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

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
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SCHOOL ON
NON-ACCELERATOR PHYSICS
25 April - 6 May 1988

PARTICLE PHYSICS WITH BALLOONS, SATELLITES AND SPACE STATIONS. (3)

by

W. V. Jones
Space Physics Division
National Aeronautics & Space Administration
Washington
U. S. A

ASTROMAG

A SUPERCONDUCTING MAGNET SPECTOMETER

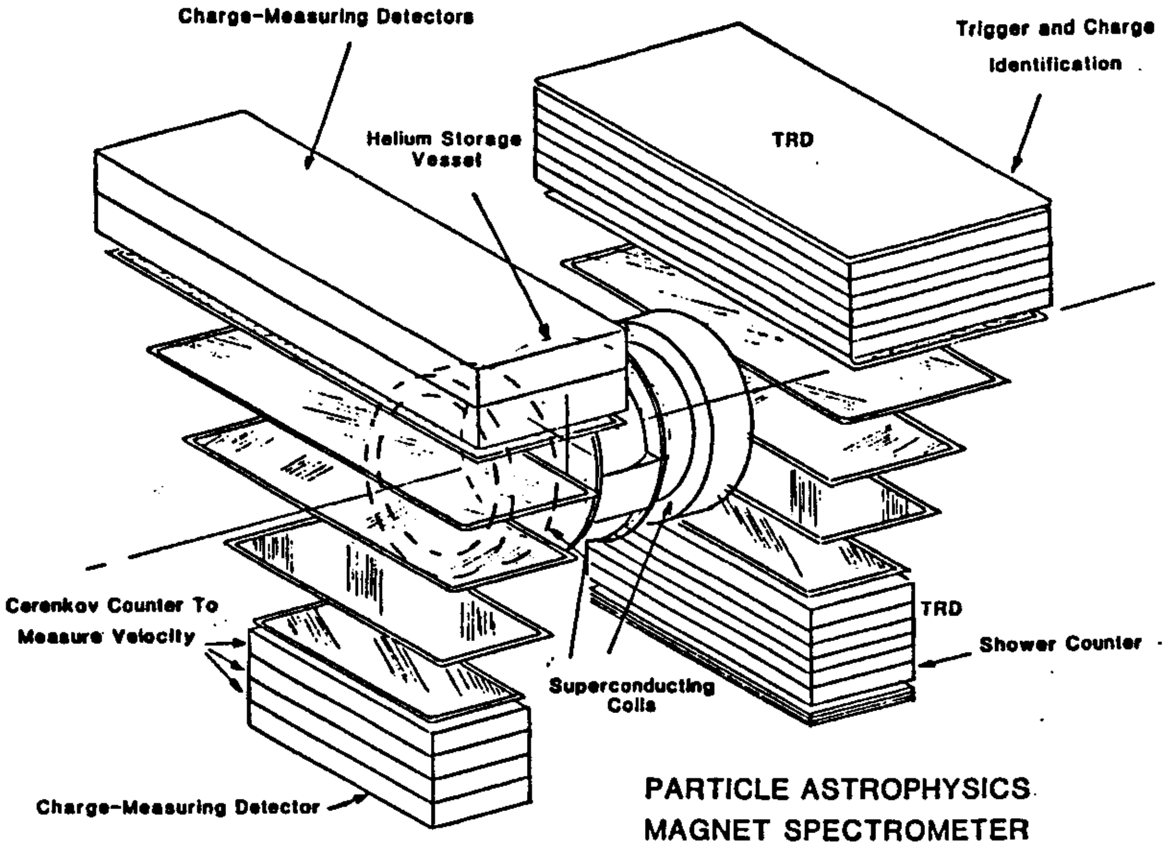
FOR PARTICLE ASTROPHYSICS

Astromag is:

- o Superconducting Magnet With "Strawman" Experiments
  - -anti-matter spectrometer
  - -isotope spectrometer
- o Space Station Attached Payload

Science:

- o Bread and Butter Science
  - -nucleosynthesis
  - -origin of cosmic rays
- o Discovery/Cosmology
  - -matter/antimatter
  - -search for dark matter candidate

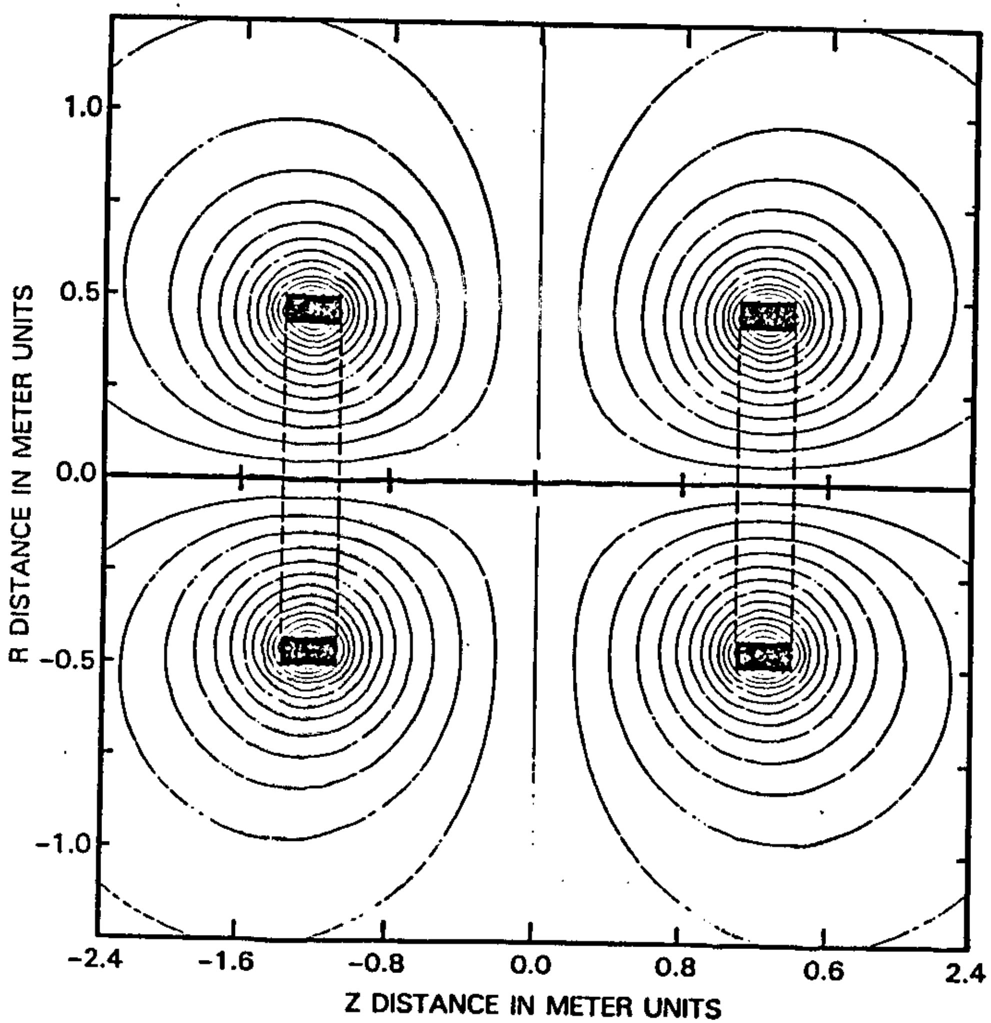


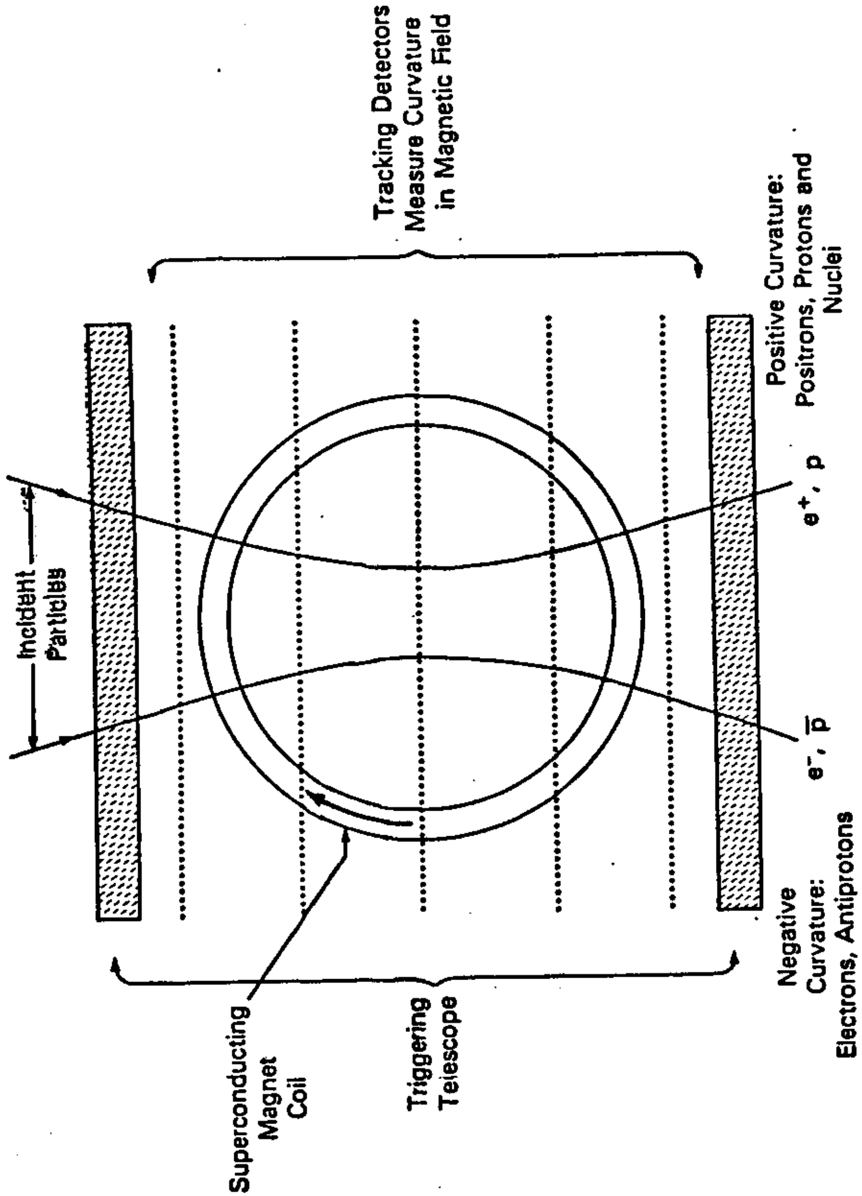
PARTICLE ASTROPHYSICS MAGNET SPECTROMETER

GENERAL STRUCTURE OF ASTROMAG

- O "ASTROMAG" = PARTICLE ASTROPHYSICS SUPERCONDUCTING MAGNET FACILITY
- O SEVERAL MAGNET DESIGNS STILL UNDER STUDY
  - FINAL CHOICE BASED ON PERFORMANCE, COST, AND SAFETY TRADE-OFFS
  - HEAO-DESIGN SELECTED AS STRAWMAN TO ASSIST IN EXPERIMENT DESIGN
    - o PROTOTYPE FOR HEAO PROGRAM WAS BUILT AND TESTED IN 1970'S
    - o PROVIDES A BASE OF EXPERIENCE FOR SPACE MAGNET
- O CURRENT IN TWO SUPERCONDUCTING COILS CIRCULATE IN OPPOSITE SENSE
  - LEAVES NO NET DIPOLE MOMENT ON THE SPACE STATION
  - FIELD DROPS TO EARTH'S FIELD INTENSITY IN ABOUT 10 METERS
- O DEWAR CONTAINING LIQUID HELIUM IS LOCATED BETWEEN THE TWO COILS
  - SPACE STATION SERVICING PERMITS CRYOGEN RE-SUPPLY
- O TWO EXPERIMENTS CAN BE OPERATED SIMULTANEOUSLY
  - ONE AT EACH END OF THE MAGNET (MAS AND CHRIS ILLUSTRATED)
  - EXPERIMENTS CAN BE MODIFIED OR EXCHANGED FOR NEW EXPERIMENTS

