Signal-to-Noise Ratio in Non-Uniform Spacing Frequency Integration

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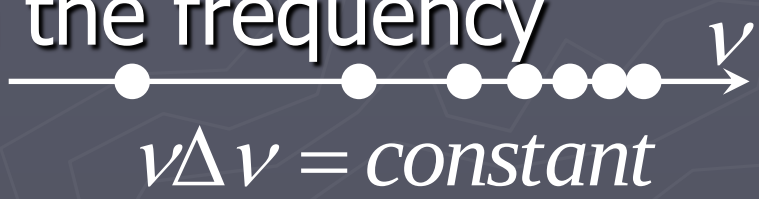
Abstract

- In wide-band observations, we can not integrate all frequencies to one point because of the difference on (u, v) plane.
- A simple simulation shows that images become more sharp in the frequency integration.
- We need some care for the uniform weighting.

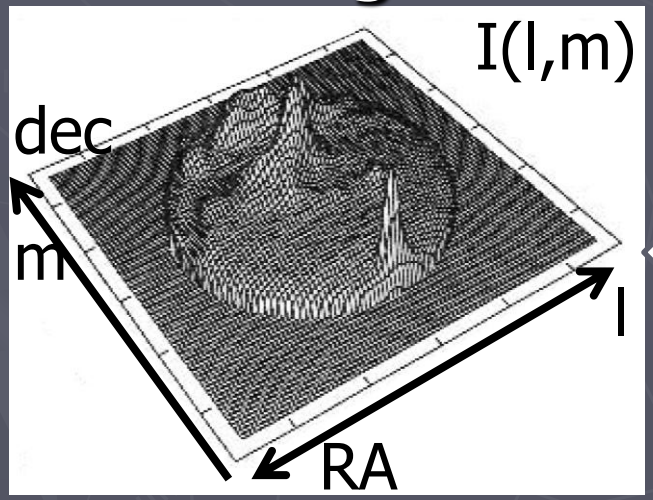


Synthesis Imaging

- Synthesized images are Fourier transforms of visibilities on (u, v) planes.

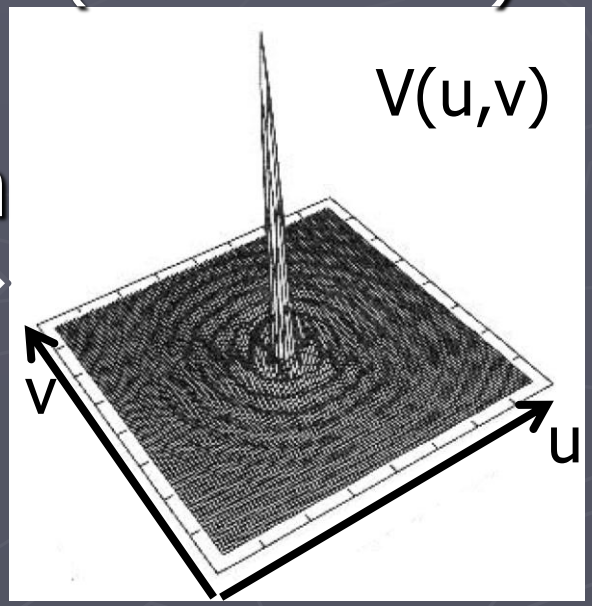
$$I(l,m) = \int_{-\infty}^{\infty} du \int_{-\infty}^{\infty} dv\, V(u,v) e^{2\pi i(ul+vm)}$$

Image



Fourier Transform

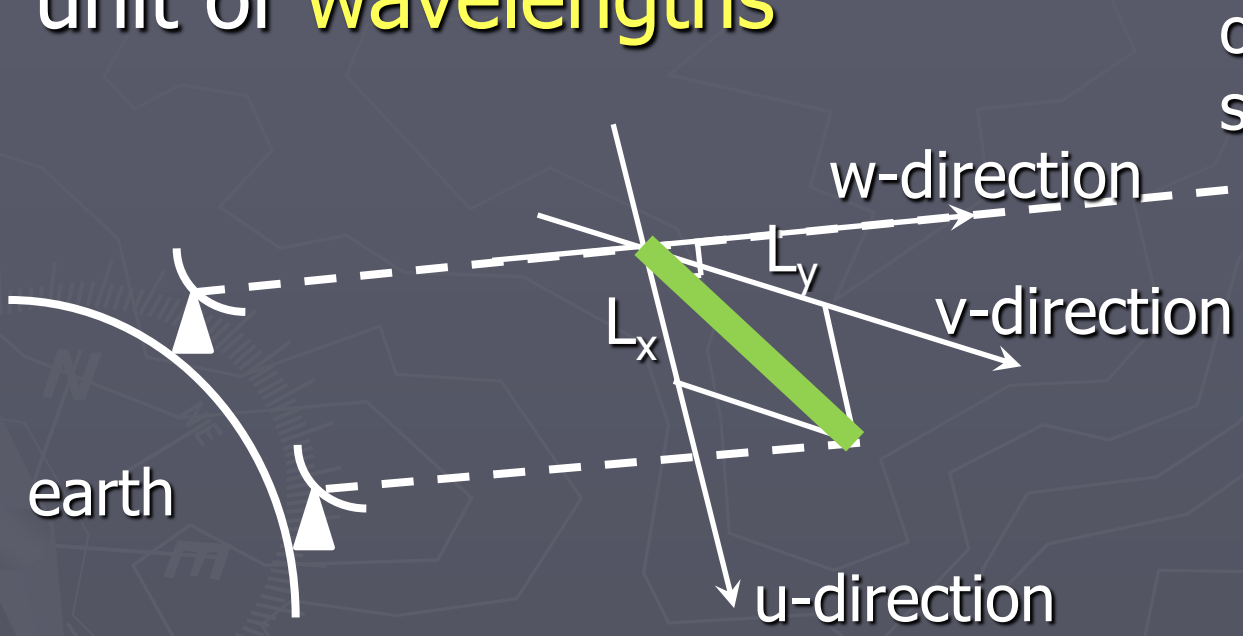
Visibilities (Observables)



(Taylor, Carilli & Perley ed. 1999)

What is (u, v)?

