THE CALIFORNIA PLANET SURVEY. I. FOUR NEW GIANT EXOPLANETS

Andrew W. Howard, John Asher Johnson, Geoffrey W. Marcy, Debra A. Fischer, Jason T. Wright, David Bernat, Gregory W. Henry, Kathryn M. G. Peek, Howard Isaacson, Kevin Apps, Michael Endl, William D. Cochran, Jeff A. Valenti, Jay Anderson, and Nikolai E. Piskunov.

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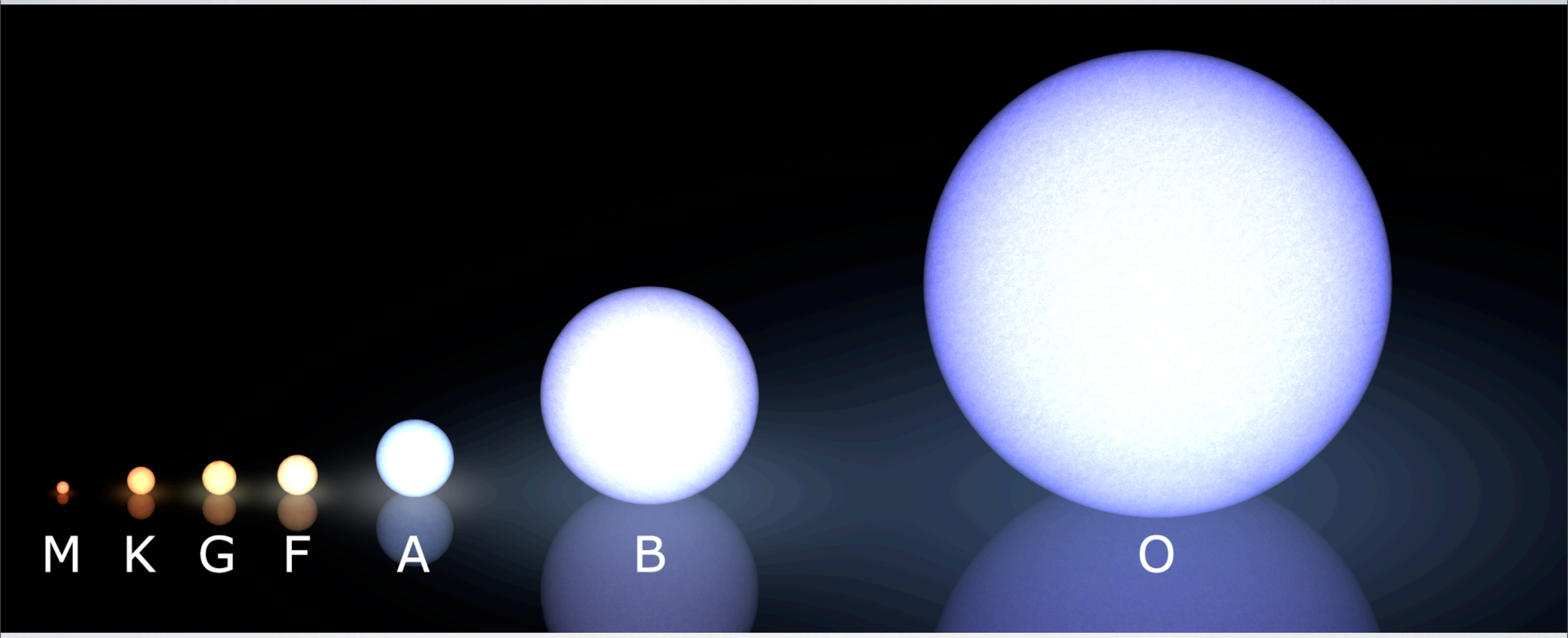
Summarized by Hazhar Ghaderi



MORGAN & KEENAN SPECTRAL CLASSIFICATION

Plan for the presentation

* The telescopes used, where they are located etc. No technical stuff.

* History and time-span of the project and the measurements.

* Graph of "Stable" stars.

* Graphs of the stars discussed in the paper in the following order:

    * HD 34445
    * HD 126614 A (part of a binary system)
    * HD 13931
    * GJ 179 (M-Dwarf)

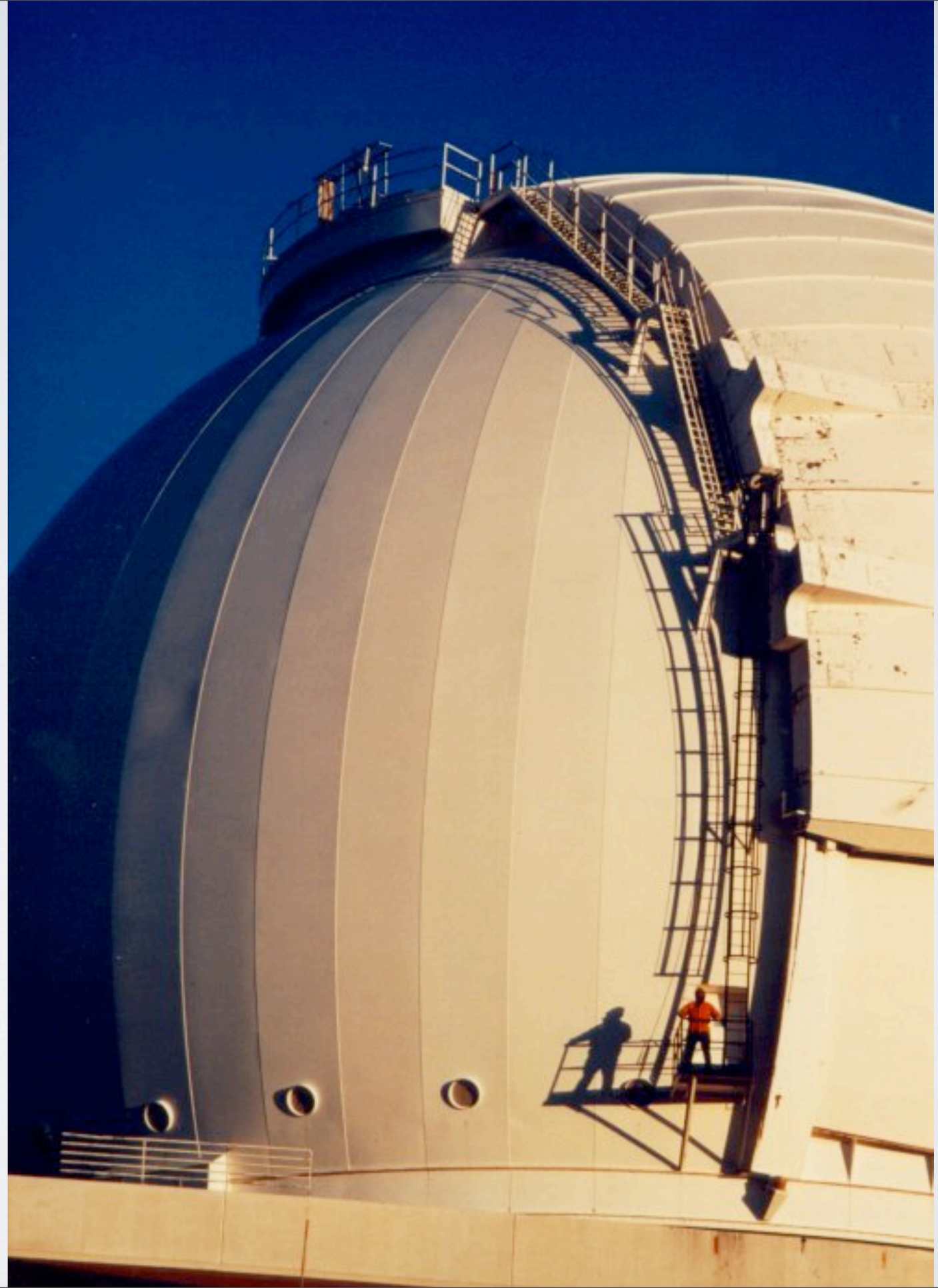
* Summary of the detected planets and some of their basic orbital properties.

