



# **A Century of Cosmic Rays and Manchester's role in their study**

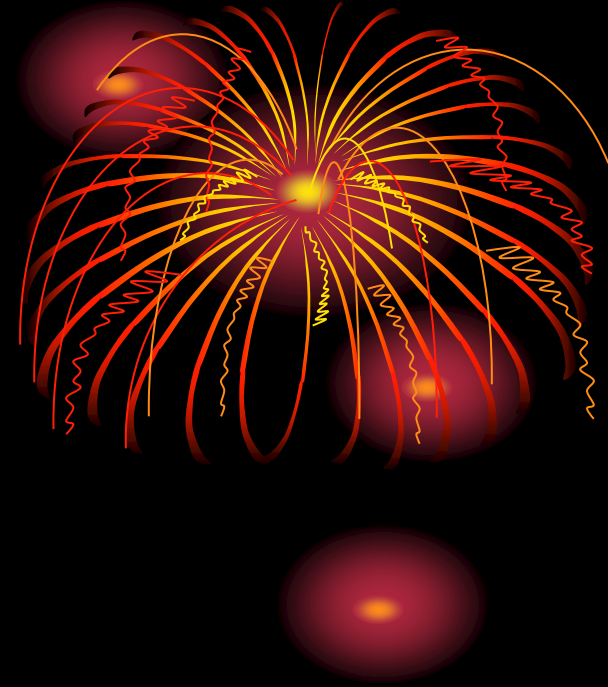
**Ralph Spencer**

**JBCA**

**Schuster Colloquium 5 Oct  
2021**

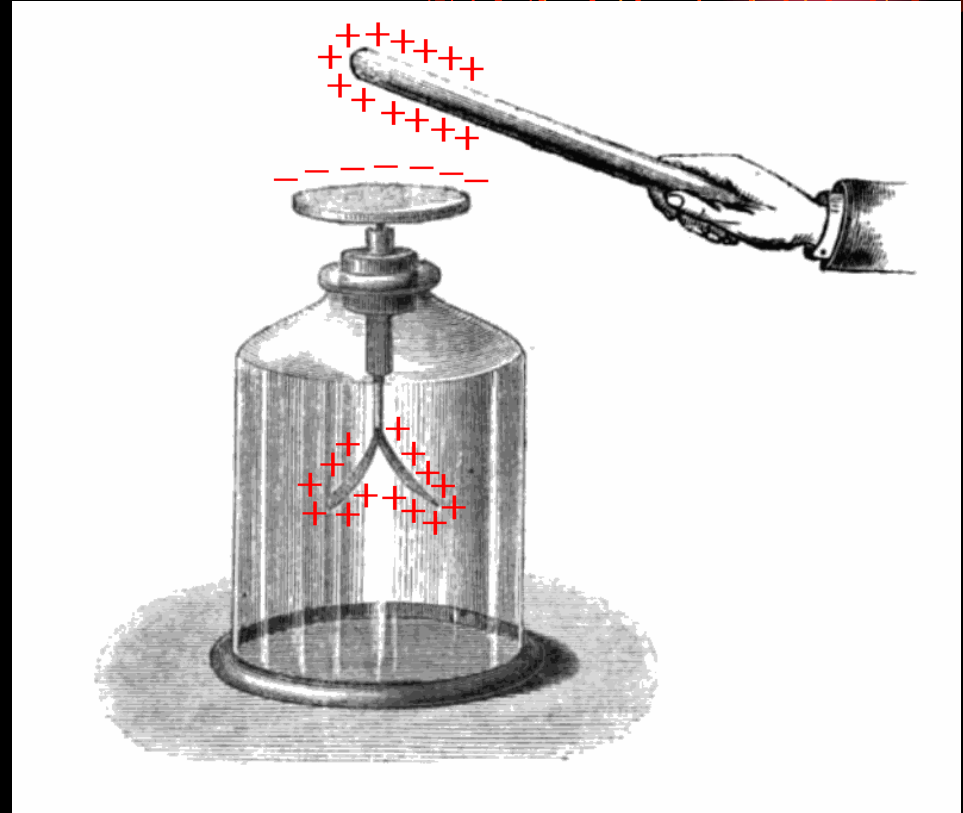
# Contents

- **Discovery**
- **Blackett and Team**
- **Extensive Air Showers**
- **Lovell and Jodrell Bank Origins**
- **V particles**
- **Radio and Cosmic Rays**
- **Cosmic rays today**



# Radioactivity

- **Radiation from the ground**
- **The Electroscope**
- **Charge repels the gold leaf**
- **Radioactivity ionises the air and charge is lost so foil collapses**
- **Activity should decrease as we get higher from the ground**



# The Eiffel Tower

- **Gustav Eiffel Engineers: Paris Grand Exhibition 1889 Centenary of the French Revolution 300 m**





# **Radiation did not decrease. We need a bigger tower!**

- **Victor Hess 1912**
- **Flew an electroscope in a Hydrogen Balloon**
- **Flew up to 5 km altitude, sometimes at night**
- **Found the radiation increased at high altitude**
- **Coming from outer space!**
- **Cosmic Rays discovered!**



# Hess electroscope Smithsonian Air and Space Museum



# Physics at Manchester

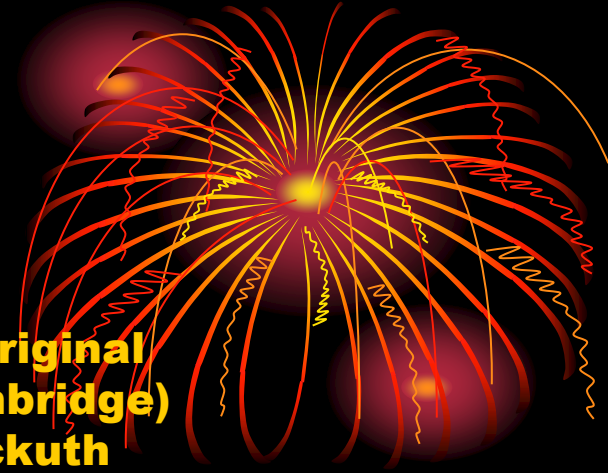


- **1907-1919 Rutherford Era**
  - **Discovery of the nucleus**
  - **The Geiger-Müller counter**
  - **Transmutation of the elements seen for the first time**
- **1919-1937 The Bragg Era**
  - **Concentration on crystallography**

**See Three Centuries of Manchester Physics, Robin Marshall, 2019**

# The Cloud Chamber

## 1937-1953 Blackett Era



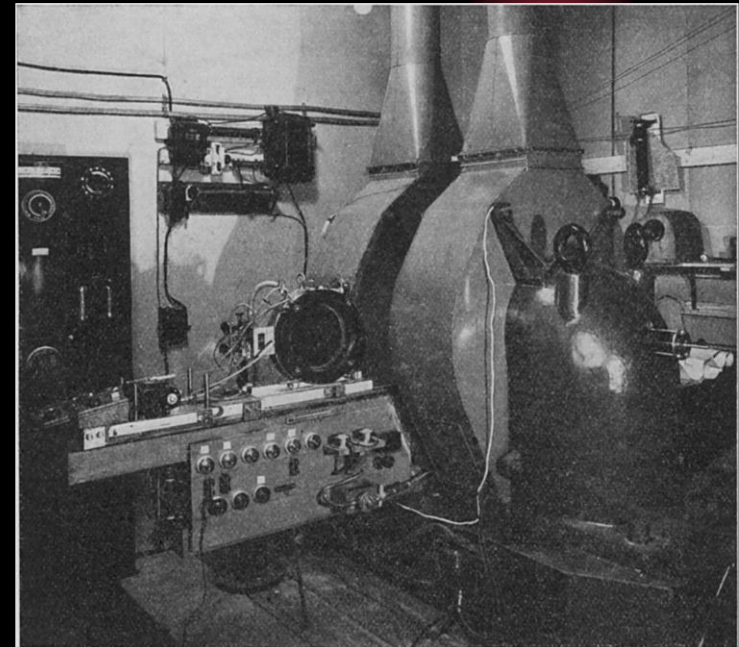
**C T R Wilson 1911 original  
(Cavendish Lab Cambridge)  
Photo credit Rolf Kickuth**



**Patrick M.S. Lord  
Blackett, Nobel prize  
1948**

**Birkbeck 1933,  
Manchester 1937,  
Imperial 1953**

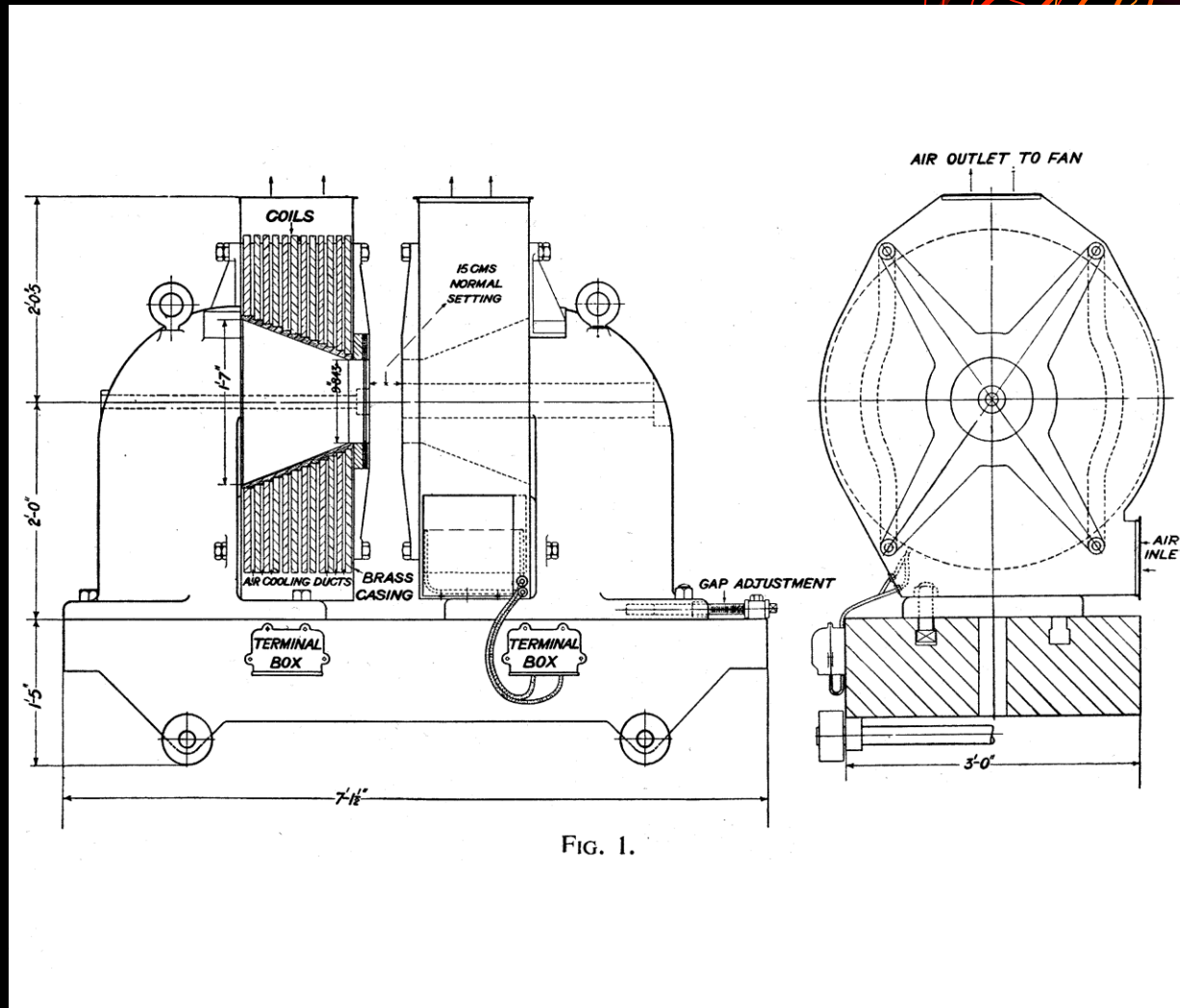
**Improved cloud  
chamber using a strong  
spring so that it could  
be fired rapidly**



