DECODING HOT JUPITER SYSTEMS:
Unveiling Formation Clues from Giant Planet Populations

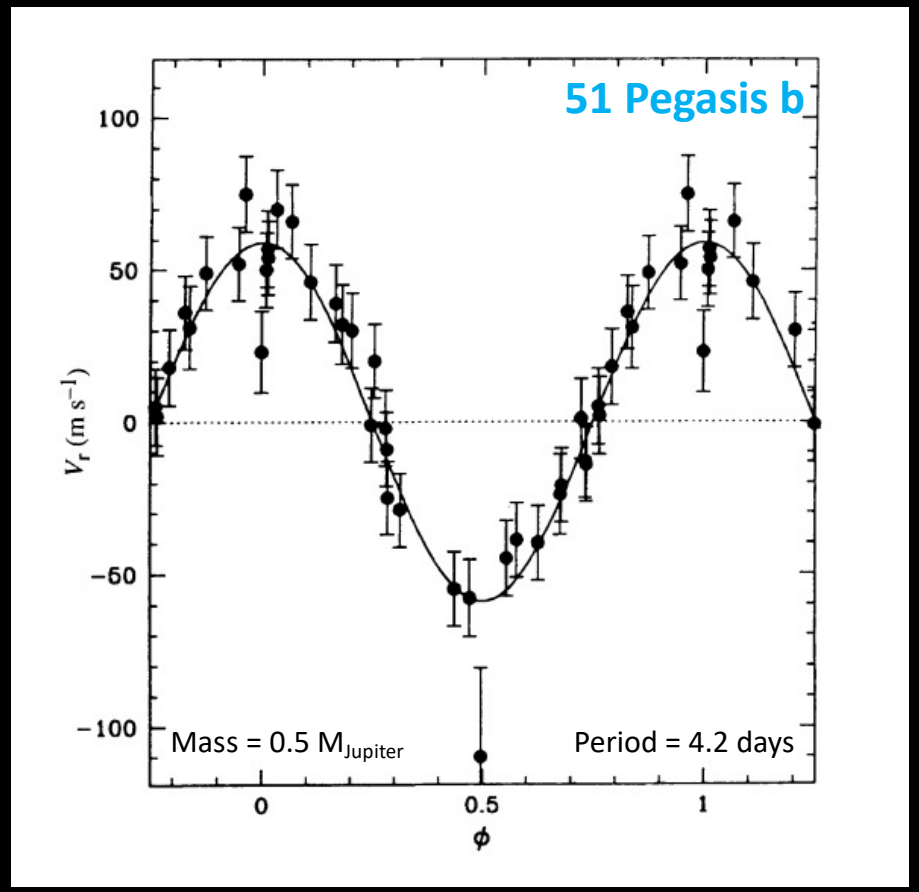
Jon Zink

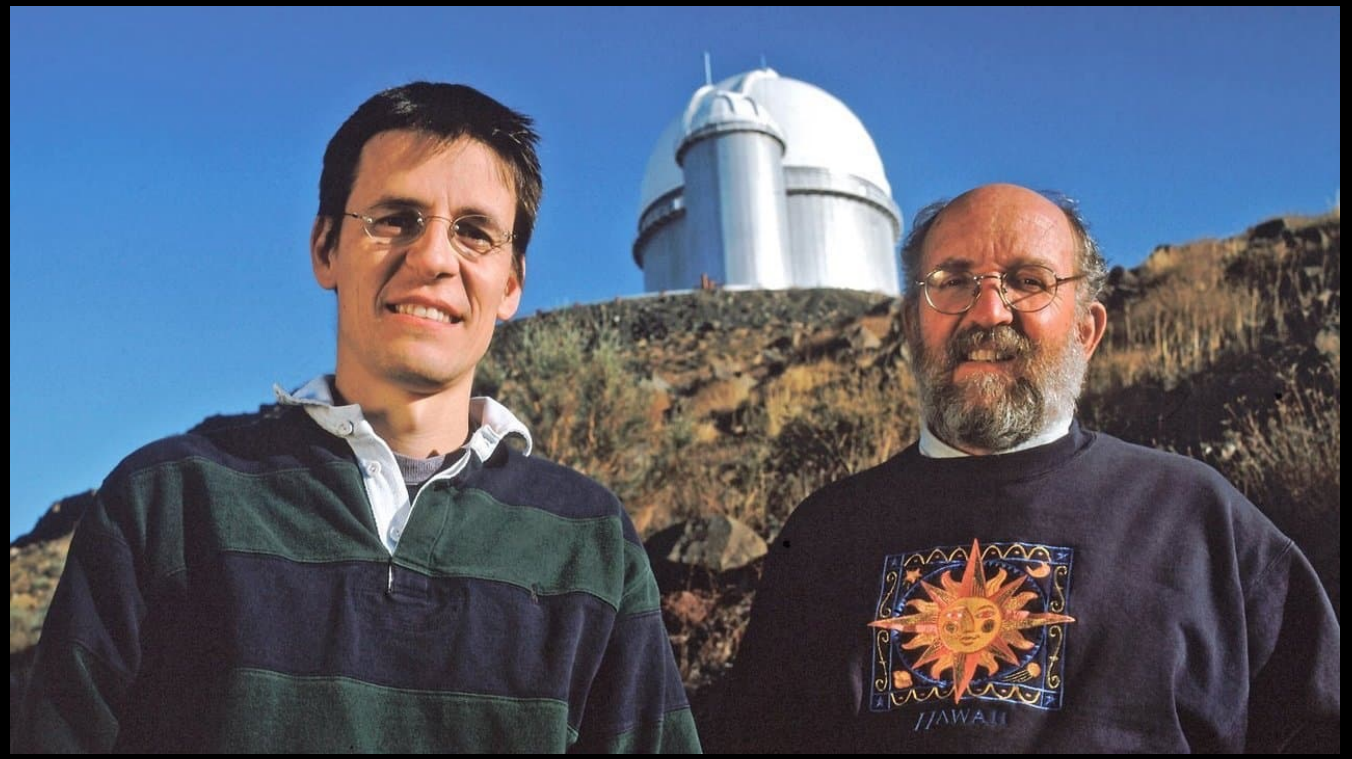
December 12th , 2023 **ExSoCal**

NASA Hubble Fellow
Caltech

www.JonZink.com
@jonKzink

51 Peg. b: A Nobel Worthy Planet





Didier Queloz & Michel Mayor 1995

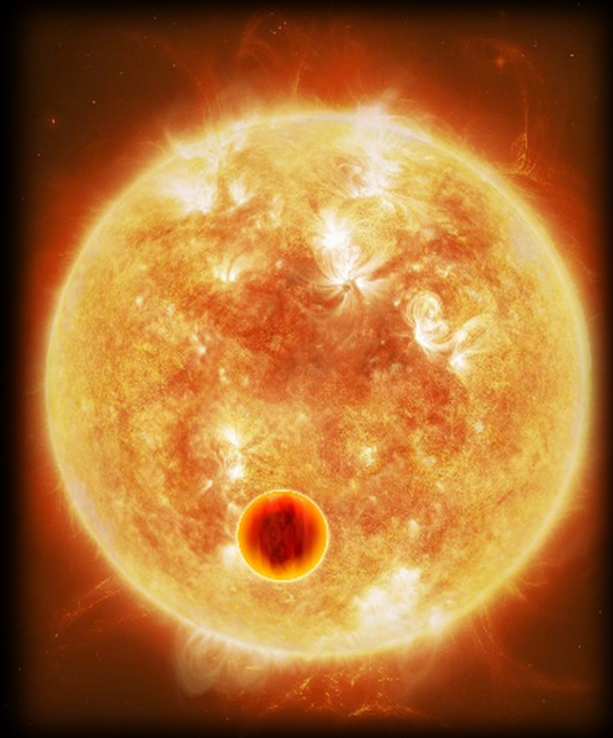
Hot Jupiter Are Strange

- Orbital periods between 1 and 10 days

  (less than 25% the orbital radius of Mercury)

- Dayside temperature ~2700K

  (hotter than many late M-dwarfs)



Hot Jupiter Are Strange

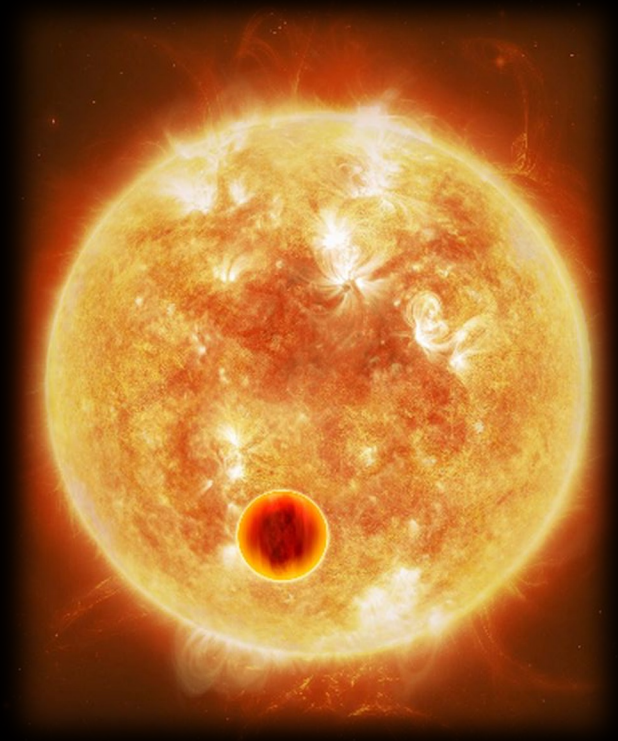
- Orbital periods between 1 and 10 days

  (less than 25% the orbital radius of Mercury)

- Dayside temperature ~2700K

  (hotter than many late M-dwarfs)

- How did they come to exist?

