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ALGORITHM OF REVISED-OTFTOOL

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ABSTRACT

We revised the OTFTOOL which was developed in Five College Radio Astronomy Observatory (FCRAO) for the On-The-Fly (OTF) observation. Besides the improvement of data resampling function of conventional OTFTOOL, we added a new SELF referencing mode and data pre-reduction function. Since OTF observation data have a large redundancy, we can choose and use only good quality samples excluding bad samples. Sorting out the bad samples is based on the floating level, rms level, antenna trajectory, elevation, T_{sys}, and number of samples. And, spikes are also removed. Referencing method can be chosen between CLASSICAL mode in which the references are taken from the OFFs observation and ELLIPSOIDAL mode in which the references are taken from the inner source free region (this is named as SELF reference). Baseline is subtracted with the source free channel windows and the baseline order chosen by the user. Passing through these procedures, the raw OTF data will be an FITS datacube. The revised-OTFTOOL maximizes the advantages of OTF observation by sorting out the bad samples in the earliest stage. And the new self-referencing method, the ELLIPSOIDAL mode, is very powerful to reduce the data. Moreover since it is possible to see the datacube at once without moving them into other data reduction programs, it is very useful and convenient to check whether the data resampling works well or not. We expect that the revised-OTFTOOL can be applied to the facilities of the OTF observation like SRAO, NRAO, and FCRAO.

Keywords: image processing, observation and data reduction techniques, OTF observation

1. INTRODUCTION

On-The-Fly (OTF) observation is an efficient observing technique to generate images over large fields. In OTF mode, telescope moves smoothly and rapidly across a field storing data and antenna position information continuously. Since it has small integration time in a point, it has two main advantages. The first is the reduction of telescope overhead. And the second is that the properties of

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the atmosphere and the system, including antenna pointing and calibration, change less in comparison to a conventional step-and-integrate mapping method (Mangum 1999). With these merits, OTF observation gives a map having the same rms with that of position-switching data in relatively short observing time.

OTF observation produces enormous data, and needs a tool to examine and manage these data effectively. Unlike the position-switching observation which generates only one spectrum during $1 \sim 2$ hours, OTF observation generates a spectrum every $0.1 \sim 1$ second and several hundreds of spectra are cumulated for an observing object. Before analyzing the observational data and yielding some scientific results, it is indispensable to inspect and manipulate the raw OTF data and to make a datacube.

Arizona Radio Observatory offers UniPops which displays individual spectra and inspects them (Mangum 1999). However, the user must use AIPS (Astronomical Image Processing System[1]) for full data analysis. Five College Radio Astronomy Observatory (FCRAO) has developed the OTFTOOL[2] which inspects, edits, and regrids the raw OTF data (Heyer, M. H., Narayanan, G., & Brewer, M. 2001). It is a graphical user interface based on the X window, hence the user can access it more easily. The user can launch the program by simply typing otftool at the shell prompt. It is composed with three pages, i.e., **Data File Selection**, **Data Assessment**, and **Regrid Data**, which set up the environment to gather, evaluate and edit, and regrid the data, respectively.

The FCRAO OTFTOOL is suitable to process the OTF data in general. However, if some data pre-reduction and pre-analysis functions are added on it, it would become more useful and powerful. For that reason, we improved the FCRAO OTFTOOL and developed the revised-OTFTOOL. In this paper, the original OTFTOOL is called FCRAO OTFTOOL and newly developed OTFTOOL is called revised-OTFTOOL. This paper introduces the revised-OTFTOOL. We show the outline of the revised-OTFTOOL in section 2 and describe the revised-OTFTOOL algorithm in section 3. Summary and discussion are in section 4, and some inspections of the revised-OTFTOOL are presented in Appendix.

2. OUTLINE OF REVISED-OTFTOOL

To show the improvements of revised-OTFTOOL more clearly, the FCRAO OTFTOOL has to be explained before everything else. The FCRAO OTFTOOL is composed with three main steps, **Data File Selection**, **Data Assessment**, and **Regrid Data**. In the first **Data File Selection** step, the user selects the raw OTF data with the source number, starting scan number, ending scan number, IF number and UT date interval. After selecting the raw OTF data file, one needs to create an input file list file or append or overwrite an existing file. And then, the user goes to the next **Data Assessment** step. The user needs to set the three parameters; i.e., reference weighting mode, assessment mode, and baseline parameters, to inspect the data quality. Besides this, the user should also determine the baseline channel windows and the baseline order to calculate the rms. With the parameters set by the user, the FCRAO OTFTOOL does the regrid work and makes a datacube in the **Regrid Data** step.

The main frame of the revised-OTFTOOL is same with that of FCRAO OTFTOOL. Figure 1 is the function tree diagram of the revised-OTFTOOL. The three **Data File Selection**, **Data Assessment**, and **Regrid Data** steps compose the main structure of the revised-OTFTOOL like FCRAO OTFTOOL. However, the revised-OTFTOOL has additional functions for data pre-reduction and pre-analysis in the second step.

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[1] http://www.aoc.nrao.edu/aips/

[2] http://donald.astro.umass.edu/~fcrao/library/manuals/otfmanual.html

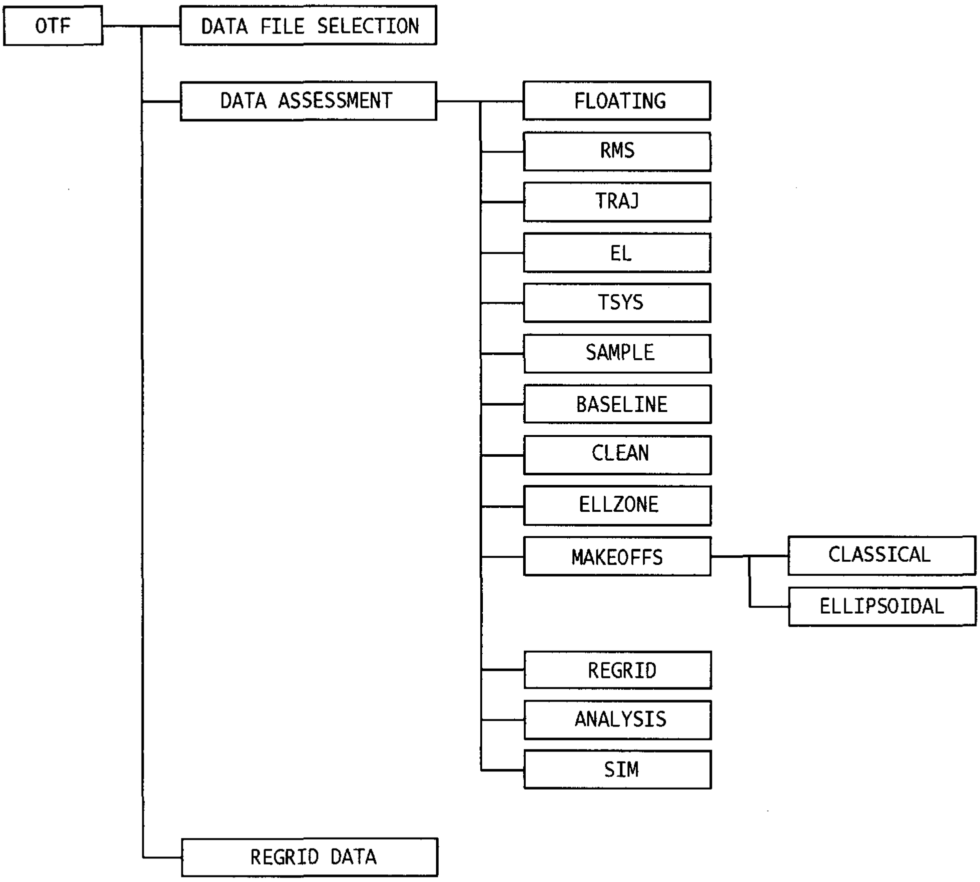
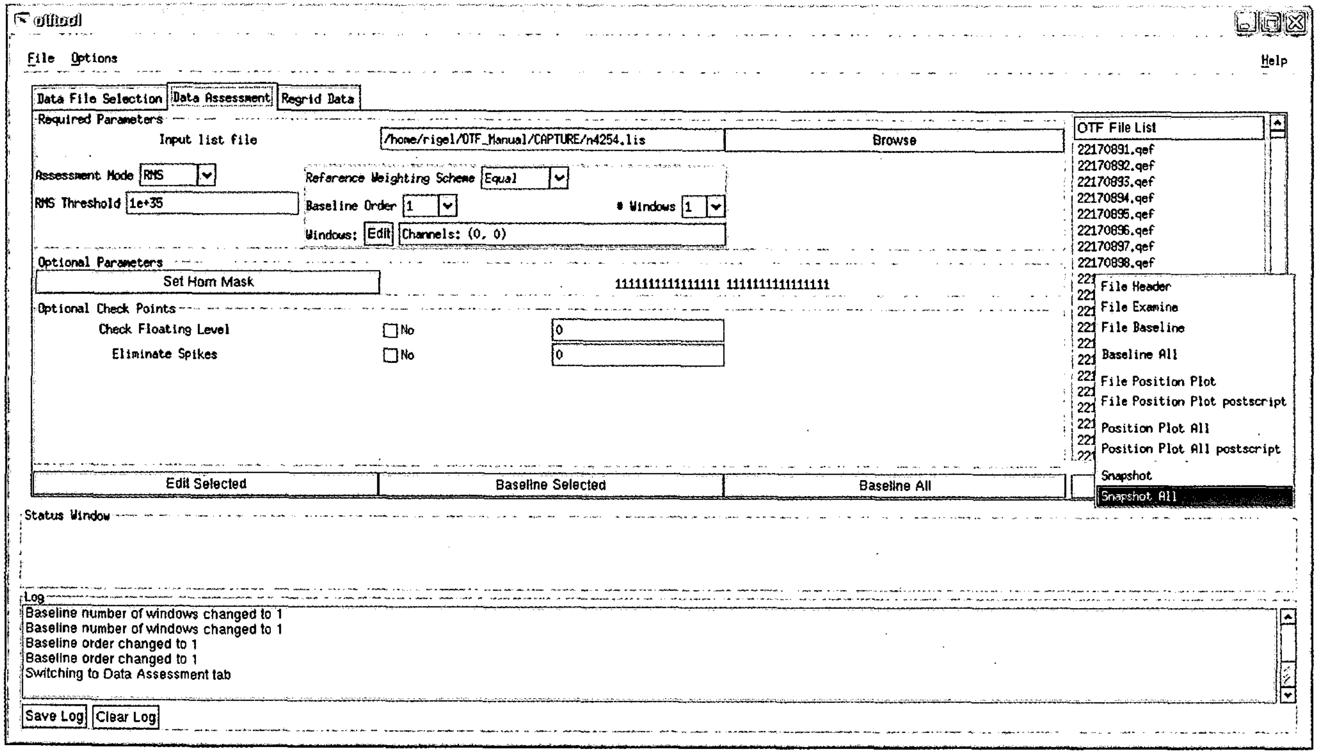


