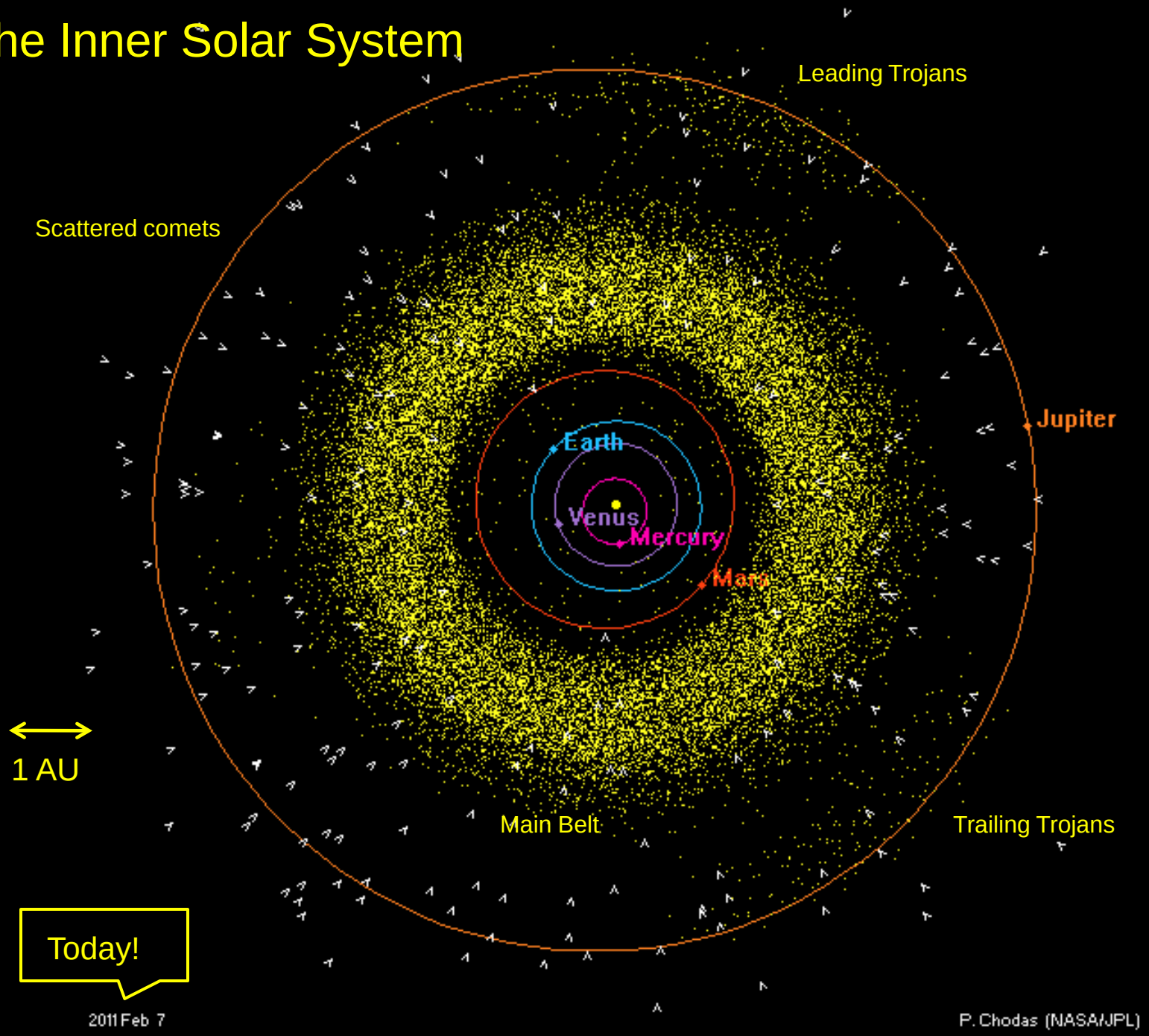
Introduction to Comets and Asteroids

Paul Chodas, JPL/Caltech

Outline

- Distinction between Comets and Asteroids
- Comets: History, nomenclature, orbital characteristics, groups
- Asteroids: Nomenclature, Main Belt & subgroups,
  spectral types, asteroid satellites, Ceres & Vesta
- Trans-Neptunian Objects and the Kuiper Belt
- Planets vs. Dwarf Planets vs. Small Solar System Bodies
- Collisions in the Solar System
- Near-Earth Objects: could a big one be headed our way?

The Inner Solar System



Comet vs. Asteroid

Comet: Appears fuzzy and/or has a tail; sometimes bright. Contains water ice and other frozen volatiles which sublimate into gases when the object gets close to the Sun.

Asteroid: Appears as a point of light even in the large telescopes. Doesn't contain much ice or doesn't get close enough to the Sun for ices to heat up and sublimate.

Both orbit the Sun, generally far from the Earth, and move slowly against the star background (unlike **meteors** which are generally small objects entering our atmosphere at high speed and burning up).

Comet
Hale-Bopp

Asteroid
Gaspra

Comets: Names, Designations and Numbers

Comet Hale-Bopp (C/1995 O1)

- Named after their discoverers
- Also designated "T/yyyy Xn"
  - T is a type: C for long-period, P for short period, D for disappeared
  - yyyy is the discovery year
  - X is the half-month (A: Jan. 1-15, B: Jan.16-31, etc.)
  - n is a sequence number
- Once a periodic comet's orbit is well known, it is assigned a number:
  - 1P/Halley, 103P/Hartley 2
- Currently, 248 numbered comets, and ~2700 unnumbered comets
- Many comets have split into fragments (eg. 73P/SW-3)
- Some have disintegrated entirely (eg. 3D/Biela)

Sir Edmund Halley's Catalog of Cometary Orbits (1705)

•Halley realized these 3 entries were the same comet and predicted the next appearance in 1758

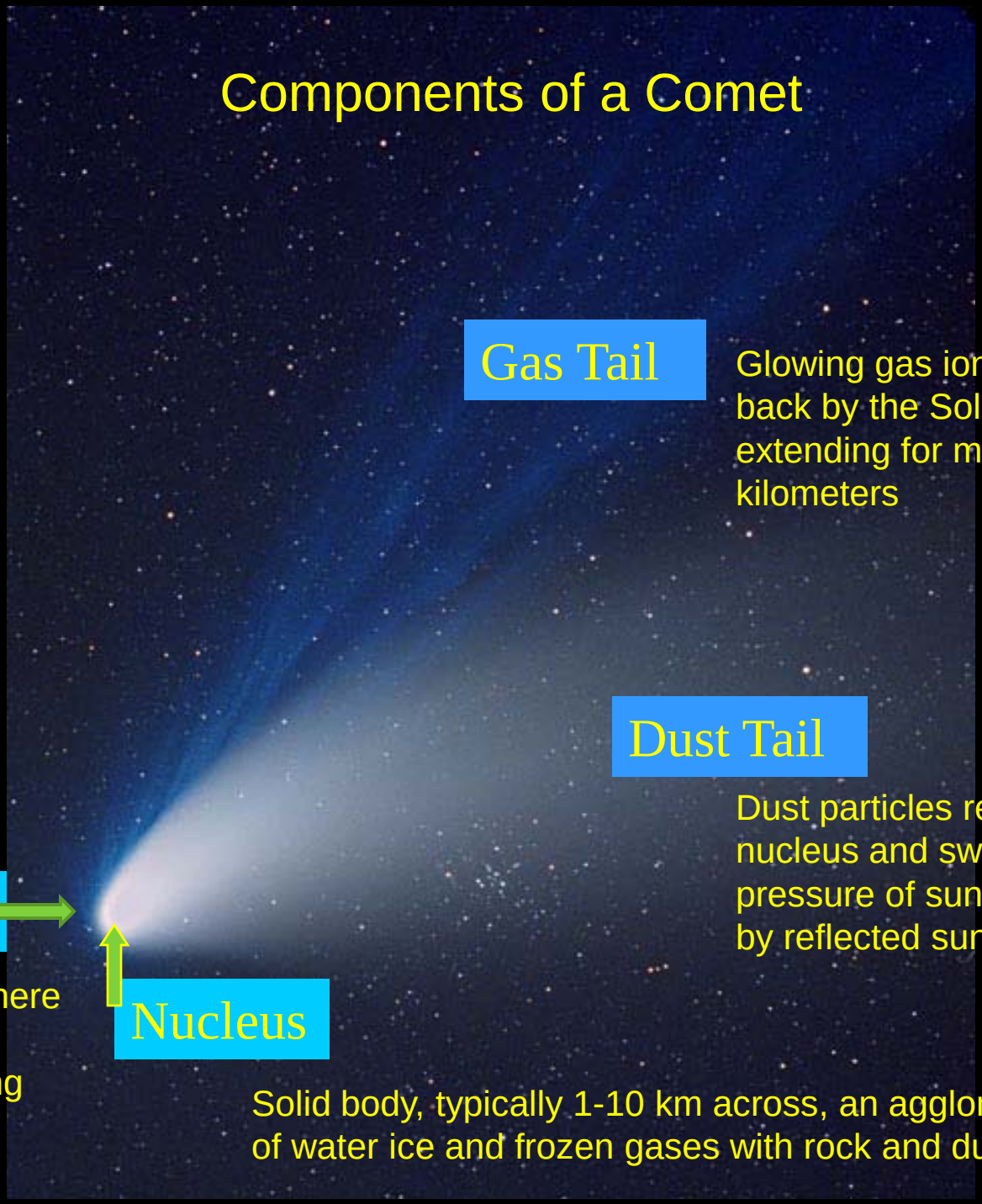
MOTUUM COMETARUM IN ORBE PARABOLICO ELEMENTA ASTRONOMICA.

