Mon. Not. R. Astron. Soc. **000**, 1–4 (2006) Printed March 20, 2006 (MN LaTeX style file v2.2)

Radial and rotational velocities of young brown dwarf candidates in Upper Scorpius OB association and ρ Ophiuchi cloud core

Ryuichi Kurosawa⋆ and Tim J. Harries
School of Physics, University of Exeter, Stocker Road, Exeter EX4 4QL

Dates to be inserted

ABSTRACT

We present the results of two-epoch radial velocity survey for 15 brown dwarf candiates in the Upper Scorpius OB association and 3 brown dwarf candiates in the ρ Ophiuchi dark cloud core to identify their multiplicities. We also present the rotational velocity of each object.

Key words: stars: formation – more to be inserted later

1 INTRODUCTION

While the exact formation mechanism of brown dwarfs (BDs) is still under debate (e.g. XXX and XXX), there are two main competing theories (see review by ant whitworth in PPV)

2 OBSERVATIONS

Our sample consist of 18 young low-mass objects previously identifiled in the star forming regions: 15 objects in the Upper Scorpius OB association from Ardila et al. (2000) and 3 objects in the ρ Ophiuchi cloud core from Luhman & Rieke (1999). The spectral type of the objects spreads between M5 and M8.5, and the age $<\sim\ 10\,\mathrm{Myr}$ (Luhman & Rieke 1999; Ardila et al. 2000; Muzerolle et al. 2003; Kraus et al. 2005). The sampe is not complete, and the selection is mainly based on the brightness and the observability. The basic infomation of the targets based on literatures is summaried in Table 2.

We obtained high resolution spectra with the Kueyen telescope of VLT (Cerro Parnal, Chile) using the UVES echelle spectrograph. The observations were carried out between April 5, 2004 and May 15, 2005 in the service mode. For each object, the spectra were obtained at two different epochs separated by 4–33 d to increase the chance of detactability for multiplicities. For each object at a given night, two separare spectra are obtained consectively. This will allow us to derive more reliable uncertatiny estimates in the RV values of our targets (c.f. Joergens 2006). The data was obtained using the read arm of UVES spectrograph with two mosaic CCDs (EEV + MIT/LL with 2k×4k pixels). The wavelength converage of 6650 – 10,250 Å(orders 94-60 CHECK) and the spectral resolution $R \approx 40,000$ (providing) were used. The slit width and length of 1” and 12” are used respectively. The typical seeing was 0.8”.

The data were reduced by the standard ESO pipeline procedures for echelle spectra at Garching. In summary, the data were corrected for bias, interorder background, sky background, sky emission lines and cosmic ray hits. Further, they are flattened, optimally extracted. Finally the merged the different orders. No binning was performed since a high wavelength resolution is required for the RV measurements. The wavelength was calibrated using the Thorium-Argon arc spectra. A typical value of the standard deviation of the dispersion solution is 5 mÅ which correspoends to XXX $\mathrm{km\,s^{-1}}$ at the central wavelngth 8600 Å. The autoguideing of the telescope keeps the star at the centre of the slit with about a tenth of the FWHM ($1\,\mathrm{km\,s^{-1}}$) which sets the upper limit for the systematic error in the RV measurements (Bailer-Jones 2004).

———————
———————-
—————

List of ojects whose Vr do not agree with our measurements.: USco 66 and USco 75. The former is a known binary and the latter is a non-constant Rv object in our data. The rotational velocity of GY 5 $v \sin i = 16.8 \pm 2.7\,\mathrm{km\,s^{-1}}$ (Muzerolle et al. 2003)

3 RESULTS

3.1 Radial velocities

About the template LHR 49: The radial velocity of the template object LHS 49 was obtained by measuring the wavelength shift of K I $\lambda\lambda$7664.911, 7698.974, and the result is $\mathrm{RV_{LHS49}} = -22.6 \pm 0.5\,\mathrm{km\,s^{-1}}$, which is in good agreement with the earliear measurment by García-Sánchez et al. (2001) who found $\mathrm{RV_{LHS49}} = -21.7 \pm 1.8\,\mathrm{km\,s^{-1}}$. In the following measuremets of the heliocelntic radial velocities of our targets, the former value will be used.

