OJ287 binary black hole system

Mauri Valtonen

Tuorla Observatory

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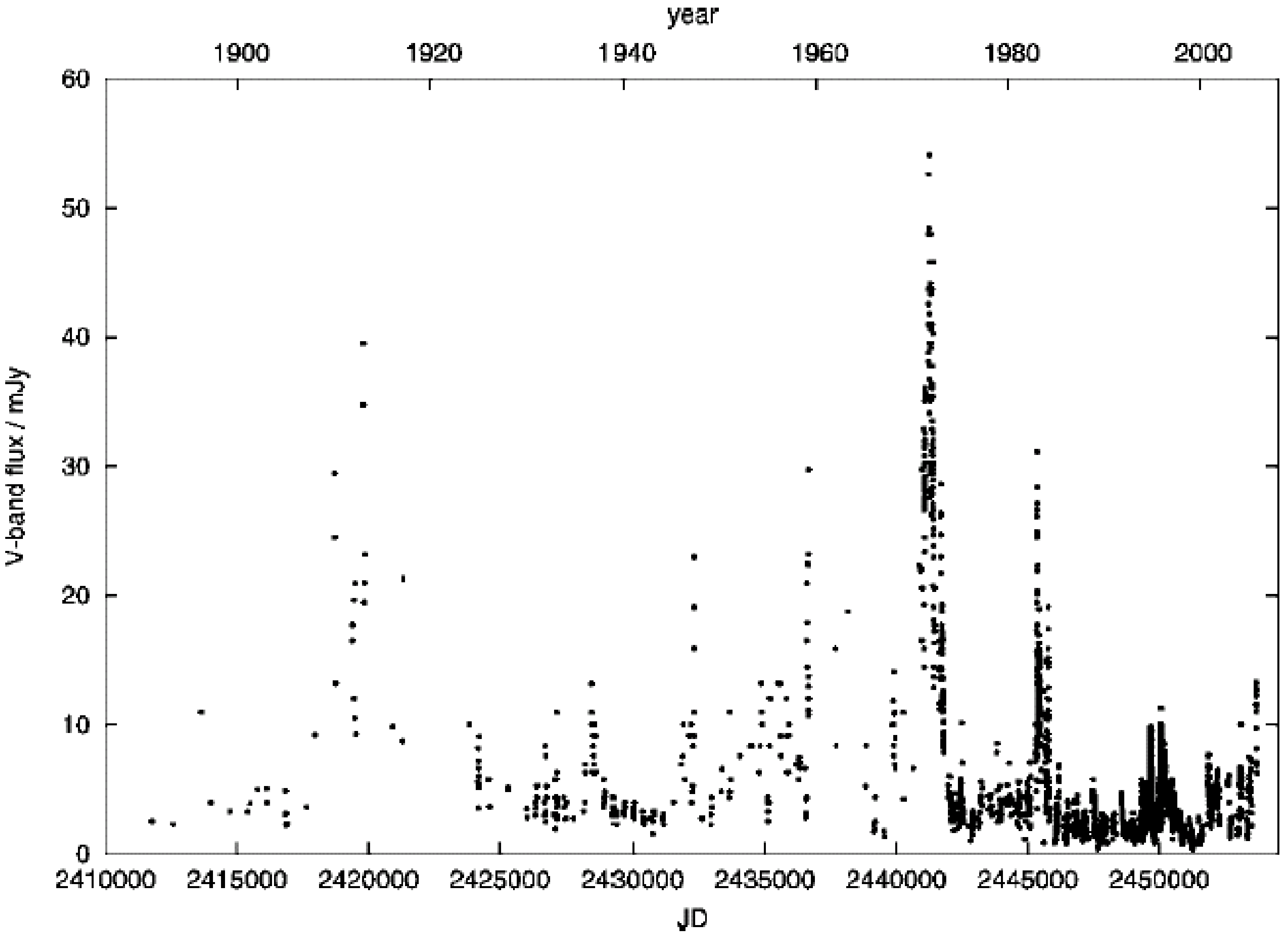
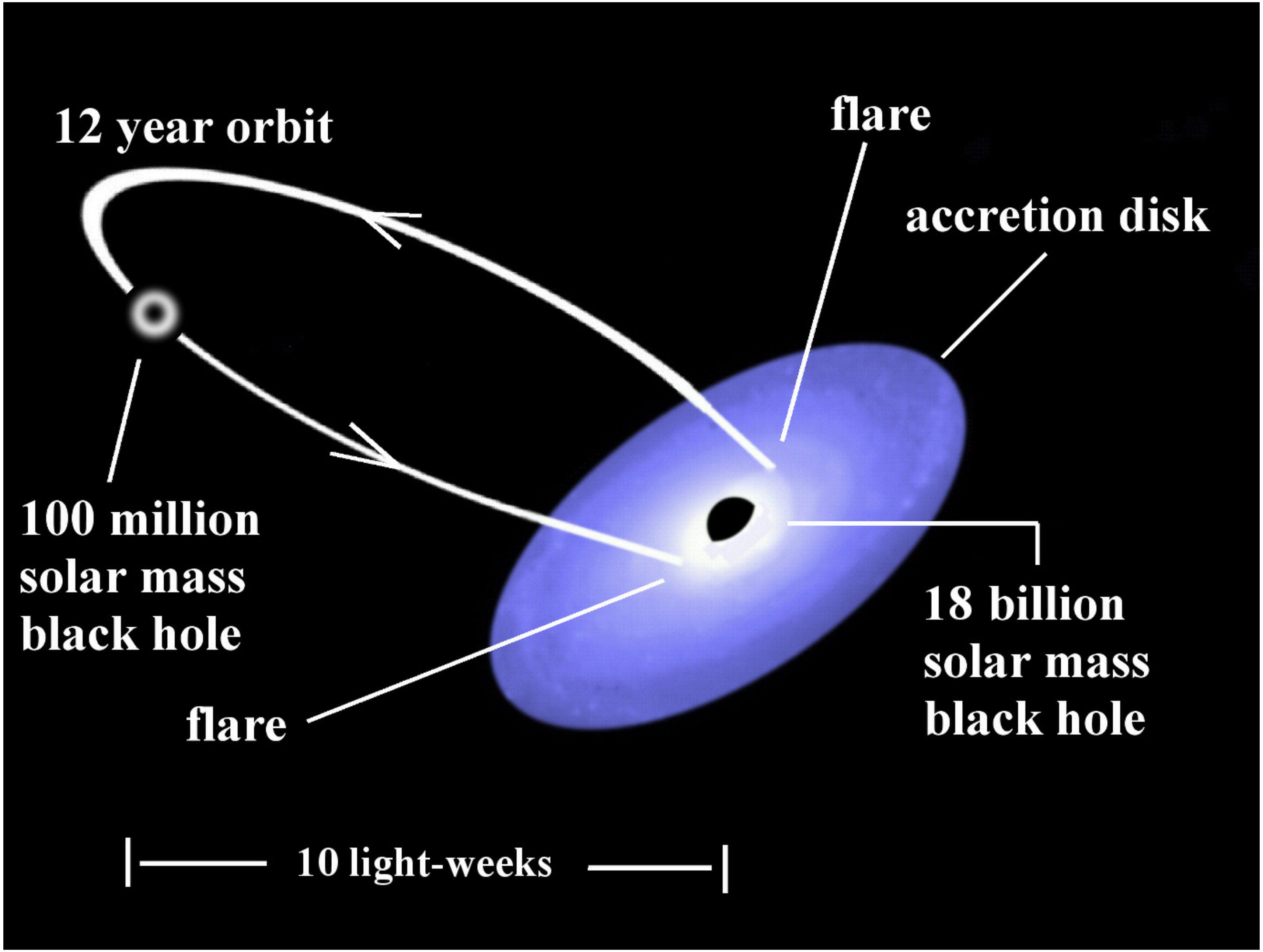
OJ287 historical light curve




12 year orbit
flare
accretion disk
100 million
solar mass
black hole
18 billion
solar mass
black hole
flare
10 light-weeks

