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*A. Benz, A. Dupree*

# At Least a Quarter of Sun-like Stars have Planets

Daniel Grether & Charles H. Lineweaver

*School of Physics, University of New South Wales and the Australian Centre for Astrobiology, Sydney, Australia*

**Abstract.** The combined results of eight high sensitivity Doppler surveys for exoplanets provides a consistent picture from which we can estimate the fraction of Sun-like stars with planets. The naive fraction of $\sim 5\%$ for the total number of planets divided by the total number of target stars increases to $\sim 11\%$ when we limit our analysis to target stars that have been monitored the longest ($\sim$ 15 years). If we further limit our analysis to stars monitored the longest and with the highest Doppler precision, at least $\sim 25\%$ possess planets.

## 1. Exoplanet Detections as a Function of Time

The success of the Doppler method for exoplanet detections has led to a known population of planets that is highly dependent on their monitored time. A potential planet host needs to be monitored for a duration greater than or approximately equal to the periods of any orbiting planets for a detection to be made. Along with the sensitivity of the survey this defines the region in $M\sin i$-$P$ parameter space that exoplanets will occupy and allows us to define areas in which planets are "Detected", "Being Detected" and as yet "Not Detected". As shown in Lineweaver & Grether (2002) and Lineweaver et al. (2003) the exoplanet period distribution is correlated with planet number density suggesting that the longer a sample of target stars is observed the larger the fraction that will possess planets.

As of June 2003, the results of the eight highest sensitivity Doppler surveys are combined (Lineweaver & Grether 2003) into the 106 giant exoplanets shown in Fig. 1. A color animated version of this plot, showing the time dependence is available here [1]. These combined surveys monitor $\sim$ 1800 nearby Sun-like stars, 92 of which have been found to host exoplanets massive enough to be detectable. Thus, at least $\sim 5\%$ of target stars possess planets. However these target stars have been monitored for different durations and at various sensitivities, indicating that this fraction is just an average for all the stars in these surveys.

We can refine this fraction by analysing the number of monitored stars versus their monitoring duration as in Fig. 2. We also show the number of detected exoplanets both at their date of detection and their date of first moni-

