CASA VLBI

WORKSHOP 2020

2-6 NOVEMBER 2020

MILLIMETER VLBI WITH rPICARD

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CASA Common Astronomy Software Applications

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BlackHoleCam

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Radboud PIpeline for the Calibration of high Angular Resolution Data (rPICARD)

- Janssen et al., A&A, 626 (2019) A75.
- The Event Horizon Telescope Collaboration, 2019, ApJL, 875, L3.
- https://bitbucket.org/M_Janssen/picard

- Based on CASA6 with own plotting functions.

- Many diagnostics, easy to tune parameters + re-run.

- For many arrays: EHT, GMVA, VLBA, EVN, …

Pipeline setup (1/3)

- Singularity, Docker, or from source:
  - http://www.jive.nl/jivewiki/doku.php?id=casa:casa

- Using Singularity (https://singularity.lbl.gov/) in the working dir:

```
$ singularity build casavlbi.pipe docker://mjanssen2308/casavlbi:latest
$ singularity run ./casavlbi.pipe
```

Pipeline preparation (2/3)

- $ cp -r /usr/local/src/picard/input_template/ input
- rPICARD will automatically identify and use files based on their extension (freely configurable). Add files or links to workdir.

- Raw visibility data
  - FITS-IDI files or MS.

- ANTAB a-priori calibration metadata

- Text files containing flagging instructions for bad data

- Other:
  - Receiver temperatures, weather data, source models.

```
michael@mjpc:~/Software/Bitbucket_repos/Picard/testing$ ls
3C84.smodel  example.antab  example_EVN.IDI1  example.flag  example.trx  input
```

Configure (3/3)

- **input/observation.inp, input/array.inp**
- Example:

observation.inp

science_target = 3C273, OJ287

calibrators_instrphase = 3C279

calibrators_bandpass = None

calibrators_rldly = None

calibrators_dterms = None

array.inp

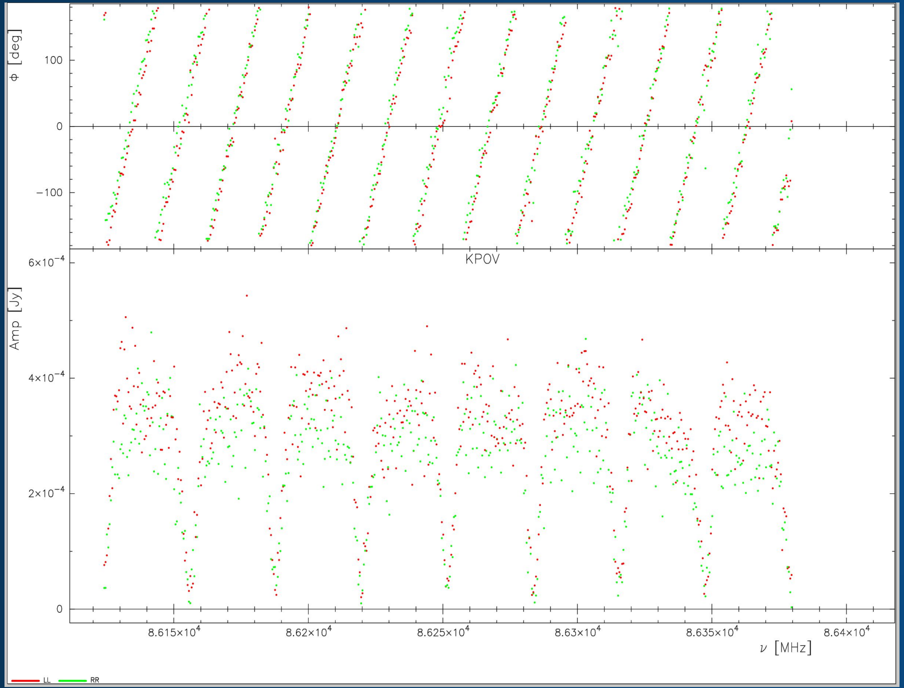
array_type = GMVA

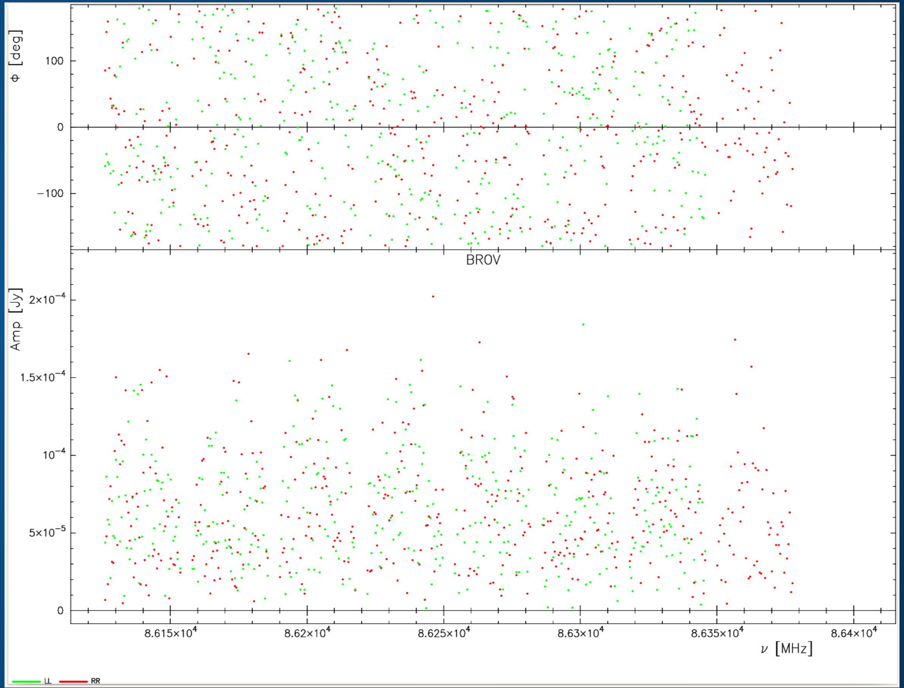
refant = LA, KP, PT

Running the software

```
$ picard -p -n 4
```

Inspect the data!!!

