MCORD - CREDO Synergy under the NICA Experiment Framework

David E. Álvarez Castillo

Joint Institute for Nuclear Research
Dubna, Russia
&
Institute of Nuclear Physics PAS
Cracow, Poland

NICA-POL Meetings
January 31, 2022

Outline

- Introduction to scientific goals.
- Studying Astrophysical sources of UHECRs
- Introduction to CREDO: multi-messenger astronomy
- Earthquakes/cosmic rays: precursors
- Dense matter studies through observations of compact stars and theoretical inputs
- Other possible applications

Scientific goals

- Search for Cosmic Ray Ensembles, fundamental physics studies.
- CREs produced nearby the Sun and the vicinity of neutron stars and black holes
- Study ultra-high-energy particles accelerated by black holes: magnetic Penrose-process
- Tests of space-time structure and variation of physical constants
- Understanding the relation of cosmic rays detections with seismological data: earthquake precursors
- Dense Matter studies through observations of compact stars and testing of theoretical models: Equation of State


Invitation to the Cosmic Ray Extremely Distributed Observatory
CREDO
THE QUEST FOR THE UNEXPECTED
+ you = stronger together
CREDO
JOURNEY

CREDO

THE QUEST FOR THE UNEXPECTED

outline

Mission (**why?**)

Strategy (**what?**)

Tactics (**how?**)

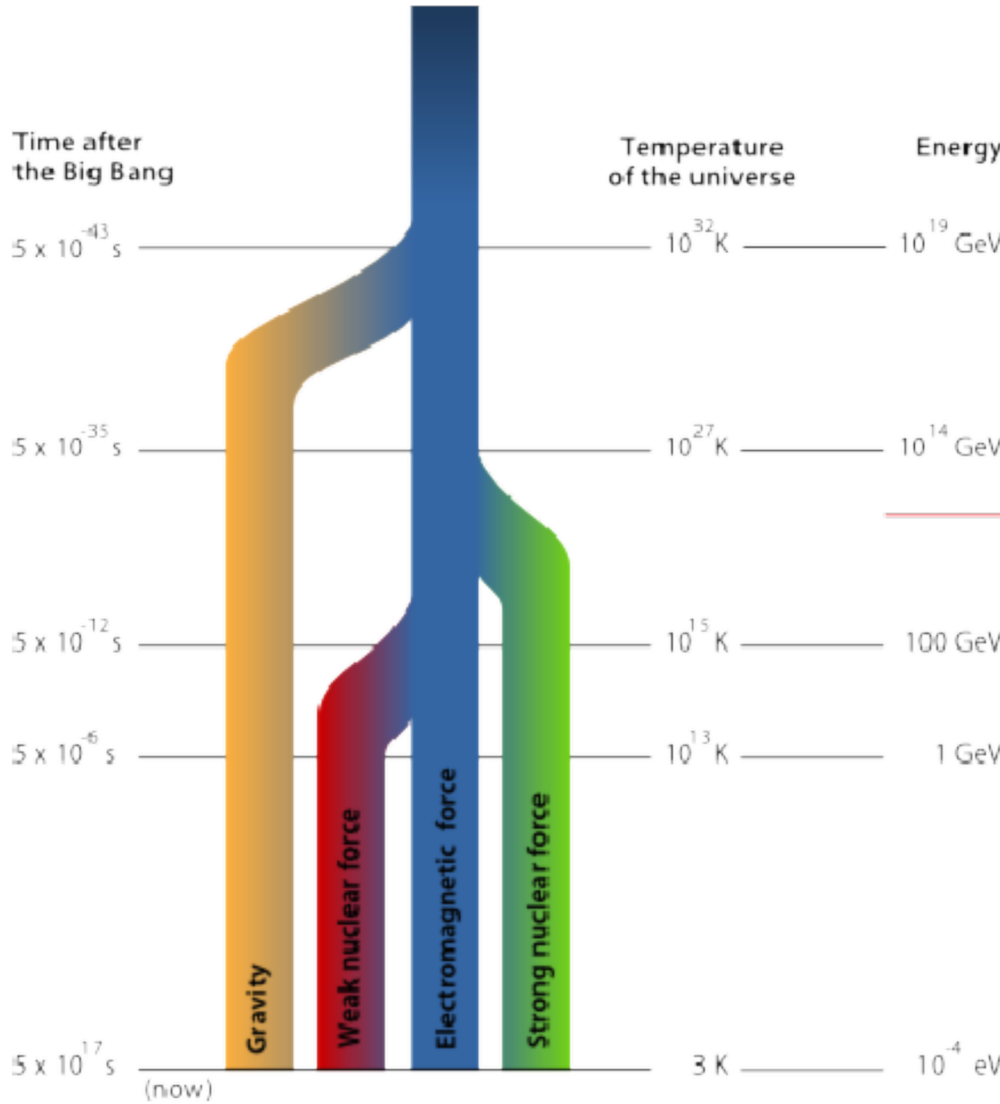
„Beyond”

Energy: the higher the better?

Theory of „Everything"
(Qunatum Gravity)?

Planck
scale

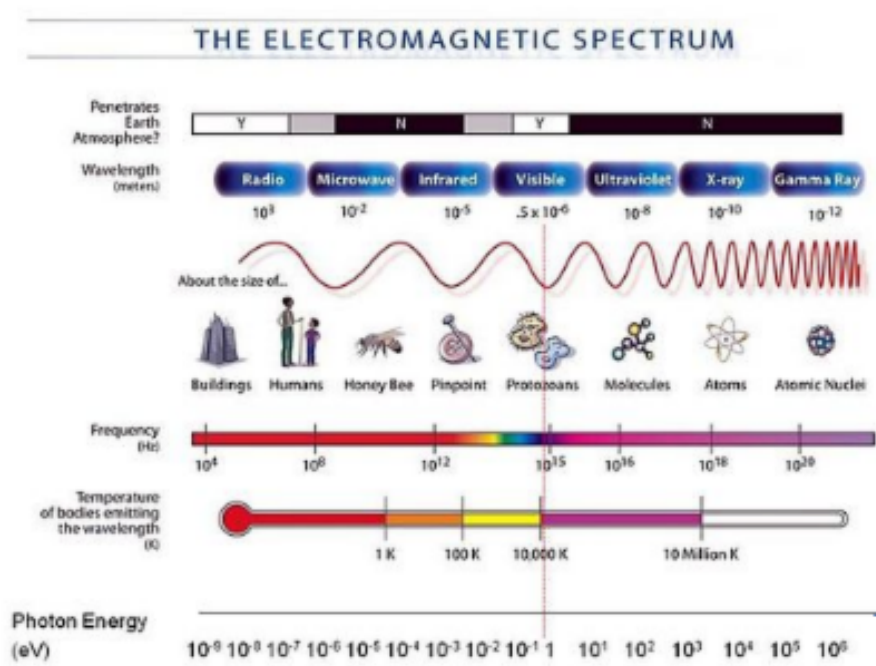
Grand Unified Theory?



Ultra-high energies (10^{20} eV)

Energy!

Photons



	Acceleratars	Gamma astronomy	Cosmic rays	Planck scale
Wavelength	10^{-18}	10^{-21}	10^{-26} m	10^{-35} m
Frequency	10^{26}	10^{29}	10^{34} Hz	10^{42} Hz
Photon Energy	10^{12}	10^{15}	10^{20} eV	10^{28} eV

≈ 16 J

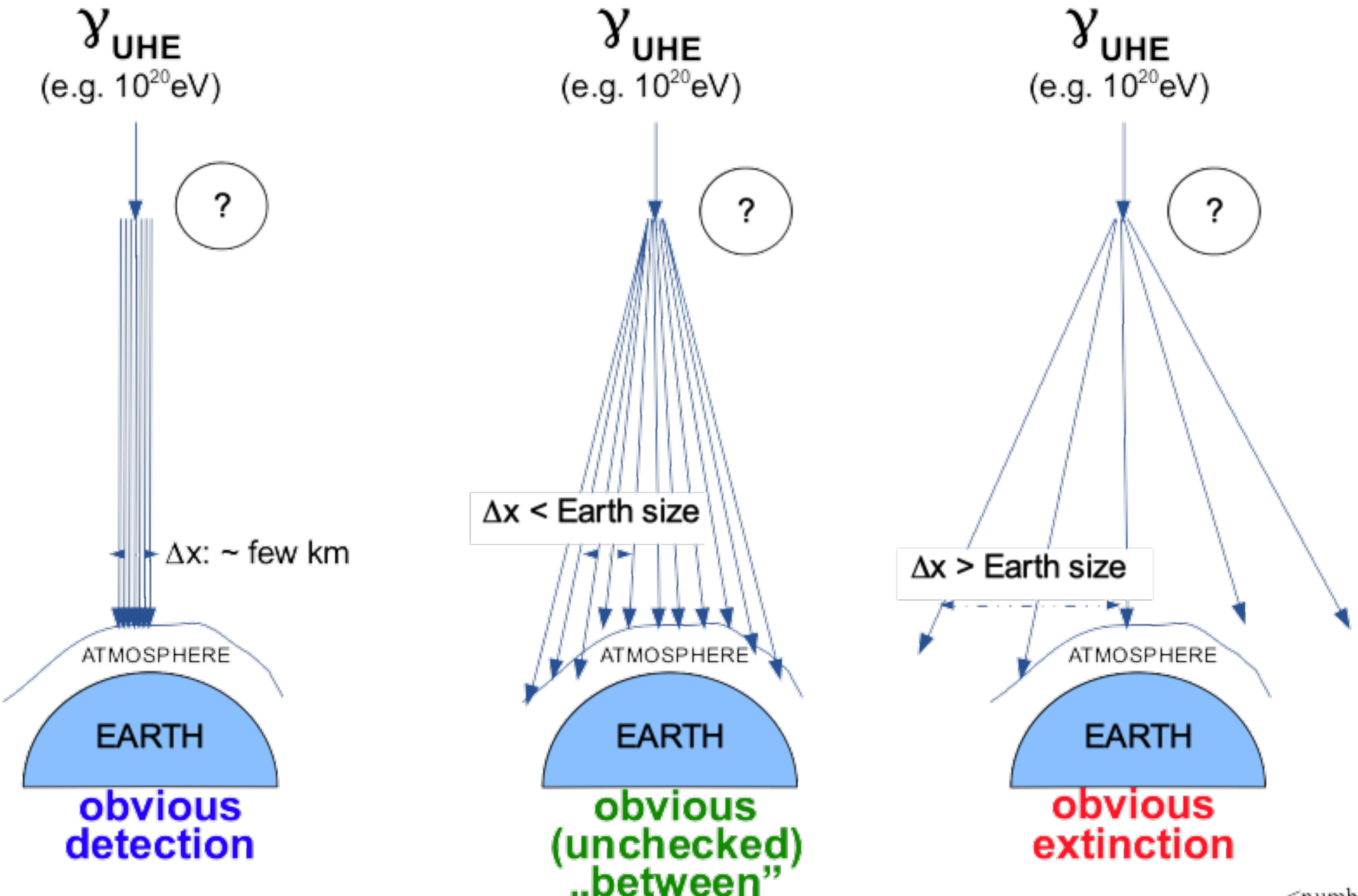
(1 eV = 1.6×10^{-19} J)

$\approx$

150 km/h

The highest energy of a particle ever observed **~10^{20} eV**

N_{ATM} >= 1: untouched ground



Studying the Variation of Fundamental Constants at The Cosmic Ray Extremely Distributed Observatory

D. Alvarez Castillo[a,b,1]

[a] Joint Institute for Nuclear Research, Dubna, Russia

[b] Institute of Nuclear Physics PAN, Cracow 31-342, Poland

The Study of the Variation of Fundamental Constants through time or in localized regions of space is one of the goals of the The Cosmic Ray Extremely Distributed Observatory which consists of multiple detectors over the Earth. In this letter, the various effects which can be potentially identified through cosmic rays detections by CREDO are presented.

