Multi-epoch observations with high spatial resolution of multiple T Tauri systems

Gergely Csépany^{1,2}, Mario van den Ancker¹, Péter Ábrahám², Rainer Köhler^{4,5}, Wolfgang Brandner³, Felix Hormuth³, and Hector Hiss³

¹ European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany

² Konkoly Observatory, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, 1121 Budapest, Konkoly Thege Miklós út 15-17, Hungary
e-mail: csepany.gergely@csfk.mta.hu

³ Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany

⁴ Institut für Astro- und Teilchenphysik, Universität Innsbruck, Technikerstr. 25/8, 6020 Innsbruck, Austria

⁵ University of Vienna, Department of Astrophysics, Türkenschanzstr. 17 (Sternwarte), 1180 Vienna, Austria

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ABSTRACT

Context. In multiple pre-main-sequence systems the lifetime of circumstellar discs appears to be shorter than around single stars, and the actual dissipation process may depend on the binary parameters of the systems.

Aims. We report high spatial resolution observations of multiple T Tauri systems at optical and infrared wavelengths. We determine whether the components are gravitationally bound and orbital motion is visible, derive orbital parameters, and investigate possible correlations between the binary parameters and disc states.

Methods. We selected 18 T Tau multiple systems (16 binary and two triple systems, yielding $16 + 2 \times 2 = 20$ binary pairs) in the Taurus-Auriga star-forming region from a previous survey, with spectral types from K1 to M5 and separations from $0.22''$ (31 AU) to $5.8''$ (814 AU). We analysed data acquired in 2006–07 at Calar Alto using the AstraLux lucky imaging system, along with data from SPHERE and NACO at the VLT, and from the literature.

Results. We found ten pairs to orbit each other, five pairs that may show orbital motion, and five likely common proper motion pairs. We found no obvious correlation between the stellar parameters and binary configuration. The $10\ \mu\text{m}$ infra-red excess varies between 0.1 and 7.2 mag (similar to the distribution in single stars, where it is between 1.7 and 9.1), implying that the presence of the binary star does not greatly influence the emission from the inner disc.

Conclusions. We have detected orbital motion in young T Tauri systems over a timescale of ≈ 20 yr. Further observations with even longer temporal baseline will provide crucial information on the dynamics of these young stellar systems.

Key words. stars: variables: T Tauri, Herbig Ae/Be – stars: pre-main sequence – stars: evolution – binaries: visual – techniques: high angular resolution – instrumentation: adaptive optics

1. Introduction

The influence of the multiplicity on the evolution of the protoplanetary disc is an open question of astronomy (see e.g. Bouwman et al. 2006; Kraus et al. 2012). Multiple systems are present abundantly among young stars, as a large fraction of stars form in binary or multiple systems, and, for example, Lada (2006) has found that the single star fraction is only $\approx 40\%$ for G-type stars, rising to 70% for late M-type stars. This shows that multiplicity might be a significant factor in the stellar evolution. The young multiple systems are of special interest, because the low-mass evolutionary models at the early phases of stellar evolution are currently only poorly constrained by observations, and observing such systems can help to refine and calibrate these models (Stassun et al. 2009).

There is evidence that the age at which the star still has a disc is shorter in multiple systems than around single stars (see e.g. Damjanov et al. 2007; Bouwman et al. 2006). In addition, Osterloh & Beckwith (1995) claimed that companions closer than 100 AU inhibit disc formation, based on a 1.3 mm continuum survey of 121 young stars. Andrews & Williams (2005)

found that among the 150 young stars in Taurus (including 62 multiple systems), the sub-millimeter flux densities (and thus the disc masses) are lower for binaries with a projected semi-major axes < 100 AU. Cieza et al. (2009) also found that circumstellar disc lifetimes are reduced in binaries with separation smaller than 10–100 AU. Although the discs of the components are usually assumed to be coeval, they may evolve with different pace. This differential disc dispersion is in the focus of recent studies (Patience et al. 2008; Kraus & Hillenbrand 2009; Cieza et al. 2009; Kraus et al. 2012; Daemgen et al. 2012a,b, 2013). However, although these studies derived some correlations between the presence of a disc and binarity, they did not perform any detailed analysis of disc content and structure. Simulations combining viscous draining and X-ray photoevaporation suggest that in systems with separation below 100 AU the secondary disc disappears first, while for wider systems this trend cannot be seen (Reipurth et al. 2014, and references therein). The actual disc removal process that causes the relatively short disc lifespan and the differential disc dispersion is unclear. The disc removal processes may consist of tidal effects in a binary or multiple systems that destabilizes the disc

structure, or the disc may deplete over time by accretion onto the star. It is also possible that planet formation is responsible for clearing the disc, or the disc may suffer photoevaporation from the star.

Which of these effects is the main driver for disc dissipation in multiple systems is still unclear. However, it is likely that the actual disc dissipation process depends on the binary parameters of the systems, such as the age, separation, mass ratios, and multiplicity of the systems. To determine which process plays the dominant role in the dissipation, we therefore need to witness the differences in disc clearing and determine binary parameters in a sample large enough to make statistical conclusions.

Obtaining orbital parameters for multiple T Tauri systems has been the focus of recent works (Schaefer et al. 2006, 2014; Köhler & Hiss 2015), and although some closer binaries have well-constrained orbital solutions, many wider systems still lack proper time coverage of their orbits (see e.g. Csépany et al. 2015, for the case of the T Tauri system). This can be alleviated by observing the same systems over a long period of time to obtain data that cover a significant fraction of the orbit.

In this paper we report high spatial resolution observations in the optical and infra-red of a sample of 18 multiple T Tauri systems. Most of the systems have been first resolved about 20 yr ago and therefore have a timeline on which we may be able to see orbital motion. One of our aims was to determine whether the systems are gravitationally bound, and if they are, to derive the orbital parameters and to ascertain a correlation between their binary configuration and disc states.

2. Sample

We studied a sample consisting of 18 T Tauri multiple systems (comprising 16 binary and 2 triple systems, which are treated as 2 binary pairs for each triplet, where the components B and C are both measured relative to A, the brightest star in the *V* or *R* bands, depending on available measurements; altogether $16 + 2 \times 2 = 20$ binary pairs) in the Taurus-Auriga star-forming region. Our sample is based on Leinert et al. (1993), who conducted a survey from September 1991 to October 1992 using speckle imaging at the 3.5 m telescope at Calar Alto. They found 44 multiple systems out of the 104 observed young low-mass stellar systems, and their measurements serve as an astrometric and photometric epoch for our targets. Our selection criteria considered observability using the employed telescope and instrumentation, together with the available observation time to ensure that we only include stars for which separation and relative brightness of the components allow a reliable detection. The selected sample covers spectral types from K1 to M5, with separations from 0.22'' to 5.8''. Most of the systems are well-studied stars, with multiple epochs available, but we also included a few systems that have not been extensively observed. Therefore our new observations present the first time at which these system have been spatially resolved since the pioneering work of Leinert et al. (1993). A detailed description of the systems is presented in Appendix A.

The proper motions of the main stars that we used for the analysis in Sect. 5 are obtained from the publicly available UCAC4 all-sky star catalogue (Zacharias et al. 2012) and for one star (FV Tau/c) from the USNO-B catalogue (Monet et al. 2003).

2.1. Naming scheme

The naming of the companions is not evident when we compile a database from observations that span several decades. Some

companions may have been resolved only recently, while others were simply renamed. The renaming usually was minor, such as “HK Tau/c” to “HK Tau B”. However, sometimes we have to be very careful, as in the case of “FV Tau”, where “FV Tau” and “FV Tau/c” denotes two binary systems with a distance of $\approx 12''$ from each other. We tried our best to match the different names with each other and to ensure that one name indeed refers to the same physical object. The naming scheme we employed is that the optically brightest star is A, the second brightest is B, and so on, with historical considerations to stay compatible with the most popular nomenclature in the literature. The final naming scheme is listed in Table 1.

2.2. Distances

Loinard et al. (2005, 2007), Torres et al. (2009, 2007, 2012) carried out a long VLBI campaign to measure the distance of the nearby star-forming regions, in which they measured three sections of the Taurus region. Taking into account all distances measured in this region and their spread (which probably reflects the three-dimensional extent of the Taurus cloud), we adopted 140 ± 21 pc as the distance of the stars in our sample.

3. Observations

3.1. AstraLux Norte

We observed the selected 18 multiple systems between November 2006 and November 2007 at Calar Alto using the 2.2 m telescope and the Astralux Norte lucky imaging system (for a detailed description of Astralux Norte and the reduction pipeline see Hormuth et al. 2008). In the lucky imaging process we took 10 000 images per object and exposed for 30–50 ms for each image. Johnson *I* and SDSS *i'* and *z'* filters were used, since at that exposure time and telescope size, those are the optimal wavelengths (800–1000 nm) to minimize the effect of the atmospheric turbulence (Fried 1965). Then we measured the Strehl ratios of the reference star in the images and selected the best 1–5% of the frames, which were composed into a final image using shift-and-add technique with the Drizzle algorithm (Fruchter & Hook 2002). This method selects the images in which the effect of the atmospheric turbulence was the lowest (as the turbulences in the air cells at the given wavelength operate at a longer time span than 30–50 ms), allowing us to reach the diffraction limit of the telescope. The typical FWHM of the primary stars in the AstraLux images range between 80 and 92 mas, depending on the filter.

The composite Fig. 1 shows six systems from the AstraLux observations, presenting a stellar pair of similar brightness, a pair of a bright and a faint component, a wide and a tight pair, and the two triple systems.

3.2. SPHERE

We also obtained observations of the V1000 Tau system during the Science Verification of SPHERE (Beuzit et al. 2008; Dohlen et al. 2008; Vigan et al. 2010; Claudi et al. 2008), the newly installed extreme adaptive optics facility at the VLT. These observations were acquired on 2014 December 10, when SPHERE was operated in the IRDIFS mode with a 155 milliarcsecond (mas) diameter apodized Lyot coronagraph, offering simultaneous Integral Field Spectrograph (IFS) observations from 0.95–1.65 μm , and imaging in the *Ks* (2.181 μm) filter. We also obtained observations with the star offset from the coronagraphic mask to be able to measure total fluxes. A point-spread

Table 1. Spectral types, extinction magnitudes, classification, and naming scheme notes of the stars.

System and Comp.		RA ¹	Dec ¹	SpT	A _V (mag) ²	T Tau class ³	Disc detected ⁴	Ref. ⁵	Notes
LkCa 3	Aa	04 14 47.97	+27 52 34.6	M2	0.4 (nr)	III	NA	1	The Aa-Ab and Ba-Bb pairs are spatially unresolved spectroscopic binaries.
LkCa 3	Ab			M4	0.4 (nr)		NA	1	
LkCa 3	Ba			K7	0.4 (nr)		NA	1	
LkCa 3	Bb			M2.5	0.4 (nr)		NA	1	
DD Tau	A	04 18 31.13	+28 16 29.0	M3	2.10	II	☑	2, 11	
DD Tau	B			M3	2.90		☐	2, 11	
LkCa 7	A	04 19 41.27	+27 49 48.5	M0	0.6 (nr)	III	NA	3	
LkCa 7	B			M3.5	0.6 (nr)		NA	3	
FV Tau	A	04 26 53.53	+26 06 54.4	K5	5.3	II	☑	4, 11	FV Tau and FV Tau/c are two binary systems at $\approx 12''$ distance.
FV Tau	B			K6	5.3		☑	4, 11	
FV Tau/c	A	04 26 54.41	+26 06 51.0	M2.5	3.25	II	☐	2, 11	FV Tau/c is also known as HBC 387.
FV Tau/c	B			M3.5	7.00		☐	2, 11	
UX Tau	A	04 30 03.99	+18 13 49.4	K5	1.8	II	☑	5, 11	The three most luminous components are usually called A, B, and C. However, UX Tau B is a binary, and when it is resolved, the pair is called B-C and C is renamed to D (Correia et al. 2006).
UX Tau	B			M2	0.26	III	☐	6, 11	
UX Tau	C			M5	0.57	II	☐	6, 11	
UX Tau	D			–	–		NA		
FX Tau	A	04 30 29.61	+24 26 45.0	M1	2.0	II	☑	7, 11	
FX Tau	B			M4	2.0		☐	7, 11	
DK Tau	A	04 30 44.25	+26 01 24.5	K9	1.3	II	☑	7, 11	
DK Tau	B			M1	1.3	II	☐	7, 11	
XZ Tau	A	04 31 40.07	+18 13 57.2	M2	1.40	II	☐	2, 11	
XZ Tau	B			M3.5	1.35			2, 11	
HK Tau	A	04 31 50.57	+24 24 18.1	M1	3.0	II	☑	7, 8, 11	B is denoted as /c in Kenyon & Hartmann (1995).
HK Tau	B			M2	2.5		☑	7, 8, 11	
V710 Tau	A	04 31 57.80	+18 21 35.1	M0.5	1.80	II	☑	6, 11	Also known as LkH α 266, HBC 51, or HBC 395.
V710 Tau	B			M2.5	1.82	II	☐	6, 11	
UZ Tau	A	04 32 43.02	+25 52 30.9	M2	0.55	II	☑	2, 11	
UZ Tau	B			M3	1.75	II	☑	2, 11	
UZ Tau	C			M1	1.00		☑	6, 11	
GH Tau	A	04 33 06.22	+24 09 34.0	M2	0.00	II	☐	2, 11	
GH Tau	B			M2	0.50			2, 11	
HN Tau	A	04 33 39.35	+17 51 52.4	K5	0.6	II	☑	3, 9, 11	
HN Tau	B			M4	0.9		☐	3, 11	
HV Tau	A	04 38 35.30	+26 10 39.0	M2	1.95 (nr)	III	☐	6, 11	AB is a close binary (74 mas, Simon et al. 1996) that is unresolved in our observations. In the WISE database, the object J043835.47+261041.8 is labelled as HV Tau A, but photometry suggests that it is actually HV Tau C. Also known as LkH α 332 G2.
HV Tau	C			M0	1.95 (nr)	I?	☑	10, 11	
V999 Tau	A	04 42 05.49	+25 22 56.3	M0.5	2.00	III	NA	2	
V999 Tau	B			M2.5	3.30		NA	2	
V1000 Tau	A	04 42 07.33	+25 23 03.2	M1	6.1 (nr)	III	NA	13	Also known as LkH α 332 G1.
V1000 Tau	B			K7	6.1 (nr)		NA	13	
RW Aur	A	05 07 49.57	+30 24 05.2	K1	0.39	II	☑	6, 12	
RW Aur	B			K5	1.56		☐	6, 12	

Notes. ⁽¹⁾ RA, Dec: coordinate of the centre of light. ⁽²⁾ nr: unresolved observation. ⁽³⁾ Based on Luhman et al. (2010), who classified the stars using *Spitzer* data. ⁽⁴⁾ Whether the presence of a disc is detected in radio observations, based on Refs. 11 and 12.

