中央研究院
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ACADEMIA SINICA
Institute of Astronomy and Astrophysics

ALMA Imaging WS 2026 9/2 ~ 9/4 @ ASIAA Taiwan

Updated version (September 5)

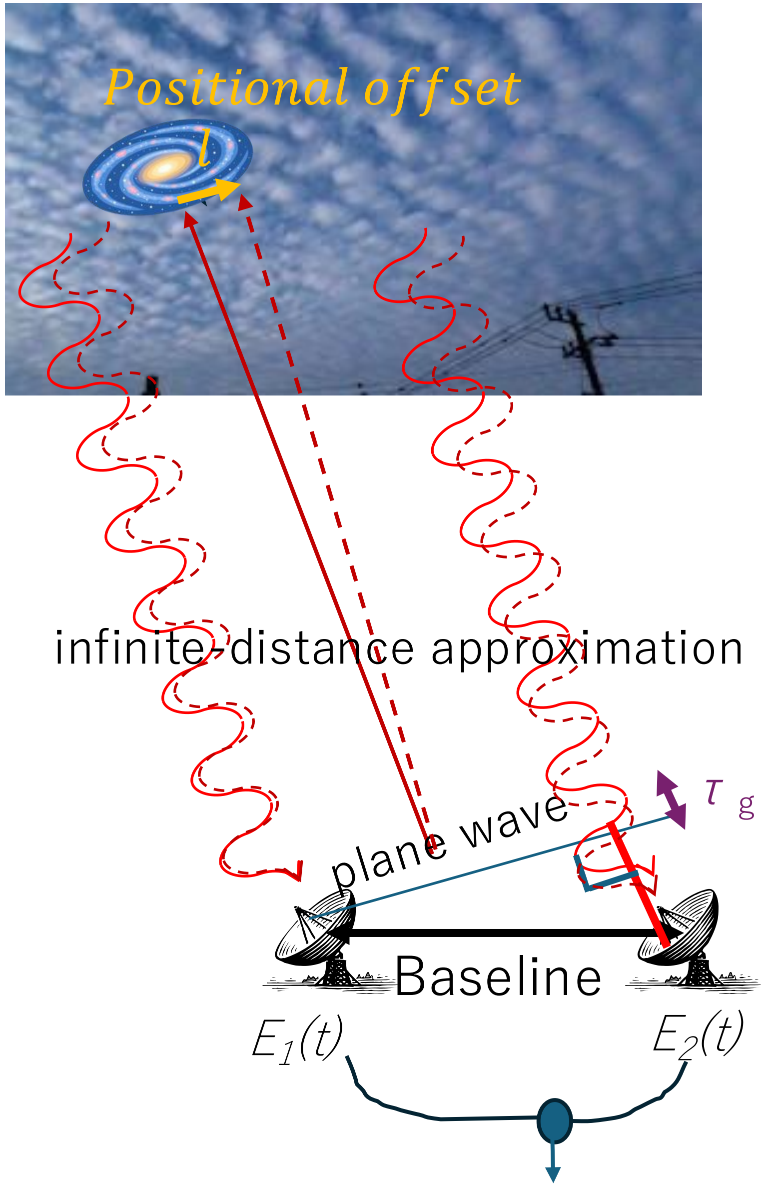
Self-Calibration

2026 9/4

Kazuya Saigo (ASIAA)

- Review the **basic concepts of interferometry**
- Review **standard ALMA calibration**
- Get an overview of **self-calibration and its workflow**
- Perform self-calibration **step by step using real ALMA data**
- Go home as a **master of ALMA imaging and self-calibration**!

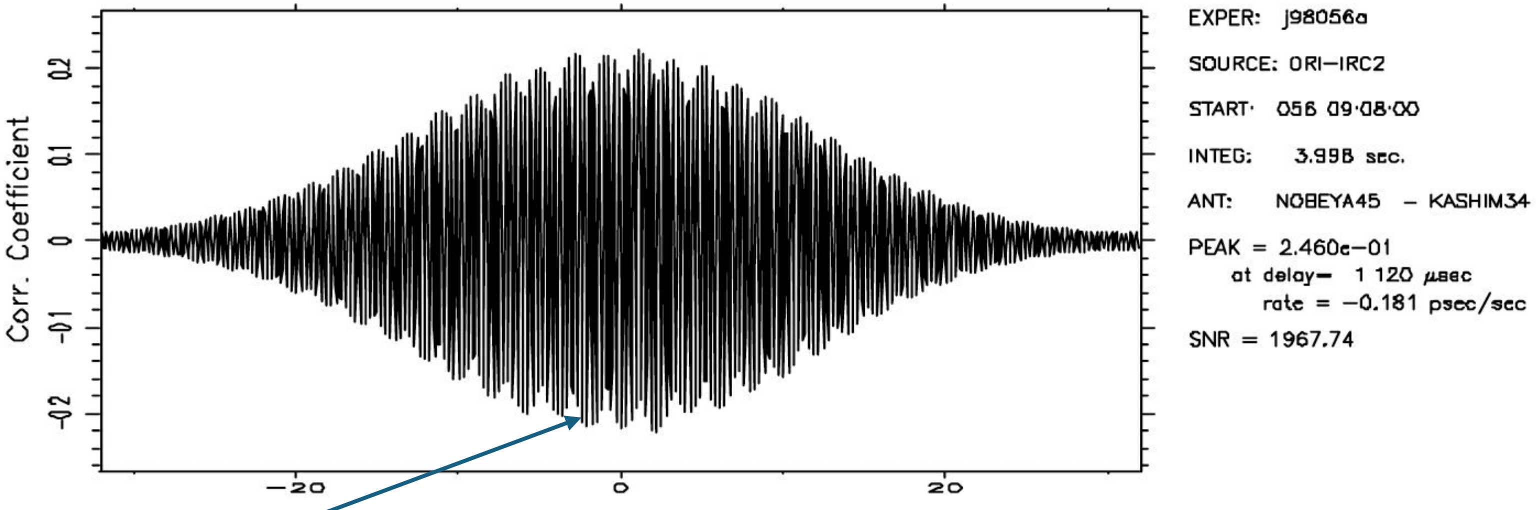
Basic Concept of Interferometry 1/2



A positional offset of the source produces a geometric path-length difference, resulting in a phase shift.

⇔ geometric delay (τ_g).

$E_1(t)\,E_2^*(t - \tau_g)$ a fringe pattern

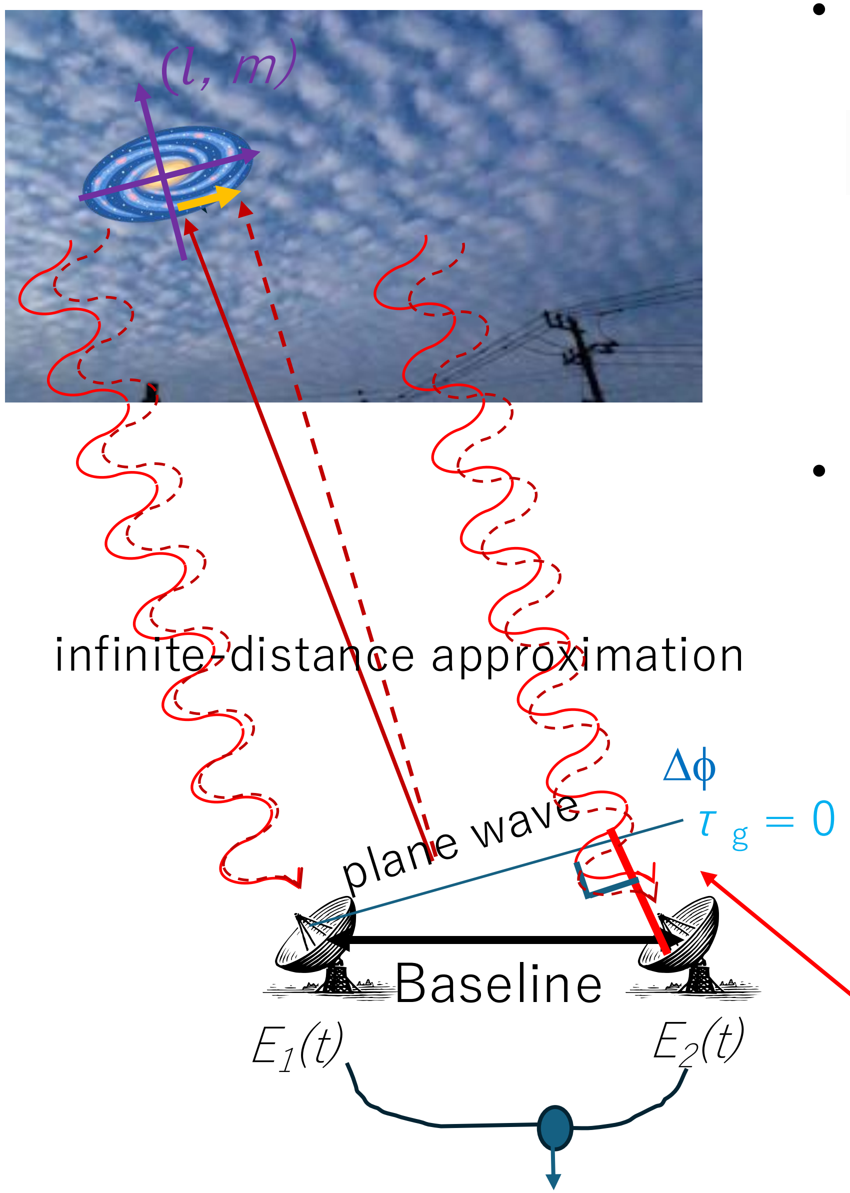


geometric delay τ_g (μsec)

Each cycle of the rapid oscillations corresponds to a phase shift of 2π.

An interferometer measures the phase differences caused by a source's position on the sky.

Basic Concept of Interferometry 2/2



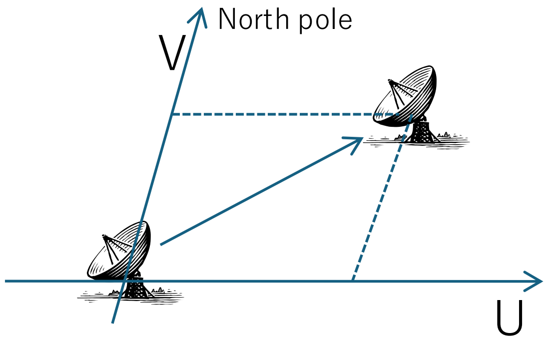
- By averaging the product $E_1(t)\ E_2^*(t)$ over time, we obtain a complex quantity, $\langle E_1(t)\ E_2^*(t)\rangle_t$ called the visibility:

$$V(u, v) = \iint I(l, m) \exp[-2\pi i(ul + vm)]\, dl\, dm$$

This yields a spatial Fourier component of the sky brightness distribution.

