

# Historical introduction

## Basic properties of Cosmic Rays



«ETTORE MAJORANA» FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE

INTERNATIONAL SCHOOL OF COSMIC-RAY ASTROPHYSICS  
«MAURICE M. SHAPIRO»

*22<sup>nd</sup> Course: “From cosmic particles to gravitational waves: now and to come”*  
*30 July – 7 August 2022*

PRESIDENT AND DIRECTOR OF THE CENTRE: PROFESSOR A. ZICHICHI

DIRECTORS OF THE COURSE: PROFESSORS J.P. WEFEL, T. STANEV, J.R. HÖRANDEL



Jörg R. Hörandel

RU Nijmegen, Nikhef, VU Brussel

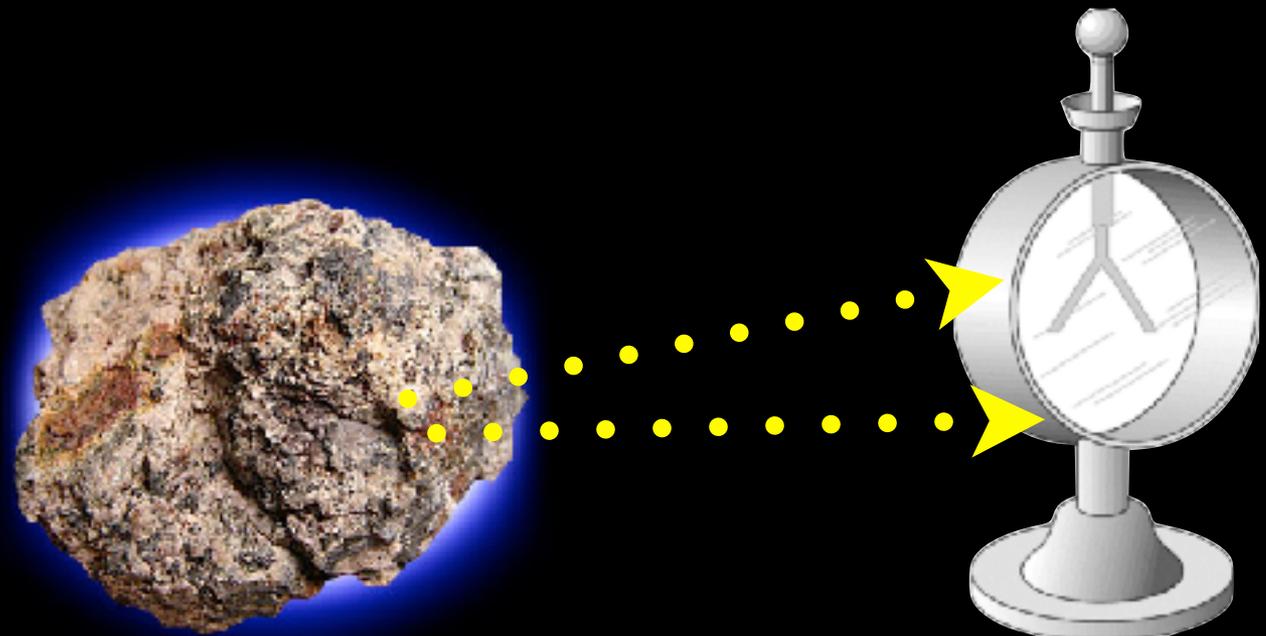
<http://particle.astro.ru.nl>

# Discovery of Radioactivity

# Discovery of Radioactivity



# Discovery of Radioactivity



# Discovery of Radioactivity

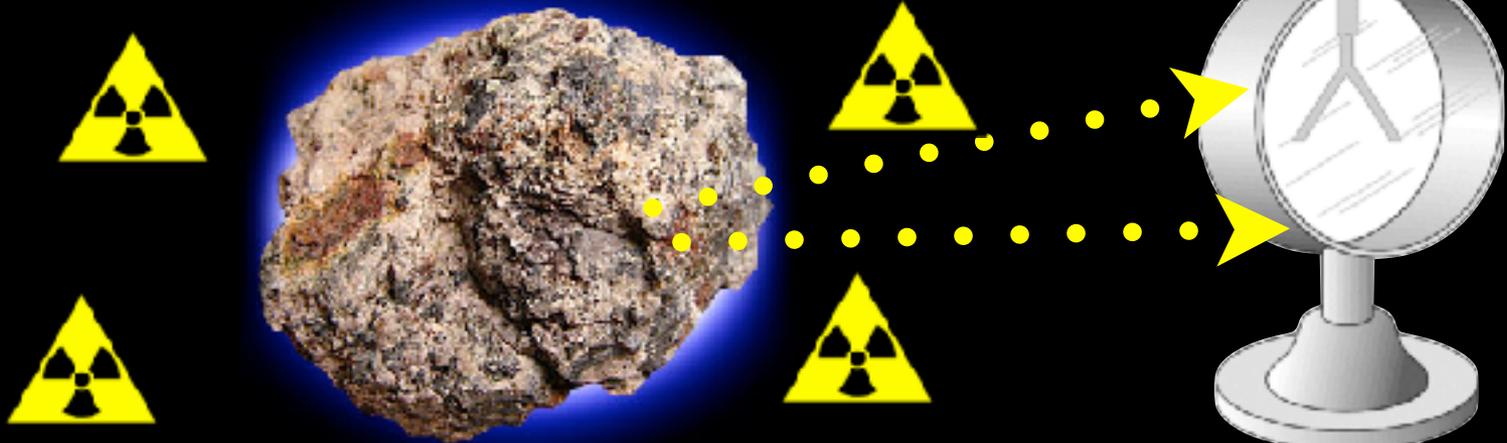


Henri Becquerel



Marie & Pierre Curie

Nobel Prize  
1903



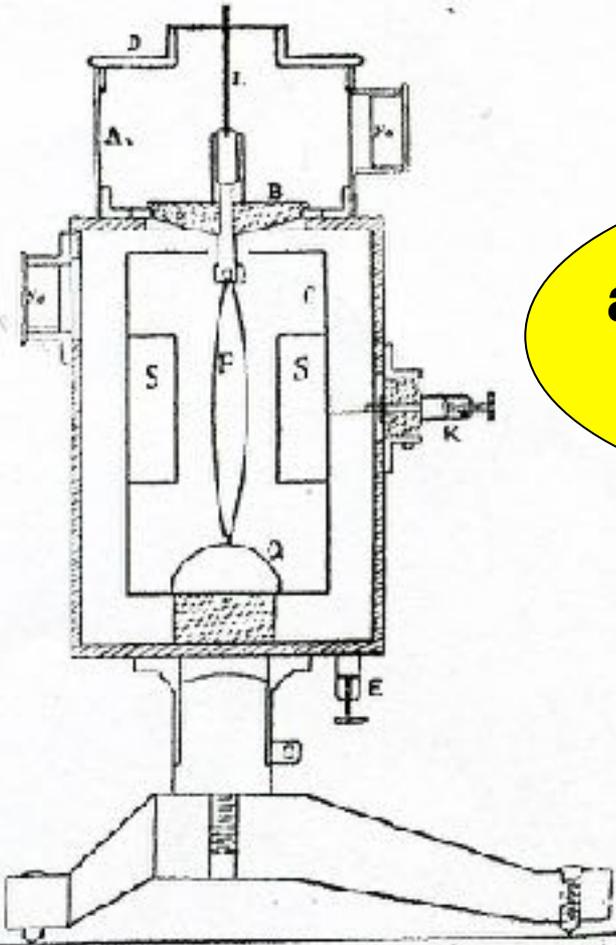
Ein neues Elektrometer für statische Ladungen.

Dritte Mitteilung<sup>1)</sup>.

Von Th. Wulf.

Mitteilung enthält einige  
weiter beschriebenen Appa-  
raturerhöhung seiner Transport-

a new electrometer  
for static charges





**Sir J.J.Thomson  
Nobel Prize 1906**

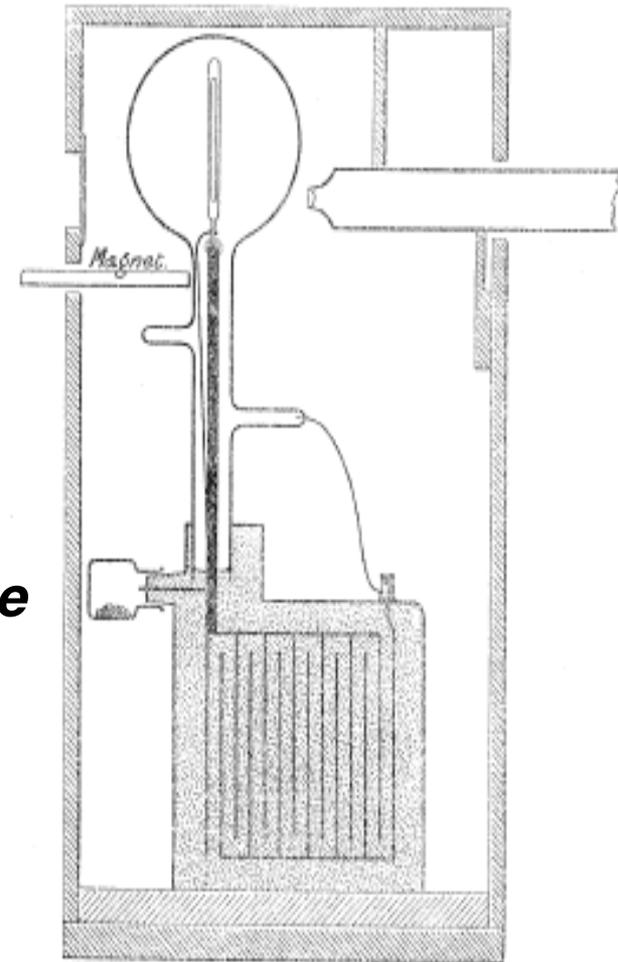


**Conduction of electricity through gases (1928):**

**It would be one of the romances of science if these obscure and prosaic minute leakages of electricity from well-insulated bodies should be the means by which the most fundamental problems in the evolution of the cosmos came to be investigated.**

Credit Alex MacDonald

## Detector used by Wilson to investigate ionization of air



***“the continuous production of ions in dust-free air could be explained as being due to radiation from sources outside our atmosphere, possibly radiation like Röntgen rays or cathode rays, but of enormously greater penetrating power”***

**C T R Wilson, Proc Roy Soc A 68 (1901) 151**

**on the origin of gamma radiation in the atmosphere**

Über den Ursprung der in der Atmosphäre vorhandenen  $\gamma$ -Strahlung.

Von Th. Wulf.

Tabelle I.

Strahlung der Wände von Gebäuden.

Ort	Material	Alter	Strahlung Ionen pro cm <sup>2</sup> u. Sekunde
Abtei Maria Laach bei Andernach a. Rh. . . . .	Vulkanisch Tuff	50 Jahre	13,7
Valkenburg, Colleg, Holland-L. . . . .	Ziegelsteine	15 "	3,7
Löwen, Colleg, Belgien	Ziegelsteine	—	8,0
Namur, Colleg N. D. de la paix, Belgien . . . . .	Ziegelsteine	ca. 100	3,7
Wynandsrade Kasteel, Holland . . . . .	Ziegelsteine	200 Jahre	0,0

Man kann den Inhalt dieser Arbeit kurz so zusammenfassen. Es wird über Versuche berichtet, welche beweisen, daß an dem Beobachtungsort die durchdringende Strahlung von primär radioaktiven Substanzen verursacht wird, welche in den obersten Erdschichten liegen, bis etwa 1 m unter der Oberfläche.

Wenn ein Teil der Strahlung aus der Atmosphäre stammt, so ist er doch so klein, daß er sich mit den gebrauchten Mitteln nicht nachweisen ließ.

Die zeitlichen Schwankungen in der  $\gamma$ -Strahlung . . . . .

**the radiation originates from the soil maybe a small contribution from the atmosphere**

Nur in dem alten holländischen Kasteel Wynandsrade, vor fast 200 Jahren aus Ziegelsteinen erbaut, zeigte sich kein Unterschied in der Strahlung im Zimmer und im Freien. — Am stärksten war die Strahlung in Maria Laach in einem



~1910



**Theodor Wulf**

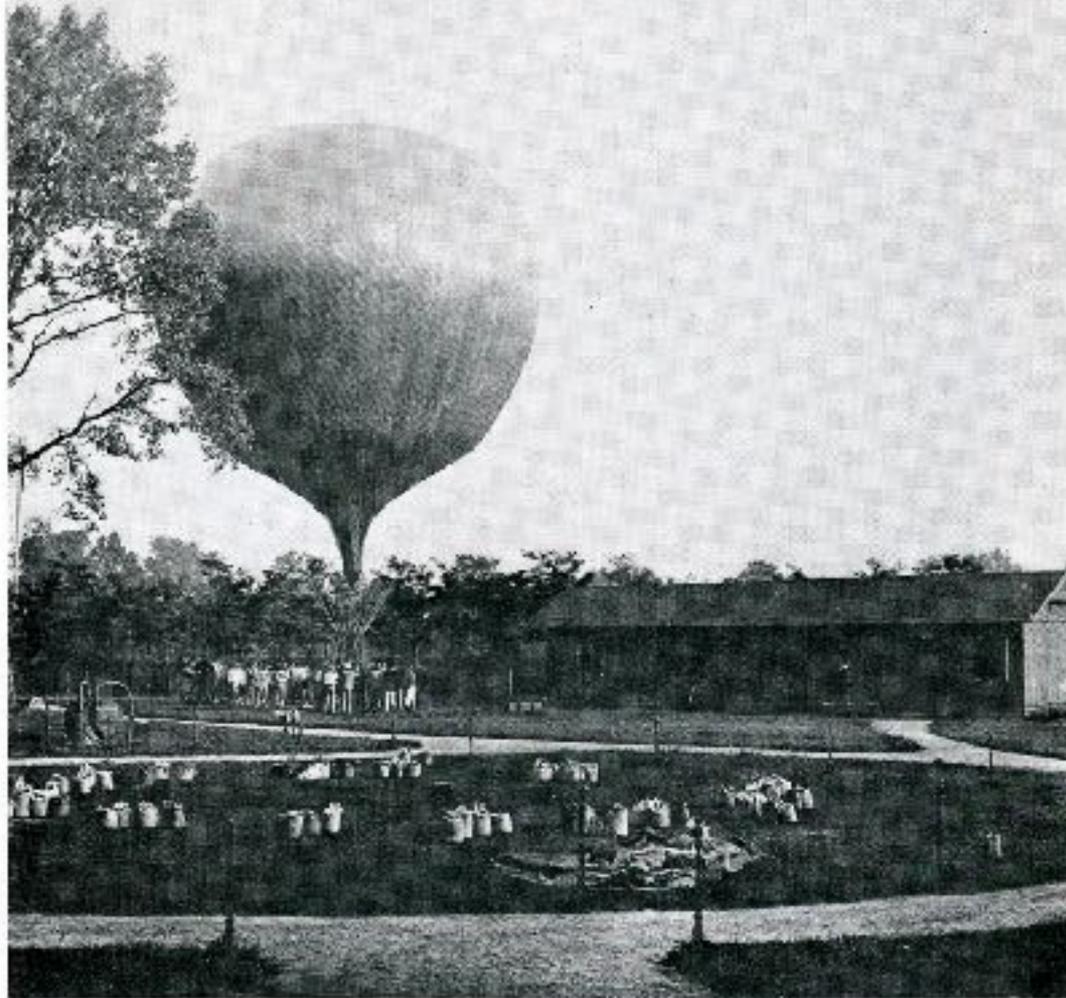
**1909: Soddy & Russel:  
attenuation of gamma rays  
follows an exponential law**

$$I = I_0 e^{-\mu L}$$

# Discovery of Cosmic Rays

## Viktor Franz Hess

### 7. August 1912



Aeronautisches Gelände im Wiener Prater, von dem aus V. F. Hess in den Jahren 1911/12 seine ersten Freiballon-Forschungsfahrten unternommen hatte. (Courtesy of Heeresgeschichtliche Museum, Vienna)

# Discovery of Cosmic Rays

## Viktor Franz Hess

### 7. August 1912



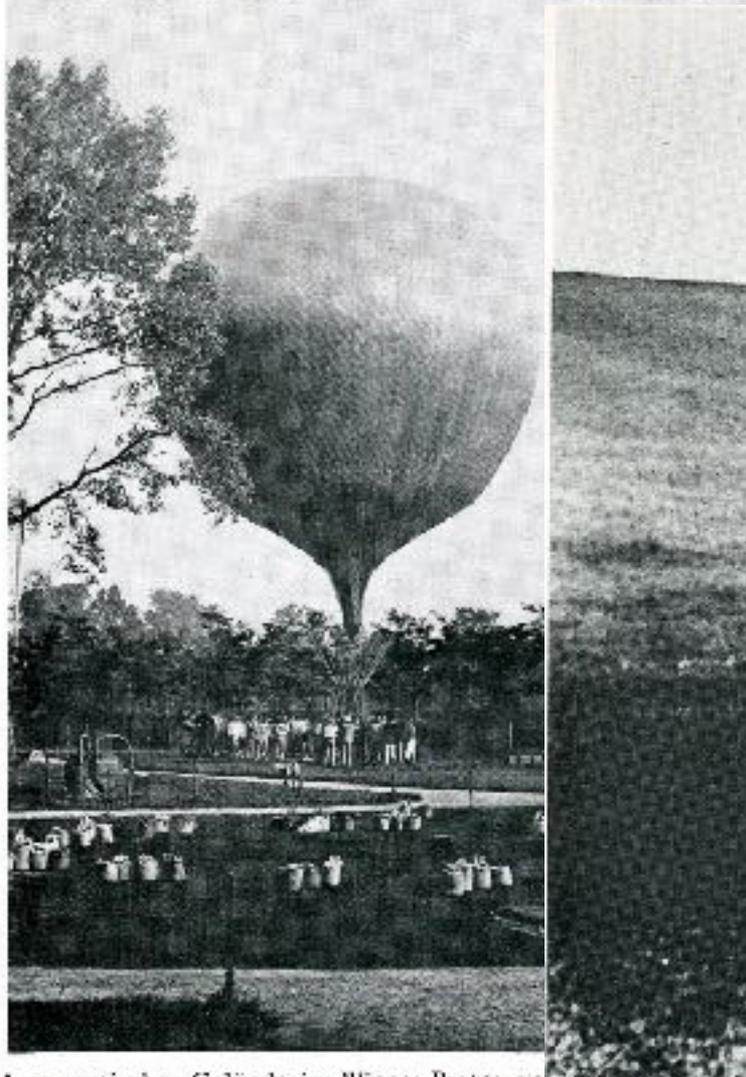
Aeronautisches Gelände im Wiener Prater, wo seine ersten Freiballon-Forschungsfahrten u schichtfleiche Mu

Hess on gondola in 1912 probably in test flight. The date and place is not clear at present.

# Discovery of Cosmic Rays

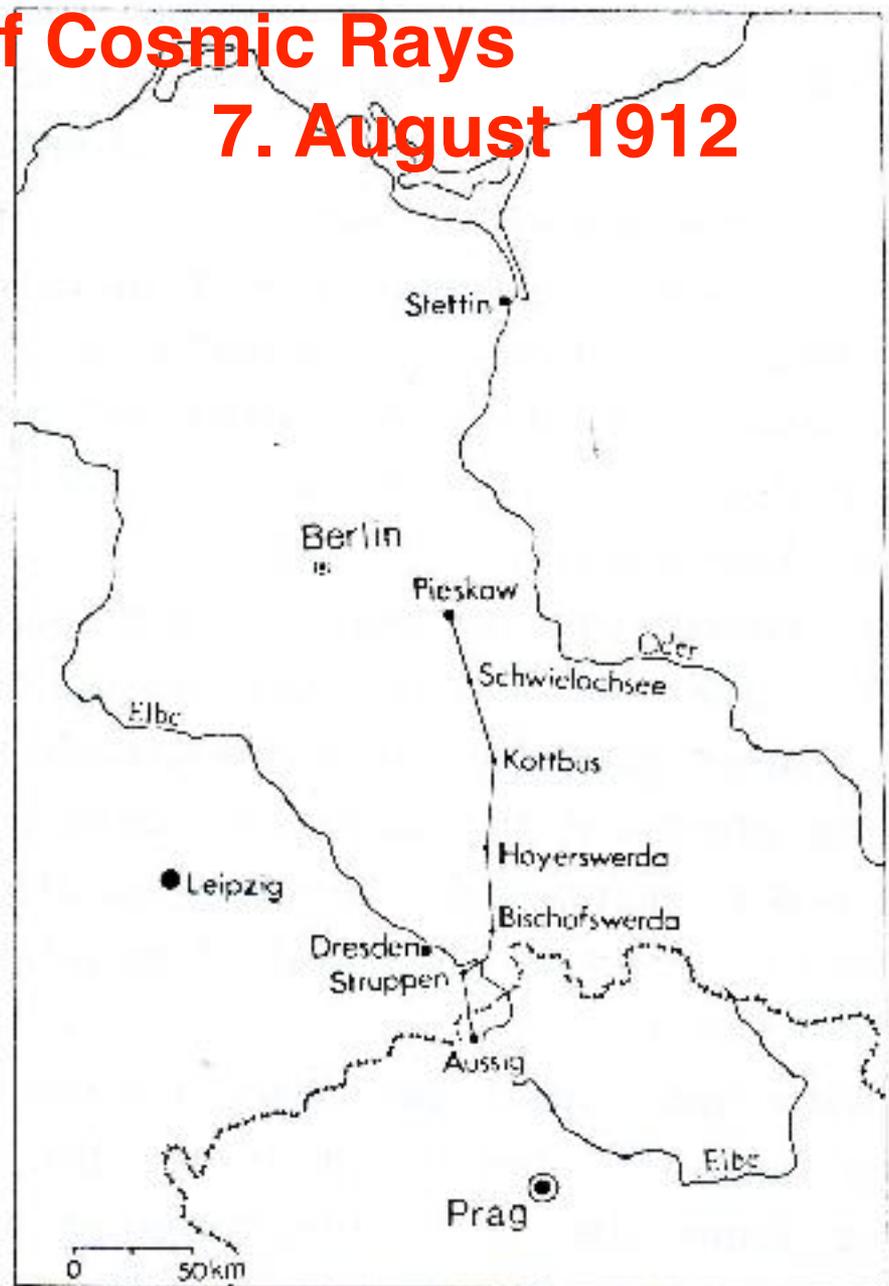
## Viktor Franz Hess

### 7. August 1912



Aeronautisches Gelände im Wiener Prater, vor seine ersten Freiballon-Forschungsfahrten u schichtflehe Mu

Hess on



Route des Entdeckungsfluges der kosmischen Strahlung.

# Discovery of Cosmic Rays

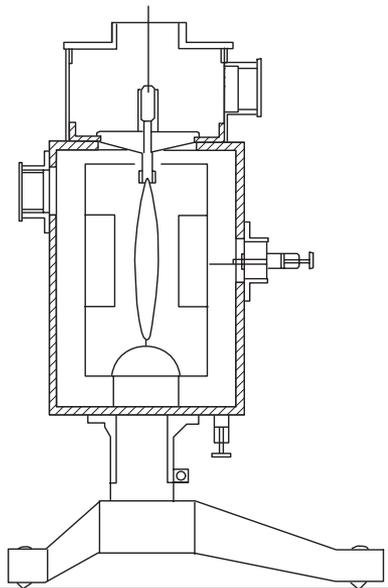
## Viktor Franz Hess

### 7. August 1912

Early cosmic-ray work published in German

Jörg R. Hörandel

Citation: *AIP Conf. Proc.* **1516**, 52 (2013); doi: 10.1063/1.4792540



**FIGURE 1.** *Left:* Electrometer after Th. Wulf [5]. *Right:* Two grandsons of V.F. Hess revealing a plaque to commemorate the discovery of cosmic rays on August 7th, 2012, close to the presumed landing site of V.F. Hess in Pieskow close to Berlin. It reads: "To commemorate the discovery of cosmic rays. On 7 August 1912 landed the Austrian physicist Victor F. Hess with a hydrogen balloon close to Pieskow. On the journey from Lower-Bohemia he reached an altitude of 5300 m and he proved the existence of a penetrating, ionizing radiation from outer space. For the discovery of cosmic rays V.F. Hess has been awarded the Nobel Prize in Physics in 1936. The participants of the symposium '100 years cosmic rays', Bad Saarow-Pieskow, 7 August 2012".

Aeronautisches Gelände im Wiener Prater, wo seine ersten Freiballon-Forschungsfahrten u schichtfliehe Mu

Hess on

Route des Entdeckungsfluges der kosmischen Strahlung.

Aus der Abteilung für Geophysik, Meteorologie  
und Erdmagnetismus:

Viktor F. Hess (Wien), Über Beobachtungen  
der durchdringenden Strahlung bei sieben  
Freiballonfahrten.

Im Vorjahre habe ich bereits Gelegenheit  
gehabt, zwei Ballonfahrten zur Erforschung  
der durchdringenden Strahlung zu unterneh-  
men: über die erste Fahrt

7. Fahrt (7. August 1912).

Ballon: „Böhmen“ (1680 cbm Wasserstoff).  
Meteorolog. Beobachter: E. Wolf.

Führer: Hauptmann W. Hoffory.  
Luftelektr. Beobachter: V. F. Hess.

		Mittlere Höhe		Beobachtete Strahlung				Temp.	Relat. Feucht. Proz.
		absolut	relativ m	Apparat 1	Apparat 2	Apparat 3			
				$\varphi_1$	$\varphi_2$	$\varphi_3$	reduz. $\varphi_3$		
1	15h 15—16h 15	156	0	17,3	12,9	—	—	1½ Tag vor dem Auf- stiege (in Wien)	
2	16h 15—17h 15	156	0	15,9	11,0	18,4	18,4		
3	17h 15—18h 15	156	0	15,8	11,2	17,5	17,5		
4		1700	1400	15,8	14,4	—	—		
		2750	2500	17,3	17,3	—	—		
		3850	3600	19,8	—	—	—		
7		4800	4700	40,7	36,7	—	—		
		(4400)	(3350)	—	—	—	—		
8	10h 45—11h 15	4400	4200	28,1	22,7	—	—		
9	11h 15—11h 45	1300	1200	(9,7)	11,5	—	—		
10	11h 45—12h 10	250	150	11,9	10,7	—	—		
11	12h 25—13h 12	140	0	15,0	11,6	—	—		

on the observation of  
the penetrating  
radiation during 7  
balloon campaigns

hydrogen!

altitude

intensity

Aus der Abteilung für Geophysik, Meteorologie  
und Erdmagnetismus:

Viktor F. Hess (Wien), Über Beobachtungen  
der durchdringenden Strahlung bei sieben

radiation with high  
penetration power  
impinges onto the  
atmosphere from  
above

no change during  
solar eclipse  
hence, Sun can be  
excluded as origin

der Verringerung der radioaktiven Substanzen  
der Atmosphäre zurückzuführen.

Die Ergebnisse der vorliegenden Beobachtungen scheinen am ehesten durch die Annahme erklärt werden zu können, daß eine Strahlung von sehr hoher Durchdringungskraft von oben her in unsere Atmosphäre eindringt, und auch noch in deren untersten Schichten einen Teil der in geschlossenen Gefäßen beobachteten Ionisation hervorruft. Die Intensität dieser Strahlung scheint zeitlichen Schwankungen unterworfen zu sein, welche bei einstündigen Ablesungsintervallen noch erkennbar sind. Da ich im Ballon weder bei Nacht noch bei einer Sonnenfinsternis eine Verringerung der Strahlung fand, so kann man wohl kaum die Sonne als Ursache dieser hypothetischen Strahlung ansehen, wenigstens solange man nur an eine direkte  $\gamma$ -Strahlung mit geradliniger Fortpflanzung denkt.

Daß die Zunahme der Strahlung erst jenseits 3000 m so stark merklich wird, ist nicht

Aus der Abteilung für Geophysik, Meteorologie  
und Erdmagnetismus:

Viktor F. Hess (Wien), Über Beobachtungen  
der durchdringenden Strahlung bei sieben



V.F. Hess in 1936–37, on the occasion of Nobel prize.

**Nobel Prize 1936**

der Verringerung der radioaktiven Substanzen  
der Atmosphäre zurückzuführen.

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Daß die Zunahme der Strahlung erst jenseits 3000 m so stark merklich wird ist nicht

erweitertes Beobachtungsmaterial wurde.

# Neue Untersuchungen über die durchdringende Hesssche Strahlung.

Von E. Steinke in Königsberg i. Pr.

Mit 25 Abbildungen. (Eingegangen am 23. März 1928.)

**absorption measurements compatible with assumption of isotropic flux of cosmic rays**

Es werde  
Eigengang  
konnte, I  
ausgeführ  
starken E  
kleinsten  
entspricht  
Radiumst  
was einer  
kommt da

in Energie theoretisch freiwerdenden Mengen. In größerer Höhe die Strahlung wesentlich weiter (mittleres  $\mu_{Pb} = 0,018$  bis  $0,025 \text{ cm}^{-1}$ ). Ein großer Teil der Ionisation wird durch noch erheblich weichere Streustrahlung hervorgerufen, die bei verschiedenen Absorptionsmedien variiert und dadurch die Messungen der Absorptionskoeffizienten leicht fälschen kann. Es wird der Nachweis erbracht, daß die Strahlung auch noch in Eisen merkliche Streustrahlung auslöst. — Die Richtungs- und Absorptionsmessungen gestatten eine einwandfreie Trennung der Hessschen von der Umgebungsstrahlung. Sie geben für die Richtungsverteilung der ersteren etwa solche Werte, wie sie sich aus der Annahme einer von allen Seiten aus dem Kosmos kommenden Strahlung unter Berücksichtigung der Absorption in den verschieden langen Luftwegen mit Hilfe eines mittleren Absorptionskoeffizienten errechnen lassen. Abweichungen hiervon deuten auf die Inhomogenität der Strahlung. — Mit allem Vorbehalt wird der Versuch einer Zerlegung der durchdringenden Strahlung in zwei Komponenten durchgeführt. — Informativische Schwankungsmessungen in 2500 m Höhe unter Ausschluß der Erdstrahlung, jedoch mit fast der gesamten Intensität der durchdringenden Strahlung, ergeben von Tag zu Tag stark wechselnde Schwankungen (Extremdifferenzen 0,8 bis 4,2 %), welche aber im Mittel um ein Vielfaches kleiner sind als die von anderen Autoren in etwa gleicher Höhe gemessenen. — Auf Schwierigkeiten bei der Deutung des Barometer-effektes wird hingewiesen.

# Absorption in the atmosphere

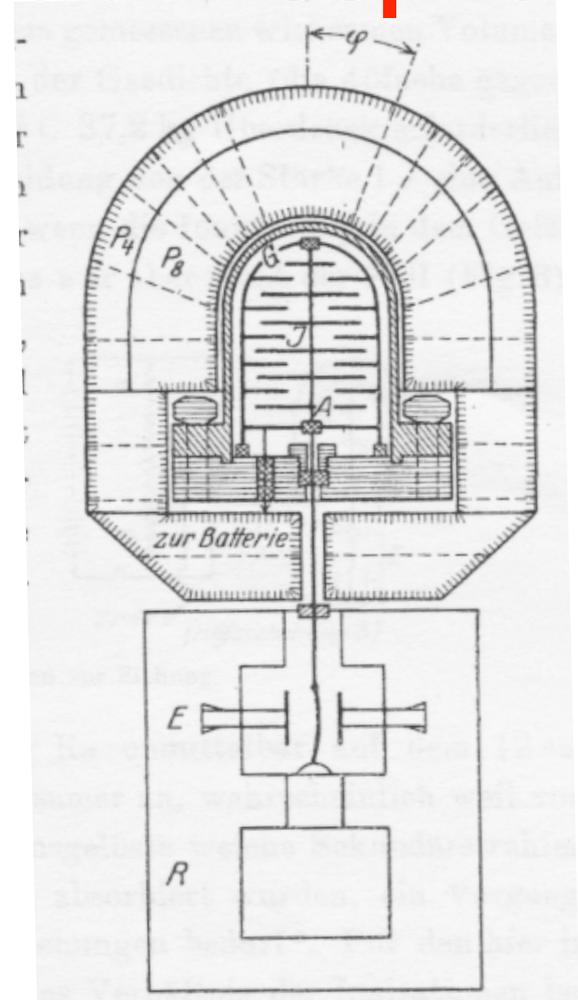


Fig. 1. Hochdruckionisationsgefäß *J* mit Drahtgitter *G* und Aufhänger *A*. Darum 12 cm Fe-Panzer (*P*<sub>4</sub>, *P*<sub>8</sub>), darunter Wulf'sches Einfadenelektrometer *E* mit Registriervorrichtung *R*.

# Neue Untersuchungen über die durchdringende Hesssche Strahlung.

Von E. Steinke in Königsberg i. Pr.

Intensity as function of zenith angle for different altitudes

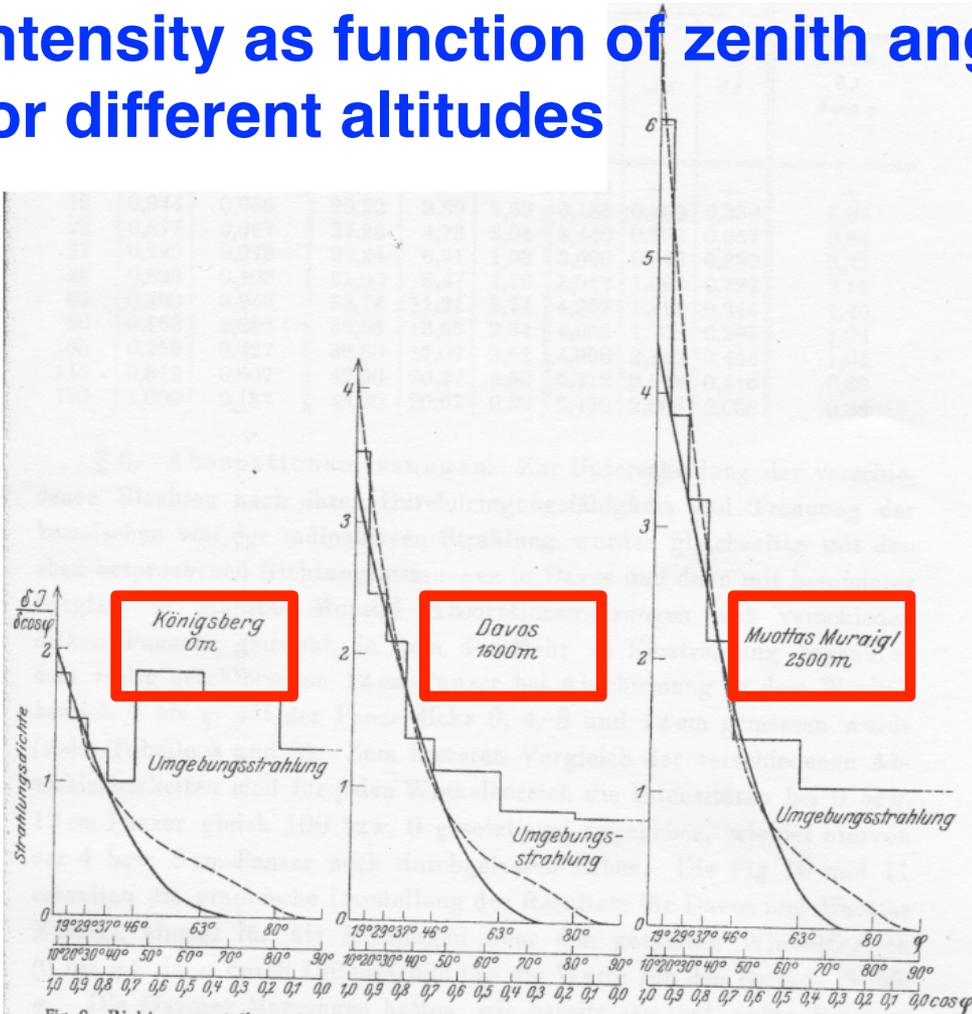


Fig. 9. Richtungsverteilung der durchdringenden Strahlung in verschiedenen Höhen. Die Treppenkurve gibt die beobachteten Werte an. Ferner bedeuten:  
 — die berechnete Kurve für  $\mu_{Pb} = 0,026 \text{ cm}^{-1}$ ,  
 - - - " " " "  $\mu_{Pb} = 0,0042$ ,  
 und  $0,05 \text{ cm}^{-1}$  zusammen (§ 12).

# Absorption in the atmosphere

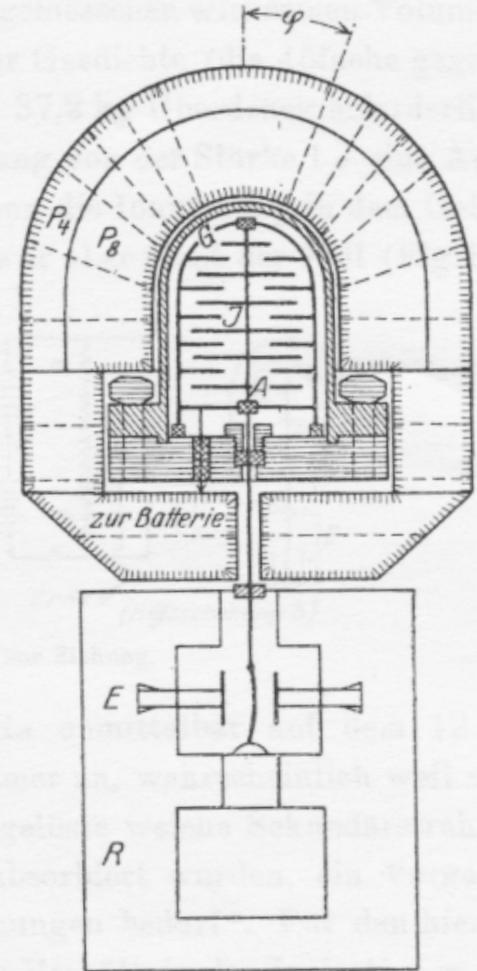


Fig. 1. Hochdruckionisationsgefäß *J* mit Drahtgitter *G* und Aufhänger *A*. Darum 12 cm Fe-Panzer ( $P_4, P_8$ ), darunter Wulf'sches Einfadenelektrometer *E* mit Registriervorrichtung *R*.

# Neue Untersuchungen über die durchdringende Hesssche Strahlung.

Von E. Steinke in Königsberg i. Pr.

# Absorption in the atmosphere

Intensity as function for different altitudes

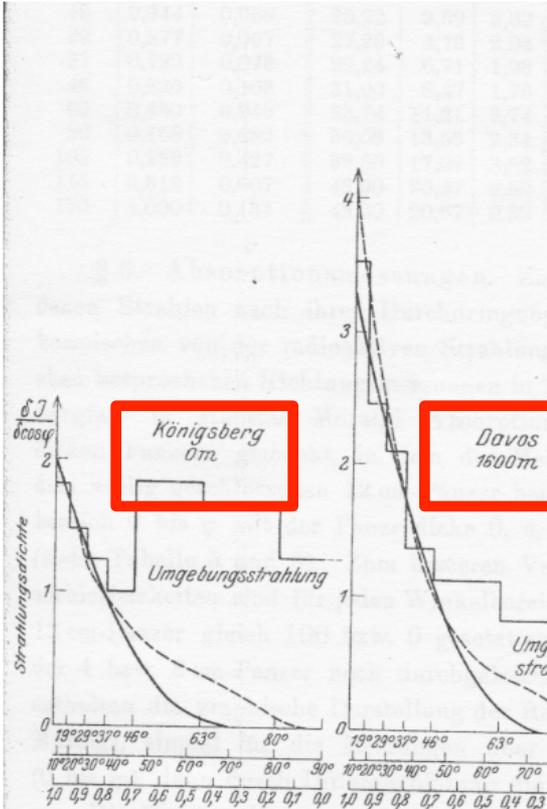
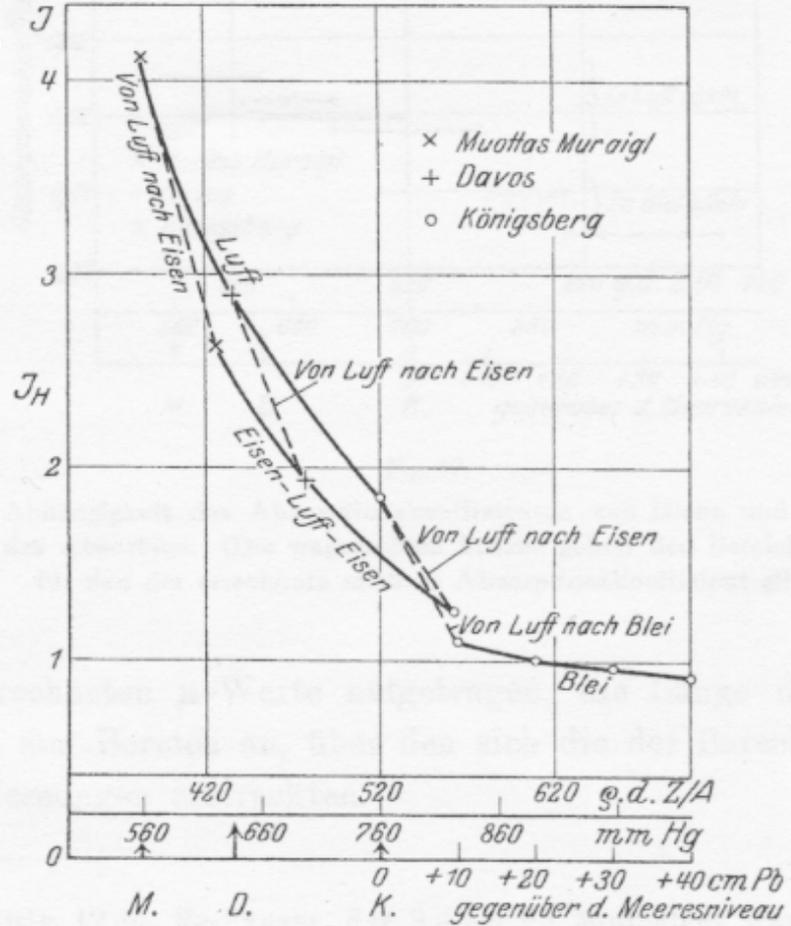


Fig. 9. Richtungsverteilung der durchdringenden Strahlung. Die durchgezogene Kurve gibt die beobachteten Werte an. Ferner bedeutet die gestrichelte Kurve die berechnete Kurve für  $\mu = 0,05 \text{ cm}^{-1}$  zusammen

intensity



atmospheric overburden

Intensität der durchdringenden Strahlung in Abhängigkeit von der Absorptionsschicht.

# Neue Untersuchungen über die durchdringende Hesssche Strahlung.

Von E. Steinke in Königsberg i. Pr.

