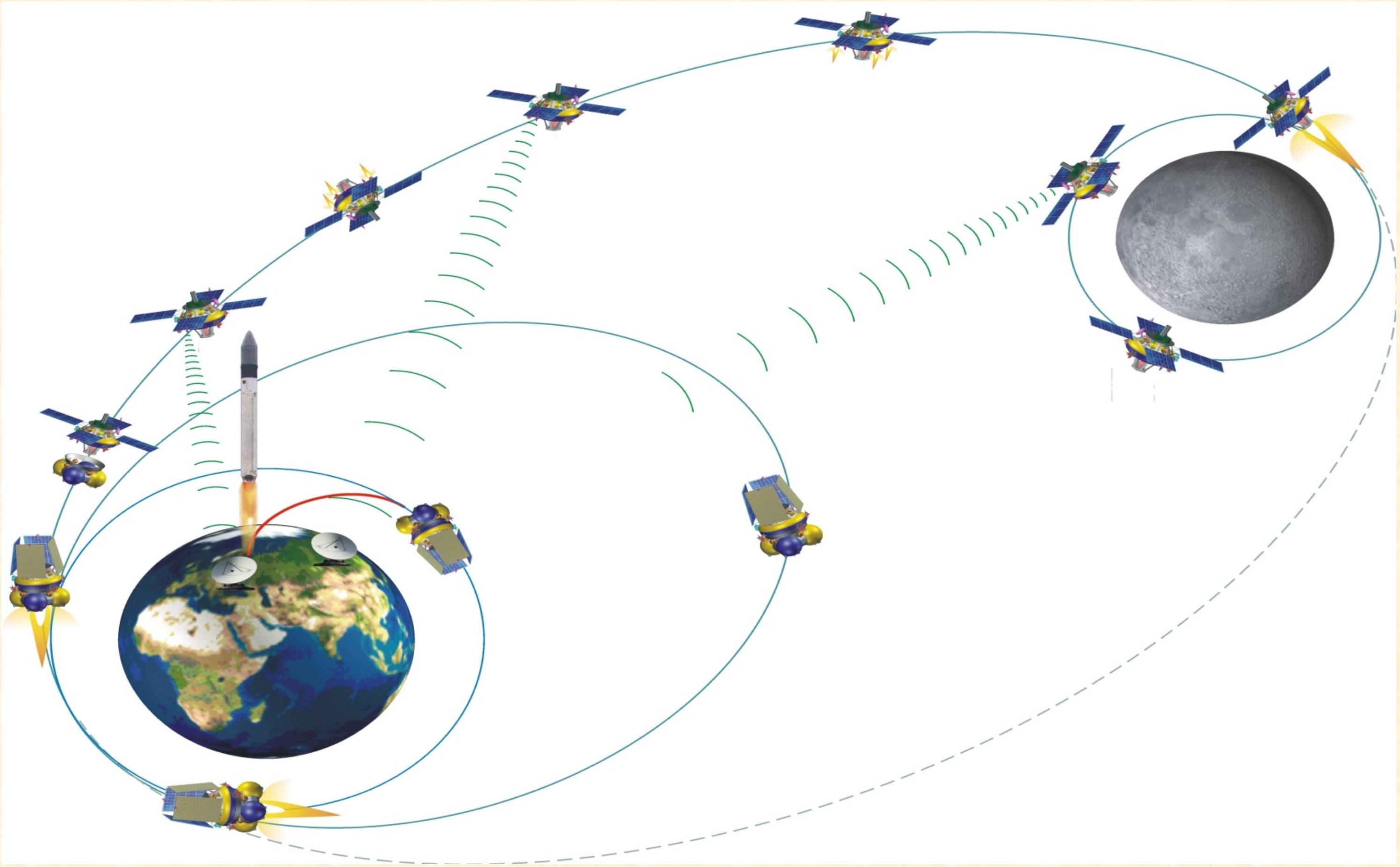




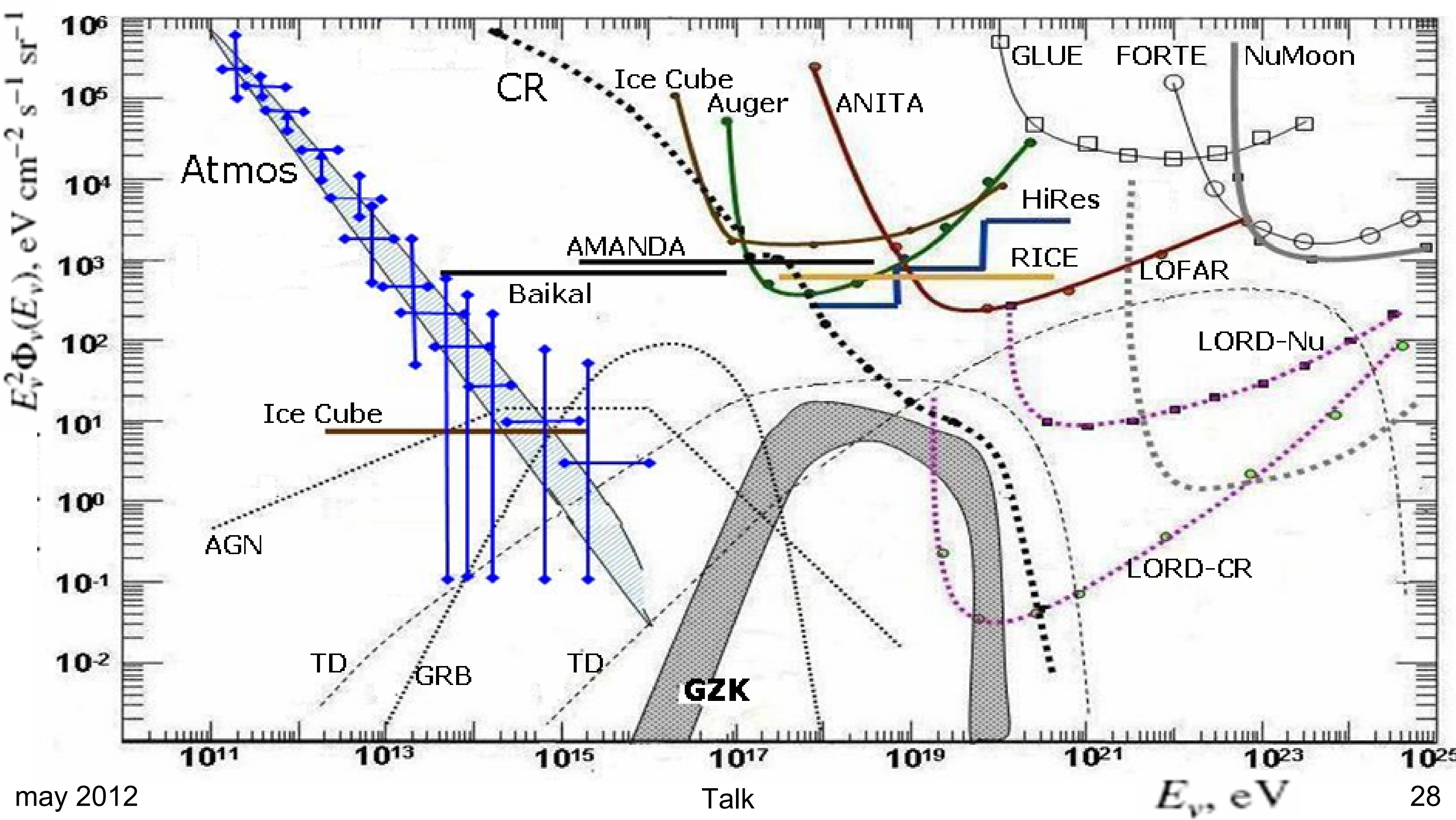
- **Height of orbit – 500-700 km**
- **Exposition Time ~ 2 years**
- **Energy range of particles detection > 10^{20}eV**

LORD

Expected “Luna-Globe” launch 2012



Limits for CR and Neutrino Fluxes



Experimental Hurdles

Triggering

- η sec time resolution
- Data rates too high for baseband recording: we must search for pulses in real time
- This requires fast (η sec) trigger logic

Sensitivity

- Coherent addition of signals from:
  - A large collection area
  - A wide bandwidth
- Large antenna will only see a fraction of the Moon – use many small dishes or PAF
- Significant beamforming requirements

RFI Discrimination

- Some terrestrial RFI still appears as a η sec pulse
  - car engines
  - internal electronics
  - unknown sources???
- How to determine real events with a few nanoseconds of data?

Ionospheric Dispersion

- The Earth's ionosphere smears our signals & destroys the coherency
- This drastically reduces sensitivity
- We must correct for this in real time!

Theoretical Hurdles

Maximising Sensitivity

- Do we point at the centre of the Moon or at the limb?
- What frequency to use?
- What dish size?

Directionality

- To which directions are we most sensitive?
- What parts of the sky currently have low limits?

Cosmic Rays

- These generate showers very similar to that of neutrinos.
- Are the differences important?

Reconstruction

- If we see a signal, what was the primary particle
  - Type (CR or nu)?
  - Energy?
  - Arrival direction?

Surface Roughness

- The Moon is rough on all size scales: large (hills, craters) and small (rocks & perturbations ~ 1 wavelength)
- These effects are currently not well modelled.