Frequently Asked Questions About the Collision of Comet Shoemaker-Levy 9 with Jupiter

06.11.94 - 35 Days until Impact

The following is a list of answers to some frequently asked questions concerning the collision of comet Shoemaker-Levy 9 with Jupiter. Thanks to all those who have contributed. Contact Dan Bruton **(astro@tamu.edu)** or John Harper **(jharper@tamu.edu)** with comments, additions, corrections, etc. The PostScript version and updates of this FAQL are available via anonymous `ftp` from `tamsun.tamu.edu (128.194.15.32)` in the `/pub/comet` directory. To subscribe to the "Comet Jupiter Collision mailing list", send mail to `listproc@seds.lpl.arizona.edu` (no subject) with the message:

```
SUBSCRIBE SL9 Firstname Lastname
```

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General Questions

Q1.1: Is it true that a comet will collide with Jupiter in July 1994?

Yes, the shattered comet Shoemaker-Levy 9 (1993e) is expected to collide with Jupiter over a 5.6 day period in July 1994. The first of 21 comet fragments is expected to hit Jupiter on July 16, 1994 and the last on July 22, 1994. The 21 major fragments are denoted A through W in order of impact, with letters I and O not used. All of the comet fragments will hit on the dark farside of Jupiter. The probablility that all of the comet fragments will hit Jupiter is greater that 99.9%. The probability that any fragment will impact on the near side as viewed from the Earth is < 0.01%.

The impact of the center of the comet train is predicted to occur at about -44° Jupiter latitude at a point 67° east (toward the sunrise terminator) from the midnight meridian These impact point estimates from Sekanina, Chodas, and Yeomans are only 5º-9º behind the limb of Jupiter as seen from Earth. About 8 to 18 minutes after each fragment hits, the impact points will rotate past the limb as seen from Earth. After these points cross the limb it will take another 18 minutes before they cross the morning terminator into sunlight.

Q1.2: Who are Shoemaker and Levy?

Eugene and Carolyn Shoemaker and David H. Levy found the 13.8 magnitude comet on March 25, 1993 on photographic plates taken on March 24, 1993. The photographs were taken at Palomar Mountain in Southern California with a 0.46 meter Schmidt camera and were examined using a stereomicroscope to reveal the comet[2, 14]. James V. Scotti confirmed their discovery with the Spacewatch Telescope at Kitt Peak in Arizona. See reference [11] for more information about the discovery.

Q1.3: Where can I find a GIF image of this comet?

GIF images can be obtained from `SEDS.LPL.Arizona.EDU (128.196.64.66)` in the `/pub/astro/SL9/images` directory. Below is a list of the images at this site. The files are listed here in reverse chronological order:

```
Comet1993eA.gif  March HST image of SL9 comet train
Comet1993eB.gif  Time comparison image of SL9 comet fragment
sl90216.gif      February 16, 1994 Image from Kitt Peak (J. Scotti)
wfpclevy.gif     Photo Montage of January 24-27 Imaging of SL9 from HST
sl9hst.gif       Post-fix HST Mosaic of SL9 (Jan. 24-27)
sl90121.gif      January 21, 1994 Image from Kitt Peak (R. Jedicke)
sl9compl.gif     Six month comparison image of SL9 (Labeled)
sl9comp.gif      Six month comparison image of SL9 (Not Labeled)
1993eha.gif      View of the comet from HST
1993ehb.gif      From HST, focused on the center of the train of fragments
1993esw.gif      Ground-based view of the comet
sl03302b.gif     March 30, 1993 Image from Kitt Peak (J. Scotti)
sl9_930330.gif   March 30, 1993 image of SL9, Spacewatch Telescope-J. Scotti
sl9w_930328.gif  March 28, 1993 image of SL9
shoelevy.gif     An early GIF image of SL9
```

