

CO versus HI in the Tully–Fisher relation for a sample of 32 galaxies

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Abstract. As a basic step for establishing the CO-line Tully–Fisher relation for distant galaxies, we made a comparative study of HI versus CO line profiles. Total line profiles of the CO line emission from 32 galaxies have been compared with the corresponding HI emission. We found a good correlation between the profiles of CO and HI. This strongly supports the thesis that CO can be used in the Tully–Fisher relation for distant galaxies where HI observations cannot reach. We also argue that CO can be used as an alternative to HI for non-isolated galaxies such as those in dense cluster of galaxies. Using the B-magnitudes and a recent calibration of the HI Tully–Fisher relation we give the distances for the galaxies derived from the CO-line Tully–Fisher relation and compare them with the corresponding HI distances.

Key words: galaxies: general – galaxies: distances – galaxies: ISM – galaxies: fundamental parameters – radio lines: galaxies

1. Introduction

The Tully–Fisher relation is one of the most powerful tools to estimate distances to galaxies (Tully & Fisher 1977; Aaronson et al. 1986; Pierce & Tully 1988; Kraan-Korteweg et al. 1988; Fouqué et al. 1990; Fukugita et al. 1991). In spite of many different photometric techniques (see the literature above), almost the same HI data set has been used (e.g., Bottinelli et al. 1989; Huchtmeier et al. 1989). HI observations are limited to galaxies with distances less than about 100 Mpc, or recession velocities of 10 000 to 15 000 km s⁻¹, even with the use of the largest telescope (see, e.g., Dickey & Kazes 1992). However, we have no routine method to determine distances to galaxies beyond this distance, except for the possible use of CO line using large-aperture mm-wave telescopes.

Beyond this distance, angular resolutions of a few arcminutes in HI observations become too large to resolve individual galaxies in a cluster. Interferometers like VLA are not useful for the purpose because of the limited number of spectral channels (velocity resolution) due to the limited number of

autocorrelator channels. Furthermore, more red-shifted HI lines have larger beam sizes which leads to more contamination and makes resolution of individual galaxies within clusters difficult.

On the other hand, CO facilities have much sharper beams (e.g., 15 arcsec with the Nobeyama 45-m telescope) which can resolve individual member galaxies in a cluster more easily, making it possible to avoid contamination by other cluster members. Moreover, the larger the redshift of an object, the lower the CO frequency, which results in a decrease in the system noise temperature due to atmospheric O₂ emission near 115 GHz. In other words, the more distant a galaxy, the more sensitive the observation system. The disadvantage of the CO line is its sensitivity, particularly for distant galaxies. Actually, we need a few mK rms data for line-width measurements with a velocity resolution of 10 km s⁻¹ for normal galaxies beyond $cz \sim 10\,000$ km s⁻¹, for which an integration time of about ten or more hours are required, and such observations are possible only by a long-term project with the largest mm-telescopes (Sofue, Schöniger, Kazes, and Dickey, private communication). However, although noise temperatures of current CO receivers, which are some hundred K in the present status, are still worse than those used in HI observations, we have the hope that they will be much improved in the near future to several tens of K, which may result in an increase of the sensitivity by one or two orders of magnitudes.

Since the distribution of HI gas is widespread in a galaxy, HI line profiles are easily disturbed by interactions among galaxies, which is inevitable in the central region of a cluster. Such disturbance might cause uncertainty in the HI line profiles for Tully–Fisher relation. On the other hand, CO gases are more tightly correlated with the stellar distribution, and are less affected by the tidal interaction. Of course, CO gas is distributed enough to a radius of several to ten kpc, so that the integrated line profiles manifest the maximum velocity part of the rotation curve (Sofue 1992).

Recently, Dickey & Kazes (1992) addressed the question whether linewidths in the CO line emission ($\lambda = 2.6$ and 1.3 mm) can be used in the Tully–Fisher relation as an alternative or supplement to HI. They found a linear correlation between

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CO and HI linewidths for the Coma and other nearby clusters of galaxies and showed the hope that the CO Tully–Fisher relation can be useful for distant clusters of galaxies. We also obtained a good correlation between CO and HI for our sample of four isolated and interacting edge-on galaxies (Sofue 1992). We suggested that the CO-line can be used not only for Tully–Fisher relation on normal galaxies, but also for interacting galaxies, which is particularly important when galaxies sitting in the central region of a cluster are concerned.

In this paper we discuss a detailed comparison of CO and HI profiles for 32 spiral and irregular field galaxies. This is the basic step toward establishing the CO Tully–Fisher relation not only for distant galaxies using the Nobeyama 45-m mm-wave telescope, but also for nearby galaxies as well as for galaxies in the central region of clusters where tidal interaction is inevitable.

Many of our sample galaxies will show peculiar features like active nuclei or interaction with a companion. We show that, despite such peculiarities, there is still a correlation between CO and HI. Further we investigate the question how strongly the eventually occurring differences between the profiles influence the resulting distances from the Tully–Fisher relation.

Then we apply the calibration of the B-band Tully–Fisher relation to determine the distances of the galaxies using the CO linewidth. We thereby use the CO linewidths just instead of HI applying a recent calibration of the HI Tully–Fisher relation. Finally we compare the resulting distances with the distances obtained from the HI Tully–Fisher relation.

2. Data

Our sample of galaxies is listed in Table 1. Column one gives the galaxy name, column two the inclination i and column three the total “face-on” blue magnitude B_0^T corrected for galactic and internal absorption which was taken from de Vaucouleurs et al. (1991).

The galaxies NGC 891, NGC 1808, NGC 3079, NGC 4565, NGC 4631 and NGC 5907 have been observed in $^{12}\text{CO}(J = 1 - 0)$ using the Nobeyama 45 m telescope, the other line profiles of CO and HI are taken from the literature. If the galaxy has been mapped in CO we have added up the individual spectra to get the total line profile. Figure 1 shows the total line profiles of CO (solid lines) for our sample with the corresponding HI profiles (dashed lines) superimposed. We measured the linewidths at the 20% and 50% level. In the following we give some notes on the individual galaxies.

