

# Two's a crowd: the difficulties of circumbinary planet formation



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# N-body: Planetesimal Response

## Problem

Extremely perturbed protoplanetary disk



High planetesimal impact velocities



Increased erosional collisions

**But... 8 detections of planets in circumbinary, p-type orbits with  $a_p < 1.2$  au**

## Numerical Code

### N-Body Code: PKDGRAV

- 🌀 3-Dimensional
- 🌀 Inter-planetesimal gravity (IPG)
- 🌀 Ultra high resolution.

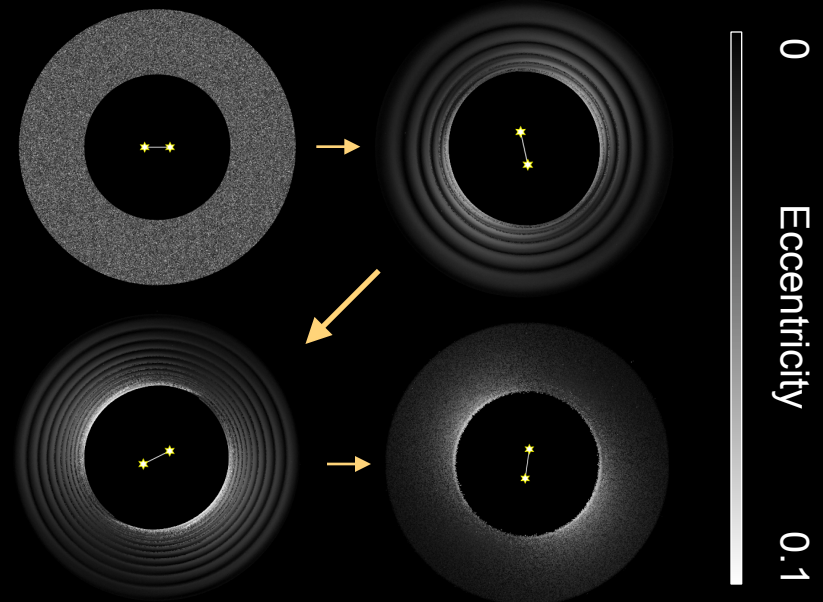
### Collision Model: EDACM (Leinhardt & Stewart 2012)

- 🌀 Multiple outcome regimes
- 🌀 Fast analytical, dependent on  $v_i$ ,  $b$  &  $q$ .

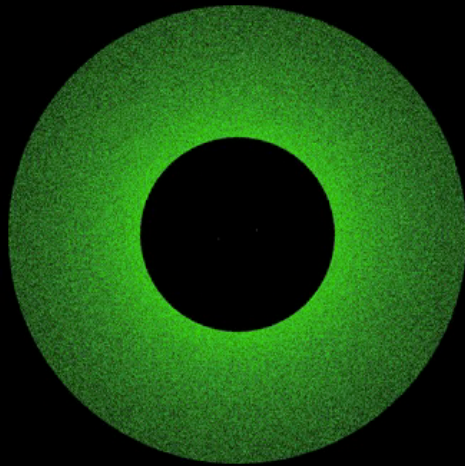
## Initial Conditions

### Disk Model

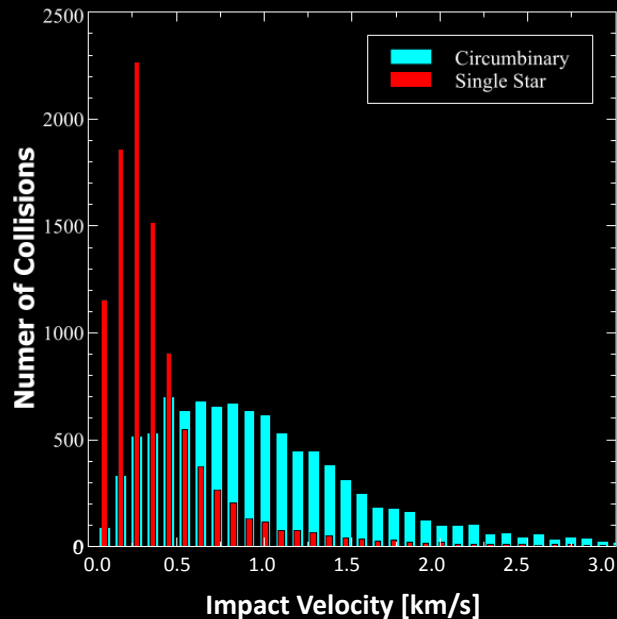
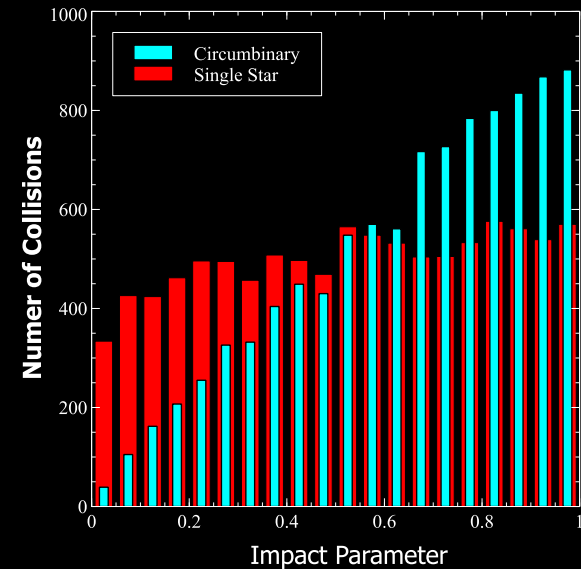
- 🌀 Kepler-34 (AB) -  $e_b \approx 0.5$ ,  $a_b \approx 0.2$  au
- 🌀  $10^6$  planetesimals,  $R_p = 100$  km
- 🌀  $R_{\text{inner}} = 0.8$  au,  $R_{\text{outer}} = 1.5$  au
- 🌀 Evolved to QSS before collisions:



