Transferring Objects Between Circumstellar Disks During Stellar Flybys

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CLOSE ENCOUNTERS
OF STARS IN STAR CLUSTERS

In dense star clusters, stars are likely to have close encounters – "stellar flybys" – that lead to these stars losing some of their circumstellar disk mass, as examined by (Lestrade et al. 2011).
The lost disk mass becomes unbound or transfers to the flyby star.

We simulate solar mass stars "flying by" different types of stars using gravitational dynamics code in the AMUSE package (Portegies Zwart et al. 2009, Pelupessy et al. 2013) in order to find

(1) The furthest distances at which flybys can transfer mass.
(2) The fraction of disk particles that transfer in each case.

(3) What the new orbits of the transferred particles look like.
(4) Whether we can see objects in our Solar System that have the signatures of these transferred orbits.

We find that low mass stars can transfer disk particles to solar mass stars for flybys as far as 400 AU from the solar mass star.

A long time ago, in the Sun's birth cluster....

The Sun still had a chance to have a close encounter – a "stellar flyby" – with a nearby star. How much of a chance?

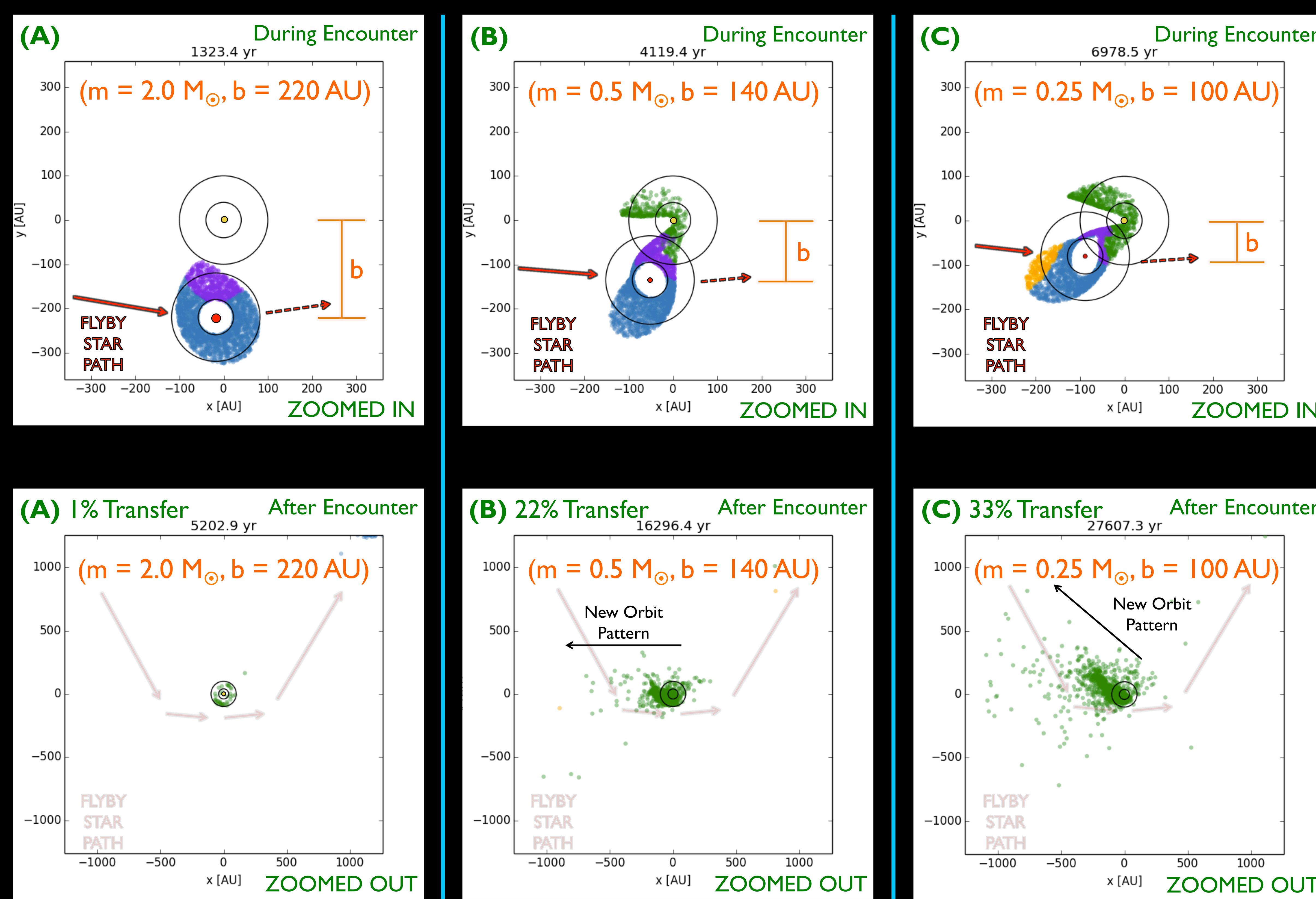
(1) The Sun had a 1 in 150 chance of an encounter with a distance of closest approach less than 100 AU.
(2) The Sun had a 1 in 27 chance of an encounter with a distance of closest approach less than 300 AU.

