INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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SCHOOL ON NON-ACCELERATOR PHYSICS
25 April - 6 May 1988

PARTICLE PHYSICS WITHE BALLOONS SATELLITES AND SPACE STATIONS

by

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SIGNIFICANCE OF PARTICLE ASTROPHYSICS

ORIGIN OF THE ELEMENTS

- How are the elements synthesized in stars and supernovae?
- How is the chemical composition of the Galaxy evolving with time?

ORIGIN OF THE SOLAR SYSTEM

- What is the composition of the Sun, and how does it differ from that of the local interstellar medium and other regions of the Galaxy?

ORIGIN OF COSMIC RAYS

- What are the mechanisms for accelerating charged particles on the Sun, in interplanetary space, in the Galaxy, and on even larger, extra-galactic scales?
- What are the sites of galactic cosmic-ray acceleration - are they compact objects or young supernovae, or are they large-scale shocks?

ORIGIN OF THE GALAXY AND THE UNIVERSE

- Is there primordial antimatter in the universe?
- Do anti-galaxies and/or anti-stars exist?
- Are there exotic forms of dark matter in the universe?

Spacecraft Carrying Cosmic-Ray Experiments
Launched since 1975 or approved

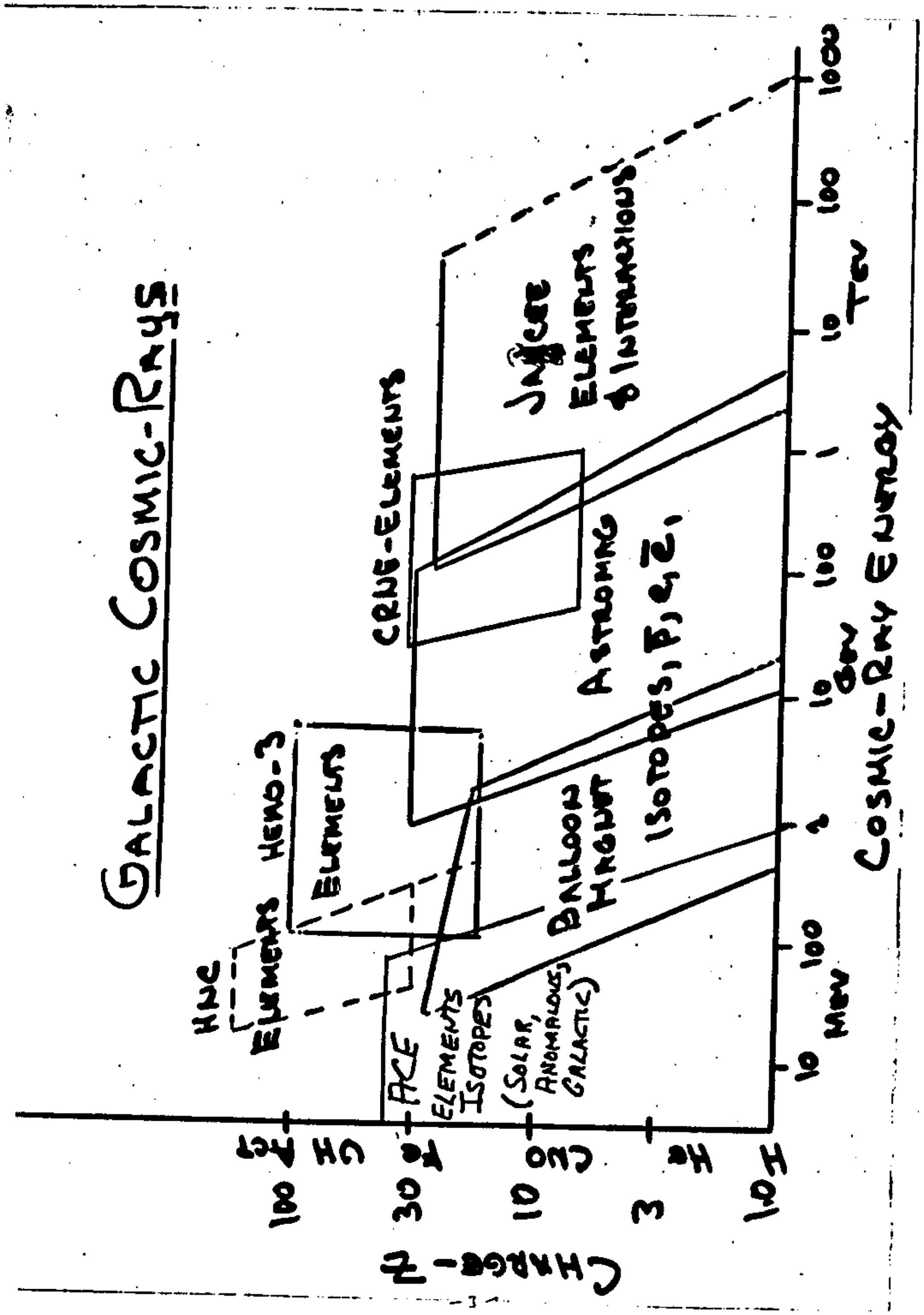
Launch

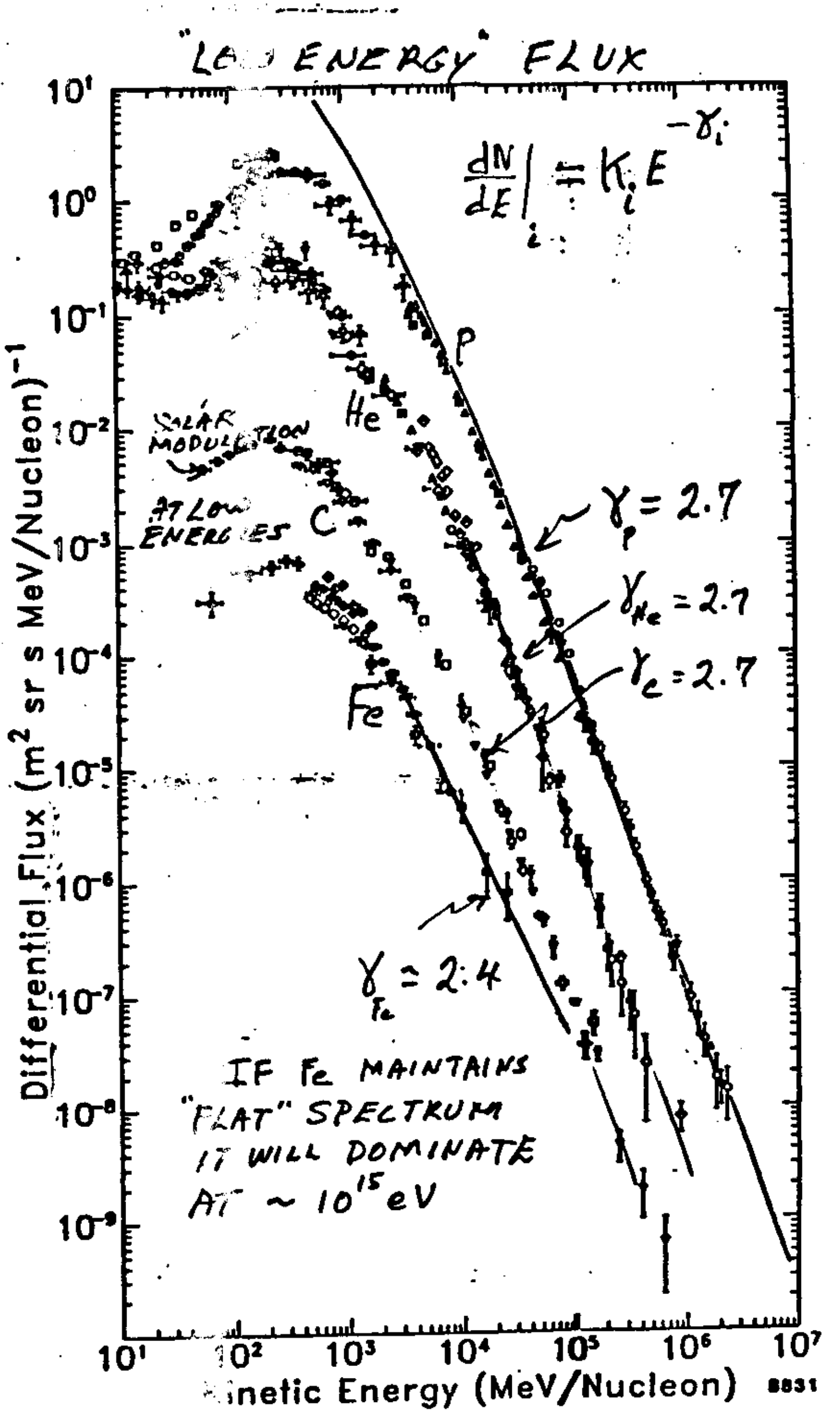
1978 ISEE-3 First clearly resolved isotopes of Be, Ne, Mg, Si, and others

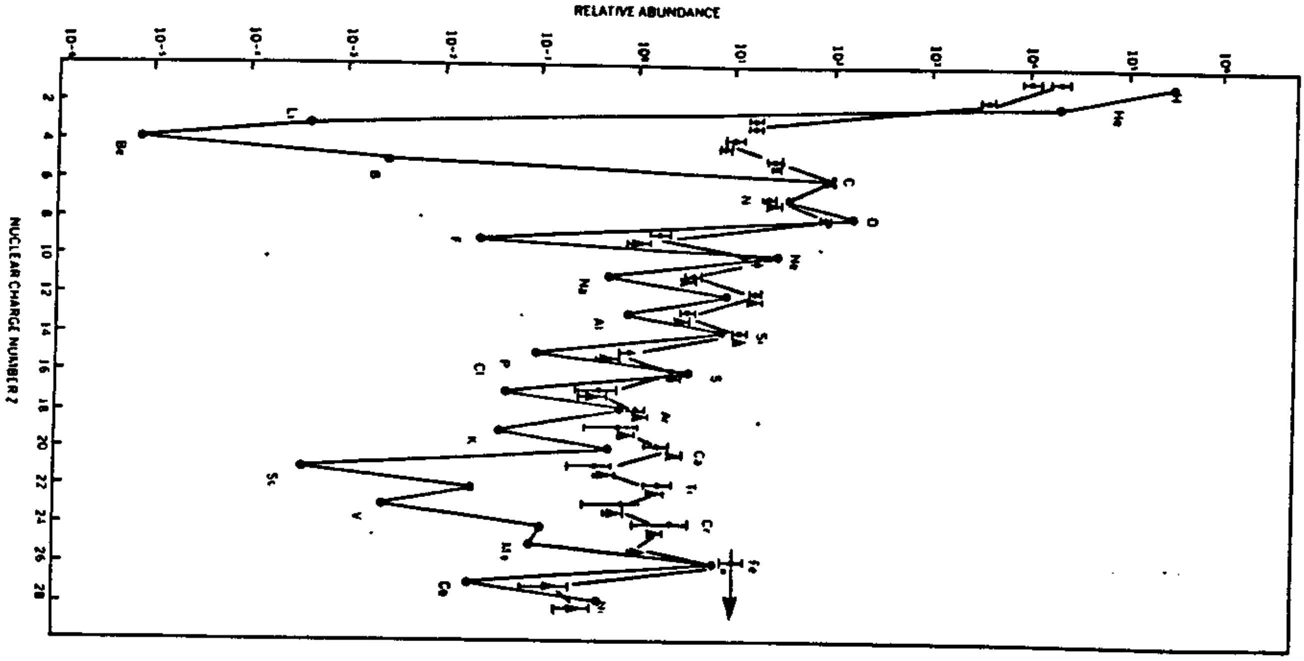
1979 HEAO-3 Element spectra for $4 \leq Z \leq 28$ to 25 GeV/amu
Individual elements resolved for $Z \leq 58$

1985 Spacelab-2 Element spectra $3 \leq Z \leq 28$
Max energy 100 to 1000 GeV/amu
limited by short exposure time

1986 Ulysses Isotopic composition
Sensitivity factor 10 better than ISEE-3


GALACTIC COSMIC-RAYS
COSMIC-RAY ENERGY
10 MeV
100 MeV
1 GeV
10 GeV
100
1 TeV
10 TeV
100
1000
CHARGE - Z
1.0 H
3 He
10 CNO
30 Fe
100 UH Act
ACE
ELEMENTS
ISOTOPES
(SOLAR, ANOMALOUS, GALACTIC)
HNC ELEMENTS
HEAO-3 ELEMENTS
BALLOON MAGNET
ISOTOPES, p̄, e, ē
CRNE-ELEMENTS
ASTROMAG
JACEE ELEMENTS & INTERACTIONS
-3-


"LOW ENERGY" FLUX
$\left.\frac{dN}{dE}\right|_i = K_i E^{-\gamma_i}$
Differential Flux (m² sr s MeV/Nucleon)⁻¹
Kinetic Energy (MeV/Nucleon)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10²
10³
10⁴
10⁵
10⁶
10⁷
P
He
C
Fe
SOLAR MODULATION AT LOW ENERGIES
$\gamma_p = 2.7$
$\gamma_{He} = 2.7$
$\gamma_C = 2.7$
$\gamma_{Fe} = 2.4$
IF Fe MAINTAINS "FLAT" SPECTRUM IT WILL DOMINATE AT ~ 10¹⁵ eV
8831



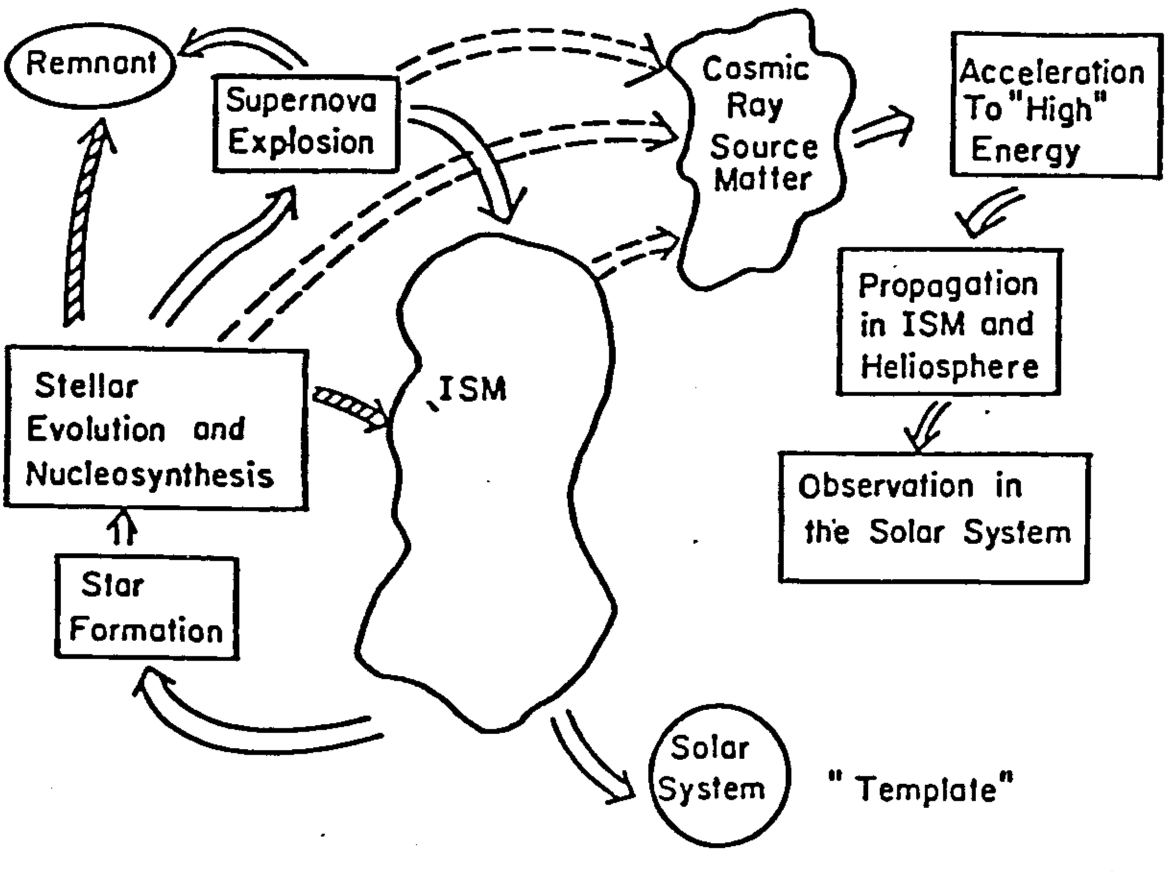


Illustration of the relationships between cosmic ray (right) and astrophysical processes which may contribute the cosmic radiation.

