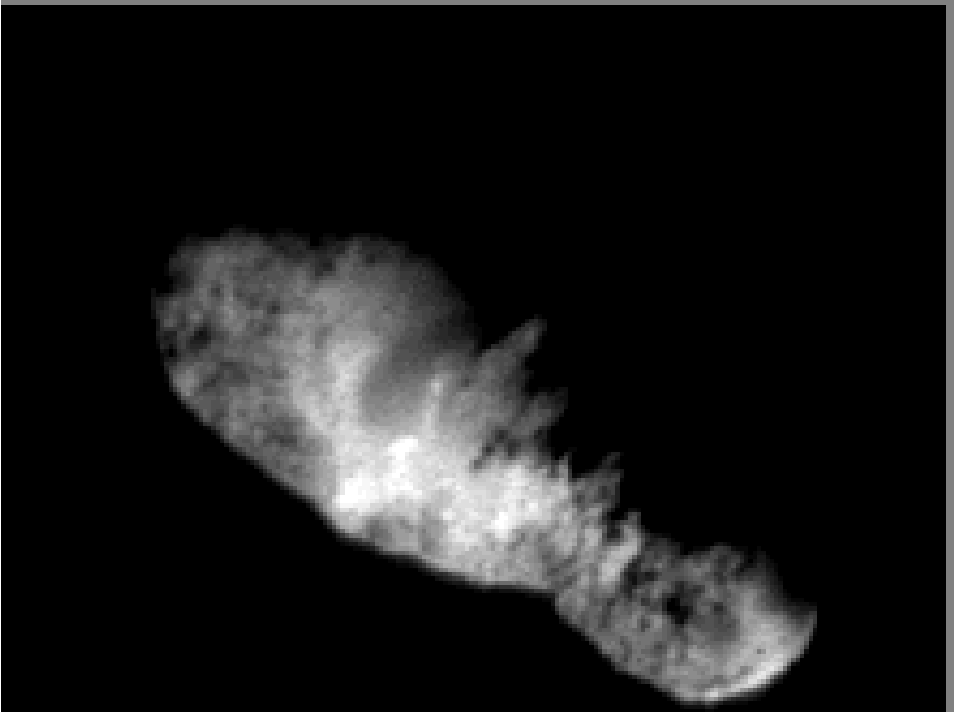
COMETS

SHORT PERIOD: FROM KUIPER BELT
LONG PERIOD: FROM ÖORT CLOUD

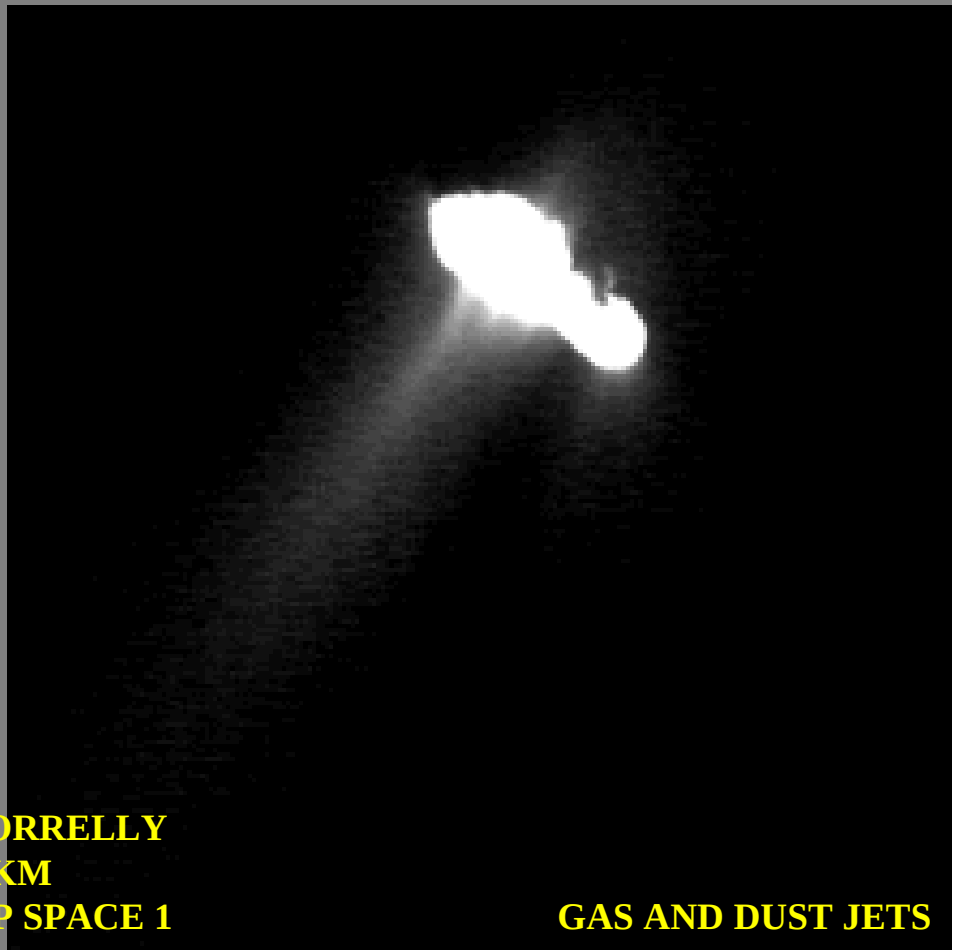
MANY IMPACT THE SUN

MAY BE A TRANSITION IN ORBITAL CHARACTERISTICS AND COMPOSITION BETWEEN A FEW ASTEROIDS AND COMETS



NUCLEUS

COMET BORRELLY
8X4 KM
NASA/DEEP SPACE 1



GAS AND DUST JETS

Comet Hyakutake -HST

CHURYUMOV-GERASIMENKO
PUCKETT PHOTO

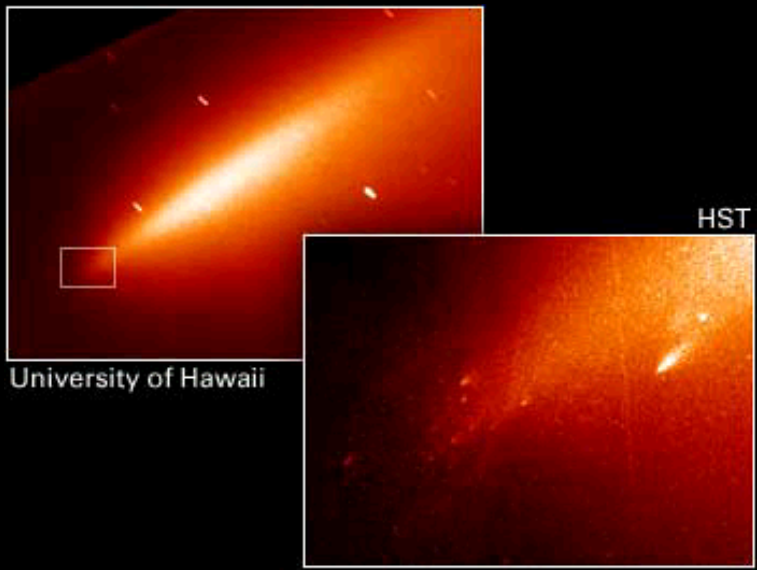
SCHWASSMAN-WACHMANN- 3
PUCKETT PHOTO

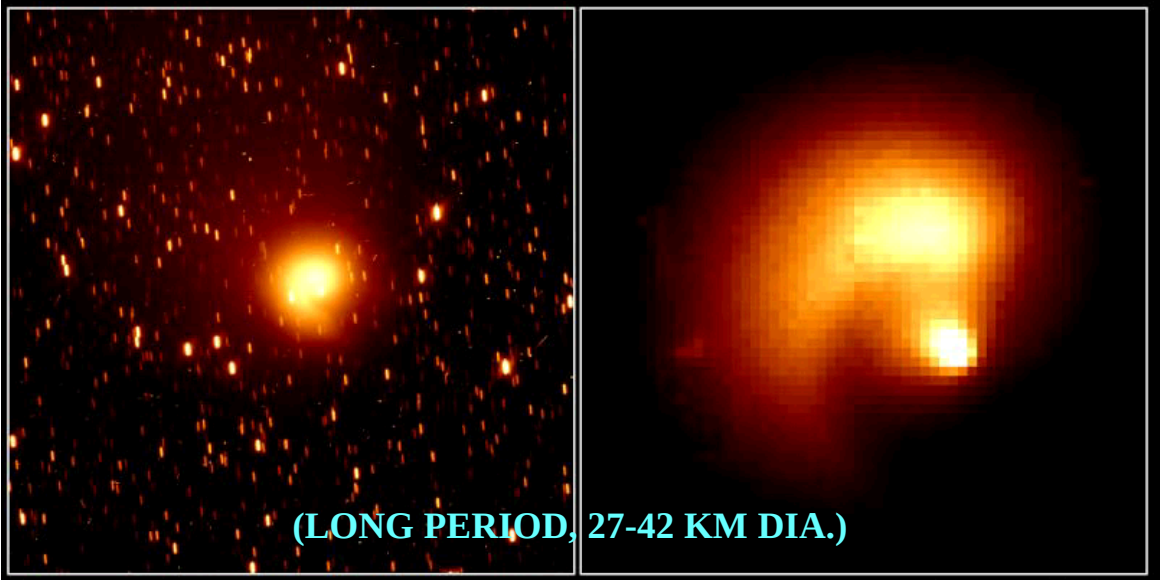
COMETS

COMET LINEAR BREAKUP - HST

NH_3 DATA INDICATES FORMATION BETWEEN SATURN AND URANUS (KAWAKITA,2001, 294, SCIENCE)

COMET LINEAR MISSING PIECES - HST

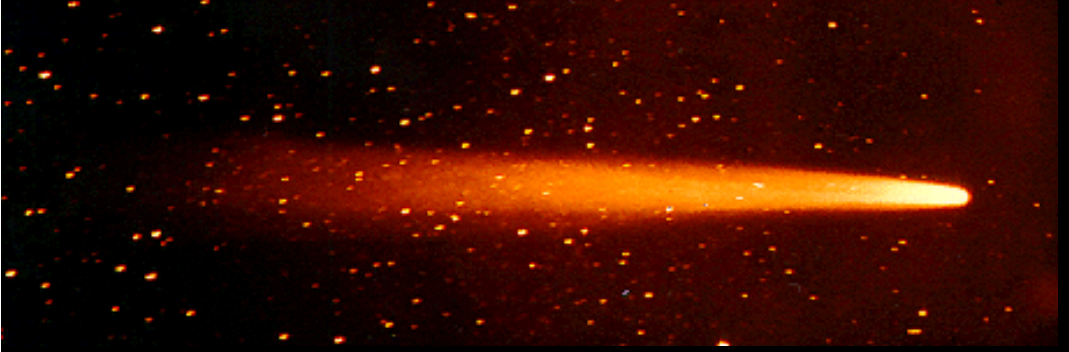




(LONG PERIOD, 27-42 KM DIA.)

