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STEPS: JPL's Astrometric Exoplanet Survey

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Exoplanet Science Fair
JPL

STEPS ground-based astrometry at Hale Telescope

- Started December, 1997. Now in 10th year.
- 30 nearby late M-dwarf stars, V= 12-16.
- Search for > 1 M_J planets and brown dwarfs
- 4k x 4k CCD, 2 arcmin field

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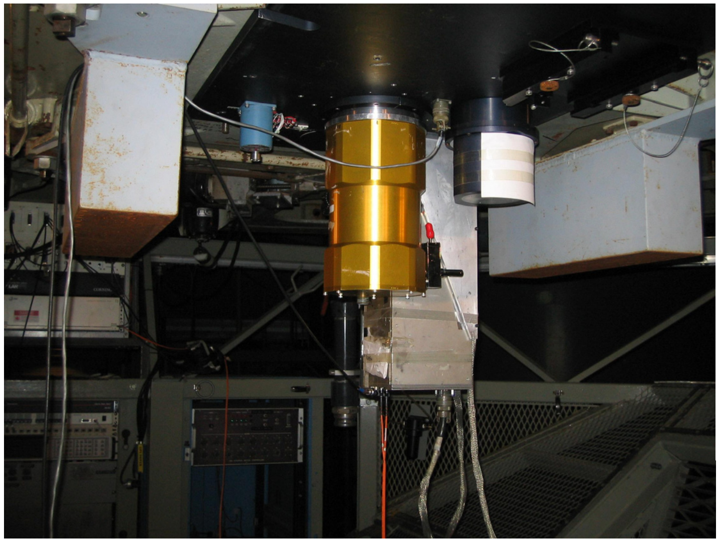
- Past and present collaborators: Fritz Benedict (spectroscopy), Michael Endl (RV), James Lloyd (AO), Shri Kulkarni (AO), Todd Henry (HST),
- Discoveries: M-dwarf and Brown Dwarf companions to several M-dwarf stars.

Instrument

- 4K Loral CCD
- LN2 Dewar
- SDSU (Leach) Electronics
  - 4 amplifiers
  - Bin pixels 2x2
  - 200 kpix read rate
- Binned pixel scale = 78 mas/pix
- Bandpass 550 – 750 nm
- Mounts at straight-Cass, f/16 on the Palomar 200 in. telescope.
  - Was also used at Keck II in 1998.
- Window has high quality lambda/30 p-v wavefront.
  - Filter glass + dielectric coating
  - Focus term due to vacuum is absorbed by the conformal model.



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Why Astrometry? Why M-dwarfs?

- **M-dwarfs**
  - **Most abundant stars: 70%, and least sampled by RV**
  - **Larger signal for a given planet mass**
  - **Additional science: Mass-luminosity relationship, finding BD companions**
- **Complementary to RV**
  - **Astrometry is best at long periods, RV is best at short periods**
  - **Astrometry improves at redder wavelengths**
    - **Better seeing, less dispersion**
  - **RV gets worse at redder wavelengths**
    - **Fewer, broader lines.**
  - **Resolves sin*i* ambiguity and measures dynamical mass**
- **Complimentary Astrometry Programs:**
  - **CAPSCAM (A. Boss, Carnegie)**
    - **Dupont Telescope: better seeing helps compensate smaller telescope**
    - **High-dynamic range detection: closer targets = larger signal**
  - **VLBA observations (Geoff Bower) of 30 M-dwarfs**
    - **200 uas, 3 yrs, 12 measurements**
    - **About half are late M-dwarf. Maybe some overlap with STEPS**

