THE FORMATION OF CIRCUMBINARY TERRESTRIAL PLANETS VIA CORE ACCRETION

ANNA CHILDS, POSTDOC - CIERA, NORTHWESTERN UNIVERSITY

Northwestern
CIERA
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

NSF
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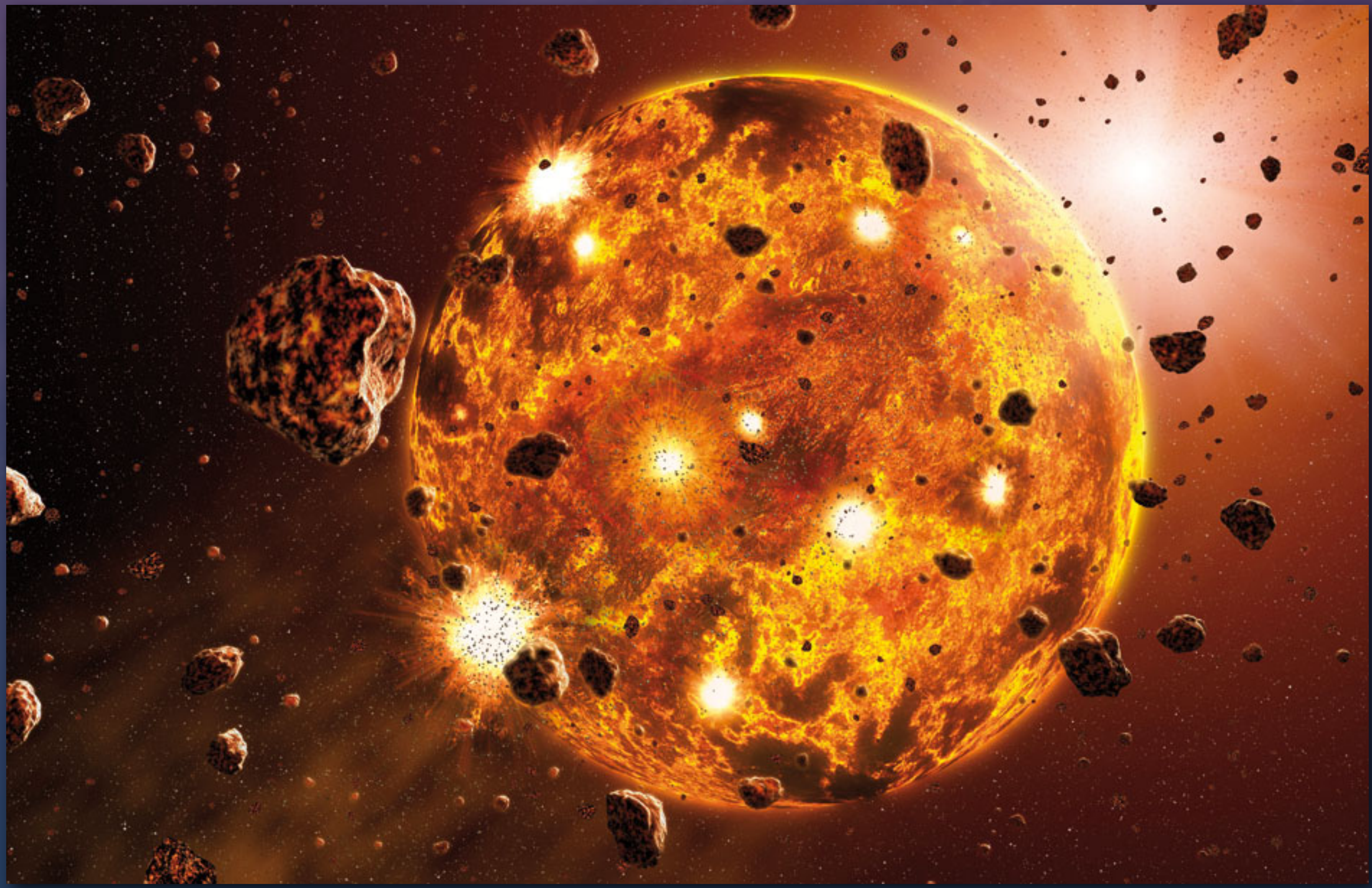
CORE ACCRETION FORMATION CHANNEL

- INSPIRED BY THE SOLAR SYSTEM
- MAJORITY OF PLANET MASS GROWTH TAKES PLACE AFTER GAS DISK DISSIPATION
- MOON AND MARS SIZED BODIES HAVE FORMED PRIOR TO GAS DISK DISSIPATION
- BODIES COLLIDE VIOLENTLY OVER MYR TIMESCALES TO FORM TERRESTRIAL PLANETS



