CASA VLBI

WORKSHOP 2020

2-6 NOVEMBER 2020

LECTURE 4: EVN CALIBRATION BASICS

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CASA Common Astronomy Software Applications

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In this talk…

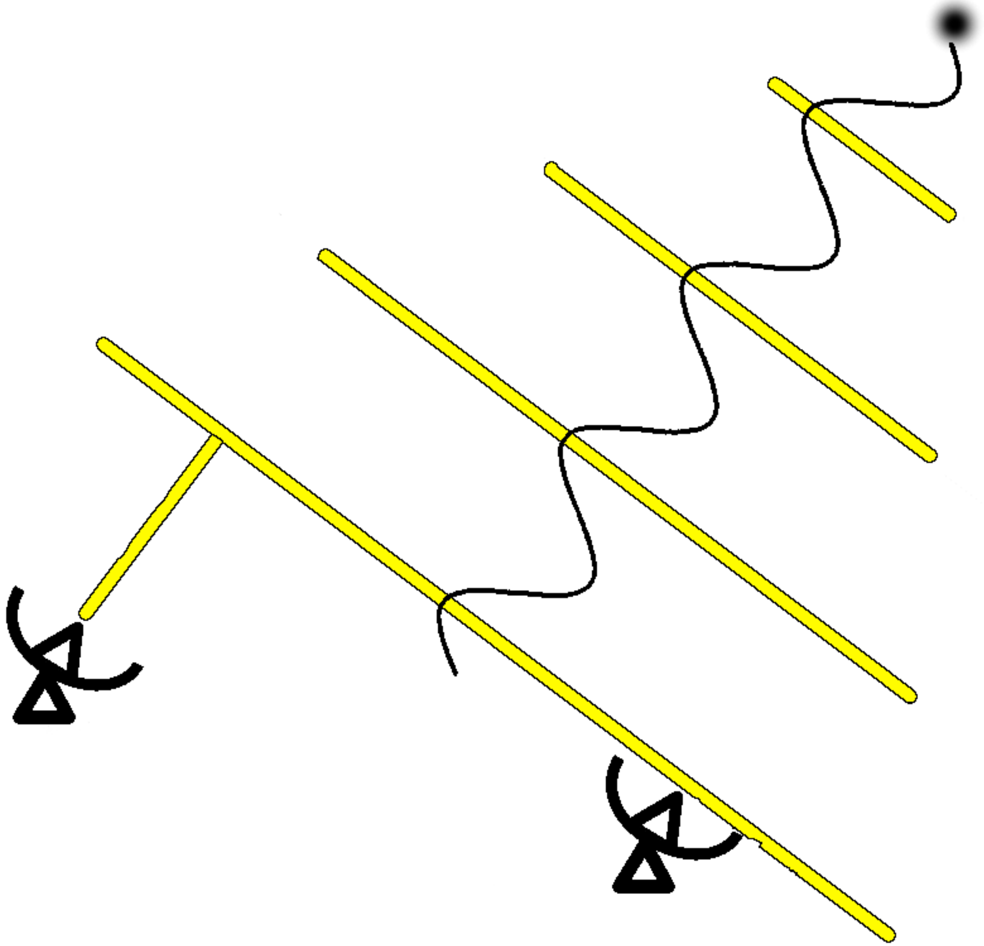
…You will get the ***concepts*** for the steps you run in CASA for EVN data

- ☑ Parallactic angle correction
- ☑ ***A-priori gain calibration***
- ☑ Bandpass calibration
- ☑ ***Fringe-fitting***
- ☑ Cleaning
- ☑ [Self-calibration]

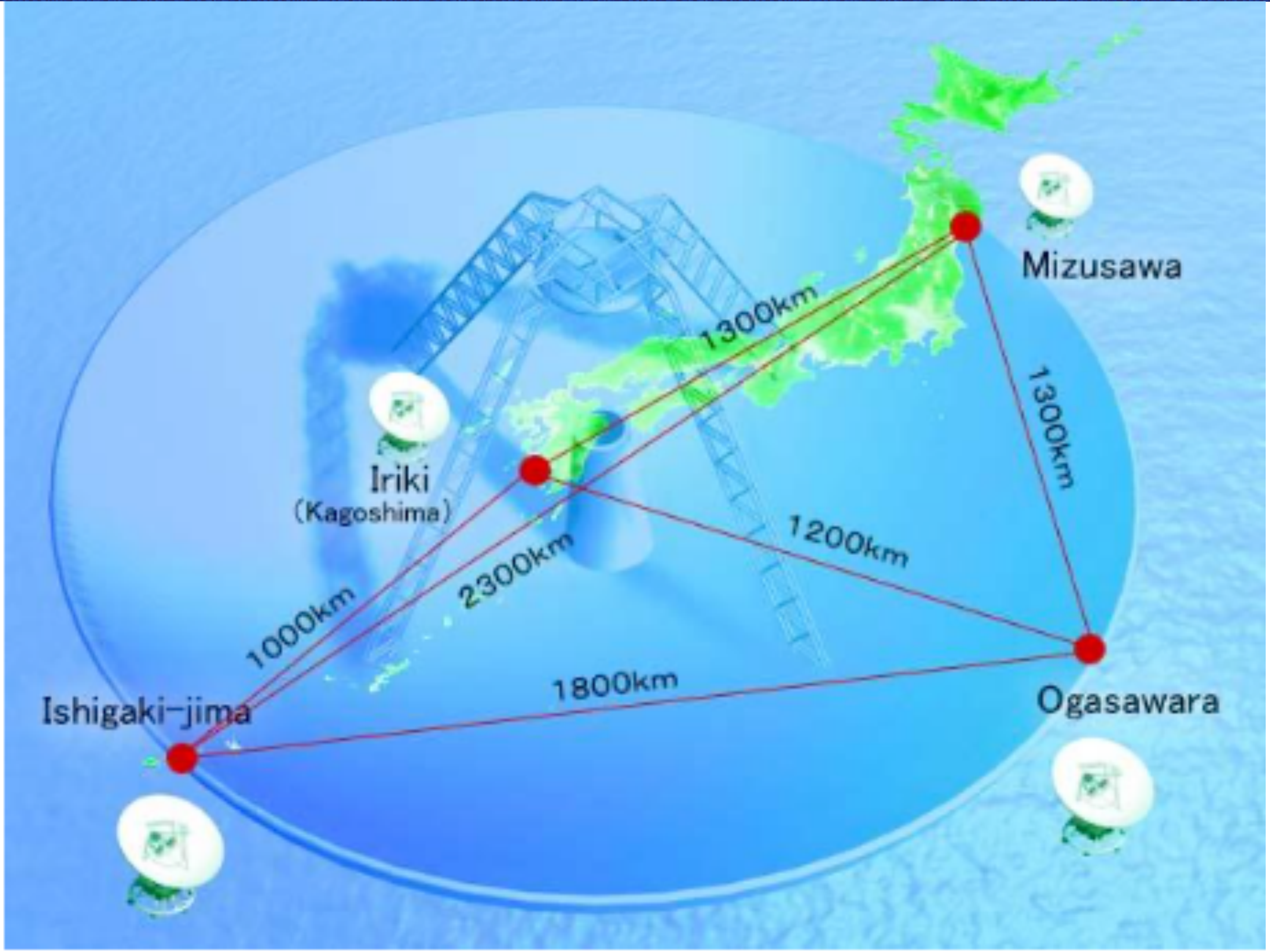
Interferometers

This is not a talk about fundamentals of radio interferometers but…

A couple of slides to refresh all's minds!



Interferometers



$$\theta_{\rm arcsec} \approx 2\frac{\lambda_{\rm cm}}{D_{\rm km}}$$

~ 10 mas at 5 cm for 1000 km

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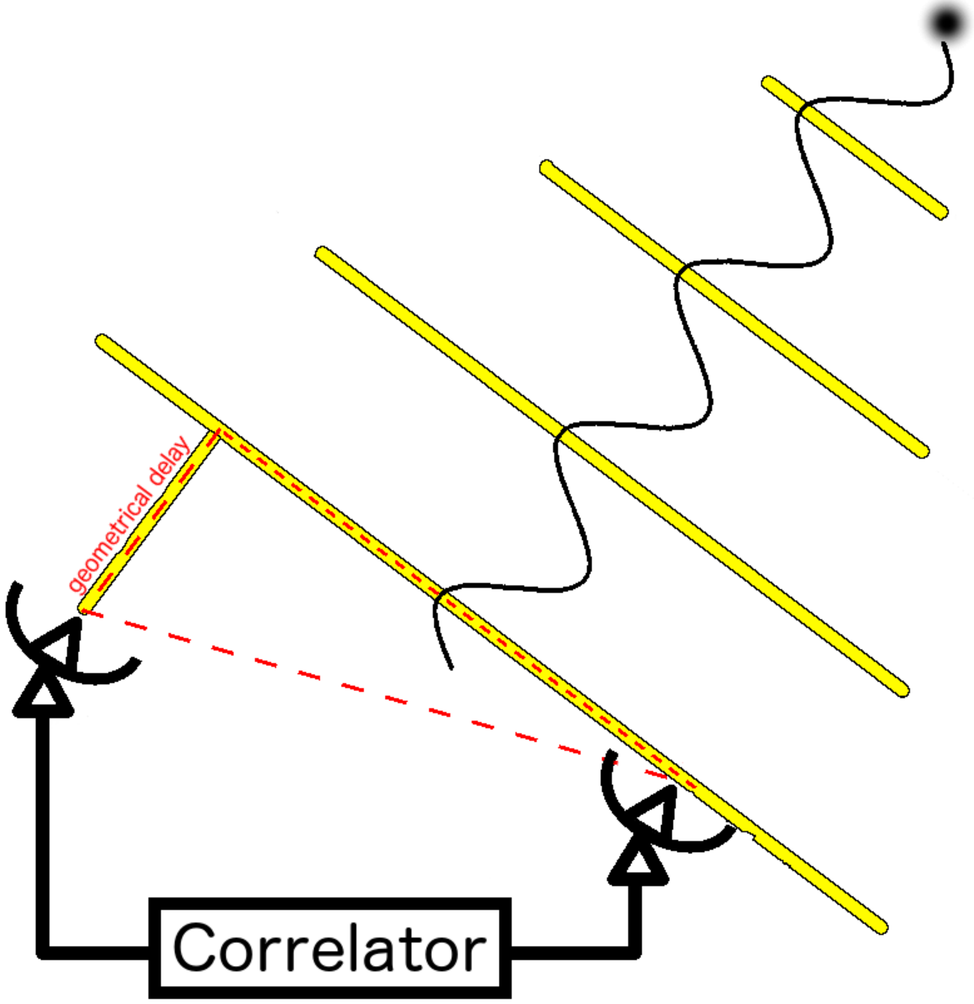
Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Interferometers

