
CubiCal Documentation

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INTRODUCTION TO CUBICAL

This is the documentation of CubiCal, a suite of fast calibration routines for radio interferometry.

CubiCal implements several accelerated gain solvers which exploit complex optimisation. Computationally intensive functions have been written in Numba to further accelerate them and multiprocessing is fully supported.

This documentation details the necessary steps for installing CubiCal, as well as how to use it. Additional information on how to get the best performance out of the package is also provided.

REQUIREMENTS AND INSTALLATION

2.1 Ubuntu 18.04

CubiCal depends on python-casacore, the dependencies of which should be installed from the [KERN-5](#) ppa. The ppa can be added as follows:

```
sudo apt install software-properties-common
sudo add-apt-repository -s ppa:kernsuite/kern-5
sudo apt-add-repository multiverse
sudo apt-add-repository restricted
sudo apt update
```

Once the ppa has been added, CubiCal's dependencies can be installed as follows:

```
CUBICAL_DEPENDENCIES=(casacore-dev \
                        casacore-data \
                        build-essential \
                        python3-pip \
                        libboost-all-dev \
                        wcslib-dev \
                        git \
                        libcfitsio-dev)
sudo apt install -y $CUBICAL_DEPENDENCIES
```

Warning: A known casacore bug can cause data corruption on large reads. If your use-case falls in this category, please [build and install casacore from source](#).

If you wish to install CubiCal in a virtual environment (recommended), see [Using a virtual environment](#).

CubiCal can be installed by running the following:

```
pip3 install git+https://github.com/ratt-ru/CubiCal.git@1.4.0
```

Note: CubiCal can predict model visibilities using [Montblanc](#), but it is not installed by default. To install CubiCal with Montblanc, run:

```
pip3 install "cubical[lsm-support]@git+https://github.com/ratt-ru/CubiCal.git@1.4.0"
```

Warning: To install in development mode, assuming that you have already cloned the repository, run:

```
pip3 install -e path/to/repo/
```

If you require Montblanc, run:

```
pip3 install -e path/to/repo/"[lsm-support]"
```

2.2 Using a virtual environment

Installing CubiCal in a virtual environment is highly recommended. To install virtualenv using apt, run:

```
sudo apt install python3-virtualenv
```

To create a virtualenv, run:

```
virtualenv -p python3 path/to/env/name
```

Activate the environment using:

```
source path/to/env/name/bin/activate
```

This should change the command line prompt to be consistent with the virtualenv name.

It is often necessary to update pip, setuptools and wheel inside the environment:

```
pip3 install -U pip setuptools wheel
```

BASIC USAGE

Once CubiCal has been successfully installed, it can be run from command line using:

```
gocubical
```

Adding the `-h` argument will print the help which provides all the command line arguments.

CubiCal can be run in one of two ways; either by specifying all the necessary arguments via the command line or by specifying a parset file. A parset file can be populated with all the arguments required to run a specific calibration.

A basic parset file looks something like this:

```
[data]
ms = measurement_set.MS
time-chunk = 32
freq-chunk = 32

[model]
list = sky_model.lsm.html

[montblanc]
dtype = double
feed-type = circular
mem-budget = 4096

[sol]
jones = G

[out]
column = CCORRECTED_DATA

[g]
time-int = 8
freq-int = 8
```

If the above parset was named `basic.parset`, it could be run by invoking:

```
gocubical basic.parset
```

This simple example only uses a fraction of the available options - unspecified options are populated from the defaults. Square bracketed values are section headers which correspond to the first part of the associated command line argument e.g. the `ms` value in the `[data]` section would be specified on the command line as:

```
gocubical --data-ms D147-LO-NOIFS-NOPOL-4M5S.MS/
```

This relationship can be inverted to add options to the parset. Consider the following example:

```
gocubical --dist-ncpu 4
```

Adding this to `basic.parset` is as simple as adding the `[dist]` section (the first part of the command line argument), and specifying `ncpu`. `basic.parset` would then look as follows:

```
[data]
ms = measurement_set.MS
time-chunk = 32
freq-chunk = 32

[model]
list = sky_model.lsm.html

[montblanc]
dtype = double
feed-type = circular
mem-budget = 4096

[sol]
jones = G

[out]
column = CCORRECTED_DATA

[g]
time-int = 8
freq-int = 8

[dist]
ncpu = 4
```

Note that a parset can be combined with options specified on the command line - the command line options will take precedence, making it easy to experiment without having to create a new parset.

PARSET OPTIONS

This page details available parset options. However, invoking `gocubical -h` should be preferred as it will always be up-to-date. The following is broken up into the various sections of the parset.

Note: These parset options can be specified via command line. For inclusion in a .parset file, omit the leading `--section-` component and place the remainder in the appropriate section.

4.1 [data]

Options pertaining to data selection and chunking strategy.

