



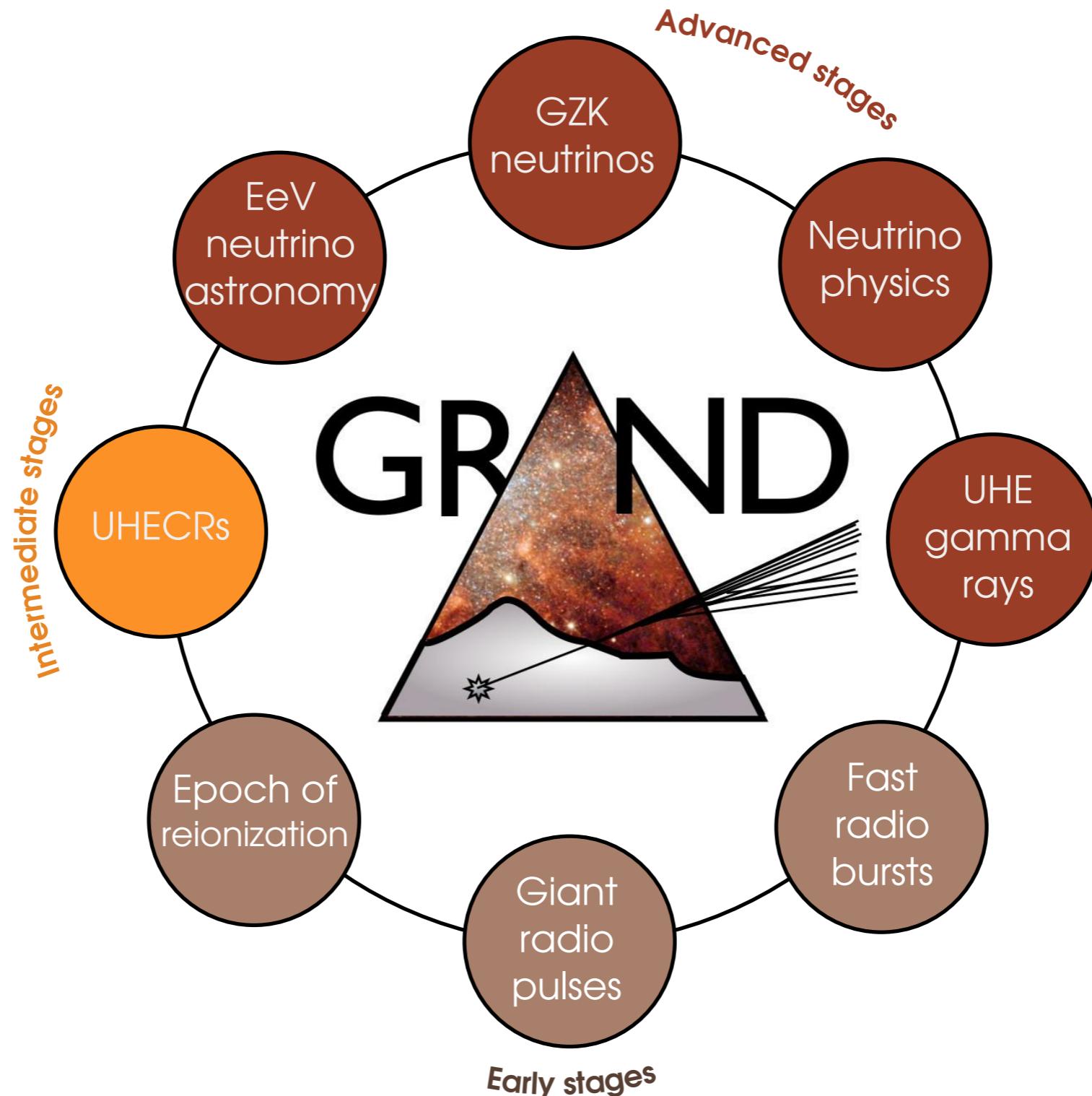
# the giant radio array for neutrino detection (**GRAND**)

**Rafael Alves Batista**

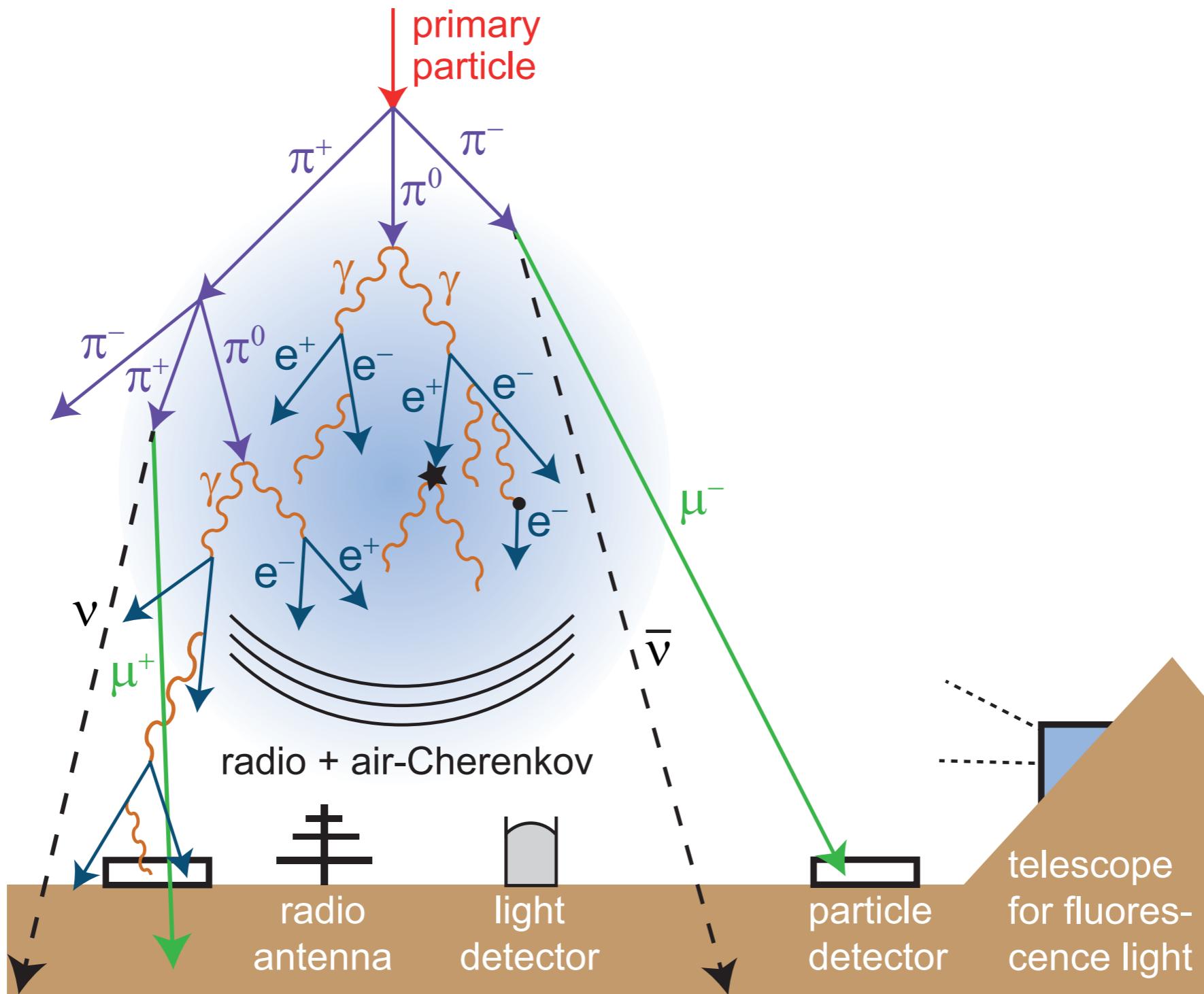
**Universidade de São Paulo  
(IAG/USP)**

[rafael.ab@usp.br](mailto:rafael.ab@usp.br)

São Paulo  
31/07/2018



# detection of extensive air showers

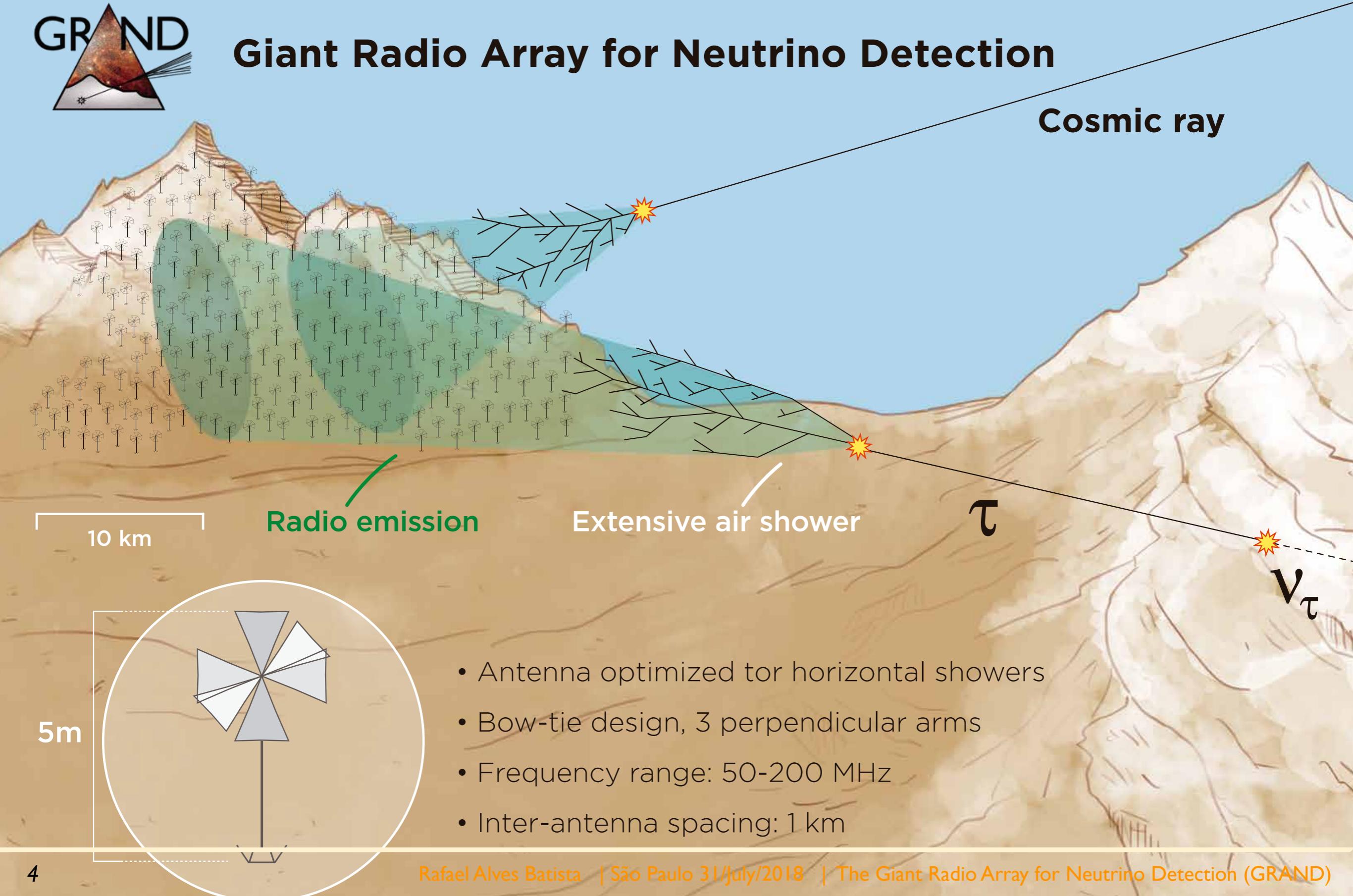


Taken from: F. Schröder. Prog. Part. Nuc. Phys. 93 (2017) 1

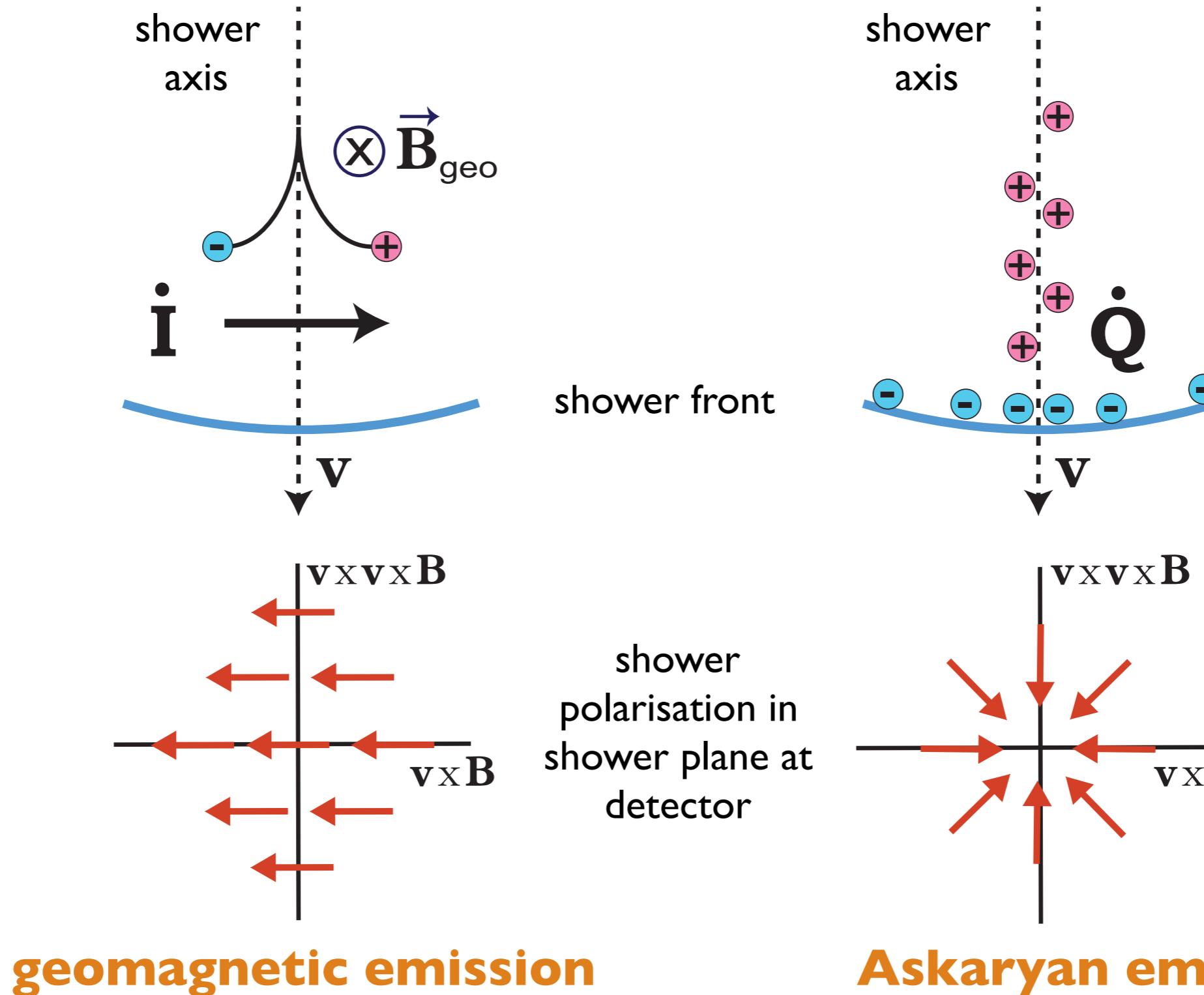
# how does GRAND work?