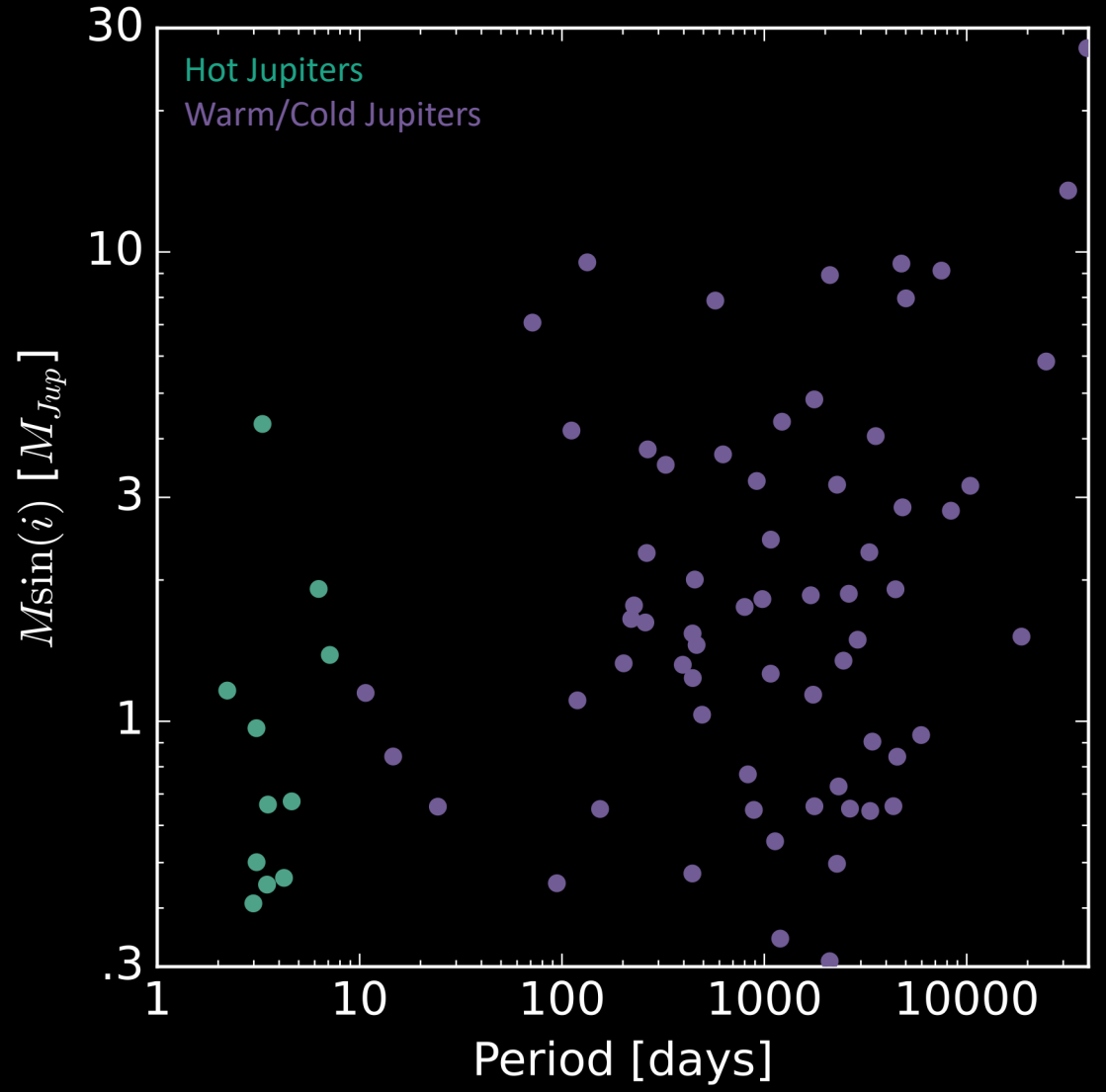


A Homogenous RV Sample

- The California Legacy Survey (CLS) monitored the radial velocities of 719 stars over 30 years. (Rosenthal et al. 2021)

Identified 127 Planets

- 11 Hot Jupiter systems
- 46 Warm/Cold Jupiter systems



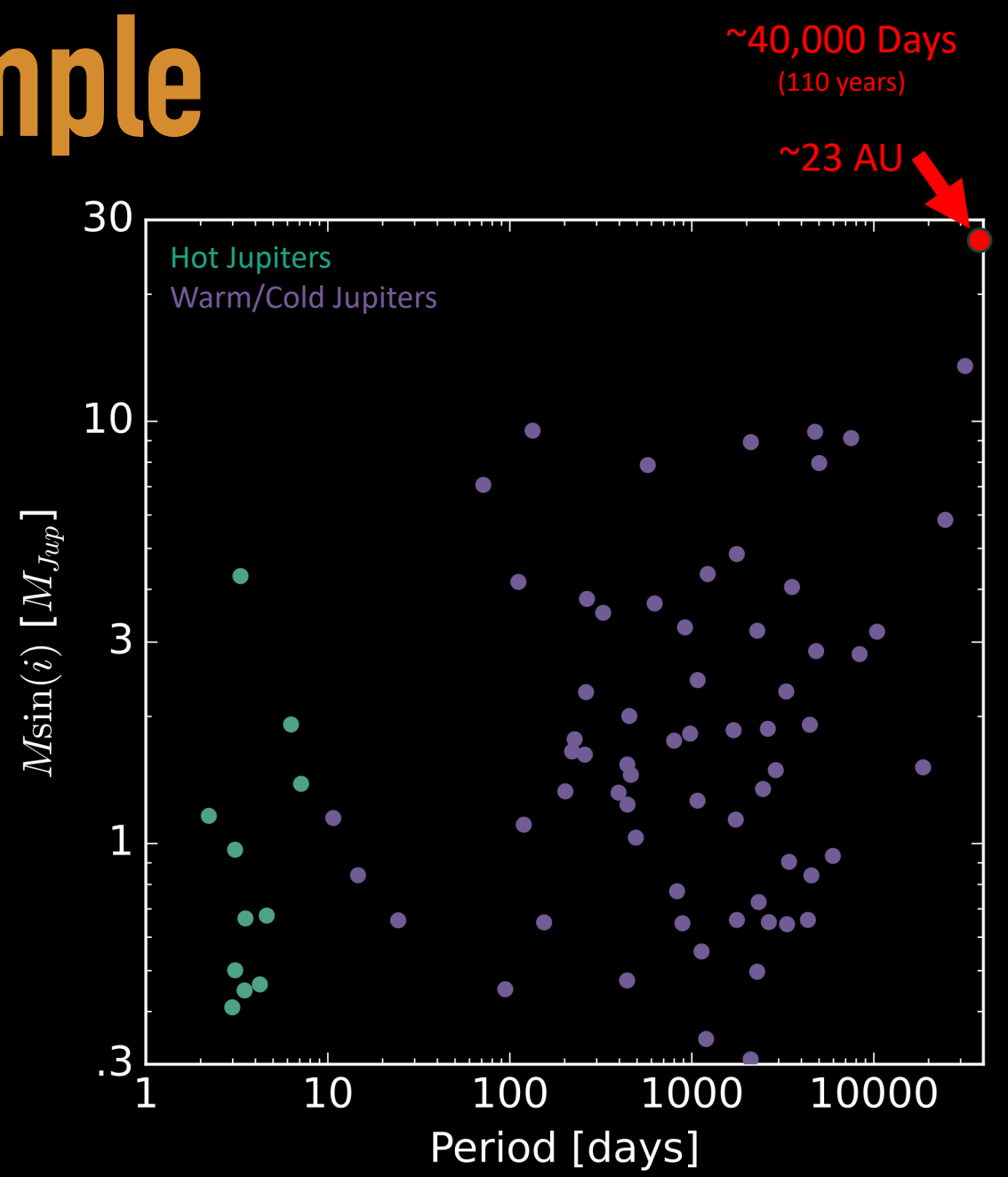
Zink & Howard 2023

A Homogenous RV Sample

- The California Legacy Survey (CLS) monitored the radial velocities of 719 stars over 30 years. (Rosenthal et al. 2021)

Identified 127 Planets

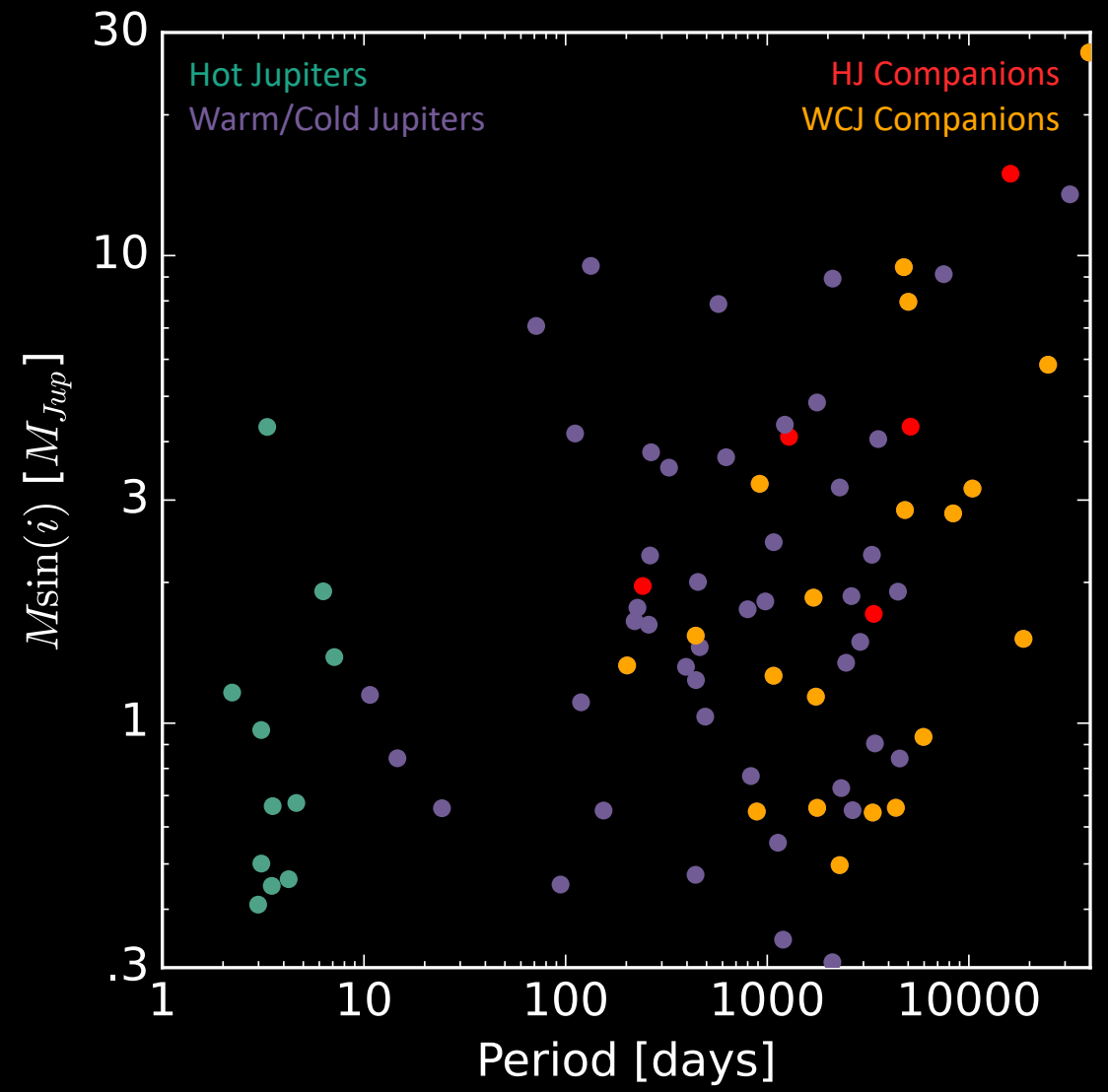
- 11 Hot Jupiter systems
- 46 Warm/Cold Jupiter systems



