

## CASA Image description for LOFAR

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## 1 Introduction

This document presents detailed schemes of the tables in a CASA Image for LOFAR, and elaborate on their exact definitions. The goal is to extend the existing CASA Image format with data needed by the LOFAR project, but stay compatible with CASA so existing tooling can be used as much as possible. The document is partially based on the LOFAR MeasurementSet definition, which is in turn based on the original AIPS++ MS 2.0 definition document (AIPS++ Note 229). CASA inherited most of its dataformats from the AIPS++ project.

The AIPS++ memo 229 can be found at these locations:

<http://aips2.nrao.edu/docs/notes/229/229.html> or  
<http://www.astron.nl/aips++/docs/notes/229/229.html>

The latest version of this document and the LOFAR MeasurementSet definition are available at:

[http://www.lofar.org/wiki/doku.php?id=public:documents:lofar\\_documents](http://www.lofar.org/wiki/doku.php?id=public:documents:lofar_documents)

This document also refers to the casacore/CASA source documentation several times. This can be found at the following locations:

<http://www.astron.nl/casacore/trunk/casacore/doc/html/index.html>  
<http://www.atnf.csiro.au/computing/software/casacore/>

Casacore itself can be found at <http://code.google.com/p/casacore/>

Some comments are in blue to signal that it's not clear if these should be included in the document or pieces are still missing in this version.

No AIPS++ memo or other documentation exists on the CASA Image as of this writing. Where possible this document refers to locations in the CASA C++ documentation for details. A few parts of this documentation are also based on forwarded correspondence between S.Bhadnagar of NRAO and A.M.Richards of MERLIN.

The standard CASA Image format itself has very limited metadata (see the description of the MAIN table) so for metadata that the LOFAR image needs which overlaps with existing tables in the MeasurementSet, those were used when possible. Other tables and fields are not inherited from either the MS or CASA Image and are LOFAR specific.

### 1.1 Important conventions

Unless otherwise specified, direction coordinates are specified in reference to the LOFAR Core. This is relevant because of the size of LOFAR a lot of objects like the Moon and planets are in near field. Also take note that SubArray Pointing was referred to as Station Beam or Beam in older versions of this and other LOFAR documents. The term Beam is now reserved for what used to be called Pencil Beam. Columns that are optional in a table have their name marked in *italics* in the description.

In the format description, either a single value or an array can be specified. If an array is specified, it will be noted in round parenthesis, for example, Double(3,2) is an 3x2 array of Double. A star (\*) symbol is used for a variable length array, for example String(\*) is a variable length array of Strings. Please also note that the various types like Double, Float, String, Int, Complex, are well defined within the CASA/AIPS++ project in endianness and IEEE compliance. See the casa::Conversion Class Reference and aipstype.h.

Some columns in the tables require coordinate and unit specification. This is done in a manner compatible with the CASA/AIPS++ Measures system. Measure frame information is implicit in the underlying MS data. See also the *Guide to AIPS++ Measures*, AIPS++ Note 223

<http://www.astron.nl/casacore/trunk/casacore/doc/notes/233.html>

All indices for antennas, feeds, spectral windows, or related quantities are assumed to start at zero.

The LOFAR CASA Image uses the CASA/AIPS++ table system, which has a powerful query language called TAQL for accessing and manipulating the data. See *Table Query Language*, AIPS++ Note 199 for details: <http://www.astron.nl/casacore/trunk/casacore/doc/notes/199.html>

## 2 General description of the image format

This section briefly describes all tables and sub-tables in a LOFAR CASA Image, and what type of information these contain. Unlike the MeasurementSet, a lot of information for the CASA Image is stored in keywords of the MAIN table.

### 2.1 Structure of the LOFAR CASA Image

In the table below a short summary of the sub-tables in a LOFAR CASA Image is presented and a brief explanation of their contents. The subsequent sections describe the function of each table.

<i>Table name</i>	<i>Short description of content</i>
MAIN	Contains the actual pixel data and some important keywords
logtable	CASA log messages
LOFAR_OBSERVATION	General observation information
LOFAR_QUALITY	Quality information
LOFAR_POINTING	Antenna pointing information
LOFAR_FIELD	Information on observed positions
LOFAR_SOURCE	Information on observed sources
LOFAR_ANTENNA	Antenna information
LOFAR_STATION	Station information
LOFAR_HISTORY	History log
LOFAR_ORIGIN	Description of datasets used to create the image

### 2.2 MAIN table

The current MAIN table of a CASA image contains only a single row with a single record with the multidimensional array containing the pixel data. It also some important keywords that will be explained in the detailed section: logtable, coords, imaginfo, units.

