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High resolution spectroscopy of two young active late type stars within 20 parsecs of the Sun *

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Abstract We present high-resolution optical echell spectroscopy of HIP 544 and HIP 46843, two nearby solar like stars. The discovery of these young stars at such a close distance to the Sun is really a surprising phenomenon. It will help us to have a better understanding of the structure and evolutionary history of the Milky Way. The radial velocities (RV) of HIP 544 and HIP 46843 are measured to be –6.88±0.13 km s^{-1} and 8.30±0.16 km s^{-1}, respectively, which are more accurate than before. The equivalent widths (EW) of the Li I 6707.8 Å absorption line of HIP 544 and HIP 46843 are measured to be 110±5 mÅ and 195±5 mÅ respectively. Based on these properties, HIP 544 is estimated to be 100–800 Myr old and HIP 46843 30–100 Myr old using three relatively creditable methods.

Key words: stars: late-type — stars: individual (HIP544, HIP46843) — stars: activity — techniques: radial velocities — techniques: spectroscopic

1 INTRODUCTION

T Tauri stars (TTSs) are pre-main sequence stars and they are separated into two subgroups based on the equivalent widths (EW) of their Hα emission lines. One of the subgroups is classical T Tauri stars (CTTSs), which have strong Hα emission (EW(Hα) $\geq$ 10 Å), and the other is weak-line T Tauri stars (WTTSs), which have weak Hα emission (EW(Hα) $\leq$ 10 Å). WTTSs have several other typical characteristics, such as a distinct Li I (6707.8 Å) absorption line, strong soft X-ray radiation, late-type spectra ($M < 2.5\,M_{\odot}$) and they mostly do not have UV excesses. All of these properties occur in their youth, where there is chromospheric activity and they mostly do not have circumstellar disks. WTTSs deplete their lithium when they evolve to the main sequence. When the F-K type WTTSs arrive at the main sequence, they belong to young active late type solar like stars.

Research on young solar like stars near the Sun remains an uncompleted but significant astronomical problem which will help us to have a clearer understanding of the structure of the Milky Way and the evolutionary history of our Sun. Zuckerman, in his review paper, summarized several young moving groups around the Sun, especially emphasizing the TW Hya Association (TWA) which is likely the nearest region of star formation (Zuckerman & Song 2004; Kastner et al. 1997). TW Hya itself is a CTTS with an age of about 20 Myr and a distance of 56.4 pc. This makes us wonder whether there are some stars which are nearer, younger or both. We checked our sample of 66 solar like late type

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active stars and found two targets which have a distance of less than 20 pc and a strong Li I (6707.8 Å) absorption line (EW(Li) $\geq$ 100 mÅ). All of the stars in our sample from which the two targets are picked are located north of –10° declination and were chosen for their strong X-ray emission.

HIP 544 and HIP 46843 have been studied many times because of their short distances from the Sun, relatively strong X-ray emission and abundant Li (Shi et al. 2002; Fuhrmann 2004).

From the Simbad database, we know that HIP 544 is a variable star. It is a late type star with a spectral type of K0V and a bright source whose V band magnitude is 6.07, which we can know from referring to the Hipparcos database. Its distance from our Sun is 13.70 pc, which is calculated from its accurate parallax measured by Hipparacos.

HIP 46843 is a high proper motion star. It is also a late type star with a spectral type of K0 and also a bright source whose V band magnitude is 7.05, referring to the Hipparcos database. Its distance from our Sun is 17.75 pc, which is also calculated from its accurate parallax from Hipparacos.

We present the details of our observations and data reduction in Section 2, results in Section 3, determinations of the ages in Section 4 and conclusions in Section 5.

