

Multiplicity study of young pre-main sequence stars in the Lupus star-forming Region

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Abstract: We have conducted a high contrast imaging search for (sub)stellar companions among 63 young pre-main sequence stars in the Lupus star forming region, using the adaptive optics imager NACO at UT4 of the ESO Paranal observatory. We detected faint co-moving companions around our targets at angular separations between about 0.1 up to several arc seconds (binaries and triple systems). Some of these companions are in the sub stellar mass regime, according to their apparent near infrared photometry at the distance of the Lupus star forming region (about 140pc). We give a progress report to our long-term project, still in execution with the follow-up spectroscopy of detected substellar companion-candidates, and present some first results.

As T Tauri stars are all very young pre main-sequence stars, they are the most favorable targets for a direct imaging search for (sub)stellar companions, because companions of young stars are also young, and therefore self luminous, due to still ongoing contraction (see e.g. Burrows et al. 1997, ApJ 491, 856).

We compiled a list of all known T Tauri stars in the Lupus star forming region (extracted e.g. from the catalogs of Schwartz 1977, ApJS 35, 161, Krautter et al. 1997, A&AS 123, 329), located at a distance of about 140 pc (e.g. Hughes et al. 1993, AJ 105, 571) with ages of about 5 Myr in average (1-2 Myr for CTTS, see Comerón et al. 2003, A&A 406, 1001, up to about 10 Myr for WTTS, as described in Wichmann et al. 1997, A&A 320, 185).

Among all these young pre-main sequence stars in Lupus we selected those stars as targets, which fulfill the following criteria:

1. The target was not observed with NACO, so far.
2. The target proper motion is well known and high.
3. The target is bright to be imaged with NACO at high Strehl-ratio.

In total, we obtained a list of 63 most preferable targets for a deep high contrast imaging search for co-moving (sub)stellar companions. All our targets were observed in 1st epoch with NACO in May 2010, and we completed successfully the follow-up imaging of all targets in June 2012.