### 2.3 logtable table

This table is pointed to from a keyword in the MAIN table. It contains log messages from CASA tools interacting with the Image. It contains a subset of the LOFAR\_HISTORY table, which will be used by LOFAR specific tools.

### 2.4 LOFAR\_OBSERVATION table

This table contains information on the project(s) and the scheduling. It contains information related to the SAS/MAC/MoM Observation and Project and the other fields common to the different dataformats for LOFAR.

### 2.5 LOFAR\_QUALITY table

This table contains quality measures of the image itself and the processes that led to its creation.

### 2.6 LOFAR\_FIELD table

This table contains positional information on the object(s) that is pointed to by the telescope.

### 2.7 LOFAR\_SOURCE table

This table gives some information of the physical properties of the source(s) observed, as well as their use in the observing strategy (calibrator or not). For spectral line observations it contains information on the line rest frequency and the velocity of the object to be observed. This table is optional.

## 2.8 LOFAR\_ANTENNA Table

The Antenna table contains information on each Antenna Field used in the observation.

## 2.9 LOFAR\_STATION table

This is a custom table for use by LOFAR only. It contains a list of all the stations that were present in the observation, mainly so the ANTENNA table can reference them with the purpose of identifying which antenna fields are part of which station.

## 2.10 LOFAR\_HISTORY table

This table allows HISTORY information so that one can trace how the image was created. It is similar to the logtable table, but with some LOFAR specific extensions in exactly the same format as the MeasurementSet HISTORY table. LOFAR tools should thus write their logging in this table instead of the logtable. Each step in the processing pipelines can store its parset file settings and other relevant data in this table to give a full history of how the image was created.

## 2.11 LOFAR\_ORIGIN table

This is an optional table for use by LOFAR only. It can contain some fields describing the MeasurementSet datasets that were used to generate the image.

### 3 Detailed description of all tables

#### 3.1 MAIN table

MAIN Table: Pixeldata			
Name	Format	Default	Comments
<i>Keywords</i>			
logtable	Table		Pointer to logtable
coords	Record		Coordinate information
imageinfo	Record		Miscellaneous information
units	String		Units of the pixel values
LOFAR_VERSION	String	0.02.00	Version of this document
<i>Data</i>			
map	Float Array (N)		Pixel values

The MAIN table consists of only a single column with a single record containing the array with the pixel values. A lot of information is stored in the keywords of this table, of which the coords and imageinfo records are so complex they are described in detail in their own subsections.

**logtable** Pointer to log table subtable.

**coords** Coordinate and axis information. See the subsection describing it in detail for what is known about its usage.

**imageinfo** Miscellaneous information. It's unclear how extensively this is used in CASA. See the subsection describing it in detail for what is known about its usage.

**units** String containing the units of the pixel values in the map. e.g. *Jy/beam*

**LOFAR VERSION** The LOFAR format revision number as defined by this document.

**map** This is an N dimensional Float Array. It contains the pixel values. The axes of the image are described in the *coords* record. Note that the CASA image (and HDF5Image in casacore) also supports double, complex<float> and complex<double>. However, currently the imagers only produce 32-bit float images. Some of the casa image analysis code can only deal with 32-bit floats.

The image format has the ability to store an arbitrary number of masks of which one can be set to be the default mask. The mask is a subtable of the image stored as a PagedArray<bool>.

It is also possible to store an arbitrary number of region definitions in the image. A casacore region can be an N-dim box or ellipsoid, 2-dim polygon, or an N-dim small mask, all in world or pixel coordinates. Furthermore they can be combined in any way (difference, union, intersection, stretch (e.g. to form a cylinder). They are stored as records and are currently not described in detail in this document, as it is unclear right now if in actual usage in CASA these are stored in images or separately.

Typically the axes for this map for LOFAR will be Right Ascension, Declination, Stokes and Frequency.