- data-ms=string** Name/path of input measurement set. Mandatory.
- data-column=string** Name of measurement set column from which to read for input data (uncalibrated visibilities). Default: 'DATA'.
- data-time-chunk=string** Data will be cut up into blocks containing this many timeslots. This limits the amount of data processed at once. Smaller chunks allow for a smaller RAM footprint and greater parallelism, but this sets an upper limit on the solution intervals that may be employed. Specify as an integer number of timeslots, or a value with a unit (e.g. '300s'). 0 means use full time axis. Default: 32.
- data-freq-chunk=string** Data will be cut up into blocks containing this many channels. This limits the amount of data processed at once. Smaller chunks allow for a smaller RAM footprint and greater parallelism, but this sets an upper limit on the solution intervals that may be employed. Specify as an integer number of channels, or a value with a unit (e.g. '128MHz'). 0 means use full frequency axis. Default: 32.
- data-chunk-by=string** If set, then time chunks will be broken up whenever the value in the named column(s) jumps by `--data-chunk-by-jump`. Multiple column names may be given, separated by commas. Set to None to disable. Default: SCAN_NUMBER.
- data-chunk-by-jump=int** The jump size used in conjunction with `--data-chunk-by`. If 0, then any change in value is a jump. If n, then the change must be >n.
- data-rebin-time=string** Rebin data in time on the fly. Specify as a number of timeslots to average together, or a value with a unit (e.g. '5s'). Default: 1
- data-rebin-freq=string** Rebin data in frequency on the fly. Specify as a number of channels to average together, or a value with a unit (e.g. '4MHz'). Default: 1

--data-single-chunk=string Each data chunk is assigned a unique identifier, e.g. 'D0T0F0'. If set, processes just one chunk of data matching the identifier. Primarily a debugging option. No default.

4.2 [sel]

Options pertaining to data selection.

--sel-field=int	FIELD_ID to read from the MS. Default: 0.
--sel-ddid=multi	DATA_DESC_IDs to read from the MS. Can be specified as e.g. "5", "5,6,7", "5~7" (inclusive range), "5:8" (exclusive range), "5:" (from 5 to last). Default reads all.
--sel-taql=string	Additional TaQL selection string. Combined with other selection options. No default.
--sel-chan=multi	Channels to read (within each DDID). Can be specified as e.g. "5", "10~20" (10 to 20 inclusive), "10:21" (same), "10:" (from 10 to end), "10:2" (0 to 9 inclusive, stepped by 2), "~9:2" (same). Default reads all.
--sel-diag=bool	Use diagonal (i.e. parallel hand) correlations only. Off-diagonals will be null in the outputs. See also <code>--JONES-diag-only</code> .

4.3 [model]

Options related to model selection and prediction.

--model-list=multi	Predict model visibilities from MS column/s and LSM/s (using Montblanc). The simplest usage is to specify a column, e.g. MODEL_DATA, or a Tiger LSM, e.g. <code>skymodel.lsm.html</code> , or, as a special case, 1 simply uses unity visibilities. (The LSM option is only available if Montblanc is installed). Use @TAG, e.g. <code>skymodel.lsm.html@dE</code> to group sources in the LSM by direction, according to the specified tag. You can also specify models for different directions by means of a colon. For example, <code>MODEL_DATA_1:MODEL_DATA_2</code> defines two directions, while <code>MODEL_DATA:skymodel.lsm.html@dE</code> defines a direction modelled by the MODEL_DATA column, and other directions as defined by the LSM. By contrast, the plus sign adds model visibilities together without splitting them into directions, e.g. <code>MODEL_DATA_1+MODEL_DATA_2:skymodel.lsm.html@dE</code> will define one direction modelled by a sum of columns, and other directions as defined by the LSM. Finally, a comma separates <i>model sets</i> . Each model set defines a separate minimization problem, weighted differently (in which case the <code>--weight-column</code> option must specify the same number of comma-separated <i>weight sets</i>). The priority of the separators is as follows: first, commas split up model sets. Within each set, colons split up directions. Finally, within each direction, plus signs split up its additive components. This can be quite a complex option, so check the log to make sure it is being interpreted correctly. No default.
--model-ddes=keyword	Enables direction-dependent models. If auto, this is determined by <code>--sol-jones</code> and <code>--model-list</code> , otherwise, enable/disable explicitly. Keywords: never, auto, always. Default: auto.

- model-beam-pattern=string** Apply beams from specified .fits files eg. “beam_\$(corr)_\$(reim).fits” or “beam_\$(CORR)_\$(REIM).fits”. No default.
- model-beam-l-axis=keyword** Specify which axis in the .fits file is associated with the l axis. Keywords: X, Y, -X, -Y. No default.
- model-beam-m-axis=keyword** Specify which axis in the .fits file is associated with the m axis. Keywords: X, Y, -X, -Y. No default.
- model-feed-rotate=multi** Apply a feed angle rotation to the model visibilities. Use ‘auto’ to read angles from FEED subtable, or give an explicit value in degrees. Default: auto.
- model-pa-rotate=bool** Apply parallactic angle rotation to model visibilities. Enable this for alt-az mounts, unless your model visibilities are already rotated. Default: True.

4.4 [weight]

Options related to weights.

- weight-column=string** Column/s to read weights from. Weights are applied by default. Specify an empty string or None to disable. Default: WEIGHT_SPECTRUM.
- weight-fill-offdiag=bool** Fill off-diagonal weights from geometric mean of diagonal weights. Use this if you have missing off-diagonal weights for whatever reason. Default: False.

4.5 [montblanc]

Options which will be used during model prediction (using Montblanc.)

- montblanc-device-type=keyword** Use CPU or GPU for simulation. Keywords: CPU, GPU. Default: CPU.
- montblanc-dtype=keyword** Precision for simulation. Keywords: float, double. Default: float.
- montblanc-feed-type=keyword** Simulate using linear or circular feeds. Keywords: linear, circular. Default: linear.
- montblanc-mem-budget=int** Memory budget in MB for simulation. Default: 1024.
- montblanc-verbosity=keyword** Verbosity level of Montblanc’s console output. Keywords: DEBUG, INFO, WARNING, ERROR. Default: WARNING.
- montblanc-threads=int** Number of OMP threads to run for Montblanc. Note that `--dist-pin-io` overrides this, if set. If 0, uses Montblanc’s internal default (all). Default: 0.

