ORBIT DETERMINATION FOR R AQUARII

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Symbiotic system binary

- Mass-losing late-type star (RG or AGB)
  + Hot, Compact Companion(WD or MS)
- Interactions in binary system
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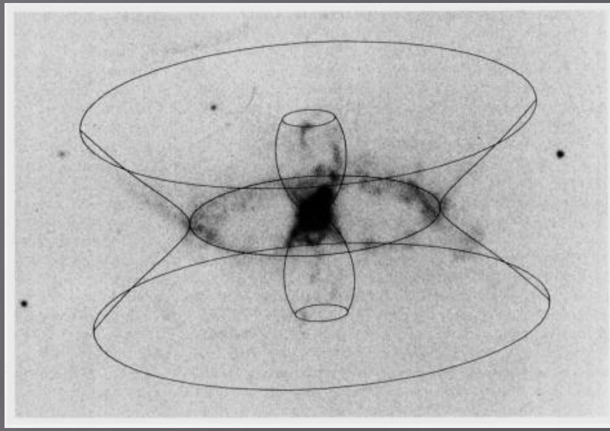
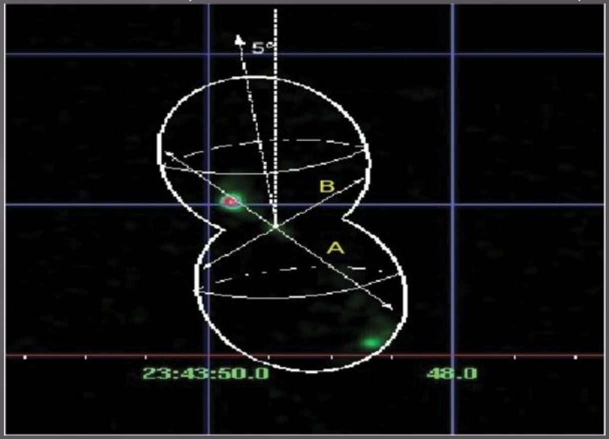
  - Accretion on to compact stars & Nova-like eruptions
  - Photoionization and radiative transfer within gaseous nebulae.
- Important implications
  - Type Ia supernovae
  - origin of Post-AGB phase (e.g. Ba star binaries)
  - the shape of planetary nebulae
- Important for investigate the late stage of stellar evolution and binary evolution

R Aquarii (R Aqr)

- Mira long period variable
  - Spectra type : M7e
  - Pulsation period P=387 days
- White dwarf (WD)
- Astronomical Jet
  - Existence of accretion disk on WD
- Inner & outer nebula



Schematic representation of the geometric structure of the inner and outer nebula (Solf & Ulrich 1985)



Chandra X-ray image of R Aqr jet + Schematic representation of the inner nebula (Nichols & Slavin 2009)

Purpose of study

- To determine orbital parameters of R Aqr
  - Extracted orbital parameter from radial velocity
  - Comparing orbital model with VLBI astrometry

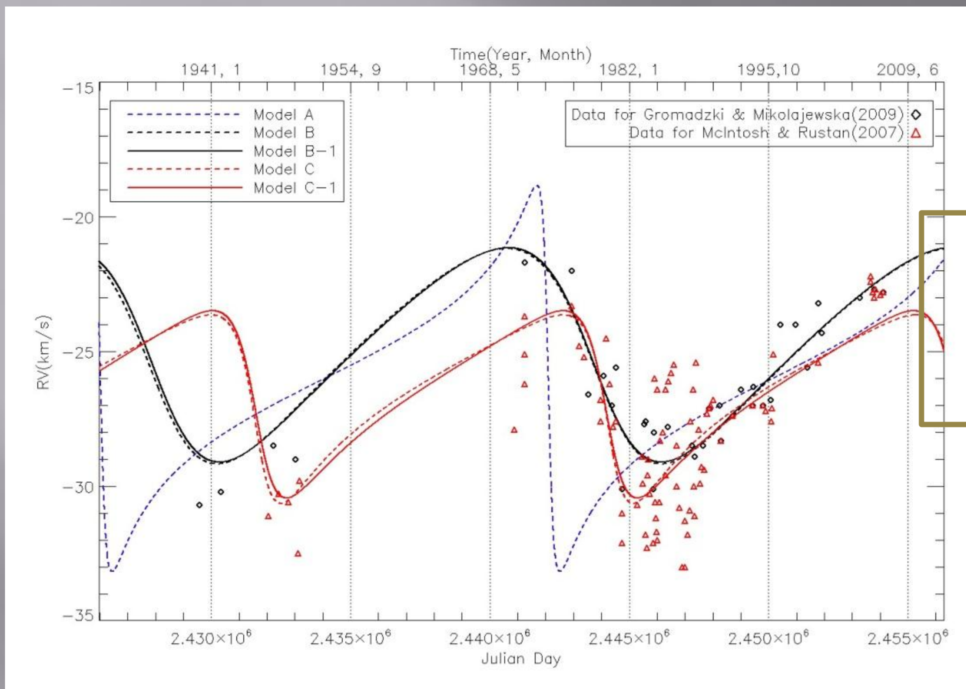
- Connection between symbiotic phenomena and orbital motion
  - Kinematics in Mira variable
  - Evolution of binary system