## 3.1.1 coords record

The coords keyword is a complex structure of records within records within records. It does not just contain coordinate information as the name suggests, but also other metadata. In some cases it's unclear why data is in this record and not in the imageinfo record, for example the telescope and observer fields don't seem to be typical coordinate information.

coords record: CASA coordinate and other information					
Name		Format	Default	Comments	
<i>Data</i>					
telescope		String	LOFAR	Name of telescope	
observer		String	Observer		
obsdate	type	String	epoch		
	refer	String	UTC		
	m0	value, unit	Double, String		
pointingcenter	value	Double (2)		Pointing Center	
	initial	Boolean	0		
telescopeposition	type	String	position		
	refer	String	ITRF		
	m0	value, unit	Double, String	m	
	m1	value, unit	Double, String	rad	
	m2	value, unit	Double, String	rad	
<i>Direction coordinate</i>					
directionX	system	String	J2000		
	projection	String		SIN, etc.	
	projection_paramaters	Double Array		Usually 2 (RA/DEC)	
	crval	Double Array		Usually 2 (RA/DEC)	
<i>Stokes coordinate</i>					
stokesX	axes	String Array	[Stokes]		
	stokes	String Array	?	e.g. [I, Q, U, V]	
	crval	Double Array			
	crpix	Double Array			
	cdelt	Double Array			
	pc	Double Array			
<i>Spectral coordinate</i>					
spectralX	version	Integer			
	system	String	TOPO?		
	restfreq	Double			
	restfreqs	Double Array			
	velType	Integer		?	
	velUnit	String	km/s?		
	formatUnit			?	
	wcs	crval	Double		
		crpix	Double		
		cdelt	Double		
		pc	Double		
		ctype	String	FREQ?	
	unit	String	Hz?		
	name	String	Frequency?		
	?	?			This field can't be displayed with
epoch	?			standard CASA tools	
system	String		TOPO		



<i>Linear coordinate</i>					
linearX					
<i>Tabular coordinate</i>					
tabularX					
<i>Coordsys coordinate</i>					
coordsysX					
<i>Axis shared attributes</i>					
worldmapX		Integer Array			Array of axis indices
worldreplaceX		Double Array			?
pixelmapX		Integer Array			Array of axis indices
pixelreplaceX		Double Array			?

In this record there are a couple of sub-records that describe several informational attributes of the image. Most seem to have to do with describing the telescope and observation. These are probably copied from the OBSERVATION table in the MeasurementSet the image was generated from. How this works for images that were generated from multiple Measurementsets is unclear.

**telescope** Name of the telescope. Should always be LOFAR for LOFAR. Should be the same as the TELESCOPE\_NAME in LOFAR\_OBSERVATION.

**observer** This is the observer. As for LOFAR most things are not observed by a single observer, the field doesn't make a lot of sense. Currently it seems "unknown" is the default, should probably be "Observer" to bring it in line with the OBSERVER field in LOFAR\_OBSERVATION.

**obsdate** Observation date. Might not always make sense if the image is a combination of multiple observations.

**pointingcenter** Pointing center. Seems to be in radians.

**telescopeposition** The position of the telescope. For LOFAR this is in ITRF.

The rest of the coords record is a repeat of records describing one or more axes. Each time a coordinate specific record (linear, direction, spectral, stokes, tabular, coordsys) is followed by 4 simple world-pixel records (worldmap, worldmapreplace, pixelmap, pixelmapreplace) The coordinate and world-pixel records are indexed with an integer starting at 0 appended to the name. So for the first described coordinate, it would become: "direction0, worldmap0, worldreplace0, pixelmap0, pixelmapreplace0", the next one could be "stokes1, worldmap1, worldreplace1, pixelmap1, pixelmapreplace1", etc.

The current description is based on combining looking at the records of actual images with the comments in the CASA code. Some records might have a structure that's more flexible than described here. For example, in the code there is reference to an "inAir" Boolean for the spectral coordinate. This has not been found in actual images.

**directionX** Record representing one or more direction coordinate axes. Will usually be 2 dimensional for RA/DEC.

**stokesX** Record representing one or more stokes coordinates axes. Please note that having multiple stokes still means you have one stokes coordinate axis, with a length of more than one. (The length would be 4 for I,Q,U,V for example).

**spectralX** Record representing one or more spectral coordinate axes. Not fully documented yet. Has some unclear fields.