4.6 [degridding]

Options for the degriddier. Only in use when predicting from DicoModels using DDFacet.

- degridding-OverS=int** Oversampling factor. Default: 11.
- degridding-Support=int** CF support size. Default: 7.
- degridding-Nw=int** Number of w-planes. Default: 100.
- degridding-wmax=float** Maximum w coordinate. Visibilities with larger w will not be gridded. If 0, no maximum is imposed. Default: 0.

- degridding-Padding=float** Facet padding factor. Default: 1.7.
- degridding-NDegridBand=int** Number of image bands for degridding. 0 means degrid each channel. Default: 16.
- degridding-MaxFacetSize=float** Maximum facet size in degrees. Default: 0.25.
- degridding-MinNFacetPerAxis=int** Minimum number of facets per direction. Default: 1.
- degridding-NProcess=int** Number of subprocesses to use in degridding-based predict. Default: 8.

4.7 [flags]

Options controlling how flags are applied and written to.

- flags-apply=string** Which flagsets will be applied prior to calibration. Use “-FLAGSET” to apply everything except the named flagset (“-cubical” is useful, to ignore the flags of a previous CubiCal run). Default: -cubical.
- flags-auto-init=string** Insert BITFLAG column if it is missing, and initialize a named flagset from FLAG and FLAG_ROW. Default: legacy.
- flags-save=string** Save flags to named flagset in BITFLAG. If none or 0, will not save. Default: cubical.
- flags-save-legacy=keyword** Controls whether output flags are written to FLAG/FLAG_ROW. Is set to ‘auto’, then follows the --flag-save option. Default: auto
- flags-reinit-bitflags=bool** If true, reinitializes BITFLAG column from scratch. Useful if you ended up with a botched one, but be careful what the state of the FLAG/FLAG_ROW column is when you use this option. Default: 0.
- flags-warn-thr=float** If more than this fraction of data is flagged by the solver, issues gentle warnings. Default: 0.3.
- flags-see-no-evil=bool** Proceed even if flag columns appear to be botched or damaged. Default: 0.

4.8 [madmax]

“Mad Max” flags visibilities on-the-fly inside the solution loop, by using a MAD filter. This computes the median absolute residual (i.e. median absolute deviation from zero), and flags visibilities exceeding the thresholds set below.

- madmax-enable=bool** Enable Mad Max flagging. Default: 0
- madmax-estimate=keyword** MAD estimation mode. Use ‘corr’ for a separate estimate per each baseline and correlation. Otherwise, a single estimate per baseline is computed using ‘all’ correlations, or only the ‘diag’ or ‘offdiag’ correlations. Default: ‘corr’
- madmax-diag=bool** Flag on on-diagonal (parallel-hand) residuals. Default: 1.
- madmax-offdiag=bool** Flag on off-diagonal (cross-hand) residuals. Default: 1
- madmax-threshold=list** Threshold for MAD flagging per baseline (specified in sigmas). Residuals exceeding $S \cdot \text{MAD} / 1.428$ (where S is the given threshold) will be flagged. MAD is computed per baseline. This can be specified as a list e.g. N1,N2,N3,... The first value is used to flag residuals before a solution starts (use 0 to disable), the next value is used when the residuals are first recomputed during the solution several iterations later (see -chi-int), etc. A final pass may be done at the end of

the solution. The last value in the list is reused if necessary. Using a list with gradually decreasing values may be sensible. Default: 0,10.

- madmax-global-threshold=list** Threshold for global MMAD flagging. MMAD is computed as the median of the per-baseline MADs. Residuals exceeding $S \cdot \text{MMAD} / 1.428$ (where S is the given threshold) will be flagged. Can be specified as a list, with the same semantics as `--madmax-threshold`. Default: 0,12.
- madmax-plot=keyword** Enable plots for Mad Max flagging. Use 'show' to show figures interactively, or '1' to save plots to files instead. Plots will show the worst flagged baseline, and a median flagged baseline, provided the fraction of flagged visibilities is above some threshold. Default: 0
- madmax-plot-frac-above=float** Threshold (in terms of fraction of visibilities flagged) above which Mad Max plots will be generated. Default: 0.01.
- madmax-plot-bl=str** Plot given baseline regardless (multiple baseline IDs may be separated by commas), No default.
- madmax-flag-ant=bool** Flag antennas with excessive residuals, based on MAD criterion. Note that currently `--madmax-plot` must be enabled for this to work. Default: False.
- madmax-flag-ant-thr=float** Threshold (in sigmas) used to flag bad antennas. Default: 5.

4.9 [postmortem]

Postmortem flagging is done on things like chi-square statistics after a solution is finished.

- postmortem-enable=bool** If True, will do an extra round of flagging at the end (post-solution) based on solution statistics, as per the following options. Default: 0.
- postmortem-tf-chisq-median=float** Intervals with chi-squared values larger than X times the median chi-square value will be flagged. Default: 1.2.
- postmortem-tf-np-median=float** Intervals with a number of valid points less than X times the median number of valid points will be flagged. Default: 0.5.
- postmortem-time-density=float** If more than the given fraction of data in a timeslot is flagged, flag entire timeslot. Default: 0.5.
- postmortem-chan-density=float** If more than the given fraction of data in a timeslot is flagged, flag entire channel. Default: 0.5.
- postmortem-ddid-density=float** If more than the given fraction of data in a DDID is flagged, flag entire DDID. Default: 0.5.

4.10 [sol]

Options pertaining to the solver.