# N-body: Planetesimal Response



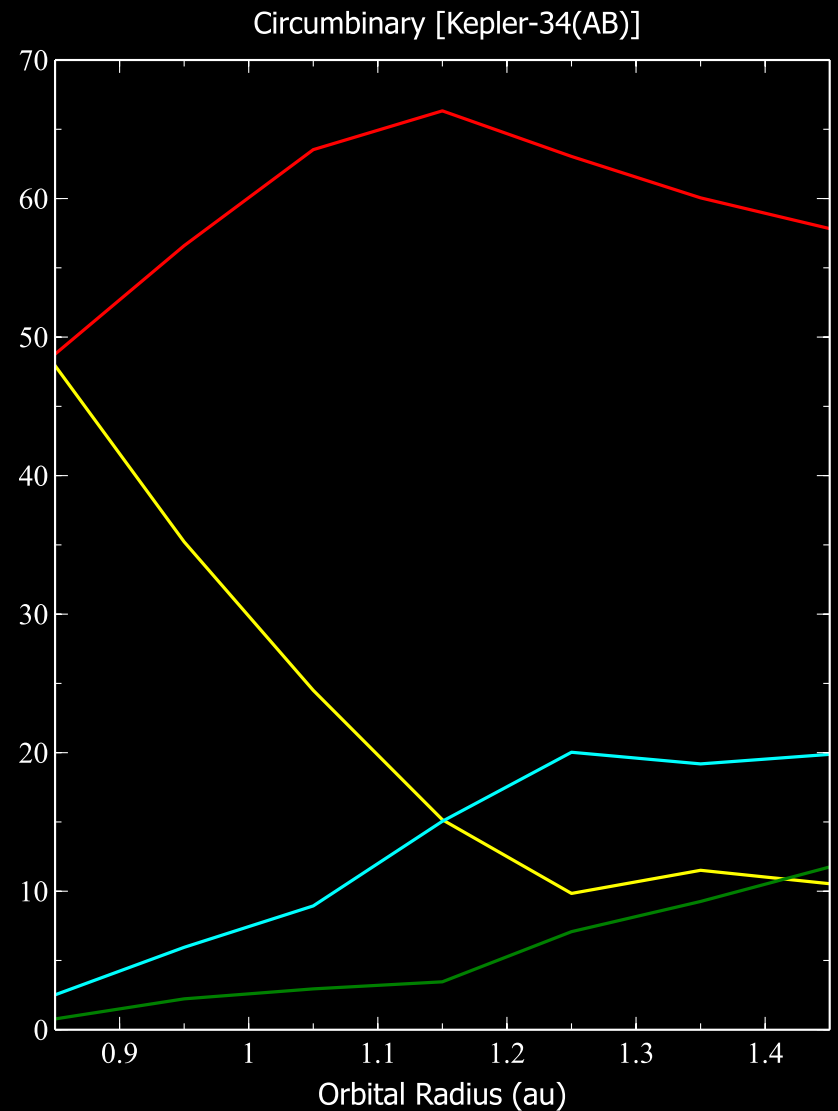
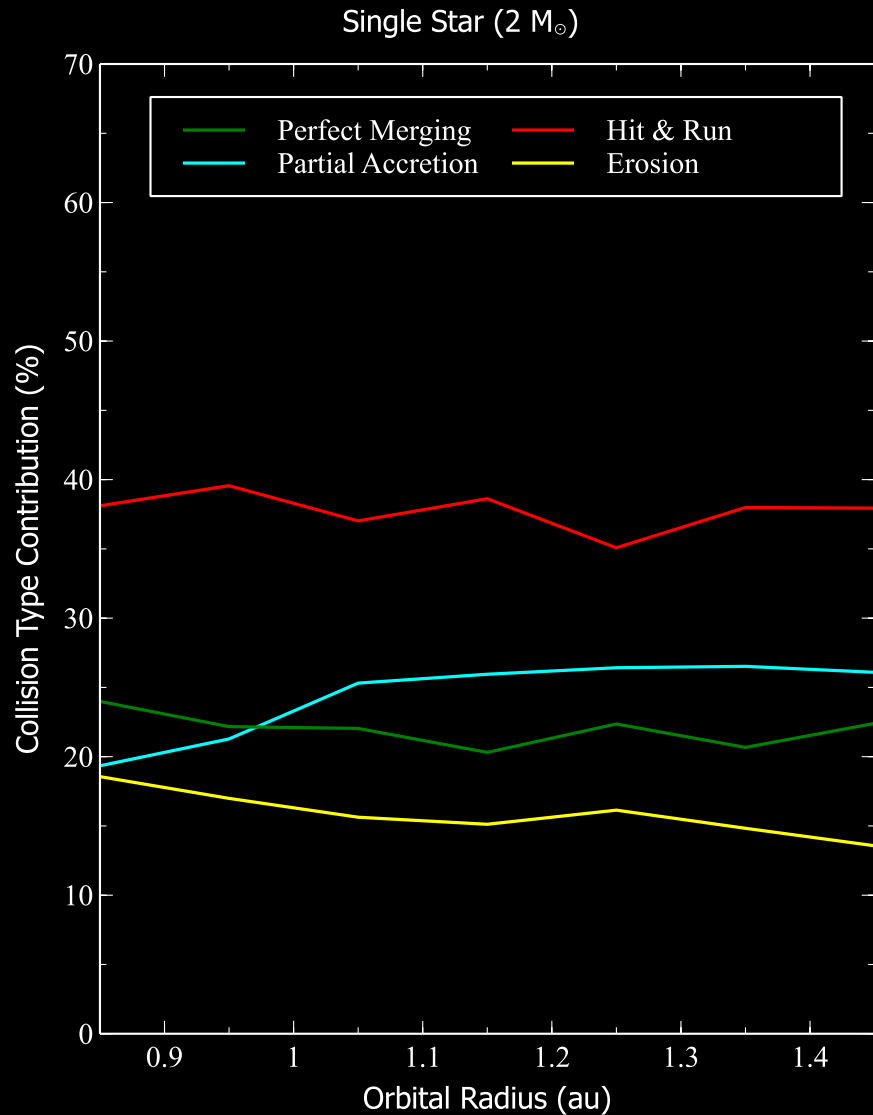
• Planetesimal Position