**linearX** Record representing one or more linear coordinate axes. Not documented yet.

**tabularX** Record representing one or more tabular coordinate axes. Not documented yet

**coordsysX** Record representing one or more coordsys coordinate axes. Not documented yet.

**worldmapX, worldmapreplaceX, pixelmapX, pixelmapreplaceX** Records indicating how to convert between world and pixel values. Note that the length of the arrays for world and pixels do not need to be the same length as CASA supports having a different number of axes for the pixel values as for the world projection.

See the casa::Coordinate Class Reference and Coordinates Module documentation for more details.

## 3.1.2 imageinfo record

The imageinfo keyword contains miscellaneous information about the image. It's unclear what can go in here, but at least the following records can be part of this record:

imageinfo record: CASA miscellaneous information					
Name		Format		Default	Comments
<i>Data</i>					
objectname		String		BEAM_0?	Name of Target?
imagetype		String			
restoringbeam	positionangle	Value, Unit	Double, String		
	minor	Value, Unit	Double, String		
	major	Value, Unit	Double, String		

The imageinfo record contains nested records, making it a complex structure, although not as complex as coords. It's unclear if apart from objectname, imagetype and restoringbeam other records can be present.

**objectname** Probably the name of the observed Target should be in here, currently the record seems to hold a value like *BEAM\_0*, it is not sure if this is a default.

**imagetype** Type of the image. From `casa::ImageInfo::ImageTypes`, which defines the following values: *Undefined, Intensity, Beam, ColumnDensity, DepolarizationRatio, KineticTemperature, MagneticField, OpticalDepth, RotationMeasure, RotationalTemperature, SpectralIndex, Velocity, VelocityDispersion, nTypes*

**restoringbeam** Positionangle, minor and major axis of the restoringbeam. Might not be present in all imagetypes, but exists at least in Intensity images.

## 3.2 logtable table

logtable Table: CASA logging messages					
Name	Format	Units	Measure	Default	Comments
<i>Data</i>					
TIME	Double	s	EPOCH		Time of the message
PRIORITY	String				Message severity
MESSAGE	String				Message content
LOCATION	String				Location in code
OBJECT_ID	String				

The logtable is the only subtable defined in the standard CASA Image format. To a certain extent it's function overlaps with the LOFAR\_HISTORY table, but that supports LOFAR specific formats this table does not support.

**TIME** Time of the log message in MJD in UTC.

**PRIORITY** The priority message as defined in `casa::LogMessage`. **The enum in this file does not match some observed values for this field though, so it's not sure if this is correct**

**MESSAGE** The informational message, seems to be the function that generated the message, e.g. `imager::clean()`

**LOCATION** Source code origin of the log message.

**OBJECT\_ID** ObjectID of distributed object that created the message.

See the `casa::TableLogSink` class documentation from the LogTables module in CASA for documentation.

## 3.3 LOFAR\_OBSERVATION table

LOFAR_OBSERVATION Table: Observation information					
Name	Format	Units	Measure	Default	Comments
<i>Data</i>					
TELESCOPE_NAME	String			LOFAR	
TIME_RANGE	Double(2)	s	EPOCH		Specified start/end times
OBSERVER	String			Observer	Name of observer
PROJECT	String			NONE	Project identification
PROJECT_TITLE	String				Project description
PROJECT_PI	String				Primary Investigator
PROJECT_CO_I	String				Co Investigators
PROJECT_CONTACT	String				Contact Author
OBSERVATION_ID	String				Observation ID
OBSERVATION_START	Double	s	EPOCH		Observation start
OBSERVATION_END	Double	s	EPOCH		Observation end
OBSERVATION_FREQUENCY_MAX	Double	MHz			Maximum frequency
OBSERVATION_FREQUENCY_MIN	Double	MHz			Minimum frequency
OBSERVATION_FREQUENCY_CENTER	Double	MHz			Centre Frequency
SUB_ARRAY_POINTING	Int				SubArrayPointing
ANTENNA_SET	String				SAS AntennaSet
FILTER_SELECTION	String				SAS FilterSelection
CLOCK_FREQUENCY	Double	MHz			SAS Clock setting
NOF_BITS_PER_SAMPLE	Int				NrBitsPerSample
TARGET	String (*)				Single or list
SYSTEM_VERSION	String				As per ICD
PIPELINE_NAME	String				Pipeline identification
PIPELINE_VERSION	String				Pipeline version
FILENAME	String				As per ICD
FILETYPE	String			uv	As per ICD
FILEDATE	Double	s	EPOCH		As per ICD
RELEASE_DATE	Double	s	EPOCH		Target release date

Notes: This table contains information specifying the observing instrument or epoch. It is indexed directly from MAIN via OBSERVATION\_ID.