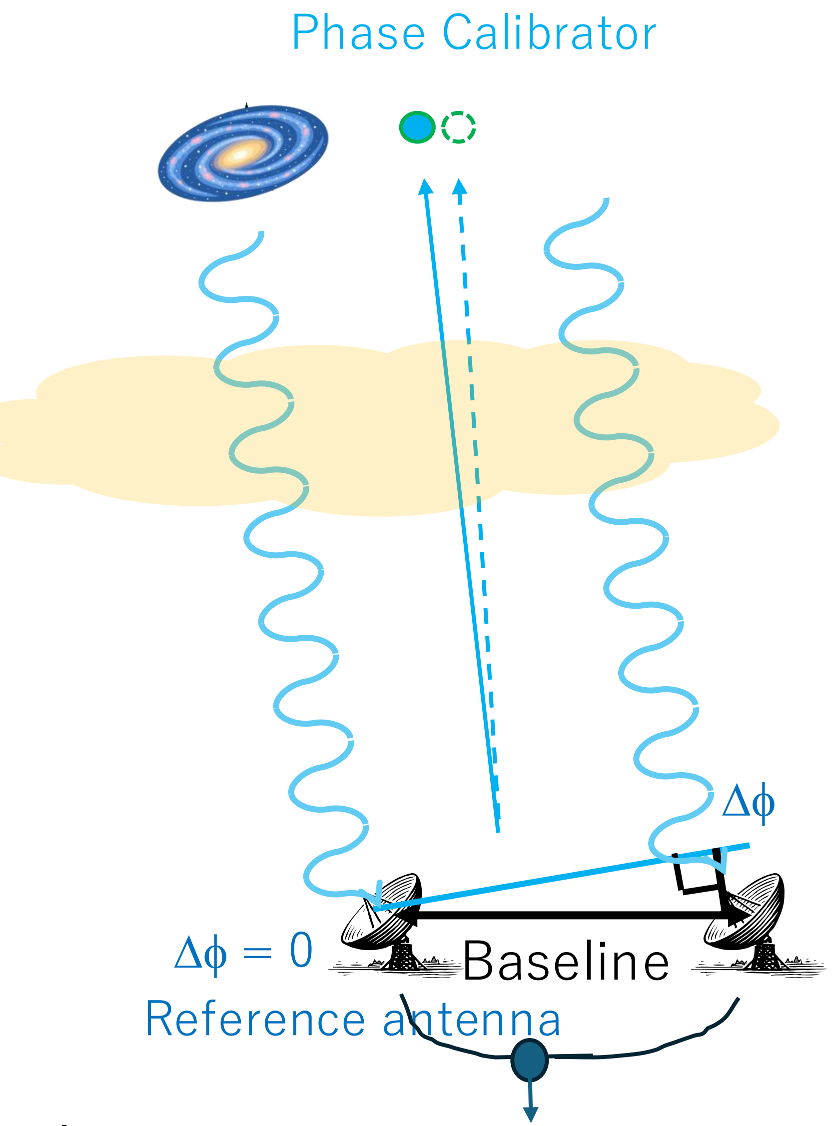
(van Cittert–Zernike theorem)

- By collecting these visibilities from many baselines and performing an inverse Fourier transform, we can reconstruct an image of the source.



We need to measure **the phase offsets from an ideal plane wave** arriving from a given direction. This corresponds to defining the origin of the sky coordinates (so-called phase center).
How can we do this?

Standard ALMA Calibration Procedures



1. Observe nearby phase calibrator (a bright point source).
   It should be close to the target to probe similar atmospheric conditions.

2. We correct the phase offsets and gain for each antenna so that the measurements from all baselines are consistent with the phase calibrator being a point source at the same position and with the same flux density.
   ** This calibration is performed in the visibility domain.*

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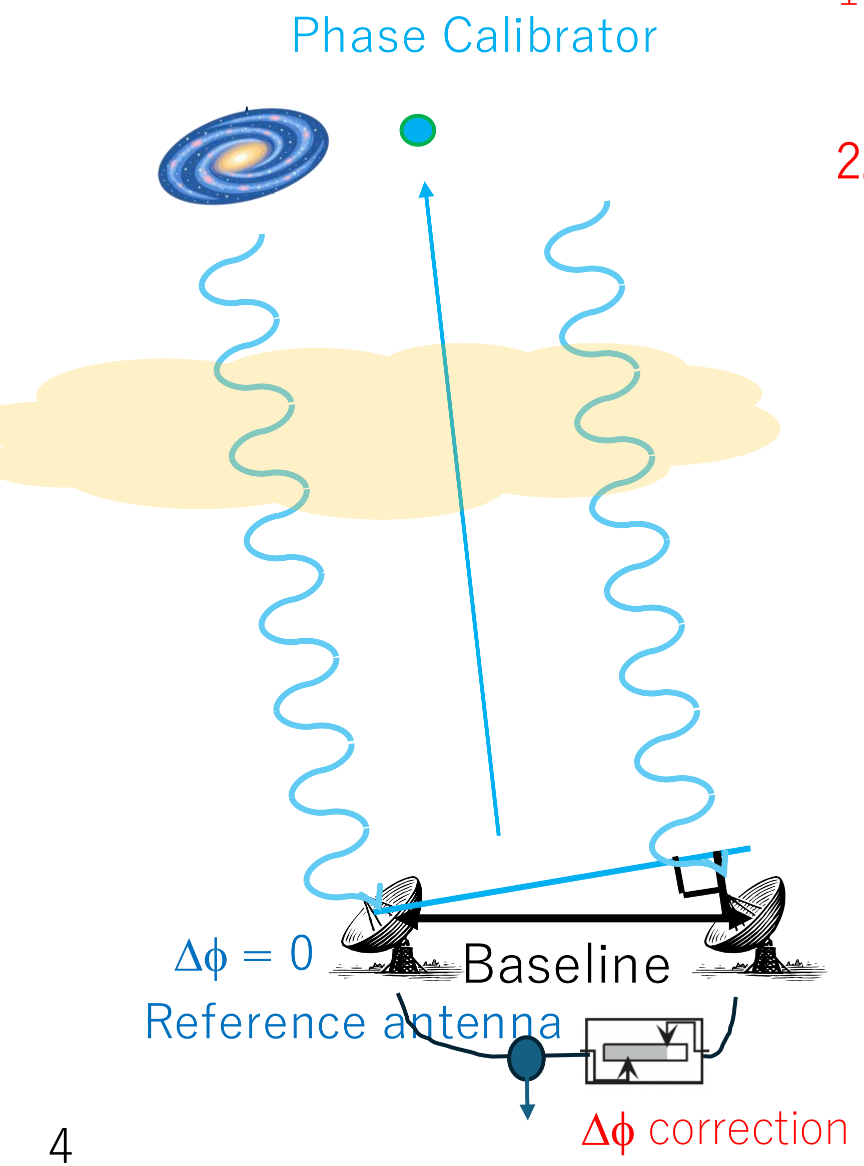

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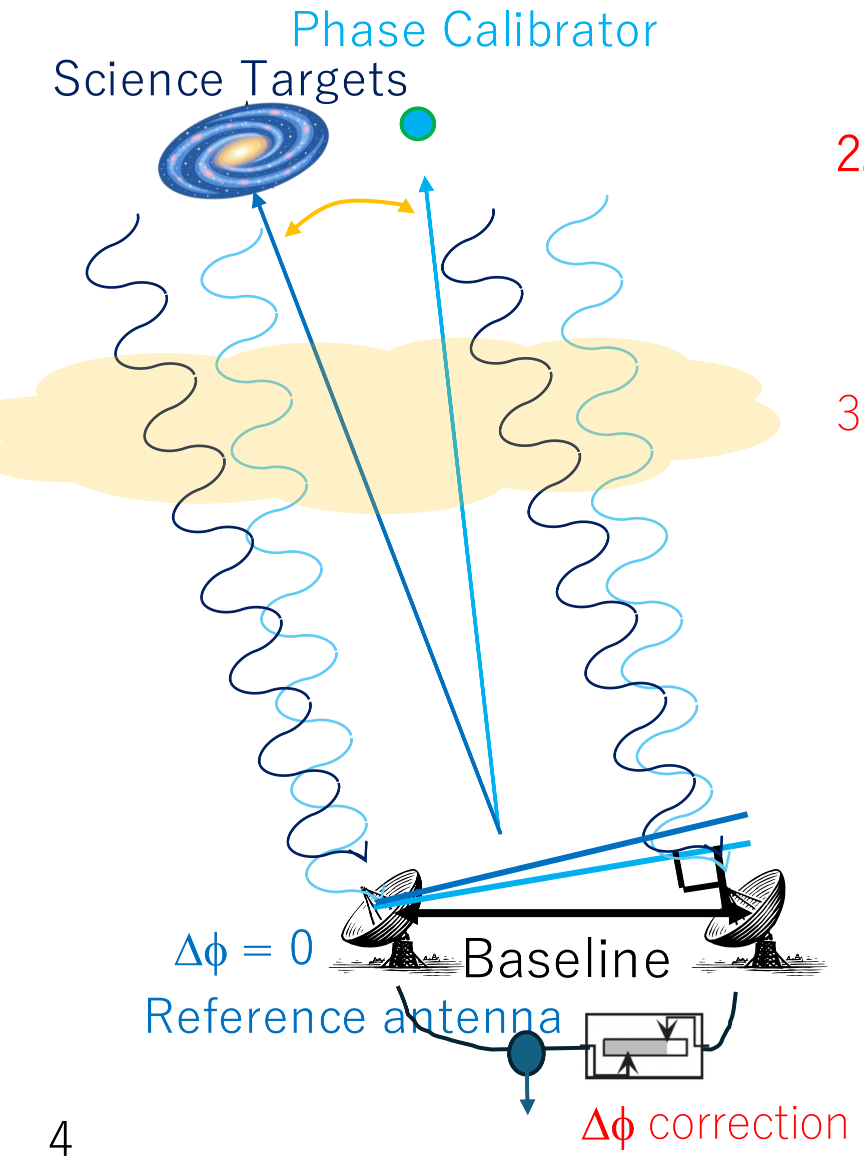

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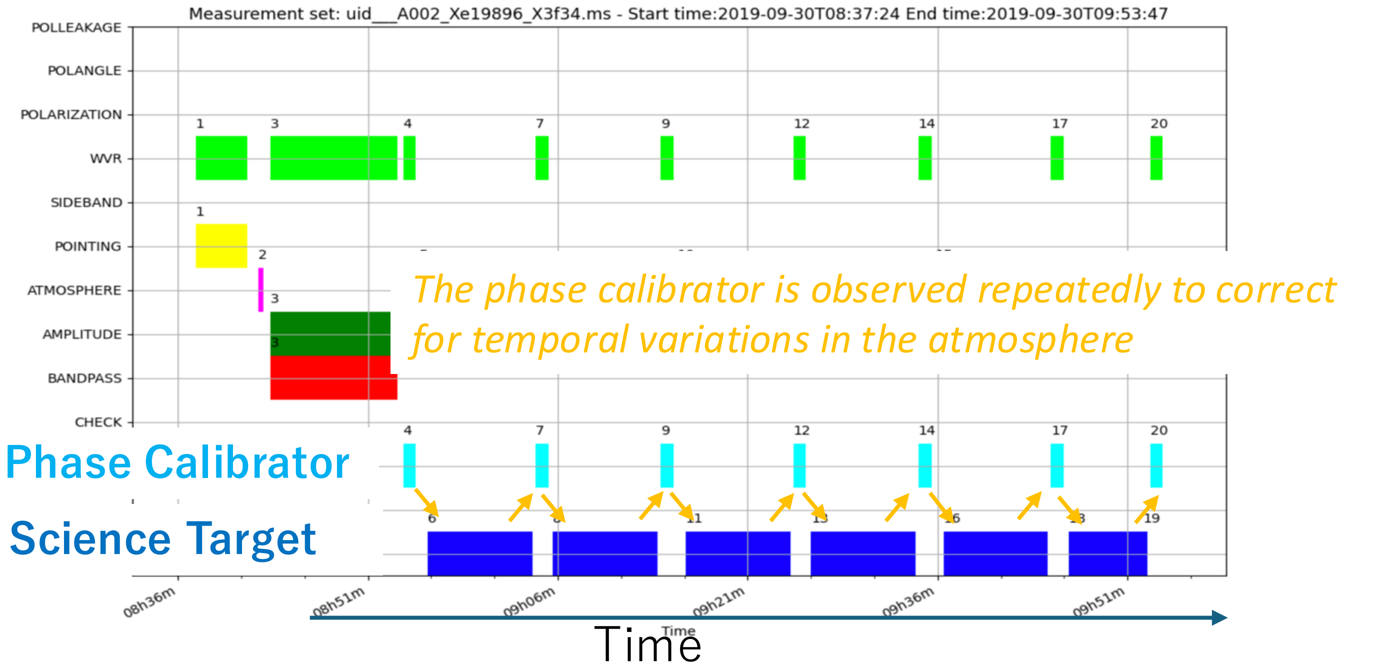
2. We correct the phase offsets and gain for each antenna so that the measurements from all baselines are consistent with the phase calibrator being a point source at the same position and with the same flux density.
   ** This calibration is performed in the visibility domain.*