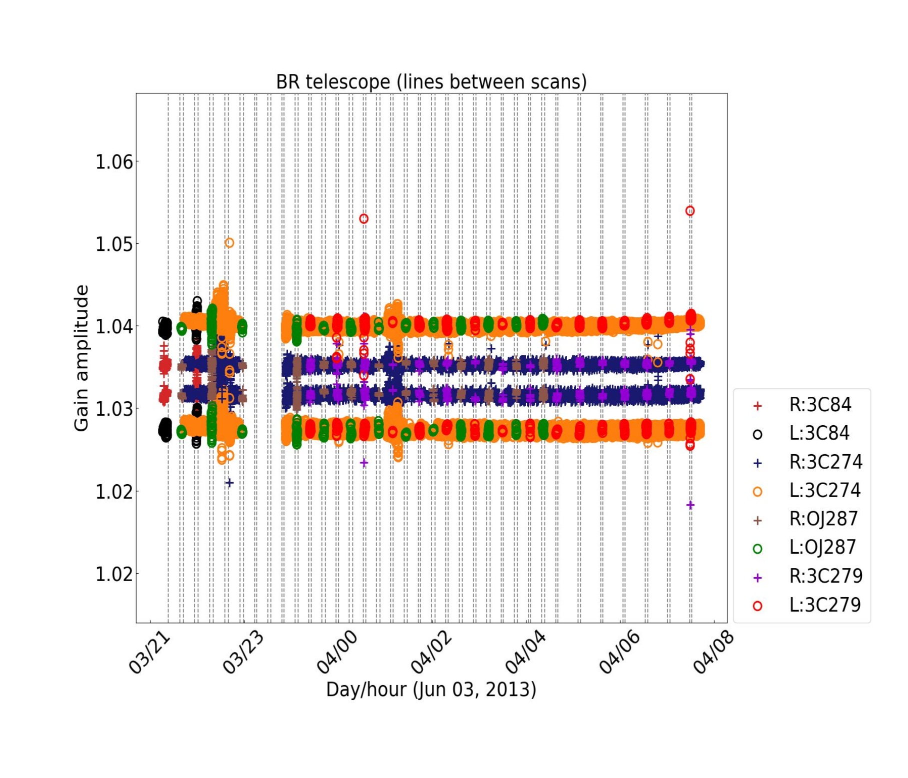


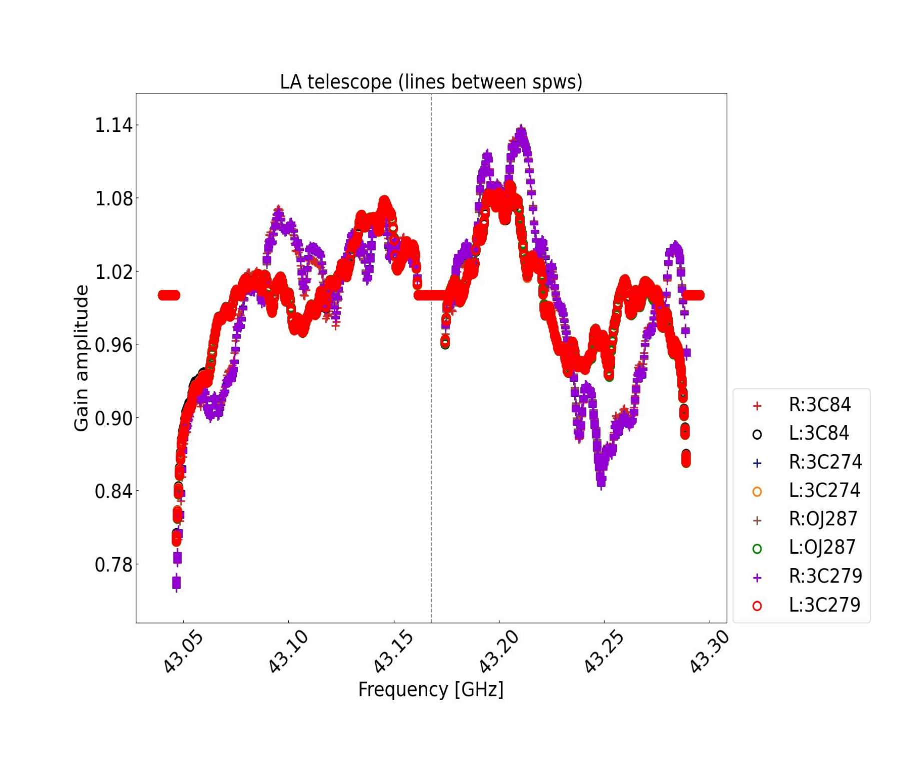


jplotter: 3mm VLBA data of 3C279 & 3C273. Project code: S6096B (scan #14 & #1).

