SAMPLE

Worlds Beyond Earth: Hot Jupiters

Exoplanets That Shouldn't Exist

Aira Astralis

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Introduction

The first planet found orbiting a sun-like star outside our solar system was nothing like the planets of our solar system. It was a gas giant, more massive than Jupiter, circling its star in an orbit of four days, so close that its year was shorter than our week and its surface, if the word applies, was heated to more than a thousand degrees. The discovery, announced in 1995, was a shock on two levels: the planet itself, a Jupiter in a place where Jupiter could not have formed, and the method of its finding, a wobble in the star's light so precise that many astronomers had doubted it could ever be measured. The class that planet founded, the hot Jupiters, remains the most extreme easily-detectable expression of the exoplanet revolution, and this book is their story.

Hot Jupiters are defined by the accident of their circumstances: gas giants, planets in the mass range of our own Jupiter and above, parked in orbits of a few days, ten to a hundred times closer to their stars than Earth is to the Sun. The closeness is the whole phenomenon. It makes them hot, dayside temperatures from a thousand to several thousand kelvins. It makes them bloated, their outer atmospheres puffed up by the stellar heat, some of them among the least dense objects known. It makes them fast, whipping around their stars in hours to days, and it makes them doomed, because the same tides that hold them in these orbits will eventually drag them in to be swallowed by their stars. A hot Jupiter is a planet on borrowed time, living out a brief, brilliant phase in a solar system's middle age.

The class matters to astronomy out of all proportion to its numbers. Hot Jupiters are rare, roughly one solar system in a hundred hosts one, but they were the first exoplanets found around sun-like stars, and they remain the easiest to find: the deep transit they cast across their star, the wobble they induce, the heat they radiate are all large signals. The exoplanet field's discovery machinery, its telescopes, its statistical methods, its atmospheric characterization techniques, was largely built on hot Jupiters, and every habitable-zone terrestrial candidate now rests on a toolkit the hot Jupiters paid for. The class is also the subject's best argument that other solar systems need not resemble ours: the discovery of 51 Pegasi's planet ended, in a single press conference, the assumption that giant planets always form far from their stars, and the field has spent three decades learning what else it had wrongly assumed.

This book takes the reader through the whole subject. It begins with the discovery's history, the decades of failed searches and the Swiss team's patient spectrography, and with the planet 51 Pegasi b itself. It explains the physics of why these planets should not exist where they do, and the

migration theories that explain how they got there. It covers their structure: the inflated radii puzzle, the interiors beneath the clouds, the dayside and nightside climates, and the winds that connect them. It follows their atmospheres as observed, from the first sodium detection through the modern transmission spectra and weather maps. It sets out the population: the occurrence rates, the period distribution, thelonely hot Jupiters and their odd companions, the tidal decay and the planets now observed falling into their stars. It ends with the open questions, the super-puffs and ultra-hot Jupiters, and the young systems where migration can be caught in the act.

A note on the numbers the reader will meet: the class's periods run from about one day to ten, the orbital distances from two to twenty stellar radii, the masses from half a Jupiter to beyond ten, the dayside temperatures from a thousand to more than four thousand kelvins, and the radii from smaller than Jupiter to nearly twice its size. Every one of these numbers, taken alone, describes an object unlike anything in the solar system, and the reader who keeps the solar system's scale as a baseline, Jupiter at five astronomical units, a thousand-kelvin difference between one side of a planet and the other, will feel the class's extremity at every step of the chapters that follow.

The reader should hold one number as the frame for everything that follows: the hot Jupiters are the exoplanet field's laboratory. Their atmospheres are the brightest planetary signals in the sky after our own planets, their transits are the deepest, their wobbles the largest, and their orbits the shortest, which means a season of observing yields more data on a hot Jupiter than a decade yields on a colder, smaller world. The class's hundreds of known members are the sample on which the field's techniques are calibrated, and the reader who understands the hot Jupiters understands the machinery of exoplanet science itself.

The last framing idea belongs to the oddity the class embodies. Our solar system is ordered: small planets inside, giants outside, everything in neat near-circles. The hot Jupiters are the proof that this order is a local custom, not a law, and their existence, explained by migration, implies that solar systems are dynamic places, that planets wander, and that the arrangement we grew up in is one snapshot of a much more turbulent possibility space. The hottest planets in the galaxy are, in this sense, the field's founding lesson in humility, and the book that follows is the lesson's full curriculum.

Chapter 01: The Discovery

The search for planets around other stars is older than the technology that eventually succeeded at it, and the discovery of the first hot Jupiter belongs to a history of claims, retractions, and patience that deserves its own telling.

The early claims were made from astrometry, the measurement of stars' positions. The nearest stars, if they hosted planets, would wobble on the sky in tiny loops, and the nineteenth and early twentieth centuries produced several announced detections, including a famous companion to Barnard's Star, that did not survive scrutiny: the signals were at the edge of the instruments' capability and, in the end, below it. The pulsar planets, found in 1992 by timing the radio pulses of a dead star, were genuine, and they hold the technical title of first confirmed exoplanets, but they orbit a stellar remnant, and their relevance to sun-like planetary systems was limited.