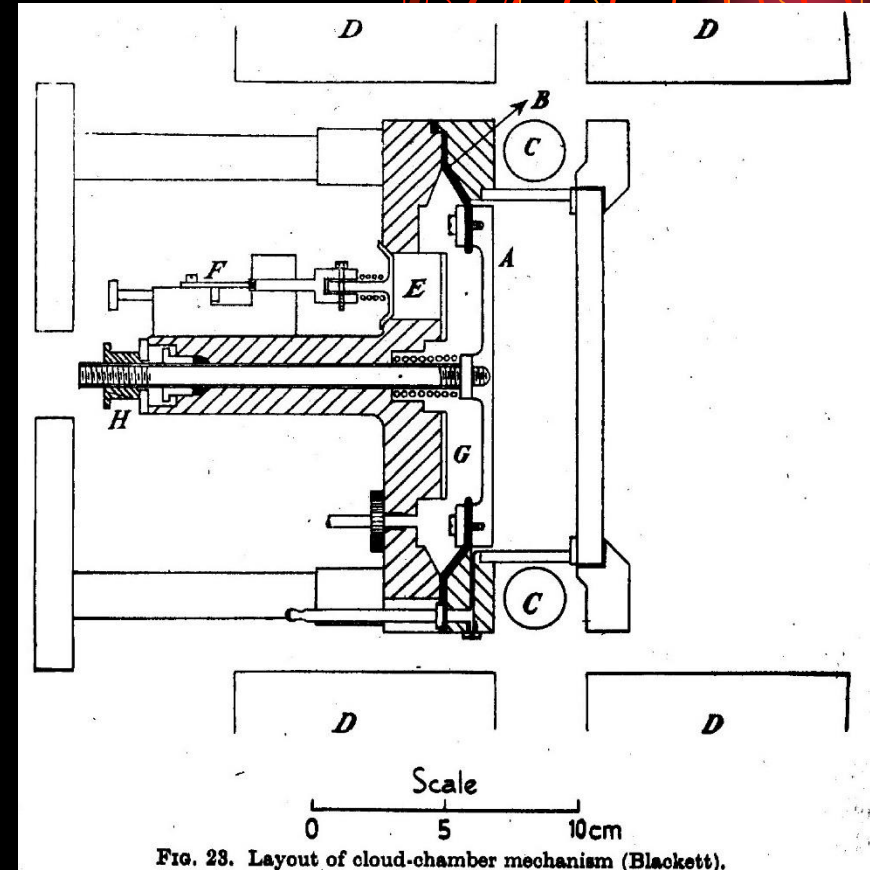
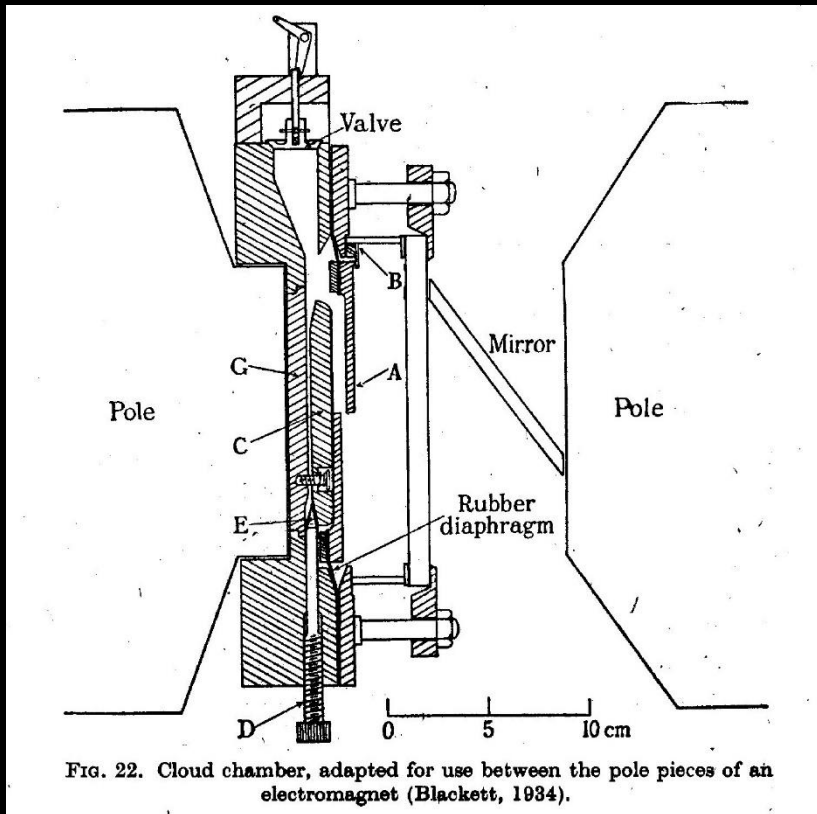
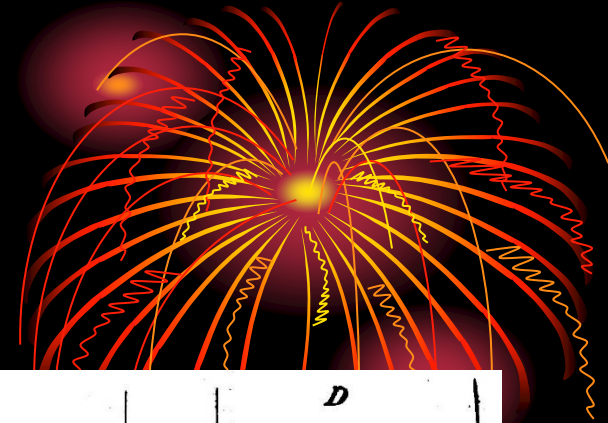
**Birkbeck magnet 1934  
Manchester 1937**



# 12 Tons, 25 kW



# Cloud Chambers

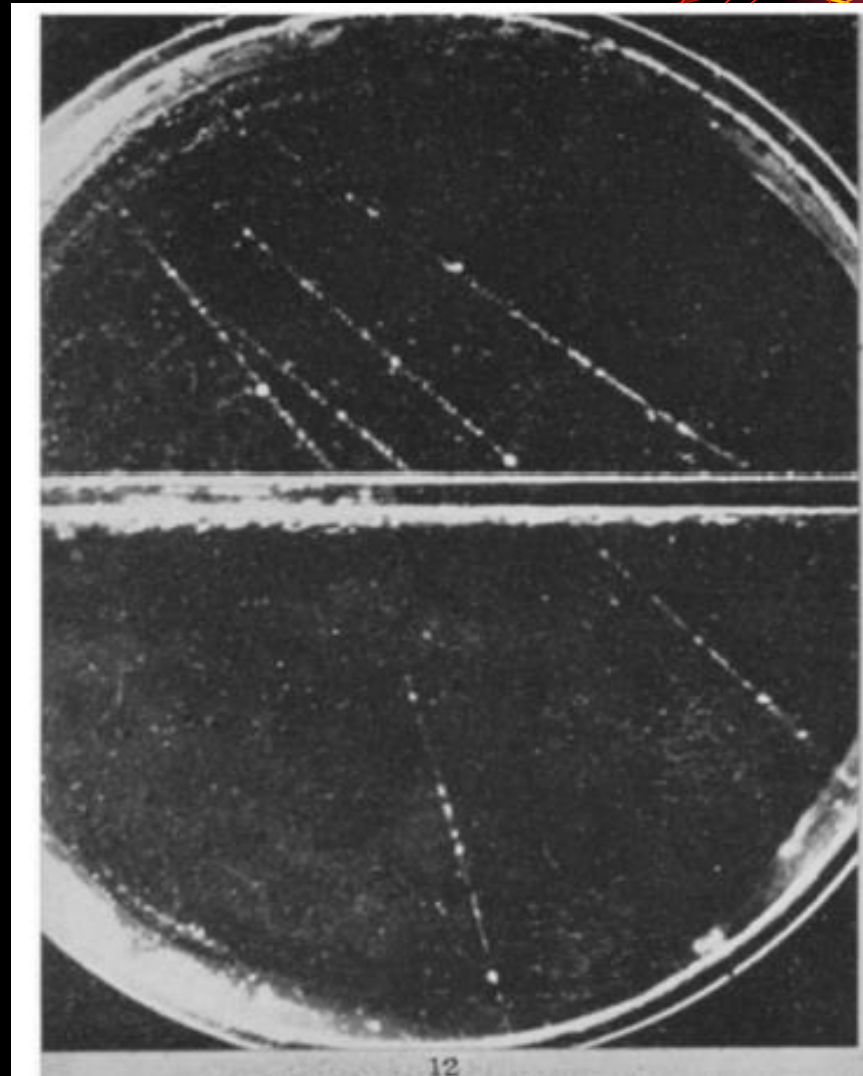


From Jánossy 'Cosmic rays' 1948



## Typical cloud chamber photograph

**Ionisation trail acts  
as condensation  
nuclei for vapour in  
Super-saturated state**



**Blackett and Occhialini 1933**

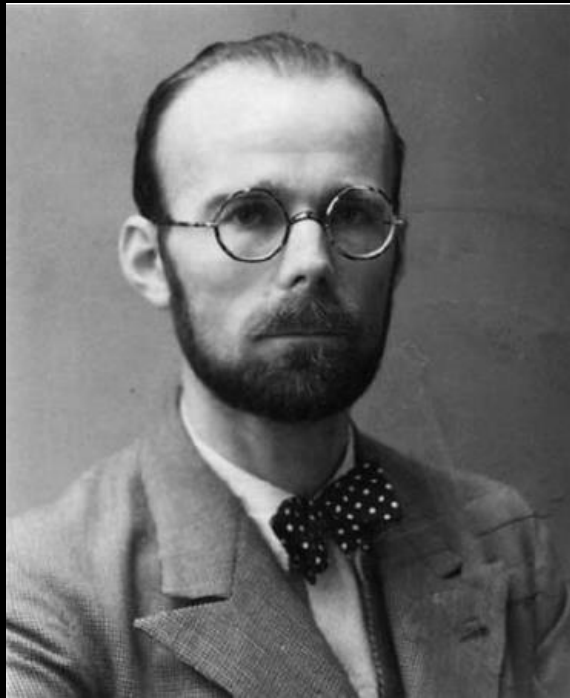
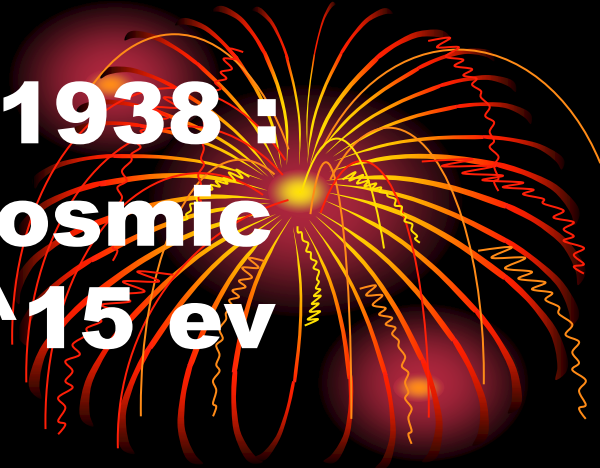


# Sir Bernard Lovell

- **A C B Lovell 1913-2012**
- **BSc Bristol 1934, PhD 1936 on thin films**
- **Manchester 1936 – worked with Blackett on cloud chambers to study cosmic rays. Designed a magnet.**
- **August 1939 about to take a cloud chamber to The Pic Du Midi. Blackett advised him not to go!**
- **1939-1945 Worked on radar. developed H2S airborne 3-cm radar system, still in use up to the 1970's**



# **Pierre Auger 1899-1993, 1938 : discovery of Extensive Cosmic Ray Showers : energy $10^{15}$ ev**

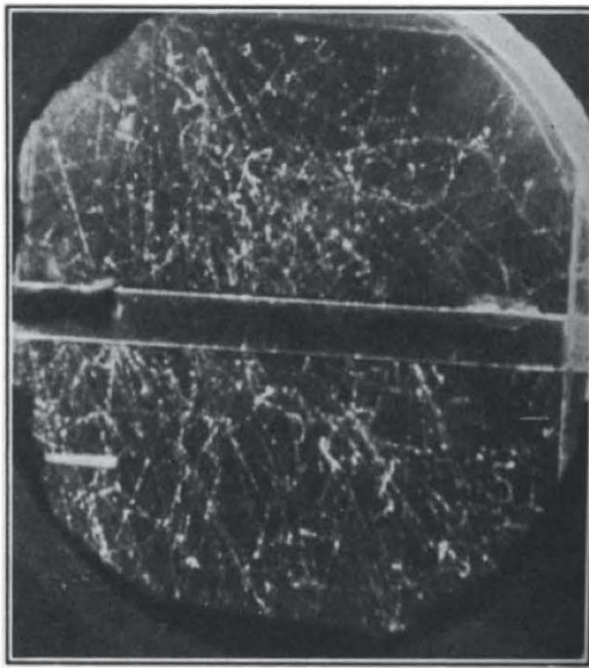


**French Acad. Sci.**

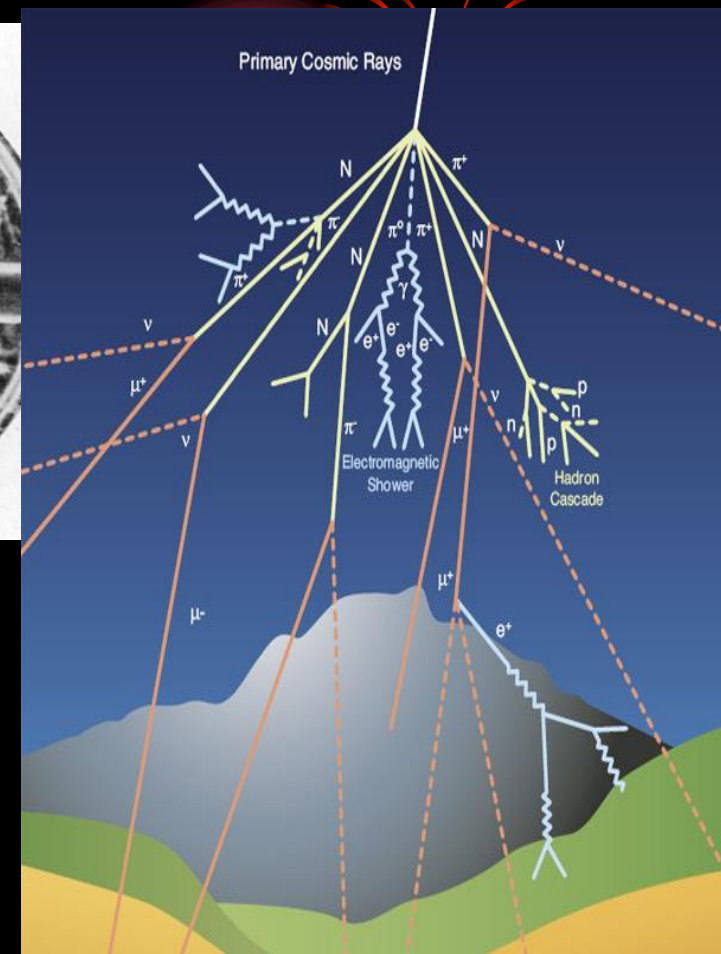
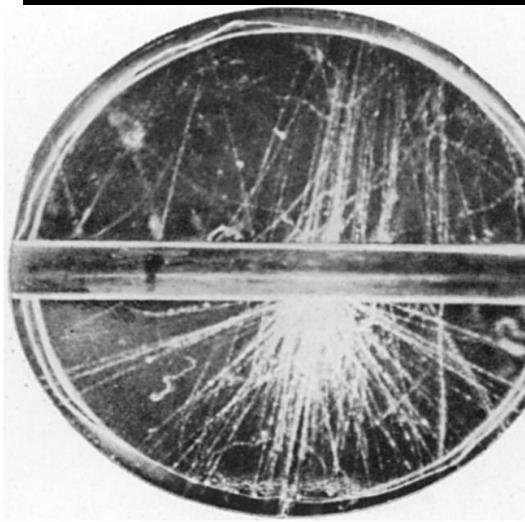
**Sphinx Observatory Jungfrauoch  
4km altitude**



**Imgur.com**



CLOUD CHAMBER PHOTOGRAPH OF AN EXTENSIVE COSMIC RAY SHOWER IN A MAGNETIC FIELD OF 800 GAUSS.