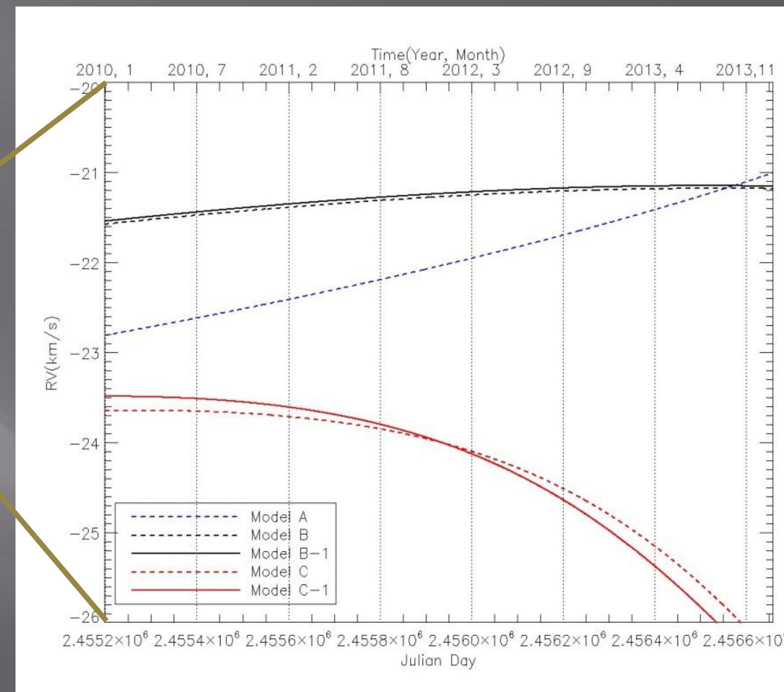
Theoretical orbital models

	Model A	Model B	Model B-1	Model C	Model C-1
Period	16071 day (44 yr)	15943 day (43.6 yr)	15846 day (43.4 yr)	12638 day (34.6 yr)	12580 day (34.4 yr)
Perisatron passage	2442100.0 JD	2444019.0 JD	2443979.0 JD	2444349.0 JD	2444290.2 JD
Radial velocity of system	-26 km/s	-24.9 km/s	-24.88 km/s	-26.5 km/s	-26.55 km/s
Velocity semi-amplitude	7.2 km/s	4.0 km/s	3.98 km/s	3.5 km/s	3.48 km/s
Eccentricity	0.8	0.25	0.25	0.52	0.48
Longitude of periastron	90°	106°	104.45°	110.7°	104.38°

NOTE : 1) Hollis et al. (1997), 2) Gromadzki & Mikolajewska (2009), 3) Best fit for Model B, 4) McIntosh & Rustan (2007), 5) Best fit for Model C

Theoretical orbital model





	Model A	Model B	Model B-1	Model C	Model C-1
2011. 2	−22.417 km/s	−21.388 km/s	−21.353 km/s	−23.710 km/s	−23.603 km/s
2011. 8	−22.219 km/s	−21.319 km/s	−22.284 km/s	−23.827 km/s	−23.768 km/s