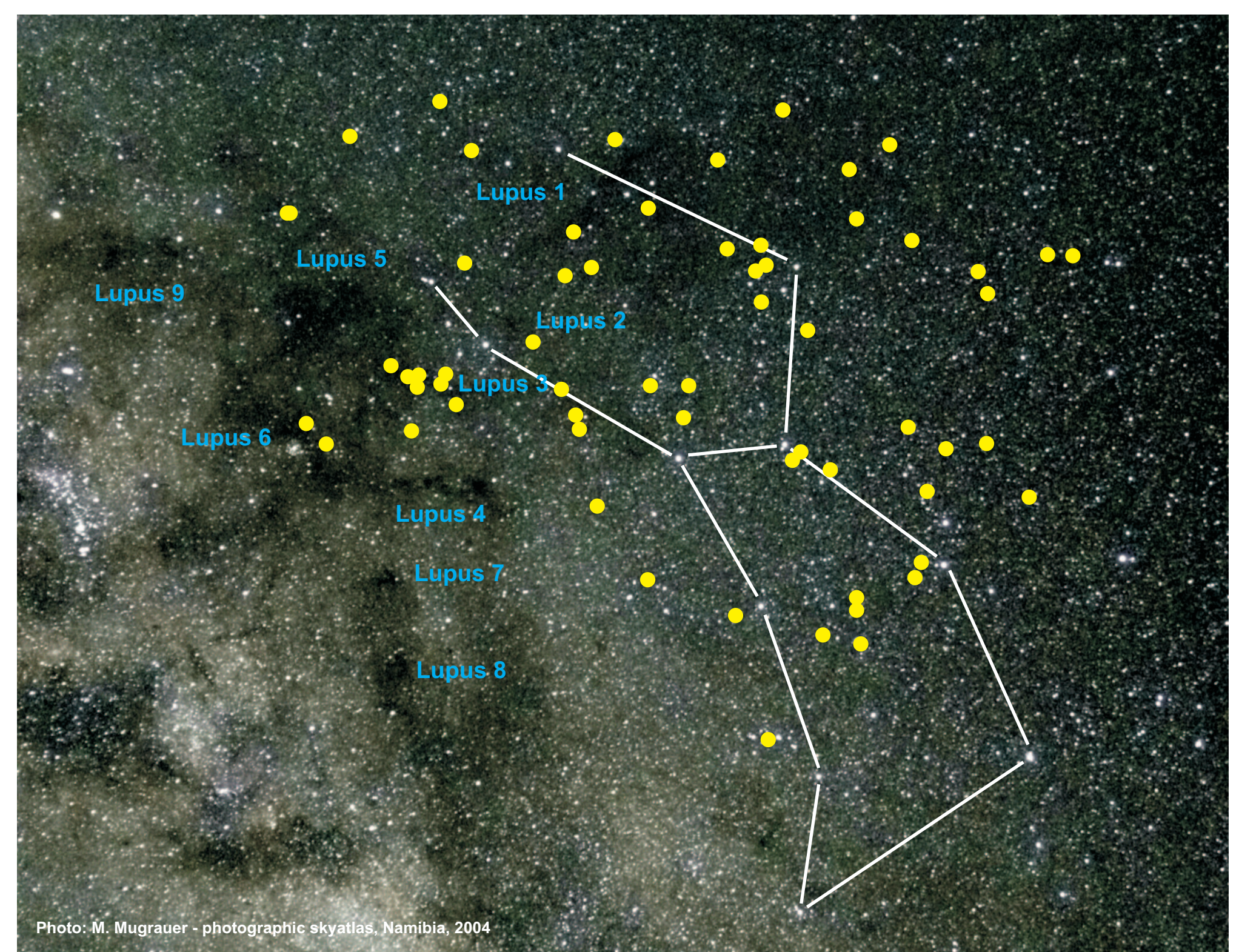
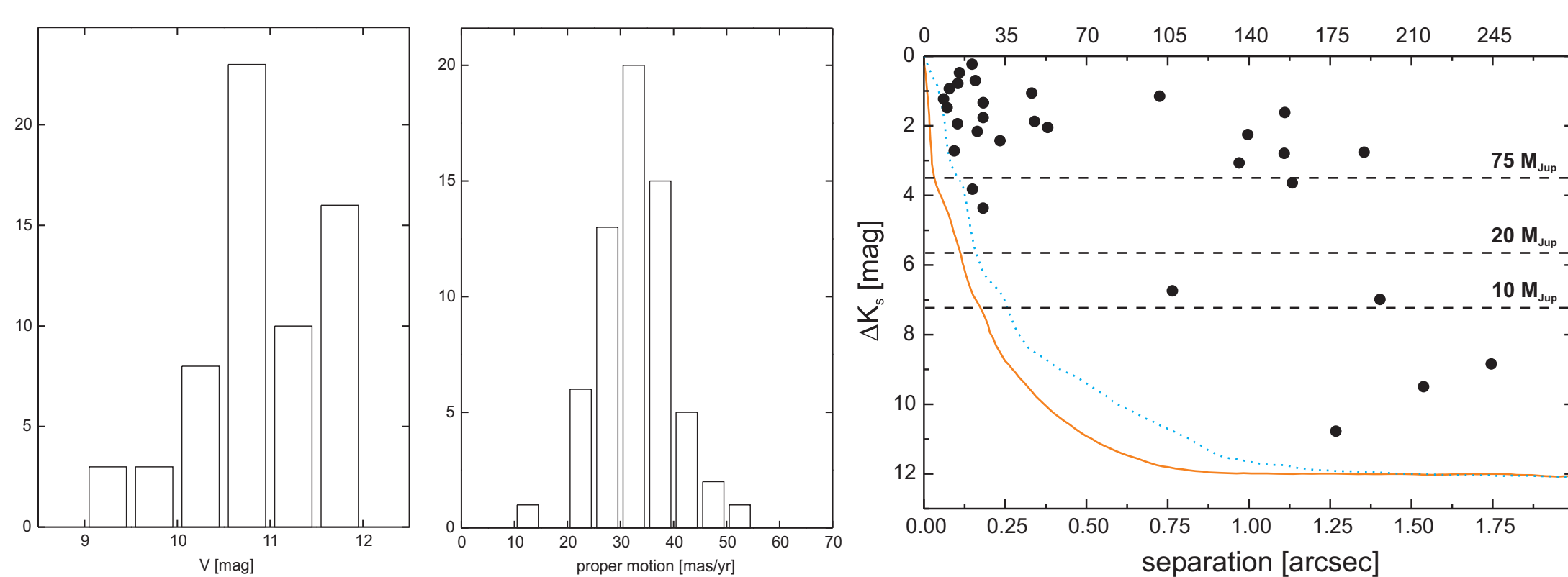