MAGNETIC FLUX LINE CONTOUR MAP
(LINES OF CONSTANT VECTOR POTENTIAL)





POTENTIAL "FIRST-GENERATION" EXPERIMENTS

MATTER-ANTIMATTER SPECTROMETER (MAS)

- O COMMONLY DESIGNATED AS ANTI-PROTON EXPERIMENT
- O OPTIMIZED FOR MEASUREMENTS OF PROTONS, ANTI-PROTONS, ELECTRONS, POSITRONS
- O ENERGY RANGE FROM A FEW GeV TO ABOUT A TeV
- O ENERGY SPECTRA MEASUREMENTS OF NUCLEI UP TO $Z = 10$ (FEW HUNDRED GeV/AMU)
- O HIGH SENSITIVITY SEARCHES FOR ANTI-NUCLEI $Z = 2 - 10$ ABOVE FEW GeV/AMU
- O POTENTIAL DETECTORS INCLUDE COMBINATIONS OF
  - SCINTILLATORS
  - TRANSITION RADIATION DETECTORS (TRD)
  - MULTI-WIRE PROPORTIONAL COUNTERS (TRAJECTORIES)
  - SHOWER COUNTERS

POTENTIAL "FIRST-GENERATION" EXPERIMENTS (CONTINUED)

COSMIC RAY ISOTOPE SPECTROMETER (CRIS)

- O OPTIMIZED TO MEASURE ISOTOPIC COMPOSITION $Z = 6 - 28$, SEVERAL GeV/AMU
- O SUITABLE FOR ELEMENTAL COMPOSITION UP TO FEW HUNDRED GeV/AMU
- O ALSO SUITABLE FOR SEARCHES FOR ANTI-NUCLEI ABOVE FEW GeV/AMU
- O DETECTORS INCLUDE
  - CHERENKOV DETECTORS OF VARIOUS INDICES OF REFRACTION
    - o MEASURE CHARGE AND VELOCITY
  - LAYERS OF SCINTILLATING OPTICAL FIBERS FOR TRAJECTORY MEASUREMENTS

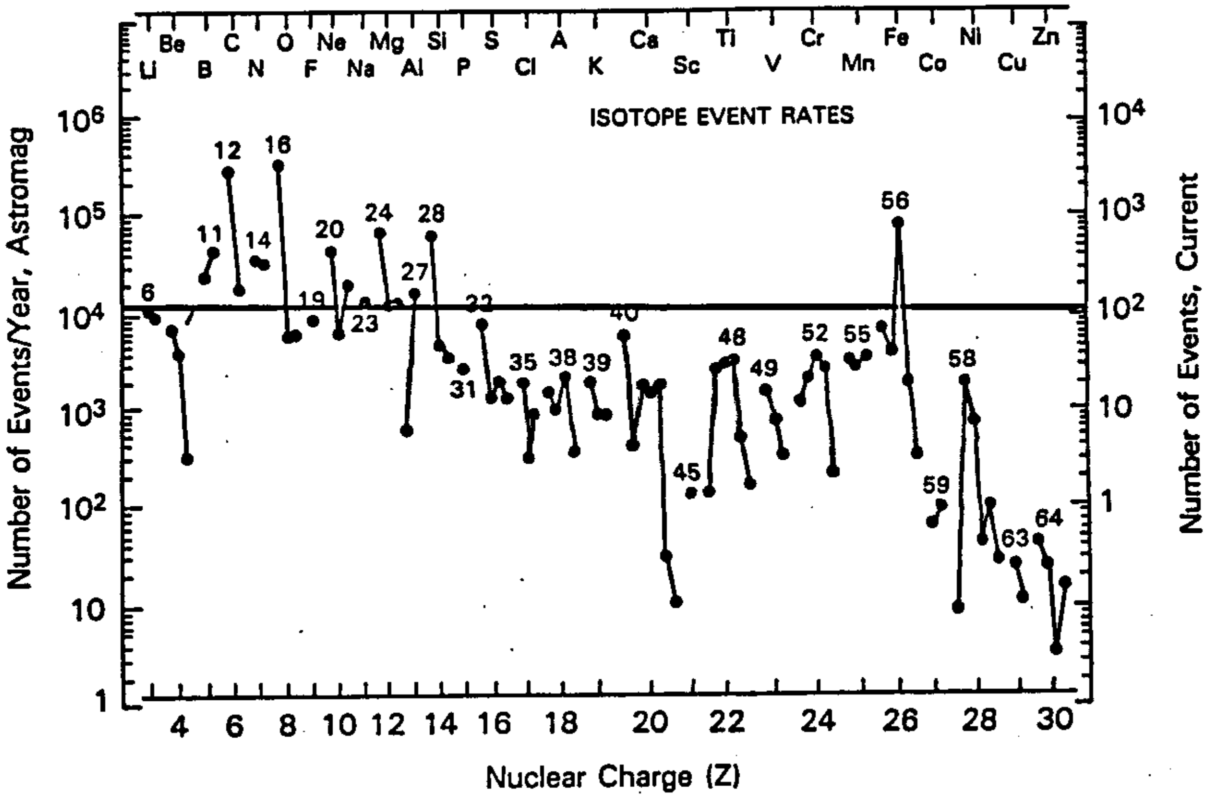
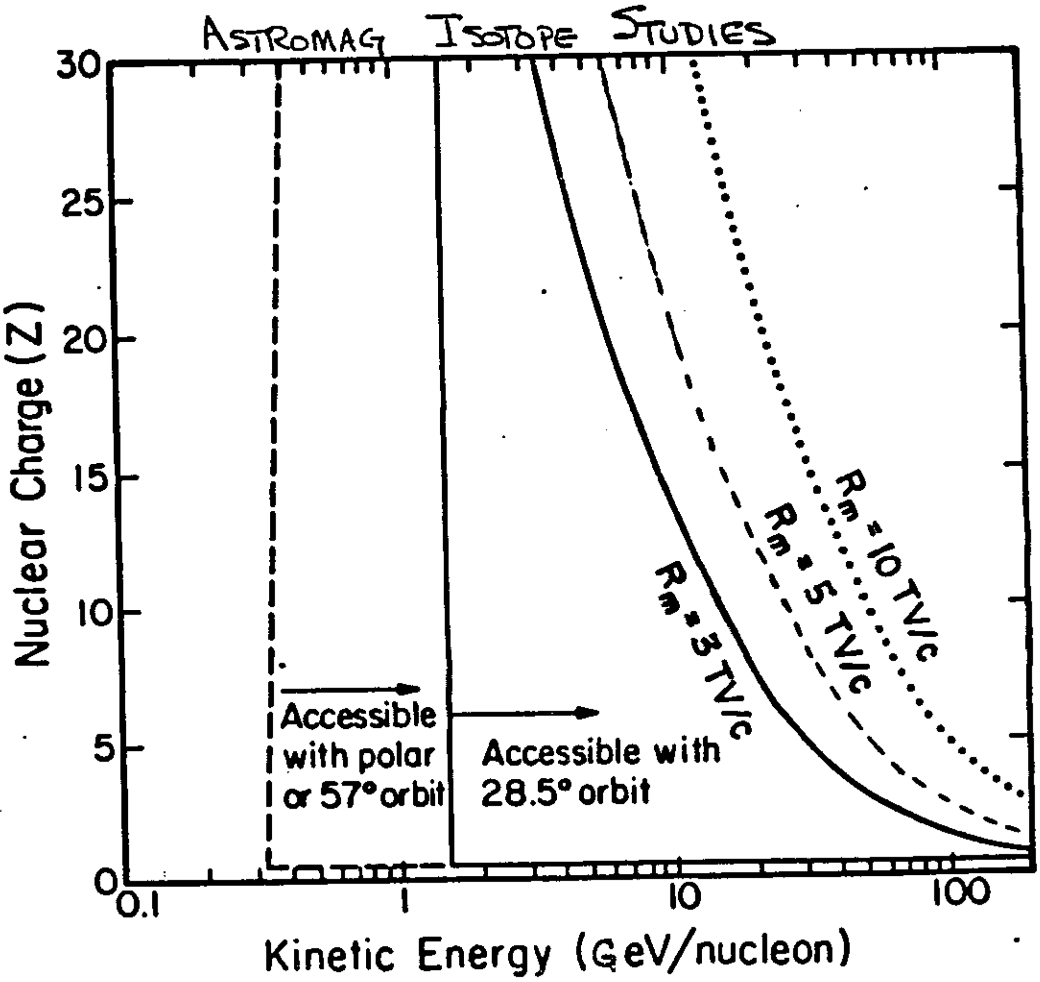

ISOTOPE EVENT RATES
Number of Events/Year, Astromag
Number of Events, Current
Nuclear Charge (Z)
Li Be B C N O F Ne Na Mg Al Si P S Cl A K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn

Figure 1


ASTROMAG ISOTOPE STUDIES
Nuclear Charge (Z)
Kinetic Energy (GeV/nucleon)
Accessible with polar or 57° orbit
Accessible with 28.5° orbit
R_m = 3 TV/c
R_m = 5 TV/c
R_m = 10 TV/c

