

## **I - Intro**

Files analyzed: 36239-58 & 36263-70 from February 2007 run.

The dither cycle 36259-62 was discarded for the time being due to the following comment in the log:

"very different polarization vectors??"

All data was collected on Feb 13 with  $\tau \sim 0.045$ . 2.5 hrs of observations; 2 arcmin chop.

## **II - Sharpinteg Results**

Program used: sharpinteg 2.3 with feb 2007 rgm. Following flags also used: "-f 1 -w -sil". A shell script, "chopnod" was written to execute sharpinteg2 through the selected data.

Numerous messages of the type:

"Q angles not within 10 degrees of 45  
U angles not within 10 degrees of 45"

are seen at run time when sharpinteg2 processes 36270. Does this indicate bad HWP angles?

The source is visible in all I maps. The top row of the array appears to yield erroneously low pixel counts. The position of the peak signal typically varies over the dither cycle over the positions:  $\sim (6,6), (8,8), (8,6), (6,8)$ . The peak signal is  $\sim 0.0034$  while the background appears to be almost a full order of magnitude lower at an absolute value of  $\sim 0.0004$ .

The efficiencies appear to be as follows:

Chop Efficiency: 67%  
Data-Taking Efficiency: 83%  
Total Efficiency: 56%

## **III - Sharpinteg results for the SNR**

I looked at the 4 central pixels of the array for this analysis. I will state at this point that one should probably compute the errors over the entire object, as M82 is extended over the array while dg tau is a point-like source. A program should probably be written to this end.

I found that the typical Q and U rms error is about  $8 \times 10^{-5}$ , compared with a source flux of  $\sim 0.003$ . Taking a conservative approach, this works out to be roughly 4% of the M82 flux is rms error. Combining the 4 pixels, we end up with an error of 2% in q and u for a single cycle. To scale to 1% errors, one would require 4 cycles of data. Assuming each cycle is 7.25min, this implies that 29min are required to achieve 1% errors.

The 350 micron flux for M82 peaks roughly at 16 Jy/beam (looking at the 350 micron map provided by Lerothodi). Our reference source (in the Table of Specifications) is 0.5 Jy/pixel. The four central pixels of the array were then compared with the peak micron flux in the following manner:

Peak signal at pixel (6,6), the pixel count is 0.0037 data units (DU's)  $\sim 16$  Jy/beam. Other pixels are: (6,7)  $\sim 0.0036$  DU, (7,6)  $\sim 0.0017$  DU, (7,7)  $\sim 0.0023$  DU. Ratio is  $16(\text{Jy/beam})/0.0037\text{DU's} = 4324.32 \text{ Jy}/(\text{DU}\cdot\text{beam})$ . Therefore this yields the fluxes:

(6,6)  $\sim 16$  Jy/beam  
(6,7)  $\sim 15.57$  Jy/beam  
(7,6)  $\sim 7.35$  Jy/beam  
(7,7)  $\sim 9.95$  Jy/beam

Therefore the mean flux per beam is calculated to be 12.22 Jy/beam. Treating the beam size to be  $9''$ , we convert this quantity to Jy/pixel:  $12.22 \text{ Jy/beam} \cdot (1/3.01) \text{ beam/pixel} = 4.06 \text{ Jy/pixel}$ . This implies M82 is 8.12 times brighter than the reference source.

The Table also assumes a 60% efficiency, while I have calculated 56%. This implies a penalty factor of 1.03.

The tau and airmass measured during the course of the observations was  $\sim 0.045$  and 1.60 respectively. Therefore, the " $\tau \sec(z)$ " = 0.072, which compares with the reference value of 0.065. As a result, we are worse off by a factor of 1.19 ( $=1/\exp[25\{0.065-0.072\}]$ ). The advantage factor relative to atm, source flux, and efficiency conditions is therefore 6.62. This is an advantage in time of a factor of 43.82. So to achieve a 1% error should require 0.11 hrs instead of the 5 hrs listed in the Table.

Comparing the 0.11hrs (6.8min) value with the 29 min value shows that our errors are roughly 100% higher than expected. This massive discrepancy may be the result of the crude nature of these calculations, a more careful and through calculation is probably need for extended sources with regards to flux/pixel quantities.