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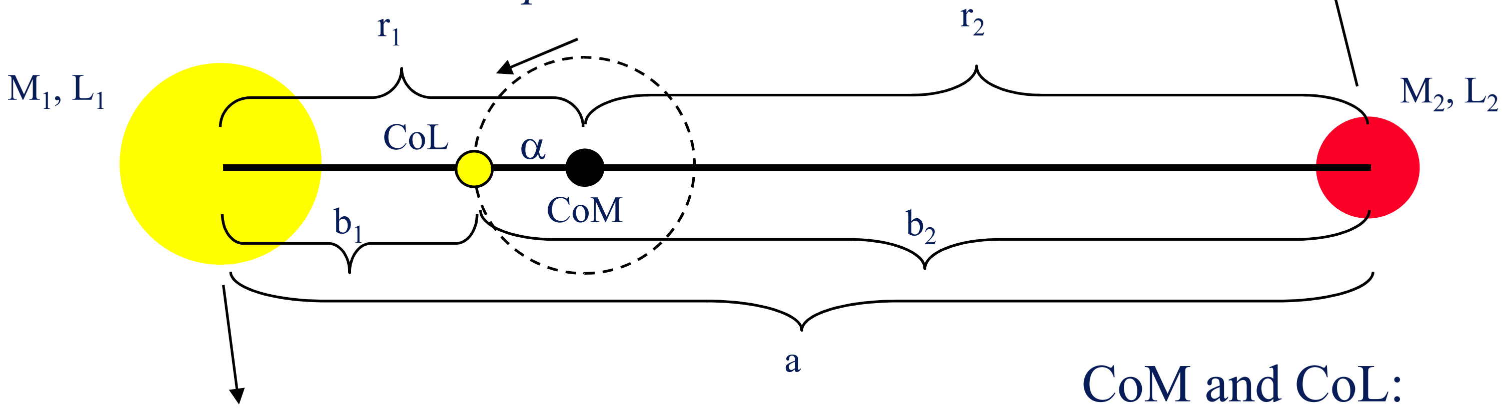
Motion of Center of Light about Center of Mass: Photocentric Orbit

For unresolved systems (< 1 arcsec separation), STEPS observes the motion of the COL about the COM. This is called the *photocentric motion*.



CoM and CoL:

r1 = a*M2/MT = a*f

b1 = a*L2/LT= a*β

$f = M_2 / M_{tot}$ (fractional mass)

$\beta = L_2 / L_{tot}$ (fractional light)

STEPS Measures:

α=CoL – CoM = r1 – b1 = a*(f-β)