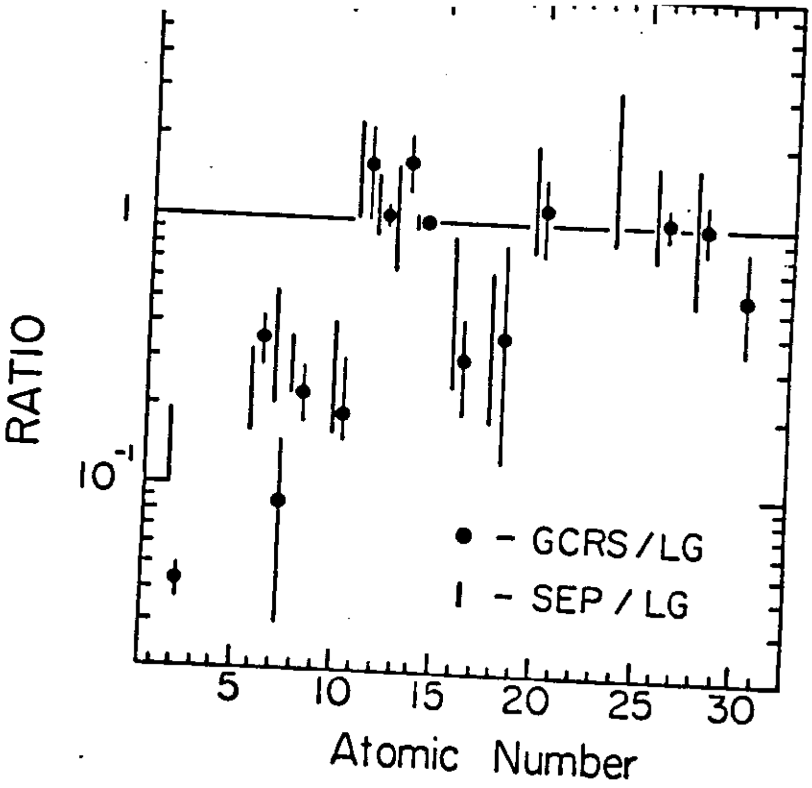
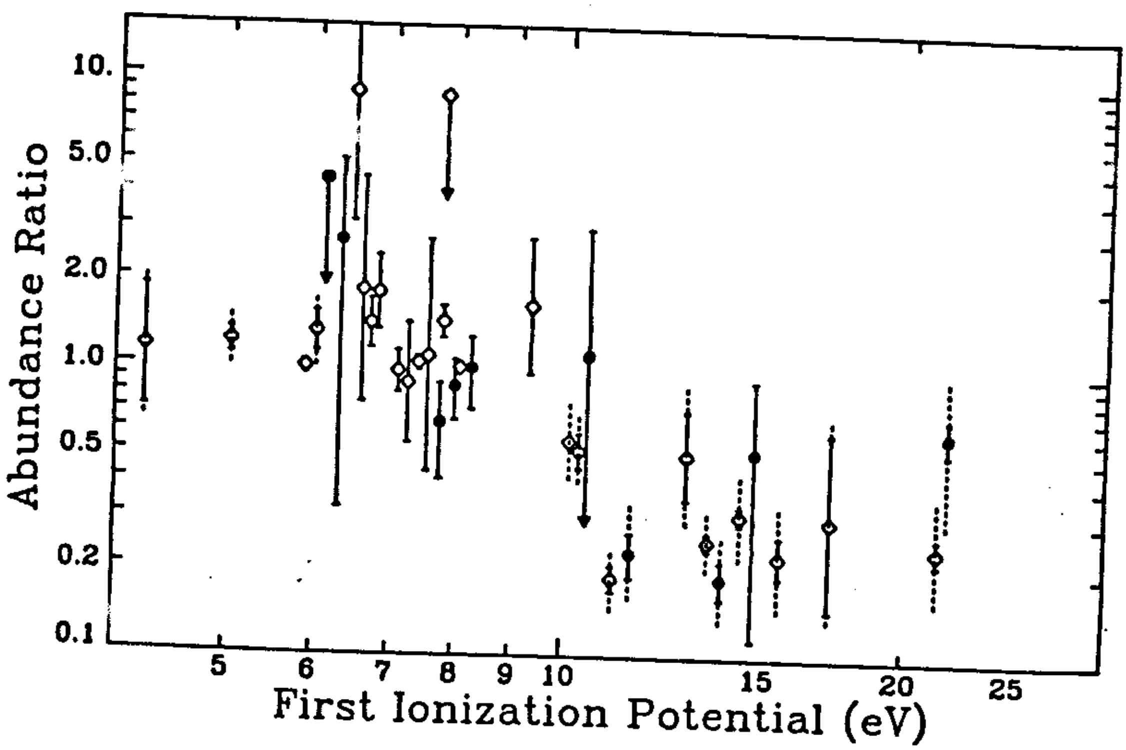
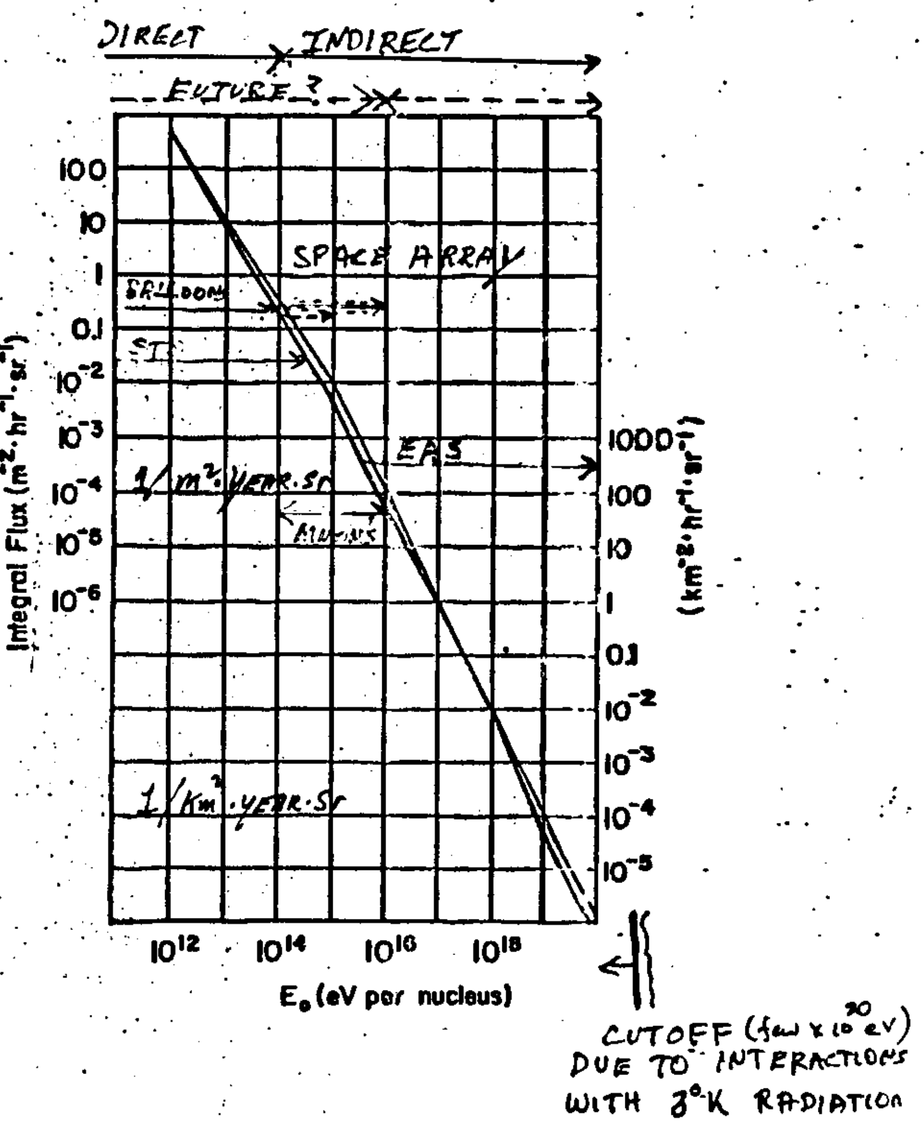


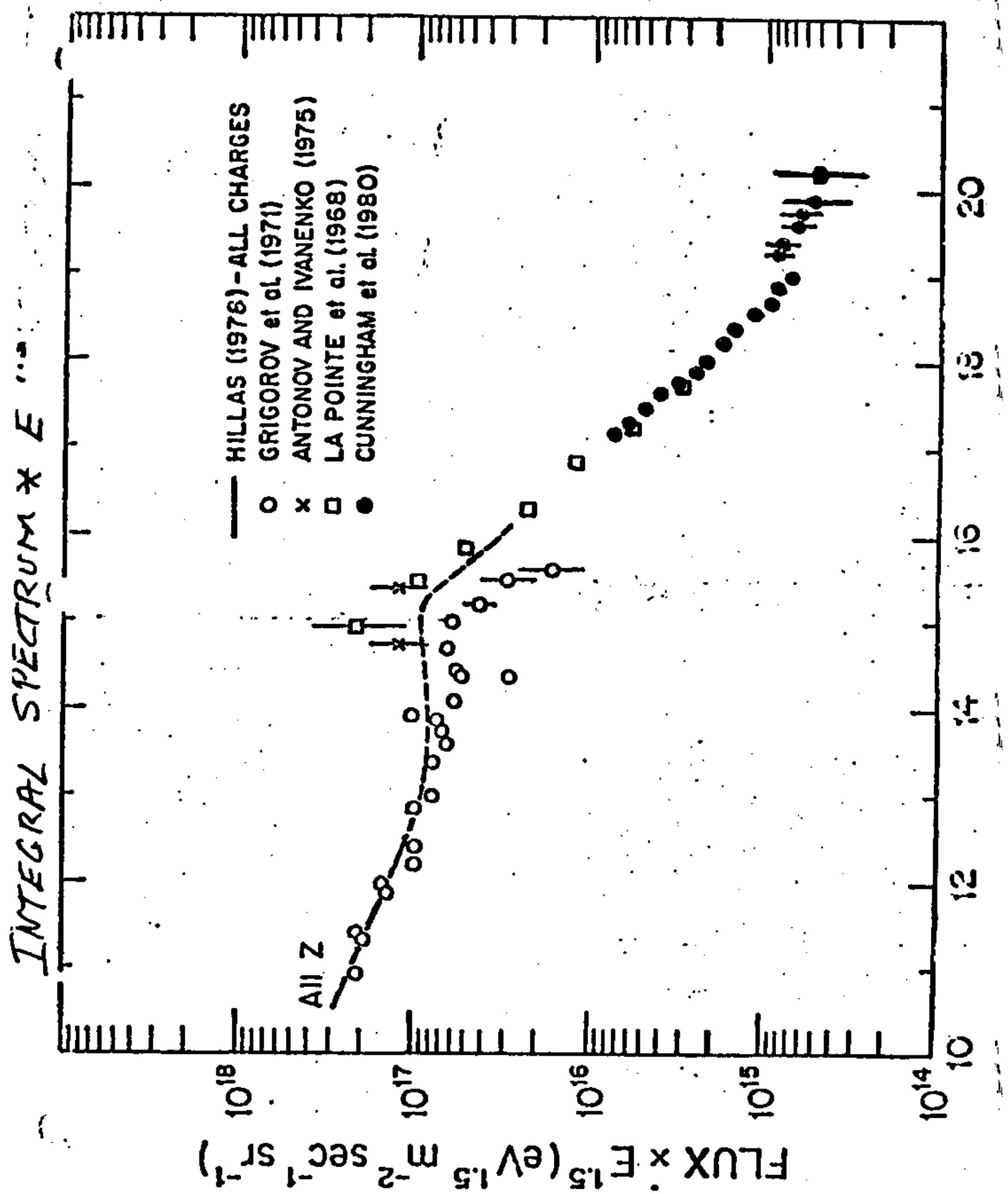
Figure 13. Ratios to the local galactic (LG) abundances of galactic cosmic ray source (GCRS) abundances and solar energetic particle (SEP) abundances (all relative to silicon) versus the atomic number of the element.



"HIGH ENERGY" COSMIC RAYS

FLUX DECREASES ~2 ORDERS MAGNITUDE FOR EACH DECADE INCREASE IN ENERGY





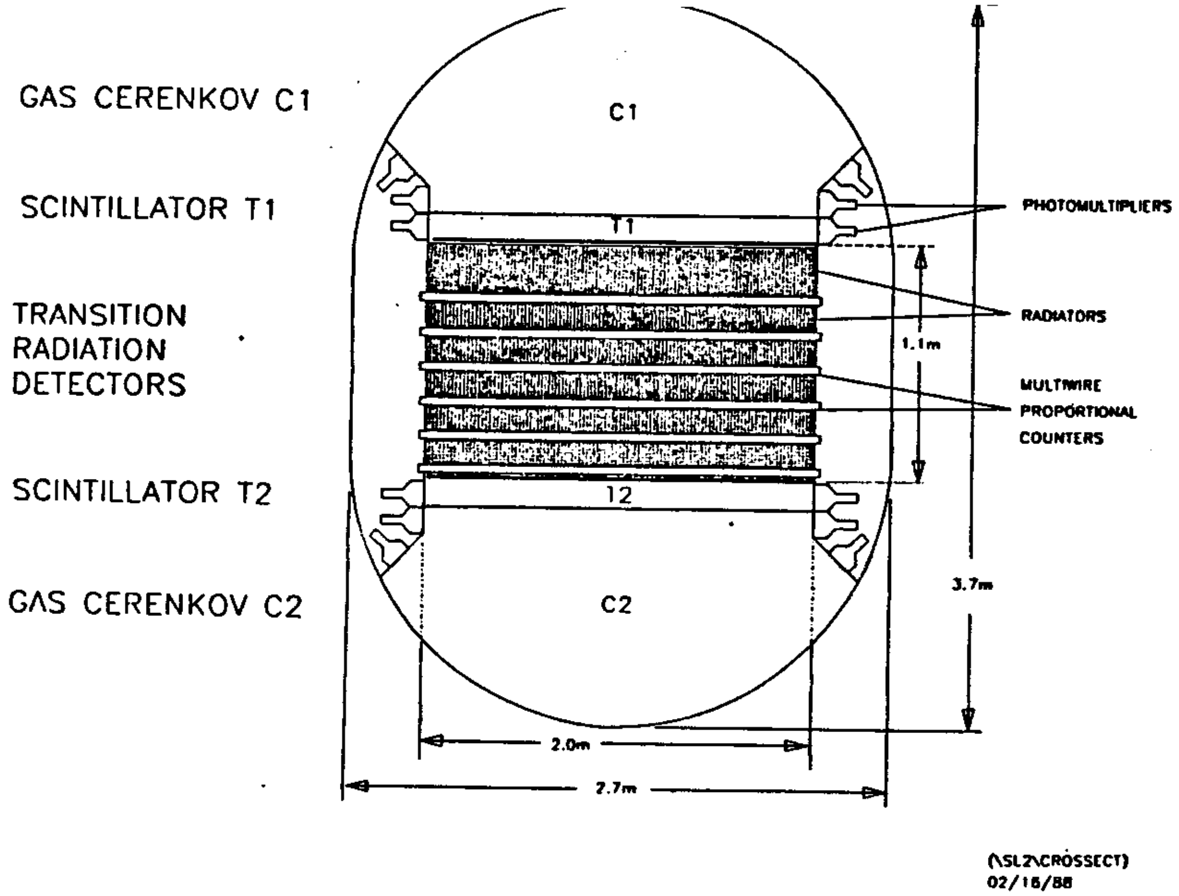
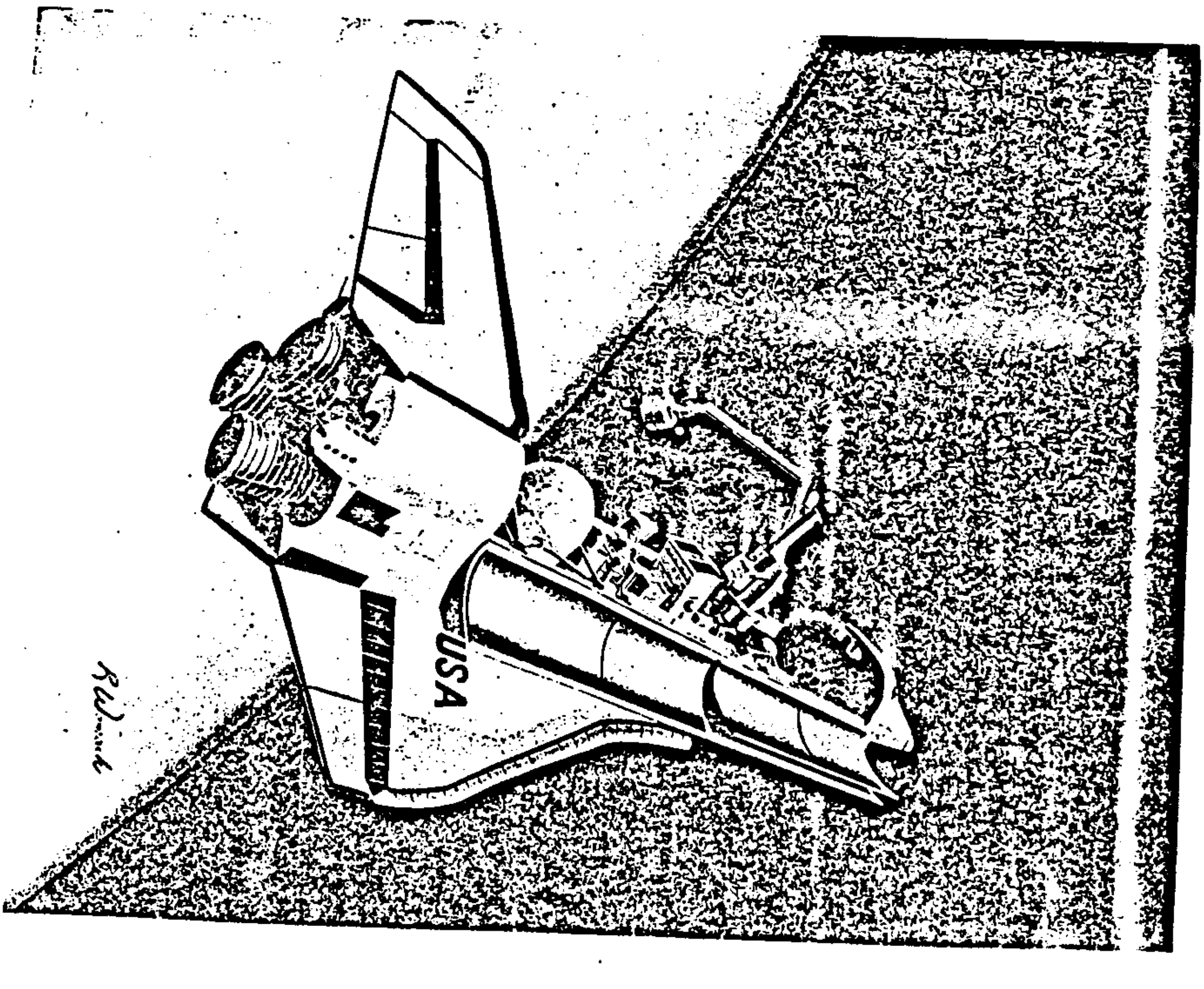
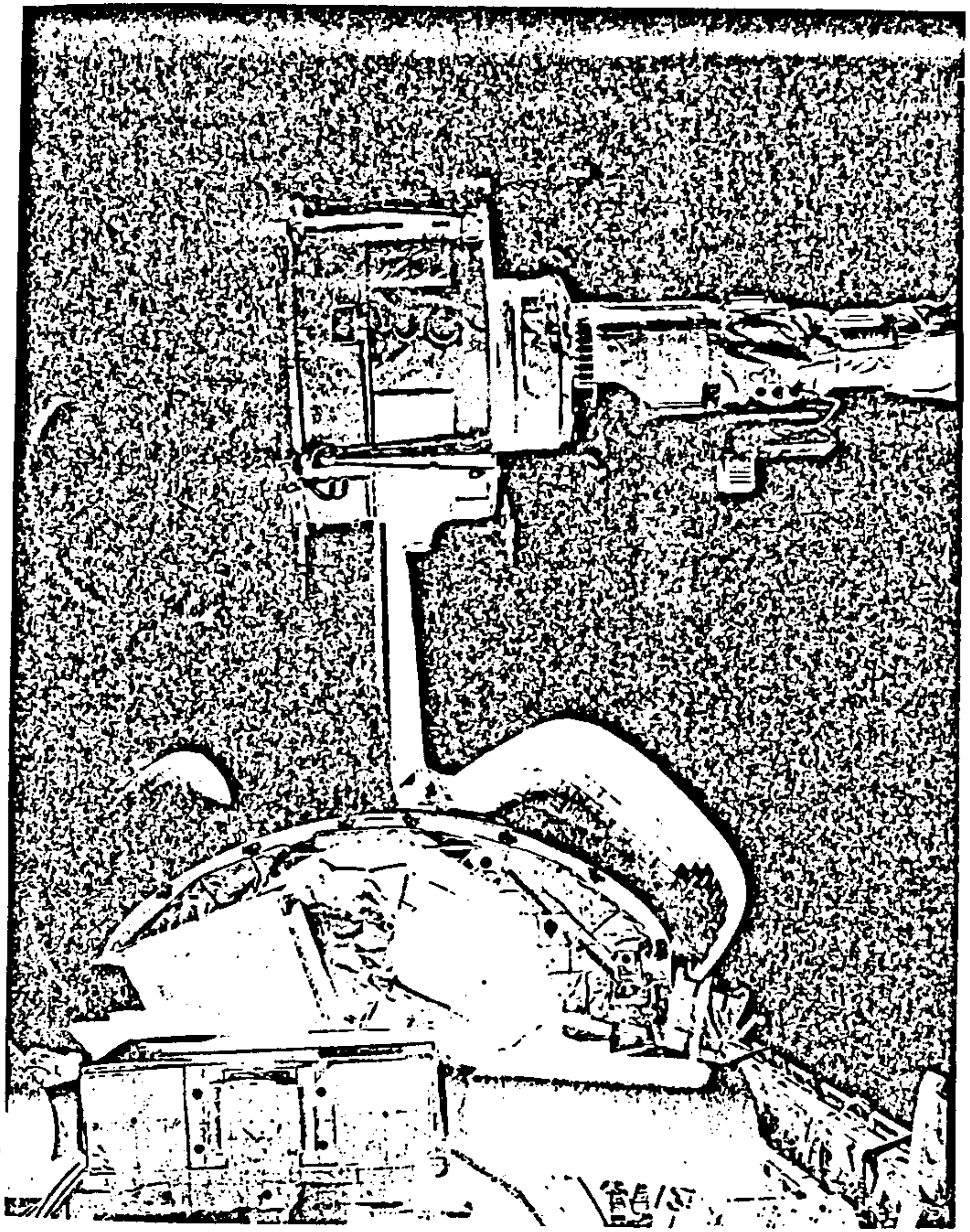


FIGURE 1: Schematic cross section of the CRN instrument.