## Giant Radio Array for Neutrino Detection



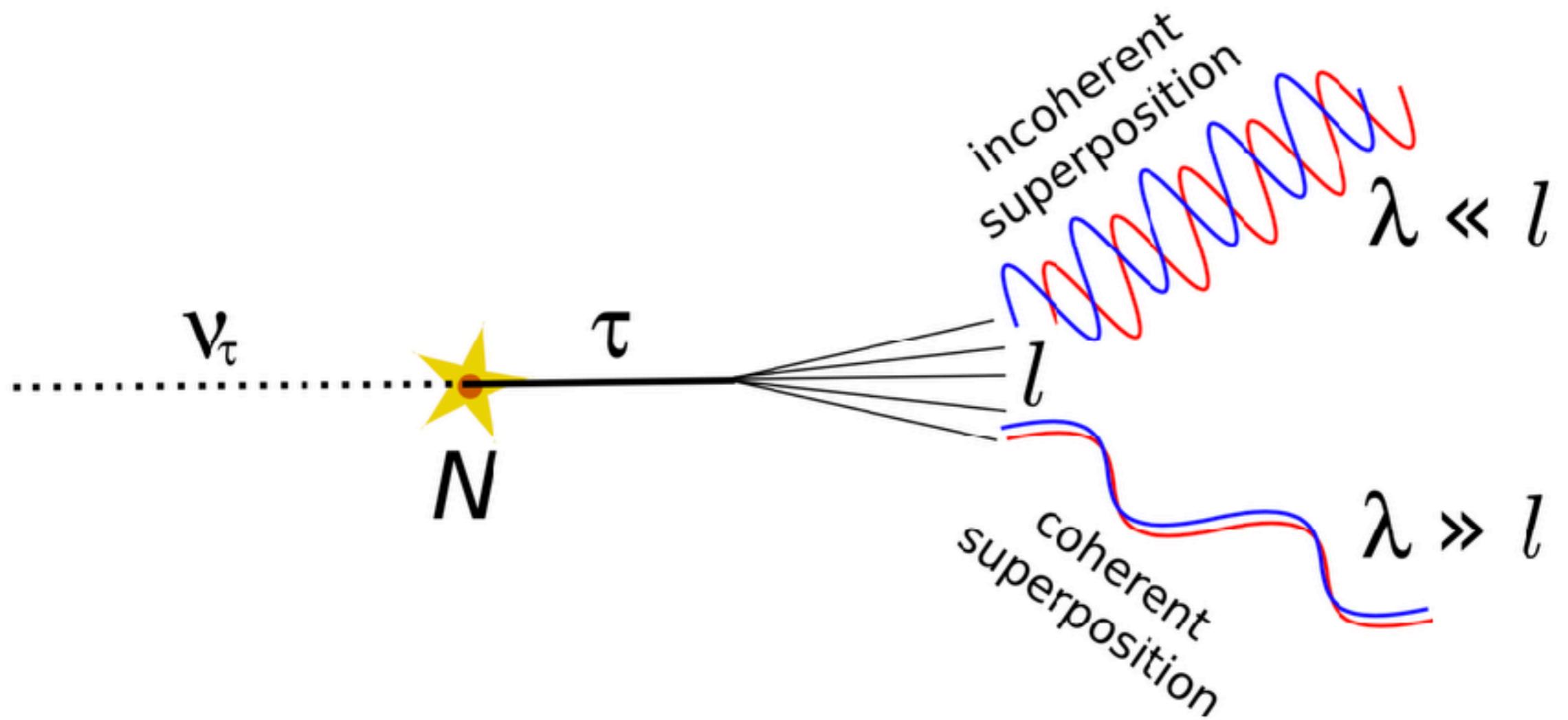
# how does GRAND work?



Adapted from: F. Schröder. Prog. Part. Nuc. Phys. 93 (2017) 1

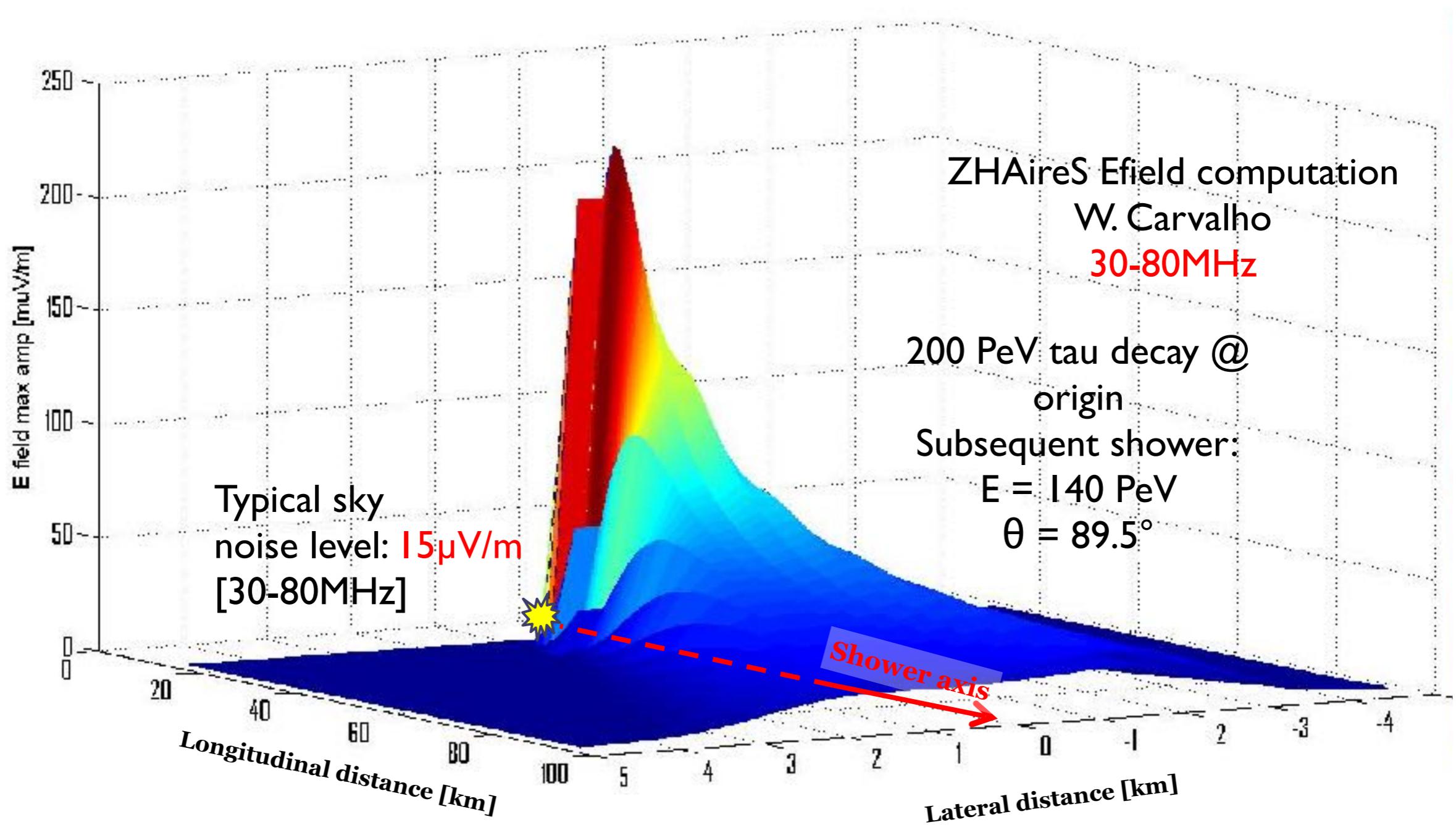
# how does GRAND work?

- ▶ the shower is compact ( $\sim 1$  cm thick and a few cm wide)
- ▶ emission is coherent at radio frequencies



credits: M. Bustamante

# horizontal EAS radio emission



# radio detection of inclined showers

- ▶ footprint increases with zenithal angle
- ▶ detectable at distances  $\sim$ km
- ▶ sparse array can cover large area
- ▶ antennas are "cheap"!
- ▶ radio is the best technique to study Earth-skimming neutrinos

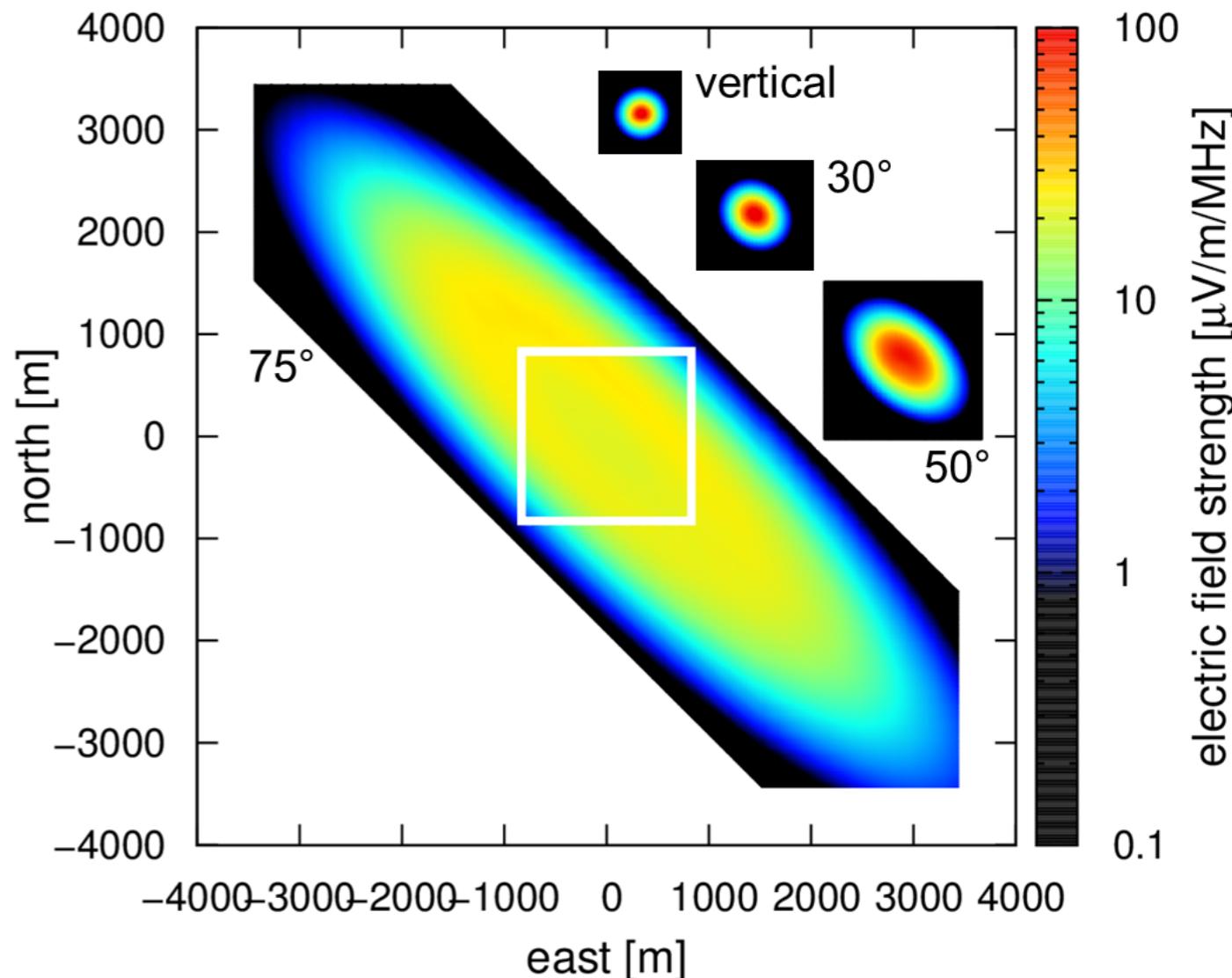
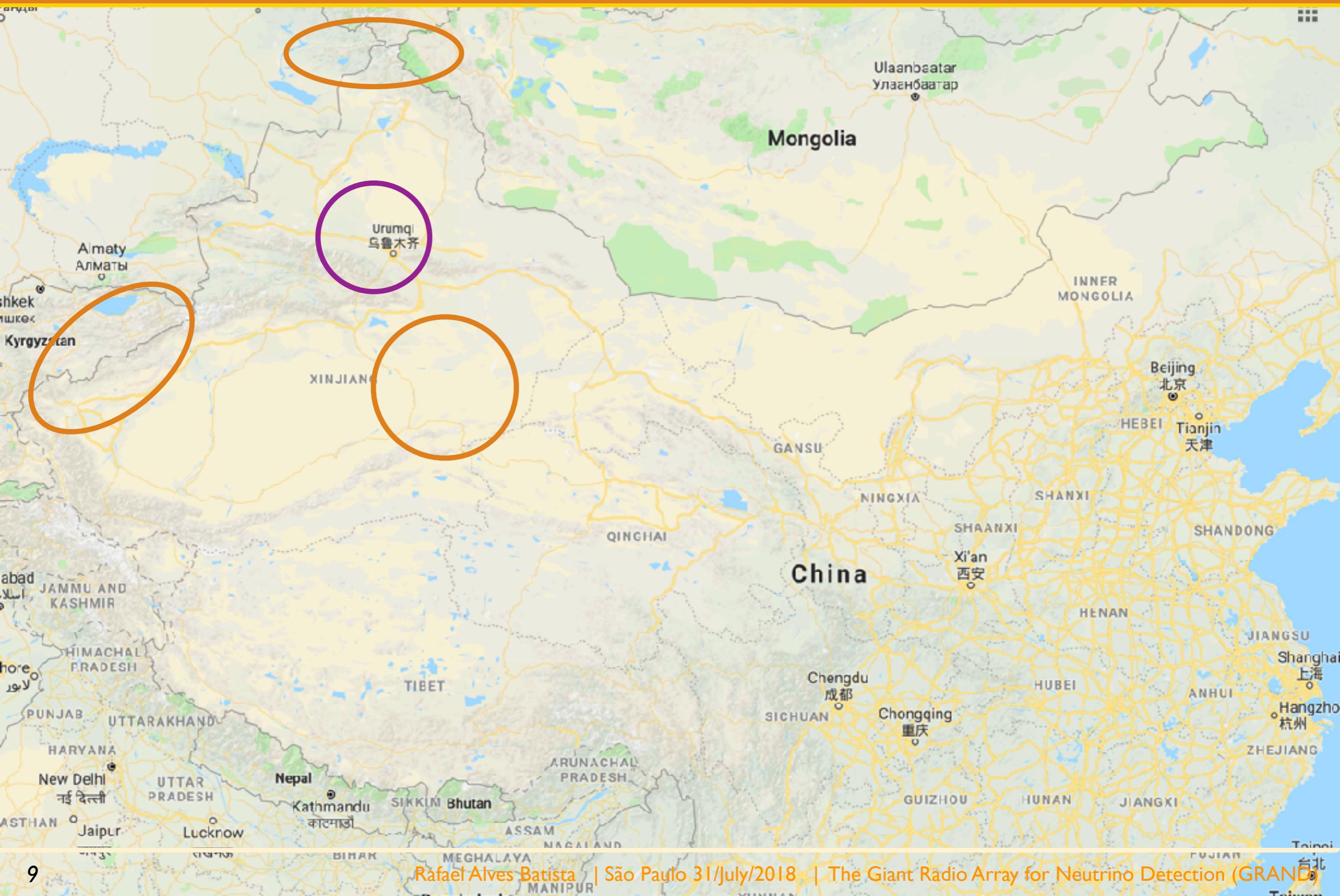


