THE DYNAMICS OF BROWN-DWARF BINARIES

Murat Kaplan
Dimitris Stamatellos
Anthony Whitworth

Cardiff University, Wales

THESIS

As one progresses to lower masses, past the H- and D-burning limits, an increasing fraction of stars are formed as secondaries, by disc fragmentation.

Talk by Dimitri Stamatellos on Thursday afternoon will show simulations of this.

NOTATION

"~BDs" means

planetary-mass objects, brown dwarfs and very low-mass H-burning stars, if they form by gravitational instability, on a dynamical time-scale, and with initially uniform elemental composition, say 0.002 $M_{\odot}$ to 0.2 $M_{\odot}$.;

as distinct from planets, which form on a much longer timescale, by core accretion, and with initially non-uniform elemental composition.

"~$\odot$" means Sun-like star, say 0.3 $M_{\odot}$ to 3 $M_{\odot}$

CONSTRAINTS ON ~BD FORMATION

The observational evidence suggests that ~BDs form in the same way as other stars, in the sense that there is not an abrupt change at the H-burning limit,

but something must be changing as one progresses to lower masses, because the process appears to become harder.

continuous IMF,
continuous binary statistics,
continuous accretion rates,
magnetospheric accretion from a disc with attendant outflows.

~BD BINARY STATISTICS

(i) The brown-dwarf desert. ~BDs that are secondaries to ~$\odot$s tend to be in wide orbits.

(ii) ~BD/~BD binaries tend to be in close orbits.

(iii) A ~BD in a wide orbit around a ~$\odot$ is more likely to have a close ~BD companion than a ~BD in the field.

DISC FRAGMENTATION -- PROS

Explains all these features, because

(i) there are very robust thermodynamic effects that deliver the brown dwarf desert, and

(ii) discs provide the perfect environment to push the opacity limit and avoid merging.

Matzner C, Levin Y, 2005, ApJ **628** 814
Whitworth AP, Stamatellos D, 2006, A&A **458** 817
Clarke CJ, 2009, MN **396** 1066

THE OPACITY LIMIT

$$t_{\mathrm{COOL}} < t_{\mathrm{DYN}} \sim t_{\mathrm{ORB}}$$

In a disc this gives

$$R > \left(\frac{h^6\, c^4\, \kappa_{\mathrm{O}}^2\, M_\star^3}{G\, \bar{m}^8} \right)^{1/9}$$

if we adopt standard interstellar opacity, with emissivity index $\beta = 2$.

DISC FRAGMENTATION – CONS

(i) Radiative feedback from the primary heats the disc and this may suppress fragmentation; Dimitri's talk on Thursday

(ii) Extended massive discs don't form when magnetic fields are included in simulations; but this needs non-ideal MHD and detailed ionisation balance.

(iii) We don't see many massive extended discs; but such discs are very short-lived.

THE CHALLENGE

To reproduce the ~BD binary statistics by some other mechanism:

(i) Dynamical fragmentation of a single core, followed by dynamic relaxation
(too fast and too tidal, merging, why no close ~$\odot$/~BD systems;

(ii) Formation in separate cores, followed by capture
(requires very high hydrostatic pressure, and capture unlikely).

PROBLEMS WITH CAPTURE

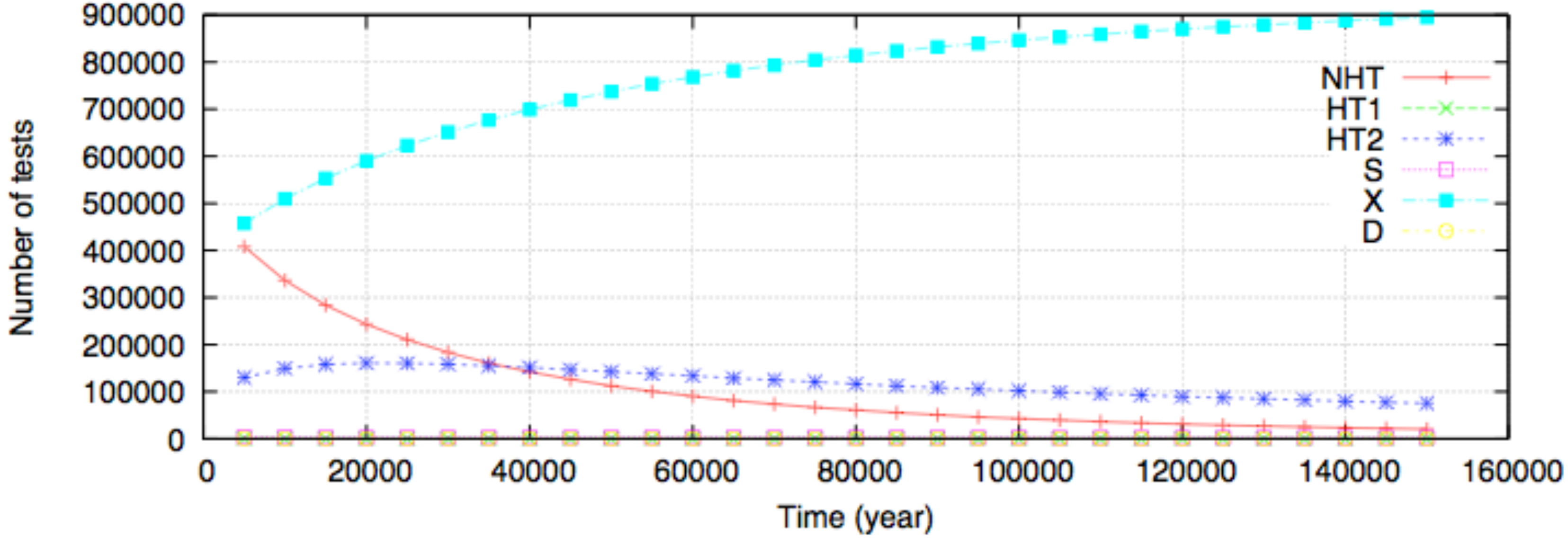
It doesn't work.