Zink & Howard 2023

OUTER COMPANION SAMPLE

- 5 Hot Jupiter Companions
- 11 Warm/Cold Jupiter Companions



Zink & Howard 2023

Giant Multiplicity Is Ubiquitous

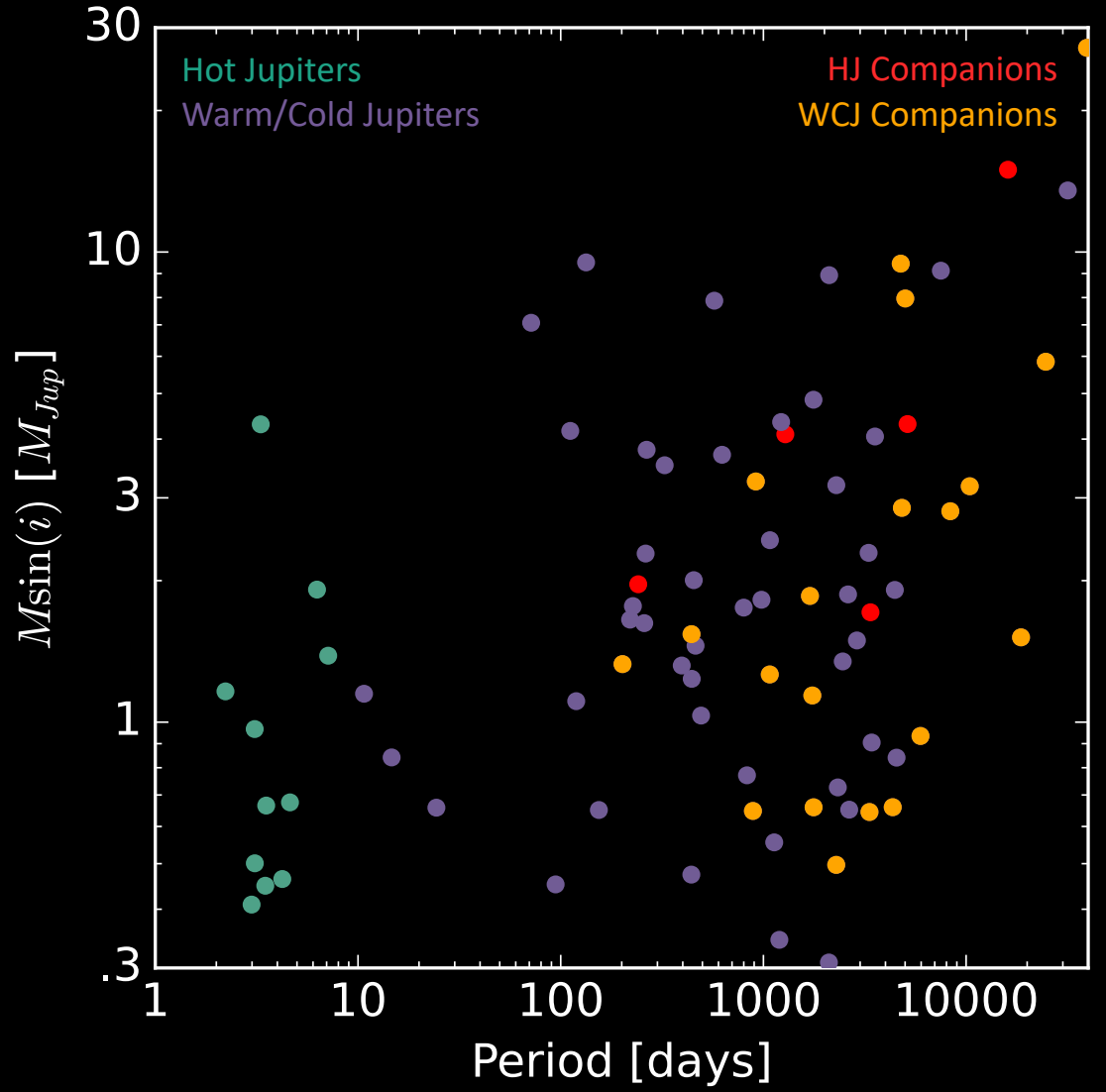
OUTER COMPANION SAMPLE

- 5 Hot Jupiter Companions
- 11 Warm/Cold Jupiter Companions

COMPANIONSHIP STATISTICS

$1.3 \pm^{1.0}_{0.6}$ Companions per HJ

1.0 ± 0.3 Companions per WCJ



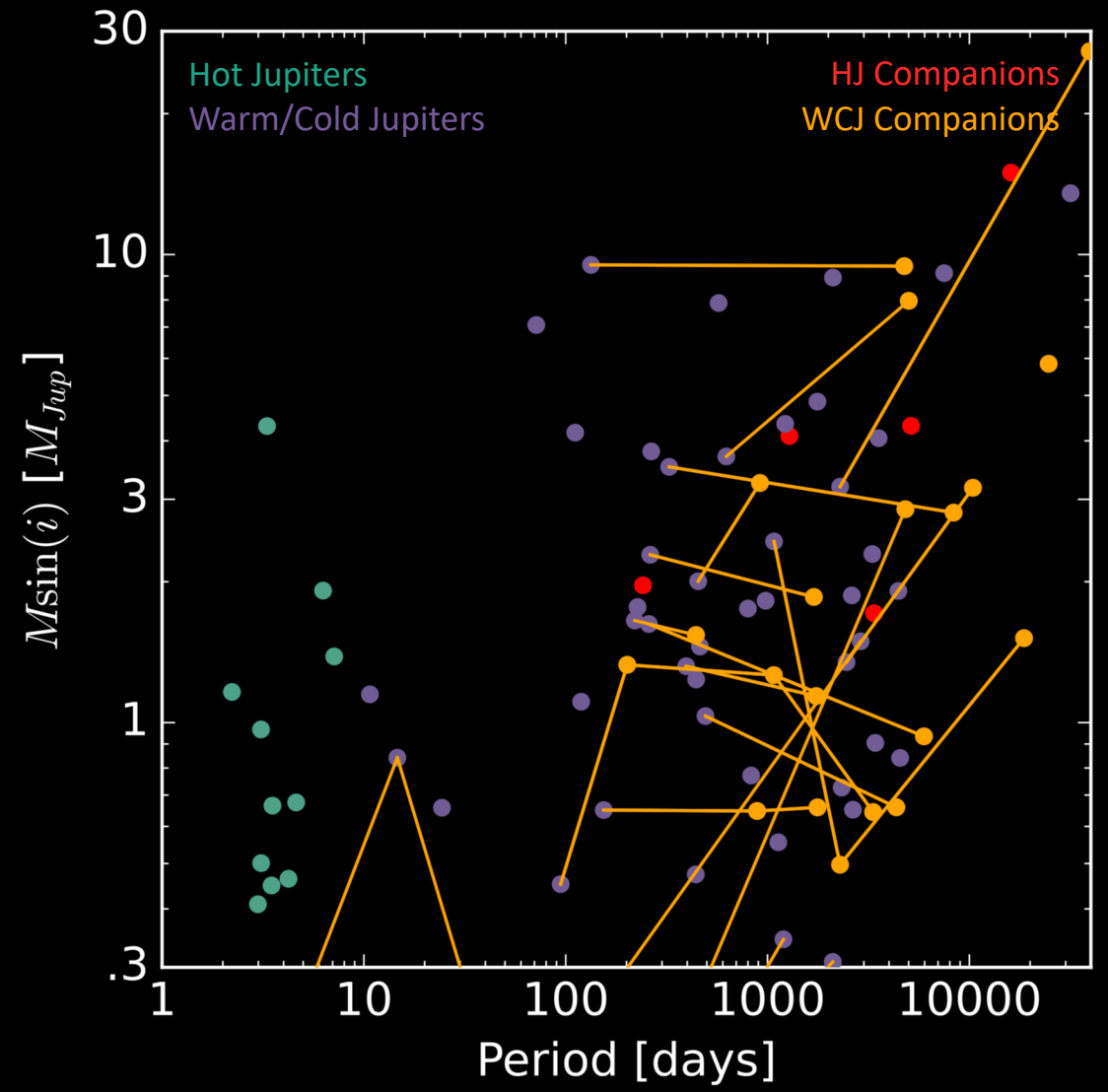
Zink & Howard 2023

AVERAGE MASS RATIO FOR EACH ARCHITECTURE

Warm/Cold Jupiter Systems

$$\frac{M_{Outer}}{M_{Inner}} \sim 1$$

Random Draw



Zink & Howard 2023