Sanity check: The accuracy of the RV measurement is checked against the radial velocity standard HD 140538 for which an high-accuracy RV measurement from the fixed-configuration, cross-dispersed échelle spectrograph Elodie (Baranne et al. 1996) is

⋆ E-mail: rk@astro.ex.ac.uk

Table 1. Summary of known properties of the targers from literatures: a. Luhman & Rieke (1999) (original list for Oph), b. Ardila et al. (2000) (original list for Upper Sco objects), c. Wilking et al. (1999), d. Muzerolle et al. (2003), and e. Kraus et al. (2005).

Object	Sp.	mass $[\mathrm{M}_\odot]$	RV $\left[\mathrm{km\,s^{-1}}\right]$	$v \sin i$ $\left[\mathrm{km\,s^{-1}}\right]$	Known multiple?
GY 5	M7[c]	0.07[d]	-6.3 ± 1.9[d]	16.8 ± 2.7[d]	no
GY 141	M8.5[a]	0.02[d]	...	...	no
GY 310	M8.5[c]	0.08[a,d]	...	...	no
USco 40	M5[b]	0.1[b]	...	...	no
USco 53	M5[b]	0.1[b]	...	...	no
USco 55	M5.5[b]	$0.10 + 0.07$[e]	...	...	yes[e]
USco 66	M6[b]	$0.07 + 0.07$[e]	-4.4 ± 0.6[d]	...	yes[e]
USco 67	M5.5[b]	0.10[e]	...	...	no
USco 75	M6[b]	0.07[e]	-5.6 ± 1.1[d]	...	no
USco 100	M7[b]	0.05[e]	-8.9 ± 0.6[d]	...	no
USco 101	M5[b]	0.05[b]	...	...	no
USco 104	M5[b]	0.05[b]	...	...	XXX
USco 109	M6[b]	$0.07 + 0.04$[e]	-3.8 ± 0.7[d]	...	yes[e]
USco 112	M5.5[b]	0.1[e]	...	...	no
USco 121	M6[b]	0.02[b]	-38.9 ± 1.0[d]	...	no
USco 128	M7[b]	0.05[e]	-3.0 ± 1.6[d]	...	no
USco 130	M7.5[e]	0.04[e]	...	...	no
USco 132	M7[b]	0.05[e]	-8.2 ± 1.1[d]	...	no

available. Our measurement $18.8 \pm 0.6\,\mathrm{km\,s^{-1}}$ is in good agreement with the Elodie radial velocity $19.00 \pm 0.05\,\mathrm{km\,s^{-1}}$ (Udry et al. 1999).

3.2 Rotational velocities

The rotational velocities of the objects are determined by measuring the widths of the cross correlation curves of the target spectra against a templates spectra from an object which is known to have a very small rotational velocity. The line boardening of the targets are assumed to be dominated by rotational broadedning. As in the cases for the radial velocity measurements, LHS 49 is chosen for our template. Using its known period ($P \approx 83\,\mathrm{d}$, REF. XXX) and radius ($R_* \approx 0.145\,\mathrm{R}_\odot$, REF. XXX), the rotational velocity of LHS 49 is estimated as $v \sin i = 2\pi R_*/P \approx 0.1\,\mathrm{km\,s^{-1}}$; hence, neglegibly small.

The width of the cross-correlation curves (σ_{CCF}) are calibrated with the rotational velocities ($v \sin i$) by cross correlating the template spectra against the same template spectra with added rotation (convolved with a given $v \sin i$), as similarly done by Tinney & Reid (1998), Mohanty & Basri (2003) and White & Basri (2003). Figure 3 shows the calibration data points measured between $0\,\mathrm{km\,s^{-1}} < v \sin i < 60\,\mathrm{km\,s^{-1}}$ with $5\,\mathrm{km\,s^{-1}}$ intervals. The data points are fitted with a cubic polynomial function, and the result is used to find a value of $v \sin i$ of our targets with a given value of the cross-correlation function width. The calibration curve shows that σ_{CCF} does not reach zero since the intrinsic width lines and the small but unknown intrinsic instrumental profile are present.

————————\\\\\\\

——————

Measureing the rotation rate ($v \sin i$) from the coorelation fucntion.