Figure 1. Function tree diagram of the revised-OTFTOOL. The main structure is same with that of original FCRAO OTFTOOL, which is composed of **Data File Selection**, **Data Assessment**, and **Regrid Data**. The additional functions are put on the second **Data Assessment** step.

In this section, we introduce the outline of the revised-OTFTOOL. The words used in the menu of revised-OTFTOOL are represented in bold strokes through this paper.

2.1. Data File Selection

The **Data File Selection** environment facilitates the consolidation of raw OTF files to be processed and creates the **Input List File** required by the **Data Assessment** and **Rigrid Data** environments. With the criteria of the **Source Name**, **Starting Scan Number**, **Ending Scan Number**, **IF Number**, and **UT Date Interval**, the data files are sorted and filtered. The user can see the filtered raw data list and all raw data by just clicking the **Filtered Raw Data List** and **All Raw Data** buttons, respectively. The left and right boxes show the file names of filtered raw and all raw data, respectively. Clicking the **All** button, the user can select all of the files. The user can add or remove the files in the filtered raw data list by choosing the file and clicking the **left arrow** button or **right arrow** button. To remove all files from the list, just click the **None** button. Finally, enter the name of the



Input list file /home/rigel/OTF_Manual/CAPTURE/n4254.lis

Assessment Mode RMS

RMS Threshold 1e+35

Reference Weighting Scheme Equal

Baseline Order 1

Windows 1

Windows: Edit Channels: (0, 0)

1111111111111111 1111111111111111

Check Floating Level ☐ No 0

Eliminate Spikes ☐ No 0

22170891.qef
22170892.qef
22170893.qef
22170894.qef
22170895.qef
22170896.qef
22170897.qef
22170898.qef

```
Baseline number of windows changed to 1
Baseline number of windows changed to 1
Baseline order changed to 1
Baseline order changed to 1
Switching to Data Assessment tab
```

Figure 2. The revised-OTFTOOL. Users can launch this window by just typing “otf” at the shell prompt. On the top, there are three tabs of **Data File Selection**, **Data Assessment**, and **Regrid Data**, and this is the **Data Assessment** page. If the user clicks the right button of mouse on the file name and choose the **Snapshot All**, then the revised-OTFTOOL launches the **SnapShot** page.

Input File List and click on the **Save List File** button. When you subsequently enter the next **Data Assessment** or **Regrid Data** environments, the **Input File List** value will be already filled with this file name.

2.2. Data Assessment

The **Data Assessment** environment contains some parameters to be set by the user to inspect the data quality, such as **Assessment Mode**, **RMS Threshold**, **Baseline Weighting Scheme**, **Baseline Order**, and **Baseline Windows**. The user can choose the yes or no of using the functions of **Check Floating Level** and **Eliminate Spikes**. These parameters are used in the next **Regrid Data** step.

The names of the raw OTF files are read into the program and displayed on the right side of the **Data Assessment** window. Right click after left click on the file name shows the **File Header**, **File Examine**, **File Baseline**, **Baseline All**, **File Position Plot**, **File Position Plot postscript**, **Position Plot All**, **Position Plot All postscript**, **Snapshot**, and **Snapshot All**, and the user can check the results by left clicking on each command (see Figure 2).

If the user wants to do data pre-reduction and check the results as soon as possible, the user can do it by clicking the **Snapshot All** command referred in the previous paragraph. This is the additional functions of revised-OTFTOOL, and we strongly recommend the user to use this.

SNAPSHOT ALL : When the user clicks the **Snapshot All**, the revised-OTFTOOL launch a new window which has 13 tabs on the top ; i.e., **Floating**, **RMS**, **Traj**, **EL**, **TSYS**, **Sample**, **Baseline**, **Clean**, **EllZone**, **MakeOffs**, **Regrid**, **Analysis**, and **Sim**. Each tab set the parameters, and the **Regrid** and **Analysis** tabs do the regrid and analysis works with the parameters input in the previous tabs. Figure 3 shows the **Floating** tab of the **Snapshot** page. Every page in Snapshot is composed of three parts. The top is input parameters for each criterion, the middle part is display of the data properties, and the bottom box displays the progressing job.

Criteria To Sort Out Bad Samples : The revised-OTFTOOL gives 6 criteria to sort out bad samples; i.e., the floating level threshold, rms, trajectory, elevation, system temperature, and number of sample. The user can set the parameters for each criterion up to 5 as shown in Figure 3.

FLOATING : The user can set the floating level threshold in each windows up to 5, and to click the **Distribution** button displays the distribution of samples.

RMS : In the **RMS** tab, the user can set the rms threshold which clips the data according as its rms level.

TRAJ : If the antenna moves irregularly, the user can treat the data as being doubtful.

EL : This Elevation criterion is used when the user wants to use data within specific elevation range.

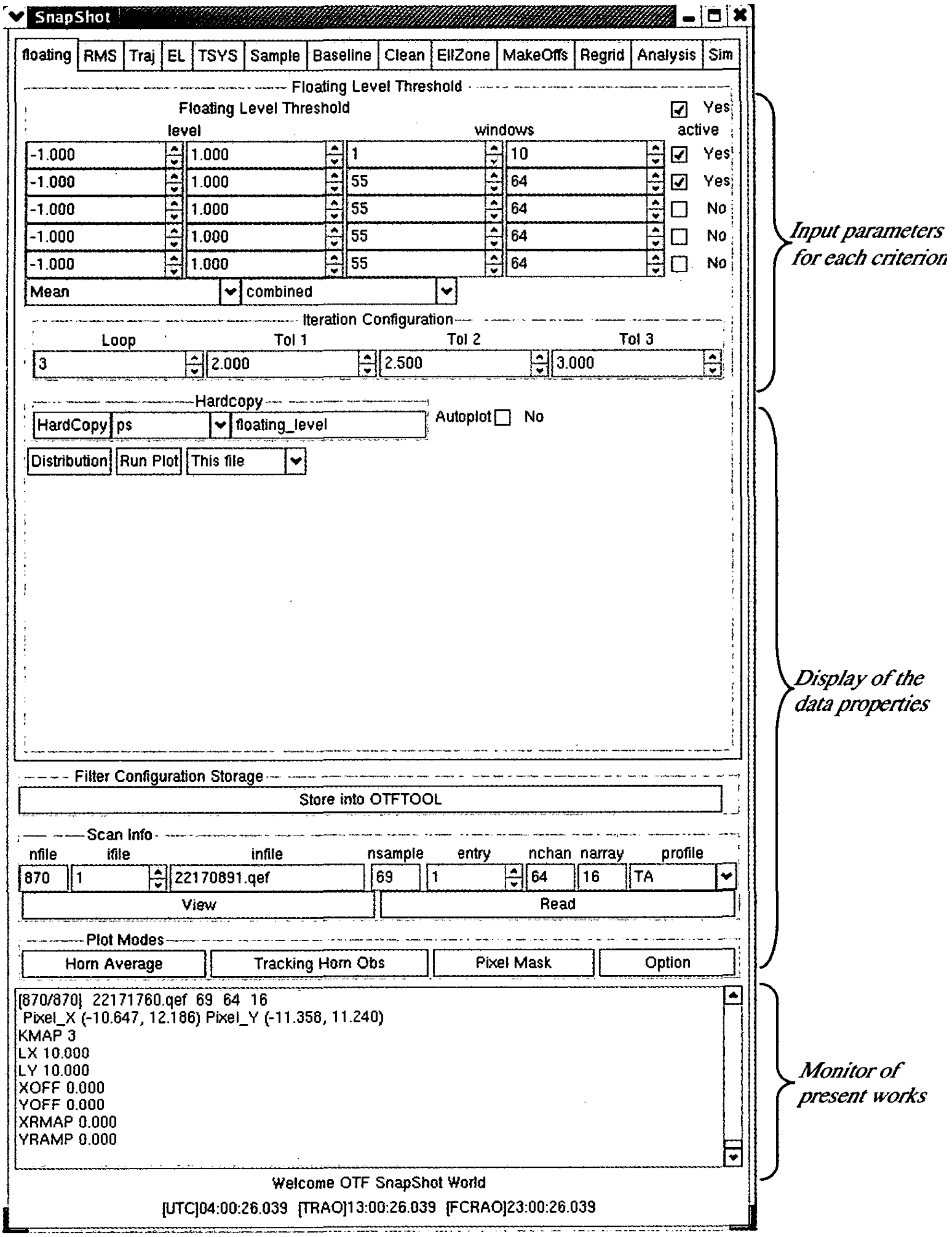
TSYS : System temperature is one of the criteria to sort out the bad sample.

