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Radial Velocity Upper Limits on Planets around Radio Exoplanet Candidates GJ 1151 and GJ 412A

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ABSTRACT

We don't find a star or giant planet around GJ 1151 or GJ 412A but we cannot rule out anything below 5 $M_\oplus$.

We infer a high resolution spectrum of GJ 1151 which is pretty cool.

1. INTRODUCTION

Extrasolar planets flourished over the last three decades to be one of the major topics in optical astronomy. The number of known planets has doubled nearly every two years since 1995 (Mamajek 2016) and this accelerating rate of discovery is projected to continue for at least the next decade if current and upcoming space-based surveys deliver their expected results. However despite extensive searches (Bastian et al. 2000; Lecavelier des Etangs et al. 2013; Lynch et al. 2018) neither exoplanets nor their host stars have been detected at radio frequencies, as the quiescent emission of such systems has been too faint for current telescopes. But as the Square Kilometre Array (SKA; Dewdney et al. 2009) and its precursors, in particular LOFAR (the LOw-Frequency ARray: van Haarlem et al. 2013) come online, the orders-of-magnitude increase in sensitivity and survey speed they provide makes the detection of nearby stars and planets a realistic prospect (Pope et al. 2019).

Rather than explicitly searching for radio emission from known exoplanet hosts, Callingham et al. (2019) cross-matched sources identified by the LOFAR Two-meter

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Sky Survey (LoTSS) with nearby stellar sources found by *Gaia*, finding the great majority of matches to be chance associations. But by restricting the survey to variable and circularly-polarized emission, the rate of chance associations with background radio galaxies is dramatically reduced. Based on this restricted cross-match, Vedantham et al. (submitted) and Callingham et al. (submitted) have detected the M dwarfs GJ 1151 and GJ 412A respectively at low radio frequencies with LOFAR, finding a high degree of circular polarization consistent with a possible star-planet magnetic interaction analogous to a scaled-up Jupiter and Io.

In this Letter we analyze new HARPS-N (High Accuracy Radial velocity Planet Searcher: Cosentino et al. 2012) observations of GJ 1151, and re-analyze archival Keck-HIRES (Butler et al. 2017) observations of GJ 412A, in order to search for radial velocity signals of the proposed planets. We do not detect either planet, but place strong upper limits of a few Earth masses on the $M \sin i$ of any possible companions, ruling out any short-period massive objects in both cases, and with great certainty any close binary companion to GJ 1151 or previously-unknown companions to GJ 412A.

2. RV DATA

We obtained 20 epochs of observations of GJ 1151 with HARPS-N from 2018-12-20 to 2019-02-27. While RVs were extracted from these using the standard HARPS pipeline, its performance on this M4.5 dwarf was very poor, resulting in a spurious RV scatter of several km/s. We therefore reprocessed these data using *wobble* (Bedell et al. 2019), a data-driven package which simultaneously non-parametrically constructs a stellar spectral template and telluric spectral components and uses these, rather than model spectral masks, to extract radial velocities. We found that the second epoch (2018-12-22) had a significantly higher extracted RV uncertainty than the others, and accordingly excluded this from the global *wobble* model. In order to assess template-dependent systematic errors, we conducted a 'leave-one-out' cross-validation, excluding one additional epoch at a time and rerunning *wobble* to search for consistency between the outputs. As seen in Figure 1, the different resulting time series are broadly consistent in their directions of deviation from the mean, with a scatter between them of order $\sim$ the quoted uncertainties. We therefore believe the uncertainties on the *wobble* RVs are realistic but that they are also model-dependent systematics, and therefore likely correlated.

In their publication, Butler et al. (2017) did not claim a detection of any planet-like Keplerian signal from GJ 412A, though they did identify a 28 day period in the S indices of activity. We do not re-extract RVs from these data, censoring only two outliers with RV > 10 m/s.

3. KEPLERIAN INFERENCE

For both stars we use *the Joker* pipeline (Price-Whelan et al. 2017), which is optimized for small numbers of irregularly-spaced observations, to fit Keplerian signals and infer posterior planet parameters.

