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Transiting “Hot Jupiters” near the Galactic Center

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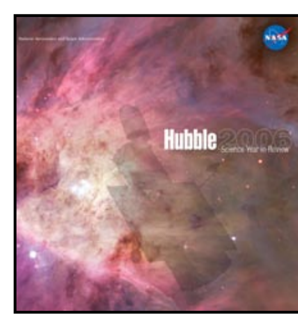

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Transiting "Hot Jupiters" near the Galactic Center

Kailash C. Sahu

Hubble has found 16 new planetary candidates orbiting a variety of stars near the center of our Milky Way galaxy. These discoveries are helpful in understanding the surprising phenomenon of "hot Jupiters" in a wider context.

In the mid-1990s, Swiss astronomers Michel Mayor and Didier Queloz regularly observed the Sun-like star 51 Pegasi for months, measuring its speed along the line of sight. They found the speed varied periodically by about 130 miles per hour, repeating every 4.2 days. After ruling out other possible explanations, they concluded this "wobbling" was due to an unseen planetary companion, whose gravity was tugging on 51 Pegasi as it orbited the star. The inferred mass was like Jupiter's, but the orbital distance was only one twentieth the distance between the Earth and Sun! Being so close to the star, this planet is expected to be hot, and according to conventional wisdom, such a hot Jupiter should not exist. No theory of star and planet formation envisions enough material to build a Jupiter-size planet so close to a young star—yet here one exists. It must have migrated inwards after forming farther out.

In the decade since the planet around 51 Pegasi was discovered, astronomers have been actively searching for more. More than 200 extrasolar planets—10% are hot Jupiters—have been detected now, mostly through this gravitational wobble in the star's motion. The wobble technique is not practical at larger distances, however, because of the increasing faintness of the stars. For this reason, no planet detected by wobble is located farther than 500 light-years from the Sun—less than 1% of the distance across our galaxy.

"Transits" offer a technique to search for planets around more distant stars. In rare cases, when a planet's orbital plane is aligned with the line of sight, the planet will pass in front of its star once per orbit, blocking some of its light. Astronomers

A notable recent example of a planet transiting the face of a star was the passage of Venus across the disk of the Sun on June 8, 2004. This image shows the planet as it nears completion of its passage. Recording the tiny drop in light that results from a planet partially blocking its star is how *Hubble* can detect Jupiter-sized planets. (Image and processing: David Cortner)

A color composite of a small region of the Sagittarius Window Eclipsing Extrasolar Planet Search (SWEEPS) field, which includes four candidates for stars with planetary companions (circled). Radial velocity measurements support the existence of a planetary companion in the case of SWEEPS–04 (bottom right). Superimposed is an artist's conception of a hot Jupiter, which shows tidal distortion of the planet and channeling of the stellar wind along magnetic field lines.