A-priori model:

- ☑ Station and source position.
- ☑ Times.
- ☑ Earth orientation (precession, notation, polar motion)
- ☑ Diurnal spin
- ☑ Tides (solid-Earth, pole)
- ☑ …



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Interferometers

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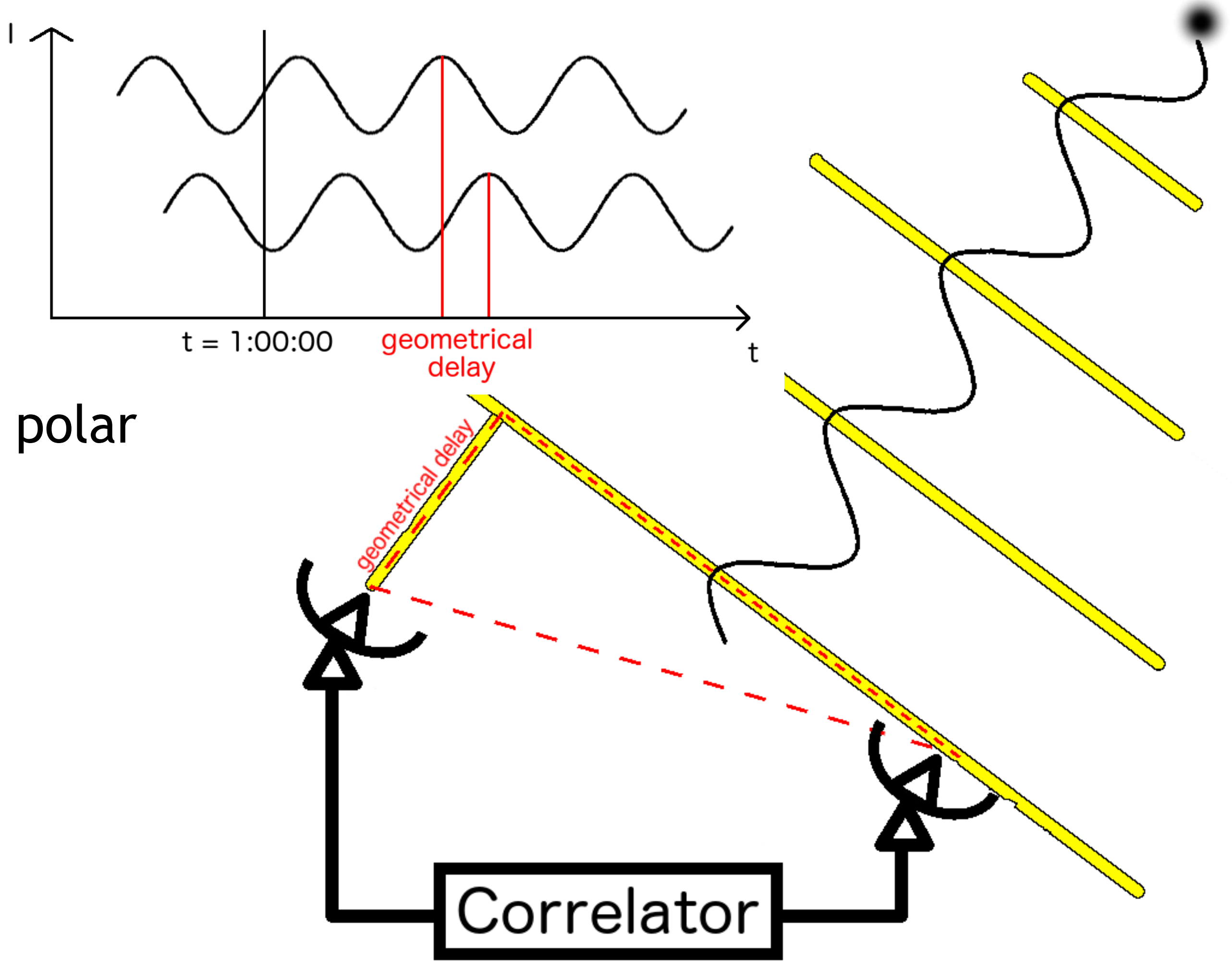


Interferometers

Visibilities

- ☑ Complex numbers: $V_{i,j}\ (u, v)$

- ☑ Baseline vector: $\mathbf{b}_{i,j} = \lambda(u, v, w) = \mathbf{r}_i - \mathbf{r}_j$

- ☑ Sky intensity: $I_\nu(l, m)$

$$V_{i,j}(u, v) = \int I_\nu(l, m)\ \mathrm{e}^{-2\pi i\ (ul+vm)} \mathrm{d}l\ \mathrm{d}m$$

Interferometers

$$V_{i,j}^{\mathrm{obs}} = M_{i,j}\,B_{i,j}\,G_{i,j}\,D_{i,j}\,E_{i,j}\,P_{i,j}\,T_{i,j}\,V_{i,j}^{\mathrm{true}}$$

Baseline-based errors

Bandpass response

Gain amplitude and phase

Instrumental polarization

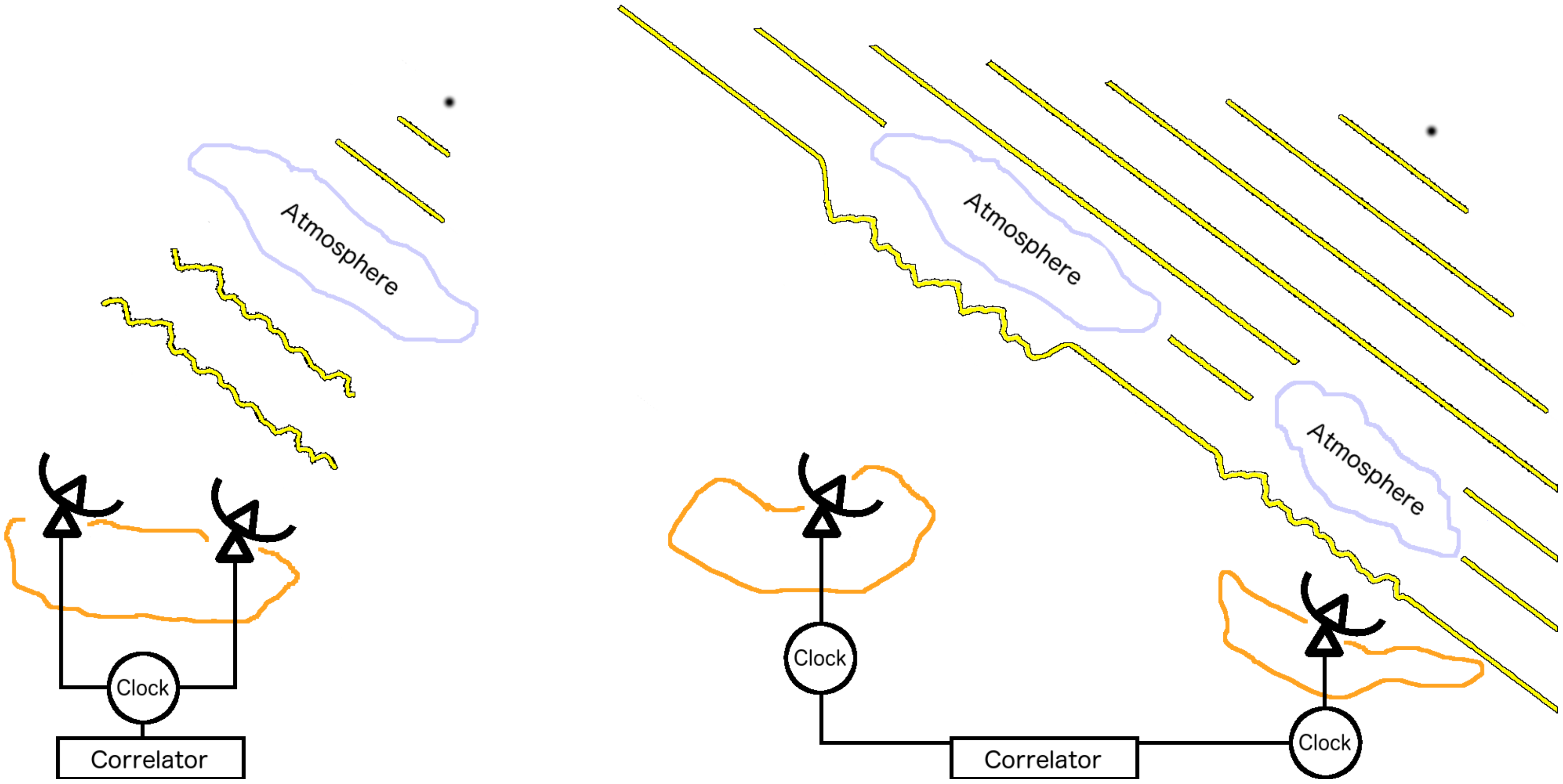
Errors due to elevation

Change in parallactic angle

Opacity and path length variation

Interferometers

Connected interferometers — Very Long Baseline Interferometry



- Different atmosphere conditions at each telescope (troposphere & ionosphere)
- Earth tectonic motions
- Instrumental effects

Interferometers

It's all about phases…

$$\tau_{\mathrm{obs}} = \tau_{\mathrm{geom}} + \tau_{\mathrm{src}} + \tau_{\mathrm{trop}} + \tau_{\mathrm{iono}} + \tau_{\mathrm{instr}} + \epsilon_{\mathrm{noise}}$$

Source/Station/Earth orientation

Propagation

Instrumental effects

Source structure

Interferometers

Phases may evolve faster with time for long baselines:

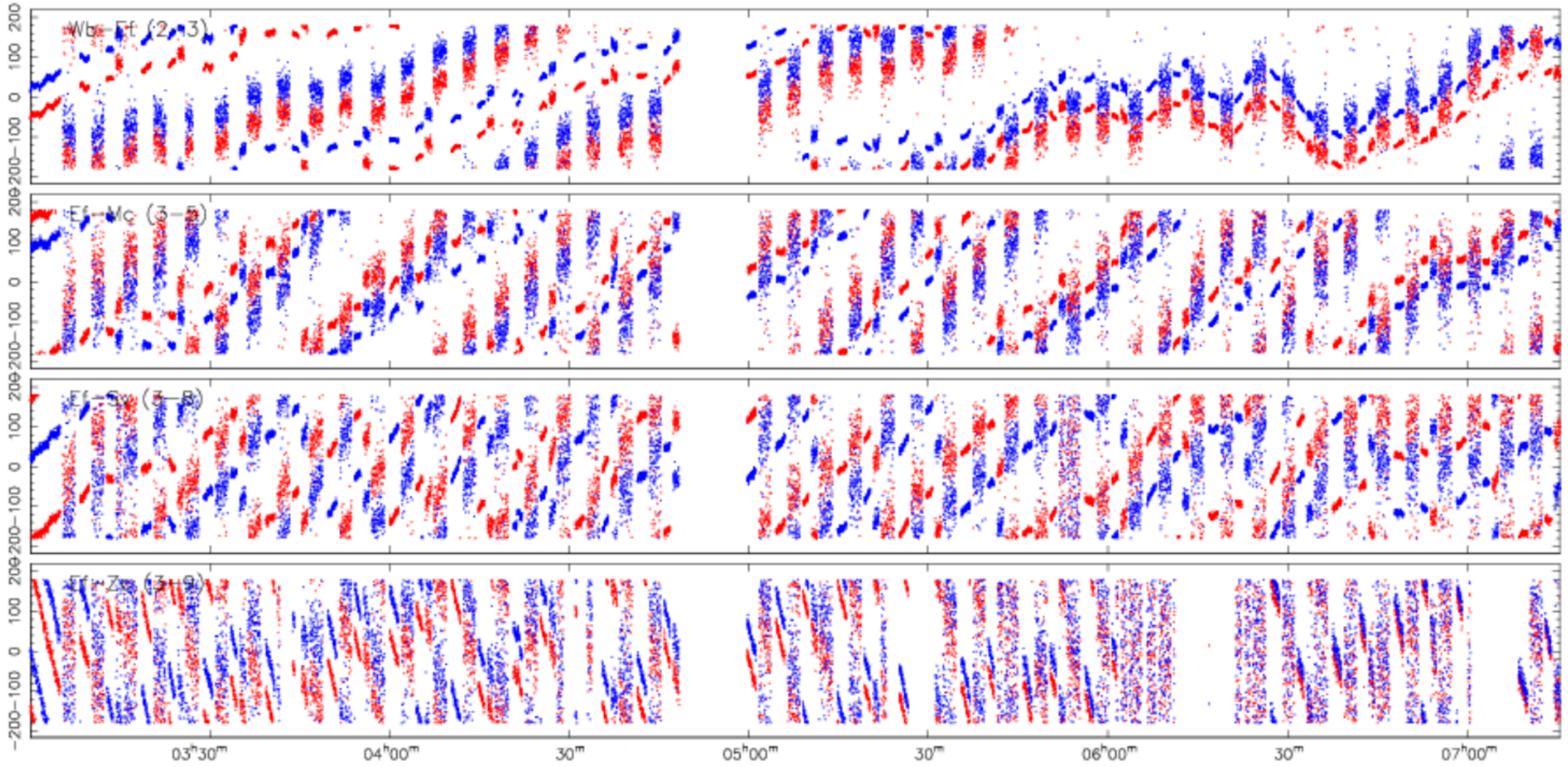
Phases: φ

Delays: $\frac{\partial \varphi}{\partial \omega}$

Rates: $\frac{\partial \varphi}{\partial t}$

(fringe-fitting)

See next lecture!



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Interferometers

- Bright (high S/N) and compact sources are mandatory for calibration purposes.
- Propagation effects are direction dependent.
  - Target: faint or resolved? —> requires a nearby phase-calibrator source.

    Absolute astrometry? —> requires a nearby calibrator source.
  - Phase calibrator: strong and compact source within a few degrees.
  - Fringe-finders (bandpass calibrators): strong sources, can be farther away.
  - Polarization calibration? —> unpolarized calibrator or with known pol.

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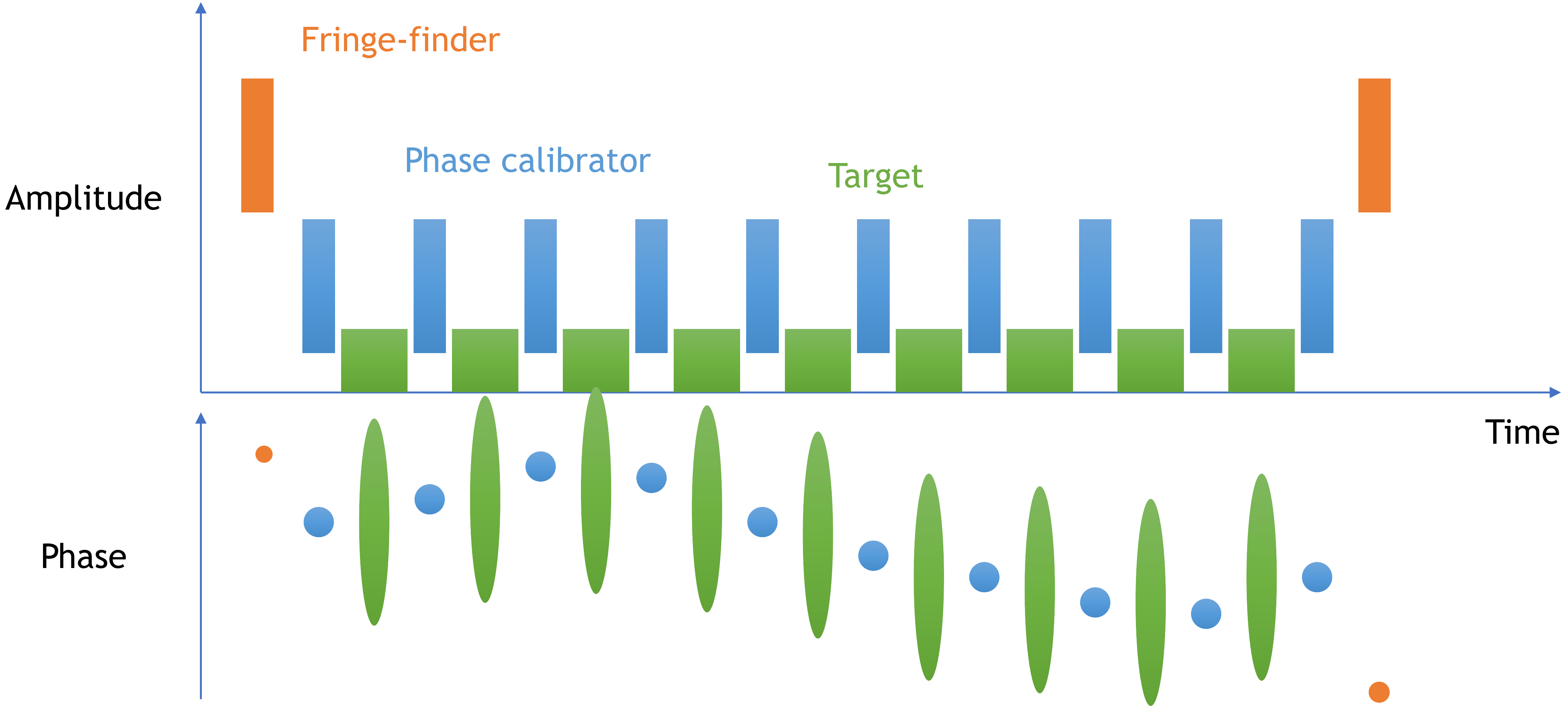
VLBI typical observation



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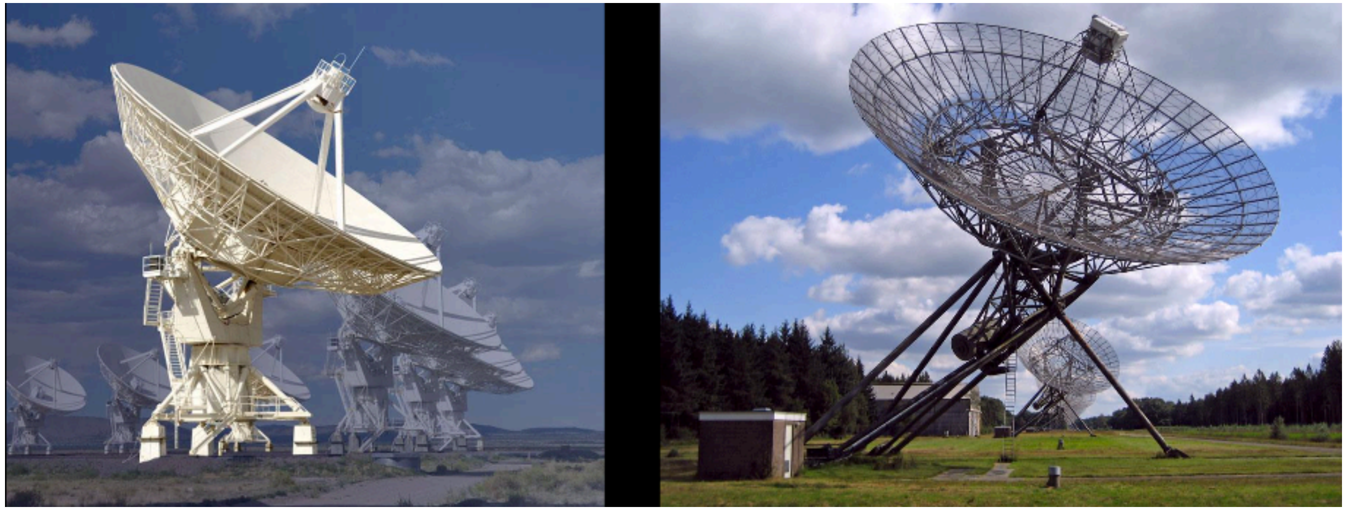
EVN calibration

Two calibration steps already performed during the internal processing of EVN data. But in CASA you need to apply the calibration:

☑ Parallactic angle & mount type

Keep parang=True



☑ A-priori gain calibration

append_tsys.py

gc.py

gencal()