Cometæ Anni.	Nodus Ascend.	Inclin. Orbitæ.	Perihelion.	Distantia Perihelia à Sole.	Logarithmus Distantiæ Perihelia à Sole.	Logarithmus Medii Motus Diurni.	Temp. Æquat. Perihel.	Perihel. à Nodo.	
	° ′ ″	° ′ ″	° ′ ″				D. H. ′	° ′ ″	
1337	♊ 24 21 0	32 11 0	♉ 7 59 0	40666	9 609236	0 546274	Junii 2 6 25	46 22 0	Retrog.
1472	♍ 11 46 20	5 20 0	♉ 15 33 30	54273	9 734584	0 358252	Feb. 28 22 23	123 47 10	Retrog
1531	♉ 19 25 0	17 56 0	♒ 1 39 0	56700	9 753583	0 329754	Aug. 24 21 18	107 46 0	Retrog.
1532	♊ 20 27 0	32 36 0	♋ 21 7 0	50910	9 706803	0 399924	Oct. 19 22 12	30 40 0	Direct.
1556	♏ 25 42 0	32 6 30	♍ 8 50 0	46390	9 666424	0 460492	Apr. 21 20 3	103 8 0	Direct.
1577	♈ 25 52 0	74 32 45	♌ 9 22 0	18342	9 263447	1 064958	Oct. 26 18 45	103 30 0	Retrog.
1580	♈ 18 57 20	64 40 0	♋ 19 5 50	59628	9 775450	0 296953	Nov. 28 15 0	90 8 30	Direct.
1585	♉ 7 42 30	6 4 0	♈ 8 51 0	109358	0 038850	9 901853	Sept. 27 19 20	28 51 30	Direct.
1590	♏ 15 30 40	29 40 40	♏ 6 54 30	57661	9 760882	0 318805	Jan. 29 3 45	51 23 50	Retrog.
1596	♒ 12 12 30	55 12 0	♏ 18 16 0	51293	9 710058	0 395041	Julii 31 19 55	83 56 30	Retrog.
1607	♉ 20 21 0	17 2 0	♒ 2 16 0	58680	9 768490	0 307393	Oct. 16 3 50	108 5 0	Retrog.
1618	♊ 16 1 0	37 34 0	♈ 2 14 0	37975	9 579498	0 590881	Oct. 29 12 23	73 47 0	Direct.
1652	♊ 28 10 0	79 28 0	♈ 28 18 40	84750	9 928140	0 067918	Nov. 2 15 40	59 51 20	Direct.
1661	♊ 22 30 30	32 35 50	♋ 25 58 40	44851	9 651772	0 482470	Jan. 16 23 41	33 28 10	Direct.
1664	♊ 21 14 0	21 18 30	♌ 10 41 25	102575½	0 011044	9 943562	Nov. 24 11 52	49 27 25	Retrog.
1665	♏ 18 2 0	76 5 0	♊ 11 54 30	10649	9 027309	1 419164	Apr. 14 5 15	156 7 30	Retrog.
1672	♍ 27 30 30	83 22 10	♉ 16 59 30	69739	9 843476	0 194914	Feb. 20 8 37	109 29 0	Direct.
1677	♏ 26 49 10	79 3 15	♌ 17 37 5	28059	9 448072	0 788020	Apr. 26 0 37	99 12 5	Retrog.
1680	♍ 2 2 0	60 56 0	♐ 22 39 30	00612½	7 787106	3 279469	Dec. 8 0 6	9 22 30	Direct.
1682	♉ 21 16 30	17 56 0	♒ 2 52 45	58328	9 765877	0 311313	Sept. 4 7 39	108 23 45	Retrog.
1683	♏ 23 23 0	83 11 0	♊ 25 29 30	56020	9 748343	0 337614	Julii 3 2 50	87 53 30	Retrog.
1684	♐ 28 15 0	65 48 40	♏ 28 52 0	96015	9 982339	9 986620	Maii 29 10 16	29 23 0	Direct.
1686	♓ 20 34 40	31 21 40	♊ 17 0 30	32500	9 511883	0 692304	Sept. 6 14 33	86 25 50	Direct.
1698	♐ 27 44 15	11 46 0	♍ 0 51 15	69129	9 839660	0 200638	Oct. 8 16 57	3 7 0	Retrog.

Halley's Comet

- Returns every 76 years and can come close to Earth
  - Last appearance: 1986
  - Next appearance: 2061
- Has been observed throughout recorded history
  - Anglo-Saxons (1066)
  - Babylonians (164 BC)
  - Chinese (240 BC)
- Nucleus size: 15 km

Components of a Comet



Gas Tail

Glowing gas ions swept back by the Solar Wind, extending for millions of kilometers

Dust Tail

Dust particles released from the nucleus and swept back by the pressure of sunlight, and shining by reflected sunlight

Coma

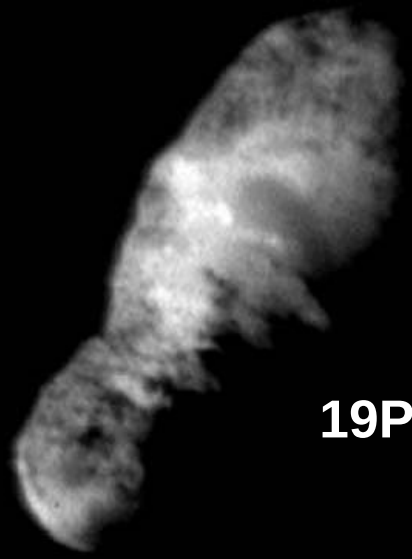
Tenuous atmosphere of gas, dust and debris surrounding nucleus

Nucleus

Solid body, typically 1-10 km across, an agglomeration of water ice and frozen gases with rock and dust

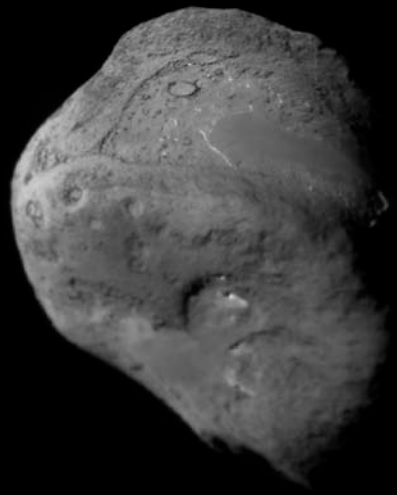
Closeups of Some Cometary Nuclei

1P/Halley



19P/Borrelly

81P/Wild 2



9P/Tempel 1

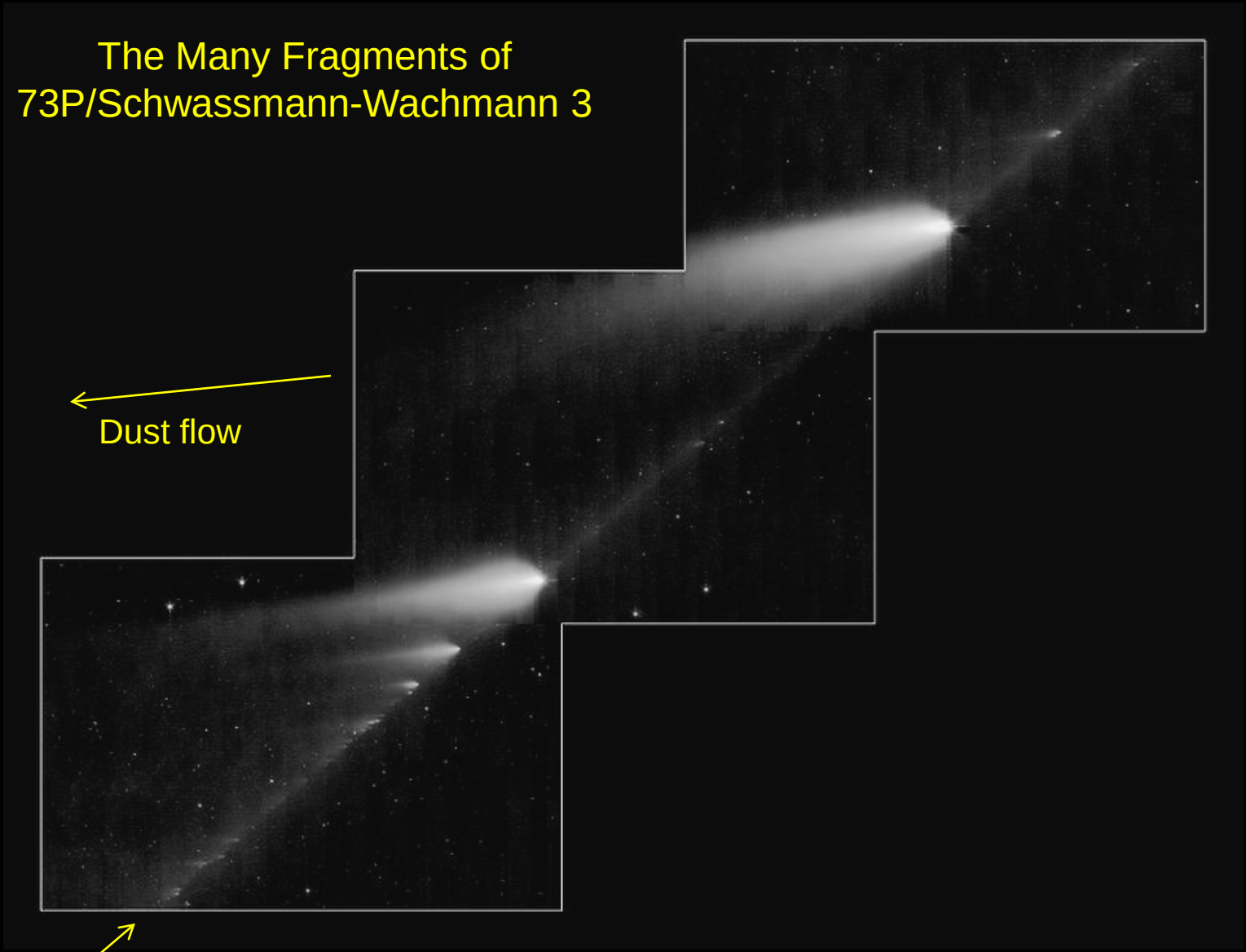
Comets: Composition and Physical Model

- Coma and Tail:
  - Principally water vapor, but also carbon monoxide, carbon dioxide, cyanogen, etc.; dust consists of CHON particles

- Nucleus:
  - Size is usually in the 1 – 10 km range (but Hale-Bopp was 40 km!)
  - "Dirty snowball": fluffy and fragile
  - Loose conglomerate of ices (eg. H_2O ice, CO_2 ice) and silicates with a dark dusty crust that insulates the interior
  - As the nucleus approaches the inner solar system, surface layers become warm enough to trigger sublimation
  - The gases escape through weak spots in the crust, producing high-speed jets of gas and dust

103P/Hartley 2 (2 km long)

Some Comets Are Very Fragile and Split Easily



Comets: Orbit Characteristics and Classes

Long-Period Comets
- Orbital Period (P) > 200 yr
- Random inclinations
- Source: Oort Cloud

C/Hale-Bopp
(P = 2500 yr)

Halley-Type Comets
- Orbital Period 20 - 200 yr
- Random inclinations
- Source: Oort Cloud

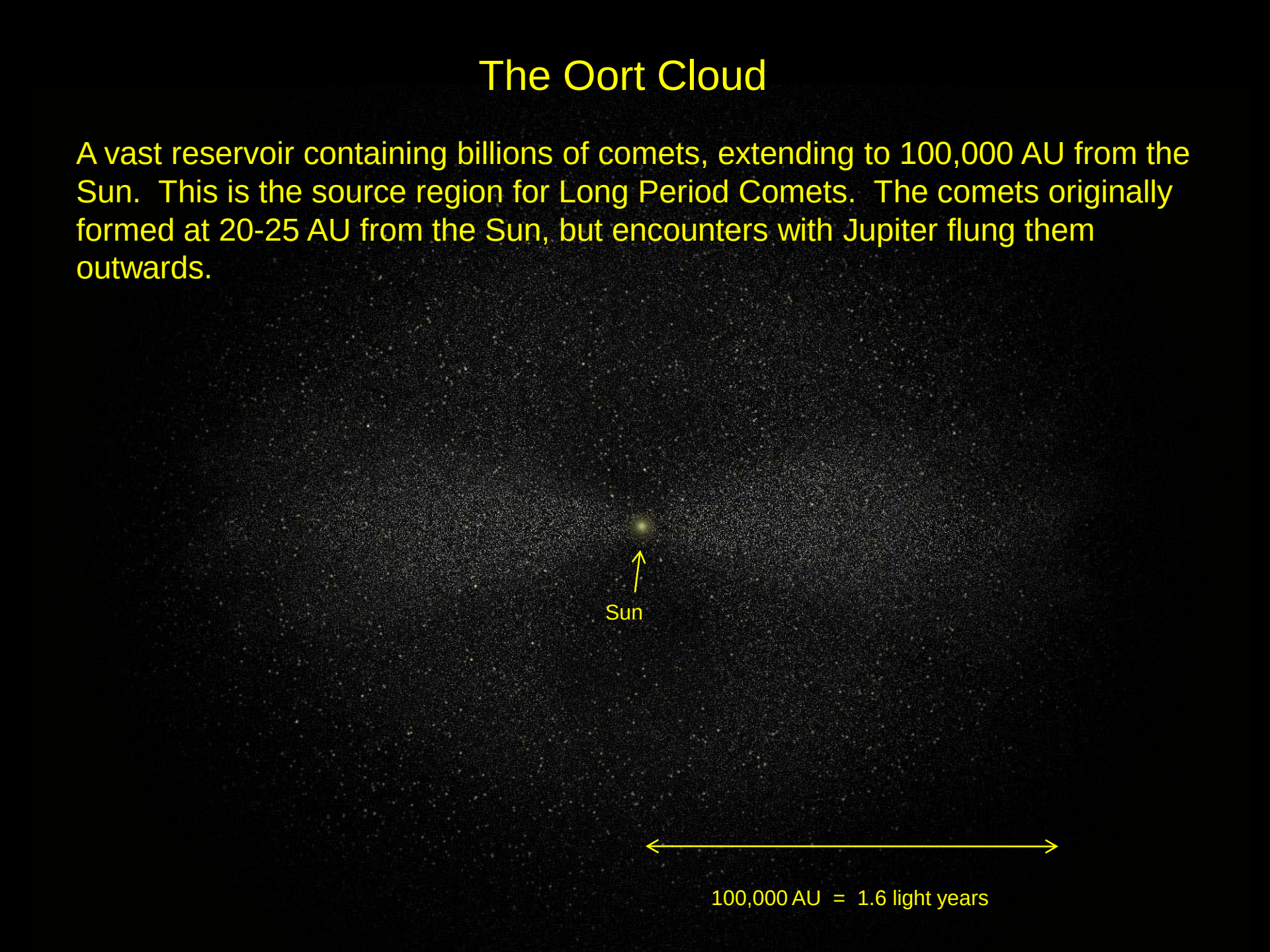
55P/Tempel-Tuttle
(P = 33 yr)