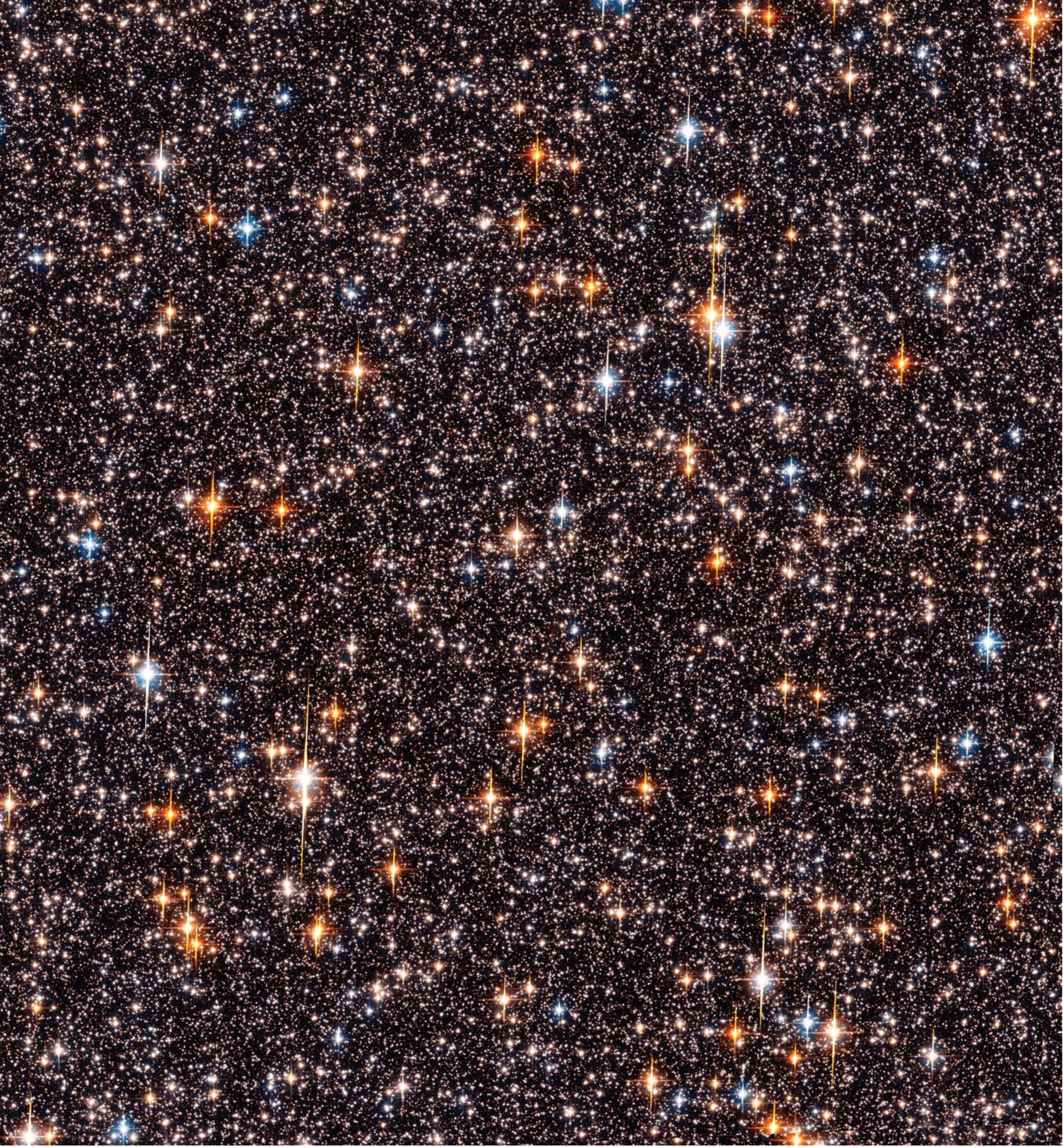
can identify transiting planets by searching for this tiny dip in the apparent brightness of the star. With this technique, astronomers using ground-based telescopes have found a handful of planets around stars as far away as 6,000 light-years from the Sun; more are expected from the many transit surveys now underway at observatories around the world.

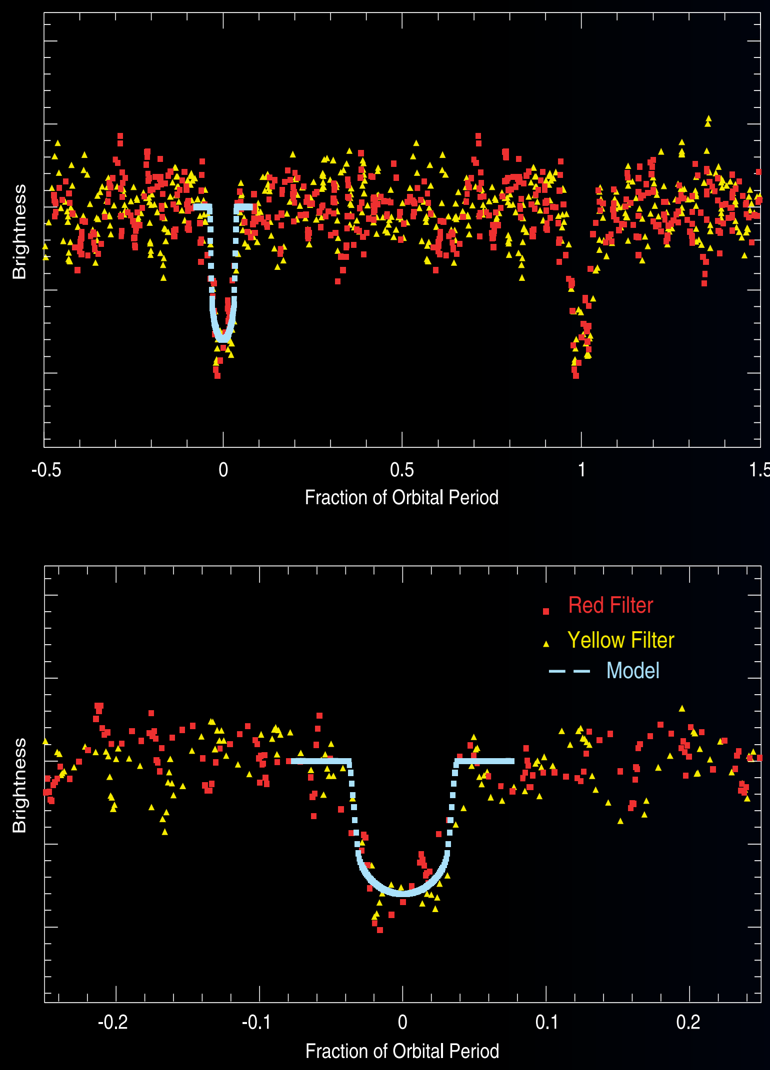
Because of its unique capabilities, a transit campaign with *Hubble* is exceptionally powerful. Operating above the atmosphere, free from most of the effects that make stars appear to flicker in brightness, *Hubble* can search farther and fainter stars for planetary transits, detecting smaller changes in brightness than is possible from the ground. Furthermore, the ground-based transit experiments suffer from false positives—artifacts masquerading as planetary transits—because of the inability to completely separate the light of adjacent stars in crowded fields. Only *Hubble* can search for transits in crowded fields—like the bulge at the center of our galaxy—which are the most desirable targets because of the increased efficiency of searching many stars at once. For such fields, the high spatial resolution of *Hubble* is crucial for minimizing false positives.