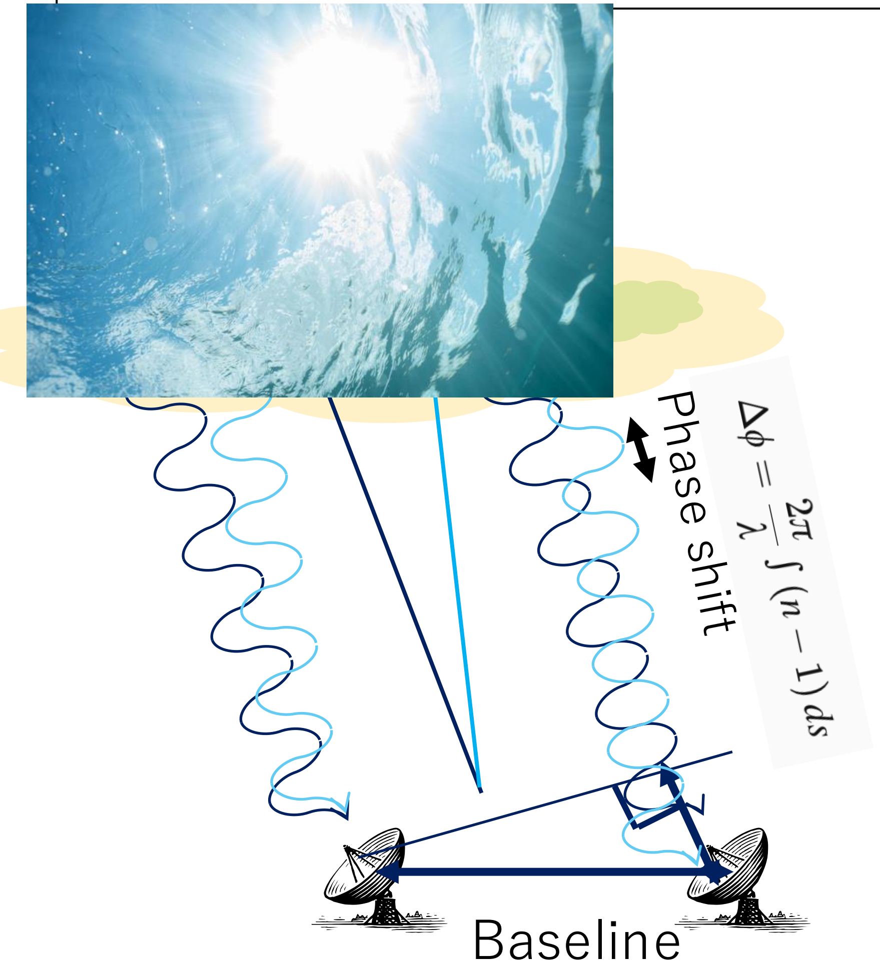
3. We apply the correction values to the target observations.

Example of an actual ALMA observing sequence from Weblog (2018.A.00061.S)



Limitations of Standard Calibration

Phase calibrator and science target are observed in different directions and at different times.
A non-uniform and time-variable atmospheric refractive index n (radio "seeing") and the atmospheric refraction introduces different phase shifts at each antenna. ➔ Residual phase errors



Simulations predicted residual phase errors (Table 4 of ALMA Memo 523)

Band (Freq. GHz)	Median Residual Phase RMS
Band 3 (90GHz)	~ 20 deg
Band 6 (230GHz)	~25 deg
Band 7 (345GHz)	~ 30 deg
Band 8-10 (490GHz ~ 850GHz)	30 deg ~ 40 deg

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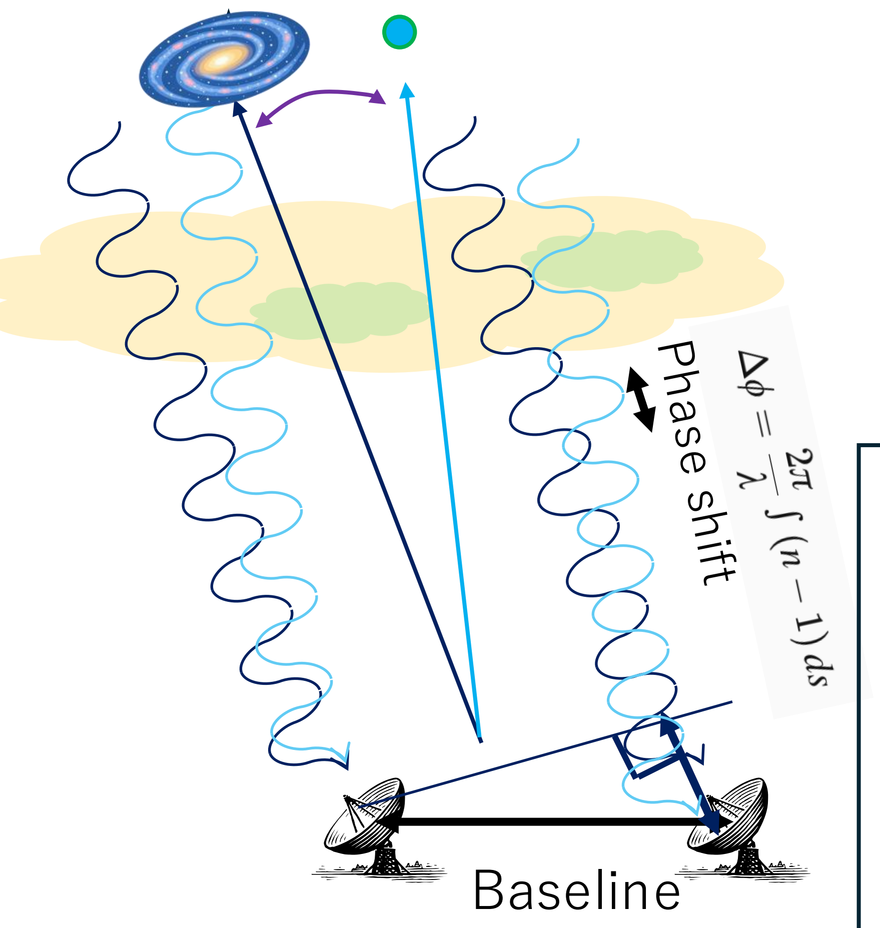

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Effects of the residual phase errors

✓ Coherence loss ➔ reduced visibility amplitude and peak intensity

Assuming random phase errors, Phase RMS ~ 30° ⇔ the coherence loss ~13%

✓ Image blurring ➔ degraded effective angular resolution and distorted image

✓ Imaging artifacts ➔ spurious features around bright emission

➔ Limited dynamic range (see. *ALMA Cycle 13 Proposer's Guide*)

In high-dynamic-range images (≳50–100), residual calibration errors may affect image quality by producing sidelobe-like artifacts.

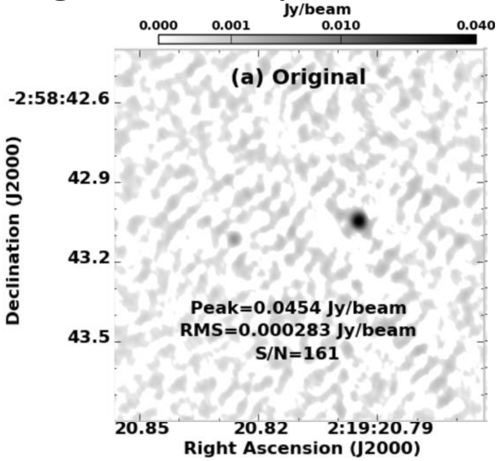
Motivation of Self-Calibration

Self-calibration is a technique that uses the science target itself as a phase calibrator. ➔ Reduces phase errors

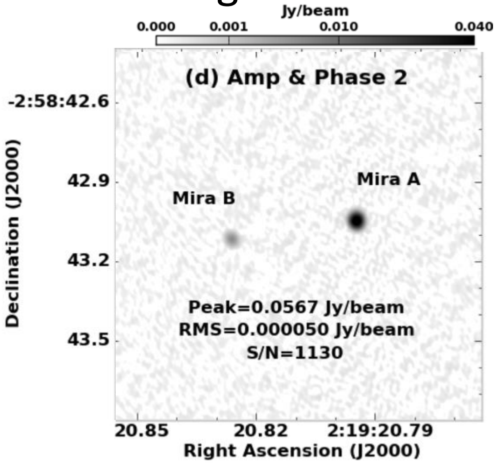
Benefits of Self-Calibration

- ✓ Reduce coherence loss and artifacts
  ➔ Improves image quality; the image S/N can increase by a factor of several under favorable conditions.
- ✓ For sufficiently bright targets, self-calibration enables reliable imaging at dynamic ranges well above 100 (*see the ALMA Cycle 13 Proposer's Guide, Appendix A.9.1).*

CLEAN Image after only Standard Calibration



CLEAN Image after Self-Calibration



Brogan et al. (2018)
https://arxiv.org/pdf/1805.05266

ALMA Science Verification data at 1.3 mm (Band 6) for the Asymptotic Giant Branch star Mira

Over the past several years, self-calibration has become increasingly common for ALMA data, particularly for (bright) continuum sources and, broad spectral lines.
Ex. Some referees often ask authors to perform self-calibration to improve image quality.

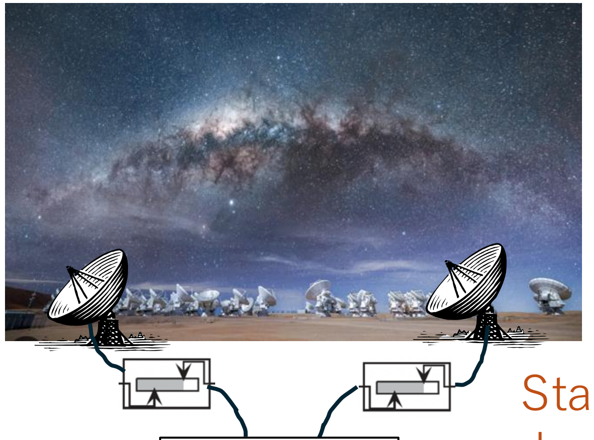
Limitations of Self-Calibration

Self-calibration has many limitations and requires careful application.