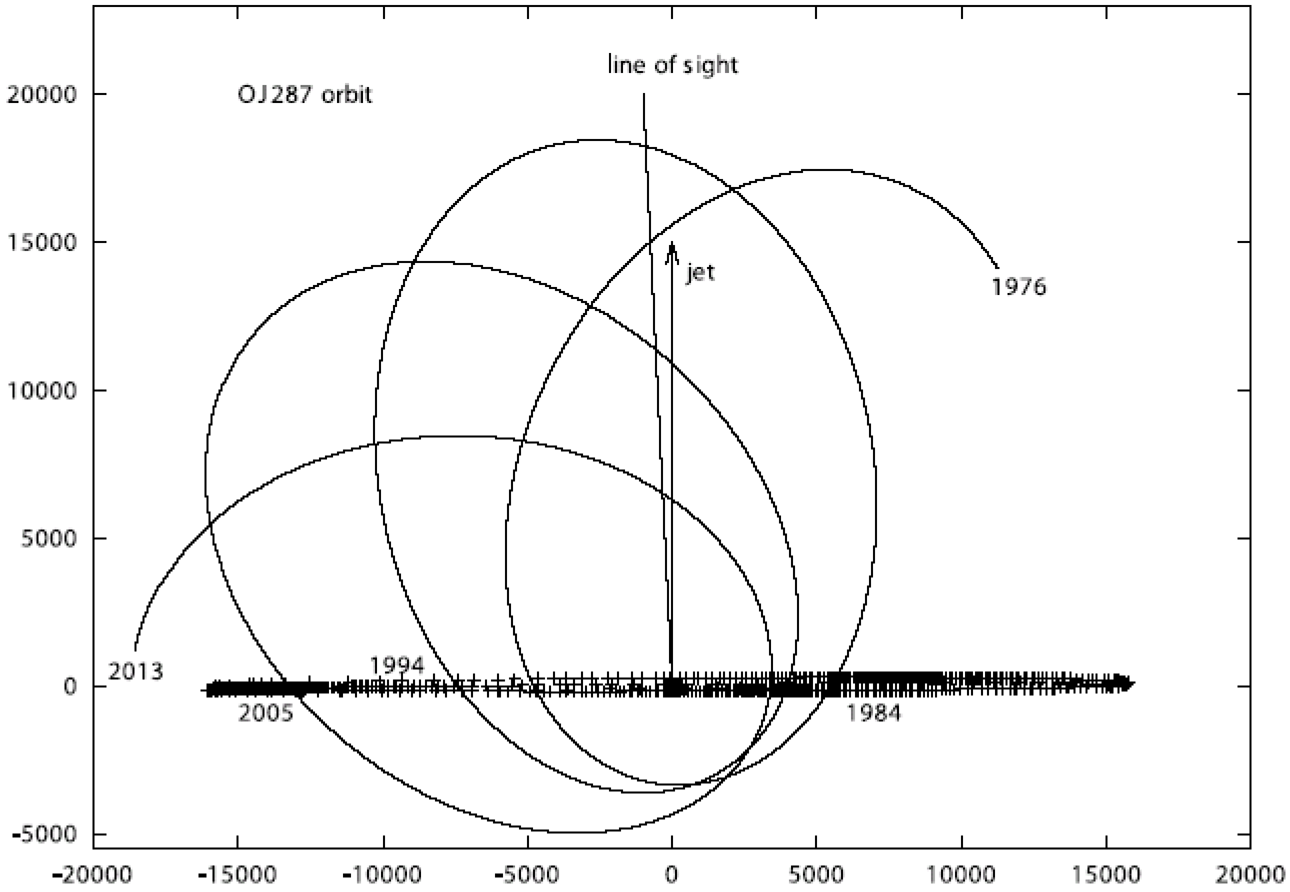
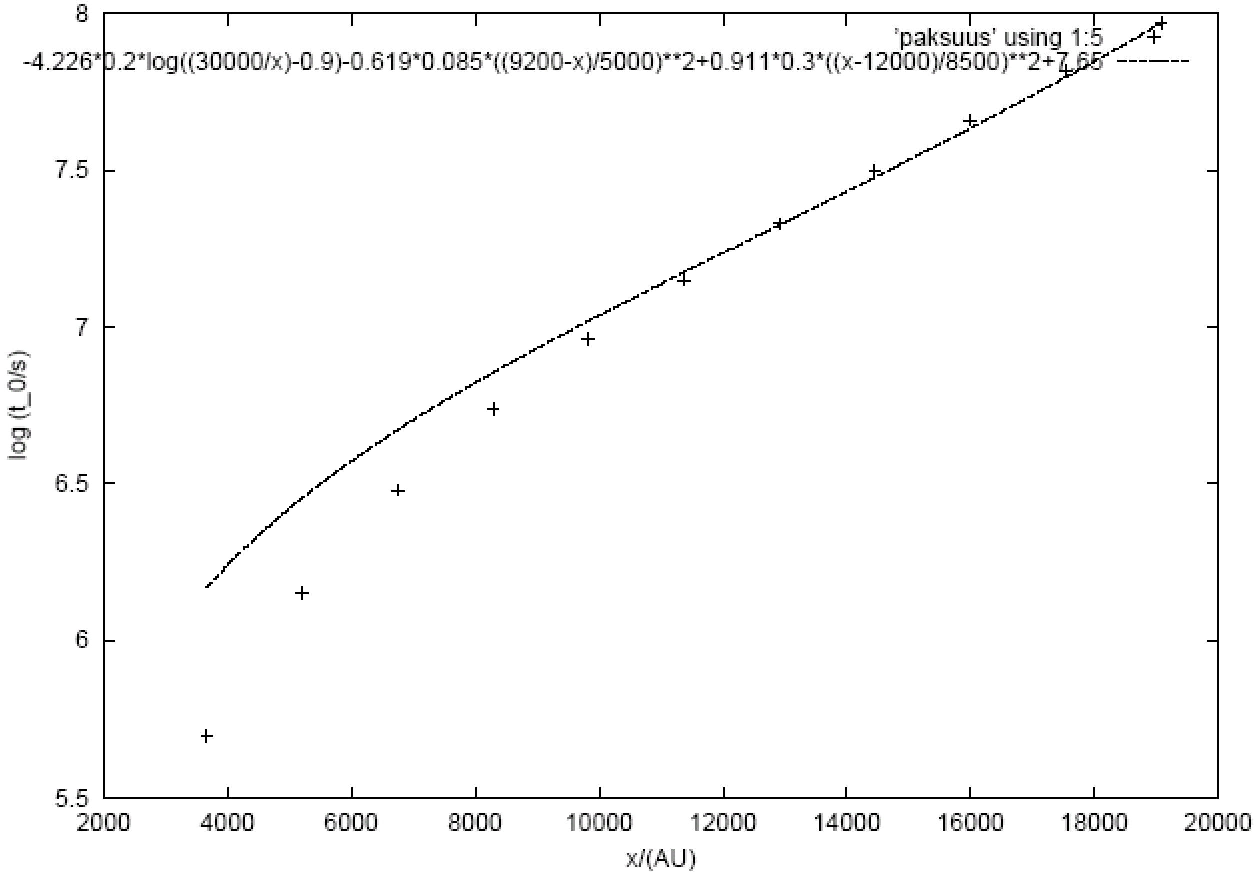


FIG. 1.—Precessing-binary model of OJ 287. The primary black hole is at coordinates (0, 0). The secondary black hole traces out a precessing elliptical orbit counterclockwise around the primary, illustrated here from 1976 to 2013. The secondary crosses the accretion disk of the primary (*horizontal set of points*) at impact sites; the 1984, 1994, and 2005 impacts are labeled. The axis of the accretion disk is labeled "jet." Not far from the jet is the line of sight to the observer. The binary orbit is at right angles to the accretion disk; Sundelius et al. (1997) have shown that this is not a restriction on the generality of the model, i.e., different relative inclinations would produce very similar results.

Unique solution

- Six outbursts ->
- Five orbit parameters
- Primary = 1.8 10^{10} Solar mass
- Eccentricity = 0.68
- Orbit phase
- Precession rate = 39 degrees/period
- Disk half-thickness = 250 AU
- Uses PN2.5 level integrator from Mikkola

Time delay



'paksuus' using 1:5
-4.226*0.2*log((30000/x)-0.9)-0.619*0.085*((9200-x)/5000)**2+0.911*0.3*((x-12000)/8500)**2+7.65
log (t_0/s)
x/(AU)
8
7.5
7
6.5
6
5.5
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000