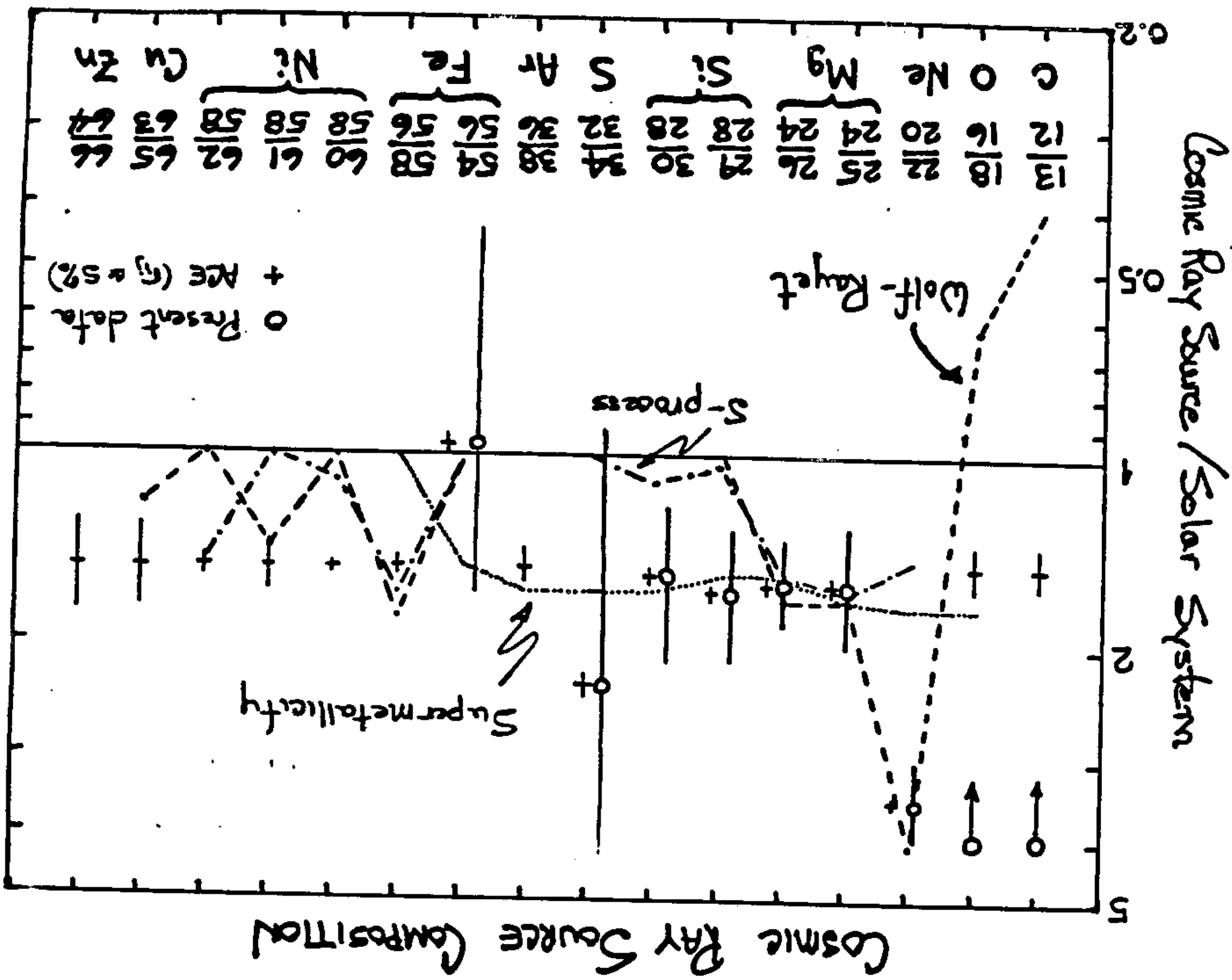
GALACTIC COSMIC RAY ISOTOPE STUDIES

- GALACTIC COSMIC RAYS REPRESENT AN ACCESSIBLE SAMPLE OF MATTER THAT ORIGINATES OUTSIDE THE SOLAR SYSTEM
  - THE ISOTOPIC COMPOSITION CONTAINS DETAILED RECORD OF ITS NUCLEAR HISTORY
    - SYNTHESIS IN STARS AND INTERACTIONS WITH INTERSTELLAR GAS
  - THE ELEMENT DISTRIBUTION IS DETERMINED PRIMARILY BY ATOMIC INTERACTIONS
- HIGH-RESOLUTION ISOTOPE MEASUREMENTS HAVE BECOME POSSIBLE ONLY RECENTLY
  - ALREADY REVOLUTIONIZED OUR VIEWS OF COSMIC RAY ORIGIN AND PROPAGATION
  - DEMONSTRATED THAT ISOTOPIC COMPOSITON OF COSMIC RAY SOURCE MATERIAL DIFFERS FROM SOLAR SYSTEM MATERIAL, I.E., HAS DIFFERENT NUCLEOSYNTETIC HISTORY
- AS A RESULT OF RECENT MEASUREMENTS, WE NOW KNOW:
  - Ne-22 IS OVERABUNDANT BY FACTOR OF AT LEAST 3, WHEN COMPARED TO SOLAR SYSTEM ABUNDANCES
  - NEUTRON-RICH ISOTOPES OF Mg-25, Mg-26, Si-29, and Si-30 ARE ENHANCED BY A FACTOR OF ABOUT 1.5

GALACTIC COSMIC RAY ISOTOPE STUDIES

CONT'D

- AS A RESULT OF RECENT MEASUREMENTS, WE NOW KNOW: (CONT'D)
  - INDEED, ALL FIVE OF THE COSMIC-RAY-SOURCE ISOTOPIC RATIOS KNOWN TO AN ACCURAGY OF 50% OR BETTER DIFFER FROM THOSE IN THE SOLAR SYSTEM
  - ISOTOPIC "ANOMALIES" MAY BE THE RULE RATHER THAN THE EXCEPTION
- THESE DISCOVERIES LED TO NUMEROUS SUGGESTIONS ON HOW THE NUCLEOSYNTHESIS OF COSMIC RAY AND SOLAR SYSTEM MATERIAL MAY HAVE DIFFERED
  - SUPERMETALICITY: HIGHER ABUNDANCE OF "METALS" (Z > CNO) IN COSMIC RAY SOURCES
  - SELECTIVE ACCELERATION OF He-BURNING PRODUCTS FROM A CLASS OF STARS OR THE INTERSTELLAR MEDIUM WITH ASSOCIATED ENHANCEMENTS OF S-PROCESS NUCLEI (S-36, Ca-48, Fe-58, Ni-60 & 62)
  - A FRACTION (~3% OF HEAVY COSMIC RAYS ARE POSTULATED TO ORIGINATE FROM MATERIAL EJECTED BY HIGH-SPEED STELLAR WINDS FROM WOLF-RAYET STARS
- THE PRECISION OF ACE IS MORE THAN ADEQUATE TO TEST THESE MODELS



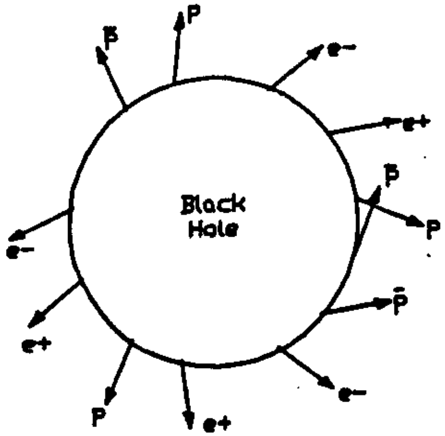
Cosmic Ray Antiprotons

Antiproton observations are a relatively new and very active area in cosmic ray research. There are two general areas that are addressed by antiproton studies:

Antiprotons are expected to be produced by collisions of primary cosmic rays with the interstellar medium. A unique feature of these secondary antiprotons is that the kinematics of the production process prevents production of antiprotons at energies below ~1 GeV. This provides a unique feature (a threshold) in cosmic ray spectra which can be used to study the amount of acceleration (or deceleration) that occurs in the interstellar medium. At present, the number of observed antiprotons is somewhat higher than most predictions. Future high energy antiproton observations and related theoretical work will do much to enlighten us regarding the production and containment of energetic particles in our galaxy.

In recent years astrophysicists and elementary particle physicists have come to believe that there are very close links between their two disciplines. Modern theories of elementary particles and cosmology are closely intertwined. The cosmic ray antiproton may prove to be a valuable observing tool for these disciplines. In modern cosmology there are a number of possible methods for producing antiprotons. These production mechanisms include annihilation of primordial photinos, spontaneous emission near black holes or propagation of cosmic rays from distant galaxies whose composition is predominantly antimatter. All of these mechanisms would result in antiprotons at energies lower than those possible by secondary production.

Production of Antiprotons
by Cosmic Ray Collisions



Production of Particles
Near a Black Hole

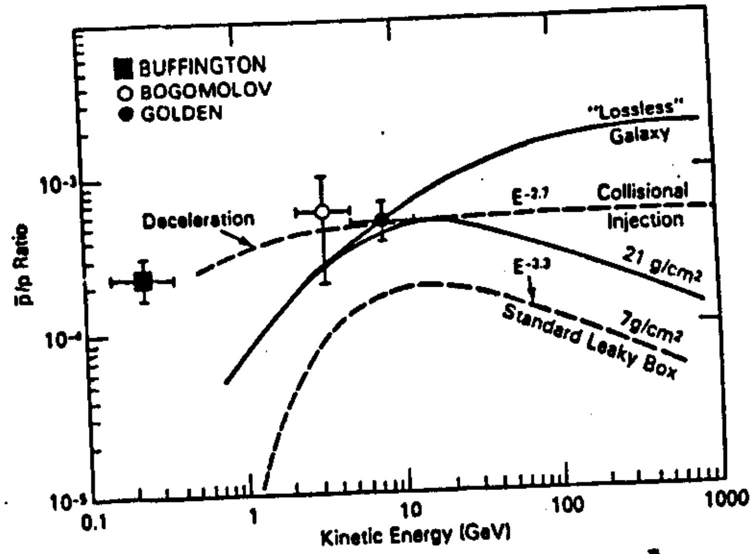


Figure II-1: A summary of recent measurements of the cosmic ray $\frac{\bar{p}}{p}$ ratio, compared with the predictions of several propagation models in which antiprotons are produced as interaction "secondaries", including the "standard leaky box" model (labeled 7 g/cm^2) that fits heavier secondary nuclei.

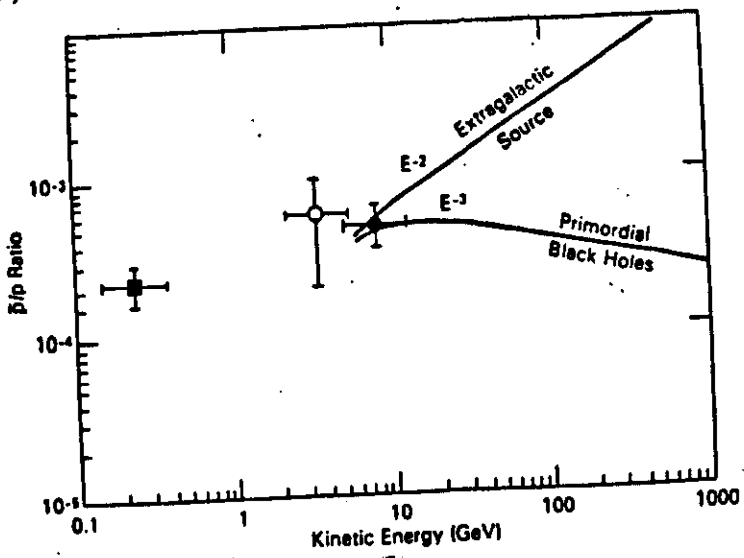


Figure II-2: The predicted spectra of cosmic ray antiprotons which originate in extragalactic sources and primordial black holes are compared with existing measurements.

above, the results of such a study would have wide-ranging implications. Antiprotons are at the very least telling us something very new about the origin of cosmic rays, and they could be telling us something of fundamental cosmological significance.

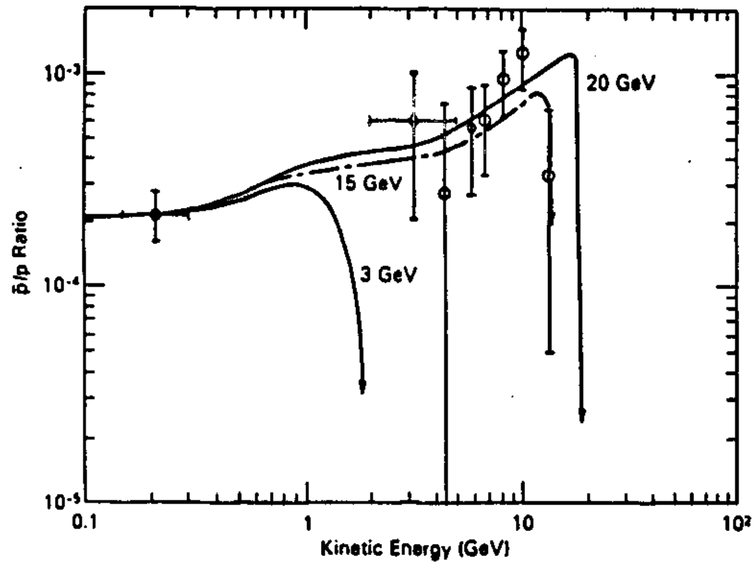
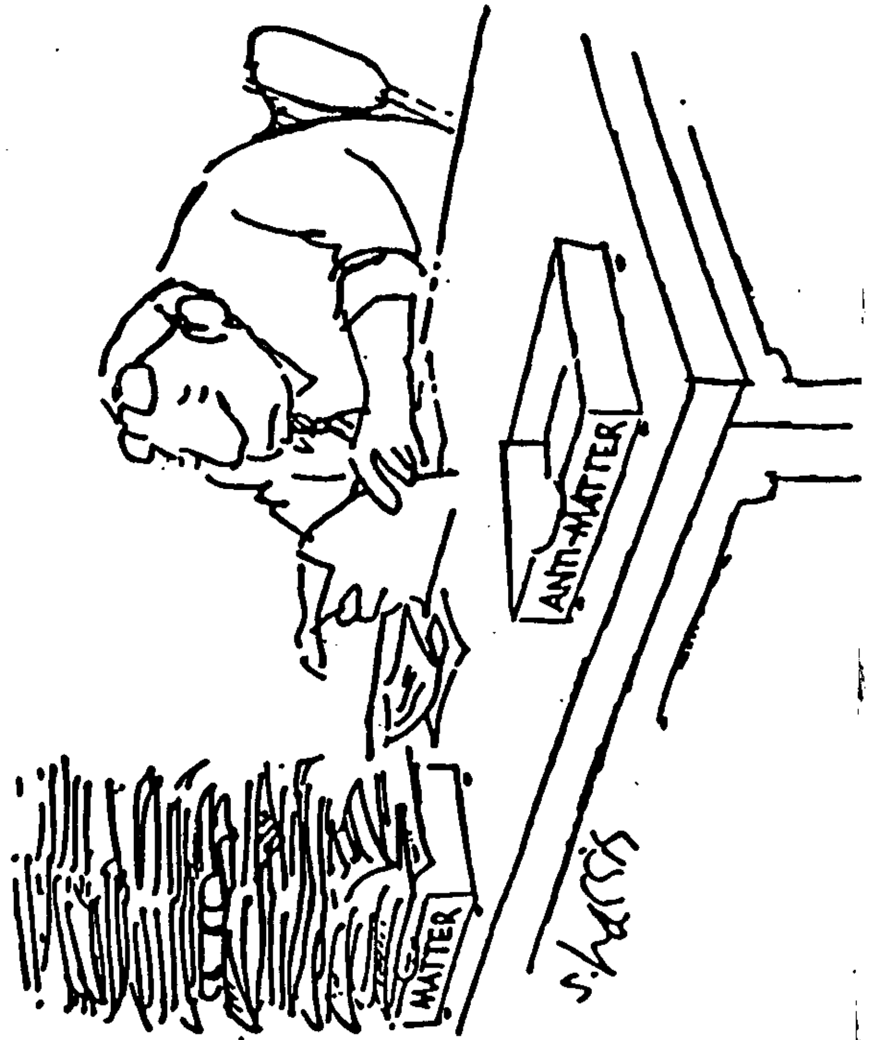