PACS: 06.20.Jr; 96.50.S−; 04.60.−m; 11.30.Cp

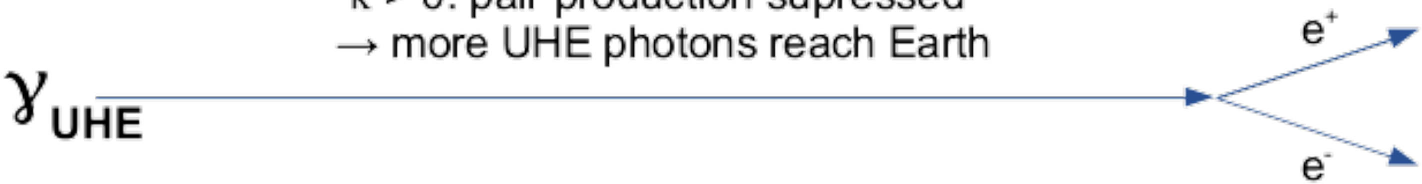
CRE and Lorentz Invariance Violation

Modified dispersion relation of a photon:

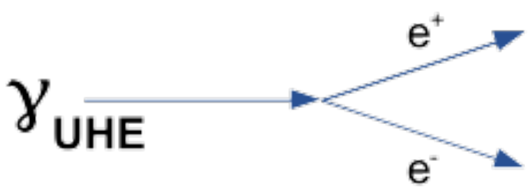
$$E_\gamma(\vec{k}) = \sqrt{\frac{(1-\kappa)}{(1+\kappa)}}|\vec{k}|$$

limits from gamma-ray astronomy,
98% C.L. (Klinkhamer & Schreck, 2008):
$6 \times 10^{-20} > \kappa > -9 \times 10^{-16}$

$\kappa > 0$: pair production supressed
→ more UHE photons reach Earth



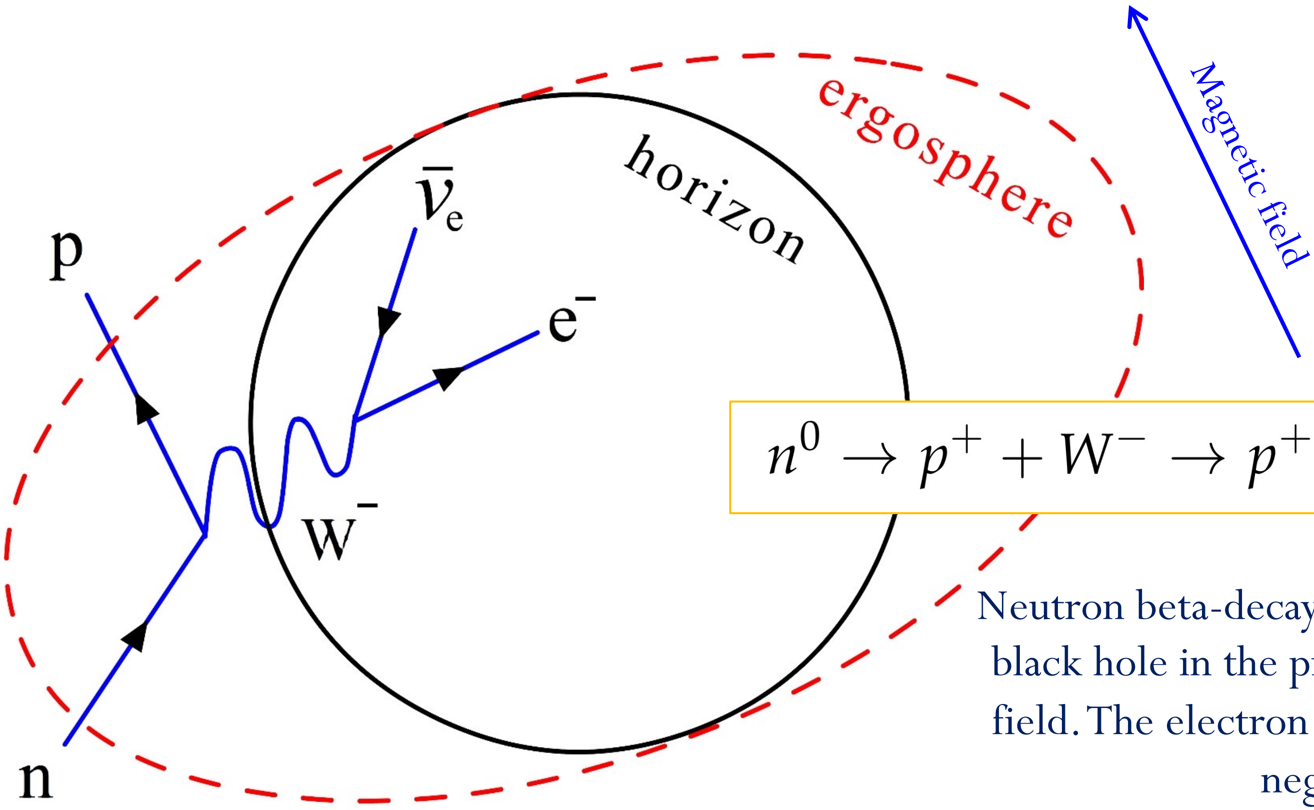
$\kappa = 0$: „normal” pair production



$\kappa < 0$: pair production enhanced
(photon lifetime ~ 1 sec.!)
→ no UHE photons reach Earth

→ critical importance for the UHE photon search!
Observation of **photon cascades** would point to $\kappa < 0$!

Beta-decay in ergosphere



$$n^0 \rightarrow p^+ + W^- \rightarrow p^+ + e^- + \bar{\nu}_e,$$

Neutron beta-decay in the ergosphere of rotating black hole in the presence of external magnetic field. The electron falls into black hole with the negative energy.

In the hot and dense torus, with temperature of $\sim 10^{11}$ K and density $>10^{10}$ g·cm^{-3}, neutrinos are efficiently produced. The main reactions that lead to their emission are the electron/positron capture on nucleons, as well as the neutron decay. Their nuclear equilibrium is described by the following reactions:

$$p + e^- \rightarrow n + \nu_e$$

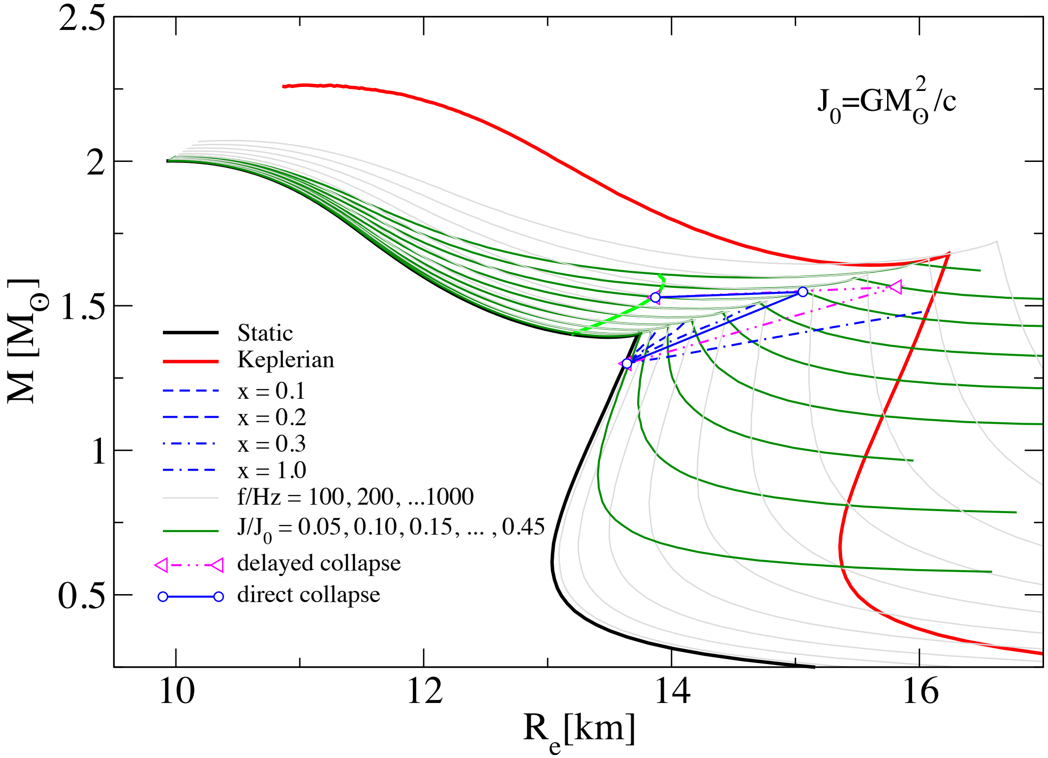
$$p + \bar{\nu}_e \rightarrow n + e^+$$

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

A. Janiuk et al, Galaxies 5, 15 (2017)

Credit: Arman Tursonov

Spin frequency vs gravitational mass of the hybrid star at birth



$$ds^2 = -e^{\nu}\left[1+2(h_0+h_2P_2)\right]dt^2 + e^{\lambda}\left[1+\frac{2(m_0+m_2P_2)}{r-2M}\right]dr^2$$
$$+r^2\left[1+2(v_2-h_2)P_2\right]\left[d\theta^2+\sin^2(d\phi-\omega dt)^2\right]+O(\Omega^3),$$

$$\frac{dJ}{dM_b} = l_{tot} = \kappa l(r_0) - l_m,$$

$$l_m = \frac{\mu^2}{9r_0^3\dot{M}_b}\left(3-2\sqrt{\frac{r_c^3}{r_0^3}}\right)$$

$$\frac{1}{\Omega r}\frac{dl}{dr} = \frac{1}{2}f_{ms}(r_0) = \left(\frac{r_m}{r_0}\right)^{7/2}\left(\sqrt{\frac{r_c^3}{r_0^3}}-1\right),$$