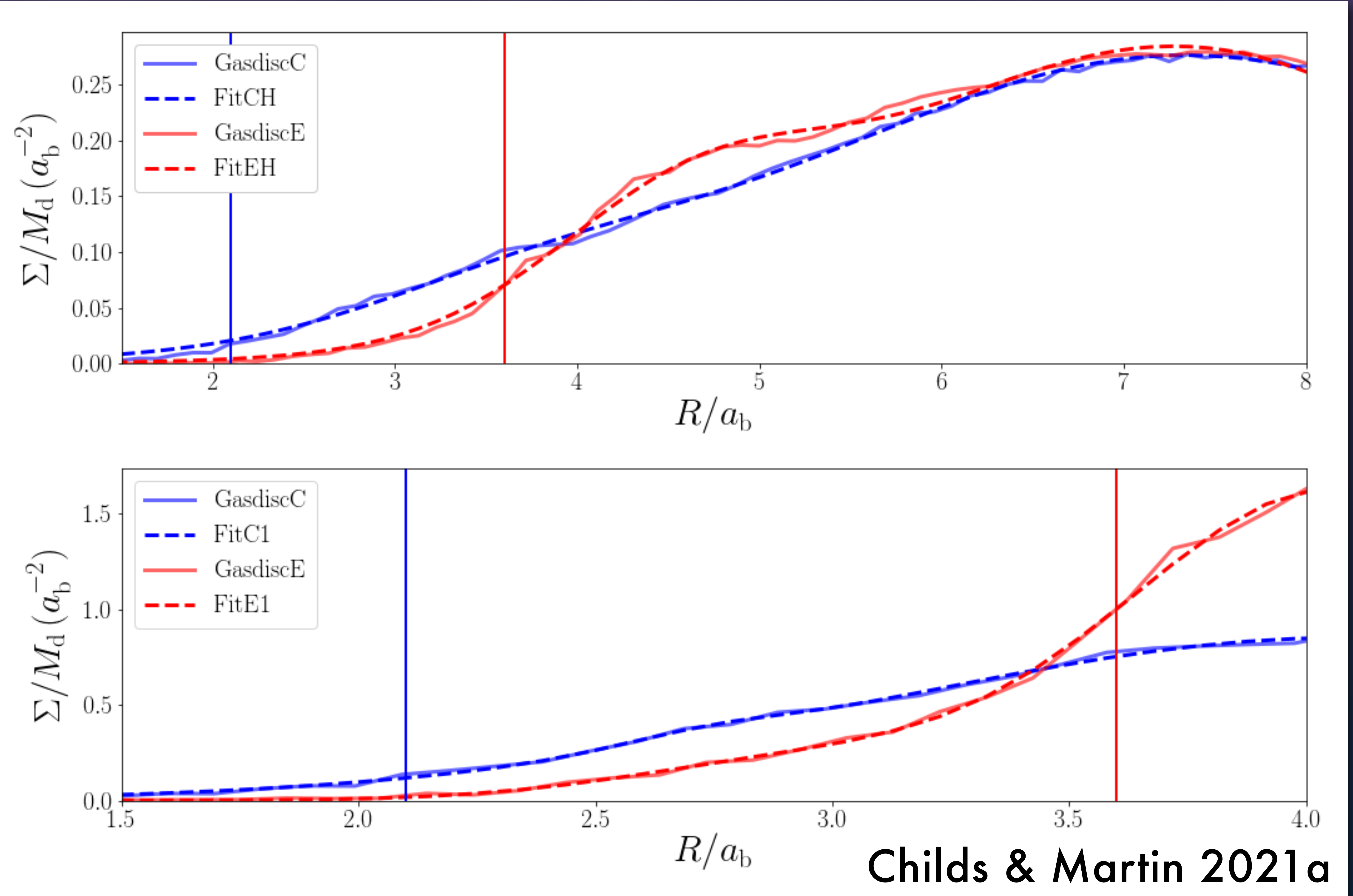
TERRESTRIAL CBP FORMATION AROUND A COPLANAR BINARY

$$a_c/a_b = 1.48 + 3.92e_b - 1.41e_b^2 + 5.14\mu + 0.33e_b\mu - 7.95\mu^2 - 4.89e_b^2\mu^2$$

(HOLMAN & WIEGERT 1999, QUARLES ET AL. 2018)

$$\mu = \frac{M_s}{M_s + M_p}$$

- CIRCULAR VS ECCENTRIC EQUAL MASSED BINARY
- 0.5 VS 1 AU a_b
- 260 MOON-SIZED PLANETESIMALS AND 26 MARS SIZED EMBRYOS
- JUPITER AND SATURN
- N-BODY CODE REBOUND
(REIN & LIU 2012)



Childs & Martin 2021a

RESULTS

Model	a_b/au	e_b	Surface density	No. of planets	$M_p/M_\oplus$	a_p/au	e	i°
SH	-	-	FitCH	5.8 ± 0.76	0.81 ± 0.60	2.59 ± 1.20	0.06 ± 0.05	1.70 ± 1.53
CH	0.5	0.0	FitCH	5.1 ± 1.28	0.89 ± 0.58	2.76 ± 0.88	0.04 ± 0.03	0.96 ± 0.66
EH	0.5	0.8	FitEH	3.4 ± 1.03	1.22 ± 0.67	3.21 ± 0.79	0.06 ± 0.04	2.63 ± 2.27
S1	-	-	FitC1	4.8 ± 0.75	0.99 ± 0.73	2.98 ± 0.95	0.04 ± 0.04	1.49 ± 1.46
C1	1.0	0.0	FitC1	2.9 ± 0.89	1.35 ± 0.72	3.45 ± 0.68	0.05 ± 0.03	1.35 ± 0.94
E1	1.0	0.8	FitE1	1.5 ± 0.57	0.30 ± 0.16	4.10 ± 0.34	0.05 ± 0.03	1.44 ± 1.25
CH_{JS}	0.5	0.0	FitCH	2.4 ± 0.91	1.35 ± 1.03	2.26 ± 0.44	0.05 ± 0.04	1.49 ± 1.10
EH_{JS}	0.5	0.8	FitEH	1.4 ± 0.69	1.43 ± 0.74	2.62 ± 0.30	0.06 ± 0.05	3.16 ± 3.01
$C1_{JS}$	1.0	0.0	FitC1	1.4 ± 0.61	0.76 ± 0.45	2.85 ± 0.31	0.06 ± 0.02	1.10 ± 0.66
$E1_{JS}$	1.0	0.8	FitE1	0.0	–	–	–	–

