Cosmic Ray Archaeology

Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

Presented by Azel Murzabekova, Jacob Rangel,
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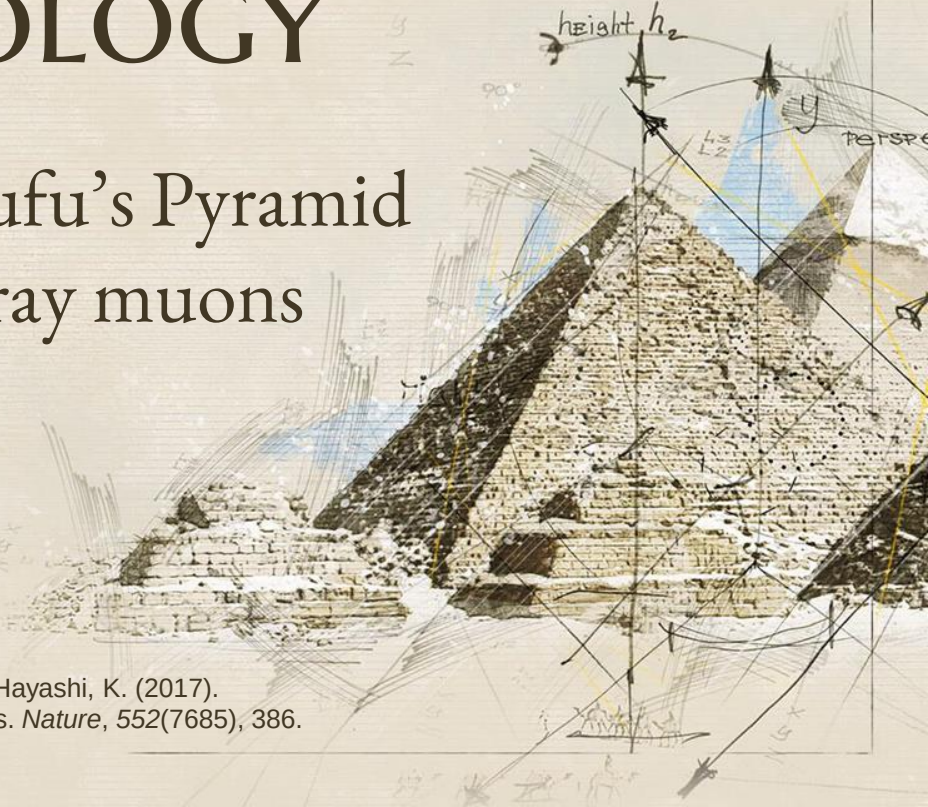
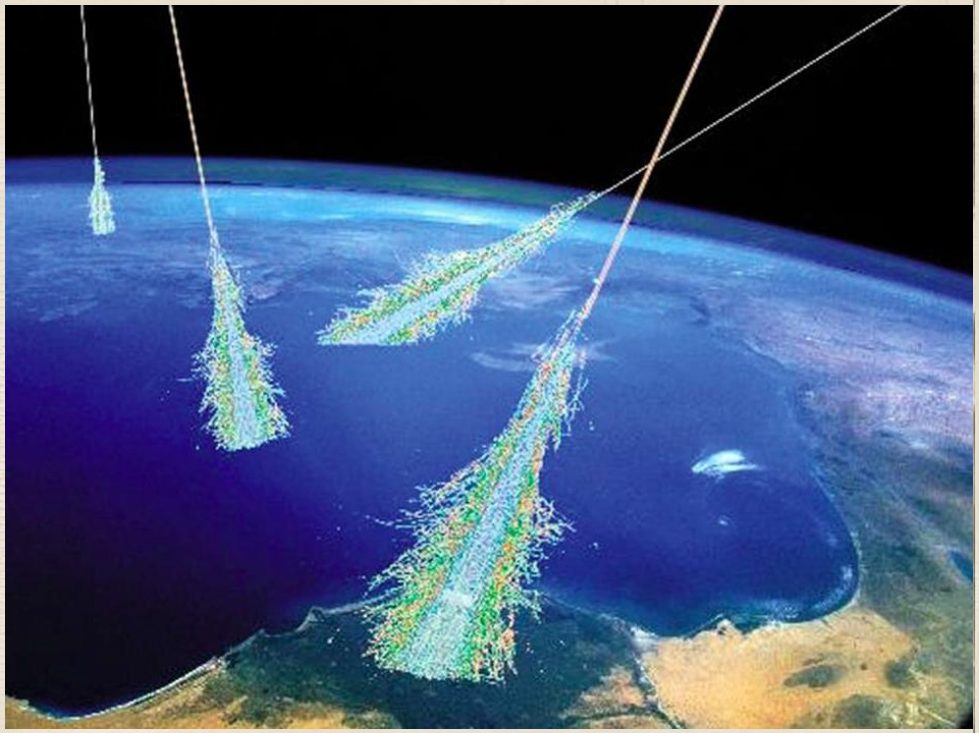


Morishima, K., Kuno, M., Nishio, A., Kitagawa, N., Manabe, Y., Moto, M., ... & Hayashi, K. (2017). Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons. *Nature*, *552*(7685), 386.

