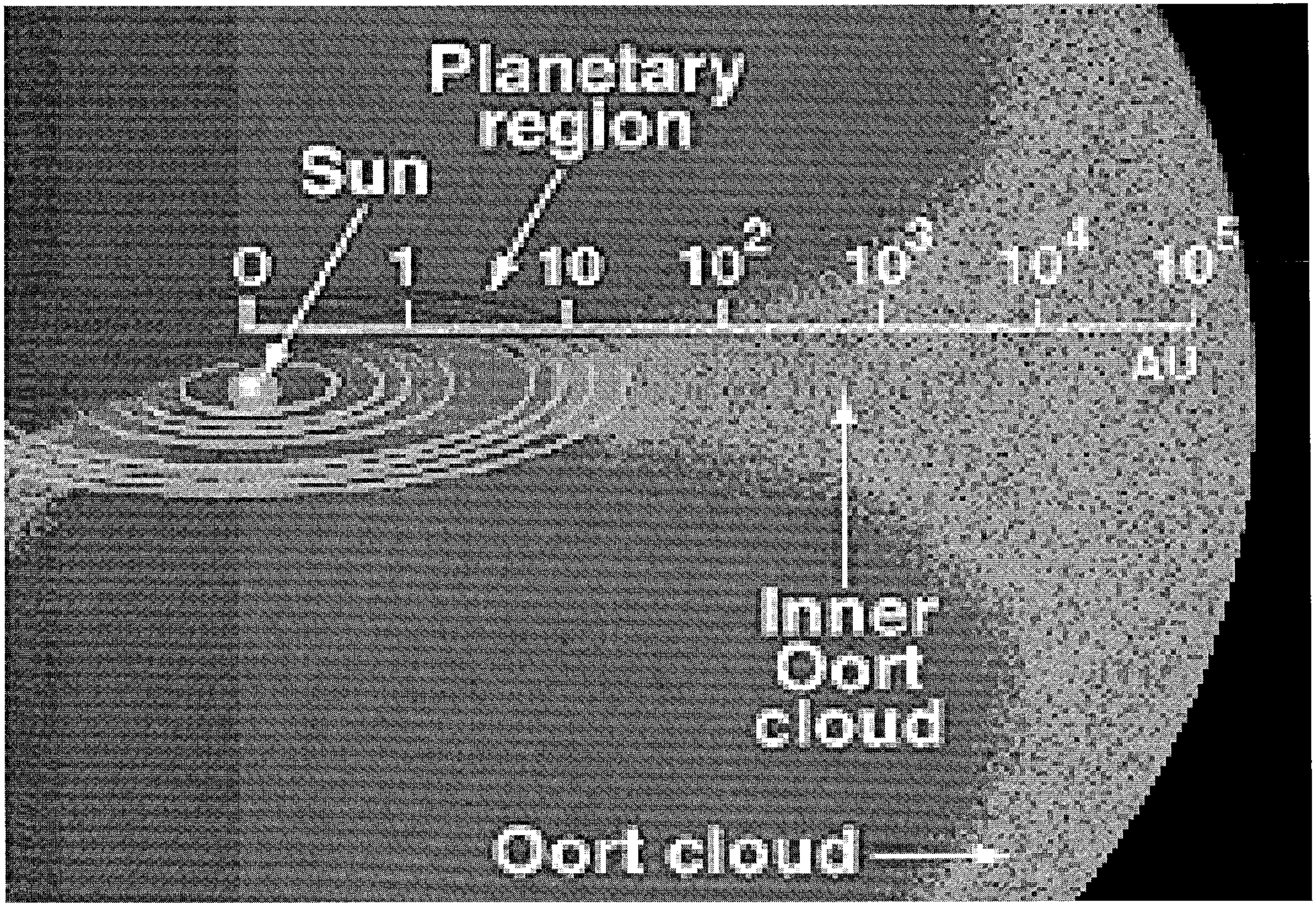
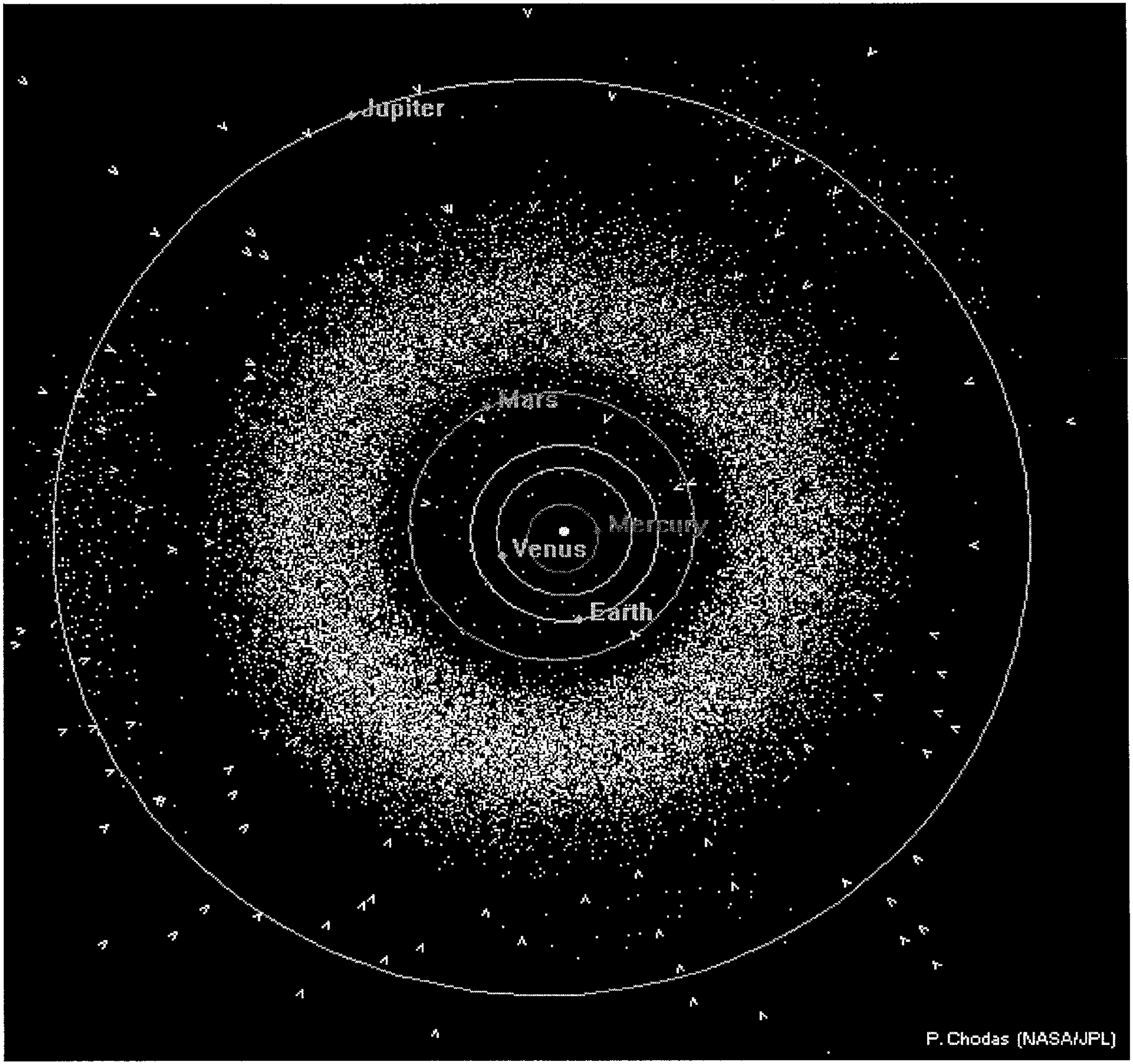
Facts & Uncertainties About NEOs –

Don Yeomans – Manager, NASA Near-Earth Object Program Office
(JPL/Caltech)