References. (1) Torres et al. (2013), (2) Hartigan & Kenyon (2003), (3) Yang et al. (2012), (4) Skemer et al. (2011), (5) Espaillat et al. (2010), (6) White & Ghez (2001), (7) Duchêne et al. (1999), (8) Stapelfeldt et al. (1998), (9) Furlan et al. (2009), (10) Duchêne et al. (2010), (11) Harris et al. (2012), (12) Cabrit et al. (2006), (13) Wahhaj et al. (2010).

Fig. 1. AstralLux images from the sample showing a pair of similar brightness, a pair of a bright and a faint component, a wide and a tight pair, and the two triple systems. The halos due to the lucky imaging addition are visible around the clearly resolved central cores of the stars. The intensity scaling is logarithmic.

function (PSF) reference star (TYC 1290-457-1) was observed immediately after the IRDIFS observation of V1000 Tau, at similar airmass and atmospheric conditions as the science target. The obtained data sets were reduced with the pre-release version 0.15.0-2 of the SPHERE pipeline. In addition to the usual steps of bias subtraction, flat-fielding, and wavelength calibration, the pipeline also includes a correction for geometric distortions. In the calculated positions of the stars, we also took into account the detector's deviation from true north orientation in the position angle ($-1.788^\circ \pm 0.008^\circ$, detailed in the SPHERE manual¹). Post-processing of the data was made using the FITSH software package (Pál 2012) to sum the data resulting from the two IRDIS channels.

3.3. NACO

We also took advantage of the extensive ESO archive and searched for publicly available data on the given systems. We found 19 previously unpublished adaptive-optics-assisted imaging observations of our targets captured by VLT/NACO (Lenzen et al. 2003; Rousset et al. 2003). We reduced the previously unpublished observations (which employed standard J , H , K and narrow-band $1.64 \mu\text{m}$, $2.12 \mu\text{m}$, $2.17 \mu\text{m}$ filters) with the ESO provided NACO pipeline² (version 4.4.0), achieving ≈ 65 – 85 mas FWHM resolution in the K band. These observations are also included in our analysis.

¹ http://www.eso.org/sci/facilities/paranal/instruments/sphere/doc/VLT-MAN-SPH-14690-0430_v96.pdf, Sect. 9.3.2, p. 64

² <http://www.eso.org/sci/software/pipelines/>

3.4. Auxiliary data from the literature

A literature search for spatially resolved data of the systems in our sample resulted in including measurements from papers listed in Table C.1. The most extensive literature data sets come from White & Ghez (2001), McCabe et al. (2006), and Correia et al. (2006). McCabe et al. (2006) observed 65 T Tauri binaries using mid- and near-infrared adaptive optics instruments on the Keck 10 m telescopes between May 1998 and November 2002, and Correia et al. (2006) observed T Tauri triple and quadruple systems employing VLT/NACO. The observations of the objects are listed in Table C.1.

4. Data analysis

In the data analysis we obtained the positions of the stars in the AstralLux, SPHERE, and NACO images and calculated their separation and brightness ratios. We combined these results with the other surveys and list them in Table C.1.

4.1. Photometry

We performed PSF photometry on the AstralLux images and aperture photometry on the other images that we analysed to calculate the brightness ratios of the binary pairs.

In the aperture photometry calculations, we included the following term in the uncertainty of the brightness ratio (n_{ph} is the raw photon count):

- $\sqrt{n_{\text{ph}}}$ due to the Poisson-process nature of observation;
- $\sqrt{\text{aperture area} \times \text{sky background}}$ due to the uncertainty caused by the sky background.

In the AstraLux PSF photometry, we used the PSF of lucky images that consists of an Airy disk convolved with a Gaussian and a Moffat function (described by Staley et al. 2010; and successfully used in AstraLux Norte images by Wöllert et al. 2014, 2015). This PSF can be expressed as

$$PSF(\mathbf{r}) = W \left(\frac{1}{r^2/\sigma_m^2 + 1} \right)^\beta + (1 - W) \left(PSF_{th}(\mathbf{r}) \cdot e^{-\frac{r^2}{2\sigma_g^2}} \right),$$

where W is a weighting factor between the two components, σ_m is the width of the Moffat-profile, β is the Moffat power-law index, and σ_g is the width of the Gaussian. We constructed the theoretical AstraLux images as

$$AstraLuxImage(\mathbf{r}) = \sum_{i=1}^{n_{stars}} A_i \cdot PSF_i(\mathbf{r}) + C_{sky},$$

where A_i are the amplitude scaling factors, the $PSF_i(\mathbf{r})$ terms are the individual stars, and C_{sky} is the sky background. The $PSF_i(\mathbf{r})$ terms share the common seeing parameters σ_m , β , and σ_g , as these parameters do not change in the field of view of the camera with images taken in 20–50 ms. We used the modelling and fitting framework of the Astropy software package (Astropy Collaboration et al. 2013) to obtain the PSF fits.

Performing photometry on the AstraLux images differs in a few points compared to the conventional CCD imaging, see for example Staley et al. (2010). The main issue affecting the PSF photometry is that the bias level of an electron multiplying CCD (EMCCD) camera can change during acquisition (“bias drift”). This bias drift can be as high as 0.6% of the pixel counts. The bias drift can be accounted for by stabilizing the temperature of the camera or by exploiting the overscan region of the camera (see e.g. Harpsøe et al. 2012). Since we did not have any of these options, we calculated the spread of the bias from each night using the sky area of the data cubes. The change in the sky area in the data cubes can be attributed to the bias drift, since no other change is foreseen in the images that were taken 20–50 ms apart. The mean standard deviation of the sky photon count is 0.7%, which we took into account as a 1% error term as a safe overestimation of this error.

The final brightness ratios are shown as magnitude differences (with uncertainties) in Table C.1.

4.2. Astrometry

In the case of the SPHERE and NACO observations, the analysis of the data is based on the pipeline-produced images (including pixel scale and detector position angle), whereas in the case of AstraLux images we calculated the pixel scale and the position angle of the images by using images of the M15 globular cluster (van der Marel et al. 2002) and the Orion Trapezium cluster (Olivares et al. 2013) taken both by the AstraLux system and by the Wide-Field Planetary Camera 2 (WFPC2) on the Hubble Space Telescope (HST). We picked five to nine stars in the clusters that were used to align the AstraLux images and calculated the pixel scale to be 23.71 ± 0.01 mas per pixel (this is the pixel scale of the re-sampled and drizzled images that we used in the further analysis; the physical pixel scale is ≈ 47.4 mas/pixel). The error of this calculation is the root-mean-square deviation of the pixel scale and the position angle of the star pairs.

The position of each companion in the images was obtained by fitting a 2D Gaussian to the stellar profiles using the FITSH software package (Pál 2012) where the binaries were wide and

bright enough to obtain a straightforward fit, and used the PSF fitting (as described in Sect. 4.1) to obtain the coordinates of the close or faint pairs.

The position of the stars relative to each other is also affected by the relative atmospheric diffraction, which we take into account by defining an error term. The possible maximum offset in the relative positions due to this effect is calculated by assuming the maximum relative shift in position of the components diffraction in the used filter (i.e. we take the extreme assumption that the spectral slope of one binary component is very blue while the other is very red, compared to each other). We took the wavelengths at the full width at half maximum (FWHM) value of the transmission function of the optical system, where the transmission function is composed of the transmission function of the filter (the AstraLux system used the RG830³, Johnson I ⁴ and SDSS i' , z' ⁵ filters) and the quantum efficiency⁶ of the CCD. Using the airmass at the observed star, we obtained the upper limit of the relative atmospheric diffraction when one or the other of the stars is shifted to the red or blue end of the transmission function.

The astrometric measurements for each epoch of each pair are listed in Table C.1. The errors listed there are the combined errors due to the uncertainty of the Gaussian fitting of the stellar positions (mean: 2.8 mas), the errors due to the relative atmospheric diffraction (mean: 57.7 mas), and the uncertainty from the pixel scale conversion (mean: 7.8 mas).

4.3. Orbital fit

We estimated the orbital elements for each companion by fitting models of circular orbits to the astrometric data. A detailed description of the procedure can be found in Köhler et al. (2008). In short, it works as follows: to find the period, we employed a grid search in the range 100 to 10 000 yr. For each period, the Thiele-Innes constants were determined using singular value decomposition. From the Thiele-Innes elements, the semi-major axis a , the position angle of the line of nodes Ω , and the inclination i were computed. We have restricted the eccentricity to be zero in all cases as the number of available epochs is moderate and only covers a small portion of the orbit. The obtained orbital parameters are listed in Table 2.

4.4. Spectral energy distribution

To properly characterize the systems in question, we need to know the spectral energy distributions (SEDs) of the stars. The SED can tell us about the extra or extended emission in the systems, which can be signs of the dust in the discs. Since for our purposes the most interesting part of the spectrum is between the optical and millimeter wavelength, we looked for photometric measurement in this region. We employed many photometric surveys: the measurements from Kenyon & Hartmann (1995), Howard et al. (2013) and the IRAS, Spitzer, 2MASS, WISE all-sky surveys, a few ALMA and HST observations, and our lucky imaging data.

³ http://sydor.com/pdfs/Schott_RG830.pdf

⁴ http://www.astrodon.com/products/filters/astrodon_photometrics_-_uvbirc/

⁵ http://www.astrodon.com/products/filters/astrodon_photometrics_-_sloan/

⁶ The data sheet of the camera used in the AstraLux system is available at: http://www.andor.com/pdfs/specifications/Andor_iXon_897_Specifications.pdf

Table 2. Parameters of the fitted orbits.

Binary pair	a (")	a (AU)	Period (yr)	Ω (°)	i (°)
LkCa 3	5.8	817	>10 000	161	95
DD Tau	7.4	1041	>10 000	84	94
LkCa 7	1.1	157	575	27	94
FV Tau	3.6	505	>10 000	49	82
FV Tau/c	0.7	103	316	113	86
UX Tau AC	2.7	383	692	2	90
UX Tau AB	11.0	1542	>10 000	100	84
FX Tau	0.9	132	417	114	100
DK Tau	4.9	683	>10 000	109	95
XZ Tau	0.3	42	182	143	116
HK Tau	8.8	1233	>10 000	88	105
V710 Tau	4.1	573	>10 000	38	130
UZ Tau AB	0.8	110	1202	87	62
UZ Tau AC	5.7	796	>10 000	165	53
GH Tau	0.3	48	575	145	138
HN Tau	11.5	1604	>10 000	51	87
HV Tau	4.0	565	501	44	92
V999 Tau	13.0	1826	>10 000	18	89
V1000 Tau	0.2	34	138	98	60
RW Aur	1.5	206	955	74	94

Notes. Eccentricity is zero for all and the χ^2_ν is listed in Table 4. a : semi-major axis (using the distance to Taurus star-forming region, see Sect. 2.2), Ω : position angle of node, i : inclination

The magnitude data were converted into λF_λ using the conversion formulas from Johnson (1966), Bessell (1979), Glass et al. (1982), Berrilli et al. (1992), Gehrz et al. (1974), Helou & Walker (1988), while the data from the surveys were either already given in Jy or had their own conversion formulas to obtain λF_λ (e.g. WISE).

We fitted an SED curve on all observations, using the NextGen2 atmospheric models from Hauschildt et al. (1999)⁷ and the extinction formulae from Cardelli et al. (1989). We adopted $R_V = 3.1$ for the total-to-selective extinction ratio, which is the general value for standard interstellar matter. We note, however, that Vrba & Rydgren (1985) also found $R_V = 3.1$ applicable to Taurus. The spectral types were collected from the literature as listed in Table 1, and we calculated the effective temperatures from the spectral types of each component (using the relations from Table 6 in Pecaut & Mamajek 2013). We used the calculated effective temperature to select the model of the correct temperature from the NextGen2 models. We fitted the SEDs up to the H band (except for DD Tau, where we had to use K -band observations because of missing resolved magnitudes at shorter wavelengths) to avoid the influence of the excess emissions from the circumstellar discs present in many systems. The fitted values were the A_V extinction and a scaling value that we obtained using a grid search. We have derived the uncertainties of the extinction magnitude using a Monte Carlo approach by randomly varying the measured flux values within 1σ and recording the extinction magnitudes of the different runs, repeated a few hundred times. We employed a “combined flux” fitting procedure

Table 3. SED fitting parameters.