# Absorption in the atmosphere

Intensity as function for different altitudes

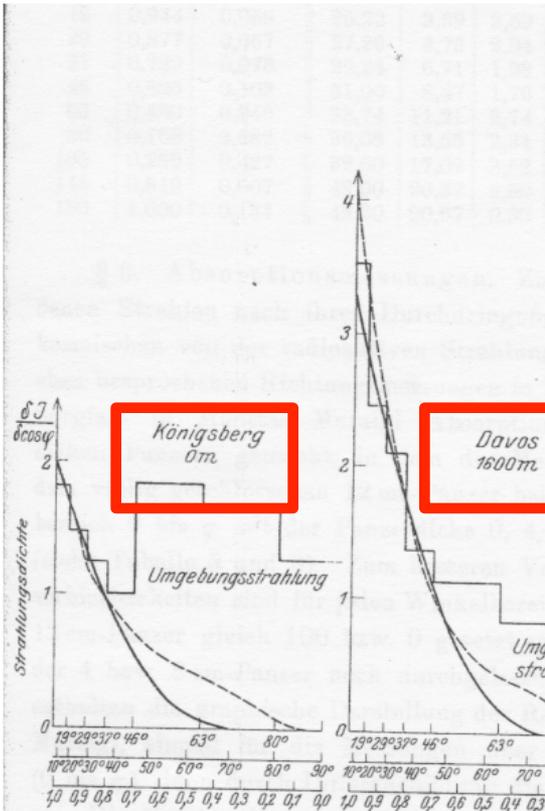
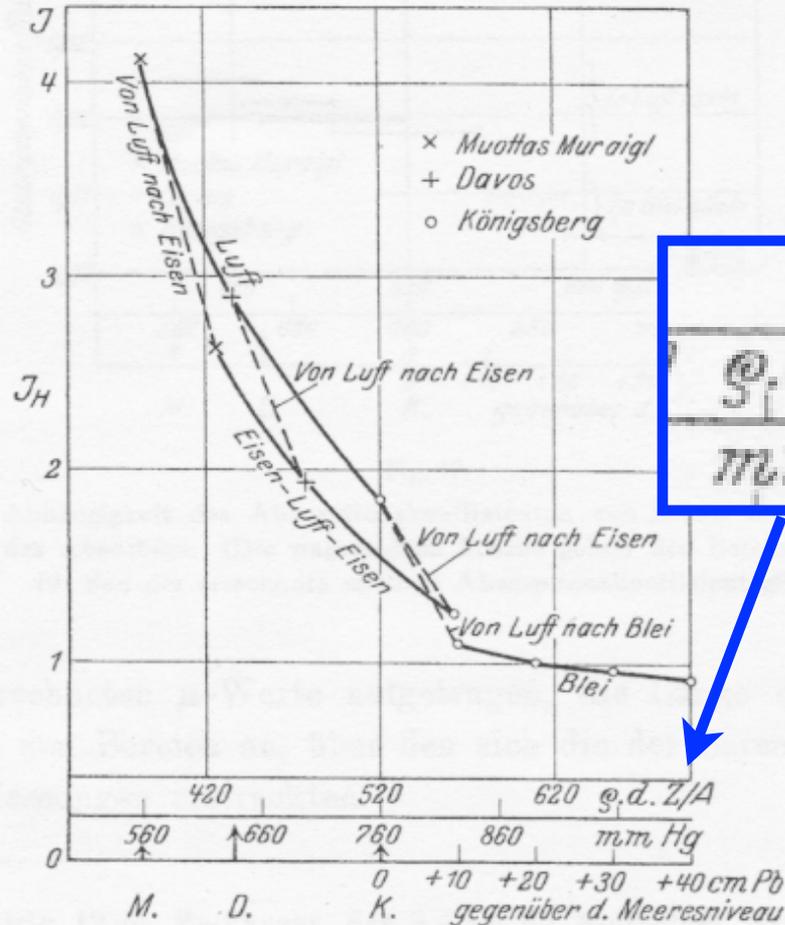


Fig. 9. Richtungsverteilung der durchdringenden Strahlung. Die Kurve gibt die beobachteten Werte an. Ferner bedeutet die berechnete Kurve für die durchdringende Strahlung mit einer Absorption von  $0,05 \text{ cm}^{-1}$  zusammen

intensity



$\frac{\text{g.d. Z/A}}{\text{mm Hg}}$

atmospheric overburden

Intensität der durchdringenden Strahlung in Abhängigkeit von der Absorptionsschicht.

# Über Schwankungen und Barometereffekt der kosmischen Ultrastrahlung im Meeresniveau.

Von E. Steinke in Königsberg i. Pr.

Mit 12 Abbildungen. (Eingegangen am 11. Juni 1930.)

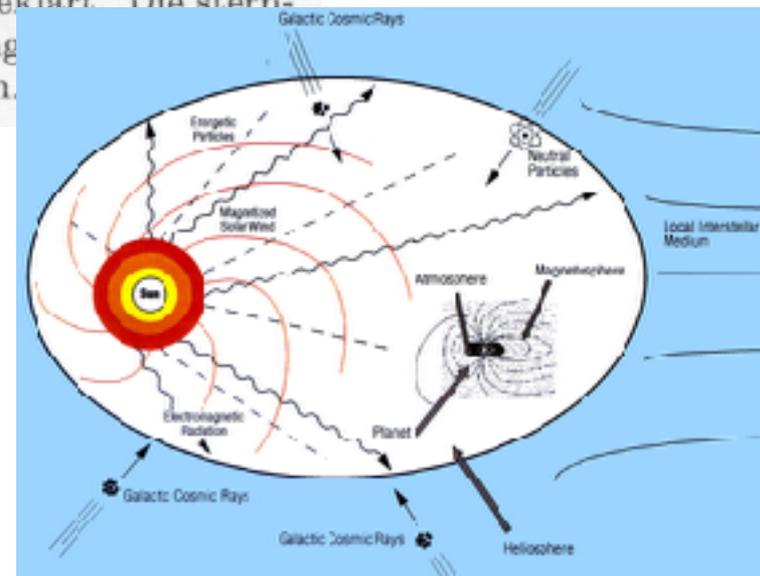
Während des Jahres 1929 wurden 20 Meßreihen mit insgesamt 100 Stunden aufgenommen teils mit allseitig geschlossenem Panzer, teils mit in der Mitte geöffnetem Panzer. Das Untersuchungsmaterial ergab, daß neben zahlreichen Strahlungsschwankungen teils periodische teils unperiodische Intensitätsänderungen vorliegen. Die periodischen Schwankungen sind teils spiegelsymmetrisch zum Barometerstand („Barometereffekt“), teils periodische Schwankungen mit der Jahreszeit, ebensolche mit der Tageszeit, unregelmäßige Intensitätsänderungen über längere Zeiträume, endlich periodische Schwankungen nach Sternzeit. Der Verlauf während der einzelnen Meßreihen ist nicht konstant, sondern schwankend, im Mittel ist er aber ungefähr gleich dem Höhenverlauf. Für das Auftreten der anderen Schwankungen sind noch nicht geklärt. Die zeitlichen Schwankungen beweisen den kosmischen Ursprung der Ultrastrahlung und die Existenz besonderer Emissionszentren.

# Barometric effect

anti-correlation with pressure  
-> barometric effect

annual modulation of cosmic rays

sidereal modulation of cosmic rays



# Über Schwankungen und Barometereffekt der kosmischen Ultrastrahlung im Meeresniveau.

Von E. Steinke in Königsberg i. Pr.

# Barometric effect

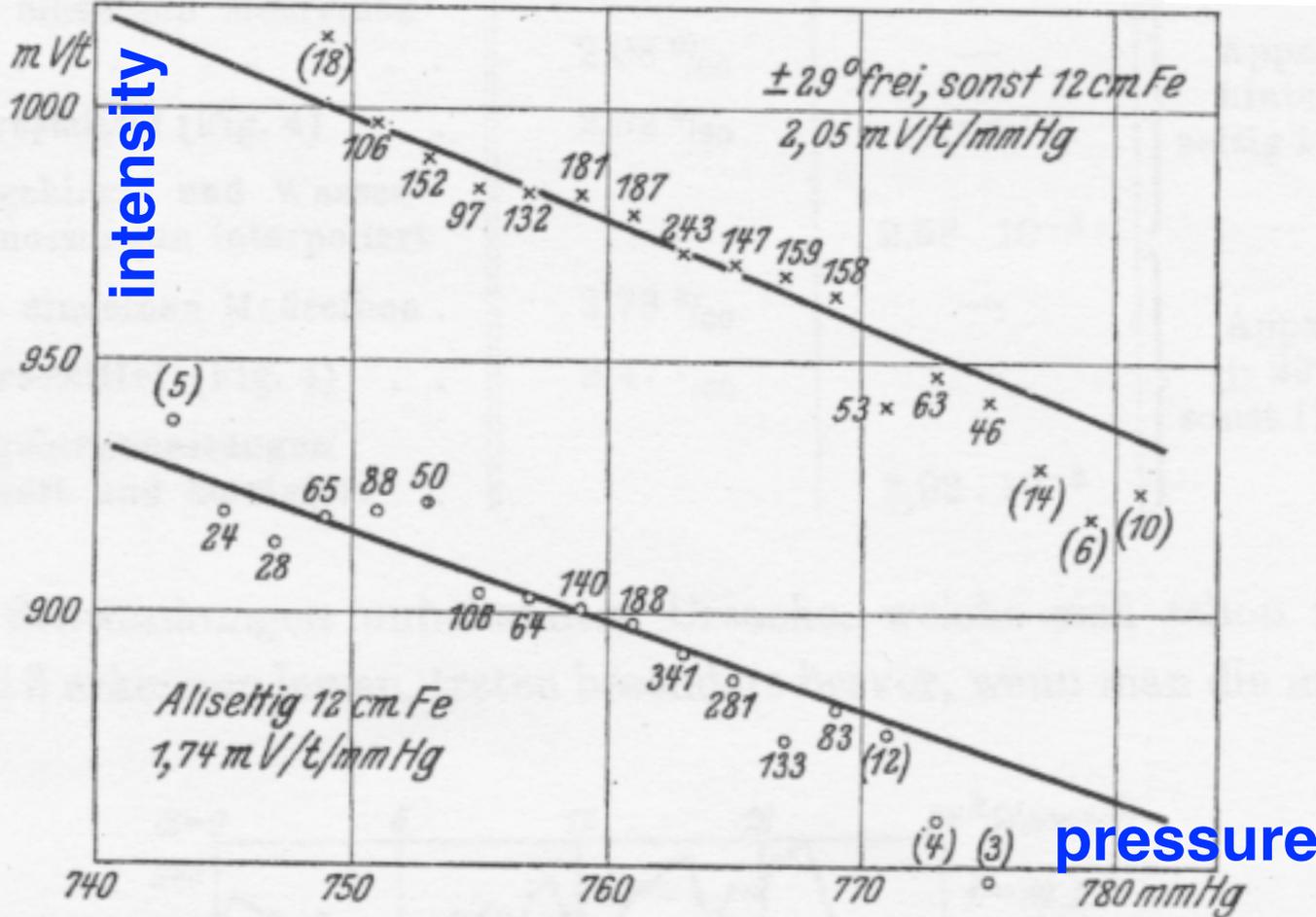
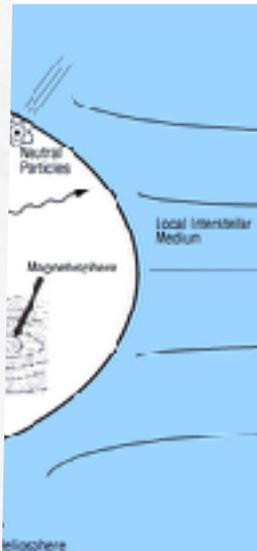


Fig. 4. Zusammenhang zwischen Barometerstand und Ionisation (Jahresmittel der Stundenwerte; die Zahlen geben die Anzahl der Stundenwerte an).

Während d  
stunden au  
Dicke, teil  
material e  
teils perio  
Schwanku  
dische Sch  
mäßige In  
endlich pe  
während c  
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zeitlichen

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si

# Absorption in Lake Constance 1928

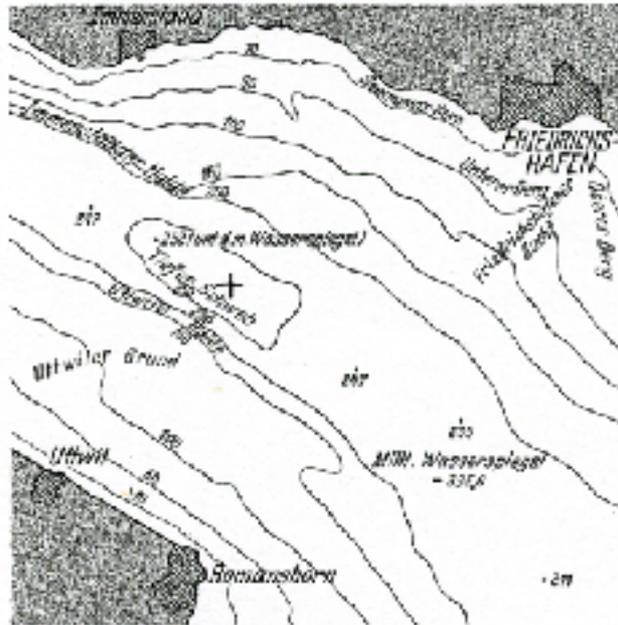


Fig. 5.

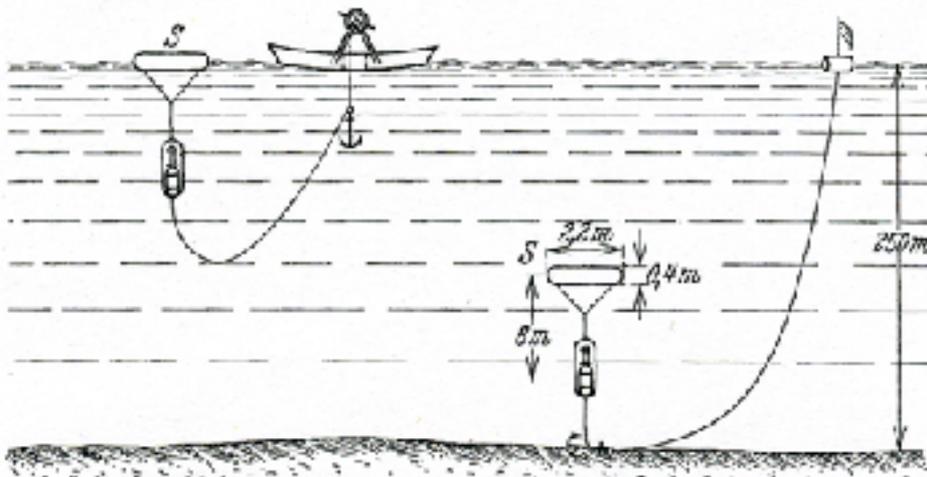
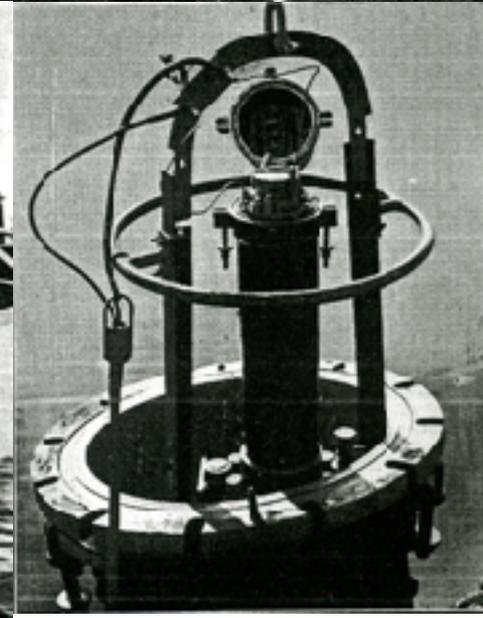
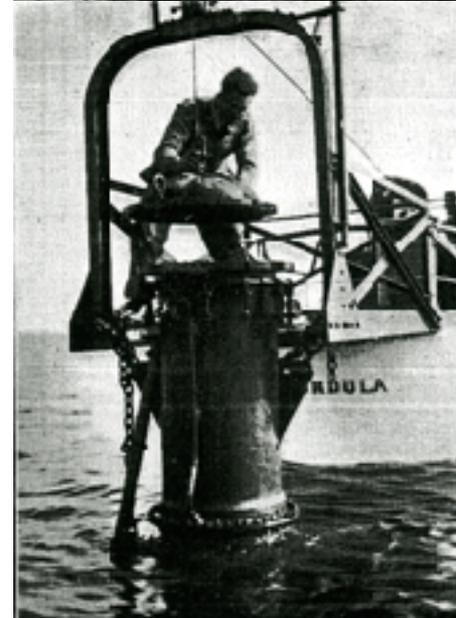
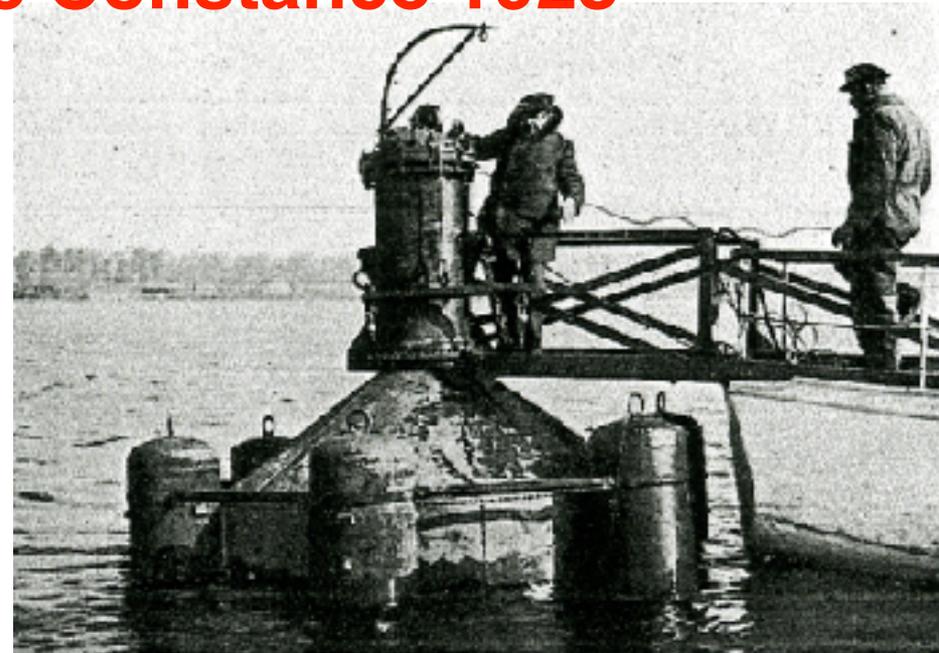


Fig. 6. Die „schwimmende“ Verankerung des Apparates.



# Absorption in Lake Constance 1928

Ionization chamber with electrometer read-out  
automatic each hour, up to 8 days

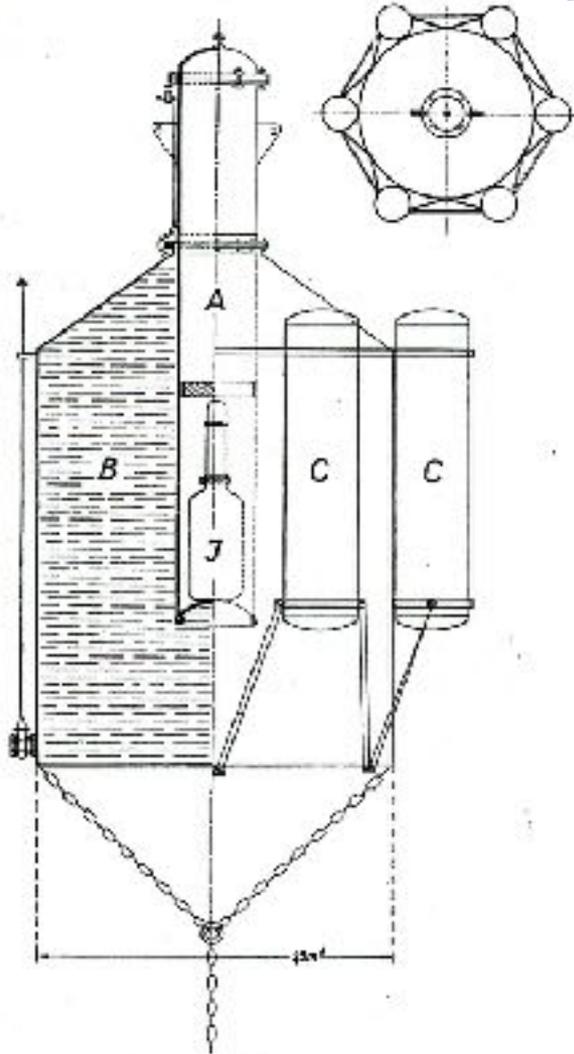
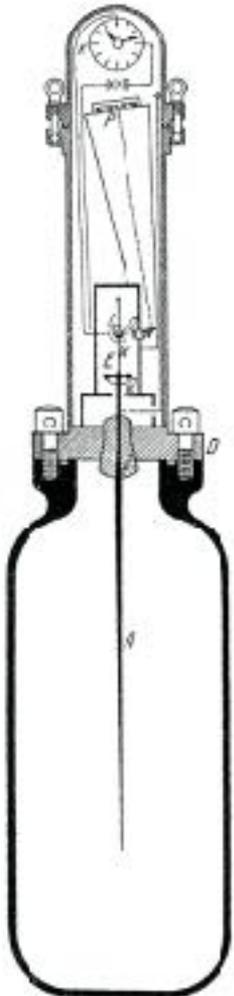


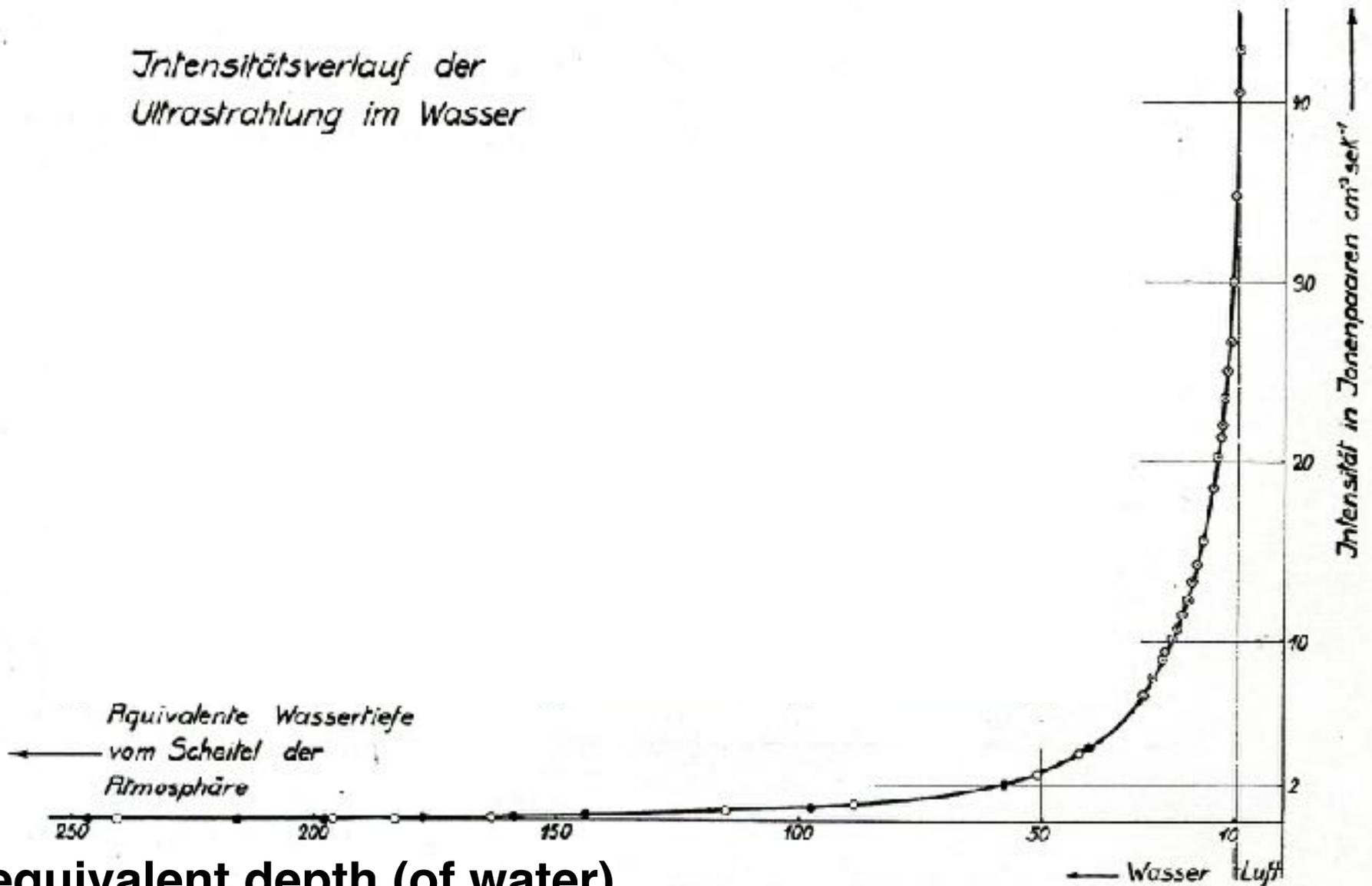
Fig. 1.

Aufbau des wasserdichten  
Registrierapparates.

Fig. 1.

# Absorption in Lake Constance 1928

Intensitätsverlauf der  
Ultrastrahlung im Wasser



equivalent depth (of water)  
from top of the atmosphere

Fig. 6.

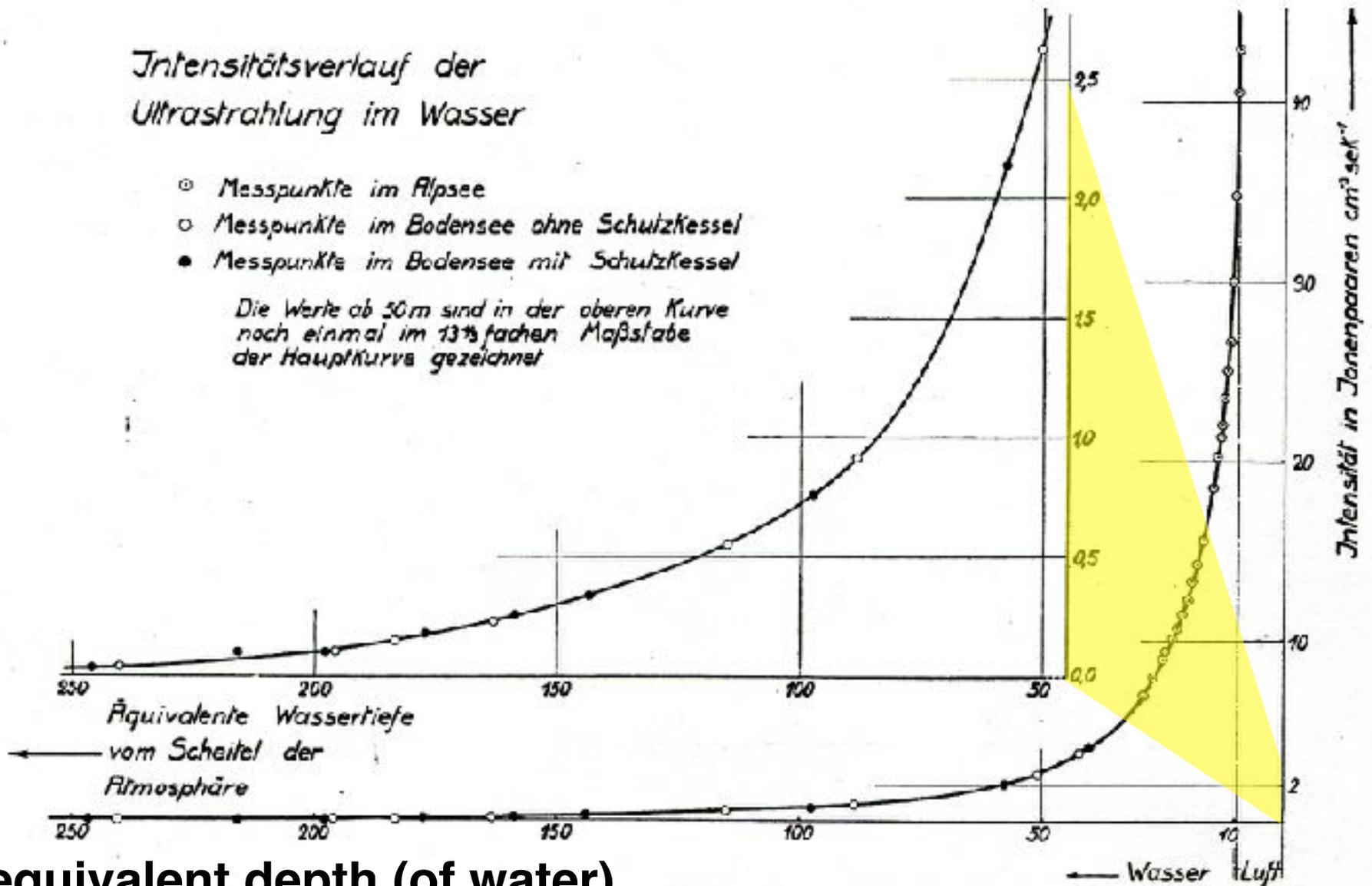
E. Regener Phys. Z. 34 (1933) 306

# Absorption in Lake Constance 1928

Intensitätsverlauf der  
Ultrastrahlung im Wasser

- ⊙ Messpunkte im Alpsee
- Messpunkte im Bodensee ohne Schutzkessel
- Messpunkte im Bodensee mit Schutzkessel

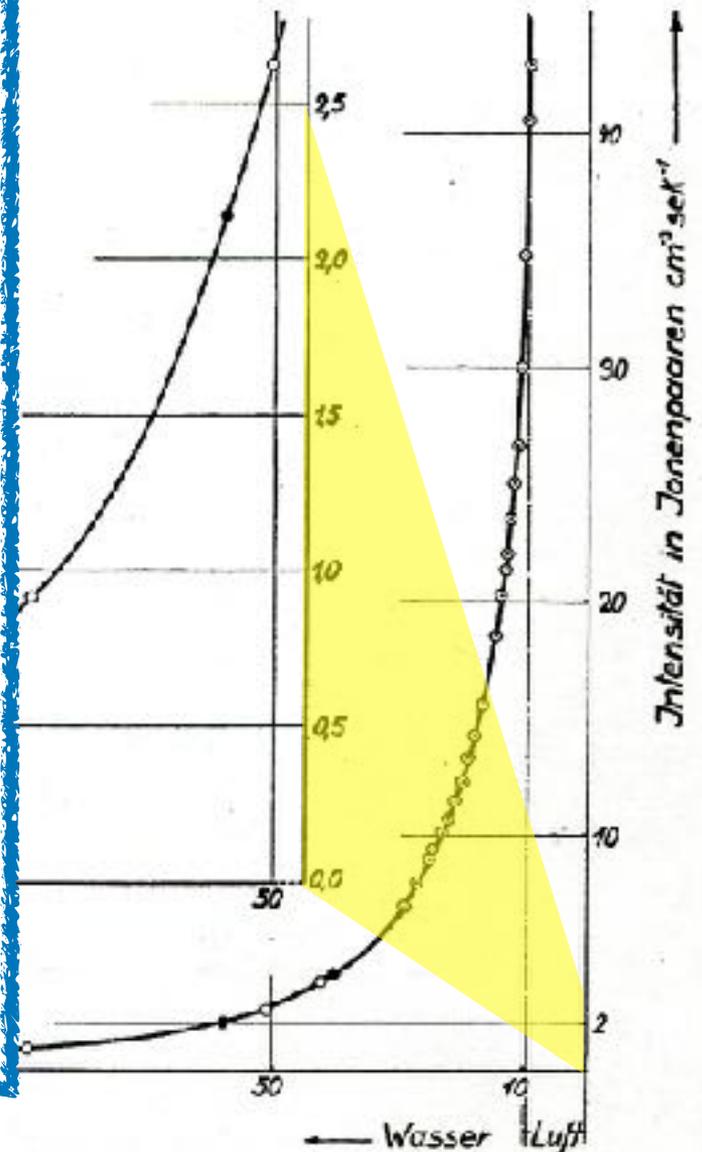
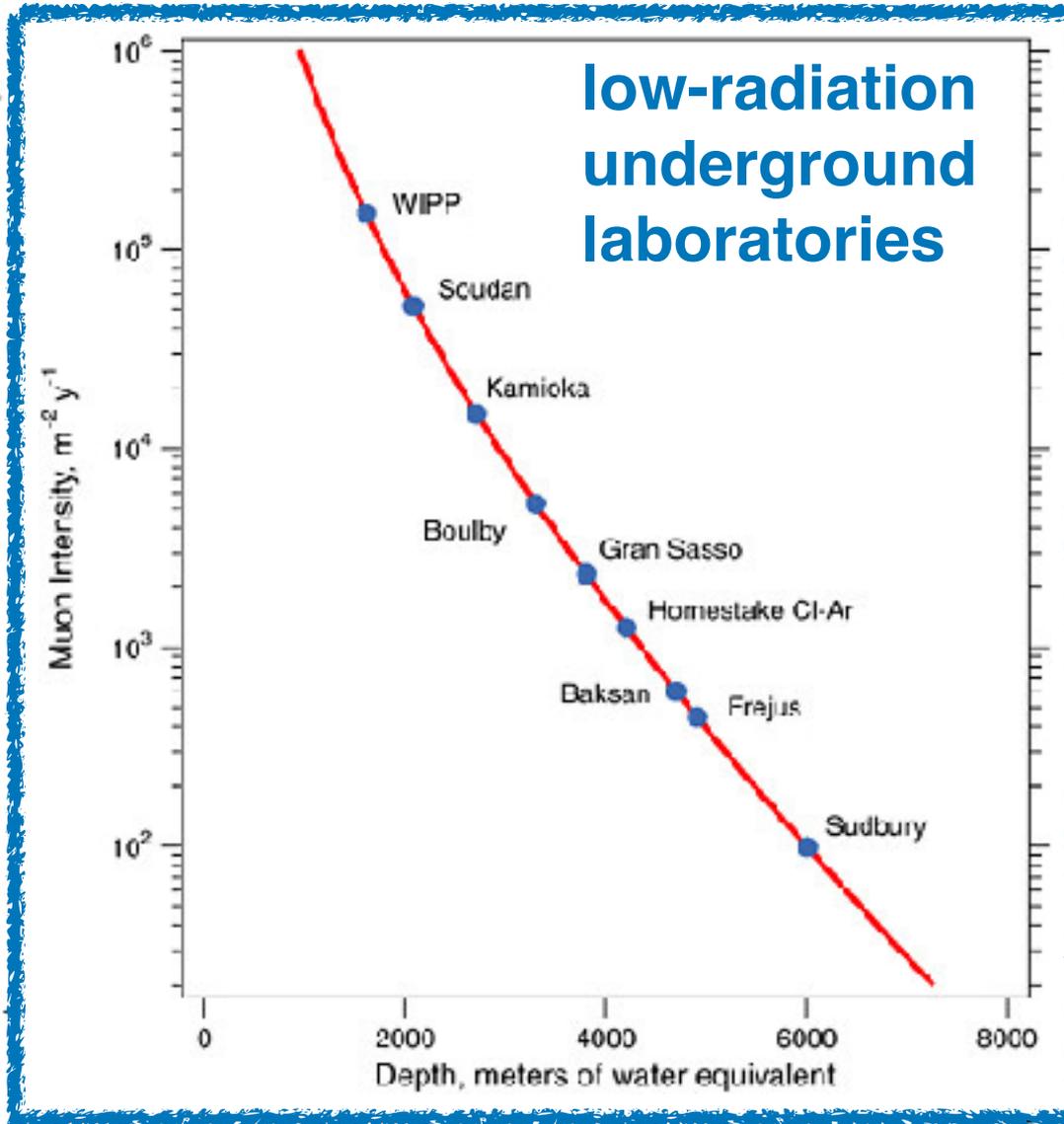
Die Werte ab 50m sind in der oberen Kurve  
noch einmal im 13% fachen Maßstabe  
der Hauptkurve gezeichnet



equivalent depth (of water)  
from top of the atmosphere

Fig. 6.

# Absorption in Lake Constance 1928



equivalent depth (of water)  
from top of the atmosphere



Hess

Steinke

Regener

**Three pioneers of Cosmic Ray research  
Regener demonstrates his balloon electrometer  
(Immenstaad/Lake Constance, August 1932).**

derung zu danken, die in den Bestrebungen von Ang...

**Kolhörster**  
**A new electrometer**

1) Oskar Taussig, "The First World Conference, London 1924", vgl. auch "Elektrotechnik", Zeitschrift des Elektrotechnischen Vereins in Wien, Heft 46, 1924.

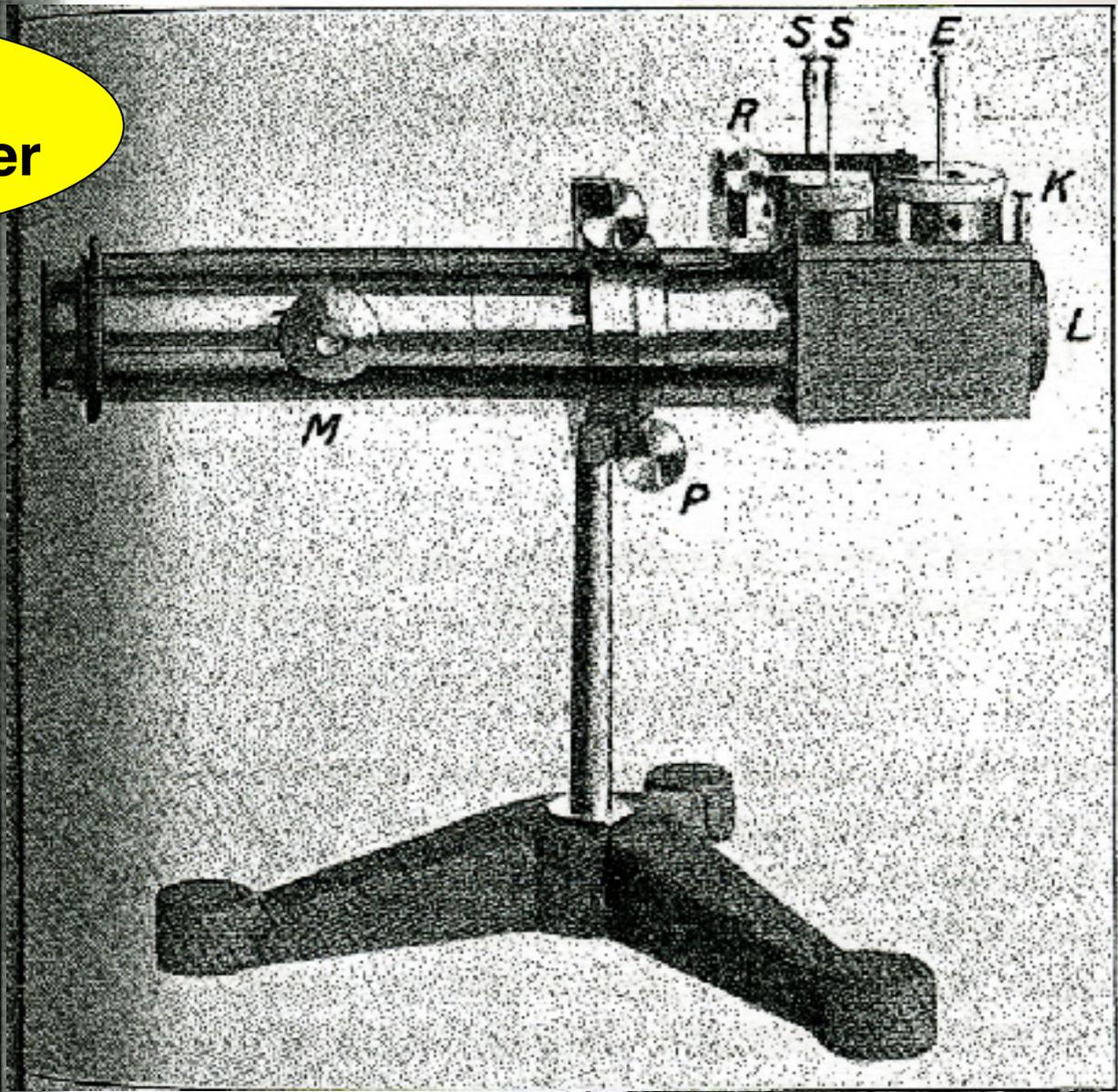
(Erschienen 28. August 1925)

**Ein neues Fadenelektrometer.**

Von Werner Kolhörster.

Zu Messungen der durchdringenden Strahlung hatte ich für meine neuen Strahlungsapparate ein Fadenelektrometer konstruiert<sup>1)</sup>, das ohne die bei derartigen Instrumenten notwendige Temperaturkompensation arbeitet. Da es sich auch für andere elektrostatische Messungen seiner Vorzüge und allgemeinen Verwendbarkeit halber als geeignet erwies, so seien hier einige Angaben über die Instrumente<sup>2)</sup> gemacht.

Prinzip: Als Gogenkraft gegen die elektrostatischen Abstoßungskräfte dient allein die Biegeelastizität der feinen Quarzfäden, die die Form vertikal stehender, frei tragender Schlingen haben und deren Enden in einigen Millimetern Abstand voneinander an einem Metallblech befestigt sind, das in den Isolator eingesetzt wird. Entsprechend den Ein- und Zweifadenelektrometern kann man Systeme mit einer oder zwei kongruenten Schlingen verwenden, die von einem Mikroskop mit Okularmikrometer am Scheitel der Schlingen abgelesen werden. Lädt man das System, so tritt keine merkliche Formänderung der Schlingen ein, diese bewegen sich vielmehr in der Horizont...