Some of the images are also available in PostScript form. The following is a list of other collision related GIF graphics and MPEG animations that are also available at `SEDS.LPL.Arizona.EDU:`

```
gipul.gif          Gipul Catena crater chain on Jupiter's moon, Callisto
chain.gif          Crater Chain on Jupiter's Moon, Callisto
orbtrain.gif       SL9's orbit showing the length of the train
schematic2.gif     Updated diagram of fragment positions as seen from HST
schematic1.gif     Old Schematic diagram of SL9 showing positions of fragments
approach.gif       View of last 18 hours of trajectory, from Earth
earthview.gif      Full-disk view from Earth
earthviewzoom.gif  Close-up view from Earth
vgr2view.gif       Full-disk view from Voyager 2
vgr2viewzoom.gif   Close-up view of impact sites from direction of Voyager 2
galview.gif        View from Galileo
ulysview.gif       View from Ulysses
poleview.gif       View from beneath Jupiter
orbjupplane.gif    SL9's orbit projected into Jupiter's orbit plane
orbsun.gif         SL9's orbit as seen from the Sun
earthjup.gif       Jupiter-Facing Hemispheres of Earth at Impact Times of SL9
impact.gif         Graph of impact times with moon eclipses
index.gif          Mosaic of all images in this directory
mitwave1.gif       Frame from MIT Flow Visualization Lab. Simulation
mitwave2.gif       Frame from MIT Flow Visualization Lab. Simulation
mitwave.mpg        MIT Flow Visualization Lab. Simulation Animation
vidjv.mpg          Animation of SL9 entering Jupiter's Atmosphere
visejz.mpg         Animation of explosion produced by SL9 entering Jupiter
sl9rend.gif        Rendering 3 views of comet-Jupiter collision
sl9rend1.gif       Larger rendering comet-Jupiter from Earth
sl9rend2.gif       Larger rendering comet-Jupiter from Voyager 2
sl9rend3.gif       Larger rendering comet-Jupiter from south pole
```

Q1.4: What will be the effect of the collision?

As seen from the Earth, the fragments will disappear behind the limb of Jupiter only 5 to 15 seconds before impact. The later fragments will be visible closer to impact. Fragment W will disappear only 5 seconds before impact, at an altitude of only about 200 km above the 1-bar pressure level: it may well start its bolide phase while still in view. Furthermore, any sufficiently dense post-impact plume will have to rise only a few hundred kilometers to be visible from Earth.

Simulations by Mark Boslough and others indicate that when the fireball resulting from an impact cools it will form a debris cloud that will rise hundreds of kilometers above the Jovian cloudtops, and will enter sunlight within minutes of the impact. The arrival time of this giant cloud into sunlight would provide data on its trajectory, which in turn would help us know how big the comet fragment was. It is possible that it would be big (bright) enough to be seen by amateurs [40,41]. Mark Boslough of Sandia National Laboratories also states that the probability is very high that these effects will be visible for some of the later impacts (e.g. W and R, visible from Hawaii, S, visible from India and the far East, Q1 and Q2, visible from Africa, parts of eastern Europe and the Middle East, L, Brazil and West Africa, K, South Pacific and Australia, and maybe even V, on the final night, visible in the Western half of the U.S.). Observers in these locations are encouraged to anticipate the possibility of seeing the fireball within tens of seconds after the impact, and a few minutes later after it has cooled, condensed, and entered the sunlight.

Each comet fragment will enter the atmosphere at a speed of 130,000 mph (60 km/s). At an altitude of 100 km above the visible cloud decks, aerodynamic forces will overwhelm the material strength of the comet, beginning to squeeze it and tear it apart. Five seconds after entry, the comet fragment will deposit its kinetic energy of around 10^{28} ergs (equivalent to around 200,000 megatons of TNT) at 100 - 150 km below the cloud layer [19]. Bigger fragments will have more energy and go deeper.

The hot (30,000 K) gas resulting from the stopped comet will explode, forming a fireball similar to a nuclear explosion, but much larger. The visible fireball will only rise 100 km or so above the cloudtops. Above that height the density will drop so that it will become transparent. The fireball material will continue to rise, reaching a height of perhaps 1000 km before falling back down to 300 km. The fireball will spread out over the top of the stratosphere to a radius of 2000 - 3000 km from the point of impact (or so the preliminary calculations say). The top of the resulting shock wave will accelerate up out of the Jovian atmosphere in less than two minutes, while the fireball will be as bright as the entire sunlit surface of Jupiter for around 45 sec [18]. The fireball will be somewhat red, with a characteristic temperature of 2000 K - 4000 K (slightly redder than the sun, which is 5000 K). Virtually all of the shocked cometary material will rise behind the shock wave, leaving the Jovian atmosphere and then splashing back down on top of the stratosphere at an altitude of 300 km above the clouds [unpublished simulations by Mac Low & Zahnle]. Not much mass is involved in this splash, so it will not be directly observable. The splash will be heavily enriched with cometary volatiles such as water or ammonia, and so may contribute to significant high hazes.