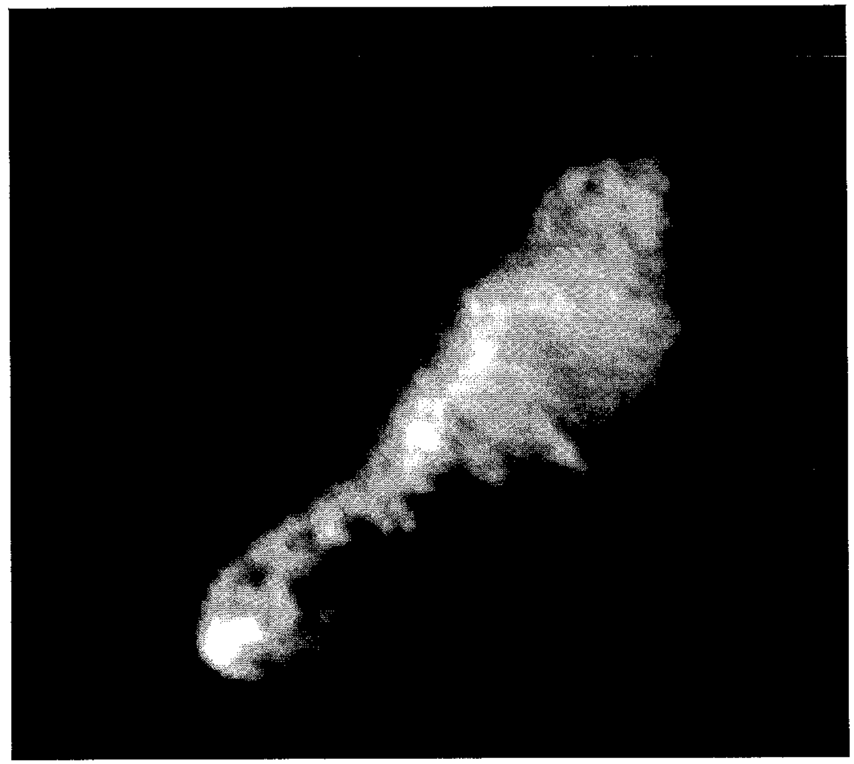
- Near-Earth Objects are defined as those asteroids and comets that can approach the sun to within 1.3 times the heliocentric distance of the Earth's orbit.
- The current Near-Earth population is:
  - 2208 near-Earth asteroids (637 larger than 1 km)
  - About 48 near-Earth short-period comets
  - About 2-3 observed long-period comets per year
- There are far more near-Earth asteroids than near-Earth comets so at least at the smaller sizes (< 1 kilometer), the near-Earth asteroid population represents the larger threat.


Planetary
region
Sun
0
1
10
10^2
10^3
10^4
10^5
AU
Inner
Oort
cloud
Oort cloud

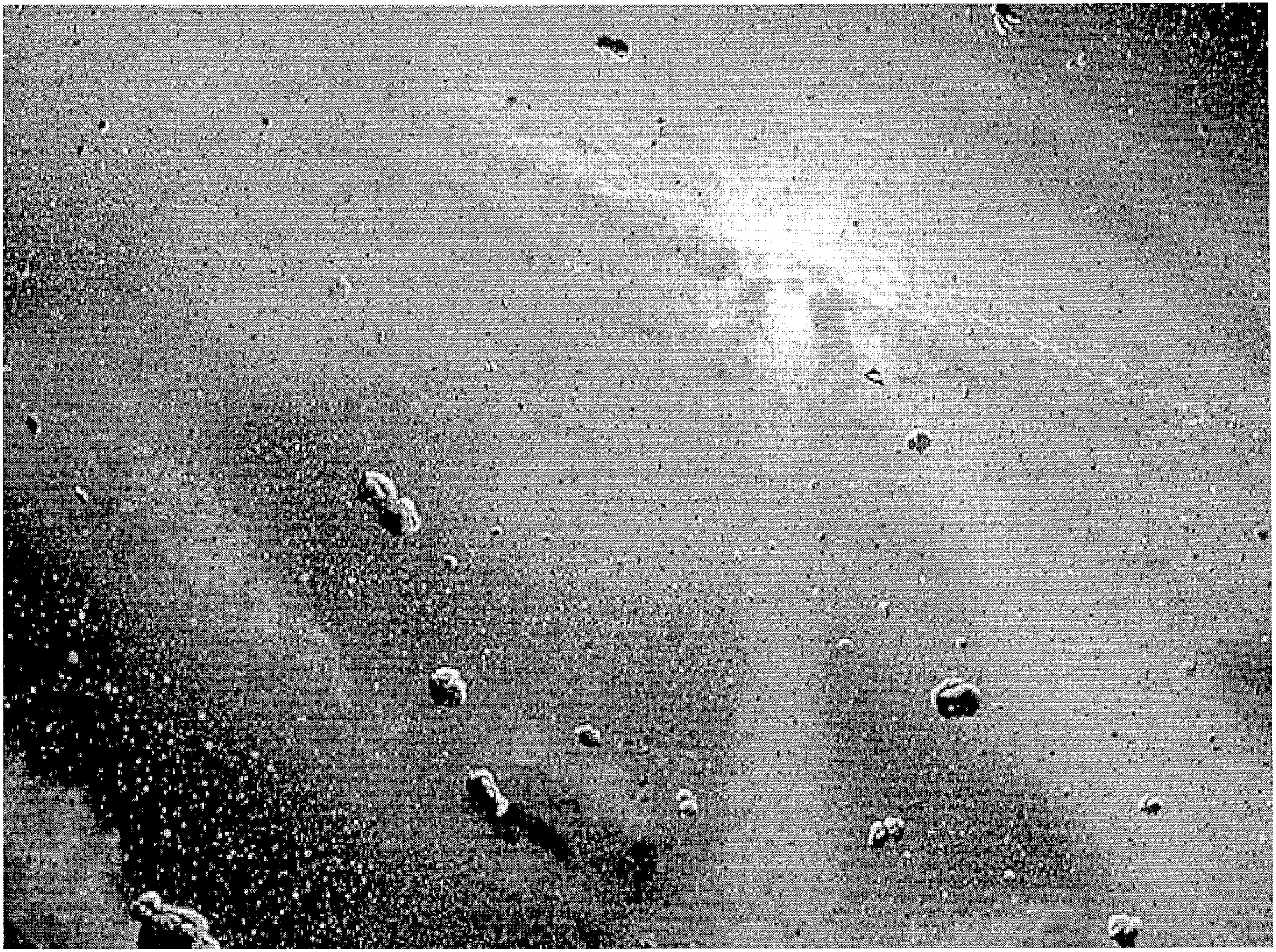

Jupiter
Mars
Mercury
Venus
Earth
P. Chodas (NASA/JPL)