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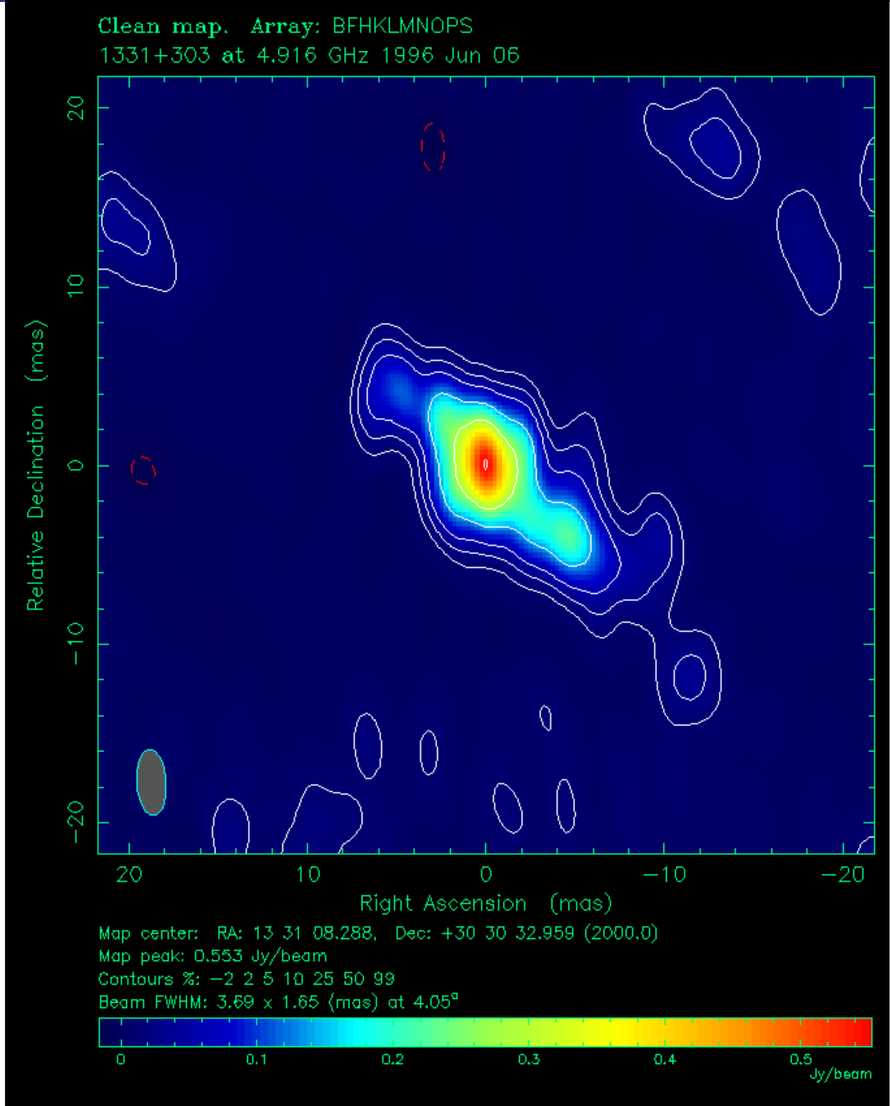
VLBI gain calibration

- In connected interferometers:
  - Observe an amplitude (or gain) calibrator:
    point-like source with no variability
    —> amplitudes known.

- In VLBI:
  - Most of the sources are resolved to some extend.
  - The compact ones are typically highly variable.



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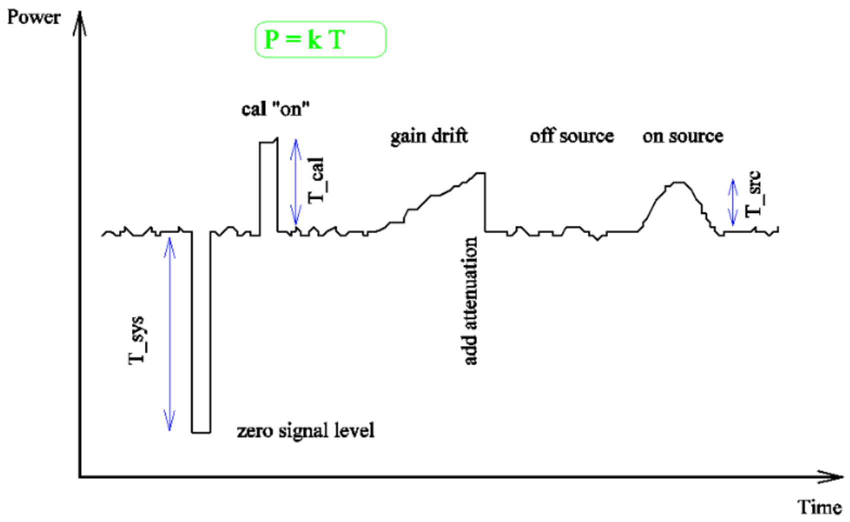
VLBI gain calibration

- ☑ ***System temperature***:
  "Power" measured by the station only from the system noise.
- ☑ ***System Equivalent Flux Density*** (SEFD).
  Flux density of a fictitious source delivering the same power as the system noise.
- ☑ ***Gain (or sensitivity)***:
  Increase in *T* for a source of 1 Jy.
  - ☑ **Absolute gain**: DPFU (degrees per flux unit)
  - ☑ **Gain curve**: dependency with zenith angle (elevation, etc...).

$$\mathrm{SEFD} = \frac{T_{\mathrm{sys}}}{\mathrm{DPFU} \cdot g(z)}$$



Always ~10% uncertainty!

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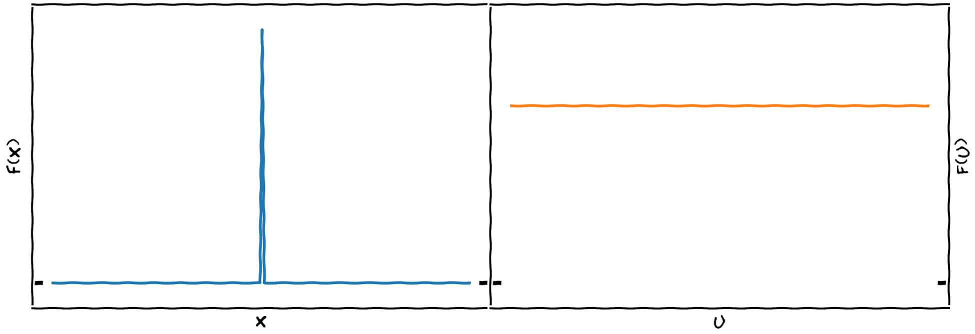
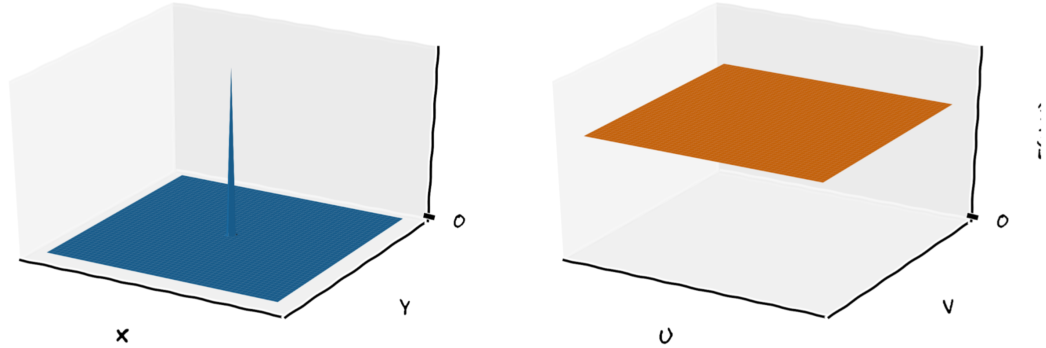
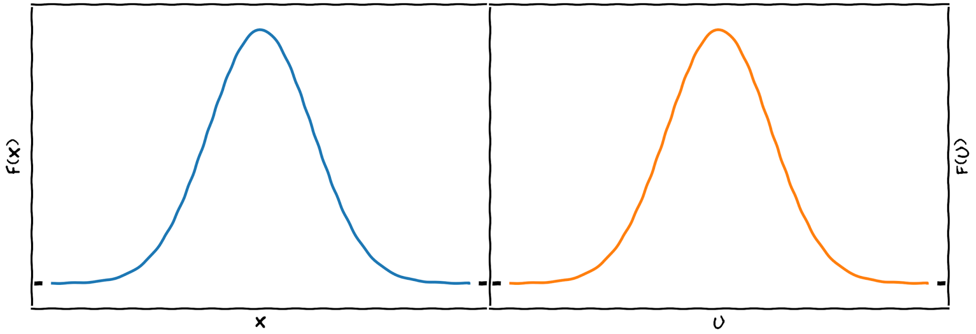
[Reminder] Fourier transforms



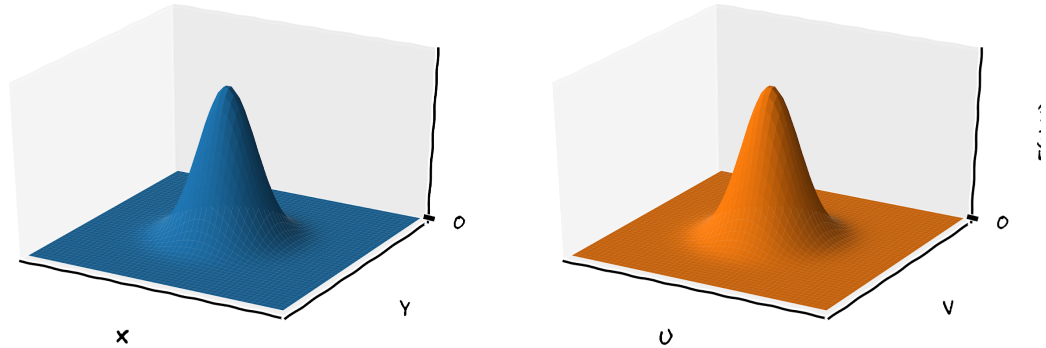
A Delta function is transformed into a constant.
* If offset from x = 0, then into a
  sinusoidal function.



A 2D Delta function is transformed into a plane (any U, V point sees the same value).



A Gaussian function is transformed into another Gaussian function.



A 2D Gaussian function is transformed into a 2D Gaussian.

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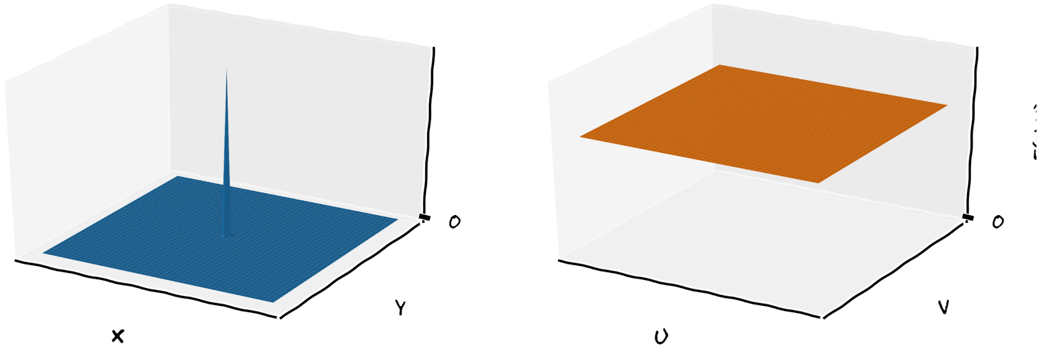
Interferometers

- ☑ A point-like source will appear with the sample amplitude at all baselines (*u*,*v* points).