- (u, v) : Projected baseline lengths in the unit of wavelengths



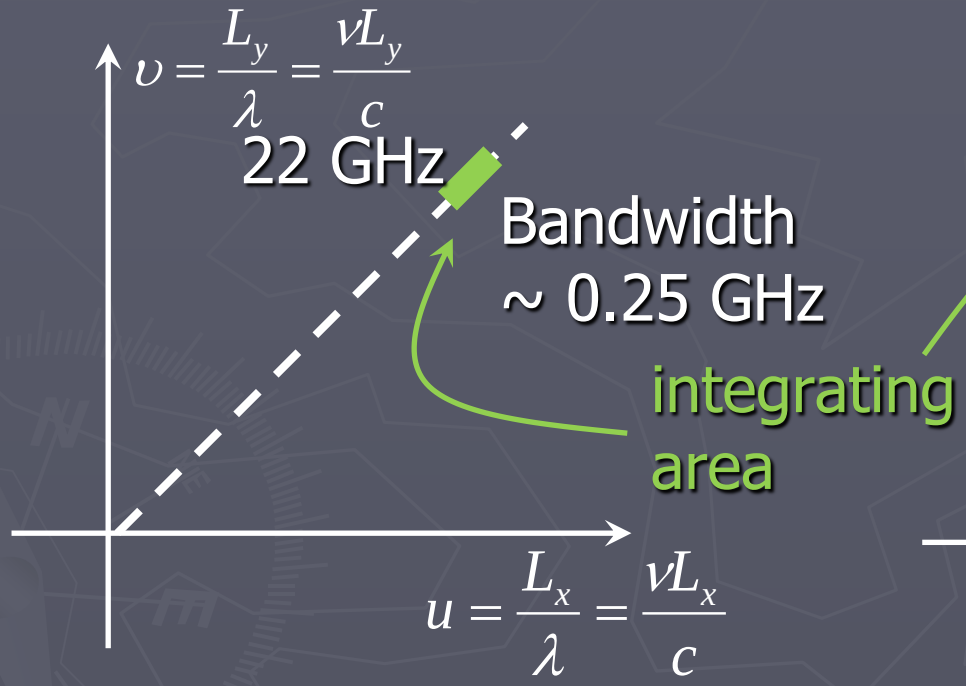
$$u = \frac{L_x}{\lambda} = \frac{\nu L_x}{c}$$

$$\upsilon = \frac{L_y}{\lambda} = \frac{\nu L_y}{c}$$

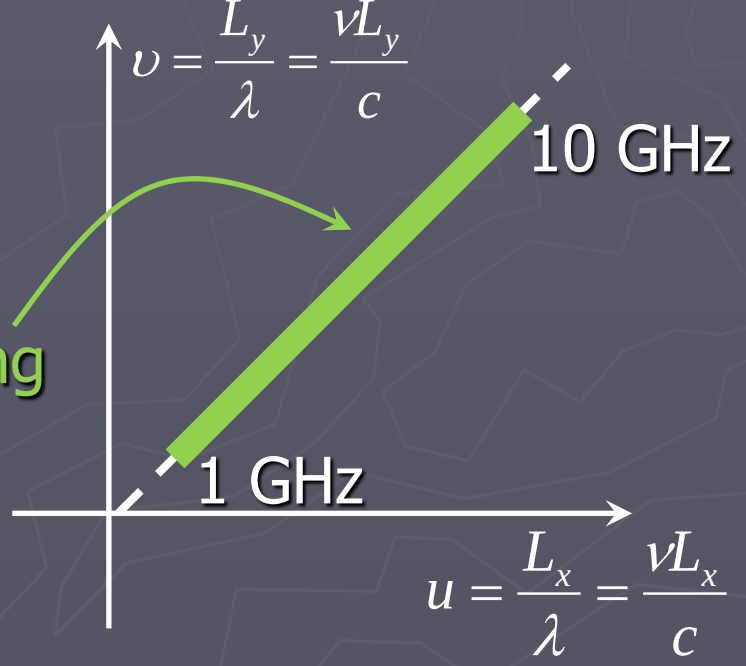
- (u, v)s depend on frequencies!

Problem in Wide-Band Observations

- e.g.) VERA



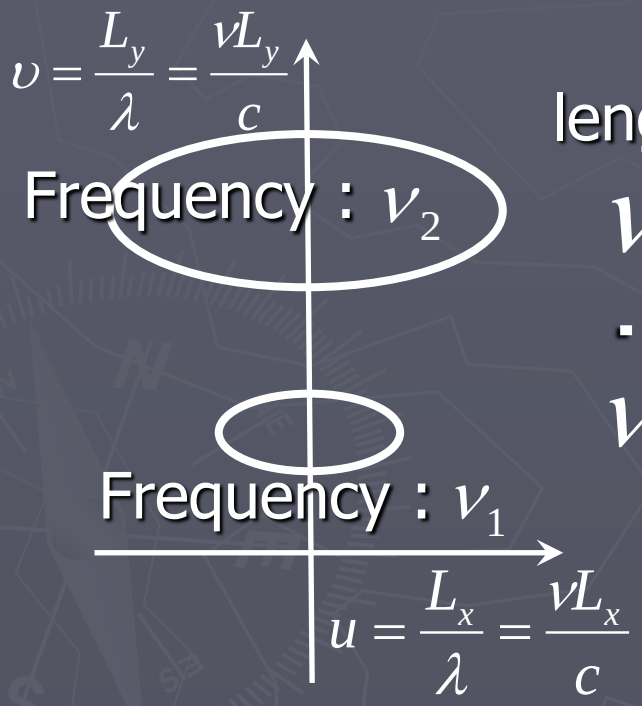
- 1 – 10 GHz band



- We can NOT ignore the effect of bandwidth in the case of wide-band observations.

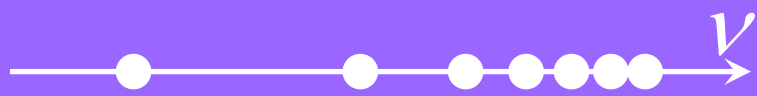
What Step Is Good for Frequency Integration?

- (u, v) change with the earth's spin.
- The loci are ellipses if we can observe for 24 hours.