Comet Hale-Bopp HST • WFPC2

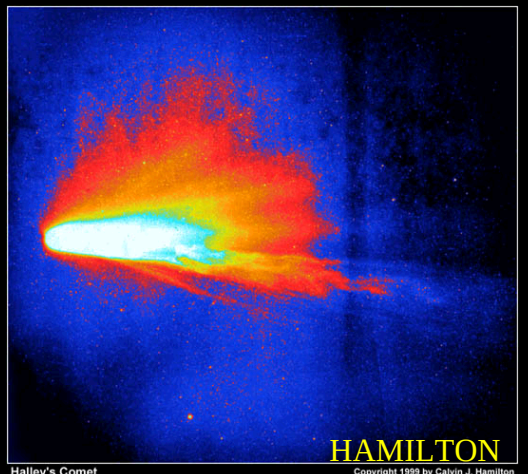
PRC95-41 • ST ScI OPO • October 5, 1995 • H. Weaver (ARC), P. Feldman (JHU), NASA



COMET HALLEY
16X8X8 KM
~ 1 GM/CM^3
76 YR PERIOD

COMPOSITION;
- **ICES (50%)**
  - **WATER (80%)**
  - **CO (15%)**
  - **FORMALDEHYDE, CO_2, METHANE AND HYDROCYANIC ACID**
  - **D/H RATIO ~3.2 X 10^{-4} , VS 1.56 X 10^{-4} FOR TERRESTRIAL OCEAN WATER AND AN ESTIMATED SOLAR NEBULA VALUE OF <1 X 10^{-4} (Meier, 1998)**
- **DUST (50%)**
- **ROCK (?)**

GIOTTO/ESA



COMET HALE-BOPP

LONG PERIOD

30-40 KM DIAMETER

COMPOSITION

CO_2, H_20, CO, CH_3OH (Jewit, et al., 1996)

D/H RATIO ~3.3 ± 0.8 X 10^{-4} ,VS 1.56 X 10^{-4} FOR TERRESTRIAL OCEAN WATER AND AN ESTIMATED SOLAR NEBULA VALUE OF <1 X 10^{-4} (Meier, 1998)

CN COMPOUNDS

C, N, AND S, ISOTOPIC RATIOS SHOW ORIGIN IN THE SOLAR SYSTEM AND NOT INTERSTELLAR (Jewitt, et al., 1997)

THREE TAILS (EOS, 1998,79, 573-574):

BRIGHT WHITE DUST TAIL FORMED BYSOLAR RADIATION PRESSURE ON DUST

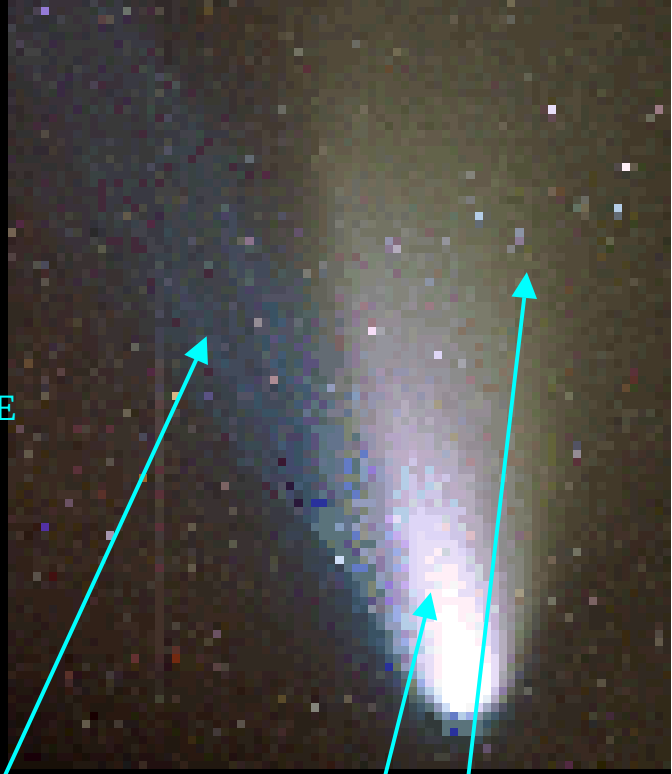
DIM BLUE ION TAIL FORMED BY SOLAR WIND AND COMETARY ION INTERACTION

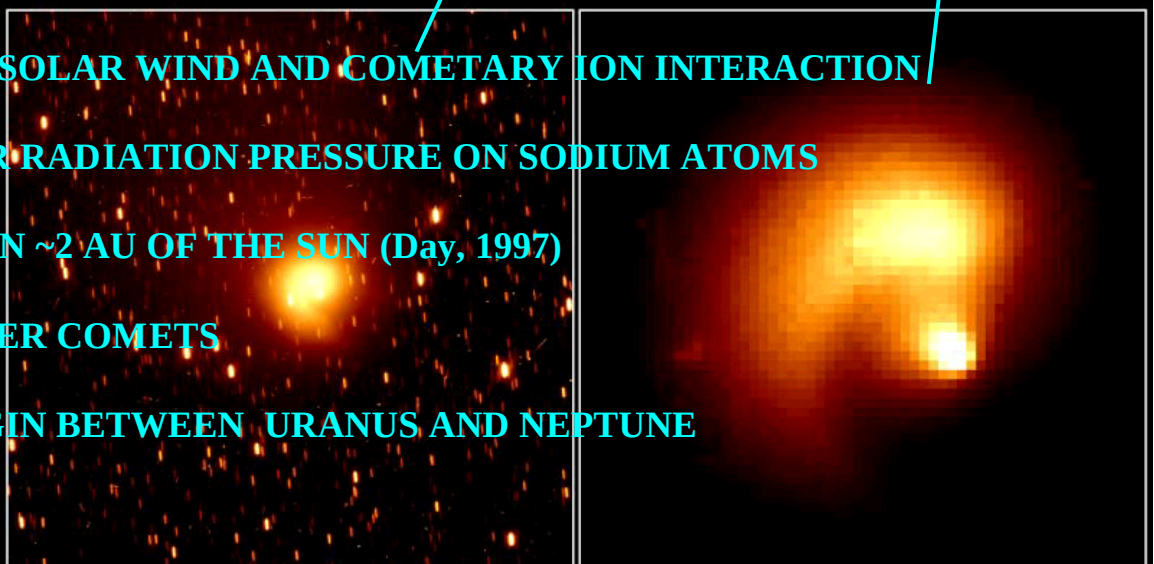
SODIUM TAIL FORMED BY SOLAR RADIATION PRESSURE ON SODIUM ATOMS

X-RAY EMISSIONS DETECTED WITHIN ~2 AU OF THE SUN (Day, 1997)

CONFIRMED ON AT LEAST 4 OTHER COMETS

ARGON DETECTION SUGGESTS ORIGIN BETWEEN URANUS AND NEPTUNE
(Science, 288, p. 2123-2124( )





COMET HYAKUTAKE

2 KM DIAMETER/6.5 HR ROTATION

UNUSUAL X-RAY AND E-UV EMISSIONS (Lisse, et al., 1996, Bingham, etal, 1997, Haberli, et al., 1997)

INTERACTION WITH SOLAR WIND AND SOLAR MAGNETIC FIELD

COMPOSTION

ABUNDANT ETHANE (C_2H_6) AND METHANE (CH_4) (Mumma, et al., 1996)

CN (SEE FIGURES TO RIGHT)

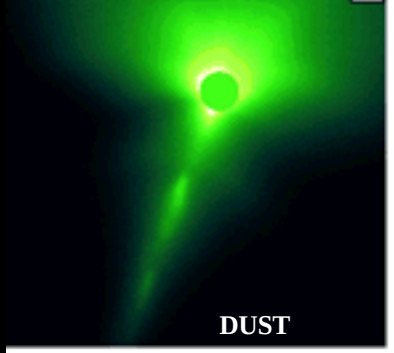
AMMONIA, ACETYLENE,METHANOL, METHYLCYANIDE, FORMALDEHYDE, AND HYDROGEN SULFIDE

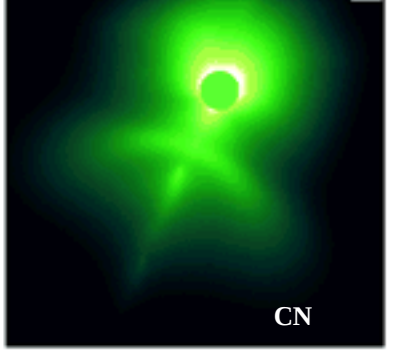
H_20 (6 TONS/SEC)

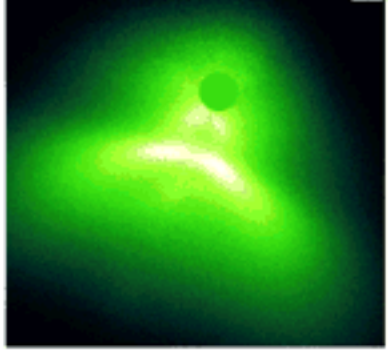
DIATOMIC SULFUR

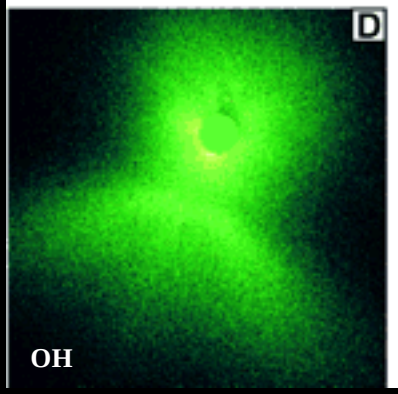
LITTLE CO

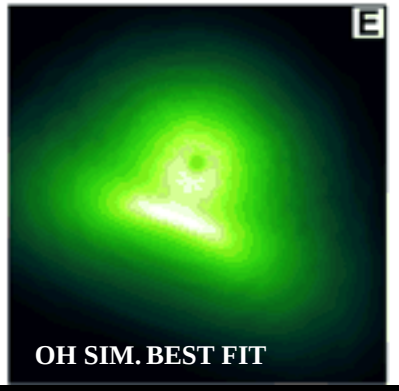
ION TAIL DETECTED 3.8AU FROM NUCLEUS (JONES, ET AL, 2000, NATURE, 404)