HJs Require 3X Mass Companions

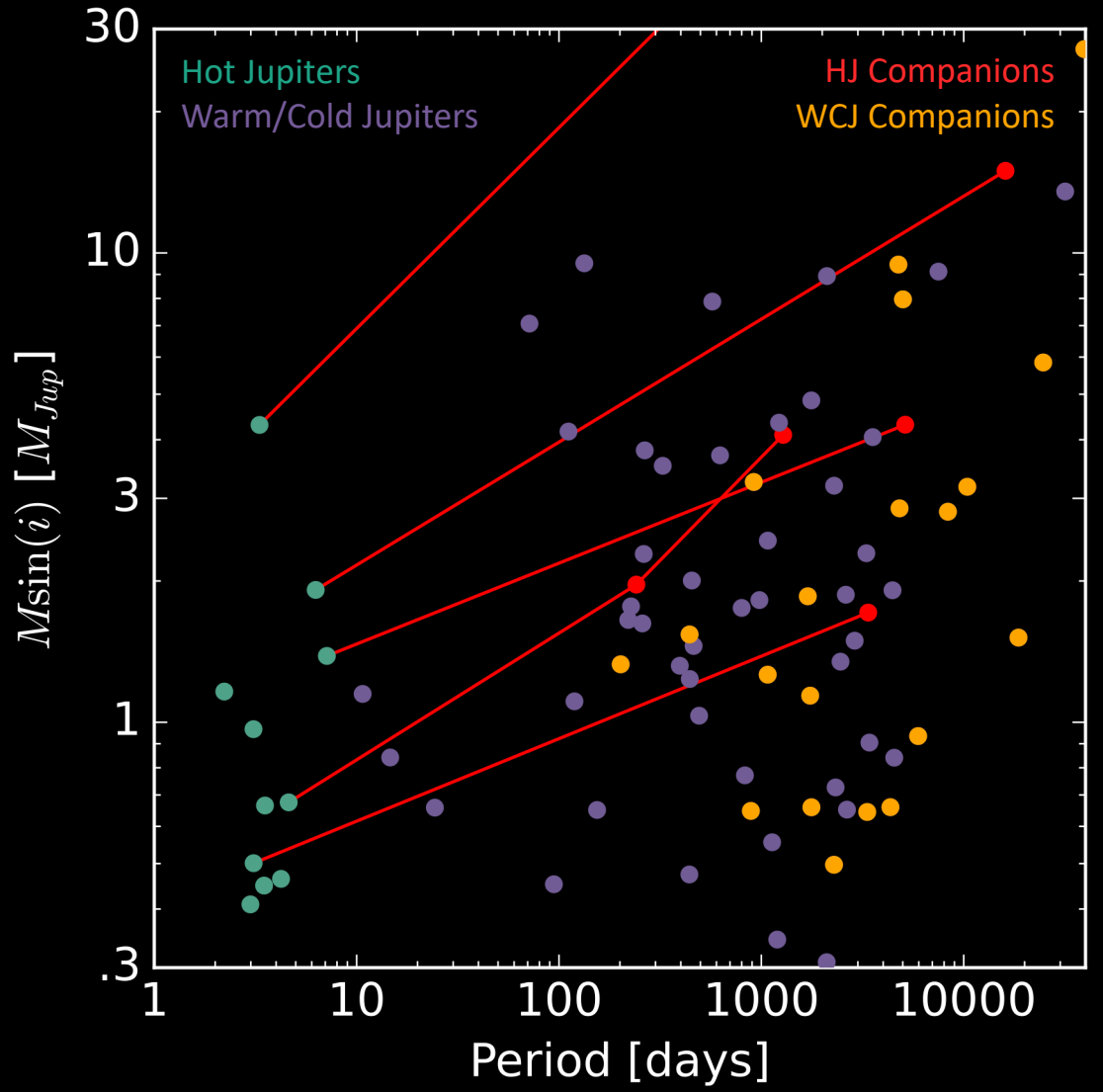
AVERAGE MASS RATIO
FOR EACH ARCHITECTURE

Warm/Cold Jupiter Systems

$$\frac{M_{Outer}}{M_{Inner}} \sim 1$$ Random Draw

Hot Jupiter Systems

$$\frac{M_{Outer}}{M_{Inner}} > 3$$ Highly Order

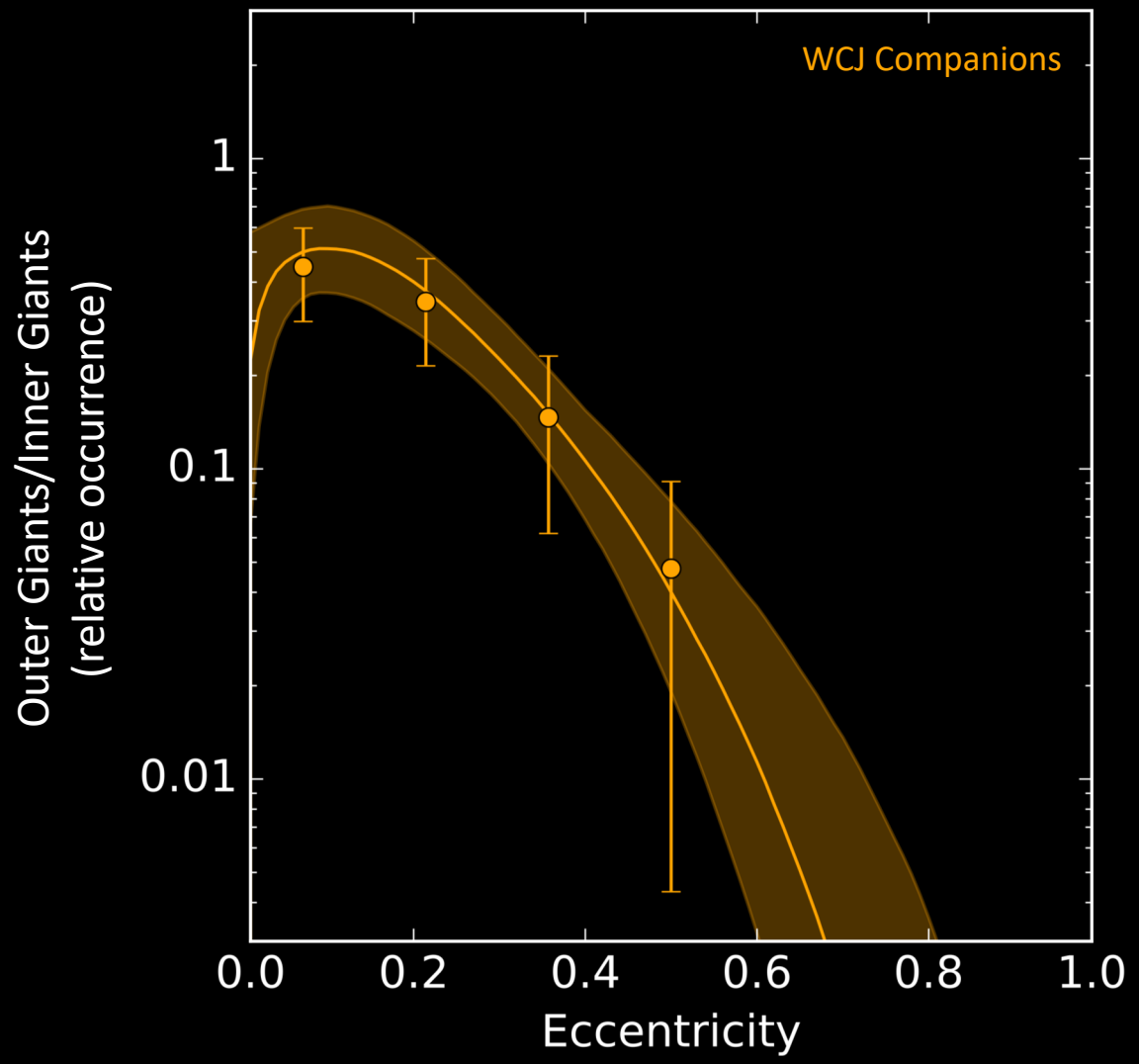


Zink & Howard 2023

AVERAGE ECCENTRICITY FOR EACH ARCHITECTURE

Warm/Cold Jupiter Companions

$$\langle e \rangle = 0.19 \pm 0.02$$



Zink & Howard 2023

HJs Companions Are More Eccentric

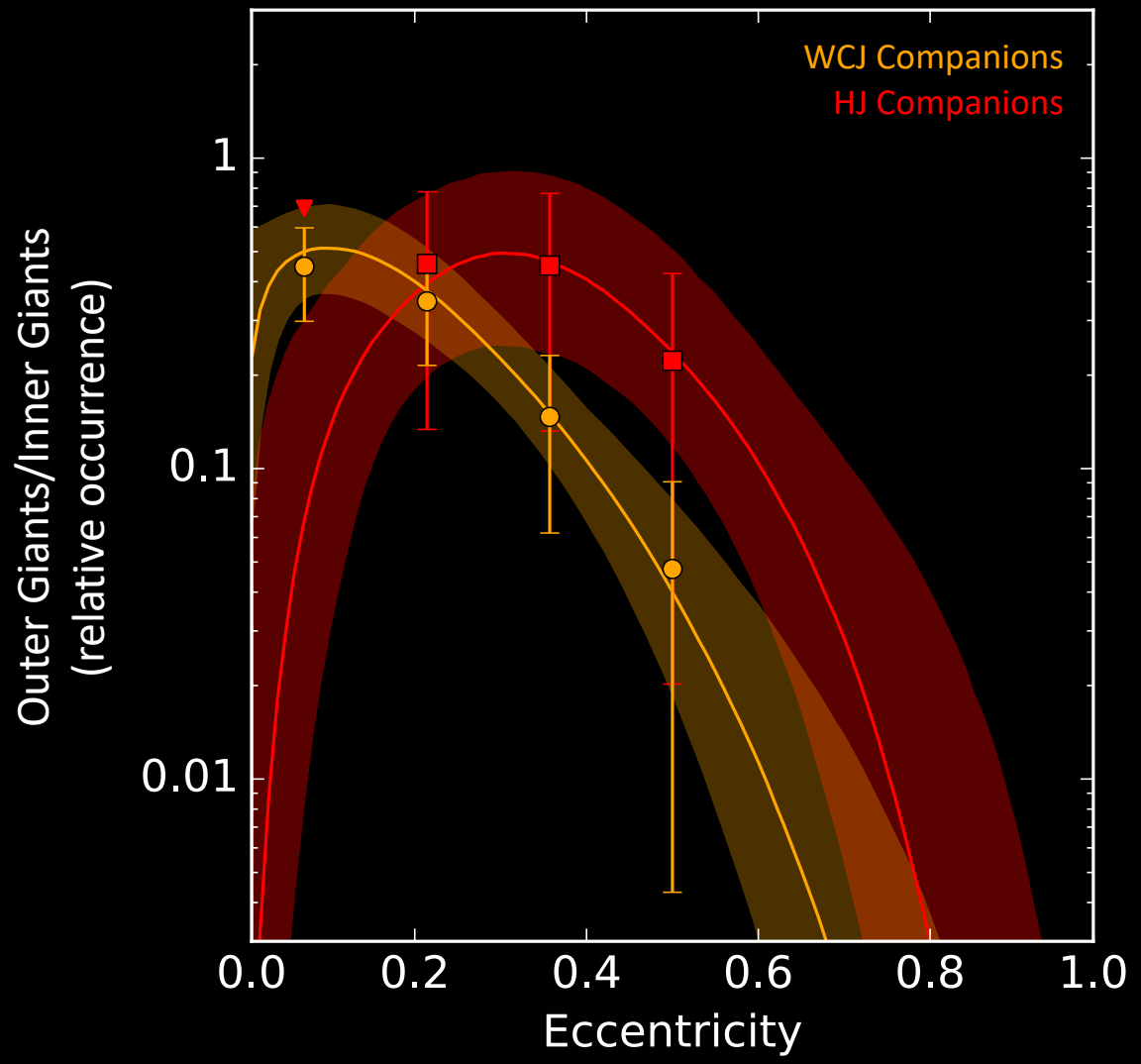
AVERAGE ECCENTRICITY
FOR EACH ARCHITECTURE

