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# APPLICATIONS OF SELF-REFERENCING METHOD TO THE VIRGO CLUSTER SPIRALS

EUN JUNG CHUNG[1], HYORYOUNG KIM[2], AND MYUNG-HYUN RHEE[3]
[1]Dept. of Astronomy, Yonsei University, Seoul 120-749, Korea
[2] Taeduk Radio Astronomy Observatory, KASI, Daejeon 305-348, Korea
[3] Yonsei University Observatory, Yonsei University, Seoul 120-749, Korea
*E-mail: rigel@galaxy.yonsei.ac.kr, hrkim@trao.re.kr, and rhee@obs.yonsei.ac.kr*
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## ABSTRACT

Self-referencing method in revised-OTFTOOL is a new method in On-The-Fly(OTF) observation mode. It uses the source free regions of the observed frame as references instead of the OFFs references. We already analyzed and discussed its proprieties and advantages in the previous paper. In this paper, we make a statistical study about the self-referencing method by applying it to OTF mapping data of 27 Virgo spiral galaxies. We found that the self-referencing method solves the crooked baseline problem for every datacube. It straightens the baseline, and conserves the emissions. Compared with other data processing, the median filtering task *'mwflt'* in AIPS, to use self-referencing method is more effective and safe not only to straighten the baseline but also to conserve the emission. For the strong CO galaxies, the data obtained by self-referencing method shows scarcely any difference from those reduced by conventional OFFs references and AIPS median filtering in the range of uncertainties. Undetected CO emissions in datacubes of conventional OFFs references are also not detected in those of self-referencing method.
The self-referencing method is expected to save the observing time and simplify data reduction processes. Besides this, using self-referencing method will offer emission-free references more safely.

*Key words :* OTF Observation – galaxies : cluster galaxies (Virgo cluster) – techniques : image processing

## I. INTRODUCTION

On-The-Fly(OTF) observation mode in radio astronomy has several advantages to the classical step-and-integrate observation. It drives the telescope smoothly and rapidly across a field storing data and antenna position information continuously. Due to its fast moving and covering the whole observational region in short observing time, the telescope overhead is reduced, the properties of the atmosphere and the system change less in comparison to a conventional step-and-integrate mapping method, and observing time is also saved (Mangum 1999).

Referencing is very important to subtract baseline in radio observation, and the position-switching method is the most commonly used one. This referencing method performed its part most effectively until now, but it is not enough to serve the purposes of OTF observation and could get some systematic problems. OTF observation mode minimizes the cumulated atmospheric and systematic uncertainties of the classical step-and-integrate observation due to the long exposure time at a position by shortening the exposure time and increasing the redundances. However the position-switching method still has too long exposure time at the reference positions in comparison with the scanning time of a source point in OTF mode. It cannot give the satisfiable information about the fast changing sky and systems, but also might hinder sky subtraction and make some false structures.

We have proposed a new referencing method which is named self-referencing method in the previous paper (Chung et al. 2005; hereafter, paper I). We found that every datacube obtained by FCRAO 14m antenna in OTF mapping mode showed severely crooked baseline. At first, we tried to solve this problem by using the median filtering task *'mwflt'* in AIPS (Astronomical Image Processing System). Secondly, we fixed our eye's upon that the crooked baseline problem is appeared in our every datacube. We analyzed the systematic effect by differential measurement. We reached a conclusion that the large time and position discrepancies between the source and references can cause the variations of the spectrum. This means that if we use a reference which has smaller time and position differences with those of sources, then the variations of spectrum can be reduced. And we applied SELF references which uses the inner source-free region as references instead of the conventional OFFs references, which can be chosen in the revised-OTFTOOL (Kim et al. in preparation).

When using the self-referencing method, we obtained very fantastic results. From the analysis, we applied the conventional OFFs references and the new

*Corresponding Author*: M.-H. Rhee

TABLE 1
OBSERVATION & DATA ACQUISITION PARAMETERS

| Galaxy | # of qef files[a] | # of maps[b] | baseline order[c] |
|---|---|---|---|
| NGC 4192 | 870 | 14 | 1 |
| NGC 4212 | 562 | 9 | 1 |
| NGC 4216 | 1201 | 20 | 1 |
| NGC 4254 | 870 | 14 | 2 |
| NGC 4293 | 441 | 7 | 2 |
| NGC 4298 | 725 | 11 | 1 |
| NGC 4302 | 1250 | 18 | 1 |
| NGC 4303 | 696 | 10 | 1 |
| NGC 4321 | 356 | 5 | 1 |
| NGC 4402 | 720 | 10 | 1 |
| NGC 4419 | 907 | 13 | 1 |
| NGC 4438 | 669 | 9 | 1 |
| NGC 4450 | 627 | 9 | 1 |
| NGC 4501 | 379 | 5 | 1 |
| NGC 4527 | 766 | 10 | 1 |
| NGC 4535 | 852 | 12 | 1 |
| NGC 4548 | 725 | 10 | 1 |
| NGC 4567[d] | 667 | 9 | 1 |
| NGC 4569 | 885 | 12 | 1 |
| NGC 4579 | 677 | 9 | 1 |
| NGC 4647 | 928 | 13 | 2 |
| NGC 4649 | 608 | 8 | 2 |
| NGC 4651 | 570 | 8 | 1 |
| NGC 4654 | 570 | 8 | 2 |
| NGC 4689 | 638 | 9 | 1 |
| NGC 4710 | 1092 | 15 | 1 |

[a] The data in each position from one OFFs to the next OFFs observation are stored in a qef file.
[b] Our OTF observation wholly covered each galaxy several times. A map means that a datacube which cover the galaxy once, and every datacube of each galaxy consists of several number of maps.
[c] Using the reference of OFFs or SELF, we subtract the baseline in the revised OTFTOOL. We applied 0, 1, and 2 order of baseline, and the baseline order in this table is that of the final datacubes.
[d] NGC 4567 & 4568

SELF references to NGC 4254 which has very strong CO emission and high S/N ratio. The self-referencing method straightened the severely crooked baseline. Comparing the final results derived by OFFs reference and AIPS median filtering works with that derived by SELF reference, they had very good agreements in CO contour map, the global profile, and the total CO flux.

We can conclude that the self-referencing method is more effective to subtract the effects from the sky and the systems. We can also use simplified data reduction process, and get the emission-free reference more safely. Besides this, we can save the observation time about 25%.

In this paper, we will apply the self-referencing method to more galaxies and analyze the results statistically. Paper I shows the differentiable analysis of the conventional OFFs references and SELF references, and tested it with only one galaxy. Now, we will confirm the efficiencies of self-referencing method by applying it to more various galaxies. Section 2 presents a brief report about the observation and data acquisition. Section 3 shows the results, channel maps and global profiles, applying the classical and self-referencing method for 27 galaxies. By comparing the results, we analyze and discuss the method statistically in Sec.4. Summary and conclusion are in section 5.

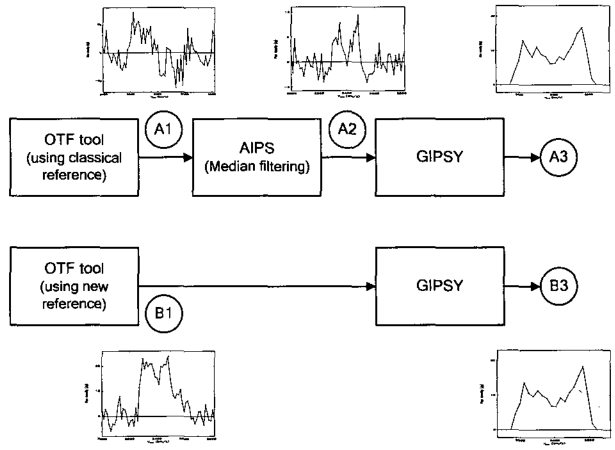


**Fig. 1.**— Data reduction flow chart : A1 and B1 are raw datacubes taken from the revised-OTFTOOL using the conventional OFFs and the new SELF references respectively. A2 is median-filtered datacube in AIPS to stretch the curved baseline. A3 and B3 are the final datacubes followed by the same data reduction steps in GIPSY. And both of them show clear zero level baseline after the *'blot'* task in GIPSY. Note that B1 skips the median-filtering works in AIPS, and reduction of B1 in GIPSY is done directly by the same procedures with A2. The spectra in each reduction step are those of NGC 4254, and they show the transitions of channel baselines by reduction processes.

