Hot Jupiters on the Move: Exploring Tidal Orbital Decay

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BACKGROUND

Hot Jupiters are massive planets that orbit close to their host stars at distances of ~0.01-0.3 au. Theory suggests that due to their proximity to their host star, the orbits of Hot Jupiters should slowly shrink (also known as orbital decay). By detecting orbital decay, we can learn more about the stellar structure of the host star by calculating the tidal quality parameter ($Q'_\star$) which determines the rate of tidal orbital decay. This effect, so far, has only been observed for the exoplanet WASP-12b.

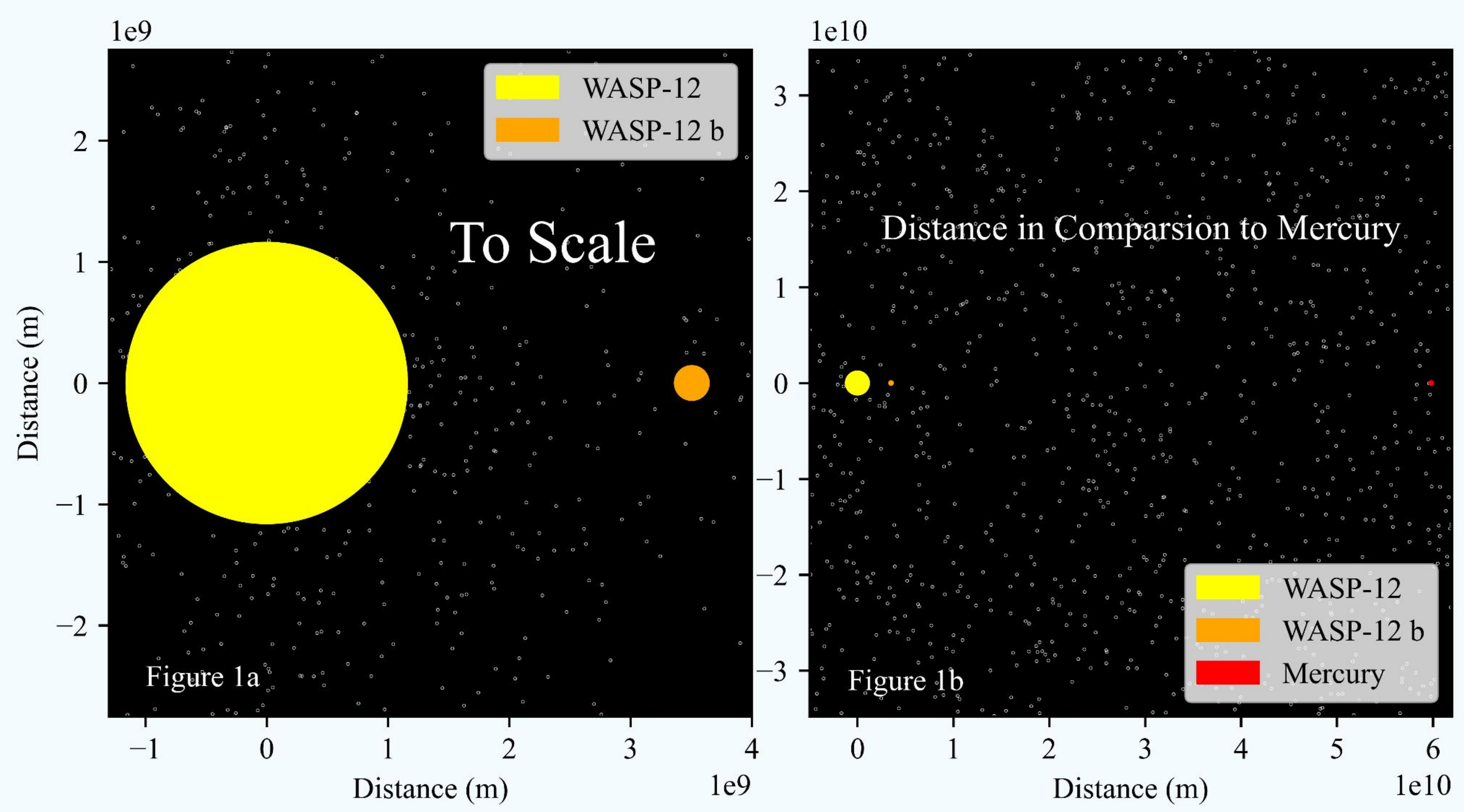


Figure 1a: To-scale diagram of the WASP-12 system.
Figure 1b: Same as Figure 1a but with Mercury included. Note that Mercury would be smaller than 1 pixel on this scale.

