

- A Binary Talk -

Binary Populations
&
Binary Formation

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Binary Populations

- Motivations
 - Star formation theory
 - Planetary systems
 - Stellar evolution
 - Angular momentum evolution
 - Late stellar evolution; interacting binaries
 - Stellar dynamics
 - Cluster evolution
 - Population synthesis
 - CMD analyses

Main Sequence Binary Population

- Duquennoy and Mayor 1991
 - Sample
 - 162 primaries
 - $1.2 M_o - 0.9 M_o$ (F7 to G9 IV-V, V, VI)
 - $d < 22$ pc ($\pi < 0.045$ arcsec)
 - $\delta > - 15^\circ$
 - Data
 - 4200 RV measurements, $\sigma \approx 0.3$ km/sec, $\Delta t \approx 13$ yr
 - visual observations
 - common proper motion pairs

Main Sequence Binary Population

- Frequency and Period Distribution

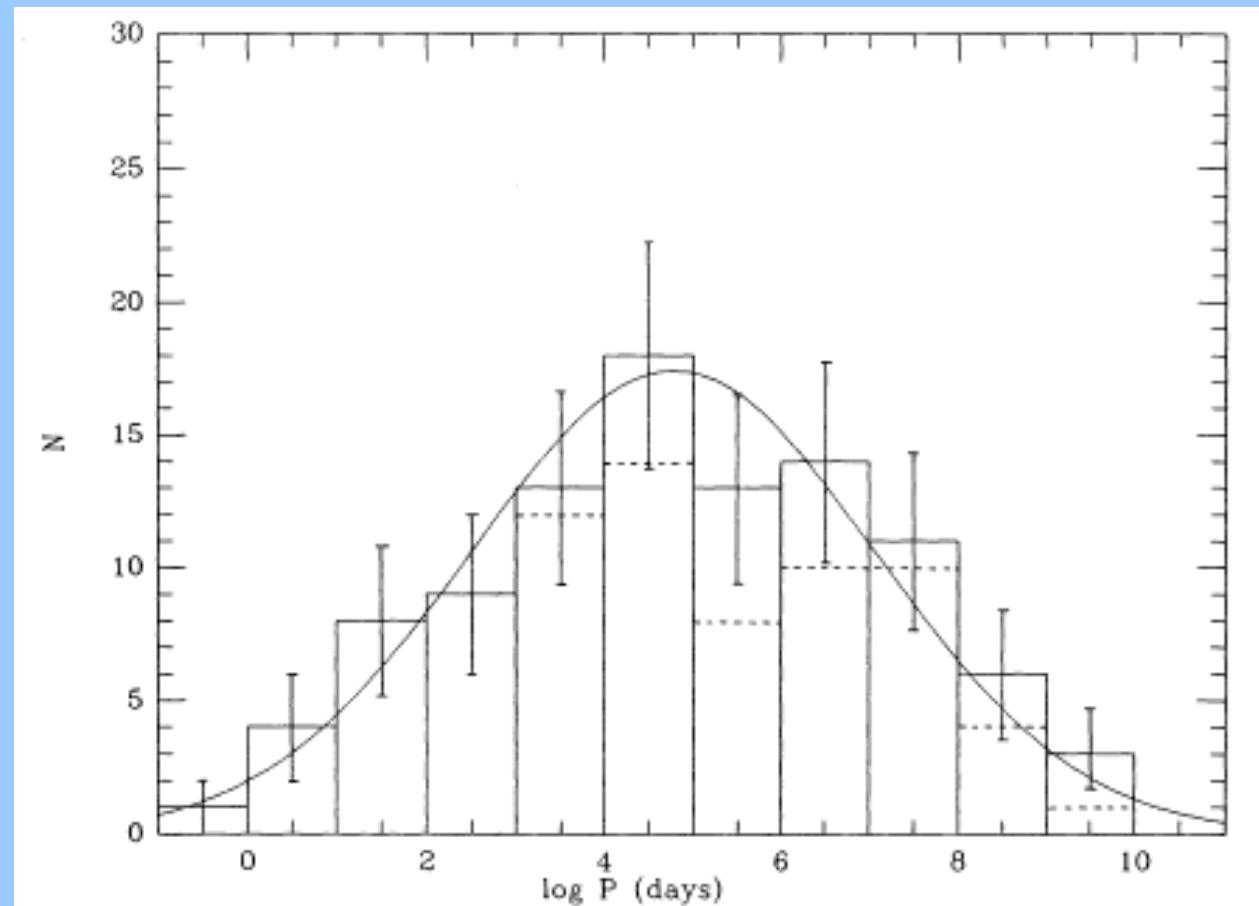
- $71 / 162 \approx 44\%$ detected

- single/double/triple/quad

- $57 : 38 : 4 : 1$

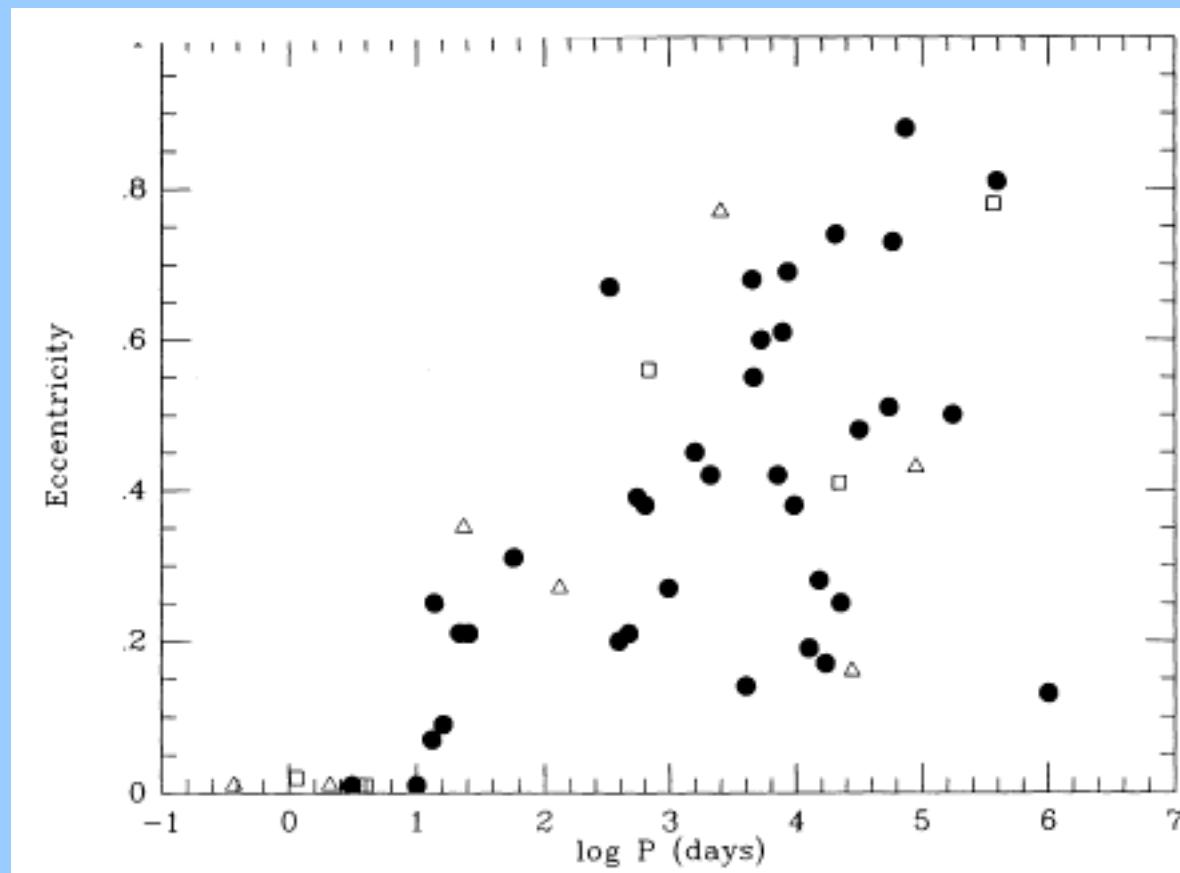
$$\langle P \rangle \approx 180 \text{ yr}$$