Meanwhile, the downward moving shock wave will heat the local clouds, causing them to buoyantly rise up into the stratosphere. This will allow spectroscopists to attempt to directly study cloud material, a unique opportunity to confirm theories of the composition of the Jovian clouds. Furthermore, the downward moving shock may drive seismic waves (similar to those from terrestrial earthquakes) that might be detected over much of the planet by infrared telescopes in the first hour or two after each impact. The strength of these two effects remains a topic of research. The disturbance of the atmosphere will drive internal gravity waves ("ripples in a pond") outwards. Over the days following the impact, these waves will travel over much of the planet, yielding information on the structure of the atmosphere if they can be observed (as yet an open question).

The "wings" of the comet will interact with the planet before and after the collision of the major fragments. The so-called "wings" are defined to be the distinct boundary along the lines extending in both directions from the line of the major fragments; some call these 'trails'. Sekanina, Chodas and Yeomans have shown that the trails consist of larger debris, not dust: 5-cm rock-sized material and bigger (boulder-sized and building-sized). Dust gets swept back above (north) of the trail-fragment line due to solar radiation pressure. The tails emanating from the major fragments consist of dust being swept in this manner. Only the small portion of the eastern debris trail nearest the main fragments will actually impact Jupiter, according to the model, with impacts starting only a week before the major impacts. The western debris trail, on the other hand, will impact Jupiter over a period of months following the main impacts, with the latter portion of the trail actually impacting on the front side of Jupiter as viewed from Earth.

The injection of dust from the wings and tail into the Jovian system may have several consequences. First, the dust will absorb many of the energetic particles that currently produce radio emissions in the Jovian magnetosphere.

The expected decline and recovery of the radio emission may occur over as long as several years, and yield information on the nature and origin of the energetic particles. Second, the dust may actually form a second faint ring around the planet.

Q1.5: Can I see the effects in my telescope?

One might be able to detect atmospheric changes on Jupiter using photography or CCD imaging. It is important, however, to observe Jupiter for several months in advance in order to know which features are due to impacts and which are naturally occurring. It appears more and more likely that most effects will be quite subtle. Without a large (> 15" ?) telescope and good detector, little is likely to be seen.

It is possible that the impacts may create a new, temporary storm at the latitude of the impacts. Modeling by Harrington et al. suggests this is possible [30]. The 21 nuclei of comet Shoemaker-Levy 9 will strike just south of the South Temperate Zone of Jupiter. Reta Beebe of New Mexico State points out that if the nuclei penetrate deep enough, water vapor may shoot high into the atmosphere where it could turn into a bluish shroud over a portion of the South Temperate Zone [31].

Impacts of the largest fragments may create one or two features. A spot might develop that could be a white or dark blue nodule and would likely have a maximum diameter of 2,000 km to 2,500 km which in a telescope would be 1" to 1.5" across. This feature would be very short-lived with the impact site probably returning to normal after just a few rotations of Jupiter. A plume might also develop that would look dark against the South Temperate Zone's white clouds or could appear as a bright jet projected from Jupiter limb [31].

The table below shows the approximate sizes of features that already exist on Jupiter for comparison.

FEATURE	SIZE ESTIMATES
Great Red Spot	29000 by 12000 km [32]
White Spots FA,BC,DE	7500 by 3000 km
Shadows of Io, Europa, and Ganymede	4300, 4200, 7100 km

Below is a list of files available at tamsun.tamu.edu in the /pub/comet directory that may be helpful in identifying features on Jupiter:

```
tracker2.zip     DOS program that displays the location of the impact sites
may1994.transit  Transit Times for Red Spot and White Spots for May 1994
may1994.moons    Jovian Moon events for May 1994 (Shadows, Eclipses, etc.)
meridian.bas     PC BASIC Program, System I & II Long. for Central Meridian
redspot.bas      PC BASIC Program; Location of GRS; System I and II Long.
redtran.bas      PC BASIC Program; Transit times of the GRS
jupe.description Description of a PC program showing features of Jupiter
```

Also, there are little anticyclonic ovals at latitudes of about -41 degrees which are typical of the South South Temperate domain. There are usually 6 or 7 around the planet and they move with the South South Temperate current, i.e. faster than BC and DE. See [38] for an photo of these ovals by Don Parker.