Figure II-3: The predicted $\frac{\bar{p}}{p}$ ratios that result from protons annihilation in the galactic halo are compared with the available cosmic ray measurements. Curves are shown for assumed photino masses of 3, 15, and 20 GeV.



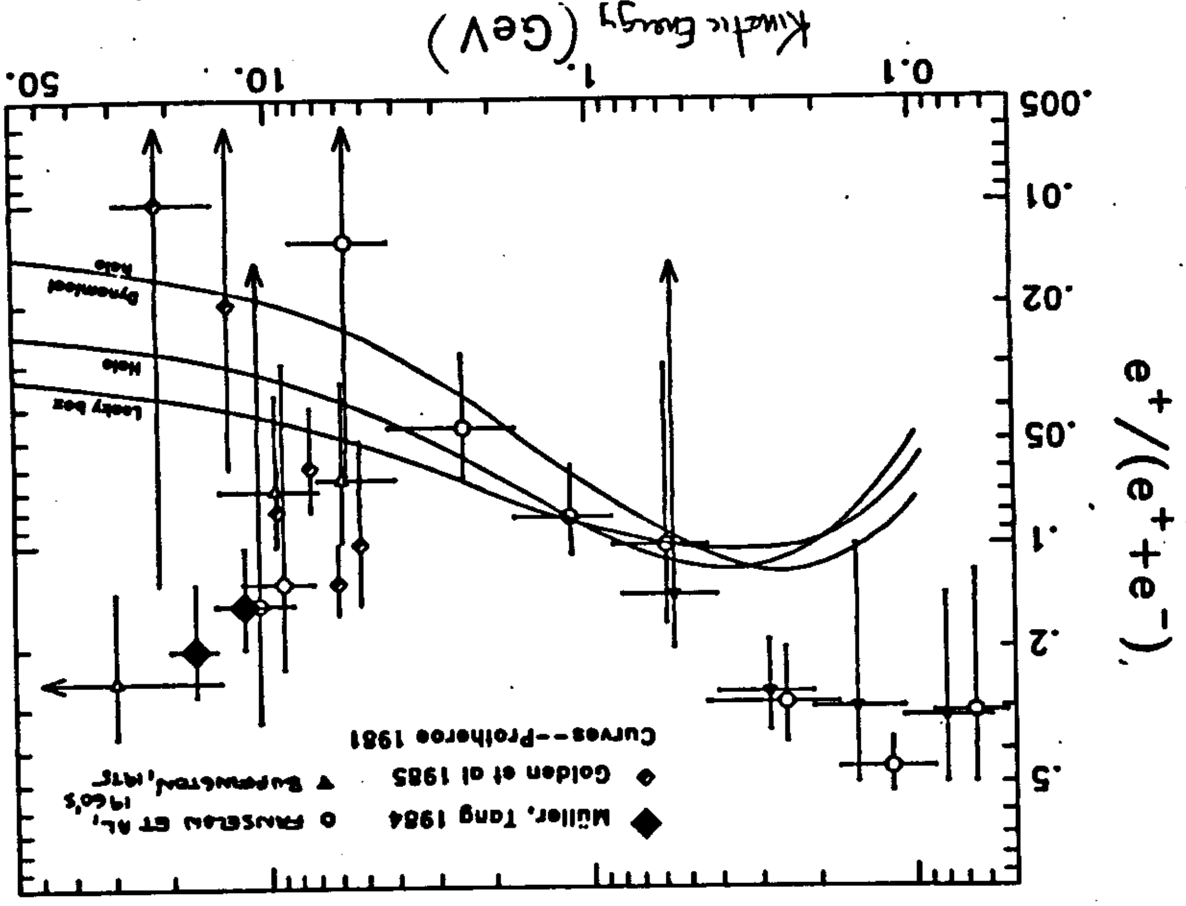
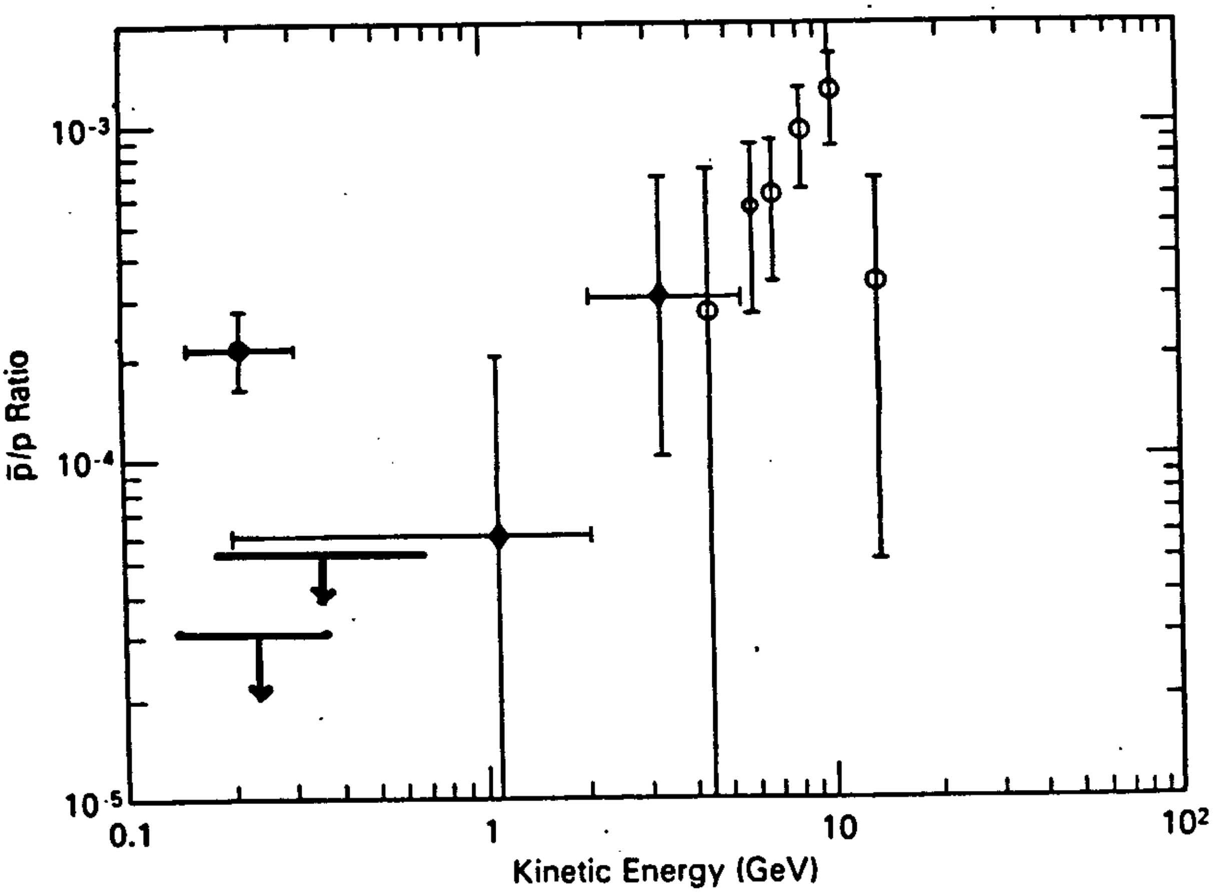


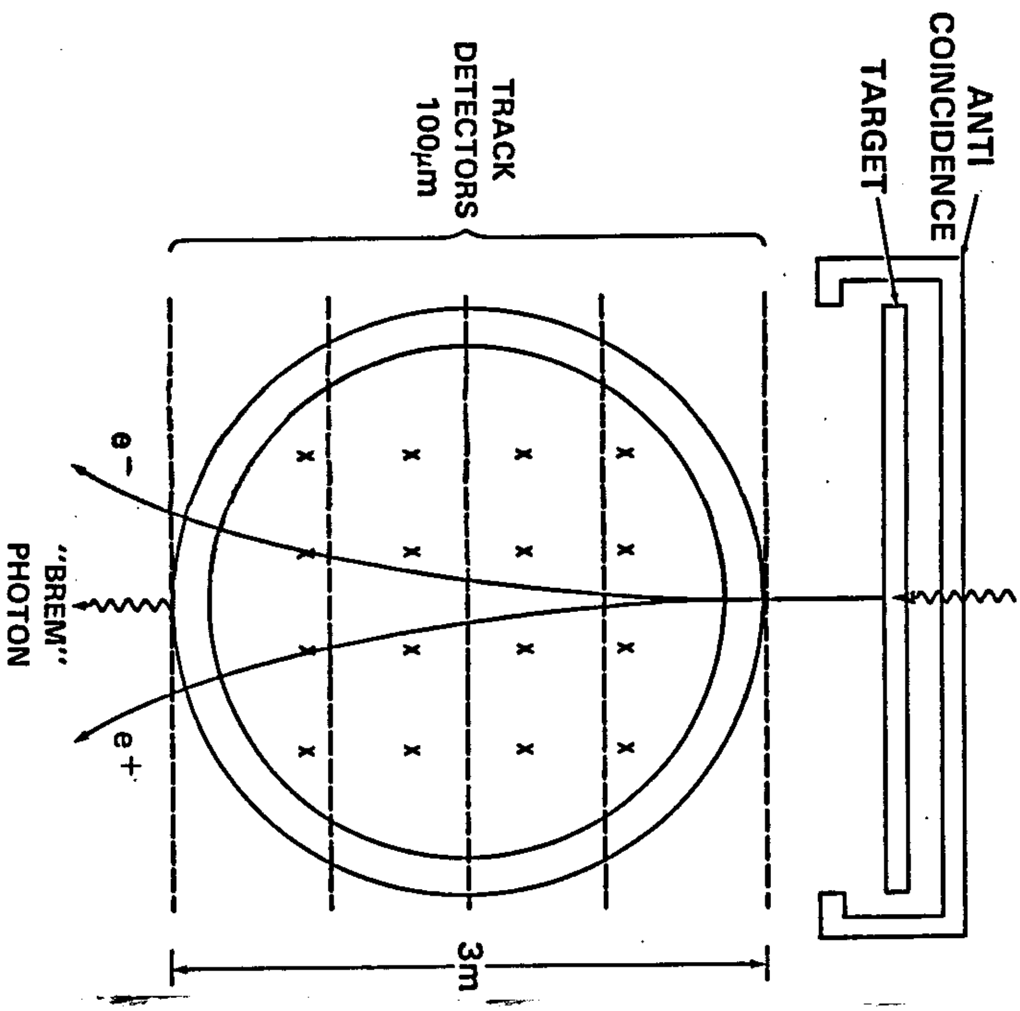
Figure II-6: Measurements of the positron to total electron ratio are compared with the predictions of three cosmic ray propagation models.