## Geiger counter triggered cloud chamber

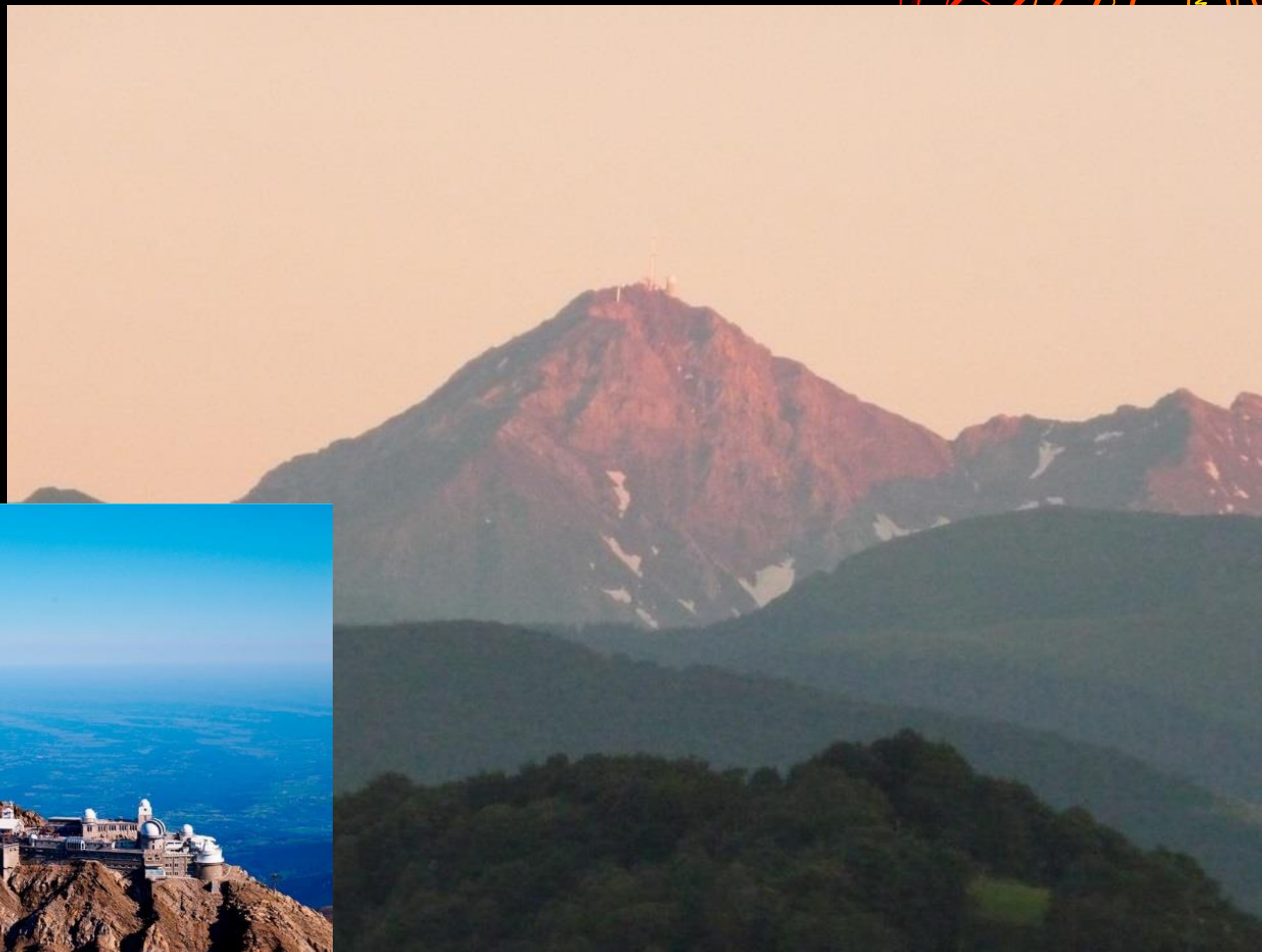
JÁNOSSY, L., LOVELL, A. 1938 Nature of Extensive Cosmic Ray Showers. Nature 142,715

Rochester, G. D., Cloud Chamber Investigation of Penetrating Showers 1946 P.Roy.Soc. 146, 464

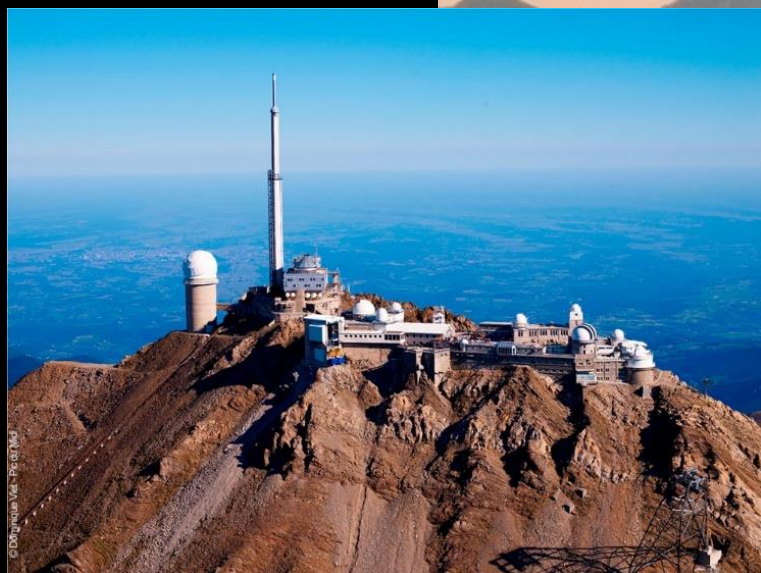
<https://www.auger.org/index.php/cosmic-rays/cosmic-ray-mystery>



# Pic Du Midi in the Pyrenees



**RES  
2013**



Le Pic du Midi de Bigorre, jour et nuit : Idées week end  
Midi toulousain - Occitanie - Routard.com



# CR and Manchester

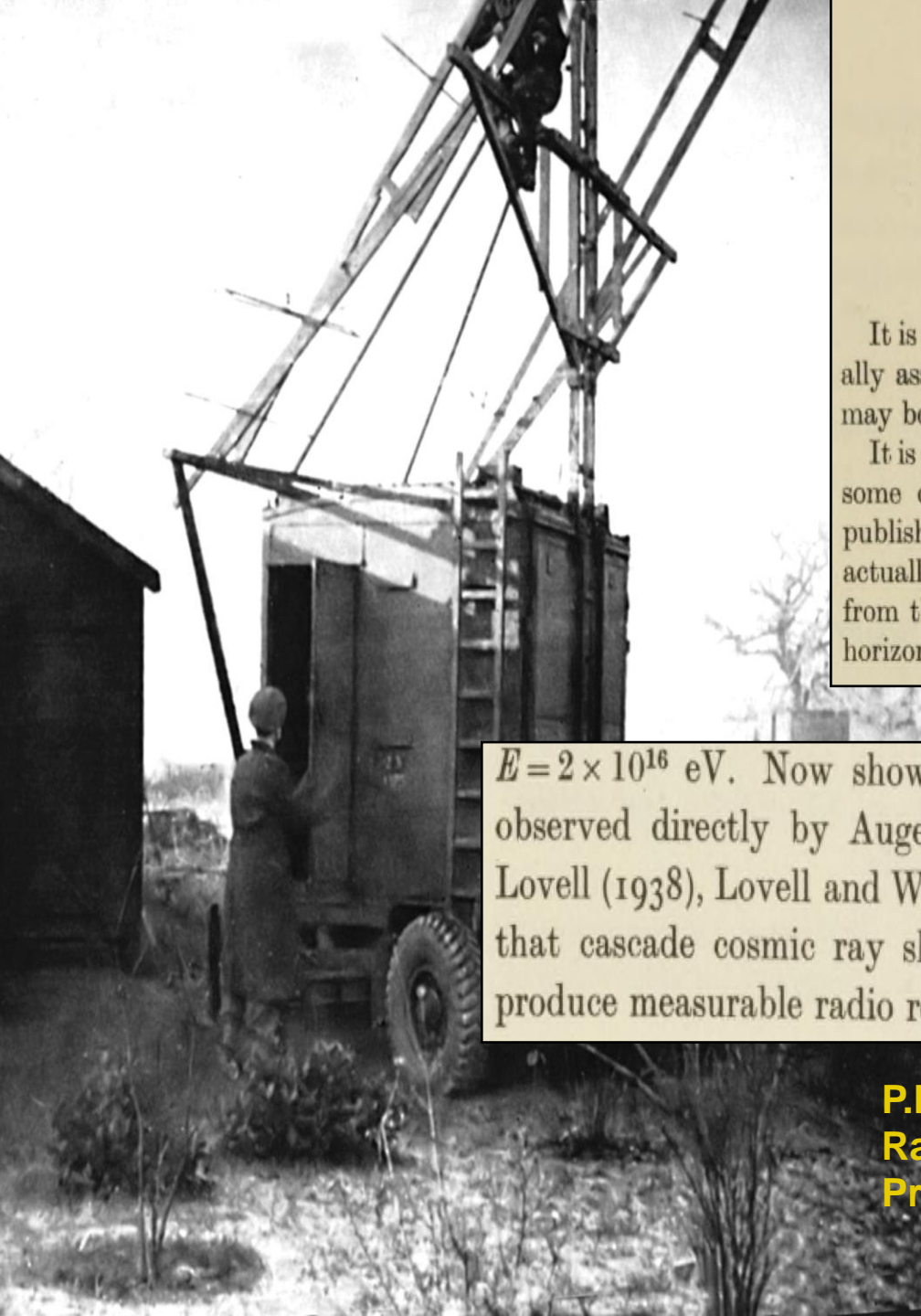


- **1937 Blackett**
  - **Cloud chambers**
- **1938 Lovell and Janossy**
  - **Extensive air showers**
- **Post war : 2 branches:----**
- **1945---Lovell--Jodrell Bank---radio astronomy**
- **1945—1956 Rochester, Butler, Wilson etc. Pic du Midi, Jungfrauoch cloud chamber:: V particles**
- **1956– Nuclear and Particle physics---present.**

# **1945 Radar Reflections from Cosmic Ray Extensive Air Showers?**



- **Trail of ionisation left behind by air shower: radar reflector?**
- **Lovell's early experiments in Coupland St. at The Victoria University of Manchester.**
- **Ruined by interference from sparking by electric trams**
- **December – moved to the botany research grounds at Jodrell Bank, in rural Cheshire**



# Radio echoes and cosmic ray showers

By P. M. S. BLACKETT, F.R.S., AND A. C. B. LOVELL

*(Received 22 October 1940)*

It is suggested that the origin of some of the transient ionic clouds, generally assumed to be responsible for the low level sporadic radio reflexions, may be due to large cosmic ray showers.

It is shown that cascade cosmic ray showers of sufficient energy to produce some of these radio reflexions certainly exist, but there is insufficient published evidence to decide whether any of the echoes already observed are actually due to such showers. More conclusive evidence could be obtained from the frequency-size distribution of the radio echoes observed from a horizontal or vertically directed beam.

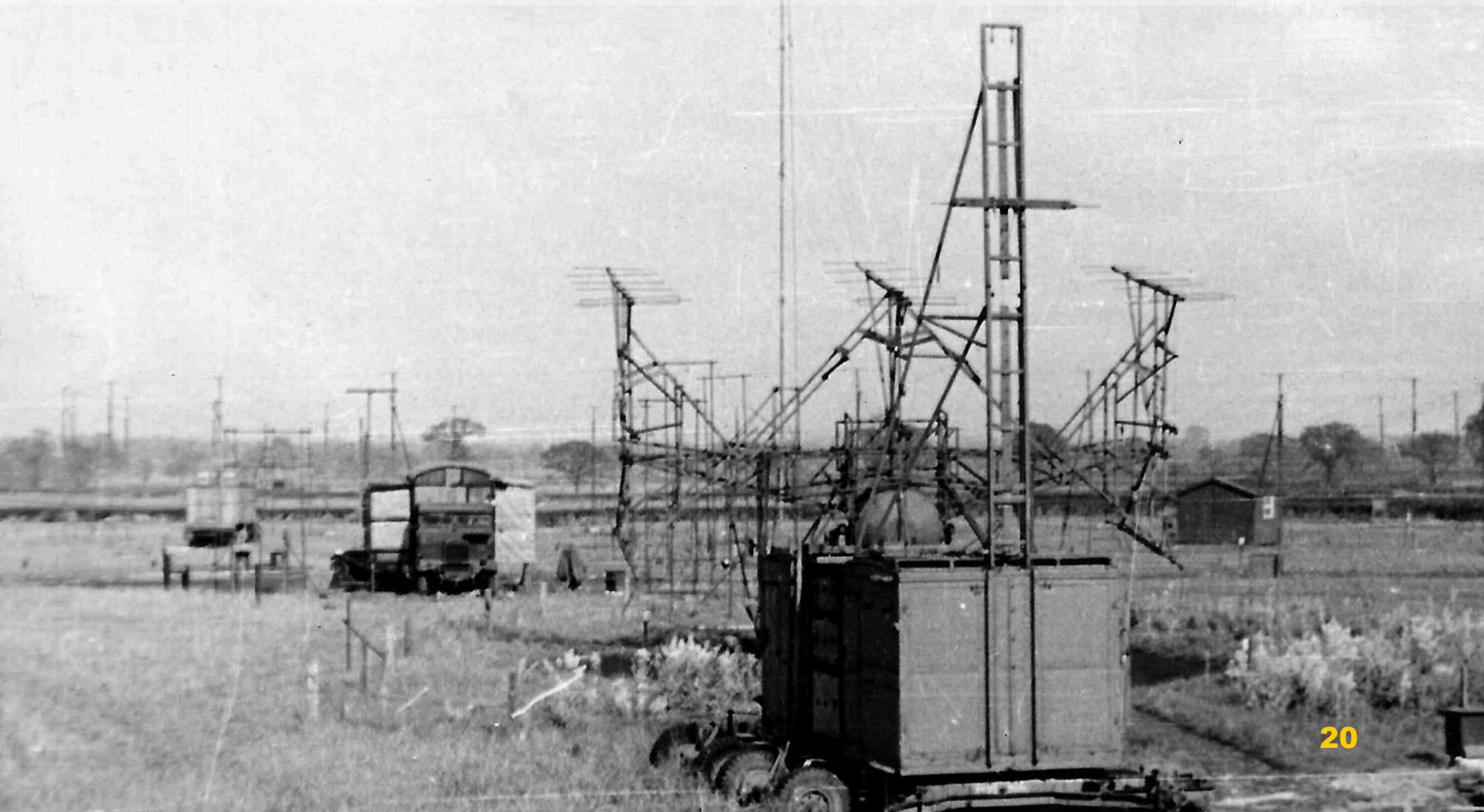
$E = 2 \times 10^{16}$  eV. Now showers of nearly this energy have already been observed directly by Auger and his collaborators (1939), Jánossy and Lovell (1938), Lovell and Wilson (1939) and others. We conclude therefore that cascade cosmic ray showers certainly exist of sufficient energy to produce measurable radio reflexions.