Figure taken from T. Huege, A. Haungs. JPS Conf. Proc. 9 (2016) 01001

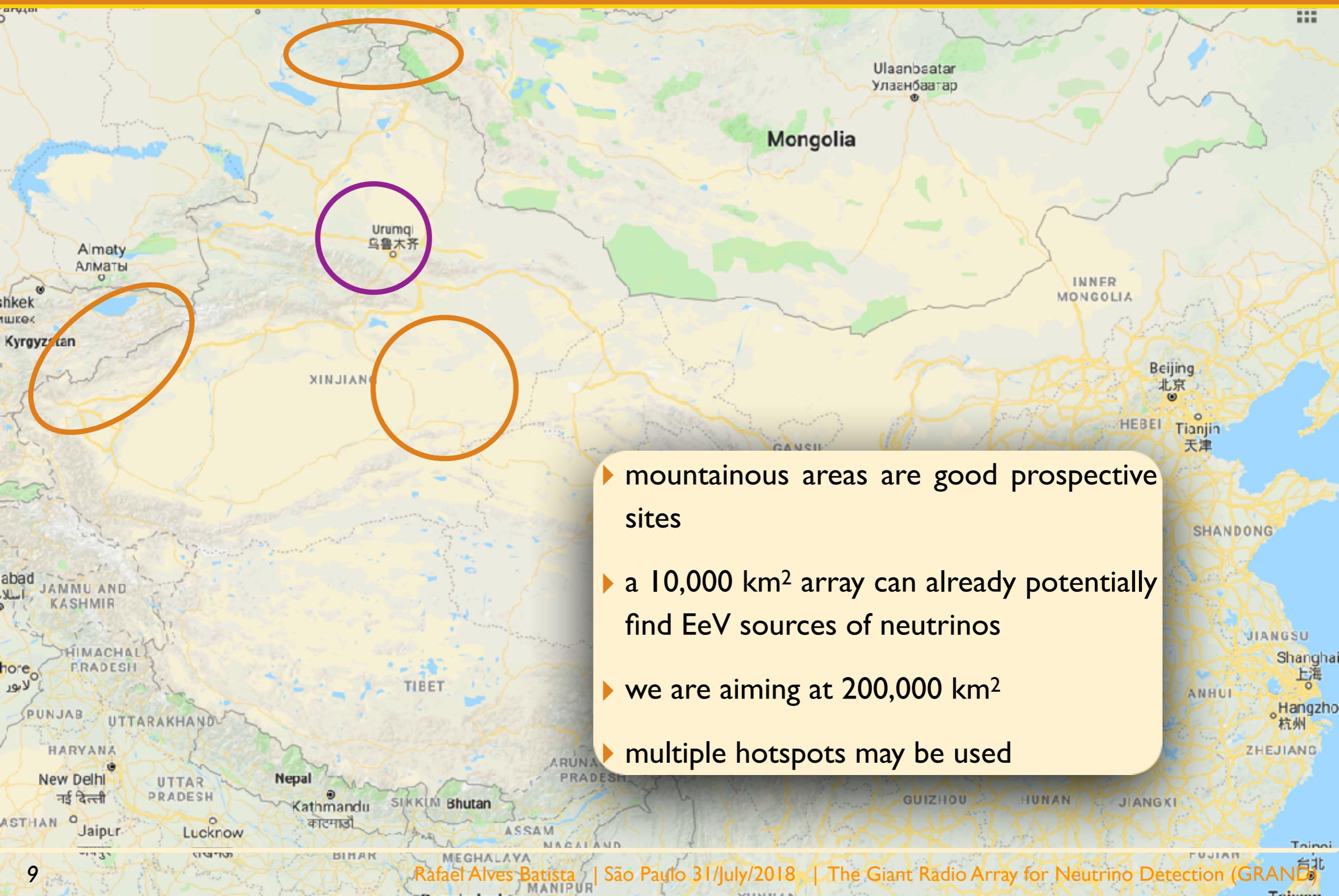
# prospective sites



# prospective sites



# prospective sites

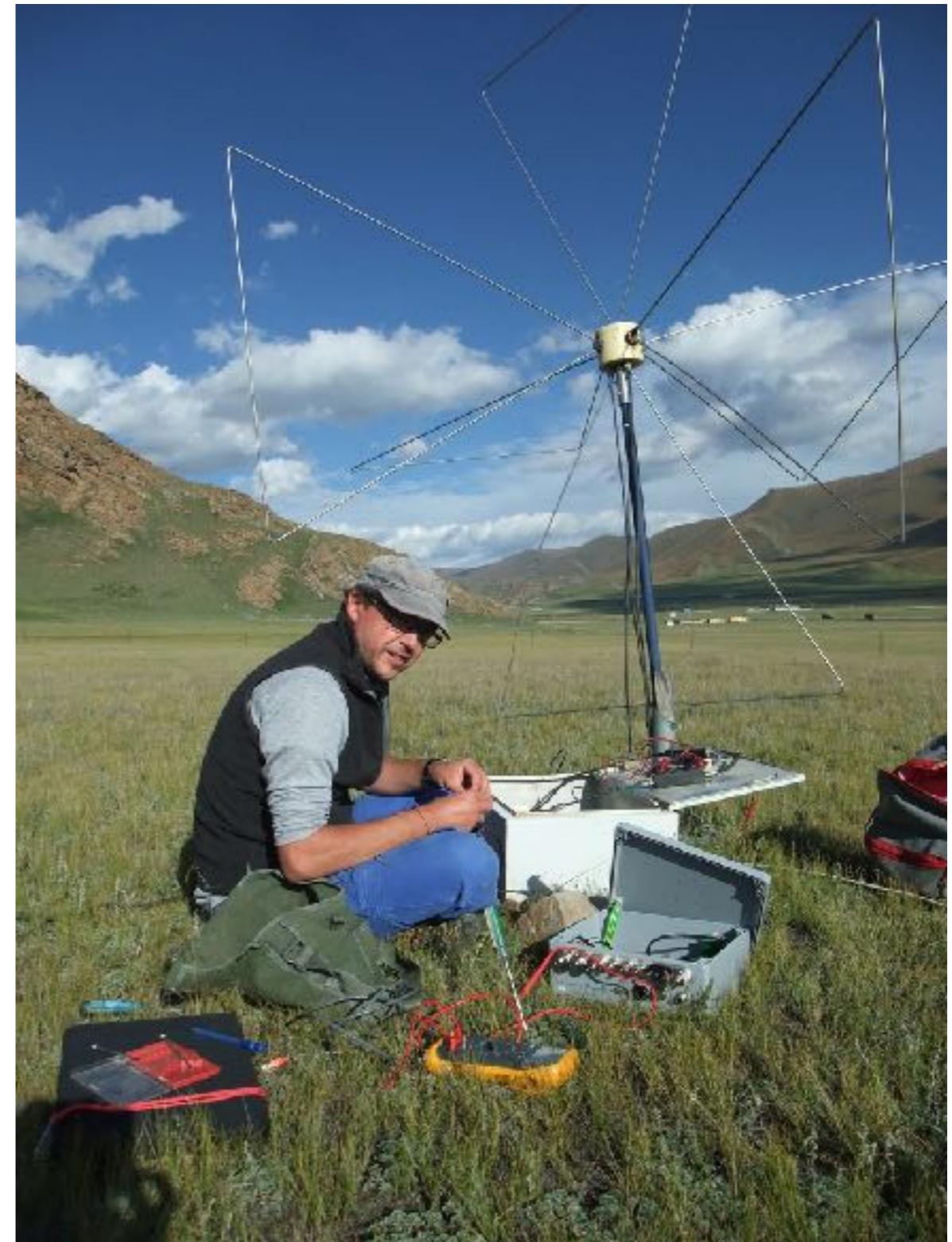


# GRAND's forefather: TREND

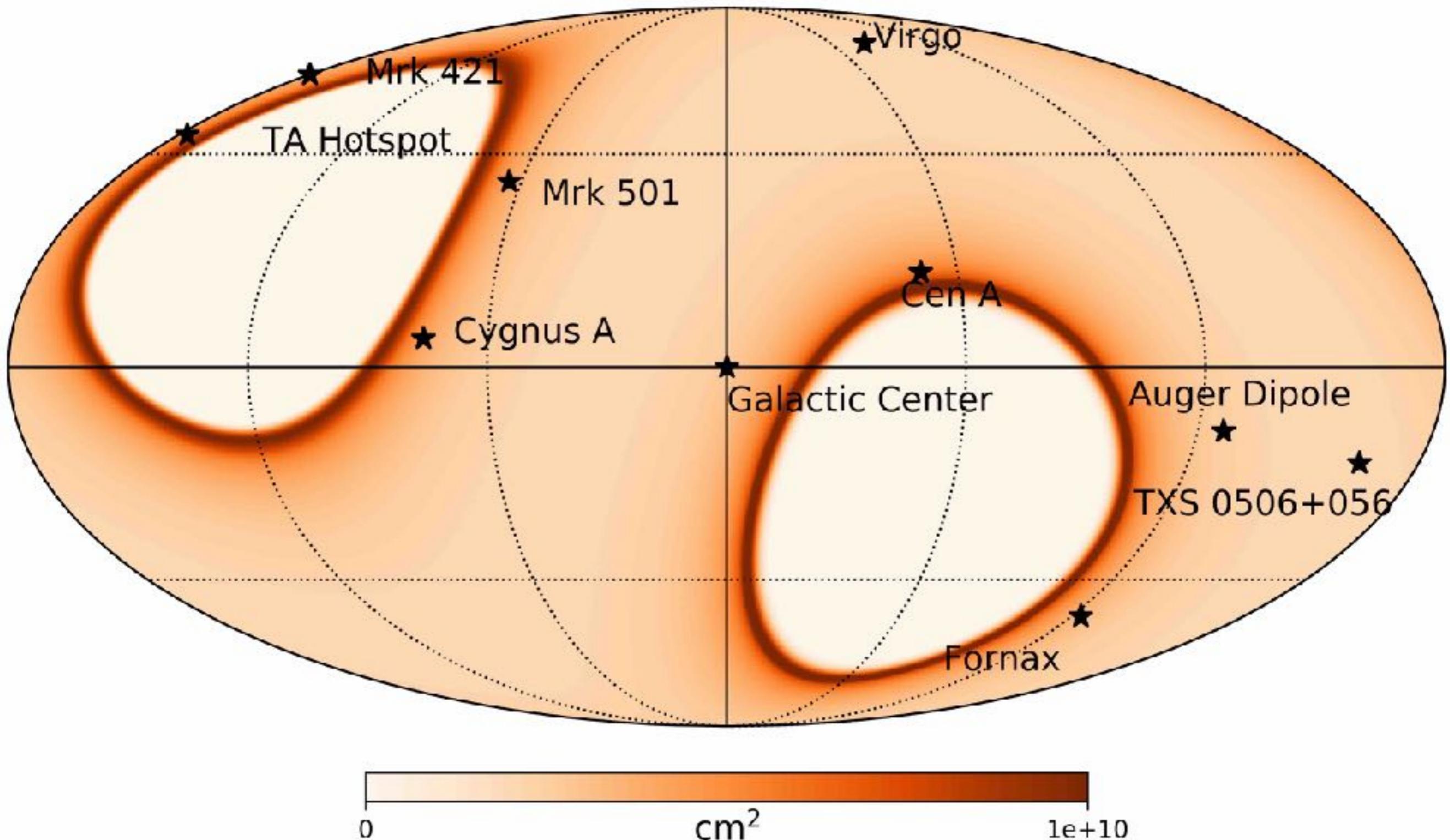


- ▶ Tianshan Radio experiment for Neutrino detection
- ▶ located at Tianshan mountains, XinJiang province, China
- ▶ original proposal: D.Ardouin et al. *Astropart.Phys.* 34 (2011) 717
- ▶ operated from 2011 to 2014
- ▶ 50 antennas with one polarisation deployed over  $1.2 \text{ km}^2$
- ▶ **achievement:** autonomous detection and identification of air showers with high background rejection