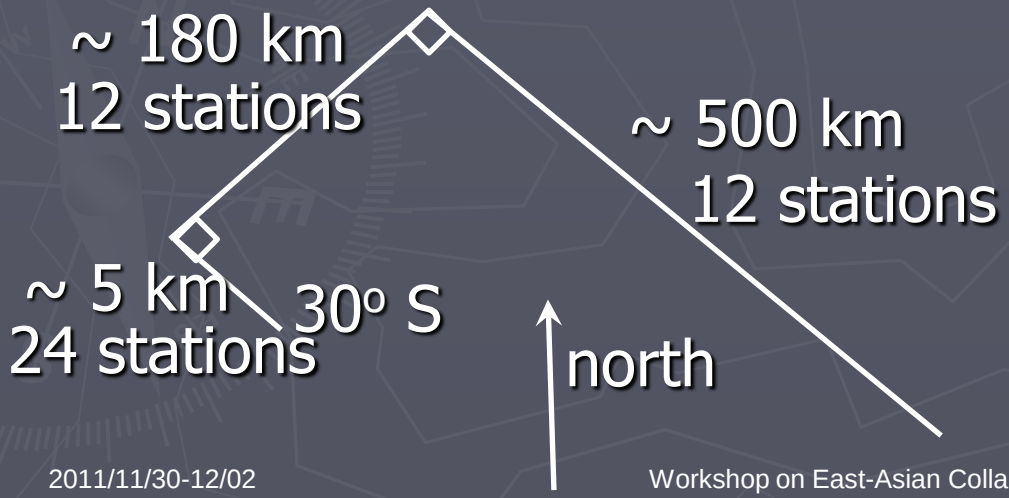
length	area
ν_2	$\nu_2 \Delta\nu_2$
..	..
ν_1	$\nu_1 \Delta\nu_1$

- The numbers of points are same for both loci.
- The point distribution is more uniform when $\nu\Delta\nu = constant$

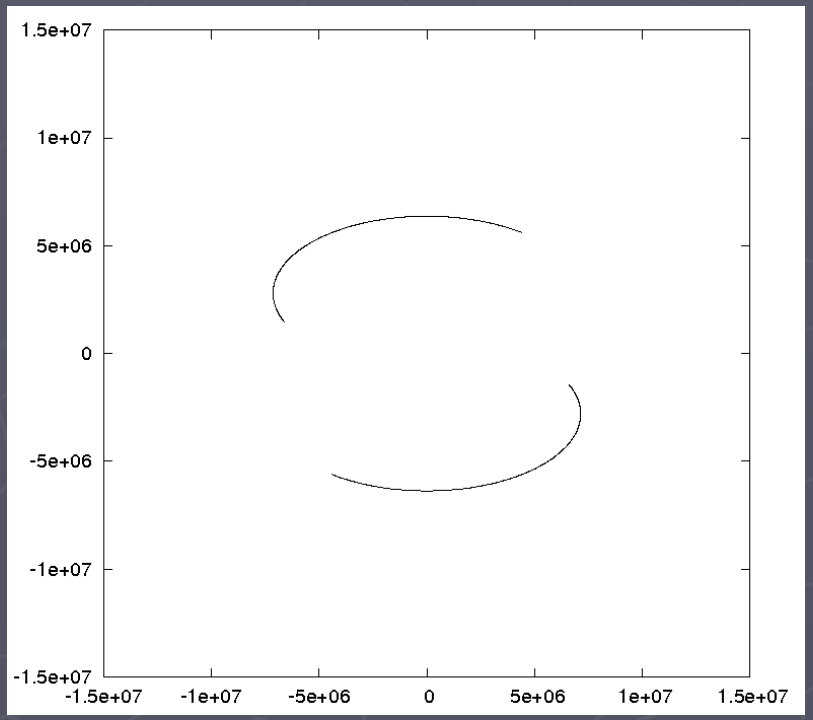


Simple Simulation

- Considering SKA…
  - Band : 1 – 10 GHz
  - 10-hour observation
  - Time step : 48 s
  - 48 stations



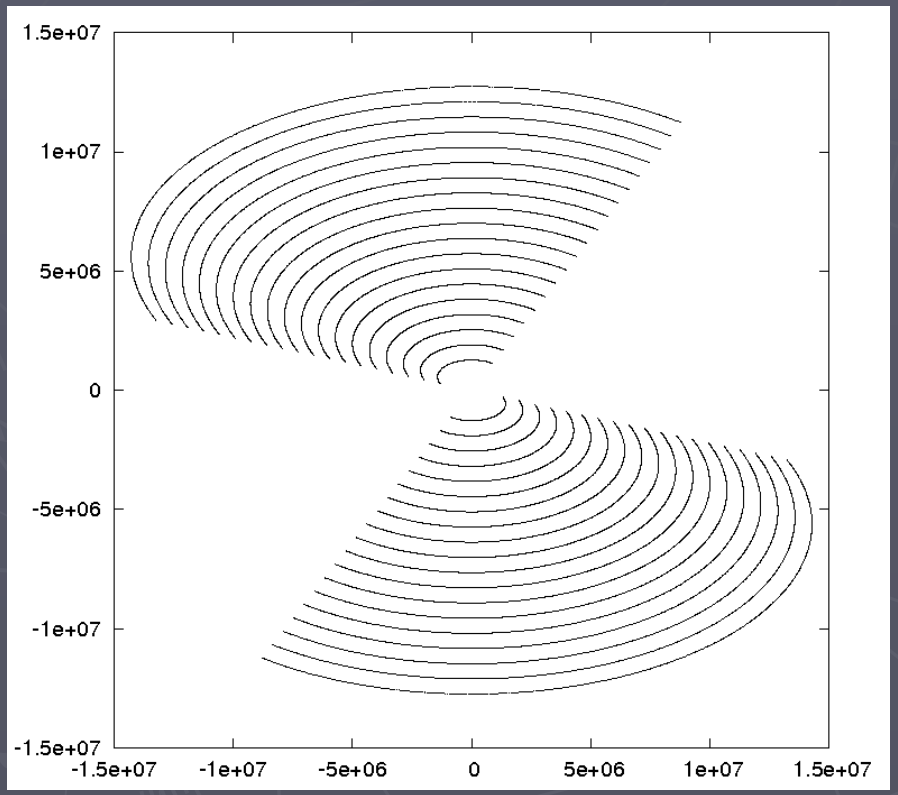
- uv loci of one baseline, one frequency point