Limitations of Self-Calibration

- ✓ The results may differ depending on how self-calibration is performed. In some cases, the results may not be reliable. You should understand the procedure and carefully check the results at each step.
  In particular, if the signal-to-noise ratio of the target is too low, we can not obtain reliable phase corrections.
- ✓ Some caution is needed for studies requiring accurate astrometry.
  Absolute target position is established by phase referencing to a phase calibrator with a known position. Self-calibration applies additional phase corrections relative to the target model and therefore does not provide an independent absolute astrometric reference.
- ✓ It does not improve the nominal synthesized beam size.
  The beam size is determined primarily by the observing wavelength, antenna configuration, and visibility weighting.

How to get Self-Calibrated Data



correlator

Calibrated data

Data (Visibility + info.)
Calibration table and calibration scripts
Reference (product) images
Report about calibration (QA 2 report, weblog,,)

Standard Calibration
by ALLMA observatory

raw data

Visibility

$$V(u,v) = \iint I(l,m)\exp[-2\pi i(ul+vm)]\,dl\,dm$$

A huge table of complex Fourier components sampled for each baseline, frequency channel, polarization, and time step.

+ obs. Info. (time, frequency, atmospheric obs. info., etc.)
+ header info. (calibrator info. , Antenna positions, etc.)
+ QA0 report

Users

Download from ALMA archive
Apply calibration table

Calibrated Measurement Set (MS).

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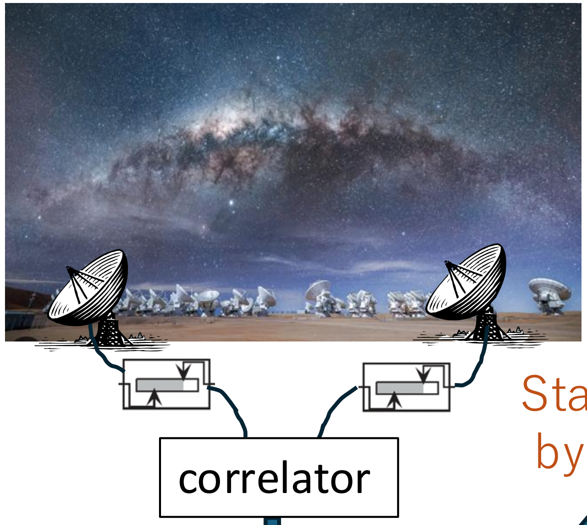

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Users

Download from ALMA archive
Apply calibration table

Calibrated Measurement Set (MS).

Perform self-calibration yourself using the calibrated MS.

Self-calibrated MS

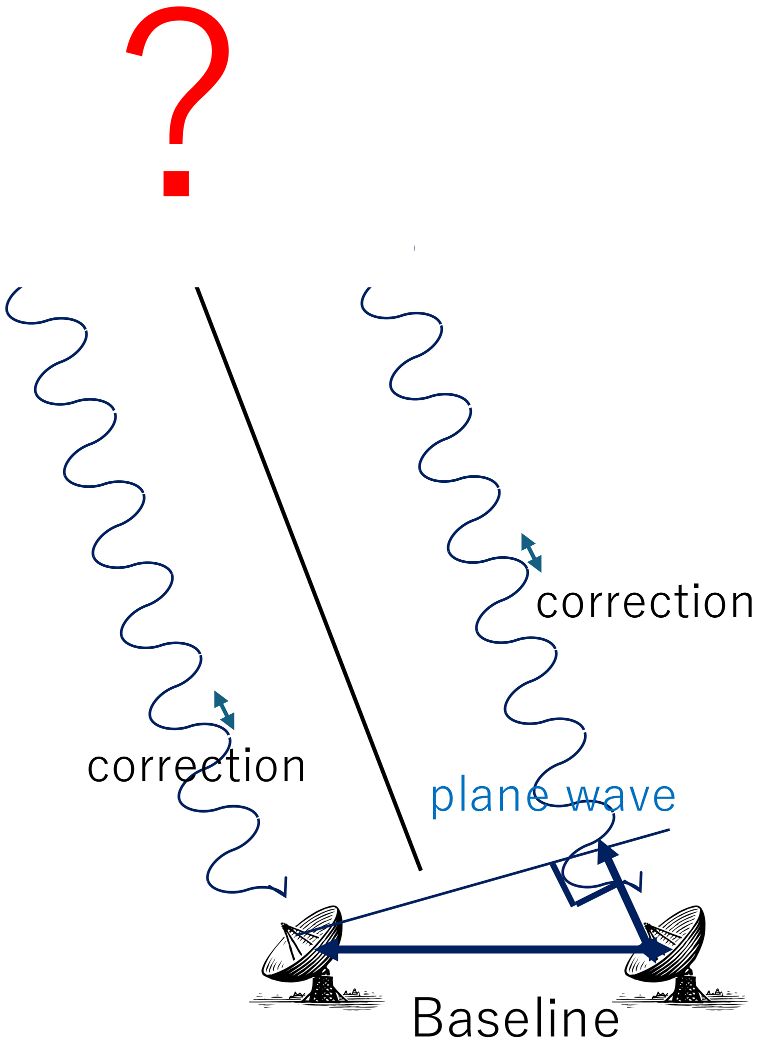
If you are lucky, the dataset after Cycle 10 (2023 Oct.) may include a self-calibrated MS (named XXX_targets.ms), together with its associated imaging products.*

** However, self-calibration is applied only to qualifying single-pointing data. And in multi-target observations, it may be applied to only some of the targets. You should check the Pipeline WebLog for details.*

Basic Concepts of Self-Calibration

If we know the shape of the target, we can use it as a model to correct the phase shifts (Same direction of the science target and at the time of its observation).

However, we do not know brightness distribution of the target.
How is the model constructed and used for calibration?



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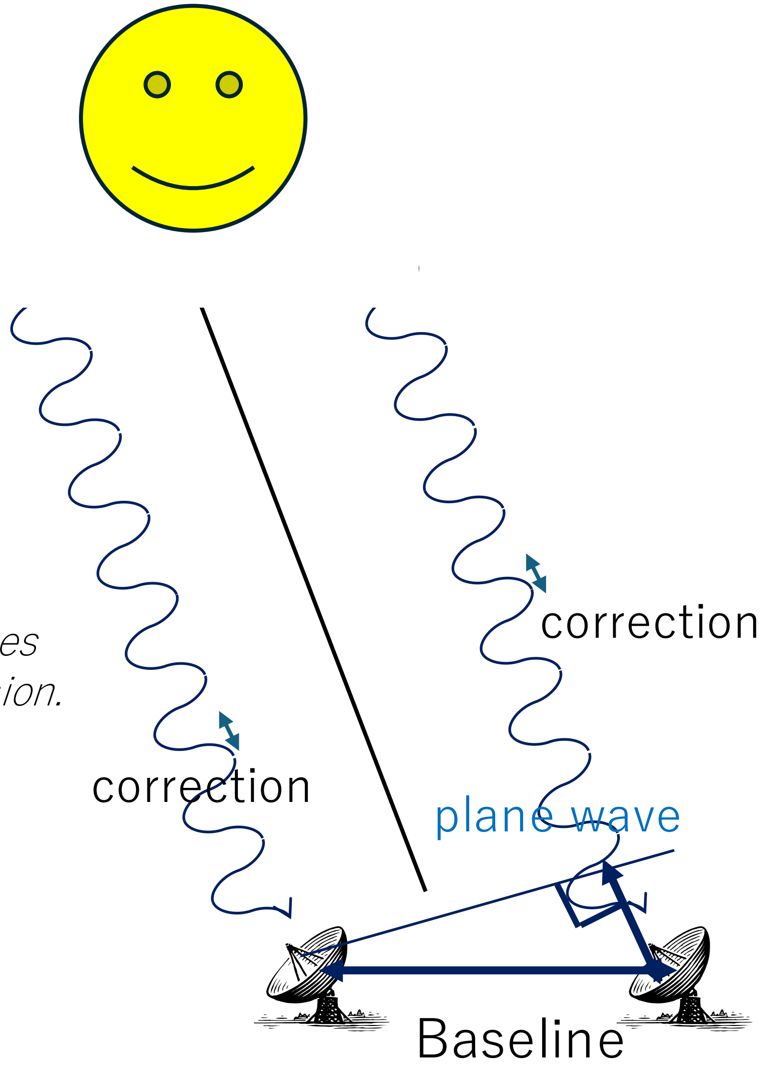
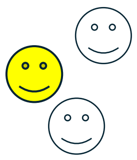


<u>Self-calibration is an iterative bootstrapping process:</u>

- Start with data in which the small phase errors. Otherwise, the nonlinear self-calibration process may not converge to a correct solution.
- We can make more reliable target model using CLEAN.
  In CLEAN, a mask is used to remove sidelobes, ghost features, and other imaging artifacts from being included in the source model.



- If the S/N is high enough with the large number of baseline keeps the sidelobes sufficiently low, we can identify which features are likely to represent real emission.

- We can obtain an accurate the point-spread function from the uv coverage.

- Each antenna is connected to many baselines, so its phase error can be estimated reliably from multiple measurements.

➔ We can correct the phase errors using a reliable source model.

Iteratively improves both the calibration and the source model.

How do we do this in CASA? overview

Start with the standard ALMA-calibrated MS data.
Standard-calibrated ALMA data are generally of sufficiently high quality

1. Make model by tclean task
2. Solve for phase (and/or amplitude) corrections by gaincal task
3. apply the corrections to the visibility data by applycal task
4. split out corrected MS data by split task

Repeat these steps iteratively with changing parameters

In the hands-on session, we will use real ALMA data to perform self-calibration with appropriate parameter settings.

Hands-on Session I

Download the script and data.
- Data: twhya_ALMAb7_cont.ms (which was used for imaging session).
- Script: selfcal2026.py

Applications:
- CASA version 6.6.6
  Script will probably work with other versions as well, but I have not tested them (*).
- Editor: vi, emacs, etc.
- CARTA

** If you use CASA versions earlier than 6.3. You should modify the script, please let me know (see CASA 6.3 Change log **CAS-12618 in** https://casadocs.readthedocs.io/en/v6.3.0/changelog.html?utm_source=chatgpt.com).*

** The scripts and data used in this hands-on session are from the 2025 Imaging Workshop by Masayuki Yamaguchi.*
https://events.asiaa.sinica.edu.tw/workshop/20250213/program.php

H.1 Preparation of data and script

Download the script and data.
- Data: twhya_ALMAb7_cont.ms (which was used for imaging session).
- Script: selfcal2026.py

1. Create a working directory (e.g., Selfcal01) and copy the downloaded data and script into it.

```
:~ saigokz$ mkdir Selfcal01
:~ saigokz$ cd Selfcal01/
:Selfcal01 saigokz$ cp ~/Downloads/twhya_ALMAb7_cont.ms.tar .
:Selfcal01 saigokz$ cp ~/Downloads/selfcal2026.py .
```

2. At the woking directory, unpack it

tar xvf twhya_ALMAb7_cont.ms.tar

```
:Selfcal01 saigokz$ tar xvf twhya_ALMAb7_cont.ms.tar
```

H.2 Check MS data

twhya_ALMAb7_cont.ms is a Measurement Set that has undergone standard calibration.

