The formation of binary stars

Motivation:

Best testbed for star formation theory

Report:

Progress in observations and simulations

And in memory of:

Eduardo Delgado Donate

3.10.77-10.2.07

Progress in observations

A SURVEY OF STELLAR FAMILIES: MULTIPLICITY OF SOLAR-TYPE STARS

DEEPAK RAGHAVAN[1], HAROLD A. MCALISTER[1], TODD J. HENRY[1], DAVID W. LATHAM[2], GEOFFREY W. MARCY[3], BRIAN D. MASON[4], DOUGLAS R. GIES[1], RUSSEL J. WHITE[1], AND THEO A. TEN BRUMMELAAR[5]

[1] Center for High Angular Resolution Astronomy, Georgia State University, P.O. Box 3969, Atlanta, GA 30302-3969, USA; raghavan@chara.gsu.edu

[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

[3] Department of Astronomy, University of California, Berkeley, CA 94720-3411, USA

[4] US Naval Observatory, 3450 Massachusetts Avenue NW, Washington, DC 20392-5420, USA

[5] The CHARA Array, Mount Wilson Observatory, Mount Wilson, CA 91023, USA

Received 2010 April 8; accepted 2010 July 2; published 2010 August 13

Fills in the gaps of Duquennoy & Mayor 1991:

454 solar type stars within 25 pc:

Adds in speckle, CHARA companions, plus further common proper motion and spectroscopic companions

Progress in observations

A SURVEY OF STELLAR FAMILIES: MULTIPLICITY OF SOLAR-TYPE STARS

Deepak Raghavan[1], Harold A. McAlister[1], Todd J. Henry[1], David W. Latham[2], Geoffrey W. Marcy[3], Brian D. Mason[4], Douglas R. Gies[1], Russel J. White[1], and Theo A. ten Brummelaar[5]
[1] Center for High Angular Resolution Astronomy, Georgia State University, P.O. Box 3969, Atlanta, GA 30302-3969, USA; raghavan@chara.gsu.edu
[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
[3] Department of Astronomy, University of California, Berkeley, CA 94720-3411, USA
[4] US Naval Observatory, 3450 Massachusetts Avenue NW, Washington, DC 20392-5420, USA
[5] The CHARA Array, Mount Wilson Observatory, Mount Wilson, CA 91023, USA
Received 2010 April 8; accepted 2010 July 2; published 2010 August 13

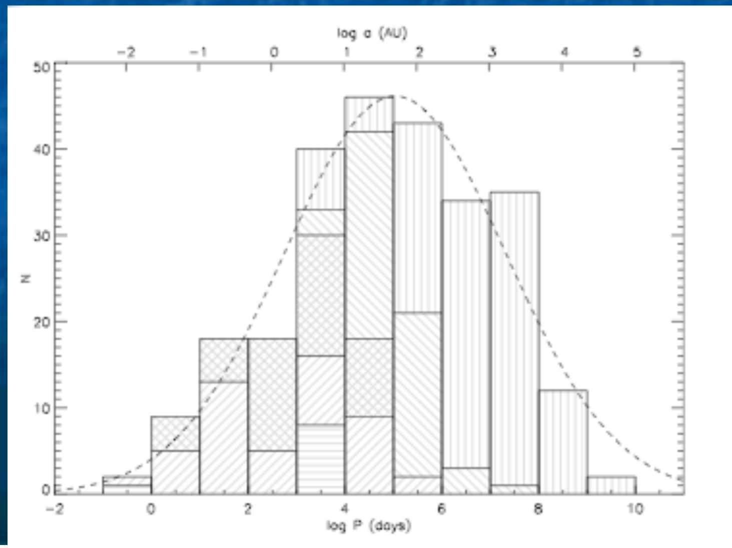
Raw results very comparable to DM 91 but apply smaller incompleteness corrections:

Sun is "typical"! ↘

Singles	56% (54%)
Binaries	33% (34%)
Triple	8% (9%)
Higher	3% (3%)

Roughly double cf DM91 ↗ (Triple)

↘ (Higher)



Need similar statistics for other primary masses:

Use to distinguish:

