Solar System Realms: Stars Taking Up Space Where Planets Could Be

RECONS
Research Consortium on Nearby Stars

www.recons.org

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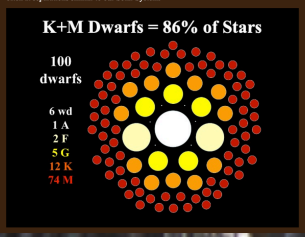
Overview and Key Results

The RECONS (REsearch Consortium On Nearby Stars, *www.recons.org*) team continues to explore the solar neighborhood by evaluating the nearest stars, both individually and as a population. Key points are becoming clear: we now know that 86% of all stars are K and M dwarfs (Henry et al. 2006, 2018), as shown below schematically for the fractions of stars within 10 parsecs. We also know that we need to reach to horizons of 50 parsecs and 25 parsecs to create samples of about 5000 K dwarf and 3000 M dwarf primaries, respectively. These two sizable samples allow us to understand the outcome of the star formation process across a factor of ten in mass as never before. Here we focus on one crucial area of research − stellar companions − with results of our surveys combining radial velocities, astrometry, high-resolution imaging, and trawls of catalogs and the literature. We reveal companions at separations from less than 1 AU to more than 1000 AU from the K and M dwarfs, with the key result that these stellar partners are found most often at separations similar to our Solar System.



Key Results

- ~15% of K dwarfs have stellar companions within 30 AU
- ~20% of M dwarfs have stellar companions within 30 AU
- M dwarf binaries exhibit a curious lack of circular orbits for periods of 10−30 years (K dwarf orbit shapes TBD)

A fair number of stars, a few brown dwarfs, and many planets are found orbiting both K and M dwarfs at similar separations, complicating our understanding of the formation processes for all three types of companions ... a fact that we must keep in mind as our solar neighborhood becomes enriched with planetary discoveries.

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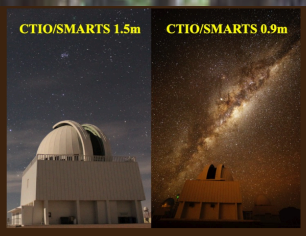
Telescopes and Instruments

To detect close companions, a large speckle survey of K dwarfs is underway at the Gemini telescopes (left and center above) in both hemispheres. The first wave of 768 K dwarfs within 40 pc has been surveyed in an equatorial sample between DEC +30 and −30. Stars have been observed using the Differential Speckle Survey Instrument (DSSI, Horch et al. 2009), which reveals companions at separations of 0.01−2.50 arcsec, thereby reaching inside the orbit of Mercury and out to 100 AU. The survey is now being expanded to a second wave including 1265 K dwarfs using 'Alopeke on Gemini-North and Zorro on Gemini-South.

A similarly large speckle survey of M dwarfs is underway at Gemini using the same cameras as for the K dwarfs (Winters et al. 2021). Of the first wave of 1120 stars, 710 have been observed to date. These observations are used in concert with a second speckle survey at SOAR with HRCam+SAM that permits orbit mapping to evaluate the sizes and shapes of orbits for stellar companions.



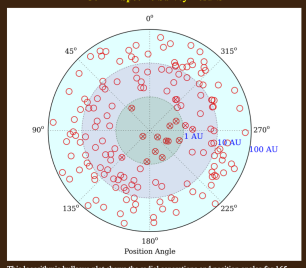
To reveal the very closest companions orbiting K dwarfs, a radial velocity survey is underway at the CTIO/SMARTS 1.5m using the CHIRON spectrograph. The first wave of 472 K dwarfs targeted is within 30 pc via *Hipparcos* measurements and comprises a subset of the equatorial sample of the speckle survey. Among these, only 172 have been previously observed, leaving a sample of 300 stars to be surveyed systematically. The sample has been recently expanded to 762 stars within 30 pc using *Gaia* results, of which 514 K dwarfs require observations because they have not been observed systematically for companions detected via radial velocities in the past.