Jupiter-Family Comets (JFCs)
- Orbital period < 20 yr
- Within 30º of the ecliptic
- Source: Scattered Disc?
- Subtype: Encke-Type Comets
  (Orbital period < 12 yr)

8P/Tuttle (P = 14 yr)

The Oort Cloud

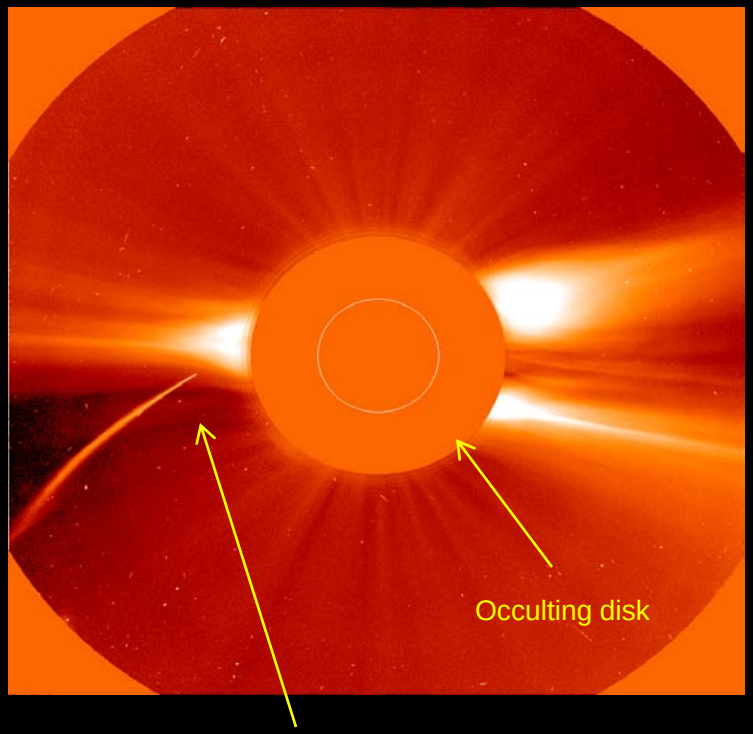
A vast reservoir containing billions of comets, extending to 100,000 AU from the Sun. This is the source region for Long Period Comets. The comets originally formed at 20-25 AU from the Sun, but encounters with Jupiter flung them outwards.



How Comets Die

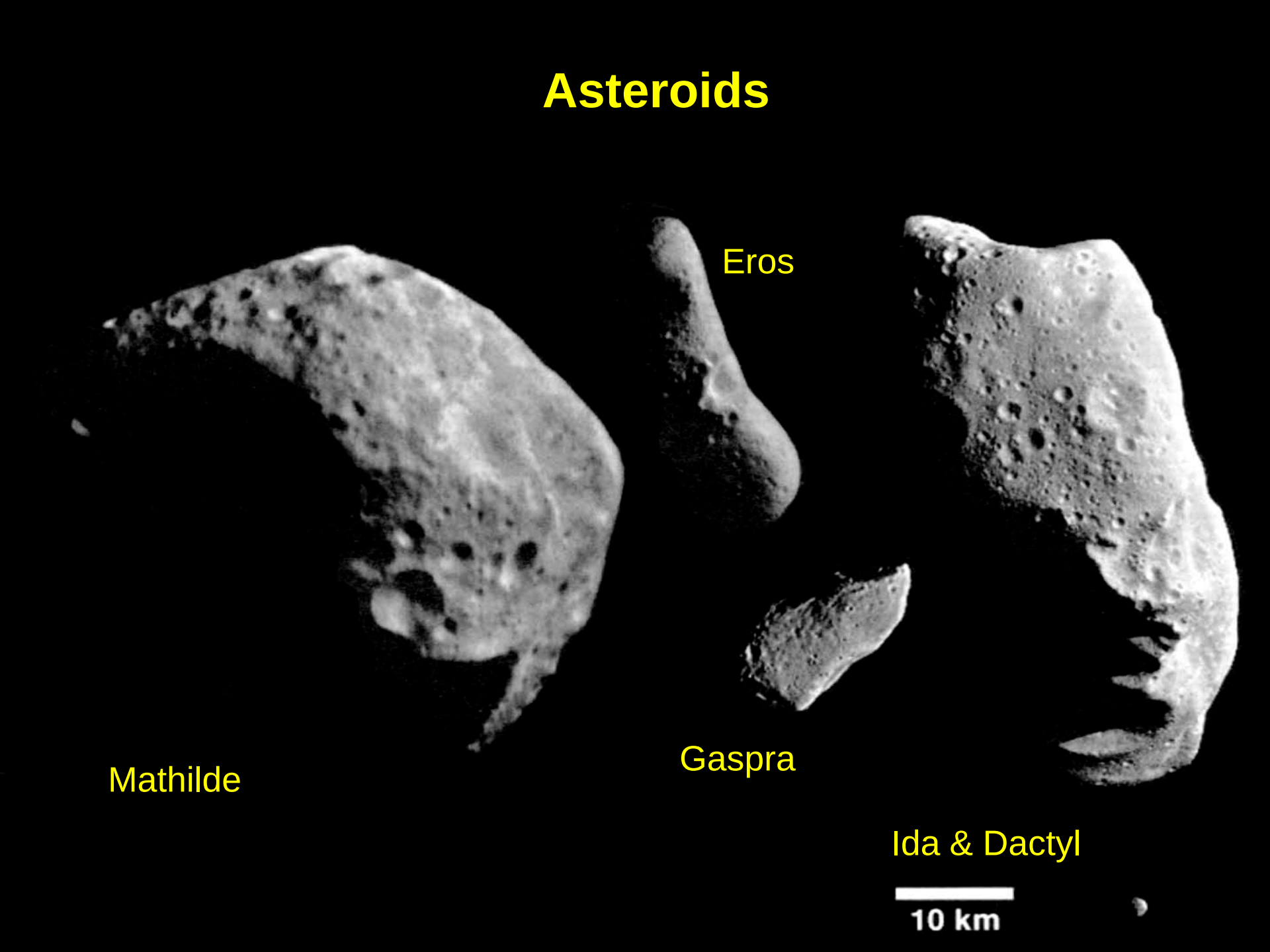
- Split into smaller comets or disintegrate entirely
- Lose all their ices, becoming asteroid-like objects (but in cometary orbits)
- Collide with the Sun or planets (eg. sungrazers or Shoemaker-Levy 9)
- Get thrown out of the Solar System (usually by Jupiter)