Summary

What Are Muons?

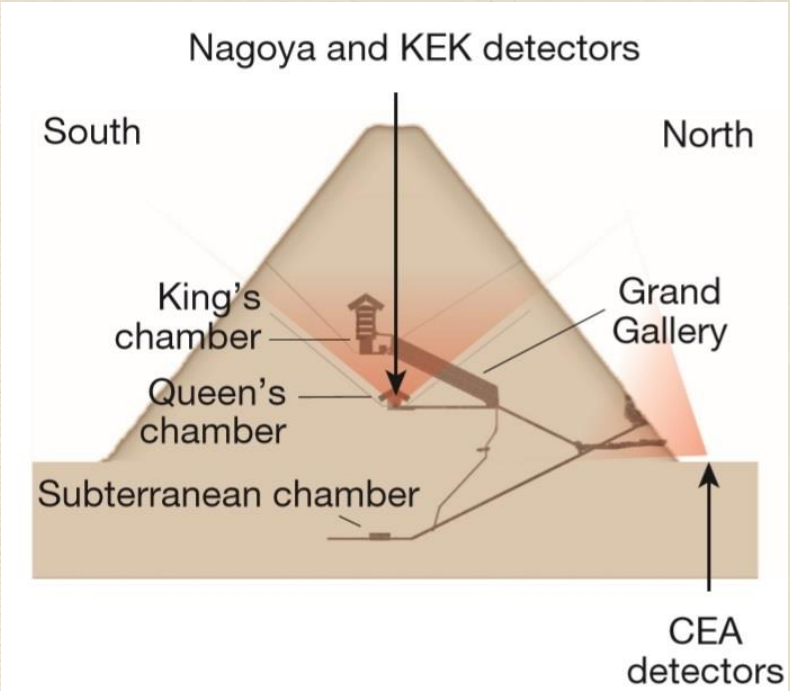
- Heavier version of the electron
- Generated by cosmic ray showers in the upper atmosphere
- Number of muons reaching detector depends on matter passed through



Cosmic ray particle showers generating muons in the earth's atmosphere

The Great Pyramid - Khufu's Pyramid

- Used muons to image the great pyramid
  - Found muon excess indicating new void
- 3 different institutions involved:
  - Nagoya University
  - High Energy Accelerator Research Organization (KEK)
  - Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA)



Side view of Khufu's pyramid including detector positions for each institution

How Muons are Detected

- Multiple detectors overlap
- Coincidence required for muon detection
- Observed angle determined by distance between detectors

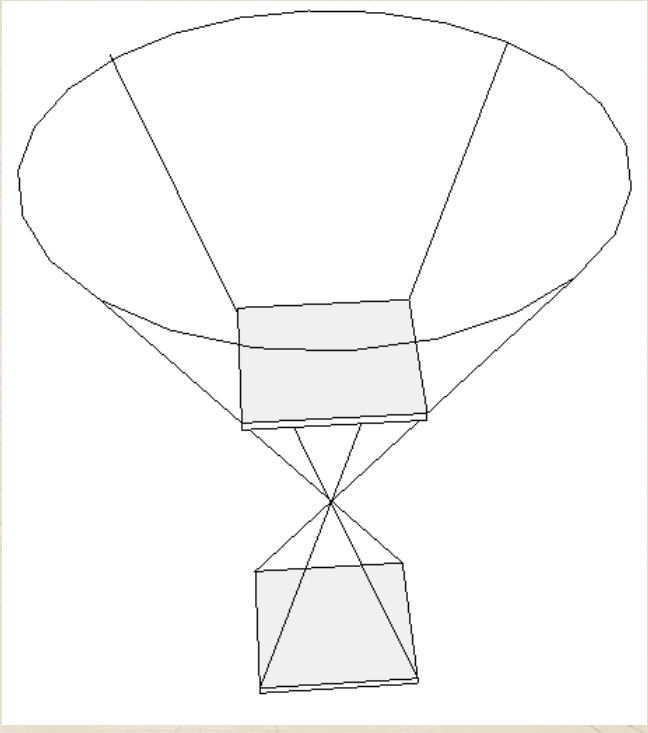
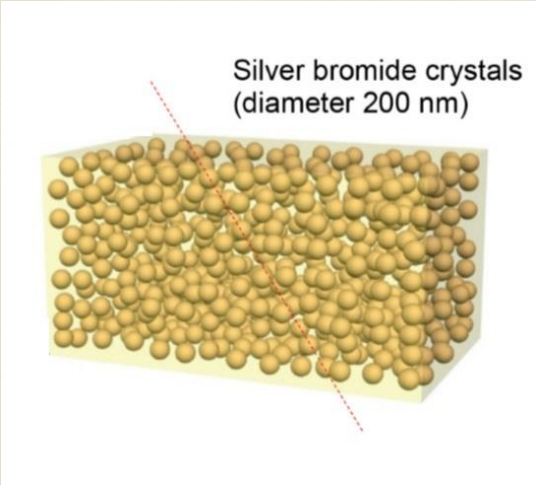