2 OBSERVATIONS AND DATA REDUCTION

High-resolution spectroscopic observations of HIP 544 and HIP 46843 were performed on 2004 December 24 using the NAOC Coude Echelle Spectrograph mounted on the 2.16 m telescope at the Xinglong station. In order to get more accurate and creditable radial velocities, we also observed two radial velocity standard stars, β Gem and α Hya, during the same night. The detector we used is a TEK CCD with 1024×1024 pixels of 24×24 μm^2. About 40 spectral orders are included in these spectra covering a range from 5550 Å to 9100 Å, with a nominal resolving power of $\lambda/\Delta\lambda \simeq 40\,000$. Technical details regarding this Coude Echelle Spectrograph can be found in Zhao et al. (2001). The signal to noise (S/N) ratios of both spectra are over 100 and the reductions of them have been performed using the ECHELLE package in IRAF[1]. The precision of our wavelength identification is 0.0037 Å.

3 RESULTS

3.1 Young Active Star Identification

Some information about our targets is presented in Table 1. The columns respectively are their Hipparcos numbers, right ascensions, declinations, spectral types, V band magnitudes, distances, $V-K$ colors and K band absolute magnitudes.

Table 1 Some Information about our Targets

Name(HIP)	Ra.(2000)	Dec.(2000)	Sp. type	V mag	Dist(pc)	$V-K$	M_K
544	00:06:36.53	29:01:18.97	K0V	6.07	13.70	1.756	3.63
46843	09:32:43.86	26:59:20.9	K0	7.05	17.75	1.951	3.87

Notes: Column(1): Identifier (Hipparcos), Col.(2): Right Ascensions, Col.(3): Declinations, Col.(4): Spectral Types (Hipparcos), Col.(5): V band Magnitude (Hipparcos), Col.(6): Distances (Hipparcos), Col.(7): $V-K$ Color (2MASS) , Col.(8): K band Absolute Magnitude (2MASS).

We present our high-resolution optical spectra of HIP 544 and HIP 46843 in the range of Hα, Li and Ca II infrared triplet (IRT) lines in Figures 1–3, respectively. For different radial velocities, their spectra have some shifts along the wavelength axis. However, we adjust them to about the rest wavelength in Figures 1–3 for a clearer comparison of their Hα, Li I 6707.8 Å and Ca II IRT lines.

Firstly, both Hα lines of HIP 544 and HIP 46843 are present in the absorption profiles in our spectra (see Fig. 1), which means there is no obvious accretion from the circumstellar matter. Secondly, both Li

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

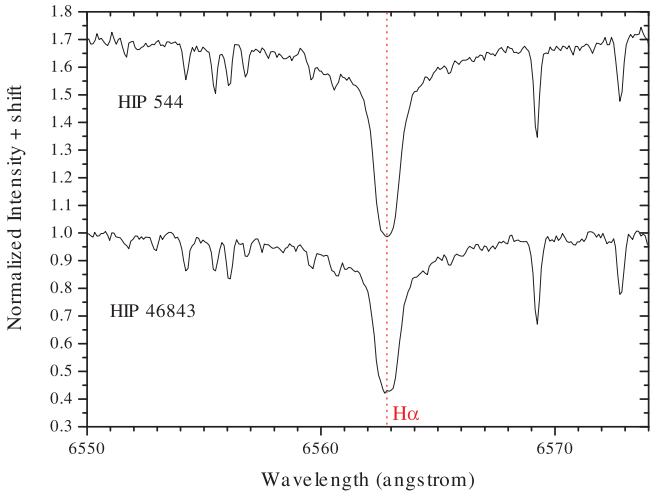

Fig. 1 High-resolution optical spectra of HIP 544 and HIP 46843 in the region of Hα (6563 Å) line. All the spectra have been adjusted to the lab rest wavelength. The Hα absorption line is marked with the dotted line.