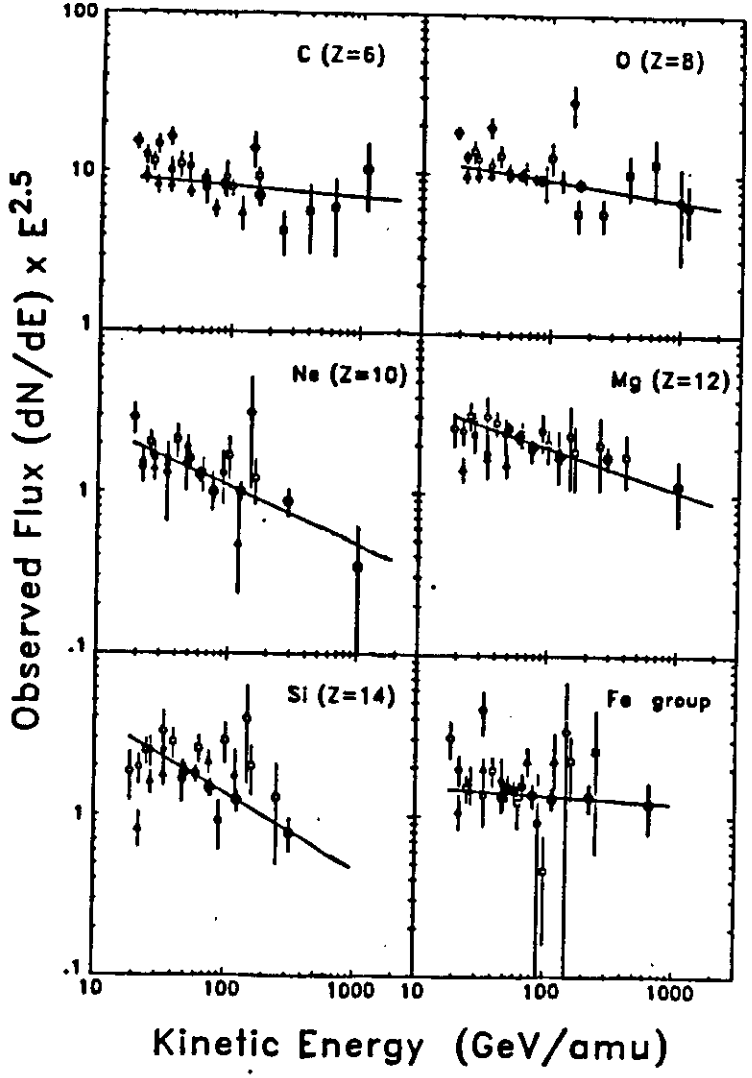
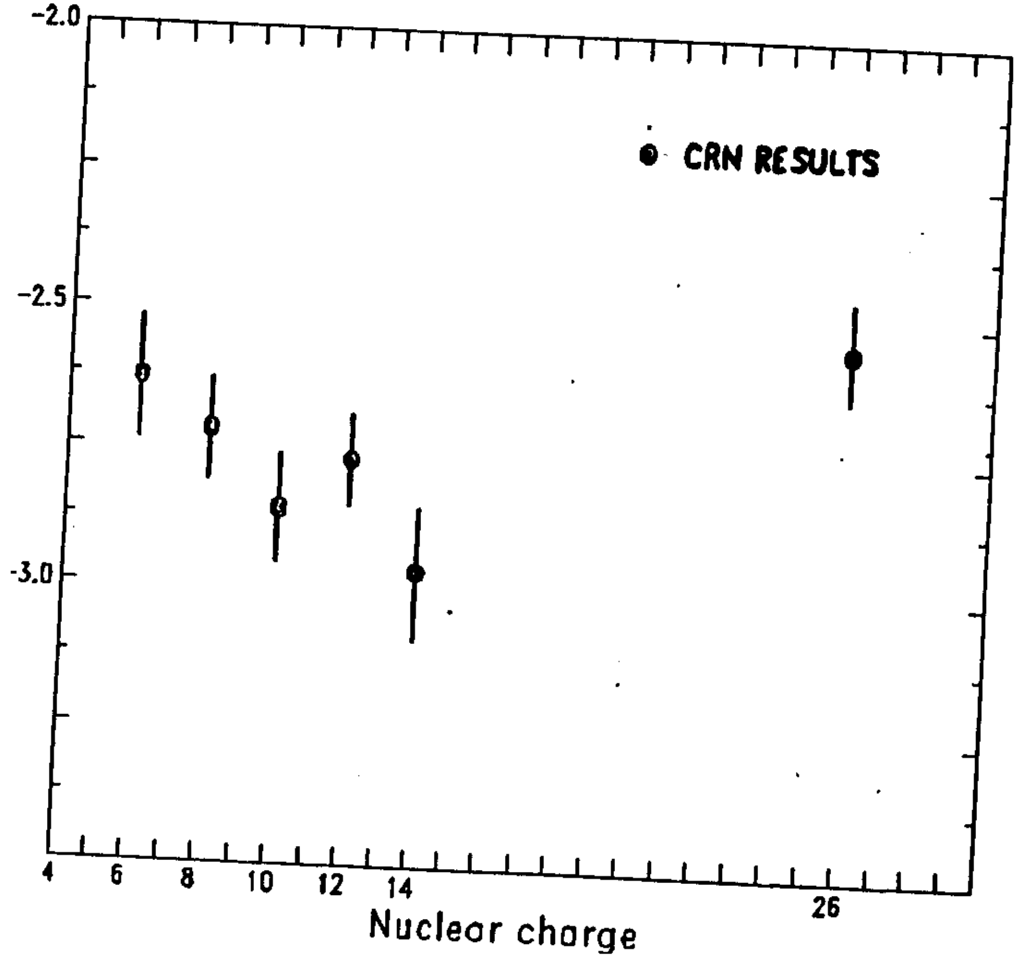


FIGURE 3: The differential energy spectra of C, O, Ne, Mg, Si, and Fe group (Z=25,26,27) nuclei as obtained in the Shuttle flight. Our results are shown as filled circles, and power-law fits to our data are given as solid lines. The spectra are multiplied by $E^{2.5}$ to emphasize spectral differences. Our spectra are compared, with an arbitrary normalization at 50 GeV amu^{-1}, with the results of previous measurements (open circles, Caldwell 1977; triangles, Juliusson 1974; squares, Simon et al. 1980; diamonds, Orth et al. 1978).



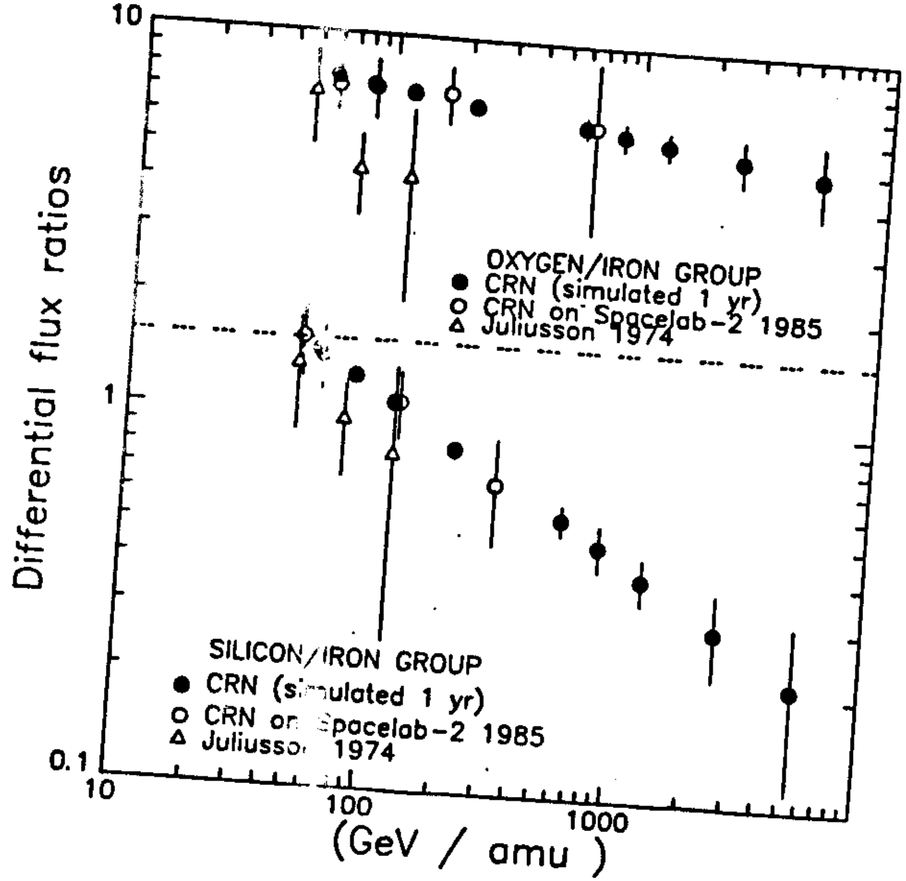


FIGURE 4: Relative abundances of Oxygen to Iron and of Silicon to Iron as obtained on Spacelab-2 (open circles) and in an earlier balloon flight (open triangles). The solid circles illustrate the kind and statistical quality of results that might become available after a 1-year spaceflight of CRN.

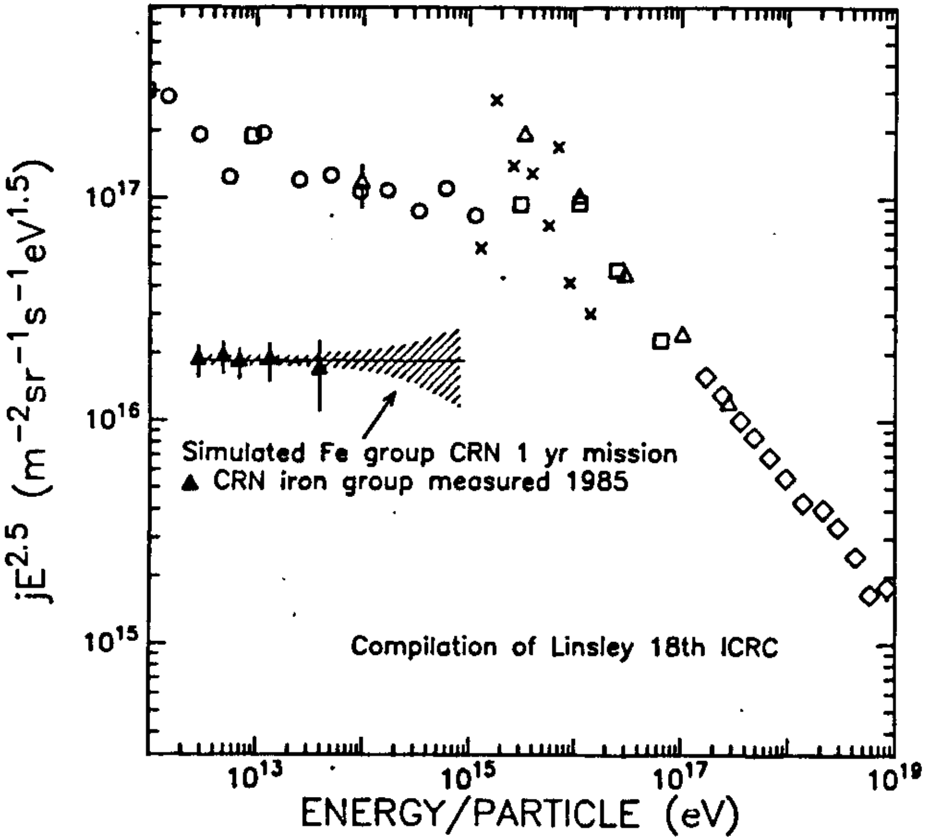


FIGURE 6: The all-particle differential energy spectrum as compiled by Linsley (Proceedings, 18th Intl. Cosmic Ray Conf., Bangalore 12, 135, 1983), and the individual spectrum of the iron-group nuclei ($25 \leq Z \leq 27$). Triangles are measured data, and the dashed area indicates the range of expected results for a one-year exposure of CRN, assuming that the iron spectrum continues as $E^{-2.5}$. Note that the maximum per-particle energy reached is about 10^{15} eV.

QUESTION?

- ARE THE "KNEE" AND "ANKLE" RELATED TO "NEW PHYSICS" OR DO THEY REFLECT CHANGE IN COMPOSITION?

OR?

- IS THERE NEW PHYSICS BEING OBSERVED BECAUSE OF CHANGE IN COMPOSITION? (AS HEAVIER IONS DOMINATE)

- SEVERAL ANOMALIES OBSERVED ABOVE ~100 TeV IN COSMIC RAYS (TYPICALLY AT FEW % LEVEL)

(AMBIGUITIES EXIST BECAUSE MOST MEASUREMENTS ARE INDIRECT!)

DIRECT OBSERVATIONS:

* JACEE IS ATTEMPTING TO BRIDGE THE GAP BETWEEN THE PREVIOUS DIRECT MEASUREMENTS BELOW 1 TeV AND THE INDIRECT MEASUREMENTS ABOVE ~10^{14-15} eV.

- MEASURE COMPOSITION 10^{12} – 10^{14} eV (10^{15}?)
- STUDY INTERACTIONS OF HEAVY NUCLEI.
- GET SOME OVERLAP WITH EXTENSIVE AIR SHOWERS

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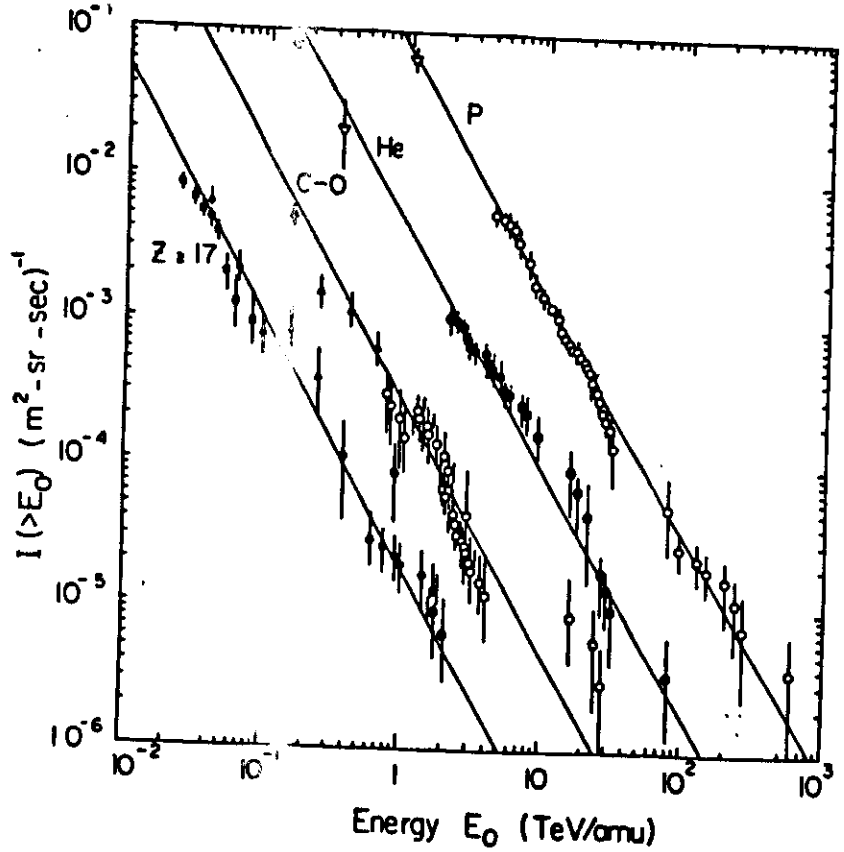
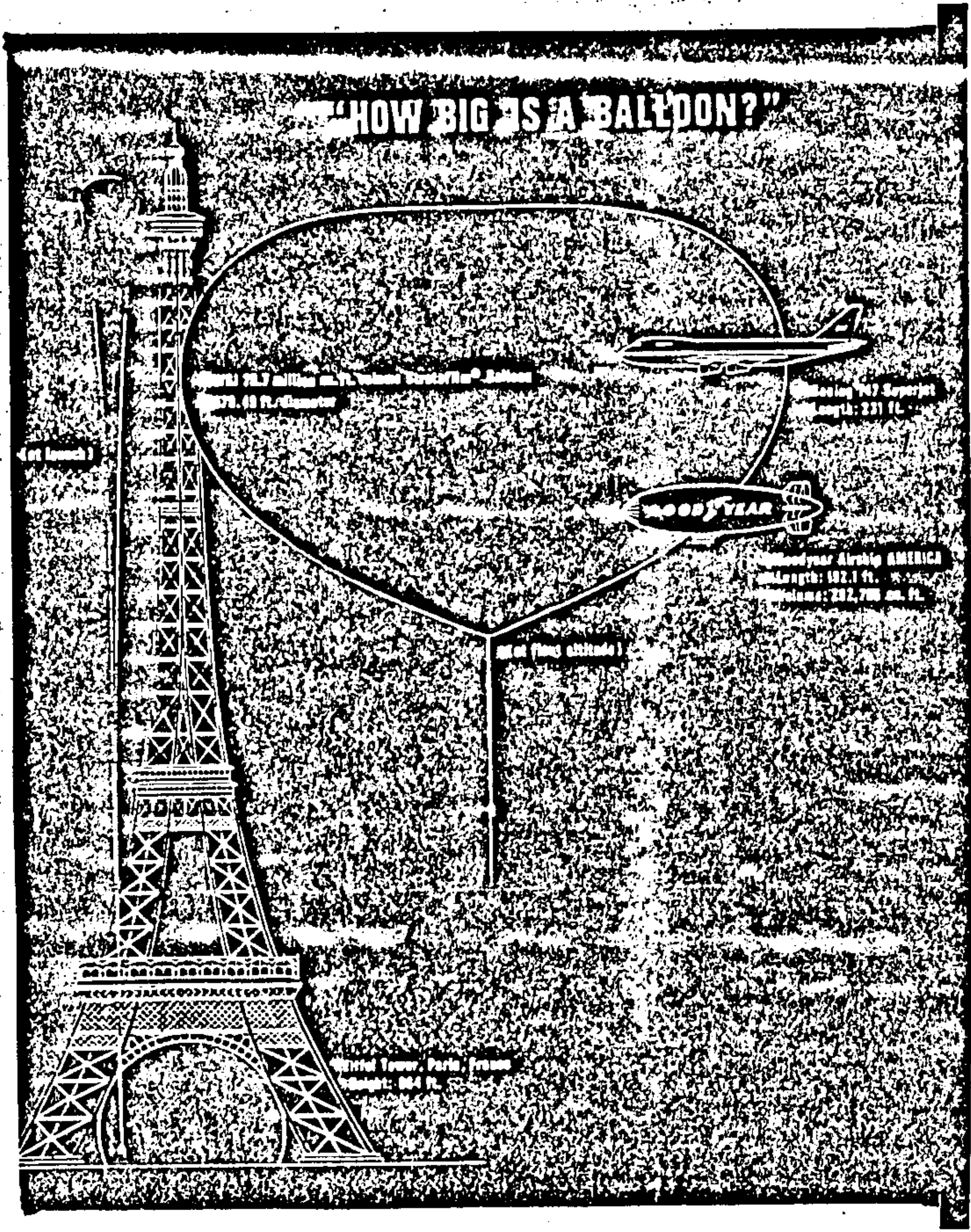
* JAPANESE-AMERICAN COOPERATIVE EMULSION EXPERIMENT.