Warm/Cold Jupiter Companions

$$\langle e \rangle = 0.19 \pm 0.02$$

Hot Jupiter Companions

$$\langle e \rangle = 0.34 \pm 0.05$$ 3σ Higher

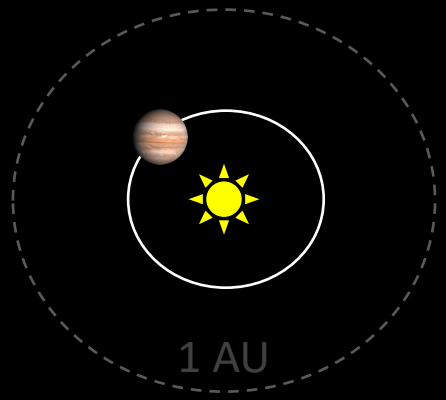


Zink & Howard 2023

Formation Pathways:

In-Situ (Batygin et al. 2016)

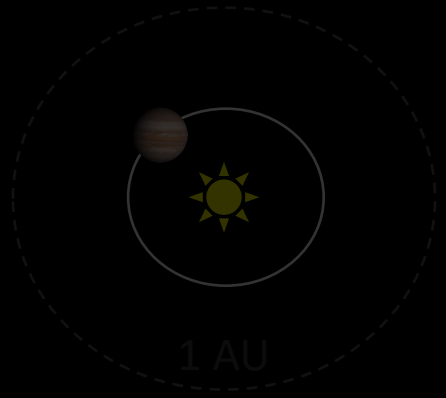
HJs form within 1 AU and undergo minimal migration.



Formation Pathways:

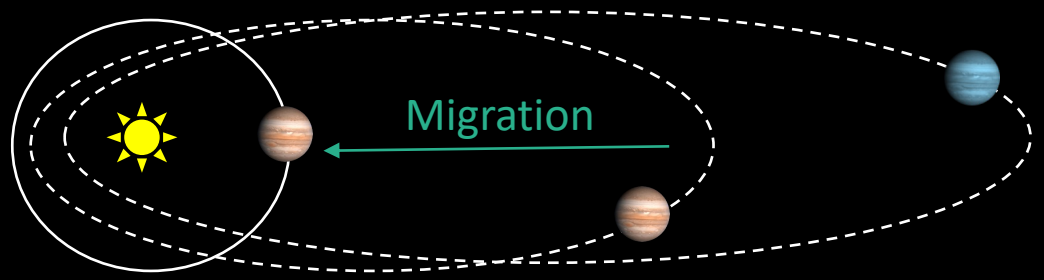
In-Situ (Batygin et al. 2016)

HJs form within 1 AU and undergo minimal migration.



Coplanar High-Eccentricity Migration (Petrovich 2015)

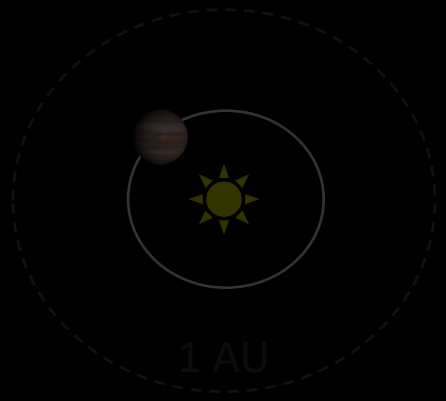
Two cold giants exchange angular momentum and tidally interact with the host star, culminating in a HJ.



Formation Pathways:

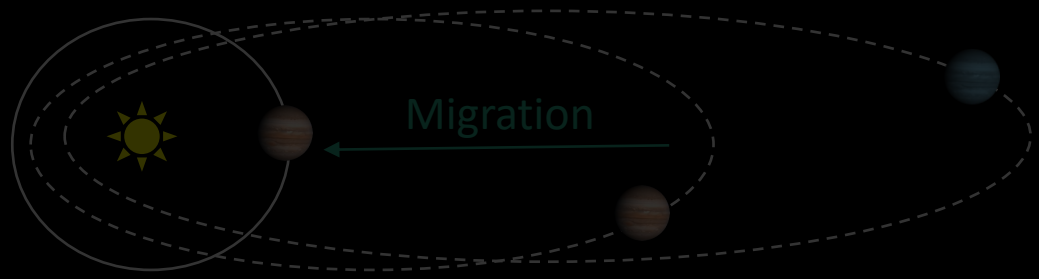
In-Situ (Batygin et al. 2016)

HJs form within 1 AU and undergo minimal migration.



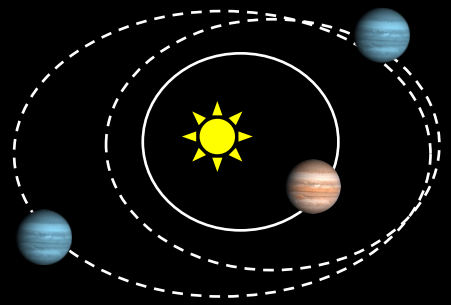
Coplanar High-Eccentricity Migration (Petrovich 2015)

Two cold giants exchange angular momentum and tidally interact with the host star, culminating in a HJ.



Secular Chaos (Wu & Lithwick 2011)

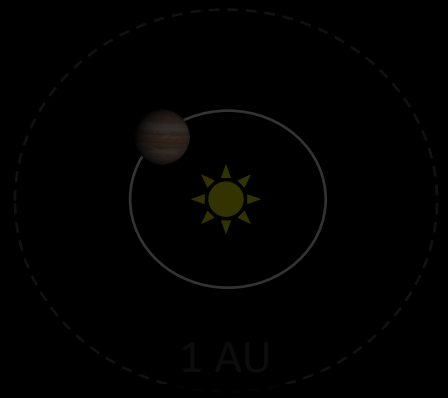
Three or more cold giants dynamically interact to produce a HJ.



Formation Pathways:

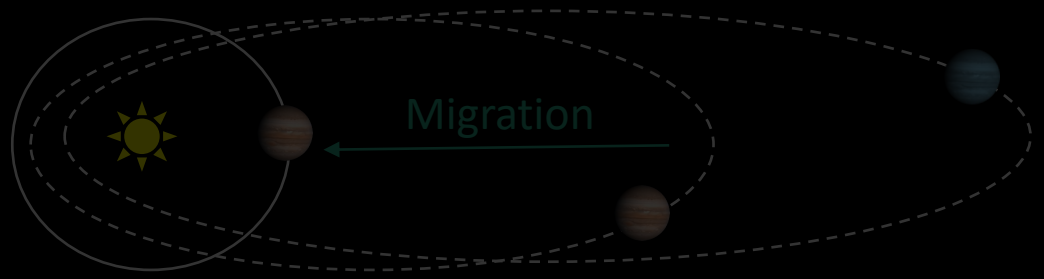
In-Situ (Batygin et al. 2016)

HJs form within 1 AU and undergo minimal migration



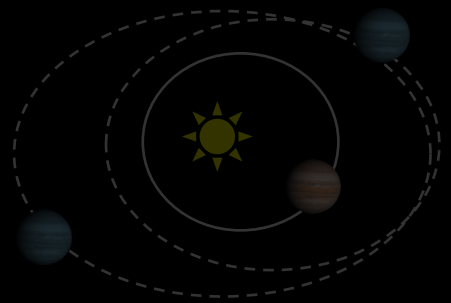
Coplanar High-Eccentricity Migration (Petrovich 2015)

Two cold giants exchange angular momentum and tidally interact with the host star, culminating in a HJ.



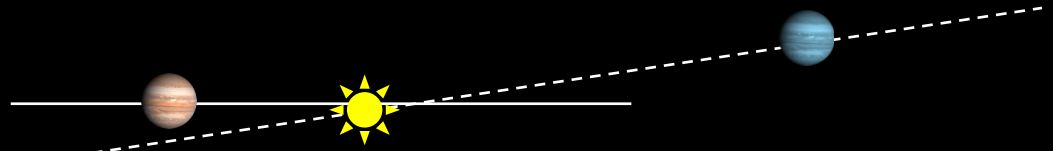
Secular Chaos (Wu & Lithwick 2011)

Three or more cold giants dynamically interact to produce a HJ.



Lidov-Kozai Cycling (Wu & Murry 2003)

Two cold giants with high initial mutual inclination undergo oscillations in eccentricity and inclination, yielding a HJ.



Formation Pathways

Mechanism:	2 Giant Multiplicity:	3X Mass Companion:	Enhanced E. Companion:	Obliquity Distribution:
In-Situ				
Coplanar High-E.				
Secular Chaos				
Kozai Oscillations				

Formation Pathways

Mechanism:	2 Giant Multiplicity:	3X Mass Companion:	Enhanced E. Companion:	Obliquity Distribution:
In-Situ	X	X	X	O
Coplanar High-E.	O	O	O	O
Secular Chaos	X	O	O	X
Kozai Oscillations	O	O	O	X

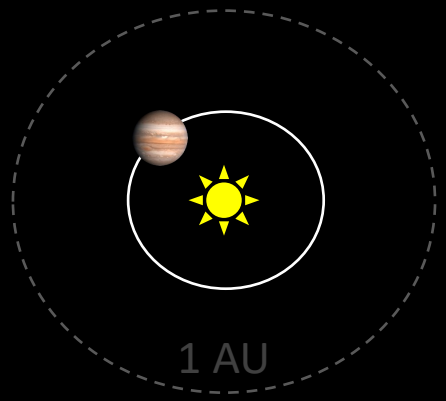
Formation Pathways

Mechanism:	2 Giant Multiplicity:	3X Mass Companion:	Enhanced E. Companion:	Obliquity Distribution:
In-Situ	X	X	X	O
Coplanar High-E.	O	O	O	O
Secular Chaos	X	O	O	X
Kozai Oscillations	O	O	O	X

Formation Pathways:

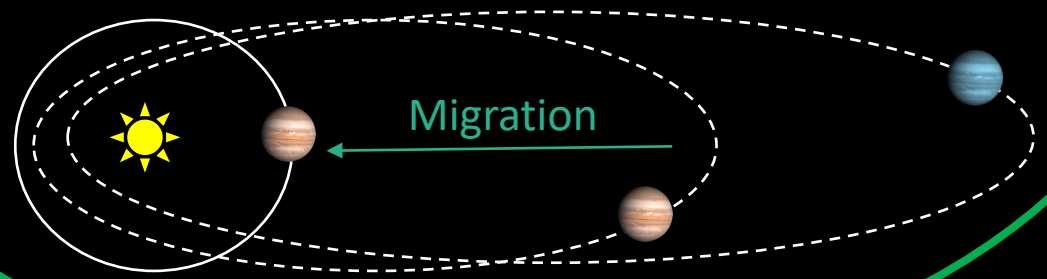
In-Situ (Batygin et al. 2016)

HJs form within 1 AU and undergo minimal migration



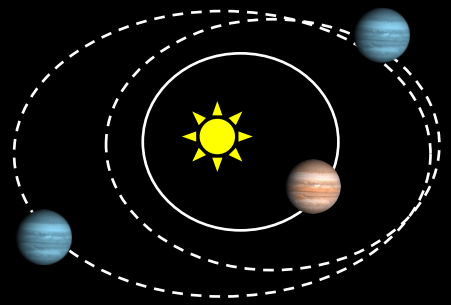
Coplanar High-Eccentricity Migration (Petrovich 2015)

Two cold giants exchange angular momentum and tidally interact with the host star, culminating in a HJ.