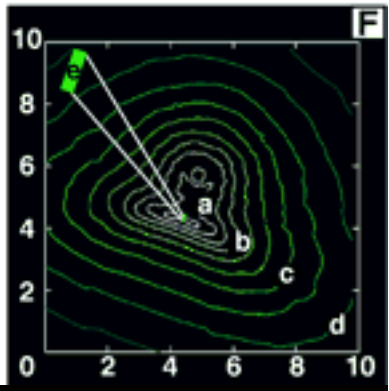




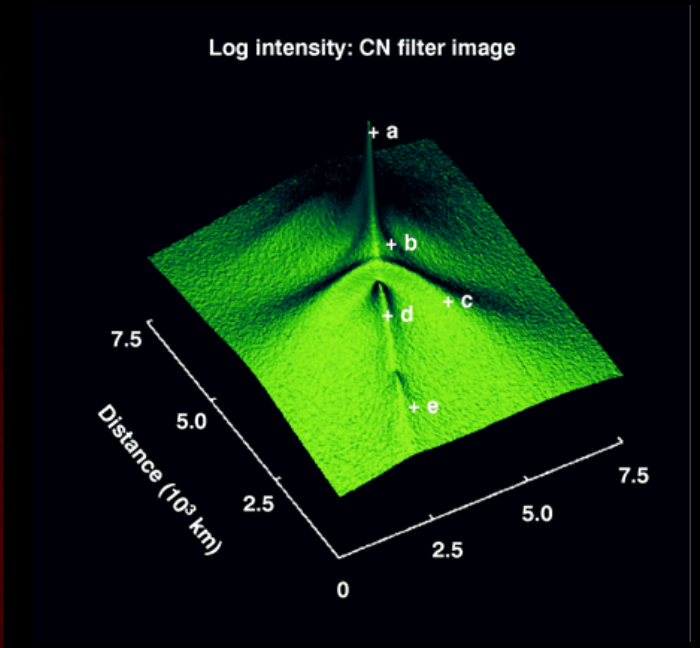








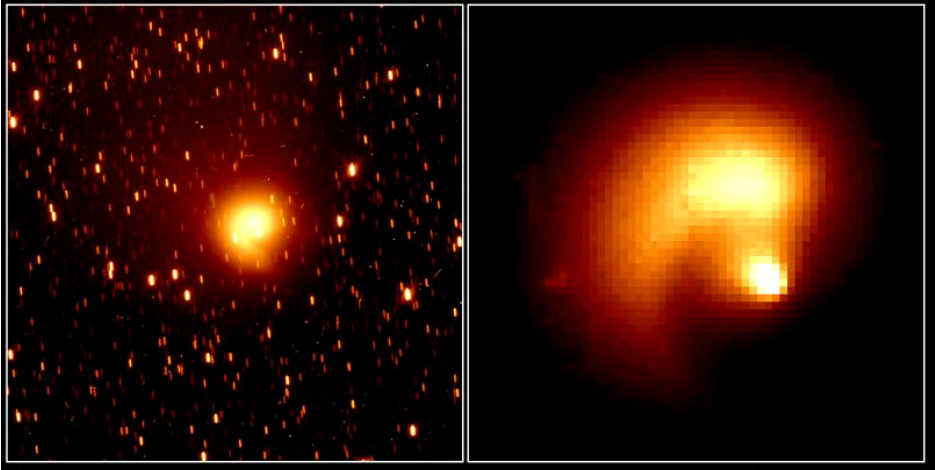
(HARRIS, ET AL, 1997, SCIENCE, 277)

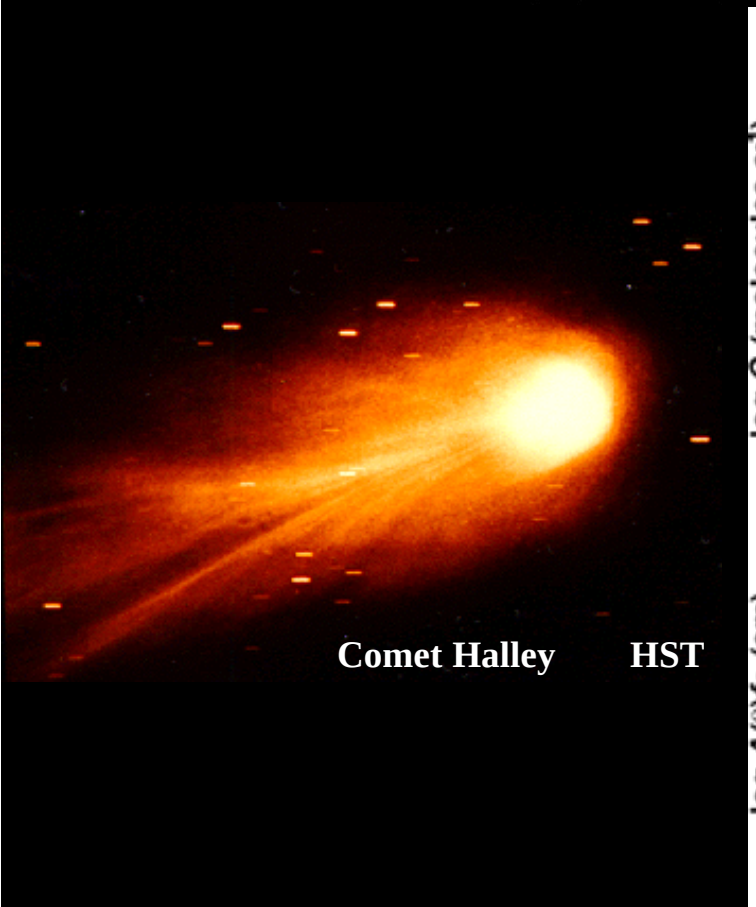


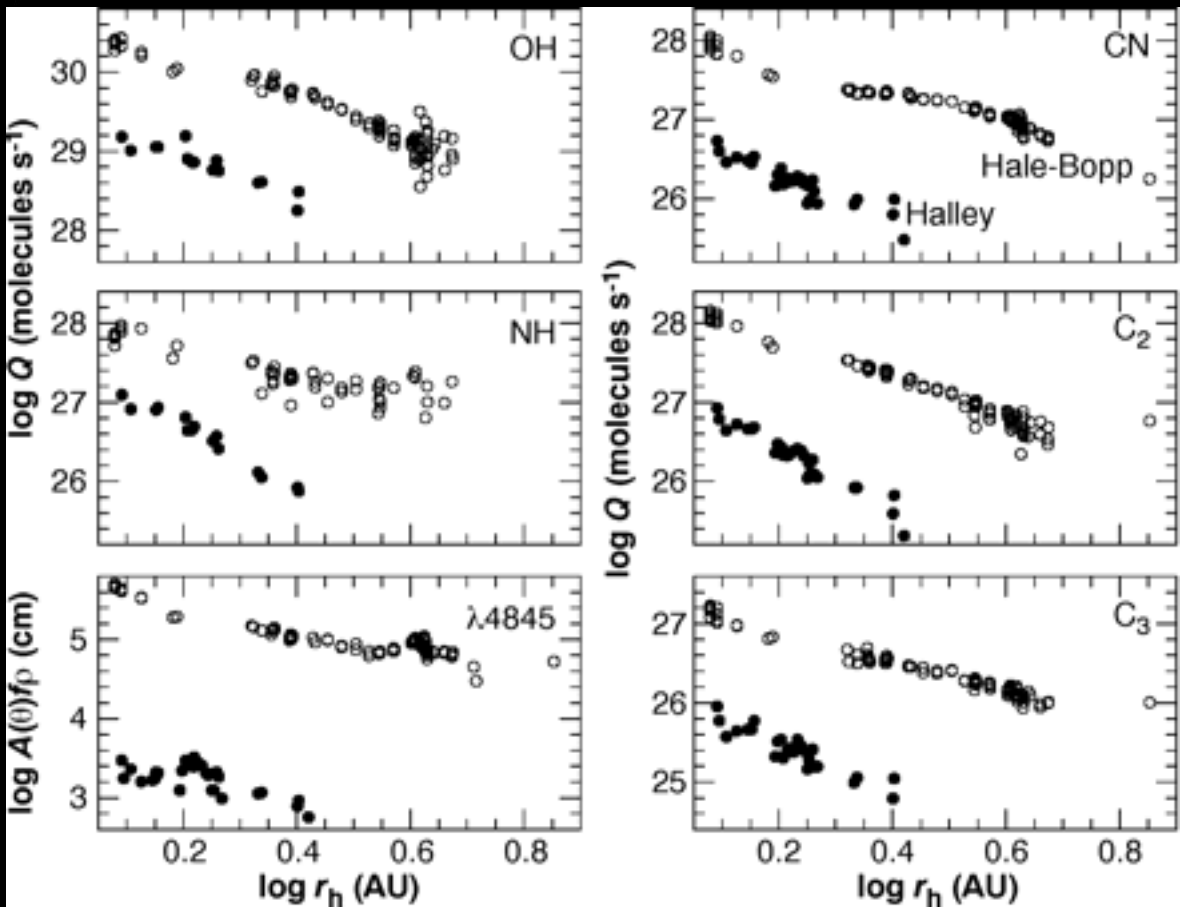
COMET HALE BOPP AND COMET HALLEY GAS SPECIES PRODUTION RATES AS FUNTION OF DISTANCE FROM SUN

(SCHLIECHER, ET AL, 1997. SCIENCE, 275)

HALE-BOPP DUST COMPOSED OF OLIVINE AND AMORPHOUS SILICATE MATERIAL
(HAYWARD AND HANNER, 1997, SCIENCE, 275)







KUIPER BELT

INNER BELT (See Luu and Jewitt, 1996)