Amplitude calibration

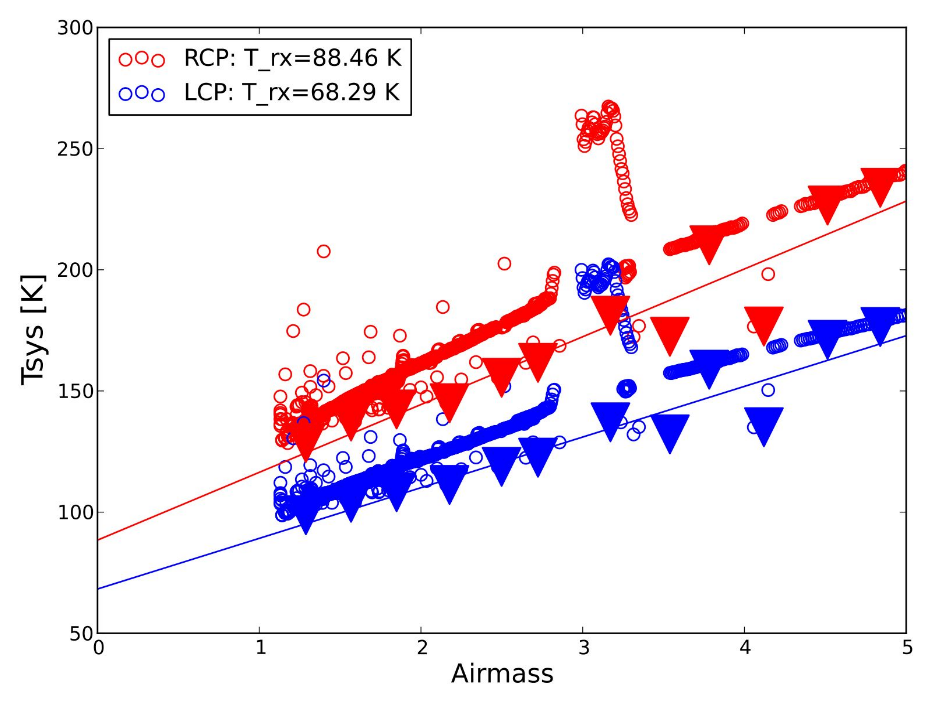
Accor & scalar bandpass (step 0, 1)

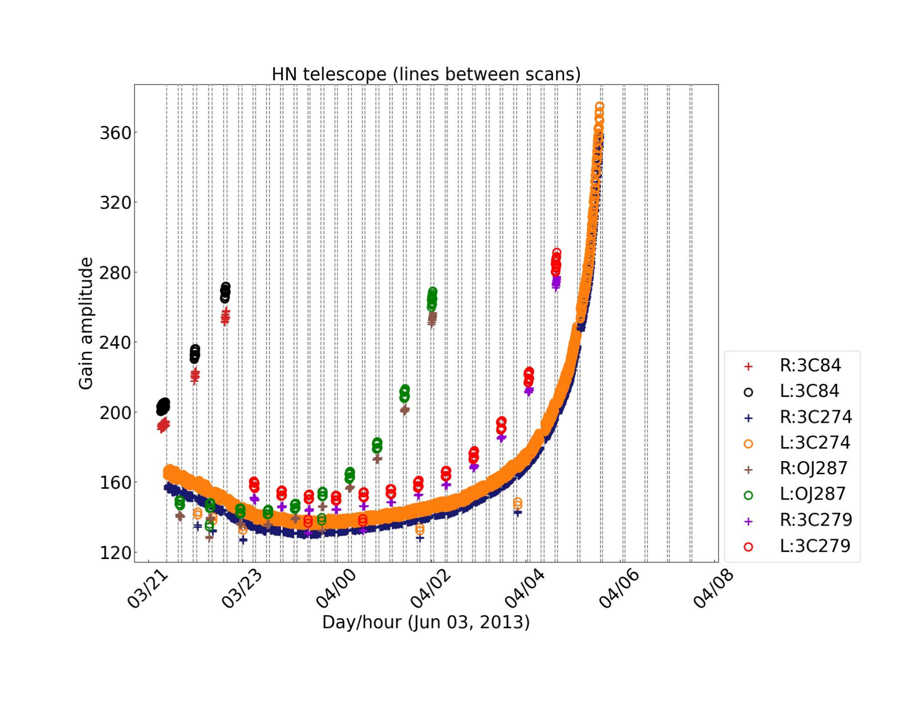




7mm VLBA data of M87. Project code: BW0106.

Flux density calibration (step 2, 3)



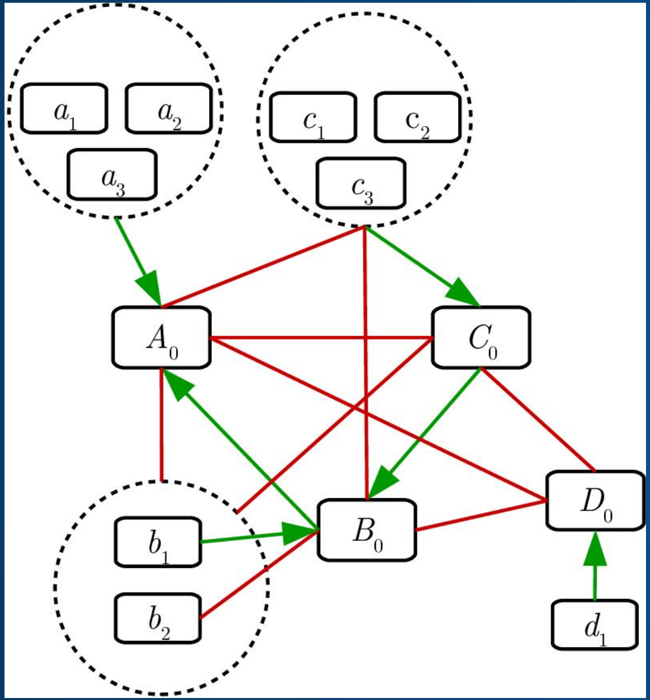


7mm VLBA data of M87. Project code: BW0106.

