Jet Propulsion Laboratory
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Generation of self-consistent exoplanet parameters using heterogeneous data

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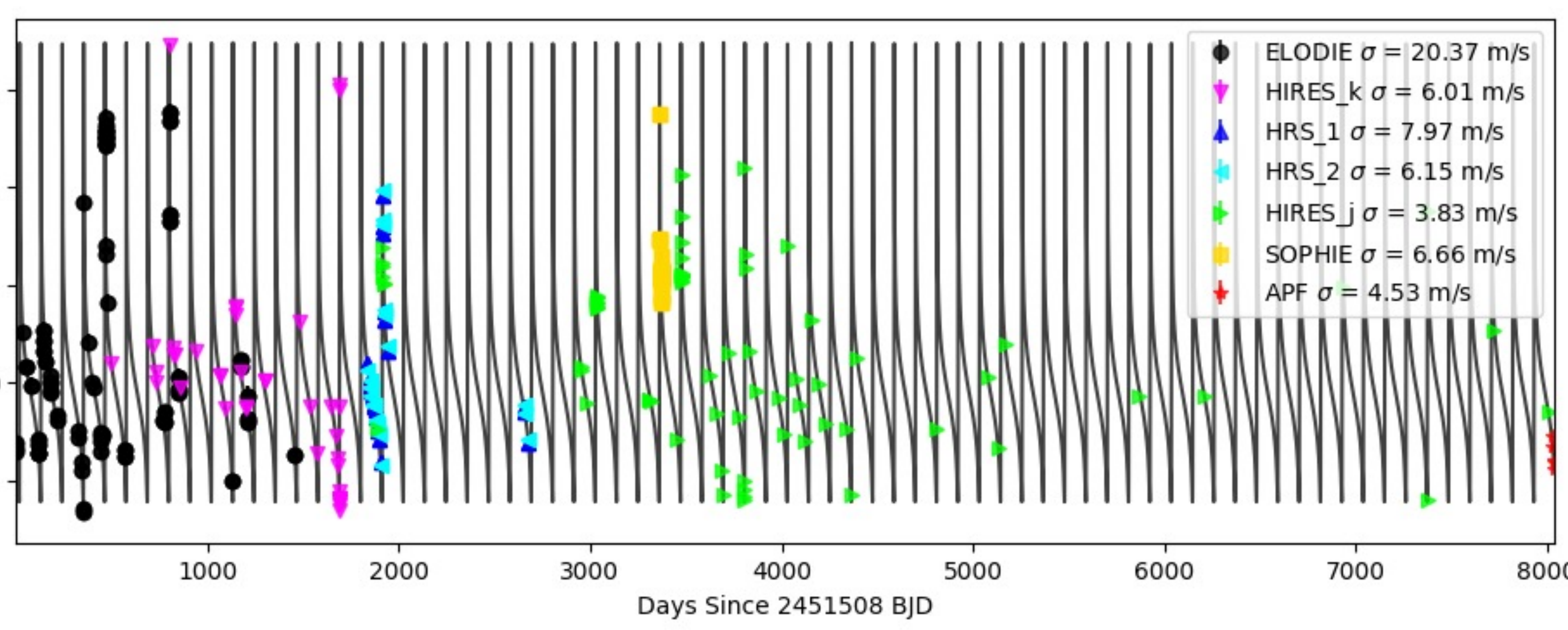