NGC 224 (M 31): This is a nearby Sb galaxy ($D=0.78$ Mpc) and one of the local calibrators for the Tully–Fisher relation. It has been mapped by Koper et al. (1991). In their paper they also gave a comparison between the HI and CO profiles which shows an almost perfect agreement between CO and HI. The good agreement between the linewidths ($W_{20}^{\text{CO}} = 535 \pm 10$ km/s, $W_{20}^{\text{HI}} = 540 \pm 10$ km/s) would lead to only -1 % difference in distances ΔD , whereas ΔD is defined as $(D_{\text{CO}} - D_{\text{HI}})/D_{\text{HI}}$.

NGC 520, NGC 660, NGC 2623 and NGC 7674: The CO profiles of these galaxies are taken from Sanders & Mirabel

(1985), the HI profiles are from Mirabel & Sanders (1988). They are all suspected of being strongly interacting contact pairs. NGC 520 ($W_{20}^{\text{CO}} = 360 \pm 20$ km/s, $W_{20}^{\text{HI}} = 420 \pm 10$ km/s), shows a narrower CO profile at 20% level, but broader when compared at 50% level. NGC 660 ($W_{20}^{\text{CO}} = 370 \pm 20$ km/s, $W_{20}^{\text{HI}} = 330 \pm 10$ km/s) and NGC 2623 ($W_{20}^{\text{CO}} = 450 \pm 20$ km/s, $W_{20}^{\text{HI}} = 400 \pm 10$ km/s) show a broader profile in CO. In the case of NGC 7674 ($W_{20}^{\text{CO}} = 190 \pm 20$ km/s, $W_{20}^{\text{HI}} = 215 \pm 20$ km/s) the HI profile in emission looks narrower, but total width including the absorption feature is broader than CO. The corresponding differences in distances for ΔD for these galaxies are -18% for NGC 660, 17% for NGC 2623, -18% for NGC 7674 and -23% for NGC 520.

NGC 891: This is a typical and “standard” edge-on galaxy of Sb type, and is isolated and not disturbed (e.g. Sandage 1961). We find an almost perfect coincidence between the CO and HI profiles, except for a slight asymmetry with respect to the systemic velocity: both the lines show an almost identical double horn profile. The linewidths at 20% of peak intensity ($W_{20}^{\text{CO}} = W_{20}^{\text{HI}} = 490 \pm 10$ km/s) are the same within the errors. The HI profile was taken from Rots (1980).

NGC 992 and NGC 7469: These galaxies also have been observed in CO by Sanders & Mirabel (1985). the HI profiles are taken from Mirabel & Sanders (1988). For NGC 992 the CO profile looks rather peculiar but the linewidths between CO and HI ($W_{20}^{\text{CO}} = 385 \pm 20$ km/s, $W_{20}^{\text{HI}} = 360 \pm 10$ km/s) agree quite well. For NGC 7469 the CO profile is blue-shifted by about 80 km/s but nevertheless the linewidths ($W_{20}^{\text{CO}} = 330 \pm 20$ km/s, $W_{20}^{\text{HI}} = 370 \pm 10$ km/s) agree approximately. This leads to a ΔD of 11% for NGC 992 and -16% for NGC 7469 respectively. Hence that NGC 992 as well as NGC 7469 both have a close companion (Condon & Condon 1982).

NGC 1068 and NGC 1808: These galaxies both have a Seyfert nucleus, in the case of NGC 1808 additionally a jet is emerging from the central region (Véron-Cetty & Véron 1985). NGC 1068 has been observed in CO by Scoville et al. (1983), the HI profile was taken from Staveley-Smith (1987). NGC 1808 has been observed using the Nobeyama 45 m telescope by Sofue et al. (1992), the HI profile was taken from Rots (1980). Both galaxies show a broader CO profile at the 50% level but the linewidths agree well at the 20% level. This suggests a falling rotation curve beyond the maximum rotational velocity for both galaxies. For NGC 1068 the linewidths ($W_{20}^{\text{CO}} = 350 \pm 20$ km/s, $W_{20}^{\text{HI}} = 345 \pm 10$ km/s) leads to a difference of 2% in distances, for NGC 1808 ($W_{20}^{\text{CO}} = 340 \pm 20$ km/s, $W_{20}^{\text{HI}} = 330 \pm 10$ km/s) to a difference of 5%.

NGC 1365: This barred spiral galaxy of Sb type has been observed in CO by Sandqvist et al. (1988). The CO is distributed along the bar and its profile ($W_{20} = 370 \pm 10$ km/s) is slightly narrower than that of HI ($W_{20} = 390 \pm 10$ km/s). The different linewidths lead to a ΔD of -9%.

NGC 1569: This is an irregular galaxy showing an extremely narrow profile. A comparison of CO and HI profiles given by Young et al. (1984) shows a good coincidence between both profiles. The CO linewidth $W_{\text{CO}} = 85 \pm 15$ km/s and the corresponding HI linewidth $W_{20} = 95 \pm 10$ km/s agree within the

Table 1. Galaxy properties and measured linewidths

Galaxy	Inclination [°]	B_0^T [mag]	W_{20}^{CO} [km/s]	W_{20}^{HI} [km/s]	W_{50}^{CO} [km/s]	W_{50}^{HI} [km/s]
NGC 224	75	3.34	535	540	510	510
NGC 520	68	11.77	360	420	280	150
NGC 660	66	11.44	370	330	305	335
NGC 891	85	9.5	490	490	460	460
NGC 992	47	13.86	385	360	300	240
NGC 1068	40	9.46	350	345	290	260
NGC 1365	61	9.90	370	390	270	370
NGC 1569	63	9.45	85	95	70	85
NGC 1808	57	10.47	340	325	315	250
NGC 2146	34	10.52	390	460	300	260
NGC 2276	27	11.44	140	200	95	95
NGC 2339	43	11.54	330	340	310	330
NGC 2623	64	13.19	450	400	400	360
NGC 3034	82	8.83	320	300	250	200
NGC 3079	85	10.45	560	510	530	450
NGC 3627	62	9.13	380	385	310	310
NGC 3628	82	9.32	470	480	330	350
NGC 4565	90	9.11	570	530	500	500
NGC 4594	85	8.39	750	790	750	770
NGC 4631	85	8.61	305	330	260	300
NGC 4736	35	8.72	250	235	230	220
NGC 5194	20	8.68	180	190	160	140
NGC 5457	30	8.19	150	190	140	170
NGC 5907	90	9.74	480	490	455	470
NGC 6643	60	11.19	330	340	230	320
NGC 6946	30	7.84	255	260	205	230
NGC 7469	45	12.75	330	370	245	230
NGC 7479	39	11.33	310	370	250	350
NGC 7674	25	13.55	190	215	160	160
IC 342	25	5.58	150	190	125	170
Mrk 231		13.97	240	230	180	160
I Zw 1		13.99	405	405	400	400

errors. Since the linewidths are so narrow even the small difference in linewidths leads to a $\Delta D = -25\%$.