1. Prepare the template which has no roation. Theory??

2. Measure the broadening by the instrument using tullric lines (suggested by Viki, but originally ....)

3. Compute the xcorr

4. Measue the sigma

5. Use

$$\sigma^2_{measured} = \sigma^2_{rot} + \sigma^2_{nat} + 2\sigma^2_{inst}$$

and find σ^2_{rot} by assuming σ^2_{nat} is neglegible. (see Bailor-Jones 2004)

1. LHS-49 is a very slow rotator. ==>

P=~83 days. R*=0.145Rsun thus.

$v \sin i = \frac{2\pi\, R_*}{P} = \frac{2\pi \times 0.145 \times 6.96 \times 10^5\, km}{83. \times 24 \times 60 \times 60}$ =~ 0.1km/s.

————————————

Following Bailor-Jones (2004), originally done by someone ... Tinney & Reid (1998), Mohanty & Basri (2003), White & Basri (2003).

So I can just use LHS-49 as a template.

Work on the convolution routine.

Accodring to David Gray's book (See their equation 17.12):

$$G\,(\Delta\lambda) = c_1 \left[1 - \left(\frac{\Delta\lambda}{\Delta\lambda_L}\right)^2\right]^{1/2} + c_2 \left[1 - \left(\frac{\Delta\lambda}{\Delta\lambda_L}\right)^2\right]$$

where $c_1 = 2\,(1-\epsilon)\,/\,(\pi\Delta\lambda_L(1-\epsilon/3))$, $c_2 = \frac{1}{2}\pi\epsilon/\,(\pi\Delta\lambda_L(1-\epsilon/3)$,

==> I already have a routine to do this!

Limb-darkening law use

$I(\mu) = I_0(1 - \epsilon(1-\mu))$

For sun, $\epsilon = 0.6$ is a good approximation.

————————-

——————

Now making the calibration curve for estimating the rotation velocity vsini of each object.

——————

———-

The result is in Fig. 3

Circles are the measuements, and the red line is the fit with cubic polynomial

The fitting function is.,,, (taking the out put from xmgrace).

y = -13.943 + 3.5087 x - 0.080654 x^2 + 0.00086939 x^3

Table 2. Summary of the observation, the heliocentric radial velocities (RV) from two-epoch and the average rotational velocities ($v \sin i$). The uncetainties of relative radial velocties ($sigma_{\rm RRV}$) with respect to the template star LHS 049 and the average radial velocties ($\overline{\rm RV}$) are also given. The last column indicates whether a target is a candidate for multiplicity i.e. the measured radial velocity changes from two different epoch is larger than $1\sigma_{\rm RRV}$ of each others (c.f. Fig. XXX).

Using RV(LHR049)=$-22.6 \pm 0.5\,{\rm km\,s^{-1}}$. So TV below is the heliocentric RV but not wrt LHR 049. $\sigma_{\rm RRV}$ is the error in the measurement of relative radial velocity. MDJ are the average of two or three consecutive spectra.