## II. OBSERVATION & DATA ACQUISITION

We carried out the array OTF observations of 27 Virgo cluster galaxies using 14m telescope of the Five College Radio Astronomy Observatory (FCRAO) as our Virgo Cluster Survey Project(Chung 2003; Kim 2003; Chung et al. in preparation). The sample consists of dynamically quiescent galaxies among the Virgo Cluster galaxies, and it is not really large, but it has advantages which provides a well-defined, volume limited, and equidistant sample. There exist galaxies containing various CO quantities. Some galaxies have strong CO emission, others have weak CO emission, and the others are not detected in CO. This will give us more general understanding about the self-referencing method.

Every galaxy had been mapped of $10' \times 10'$ size(ONs) The antenna moved at $45''$ per second, and the data were stored in every 0.25 seconds. OFFs references were obtained at the position with 30 arcminute offset in the azimuth direction. The pointing and focus of the telescope were measured normally at the beginning of each observing run, and occasionally during the middle of the run when the weather condition varies much. We have measured an rms pointing error of $\sim 3''$ in both azimuth and elevation, or $\sim 5''$ in total. We synthesized the raw datacubes in revised-OTFTOOL. Each OTF raw data consists of hundreds of qef files, and

TABLE 2
TOTAL CO FLUX AND ITS RMS

| Galaxy | Final Result using OFFs (Phase of A3) Total CO Flux (Jy Km/s) | rms (K) | Final Results using SELF (Phase of B3) Total CO Flux (Jy Km/s) | rms (K) | $\triangle S_{CO}^{OFFs}$ [a] (%) | $\triangle S_{CO}^{SELF}$ [b] (%) |
|---|---|---|---|---|---|---|
| Group I | | | | | | |
| NGC 4254 | 2110 | 0.015 | 2380[c] | 0.015 | 39 | -28 |
| NGC 4302 | 370 | 0.012 | 420 | 0.019 | 13 | -12 |
| NGC 4303 | 1380 | 0.026 | 1840 | 0.026 | 33 | -25 |
| NGC 4321 | 1640 | 0.026 | 2360 | 0.027 | 44 | -30 |
| NGC 4501 | 1750 | 0.020 | 2120 | 0.018 | 21 | -17 |
| NGC 4527 | 1200 | 0.019 | 1160 | 0.018 | -4 | 4 |
| NGC 4567[d] | 1290 | 0.023 | 1500 | 0.024 | 17 | -15 |
| NGC 4569 | 1240 | 0.030 | 900 | 0.024 | -27 | 37 |
| NGC 4647 | 530 | 0.025 | 470 | 0.015 | -11 | 13 |
| NGC 4654 | 550 | 0.024 | 640 | 0.021 | 17 | -15 |
| NGC 4689 | 310 | 0.020 | 390 | 0.019 | 26 | -21 |
| Group II | | | | | | |
| NGC 4298 | 400 | 0.012 | 520 | 0.012 | 28 | -22 |
| NGC 4402 | 280 | 0.026 | 350 | 0.035 | 27 | -21 |
| NGC 4419 | 300 | 0.013 | 310 | 0.016 | 5 | -5 |
| NGC 4438 | 120 | 0.014 | 220 | 0.016 | 87 | -46 |
| NGC 4535 | 990 | 0.038 | 1650 | 0.032 | 66 | -40 |
| NGC 4548 | 390 | 0.014 | 710 | 0.016 | 81 | -45 |
| NGC 4579 | 330 | 0.013 | 460 | 0.011 | 37 | -27 |

[a] differences of $S_{CO}^{SELF}$ from $S_{CO}^{OFFs}$ in %, where $\triangle S_{CO}^{OFFs} = (S_{CO}^{SELF} - S_{CO}^{OFFs})/S_{CO}^{OFFs} \times 100$. We used the notation of $\triangle S_{CO}^{OFFs}$ because we set $S_{CO}^{OFFs}$ as a standard of comparison.

[b] differences of $S_{CO}^{OFFs}$ from $S_{CO}^{SELF}$ in %, where $\triangle S_{CO}^{SELF} = (S_{CO}^{OFFs} - S_{CO}^{SELF})/S_{CO}^{SELF} \times 100$. As written above, we set $S_{CO}^{SELF}$ as a standard of comparison.

[c] In the data reduction processing for all galaxies, the total CO flux of NGC 4254 has changed from 2280 Jy km/s in paper I to 2380 Jy km/s in here. They are in the uncertainty range.

[d] The entries of NGC4567 are the total values for the pair of NGC4567 and NGC4568.

each qef file contains 69 or 135 samples(see Table 1). For each galaxy, we picked out bad data of the samples, and calibrated and regridded only with the remained good samples on the basis of the floating level, rms, trajectory, elevation, and $T_{sys}$. In the step of choosing the reference, we applied the conventional OFFs reference and the new SELF reference. And we used jinc-gaussian function to regrid. We fixed the cell size to be 15″ (Kim 2003). From these phases, we made two different datacubes for each galaxy. Table 1 presents the observation and data acquisition parameters. Figure 1 shows the data reduction flow chart. A1 and B1 will show the discrepancies between the OFFs and SELF references, and the comparison between A3 and B3 will give the authentication of SELF references.

Our sample is very suitable to test the self-referencing method. Every 27 galaxy is mapped by $10' \times 10'$ size which is enough to cover not only the entire of each galaxy but also the outer region as SELF reference. Besides this, because the sample contains both strong and weak CO emissions of galaxies, it is very suitable to study the SELF reference statistically.

## III. RESULTS

In this section, we present the channel maps and global profiles of every datacube obtained from using the classical OFFs reference and the SELF reference. We divided the galaxies into three groups. The first group contains galaxies which have strong CO emission, the second is composed of galaxies which have weak but distinguishable CO emission, and the third of the non-detected galaxies in CO.

The channel maps and global profiles of each galaxy are shown in Figure 2, 3, and 4, respectively. The left channel map and global profile are gotten from using the classical OFFs references and the right ones are from using the SELF references. Each channel map has different color range, and the limit is fixed in its own minimum and maximum values. To compare the datacube of conventional OFFs references with SELF references, we make the range of the ordinate of the global profiles be the same between them. If we adjust the scale properly, the CO emission is clearly shown for the strong CO galaxies, as shown in the channel maps. Note that every datacube obtained by the classical OFFs references has severe U-shaped baseline. The extent of variations between the channels are about an order of magnitudes. However, the baselines are perfectly straightened when using the SELF references.

## IV. ANALYSIS & DISCUSSION

In the previous section, we confirmed that using SELF references makes the baselines be straightened not only for the strong CO but also weak or no-detected CO galaxies, qualitatively. Now, we will study the works of SELF references more deeply and quantita-

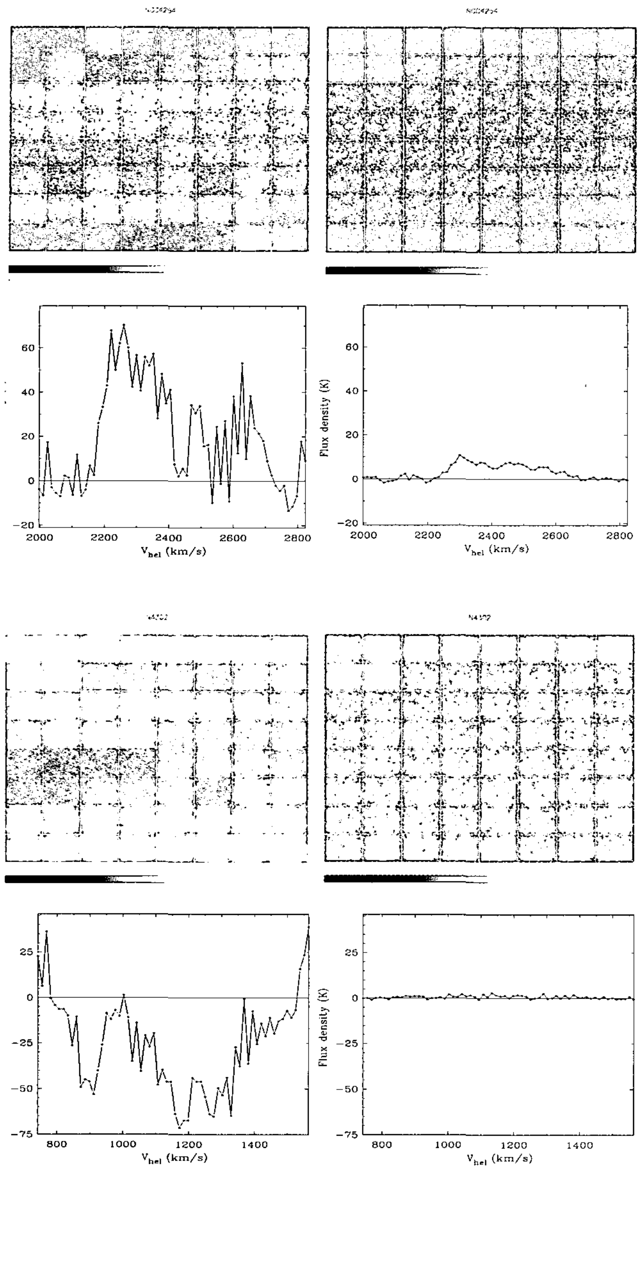


**Fig. 2.**— Channel maps and global profiles of group I galaxies, NGC 4254 (top) & NGC 4302 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