...leitung zu verändern. Eine feinere Änderung läßt sich durch Verschwenken der Schneiden erzielen, die um die längere Rechteckseite drehbar, mehr oder weniger den Fäden genähert



# Kohlhörster - balloon flight 13. May 1934

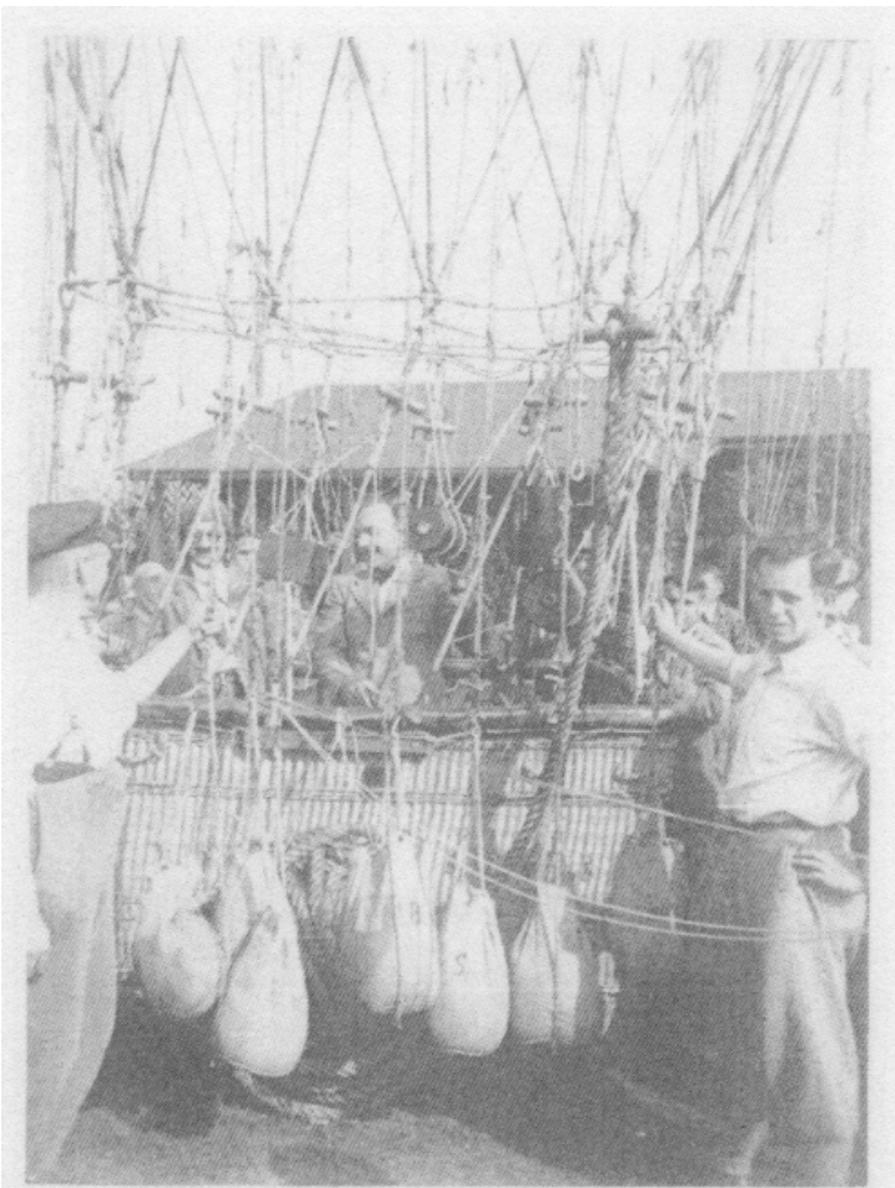
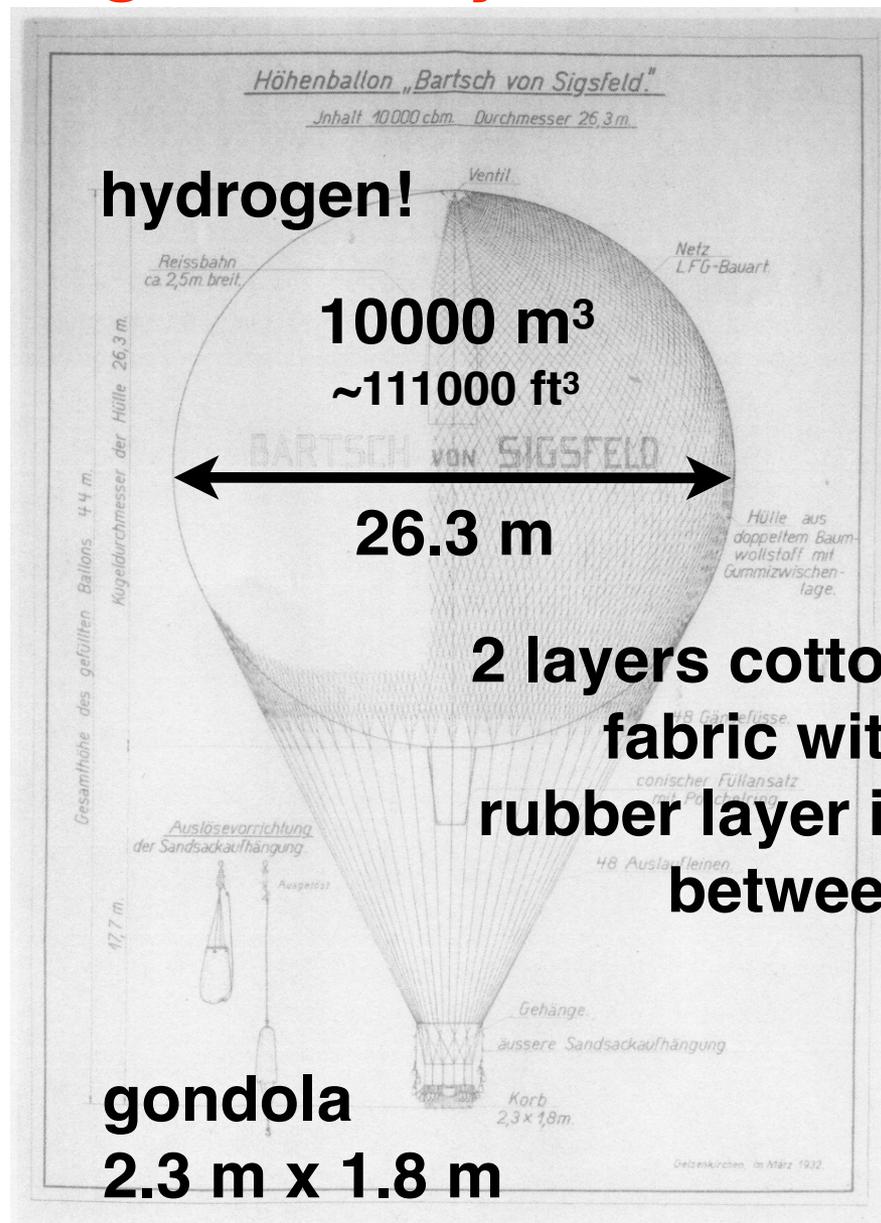


Abb.12 Vor dem Aufstieg



**gondola**  
**2.3 m x 1.8 m**

Abb.19 Höhenballon "Bartsch von Sigsfeld"  
Füllung am 13.5.34 rd. 4400 m<sup>3</sup>.

# Kohlhörster - balloon flight 13. May 1934



Abb. 17

**Dr. Schrenk**

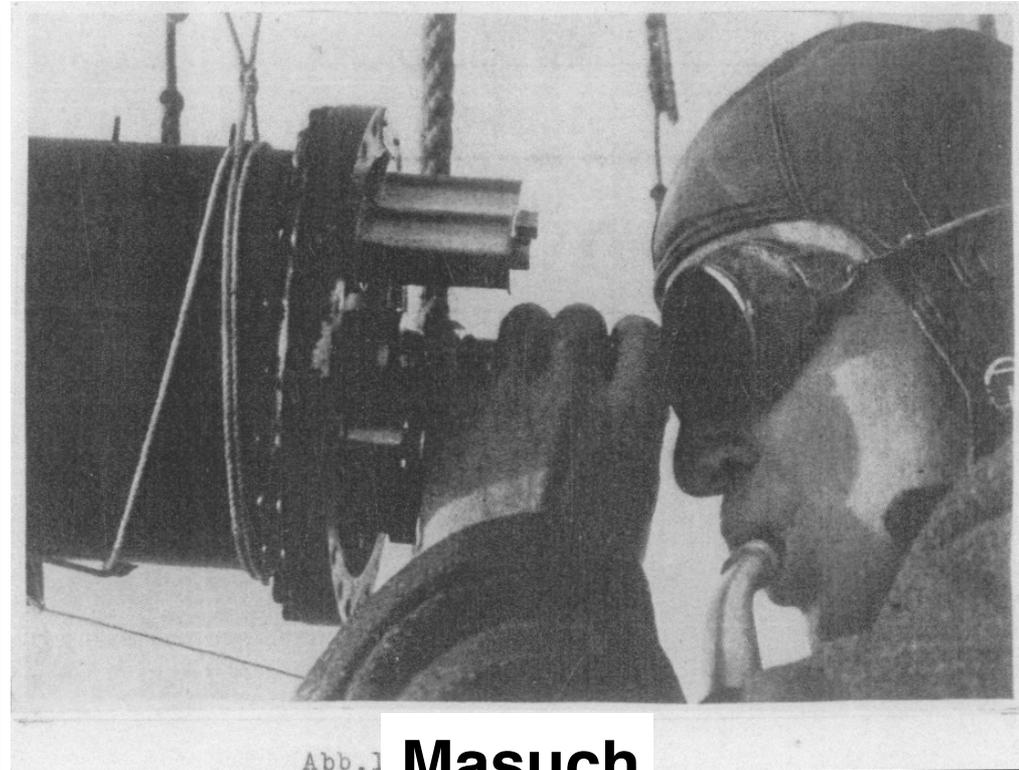


Abb. 1

**Masuch**

**Measurements of the cosmic-ray intensity (Höhenstrahlung) up to 12000 m**

# Das Wesen der Höhenstrahlung.

Von W. Bothe und W. Kolhörster.

Mit 8 Abbildungen. (Eingegangen am 18. Juni 1929.)

the nature of the „high-altitude radiation“

coincidence technique

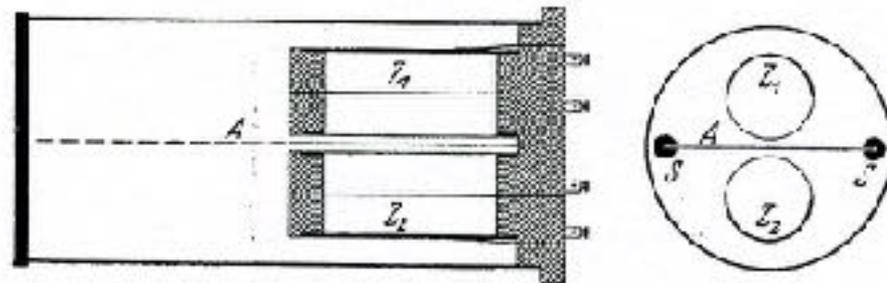


Fig. 2.

absorber

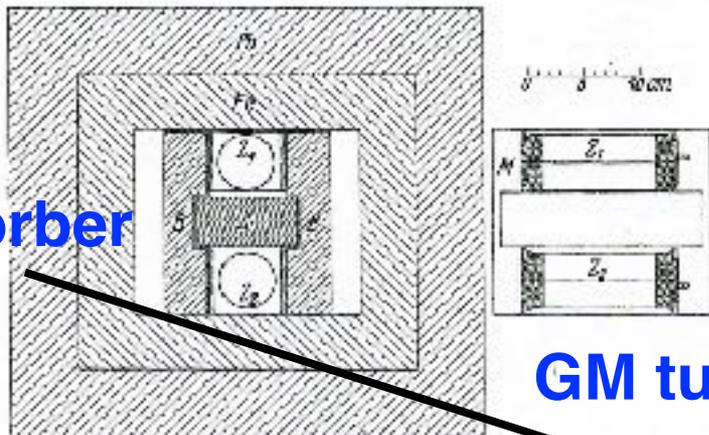


Fig. 1.

GM tube

coinc./min

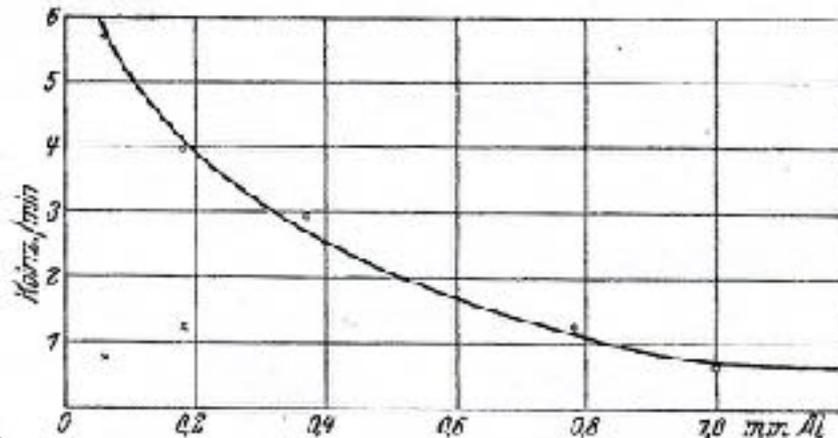


Fig. 3.

absorber thickness



W. Bothe  
Nobel Prize 1954

W. Bothe & W. Kolhörster, Z. f. Phys. 56 (1929) 751

innen 5 cm Durchmesser und 10 cm Länge; sie waren anfangs aus 1 mm starkem Messing, später aus 1 mm starkem Zink hergestellt und an den Enden mit Ebenitstopfen verschlossen, welche die zentralen Drähte trugen. Diese waren nach dem Verfahren von Geiger und Müller präpariert. Die Zählrohre waren mit trockener, kohlenwasserstoff- und emanationsfreier Luft von 4 bis 6 cm Hg-Druck gefüllt. Sie wurden durch ein Messinggestell M getragen, welches so eingerichtet war, daß Absorberschichten bis zu 45 mm Dicke zwischen die Zählrohre gebracht werden konnten. Seitlich waren die Rohre durch Bleiklötze BB geschützt; diese hatten Nuten, in welche der Absorber eingriff. Die Dicke dieser Seitenblenden war stets so bemessen, daß ein Strahlenteilchen, welches etwa durch Streuung um den Absorber herum aus dem einen Zählrohr in das andere gelangen

# Dreifachkoinzidenzen der Ultrastrahlung aus vertikaler Richtung in der Stratosphäre \*).

## I. Meßmethode und Ergebnisse.

Von Georg Pfozter in Stuttgart.

Mit 11 Abbildungen. (Eingegangen am 9. Juni 1936.)

Mit einer selbstaufzeichnenden Apparatur werden bei drei Registrierballonaufstiegen Dreifachkoinzidenzen der Ultrastrahlung aus vertikaler Richtung bis zu 10 mm Hg Luftdruck (29 km Höhe ü. M.) gemessen. Die Kurve der Zählrohrkoinzidenzen in Abhängigkeit vom Luftdruck zeigt ein Maximum bei 80 mm Hg und einen Buckel bei 300 mm Hg. Die Kurve kann gegen das Ende der Atmosphäre extrapoliert werden.

three-fold coincidences of the ultra rays from vertical direction in the stratosphere

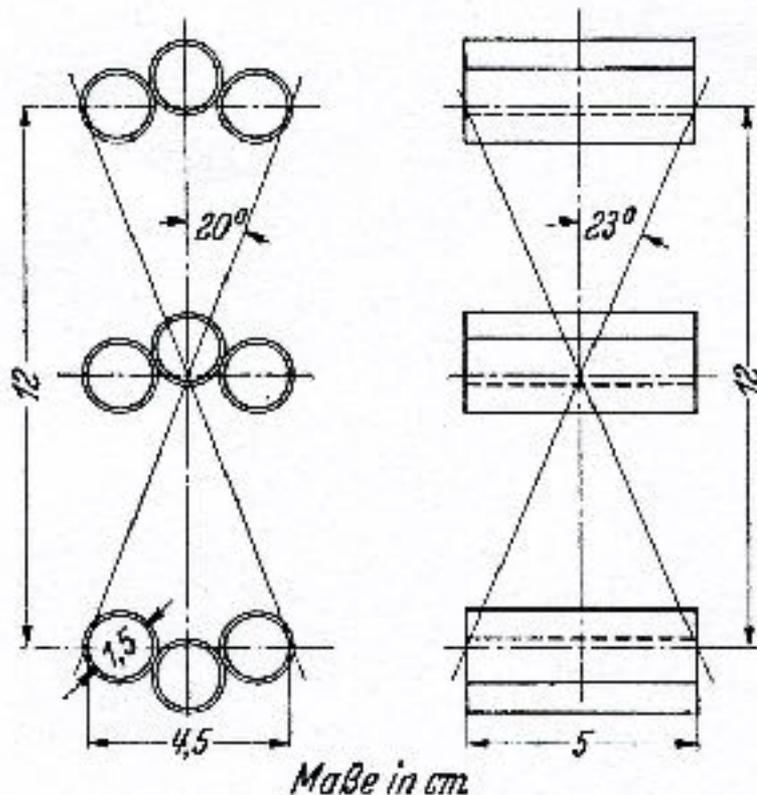


Fig. 1. Größenverhältnisse und Ausblendung der Koinzidenzanordnung.

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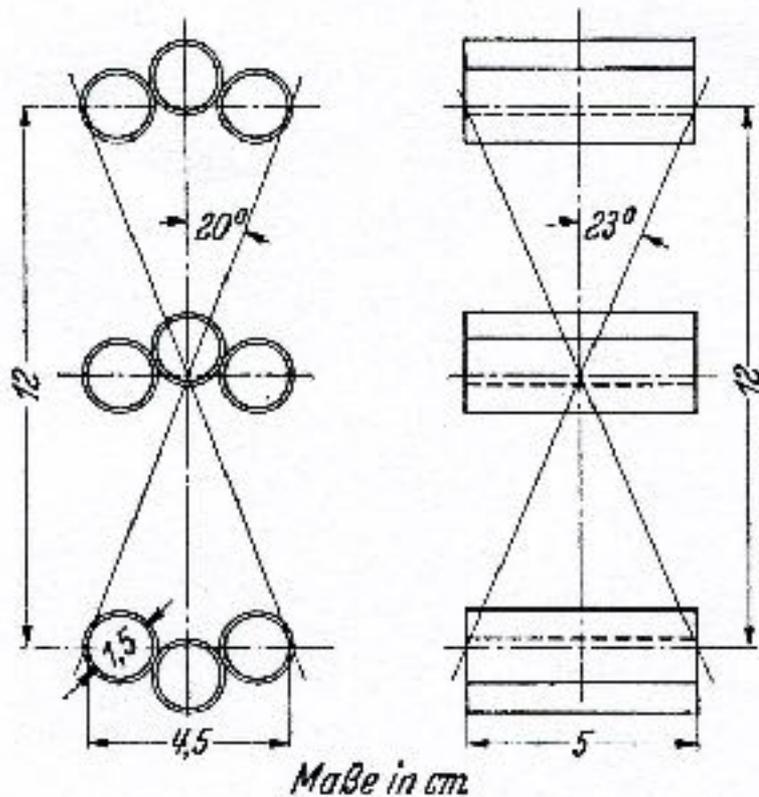


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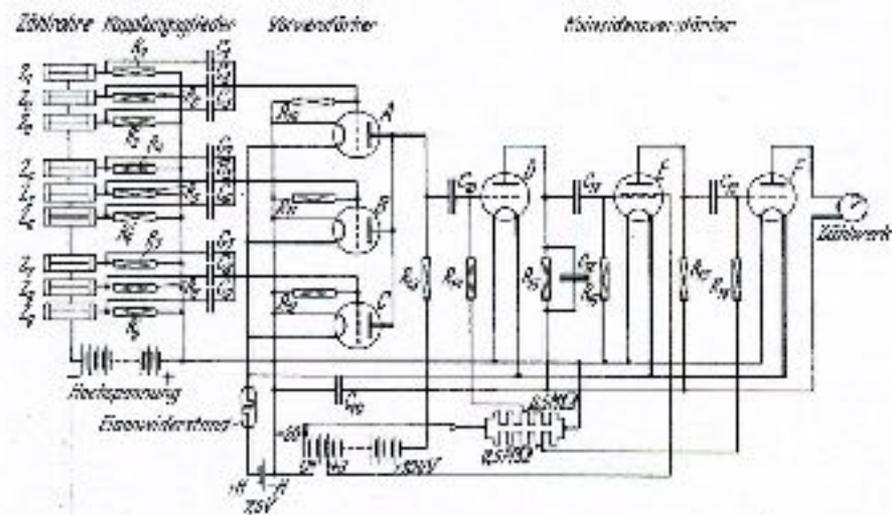


Fig. 2. Schaltenschema des Koinzidenzenverstärkers.

- |  |                                      |
|--|--------------------------------------|
| $R_1 - R_9 = 10^2 \text{ Ohm},$                        | $C_1 - C_5 = 25 \mu\text{F},$        |
| $R_{10} - R_{12} = 10^4 \text{ Ohm},$                  | $C_6 = 100 \mu\text{F},$             |
| $R_{13} = 0,5 \cdot 10^4 \text{ Ohm},$                 | $C_{11} - C_{12} = 500 \mu\text{F},$ |
| $R_{14} - R_{15} - R_{17} = 5 \cdot 10^4 \text{ Ohm},$ | $C_{13} = 1500 \mu\text{F},$         |
| $R_{16} - R_{18} = 5 \cdot 10^6 \text{ Ohm},$          | $C_{14} = 1 \mu\text{F},$            |

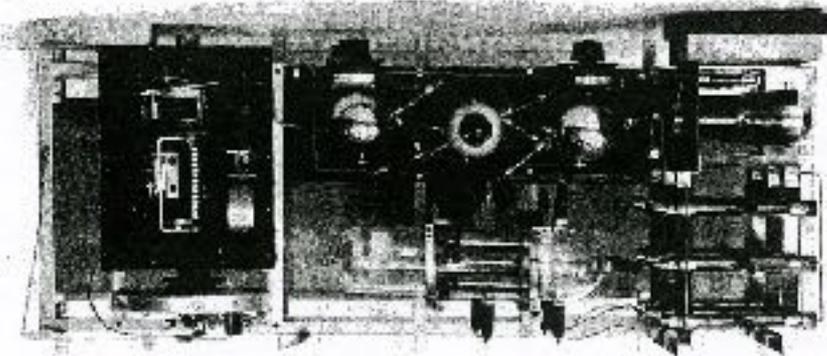
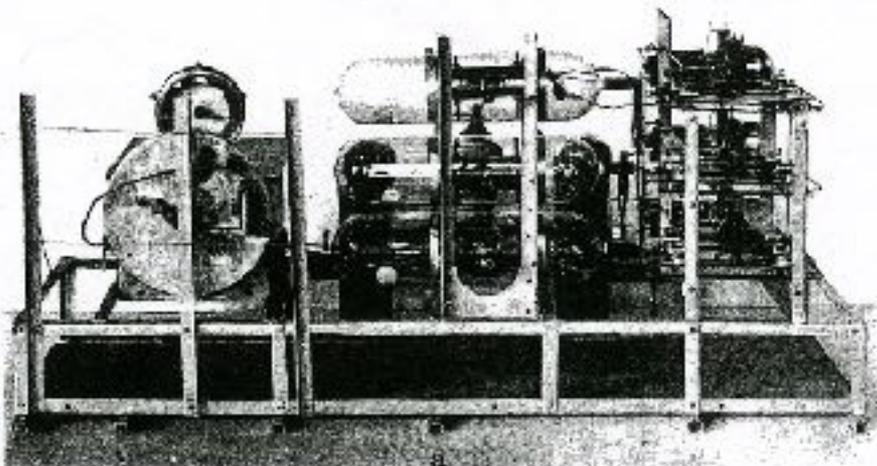
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b

Fig. 6. Außen der Registrierapparatur. a) Von der Seite b) von oben gesehen.

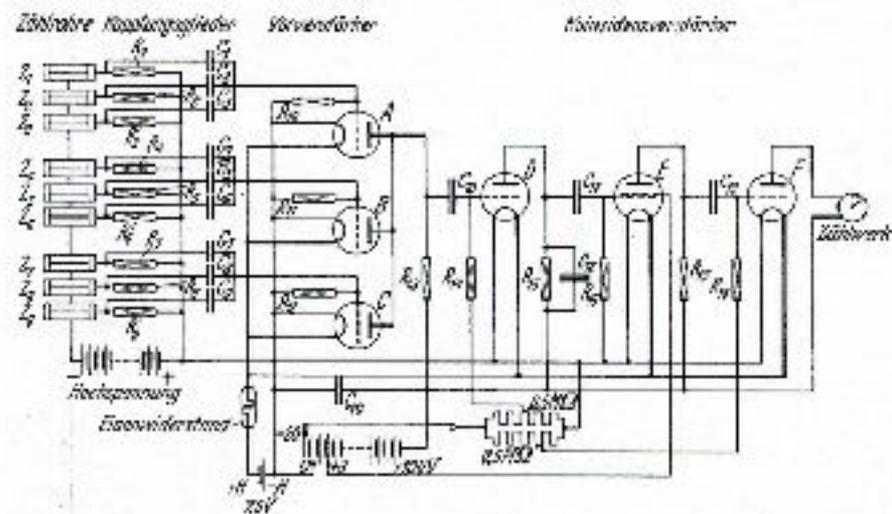


Fig. 2. Schaltschema des Koinzidenzverstärkers.

- $R_1 - R_9 = 10^7 \text{ Ohm}$ ,  $C_1 - C_4 = 25 \mu\text{F}$ ,
- $R_{10} - R_{12} = 10^6 \text{ Ohm}$ ,  $C_{11} = 100 \mu\text{F}$ ,
- $R_{13} = 0,5 \cdot 10^6 \text{ Ohm}$ ,  $C_{12} = 500 \mu\text{F}$ ,
- $R_{14} - R_{15} - R_{17} = 5 \cdot 10^6 \text{ Ohm}$ ,  $C_{13} = 1500 \mu\text{F}$ ,
- $R_{16} - R_{18} = 5 \cdot 10^6 \text{ Ohm}$ ,  $C_{14} = 1 \mu\text{F}$ .

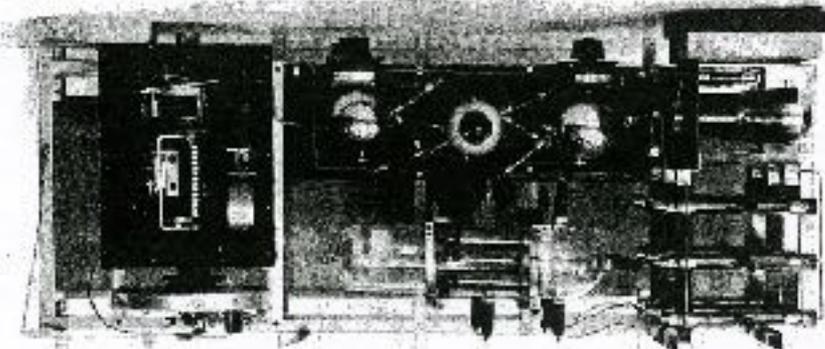
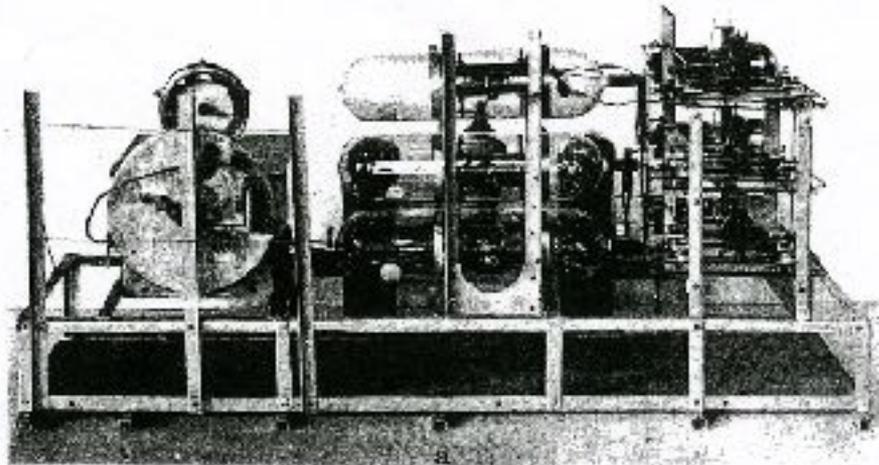
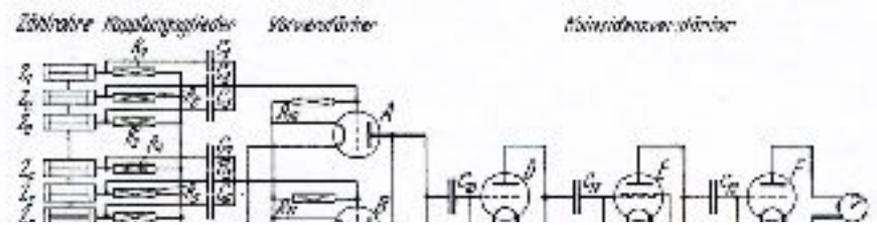
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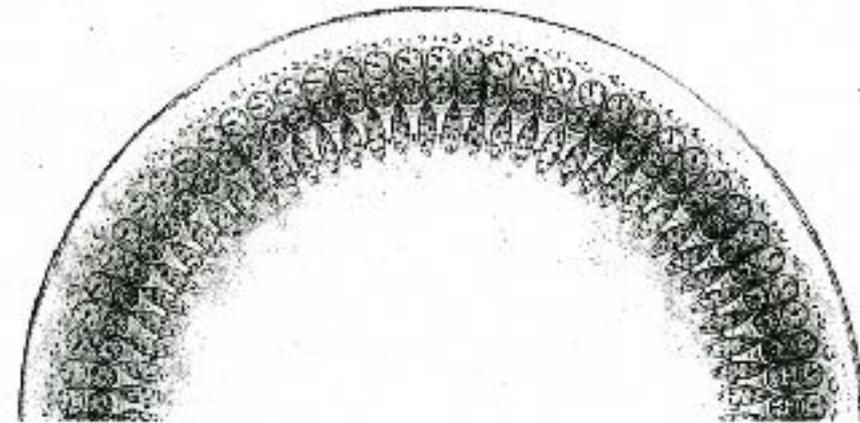
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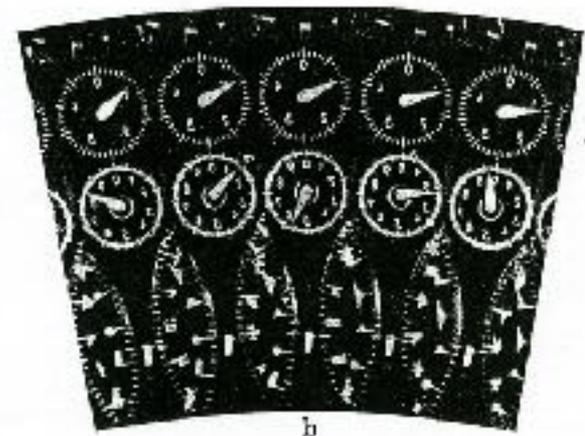


b

Fig. 6. Außen der Registrierapparatur. a) Von der Seite b) von oben gesehen.



a



b

Fig. 4. a) Aufsteigplatte (nach Größe, Fülle); b) Vergrößerter Ausschnitt.

3) Die Firma Gebr. Junghans, Schramberg, hat uns freundlicherweise diese schönen Zählwerke hergestellt.

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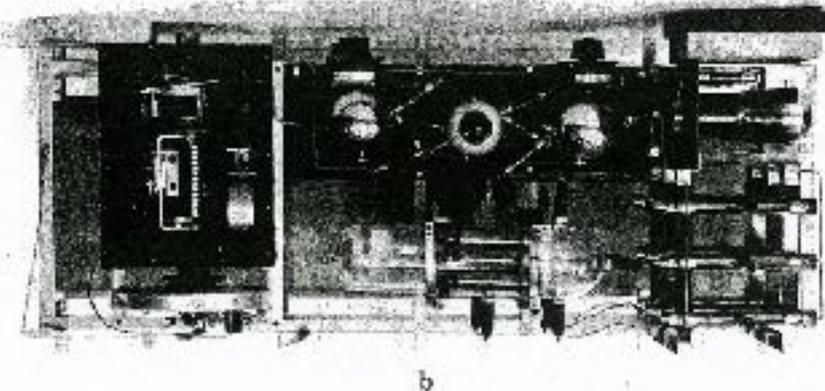
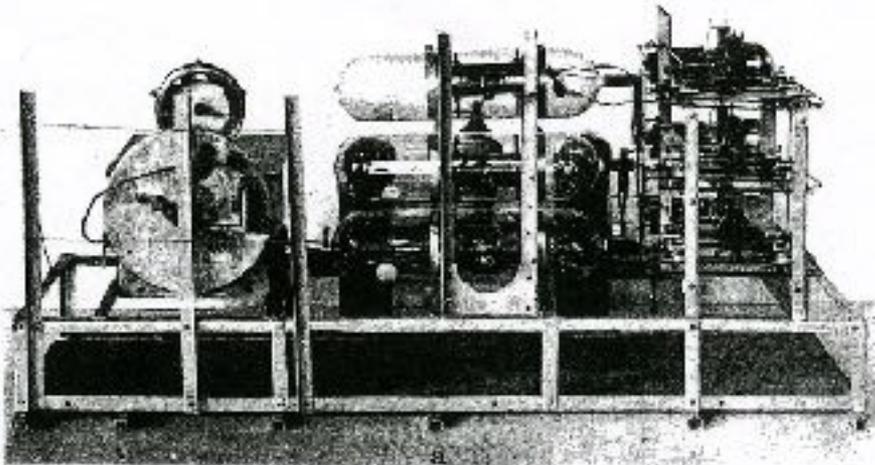


Fig. 6. Außen der Registrierapparatur. a) Von der Seite b) von oben gesehen.



Fig. 5. Launching of a balloon train from the courtyard of the institute.

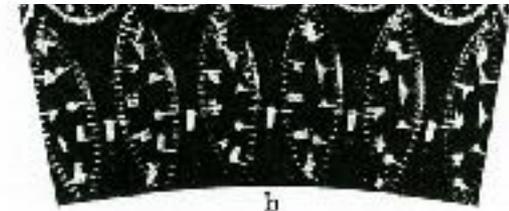


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# of coincidences in 4 min

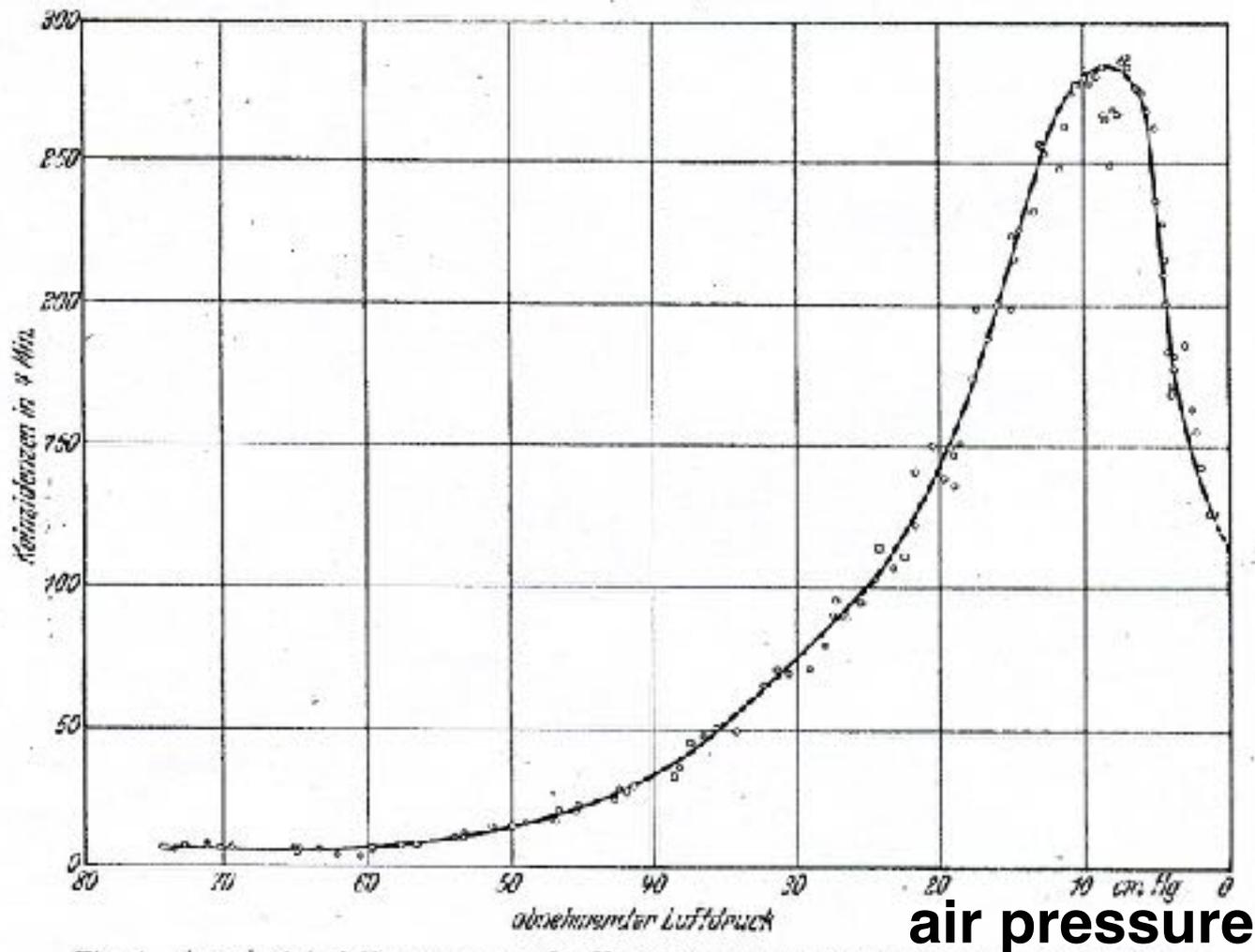


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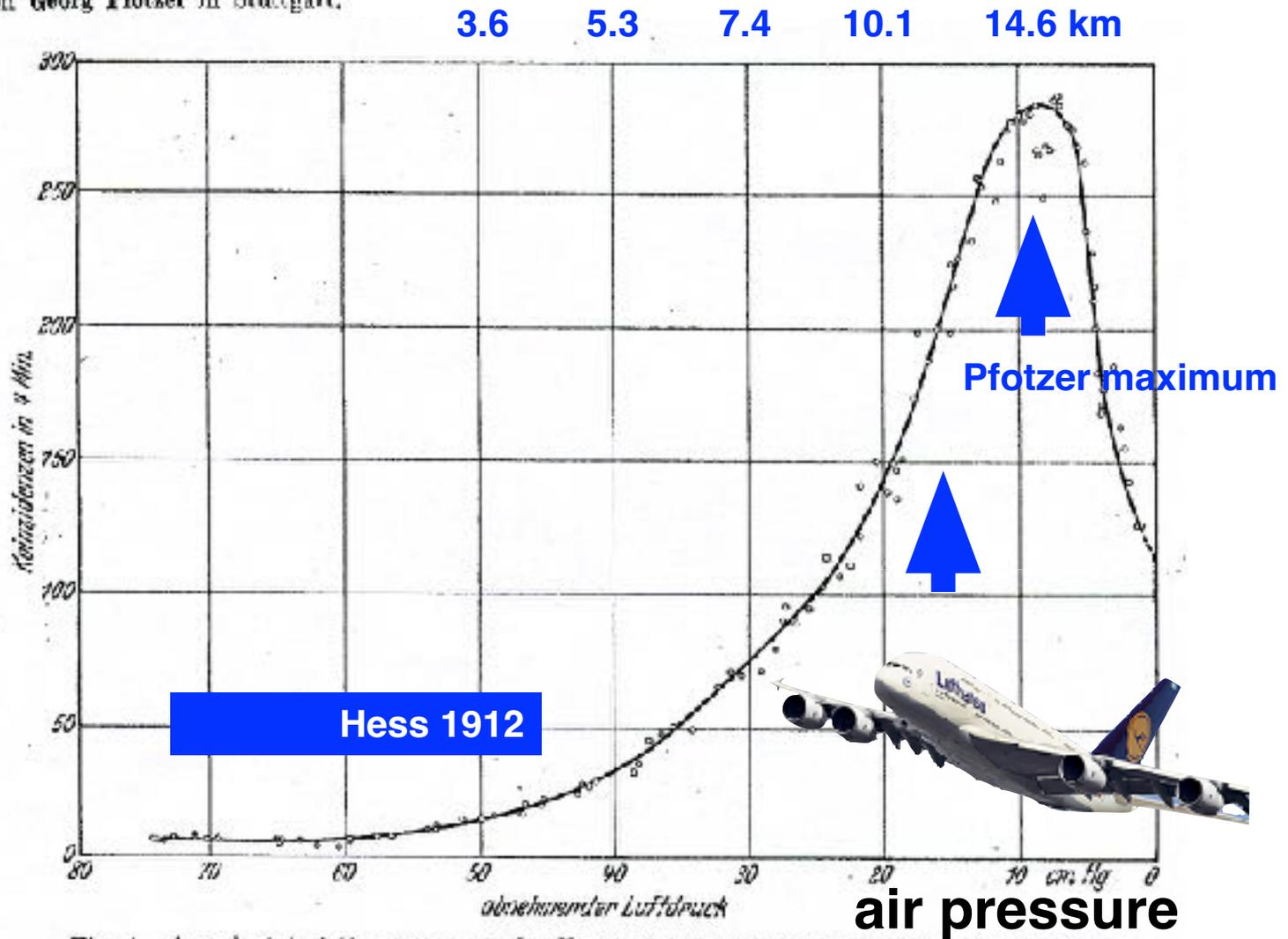


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# Latitude effect

## Letters to the Editor

[The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, nor to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. No notice is taken of anonymous communications.]

### Latitude Effect of Cosmic Radiation

ON the expedition organised by the Deutscher und Oesterreichischer Alpenverein in 1932 to the Andes of Peru, observations of cosmic rays were made at several heights up to 6,100m. and during the sea-voyage. From Bremen to Peru one apparatus worked during March and April 1932 on board the M.S. *Erfurt* of the Norddeutscher Lloyd line. On the return voyage in January and February 1933, three apparatuses were in full action from Peru through the Strait of Magellan to Hamburg on board the M.S. *Isis* of the Hamburg-Amerika line. The self-recording electrometers were constructed by Prof. E. Regener on the same principle as those used for his researches in Lake Constance<sup>1</sup> and in the upper atmosphere<sup>2</sup>. The electrometer wire is inside an ionisation chamber of 16 cm. diameter with 'deltametal' walls of 1 cm. thickness. The position of the wire is photographed every half-hour on a fixed photographic plate.

Instrument No. 1 was filled with carbon dioxide at 9.7 atmospheres pressure and 16° C. With a radium capsule, I found the temperature effect on ionisation to be + 0.13 per cent for every + 1° C. difference. The correction for barometric pressure was 0.29 per cent per millimetre of mercury. All data were reduced to 16° C. and 760 mm. pressure. The ionisation due to radioactivity in the chamber itself was allowed for as 0.8 volts per hour as found on the bottom of Lake Constance at a depth of 250 m. Eight hemispherical shells of iron were fitted round the chamber. The combined thickness of this iron wall was 10 cm.

In Fig. 1 are recorded the data of apparatus No. 1, the iron case of which was open on the upper side. The graph shows the intensity of cosmic radiation in volts per hour for different geomagnetic latitudes on the voyage from the Strait of Magellan to Hamburg. The geographical position of the geomagnetic north pole was taken to be 78° 32' N. and 69° 08' W. Each point of the curve corresponds to an average of a twenty hours' registration. The points give a smooth curve which shows the accuracy of the recording method employed. The intensity increases by about 12 per cent when going from the equatorial region to 55° N. geomagnetic latitude.

Apparatus No. 2 was wholly encased in the iron shell. Apparatus No. 3 worked without any iron shell. Every instrument shows substantially the same effect.

In general, the curves agree with the observations of Clay<sup>3</sup> and with those of A. H. Compton<sup>4</sup> made at about the same time. It is very interesting that the northern and southern parts of the curve are not

symmetrical with respect to either the geomagnetic or the geographical equator. Considering the accuracy of our uninterrupted registration, this result is quite trustworthy.

From the fact that a latitude effect of 12 per cent of the radiation exists, it must be concluded that this part of the radiation consists of corpuscles before entering the earth's atmosphere. For the magnitude of this part of the radiation, reference should be made to the analysis of the components of cosmic rays by Regener<sup>2</sup> and Lenz<sup>5</sup>.

A more detailed report of these observations and of the researches in the Andes will be published in the *Zeitschrift für Physik*.

H. HOERLIN.

Physikalisches Institut  
der Technischen Hochschule,  
Stuttgart. June 8.