Expected radial velocity at Feb. 2011 to Aug. 2011

VERA observations

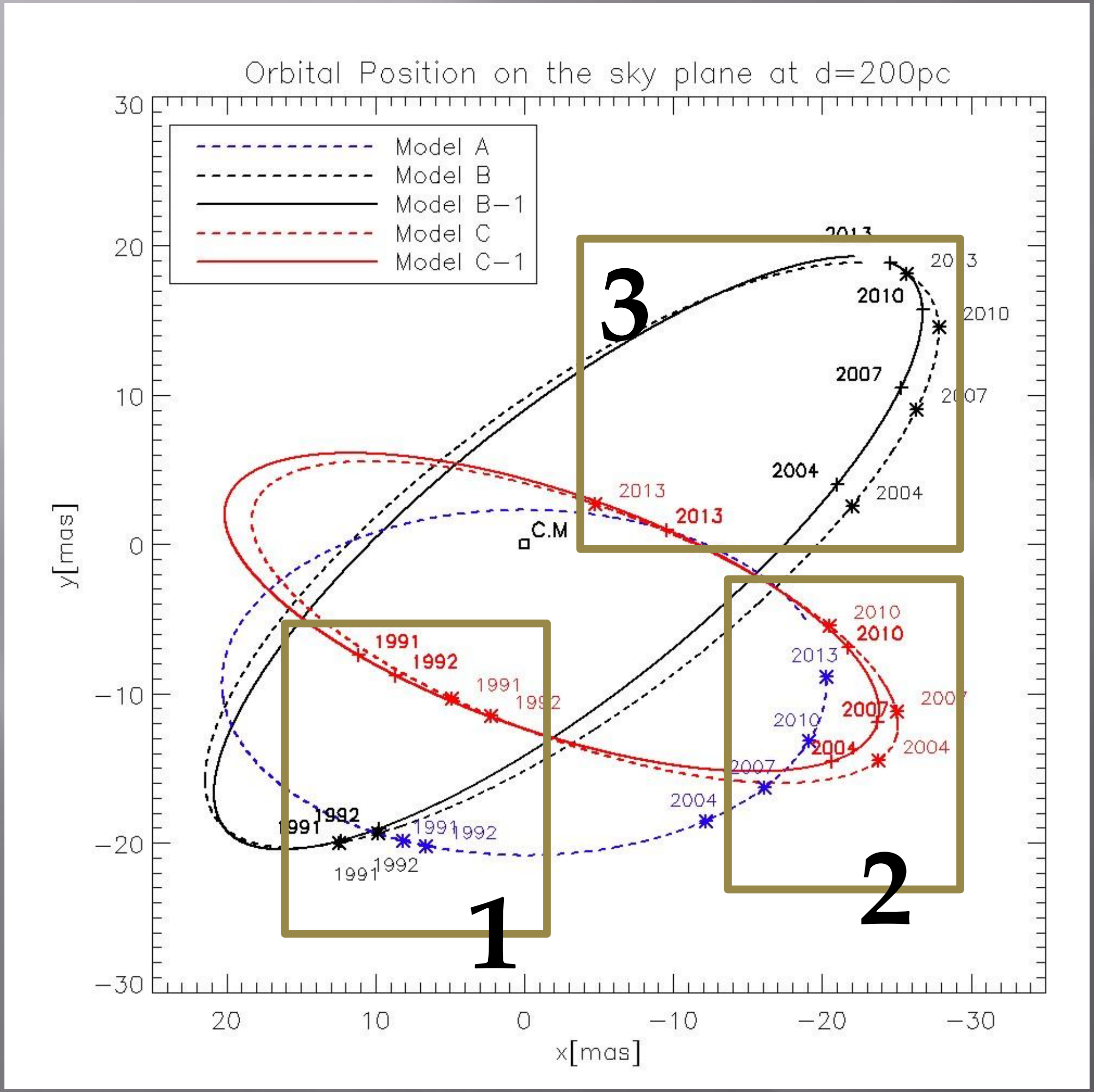
- Kamohara et al. (2010)
  - SiO v=1, v=2 J=1→0 maser
  - 11 epochs (Dec. 2004 -Oct. 2006)
  - Determining the annual parallax and proper motion by fitting ring-like distribution of the absolute coordinates of the maser spots
  - Parallax π = 4.7±0.8 mas (d = 214 +45/-32 pc)
    - Hipparcos value π = 5.07±3.15 mas
  - Proper motion

    μ_{RA} = 32.2±0.8mas/yr, μ_{dec} = -29.5±0.7mas/yr

※ Hipparcos value (μ_{RA} = 32.98±1.46mas/yr, μ_{dec} = -32.61±1.13mas/yr)