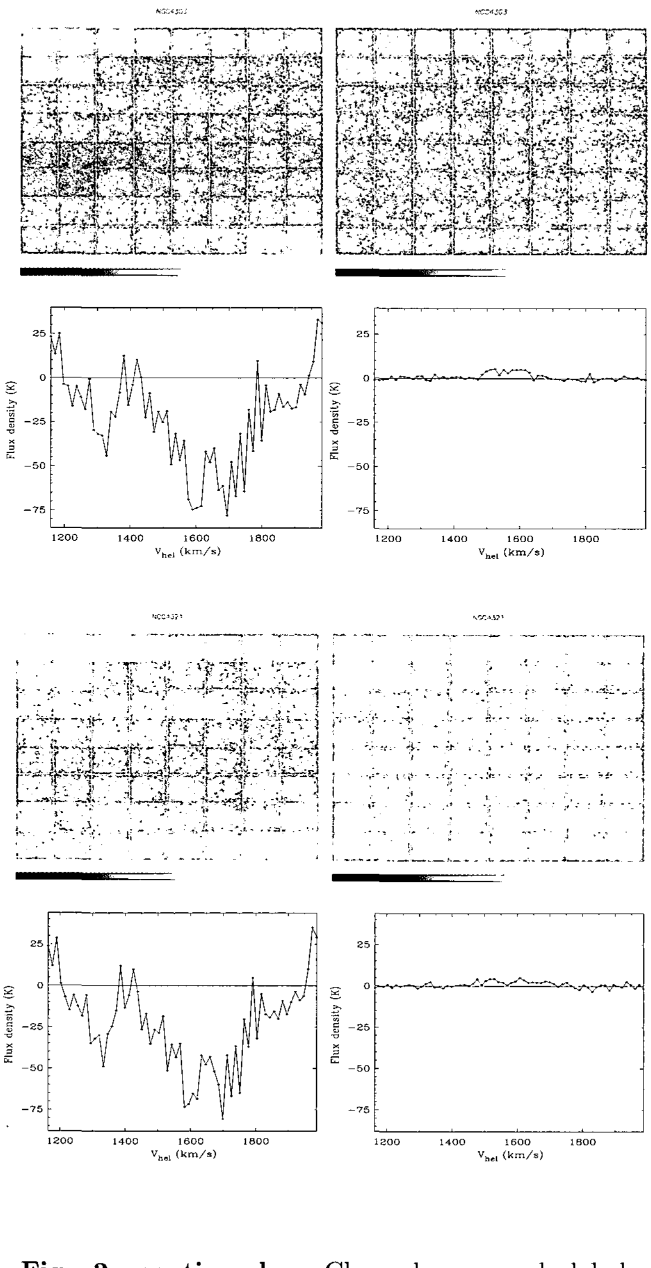


**Fig. 2. continued.**— Channel maps and global profiles of group I galaxies, NGC 4303 (top) & NGC 4321 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

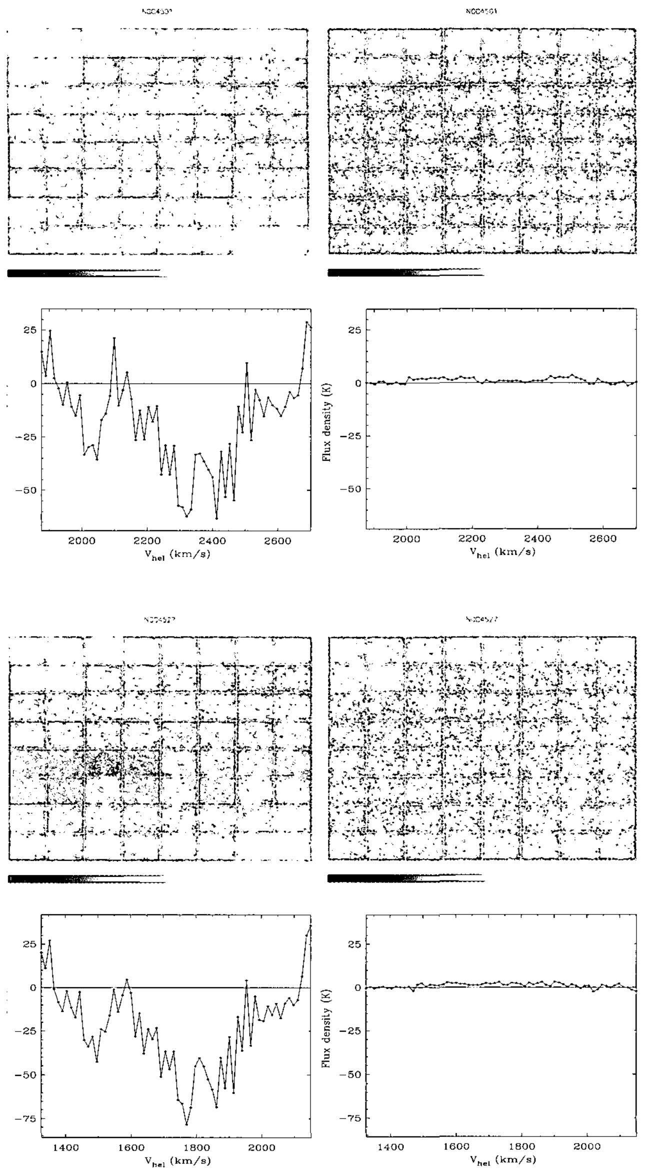

**Fig. 2. continued.**— Channel maps and global profiles of group I galaxies, NGC 4501 (top) & NGC 4527 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

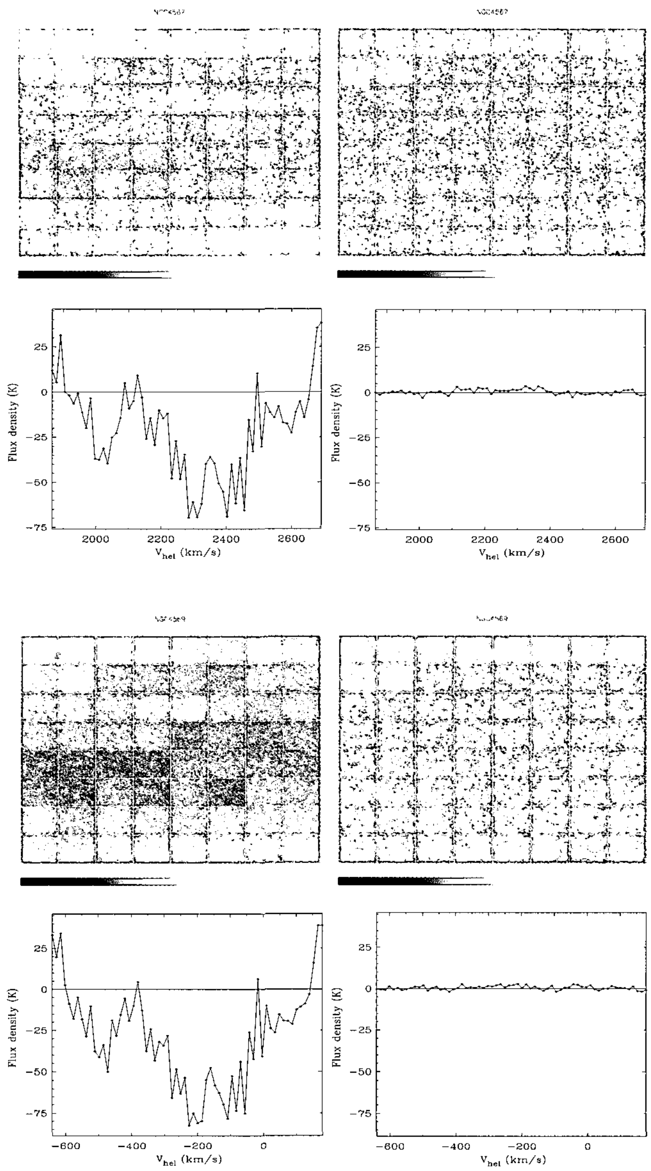

**Fig. 2. continued.**— Channel maps and global profiles of group I galaxies, NGC 4567 (top) & NGC 4569 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