## IV - Sharpinteg Results for Q and U Maps

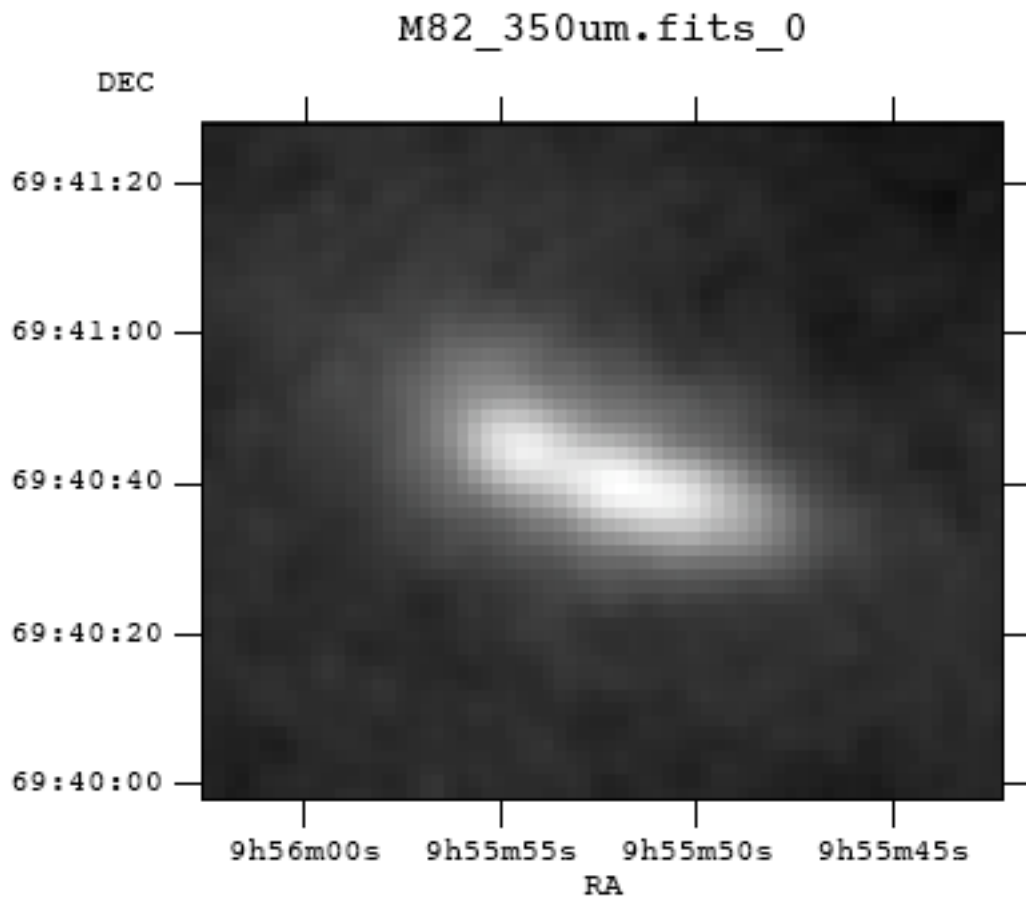
Some of the Q and U maps appear as random Gaussian noise, however many appear to have "structure" towards the top and right-hand edge of the maps that appears to be almost an order of magnitude brighter than the rest of the array. This structure appears to be unrelated to the presence of M82; in fact there is no obvious structure in the Q and U maps due to M82 (as one would expect from this relatively unpolarized and faint source). Some maps appear to show a gradient running from the lower left hand corner to the upper right hand corner while other files appear to show a slight DC offset.