$$\langle a \rangle \approx 25 \text{ AU}$$



Main Sequence Binary Population

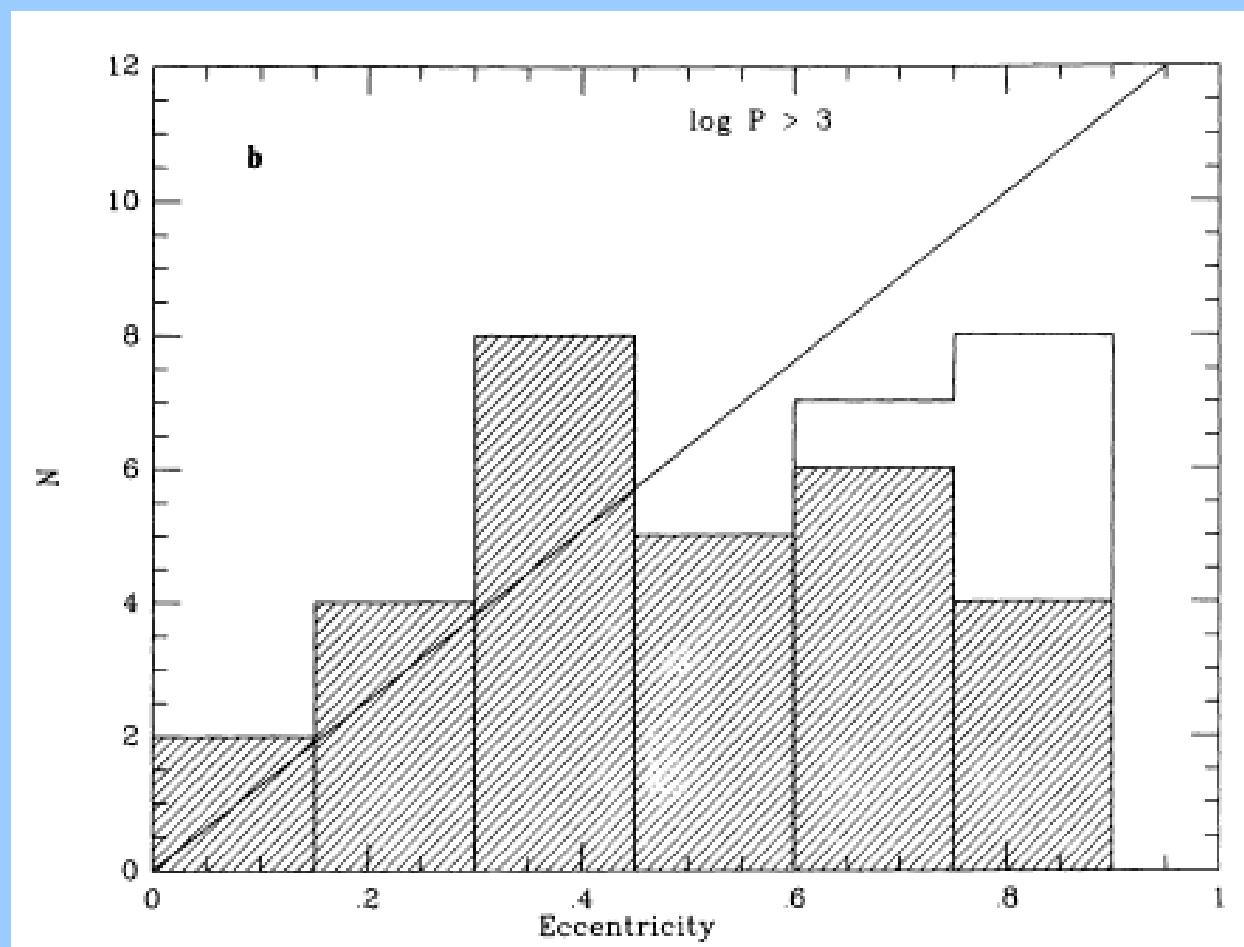
- Period-Eccentricity Distribution



Main Sequence Binary Population

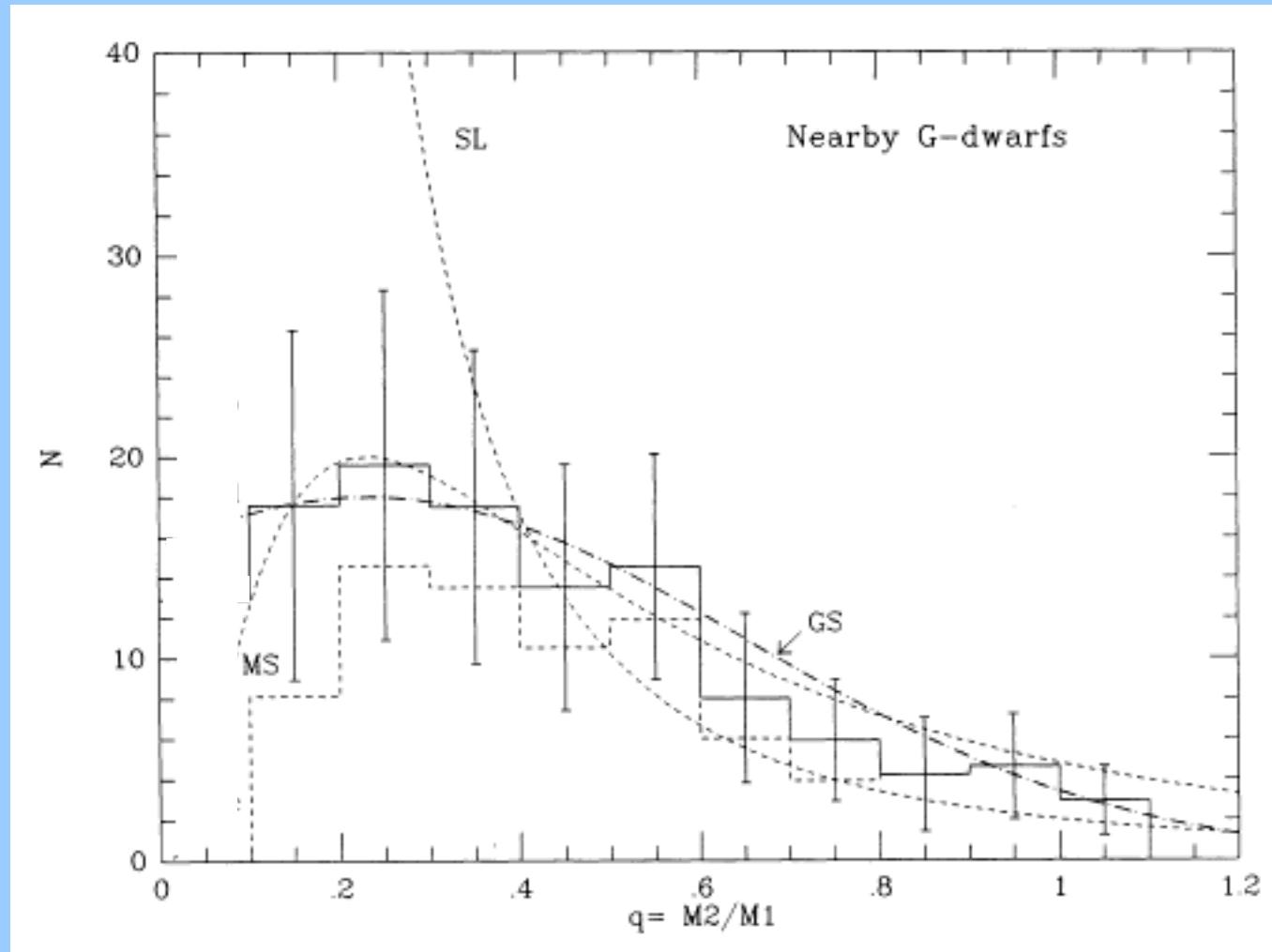
- Orbital Eccentricity Distribution

$$f(e) = 2e ?$$



Main Sequence Binary Population

- Mass Ratio q Distribution



Main Sequence Binary Population

- Mass Ratio q Distribution

$P < 3000^d$

Mazeh *et al.* 1992

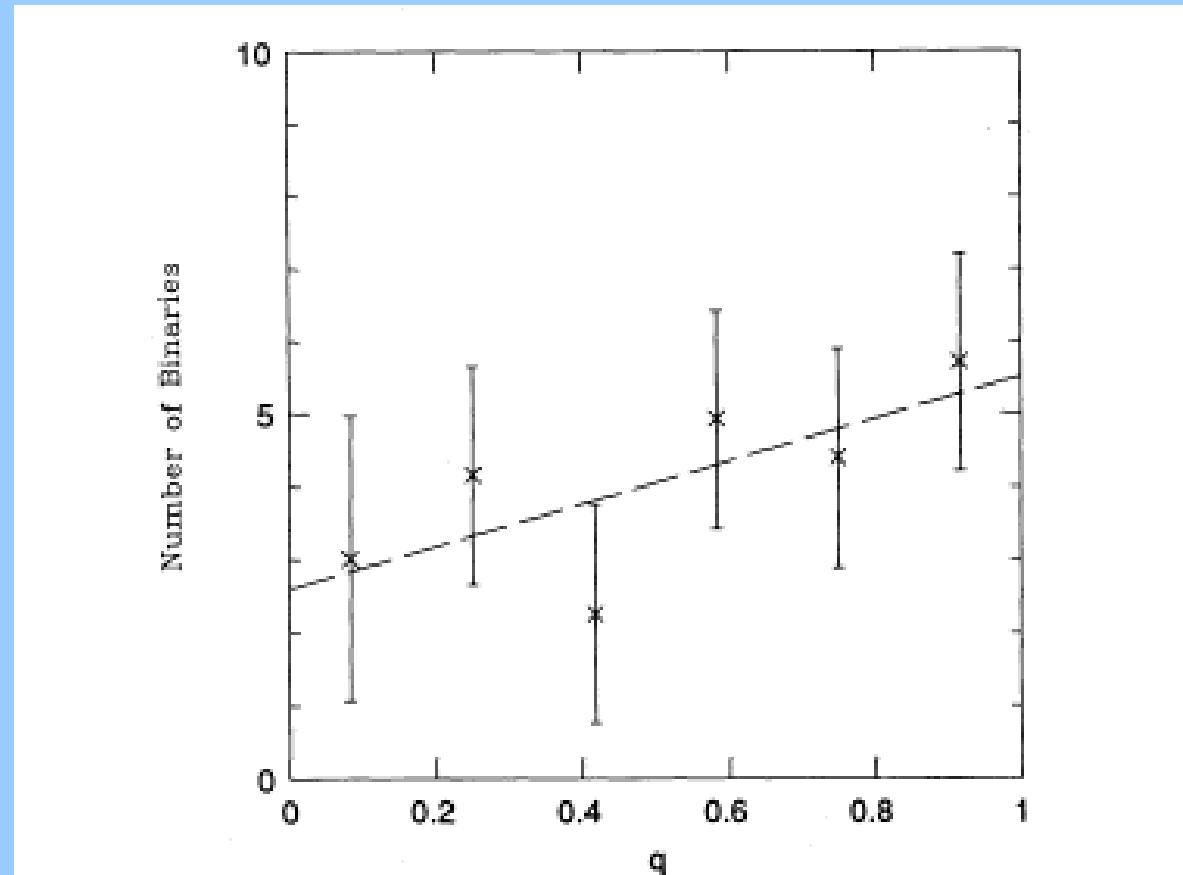


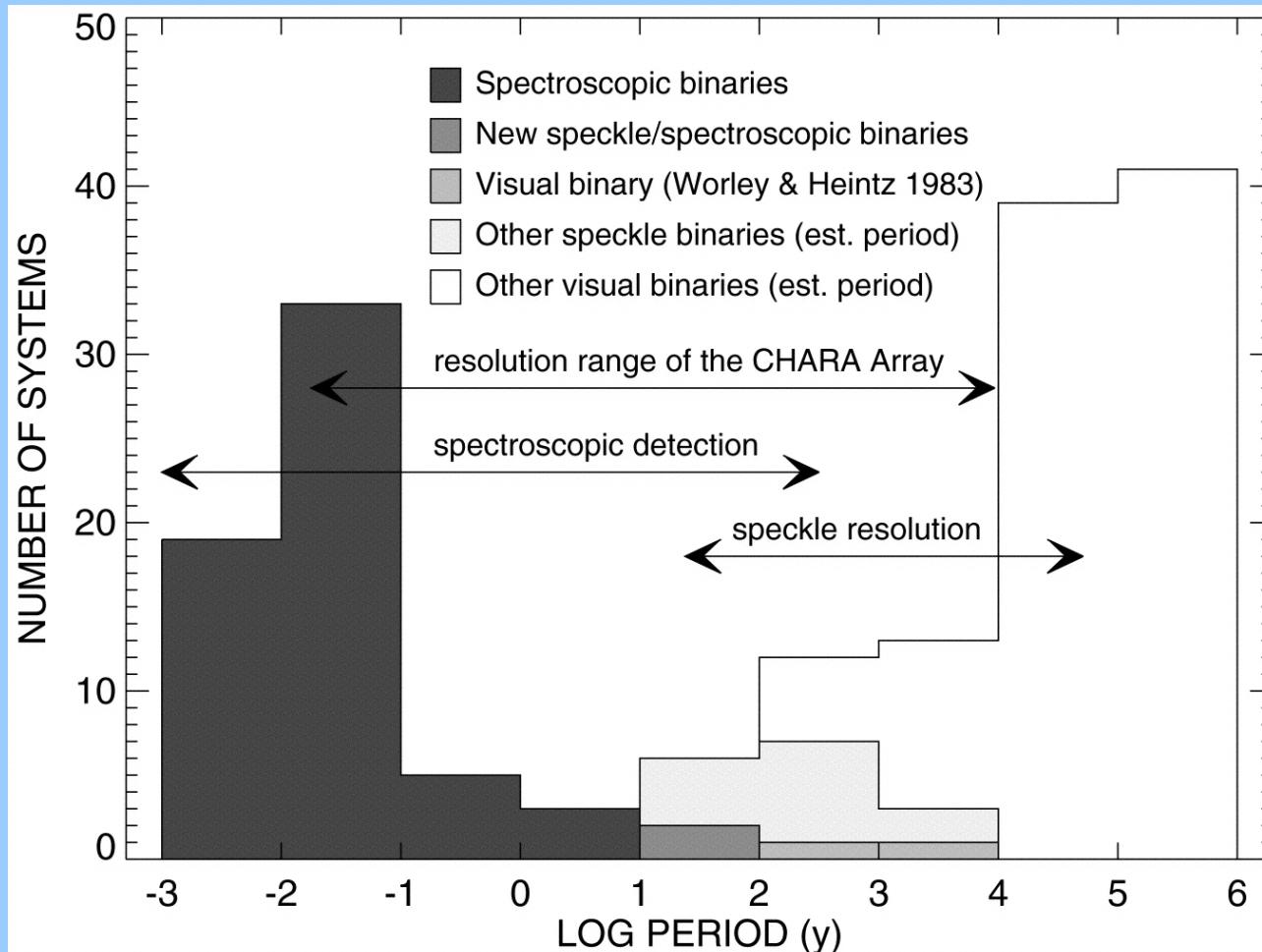
FIG. 1.—The number of binaries, N , as a function of the mass ratio for the G-dwarf sample.

Main Sequence Binary Population

- Mason *et al.* 1998
 - Sample
 - 227 O-type systems (254 stars)
 - $V < 8$
 - Data
 - speckle measurements, $0.035'' < \rho < 1.5''$, $\Delta m < 3$
 - 496 observations, $\Delta t > 10$ yr
 - spectroscopic orbits
 - visual observations
 - common proper motion pairs

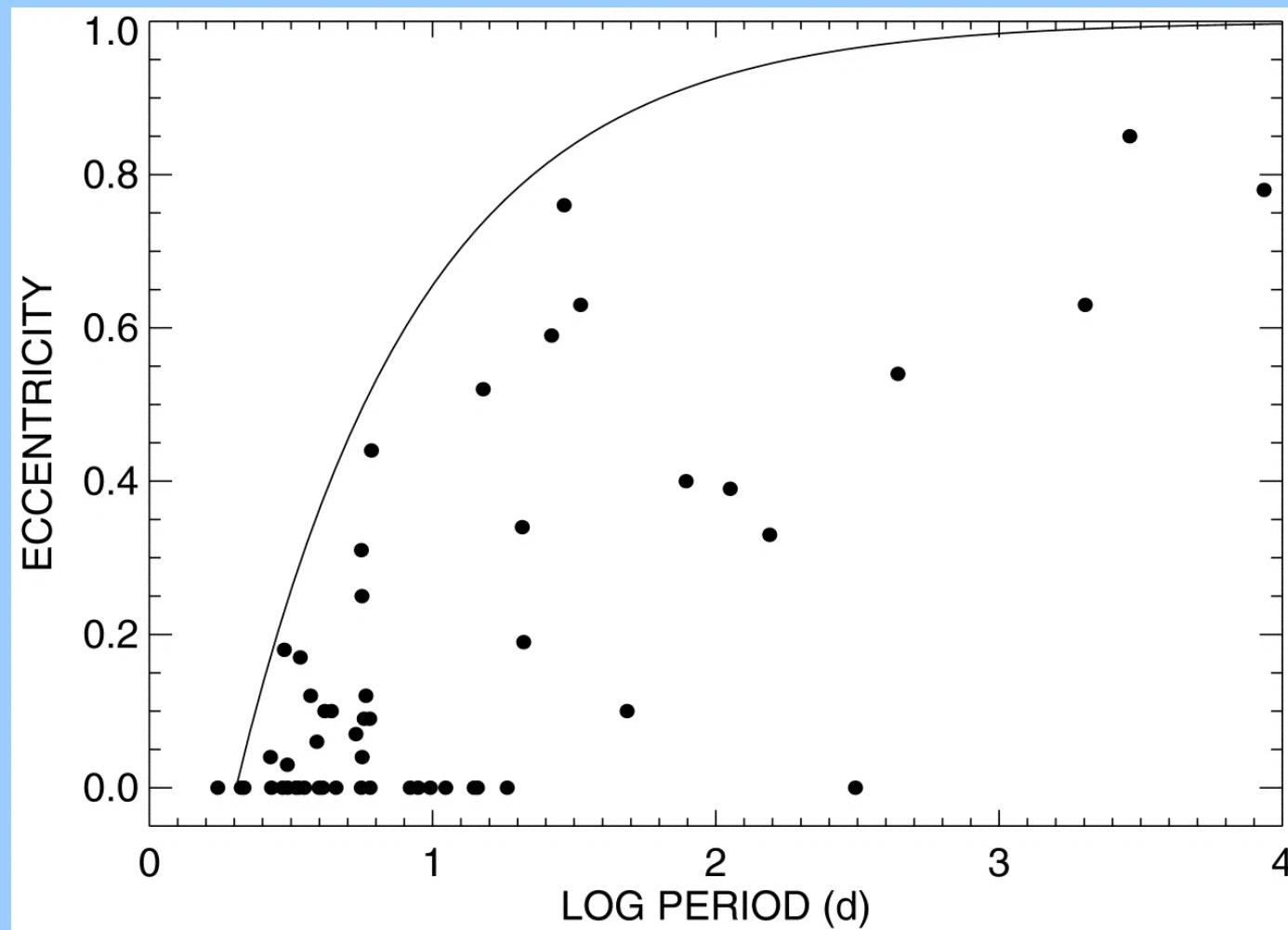
Main Sequence Binary Population

- Frequency and Period Distribution
 - > 59 % companions in clusters and associations