TERRESTRIAL CBP FORMATION IS EASIER AROUND A CIRCULAR COPLANAR BINARY THAN AN ECCENTRIC COPLANAR BINARY

Childs & Martin 2021a

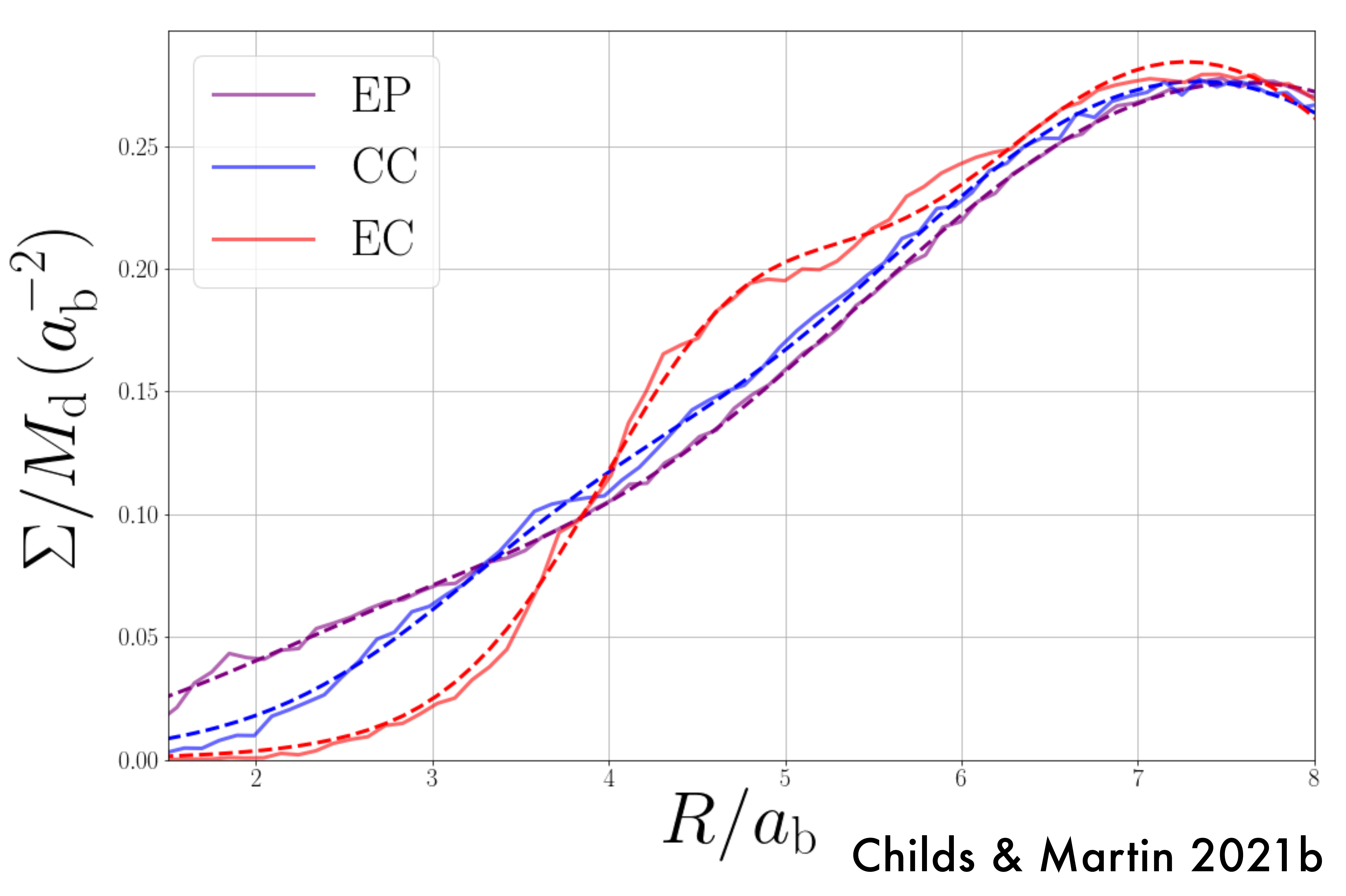
MISALIGNED DISKS

- MISALIGNED CBP DISKS ARE COMMONLY OBSERVED IN NATURE
- DISK MISALIGNMENT MECHANSIMS: TURBULENT/ CHAOTIC ACCRETION, FLYBYS, INTERACTION WITH A TERTIARY COMPANION ETC.

- A COPLANAR AND POLAR INCLINED DISK (90°) ARE STATIONARY STATES
- NODAL PRECESSION TAKES PLACE IN INTERMEDIATE INCLINATIONS