BEYOND NEPTUNE ORBIT BUT IN 3:2 ORBITAL PERIOD RESONANCE WITH NEPTUNE

>400 IDENTIFIED TO DATE

INCLINED, ELLIPTICAL, DYMAMICALLY STABLE ORBITS

CLASSICAL BELT AND SCATTERED DISK
OUTSIDE THE 3:2 RESONANCE WITH NEPTUNE

LOW INCLINATION, CIRCULAR, NON-RESONANT ORBITS

SCATTERED CLASS
INCLINED, ELIPTICAL, VERY LARGE ORBITS

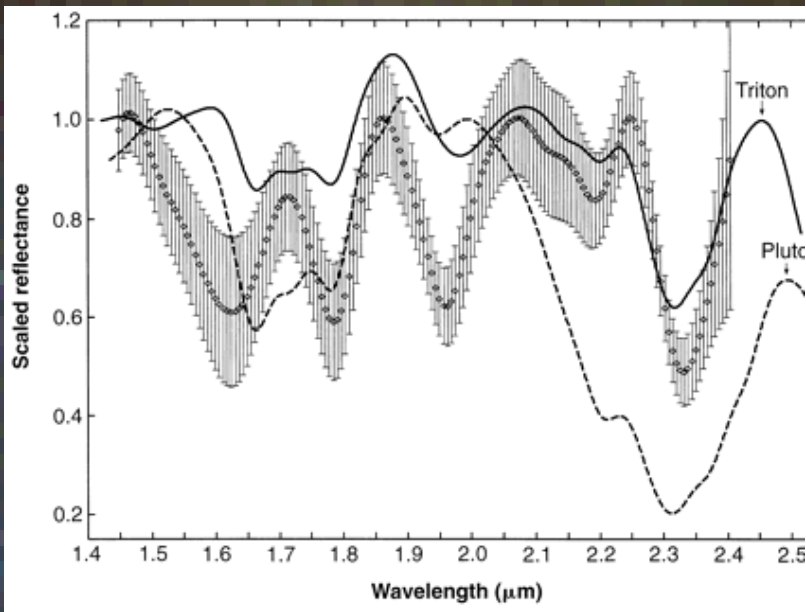
100-400 KM DIAMETERS

WIDE RANGE OF COLORS, GENERALY IN THE REDS OR GRAYS

TOTAL MASS 100S TIMES ASTEROID BELT
ESTIMATED >10^8 OBJECTS > 10KM DIAMETER
(COCHRAN, ET AL, 1995, ASTRO. JOURNAL, 110)

MAY HAVE INCLUDED PLUTO (2300 KM) AND ITS MOON CHARON (1100 KM, 6 HR ROTATION RATE)
ALSO THE CENTAUR AND TROJAN OBJECTS IN THE JUPITER /NEPTUNE REGION

>160 COMETS CONTROLLED BY JUPITER
(LEVINSON, 1996)



OBJECT 1993SC SPECTRA SHOW PRESENCE OF SIMPLE HYDROCARBON ICE (CH_4, ETC) AS WELL AS MORE COMPLEX HYDROCARBONS.
(BROWN, ET AL, 1997, SCIENCE, 276)

SOME OBJECTS OUTSIDE THE ORBIT OF NEPTUNE
OBJECT 2000 CR_{105}
~400KM IN DIAMETER
PERIGEE 6.6B KM OUTSIDE NEPTUNE'S ORBIT
PERIOD 3175 YEARS

COMET HALE-BOPP
~ 40KM DIAMETER

KUIPER BELT -2

PRIMORDIAL MASS ESTIMATE IS 30 EARTH MASSES

CURRENT MASS ESTIMATE IS 0.06-0.3 EARTH MASSES

EARLY INTERACTIONS WITH NEPTUNE AND/OR MASSIVE PLANETESIMALS MAY EXPLAIN THE DIFFERENCE

COULD THIS BE A SOURCE FOR THE IMPACTORS DURING THE LARGE BASIN STAGES OF LUNAR EVOLUTION AT 4.1-3.9 BY? (see Lecture 9 and Malhotra, 1993)

CONSIDER THAT NEPTUNE MAY HAVE FIRST FORMED IN AN ORBIT CLOSER TO SATURN, GRADUALLY INCREASING ITS INTERATION WITH THE KUIPER/EDGEWORTH BELT OBJECTS, UNTIL AT ABOUT 4.1 BY, THAT INTERACTION BECAME MUCH MORE INTENSE AND LED TO THE PRESENT ORBITS AND DISTRIBUTION

OBJECT 1993C IN KUIPER BELT/EDGEWORTH BELT (Brown, 1997)

IR SPECTRA SUGGEST HYDROCARBON ICE (METHANE, ETHANE, ETHELENE OR ACETYLENE AND POSSIBLY MORE COMPLEX COMPOUNDS)

OBJECT 1996 TO66 IN KUIPER/EDGEWORTH BELT (Science News, 1998, 154, 310; Luu and Jewitt, 1998))

BRIGHTER THAN OTHER KNOWN OBJECTS

IR ABSORPTION ABSENT

~600 KM DIAMETER

6.25 HR ROTATION

CHIRON - “ESCAPED KUIPER BELT OBJECT (?)