Specifics

Q2.1: What are the impact times and impact locations of each comet fragment?

This information was provided P.W. Chodas and D.K. Yeomans (JPL/Caltech):

```
Predicted Impact Parameters for Fragments of P/Shoemaker-Levy 9
P.W. Chodas and D.K. Yeomans (JPL/Caltech)
Predictions as of 1994 June 3
Date of last astrometric data in these solutions: 1994 June 1
```

Immediately to the right of the predicted impact times, we give the 1-sigma uncertainties in those times for all fragments except Q2. We have made an effort to make these uncertainties realistic: they are not formal uncertainty values. NOTE: To obtain a 95% confidence level, one should use a +/- 2 sigma window around the predicted impact time. The uncertainties for fragment Q2 have not been quantified, but are probably comparable to those for P2.

The dynamical model used for the predictions includes perturbations due to the Sun, planets, Galilean satellites and the oblateness of Jupiter. The planetary ephemeris used was DE245.

Fragment	Impact Date/Time July	(UT)	1-sig Unc. (min)	Jovicentric Lat. (deg)	Long. (deg)	Meridian Angle (deg)	Angle E-J-F (deg)	Orbit Ref.
		h	m					
A = 21	16	19:55	26	-43.23	176	63.56	99.35	A10
B = 20	17	03:07	23	-43.45	77	63.67	99.22	B11
C = 19	17	06:59	24	-43.33	217	64.53	98.64	C8
D = 18	17	11:18	28	-43.34	14	63.49	99.36	D9
E = 17	17	15:30	17	-43.70	164	66.13	97.41	E25
F = 16	18	00:40	23	-43.79	139	64.17	98.77	F16
G = 15	18	07:52	16	-43.80	37	66.99	96.77	G25
H = 14	18	19:47	16	-43.86	109	67.32	96.52	H23
K = 12	19	10:39	16	-43.96	287	68.15	95.90	K24
L = 11	19	22:40	16	-44.07	2	68.95	95.31	L25
N = 9	20	10:21	26	-44.59	67	67.13	96.49	N12
P2= 8b	20	15:27	25	-44.82	253	66.46	96.91	P11
Q2= 7b	20	19:49		-44.48	48	69.27	95.00	
Q1= 7a	20	20:16	15	-44.20	64	69.69	94.75	Q27
R = 6	21	05:59	19	-44.27	57	70.24	94.34	R22
S = 5	21	15:46	17	-44.26	51	70.76	93.97	S32
T = 4	21	18:16	44	-45.28	145	67.43	96.14	T7
U = 3	22	00:25	85	-45.19	3	71.74	93.15	U6
V = 2	22	04:06	31	-44.52	141	68.16	95.77	V8
W = 1	22	08:34	19	-44.29	299	71.32	93.57	W25

Notes:

1. Fragments J=13 and M=10 are omitted because they have faded from view. Fragments P=8 and Q=7 each consist of multiple components. The March'94 HST image shows that P1=8a has almost completely faded away (so it too is omitted from the Table), and that P2=8b has split. We do not as yet have sufficient data to obtain independent predictions for the two components of P2=8b.

2. The impact date/time is the time the impact would be seen at the Earth (if the limb of Jupiter were not in the way); the date is the day in July 1994; the time is given as hours and minutes of Universal Time.

3. The impact latitude is Jovicentric (latitude measured at the center of Jupiter); the Jovigraphic latitudes are about 3.84 deg more negative.

4. The impact longitude is in System III, measured westwards on the planet.

5. The meridian angle is the Jovicentric longitude of impact measured from the midnight meridian towards the morning terminator. This relative longitude is known much more accurately than the absolute longitude.