- ☑ A resolved source will show a lower amplitude at longer baselines (even down to zero).



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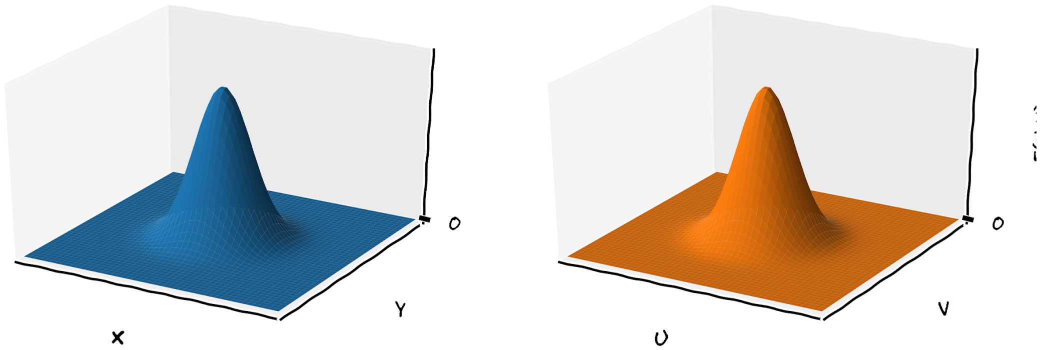
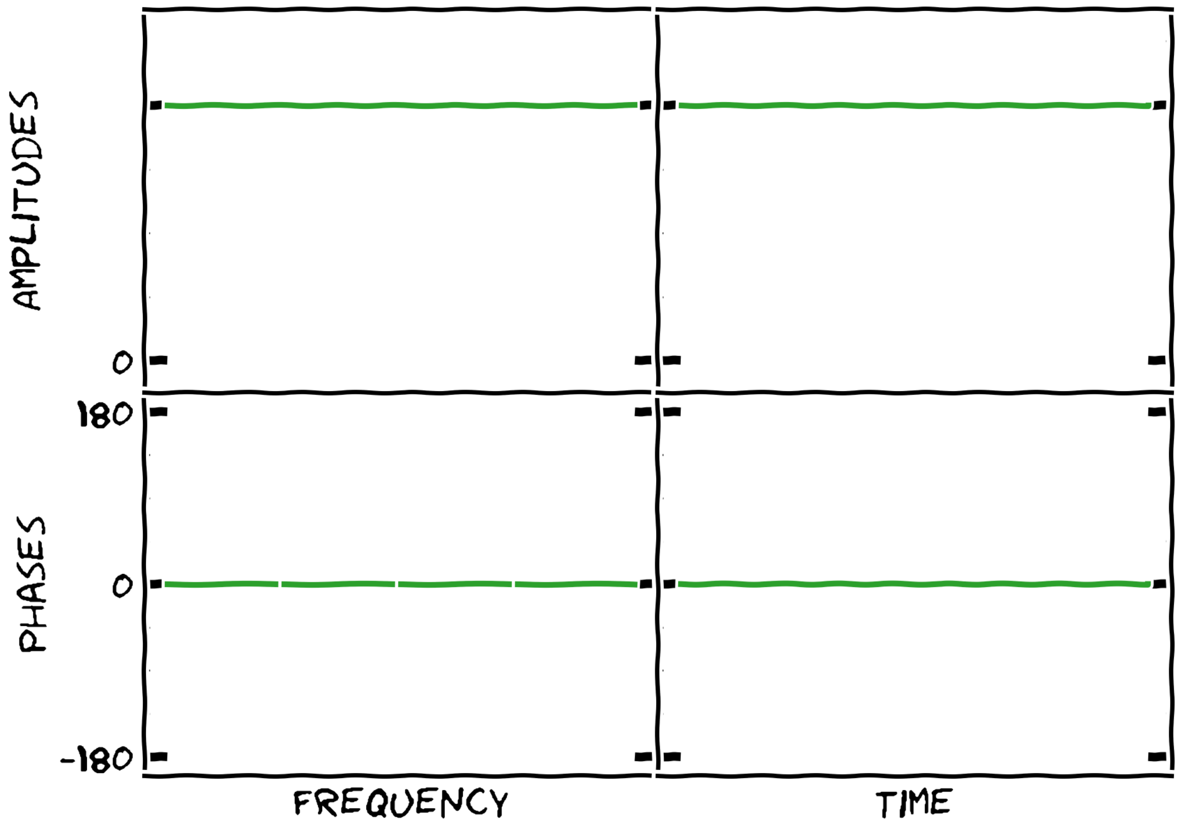


A 2D Gaussian function is transformed into a 2D Gaussian.

VLBI calibration

- When you point to a strong, unresolved, source at the phase center (correlated position; e.g. pointing position):
  - Constant amplitudes.
  - Zero phases.

  - Along the time.
  - Along the frequency.



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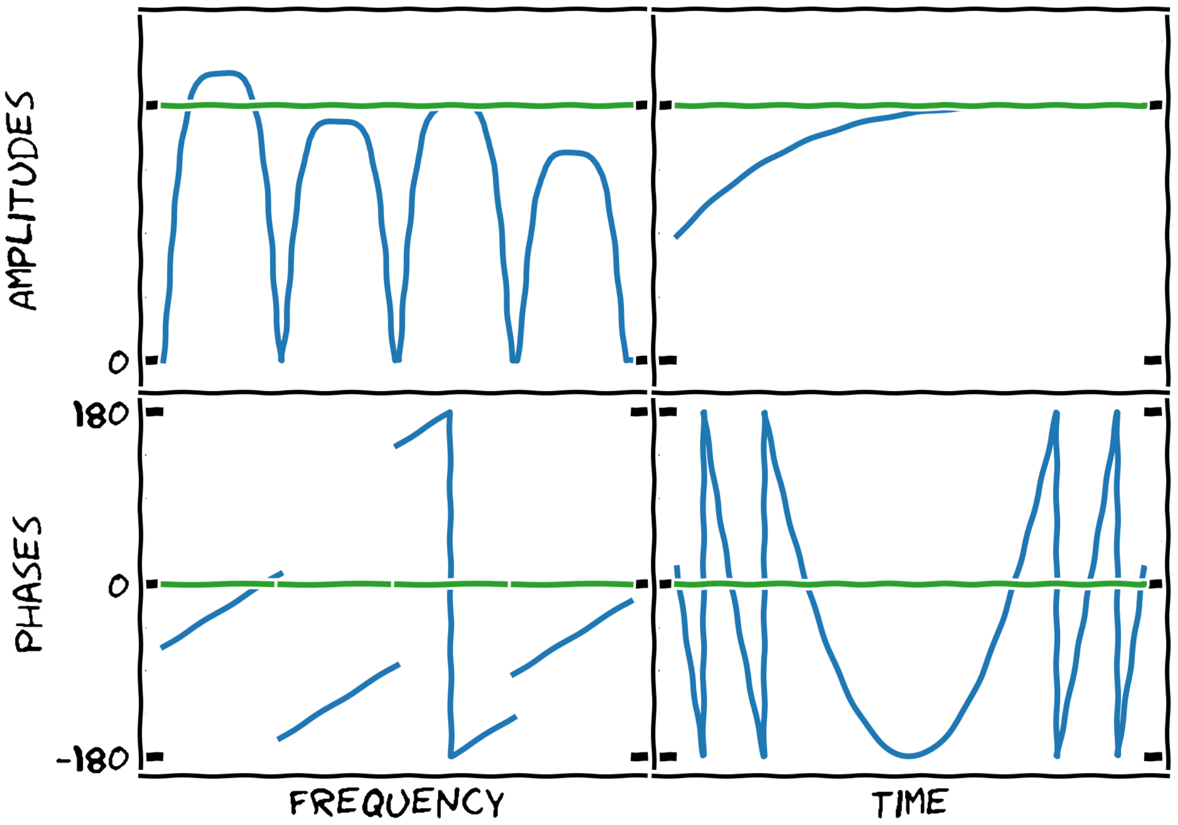

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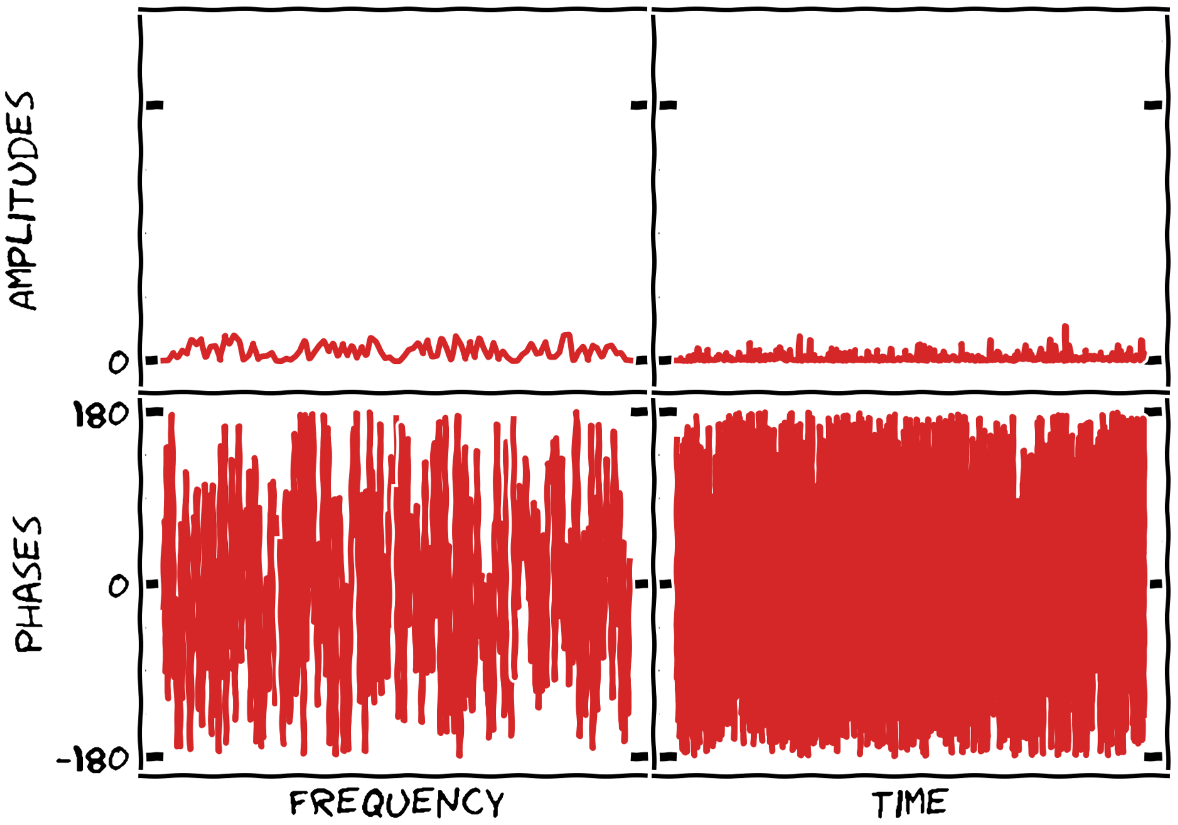

