DRAFT VERSION FEBRUARY 28, 2022
Typeset using LaTeX **modern** style in AASTeX63

Three 38 Million Year Old Mini-Neptunes from Kepler, TESS, and Gaia

L. G. BOUMA,[1,*] R. KERR,[2] J. L. CURTIS,[3,4] L. A. HILLENBRAND,[1] A. W. HOWARD,[1] H. ISAACSON,[5] AND A. L. KRAUS[2]

[1]*Cahill Center for Astrophysics, California Institute of Technology, Pasadena, CA 91125, USA*
[2]*Department of Astronomy, The University of Texas at Austin, Austin, TX 78712, USA*
[3]*Department of Astronomy, Columbia University, 550 West 120th Street, New York, NY 10027, USA*
[4]*Department of Astrophysics, American Museum of Natural History, New York, NY 10024, USA*
[5]*Astronomy Department, University of California, Berkeley, CA 94720, USA*

(Received 2021 Oct 12; Revised —; Accepted —)

ABSTRACT

Stellar positions and velocities from Gaia are yielding a refined view of stellar clusters during the first hundred million years of their lives. Here we present an analysis of a group of 38 ± 6 million year old stars in the Cepheus-Hercules region, hereafter the Cep-Her complex. This group of stars includes four previously known Kepler Objects of Interest: Kepler-1627 Ab ($R_p = 3.85 \pm 0.11\,R_\oplus$, $P = 7.2$ days), Kepler-1643 b ($R_p = 2.32 \pm 0.14\,R_\oplus$, $P = 5.3$ days), KOI-7368 b ($R_p = 2.22 \pm 0.12\,R_\oplus$, $P = 6.8$ days), and KOI-7913 Ab ($R_p = 2.34 \pm 0.18\,R_\oplus$, $P = 24.2$ days). Kepler-1627 is a previously validated young planet in a component of the Cep-Her complex called the δ Lyr cluster (**?**). Here we focus on the latter three systems, which are in other sub-components of the complex (RSG5 and CH-2). Based on kinematic evidence from Gaia, stellar rotation periods from TESS, and spectroscopy, these three systems are also 38 ± 6 million years old. Based on the transit shapes and high resolution imaging, we statistically validate that they are all most likely planets (false positive probabilities of 6×10^{-9}, 5×10^{-3}, and 1×10^{-4} for Kepler-1643, KOI-7368, and KOI-7913 respectively). Supplemented by Gaia and TESS, the main Kepler mission is now contributing to the census of young close-in planets, and Kepler-1643 and KOI-7913 are the first empirical demonstration that mini-Neptunes with sizes of $\approx$2 Earth radii exist at ages of roughly 40 million years.

Keywords: exoplanet evolution (491), open star clusters (1160), stellar ages (1581)