1. Lunch CASA on the working directory.

2. Check data information using the listobs task (remember Day 2)

listobs(vis='twhya_ALMAb7_cont.ms', listfile='twhya_ALMAb7_cont.ms.listobs’)

You can view the contents of the generated text file (twhya_ALMAb7_cont.ms.listobs), for example, as follows:
* any method is fine.

```
CASA <2>: !vi twhya_ALMAb7_cont.ms.listobs
```

Task 1. When was this dataset observed?
Task 2. What source name (see Field section) is listed in the data?
Field name or field number use in the subsequent steps.

Note that field name of “TW Hya” was assigned arbitrarily by the proposer, so the same source may have a different field name in another dataset, such as ”TW-Hya”, “HWA 1”, “HIP 53911”, etc.

H.3 Self-Calibration - First Iteration, Step 1-

Copy and paste the first CLEAN section of the script into CASA.

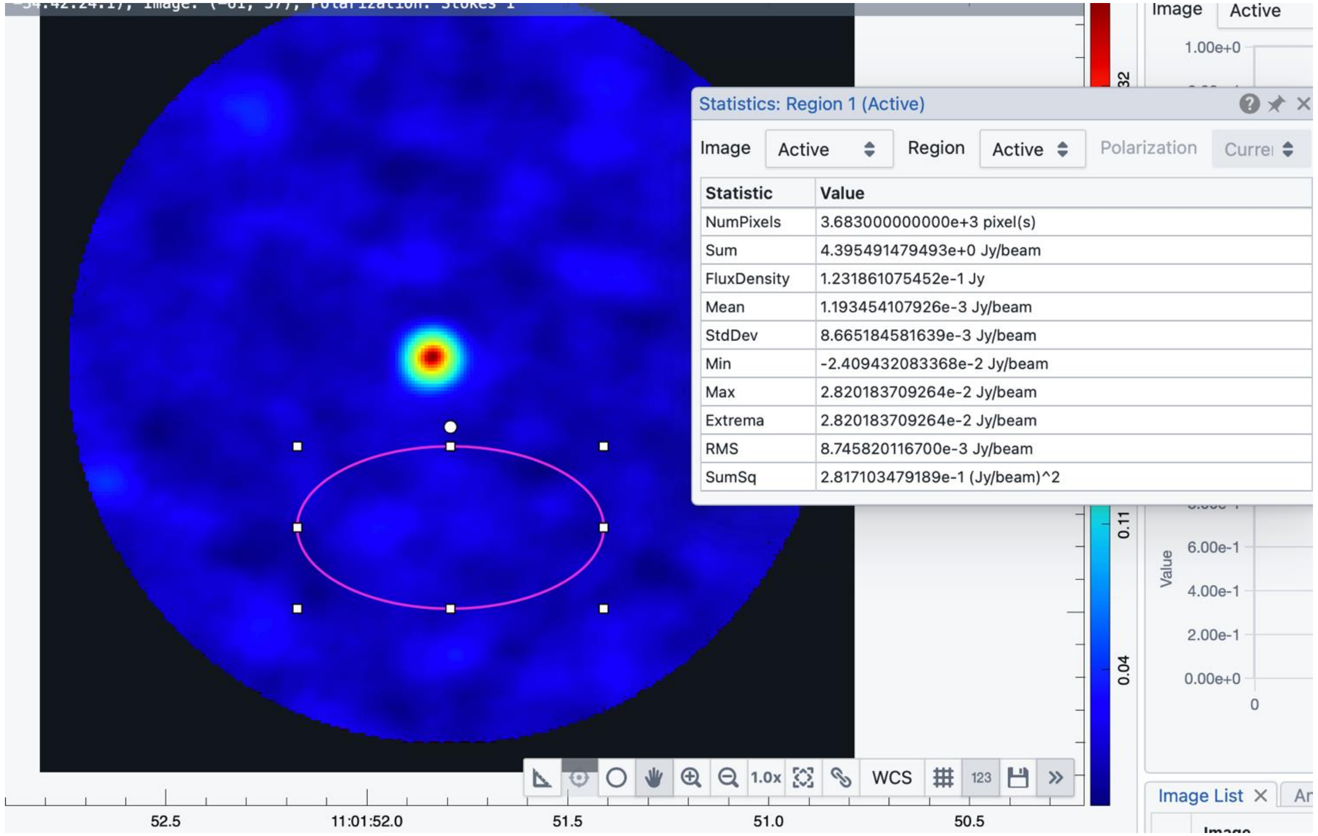
```
CASA <3>: os.system('rm -rf first_clean.*')
     ...: tclean(vis='twhya_ALMAb7_cont.ms',
     ...:        imagename='first_clean',
     ...:        datacolumn  ='data',
     ...:        field='0',
     ...:        spw='',
     ...:        specmode='mfs',
     ...:        deconvolver='hogbom',
     ...:        nterms=1,
     ...:        gridder='standard',
     ...:        mask = 'circle[[125pix,125pix],3.0arcsec]', # [x,y, radius]
     ...:        imsize=[250,250],
     ...:        cell=['0.1arcsec'],
     ...:        weighting='natural',
     ...:        threshold='16.0mJy', # 2 x rms noise
     ...:        niter=10000,
     ...:        interactive=False,
     ...:        savemodel='modelcolumn')
     ...:
```

1. Make model by tclean task
2. Solve for phase (and/or amp.) corrections by gaincal task
3. apply the corrections to the visibility data by applycal task
4. split out corrected MS data by split task

[Key Point 1]
Run tclean with savemodel='modelcolumn' to construct an improved CLEAN model and save its Fourier-transformed model visibilities in the **MODEL_DATA column**.

[Task] Inspect the resulting image, first_clean.image, using CARTA. Measure its RMS noise and peak intensity.
The results are on the next page.

H.4 Self-Calibration - First Iteration, Step 1-



[Key Point 2] Model

tclean with savemodel='modelcolumn' option

Fourier-transform this CLEAN (model) image and write the resulting model visibilities to MODEL_DATA column of the MS data, twhya_ALMAb7_cont.ms.

data	corrected	model
observations		CLEAN model

CLEAN result of non-self-calibrated data (tclean at 1st Iteration)
rms = 8.75 mJy/Beam, peak intensity = 365. mJy/Beam ➔ S/N ~ 41

H.5 Self-Calibration - First Iteration, Step 1-

Optional step of step 1: export fits file from CASA image format

```
os.system("rm -rf first_clean.image.fits")
exportfits(imagename = "first_clean.image",
        fitsimage = "first_clean.image.fits",
        history=False)
```

```
CASA <7>:
     ...: os.system("rm -rf first_clean.image.fits")
     ...: exportfits(imagename = "first_clean.image",
     ...:            fitsimage = "first_clean.image.fits",
     ...:            history=False)
     ...:
```

H.6 Self-Calibration - First Iteration, Step 2-

The gaincal task solves an inverse problem to determine phase and/or amplitude corrections for each antenna that make the observed visibilities consistent with the model visibilities.

Copy and paste the first gincal section of the script into CASA.

```
CASA <8>: os.system("rm -rf phase.cal")
    ....: gaincal(vis='twhya_ALMAb7_cont.ms',
    ....:         caltable="phase.cal",
    ....:         field="0",
    ....:         spw  = '*',
    ....:         solint="inf",
    ....:         calmode="p",
    ....:         refant="DV22",
    ....:         gaintype="G")
```

Output gaintable

1. Make model by tclean task
2. Solve for phase (and/or amp.) corrections by gaincal task
3. apply the corrections to the visibility data by applycal task
4. split out corrected MS data by split task

refant =“DV22” ← Specify the reference antenna, preferably select based on the calibration report (QA2 repot or WebLog).

solint = 'inf' ← Specifies the solution interval. solint='inf' averages the data over each scan and derives one solution per scan.

calmode = ‘p’ ← calmode='p': solves for phase only; generally recommended for the most iteration
calmode='ap': solves for both phase and amplitude; typically used in the final stages of self-calibration

gaintype ← I will skip the details here. If you are unsure, set gaintype='G’.
'G' solves for separate gain solutions for XX and YY for polarization-dependent phase corrections.
'T’ averages gains over both polarizations.

Appendix A: Reference Antena

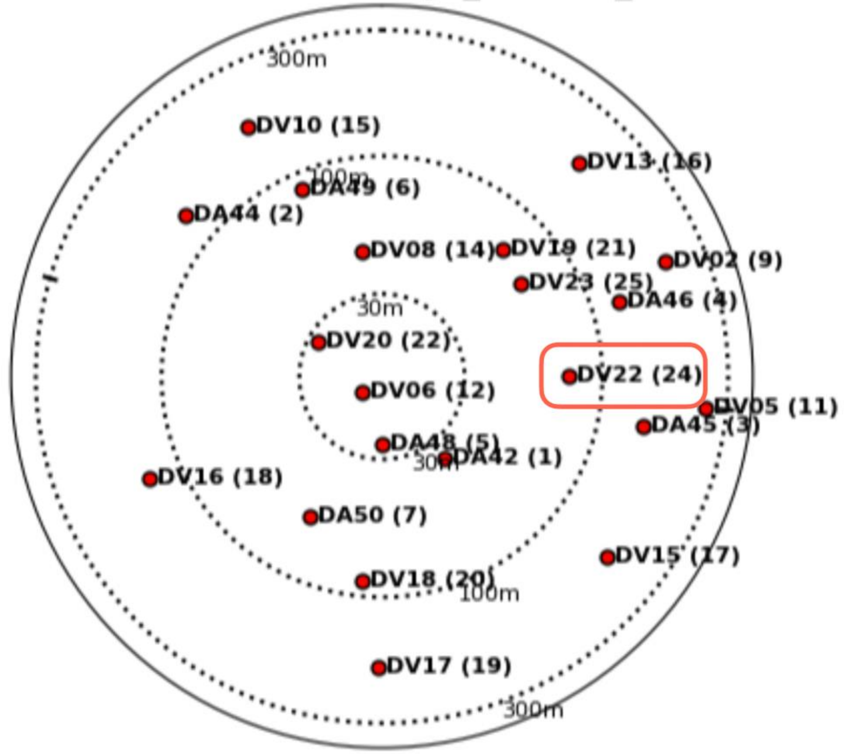
In gaincal, a reference antenna must be specified (e.g. refant =“DV22”).

It defines the phase reference for calculating the relative phase offsets. A well-performing antenna located near the center of the array is generally preferred.
Although the antenna configuration can be displayed in CASA, I recommend to check the QA2 report or pipeline weblog available from the ALMA Science Archive.