NGC 2146: An Sb galaxy with a narrower profile in CO ($W_{20} = 390 \pm 20$ km/s) than in HI ($W_{20} = 460 \pm 10$ km/s). The CO profile is taken from Young et al. (1986), the HI profile is from Tift & Cocke (1988). The corresponding value of ΔD is -23% .

NGC 2276: An infrared bright SBc galaxy which has been observed in CO by Young et al. (1986). The CO profile ($W_{20} = 140 \pm 20$ km/s) is narrower than the corresponding HI profile ($W_{20} = 200 \pm 20$ km/s) taken from Shostak (1978). This corresponds to a ΔD of -36% .

NGC 2339: Another infrared bright spiral also taken from Young et al. (1986). The CO profile ($W_{20} = 330 \pm 20$ km/s) and the HI profile ($W_{20} = 340 \pm 10$ km/s) coincide within the errors, despite the CO profile is blueshifted by about 70 km/s against HI. For this galaxy ΔD is -5% .

NGC 3034 (M82): This famous irregular galaxy has been observed in CO ($W_{20} = 320 \pm 20$ km/s) by Young & Scoville (1984), the HI profile ($W_{20} = 300 \pm 20$ km/s) is from Crutcher et al. (1978). Despite the peculiarity of this galaxy the profiles

agree approximately. The distances derived from CO and HI respectively differ by $\Delta D = 11\%$.

NGC 3079: This amorphous edge-on galaxy is known for its vertical radio lobes and a variety of activity (e.g., Duric et al. 1983). The CO gas is highly concentrated near the nucleus, displaying a high velocity dispersion (Young et al. 1988; Sofue & Irwin 1992). We also show a total profile constructed from a position-velocity diagram along the major axis obtained by the Nobeyama mm Array (NMA) (Sofue & Irwin 1992), where the effective beam is $1' \times 4''$ (4.4 kpc \times 0.29 kpc). An HI profile is reproduced from Irwin & Seaquist (1991). The CO profile is single peaked and smooth, while the HI profile has doublehorns. The CO width ($W_{20}^{\text{CO}} = 560 \pm 10$ km/s) is broader than that of HI ($W_{20}^{\text{HI}} = 510 \pm 10$ km s $^{-1}$). The corresponding ΔD is 17% .

NGC 3627 and 3628: These two galaxies belong to the Leo Triplet and have been observed in CO by Young et al. (1983). The authors also give a comparison of the total line profiles of CO and HI for these two galaxies, which are reproduced here. The good agreement between the profiles for both galaxies can clearly be seen. For NGC 3627 we get $W_{20}^{\text{CO}} = 380 \pm 20$ km/s and $W_{20}^{\text{HI}} = 385 \pm 20$ km/s. The linewidths of NGC 3628

are $W_{20}^{\text{CO}} = 470 \pm 20$ km/s and $W_{20}^{\text{HI}} = 480 \pm 20$ km/s. This corresponds to differences in distances of -2% for NGC 3627 and 3% for NGC 3628 respectively.

NGC 4565: This is a “standard” edge-on galaxy of Sb type, without any sign of interaction and warping. Again, we find almost identical line profiles both for CO and HI, even including the lopsidedness with respect to the systemic velocity. Both the HI and CO profiles are associated with a high-velocity wing at its 10–20% level, with the CO wing being slightly stronger ($W_{20}^{\text{CO}} = 570 \pm 10$ km/s, $W_{20}^{\text{HI}} = 530 \pm 10$ km/s). ΔD for this galaxy is 13%.

NGC 4594: This edge-on galaxy has been observed by Bajaja et al. (1991). Its morphological type is most likely to be Sa and the total linewidths of these galaxy are extremely wide. Superimposed on the CO spectrum is the result of an HI observation from Bajaja et al. (1984). The total linewidths of CO and HI show a agree approximately ($W_{20}^{\text{CO}} = 750 \pm 20$ km/s, $W_{20}^{\text{HI}} = 790 \pm 20$ km/s). This leads to a difference in resulting distance of -8%.

NGC 4631: This is a peculiar and interacting edge-on galaxy of Sc type, and its morphology is rather amorphous (Sandage 1961). Both the HI and CO profiles have a similar double-horn + central peak structure. The HI systemic velocity is blue-shifted by about 20 km/s from CO, which may be due to a tidal disturbance on the outer HI gas (Weliachew et al. 1978). The HI line width ($W_{20}^{\text{HI}} = 330 \pm 10$ km/s) is broader than CO ($W_{20}^{\text{CO}} = 300 \pm 10$ km/s), which may be also due to tidal disturbance on the HI envelope. ΔD for this Galaxy is -15%.

NGC 4736: The linewidths of CO ($W_{20} = 250 \pm 20$ km/s) and HI ($W_{20} = 235 \pm 20$ km/s) agree very well for this Sab galaxy which has been observed in CO by Garman & Young (1986) and in HI by Rots (1980). The corresponding difference in distances is 10%.

NGC 5194 (M51): The CO profile ($W_{20} = 180 \pm 20$ km/s) from Scoville & Young (1983) and the corresponding HI profile ($W_{20} = 190 \pm 10$ km/s) from Rots (1983) show a good agreement despite the peculiarities of this galaxy such as the close companion NGC 5195. CO and HI distances differ by $\Delta D = -9\%$.