α/a = ratio of photocentric to Keplerian orbit= f - β

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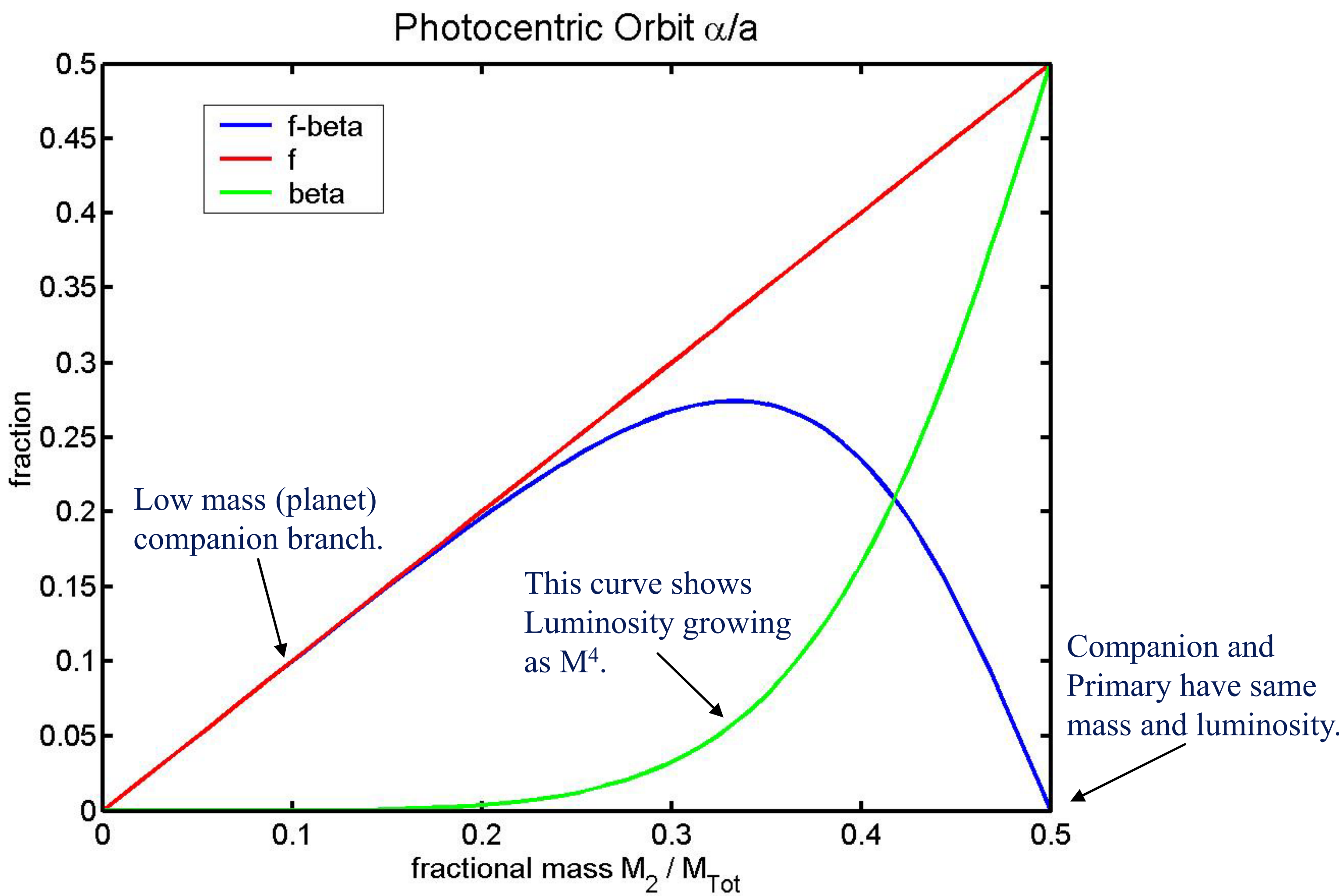
Photocentric Motion vs. Fractional Mass