### Va – Pointing corrections for M82

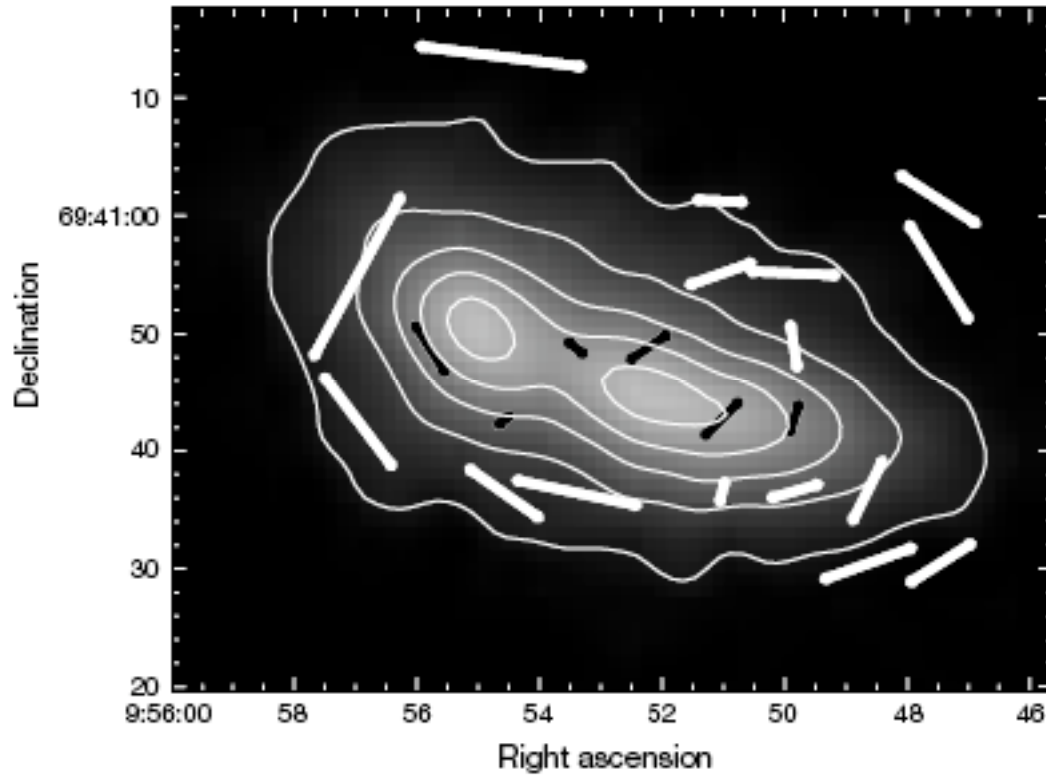
The following equations were used to compute the pointing corrections in the M82 data.

$$1) \Delta\vec{\theta}_s = \vec{\theta}_{fit} - \vec{\theta}_{cat},$$

where  $\vec{\theta}_{fit}$  is the location of the centroid of the source,  $\vec{\theta}_{cat}$  is the location of the catalog coordinates, and  $\Delta\vec{\theta}_s$  is the displacement between these two quantities.  $\vec{\theta}_{cat}$  is provided within the header of the FITS image, and in this case was recorded as  $\vec{\theta}_{cat} = \{9.862081(hrs), +69.91689(deg)\}[1950]$ . Converting this into 2000 coordinates with "astro.pro" (available online) we get:  $\vec{\theta}_{cat} = \{9h : 55m : 52.23s, +69 : 40' : 46.7''\}[2000]$ .  $\vec{\theta}_{fit}$  was estimated by eye from Lerothodi's 350 micron M82 map, however the coordinates that appear on the axis's of this image do not appear to be well calibrated. Therefore, the 350 micron FITS map has to be compared with the 450 micron greyscale map provided by Greaves et al. 2000, which is assumed to be well calibrated. These maps are depicted below:



**Figure 1:** 350 micron FITS image of M82 with a linear grey scale ranging from -2.01 to 16.21 data units.



**Figure 2:** 450 micron grey scale (850 micron polarimetry) map of M82 provided by Greaves et al. 2000.

The offset between these two maps is estimated to be:

$\Delta = \bar{\theta}_{350\mu m} - \bar{\theta}_{450\mu m} = -\{0.91s, 9.03''\}$ . The centroid of the 350 micron map is estimated to be at:  $\bar{\theta}_{fit} = \{9h : 55m : 52.20s, +69 : 40 : 39.69\}[2000]$ , so if we now take into account the correction term we have:

$$\bar{\theta}_{fit} = \{9h : 55m : 52.20s, +69 : 40 : 39.69\} - \Delta$$

$$\bar{\theta}_{fit} = \{9h : 55m : 53.11s, +69 : 40 : 48.72\}$$

Note that this last coordinate appears to match the “eyeballed” centroid of the Greaves et al. map. Also note that  $\bar{\theta}_{cat}$  matches the position of the western peak in the Greaves et al. map.