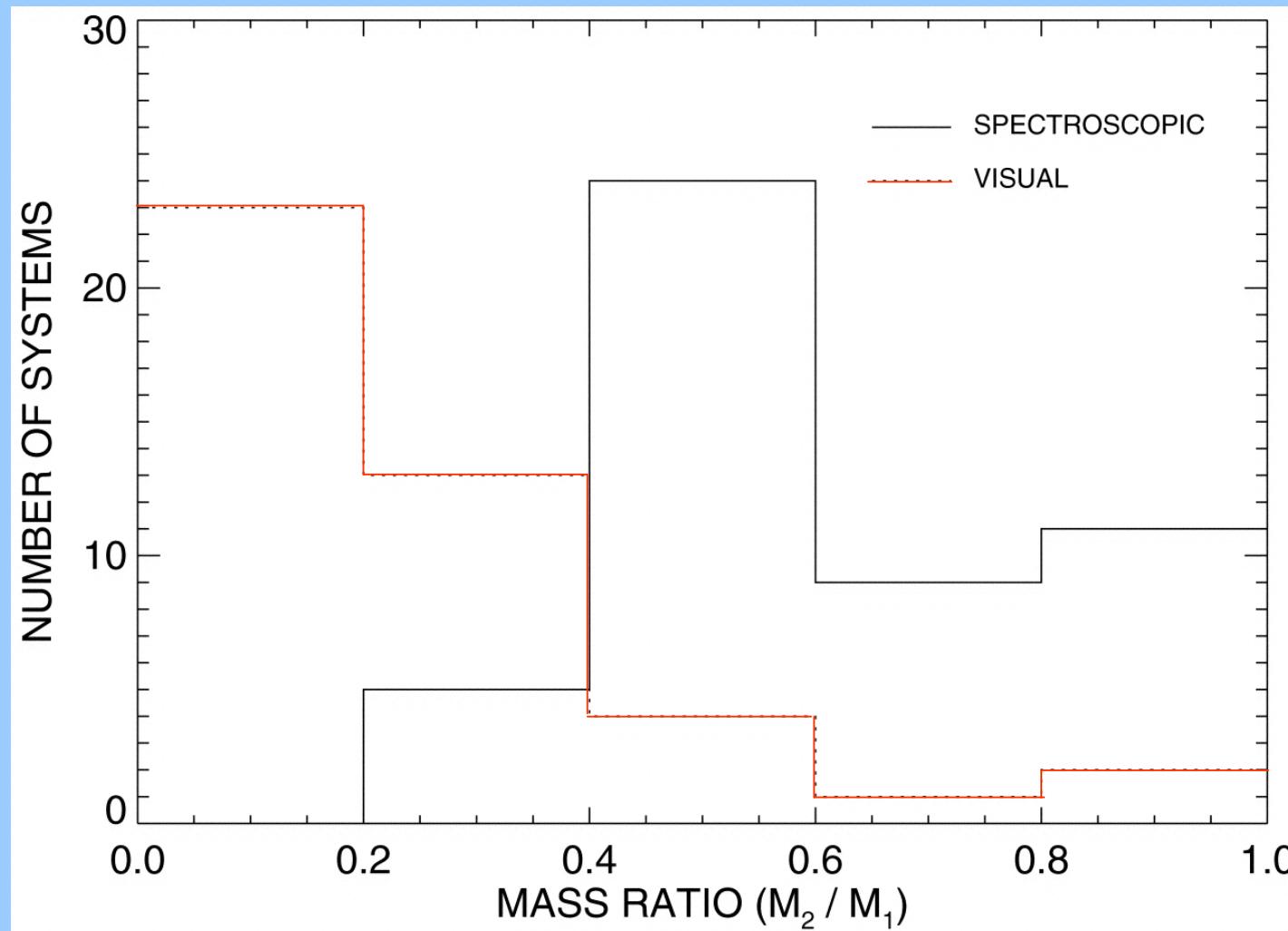
Main Sequence Binary Population

- Orbital Eccentricity Distribution



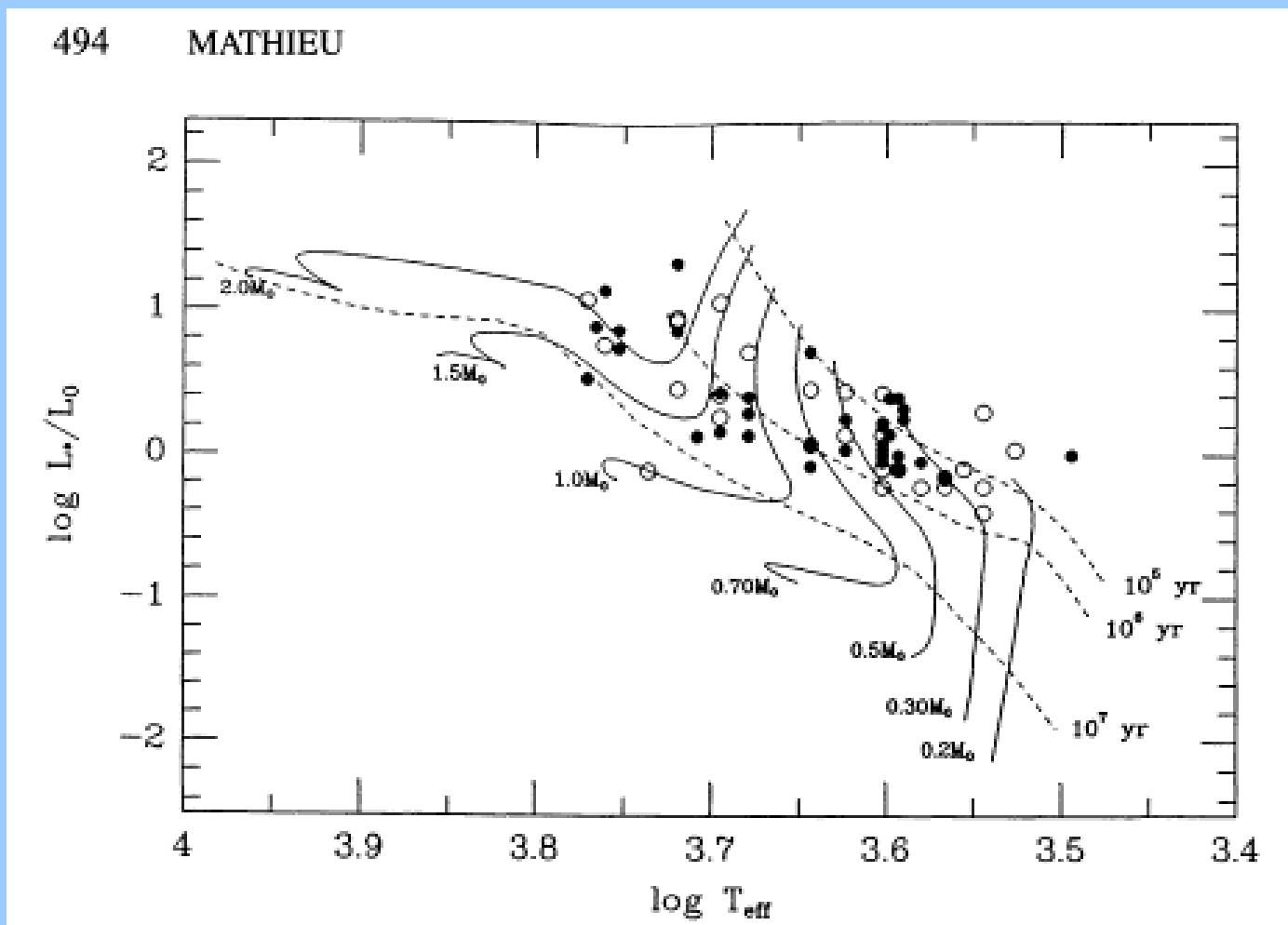
Main Sequence Binary Population

- Mass Ratio Distribution

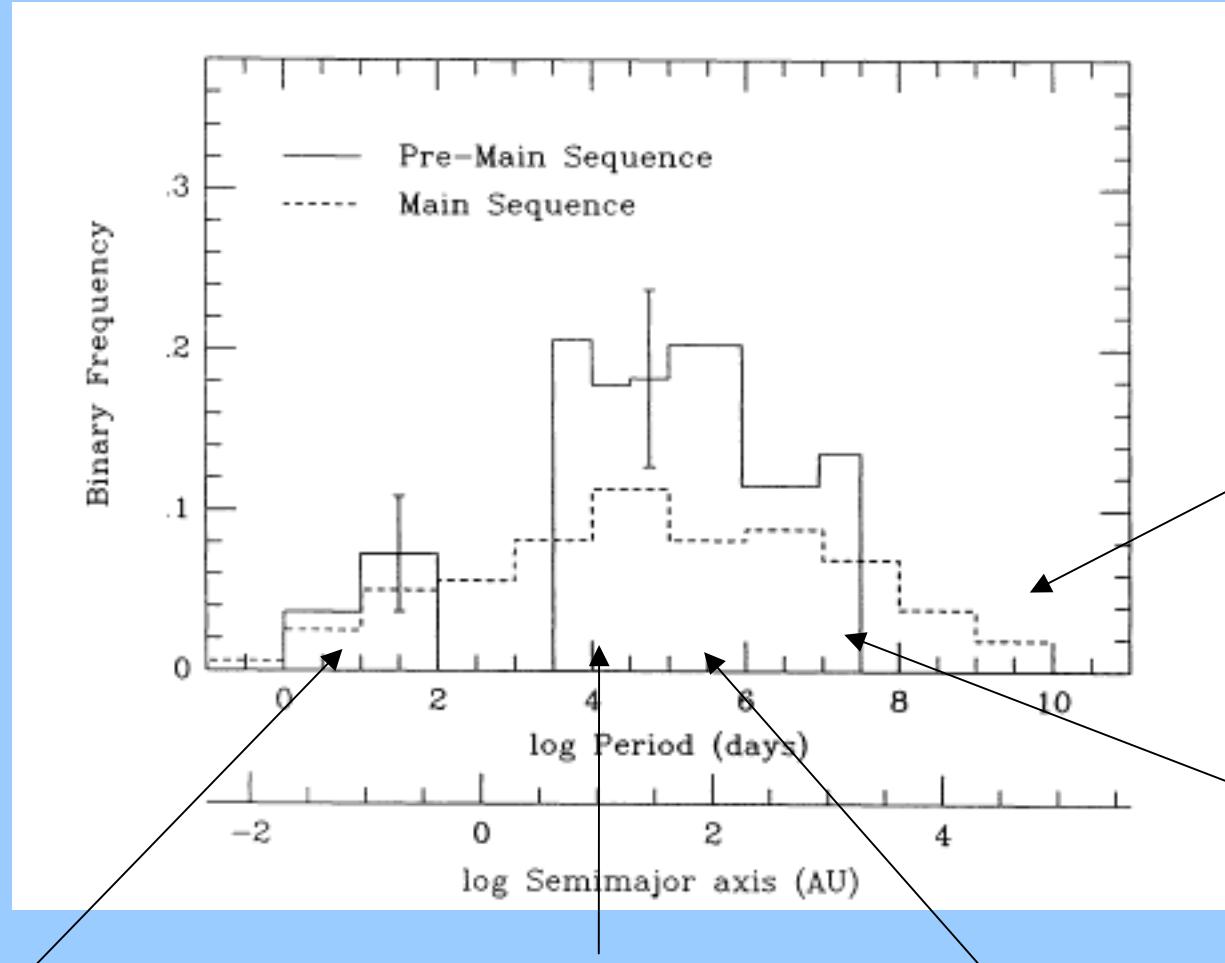


Pre-Main Sequence Binary Population

- Taurus-Auriga (140 pc)
 - Sample 178 primaries 63 CTTS, 106 WTTS, 9 ?



Pre-Main Sequence Binary Population



Spectroscopic

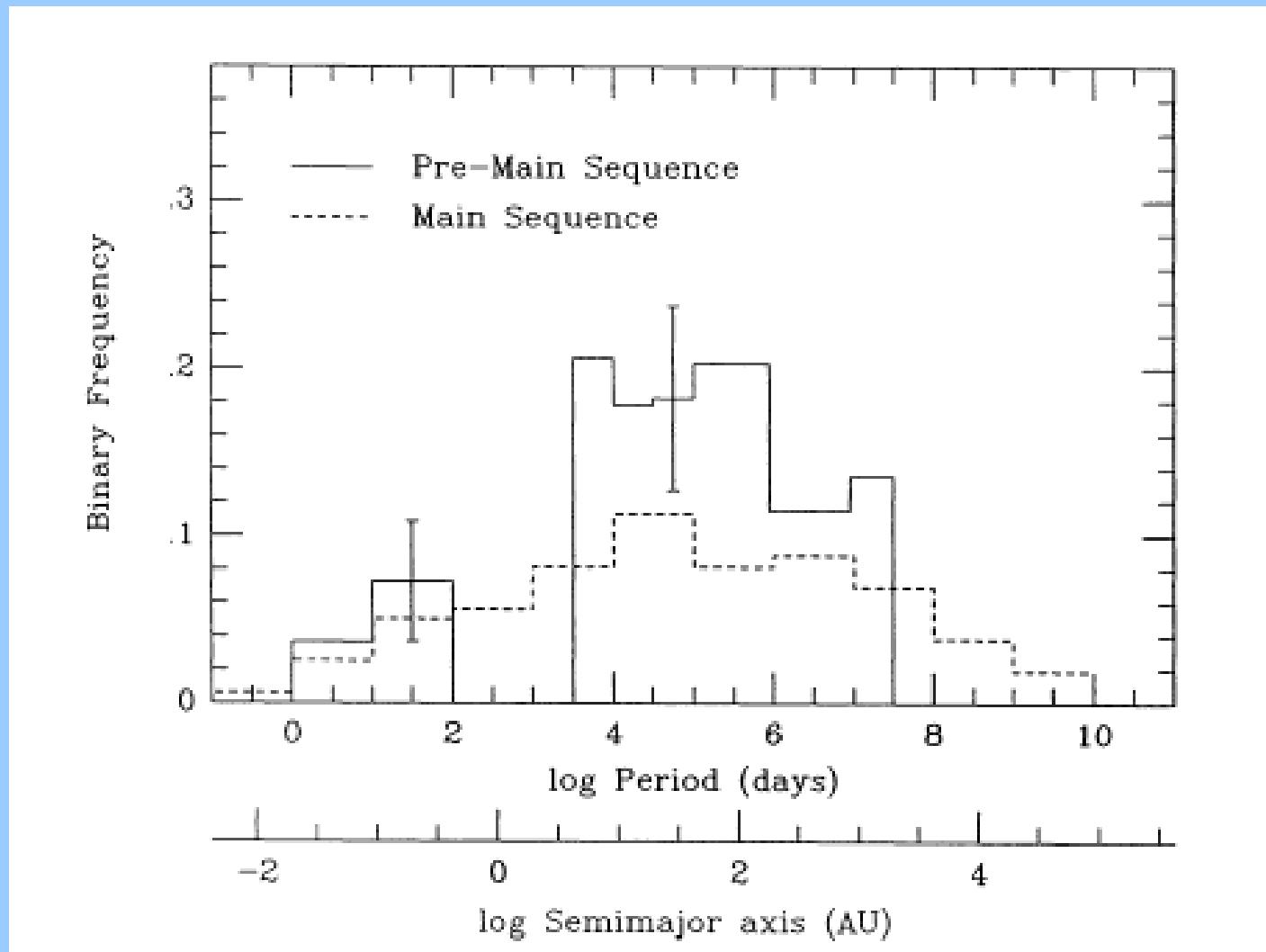
Lunar
Occultation

Infrared Speckle
($K < 9.5$)