Object	Date	MDJ-2453100	RV $[{\rm km\,s^{-1}}]$	$\sigma_{\rm RRV}$ $[{\rm km\,s^{-1}}]$	$\overline{\rm RV}$ $[{\rm km\,s^{-1}}]$	$v \sin i$ $[{\rm km\,s^{-1}}]$	candidate?
GY 5	2004-Apr-25	20.22051	-6.14 ± 0.84	0.68			
	2004-May-08	33.27776	-5.96 ± 0.60	0.34	-6.05 ± 1.03	16.5 ± 0.6	no
GY 141	2004-May-11	36.16016	-4.39 ± 0.60	0.34			
	2004-May-18	43.15707	-2.95 ± 0.51	0.11	-3.67 ± 0.79	4.4 ± 1.4	yes
GY 310	2004-Apr-25	20.32700	-4.83 ± 0.74	0.54			
	2004-May-10	35.31139	-8.43 ± 0.51	0.11	-6.63 ± 0.90	11.1 ± 6.0	yes
USco 40	2004-Apr-06	01.25900	-7.15 ± 0.74	0.54			
	2004-May-08	33.25324	-6.80 ± 0.51	0.11	-6.98 ± 0.90	34.2 ± 0.5	no
USco 53	2004-Apr-05	00.39651	-7.27 ± 0.93	1.21			
	2004-May-03	28.23079	-5.43 ± 0.74	0.55	-6.35 ± 1.19	40.0 ± 0.6	no
USco 55	2004-Apr-06	01.33509	-5.39 ± 0.50	0.02			
	2004-May-03	28.30546	-6.38 ± 0.53	0.27	-6.38 ± 0.73	22.9 ± 0.8	yes
USco 66	2004-Apr-06	01.29007	-5.32 ± 0.57	0.29			
	2004-May-03	28.28683	-6.41 ± 0.65	0.42	-5.87 ± 0.86	25.9 ± 1.2	no
USco 67	2004-Apr-06	01.21481	-6.01 ± 0.74	0.55			
	2004-May-03	28.21759	-6.83 ± 0.59	0.31	-6.42 ± 0.90	18.4 ± 0.4	no
USco 75	2004-Apr-05	00.37453	-6.75 ± 0.67	0.44			
	2004-May-08	33.09532	-9.88 ± 1.94	1.88	-8.32 ± 2.05	55.6 ± 3.0	yes
USco 100	2004-Apr-06	01.30836	-6.76 ± 2.74	2.69			
	2004-May-03	28.26425	-10.23 ± 1.80	1.73	-8.47 ± 3.28	43.7 ± 3.2	no
USco 101	2004-Apr-05	00.30191	-4.22 ± 0.87	0.71			
	2004-May-03	28.14804	-6.07 ± 0.69	0.48	-5.15 ± 1.11	19.1 ± 0.3	yes
USco 104	2004-Apr-05	00.27545	-5.83 ± 0.50	0.02			
	2004-May-03	28.12391	-7.48 ± 0.50	0.06	-6.66 ± 0.06	16.7 ± 0.4	yes
USco 109	2004-Apr-06	01.23587	-4.15 ± 0.52	0.16			
	2004-May-08	33.11929	-4.41 ± 0.50	0.03	-5.12 ± 0.72	8.6 ± 1.2	possibly
USco 112	2004-Apr-05	00.34486	-2.70 ± 0.69	0.47			
	2004-May-08	33.07139	-3.46 ± 0.51	0.11	-3.08 ± 0.86	5.8 ± 1.2	possibly
USco 121	2004-Apr-25	20.19466	-39.47 ± 0.51	0.11			
	2004-May-03	28.18537	-42.43 ± 0.50	0.02	-40.95 ± 0.71	17.6 ± 1.3	yes
USco 128	2004-May-14	39.28595	-7.41 ± 0.85	0.69			
	2004-May-18	43.09885	-6.94 ± 1.16	1.05	-7.18 ± 1.44	3.6 ± 1.1	no
USco 130	2004-May-10	35.26060	-4.83 ± 0.54	0.21			
	2004-May-14	39.34201	-4.95 ± 0.74	0.55	-4.89 ± 0.92	15.2 ± 1.1	no
USco 132	2004-May-12	37.28394	-7.18 ± 0.58	0.30			
	2004-Jun-18	43.12719	-7.37 ± 1.02	0.89	-7.28 ± 1.17	9.1 ± 0.7	no

USCO-121==> Only 7 days apart!
1USco-128 and USco-130 ==>only 4 days apart!

4 DISCUSSION

Comparinsons with earliear works may be presented here. and more

5 CONCLUSIONS

We have presented XXX and YYY. We found that ...

ACKNOWLEDGEMENTS

This work is supported by PPARC rolling grant PP/C501609/1.

References

Ardila D., Martín E., Basri G., 2000, AJ, 120, 479
Bailer-Jones C. A. L., 2004, A&A, 419, 703
Baranne A., Queloz D., Mayor M., Adrianzyk G., Knispel G., Kohler D., Lacroix D., Meunier J.-P., Rimbaud G., Vin A., 1996, A&AS, 119, 373
García-Sánchez J., Weissman P. R., Preston R. A., Jones D. L., Lestrade J.-F., Latham D. W., Stefanik R. P., Paredes J. M., 2001, A&A, 379, 634
Joergens V., 2006, A&A, 446, 1165
Kraus A. L., White R. J., Hillenbrand L. A., 2005, ApJ, 633, 452
Luhman K. L., Rieke G. H., 1999, ApJ, 525, 440
Muzerolle J., Hillenbrand L., Calvet N., Briceño C., Hartmann L., 2003, ApJ, 592, 266
Udry S., Mayor M., Queloz D., 1999, in ASP Conf. Ser. 185: IAU