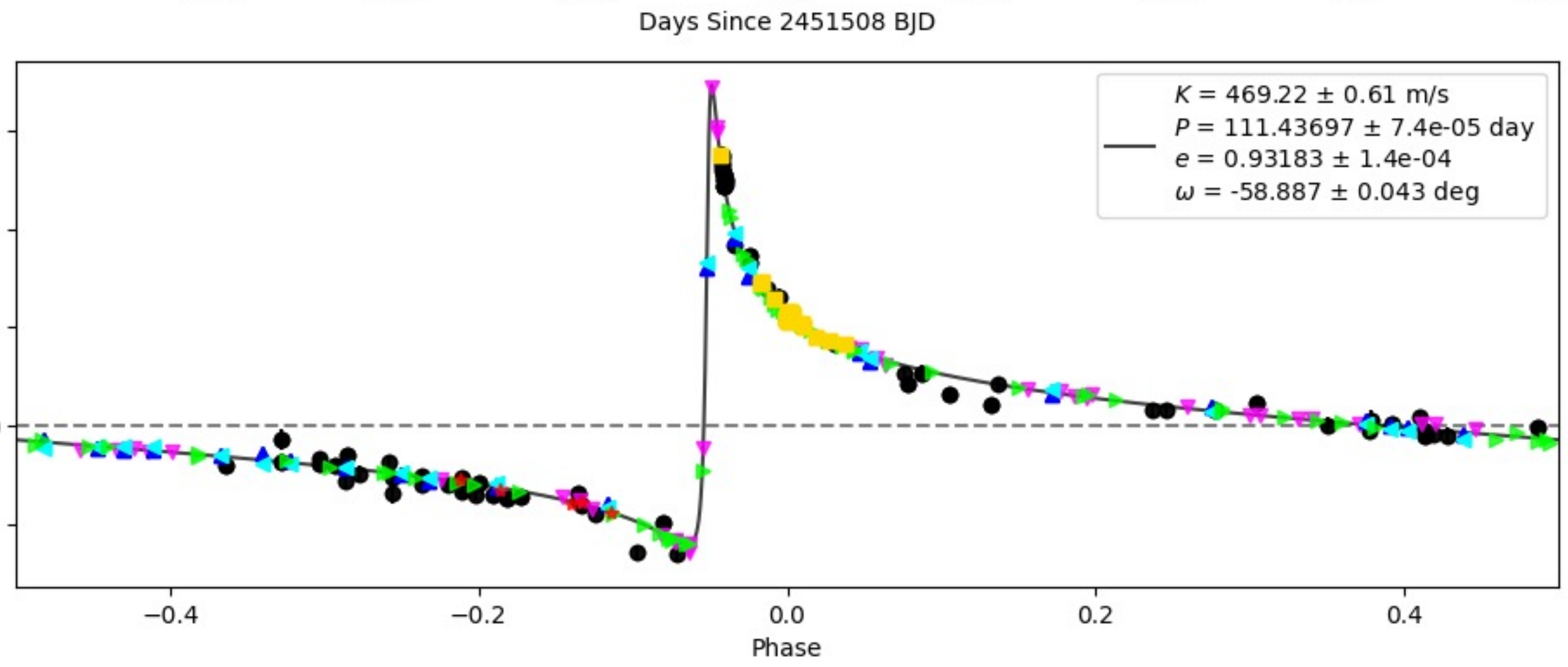
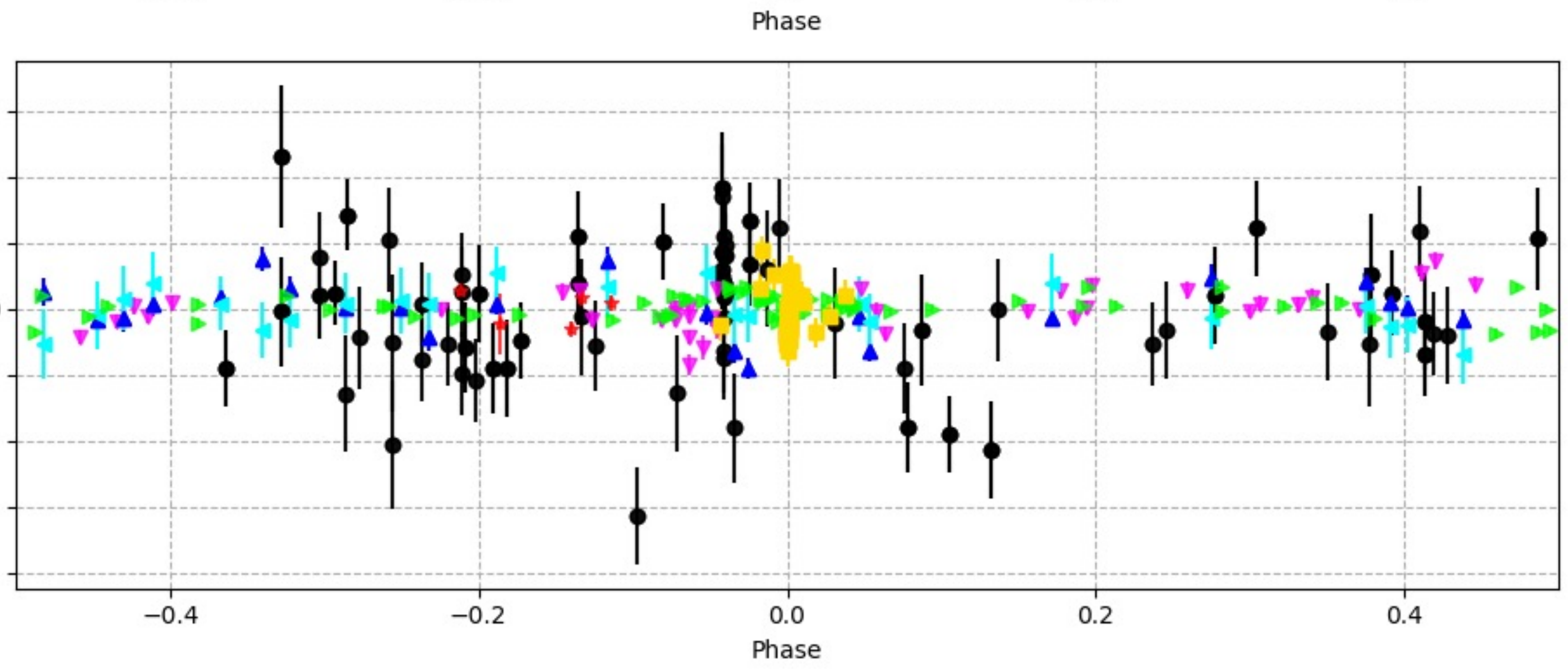
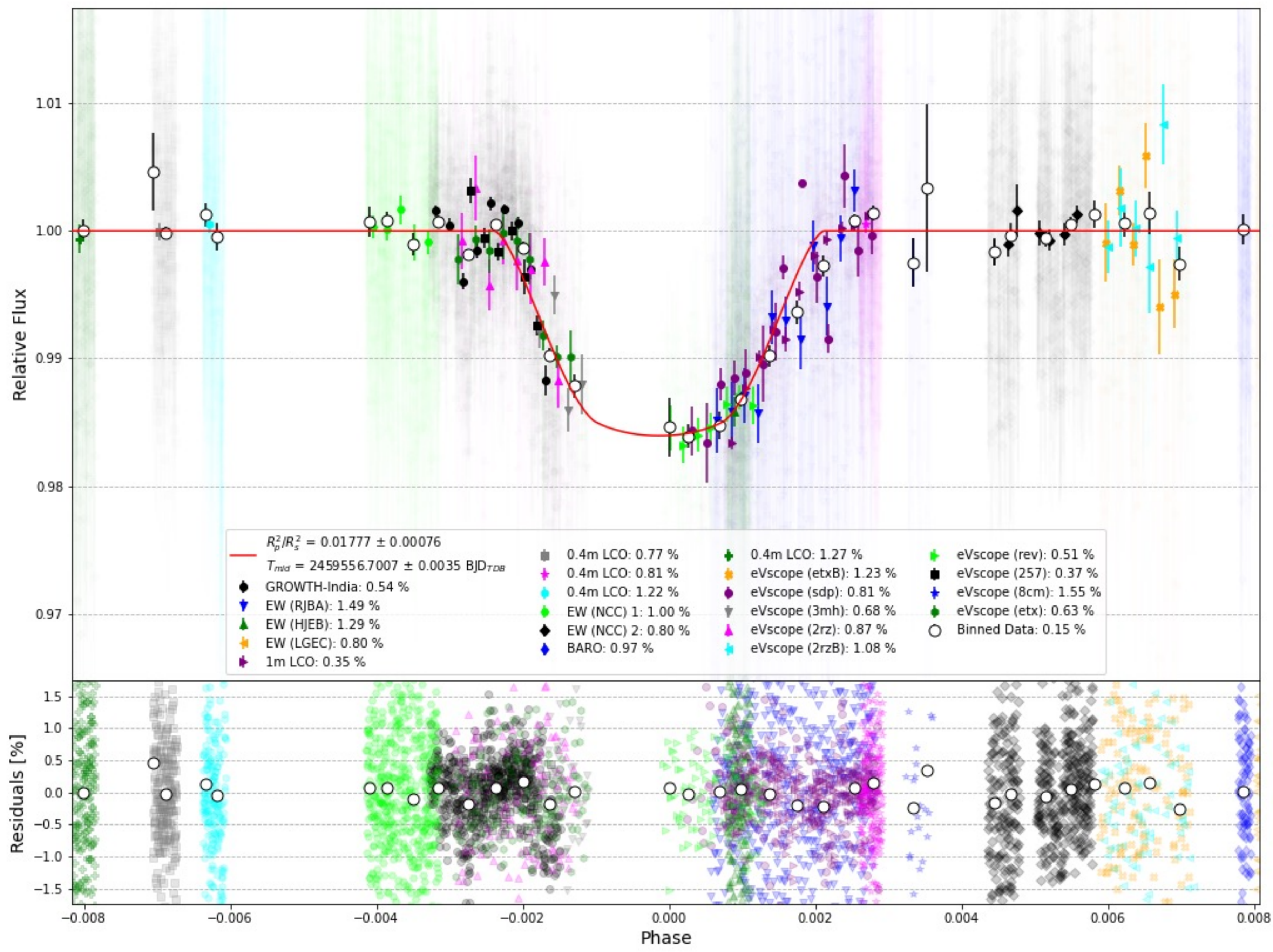
Objectives:

Analysis of exoplanet science observations requires using "system parameters" – that is knowledge of the planet's orbit and characteristics of the parent star. ***These parameters should be determined in a self-consistent way but heterogeneous data and analysis make the determination of self-consistent system parameters a major challenge***. Especially for studies of the composition of exoplanet atmospheres, high-precision knowledge of system parameters is essential. In this rapidly evolving environment, it is simply not feasible for human scientists to review all the current observations for a given target and then, using judgment and expertise, select parameters that are approximately self-consistent from numerous, and differently executed studies in the published literature. Therefore, we must automate the decision processes used by human experts to construct approximately self-consistent parameters in a fundamentally inhomogeneous environment.



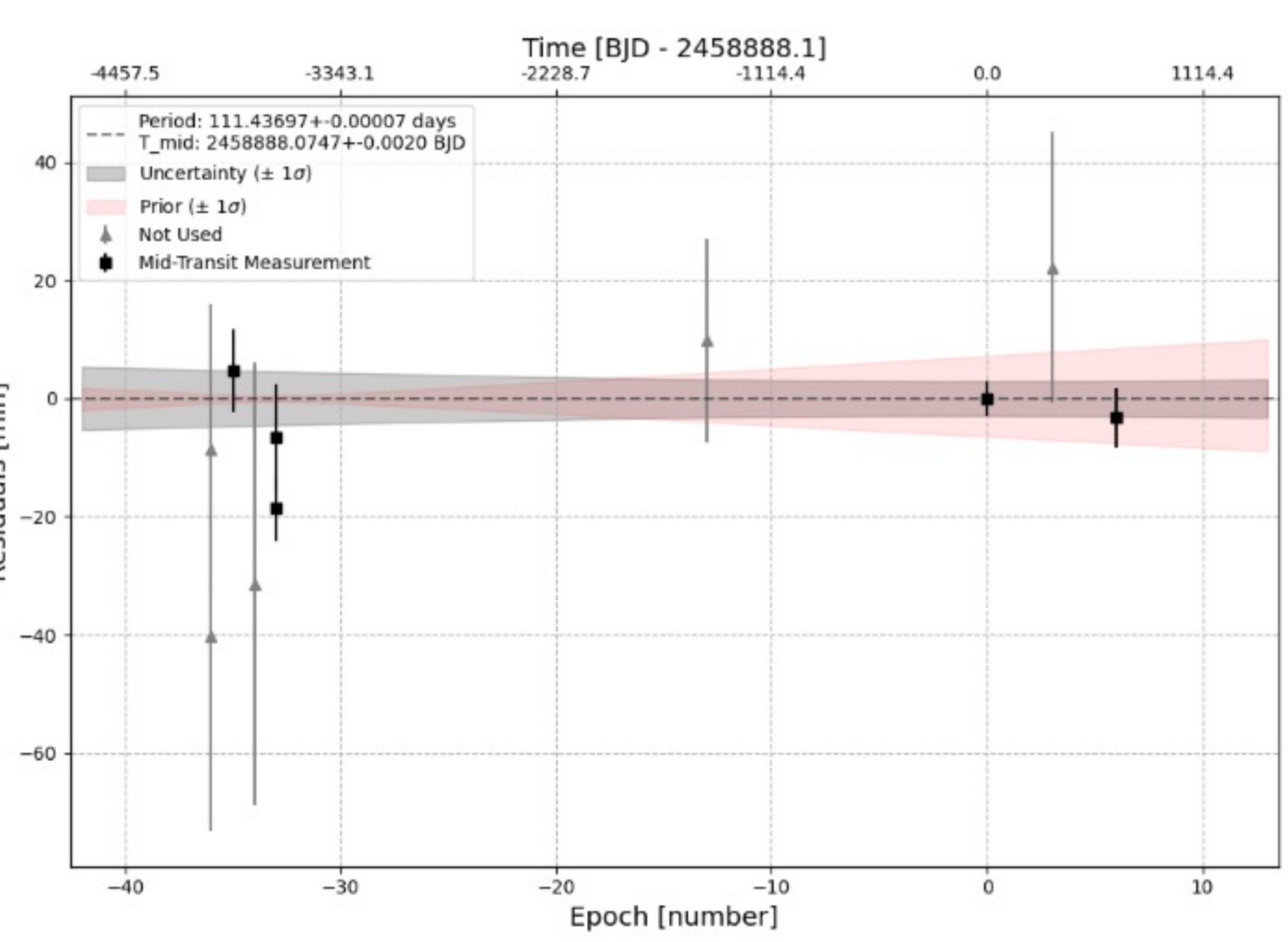


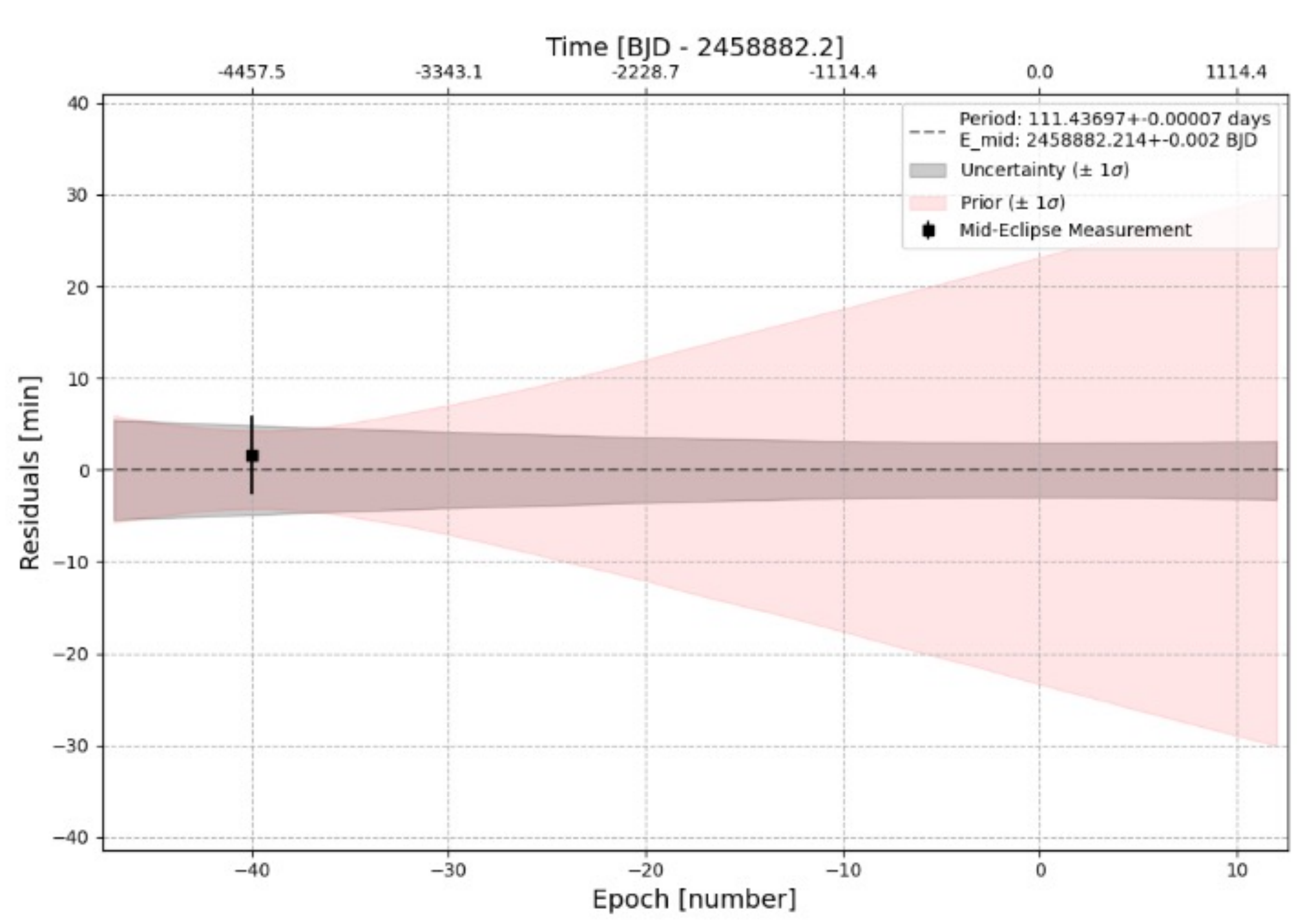




Background & Approach:

The standard way to derive a self-consistent solution involves a joint simultaneous fit of heterogenous data linked through a physical model for the system. Producing a statistically robust fit relies on a combination of Monte Carlo sampling and Bayesian inference in order to explore a parameter space efficiently. Monte Carlo (MC) methods like Markov chains (MCMC) and nested sampling