RESULTS

To model a light curve, we use several free parameters, including mid-transit time (t_0), impact parameter ($b=acos(i)/R_\star$), scaled ratio of stellar radius ($R_\star/a$), and planet-to-star radius ratio (Mandel & Agol 2002). A linear function with two free parameters accounts for airmass, while we hold the period and the quadratic limb darkening coefficients fixed. We use quadratic limb darkening coefficients from Claret & Bloemen's tabulated values (2011), interpolated using Eastman et al.'s code (2013). To determine the best-fit parameters, we employ emcee, an affine invariant Markov Chain Monte Carlo (MCMC) ensemble sampler (Foreman-Mackey et al. 2013).

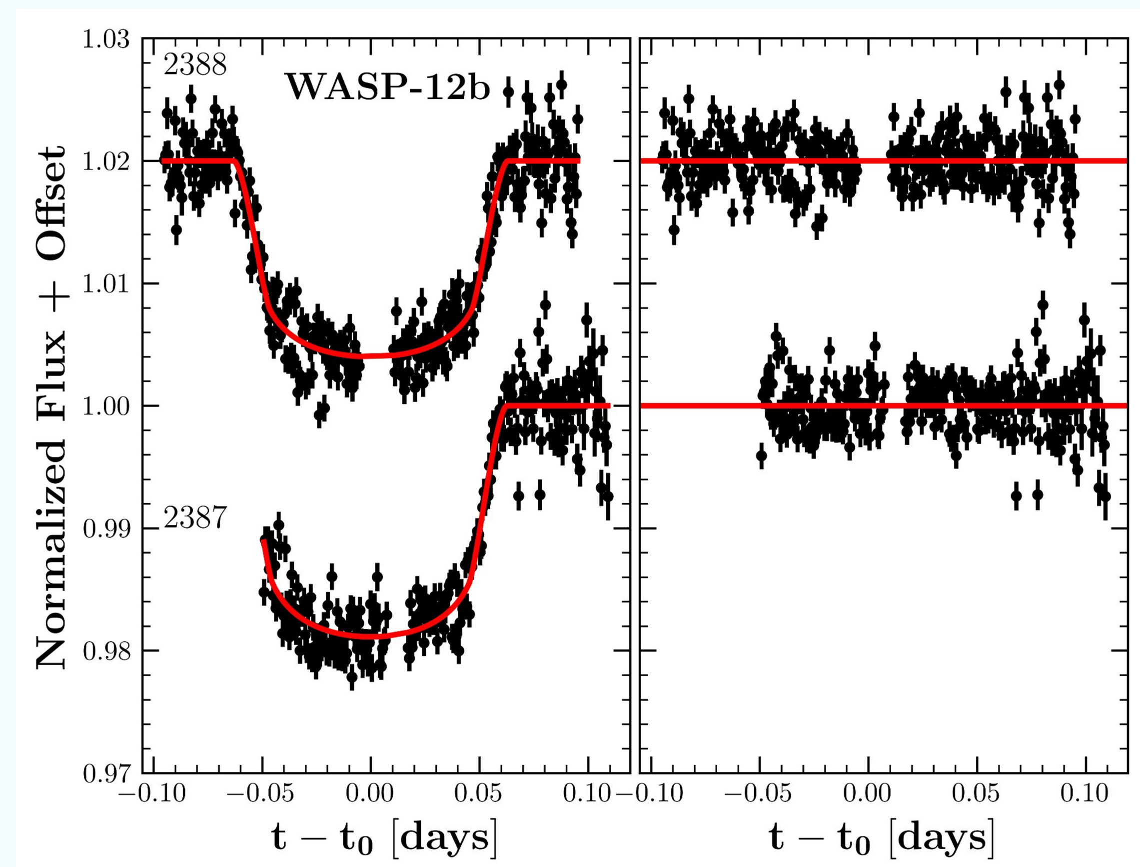


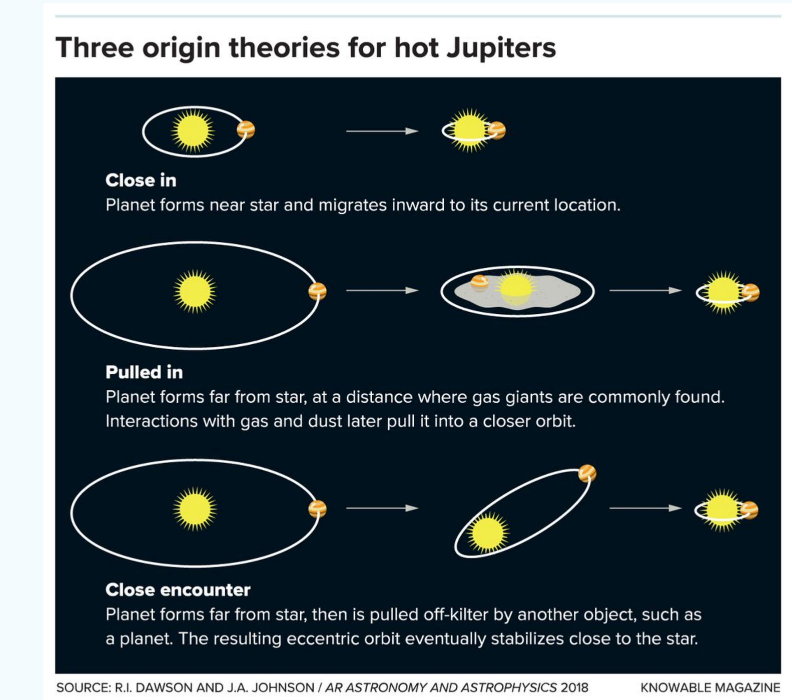
Figure 3: Each data point is an exposure. We fitted the theoretical model (red) to the data. The epoch number is on the left-hand side of the panel. In the panel to the right, we present the residuals showing the goodness of fit.

CONCLUSION

$$\frac{dP}{dt} = -\frac{27\pi}{2Q'_\star}\left(\frac{M_P}{M_\star}\right)\left(\frac{R_\star}{a}\right)^5$$

We have detected orbital decay for WASP-12b at a rate of (-29.78±1.21 ms/yr), and have found $Q'_\star$ to be 1.7×10^5. Currently, the prevalence of orbital decay among Hot Jupiters is unknown. By constraining $Q'_\star$, we can gain deeper insights into the internal structure of stars and advance our understanding of the formation mechanisms of Hot Jupiters. Therefore, this study highlights the critical role played by observations of orbital decay in unraveling the dynamic evolutionary processes of exoplanet systems.

Figure 5: These are current theories on how Hot Jupiters form. Understanding the dynamics of these systems is crucial for making accurate predictions about planetary formation.



METHODS/ DATA ACQUISITION

Our plan to detect orbital decay of WASP-12b involves obtaining light curves to calculate the mid-transit time. We then compare our data with past mid-transit times against two models: one with a constant period and another that takes into account a small change in the orbital period.

Observations were conducted using the 1-m Nickel Telescope at Lick Observatory. Each transit lasted roughly 3 hours (2.928 hrs), with each exposure recorded every 20 seconds, resulting in over 300 exposures each night. We calibrated the images and performed aperture photometry on our target star using AstroImageJ (AIJ).