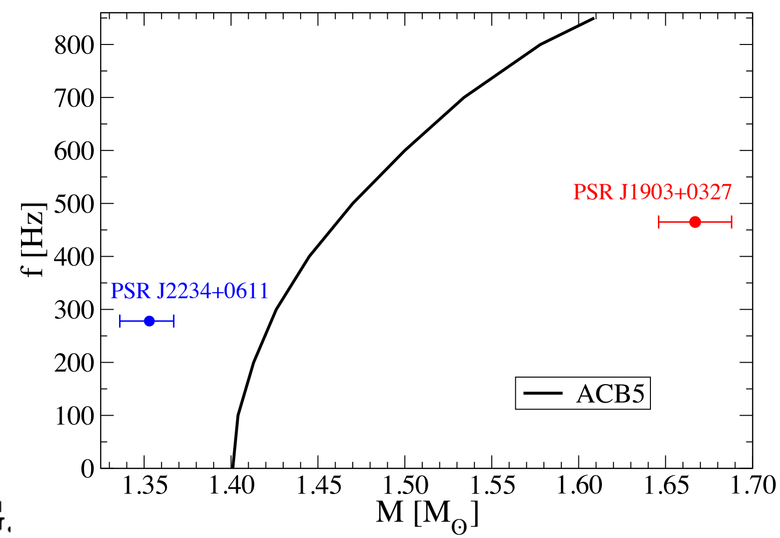
$$r_m = \frac{\mu^{\frac{4}{7}}}{(GM)^{\frac{1}{7}}\dot{M}_b^{\frac{2}{7}}},$$

$$r_c = \left(\frac{GM}{\Omega^2}\right)^{1/3},$$

$$0 = f_{ms}(r_{ms}).$$

$$B(M_{acc}) = \frac{B_i}{1+M_{acc}/m_B}.$$

$$\dot{M}_b \cong 10^{-9}M_{\odot},\quad B_i \cong 10^8\ \mathrm{G}.$$



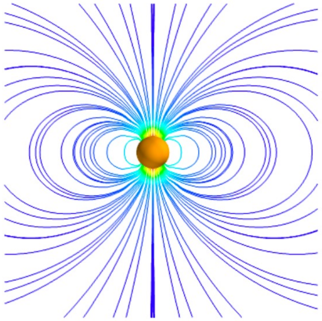
Astron. Nachr. 2019;340:878-884. Eprint: arXiv: 1912.08782

Simulations of SPS at the vicinity of the Sun

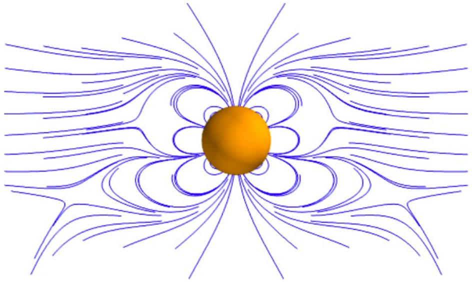
Two approaches to the description of the magnetic field of the Sun:

- Dipole field approximation[1] considering the magnetic moment of the Sun as $M_S = 6.87\times 10^{32}\ \mathrm{G\cdot cm^3}$.

- Dipole – quadrupole– current sheet[2] (DQCS) which is more realistic than the dipole model even at larger distances from the Sun. It provides a more accurate tracking of electron-positron pairs on their way towards the Earth, and a better treatment of the magnetic Bremsstrahlung process.



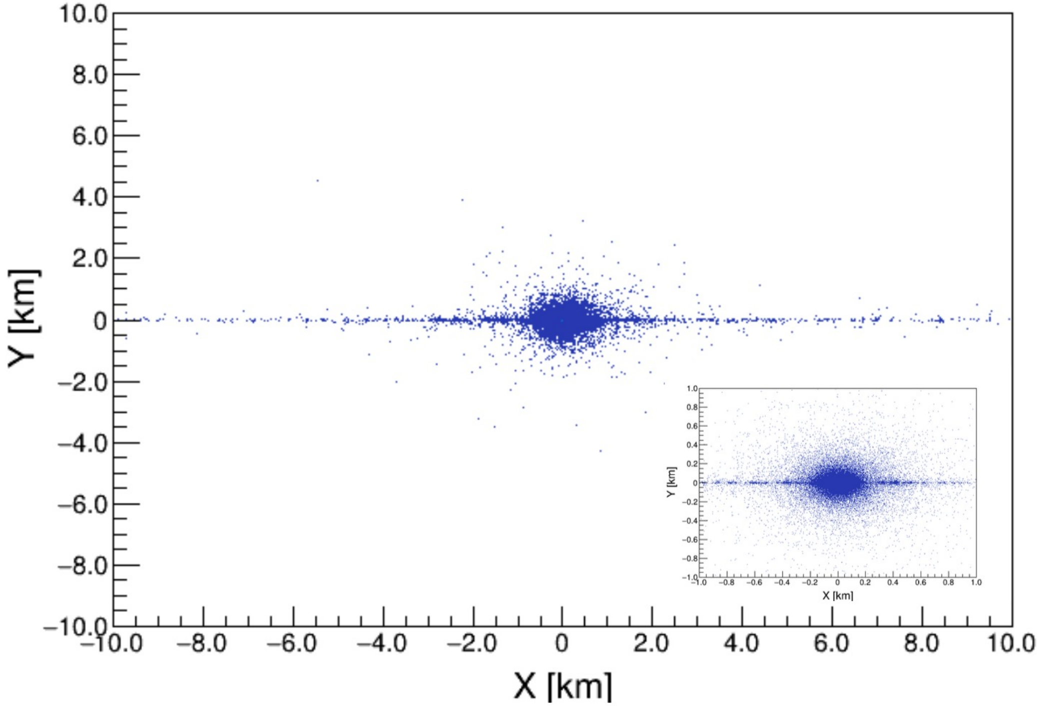
Dipole model



DQCS model

[1]W. Bednarek 1999, arXiv:astro-ph/9911266
[2]Banaszkiewicz et al. 1998, A&A

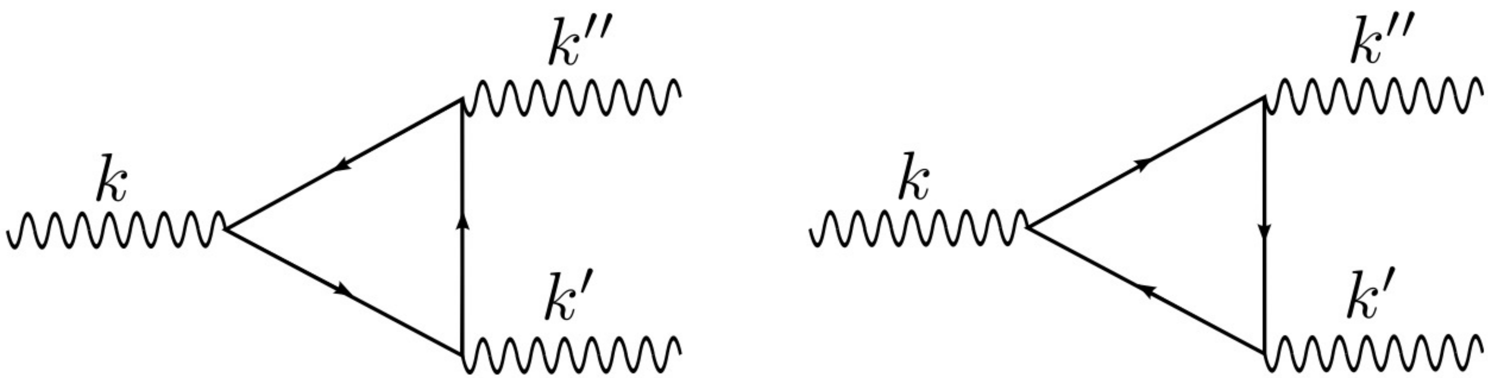
Simulations of SPS at the vicinity of the Sun



Shower footprint derived from the CORSIKA simulation program for particles that are tracked through the atmosphere that eventually react with air nuclei. The inset displays the core of the footprint in a smaller area.

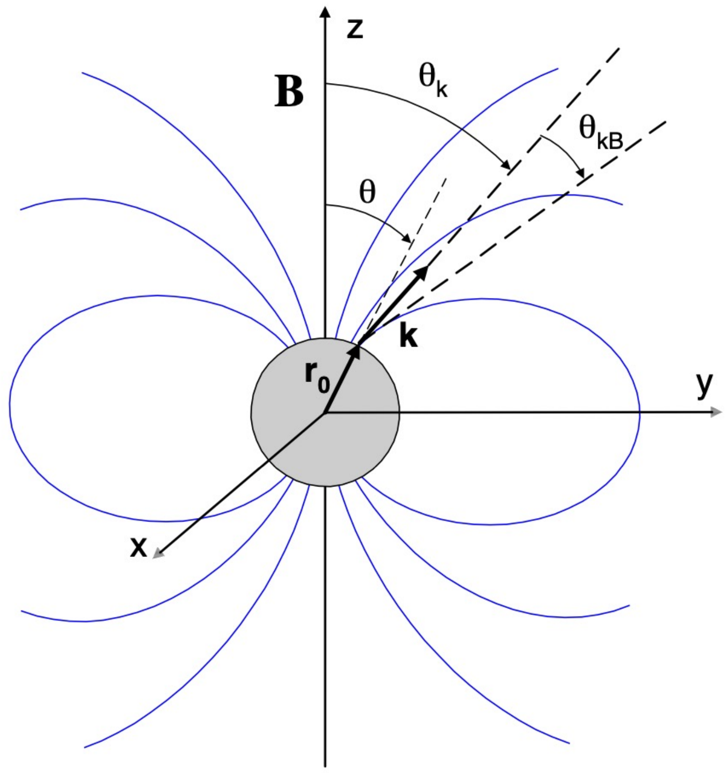
[1]N. Dhital, P. Homola, D. Alvarez-Castillo et al., arXiv:1811.10334