$T_{sys} \sim T_{rx} + (1 - e^{-\tau})T_{atm} \rightarrow T_{sys} * e^{\tau}$

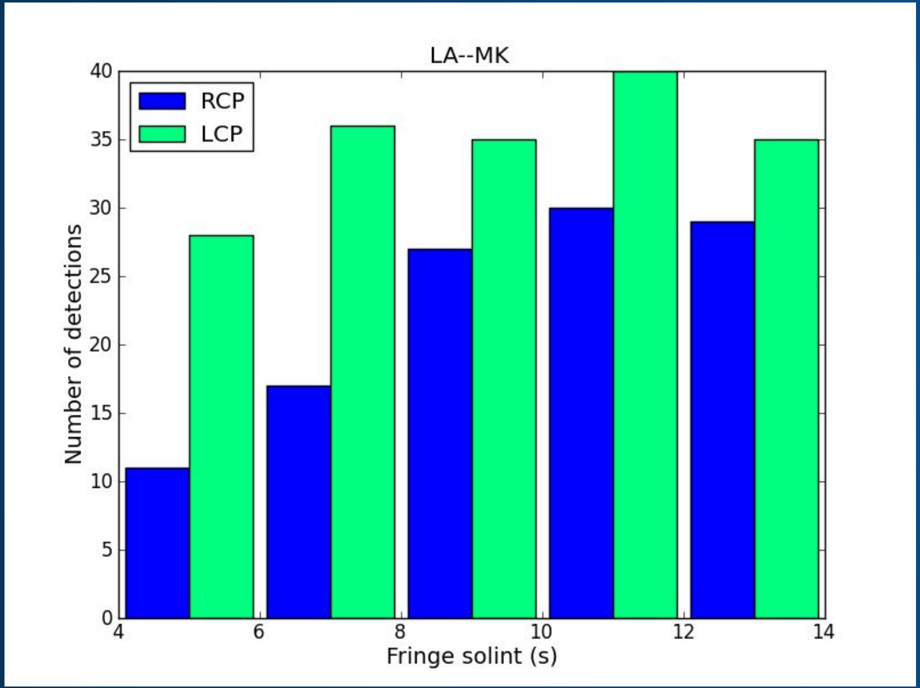
Phase calibration

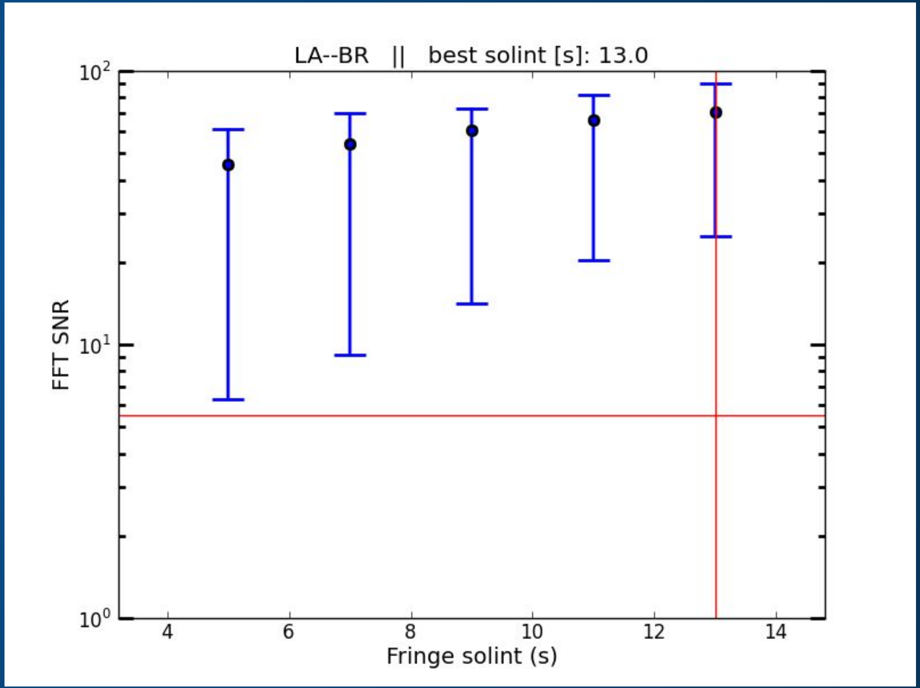
Intra-scan exhaustive fringe search



- A_0, B_0, C_0, D_0 list of prioritized reference stations.
- Green : detection.
- Red: Non-detection.
- D_0 and d_1 still un-calibratable.
- b_1, C_0, c_i calibratable via re-referencing.

Solution interval estimation (step 4)





3mm VLBA data of 3C279. Project code: S6096B.

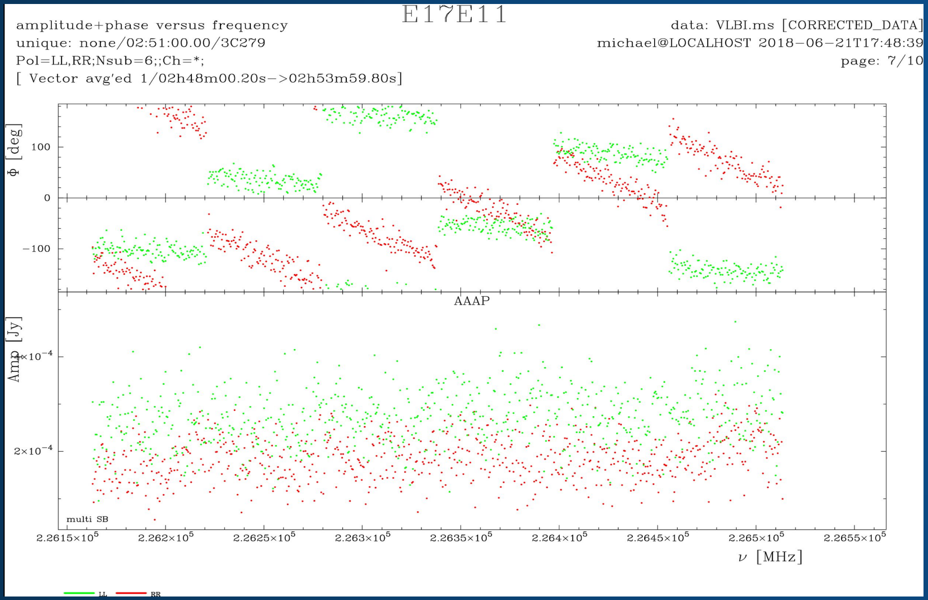
First: calibrator sources→solve instrumental effects