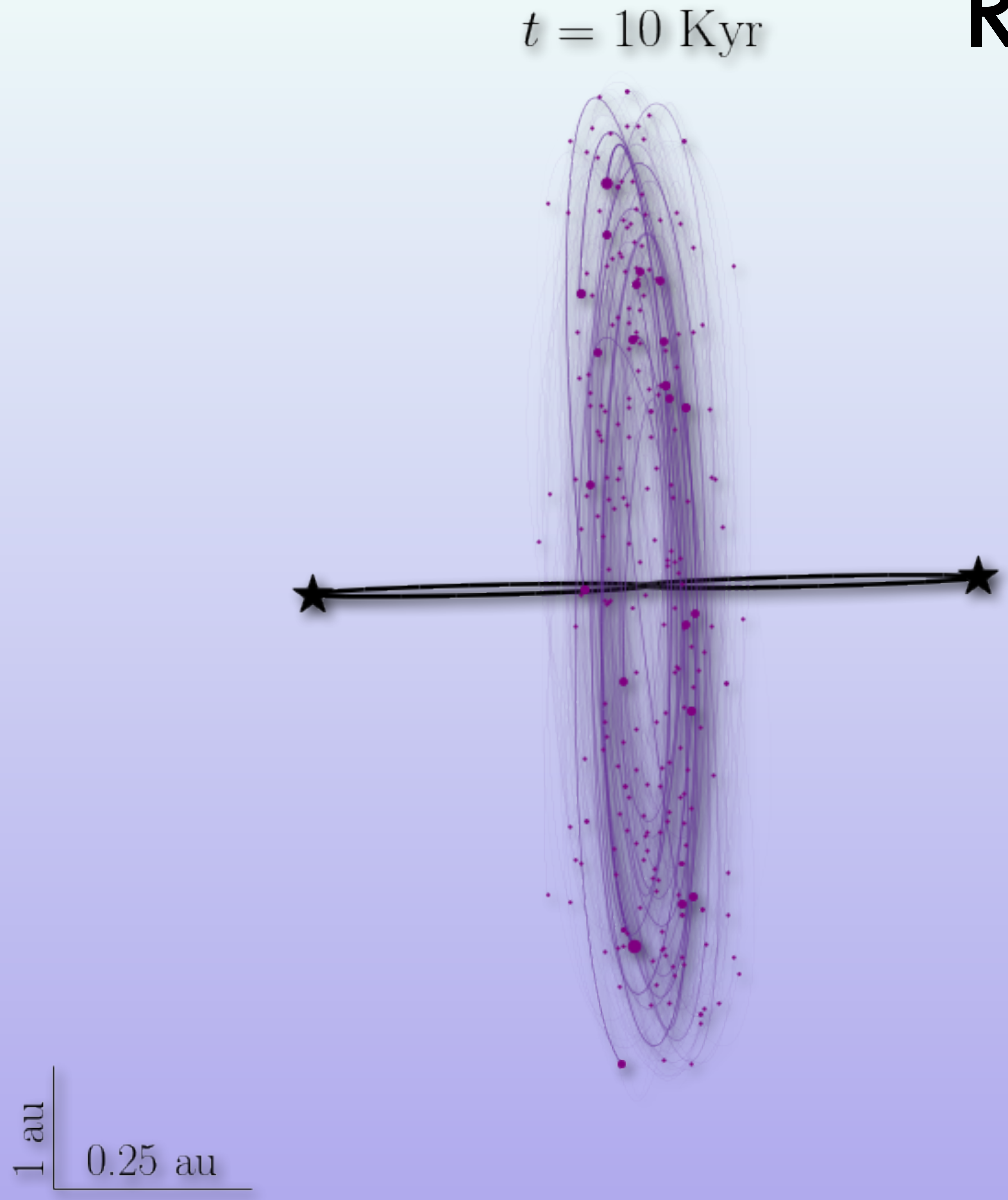
POLAR TERRESTRIAL CBP FORMATION

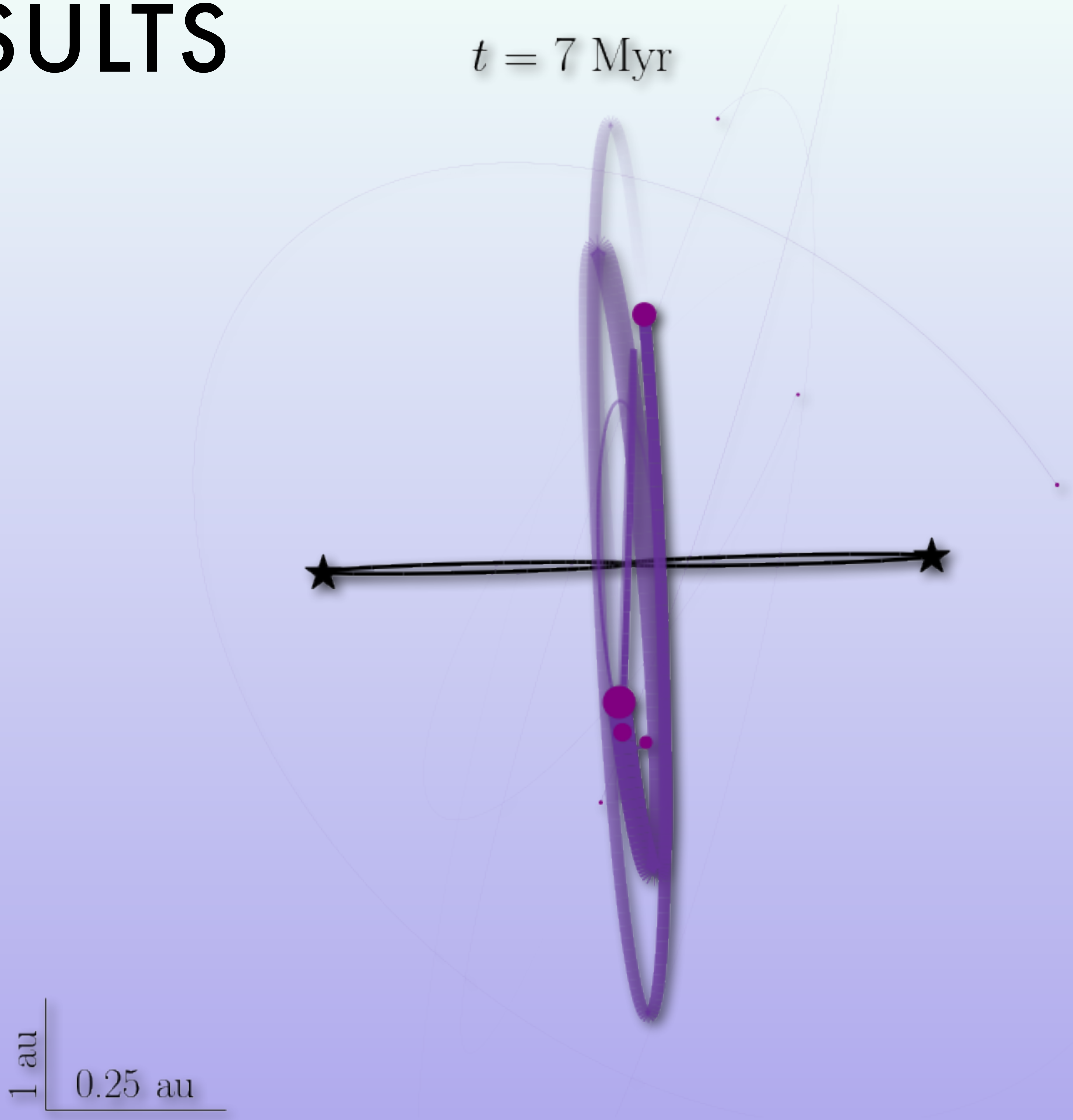
- CIRCULAR VS ECCENTRIC EQUAL MASSED BINARY ($e_{\rm b} = 0, 0.8$)
- COPLANAR VS POLAR
- 260 MOON-SIZED PLANETESIMALS AND 26 MARS SIZED EMBRYOS



