EPSC Abstracts
Vol. 13, EPSC-DPS2019-396-1, 2019
EPSC-DPS Joint Meeting 2019


EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

# The Multiple Origins of Hot Jupiters

**Elizabeth Bailey (1)**, Konstantin Batygin (1), Smadar Naoz (2)
(1) California Institute of Technology, USA, (2) University of California, Los Angeles, USA (ebailey@caltech.edu)

## Abstract

Prior to the detection of Jovian exoplanets on several-day orbits [8], the notion that runaway core accretion of giant planets is permitted strictly beyond the snow lines of stars seemed to account satisfactorily for the arrangement of planets in our own solar system. Accordingly, the discovery that stars similar to the sun can harbor such an exotic planetary arrangement immediately begged for an explanation. The major result that followed was an extensive body of research dedicated to the mechanisms by which giant planets, having initially formed on several-au orbits in a manner similar to Jupiter, can become hot Jupiters through various possible modalities of long-range inward migration. More recently, it has been demonstrated [2] that the alternative scenario of in situ core accretion [4], where hot Jupiters form via core accretion at close-in distances similar to their present-day observed orbital radii, appears to be a viable mechanism for the production of these planets, and in fact can account for their semi-major axis - mass distribution [1]. While high-eccentricity migration is unlikely to account for the majority of the hot Jupiter population, the rare, highly eccentric planets that arise from this mechanism can encode planetary tidal evolution histories.

## 1. Introduction

Two overall mechanistic categories of long-range inward migration have been suggested as potential hot Jupiter formation pathways. In the case of disk-driven migration [7], the giant planet forms at an initial orbital radius of several au, then migrates inward by donating angular momentum to the protoplanetary disk. Moreover, in the scenario of high-eccentricity migration, the giant planet likewise forms on an initially wide orbit before some process, either scattering by a companion [3] or Lidov-Kozai evolution [10], excites the planet's eccentricity to the extent that significant tidal dissipation occurs at periastron passage, facilitating the planet's orbital decay. Following the discovery of hot Jupiters over two decades ago, the predominant

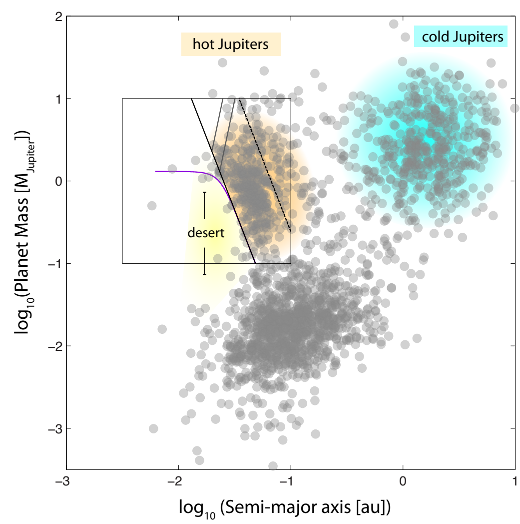


Figure 1: In the semimajor axis - mass diagram of observed exoplanets, the $a \propto M^{-2/7}$ power law [1] (black lines) shows empirical agreement with the boundary between the hot Jupiter population and the relatively unpopulated "desert," while tidal corrections appear to account for the hot Jupiters crossing this empirical boundary (purple line), as well as the truncated appearance of the population at higher mass range (grey lines).

view has been that these planets must form via long-range migration. However, in recent years, the alternate hypothesis–that many hot Jupiters may actually form via core accretion at close-in orbital radii similar to their presently observed locations–has gained newfound consideration.

