Comets and Cometary Fragmentation: Their Possible Effect on Life in Planetary Systems

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Abstract

Recently a large number of comets, including many multiple comets, have been discovered on images taken by the Solar and Heliospheric Observatory (SOHO). This has many implications for the Solar System population of comets, the composition of comet nuclei, the possible impact danger with spacecraft and planets, and the possibility that life may have been seeded by comets.

1. Introduction

Until space observatories were placed above the Earth's atmosphere very few sungrazing comets were known, then SOLWIND discovered 6 sungrazers between 1979–1984, followed by Solar Maximum Mission with 10 comets from 1987-1989. After the launch of the Solar and Heliospheric Observatory (SOHO) in December 1995 another 100 were found in the first four years. In 2000 the author started to search the images taken with SOHO and discovered a great many more, of the 326 comets found with SOHO, 124 have been discovered by the author.

It has been known for many years that comets breakup. Some notable examples have been Comet P/Brooks 2 discovered in 1889, which 3 years earlier had passed close to Jupiter and three pieces broke off (Mitton, 1995). Comet West in March 1976 broke into four pieces (Mitton, 1995). More recently the famous Comet Shoemaker-Levy 9 broke into 21 fragments as it passed close to Jupiter. Figure 1.

Other recent comets include; Comet 1996 B2 (Hyakutake) Figure 2. Comet 1999 S4 (LINEAR), which quite suddenly came apart in dramatic fashion in Aug 2000, Figure 3. and the Great comet of 1997 - Comet Hale-Bopp, which shed debris in clumps (STScI-PRC95-41).

In his book *'Rogue Asteroids and Doomsday Comets'* Duncan Steel writes *"...it is entirely to be expected that some comets, perhaps the majority, will crumble into smaller fragments either in single catastrophic episodes (like P/Shoemaker-Levy 9 and the Kreutz group progenitor as they pass close to massive objects), in gentler splittings in interplanetary space (as did P/Machholz 2 and P/Biela and more than a dozen other comets in the past two centuries), or as a result of gradual erosion."*

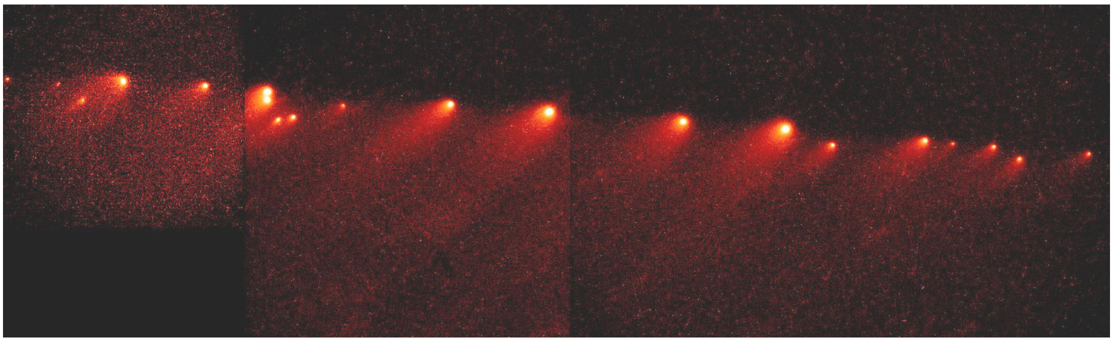


Figure 1. Comet P/Shoemaker-Levy 9 imaged by the Hubble Space Telescope

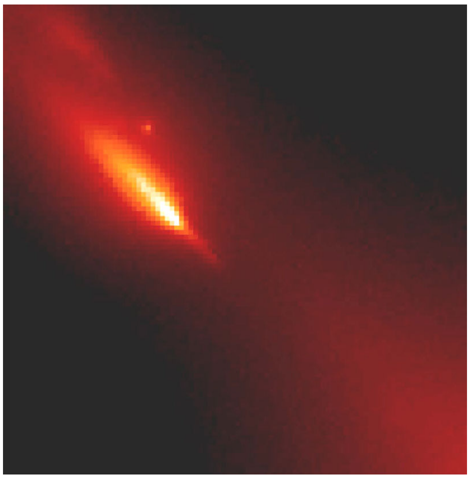


Figure 2. A fragment of comet 1996 B2 (Hyakutake)
March 25 1996
The nucleus is off the image, bottom right
Hubble Space Telescope WFPC2