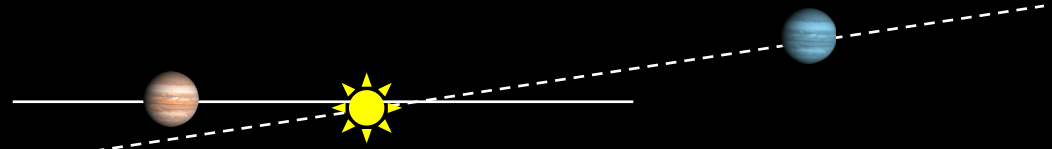
Secular Chaos (Wu & Lithwick 2011)

Three or more cold giants dynamically interact to produce a HJ.

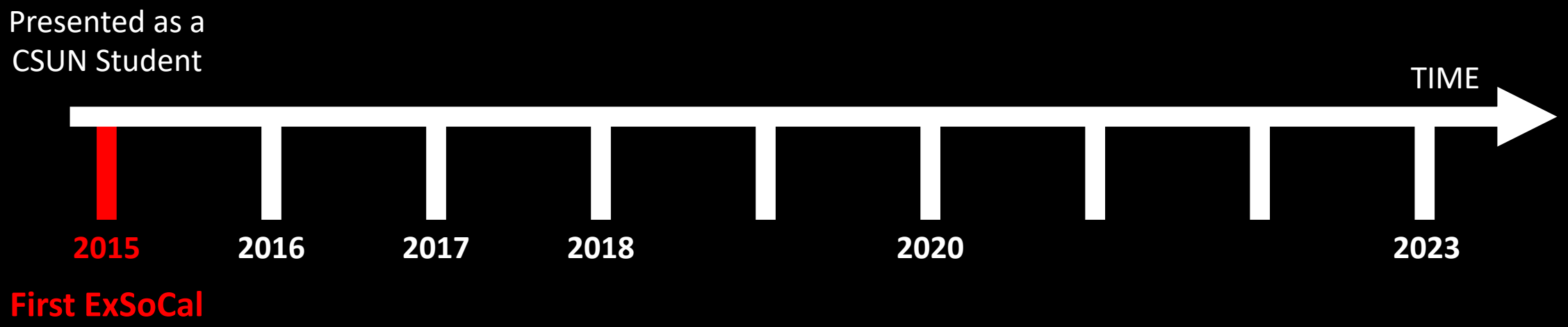


Lidov-Kozai Cycling (Wu & Murry 2003)

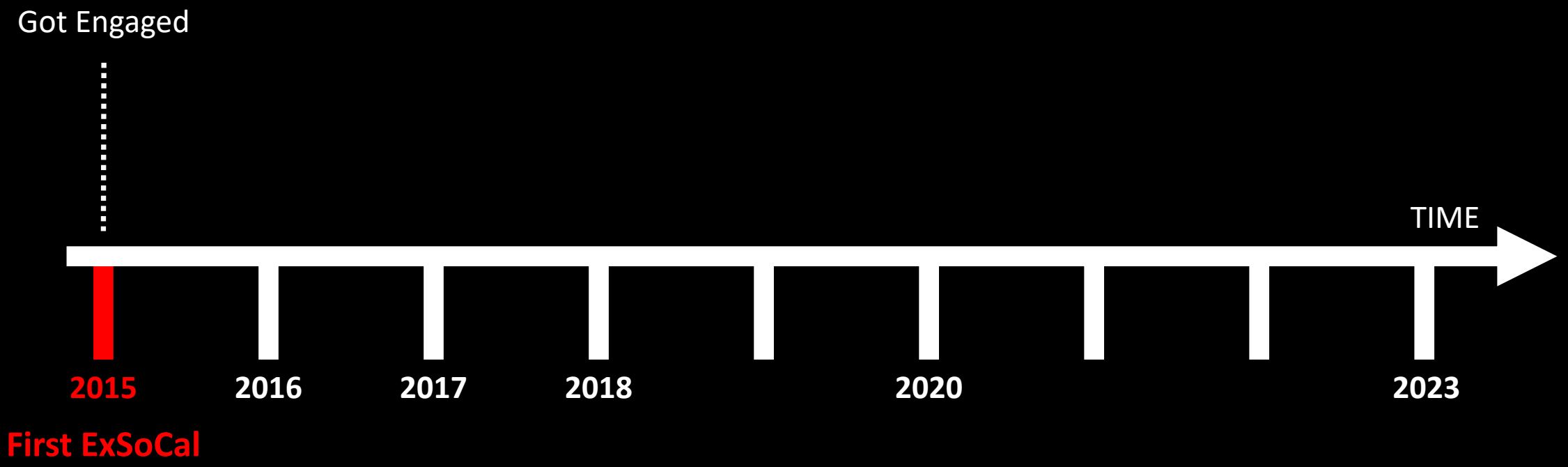
Two cold giants with high initial mutual inclination undergo oscillations in eccentricity and inclination, yielding a HJ.