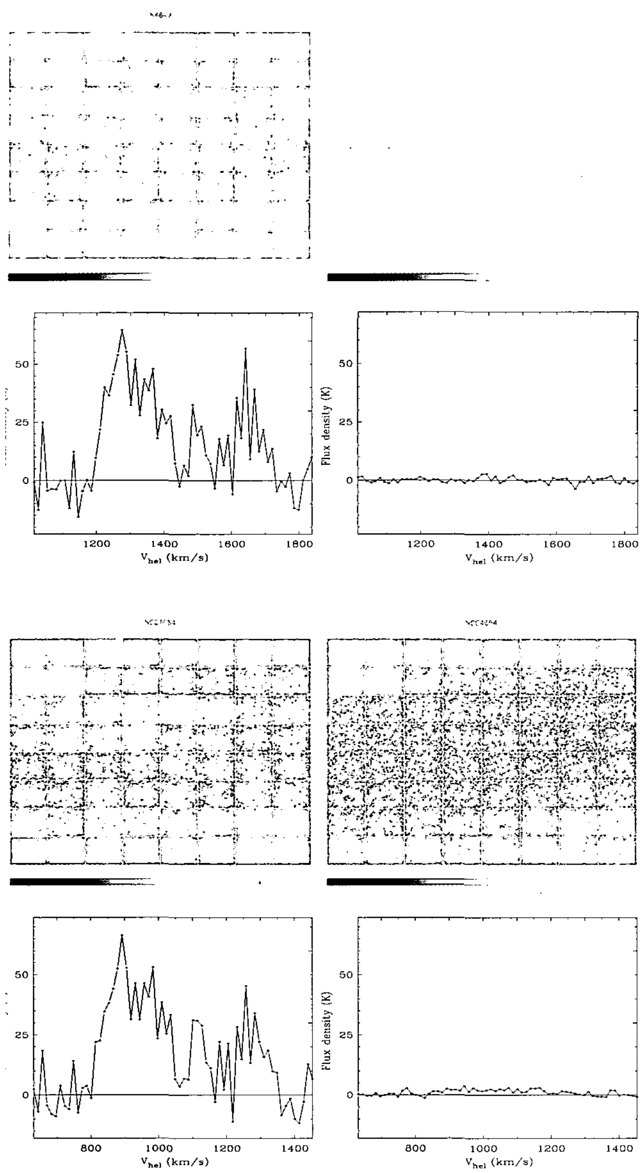

Fig. 2. continued.— Channel maps and global profiles of group I galaxies, NGC 4647 (top) & NGC 4654 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

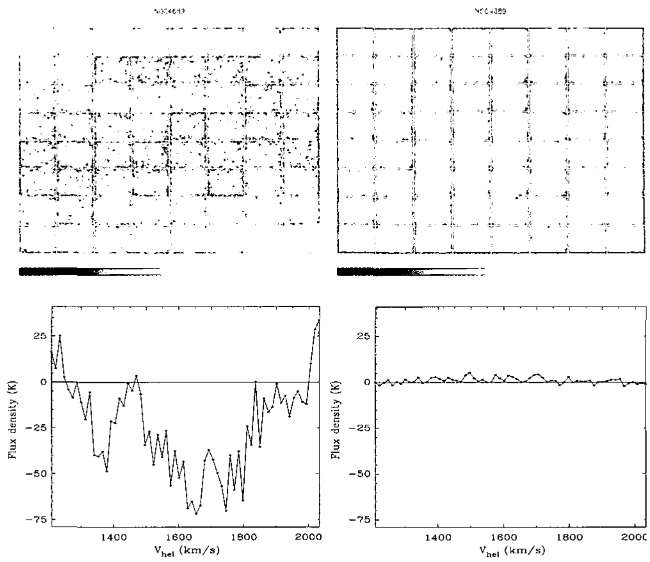

Fig. 2. continued.— Channel maps and global profiles of group I galaxy, NGC 4689. The left are gotten from using the classical OFFs references and the right are from using the SELF references.

tively with respect to the CO strengths. For this, we will examine the datacubes in two different directions. The first is whether the CO quantities are conserved or not. If using the SELF references makes the CO quantities severely change, then the SELF reference cannot be trusted. The second is how many galaxies' baselines are straightened by the SELF references. If the self-referencing method satisfies the two conditions, CO quantities are preserved in the range of uncertainty and the baselines are straightened, then we can say that the self-referencing method is trustworthy.

## (a) CONSERVATION OF CO FLUX

Table 2 presents the total CO flux and its rms of the final results. Though not presented in this table, the datacubes in A1 step have largely puffed out CO intensity in positive or negative directions, and it may be caused by the extremely crooked baseline. There is no difference between strong and no detected CO galaxy, and not only the weak CO but also the strong CO emission is also concealed by the baseline fluctuations. The channel maps and global profiles in section 3 show these results more clearly.

It is interesting to compare the total CO flux and

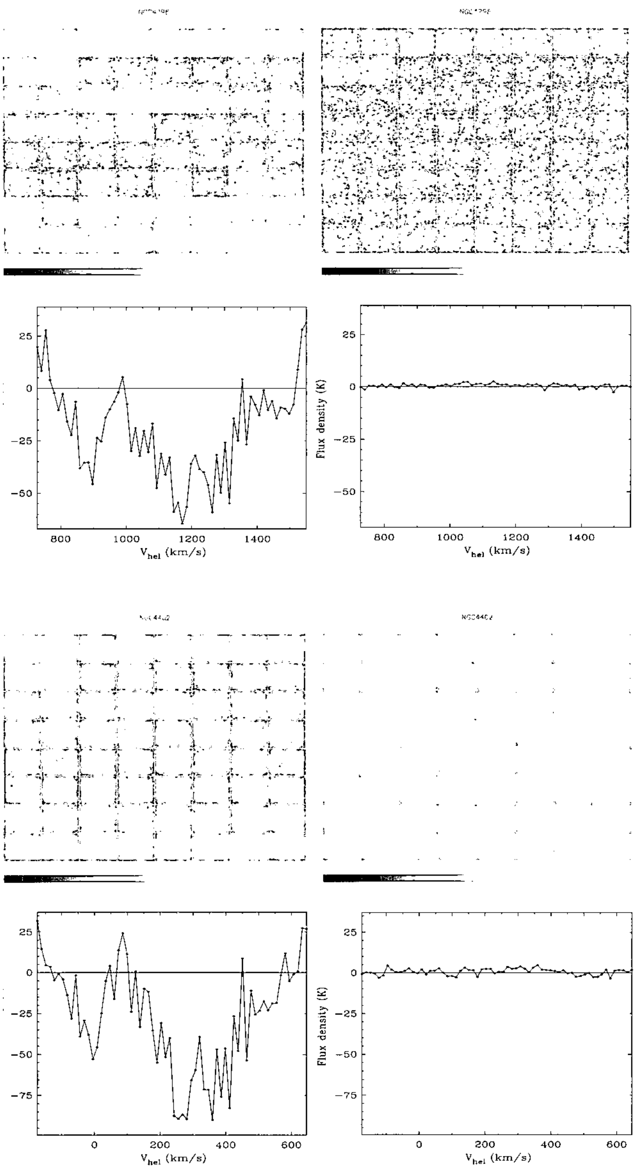


**Fig. 3.**— Channel maps and global profiles of group II galaxies, NGC 4298 (top) & NGC 4402 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