Childs & Martin 2021b

RESULTS





Childs & Martin 2021b

RESULTS

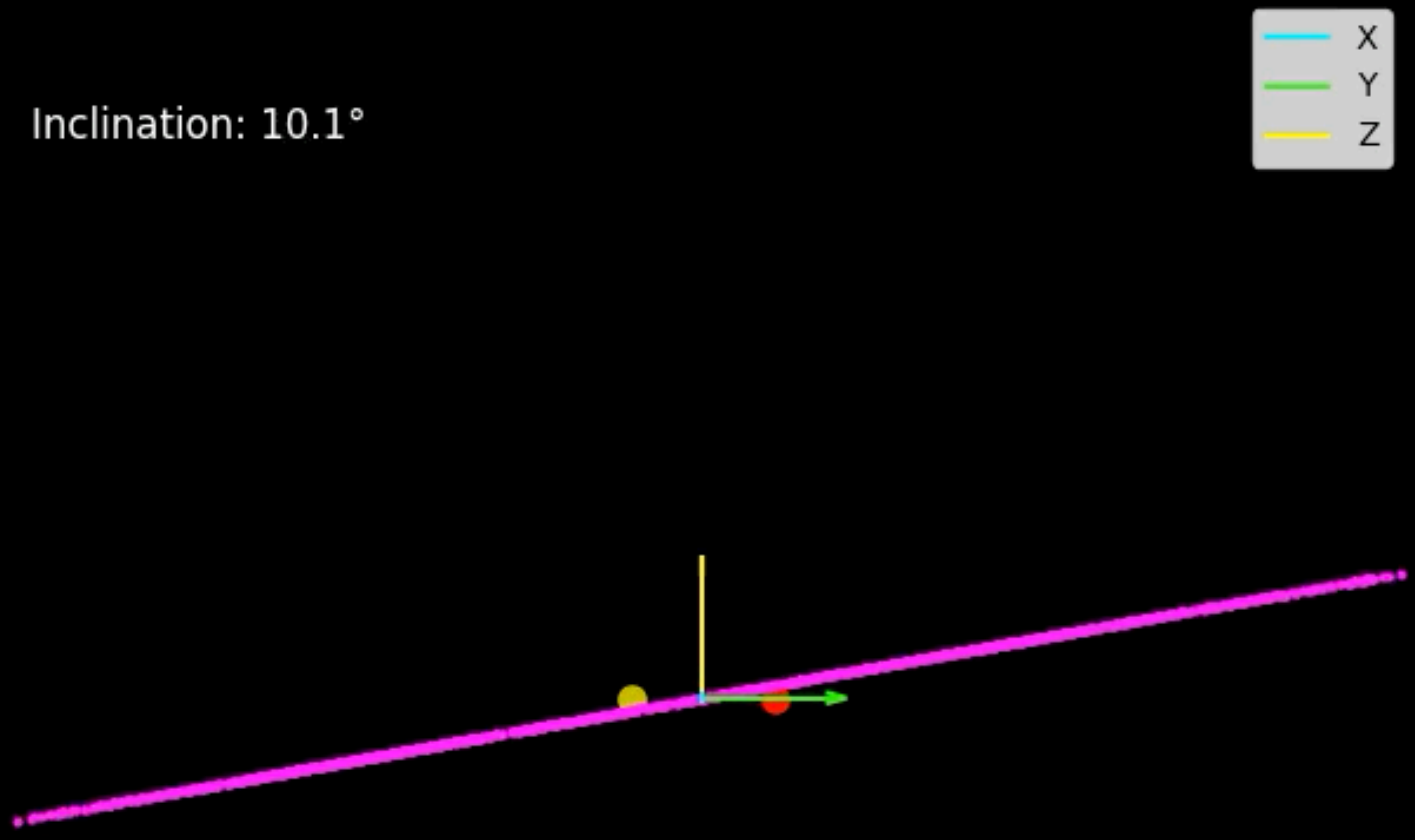
Model	a_b/au	e_b	i_b°	No. of planets	$M_p/M_\oplus$	a_p/au	e	i°	$M_d/M_\oplus$
EP	0.5	0.8	90.0	4.8 ± 0.8	0.95 ± 0.61	2.80 ± 0.96	0.05 ± 0.03	89.99 ± 1.02	4.62 ± 0.04
EP_{GR}	0.5	0.8	90.0	4.6 ± 0.8	0.98 ± 0.63	2.77 ± 0.96	0.05 ± 0.03	89.96 ± 0.93	4.62 ± 0.04
CC	0.5	0.0	0.0	5.1 ± 1.28	0.89 ± 0.58	2.76 ± 0.88	0.04 ± 0.03	0.96 ± 0.66	4.71 ± 0.01
EC	0.5	0.8	0.0	3.4 ± 1.03	1.22 ± 0.67	3.21 ± 0.79	0.06 ± 0.04	2.63 ± 2.27	4.19 ± 0.27