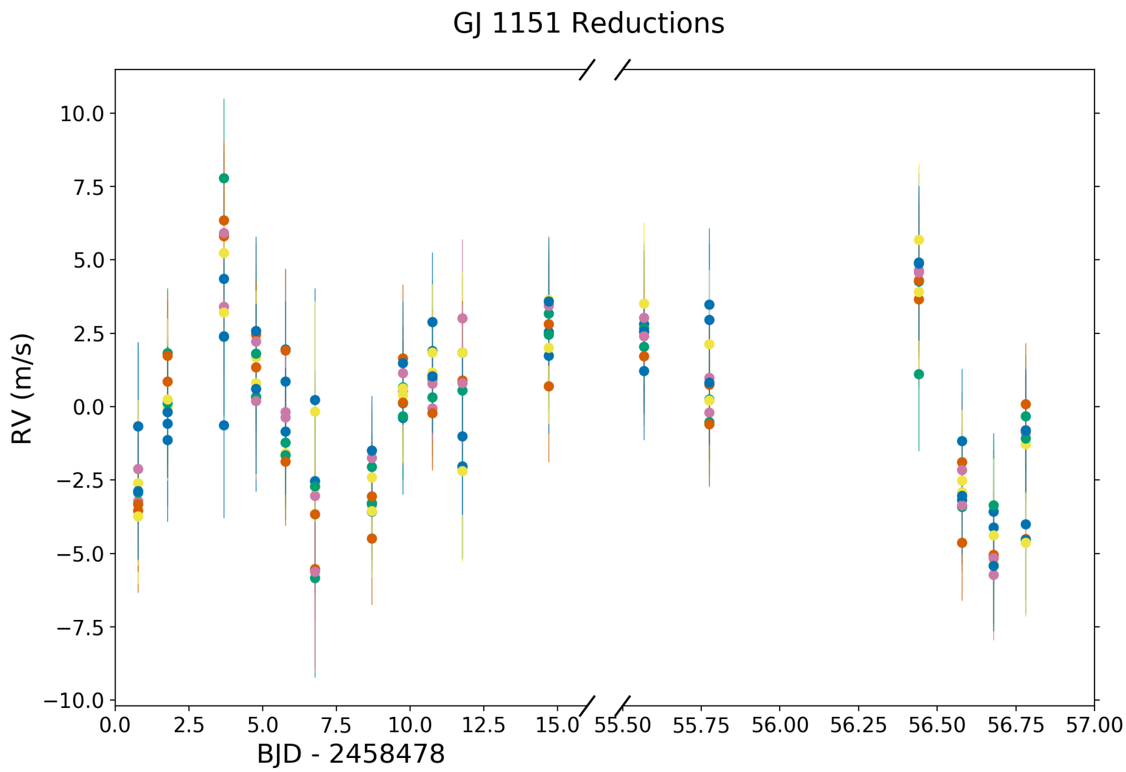

Figure 1. Leave-one-out cross-validation of *wobble* RVs. One epoch at a time is left out of the global model, and the results of processing the remaining epochs are shown in different colours. There is overall consistency between the different time series, with a diversity of order $\sim$ the quoted uncertainty between the individual realizations.

4. DISCUSSION

5. CONCLUSIONS

The results of this analysis conclusively rule out binary companions or planets on short orbits more massive than Neptune as the origin of the radio signals from GJ 1151 and GJ 412A. We nevertheless cannot rule out in either case planets less massive than a few Earth masses. Given that Vedantham et al. (submitted) find that even a planet with a mass around that of $\sim$Mercury could explain these signals, there is a very large region of parameter space for these planets that cannot be excluded and the planet hypothesis remains reasonable.