1. INTRODUCTION

Corresponding author: L. G. Bouma
luke@astro.caltech.edu

* 51 Pegasi b Fellow

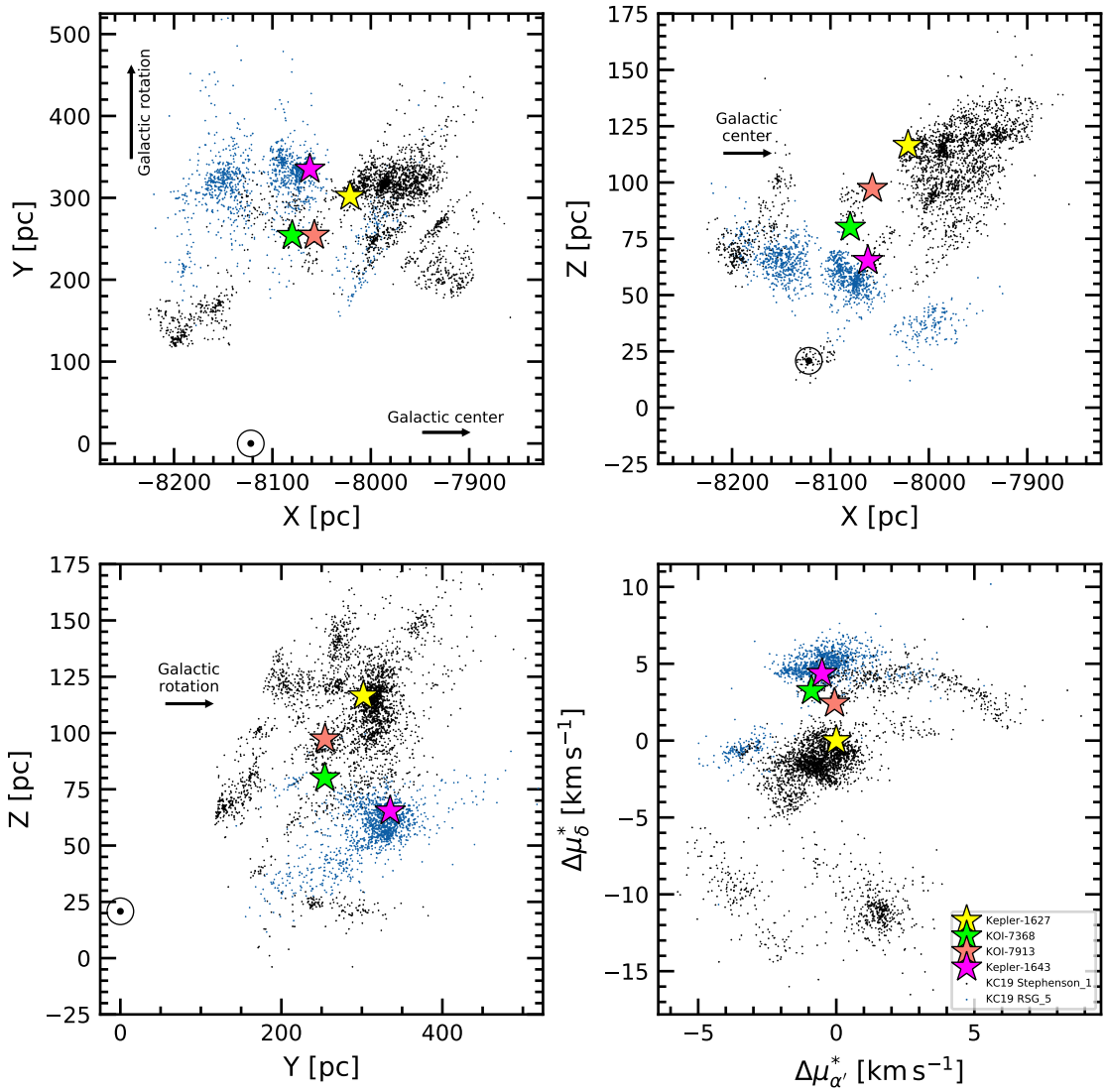

Figure 1. Galactic positions and tangential velocities of stars in the δ Lyr cluster.

Is a binary.