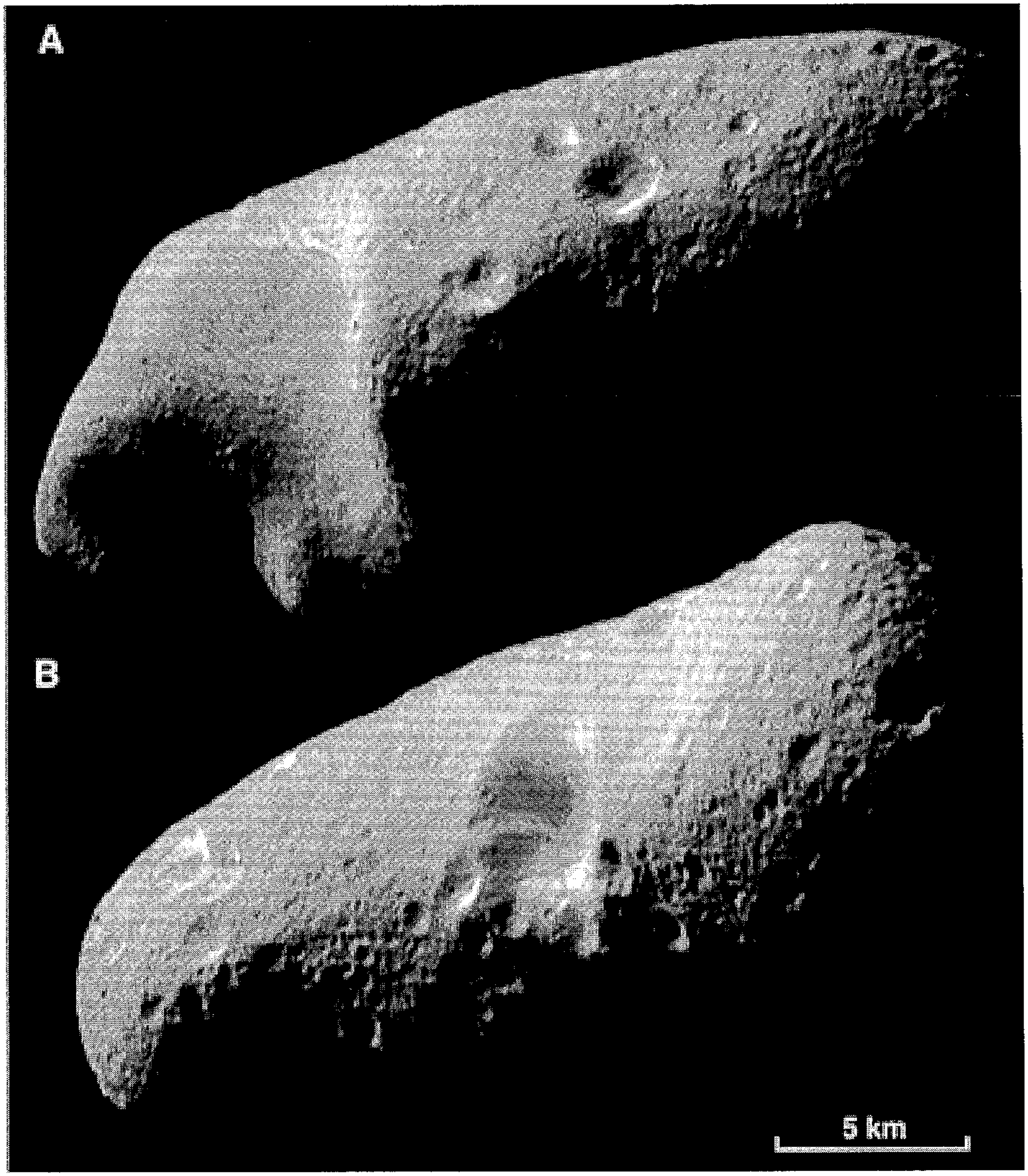
Importance of Near-Earth Objects

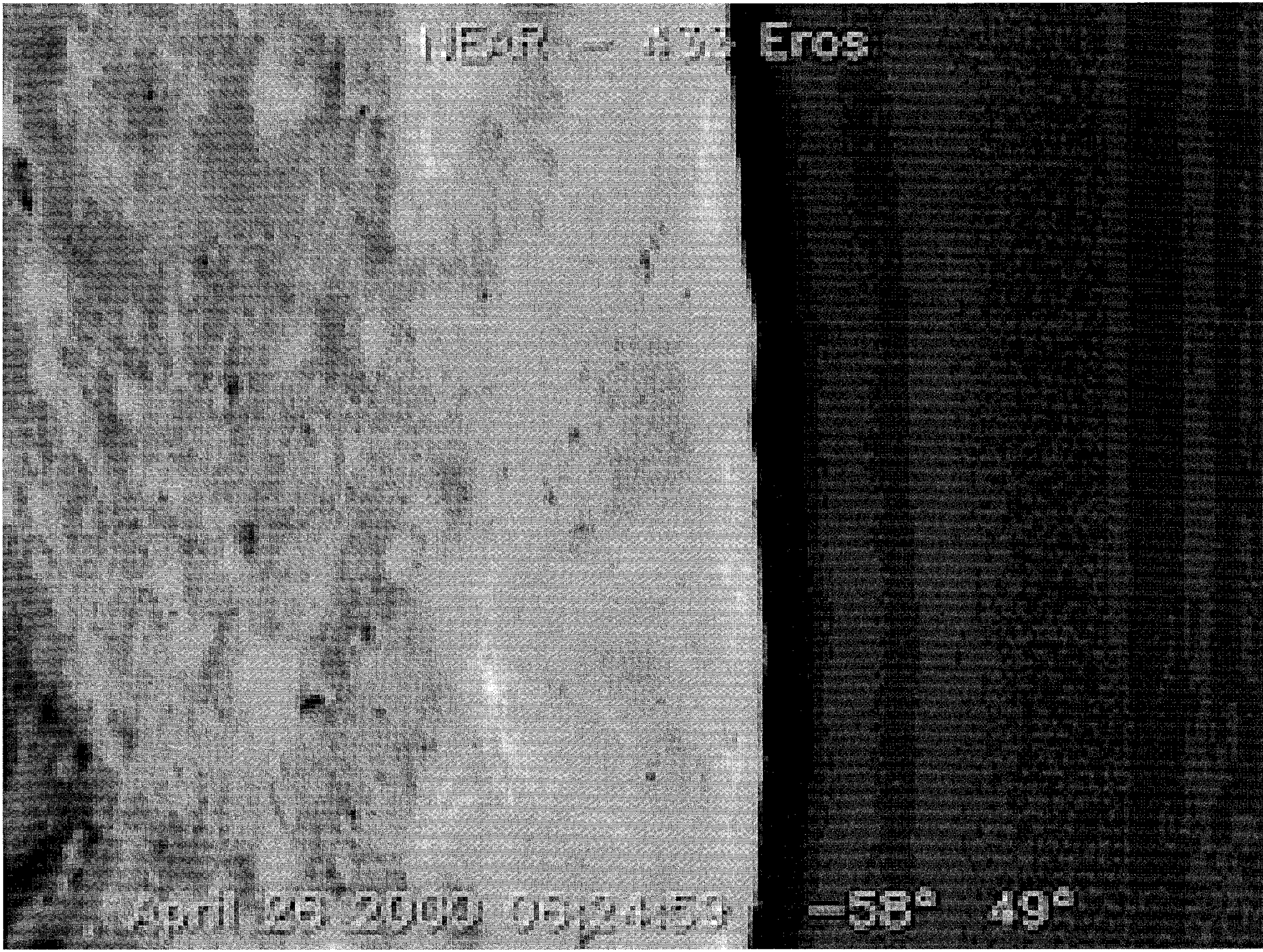
- Primitive debris from solar system formation process (4.6 billion years ago)
- Delivered life-enabling water and carbon-based materials to early Earth & affected subsequent evolutionary processes
- Rich & accessible raw materials for future space structures, water and rocket fuel



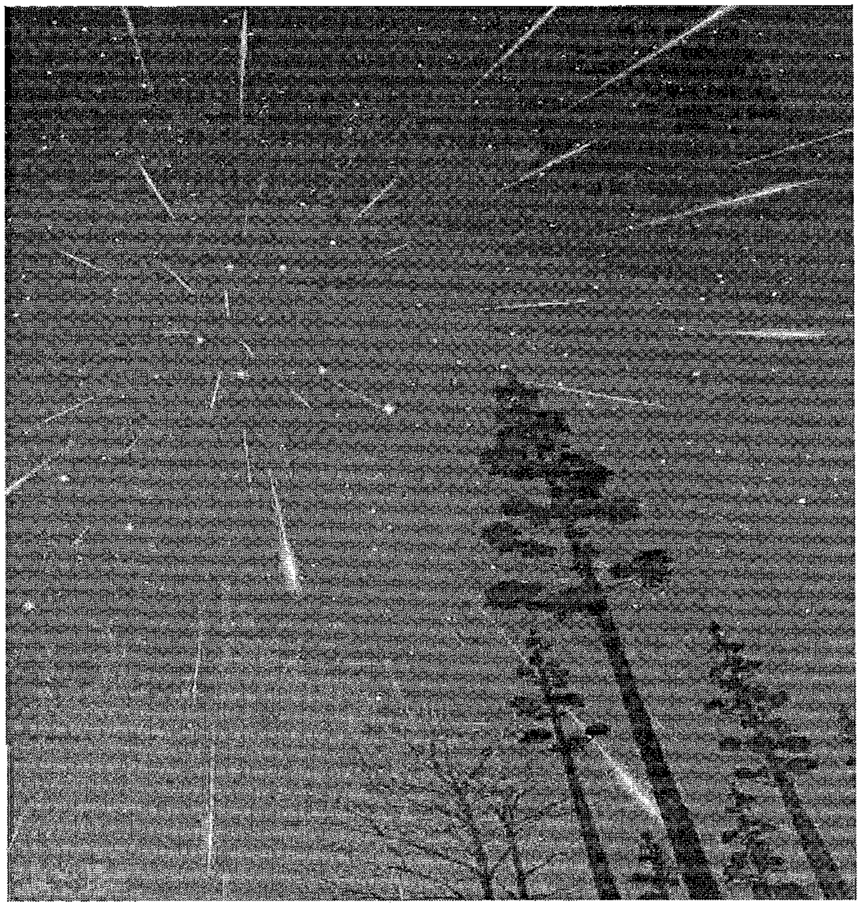
Nucleus of comet Borrelly observed by the DS1 spacecraft on Sept. 22, 2001