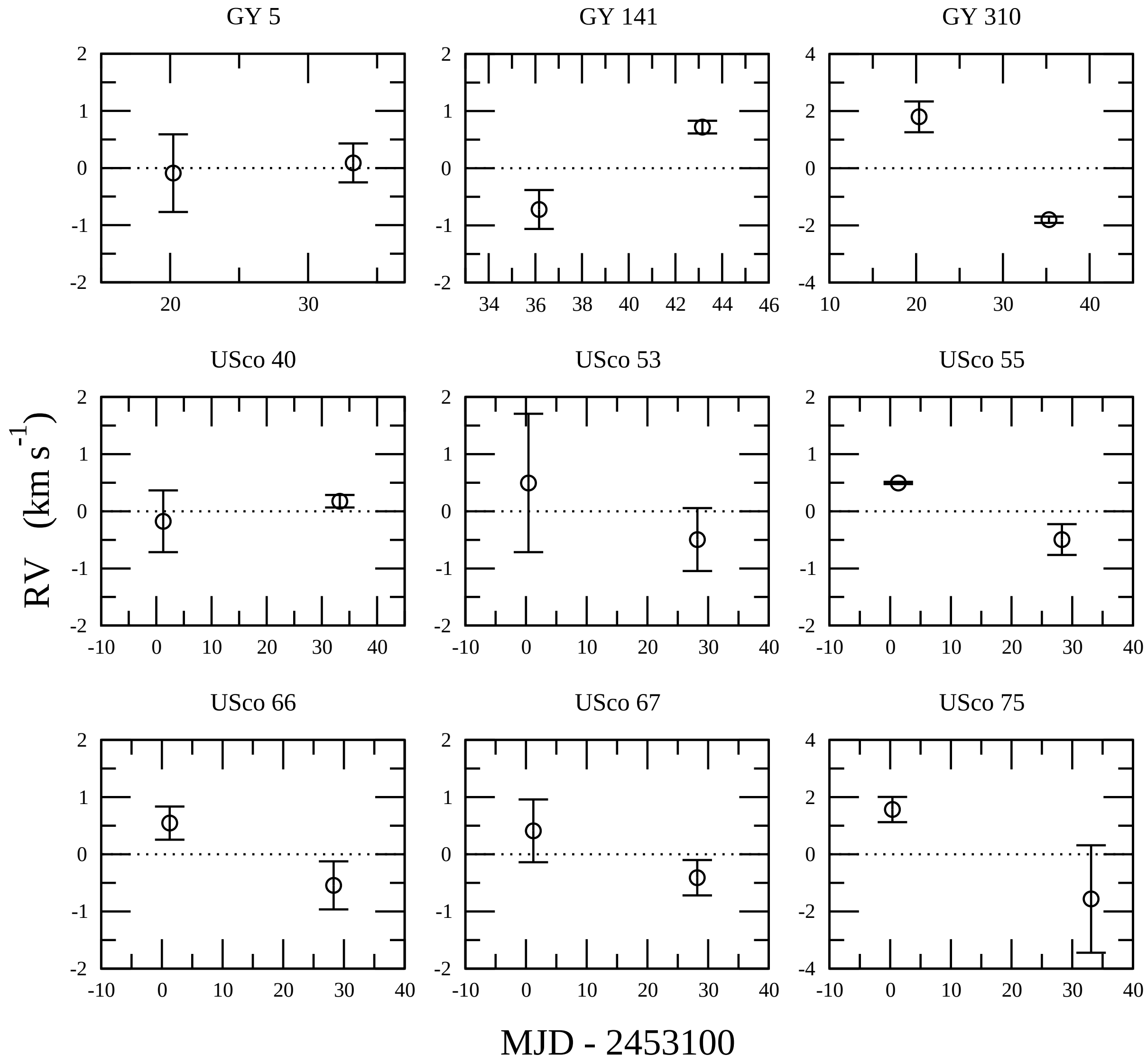

Figure 1. Relative radial velocities (RVs) of objects measured in two different epochs. The vertical axes indicate are the amount of diviation from the the average radial velocity ($\overline{\mathrm{RV}}$) in Table 3.1), and the horizontal axes indicate the time of the observation in modified Julian date (MJD). The objects are considered to have a non-constant radial velocity when the error bars of two data points do not overlap each other.