Component	SpT	T_{eff}^1 (K)	A_V (mag) fit	L^2 ($L_\odot$)	Mass ($M_\odot$)	IR ex. ³ (mag)
LkCa 3 A	M2	3490	$0.8^{+0.8}_{-0.3}$	0.75	0.511	1.6
LkCa 3 B	K7	3970	$3.7^{+4.3}_{-2.2}$	0.49	1.200	1.0
DD Tau A	M3	3360	$0.7^{+2.5}_{-0.7}$	0.15	0.274	6.8
DD Tau B	M3	3360	$7.7^{+0.3}_{-1.3}$	0.27	0.993	3.8
LkCa 7 A	M0	3770	$0.7^{+0.7}_{-0.5}$	0.39	0.536	–
LkCa 7 B	M3.5	3260	$1.7^{+3.1}_{-0.8}$	0.23	0.259	–
FV Tau A	K5	4140	$6.5^{+1.5}_{-3.0}$	0.29	1.294	5.4
FV Tau B	K6	4020	$8.0^{+0.0}_{-0.3}$	0.16	1.041	4.9
FV Tau/c A	M2.5	3425	$3.1^{+0.1}_{-0.5}$	0.16	0.343	–
FV Tau/c B	M3.5	3260	$8.0^{+0.0}_{-0.9}$	0.03	0.234	–
UX Tau A	K5	4140	$1.0^{+2.5}_{-0.0}$	0.86	1.005	3.9
UX Tau B	M2	3490	$7.0^{+1.0}_{-7.0}$	0.27	1.032	0.1
UX Tau C	M5	2880	$8.0^{+0.0}_{-0.0}$	0.01	0.087	1.5
FX Tau A	M1	3630	$2.1^{+0.8}_{-1.2}$	0.34	0.514	4.7
FX Tau B	M4	3160	$4.6^{+2.8}_{-2.4}$	0.19	0.180	3.4
DK Tau A	K9	3880	$0.0^{+3.2}_{-0.0}$	0.36	0.552	7.2
DK Tau B	M1	3630	$5.3^{+2.7}_{-5.3}$	0.55	1.315	3.7
XZ Tau A	M2	3490	$1.1^{+0.4}_{-0.2}$	0.15	0.334	–
XZ Tau B	M3.5	3260	$2.3^{+0.8}_{-0.7}$	0.07	0.228	–
HK Tau A	M1	3630	$2.8^{+0.4}_{-0.7}$	0.13	0.423	–
HK Tau B	M2	3490	$7.6^{+0.4}_{-0.7}$	0.03	0.334	–
V710 Tau A	M0.5	3700	$2.1^{+0.5}_{-0.9}$	0.37	0.567	–
V710 Tau B	M2.5	3425	$8.0^{+0.0}_{-4.2}$	0.27	1.258	–
UZ Tau A	M2	3490	$0.5^{+2.5}_{-0.5}$	0.50	0.417	5.4
UZ Tau B	M3	3360	$4.0^{+4.0}_{-4.0}$	0.35	0.482	4.5
UZ Tau C	M1	3630	$4.5^{+3.5}_{-4.5}$	0.30	0.715	3.1
GH Tau A	M2	3490	$0.6^{+2.5}_{-0.6}$	0.29	0.360	4.5
GH Tau B	M2	3490	$3.1^{+4.9}_{-2.3}$	0.37	0.511	3.0
HN Tau A	K5	4140	$3.0^{+0.2}_{-1.6}$	0.15	0.715	–
HN Tau B	M4	3160	$7.6^{+0.4}_{-3.2}$	0.02	0.190	–
HV Tau A	M2	3490	$2.8^{+0.4}_{-2.5}$	0.31	0.458	1.6
HV Tau C	M0	3770	$8.0^{+0.0}_{-0.0}$	0.08	0.572	2.6
V999 Tau A	M0.5	3700	$3.2^{+0.0}_{-0.4}$	0.27	0.567	–
V999 Tau B	M2.5	3425	$8.0^{+0.0}_{-3.0}$	0.21	0.897	–
V1000 Tau A	M1	3630	$4.3^{+1.7}_{-1.0}$	0.24	0.564	–
V1000 Tau B	K7	3970	$5.3^{+2.5}_{-1.0}$	0.15	0.722	–
RW Aur A	K2	4760	$3.2^{+0.0}_{-0.7}$	0.21	1.155	6.3
RW Aur B	K5	4140	$3.3^{+0.3}_{-0.8}$	0.81	1.294	1.6

Notes. ⁽¹⁾ The effective temperature was calculated from the spectral type, and the masses were obtained using the 2 Myr isochrones from Baraffe et al. (2015). ⁽²⁾ Luminosity. ⁽³⁾ IR excess at 10 μm , individual flux, the empty cells (–) indicate stars without resolved 10 μm observations.

where we took into account both the individual flux of the components and the combined flux of the whole system at the same time.

The obtained extinction magnitudes are listed in Table 3, and plots of the fluxes and SED curves are shown in Fig. 2. The fitted

⁷ We used the SEDs available at <http://www.am.ub.edu/~carrasco/models/NextGen2/>, with the parameters $M/H = 0.0$, $\alpha/\text{Fe} = 0.0$ and $\log g = 4.0$.

Fig. 2. SED plots. The triangles show upper limits, the filled markers designate the combined flux from the systems, and the empty markers show the measurements of the individual components. The dotted curves are fitted SED models.

extinctions agree with the literature data within uncertainties for many systems, but there are exceptions. In a few systems, only the extinction of the primary is in agreement with the literature (FV Tau, FV Tau/c, HK Tau, V710 Tau, GH Tau, and HV Tau); in these cases we anticipate that the discrepancy is attributed to the low number of resolved observations to fit (FV Tau/c, HK Tau, V710 Tau, GH Tau), that our optical measurement shows a higher extinction for the secondary (in the case of FV Tau), or that we know that the secondary probably has a high extinction

magnitude due to an edge-on disc (in the case of HV Tau), where the companion may be seen through their discs. There are five systems where the obtained extinction magnitudes do not agree with the literature (LkCa 3, XZ Tau, HN Tau, V999 Tau, and RW Aur), where we know that two of them show significant variability in time (XZ Tau and RW Aur, see the notes in Appendix A), one system that is a known quadruple system consisting of two spectroscopic binary systems (LkCa 3, [Torres et al. 2013](#)), and there are two systems where the optical fluxes may be the cause

Fig. 2. continued.

of discrepancy (HN Tau and V999 Tau). The latter case, V999 Tau, simply lacks reliable optical measurements (although it was observed in the SDSS, it is flagged as a not clean observation), and HN Tau features a fairly flat SED in the optical that we cannot achieve a reliable fit using the NextGen2 models.

The NextGen2 models only provide the photospheric SED curve up to $2.5 \mu\text{m}$. To measure the infra-red excess at higher wavelengths, we therefore attached a black-body radiation curve to the K -band section of the model curve (with the same effective temperature that we used in the NextGen2 model), making the SED available in the whole wavelength range.

5. Results

5.1. Astrometry

The individual epochs of the system are shown in Fig. 3 in RA-Dec plots. The markers of different colours indicate different epochs, the blue markers show the oldest epochs and the brown markers the latest (the epochs are listed in Table C.1). The dark red curve is a circular fitted orbit (see details in Sect. 4.3).

We also show the individual epochs and the proper motion together in Fig. 4. Here we separated the RA and Dec coordinates to display the movement of the companion in a (time - spatial dimension) plot. The motions of the systems are summarized in Table 4.

If the companion were a background star, its epochs would line up with the proper motion of the primary star. However, we can see that in all systems the epochs deviate from the expected proper motion (see the deviation of the black markers from the blue line in Fig. 4). Since none of our binaries show motion comparable with the proper motion, we can conclude that each pair is either a common proper motion pair or a gravitationally bound pair.

5.2. Orbital fit

We studied the relative motion of the companion around the primary by obtaining orbital fits to decide whether the pair is a common proper motion pair or is gravitationally bound (see Sect. 4.3 for the description of the fitting procedure). We calculated the average relative motion of the companions and compiled Table 4 to convey the following classifications: *relative motion over 3σ* , which shows whether there is at least a 3σ difference between any two astronomical epochs, that is to say, there is detectable relative motion; and *orbital motion*, which is a classification of the binary pair based on the χ^2_ν value of the orbital fit and the visual inspection in Fig. 5.

We based our visual inspection on the expectation that if the companion is orbiting the primary, then its coordinates must show a rising or decreasing trend in either RA or Dec (or both), in Fig. 5. If we do not see such a trend, then the companion is likely to move with the same proper motion as the primary star. The classification letters in Table 4 indicate the pairs orbiting each other with “Y” (which are also gravitationally bound); those that are probably orbiting each other, but the observational uncertainties are too high to draw certain conclusions with “C”; and those that do not show orbital motion with “N”. The last group most likely contains common proper motion pairs, because we do not see any pairs where the companion would be a background star (as mentioned in Sect. 5.1 and shown in Fig. 4). Since stars in the same star-forming region may have a similar evolutionary history, it is possible to find several binary pairs that have similar proper motions without being gravitationally bound. As for the statistics, there are ten pairs with detected

orbital motion, five with possible orbital motion, and five that are most likely common proper motion pairs.

5.3. Stellar parameters and disc statistics

We calculated several properties from the SED fits. In Table 3 we list the parameters of the SEDs (spectral type, effective temperature, and extinction) and the derived parameters (luminosity, mass, and IR excess).

We calculated the stellar masses by using the 2 Myr isochrones from Baraffe et al. (2015), where we used the effective temperature and the luminosity as input parameters from Sect. 4.4. The derived masses of the components vary mainly between 0.08 and $1.32 M_\odot$, which agrees with the general assumption that T Tauri stars are low-mass stars.

Infrared excesses were calculated at $10 \mu\text{m}$, using either N -band, W3 (WISE), or IRAS $11.8 \mu\text{m}$ measurements. The difference is calculated between the fitted SED curve (which depends on the effective temperature and therefore on the spectral type) and the individual photometric data points, that is, we calculate the excess over the photospheric level. The IR excesses of the individual stars vary between 0.1 and 7.2 mag .

There are two resolved triple systems in our sample, UX Tau and UZ Tau. Unlike binary systems, triple systems can be unstable in some configurations. We studied two stability indicators, the separations and the masses.

Reipurth & Mikkola (2015) have examined the stability of triple systems based on the masses of the companions. Their triple diagnostic diagram is based on the M_a/M_b and $M_c/(M_a + M_b + M_c)$ ratios of the systems. Based on our derived stellar masses, the ratios in the UX Tau system are $M_b/M_a = 0.97$ and $M_c/(M_a + M_b + M_c) = 0.04$. In the UZ Tau system, they are $M_b/M_a = 0.67$ and $M_c/(M_a + M_b + M_c) = 0.26$. These ratios place both the UX Tau and the UZ Tau system in the disrupted regime of the triple diagnostic diagram.

It is well known that triple systems, in which the third body is closer than ~ 10 times the separation of the other two bodies, are inherently unstable (Reipurth et al. 2014). In UX Tau, the semi-major axes are 383 AU and 1541 AU , while in the other triple system, UZ Tau, the semi-major axes are 110 AU and 797 AU . These values would indicate an unstable configuration in both cases. Moreover, we found that UX Tau AB and UZ Tau AC are very likely gravitationally bound, but UX Tau AC and UZ Tau AB do not show orbital motion. Therefore it is possible that these systems are not physical triple systems, but only binary pairs coupled with common proper motion stars. However, since the fraction of the orbits covered by the observations so far is small, the determined semi-major axes may be significantly affected by the inclination of the orbits to our line of sight, thus we cannot confirm the classification of either UX Tau or UZ Tau as a stable or unstable triple system.

6. Discussion

We plot the derived stellar and binary parameters as a function of the IR excesses in Fig. 6. The star markers show stars around which the long-wavelength observations did not resolve a disc, the filled circles show the stars where these observations did resolve a disc, and the diamonds are the stars that do not have long-wavelength measurements. The long-wavelength observations probe the emission from the outer disc (Beuther et al. 2014, and references therein), while the IR excess at $10 \mu\text{m}$ shows the emission from the inner disc.

Fig. 3. Motion of the companions. The coordinates are relative to the primary star, which is at (0, 0) in the plots (it is marked with a black star symbol when the (0, 0) coordinate is in the plotted area). The blue markers show the oldest and the brown markers the latest epochs. The maroon curve shows the fitted orbit with $e = 0$.

Fig. 4. Motion of the companions, plotted separately for the RA and Dec dimensions, time dependent. The red line is the average separation, i.e. if the companion is gravitationally bound and has no observable movement, it would line up on the red line. The blue line is the proper motion with the parallax added, the dashed blue line shows the uncertainty of the proper motion.

Fig. 4. continued.

Fig. 4. continued.

 Table 4. Proper motions, average movements per year, reduced χ^2 of the orbital fits, and classification of the binary pairs.