PERI. 8.46 AND APHE. ~19 AU
BETWEEN JUPITER & URANUS

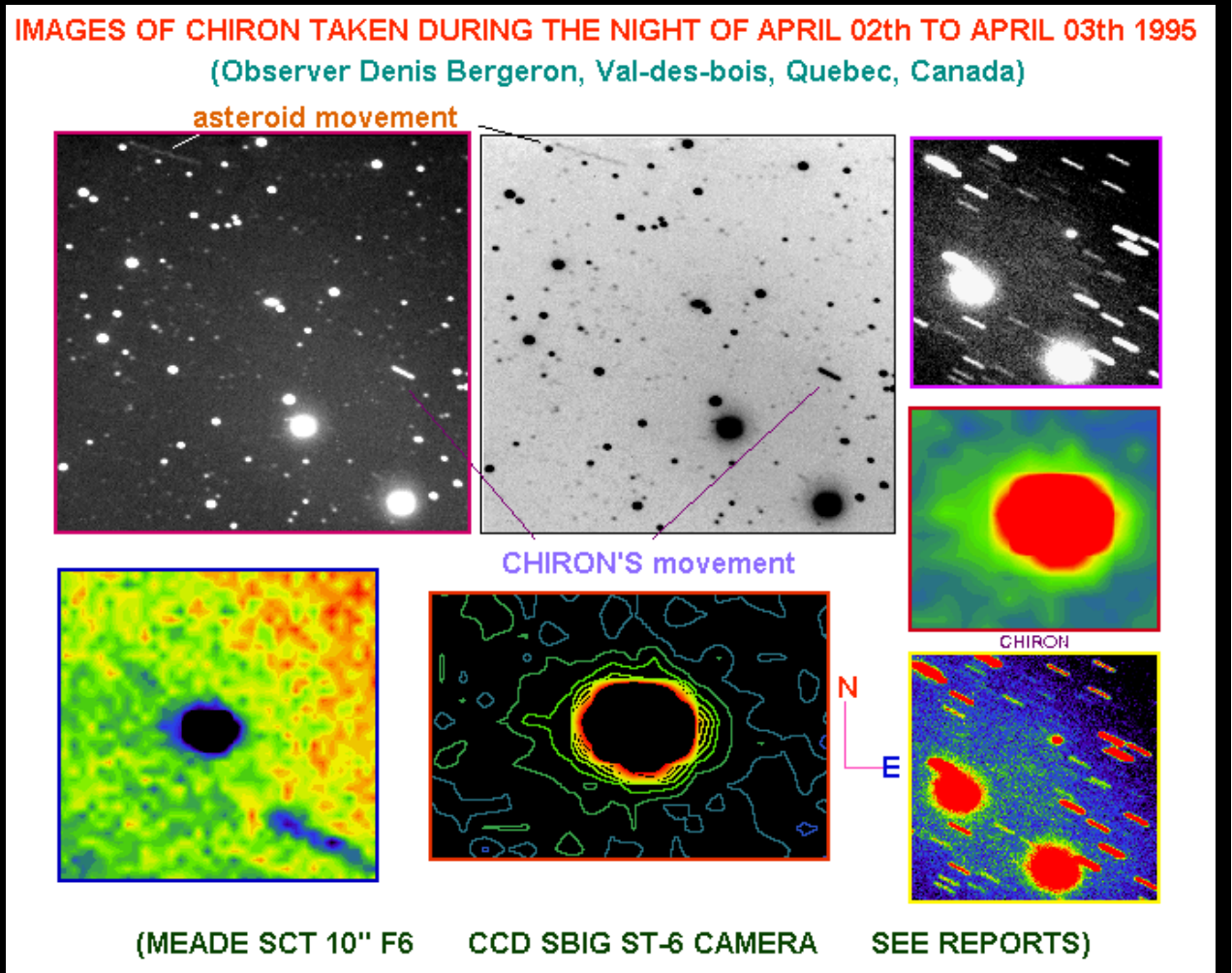
ORBIT INCLINATION 6.93°

PRESENCE OF COMA AT LOW T
>2 M KM DIAMETER
INDICATES CH_4, CO_2, OR N_2

DUST ATMOSPHERE
~1200 KM DIAMETER

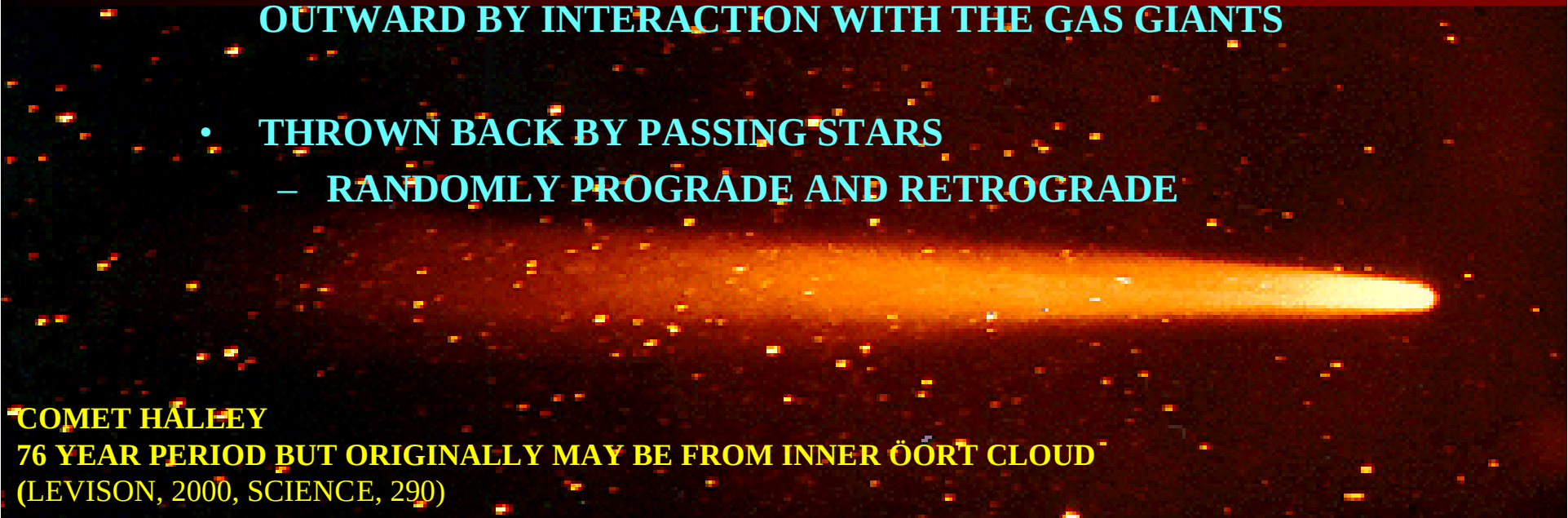
148-208 DIAMETER

ROTATION 5.9 HRS



ÖORT CLOUD

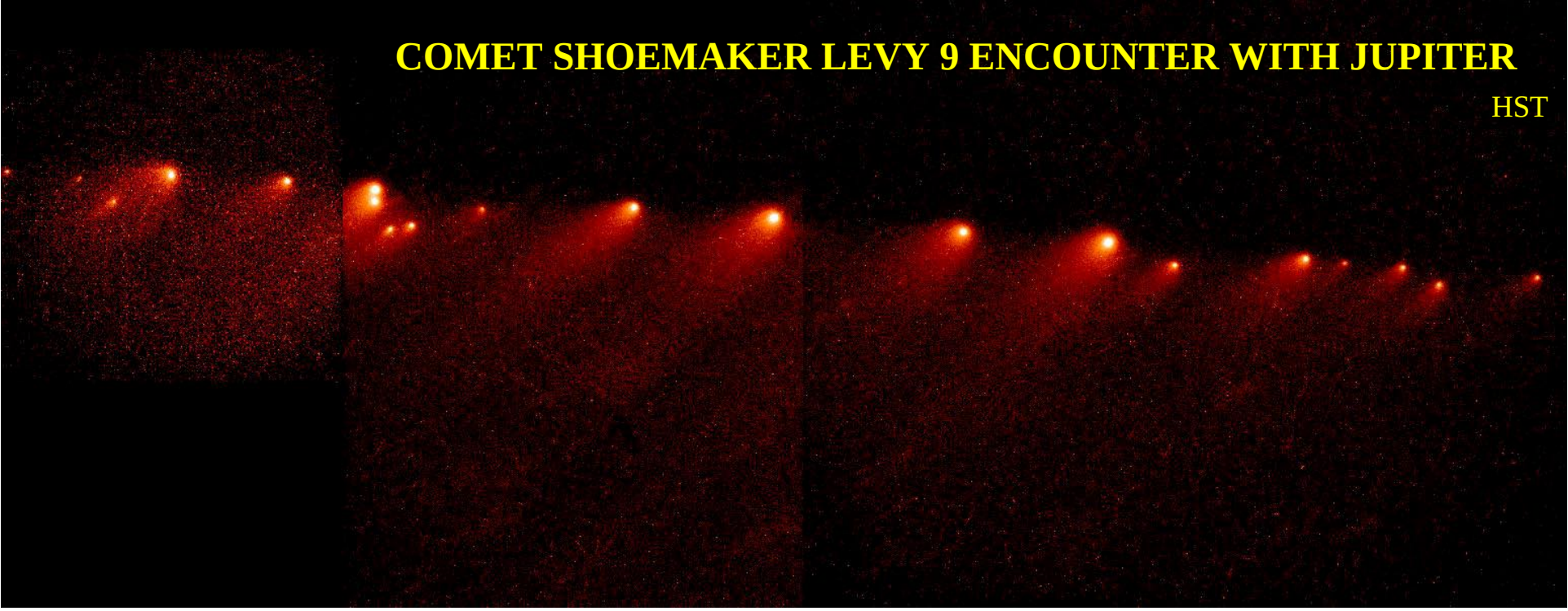
- SOURCE OF COMETS WITH LONG PERIODS
  - PROPOSED BY JAN ÖORT
- NO DIRECT OBSERVATIONAL EVIDENCE
- MAY EXTEND FROM 20,000 TO 100,000AU
- FRAGMENTS FROM THE OUTER PLANETS REGION PROPELLED OUTWARD BY INTERACTION WITH THE GAS GIANTS
- THROWN BACK BY PASSING STARS
  - RANDOMLY PROGRADE AND RETROGRADE

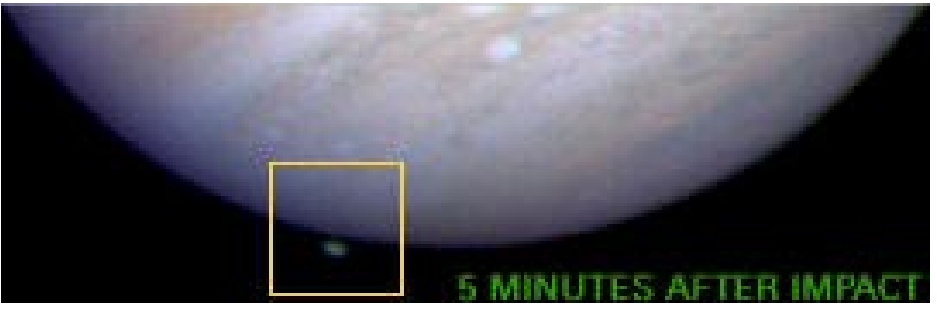


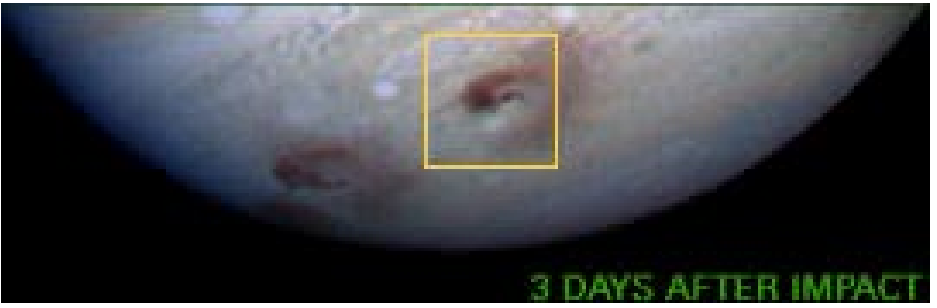
COMET HALLEY
76 YEAR PERIOD BUT ORIGINALLY MAY BE FROM INNER ÖORT CLOUD
(LEVISON, 2000, SCIENCE, 290)

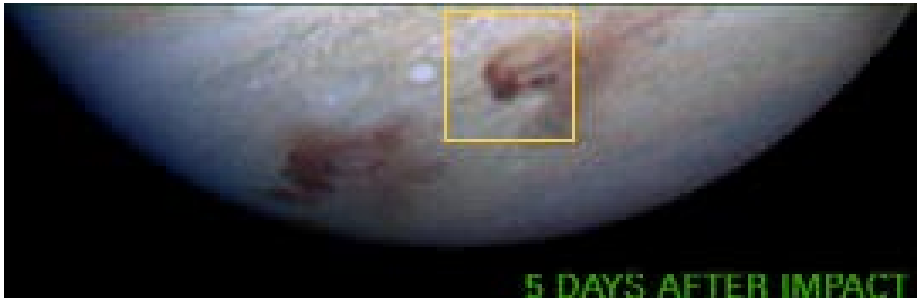
COMET SHOEMAKER LEVY 9 ENCOUNTER WITH JUPITER