And so now we get:  $\Delta\bar{\theta}_s = \bar{\theta}_{fit} - \bar{\theta}_{cat} = \{4.42arc\ sec, 2.02arc\ sec\}[2000]$ .

$$2) \Delta\bar{\theta}_m = \Delta\bar{\theta}_s + \Delta\bar{\theta}_d + \Delta\bar{\theta}_e,$$

where  $\Delta\bar{\theta}_m$  is the measured offset of the centroid from the image center,  $\Delta\bar{\theta}_s$  is

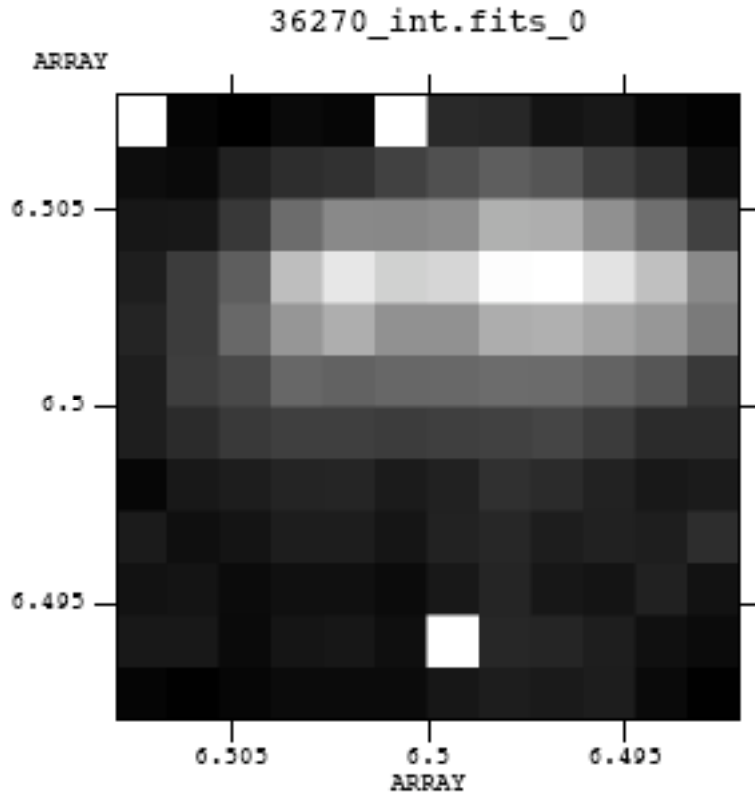
discussed above,  $\Delta\bar{\theta}_d$  is the offset due to the dither motion, and  $\Delta\bar{\theta}_e$  is the offset due to error in pointing.  $\Delta\bar{\theta}_d$  is recorded in the observing logbook, and  $\Delta\bar{\theta}_m$  is measured using fitgauss 3.0 with the elliptical fit feature enabled. With this information equation 2 can be solved for  $\Delta\bar{\theta}_e$ . Two points of interest should be addressed here: i) the capabilities of fitgauss 3.0 to fit to M82 ii) coordinate conversions.

*Fitting to M82 with fitgauss 3.0*

Fitgauss 3.0 was written by Darren Dowell and is available on the SHARP website. Presented below are the results of this program with a sub-set of the M82 data used in this analysis.

File	Center (by eye)	Center (by fitgauss)	Difference
36239	(5.5,6.0)	(5.584,5.450)	(0.084,-0.55)
36242	(5.5,6.5)	(5.925,6.620)	(0.425,0.12)
36246	(6.3,7.3)	(6.165,6.954)	(-0.135,-0.346)
36250	(6.0,7.3)	(6.316,7.478)	(0.316,0.178)
36255	(6.5,6.5)	(6.934,6.819)	(0.434,0.319)
36263	(7.5,7.5)	(7.524,7.630)	(0.024,0.130)
36270	(7.5,9.0)	(7.866,8.824)	(0.366,-0.176)

As an example to the reader the I map for file 36270 is included below:

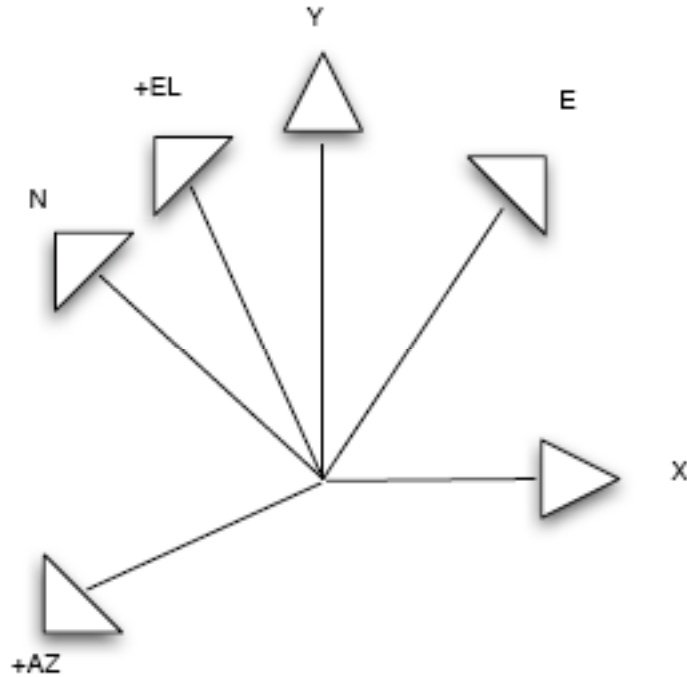


**Figure 3** : M82 I map as generated by sharpinteg. Three bad pixels are present in this image and appear as bright white. The linear grey scale ranges from 0 to 0.004 data units.

The results above appear to indicate that fitting with fitgauss 3.0 is accurate to roughly 0.5 pixels on M82. This is accurate enough for the present analysis.

### *Coordinate Conversions*

To solve equation 2 properly, one needs to transform from RA & DEC, Alt & AZ, and pixel space coordinates. Figure 4 illustrates the relationship between these coordinate systems.



**Figure 4** : Graphical depiction of the three coordinate systems being considered here; RA & DEC (E and N vectors), Alt & AZ (+EL and +AZ vectors), and pixel space (X & Y vectors). Note that the elevation angle is the angular displacement between the Y and +EL vectors, and the parallactic angle is the angular displacement between the +EL and N vectors.

The conversion from RA & DEC to pixel space then follows as:

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \frac{1}{4.6} \begin{bmatrix} \cos(\theta_p + \theta_e) & -\sin(\theta_p + \theta_e) \\ \sin(\theta_p + \theta_e) & \cos(\theta_p + \theta_e) \end{bmatrix} \begin{bmatrix} RA \\ DEC \end{bmatrix}$$

The conversion from RA & DEC to Alt & AZ follows as:

$$\begin{bmatrix} AZ \\ EL \end{bmatrix} = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\theta_p) & -\sin(\theta_p) \\ \sin(\theta_p) & \cos(\theta_p) \end{bmatrix} \begin{bmatrix} RA \\ DEC \end{bmatrix}$$

$$\begin{bmatrix} AZ \\ EL \end{bmatrix} = \begin{bmatrix} -\cos(\theta_p) & \sin(\theta_p) \\ \sin(\theta_p) & \cos(\theta_p) \end{bmatrix} \begin{bmatrix} RA \\ DEC \end{bmatrix}$$

The conversion from Alt & AZ to pixel space is:



$$\begin{bmatrix} X \\ Y \end{bmatrix} = \frac{1}{4.6} \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\theta_e) & \sin(\theta_e) \\ -\sin(\theta_e) & \cos(\theta_e) \end{bmatrix} \begin{bmatrix} AZ \\ EL \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \frac{1}{4.6} \begin{bmatrix} -\cos(\theta_e) & -\sin(\theta_e) \\ -\sin(\theta_e) & \cos(\theta_e) \end{bmatrix} \begin{bmatrix} AZ \\ EL \end{bmatrix}$$