Astromag is a facility...

Possible Second Generation Experiments:

- -High Z Isotopes: improved tracking detectors
- -Low Z Isotope Experiments: Deuterium, 3He/4He
- -High Sensitivity anti-Helium Search
- -500MeV to 500GeV Gamma Ray Telescope: $E/\Delta E \sim 100$
- -Time Projection Chamber-Quark Nuggets



SPACE STATION IS "GOOD FOR ASTROMAG"...

- LIQUID HELIUM RESUPPLY
- EXPERIMENT ASSEMBLY AND CHANGEOUT
- SPACE STATION FUNCTIONS PROVIDED:

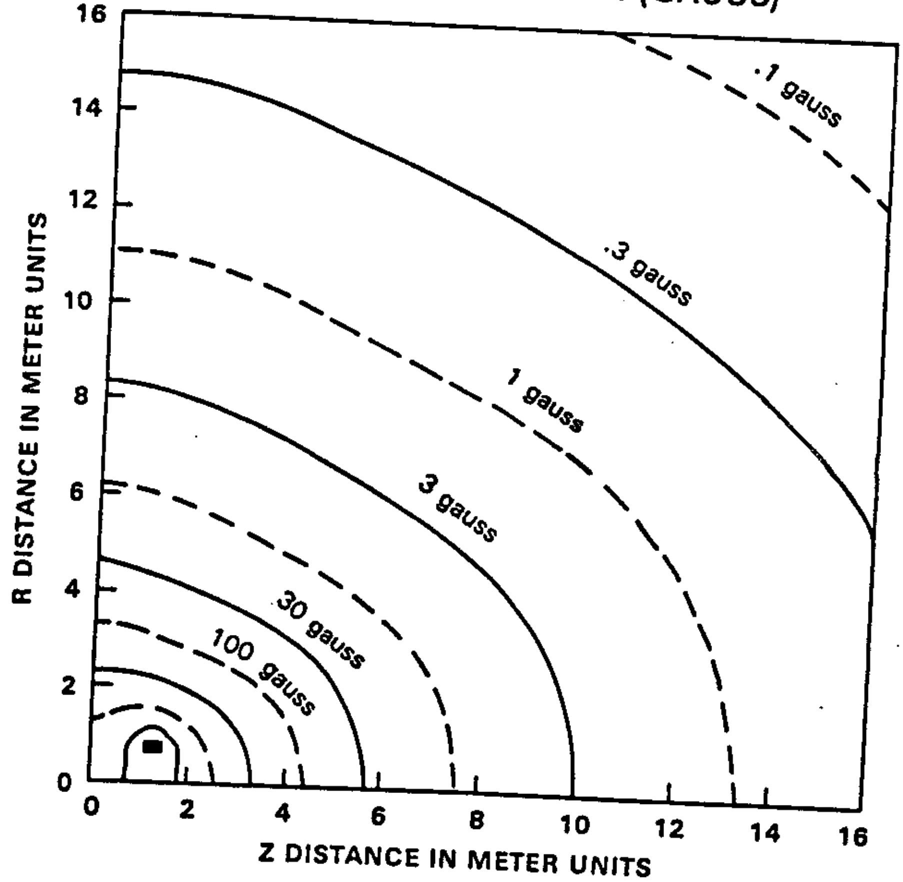
  VERTICAL ORIENTATION, POWER, DATA

BUT, IS ASTROMAG GOOD FOR SPACE STATION?

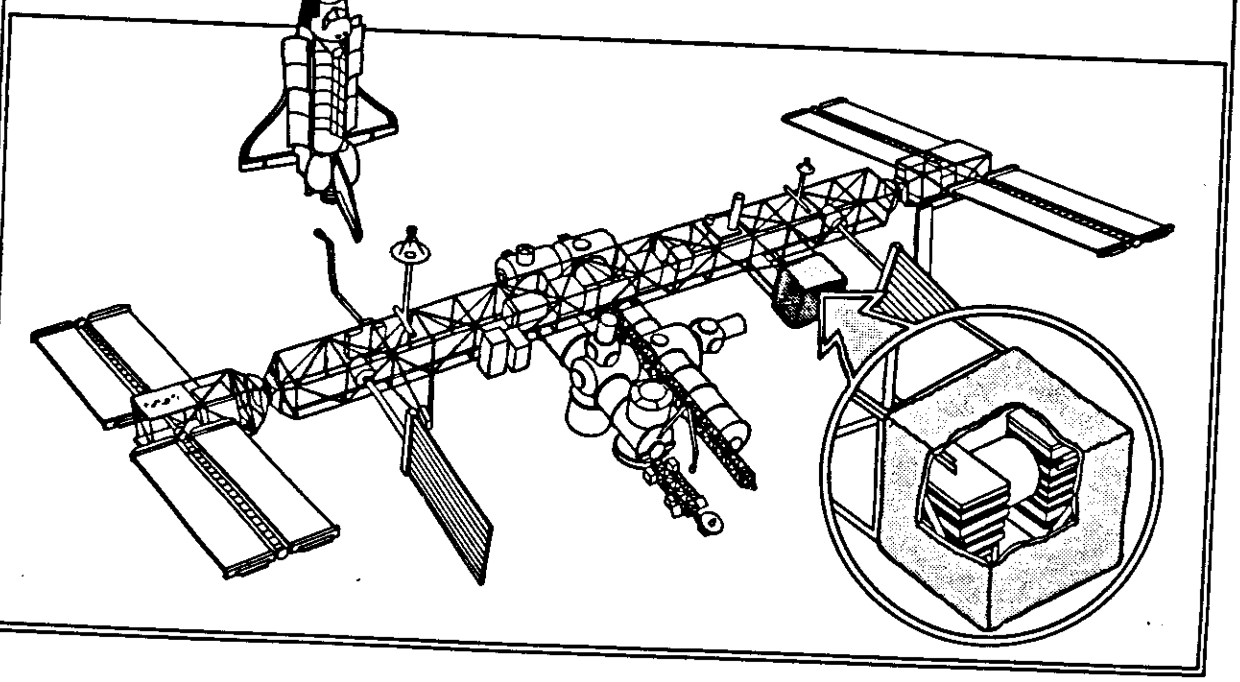
CONCERNS:

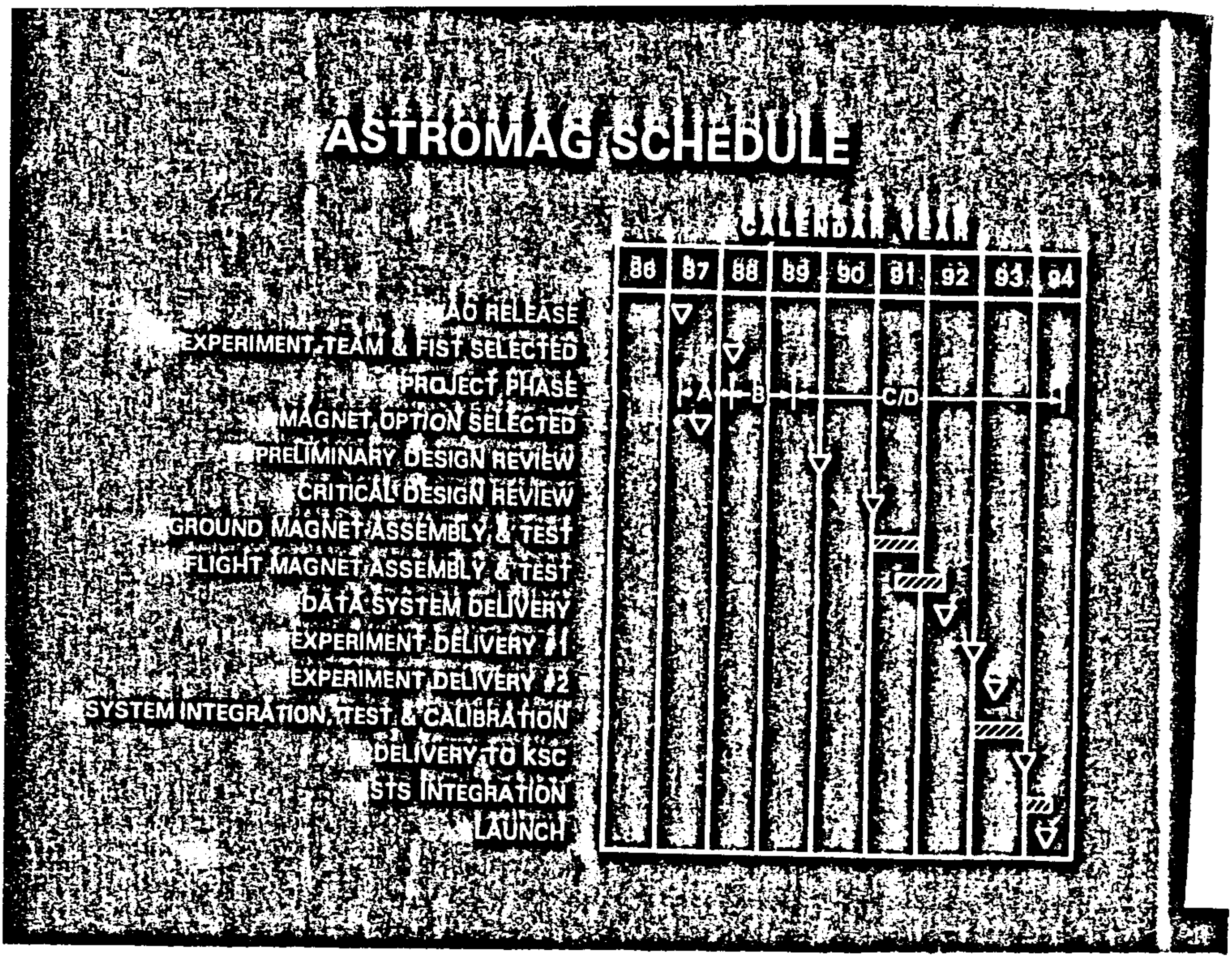
- TORQUING THE SPACE STATION (OPPOSED COILS)
- INTENSE MAGNETIC FIELD (PROTECTION NET, RED BUTTON)
- MAGNETIC FIELD QUENCH (GAS PHASE COOLING DESIGN)
- CRYOSTAT HEAT LEAK (BURST DISKS, PRIOR EXPERIENCE)
- HELIUM SPILLS (TRANSCENDS ASTROMAG)

FIELD CONTOUR MAP
MAGNETIC INDUCTION (GAUSS)



ASTROMAG ON SPACE STATION





ASTROMAG CHARACTERISTICS

SIZE:		
	COIL DIAMETER	1.3 M
	COIL SEPARATION	1.5 M
	FACILITY, EXCEPT NET	4.5 x 4 x 3 M
SPECTROMETER:		
	FIELD INTEGRAL	0.2 TO 0.5 T-M (TESLA METERS)
	TRACKING RESOLUTION	30 TO 50 UM
	MAX DETECTABLE MOMENTUM	1 TO 5 TEV/C
	STORED (FIELD) ENERGY	5 TO 10 MJ
	COIL UNBALANCE	< 1%
	PERSISTANCE	10% DECAY PER YEAR
CRYOSTAT:		
	VOLUME	3000 LITERS
	LIFETIME	2 TO 2.5 YEARS
	COOLANT	SUPERFLUID HELIUM AT < 1.7 K
	VENT RATE	7 L/DAY
FACILITY:		
	POWER	1 TO 2 KW, CONTINUOUS
	DATA RATE	100 TO 500 KB/S, CONTINUOUS
	TOTAL MASS	5000 KG