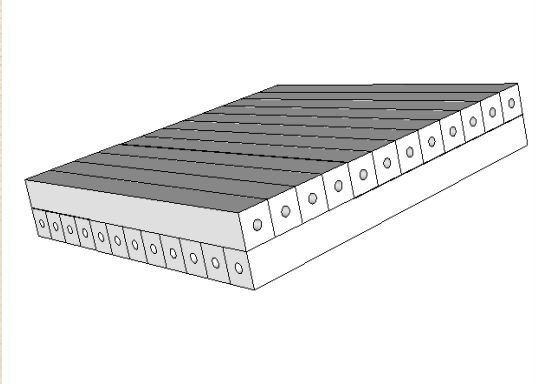
Diagram illustrating solid angle observed

There are Three Common Detection Methods for Muons

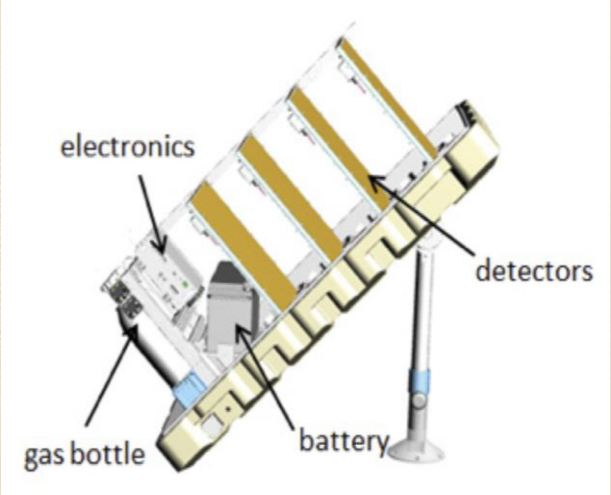
- Nuclear Emulsion Films
- Scintillator Hodoscopes
- Gas Detectors