- ▶ TREND has proven that it is possible to identify showers using radio only
- ▶ 35 antennas are currently being deployed
- ▶ each antenna has 3 arms for polarisation measurements
- ▶ fast DAQ system: 100% duty cycle (up to 1 kHz)
- ▶ cross checks using scintillators are also being done



# GRAND's field of view



# the multimessenger connection

$$p + \gamma \rightarrow p + e^+ + e^-$$

$$p + \gamma \rightarrow p + \pi^0$$

$$p + \gamma \rightarrow n + \pi^+$$

$$_Z^AX + \gamma \rightarrow _Z^{A-1}X + n$$

$$_Z^AX + \gamma \rightarrow _Z^AX + e^+ + e^-$$

$$_Z^AX + \gamma \rightarrow _{Z-1}^{A-1}X + p$$

$$\pi^0 \rightarrow 2\gamma$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$n \rightarrow p + e^- + \bar{\nu}_e$$

$$e^+ + e^- \rightarrow \gamma$$

# the multimessenger connection

$$p + \gamma \rightarrow p + e^+ + e^-$$

$$p + \gamma \rightarrow p + \pi^0$$

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photons

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$$\pi^0 \rightarrow 2\gamma$$

neutrinos

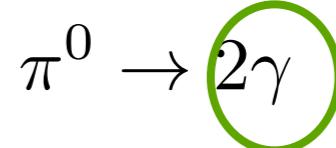
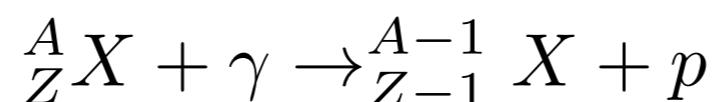
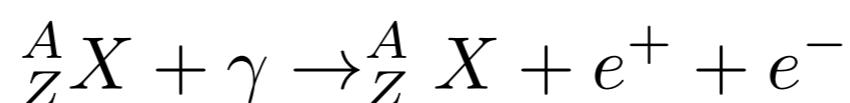
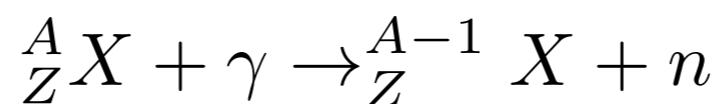
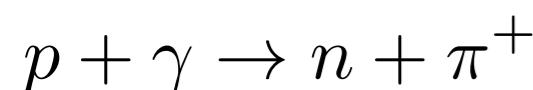
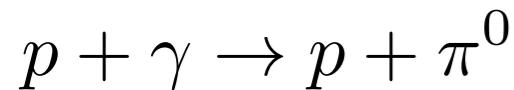
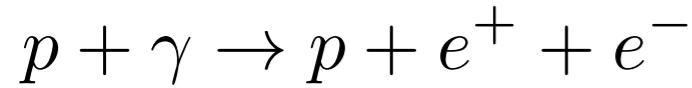
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$n \rightarrow p + e^- + \bar{\nu}_e$$

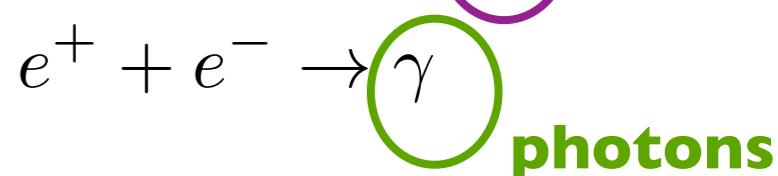
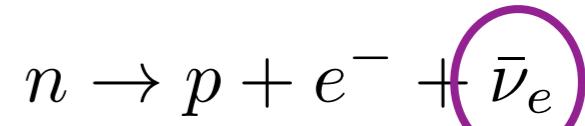
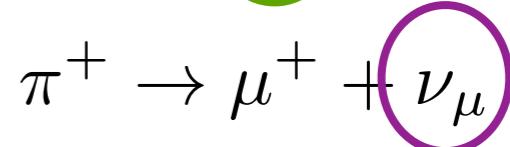
$$e^+ + e^- \rightarrow \gamma$$

photons

# the multimessenger connection



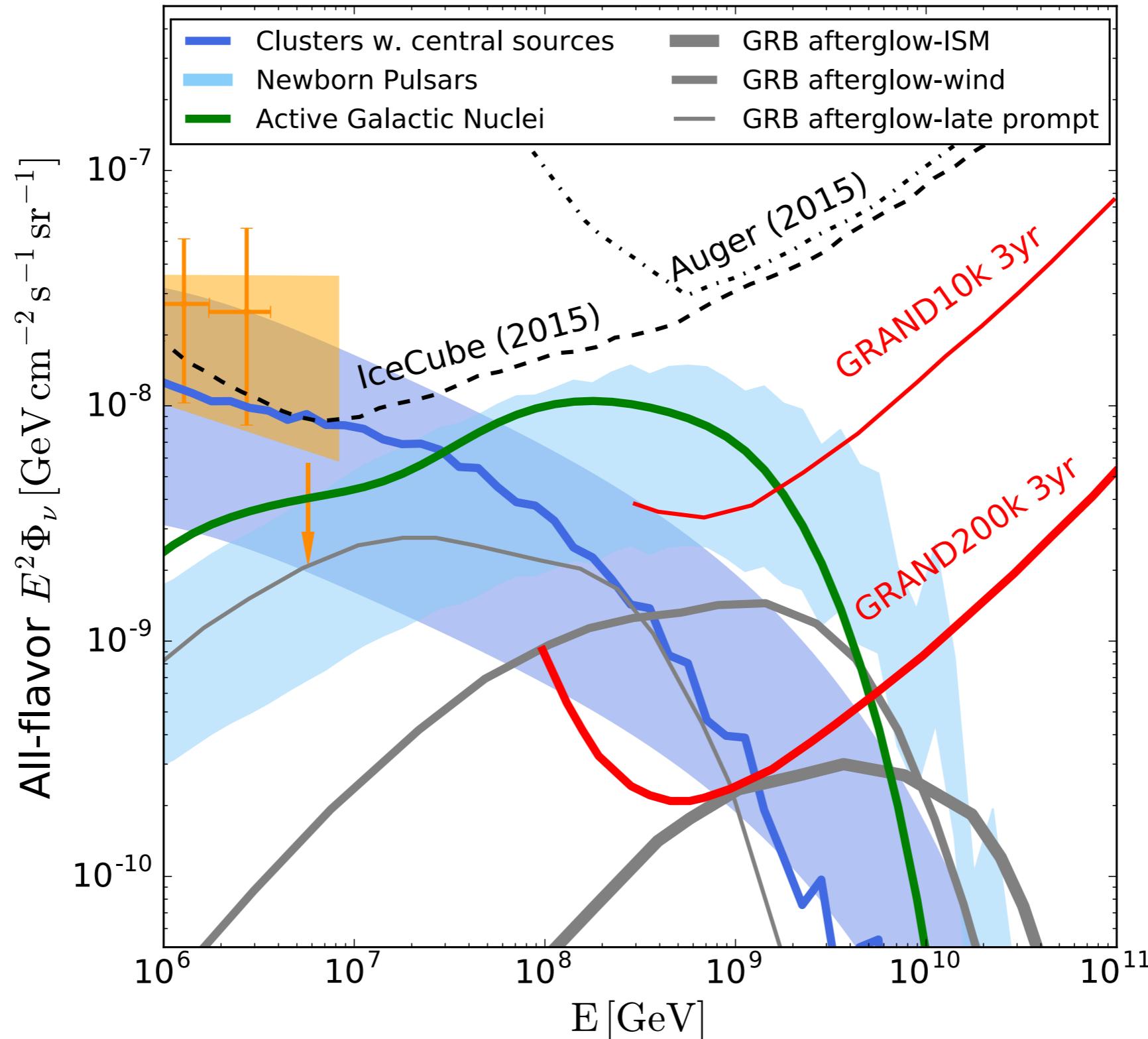
**neutrinos**



**photons**

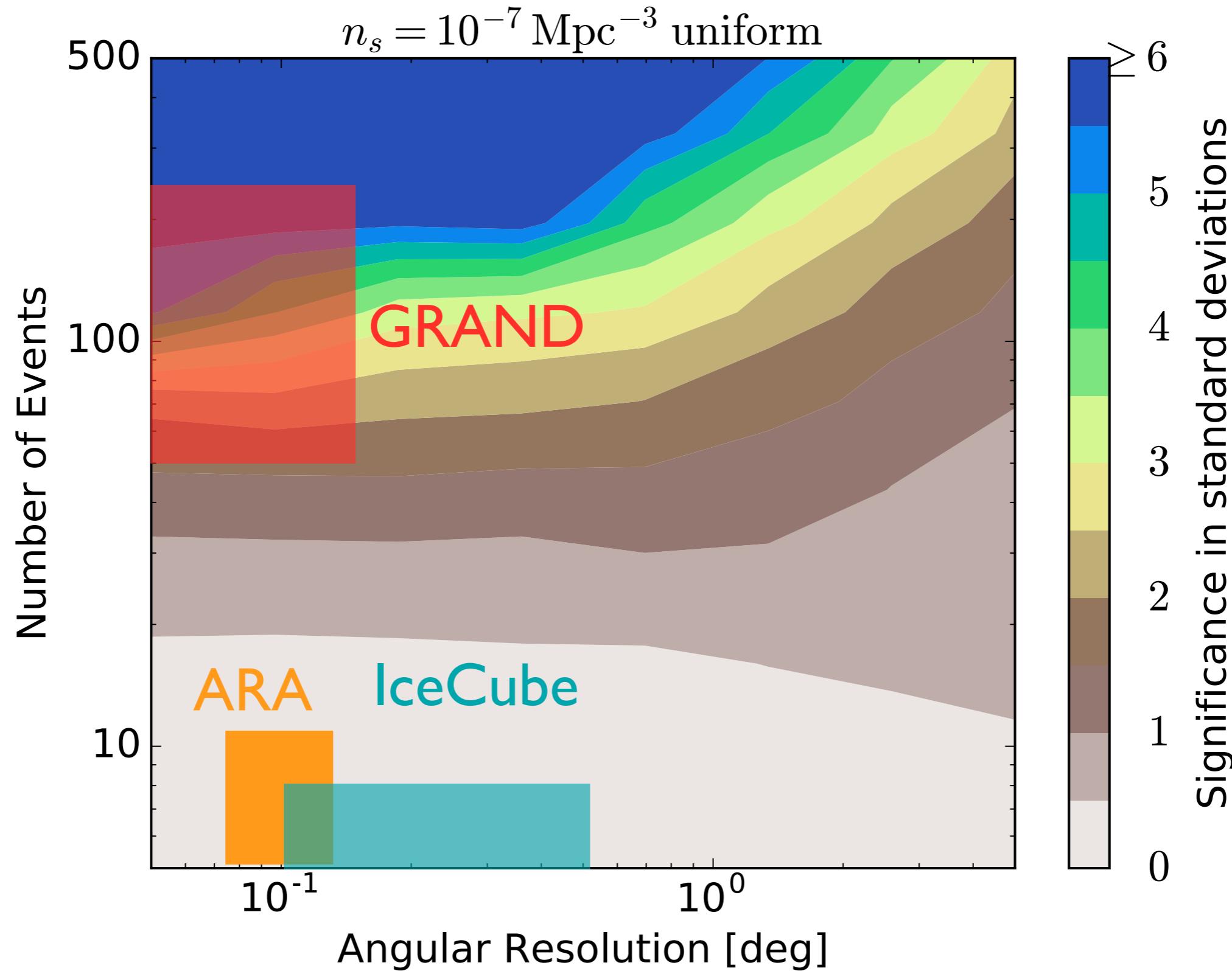
	UHECRs	gamma rays	neutrinos
how far can we see with it?	100 Mpc at 50 EeV 🤐	10 Mpc at 1 EeV 🤐	observable universe 🤗
suitability for astronomy	👎	👍	👍
how hard it is to be detected?	👍	👍	👎