- sol-jones=multi** Comma-separated list of Jones terms to enable, e.g. "G,B,dE". These tags must correspond to the user-defined gain templates at the bottom of the .parset file. Default: G.
- sol-precision=keyword** Solve in single or double precision. Keywords: 32, 64. Default: 32.
- sol-delta-g=float** Threshold for gain accuracy - gains which improve by less than this value are considered converged. Default: 1e-6.

- sol-delta-chi=float** Threshold for solution stagnancy - if the chi-squared is improving by less than this value, the gain is considered stalled. Default: 1e-6.
- sol-chi-int=int** Number of iterations to perform between chi-squared checks. This is done to avoid computing the expensive chi-squared test every iteration. Default
- sol-last-rites=bool** Re-estimate chi-squared and noise at the end of a solution cycle. Disabling last rites can save a bit of time, but makes the post-solution stats less informative. Default: 1.
- sol-stall-quorum=float** Minimum percentage of solutions which must have stalled before terminating the solver. Default: 0.99.
- sol-term-iters=multi** Number of iterations per Jones term. If empty, then each Jones term is solved for once, up to convergence, or up to its -max-iter setting. Otherwise, set to a list giving the number of iterations per Jones term. For example, given two Jones terms and `--sol-term-iters 10,20,10` it will do 10 iterations on the first term, 20 on the second, and 10 again on the first. No default.
- sol-min-bl=float** Min baseline length to include in solution. Default: 0.
- sol-max-bl=float** Max baseline length to include in solution. If 0, no maximum is applied. Default: 0.0.
- sol-subset=str** Additional subset of data to actually solve for. Any TaQL string may be used. No default.

4.11 [bbc]

Options related to baseline-based corrections.

- bbc-load-from=str** Load and apply BBCs computed in a previous run. Apply with care! This will tend to suppress all unmodelled flux towards the centre of the field. No default.
- bbc-compute-2x2=bool** Compute full 2x2 BBCs (as opposed to diagonal-only). Only useful if you really trust the polarisation information in your sky model. Default: 0.
- bbc-apply-2x2=bool** Apply full 2x2 BBCs (as opposed to diagonal-only). Only enable this if you really trust the polarisation information in your sky model. Default: 0.
- bbc-save-to=str** Compute suggested BBCs at end of run, and save them to the given database. It can be useful to have this always enabled, since the BBCs provide useful diagnostics of the solution quality (and are not actually applied without a load-from setting). (default: "{data[ms]}/BBC- field:{sel[field]}-ddid:{sel[ddid]}.parmdb")
- bbc-per-chan=bool** Compute BBCs per-channel (instead of across the entire band). Default: 1.
- bbc-plot=bool** Generate output BBC plots. Default: 1.

4.12 [dist]

Options related to parallelism.

- dist-ncpu=int** Max number of CPU cores to use. 0 disables parallelism. Default: 0.
- dist-nworker=int** Number of worker processes to launch (excluding the IO worker). When 0, determined automatically from the `--dist-ncpu`. Default: 0.
- dist-nthread=int** Number of OMP threads to use. When 0, determine automatically. Default: 0.
- dist-max-chunks=int** Maximum number of time/freq data-chunks to load into memory simultaneously. If 0, then as many as possible will be loaded. Default: 0.
- dist-min-chunks=int** Minimum number of time/freq data-chunks to load into memory simultaneously. If 0, determined automatically. Default: 0.
- dist-pin=multi** If empty or None, processes will not be pinned to cores. Otherwise, set to the starting core number, or “N:K” to start with N and step by K. Default: 0.
- dist-pin-io=bool** If not 0, pins the I/O & Montblanc process to a separate core, or cores (if `--montblanc-threads` is specified). Ignored if `--dist-pin` is not set. Default: 0.
- dist-pin-main=keyword** If set, pins the main process to a separate core. If set to “io”, pins it to the same core as the I/O process, if I/O process is pinned. Ignored if `--dist-pin` is not set. Keywords: 0, 1, io. Default: io.

4.13 [out]

Options controlling output locations and types.

- out-dir=str** Base name of directory for output files. The suffix `.cc-out` will be implicitly appended, unless `OUTDIR` ends with a slash. Default: cubical.
- out-name=str** Base name for output files. Full base path will be `OUTDIR[.cc-out]/OUTNAMExxx`, unless `OUTNAME` contains a slash, in which case `OUTDIR` is ignored and `OUTNAME` is taken to be a full base path. Default: cc.
- out-overwrite=bool** Allow overwriting of existing output files. If this is set, and the output parset file exists, will raise an exception. Default: False.
- out-backup=bool** Allow automatic backup of existing output directories. Automatic backup is only used when `OUTDIR` is used (i.e. `OUTNAME` doesn’t contain any slashes), and it ends with `.cc-out` (implicitly or explicitly). In this case, existing output directories are renamed to `.cc.out.0`, `.1`, etc. Default: True.
- out-mode=keyword** Operational mode. [so] solve only; [sc] solve and generate corrected visibilities; [sr] solve and generate corrected residuals; [ss] solve and generate uncorrected residuals; [ac] apply solutions, generate corrected visibilities; [ar] apply solutions, generate corrected residuals; [as] apply solutions, generate uncorrected residuals. Keywords: so, sc, sr, ss, ac, ar, as. Default: sc.
- out-apply-solver-flags=bool** Apply solver flags when writing new data to measurement set. Default: True.
- out-derotate=multi** Explicitly enables or disables derotation of output visibilities. Default (None) is to use the `-model-pa-rotate` and `-model-feed-rotate` settings. Options: None | 0 | 1.