TERRESTRIAL CBP FORMATION AROUND AN ECCENTRIC BINARY IS EASIER IN THE POLAR CONFIGURATION

Childs & Martin 2021b

NON-STATIONARY INCLINATIONS

- NODAL PRECESSION ABOUT THE BINARY ANGULAR MOMENTUM VECTOR $\implies$ COPLANAR ALIGNMENT
- NODAL PRECESSION ABOUT THE BINARY ECCENTRICITY VECTOR $\implies$ POLAR ALIGNMENT

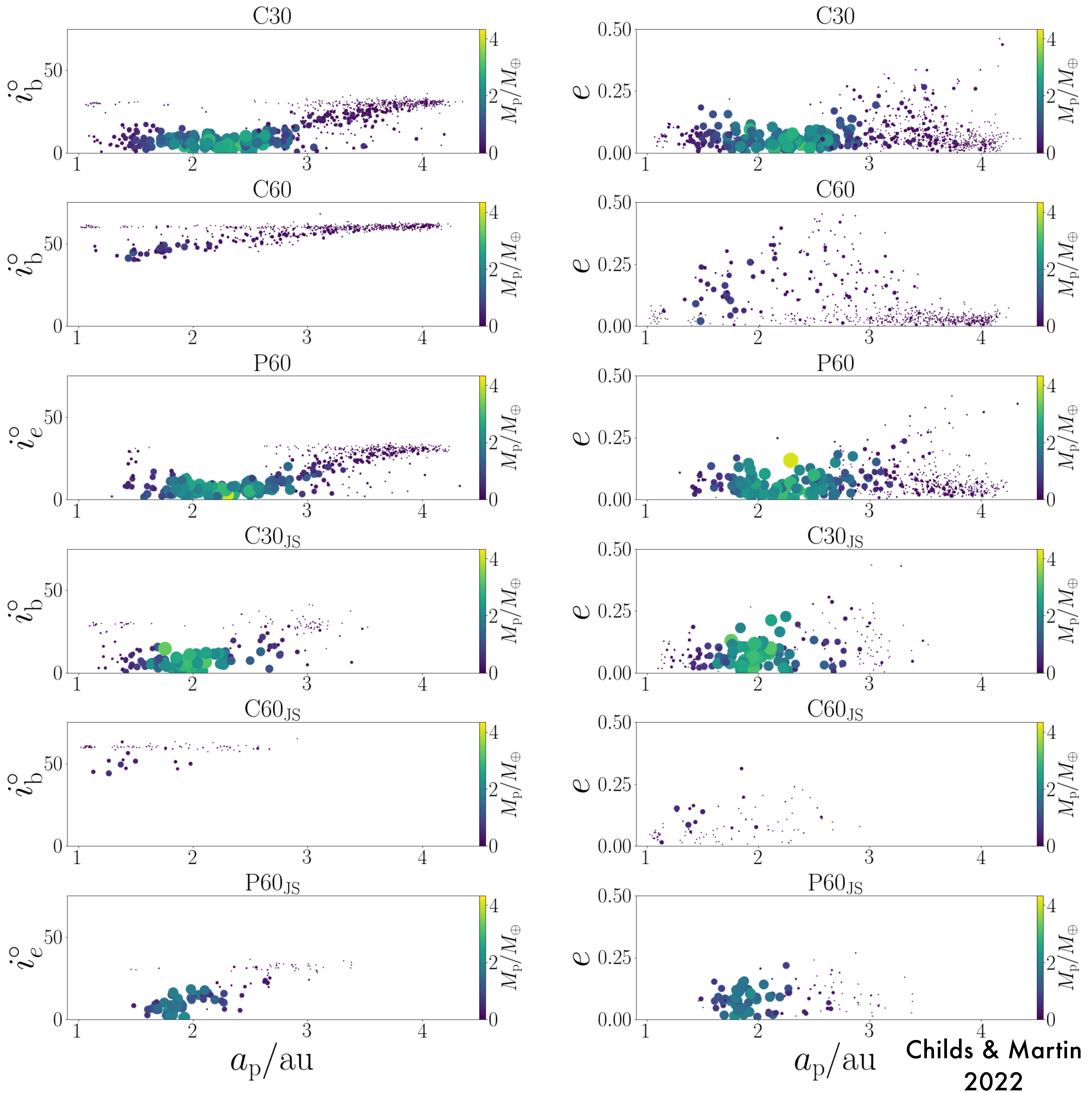


- INITIAL MISALIGNMENT DETERMINES ALIGNMENT DIRECTION
- CRITICAL INCLINATION

$$i_{\mathrm{crit}} = \sin^{-1}\sqrt{\frac{1 - e_b^2}{1 + 4e_b^2}}$$

SETUP

- C30, C60, E60
- BODIES PRECESS ABOUT THE ANGULAR MOMENTUM VECTOR OF A CIRCULAR BINARY
- BODIES PRECESS ABOUT THE ECCENTRICITY VECTOR OF AN ECCENTRIC BINARY
- FRAGMENTATION (CHILDS & STEFFEN 2022)
- JUPITER AND SATURN