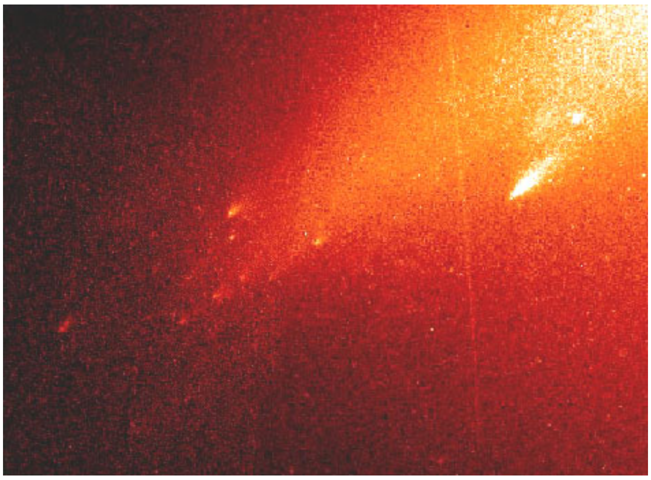


Figure 3. Comet 1999 S4 (LINEAR) Aug. 5 2000
Hubble Space Telescope WFPC2

2. Kreutz Sungrazers

The Kreutz sungrazers are a family of comets named after Heinrich Kreutz who studied the sungrazer group in the 1880's. There is one recent famous bright sungrazer Comet 1965 S1 (Ikeya-Seki) that was well observed on the Earth. These comets have similar orbits that pass through the solar atmosphere within one solar radius. It was speculated that a number of these comets were fragments of a larger comet that had split some time earlier. B. Marsden took this study further with papers in 1967 & 1989 and deduced that the comets probably originated from the breakup of a comet seen in 371 B.C. Marsden states that the subsequent comets split a number of times over successive orbits producing the many smaller sungrazers we observe today.