[1] http://bat.phys.unsw.edu.au/ charley/download/whatfrac

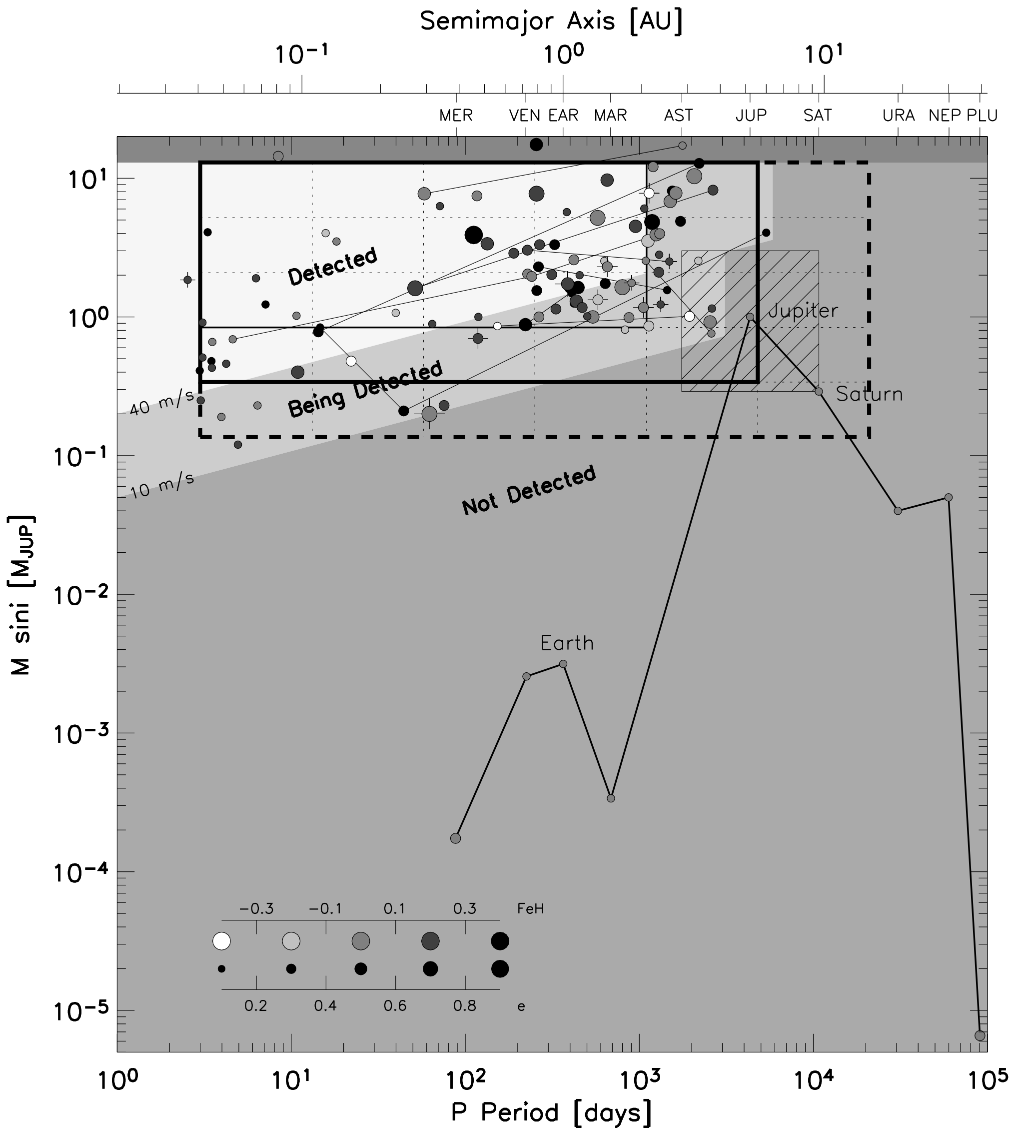


Figure 1. Our Solar System compared to the relatively small region of the planet mass and period plane where the eight high-sensitivity Doppler surveys analyzed here have detected 106 exoplanets. The selection effects due to the limited time of observation and the limited radial velocity sensitivity are indicated by the three regions labeled "Detected", "Being Detected" and "Not Detected". The planets marked with a '+' have been detected since August 2002. These detections required a long monitoring duration either because they have a large period or fall in the region of $M\sin i$-$P$ plane that requires a very high Doppler precision. See Lineweaver & Grether (2003) for additional details.