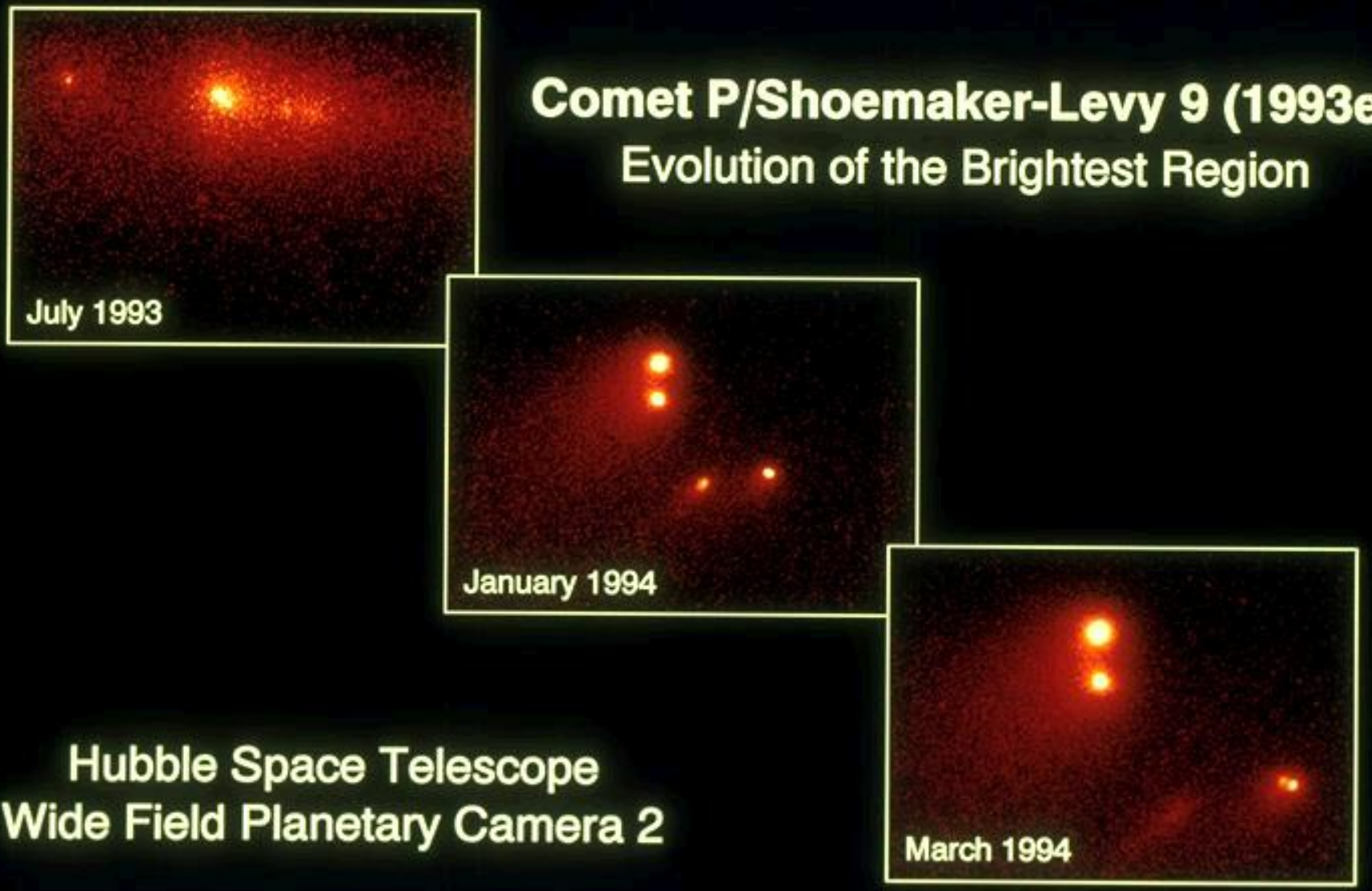
HST







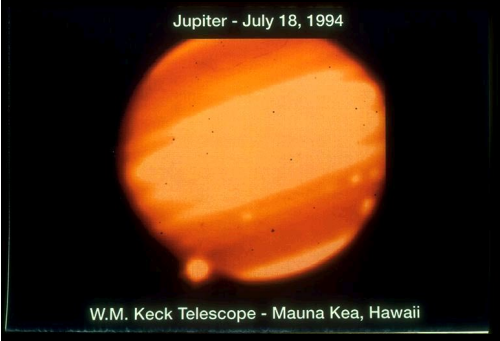



Comet P/Shoemaker-Levy 9 (1993e)
Evolution of the Brightest Region
July 1993
January 1994
March 1994
Hubble Space Telescope
Wide Field Planetary Camera 2

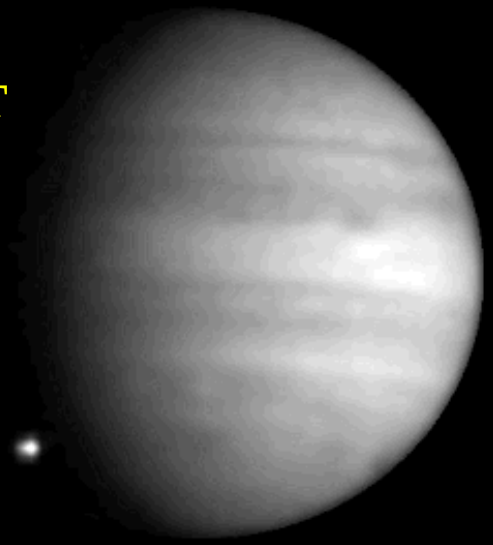
SHOEMAKER LEVY FRAGMENT W IMPACT ON JUPITER

