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A Word of Caution about Exoplanet Archival Data

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ABSTRACT

In addition to original results from observations, exoplanet archives such as exoplanets.org and exoplanet.eu contain auxiliary products (unpublished semimajor axes and/or stellar parameters taken from supplementary studies) that are not sufficiently documented and/or not up-to-date, even for famous extrasolar systems. The NASA Exoplanet Archive does not publish auxiliary products, but a number of its entries are outdated; researchers should be encouraged to submit their results upon publication. In this note, we describe our recent experience with auxiliary products in three such systems, Kepler-223, Kepler-11, and GJ 876. We summarize the (in) compatible dynamical data that we obtained so that others may not have to go through the same trouble, even if this means relying on the original publications and private communications with the authors. At the same time, large statistical surveys utilizing only archival data are bound to be inaccurate to a certain extent.

KEPLER-223

Archives exoplanets.org and exoplanet.eu use the following data from Rowe et al. (2014): stellar radius $R^* = 1.017R_0$ and mean stellar density $\rho^* = 1.258$ g cm^{-3}; orbital periods P = 7.384108, 9.848183, 14.788759, and 19.721734 days for planets b-e, respectively; and exoplanets.org calculates somehow semimajor axes (set 1):

$$a = 0.0742, 0.0899, 0.1179, \text{and } 0.1429 \text{ AU},$$

Respectively. These calculated values are larger by ∼2.1% than the actual values (listed also in exoplanet.eu in rounded form with a minor rounding glitch in their $a_d = 0.116$ AU) that should have been obtained from the Keplerian formula $(a/R^*)^3 = G\rho^* P^2/(3\pi)$ given in Rowe et al. (2014) (set 2):

$$a = 0.0727, 0.0880, 0.1154, \text{and } 0.1399 \text{ AU},$$

Respectively. The stellar parameters also imply a stellar mass of $M^* = 0.9383M_0$, a value not listed. Except for the NASA Exoplanet Archive, the other two archives have not been updated with the more recent results
of Mills et al. (2016) who find quite similar orbital periods P = 7.38449, 9.84564, 14.78869, and 19.72567 days for planets b-e, respectively. As indicated in the NASA Exoplanet Archive, Mills et al. (2016) did not list semi major axes, but their best-fit C2 model has $R^* = 1.72R_0$ and $M^* = 1.125M_0$, implying that $\rho^* = 0.3118$ g cm^{-3} (4× lower); had they listed them, their best-fit semimajor axes would be ∼6.2% larger than in set 2 above (see set 3 below). From these stellar values and the Keplerian formula given above, we calculate set 3 (the most reliable set of semimajor axes at present):

$$a = 0.0772, 0.0935, 0.1226, \text{and } 0.1486 \text{ AU},$$

for planets b-e, respectively.
The difference in mean densities is notable. In the Mills et al. (2016) C2 model, the stellar structure of Kepler-223 bears no resemblance to that of our sun; but the planetary orbit sizes are comparable because the factor R ρ1/3 ∝ M 1/3
is only 6.2% larger for the semimajor axes of set 3. The same conclusion holds for their model 3 with R* = 1.622R0 and ρ* = 0.3718 g cm−3 because it uses the same M* value.

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KEPLER-11

The archived stellar parameters are superseded by the more recent results of Bedell et al. (2017). For M* = 0.961M0
and R = 1.065R implying that ρ = 1.122 g cm−3 (Lissauer et al. 2013), the archived values give R ρ1/3 = 7.70×1010
in cgs units which reproduces the listed semimajor axes of the orbits for the given orbital periods. On the other hand,
the spectroscopic and photodynamic results of Bedell et al. (2017) are not in agreement with the listed values. Some of the discrepancies have already sneaked into the literature (column d0 in Table 1 of Kubyshkina et al. 2019).
The results of Bedell et al. (2017) are in tension at a level of ∼2σ, so we need to be aware of two current dynamical models for Kepler-11: (a) Stellar evolutionary modeling indicates that M* = 1.042M0 and R* = 1.021R0, implying
that ρ = 1.381 g cm−3 and R ρ1/3 = 7.91 × 1010 in cgs units for which the orbits are wider by 2.7% relative to the
archived values (Lissauer et al. 2013). (b) Transit analysis with fixed M* = 1.04M0 indicates that R* = 1.07R0,
implying that ρ = 1.19 g cm−3 and R ρ1/3 = 7.89 × 1010 in cgs units for which the orbits are wider by 2.5% relative
to the archived values. For this N SI model, only planet masses (b-g) were published by Bedell et al. (2017):

m = 2.78, 5.00, 8.13, 9.48, 2.53, and < 27 M⊕,

so here we use the archived periods (Lissauer et al. 2013) (after correcting for the motion of Kepler-11 toward the solar system) in order to calculate the corresponding (b-g) semimajor axes:

P = 10.3059, 13.0266, 22.6888, 32.0057, 46.6977, and 118.4032 days,

a = 0.09371, 0.1095, 0.1586, 0.1995, 0.2566, and 0.4771 AU.