Clarke 1996

- Scale free fragmentation of cores

➔ Binary fraction independent of primary mass

Mass ratio distribution independent of primary mass

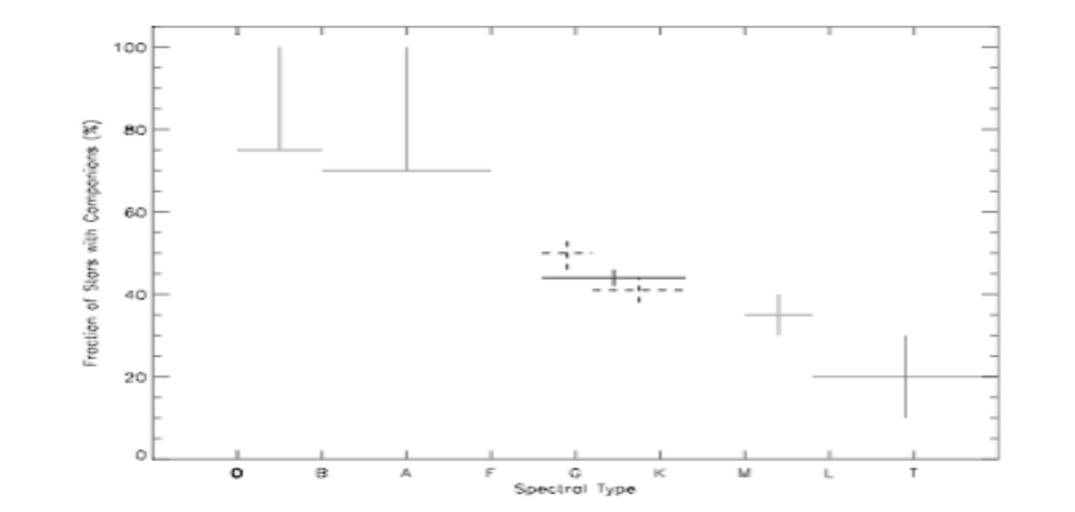
- Dynamical formation involving small N cluster dynamics

➔ Binary fraction strong positive function of mass (`dynamical biasing')

Shape of companion mass function independent of primary mass

Do we have the statistics?

Possibly yes for binary fractions but problems with mass ratio distributions and companion mass functions

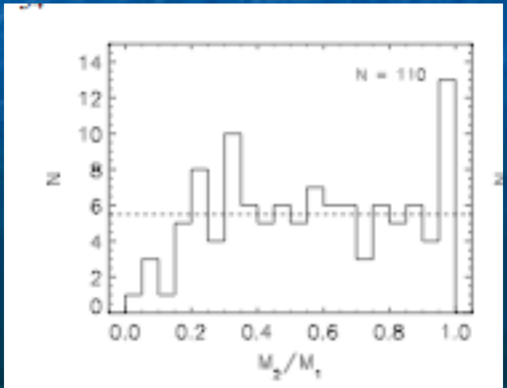


- M dwarfs: still rely on Fischer & Marcy 1992 - issues of sample size and large mass range
- VLM binaries - strongly peaked towards q=1 (Siegler)

But see Bergfors et al 2010

cf

solar



How well do we know the mass ratios of VLM binaries?

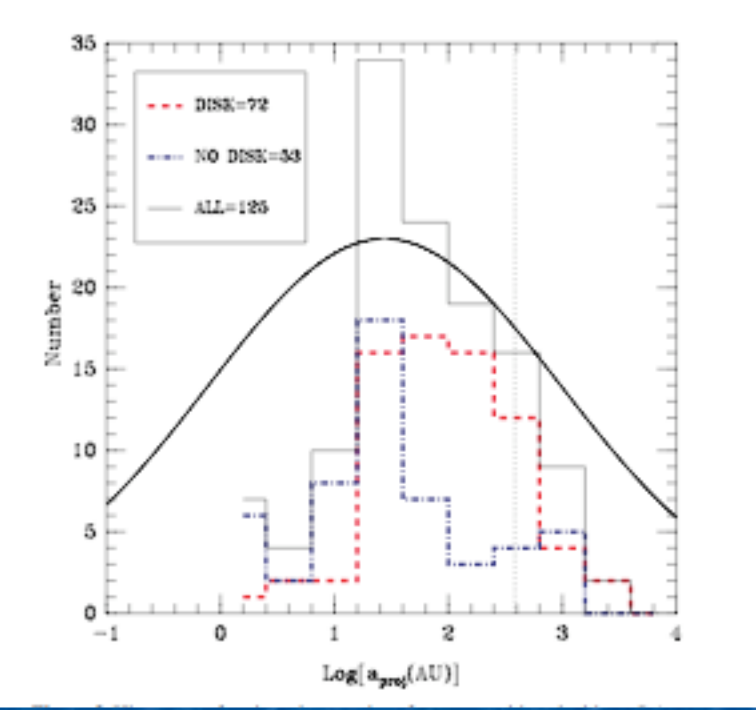
Konopacky et al 2010:

	Dynamical masses	DUSTY	TUCSON
2MASS 0746+20AB	0.25	1.0	0.86
2MASS 2140+16AB	0.25	0.57	0.86
2MASS 2206-20AB	0.25	0.81	0.78
GJ569b AB	0.71	0.5	0.67
LHS2397a AB	0.67	0.5	0.75
LP349-25 AB	0.5	1.0	0.75

Progress in observations

Circumstellar matter in young binaries

Cieza et al 2009



- Finally: the evidence that disc lifetime is reduced in shorter period binaries

Cf Monin et al 2007 PPV

- … and that the secondary dissipates first (difference in lifetime evident from Class I stage)

Patience et al 2008

↑ Prob same distns = 2.4 x10^-5

✔ As expected once infall has ceased: viscous lifetime depends on truncation radius, depends on a and q

Armitage et al 1999

Progress in theory

Simulations that add more physics

↓

Thermal feedback — Bate 2009, Ofner et al 2009

B fields — Hennebelle & Teyssier 2008, Price & Bate 2009

Simulations that improve statistics

↓

`Vanilla' calculations:

barotropic equation of state

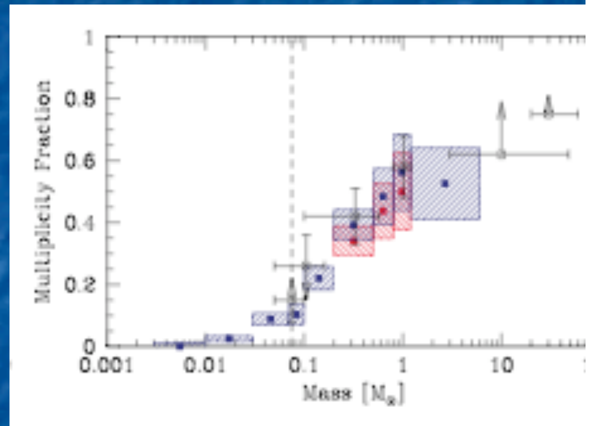
no feedback,

no B field

Bate et al 2002, 2003
Delgado Donate et al 2003,2004a,b,
Goodwin et al 2004a,b 2006
**Bate 2009 => Moeckel & Bate 2010

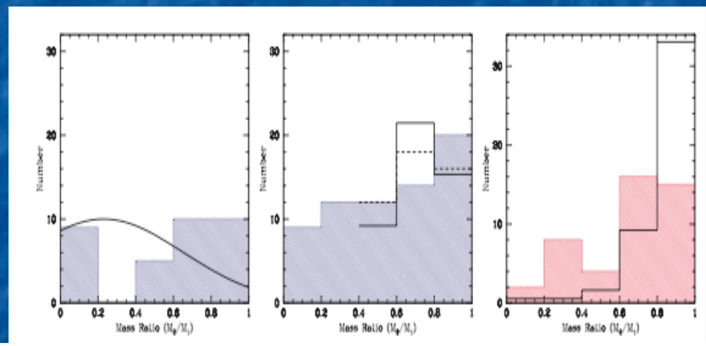
`Vanilla' calculations surprisingly (?) successful at reproducing most binary statistics

