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

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ExSoCal

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51 Peg. b: A Nobel Worthy Planet

Mass = 0.5 \text{ } M_{\text{Jupiter}}

Period = 4.2 \text{ days}

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

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- 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
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~40,000 Days (110 years)
~23 AU
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 Companions per HJ
1.0 $\pm$ 0.3 Companions per WCJ
AVERAGE MASS RATIO
FOR EACH ARCHITECTURE

Warm/Cold Jupiter Systems

\[
\frac{M_{\text{outer}}}{M_{\text{inner}}} \sim 1
\]

Random Draw
HJs Require 3X Mass Companions

AVERAGE MASS RATIO FOR EACH ARCHITECTURE

Warm/Cold Jupiter Systems

\[ \frac{M_{\text{outer}}}{M_{\text{inner}}} \approx 1 \]

Random Draw

Hot Jupiter Systems

\[ \frac{M_{\text{outer}}}{M_{\text{inner}}} > 3 \]

Highly Order

Zink & Howard 2023
AVERAGE ECCENTRICITY FOR EACH ARCHITECTURE

Warm/Cold Jupiter Companions

\[ \langle e \rangle = 0.19 \pm 0.02 \]
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

\[ \langle e \rangle = 0.34 \pm 0.05 \quad 3\sigma \text{ Higher} \]
Formation Pathways:

**In-Situ** (Batygin et al. 2016)
HJs form within 1 AU and undergo minimal migration.
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Two cold giants with high initial mutual inclination undergo oscillations in eccentricity and inclination, yielding a HJ.
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JZ & ExSoCal: A Joint History

Presented as a CSUN Student

First ExSoCal
JZ & ExSoCal: A Joint History

- Got Engaged: 2015
- First ExSoCal
JZ & ExSoCal: A Joint History

Got Engaged

First ExSoCal

2015 2016 2023

TIME
JZ & ExSoCal: A Joint History

- 2015: First ExSoCal
- 2016: Attended as a UCLA Grad
- 2016: Got Engaged
JZ & ExSoCal: A Joint History

- 2015: First ExSoCal
- 2016: Presented as a UCLA Grad
- 2017: Got Engaged
JZ & ExSoCal: A Joint History

Got Engaged

Presented as a UCLA Grad

2015

First ExSoCal
JZ & ExSoCal: A Joint History

- **2015**: Got Engaged
- **2016**: Got Married
- **2017**: First ExSoCal
JZ & ExSoCal: A Joint History

- Got Engaged
- Got Married
- Presented as a UCLA Grad

First ExSoCal
JZ & ExSoCal: A Joint History

- Got Engaged
- Got Married
- Presented as a UCLA Grad
- First ExSoCal
- Some Planets are Lost Due to Injections
  - Start with 4,034 Kepler Candidates
  - Inject One Planet into Each System
  - Solar System Passed
  - One 2.99 Radio Candidates Returned
  - 69 Candidates are Lost
- Time Line: 2015, 2023
JZ & ExSoCal: A Joint History

- 2015: First ExSoCal
- 2016: Got Engaged
- 2017: Got Married
- 2020: Presented as a UCLA Grad
- 2023:
K2 — Probing Different Regions of the Local Galaxy

Adibekyan et al. (2012) – Evidence of alpha-element abundance surplus in exoplanet-hosting stars

K2 provides an opportunity to further consider the alpha elements effect on planet occurrence.
JZ & ExSoCal: A Joint History

- 2015: Got Engaged
- 2016: Got Married
- 2018: First ExSoCal
- 2020: Defended PhD
- 2023: Time
JZ & ExSoCal: A Joint History

- Got Engaged: 2016
- Got Married: 2017
- Defended PhD: 2020
- Child Born: 2023

First ExSoCal
JZ & ExSoCal: A Joint History

- 2015: Got Engaged
- 2016: Got Married
- 2017: First ExSoCal
- 2018: Defended PhD
- 2020: Child Born
- 2023: Presenting as a Caltech Postdoc

Today: JZ & ExSoCal: A Joint History
Hot Jupiters have 3X more massive outer companions.

Thank you!