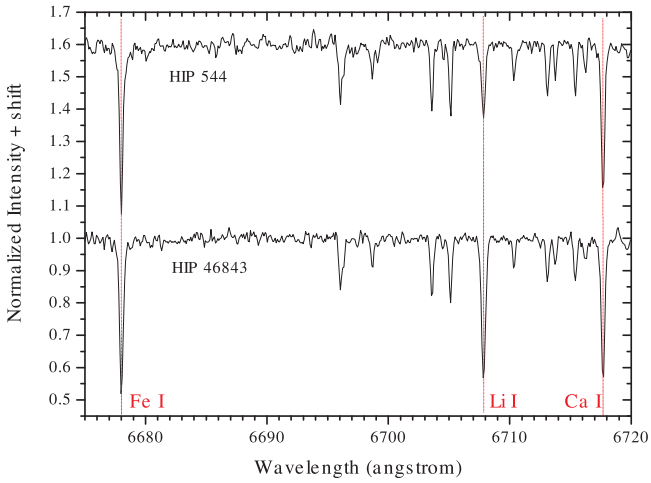

Fig. 2 High-resolution optical spectra of HIP 544 and HIP 46843 in the region of the Li I (6708 Å) line. All the spectra have been adjusted to the lab rest wavelength. The Fe I (6677.993 Å), Li I and Ca I (6717.685 Å) absorption lines are marked with the dot-dashed lines.

I 6707.8 Å lines of these two stars are strong (see Fig. 2), which means they are much younger than the Sun. The equivalent width of Li I 6707.8 Å of HIP 544 and HIP 46843 is about 110 mÅ and 195 mÅ respectively with an uncertainty of less than 5 mÅ. The uncertainty here mostly comes from the identification of the continuum of a spectrum. Thirdly, there are weak emissions in Ca II IRT 8498 Å and 8542 Å lines of HIP 544 (see Fig. 3), which means the chromosphere of HIP 544 is active. Furthermore, there are obvious emissions in the Ca II IRT lines of HIP 46843 (see Fig. 3), which means the chromosphere of HIP 46843 is very active. Based on the weak Hα lines, the strong Li I 6707.8 Å absorptions,

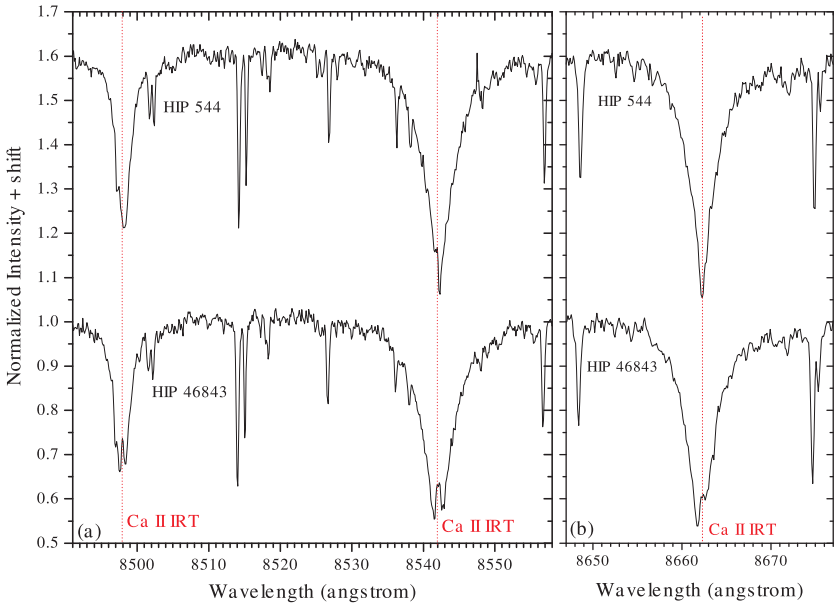

Fig. 3 High-resolution optical spectra of HIP 544 and HIP 46843 in the regions of the Ca II IRT ((a) 8498 Å and 8542 Å, (b) 8662 Å) triple lines. All the spectra have been adjusted to the lab rest wavelength. These three lines are marked with the dotted lines.

the strong X-ray emissions and the late type spectra, both HIP 544 and HIP 46843 are identified by us to be young active late type stars.