A
B
5 km


Eros
2000

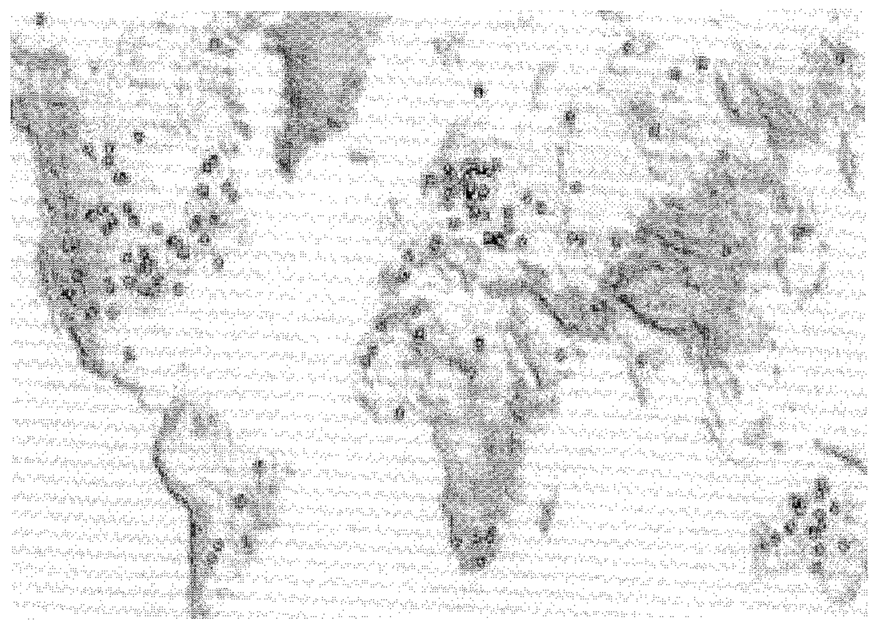
Target Earth

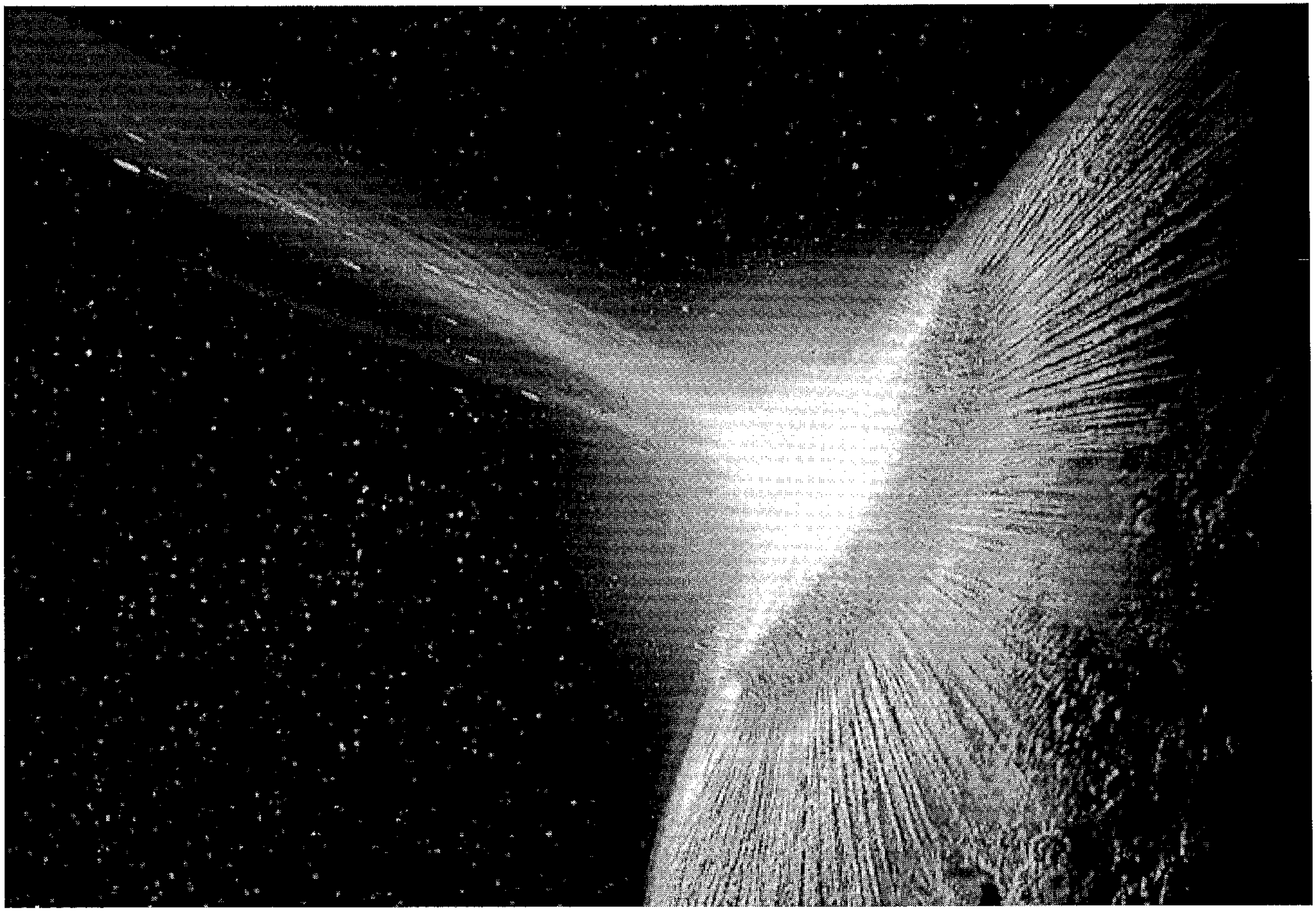


- More than 400 tons of interplanetary material rains down upon the Earth daily (on average)
- City block-sized objects pass within a lunar distance monthly
  - 2002 MN June 14, 2002
  - 2002 XV90 Dec. 11, 2002 (0.3 Lunar Distances)

Target Earth

- There are about 160 recognized impact craters on Earth.
- Wind and water erosion processes responsible for erasing the vast majority of Earth's impact craters





OECD Global Science Forum -
Workshop on NEOs - Jan. 2003

Near-Earth Object Discovery Teams

- Lincoln Near-Earth Asteroid Reconnaissance (LINEAR)
  - Grant Stokes, Principal Investigator (MIT/Lincoln Lab)
  - Cooperative effort with Air Force near Socorro, New Mexico
  - Two full time 1-meter aperture Air Force Telescopes
  - 0.5 m telescope on line in 2002 for follow-up observations
- Near-Earth Asteroid Tracking (NEAT)
  - Ray Bambery, PI (NASA/JPL)
  - Cooperative effort with Air Force at Maui, HI
    - Air Force 1.2-m telescope operational
  - 1.2-m Palomar Schmidt operational in early 2001
    - Yale Quest camera (112 CCD array, 9.4 sq. deg. FOV) to be delivered in early 2003 with NEAT/Yale/Caltech sharing time.