Confusion
Limited

Infrared
Imaging

Pre-Main Sequence Binary Population



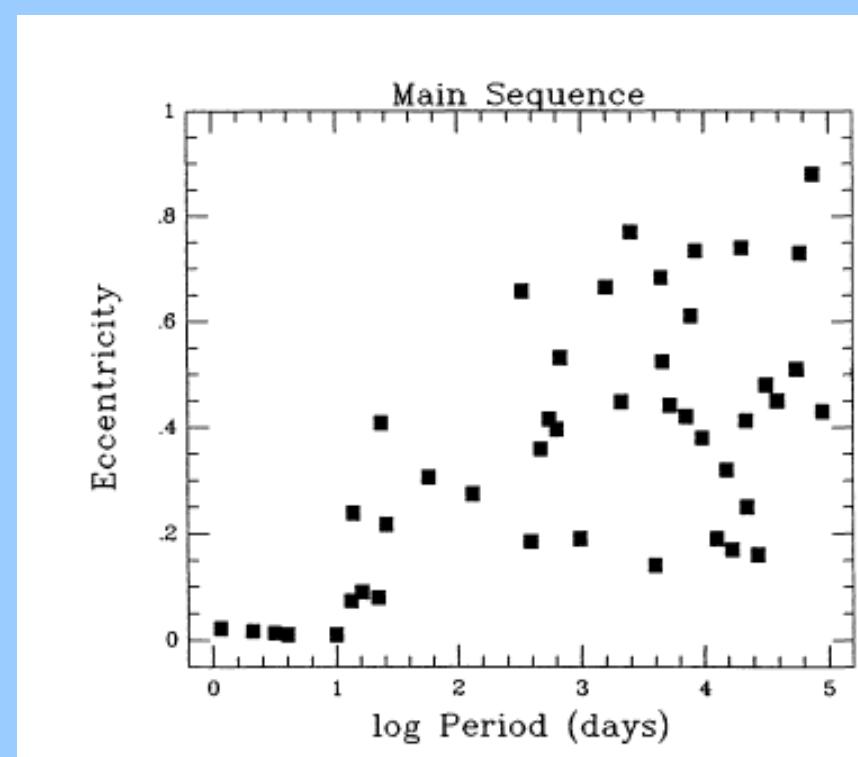
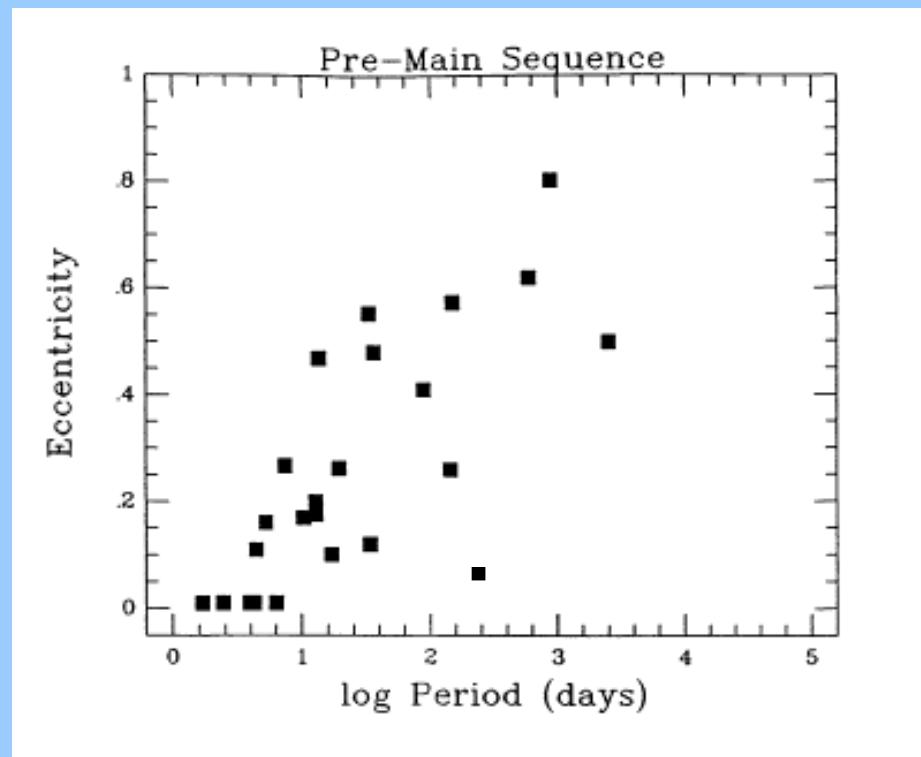
Pre-Main Sequence Binary Population

RECENT PMS BINARY SURVEYS

Region	N	Sep. Range (AU)	Bin. Freq.	Result/Field	Ref.
Taurus	178	19-1900	0.43 ± 0.05	1.93 ± 0.23	Köhler and Leinert (1998)
Ophiuchus	87	15-1800	0.20 ± 0.05	1.9 ± 0.5	Ghez et al. (1997a)
Upper Scorpius	118	19-86	0.36 ± 0.05	1.57 ± 0.34	Köhler et al. (1998)
Chamaeleon	195	120-1800	0.14 ± 0.03	0.97 ± 0.31	Brandner et al. (1996)
Cha/Lupus/CrA	104	15-1800	0.27 ± 0.06	2.2 ± 0.5	Ghez et al. (1997a)
IC 348	67	37-2560	0.19 ± 0.05	0.83 ± 0.3	Duchêne et al. (1999a)
NGC 2024, 2068 and 2071	99	138-1050	0.15 ± 0.04	1.3 ± 0.4	Padgett et al. (1997)
Orion Trapezium	50	138-828	0.14 ± 0.05	1.3 ± 0.4	Padgett et al. (1997)
Orion Trapezium	45	63-225	0.059 ± 0.04	0.7 ± 0.5	Petr et al. (1998)
Orion Trapezium	292	132-264	0.03 ± 0.01	1.0 ± 0.3	Simon et al. (1999)
α Per	102	26-595	0.05 ± 0.02	0.3 ± 0.4	Patience et al. (1998b)
Pleiades	144	11-910	0.28 ± 0.04	1.04 ± 0.14	Bouvier et al. (1997)
Hyades	167	5-50	0.30 ± 0.06	2.1 ± 0.6	Patience et al. (1998a)
Praesepe	50	26-595	0.16 ± 0.06	0.9 ± 0.4	Patience et al. (1998b)

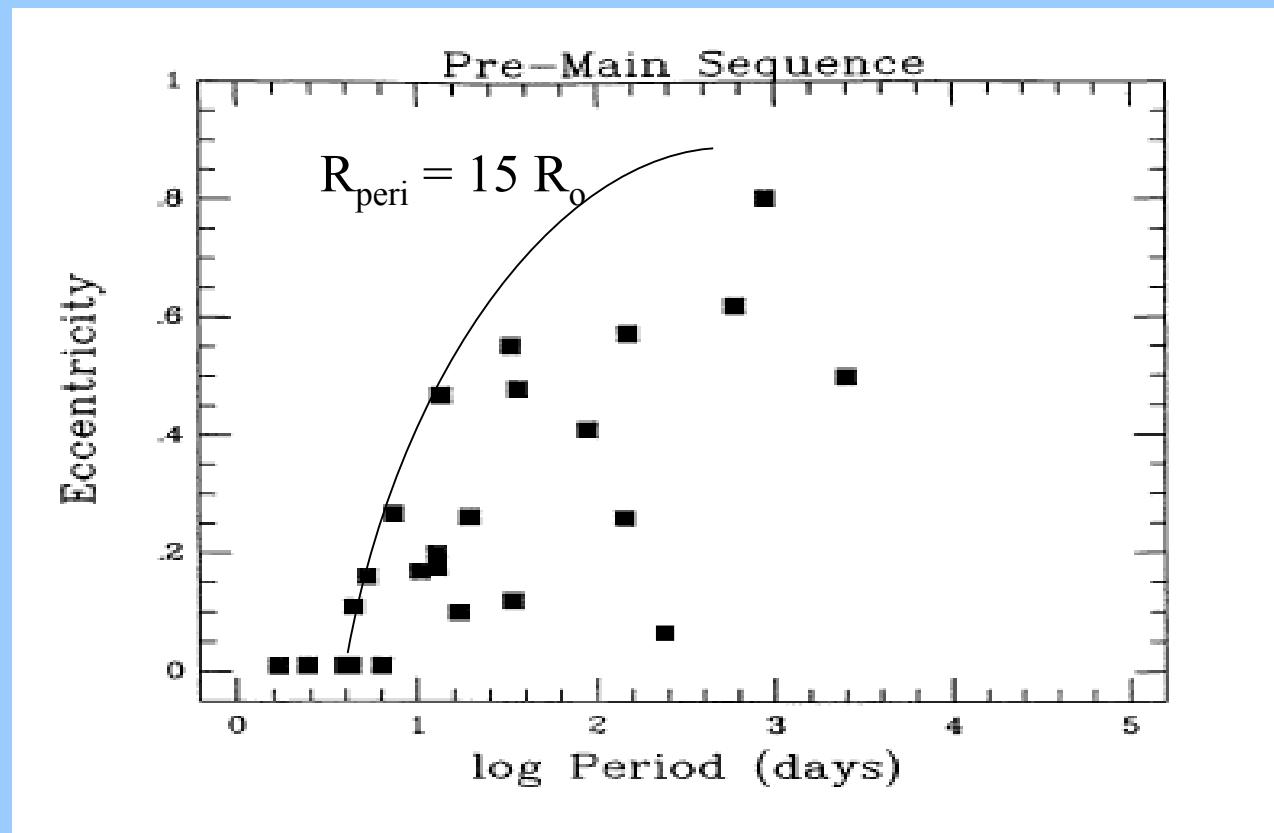
Pre-Main Sequence Binary Population

- Orbital Eccentricity Distribution



Pre-Main Sequence Binary Population

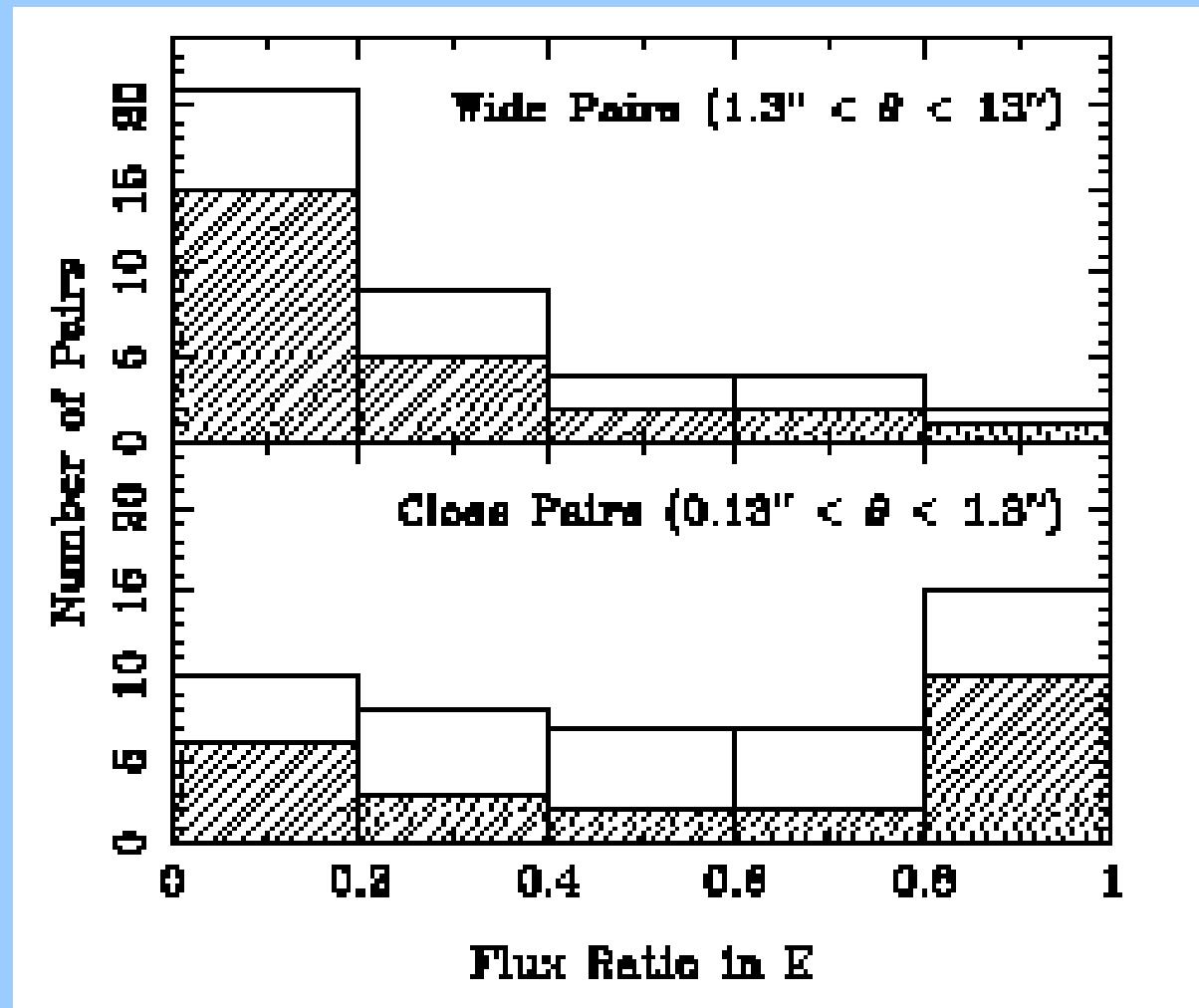
- Orbital Eccentricity Distribution
 - Orbital Evolution!



Pre-Main Sequence Binary Population

- Flux ratio distribution

Kohler & Leinert 1999



Protoplanetary Disks and Binary Stars

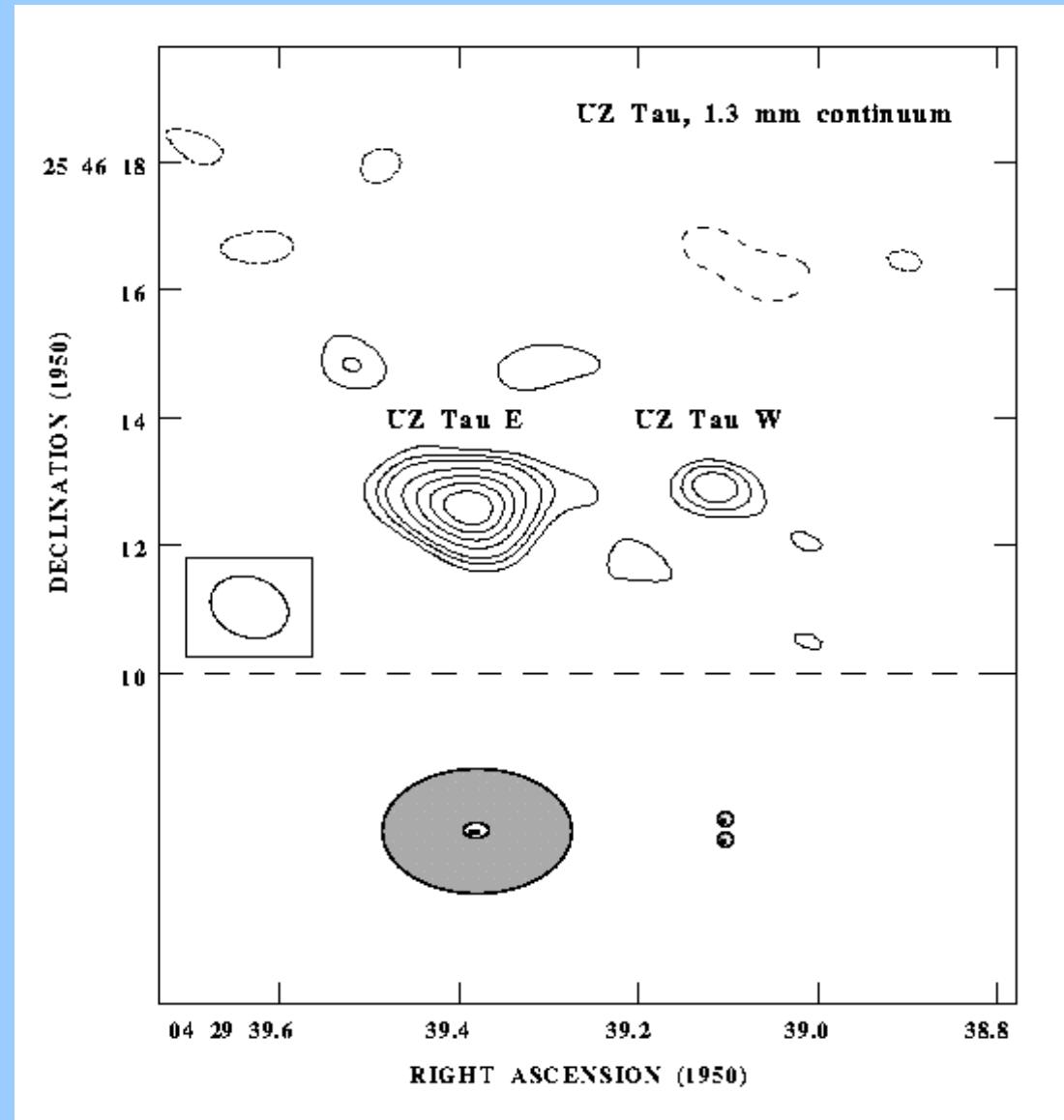
- Binaries of all separations show
 - Diagnostics for accretion at stellar surfaces
 - H α emission
 - Spectral veiling
 - Irregular large-amplitude variability
 - Infrared emission excesses
 - Resolved millimeter emission