The Sagittarius Window Eclipsing Extrasolar Planet Search (SWEEPS) program searched a dense star field close to the galactic center, looking for transits by orbiting planets with periods less than about four days. The SWEEPS field contains about 300,000 stars, about 60% of which are bright enough for *Hubble* to detect transits by planets the size of Jupiter. (These stars are up to 5,000 times fainter than those that have been searched for transits from the ground.) *Hubble* took 530 pictures of the star field, collecting over 100 gigabytes of data—the most data *Hubble* has ever obtained in a single week.

The observing team developed special software to measure the brightness variations of all the stars in the SWEEPS images, being careful to correct all known instrumental effects, such as small variations in the focus of the telescope. To eliminate false positives, the definite signature of a transit was sought: the light from the star must dip down slightly for a few minutes or hours, with the same variation in two wavelength bands, and then recover at the same rate as the initial dip. A few hours or days later, the same signature must repeat. Furthermore, these dips must be unique to one star and not occur at the same time in any neighboring star, which would indicate cross-contamination of light.

Next Page: One-half of the SWEEPS field observed with *Hubble*'s Advanced Camera for Surveys. Sixteen of the 180,000 stars in the SWEEPS field showed small dips in brightness during the week of observations. The dips suggest that a planet about the size of Jupiter passed between us and the star.





Observed light curve of SWEEPS–11 with clear evidence of a transiting planet with a radius of 30% larger than Jupiter. The top panel shows the full data set plotted against the fraction of the derived orbital period. The bottom panel shows an expanded view around the transit itself, along with the theoretical prediction (in light blue) for the shape of a dip that would be caused by a planetary object. The fit is excellent, and confidence in the interpretation is high. Radial velocity observations, obtained with the 8 m Very Large Telescope of the European Southern Observatory in Chile, supports the planetary nature of SWEEPS–11.

Analyzing the data with this software, astronomers found 16 cases where dips in brightness are probably due to planetary transits. The candidate planets are typically the size of Jupiter and have orbital periods ranging from 10 hours to 4 days. A large fraction of the host stars have low mass, the lowest being 45% that of the Sun. Previously, astronomers did not know if stars of such low mass were capable of forming planetary systems; *Hubble* has now proved they can.

The planet candidates preferentially revolve around stars abundant in elements heavier than hydrogen and helium, which confirms a previous finding from stars found with planets in the solar neighborhood: heavy-element abundance favors planetary formation.

Because of the faintness and crowding of the targets, most of the SWEEPS candidates cannot be confirmed by the wobble technique. Nevertheless, the wobble technique was successfully applied to two of the brightest candidates, which further confirmed the planetary nature of these candidates. This strongly supports the estimate that at least 45% of the SWEEPS candidates are genuine planets.

A few of the planets orbit so fast that their year—the time for one complete revolution around the star—is less than 24 hours. These ultra-short period planets occur only around stars less massive than the Sun. One possible explanation is that any planet orbiting so close to more massive stars—which are much hotter and brighter—would get so hot that it would evaporate. If so, a future search around younger stars should find hot Jupiters before they evaporate.

Hubble has contributed important new information on extrasolar planets. It has confirmed that conditions for planet formation are more favorable around stars with a greater abundance of heavy elements, and that planets not only form and survive around all classes of stars, but their occurrence rate is similar all across the galaxy.

Kailash Sahu is an Associate Astronomer at the Space Telescope Science Institute. He is an instrument scientist for the Advanced Camera for Surveys. His research interests include the search for extrasolar planets through transits and microlensing, the nature of dark matter, and gamma-ray bursts. He is a founding member of the Probing Lensing Anomalies NETwork (PLANET) collaboration, which searches for planets using gravitational microlensing, and he is the Principal Investigator of the SWEEPS project which uses *Hubble* to detect planets passing in front of stars in the galactic bulge.

The constellation of Sagittarius provides a virtual treasure chest of stars to search for possible planets. This *Hubble* image is of a different but similar section of sky to the Sagittarius Window Eclipsing Extrasolar Planet Search (SWEEPS) field described in this article.