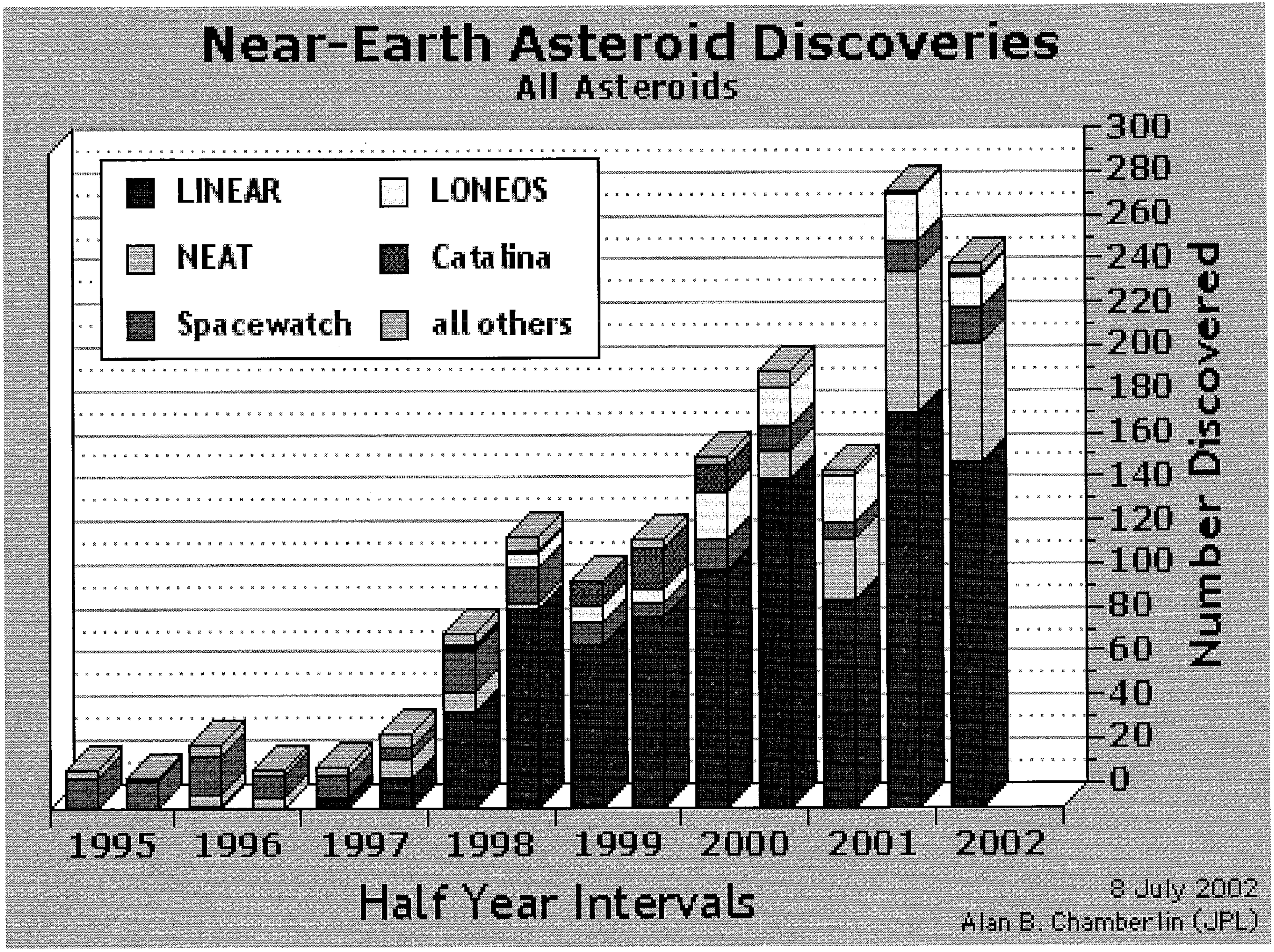
Near-Earth Object Discovery Teams

- Spacewatch (near Tucson, AZ)
  - Bob McMillan P.I.. (University of Arizona)
  - 0.9 and 1.8 meter aperture telescopes
  - 0.9 m recently equipped with 4 x (4608x2048) CCD mosaic
  - 18 nights/month down to 21st magnitude
  - Finds most small near-Earth objects and many Kuiper belt objects
- Lowell Observatory Near-Earth Object Survey (LONEOS)
  - Ted Bowell, Principal Investigator (Flagstaff Arizona)
  - 0.6 meter aperture, wide-field telescope, 15 nights/mon.
  - Designed to survey entire sky each month
  - USNO 1.3 m telescope being phased in for NEO search

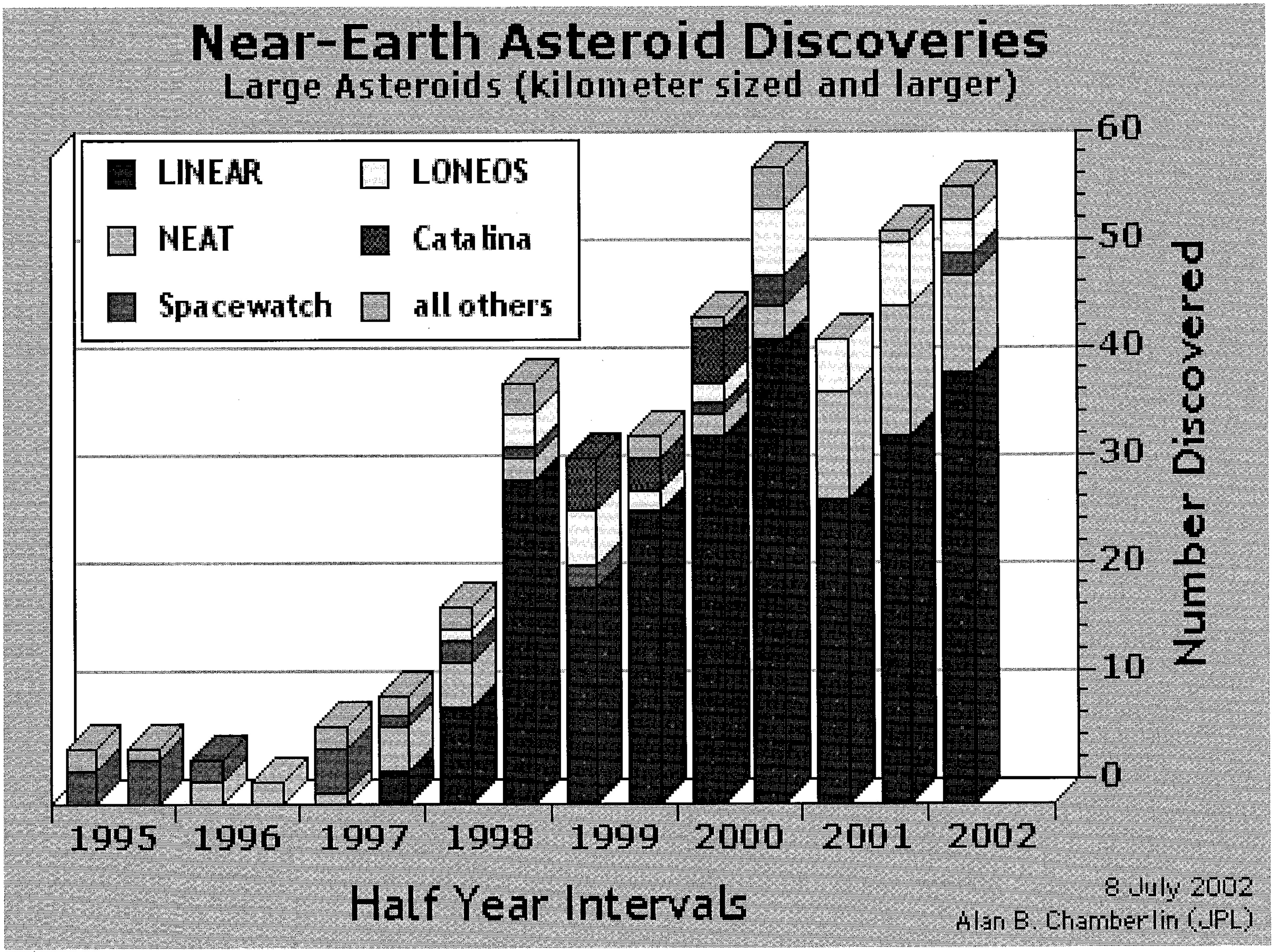
Near-Earth Object Discovery Teams

- Catalina Sky Survey
  - Steve Larson, Principal Investigator (Tucson AZ)
  - 0.7 meter aperture telescope (currently off line for modifications)
    - ~15 nights/month
  - 1.5 m follow-up telescope at Mt. Lemmon, AZ
  - 0.6 m Schmidt available at Siding Spring, Australia
    - First southern hemisphere NEO site may be on line in 2003