Photon Splitting around compact objects



Alice K. Harding, Matthew G. Baring, and Peter L. Gonthier - ApJ 476 246 (1997)

Photon Splitting around compact objects



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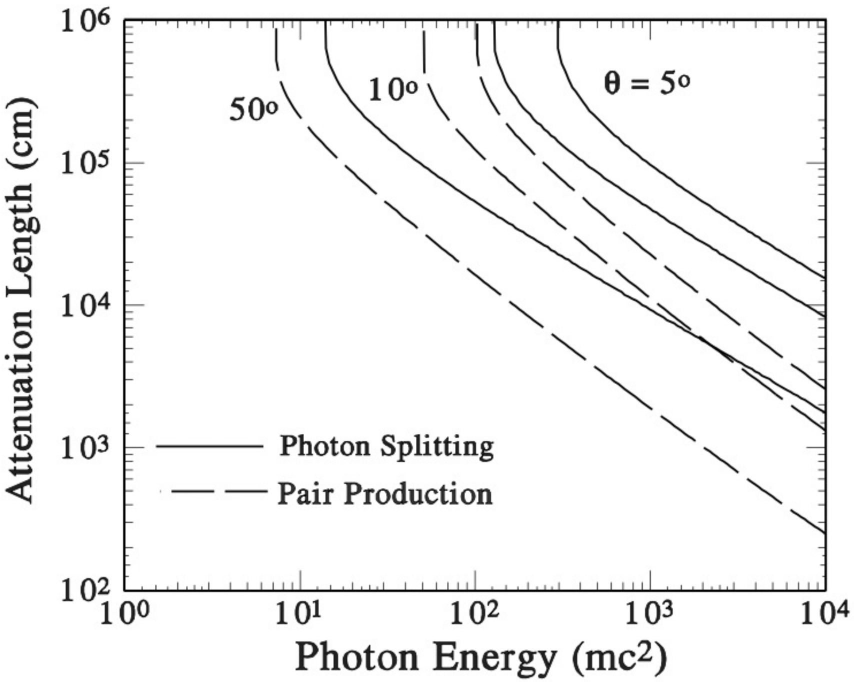
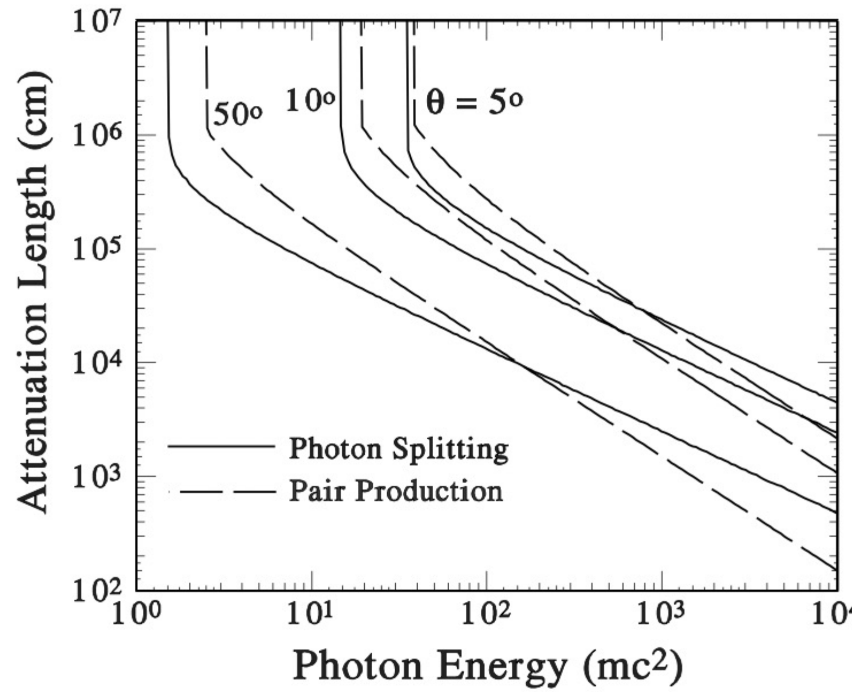
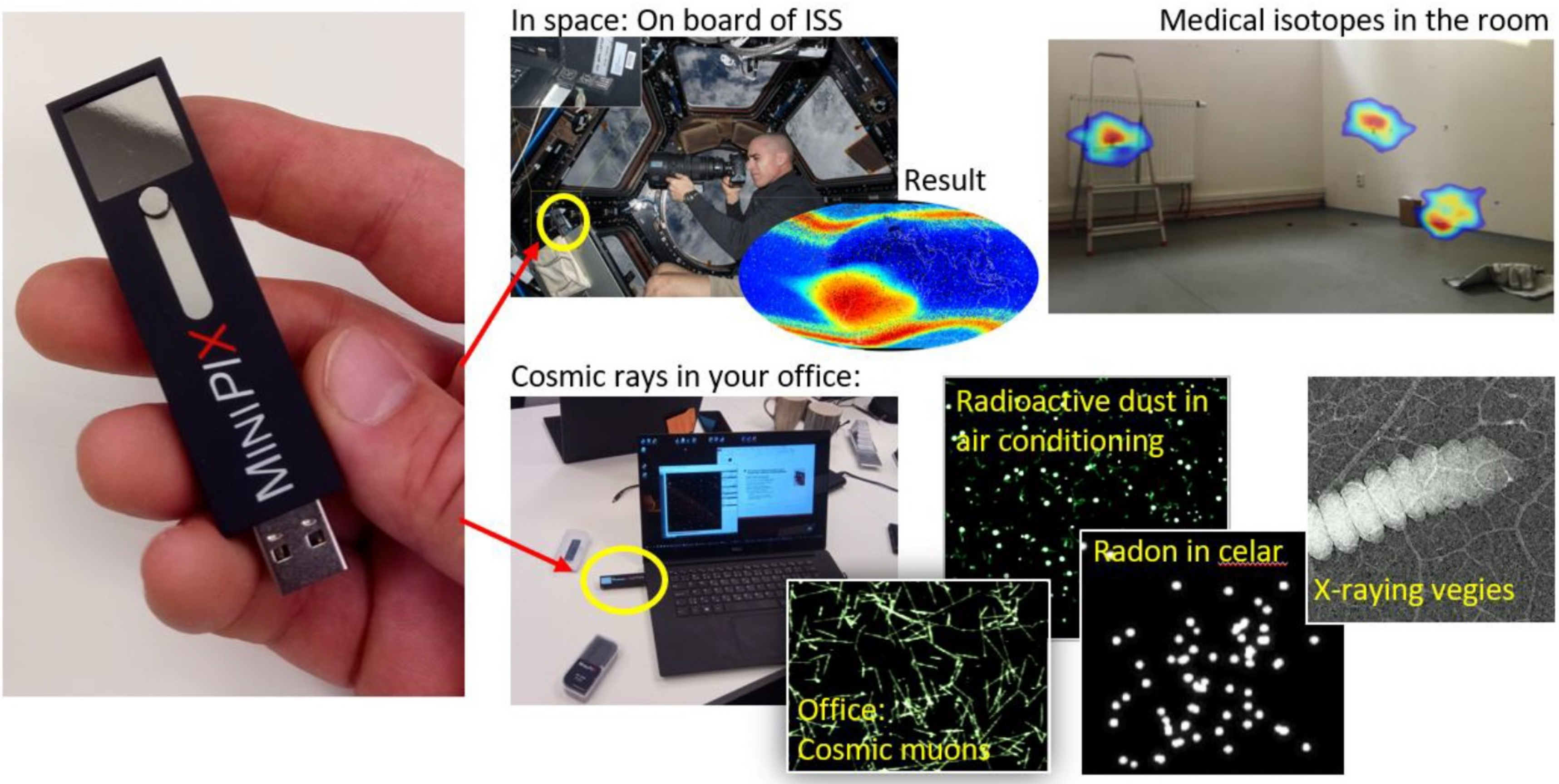


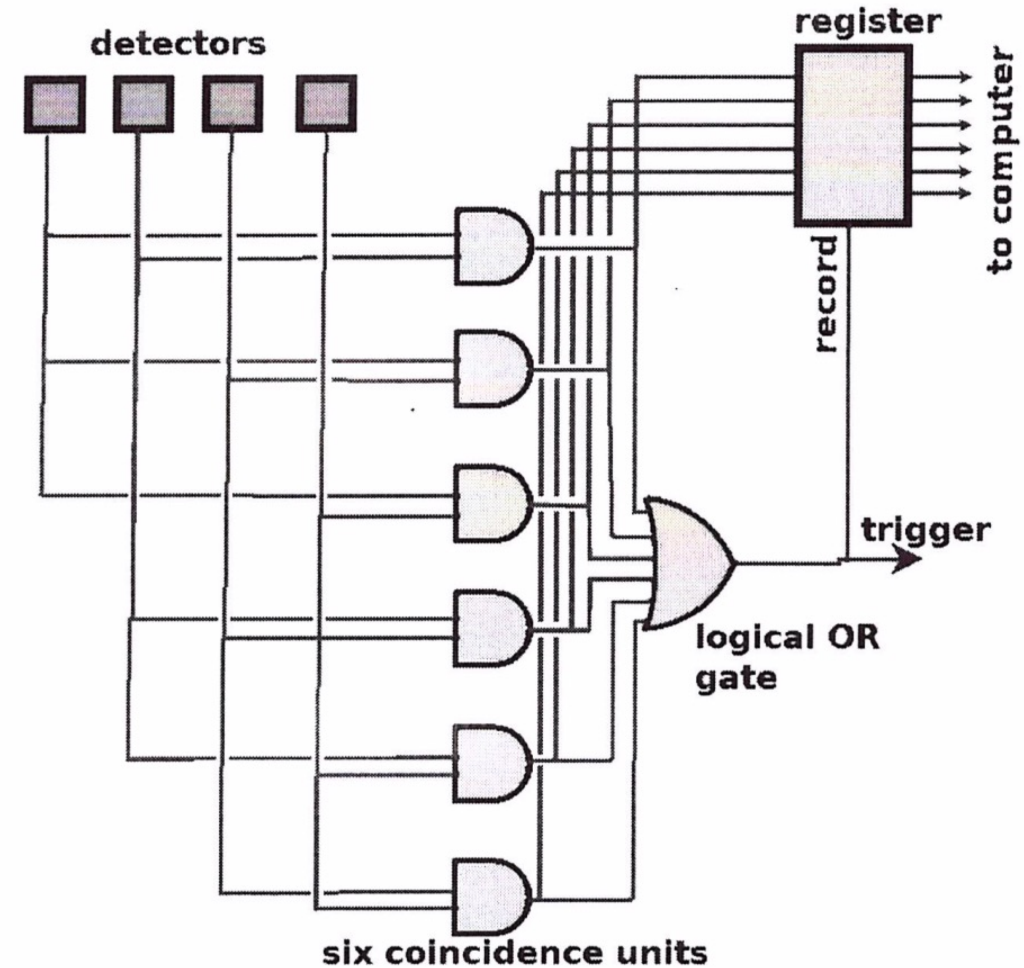


Alice K. Harding, Matthew G. Baring, and Peter L. Gonthier - ApJ 476 246 (1997)

ADVACAM MiniPix



CREDO-MAZE Detector



Earthquake Precursors

Large scale correlations between cosmic rays and earthquakes presumably related to earthquakes precursors has been observed. The found periodicity is rather similar to the sun spots solar cycle.