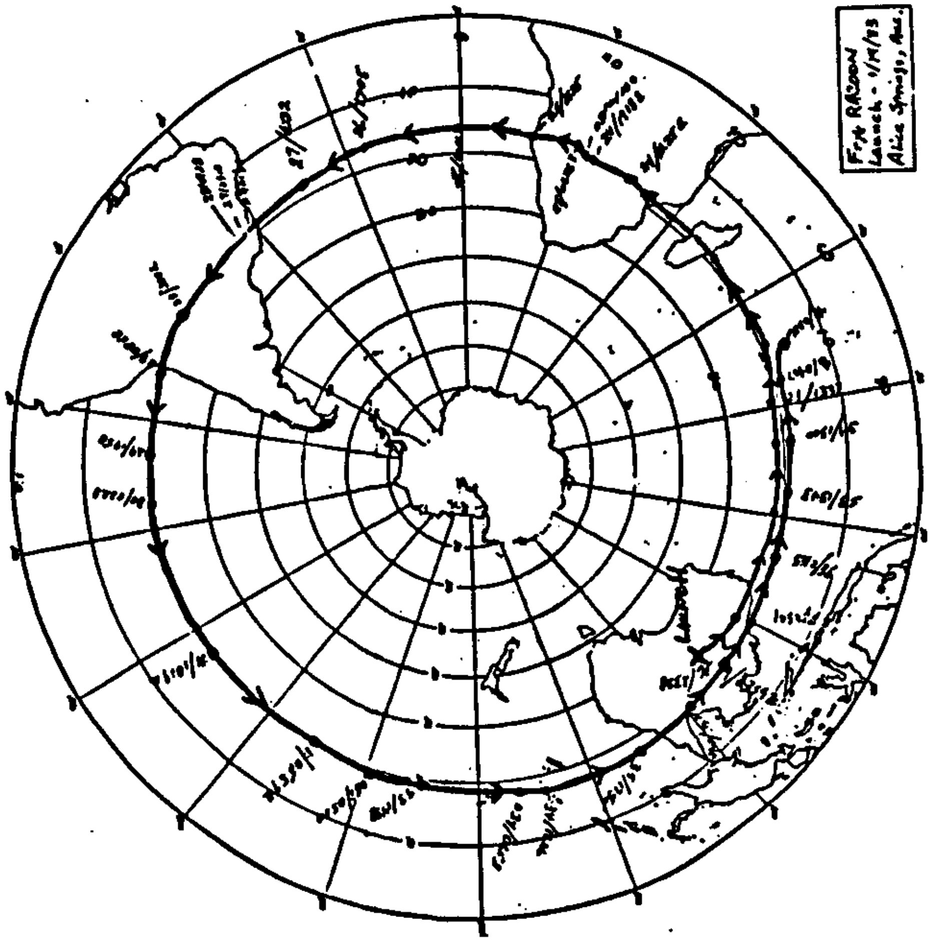
JAPAN: ICR, UNIV. OF TOKYO
KOBE UNIVERSITY
OSAKA UNIVERSITY
WASEDA UNIVERSITY

USA: LOUISIANA STATE UNIV.
MARSHALL SPACE FLIGHT CENTER
UNIV. OF ALABAMA HUNTSVILLE
UNIV. OF WASHINGTON

POLAND: INSTITUTE FOR NUCLEAR PHYSICS (KRAKOW)

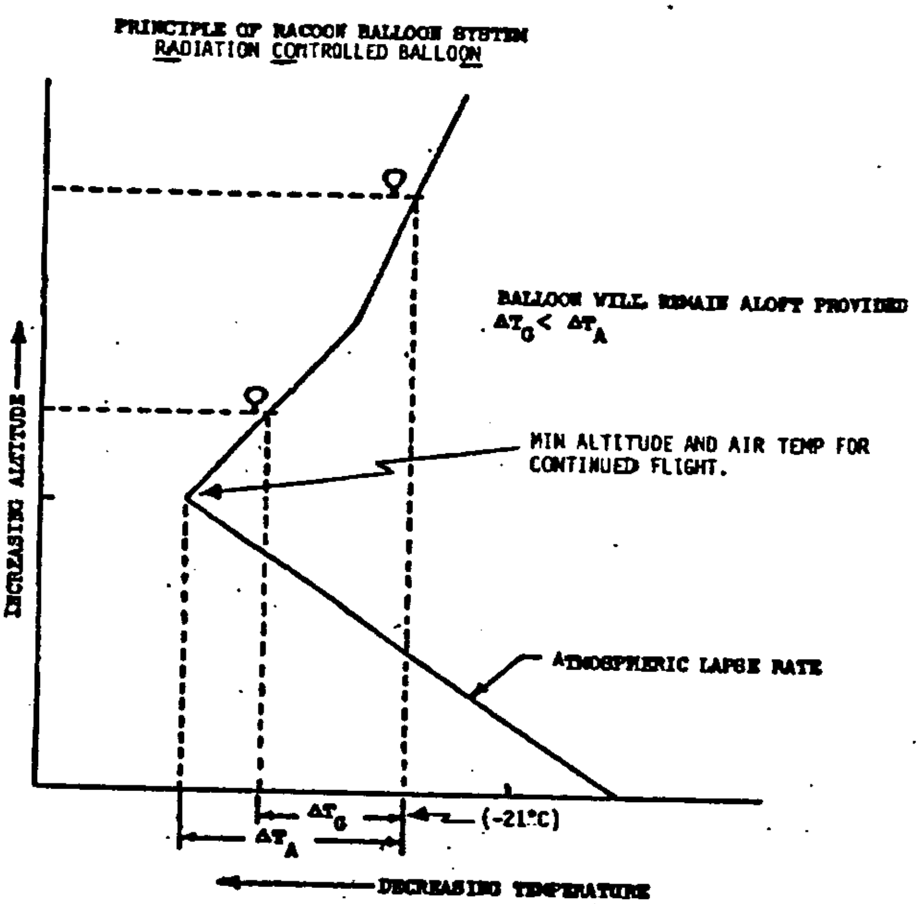



"HOW BIG IS A BALLOON?"
GOODYEAR

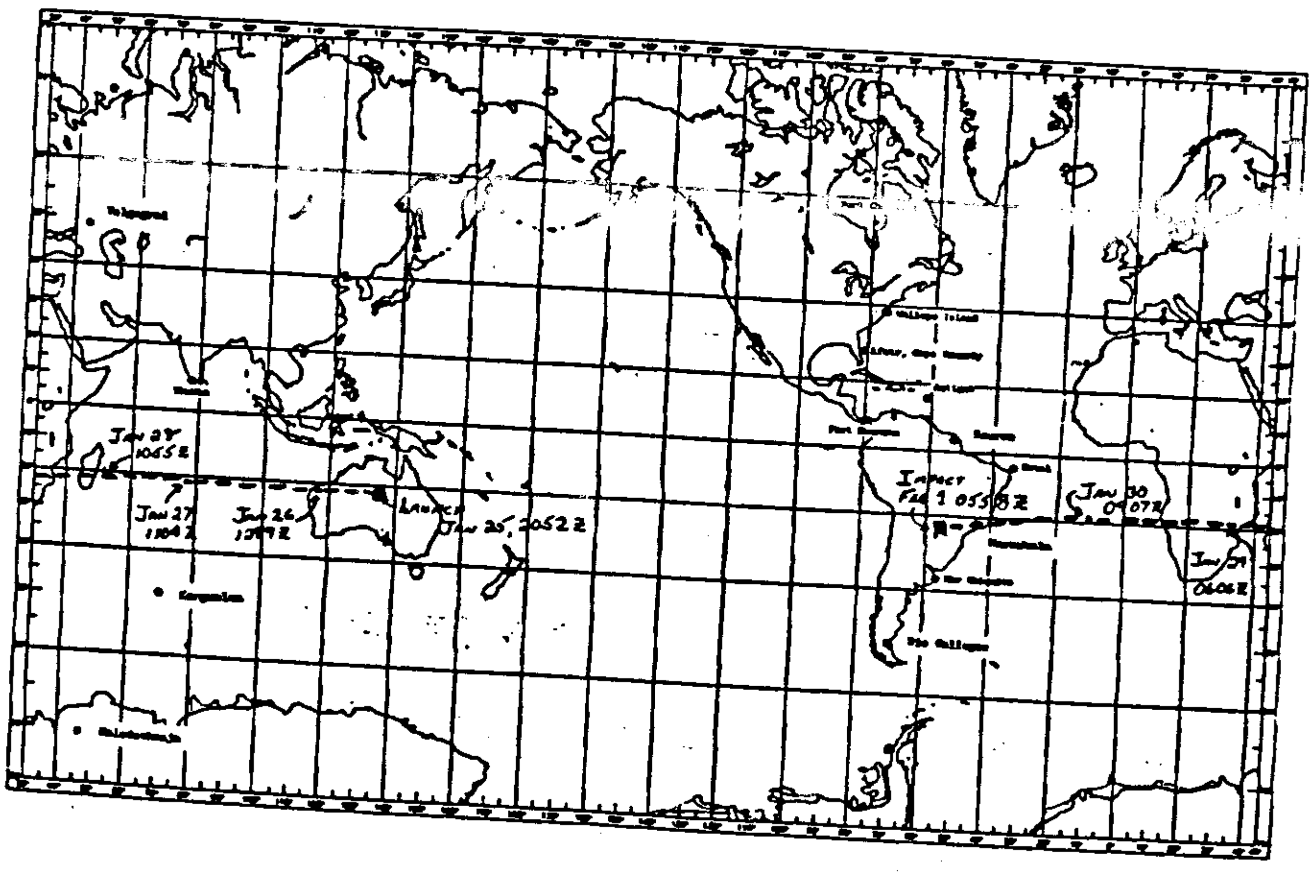


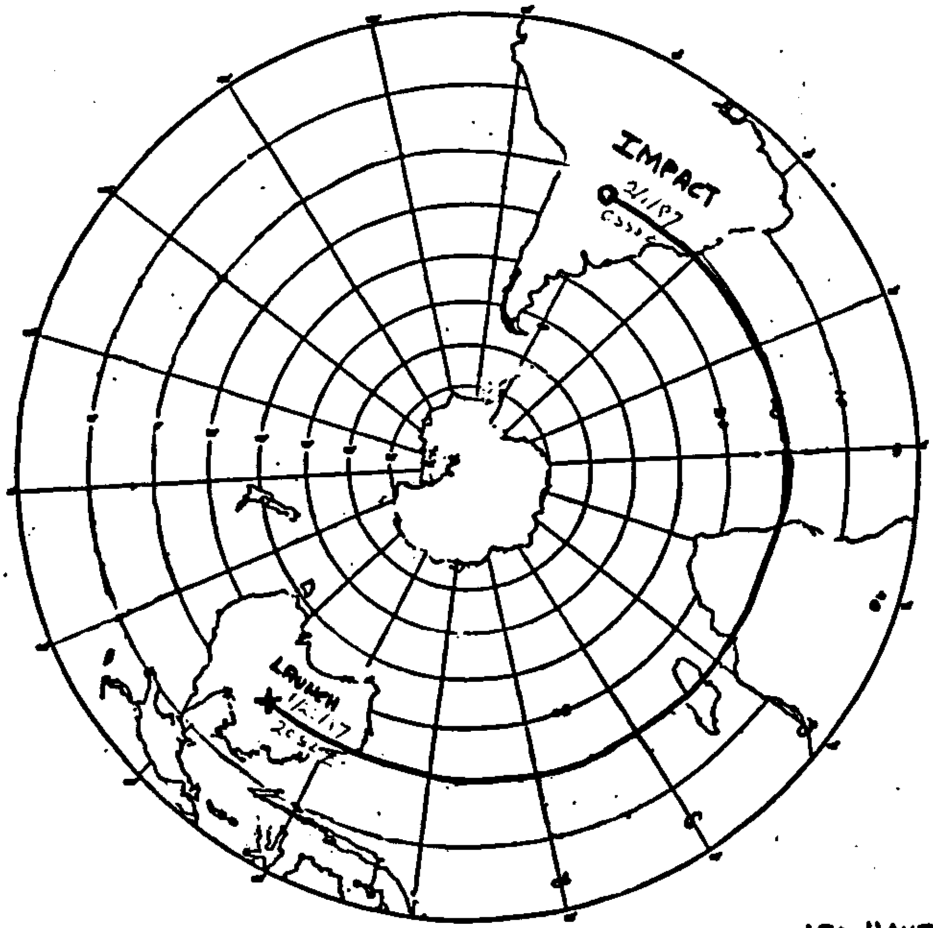
TG= GAS TEMP
TA= AIR TEMP

LAT	MIN TEM(°C)	ALT(KFT)
15°	-81	54
30°	-70	52-49
45°	-58	52-33
60°	-49	75-33
75°	-48	75-30



FLIGHT PATH
212-N (WEFEL/LSU)





TRAJECTORY - LONG DURATION BALLOON

~150 HOURS AT FLOAT 100K - 130K FT.