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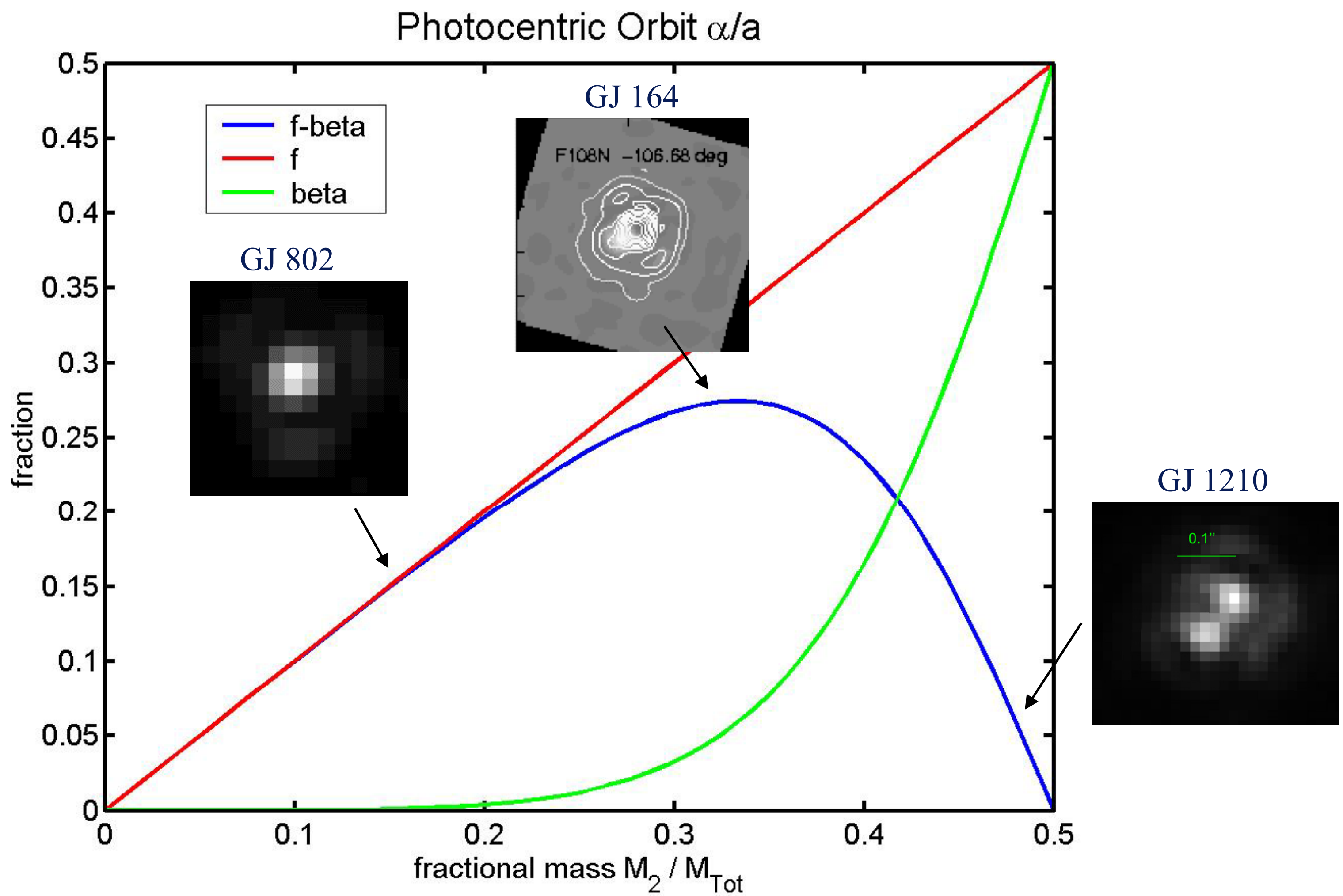
High-Resolution Imaging of STEPS Targets



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GJ 802
One possible orbit plotted with data, Keplerian frame