NGC 5457 (M 101): This giant Sc galaxy is one of the largest and nearest face-on late-type spirals. CO ($W_{20} = 150 \pm 20$ km/s) and HI ($W_{20} = 190 \pm 20$ km/s) profiles differ significantly in their width for this galaxy. The CO profile is taken from Solomon et al. (1983), the HI profile comes from Rots (1983). The CO and HI distances therefore differ by $\Delta D = -33\%$ for this galaxy.

NGC 5907: This edge-on Sc galaxy has been observed with the Nobeyama 45m-telescope in December 1992. The total line profiles of CO and HI (Rots 1983) both show a double horned structure and coincide almost perfect ($W_{20}^{\text{CO}} = 480 \pm 20$ km/s, $W_{20}^{\text{HI}} = 490 \pm 20$ km/s). This difference between the linewidths corresponds to a ΔD of only -3%.

NGC 6643: The CO observation of this SAc galaxy was taken from Sanders & Mirabel (1985), the HI profile was taken from Staveley-Smith (1988). The agreement between CO ($W_{20} = 330 \pm 20$ km/s) and HI ($W_{20} = 340 \pm 10$ km/s) is pretty good, ΔD is -5%.

NGC 6946 and IC 342: These rather face-on Scd galaxies have been mapped in CO by Young & Scoville (1982), the HI data was taken from Rots (1979). For NGC 6946 the agreement is pretty good with a slightly broader profile in HI ($W_{20}^{\text{CO}} = 255 \pm 10$ km/s, $W_{20}^{\text{HI}} = 260 \pm 20$ km/s). IC 342 also shows a broader HI profile but with a bigger difference between the linewidths ($W_{20}^{\text{CO}} = 150 \pm 20$ km/s, $W_{20}^{\text{HI}} = 190 \pm 10$ km/s). This difference between the linewidths corresponds to a ΔD of -33% for IC 342 and 3% for NGC 6946 respectively.

NGC 7479: A Sb galaxy with a broader HI profile ($W_{20} = 370 \pm 10$ km/s) compared to CO ($W_{20} = 310 \pm 20$ km/s). The CO profile was taken from Young & Scoville (1983) and the HI profile was taken from Staveley-Smith et al. (1988). For this galaxy ΔD is 23%.

UGC 8058 (Markarian 231): A comparison of CO and HI profiles for this galaxy with a very high infrared luminosity of more than $10^{12} L_{\odot}$ has been published by Sanders et al. (1987). HI is observed in absorption but the linewidths ($W_{20} = 230 \pm 20$ km/s for HI, $W_{20} = 240 \pm 20$ km/s for CO) are very similar. No inclination is given for this galaxy but the good agreement between CO and HI would lead to no notable difference in distances.

I Zw 1: This is a quasar host galaxy and the CO data has been taken from Barvainis & Alloin (1989). The HI profile is from Condon et al. (1985) and it coincides very well with the corresponding CO profile. The linewidths both are the same ($W_{20}^{\text{CO}} = 405 \pm 20$ km/s, $W_{20}^{\text{HI}} = 405 \pm 20$ km/s). It is the most distant galaxy of our sample with a systemic velocity of 18313 km/s. Since there is no inclination measurement for this galaxy we can not use the Tully–Fisher relation to determine the distance. Hence, there would also be no notable difference between CO and HI distances.

3. Results

A compilation of the measured linewidths at the 20% and at the 50% level of peak intensity for our sample of galaxies is shown in column four to seven of Table 1.

Figure 2 shows a plot of the HI linewidths versus the CO linewidths at the 20% and at the 50% level. The correlation is better at the 20% level where we get $W^{\text{CO}}/W^{\text{HI}} = 0.96 \pm 0.10$, whereas for the 50% level we found $W^{\text{CO}}/W^{\text{HI}} = 1.03 \pm 0.21$.

Finally we give the distances to the galaxies of our sample using the linewidth measured in HI and secondly the distances resulting from the CO Tully–Fisher relation. We thereby apply the most recent calibration of the B-band Tully–Fisher relation given by Pierce & Tully (1992):

$$M_B = -7.48 (\log W^i - 2.50) - 19.55 + \delta m_B \quad (1)$$

$\log W^i$ are the logarithms of the linewidths corrected for internal turbulence (Tully & Fouqué 1985) and inclination. δm_B is a correction term for cluster galaxies and does not apply to the relatively isolated galaxies we discuss here. To calculate the distances we used the apparent blue magnitudes which are listed in Table 1 and the absolute magnitudes determined by