Those odds – derived from estimates of the number density of stars in the Sun's birth cluster by (Adams 2010) – show that the Sun closely "flying by" another star was not very likely.
Plus, we know an encounter within 100 AU could not have happened or else it would have disrupted the Kuiper Belt (Portegies Zwart 2009).

Nonetheless, in the majority of our simulations, we are able to reproduce a pattern identified by (Trujillo et al. 2014), who note that the 12 most distant objects in the Solar System have a range of "arguments of pericenter" of just 110 degrees.
This supports the claim of (Kenyon et al. 2004) that despite the low chance of an encounter, a "flyby" star transferred these objects into our Solar System.

References
(1) Adams, F. C. 2010, ARA&A, 48, 47
(2) Lestrade, J.-F. et al. 2011, A&A, 532, A120
(3) Kenyon, S. J., Bromley, B. C. 2004, Nat., 432, 598
(4) Pelupessy F. I., et al. 2013, A&A, 557, 84
(5) Portegies Zwart, S. F. 2009, 696, L13
(6) Portegies Zwart, S. F. et al. 2009, New Astr., 14, 369
(7) Trujillo C. A., Sheppard S. S. 2014, Nature, 507, 471

Example Flyby Simulations (Close Encounters with Other Stars)



Particle Types

Transferred to New Star
Still Bound to Disk Star
"Bound" to Both Stars
Completely Unbound

Simulation Parameters

(1) Two Stars:
- (i) Solar Mass Star – No Disk
- (ii) Star with mass 'm' for {0.1 $M_\odot$ < m < 3.0 $M_\odot$} – 2500 particle Disk

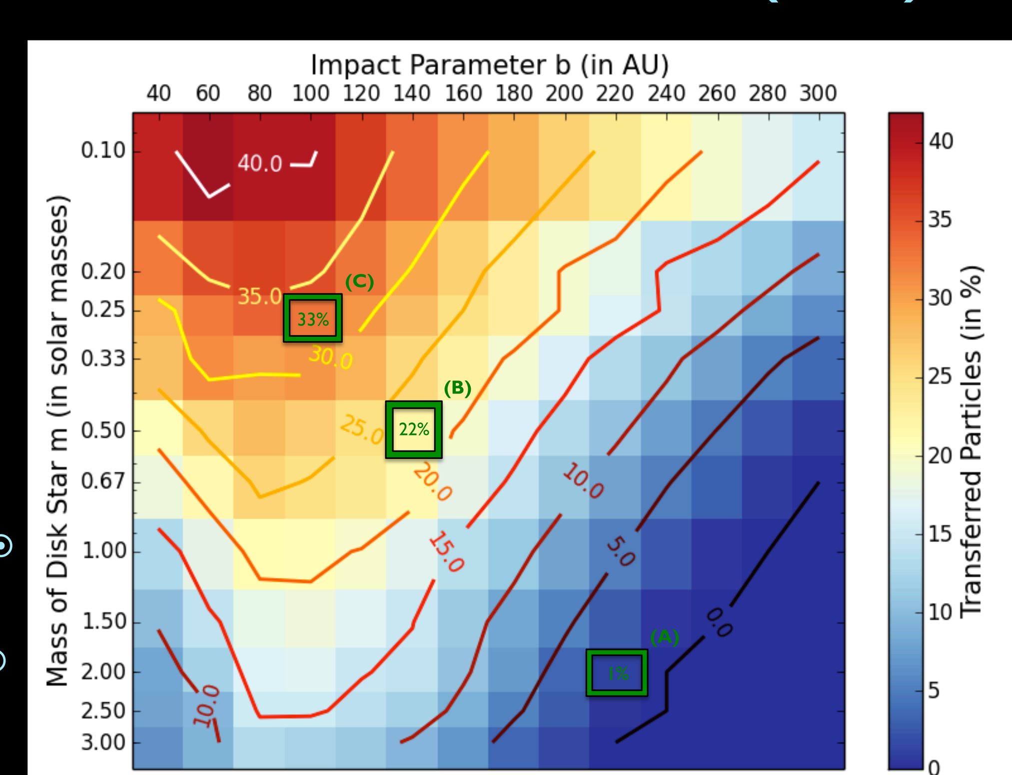
(2) Flyby Orbits
- (i) Parabolic Orbit
- (ii) Stars co-planar w/ disk
- (iii) Distance of Closest Approach 'b' for {40 AU < b < 300 AU}