6. Angle E-J-F is the Earth-Jupiter-Fragment angle at impact; values greater than 90 deg indicate a farside impact. All impacts will be just on the farside as viewed from Earth; later impacts are closer to the limb.

7. The angle of incidence of the impacts is between 41 and 42 degrees

for all the fragments.

The following are the 1-sigma (uncertainty) predictions for the fragment impact times:

```
on March 1          -  30 min
on May 1            -  24 min
on June 1           -  16 min
on July 1           -  10 min
on July 15          -   6 min
at impact - 18 hr   -   3 min
```

The time between impacts is thought to be known with more certainty than the actual impact times. This means that if somehow the impact time of the first fragment can be measured experimentally, then the impact times of the fragments that follow can be predicted with more accuracy.

Q2.2: Can the effects of the collision be observed with radio telescopes?

The cutoff of radio emissions due to the entry of cometary dust into the Jovian magnetosphere during the weeks around impact may be clear enough to be detected by small radio telescopes. Furthermore, impacts may be directly detectable in radio frequencies. Some suggest to listen in on 15-30 MHz during the comet impact. So it appears that one could use the same antenna for both the Jupiter/Io phenomenon and the Jupiter/comet impact. There is an article in *Sky & Telescope* magazine which explains how to build a simple antenna for observing the Jupiter/Io interaction [4,24,25]. This antenna is less directional than a dipole or long-wire antenna.

For those interested in radio observations during the SL9 impact, Leonard Garcia of the University of Florida has made some information available. The following files are available via anonymous ftp on the University of Florida, Department of Astronomy site `astro.ufl.edu` in the `/pub/jupiter` directory:

```
README.DOC      Explanation of predicted Jupiter radio storms tables
jupradio.txt    Jovian Decametric Emission and the SL9/Jupiter Collision
jupradio.ps     Postscript version of jupradio.txt
hist.ps         Histogram of occurrence probabilities of Jupiter radio
                      emission at different frequencies.
may94.txt       Tables of predicted Jupiter radio storms for May 1994
june94.txt      Tables of predicted Jupiter radio storms for June 1994
july94.txt      Tables of predicted Jupiter radio storms for July 1994
```

The antenna required to observe Jupiter may be as simple as a dipole antenna constructed with two pieces of wire 11 feet 8.4 inches in length, connected to a 50 ohm coax cable. This antenna should be laid out on a East-West line and raised above the ground by at leat seven feet. The Directional Discontinutiy Ring Radiator (DDRR) antenna is also easy to construct and can be made from 1/2 inch copper tubing 125.5 inches in length (21Mhz). The copper tube should be bent into a loop and placed 5 inches above a metallic screen. A good preamp is required for less sensitive shortwave receivers [39].

Q2.3: Will light from the explosions be reflected by any of Jupiter's moons?

The following information was provided by John Spencer, 11 Apr 1994:

```
COMET IMPACT SATELLITE REFLECTIONS

Here's an updated table of satellite reflector availability, based on
the latest (1994/02/23) Chodas and Yeomans ephemerides.  Times haven't
changed much but uncertainties have gone down.  No impact times are yet
available for P1=8a and Q2=7b.

In the table, a "+" next to the orbital longitude means that the
impact will be visible from the satellite.  Longitudes greater than 90
degrees will be less useful as the phase angle of the reflected light
```

(to first order, equal to the longitude) will be high and its brightness will be greatly reduced. An "e" means the satellite will be visible in eclipse, allowing higher sensitivity observations, and an "o" means it will be occulted by Jupiter. I've included Callisto (J4) for completeness but it's likely to be too far out to be useful- the same may be true for Ganymede (J3).