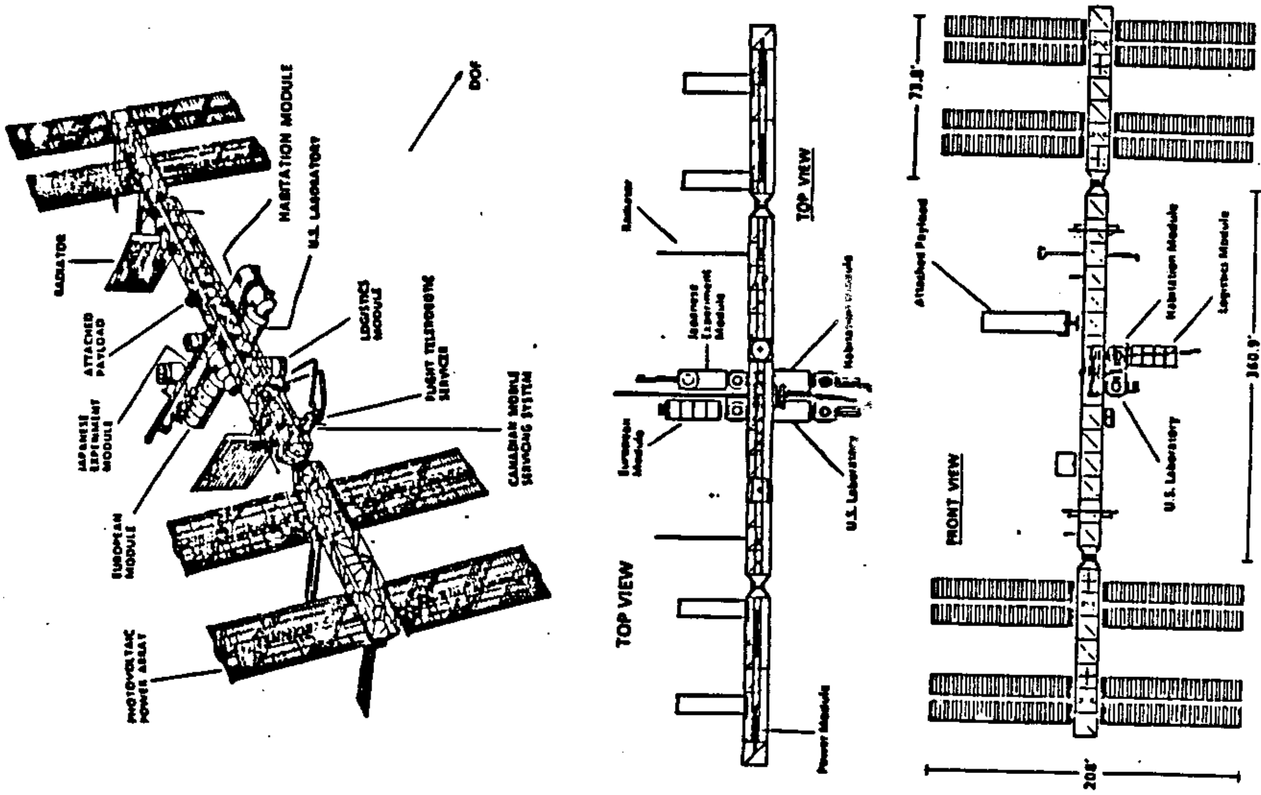


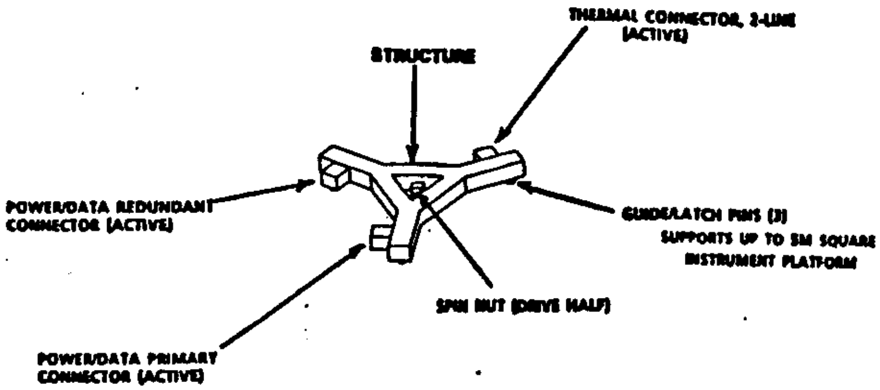
Figure A-1. Space Station Baseline Configuration

SPACE STATION ASSEMBLY SEQUENCE (3/31/88 PLAN)

1.	FEL	MB-1	18.75 PV MODULE, STBD TRUSS, ALPHA JOINT, ERECTOR SET, AVIONICS, TANK FARM WATER ELECTROLYSIS. RCS MODULES (2), UNPRESS. DOCK. ADAPTER, S-BAND ANTENNA	1-JAN-95
2.		MB-2	AFT STBD NODE, STBD TCS W/9 RAD. PANELS, FTS & SHELTER, STINGER/RESISTOJET, TDRSS, ANTENNA, TANK FARM, PRESS. DOCKING ADAPTER, CMGs (6)	1-APR-95
3.		MB-3	AFT PORT NODE, MSC PHASE 1, TANK FARM, STBD RADIATOR PANELS, PRESS. DOCKING ADAPTER, FMAD, STANDARD AIRLOCK	1-JUL-95
4.	EMTC	MB-4	U.S. LAB MODULE	1-SEP-95
5.		P-1	U.S. POLAR PLATFORM	22-OCT-95
6.		MB-5	PORT INBD P.V. MODULE, ALPHA JOINT, PORT TRUSS, RCS MODULES (2), PORT RADIATOR, STBD RADIATOR PANELS, TANK FARM, SSEMU VERIF. UNIT	1-NOV-95
7.		OF-1	PRESS. LOG MOD, MODULE OUTFITTING	1-JAN-96
8.		MB-6	SSRMS-2, HB AIRLOCK, ATTACH P/L & EQUIP.	1-MAR-96
9.		MB-7	U.S. HAB MODULE	1-MAY-96
10.		MB-8	FORWARD NODES, CUPOLAS (2)	1-JUL-96
11.	PMC	MB-9	CREW (4), LOGISTICS MODULES, SSEMUs (4)	1-OCT-96
12.		MB-10	STBD, PORT OUTBOARD PV. MODULES	15-NOV-96
13.		L-1	LOGISTICS MODULES, SPDM	1-JAN-97
14.		MB-11	JEM MODULE, JEM EXPOSED FACILITY #1, CREW (8)	15-FEB-97
15.		L-2	LOGISTICS MODULES, ATTACH P/L & EQUIP.	1-APR-97
16.		MB-12	ESA MODULE	15-MAY-97
17.		L-3	LOGISTICS MODULES, MMD PHASE 1	1-JUL-97
18.		MB-13	JEM EXPOSED FACILITY #2, JEM ELM, JEM LOGISTICS & PAYLOADS	15-AUG-97
19.		L-4	LOGISTICS MODULES	1-OCT-97
20.		OF-2	PRESS. LOG MOD. MODULE OUTFITTING	15-NOV-97

ASSEMBLY COMPLETE

PAYLOAD INTERFACE ADAPTER



STATION INTERFACE ADAPTER

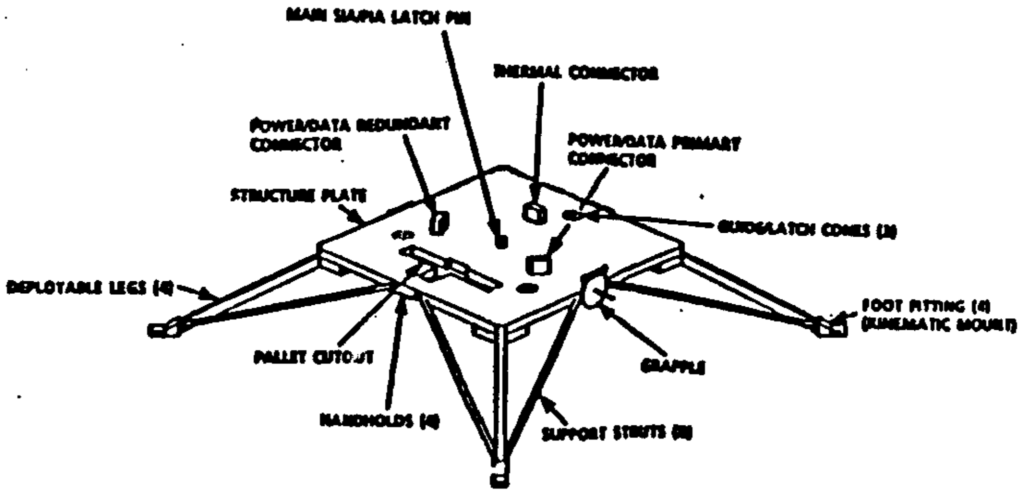


Figure A-4. Payload Mechanical Attachment Interfaces

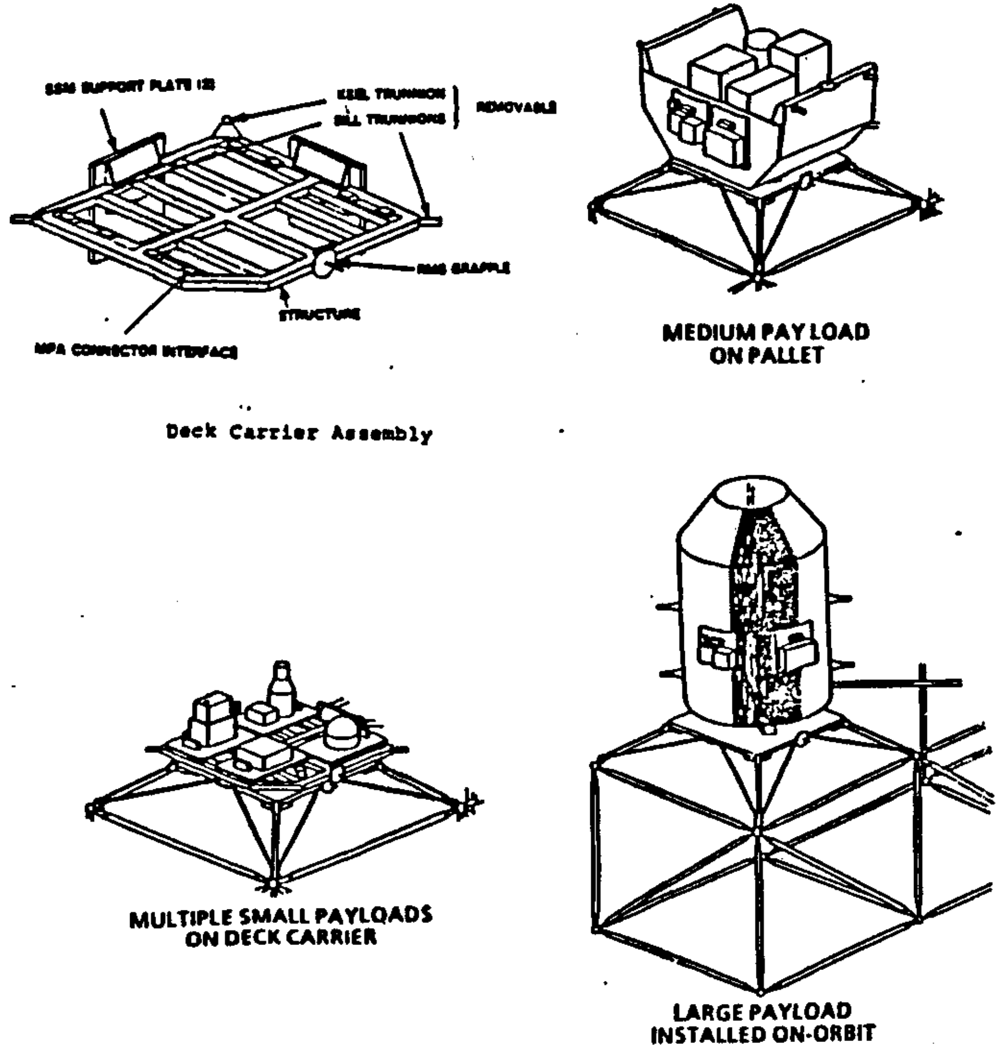
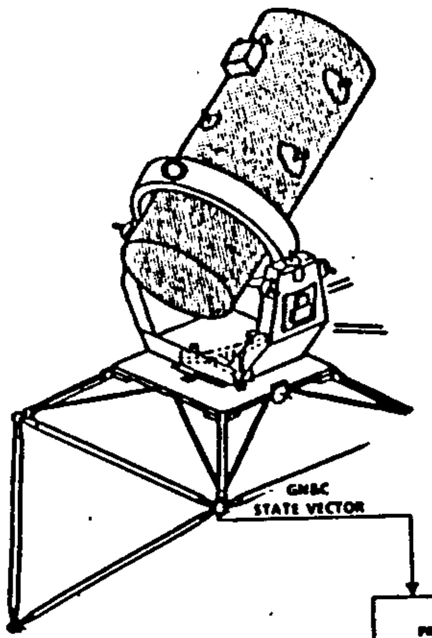