SAMPLE : Number of sample is a criterion for the problem of program operation such as antenna aborting.

BASELINE : The user sets the baseline order between 0 and 2 and the baseline windows. It is recommended to determine the baseline order after checking the baseline shape at the analysis page. And, for the baseline channel windows, it is also safe to check the emission free channel at the analysis page and determine it again.

CLEAN : The user can select the levels to remove the spikes in the **CLEAN** page.

ELLZONE : This tab is related with the reference of the next **MAKEOFFS** tab (Section 3 gives full explanation about the referencing methods). If the user chooses the **ELLIPSOIDAL** (which is called SELF references), one can specify the ellipsoidal zone for observation and the ellipsoidal zone for SELF references. The user can also set the area shape to be ellipsoidal or rectangular, the lengths of semi-major and -minor axis, and the rotation. Figure 4 shows the **ELLZONE** page and display of ellipsoidal zone. Clicking the **Show Ellipsoidal Zone** button shows the chosen observational region and ellipsoidal zone on the window. The yellow circle is the emission contained region, and the blue



Floating Level Threshold ☑ Yes

level		windows		active
-1.000	1.000	1	10	☑ Yes
-1.000	1.000	55	64	☑ Yes
-1.000	1.000	55	64	☐ No
-1.000	1.000	55	64	☐ No
-1.000	1.000	55	64	☐ No

Mean combined

Loop	Tol 1	Tol 2	Tol 3
3	2.000	2.500	3.000

HardCopy ps floating_level Autoplot ☐ No

This file

nfile	ifile	infile	nsample	entry	nchan	narray	profile
870	1	22170891.qef	69	1	64	16	TA

```
[870/870] 22171760.qef 69 64 16
 Pixel_X (-10.647, 12.186) Pixel_Y (-11.358, 11.240)
KMAP 3
LX 10.000
LY 10.000
XOFF 0.000
YOFF 0.000
XRMAP 0.000
YRAMP 0.000
```

Welcome OTF SnapShot World

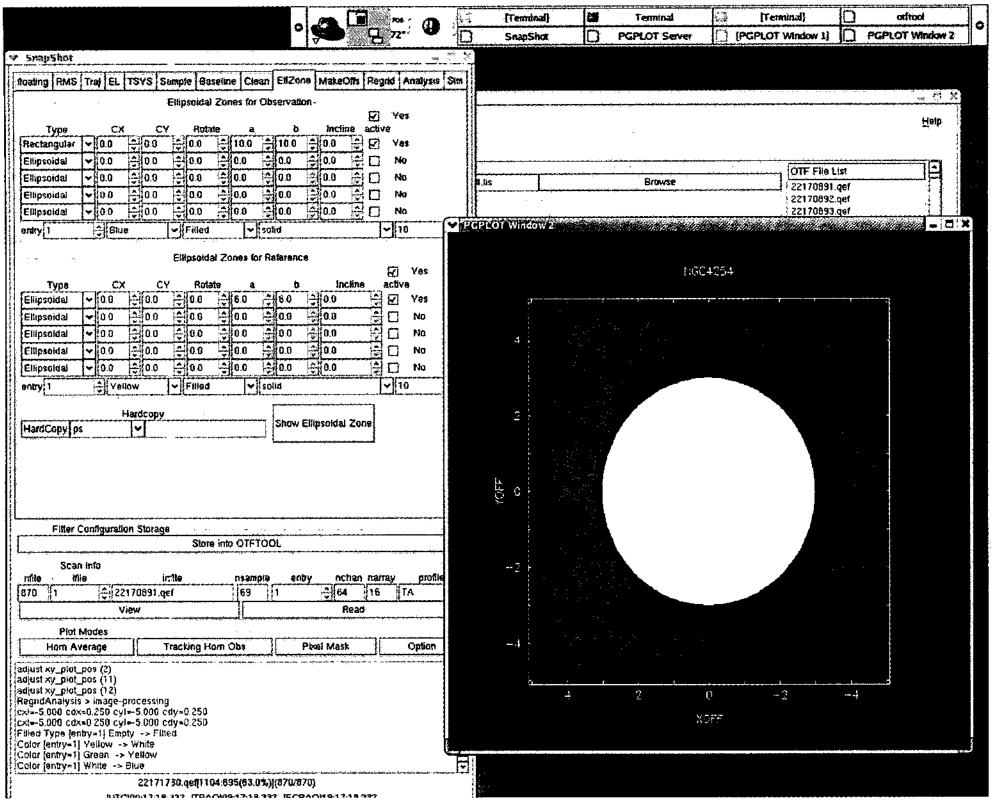
[UTC]04:00:26.039 [TRAO]13:00:26.039 [FCRAO]23:00:26.039

Input parameters for each criterion

Display of the data properties

Monitor of present works

Figure 3. The **Floating** tab of the **Snapshot** page. Every tab of the **Snapshot** page is composed of 3 parts; i.e., input criterion level and windows, some valuable buttons to display data properties, and monitoring window of the program.



Ellipsoidal Zones for Observation

Type	CX	CY	Rotate	a	b	Incline	active ☑ Yes
Rectangular	0.0	0.0	0.0	10.0	10.0	0.0	☑ Yes
Ellipsoidal	0.0	0.0	0.0	0.0	0.0	0.0	☐ No
Ellipsoidal	0.0	0.0	0.0	0.0	0.0	0.0	☐ No
Ellipsoidal	0.0	0.0	0.0	0.0	0.0	0.0	☐ No
Ellipsoidal	0.0	0.0	0.0	0.0	0.0	0.0	☐ No

entry 1 | Blue | Filled | solid | 10

Ellipsoidal Zones for Reference

Type	CX	CY	Rotate	a	b	Incline	active ☑ Yes
Ellipsoidal	0.0	0.0	0.0	6.0	6.0	0.0	☑ Yes
Ellipsoidal	0.0	0.0	0.0	0.0	0.0	0.0	☐ No
Ellipsoidal	0.0	0.0	0.0	0.0	0.0	0.0	☐ No
Ellipsoidal	0.0	0.0	0.0	0.0	0.0	0.0	☐ No
Ellipsoidal	0.0	0.0	0.0	0.0	0.0	0.0	☐ No

entry 1 | Yellow | Filled | solid | 10

Hardcopy: HardCopy ps

Filter Configuration Storage

Scan Info

nfile	ifile	infile	nsample	entry	nchan	narray	profile
870	1	22170891.qef	69	1	64	16	TA

Plot Modes

```
adjust xy_plot_pos (2)
adjust xy_plot_pos (11)
adjust xy_plot_pos (12)
RegridAnalysis > image-processing
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
cxl=-5.000 cdx=0 250 cyl=-5.000 cdy=0.250
Filled Type [entry=1] Empty  -> Filled
Color [entry=1] Yellow  -> White
Color [entry=1] Green  -> Yellow
Color [entry=1] White  -> Blue
```

22171730.qef[1104:695(63.0%)](870/870)

