Limits on Planetary Companions from Doppler Surveys of Nearby Stars

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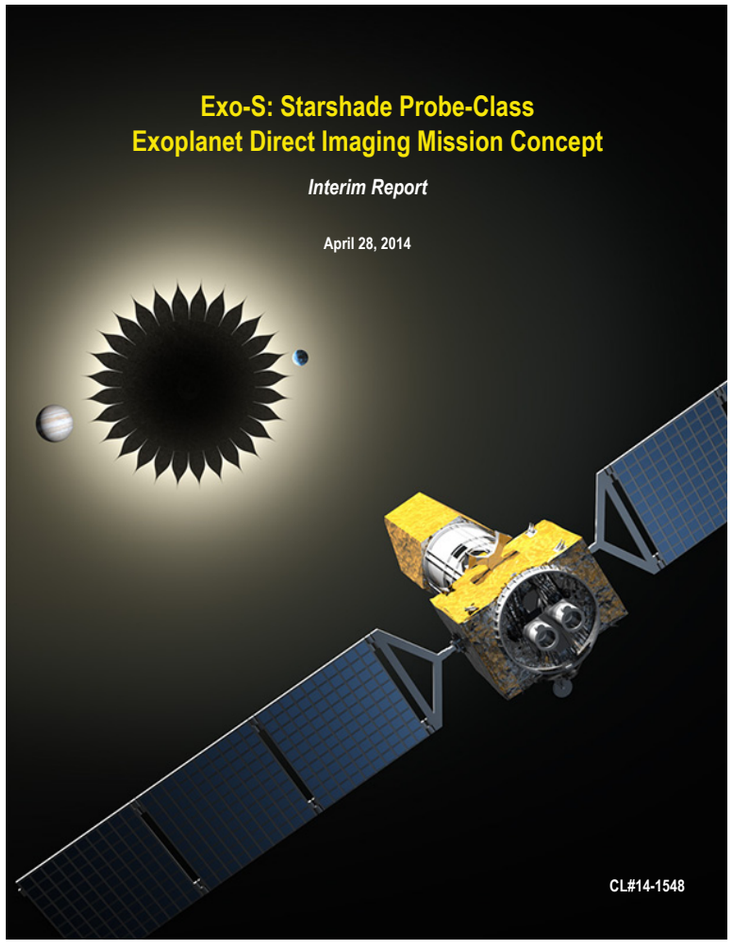
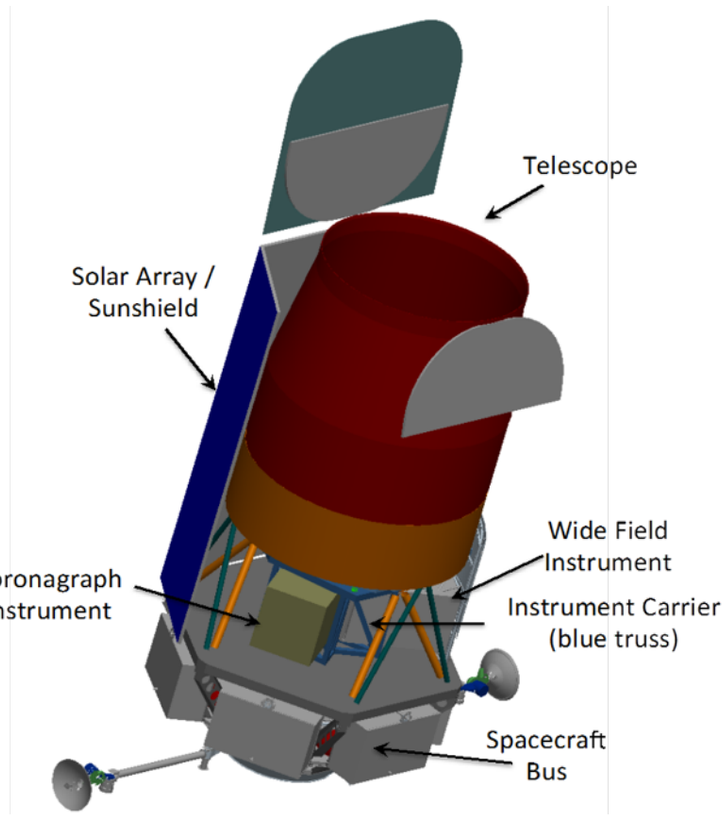
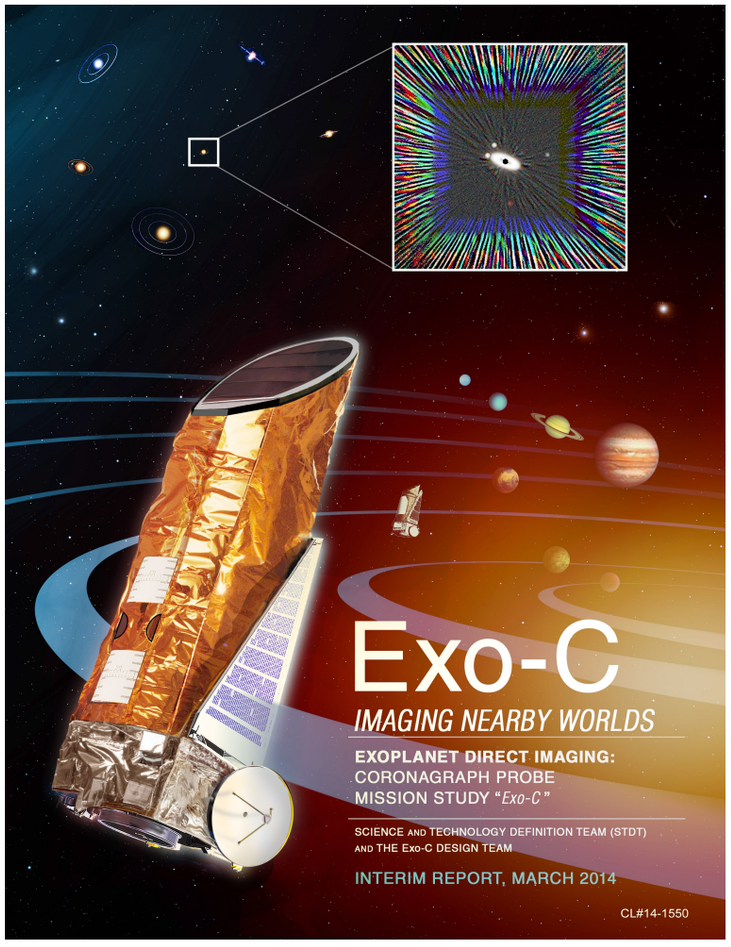
High-Contrast Imaging Mission Studies







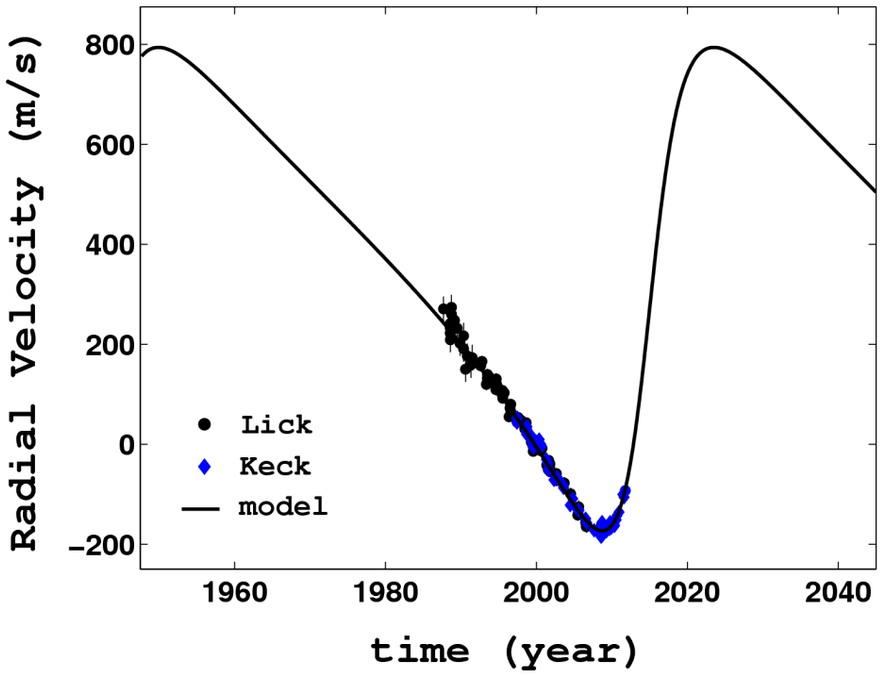
Exo-S (Starshade)

WFIRST/AFTA

Exo-C (Coronagraph)