- out-column=str** Output MS column name (if applicable). Default: CORRECTED_DATA.
- out-model-column=str** If set, model visibilities will be written to the specified column. No default.
- out-weight-column=str** If set, weights from the Robust Solver will be written to the specified column. This should be set only if we are using the robust solver. No default.
- out-reinit-column=bool** Reinitialize output MS column. Useful if the column is in a half-filled or corrupt state. Default: 0.
- out-subtract-model=int** Index of model to subtract, if generating residuals. Default: 0.
- out-subtract-dirs=multi** Which model directions to subtract, if generating residuals. ":" subtracts all. Can also be specified as "N", "N:M", ":N", "N:", "N,M,K". Default: :.
- out-plots=bool** Generate summary plots. Default: 1.
- out-plots-show=bool** Show summary plots interactively. Default: 0.
- out-casa-gaintables=bool** Export gaintables to CASA caltable format. Tables are exported to same directory as set for cubical databases. Default: 1.

4.14 [log]

Options to allow control of logging functionality.

- log-memory=bool** Log memory usage. Default: 1.
- log-boring=bool** Disable progress bars and some console output. Default: 1.
- log-append=bool** Append to log file if it exists. Default: 0.
- log-verbose=multi** Default console output verbosity level. Can either be a single number, or a sequence of "name=level,name=level,..." assignments. Default: 0.
- log-file-verbose=multi** Default logfile output verbosity level. Can either be a single number, or a sequence of "name=level,name=level,..." assignments. If None, then this simply follows the console level. Default: None.

4.15 [debug]

Options pertaining to debugging. Mainly for developers.

- debug-pdb=bool** Jumps into pdb on error. Default: 0.
- debug-panic-amplitude=float** Throw an error if a visibility amplitude in the results exceeds the given value. Useful for troubleshooting. Default: 0.0.
- debug-stop-before-solver=bool** Invoke pdb before entering the solver. Default: 0.

4.16 [gainterm]

Options pertaining to a specific gain term. This is not a unique section in the parset. Each gain term specified in `--sol-jones` must have a (not necessarily complete) section like this one. For the example given in `--sol-jones`, there should be three separate sections like this, one for [g], [b] and [de] respectively. Their options will be specified by `--g-`, `--b-` and `--de-` respectively.

- gainterm-solvable=bool** Set to 0 (and specify `-load-from` or `-xfer-from`) to load a non-solvable term from disk. Not to be confused with `--sol-jones`, which determines the active Jones terms. Default: 1.
- gainterm-type=keyword** Type of Jones matrix to solve for. Note that if multiple Jones terms are enabled, then only `complex-2x2` is supported. Keywords: `complex-2x2`, `complex-diag`, `phase-diag`, `robust-2x2`, `f-slope`, `t-slope`, `tf-plane`. Default: `complex-2x2`.
- gainterm-load-from=str** Load solutions from given database. The DB must define solutions on the same time/frequency grid (i.e. should normally come from calibrating the same pointing/observation). By default, the Jones matrix label is used to form up parameter names, but this may be overridden by adding an explicit `//LABEL` to the database filename. No default.
- gainterm-xfer-from=str** Transfer solutions from given database. Similar to `-load-from`, but solutions will be interpolated onto the required time/frequency grid, so they can originate from a different field (e.g. from a calibrator). (default:)
- gainterm-save-to=str** Save solutions to given database. Default: `{data[ms]} /{JONES}-field:{sel[field]}-ddid:{sel[ddid]}.parmdb`.
- gainterm-dd-term=bool** Determines whether this term is direction dependent. `--model-ddes` must be enabled. Default: 0.
- gainterm-fix-dirs=multi** For DD terms, makes the listed directions non-solvable. No default.
- gainterm-update-type=keyword** Determines update type. This does not change the Jones solver type, but restricts the update rule to pin the solutions within a certain subspace: `'full'` is the default behaviour; `'diag'` pins the off-diagonal terms to 0; `'phase-diag'` also pins the amplitudes of the diagonal terms to unity; `'amp-diag'` also pins the phases to 0. Keywords: `full`, `phase-diag`, `diag`, `amp-diag`. Default: `full`.
- gainterm-time-int=int** Time solution interval for this term. Default: 1.
- gainterm-freq-int=int** Frequency solution interval for this term. Default: 1.
- gainterm-max-prior-error=float** Flag solution intervals where the prior error estimate is above this value. Default: 0.1.
- gainterm-max-post-error=float** Flag solution intervals where the posterior variance estimate is above this value. Default: 0.1.
- gainterm-low-snr-warn=float** Trigger SNR warning to the user at this threshold. Default: 75.
- gainterm-high-gain-var-warn=float** Trigger posterior gain variance warning to the user at this threshold. Default: 30.
- gainterm-clip-low=float** Amplitude clipping - flag solutions with diagonal amplitudes below this value. Default: 0.1.
- gainterm-clip-high=float** Amplitude clipping - flag solutions with any amplitudes above this value. 0 disables. Default: 10.0.
- gainterm-clip-after=int** Number of iterations after which to start clipping this gain. Default: 5.