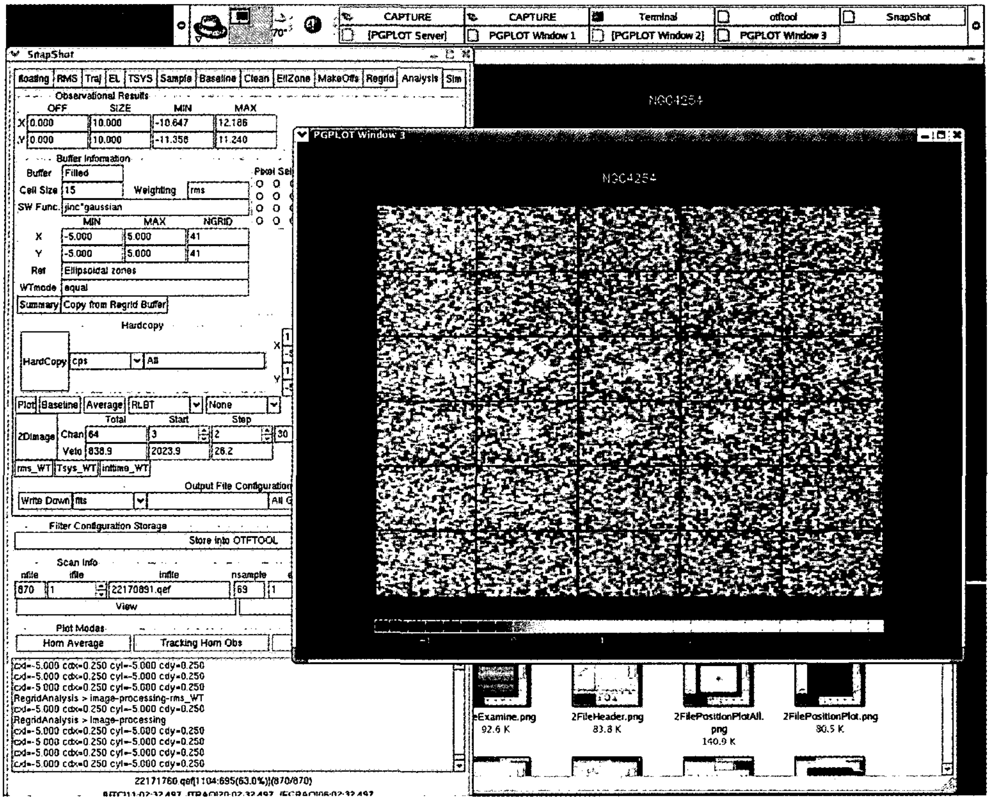
Figure 4. The EllZone tab and Ellipsoidal region. The rectangle box indicates the observing region, and the yellow circle indicates the emission containing region. Then the outer blue region will be used as the SELF references instead of the classically used OFFs references.

region is the SELF reference region. If the user just select the classical OFFs reference, one just select **NO** in every parameter.

MAKEOFFS : In this tab, it shows the observation parameters of spectral data buffer. The user needs to select the reference between **Classical** and **Ellipsoidal**. The **Classical** and **Ellipsoidal** use the OFFs references and SELF references, respectively.

REGRID : The **Regrid** tab shows the parameters set in the previous steps. The user can set the regrid configuration of the cell size, the weighting method, the regrid function, the map size, and the activated SEQUOIA horns. Clicking the **Regrid** button commands the revised-OTFTOOL to regrid the data.

ANALYSIS : Analysis tab is very useful to check the generated data at a time without using other data reduction tools. The user can get the regrided data by clicking the **Copy From Regrid Buffer** button, and see the maps and spectra with the **2DImage** button by setting the numbers of x, y, and the channel. Figure 5 shows the **Analysis** tab and the channel map of NGC 4254. The user can make hard copy of the 2-dimensional image. If the user contents with the result, then one should input the output file name and click the **Write Down** button. However, if the user doesn't satisfy for



	OFF	SIZE	MIN	MAX
X	0.000	10.000	-10.647	12.186
Y	0.000	10.000	-11.356	11.240

Buffer: Filled
Cell Size: 15
Weighting: rms
SW Func.: jinc*gaussian

	MIN	MAX	NGRID
X	-5.000	5.000	41
Y	-5.000	5.000	41

Ref: Ellipsoidal zones
WTmode: equal
HardCopy: cps, All
Average: RLBT, None

	Total	Start	Step
Chan	64	3	2
Velo	838.9	2023.9	26.2

Write Down: fits

nfile	ifile	infile	nsample
870	1	22170891.qef	69

```
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
RegridAnalysis > image-processing-rms_WT
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
RegridAnalysis > Image-processing
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
cxl=-5.000 cdx=0.250 cyl=-5.000 cdy=0.250
```

22171760.qef[1104:695(63.0%)](870/870)

Figure 5. The **Analysis** tab. The revised-OTFTOOL has analysis functions of the regrided datacube. The user can see the regrided datacube's channel map and intensity map. For example, the channel map of the figure is of NGC 4254. It shows the channels at every 2 step from the 3rd channel to 51th channel.

the results, one can go back to the previous page, change the parameter setting, regrid, and analyze again.

SIM : The user can see the regrid function in the **Sim** tab. Clicking the **Plot** button shows each function with 2-dimensional graph.

2.3. Regrid Data

If the user generates FITS file in the previous **Snapshot** page of the **Data Assessment** tab, the user has nothing to do in this tab. This tab contains the menu for both required and optional parameters which affect the construction of convolved, and regrided spectra. The **Input List File**, **RMS Threshold**, **Reference Weighting Scheme**,and **Set Horn Mask** are redisplayed. The user needs to set the **Output File Name**, **Output File Type**, **Output Cell Size**, and **Spatial Filtering Kernel**. After choosing the yes or no of the **Flat Field**, **Remove Baselines**, **Noise Weighting**, and **Include Ramps**, clicking the **Compute OTF Map** button starts to regrid and generate a datacube. The parameters set in the **Snapshot** page are not applied in this page. Only the parameters set in the **Data Assessment** and **Regrid** pages are used to make the output file.

3. THE REVISED-OTFTOOL ALGORITHM

In this section, we represent the revised-OTFTOOL algorithm. As you saw in Section 2, the revised-OTFTOOL has the main structure of the original FCRAO OTFTOOL and the new data pre-reduction and pre-analysis functions are added in the **Snapshot** page. So, the revised-OTFTOOL algorithm dealt in this section is focused on the functions of **Snapshot** page.

Figure 6 simply shows the revised-OTFTOOL algorithm. It can be divided into three main stages, i.e., selection and input of the raw OTF data files, pre-reduction process of data, and writing the output files. The first work of selection and input of the raw OTF data files are done in the **Data File Selection** page. And, the second data pre-reduction process is composed of 3 steps, i.e., referencing, data filtering and cleaning, and regriding. In this section, we follow the algorithm sequence and describe each step in detail.

3.1 Referencing

In OTF observation, references are conventionally taken with the position-switching method. It is taken at a distance from the center followed by one or more total power scanning rows. And, one or more consecutive source positions were shared with a single off-source reference (OFFs references). However, when atmospheric condition changes rapidly, OFFs references and the source frame can have too much different sky condition. When the system condition is unstable, OFFs references may also have severe different values from that of the sources.

In the revised-OTFTOOL, we added a new referencing method (SELF referencing method) which uses the inner source free region as references instead of the OFFs reference (for the details, see Chung et al. 2005a & 2005b). Figure 7 shows the concept of SELF referencing method. The antenna moves and scans the target region. The rectangle is the region being scanned and to be regrided into a datacube. The circle is the region which contains emission source. Then, there exists emission free region in the observing region, which is the inner rectangle and the outer circle. SELF referencing is possible because OTF observation maps enough large area, and it is from the idea that don't waste the existing emission free data and use it as SELF references. This is suitable idea because SELF references have smaller discrepancy of time and position with those of observing data than the OFFs references have.

3.2 Data Filtering & Cleaning

In step-and-integrate observation, we obtain only one data per a point and have to use the whole data. If a problem happens during the observation, it affects the whole data. In case of very serious problem, the data cannot be used and observation must be done again. While on the other, the OTF observation has a large number of redundancies differently from the conventional step-and-integrate observation. If a serious problem happens during the observation, we can sort out the bad samples. By this sorting work, we can get data of better quality. There are 6 criteria to determine whether a sample is good or bad; i.e., floating level, rms, trajectory, elevation, system temperature(T_{sys}), and number of samples.

For each criterion, we explain the reason why it is a criterion of sample selection. And we show the distribution of data which is obtained by OTF observation using FCRAO 14m antenna with SEQUOIA (SEcond QUabbin Optical Imaging Array) which contains 16 horns with 44″ beam size and configures 4 × 4 array. The target galaxy is NGC 4254, which is a spiral galaxy of the Virgo cluster.