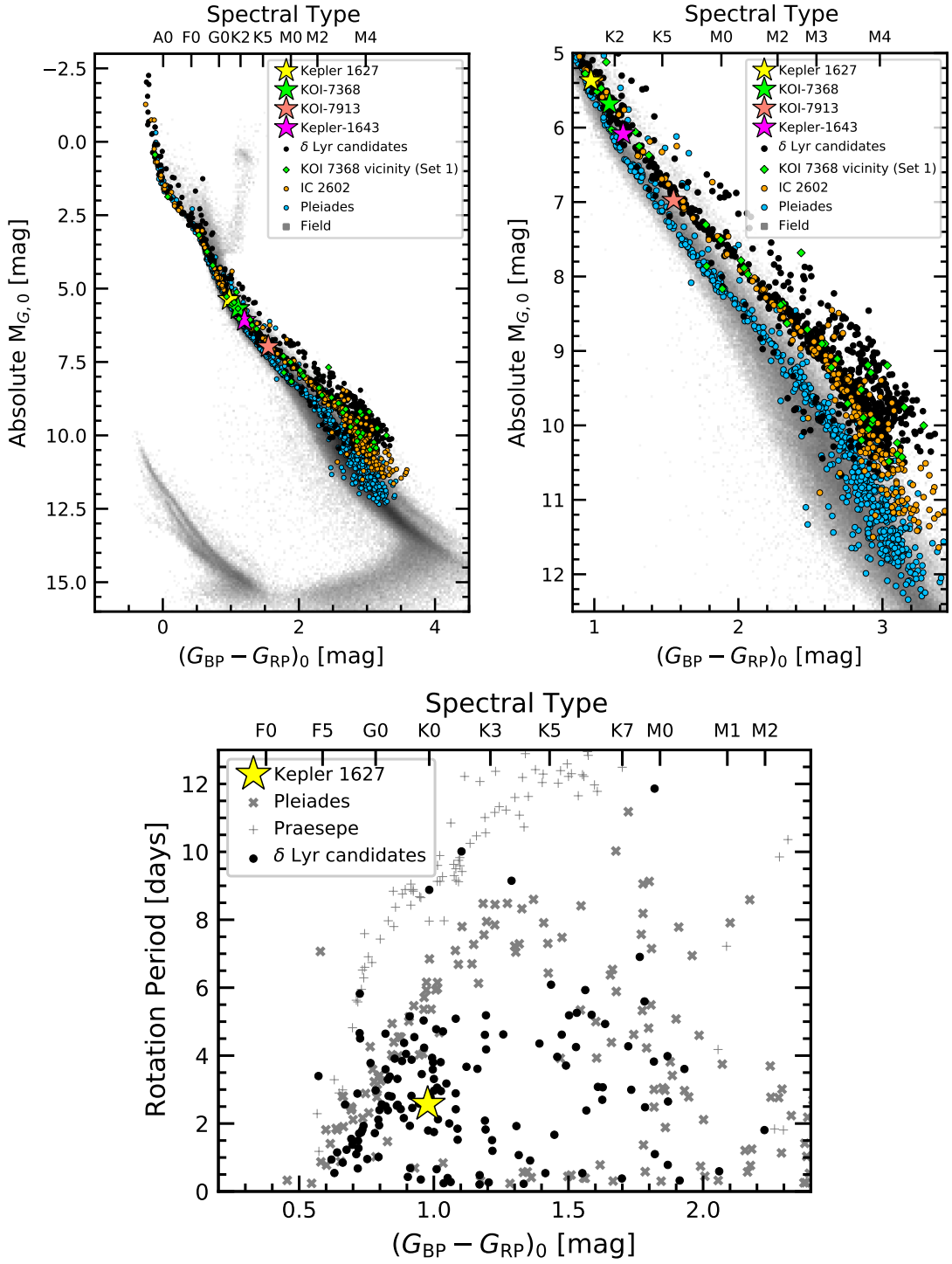

Figure 2. The Cep-Her complex is 38^{+6}_{-5} Myr old.