	UT date of impact	Bright -ness	Satellite Orbital Longitudes (degrees past superior conj.)				
Nucleus	(July)	Index	J5	J1	J2	J3	J4
A=21	16.81	1	193	340	103+	75+	35+
B=20	17.11	1	50+	41+	133+	90+	42+
C=19	17.27	1	165	74+	149+	98+	45+
D=18	17.48	1	317	116+	171	109+	50+
E=17	17.61	2	51+	143+	184	116+	52+
F=16	18.02	2	347o	226	225	136+	61+
G=15	18.30	3	190	283	254	150+	67+
H=14	18.78	3	177	21+	302	174	78+
K=12	19.42	3	279	151+	7e	207	91+
L=11	19.89	3	259	246	55+	230	101+
N=9	20.41	1	274	352o	107+	256	113+
P2=8b	20.61	2	59+	33+	128+	266	117+
P1=8a		1					
Q2=7b		2					
Q1=7a	20.80	3	196	72+	147+	276	121+
R=6	21.28	2	183	169+	196	300	131+
S=5	21.61	3	61+	236	229	317	138+
T=4	21.75	1	162	265	243	324	141+
U=3	21.88	1	256	291	256	330	144+
V=2	22.18	2	113+	352o	287	345	151+
W=1	22.32	2	214	21+	301	352+	154+
Uncertainties (1-sigma):							
	0.03	1	22	6	3	1.5	1

As before, the "brightness index" subjectively rates comet fragment brightnesses, 3 being brightest. Brightnesses are eyeballed from the press-released HST image where possible and are different from those in previous versions of the table.

There's a good chance that reflections from the impact of the bright fragment K=12 will be visible off Europa in eclipse, very close to Jupiter: this impact can be seen in a dark sky from Australia, New Zealand, and Hawaii.

Given the uncertainties, there's nearly a 50% chance that the impact of either H=14 (a bright fragment) or W=1 will be seen reflected off Io in eclipse. The H=14 impact will be visible in darkness from East and South Africa, and the middle East, the W=1 impact from New Zealand and Hawaii.

The table below gives the orbital longitudes (in degrees) of satellites when in Jupiter eclipse and occultation (used to annotate the above table). Values should be good to about one degree.

Satellite	Occulted	Eclipsed
J5: Amalthea	337 - 023	023 - 034
J1: Io	351 - 009	009 - 020
J2: Europa	355 - 005	005 - 016

```
J3: Ganymede   358 - 002  009 - 013
J4: Callisto   No occultations or eclipses
-----------------------------------
```

One may be able to witness the collisions indirectly by monitoring the brightness of the Galilean moons that may be behind Jupiter as seen from Earth. One could monitor the moons using a photometer, a CCD camera, or a video camera. However, current calculations suggest that the brightenings may be as little as 0.05% of the sunlit brightness of the moon [18]. If a moon can be caught in eclipse but visible from the earth during an impact, prospects will improve significantly. According to current predictions, the only impact certain to occur during a satellite eclipse is K=12 with Europa eclipsed. However, H=14 and W=1 impact only about 2 sigma after Io emerges from eclipse at longitude 20 deg, and B=20, E=17 and F=16 impact 0.5-2 sigma after Amalthea emerges from eclipse at longitude 34 deg.

The following files contain information concerning the reflection of light by Jupiter's moons and are available at `seds.lpl.arizona.edu`:

```
impact_24apr.ps   PostScript Plot of impact times at satellite availability
jsat8.export      Jovian satellite locations (condensed version)
jsat8. full       Jovian satellite locations (full version)
impacts.940423    More on Jovian Satellites
galsat51.zip      MSDOS Program that Displays relative positions of
                   Jupiter's Moons during times of impact
```

Q2.4: What are the orbital parameters of the comet?

Comet Shoemaker-Levy 9 is actually orbiting Jupiter, which is most unusual: comets usually just orbit the Sun. Only two comets have ever been known to orbit a planet (Jupiter in both cases), and this was inferred in both cases by extrapolating their motion backwards to a time before they were discovered. S-L 9 is the first comet observed while orbiting a planet. Shoemaker-Levy 9's previous closest approach to Jupiter (when it broke up) was on July 7, 1992 according to the new solution; the distance from the center of Jupiter was about 96,000 km, or about 1.3 Jupiter radii. The comet is thought to have reached apojove (farthest from Jupiter) on July 14, 1993 at a distance of about 0.33 Astronomical Units from Jupiter's center. The orbit is very elliptical, with an eccentricity of over 0.995. Computations by Paul Chodas, Zdenek Sekanina, and Don Yeomans suggest that the comet has been orbiting Jupiter for 20 years or more, but these backward extrapolations of motion are highly uncertain. See `elements.940422` and `ephemeris.940422` at `seds.lpl.arizona.edu` for more information.