**TELESCOPE\_NAME** Telescope name ("LOFAR").

**TIME\_RANGE** The start and end times of the overall observing period spanned by the actual recorded data in MAIN. Required to use the same TIME Measure reference as in MAIN.

**OBSERVER** The name(s) of the observer(s).

**LOG** The observing log, as supplied by the telescope or instrument.

**SCHEDULE\_TYPE** The schedule type, with current reserved types ("VLBA-CRD", "VEX", "WSRT", "ATNF"). "LOFAR" for LOFAR.

**SCHEDULE** Unmodified schedule file, of the type specified, and as used by the instrument.

**PROJECT** Project code (e.g. "LEA1234")

**PROJECT\_TITLE** Description if the project (e.g. "Polarization properties of 3C1234")

**PROJECT\_PI** Project primary investigator

**PROJECT\_CO\_I** comma separated list of co-investigators

**PROJECT\_CONTACT** e-mail address of the contact author

**OBSERVATION\_ID** Observation ID as used by SAS, MAC and MOM based on the SAS VIC tree number.

**OBSERVATION\_START** Observation start time/date. Doesn't need to be the same as for this specific SubArrayPointing or MeasurementSet.

**OBSERVATION\_END** Observation end time/date. Doesn't need to be the same as for this specific SubArrayPointing or MeasurementSet.

**OBSERVATION\_FREQUENCY\_MAX** Observation maximum frequency. Not for a single spectral window, but for the entire observation.

**OBSERVATION\_FREQUENCY\_MIN** Observation minimum frequency. Not for a single spectral window, but for the entire observation.

**OBSERVATION\_FREQUENCY\_CENTER** Observation center frequency. Not for a single spectral window, but for the entire observation.

**SUB\_ARRAY\_POINTING** Number of the SubArrayPointing used for this measurement within the SAS observation.

**ANTENNA\_SET** SAS AntennaSet setting (e.g. "LBA\_SPARSE\_INNER", "HBA\_ONE")

**FILTER\_SELECTION** SAS FilterSelection setting (e.g. "10-90 MHz")

**CLOCK\_FREQUENCY** SAS ClockFrequency setting (e.g. "160 Mhz")

**NOF\_BITS\_PER\_SAMPLE** SAS NrBitsPerSample setting: 4, 8 or 16

**TARGET** Single or list of targets. This should basically be a condensed version of the SOURCES table. Can be empty.

**SYSTEM\_VERSION** Data processing system name and version number

**PIPELINE\_NAME** Pipeline processing name. If there are multiple runs only the first one will be identified here, further processing details can still be found in the HISTORY table.

**PIPELINE\_VERSION** Pipeline version.

**FILENAME** File name.

**FILETYPE** File type "uv" for MeasurementSets.

**FILEDATE** File creation date.

**RELEASE\_DATE** Project release date. This is the date on which the data may become public if the project finishes as scheduled.

Notes: The OBSERVATION\_NOF\_STATIONS and OBSERVATION\_STATIONS\_LIST as used in the ICDs are not used here, as the information is readily available from the LOFAR\_STATION table.

### 3.4 LOFAR\_QUALITY table

LOFAR_QUALITY Table: Image quality information					
Name	Format	Units	Measure	Default	Comments
<i>Data</i>					
QUALITY_MEASURE	String				Name of Quality Measure
VALUE	String				Value
<i>Flag information</i>					
FLAG_ROW	Bool			False	Row flag

Notes: This is a custom table for use by LOFAR only. It should contain a list of Quality Measures with their values. These are properties of the Image itself and processes that generated the image, which can be used to give an indication of the quality of the image. Some examples are: Dynamic Range of the image, Percentage Flagged of the visibility data used to generate the image, Noise Level of the image.