To reveal unseen companions orbiting M dwarfs, an astrometric survey has been underway since 1999 at the CTIO/SMARTS 0.9m using a Tek 2K imaging camera. The sample includes 464 M dwarf primaries within 17 parsecs and south of DEC = 0, of which 203 have been observed for more than 10 years already. This allows long-period companions to be detected and have orbits mapped, at timescales exceeding any other study, including *Gaia*.

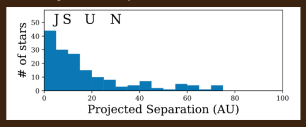
K Dwarfs

The ultimate goal is to survey 5000 K dwarfs within 50 parsecs.

Gemini Speckle Survey Results



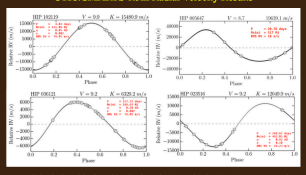
This logarithmic bullseye plot shows the radial separations and position angles for 165 companions resolved orbiting K dwarfs in the 880nm band with DSSI. Circles with Xs indicate uncertain position angles at the smallest separations. 0 degrees corresponds to north and 90 degrees to east on the sky.



A sweep around the bullseye plot shown above yields the histogram shown here. The separations of J(upiter), S(atum), U(ranus), and (N)eptune in our Solar System are shown for comparison.

It is clear that most stellar companions orbiting K dwarfs are found within 30 AU.

CTIO/SMARTS 1.5m Radial Velocity Results

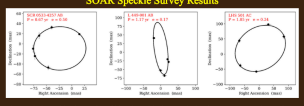


Four radial velocity orbits for K binaries from the 1.5m with the CHIRON spectrograph are shown with periods of 4−269 days. These stellar companions are typically beyond the reach − either in separation or mass − of the speckle cameras. Among the 300 stars in the first wave of observations, 88 companions have been detected, of which 66 are new discoveries (Paredes et al. 2021).

M Dwarfs

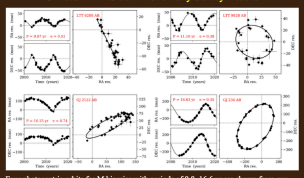
The ultimate goal is to survey 3000 M dwarfs within 25 parsecs.

SOAR Speckle Survey Results



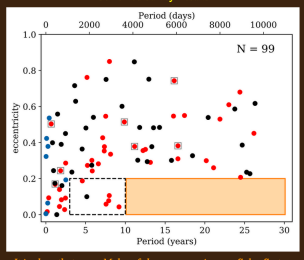
Three relative orbits for M dwarf binaries with short periods of 0.7–1.9 yr are shown from our SOAR speckle program (Vrijmoet et al. 2020). The first wave of targets includes 335 stars, of which 270 have been observed at least once and *160 systems have been resolved, nearly all within 30 AU.*

CTIO/SMARTS 0.9m Astrometry Survey Results



Four photocentric orbits for M binaries with periods of 9.8–16.6 yr are shown from our long-term astrometry program at the CTIO/SMARTS 0.9m (Vrijmoet et al. 2020). For each binary, the astrometric residuals in milliarcseconds (mas) in the RA and DEC axes are shown to the left, after solving for parallax and proper motion, and the resulting orbit is plotted on the right. *Of the 464 M dwarfs being followed in the program, 102 already are known to have stellar companions, and at least 80 of those are within 30 AU.* Among these 80 systems, 43 have more than 10 years of astrometric coverage; dozens more orbits have wrapped in our datasets.

Combined Survey Results



It is clear that many M dwarfs have companions on Solar System scales.

Initial results are shown for 99 M dwarf binaries in the orbital period vs. eccentricity diagram. Red points indicate systems from RECONS work (boxed points have orbits shown above), black points are from the literature, and blue points are from radial velocity work. The dotted box outlines a curious dearth of circular orbits for P_{orb} = 3–10 yr and the orange box highlights a "zone of avoidance" for P_{orb} = 10–30 yr. Apparently, low mass stellar multiples rarely form with circular orbits beyond a few AU (Vrijmoet et al. 2021).