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Orbital Debris Hazard

by Donald J. Kessler, NASA/JSC

Orbital debris has been studied at the NASA/Johnson Space Center (JSC) since 1977. A 1982 Workshop held at JSC identified the most significant need for these studies was to measure the orbital debris environment at sizes smaller than the 5000 objects normally catalogued by NORAD. Significant advances were made in the last year in measuring this population. The techniques used were (1) ground based radar, (2) ground based optical telescopes, (3) orbiter window surfaces, and (4) returned Solar-Max thermal insulation surfaces. Each of these techniques revealed a significantly increasing population with decreasing size.

Ground Based Radar. Teledyne Brown Eng. was contracted to examine data taken by NORAD's PARCS radar, located in North Dakota. This radar routinely detects objects as small as 8 cm in diameter; however, the information is normally ignored. While analysis is continuing, preliminary results indicate that there is at least a thousand uncatalogued objects in the size interval 8 cm to 20 cm.

Ground Based Optical Telescopes. Lincoln Laboratory was contracted to use their Experimental Test Site (ETS) to search for centimeter sized debris in low earth orbit. The ETS consists of two, 31 inch telescopes located in White Sands, New Mexico. The telescopes tracked identical overhead star fields for about an hour when the region of space between about 500 km to 1000 km was sunlight. The star images were detected using low-light level TV cameras and recorded on video tape. Centimeter size objects were seen as 16th magnitude objects moving at several degrees per second through the field of view. Two telescopes were required to obtain the altitude of the object, using parallax. This permitted discrimination between space debris and meteors which are always found below 120 km. Part of the observing program was coordinated with NORAD. The search detected eight times as many orbiting objects as was predicted using the catalogued population, indicating that a total population of approximately 40,000 objects larger than 1 cm are in low earth orbit. Additional tests of this type are planned to determine probable sources.

Orbiter Window Surfaces. Three days after the launch of STS-7, the crew reported a pit, about 4 mm in diameter, on the external surface of one of the windows. This damage exceeded safety requirements for launch and the window was replaced. Consequently, the window was examined to the same detail as were previous Apollo windows for meteoroid impacts. This pit along with several other smaller pits was removed intact from the window by the Solar System Exploration Division of JSC and subjected to Scanning Electron Microscope (SEM) examination. Energy Dispersive X-ray Analysis (EDS) was used to determine the composition of partially fused material found in the bottom of the pit. Only titanium and a small amount of aluminum was found added to the pit glass. Crater morphology places the impacting particle diameter at 0.2 mm, and a velocity between 3 km/sec and 6 km/sec. From this data, it is concluced that the particle was man-made and in earth orbit. This is the first conclusive case where orbital debris can be shown to have caused the operational loss to a space vehicle subsystem. The source of the titanium is unknown, although there may be a relationship to material found in impact craters on surfaces returned from the Solar Max satellite.

Solar-Max Thermal Insulation Surfaces. Approximately 0.5 sqare meter of thermal insulation surface from the returned Solar-Max satellite is being examined by the Solar System Exploration Division at JSC. Solar Max was in orbit for about 50 months at an altitude just above 500 km. The thermal insulation consisted of 17 layers of aluminized Kapton, each separated by a dacron net. This type of surface has capture properties similar to the capture cell experiment on LDEF and offers an excellent opportunity to obtain chemistry of impacting particles. About 160 impacts were found which had penetrated the outer layer, depositing ejecta on the following layers. Over a thousand craters were found which did not penetrate the 1st layer -- more than expected from meteoroid impacts alone. EDS analyses shows clear evidence that most of the smaller craters were produced by particles with sufficient velocity to produce melting. EDS analysis also shows that a large number of these pits contain titanium, zinc, potassium, silicon and chlorine. Except for chlorine, this chemistry corresponds to the chemistry of thermal paints currently used by NASA for space applications. It is possible that the titanium found in the window pit represents the surviving material from a similar particle. Other pits contained only aluminum, but it is not now clear whether the aluminum came from the impacting particle or from the thermal insulation. One definite meteoroid impact has been identified. While analysis is far from complete, these preliminary results are suggesting that billions of 0.1 mm debris particles are in earth orbit. More SEM studies are planned to determine the ratio of debris to meteoroid impacts, and to identify the sources of debris.

ORBITAL DEBRIS HAZARD

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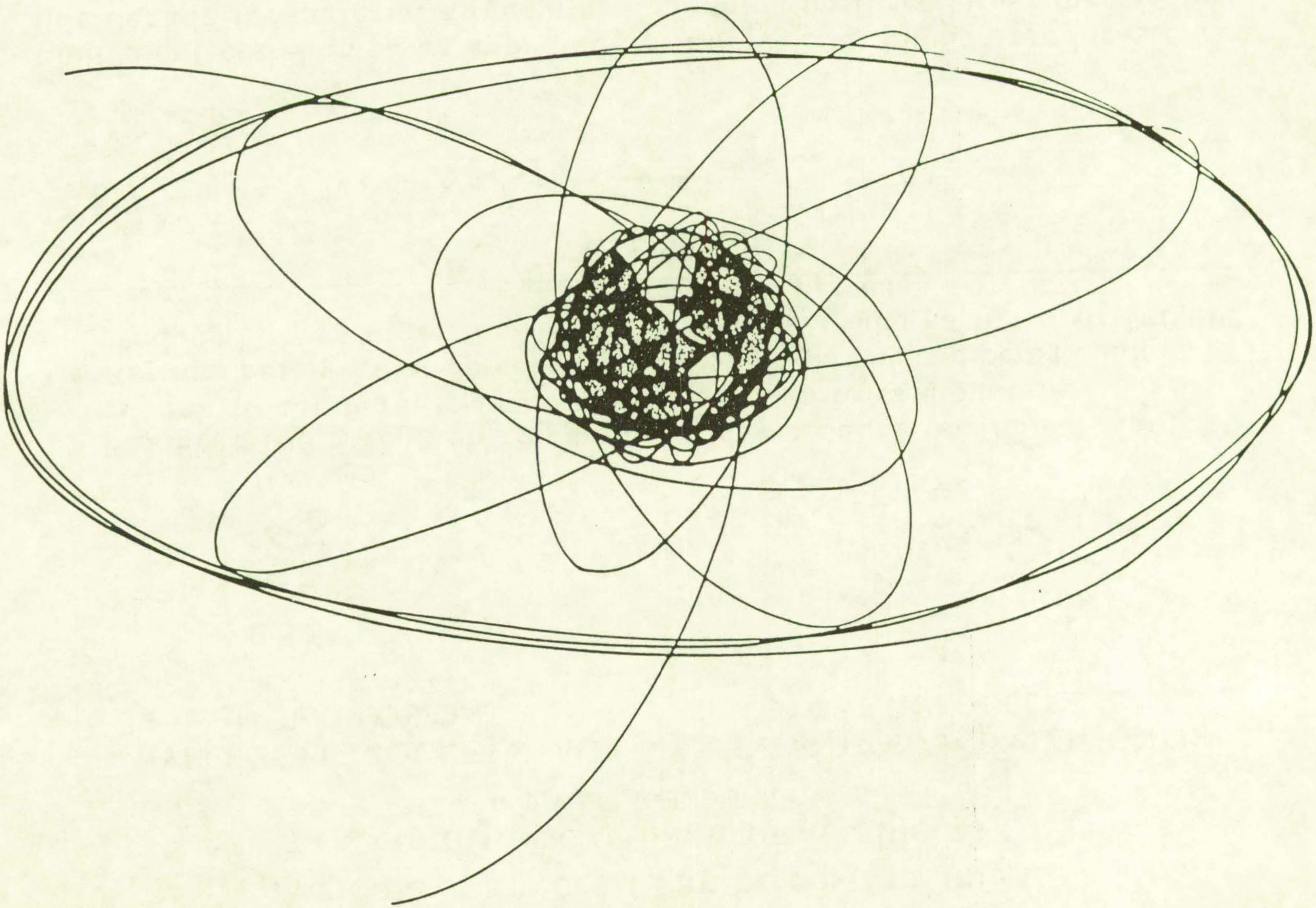
BACKGROUND