3.2 Radial Velocity Measurement

Though HIP 544 and HIP 46843 have been studied many times, the precisions of their radial velocities presented before are not better than 2 km s^{-1}, so their more accurate radial velocities are presented here based on our high resolution spectra.

The radial velocities of HIP 544 and HIP 46843 are –8.2 km s^{-1} and 13.8 km s^{-1} respectively with an uncertainty of 2 km s^{-1} which was presented by Wilson (1953). We adopt the radial velocities of the standard stars as follows: RV(β Gem) = 3.26$\pm$0.07 km s^{-1} and RV(α Hya) = –4.38$\pm$0.05 km s^{-1} (Stefanik et al. 1999). We choose three absorption lines (Fe I 6677.993, Ca I 6717.685 Å, Fe I 6750.152 Å) to measure the shifts of the spectra for calculating the radial velocities. The average difference between our measurements and the standard values of these two standard stars for Fe I 6677.993 Å line is –0.234 km s^{-1} and for Ca I 6717.685 Å line and Fe I 6750.152 Å line is 1.167 km s^{-1} and 0.283 km s^{-1}, respectively. The average difference is not too great for each line and this means that our observation system does not have a large shift from the standard system. We then use these average differences for each line to adjust the measured radial velocities of HIP 544 and HIP 46843. After that, we calculate the average of the radial velocities measured from these three lines and adjust for these two standard stars. As a result, the radial velocities of HIP 544 and HIP 46843 are –6.88$\pm$0.13 km s^{-1} and 8.30$\pm$0.16 km s^{-1}, respectively.

4 AGES

Stellar age determination is difficult and we can often obtain somewhat different stellar ages by using different methods. Here we choose three relatively creditable ways to discuss the ages of our targets.

Table 2 Equivalent Widths of Li I of our Targets

Name(HIP)	$B-V$	Ew(Li) (mÅ)	ΔEw(Li) (mÅ)
544	0.752	110	5
46843	0.779	195	5

Notes: Column (1): Identifier (Hipparcos), Col. (2): $B-V$ Color (Hipparcos), Col.(3): Equivalent Width of Lithium (this work), Col.(4): Uncertainty of our Measurement.

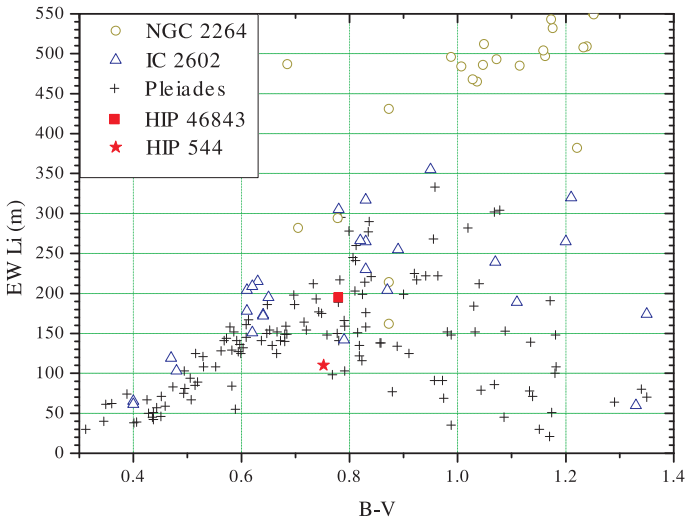

Fig. 4 Equivalent width of Li I 6707.8 Å vs. $B-V$. Displayed equivalent widths are not corrected for possible contamination by Fe I 6607.44 Å and measurement uncertainty of equivalent widths is less than 5 mÅ. Cluster ages are as follows: NGC 2264 (<5 Myr), IC 2602 (∼30 Myr), Pleiades (∼100 Myr). The age of HIP 544 is estimated to be about 100 Myr and that of HIP 46843 about 30 Myr.