Binary pair	Proper motion		Movement per year		Relative motion $>3\sigma$	Orbital fit, χ^2_ν	Orbital ¹ motion
	RA (mas/yr)	Dec (mas/yr)	RA (mas/yr)	Dec (mas/yr)			
LkCa 3	$+11.5 \pm 1.0$	-22.8 ± 1.2	$+0.5 \pm 2.3$	$+4.4 \pm 1.1$	☑	0.93	Y
DD Tau	-16.7 ± 18.8	-65.8 ± 13.6	-3.0 ± 4.7	-1.2 ± 2.8	☐	0.47	C
LkCa 7	$+4.7 \pm 1.5$	-26.5 ± 2.1	$+2.4 \pm 5.8$	-2.1 ± 3.2	☑	0.76	Y
FV Tau	$+32.3 \pm 18.9$	$+0.1 \pm 10.5$	-1.8 ± 2.1	$+1.5 \pm 3.6$	☑	0.35	Y
FV Tau/c	-4.0 ± 7.0	-16.0 ± 4.0	-6.7 ± 8.7	-1.8 ± 6.9	☑	0.66	Y
UX Tau AB	$+14.1 \pm 3.4$	-14.2 ± 1.9	$+2.4 \pm 1.6$	-0.3 ± 0.6	☑	10.14	N
UX Tau AC	$+14.1 \pm 3.4$	-14.2 ± 1.9	$+1.1 \pm 7.5$	-0.8 ± 4.0	☑	0.76	Y
FX Tau	$+6.1 \pm 2.7$	-18.5 ± 3.1	-1.0 ± 5.6	-5.9 ± 10.1	☑	0.83	C
DK Tau	$+1.5 \pm 10.3$	-22.0 ± 6.1	$+18.6 \pm 16.6$	$+1.7 \pm 26.3$	☐	0.84	C
XZ Tau	$+10.1 \pm 1.1$	-18.9 ± 1.2	-3.3 ± 1.2	$+4.0 \pm 0.9$	☑	24.84	Y
HK Tau	$+13.8 \pm 6.4$	-19.5 ± 5.9	-7.8 ± 6.9	$+3.1 \pm 4.3$	☑	1.84	N
V710 Tau	$+12.1 \pm 3.0$	-46.2 ± 6.3	-7.9 ± 8.0	$+4.9 \pm 4.9$	☐	1.71	N
UZ Tau AB	$+79.9 \pm 42.5$	-32.4 ± 8.2	-3.4 ± 4.3	$+1.3 \pm 2.7$	☑	1.47	Y
UZ Tau AC	$+79.9 \pm 42.5$	-32.4 ± 8.2	-1.9 ± 0.7	$+4.8 \pm 1.1$	☑	9.51	N
GH Tau	$+46.0 \pm 3.8$	-50.5 ± 4.3	-0.4 ± 0.6	$+3.3 \pm 0.9$	☑	1.84	Y
HN Tau	$+9.6 \pm 4.3$	-18.5 ± 3.6	$+11.5 \pm 7.6$	$+3.3 \pm 6.1$	☑	0.87	C
HV Tau	$+43.5 \pm 6.6$	$+19.7 \pm 8.6$	$+2.6 \pm 35.5$	$+13.6 \pm 35.5$	☐	2.44	N
V999 Tau	$+2.9 \pm 3.6$	-10.9 ± 5.9	-5.6 ± 6.2	$+6.2 \pm 12.1$	☑	1.88	Y
V1000 Tau	$+1.0 \pm 3.9$	-28.1 ± 4.3	-0.7 ± 0.8	-5.4 ± 0.9	☑	5.26	Y
RW Aur	$+5.7 \pm 1.6$	-23.6 ± 0.8	$+3.6 \pm 0.8$	-1.0 ± 0.5	☑	6.43	C

 Notes. ⁽¹⁾ Y: orbital motion visible, C: orbital motion possible (candidate pair), N: orbital motion not seen.

Fig. 5. Motion of the companions, plotted separately for the RA and Dec dimensions, time dependent. The red line is the orbit from the orbital fit. The black markers are literature data points, the blue markers are data points from our observations.

Fig. 5. continued.

Fig. 5. continued.

Fig. 6. Scatter correlation plots. The filled circles show stars with discs observed at long wavelengths, the star markers stand for the stars without a disc detected at long wavelengths (however, we stress that a disc could still be present at detection levels lower than what was used by [Harris et al. 2012](#) or [Cabrit et al. 2006](#)) and the diamonds are the stars where we have no high spatial resolution long-wavelength observation of the systems. The blue markers are primary, the green markers are secondary or tertiary stars.

In Fig. 6 (left panel, IR excess – A_V) there are stars in all quadrants in this projection of the parameter space, and we do not see a correlation. The middle and right panels in Fig. 6 (IR excess – T_{eff} and IR excess – semi-major axis) also shows no correlations, which also applies to the mass and luminosity as a function of IR excess.

In the IR excess plots we can see that all but one star with discs detected at long wavelengths have $10\ \mu\text{m}$ IR excess over 3.9 mag. From the opposite direction, we can also see that all but one star with IR excesses over 3.9 mag have a disc detected at longer wavelengths. In the first case the exception is HV Tau C, which is a star with an edge-on disc, and its T Tauri classification falls between Class I and II because of its flat SED around $10\ \mu\text{m}$.

Its IR excess is only moderate although it definitely harbours a disc, but the edge-on disc may decrease the detectable IR excess. In the second case the exception is GH Tau A, which has an IR excess of 4.5 mag, but we note that the uncertainties of its $10\ \mu\text{m}$ measurements are high, therefore it may be labelled as an outlier. We also note that the intrinsic variability of T Tauri stars can be significant, and the outliers might be attributed to the fact that many of the photometric measurements were taken apart in time.

In a binary pair of young stars it is possible that one star has an influence on the disc of the other star, and such influence may be visible in the emission originating from the disc. Therefore we examined the distribution of IR excess in single T Tauri stars to determine whether we can see any difference between the

distribution of the IR excess of single stars and stars in multiple systems. We selected 40 single stars that have full *UVBRI* photometry, have no sign of multiplicity, and present a similar spectral type distribution as the binary sample. We selected the single stars from the [Kenyon & Hartmann \(1995\)](#), [Sicilia-Aguilar et al. \(2004\)](#) and [Luhman et al. \(2017\)](#) papers, among six other stars found in SIMBAD by querying the Taurus-Auriga region for T Tauri objects of specific spectral types (listed in Table B.1). To ensure that the selected stars are single, we checked the stars in SIMBAD, VizieR, and the Washington Double Star Catalog (WDS), looking for any sign of multiplicity, such as dual SED curves, dual spectral types, notes on duality, or components present in the WDS with a separation smaller than $5.8''$, which is the upper limit of separations in our sample. The resulting sample was analysed in a way similar to our multiple system: we added $10\ \mu\text{m}$ photometry data from the WISE survey, fitted the SED curves, and derived the IR excess.

The $10\ \mu\text{m}$ IR excess is measured in the Rayleigh-Jeans region of the SED, which is not as dependent on the effective temperature as the *K*-band magnitudes, for instance, but it is still affected by it.

The results of the comparison of the $10\ \mu\text{m}$ excesses is plotted in Fig. 7; the IR excesses of the single stars are between 1.7 and 9.1 mag. The main difference between the two distributions is that the multiple sample has slightly more stars with high IR excesses, while the single sample has more stars with low IR excesses. We performed a Kolmogorov-Smirnov test to compare the two distributions of the IR excesses. The resulting $D_{KS} = 0.27$ difference and $p_{KS} = 0.20$ probability indicates that the null hypothesis (in which the underlying distributions would be identical) cannot be rejected at a value of $p < 0.05$ (and a confidence of >0.95). Therefore, although one could expect that the presence of a companion could affect the emission coming from the inner disc, the apparent difference between the IR excess of the single and multiple objects may be due to statistical fluctuations.

7. Conclusions

We have carried out a survey of 18 multiple T Tauri systems with the goal to detect orbital motion, determine orbital parameters, and also study correlations between the binary configuration, the disc state, and stellar parameters. Our sample covers binary separations from $0.22''$ to $5.8''$ and spectral types K1 to M5 (corresponding to masses between 0.08 and $1.32\ M_{\odot}$).

We found that 10 pairs out of 20 are orbiting each other, 5 pairs may show orbital motion, and 5 are very likely common proper motion pairs. We found no obvious correlation between the stellar parameters and binary configuration. The $10\ \mu\text{m}$ IR excess of the multiple systems varies between 0.1 and 7.2 mag, while it is between 1.7 and 9.1 in the sample of single stars. The distribution of the IR excesses in the two samples provides no statistical evidence for being different distributions, therefore the presence of the companion does not affect the emission coming from the inner disc.

We note that we did not detect any signs of circumbinary discs, which are usually also present in young multiple stellar system. However, they are more abundant around very close binaries with a separation of a few AU ([Reipurth et al. 2014](#)), which is not the case for our sample. Moreover, the circumbinary discs have to have larger inner holes because of the central stars (in our sample the holes would be larger than 30 AU), therefore their infrared excess can easily be below the sensitivity of our observations.

Fig. 7. $10\ \mu\text{m}$ IR excesses by multiplicity. Blue: single stars, Red: multiple systems (individual flux measurements).

The obtained orbital periods vary from 138 year to over 10 000 yr. This suggests that even for the shortest orbital periods, the observation from the past ≈ 20 years may only cover $\approx 15\%$ of the orbit, therefore obtaining precise orbital fits is not yet viable. We may be able to obtain a meaningful astrometric orbit by re-observing seven of the systems included in our study in 15 yr.

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Appendix A: Description of the individual targets

LkCa 3: This system was long known as a visual binary (since it was resolved by [Woitas et al. 2001](#)), but recent observations from [Torres et al. \(2013\)](#) have shown that it is a hierarchical quadruple system of M-type stars. With the assumption of co-evality, Torres et al. found an age of 1.4 Myr and a distance of 133 pc for the system, which is consistent with previous estimates for the region of LkCa 3 and suggests that the system is on the near side of the Taurus complex.

DD Tau: It was resolved as a binary by [Bouvier et al. \(1992\)](#), who have obtained high-resolution images of the T Tauri star DD Tau at optical and near-IR wavelengths, between 0.5 and 3.9 μm . The system was resolved into two intensity peaks, with a separation of $0.56 \pm 0.01''$ and position angle (PA) of $184 \pm 2^\circ$. The photometry of the two components suggested that DD Tau is a binary system consisting of two active T Tauri stars of similar luminosity. The authors also found evidence for an extended nebulosity, which may be a reflection nebula illuminated by the two stars. [Gomez de Castro & Pudritz \(1992\)](#) presented high-resolution and narrow-band images of DD Tau, obtained with the High-Resolution Camera of CFHT, in which they also resolved the forbidden line emission region. They found that the bulk of the continuum emission is concentrated in two knots that are separated by $0.55''$ and oriented in a PA of 6.4° . The forbidden-line morphology was found to be distinctly different from that of the continuum. The forbidden N II emission appeared to be a “jetlike” extension connecting the two continuum knots, while the forbidden S II emission seems to be confined to the northern knot. The southern knot (DD Tau B) is extended in the of PA $\approx 130^\circ$. The orientation of the disc as defined by IR polarization measurements is PA $\approx 125^\circ$.

LkCa 7: The high-resolution survey by [Leinert et al. \(1993\)](#) showed that it is a binary system. The primary is known to be a weak-line T Tauri star, as observed by [Grankin \(1998\)](#), for example. It was part of a long-term variability survey ([Grankin et al. 2008](#)), where they measured the stellar rotation period.

FV Tau and FV Tau/c: These two binary systems are separated by $12.29''$ ([Kraus & Hillenbrand 2009](#)). They are usually included in the T Tauri binary surveys and are referred to as a wide binary pair, probably forming a quadruple system (see e.g. [Ghez et al. 1993](#); [Hartigan & Kenyon 2003](#)). However, there is no evidence that they are gravitationally bound, thus we handle them as two separate systems. Since their separation is too large for most of the high spatial resolution instruments that we used, combining the separations from two different pointings would lead to higher astrometric uncertainties. Therefore our data do not allow us to test whether FV Tau and FV Tau/c indeed form a common proper motion quadruple system.

FV Tau: This system was first resolved by [Chen et al. \(1990\)](#) using lunar occultation measurements, but [Leinert et al. \(1991\)](#) measured the binary parameters first. FV Tau (and FV Tau/c) was included in a recent survey conducted by [Akeson & Jensen \(2014\)](#), who used ALMA at two wavelengths (850 μm and 1.3 mm). They derived the stellar and disc masses of the primary, $1.2^{+0.21}_{-0.42} M_\odot$ and $(6.3 \pm 1.4) \times 10^{-4} M_\odot$, respectively.

FV Tau/c (also as HBC 387): [Simon et al. \(1992\)](#) resolved this binary. As its name suggests, it is very close to FV Tau ($12.3''$) and was also included in the survey by [Akeson & Jensen \(2014\)](#) (using ALMA at 850 μm and 1.3 mm). However, the measured separation does not agree with the previous observations (the discrepancy is $\approx 3\sigma$ in the separation, suggesting another body that emits the radio), therefore we did not include this epoch in our analysis.

UX Tau: The two brightest components (A and B) in UX Tau have been resolved in 1944 by [Joy & van Biesbroeck \(1944\)](#). The third component (C) was seen by Herbig in 1975 ([Jones & Herbig 1979](#)), but [Della Prugna et al. \(1992\)](#) were the first to measure the actual separation. The fourth component (D) was discovered by [Duchêne \(1999\)](#) at CFHT, using adaptive optics.

[Espaniat et al. \(2007\)](#) have analysed the *Spitzer* IRS spectra for UX Tau A, and their SED fittings suggested the existence of a disc gap of ≈ 56 AU. A few years later, [Espaniat et al. \(2010\)](#) measured the gap to be 71 AU wide, using near-infrared spectral measurements. [Tani et al. \(2012\)](#) also examined the disc around UX Tau A, using near-infrared observations from the Subaru telescope, who found a strongly polarized circumstellar disc surrounding UX Tau A and extending to 120 AU, at a spatial resolution of $0.1''$ (14 AU). The disc is inclined by $46^\circ \pm 2^\circ$, with the west side being the nearest. They did not detect the gap that was suggested by SED models at the limit of their inner working angle (23 AU) at the near-infrared wavelength.

UX Tau C was observed by [White & Basri \(2003\)](#) using the Keck I telescope to obtain high-resolution spectra. They re-determined the spectral type to be M5 and calculated the mass to be $0.166 \pm 0.047 M_\odot$. [Andrews et al. \(2011\)](#) found no evidence for remnant disc material and failed to detect 880 μm emission. This is in agreement with [McCabe et al. \(2006\)](#), who determined UX Tau A to be a classical T Tauri star, while UX Tau B and C are weak-line T Tauris.

FX Tau: This system was also resolved by [Leinert et al. \(1993\)](#). [Akeson & Jensen \(2014\)](#) observed this system with ALMA, but did not detect the companion.

DK Tau: The first observer of this binary system was [Weintraub \(1989\)](#), who used speckle imaging. [Simon et al. \(1992\)](#) also resolved the binary using occultation and optical measurements, but the position they reported deviates by more than 5σ from the other astrometric observations. However, their numbers strongly suggest a coordinate conversion error (a sign error in the right ascension H:M:S $\rightarrow$ degree conversion), thus we revisited their data and recalculated the astrometric position. Recently, the system was resolved by [Akeson & Jensen \(2014\)](#) using ALMA, but since the separation does not agree with the positions therein, we recalculated the separation based the RA and Dec coordinates reported there.