Cosmic ray data correspond to the measurements at the Pierre Auger observatory in Malargüe, Argentina, whereas seismic data is taken from Moscow and Oulu stations located in Russia and Finland, respectively.

A 6σ correlation effect has been observed in a period of about 4.5 years. Details can be found in a publication being peer reviewed at the moment and soon to be publicly available.

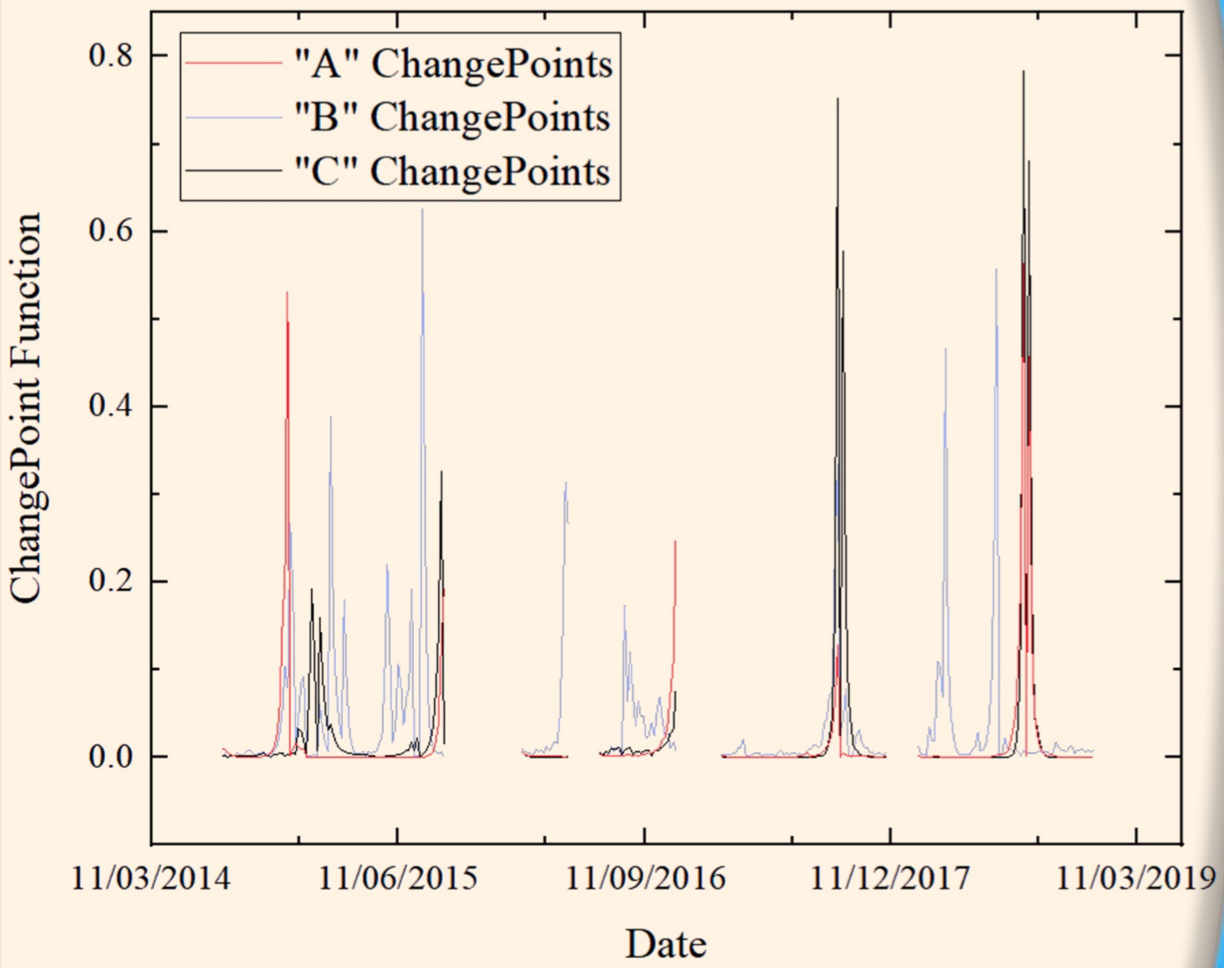
Bayesian Analysis of Cosmic Ray Data for Earthquake Predictions

Clementine Mostyn

Bartosz Grygielski

Tutor: Dr David Alvarez

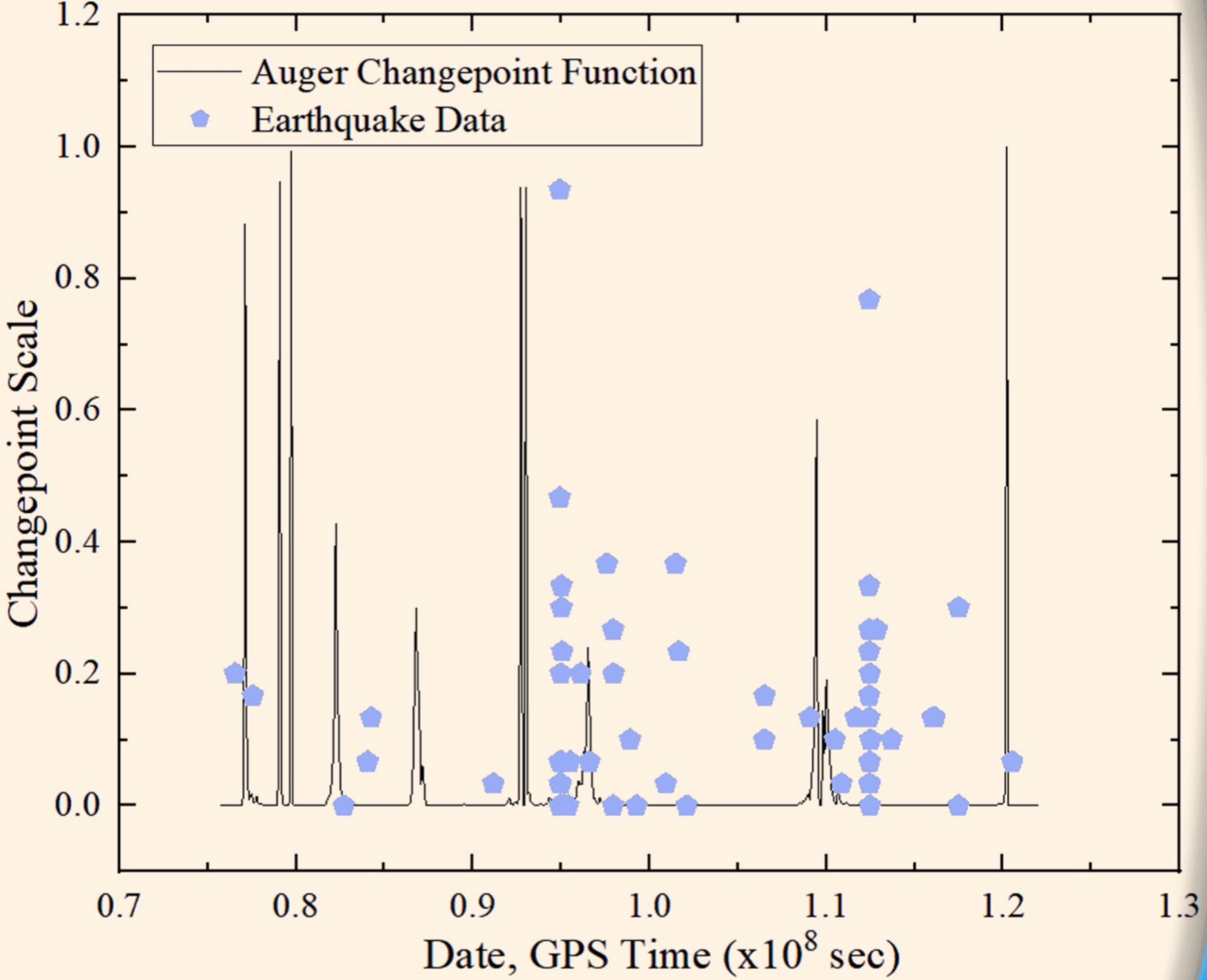
Bayesian Analysis and Changepoints



Changepoints in C are Closer in Position to Those in A

Earthquake Data has Large Impact on Correlation, Shift in Time and Magnitude of Effect in Cosmic Ray Data Likely to be Dependent on Earthquake Properties Like Magnitude

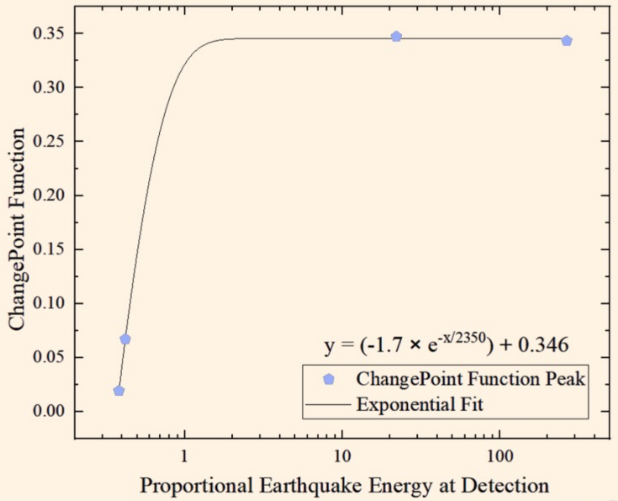
Smaller Scale Data

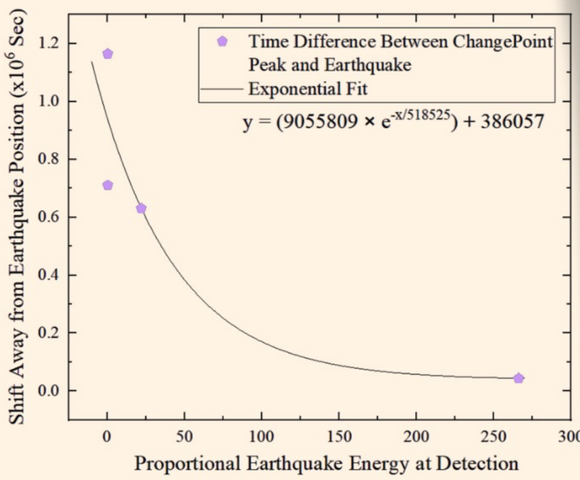


Changepoints Found for the Count of Cosmic Ray Events with Energy Above 0.4 EeV (x10^{18} eV), Shifted by 25 Days