- <sup>1</sup> Regener, E., *Z. Phys.*, **74**, 433; 1932.
- <sup>2</sup> Regener, E., *Phys. Z.*, **34**, 306; 1933.
- <sup>3</sup> Clay, J., *Naturwiss.*, **20**, 687; 1932.
- <sup>4</sup> Compton, A. H., *Phys. Rev.*, **43**, 387; 1933.
- <sup>5</sup> Lenz, E., *Z. Phys.*; in the press.

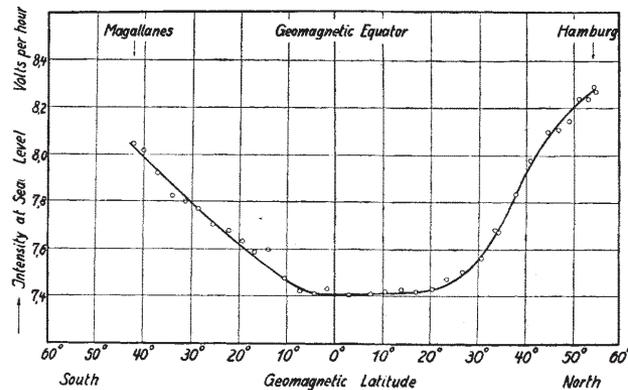


FIG. 1.

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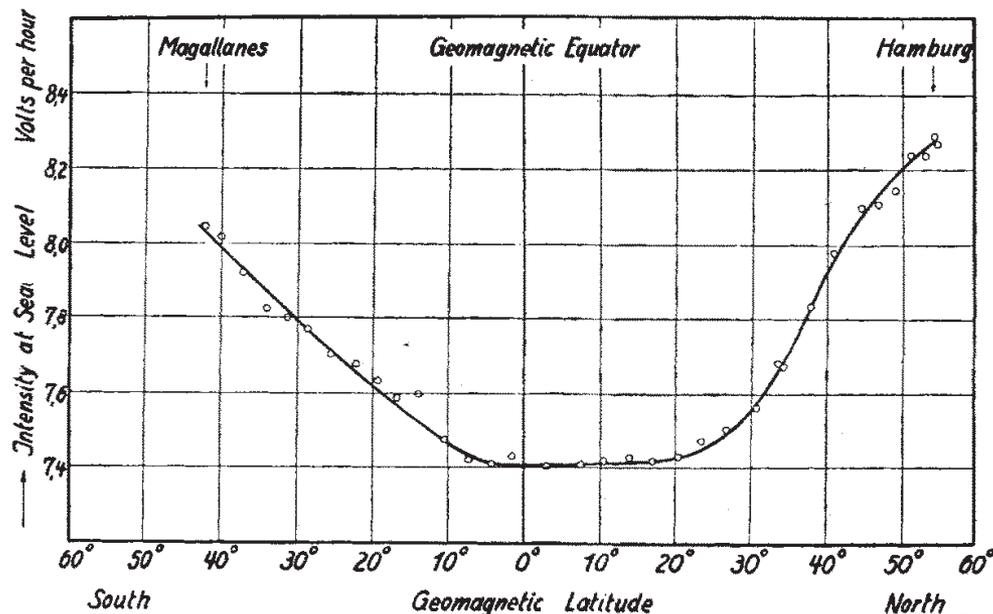


FIG. 1.

# Clay: Latitude Effect

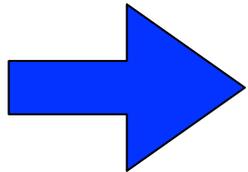
RESULTS OF THE DUTCH COSMIC RAY EXPEDITION 1933

II. THE MAGNETIC LATITUDE EFFECT OF COSMIC RAYS  
A MAGNETIC LONGITUDE EFFECT

by J. CLAY, P. M. VAN ALPHEN and C. G. 'T HOOFT

Natuurkundig Laboratorium, Amsterdam

journey from Holland to Java  
intensity varies with latitude



cosmic rays are  
charged particles

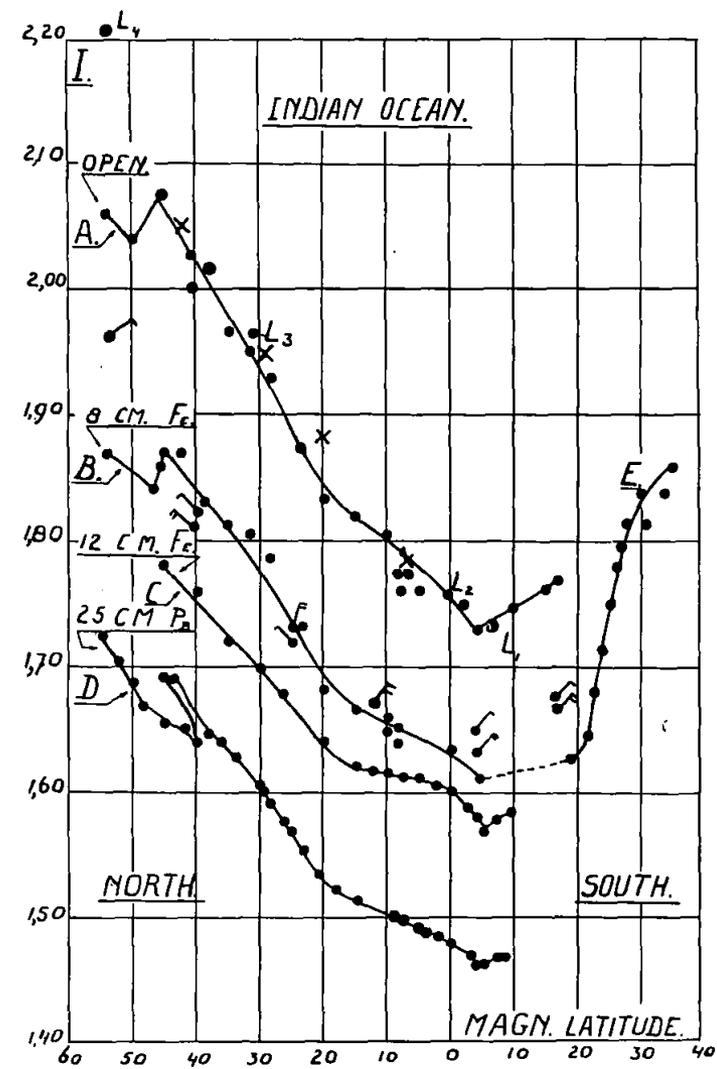


Fig. 1. Records of the variation of Cosmic Radiation with latitude on two different routes under different shielding with different instruments

- × ..... × results with instrument *D* open (Amsterdam—Batavia)
- ( $L_1, L_2, L_3, L_4$ ) results with instrument  $D_1$  open (Batavia—Amsterdam)
- • Results 1928 and 1929.

# Compton: World-wide survey of intensity of radiation

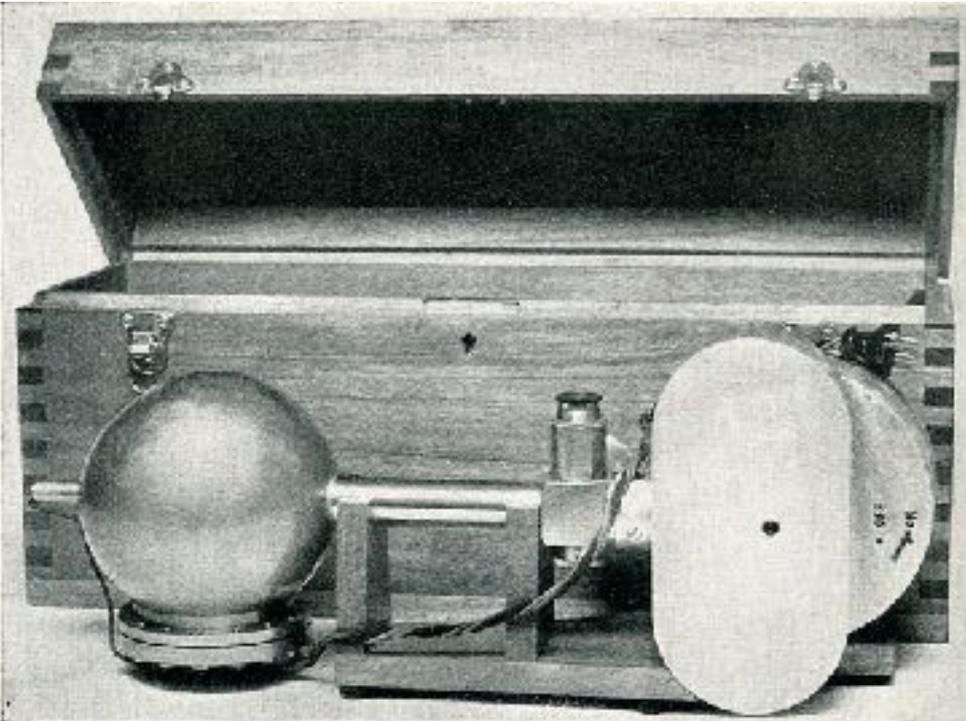


Fig. 24. The instrument used in this survey is usually shielded with lead and is placed in the box when used in most airplane flights.

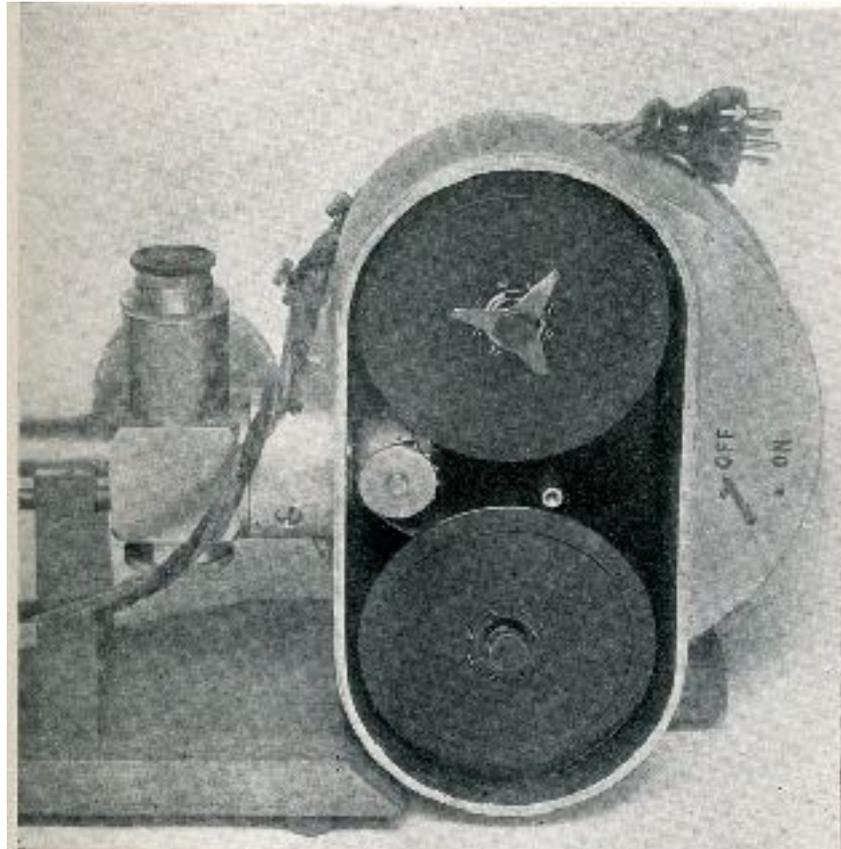


Fig. 25. The camera will take a one-hundred-foot reel of 35 mm motion picture film which is driven at a constant rate past the slit by a power clock. Changeable gears allow various rates of film speeds to be used, depending on the expected ionization.

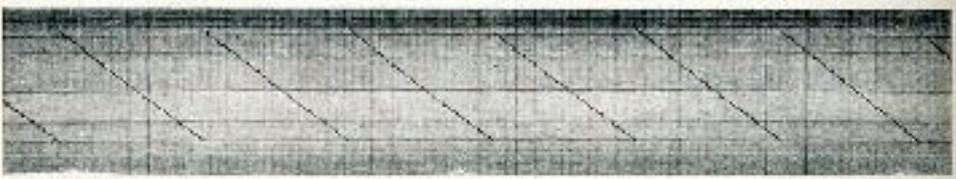


Fig. 27. Showing the type of record obtained at sea level in this world survey. Two of the horizontal lines give barometric and temperature records.

~1930

# THE PHYSICAL REVIEW

A Journal of Experimental and Theoretical Physics

Vol. 43, No. 6

MARCH 15, 1933

SECOND SERIES

## A Geographic Study of Cosmic Rays

ARVID H. COOMBS, *University of Chicago*

(Received January 30, 1933)

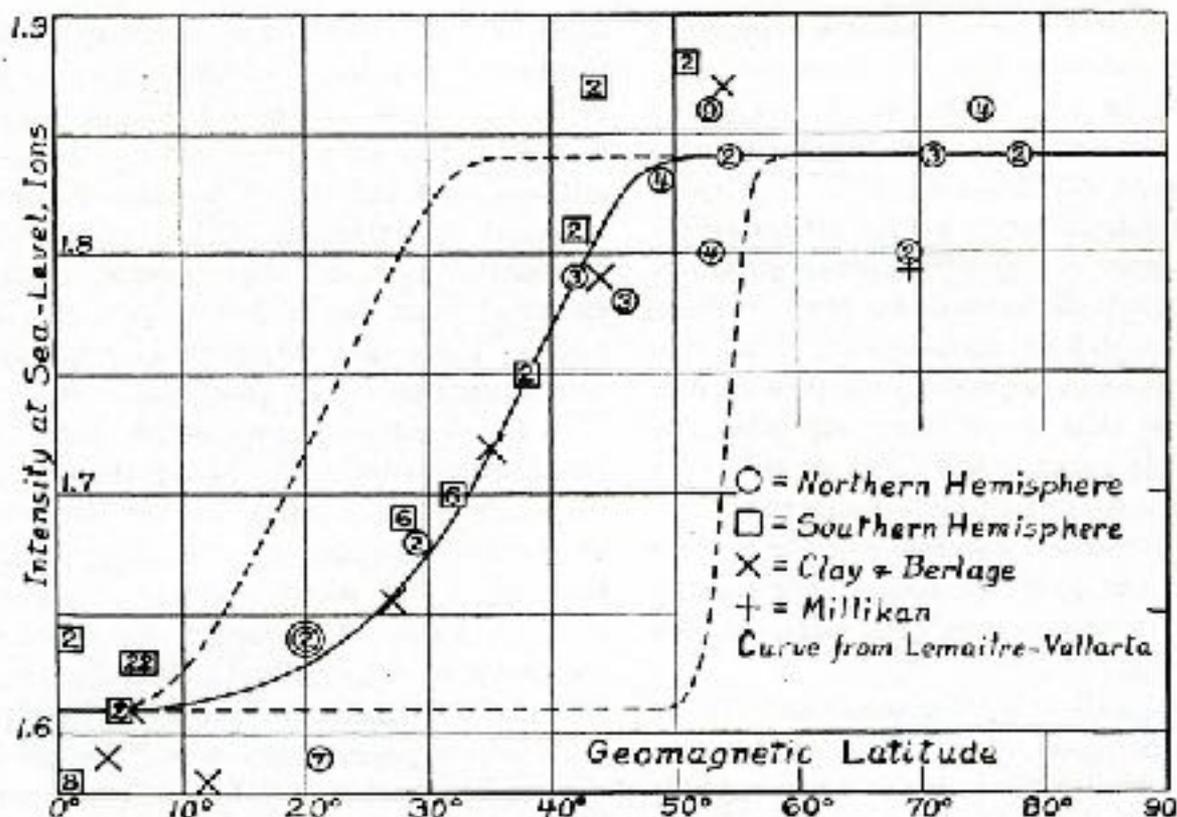


FIG. 7. Intensity vs. geomagnetic latitude at sea level, including data of Clay and Millikan.

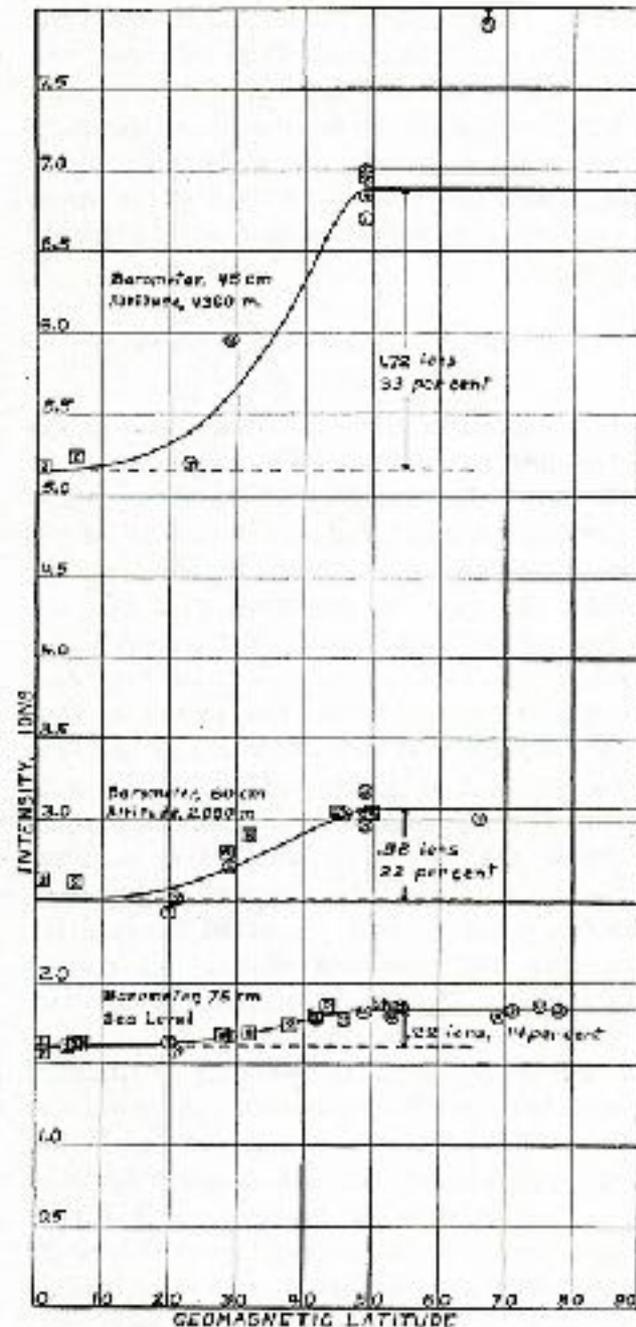


FIG. 6. Intensity vs. geomagnetic latitude for different elevations.

# 1931-34 A.H. Compton 12 expeditions → ~100 locations

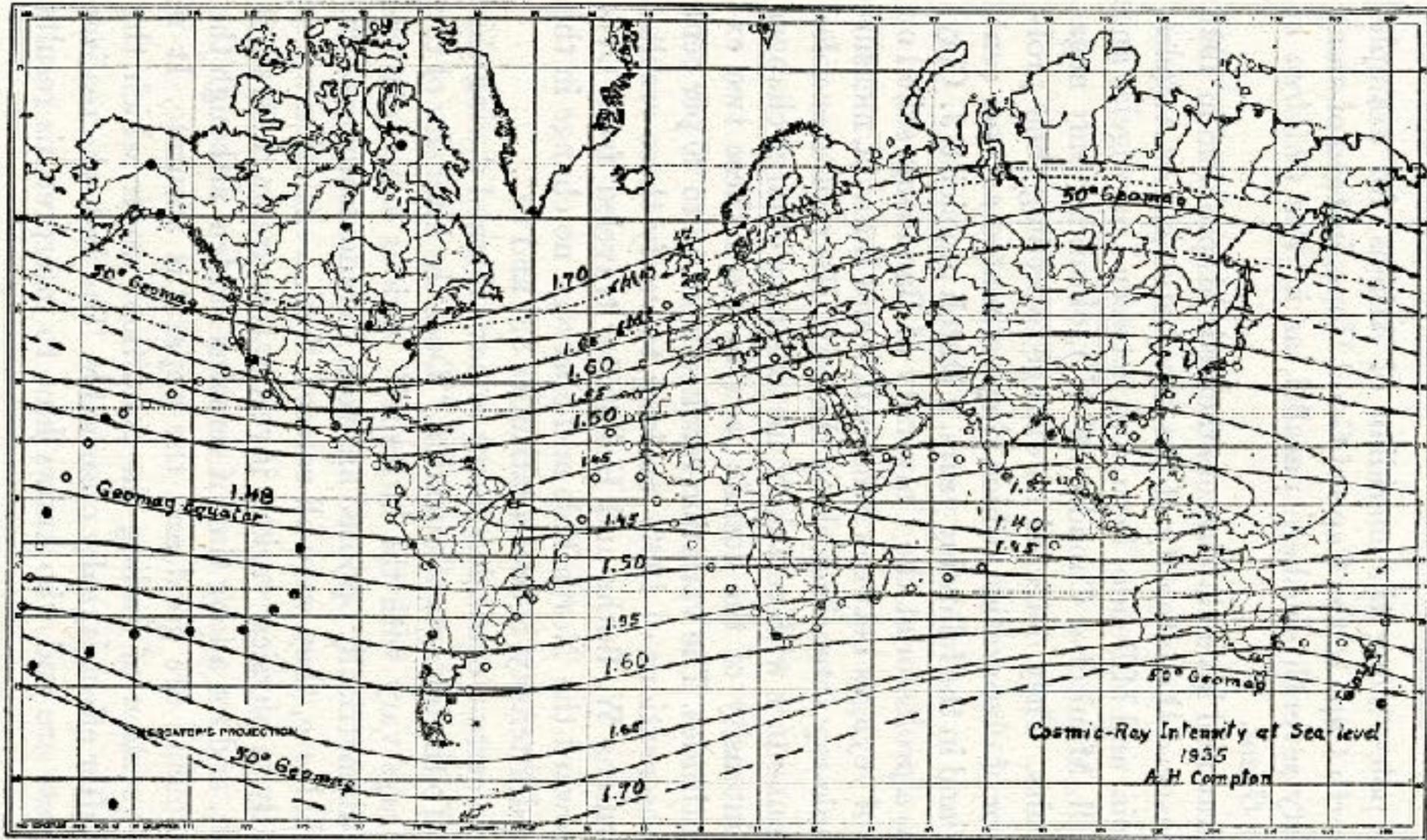


FIG. 6.—Compton's world map of isocosms. Note the parallelism of these lines of equal cosmic-ray intensity and the dotted curves of geomagnetic latitude ( $50^{\circ}$  N. and S.).



cosmic rays are charged particles

# 1931-34 A.H. Compton 12 expeditions → ~100 locations

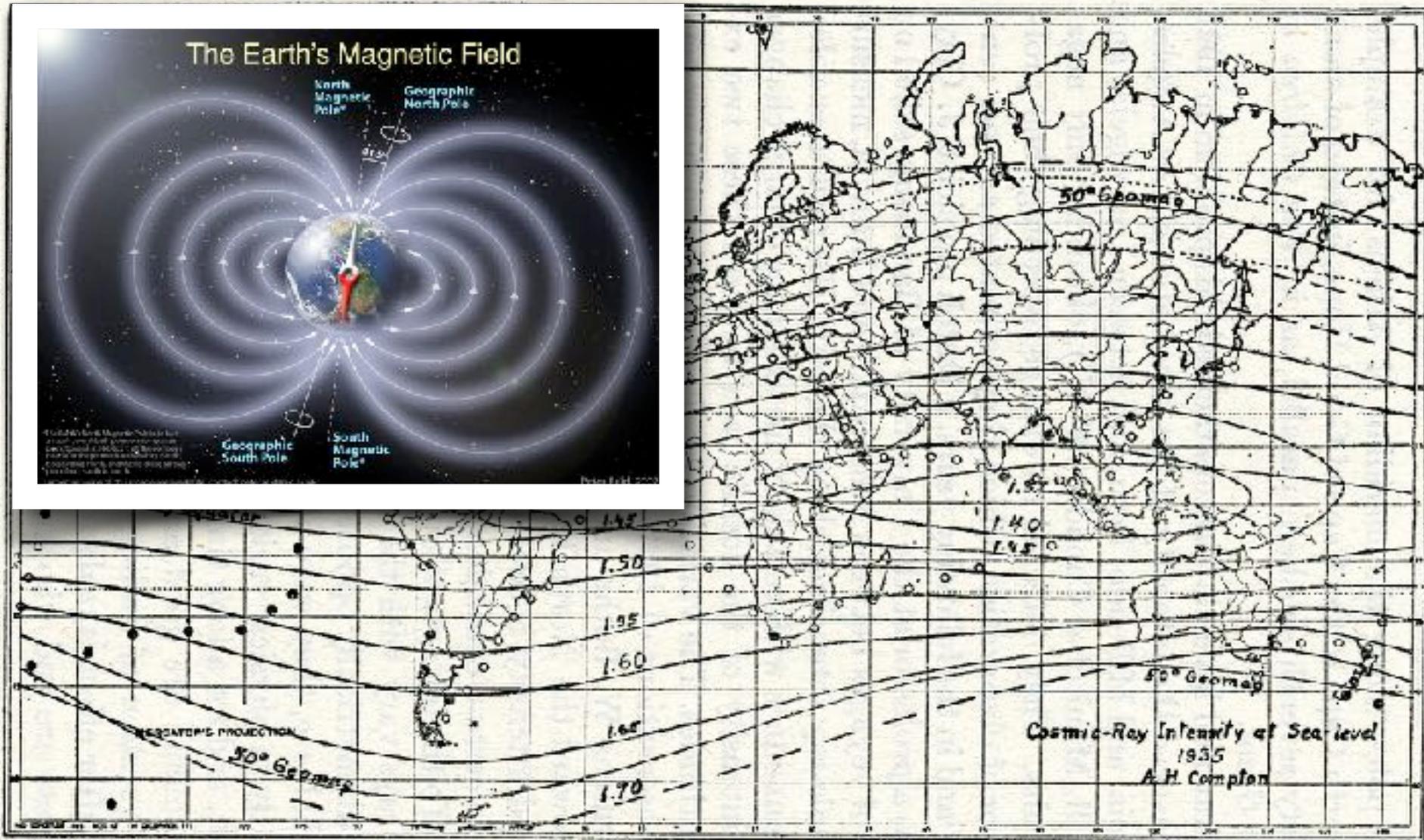


FIG. 6.—Compton's world map of isocosms. Note the parallelism of these lines of equal cosmic-ray intensity and the dotted curves of geomagnetic latitude (50° N. and S.).



cosmic rays are charged particles

# ~1937 East-West Effect of Cosmic-Ray Intensity

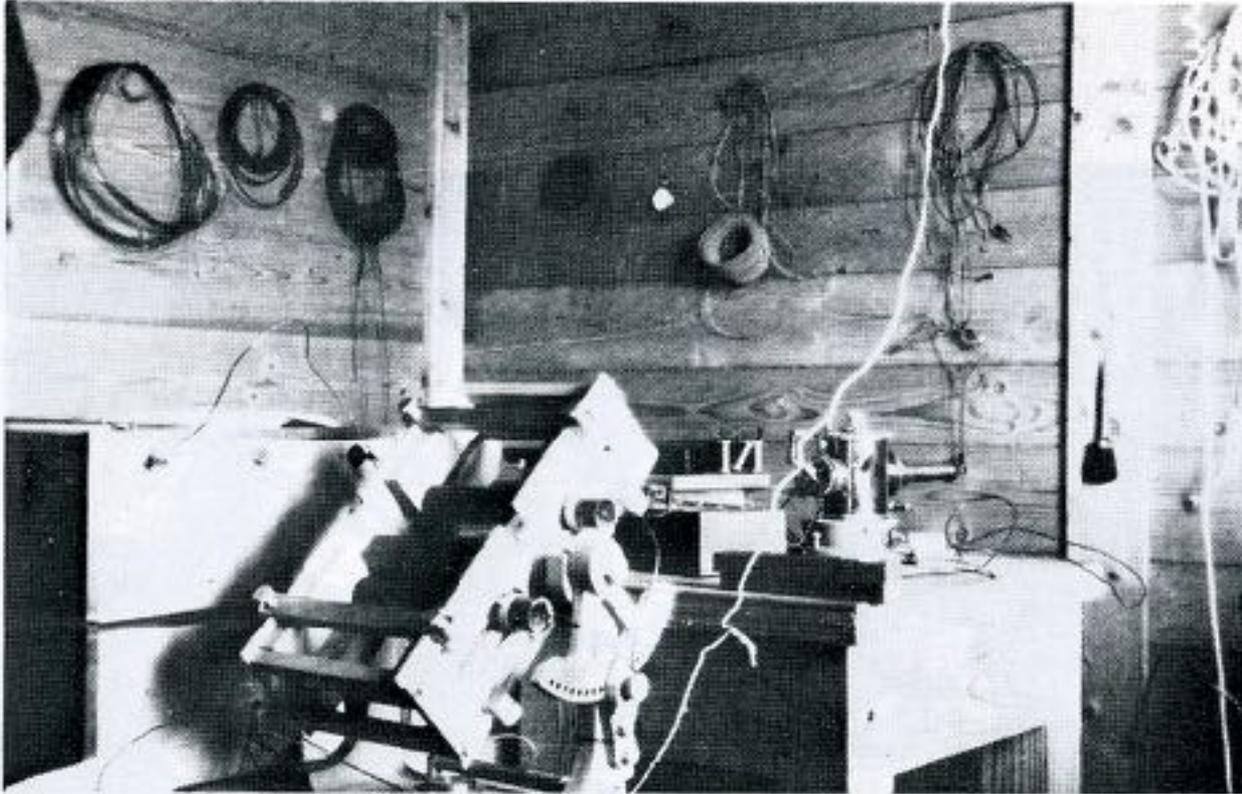


Fig. 14. The equipment for the E-W experiment.

**Rossi and others**

**higher intensity from the west**

**➡ cosmic rays are mostly positively charged**

~1930 „elementary particles“:    charged    neutral

Rutherford    (1919)    **p**    **n**    (1932)    Chadwick

Thomson    (1897)    **e<sup>-</sup>**    **γ**    (1905/26)    Einstein



~1930 „elementary particles“: charged neutral

Rutherford (1919) **p** **n** (1932) Chadwick

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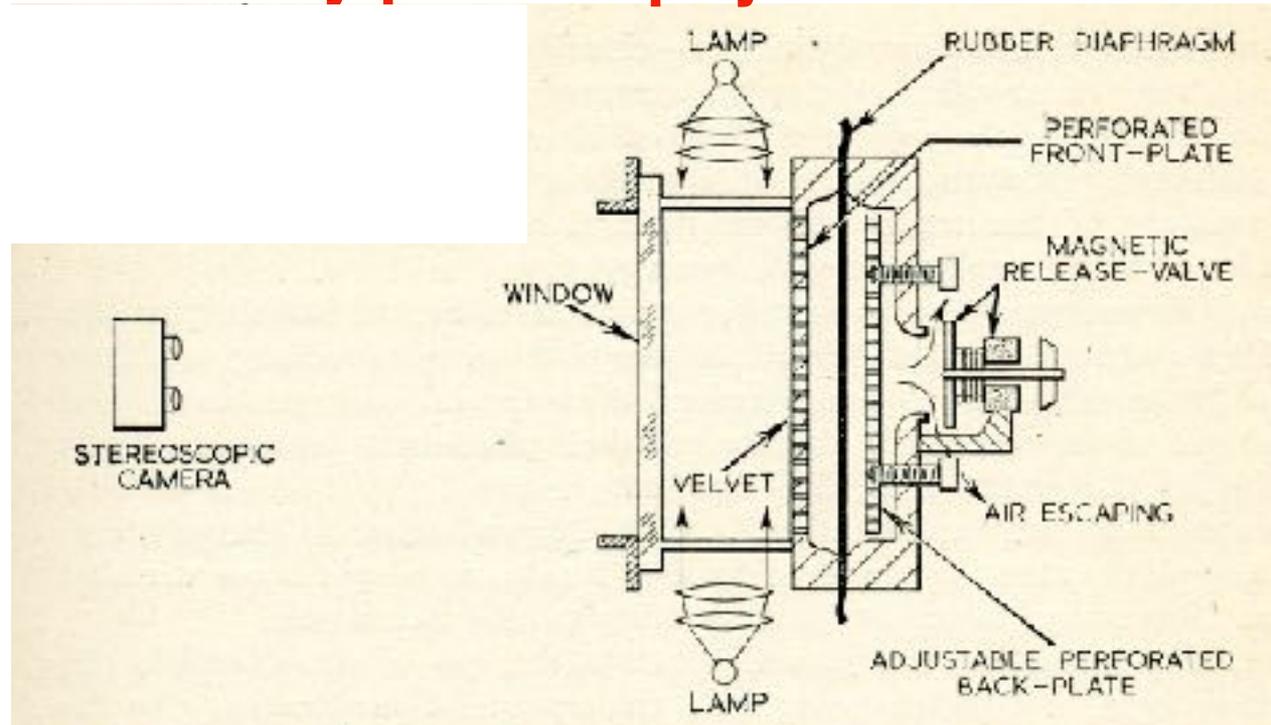
## Discovery of new particles in cosmic rays

~1930 – 1950

birth of elementary particle physics



cloud chamber  
C.T.R. Wilson  
Nobel Prize 1927



## The Positive Electron $e^+$

CARL D. ANDERSON, *California Institute of Technology, Pasadena, California*

(Received February 28, 1933)

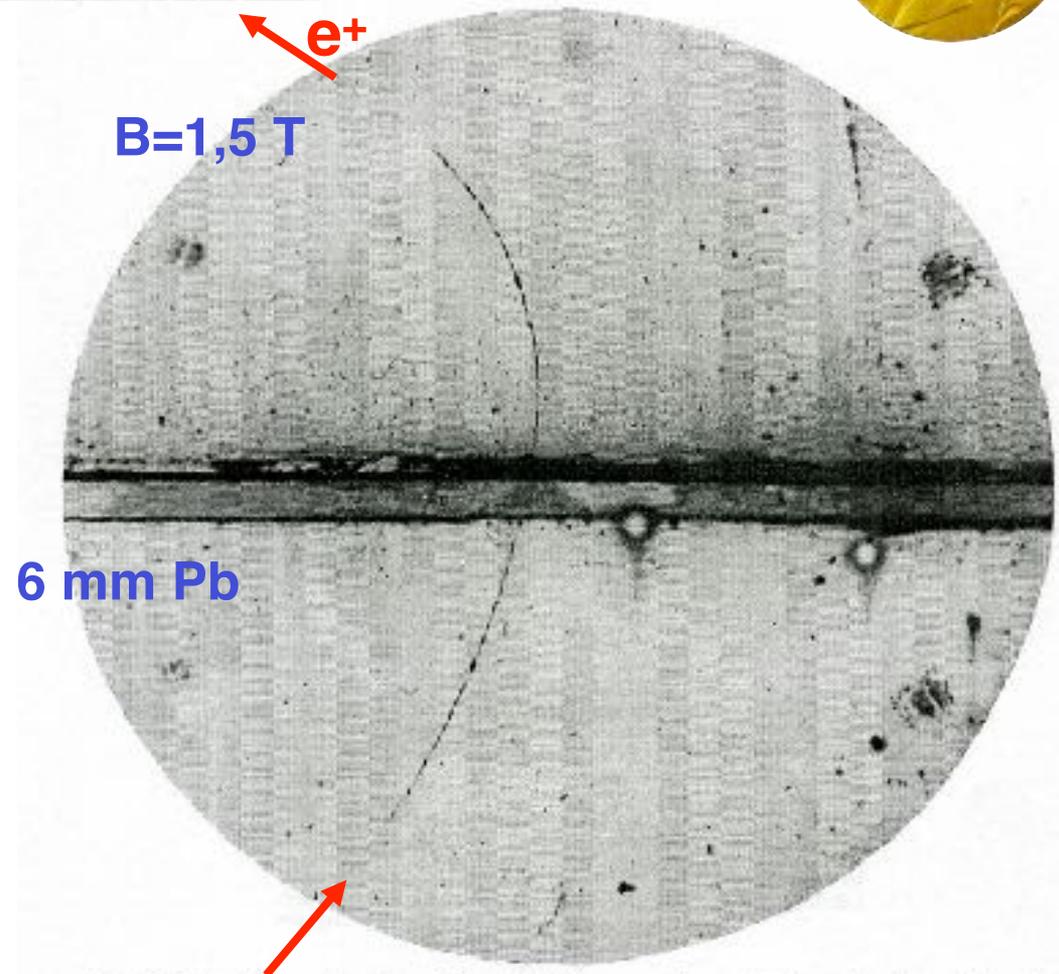
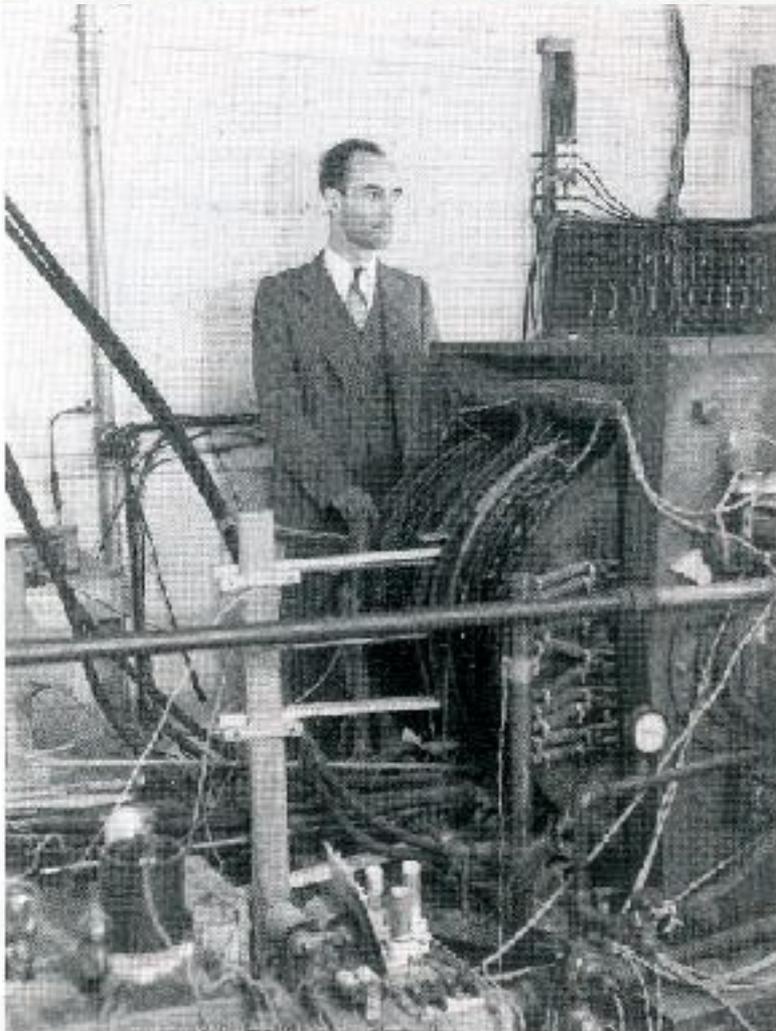
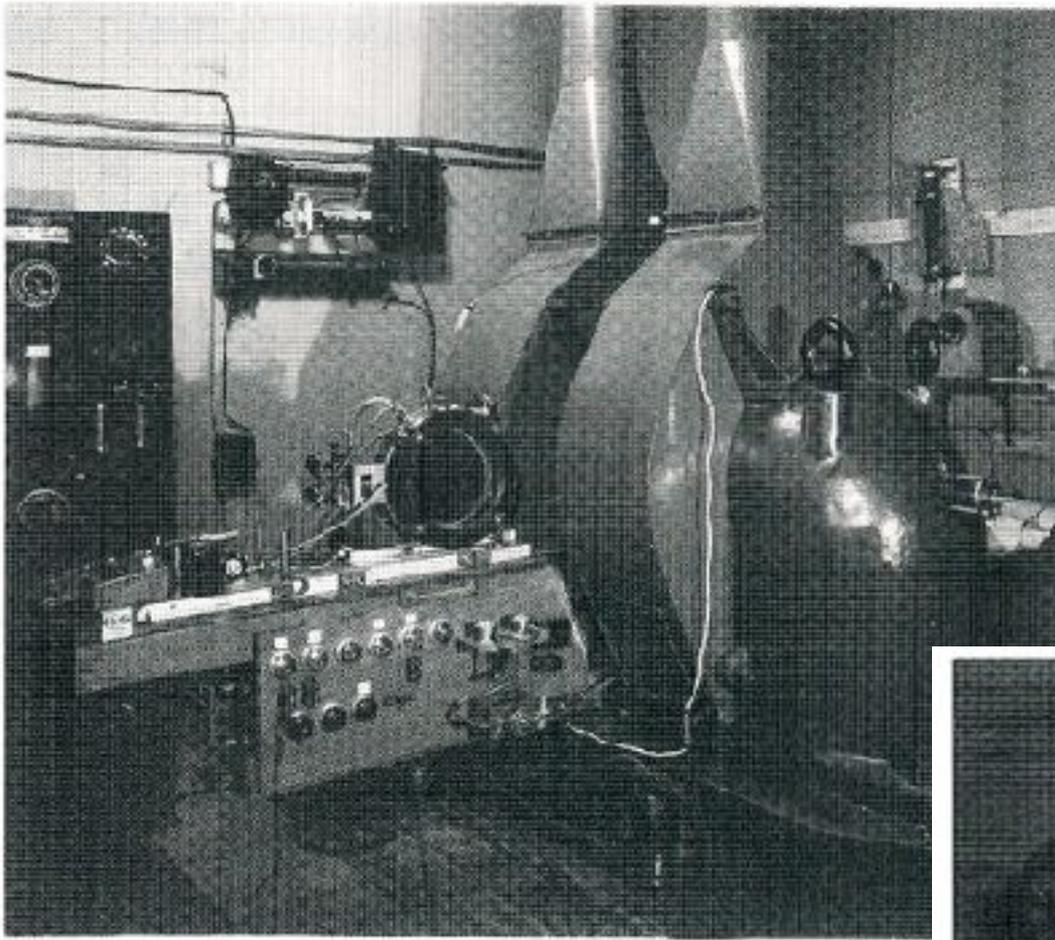


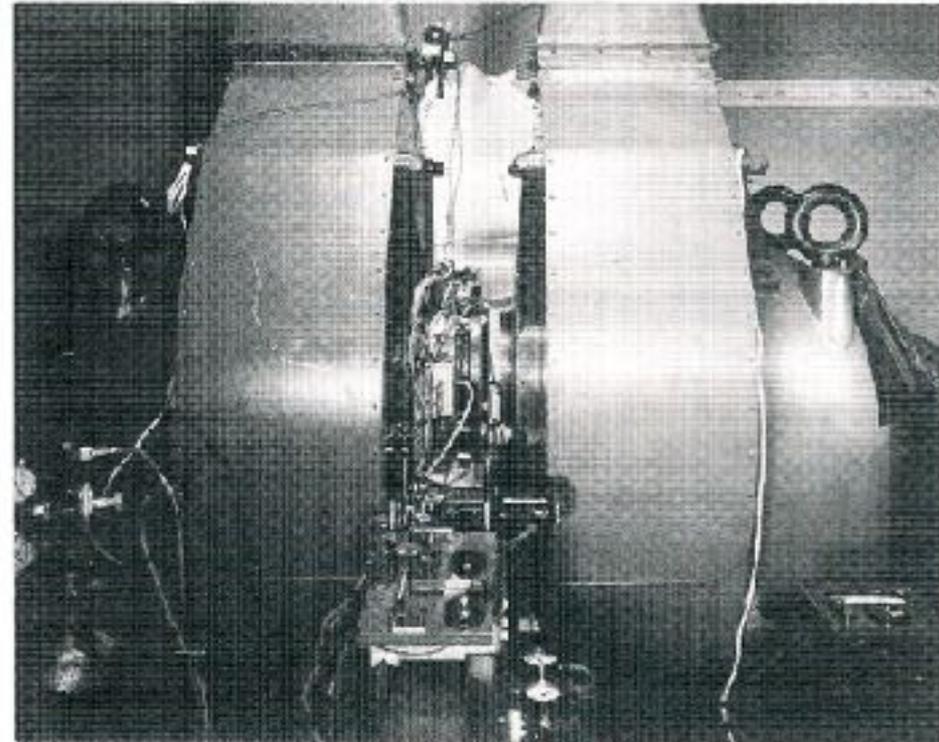
FIG. 1. A 63 million volt positron ( $H_p = 2.1 \times 10^6$  gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ( $H_p = 7.5 \times 10^6$  gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