The prize, a planet around a normal star, went to the Doppler method. A star with an orbiting companion is pulled around the system's center of mass, and its light is alternately blue-shifted and red-shifted by the wobble; the shift, for a Jupiter-mass planet at Jupiter-like distances, is a few meters per second, a walking pace, measurable as a tiny periodic shift in the star's spectral lines. The technique required spectrographs of extreme stability, calibration lamps of extreme precision, and years of patience, since a true Jupiter at a Jupiter distance takes twelve years to complete one measurable cycle.

The Swiss team, Michel Mayor and his young colleague Didier Queloz, ran a spectrograph at the Observatoire de Haute-Provence and was not specifically hunting hot Jupiters, because nobody knew they existed. They were surveying nearby sun-like stars for Jupiter analogs, and their strategy, checking each star frequently, was well suited to short-period signals should any appear. In the summer of 1995, they found one: the star 51 Pegasi, a near twin of the Sun at fifty light-years, was wobbling with a four-day period and an amplitude implying a companion of at least half a Jupiter mass. The team checked everything: stellar activity, rotation, the instrument. The signal held, and in October 1995 they announced it.

The skepticism earns a separate paragraph, because it was rational. Four-day periods were a known artifact: close binary stars, star spots, stellar pulsations, and the orbit of the star itself could all mimic a short-period wobble, and the early decades' false alarms had made the community careful. The Swiss team's own checks, and the Californian team's independent data, closed the list, and within a year the planet was uncontested. The community's rapid acceptance, though, owed as much to theory as to data: within months, the

migration papers appeared, and by the time the object was confirmed the theorists had already explained how it got there, a reversal of the usual order that set the tone for the field.

The announcement was received with justified skepticism, quickly overcome. Within days, a team in California confirmed the signal with their own data, and the planet, 51 Pegasi b, entered the canon. The discovery earned the 2019 Nobel Prize in Physics, shared between Mayor, Queloz, and the theorist Jim Peebles, and the citation's phrasing, the first discovery of an exoplanet orbiting a sun-like star, marks the event the field counts as its beginning.

The planet itself earns a separate paragraph, because it remains the class's type specimen. 51 Pegasi b orbits its star at a twentieth of the Earth-Sun distance, with a period of 4.2 days, and its minimum mass, the Doppler method's inherent limitation, is half a Jupiter. Its equilibrium temperature is above a thousand kelvins, its atmosphere, by all modeling, is a hot hydrogen-helium envelope over an unknown core, and its discovery provoked an immediate theoretical crisis: no one had a theory by which a giant planet could form there, and the resolution of that crisis, migration, is the subject of the next chapter.

The naming deserves a sentence, since the class's name was an argument. The planet's discoverers called it a companion of a sun-like star, the community quickly settled on a gas giant by mass, and the name hot Jupiter, coined in the discovery's first year, was a coinage that carried a claim: the object is a Jupiter, the familiar planet, and only its location is strange. The name's comfort was strategic, an anchor for a disorienting discovery, and the class's whole subsequent history, the inflation and the winds and the doom, is the account of how the familiar planet, moved to unfamiliar circumstances, became an unfamiliar object after all.

The aftermath transformed the field. Within five years, the Doppler surveys had found dozens of planets, and the period distribution that emerged was dominated by short periods, a selection effect, since short-period signals are found fastest, but also a genuine population: hot Jupiters and their slightly cooler cousins, the warm Jupiters, were the early harvest, and their abundance forced the theorists to rebuild planet formation from the ground up. The reader should hold the chronology in mind: the first planet found was an object the theory said should not exist, and the theory, not the observation, was what had to change.

The discovery chapter closes on the mood it ended. Before the first hot Jupiter, the field's working picture of other solar systems was a copy of the home one, small rocky worlds inside, gas giants at a polite distance, and the search

programs were designed, quite literally, to find what they already believed; the first result instead found what nobody was looking for, and the reader should sit with the fact that the first planet found around a star like the Sun was one the standard theory of the time said could not exist. The chapters that follow are the story of how a science absorbed that shock, and the class it centers on is the standing reminder that a census of the unknown must be built for the universe as it is, not as it is drawn.

The discovery's aftermath also deserves its editorial note, on what the first find did to the search itself. The surveys that followed were tuned to the finding's example, short orbits, large masses, sun-like stars, and for years the known population was dominated by more of the same, a selection effect baked into the observing programs, with the quieter planetary systems, the small, the slow, the far, remaining invisible until the techniques matured. The parting observation is that the first hot Jupiter did not open a window so much as it opened one window, and the field spent its next decade climbing through that one before the wider views arrived.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.