Earthquakes with Magnitude Above 6 Within a Range of 700 km from the Auger Observatory Also Plotted

Energy Ranges and Earthquake Magnitude





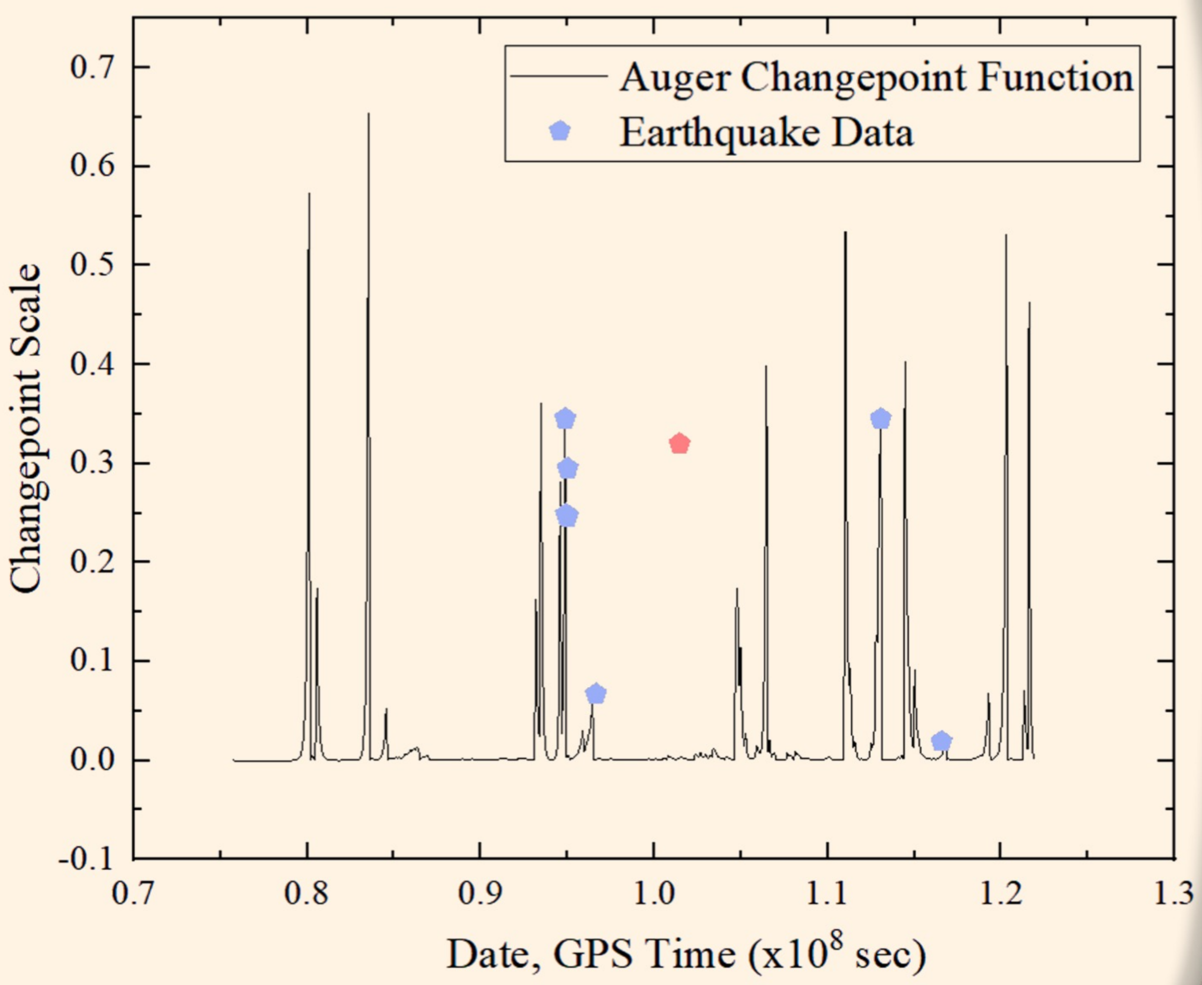
All But One Earthquake Caused the Largest Response in Event Energy Range of 1.5 to 2 EeV

Distance Accounted for Using Energy as

$$\log_{10}(\mathrm{E}) = 5.24 + (1.44M)$$

$$E' = \frac{E}{\pi(depth \times distance)^2}$$

Rescaling and Final Changepoint Plot

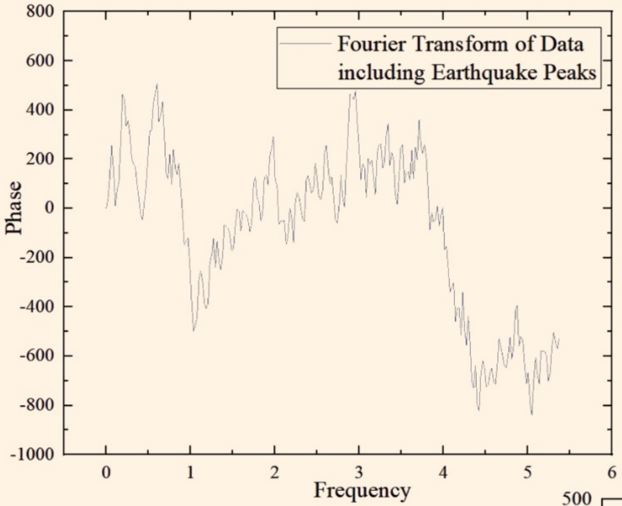


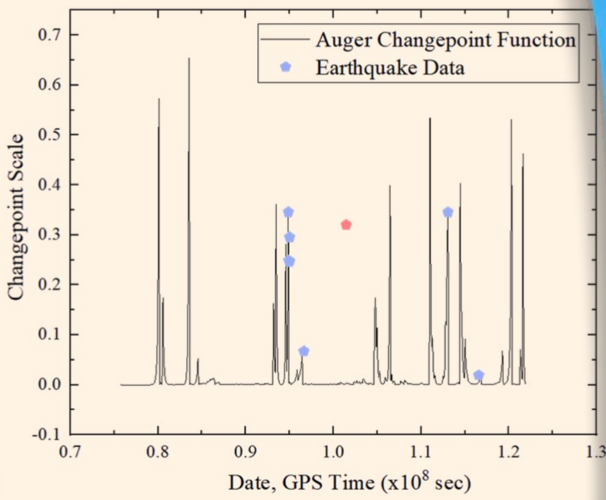
Final Plot of the Changepoint Function for Cosmic Ray Events with Energies Between 1.5 and 2 EeV

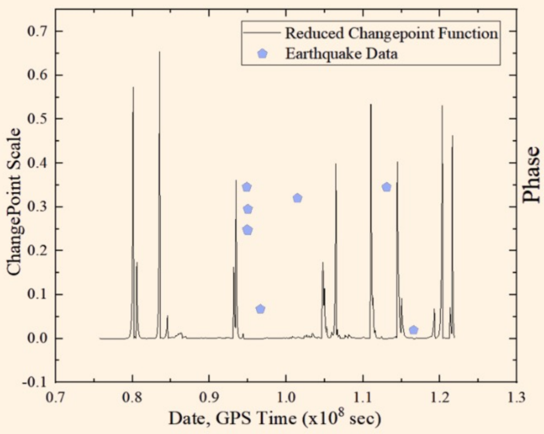
Most Earthquakes Accurately Predicted with Exception of the Closest

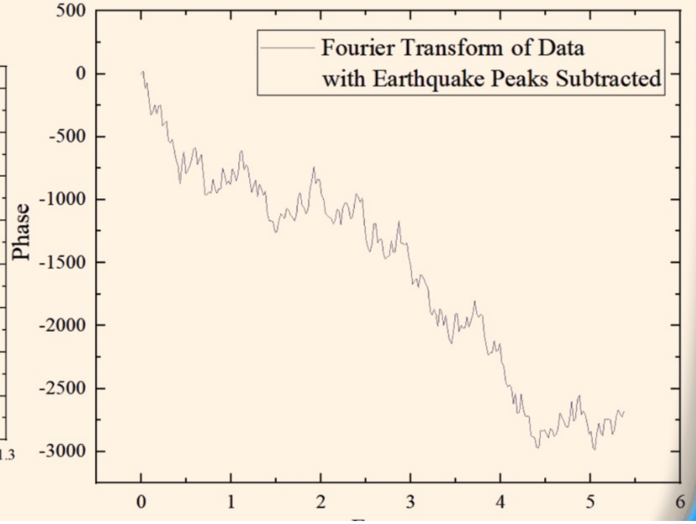
Gives Radius Around Observatory in Which Earthquakes May Occur and Predicts Magnitudes at Each Distance in that Radius

Identifying Relevant Peaks









Fourier Transforms of Changepoint Plot With and Without the Peaks Related to Recorded Earthquakes