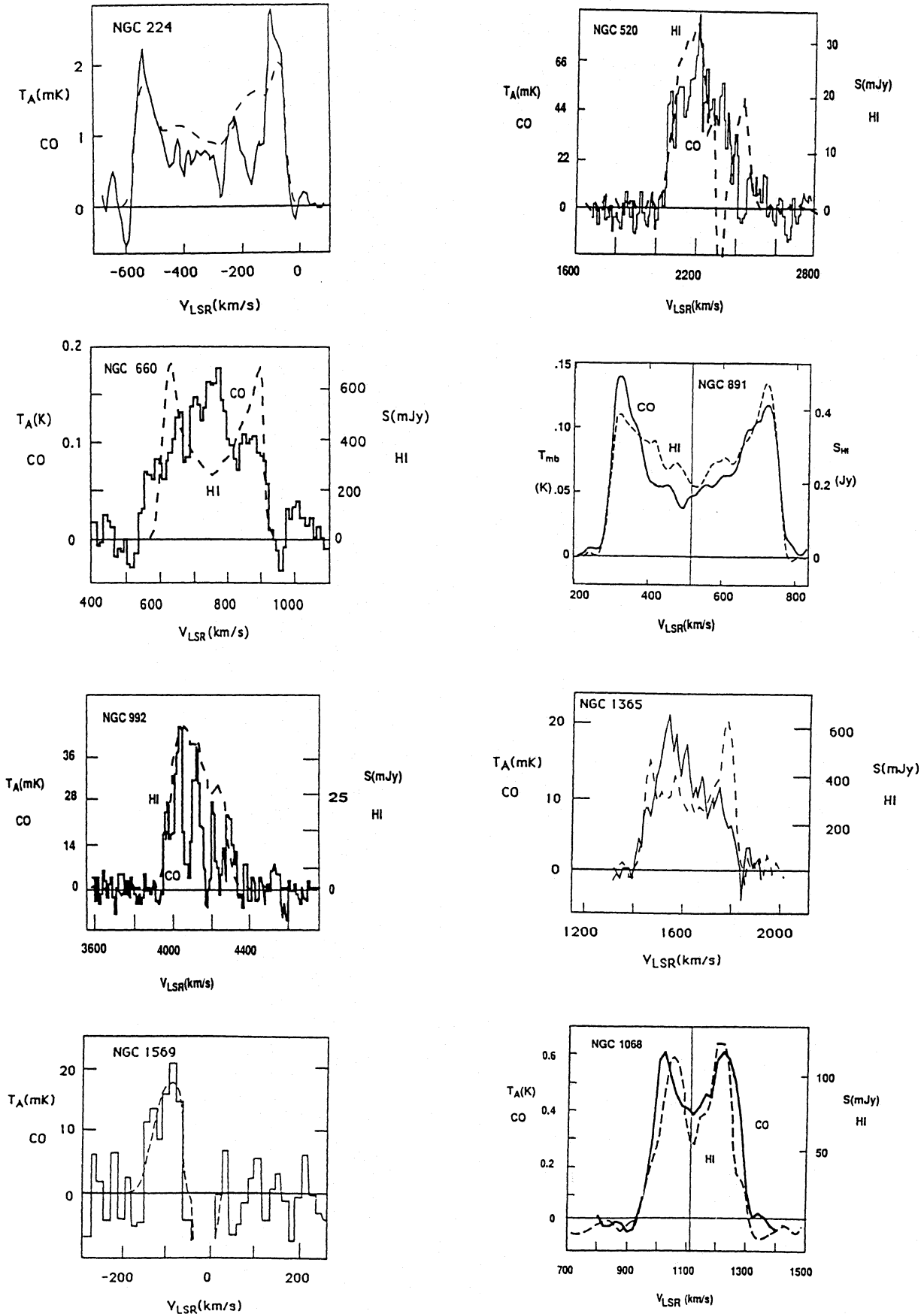


Fig. 1. The total line profiles of CO (solid lines) and HI (dashed lines) for our sample of galaxies

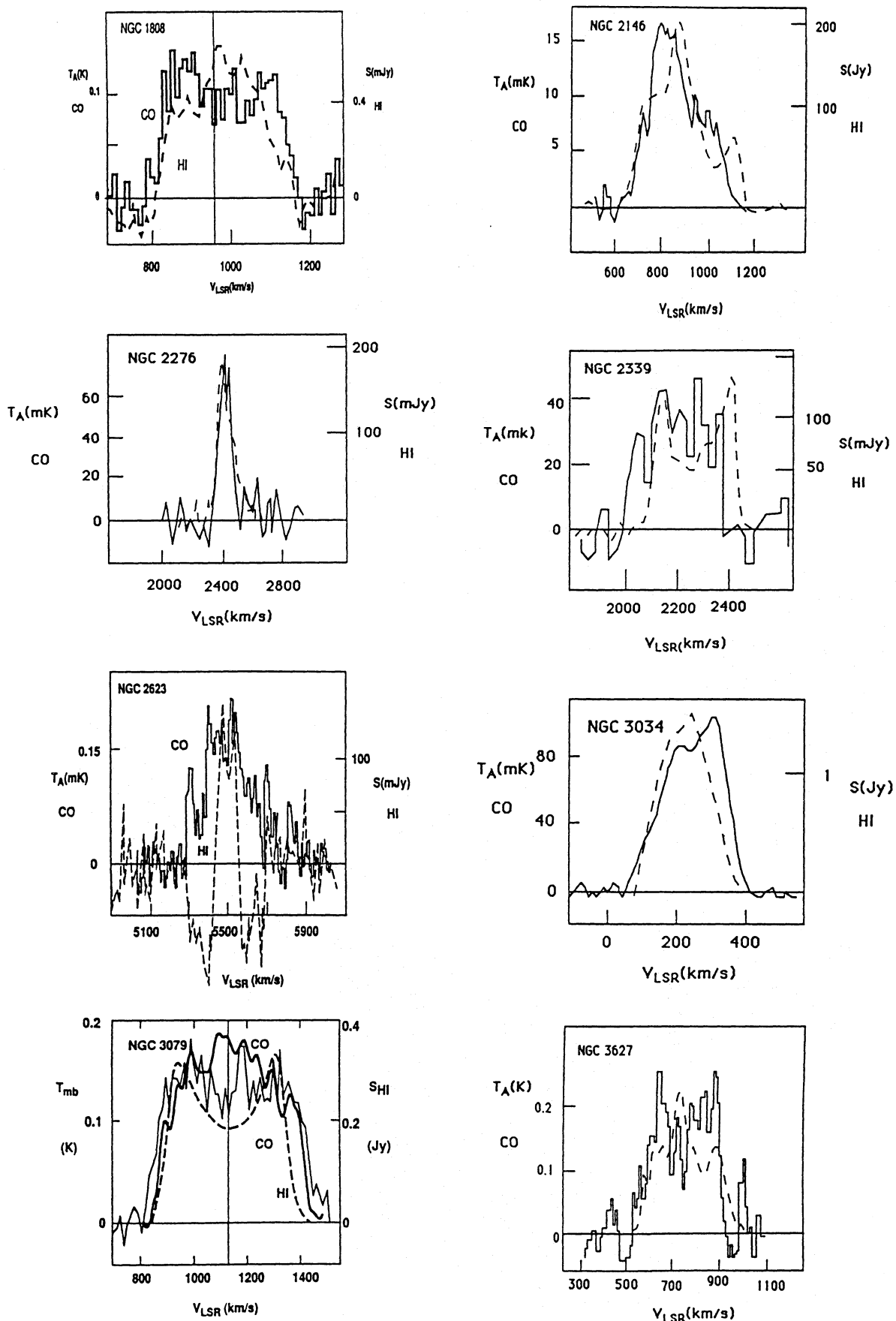


Fig. 1. (continued)