# source-produced neutrinos



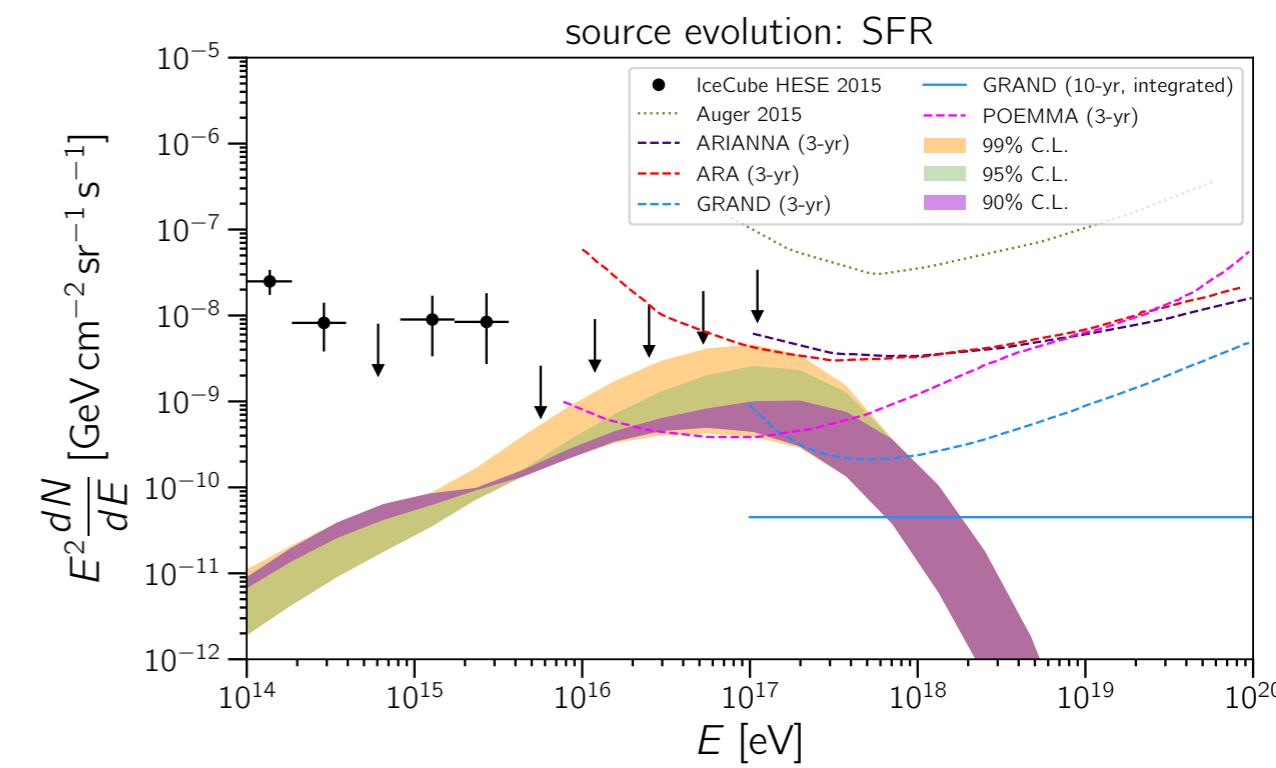
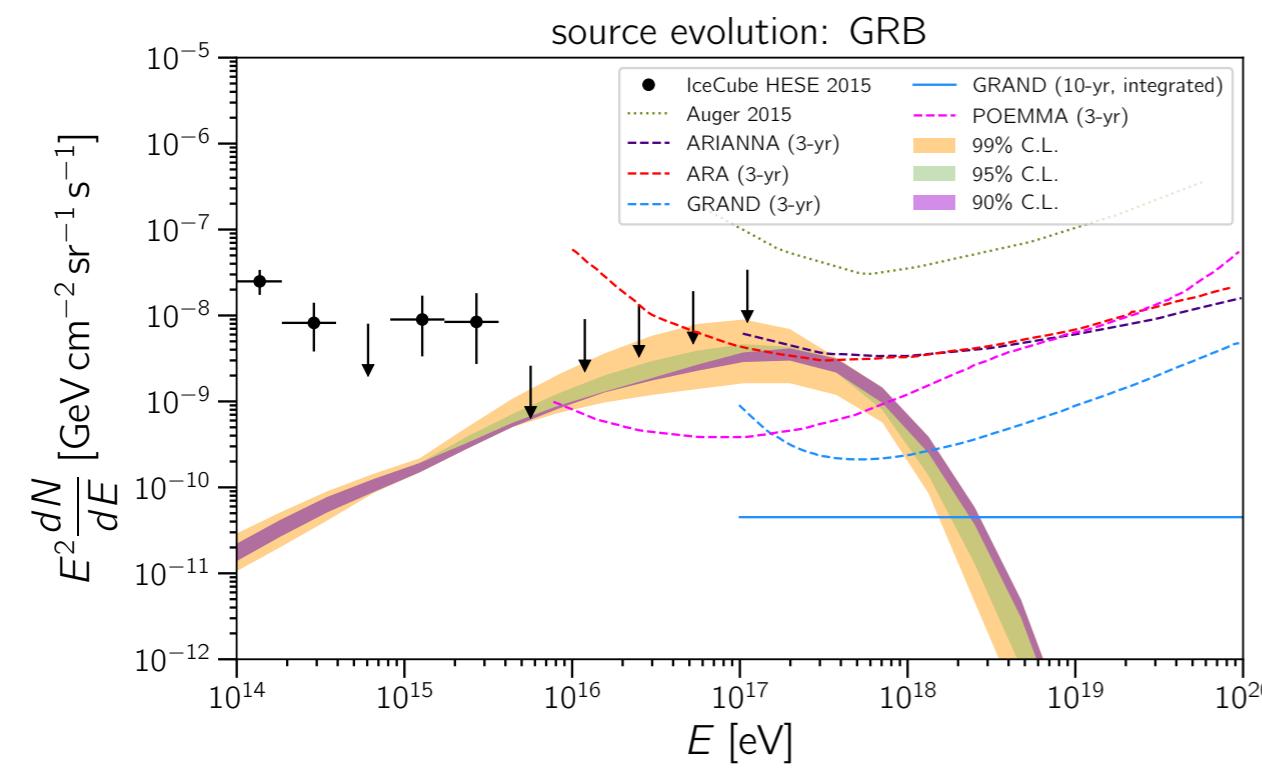
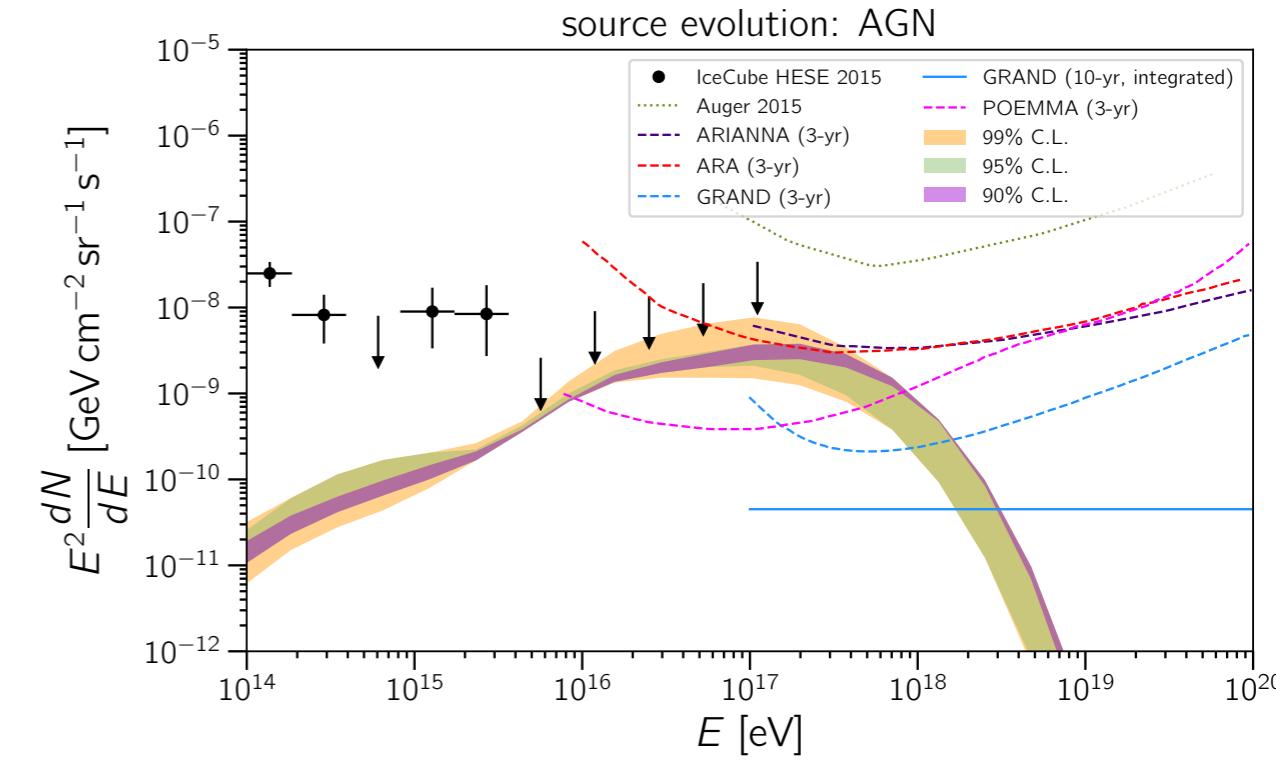
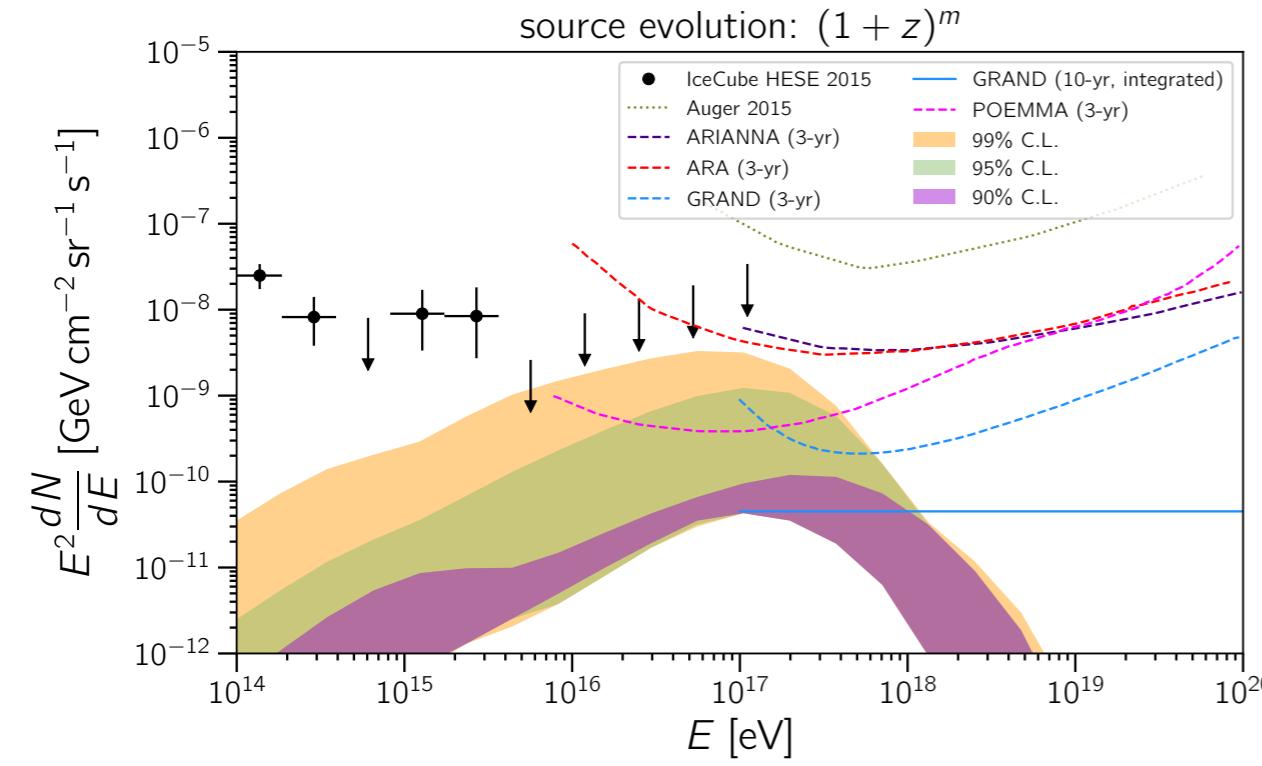
# source-produced neutrinos

K. Fang et al. JCAP 12 (2016) 017



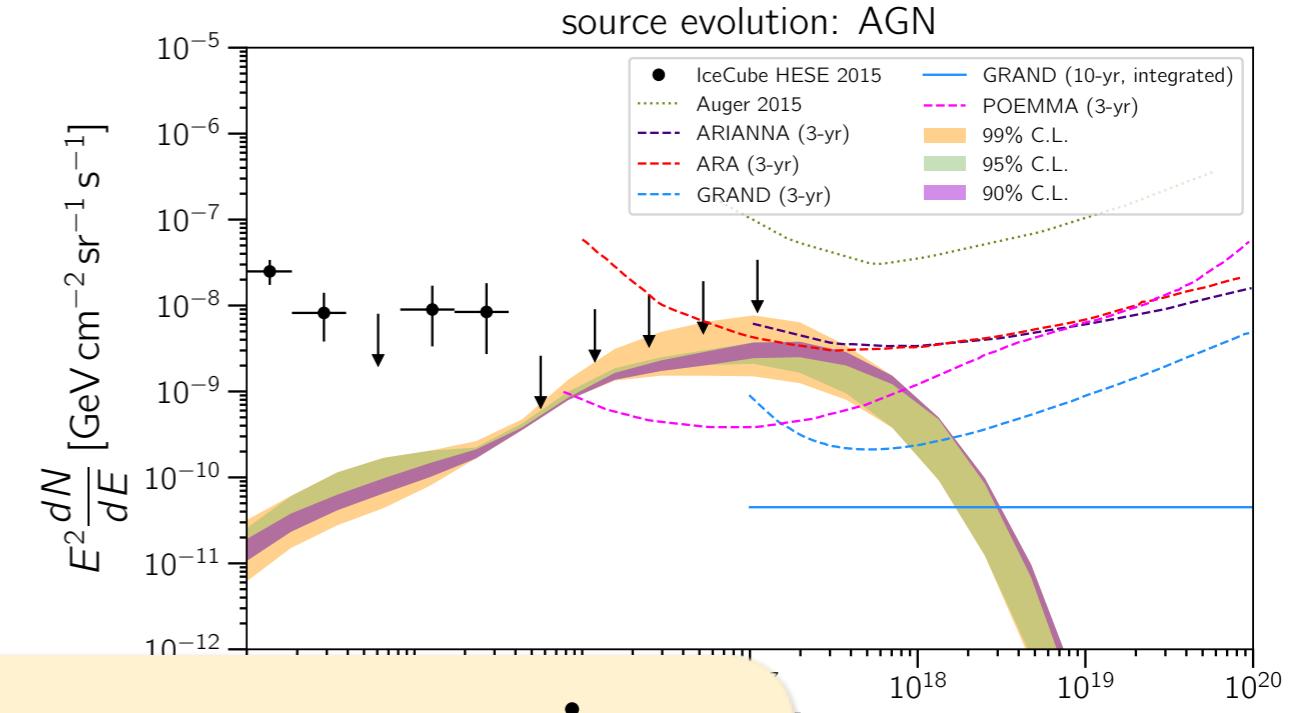
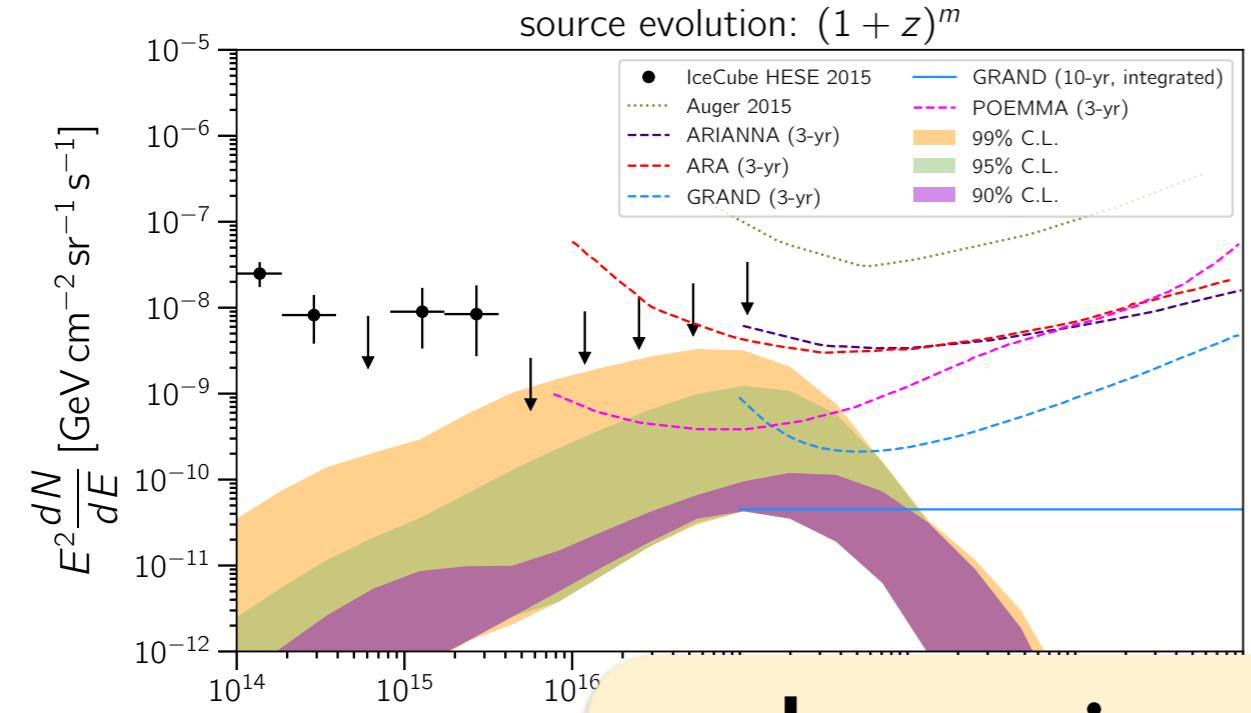
# cosmogenic neutrinos