**P.M.S. Blackett**  
**Nobel Prize 1948**

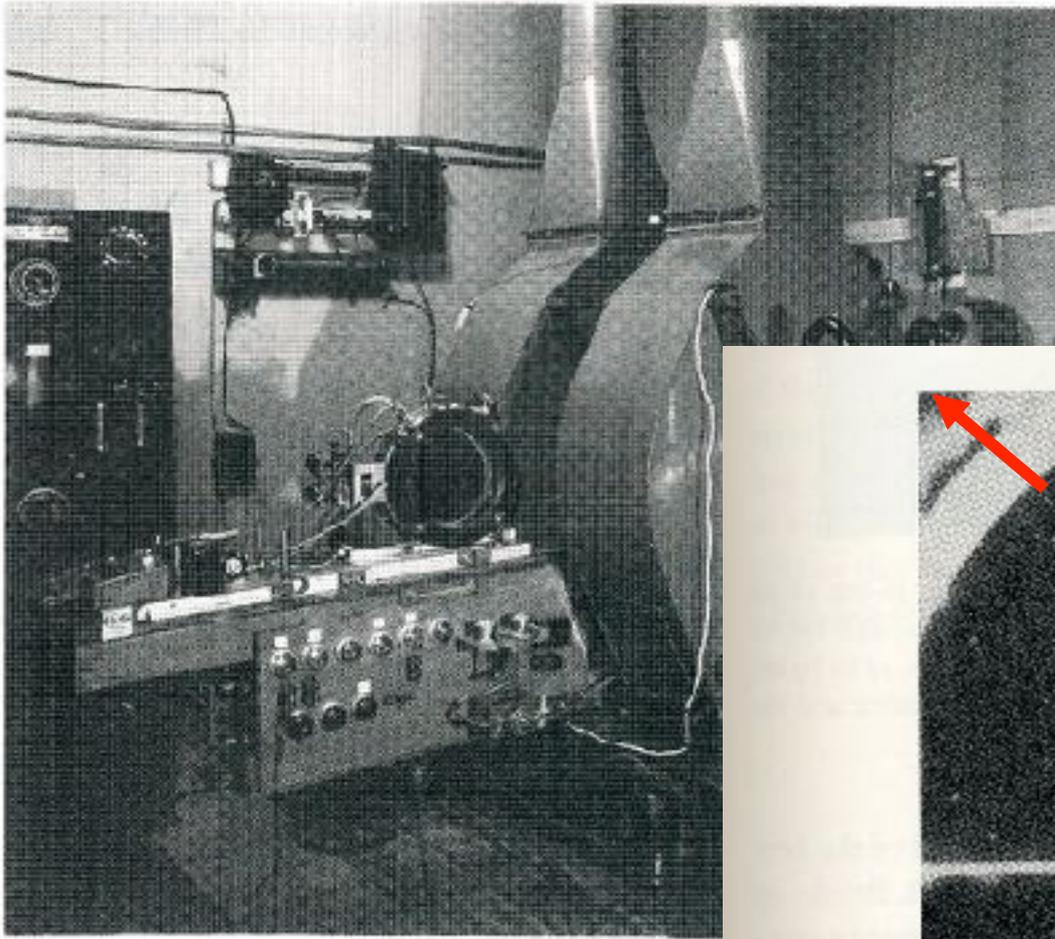


**1933 Blackett & Occhialini**

**10 t electromagnet**  
**30 cm cloud chamber**

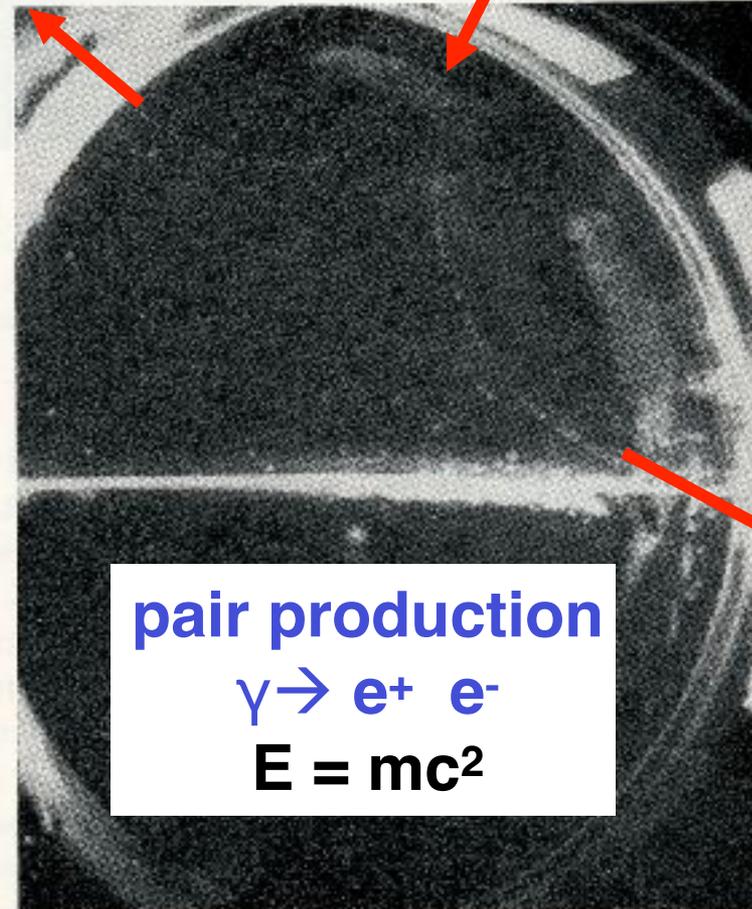


P.M.S. Blackett  
Nobel Prize 1948



1933 Blackett & Occhialini

10 t electromagnet  
30 cm cloud chamber



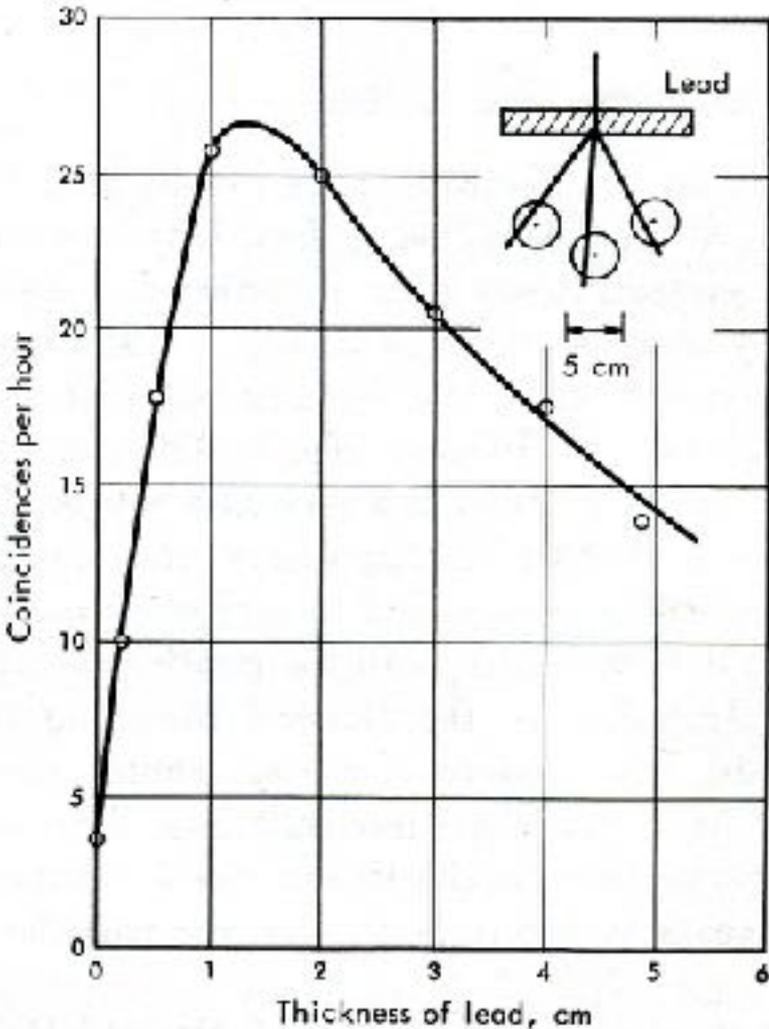
pair production

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

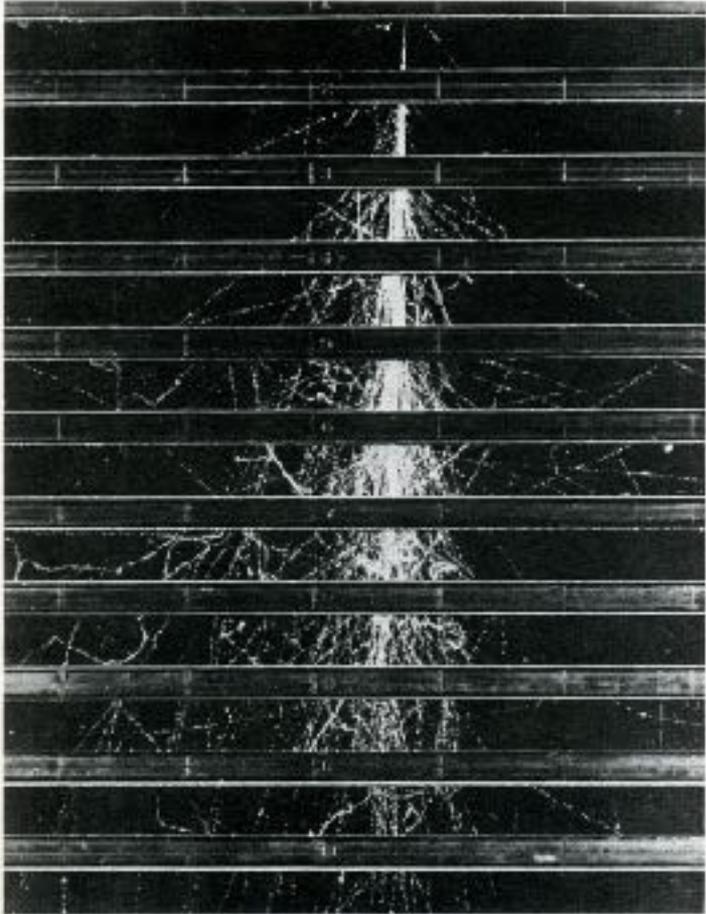
$$E = mc^2$$

Fig. 9. Pair of positive and negative electrons produced by gamma rays. (Chadwick, Blackett, and Occhialini, 1934)

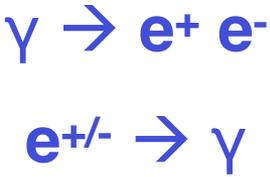
# Electromagnetic Cascades B. Rossi 1933



**Fig. 7-1 Shower curve.** The number of coincidences per hour is plotted as a function of the thickness of lead above the counters. The experimental arrangement is shown schematically in the inset. The circles are experimental points. (This figure is based on one appearing in a paper by the author in *Zeitschrift für Physik*, vol. 82, p. 151, 1933.)



**Fig. 7-5** A shower developing through a number of brass plates 1.25 cm thick placed across a cloud chamber. The shower was initiated in the top plate by an incident high-energy electron or positron. The photograph was taken by the MIT cosmic-ray group.



# Discovery of the Muon

1937 Anderson & Neddermeyer:  $\mu$  in cloud chamber

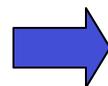
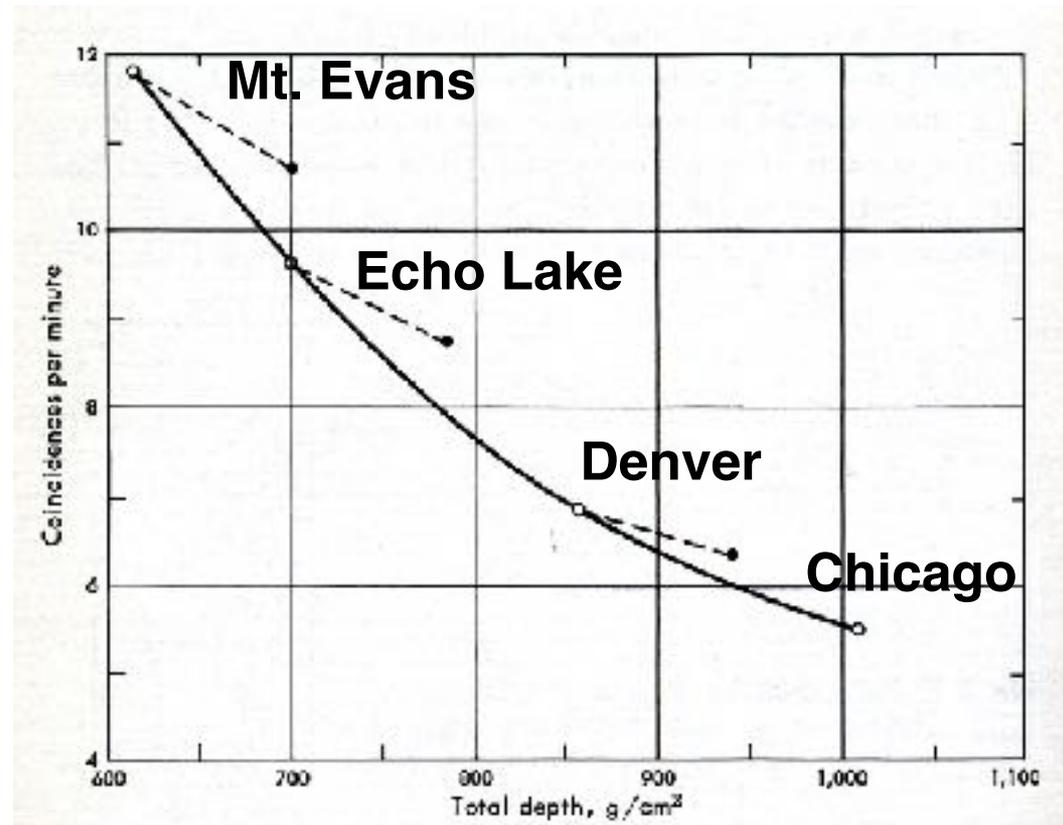
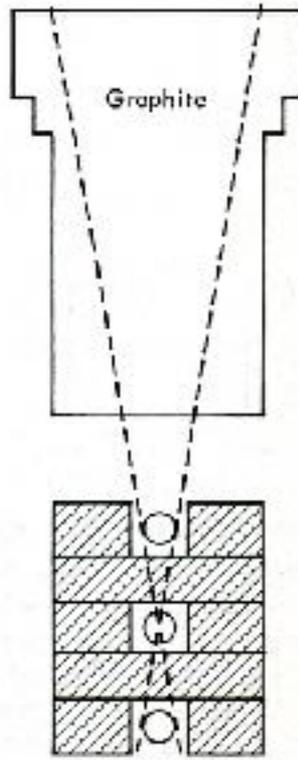
$$m_{\mu} \sim 200 m_e$$

# Discovery of the Muon

1937 Anderson & Neddermeyer:  $\mu$  in cloud chamber

$$m_{\mu} \sim 200 m_e$$

1939 B. Rossi: life time



life time  $\tau \sim 2 \mu\text{s}$

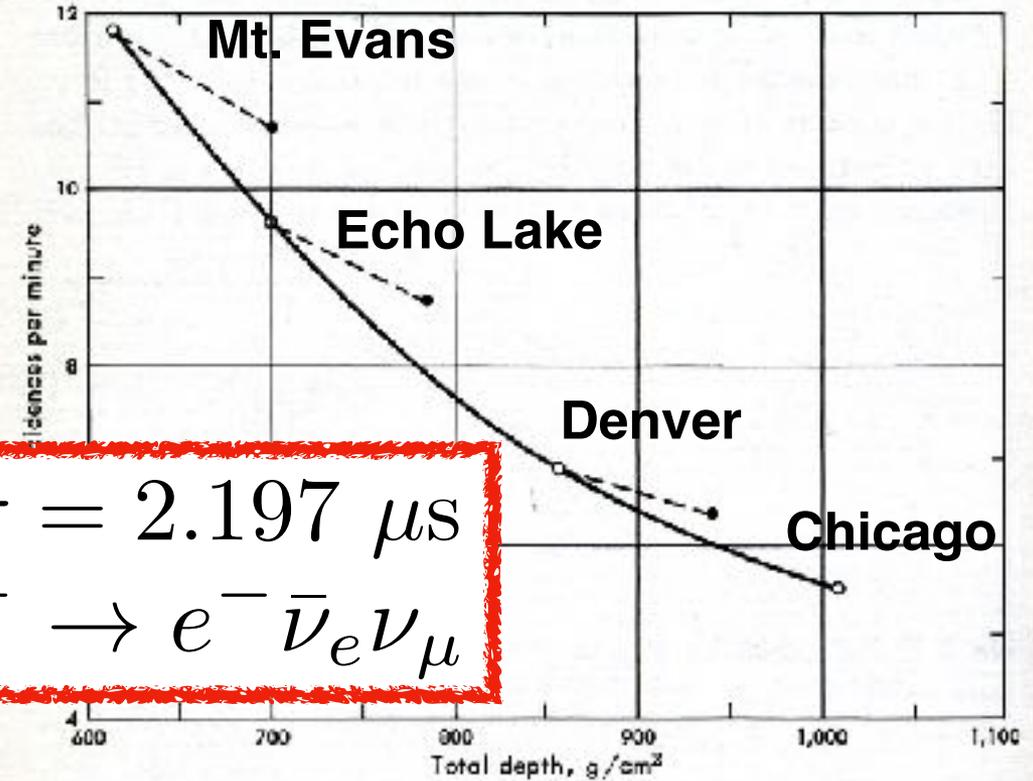
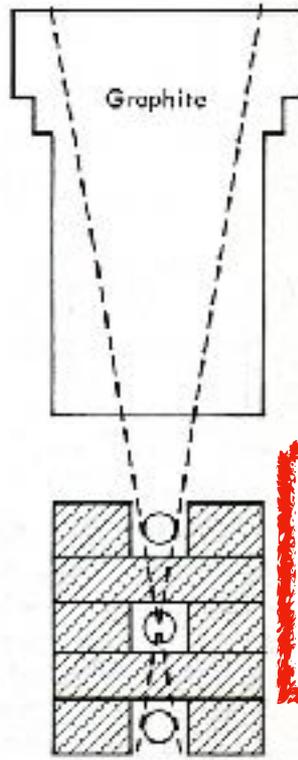
$\mu \rightarrow e + \dots$

# Discovery of the Muon

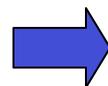
1937 Anderson & Neddermeyer:  $\mu$  in cloud chamber

$$m_{\mu} \sim 200 m_e$$

1939 B. Rossi: life time



PDG:  $\tau = 2.197 \mu\text{s}$



life time  $\tau \sim 2 \mu\text{s}$

$\mu \rightarrow e + \dots$

pretation of the band at  $4\mu$ , and there seems to be no reason why it should not be interpreted as  $\nu_3 + \nu_4$ . An examination of the behavior of this band at low temperatures would perhaps be the best method of checking its assignment as a sum, rather than a difference, of two fundamentals.

The writer wishes to acknowledge the benefit of discussing this matter with Professor Barker.

G. B. B. M. SUTHERLAND\*

Pembroke College,  
Cambridge, England,  
September 15, 1939.

\* At present Leverhulme Research Fellow.  
† E. F. Barker, Phys. Rev. 55, 657 (1939).

### Magnetic Anisotropy of Nickel at 20°K

The only experiments on ferromagnetic anisotropy that have been carried out below the temperature of liquid nitrogen are those of Honda, Masumoto and Shirakawa<sup>1</sup> on nickel in liquid hydrogen. Their results indicate a large increase in the anisotropy as the temperature is lowered from 77° to 20°K, the constant  $K_1$  changing by a factor of about 5. On the other hand, Brukhatov and Kirensky<sup>2</sup> have found that in the temperature range from 77° to 350°K, the constant is given by the relation

$$K_1 = K_0 e^{-\alpha/T^2} \quad (1)$$

which predicts an increase of but 20 percent in going from 77° to 20°K. Accordingly we have undertaken, with the kind cooperation of Drs. H. A. Boorse and S. L. Quimby of Columbia University, to measure again the anisotropy constants at 77° and 20°K, using this time the more accurate method of torques.

The ratio of the constants was found to be about 1.2 (accuracy about 10 percent), as compared with the ratio 5 derived from the data of Honda, Masumoto and Shirakawa and 1.21 from the equation of Brukhatov and Kirensky. Our absolute values at 77°K and above are very close to those of Brukhatov and Kirensky. Thus our work extends the validity of this equation to lower temperatures (see Fig. 1) and shows that there is no unusual behavior in the ferromagnetic anisotropy at these low temperatures. This clarifies the theoretical situation since Van Vleck<sup>3</sup> in his discussion of the wave-mechanical theory of anisotropy, has not been able to find any basis for a difference in variation with temperature of the constants for iron and for nickel.

The crystal of nickel used was grown<sup>4</sup> in pure hydrogen from high purity nickel kindly supplied by Mr. E. Wise of the International Nickel Company. It was cut in the form of a disk with planes parallel to (100) and edges rounded to a semi-circle. The thickness was 0.29 cm, the largest diameter 1.38 cm. The liquid hydrogen was introduced into the Dewar flask surrounding the crystal through a straight Dewar tube of stainless steel connected directly to the bottom of the liquefier. The flask and crystal and torsion-measuring apparatus<sup>5</sup> were then removed to the electromagnet for measurement of the torque when the field was inclined at various angles to [011], the direction of easiest magnetization in the (100) plane. The highest field used was about 4000 oersteds. This was not sufficient

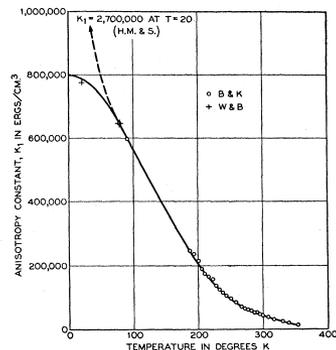


Fig. 1. Anisotropy constant of nickel as dependent on temperature. Data from 77° to 350°K, inclusive, by Brukhatov and Kirensky. Data at 77° and 20°K by the authors, adjusted slightly to fit the former data at 77°K. Curve calculated from Eq. (1) using  $K_0 = 800,000$ ,  $\alpha = 0.000034$ .

to permit observation of the torque at saturation, but was so near this point that the ratio of the constants at 77° and 20°K could be determined with some accuracy. Saturation was later observed at 77°K in a field of about 5000 oersteds.

We wish to express our appreciation to Dr. Boorse and Dr. Quimby and others of the Cryogenic Laboratory of Columbia University, for supplying the liquid hydrogen.

H. J. WILLIAMS  
R. M. BOZORTH

Bell Telephone Laboratories,  
New York, New York,  
September 25, 1939.

<sup>1</sup> K. Honda, H. Masumoto and Y. Shirakawa, Sci. Rep. Tohoku Imp. Univ. 24, 391 (1935). The anisotropy constant was derived by one of us (R. M. B., J. App. Phys. 8, 575 (1937)) from their magnetization curves for the [100] and [110] directions. A similar calculation by L. W. McKeehan (Phys. Rev. 52, 18 (1935)) yielded an even higher value of  $K_1$ . Its value is somewhat uncertain on account of the extrapolation of the magnetization curves to saturation.

<sup>2</sup> N. L. Brukhatov and L. V. Kirensky, Soviet Phys. 12, 602 (1937).

<sup>3</sup> J. H. Van Vleck, Phys. Rev. 52, 1178 (1937).

<sup>4</sup> By Mr. O. L. Boothby, using the method described by P. P. Cioffi and O. L. Boothby, Phys. Rev. 55, 673 (1939).

<sup>5</sup> Similar in design to that described by H. J. Williams, Rev. Sci. Inst. 8, 56 (1937).

### The Disintegration of Mesotrons

In order to test the hypothesis of the spontaneous decay of mesotrons we have compared the absorption of the mesotron component of cosmic radiation in air and in carbon.

The mesotrons were detected by the coincidences of three Geiger-Müller tubes arranged in a vertical plane. The counters were shielded with 10 cm of lead on each side to prevent coincidences from the air showers. Also, 12.7 cm of lead was placed between the counters in order to cut off the soft component.

The absorption in air was measured by counting coincidences at different heights from Chicago up to the top of Mt. Evans, Colorado, (4300 m). The absorption in carbon

was measured by putting layers of graphite above the counters.

It was consistently found that the mass absorption in air was considerably larger than that in carbon. One set of measurements, for instance, gave the following results: Mt. Evans (4300 m, atmospheric pressure 618 g/cm<sup>2</sup>) without graphite:  $11.9 \pm 0.07$  coinc./min. *Ibid.*, under 84 g/cm<sup>2</sup> graphite:  $11.0 \pm 0.057$  coinc./min. Echo Lake (3240 m, atmospheric pressure 700 g/cm<sup>2</sup>) without graphite:  $9.7 \pm 0.046$  coinc./min.

Thus the additional air layer of 82 g/cm<sup>2</sup> between Mt. Evans and Echo Lake reduced the intensity of the mesotrons by more than twice as much as did the graphite screen of 84 g/cm<sup>2</sup>. It is obvious that this large difference cannot be ascribed to the difference in stopping power of air and carbon. We see, therefore, definite evidence for the disintegration of the mesotrons.

The above results show that 1.3 mesotrons out of 11 disintegrate while traveling a distance of  $4.30 \times 10^8 - 3.24 \times 10^8 = 1.06 \times 10^8$  cm. Their mean-free-path for the disintegration is, therefore,  $L = 1.06 \times 10^8 / \log(11/9.7) = 8.5 \times 10^8$  cm.

$L$  is connected with the lifetime  $\tau_0$  by the formula:  $c\tau_0 = \mu c L / \beta$  where  $\mu$  is the mass and  $\beta$  the momentum of the mesotrons. At sea level the average value of  $\mu c / \beta$  was estimated to be about  $0.07$ .<sup>1</sup> Assuming tentatively the same value in our case, one finds  $\tau_0 = 2 \times 10^{-6}$  sec.

A fuller account of these experiments will be published later. The writers acknowledge with thanks the helpful discussions and support given to this work by Professor A. H. Compton. They also wish to express their appreciation for the facilities made available in Colorado by Dr. Joyce Stearns, as well as for the assistance of Mr. O. E. Polk and Mr. W. Bostick.

BRUNO ROSSI  
H. VAN NORMAN HILBERRY  
J. BARTON HOAG

Ryerson Physical Laboratory,  
University of Chicago,  
Chicago, Illinois,  
September 30, 1939.

<sup>1</sup> B. Rossi, Cosmic Ray Symposium, Chicago, June, 1939; Rev. Mod. Phys. July-October (1939).

### Gamma-Radiation

Richardson<sup>1</sup> has reported that the decay of  $N^{13}$  is accompanied by a gamma-ray of  $280 \pm 30$  kev in addition to the well-known positron annihilation radiation. This gamma-ray is estimated to occur in 40 percent of all  $N^{13}$  disintegrations which take place.

The same radiation has been reported by Lyman<sup>2</sup> who estimates it to occur in  $20 \pm 15$  percent of all disintegrations; and by Watase and Itoh<sup>3</sup> who estimate it to occur in 20 percent of all disintegrations. The estimates of Richardson and of Watase and Itoh are uncertain by a factor of two. In view of the general interest in  $N^{13}$ , it has seemed desirable to make further observations on this radiation, using a method which is free from statistical errors.

The  $N^{13}$  gamma-ray spectrum was explored by measuring the energy and intensity of the secondary electrons ejected

from lead and aluminum foils of equivalent thickness. The magnetic spectrograph used was of the usual semi-circular focusing type, constructed largely of lead. The slit jaws and other parts nearest the radioactive source were faced with graphite in order to minimize the background. The radioactive sources were produced by bombarding 0.5 mm thick graphite plates with 4.3-Mev deuterons. Eastman "No Screen" x-ray film was used, and was developed for eight minutes in D19 developer at 66°F.

The Pb and Al foils were placed in contact with the radioactive sources. A particular gamma-ray will eject both photoelectrons and recoil electrons from lead, but only recoil electrons from aluminum because of the different  $Z$  dependence of the two effects. The photoelectrons from a particular gamma-ray, having an initially homogeneous velocity, will appear on the spectrogram as a group with a sharp upper energy limit followed by a gradual decrease in intensity toward lower energies because of a straggling in the emitting foil. The recoil electrons ejected by the same gamma-ray under these conditions will have a much less homogeneous energy distribution because their energies depend greatly upon their directions of emission with respect to those of the quanta.

In this experiment the photoelectron spectrum of lead irradiated by  $N^{13}$  gamma-radiation was isolated from the recoil spectrum as well as from the instrumental background. This was done by successive exposures with lead and aluminum secondary emitters, the latter distribution being subtracted from the former. The relative photoelectron intensities due to any gamma-rays present may thus be directly compared without making any estimates of the contribution of recoil electrons as was necessary in the experiments of Watase and Itoh.

The data are shown in Fig. 1, which gives the film opacity as a function of  $H\beta$ . Because of differences in source intensities it was necessary to multiply the aluminum ordi-

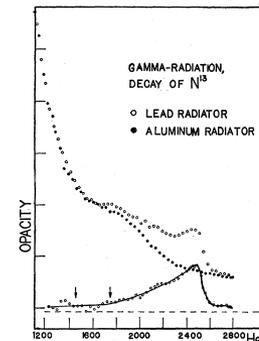


Fig. 1. Photometric measurements of films exposed to secondary electron spectra from lead and aluminum irradiated by  $N^{13}$  gamma-radiation. The lowermost curve is the difference between the Pb and Al data. The vertical arrows indicate the  $H\beta$  region corresponding to lead K photoelectrons from a gamma-ray of  $280 \pm 30$  kev.

## The Disintegration of Mesotrons

In order to test the hypothesis of the spontaneous decay of mesotrons we have compared the absorption of the mesotron component of cosmic radiation in air and in carbon.

The mesotrons were detected by the coincidences of three Geiger-Müller tubes arranged in a vertical plane. The counters were shielded with 10 cm of lead on each side to prevent coincidences from the air showers. Also, 12.7 cm of lead was placed between the counters in order to cut off the soft component.

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REVIEWS OF  
**MODERN PHYSICS**

VOLUME II

III, 5-OCTOBER, 1936

NUMBER 3-4

**SYMPOSIUM ON COSMIC RAYS**

*held at*

**THE UNIVERSITY OF CHICAGO**

*June, 1939*



Fig. 1. Participants at the Cosmic Ray Conference (Symposium on Cosmic Rays, 1939) convened at the University of Chicago in the summer of 1939. The identification of participants is given by numbers in the overlay of this photograph as follows:

- |                          |                               |                                   |
|--------------------------|-------------------------------|-----------------------------------|
| 1. H. Bethe              | 18. W. Bothe                  | 35. W. Bostick <sup>+</sup>       |
| 2. D. Froman             | 19. W. Heisenberg             | 36. C. Eckart                     |
| 3. R. Brode              | 20. P. Auger                  | 37. A. Code <sup>+</sup>          |
| 4. A.H. Compton          | 21. R. Serber                 | 38. J. Stearns (Denver?)          |
| 5. E. Teller             | 22. T. Johnson                | 39. J. Hopfield                   |
| 6. A. Baños, Jr.         | 23. J. Clay (Holland)         | 40. E.O. Wollan <sup>*</sup>      |
| 7. G. Groetzinger        | 24. W.F.G. Swann              | 41. D. Hughes <sup>+</sup>        |
| 8. S. Goudsmit           | 25. J.C. Street (Harvard)     | 42. W. Jesse <sup>*</sup>         |
| 9. M.S. Vallarta         | 26. J. Wheeler                | 43. B. Hoag                       |
| 10. L. Nordheim          | 27. S. Neddermeyer            | 44. N. Hillberry <sup>+</sup>     |
| 11. J.R. Oppenheimer     | 28. E. Herzog (?)             | 45. F. Shonka <sup>+</sup>        |
| 12. C.D. Anderson        | 29. M. Pomerantz              | 46. P.S. Gill <sup>+</sup>        |
| 13. S. Forbush           | 30. W. Harkins (U. of C.)     | 47. A.H. Snell                    |
| 14. Nielsen (of Duke U.) | 31. H. Beutler                | 48. J. Schremp                    |
| 15. V. Hess              | 32. M.M. Shapiro <sup>+</sup> | 49. A. Haas <sup>?</sup> (Vienna) |
| 16. V.C. Wilson          | 33. M. Schein <sup>*</sup>    | 50. E. Dershem <sup>*</sup>       |
| 17. B. Rossi             | 34. C. Montgomery (Yale)      | 51. H. Jones <sup>+</sup>         |

<sup>\*</sup>Then research associate of Compton.

<sup>+</sup>Then graduate student of Compton.



ICS

Number 3-4

RAYS

AGO

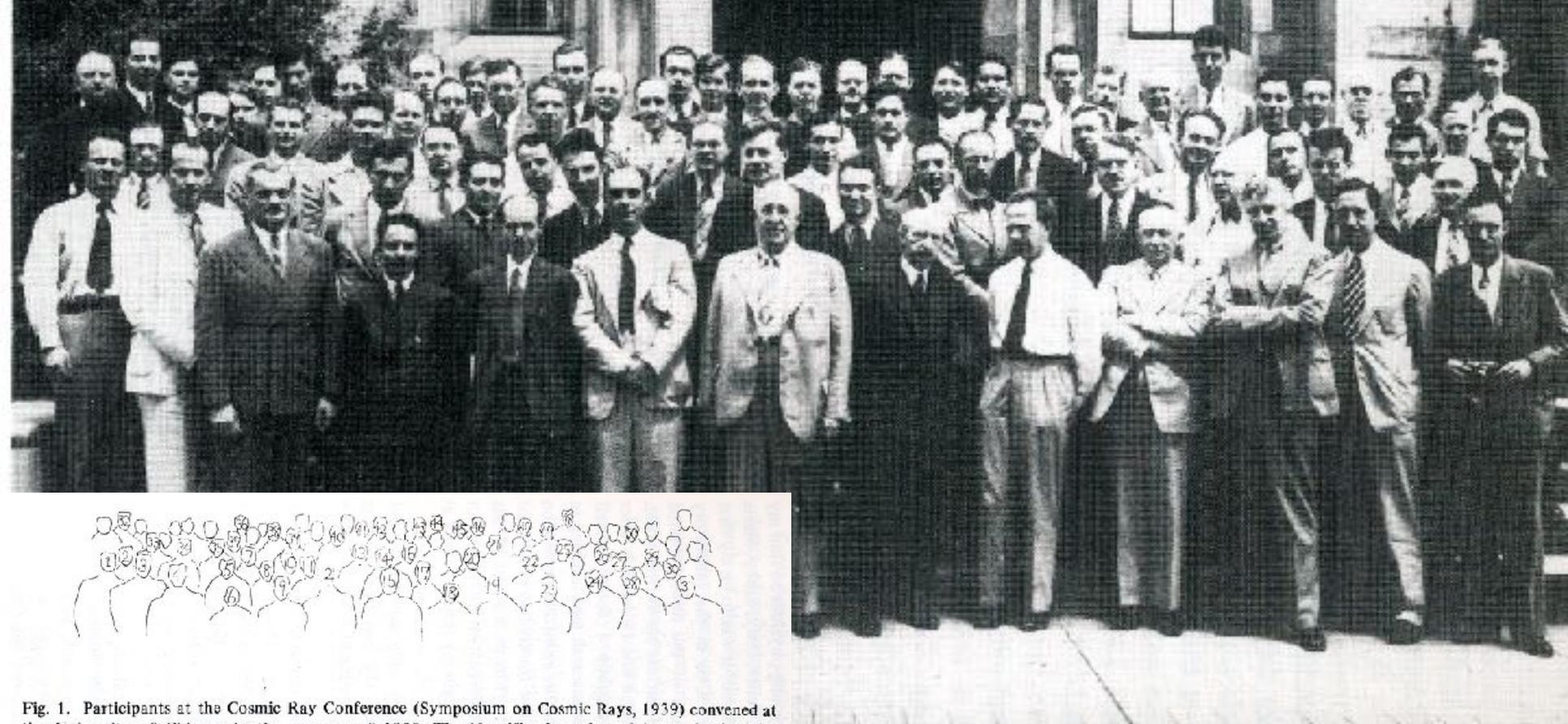


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REVIEWS OF  
**MODERN PHYSICS**

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VOLUME II      JULY-OCTOBER, 1939      NUMBER 3-4

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**SYMPOSIUM ON COSMIC RAYS**

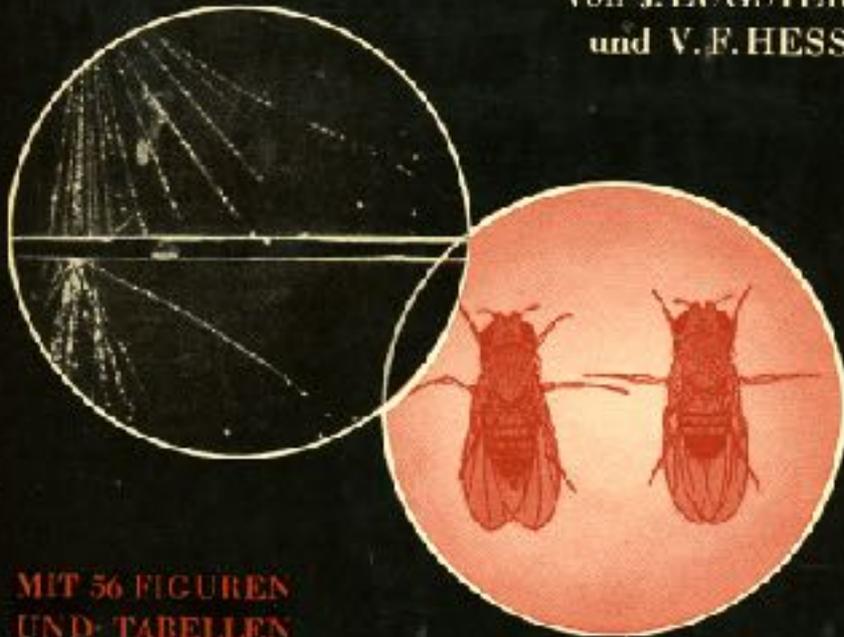
*held at*

**THE UNIVERSITY OF CHICAGO**

*June, 1939*

# Die Weltraumstrahlung und ihre biologische Wirkung

von J. EUGSTER  
und V. F. HESS



MIT 56 FIGUREN  
UND TABELLEN

Die Kosmischen Strahlen, vor ca. 30 Jahren durch HESS entdeckt, und heute schon photographier- und meßbar, beeinflussen nachhaltig Wachstum, Fruchtbarkeit und Krebs, was EUGSTER in langjährigen Versuchen an Tieren und Pflanzen bewies. Das Buch gibt Physikern und Biologen, aber auch gebildeten Laien eine wertvolle Zusammenfassung der äußerst vielseitigen Forschungsergebnisse.

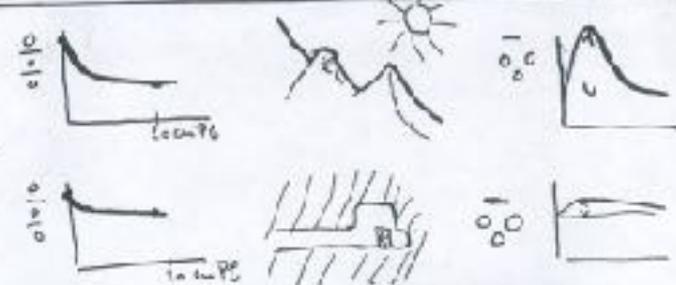
## Space radiation and its biological effect

The cosmic rays, discovered ca. 30 years ago by Hess are today measurable. They influence the growth, fertility and cancer. Eugster has demonstrated this with experiments using plants and animals. The book gives physicists and biologists, as well as interested layman a valuable summary of a broad field of research.