rely on iteratively sampling a prior distribution in order to build a posterior from which to infer from. Traditional MC techniques are computationally expensive depending on the physical model and grow in complexity with the number of free parameters. Handling large optimizations requires careful tuning of the priors in order to guide convergence in a reasonable amount of time and to allow more parameters and datasets to be fit. We create a smart sampler based on individual posteriors from each data set in order to constrain a global optimization over heterogeneous data which ensures the derivation of self-consistent parameters by linking the data to a physical model. Constraining the optimization using smart priors improves the rate of convergence by 50-75%. In order to demonstrate the algorithm's capability, we validate it using 20 years of heterogeneous data on one of the most eccentric exoplanets and future JWST targets, HD80606b. The transiting planet HD 80606 b undergoes a 1000-fold increase in insolation during its 111-day orbit due to it being highly eccentric (e=0.93). The planet's effective temperature increases from 400 K to over 1400 K in a few hours as it makes a rapid passage to within 0.03 AU of its host star during periapsis. Spectroscopic observations during the eclipse (which is conveniently oriented a few hours before periapsis) of HD~80606~b with the James Webb Space Telescope (JWST) are poised to exploit this highly variable environment to study a wide variety of atmospheric properties, including composition, chemical, and dynamical timescales, and large scale atmospheric motions. **Critical to planning and interpreting these observations is an accurate knowledge of the planet's orbit.**





Results:

We report on 20 years of observations for the target HD 80606 b spanning transit measurements, radial velocity, eclipse, and mid-transit times. We apply a new joint analysis algorithm in order to greatly improve the planet's orbital ephemeris. To aid with convergence, each observation was fit individually before being fit simultaneously and given priors to reflect +/- 5 sigma around the individual fits. Constraining the optimization using smart priors improves the rate of convergence by 50-75% depending on how complex the optimization is. Our new orbit solution reduces the uncertainty in the transit and eclipse timing of the JWST era from tens of minutes to a few minutes. When combined with the planned JWST observations, this new precision may be adequate to look for non-Keplerian effects in the orbit of HD 80606 b.

Publications:

Utilizing a global network of telescopes to update the ephemeris for the highly eccentric planet HD 80606 b and to ensure the efficient scheduling of JWST. Kyle A. Pearson, Chas Beichman, B.J. Fulton, et. al (38+ more authors). AJ 2022. In Press. https://arxiv.org/abs/2208.14520

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