Doppler / High-contrast Imaging Synergy

RV Detection



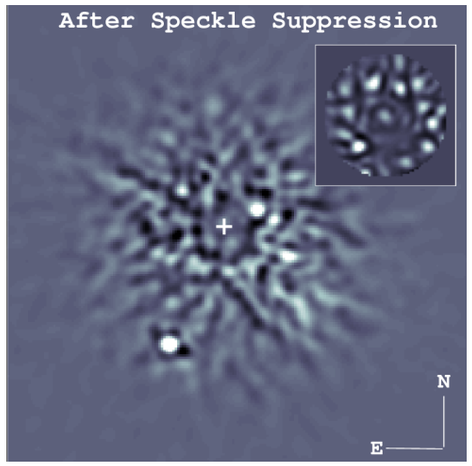
Doppler Measurements Provide:

Target Identification
Target Exclusion (non-detection limits)
Dynamical Masses

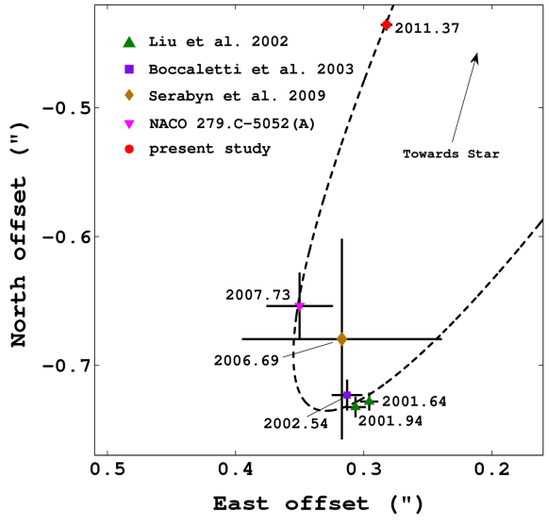
RV / Imaging Synergy:

Brown Dwarf discovery & characterization
e.g. HR 7672 - Crepp+ 2012; Liu+ 2002
RV trend → imaging → spectra / mass