3.2.1 Floating level

Radio observation is basically a differential measurement between the source and the empty sky. In an ideal case, the floating level (source-sky) is to be zero. However, it would not be zero

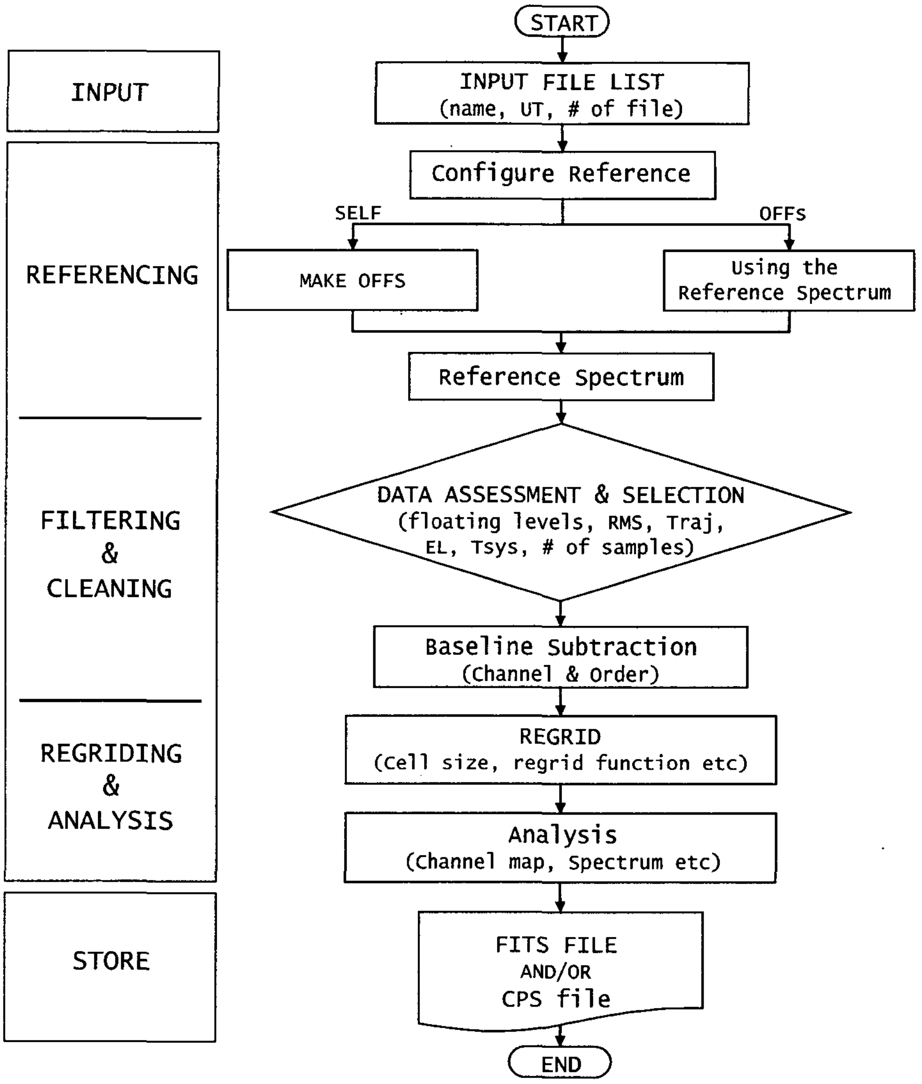


Figure 6. Algorithm of the revised-OTFTOOL. It has three main stages; i.e., input the raw OTF data, data pre-reduction, and storing the output data. The data pre-reduction part is composed of referencing, data filtering and cleaning, and regriding steps.

due to the change of sky and instrument conditions. Thus, the floating level can be a criterion to decide whether a spectrum is stable or not. The user can choose the channel window and floating level threshold. The floating level is calculated in the channel window chosen by the user. And if the floating level of a spectrum is out of the floating level threshold, then the spectrum is sorted out. Hence, the user should determine the channel windows which seem to have no emission. There are five channel windows and floating level thresholds which are to be chosen by the user. Figure 8

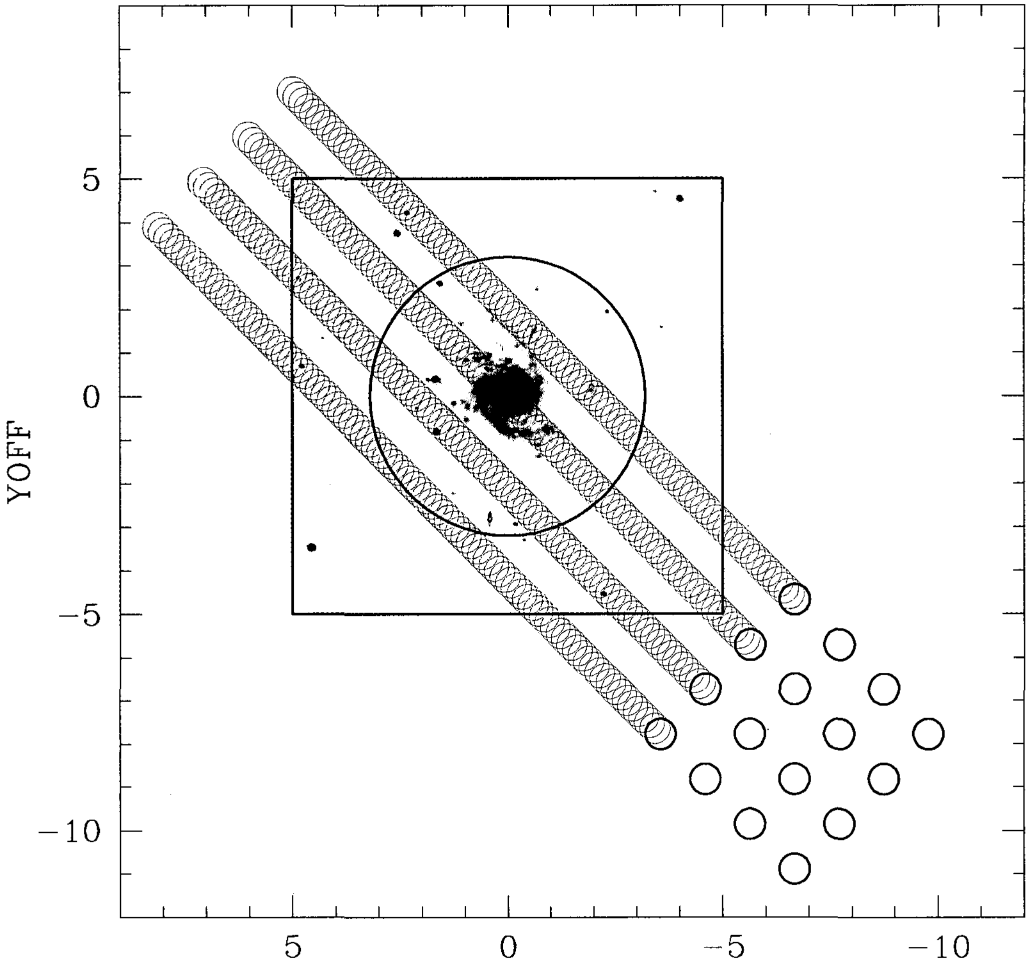


Figure 7. Since OTF observation makes large area mapping which covers the whole galaxy, the inner source free region can be used as references (SELF references). The box indicates the scanned region, and the circle indicates the emission containing region. Then the inner box and outer circle region can be used as the SELF references.

shows the floating level distribution. The abscissa is floating level and the ordinate is the number of samples. Blue and orange lines in Figures 8, 9, 11, 12, and 13 in this paper represent the distribution of sample data and their accumulation profile, respectively. And, the Px on the top left of the boxes in the Figures mean the horn number among 16 horns.

3.2.2 RMS

According to the Nyquist theorem, rms (thermal noise) of a signal gotten from an experiment depends on the system temperature, observing frequency, and bandwidth (Engberg & Larsen 1995,

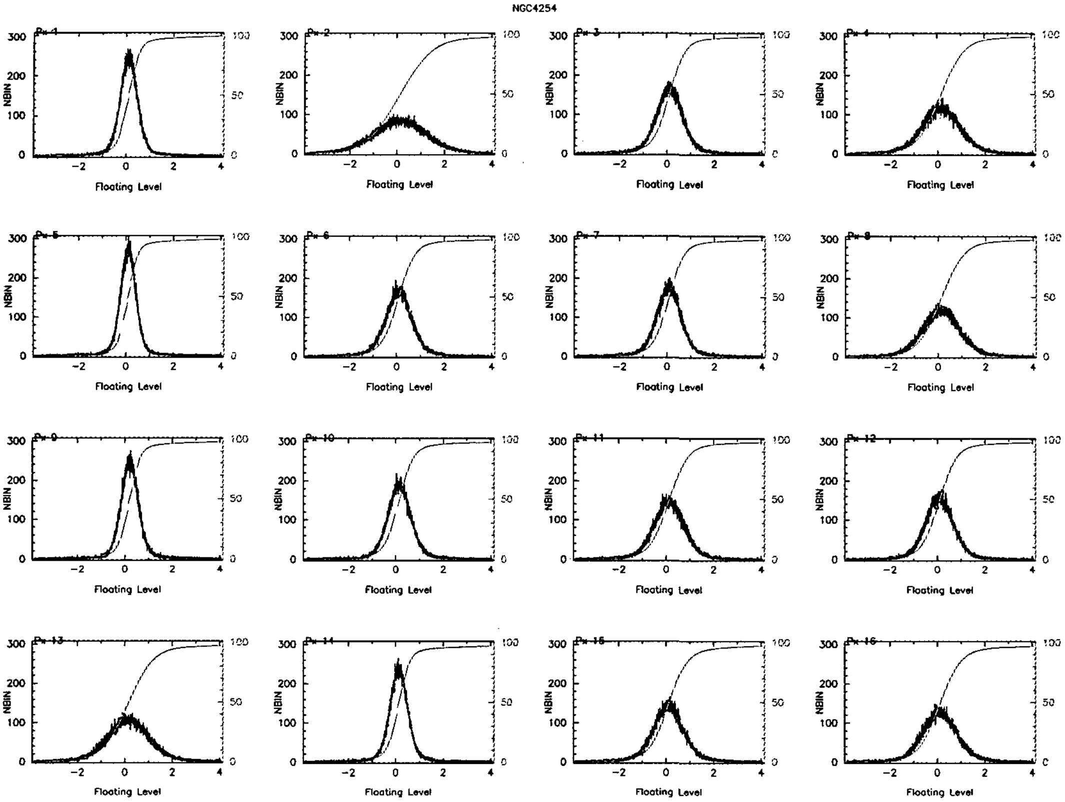


Figure 8. Floating level distribution of 16 horns. The abscissa is floating level and the ordinate is the number of files. The blue line represents the distribution of sample data and the orange line represents their accumulation profile. The Px on the top left of the boxes mean the horn number. It can be seen that the floating level of most sample data lies between -1 and +1, while -2 and +2 for some horns.