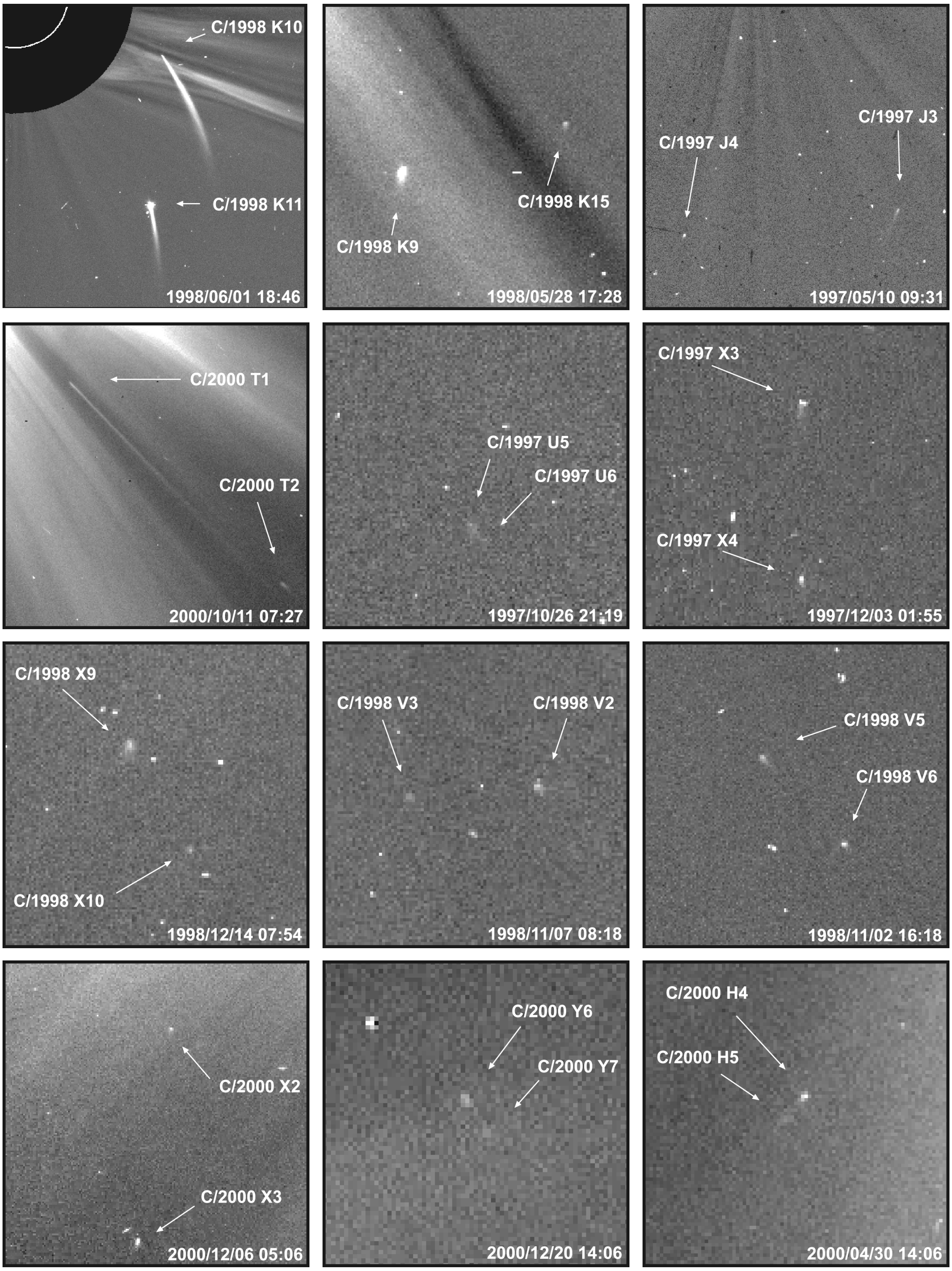
Prior to 2000 there was only one known 'twin' comet discovered on images taken by SOHO, but after the author (and others) examined four years of archive data, plus more rigorous checking of the current data, the occurrence of these multiple comets was found to be quite common, with 14 pairs of comets found (Table I). In addition, a large number of comets were also to be found in the wake of larger known comets. This implies that as a comet breaks up, the smaller fragments slowly disperse and continue to follow on behind the main body of the comet, in some cases the fragments were ahead of the main body. These comets may have been several hours apart and are not included in Table I, but are far more numerous. Not only the Kreutz sungrazers have been found to split, about 7% of comets discovered on LASCO images are not members of the Kreutz sungrazer group, but are 'normal' (or Sporadic[1]) comets that have close perihelion distances to the Sun. Of these sporadic comets, there have been two associated pairs and one double comet. The existence of these pairs could be the result of low-velocity, non-tidal fragmentation at large heliocentric distances, that have occurred after a near-perihelion splitting of progenitor fragments during their previous return to the Sun. (Sekanina, 2000).

3. Discovery of SOHO Comets

The comets are detected with two instruments on the SOHO spacecraft, LASCO (Large Angle and Spectrometric Coronagraph) C2 & C3. The C2 instrument has a field of view of approx. 3.2°, while C3 is approx. 17°. Most of the author's comets have been discovered in LASCO C2 images, as these had not previously been checked thoroughly. It is the authors opinion that most of the Kreutz sungrazers have been found in the archive LASCO C2 data, but as the whole frames were not searched thoroughly, there could be more sporadic comets to be found. There is a vast amount of data, which could take years to analyze.

[1] *Sporadic:* used in the same sense as meteors, where some meteors do not emanate from any particular point in the sky (radiant), but can appear anywhere, traveling in any direction.

Figure 4. Images of the 'Twin' and multiple comets



See Table I for the apparent separation data for each of the above comet pairs.