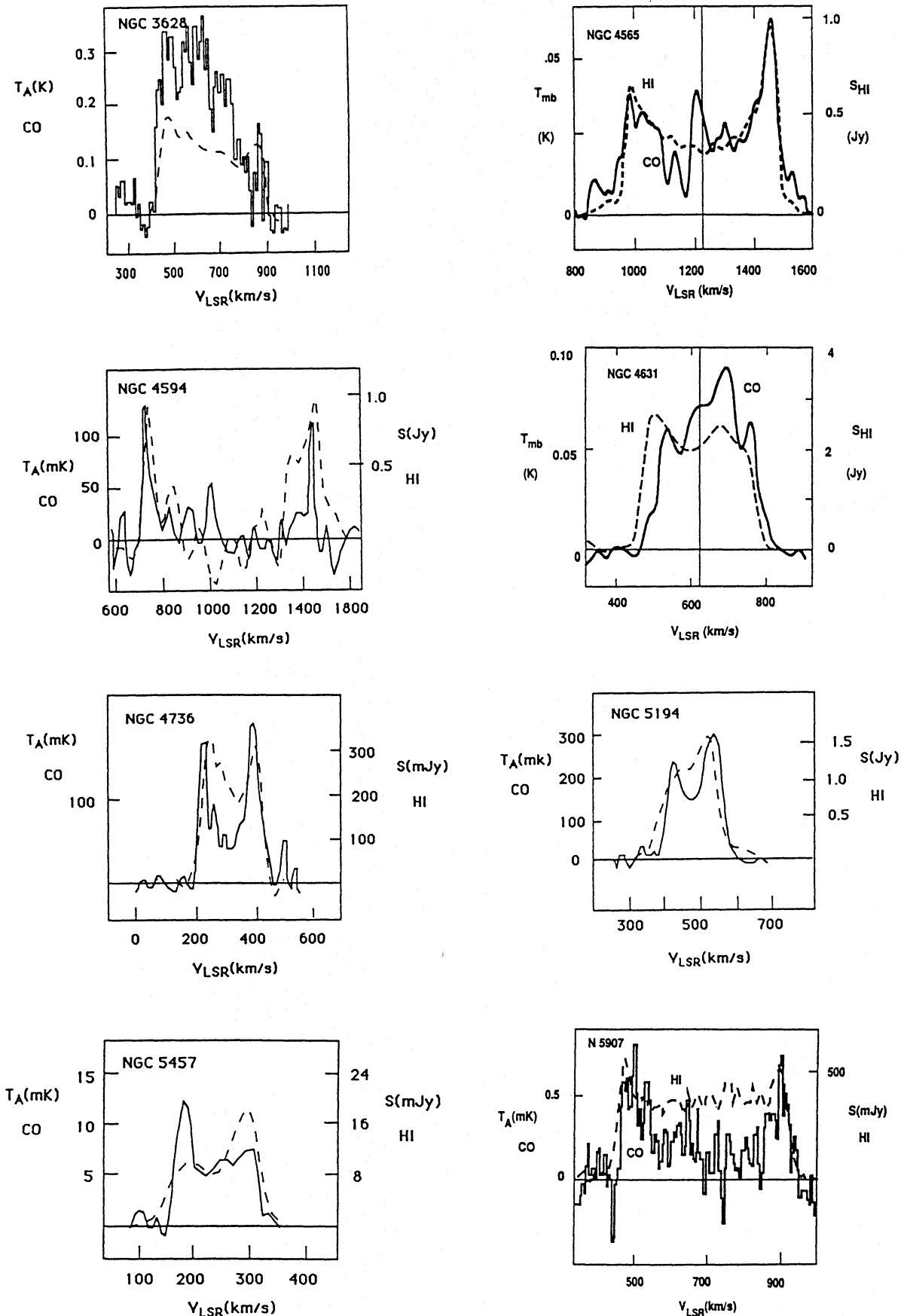


Fig. 1. (continued)