Nyquist 1928). And, if an experiment is done iteratively, the rms of the spectra are expected to have specific distribution within a range. And a spectrum which has abnormally large rms can be considered as bad data. The user can choose the channel windows and rms threshold. The rms is calculated in the chosen channel windows. And if the calculated rms of a spectrum is beyond the rms threshold, then the spectrum is picked out. The user should determine the channel windows which seem to have no emission. There are five channel windows and rms thresholds which are to be chosen by the user. Figure 9 shows the rms level distribution. The abscissa is rms level of a spectrum and the ordinate is the number of samples.

3.2.3 Trajectory

Trajectory is related with the beam shape. Single dish antenna has a circular beam shape, and the beam is expected to be stable and not changed. However, in OTF mode, beam is somewhat elongated due to the observational characteristics. OTF observation makes a dump while the antenna moves smoothly and continuously, and its shape is shown as an ellipse elongated to the moving direction

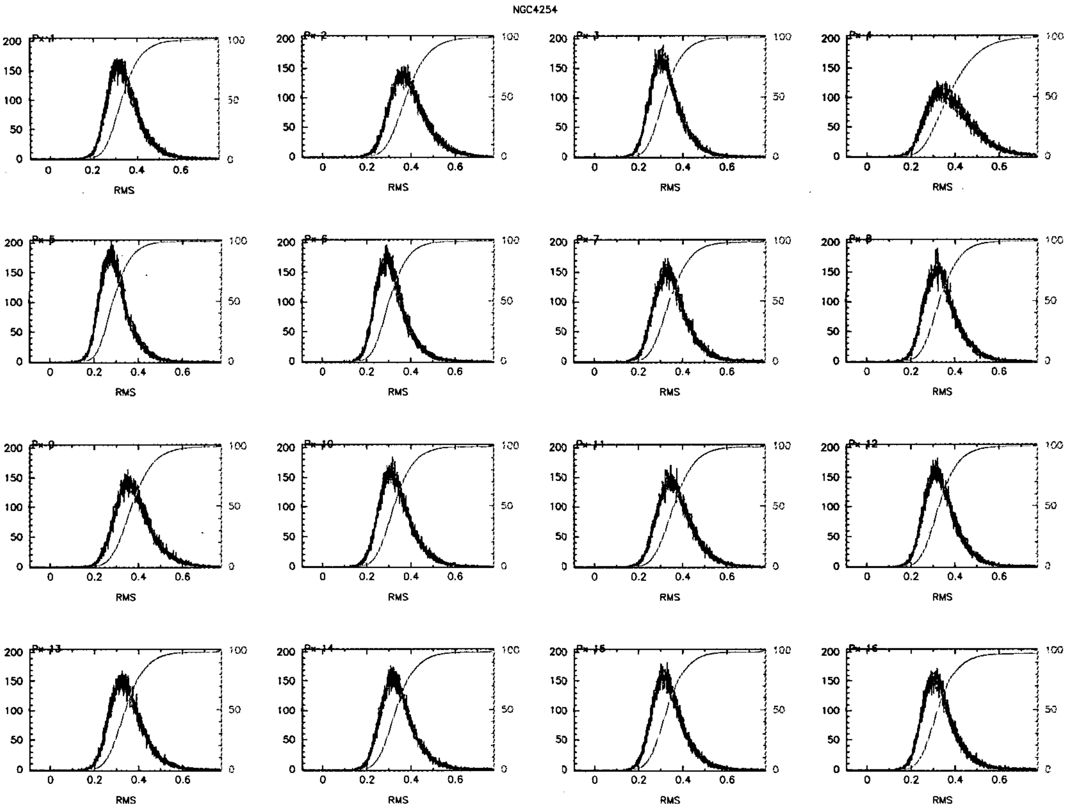


Figure 9. Distribution of rms threshold of 16 horns. The abscissa is rms level and the ordinate is the number of files. Most sample data are shown to have the rms between 0.2 and 0.6.

of antennae. Figure 10 shows the beam trajectory when it makes 4 dumps per a second. Seriously elongated or anomalous shape beam can cause problems such as making a ghost image. To avoid these problems, we added the antennae trajectory as one of the filtering criteria. When the user determines the trajectory threshold level, then the data is strained off by bandpass filtering procedure. Figure 11 shows the trajectory distribution. The abscissa is trajectory level and the ordinate is the number of samples.

3.2.4 Elevation

In radio observation, air-mass is generally thought to be corrected by chopper-wheel method, and there is no more process for the air-mass correction. When the air-mass affects severely and critically to the data, grouping by elevation and reducing each group of data separately is more effective. In addition, it can be also used to test the air mass effect on the radio observation. The user chooses the clipping elevation window, and then the data which has the elevation in the range of the clipping elevation windows is selected by bandpass filtering procedure. Figure 12 shows the distribution of beam's elevations. The abscissa is elevation and the ordinate is the number of samples.

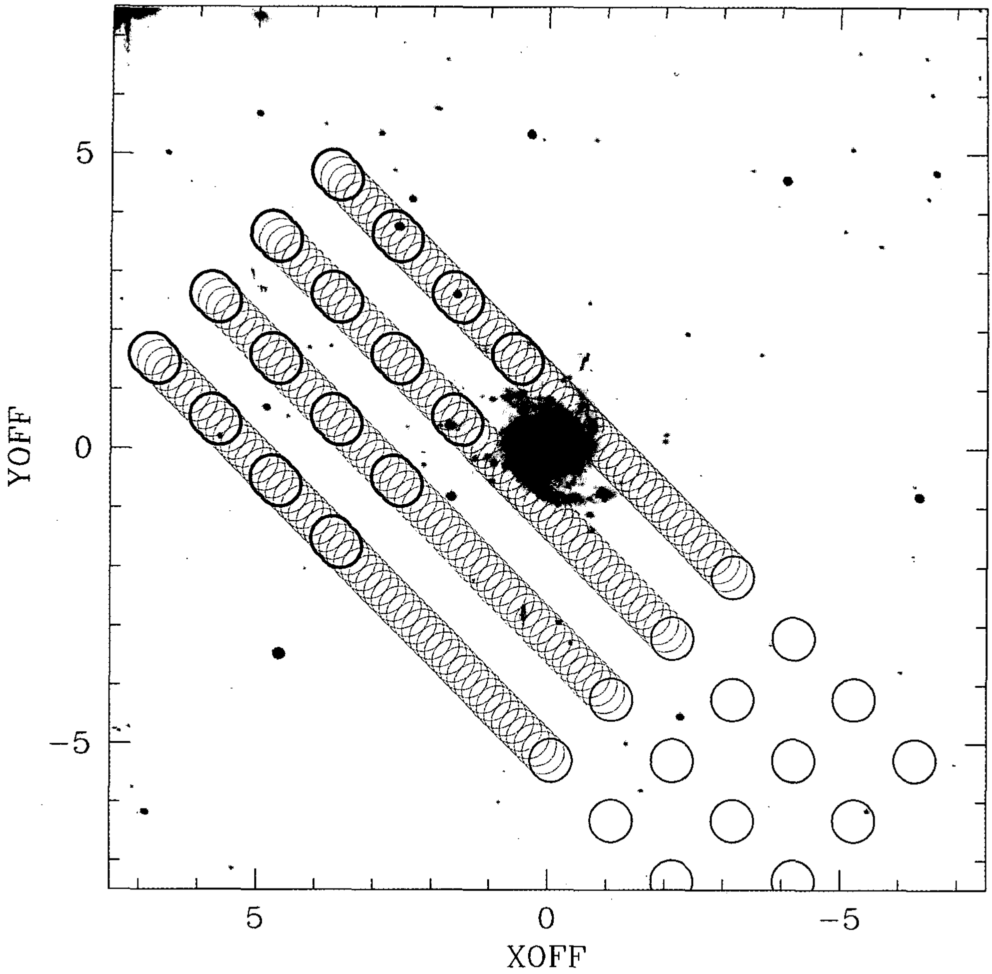


Figure 10. Beam trajectory of OTF observation. Each circle presents the beam starting position of one exposure. In reality, since the antenna moves continuously, OTF beam is elongated in the direction of antenna moving represented as thick ellipses in the figure.