XZ Tau: [Haas et al. \(1990\)](#) resolved XZ Tau as a binary system using near-infrared speckle observations. [Close et al. \(1997\)](#) resolved the system and performed astrometric and photometric measurements. However, since their focus was HL Tau, they only provided coarse photometry for XZ Tau, which includes outflows around the system. [Krist et al. \(2008\)](#) have monitored the system and its bipolar outflow over ten years using the HST. They found traces of shocked emission as far

as 20'' south of the binary. VLA observations carried out by Carrasco-González et al. (2009) resolved the southern component into a double system with a separation of 90 mas, making the XZ Tau system a triple. The third component is likely deeply embedded and not visible at optical and IR wavelengths. Forgan et al. (2014) revisited the possibility of a third component by observing the system again with VLA, but they found no trace of that third component. Dodin et al. (2016) recently observed the system using a 6 m class telescope with speckle imaging and also derived preliminary orbital parameters.

HK Tau: It was first resolved by Moneti & Zinnecker (1991) using classical infra-red imaging. It was also included in the ALMA survey by Akeson & Jensen (2014). It is known to be the first young binary system where an edge-on disc was found using HST (Stapelfeldt et al. 1998; McCabe et al. 2011). The secondary star is heavily extincted due to its disc, and, in optical and IR, only the scattered light is detectable from that companion. Later observations revealed that the primary also harbours a disc, making this system a young pre-main-sequence binary with two circumstellar discs (Harris et al. 2012).

V710 Tau: This system was first resolved by Cohen & Kuhi (1979) using infra-red spectroscopy, and the binary parameters were determined later by Leinert et al. (1993) and Hartigan et al. (1994). It is a classic and weak-line T Tauri star pair, the primary is slightly more massive than the secondary (White & Ghez 2001; Jensen & Akeson 2003). Shukla et al. (2008) spatially resolved the system using Chandra and they found that both components emit X-rays. V710 Tau was observed by Akeson & Jensen (2014) as well using ALMA, but they could only detect the primary star.

UZ Tau: The two brightest star of this multiple system have been noted by Joy & van Biesbroeck (1944), and the system was later resolved as a triple system by Simon et al. (1992). The UZ Tau W binary was extensively examined by Jensen et al. (1996), and in the same year, Mathieu et al. (1996) obtained spectroscopic measurements of UZ Tau E that showed it to be a spectroscopic binary, making the system quadruple. The UZ Tau E binary was closely examined by Jensen et al. (2007), who found that the brightness varies with a period of 19.16 ± 0.04 days, which is consistent with the previous spectroscopic binary period of 19.13 days. Their best orbital fit resulted in a separation of 0.124 ± 0.003 AU, which converts into a spatial separation smaller than 1 mas, making it an as yet unresolvable binary.

GH Tau: The GH Tau binary was resolved first by Leinert et al. (1993). This binary was included in the surveys later by McCabe et al. (2006) and Hartigan & Kenyon (2003).

HN Tau: HN Tau was resolved as a binary system by Moneti & Zinnecker (1991). It was also observed in the ALMA survey by Akeson & Jensen (2014), but they did not detect the secondary.

HV Tau: This is a triple system, resolved first by Simon et al. (1992). HV Tau A-B is a close binary (74 mas, measured in 1996) with similar brightnesses, therefore in many surveys only the HV Tau AB-C pair is resolved. The HV Tau A-B pair was recently re-observed by Kraus et al. (2011) using the Keck

telescope, and they reported 36.0 ± 0.2 mas for the separation and 326.6 ± 0.3 degree for the position angle. The system was closely examined by Duchêne et al. (2010) using NACO at the VLT. They found that HV Tau AB-C is a common proper motion pair and that the orbital motion within the close HV Tau AB system is slow, suggesting a highly eccentric orbit or a large de-projected physical separation. Previous spectroscopic and photometric measurements also showed that the AB subsystem does not experience accretion, nor does it show infra-red excess (White & Ghez 2001). HV Tau C star has an almost edge-on disc, which has a mass in the range of $M_{\text{disc}} \sim 10^{-3} M_{\odot}$, and $R_{\text{out}} = 50$ AU size (Duchêne et al. 2010).

The T Tauri classification of HV Tau C is ambiguous, it is usually classified as “I?” because the SED is rising in the NIR regime, but it levels out after $\approx 20 \mu\text{m}$. Owing to its almost edge-on and optically thick disc that totally block out the star as a point source, Stapelfeldt et al. (2003) suggested that an extinction magnitude of $A_V > 50$ should be adopted for this system. The edge-on disc also prevented us from precisely locating the position of the star, which can be seen in the positional plot in Fig. 3, where the astrometric epochs overlap each other at the assumed position of the star. This makes the possible orbital fit difficult, and we would either need to measure the exact position of the star more accurately or wait for the companion to orbit around the primary for a few more decades before deriving precise orbital parameters for this system.

V955 Tau, V999 Tau, V1000 Tau: These stars are also known as LkH α 332, LkH α 332 G2, LkH α 332 G1, respectively. They are three close binary pairs that are $\approx 11''$ and $\approx 26''$ away from each other, probably forming a wide triple system (Kraus & Hillenbrand 2009). All three stars were resolved to be binaries by Woitatz et al. (2001) and V1000 Tau was resolved slightly earlier by Ghez et al. (1995). Hartigan & Kenyon (2003) have determined V955 Tau to be a classical T Tauri pair, while V999 Tau is a weak-line T Tauri pair.

RW Aur: This star was resolved by Joy & van Biesbroeck (1944) as a binary, and it is also shown as a binary pair in the third Herbig-Bell catalogue (Herbig & Bell 1988). Cabrit et al. (2006) resolved an optically thick disc around the primary that has a radius of 40–57 AU. The primary also features one of the highest known accretion rates for a T Tauri star (Hartigan et al. 1995). The primary star features an optically visible asymmetric bipolar outflow and was recently resolved by Skinner & Güdel (2014) using Chandra. They found that both components are visible in X-rays, and the luminosity of the less-massive secondary is at least twice that of the primary and is variable. This binary also features a peculiar dynamical configuration: the disc around RW Aur A is counter-rotating with respect to the binary orbital motion (Bisikalo et al. 2012). It is a significantly variable system. Rodriguez et al. (2013) observed a dimming that had a depth of ≈ 2 mag and a duration of ≈ 180 days between 2010 September and 2011 March. They speculated that the dimming may be attributed to a one-time occultation by the tidally disrupted disc around the primary.

Antipin et al. (2015) obtained resolved *UBVRI* photometry of the system in 2015. However, they found that the primary has suffered a 3 mag grey extinction, while the secondary became 0.7 mag brighter in all bands, compared to the measurements of White & Ghez (2001). Therefore, since this is a high difference in magnitudes, we refrained from including this photometry data in our analysis. The variability was also observed in the

IR regime: [Shenavrin et al. \(2015\)](#) noted ≈ 1.5 mag variability in the J band over four years.

RW Aur B had two astrometric epochs that deviate significantly from the hypothetical orbit and the other data points. One epoch is a Keck observation in a narrow-band N -band

observation (1999-11-16, IHW18 filter), which may have captured some other feature, such as scattered light from the jets, disc, or nebula around RW Aur. The other deviating epoch comes from the survey of [Leinert et al. \(1993\)](#).

Appendix B: Single star sample

In the following we list the single T Tauri stars that are used in Sect. 6 to compare the distribution of the 10 μm IR excess of single stars and stars in multiple systems.

Table B.1. Single star sample and their 10 μm IR excesses.

Star	SpT	T_{eff} (K)	A_V lit.	A_V fit	Lum. ($L_{\odot}$)	IR excess (mag)
V1304 Tau	M1	3630	–	$0.8^{+0.8}_{-0.4}$	0.25	1.9
2MASS J04110570+2216313	M4	3200	–	$1.1^{+0.1}_{-0.2}$	0.10	1.7
LkCa 1	M4	3200	1.0	$1.0^{+0.3}_{-0.5}$	0.33	1.7
IRAS 04108+2910	M3	3400	–	$0.0^{+5.7}_{-0.0}$	0.01	9.1
FM Tau	M0	3770	0.7	$1.1^{+3.3}_{-1.1}$	0.19	4.7
FN Tau	M5	2880	1.4	$1.7^{+3.0}_{-1.7}$	0.17	6.2
XEST 20-071	M3	3400	–	$4.2^{+1.8}_{-3.9}$	0.22	2.5
CY Tau	M2	3490	1.3	$1.3^{+0.7}_{-0.8}$	0.30	4.2
HBC 372	K5	4140	0.0	$0.0^{+1.1}_{-0.0}$	0.12	2.0
2MASS J04202606+2804089	M4	3200	–	$0.3^{+0.3}_{-0.2}$	0.09	5.2
DE Tau	M3	3400	0.6	$0.8^{+1.0}_{-0.8}$	0.49	4.7
DG Tau	K5	4140	2.2	$1.1^{+3.1}_{-1.1}$	0.56	8.1
HBC 388	K1	4920	0.1	$0.3^{+0.9}_{-0.3}$	1.31	1.9
IQ Tau	M1	3630	1.3	$1.2^{+2.7}_{-1.2}$	0.36	5.0
V1076 Tau	K7	3970	0.7	$1.2^{+0.7}_{-0.5}$	0.24	1.8
RX J0432.8+1735	M2	3490	–	$0.7^{+1.3}_{-0.7}$	0.16	2.7
V830 Tau	M0	3770	0.3	$0.6^{+0.7}_{-0.6}$	0.51	1.8
IRAS 04303+2240	M1	3630	15.1	$5.2^{+0.8}_{-2.2}$	0.03	8.4
2MASS J04334171+1750402	M4	3200	–	$1.8^{+0.5}_{-0.2}$	0.05	3.5
DM Tau	M2	3490	0.0	$0.0^{+1.6}_{-0.0}$	0.13	6.5
HO Tau	M1	3630	1.1	$0.4^{+1.5}_{-0.4}$	0.07	5.3
DN Tau	M1	3630	0.5	$0.7^{+0.8}_{-0.7}$	0.56	4.3
2MASS J04355881+2438404	M3	3400	–	$2.1^{+0.2}_{-0.3}$	0.10	1.7
2MASS J04360131+1726120	M3	3400	–	$0.7^{+3.7}_{-0.7}$	0.03	5.7
LkCa 15	K5	4140	0.6	$1.3^{+3.0}_{-1.1}$	0.51	4.2
GO Tau	K5	4140	1.2	$1.7^{+2.1}_{-1.7}$	0.07	5.4
IRAS 04429+1550	M3	3400	–	$1.8^{+0.3}_{-1.8}$	0.17	5.5
2MASS J04505356+2139233	M2	3490	–	$1.6^{+1.6}_{-1.6}$	0.17	1.7
GM Aur	K6	4020	1.4	$1.2^{+0.8}_{-1.0}$	0.55	3.9
XEST 26-071	M4	3200	–	$1.7^{+0.2}_{-0.6}$	0.07	4.3
V1353 Tau	M1	3630	–	$1.2^{+0.5}_{-0.5}$	0.12	1.8
2MASS J04590305+3003004	M2	3490	–	$0.6^{+0.3}_{-0.2}$	0.11	4.4
V836 Tau	K7	3970	0.6	$1.4^{+0.6}_{-1.0}$	0.29	4.3
2MASS J05044139+2509544	M4	3200	–	$1.7^{+1.1}_{-1.2}$	0.07	4.3
2MASS J05122759+2253492	M3	3400	–	$1.2^{+0.6}_{-0.7}$	0.20	3.0
2MASS J05290743+0150319	M2	3490	0.3	$1.1^{+0.4}_{-0.3}$	0.04	1.7
2MASS J05374702-0020073	M2	3490	0.3	$1.0^{+0.9}_{-1.0}$	0.03	4.7
2MASS J05465241+0020016	K9	3880	3.3	$3.2^{+2.3}_{-1.0}$	0.02	5.7
2MASS J05470397+0011143	M2	3490	0.9	$0.6^{+0.2}_{-0.2}$	0.01	6.8
[SHB2004] Trumpler 37 24-1736	M1	3630	1.0	$3.0^{+1.1}_{-0.4}$	0.01	3.4

Appendix C: Additional table

Table C.1. Astrometric epochs of each pair in our sample.