Particle model for the disk

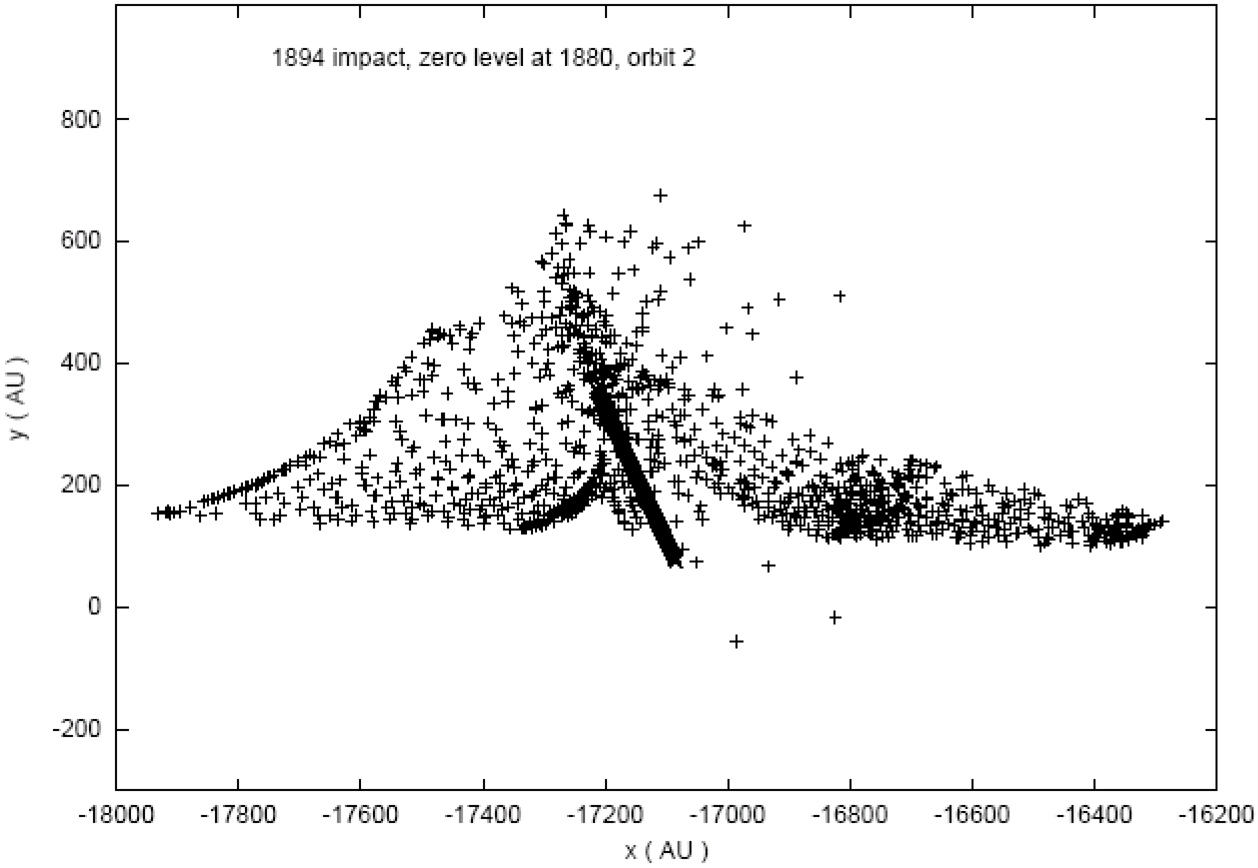


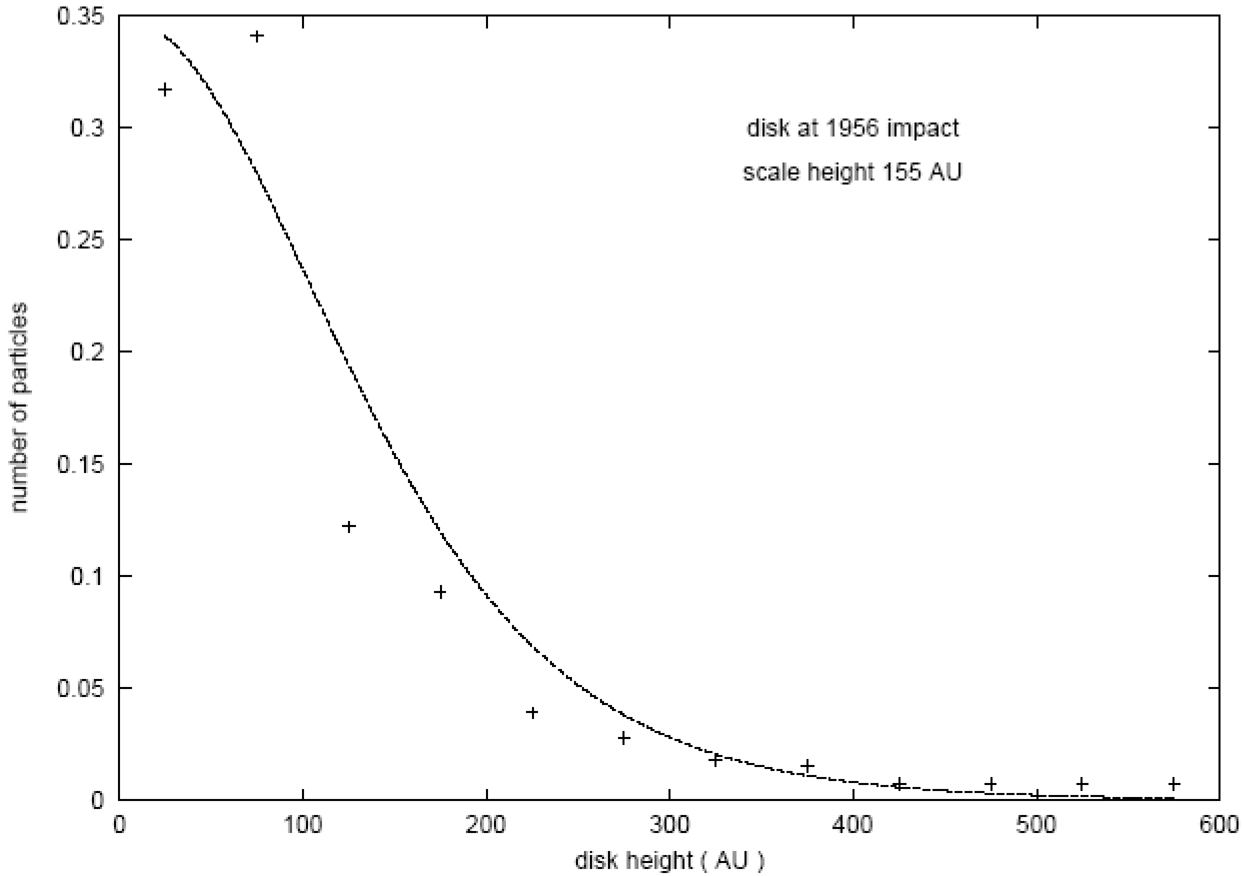
TABLE 1

Disk Crossings and Outburst Times in Orbit 1: Precession 39.1°, Time Delay 1.03, Primary Mass $1.825 \times 10^{10}\ M_{\odot}$, Eccentricity 0.661

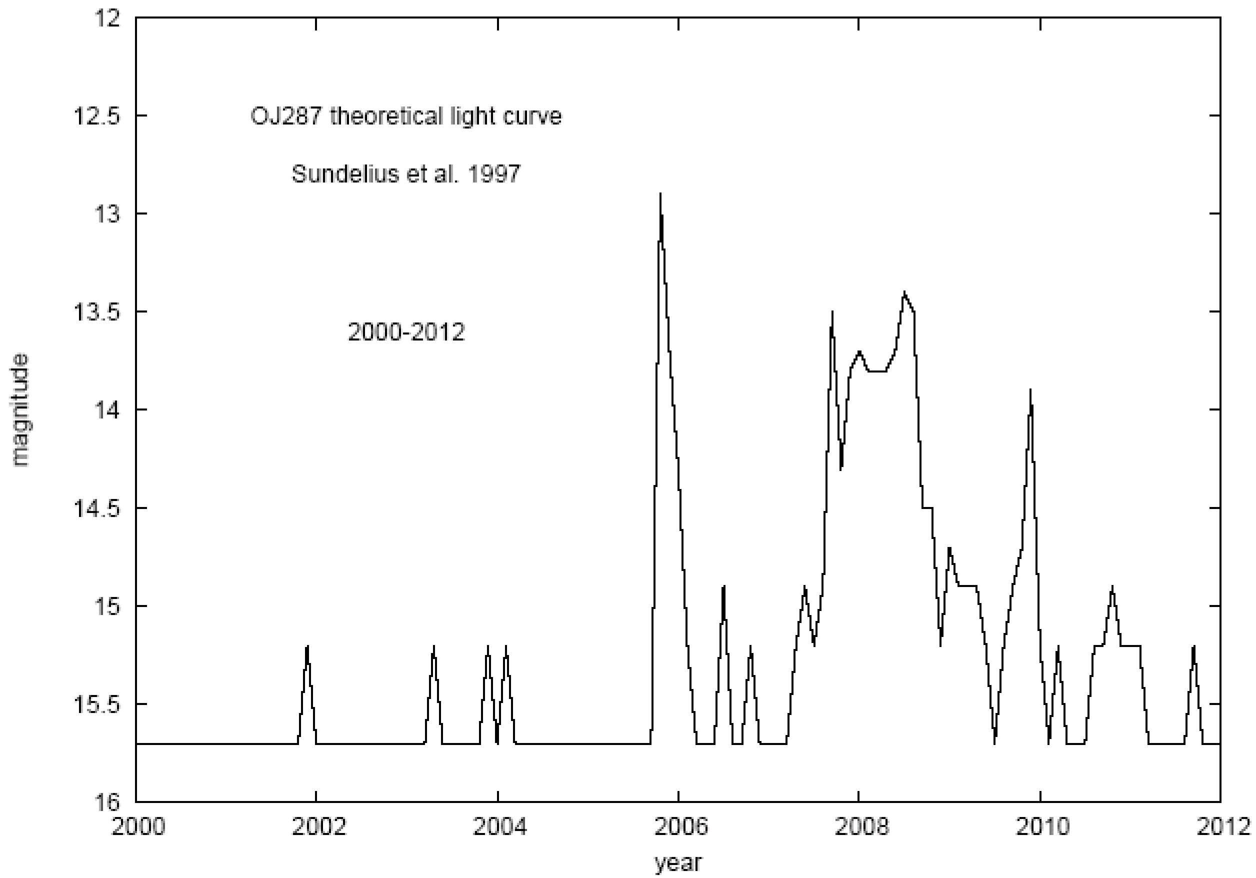
Disk Crossing	Time Delay (yr)	Time Ahead (yr)	Distance (AU)	Disk Level (AU)	Outburst Time (yr)
1895.59	1.19	−0.21	15042	33	1896.57
1898.59	0.04	...	3399	...	1898.63
1903.60	2.83	−0.21	18572	157	1906.21
1910.57	0.05	...	3506	...	1910.62
1912.61	0.55	−0.13	11650	41	1913.02
1922.50	0.07	...	4247	...	1922.57
1923.67	0.16	−0.07	6658	4	1923.77
1934.27	0.14	...	6149	15	1934.40
1935.39	0.07	−0.04	4470	−6	1935.42
1945.48	0.43	...	10555	259	1945.91
1947.28	0.05	−0.04	3591	...	1947.30
1954.89	2.30	−0.06	17770	72	1957.14
1959.21	0.04	−0.03	3376	...	1959.22
1962.69	1.58	−0.06	16227	247	1964.20
1971.13	0.05	−0.04	3701	...	1971.14
1972.67	0.31	+0.01	9217	−73	1972.99
1982.96	0.08	−0.04	4801	−53	1983.00
1984.04	0.11	...	5547	−30	1984.16
1994.53	0.20	−0.09	7469	87	1994.64
1995.80	0.06	...	4010	−17	1995.86
2005.19	0.81	−0.17	13333	265	2005.82
2007.66	0.05	...	3437	−33	2007.71
2013.53	3.03	−0.21	18837	148	2016.35
2019.54	0.05	...	3434	...	2019.58
2021.94	0.76	−0.17	13091	−235	2022.54

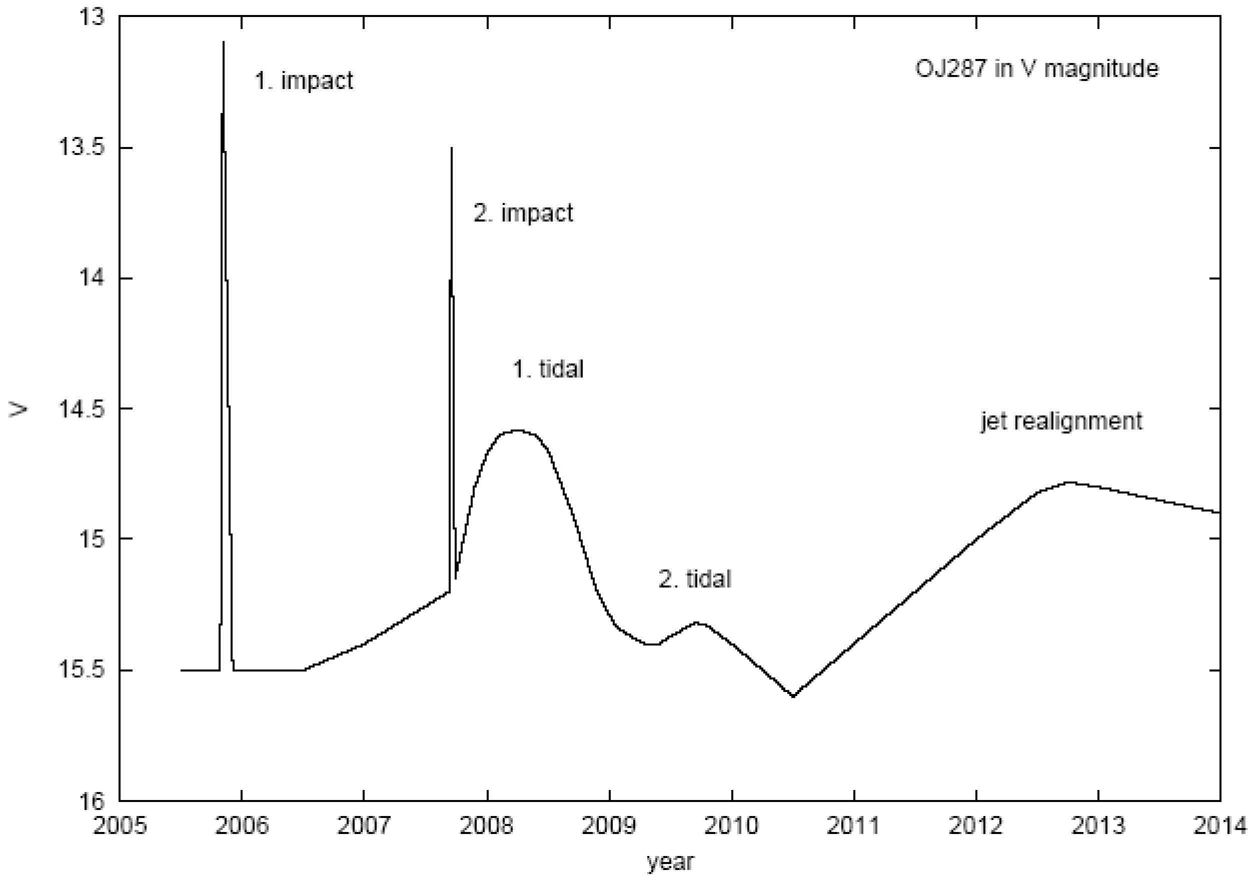
Year	Observed	Comment
1896.25.................	1896.18	Single high point
1898.74.................	1897.25–1899.20	Data gap
1906.27.................	1903.07–1905.02, 1905.11–1907.17	Data gap
1910.68.................	1910.19–1911.90	Data gap
1912.98.................	1913.07–1913.25	Flux decline
1922.58.................	1917.23–1924.17	Data gap
1923.77.................	1924.17	Single high point
1934.37.................	1934.25–1934.97	Data gap
1935.45.................	1935.18–1936.01	Data gap
1945.80.................	1945.17–1946.00	Data gap
1947.30.................	1947.07–1947.32	Flux rise
1956.27.................	1956.26–1956.34, 1957.14–1957.17	Flux decline
1959.22.................	1959.12–1959.25	Flux rise
1964.04.................	1963.31–1963.98, 1964.12–1965.15	Data gap
1971.15.................	1971.08–1971.19	Flux rise
1972.99.................	1972.94–1973.00	Flux rise
1983.00.................	1982.96–1983.02	Flux rise
1984.16.................	1984.10–1984.18	Flux rise
1994.70.................	1994.69–1994.75	Flux rise
1995.89.................	1995.84–1995.86, 1995.90–1995.93	Flux rise
2005.82.................	2005.75–2005.84	Flux rise
2007.77.................	...	...
2015.82.................	...	...
2019.71.................	...	...