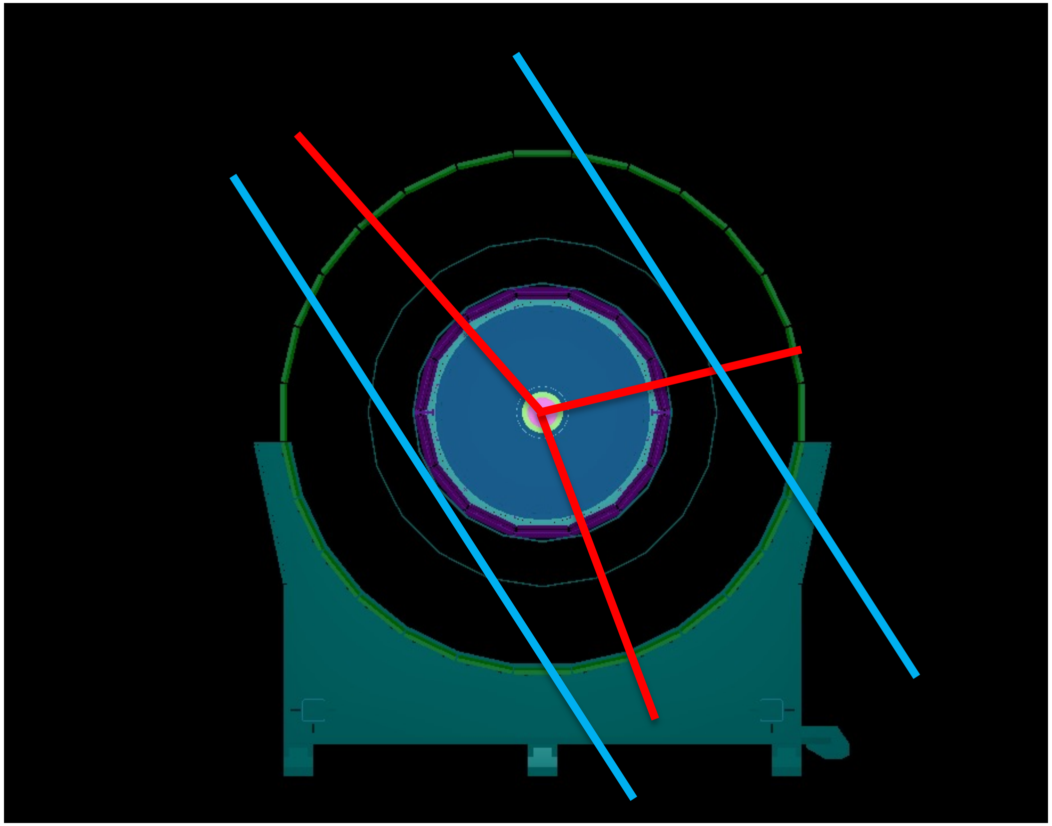
Rough Linear Trend Observed When Earthquake Peaks Not Included

If Analysis Was Repeated for Other Observatories This Could be Used to Identify Which Peaks Correspond to Earthquakes

How to distiguish between muons from space and collisions

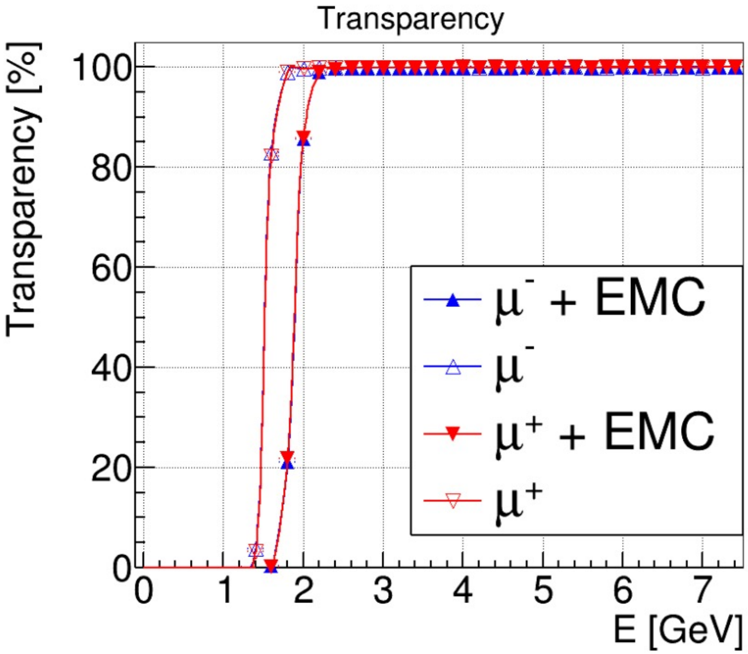
(DANIEL WIELANEK)

1. Topology



- Particles produced at collsions must come from event vertex
- Only small fraction of cosmic rays will pass near the vertex position

2. Time of flight



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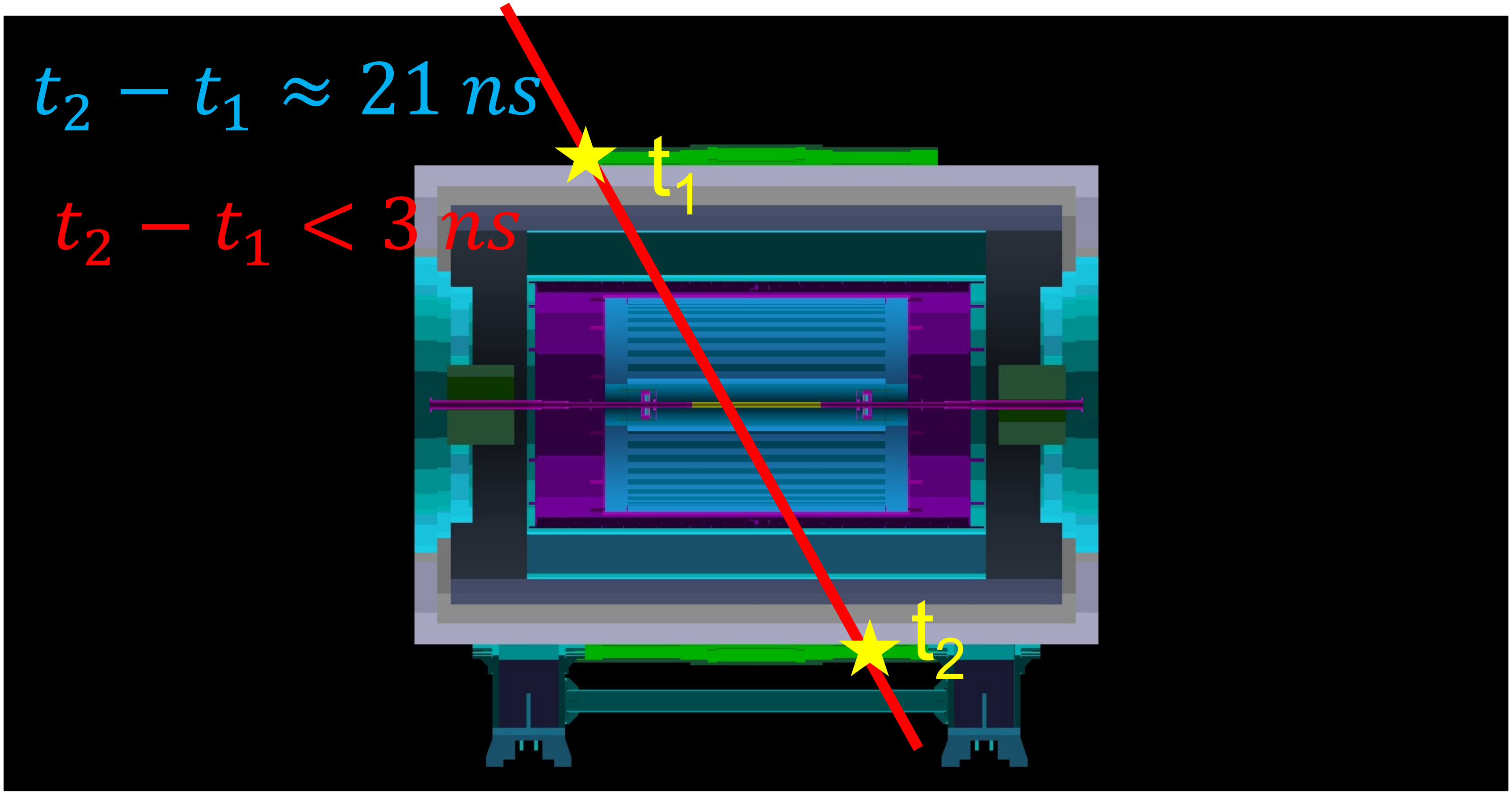
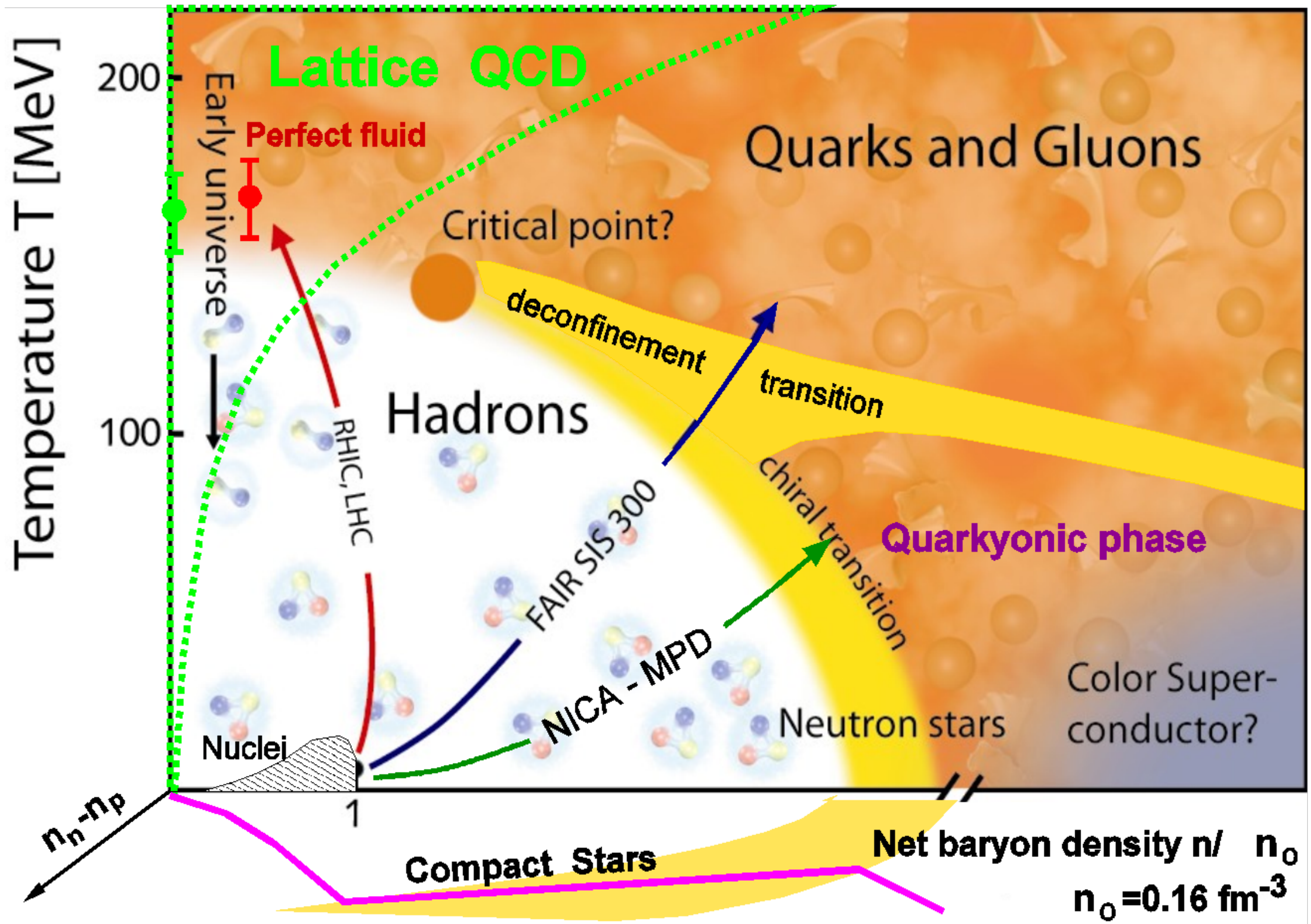