GJ 876

The mentioned archives list data from Rivera et al. (2010), although some masses from a six-planet model (Jenkins et al. 2014) have crept into exoplanet.eu; and exoplanets.org did not list the inclination of the system given in Rivera et al. (2010) while, at the same time, it pointed to the old catalog of Butler et al. (2006) for calculations. For consistency, we give here the values determined by Rivera et al. (2010) for their best-fit model of planets d, c, b, e:

P = 1.937780, 30.0881, 61.1166, and 124.26 days,
a = 0.02080665, 0.129590, 0.208317, and 0.3343 AU,
m = 6.83, 227.0, 723.2, and 14.6 M⊕,

Which were derived by using M* = 0.32M0 and R* = 0.3R0, implying that ρ* = 16.7 g cm−3 (∼12× larger than the mean ρ value) and that R ρ1/3 = 5.34 × 1010 in cgs units.

The archived values are superseded by the more recent results of Millholland et al. (2018). For planets d, c, b, e:

P = 1.937793, 30.0972, 61.1057, and 123.83 days
a = 0.021838, 0.136044, 0.218627, and 0.3501 AU,
m = 7.55, 265.6, 845.2, and 15.8 M⊕,

which were derived by using M* = 0.37M0 and R* = 0.3761R0 (von Braun et al. 2014), implying that ρ* = 9.81 g cm−3 (~7× larger than ρ) and that R ρ = 5.60 × 1010 in cgs units. Thus, the semimajor axes are 5% larger and the planet masses are 8-17% larger than the corresponding values in Rivera et al. (2010).

GLOBAL MEAN-MOTION RESONANCES

In these systems, the planets participate in the global mean-motion resonances of the most massive planet:

(a) In Kepler-223, the period ratios are close to 1:2, 2:3, 1:1, and 4:3 relative to planet d (deviations 0.04-0.14%).
(b) In Kepler-11, the period ratios are close to 1:3, 2:5, 2:3, 1:1, 3:2, and 11:3 relative to planet e (deviations 1-6%).
(c) In GJ 876, the period ratios are close to 1:32, 1:2, 1:1, and 2:1 relative to planet b (deviations 1.3-1.5%). In the six-planet model of Jenkins et al. (2014), there are also unconfirmed planetary signals at the 1:6 and 1:4 resonances.

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REFERENCES

Bedell, M., Bean, J. L., Mel´endez, J., et al. 2017, ApJ, 839, 94, doi:10.3847/1538-4357/aa6a1d
Butler, R. P., Wright, J. T., Marcy, G. W., et al. 2006, ApJ, 646, 505, doi:10.1086/504701
Jenkins, J. S., Becerra Yoma, N., Rojo, P., et al. 2014, MNRAS, 441, 2253, doi:10.1093/mnras/stu683
Kubyshkina, D., Fossati, L., Mustill, A. J., et al. 2019, A&A, 632, A65, doi:10.1051/0004-6361/201936581
Lissauer, J. J., Jontof-Hutter, D., Rowe, J. F., et al. 2013, ApJ, 770, 131, doi:10.1088/0004-637X/770/2/131

Millholland, S., Laughlin, G., Teske, J., et al. 2018, AJ, 155, 106, doi:10.3847/1538-3881/aaa894
Mills, S. M., Fabrycky, D. C., Migaszewski, C., et al. 2016, Nature, 533, 509, doi:10.1038/nature17445
Rivera, E. J., Laughlin, G., Butler, R. P., et al. 2010, ApJ, 719, 890, doi:10.1088/0004-637X/719/1/890
Rowe, J. F., Bryson, S. T., Marcy, G. W., et al. 2014, ApJ, 784, 45, doi:10.1088/0004-637X/784/1/45
von Braun, K., Boyajian, T. S., van Belle, G. T., et al. 2014, MNRAS, 438, 2413, doi:10.1093/mnras/stt2360