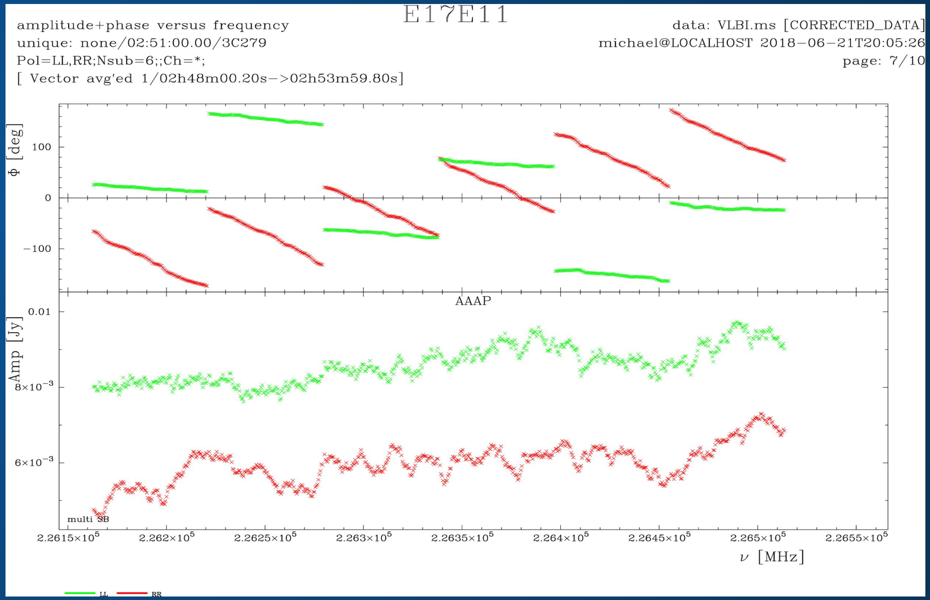
Then: weaker science targets

Coherence calibration (step 5)

Atmospheric phase stabilization

===========================>

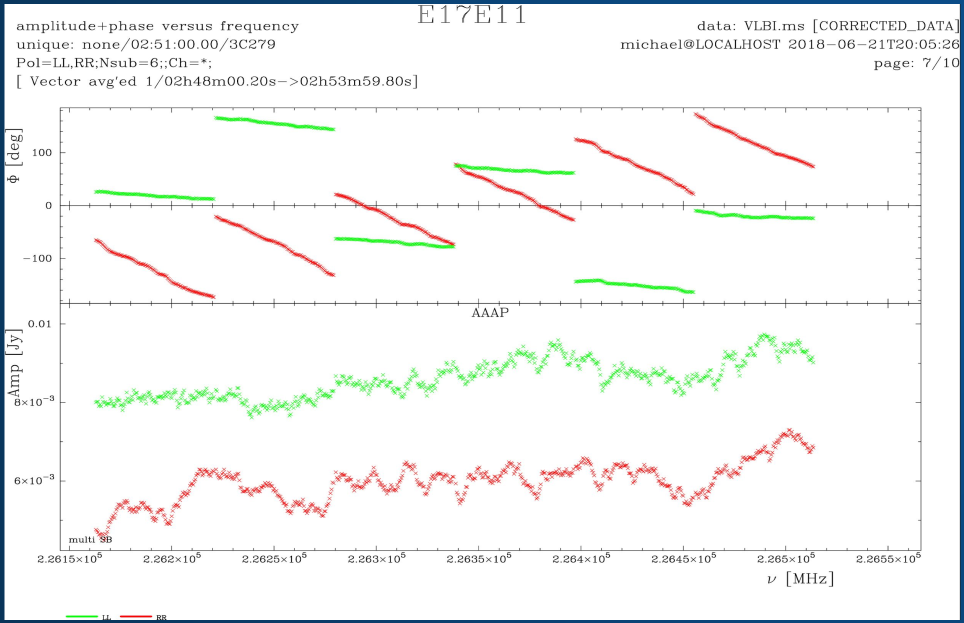


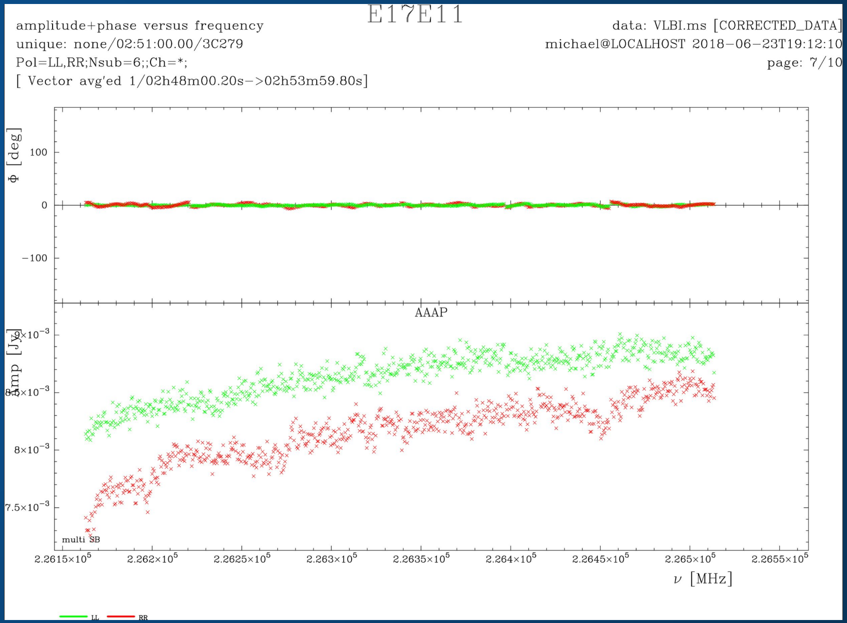


Some EHT data (1mm).