- METEOROID HAZARD STUDIES OF 1960'S
  - ENVIRONMENT DEFINITION AND HYPERVELOCITY TESTS
  - PRODUCED MARGINAL DESIGN CHANGES FOR SPACECRAFT AT THAT TIME
- EARLY DEBRIS STUDIES OF 1970'S
  - CONCENTRATED ONLY ON LARGER, TRACKABLE POPULATION
  - SIGNIFICANT HAZARD FOR ONLY LARGE (100m) STRUCTURES
- CURRENT DEBRIS STUDIES
  - CONCENTRATE ON FRAGMENTS PRODUCED BY TRACKABLES
  - MAY EASILY EXCEED METEOROID HAZARD TO MOST S/C
  - NEW GENERATION OF SPACECRAFT MORE SENSITIVE TO ENVIRONMENT

ORBITS CURRENTLY BEING USED

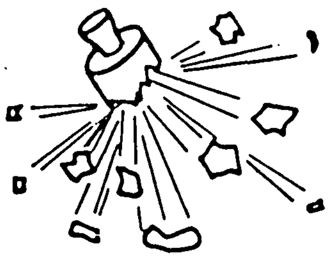
~ 4% sample



A single spacecraft can be responsible for a multitude of hazardous objects

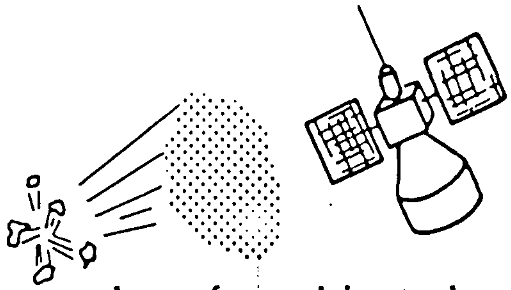
(estimates based on limited data)

HYPERGOLIC ROCKET STAGE EXPLOSION



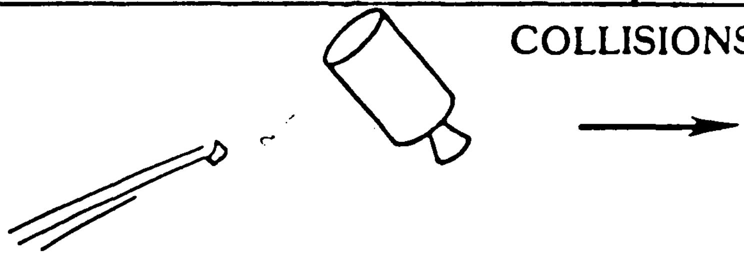
- Produces 100 to 200 objects large enough to catalogue
- Approximately 1000 objects produced, most larger than 1 cm

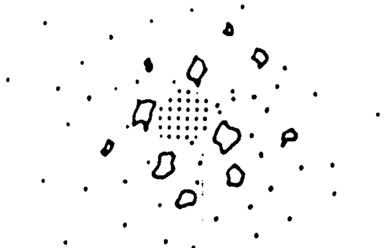
INTENTIONAL EXPLOSION OR PARTICLE RELEASE



- May produce few objects large enough to catalogue
- 100 kgm payload could contain 100 million 1 mm particles, or 100,000 1 cm particles

COLLISIONS

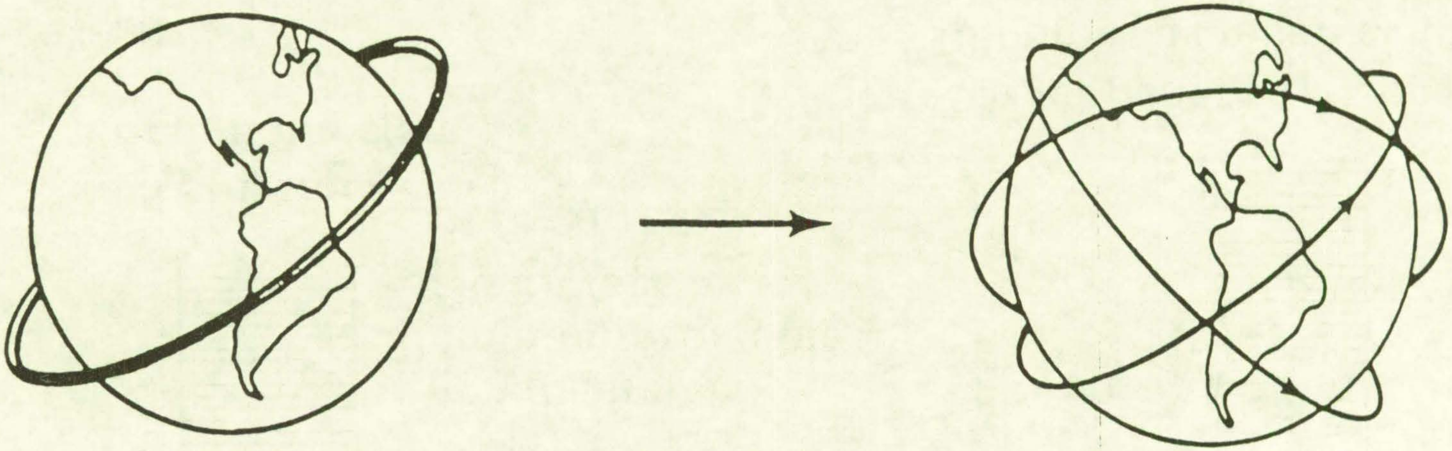




Equivalent collision to be expected in this decade for material already in orbit is between old payload or rocket body and 5 kgm (10 lb) explosion fragment

Equivalent collision produces 4 million particles larger than 1 mm, and 10 thousand particles larger than 1 cm