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BJSP acknowledges being on the traditional territory of the Lenape Nations and recognizes that Manhattan continues to be the home to many Algonkian peoples. We

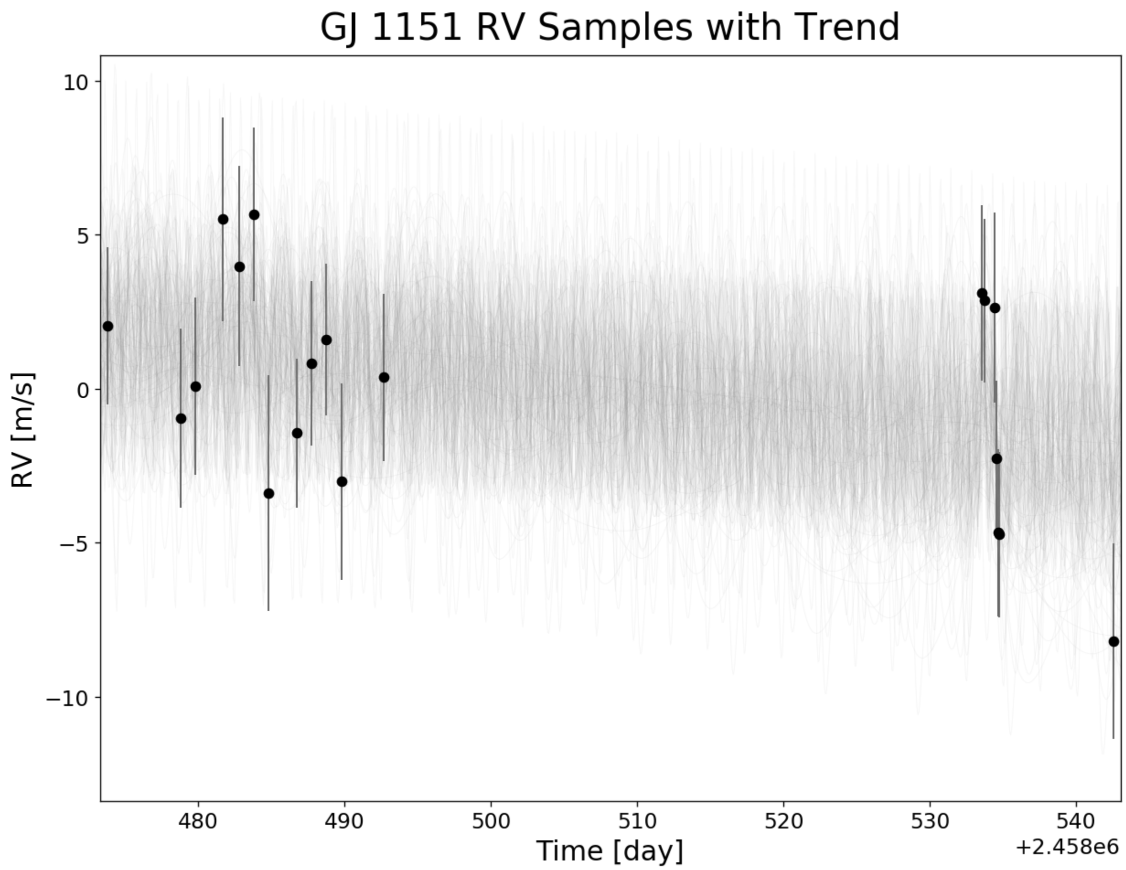

Figure 2. *The Joker* posterior samples for GJ 1151.

give blessings and thanks to the Lenape people and Lenape Nations in recognition that we are carrying out this work on their indigenous homelands.

This research made use of NASA's Astrophysics Data System; the SIMBAD database, operated at CDS, Strasbourg, France; the IPython package (Pérez & Granger 2007); SciPy (Jones et al. 2001); and Astropy, a community-developed core Python package for Astronomy (Astropy Collaboration et al. 2013). Some of the data presented in this paper were obtained from the Mikulski Archive for Space Telescopes (MAST). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. Support for MAST for non-HST data is provided by the NASA Office of Space Science via grant NNX13AC07G and by other grants and contracts.