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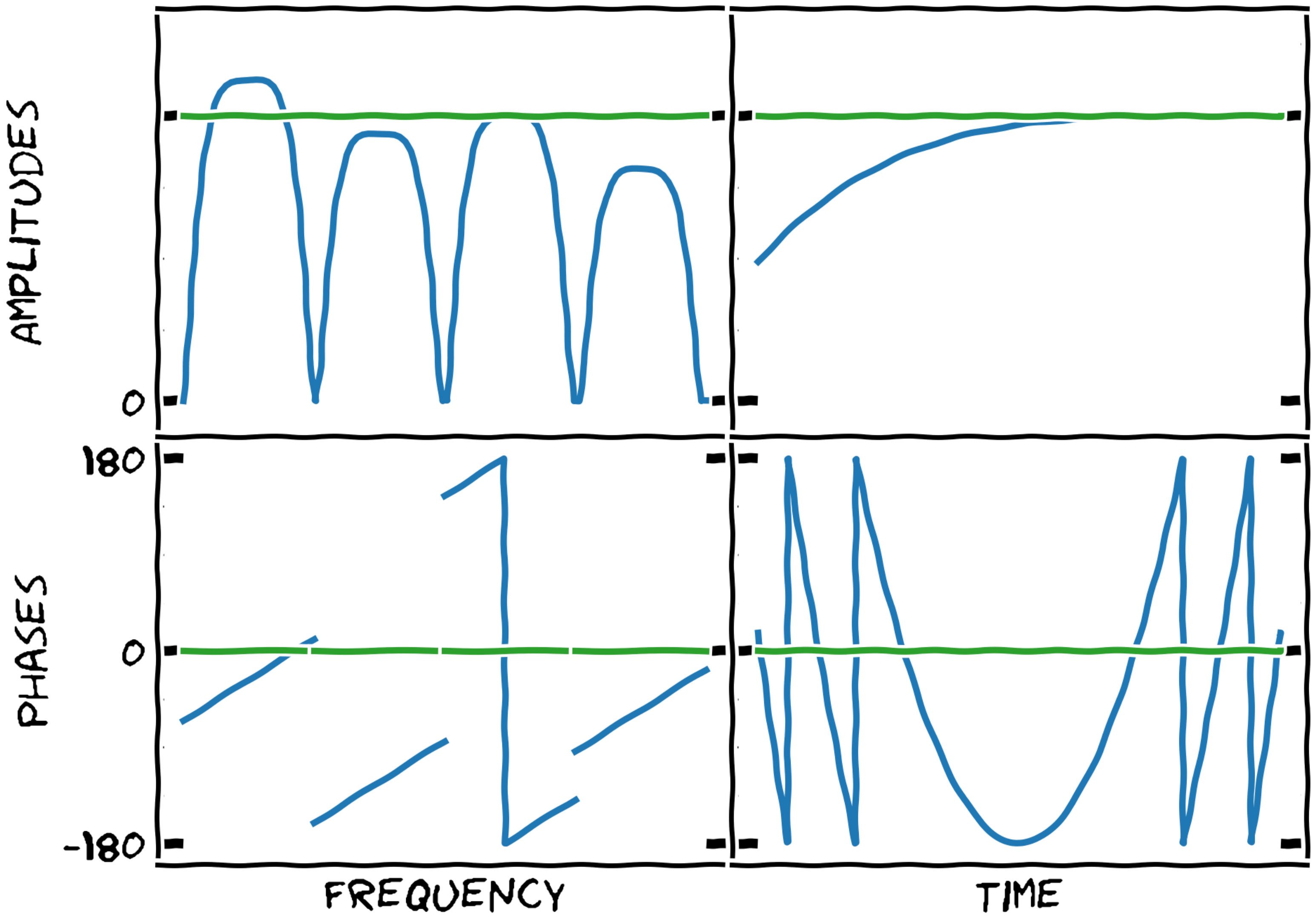

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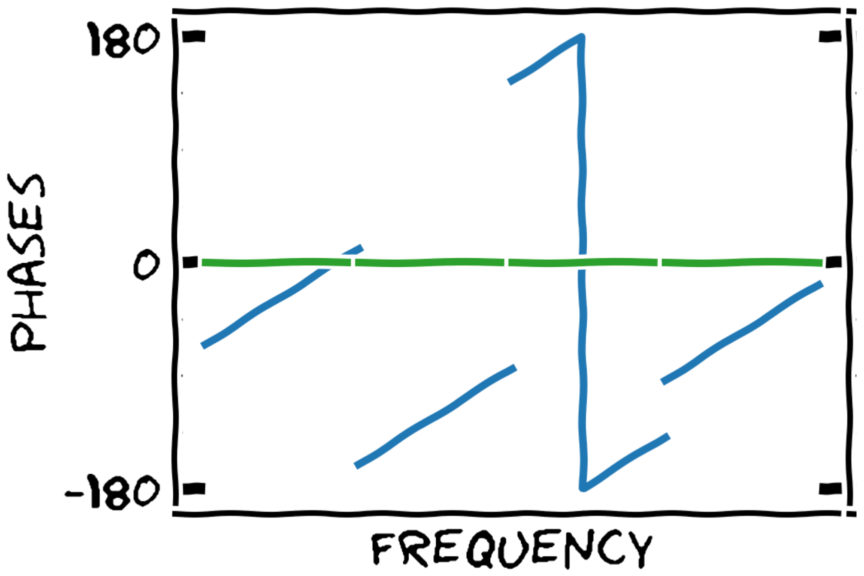
VLBI calibration



Instrumental delay correction:

- ☑ Picking up just a single scan (e.g. fringe finder).
- ☑ Phase slope that will be corrected.
- ☑ Phase jumps between (some) subbands. Different hardware —> instrumental delays
- ☑ These jumps should be consistent along the observation.

```
fringefit(vis='experiment.ms',
    caltable='cal.sbd'
    field='fringe-finder-name',
    timerange='a-couple-of-minutes',
    solint='inf',
    zerorates=True,
    refant='EF',
    minsnr=10,
    gaintable=['cal.tsys', 'cal.gcal', ...],
    parang=True)
```

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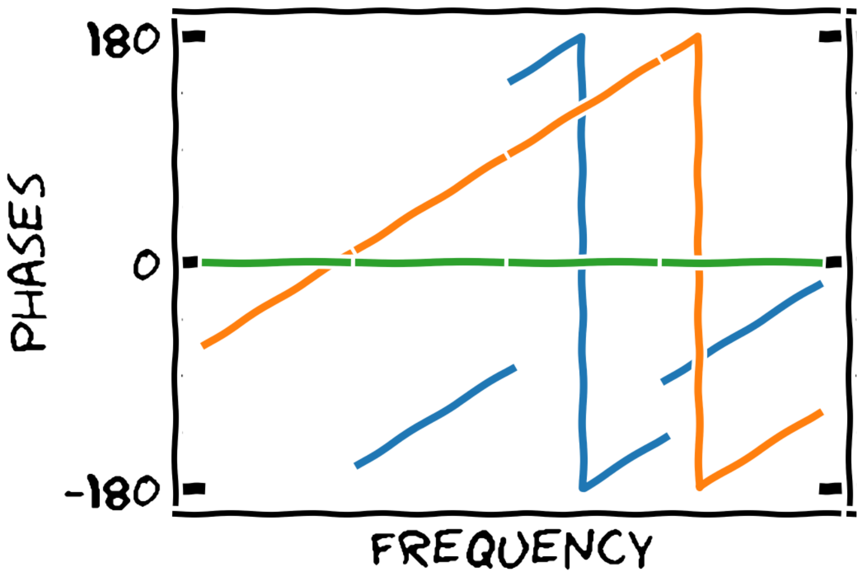
VLBI calibration



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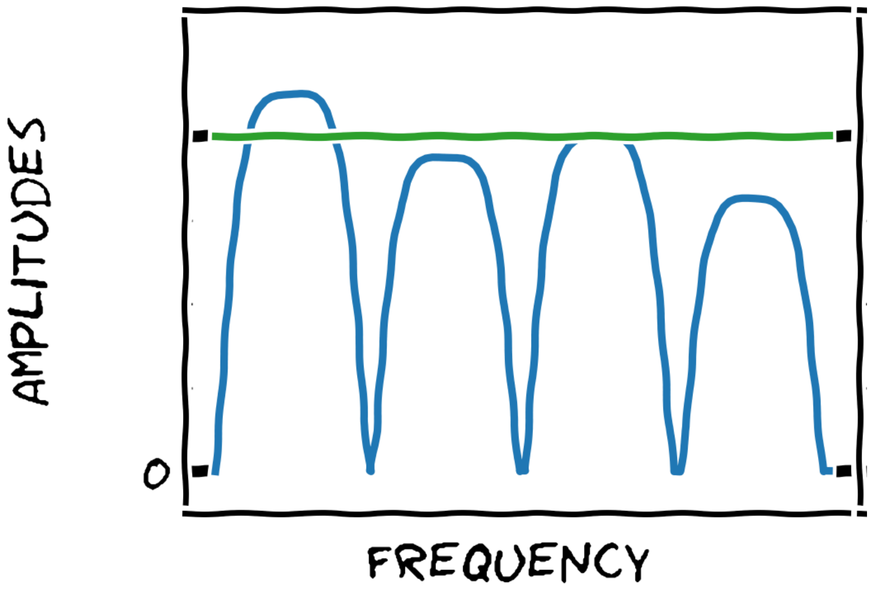
VLBI calibration



Bandpass calibration:

- ☑ Correct for the effect of the band in the different subbands.
- ☑ *Instrumental effect*. Constant in time/source.
- ☑ Use the brightest source for that (highest S/N) —> fringe finder(s).

```
bandpass(vis='experiment.ms',
    caltable='cal.bpass'
    field=‘fringe-finder-name‘,
    gaintable=['cal.tsys', 'cal.gcal', ...],
    solnorm=True,
    solint='inf',
    refant='EF',
    bandtype='B',
    parang=True)
```