For more information on the discoveries and their detection see the article by Kilburn, K. J., *"Hunting for SOHO Comets Using the Internet"* in the October 2000 edition of Sky & Telescope and the authors web site.[1]

4. Comet Sizes

These are small body objects, and their size cannot be measured directly. Recent observations using the UVCS[2] instrument has enabled the SOHO team to calculate the size by measuring the ultraviolet light from hydrogen atoms, made by the breakup of water vapor released from the comet by the Sun's heat (ESA News 23/02/2001). The results show that C/2001 C2 (SOHO) was 10-20 m in diameter, this could be quite typical, some being slightly larger, but most being smaller. A previous comet C/1996 Y1 (SOHO), one of the brightest Kreutz comets observed by SOHO, was given a size of 6.7 m in diameter. (Biesecker, 2000)

5. Comet Population

Before these recent discoveries there were thought to be about 20,000 members of the Kreutz sungrazer family spread along the orbit (Biesecker, ESA press release Nr. 02-2000), but with the new data this number has increased to about 50,000.[3]

These small comets are only detected when they come close enough to the Sun to be affected by the solar radiation, as this radiation falls off at a rate inversely proportional to the square of the distance, the comets need to be very close to the Sun to get bright enough to be observed with space telescopes. A large number of small bodies in the Solar System will go undetected, as the comets may be too faint to be detected by SOHO, or they are outside the field of view. Increased sensitivity of telescopes and instrumentation, will help to discover more, but he author feels that the true number of small bodies may never be known.

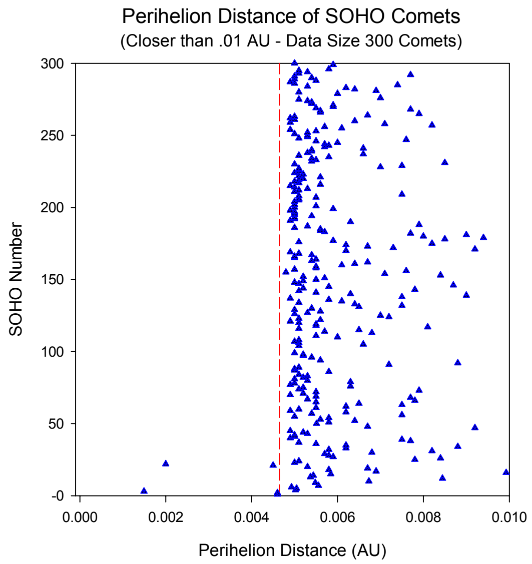


Figure 5. Shows a plot of all the SOHO Kreutz Sungrazers, the diameter of the Sun is 0.00465 AU (dashed line). Some of these comets hit the Sun but most are destroyed by passing through the corona, with very few surviving perihelion.

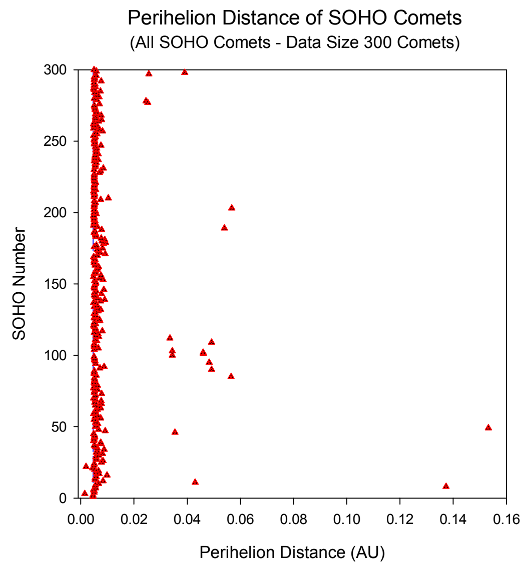


Figure 6. A plot of all the SOHO Comets including the non-Kreutz Sungrazers. One comet has been omitted from this plot as this has a perihelion distance of 1.5463 AU and was discovered with the SWAN instrument on SOHO.

The members of the Kreutz group of comets are not a threat to the Earth, as their orbit does not bring them anywhere near the Earth's orbit. Any of the sporadic comets found with SOHO could be a threat, but those found so far are not. If a comet was to approach the Sun from behind (in relation to the Earth), larger comets could be detected by SOHO and not by any other instrument. As the size of the comets only a few meters across, there is a good chance that if any of these were to hit the

[1] Mike's SOHO Comet Hunt: http://www.ph.u-net.com/comets/
[2] UVCS: Ultraviolet Coronagraph Spectrometer on SOHO.
[3] This figure assumes that the distribution of the comets along the 800 year orbit is fairly uniform.