    * HD 34445 b
    * HD 126614 Ab
    * HD 13931 b
    * GJ 179 b

Sunset over four telescopes of the Mauna Kea Observatories.
Keck I is the second from left.

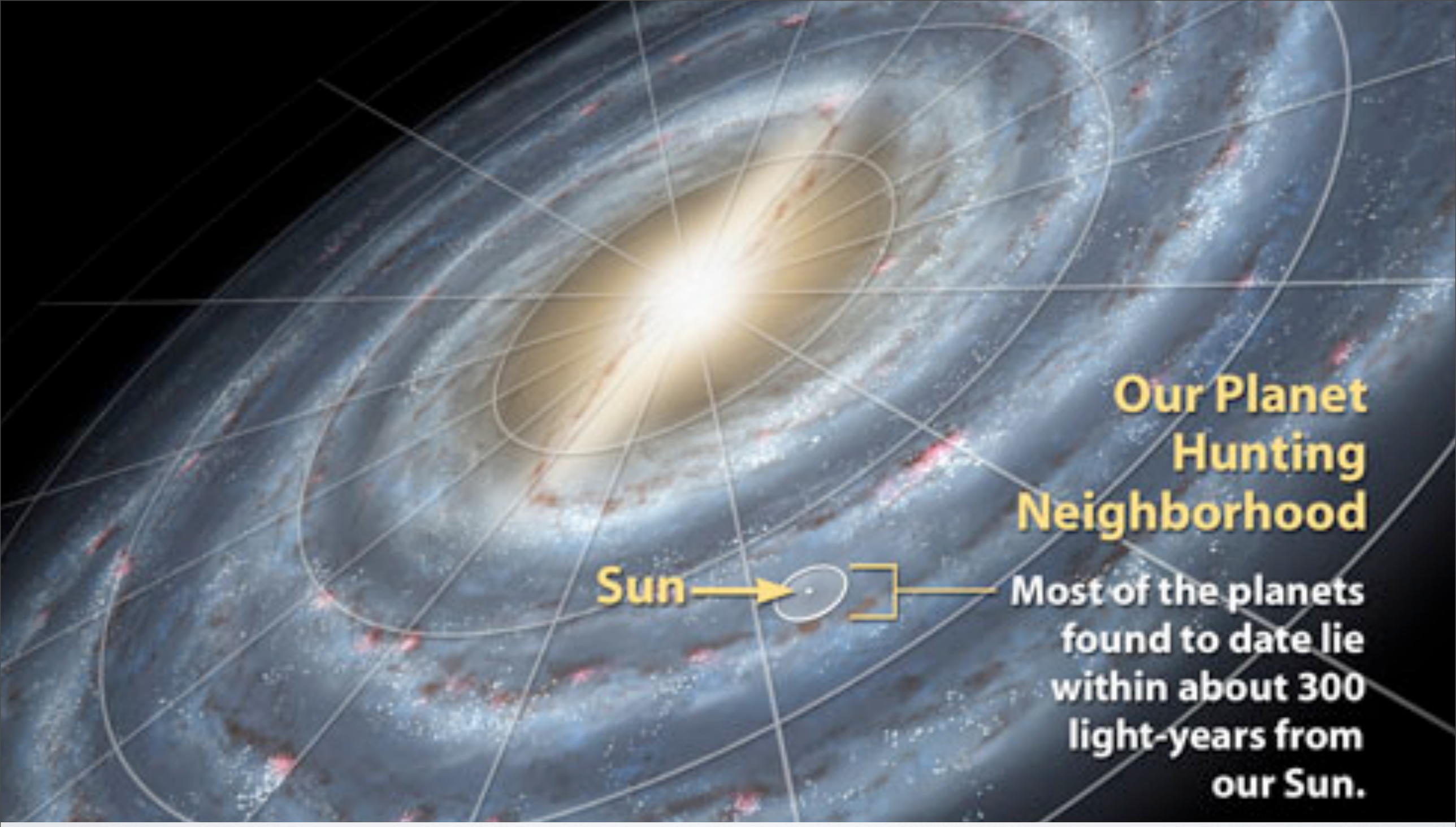
KECK I

Mirror diameter 10m



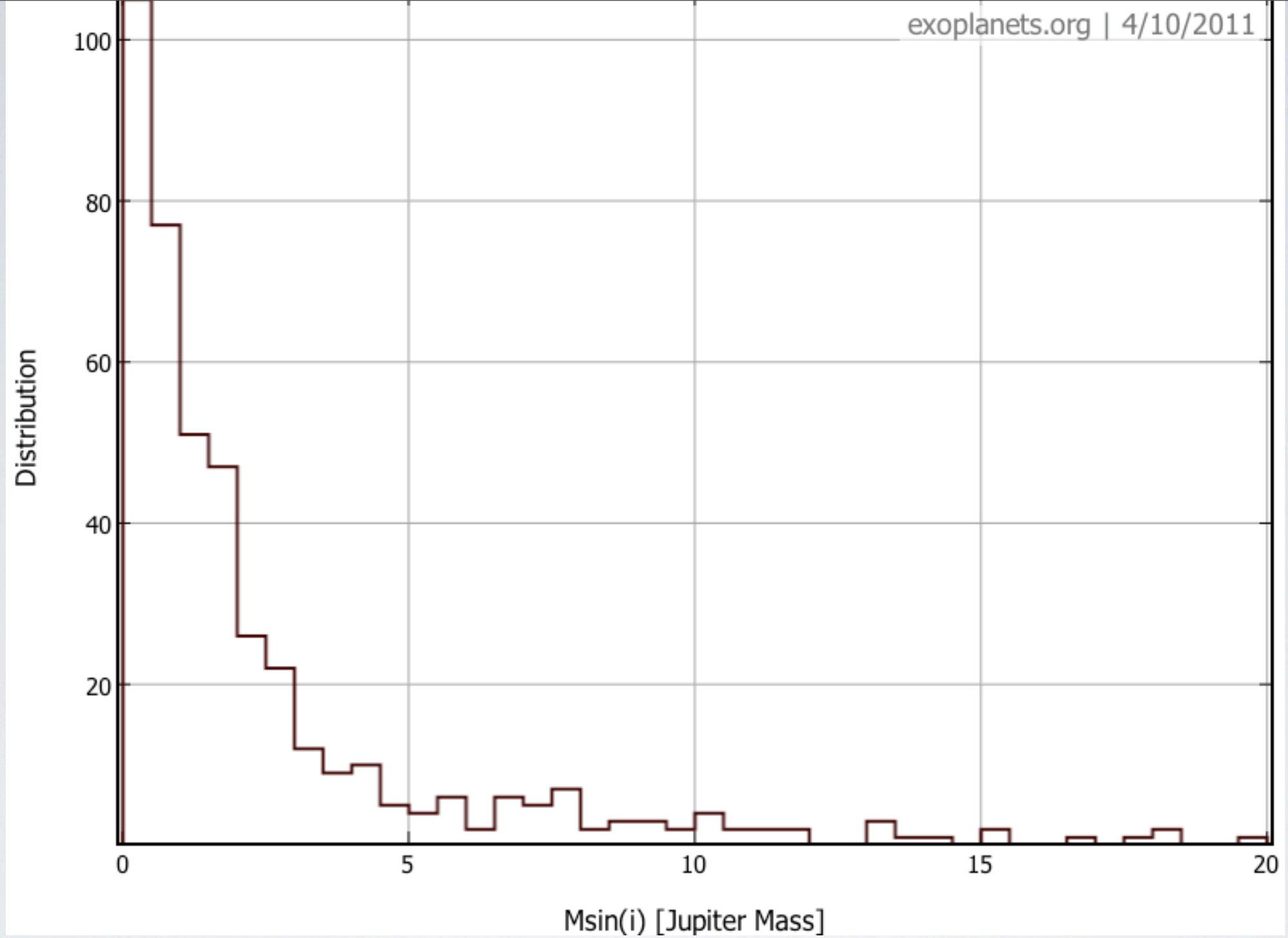
HOBBY-EBERLY TELESCOPE. (HET)

McDonald Observatory (Austin Texas).
Effective aperture 9.2m



SEARCH AREA

Our planet hunting neighborhood



OVER 400 CANDIDATES (2011)

* In **1997**, we began a Doppler search for giant planets in Jovian orbits at Keck Observatory.
We monitor over **1800 stars within 50 pc**, with special attention given to those **within 20 pc.**

* The analysis of Doppler completeness showed that **15%–18%** of all nearby stars have giant planets between 3 and 20 AU

* Out of the 1800 stars, 1330 of them were monitored from 1997
with a precision of **1-3 m/s**

Measurements and derivations

* Atmospheric parameters of the target stars were measured by LTE spectroscopic analysis of the Keck/HIRES spectra using the Spectroscopy Made Easy (**SME**) code of Valenti & Piskunov.

* The analysis yields a best-fit estimate of several important observables e.g. the effective temperature

* The luminosity of each star was determined from the apparent V-band magnitude, the bolometric correction and the parallax from Hipparcos.

* From the effective temperature and the luminosity one determines the stellar mass, radius, age estimate (from stellar models) and so on.

* For the star GJ 179 other methods were used, since its not hot enough for the SME.

MEASUREMENTS CONT'D.

* Using the HIRES echelle spectrometer mounted with an iodine cell in front of the spectrometer slit, the stars were observed 30-70 times each over 10-12 yrs.

* Typical exposure times: 100- 500 seconds.

* Two of the stars (HD34445 and GJ 179) were also observed with the HET.