“The most classical of classical T Tauri stars are binaries, including T Tau itself”

Protoplanetary Disks and Binary Stars

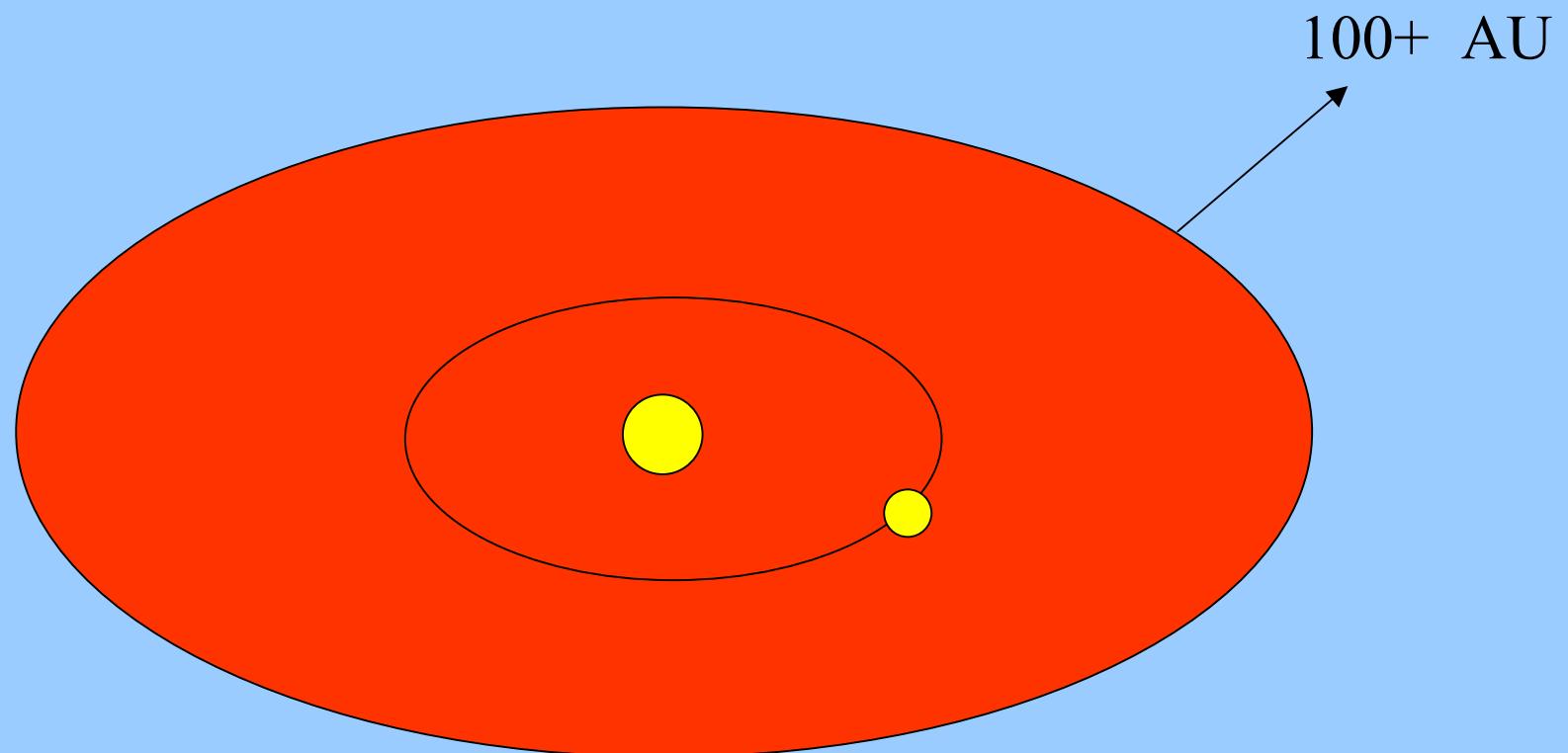
- UZ Tau E and W

Jensen et al. 1996



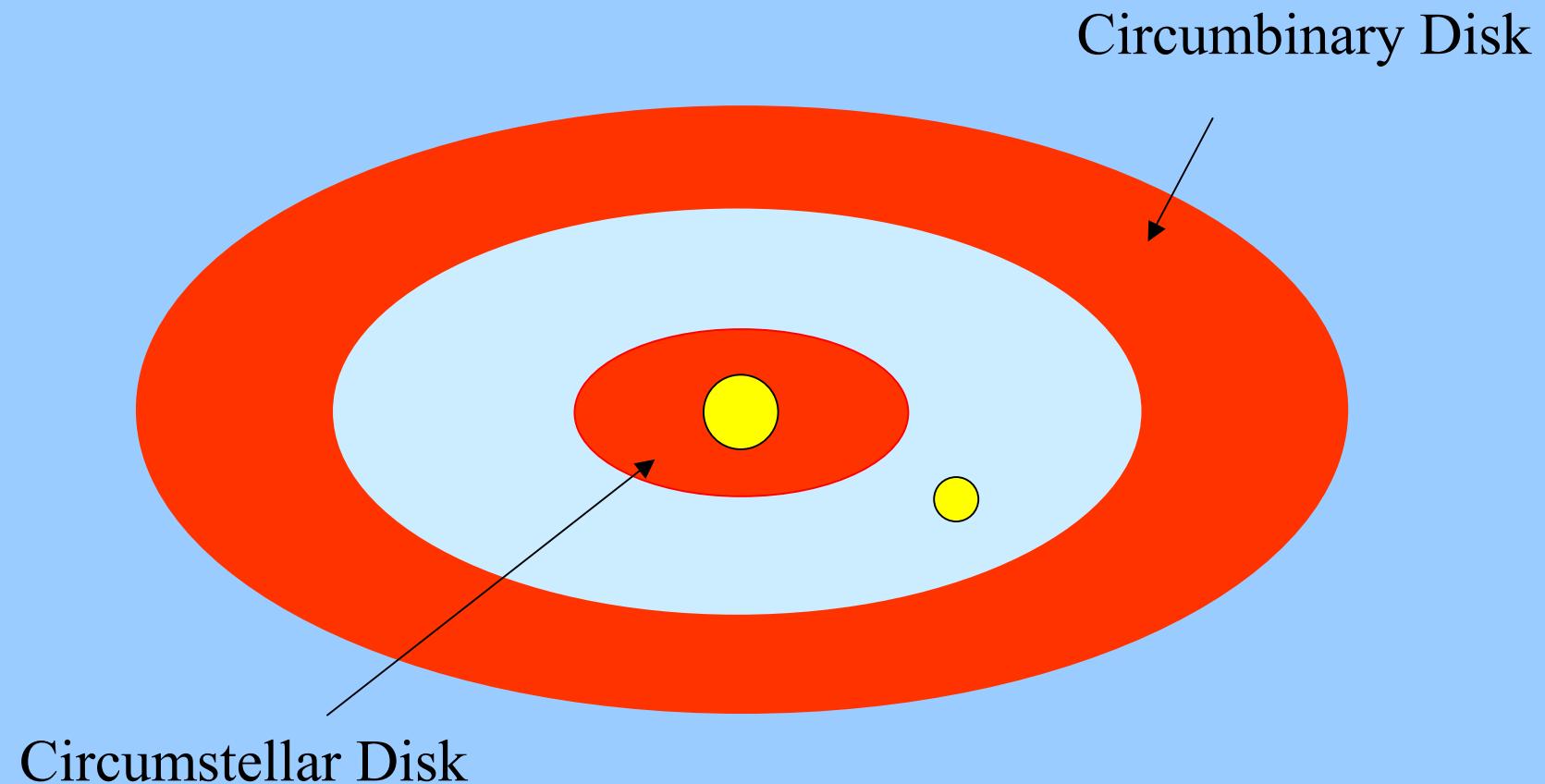
Protoplanetary Disks and Binary Stars

- Dynamical Expectations
 - Cartoon model, $q \ll 1$



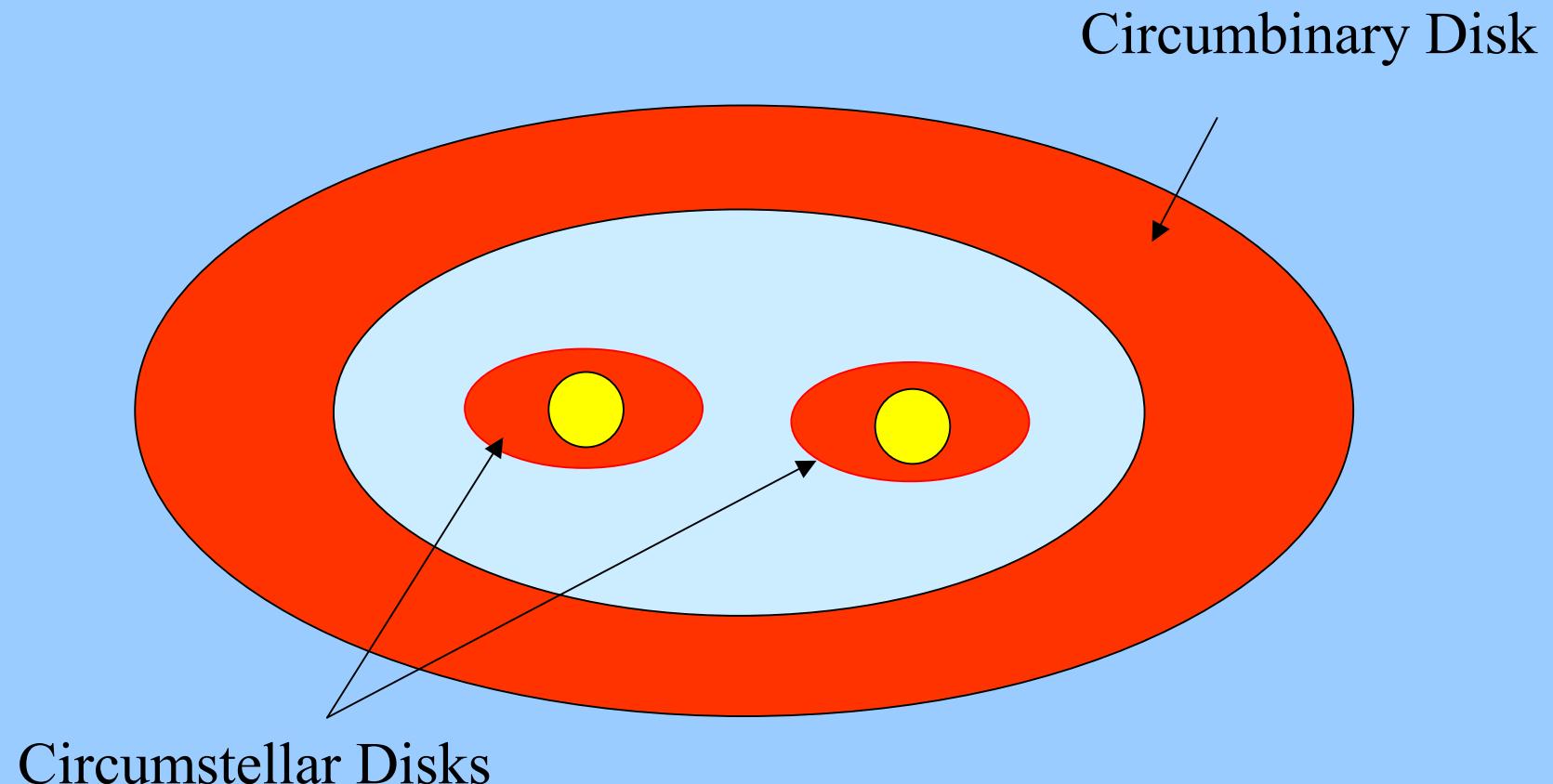
Protoplanetary Disks and Binary Stars

- Dynamical Timescale
 - Gap Clearing



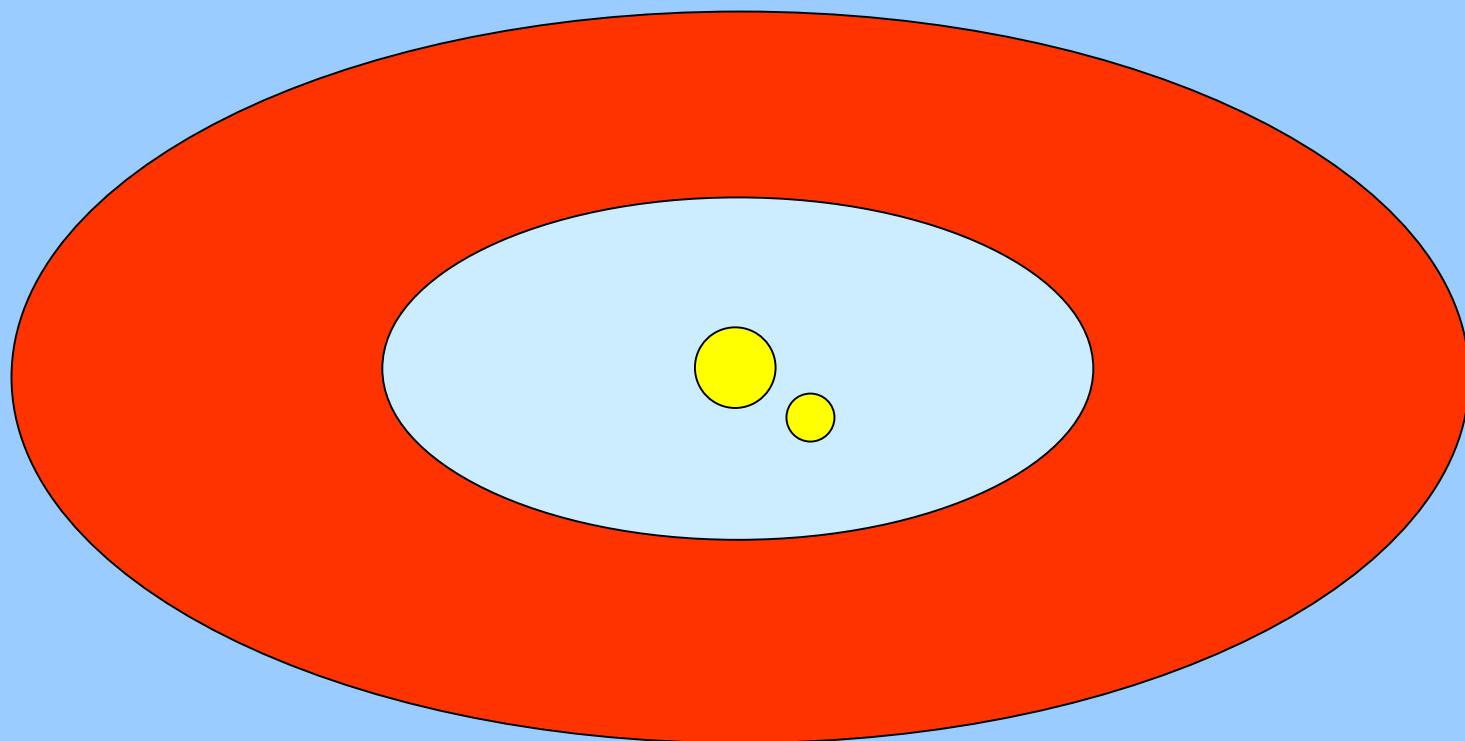
Protoplanetary Disks and Binary Stars

- Dynamical Timescale
 - Gap Clearing, $q \approx 1$