BALLOON PROGRAM (CONT'D)

LONG DURATION OPTIONS DURING EARLY 1990"S

- JANUARY-FEBRUARY (MUTUALLY EXCLUSIVE WINDOWS OF 6 - 8 WEEKS)
  - AUSTRALIA - BRAZIL — 5 - 12 DAYS
    - •• CAN MAINTAIN NEARLY FULL ALTITUDE/1500 LB PAYLOAD
    - •• RELATIVELY HIGH SUCCESS RATE EXPECTED
  - AUSTRALIA - AUSTRALIA — 10 - 20 DAYS
    - •• RACOON METHOD NOT ADEQUATELY TESTED WITH NEW BALLOONS
    - •• SIGNIFICANT RISK OF LOSING PAYLOAD
  - NEW ZEALAND - ARGENTINA — 5 - 12 DAYS
    - •• BEGINNING NEGOTIATIONS
    - •• SHOULD BE SIMILAR TO FLIGHTS FROM AUSTRALIA TO BRAZIL
    - •• HIGHER LATITUDES/LOWER GEOMAGNETIC CUTOFF
  - ANTARTICA (McMURDO AND OR POLE-STATION) — 5 - 15 DAYS
    - •• RALATIVELY SMALL BALLOONS (MAXIMUM UP TO FEW MCF)
    - •• HIGH PROBABILITY FOR LOSING PAYLOAD

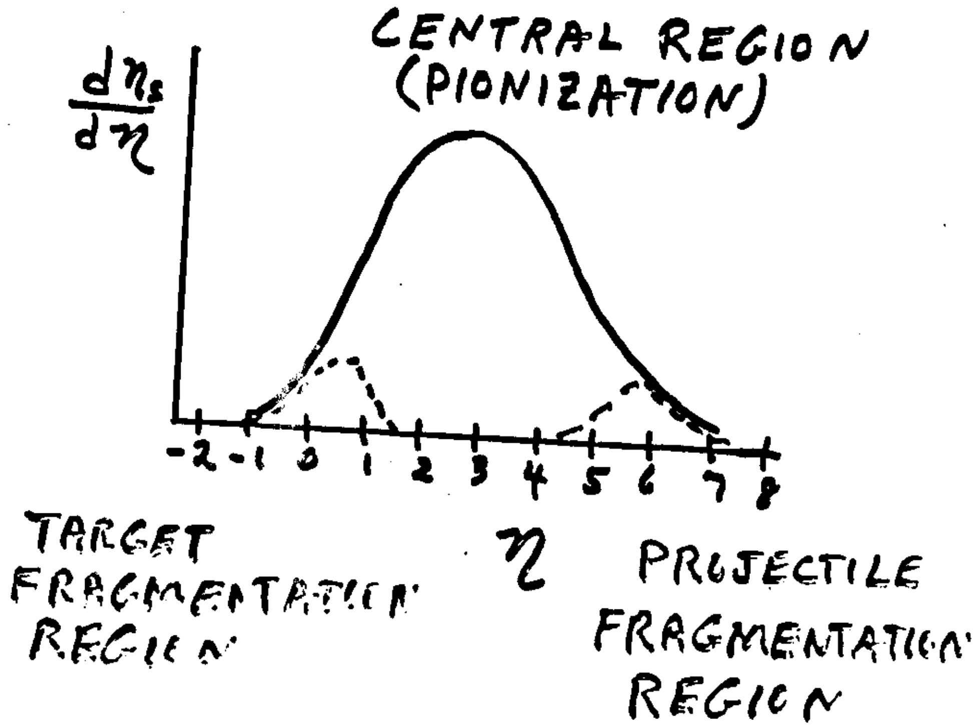
BALLOON PROGRAM (CONT'D)

LONG DURATION OPTIONS DURING EARLY 1990'S (CONT'D)

- JUNE - JULY (MUTUALLY EXCLUSIVE WINDOWS OF 6 - 8 WEEKS)
  - SOUTH CAROLINA - NEW MEXICO/ARIZONA — 2 - 3 DAYS
    - : SEVERAL FLIGHTS CARRIED OUT IN 1982 (40 -70 HOURS)
    - : FM TELEMETRY TO GROUND STATIONS
    - : MINIMUM RISK
  - BERMUDA - NEW MEXICO/ARIZONA — 3 - 5 DAYS
    - : NOT YET TESTED, BUT SIMILAR TO SOUTH CARILONA - NEW MEXICO
  - SICILY - USA — 4 - 8 DAYS
    - : SOME EXPERIENCE IN MID-1970'S
    - : USA REJECTED FOR SAFETY REASONS
    - : COULD REVISIT, NOW THAT BALLOONS SEEM TO BE RELIABLE
  - USA - CHINA — 5 - 12 DAYS
    - : CURRENTLY NO SPACE AGREEMENT WITH CHINA
    - : BALLOONING COULD BE PART OF SPACE AGREEMENT UNDER NEGOTIATIOS
    - : USA - JAPAN - CHINA BALLOON PROGRAM NIXED BY JAPAN

(PSEUDO) RAPIDITY DISTRIBUTIONS

$$\eta = -\ln \tan \theta/2$$



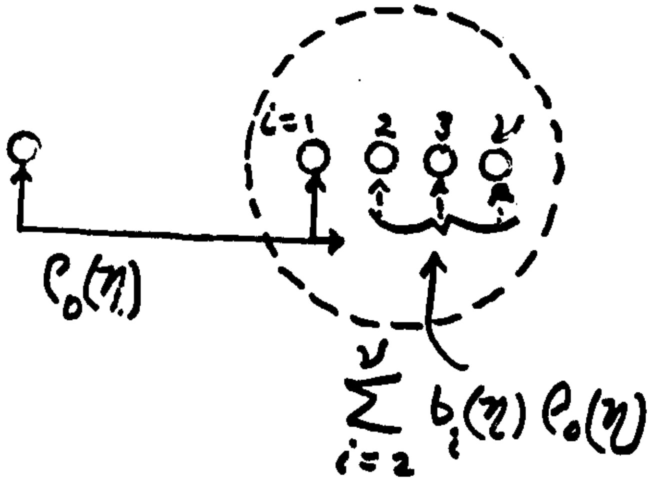
EMULSION TERMINOLOGY:

PROJECTILE + TARGET $\rightarrow n_s + N_h$

$N_h = N_b + N_g$ $\xrightarrow{\text{REFLECTS}}$ NUCLEAR TARGET RESPONSE

DIRECT STUDIES OF N-N AND h-A INTERACTIONS

GIVES FOLLOWING PICTURE FOR h-A COLLISIONS



RAPIDITY DENSITY $\rho(\eta) = \frac{1}{\sigma}\frac{d\sigma}{d\eta}$
OR PSEUDO-RAPIDITY, η

$\eta = -\ln \tan \theta/2$

$$\rho(\eta) = \underbrace{\rho_0(\eta)}_{i=1} + \sum_{i>1} b_i(\eta)\,\rho_0(\eta)$$

<u>WE CAN</u>

EXTRAPOLATE h-A PICTURE TO B-A COLLISIONS, USING LINEAR SUPERPOSITION.

IF DATA AGREES WITH SUCH EXTRAPOLATION, THEN STUDY OF B-A COLLISIONS NOT INTERESTING.

BUT, DEVIATIONS TELL US THAT THE NUCLEAR ENVIRONMENT IS IMPORTANT

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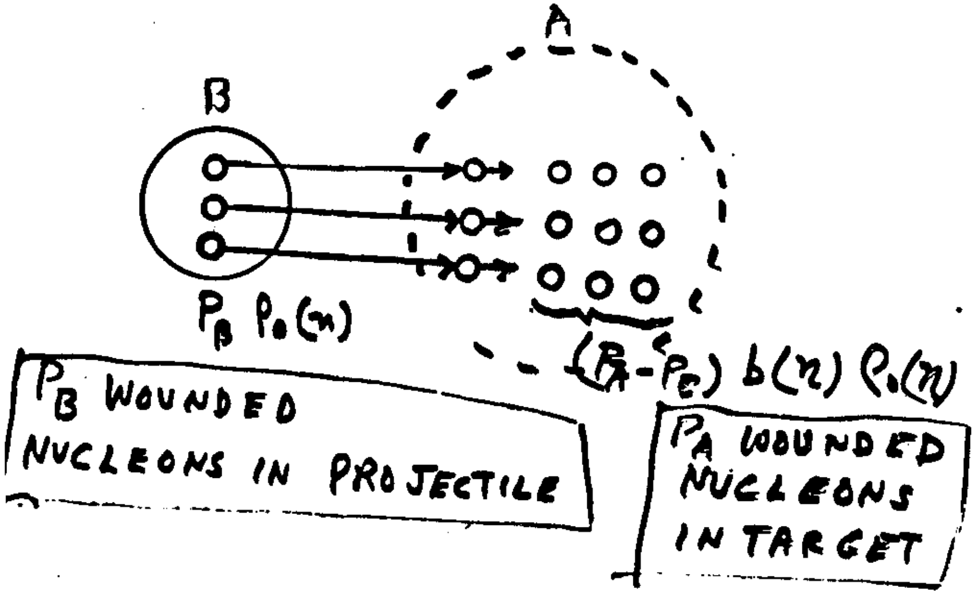
* <u>SUPERPOSITION</u> OF N-N OR h-A COLLISIONS SUPPLIES <u>THE NORM TO TEST MODELS</u> FOR B-A COLLISIONS

EXISTING DATA FOR B-A COLLISIONS TOO POOR TO CHOOSE BETWEEN DETAILS OF MODELS!

BUT SIMPLE PICTURE FOR B-A COLLISIONS (B<A)

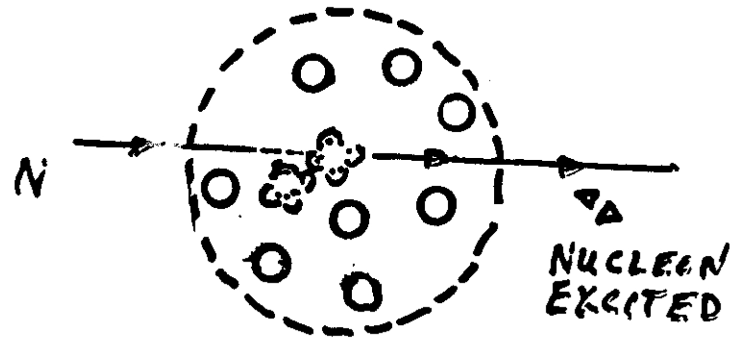


$$\rho(\eta) = P_B\, \rho_0(\eta) + (P_A - P_B)\, b(\eta)\, \rho_0(\eta)$$

IF ALL NUCLEONS WOUNDED

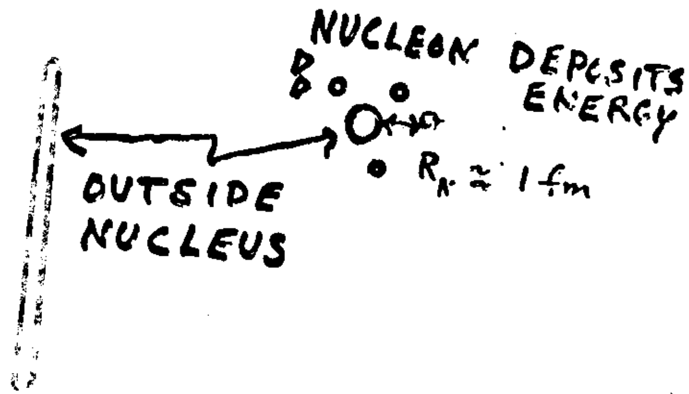
$$\rho(\eta)_{MAX} = B\, \rho_0(\eta) + (A-B)\, b(\eta)\, \rho_0(\eta)$$

NUCLEON - NUCLEUS:



TARGET FRAME

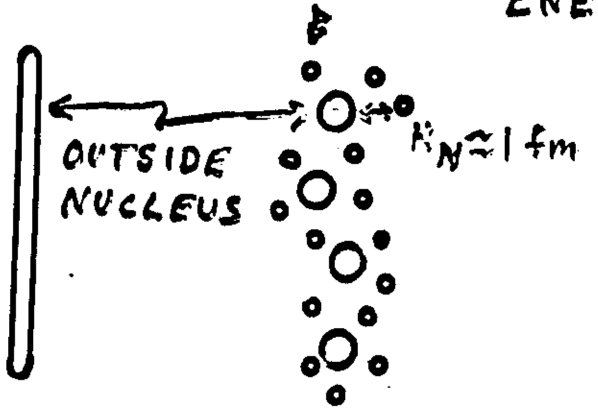
NUCLEAR TRANSPARANCY



PROJECTILE FRAME

(LORENTZ CONTRACTION $\Rightarrow t_{formation} \gg t_{transit}$)

NUCLEUS - NUCLEUS:



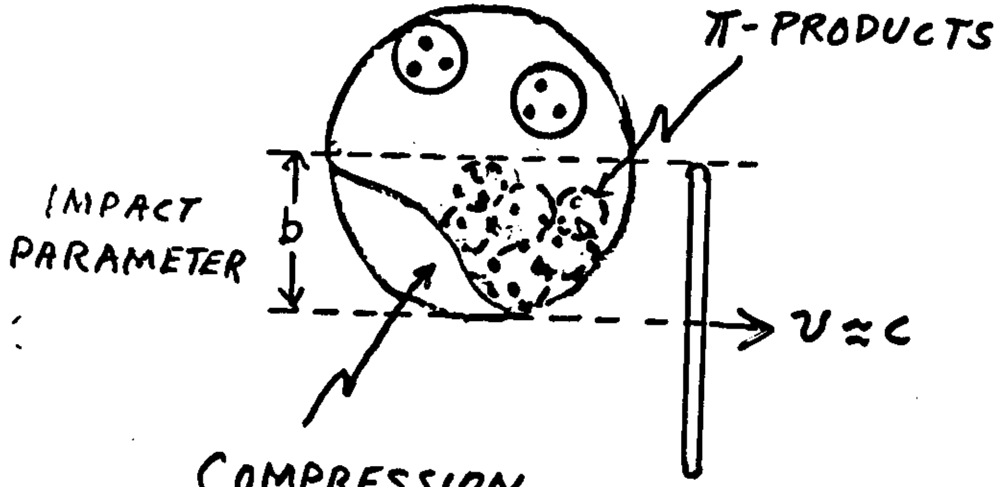
PROJECTILE FRAME

EXPECTED REASON FOR DEVIATION FROM SUPERPOSITION MODELS

MANY EXCITED NUCLEONS CAN RESCATTER OFF EACH OTHER

⇒ POSSIBLY HOT DENSE FIREBALL VIA PARTICLE PRODUCTION

HEATING BY DIRECT COMPRESSION:



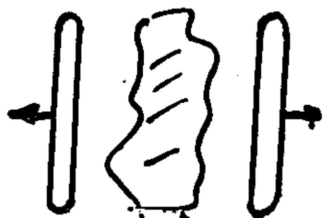
THE "WOUNDED" PART OF TARGET IS HEATED BY COMPRESSION IN ADDITION TO HEATING SUPPLIED BY PARTICLE PRODUCTION.

IN COLLISIONS OF TWO HEAVY IONS
SAME HEATING PROCESS IN
BOTH PROJECTILE AND TARGET

IF THERE IS ABUNDANT PROD.
OF SLOW (IN CMS) PIONS WHEN
TWO HEAVY NUCLEI COLLIDE,

A PHASE TRANSITION MAY
RESULT FROM ENERGY LEFT
BEHIND IN REGION CONNECTING
THE SEPARATING NUCLEI

AFTER TRANSIT



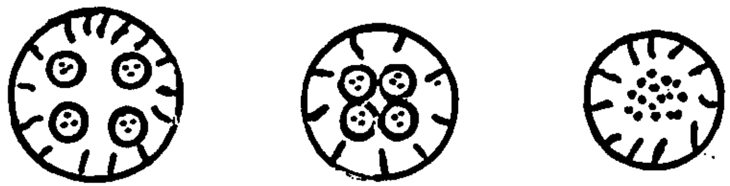
LOW MOMENTUM MATTER

BIG QUESTION: IS ENERGY DENSITY
SUFFICIENT TO FORM QUARK-GLUON PLASMA

USING QCD ONE CAN HOPE TO
COMPUTE CRITICAL DENSITY, ρ_c,
WHEN MATTER SHIFTS FROM
HADRON TO QUARK PHASE

VARIOUS ESTIMATES STARTING
AT A FEW TIMES THE DENSITY
OF COLD NUCLEAR MATTER, ρ_0.

$\left\{ \begin{array}{l} (\rho_c \gtrsim \text{SEVERAL} \cdot \rho_0) \\ (\text{PERHAPS } \rho_c \gtrsim 1\ \text{GeV}/\text{fm}^3) \end{array} \right.$



NUCLEAR MATTER | CRITICAL DENSITY | QUARK MATTER

INCREASING DENSITY →

IS THERE ANY EXPERIMENTAL EVIDENCE FOR EXISTENCE OF QUARK MATTER?

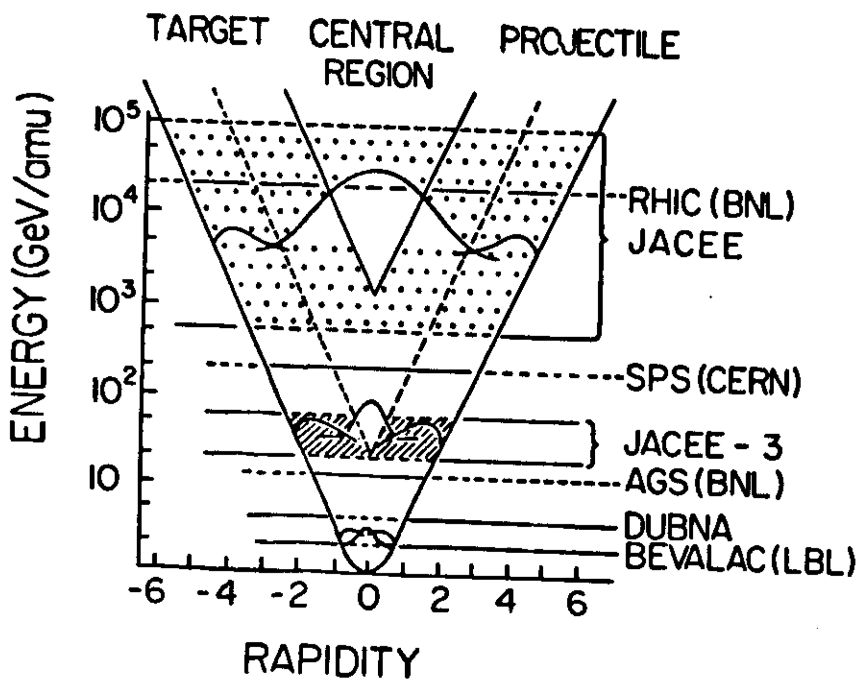
WE ARE NOT SURE!