Earth, they would not pass through the atmosphere (Melosh, 1997). Nevertheless the threat of a SOHO comet hitting the Earth is very real (albeit very small), as is impact with spacecraft. The Moon could be hit quite regularly, a small comet may not create a large crater and could go undetected. Some of the Transient Lunar Phenomena (TLP's) that some amateur astronomers have reported, could be such impacts.

6. Life in Planetary Systems

It has long been thought that molecules in comets, together with water, may have seeded life on the Earth (Hoyle, & Wickramasinghe, 1999). As the comet population is now known to be significantly larger, long after the Solar System was formed, the period of time for starting life could therefore be increased, as comets could still be depositing water and materials on planets, over a very long period of time, albeit in much reduced quantities. The extended time period is important, as this allows the newly formed planet and atmosphere to become more stable, especially after the initial bombardment in its early history, making it more receptive to life.

Recently observations of C/1999 S4 (LINEAR), with the NASA Infrared Telescope Facility (IRTF) and the W. M. Keck Observatory on Mauna Kea, Hawaii, show that it had a chemistry that indicates its water had the same isotopic composition as the water actually found on Earth. (Mumma, 2001)

Two mechanisms for depositing organic molecules from comets have recently been discussed:

6.1 Mechanism One

As comets approach the Sun, they spawn vast amounts of dust and meteoroids. Duncan Steel and Christopher McKay have shown that many may contain heavy organic compounds similar to tar. They would burn up at a lower temperature and a far higher altitude than lumps of rock or metal, releasing organic chemicals into the atmosphere, and they would take decades to float down to the surface and into oceans. These faint meteors have been detected in large numbers with Radar using the MF and HF bands as opposed to the traditional VHF band. (Steel, & McKay, 2001)

6.2 Mechanism Two

Jennifer Blank, on April 5 2001 at the national meeting of the American Chemical Society in San Diego, California, reported preliminary findings on experiments conducted to see if organic molecules in comets could withstand the severity of impact with the Earth. The tests showed that if the comet came in at an angle of less than 25 degrees from the horizontal some organic molecules would remain intact, it was also found that in the process of impact many polymerized into chains of two, three and four amino acids, so-called peptides. Peptides with longer chains are called polypeptides, while even longer ones are called proteins. The simulated comet impacts where done in a laboratory by shooting a 'soda-can sized bullet into a nickel-sized metal target' containing a teardrop of water mixed with amino acids, the building blocks of proteins.

7. Conclusion

The study of the SOHO comets shows that fragmentation is not a once only occurrence. A comet such as Comet 1999 S4 (LINEAR), that fragmented into many pieces, does not disappear, but the fragments will remain in orbit undetected due to their small size, each of these may fragment further. The Solar System is littered with such remains of comets, one obvious way in which we see the debris is in the form of meteor showers, whose origin is known without any doubt to be associated with comets. Until the recent discoveries of the SOHO comets, it may not have been appreciated that so many small bodies existed that could pose a threat to future space flight.

A huge increase in the number of comets known in the Solar System, combined with recently discovered mechanisms for depositing organic molecules from comets onto planets, gives great optimism that life may have been started by comets. This may also have been the mechanism for life to begin on other planetary systems, even though comets may well have played a part in the destruction of life on the Earth, judging by the large number of known impact craters on our planet, coupled with numerous species extinction events.

An amateur astronomer since 1985, Michael Oates is an active member of the Manchester Astronomical Society, and also a member of the BAA[1], SPA[2] and the RAS[3]. He has been awarded the David R Keedy award from the BAA Comet Section in 2000, the Steavenson prize in 2001 from the BAA and has also been made an honorary life member of the Manchester Astronomical Society for his comet discoveries. This paper is based on a paper produced for the *'Life in the Universe'* course at Jodrell Bank, Manchester University 27 April 2001.