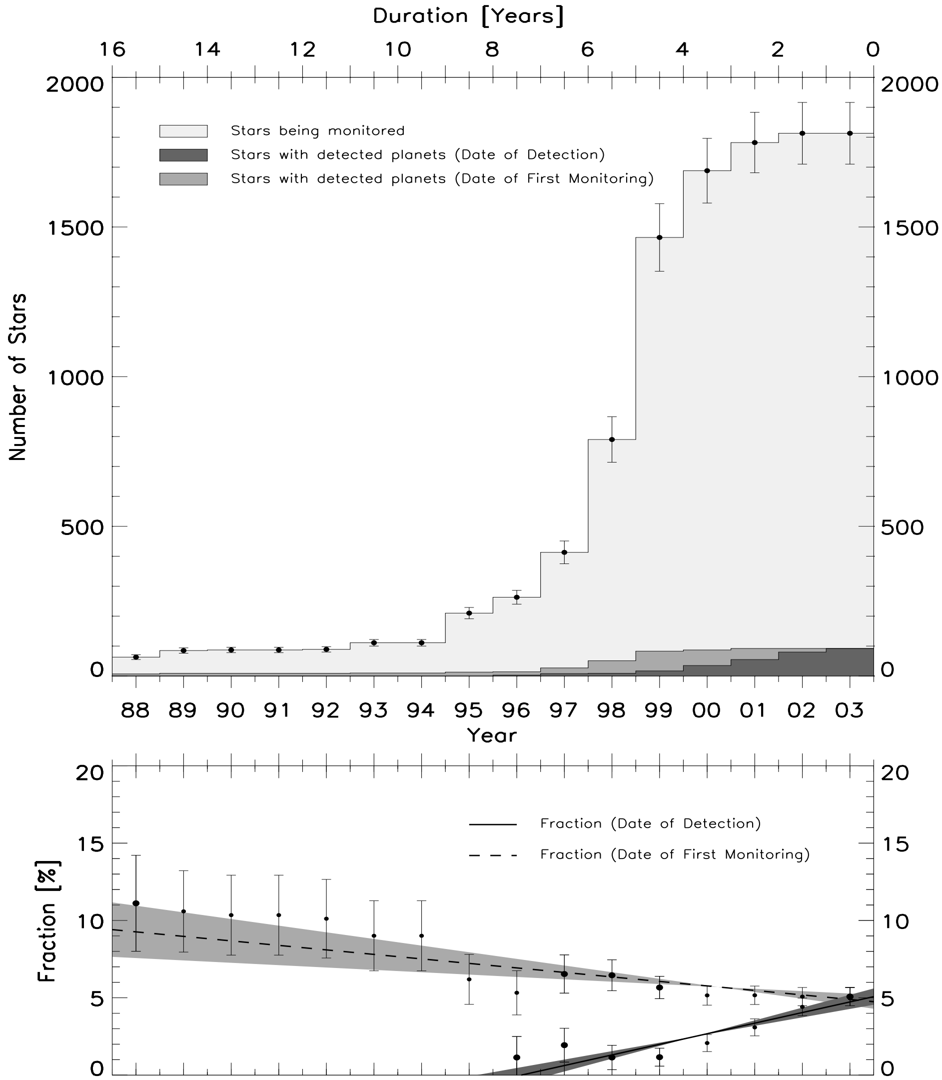


Figure 2. The fraction of stars with planets as a function of time. TOP: Histograms of the increasing number of target stars and the increasing number of them found to be hosting at least one exoplanet. BOTTOM: Using the date-of-detection binning (darkest histogram) yields the intuitive result that the fraction of host stars starts at zero in 1995 and climbs monotonicallyuntil its current value of $5 \pm 1\%$. The date-of-first-monitoring binning starts on the far left at $11 \pm 3\%$ from the bin of target stars that has been monitored the longest. The fraction decreases as we average in more stars that have been monitored for shorter durations. The last bin on the right is the same in both binning methods and includes all Sun-like target stars. Thus, $\sim 5\%$ is an average fraction from target stars that have been monitored for times varying between 0 and 16 years, while $\sim 11\%$ is the fraction from target stars that have been monitored the longest ($\sim$ 15 yrs).

toring. Sixteen years after the start of the first high precision Doppler exoplanet survey (Lick), in June 1987 (Cumming et al. 1999), we still have centuries to wait before all of these original targets will have been looked at long enough to determine whether they have orbiting planets detectable with the original Doppler sensitivity. The date-of-first-monitoring binning shows that the fraction of target stars hosting planets has a maximum of $\sim$ 11% from the longest monitored targets and then decreases as we average in target stars that have been monitored for shorter times. The date-of-detection binning convention rises monotonically from zero in 1995 with the first exoplanet detection (Mayor & Queloz 1995) to its current value of $\sim$ 5%, at which point both methods are equivalent. Although this 11% estimate is based on the result of a small sample of target stars belonging to the two longest running surveys (Lick & McDonald), it is consistent with the increasing fraction based on the monitoring duration of all target stars.