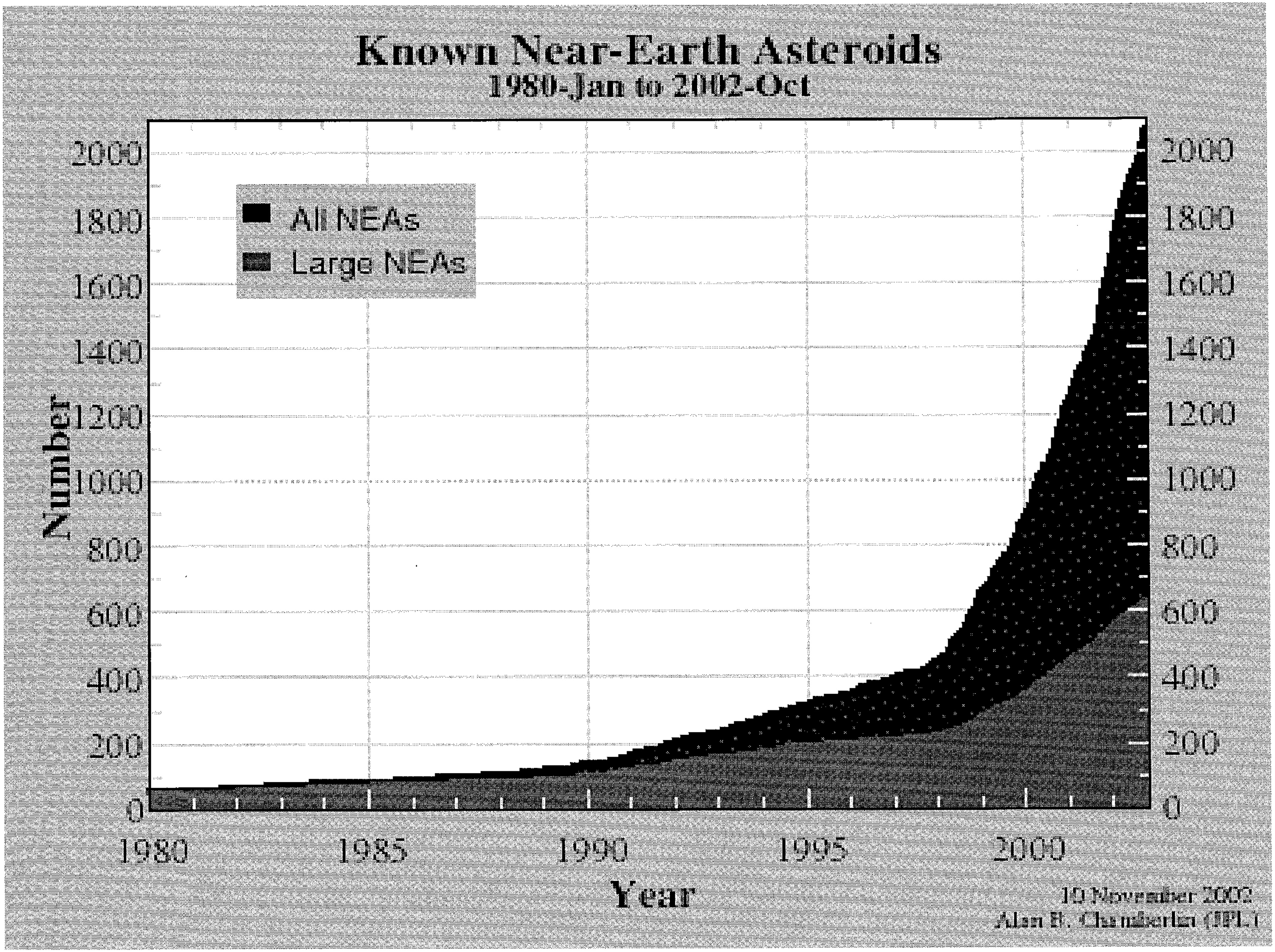
- Japanese Spaceguard (S. Isobe, PI)
  - 0.5m & 1-m, wide field of view telescope near Bisei Town, Japan
  - Program involves search for NEOs and observations of Earth orbital debris

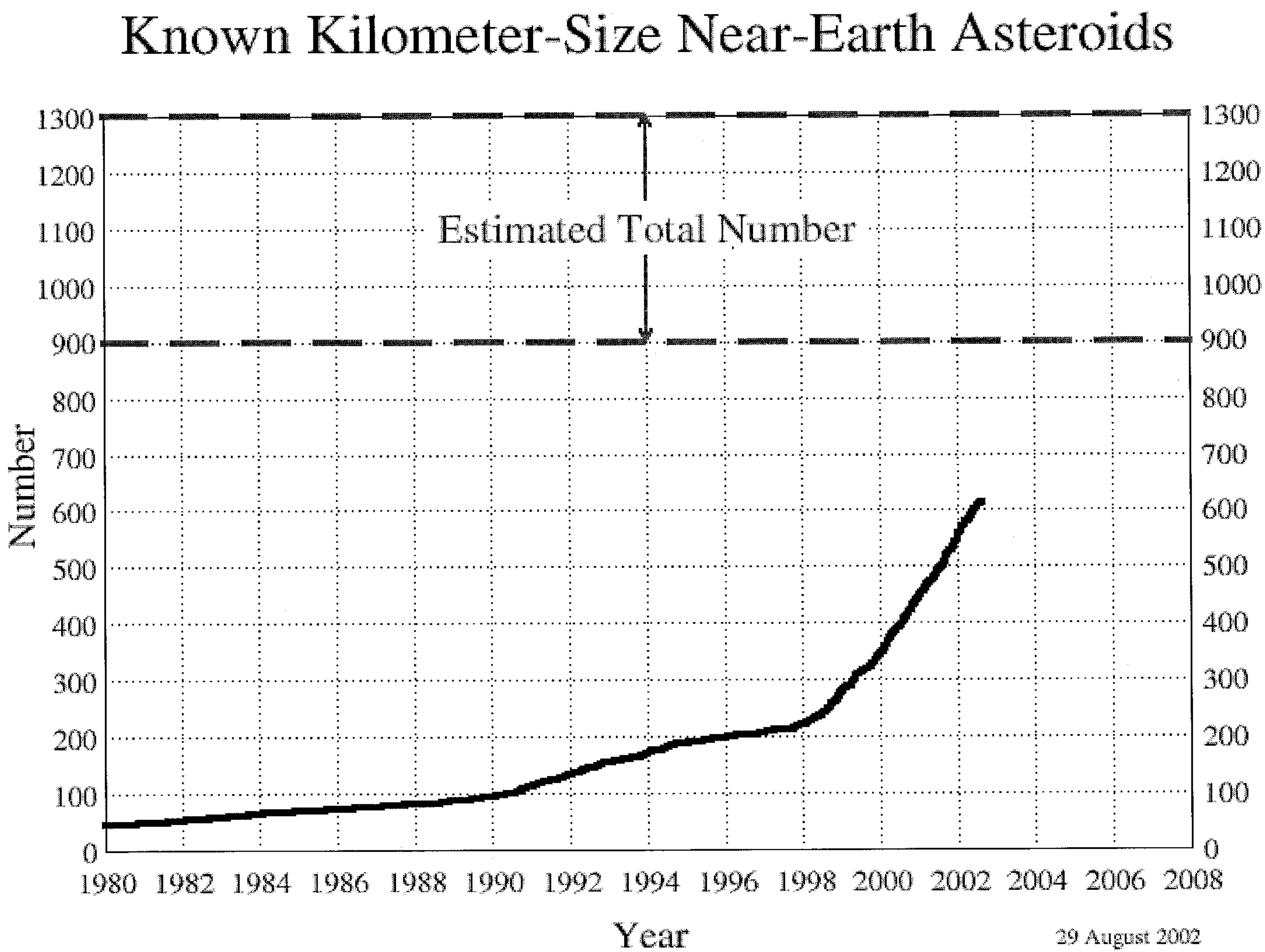


Near-Earth Asteroid Discoveries
All Asteroids
LINEAR
LONEOS
NEAT
Catalina
Spacewatch
all others
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Number Discovered
1995
1996
1997
1998
1999
2000
2001
2002
Half Year Intervals
8 July 2002
Alan B. Chamberlin (JPL)



Near-Earth Asteroid Discoveries
Large Asteroids (kilometer sized and larger)
LINEAR
LONEOS
NEAT
Catalina
Spacewatch
all others
0
10
20
30
40
50
60
Number Discovered
1995
1996
1997
1998
1999
2000
2001
2002
Half Year Intervals
8 July 2002
Alan B. Chamberlin (JPL)


Known Near-Earth Asteroids
1980-Jan to 2002-Oct
All NEAs
Large NEAs
Number
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1980
1985
1990
1995
2000
Year
10 November 2002
Alan B. Chamberlin (JPL)