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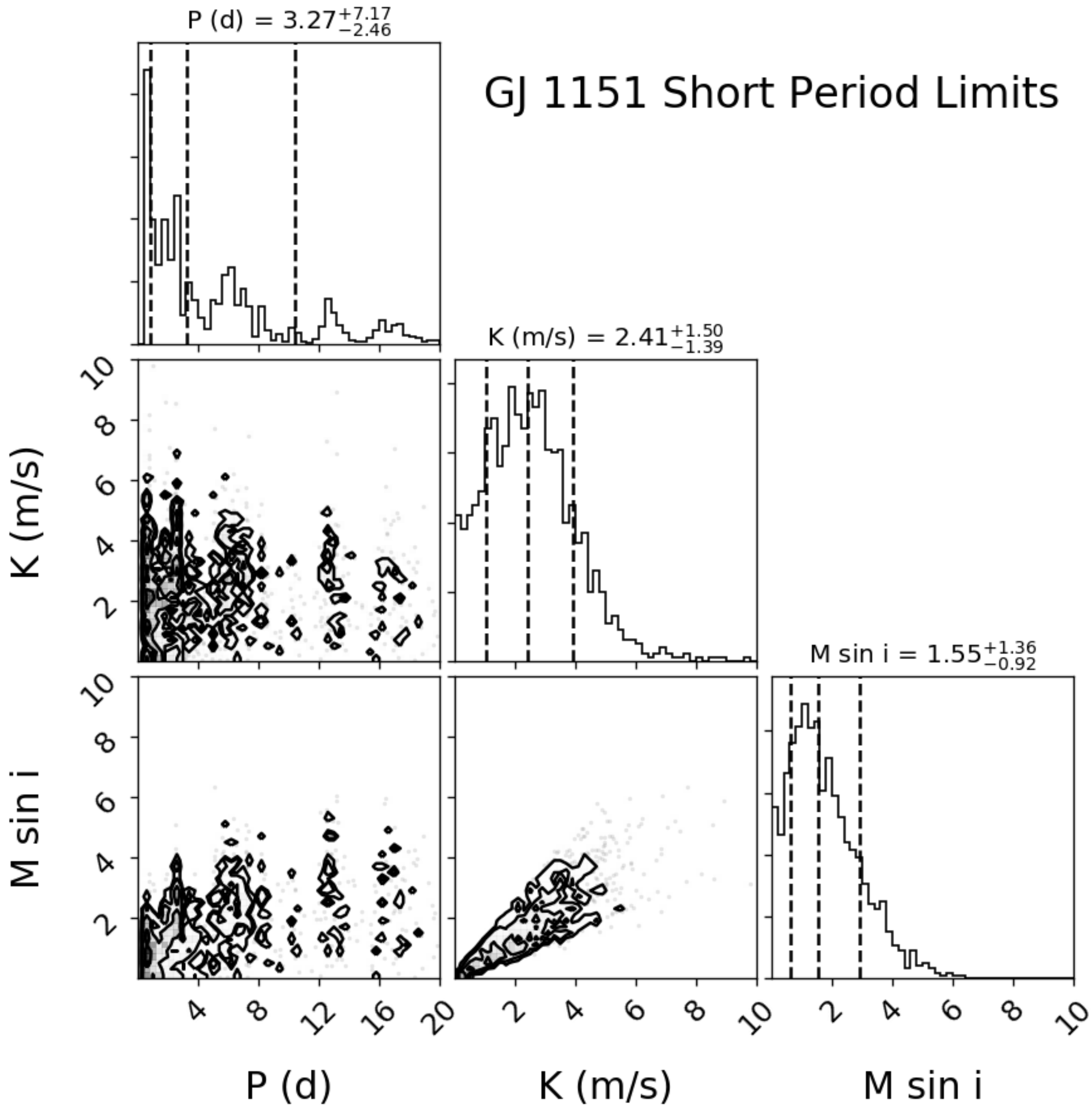

Figure 3. Cornerplot of posterior samples from *The Joker* for GJ 1151.

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