Protoplanetary Disks and Binary Stars

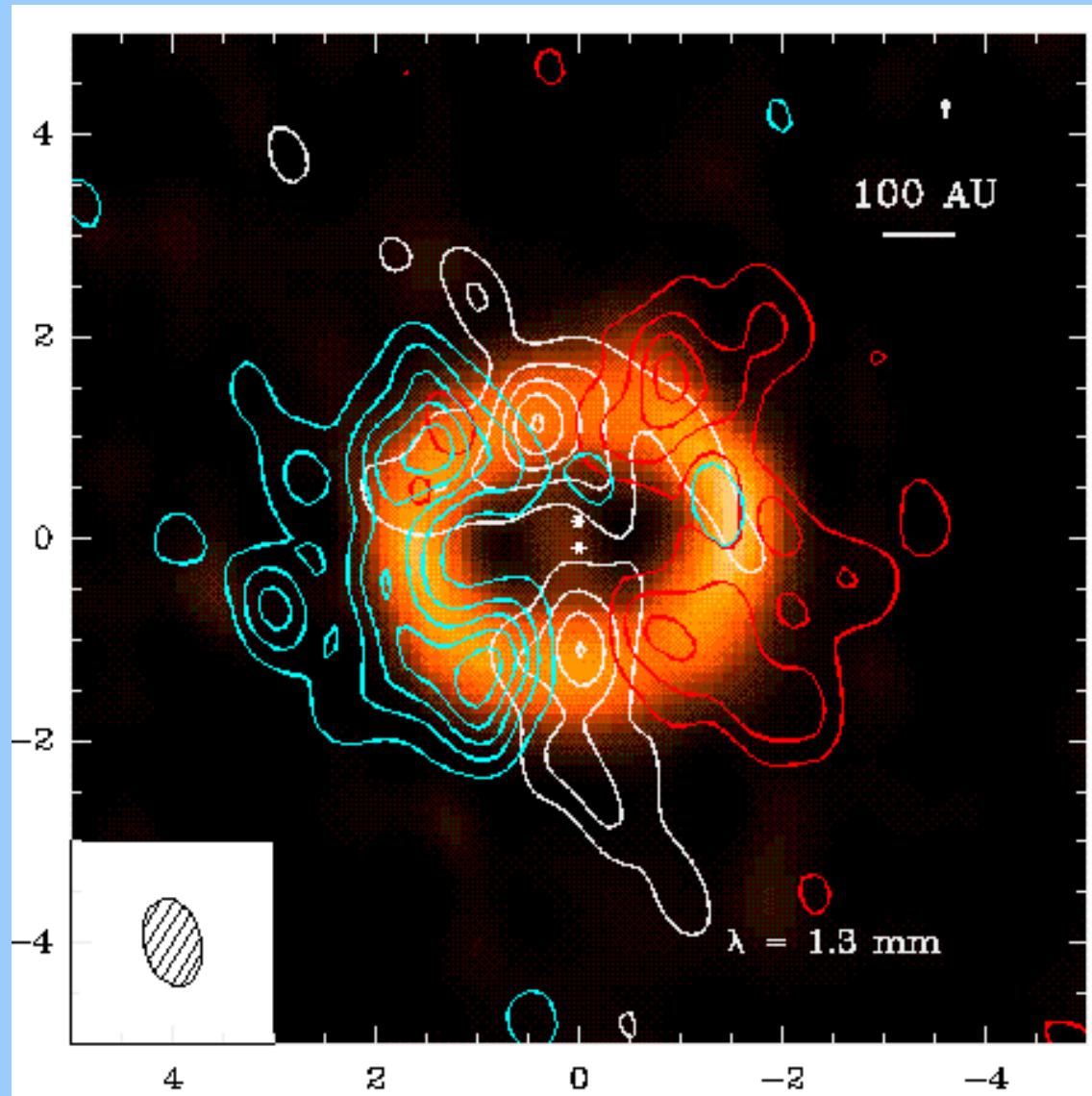
- Viscous Timescale
 - Orbital migration and eccentricity increase
 - Circumstellar disk depletion



Protoplanetary Disks and Binary Stars

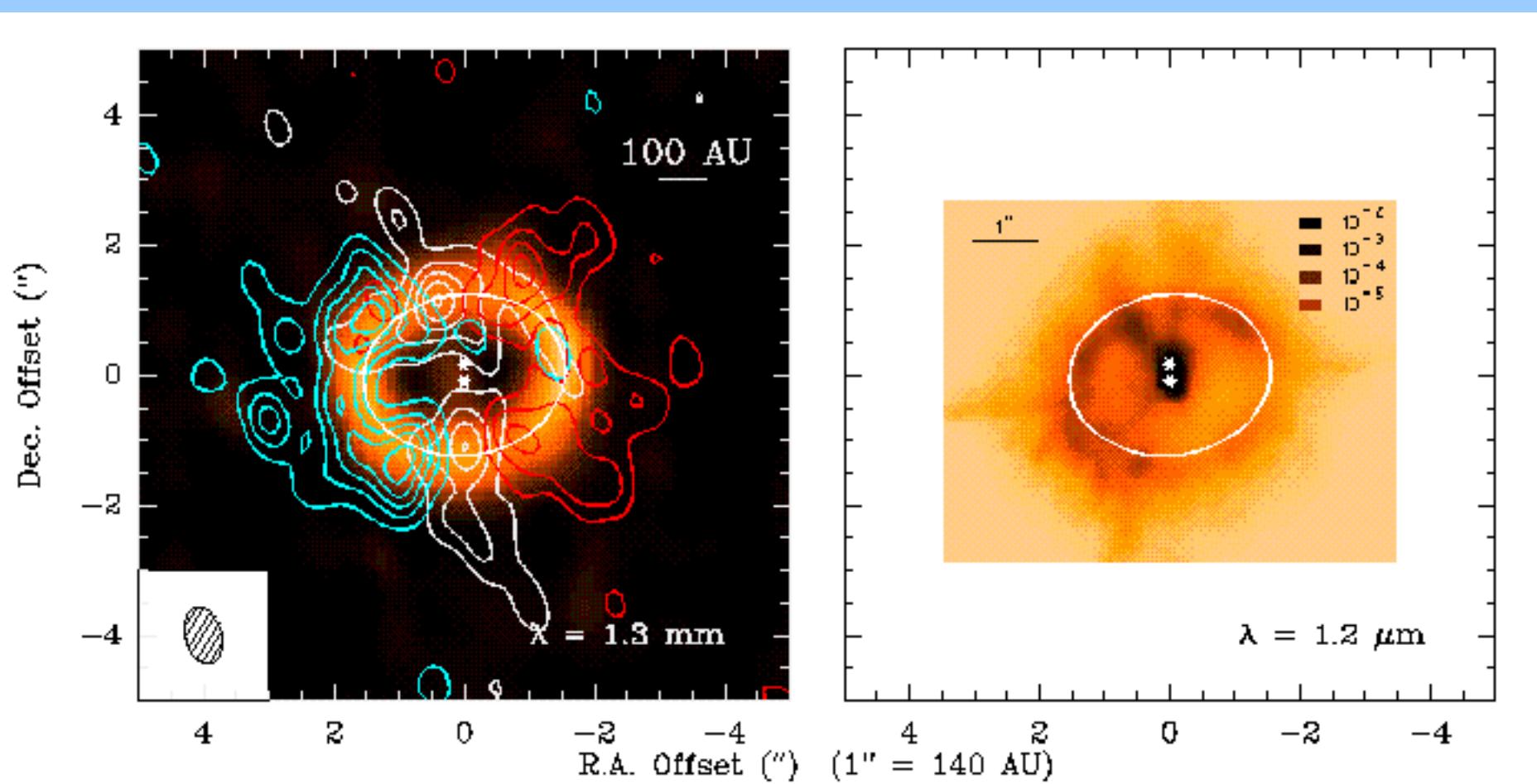
- GG Tau

Guilloteau et al. 1999



Protoplanetary Disks and Binary Stars

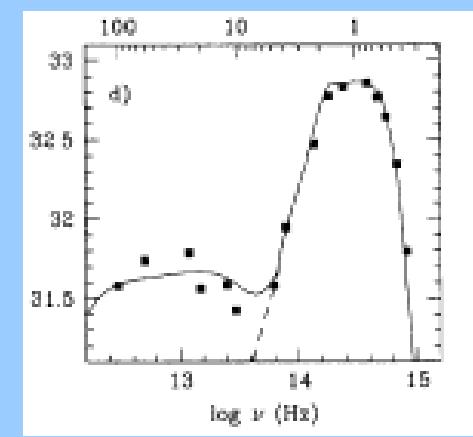
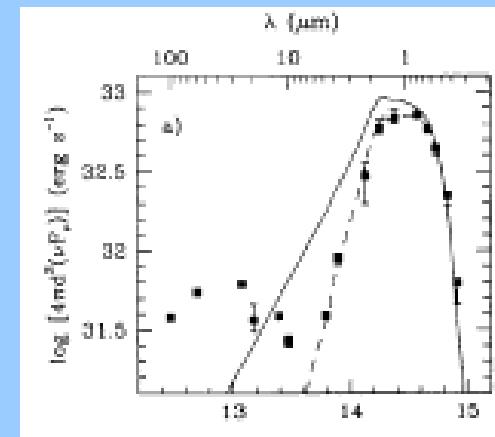
- GG Tau



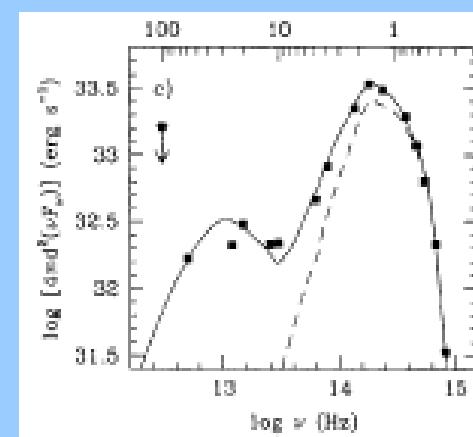
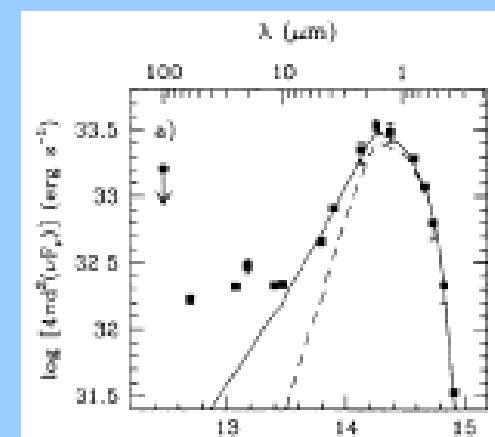
Protoplanetary Disks and Binary Stars

- Circumstellar disks (Jensen & Mathieu 1998)