4. THE PLANETS

5. DISCUSSION & CONCLUSIONS

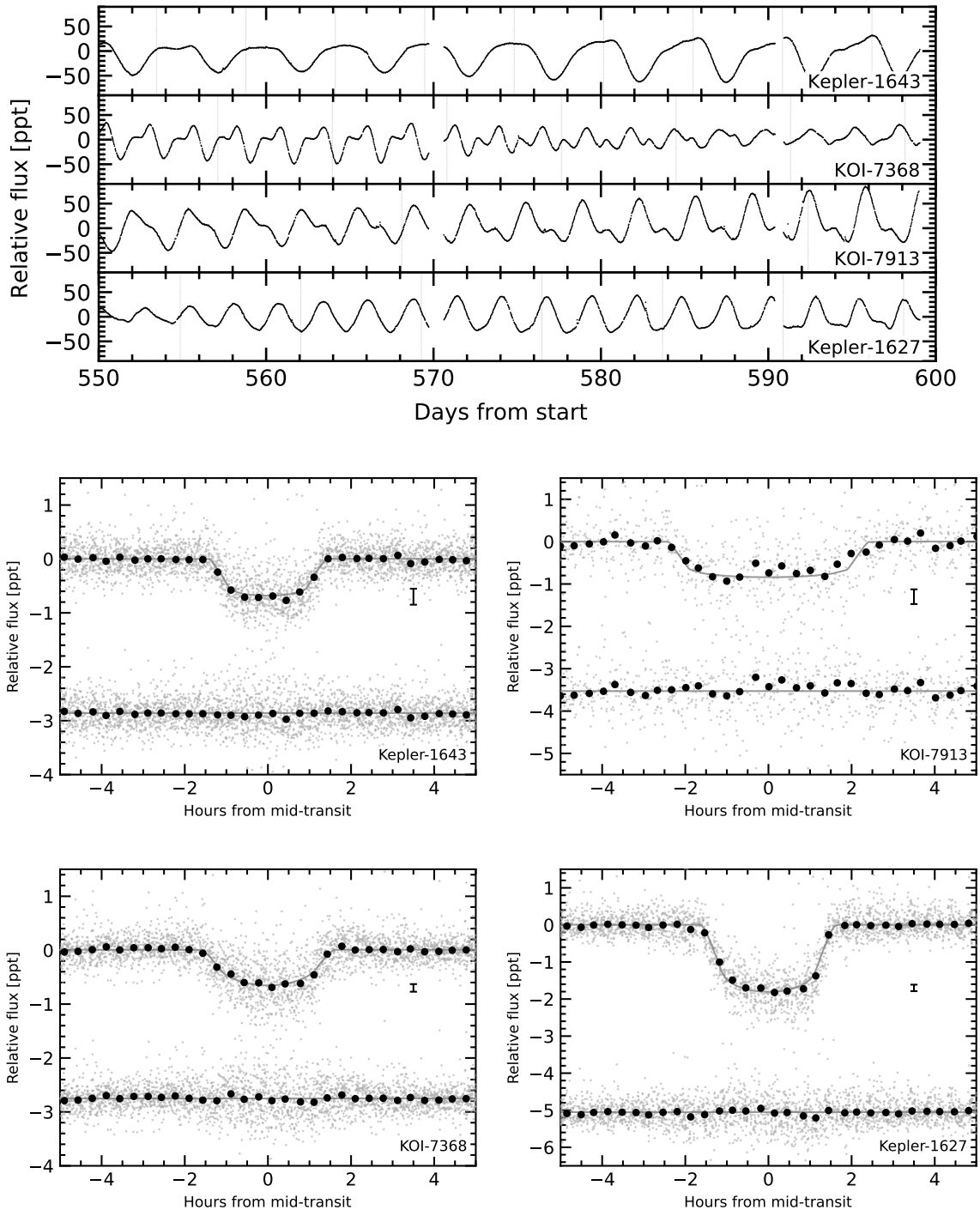

Figure 3. Raw and processed light curves for the objects of interest. Top: raw. Bottom: processed.