Disk thickness



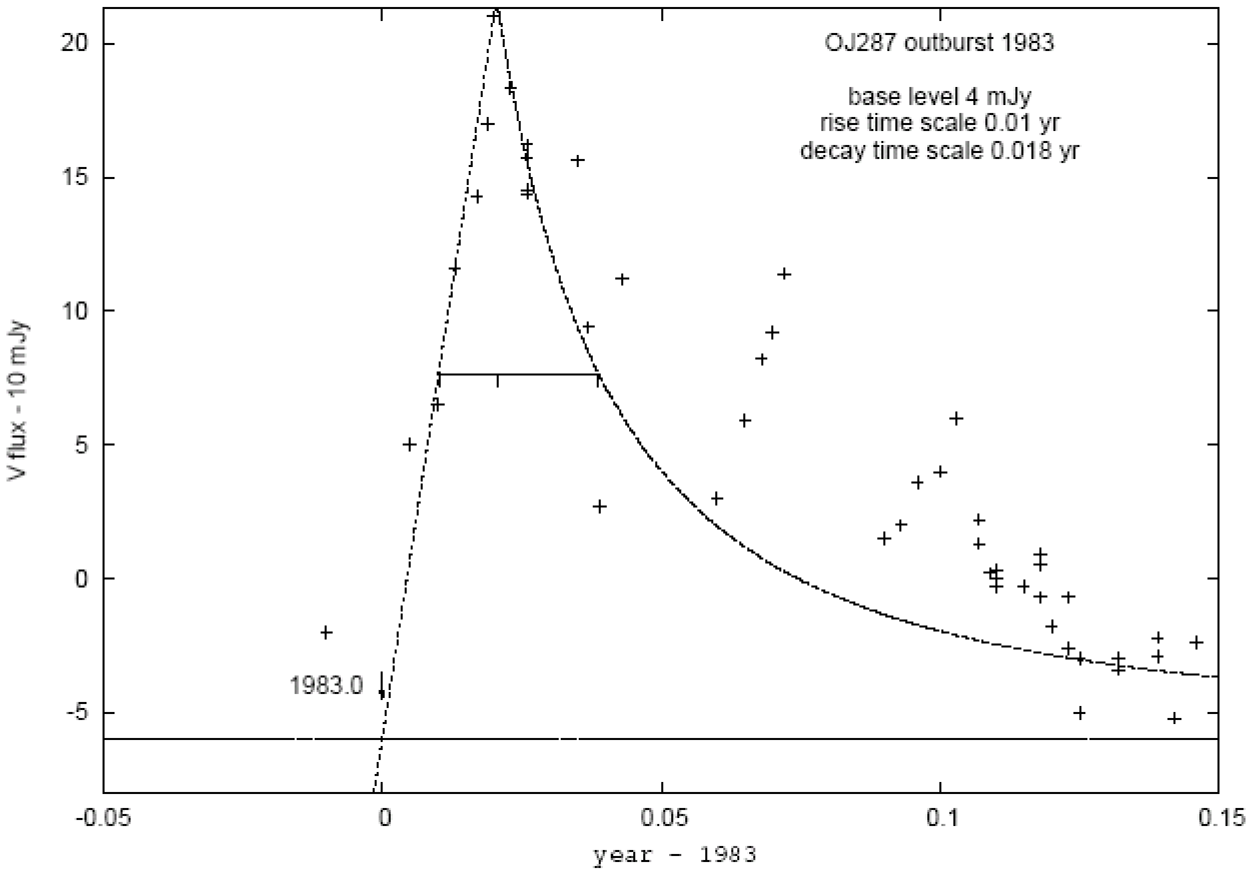
Predicted light curve





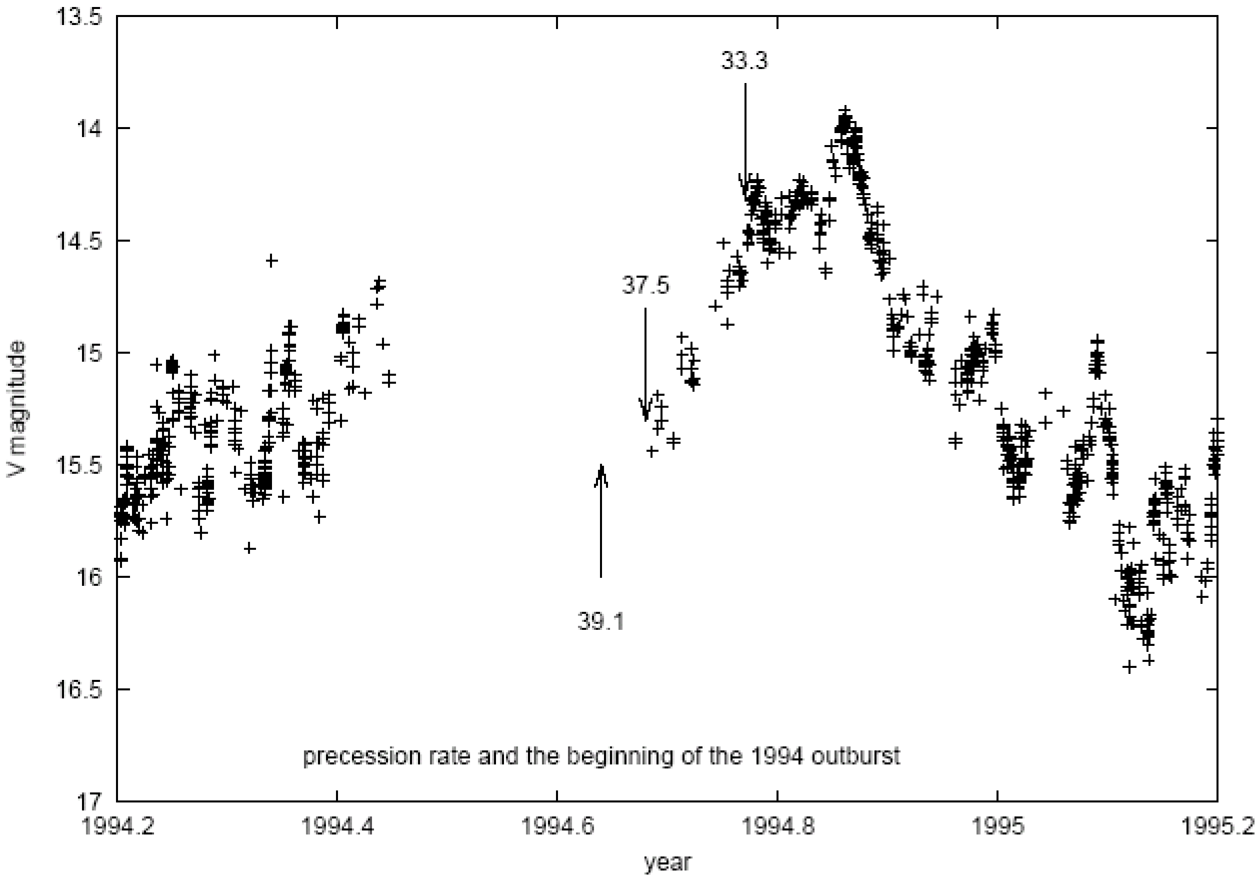
OJ287 in V magnitude
1. impact
2. impact
1. tidal
2. tidal
jet realignment
V
13
13.5
14
14.5
15
15.5
16
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
year

1983

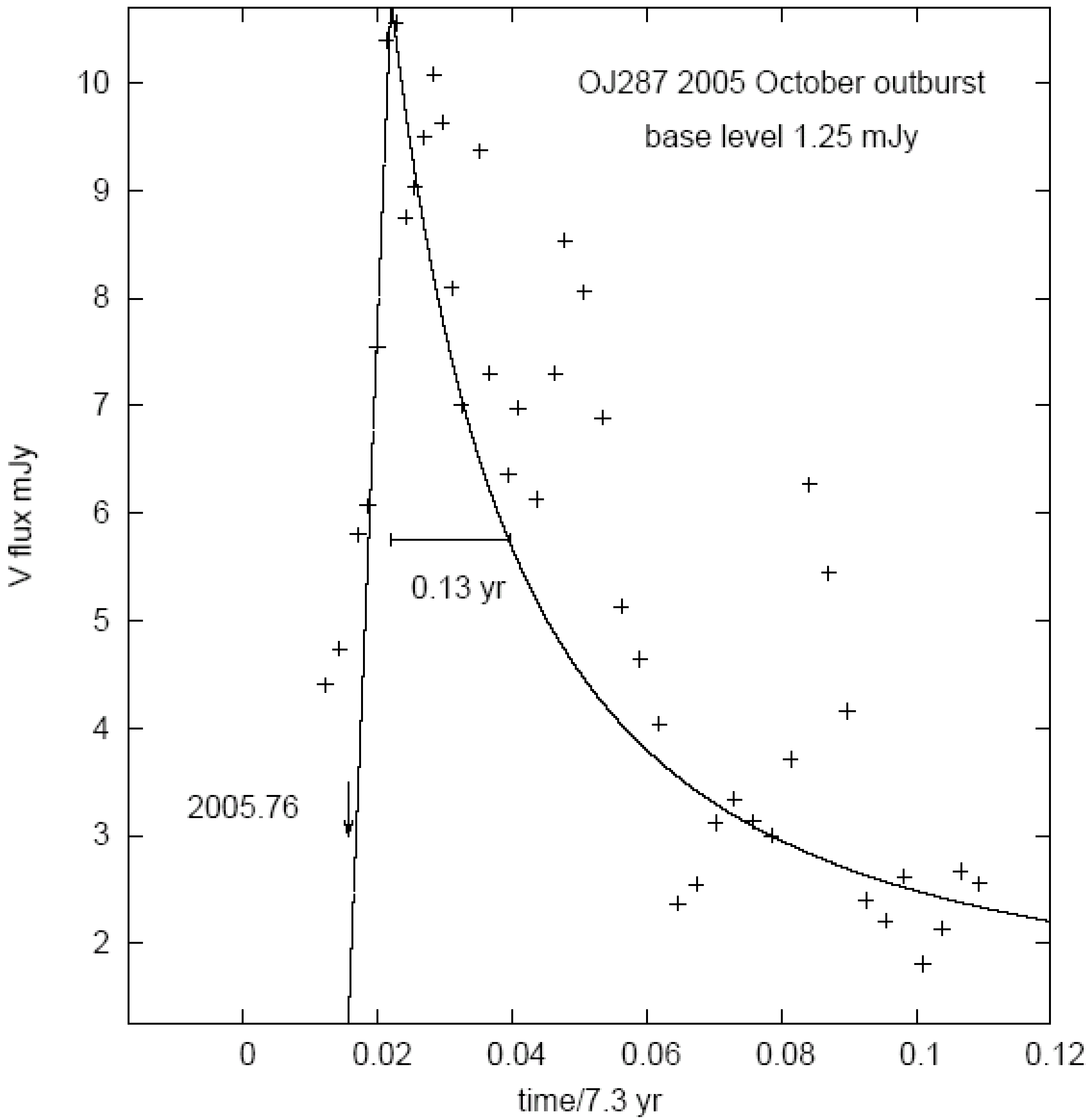


OJ287 outburst 1983
base level 4 mJy
rise time scale 0.01 yr
decay time scale 0.018 yr
1983.0
V flux - 10 mJy
year - 1983
20
15
10
5
0
-5
-0.05
0
0.05
0.1
0.15