SOME POSSIBILITES THAT HAVE BEEN SUGGESTED (CHALZEN, McLERRAN, ETC) ARE THE APPARANT "ANOMALIES" IN COSMIC RAY OBSERVATIONS ABOVE A THRESHOLD ~ 100 TeV:

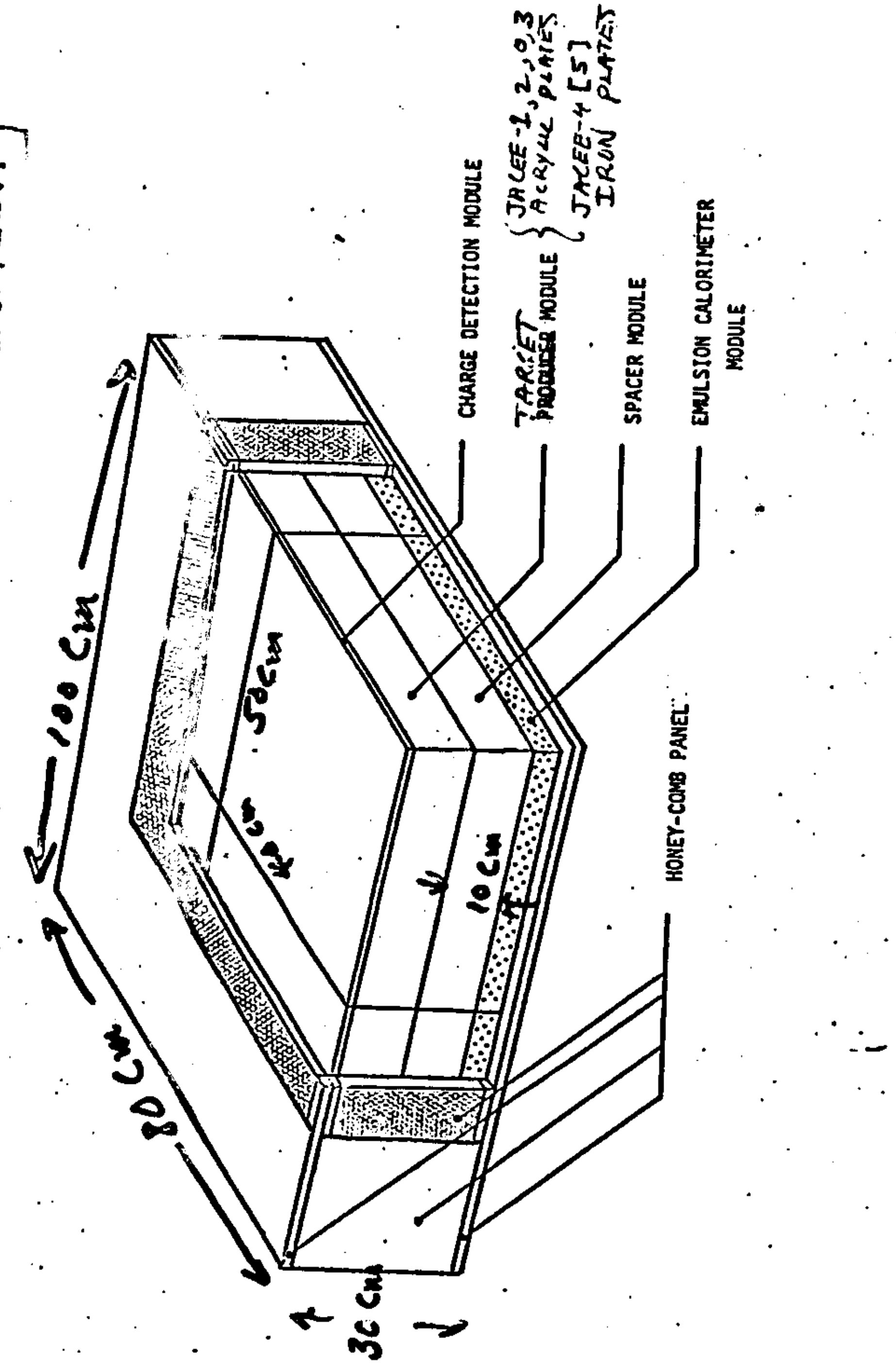
e.g.
- HIGH MULTIPLICITY EVENTS
- LARGE ENERGY DEPOSITION IN EARLY STAGES OF A SHOWER
- CENTAUROS
- CHIRONS
- LONG FLYING COMPONENT
- DELAYED PARTICLES
- EXCESS OF γ-RAYS

CRUCIAL PROBLEM (FOR QGM)

- FIND ADEQUATE EXPERIMENTAL SIGNATURE TO ANALYZE EXISTING DATA
- ACCUMULATE NEW DATA WITH EXISTING FACILITIES ACCELERATORS, BALLOONS, ETC.
- BUILD NEW FACILITIES IDEALLY A-A COLLIDER
  $E \gtrsim 100$ GeV/nucl
  A UP TO URANIUM



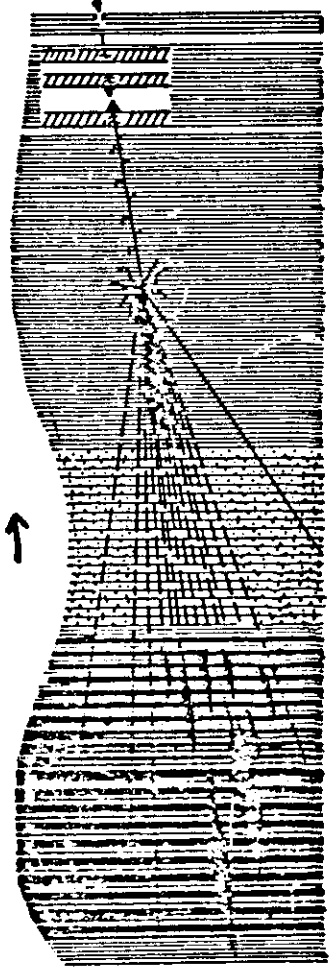
JACEE-1, JACEE-2, JACEE-4
[JACEE-0 was 1/4-size ENGINEERING FLIGHT]



VERTICAL STACK-UP
("HIGH ENERGY JACEE")

~ 300 layers

Z, E_0



Z

Z_f, n_s, θ_s

Tracing ↑

$\Sigma E_\gamma \to E_0$ (k_γ)

θ_γ, E_γ

Event Ti

DARK SP. IN X-RA

CHARGE DETECTOR
- Thick Emul. 200-400 μm
- CR-39
- CN

TARGET
{Low Z - ACRYLIC}
{HIGH Z - Fe}
- Thin Emul. 50 - 75 μm
- CR-39

SPACER
- Honey-comb Paper
- Thin Emul. (few)

CALORIMETER
{HIGH Z - LEAD}
- Thin Emul.
- X-Ray Film
- Lead Sheets 1 mm, 2.5 mm

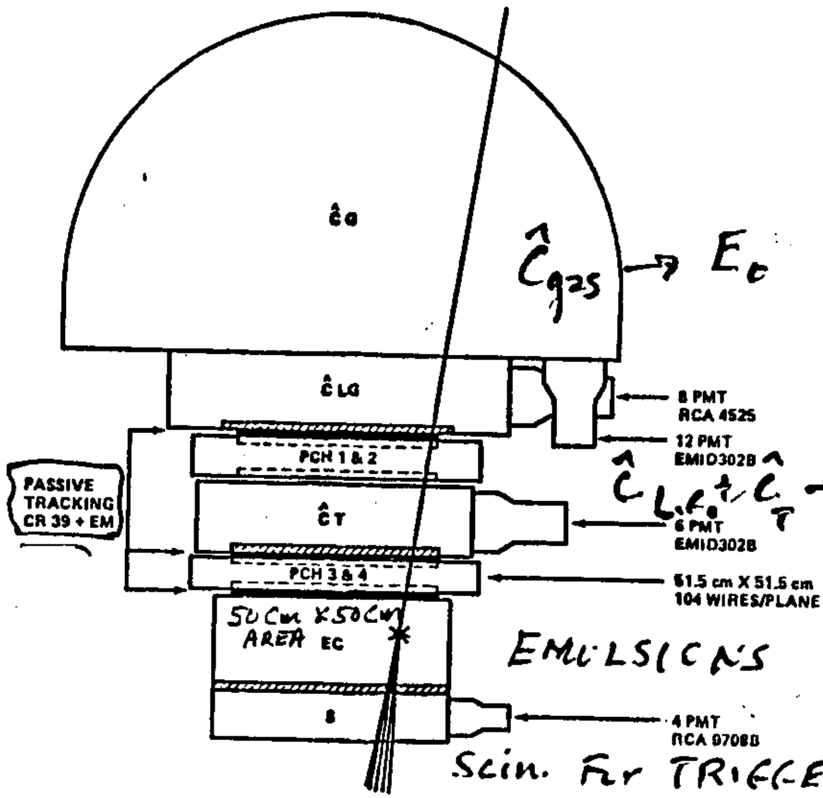
$7X_0$

JACEE-3 ("LOW ENERGY JACEE") (FLOWN)

COUNTER-EMULSION (1982)

.100% Eff. Fe-EMUL E = 20-80 GeV/nucl

JACEE – III CONFIGURATION



$\hat{C}_{gas} \to E_0$

$\hat{C}_{L.G.} + \hat{C}_T \to Z$

EMULSIONS

Scin. For TRIGGER

CG – GAS ĈERENKOV, F12, 1 ATMOSPHERE
CLG – LEAD GLASS ĈERENKOV
CT – TEFLON ĈERENKOV
EC – EMULSION CHAMBER
S – SCINTILLATOR

JACEE Balloon Flights

Flight	Date	Launch Site	Residual Altitude (g/cm^2)	Time (hrs)	Area (m^2)
JACEE-0	5/79	Sanriku (Japan)	8.0	29.0	0.20
JACEE-1	9/79	Palestine (USA)	3.7	26.5	0.80
JACEE-2	10/80	Palestine (USA)	4.0	29.6	0.80
JACEE-3	6/82	Greenville (USA)	5.0	39.0	0.25
JACEE-4	9/83	Palestine (USA)	4.5	59.5	0.80
JACEE-5	10/84	Palestine (USA)	5.0	15.0	0.80
JACEE-6	5/86	Palestine (USA)	5.0	30.0	0.80
JACEE-7	1/87	Australia-Paraguay	5.0	150	0.60
JACEE-8	2/88	Australia-Brazil	5.0	100	0.60

FLUX FOR JACEE BALLOON PROGRAM

MINIMUM GOAL ?!

Table 3. Expected integral number of events for 500 m^2-sr-hr exposure as a function of total energy per nucleus.

Particle Type	Threshold Total Energy (eV/nucleus) 10^{12}	10^{13}	10^{14}
P	1.2×10^5	2450	50
He	6.2×10^4	1240	25
C+O	2.6×10^4	520	11
Ne+Mg+Si	2.0×10^4	390	8
$\gamma = -1.7$ Fe	3.1×10^4	615	12
-1.4 $Fe^{(a)}$	4.0×10^4	800	16
-1.6 $Fe^{(b)}$	1.5×10^5	2900	58

NOTES: See Table 2.

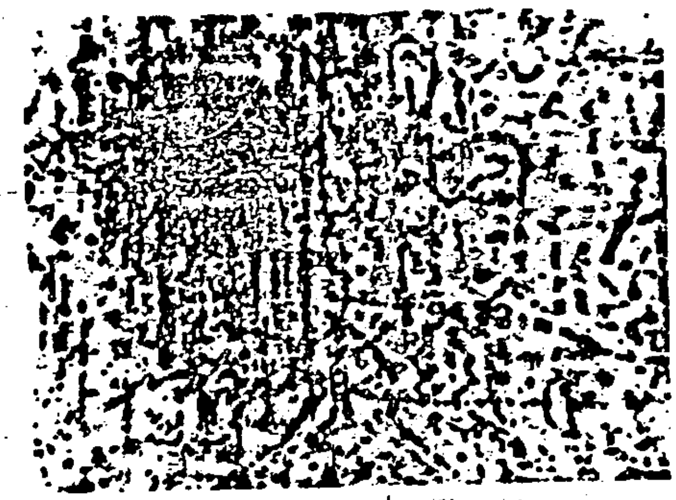
PROPOSED 1000 m^2-sr-hr

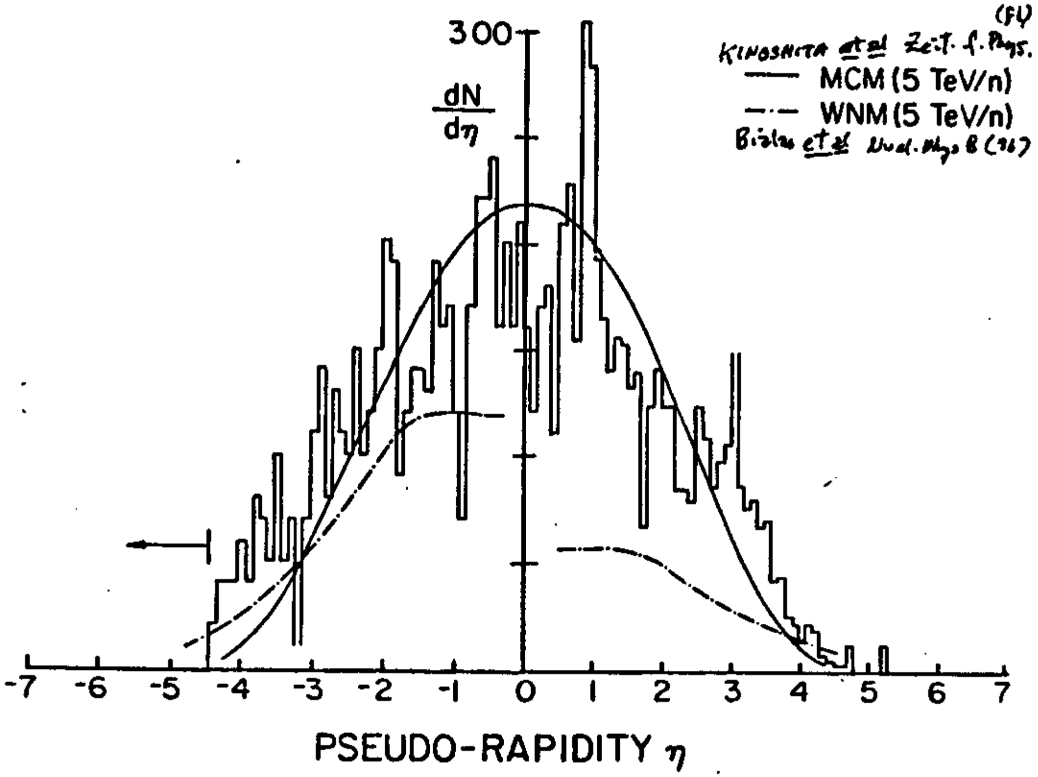
[SOME OVERLAP WITH EAS]

⟹ COVER GAP IN OBSERVATION BETWEEN GOOD DATA FROM BALLOONS AND SATELLITES (≲ 100 GeV/n) AND THE EAS DATA (≳ 10^{15} eV Total Energy)

Si + AgBr → 5 N_h + 1010 ± 30 N_{ch} + >170 γ
(4 TeV/nucl)

800 μm
BASE PLATE



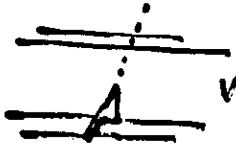


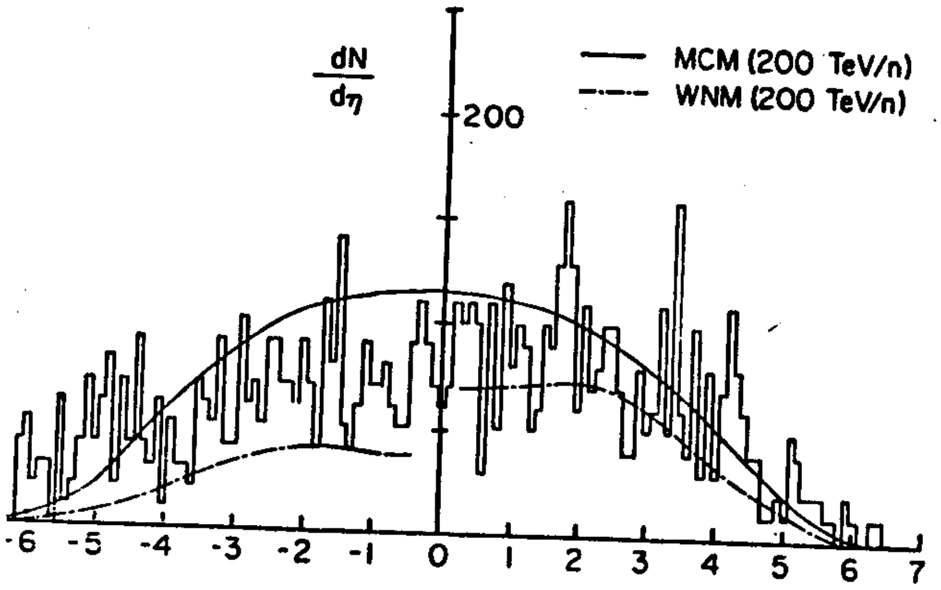
ACRYLIC !!

$Ca + C \rightarrow He + 760 \pm 30 N_{ch} + > 300\,\gamma$

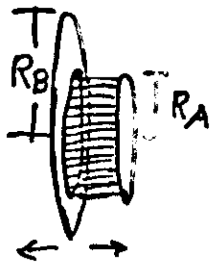
$E_0 \simeq 2.6 \times 10^{15}$ eV

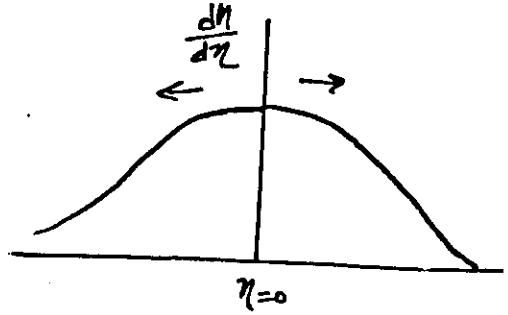
Highest energy event ever observed "directly"





ESTIMATE OF THE ENERGY DENSITY
FROM PSEUDO RAPIDITY DISTRIBUTIONS
[CENTRAL RAPIDITY DENSITY]
BJORKEN FORMULA





$$\epsilon = \left\langle \sqrt{p^2+m^2} \right\rangle \frac{3}{2} \frac{dn}{d\eta} \Big/ \pi R_A^2 t$$

$$\geq \sqrt{\langle p_\perp^2 \rangle + m^2}\ \frac{3}{2} \frac{dn}{d\eta} \Big/ \pi R_A^2 t$$

High Energy Central Collision Candidates ($N_{ch} > 400$)

A + B	E_o (TeV/amu)	N_{ch}	$dN/d\eta_c$	$\langle p_{T\pi} \rangle$ (GeV/c)	ε (GeV/fm^3)
Ca + C	100.0	760 ± 30	81 ± 8	0.53 ± 0.04	2.0
Si + Em	4.1	1010 ± 30	183 ± 10	$0.55^{+0.12}_{-0.05}$	2.7
V + Pb	1.5	1050^{+300}_{-50}	258 ± 12	0.55 ± 0.05	2.5
Ti + Pb	1.0	416	139 ± 8	$1.00^{+0.2}_{-0.15}$	2.4
Ca + Pb	1.8	452	100 ± 16	$1.1^{+1.0}_{-0.35}$	2.2
Ca + Pb	0.5	670 ± 40	142 ± 8	1.1 ± 0.5	3.3
Si + Pb	4.0	790^{+40}_{-25}	147 ± 8	$1.0^{+0.2}_{-0.15}$	3.8
C + Pb	71.5	400^{+15}_{-30}	81 ± 7	>1.2	4.5