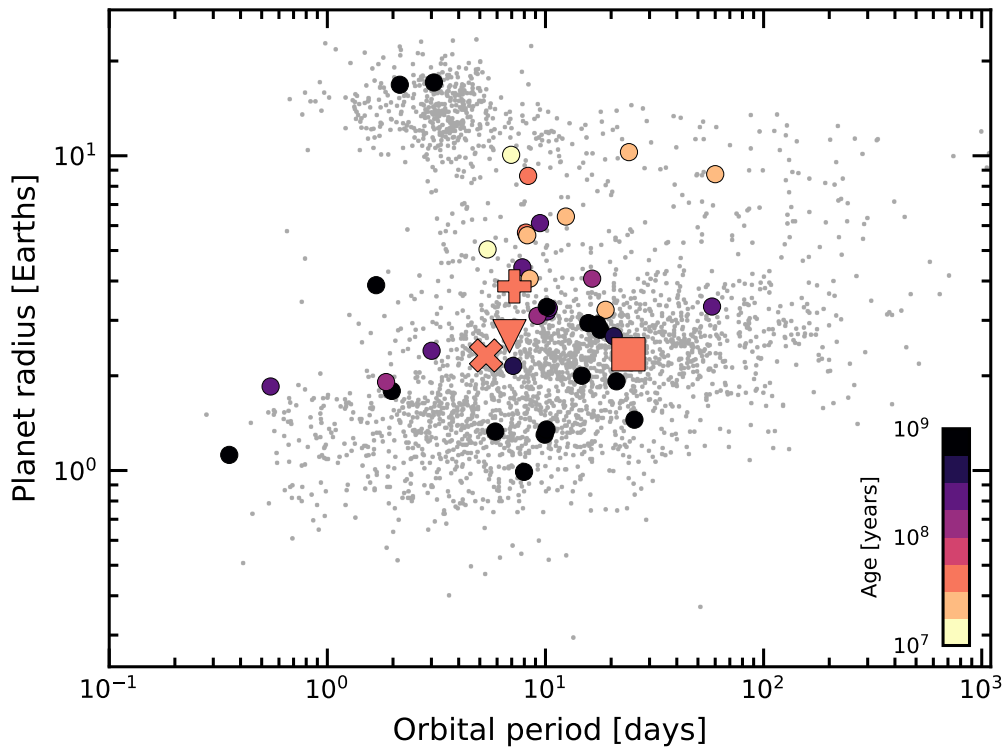

Figure 4. Radii, orbital periods, and ages of transiting exoplanets. Planets younger than a gigayear with $\tau/\sigma_\tau > 3$ are emphasized, where τ is the age and σ_τ is its uncertainty. STAR, SQUARE, DIAMOND. The large sizes of the youngest transiting planets could be explained by their primordial atmospheres not yet having evaporated; direct measurements of the atmospheric outflows or planetary masses would help to confirm this expectation. Selection effects may also be important. Parameters are from the NASA Exoplanet Archive (2021 Sept 15).

ACKNOWLEDGMENTS

L.G.B. acknowledges support from the TESS GI Program (NASA grants 80NSSC19K0386 and 80NSSC19K1728) and the Heising-Simons Foundation (51 Pegasi b Fellowship). Keck/NIRC2 imaging was acquired by program 2015A/N301N2L (PI: A. Kraus). This paper also includes data collected by the TESS mission, which are publicly available from the Mikulski Archive for Space Telescopes (MAST). Funding for the TESS mission is provided by NASA's Science Mission directorate. We thank the TESS Architects (G. Ricker, R. Vanderspek, D. Latham, S. Seager, J. Jenkins) and the many TESS team members for their efforts to make the mission a continued success. Finally, we also thank the Keck Observatory staff for their support of HIRES and remote observing. We recognize the importance that the summit of Maunakea has within the indigenous Hawaiian community, and are deeply grateful to have the opportunity to conduct observations from this mountain.

Software: `astrobase` (**?**), `astropy` (**?**), `astroquery` (**?**), `corner` (**?**), `exoplanet` (**?**), and its dependencies (**????**), `PyMC3` (**?**), `scipy` (**?**),

Facilities: *Astrometry*: Gaia (**??**). *Imaging*: Second Generation Digitized Sky Survey. Keck:II (NIRC2; www2.keck.hawaii.edu/inst/nirc2). *Spectroscopy*: Tillinghast:1.5m (TRES; **?**). Keck:I (HIRES; **?**). *Photometry*: Kepler (**?**), TESS (**?**).

REFERENCES

Agol, E., Luger, R., & Foreman-Mackey, D. 2020, AJ, 159, 123

Astropy Collaboration, Price-Whelan, A. M., Sipőcz, B. M., et al. 2018, AJ, 156, 123

Bhatti, W., Bouma, L. G., & Wallace, J. 2018, `astrobase`, https://doi.org/10.5281/zenodo.1469822

Borucki, W. J., Koch, D., Basri, G., et al. 2010, Science, 327, 977

Bouma, L. G., Curtis, J. L., Masuda, K., et al. 2022, AJ, 163, 121

Fűrész, G., Szentgyorgyi, A. H., & Meibom, S. 2008, 287

Foreman-Mackey, D. 2016, Journal of Open Source Software, 1, 24

Foreman-Mackey, D., Czekala, I., Luger, R., et al. 2020, exoplanet-dev/exoplanet v0.2.6

Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018, A&A, 616, A1

—. 2021, A&A, 649, A1

Ginsburg, A., Sipocz, B., Madhura Parikh, et al. 2018, Astropy/Astroquery: V0.3.7 Release

Jones, E., Oliphant, T., Peterson, P., et al. 2001, Open source scientific tools for Python

Kipping, D. M. 2013, MNRAS, 435, 2152

Luger, R., Agol, E., Foreman-Mackey, D., et al. 2019, AJ, 157, 64

Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2015, JATIS, 1, 014003

Salvatier, J., Wieckiâ, T. V., & Fonnesbeck, C. 2016, PyMC3: Python probabilistic programming framework

Theano Development Team. 2016, arXiv e-prints, abs/1605.02688

Vogt, S. S., Allen, S. L., Bigelow, B. C., et al. 1994, SPIE Conference Series, ed. D. L. Crawford & E. R. Craine, Vol. 2198