RAB, R. M. de Almeida. B. Lago, K. Kotera. Submitted JCAP. arXiv:1806.10879

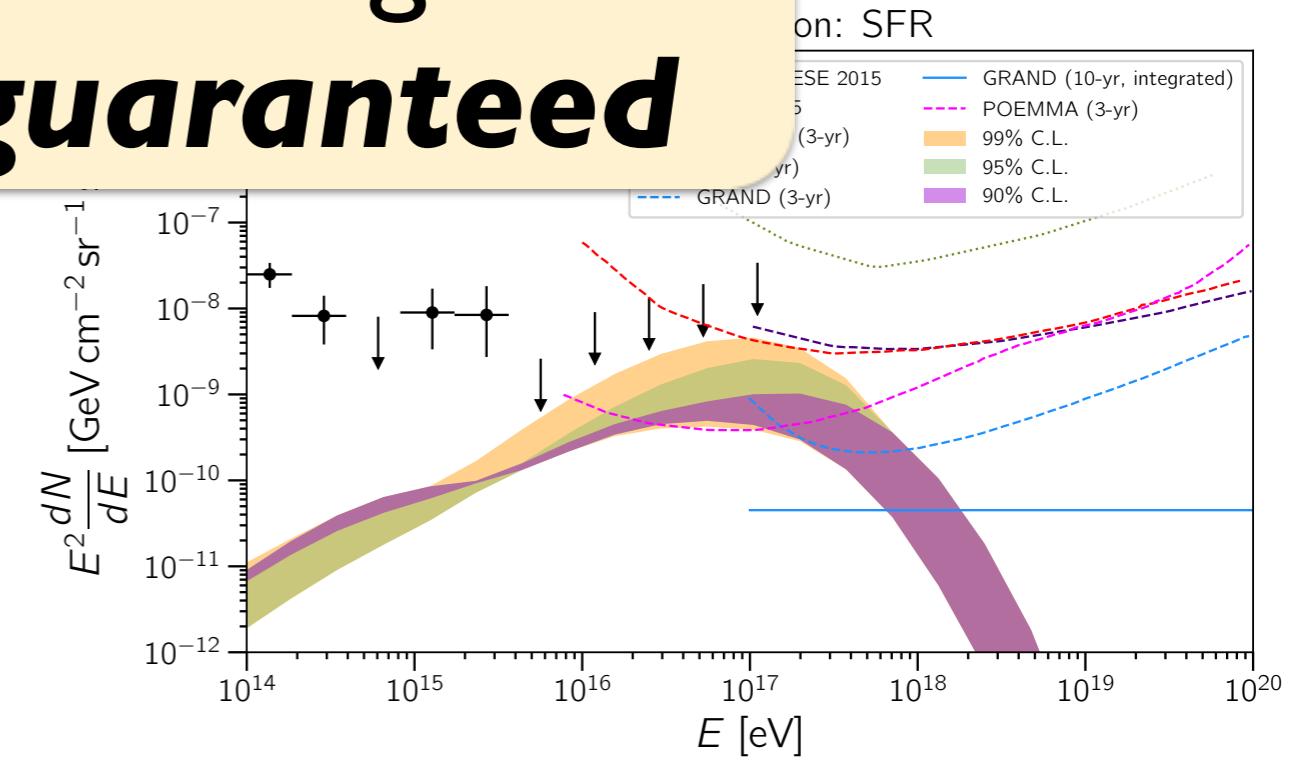
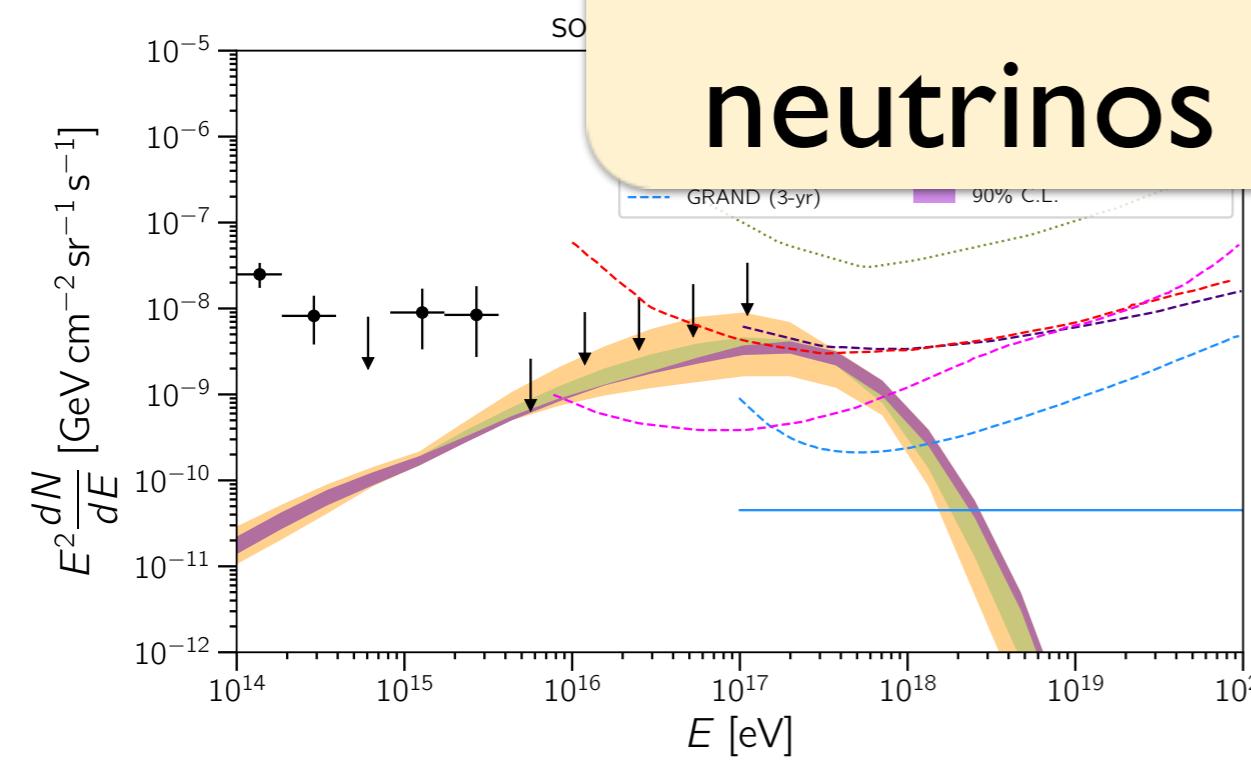


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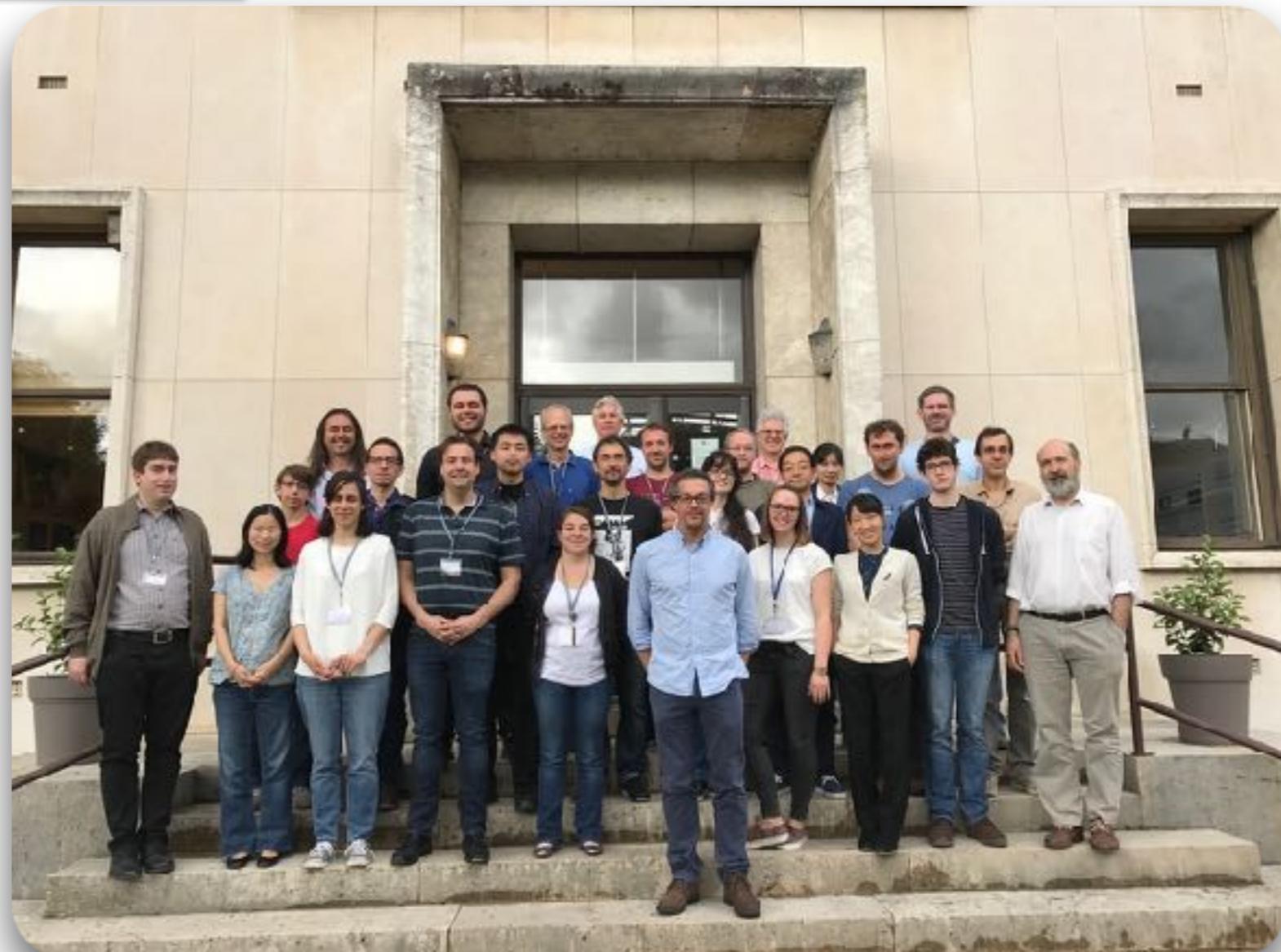
detection of cosmogenic  
neutrinos is **guaranteed**