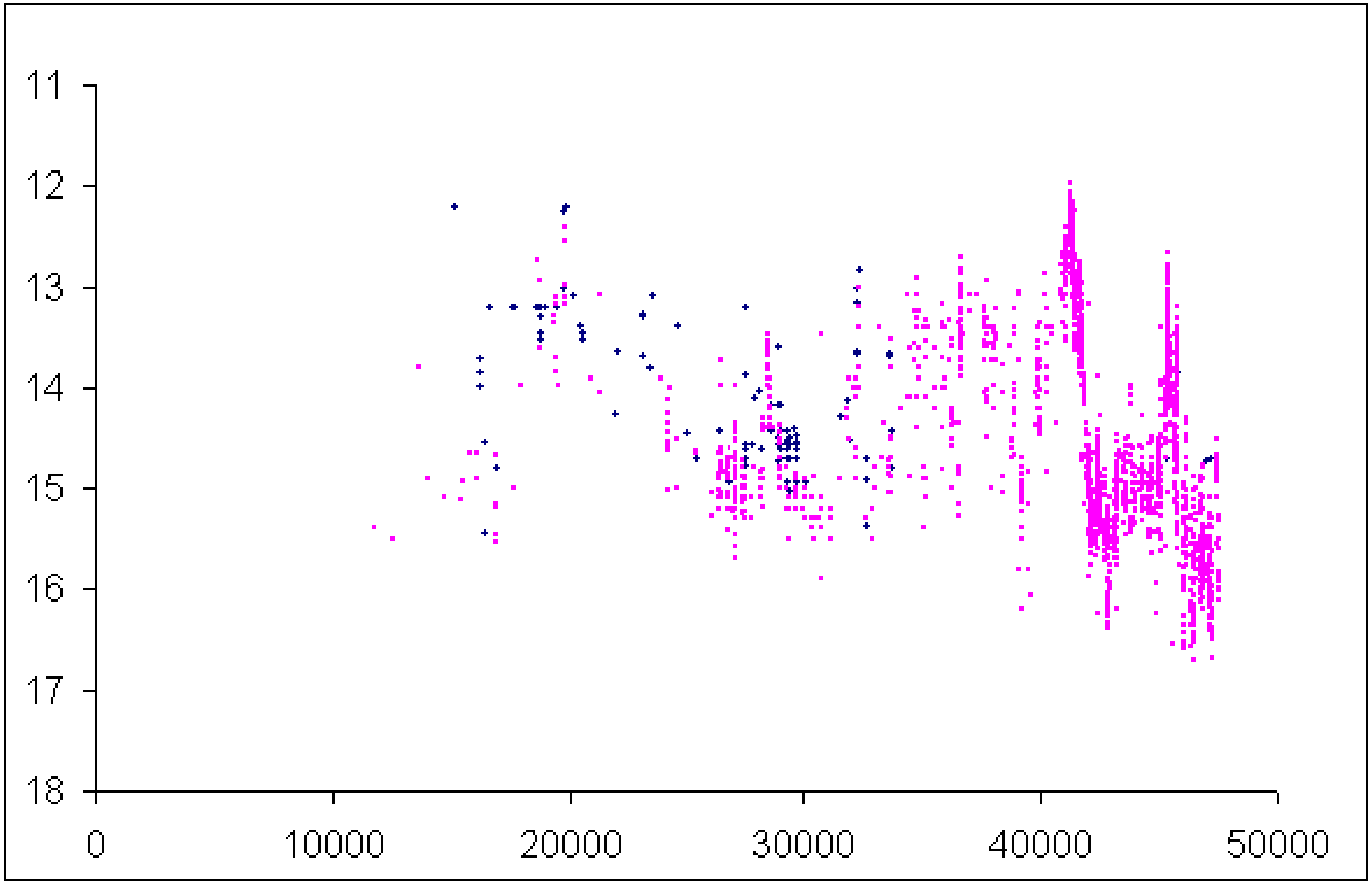
1994

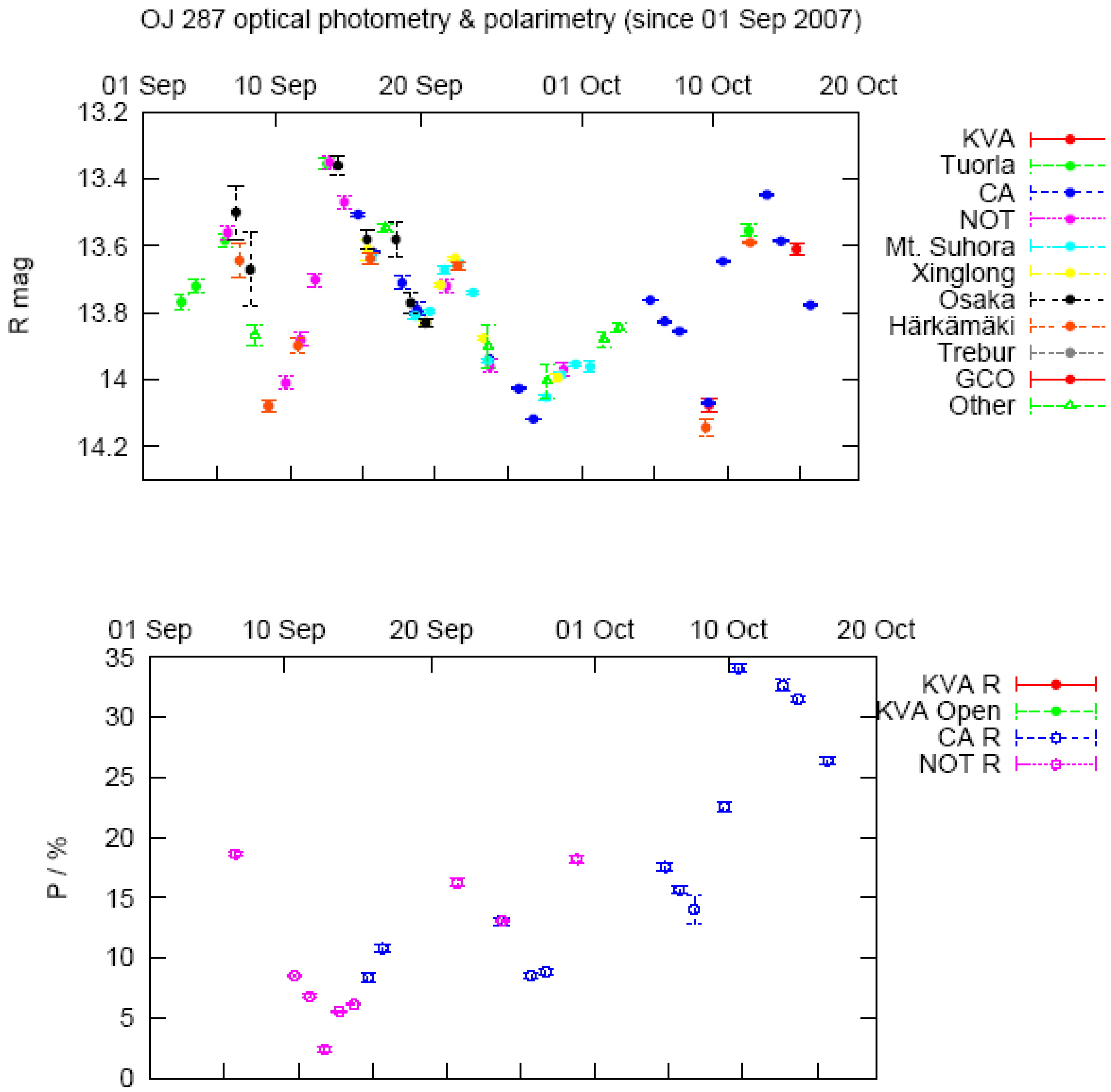


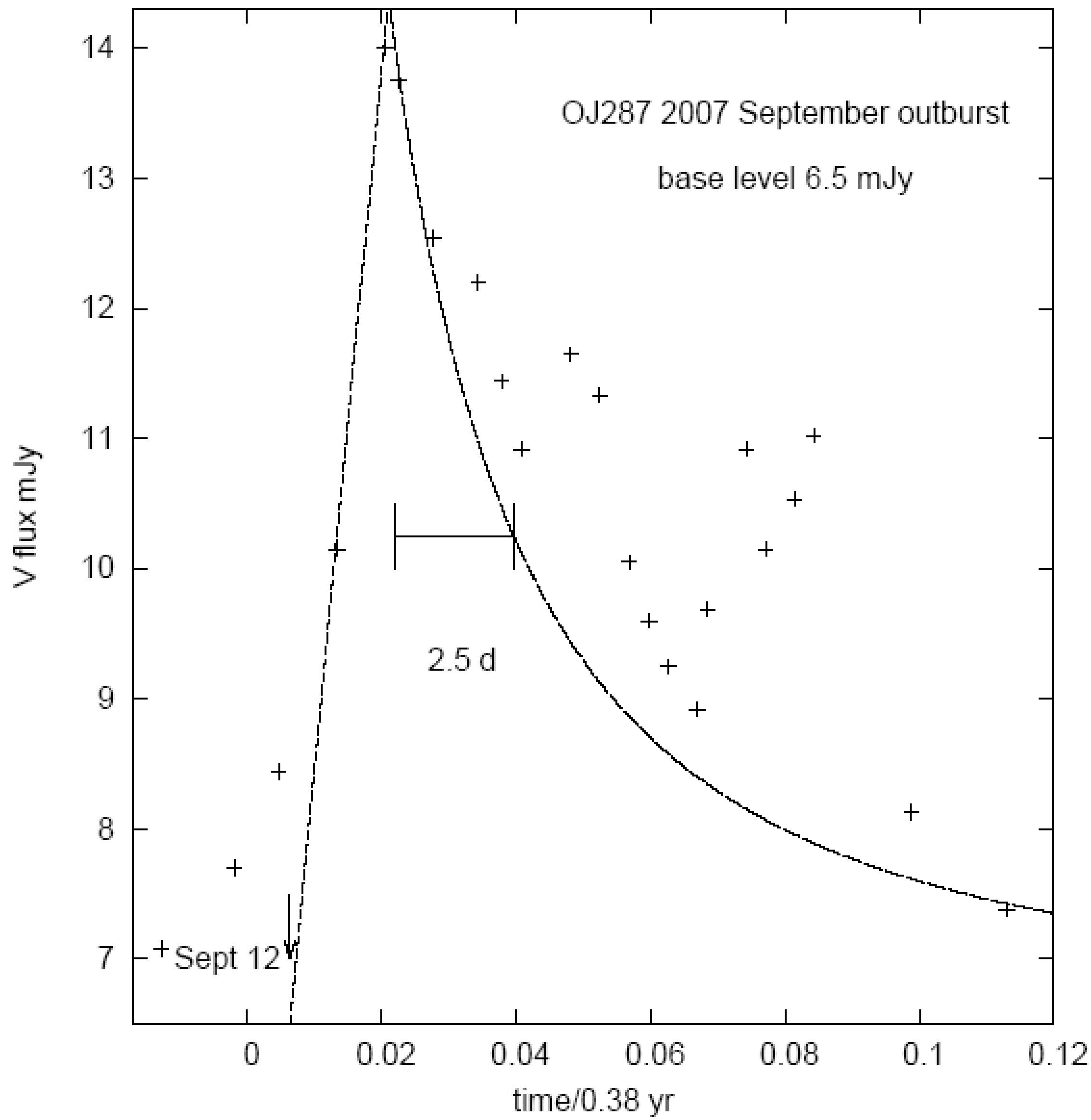
13.5
14
14.5
15
15.5
16
16.5
17
V magnitude
1994.2
1994.4
1994.6
1994.8
1995
1995.2
year
33.3
37.5
39.1
precession rate and the beginning of the 1994 outburst


OJ287 2005 October outburst
base level 1.25 mJy
0.13 yr
2005.76
V flux mJy
time/7.3 yr
10
9
8
7
6
5
4
3
2
0
0.02
0.04
0.06
0.08
0.1
0.12

Harvard plates, preliminary



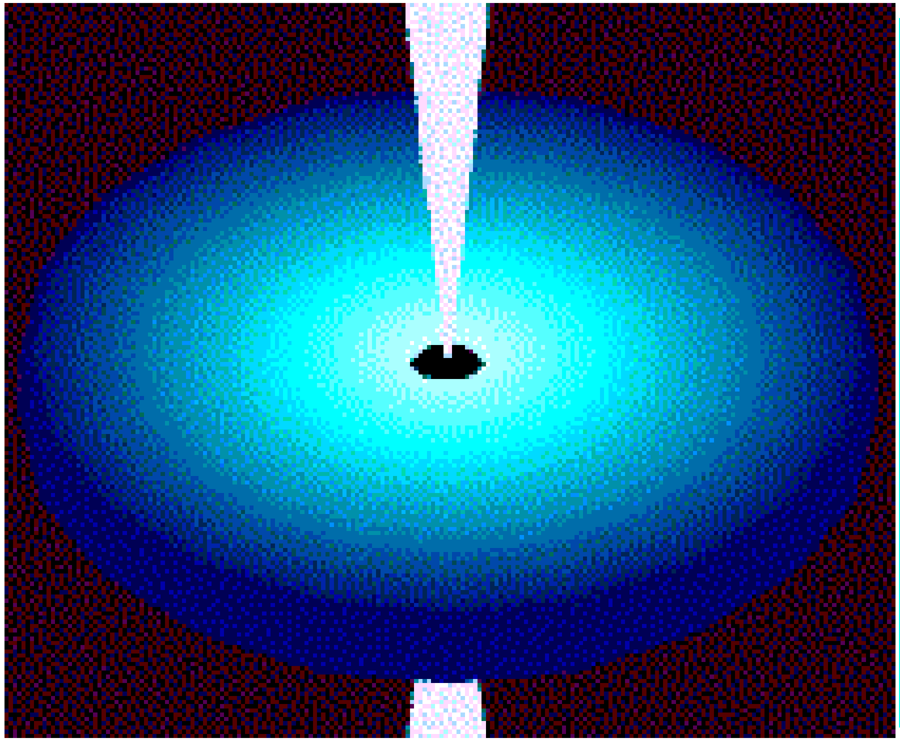

OJ 287 optical photometry & polarimetry (since 01 Sep 2007)
01 Sep
10 Sep
20 Sep
01 Oct
10 Oct
20 Oct
R mag
13.2
13.4