Now we take the about equation, solve for the Alt & AZ coordinates, and convert the elevation angle to zenith angle:

$$\begin{bmatrix} AZ \\ ZA \end{bmatrix} = 4.6 \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} -\cos(\theta_e) & -\sin(\theta_e) \\ -\sin(\theta_e) & \cos(\theta_e) \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix}$$

$$\begin{bmatrix} AZ \\ ZA \end{bmatrix} = 4.6 \begin{bmatrix} -\cos(\theta_e) & -\sin(\theta_e) \\ \sin(\theta_e) & -\cos(\theta_e) \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix}$$

$$3) \overrightarrow{F.O.true} = \overrightarrow{F.O.used} + \Delta\theta_e,$$

where  $\overrightarrow{F.O.true}$  is the true fixed offset (either in AZ or ZA), and  $\overrightarrow{F.O.used}$  is the offset actually used while taking observations. The results of this analysis are indicated below in the following table.

File	FAZO (used)	FZAO (used)	FAZO (true)	FZAO (true)
36239	-117	90	-120.8404	87.2633
36240	-117	90	-119.0454	90.0468
36241	-117	90	-121.7553	89.3291
36242	-117	90	-119.8954	91.6224
36243	-117	90	-121.8925	91.2033
36244	-117	90	-122.1109	92.2569
36245	-117	90	-123.4528	90.8721
36246	-117	90	-122.0872	91.8163
36247	-117	90	-122.6546	90.9918
36248	-117	90	-122.1969	91.4315
36249	-117	90	-123.2228	91.2315
36250	-117	90	-124.4605	91.1432
36251	-117	90	-121.991	91.1912
36252	-117	90	-121.8028	92.1155
36253	-117	90	-122.4774	91.2695
36254	-117	90	-120.7833	90.5724
36255	-117	90	-124.3153	89.7207
36256	-117	90	-123.0027	91.0288
36257	-117	90	-122.1604	91.3337
36258	-117	90	-119.8056	91.9819
36263	-117	90	-122.2047	90.5936
36264	-117	90	-122.1577	91.2178
36265	-117	90	-121.9832	91.7721
36266	-117	90	-122.3178	94.7219
36267	-117	90	-120.6504	93.2662

36268	-117	90	-123.8569	96.0031
36269	-117	90	-120.7307	96.9497
36270	-117	90	-121.0061	95.6698

**Table 1** : Results for the pointing analysis conducted for the M82 data set.

**Vlb - Sharp\_combine: tests of background subtraction, smoothed tau application, and pointing corrections.**

Version used is 4.10. The program is called at the command line as:

```
./sharp_combine chop.list combine.fits -hwp 50 -l 51 51 -sm 2 -ma 5 -ps 6 -pm 6 -q -bg 10 0
```

Note that the file "chop.list" contains pointing corrections and smooth tau values. The smoothed tau values were obtained from the SHARP web page. The pointing corrections were worked out from information provided in the logbook for the February 2007 run and the 250 micron map provided by Lerothodi Leeuw.

Depicted below are the results from the M82 data, illustrating the effects of background subtraction, tau, and pointing corrections.

<i>Conditions</i>	<i>smthd l pk flux</i>	<i>smthd l pk loc</i>	<i>q</i>	<i>sig-q</i>	<i>u</i>	<i>sig-u</i>
<i>no bckgnd</i>	0.0167	(28,26)	0.0058	0.0066	0.0029	0.0065
<i>add bckgnd</i>	0.0191	(28,26)	0.0046	0.0057	0.0030	0.0057
<i>add smthd tau</i>	0.0240	(28,26)	0.0069	0.0052	0.0046	0.0052
<i>add pnting</i>	0.0240	(26,26)	0.0065	0.0050	0.0070	0.0050

\*\*\*Note that the above values for q, u and there errors are taken at the peak locations identified in the l map.

\*\*\*In addition, with no background subtraction the ratio from peak to edge values in the intensity map is 15:1. With background subtraction, this is brought to 20:1.

To test the effect of the iteration # on the background subtraction, sharp\_combine was run over the entire data set 4 times with varying iteration values. The results are presented below (analysis includes tau and pointing corrections):

# iteration	q	sig-q	u	sig-u
1	0.0065	0.0050	0.0070	0.0050
3	0.0065	0.0050	0.0070	0.0050

10	0.0065	0.0050	0.0070	0.0050
20	0.0065	0.0050	0.0070	0.0050