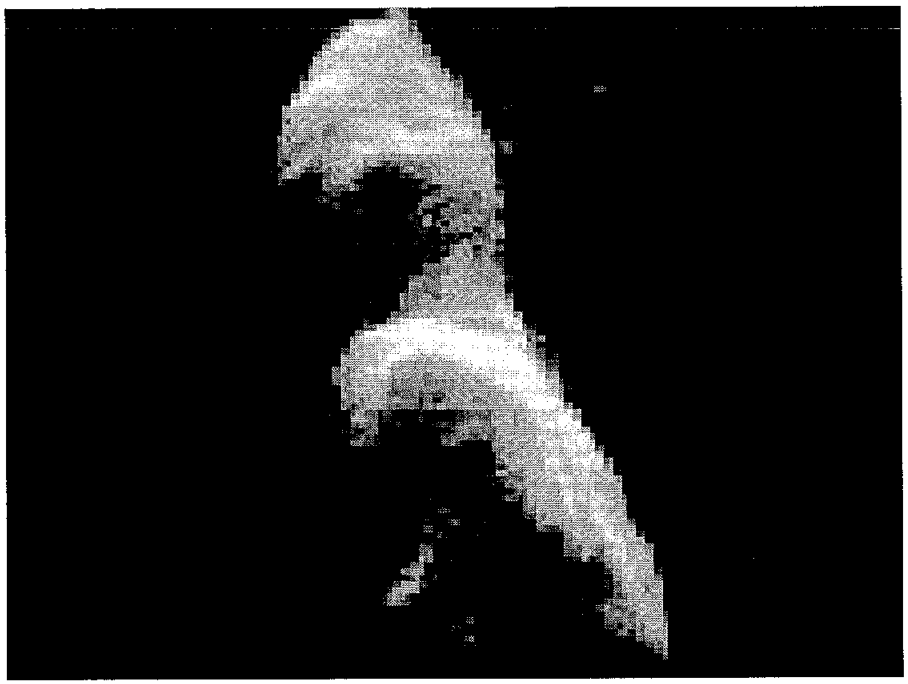


29 August 2002
Alan B. Chamberlin (JPL)

NASA NEO Program Office
http://neo.jpl.nasa.gov

- Updated Close Approach Tables (& SENTRY Risk page)
- Up-to-date statistics & metrics on NEO population
  - Cumulative total of NEOs, NEAs, Large NEAs,PHAs
  - Efficiency of discoveries by NASA-supported sites
- Summaries of Discovery Teams (with links)
- Summaries of Comet/Asteroid missions (with links)
- User requested interactive ephemerides & orbital data
- Current NEO news items (and links)
- Interactive 3-D orbital movies for all comets and asteroids
- Comet/Asteroid Images & NEO Essays
  - Scientific interest in NEOs, NEOs as Future Resources
  - Potential Hazards, NEOs and Origin of Life

NEO Physical Characterization

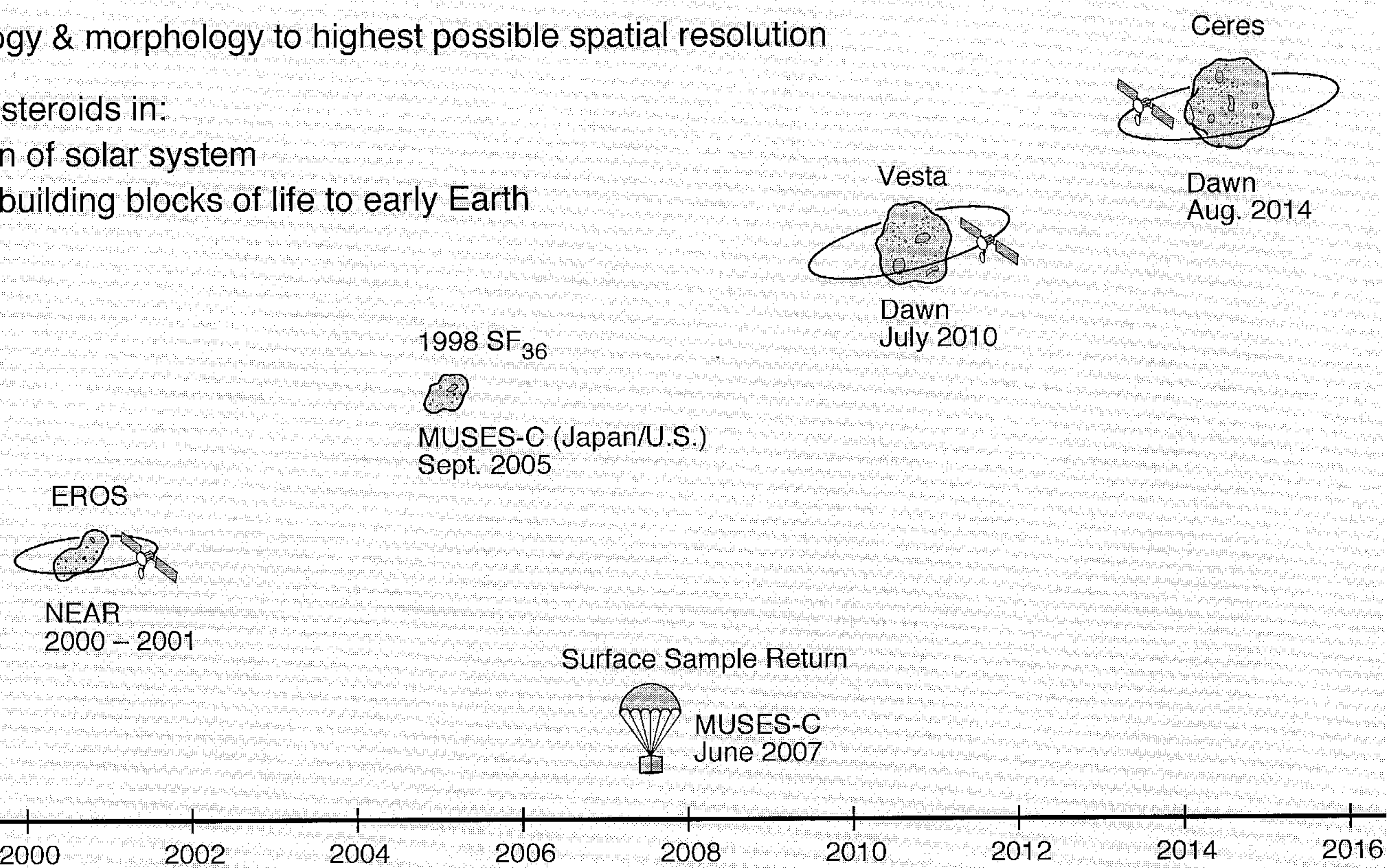


Radar image of asteroid Toutatis taken Dec. 6, 1996. Extent is about 4.5 km

- Before a mitigation effort can be undertaken, the threatening NEO's mass, composition, rotation state and structure must be well understood.
- Ground-based optical, infrared and radar observations can provide:
  - Rotation characteristics
  - Size, shape, binary?
  - Spectral type, albedo, surface roughness
  - Constraints on structure and composition

Asteroid Rendezvous Missions

- Study composition of diverse asteroids & identify meteorite parent bodies
- Determine global physical structures of diverse asteroids
- Examine geology & morphology to highest possible spatial resolution
- Study role of asteroids in:
    - Formation of solar system
    - Bringing building blocks of life to early Earth