With “plotants” task in CASA:

```
plotants(vis =“twhya_ALMAb7_cont.ms",
              showgui = False,
              antindex = True,
              checkbaselines = True,
              logpos = True,
              figfile = “ant_positions.png")
```

Antenna Positions for twhya_ALMAb7_cont.ms



Appendix B: solint and gaintype options in gaincal task

In gaincal, the amount of averaging in time and polarization is controlled by task parameters.
Increasing the averaging—for example, by using a longer solution interval or combining polarizations—reduces the noise. This allows the gain solutions to be derived more safely and reliably.
However, it may also average out real temporal variations. Therefore, self-calibration usually starts with solint='inf' in the first iteration, averaging all data within each scan (*). The solution interval is then gradually shortened in subsequent iterations.
* To combine data across scan boundaries, combine='scan' must also be specified.

Solution Interval for `solint = 'inf'`

- The solution interval corresponds to the **longest continuous time span of data** within each scan.

In twhya_ALMAb7_cont.ms.listfile

Scan	Start Time (UTC)	End Time (UTC)	Duration (sec)
12	07:56:23.5	08:02:11.3	**347.8 sec**
16	08:08:09.6	08:13:57.3	**347.7 sec**
20	08:19:53.9	08:25:41.7	**347.8 sec**
24	08:32:00.5	08:37:48.2	**347.7 sec**
28	08:43:45.6	08:49:33.4	**347.8 sec**
36	09:05:15.6	09:07:31.6	**136.0 sec**

If you set **solint = 'inf'**, then the solution interval (time) will be the entire scan duration for each scan.
For scans 12, 16, 20, 24, and 28, the solution interval is 348 sec.
For scan 36, the solution interval is 136 sec.
Each scan will have a single gain solution over the respective time duration.

Appendix C: calmode option

calmode='p': Solves only for phase corrections while keeping the amplitudes unchanged. This is generally used in the initial self-calibration iterations.

calmode='ap': Solves for both amplitude and phase corrections. This is generally used after the phase solutions have become stable and requires a higher signal-to-noise ratio.

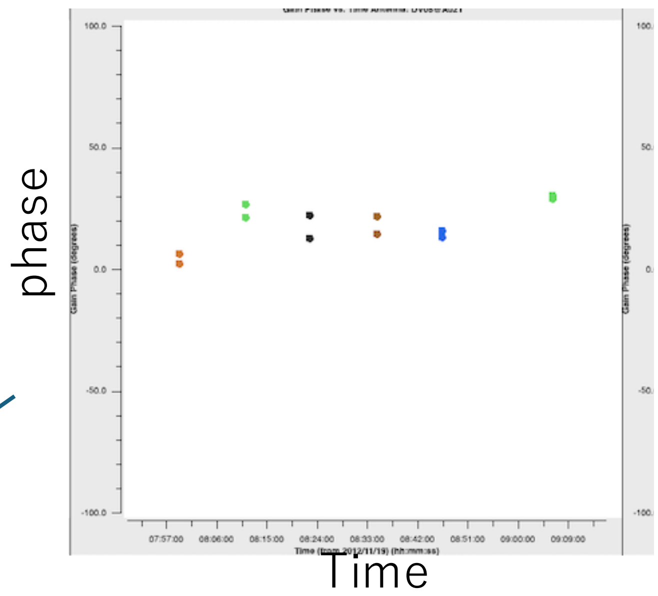
I recommend starting with calmode='p' and not solving for amplitude until the phase solutions have sufficiently converged. When calmode='ap' is used, the solutions may occasionally become unstable or diverge.
You should carefully check the image for unexpected artifacts or other problems after every iteration.

H.7 Self-Calibration - First Iteration, Step 2-

Check of the gain solution (gain tale ‘phase.cal’)

```
CASA <10>:
    ....: plotms(vis='phase.cal',
    ....:        xaxis='time',
    ....:        yaxis='phase',
    ....:        iteraxis='antenna',
    ....:        gridrows=5,
    ....:        gridcols=6,
    ....:        coloraxis='scan',
    ....:        plotrange=[0,0,-100,100],
    ....:        showgui     = False,
    ....:        overwrite   = True,
    ....:        height = 2500,
    ....:        width = 3000,
    ....:        plotfile    = 'phasecal.png')
```

Ex. Example of DV08 antenna



By default, this script saves all plots to the phasecal.png file.
To display the plots directly on the screen, remove the plotfileparameter.

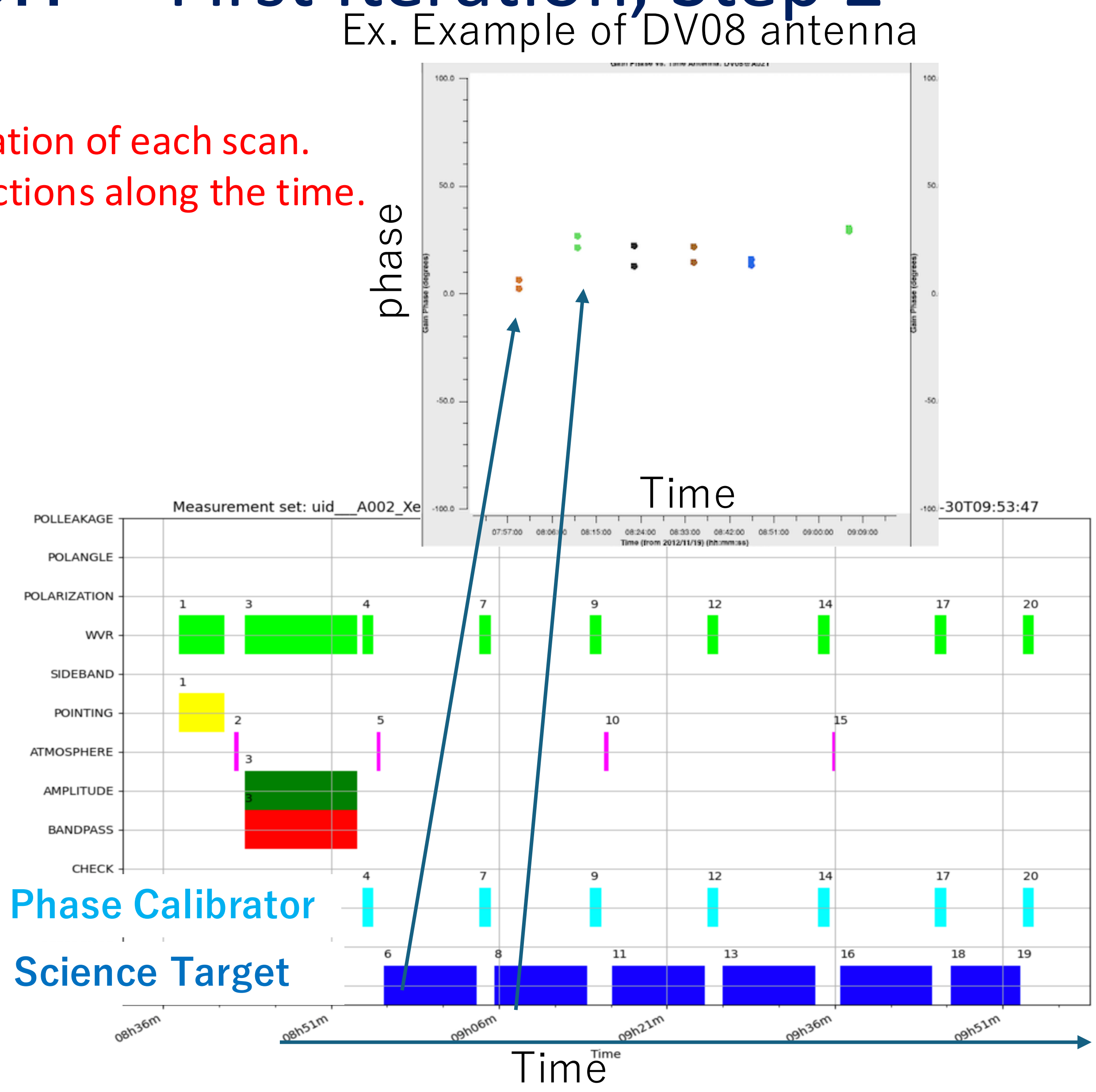
Task: Quickly inspect the phase solutions as a function of time for each antenna.

If the phase points are stable around zero, it means that self-calibration successfully corrected phase errors.

If you find discontinuities or widely scattered solutions may indicate that the phases were not solved reliably.

H.7 Self-Calibration - First Iteration, Step 2-

The solint = ‘inf’ option average over the duration of each scan.
The plotms display the resulting phase corrections along the time.



A figure illustrating the relationship between the plotms output and the scans (different observation project from the hands-on dataset).

H.8 Self-Calibration - First Iteration, Step 3-

The applycal task applies the calibration solutions stored in the gain table to the visibilities in the DATA column and writes the self-calibrated visibilities to the CORRECTED_DATA column.

Copy and paste the first applycal section of the script into CASA.

```
CASA <13>:
   ...: applycal(vis="twhya_ALMAb7_cont.ms",
   ...:          calwt = True,
   ...:          gaintable=["phase.cal"],
   ...:          interp="linear",
   ...:          applymode = "calonly")
   ...:
```

Specify gaintable

1. Make model by tclean task
2. Solve for phase (and/or amp.) corrections by gaincal task
3. apply the corrections to the visibility data by applycal task
4. split out corrected MS data by split task

applymode='calonly' prevents data without valid solutions from being flagged. Otherwise, the beam size may increase.

applycal

Structure of MS data (Columns)

data	corrected	model
observations		CLEAN model

H.9 Self-Calibration - First Iteration, Step 4-

The applycal task applies the calibration solutions stored in the gain table to the visibilities in the DATA column and writes the self-calibrated visibilities to the CORRECTED_DATA column.

Copy and paste the first applycal section of the script into CASA.

```
CASA <13>:
    ...: applycal(vis="twhya_ALMAb7_cont.ms",
    ...:          calwt = True,
    ...:          gaintable=["phase.cal"],
    ...:          interp="linear",
    ...:          applymode = "calonly")
    ...:
```

Specify gaintable

1. Make model by tclean task
2. Solve for phase (and/or amp.) corrections by gaincal task
3. apply the corrections to the visibility data by applycal task
4. split out corrected MS data by split task

applymode='calonly' prevents data without valid solutions from being flagged.
Otherwise, the beam size may increase.

applycal

Structure of MS data (Columns)

data	corrected	model
observations		CLEAN model

H.10 Self-Calibration - First Iteration, Step 4-

Copy and paste the first split task section of the script into CASA.

```
CASA <14>:
   ...: os.system("rm -rf twhya_ALMAb7_cont_selfcal.ms*")
   ...: split(vis="twhya_ALMAb7_cont.ms",
   ...:       outputvis="twhya_ALMAb7_cont_selfcal.ms",
   ...:       datacolumn="corrected")
   ...:
```

1. Make model by tclean task
2. Solve for phase (and/or amp.) corrections by gaincal task
3. apply the corrections to the visibility data by applycal task
4. split out corrected MS data by split task

The split task copy the data in the CORRETED column to the DATA column of the new MS.

Structure of MS data (Columns)

data	corrected	model
observations	Self-calibrated data	CLEAN model

copy

New MS data

twhya_ALMAb7_cont_selfcal.ms

data	corrected	model
Self-calibrated data		

Therefore, during the calibration process, it is important to understand which data are stored in each column.

In particular, important to remember, applycal always applies the calibration tables to the DATA column and writes the results to the CORRECTED_DATA column..