Childs & Martin 2022

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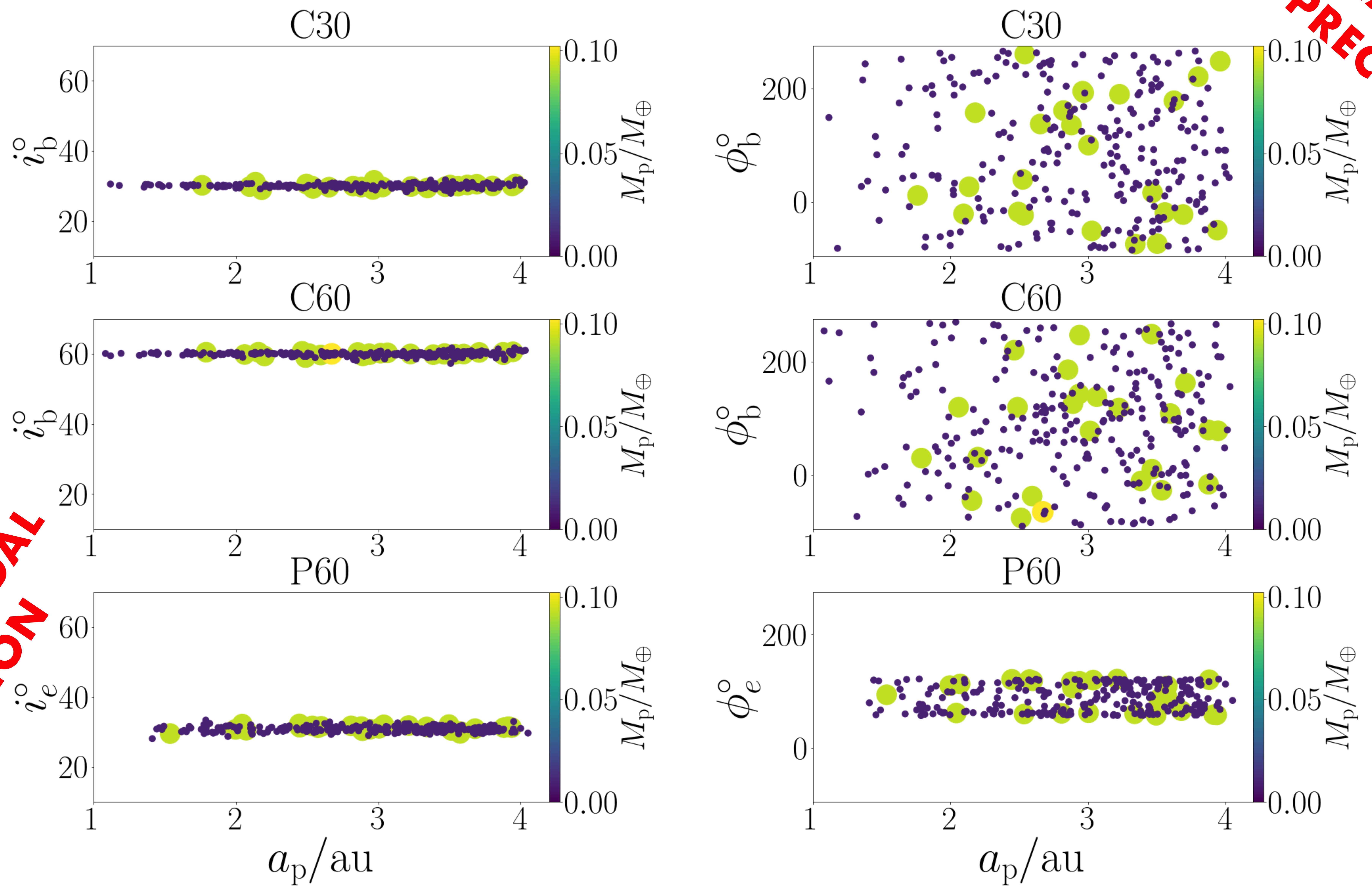