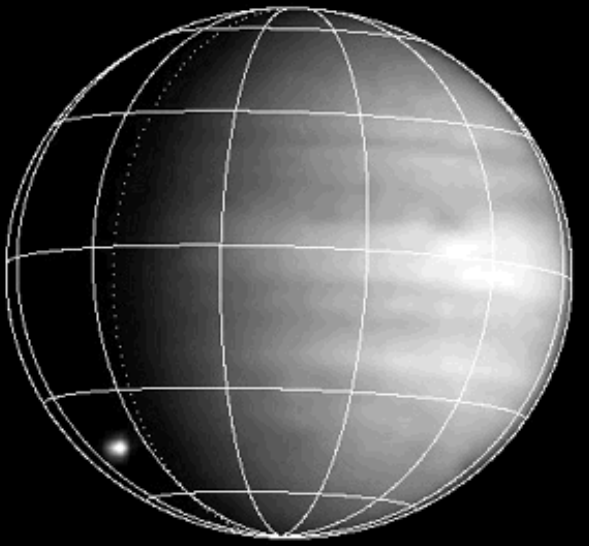
NASA/GALILEO/JPL

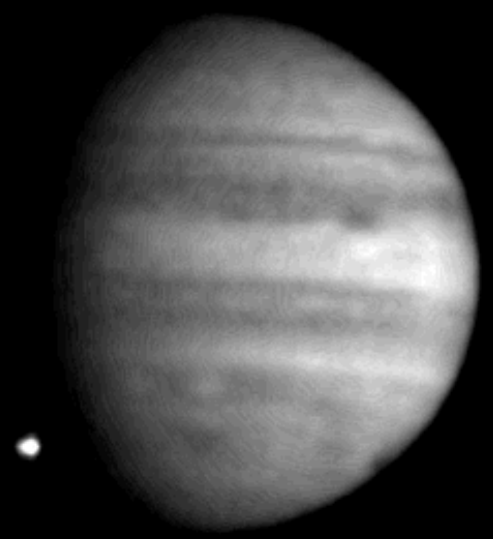
HUBBLE

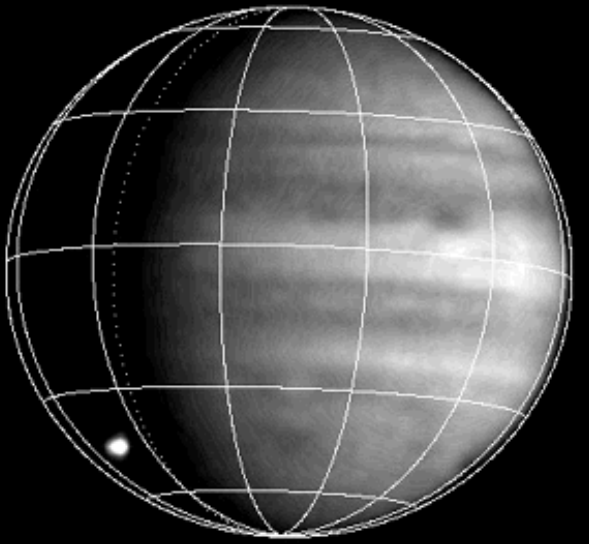


KECK

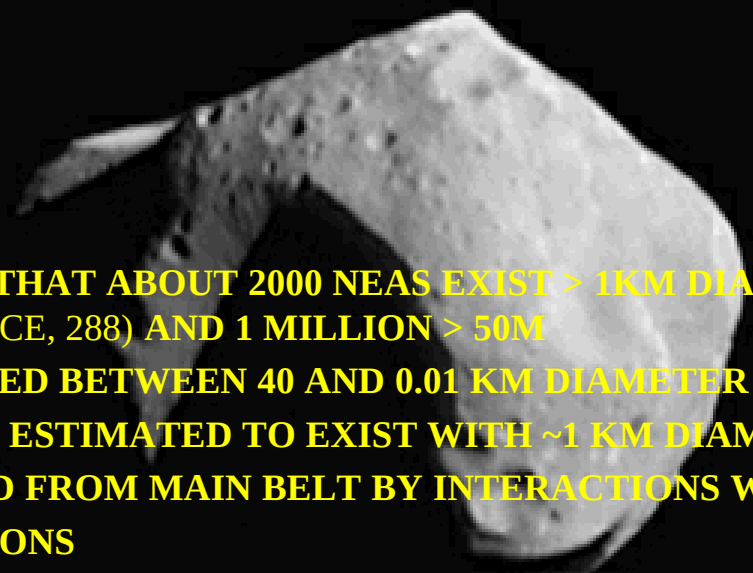








NEAR EARTH ASTEROIDS

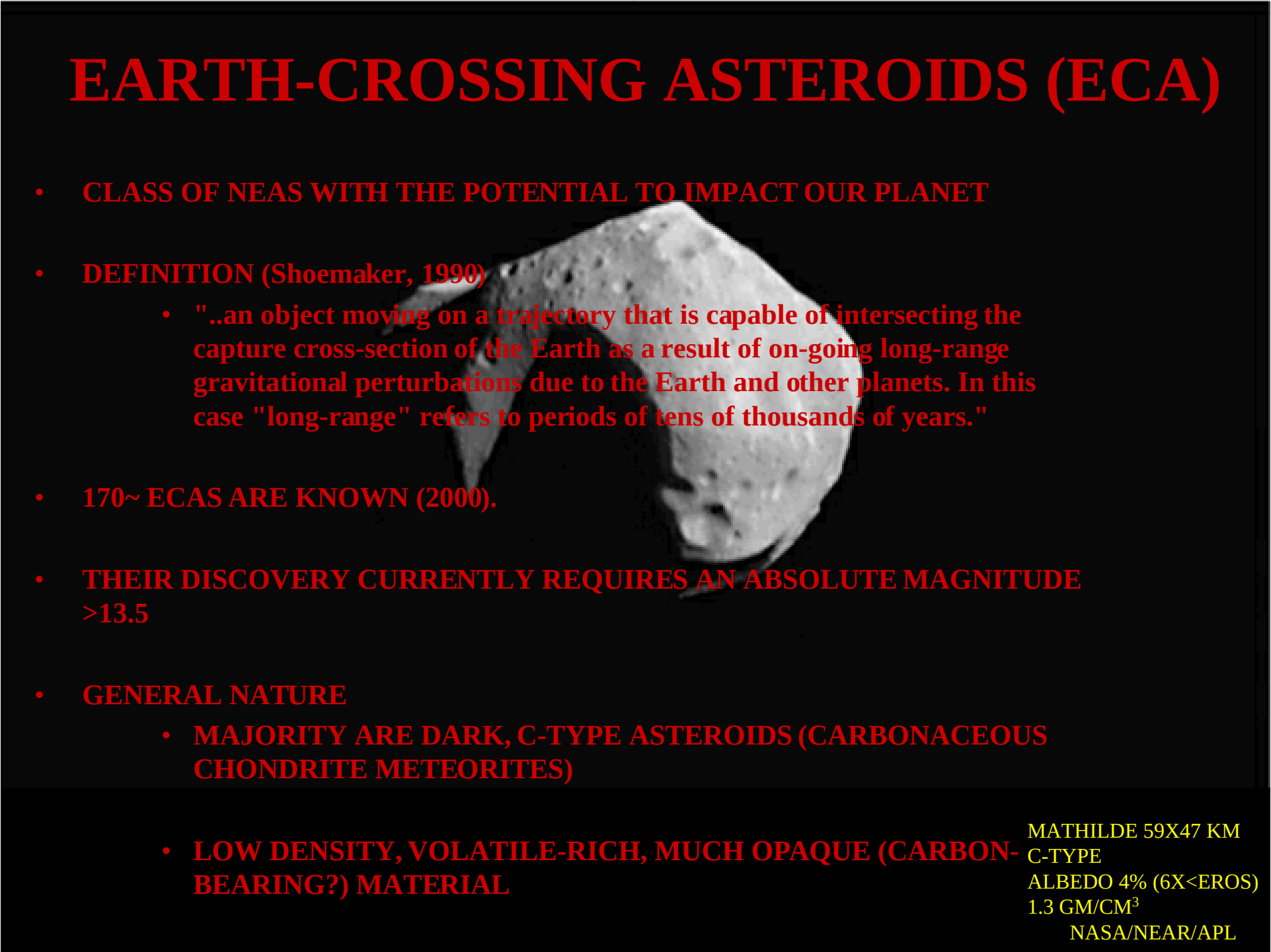


- **ESTIMATES ARE THAT ABOUT 2000 NEAS EXIST > 1KM DIAMETER (**SEE BOTTKE, ET AL, 2000, SCIENCE, 288) **AND 1 MILLION > 50M**
  - **~950 DETECTED BETWEEN 40 AND 0.01 KM DIAMETER**
  - **~900 OTHERS ESTIMATED TO EXIST WITH ~1 KM DIAMETER (H < 18)**
    - **EJECTED FROM MAIN BELT BY INTERACTIONS WITH JUPITER.**
    - **COLLISIONS**
      - **CHAOTIC DYNAMICS INCREASE ORBITAL ECCENTRICITY.**
    - **RELATIVELY SHORT (10-100 MYR) LIFETIMES AND THUS MUST BE REPLENISHED RAPIDLY COMPARED TO THE AGE OF THE SOLAR SYSTEM.**
    - **AMOR TYPE (~29%)**
      - **ORBIT OUTSIDE THE EARTH'S**
    - **APOLLO TYPE (~65%) 165 KNOWN, 590 PREDICTED (~1 KM)**
      - **ORBIT CROSSES EARTH'S.**
    - **ATEN TYPE (~6%) 19 KNOWN 56 PREDICTED (~1 KM)**
      - **ORBIT INSIDE THE EARTH'S.**

MATHILDE 59X47 KM
ALBEDO 3-4%
17.4DAY ROTATION
DENSITY 1.3
C TYPE
NASA/NEAR/APL

EARTH-CROSSING ASTEROIDS (ECA)

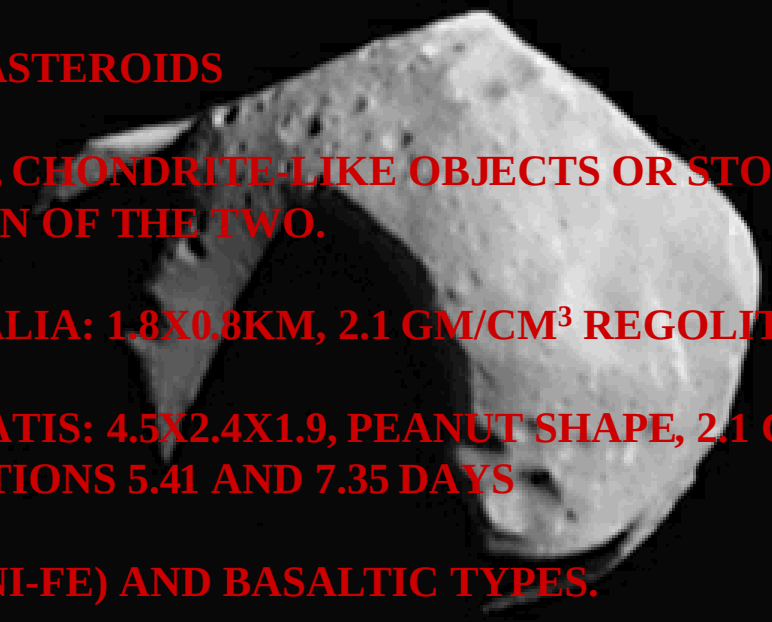
- CLASS OF NEAS WITH THE POTENTIAL TO IMPACT OUR PLANET
- DEFINITION (Shoemaker, 1990)
  - "..an object moving on a trajectory that is capable of intersecting the capture cross-section of the Earth as a result of on-going long-range gravitational perturbations due to the Earth and other planets. In this case "long-range" refers to periods of tens of thousands of years."
- 170~ ECAS ARE KNOWN (2000).
- THEIR DISCOVERY CURRENTLY REQUIRES AN ABSOLUTE MAGNITUDE >13.5
- GENERAL NATURE
  - MAJORITY ARE DARK, C-TYPE ASTEROIDS (CARBONACEOUS CHONDRITE METEORITES)
  - LOW DENSITY, VOLATILE-RICH, MUCH OPAQUE (CARBON-BEARING?) MATERIAL



MATHILDE 59X47 KM
C-TYPE
ALBEDO 4% (6X<EROS)
1.3 GM/CM^3
NASA/NEAR/APL

EARTH-CROSSING ASTEROIDS (ECA) -2

GENERAL CHARACTERISTICS, CONTINUED



MANY ARE S-TYPE ASTEROIDS

EITHER STONY, CHONDRITE-LIKE OBJECTS OR STONY-IRON OBJECTS OR A COMBINATION OF THE TWO.

CASTALIA: 1.8X0.8KM, 2.1 GM/CM^3 REGOLITH, ROTATION 4 HR.

TOUTATIS: 4.5X2.4X1.9, PEANUT SHAPE, 2.1 GM/CM^3 REGOLITH ROTATIONS 5.41 AND 7.35 DAYS

A FEW METALLIC (NI-FE) AND BASALTIC TYPES.

PHYSICAL CHARACTERISTICS

HIGHLY IRREGULAR SHAPES
WELL DEVELOPED REGOLITHS
SOME VERY RAPID SPINS
SOME MAY BE CONTACT BINARIES OR LOOSE AGGREGATES.

MATHILDE 59X47 KM
C-TYPE
ALBEDO 4% (6X<EROS)
1.3 GM/CM^3
NASA/NEAR/APL

NEAR EARTH OBJECTS (NEOS)

- ASTEROIDS AND SHORT PERIOD COMETS
- ATMOSPHERE PROTECTS EARTH UP TO ~50M DIAMETER
  - 5 MEGATONS ENERGY
- GLOBAL ECONOMIC AND POLITICAL CONSEQUENCES UPTO ~2 KM
- GLOBAL ENVIRONMENTAL CONSEQUENCES ABOVE ~2 KM DIAMETER
  - 1 MILLION MEGATONS ENERGY
- MASS EXTINCTIONS ABOVE ~10 KM
  - CRETATOUS - TERTIARY BOUNDARY: ~15 KM OBJECT AND 100 MEGATONS
- STATISTICAL ANALYSIS INDICATES A 2 KM OBJECT HITS THE EARTH 1-2 TIMES PER MILLION YEARS
  - SMALLER EVENTS OF SIGNIFICANCE EVERY FEW CENTURIES
    - 1908 TONGUSKA EVENT - ~15 METATON AIR BURST OVER SIBERIA
- PROTECTION:
  - DETECTION
  - INTERCEPT AND GRADUAL DIVERSION
    - HEAVY LIFT LAUNCH AND HIGH ISP, IN-SPACE PROPULSION SYSTEM (FISSION OR FUSION)
    - EXPLOSIVES PROBABLY NOT A GOOD IDEA

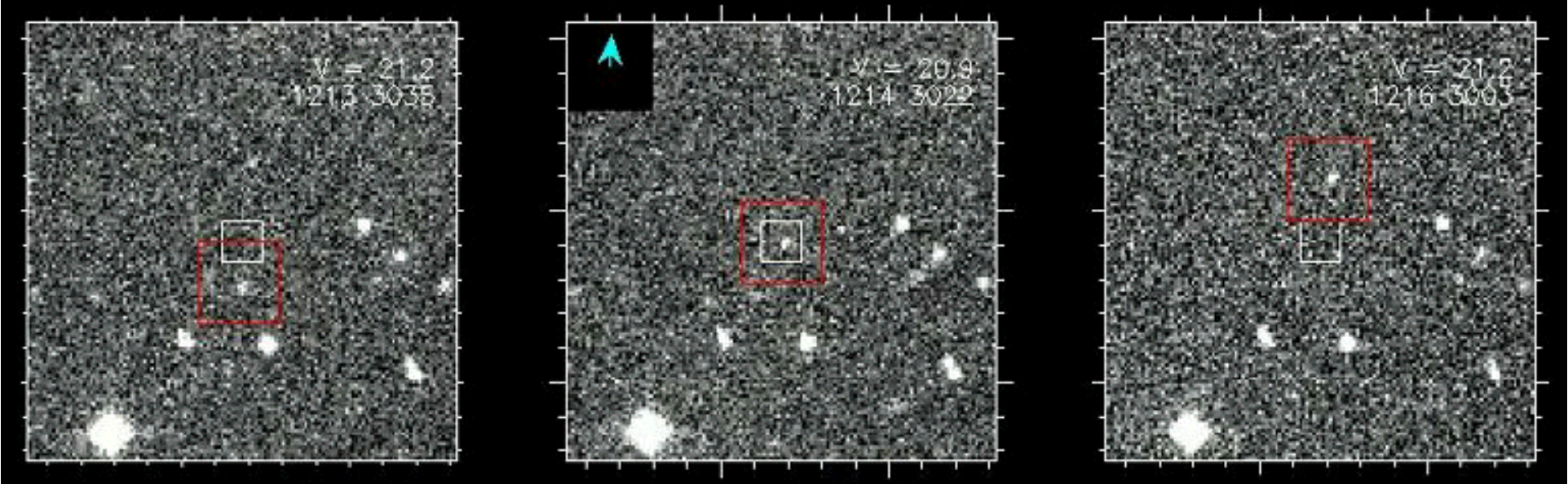
TOUTATIS
NASA GOLDSTONE

ECA 2000 BF 19

COLLISION COURSE WITH EARTHFOR IMPACT IN 2011!!!!