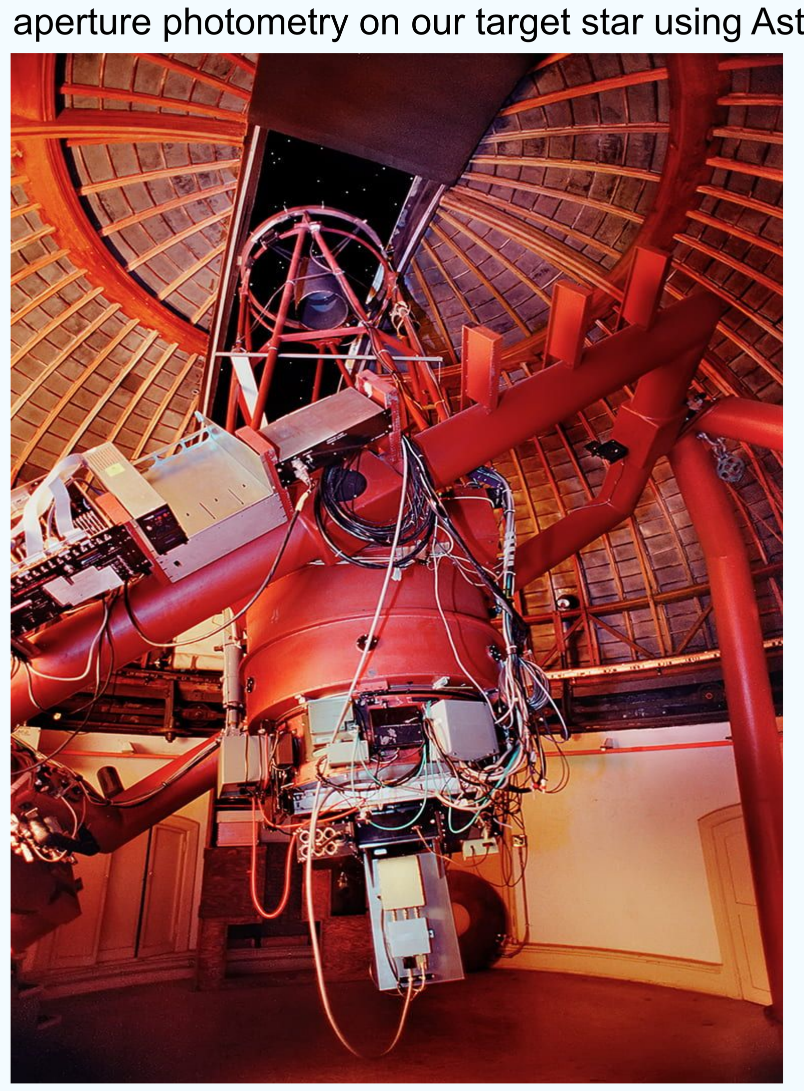


Figure 2a: The 1-m Nickel Telescope at Lick Observatory. Image by Laurie Hatch.