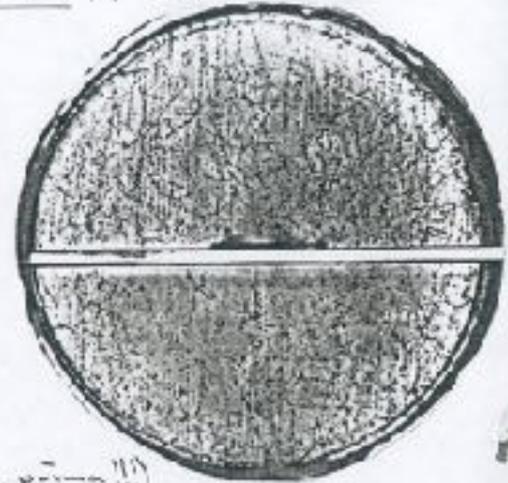
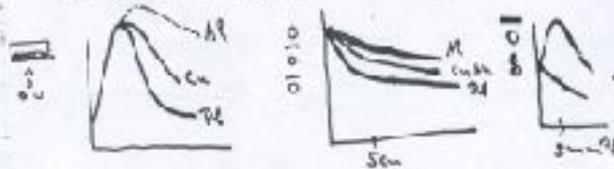
1939

# P. Auger Jungfrauoch

Pierre Auger }  
 Paul Elveufst } 2-24 IX '34  
 Louis Leprieux Ringuelet }  
 Wilson Hammer viele "Shower"

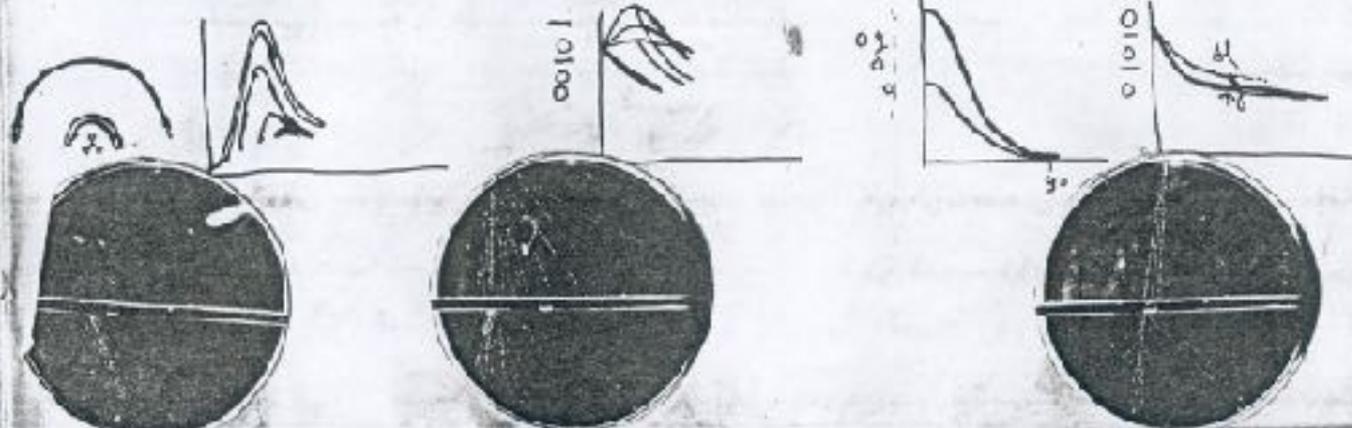


Pierre Auger }  
 Louis Leprieux Ringuelet } 16 IV - 24 IV }  
 Francis Perrin } 29 IV - 5 V } 1935  
 Paul Elveufst } 16 IV - 12 V }



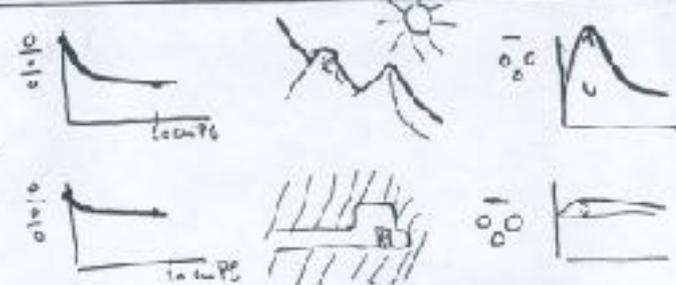
Doppelta Wilson-Ringuelet Hammer,  
 grosse Shower

Pierre Auger } 2 IX - 23 IX, 3 IX - 6 IX }  
 Paul Elveufst } 2 IX - 19 IX (15-19 IX) } Ende Wackerholz, Perrin !!  
 André Fieschi } } 1936  
 Suzanne Auger } 5 IX - 15 IX }  
 Jean Mauvain } }  
 Salomon Rosenblum (Baby) } 20 IX - 3 IX }



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Paul Ehrenfest  
Louis Leprince-Ringuet } 2-26 IX 1934  
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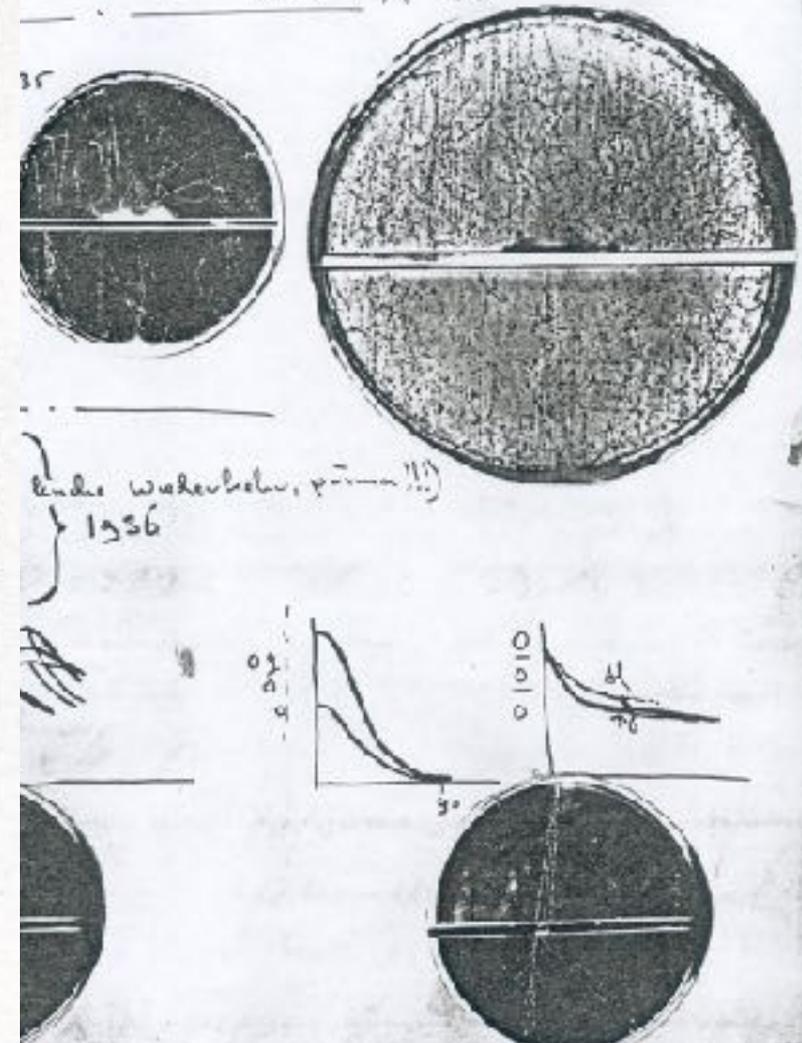


The sketches include two graphs showing particle tracks over time, a diagram of a detector with a sun and clouds, and another diagram showing a particle track through a detector with a 'C' label.



MEASURING COSMIC RAYS IN THE SWISS ALPS

The author (left) and his collaborator, P. Ehrenfest, set up their apparatus in the Jungfraujoch.



# WHAT ARE COSMIC RAYS?

*Revised and Enlarged American Edition*

BY PIERRE AUGER

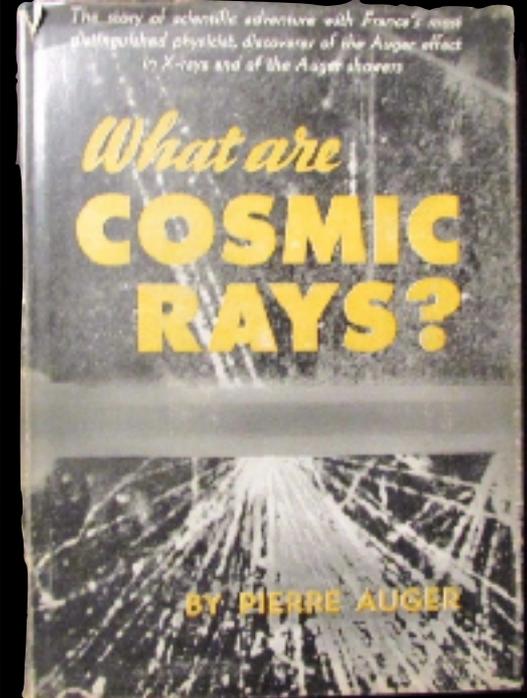
TRANSLATED FROM THE FRENCH

by

MAURICE M. SHAPIRO



UNIVERSITY OF CHICAGO PRESS · CHICAGO



Für die kurzen Originalmitteilungen ist ausschließlich der Verfasser verantwortlich.

Gekoppelte Höhenstrahlen.

Bei Bestimmungen der Zufallskoinzidenzen hoch auflösender Zählrohrverstärkeranordnungen (bis  $5 \cdot 10^{-7}$  sec) ergab sich eine wesentlich größere Anzahl, als nach den elektrischen Konstanten der Anordnung zu erwarten war, ferner ihre Anzahl abhängig vom gegenseitigen Abstand der Zählrohre, wie z. B. für Zählrohre von 430 qcm wirksamer Oberfläche ( $90 \cdot 4,8$ ) und  $\tau = 5 \cdot 10^{-6}$  sec Tabelle 1 zeigt.

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Mit zunehmendem Abstand der Zählrohre voneinander nimmt die Anzahl der Zufallskoinzidenzen zunächst dauernd ab, bis sich bei über 10,0 m Abstand (Beobachtungen im Experimentierraum) konstante Werte einstellen und überschüssige Koinzidenzen nicht mehr nachweisbar sind. Wurde ein Bleipanzter ( $10 \cdot 10 \cdot 40$  cm<sup>3</sup>) so zwischen die Zählrohre gebracht, daß er den Durchgang ein und desselben Strahles durch die beiden horizontal liegenden Rohre hinderte, so änderte sich wesentlich nichts, wie ja nach der Richtungsverteilung der Höhenstrahlen zu erwarten ist. Wohl aber machten sich die zusätzlichen Koinzidenzen nicht mehr bemerkbar, wenn die Rohre allseitig durch 10 cm Blei geschirmt wurden. Dann erhielt man auch bei nahe aneinander liegenden Rohren dieselben konstanten Werte für  $\tau$  wie bei über 10 m Abstand ungepanzert. Die zusätzlichen Koinzidenzen mußten demnach von Strahlen herrühren, die durch 10 cm Blei weitgehend absorbiert werden. Bei starker Erhöhung der Stoßzahlen durch radioaktive Bestrahlung wird der Einfluß der Höhenstrahlen unwirksam. Dann ergab sich ebenfalls bei kleinerem Zählrohrabstande (5 m) der Wert des Auflösungsvermögens, der 1. nach den elektrischen Daten, 2. nach den Bestimmungen mit allseitigem Panzer und 3. nach den Messungen über 10 m Abstand ungepanzert das wahre Auflösungsvermögen der Anordnung darstellt.

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Sollten sie bevorzugt in der Decke ausgelöst werden, so würden nach der Geometrie der Anordnung dabei Strahlen bis zu  $80^\circ$  aus ihrer ursprünglichen Richtung abgelenkt worden sein. Indessen ist bei einem Äquivalent der Decke von nur 1 cm Blei und dem Absorptionskoeffizienten der Strahlen von  $\mu_{Pb} = 0,12$  cm<sup>-1</sup> anzunehmen, daß die Strahlen überwiegend in der Atmosphäre bis zu großen Höhen über Boden erzeugt werden. Die Decke wird also mehr absorbierende als strahlenauslösende Wirkung haben, so daß im Freien eine größere Anzahl von Strahlen unter gleichen Bedingungen zu erwarten ist. Dies bestätigen die Messungen mit der 2-fach-Koinzidenzanordnung. Im Freien konnten die zusätzlichen Koinzidenzen bis auf Abstände von über 20 m sicher beobachtet werden, so daß gekoppelte Höhenstrahlen im Freien sogar bis über 400 qm Fläche auftreten (Tabelle 1). Selbst bei 75 m Abstand schien noch ein kleiner Überschuß vorhanden, der aber erst durch sehr lange Meßreihen sichergestellt werden müßte.

Aus dem niedrigen Absorptionskoeffizienten ist zu folgern, daß selbst Schauerstrahlen, die bis etwa 2 km Höhe über dem Boden entstehen, diesen noch erreichen müssen. Diese würden dann über eine sehr große Fläche verteilt sein. Da für solche Schauer trotz des großen Strahlenreichtums die räumliche Dichte der Strahlen in Bodennähe nur außerordentlich gering sein kann, ist es durchaus verständlich, wenn sie als zusätzliche Koinzidenzen über größere Abstände nachweisbar sein lassen. Bei den hier ausgeführten Messungen bis zu 20 m würde, die Entstehung dieser Höhenstrahlen vorausgesetzt, der Winkel gegenüber der Vertikalen als  $1^\circ$  sein.

Die Höhenstrahlen bestehen, den Ursprungsort genauer zu bestimmen dadurch, daß die Koinzidenzanordnungen angepeilt. Dies ist jedoch erst diskutiert werden, wenn es festgestellt sein wird. Die vorliegenden Untersuchungen hatte der Verfasser im Jahre 1938 in einem Vortrage im Rahmen der Tagung der Technischen Hochschule

# Kolhörster discovery of air showers

wird sich also um Sekundärstrahlen handeln, die durch die Schauer, handeln. Das zeigen auch folgende Versuche mit einer 3fachen Koinzidenzapparatur, deren Auflösungsvermögen mit einer besonderen Anordnung zu  $5 \cdot 10^{-6}$  sec bestimmt worden war. Bei Aufstellung der Zählrohre horizontal und radial auf einem Kreise ist dann überhaupt keine meßbare Anzahl von Zufallskoinzidenzen zu erwarten (höchstens  $10^{-4}$  Koi/Std.). Es ergaben sich aber bei Zählrohren von 216 qcm wirksamer Fläche

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Dresden kurz berichtet.  
Berlin, Institut für Höhenstrahlenforschung der Universität Berlin, den 25. August 1938.  
W. KOLHÖRSTER. I. MATTHES. E. WEBER.

## Neue Messungen der Fluoreszenz-Intensitäts-Änderungen grüner Pflanzen.

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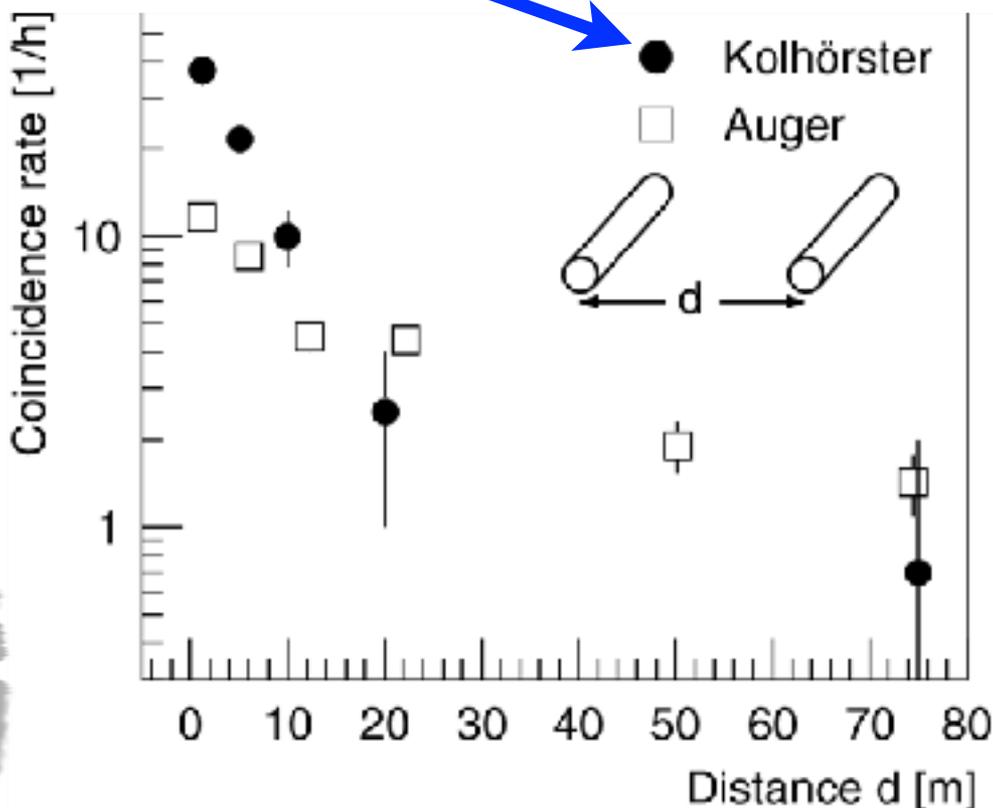
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**Kolhörster discovery of air showers**



P. Auger et al., Comptes renduz 206 (1938) 1721

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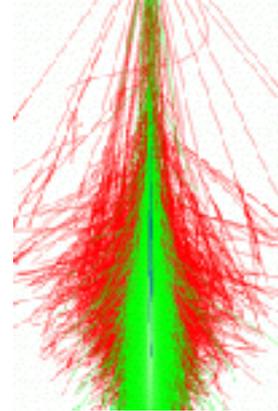
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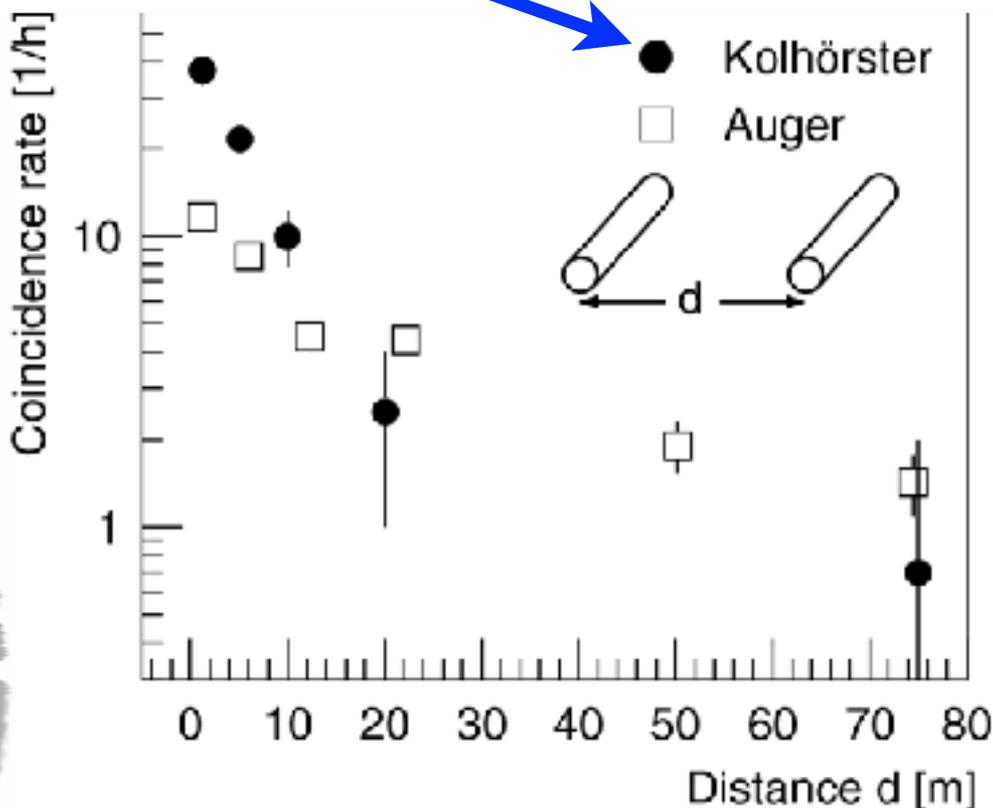
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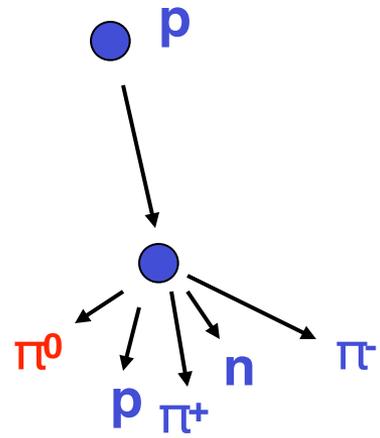
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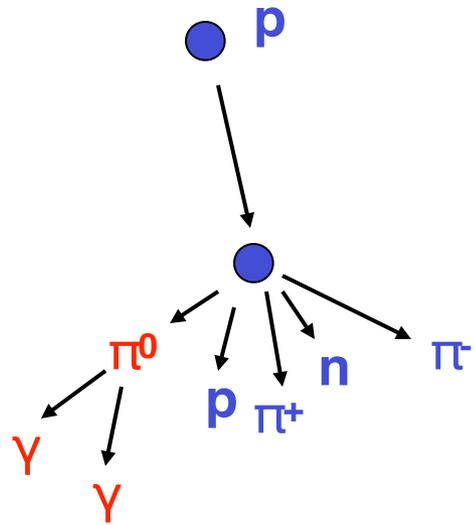
# Extensive Air Shower



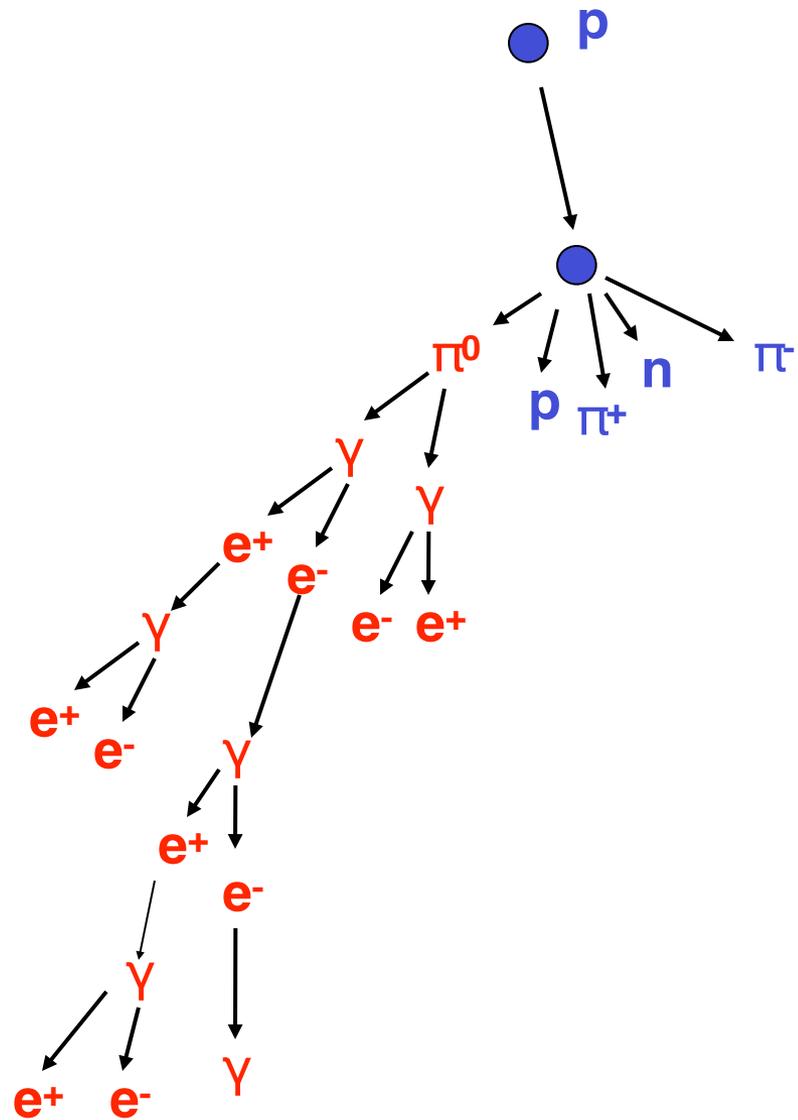
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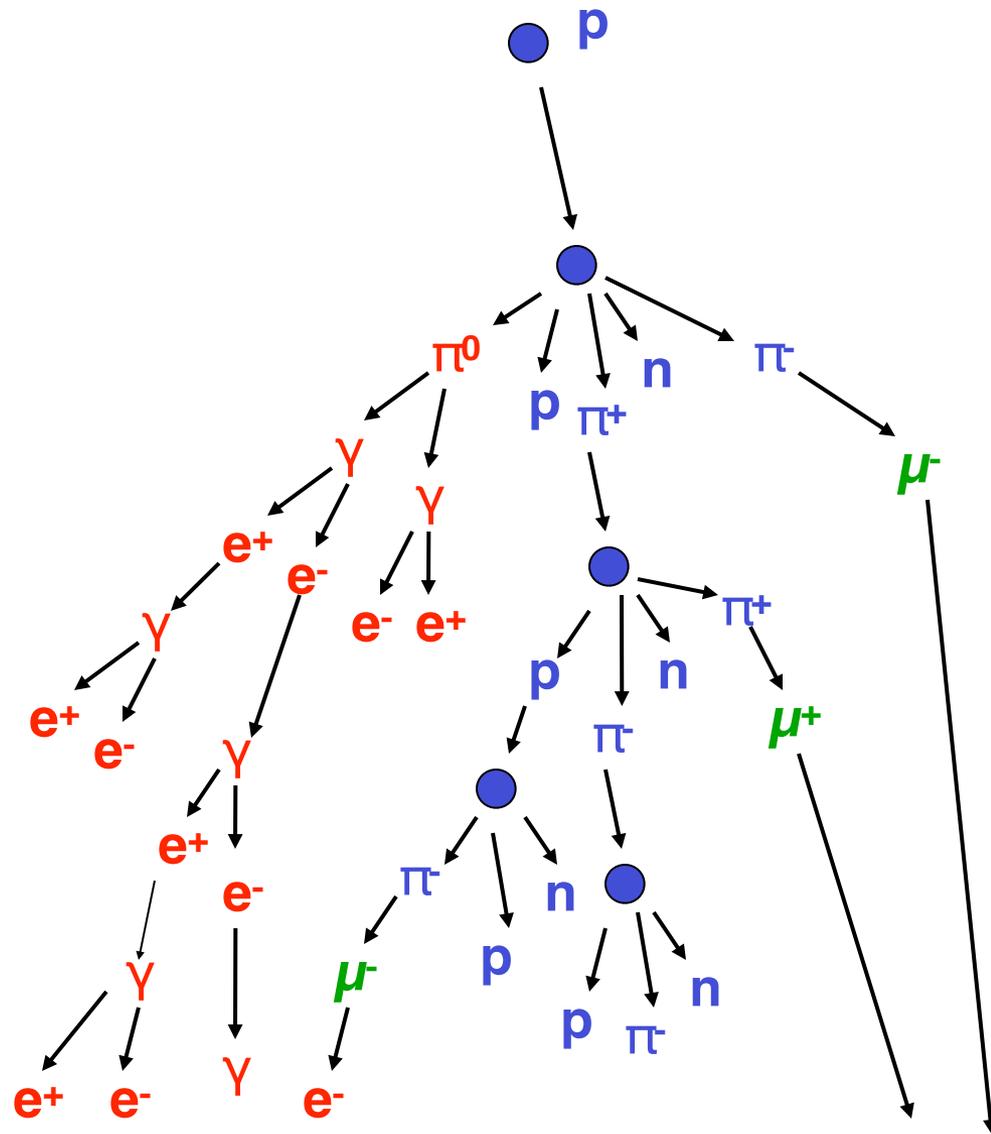


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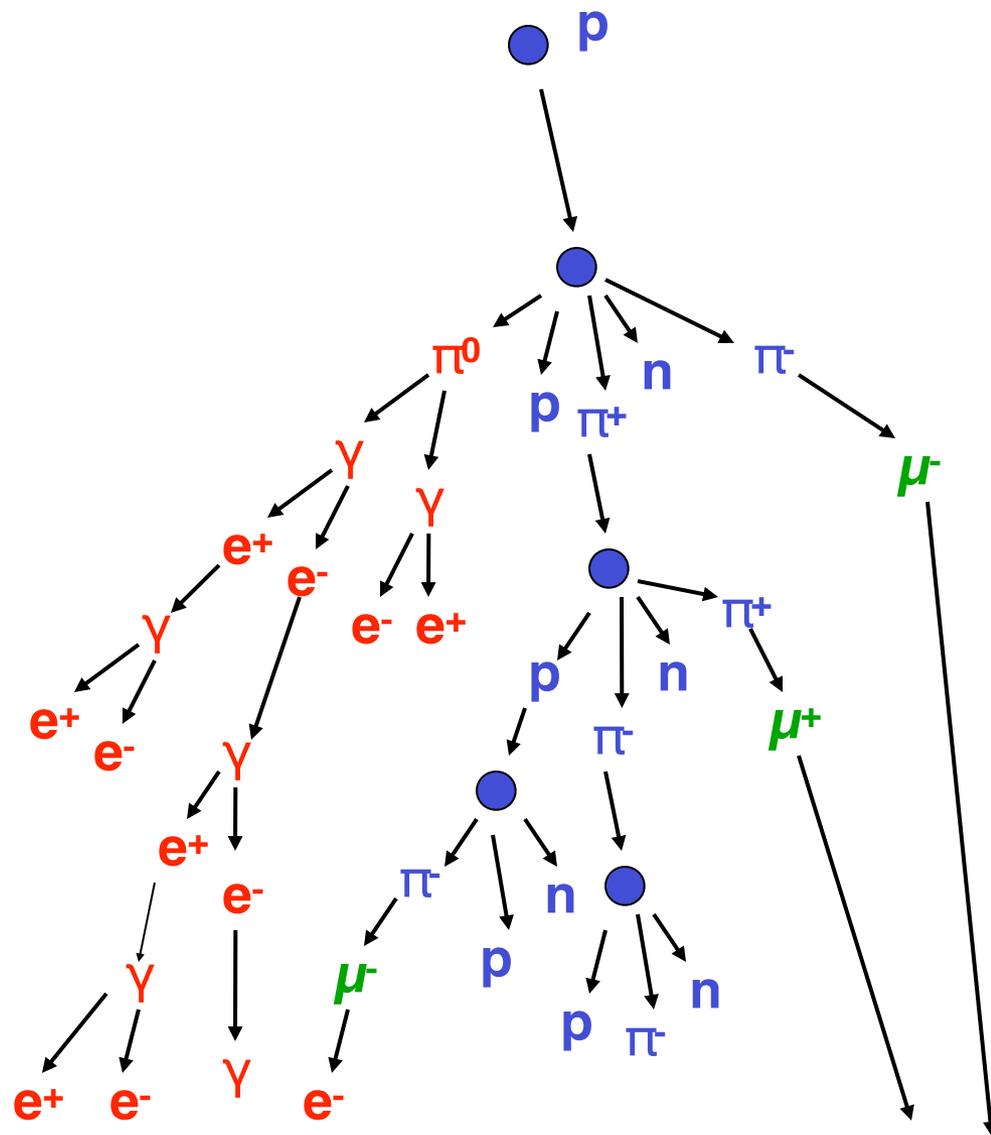




# Extensive Air Shower



# Extensive Air Shower



**electromagnetic**

**hadronic**

**muonic**

**shower component**

# Extensive Air Shower

Proton  $10^{15}$  eV:  
on ground

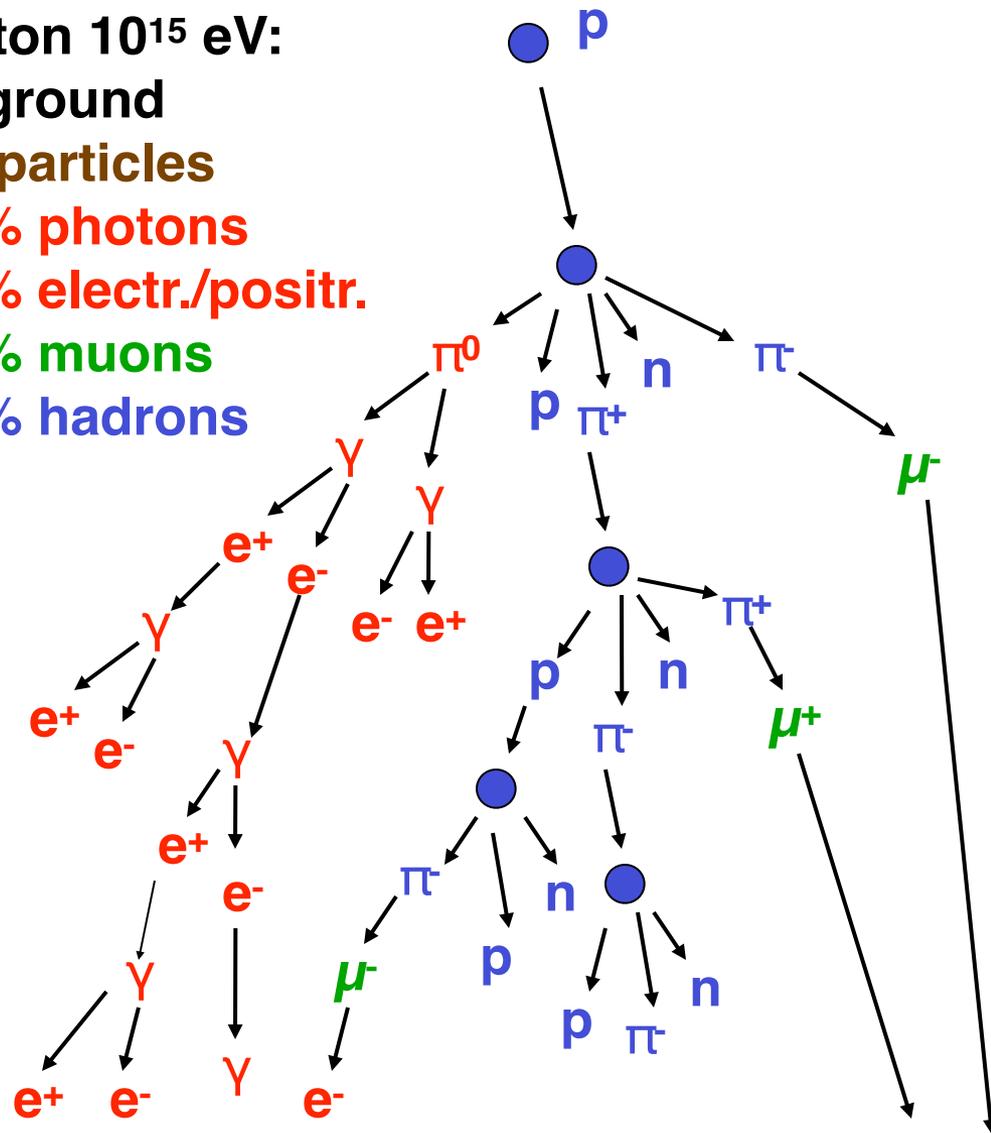
$10^6$  particles

80% photons

18% electr./positr.

1.7% muons

0.3% hadrons



electromagnetic

hadronic

muonic

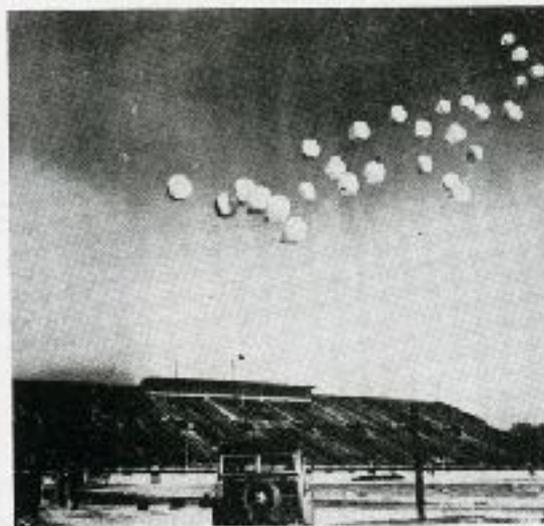
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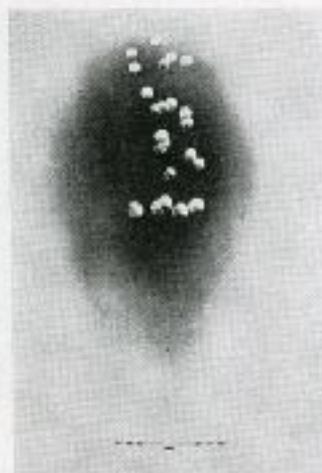
# 1943

## The University of Chicago

A



B



C

**P. Auger**

BALLOON FLIGHT OF JANUARY, 1943, CONDUCTED BY THE AUTHOR, SCHEIN,  
AND ROGOWSKI FOR THE MEASUREMENT OF EXTENSIVE (OR  
AUGER-) SHOWERS IN THE STRATOSPHERE

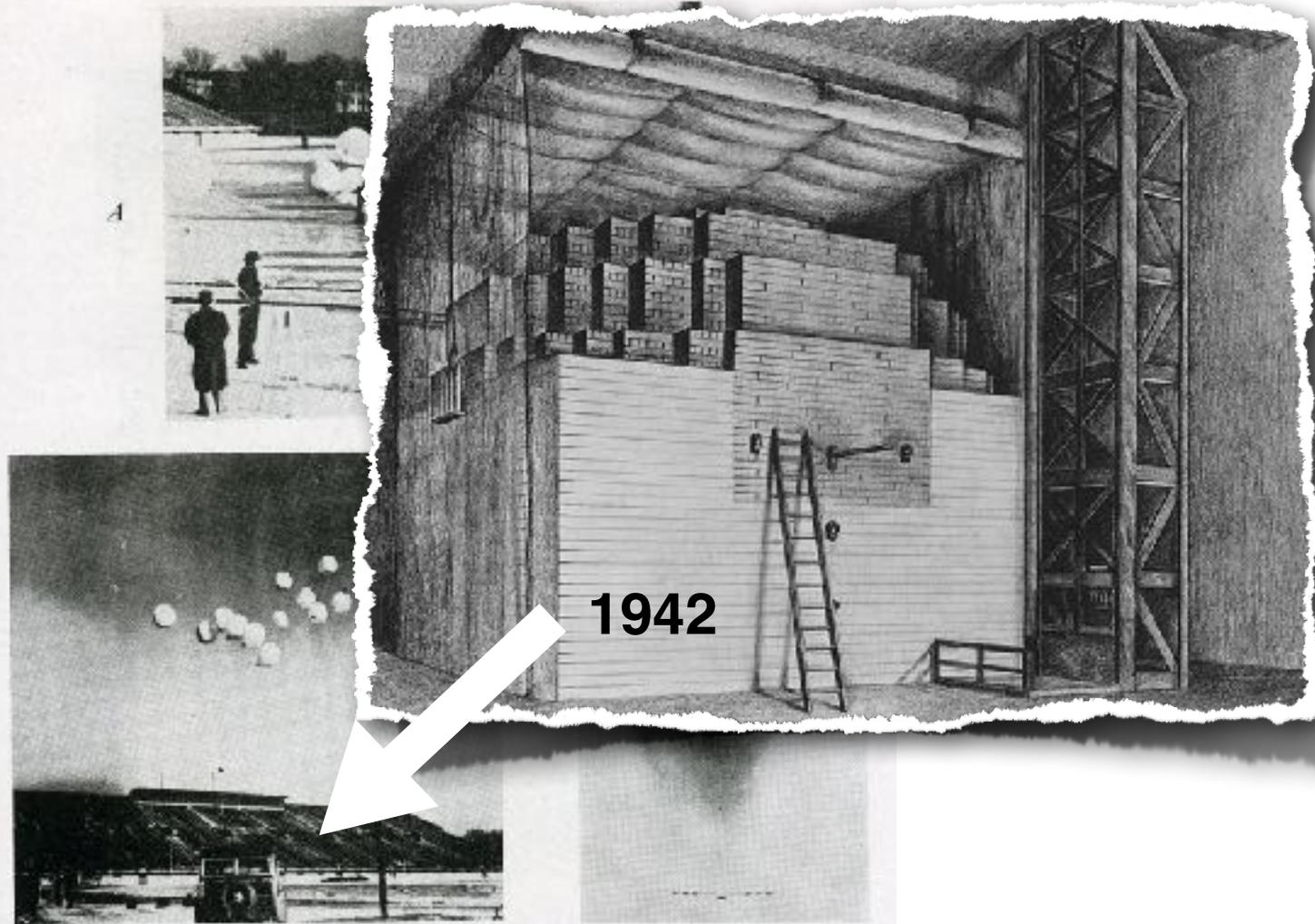
A. The balloons are assembled on Stag Field at the University of Chicago, Chicago, Illinois. In the foreground can be seen the long frame which was required for the wide separation of the cosmic-ray counters.

B. The large cluster of balloons as it is about to be released.

C. The balloon train sails into the sky after its release. Suspended below the balloons is the frame supporting the counters and recording apparatus.

# 1943

## The University of Chicago



1942

*B*

*C*

**P. Auger**

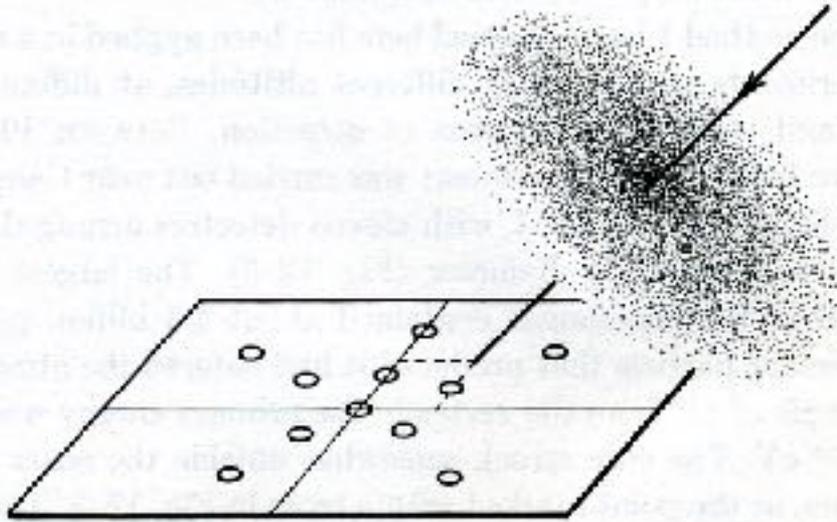
BALLOON FLIGHT OF JANUARY, 1943, CONDUCTED BY THE AUTHOR, SCHEIN, AND ROGOWSKI FOR THE MEASUREMENT OF EXTENSIVE (OR AUGER-) SHOWERS IN THE STRATOSPHERE

*A*. The balloons are assembled on Stag Field at the University of Chicago, Chicago, Illinois. In the foreground can be seen the long frame which was required for the wide separation of the cosmic-ray counters.

*B*. The large cluster of balloons as it is about to be released.

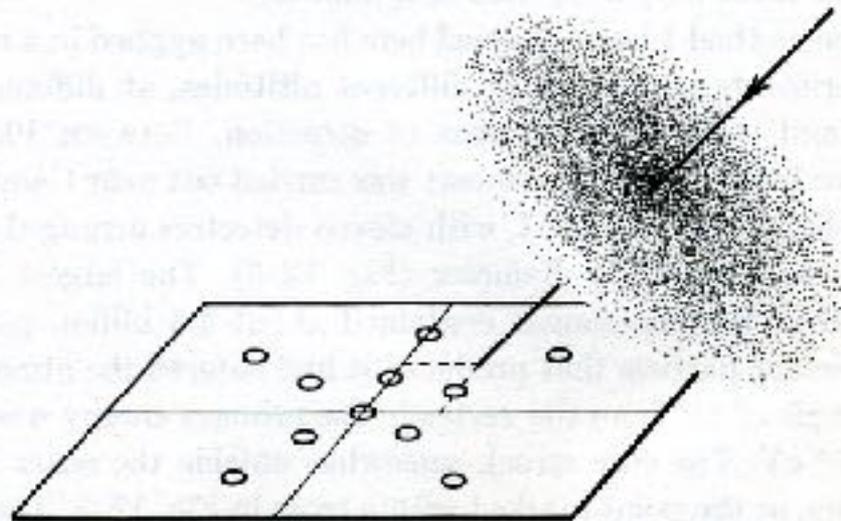
*C*. The balloon train sails into the sky after its release. Suspended below the balloons is the frame supporting the counters and recording apparatus.