4.1 EW of Lithium

The equivalent widths of Li I are measured for our targets and presented in Table 2. Those for NGC 2264 (about 5 Myr), IC 2602 (about 30 Myr) and the Pleiades (about 100 Myr) also are plotted in Figure 4. The data of Li abundance of these three young clusters are chosen from Soderblom et al. (1993, 1999) and Randich (2001) respectively. We can see from Figure 4 that the age of HIP 544 is close to the Pleiades and that of HIP 46843 is between IC 2602 and the Pleiades. We then estimate the age of HIP 544 to be about 100 Myr and that of HIP 46843 to be 30–100 Myr.

4.2 Color-magnitude Diagram (CMD) Location

We plot our two targets on a $V-K$ color-magnitude diagram (CMD) in Figure 5. The $V-K$ versus M_K CMD based on $V-K$ color is more creditable than the other CMD based on the other colors (e.g. $B-V, V-I$ and $J-H$) because the advantage of a larger baseline ($V-K$) could reduce the photometric measurement errors, any uncertainties in zero-points or passband placements and intrinsic stellar variability (Cohen et al. 1978). Cohen et al. (1978) used this method in globular cluster giants and Song et al. (2003) used it in pre-main-sequence stars.

We also plot the Hyades cluster (600–800 Myr) and the β Pictoris group (20±10 Myr) (Barrado et al. 1999) on the plane for comparison. The members of Hyades are chosen from Perryman et al. (1998)

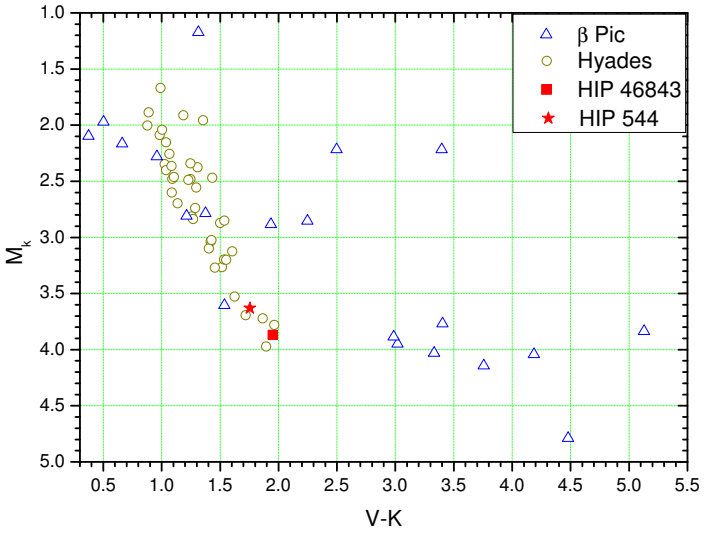

Fig. 5 Absolute K magnitude vs. $V - K$ color (CMD) of our stars. All plotted stars have Hipparcos measured distances. The star symbol is HIP 544 and the square is HIP 46843. The open triangles are stars of β Pictoris (2±10 Myr) and the olive open circles are stars of the Hyades (600–80 Myr).

and those of β Pictoris are chosen from Zuckerman et al. (2001) and Song et al. (2003). Their V band magnitudes and their parallaxes are chosen from Hipparcos and the K band magnitudes are chosen from 2MASS. We can see from Figure 5 that HIP 544 and HIP 46843 both have an age between the Hyades and the β Pictoris group. In other words, neither of them are older than the Hyades (600–800 Myr) or younger than the β Pictoris group (20±10 Myr).