In the abstract "The Orbit of Comet Shoemaker-Levy 9 about Jupiter" by D.K. Yeomans and P.W. Chodas (1994, BAAS, 26, 1022), the elements for the brightest fragment Q are listed. These elements are Jovicentric and for Epoch 1994Jul15.

```
1994 Periapses      Jul 20.7846
Eccentricity        0.9987338
Periapses dist.     34776.7 km
Arg. of periapses   43.47999
Long. of asc. node  290.87450
inclination         94.23333
```

Q2.5: Why did the comet break apart?

The comet is thought to have broken apart due to tidal forces on its closest approach to Jupiter (perijove) on July 7, 1992, when it passed well within the theoretical Roche limit of Jupiter. Shoemaker-Levy 9 is not the first comet observed to break apart. Astronomers believe that in 1886 Comet Brooks 2 was ripped apart by tidal forces near Jupiter [2], and in 1976 Comet West shattered near the Sun [3].

Furthermore, images of Callisto and Ganymede show crater chains which may have resulted from the impact of a comet similar to Shoemaker-Levy 9 [3, 17]. The satellite with the best example of aligned craters is Callisto with 13 crater chains. There are three crater chains on Ganymede. These were first thought to be from basin ejecta; in other words secondary craters. See [27 for more photos of crater chains.

There are also a few examples on our Moon. Jay Melosh and Ewen Whitaker have identified two possible crater chains on the moon which would be generated by near-Earth tidal breakup. One is called the "Davy chain" and is very tiny but shows up as a small chain of craters aligned back toward Ptolemaeus. In near opposition images, it appears as a high albedo line; in high phase angle images, you can see the craters themselves. The second is between Almanon and Tacitus and is larger (comparable to the Ganymede and Callisto chains in size and length).

Q2.6: What are the sizes of the fragments?

Using measurements of the length of the train of fragments and a model for the tidal disruption, J.V. Scotti and H.J. Melosh have estimated that the parent nucleus of the comet (before breakup) was only about 2 km across [13]. This would imply that the individual fragments are no larger than about 500 meters across. However, images of the comet taken with the Hubble Space Telescope in July 1993 indicate that the fragments are 3 - 4 km in diameter (based on their brightness). A more elaborate tidal disruption model by Sekanina, Chodas and Yeomans [20] predicts that the original comet nucleus was at least 10 km in diameter. This means the largest fragments could be 3 - 4 km across, a size consistent with estimates derived from the Hubble Space Telescope's July 1993 observations.

The new images, taken with the Hubble telescope's new Wide Field and Planetary Camera-II instrument on January 24 - 27, 1994, have given us an even clearer view, which should allow a refinement of the size estimates. In addition, the new images show strong evidence for continuing fragmentation of some of the remaining nuclei, which will be monitored by the Hubble telescope over the next several months.

Q2.7: How long is the fragment train?

The angular length of the train was about 51 arcseconds in March 1993 [2]. The length of the train then was about one half the Earth-Moon distance. In the day just prior to impact, the fragment train will stretch across 20 arcminutes of the sky, more that half the Moon's angular diameter. This translates to a physical length of about 5 million kilometers. The train expands in length due to differential orbital motion between the first and last fragments. Here is a table with data on train length based on Sekanina, Chodas, and Yeomans's tidal disruption model:

Date	Angular Length (arcsec)	Physical Length (km)
93 Mar 25	49	158,000
Jul 1	67	265,000
94 Jan 1	131	584,000
Feb 1	161	669,000
Mar 1	200	762,000
Apr 1	255	893,000
May 1	319	1,070,000
Jun 1	400	1,366,000
Jul 1	563	2,059,000
Jul 15	944	3,593,000
Impact A	1286	4,907,000

Q2.8: Will Hubble, Galileo, etc. be able to observe the collisions?

The Hubble Space Telescope, like earthlings, will not be able to see the collisions but will be able to monitor atmospheric changes on Jupiter. The new impact points are more favorable for viewing from spacecraft: it can now be stated with certainty that the impacts will all be visible to Galileo, and now at least some impacts will be visible to Ulysses. Although Ulysses does not have a camera, it will monitor the impacts at radio wavelengths.