**P.M.S. Blackett and A.C.B. Lovell 1941,  
Radio echoes and cosmic ray showers,  
Proc. Royal Society Lond. A, 177, 183–186**



1946: Moved north into a neighboring field

- Creates 'The Fairground'
- Range of radio antennas & projects
- Gathering of scientists & engineers





# Radar Echoes from Meteor Trails



- **No echoes from Cosmic ray showers**
  - **The damping factor**
- **Echoes from meteor trails**
- **1946 Radio astronomy started at Jodrell Bank – initially radio emission from the sun**
- **What we need is a bigger telescope!**

## 1947: 218-foot (66m) Transit Telescope

- Largest in the world at the time.
- Remains exist above and below ground
- Detection of radio waves from the Andromeda Galaxy



1948: The first buildings constructed – maybe this is a long-term project:  
Radio astronomy established



# **Meanwhile back in Manchester: more work with Cloud Chambers:**

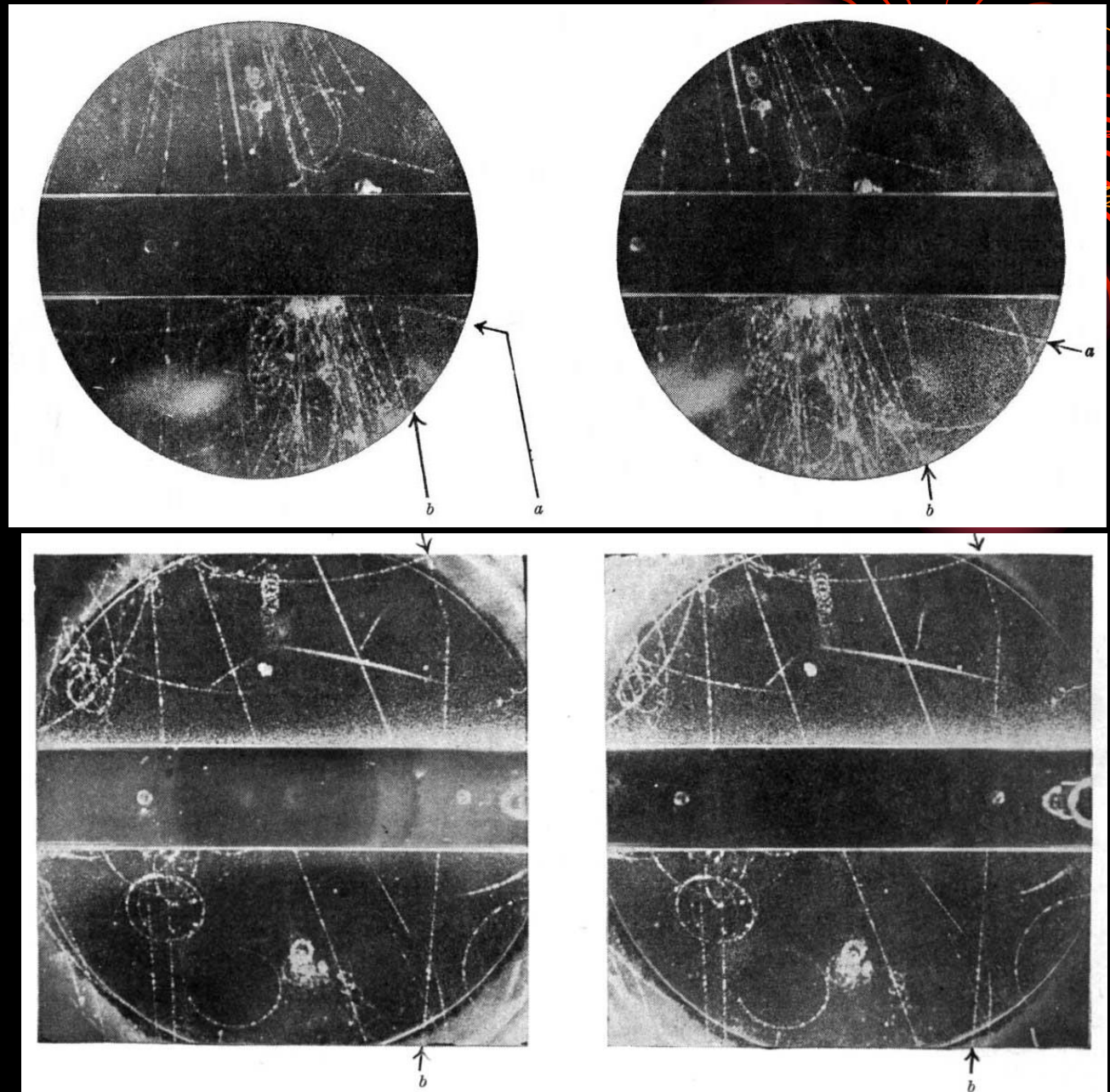


- **Under leadership of Patrick Blackett:**
- **Rochester, Butler, Wilson  
Wolfendale, Braddick, Nash, Powell,  
Elliot, Ring etc.**
- **Discovery of V particles:**
- **Strange particles, lifetimes**
- **$\sim 10^{-10}$  secs**



**V particles:  
Rochester and  
Butler 1947,  
Nature 160, 855**

**Rate at  
Manchester very  
low – need high  
altitude sites:  
Pic du Midi and  
Jungfraujoeh**



**Cloud chamber (by  
Newth) used at  
Jungfrauoch  
Later moved to Leeds,  
used in undergraduate  
teaching labs.  
Moved back to  
Manchester by Robin  
Marshall and Brian Cox  
1997**



**Photo: Andrew Smith, Manchester**

**Newth, J. A,  
1954 N. Cim.  
11S, 290**

**Discovery of  
'strange'  
particles:  
decays of  
neutral and  
charged  
hyperons**

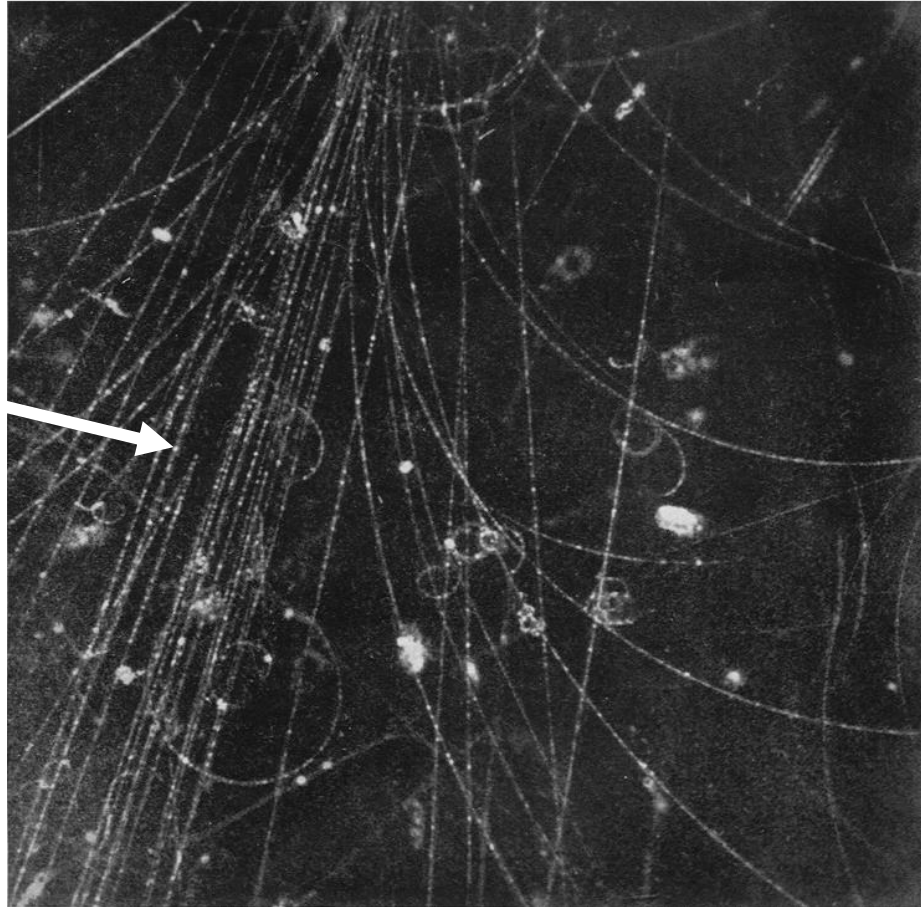
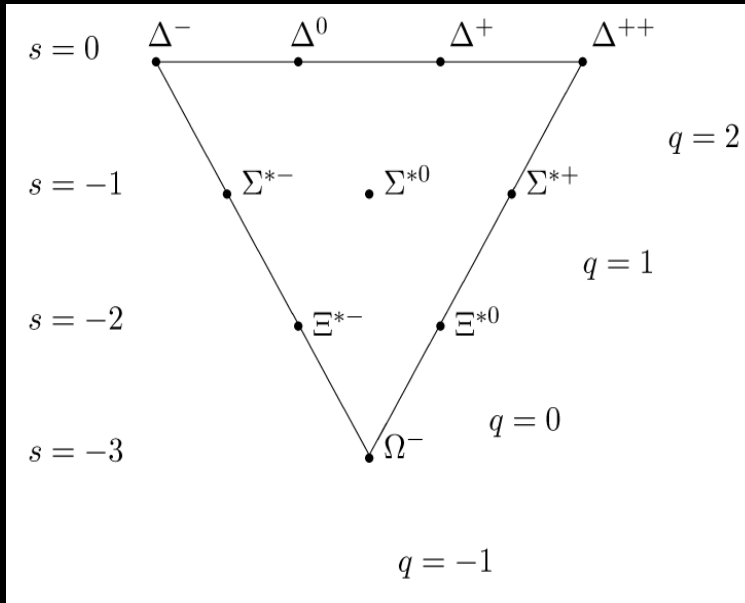
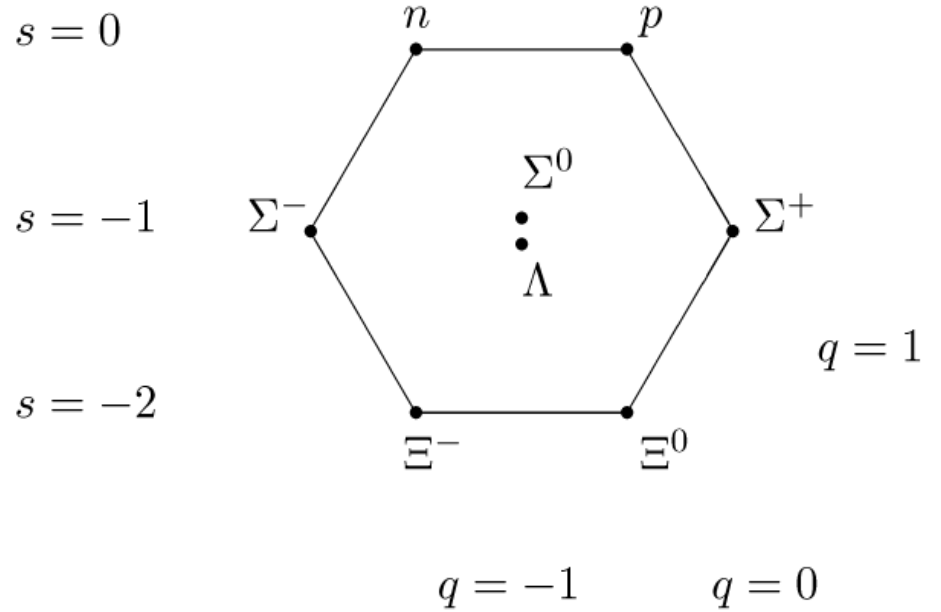


Plate I. - A high-energy jet containing a neutral V-particle. There is detectable convective distortion in the tracks forming the jet.





# Murray Gell Mann 1963 SU(3) and the discovery of quarks





- **1948**
- **Patrick Blackett again:**
- **Massive spinning conductors create a magnetic field?**
- **Evidence from planets and stars**
- **Designed a very sensitive magnetometer**
- **Rotating Metal cylinders including 15 kg Gold !**
- **In a non-magnetic hut (no iron!) at Jodrell Bank**
- **No effect seen!**

bottom by an aluminium plate to damp the rotational motion of the magnetometer by the eddy currents induced by the lower magnetometer magnets. Vertical adjustments of the quartz fibre holder allowed the damping to be adjusted as required, usually to near critical damping.

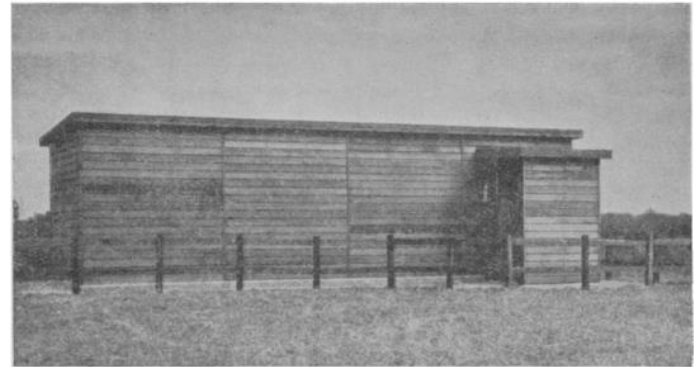


FIGURE 6. Photograph of magnetometer hut.

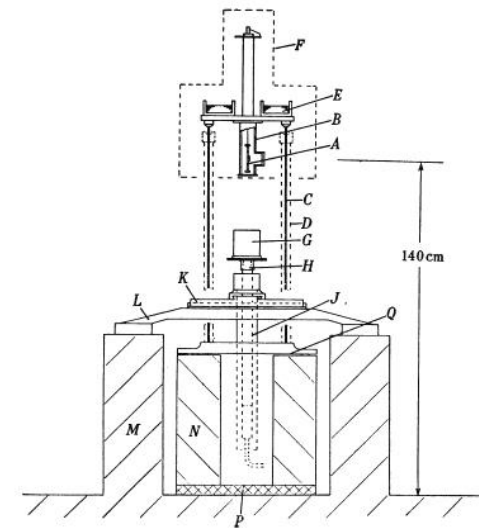


FIGURE 7. Arrangement of magnetometer; description in text.