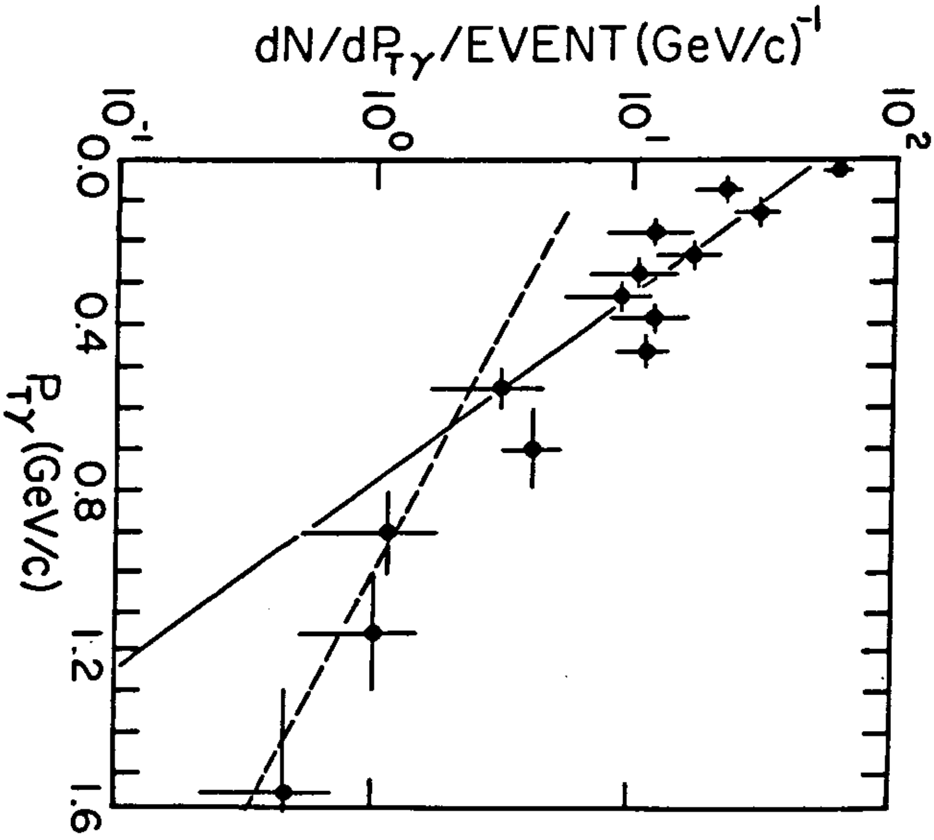
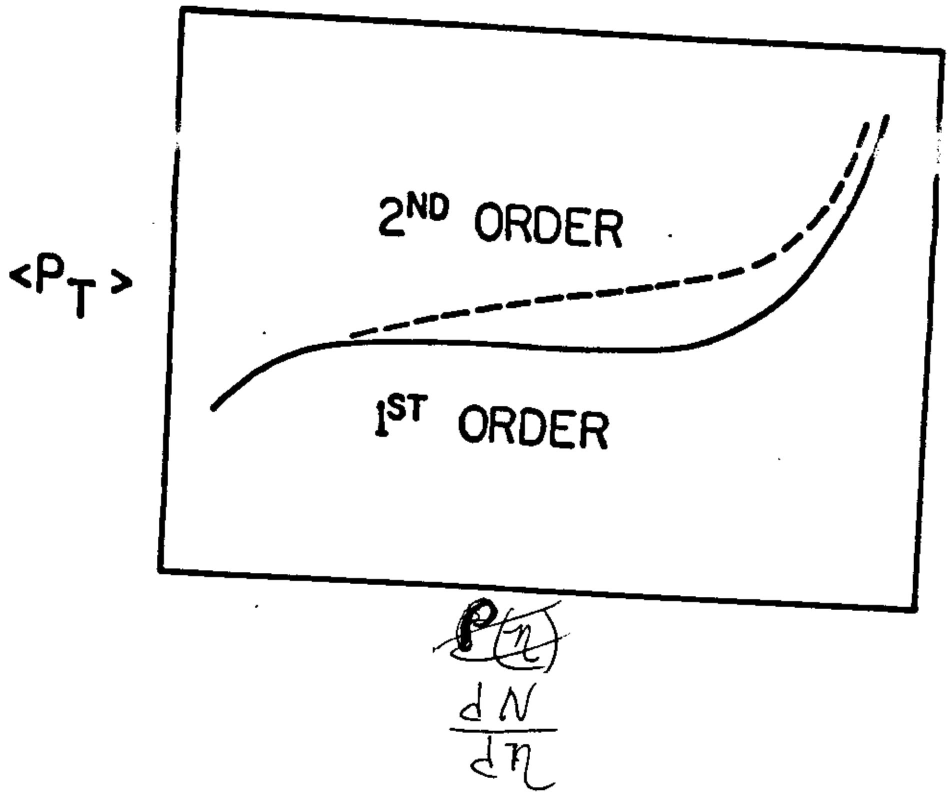


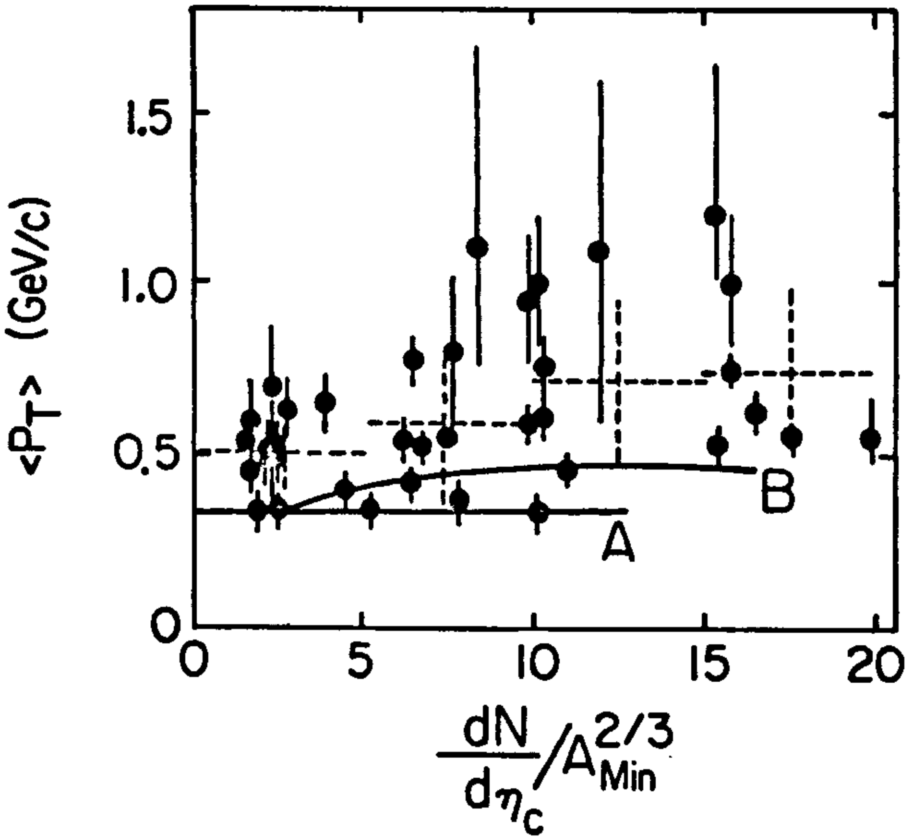
Figure 14. Schematic representation of the expected dependence of average transverse momentum on rapidity density for first and second order phase transitions.

Figure 15. Dependence of the average transverse momentum on the central rapidity density per unit colliding volume. The average dependence is indicated by dashed crosses. Curve A denotes proton-proton data (61) up to 1.7 TeV with $\langle P_T \rangle = 0.34$ GeV/c. Curve B represents the CERN proton-antiproton data (62) at 150 TeV laboratory energy.

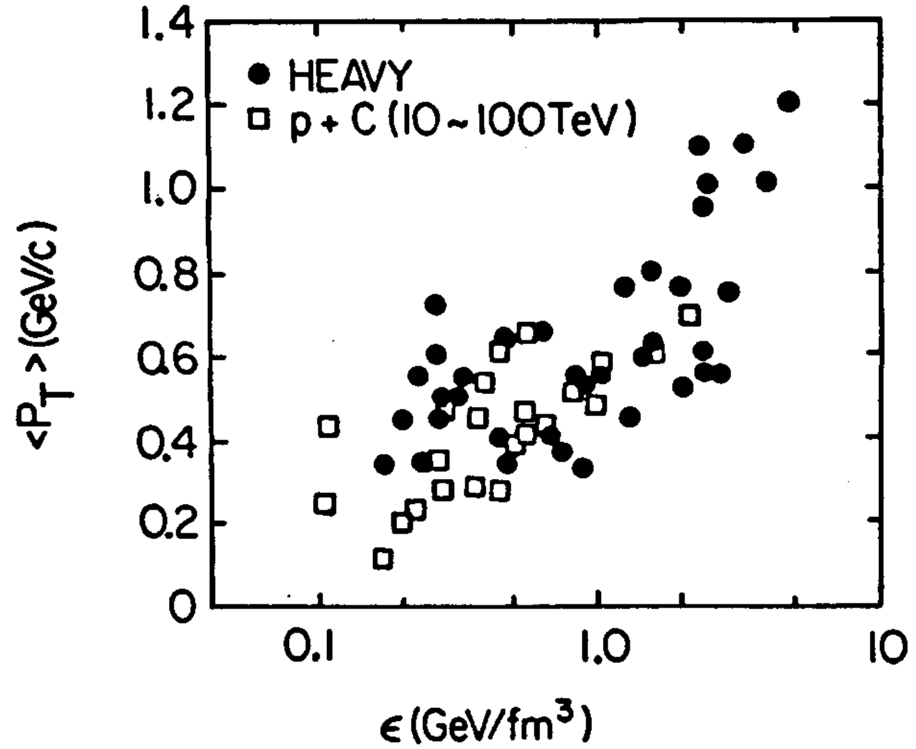
Figure 16 Dependence of average transverse momentum on energy density. The solid circles are for individual events $(2 < Z_p > 26)$ and the open squares are for proton + CHO events.

Figure 17. Example of an event with a "central-dip" in the η distribution: $N_{ch} = 452$ for this 1.8 TeV/amu Ca + Pb interaction.

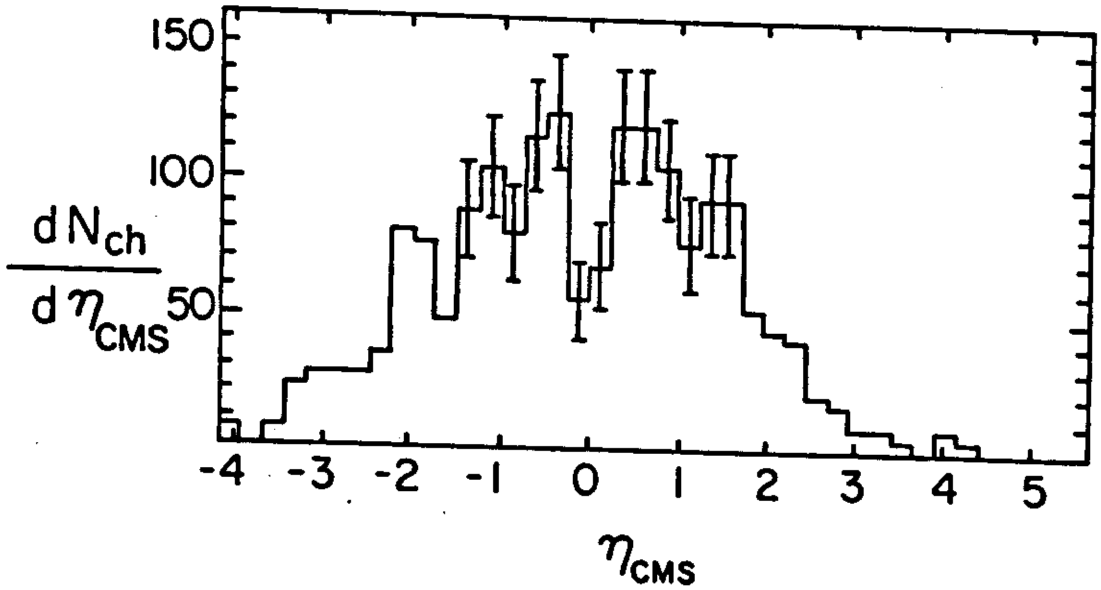


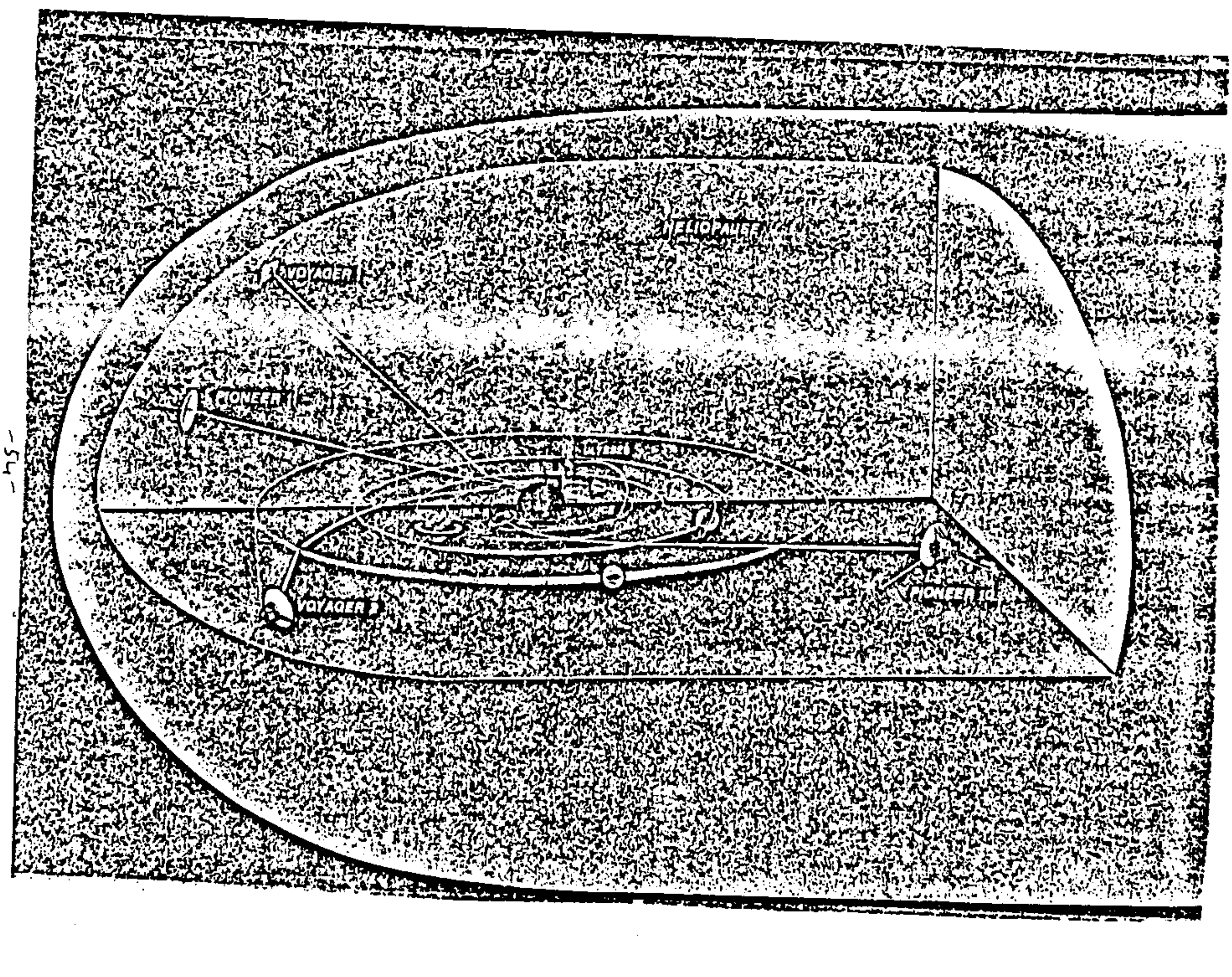


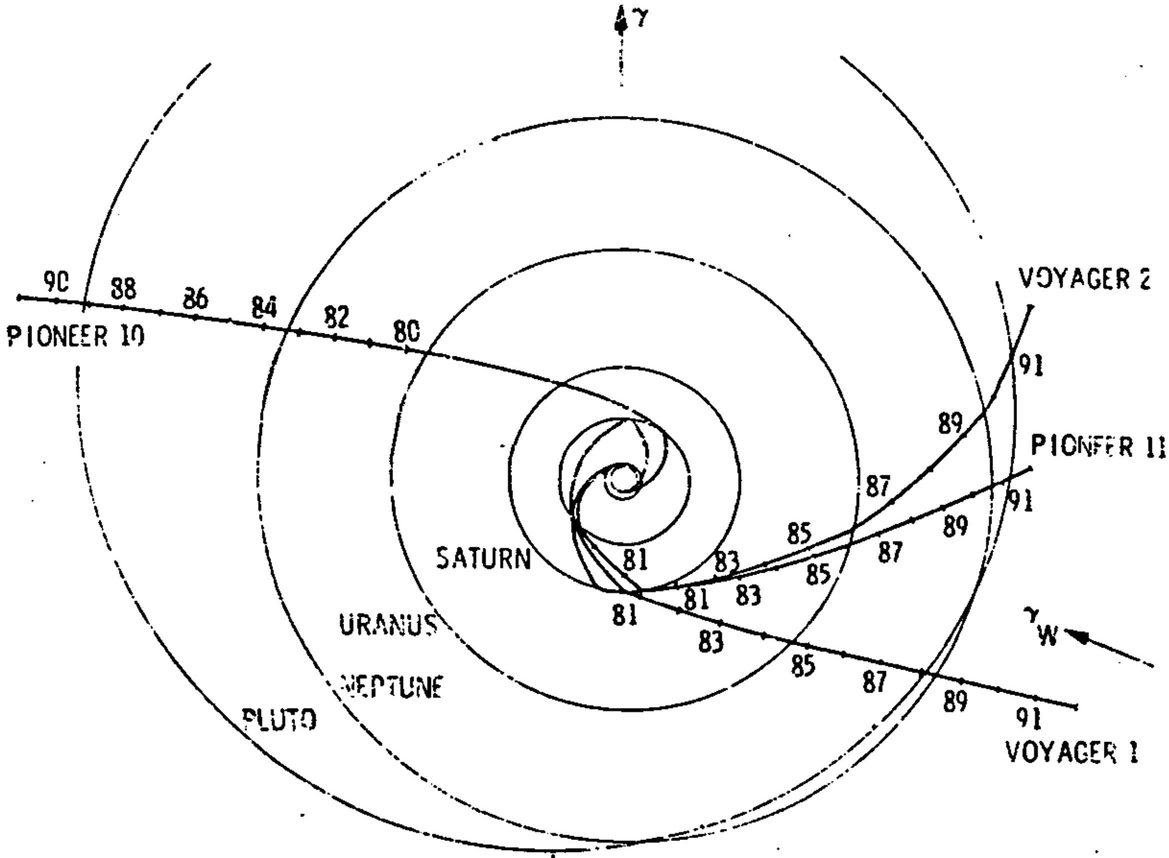
<PT> (GeV/c)
0
0.5
1.0
1.5
0
5
10
15
20
A
B
dN/dηc /A2/3Min