Colloq. 170: Precise Stellar Radial Velocities, Hearnshaw J. B., Scarfe C. D., eds., p. 367

Wilking B. A., Greene T. P., Meyer M. R., 1999, AJ, 117, 469

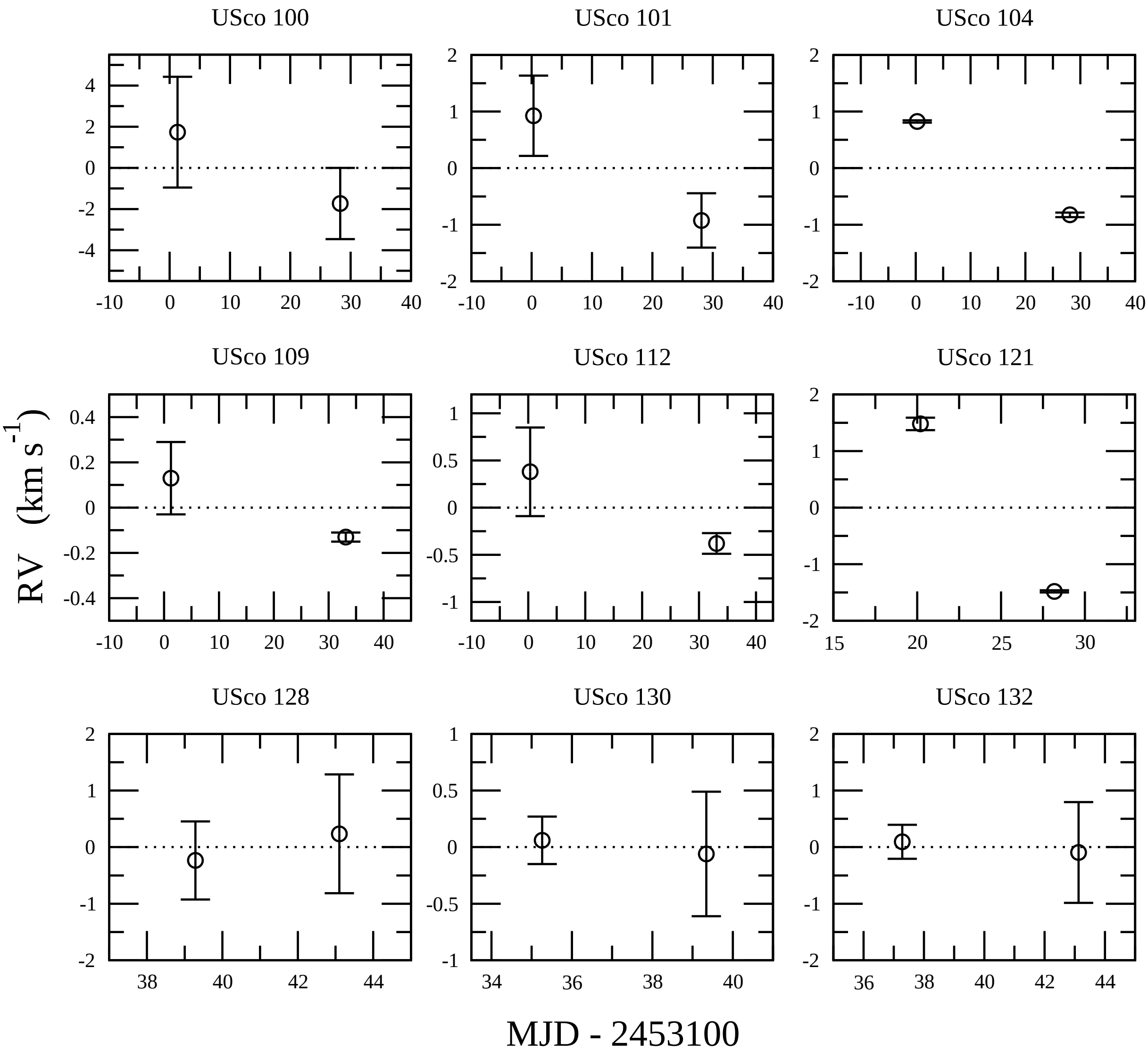

Figure 1. continued

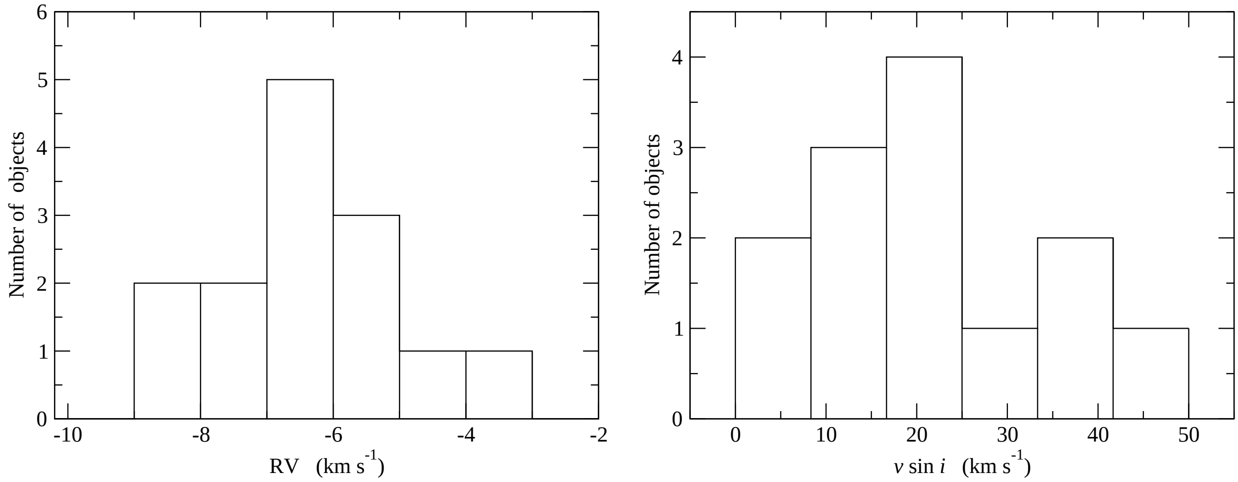

Figure 2. Histogram of the average raial velocities (left) and of the rotational velocities (right) for 14 USco objects listed in Table 3.1 (excluding USco 121, non-member). The full-width half maximum (FWHM) and the peak position of the radial velocity distribution (left) are $2.8\,\mathrm{km\,s^{-1}}$ was $-5.9\,\mathrm{km\,s^{-1}}$ respectively, and are $22.7\,\mathrm{km\,s^{-1}}$ was $29.9\,\mathrm{km\,s^{-1}}$ for the rotational velocity distribution (right).