(3) Initial Disk Conditions
- (i) Inner radius = 10 AU
- (ii) Outer rad. = 100 AU
- (iii) Massless Particles
- (iv) Circular Orbits

Results

Transferred Particles (as %)

Mass of Disk Star Range (m) 0.1 $M_\odot$ to 3.0 $M_\odot$



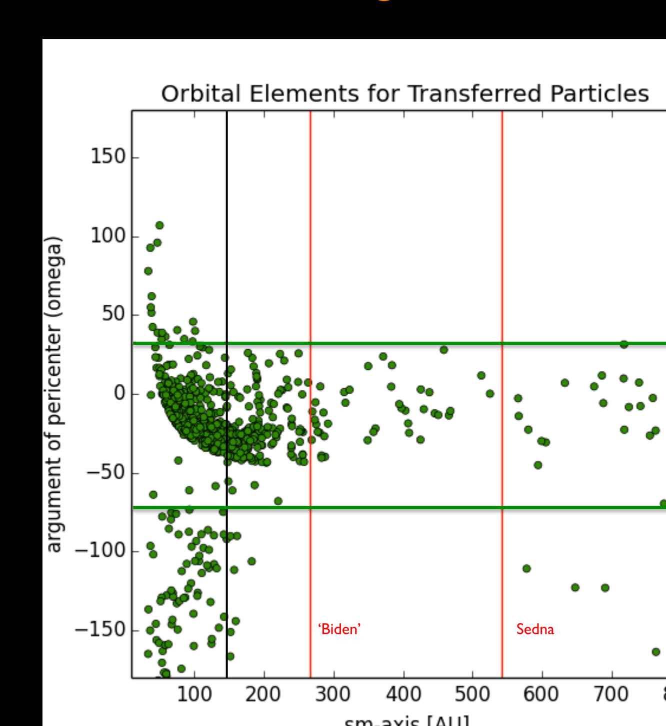
Impact Parameter Range (b) : 40 AU to 300 AU

(1) More particles transfer for low 'm' and low 'b'.
(2) At b = 300 AU, stars w/ m ≤ 0.5 $M_\odot$ still transfer.

New Orbits of the Transferred Disk Particles

(C) 33% Transfer
(m = 0.25 $M_\odot$, b = 100 AU)

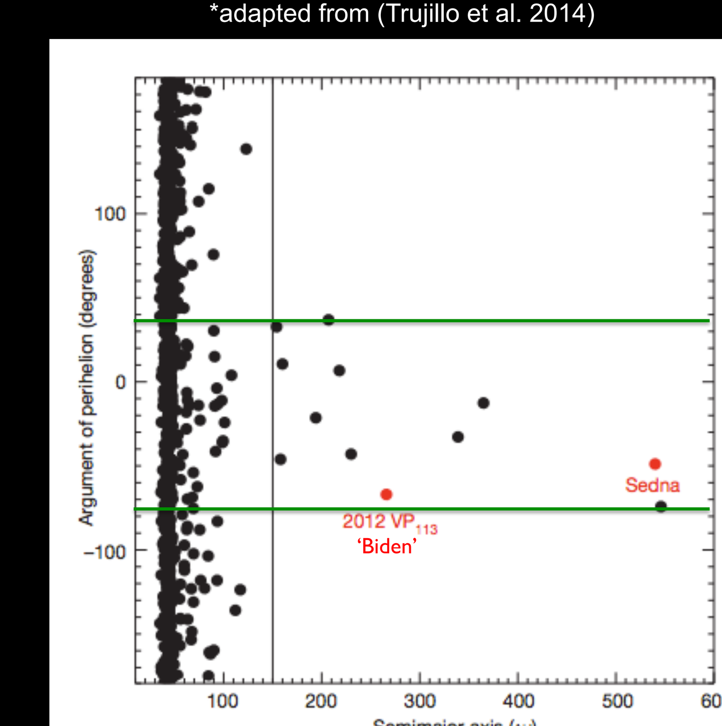
Argument of Pericenter (omega)



Semi-major axis (a)

Objects in the Outer Solar System*

*adapted from (Trujillo et al. 2014)



Semi-major axis (a)

We produce a distribution of orbits where omega is constrained to a range of 110° beyond a >150 AU, matching a pattern observed in the Solar System.