Object	Date	Telescope	Method ¹	Filter	Sep. (")	PA (°)	Magn. diff.	Ref.
LkCa 3 B	1990-12-06	CAHA 3.5 m	SI	<i>K</i>	0.470 ± 0.040	78.0 ± 1.0	0.753 ± 0.055	19
	1991-10-18	Palomar/Hale 5.1 m	SI	<i>K</i>	0.491 ± 0.009	77.0 ± 1.0	0.049 ± 0.006	9
	1993-10-05	CAHA 3.5 m	SI	<i>J</i>	0.494 ± 0.013	74.5 ± 0.7	0.519 ± 0.036	19
	1996-09-29	CAHA 3.5 m	SI	<i>H</i>	0.485 ± 0.004	74.2 ± 0.3	0.170 ± 0.014	19
	1997-11-19	CAHA 3.5 m	SI	<i>K</i>	0.485 ± 0.004	73.4 ± 0.1	0.305 ± 0.011	19
	1997-12-05	NASA ITF/NSFCAM	SI	<i>K</i>	0.479 ± 0.010	72.8 ± 1.0	0.225 ± 0.044	20
	1997-12-09	NASA ITF/NSFCAM	SI	<i>L</i>	0.478 ± 0.009	73.0 ± 1.4	0.120 ± 0.044	20
	2001-12-01	Keck	I	<i>K</i>	0.470 ± 0.010	72.0 ± 1.0	0.180 ± 0.028	26
	2001-12-01	Keck	I	<i>L</i>	0.470 ± 0.010	72.0 ± 1.0	0.170 ± 0.010	26
	2002-11-13	Keck	I	SiC	0.480 ± 0.020	76.0 ± 2.0	0.373 ± 0.047	26
	2006-11-11	CAHA 2.2 m	LI	RG830	0.477 ± 0.020	68.7 ± 1.9	0.575 ± 0.021	40
	2008-01-17	Keck	AO	<i>K</i>	0.484 ± 0.001	69.1 ± 0.1	0.067 ± 0.009	32
DD Tau B	1990-10-23	CFHT	I	H- α , cont	0.550 ± 0.030	184.0 ± 2.0	0.450 ± 0.101	6
	1990-11-06	CFHT	I	<i>R</i>	0.560 ± 0.020	184.0 ± 2.0	0.100 ± 0.101	6
	1990-11-08	CFHT	I	6840/90	0.560 ± 0.040	185.0 ± 3.0	0.000 ± 0.201	6
	1990-12-05	CFHT	SI	<i>L</i>	0.560 ± 0.010	186.2 ± 1.5	0.649 ± 0.040	6, 11
	1990-12-15	CAHA 3.5 m	SI	<i>K</i>	0.570 ± 0.030	188.0 ± 2.0	0.485 ± 0.017	8, 10
	1991-10-04	Palomar/Hale 5.1 m	SI	<i>K</i>	0.560 ± 0.010	186.0 ± 1.0	0.708 ± 0.012	9
	1991-10-11	CFHT	I	<i>V</i>	0.560 ± 0.020	182.0 ± 3.0	0.000 ± 0.151	6
	1991-10-11	CFHT	I	<i>I</i>	0.550 ± 0.020	184.0 ± 2.0	0.000 ± 0.101	6
	1996-12-05	NASA ITF/NSFCAM	SI	<i>K</i>	0.555 ± 0.010	182.3 ± 1.0	0.173 ± 0.055	20
	1996-12-06	NASA ITF/NSFCAM	SI	<i>L</i>	0.557 ± 0.011	182.7 ± 1.1	0.589 ± 0.083	20
	1997-12-05	NASA ITF/NSFCAM	SI	<i>K</i>	0.555 ± 0.010	182.1 ± 1.0	0.402 ± 0.035	20
	1999-09-06	HST	I	Clear	0.568 ± 0.014	182.1 ± 1.0	–	22
	1999-11-17	Keck	I	<i>N</i>	0.540 ± 0.010	179.0 ± 2.0	0.608 ± 0.050	26
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.568 ± 0.034	179.0 ± 3.3	1.123 ± 0.055	40

Notes. The magnitude difference between the two stars are also shown where we had photometric data. For a few epochs, we had no precise observation date available, in those cases we used a period in which the data could have been acquired and use the middle of that period in the calculations. ⁽¹⁾ Method: SI: speckle interferometry, LI: lucky imaging, I: imaging, AO: adaptive optics, XAO: extreme adaptive optics, R: radio observations, X: X-ray observations. ⁽²⁾ FV Tau B has two data points from 1999-11-17 which do not agree within the uncertainties, therefore we dismissed the measurement that is clearly an outlier. ⁽³⁾ We obtained the values of UX Tau AB from the separations and positions angles of UX Tau A-Ba and UX Tau A-Bb as listed in [Schaefer et al. \(2014\)](#) by linearly interpolating the positions using the flux ratio provided for UX Tau Ba-Bb therein. ⁽⁴⁾ We recalculated the 1990-10-08 epoch of DK Tau, because their numbers strongly suggest a coordinate conversion error. We also recalculated the 2012-11-17 epoch of DK Tau, because the quoted separation does not agree with the quoted coordinates. ⁽⁵⁾ We re-analysed these observations using the current NACO pipeline to be able to draw conclusions from a consistently analysed data set. ⁽⁶⁾ These dates are the middle of the time interval 1990-12–1992-10 provided by [Leinert et al. \(1993\)](#) for the time of their observations. ⁽⁷⁾ We opted to re-analyse the original VLT/NACO images using the current NACO pipeline, because the original paper does not feature a magnitude difference measurement, but the companion is actually clearly visible and measurable. Other notes: We did not include the binary survey by [Reipurth & Zinnecker \(1993\)](#), because their measurements do not cite accurate dates (only a six year long interval) and also does not cite astrometric errors. We have omitted the observation of the UX Tau AC pair by [Della Prugna et al. \(1992\)](#) because they do not give any hint on the actual observation date. We have omitted the observation of FV Tau B by [Chen et al. \(1990\)](#) because they employed lunar occultation and they were only able to determine the separation along the direction of the occultation. We have omitted the observation of V710 Tau, HN Tau and HK Tau by [Cohen & Kuhl \(1979\)](#) because they do not list the uncertainties of their measurements.

References. 1: [Joy & van Biesbroeck \(1944\)](#), 2: [Weintraub \(1989\)](#), 3: [Haas et al. \(1990\)](#), 4: [Moneti & Zinnecker \(1991\)](#), 5: [Leinert et al. \(1991\)](#), 6: [Bouvier et al. \(1992\)](#), 7: [Simon et al. \(1992\)](#), 8: [Zinnecker et al. \(1992\)](#), 9: [Ghez et al. \(1993\)](#), 10: [Leinert et al. \(1993\)](#), 11: [Tessier et al. \(1994\)](#), 12: [Hartigan et al. \(1994\)](#), 13: [Ghez et al. \(1994\)](#), 14: [Ghez et al. \(1995\)](#), 15: [Close et al. \(1997\)](#), 16: [Krist et al. \(1997\)](#), 17: [Woitas & Leinert \(1998\)](#), 18: [Krist et al. \(1999\)](#), 19: [Woitas et al. \(2001\)](#), 20: [White & Ghez \(2001\)](#), 21: [Duchêne et al. \(2003\)](#), 22: [Hartigan & Kenyon \(2003\)](#), 23: [McCabe et al. \(2003\)](#), 24: [Cabrit et al. \(2006\)](#), 25: [Correia et al. \(2006\)](#), 26: [McCabe et al. \(2006\)](#), 27: [Connelley et al. \(2008\)](#), 28: [Krist et al. \(2008\)](#), 29: [Carrasco-González et al. \(2009\)](#), 30: [Duchêne et al. \(2010\)](#), 31: [Bisikalo et al. \(2012\)](#), 32: [Torres et al. \(2013\)](#), 33: [Schaefer et al. \(2014\)](#), 34: [Akeson & Jensen \(2014\)](#), 35: [Skinner & Güdel \(2014\)](#), 36: [Forgan et al. \(2014\)](#), 37: [Daemgen et al. \(2015\)](#), 38: [ALMA Partnership et al. \(2015\)](#), 39: [Dodin et al. \(2016\)](#), 40: this work.

Table C.1. continued.

Object	Date	Telescope	Method ¹	Filter	Sep. (")	PA (°)	Magn. diff.	Ref.
LkCa 7 B	1991-09-15	CAHA 3.5 m	SI	<i>K</i>	1.050 ± 0.010	25.0 ± 2.0	0.630 ± 0.039	8, 10
	1997-12-09	NASA ITF/NSFCAM	SI	<i>L</i>	1.021 ± 0.019	24.3 ± 1.0	0.594 ± 0.059	20
	1999-01-26	HST	I	Clear	1.035 ± 0.014	25.2 ± 0.6	–	22
	2001-12-01	Keck	I	<i>K</i>	0.980 ± 0.020	25.0 ± 1.0	0.669 ± 0.030	26
	2001-12-01	Keck	I	<i>L</i>	0.990 ± 0.020	25.0 ± 1.0	0.677 ± 0.012	26
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	1.006 ± 0.031	23.9 ± 1.8	0.881 ± 0.054	40
FV Tau B	1989-10-17	CAHA 3.5 m	O	<i>K</i>	0.735 ± 0.015	271.5 ± 1.5	0.182 ± 0.010	5
	1990-07-18	IRTF	O	<i>K</i>	0.720 ± 0.010	270.0 ± 5.0	0.200 ± 0.011	7
	1991-10-20	Palomar/Hale 5.1 m	SI	<i>K</i>	0.730 ± 0.010	272.0 ± 1.0	0.483 ± 0.028	9
	1996-12-05	NASA ITF/NSFCAM	SI	<i>K</i>	0.704 ± 0.013	271.6 ± 1.0	0.429 ± 0.008	20
	1996-12-05	NASA ITF/NSFCAM	SI	<i>L</i>	0.712 ± 0.014	271.9 ± 1.0	0.408 ± 0.031	20
	1997-03-06	HST	I	<i>F814W</i>	0.718 ± 0.002	272.5 ± 0.2	0.891 ± 0.006	20
	1999-11-17	Keck	I	<i>N</i>	0.710 ± 0.020^2	272.1 ± 0.8^2	0.856 ± 0.099	26
	2000-12-02	HST	I	Clear	0.711 ± 0.014	273.0 ± 0.8	–	22
	2002-11-13	VLT/NACO	I	NB_1.64	0.703 ± 0.004	273.3 ± 0.2	1.818 ± 0.003	25, 40
	2002-11-13	VLT/NACO	I	NB_2.12	0.707 ± 0.004	273.1 ± 0.2	1.299 ± 0.005	25, 40
	2002-11-13	VLT/NACO	I	NB_2.17	0.710 ± 0.004	273.2 ± 0.2	1.276 ± 0.006	25, 40
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.684 ± 0.041	272.2 ± 1.6	2.677 ± 0.058	40
	2012-09-25	Gemini North	AO	<i>K</i>	0.693 ± 0.001	274.5 ± 0.1	1.010 ± 0.011	37
	2012-11-17	ALMA	R	1.3 mm	0.696 ± 0.046	274.4 ± 3.0	0.043 ± 0.044	34
	2012-11-17	ALMA	R	850 μ m	0.696 ± 0.046	274.4 ± 3.0	0.140 ± 0.065	34
FV Tau/c B	1990-07-18	IRTF	O	<i>K</i>	0.743 ± 0.140	293.0 ± 3.0	1.900 ± 0.096	7
	1996-12-05	NASA ITF/NSFCAM	SI	<i>K</i>	0.701 ± 0.014	293.3 ± 1.0	2.211 ± 0.029	20
	1996-12-06	NASA ITF/NSFCAM	SI	<i>L</i>	0.703 ± 0.014	293.8 ± 1.0	1.160 ± 0.056	20
	1997-03-06	HST	I	<i>F814W</i>	0.713 ± 0.002	294.0 ± 0.1	3.696 ± 0.116	20
	1998-12-06	HST	I	Clear	0.701 ± 0.014	293.6 ± 0.8	–	22
	1999-11-17	Keck	I	<i>N</i>	0.670 ± 0.020	292.0 ± 1.0	0.327 ± 0.133	26
	2002-11-12	Keck	I	SiC	0.680 ± 0.020	295.0 ± 1.0	0.312 ± 0.058	26
	2002-11-13	VLT/NACO	I	NB_1.64	0.688 ± 0.004	294.5 ± 0.3	1.924 ± 0.003	25, 40
	2002-11-13	VLT/NACO	I	NB_2.12	0.688 ± 0.004	294.5 ± 0.3	1.632 ± 0.006	25, 40
	2002-11-13	VLT/NACO	I	NB_2.17	0.689 ± 0.004	294.6 ± 0.3	1.746 ± 0.006	25, 40
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.630 ± 0.044	294.4 ± 3.2	3.111 ± 0.060	40
UX Tau AC	1988-01-15	CTIO	I	<i>K</i>	2.700 ± 0.100	181.0 ± 2.0	2.910 ± 0.021	4
	1991-10-27	Kitt Peak/0.9 m	I	<i>R</i>	2.600 ± 0.053	182.0 ± 1.0	4.430 ± 0.191	12
	1997-12-06	NASA ITF/NSFCAM	I	<i>K</i>	2.632 ± 0.027	180.2 ± 1.0	3.070 ± 0.103	20
	1997-12-06	NASA ITF/NSFCAM	I	<i>L</i>	2.634 ± 0.033	180.2 ± 1.0	3.451 ± 0.091	20
	2002-10-22	VLT/NACO	I	NB_1.64	2.684 ± 0.005	181.5 ± 0.1	3.392 ± 0.002	25, 40
	2002-10-22	VLT/NACO	I	NB_2.12	2.684 ± 0.005	181.6 ± 0.1	2.970 ± 0.001	25, 40
	2002-10-22	VLT/NACO	I	NB_2.17	2.682 ± 0.005	181.6 ± 0.1	3.135 ± 0.001	25, 40
	2002-11-12	Keck	I	SiC	2.500 ± 0.300	181.0 ± 5.0	4.440 ± 0.131	26
	2006-11-12	CAHA 2.2 m	LI	RG830	2.705 ± 0.047	180.5 ± 0.5	3.478 ± 0.055	40
	2009-10-26	Keck II	AO	<i>K</i>	2.711 ± 0.004	181.6 ± 0.1	3.212 ± 0.107	33
	2011-10-12	Keck II	AO	<i>K</i>	2.716 ± 0.002	181.6 ± 0.1	3.122 ± 0.062	33
	2013-01-28	Keck II	AO	<i>K</i>	2.720 ± 0.003	181.6 ± 0.1	2.845 ± 0.182	33

Table C.1. continued.