Bate 2009

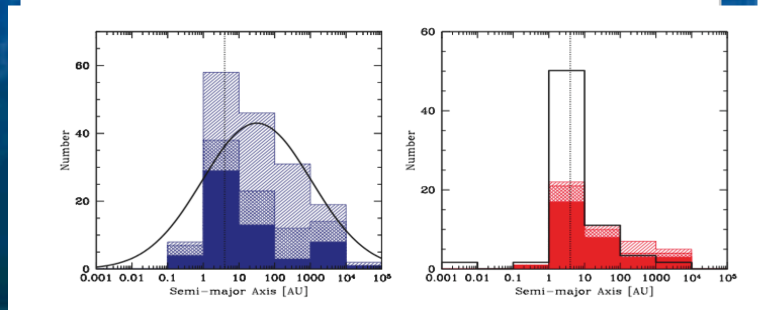


- Binary fraction as function of primary mass ✔

solar VLM



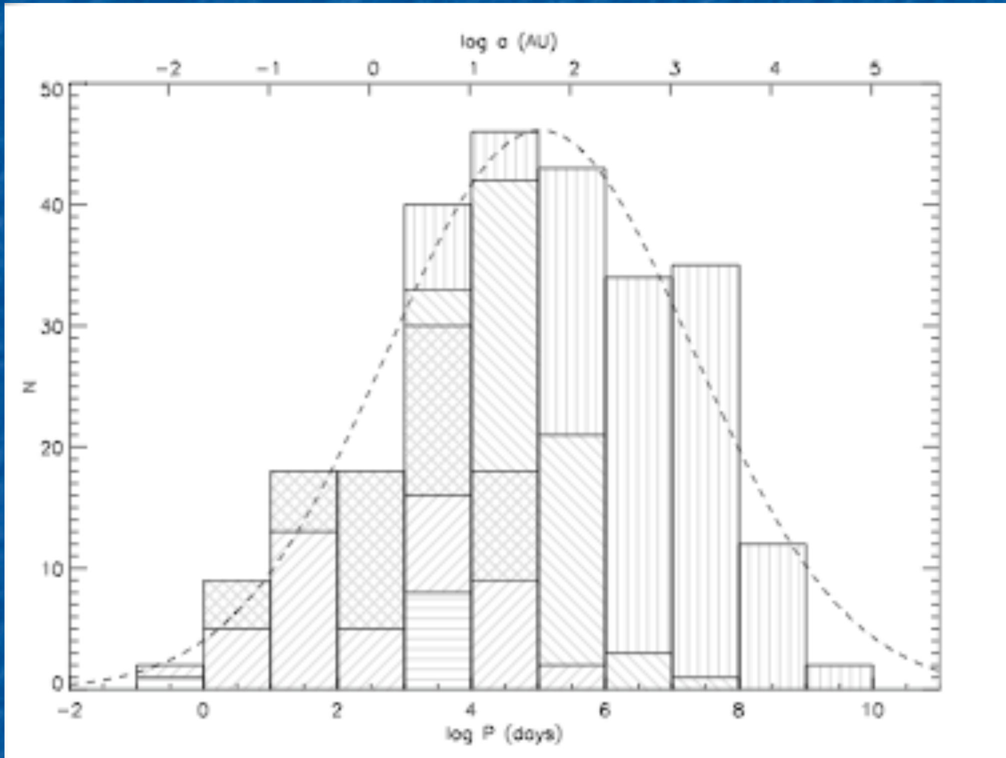
- q distributions as function of primary mass ?



- a distribution as function of primary mass ✔

Focus on wide binaries

↓ Population pruned by dynamical interactions in Galactic field



How to form at separations > Jeans length (or dense core size)?

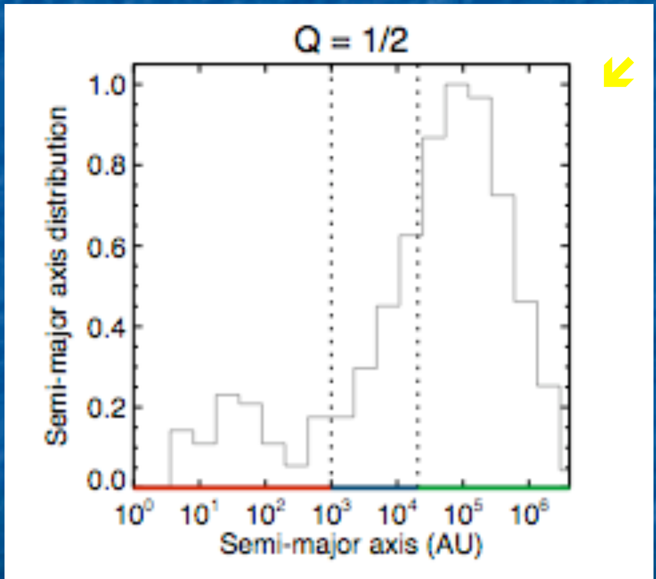
….and if formed, how can survive birth environment?

Raghavan et al 2010

Possible solution:

- Kouwenhoven et al 2010
  Moeckel & Bate 2010

Nbody integration of ~ 1000 star cluster following gas loss



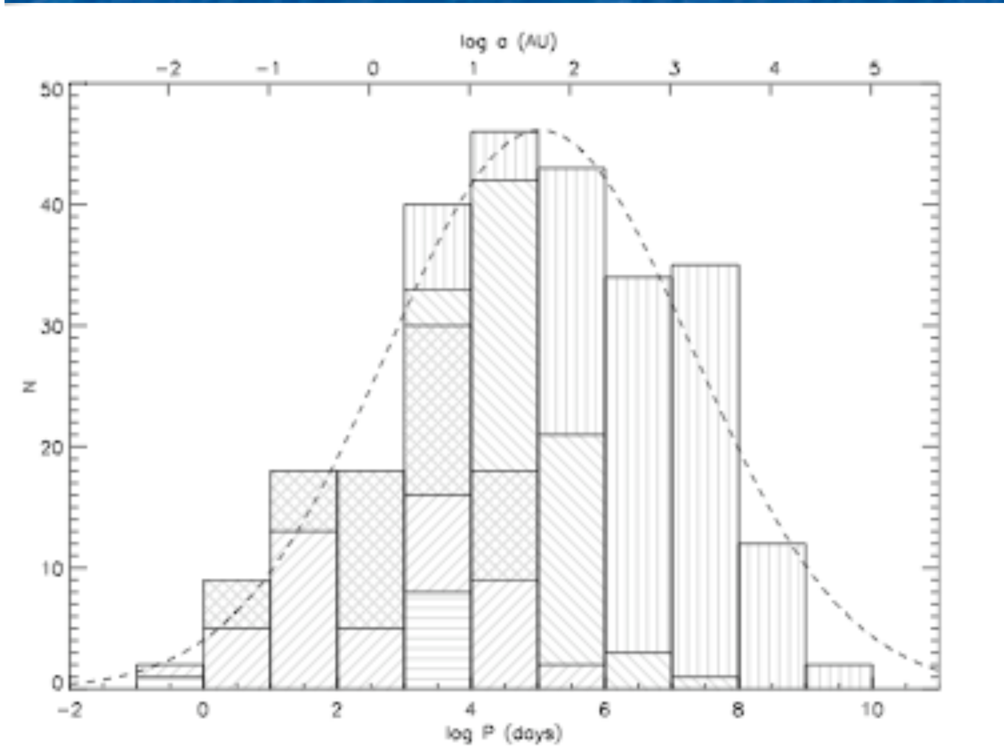
Form binaries with separation ~ initial cluster scale (~ few x 10^4 A.U.)

This "dissolution peak" contains up to 3-10% of stars (instantaneously bound pairs)

Cf 1% observed binaries in this category (> 10^4 A.U.)

Hard-soft borderline

Could work for a > 10^4 A.U.

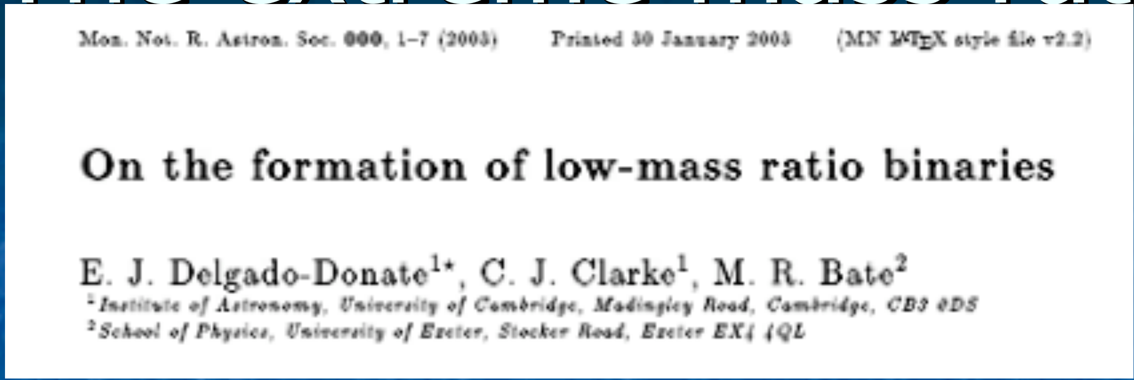


But population 10^3-10^4 AU must be primordial….

Note absence of such binaries in ONC….

Scally et al 1999

The extreme mass ratio problem


Mon. Not. R. Astron. Soc. 000, 1–7 (2003) Printed 30 January 2003 (MN LaTeX style file v2.2)

On the formation of low-mass ratio binaries

E. J. Delgado-Donate[1*], C. J. Clarke[1], M. R. Bate[2]
[1] *Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge, CB3 0DS*
[2] *School of Physics, University of Exeter, Stocker Road, Exeter EX4 4QL*