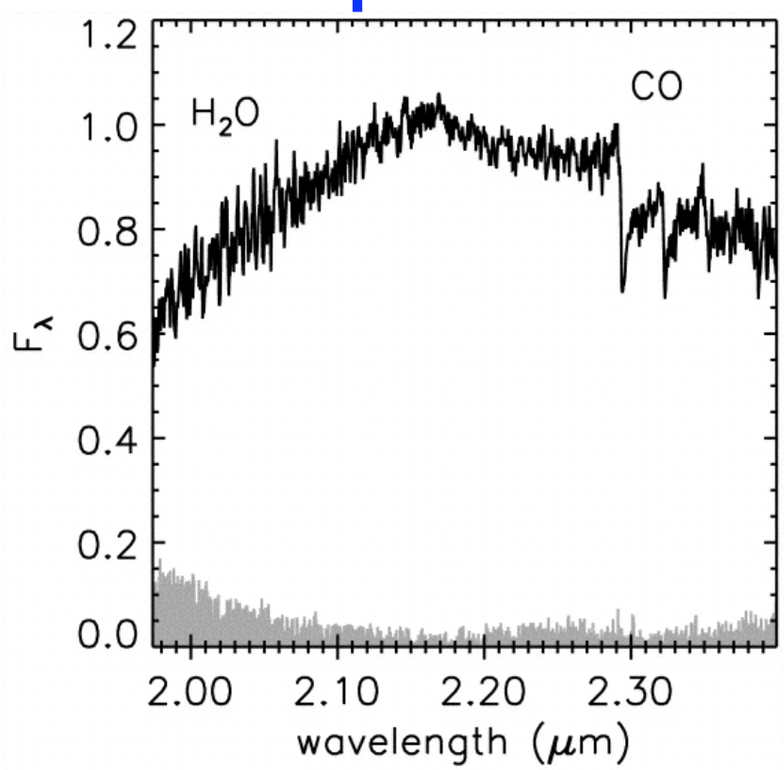
Direct Image



Astrometry

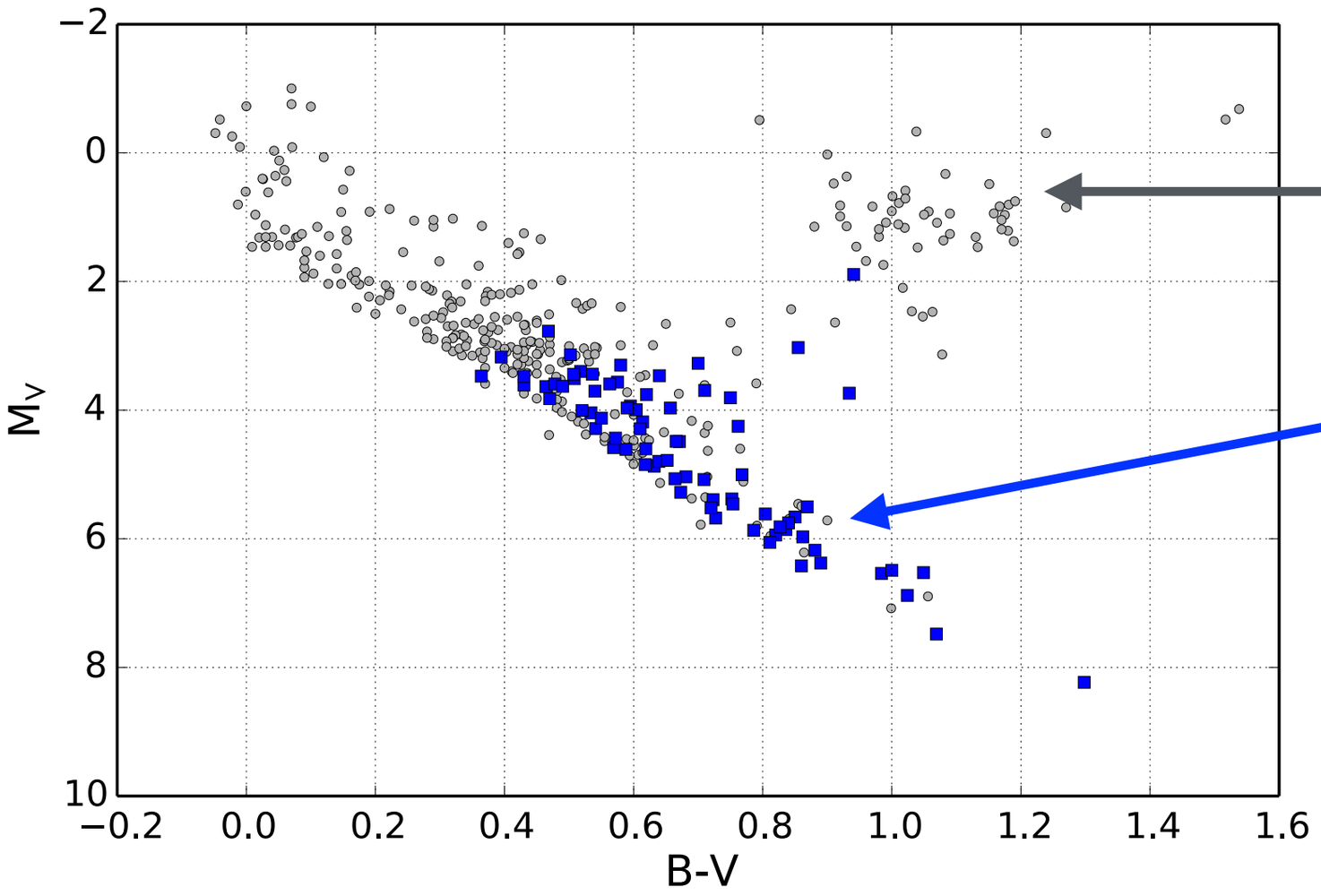


Spectrum



Star Lists and Data

Lick and Keck Observatory Star Lists



No Keck/Lick RVs
300 stars

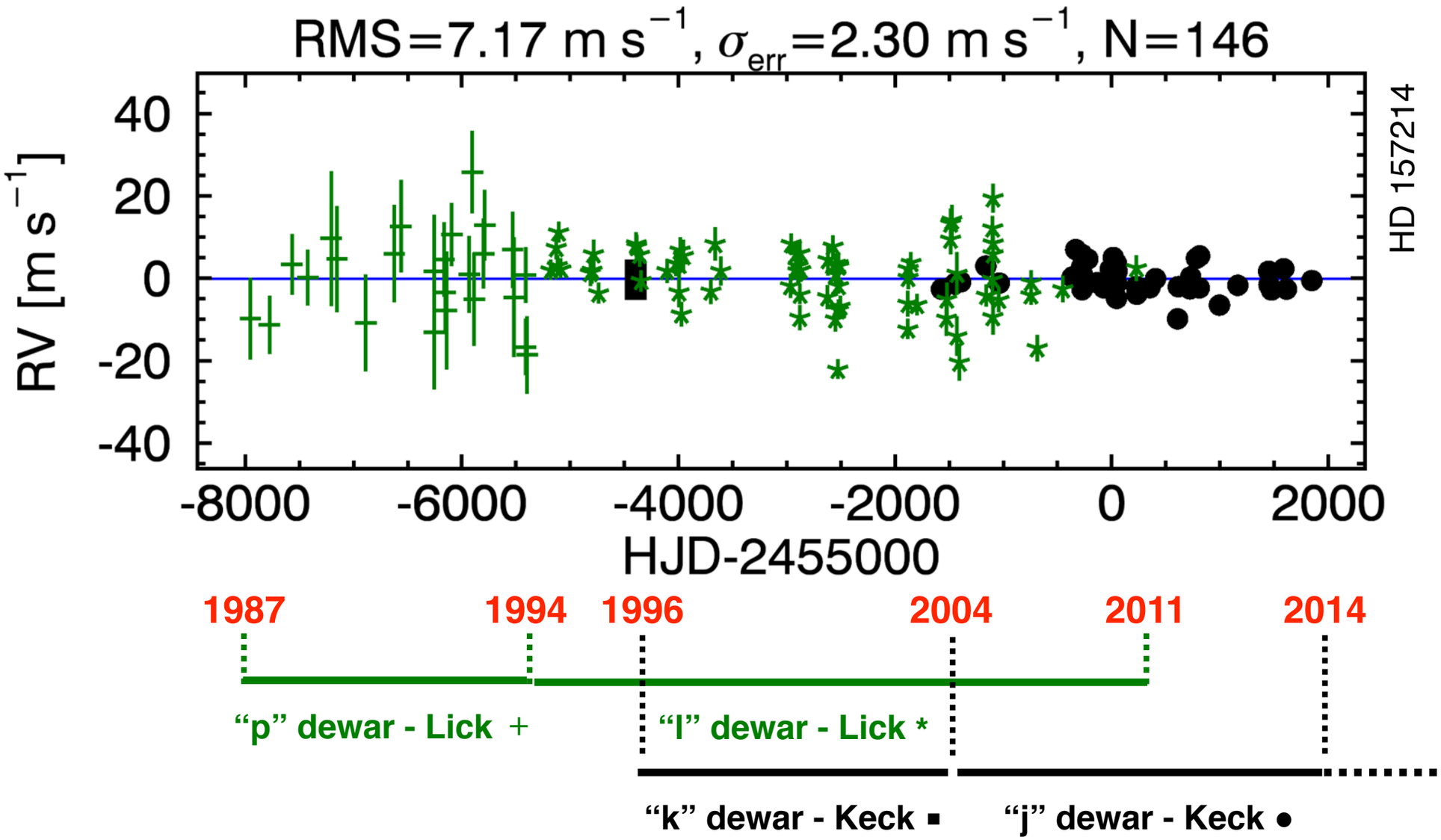
With Keck/Lick RVs
76 stars

<u>Excluded from Lick/Keck Search:</u>

1. Southern Hemisphere ($\delta \lessapprox$ -30-40°)
2. Early spectral type (< ~F8)
3. Evolved (subgiants & giants)
4. Young and active
5. Binaries (sep < 2”)