Object	Date	Telescope	Method ¹	Filter	Sep. (")	PA (°)	Magn. diff.	Ref.
UX Tau AB	1944-04-01	McDonald/2.1 m	I	<i>Z</i>	5.740 ± 0.109	270.1 ± 0.2	–	1
	1988-01-15	CTIO	I	<i>K</i>	5.900 ± 0.100	269.0 ± 2.0	1.350 ± 0.021	4
	1991-10-27	Kitt Peak/0.9 m	I	<i>R</i>	5.800 ± 0.116	270.0 ± 1.0	1.840 ± 0.016	12
	1997-12-06	NASA ITF/NSFCAM	I	<i>K</i>	5.860 ± 0.110	269.4 ± 1.0	1.480 ± 0.087	20
	1997-12-06	NASA ITF/NSFCAM	I	<i>L</i>	5.860 ± 0.110	269.3 ± 1.0	2.149 ± 0.029	20
	2002-10-22	VLT/NACO	I	NB_1.64	5.846 ± 0.009	269.7 ± 0.1	2.216 ± 0.004	25, 40
	2002-10-22	VLT/NACO	I	NB_2.12	5.839 ± 0.009	269.7 ± 0.1	2.188 ± 0.002	25, 40
	2002-10-22	VLT/NACO	I	NB_2.17	5.841 ± 0.009	269.7 ± 0.1	2.097 ± 0.003	25, 40
	2002-11-12	Keck	I	SiC	5.600 ± 0.100	268.0 ± 1.0	2.689 ± 0.165	26
	2006-11-12	CAHA 2.2 m	LI	RG830	5.874 ± 0.053	268.6 ± 0.5	1.422 ± 0.054	40
	2009-10-26	Keck II	AO	<i>K</i>	5.921 ± 0.003^3	270.1 ± 0.1^3	2.269 ± 0.054	33
	2011-10-12	Keck II	AO	<i>K</i>	5.908 ± 0.002^3	269.9 ± 0.1^3	2.181 ± 0.081	33
	2013-01-28	Keck II	AO	<i>K</i>	5.906 ± 0.007^3	269.9 ± 0.1^3	2.354 ± 0.313	33
FX Tau B	1990-12-15	CAHA 3.5 m	SI	<i>K</i>	0.910 ± 0.010	292.0 ± 3.0	0.649 ± 0.020	8, 10
	1991-10-18	Palomar/Hale 5.1 m	SI	<i>K</i>	0.900 ± 0.020	291.0 ± 1.0	0.733 ± 0.001	9
	1997-12-07	NASA ITF/NSFCAM	SI	<i>K</i>	0.890 ± 0.017	289.0 ± 1.0	0.857 ± 0.008	20
	1997-12-07	NASA ITF/NSFCAM	SI	<i>L</i>	0.885 ± 0.017	289.0 ± 1.0	1.182 ± 0.013	20
	1999-11-18	Keck	I	<i>N</i>	0.870 ± 0.020	289.4 ± 0.4	1.098 ± 0.044	26
	1999-11-18	Keck	I	IHW18	0.840 ± 0.020	290.5 ± 0.5	1.114 ± 0.129	26
	2001-12-01	Keck	I	<i>L</i>	0.850 ± 0.020	289.0 ± 1.0	1.050 ± 0.034	26
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.864 ± 0.075	286.6 ± 4.6	1.625 ± 0.059	40
DK Tau B	1988-10-20	Lick	SI	<i>K</i>	2.800 ± 0.300	115.0 ± 7.0	1.505 ± 0.435	2
	1990-10-08	IRTF	O	<i>K</i>	2.330 ± 0.050	120.0 ± 2.0	1.300 ± 0.101	7
	1997-12-06	NASA ITF/NSFCAM	I	<i>K</i>	2.304 ± 0.045	117.6 ± 1.2	1.561 ± 0.078	20
	1997-12-06	NASA ITF/NSFCAM	I	<i>L</i>	2.337 ± 0.056	117.6 ± 1.3	1.511 ± 0.036	20
	2002-11-13	Keck	I	SiC	2.270 ± 0.060	117.0 ± 1.0	2.327 ± 0.006	26
	2002-11-13	VLT/NACO	I	NB_1.64	2.354 ± 0.005	119.1 ± 0.2	1.150 ± 0.008	25, 40
	2002-11-13	VLT/NACO	I	NB_2.12	2.350 ± 0.005	119.1 ± 0.1	1.373 ± 0.004	25, 40
	2002-11-13	VLT/NACO	I	NB_2.17	2.350 ± 0.005	119.1 ± 0.1	1.386 ± 0.004	25, 40
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	2.358 ± 0.076	118.2 ± 1.9	1.422 ± 0.054	40
	2012-11-17	ALMA	R	1.3 mm	2.382 ± 0.047^4	118.7 ± 0.6^4	2.555 ± 0.072	34
XZ Tau B	2012-11-17	ALMA	R	850 μ m	2.382 ± 0.047^4	118.7 ± 0.6^4	2.659 ± 0.085	34
	1989-10-17	CAHA 3.5 m	SI	<i>K</i>	0.300 ± 0.020	154.0 ± 3.0	1.140 ± 0.063	3
	1991-10-20	Palomar/Hale 5.1 m	SI	<i>K</i>	0.310 ± 0.010	151.0 ± 2.0	0.731 ± 0.028	14
	1994-01-27	CAHA 3.5 m	SI	<i>J</i>	0.307 ± 0.004	146.1 ± 0.6	0.447 ± 0.022	19
	1994-01-28	CAHA 3.5 m	SI	<i>K</i>	0.306 ± 0.005	146.8 ± 1.0	0.968 ± 0.027	19
	1994-12-19	Palomar/Hale 5.1 m	SI	<i>K</i>	0.296 ± 0.002	147.0 ± 0.4	–	14
	1995-01-05	HST	I	<i>R</i>	0.306 ± 0.003	147.2 ± 0.5	1.770 ± 0.089	16, 28
	1995-11-15	CFHT 3.6 m	I	<i>K</i>	0.290 ± 0.030	147.0 ± 5.0	0.890 ± 0.121	15
	1996-09-29	CAHA 3.5 m	SI	<i>K</i>	0.299 ± 0.004	145.4 ± 0.3	–	19
	1996-11-30	CAHA 3.5 m	SI	<i>J</i>	0.309 ± 0.010	145.7 ± 0.7	1.373 ± 0.096	19
	1996-12-05	NASA ITF/NSFCAM	SI	<i>K</i>	0.300 ± 0.006	144.5 ± 1.0	0.556 ± 0.040	20
	1996-12-05	NASA ITF/NSFCAM	SI	<i>L</i>	0.299 ± 0.029	142.1 ± 1.1	1.307 ± 0.174	20
	1997-03-08	HST	I	<i>F814W</i>	0.301 ± 0.002	146.4 ± 0.7	2.113 ± 0.012	20
	1997-11-19	CAHA 3.5 m	SI	<i>K</i>	0.302 ± 0.004	140.9 ± 0.5	1.251 ± 0.025	19
	1998-03-25	HST	I	<i>R</i>	0.302 ± 0.009	145.5 ± 0.3	2.590 ± 0.130	18
	1998-12-01	HST	I	<i>R</i>	0.298 ± 0.003	145.5 ± 0.5	2.590 ± 0.130	28
	1999-02-03	HST	I	<i>R</i>	0.301 ± 0.003	144.4 ± 0.5	1.500 ± 0.076	28
	2000-02-06	HST	I	<i>R</i>	0.299 ± 0.003	142.6 ± 0.5	1.020 ± 0.052	28
	2000-12-02	HST	I	Clear	0.299 ± 0.014	142.6 ± 2.0	–	22
	2001-02-10	HST	I	<i>R</i>	0.297 ± 0.003	141.6 ± 0.5	0.500 ± 0.026	28
	2002-02-12	HST	I	<i>R</i>	0.291 ± 0.003	141.6 ± 0.5	2.230 ± 0.112	28
	2003-12-13	VLT/NACO	I	<i>Ks</i>	0.292 ± 0.025	139.3 ± 4.8	1.445 ± 0.001	25, 40
	2003-12-13	VLT/NACO	I	<i>J</i>	0.289 ± 0.086	139.7 ± 16.6	0.911 ± 0.002	25, 40

Table C.1. continued.

Object	Date	Telescope	Method ¹	Filter	Sep. (″)	PA (°)	Magn. diff.	Ref.
HK Tau B	2004-01-20	HST	I	<i>R</i>	0.294 ± 0.003	142.3 ± 0.5	2.710 ± 0.136	28
	2004-01-22	VLA	R	7 mm	0.301 ± 0.006	138.6 ± 0.5	1.505 ± 0.747	29
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.256 ± 0.100	135.4 ± 20.6	0.935 ± 0.054	40
	2006-11-20	VLT/NACO	I	<i>Ks</i>	0.289 ± 0.005	136.9 ± 0.2	0.618 ± 0.002	25, 40
	2012-10-11	VLA	R	7 mm	0.282 ± 0.004	129.7 ± 0.1	0.469 ± 0.192	36
	2014-02-14	BTA-6	SI	<i>I</i>	0.270 ± 0.003	131.5 ± 0.7	—	39
	2014-04-11	BTA-6	SI	<i>I</i>	0.268 ± 0.004	131.4 ± 0.9	0.370 ± 0.351	39
	2014-10-14	ALMA	R	2.9 mm	0.273 ± 0.001	128.7 ± 0.5	0.462 ± 0.040	38
	1988-01-15	CTIO	I	<i>K</i>	2.400 ± 0.100	175.0 ± 2.0	3.070 ± 0.021	4
	1997-12-06	NASA ITF/NSFCAM	I	<i>K</i>	2.342 ± 0.061	170.4 ± 1.1	3.321 ± 0.057	20
	1997-12-06	NASA ITF/NSFCAM	I	<i>L</i>	2.284 ± 0.053	168.8 ± 2.4	3.678 ± 0.114	20
	1998-12-17	IRAM	R	1.4 mm	2.440 ± 0.050	171.7 ± 1.1	0.582 ± 0.084	21
	2001-12-01	Keck	I	<i>L</i>	2.390 ± 0.100	168.1 ± 2.7	3.516 ± 0.103	26
2002-11-13	Keck	I	SiC	2.228 ± 0.056	170.3 ± 1.2	3.698 ± 0.172	23	
2002-11-19	VLT/NACO	I	<i>Ks</i>	2.413 ± 0.060 ⁵	169.8 ± 1.2 ⁵	2.442 ± 0.001	25, 40	
2002-11-19	VLT/NACO	I	NB_2.12	2.421 ± 0.057 ⁵	170.0 ± 1.1 ⁵	4.191 ± 0.001	25, 40	
2004-02-11	UKIRT/UFTI	I	<i>L</i>	2.300 ± 0.010	171.4 ± 0.1	3.500 ± 0.051	27	
2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	2.305 ± 0.093	169.3 ± 1.6	3.283 ± 0.057	40	
2012-11-17	ALMA	R	1.3 mm	2.349 ± 0.036	170.1 ± 0.5	0.811 ± 0.018	34	
2012-11-17	ALMA	R	850 μm	2.349 ± 0.036	170.1 ± 0.5	0.287 ± 0.040	34	
V710 Tau B	1990-11-26	San Pedro Martir/0.9 m	I	<i>R</i>	3.300 ± 0.066	179.0 ± 1.0	0.120 ± 0.016	12
	1991-11-01 ⁶	CAHA 3.5 m	SI	<i>K</i>	3.240 ± 0.100	177.0 ± 1.0	0.202 ± 0.014	10
	1997-12-06	NASA ITF/NSFCAM	I	<i>K</i>	3.168 ± 0.062	176.2 ± 1.1	0.270 ± 0.042	20
	1997-12-06	NASA ITF/NSFCAM	I	<i>L</i>	3.178 ± 0.064	176.5 ± 1.2	0.140 ± 0.042	20
	2002-10-22	VLT/NACO	I	NB_1.64	3.236 ± 0.005	177.8 ± 0.1	0.367 ± 0.051	25, 40
	2002-10-22	VLT/NACO	I	NB_2.12	3.229 ± 0.004	177.8 ± 0.1	0.007 ± 0.072	25, 40
	2002-10-22	VLT/NACO	I	NB_2.17	3.231 ± 0.004	177.7 ± 0.1	0.007 ± 0.161	25, 40
	2002-11-12	Keck	I	SiC	3.060 ± 0.080	178.0 ± 1.0	2.762 ± 0.010	26
	2006-11-12	CAHA 2.2 m	LI	RG830	3.226 ± 0.042	176.7 ± 0.5	0.175 ± 0.054	40
UZ Tau AB	1990-10-08	IRTF	O	<i>K</i>	0.340 ± 0.060	0.0 ± 8.0	1.100 ± 0.056	7
	1990-11-10	Palomar/Hale 5.1 m	SI	<i>K</i>	0.359 ± 0.002	357.4 ± 0.3	—	14
	1994-01-26	CAHA 3.5 m	SI	<i>J</i>	0.358 ± 0.010	1.3 ± 1.0	0.298 ± 0.101	19
	1994-07-24	HST	I	<i>F814W</i>	0.368 ± 0.001	0.1 ± 0.2	0.292 ± 0.025	20
	1994-12-19	Palomar/Hale 5.1 m	SI	<i>K</i>	0.360 ± 0.003	1.3 ± 0.4	—	14
	1996-09-29	CAHA 3.5 m	SI	<i>K</i>	0.366 ± 0.004	1.3 ± 0.2	0.451 ± 0.033	19
	1996-12-06	NASA ITF/NSFCAM	SI	<i>K</i>	0.360 ± 0.007	0.8 ± 1.0	0.544 ± 0.066	20
	1996-12-06	NASA ITF/NSFCAM	SI	<i>L</i>	0.369 ± 0.007	3.4 ± 1.1	0.800 ± 0.198	20
	1999-11-03	HST	I	Clear	0.369 ± 0.014	3.6 ± 1.6	—	22
	1999-11-16	Keck	I	<i>N</i>	0.370 ± 0.010	3.7 ± 0.6	0.170 ± 0.065	26
	1999-11-17	Keck	I	IHW18	0.370 ± 0.010	2.1 ± 0.9	0.310 ± 0.041	26
	2001-12-01	Keck	I	<i>L</i>	0.350 ± 0.010	4.0 ± 1.0	0.544 ± 0.040	26
	2002-11-14	VLT/NACO	I	NB_1.64	0.369 ± 0.004	6.2 ± 0.6	0.662 ± 0.089	25, 40
	2002-11-14	VLT/NACO	I	NB_2.12	0.368 ± 0.004	5.8 ± 0.5	0.868 ± 0.057	25, 40
	2002-11-14	VLT/NACO	I	NB_2.17	0.368 ± 0.004	5.4 ± 0.5	0.668 ± 0.051	25, 40
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.355 ± 0.099	5.6 ± 10.2	0.540 ± 0.054	40
	2006-12-26	VLT/NACO	I	<i>Ks</i>	0.369 ± 0.001	8.1 ± 0.2	0.588 ± 0.003	40
	2012-09-28	Gemini North	AO	<i>K</i>	0.375 ± 0.001	11.5 ± 0.1	0.370 ± 0.051	37

Table C.1. continued.