"STABLE" STARS

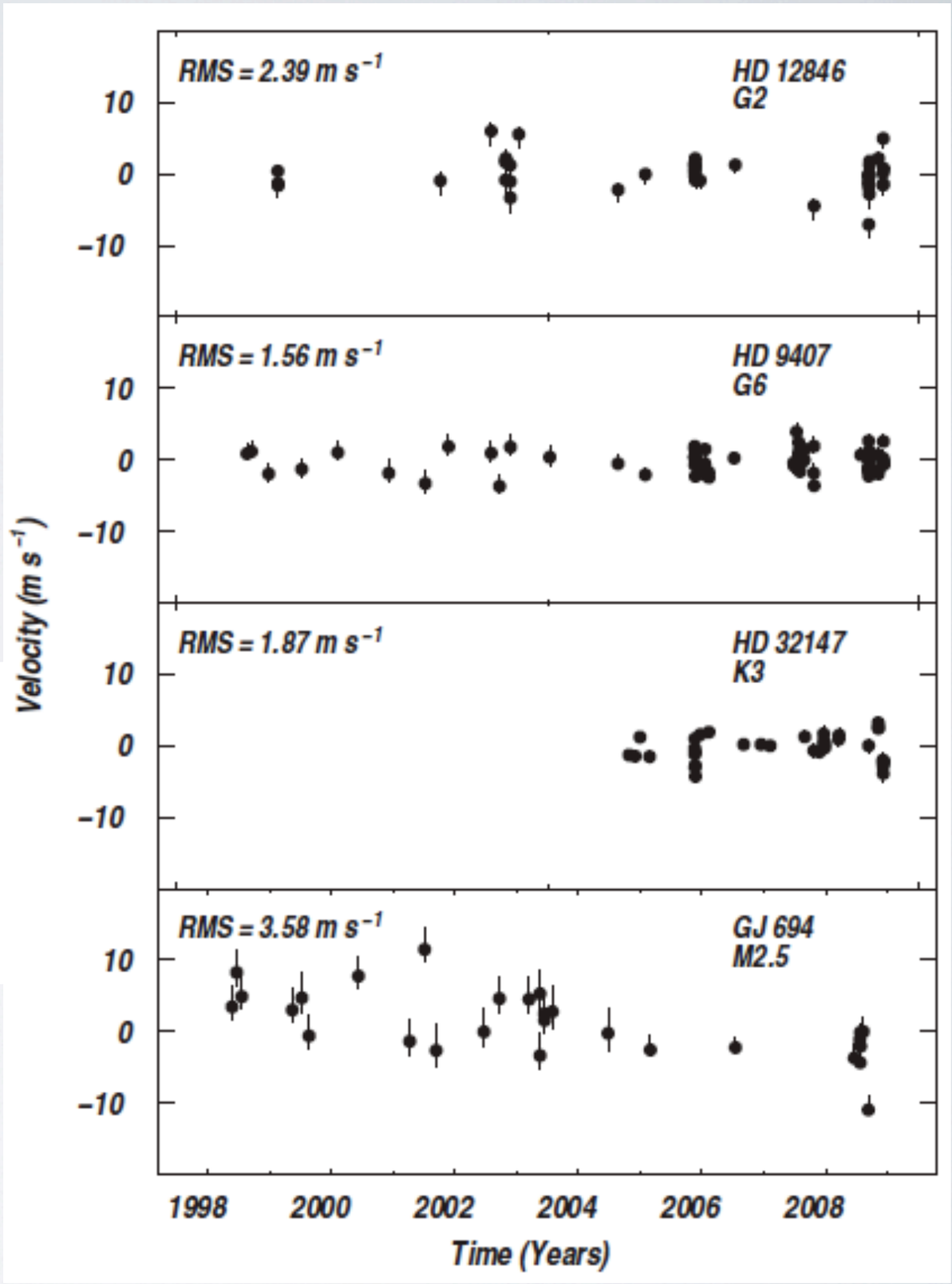


Figure 2. Radial velocity time series for four stable stars in our Keck Doppler survey. These stars demonstrate long-term velocity stability over a wide range of spectral types. Gl 694 (M2.5, V = 10.5) shows that our velocity precision is reduced around faint, late spectral type stars, but that it is sufficient to detect the planet around Gl 179 (M3.5, V = 11.96). The binned velocities with measurement uncertainties (but not jitter) are plotted. Panels are labeled with star name, spectral type, and rms to a linear fit.