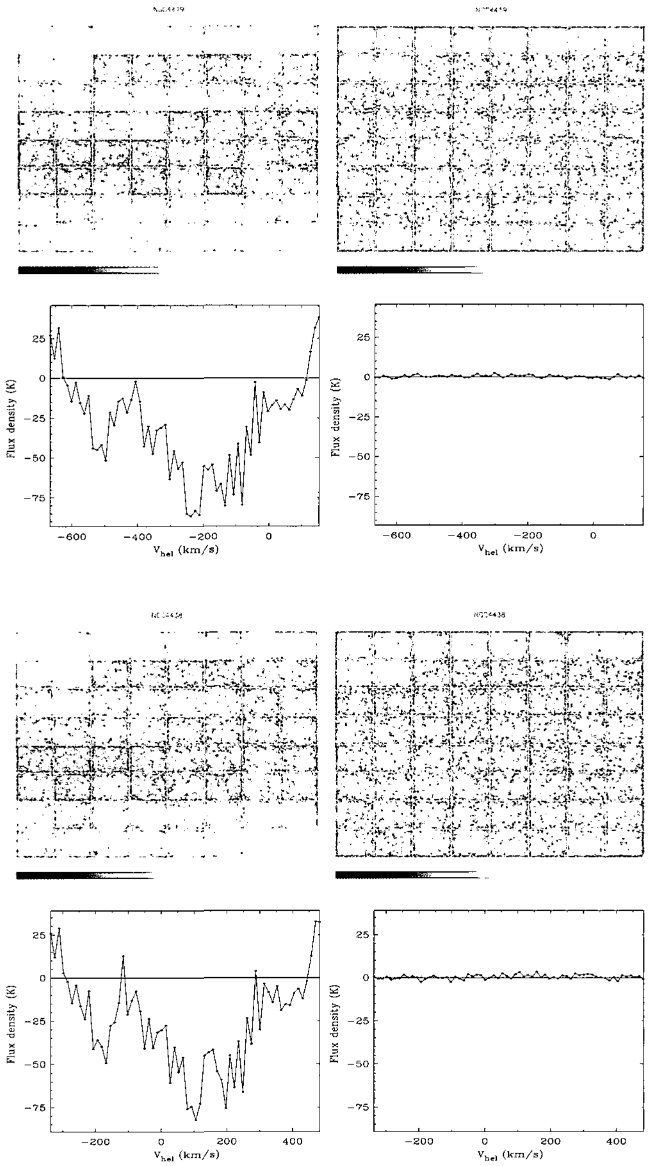


**Fig. 3. continued.**— Channel maps and global profiles of group II galaxies, NGC 4419 (top) & NGC 4438 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

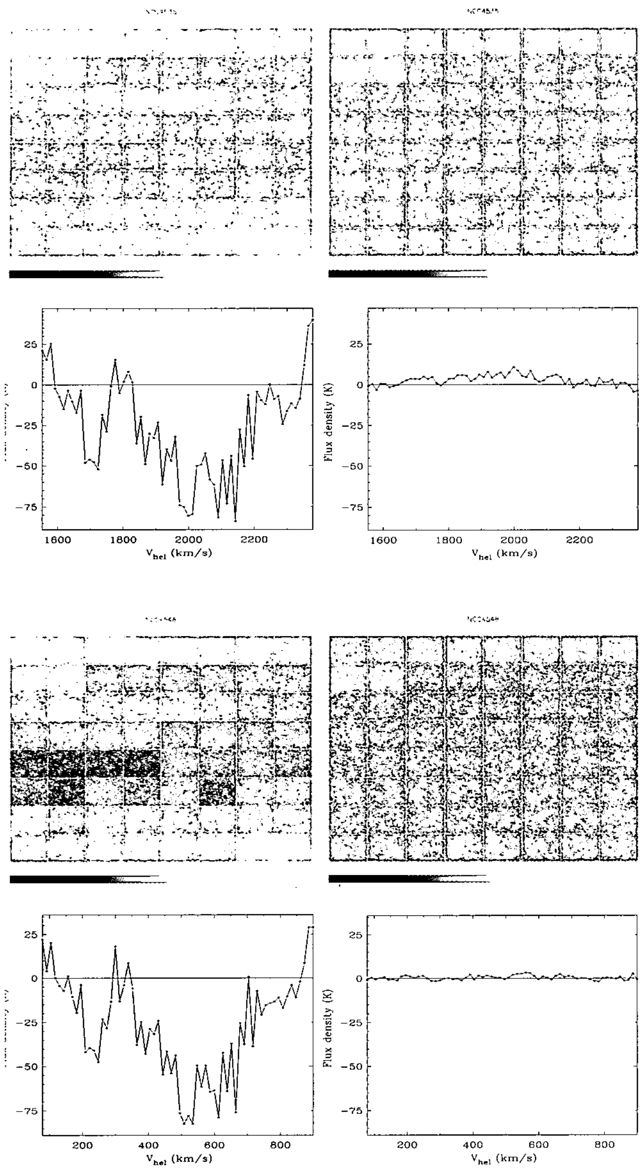


**Fig. 3. continued.**— Channel maps and global profiles of group II galaxies, NGC 4535 (top) & NGC 4548 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

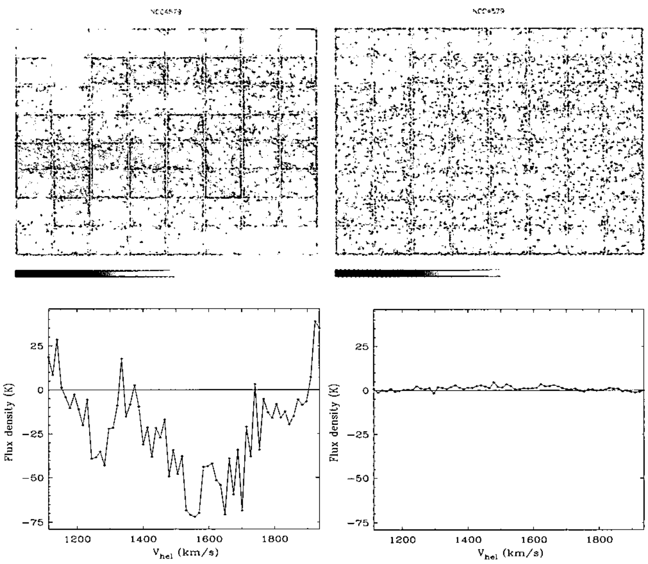


**Fig. 3. continued.**— Channel maps and global profiles of group II galaxy, NGC 4579. The left are gotten from using the classical OFFs references and the right are from using the SELF references.

rms between the phases of A3 and B3. To straighten the baseline of A1, we used median-filtering task in AIPS. And in A3 and B3, we used the *'blot'* task in GIPSY (Groningen Image Processing SYstem) to exclude the noisy components and leave only CO emission. We determine whether some points are emission or not by observing its continuities of the spatial and dynamic distributions accurately. It is very reliable since our data has low signal to noise ratio and there exist many noisy components around the genuine CO components. Passing through the blotting steps, we can experiment the effectiveness and safety of self-referencing method.

The strong CO galaxies of Group I show very good agreement between the two results of A3 and B3. The discrepancies of most galaxies don't exceed 30%, and this is in the range of uncertainties. For weak CO galaxies of Group II, 3 of 7 galaxies, NGC 4438, NGC 4535, and NGC 4548, have larger total CO flux. Figure 5 shows the global profiles of these three galaxies. The left global profiles are those in phase A3 which used the classical OFFs reference and median filtering task in AIPS and the right are in phase B3 which used the SELF references and no median filtering works. From