Figure A-5. Payload Attachment Options

PAYLOAD POINTING SYSTEM

- UP TO 3M DIAMETER PAYLOADS
- CENTER-OF-MASS PAYLOAD SUSPENSION
- CENTER OF ROTATION TO YOKE BASE - 2.5M
- UP TO 6000 KGM PAYLOAD IF ASSEMBLED ON-ORBIT
- ± 60 ARC-SEC POINTING
- 30 ARC-SEC PEAK-TO-PEAK STABILITY OVER 1/2 HOUR
- < 15 ARC-SEC/SEC JITTER
- IMPROVED PERFORMANCE IF PAYLOAD PROVIDES ERROR SIGNALS



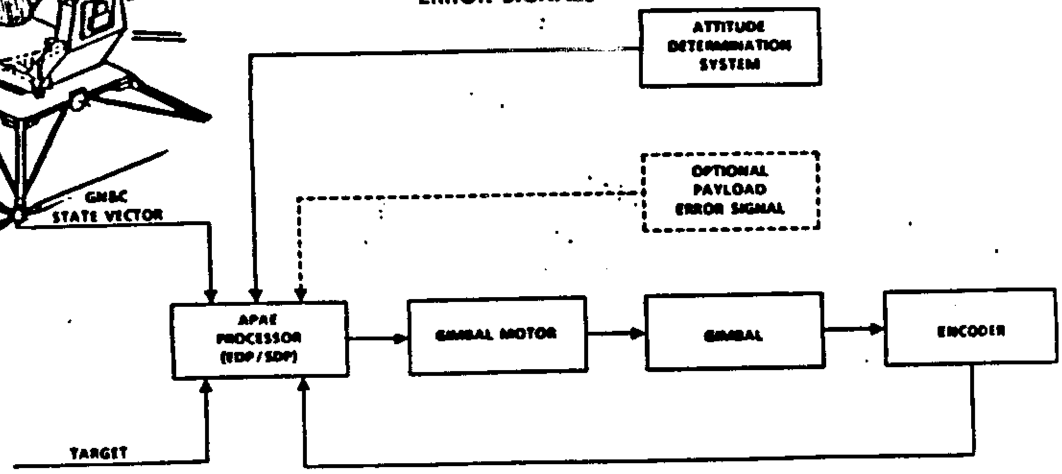


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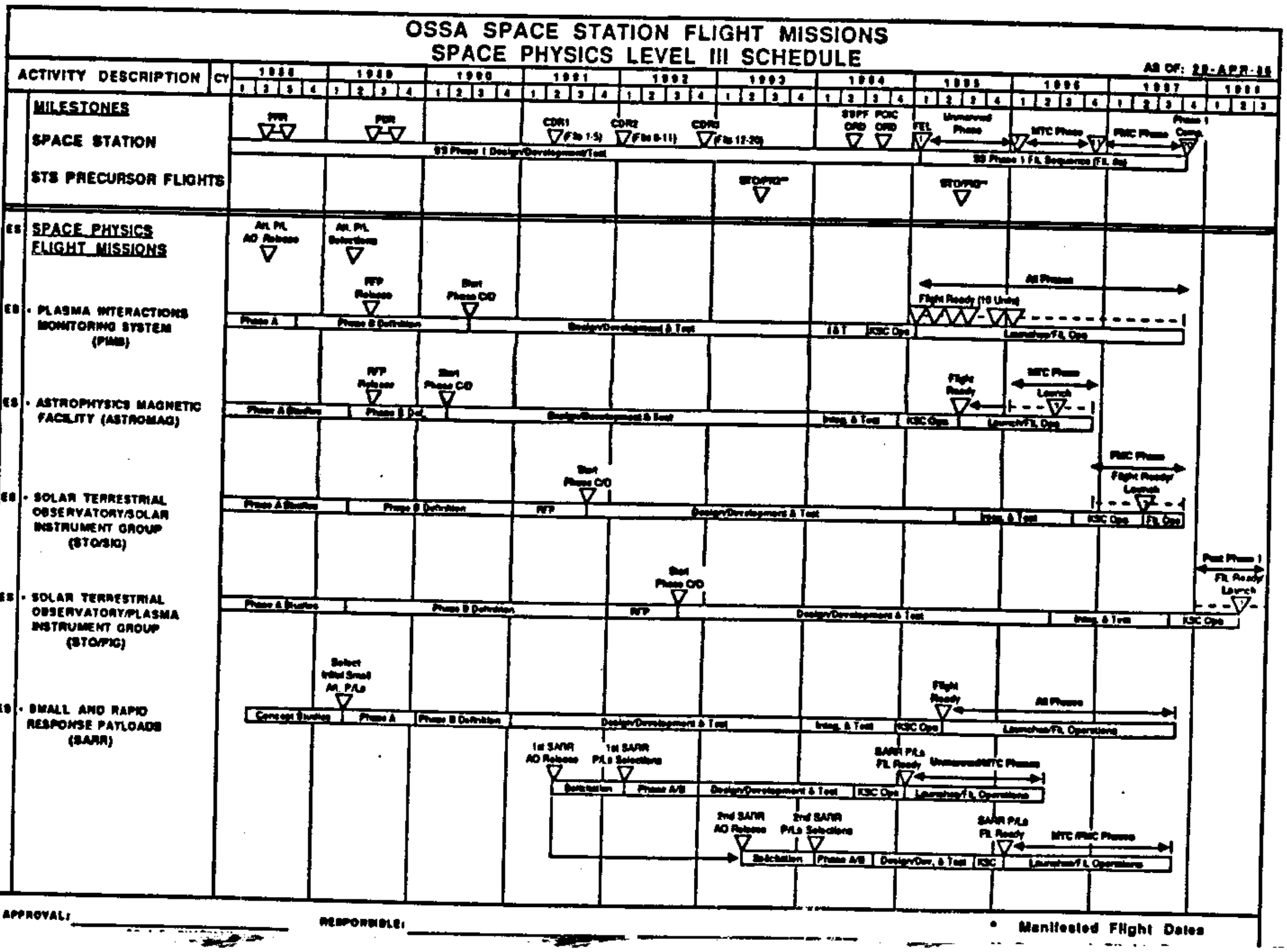
Figure A-6. Payload Pointing System



Definition of a Small Attached Payload

A) No major impact on Space Station operation

B) No major STS requirements.

C) No major cost impact.

But they could be:

- moderate in mass and volume

Interfaces:

- Standardized
- Modest telemetry/power requirements.

Concepts Presented by Small Payloads Working Group Applicants (10/87)

γ-ray Astronomy	=	9
X-ray Astronomy	=	15
UV Astronomy	=	10
Visible Astronomy	=	5
IR and Submm Astronomy	=	10
Astrometry and Interferometry	=	4
Solar Physics	=	4
Cosmic Ray Physics	=	7
Miscellaneous	=	6
TOTAL		70

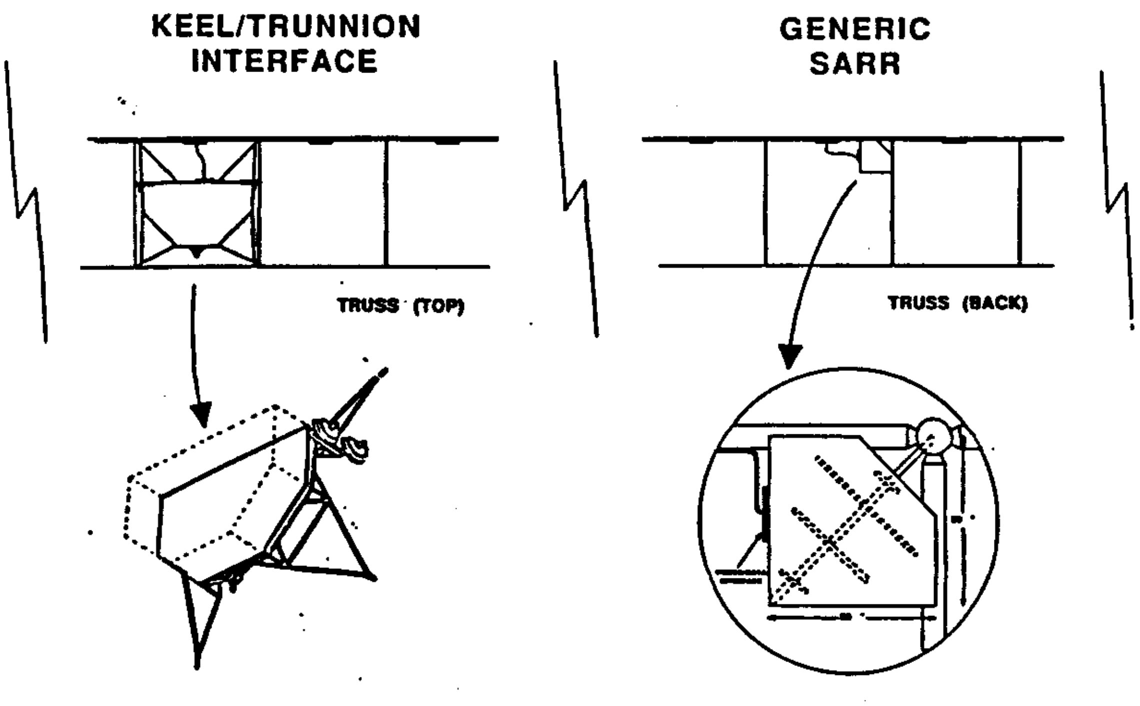
Framework for Experimentation

- Emphasis on "level-of-effort" activities.
- Time horizons of ~2 years (concept-to-flight), to once again permit a role for graduate student research.
- Optional provision of "standard modules" to the experiment (e.g., data acquisition and storage units, pointing modules, protective cannisters).
- "R^3" -- a possible approach.