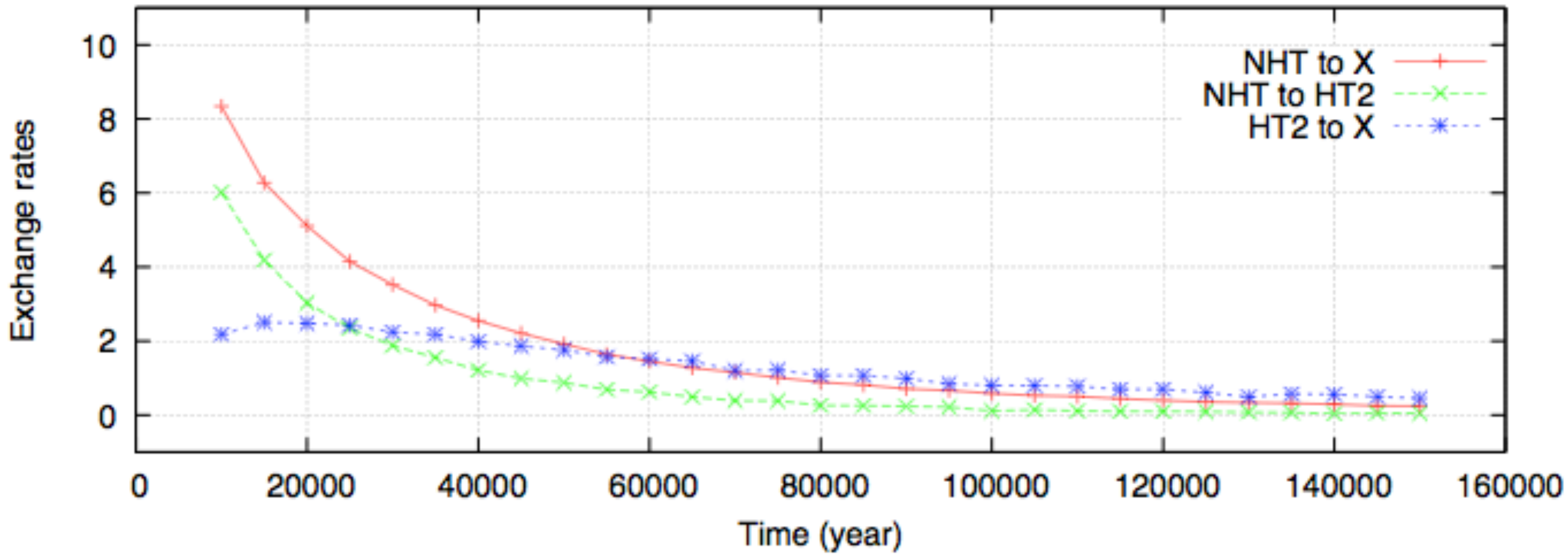
Interactions between a ~BD/~BD binary and a ~☉ produce *either* an hierarchical triple with a close ~☉/~BD at the centre and the second ~BD orbiting further out, *or* a close ~☉/~BD and an ejected ~BD.

MONTE CARLO NUMERICAL EXPERIMENT

Place a ~BD/~BD binary at the centre of coordinates, in a circular orbit with random phase and random orientation (e.g. 0.05 $M_\odot$ + 0.05 $M_\odot$ @ 4 AU).

Fire a ~$\odot$ at it with impact parameters satisfying $p_b\, db = 2\, b\, db$
(e.g. b in units of 100 AU and v = 1 km/s)


Number of tests
Time (year)
NHT
HT1
HT2
S
X
D


Exchange rates
Time (year)
NHT to X
NHT to HT2
HT2 to X

WHY ARE DISCS GOOD PLACES TO PRODUCE ~BDs ?

(i) Brown dwarf desert explained by robust thermodynamic effects.
(ii) Fragment masses are just right.
(iii) Protostellar properties are right.
(iv) Impulsive perturbations are not needed.
(v) Merging is avoided.
(vi) They produce close ~BD/~BD systems like those observed,
(vii) … and in the places where they are observed.

CONCLUSION

“ If brown dwarfs don’t form in discs, find a better place “   (Eddington)

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