13.6
13.8
14
14.2
KVA
Tuorla
CA
NOT
Mt. Suhora
Xinglong
Osaka
Härkämäki
Trebur
GCO
Other
01 Sep
10 Sep
20 Sep
01 Oct
10 Oct
20 Oct
P / %
35
30
25
20
15
10
5
0
KVA R
KVA Open
CA R
NOT R

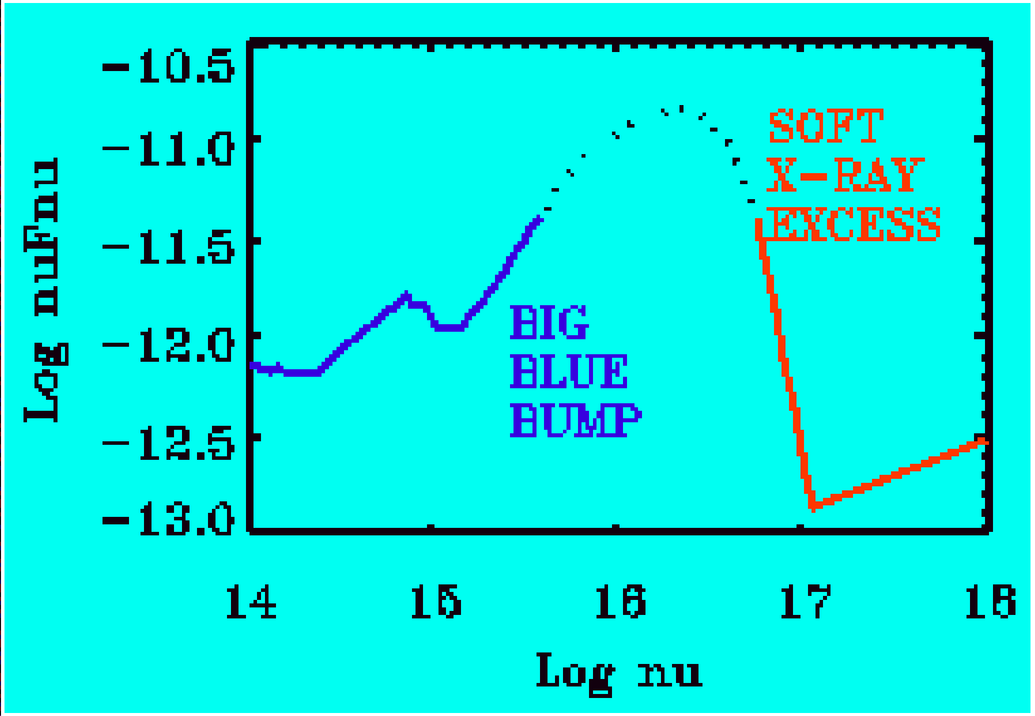


OJ287 2007 September outburst
base level 6.5 mJy
2.5 d
Sept 12
V flux mJy
time/0.38 yr
14
13
12
11
10
9
8
7
0
0.02
0.04
0.06
0.08
0.1
0.12

OJ287 becomes

SEXy



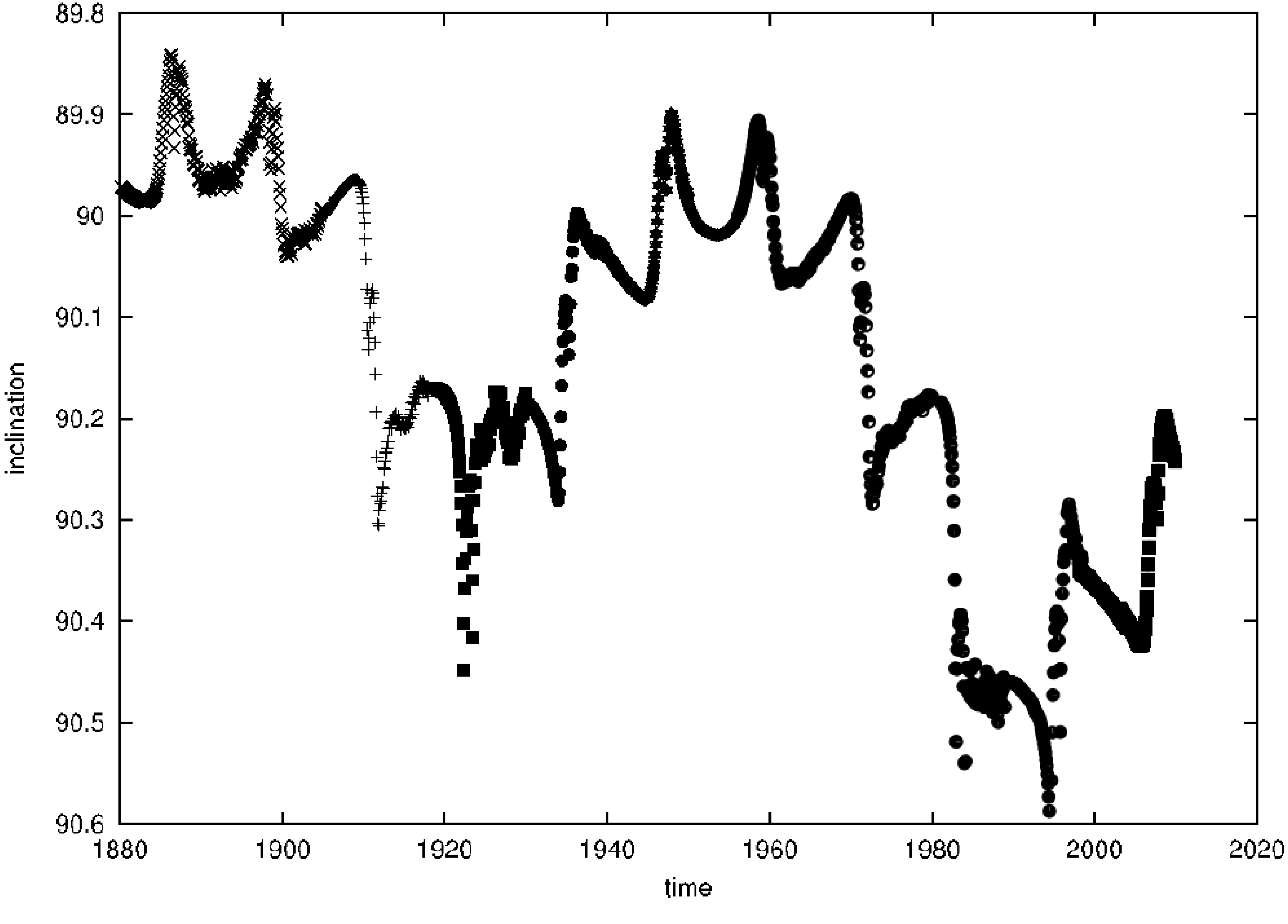


OJ 287 optical variations

1. Jet wobble, 60 yr cycle + 12 yr steps
2. Tidal variations in jet flow, 12 yr cycle
3. Disk impacts, advance relative to the 12 year cycle due to precession