Orbits tend to disperse, producing high intersecting velocities

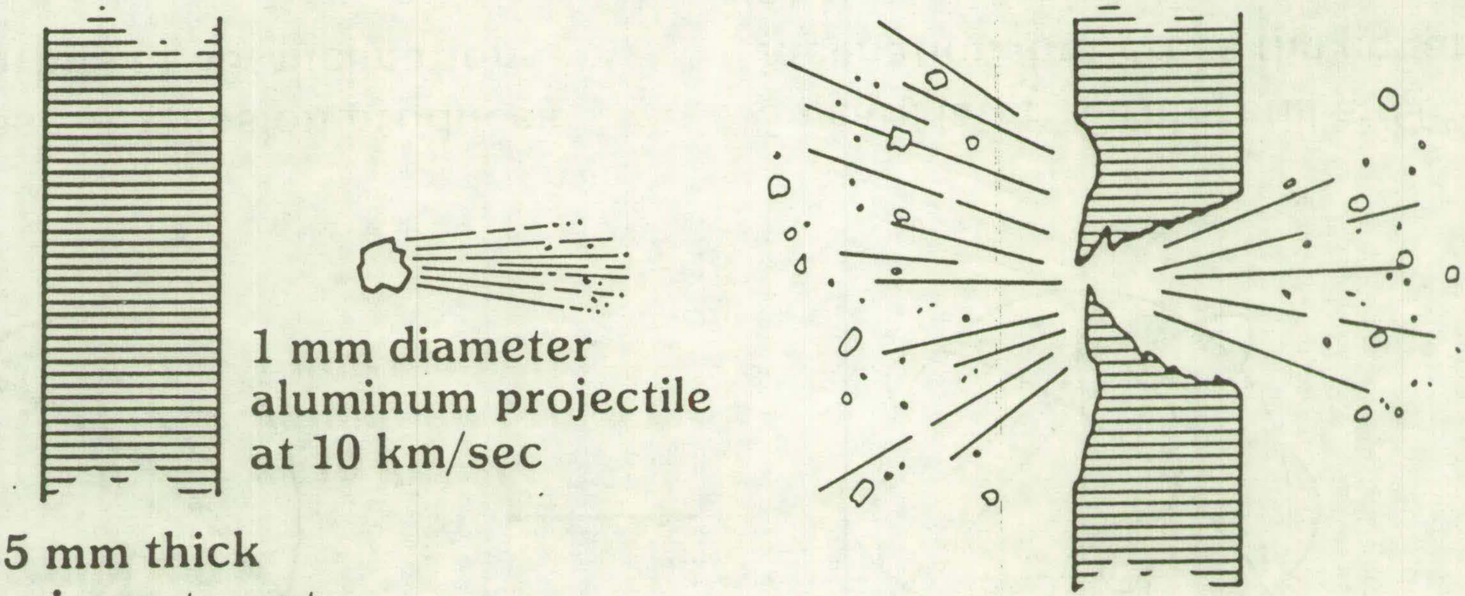


Example case: Explosion produces a torus of orbits at 60° inclination

5 years later: Orbits still at 60° inclination, but cross the equator at random points

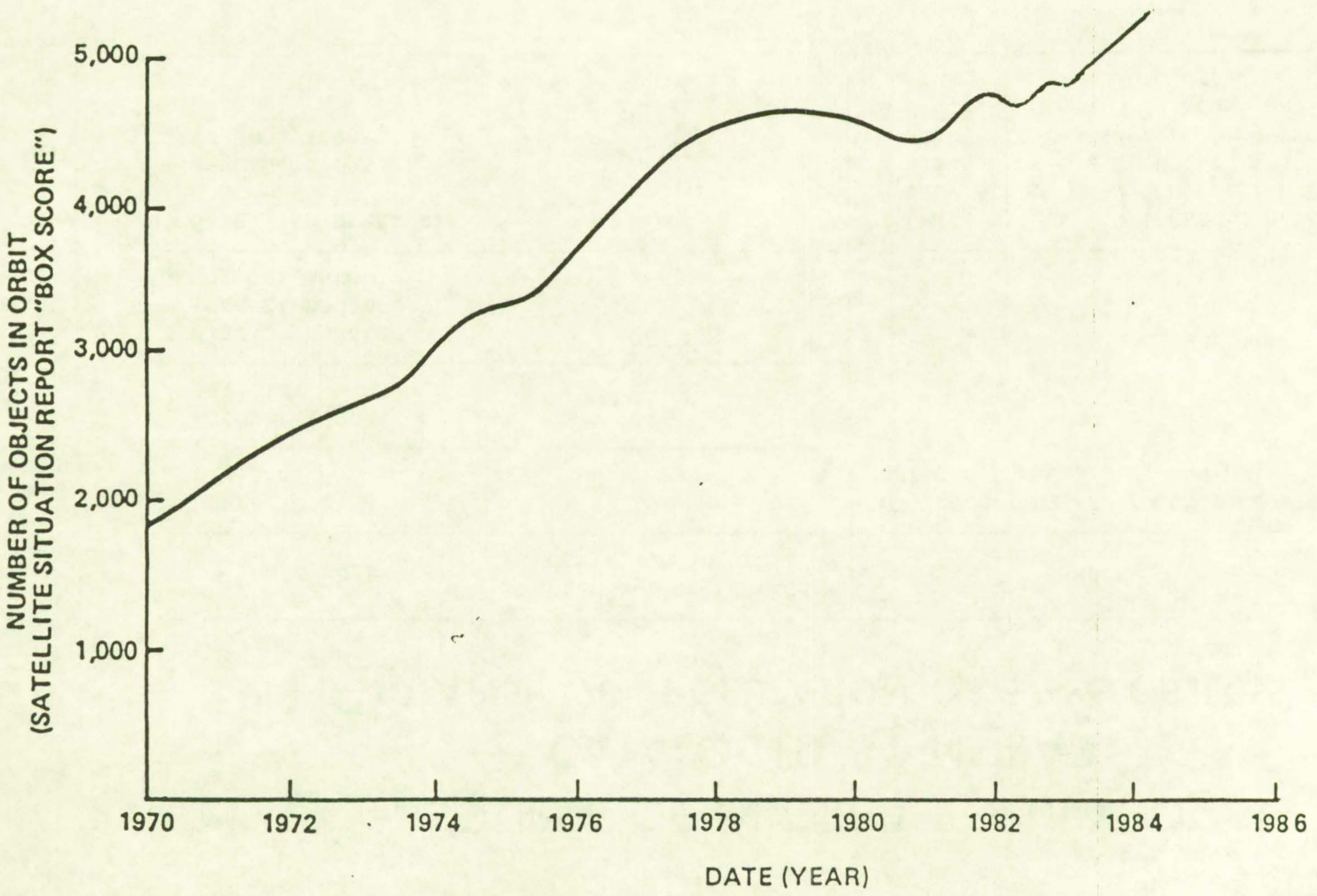
General case: Average collision velocity between orbiting objects is 10 km/sec or 6 miles/sec.

At 10 km/sec, even small projectiles cause considerable damage



Orbital debris will penetrate approximately 5 particle diameters into a single sheet target.