Comet SW-3 as seen by Hubble



Sungrazing comet as seen by SOHO

Asteroids

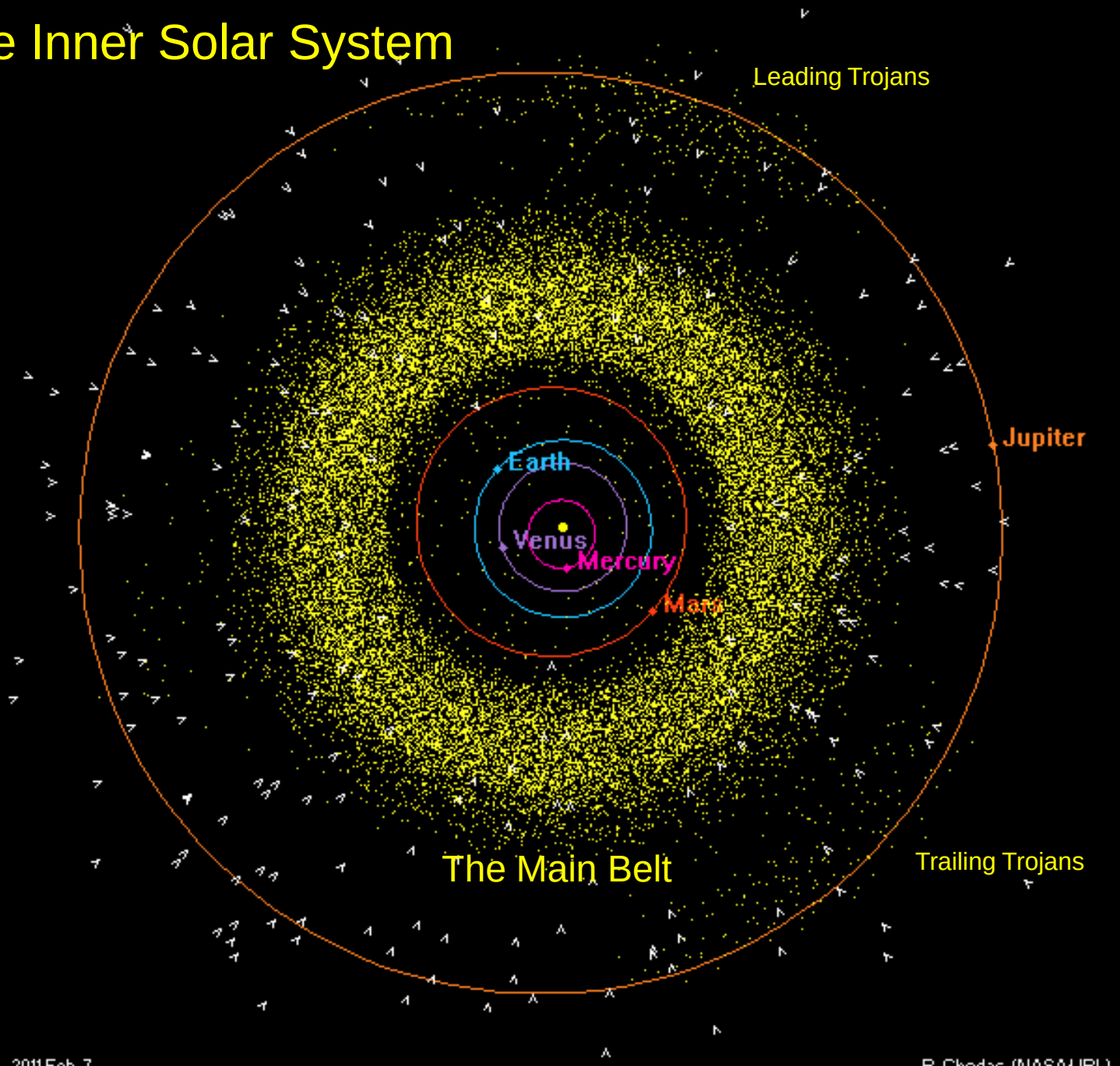


Asteroids: Designations, Numbers and Names

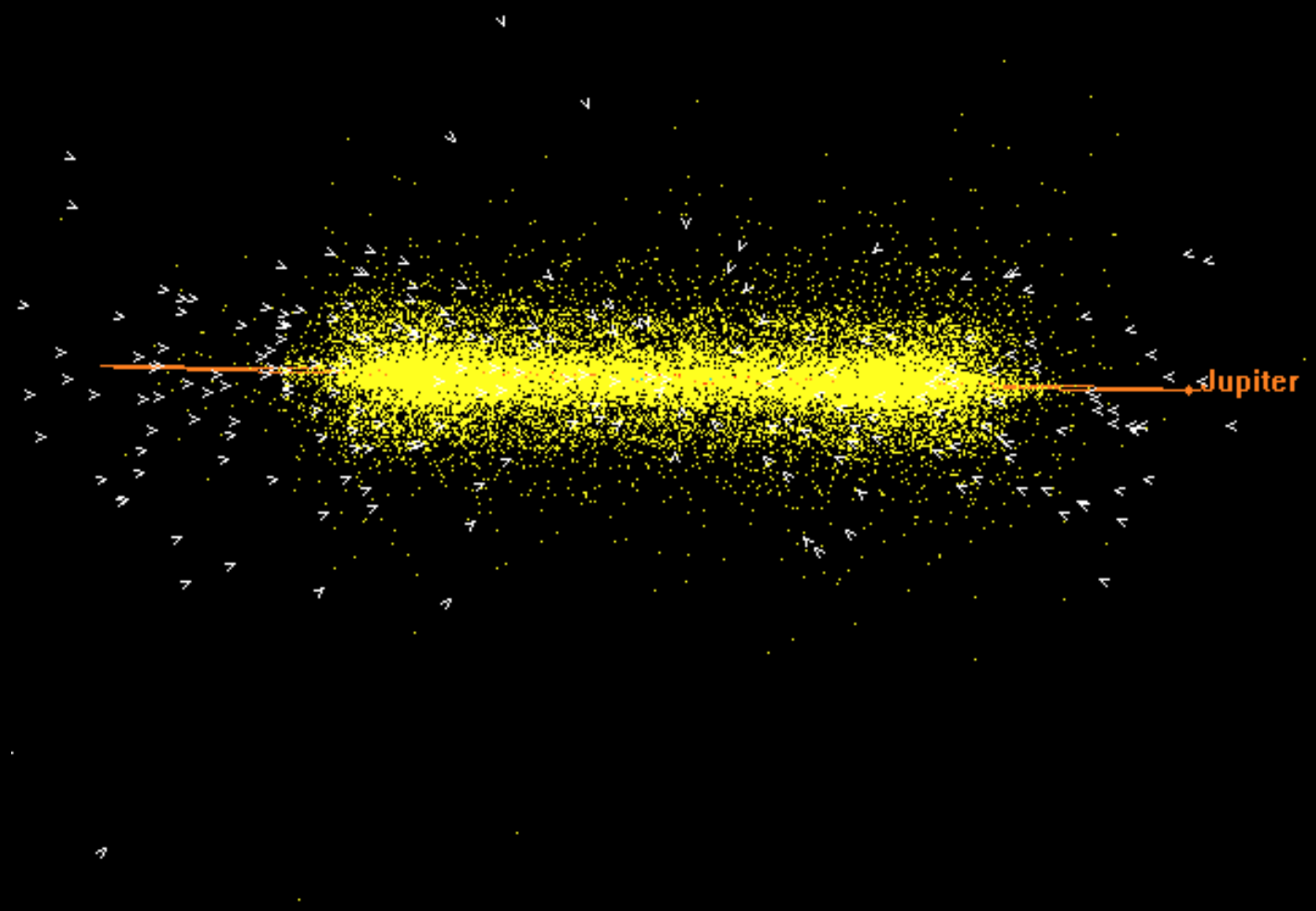
- When first discovered and confirmed, an asteroid receives a *designation* of the form "2011 XYnn"
  - Yyyy is the discovery year
  - X indicates the half-month (A: Jan. 1-14, B: Jan. 15-31, etc.)
  - Ynn is a letter plus sequence number
  - Eg. Near-Earth Object 2011 BJ24 discovered last weekend
- Orbit is computed from observations, initially *very uncertain*!
- Once an asteroid has been observed long enough to have a well-established orbit, it is *numbered* (eg. 1 Ceres, 243 Ida, etc.)
  - Currently 264,258 numbered asteroids (and 279,454 unnumbered asteroids, for a total of 543,712)
- Once an asteroid is numbered, its discoverer can propose a *name* to the IAU Small Bodies Naming Committee
  - Currently 16,216 named asteroids (only 6%)

Discovery & Designation → Observations… → Numbering → Naming

The Inner Solar System



The Inner Solar System, Side View

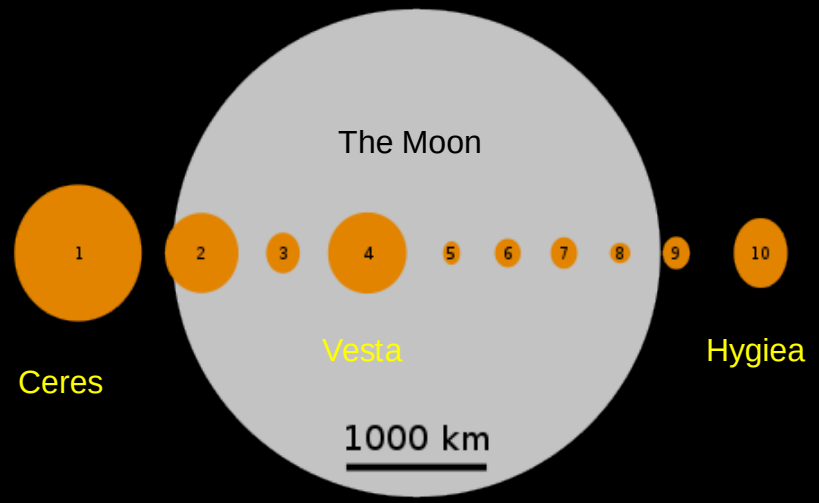


2011 Feb 7

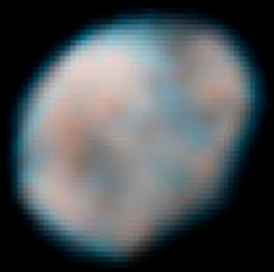
P. Chodas (NASA/JPL)

Large Asteroids: Surviving Protoplanets?

Asteroids 1-10



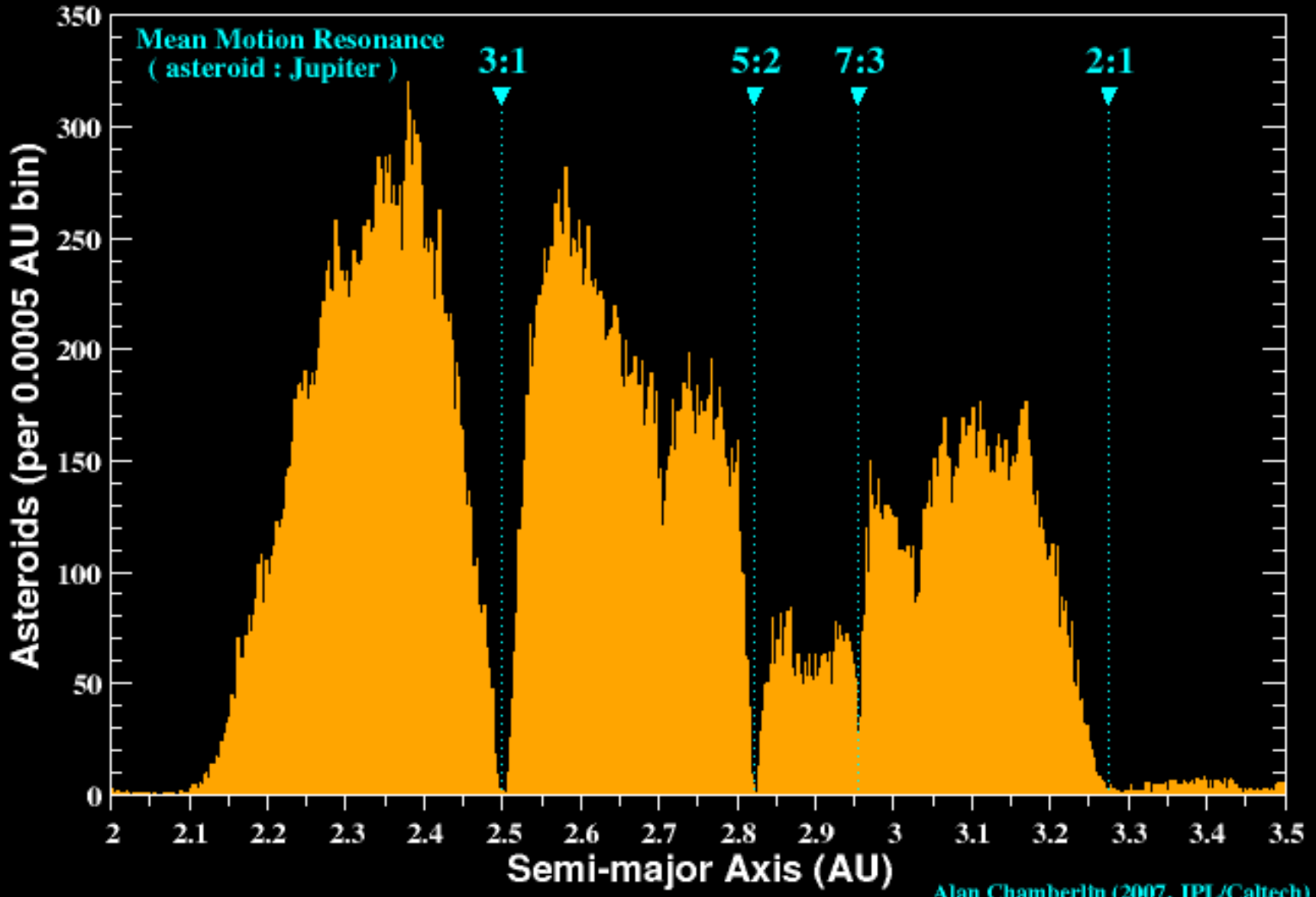
Dwarf Planet Ceres



Candidate Dwarf Planet Vesta

Asteroid Main-Belt Distribution

Kirkwood Gaps



Alan Chamberlin (2007, JPL/Caltech)

Asteroids: Spectral Classes and Compositions

- Asteroids can be classified according to features of their reflectance spectra:
  - C-type Dark, carbonaceous objects; dominant in central Main Belt
  - S-type Moderately bright; silicates (eg. olivine) mixed with metals (nickel-iron); reddish, possibly due to “space-weathering”; dominant in inner Main Belt
  - M-type Moderately bright; often nickel-iron, but not necessarily
  - D-type Dark, water-ice components with organic compounds; dominant at the outer edge of the Main Belt
  - V-type Similar spectrum to Vesta (basaltic lava flows?); asteroids of this type are probably fragments of Vesta
- A long-standing problem is to link these spectral classes with the types of meteorites

Which types from which types?