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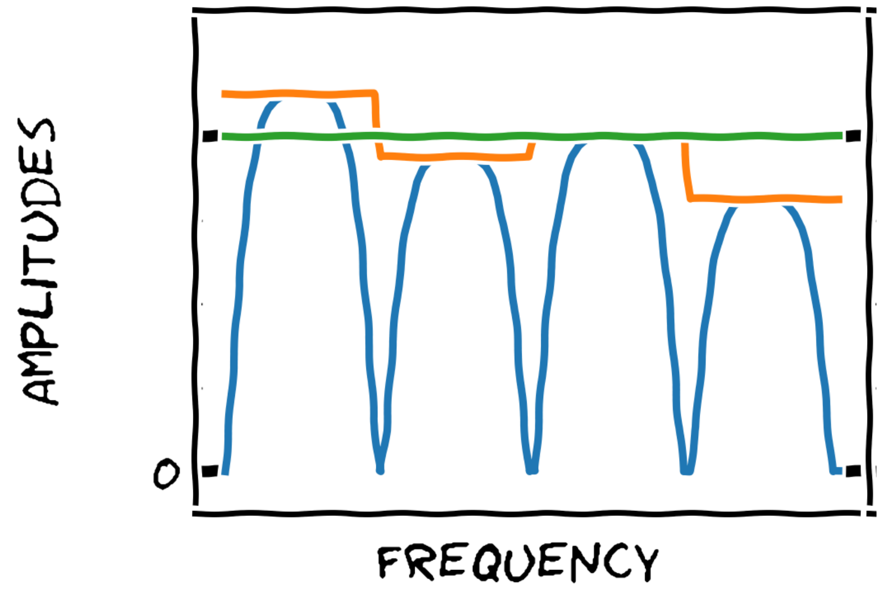
VLBI calibration



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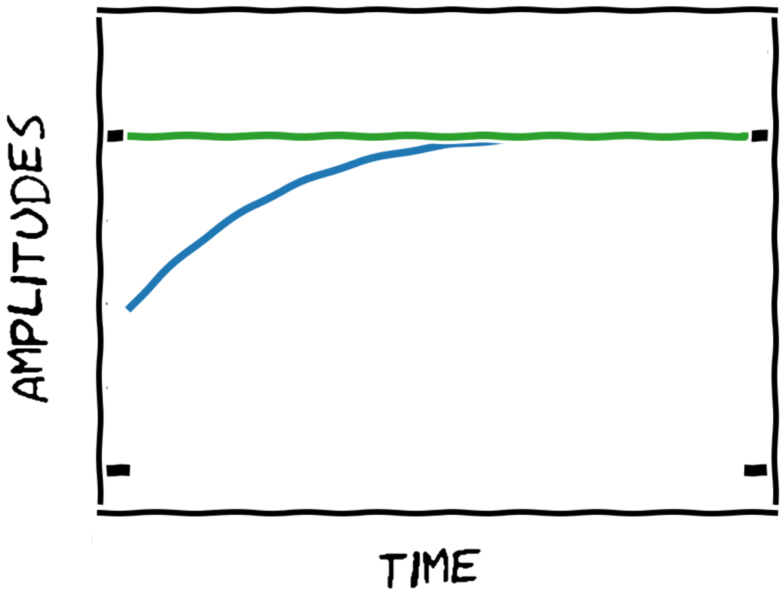
```

VLBI calibration

- The main amplitude calibration is then done between the initial *a-priori* gain corrections with the system temperatures and the bandpass.

- Small deviations, also depending on the source elevation, etc. could still be present.

- ***Self-calibration*** (Lecture 9, Wednesday) would solve them.



VLBI calibration

Global fringe

(or frequency- and time-dependent phase calibration)

- ☑ Fit the evolution of delays and rates for **each calibrator** source along the observation.
- ☑ Corrections depend on the propagation effects (atmosphere).