3.2.5 System Temperature

T_{sys} can affect to the rms as written above, and data quality is closely connected with T_{sys}. There can be some problems during observation and T_{sys} changes abruptly. In this case, T_{sys} clipping will perform its part most effectively. The user can choose clipping T_{sys} windows. If the T_{sys} of the data is outside of the clipping windows, the data will be excluded. Figure 13 shows the T_{sys} distribution of the data. The abscissa is T_{sys} and the ordinate is the number of samples.

3.2.6 Number of Sample

Number of sample per one scanning raw is fixed on the basis of the map size and data dumping interval, and is maintained constant value. However, if there are some problems in program operation

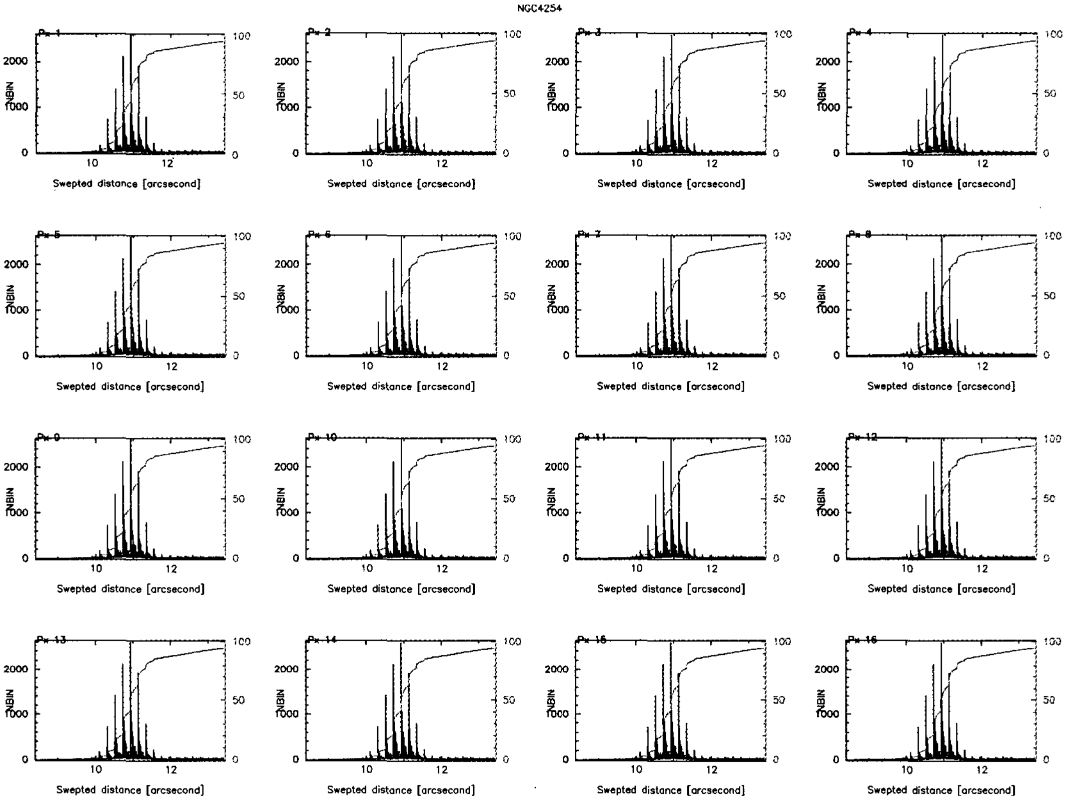


Figure 11. Trajectory distribution for 16 horns. It shows that most data lie between 10 and 12 arcsecond of trajectory. The abscissa is trajectory of the antenna and the ordinate is the number of files.

such as antenna aborting during antenna scans, then the antenna stops and goes back to the next raw of starting point. And it starts to scan again. So, the smaller number of sample than the pre-fixed one can be a criterion to sort out bad samples. The user can choose the clipping number of sample windows. If the number of sample of the data is outside of the clipping window, the data will be sorted out.

3.2.7 Cleaning

Different characteristics between channels make the baseline of spectrum to be warped. To straighten this curved baseline, we subtract the baseline by giving the emission free windows and baseline subtraction order from 0 to 2. Before baseline subtraction, the values which were flagged as spikes are substituted with the average value of the two adjacent channel values. Removing spike is done by determining the spike level and channel windows. In the channel windows, the spikes are removed. There are 5 levels and channel windows which can be chosen by the user. Hence, the user can apply different level into different channel window. For example, the user can apply one for the emission free channel window and another for the channel window which includes the source.

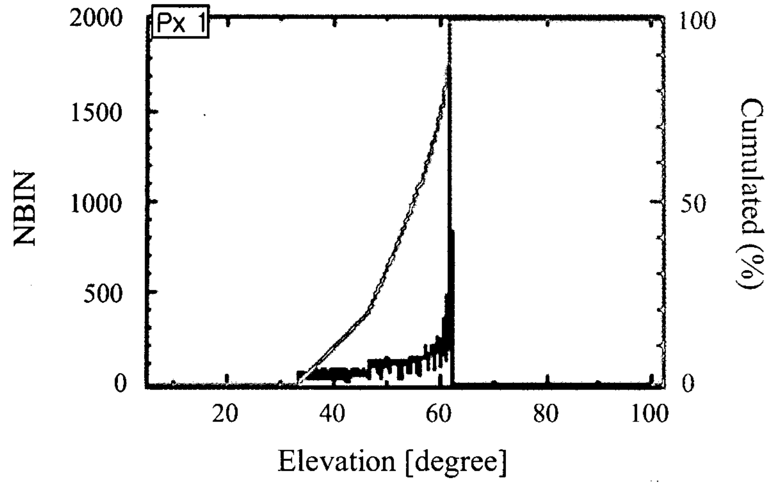


Figure 12. Elevation distribution of 1st horn (Px 1). The abscissa is elevation and the ordinate is the number of files. It shows that most data points have the elevation between 30 and 70 degree.

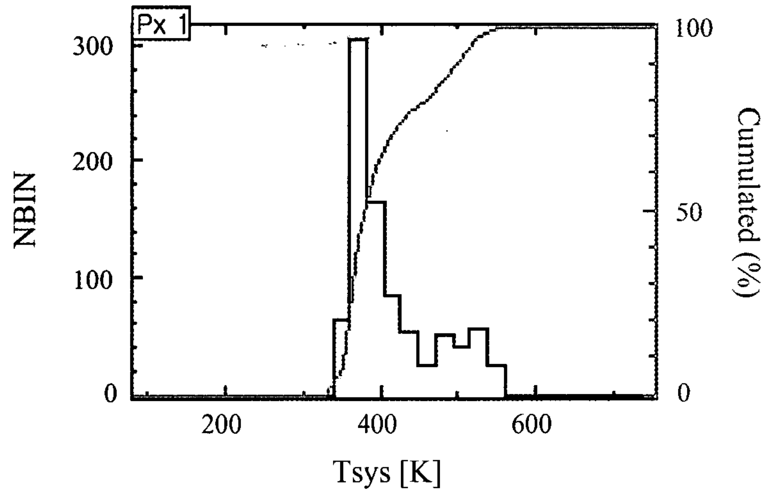


Figure 13. System temperature distribution of 1st horn (Px 1) among 16. The abscissa is system temperature and the ordinate is the number of files. It shows most data lie between 300 and 600 K of T_{sys}.

3.3 Regriding

3.3.1 Weighting method

It is reasonable to give more weighting to the high quality data and less weighting to the low quality data. One of the advantages of OTF observation is that it is possible to manipulate each sample spectrum. And, it is very useful to give different weighting to each spectrum.

$$S(x,y) = \frac{\sum S_{\mathrm{k}}(x_{\mathrm{k}}, y_{\mathrm{k}}) w_{\mathrm{k}}}{\sum w_{\mathrm{k}}} \tag{1}$$

where $S_{\mathrm{k}}(x_{\mathrm{k}}, y_{\mathrm{k}})$ is the observed spectrum, w_{k} is weighting function, and $S(x,y)$ is the datacube which is total sum of weighted spectra, respectively.

In general, w_{k} is given by the integration time Δt. However, in OTF observation it is meaningless to use Δt for the weighting, because the Δt is all the same to every spectrum. Hence, other parameter which can work for a function of Δt is needed. And, it is natural to bring the rms which is calculated by

$$\sigma(T_{\mathrm{A}}) = \frac{c \times T_{\mathrm{sys}}}{\sqrt{\Delta\nu\Delta t}} \tag{2}$$

where T_{sys} is the system temperature, $\Delta\nu$ the instrumental resolution, Δt integration time, and c the calibration factor, respectively.

From the above equation, we know that

$$\Delta t \propto \frac{1}{\sigma^2}. \tag{3}$$

And, this shows that the inverse of σ^2 can be used as a weighting function instead of the integration time.