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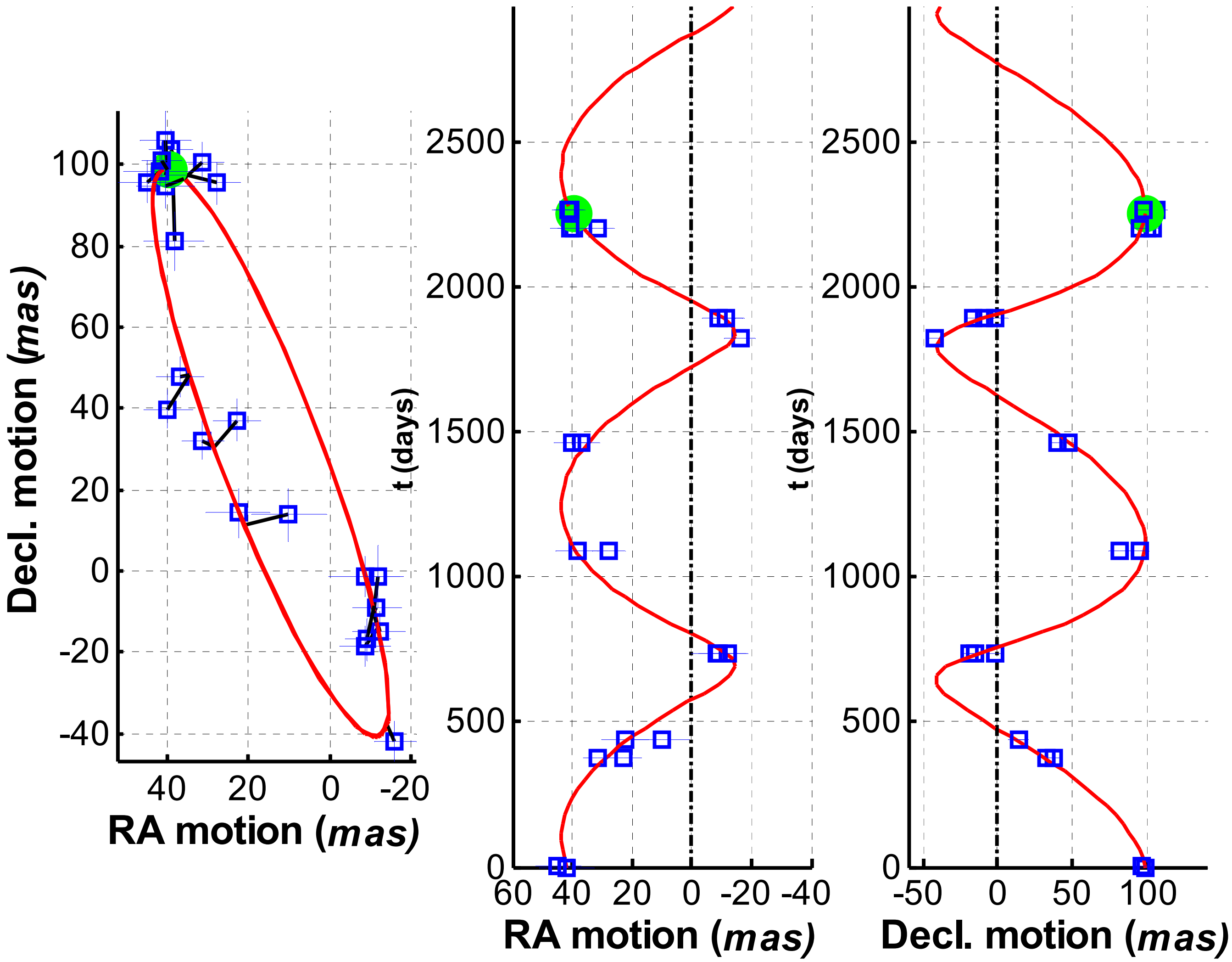

GJ 802 Results

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Table 1. GJ 802 Known Properties

RA (2000)[a]	20 43 19.41
Dec (2000)[a]	+55 20 52.0
V^b	14.69
J^c	9.563 ± 0.023
H^c	9.058 ± 0.019
K^c	8.753 ± 0.013
Type	dM5e
Parallax[d] (*mas*)	63 ± 5.5
Proper Motion[e] (*mas* y^{-1})	1915 ± 13
Position Angle[e] (deg)	27.6 ± 0.6

Table 2. STEPS Astrometric Measurements[a] of GJ 802

Relative Parallax (*mas*)	61 ± 2
Proper Motion (*mas* y^{-1})	1933 ± 1
Position Angle (deg)	27.0 ± 0.1
Period (y)	3.14 ± 0.03
Total Mass ($M_\odot$)	0.215 ± 0.045
Semi-Major Axis (AU)	1.28 ± 0.10
Eccentricity, *e*	0.56 ± 0.30
Inclination (deg)	80.5 ± 1.5
Lon. Asc. Node[b] (deg)	17.5 ± 3.5
Primary Mass, M_{pri} ($M_\odot$)	0.160 ± 0.03
Secondary Mass, M_{sec} ($M_\odot$)	0.057 ± 0.021

Beware of Wannabe Astrometrists

- **A paper is coming out in ApJ claiming to make the most precise mass measurement of a Brown Dwarf.**
- **It is largely based on estimates of our published GJ802b plot, shown below.**
  - **The authors measured the points in the published plot, estimated the observation date, then tried to reconstruct the original data by adding in the estimated parallax and proper motion.**
  - **They combined this data with their own imaging data and for good measure they threw out their original detection data because it had been incorrectly processed.**