- gainterm-max-iter=int** Maximum number of iterations spent on this term. Default: 20.
- gainterm-epsilon=float** Convergence threshold. Solutions that change by less than this value are considered converged. Default: 1e-6.
- gainterm-delta-chi=float** Threshold for solution stagnancy – if the chi-squared is improving by less (relatively), then the solution is marked as stalled. Default: 1e-6.
- gainterm-conv-quorum=float** Minimum percentage of converged solutions to accept. Default: 0.99.
- gainterm-ref-ant=int** Reference antenna - its phase is guaranteed to be zero. Default: None.
- gainterm-prop-flags=keyword** Flag propagation policy. Determines how flags raised on gains propagate back into the data. Options are 'never' to never propagate, 'always' to always propagate, 'default' to only propagate flags from direction-independent gains. Keywords: never, always, default. Default: default.
- gainterm-estimate-pzd=bool** Estimate phase-zero difference and initialize the gains with it. Use for polarization calibration. Default: False.
- gainterm-diag-only=bool** Use only diagonal (parallel-hand) data and model terms for the solution. Note that gains are still applied to the full 2x2 data (unless `--sel-diag` is also set). Default: False.
- gainterm-offdiag-only=bool** Use only off-diagonal data and model terms for the solution, and only solve for off-diagonal Jones elements, pinning the on-diagonals to 1. Default: False.
- gainterm-robust-cov=keyword** Determines how the residuals covariance matrix is computed if the robust-2x2 solver is selected. Options are 'compute' to compute normally, 'identity' to set the covariance to 1 (identity matrix) as in the Robust-t paper, and 'hybrid' which is the default computes the covariance matrix C but sets it to 1 if the elements are greater than 1. Keywords: compute | identity | hybrid.
- gainterm-robust-scale=bool** Scales down the residuals covariance matrix. Simulations show that this improves the results with unmodelled sources. Default: True.
- gainterm-robust-npol=int** The number of correlations (polarizations) actually present in the visibilities. This option only applies if the robust-2x2 solver is selected. Expectings 2 or 4 correlations. Default: 2.
- gainterm-robust-int=int** Number of iterations after which the v-parameter is recomputed for the robust solver. Default: 1.
- gainterm-robust-save-weights=bool** Determines if the applied weights from the robust-2x2 solver are stored. This option only applies if the robust-2x2 solver is selected. If this option is set, `output-weight-column` must be set too. Default: False.

EXAMPLE PARSETS

This page provides some example parsets for common calibration tasks. To use one of the following parsets, simply copy the text into an empty file and save as a .parset.

Note: The parsets provided in this section will work, but do not include every available option. For a full list, please see [Parset Options](#).

5.1 Phase-only selfcal

The following performs diagonal, phase-only selfcal using a measurement set column and produces corrected residuals.

```
[data]
_Help = Visibility data options
ms = ms.ms                # Your measurement set name.
column = DATA             # Column in which the data lives.
time-chunk = 100          # Number of time slots in a chunk.
                           # Implicitly controls memory footprint.
freq-chunk = 64           # Number of frequency channels in a chunk.
                           # Implicitly controls memory footprint.

[sel]
_Help = Data selection options
field = 0                 # Select a field/fields.
ddid = None               # Select spectral window/s.
chan =                   # Select channel/s.

[out]
_Help = Options for output products
dir = cubical             # Output directory name.
name = cubical.cc-out/cubical # Output path for non-visibility outputs.
overwrite = True          # Overwrite existing output.
mode = sr                 # Produce corrected residuals.
                           # Check --help for other options.
column = CORRECTED_DATA   # Output visibility column.

[model]
_Help = Calibration model options
list = MODEL_DATA         # Input visibility column.
                           # Can also be a Tigger .lsm file.
```

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```

[weight]
_Help = Weighting options
column = None                                # Weight column to use.

[flags]
_Help = General flagging options
apply = -cubical                            # Ignore existing cubical flags.

[sol]
_Help = Solution options which apply at the solver level
jones = G                                    # Term/s to solve for.
                                           # Corresponding section/s below.
delta-g = 1e-06                             # Stopping criteria on gains.
delta-chi = 1e-06                           # Stopping criteria on chi-squared.
term-iters = 20                             # Iteration recipe.
                                           # Overrides individual term settings.

[dist]
_Help = Parallelization and distribution options
ncpu = 4                                    # Number of processes to use.
                                           # Implicitly controls memory footprint.
max-chunks = 12                             # Maximum number of simultaneous chunks.
                                           # Ideally >= ncpu.
min-chunks = 12                             # Minimum number of simultaneous chunks.
                                           # Ideally = ncpu.
safe = 1.0                                  # Fraction of total memory CubiCal may use.
                                           # Will crash deliberately if exceeded.

[g]
_Help = Options for G-Jones term
label = G                                    # This term's name.
                                           # Must match [sol] section's jones option.
type = phase-diag                           # Solve for a diagonal phase-only gain.
time-int = 1                                # Number of timeslots per solution.
freq-int = 1                                # Number of channels per solution.
max-iter = 20                               # Maximum number of iterations.
                                           # May be ignored if [sol] term-iters is set.
_Templated = True                          # Other parameters polulated from defaults.
                                           # Can be safely ignored.

```

5.2 Phase and amplitude selfcal

The following performs diagonal, phase and amplitude selfcal using a Tigger .lsm sky model and produces corrected data. Note that using sky models requires CubiCal to be installed with lsm-support.