Many Small Asteroids are Rubble Piles

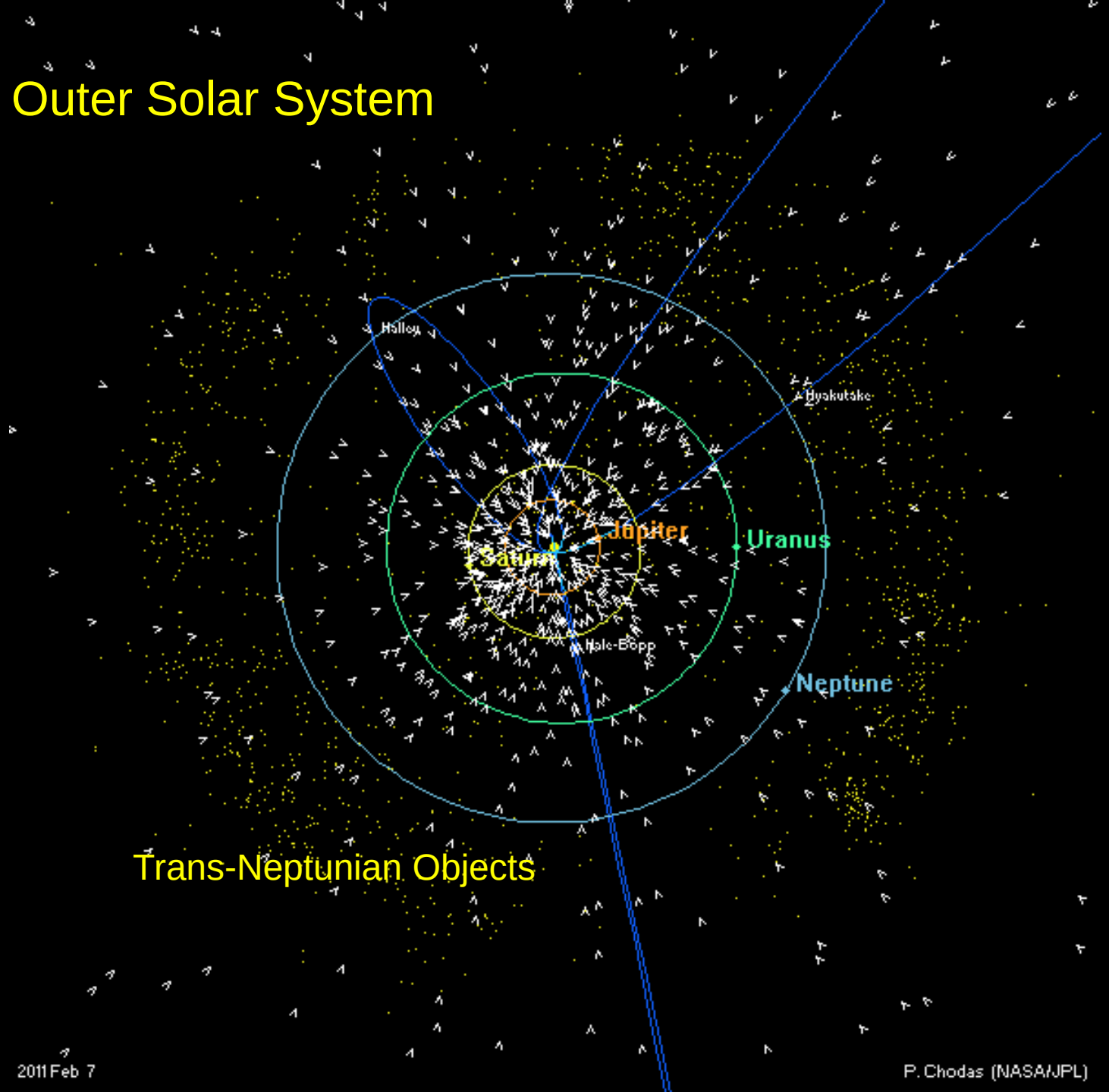
Near-Earth Asteroid 25143 Itokawa (about 500 m long)

Asteroid Satellites

- About 200 asteroids are known to have satellites
- The satellites are thought to have been lifted off their primary bodies through some sort of disruption (eg. collision, tidal disruption, or spinup of the primary)

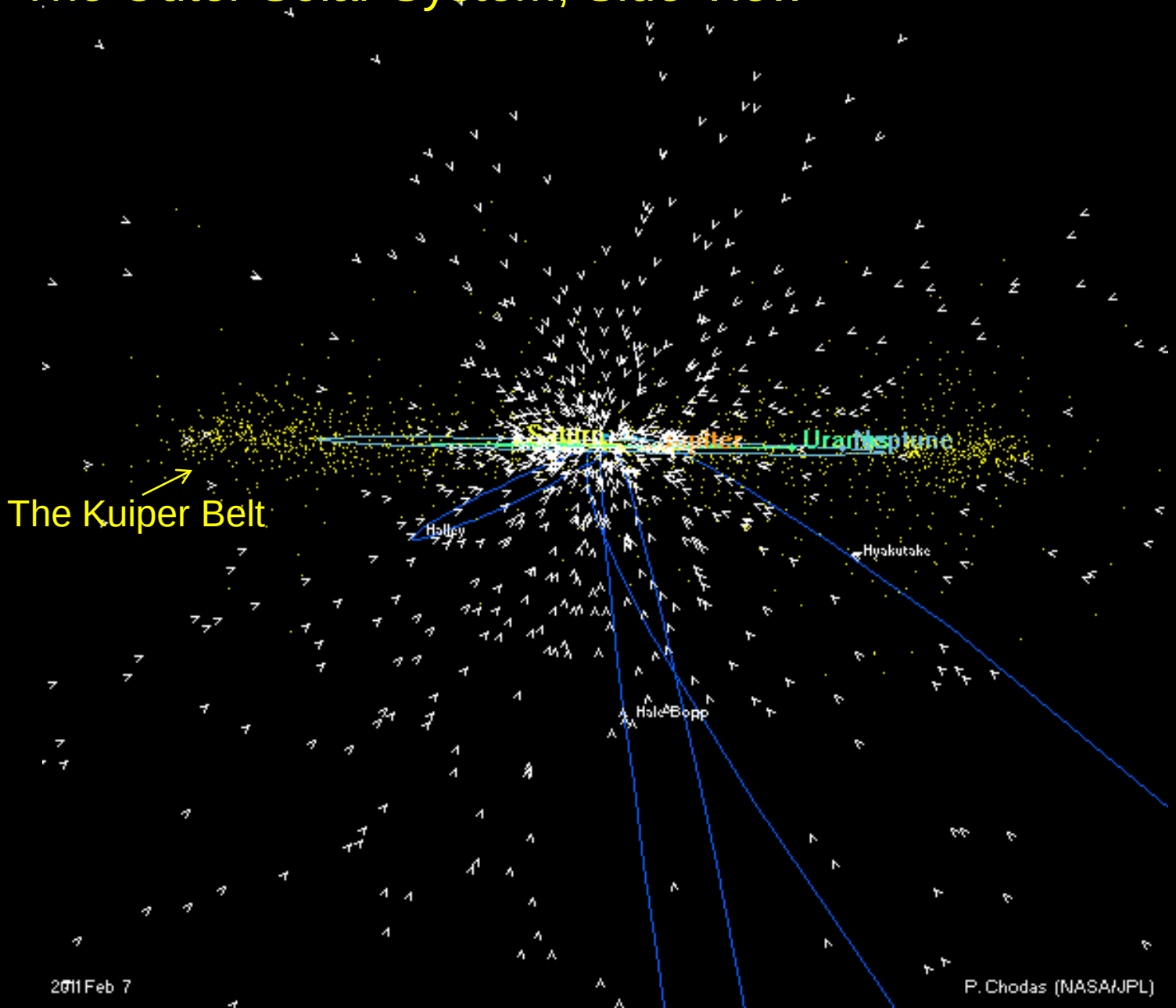
243 Ida (54 km) Dactyl (1 km)