* The star GJ 694 is faint and late spectral type hence larger error

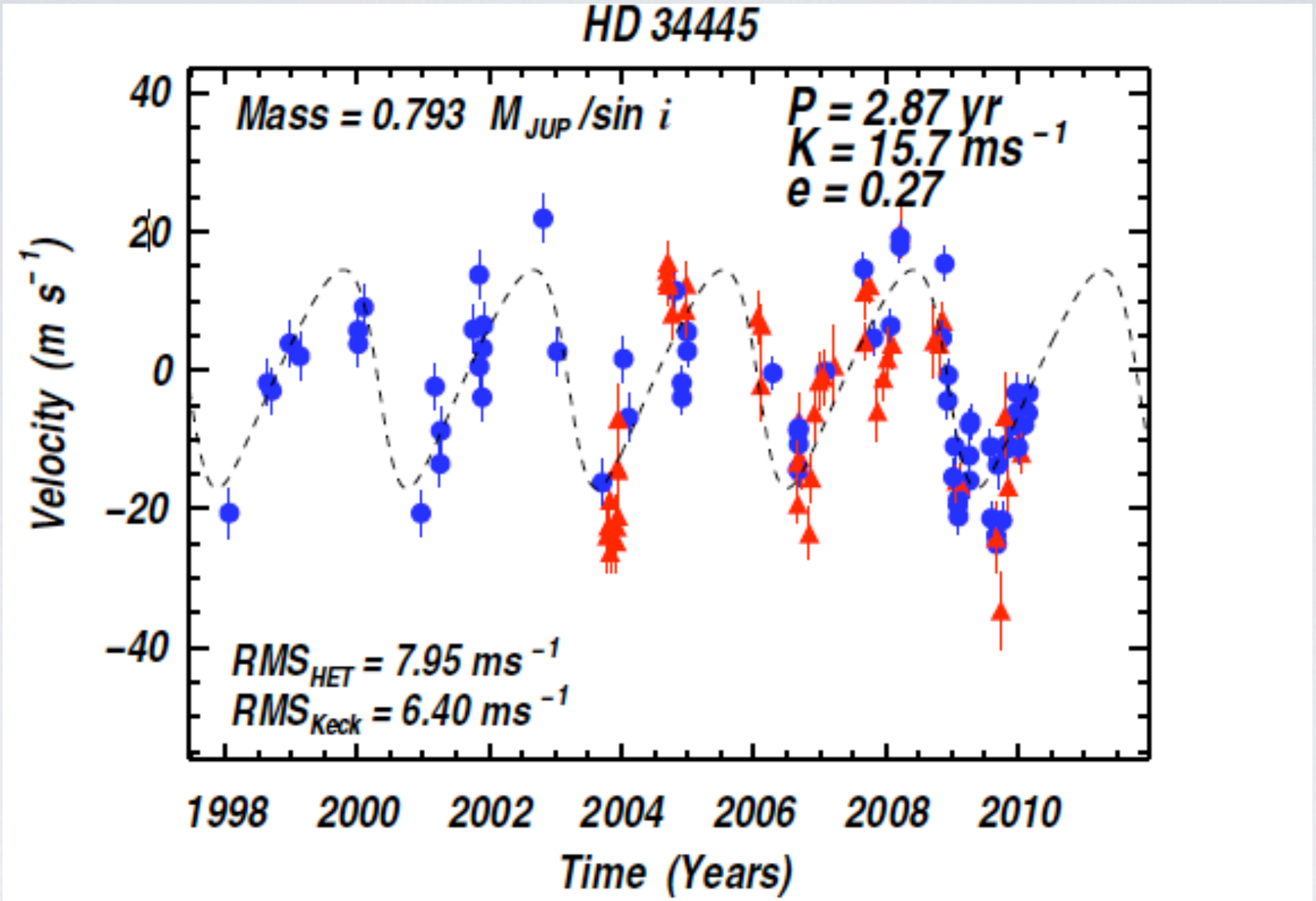


Figure 3. Measured velocity vs. time for HD 34445 with the associated best-fit Keplerian model (dashed line). Filled blue circles represent measurements from Keck, while filled red triangles represent HET measurements. The error bars show the quadrature sum of measurement uncertainties and jitter.

HD 34445

* Monitored 12 yr at Keck (blue) and 6 yr at HET (red).
* Period about 2.8 years.
* A single-planet Keplerian model would imply a planet of minimum mass M sin(i) = 0.79 M_Jup with a = 2.35 AU

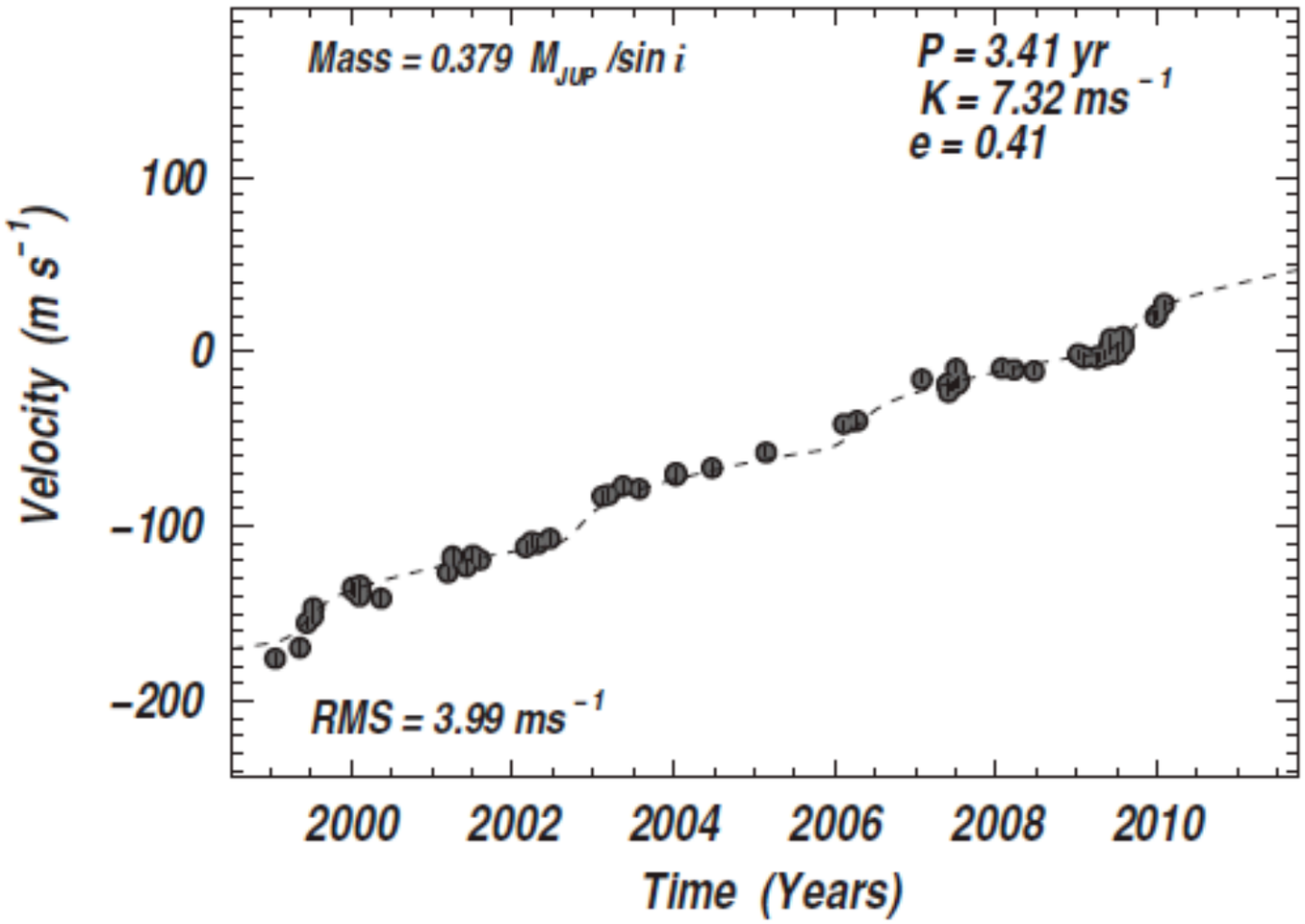


Figure 4. Measured velocity vs. time for HD 126614 A (filled circles) and best-fit Keplerian model (dashed line). The strong linear trend of $dv/dt = 16.2$ m s^{-1} yr^{-1} is clearly seen. The error bars that represent the quadrature sum of measurement uncertainties and jitter are not visible on this scale. These data are plotted again with the linear trend removed in Figure 5.