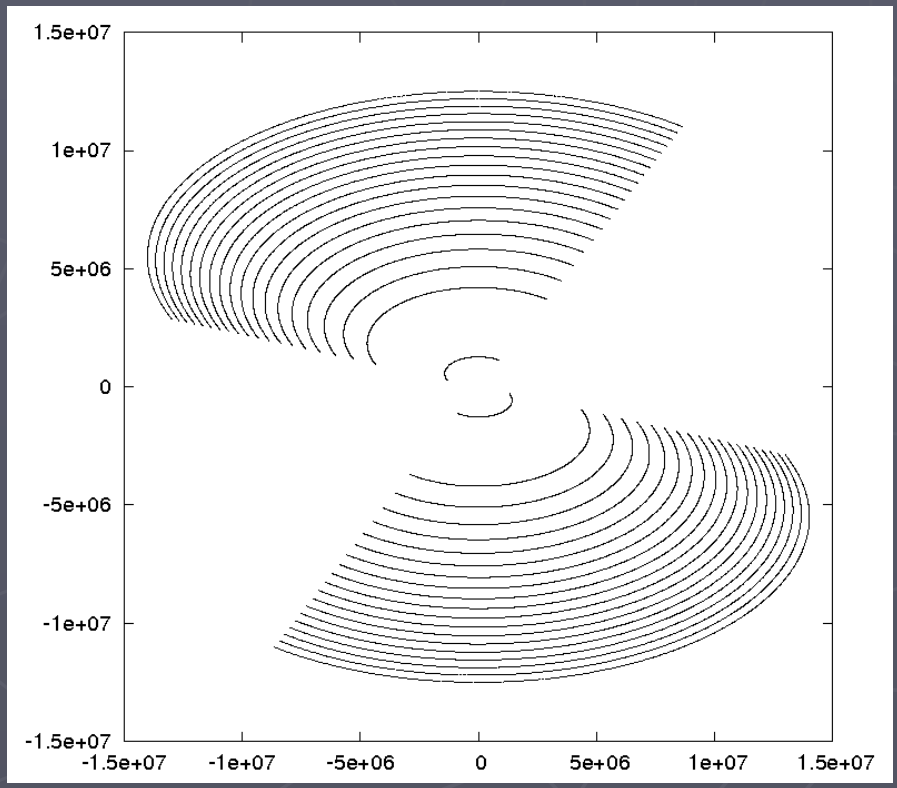


(u, v) Loci of One Baseline

$\Delta\nu = constant$

$\nu\Delta\nu = constant$

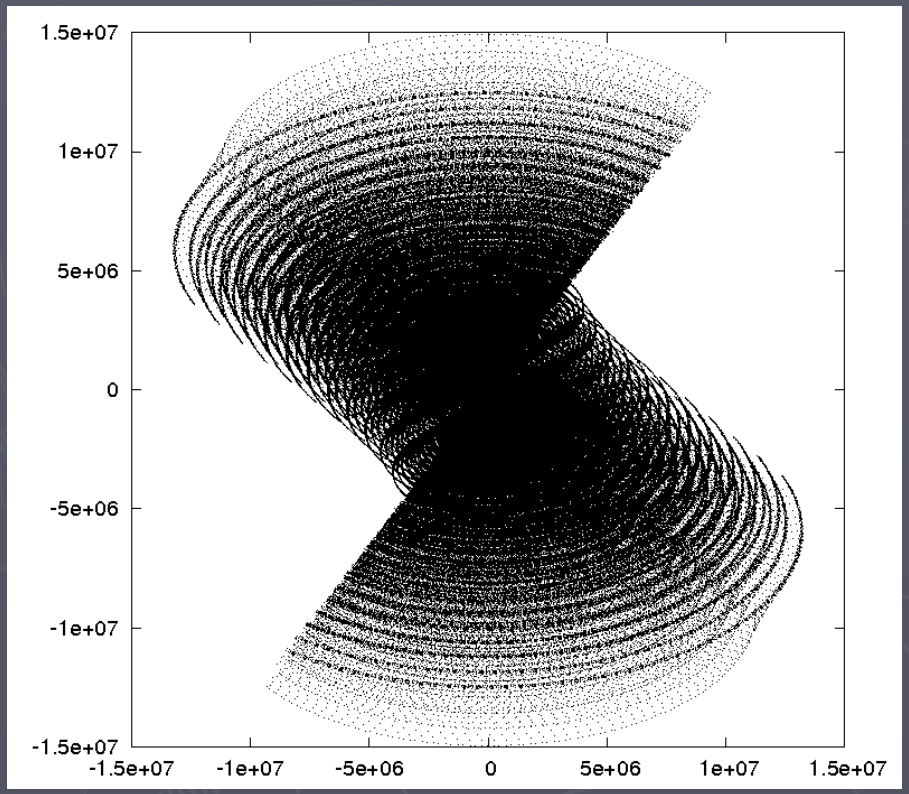


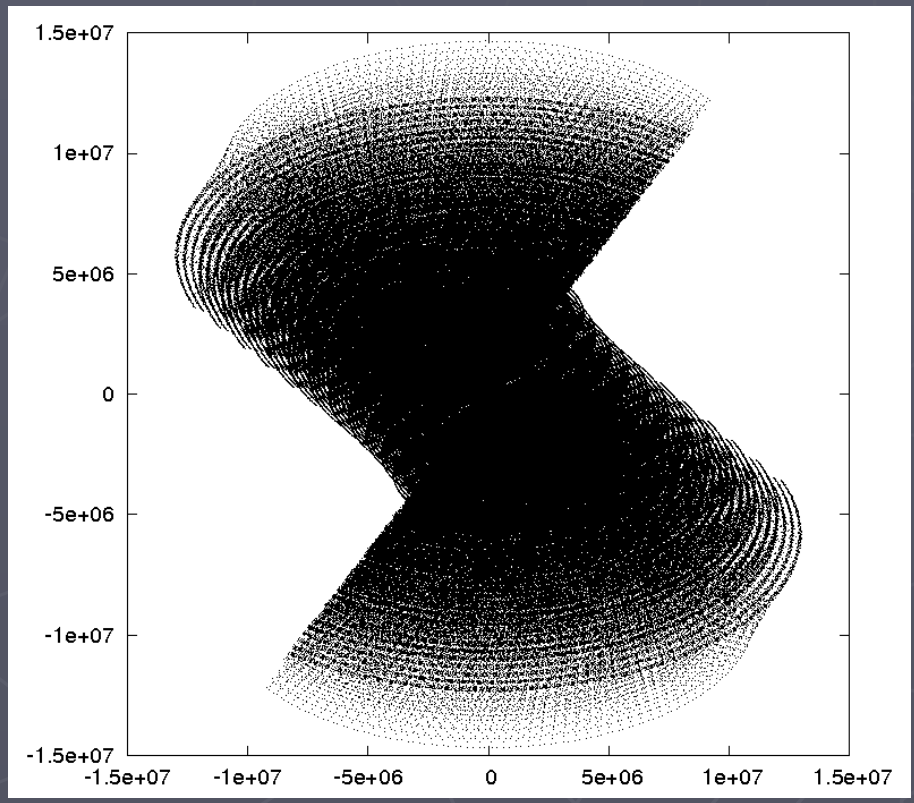


(u, v) Loci of All Baselines

$\Delta\nu = constant$

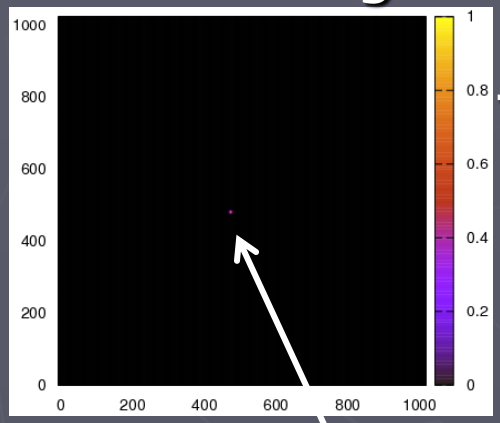
$\nu\Delta\nu = constant$





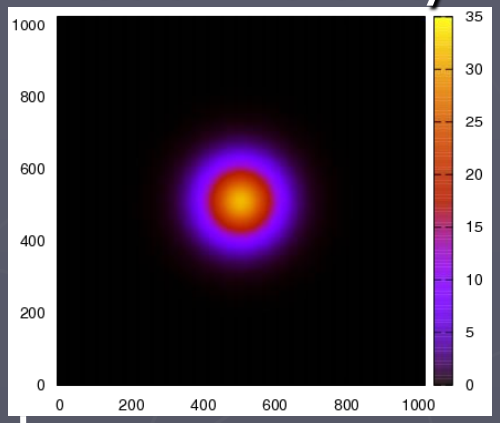
Imaging Simulation

Model Image



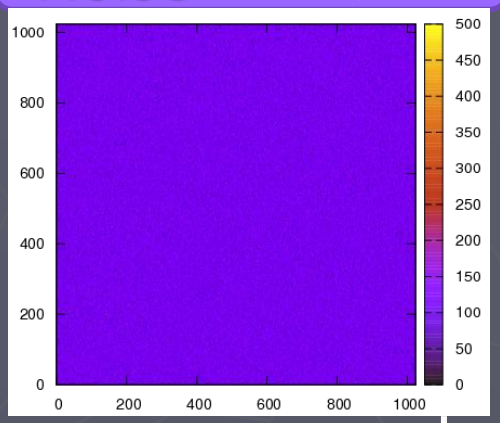
Fourier Transform