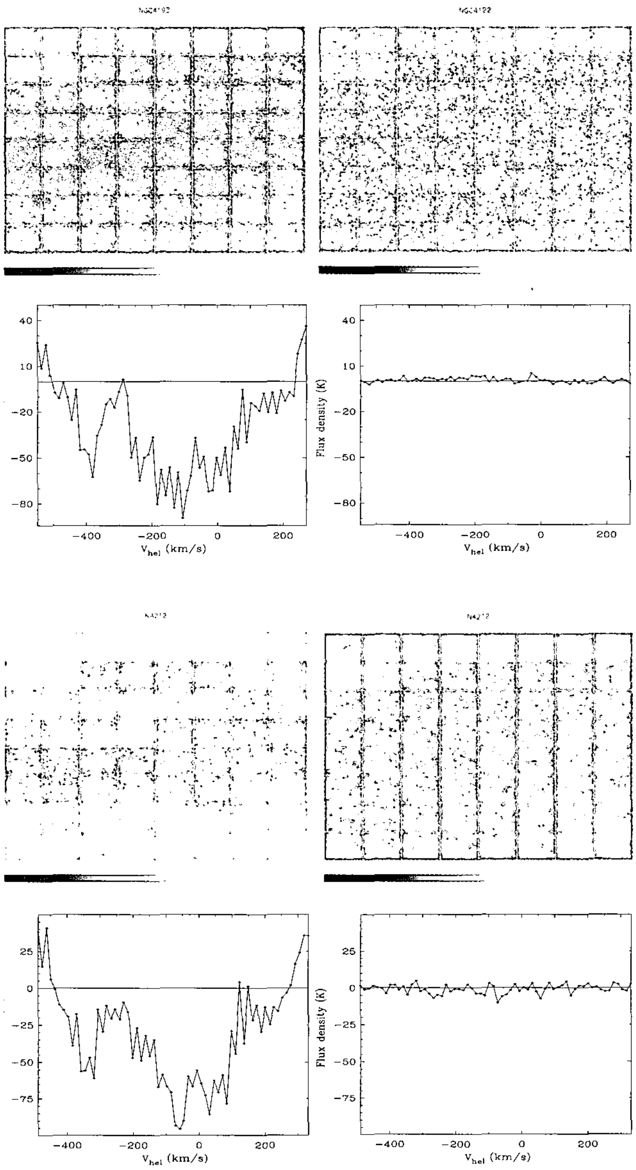


**Fig. 4.**— Channel maps and global profiles of group III galaxies, NGC 4192 (top) & NGC 4212 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

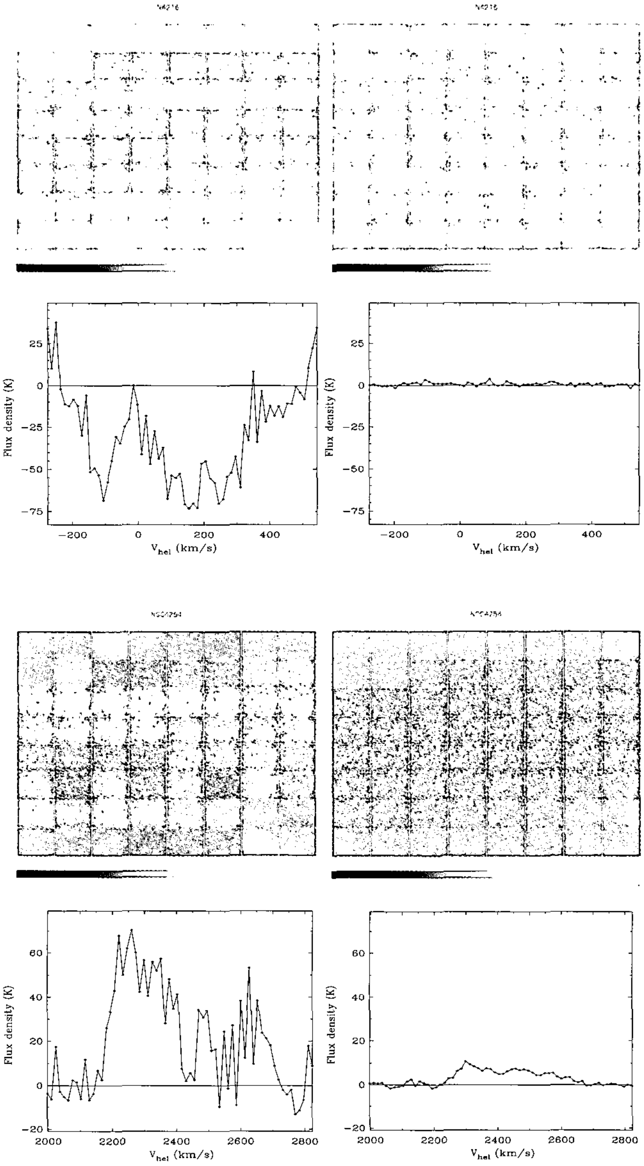


**Fig. 4. continued**— Channel maps and global profiles of group III galaxies, NGC 4216 (top) & NGC 4293 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

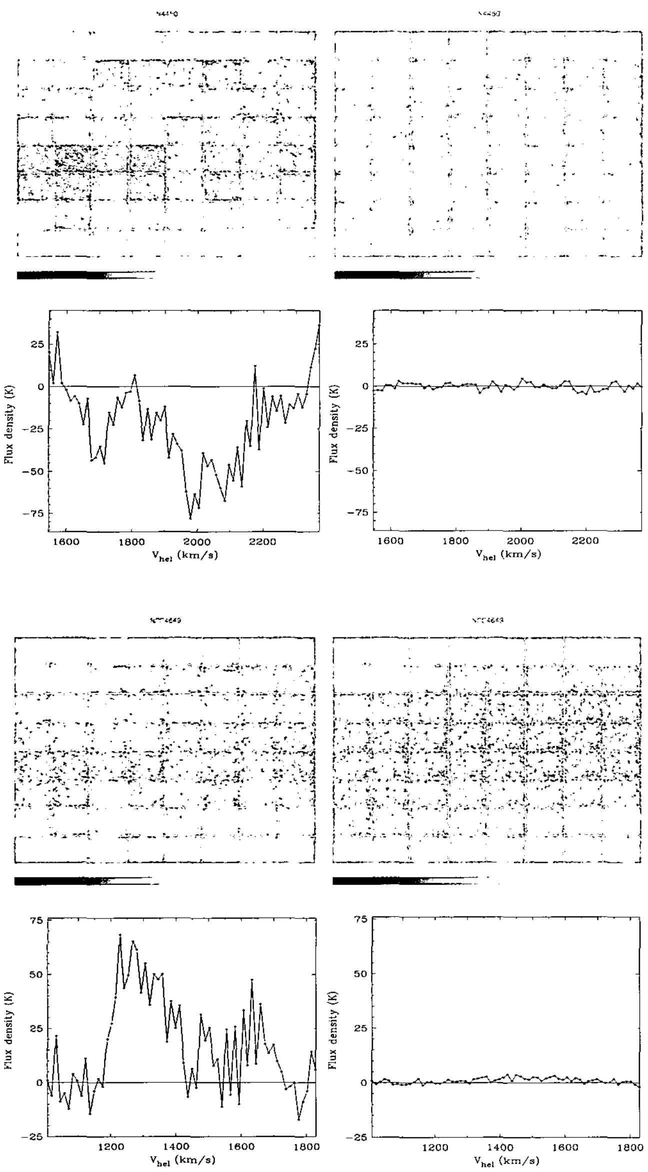


**Fig. 4. continued.**— Channel maps and global profiles of group III galaxies, NGC 4450 (top) & NGC 4649 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

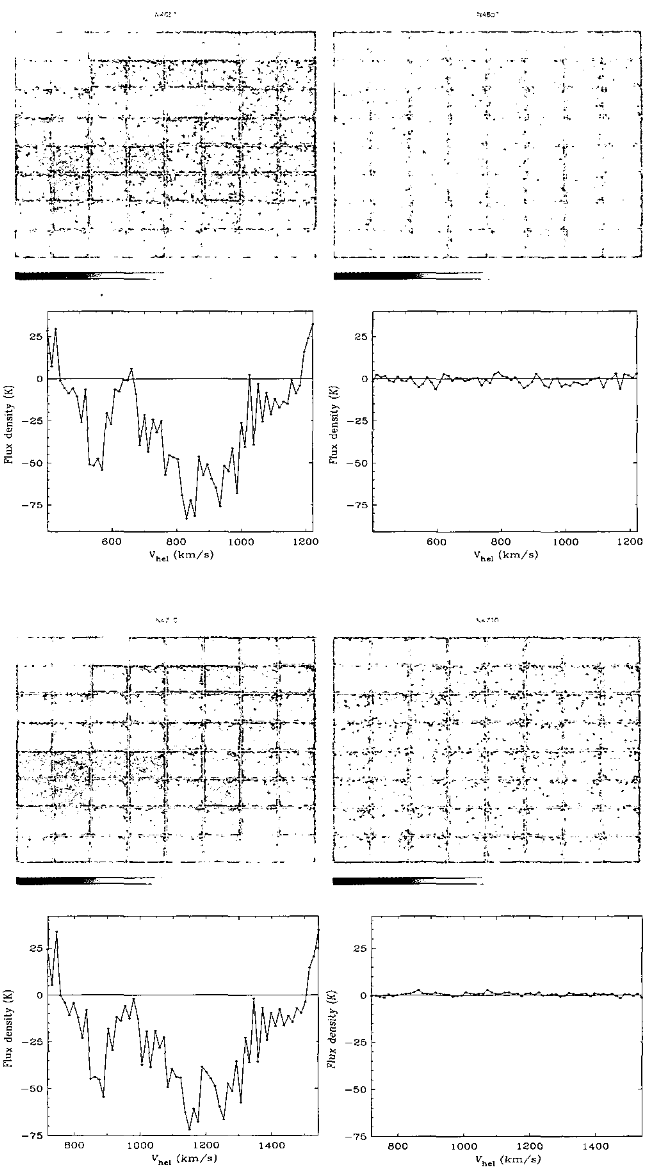


**Fig. 4. continued.**— Channel maps and global profiles of group III galaxies, NGC 4651 (top) & NGC 4710 (bottom). The left are gotten from using the classical OFFs references and the right are from using the SELF references.