# ~ 1950 large detector arrays to measure extensive air showers

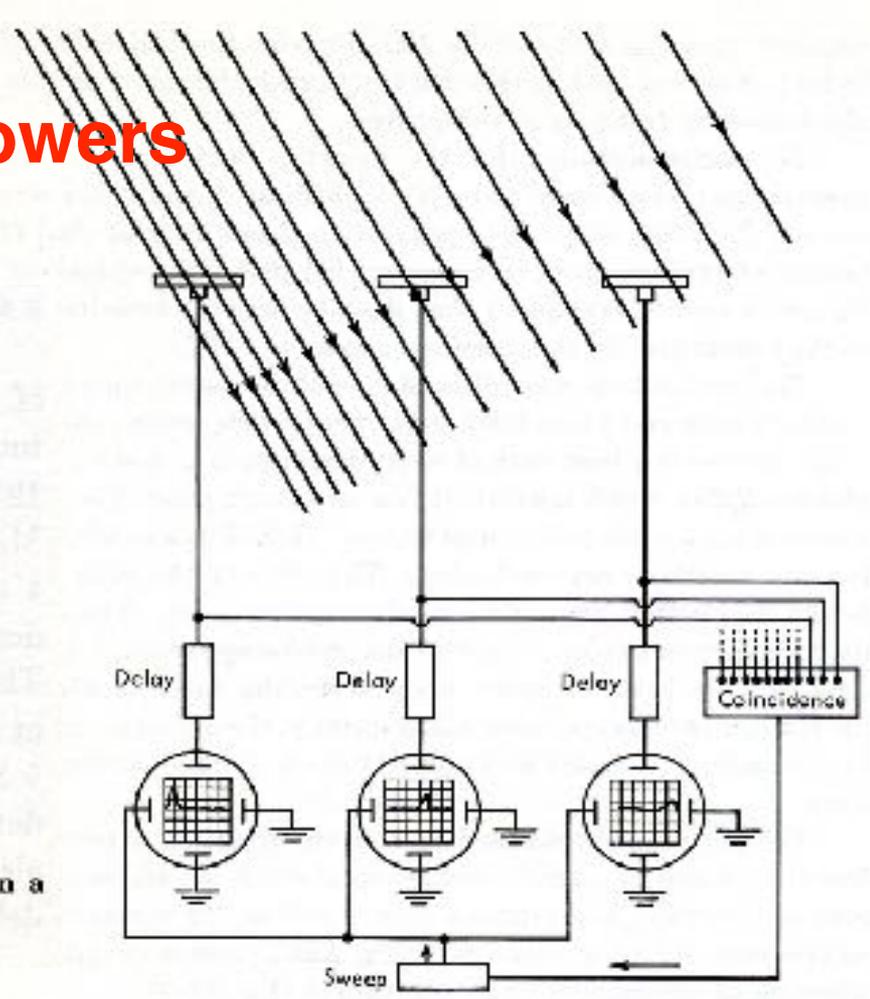


**Fig. 12-4** Shower disk approaching detectors (represented by circles on a horizontal plane).

# ~ 1950 large detector arrays to measure extensive air showers



**Fig. 12-4** Shower disk approaching detectors (represented by circles on a horizontal plane).



**Fig. 12-3** Experimental arrangement used by the MIT cosmic-ray group to study air showers. Fluorescent plastic disks (thin rectangles at top) emit flashes of light when struck by charged particles. At the center of each disk is a photomultiplier tube that converts the light into an electrical pulse; the amplitude of the pulse is proportional to the brightness of the flash. Pulses travel to cathode-ray oscilloscopes (circles) through transmission lines containing delay circuits, which equalize the lengths of the electrical paths. Horizontal sweeps of all oscilloscope screens (grids) are triggered at the same time whenever three or more pulses pass through the coincidence circuit simultaneously. The amplitudes of the "spikes" (that is, the heights of the vertical deflections in the oscilloscope traces) indicate the numbers of particles striking the corresponding detectors. The positions of the spikes in the horizontal traces show the relative arrival times of the particles.

## EVIDENCE FOR A PRIMARY COSMIC-RAY PARTICLE WITH ENERGY $10^{20}$ eV†

John Linsley

Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received 10 January 1963)

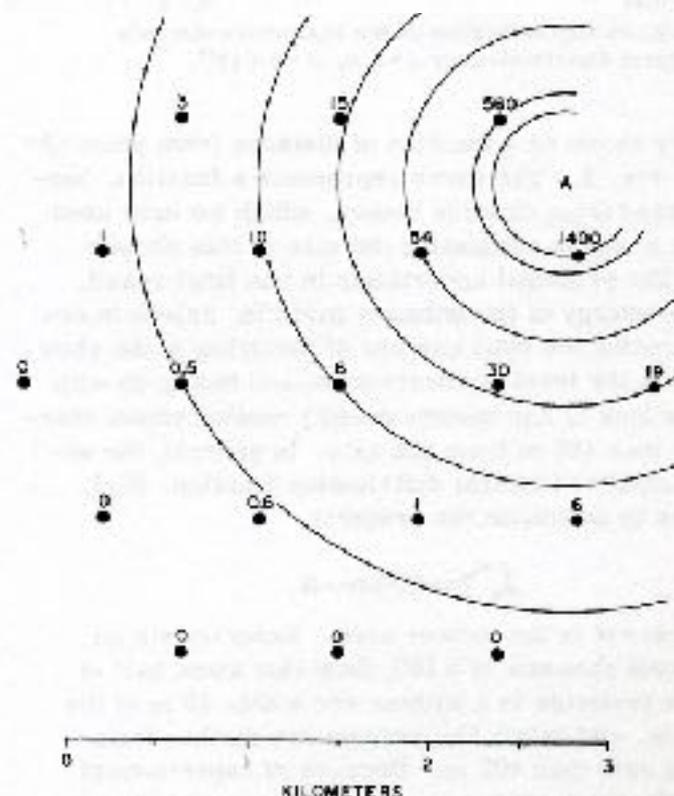


FIG. 1. Plan of the Volcano Ranch array in February 1962. The circles represent  $3.3\text{-m}^2$  scintillation detectors. The numbers near the circles are the shower densities (particles/ $\text{m}^2$ ) registered in this event, No. 2-4834. Point "A" is the estimated location of the shower core. The circular contours about that point aid in verifying the core location by inspection.

# emulsion chambers at high-altitude lab above Innsbruck (Austria)

about it is the simultaneous emission of so many heavy particles with such long ranges, which excludes any confusion with 'stars' due to radioactive contamination. A similar configuration of tracks by chance is equally out of question. Brode and others<sup>1</sup>

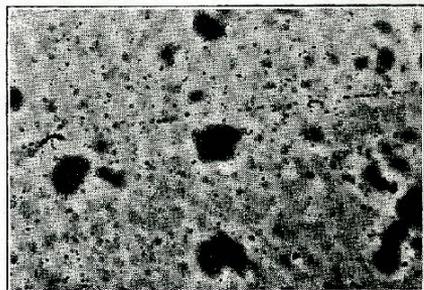
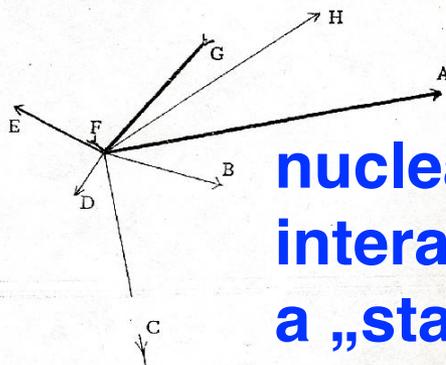


FIG. 1.

observed a single case of a disintegration with three heavy particles in a Wilson cloud chamber. The phenomenon which Wilkins believes was a shower of protons is perhaps a similar process, but he did not observe a centre<sup>2</sup>.



nuclear interactions a „star“

FIG. 2.

THICK LINES INDICATE A COMPARATIVELY LARGE NUMBER OF GRAINS PER UNIT OF LENGTH OF THE TRACK. AN INTERRUPTED LINE MEANS THAT THE TRACK IS TOO LONG TO BE REPRODUCED ON THE SAME SCALE. THE ARROWS INDICATE THE DIRECTION FROM THE SURFACE OF THE EMULSION TO THE GLASS.

The total energy involved in the process cannot as yet be calculated as most of the particles do not end in the emulsion. We hope to give further details before long in the Wiener Akademie-Berichte.

M. BLAU.  
H. WAMBACHER.

Radium Institut  
11. 2 Physik. Institut,  
Wien.  
Aug. 25.

<sup>1</sup> Brode, R. L., and others, *Phys. Rev.*, 50, 581 (October, 1936).  
<sup>2</sup> Wilkins, *Nat. Geog. Soc., Stratosphere Series*, No. 2, 37 (1936).

Disintegration Processes by Cosmic Rays with the Simultaneous Emission of Several Heavy Particles

On photographic plates which had been exposed to cosmic radiation on the Hafelekar (2,300 m. above sea-level) near Innsbruck for five months, we found, apart from the very long tracks (up to 1,200 cm. in length) which have been reported recently in a note in the Wiener Akademie-Berichte, evidence of several processes described below.

From a single point within the emulsion several tracks, some of them having a considerable length, take their departure. We observed four cases with three particles, four with four and 'stars' with six, seven, eight and nine particles, one of each kind.

The longest track corresponded to a range in air (15°, 760 mm. Hg) of 176 cm. The ionization produced by the particles is different in the different cases. Most of the tracks show much larger mean grain-distances than  $\alpha$ -particles and slow protons.

In Fig. 1 a 'star' with eight tracks is reproduced. On account of the rather steep angles at which some of the particles cross the emulsion-layer (approximately 70  $\mu$  thick) it is not possible to have all the tracks of a 'star' in focus simultaneously. Fig. 2 shows a sketch of the same 'star'. Measurement of the tracks gives the results in the accompanying table.

Track	Length in cm. of air (15°, 760 mm.)	Number of grains	Position of the end of the track
A	30.0 cm.	113	Within the emulsion
B	11.0 "	15	" " "
C	44.6 "	71	Glass
D	6.2 "	11	"
E	7.0 "	22	"
F	1.2 "	5	Within the emulsion
G	13.6 "	67	Surface of the emulsion
H	23.9 "	58	Glass

Centre of the 'star' 25  $\mu$  under the surface of the emulsion.

We believe that the process in question is a disintegration of an atom in the emulsion (probably Ag or Br) by a cosmic ray. The striking feature



Die "Station für Ultraviolettforchung" auf dem Hafelekar bei Innsbruck (2300 m), 1950, vor dem späteren Ausbau.



# emulsion chambers at high-altitude lab above Innsbruck (Austria)

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## Disintegration Processes by Cosmic Rays with the Simultaneous Emission of Several Heavy Particles

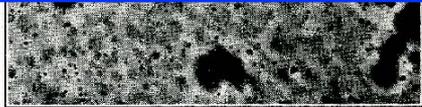


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M. BLAU.  
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Radium Institut  
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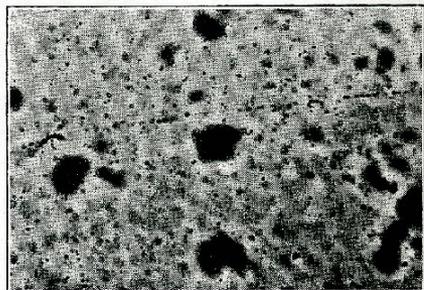
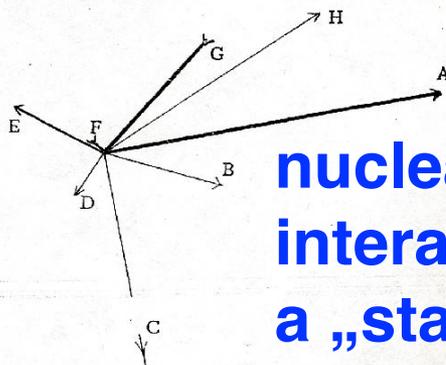


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Die "Station für Ultraviolettforchung" auf dem Hafelekar bei Innsbruck (2300 m), 1950, vor dem späteren Ausbau.



# Tracks of Nuclear Particles in Photographic Emulsions

MAURICE M. SHAPIRO

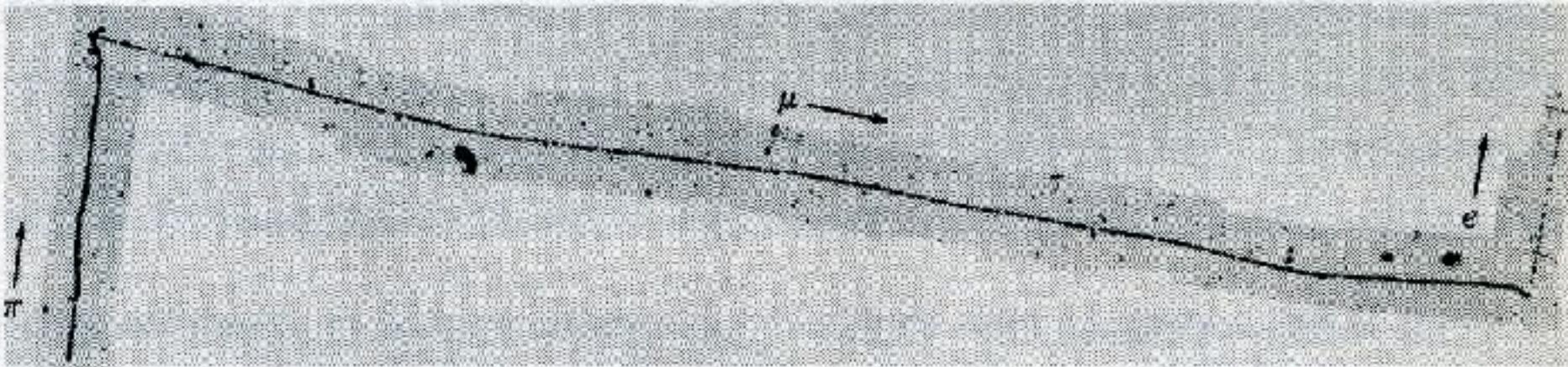
*Ryerson Laboratory, University of Chicago, Chicago, Illinois*

## CONTENTS

I. Early history of the direct photographic method . . . . .	58
II. Nature of the photographic technique—its advantages and limitations . . . . .	61
III. Contributions of the photographic method in the field of cosmic rays . . . . .	63
IV. Contributions of the photographic method to other problems in nuclear physics . . . . .	68

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# 1947 Discovery of the Pion



**Fig. 9-4** Photomicrograph of tracks in a nuclear emulsion, showing a  $\pi$  meson ( $\pi$ ) that comes to rest and decays into a  $\mu$  meson ( $\mu$ ). The  $\mu$  meson in turn comes to rest and decays into an electron ( $e$ ). (From R. H. Brown, U. Camerini, P. Fowler, H. Muirhead, C. F. Powell, and D. M. Ritson, *Nature*, vol. 163, p. 47, 1949.)

**C.F. Powell**  
**Nobel Prize 1950**

$$m_{\pi} \sim 280 m_e$$

**Pion: nuclear interaction**

$$\text{decay } \pi^{+/-} \rightarrow \mu^{+/-} \rightarrow e^{+/-}$$

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



# End 1940s plastic balloons



Fig. 7. Inflation of balloon of polyethylene just after dawn. The balloon has a total length of about 120 ft. and most of the fabric is on the ground. Such a balloon can in favorable conditions give level flight at about 90,000 ft. for many hours with a load of 40 kg.

# 1941 protons (M. Schein)

# End 1940s plastic balloons



Fig. 1. Inflation of balloon of polyethylene just after dawn. The balloon has a total length of about 120 ft. and most of the fabric is on the ground. Such a balloon can in favorable conditions give level flight at about 90,000 ft. for many hours with a load of 40 kg.

1941 protons (M. Schein)

1948 heavy nuclei (Brandt & Peters)

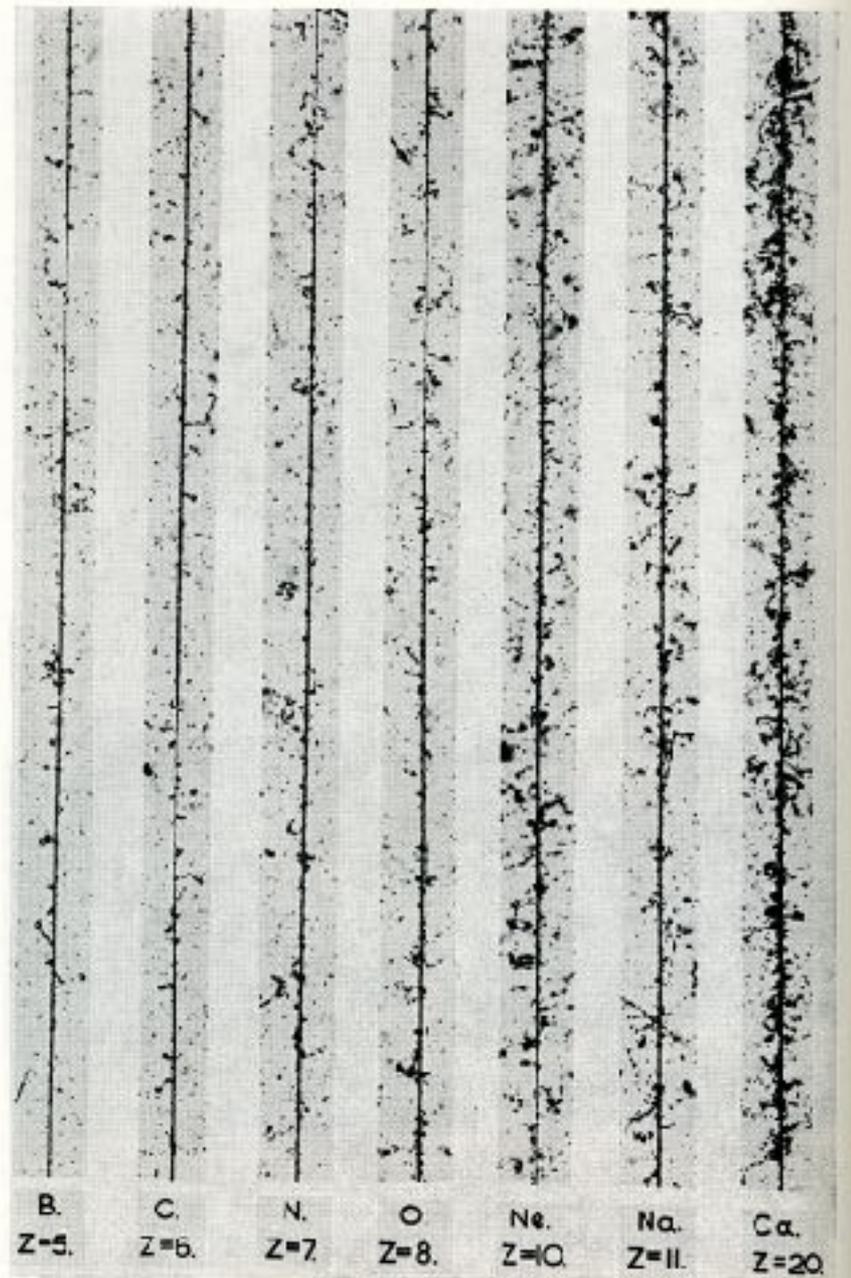


Fig. 2. Examples of the tracks in photographic emulsions of primary nuclei of the cosmic radiation moving at relativistic velocities.

## The Cosmic-Ray Counting Rate of a Single Geiger Counter from Ground Level to 161 Kilometers Altitude

J. A. VAN ALLEN AND H. E. TATEL\*

*Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland*

(Received October 16, 1947)

The cosmic-ray counting rate of a single Geiger counter has been measured from ground level to an altitude of 161 kilometers. The equipment was carried in a V-2 rocket at geomagnetic latitude  $\lambda=41^{\circ}\text{N}$ . Especial care was taken to avoid multiplicative effects from surrounding material. A value of the charged primary cosmic-ray flux of  $j=0.12/\text{sec./cm}^2/\text{steradian}$ , averaged over the upper hemisphere, is implied by the data above 55 km. This interpretation of the counting rate must be qualified by the as yet unknown contribution from secondaries which emerge from the atmosphere and execute orbits in the earth's magnetic field.

### 1. INTRODUCTION

THIS is one of a series of reports on cosmic ray experiments conducted by this laboratory in flights of V-2 rockets during the past year and a half. The data presented herein were obtained during the flight of July 29, 1947.

\* Now at Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C.

They are believed to be reliable but are provisional in the sense that they have been obtained in only one flight. A description of this work is thought to be worthwhile at this time for several reasons:

- (a) No previous comparable data are known to us.
- (b) The technique of using high altitude rockets as vehicles for scientific measurements is not as yet very generally known.

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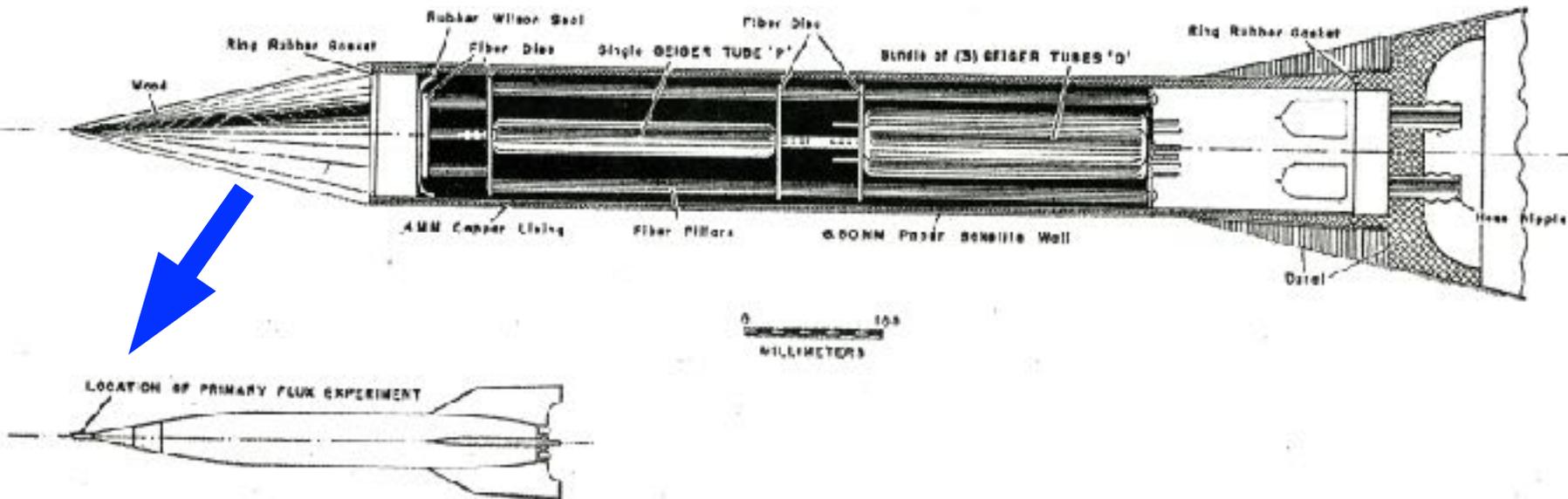


FIG. 1. Diagram of equipment, drawn to scale and showing location in V-2 rocket.

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counting rate

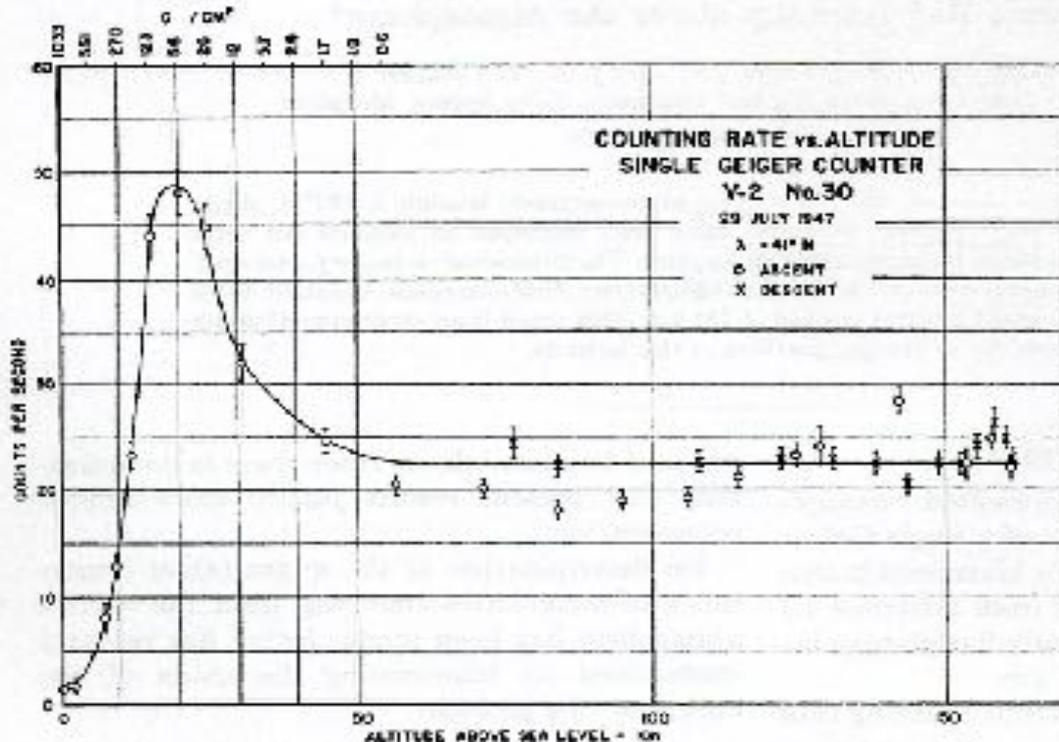
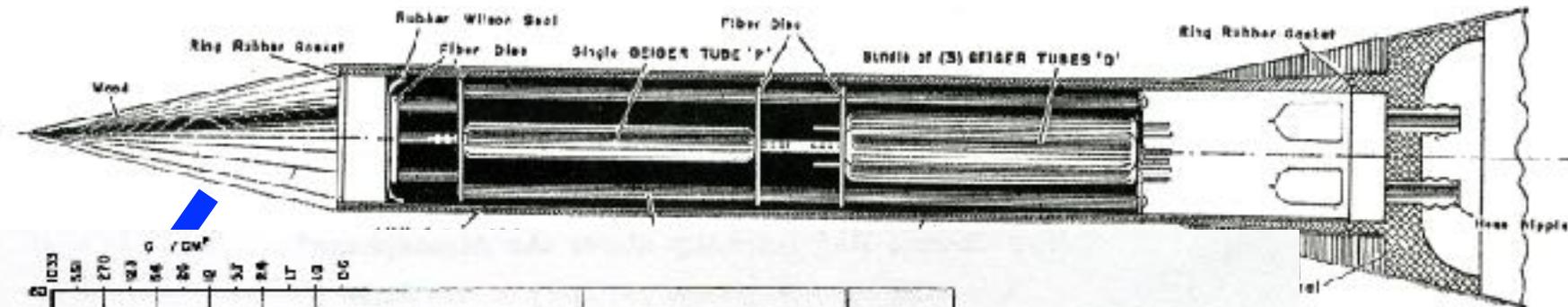
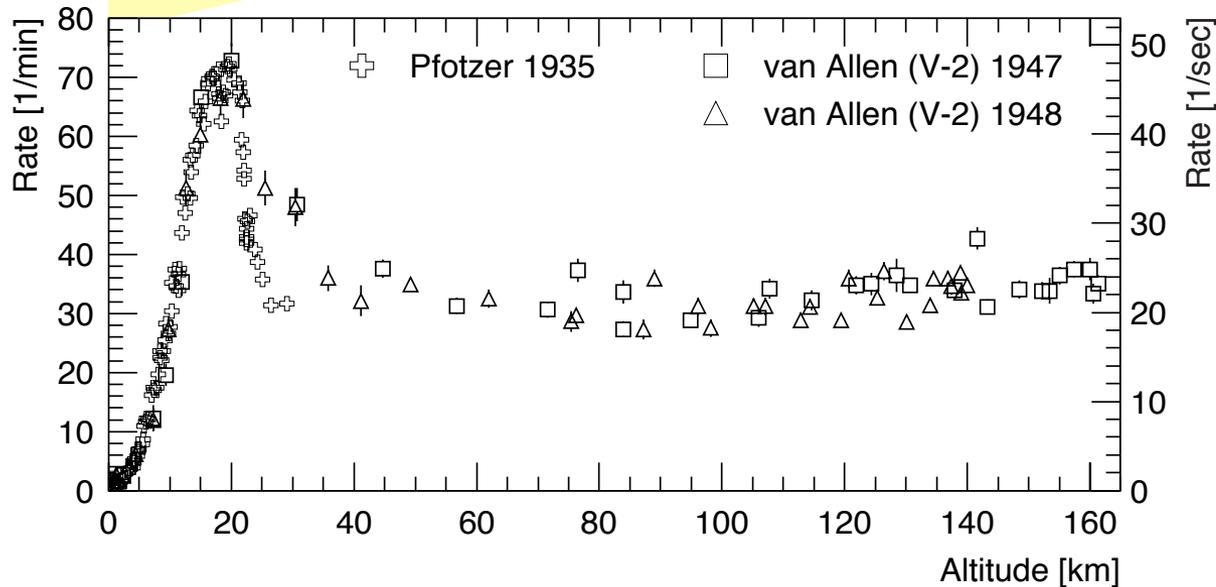
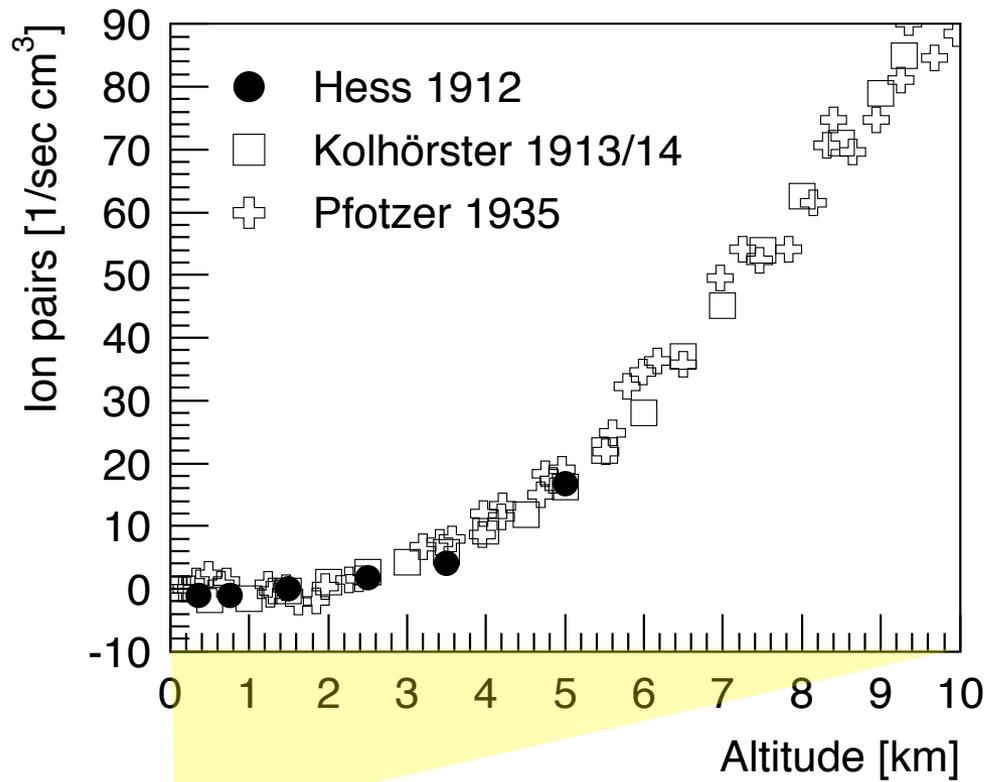


FIG. 1. Counting rate of a single Geiger counter as a function of altitude.

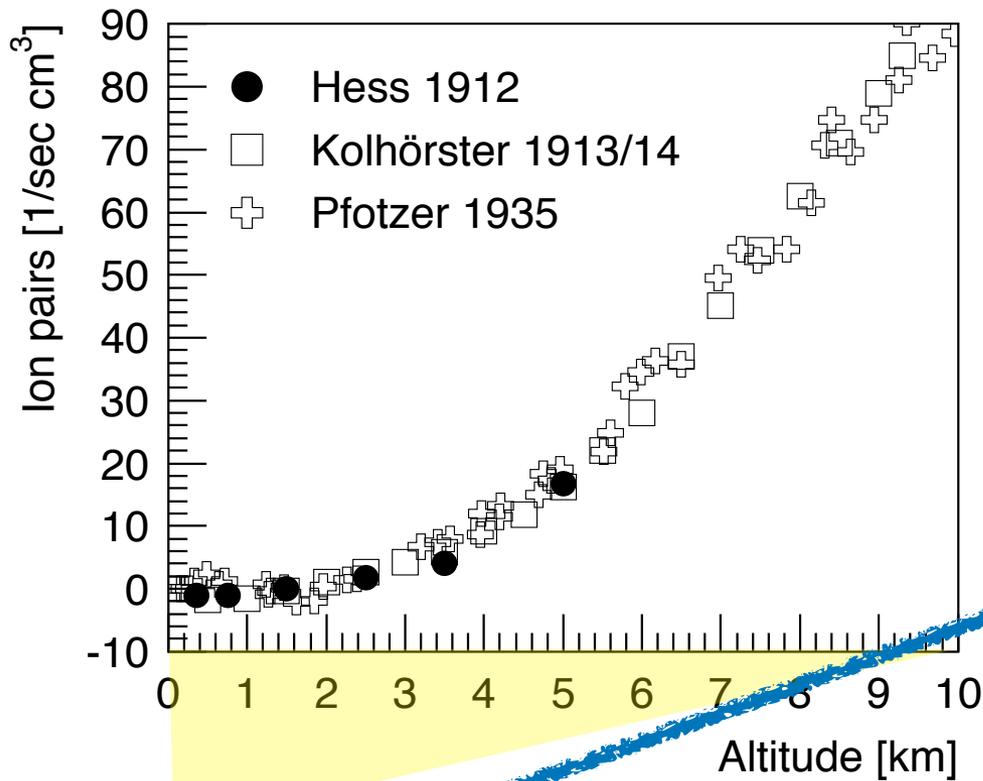
50 km

150 km

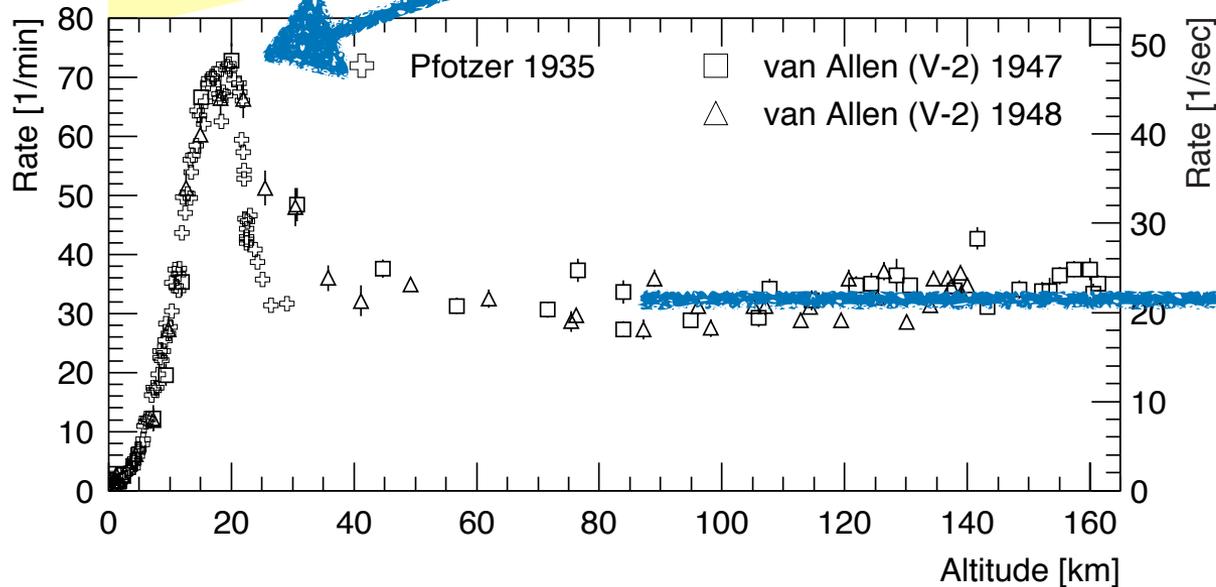
# Intensity vs. height



# Intensity vs. height



cosmic rays with  
~GeV energies  
initiate cascades in  
the atmosphere



(galactic)  
cosmic rays

## Stars and Heavy Primaries Recorded during a V-2 Rocket Flight

HERMAN YAGODA, HERVASIO G. DE CARVALHO,\* AND NATHAN KAPLAN  
*Laboratory of Physical Biology, Experimental Biology and Medicine Institute,  
 National Institutes of Health, Bethesda, Maryland*

(Received February 23, 1950)

Plates flown to an altitude of 150.7 km in a V-2 rocket exhibit a differential star population of  $5000 \pm 800$  per cc per day and a flux of heavy primaries of about 0.03 per  $\text{cm}^2$  per min. above the stratosphere. The star intensity is about 3.6 times greater than that recorded by plates exposed in the stratosphere, the increment being attributable to secondary star forming radiations created by interaction of cosmic-ray primaries with the massive projectile. The flux of heavy primaries is essentially of the same order of magnitude as reported for elevations of 28 km.

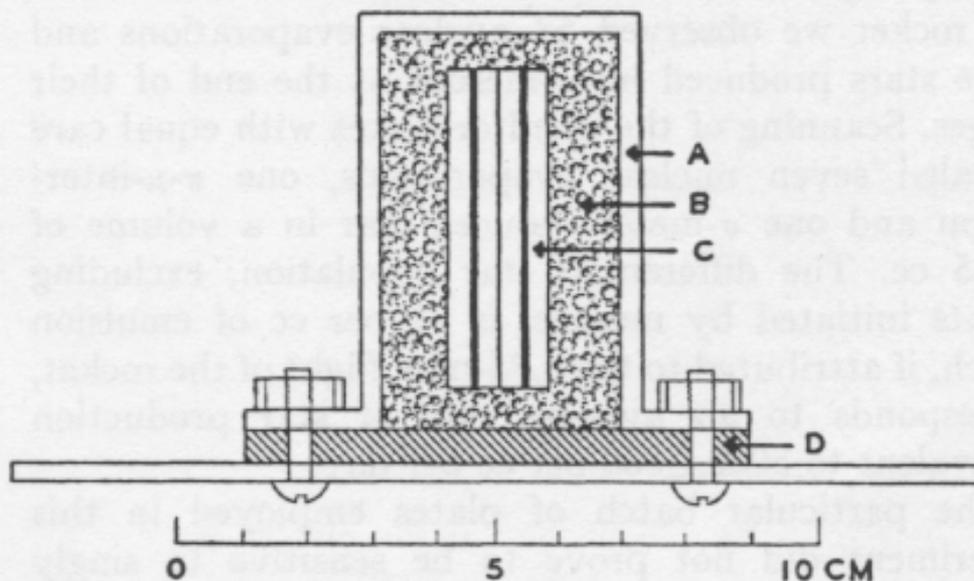


FIG. 1. Cross section of plate holder. A. Aluminum jacket 3 mm thick. B. Sponge rubber packing. C. Plates assembled with emulsion layers adjacent to each other. D. Rubber gasket.

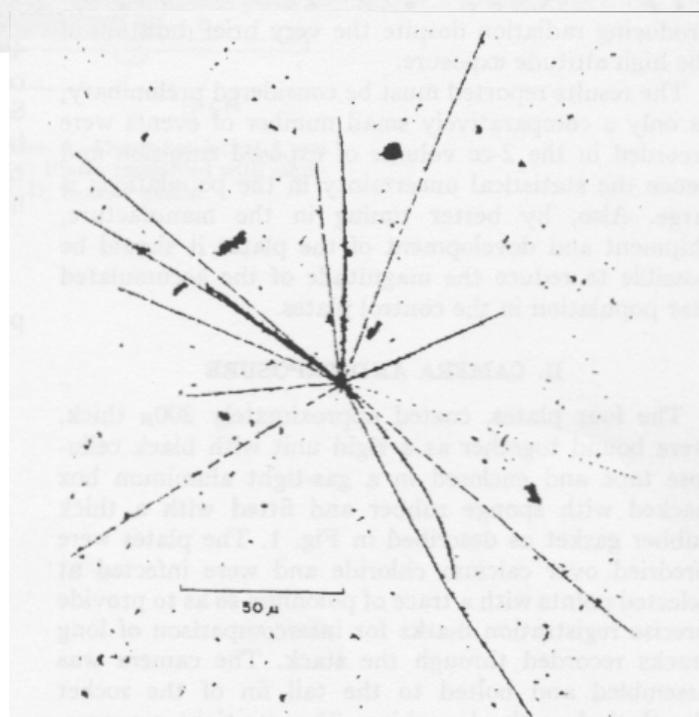


FIG. 3. Nuclear evaporation recorded in one of the rocket plates.

# 1953 Cosmic-Ray Conference

## birth of particle physics

### particles discovered in cosmic rays:

- 1932  $e^+$  Anderson
- 1937  $\mu$  Anderson/  
Neddermeyer
- 1947  $\pi$  Lattes,  
Occhialini, Powell
- 1947  $K$  Rochester,  
Butcher, Powell
- 1951-53 hyperons  
 $\Lambda$   $\Xi$   $\Sigma$

CONGRÈS INTERNATIONAL  
SUR LE  
RAYONNEMENT COSMIQUE

ORGANISÉ PAR  
L'UNIVERSITÉ DE TOULOUSE  
SOUS LE PATRONAGE DE L'UIPPA  
AVEC L'APPUI DE L'UNESCO

BAGNÈRES DE BIGORRE JUILLET 1953

# Rocket Determination of the Ionization Spectrum of Charged Cosmic Rays at $\lambda = 41^\circ\text{N}$

G. J. PERLOW,\* L. R. DAVIS, C. W. KISSINGER, AND J. D. SHIPMAN, JR.  
*U. S. Naval Research Laboratory, Washington, D. C.*

(Received June 30, 1952)

In a V-2 rocket measurement at  $\lambda = 41^\circ\text{N}$  an analysis has been made of the various components of the charged particle radiation on the basis of ionization and absorption in lead. The ionization was determined by two proportional counters, the particle paths through which were defined by Geiger counters. With increasing zenith angle toward the north, the intensity is found to be substantially constant until the earth ceases to cover the under side of the telescope. The intensity of all particles with range  $\geq 7 \text{ g/cm}^2$  is  $0.079 \pm 0.005 \text{ (cm}^2 \text{ sec steradian)}^{-1}$ . Of this an intensity  $0.012 \pm 0.002$  is absorbed in the next  $14 \text{ g/cm}^2$ . The ionization measurement is consistent with  $\frac{2}{3}$  of these soft particles being electrons of  $< \sim 60 \text{ Mev}$ , the remainder being slow protons and alpha-particles. For the particles with greater range an ionization histogram is plotted, the smaller of the two ionization measurements for a single event being used to improve the resolution. The particles divide into protons, alpha-particles, and one carbon nucleus, with  $N_p/N_\alpha = 5.3 \pm 1.0$ . Their absorption is exponential with mean free path  $440 \pm 70 \text{ g/cm}^2 \text{ Pb}$ . Extrapolating to zero thickness, the total primary intensity is  $0.070 \pm 0.005 \text{ (cm}^2 \text{ sec steradian)}^{-1}$  with  $0.058 \pm 0.005$  as protons,  $0.011 \pm 0.002$  as alpha-particles, and  $0.001 \pm 0.001$  as  $Z > 2$ .