3.3.2 Regrid Function

Before talking about the regrid functions, we describe here about the redundancy because it is one of the most important properties of OTF observation. Fast moving of the antenna and short exposure time of OTF observation minimize the atmospheric and systemic uncertainties, but detection of the source is difficult because of the short exposure time even if the source has a strong emission. Increasing the redundancy can resolve this difficulty of detection. However, redundancy doesn't mean that the accurately same point is observed repeatedly but a fixed point is included in a large number of snapshots. Although the antenna has been set to observe along the fixed path at regular interval, every snapshot has different position because of the rotation of the sky by the earth's rotation and the systemic error. Nevertheless we say that the OTF observation has a large redundancy, because the beam is not a point but has spatial size and there exist many overlapping regions. A point is contained in many snapshots and has large redundancy. Now, there remains to redistribute the energies of the samples and make them to a 3-dimensional data cube. The revised-OTFTOOL provides 8 regriding functions; i.e., jinc-gaussian, sinc-gaussian, sinc, gaussian, pillbox, exponential, and sinc × gaussian functions. Jinc-gaussian is most recommended and used for the regriding.

4. SUMMARY AND DISCUSSION

We developed the revised-OTFTOOL which is an improved version of the FCRAO OTFTOOL. Besides the improvement of data resampling function of FCRAO OTFTOOL, we added the data prereduction functions and pre-analysis functions of the preliminary data. The OTF observation data have a large redundancy, and we can use enough samples of good quality even though excluding substantial bad samples. Sorting out the bad samples are based on the floating level, rms level, antenna trajectory, elevation, $\mathrm{T_{sys}}$, and number of samples, and sample spectra containing spikes are also excluded. Referencing method can be chosen between the CLASSICAL OFFs in which the references are taken from the OFFs observation and the ELLIPSOIDAL SELF method in which the references are taken from the inner source free region. Baseline will be subtracted with the chosen source free channel windows and baseline order. Passing through these procedures, the raw OTF data would be an FITS datacube.

The revised-OTFTOOL is very easily accessible as it is graphical user interface based on the X window. Moreover, it is more powerful since its functions of data pre-reduction and pre-analysis are added. It is expected that the revised-OTFTOOL would be applied to the other OTF facilities such as SRAO, TRAO, and FCRAO and used.

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APPENDIX. INSPECTION OF THE REVISED-OTFTOOL

To inspect the revised-OTFTOOL, we make several datacubes with changing parameters from floating level to referencing method. In Figure 14, we show the spectra of only four different cases which show remarkable differences. Table 1 represents the parameters which we applied to each spectrum. The 6 parameters; i.e., rms, trajectory, elevation, T_{sys}, number of sample, and spikes, which don't affect to the results so much are set to be the same for all spectra.

The variable parameters are floating level, baseline, and references. Figure 14a and 14b are the global profiles and CO intensity maps of regrided results with different floating level of $-2 \sim 2$ and $-1 \sim 1$, respectively. Figure 14c shows the results when the baseline subtraction function is added to Figure 14b. And, Figure 14d shows the results when the SELF references are applied while the foregoing cases are applied by the OFFs references.

The global profiles and CO intensity maps show that the additions of each function make significant progresses. The global profile (and the CO intensity maps) of Figure 14a and 14b have the same extent. Both of them are very close to the raw data which is not filtered by any conditions but only by the floating level. As seen in Figure 14a global profile, our data has a severe baseline problem. The crooked shape of the baseline as well as its level is a problem to be resolved. In the spectrum in Figure 14b of which floating level is fixed the value of -1 and 1, the baseline shape and level are still awaiting solution. Besides, we cannot find any CO emission in the CO intensity maps of Figure 14a and 14b.

Figure 14c and 14d show that the subtracting baseline and using the SELF references resolve the baseline problem. The global profile and the CO intensity map of Figure 14c show the baseline subtraction results. By doing the baseline subtraction with the emission free channels and the baseline order 0, the baseline level becomes close to 0. Even though its baseline shape is still severely crooked, the emission is appeared in the CO intensity map. Figure 14d is the results of the data derived by applying the SELF references. The crooked baseline shape shown on the every global profile above is disappeared. The global profile of Figure 14d has a very stable and flat baseline, and the emission is very clear in the middle channel of the spectrum. In the CO intensity map, the emission is more obvious than in the CO intensity map of Figure 14c.

Table 1. Input Parameters of Figure 14.

	RMS [Window] (level)	Traj (level)	EL [Window]	T_{sys} [Window]	Sample [Window]	Clean [Window] (level)	Floating [Window] (level)	Baseline [Window] (order)	Ref.
(a)	[1$\sim$10, 54$\sim$64] (0$\sim$0.6)	(8$\sim$14)	[30$\sim$90]	[1$\sim$10^5]	[1$\sim$10^6]	[1$\sim$64] (6.0)	[1$\sim$10, 54$\sim$64] (-2$\sim$2)	NO	OFFs
(b)	〃	〃	〃	〃	〃	〃	[1$\sim$10, 54$\sim$64] (-1$\sim$1)	〃	〃
(c)	〃	〃	〃	〃	〃	〃	〃	[1$\sim$18, 47$\sim$64] (0)	〃
(d)	〃	〃	〃	〃	〃	〃	〃	〃	SELF

Parameters of each case (a), (b), (c), and (d) of Figure 14. 6 parameters; i.e., rms, trajectory, elevation, T_{sys}, number of sample, and clean, are set to be all the same for (a), (b), (c), and (d). Floating level, baseline subtraction, and the reference are applied differently to show their functions.

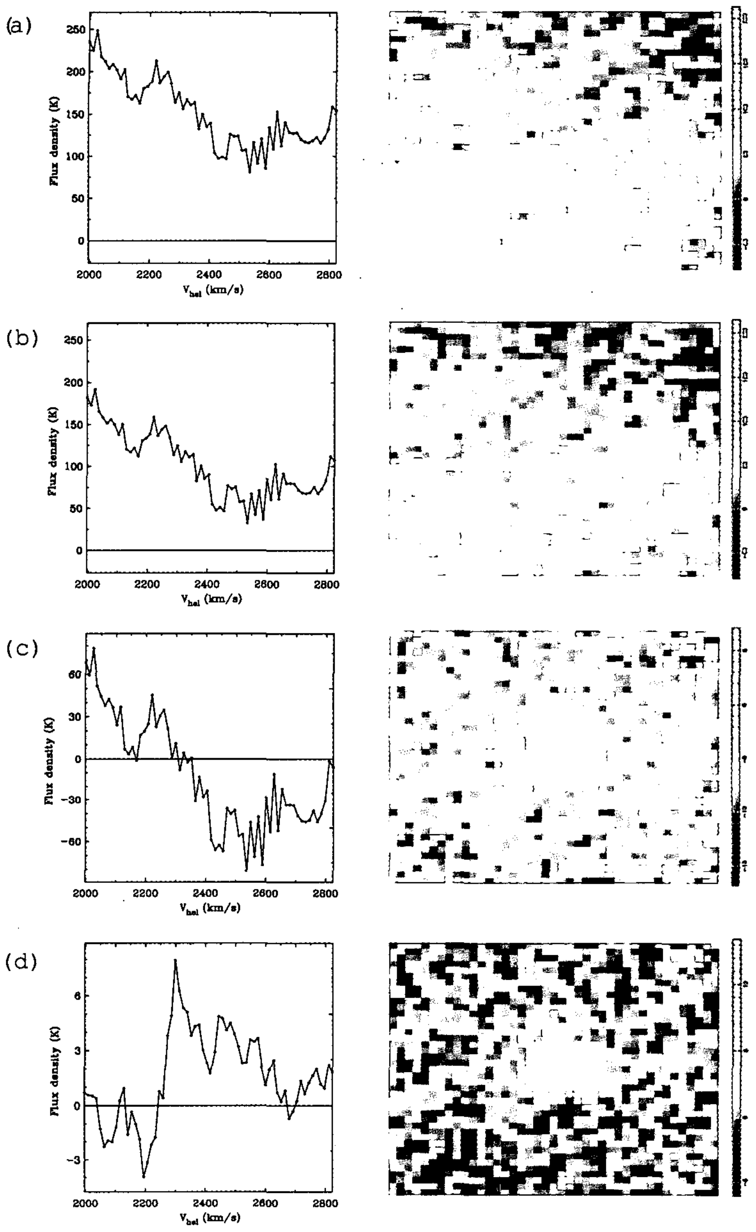

Figure 14. Global profiles and CO intensity maps derived from the revised-OTFTOOL. We used the OTF raw data of NGC 4254 which has a good signal to noise ratio. Each spectrum (and its CO intensity map) is derived with differently specified parameters. (a) is only set the floating level of -2 and 2. (b) is also only set the floating level, but of -1 and 1. (c) is added the baseline subtraction of yes with order 0 over spectrum (b). And, (d) is changed the referencing method from OFFs to SELF of spectrum (c). The parameters for each spectrum are represented in Table 1. The transitions of the spectra and CO intensity maps clearly show that each function of the revised-OTFTOOL performs each part most effectively.