The Outer Solar System



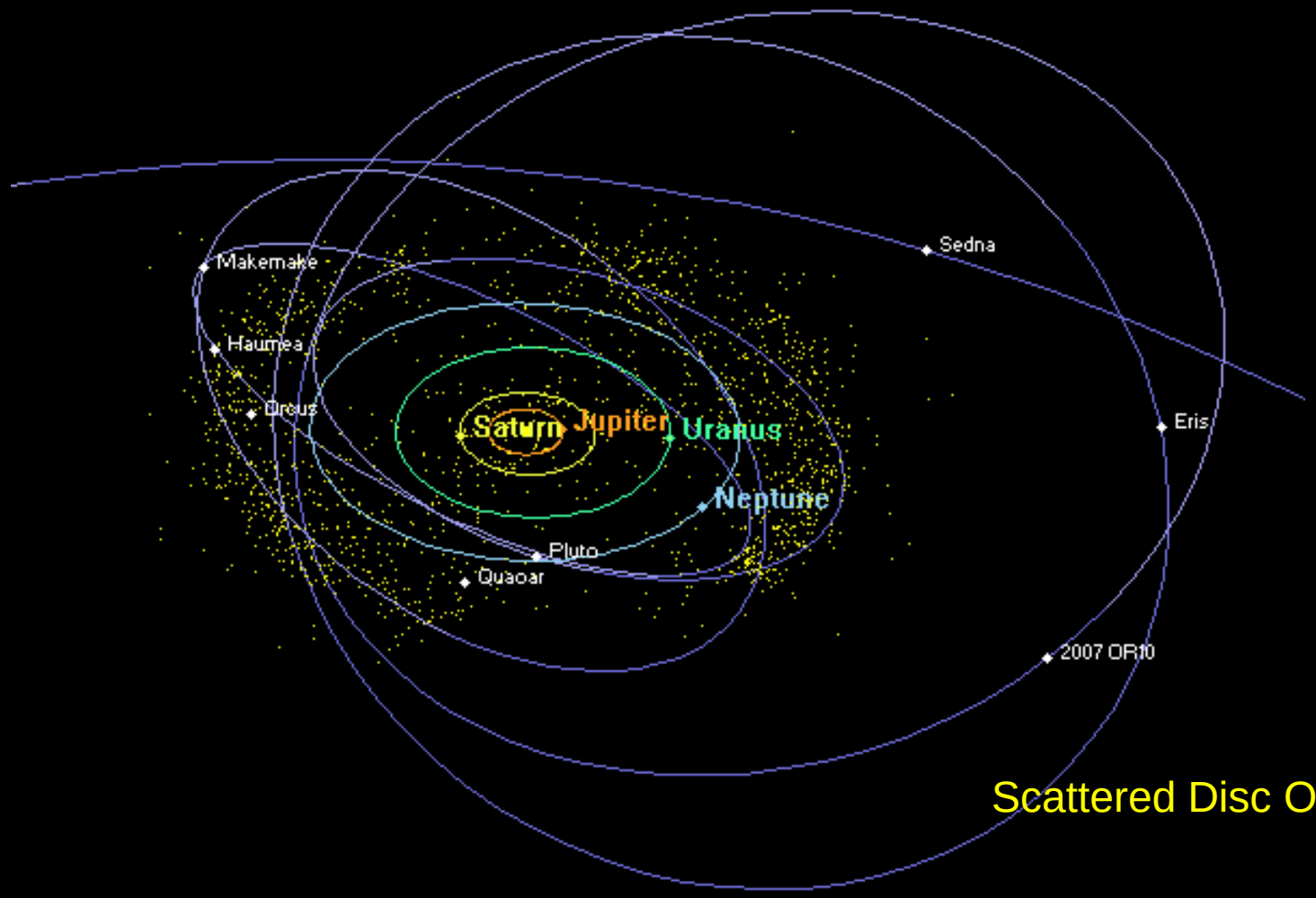
Trans-Neptunian Objects

The Outer Solar System, Side View



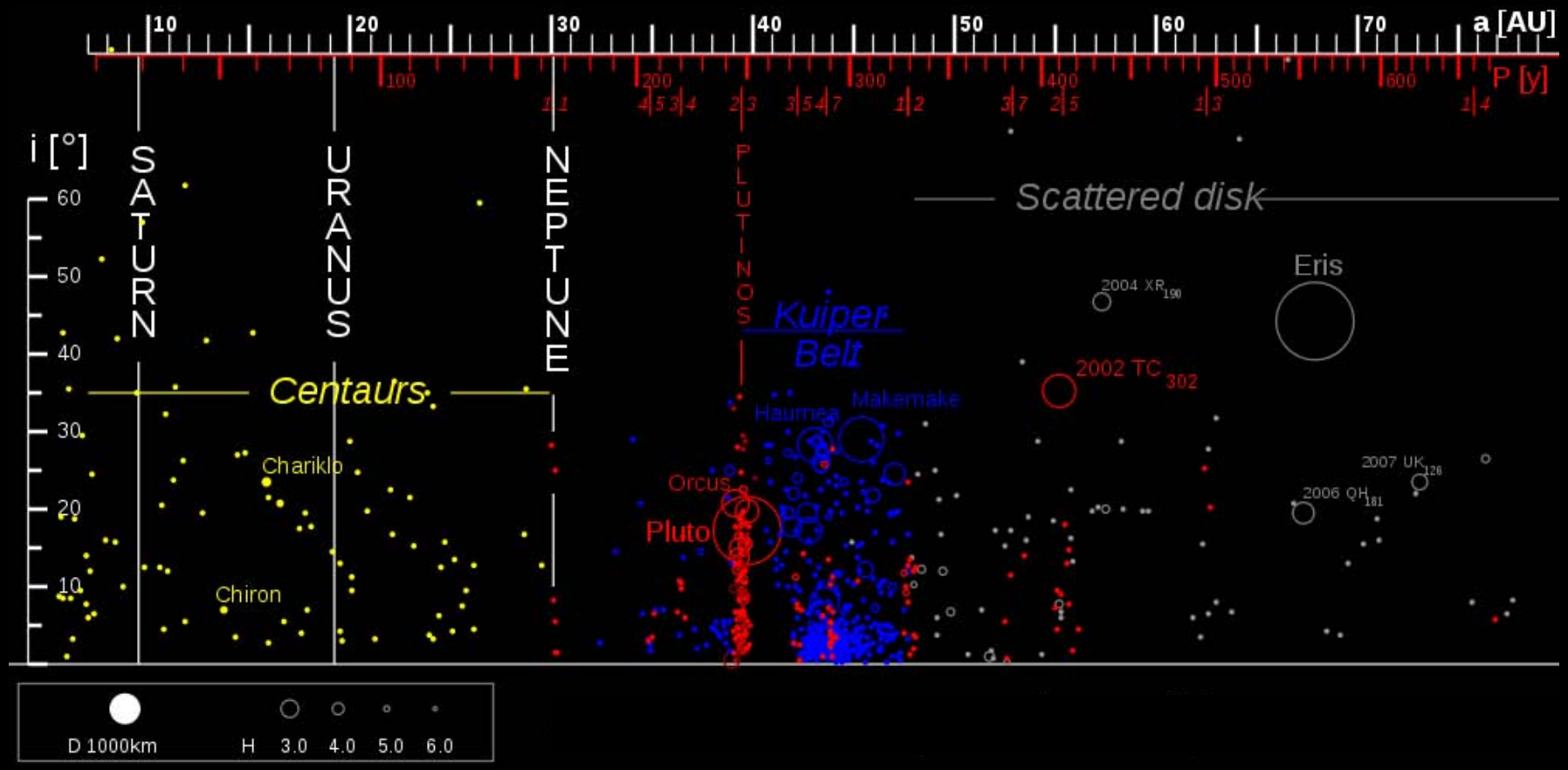
The Kuiper Belt

The Distant Solar System



Scattered Disc Objects

Centaurs, Trans-Neptunian Objects and the Kuiper Belt



Large Trans-Neptunian Objects

Dwarf Planets

Candidate Dwarf Planets

- Discovery of Eris led the IAU to re-examine the definition of a planet in terms of:
  - Roundedness: Becoming rounded through its own self gravity
  - Clearing the neighborhood: Becoming the dominant object at its distance

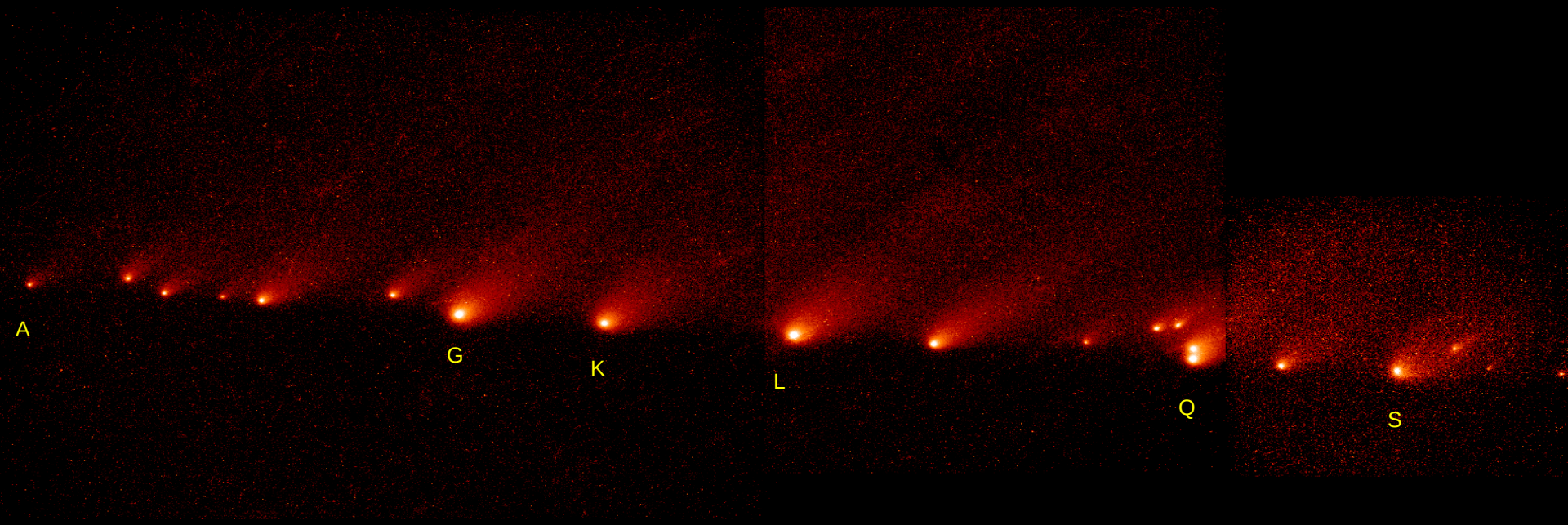
Planet: Massive enough to be rounded *and* clear its orbital neighborhood
Dwarf Planet: Massive enough to be rounded, *but not* to clear its neighborhood
Small Solar System Body: Not massive enough to do either
Minor Planet: Small Solar System Body or Dwarf Planet

A Likely Collision in the Main Belt (2010)

- P/2010 A2, cataloged as a comet, is probably just the result of a collision (a previously unknown120-m asteroid hit by a 5-m object)

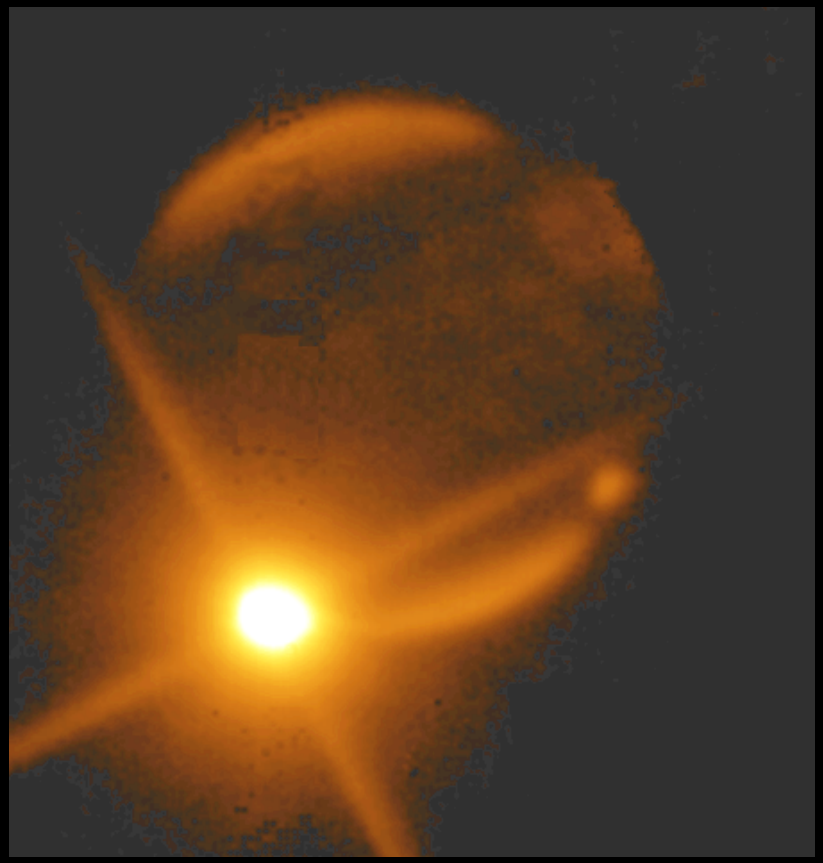
Comet Shoemaker-Levy 9 (SL9) (1993)

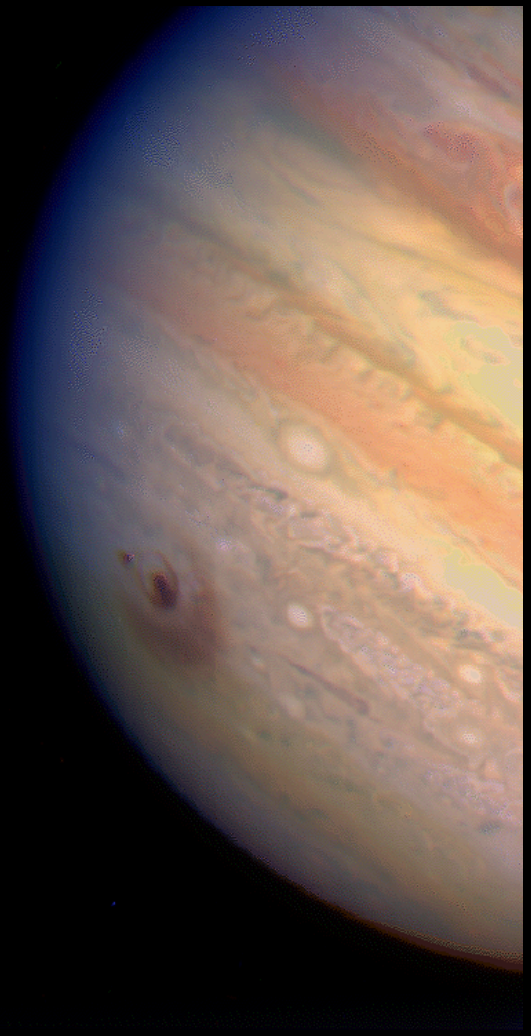
- Discovered in orbit about Jupiter, already broken into 21 fragments
- Orbit calculations indicated it would impact Jupiter 1 year later



Impact of SL9 Fragment G on Jupiter (1994)