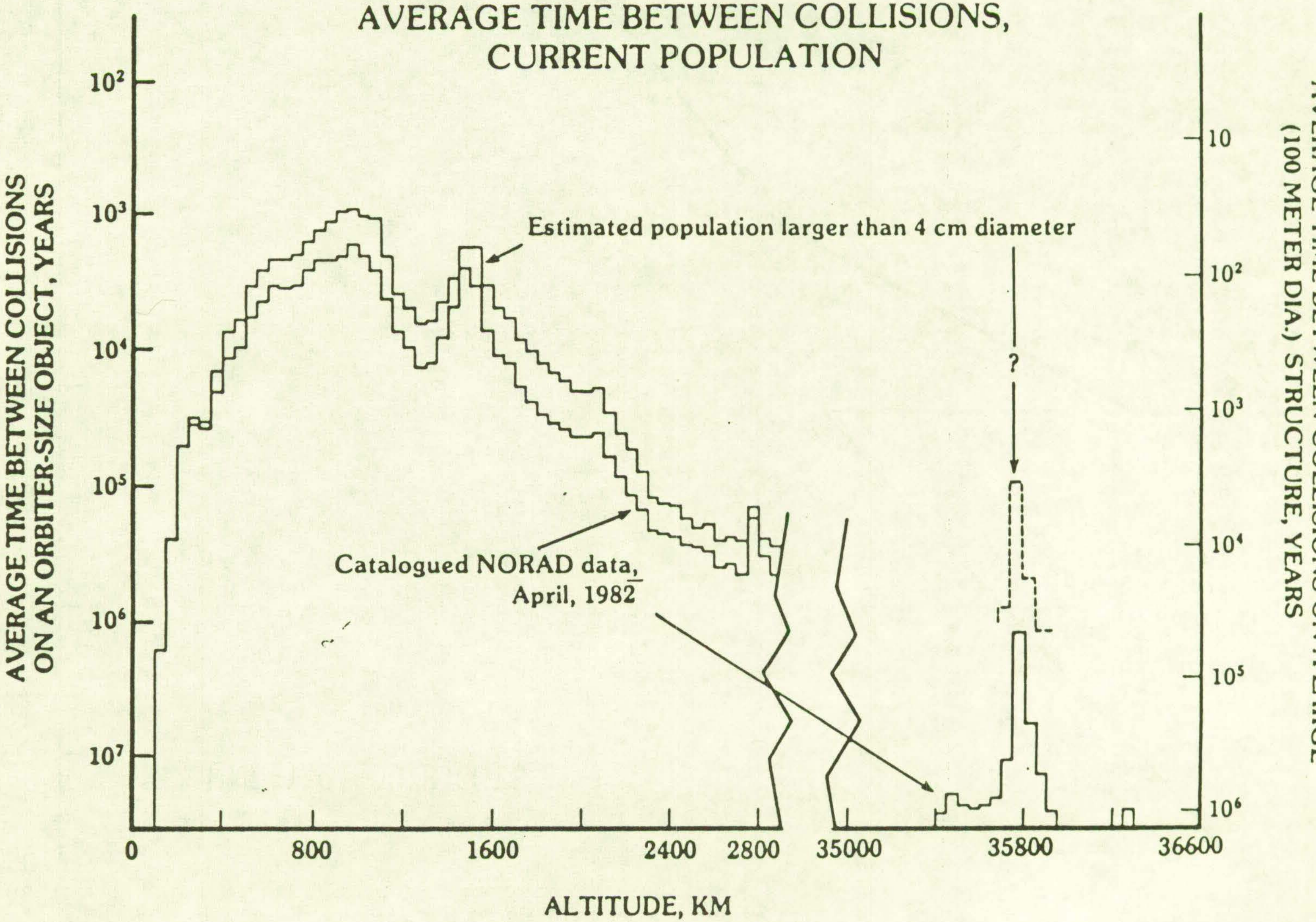
HISTORICAL RECORD OF OBJECTS IN SPACE



SOURCE OF IN-ORBIT POPULATION CATALOGED BY NORAD

[30 APRIL 1984 POPULATION OF 5,266 OBJECTS]

Space Object	Percentage of Tracked Population in Orbit	Notes
Operational payloads	5	Distributions are roughly equally divided between the U.S.S.R. and U.S.
Nonoperational payloads	21	
Mission related (rocket bodies, shrouds, etc.)	25	
Satellite breakups • Explosions • Unexplained	49	7 Delta stages 4 U.S. other 8 U.S.S.R. satellite tests 4 U.S.S.R. other } These 23 breakups account for 93% of the tracked fragments resulting from the 74 known explosions to date.


AVERAGE TIME BETWEEN COLLISIONS, CURRENT POPULATION
AVERAGE TIME BETWEEN COLLISIONS ON AN ORBITER-SIZE OBJECT, YEARS
10^2
10^3
10^4
10^5
10^6
10^7
Estimated population larger than 4 cm diameter
?
Catalogued NORAD data, April, 1982
0
800
1600
2400
2800
35000
35800
36600
ALTITUDE, KM
AVERAGE TIME BETWEEN COLLISIONS ON A LARGE (100 METER DIA.) STRUCTURE, YEARS
10
10^2
10^3
10^4
10^5
10^6