H.11 Self-Calibration - 2nd Iteration, Step 1-

Using the self-calibrated MS created with split in Step Step 4 following the first first phase-only self-calibration (solint='inf', calmode='p'), perform a second self-calibration iteration.

twhya_ALMAb7_cont_selfcal.ms

1. Make model by tclean task
2. Solve for phase (and/or amp.) corrections by gaincal task
3. apply the corrections to the visibility data by applycal task
4. split out corrected MS data by split task

This step produces the image from the first self-calibration iteration. Note that the iteration numbering can be confusing.

In the second iteration, derive the gain solutions with gaincal using a shorter solution interval.

Task: Please CLEAN result of 1 st self-calibrated data by CARTA and measure its RMS noise and peak intensity.

H.12 Self-Calibration - 2nd Iteration ,Step 1-

Create a CLEAN model using the self-calibrated MS that we created with split earlier.
Note that we specify datacolumn='data' because the corrected data were written to the DATA column during the split.

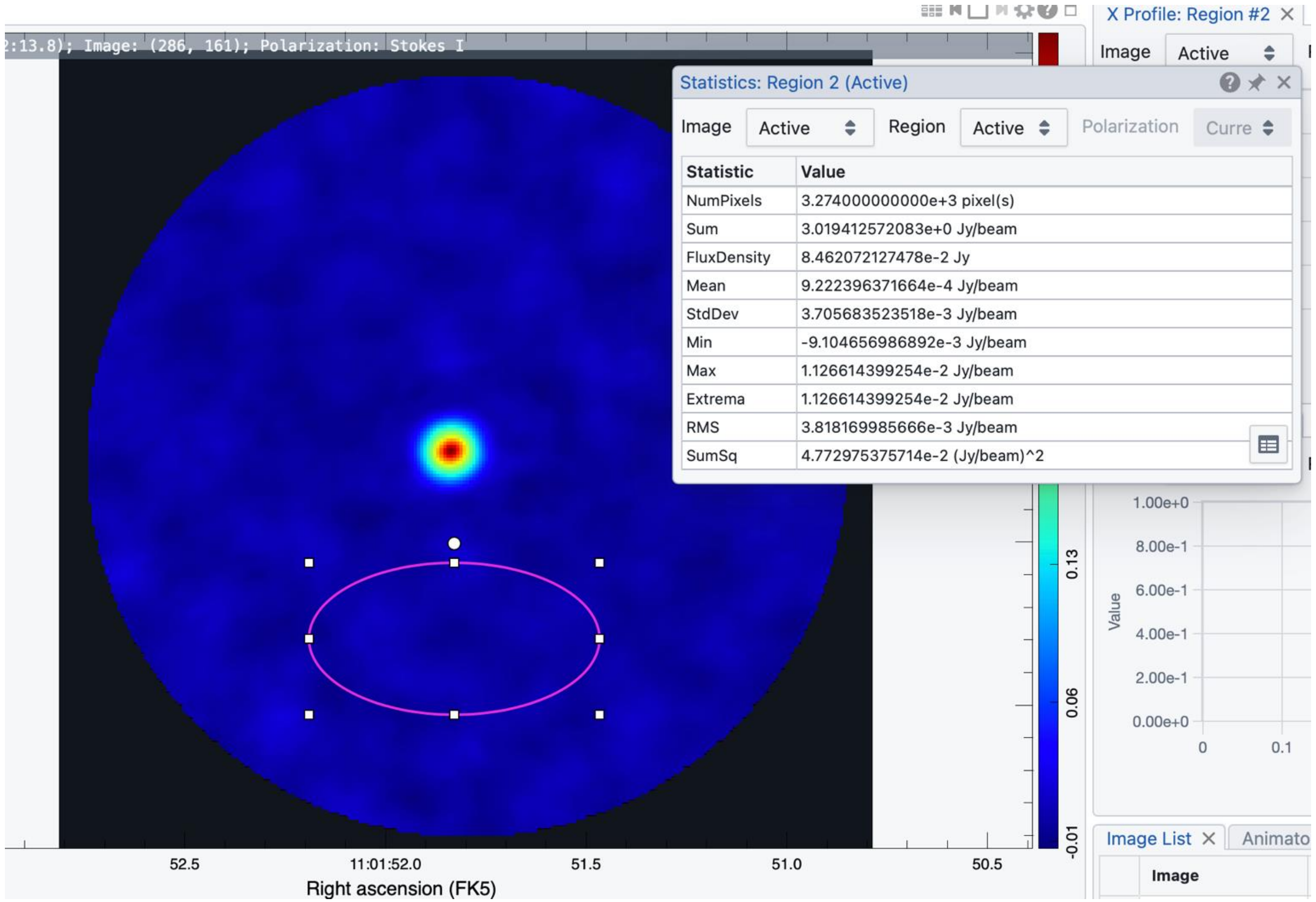
```
CASA <12>: os.system('rm -rf second_clean.*')
      ...: tclean(vis='twhya_ALMAb7_cont_selfcal.ms',
      ...:        imagename='second_clean',
      ...:        datacolumn  ='data',
      ...:        field='0',
      ...:        spw='',
      ...:        specmode='mfs',
      ...:        deconvolver='hogbom',
      ...:        nterms=1,
      ...:        gridder='standard',
      ...:        mask = 'circle[[125pix,125pix],3.0arcsec]', # [x,y, r
      ...:        imsize=[250,250],
      ...:        cell=['0.1arcsec'],
      ...:        weighting='natural',
      ...:        threshold='0mJy',
      ...:        niter=10000,
      ...:        interactive=False,
      ...:        savemodel='modelcolumn')
      ...:
      ...: os.system("rm -rf second_clean.image.fits")
      ...: exportfits(imagename = "second_clean.image",
      ...:            fitsimage = "second_clean.image.fits",
      ...:            history=False)
```

This creates an image from the MS self-calibrated in the first iteration.

Optional Step

[Task] Inspect the resulting image using CARTA. Measure its RMS noise and peak intensity.
➔ Confirm the improvement in S/N.   (The results are on the next page.)

H.13 Self-Calibration - 2nd Iteration, Step 1-



CLEAN result of 1 st self-calibrated data (tclean at 2nd Iteration)
rms = 4.17 mJy/Beam, peak intensity = 396. mJy/Beam ➔ S/N ~ 94

H.14 Self-Calibration - 2nd Iteration, Step 2 -

[Point] In the second iteration, we use a shorter solution interval in gaincal. This allows us to correct phase variations on shorter timescales.

```
CASA <12>: os.system("rm -rf phase_2.cal")
      ...: gaincal(vis="twhya_ALMAb7_cont_selfcal.ms",
      ...:         caltable="phase_2.cal",
      ...:         field="0",
      ...:         solint="170s",
      ...:         calmode="p",
      ...:         refant="DV22",
      ...:         gaintype="G")
```

refant ="DV22" ← Specify the reference antenna, preferably select based on the calibration report (QA2 repot or WebLog).

solint = '170s' ← Specifies the solution interval. solint='170s' averages the data over 170 second each scan.
** In this dataset, each scan is ~340 seconds long, so we divide each scan into two time intervals and solve for the gain separately in each interval.*

calmode = 'p' ← calmode='p': solves for phase only; generally recommended for the most iteration
calmode='ap': solves for both phase and amplitude; typically used in the final stages of self-calibration

gaintype ← I will skip the details here. If you are unsure, set gaintype='G'.
'G' solves for separate gain solutions for XX and YY for polarization-dependent phase corrections.
'T' averages gains over both polarizations.

H.15 Self-Calibration - 2nd Iteration, Step 2-

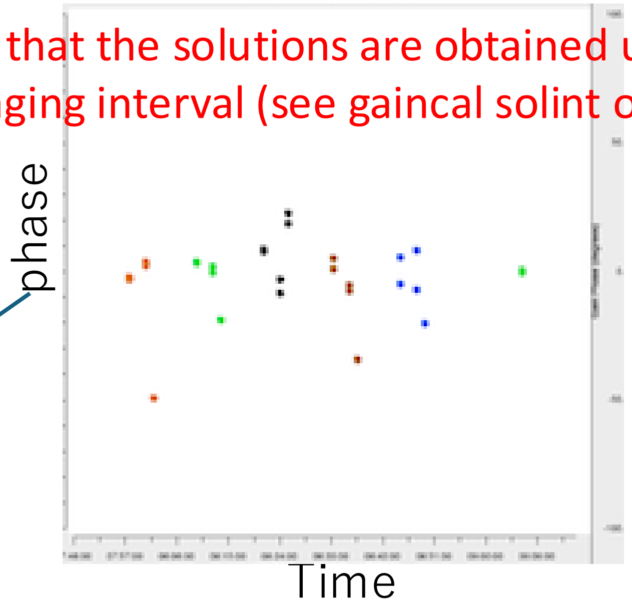
Check of the gain solution (gain tale ‘phase.cal’)

```
CASA <12>: plotms(vis='phase_2.cal',
      ...:         xaxis='time',
      ...:         yaxis='phase',
      ...:         iteraxis='antenna',
      ...:         gridrows=5,
      ...:         gridcols=6,
      ...:         coloraxis='scan',
      ...:         plotrange=[0,0,-100,100],
      ...:         showgui     = False,
      ...:         overwrite   = True,
      ...:         height = 2500,
      ...:         width = 3000,
      ...:         plotfile    = 'phasecal_2.png')
```

gaintable of 2nd iteration

Ex. Example

Note that the solutions are obtained using a shorter time-averaging interval (see gaincal solint option in previous page).



Task: Quickly inspect the phase solutions as a function of time for each antenna.

H.16 Self-Calibration - 2nd Iteration, Step 3 and 4-

```
CASA <13>: applycal(vis="twhya_ALMAb7_cont_selfcal.ms",
      ...:          field="0",
      ...:          calwt = True,
      ...:          gaintable=["phase_2.cal"],
      ...:          interp="linear",
      ...:          applymode = "calonly")
      ...:
      ...:
      ...: os.system("rm -rf twhya_ALMAb7_cont_selfcal_2.ms*")
      ...: split(vis="twhya_ALMAb7_cont_selfcal.ms",
      ...:       outputvis="twhya_ALMAb7_cont_selfcal_2.ms",
      ...:       datacolumn="corrected")
      ...:
```

[Task] Quations

What is the name of the MS created after applying the second round of self-calibration and running split, and in which data column are the split visibilities stored?

H.17 Self-Calibration - all Iteration -

In this Hands-On session, we will skip the details following iterations (3rd and 4th) to save time.
Run the following steps to complete the entire script.

Please check how the gaincal parameters changes in the following iterations .