Instrumental phases and delays (step 6)

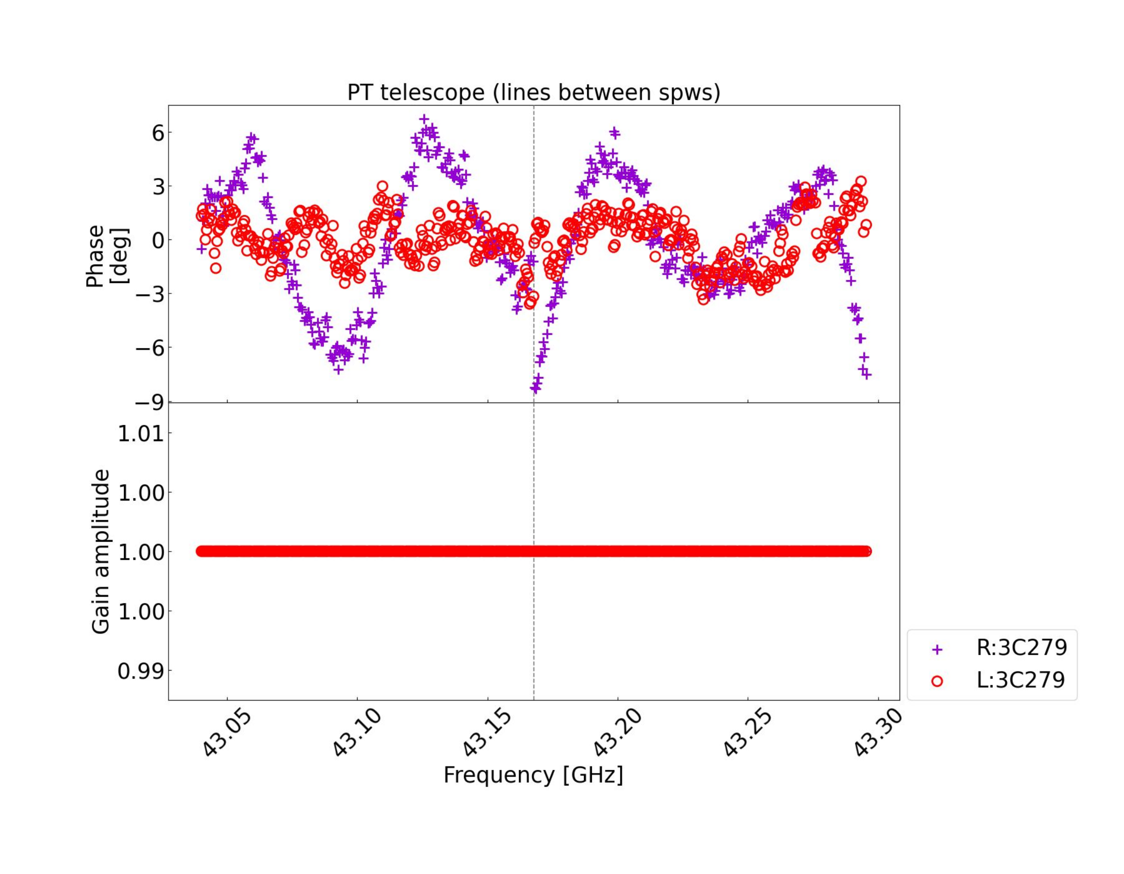
Per-spw fringefit
=============>





Some EHT data (1mm).

Complex bandpass (step 8)



7mm VLBA data of M87.
Project code: BW0106.

Now: All instrumental effects are taken out

→ Calibrate science targets

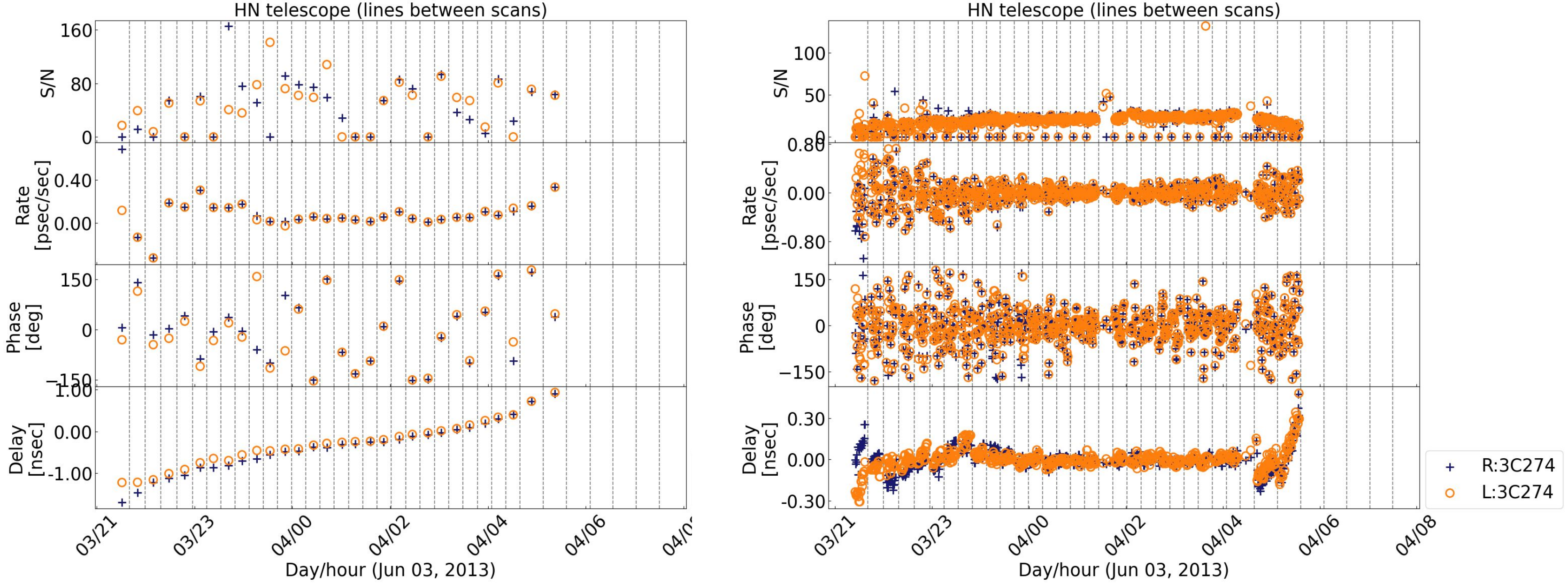
Last calibration steps: fringe-fit science targets (steps 12, 13, 14)

- First: long integration (entire scan) to take out bulk delay or rate with maximized SNR.
  → Source detected or not?
  Typically with open FFT search windows.