# 1957 The Mk 1 Telescope

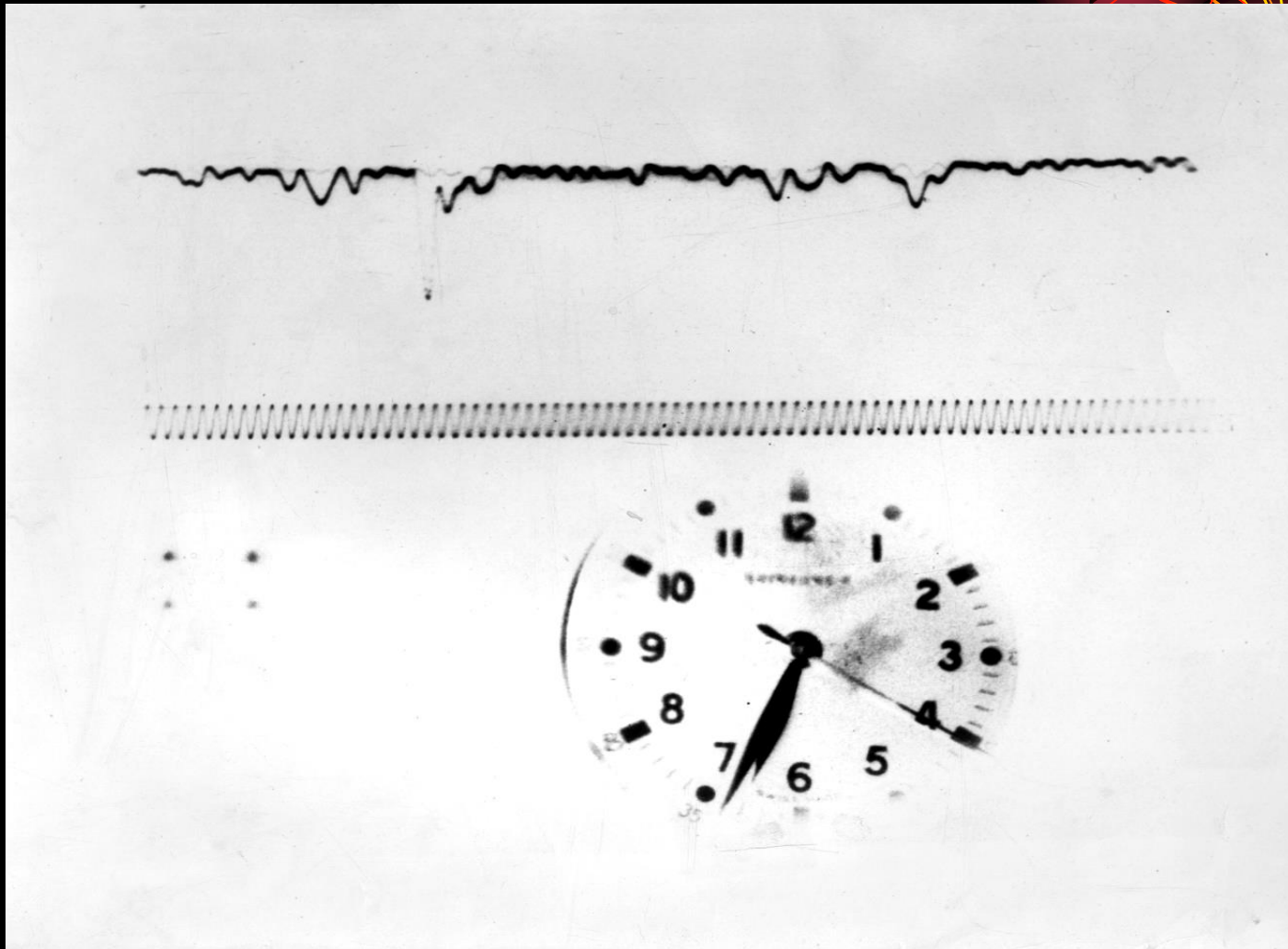


**1965 John Jelley ( Harwell) wrote to Graham Smith (JB) suggesting we looked at radio emission from CR again (Askayan charge excess)**



**Blackett's Field ~1965, Porter MSc**



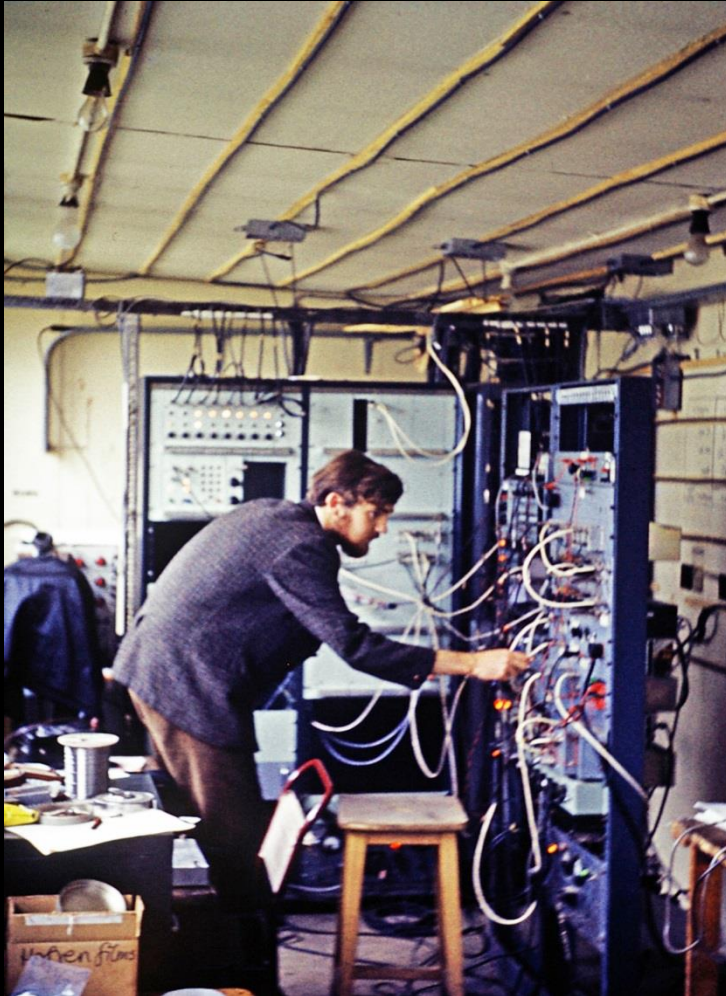


Jelley et al Nature 1965, R. A. Porter MSc Thesis 1967,  
Radiation generated by the shower itself.



# 1966-1970 RES PhD on radio emission from cosmic rays

## Inside Blacketts Hut:

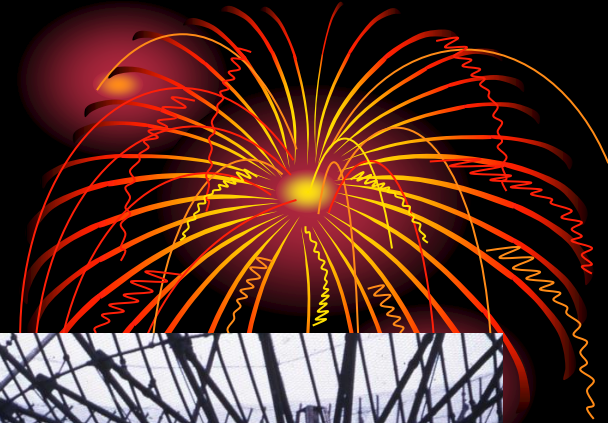


1968



1970

33





**from Fegan, D. J., 1967 NIM PA 662 supp 1, 2012**



**CR work ceased at JBO n 1971 :Blackett's Hut 2013**





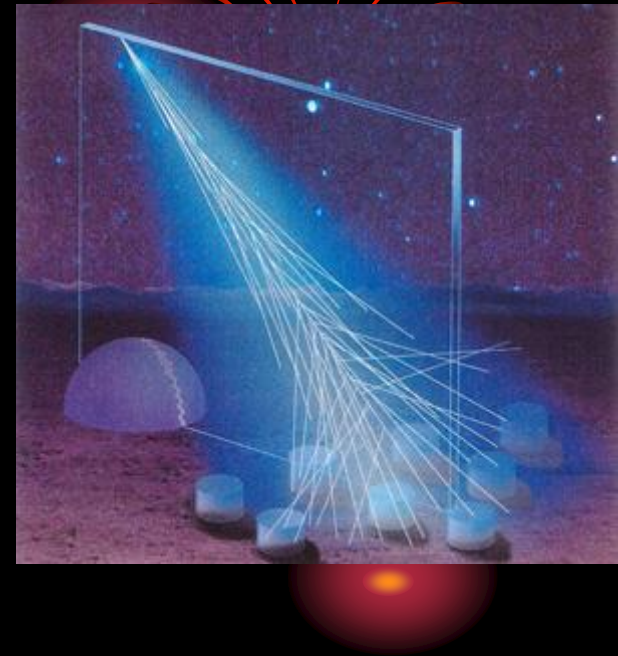
## Blackett's Hut 2020





# What are Cosmic Rays?

- **Particles with a very large energy range**
- **Low energy – MeV – from Sun**
- **High energy particles ( H , He, Li etc. including Fe nuclei) : physics at energies > LHC -- EeV**
- **Hit the Earth's atmosphere and generate showers of muons, electrons and gamma rays**
- **Studied by large arrays of particle detectors (Auger, Telescope Array, Tungu Rex, KASCADE, etc.)**
- **The electron tracks are curved by the Earth's magnetic field and Cerenkov from the charge excess: radiates at radio frequencies**



# Where are they from?



- **Rare at the highest energy**
- **1/sq km/century at  $>10^{20}$  ev**
- **Change in origin from our galaxy to extragalactic at  $\sim 10^{18}$  ev**
- **Maybe a change in composition?**
- **Sources – unknown! Super-novae, Pulsars, Black holes, galaxies???**
- **Highest energy ones must be extragalactic?**

# The Pierre Auger Array



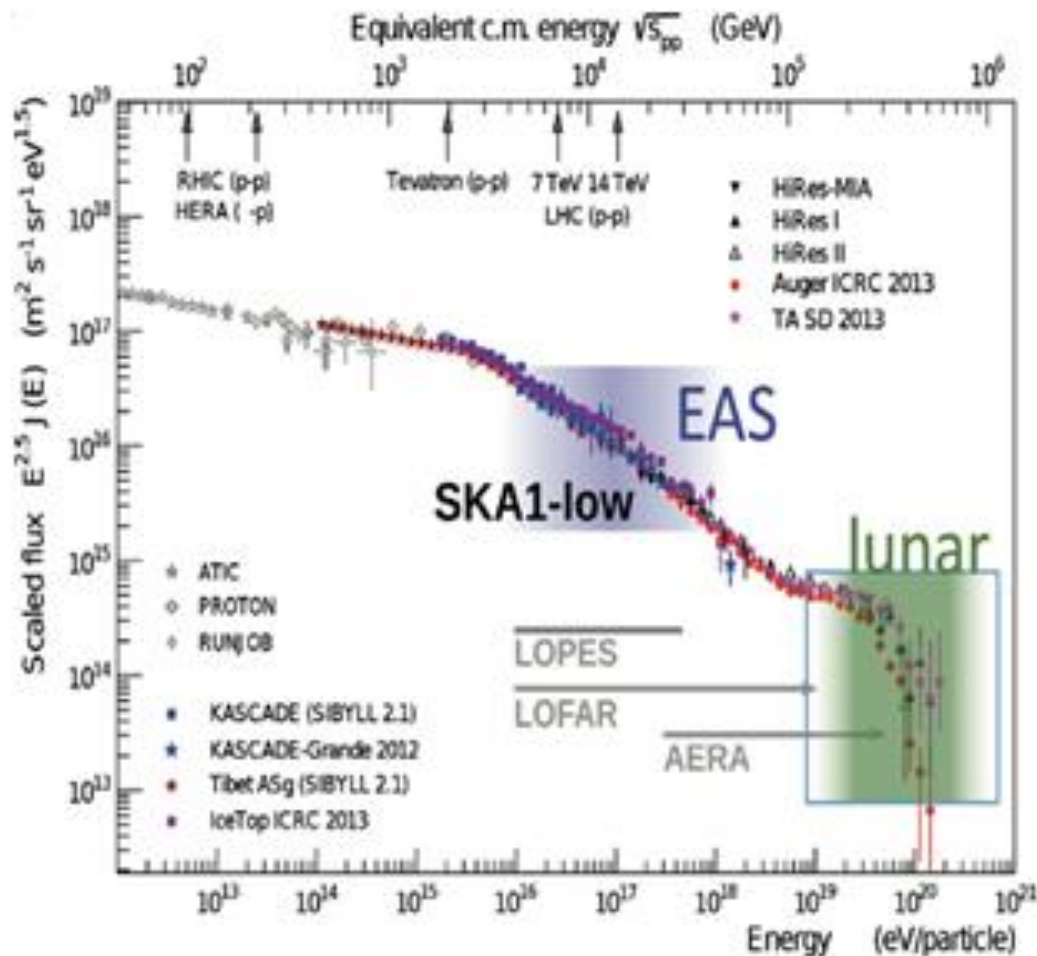
- **Pampa Amarilla Argentina**
- **1660 water tank particle detectors, 1.5 km apart**
- **27 fluorescence detectors**
- **Covers 1000's sq km**

# The Return of the Radio



- **Radio emission studies out of favour in 1970's.**
- **Revived in 2000's due to digital technology and computer modelling**
- **Shower development can be studied using radio – gives energy and composition**
- **LOFAR, MWA, SKA – large radio arrays**
- **Only small particle detector arrays needed for trigger.**

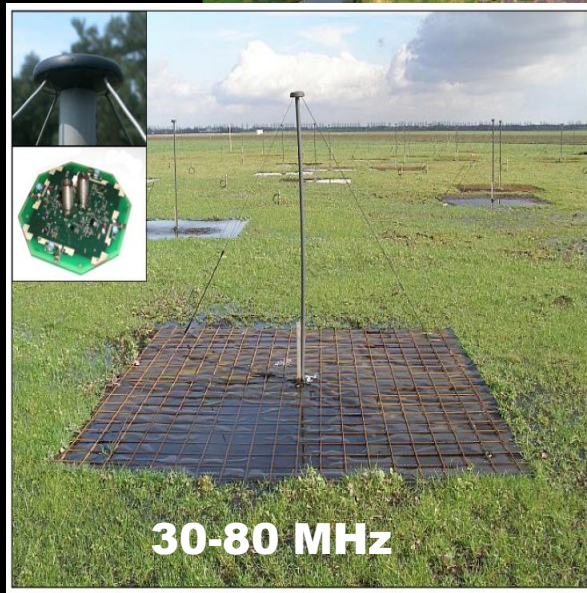




The cosmic-ray spectrum, extending over 8 orders of magnitude in energy and 24 orders of magnitude in flux. The energies probed by SKA-EAS and SKA-lunar are shown. These are compared to the centre-of-mass energies of the collisions (top axis). Image credit: T. Pierog et al (EPJ W 89 (2015) 01003; T. Huege, C.W. James.



# LOFAR array in The Netherlands





# X Max = depth in the atmosphere of peak particle numbers

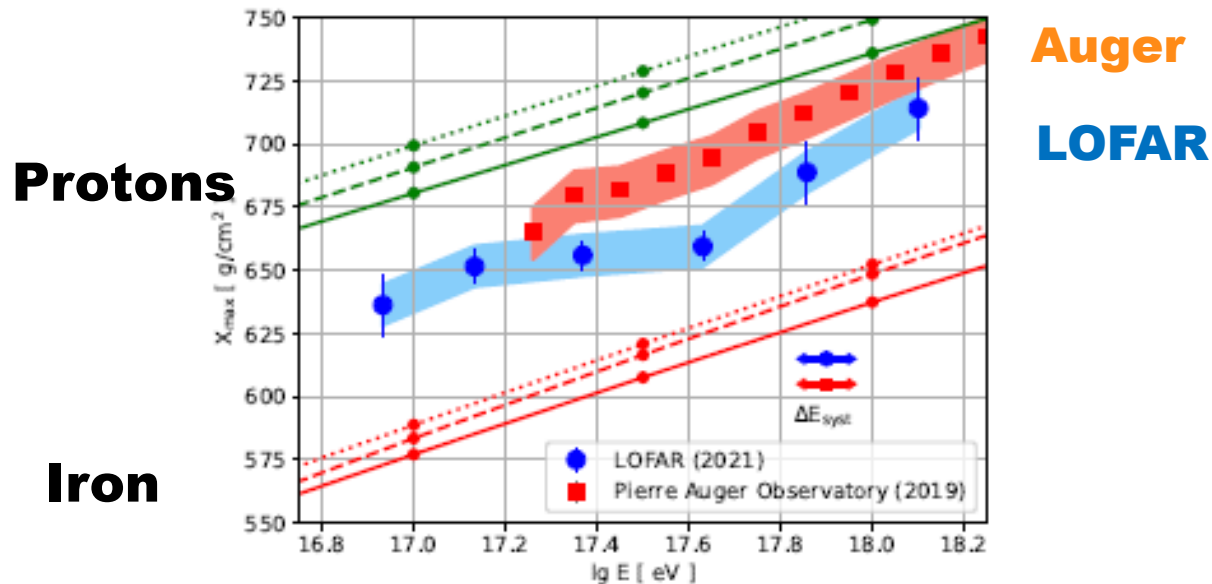


Figure 5: Average  $X_{\text{max}}$  versus primary energy, for LOFAR and Pierre Auger Observatory, with colored bands indicating their systematic uncertainty on  $X_{\text{max}}$ . The uncertainty margins per data point are statistical uncertainties only. The systematic uncertainty on energy is the same for both experiments, and is indicated by the arrows to the lower right.