TYPICAL SARR PAYLOAD CHARACTERISTICS

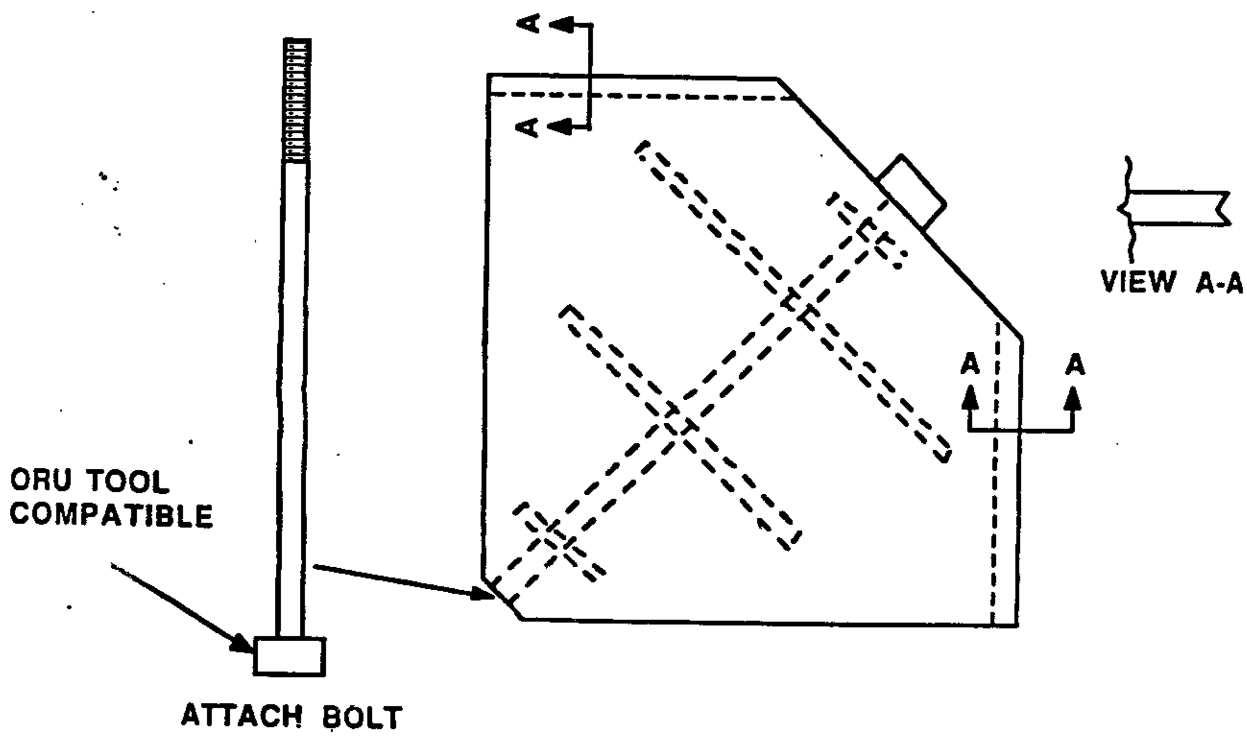
- **Similar in nature to Hitchhiker (HH-G & HH-M) and Get-Away-Specials (GAS). It is anticipated that the "Quick is Beautiful" concept will fit under SARR clasification.**
- **Interfaces must be non-unique (even if internally the payload is complex); hence easily accommodated.**
- **Can effectively utilize area and volume available to space station SARR payloads.**
- **Utilize standard interface hardware and limited resource allocations (weight, volume, power, data storage, commands, channels, telemetry, etc.) that can be worked ahead of time for rapid integration.**
- **Quick manifesting: 6 to 24 months before flight.**
- **Depending upon a specific flight mission, its objectives and crew; there can be limited crew involvement with a SARR payload.**

SMALL AND RAPID RESPONSE (SARR) IMPLEMENTATION CONCEPT



ATTACHMENT HARDWARE
ESTIMATED WEIGHT IS 700 lbs.

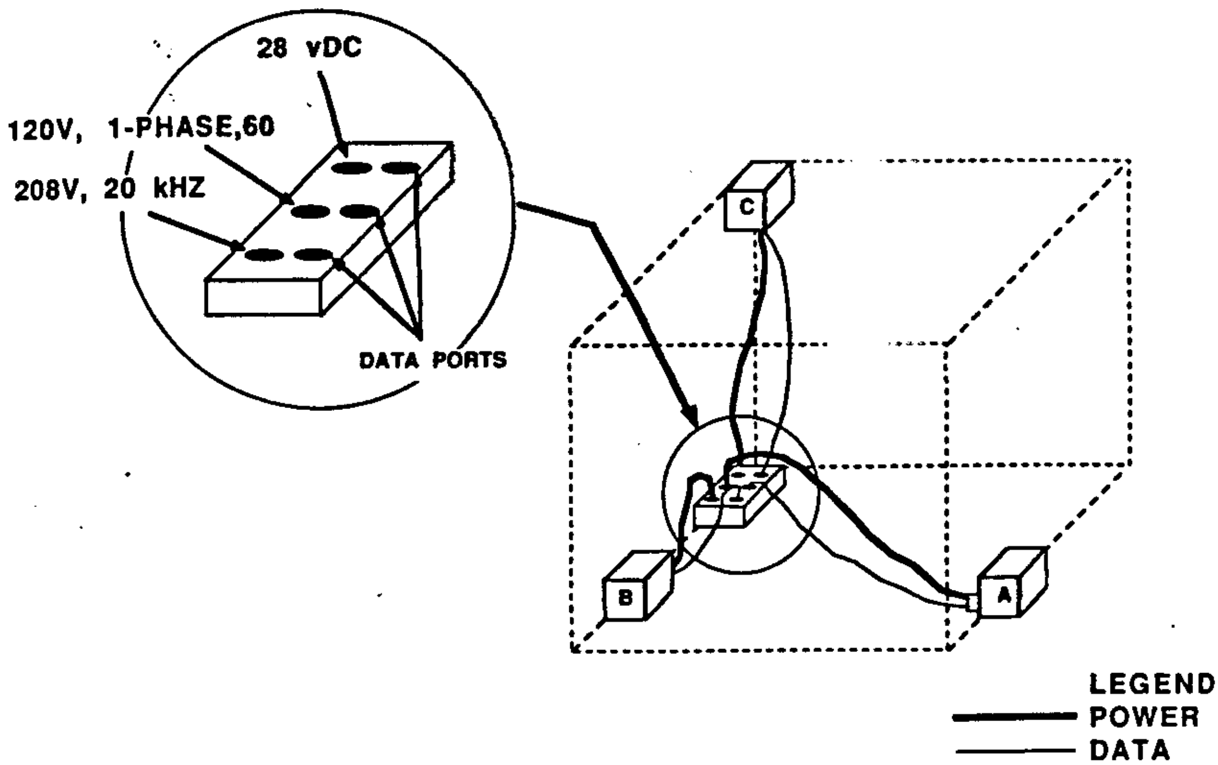
ATTACHMENT HARDWARE
ESTIMATED WEIGHT IS 150 lbs.



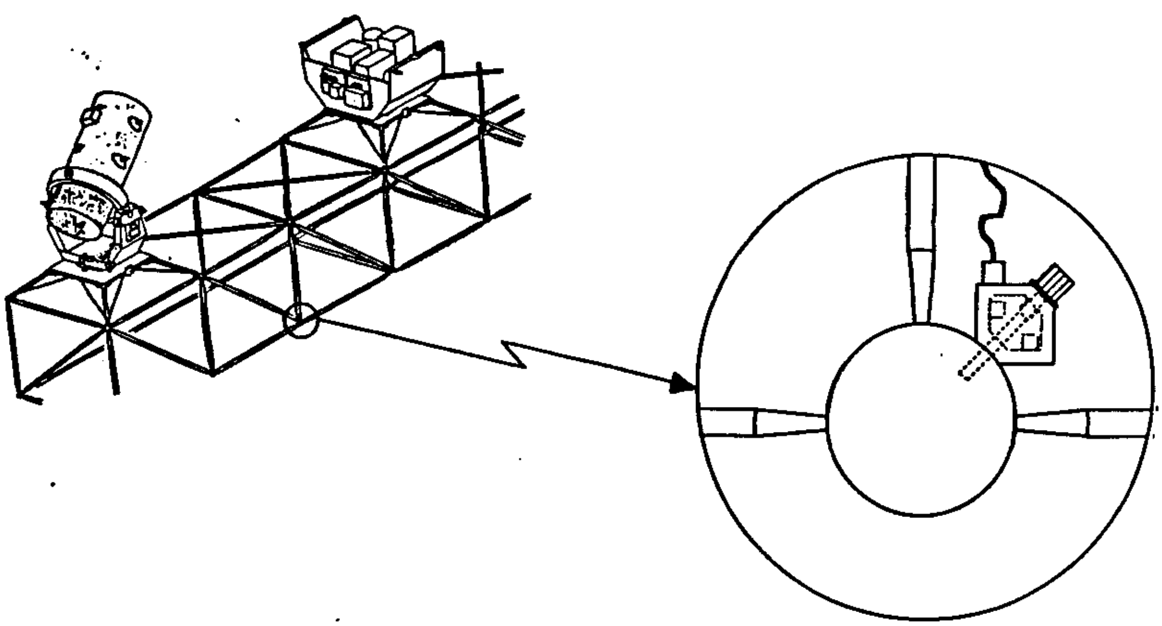
ATTACHMENT HARDWARE FOR GENERIC SARR

SMALL AND RAPID RESPONSE (SARR) PAYLOAD ACCOMMODATIONS

TYPICAL MINOR PORT FOR THREE SARR PAYLOADS



DISTRIBUTED SENSOR PAYLOADS IMPLEMENTATION CONCEPT



Hitchhiker Program

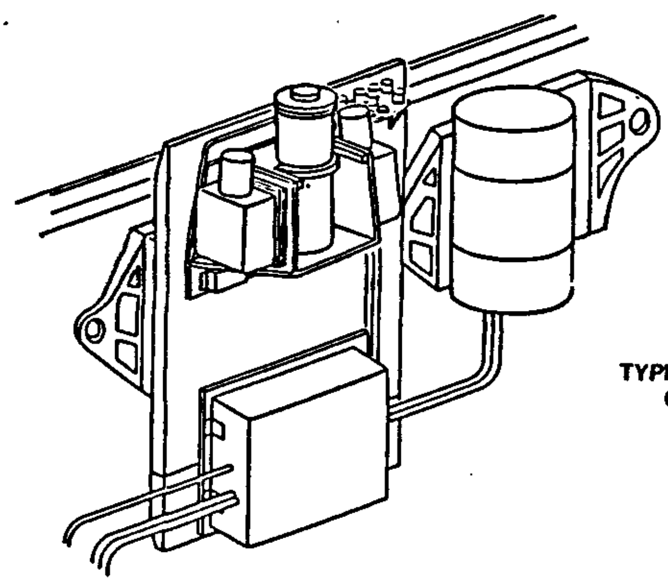
Concepts

- Conservative Design Envelope
  - Retain resources margins
- Simple/Fixed Interfaces
  - Orbiter to carrier
  - Carrier to payload
- Fixed Port Design
  - No variations between flights
  - No optional services
- Flight Readiness Within 6 Months
- Streamline Paper Process
  - Generic PIP
  - Reduced analysis/reviews
- Standard Operations
  - Interface verification only
  - No timeline or profile impacts
  - Minimum crew involvement
- Standby Payload/Carrier System
  - Neither flight date nor orbit guaranteed

SMALL AND RAPID RESPONSE (SARR) PAYLOAD CARRIERS

HITCHHIKER (G)

PROVISIONS	SHUTTLE	SPACE STATION
PAYLOAD WEIGHT (LBS)	600	TBD
POWER (KW)	1.3	TBD
COOLING	PASSIVE	TBD
UPLINK COMMAND	YES	TBD
DOWNLINK DATA (BPS)	1.3M	TBD
DATA STORAGE	ORBITER TAPE RECORDER	TBD



TYPICAL HITCHHIKER (G) CONFIGURATION

SMALL AND RAPID RESPONSE (SARR) PAYLOAD CARRIERS

GET AWAY SPECIAL (GAS)

PROVISIONS	SHUTTLE	SPACE STATION
PAYLOAD WEIGHT (LBS)	200/ 100/ 60	TBD
PAYLOAD VOLUME (CU. FT.)	5/ 2.5	TBD
POWER (KW)	USER PROVIDED	TBD
COOLING	PASSIVE	TBD
UPLINK COMMAND (3 CREW CONTROLLED RELAYS)	NO	TBD
DOWNLINK DATA (BPS)	NONE	TBD

GAS CAN