- Then: Use narrow windows (small false detection probability) to solve for residual intra-scan atmospheric effects on short timescales.
  → Using optimized solution intervals.

- Can also enable phase-referencing mode.
  - Possibility for residual fringe search on sufficiently strong science targets.

Last calibration steps: fringe-fit science targets



7mm VLBA data of M87. Project code: BW0106.

THANKS TO OUR SPONSORS:

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Backup slides

Pipeline installation

- Get a test data set when not using your own:
  $ wget https://ftp.science.ru.nl/astro/mjanssen/S6096B.tar.gz
- Using Singularity (for Docker see README) in the working dir:
  $ singularity build casavlbi.pipe docker://mjanssen2308/casavlbi:latest
  $ singularity run ./casavlbi.pipe
  $ cp -r /usr/local/src/picard/input_template/ input
- From source for Ubuntu (Linux only, can have multiple CASA versions) in src dir:
  $ git clone https://bitbucket.org/M_Janssen/picard
  $ curl -L "$(cat picard/README.md | grep wget | cut -d' ' -f3)" -o CASA.picard.tar.xz
  $ tar xJf CASA.picard.tar.xz && rm -rf CASA.picard.tar.xz
  $ python picard/setup.py -a -p /usr/local/src
  $ printf '\nexport PATH=$PATH:'"$(pwd)"'/picard/picard\n' >> ~/.bashrc
  $ printf '\nexport PYTHONPATH=$PYTHONPATH:'"$(pwd)"'/picard/picard\n' >> ~/.bashrc
  $ sudo apt-get install singularity-container
  Or install https://github.com/haavee/jiveplot.
  $ cd /path/to/working/dir && cp -r /path/to/picard/picard/input .

Running the software

- To run the full pipeline:
  $ picard -p -n 4

- Show command line arguments:
  $ picard -h

- Generate raw data visibility plots: $ picard -p -n 2 -q h,k

rPICARD steps

```
The pipeline will execute the following steps for the
VLBAhi array in the given order:
   a : load models of observed sources (if present)
   b : use online flags from idi files (if present)
   c : use flags from metadata (if present)
   d : flag based on outlier detection from auto-correlations vs time
   e : flag based on outlier detection from auto-correlations vs frequency
   f : flag edge channels
   g : flag start and end segments of scans (quacking)
   0 : task_accor
   1 : task_scalar_bandpass
   2 : task_tsys_add_exptau
   3 : task_gaincurve
   4 : task_fringefit_single
   5 : task_fringefit_solint_cal
   6 : task_fringefit_multi_cal_short
   7 : task_complex_bandpass
   8 : task_rldelay
   9 : task_rlphase
  10 : task_dterms
  11 : task_fringefit_multi_sci_long
  12 : task_fringefit_solint_sci
  13 : task_fringefit_multi_sci_short
   h : clear the calibrated data column of the MS from previous applycal runs
   i : apply all existing tables from all_calibration_steps
   j : print overview of flagged data (can be slow)
   k : make diagnostic plots of calibrated visibilities and create a calibration summary file
   l : average and export the calibrated data
Can use quickmode [-q] to execute only a subset of these steps.
```

Pre-calibration steps

1. Load data into MS, create obs summary file (*listobs*).

2. Prepare flux density calibration metadata.

3. Create and manage flag versions.

4. Load source models.

5. <u>Flagging</u>
    5.1. Correlator (attached to FITS-IDI files).
    5.2. Txt files.
    5.3. Automated outlier detection in auto-correlations.
    5.4. Edge channels.
    5.5. Quack (scan start and end times).

Solution interval estimation (step 5, 12)

- Fringe-fitting can be used to calibrate for intra-scan atmospheric effects on short timescales.
- A source is detected when the SNR of the initial FFT is high enough.
  The more detections per scan, the better the atmospheric calibration.
- Input parameter: Search range depending on array sensitivity and observing frequency.
  Set to ‘estimate’ by default.
- For each scan, the solution interval which yields the most detections on all baselines is used.
- Can calibrate sensitive baselines on short timescales and still get detections on longer timescales for baselines with weak signals.
  → Fringe-fit scans with 2 different solution intervals and merge calibration solutions.

Determine reference stations for global fringe-fit

- Two input parameters
  - List of prioritized reference stations, e.g. EF, YS, MC, NT.
  - Minimum fraction of valid (unflagged) data that must be present in a scan χ.
- For each scan, the first antenna in the refant list with valid data > χ is picked as refant for that scan.
- If all valid data fractions < χ, the antenna with the most valid data is picked.

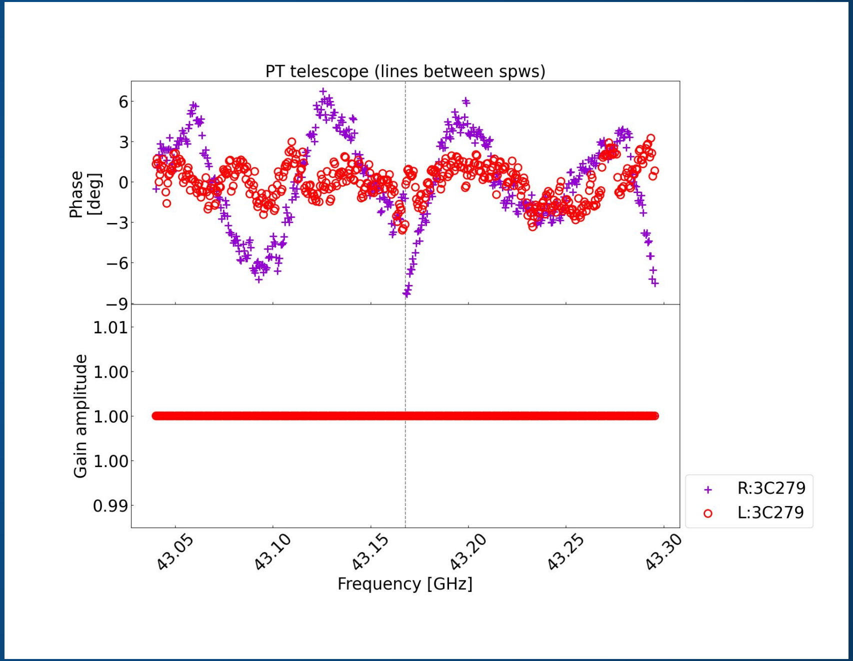
- χ should be small for polarization experiments and/or when a single very sensitive station is present in the array (e.g., ALMA).