```
fringefit(vis='experiment.ms',
    caltable='cal.mbd',
    solint='t min',
    combine='spw',
    field='calsource1, calsource2,...',
    refant='EF',
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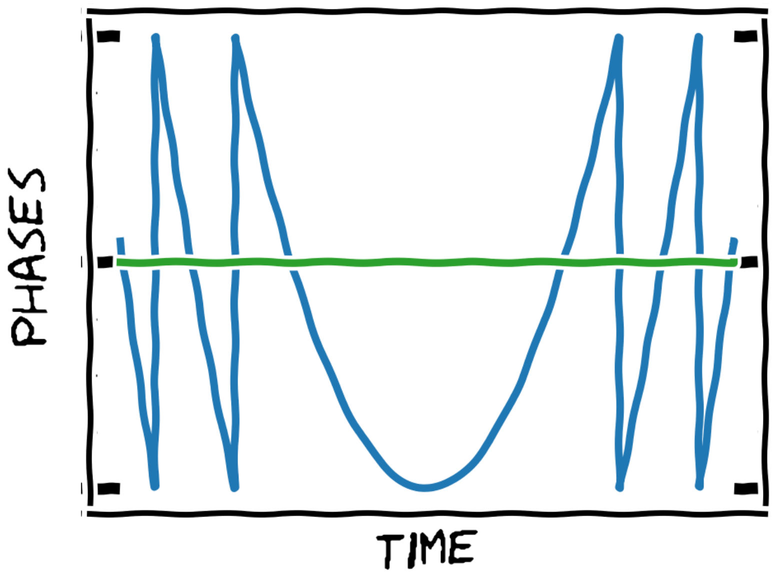
```



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```

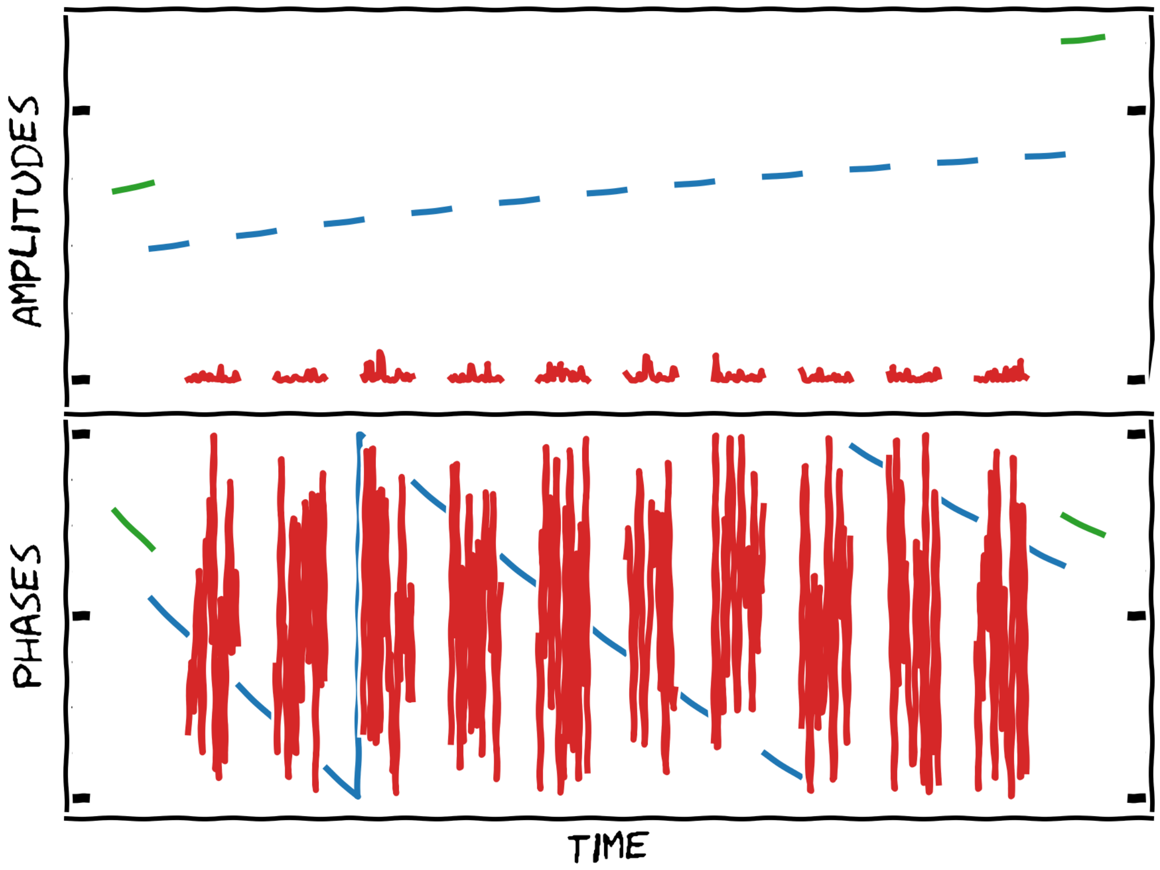

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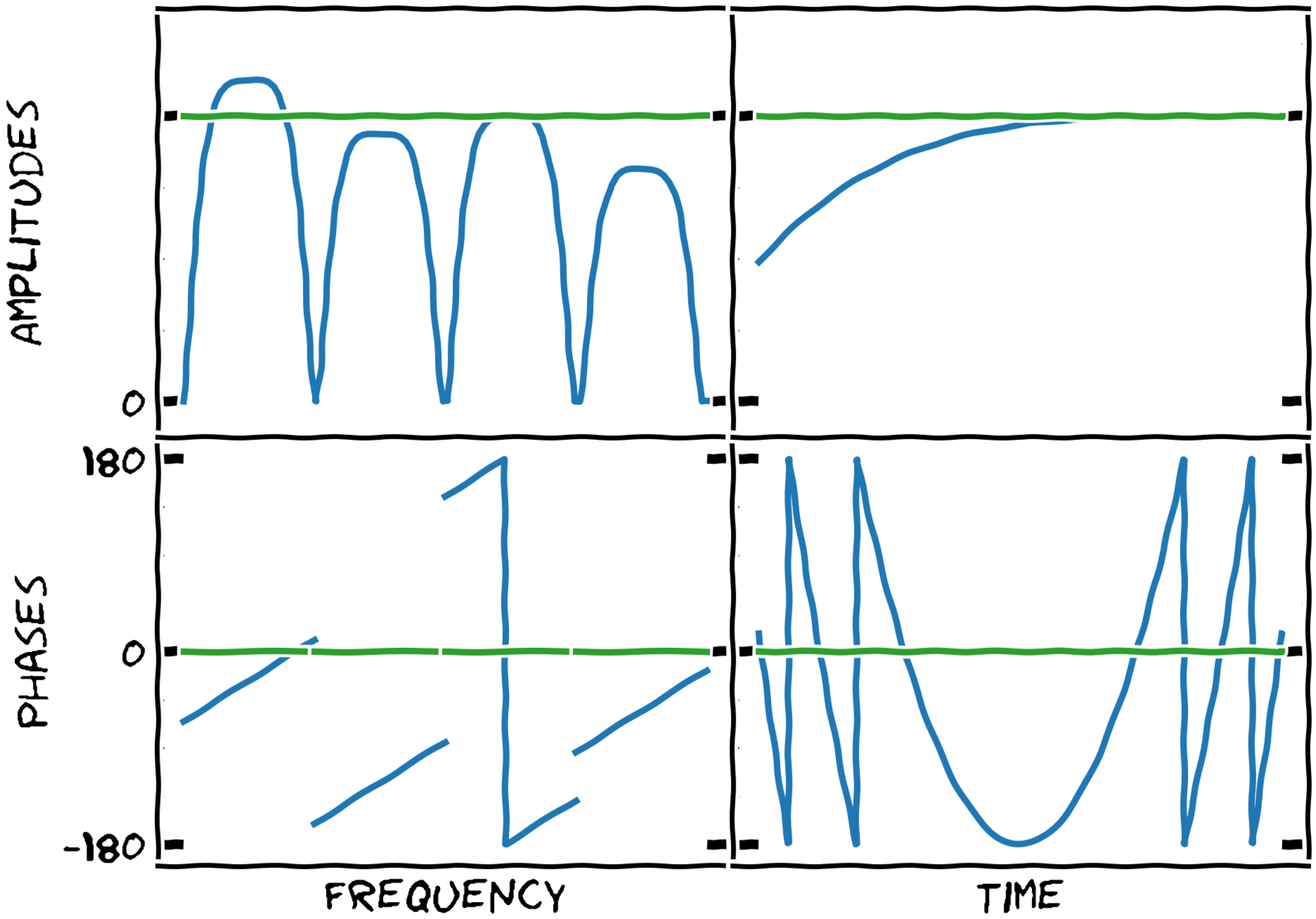
VLBI calibration



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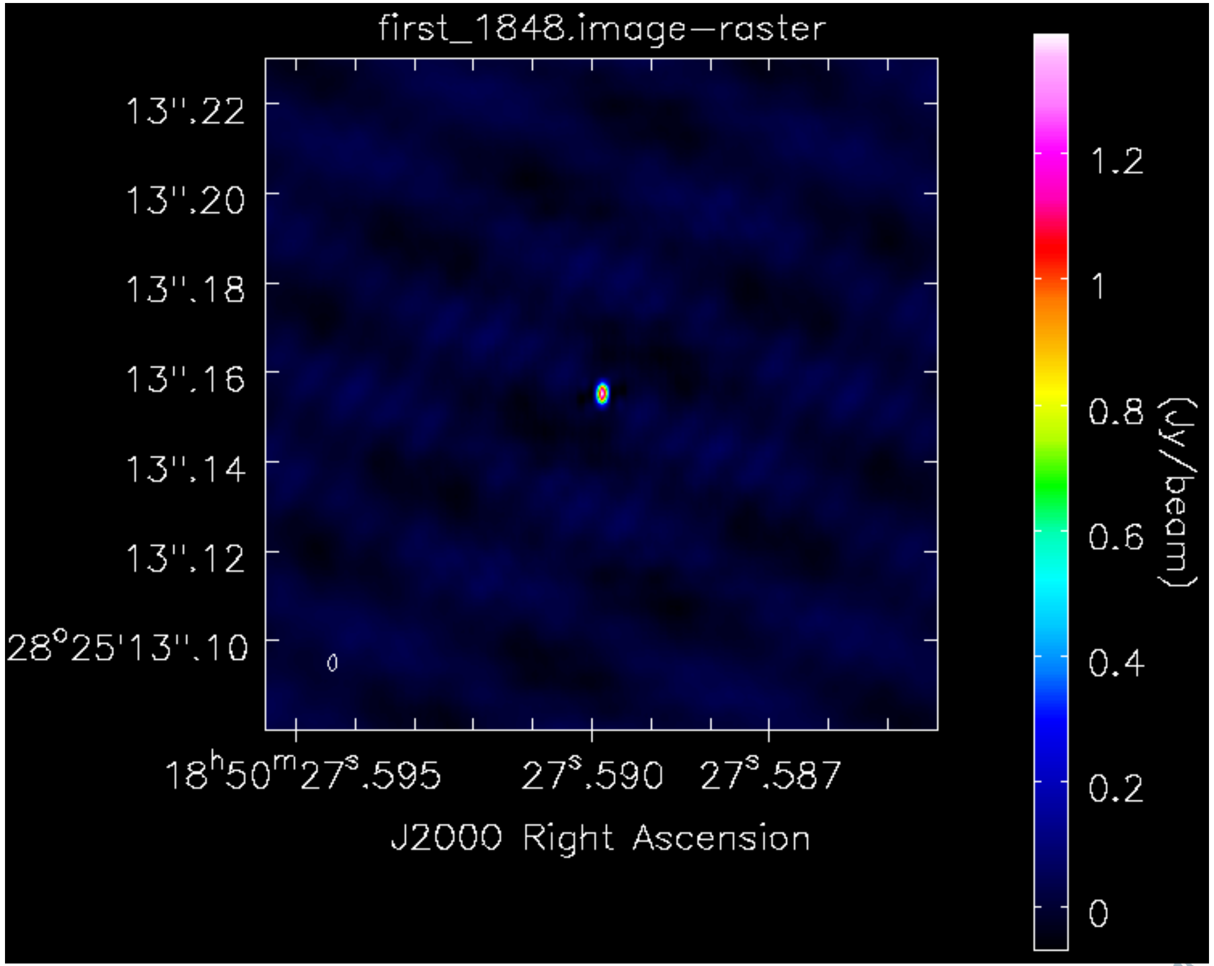
VLBI calibration

- ☑ Transfer the solutions to the target source (applycal).
- ☑ Imaging
  - ☑ Self-calibration
  - ☑ And iterate!



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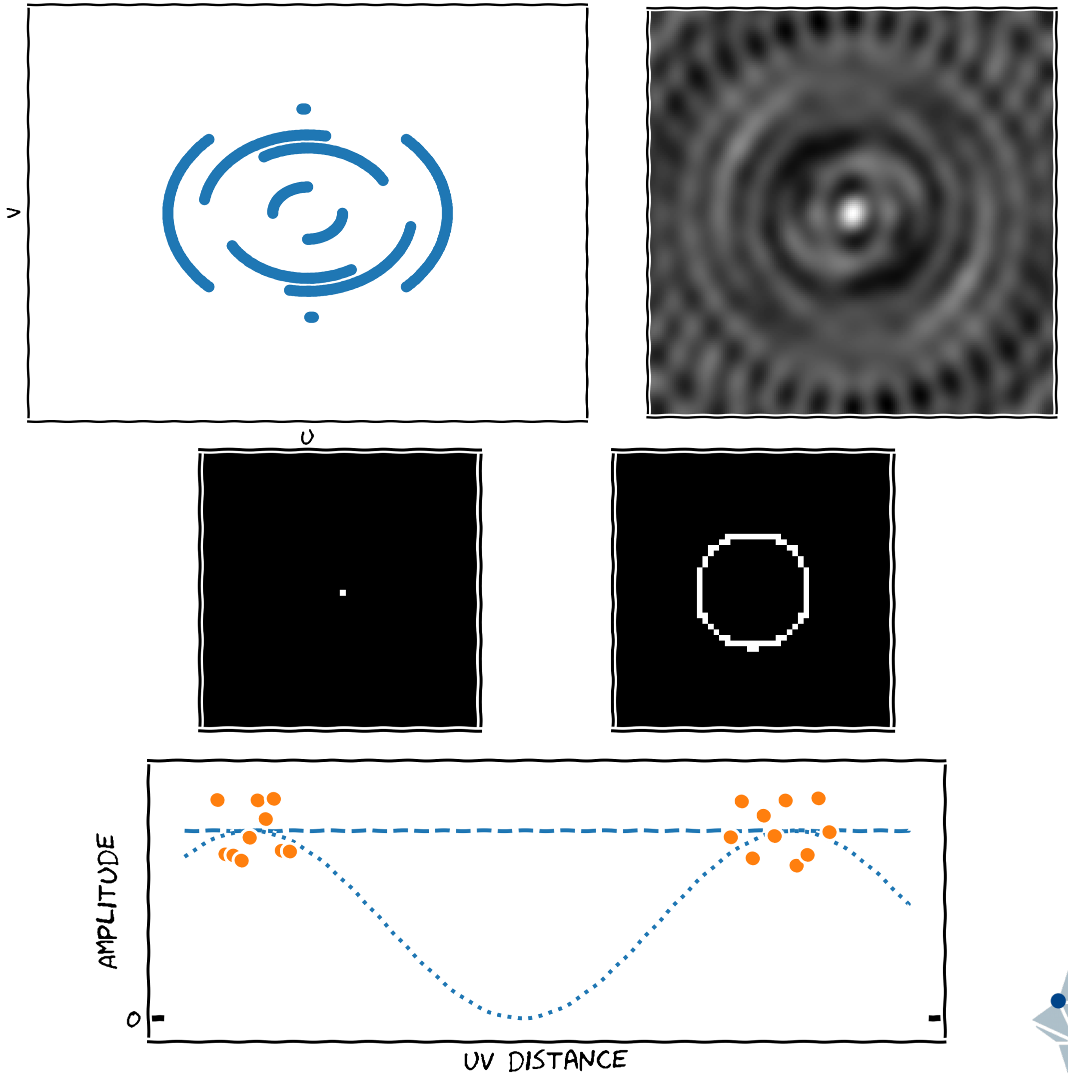
VLBI images
Some important remarks

The more sparse *uv* coverage implies:

- ☑ ***Non-gaussian noise***.
  Strongest spikes in the imaged field: 6-σ level required.
- ☑ Measured flux densities may (slightly) differ when doing in the image plane or *uv* plane.
- ☑ Images with source structures may be sensitive to calibration. Check your calibration!



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Self-calibration

Always with extreme caution!

- ☑ You “modify” your data to *fit* your model.
- ☑ Can easily scale up/down your station amplitudes (artificially).
- ☑ **Lecture 9** on Wednesday 9:30UT (Javier Moldón)

Summary

- ☑ EVN Data Reduction Guide:
  https://www.evlbi.org/evn-data-reduction-guide

- ☑ But doing a convenient scheduling is the first step for a good calibration:
  https://www.evlbi.org/evn-scheduling

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