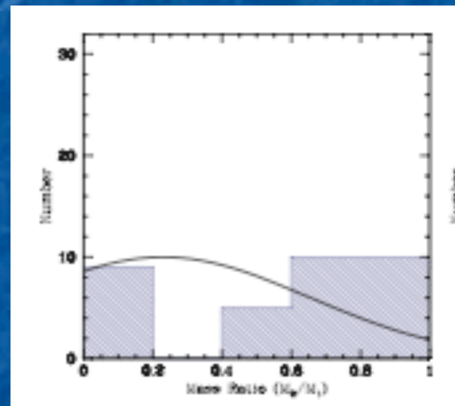
- The problem: simulations produce binaries with mass ratio > 0.5 (+ population of VLM `outliers' tenuously bound) Delgado-Donate et al 2004

Regardless of initial properties at fragmentation

↗

See Connelley et al 2008

Bate 2009 found likewise:



- Delgado-Donate et al found outliers stripped off after 10 Myr Nbody integration, leaving q distribution too biased to q > 0.5 cf DM 91

Reason for large population at q > 0.5

- Effect of continued accretion onto protobinary from late infall
- Late infall has higher specific angular momentum cf original binary
- => preferentially flows onto secondary => q increases

Bate & Bonnell 1997, Bate 2000

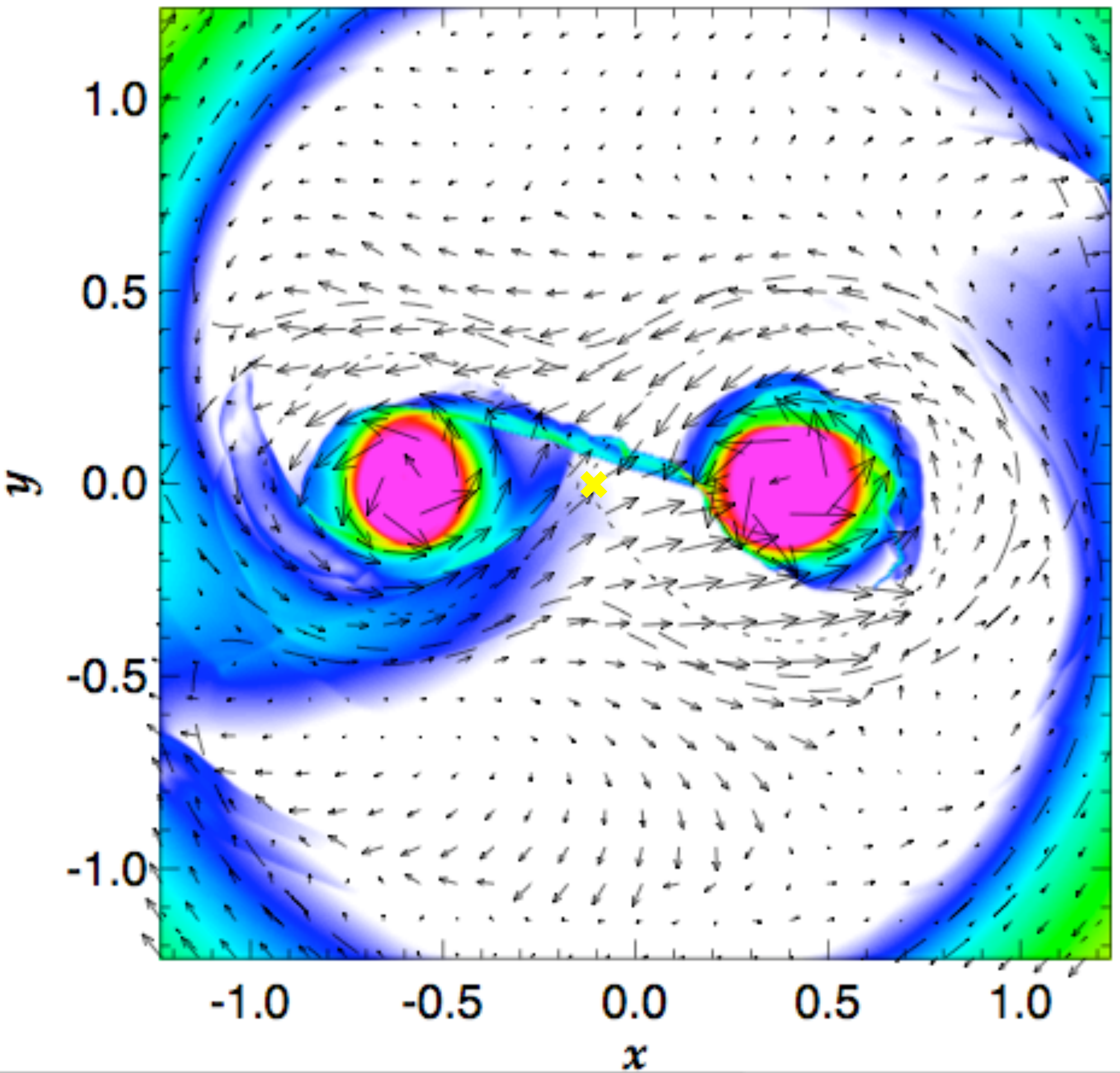
But then ….