- In the end all fringe solutions are re-referenced to one common antenna over the entire experiment to keep the R-L phase difference to a constant value from a single reference antenna.

Multi-band calibrator fringe-fit & complex bandpass (steps 7, 8)

- After instrumental phase and delay offsets have been solved: Combine full band data for a fringe-fit to solve for atmospheric multi-band delays.

- If SNR is good enough: Can combine all all calibrator data (SNR weighted) to fit for a complex (phase) bandpass.
  - Per channel corrections or polynomial fit.



7mm VLBA data of M87. Project code: BW0106.

Polarization calibration (step 8, 9, 10)

- Solve for instrumental RL phase and delay offsets.

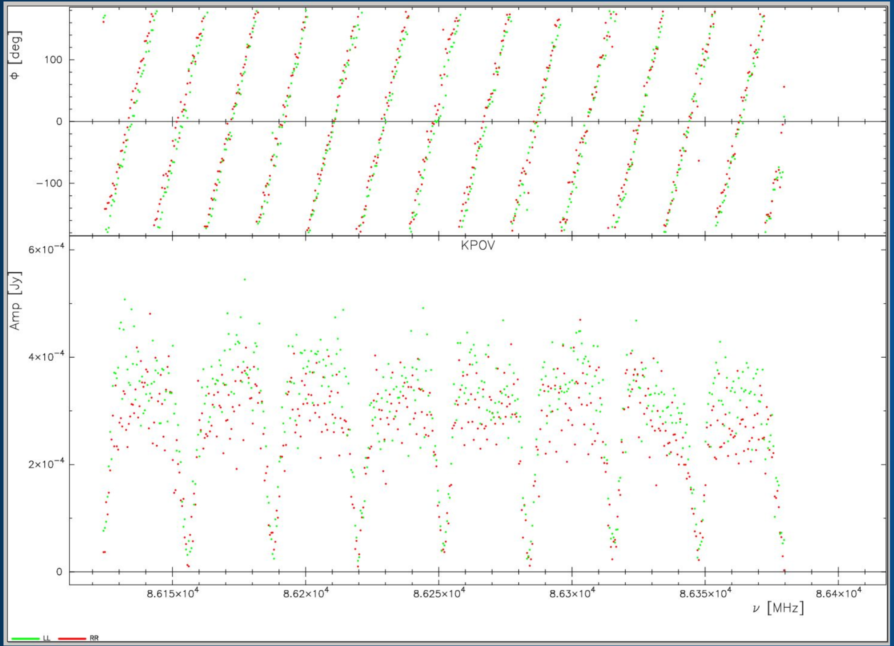
- Simple CASA task available to solve for polarization leakage / D-terms.

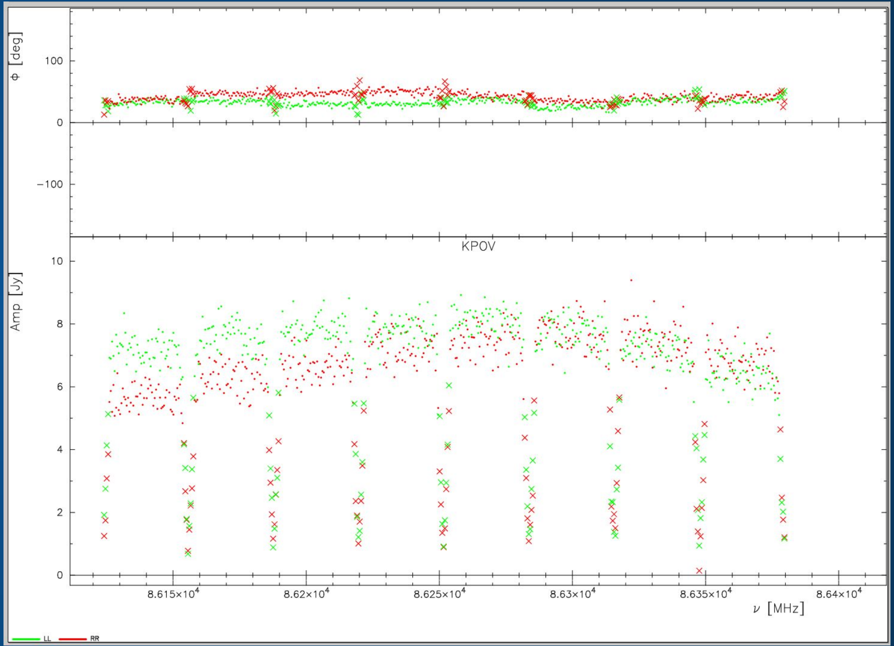
- More advanced task in development [IMV].
  - Solve for non-linear effects.
  - Handle varying polarized structure of extended sources.

Post-calibration steps

1. Clear previous calibration.
2. Apply solution tables.
3. Print overview of flagged data percentages.
4. Make plots of visibilities.
5. Average (only channels by default) and export calibrated data.

Calibration result





3mm VLBA data of 3C279. Project code: S6096B (scan #14).