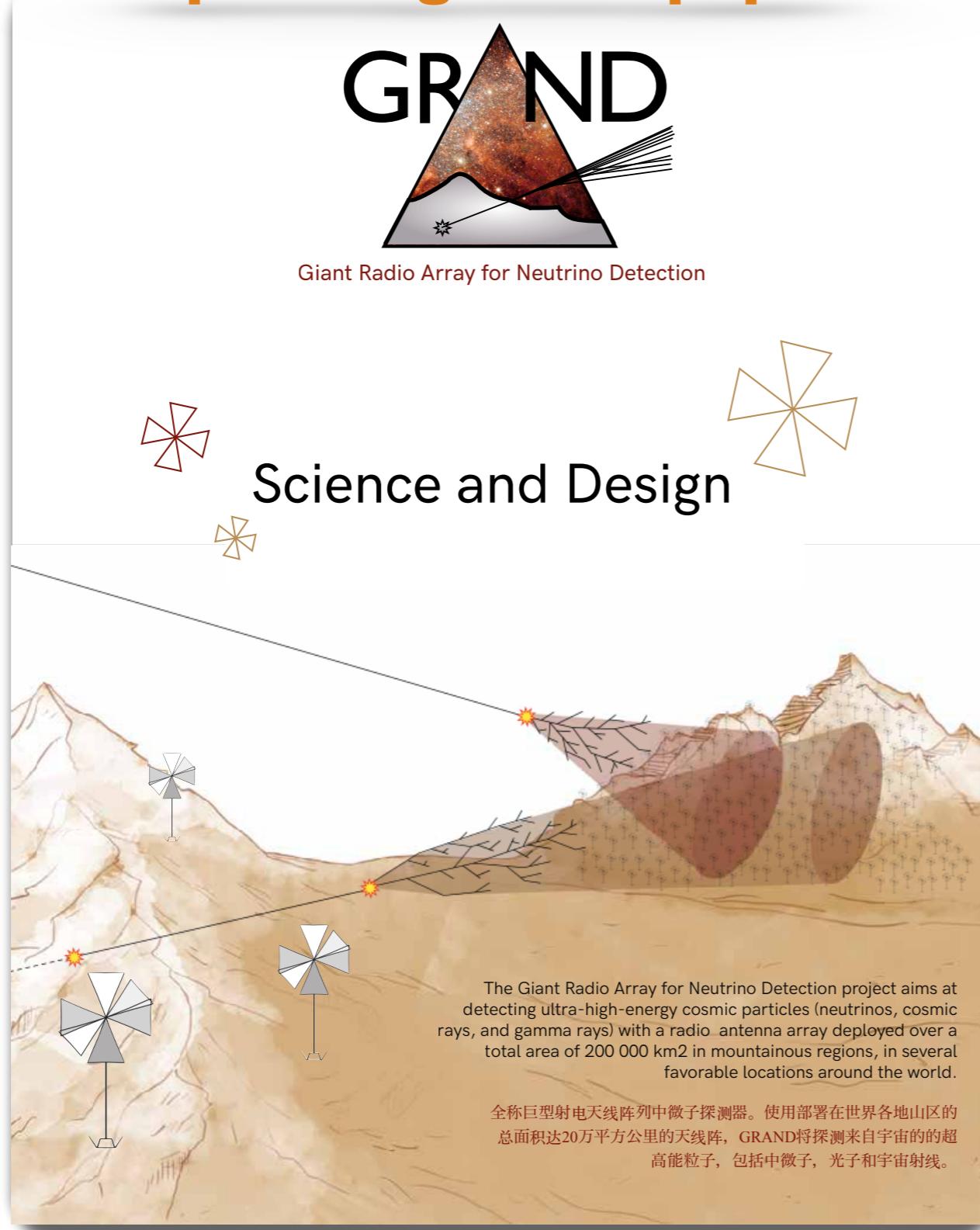
GRAND collaboration. Proc. of Science (ICRC2017) 996. arXiv:1708.05128

## GRAND: Giant Radio Array for Neutrino Detection

Jaime Álvarez-Muñiz<sup>1</sup>, Rafael Alves Batista<sup>2</sup>, Mauricio Bustamante<sup>3,4</sup>, Washington Carvalho Jr.<sup>5</sup>, Didier Charrue<sup>6</sup>, Ismaël Cognard<sup>7,8</sup>, Sijbrand De Jong<sup>9,10</sup>, Krijn De Vries<sup>11</sup>, Ke Fang<sup>12,13</sup>, Chad Finley<sup>14,15</sup>, QuanBu Gou<sup>16</sup>, JunHua Gu<sup>17</sup>, Caire Guépin<sup>18</sup>, Jordan Hanson<sup>3,4</sup>, Hongbo Hu<sup>16</sup>, Kumiko Kotera<sup>19,10,\*</sup>, Sandra Le Coz<sup>17</sup>, Yi Mao<sup>20</sup>, Olivier Martineau<sup>21,\*</sup>, Clementina Medina<sup>21,22</sup>, Miguel Mostafa<sup>23,24,25</sup>, Fabrice Mottez<sup>26</sup>, Kohta Murase<sup>23,24,25</sup>, Valentin Niess<sup>27</sup>, Fotini Oikonomou<sup>23,24,25</sup>, Frank Schröder<sup>28</sup>, Cyril Tasse<sup>29</sup>, Charles Timmermans<sup>9,10</sup>, Nicolas Renaut-Tinacci<sup>13</sup>, Matías Tueros<sup>22</sup>, Xiang-Ping Wu<sup>17</sup>, Philippe Zarka<sup>30</sup>, Andreas Zech<sup>26</sup>, Yi Zhang<sup>16</sup>, Qian Zheng<sup>17</sup>, and Anne Zilles<sup>18</sup>



## upcoming white paper



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# roadmap

	GRANDProto300			
	GRANDProto35	GRAND10k	GRAND200k	GRAND
Goals	2018	2020	2025	203X
Standalone radio detection of EAS Very good background rejection	Standalone radio detection of <b>very inclined showers</b> ( $\theta > 65^\circ$ ) induced by high energy cosmic rays ( $> 10^9$ GeV)	First GRAND subarray, <b>sensitivity comparable to ARA/ARIANNA on similar time scale</b> , allowing potential 1st discovery of cosmogenic neutrinos	First neutrino detection at $10^9$ GeV even with pessimistic fluxes and/or neutrino astronomy	
35 radio antennas 21 scintillators 	<ul style="list-style-type: none"> <li>• 300 Horizon Antennas over 300 km<sup>2</sup></li> <li>• Fast DAQ</li> <li>• Solar pannels (day use) + WiFi data transfer</li> <li>• TBD: Array of surface muon detectors</li> </ul>	DAQ with discrete elements, but mature design for trigger, data transfer, consumption	200'000 antennas over 200'000 km <sup>2</sup> Hotspots could be in different continents	
160k€, fully funded by NAOC+IHEP, deployment 2018 @ Ulustai	1.3 M€ to be deployed in 2019	1500€ / detection unit	Industrial scale allows to cut costs down: 500€/unit → 120M€ in total	

# conclusions and outlook

- ▶ GRAND: next-generation high-energy neutrino detector
- ▶ autonomous radio detection: good for physics and cheap
- ▶ discovery sources of UHE neutrinos
- ▶ guaranteed detection of cosmogenic neutrinos
- ▶ 200,000 km<sup>2</sup> and ~200k antennas required to reach the goal
- ▶ the white paper describing the science case and projected sensitivity is currently being written
- ▶ check out our website: [grand.cnrs.fr](http://grand.cnrs.fr)

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thank you

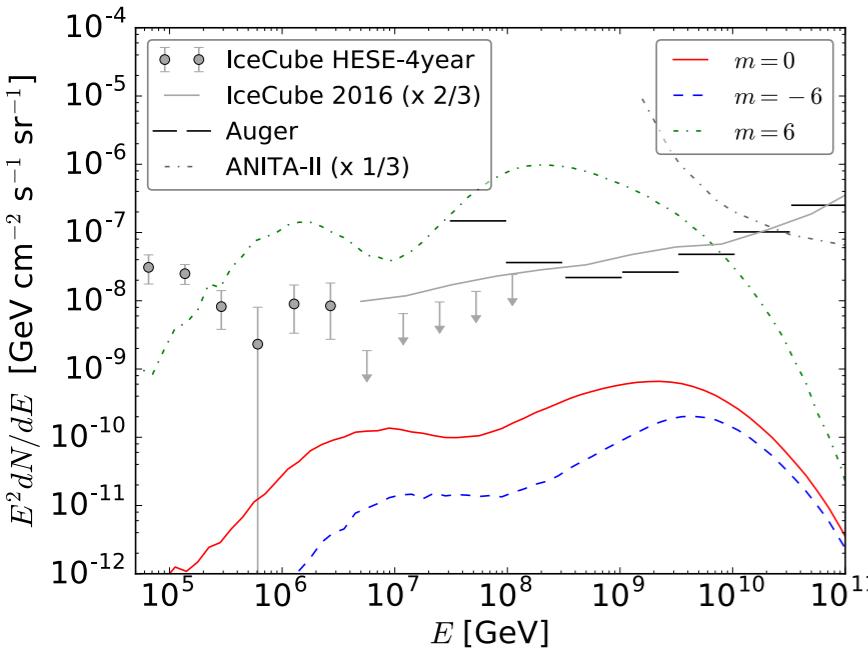
# backup slides

# what does the neutrino spectrum depend on?

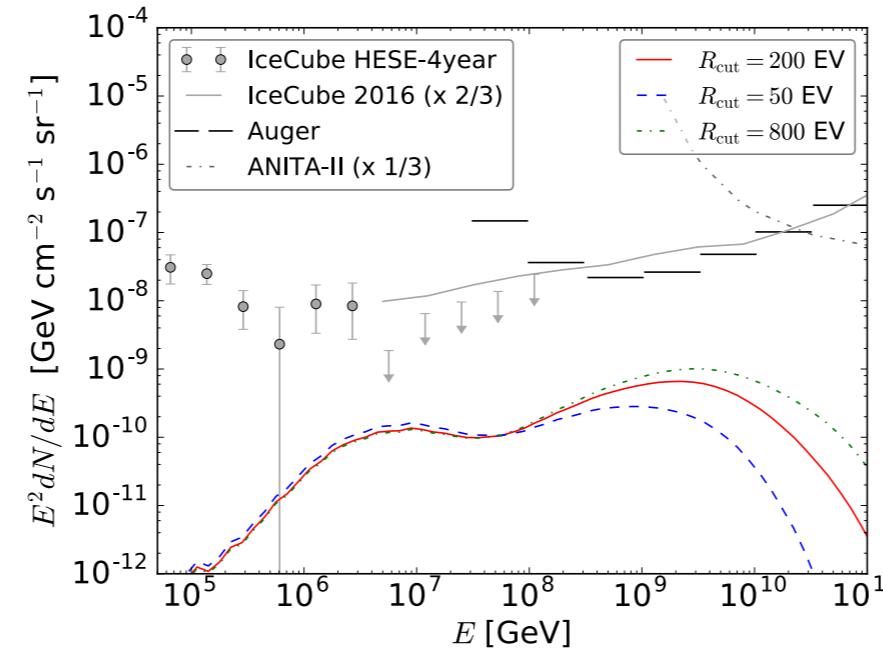
A. van Vliet, J. Hörandel, RAB. PoS (ICRC2017) 562. arXiv:1707.04511

- ▶ what parameters are more relevant to compute the cosmogenic neutrino spectrum?
- ▶ let's adopt a reference scenario to get an idea:  $R_{\text{cut}}=200 \text{ EV}$ ,  $m=0$ ,  $\alpha=2.5$
- ▶ we vary one parameter at a time

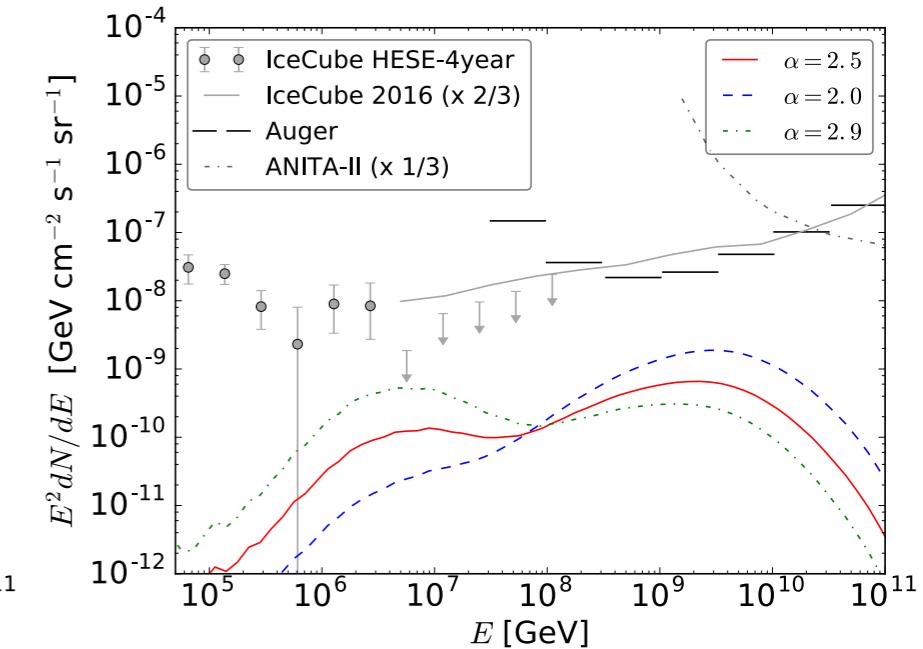
source evolution



maximum rigidity



spectral index



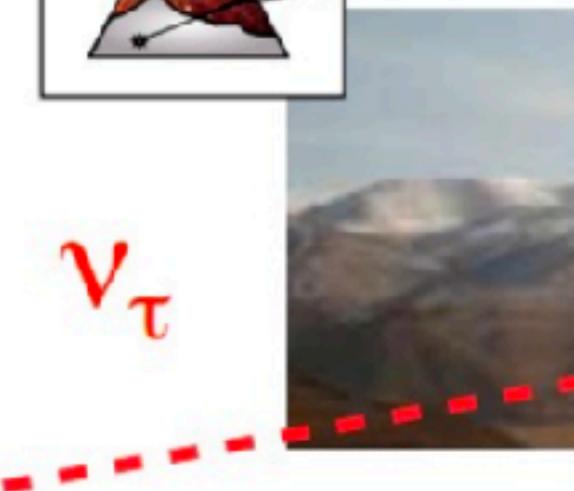
## air

- ▶ better energy estimates → calorimetric measurement
- ▶ mass composition measurements
- ▶ very high duty cycle
- ▶ maximum frequency for coherent emission: ~ 10-100 MHz