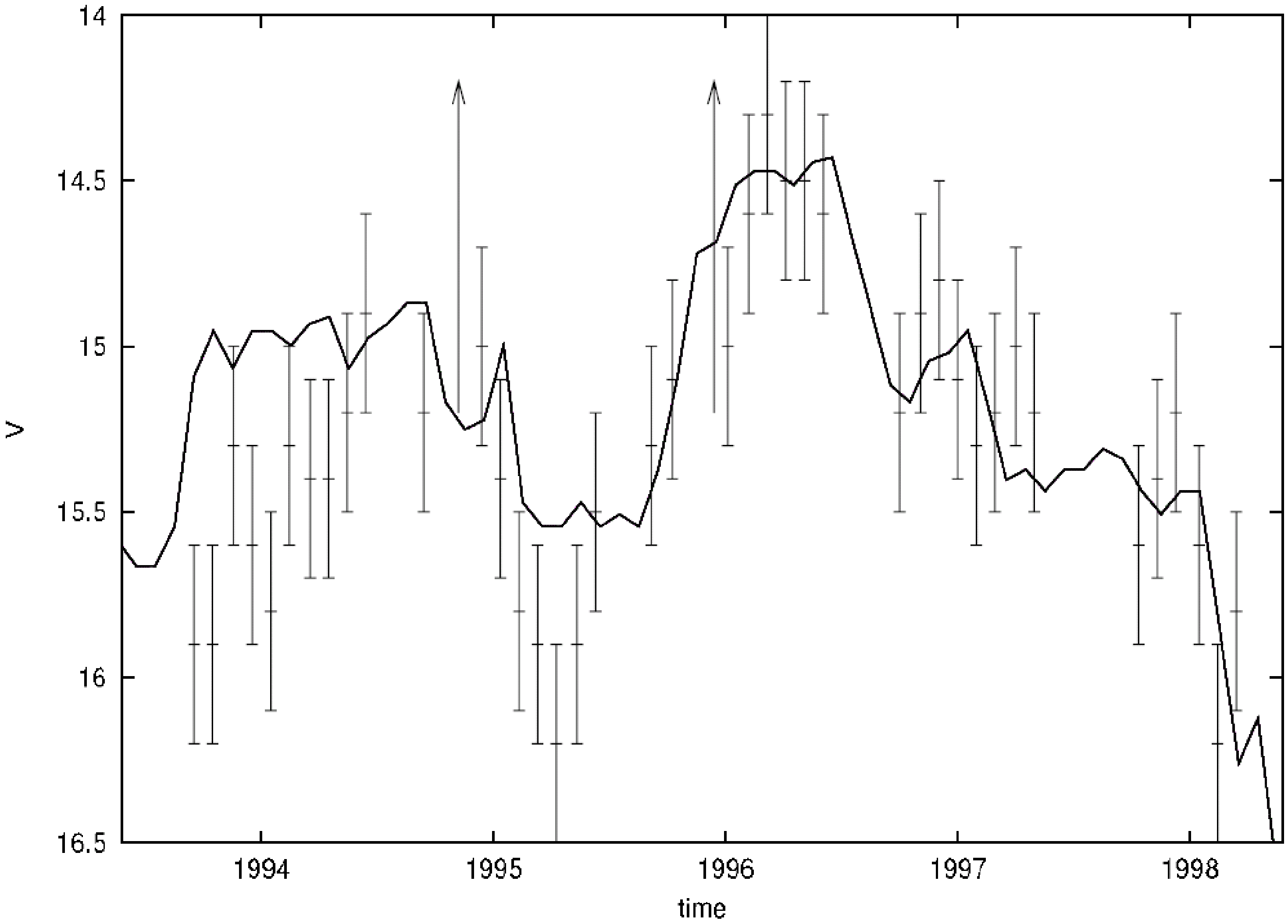
Complete solution of the problem: timing of 6 outbursts

Jet wobble

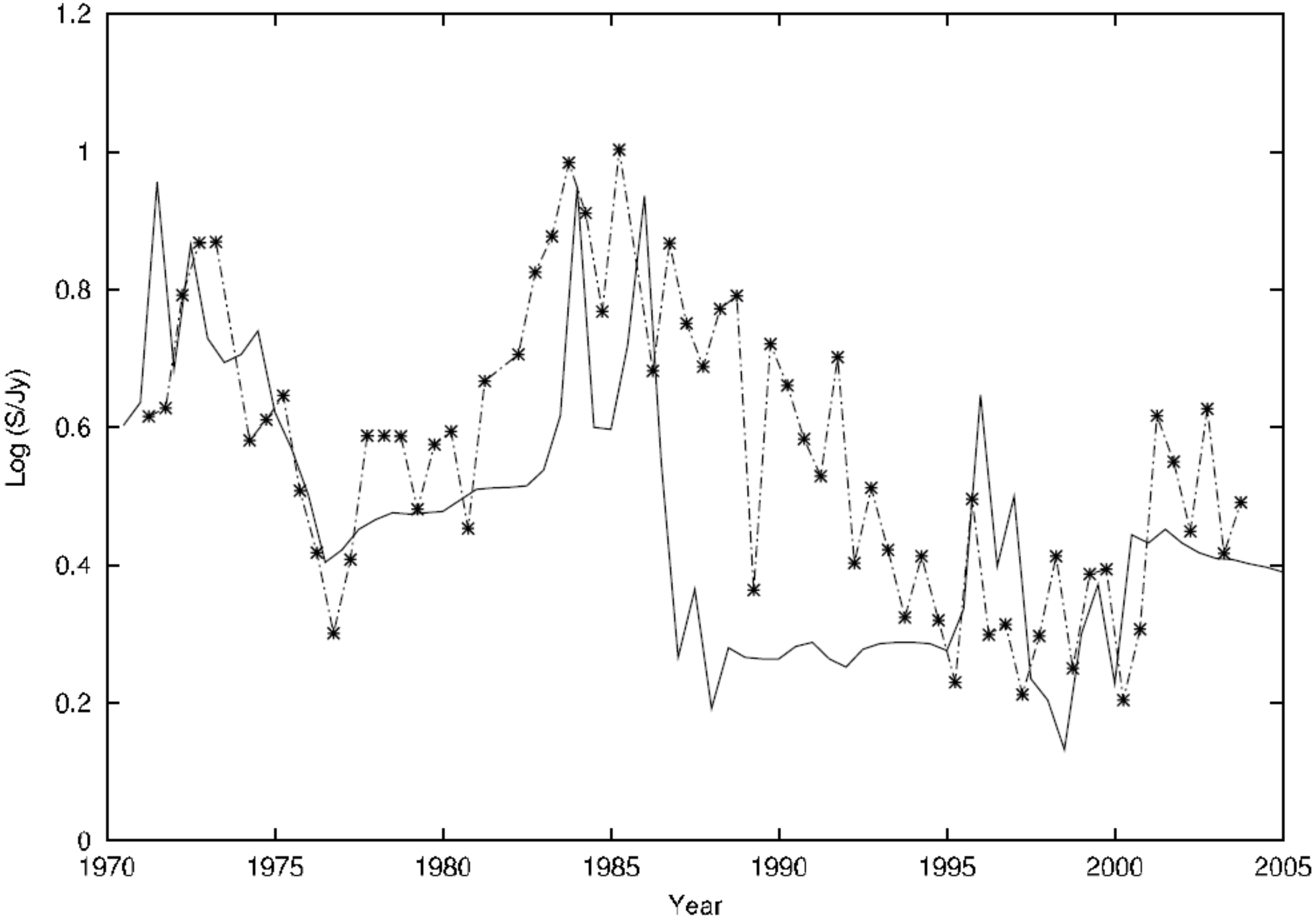


89.8
89.9
90
90.1
90.2
90.3
90.4
90.5
90.6
inclination
1880
1900
1920
1940
1960
1980
2000
2020
time