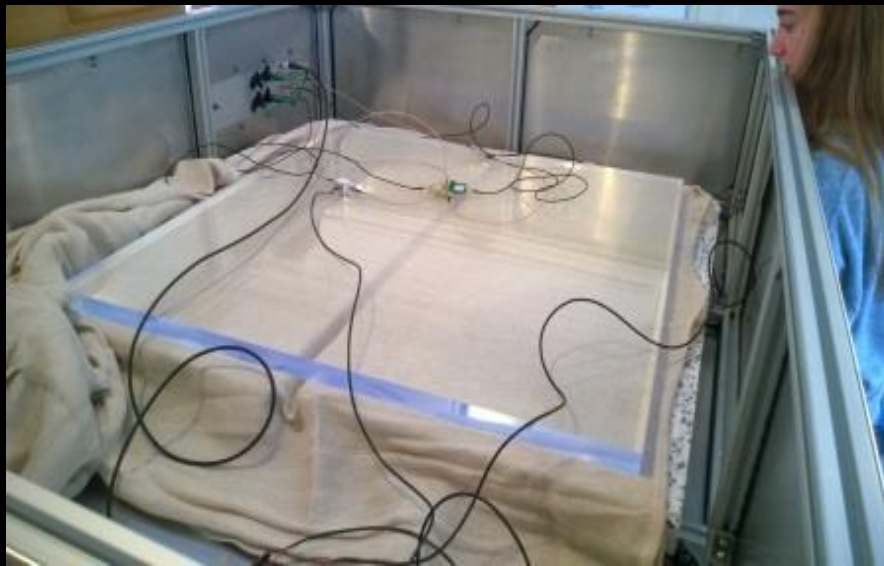
**Corstanje+2021**

# Work at JBO

- **Developing particle detectors to be used as a trigger so that the radio emission can be recorded**
- **Prototype at Metre Wavelength Array (MWA) in W. Australia**
- **8 detectors currently being built at JBO**
- **Uses plastic scintillator slabs from KIT**







# Square Kilometre Array (SKA)

- **2 sites:**
- **South Africa (Mid)**
- **Australia (Low)**
- **Procurement started**
- **1<sup>st</sup> science 2025?**

Australia

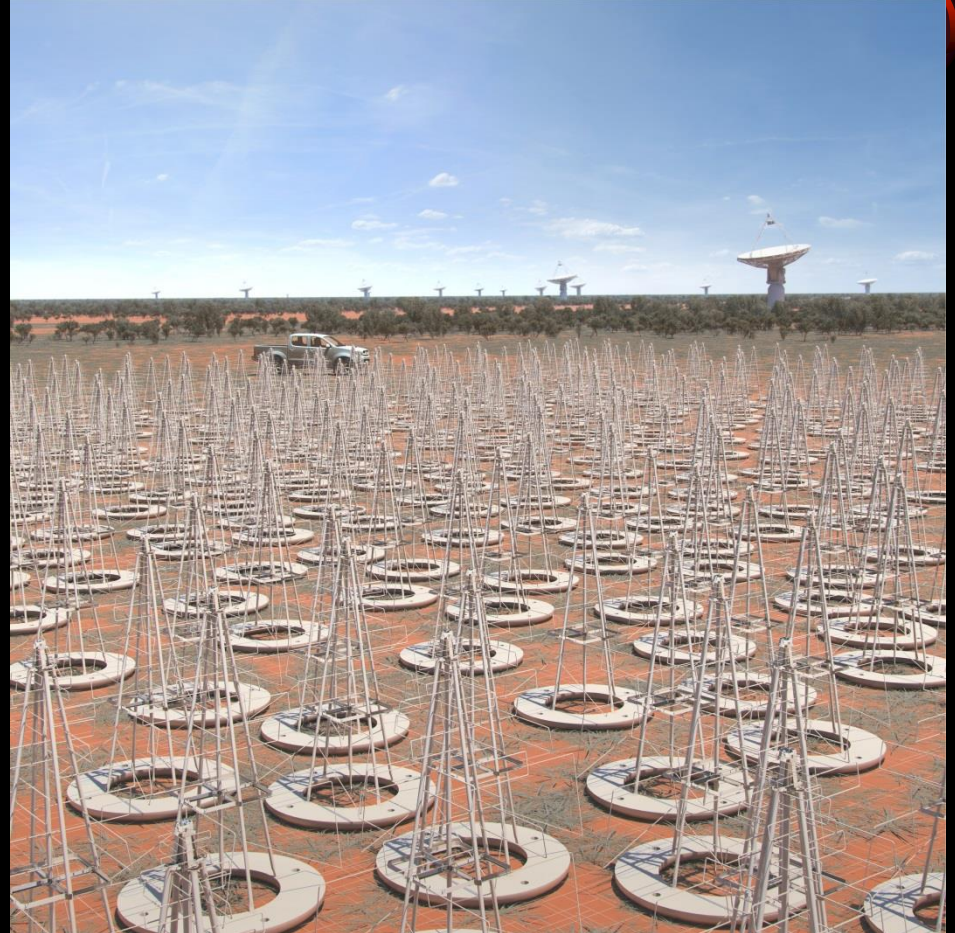


SKA2\_LOW  
250 x Low Frequency  
Aperture Array Stations

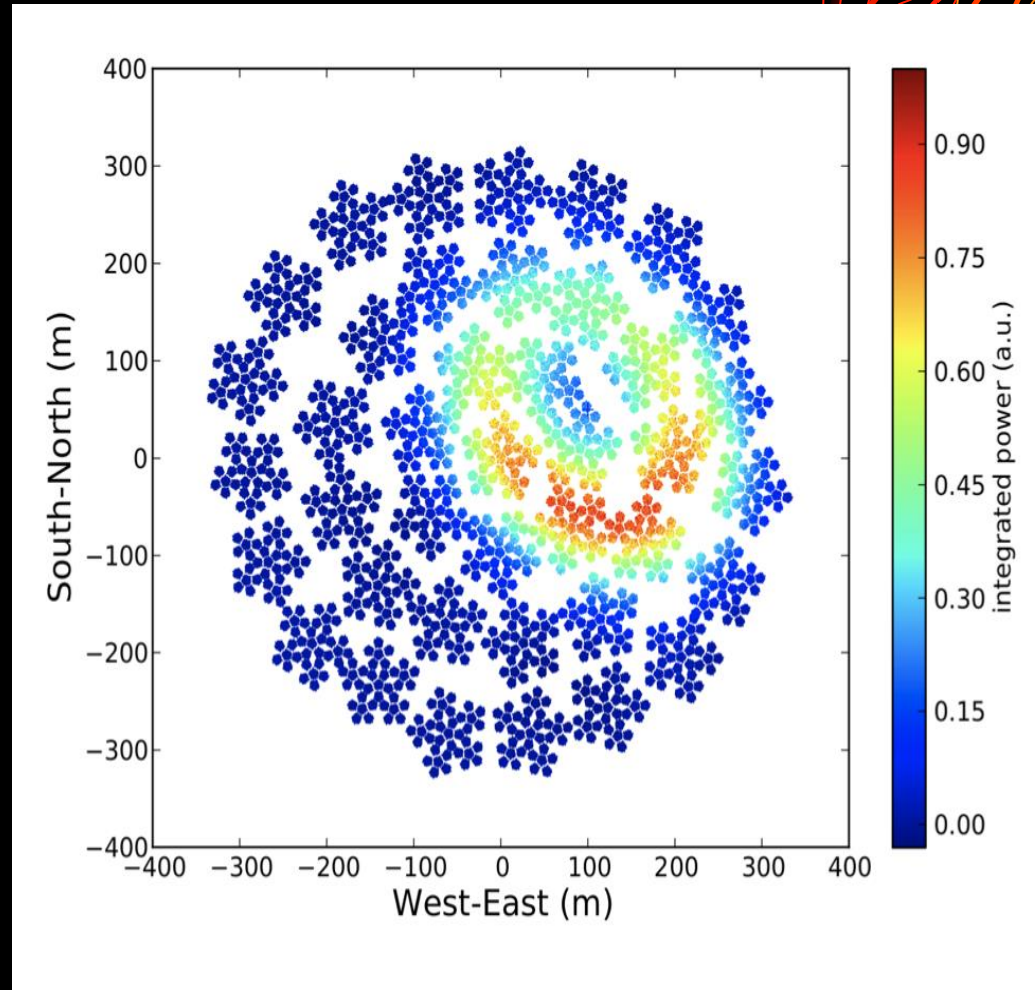


# The Future and SKA

- **Could the SKA be used as a large area CR detector?**
- **Low frequency array 50-350 MHz**
- **131,000 antennas**
- **Murchison, W Australia**
- **Tenders out 2021-2022**
- **Need ~200 particle detectors**

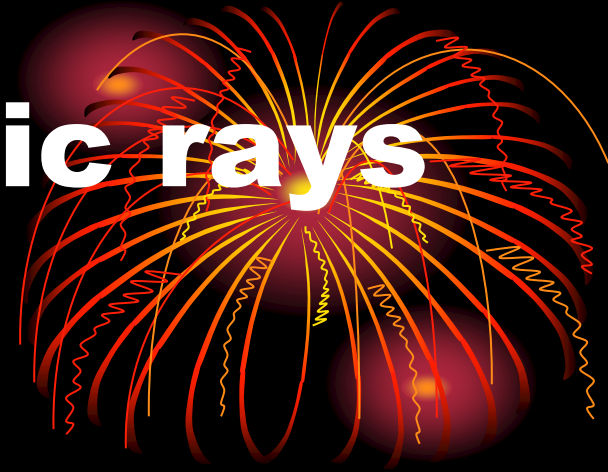


**Sample whole Electric field distribution on the ground: Can find composition of primaries and study high energy physics**





# Conclusion, Cosmic rays and JBO



- **Exciting beginnings 1912---**
- **Radio work 1960's**
- **Radio barely alive in its middle age 1970's-  
revived 2000's**
- **(I worked on imaging quasars and galaxies  
from 1971, still do)**
- **Exciting future MWA 2022, SKA 2024—**
- **Maybe we will finally know where they  
come from.**
- **(All we need is the money for the detectors  
<£1M inc. staff!)**

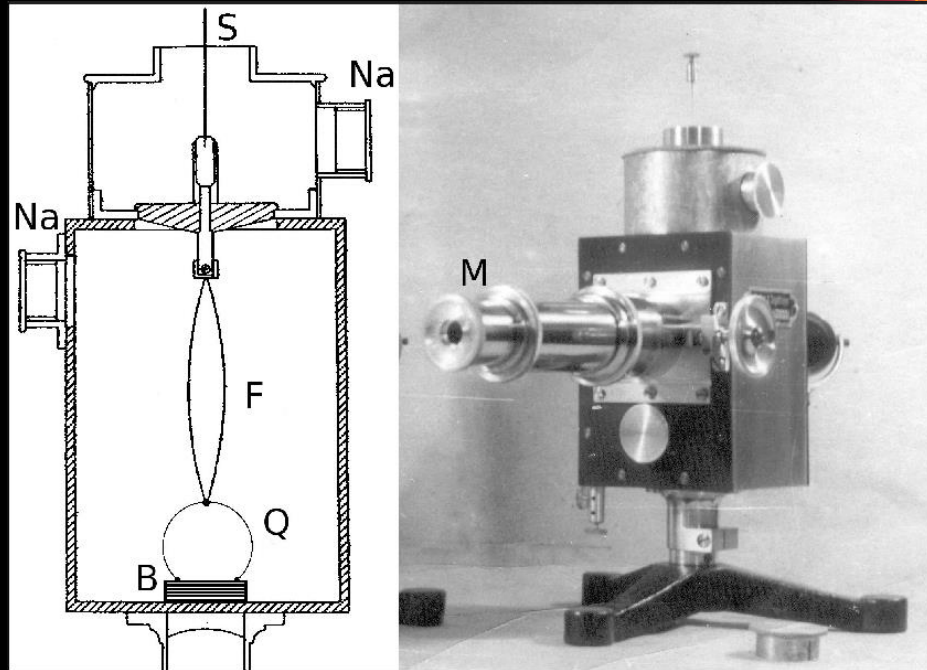
# Questions?