V4046 Sgr



162814-2427

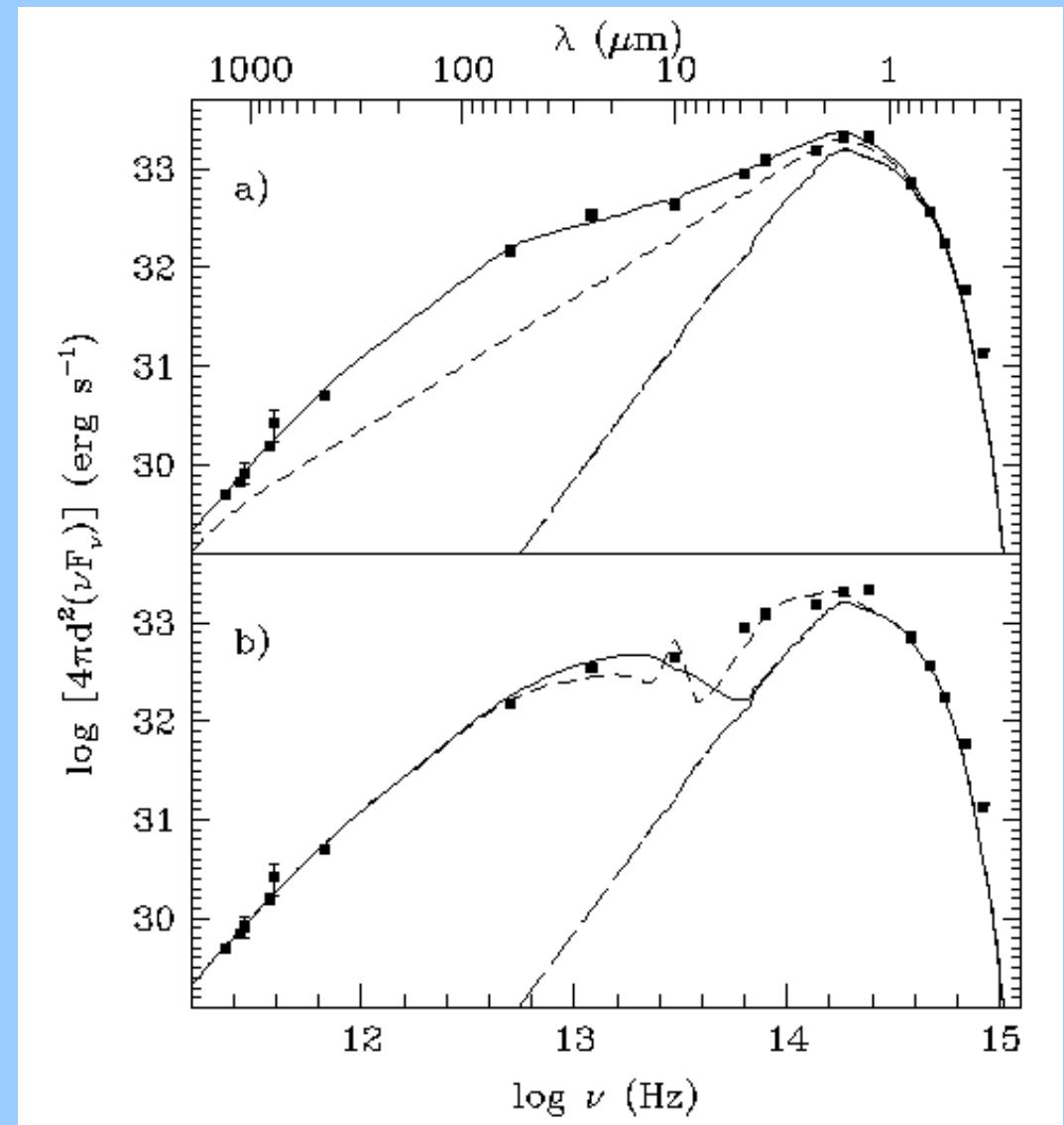


Protoplanetary Disks and Binary Stars

- Circumstellar disks

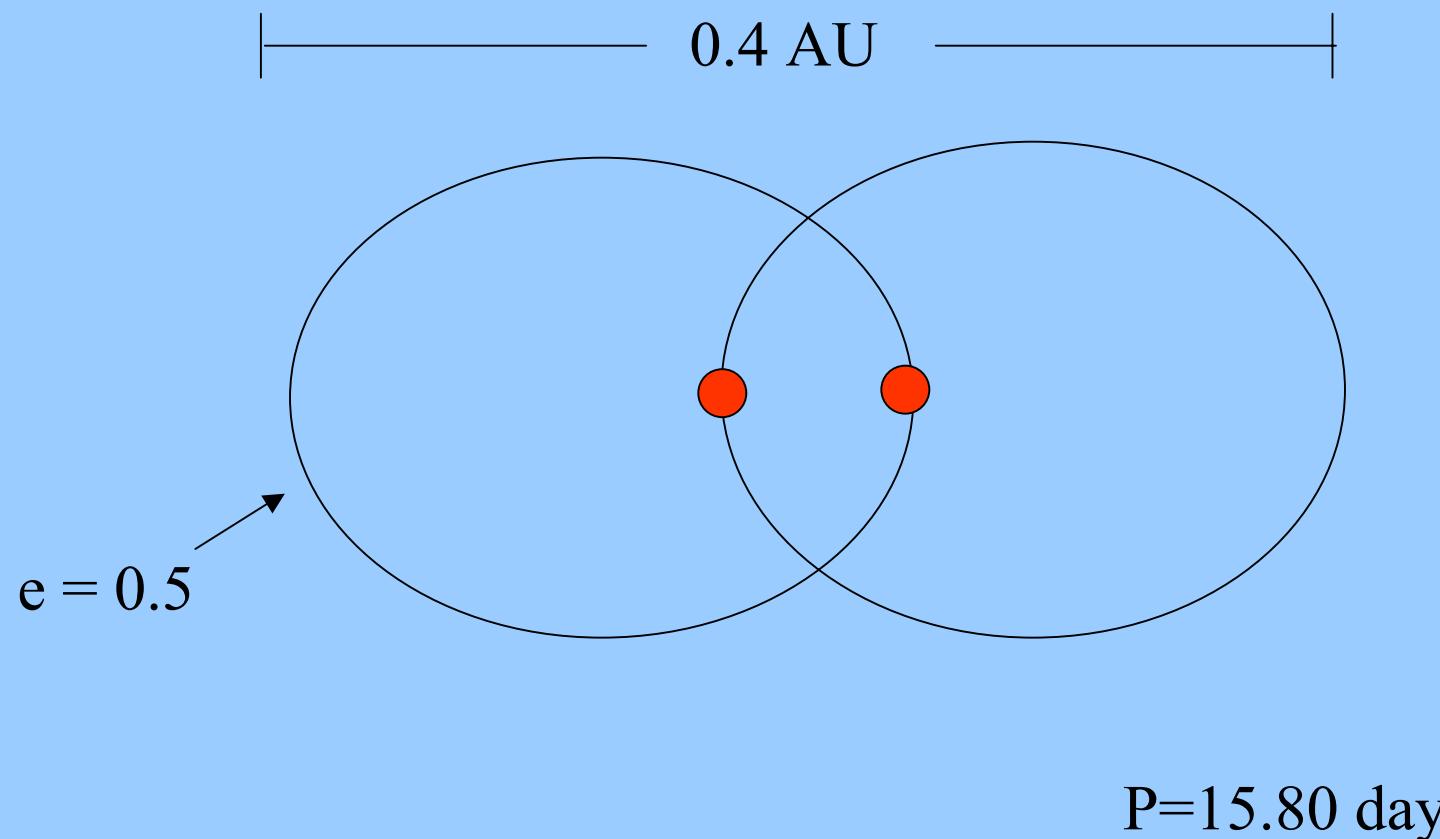
Mathieu et al. 1997

DQ Tau



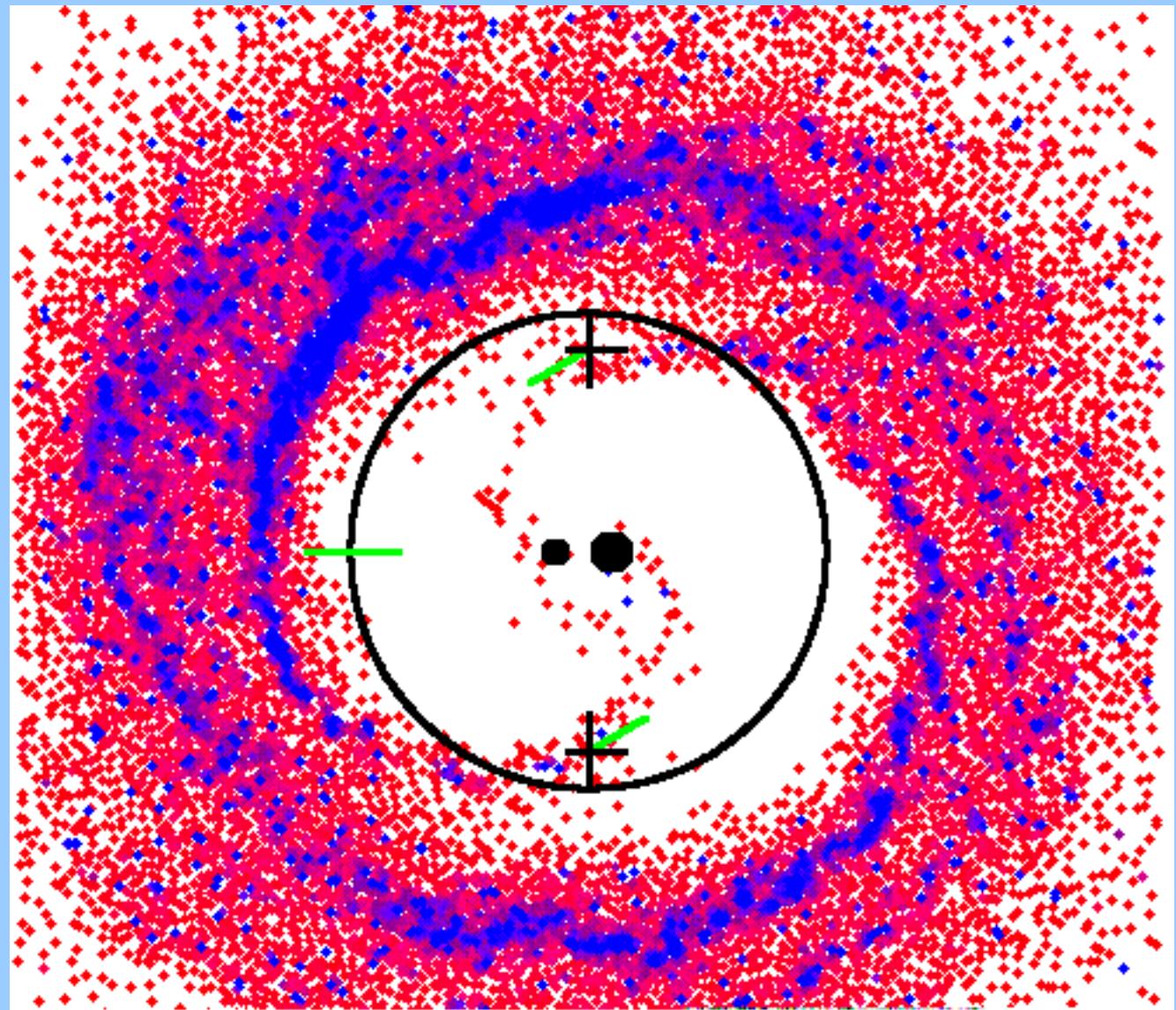
Protoplanetary Disks and Binary Stars

DQ Tau



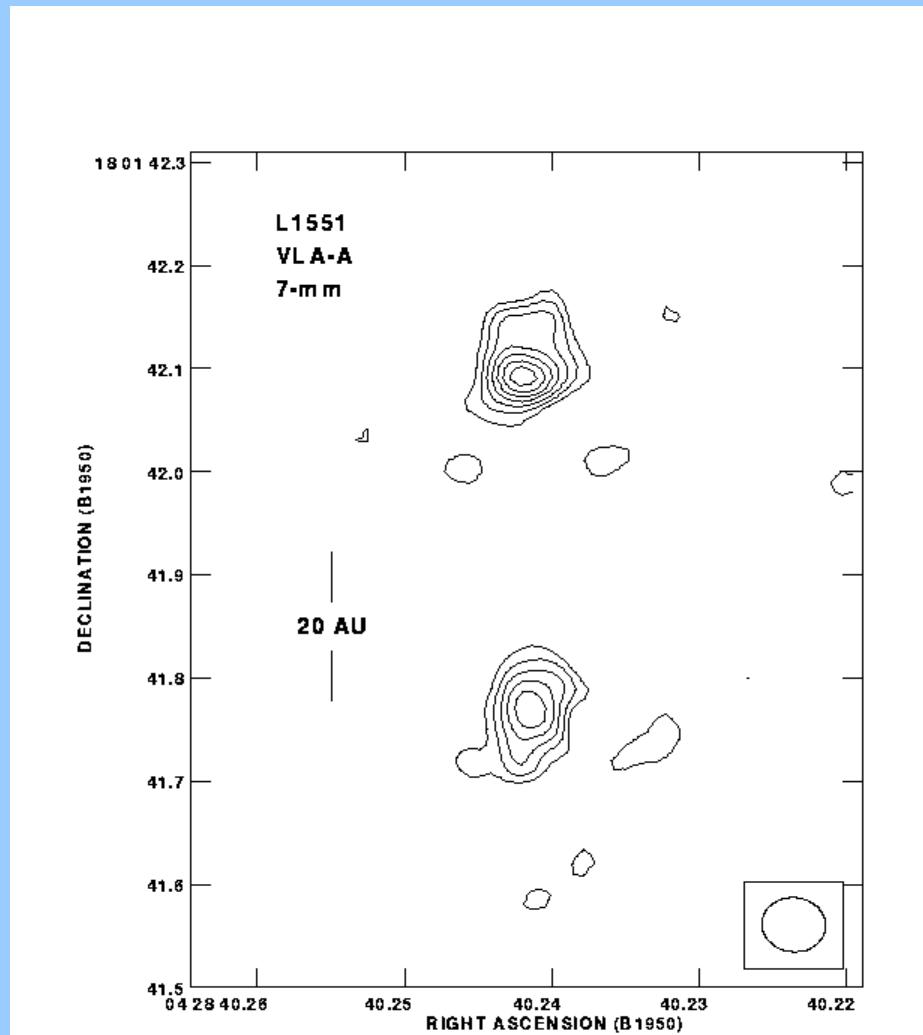
Protoplanetary Disks and Binary Stars

Artymowicz &
Lubow 1996



Protoplanetary Disks and Binary Stars

Rodriguez et al. 1998



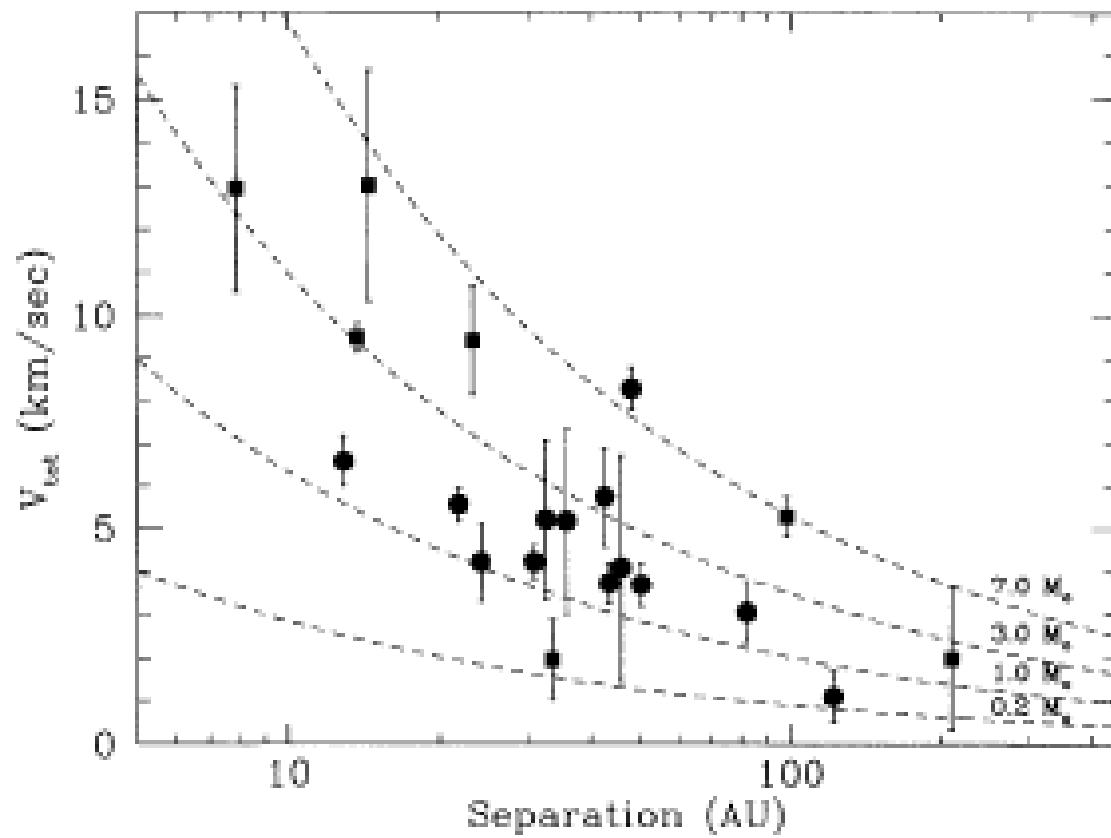
Pre-Main Sequence Stellar Masses

- Astrometric Orbits
 - Tangential velocities
 - Partial orbits
- Astrometry + Radial Velocities
 - NTTS 045251+3016