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Internet Resources

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ESA press release Nr. 02-2000 - Paris, 8 February 2000 "100 and counting" : SOHO's score as the world's top comet finder. http://sohowww.nascom.nasa.gov/gallery/ESAPR/022000pr/
LASCO Handbook, http://lasco-www.nrl.navy.mil/handbook/hndbk.html
Photo Release No.: STScI-PRC95-41 October 10, 1995. http://oposite.stsci.edu/pubinfo/PR/2000/27/related.html
SOHO website, http://sohowww.nascom.nasa.gov/
Solar Orbiter mission, http://solarsystem.estec.esa.nl/projects/solar_orbiter.htm
Sungrazer website, http://sungrazer.nascom.nasa.gov/

Image Credits

LASCO These images were obtained by the LASCO instrument, on the SOHO satellite. The LASCO instrument was built and is operated by the LASCO consortium of the Naval Research Laboratory (Washington D.C.), The Laboratory for Space Astronomy, Marseilles (France), The Max Plank Institute for Aeronomy, Lindau (Germany) and The Department of Space Research, Birmingham (UK). SOHO is a joint ESA/NASA mission of international cooperation.

[1] BAA: British Astronomical Association.
[2] SPA: Society for Popular Astronomy.
[3] RAS: Royal Astronomical Society.

Table I
Twin[1], Multiple[2] & Associated[3] Comets
Listed in order of discovery

Date (T)	Comet A	Comet B	Apparent Separation[4] (Arc Seconds) & Instrument		Notes:
1998/06/01-02	C/1998 K10 (SOHO-54)	C/1998 K11 (SOHO-55)	2155	C2	The Original 'Twins' Also in C3
2000/02/03-07	C/2000 C2 (SOHO-100)	C/2000 C5 (SOHO-103)	-	C2	Non-Kreutz: Associated
2000/02/04-05	C/2000 C3 (SOHO-102)	C/2000 C2 (SOHO-101)	-	C2	Non-Kreutz: Associated
1998/05/29	C/1998 K9 (SOHO-53)	C/1998 K15 (SOHO-143)	1157	C2	Twin: 'The Sister Comets'
1997/05/10	C/1997 J3 (SOHO-178)	C/1997 J4 (SOHO-179)	2514	C2	Twin, 2.6 Solar radii separation
2000/10/11	C/2000 T1 (SOHO-204)	C/2000 T2 (SOHO-205)	2959	C2	Multiple: following on
1997/10/27	C/1997 U5 (SOHO-225)	C/1997 U6 (SOHO-226)	89	C2	Multiple: following on, very close.
1997/12/03	C/1997 X3 (SOHO-233)	C/1997 X4 (SOHO-234)	912	C2	Multiple: following on
1998/12/14	C/1998 X9 (SOHO-250)	C/1998 X10 (SOHO-251)	577	C2	Twin: Comet A brighter
1998/11/07	C/1998 V2 (SOHO-252)	C/1998 V3 (SOHO-253)	530	C2	Twin: Comet A brighter
1998/11/02-03	C/1998 V5 (SOHO-264)	C/1998 V6 (SOHO-265)	684	C2	Multiple: following on
2000/12/06	C/2000 X2 (SOHO-267)	C/2000 X3 (SOHO-266)	1535	C2	Multiple: following on
2000/12/20	C/2000 Y6 (SOHO-277)	C/2000 Y7 (SOHO-278)	103	C2	Non-Kreutz: Multiple: very close.
2000/04/30	C/2000 H4 (SOHO-287)	C/2000 H5 (SOHO-291)	89	C2	Multiple: following on, very close.

[1] *Twin:* two comets that appear on the same image, approximately side by side on a parallel path.
[2] *Multiple:* two or more comets that are very close and may lie within the coma or tail of another, or when one or more follow on behind, but are all on the same image.
[3] *Associated:* this applies to non-kreutz or 'sporadic' comets only, as all Kreutz comets are associated. These also include comets that are not on the same image.
[4] Separation calculated using; LASCO C2 pixel size = 11.4 arc second & C3 pixel size = 56 arc second, obtained from LASCO Handbook