- **Thanks to Anna Scaife, Justin Bray, Tim O'Brien, University of Manchester, Karlsruhe Institute of Technology, ASTRON, University of Western Australia Perth, Ogden Trust and lots of undergraduate students at Manchester**



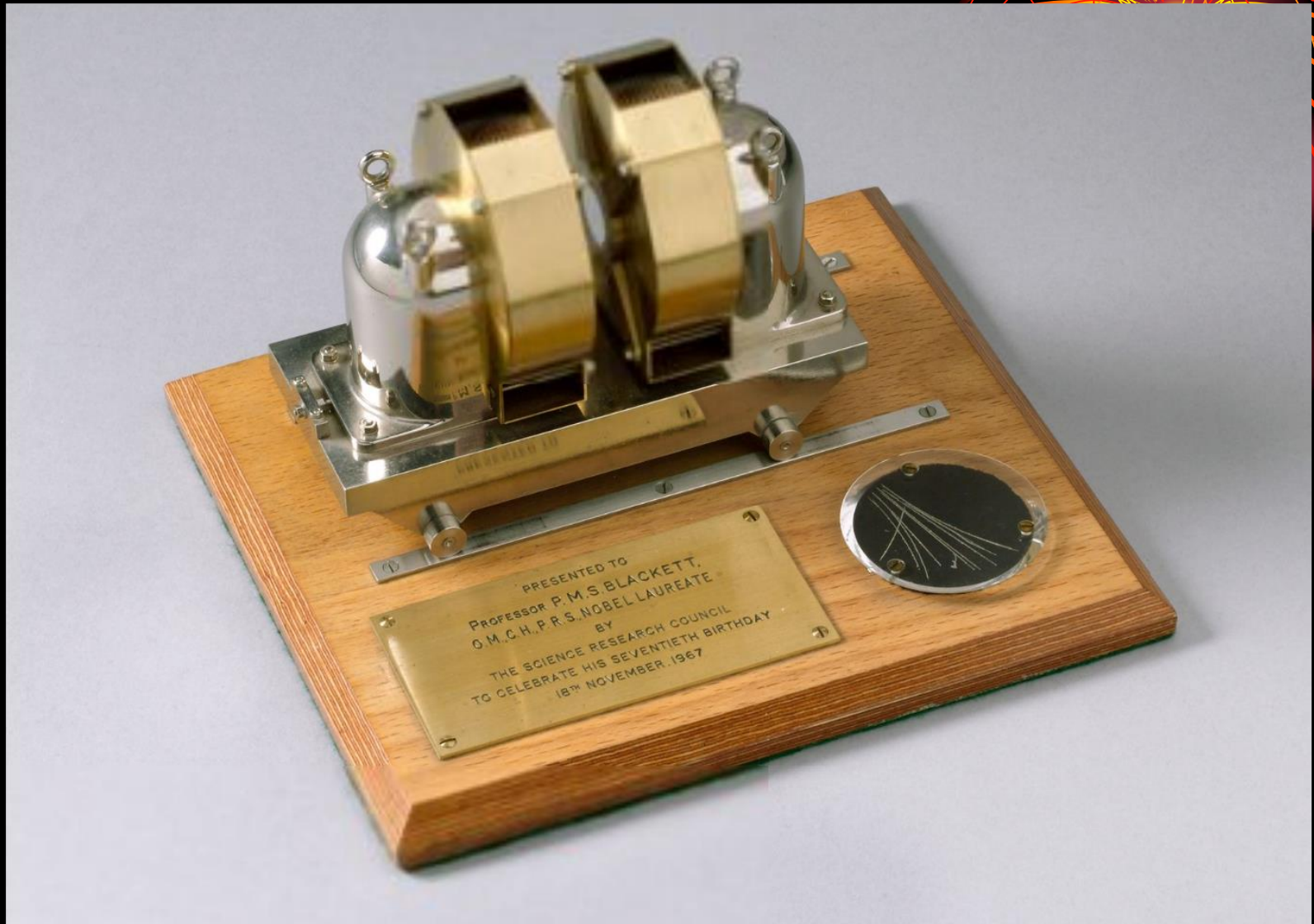




**Wulf's bifilar electrometer (cross section, left). The lower end of metal filaments (F) was fixed to a quartz string (Q), using its elasticity as a repulsive force. The string was mounted on an amber insulator (B). The spread of the filaments was read with a microscope (M). Two openings (Na) could be connected to a sodium-drying device. The complete instrument is shown at right. Wulf received a patent on this device in 1906 (DRP 181284).**

## **Janossy and Lovell Nature 142, 715, 1938**

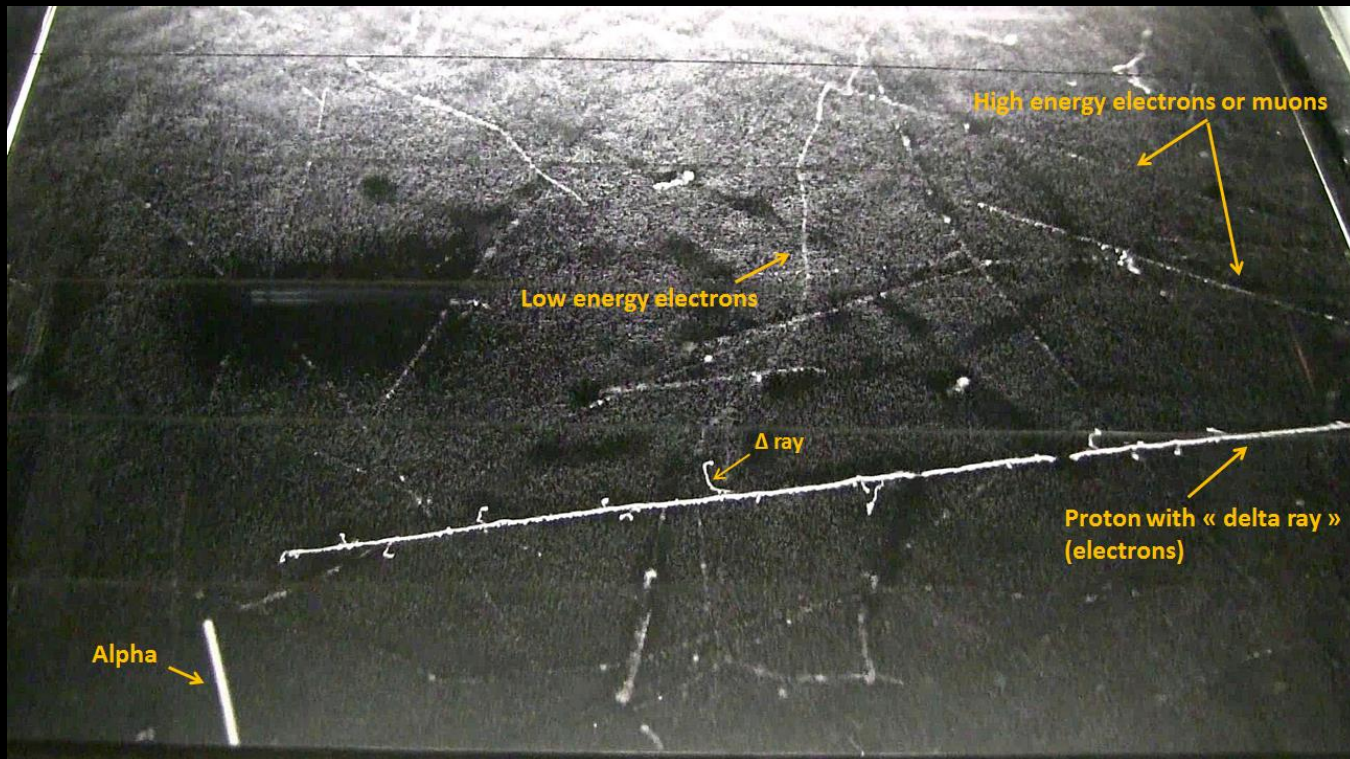
**THE counter experiments of Auger, Maze and Grivet-Meyer<sup>1</sup>, and those of Kolhörster, Matthes and Weber<sup>2</sup>, indicate the existence of very large cosmic ray showers, extending over an area of many square metres, and consisting of several thousand particles. In order to obtain information about the constituents of these showers, a cloud chamber with a 2 cm. lead plate across its centre, situated in a room with a light roof, has been used in a magnetic field of 800 gauss. The chamber was controlled by the five-fold coincidences of counters, distributed so that the outer counters were separated by 5 metres. With this counter arrangement the chamber took, on the average, 0·2 photographs per hour.**





# Pic du Midi 2877 m

- Rare photograph of a cloud chamber at the Pic Du Midi showing 4 types of particle detected







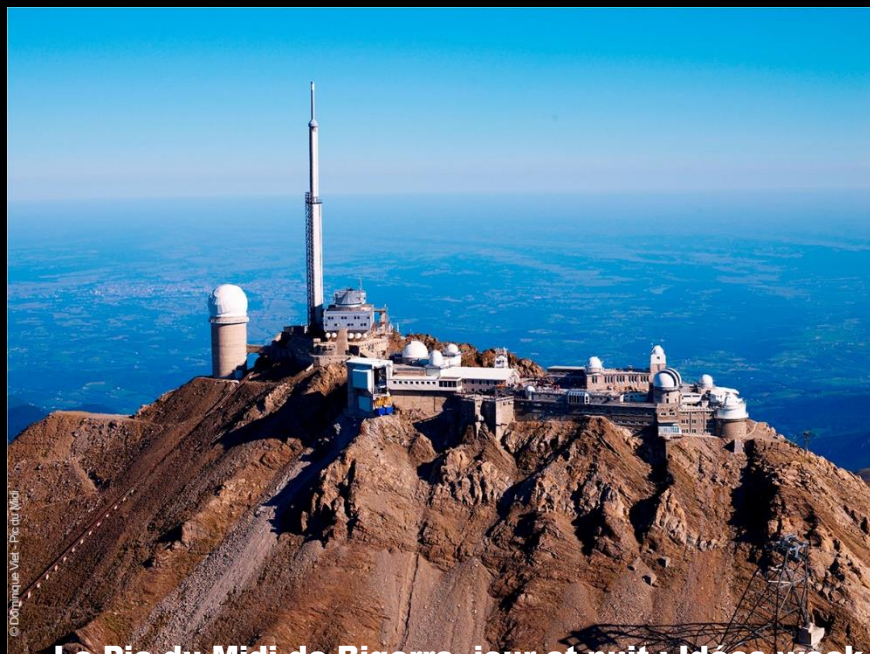
From mesons all manner of forces you get;  
The infinite part you may simply forget.  
The divergence is large, the divergence is small:  
In meson field quanta there is no sense at all.  
What, no sense at all?  
No, no sense at all.  
Or, if there's some sense, it's exceedingly small.\*

H. V. NEHER

*California Institute of Technology*

\*Edward Teller, "The Meson Song," Proceedings of the Echo Lake Cosmic-Ray Symposium, June, 1949.