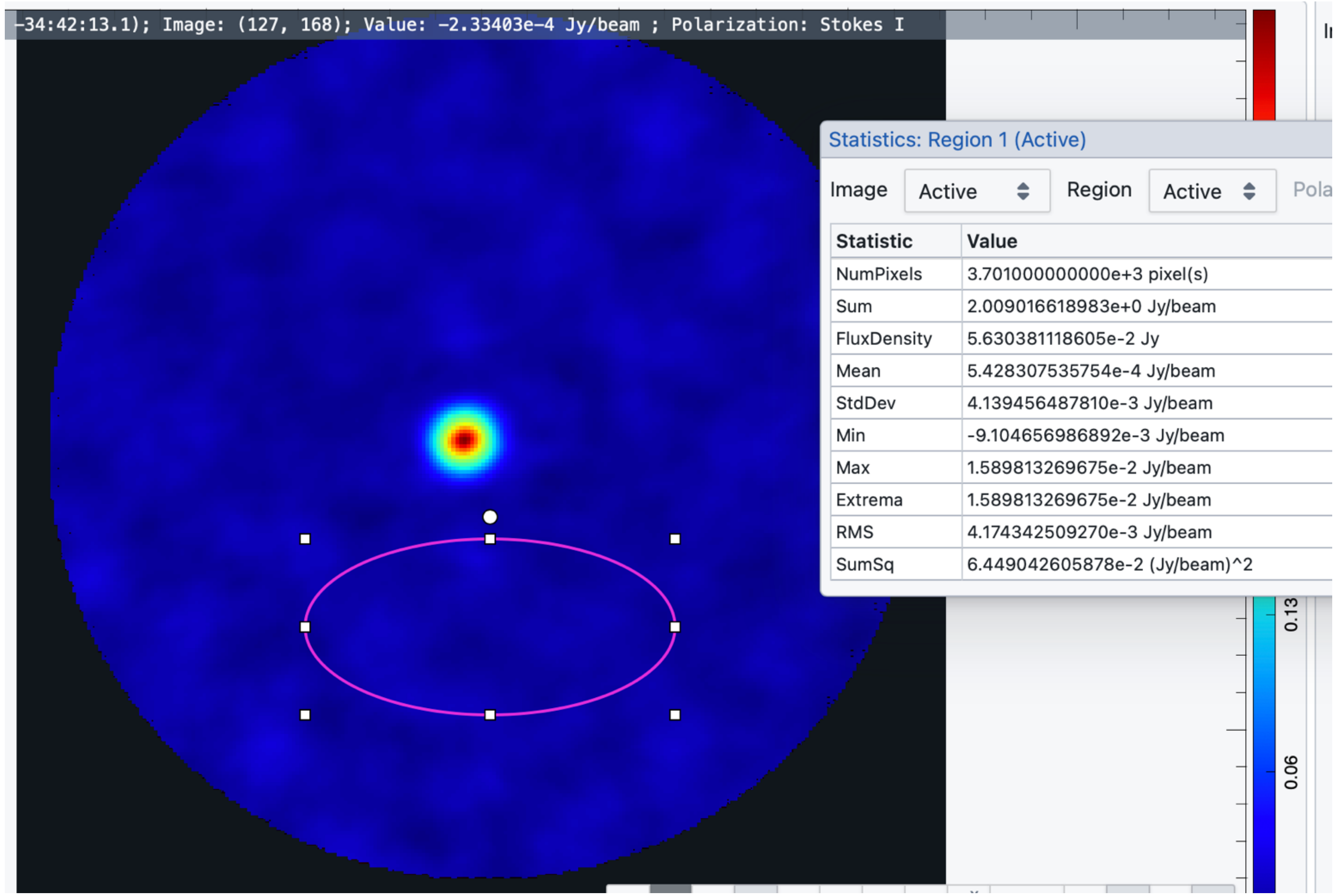
```
CASA <26>: execfile("selfcal2026.py")
```

If you run the script using execfile, all five iterations, from the first to the fifth, will be executed sequentially in a single run.

Task: Measure the rms noise of each iteration and check how the signal-to-noise ratio (S/N) changes throughout the self-calibration process.

H.18 Self-Calibration - 3rd Iteration, Step 1-

CLEAN result of 2nd self-calibrated data (tclean at 3rd Iteration)

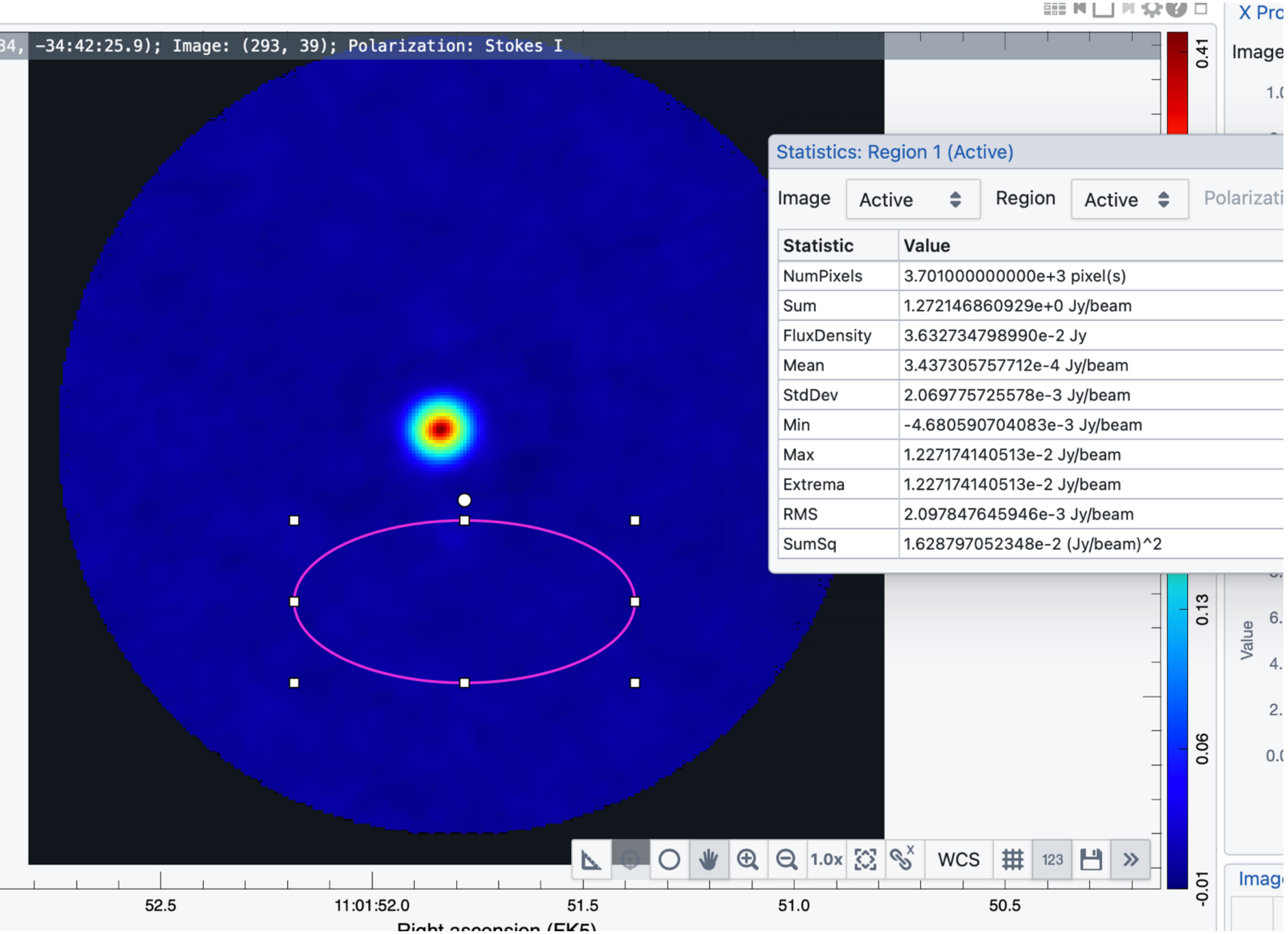


➔ rms = 4.17 mJy/Beam, peak intensity = 396. mJy/Beam ➔ S/N ~ 94

H.19 Self-Calibration - 4th Iteration, Step 1-

Phase + Amplitude

CLEAN result of 3rd self-calibrated data (tclean at 4th Iteration)



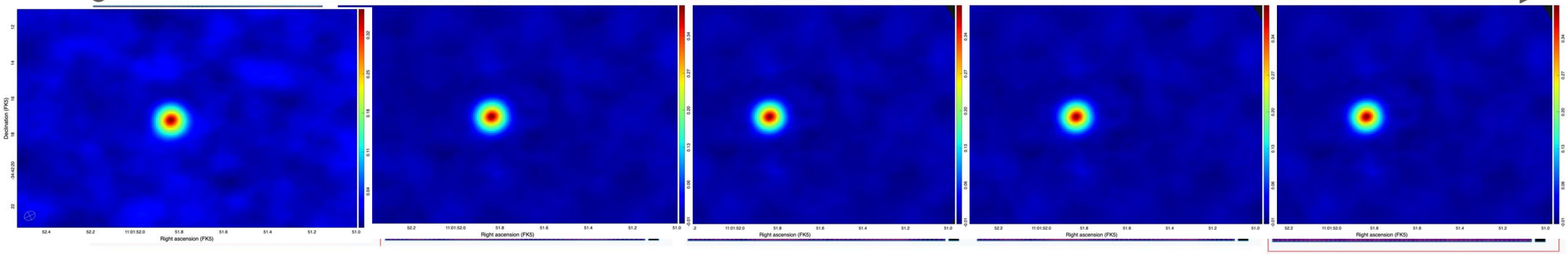
In this fourth iteration, calmode='ap' **is used in** gaincal process (see script).
The gaincal with calmode='ap' **option solves simultaneously for both phase and amplitude corrections (see gaincal page).**

Note that solving for the amplitude sometimes produce unstable solutions, so caution is required. "amplitude self-calibration" only after the phase solutions have well converged, and you should carefully inspect the results, as the flux density may not be preserved.
On the other hand, it can dramatically improve the image quality, as shown in this example.

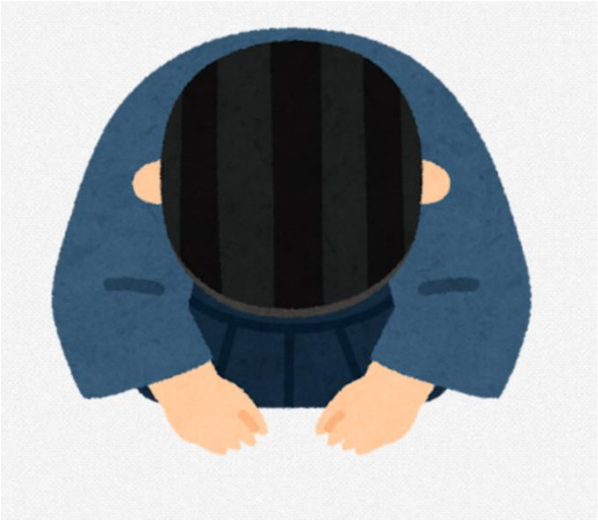
➔ rms = 2.10 mJy/Beam, peak intensity = 418. mJy/Beam ➔ S/N ~ 199

CARTA allows you to check the resulting images and calculate their SNR (peak intensity/RMS noise).

1st CLEAN image	2nd CLEAN image	3rd CLEAN image	4th CLEAN image	5th CLEAN image
without selfcal	after first phase cal solint = “inf” (entire scan duration)	after second phase cal solint = “170sec” (half scan duration)	after third phase cal solint=“30sec” (1/10 scan duration)	after amp & phase cal solint=“inf” (entire scan duration)



S/N ~ 41 | S/N ~ 96 | S/N ~ 94 | S/N ~ 95 | S/N ~ 199



Thank you for your hard work.

All the sections of the imaging workshop are finished.

If you have any questions, please stay and ask the tutors.