Pre-Main Sequence Stellar Masses

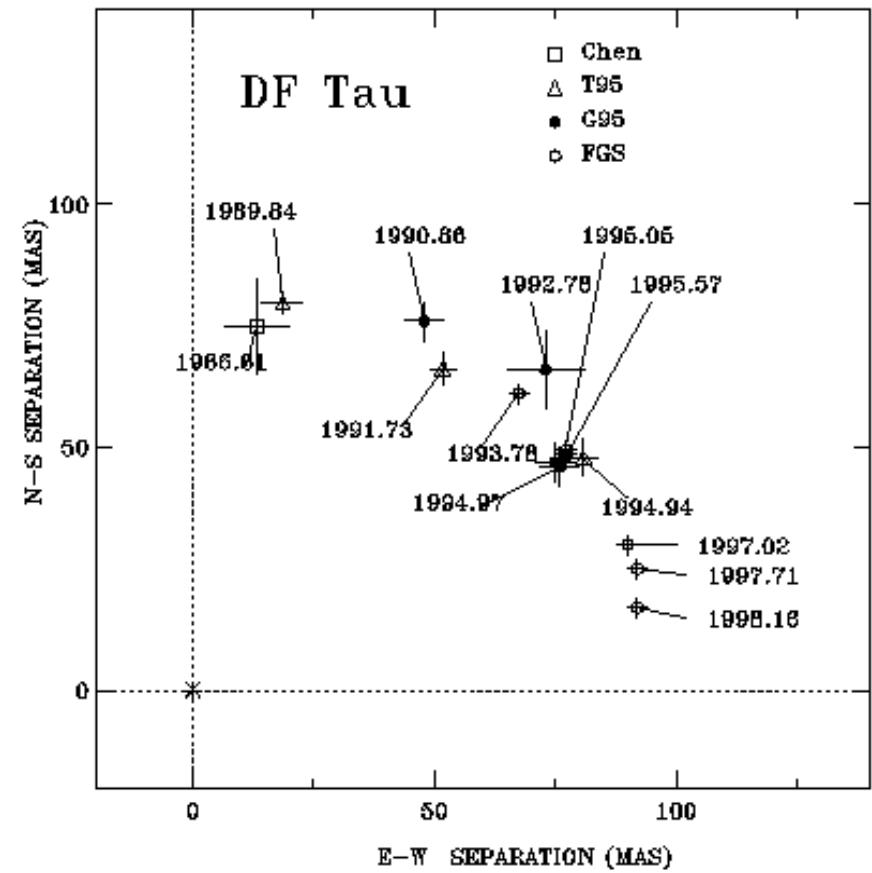
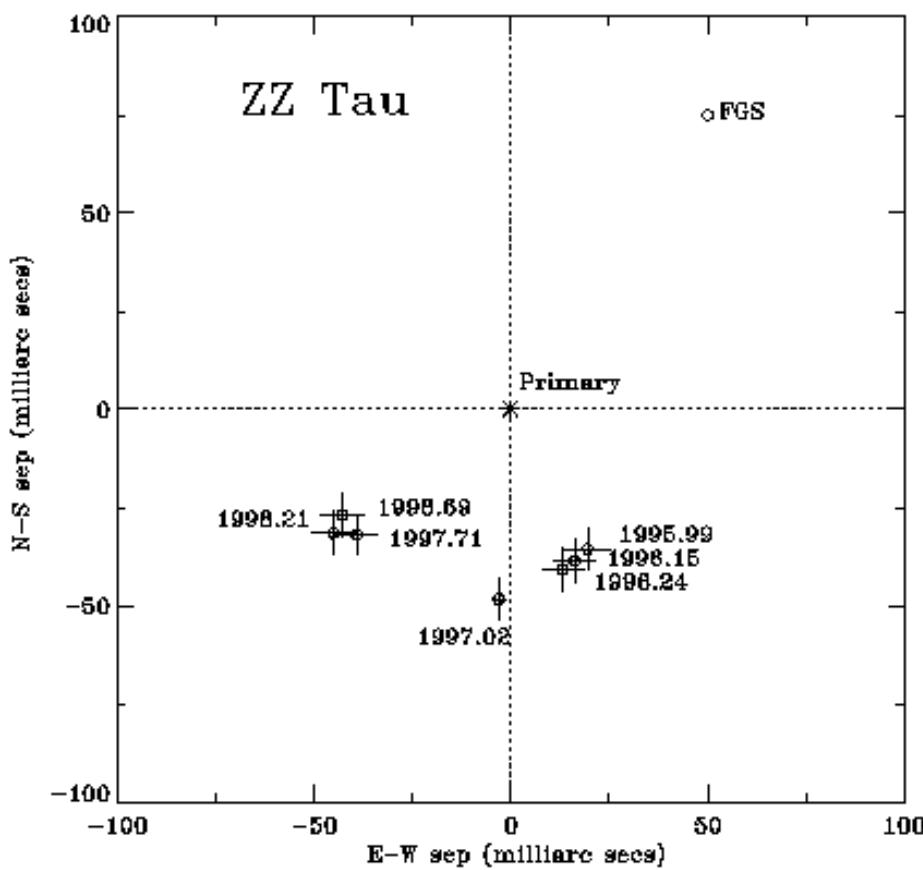
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GHEZ *ET AL.*: T TAU BINARIES



Pre-Main Sequence Stellar Masses

Simon *et al.* (in prep)



Pre-Main Sequence Stellar Masses

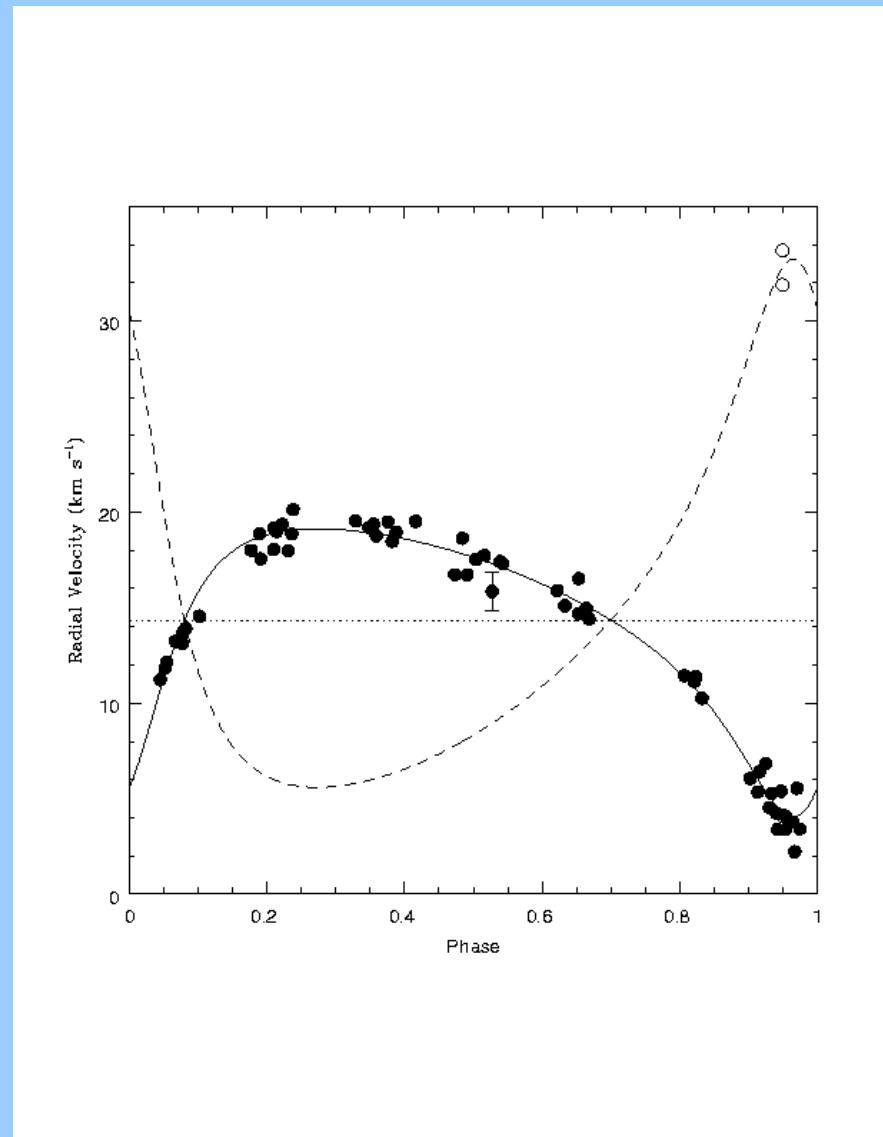
NTTS 045251+3016

$$P = 6.913 \text{ yr}$$

$$e = 0.457$$

$$M_2/M_1 = 0.56$$

Steffen *et al.* 2000



Pre-Main Sequence Stellar Masses

NTTS 045251+3016

$$P = 6.913 \text{ yr}$$

$$e = 0.457$$

$$i = 113.8^\circ$$

$$a = 0.0328''$$

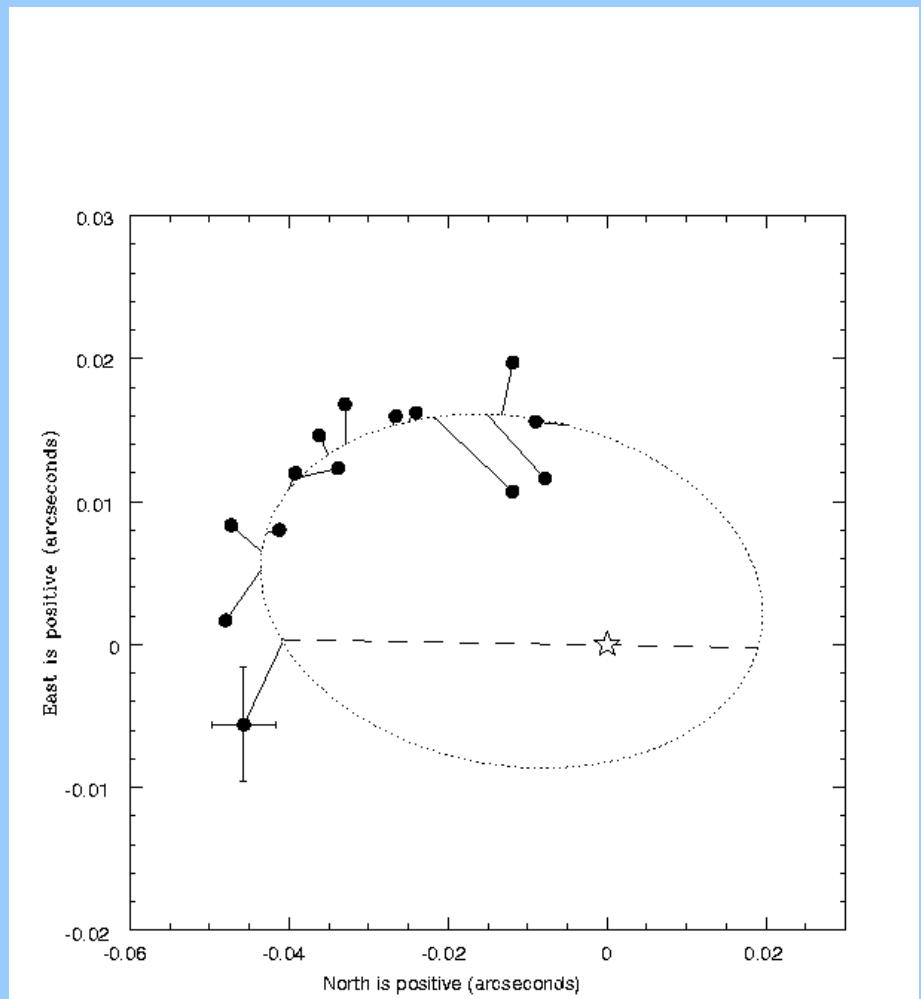
$$= 4.76 \text{ AU}$$

$$M_1 = 1.46 M_\odot$$

$$M_2 = 0.81 M_\odot$$

$$M_2/M_1 = 0.56$$

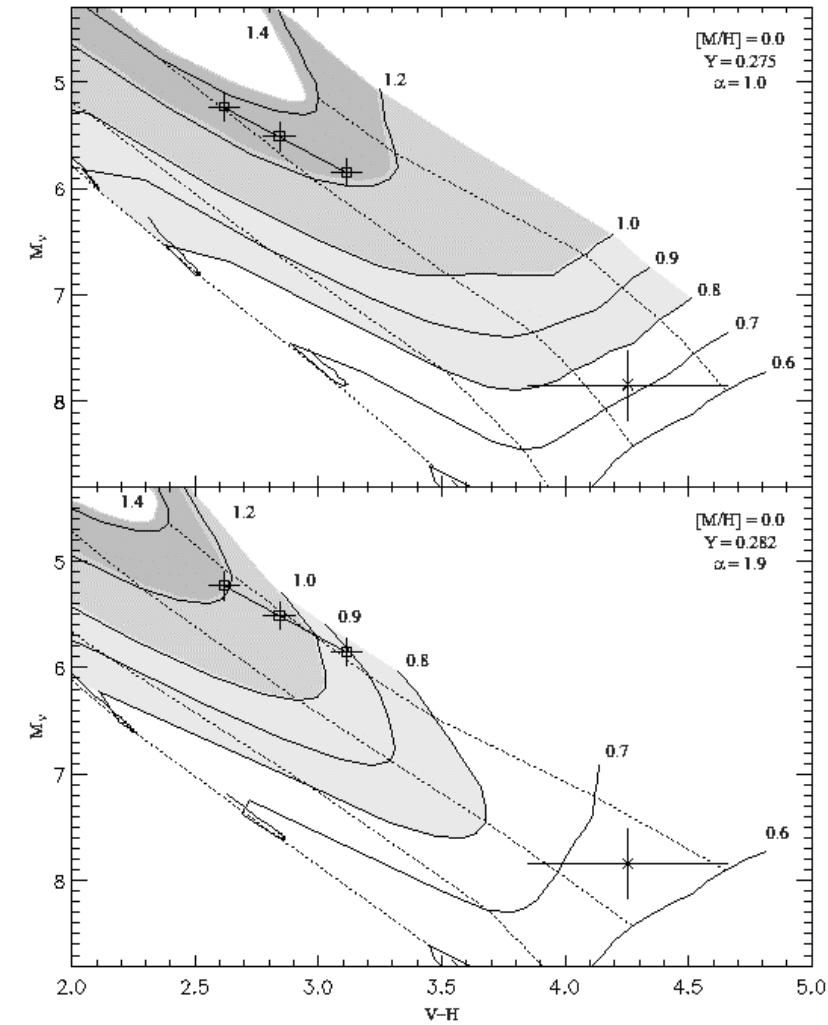
$$D = 145 \text{ pc}$$



Pre-Main Sequence Stellar Masses

NTTS 045251+3016

Baraffe et al. tracks



Pre-Main Sequence Stellar Masses

NTTS 045251+3016

D'Antona & Mazzitelli 1997