## 2. In situ formation of hot Jupiters

### 2.1. The $a \propto M^{-2/7}$ power law as a signature of in situ formation

Recently, it has been shown [1] that the boundary of the hot Jupiters with the relatively unpopulated exoplanet "desert" [9] (Figure 1) can be explained as a manifestation of a power law $a \propto M^{-2/7}$ arising from considering the disk's magnetospheric truncation radius as the approximate innermost limiter of giant planet formation, together with the assumption that viscous accretion of the disk would supply material to an accreting hot Jupiter core. This power law, in conjunction with the change in magnetic truncation radius as the star contracts along the Hayashi track, appears to provide bounds that empirically agree with the most populated region of the hot Jupiter semimajor axis -mass diagram. Furthermore, tidal corrections to this law can further explain the shape of the hot Jupiter population. This work appears to provide evidence in favor of in situ formation as the dominant hot Jupiter formation pathway.

### 2.2. Fate of close-in companions to hot Jupiters

While a lack of observed close-in companions has been interpreted as evidence that hot Jupiters form via a different process than the so-called *warm* Jupiters, two observed systems, WASP-47 and Kepler-30, provide examples of hot Jupiters flanked by both interior and exterior massive companions. These companions can become misaligned due to a secular resonant mechanism [2, 14], which may account for the apparent "loneliness" of hot Jupiters. We will discuss the related behavior arising in the generalized case of multiple close-in super-Earth companions.

## 3. Dynamical implications of highly eccentric hot Jupiters

A small number of hot Jupiters have been found to reside on highly eccentric, close-in orbits with circularization timescales much shorter than the age of their system–an apparent smoking gun for the process of high-eccentricity migration. Although recent observations [5, 6, 11, 12, 13] appear to suggest that high-eccentricity migration is not the dominant formation channel, the exotic class of eccentric hot Jupiters produced by this means, due to the fact that they presently encode information about their orbital evolution histories, offers a window into the processes of tidal dissipation in giant planets. Specifically, eccentric exoplanets can reveal information about the tidal quality factor $Q$ in giant planets, for which the existing understanding has long suffered, in part, from a paucity of examples in our own solar system.

## References


[1] Bailey, E., Batygin, K.: The hot Jupiter period-mass distribution as a signature of in situ formation, ApJL, 866,1, 2018.

[2] Batygin, K., Bodenheimer, P. H., and Laughlin, G. P.: In situ formation and dynamical evolution of hot Jupiter systems, ApJ, 829, 2, 2016.

[3] Beauge, C. and Nesvorny, D.: Multiple-planet scattering and the origin of hot Jupiters, ApJ, 751, 2, 2012.

[4] Bodenheimer, P., Hubickyj, and Lissauer, J. J.: Models of the in situ formation of detected extrasolar giant planets, Icarus, 143, 2, 2000.

[5] Dawson, R. I., Murray-Clay, R. A., Johnson, J. A.: The photoeccentric effect and proto-hot-Jupiters. III. ApJ, 798, 2, 2014.

[6] Knutson, H., et al.: Friends of hot Jupiters. IV., ApJ, 827,1,2016.

[7] Lin, D. N. C., Bodenheimer, P., and Richardson, D. C.: Orbital migration of the planetary companion of 51 Pegasi to its present location, Nature, 380, 606, 1996.

[8] Mayor, M. and Queloz, D.: A Jupiter-mass companion to a solar-type star, Nature, 378, 355, 1995.

[9] Mazeh, T., Holczer, T., and Faigler, S.: Dearth of short-period Neptunian exoplanets: A desert in period-mass and period-radius planes, A&A, 589, A75, 2016.

[10] Naoz, S., Farr, W. M., Lithwick, Y., Rasio, F. A., Teyssandier, J.: Hot Jupiters from secular planet-planet interactions, Nature, 473, 187, 2011.

[11] Ngo, H., et al.: Friends of hot Jupiters. II., ApJ, 800,1, 2015.

[12] Ngo, H., et al.: Friends of hot Jupiters. IV., ApJ, 827, 1, 2016.

[13] Piskorz, D., et al.: Friends of hot Jupiters. III., ApJ, 814, 2, 2015.

[14] Spalding, C. and Batygin, K.: A secular resonant origin for the loneliness of hot Jupiters, AJ, 154, 3, 2017.