TABLE 3
OBSERVING PARAMETERS FOR EXPECTED RMS

| Galaxy | $\Delta\nu$ (MHz) | $T_{sys}$ (K) | $\Delta t$ (hour) | $\sigma_{exp}$[a] (mK) |
|---|---|---|---|---|
| N4192 | 5 | 600 | 3.2 | 4.5 |
| N4212 | 5 | 500 | 2.1 | 4.7 |
| N4216 | 5 | 500 | 4.4 | 3.2 |
| N4254 | 5 | 400 | 3.2 | 3.0 |
| N4293 | 5 | 350 | 1.6 | 3.8 |
| N4298 | 5 | 400 | 2.6 | 3.3 |
| N4302 | 5 | 400 | 4.5 | 2.5 |
| N4303 | 5 | 450 | 2.5 | 3.8 |
| N4321 | 5 | 450 | 2.5 | 3.8 |
| N4402 | 5 | 400 | 2.6 | 3.3 |
| N4419 | 5 | 500 | 3.3 | 3.7 |
| N4438 | 5 | 500 | 2.4 | 4.3 |
| N4450 | 5 | 400 | 2.3 | 3.6 |
| N4501 | 5 | 350 | 2.6 | 2.9 |
| N4527 | 5 | 400 | 2.8 | 3.2 |
| N4535 | 5 | 550 | 3.0 | 4.3 |
| N4548 | 5 | 450 | 2.6 | 3.7 |
| N4567 | 5 | 450 | 2.4 | 3.9 |
| N4569 | 5 | 550 | 3.2 | 4.1 |
| N4579 | 5 | 400 | 2.4 | 3.5 |
| N4647 | 5 | 400 | 3.4 | 2.9 |
| N4649 | 5 | 450 | 2.2 | 4.1 |
| N4651 | 5 | 400 | 2.1 | 3.7 |
| N4654 | 5 | 400 | 3.3 | 3.0 |
| N4689 | 5 | 450 | 2.3 | 4.0 |
| N4710 | 5 | 400 | 4.0 | 2.7 |

[a] expected rms level derived by

$$\sigma_{exp} = \frac{c \times T_{sys}}{\sqrt{\Delta\nu\Delta t}} \quad (1)$$

where c is a factor (we adopted 1.8), $T_{sys}$ is the system temperature in K, $\Delta\nu$ is the frequency resolution in Hz, and $\Delta t$ is the observing time in second.
$\sigma_{rms}$ is a good criterion to decide whether the rms of a datacube is reasonable or not.

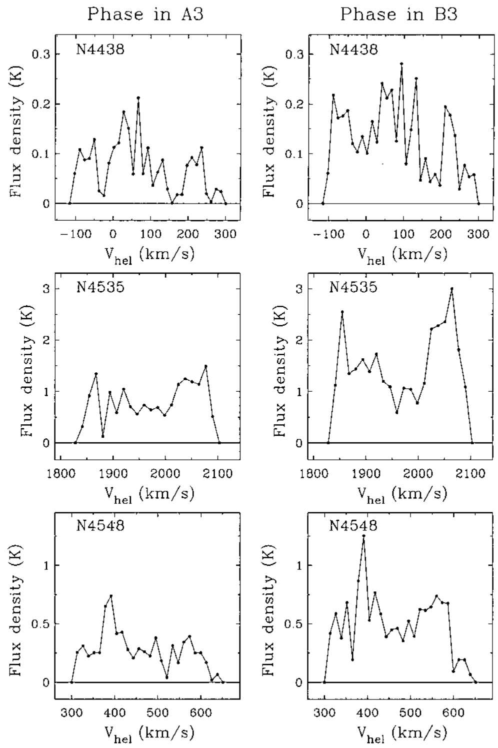


**Fig. 5.**— Top left is NGC 4438 in phase A3 & right in phase B3, Middle left NGC 4535 in phase A3 & right in phase B3, and Bottom left NGC 4548 in phase A3 & right in phase B3. The phase A3 is done by OFFs references and the AIPS median filtering, and the phase B3 is done by SELF references.

the global profiles, we can see that CO emission in each channel becomes larger when using SELF reference. The median filtering task in AIPS makes the data smoother and it is very effective to remove the noise components and straighten the crooked baseline. However it can also have a risk of crushing and lessen the genuine emissions. For the Group III galaxies, the baselines are straightened by using the SELF reference. At first, we expected that self-referencing method makes expose the CO emission which doesn't appear when using the OFFs references. However, there are no Group III galaxies which show CO emission in phase B1 or B3.

We see the discrepancies between $S_{CO}^{OFFs}$ and $S_{CO}^{SELF}$ in %. For some galaxies, the results using SELF references have larger total CO flux than that using OFFs references. This means that the CO total flux can be affected by references, and if the SELF references offer more stable references, then the results using OFFs references can be underestimated. In our paper on the Virgo Cluster (Chung et al. in preparation), we will compare the OTF observation results with the step-and-integrate observation results, and study the effectiveness of OTF observation. To do this, the referencing method becomes more important to provide accurate CO flux. In the following section, we will check which reference method is more stable and effective.

### (b) CHANGES OF BASELINE ORDER

We have checked that the CO flux derived by using the self-referencing method is the same as those by using the OFFs references in the range of uncertainties. Now, we will look into the variations of the baseline order of datacubes when each reference is applied.

In phase A1 and B1 of Figure 1, we applied three baseline order 0,1, and 2 to subtract the baseline with the OFFs and SELF references, and make 3 datacubes for each reference method. We will choose the optimal baseline order among the three, 0, 1, and 2. Since our attention is to stretch the crooked baseline, we determine the optimal baseline order which minimizes the rms. However, because rms which is smaller than the expected rms has no physical meaning, we consider not only the minimum rms but also the expected rms. Considering these two factors, we determine the optimal baseline order.