- Claim by Ochi et al 2005 that q should decline when accrete high j material!

- Agree that such gas preferentially enters secondary's Roche lobe but find - from grid code - that then passes through L1 into primary's Roche lobe. Suggest SPH calculations too viscous to do this….

Conversely, concerns about gravitational softening in grid code….

Refined by Hanawa et al 2009



- Found indeed that flow 2->1 decreased as reduce softening

But still found net decrease of q

Note NW-SE shock separating flows

Re-examination with SPH

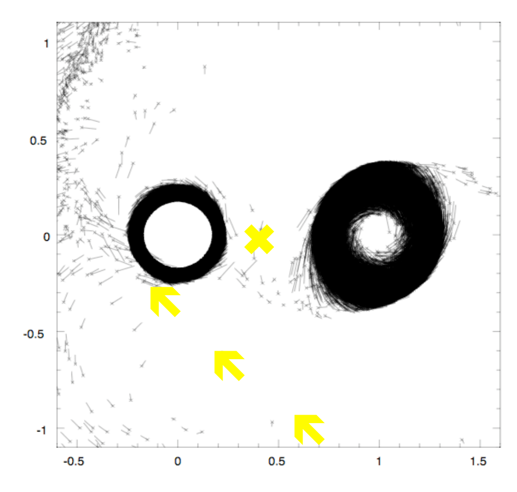
Delgado-Donate, Clarke & Bonnell in prep.

- Convergence test shows no change in sign of qdot (q ↑) (though small decrease in magnitude at high resolution)
- Check conservation of Jacobi constant

$$J = \frac{|\boldsymbol{u}|^2}{2} + \Phi\,, \qquad J' = J + c_s^2 \ln \Sigma.$$

$$\Phi = -\sum_{k=1}^{2} \frac{GM_k}{|\boldsymbol{r} - \boldsymbol{r}_k|} - \frac{1}{2}\left(\boldsymbol{\Omega} \times \boldsymbol{r}\right)^2,$$

✔



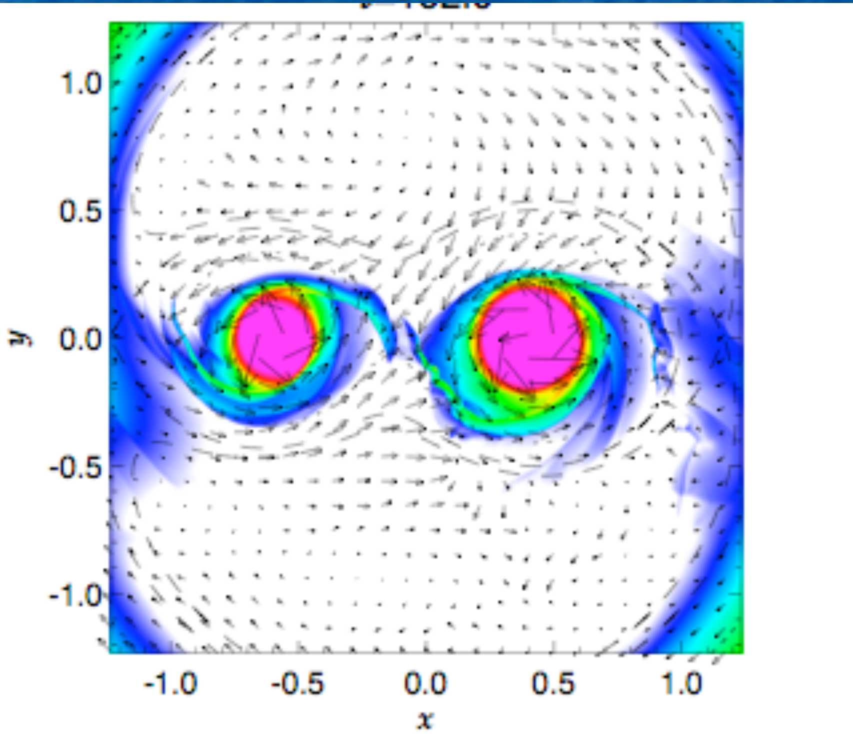
- Flow exhibits jump in J′ as undergoes shock HERE - thereafter J conserved over many orbits and flow remains within Roche lobe