FURTHER OBSERVATIONS INDICATED NO COLLISION WITHIN 50 YEARS.

(SPACEWATCH, http://www.lpl.arizona.edu/spacewatch/2000bf19.html)



SHOULD THE HUMAN SPECIES WORRY ABOUT THIS AND OTHER ASTEROID HAZARDS AND THE ASSOCIATED RISK?

SHOULD A DETECTION AND TRACKING SYSTEM BE A HIGH PRIORITY ALONG WITH EVERYTHING ELSE?

IF SO, SHOULD A CONTINUOUSLY UPGRADED CAPABILITY BE ESTABLISHED TO DEFLECT A THREATENING ECA?

NATURE OF THE ASTEROID HAZARD

"LOW PROBABLILITY - HIGH CONSEQUENCE" CATEGORY OF RISK

130+ KNOWN TERRESTRIAL CRATERS

65M YEAR AGO EVENT GAVE MOST RECENT MASS EXTINCTION

(ALVEREZ, ET AL, 1980; CYGAN, ET AL, 1996)

180 KM CRATER

~20,000 KM^3 OF MELT VOLUME

~10 KM OBJECT AT 15-20 KM/SEC

10-20% DECREASE IN INSOLATION

CO_2 AND SO_2 EFFECTS DUE TO SULFATE-RICH ROCK AT IMPACT SITE

DEPRESSION OF GLOBAL TEMPERATURES

ACID RAIN?

OZONE DEPLETION?

EFFECTS OF 1 KM OBJECT IMPACTING EARTH AT 20 KM/SEC

(SILVER AND SCHULTZ, 1982)

~26 KM CRATER WITH 100 TIMES MASS OF IMPACTOR EJECTED

CONTINOUS EJECTA TO 1+ CRATER DIAMETER

SECONDARY EJECTA TO MANY CRATER DIAMETERS

FIRE BALL AND EJECTA TO ABOVE THE ATMOSPHERE

TSUNAMI OF MASSIVE SCALE IF OCEAN IMPACT

LARGE QUANTITIES OF NO FORMED AT BOW SHOCK IN ATMOSPHERE

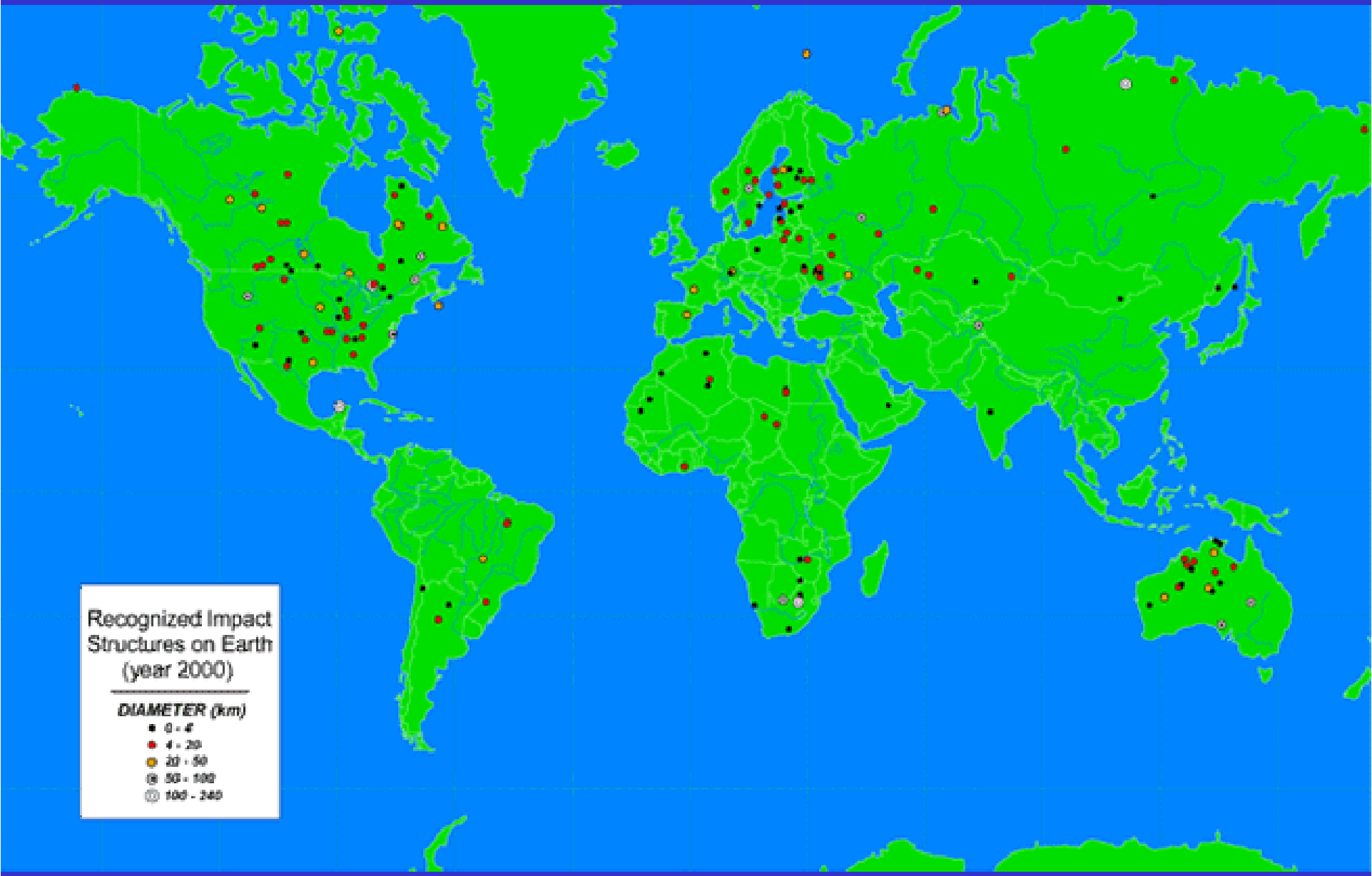
CL_2, CH_4 AND SO_2 FORMED IF OCEAN IMPACT

CO_2, SO_2, AND S_2 IF IMPACT IS IN CARBONATE AND SULFATE ROCKS

LARGE QUANTITIES OF FINE DUST (10% OF IMPACTOR?)

COMPLETE BLOCKAGE OF INSOLATION FOR 3-6 MONTHS

RIES EVENT 14M YEARS AGO GAVE 26KM CRATER


Recognized Impact Structures on Earth (year 2000)
DIAMETER (km)
0 - 4
4 - 20
20 - 50
50 - 100
100 - 240

MAJOR IMPACT RELATED EVENTS ON EARTH

- 4.5-3.8 B.Y. - PERIOD OF INTENSE CRATERING AND LARGE BASIN FORMATION
  - ASSISTANCE TO BUT ALSO PREVENTION OF PERMANENT LIFE DEVELOPMENT
- 2.6 B.Y. IR ANOMALY, SILICATE SPHERULES
- 2.0 B.Y. VERTEFORT - 300 KM IMPACT STRUCTURE
- 1.85 B.Y. SUDBURY - >250 KM IMPACT STRUCTURE
- ~ 380 M.Y. - IR & OTHER ANOMALIES , C ISOTOPE RATIOS, TSUNAMI BRECCIA,
  - INTRA-DEVONIAN (FRASNIAN/FAMENNIAN BOUNDARY) MASS EXTINCTION-
- 251 M.Y. - W. AUSTRALIA BURIED IMPACT STRUCTURE OR OCEAN IMPACT (?) - SULFUR RELEASE, 3HE ANOMALY, FULLERENES
  - PERMIUM-TRIASSIC MASS EXTINCTION - MOST SEVERE YET KNOWN
- 65 M.Y. - CHICXULUB - ~180 KM BURIED IMPACT STRUCTURE
  - CRETACEOUS-TERTIARY BOUNDARY MASS EXTINCTION - DINOSAURS DOWN / MAMMALS UP
- 35.5 M.Y. CHESAPEAKE - 90 KM BURIED IMPACT STRUCTURE - TECTITES

LARGE TERRESTRIAL IMPACT CRATERS

http://cass.jsc.nasa.gov/publications/slidesets/impacts.html

Crater Name	Location	Latitude	Longitude	(My)	(km)
Vredefort	**South Africa**	**27.0 S**	**27.5 E**	**2023**	**300**
Sudbury	**Canada**	**46.6 N**	**81.2 W**	**1850**	**250**
Chicxulub	**Mexico**	**21.3 N**	**89.5 W**	**65**	**170**
Manicougan	**Canada**	**51.4 N**	**68.7 W**	**214**	**100**
Popigai	**Russia**	**71.7 N**	**111.7 E**	**35**	**100**
Chesapeake Bay	**United States**	**37.3 N**	**76.0 W**	**36**	**90**
Acraman	**Australia**	**32.0 S**	**135.5 E**	**590**	**90**
Puchezh-Katunki	**Russia**	**57.1 N**	**43.6 E**	**175**	**80**
Morokweng	**South Africa**	**26.5 S**	**23.5 E**	**145**	**70**
Kara	**Russia**	**69.2 N**	**65.0 E**	**73**	**65**
Beaverhead	**United States**	**44.6 N**	**113.0 W**	**600**	**60**
Tookoonooka	**Australia**	**27.1 S**	**142.8 E**	**128**	**55**
Charlevoix	**Canada**	**47.5 N**	**70.3 W**	**357**	**54**
Kara-Kul	**Tajikstan**	**39.0 N**	**73.5 E**	**5**	**52**
Siljan	**Sweden**	**61.0 N**	**14.9 E**	**368**	**52**

- Crater information from The New Solar System, Beatty et al., Cambridge, 1999.

CLEARWATERLAKES, CANADA

A FINAL THOUGHT

BEGINNING IN THE 1960'S, THE HUMAN SPECIES HAS HAD THE COPMBINED TECHNICAL AND ECONOMIC FOUNDATIONS TO REMOVE THE THREAT OF ITS EXTINCTION THROUGH ASTEROID OR COMET IMPACT.

THE QUESTION REMAINS, WILL SOME ENTITY, NATION, OR GROUP OF NATIONS MOBILIZE THIS CAPABILITY, A CAPABILITY THAT ALSO WOULD SERVE THE SPECIES IN MEETING MANY OTHER FUTURE CHALLENGES?

HARRISON H. SCHMITT - NOVEMBER 23, 2001
HAPPY THANKSGIVING!