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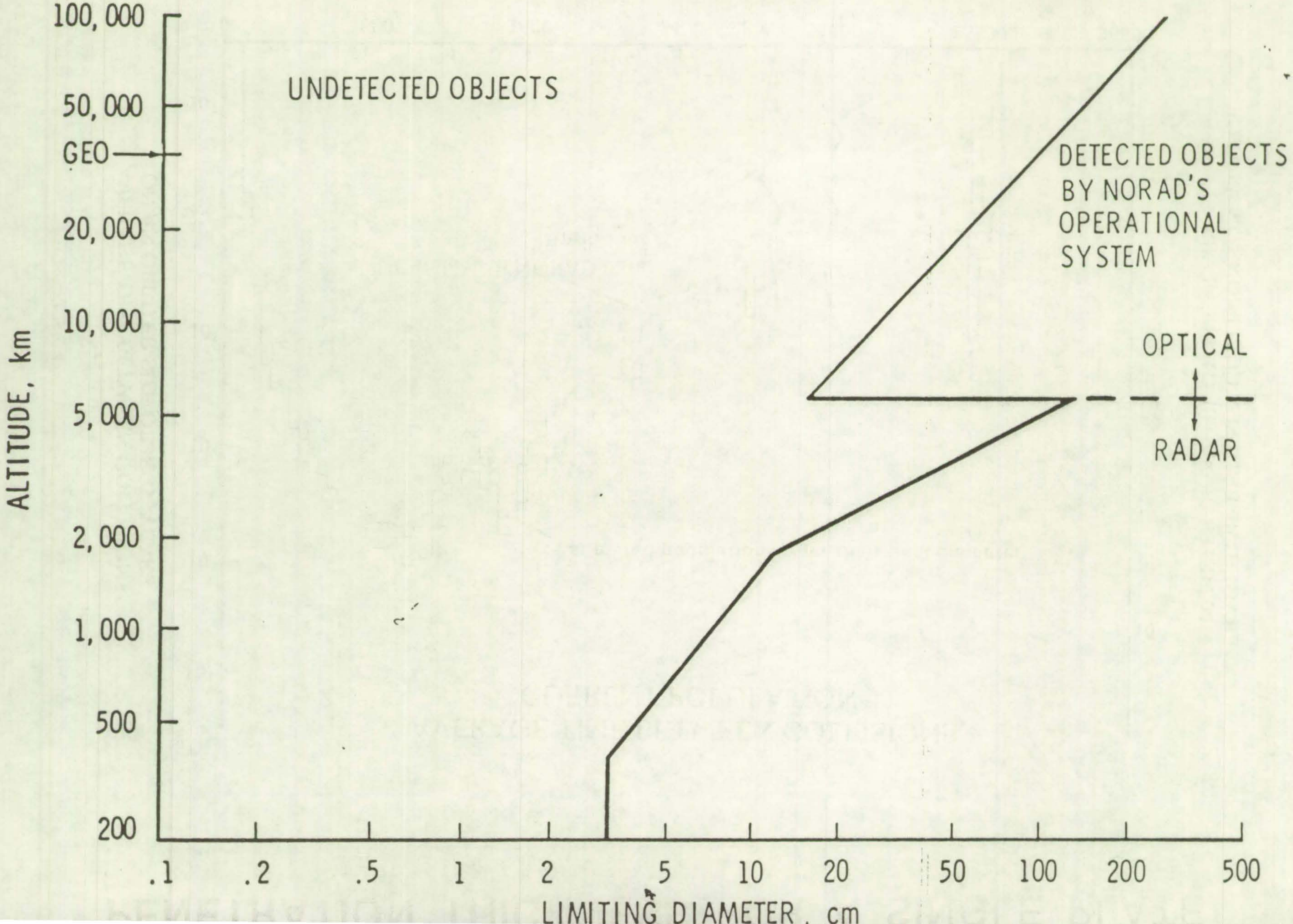
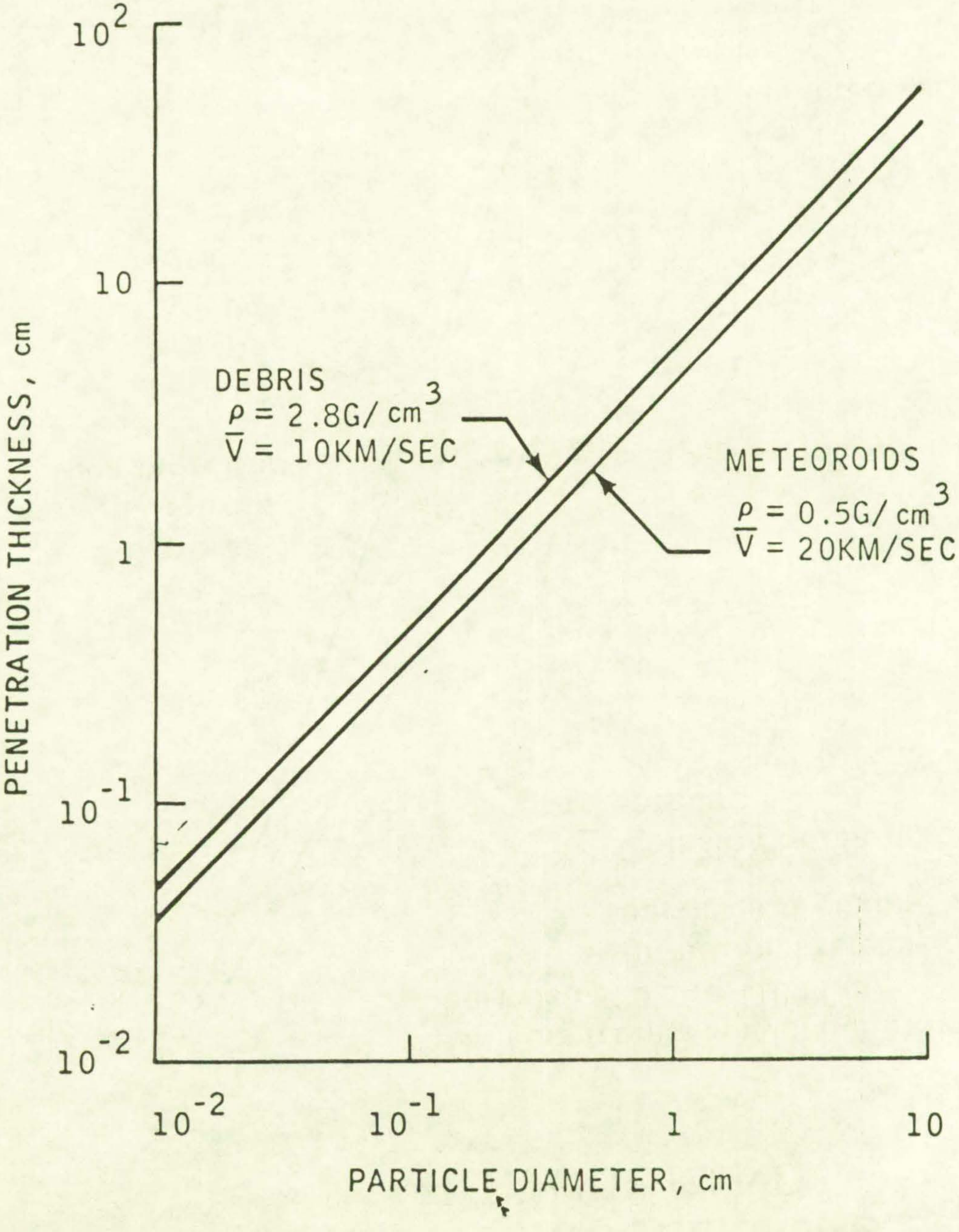
NORAD'S OPERATIONAL CAPABILITY TO DETECT OBJECTS