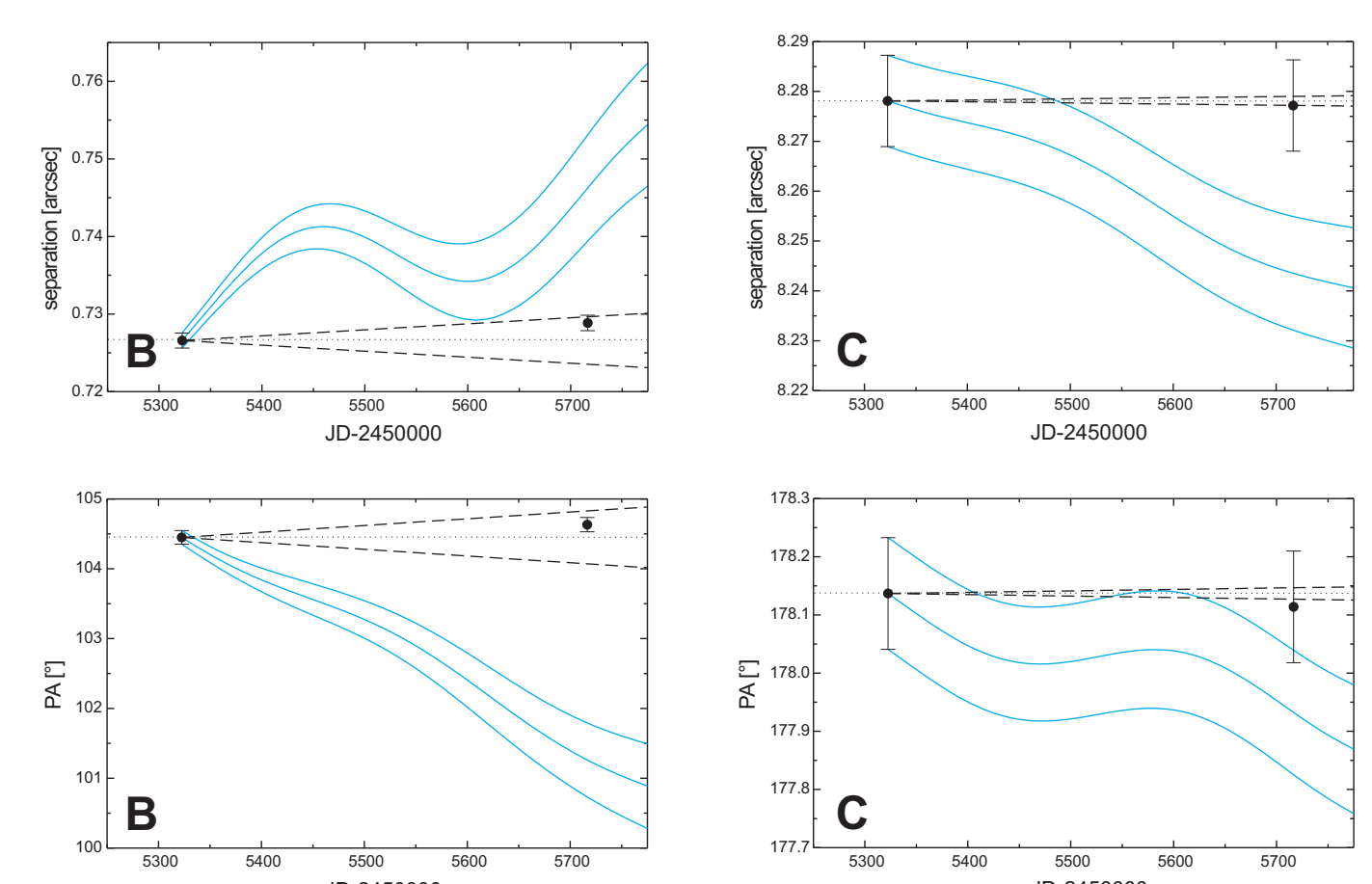
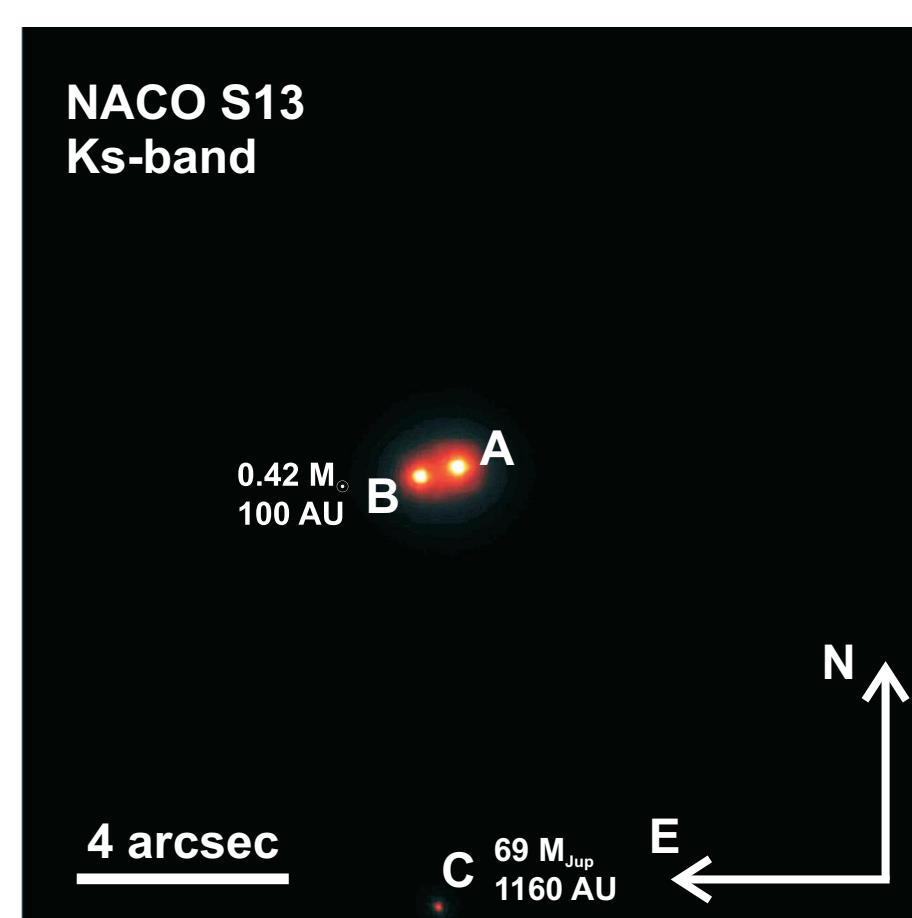
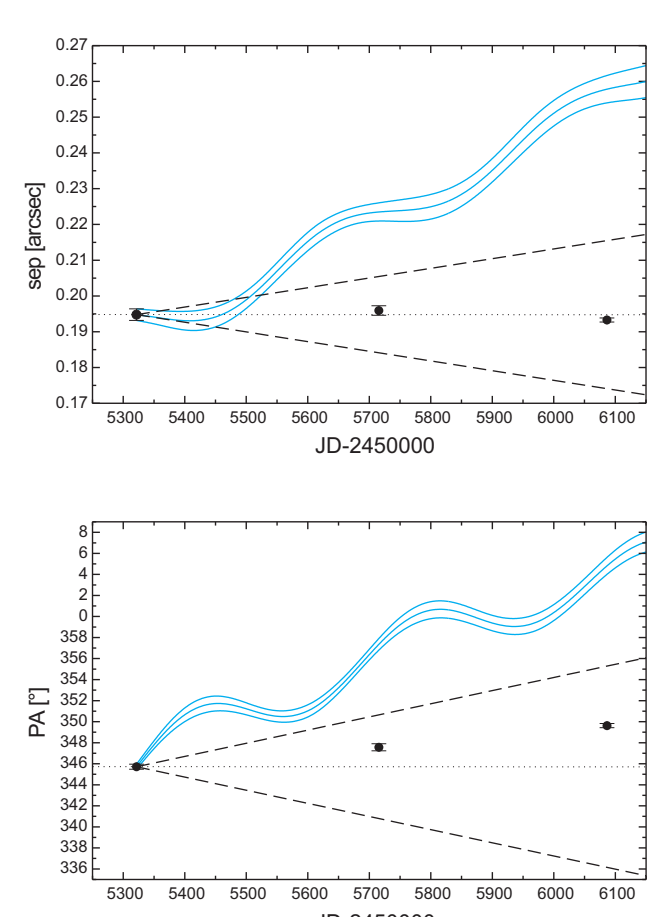
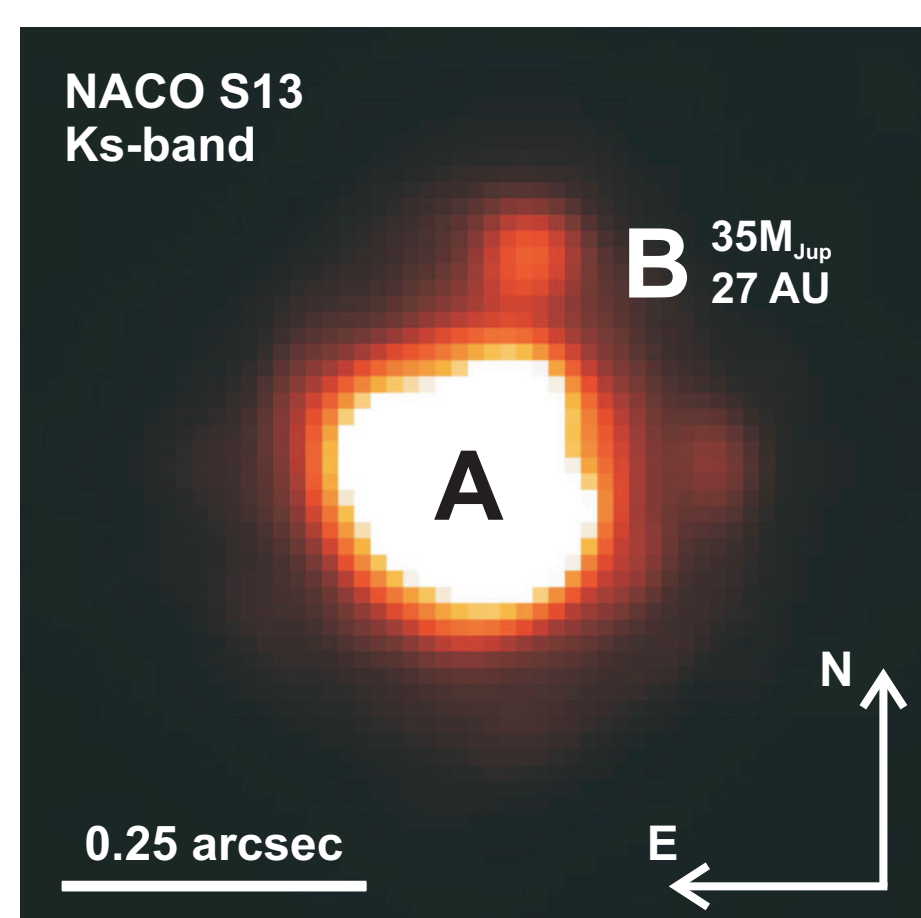
Image of the constellation Lupus with its dark clouds, taken in the optical spectral range. The positions of all T Tauri stars, whose multiplicity is studied in our high contrast imaging project, are indicated as yellow dots.