```

[data]
_Help = Visibility data options
ms = ms.ms                                  # Your measurement set name.
column = DATA                              # Column in which the data lives.
time-chunk = 100                           # Number of time slots in a chunk.
                                           # Implicitly controls memory footprint.
freq-chunk = 64                             # Number of frequency channels in a chunk.
                                           # Implicitly controls memory footprint.

```

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```

[sel]
_Help = Data selection options
field = 0                      # Select a field/fields.
ddid = None                    # Select spectral window/s.
chan =                         # Select channel/s.

[out]
_Help = Options for output products
dir = cubical                  # Output directory name.
name = cubical.cc-out/cubical # Output path for non-visibility outputs.
overwrite = True               # Overwrite existing output.
mode = sc                      # Produce corrected data.
                                # Check --help for other options.
column = CORRECTED_DATA       # Output visibility column.

[model]
_Help = Calibration model options
list = skymodel.lsm.html      # Input sky model .lsm file.
                                # Can also be a measurement set column.

[weight]
_Help = Weighting options
column = None                  # Weight column to use.

[flags]
_Help = General flagging options
apply = -cubical               # Ignore existing cubical flags.

[sol]
_Help = Solution options which apply at the solver level
jones = G                      # Term/s to solve for.
                                # Corresponding section/s below.
delta-g = 1e-06                # Stopping criteria on gains.
delta-chi = 1e-06              # Stopping criteria on chi-squared.
term-iters = 20                # Iteration recipe.
                                # Overrides individual term settings.

[dist]
_Help = Parallelization and distribution options
ncpu = 4                       # Number of processes to use.
                                # Implicitly controls memory footprint.
max-chunks = 12                # Maximum number of simultaneous chunks.
                                # Ideally >= ncpu.
min-chunks = 12                # Minimum number of simultaneous chunks.
                                # Ideally = ncpu.
safe = 1.0                     # Fraction of total memory CubiCal may use.
                                # Will crash deliberately if exceeded.

[g]
_Help = Options for G-Jones term
label = G                      # This term's name.
                                # Must match [sol] section's jones option.
type = complex-diag            # Solve for a diagonal complex gain.
time-int = 1                   # Number of timeslots per solution.
freq-int = 1                   # Number of channels per solution.
max-iter = 20                  # Maximum number of iterations.
                                # May be ignored if [sol] term-iters is set.

```

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```

_Templated = True                                # Other parameters polulated from defaults.
                                                # Can be safely ignored.

```

5.3 Gain and bandpass selfcal

The following performs gain and bandpass calibration simultaneously, using a measurement set column as input and produces uncorrected residuals.

```

[data]
_Help = Visibility data options
ms = ms.ms                                     # Your measurement set name.
column = DATA                                # Column in which the data lives.
time-chunk = 100                              # Number of time slots in a chunk.
                                                # Implicitly controls memory footprint.
freq-chunk = 64                               # Number of frequency channels in a chunk.
                                                # Implicitly controls memory footprint.

[sel]
_Help = Data selection options
field = 0                                     # Select a field/fields.
ddid = None                                   # Select spectral window/s.
chan =                                        # Select channel/s.

[out]
_Help = Options for output products
dir = cubical                                 # Output directory name.
name = cubical.cc-out/cubical                 # Output path for non-visibility outputs.
overwrite = True                             # Overwrite existing output.
mode = ss                                     # Produce uncorrected residuals.
                                                # Check --help for other options.
column = CORRECTED_DATA                       # Output visibility column.

[model]
_Help = Calibration model options
list = MODEL_DATA                            # Input visibility column.
                                                # Can also be a Tigger .lsm file.

[weight]
_Help = Weighting options
column = None                                 # Weight column to use.

[flags]
_Help = General flagging options
apply = -cubical                             # Ignore existing cubical flags.

[sol]
_Help = Solution options which apply at the solver level
jones = B,G                                  # Term/s to solve for.
                                                # Corresponding section/s below.
delta-g = 1e-06                              # Stopping criteria on gains.
delta-chi = 1e-06                            # Stopping criteria on chi-squared.
term-iters = [20, 20, 20, 20]               # Iteration recipe. Loops over jones above.
                                                # This will do 20 iterations on B,
                                                # 20 on G, 20 on B and finally 20 on G.

```

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```

# Overrides individual term settings.

[dist]
_Help = Parallelization and distribution options
ncpu = 4 # Number of processes to use.
# Implicitly controls memory footprint.
max-chunks = 12 # Maximum number of simultaneous chunks.
# Ideally >= ncpu.
min-chunks = 12 # Minimum number of simultaneous chunks.
# Ideally = ncpu.
safe = 1.0 # Fraction of total memory CubiCal may use.
# Will crash deliberately if exceeded.

[g]
_Help = Options for G-Jones term
label = G # This term's name.
# Must match [sol] section's jones option.
type = complex-2x2 # Solve for a full 2x2 complex gain.
# This can be restricted using update type.
update-type = phase-diag # Discard amplitude and off diagonal
# components of the solution.
# This makes the term phase-only.
time-int = 0 # Number of timeslots per solution.
# 0 is the entire chunk axis.
freq-int = 1 # Number of channels per solution.
max-iter = 20 # Maximum number of iterations.
# May be ignored if [sol] term-iters is set.
_Templated = True # Other parameters polulated from defaults.
# Can be safely ignored.

[b]
_Help = Options for G-Jones term
label = b # This term's name.
# Must match [sol] section's jones option.
type = complex-2x2 # Solve for a full 2x2 complex gain.
# This can be restricted using update type.
time-int = 1 # Number of timeslots per solution.
freq-int = 0 # Number of channels per solution.
# 0 is the entire chunk axis.
max-iter = 20 # Maximum number of iterations.
# May be ignored if [sol] term-iters is set.
_Templated = True # Other parameters polulated from defaults.
# Can be safely ignored.

```

5.4 Direction-independent and direction-dependent selfcal

The following performs DI and DD gain calibration simultaneously, using a tagged sky model as input and produces corrected residuals. Note that using sky models requires CubiCal to be installed with lsm-support.

Note: DD model specification in CubiCal (via `--model-list` or the appropriate section of the parset) is flexible, allowing the use of both sky models and measurement set columns in fairly complex configurations. Here are some examples:

- `COL_NAME1:COL_NAME2` This will create a model with two directions, one for each of the supplied measure-

ment set columns.