HD 126614 A

* Linear trend is observed (Relatively large 16.2 m/s yr). WHY?
* Probably due to a long-period stellar or a planetary companion. (Other alt. such as Secular accel. were ruled out since dv/dt ~ 0.1 m/s yr)

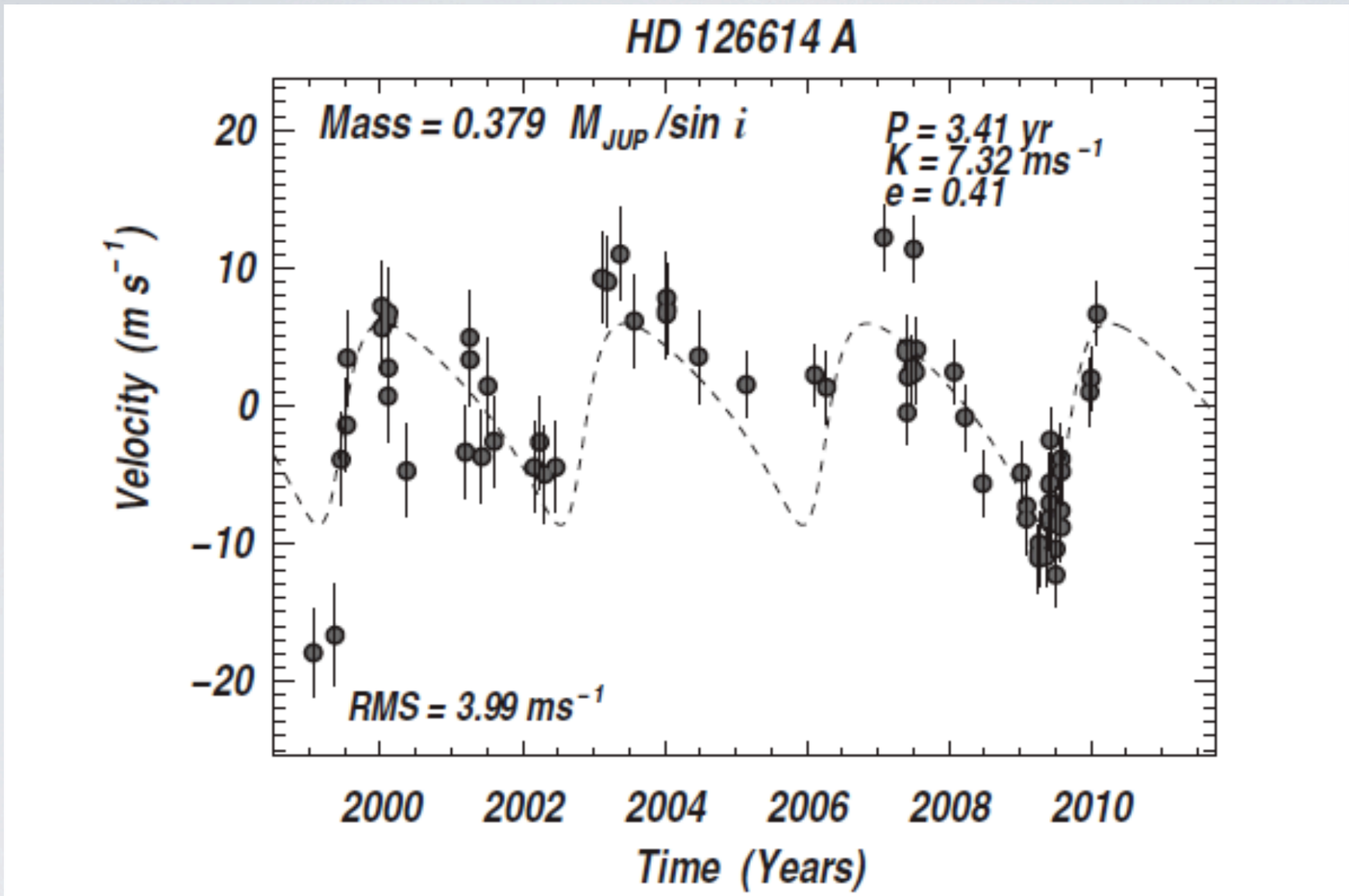


Figure 5. Same measured velocities (filled circles) and single planet Keplerian model (dashed line) for HD 126614 A as plotted in Figure 4, except the linear trend was subtracted before plotting.

HD 126614A

* Actually makes an binary system with the M-dwarf HD126614 B. This was not identified as such in the Draper & Hipparcos catalogs.
* Best-fit parameters imply a planet of minimum mass of M sin(i) = 0.38 M_jup, with a=2.35 AU.