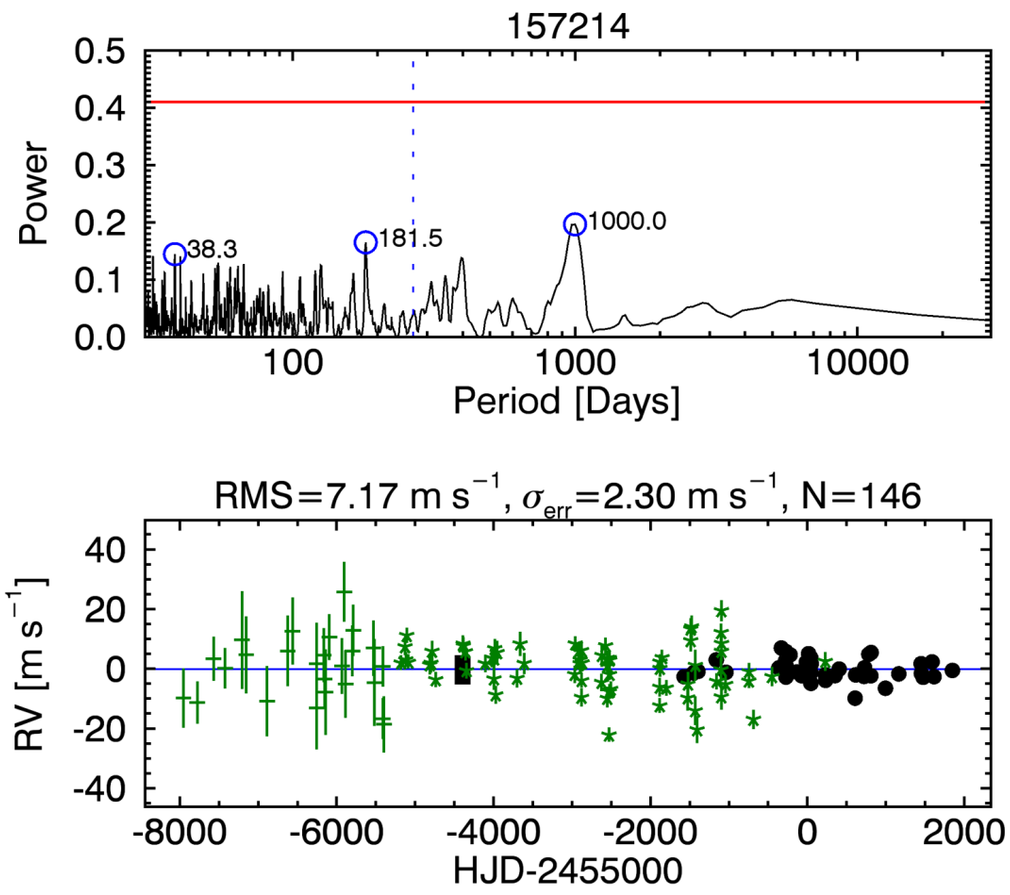
Star Lists and Data

Lick and Keck Observatory Data

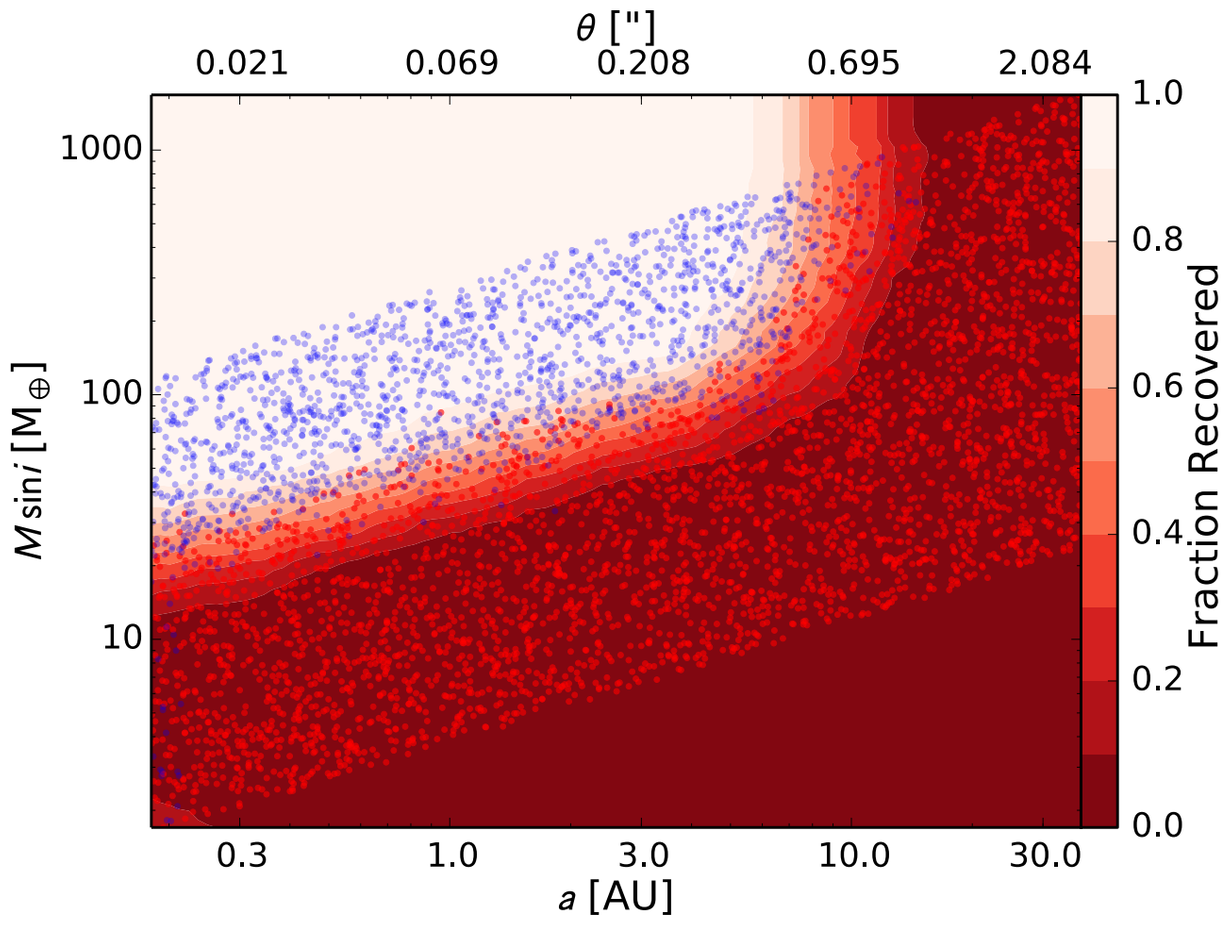


Automated Search & Completeness

HD 157214



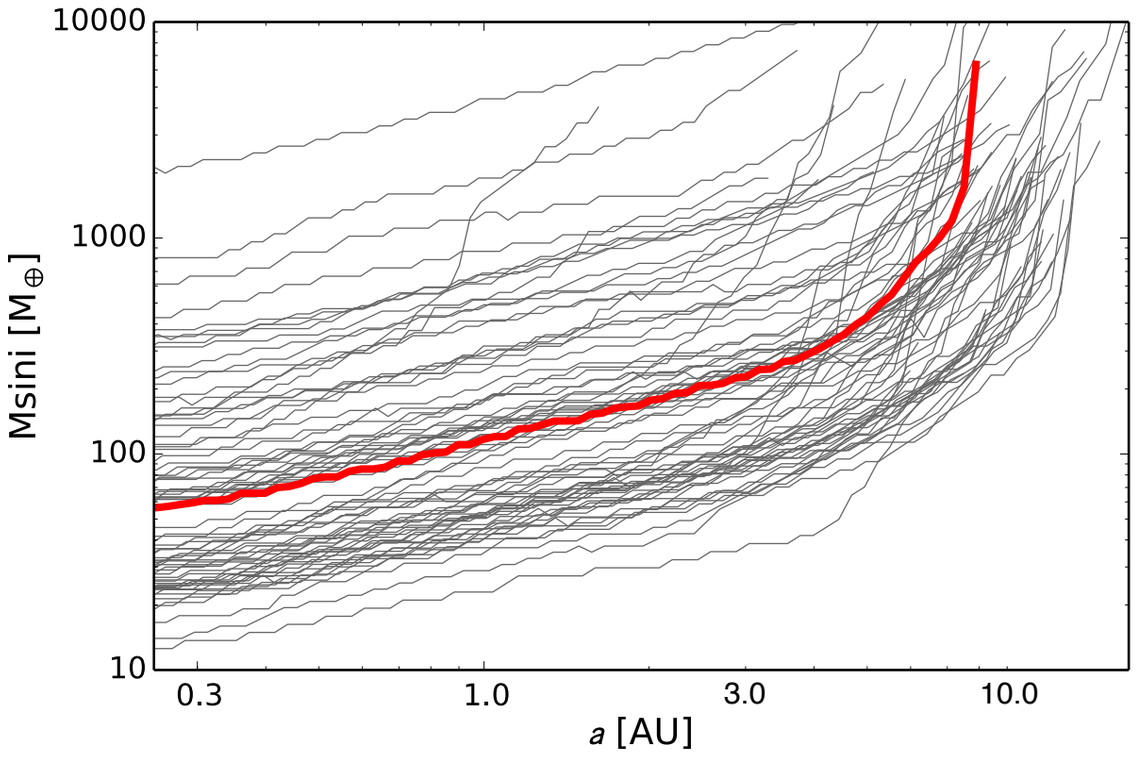
RV Time Series & Periodogram



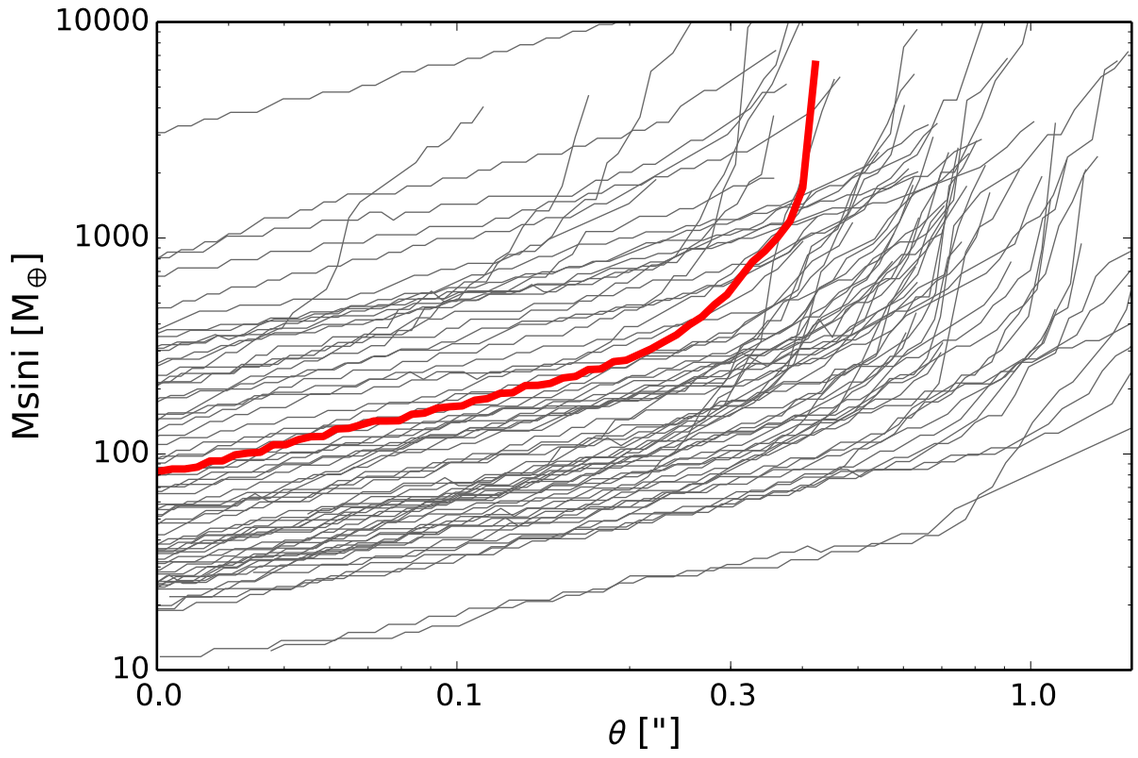
Completeness Limits

Survey Completeness

Completeness vs. Semi-major axis



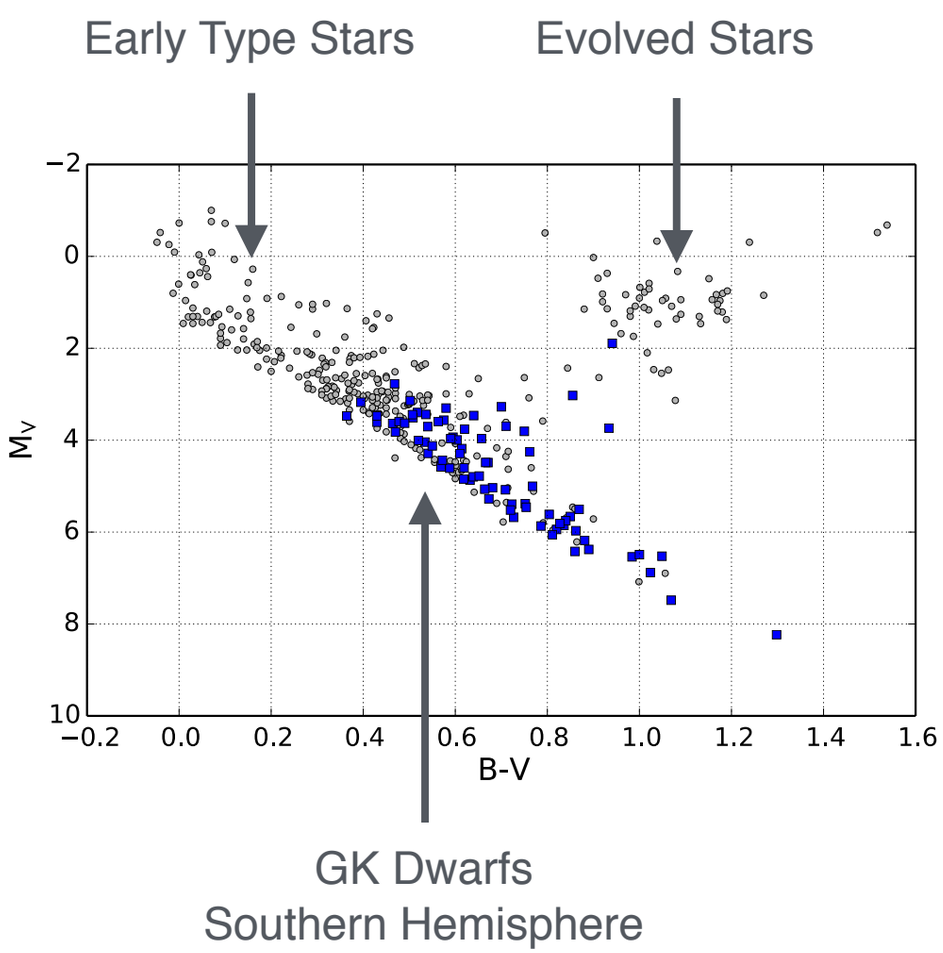
Completeness vs. Projected Separation



Completeness for all 76 Stars with RV Data

What about the Missed Stars?

Jitter Estimates - σ_{RV}



Early Spectral Type (hot, < ~F8):

few and broad lines