Object	Date	Telescope	Method ¹	Filter	Sep. (")	PA (°)	Magn. diff.	Ref.
UZ Tau AC	1944-04-01	McDonald/2.1 m	I	<i>Z</i>	3.680 ± 0.046	271.5 ± 0.6	0.275 ± 0.083	1
	1988-01-15	CTIO	I	<i>K</i>	3.600 ± 0.200	274.0 ± 2.0	0.720 ± 0.021	4
	1990-10-08	IRTF	O	<i>K</i>	3.780 ± 0.070	273.0 ± 1.0	1.100 ± 0.056	7
	1990-11-26	San Pedro Martir/0.9 m	I	<i>R</i>	3.500 ± 0.070	275.0 ± 1.0	0.390 ± 0.016	12
	1992-12-10	UKIRT	I	$9.5 \mu\text{m}$	3.600 ± 0.100	275.0 ± 2.0	1.659 ± 0.194	13
	1994-07-24	HST	I	<i>F814W</i>	3.539 ± 0.003	273.1 ± 0.1	0.276 ± 0.186	20
	1999-11-03	HST	I	Clear	3.551 ± 0.014	273.2 ± 0.2	—	22
	1999-11-16	Keck	I	<i>N</i>	3.520 ± 0.060	272.9 ± 0.4	2.260 ± 0.120	26
	1999-11-17	Keck	I	IHW18	3.440 ± 0.060	273.0 ± 0.4	2.360 ± 0.149	26
	2001-12-01	Keck	I	<i>K</i>	3.500 ± 0.100	275.0 ± 1.0	0.644 ± 0.048	26
	2001-12-01	Keck	I	<i>L</i>	3.500 ± 0.100	276.0 ± 1.0	0.999 ± 0.035	26
	2002-11-14	VLT/NACO	I	NB_1.64	3.558 ± 0.006	273.4 ± 0.1	1.037 ± 0.024	25, 40
	2002-11-14	VLT/NACO	I	NB_2.12	3.550 ± 0.006	273.5 ± 0.1	1.477 ± 0.009	25, 40
	2002-11-14	VLT/NACO	I	NB_2.17	3.548 ± 0.006	273.5 ± 0.1	1.307 ± 0.009	25, 40
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	3.553 ± 0.100	272.5 ± 1.5	0.750 ± 0.054	40
	2006-12-26	VLT/NACO	I	<i>Ks</i>	3.553 ± 0.021	273.3 ± 0.2	1.110 ± 0.001	40
	2012-09-28	Gemini North	AO	<i>K</i>	3.575 ± 0.010	276.8 ± 0.2	0.630 ± 0.041	37
GH Tau B	1991-10-19	Palomar/Hale 5.1 m	SI	<i>K</i>	0.314 ± 0.006	119.0 ± 2.0	0.638 ± 0.013	9
	1991-11-01 ⁶	CAHA 3.5 m	SI	<i>K</i>	0.350 ± 0.010	120.0 ± 1.0	0.102 ± 0.060	10
	1994-12-19	Palomar/Hale 5.1 m	SI	<i>K</i>	0.307 ± 0.002	116.0 ± 0.4	—	14
	1996-12-05	NASA ITF/NSFCAM	SI	<i>K</i>	0.305 ± 0.006	114.8 ± 1.1	0.208 ± 0.079	20
	1996-12-05	NASA ITF/NSFCAM	SI	<i>L</i>	0.312 ± 0.007	115.3 ± 1.6	0.372 ± 0.091	20
	1998-12-05	HST	I	<i>F814W</i>	0.311 ± 0.002	114.6 ± 0.2	0.084 ± 0.009	20
	1999-11-17	Keck	I	<i>N</i>	0.300 ± 0.010	111.0 ± 2.0	0.403 ± 0.038	26
	2001-01-22	HST	I	Clear	0.304 ± 0.014	113.7 ± 2.0	—	22
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.286 ± 0.112	109.0 ± 21.4	0.378 ± 0.067	40
	2006-12-26	VLT/NACO	I	<i>Ks</i>	0.298 ± 0.019	109.3 ± 1.6	0.088 ± 0.005	40
	2008-12-18	Keck II	AO	<i>K</i>	0.299 ± 0.001	108.5 ± 0.1	0.079 ± 0.010	33
	2012-09-28	Gemini North	AO	<i>K</i>	0.297 ± 0.001	106.3 ± 0.1	0.130 ± 0.011	37
	2013-01-28	Keck II	AO	<i>K</i>	0.295 ± 0.002	106.2 ± 0.3	0.118 ± 0.030	33
HN Tau B	1988-01-15	CTIO	I	<i>K</i>	3.100 ± 0.100	215.0 ± 2.0	3.430 ± 0.102	4
	1990-11-26	San Pedro Martir/0.9 m	I	<i>R</i>	3.100 ± 0.063	220.0 ± 1.0	3.090 ± 0.016	12
	1997-12-06	NASA ITF/NSFCAM	I	<i>K</i>	3.109 ± 0.082	219.1 ± 1.1	3.721 ± 0.085	20
	1997-12-06	NASA ITF/NSFCAM	I	<i>L</i>	3.150 ± 0.330	219.2 ± 2.5	4.532 ± 0.201	20
	2003-02-18	VLT/NACO	I	NB_2.17	3.136 ± 0.006^7	219.9 ± 0.1^7	3.603 ± 0.001	25, 40
	2006-11-12	CAHA 2.2 m	LI	Johnson <i>I</i>	3.152 ± 0.084	218.8 ± 1.5	2.299 ± 0.056	40
	2012-09-28	Gemini North	AO	<i>K</i>	3.210 ± 0.019	220.0 ± 0.2	3.090 ± 0.051	37
HV Tau C	1990-10-08	IRTF	I	<i>K</i>	4.000 ± 0.400	45.0 ± 5.0	3.300 ± 0.166	7
	1996-08-26	UKIRT	I	<i>K</i>	3.980 ± 0.030	43.5 ± 0.4	4.220 ± 0.093	17
	1996-08-30	UKIRT	I	<i>N</i>	3.990 ± 0.310	44.0 ± 5.0	0.990 ± 0.432	17
	1998-02-14	UKIRT	I	Bry	4.030 ± 0.240	45.8 ± 2.0	4.470 ± 0.224	17
	2000-03-09	HST	I	<i>F606W</i>	4.045 ± 0.071	44.1 ± 1.1	2.979 ± 0.020	30, 40
	2000-03-09	HST	I	<i>F814W</i>	4.044 ± 0.071	43.7 ± 1.1	2.095 ± 0.006	30, 40
	2001-12-01	Keck	I	<i>K</i>	4.000 ± 0.200	43.0 ± 1.0	4.663 ± 0.123	26
	2001-12-01	Keck	I	<i>L</i>	3.900 ± 0.200	43.0 ± 1.0	3.903 ± 0.054	26
	2002-11-13	Keck	I	SiC	4.100 ± 0.100	43.0 ± 1.0	0.198 ± 0.010	26
	2002-11-24	VLT/NACO	I	<i>Ks</i>	4.001 ± 0.074	44.1 ± 1.1	4.279 ± 0.001	30, 40
	2002-11-24	VLT/NACO	I	<i>H</i>	3.977 ± 0.085	44.1 ± 1.3	4.985 ± 0.001	30, 40
	2002-11-24	VLT/NACO	I	<i>J</i>	3.987 ± 0.109	44.0 ± 1.6	4.944 ± 0.001	30, 40
	2002-12-13	Keck II-NIRC2	I	<i>L</i>	4.030 ± 0.010	44.9 ± 0.1	0.689 ± 0.082	30
	2002-12-13	Keck II-NIRC2	I	<i>Ms</i>	4.070 ± 0.020	44.7 ± 0.2	—	30
	2004-12-13	Keck II-NIRC2	I	<i>L</i>	4.020 ± 0.010	44.4 ± 0.1	0.573 ± 0.093	30
	2006-11-12	CAHA 2.2 m	LI	Johnson <i>I</i>	4.129 ± 0.036	42.4 ± 0.5	4.089 ± 0.058	40

Table C.1. continued.

Object	Date	Telescope	Method ¹	Filter	Sep. (″)	PA (°)	Magn. diff.	Ref.
V999 Tau B	1991-10-27	CAHA 3.5 m	SI	<i>K</i>	0.300 ± 0.010	243.0 ± 20.0	0.555 ± 0.091	19
	1994-01-27	CAHA 3.5 m	SI	<i>J</i>	0.260 ± 0.004	236.4 ± 0.3	0.848 ± 0.008	19
	1994-12-15	CAHA 3.5 m	SI	<i>K</i>	0.252 ± 0.004	237.5 ± 1.0	0.689 ± 0.035	19
	1996-09-28	CAHA 3.5 m	SI	<i>H</i>	0.239 ± 0.004	240.1 ± 0.7	0.965 ± 0.032	19
	1997-11-17	CAHA 3.5 m	SI	<i>K</i>	0.234 ± 0.004	241.6 ± 0.4	0.831 ± 0.052	19
	1997-12-08	NASA ITF/NSFCAM	SI	<i>L</i>	0.234 ± 0.005	244.8 ± 2.9	0.779 ± 0.101	20
	1998-12-13	HST	I	Clear	0.226 ± 0.014	242.0 ± 3.1	–	22
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.230 ± 0.043	278.6 ± 6.2	0.222 ± 0.156	40
	2006-12-26	VLT/NACO	I	<i>Ks</i>	0.188 ± 0.004	257.0 ± 0.6	0.487 ± 0.003	40
V1000 Tau B	1990-10-04	Palomar/Hale 5.1 m	SI	<i>K</i>	0.208 ± 0.002	77.6 ± 0.4	–	14
	1991-10-27	CAHA 3.5 m	SI	<i>K</i>	0.230 ± 0.020	85.0 ± 2.0	0.591 ± 0.057	19
	1993-11-25	Palomar/Hale 5.1 m	SI	<i>K</i>	0.230 ± 0.010	83.0 ± 2.0	–	14
	1994-10-18	Palomar/Hale 5.1 m	SI	<i>K</i>	0.224 ± 0.002	82.7 ± 0.4	–	14
	1994-12-12	CAHA 3.5 m	SI	<i>K</i>	0.228 ± 0.004	83.8 ± 0.3	0.639 ± 0.012	19
	1996-09-28	CAHA 3.5 m	SI	<i>H</i>	0.228 ± 0.004	86.3 ± 0.4	0.630 ± 0.018	19
	1996-11-29	CAHA 3.5 m	SI	<i>J</i>	0.236 ± 0.005	87.4 ± 0.3	0.729 ± 0.056	19
	1997-03-08	HST	I	<i>F814W</i>	0.232 ± 0.003	86.9 ± 0.4	0.375 ± 0.010	20
	1997-11-22	CAHA 3.5 m	SI	<i>K</i>	0.230 ± 0.004	91.0 ± 0.3	0.731 ± 0.426	19
	1997-12-08	NASA ITF/NSFCAM	SI	<i>L</i>	0.238 ± 0.005	90.7 ± 1.3	0.602 ± 0.018	20
	2006-11-11	CAHA 2.2 m	LI	Johnson <i>I</i>	0.151 ± 0.049	73.4 ± 14.1	0.739 ± 0.055	40
	2006-12-26	VLT/NACO	I	<i>Ks</i>	0.241 ± 0.001	100.7 ± 0.2	0.475 ± 0.003	40
	2014-12-11	VLT/SPHERE	XAO	<i>K</i>	0.235 ± 0.018	111.3 ± 2.7	0.592 ± 0.007	40
RW Aur B	1944-04-01	McDonald/2.1 m	I	<i>Z</i>	1.220 ± 0.056	254.3 ± 0.6	1.500 ± 0.101	1
	1990-11-09	Palomar/Hale 5.1 m	SI	<i>K</i>	1.390 ± 0.030	256.0 ± 1.0	2.258 ± 0.136	9
	1991-11-01 ⁶	CAHA 3.5 m	SI	<i>K</i>	1.500 ± 0.010	258.0 ± 1.0	1.596 ± 0.048	10
	1994-11-09	HST	I	<i>F814W</i>	1.417 ± 0.004	255.5 ± 0.1	2.380 ± 0.032	20
	1996-12-06	NASA ITF/NSFCAM	SI	<i>K</i>	1.397 ± 0.026	254.6 ± 1.0	1.566 ± 0.042	20
	1996-12-06	NASA ITF/NSFCAM	SI	<i>L</i>	1.396 ± 0.026	254.5 ± 1.0	1.974 ± 0.043	20
	1999-11-16	Keck	I	<i>N</i>	1.420 ± 0.020	254.6 ± 0.4	2.836 ± 0.005	26
	1999-11-16	Keck	I	IHW18	1.380 ± 0.020	254.7 ± 0.4	2.593 ± 0.046	26
	2002-11-17	VLT/NACO	I	NB_1.64	1.446 ± 0.005	254.8 ± 0.2	2.052 ± 0.003	25, 40
	2002-11-17	VLT/NACO	I	NB_2.12	1.442 ± 0.004	255.0 ± 0.2	1.943 ± 0.003	25, 40
	2002-11-17	VLT/NACO	I	NB_2.17	1.444 ± 0.004	255.1 ± 0.2	1.990 ± 0.003	25, 40
	2003-06-01	IRAM	R	1.3 mm	1.468 ± 0.056	255.3 ± 0.5	1.812 ± 0.086	24
	2006-11-12	CAHA 2.2 m	LI	RG830	1.455 ± 0.013	253.7 ± 0.4	1.304 ± 0.054	40
	2007-06-04	SAO 6 m	SI	<i>V</i>	1.448 ± 0.005	255.9 ± 0.3	1.880 ± 0.041	31
	2007-06-04	SAO 6 m	SI	<i>I</i>	1.445 ± 0.004	255.9 ± 0.3	1.430 ± 0.021	31
	2013-01-12	Chandra	X	–	1.480 ± 0.010	254.3 ± 0.5	1.175 ± 0.039	35