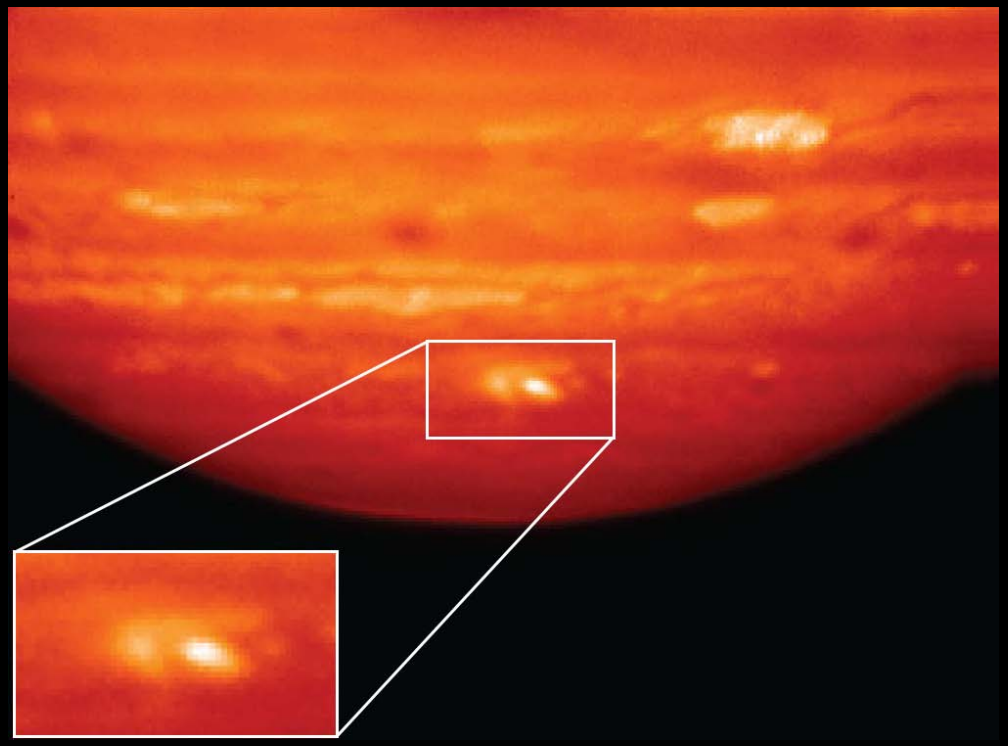
- Fragment G was between 200 and 1000 m in size
- Impact energy: 6 million megatons of TNT





Jupiter Impact in 2009

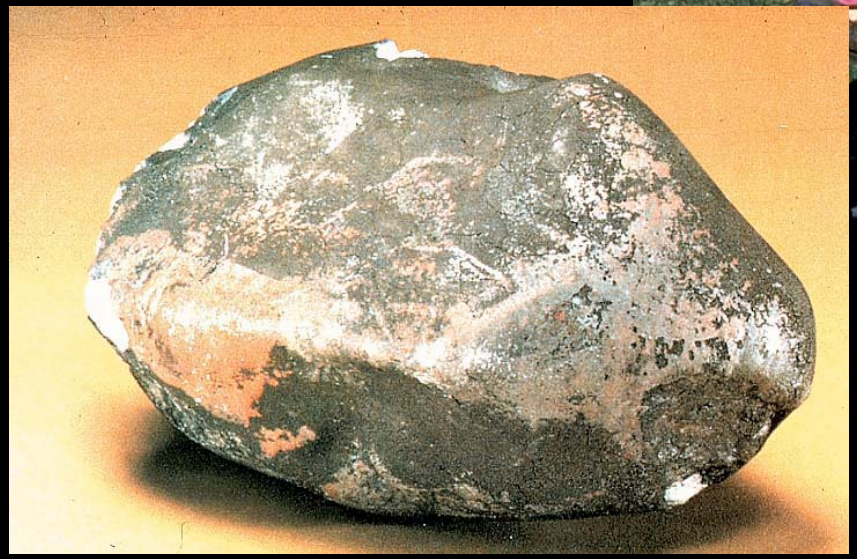
- Impact scar discovered by an amateur
- Object not detected before impact
- Spectroscopic evidence indicates the object was an asteroid



Small Objects Hit the Earth Frequently

- Most meteors are pea-, pebble- and rock-sized debris
- 100 tons of material impacts the Earth every day (mostly dust)

Impact Point of Peekskill Bollide, Oct. 1992



Meteor Crater, Arizona

- A 60m object, 1-km crater
- Impacts like this occur every few thousand years

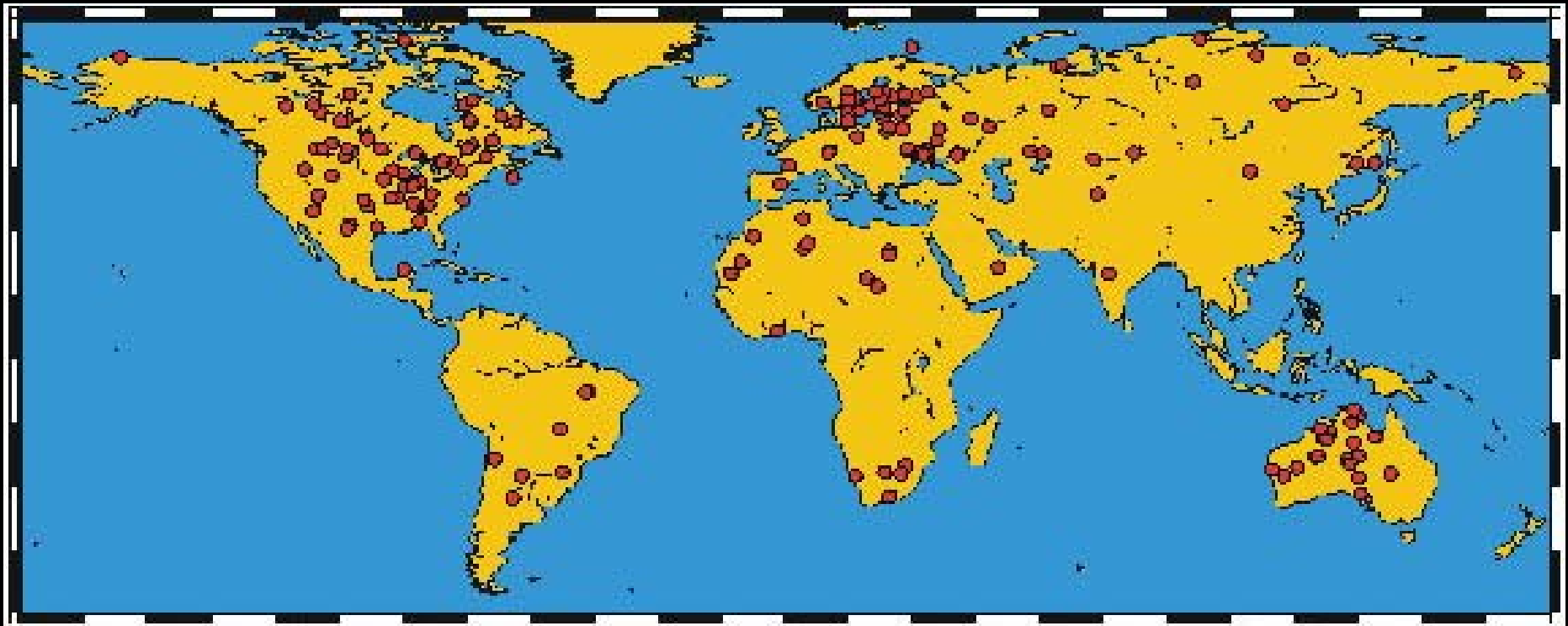
Tunguska, Siberia (1908)

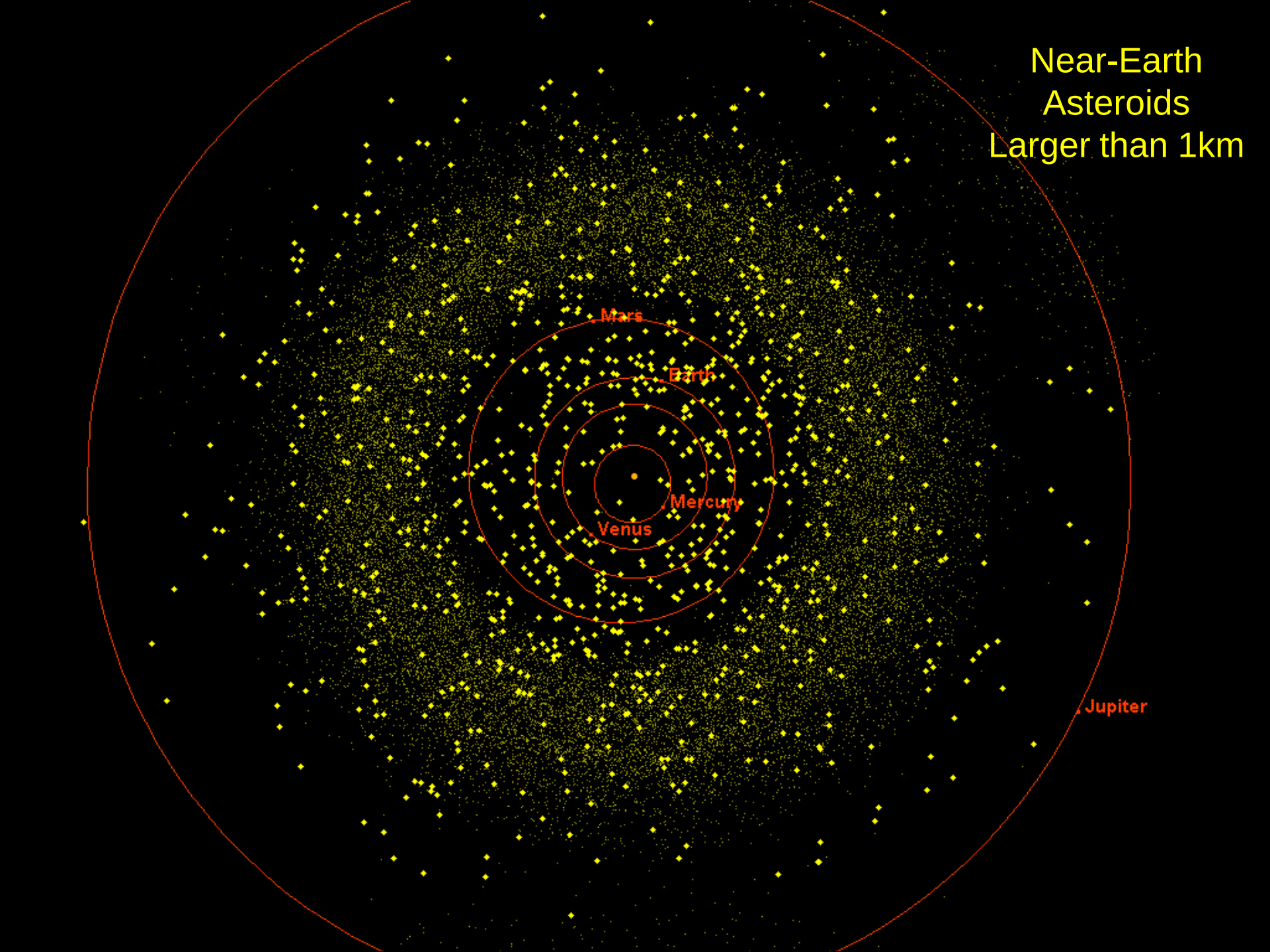
•40m object; impacts of this size every few hundred years