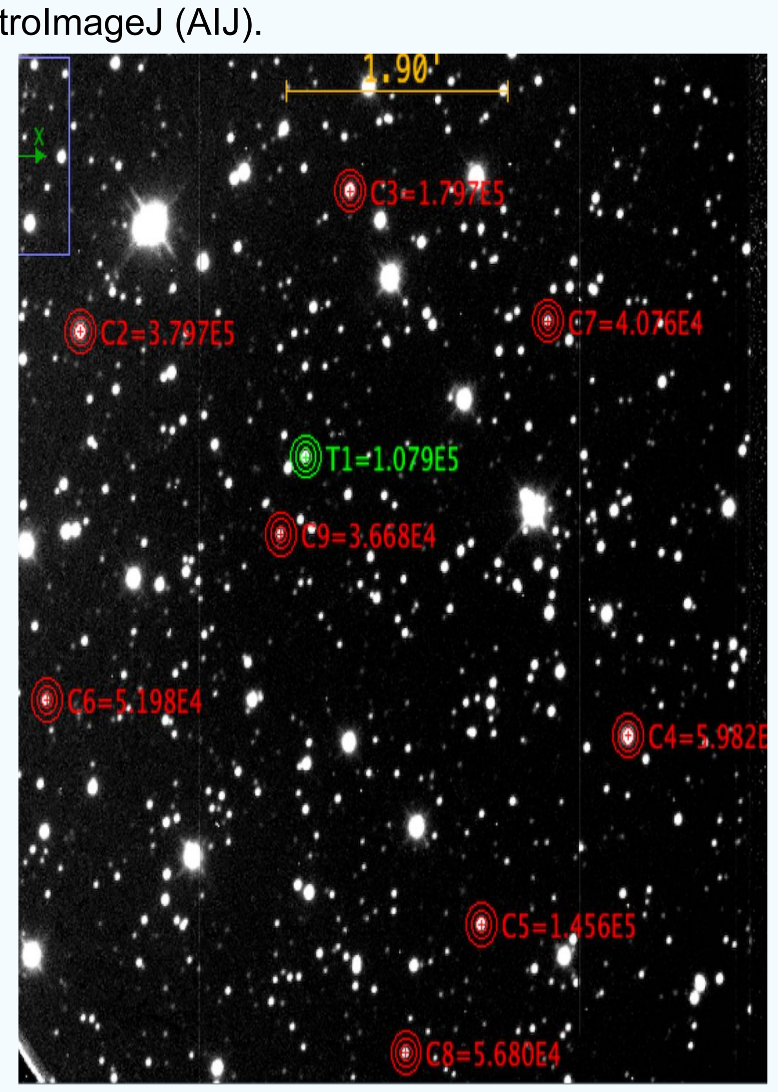


Figure 2b: One of the 300 exposures of the night. Performing aperture photometry on AIJ.

DISCUSSION

We performed a joint analysis of our data and transit times from past literature using MCMC to fit two models: a constant period model and an orbital decay model. The mid-transit time (t_0), period (P), and the rate of change in period (dP/dt) were treated as free parameters. Residuals were plotted to assess the goodness of fit of the models to the data.