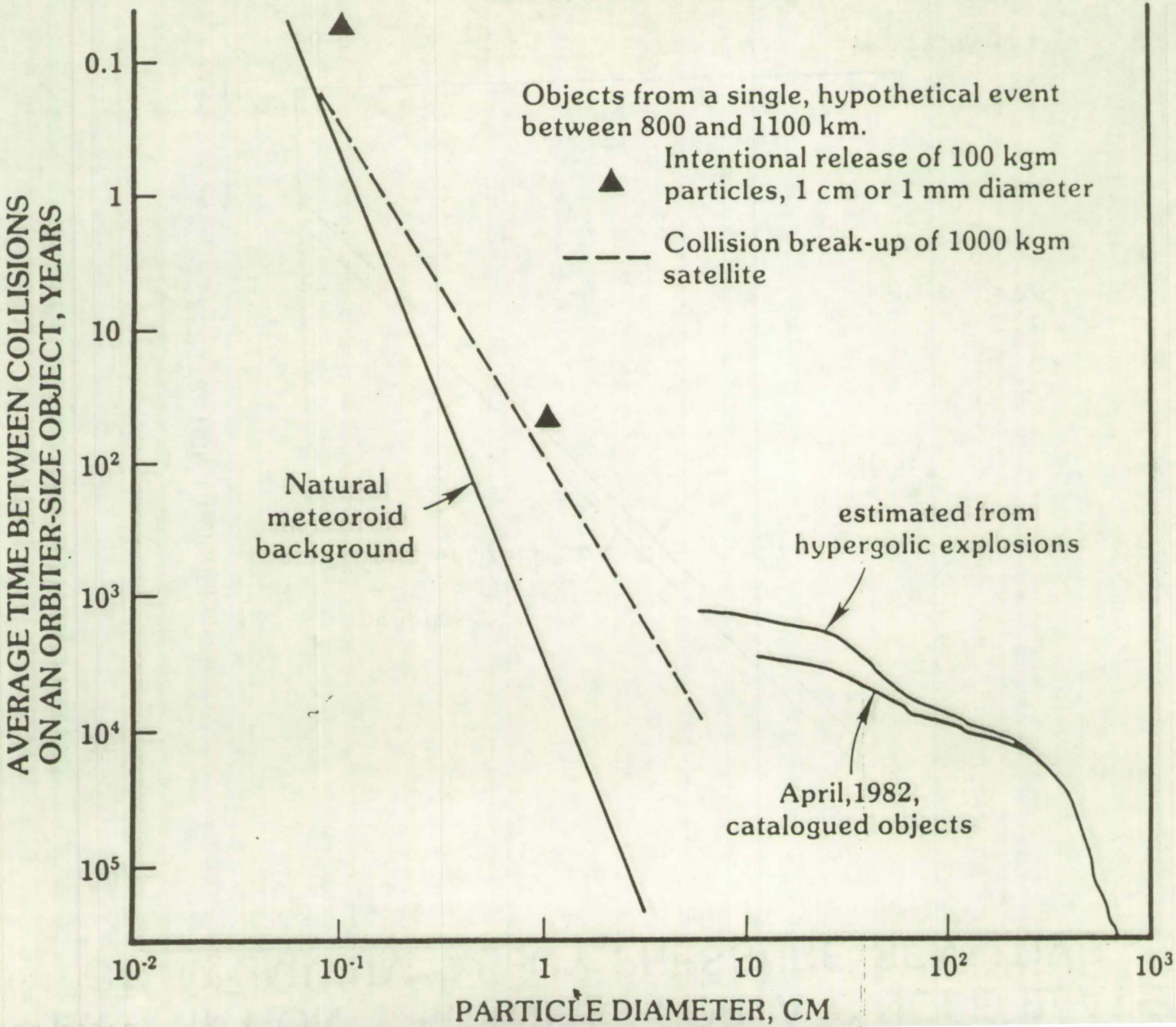


300

PENETRATION THICKNESS FOR A SINGLE PLATE OF ALUMINUM ALLOY, PRESSURE SENSITIVE



AVERAGE TIME BETWEEN COLLISIONS, 800 TO 1100 KM ALTITUDE BAND



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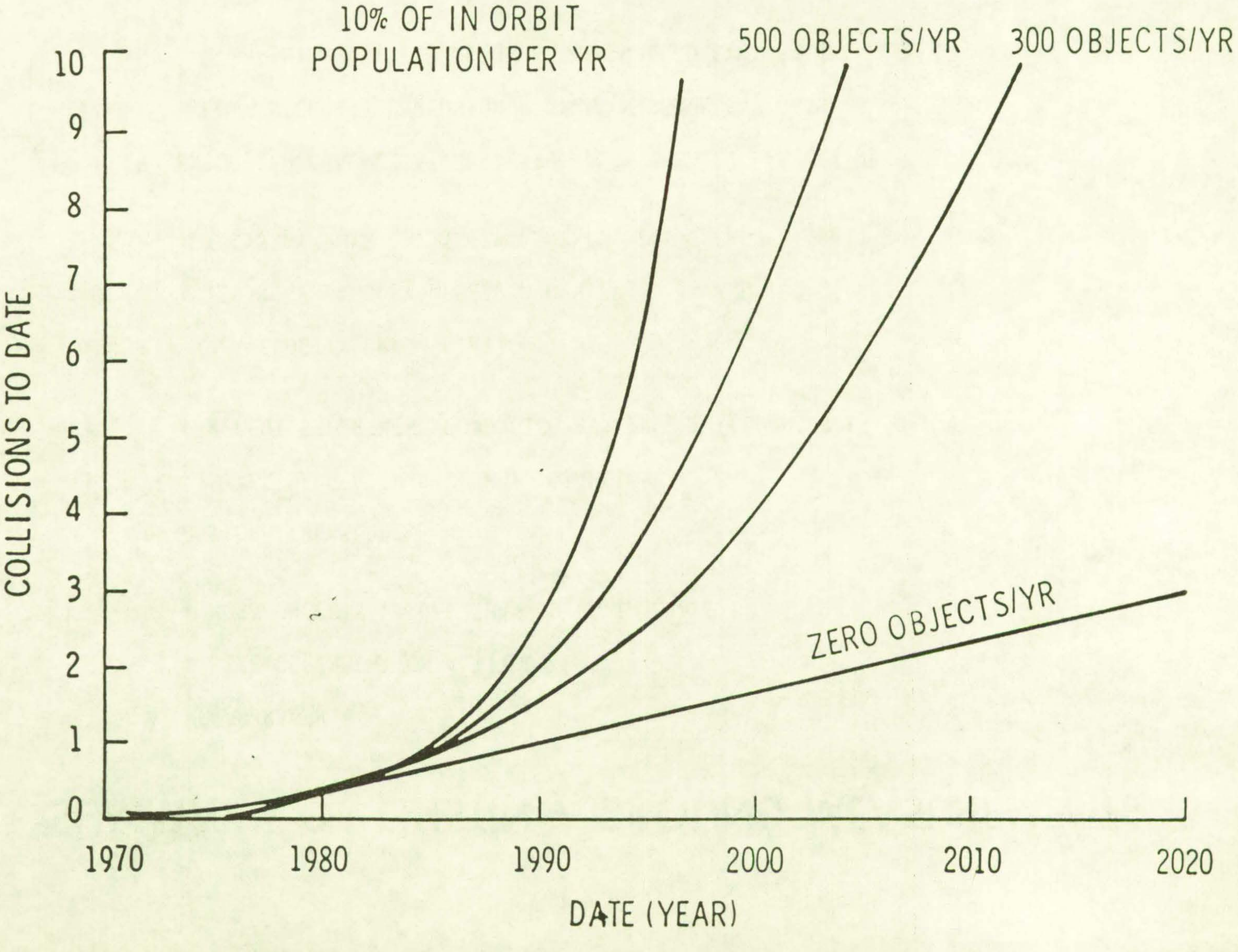
NUMBER OF COLLISIONS EXPECTED BY GIVEN DATE ASSUMING VARIOUS POPULATION GROWTHS FROM THE 1978 CORRECTED TO 4cm POPULATION