## 2. Stellar Activity and High Doppler Precision

In addition to the level of instrumental sensitivity, the amount of stellar activity on a star's surface is an important limit on a Doppler survey's ability to detect planets. Lower main-sequence stars with a low surface activity are found to have a high stellar chromospheric emission ratio $R'_{HK}$ (Noyes et al. 1984) which is correlated with a low stellar rotation period or projected rotational velocity $v\sin\, i$. Recent exoplanet target lists have been selected for higher Doppler precision by limiting $R'_{HK}$ or $v\sin\, i$ (Lineweaver & Grether 2003).

Fischer et al. (2003) analyzed a group of high Doppler precision stars from the original Lick sample and found that 15% possessed planets. We extend this idea in Fig. 3 by only plotting the fraction of target stars with planets that have been monitored the longest as a function of their stellar activity as measured by their excess radial velocity dispersion $\sigma'_v$ (Saar et al. 1998). We find that as long as high precision Doppler stars are an unbiased sample of Sun-like stars, at least $\sim$ 25% possess planets.

If at least a quarter of Sun-like stars have planets and we assume that this fraction is similar for all stars, then at least 75 billion of the $\sim$ 300 billion stars in our galaxy possess one ore more planets. Fischer et al. (2001) notes that $\sim$ 40% of stars that have an accompanying planet show signs of having additional planets. Thus our galaxy probably contains in excess of 100 billion planets.

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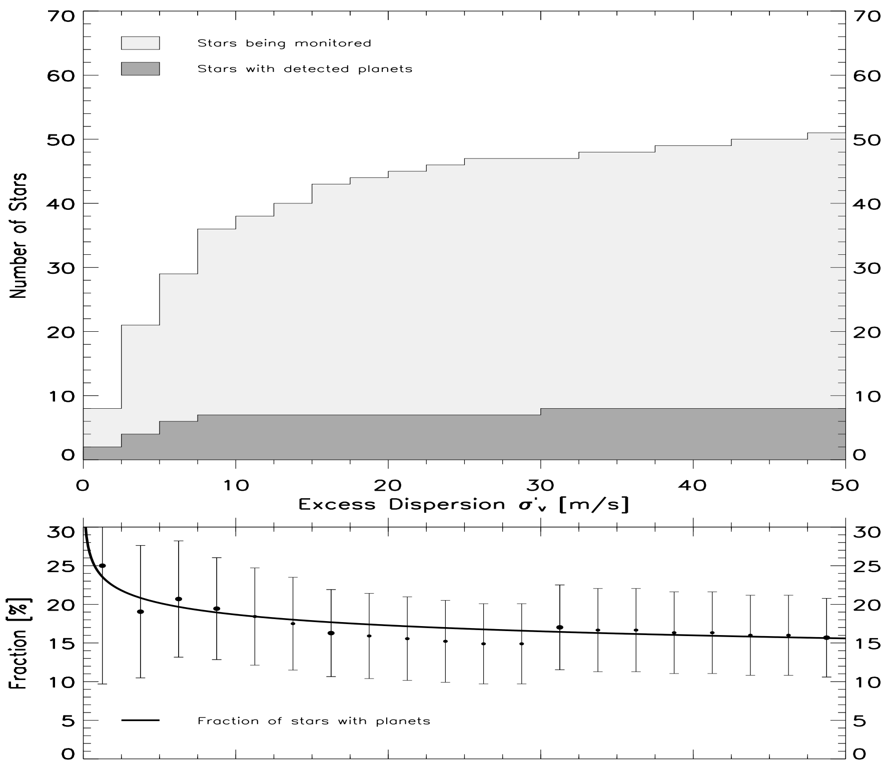


Figure 3. When stellar activity is low, high measurement precision is possible and a higher fraction of targets are found to host planets. TOP: The number of targets in the original Lick survey that have been monitored the longest and that have an excess radial velocity dispersion $\sigma'_v$ less than the value on the x axis. The ratio (BOTTOM) gives the fraction of stars with planets as a function of $\sigma'_v$ threshold. Thus, as we select for higher Doppler precision, the fraction of targets possessing planets increases to 25% for the stars with the highest precision ($\sigma'_v <$ 2.5 m/s).

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