  - Difference of motion in dec : the sign of the orbital motion

VERA observations and Orbital models



- 1: Hipparcos (1991.25)
- 2: VERA obs. (2004-2007)
- 3: Future (2010-2013)

VERA observations and Orbital models

Time	[mas/yr]	Model A	Model B	Model B-1	Model C	Model C-1
1991~1992	V_X	-1.53~-1.56	-2.70~-2.53	-2.59~-2.43	-2.65~-2.60	-2.42~-2.55
	V_Y	-0.38~-0.31	0.48~ 0.79	0.64~ 0.95	-1.23~-1.11	-1.41~-1.30
2004~2007	V_X	-1.42~-1.19	-1.86~-1.02	-1.81~-0.99	-1.03~ 0.35	-1.58~-0.35
	V_Y	0.60~ 0.88	2.04~ 2.25	2.00~ 2.26	0.76~ 1.41	0.52~ 1.24
2010~2013	V_X	-0.77~0.11	0.07~ 1.41	0.07~ 1.41	2.95~ 7.65	1.98~ 6.43
	V_Y	1.22~ 1.70	0.74~ 1.59	0.55~ 1.46	2.39~ 2.58	2.18~ 2.85

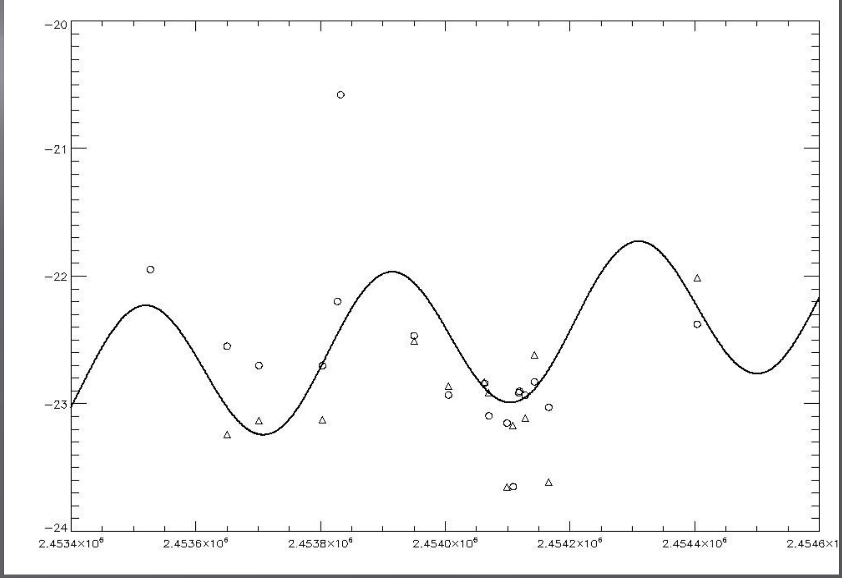
NOTE : 1) Hollis et al. (1997), 2) Gromadzki & Mikolajewska (2009), 3) Best fit for Model B, 4) McIntosh & Rustan (2007), 5) Best fit for Model C

Kamohara et al. (2010) : μ_{RA} = 32.2±0.8mas/yr, μ_{dec} = -29.5±0.7mas/yr
Hipparcos : μ_{RA} = 32.98±1.46mas/yr, μ_{dec} = -32.61±1.13mas/yr

Future works

- Correlation between orbital and pulsation period in radial velocity
  - Relation between the orbital motion and pulsation

Elements	Model B	Model B + Kagoshima
Period	15943 ± 471 days	15568.70 ± 485.51 days
Eccentricity	0.25 ± 0.07	0.27 ± 0.06
Periastron Passage	2444019 ± 728 JD	2444214 ± 611.15 JD
Longitude of Periastron	106 ± 19 °	112.67 ± 17.19 °
Radial velocity of system	−24.9 ± 0.2 km/s	−25.05 ± 0.19 km/s
Velocity semi-amplitude of LPV	4.0 ± 0.4 km/s	3.77 ± 0.27 km/s
Pulsation period		395.71 ± 1.47 days
Pulsation amplitude		0.57 ± 0.22 km/s



Resonanced orbital motion and pulsation in period 2005 to 2007

Summary

- To determine orbital parameters
  - Adopt threee orbital parameters from before studies, and reanalyze the radial velocity data
  - Need more data points since 2007
- Improve orbital model
  - Compare with VLBI observations (KVN + VERA)