JZ & ExSoCal: A Joint History



JZ & ExSoCal: A Joint History



JZ & ExSoCal: A Joint History

Got Engaged

TIME

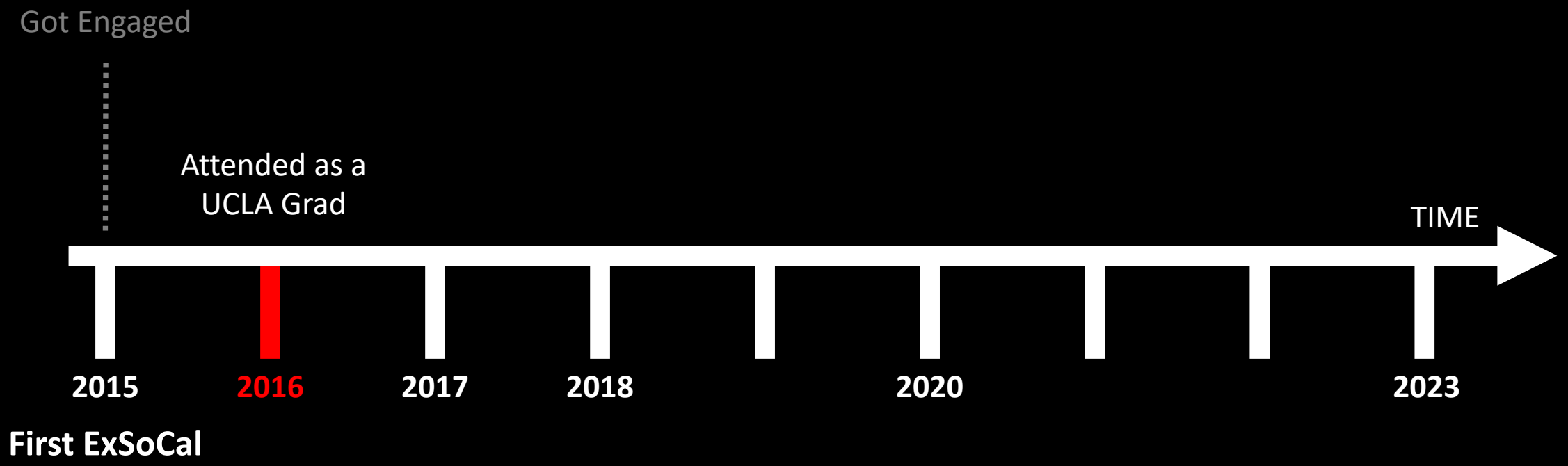
2015

First ExSoCal

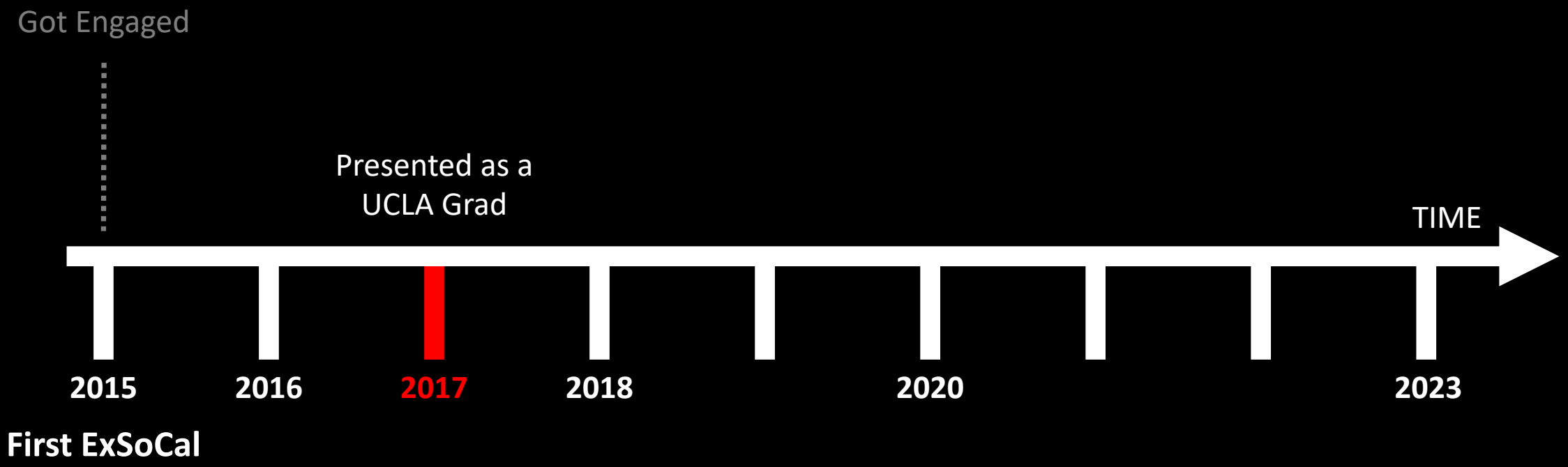
2016

2023

JZ & ExSoCal: A Joint History



JZ & ExSoCal: A Joint History



JZ & ExSoCal: A Joint History

Got Engage

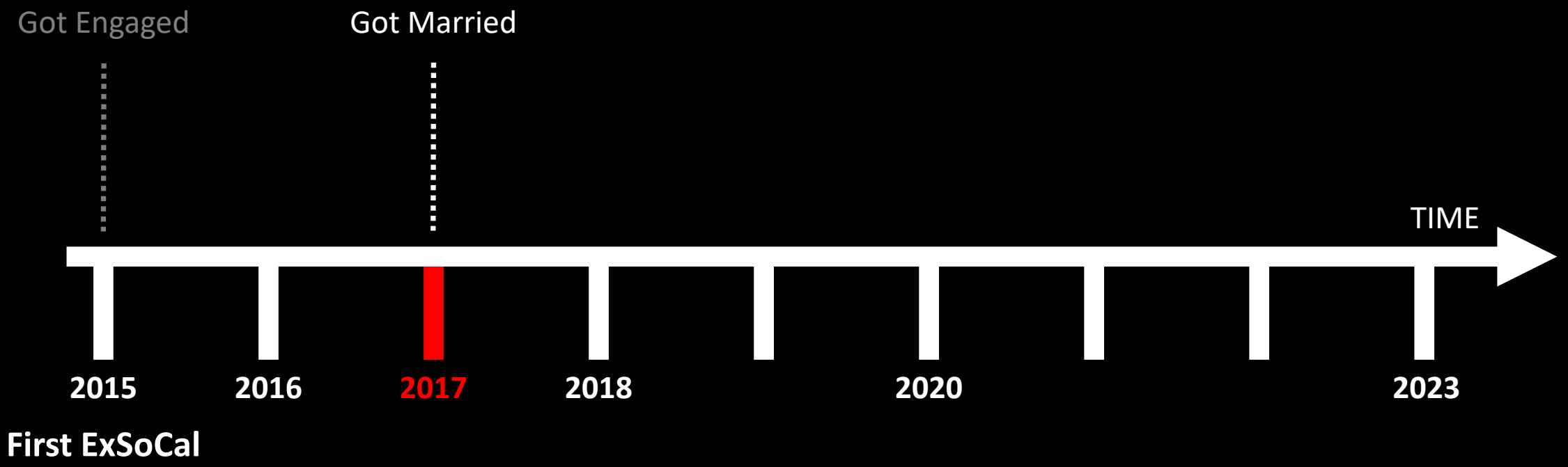
2015

First ExSoC

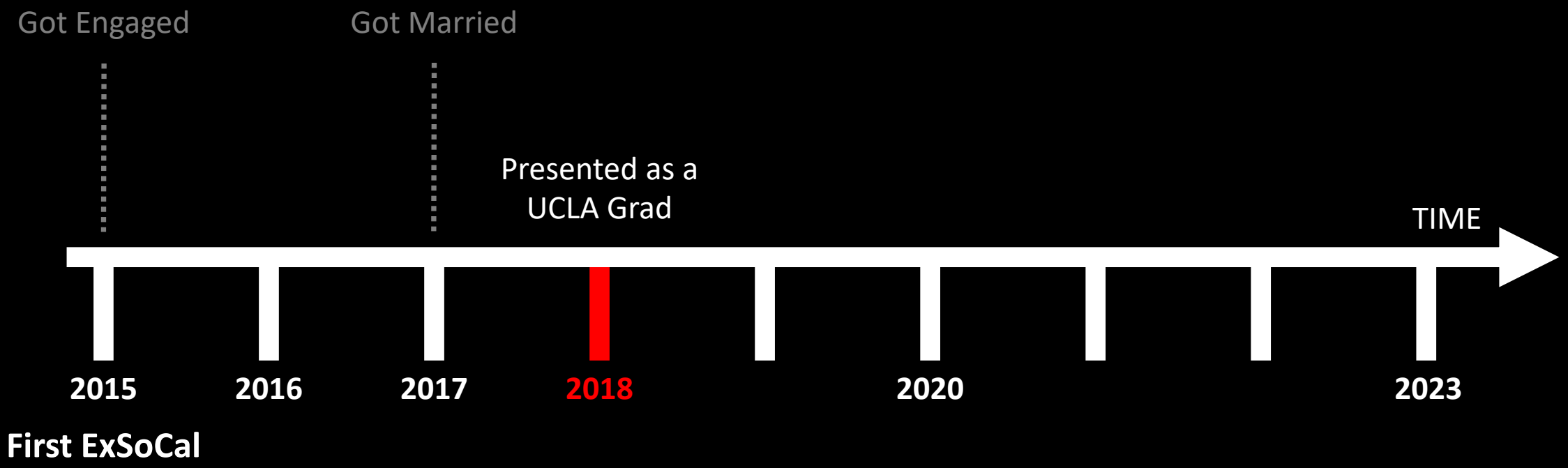
TIME

2023

JZ & ExSoCal: A Joint History



JZ & ExSoCal: A Joint History



JZ & ExSoCal: A Joint History

Got Engaged

2015