4.3 Kinematics

We have calculated the galactic velocity components with radial velocities, accurate parallaxes, proper motions and J2000 coordinates using the method of Johnson and Soderblom (1987). We use a right-handed coordinate system (U towards the Galactic center, V in the direction of the Galactic rotation and W towards the north Galactic pole) and all of these velocities (U, V and W) are with respect to the Sun. The results are presented in Table 3. We adopt the population criteria from Leggett (1992) from which we know that young disk stars are those with –50 km s^{-1} $\leq U \leq$ 20 km s^{-1}, –30 km s^{-1} $\leq V \leq$ 0 km s^{-1} and –25 km s^{-1} $\leq W \leq$ 10 km s^{-1}, while old disk stars within an elliptical region whose eccentricity is less than 0.5 in the UV plane, but lie outside the young disk star region. In Figure 6, we also plot the population criterion from Eggen (1984, 1989) with a dashed line. With this criterion, the young disk stars are those in the region circled by the dashed line. HIP 544 and HIP 46843 with (U,V,W) of (–14.96, –21.58, –10.06) and (–10.03, –22.84, –5.45), respectively, certainly are located in the young disk star region according to both criteria (see Fig. 6).

Table 3 Galactic Velocity Components (U, V, W) and the Radial Velocities (RV) of our Targets

Name (HIP)	U (km s^{-1})	V (km s^{-1})	W (km s^{-1})	RV (km s^{-1})	Δ RV (km s^{-1})
544	–14.96	–21.58	–10.06	–6.88	0.13
46843	–10.03	–22.84	– 5.45	8.30	0.16

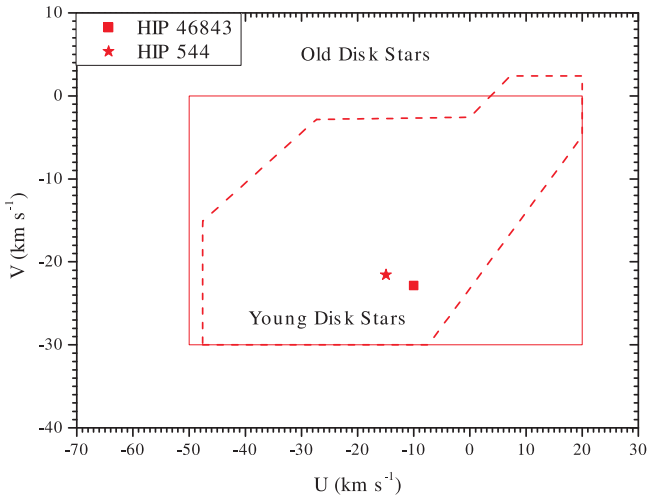

Fig. 6 The locations of HIP 544 and HIP 46843 on the U vs. V diagram. The star symbol is HIP 544 and the filled square is HIP 46843. The open rectangle represents the region of the young disk stars and outside of it in this diagram is the region of the old disk stars, which was presented by Leggett (1992). The irregularly shaped region which was encircled by a dashed line represents the region of the young disk stars and outside of it is the region of the old disk stars, which was presented by Eggen (1984, 1989). HIP 544 and HIP 46843 are located in the region of the young disk stars according to both criteria.

4.4 Final Ages

Considering all the determinations above, we finally estimate the age of HIP 46843 to be 30–100 Myr and that of the HIP 544 to be 100–800 Myr.

5 CONCLUSIONS

The RV of HIP 544 and HIP 46843 is measured to be –6.88±0.13 km s^{-1} and 8.30±0.16 km s^{-1}, respectively, based on our high-resolution spectra, which was more accurate than before. The EW of the Li I 6707.8 Å absorption line of HIP 544 and HIP 46843 is measured to be 110±5 mÅ and 195±5 mÅ , respectively. Based on these properties, HIP 544 is estimated to be 100–800 Myr old and HIP 46843 30–100 Myr old using the three relatively creditable methods. Both of them are young active late type solar like stars. The discovery of such young stars at such a close distance to the Sun is really a surprising phenomenon. It will help us to have a better understanding of the structure and evolutionary history of the Milky Way.

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