**T.B.D.:** Should this have a predefined (extendable) list of known Quality Measures to allow for more consistency?

### 3.5 LOFAR\_FIELD table

LOFAR_FIELD Table: Field positions for each source					
Name	Format	Units	Measure	Default	Comments
<i>Data</i>					
NAME	String				Name of field
CODE	String				Special characteristics
TIME	Double	s	EPOCH		Time origin for the directions and rates
NUM_POLY	Int			0	Polynomial series order
DELAY_DIR	Double (2, NUM_POLY+1)	rad	DIRECTION		Direction of delay centre
PHASE_DIR	Double (2, NUM_POLY+1)	rad	DIRECTION		Direction of Phase centre
REFERENCE_DIR	Double (2, NUM_POLY+1)	rad	DIRECTION		Direction of Reference centre
SOURCE_ID	Int			-1	Index in SOURCE table
LOFAR_TILE_BEAM_DIR	Double (2, NUM_POLY+1)	rad	DIRECTION		Direction of Tile Beam
<i>Flag information</i>					
FLAG_ROW	Bool			False	Row flag

Notes: The FIELD table defines a field position on the sky. For interferometers, this is the correlated field position.

**NAME** Field name: user specified in proposal or MoM.

**CODE** Field code indicating special characteristics of the fields, user specified.

**TIME** Time reference for the directions and rates. Required to use the same TIME Measure reference as in MAIN. We use the start time of the observation.

**NUM\_POLY** Series order for the \* DIR columns. This can be used to describe time-variant behaviour of these direction columns. Time origin is given by the TIME field. Default value is 0 (no polynomial expansion).

**DELAY\_DIR** Direction of delay centre: This can be expressed as a polynomial in time, but we will only give constant values. Final result converted to the defined Direction Measure type.

**PHASE\_DIR** Direction of phase (fringe stopping) centre: This can be expressed as a polynomial in time, but we will only give constant values. Final result converted to the defined Direction Measure type.

**REFERENCE\_DIR** Reference centre: This can be expressed as a polynomial in time, but we will only give constant values. Final result converted to the defined Direction Measure type. For interferometric data, this is the original correlated field centre, and may equal DELAY\_DIR or PHASE\_DIR.

**SOURCE\_ID** Points to an entry in the (optional) SOURCE subtable, a value of -1 indicates there is no corresponding source defined.

**LOFAR\_TILE\_BEAM\_DIR** Direction of Tile Beam centre: During multi beam observations, the tile beam can only point into one direction, which means it needs to be specified separately.

**FLAG\_ROW** True if data in this row are invalid, else False. Does not imply flagging in MAIN.

When doing position mosaic, the number of entries in this table will equal the number of mosaic positions.

## 3.6 LOFAR\_SOURCE table (Optional)

LOFAR_SOURCE Table: Source information					
Name	Format	Units	Measure	Default	Comments
<i>Key</i>					
SOURCE_ID	Int				
TIME	Double	s	EPOCH		Midpoint of interval
INTERVAL	Double	s			Duration of interval
<i>Data description</i>					
NUM_LINES	Int				Number of Spectral lines
<i>Data</i>					
NAME	String				Name of source during observation
CODE	String				Special characteristics of source, e.g. Bandpass calibrator
DIRECTION	Double(2)	rad	DIRECTION		Direction of Source
PROPER_MOTION	Double(2)	rad/s		0	
FLUX	Double(n)	Jy			Flux
SPINX	Double				Spectral Index
SHAPE	Double(3)	?,?,rad		0,0,0	Axes of a gaussian source (Major, Minor, Phi)
REF_FREQUENCY	Double	MHz			Reference frequency

Notes: This table contains time-variable source information, optionally associated with a given FIELD ID.

**SOURCE\_ID** Source identifier ( $\geq 0$ ), as specified in the FIELD sub-table.

**TIME** This is the mid-point of the time interval for which the data in this row are valid. Required to use the same TIME Measure reference as in MAIN.

**INTERVAL** Time interval for which the data in this row are valid.

**NUM\_LINES** Number of spectral line transitions associated with this source.

**NAME** Source name: User specified.

**CODE** Source code, used to describe any special characteristics of the source, such as the nature of a calibrator. Reserved keyword, including ("BANDPASS CAL").