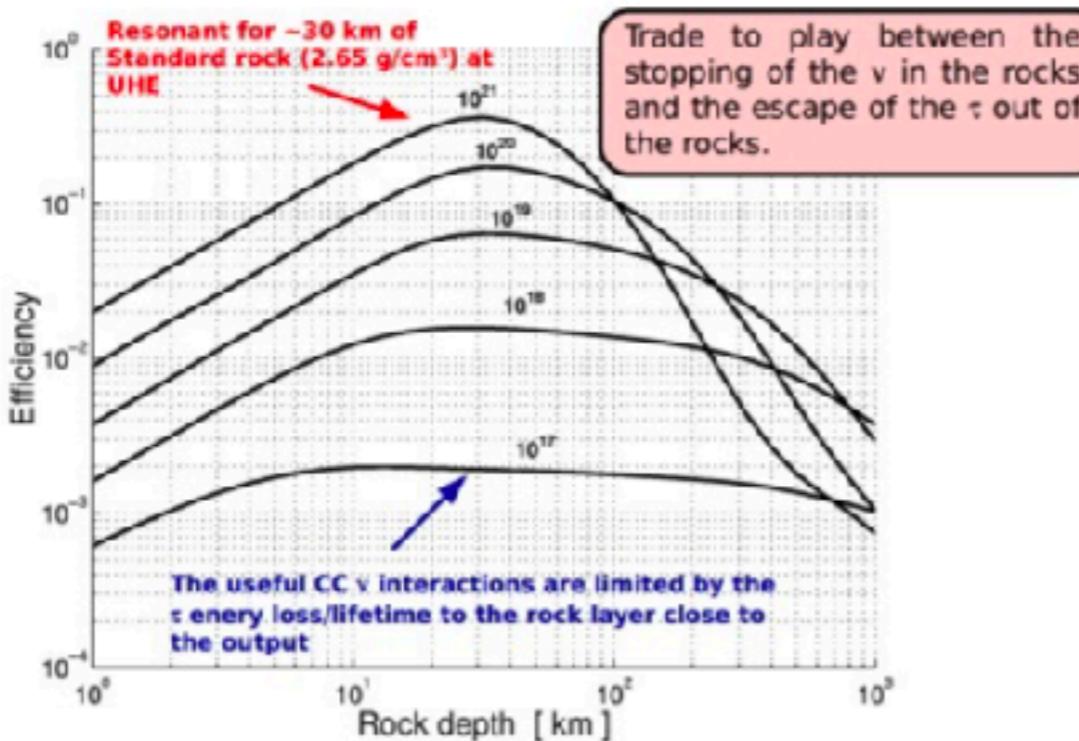
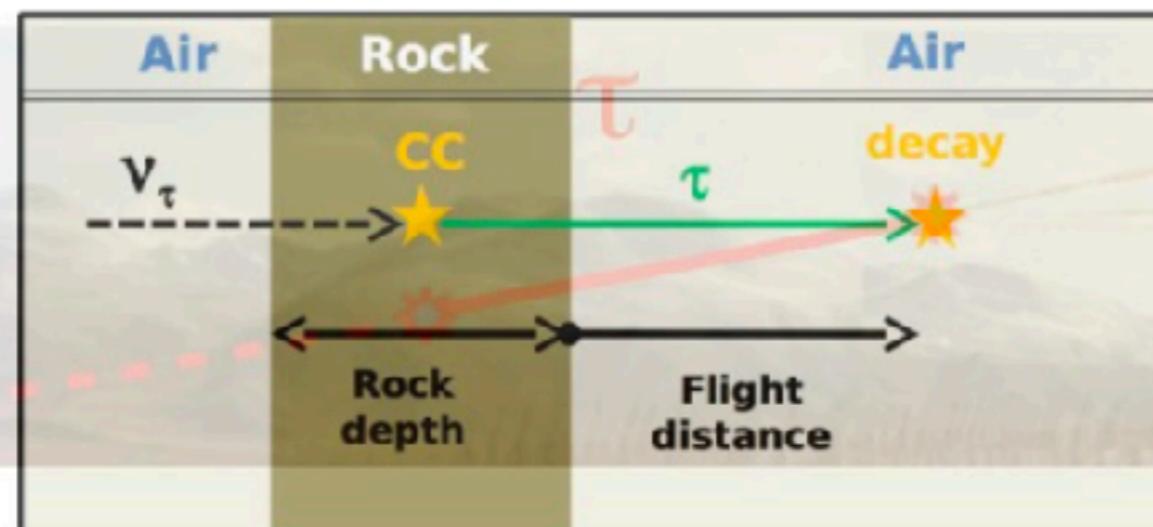
## other media

- ▶ very cheap detectors: antennas
- ▶ higher detection rate
- ▶ maximum frequency for coherent emission: ~ GHz

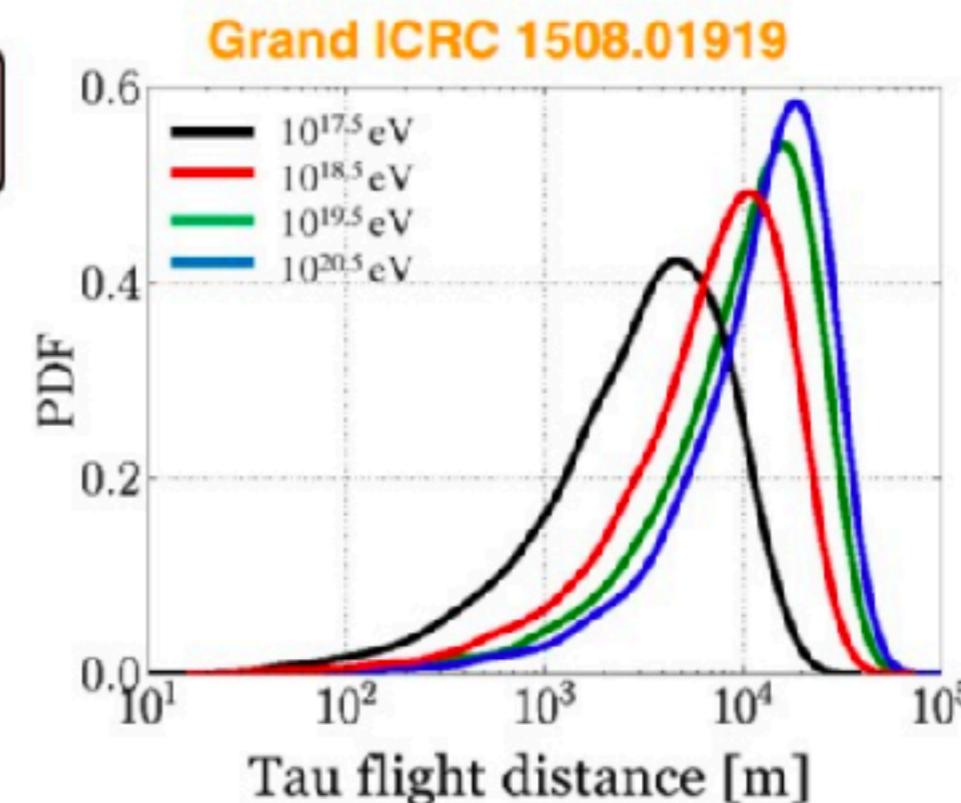
# detection principle



## From Neutrino to Lepton



Conversion efficiency from neutrino to tau lepton decaying in the air

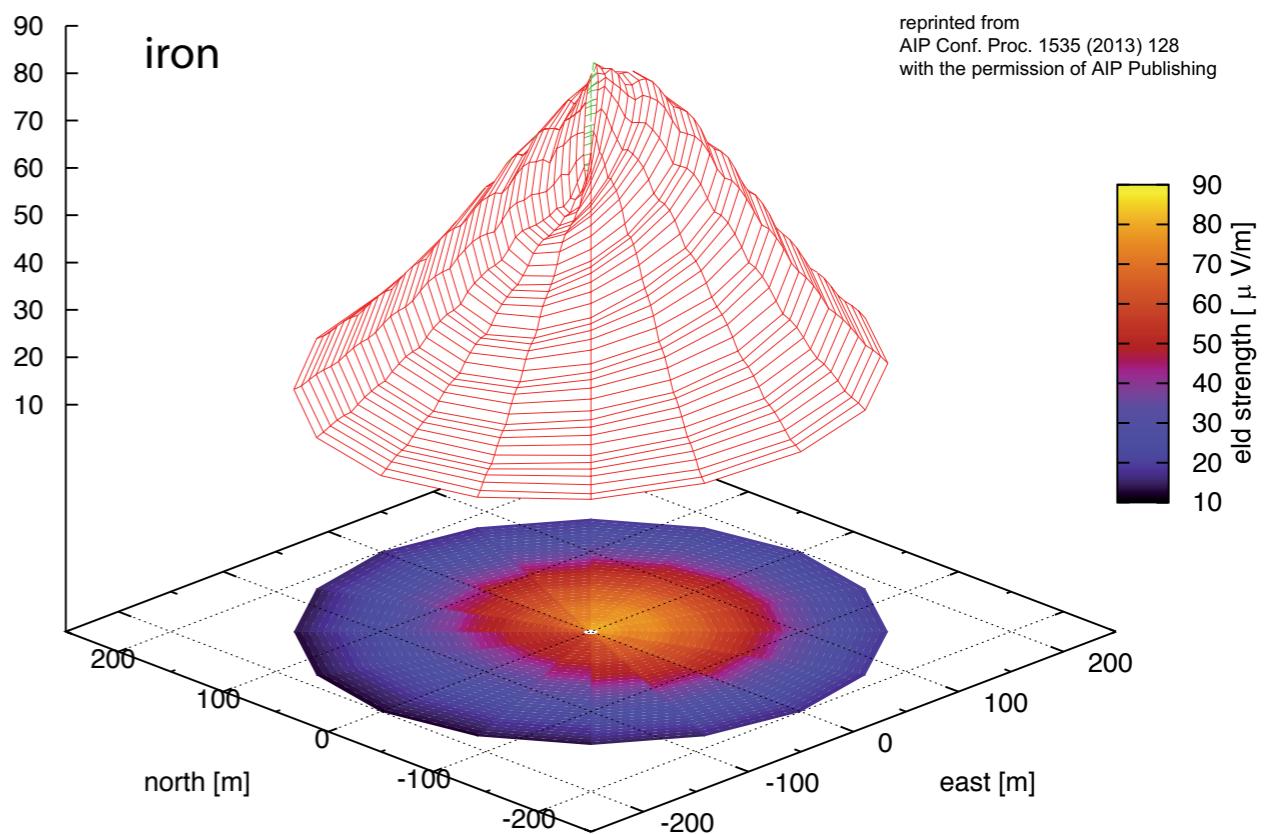
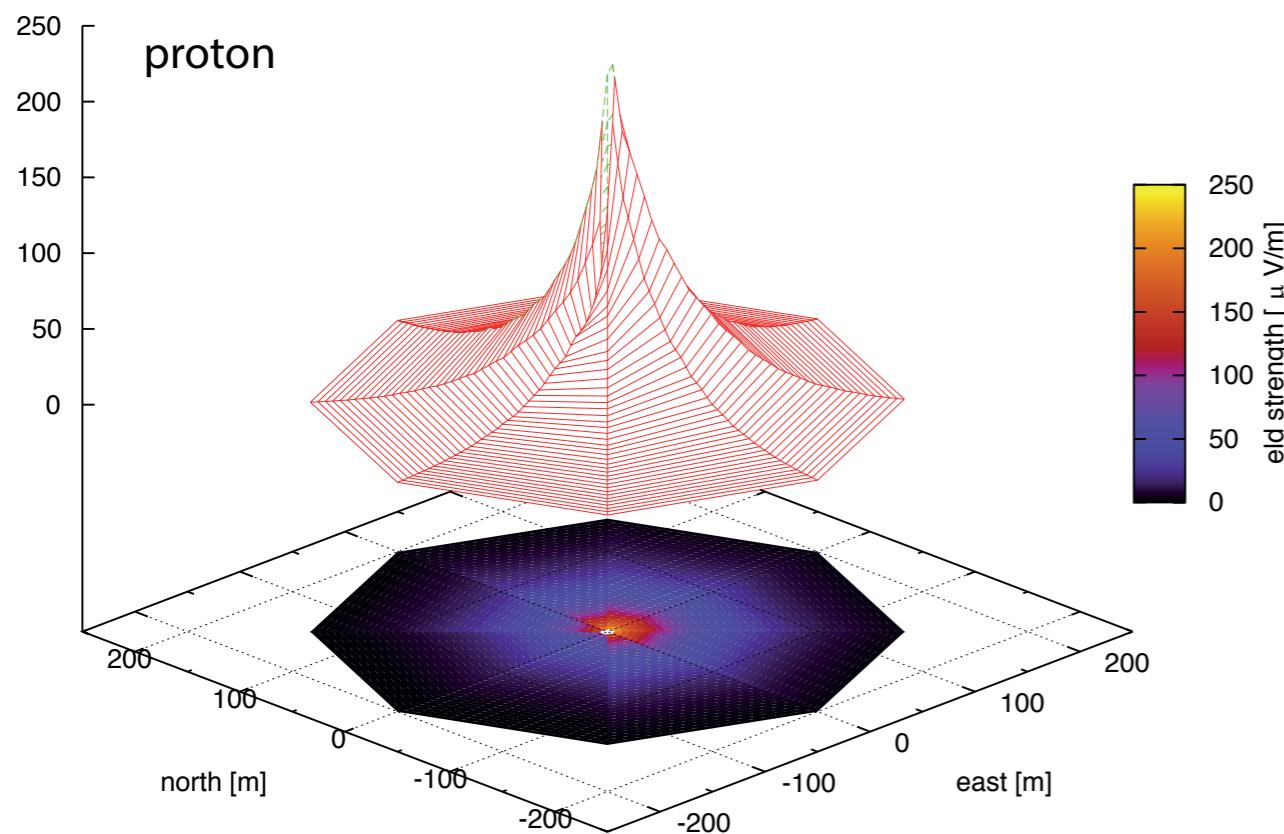


Prob. Distribution of flight distance

Credits: K. Fang

# detection principle

- ▶ example: simulation with CoREAS for the LOPES experiment
- ▶ colour: electric field strength of the radio signal.
- ▶ steepness and shape of footprint: depend on the distance from observation plane to the shower maximum
- ▶ footprint correlates with the composition



F. Schröder. Prog. Nuclear and Part. Phys. 93 (2017) 1.