CIRCULATING NODAL PRECESSION

LIBRATING NODAL PRECESSION

Childs & Martin 2022

RESULTS

Childs & Martin 2022

RESULTS

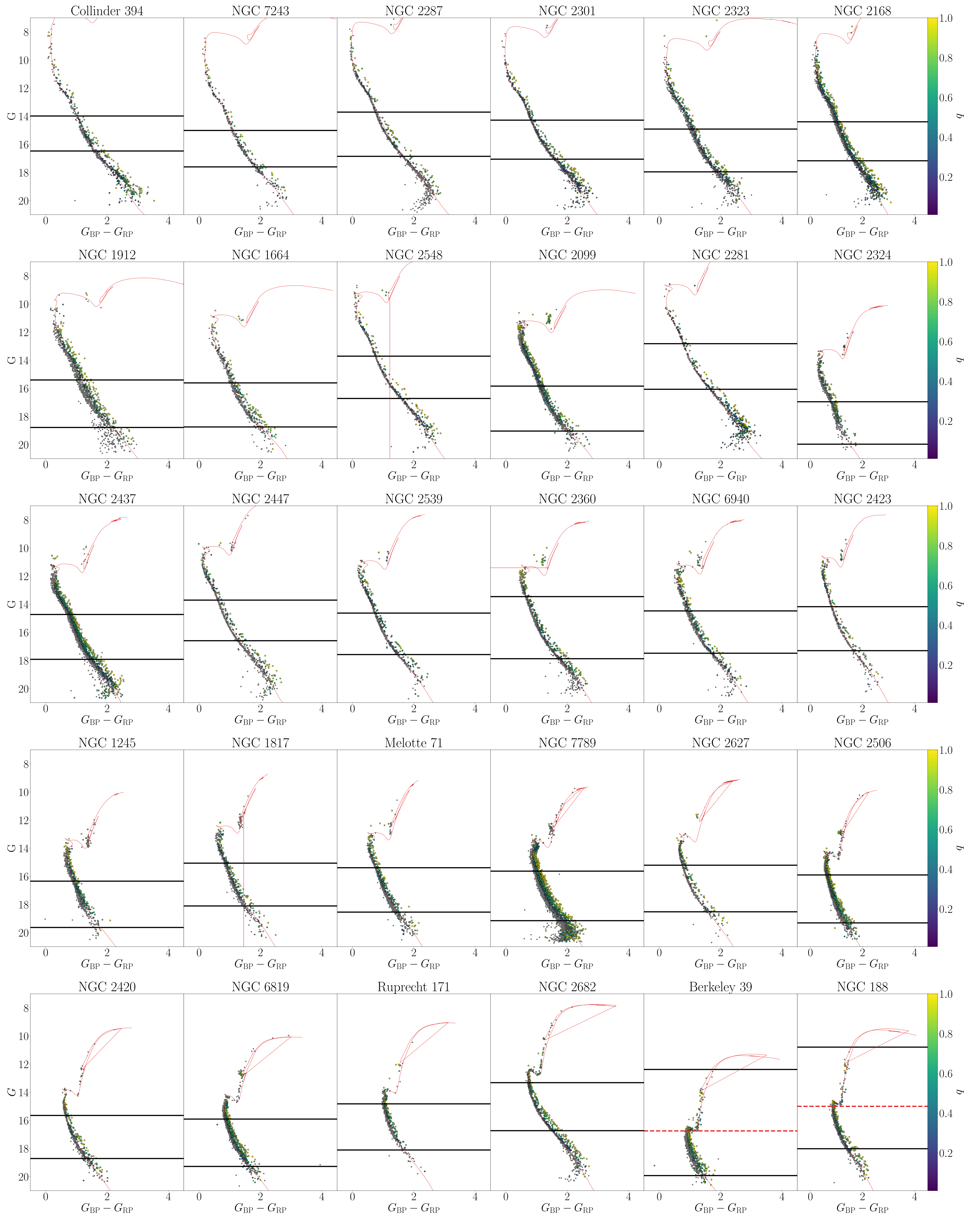
				$M_p/M_\oplus \geq 0.1$					$M_p/M_\oplus \geq 1.0$					
Model	e_b	i°_{b0}	Σ	#	$M_p/M_\oplus$	a_p/au	e	$i^\circ_{e/b}$	#	$M_p/M_\oplus$	a_p/au	e	$i^\circ_{e/b}$	M_e/M_d
C30	0.0	30.0	CC	4.8 ± 1.3	0.9 ± 0.8	2.6 ± 0.8	0.07 ± 0.06	12.6 ± 8.1	1.9 ± 0.5	1.8 ± 0.5	2.2 ± 0.3	0.06 ± 0.03	6.9 ± 2.9	0.06 ± 0.02
C60	0.0	60.0	CC	1.5 ± 0.9	0.3 ± 0.2	2.4 ± 0.7	0.16 ± 0.10	51.5 ± 5.5	0.02 ± 0.13	1.1 ± 0.0	1.5 ± 0.0	0.02 ± 0.0	44.7 ± 0.0	0.84 ± 0.07
P60	0.8	60.0	EP	3.7 ± 1.0	1.1 ± 0.9	2.5 ± 0.7	0.07 ± 0.04	13.4 ± 8.6	1.8 ± 0.5	1.9 ± 0.5	2.3 ± 0.4	0.06 ± 0.04	7.0 ± 3.3	0.13 ± 0.05

TERRESTRIAL CBP FORMATION VIA CORE ACCRETION IN HIGHLY MISALIGNED DISKS (*RELATIVE TO THE PRECESSION VECTOR*) IS **INHIBITED**

Childs & Martin 2022

- BAYESIAN STELLAR EVOLUTIONARY CODE -9 (BASE-9)
- CONSTRAINS OC PARAMETERS, BINARY FRACTION (f_{b}), AND STELLAR MASSES
- 32 OCS
- SEARCHING FOR f_{b} VS OC PARAMETER TRENDS

Childs & Geller (in prep)



SUMMARY

- TERRESTRIAL CBPS CAN FORM EITHER COPLANAR OR POLAR TO THE BINARY THROUGH CORE ACCRETION
- CORE ACCRETION AROUND AN ECCENTRIC BINARY IS MORE EFFICIENT IN THE POLAR ALIGNMENT
- A PLANETESIMAL DISK THAT IS HIGHLY MISALIGNED AFTER GAS DISK DISSIPATION WILL EJECT MOST OF ITS MATERIAL
- WE HAVE CONSTRAINED f_{b} FOR 32 OCS TO LOOK FOR TRENDS IN BINARY FORMATION AND EVOLUTION

ANNA.CHILDS@NORTHWESTERN.EDU