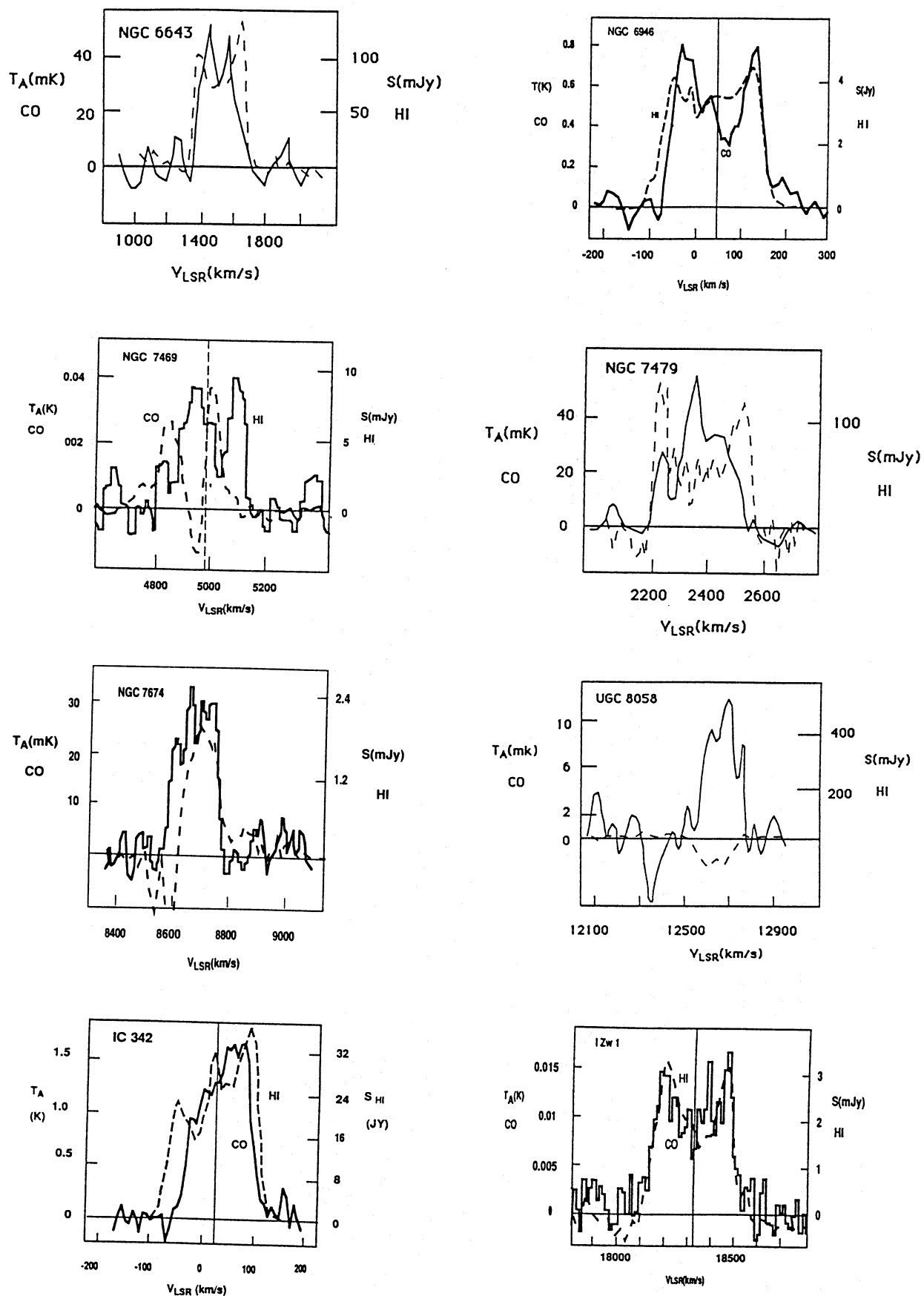


Fig. 1. (continued)

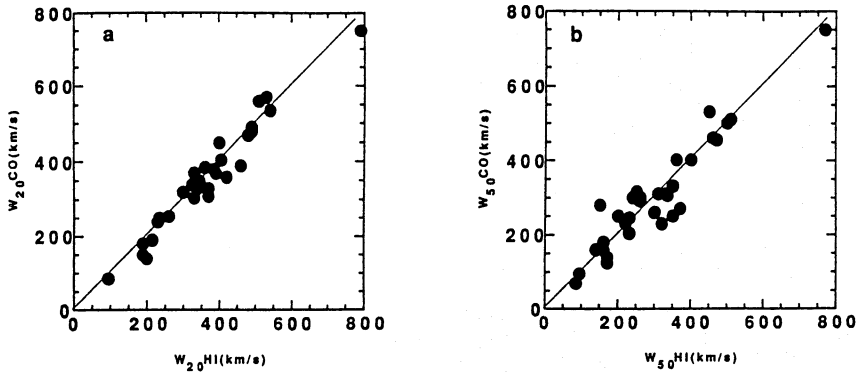


Fig. 2a and b. CO linewidths plotted against the corresponding HI linewidths at the 20% level a and at the 50% level b

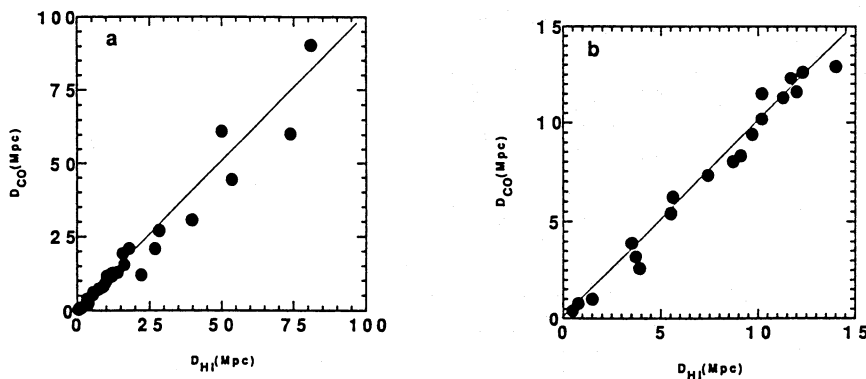


Fig. 3a and b. The CO distances plotted against the corresponding HI distances for all galaxies a and for the galaxies with distances up to 15 Mpc b

the calibration of the Tully–Fisher relation and our measured linewidths.

Table 2 shows a compilation of the result. The first column gives the galaxy name, the second the distance derived from the HI Tully–Fisher relation, the third the distance from the CO Tully–Fisher relation and column four shows the deviation of the CO distances from that of HI.

In Fig. 3 the CO distances are plotted against the HI distances. The scatter for the distances is slightly broader than for the linewidths and we get a value of $D_{\text{CO}}/D_{\text{HI}} = 0.94 \pm 0.16$.

Figure 3 also shows the correlation for the galaxies with distances up to 15 Mpc. In this plot the very good correlation is obvious.

4. Discussion

4.1. Deviation between CO and HI profiles for some galaxies

Although most of the sample galaxies showed good correlation between CO and HI, some cases were found in which they do not coincide sufficiently. In the following we make some remarks about possible reasons for larger deviations from the overall correlation between CO and HI.

Tidal interactions:

It is interesting that most of the galaxies where the differences in resulting distances from using CO instead of HI exceed 10% are suspected to be interacting with a companion (Condon

& Condon 1982). This suggests that interactions play a role in disturbing the reliability of the Tully–Fisher relation as a distance indicator. Since CO is more concentrated to the center than HI it is not as sensitive to tidal interactions as HI. Therefore the intrinsic scatter of the CO Tully–Fisher relation might even be better than for HI and it could well be a useful tool not only for distant but also for nearby galaxies.

However, from our data we can not decide whether the linewidths of CO or HI are better for determining the rotational characteristics of a galaxy, since the distances so far obtained for these galaxies are too crude to calibrate the Tully–Fisher relation. To look at the intrinsic scatter of the CO Tully–Fisher relation further observations of clusters of galaxies are necessary.