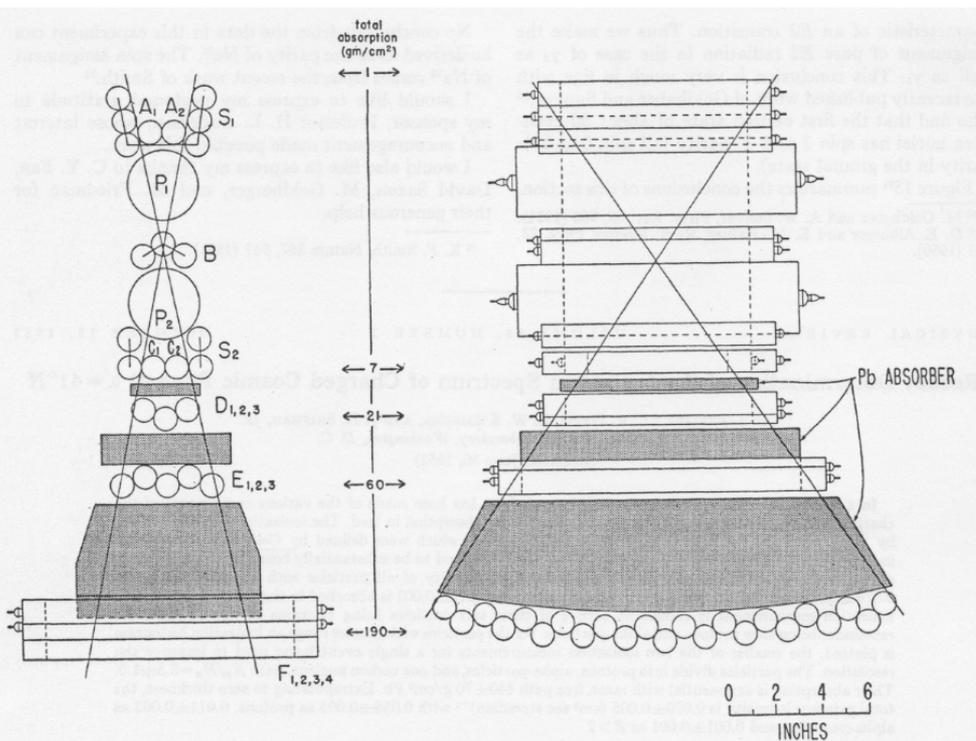


FIG. 1. Diagram of telescope.

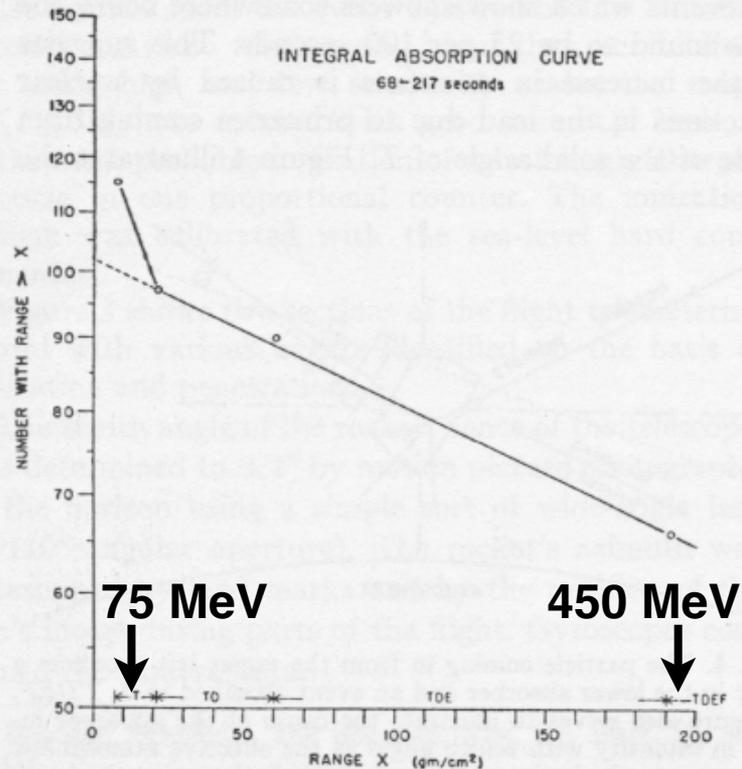


FIG. 6. Absorption in lead of the total radiation.

## Radiation Around the Earth to a Radial Distance of 107,400 km.

JAMES A. VAN ALLEN & LOUIS A. FRANK

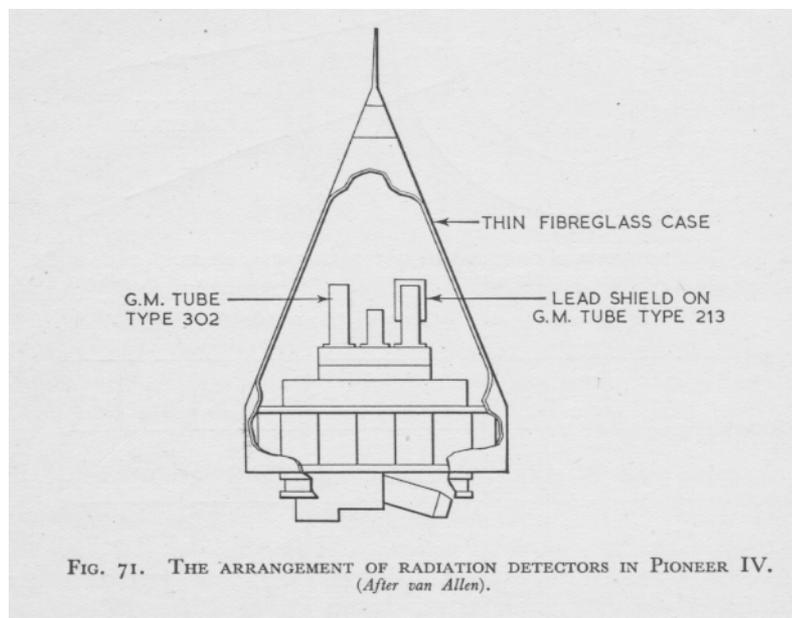


FIG. 71. THE ARRANGEMENT OF RADIATION DETECTORS IN PIONEER IV. (After van Allen).

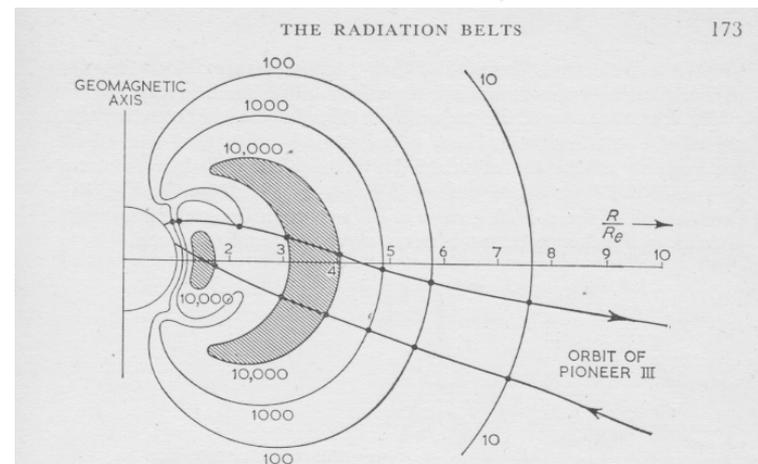


FIG. 69. THE DISTRIBUTION OF INTENSITY IN THE RADIATION BELTS. (6 DEC. 1958). The diagram represents a cross section through a meridian plane.  $R_e$  ( $\sim 6400$  km) is the radius of the earth. (After van Allen and Frank, *Nature*, 183, 430 (1959)).

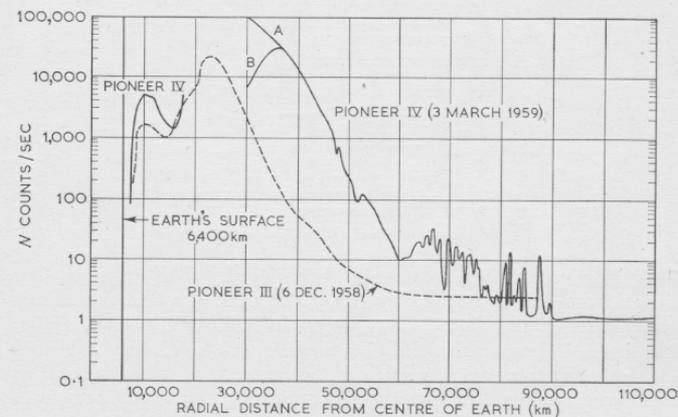


FIG. 70. A COMPARISON OF THE INTENSITIES OF RADIATION FOUND WITH NEARLY IDENTICAL COUNTERS IN PIONEER III AND PIONEER IV. The trajectories of the two probes were almost, but not quite, the same. At the peak of the second belt the readings of the intensity from Pioneer IV were ambiguous and followed either curve A or curve B. Curve A is more probable. (After van Allen and Frank, *Nature* 184, 219 (1960)).



## John Simpson (Chicago)

**Precision  
measurements of CR  
abundances**

**dE/dx vs. E technique with  
solid state detectors in  
space**

**1958 PIONEER 2**

**1959 EXPLORER 6**

**subsequently, more than 20 other space missions**

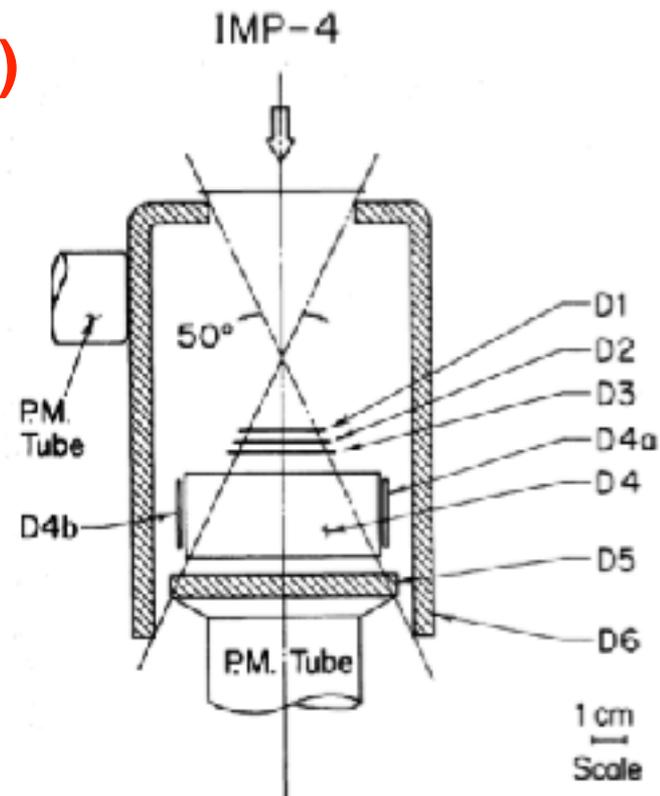
**including: IMP1-8; OGO 1,3,5 - Earth orbit**

**PIONEER 5,6,7 - Solar orbit;**

**PIONEER 10,11 - out of Solar System**

**ULYSSES - out of ecliptic plane (Jupiter flyby)**

- **Elemental composition of cosmic rays**
- **Isotopic composition**
- **Measurement of anomalous cosmic rays**
- **Particles and fields in the Heliosphere**
- **Planetary magnetospheres**
- **Solar modulation to outer Heliosphere**





**John Simpson**

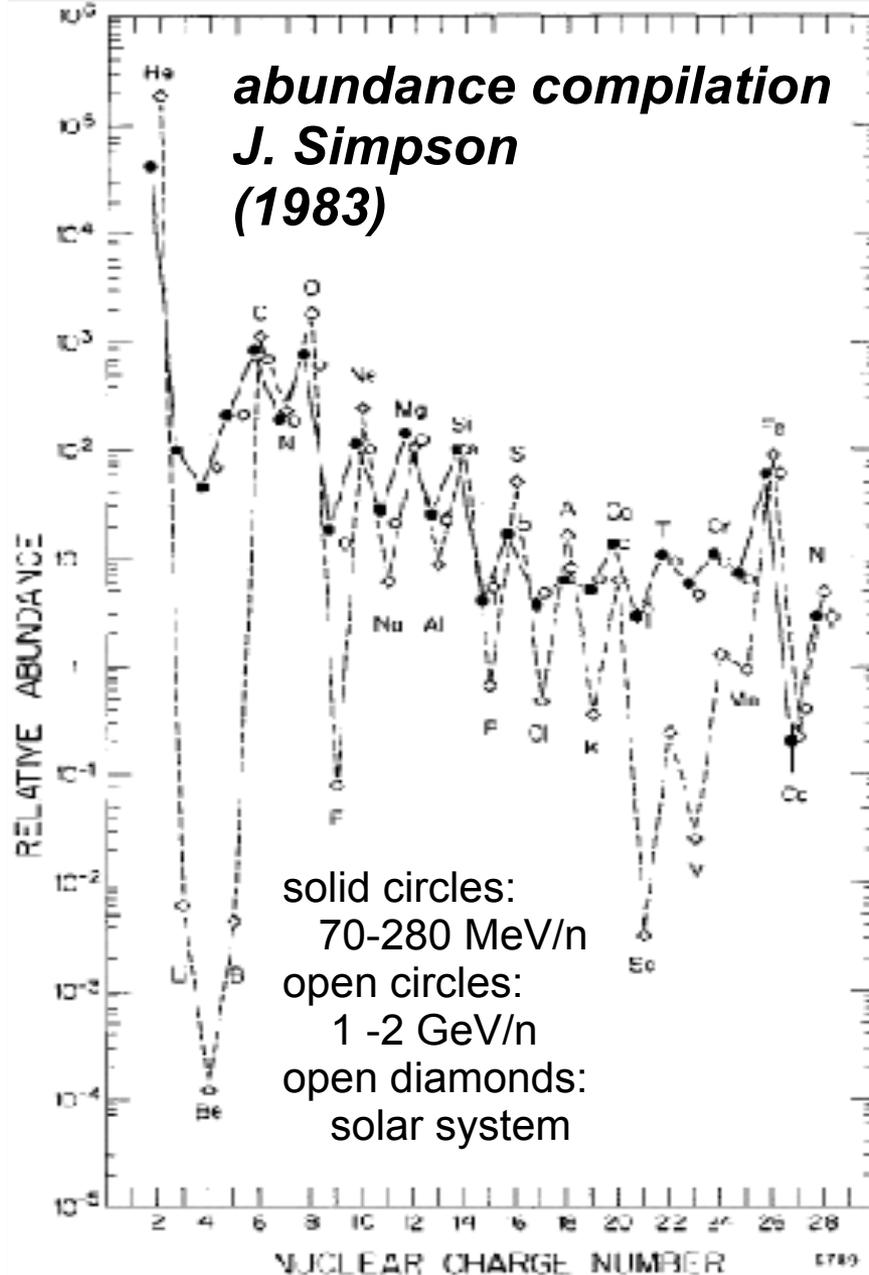
**Precise  
measur  
abunda  
dE/dx vs  
solid sta  
space**

**1958 PIONEER 2**

**1959 EXPLORER 6**

subsequently, more than 20 o  
*including: IMP1-8; OGO 1,3,5*  
*PIONEER 5,6,7 - S*  
*PIONEER 10,11 - o*  
*ULYSSES - out of*

- **Elemental composition of co**
- **Isotopic composition**
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- **Particles and fields in the He**
- **Planetary magnetospheres**
- **Solar modulation to outer He**



## THE AGE OF THE GALACTIC COSMIC RAYS DERIVED FROM THE ABUNDANCE OF $^{10}\text{Be}^*$

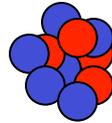
M. GARCIA-MUNOZ, G. M. MASON, AND J. A. SIMPSON†

Enrico Fermi Institute, University of Chicago

*Received 1977 March 14; accepted 1977 April 21*



$^{10}\text{Be}$

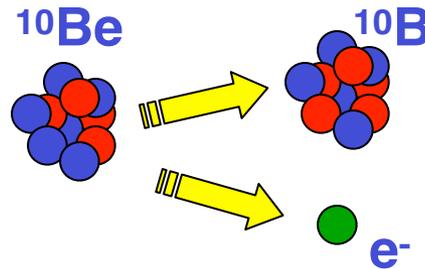


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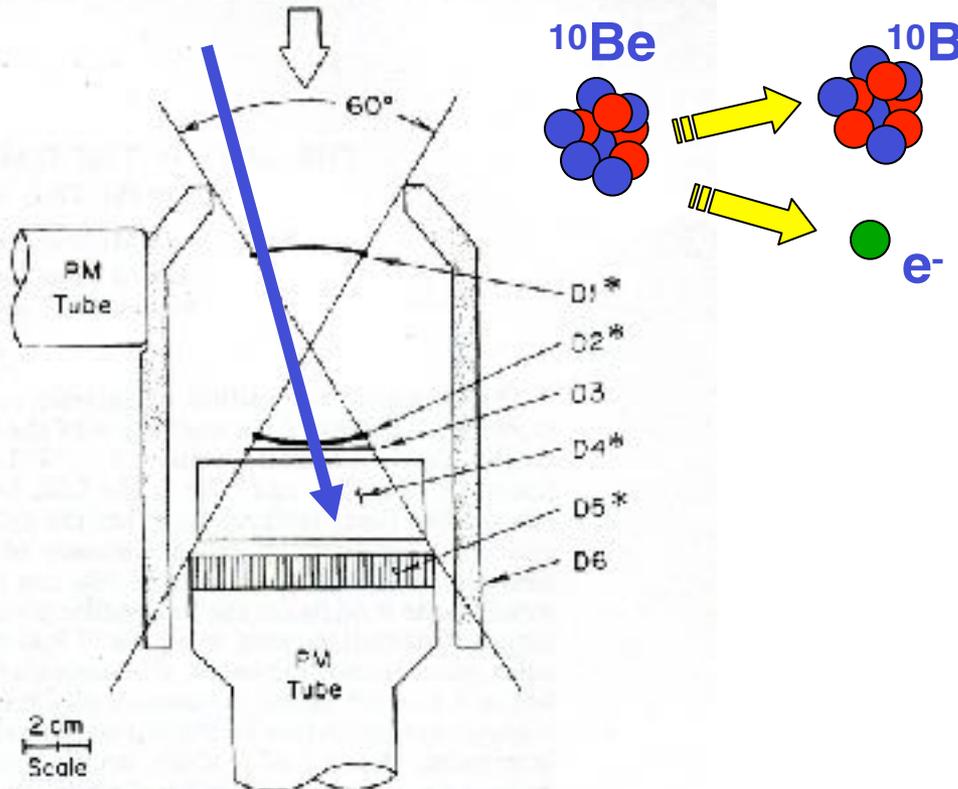


FIG. 1.—Cross section of the IMP-7 and IMP-8 telescopes. D1, D2, and D3 are lithium-drifted silicon detectors of thickness 750, 1450, and 800  $\mu\text{m}$ , respectively. D4 is an  $11.5 \text{ g cm}^{-2}$  thick CsI (Tl) scintillator viewed by four photodiodes. D5 is a sapphire scintillator/Cerenkov radiator of thickness  $3.98 \text{ g cm}^{-2}$ , and D6 is a plastic scintillation guard counter viewed by a photomultiplier tube. Asterisks denote detectors whose output is pulse-height analyzed.

# Age of cosmic rays

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$$\tau = 17 \cdot 10^6 \text{ a}$$

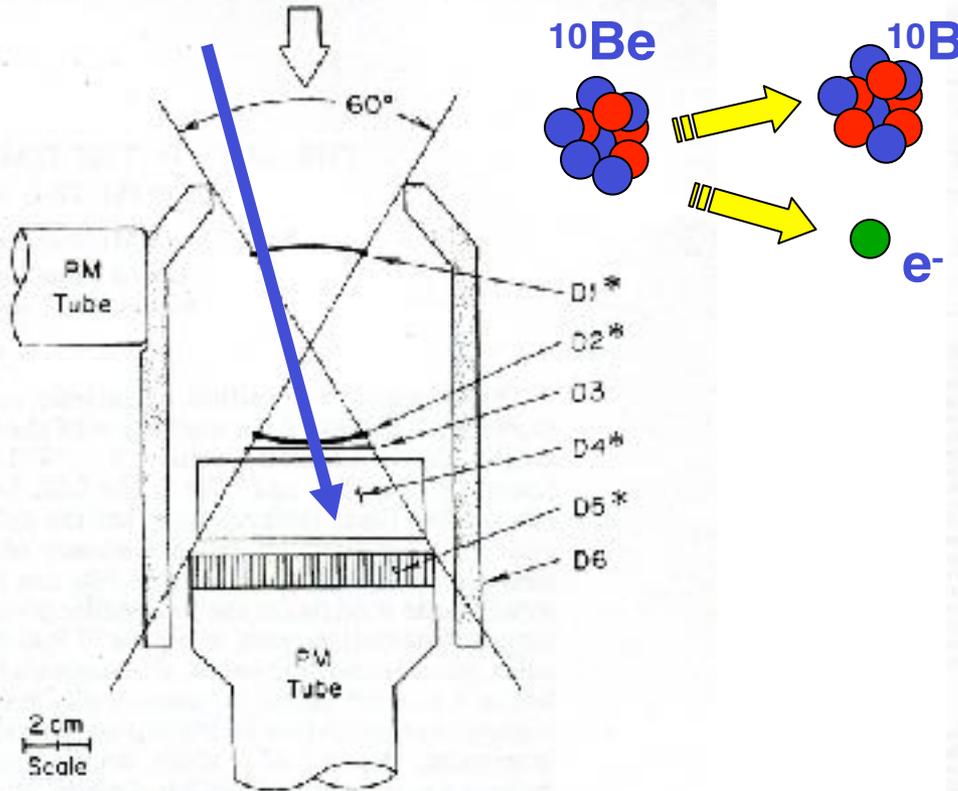
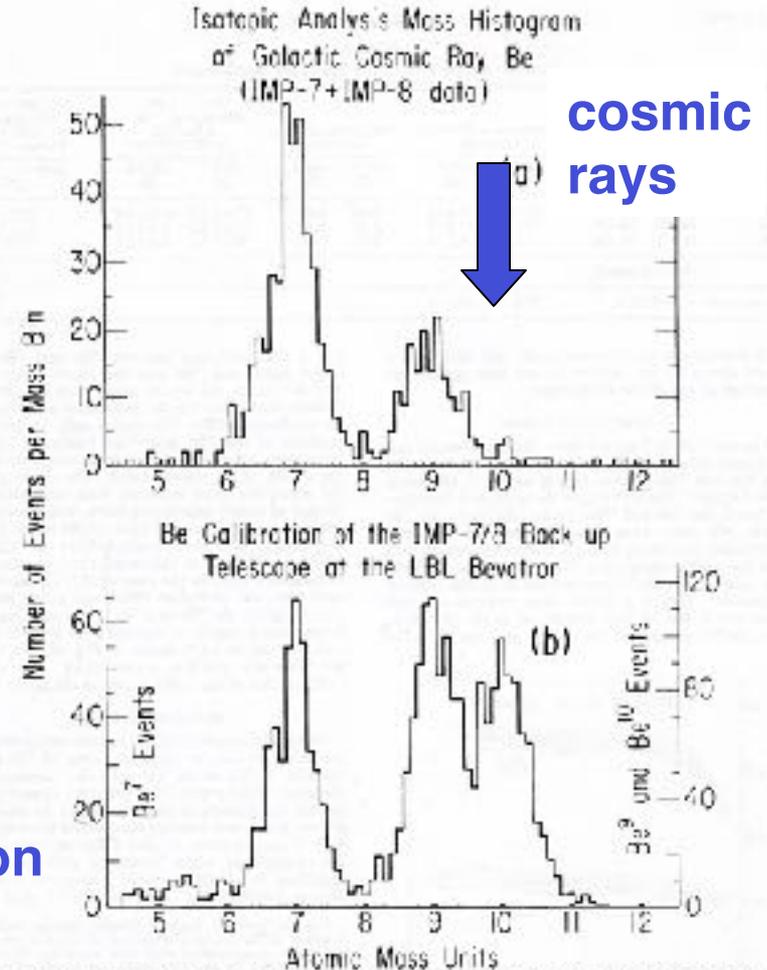
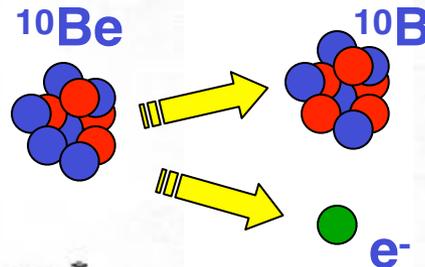


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calibration

FIG. 1.—(a) Mass histogram of Be isotopes from IMP-7 and IMP-8 combined. (b) Corresponding mass histogram obtained with the backup instrument at the Bevatron calibration.

# Path length of cosmic rays

## Composition of Cosmic-Ray Nuclei at High Energies\*

Einar Juliusson, Peter Meyer, and Dietrich Müller

*Enrico Fermi Institute and Department of Physics, University of Chicago, Chicago, Illinois 60637*

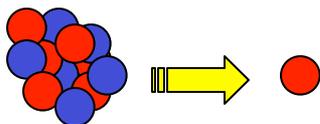
(Received 26 May 1972)

We have measured the charge composition of cosmic-ray nuclei from Li to Fe with energies up to about 100 GeV/nucleon. A balloon-borne counter telescope with gas Cherenkov counters for energy determination was used for this experiment. Our first results show that, in contrast to low-energy observations, the relative abundances change as a function of energy. We find that the ratio of the galactic secondary nuclei to primary-source nuclei decreases at energies above about 30 GeV/nucleon.

g/cm<sup>2</sup>



## spallation



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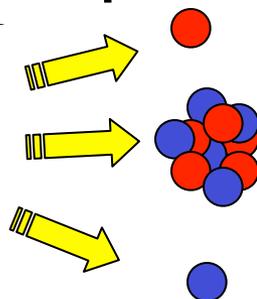
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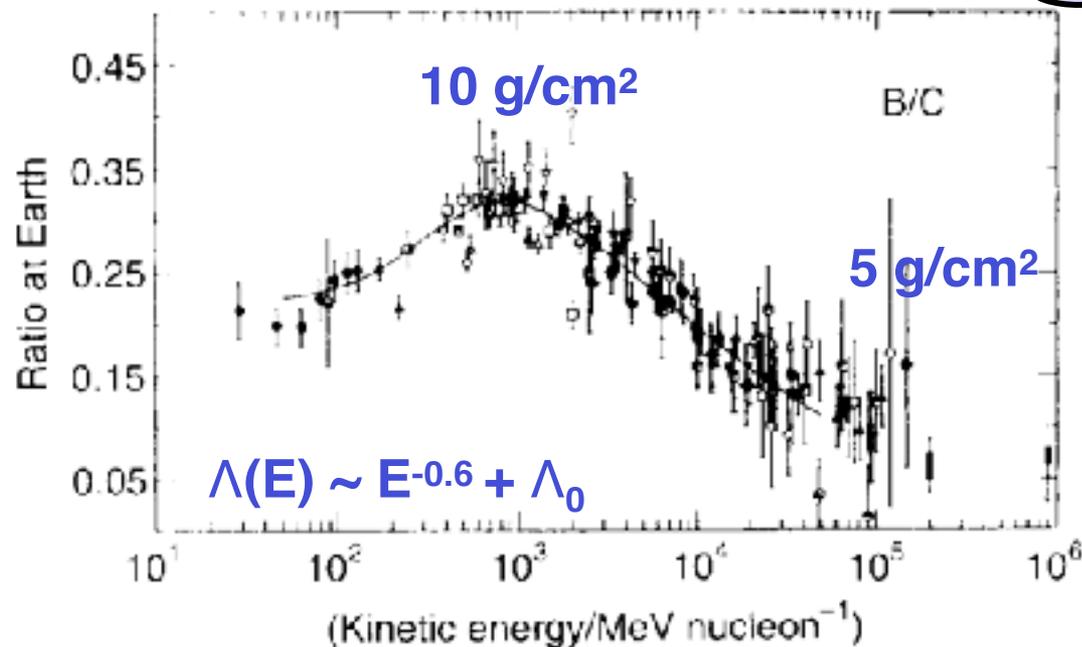
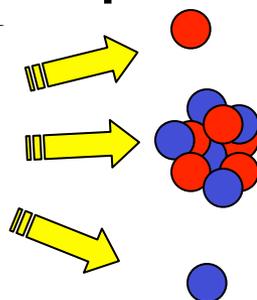
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g/cm<sup>2</sup>



### B/C-ratio

### spallation



# Origin of Cosmic Rays?

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1927 R.A. Millikan: „death cries of atoms“



# Origin of Cosmic Rays?

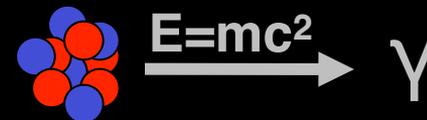
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1933 Regener: E density in CRs  $\sim$  E density of B field in Galaxy

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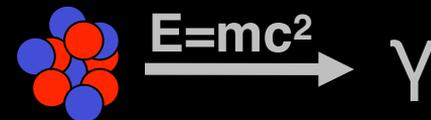
1934 Supernovae



Walter Baade Fritz Zwicky

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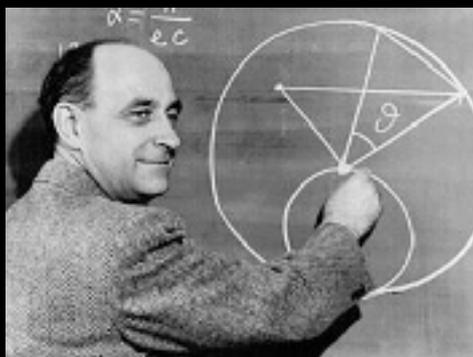
1933 Regener: E density in CRs  $\sim$  E density of B field in Galaxy

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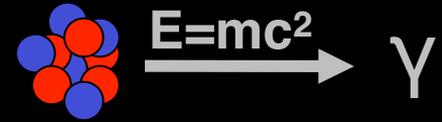
Walter Baade Fritz Zwicky

1949 E. Fermi: acceleration at magnetic clouds



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1927 R.A. Millikan: „death cries of atoms“



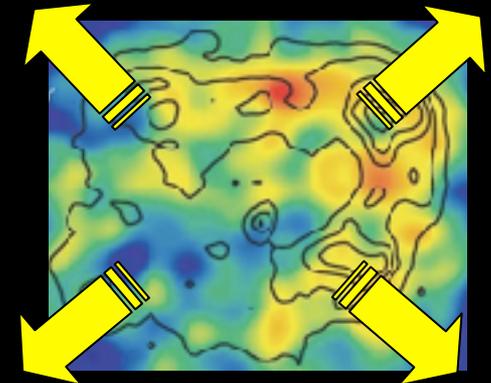
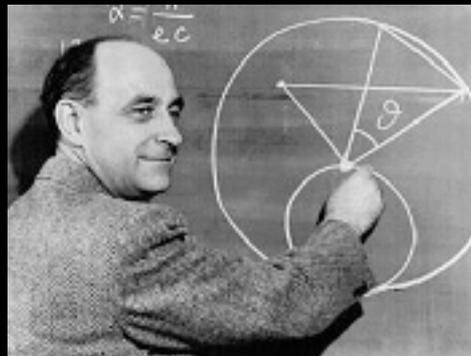
1933 Regener: E density in CRs  $\sim$  E density of B field in Galaxy

1934 Supernovae



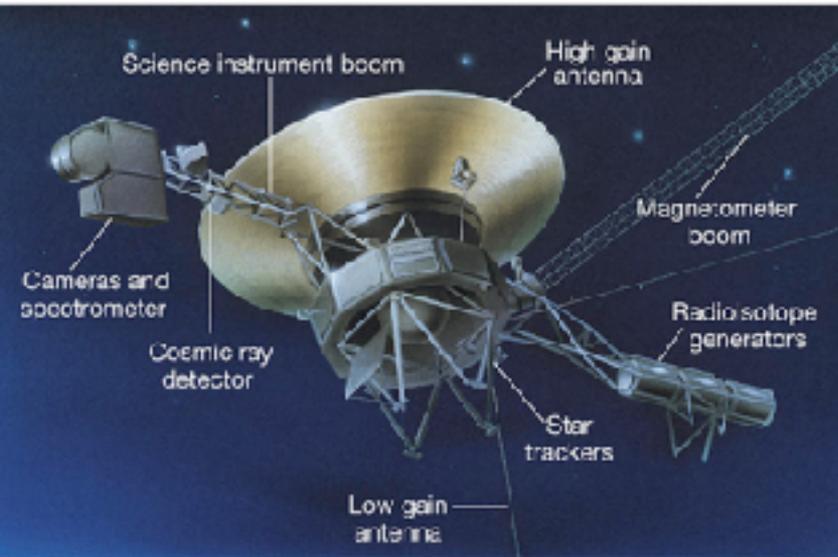
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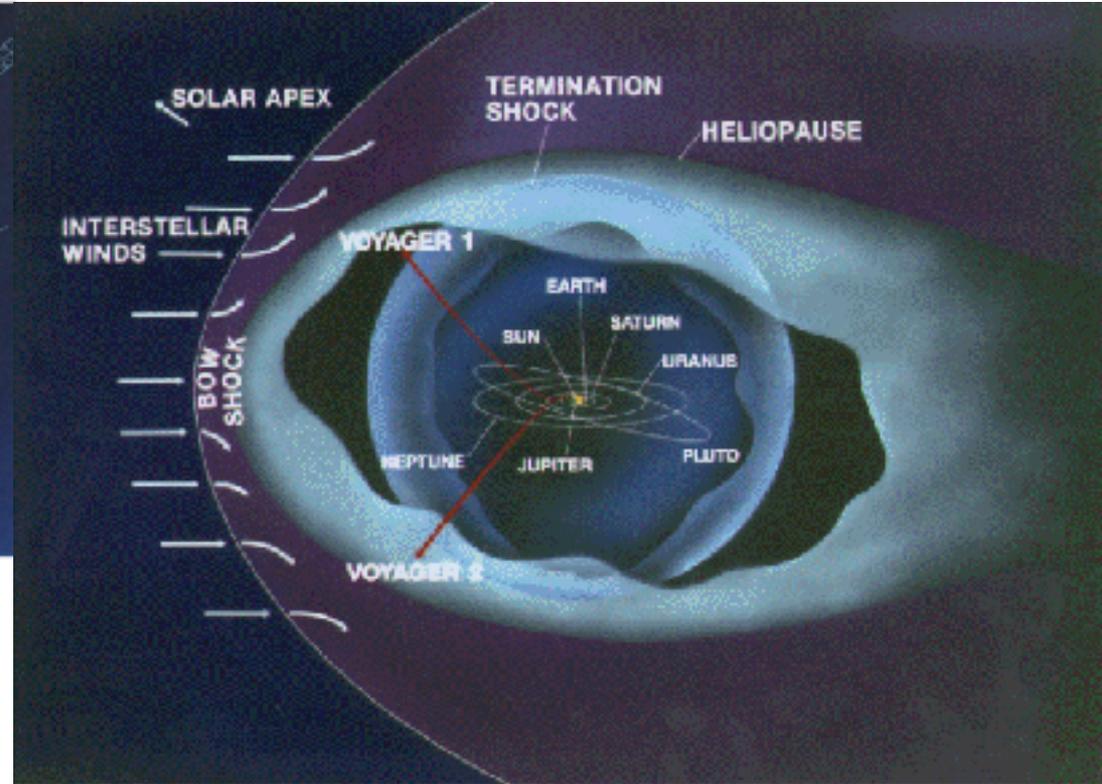
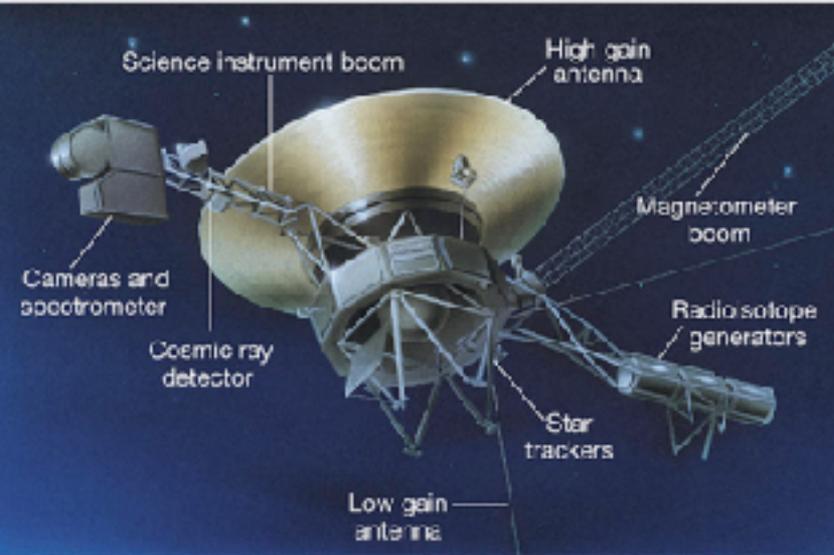
1978 R.D. Blanford, J.P. Ostriker: acceleration at strong shock front  
(1st order Fermi acceleration)

# Beyond the boundaries of our Solar System



**Voyager 2: 20 August 1977**  
**Voyager 1: 5 September 1977**  
**Kenedy Space Center**

# Beyond the boundaries of our Solar System

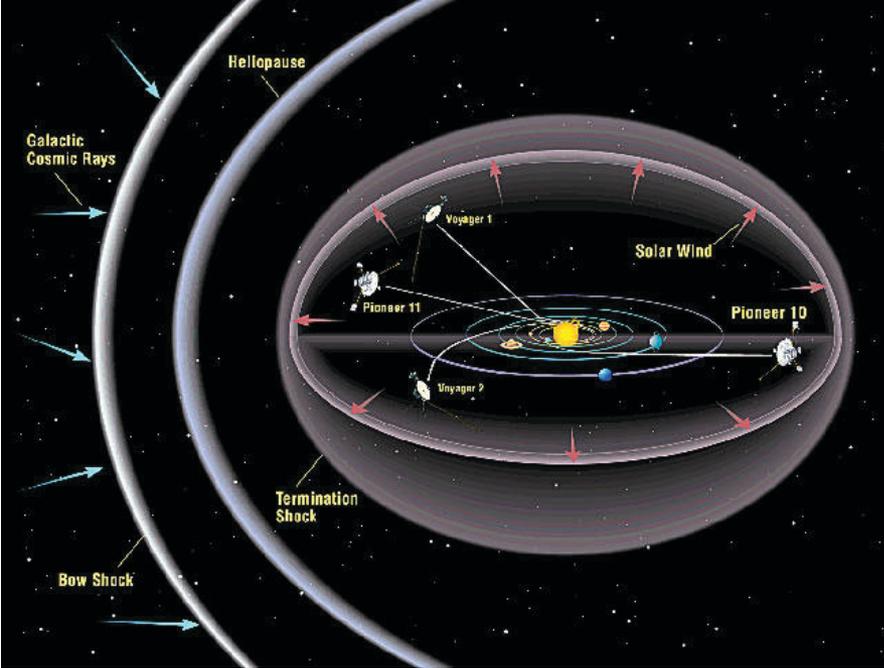


passage through termination shock ended  
Voyager 1: 94 AU, December 2004  
Voyager 2: 84 AU, August 2007

February 2012: Voyager 1: 119.7 AU from Sun  
Voyager 2: 97.7 AU from Sun

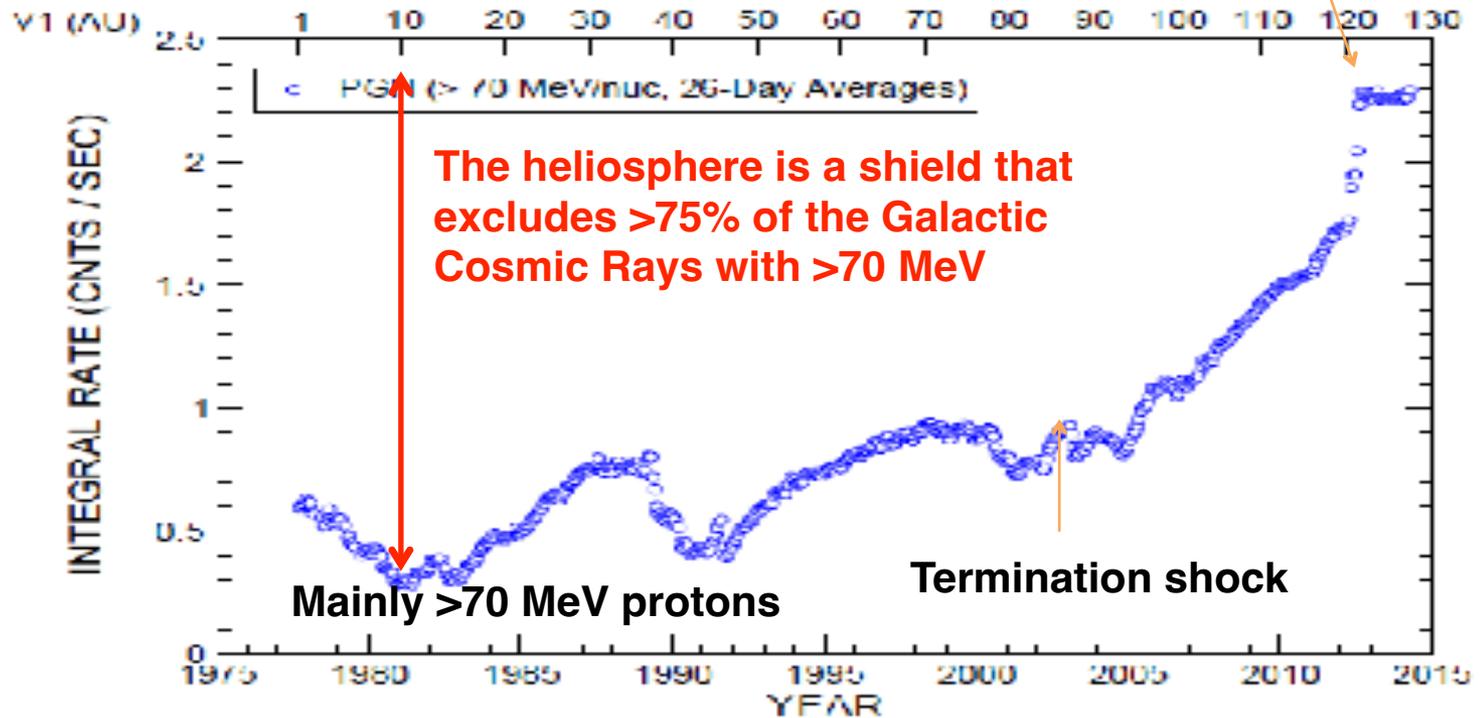
Voyager 2: 20 August 1977  
Voyager 1: 5 September 1977  
Kennedy Space Center

# Galactic Cosmic Rays and the Heliosphere



Voyager 1, launched September 5th, 1977

August 25th, 2012  
Interstellar Space



# Historical introduction

## Basic properties of Cosmic Rays



«ETTORE MAJORANA» FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE

INTERNATIONAL SCHOOL OF COSMIC-RAY ASTROPHYSICS  
«MAURICE M. SHAPIRO»

*22<sup>nd</sup> Course: "From cosmic particles to gravitational waves: now and to come"*  
*30 July – 7 August 2022*

PRESIDENT AND DIRECTOR OF THE CENTRE: PROFESSOR A. ZICHICHI

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Nikhef



Jörg R. Hörandel

RU Nijmegen, Nikhef, VU Brussel

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