Left: The V-band magnitude distribution of our targets, which are all sufficiently bright to be imaged with NACO at high Strehl-ratios in average of 42%. All targets are also faint enough not to saturate the NACO detector with the S13 optics at shortest possible DITs in cube mode, most important to obtain precise relative astrometry and photometry between our targets and detected companion-candidates.

Middle: The proper motion distribution of our targets (average is 33 mas/yr). As one target selection criteria only those stars were chosen which move faster than 13 mas/yr (i.e. 1 NACO S13 pixel/yr) to guarantee that co-moving companions can be clearly identified already after one year of epoch difference.

Right: The detection limit of our deep NACO Ks-band imaging plotted for a range of angular separation up to 2'' (projected separations in AU are shown at the top) achieved with (red curve) and without PSF subtraction (blue dotted curve). Detected close companion-candidates are indicated as black dots. The horizontal dashed lines show the expected magnitude differences of (sub)stellar companions at the average age and distance of our targets. After the PSF subtraction all brown dwarf companions can be detected beyond 0.17'' (24 AU) around our targets. Many of such faint objects were found around our targets and several of them turned out to be co-moving companions, identified by us with NACO follow-up imaging observations.



As example for the companions detected in our project, we show here a new brown dwarf companion imaged in three epochs close (only 27 AU of projected separation) to one of our targets in the Lupus star forming region. As it is illustrated in the two plots on the right side the companion clearly shares a common proper motion with its primary and even orbital motion could significantly be detected in position angle. The expected maximal change of separation and position angle due to orbital motion is shown as straight dashed lines. The expected change of both quantities for a none-moving background source is illustrated as blue wobbled lines. Based on its infrared photometry the newly found co-moving companion exhibits a mass of about 35 M_{Jup} .

Here we show another example of our targets with detected co-moving companions, all identified in our high contrast imaging project among T Tauri stars in the Lupus star forming region. The observed target, shown here, exhibits a close bright companion at 100 AU of projected separation, which is clearly co-moving to its primary. The infrared photometry of this companion is consistent with a low-mass star of about 0.42 M_{\odot} , whose orbital motion could also be detected in both separation and position angle. In addition to this close stellar companion of the observed target we identified a further but much fainter companion of this star at a projected separation of about 1160 AU. The faint companion is clearly co-moving to our target and its infrared photometry is consistent with a brown dwarf with a mass of about 69 M_{Jup} . Hence, this T Tauri star in Lupus, previously only known as a single star, actually emerges as a hierarchical triple system with a wide substellar companion. Several of these systems were detected in our project, and follow-up spectroscopy is scheduled to confirm the substellar nature of the detected faint companions.