Galileo will get a direct view of the impacts rather than the grazing limb view previously expected. The Ida image data playback is scheduled to end at the end of June, so there should be no tape recorder conflicts with observing the comet fragments colliding with Jupiter. The problem is how to get the most data played back when Galileo will only be transmitting at 10 bps (bits/second). One solution is to have both Ulysses and Galileo record the event and and store the data on their respective tape recorders. Ulysses observations of radio emissions data will be

played back first and will at least give the time of each comet fragment impact. Using this information, data can be selectively played back from Galileo's tape recorder. From Galileo's perspective, Jupiter will be 60 pixels wide and the impacts will only show up at about 1 pixel, but valuable science data can still collected in the visible and IR spectrum along with radio wave emissions from the impacts. (See galileo.txt at seds.lpl.arizona.edu for more information.

The impact points are also viewable by both Voyager spacecraft, especially Voyager 2. Jupiter will appear as 2.5 pixels from Voyager 2's viewpoint and 2.0 pixels from Voyager 1. However, it is doubtful that the Voyagers will image the impacts because the onboard software that controls the cameras has been deleted, and there is insufficient time to restore and test the camera software. The only Voyager instruments likely to observe the impacts are the ultraviolet spectrometer and the planetary radio astronomy instrument. Voyager 1 will be 52 AU from Jupiter and will have a near-limb observation viewpoint. Voyager 2 will be in a better position to view the collision from a perspective of looking directly down on the impacts, and it is also closer at 41 AU.

Q2.9: To whom can I report my observations?

Observation forms by Steve Lucas are available via `ftp` at `tamsun.tamu.edu` in the `/pub/comet` directory. These forms also contain addresses of "Jupiter Watch Program" section leaders. `jupcom.zip` contains Microsoft Write files. The Association of Lunar and Planetary Observers (ALPO) will distribute a handbook to interested observers. The handbook "The Great Crash of 1994" is available for $10 from:

ALPO Jupiter Recorder
Phillip W. Budine
R.D. 3, Box 145C
Walton, NY 13856 U.S.A.

The cost includes printing, postage and handling.

John Rogers, the Jupiter Section Director for the British Astronomical Association, will be collecting data from regular amateur Jupiter observers in Britain and worldwide. He can be reached via email **(jr@mole.bio.cam.ac.uk)** or fax `(UK [223] 333840)`. For other addresses see page 44 of the January 1994 issue of *Sky & Telescope* magazine [14].

Q2.10: Where can I find more information?

The SL9 educator's book put out by JPL is in the `/pub/astro/SL9/EDUCATOR` directory of `seds.lpl.arizona.edu`.See also "factsheet.txt" or "factsheet.ps" in the /pub/astro/SL9/info directory of this site.

There are two technical papers [18,19] on the atmospheric consequences of the explosions available via anonymous ftp from oddjob.uchicago.edu in the pub/jupiter directory. The paper and figures are available in UNIX compressed PostScript format; a couple of the computational figures are also available in TIFF format.

SEDS (Students for the Exploration and Development of Space) has set up an anonymous account which allows you to use "lynx" - a VT100 WWW browser. To access this service, telnet to `seds.lpl.arizona.edu` and login as "www" (no password required). This will place you at the SEDS home page, from which you can select Shoemaker-Levy 9. A similar "gopher" interface is available at the same site. Just login as "gopher".

Below is a list of FTP and WWW sites with SL9 information:

FTP SITE NAME	IP ADDRESS	DIRECTORY	CONTENTS
seds.lpl.arizona.edu	(128.196.64.66)	/pub/astro/SL9	Images & Info
tamsun.tamu.edu	(128.194.15.32)	/pub/comet	Images & Info
oddjob.uchicago.edu		/pub/jupiter	Article & figures
jplinfo.jpl.nasa.gov	(137.78.104.2)	/news and /images	Images
ftp.cicb.fr	(129.20.128.34)	/pub/Images/ASTRO/hst	Images

WORLD WIDE WEB SITES	CONTENTS

```
http://seds.lpl.arizona.edu/sl9/sl9.html                          Images and Info
http://pscinfo.psc.edu/general/research/mac_low/mac_low.html      Animations
http://info.cv.nrao.edu/staff/pmurphy/jove-comet-wham-2.html      Info and Images
```

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