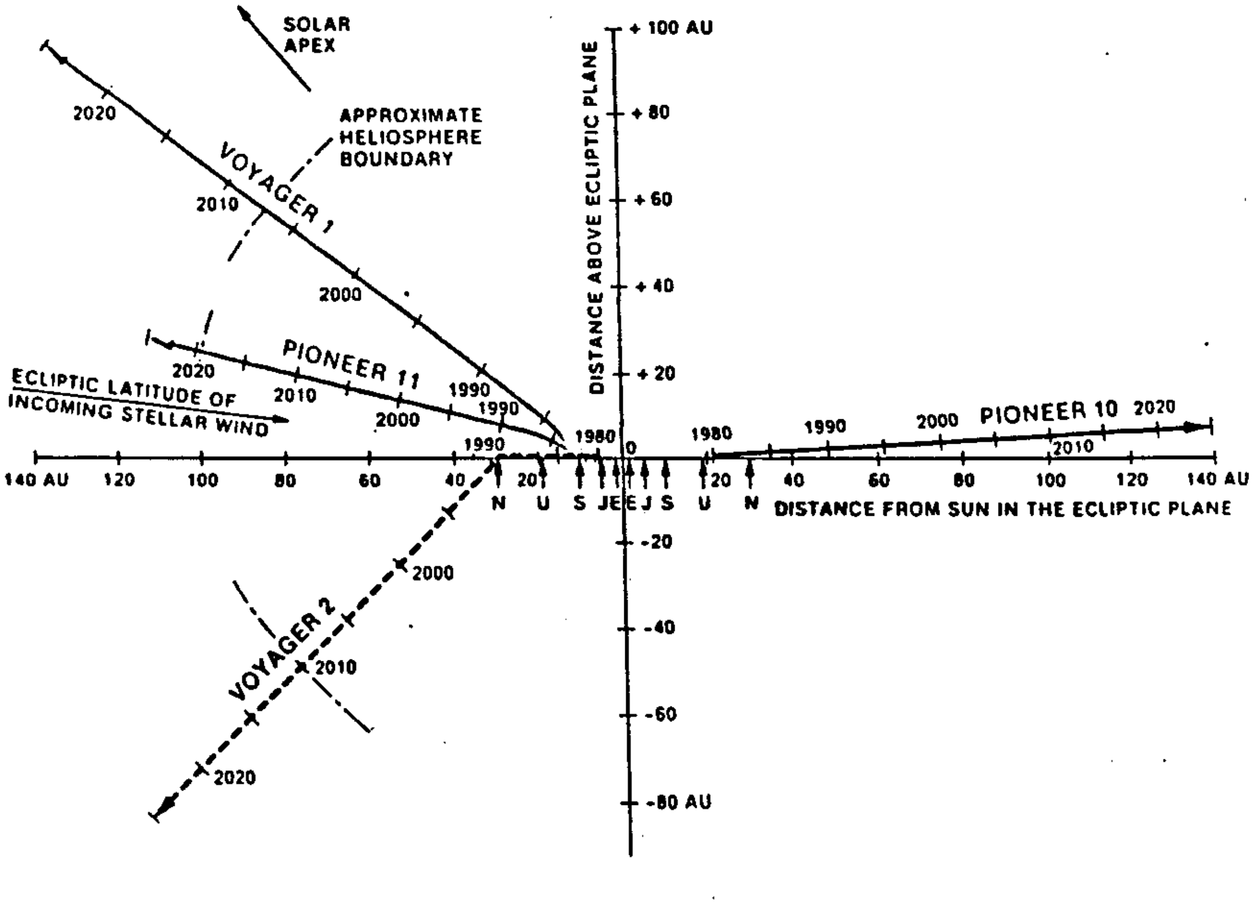
<PT >(GeV/c)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
HEAVY
p + C (10 ~ 100TeV)
0.1
1.0
10
ε (GeV/fm3)


150
100
50
$\frac{dN_{ch}}{d\eta_{CMS}}$
-4 -3 -2 -1 0 1 2 3 4 5
η_{CMS}


HELIOPAUSE
VOYAGER
PIONEER
VOYAGER
PIONEER



Trajectories of Pioneers 10 and 11 and Voyagers 1 and 2



Heliographic Latitudes of Pioneer 10, 11 and Voyagers 1, 2.

The Heliosphere

1 Interstellar medium

2 Interstellar wind/velocity vector

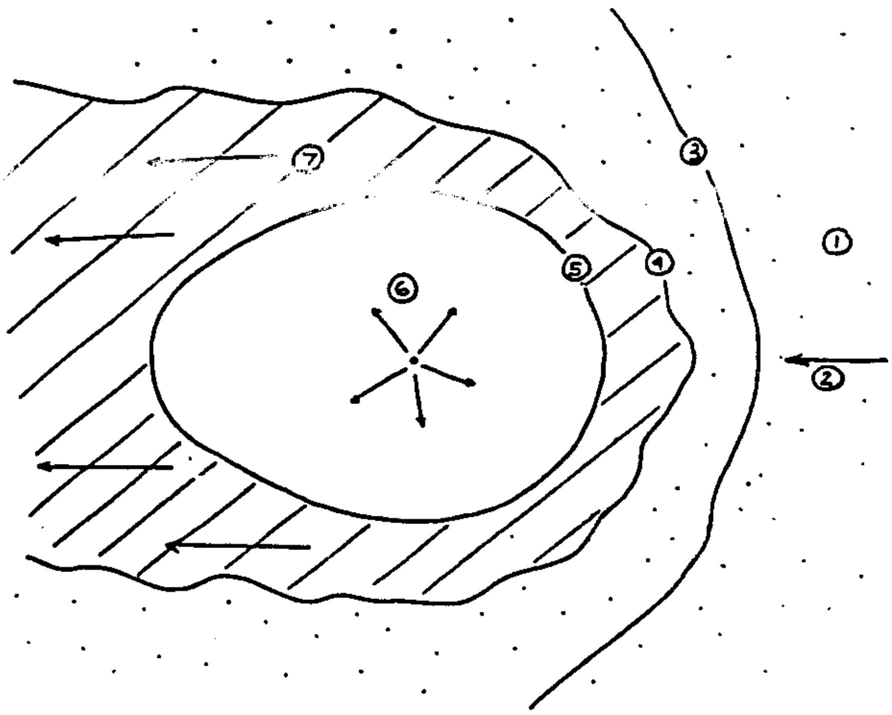
3 Interstellar bow shock

4 Heliopause

5 Terminal/inner shock

6 Supersonic solar wind flow

7 Subsonic solar wind flow



Various sites in the heliosphere at which particles are accelerated.

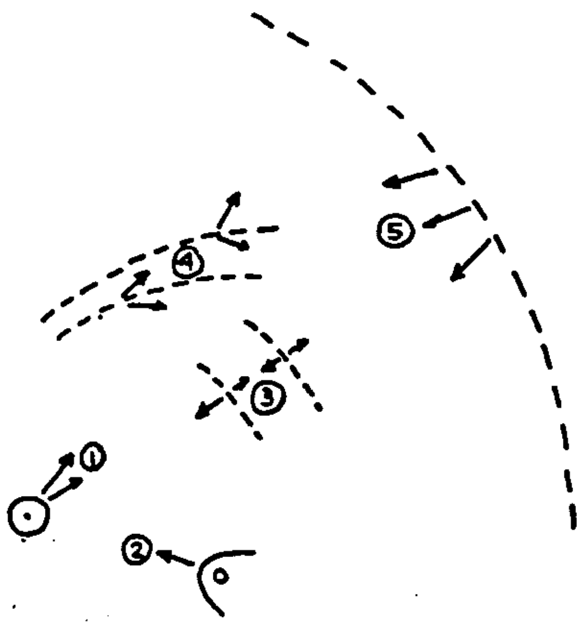
1 Acceleration at the sun by solar flares

2 Particles upstream of planetary bow shock

3 Acceleration at forward and reverse shocks associated with a travelling interplanetary disturbance/transient.

4 Acceleration at forward-reverse shock pair accompanying a corotating interaction region

5 Acceleration of anomalous cosmic ray component at terminal shock



Solar energetic particles associated with a flare.

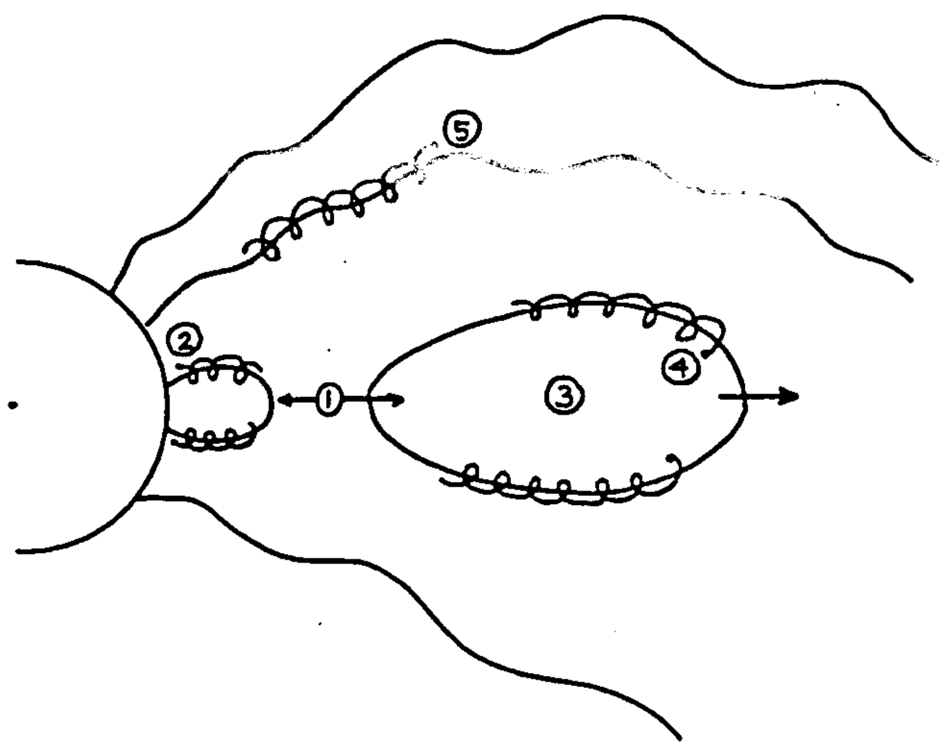
1 Acceleration region, presumed to involve magnetic reconnection.

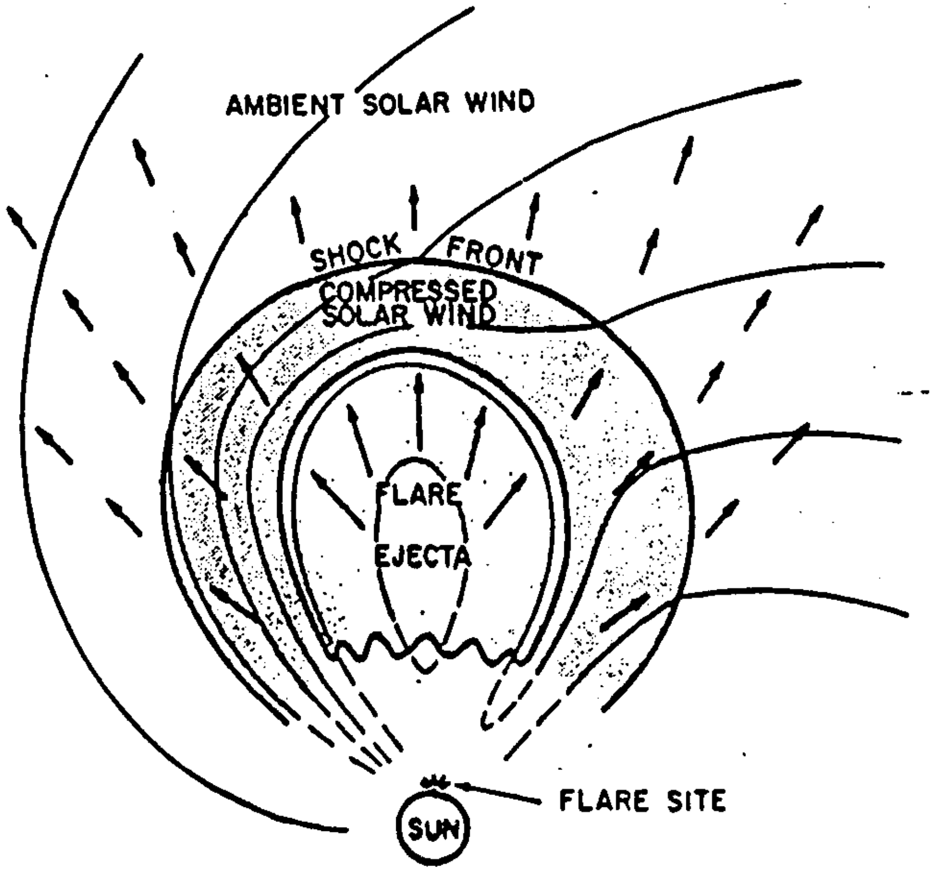
2 Flux loop descending toward sun containing trapped energetic particles

3 Plasmoid or magnetic loop or coronal mass ejection

4 Bi-directional energetic particles trapped in magnetic loop

5 Accelerated particles that have reached open field lines and are propagating outward





Solar wind structure associated with a flare-generated transient (Coronal Mass Ejection).

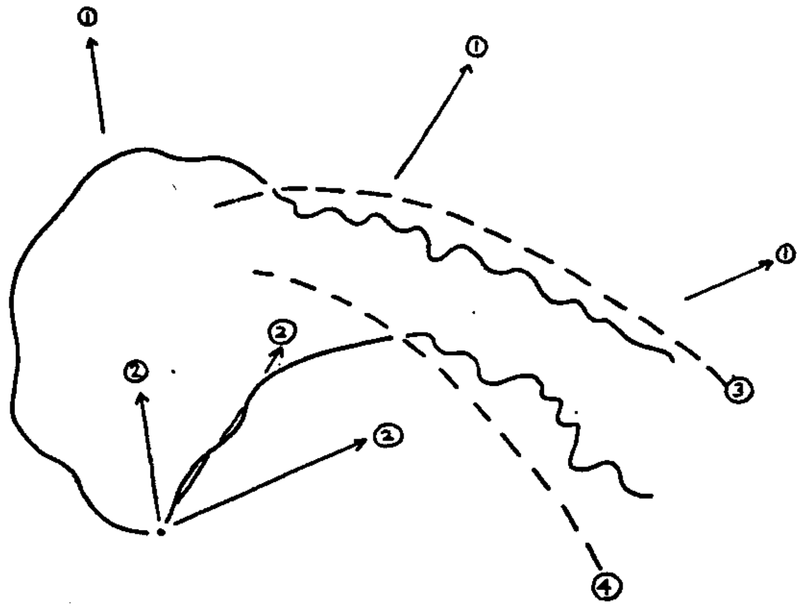
Forward-Reverse shocks accompanying a corotating fast solar wind stream

1 Slow solar wind

2 Fast solar wind

3 Forward shock

4 Reverse shock



SCHEMATIC REPRESENTATION OF ACCELERATION MECHANISMS

- ON THE SUN
- IN THE HELIOSPHERE

VARIOUS POPULATIONS OF ENERGETIC PARTICLES THAT RESULT

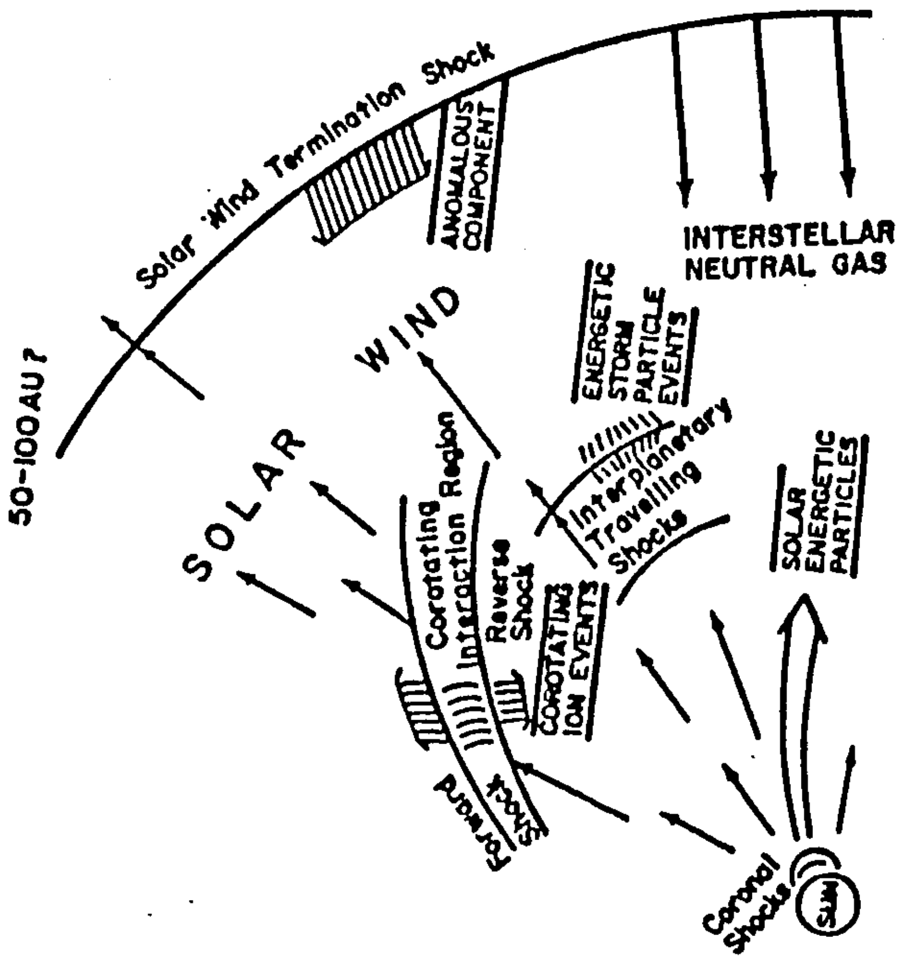
- SW — SOLAR WIND PARTICLES
- SEP — SOLAR ENERGETIC PARTICLES
  - PARTICLES FROM SOLAR FLARES
- CIR — CO-ROTATING ION REGION EVENTS
  - PARTICLES ACCELERATED IN CO-ROTATING INTERACTION REGIONS
- ESP — ENEGETIC STORM PARTICLES
  - PARTICLES ACCELERATED BY SOLAR-TRANSIENT-GENERATED INTERPLANETARY SHOCKS

SW AND SEP PROVIDE DIRECT SAMPLE OF SOLAR MATERIAL

CIR AND ESP ORIGINATE FROM SOLAR MATERIAL, PROBABLY SOLAR WIND

ANOMALOUS COMPONENT

- INTERSTELLAR NEUTRAL MATERIAL ENTERS HELIOSPHERE
- GETS ONCE-IONIZED AND THEN LOCALLY ACCELERATED


Solar Wind Termination Shock
50-100 AU ?
ANOMALOUS COMPONENT
INTERSTELLAR NEUTRAL GAS
SOLAR WIND
ENERGETIC STORM PARTICLE EVENTS
Corotating Interaction Region
Reverse Shock
Interplanetary Travelling Shocks
SOLAR ENERGETIC PARTICLES
COROTATING ION EVENTS
Forward Shock
Coronal Shocks
SUN