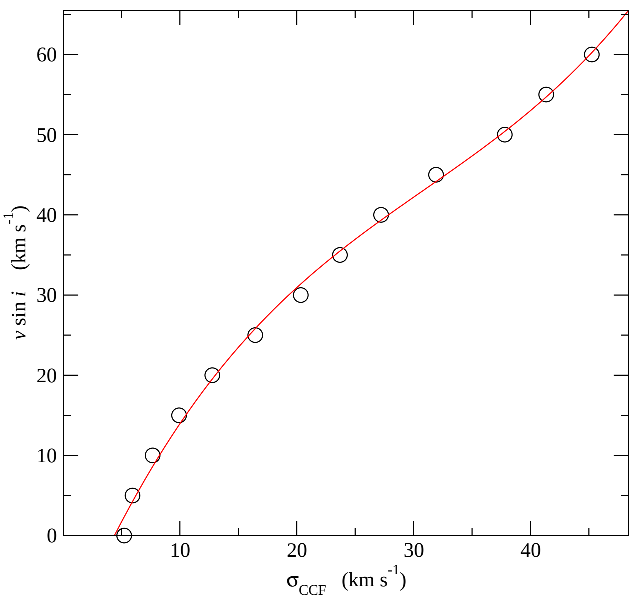

Figure 3. Calibration curve for rotational velocity measurements. The template spectra of LHS 49 are convolved with $v \sin i$, and the widths of the cross correlation function of the orignal and the convolved spectra are measured. The circles shows the actual measeuements of the widths of the cross correlation function, and the solid line is the result of qubic polynomial fit. σ_{CCF} does not reach zero value becuase of the intrinsic line width (and the small but unknown intrinsic instrumental profile.