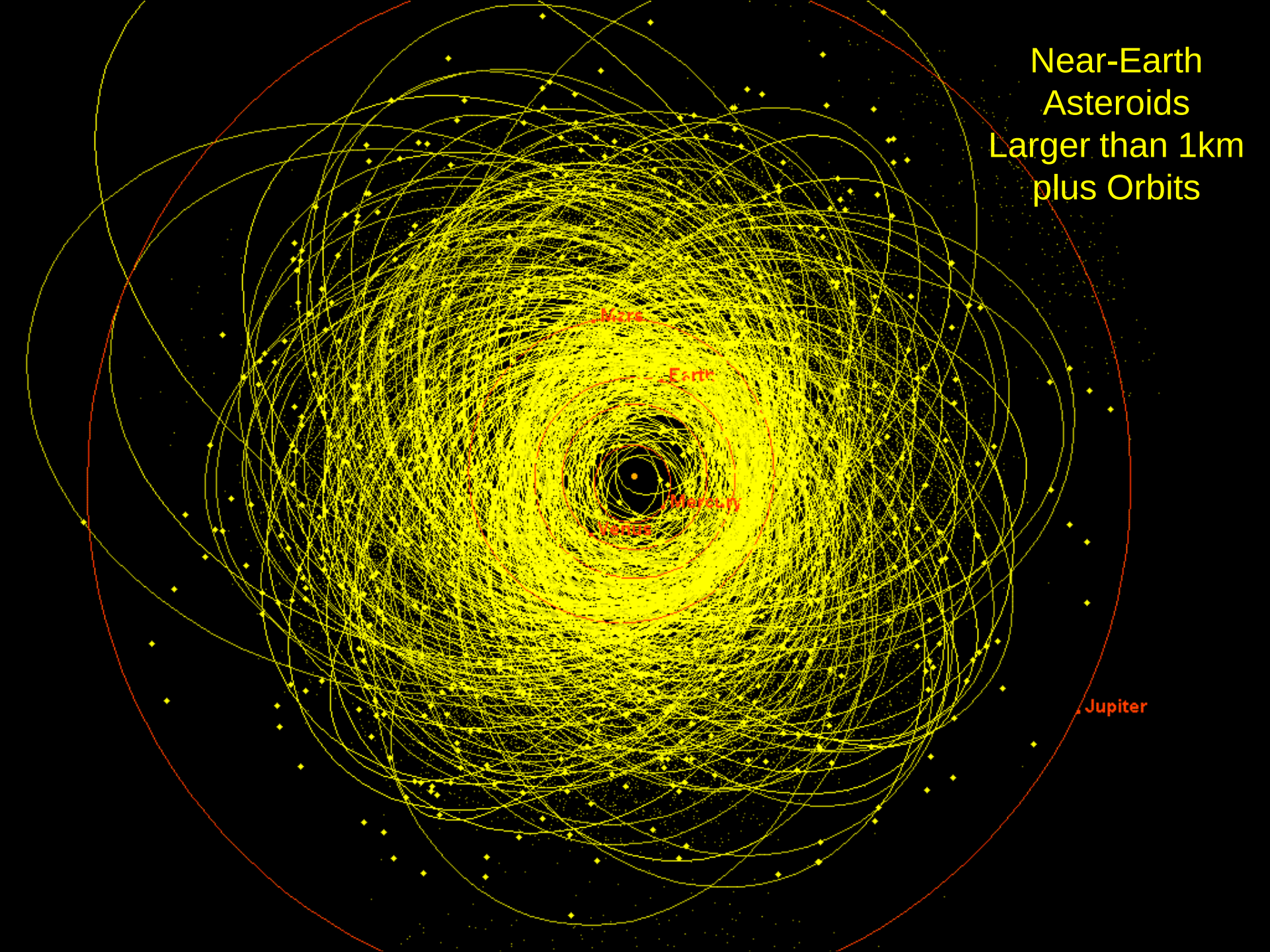
Chixulub, Yucatan, 65 million years ago

•10-km object; impacts of this size every 100 millions years

Known Impact Craters on the Earth




Near-Earth
Asteroids
Larger than 1km
Mars
Earth
Mercury
Venus
Jupiter


Near-Earth
Asteroids
Larger than 1km
plus Orbits
Mars
Earth
Mercury
Venus
Jupiter

Near-Earth Objects (NEOs)

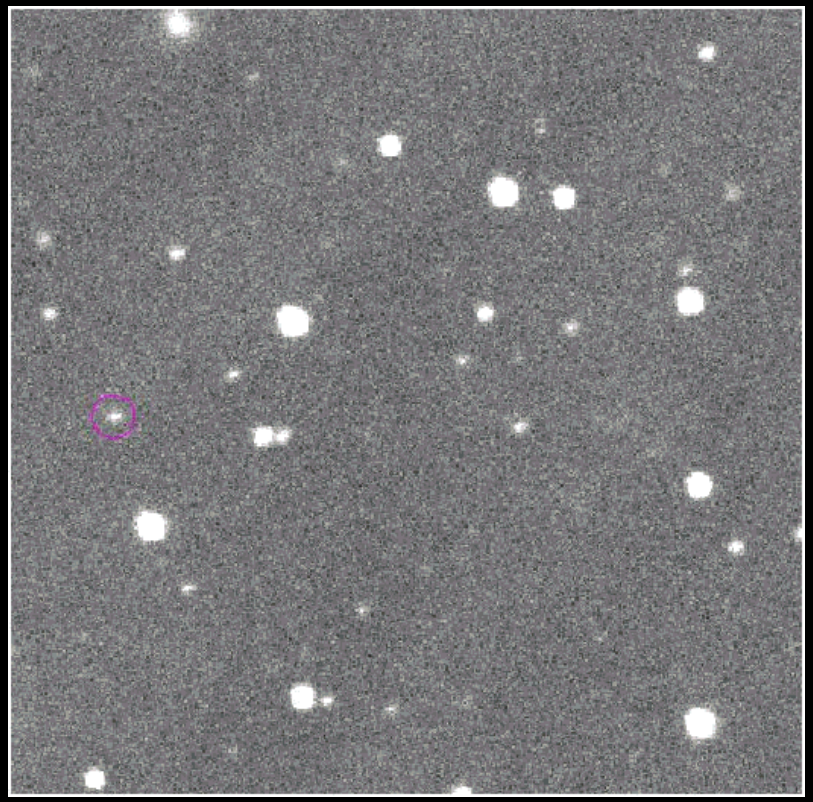
- A Near-Earth Object (NEO) is an asteroid or comet which can get within 1.3 AU of the Sun
- Currently, there are **7745** NEOs, **822** of them are kilometer-sized
- The impact of a kilometer-sized object on the Earth would likely be globally catastrophic (potentially changing the climate)

- NASA's Spaceguard Survey, set up 10 years ago, has the goal of discovering 90% of the kilometer-sized asteroids and assessing the risk of impact
- So far, 80-85% have been discovered; many smaller NEOs have been discovered as well
- NASA's NEO Program assesses impact risk for all known NEOs: <http://neo.jpl.nasa.gov>

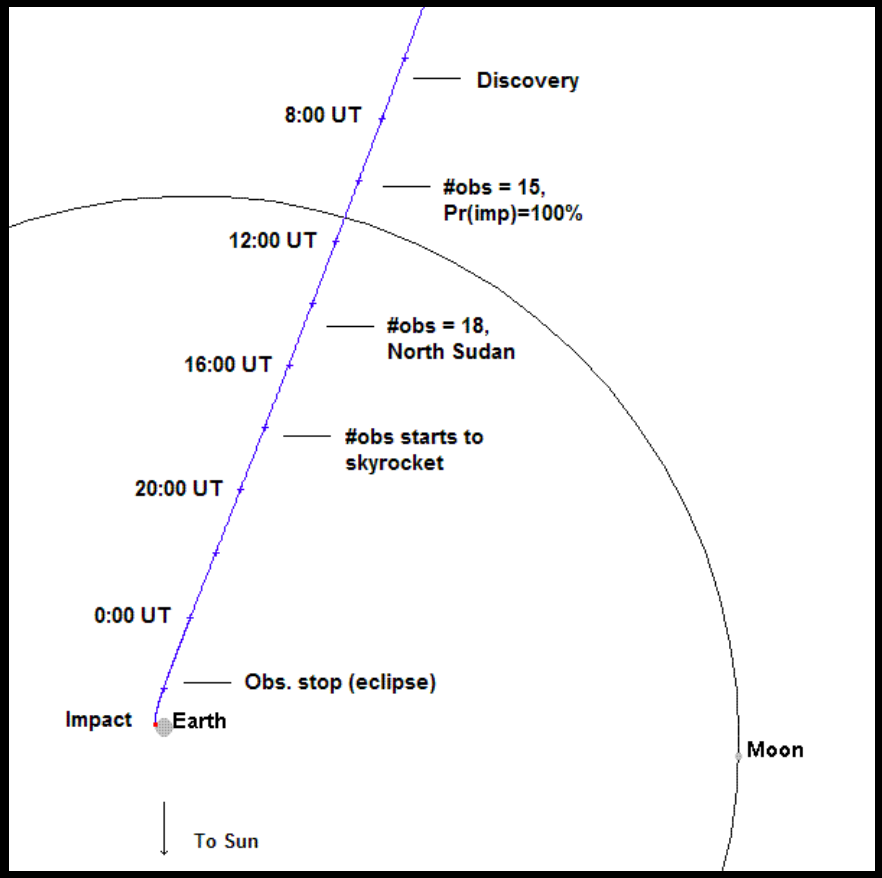
Catalina Sky Survey observatory

2008 TC3: The First Predicted NEO Impact

- Discovered 1 day before impact; clearly a small object (4-5m)
- Predicted to hit in northern Sudan 11 hours before impact



Discovery images from Catalina Sky Survey



Impact Site in Nubian Desert of N. Sudan

•Meteorites found along predicted ground track (red dots)

NASA's Near Earth Object Program

<http://neo.jpl.nasa.gov>

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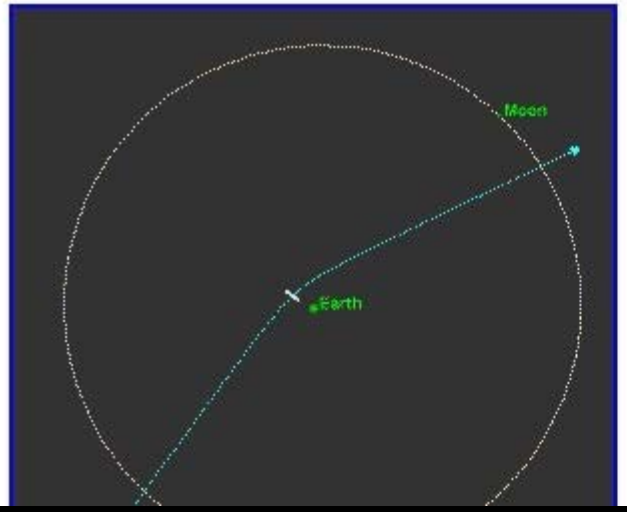
Radar Observations Refine the Future Motion of Asteroid 2004 MN4



Paul Chodas, Steve Chesley, Jon Giorgini, Don Yeomans
NASA's Near Earth Object Program Office
February 3, 2005

Radar observations taken at the Arecibo Observatory in Puerto Rico on January 27, 29, and 30 have significantly improved our estimate for the orbit of asteroid 2004 MN4 and changed the circumstances of the Earth close approach in 2029. On April 13, 2029, the predicted trajectory now passes within 5.7 Earth radii (36,350 km or 22,600 miles) of the Earth's center - just below the altitude of geosynchronous Earth satellites. However, an Earth collision in 2029 is still ruled out. The asteroid's motion subsequent to the 2029 Earth close approach is very sensitive to the circumstances of the close approach itself and a number of future Earth close approaches will be monitored as additional observations are received. However, our current risk analysis for 2004 MN4 indicates that no subsequent Earth encounters in the 21st century are of concern.

FULL STORY