Critical Endpoint in QCD



Probing Dense Matter

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Thermodynamic properties of the trigonometric Rosen–Morse potential and applications to a quantum gas of mesons

Aram Bahroz Brzo

Physics Department, College of Education, University of Sulaimani,
New Camp, Tasluja, Street 1, Zone 501 Sulaimania, As Sulaymaniyah, Iraq
aram.brzo@univsul.edu.iq

David Alvarez-Castillo*

Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences (PAS),
152 Ul. Radzikowskiego, Cracow 31-342, Poland
Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research (JINR),
6 Joliot-Curie Street, Dubna 141980, Russian Federation
alvarez@theor.jinr.ru

Probing Dense Matter

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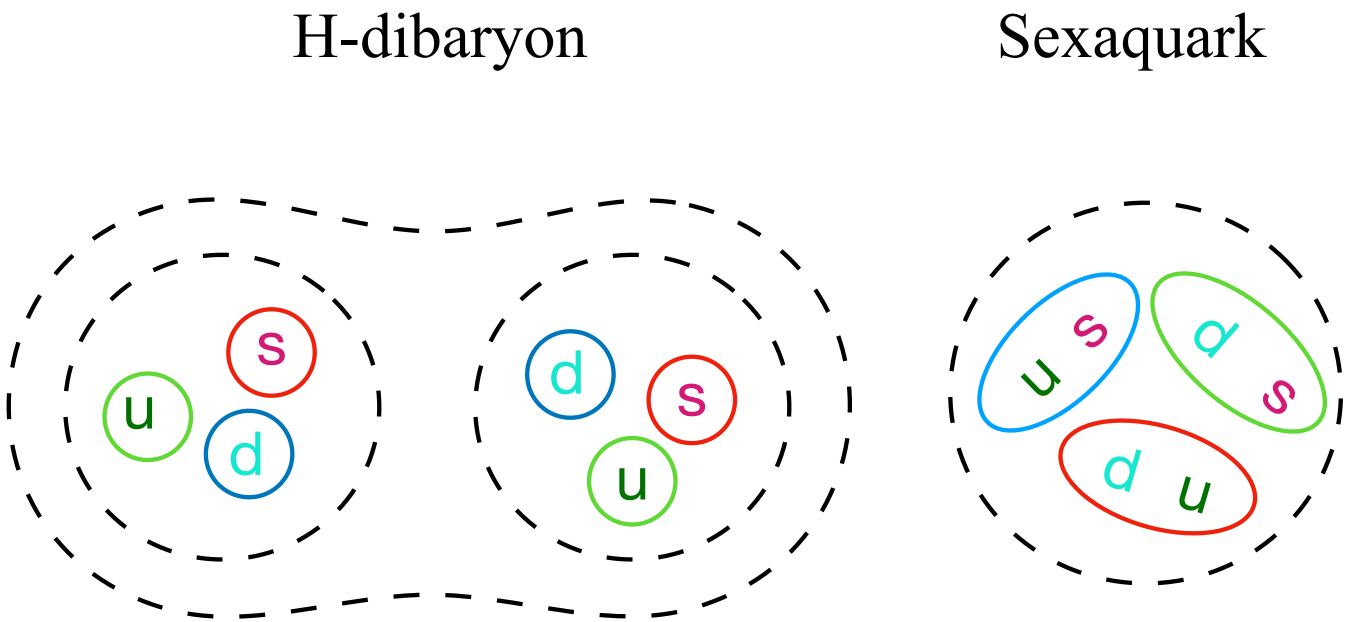
Regular Article - Theoretical Physics

Bayesian analysis of multimessenger M-R data with interpolated hybrid EoS

A. Ayriyan[1,2,3,a], **D. Blaschke**[4,5,6,b], **A. G. Grunfeld**[7,8], **D. Alvarez-Castillo**[5,9], **H. Grigorian**[1,2,10], **V. Abgaryan**[1,11,12]

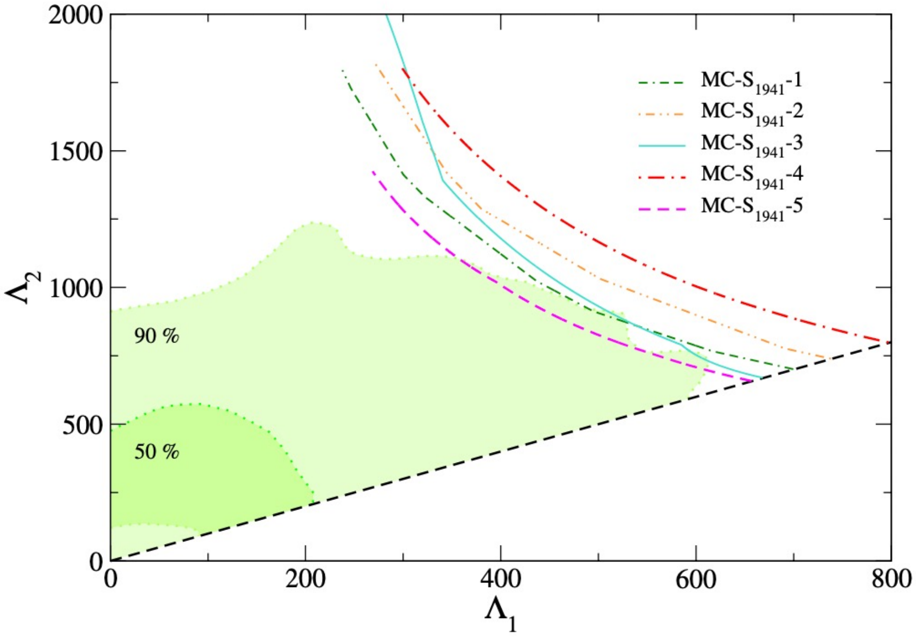
[1] Laboratory of Information Technologies, JINR, 6 Joliot-Curie Str., Dubna 141980, Russian Federation
[2] IT and Computing Division, A. Alikhanyan National Laboratory, 2 Alikhanian Brothers Str., 0036 Yerevan, Armenia
[3] Dubna State University, 19 Universitetskaya Str., Dubna 141980, Russia
[4] Institute of Theoretical Physics, University of Wroclaw, 9 M. Borna Sq, 50-204 Wrocław, Poland
[5] Bogoliubov Laboratory of Theoretical Physics, JINR, 6 Joliot-Curie Str., Dubna 141980, Russian Federation
[6] National Research Nuclear University (MEPhI), 31 Kashirskoe Hwy, Moscow 115409, Russian Federation
[7] CONICET, Godoy Cruz 2290, Buenos Aires, Argentina
[8] Departamento de Física, Comisión Nacional de Energía Atómica, Av. Libertador 8250, (1429), Buenos Aires, Argentina
[9] Henryk Niewodniczański Institute of Nuclear Physics, 152 Radzikowskiego Str, 31-342 Kraków, Poland
[10] Department of Physics, Yerevan State University, 1 Alex Manoogian Str, 0025 Yerevan, Armenia
[11] Theoretical Physics Division, A. Alikhanyan National Laboratory, 2 Alikhanian Brothers Str., 0036 Yerevan, Armenia
[12] Peoples' Friendship University of Russia (RUDN University), 6 Miklukho-Maklaya Str., Moscow 117198, Russian Federation

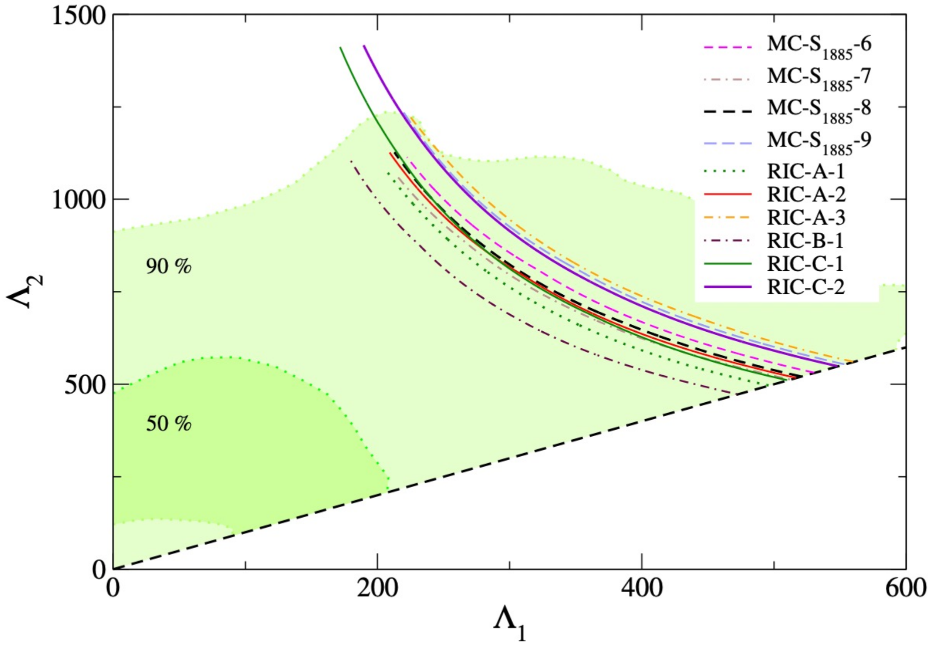
Sexaquarks in NS



M. Shahrbaf, D. Blaschke, S. Typel, D. A-C, and G. R. Farrar, *in preparation*, (2022)

Tidal deformabilities from GW170817





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