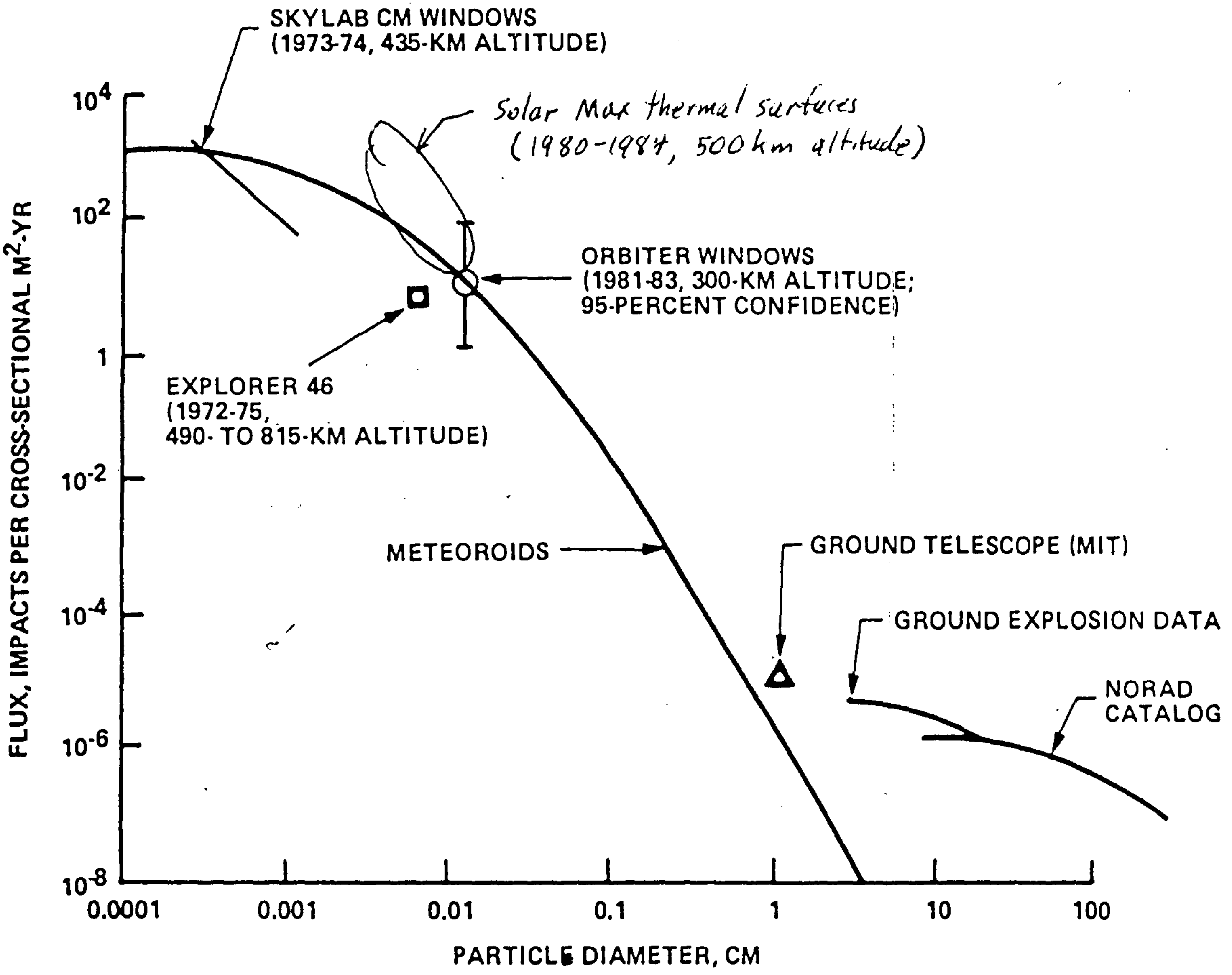
SUMMARY OF EXISTING GROUND MEASUREMENTS

- NORAD RADAR
  - SIZE DEPENDENT ON ALTITUDE
  - MOST OBJECTS LARGER THAN 10 CM IN DIAMETER
- OPTICAL TELESCOPE
  - SIZES LARGER THAN 1 CM IN DIAMETER
  - RECENT EXPERIMENT CONDUCTED BY LINCOLN LABORATORIES AT MIT
- HYPERVELOCITY FRAGMENTATION TESTS
  - TESTS BY LANGLEY RESEARCH CENTER, 0.4- AND 1.7-G PROJECTILE
  - TESTS BY PHYSICAL SCIENCES INC., 240-G PROJECTILE
- EXPLOSION FRAGMENTATION TESTS - COMPILED BY LANGLEY RESEARCH CENTER
  - LOW-INTENSITY EXPLOSION - ATLAS MISSILE EXPLOSION
  - HIGH-INTENSITY EXPLOSION - THIN-WALLED CYLINDRICAL SHELLS
- SOLID ROCKET MOTORS
  - PARTICLE COLLECTIONS IN TEST CHAMBER
  - PARTICLE COLLECTIONS IN STRATOSPHERE

SUMMARY OF EXISTING IN-SPACE MEASUREMENTS

- SKYLAB IV COMMAND MODULE WINDOWS (435 KM, 1973-74)
  - ALUMINUM-LINED PITS
  - PROBABLY Al_2O_3 FROM SOLID ROCKET MOTORS
  - PARTICLES SMALLER THAN 10 μM
- EXPLORER 46 METEOROID BUMPER EXPERIMENT (490 TO 815 KM, 1972-75)
  - DIRECTIONALITY INDICATES EARTH-ORBITING POPULATION
  - TIME CORRELATION WITH SOLID ROCKET MOTORS FIRED IN SPACE
  - PARTICLES APPROXIMATELY 0.1 MM IN DIAMETER
- STS-7 WINDOW PIT (300 KM, 1983)
  - CONTAINED TITANIUM WITH TRACE OF ALUMINUM
  - PIT MORPHOLOGY INDICATES VELOCITY BETWEEN 3 AND 6 KM/SEC
  - SOURCE UNKNOWN
  - PARTICLE APPROXIMATELY 0.2 MM IN DIAMETER
- Solar Max thermal surfaces (500 km, 1980-1984)
  - Many more pits than expected from meteoroids
  - Chemistry matches "paint" & with chlorine