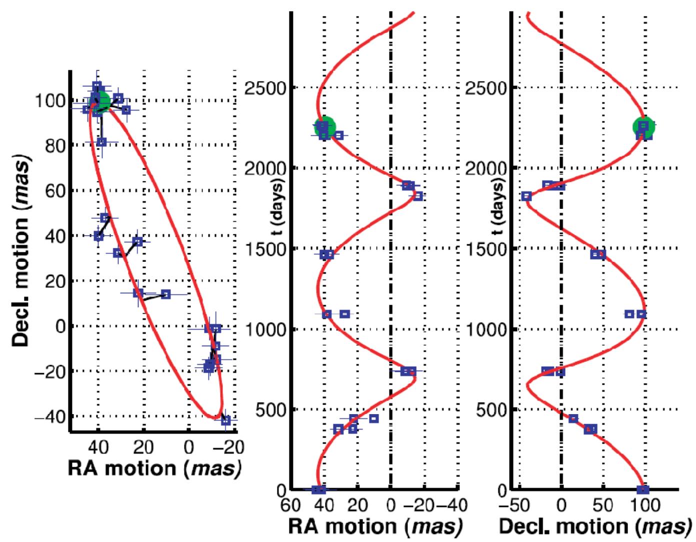

Fig. 1.—STEPS data (*points*) are superposed on a model of the Keplerian circular orbit (*solid red lines*). The right ascension and declination dimensions vs. time are shown separately. The 1 σ error bars on the points are our photocentric measurement errors multiplied by the ratio of the Keplerian to the photocentric orbit. The position of the AO observation is also shown (*green filled circle*).

- **WE DO NOT ENDORSE THEIR RESULT.**

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STEPS Future

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- Continued observation at Palomar 200 in.
  - We are in our 10th year, and have the sensitivity to detect Jupiter mass objects in 10-yr orbits around several stars.
- Explore Mount Wilson 100 in. for higher temporal sampling
  - R&TD funding ~ 10-12 nights
- RV and imaging collaborations
  - Flux ratios for MLR
  - Velocities for improved orbits
- Astrometric collaborations
  - Overlapping target lists to confirm discoveries, improve orbital fits, help distinguish systematic errors from real motions.
- Investigate new HAWAII-2RG detectors: higher dynamic range possible
- GIMLI: Proposed moderate cost space mission
  - J-band, meter-class aperture, 50 uas astrometry and coronagraphy (10^{-6} contrast).
  - 1000 astrometric targets, sensitivity to 0.1 M_J
  - See accompanying talk by Steve Pravdo

STEPS Papers

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- "Masses of Astrometrically Discovered and Imaged Binaries: G78-28AB and GJ 231.1BC" Pravdo, Shaklan, et al., ApJ, 649, 398 (2006)
- "Astrometric Discovery of GJ802b: In the Brown Dwarf Oasis?" Pravdo, Shaklan, Lloyd, ApJ, 630, 528 (2005)
- "Discovering M-dwarf Companions with STEPS," Pravdo, Shaklan, Lloyd, Benedict, ASP Conf. Series, Astrometry in the Age of the Next Generation of Large Telescopes (Flagstaff, 2005).
- "Astrometric Discovery of GJ164B," Pravdo, Shaklan, Henry, Benedict, ApJ 617, 1323-1329 (2004).
- "Stellar Planet Survey," Pravdo & Shaklan, Scientific Frontiers in Research on Extrasolar Planets, ASP Conference Series, Vol 294, 107-110 (2003).
- "Astrometric Detection of Extrasolar Planets: Results of a Feasibility Study with the Palomar 5 Meter Telescope," Pravdo & ApJ 465, 264-Astrophysical Journal v.465, p.264-277 (1996)
- "High-precision measurement of pixel positions in a charge-coupled device," Shaklan, Pravdo, Sharmon, Appl. Opt. 34, 6672-6681 (1995).