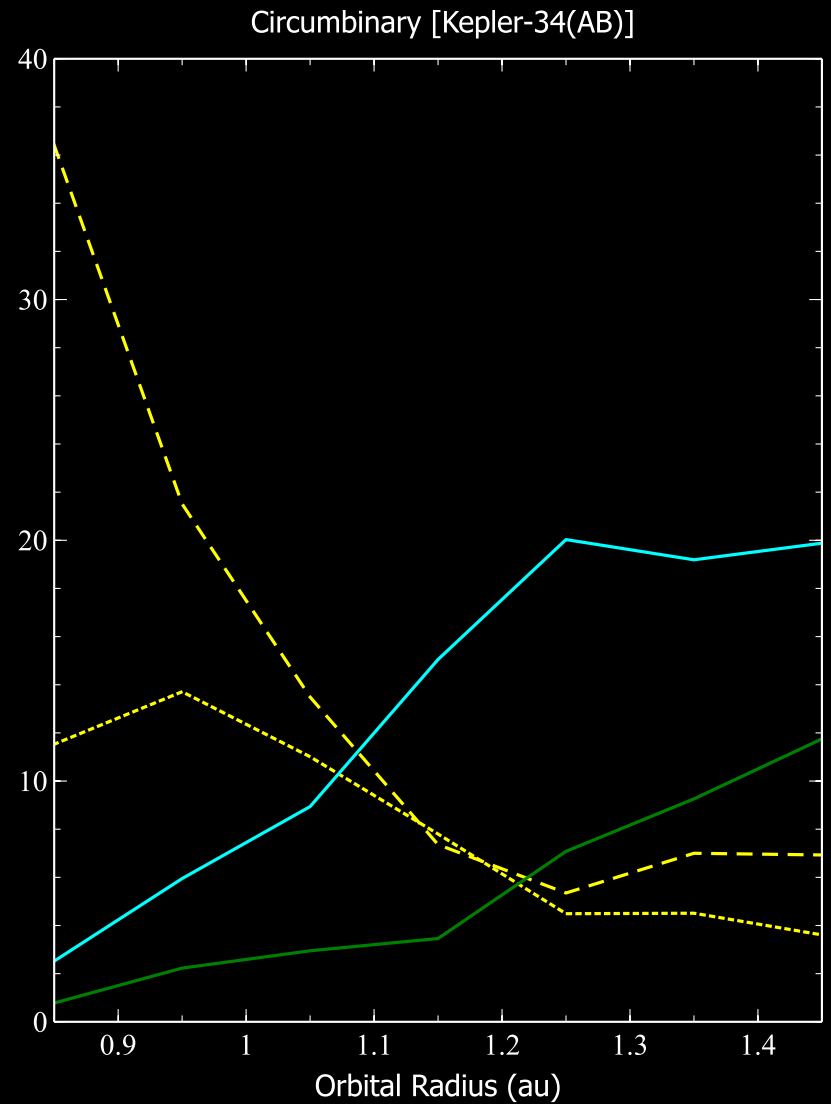
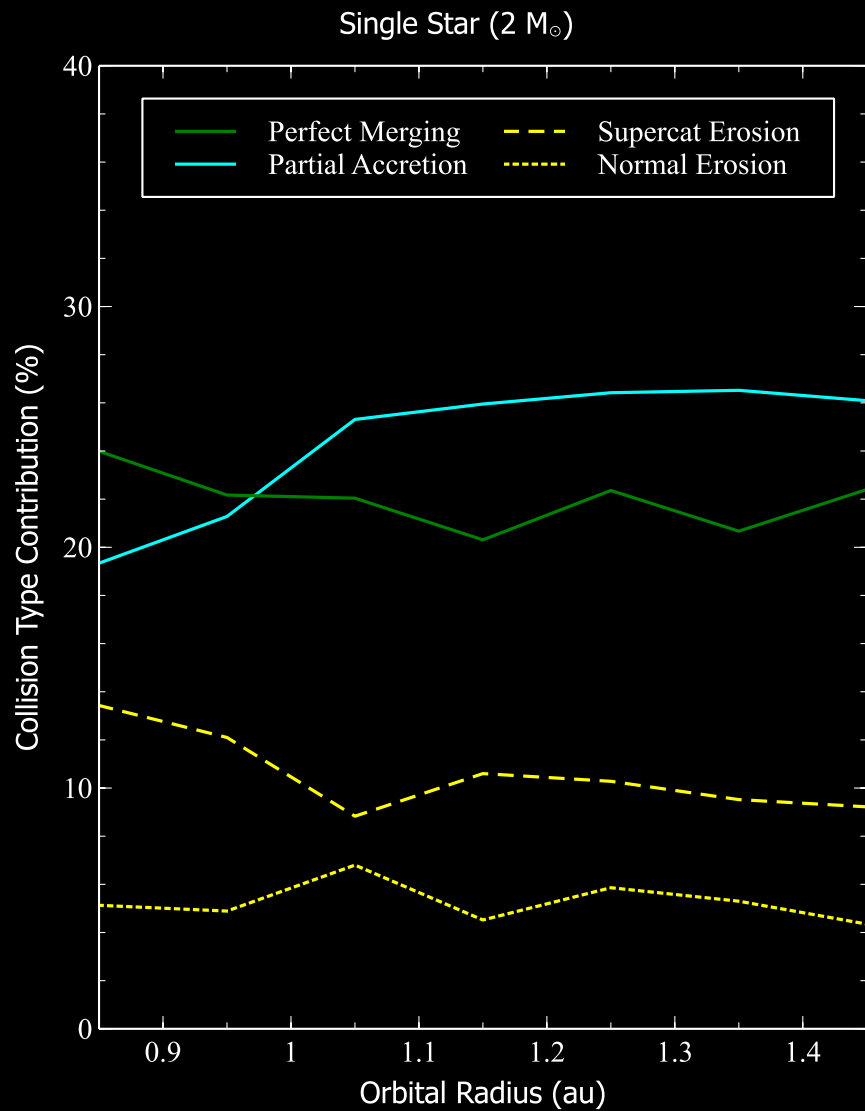
## Results

- Higher impact parameter,  $b$
- Expected from orbit crossings
- Broader impact velocity,  $V_i$ , range
- $V_i$  increase from binary kick

# N-body: Planetesimal Response








# N-body: Planetesimal Response



# Conclusions

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-  We run 3D, high resolution  $N$ -body simulations of a perturbed protoplanetary disk alongside a powerful collision model.
-  Circumbinary disk close to binary *is* a hostile environment for planet formation due to high impact velocities between planetesimals caused by orbit crossings.
-  In Kepler-34(AB) we find that these high velocities contribute to the dominant collision mechanism: supercatastrophic erosions.
-  Sustained accretion is not possible even for such large planetesimals up to and including the location of the observed planet Kepler-34(AB)b. Likely issue for most other circumbinary planets too.
-  In-situ formation unlikely - migration?