Model Visibility

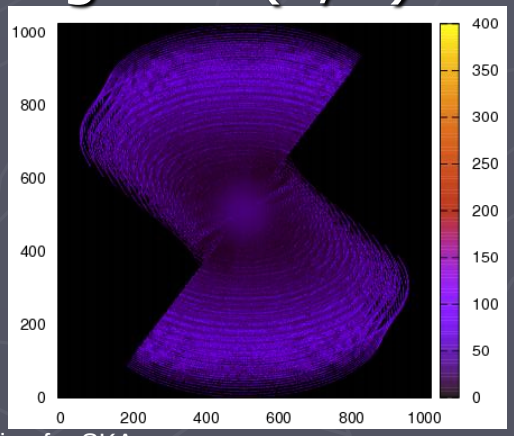


+

Noise $\propto 1/\sqrt{\Delta\nu}$



Gridding with (u, v) coverage



Fourier Transform

Result ?

Natural and Uniform Weighting

- Natural weighting
  - All data points have same weight

Weight of each data :

1 1

Weight of each grid :

3 1

- Uniform weighting
  - All grid points have same weight

Weight of each data :

1/3 1

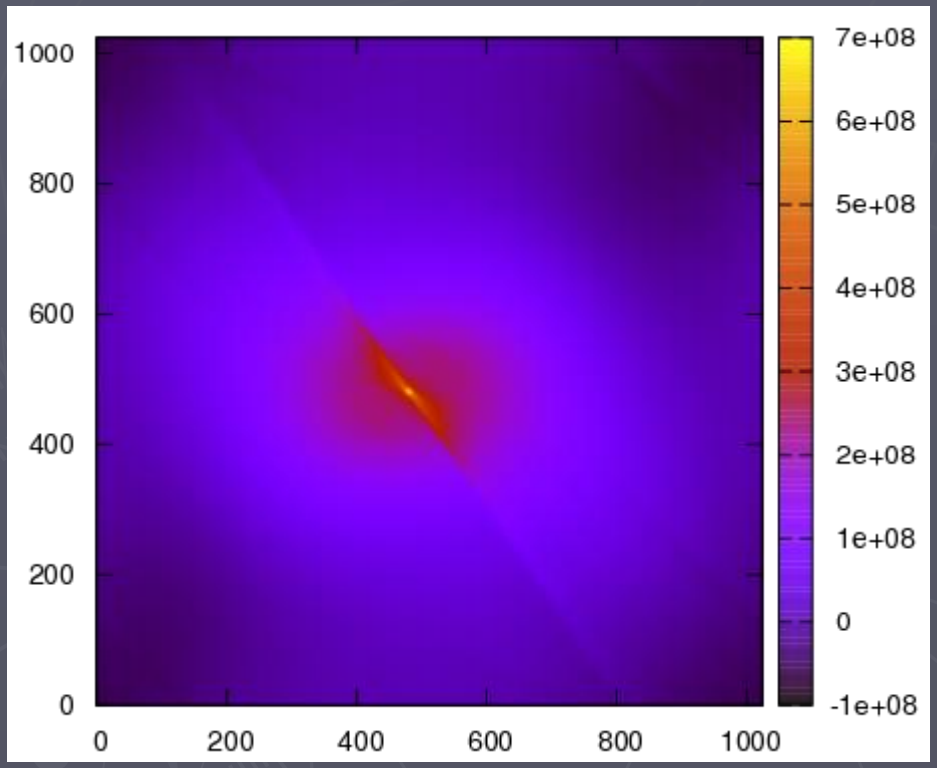
Weight of each grid :