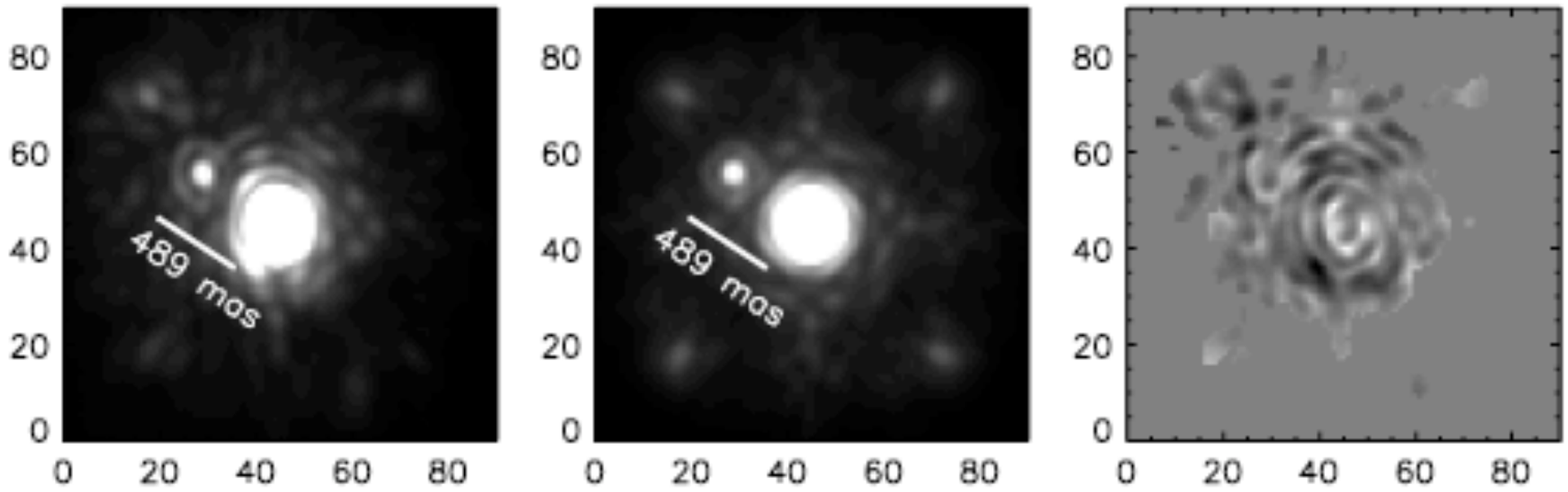


Figure 6. Direct observations with adaptive optics of HD 126614 A and HD 126614 B taken with the PHARO imager on Hale 200″ Telescope at Palomar Observatory. The three panels show K_s-band images of the target image (left), the best two-PSF fit (center), and fit residuals (right). Each image is oriented North-up and East-left. The fainter star, HD 126614 B, is clearly detected to the Northeast of the brighter target star, HD 126614 A. The vertical and horizontal axes of each image are labeled with detector pixels (the plate scale is 25.2 mas pixel^{-1}). The image gray scale has been chosen to highlight the companion, Airy rings, and diffraction spikes; the residuals (right panel) have been stretched by a factor of 150. The full width half-maximum of the AO-corrected PSF was ~100 mas in each band (with Strehl ratios of 30% in K_s band and 10% in J band).

HD 126614 A and B

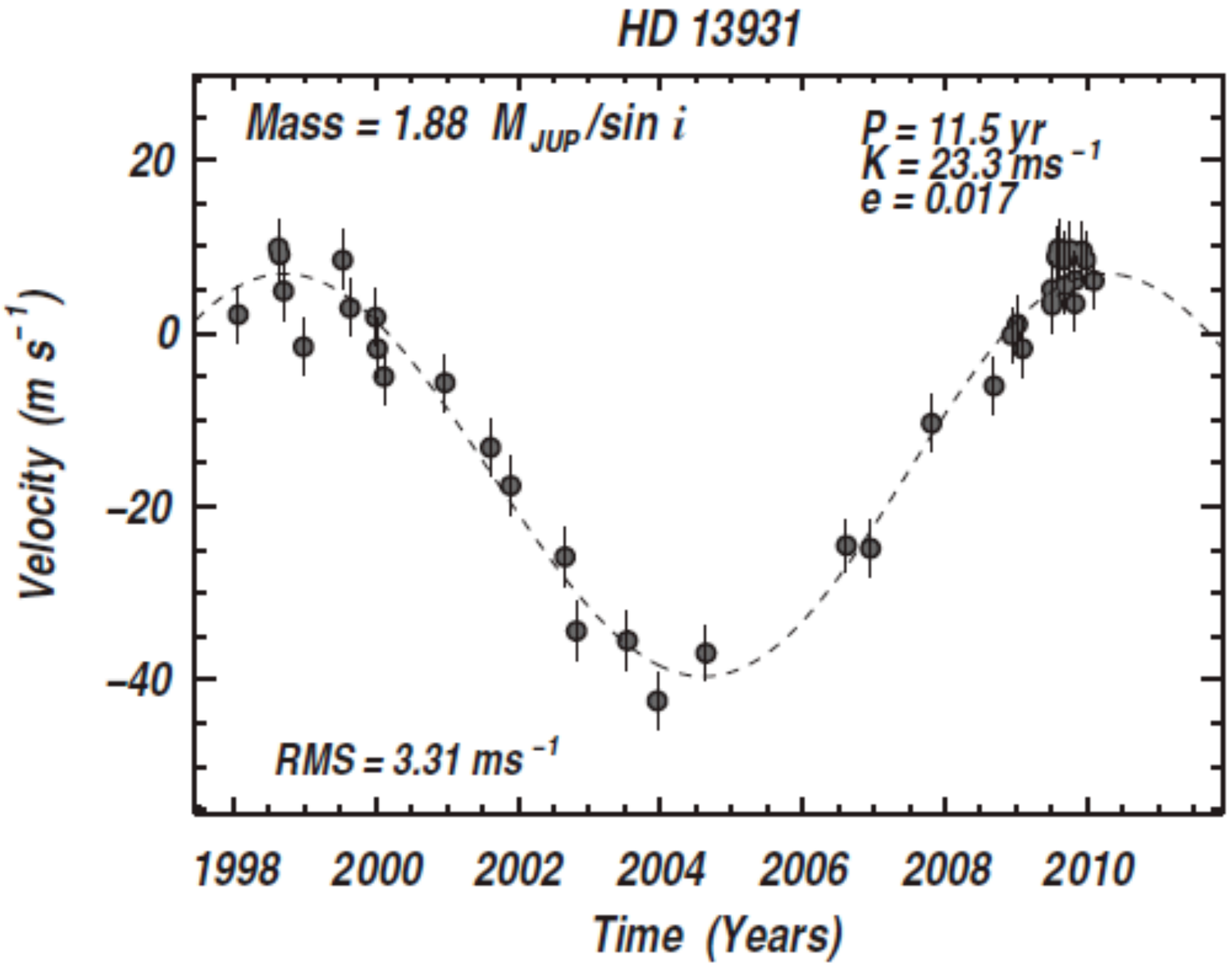


Figure 7. Measured velocity vs. time for HD 13191 (filled circles) with the associated best-fit Keplerian model (dashed line). The error bars show the quadrature sum of measurement uncertainties and jitter.