N.B. This run has c_s = 0.05 v_orb| bin, e.g. T=10 K for solar mass binary separation 55 AU

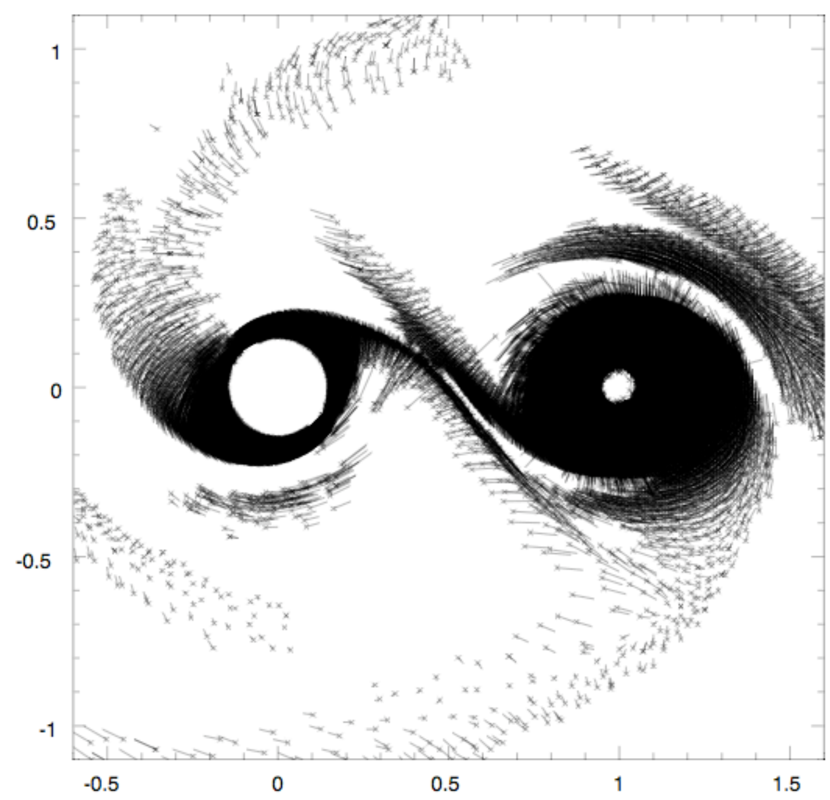
Difference is different temperature - not numerical technqiue!

COMPARE RUNS WITH C_s= 0.25   [T x 25]

Grid: Hanawa et al 2009



SPH:Delgado Donate et al…



- See identical structures: no shock to SW
- Both find that q falls

Conclude

- Techniques agree in regime that can be handled by both

- But for realistically cold flows (treatable only with SPH) confirm that q **should** rise

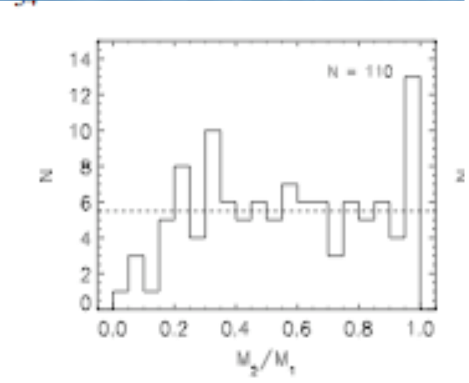
Bate & Bonnell 1997 ✔
Bate 2000

Don't solve the low q binary problem this way

But maybe isn't a problem after all?

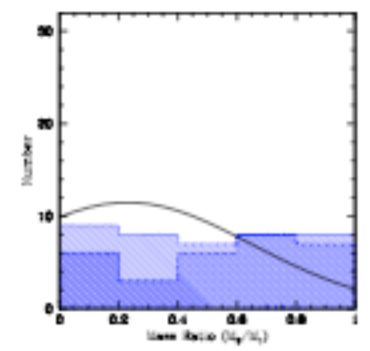
- Fewer low q systems than thought

Raghavan et al 2010



- Reconfiguration of multiples over first 10 Myr *may* fill in systems at low q

Moeckel & Bate 2010



The `vanilla' calculations arguably work better than they should!

No obvious failures to date…..

Better data for subsolar mass primaries will provide more stringent tests….

Eduardo Delgado Donate

3.10.77-10.2.07