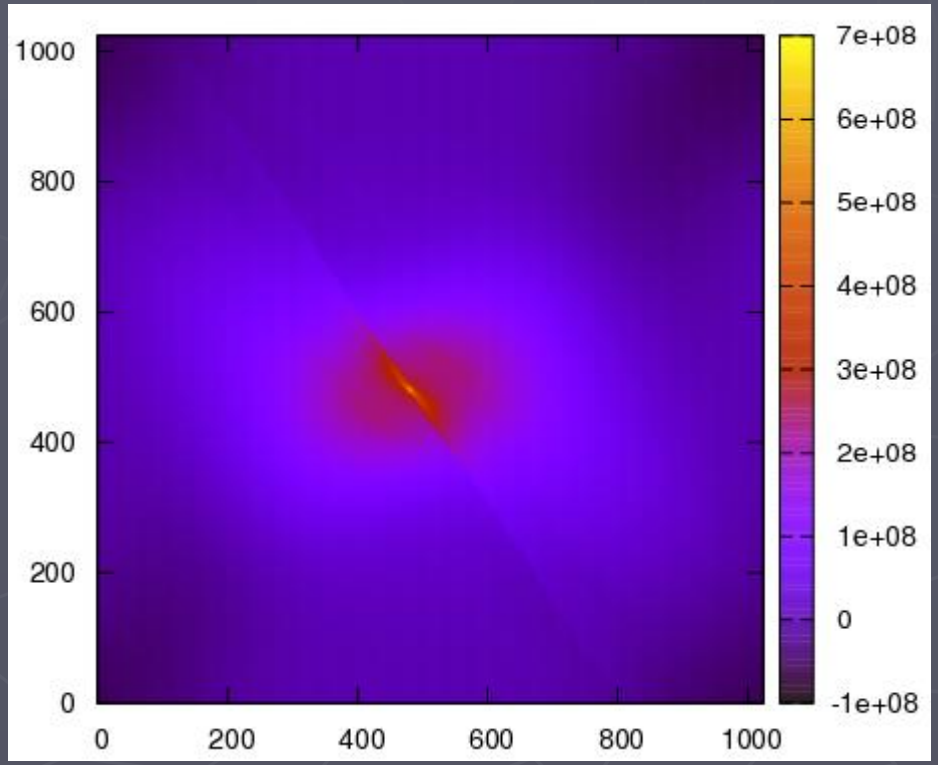
1 1

Results : Natural Weighting

$\Delta\nu = constant$

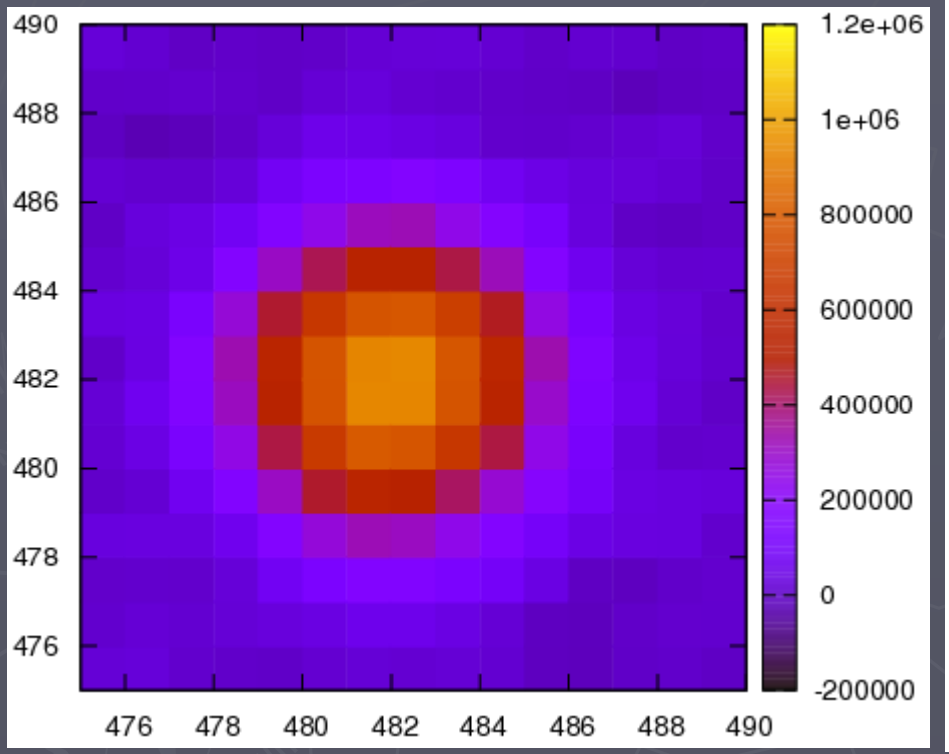
$\nu\Delta\nu = constant$



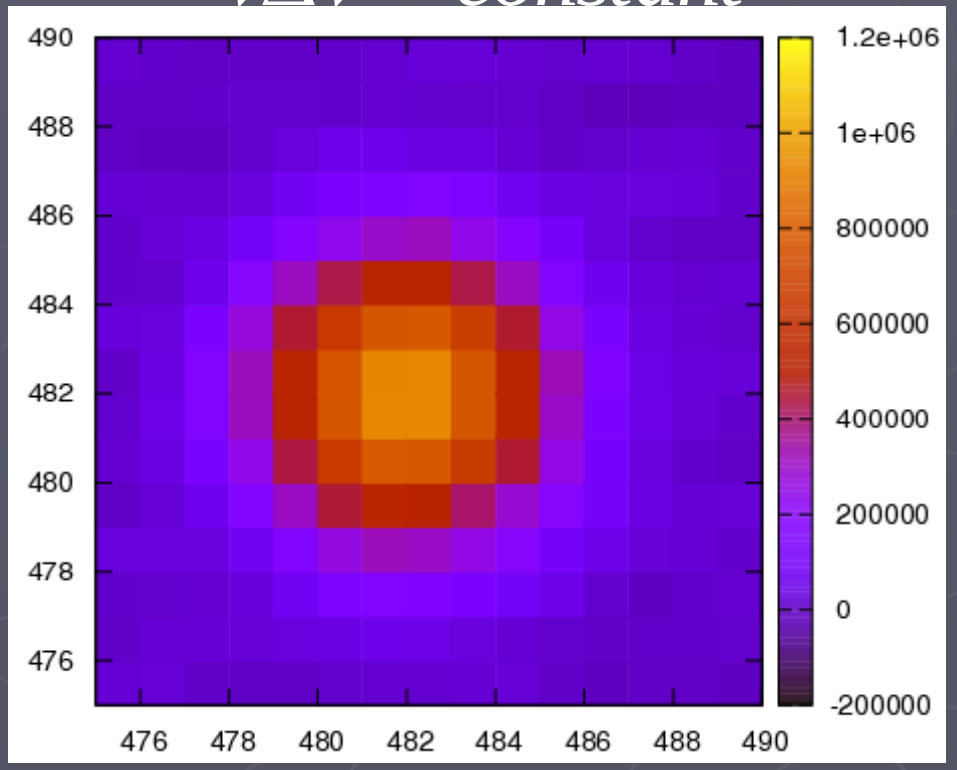


Results : Uniform Weighting

$\Delta\nu = constant$

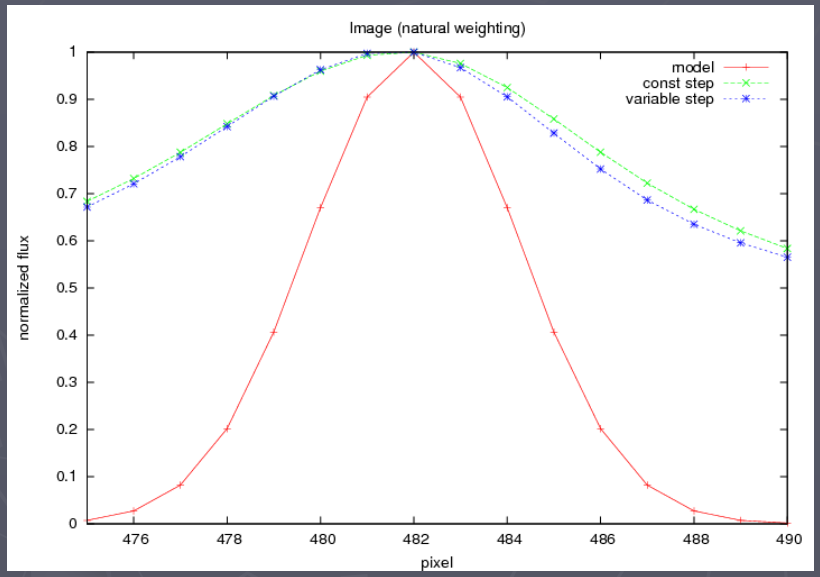


$\nu\Delta\nu = constant$

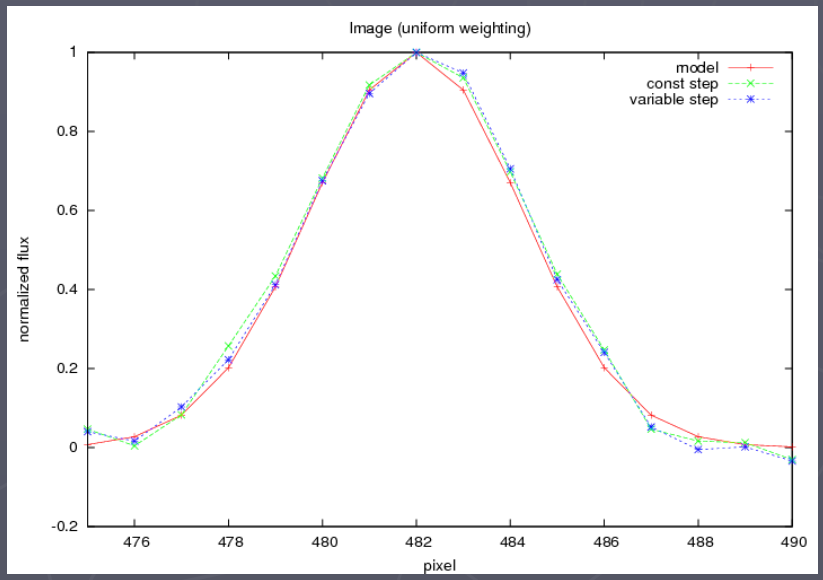


Comparison of Images

- Natural weighting



- Uniform weighting



Red : Model

Green : const step

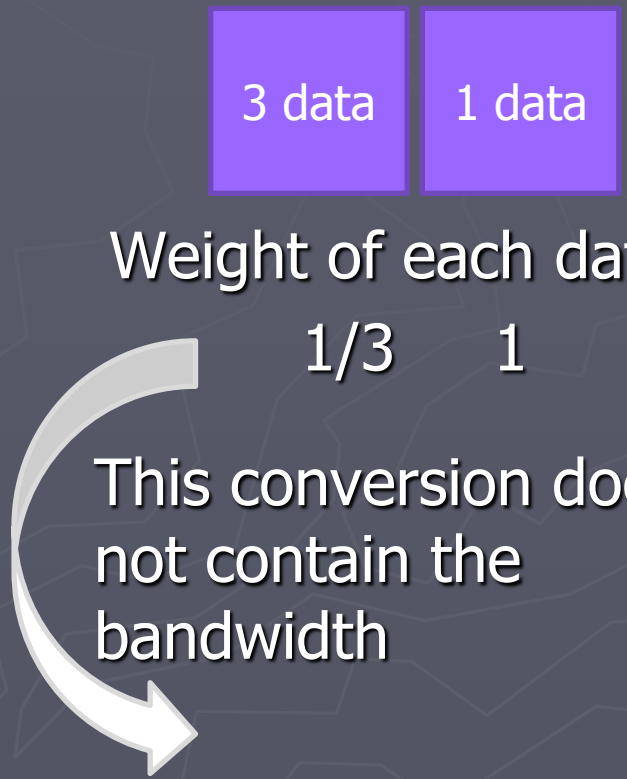
$\Delta\nu = constant$