Graphic representation of a nuclear emulsion film



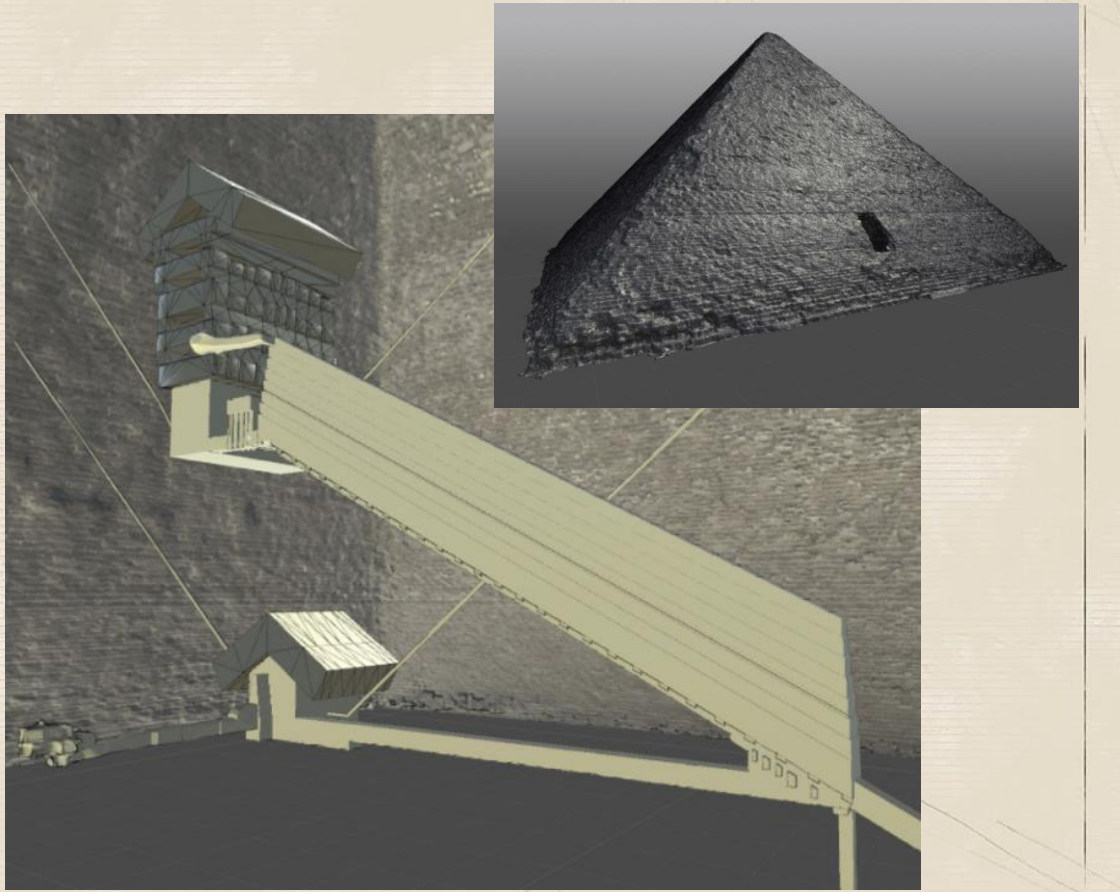
Graphic representation of a scintillator hodoscope



Graphic representation of the gas detector used.

Three Different Data Analysis Models were Used

- Three independent simulations
  - Geant4
  - Monte Carlo
  - CRY/Geant4
- Detailed 3D model
- Normalized data to these models



3D model of the pyramid which was compared with data

Comparison with Previous Work

Other Surveys of The Great Pyramid

- Microgravimetry surveys
  - Measurement of slight variations in gravity caused by variations in the amount of matter
  - Attempted to find the ‘hidden room’ but found sand instead
- Ground penetrating radar survey
  - Usage of radar signals to create an image of the surface
  - Suggested that there might be an unknown corridor
  - Neither confirmed nor refuted

Other Muon Detector Applications

- In particle accelerators, detection of muons captures data from particle collisions
- Spark chambers used as muon detectors in Khafre's Pyramid
  - Concluded no new chambers with similar volumes to four known chambers
- Homeland security
  - Muon tomography: probe through shielded material by measuring deflections of cosmic ray muons
- Other archaeological sites: Rome, Naples, Teotihuacan Pyramid

Critical Analysis

Scientific Validity

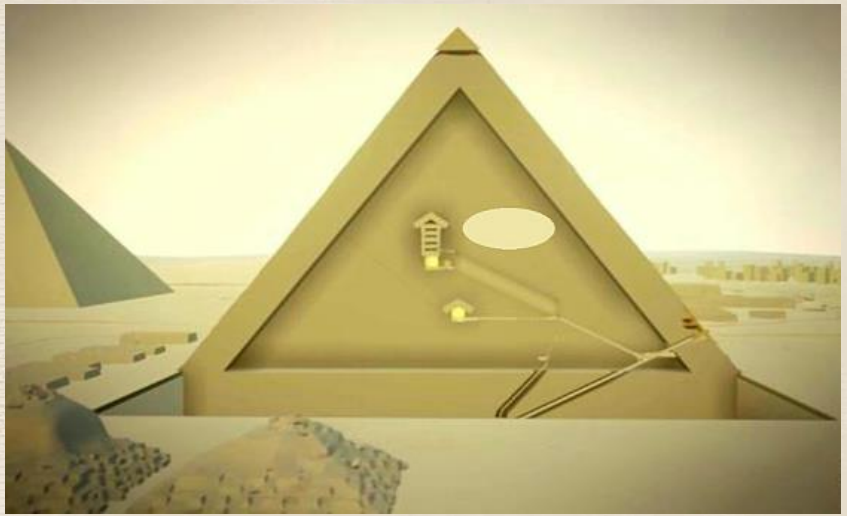
- Able to detect known structures with this technology
- Three consistent independent detections of the void, compared to detailed simulations
- Remaining questions:
  - Why only use a subset of nuclear emulsion film data?
  - Why enlarge solid angle when using scintillator hodoscopes?