Galactic contamination:

In the case of IC 342 the rather large difference between the CO and HI distances of -33% might be due to Galactic contamination, since the systemic velocity of this galaxy is close to zero. Another explanation also might be the interaction with a companion (Rots 1979).

4.2. Normal vs peculiar galaxies

Among the 32 galaxies in the sample, there are two with large systemic velocities (NGC 2623 and Izw 1), both of which are galaxies with unusual activity. NGC 3034 (M82) is a peculiar starburst galaxy, and NGC 1068 is a Seyfert that also shows

Table 2. Resulting distances

Galaxy	D_{CO}	D_{HI}	$\Delta D = \frac{(D_{\text{CO}} - D_{\text{HI}})}{D_{\text{HI}}}$
	[Mpc]	[Mpc]	[%]
NGC 891	11.3	11.3	0
I Zw 1			0
Mrk 231			0
NGC 224	0.77	0.78	-1
NGC 1068	12.6	12.3	2
NGC 3627	7.3	7.4	-2
NGC 3628	9.4	9.7	-3
NGC 6946	5.4	5.5	-3
NGC 5907	11.6	12.0	-3
NGC 2339	27.0	28.3	-5
NGC 6643	15.4	16.2	-5
NGC 1808	12.3	11.7	5
NGC 4594	12.9	14.0	-8
NGC 5194	8.3	9.1	9
NGC 1365	8.0	8.7	-9
NGC 4736	6.2	5.6	10
NGC 992	90.2	80.8	11
NGC 3034	3.9	3.5	11
NGC 4565	11.5	10.2	13
NGC 4631	3.2	3.7	15
NGC 7469	44.4	53.6	-17
NGC 3079	20.9	17.9	17
NGC 7674	60.3	73.9	-18
NGC 660	19.2	15.8	22
NGC 2623	61.1	50.0	22
NGC 520	20.8	26.9	-23
NGC 2146	30.5	39.7	-23
NGC 7479	25.2	33.7	25
NGC 1569	0.4	0.5	-25
NGC 5457	2.6	3.9	33
IC 342	1.0	1.5	-33
NGC 2276	12.0	22.1	-36

starburst activity. It is rather surprising that the total line widths (including absorption for HI) for HI and CO in these peculiar cases show a good coincidence. This fact provides an interesting case about studying the rotation and interstellar properties of such peculiar active galaxies, besides the interest in Tully–Fisher relation. A thorough investigation for the reason of the agreement, particularly for the former two cases, is needed by obtaining higher-resolution imaging data in CO and HI.

Moreover, our result gives a clear answer to the current guess that since CO is concentrated in the central region of galaxies, its line profiles would be significantly different from HI and would be not adequate for such a purpose to measure rotation velocities. This is not the case as Fig. 1 indicates. The reason for the HI–CO coincidence has been investigated by Sofue (1992), who examined the rotation characteristics and molecular hydrogen and HI distributions in the well-resolved edge-on galaxies NGC 891 and NGC 4565.

4.3. On the use of the CO Tully–Fisher relation

The Tully–Fisher relation makes use of the properties of normal galaxies. Except for some galaxies as raised above, most of the sample galaxies are normal spirals. The accuracy of velocity width measurements is usually $\pm 10 \text{ km s}^{-1}$ in CO-line observations, and is comparable with that of HI. Moreover, the CO data which we demonstrated here are taken from the literature except for several galaxies from the 45-m telescope, and have not been obtained properly for the purpose of distance measurements. Nevertheless, we obtained a good correlation. Hence, by a systematic measurement program of CO-line width using adequate telescopes equipped with the best receivers, CO width data of accuracy $\pm 5 \text{ km s}^{-1}$ would be routinely obtained by integration time of a few hours for galaxies below $cz \sim 10\,000 \text{ km s}^{-1}$. For Tully–Fisher relation of more distant cluster galaxies, to which HI cannot reach, we certainly need the largest facilities such as the Nobeyama 45-m telescope and the IRAM 30-m telescope.

It would be worthwhile to demonstrate that CO Tully–Fisher relation measurement is quite possible for distant cluster galaxies using the 45-m telescope: Normal Sb and Sc galaxies of NGC 891 size contain molecular hydrogen in mass of the order of $10^9\text{--}10 M_{\odot}$. This mass corresponds to CO ($J = 1 - 0$) line intensity of $I_{\text{CO}} \simeq 4(D/100\text{Mpc})^{-2} \text{ K km s}^{-1}$ with the 45-m telescope (beam width $15''$) for a normal CO-to-H₂ conversion factor (Bloemen et al. 1986). For a typical line width of about 400 km s^{-1} , we may expect a main-beam brightness temperature of about $T_{\text{mb}} \simeq 10 - 100(D/100\text{Mpc})^{-2} \text{ mK}$. This implies that measurements with rms noise of a few mK are required for a velocity resolution of 10 km s^{-1} , which is quite possible by an integration time of a few hours in the present status of telescope under a good weather condition. If the system noise temperature decreases by a factor of ten, due to improvements of receivers as well as due to larger redshift of galaxies, we may be able to obtain CO line-width data rather “routinely”, as is usually done in HI for nearby galaxies. To this end we have started a long-term project of CO-line observations for the Tully–Fisher relation using the 45-m telescope at Nobeyama.

5. Conclusion

We compared the total line profiles of CO and HI for a sample of 32 galaxies. Confirming the work of Dickey & Kazes (1992) and Sofue (1992) we also found a correlation between CO and HI. However, for the galaxies of our sample which are supposed to be interacting we obtained larger differences between CO and HI than they found in their sample. This might indicate the presumably better reliability of the CO linewidth compared to HI for interacting galaxies. In order to confirm this further studies of cluster galaxies at the same distance are necessary to look at the intrinsic scatter of the CO–Tully–Fisher relation.

Since the mean value of $D_{\text{HI}}/D_{\text{CO}}$ is close to one and the scatter relatively low, our study shows that CO is a promising tool, even if the intrinsic scatter proves not to be significantly better than for the HI Tully–Fisher relation.

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