Table 3 shows the observing parameters. We calcu-

TABLE 4
$\sigma$ VARIATIONS ACCORDING TO THE BASELINE ORDER

| Galaxy | $\sigma_{exp}$ (mK) | Datacube using OFFs $\sigma$ ($0^a$) (mK) | $\sigma$ ($1^a$) (mK) | $\sigma$ ($2^a$) (mK) | B.O.[b] | Datacube using SELF $\sigma$ ($0^a$) (mK) | $\sigma$ ($1^a$) (mK) | $\sigma$ ($2^a$) (mK) | B.O.[b] |
|---|---|---|---|---|---|---|---|---|---|
| Group I | | | | | | | | | |
| N4254 | 3.2 | 26.3 | 10.5 | 7.0 | $\geq 2$ | 1.1 | 0.9 | 0.9 | 0 |
| N4302 | 4.5 | 39.9 | 12.3 | 6.1 | $\geq 2$ | 0.7 | 0.4 | 0.4 | 0 |
| N4303 | 2.5 | 31.9 | 10.1 | 5.4 | $\geq 2$ | 1.2 | 1.2 | 1.1 | 0 |
| N4321 | 2.5 | 33.0 | 10.8 | 7.0 | $\geq 2$ | 1.6 | 1.2 | 1.2 | 0 |
| N4501 | 2.6 | 28.4 | 8.8 | 5.1 | $\geq 2$ | 1.0 | 1.0 | 1.0 | 0 |
| N4527 | 2.8 | 30.5 | 10.3 | 5.6 | $\geq 2$ | 1.0 | 0.9 | 0.9 | 0 |
| N4567 | 2.4 | 28.1 | 11.3 | 6.6 | $\geq 2$ | 0.8 | 0.8 | 0.8 | 0 |
| N4569 | 3.2 | 48.1 | 13.8 | 6.6 | $\geq 2$ | 0.8 | 0.8 | 0.9 | 0 |
| N4647 | 3.4 | 36.8 | 11.7 | 6.1 | $\geq 2$ | 6.7 | 0.9 | 0.8 | 1 |
| N4654 | 3.3 | 34.5 | 10.4 | 5.9 | $\geq 2$ | 0.9 | 0.8 | 0.7 | 0 |
| N4689 | 4.0 | 34.9 | 10.0 | 6.0 | $\geq 2$ | 1.1 | 0.9 | 0.8 | 0 |
| Group II | | | | | | | | | |
| N4298 | 2.6 | 35.4 | 10.2 | 6.0 | $\geq 2$ | 1.0 | 0.6 | 0.6 | 0 |
| N4402 | 2.6 | 56.7 | 11.2 | 7.1 | $\geq 2$ | 1.8 | 1.5 | 1.4 | 0 |
| N4419 | 3.3 | 43.3 | 12.3 | 5.6 | $\geq 2$ | 1.1 | 0.6 | 0.6 | 0 |
| N4438 | 2.4 | 44.7 | 11.5 | 6.1 | $\geq 2$ | 1.1 | 0.8 | 0.7 | 0 |
| N4535 | 3.0 | 31.6 | 11.8 | 11.8 | 1 | 3.4 | 1.5 | 1.2 | 1 |
| N4548 | 2.6 | 46.1 | 10.0 | 4.9 | $\geq 2$ | 1.5 | 1.2 | 1.1 | 0 |
| N4579 | 2.4 | 31.7 | 11.2 | 6.1 | $\geq 2$ | 1.0 | 0.9 | 0.9 | 0 |
| Group III | | | | | | | | | |
| N4192 | 4.5 | 49.9 | 11.3 | 11.3 | 1 | 1.2 | 1.2 | 1.1 | 0 |
| N4212 | 4.7 | 58.1 | 14.8 | 6.5 | $\geq 2$ | 2.5 | 2.3 | 2.2 | 0 |
| N4216 | 4.4 | 52.7 | 12.6 | 6.9 | $\geq 2$ | 1.0 | 0.7 | 0.7 | 0 |
| N4293 | 1.6 | 40.1 | 10.6 | 5.3 | $\geq 2$ | 0.8 | 0.7 | 0.7 | 0 |
| N4450 | 2.3 | 32.6 | 11.2 | 6.2 | $\geq 2$ | 3.0 | 2.4 | 2.4 | 1 |
| N4649 | 2.2 | 31.7 | 11.1 | 6.2 | $\geq 2$ | 0.9 | 0.7 | 0.8 | 0 |
| N4651 | 2.1 | 45.0 | 12.0 | 5.7 | $\geq 2$ | 2.3 | 1.9 | 1.7 | 0 |
| N4710 | 2.7 | 37.4 | 11.4 | 6.1 | $\geq 2$ | 0.8 | 0.5 | 0.4 | 0 |

[a]baseline order applied in the revised-OTFTOOL
[b]optimal baseline order which makes $\sigma$ of the global profile be minimized
$\sigma$ in this table is the standard deviations of the global profile in mK unit. We calculated $\sigma$ of channel number $1 \sim 10$ and $55 \sim 64$ among the total 64 channels for all galaxies. They contain no CO emission and thus are true baseline channels.

lated the expected rms for each galaxy by the method of single beam observations. For the expected rms of multi-beam observations, we should study deep into that subject. We leave that to the next paper and present the expected rms derived here as a criterion in this paper. Table 4 represents the standard deviations of each galaxy's global profile according to the baseline order. At first, we can see that the datacubes using SELF references have much smaller standard deviations than those of the datacubes using OFFs references for every baseline order. And when using the OFFs references, the rms of datacubes are much larger than expected rms, even though baselines are subtracted with baseline order 2. However, when using the SELF references, most datacubes have satisfiable rms values with baseline order 0 and 1.

Fig. 6. shows the transitions of optimal baseline order more clearly. (a), (b), (c), and (d) of Figure 6 show the distributions of the optimal baseline order for total galaxies, group I, II, and III, respectively. The *"OFFs"* in each box means that OFFs references were used in OTFTOOL and the *"SELF"* SELF references. The results are very impressive. The datacubes using SELF references has lower optimal baseline order, and this is good evidence for the SELF references' effectiveness of stretching the crooked baseline.

Looking at the results along the groups, we can see the same results. The optimal baseline order of most galaxies changes from 2 to 0 when using the self-referencing method. We can conclude that the SELF references are effective to straighten the baseline for all of strength of emission galaxies.

From the rms variations along the baseline order, we can confirm that the self-referencing method offers more safe and stable observational results. By using the results from SELF references, we expect that we can find more interesting results about the CO properties in Virgo cluster galaxies.

## V. SUMMARY & CONCLUSION

As mentioned in Paper I, we applied the self-referencing method to 27 Virgo cluster spiral galaxies and compared them with the results using the conventional OFFs references. We reached the following conclusions :

1. The self-referencing method solved the crooked baseline problem.
2. Compared with the median filtering task in AIPS, to use self-referencing method is more effective and safe not only to straighten the baseline but also to conserve the emissions.
3. For the strong CO emission galaxies, the self-referencing method shows no difference from the conventional OFFs references and median filtering in AIPS in the range of uncertainties.

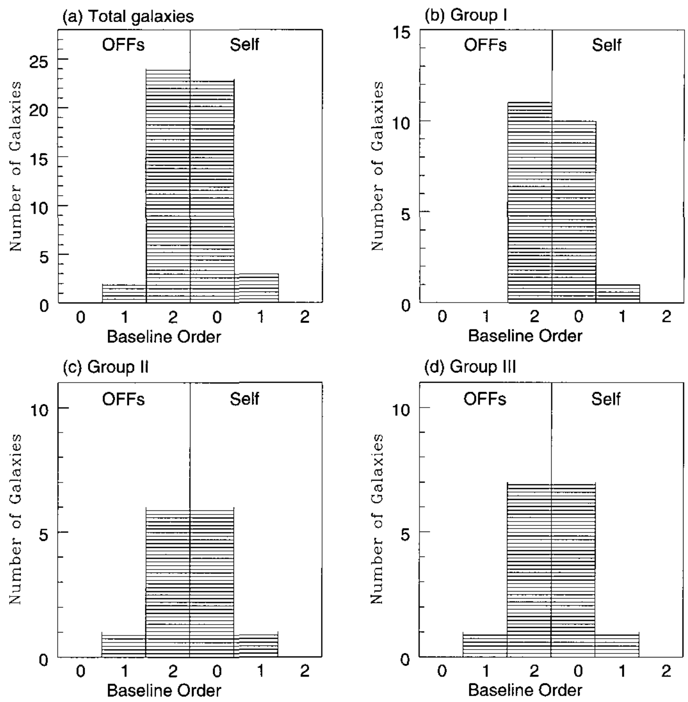


**Fig. 6.—** distributions of galaxies' optimal baseline order which minimizes the standard deviations of global profiles. (a) is for total galaxies, (b) the group I galaxies, (c) the group II galaxies, and (d) the group III galaxies, and OFFs and SELF denote the used references in the revised-OTFTOOL. Notice that when using the SELF references, the optimal baseline orders shift from higher to lower order.

4. Considering the risk of the crushing and lessen the genuine emission by AIPS median-filtering, the self-referencing method is expected to be very useful for the observations of galaxies of weak CO emissions.
5. In our data sample, the self-referencing method cannot recover and/or make appear the emission which is too weak to be shown in the previous data gotten from using conventional OFFs references.

With these conclusions, we used the self-referencing method to reduce the data of the Virgo cluster spirals(Virgo I paper : Chung et al. in preparation). Introducing the conclusions of Virgo I paper, we obtained CO atlas for 18 galaxies among the 27 observed galaxies. By comparing with the position-switching observations (Young et al. 1995), we found that the CO properties derived by the best fitting model done by Young et al. have a tendency of being overestimated to OTF mapping results. When using SELF references, the discrepancies are slightly decreased.

The self-referencing method has advantages of offering more proper references to OTF observation and reducing the observation and data reduction time. It can be easily applied to the established facilities like SRAO and FCRAO. A project already started to apply the self-referencing method to SRAO. In this project, we will test its effectiveness of saving the observation time and applicability of the SELF reference to the observations of not only external galaxies but also complex molecular clouds. After going through these examinations, the self-referencing method can be used at FCRAO. Besides this, it can be also applied to LMT as one of the observation mode, and we expect that this will give improvements in many aspects such as saving of observation time and giving higher data quality.

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