$$\textbf{Constant Period: } t(E) = t_0 + PE$$

$$\textbf{Orbital Decay: } t(E) = t_0 + PE + \frac{1}{2}P\frac{dP}{dt}E^2$$

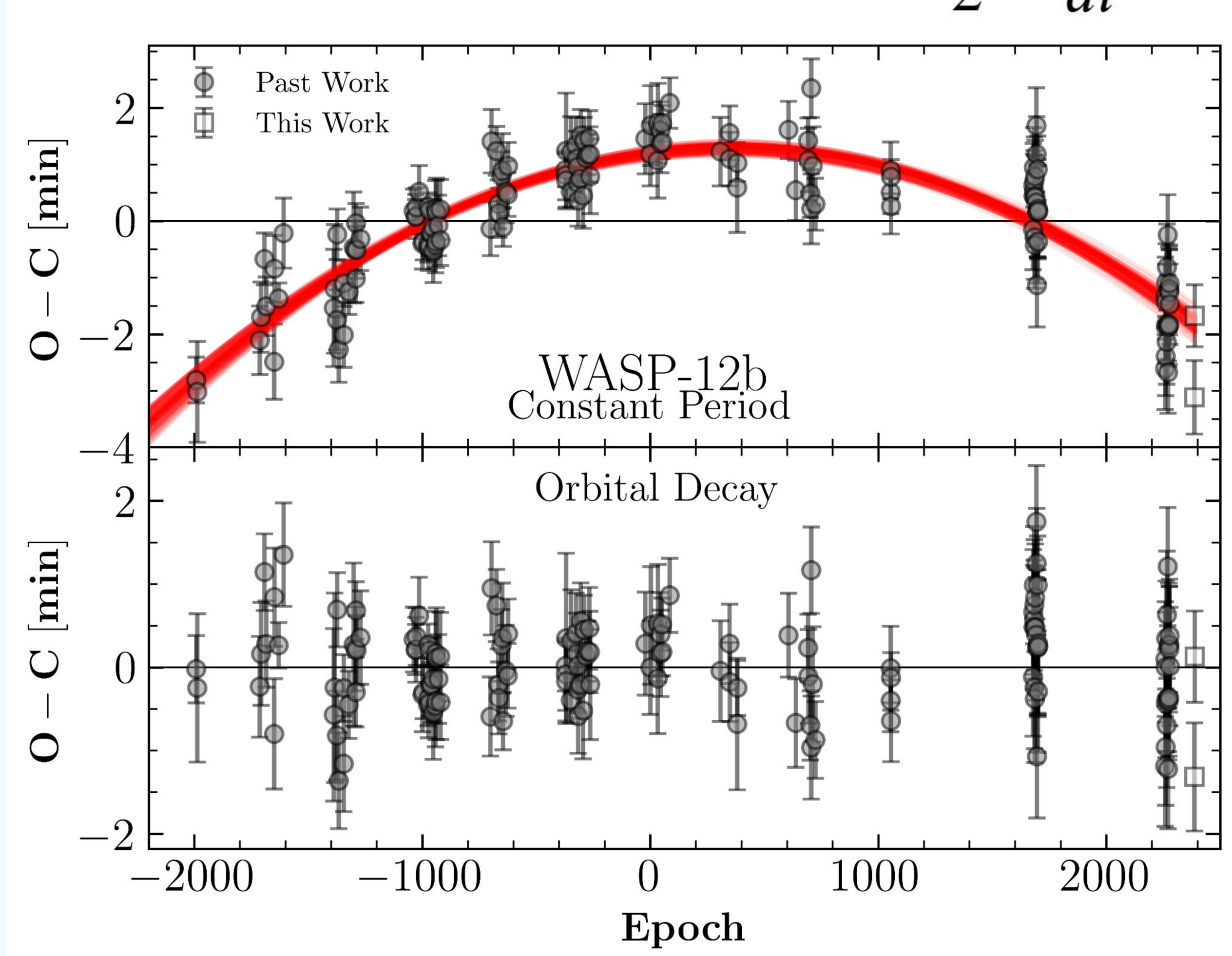
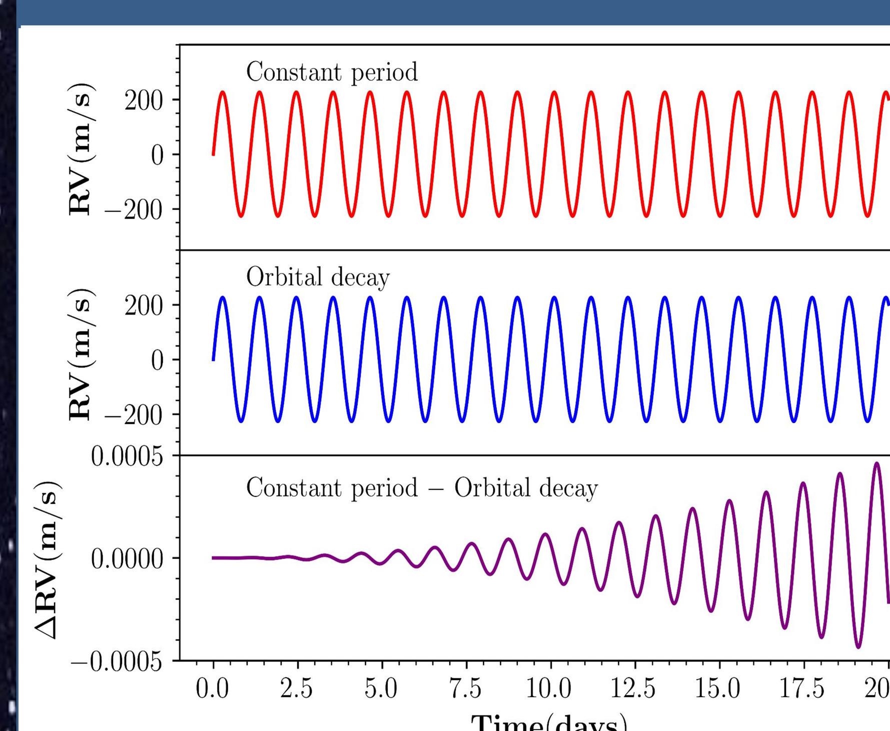


Figure 4: The top panel shows transit times subtracted from the constant model. The red curves represent 1σ uncertainty in the orbital decay model. The bottom panel accounts for a quadratic trend which shows a good fit for the data.

FUTURE WORK



- We have a proof of concept for fitting radial velocity data that considers orbital decay.
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- We would like to acquire more transits in hopes of detecting acceleration orbital decay.
- We will try to expand this study to multiple Hot Jupiter systems.

Figure 6: Small changes due to orbital decay are hard to see. Radial-velocity fitting would provide a different method to detect tidal orbital decay.

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CITATION/ LinkedIn

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