Blue : variable step

$\nu\Delta\nu = constant$

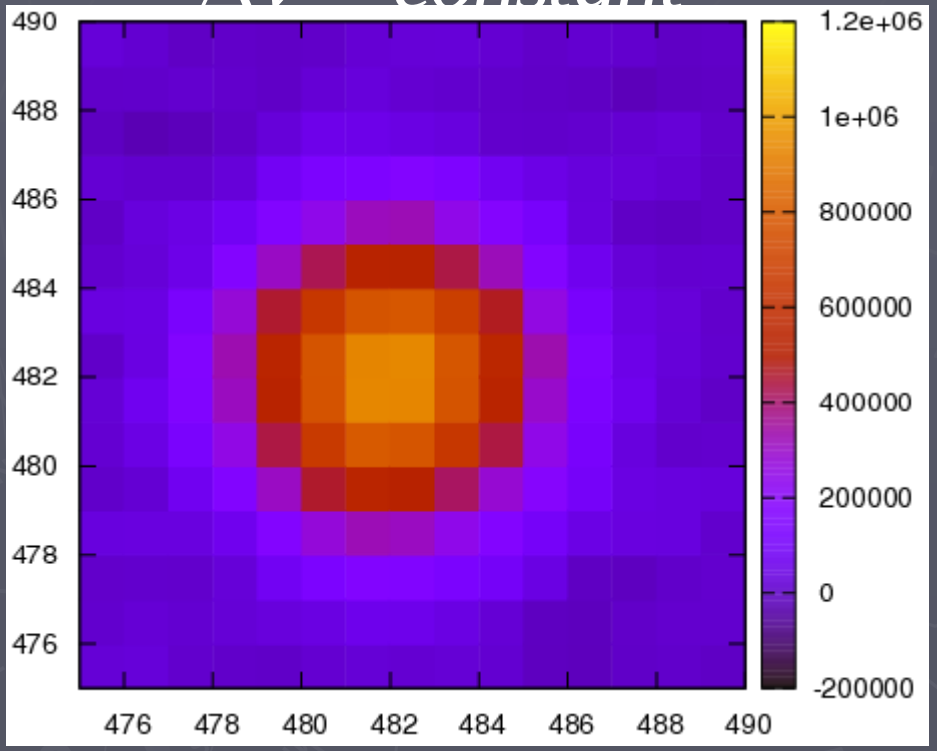
Are They Really "Uniform Weighting"?

- In variable-step frequency integration,
  - Bandwidths are different between points.
  - SNRs are also different.
- We must consider the bandwidths in the weighting process.

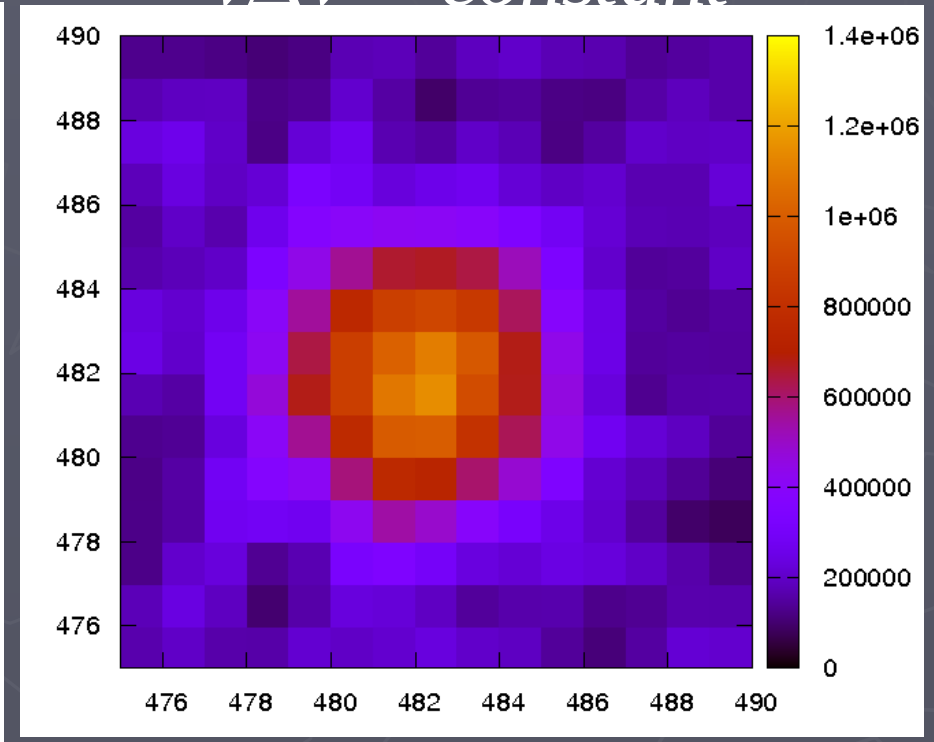


Results : Uniform Weighting Considering Bandwidths

$\Delta\nu = constant$



$\nu\Delta\nu = constant$

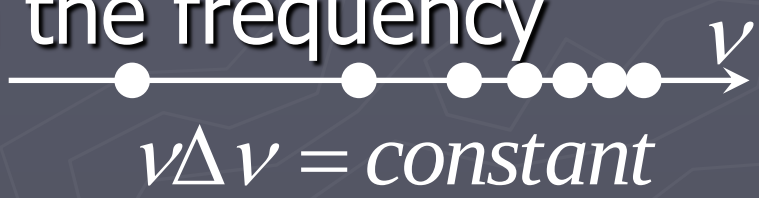


Test Observations with VERA

- 4 Gbps (bandwidth 1 GHz) facilities are installed for all four stations
- 8 Gbps (bandwidth 2 GHz) facilities are installed for three stations except Mizusawa
- (obs freq) : (bandwidth) = 22 GHz : 2 GHz
  = 10 : 1
- Extension of VERA, KVN, CVN, EAVN can be pilot observations for SKA

Summary

- In wide-band observations, we can not integrate all frequencies to one point because of the difference on (u, v) plane.
- A simple simulation shows that images become more sharp in the frequency integration.



- We need to consider the bandwidth of each data point for the uniform weighting.