$\sigma_{RV} \approx 0.16 * V\sin i^{1.5}$

Evolved Stars (subgiants, giants):

oscillations

$\sigma_{RV} \approx v_{osc} = 0.234(L_\star/M_\star)$ m/s

Southern Hemishere (GK dwarfs):

< 3 m/s; limited by spectrometer?

Young Stars:

line distortions; rotational spot modulation

100 m/s → < 3 m/s (function of $\log R'_{HK}$)

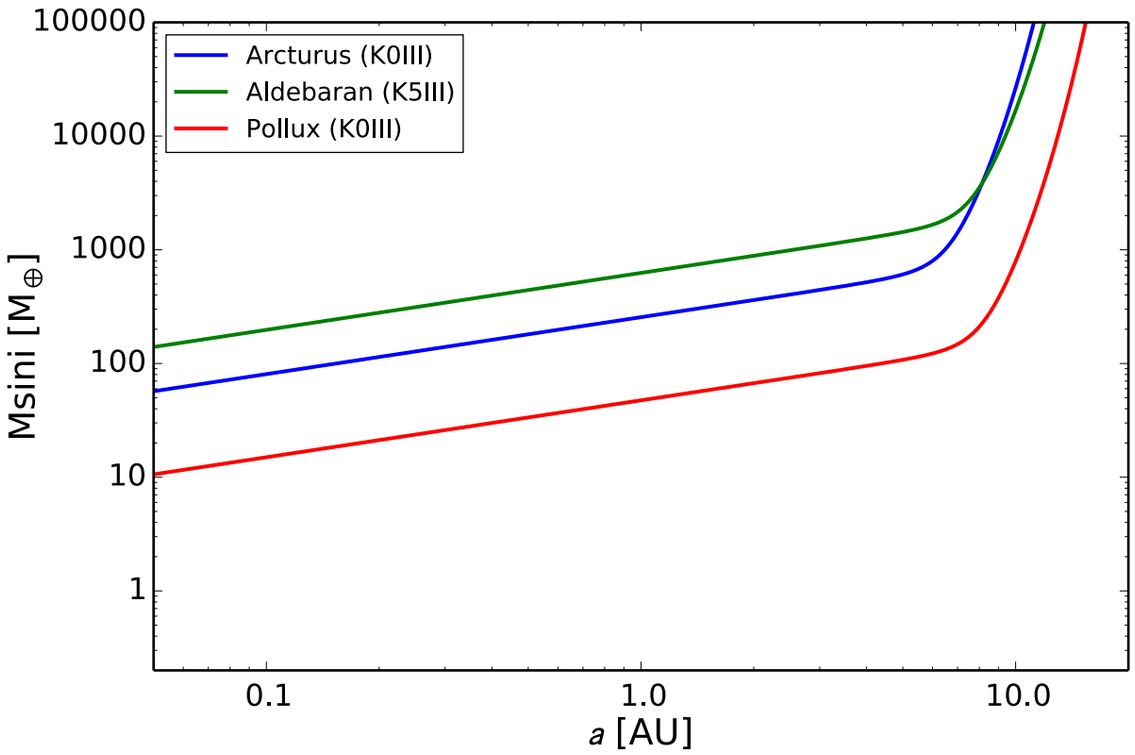
Binaries:

too hard, not recommended

Projected Sensitivity:
A Dedicated RV Campaign for the Missed Stars

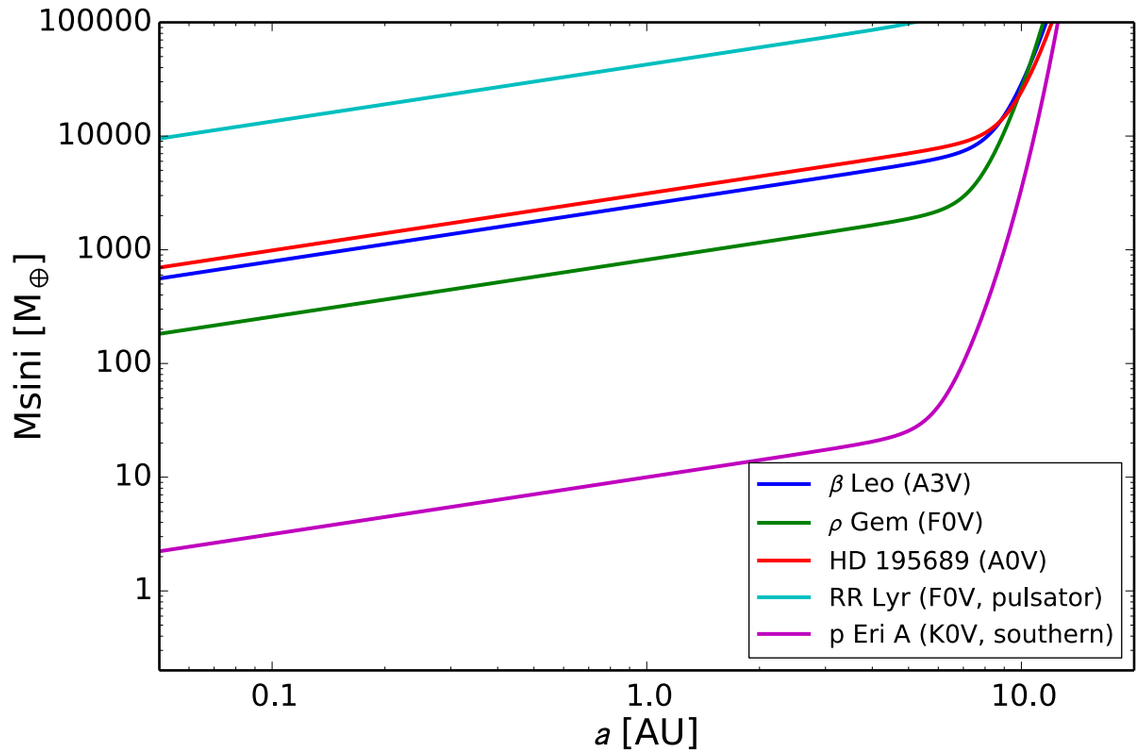
Giant Stars

Sensitivity: Jupiters/Saturns at ~1-5 AU



Hot Stars

Sensitivity: super-Jupiters/BDs at ~1-5 AU



Survey Parameters:

σ_{RV} estimated for each star

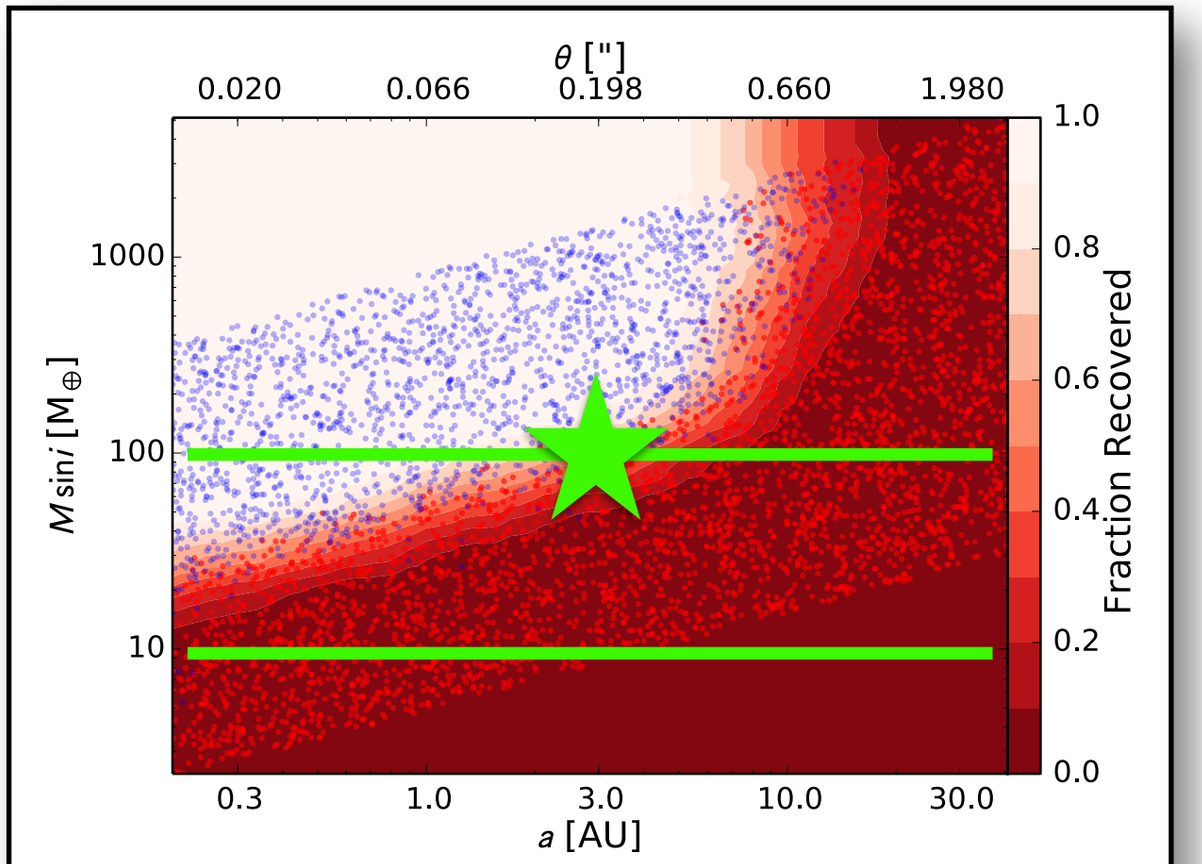
N_{obs} = 100 RVs

T_{span} = 10 yr

α = 6

Sensitivity Gain

HD 182572 (G8 dwarf, 15 pc)

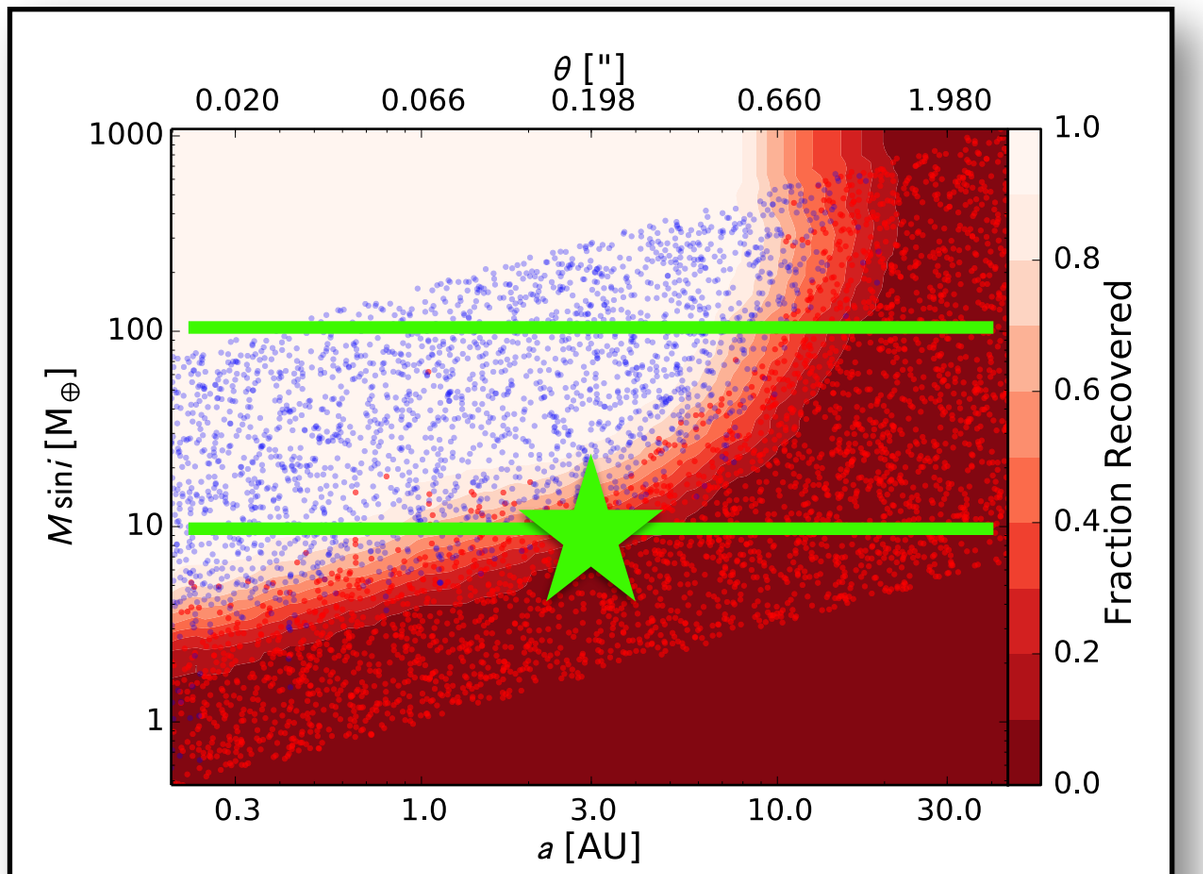


Current RVs:

N_{obs} = 82 RVs

T_{span} = 17.8 yr

σ_{RV} = 4.0 m/s



Ideal Survey:

N_{obs} = 82 + 100 RVs

T_{span} = 17.8 yr + 10 yr

σ_{RV} = 0.5 m/s (new RVs)

Recommendations

Long-term RV Surveys - Fading!

Difficult to get telescope time & funding

1. Include Doppler Measurements in Mission Requirements

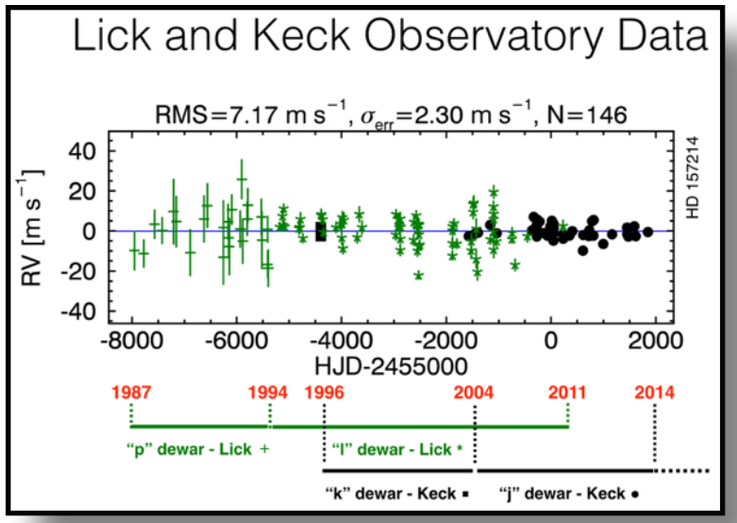
2. Invest in a Dedicated RV Facility and for pre-imaging survey

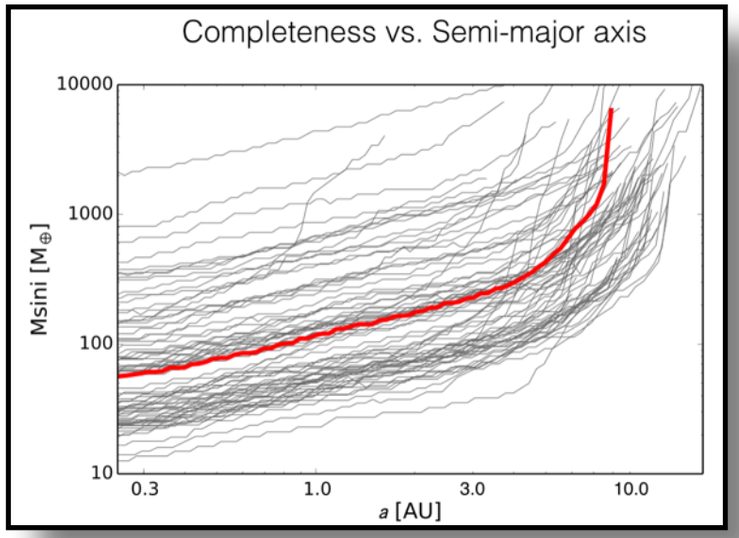
3. Measure the Jitter (σ_{RV}) of every plausible direct imaging target.