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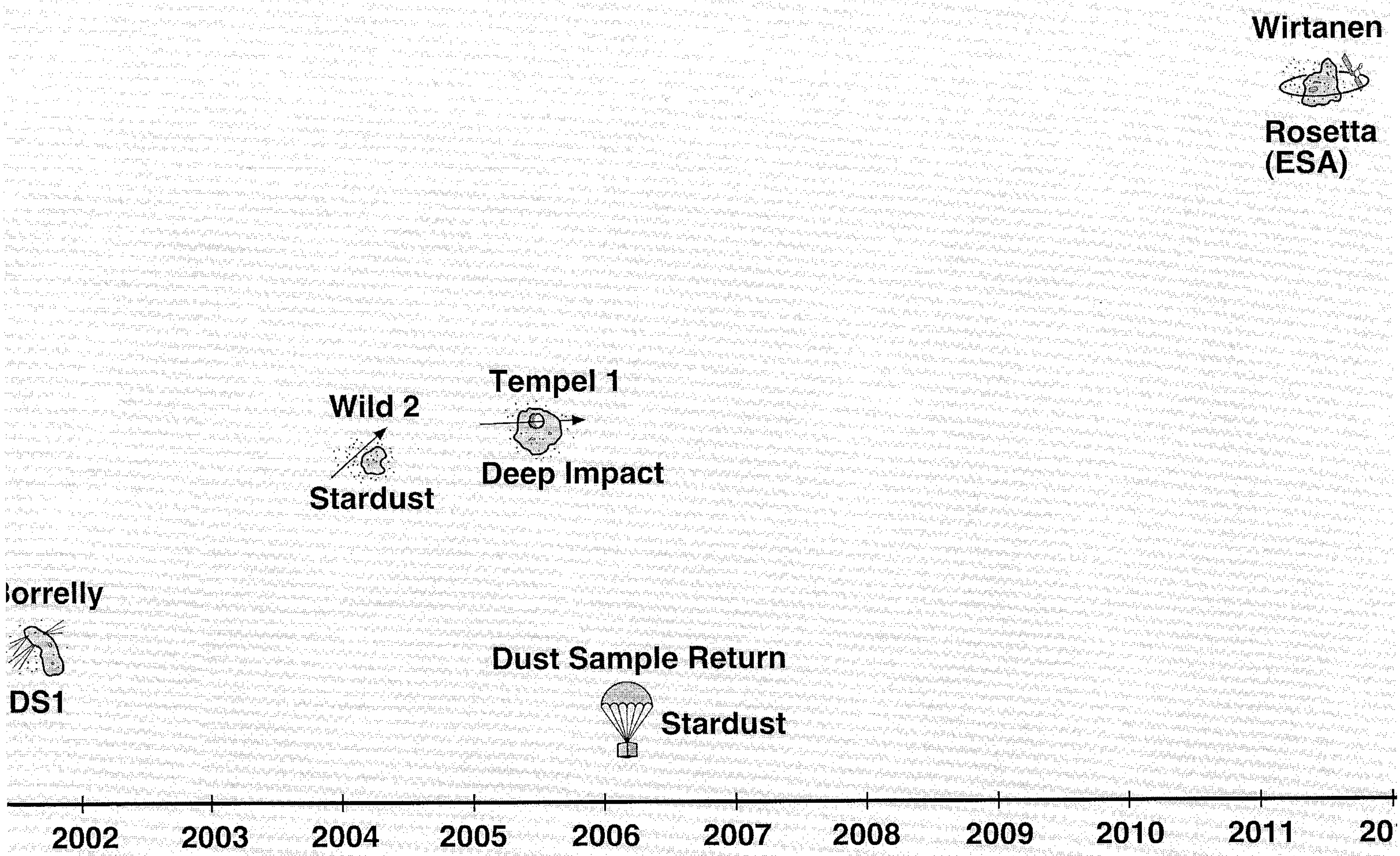
A Decade of Cometary Exploration



Yeomans –

Future NEO Issues

NASA recently formed NEO Science Definition Team and asked them to respond to the following:

- After the majority of the large Near-Earth Asteroids have been found, what sized objects would be expected to cause the largest threat (e.g., in terms of the damage done by Tsunamis)?
- For some size NEO diameter (and less), discovery, cataloging and mitigation is not worth the effort. What size is that?
- What would be the optimal use of technically feasible ground- and/or space-based assets to most efficiently find this hazardous NEO population? What would be the costs and how long would such a search take?
- What, if anything, needs to be done for the Earth threatening long-period comets that will provide very little warning time?

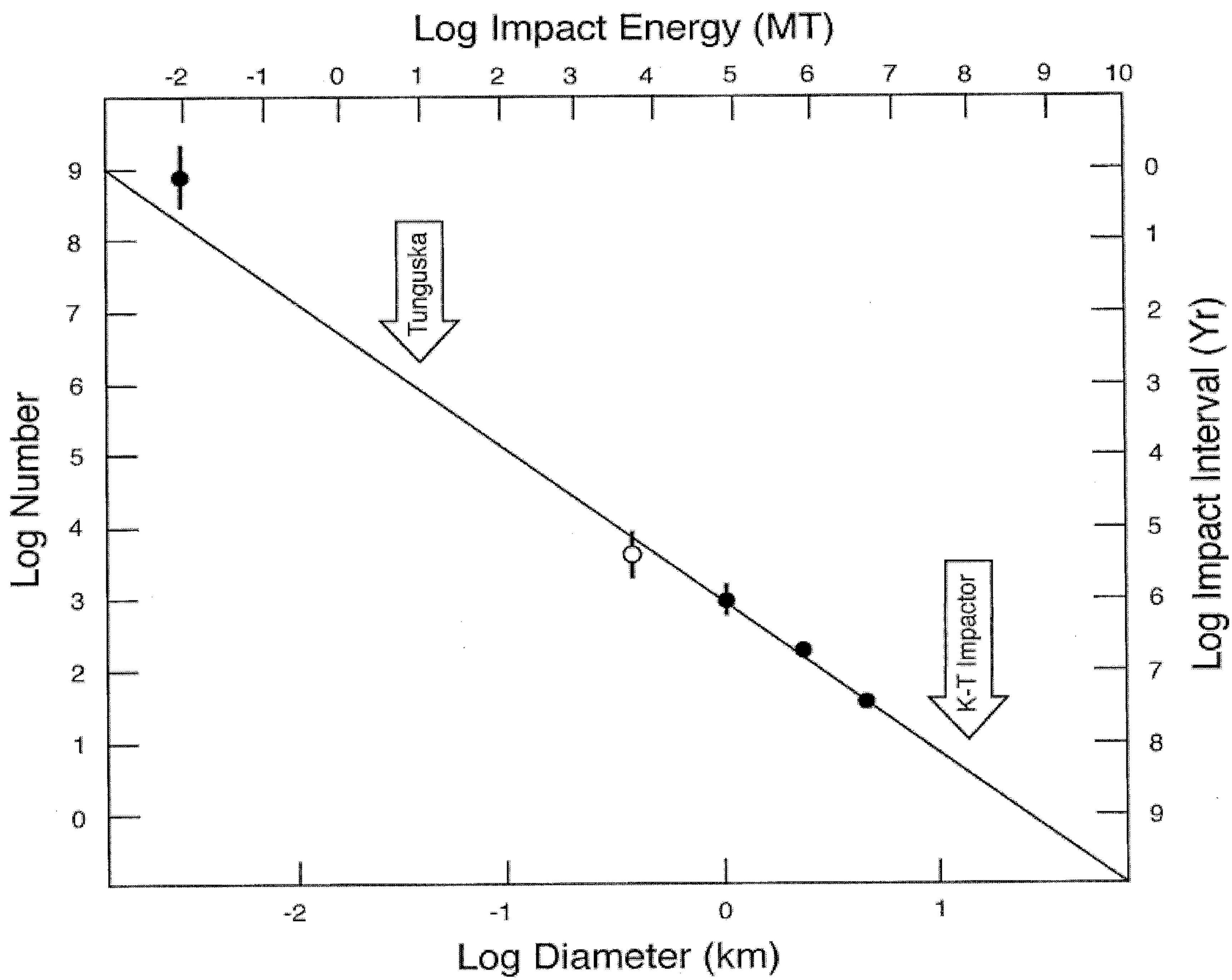
Future NEO Issues

How can the NEO search be made more international?

- No discovery teams in southern hemisphere
- Few search teams outside of U.S.
- No chain of responsibility exists for when an Earth threatening object is found

What will be the role of future, large field-of-view surveys that may go far fainter than current surveys? (e.g., LSST, PAN STARRS, GAIA)

Should the emphasis for NEO searches be shifted from opposition-oriented surveys to "near-sun" searches to more efficiently find **hazardous** NEOs – at the expense of finding more total NEOs?



Log Impact Energy (MT)
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Log Number
9
8
7
6
5
4
3
2
1
0
Log Impact Interval (Yr)
0
1
2
3
4
5
6
7
8
9
Tunguska
K-T Impactor
-2
-1
0
1
Log Diameter (km)

Comparative Risks for USA and Canada

Average Annual Risk of Death in Units of One in a Million

300	Accidents (not motor vehicle)
200	Homicide & suicide (lower in Canada)
160	Motor vehicle accidents
10	Fire
5	Electrocution
1	Airplane accidents (depends on flight frequency)
0.3	TOTAL IMPACTS (global threshold = 1 million Mt)
0.3	Storms and floods (declining)
0.1	Earthquakes (poor statistics)
0.003	TUNGUSKA-TYPE IMPACTS
<<0.001	Nuclear accidents (design goals)

Comparison with Other Risks

Statistical risk of death from impacts is about 1 in 4 million per year, or about 1:50,000 lifetime risk

- Comparable with other natural hazards (*e.g.* earthquakes, floods)
- Near threshold for hazards most people worry about
- Well above threshold for U.S. governmental or regulatory action
- Much less (in U.S.) than auto accidents, shootings

- **Severity of disasters (billions of people killed) is greater than any other *known* hazard we face**
  - Apparently unique in its threat to civilization
  - Places this disaster in a class by itself
- **Average interval between major disasters (million yrs) is larger than for other hazards**
  - Causes some to question credibility of hazard