EXISTING ORBITAL DEBRIS MEASUREMENTS COMPARED TO METEOROID FLUX

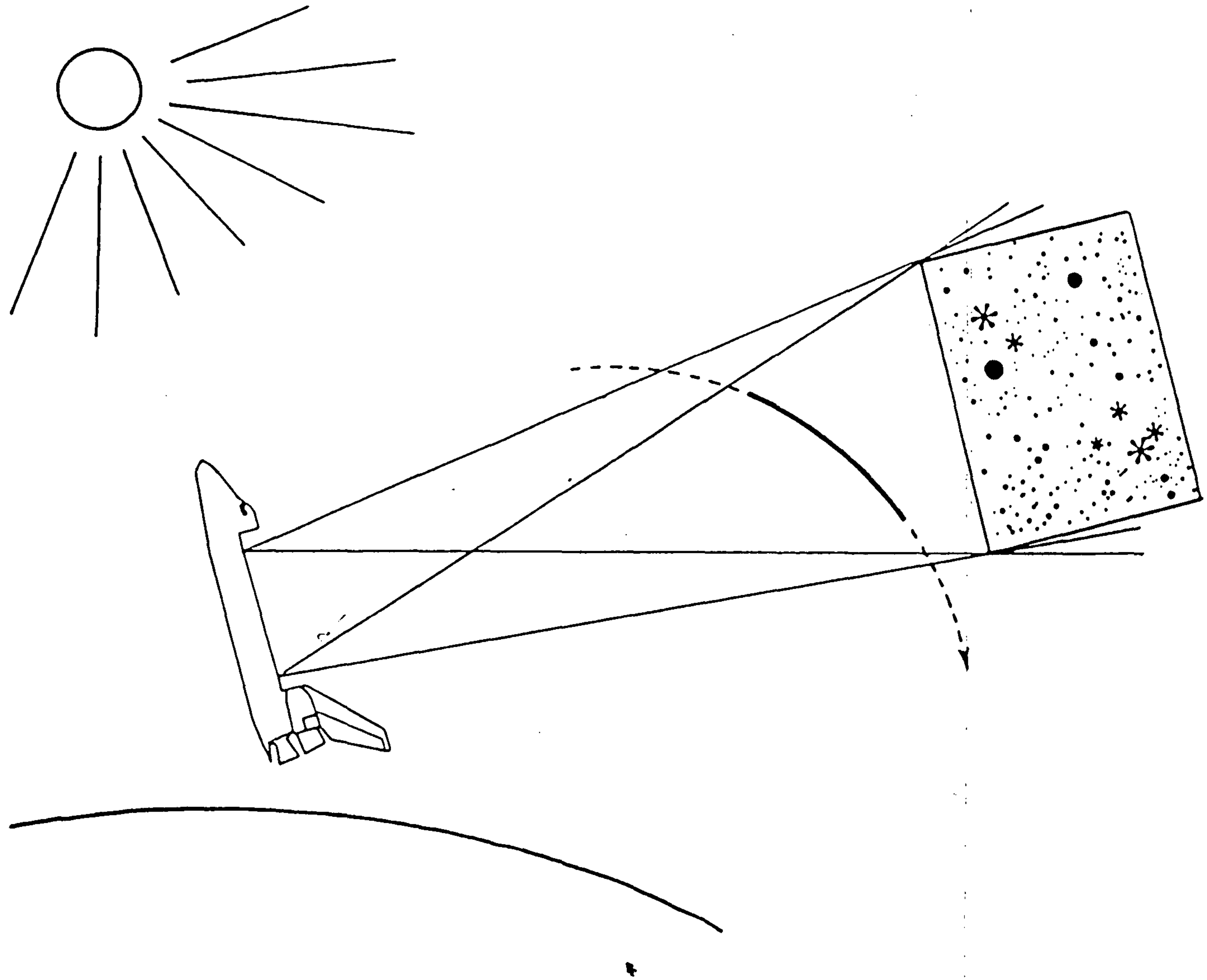


PROPOSED FUTURE TECHNIQUES TO MEASURE SMALL ORBITAL DEBRIS IN SPACE

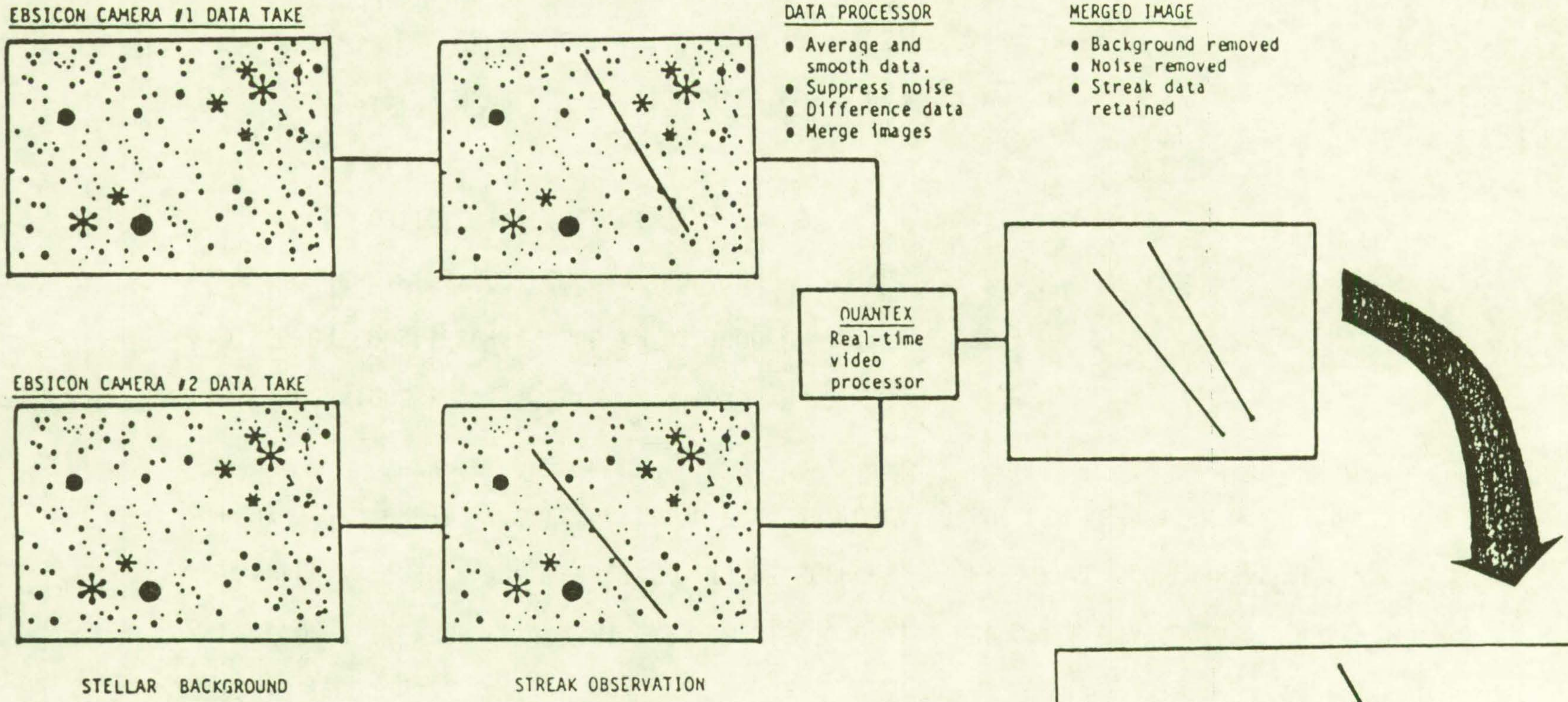
- IMPACT SENSORS (AS USED FOR METEOROID DETECTION) - COLLECTING AREA LIMITS DIAMETER SIZE TO LESS THAN 0.1 MM
- REMOTE SENSORS (G.E. STUDY) - CAN DETECT AND DETERMINE ORBITS FOR 1-MM AND LARGER OBJECTS
  - RADAR } MOST EXPENSIVE LEAST EVENT RATE
  - LIDAR }
  - PASSIVE OPTICAL - PREFERRED CONCEPT, TWO TELESCOPES SEPARATED BY 10 M
- ALTERNATIVE REMOTE SENSORS (BATTELLE, SANTA BARBARA RESEARCH)
  - PIGGYBACK, SMALL PASSIVE OPTICAL
  - INFRARED DETECTOR
  - IRAS

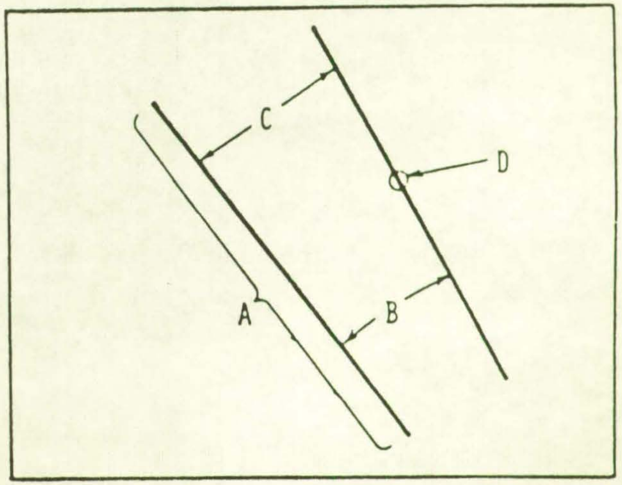
Lyndon B. Johnson Space Center

PRESENTATION TITLE	ORGANIZATION	
308 DATA TAKE GEOMETRY	SPACE SCIENCE BRANCH	
	NAME: Richard Williams	DATE: 6-19-84



TITLE	ORGANIZATION
SCHEMATIC OF DATA CAPTURE AND OUTPUT	SPACE SCIENCE BRANCH
NAME	DATE
Richard Williams	6-19-84





PARAMETER MEASUREMENTS

A - Length of streak

B - Angular convergence

C - Parallax distance

D - Streak brightness

ORBITAL DEBRIS MONITORING SYSTEM FOR SPACE STATION

OBJECTIVE:

MONITOR THE ORBITAL DEBRIS ENVIRONMENT TO IDENTIFY CHANGES AND NEW SOURCES OF POTENTIALLY HAZARDOUS PARTICULATES.

APPROACH:

DEVELOP A PACKAGE OF FLIGHT EXPERIMENTS TO ORBIT THRU SPACE STATION ALTITUDE AS WELL AS THRU ALTITUDE LIKELY TO BE SOURCES. THE PACKAGE SHOULD MEASURE FLUX, SIZE, ORBIT, AND COMPOSITION FOR PARTICULATES SMALLER THAN 1 CM DIAMETER.

POSSIBLE TECHNIQUES:

- O DEDICATED SATELLITE, 500 KM BY 1000 KM ALTITUDE ORBIT
  - O REMOTE SENSOR FOR PARTICULATES, 1 MM TO 1 CM DIA
    - O OPTICAL (VISIBLE, IR)
    - O RADAR
  - O IMPACT SENSOR FOR PARTICULATES LESS THAN 0.1 MM
- O CAPTURE CELL EXPERIMENT ATTACHED TO SPACE STATION

CONCLUSIONS

- ORBITAL DEBRIS ENVIRONMENT FOR THE SPACE STATION IS UNMEASURED
- LIMITED DATA AND MODELING INDICATES THAT SPACE STATION DESIGN WILL BE AFFECTED BY ORBITAL DEBRIS
- FUTURE CHANGES IN ENVIRONMENT SHOULD BE MONITORED