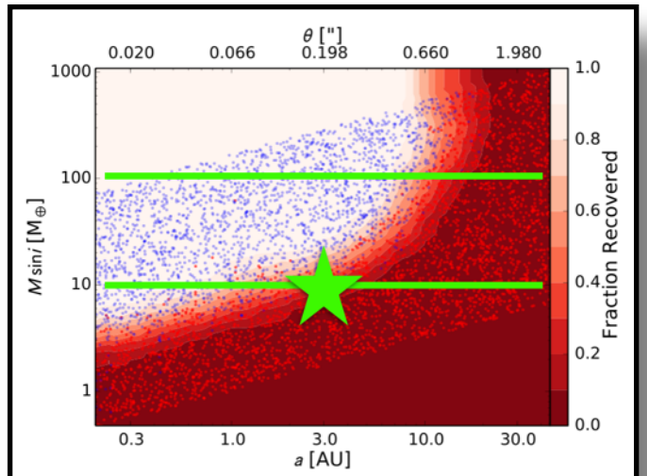

Photo: Laurie Hatch


Photo: Ethan Tweedie

Summary

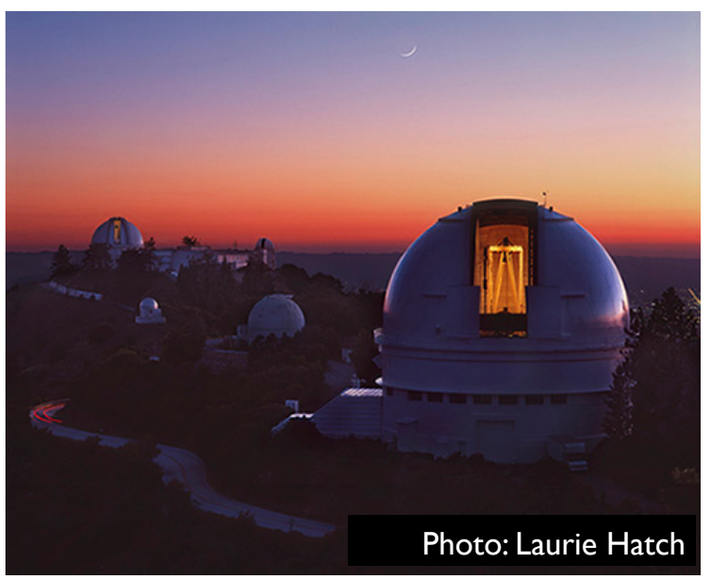






Ideal Survey:
N_{obs} = 82 + 100 RVs
T_{span} = 17.8 yr + 10 yr
σ_{RV} = 0.5 m/s (new RVs)

Recommendation: Include Doppler Measurements in Mission Requirements



Extra Slides

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Idealized Completeness

Prescription for Computing Completeness for Hypothetical Observing Campaign

1. Choose N_{obs} and T_{span} for survey and $M_\star$ and σ_{RV} for stars.
2. Compute $K_{50}(P)$
3. Convert $K_{50}(P)$ to $Msini_{50}(P)$
4. Convert $Msini_{50}(P)$ to $Msini_{50}(a)$

$$K_{50}(\tau) = \frac{\sigma_{\mathrm{RV}}\,\alpha}{\sqrt{N_{\mathrm{obs}}}} \cdot \sqrt{1 + (10^{\tau - 1.5})^2}$$

What is σ_{RV} for Exo-C/Exo-S/AFTA Target Stars?

Idealized Completeness

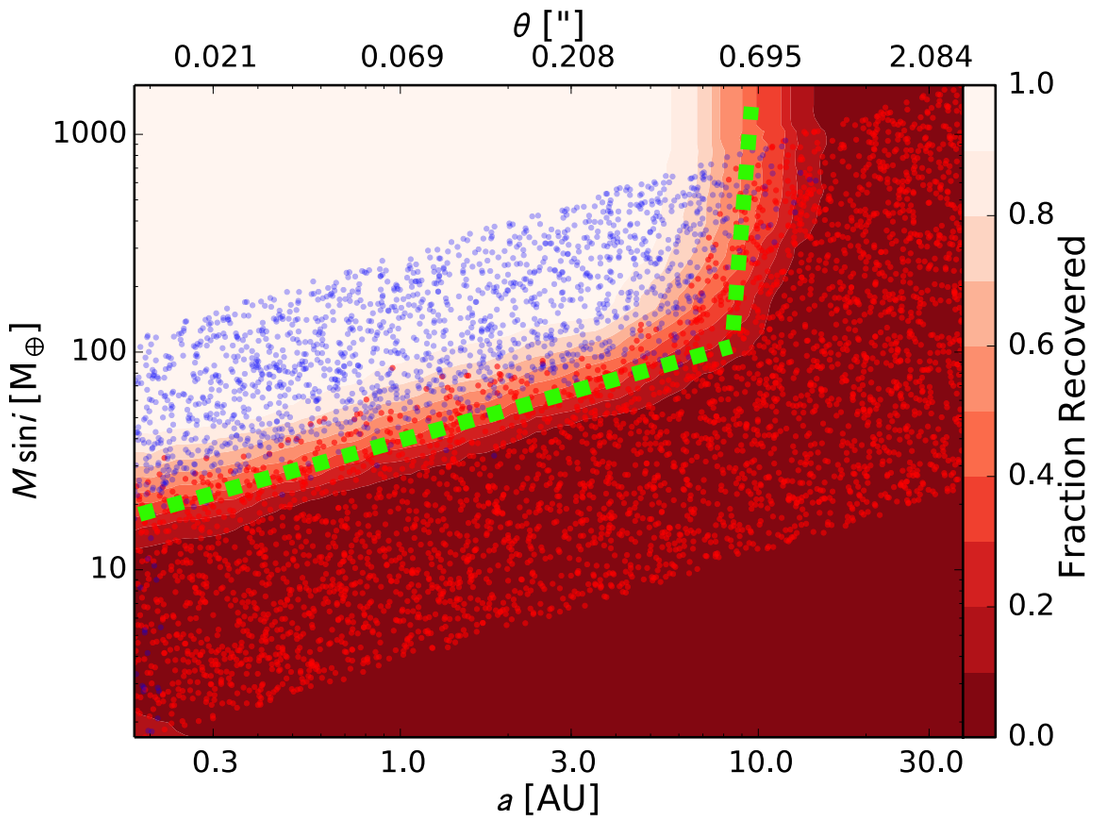
50% Detection Completeness

RV Precision

$$K_{50} = \alpha \frac{\sigma_{\mathrm{RV}}}{\sqrt{N_{\mathrm{obs}}}}$$

What is α?

Number of RVs



α = SNR of a successful detection

Idealized Completeness

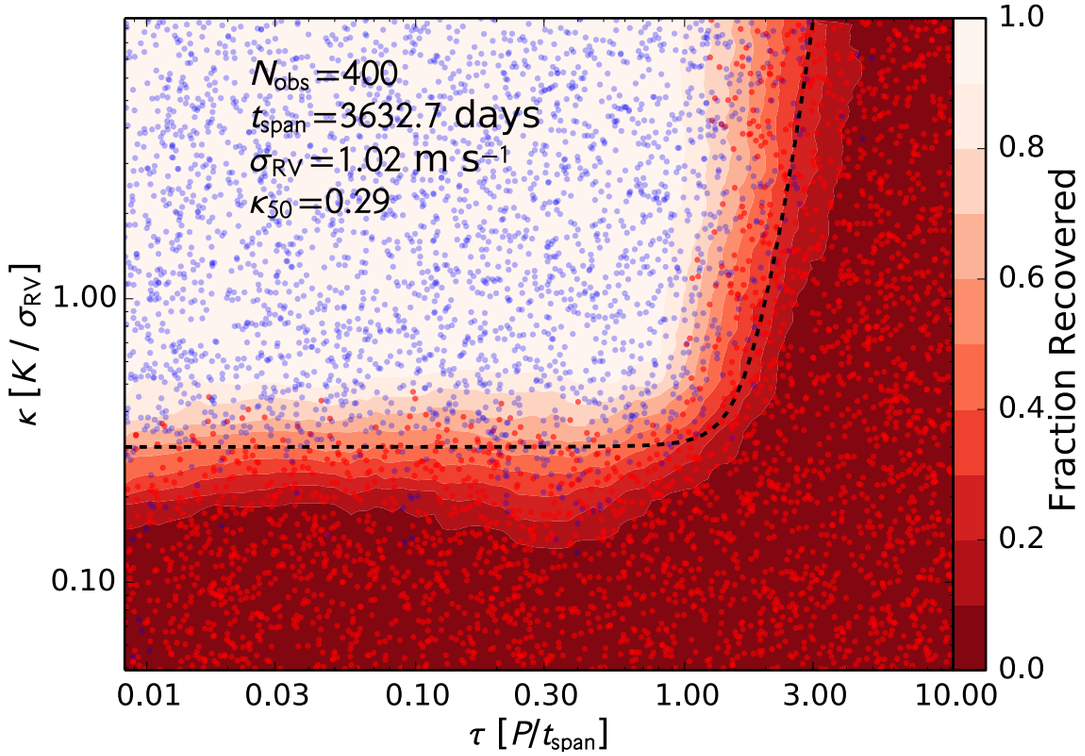
Make Problem Dimensionless

Dimensionless Doppler Amplitude:

$$\kappa_{50} = \frac{K_{50}}{\sigma_{\rm RV}} = \frac{\alpha}{\sqrt{N_{\rm obs}}}$$

Dimensionless Time:

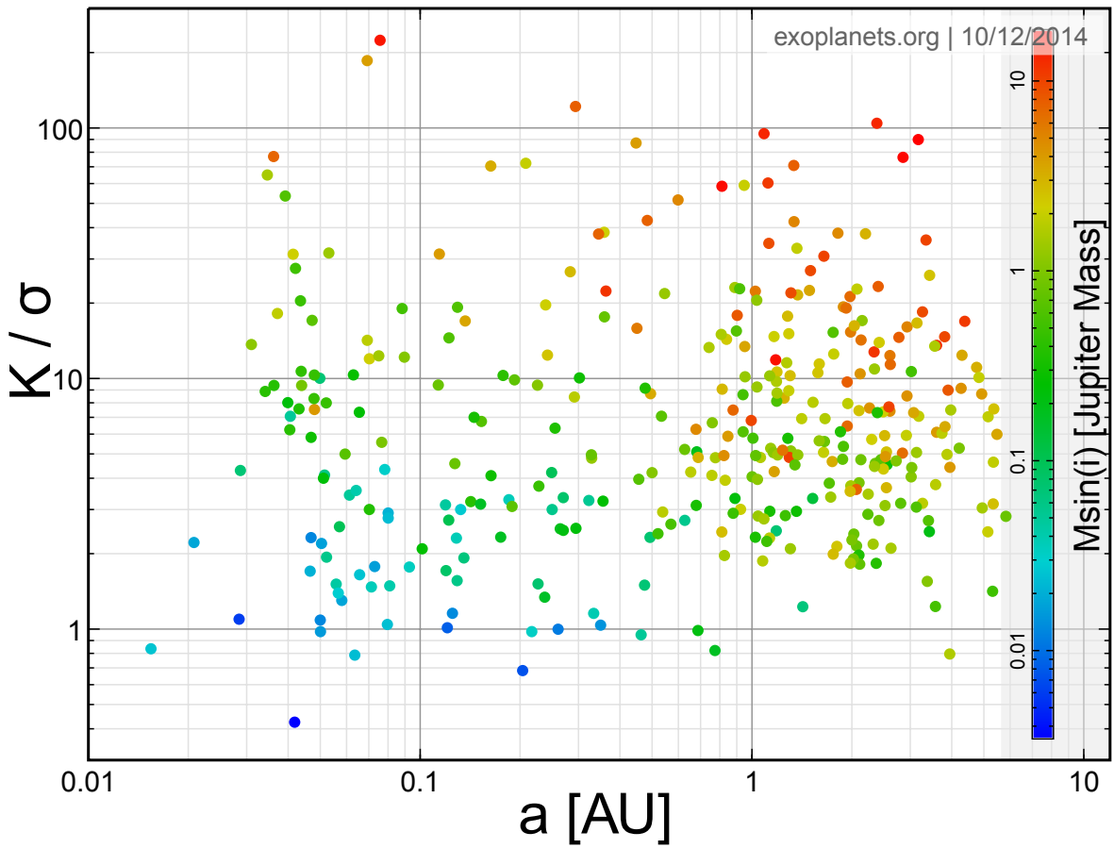
$$\tau = P/t_{\rm span}$$

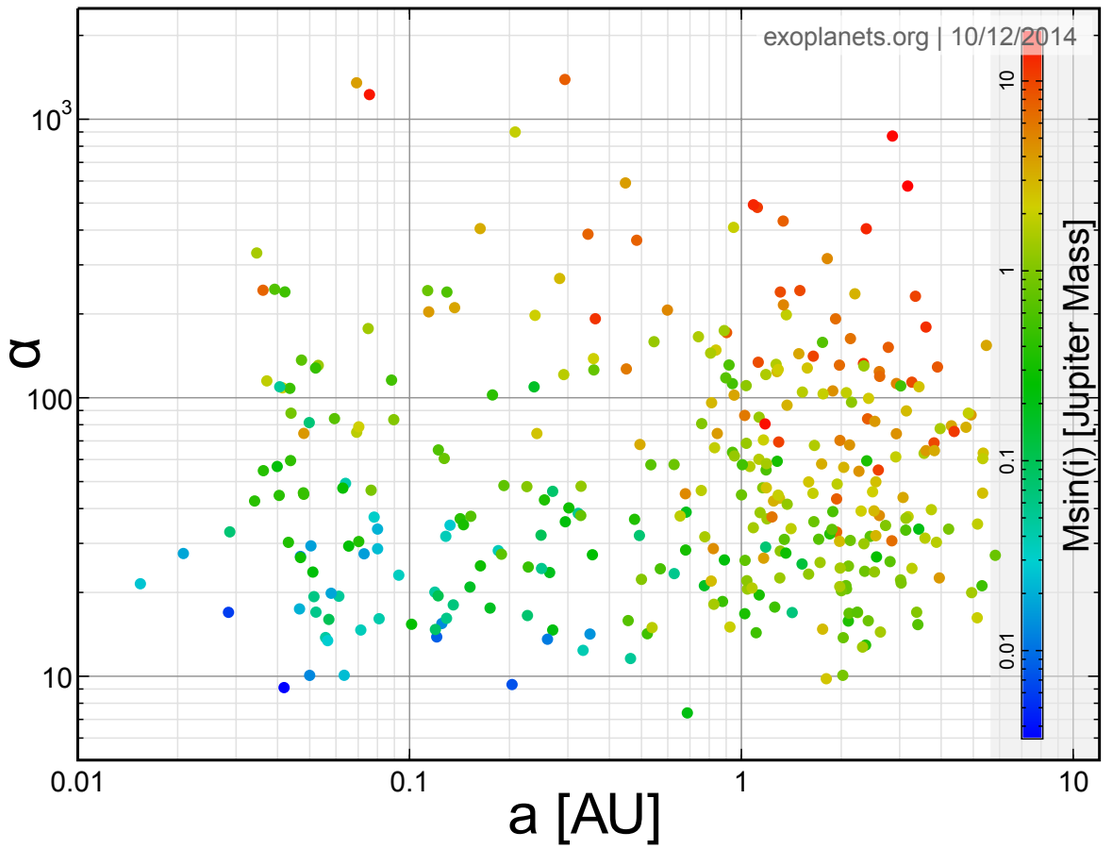


$$K_{50}(\tau) = \frac{\sigma_{\rm RV}\,\alpha}{\sqrt{N_{\rm obs}}} \cdot \sqrt{1 + (10^{\tau - 1.5})^2}$$

α ≈ 6 — Injection/recovery Simulations

Idealized Completeness





α ≈ 10 — Real Planets on exoplanets.org

Recommendations

1. Needed RV measurements should be written into mission requirements. Current Doppler surveys cannot observe (TACs won't support observations of) imaging targets without justification.

2. Invest in a dedicated facility with the time baseline and RV precision to prepare for 10+ yr for the imaging missions.

3. Start dedicated RV campaigns to measure the jitter (σ_{RV}) of every plausible direct imaging target.

Recommendations (2)

4. We recommend that all target G and K dwarfs (in the North and South) be observed at least 10 times per year with as high of a precision as possible (≤ 2 m/s) to detect or place limits on super-Earths and Neptune-mass planets in few AU orbits.

5. For stars showing low enough jitter to enable completeness encompassing giant planets in few AU orbits, we recommend 10 RV epochs per year for 10 yr, with a short-term observing cadence designed to average over photospheric jitter.