Importance

- The first confident detection of an inner structure in this pyramid since the 19th century.
- Also the first time a void has ever been detected from outside a structure.
- This paper furthers efforts in the fields mentioned previously:
  - Other archaeological surveys around the world
  - High energy physics (particle accelerators)
  - Studies using this idea were used for nuclear security

Broad Interest

- Of interest to both the archaeological & physics communities
- Overall, language of paper is clear, concise and avoids jargon.
- However, methods section could be made more accessible to non-experts by adding more diagrams

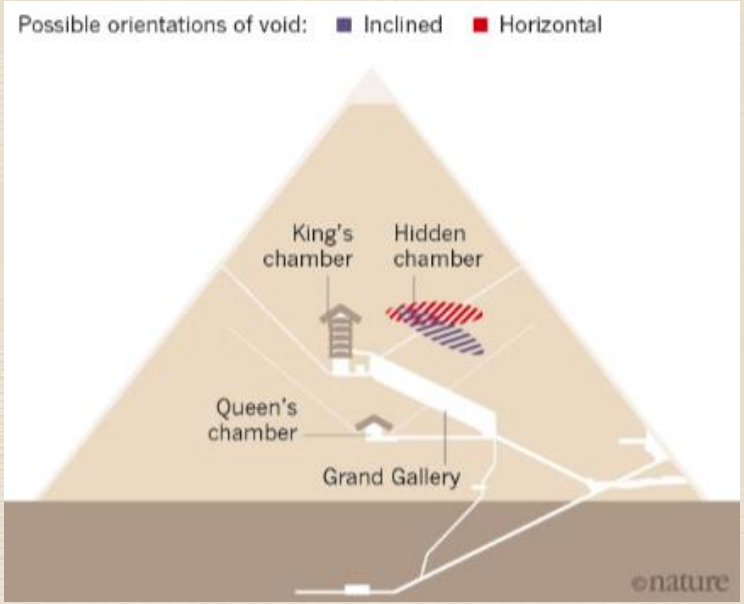


Side view of the pyramid, including the newly discovered void

Conclusions

Author's Conclusions

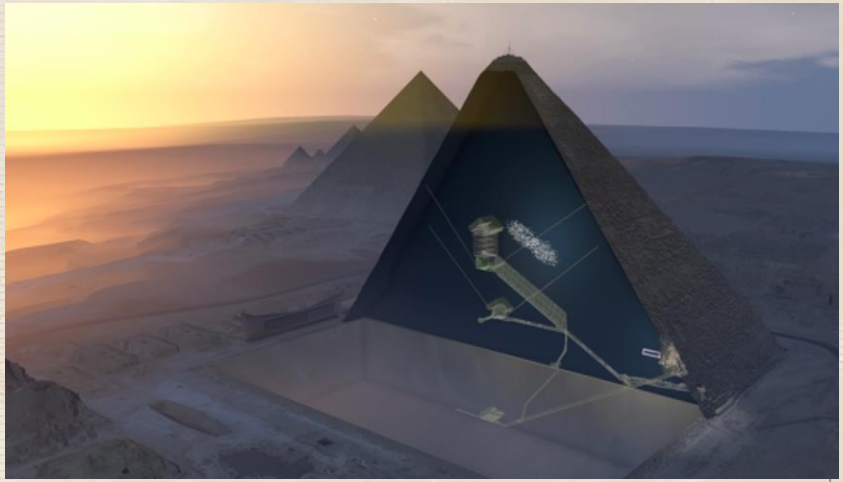
- Discovered large void of same cross-sectional area as Grand Gallery, minimum length 30 m
- Void's purpose and exact shape still unclear
- Void could consist of one or several adjacent voids, either inclined or horizontal



Inner structure of the pyramid, including possible orientations of the void

Our Conclusion

- We recommend this paper for publication
  - Scientifically valid
  - Important
  - Broad interest
- Suggest the small edits mentioned previously
  - Justify methods



Cross-sectional interior view of the 3d model of the Great pyramid

Work That Followed This Paper

- Scopus field weighted citation impact: 5.28
  - Average paper weight impact is 1.0, for reference
- Cited by 55 other papers
- Among those:
  - The MEV Project: high-resolution telescope for muography of Etna Volcano
  - Neutron Imaging at LANSCE: imaging of metallic and ceramic nuclear fuels

Reference list

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