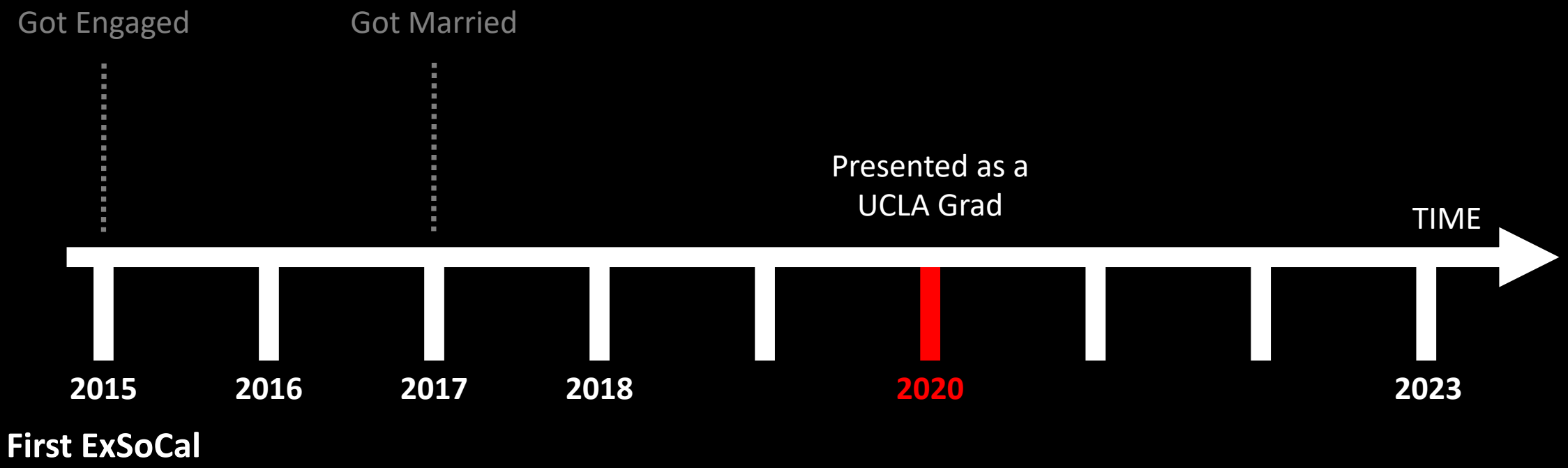
First ExSoCal

20

TIME

2023

JZ & ExSoCal: A Joint History

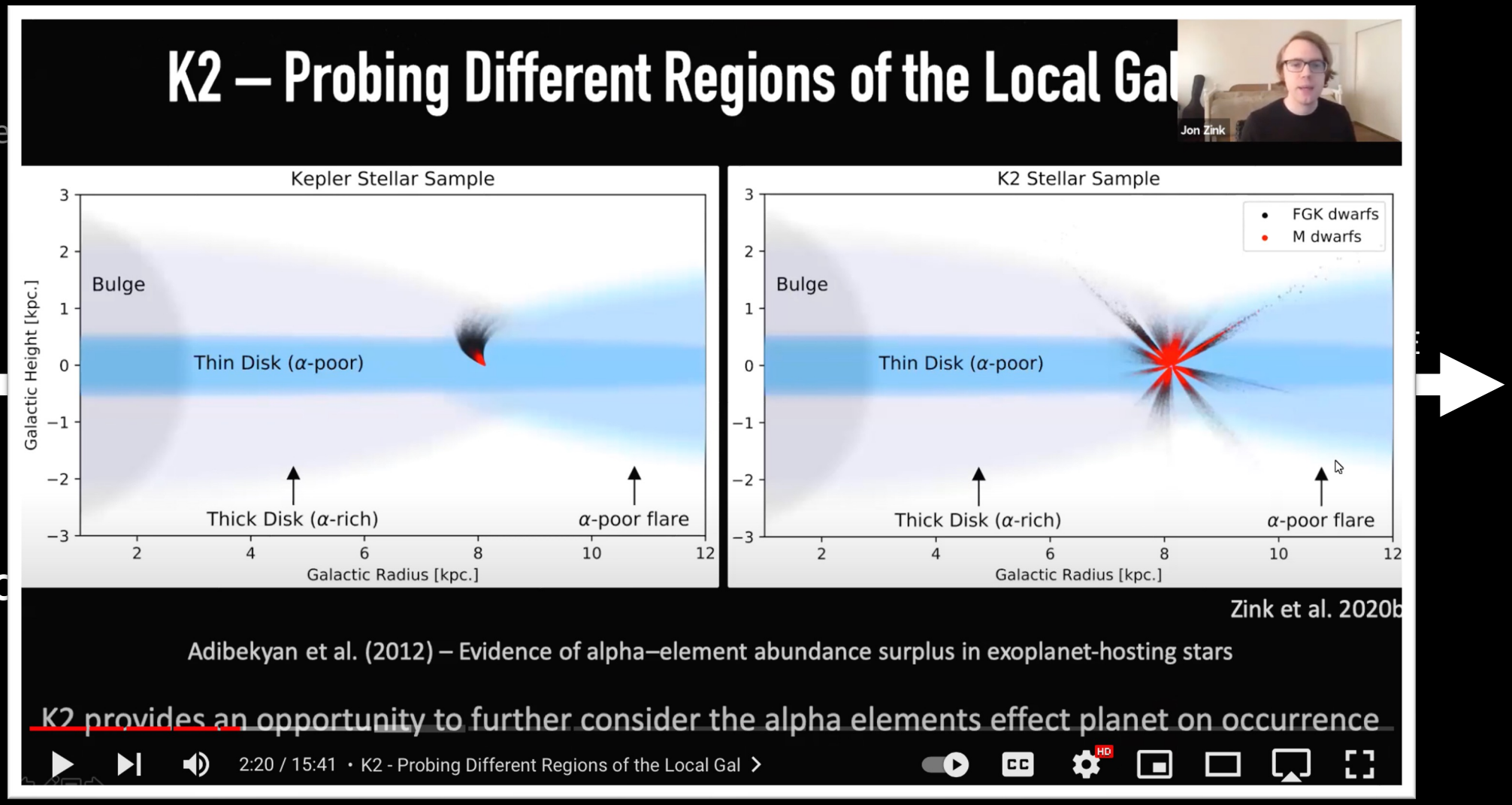


JZ & ExSoCal: A Joint History

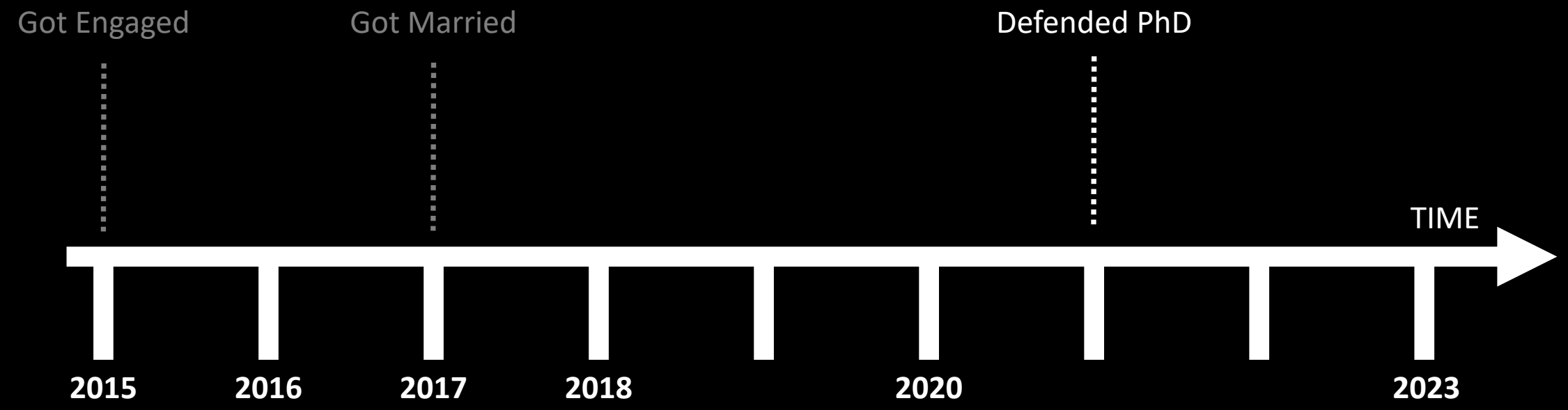
Got Engage

2015

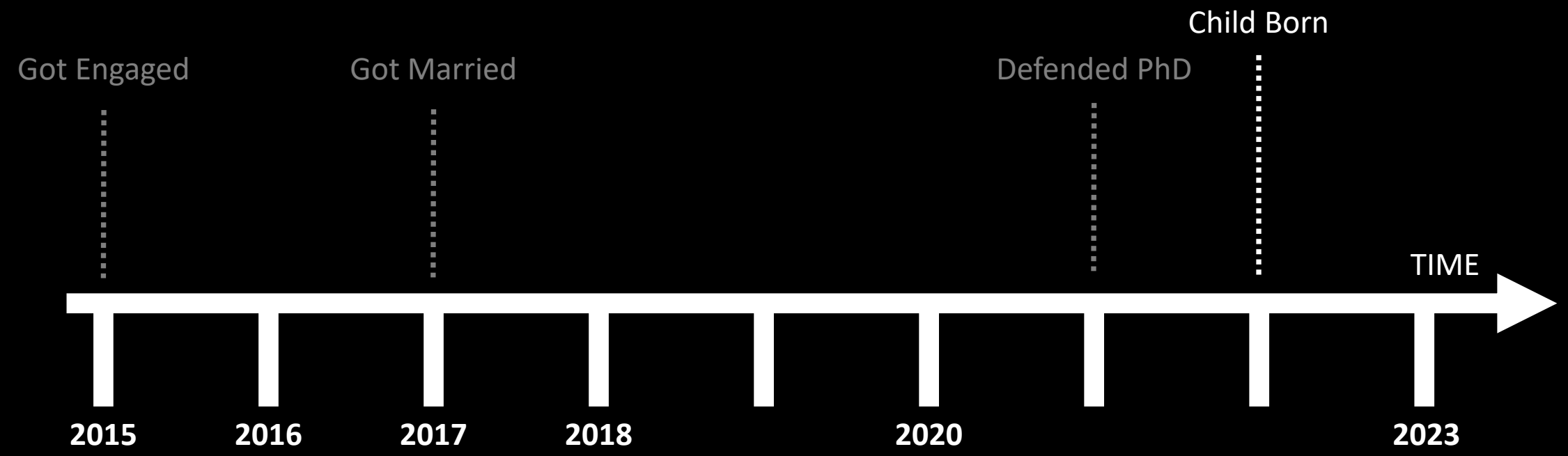
First ExSoC



JZ & ExSoCal: A Joint History

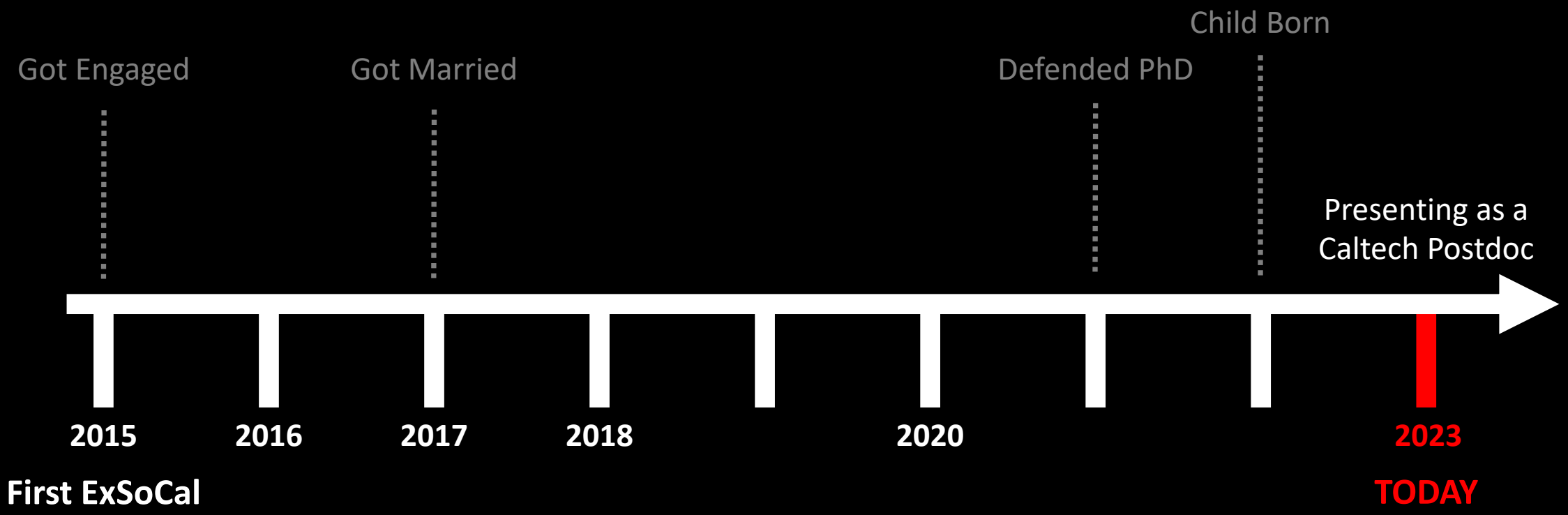


JZ & ExSoCal: A Joint History

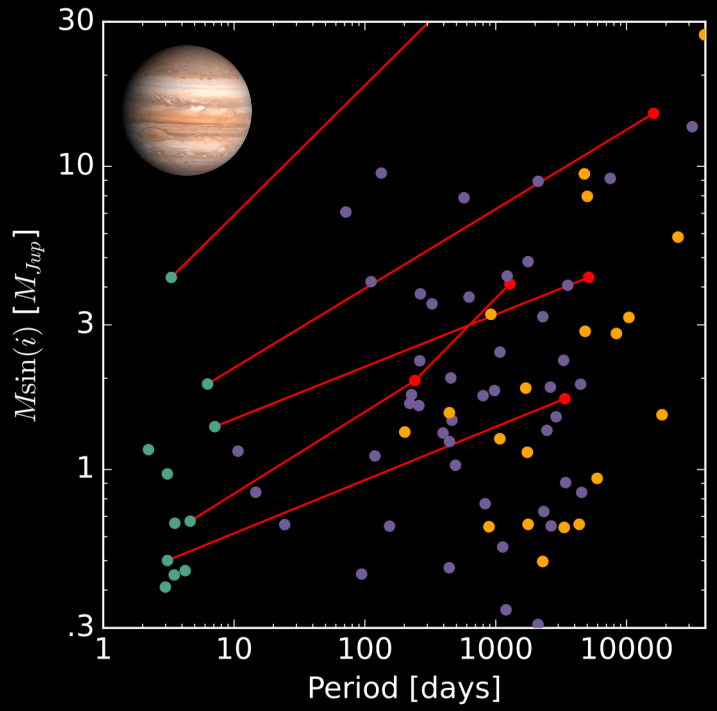


First ExSoCal

JZ & ExSoCal: A Joint History



Summary: DECODING HOT JUPITER SYSTEMS



Hot Jupiters have 3X more massive outer companions.

Thank you!