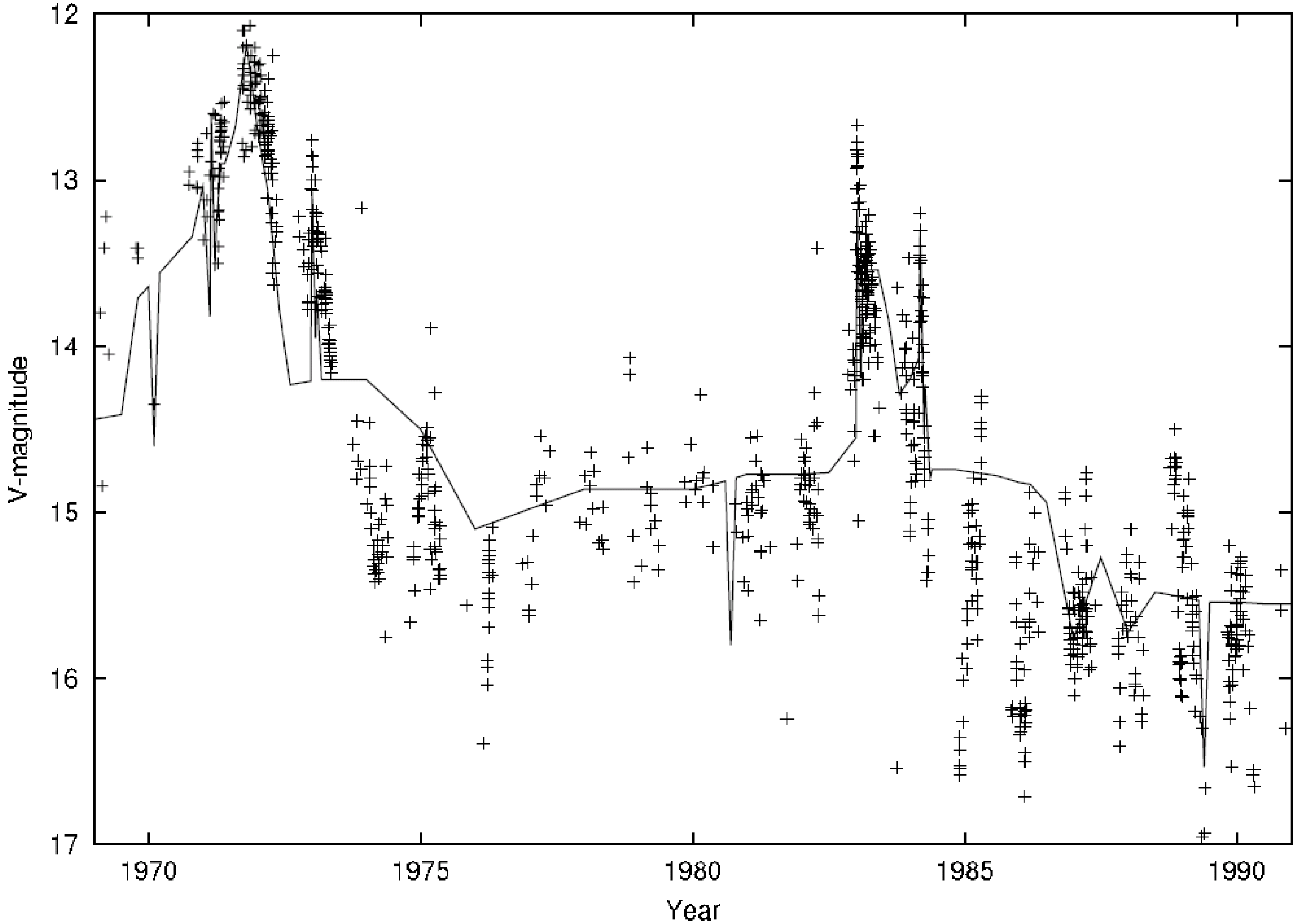
1994-1996 outbursts: tidal model



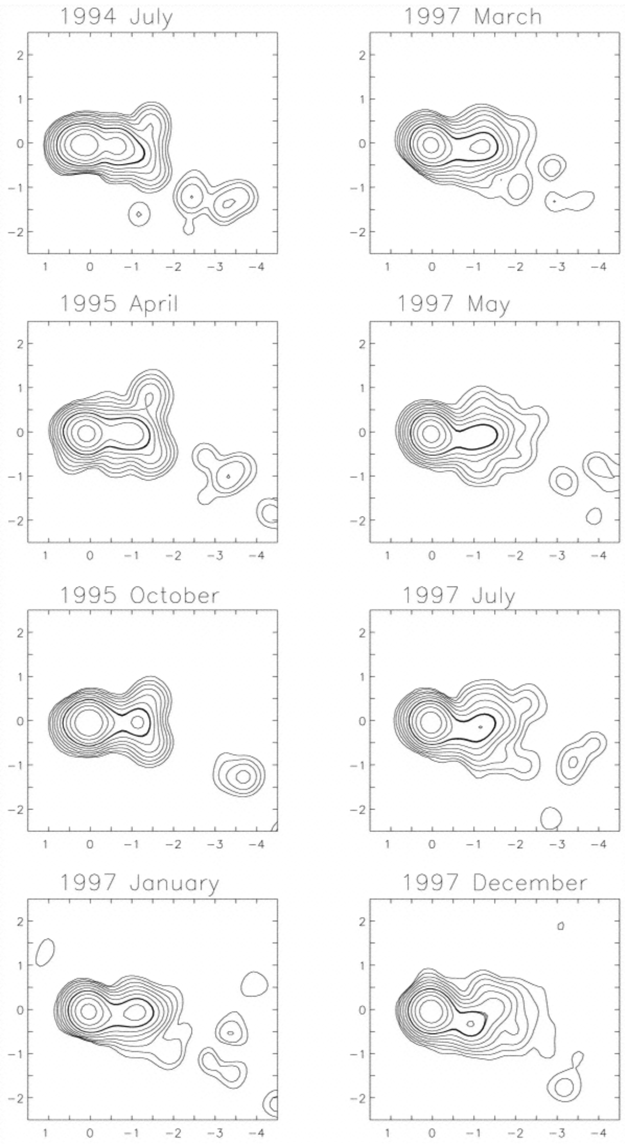
Radio data & theory

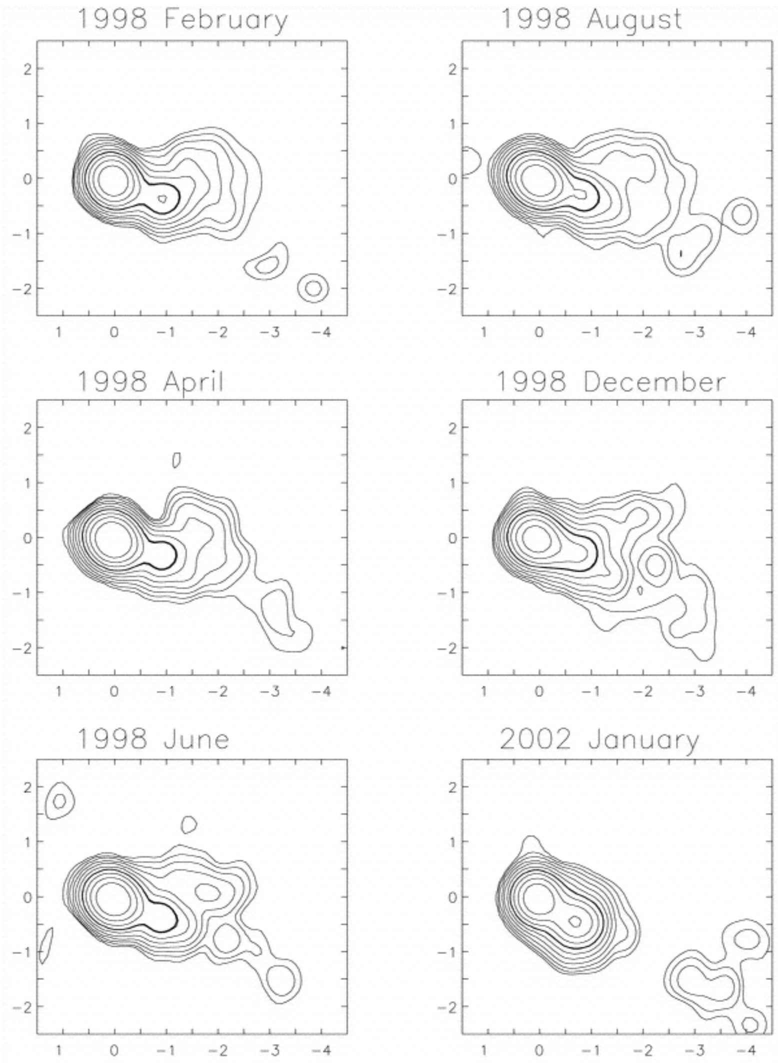


Optical data & theory

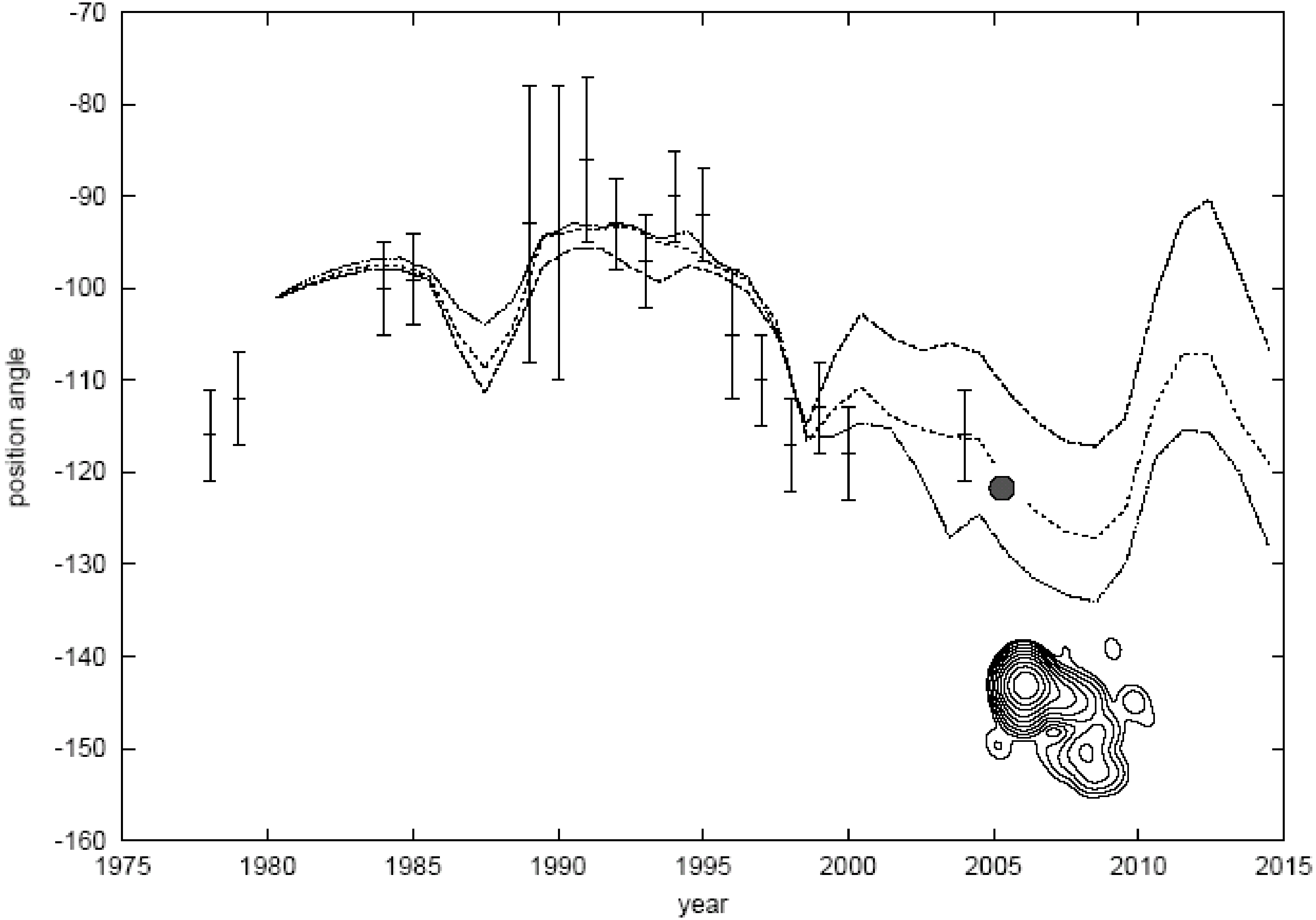


Radio Jet


1994 July
1997 March
1995 April
1997 May
1995 October
1997 July
1997 January
1997 December


1998 February
1998 August
1998 April
1998 December
1998 June
2002 January

Radio jet P.A.



-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
position angle
1975
1980
1985
1990
1995
2000
2005
2010
2015
year

Binary model