- `skymodel.lsm.html+-COL_NAME:COL_NAME` This will create a model with two directions, one containing the visibilities associated with the sky model minus the contribution of the MS column and the other containing just the MS column.
- `skymodel.lsm.html:COL_NAME1:COL_NAME2` This will create a model with three directions, one containing the visibilities associated with the sky model, the second containing the visibilities from the first MS column and the third containing the visibilities of the second MS column.
- `COL_NAME1+COL_NAME2:skymodel.lsm.html@dE` This will create a model with at least two directions. This first will contain the sum of the specified MS columns and the remaining will be generated from the dE tagged sources in the sky model.

The following example makes use of a tagged Tigger .lsm file to predict visibilities in several directions.

```
[data]
_Help = Visibility data options
ms = ms.ms                # Your measurement set name.
column = DATA             # Column in which the data lives.
time-chunk = 100          # Number of time slots in a chunk.
                           # Implicitly controls memory footprint.
freq-chunk = 64           # Number of frequency channels in a chunk.
                           # Implicitly controls memory footprint.

[sel]
_Help = Data selection options
field = 0                 # Select a field/fields.
ddid = None               # Select spectral window/s.
chan =                   # Select channel/s.

[out]
_Help = Options for output products
dir = cubical             # Output directory name.
name = cubical.cc-out/cubical # Output path for non-visibility outputs.
overwrite = True         # Overwrite existing output.
mode = sr                # Produce DI corrected residuals.
                           # Corrected data cannot be produced for DD_
→gains.                  # Check --help for other options.
column = CORRECTED_DATA  # Output visibility column.

[model]
_Help = Calibration model options
list = skymodel.lsm.html+-skymodel.lsm.html@dE:skymodel.lsm.html@dE
                           # Input recipe.
                           # This creates a direction dependent model.
                           # Directions are separated by colons.
                           # In this example, direction 0 will be
                           # the entire sky model minus the contributions
                           # from the tagged dE sources. The remaining
                           # directions will be those tagged in The
                           # sky model. Multiple columns can be specified
                           # in a similar fashion.

[weight]
_Help = Weighting options
column = None             # Weight column to use.
```

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```

[flags]
_Help = General flagging options
apply = -cubical                # Ignore existing cubical flags.

[sol]
_Help = Solution options which apply at the solver level
jones = G,dE                    # Term/s to solve for.
                                # Corresponding section/s below.
delta-g = 1e-06                 # Stopping criteria on gains.
delta-chi = 1e-06               # Stopping criteria on chi-squared.
term-iters = [20, 20, 20, 20]   # Iteration recipe. Loops over jones above.
                                # This will do 20 iterations on G,
                                # 20 on dE, 20 on G and finally 20 on dE.
                                # Overrides individual term settings.

[dist]
_Help = Parallelization and distribution options
ncpu = 4                        # Number of processes to use.
                                # Implicitly controls memory footprint.
max-chunks = 12                 # Maximum number of simultaneous chunks.
                                # Ideally >= ncpu.
min-chunks = 12                 # Minimum number of simultaneous chunks.
                                # Ideally = ncpu.
safe = 1.0                      # Fraction of total memory CubiCal may use.
                                # Will crash deliberately if exceeded.

[g]
_Help = Options for G-Jones term
label = G                       # This term's name.
                                # Must match [sol] section's jones option.
type = complex-2x2              # Solve for a full 2x2 complex gain.
                                # This can be restricted using update type.
time-int = 1                    # Number of timeslots per solution.
                                # 0 is the entire chunk axis.
freq-int = 1                    # Number of channels per solution.
max-iter = 20                   # Maximum number of iterations.
                                # May be ignored if [sol] term-iters is set.
_Templated = True               # Other parameters polulated from defaults.
                                # Can be safely ignored.

[de]
_Help = Options for G-Jones term
label = dE                      # This term's name.
                                # Must match [sol] section's jones option.
type = complex-2x2              # Solve for a full 2x2 complex gain.
                                # This can be restricted using update type.
dd-term = 1                     # This term is direction dependent.
time-int = 20                   # Number of timeslots per solution.
freq-int = 32                   # Number of channels per solution.
                                # 0 is the entire chunk axis.
max-iter = 20                   # Maximum number of iterations.
                                # May be ignored if [sol] term-iters is set.
_Templated = True               # Other parameters polulated from defaults.
                                # Can be safely ignored.

```


PERFORMANCE TUNING

One of CubiCal's main features is high-speed gain calibration. However, its performance is highly dependent on its input parameters. This is unfortunate, but unavoidable given variety of problems which CubiCal can solve.

A very simple performance consideration for multi-core architectures is the number of processes which CubiCal spawns. This is specified by `-dist-ncpu` from command line or in the `[dist]` section of a parset. If this number is greater than one, multiprocessing will be used and one process will be dedicated to simulation/IO. Practically, this means that there is always one fewer process performing compute than is specified. This becomes important when tiling the problem, as ideally the number of chunks per tile will be divisible by the number of processes minus one.

The second, and probably most crucial, step in making CubiCal as fast as possible is in the selection of time and frequency chunk sizes. If these chunks are too large, it will lead to a massive increase in cache-misses on the CPU. This will degrade performance quite substantially. There is no hard-and-fast rule for selecting the sizes, but users should be aware of the negative impact of setting them too large, as well as the wasted compute if they are too small. Due to the dependence of this problem on architecture, it may take users a while to get a feel for the optimal. Note that solution intervals can only be as large as a chunk; for large time/frequency solution intervals there is no alternative but to accept the decreased performance.

LICENCE

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