HD 13931

* The bestfit singel-planet Keplerian model with P = 11.5 ± 1.1 yr (and e = 0.02, K = 23.3 m/s) imply a planet of minimum mass M sin(i) = 1.88 M_Jup orbiting with semimajor axis a = 5.15 AU

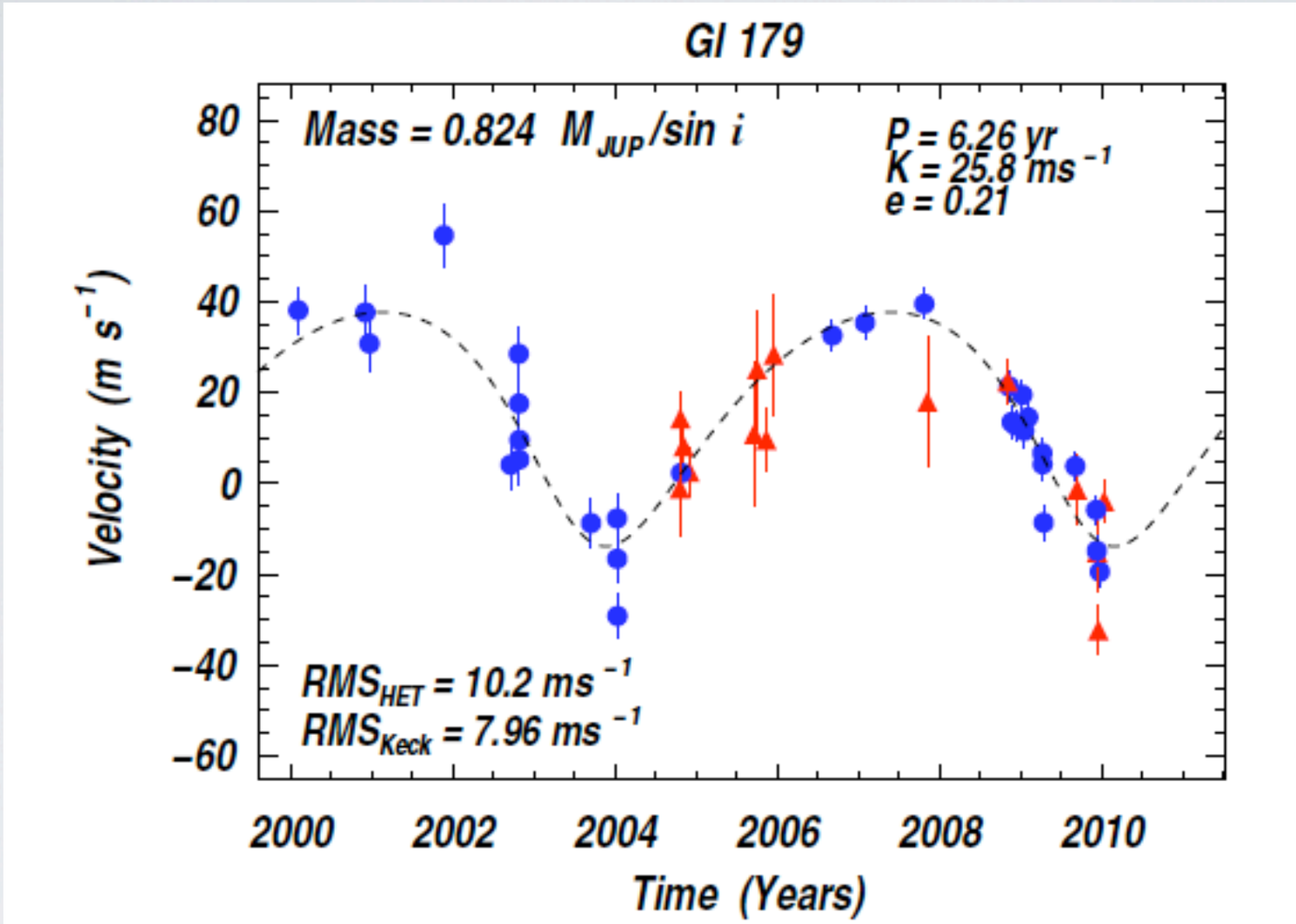


Figure 8. Measured velocity vs. time for Gl 179 (filled circles) with the associated best-fit Keplerian model (dashed line). Filled blue circles represent measurements from Keck, while filled red triangles represent HET measurements. The error bars show the quadrature sum of measurement uncertainties and jitter.

GJ 179

Finally:

* Since GJ 179 is a faint M-Dwarf, the measurements have lower signal to noise ratios and larger uncertainties compared with the other stars above.

* Best-fit of parameters yield a planet of minimum mass M sin(i) = 0.82 M_Jup, a = 2.41 AU.

* The relatively large value of the fluctuations in the statistics of this M-Dwarf gives a hint that there might be additional planets in this system. Observations of this system will be continued in search for additional planets.

Summary of the detected planets

HD 34445 b

* A massive planet **M sin(i) = 0.79 M_Jup**.
* Mildly eccentric **e= 0.27**, long period **P = 2.87 yr**.
* Orbiting around an old G0 dwarf.
* Relatively large residuals to the one-planet fit (rms = 6-7 m/s) hint a second unresolved planet in the system.

HD 126614 Ab

* A massive planet (**M sin i = 0.38 M_Jup**)
* Long-period (**P = 3.41 yr**), eccentric (**e = 0.41**) orbit around an extremely **metal-rich star**.

HD 126614 A has the highest metallicity of the 1040 stars
in the SPOCS catalog.

Measurements (metalicity of) on this star along with the detection of HD 126614 Ab, add statistical weight to the strong positive correlation between **giant planet occurrence and metallicity**

In addition to the planet orbiting HD 126614 A, **a faint M-dwarf companion was detected** using AO and the PHARO camera
at Palomar Observatory. This previously undiscovered star, HD 126614 B, has an estimated mass of 0.32M⊙ and is separated from HD 126614 A by 489 mas at position angle 56.1 deg. This corresponds to a projected separation
of 33 AU. Compare with semi-major of Neptune ~30 AU

HD 13931 b

* Is reminiscent of Jupiter in orbital period (P =11.5 yr), eccentricity (e = 0.02), and to a lesser extent mass (M sin i = 1.88 MJup).

* The host star, HD 13931, is also similar to the Sun in mass (M= 1.02 M⊙) and metallicity. HD 13931 b is one of only four known RV-detected planets with orbital periods longer than 10 yr. The other such planets are all in multi-planet systems.

GJ 179 b

* Is a Jovian-mass (M sin i = 0.82 MJup) planet in a long-period (P = 6.3 yr) orbit.

* The host star, GJ 179, is one of only ~ 10 M-dwarfs currently known to host a planet and is among the faintest (V = 11.96) [compare Sun V ~4.8] stars with a planet discovered by RV measurements.

*This planet is detected in the Keck velocities alone, but without the HET measurements, the orbital parameters, especially eccentricity and minimum mass, would be determined more poorly.