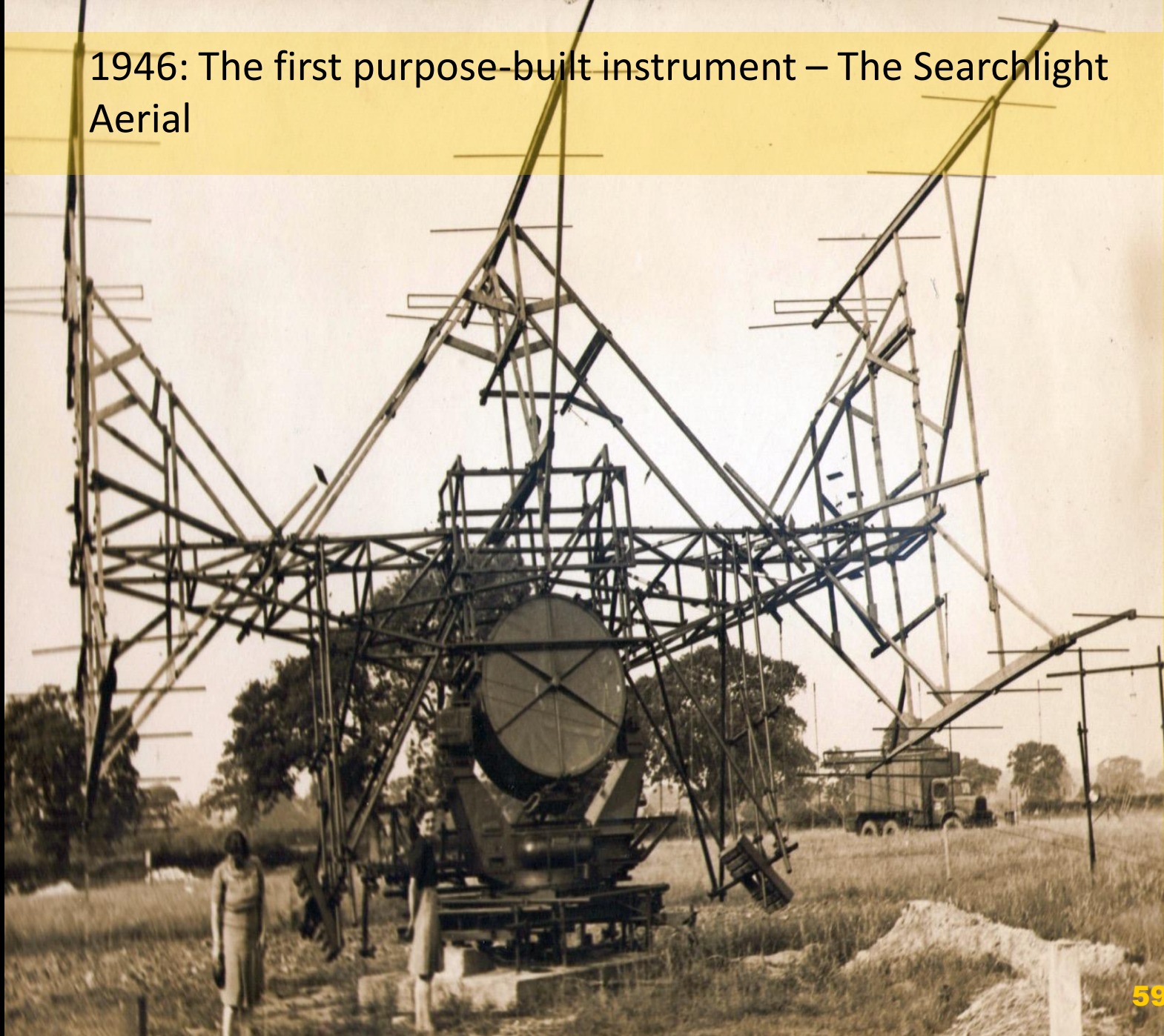




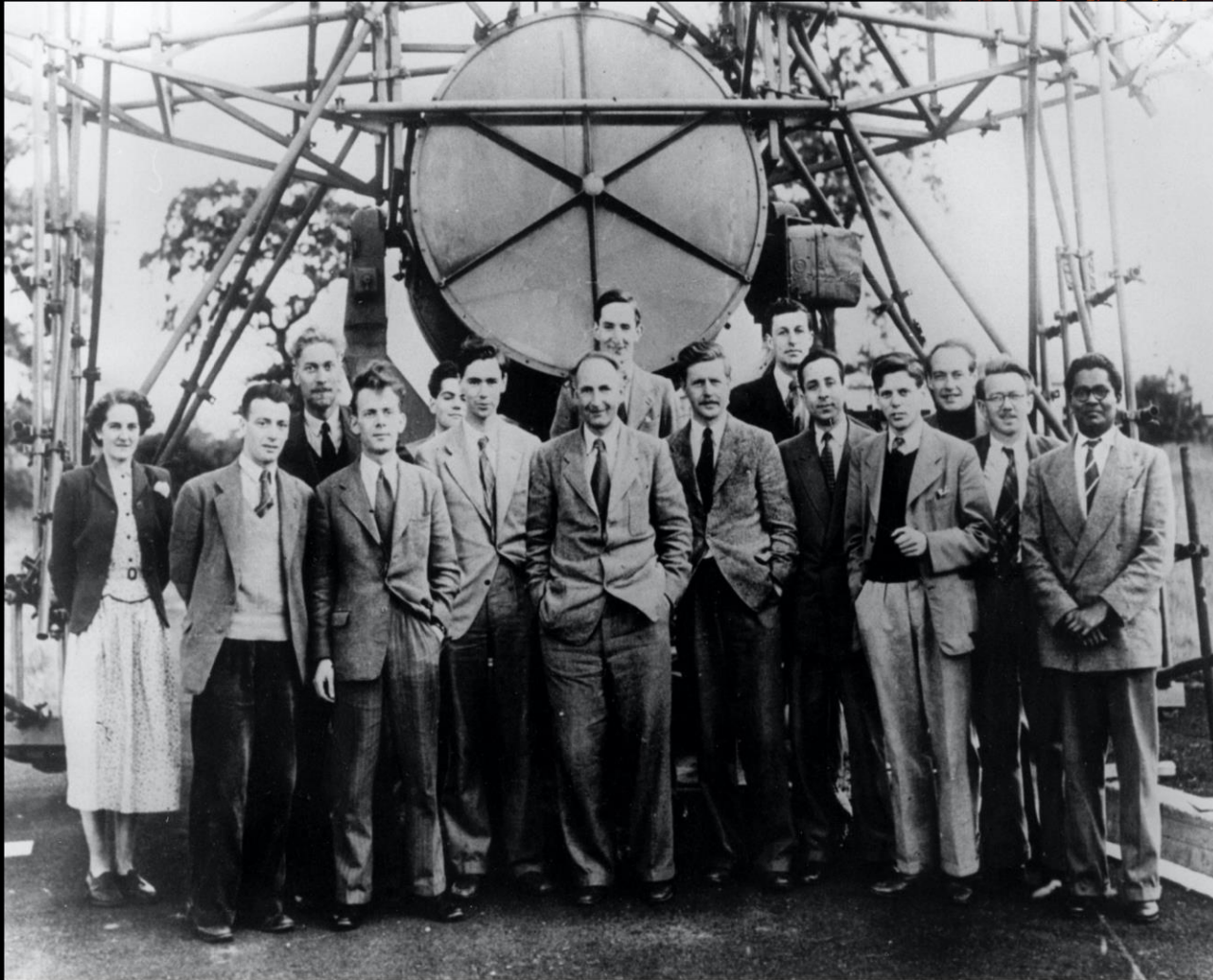
**Le Pic du Midi de Bigorre, jour et nuit : Idées week end Midi toulousain - Occitanie - Routard.com**



# 1946: The first purpose-built instrument – The Searchlight Aerial

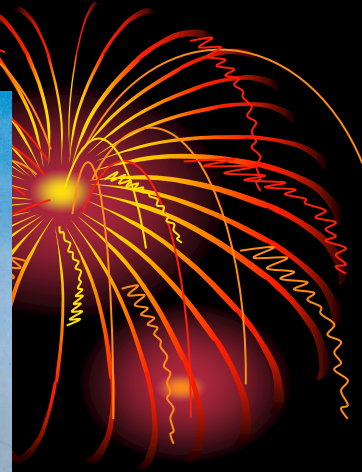


# 1951 ACBL: The 1<sup>st</sup> professor of Radio Astronomy



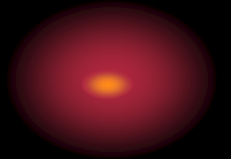


## Mark Ia Upgrade – 1970/71



**Diversification needed : moon radar, cosmic rays**

# Blackett's field 1970





## Aab + 2014 Auger and Telescope array results

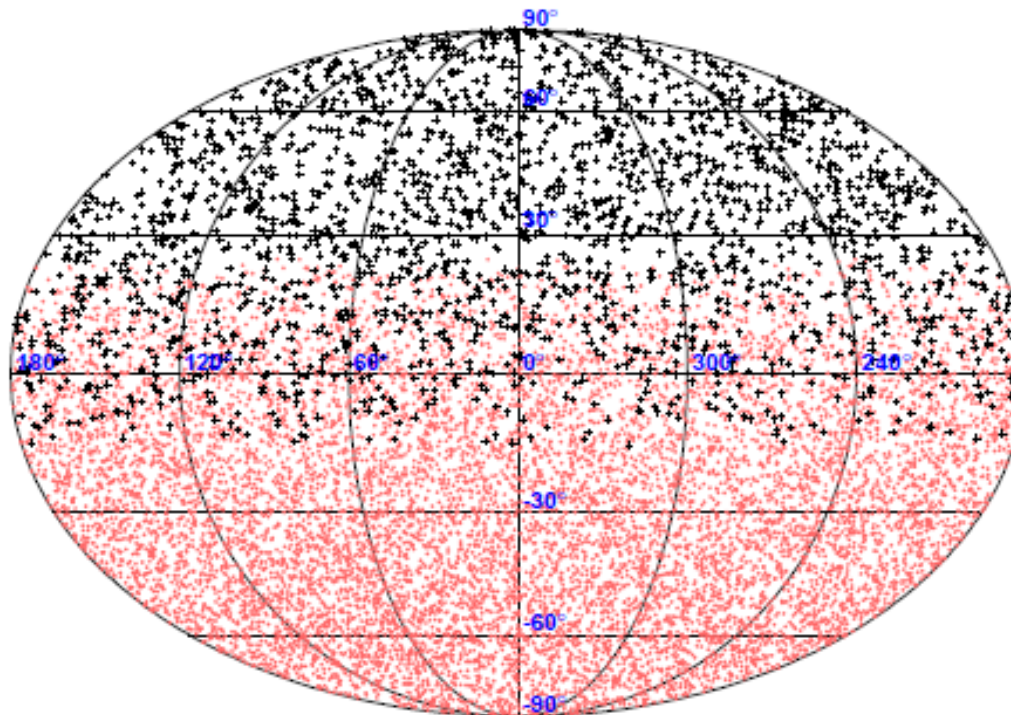
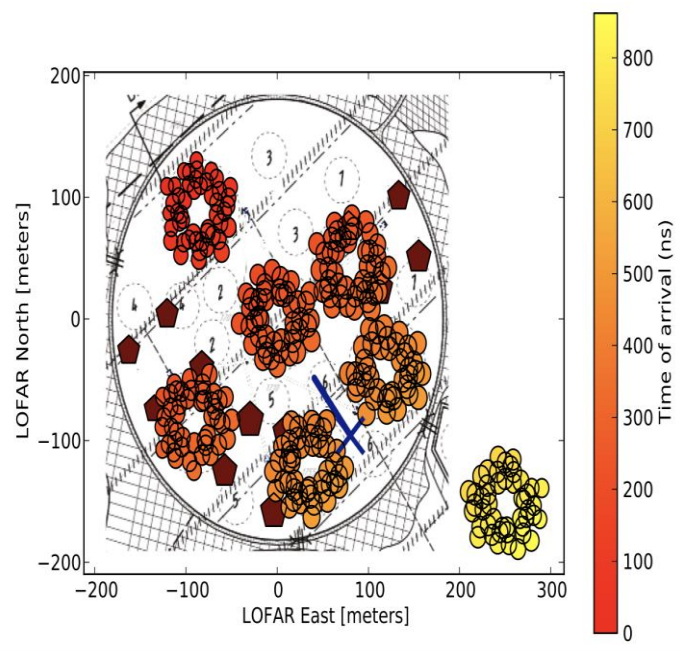


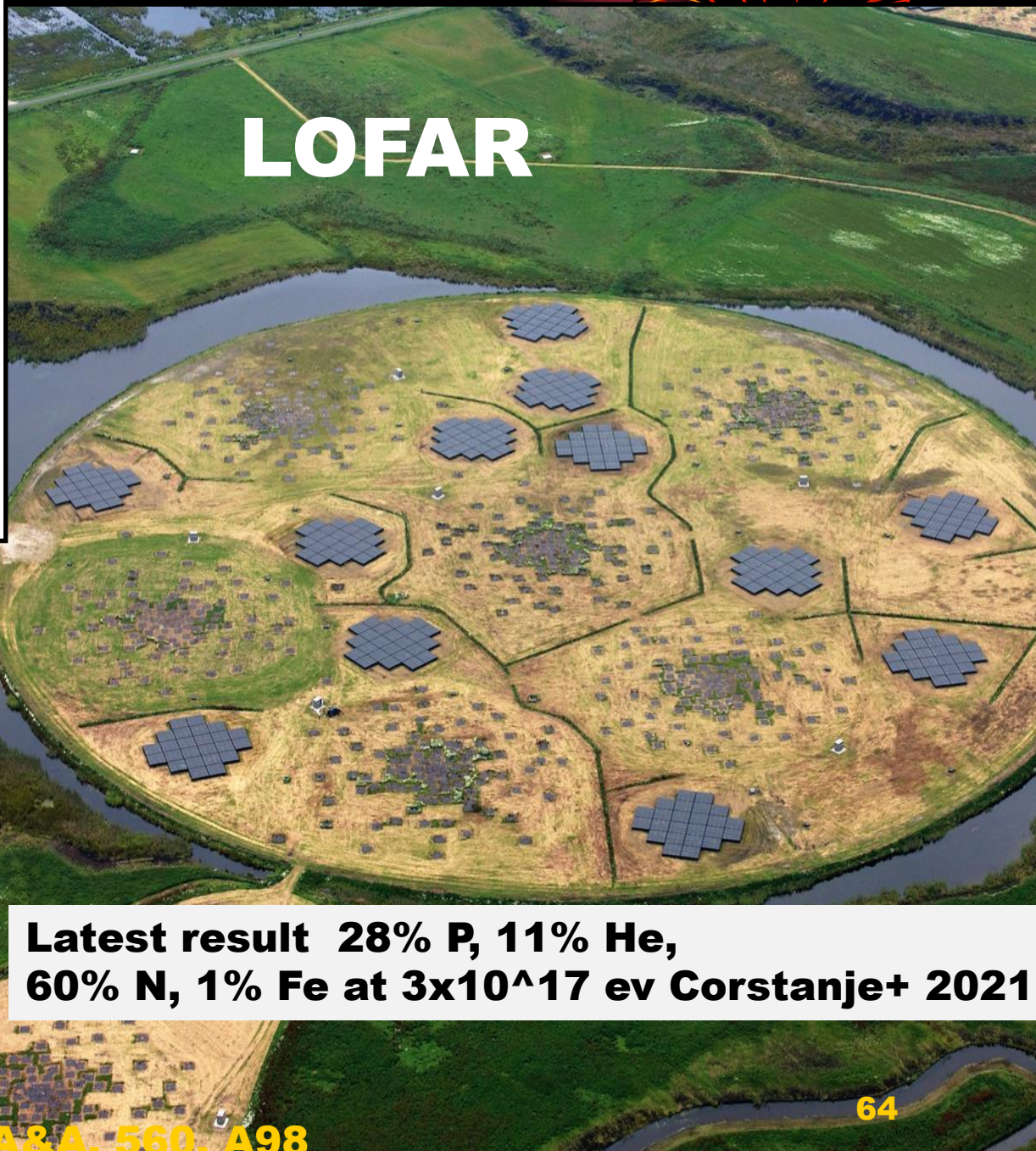
Fig. 7.— Arrival directions of Auger events (red points in the South hemisphere) and Telescope Array ones (black crosses in the Northern hemisphere) above  $10^{19}$  eV in equatorial coordinates, using a Mollweide projection.

**Isotropic!**





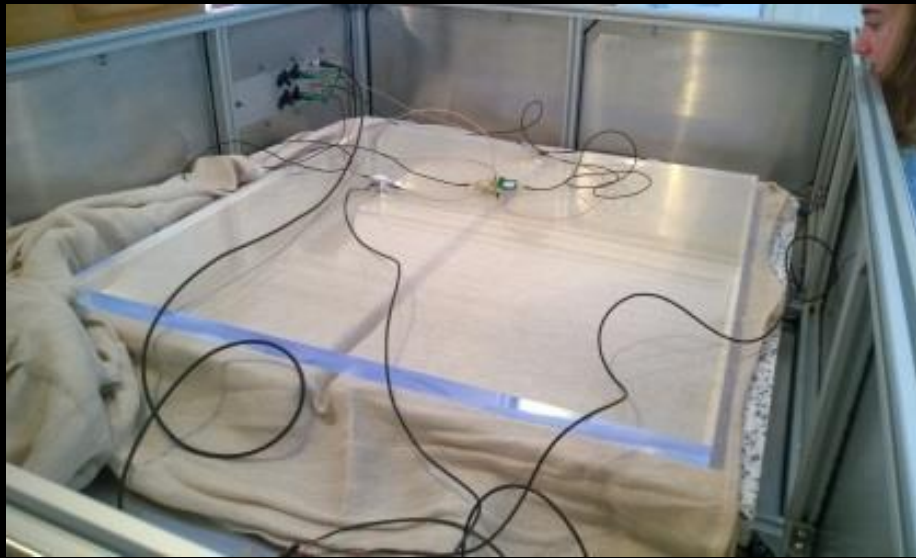
# LOFAR



**Latest result 28% P, 11% He,  
60% N, 1% Fe at  $3 \times 10^{17}$  ev Corstanje+ 2021**

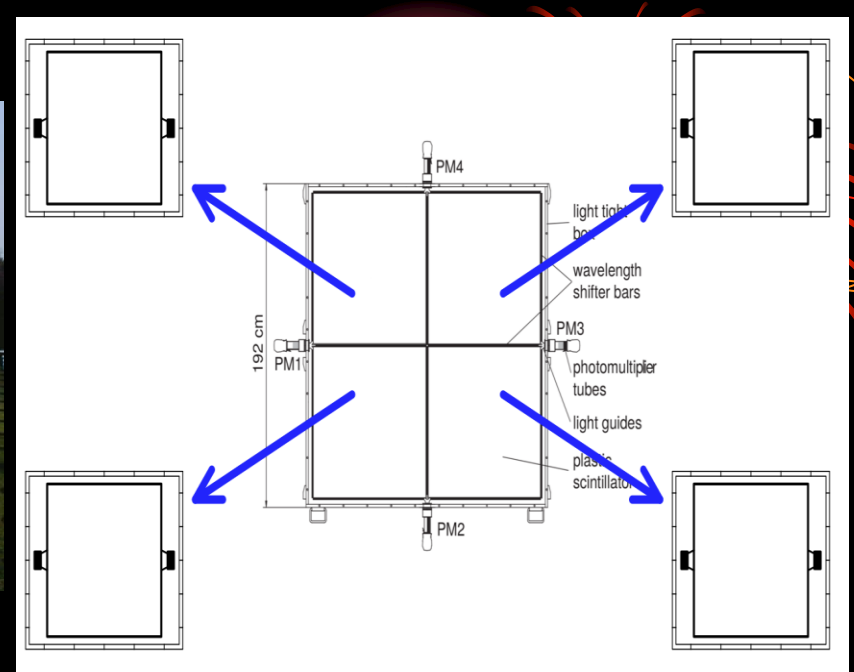
**Schellart P. et al., 2013, A&A, 560, A98**







# KIT KASCADE



**U. W. Australia Perth**



**MWA site Murchison**