**DIRECTION** Source direction at this TIME.

**PROPER MOTION** Source proper motion at this TIME.

**FLUX** Source flux per Stokes (see MAIN.coords record).

**SPINX** Spectral index of the source.

**SHAPE** Major, minor axis and angle of the source if Gaussian in shape.

**REF\_FREQUENCY** Reference frequency for the spectral index.

### 3.7 LOFAR\_ANTENNA table

LOFAR_ANTENNA Table: Antenna Field Characteristics					
Name	Format	Units	Measure	Default	Comments
<i>Data</i>					
NAME	String			LOFAR	Unique antenna field names
STATION_ID	Int				Pointer to STATION table
TYPE	String			GROUND-BASED	Antenna Type
MOUNT	String			X-Y	Antenna Mounting
POSITION	Double (3)	m	POSITION		Antenna center of light position in ITRF or WGS84
OFFSET	Double (3)	m	POSITION	0	Axes offset of mount to FEED_REFERENCE point
DISH_DIAMETER	Double	m		0	No meaning for LOFAR
PHASE_REFERENCE	Double (3)	m	POSITION		Beam forming phase reference
ORIGIN_ID	Int				Pointer to LOFAR_ORIGIN table
<i>Flag information</i>					
FLAG_ROW	Bool			False	Row flag

Notes: This sub-table contains the global antenna field properties for each antenna field in the data that was used to generate the image.

**NAME** Antenna field name. This is either HBA, LBA, HBA0 or HBA1.

**LOFAR\_STATION\_ID** This is the station identifier ( $\geq 0$ ), a direct index into the LOFAR\_STATION sub-table *rownr*.

**TYPE** Antenna type. Reserved keywords include: ("GROUND-BASED" - conventional antennas; "SPACE-BASED" - orbiting antennas; "TRACKING-STN" - tracking stations). We will use "GROUND-BASED".

**MOUNT** The mount type of the antenna. Reserved keywords include: ("EQUATORIAL" - equatorial mount; "ALTAZ"- azimuth-elevation mount; "X-Y" - x-y mount; "SPACE-HALCA" - specific orientation model.). For LOFAR we will use "X-Y".

**POSITION** In a right-handed frame, X towards the intersection of the equator and the Greenwich meridian, Z towards the pole. The exact frame should be specified in the MEASURE\_REFERENCE keyword (ITRF or WGS84) attached to this column. On traditional telescopes the reference point is the point on the azimuth or horizontal ascension axis closest to the elevation or declination axis. For LOFAR this is the effective centre of the collecting area of the antenna field, usually a weighted average of the positions of the individual antennas. It is needed because one calculates the (u,v,w) coordinates as differences of the center of light positions between antenna fields, not the phase reference positions.

**OFFSET** Axes offset of mount to feed reference point.

**DISH\_DIAMETER** This is the nominal diameter of dish, as opposed to the effective diameter. This is not a constant for LOFAR. For LOFAR this is set at 0 meter to make it obvious that it should not be used.

**FLAG\_ROW** This is the boolean flag to indicate the validity of this entry. Set to True for an invalid row. This does not imply any flagging of the data in MAIN, but is necessary as the ANTENNA index in MAIN points directly into the ANTENNA sub-table. Thus FLAG ROW can be used to delete an antenna entry without re-ordering the ANTENNA indices throughout the MS.

**LOFAR\_PHASE\_REFERENCE** This is the phase reference position, the location at which the antenna field tries to adjust the "phases" for all of the dipoles of an antenna field to be equal for the Sub Array Pointing direction.

**ORIGIN\_ID** This is an direct index into the LOFAR\_ORIGIN table. This Column is optional as it's only needed if more than one MeasurementSet was used in generating the image.



Time variant LOFAR antenna field and station properties (e.g., switching individual dipoles in a field off during an observation) cannot be handled directly in the antenna table. This is only relevant when such a change leads to different antenna characteristics (e.g., center of light position). For the current version of the LOFAR Measurement Set the choice has been made to handle this through the LOFAR\_ELEMENT\_FAILURE table. This means that the effect such changes have on the center of light position are not reflected in the POSITION in this table.

### 3.8 LOFAR\_STATION table

LOFAR_STATION Table: Station information					
Name	Format	Units	Measure	Default	Comments
<i>Data</i>					
NAME	String				Name of the station
CLOCK_ID	Int				Index of shared clock
<i>Flag information</i>					
FLAG_ROW	Bool			False	Row flag

Notes: This is a custom table for use by LOFAR only. It contains a list of all the stations that were present in the observation, mainly so the ANTENNA table can reference with the purpose of identifying which antenna fields are part of which station. It is indexed directly from ANTENNA through STATION\_ID. It currently only contains a few fields, but will probably be extended in the future.

**NAME** Name of the station. (e.g. "CS103", "DE602")

**CLOCK\_ID** Number identifying a clock signal. It should be the same number for stations sharing a clock signal. Currently stations in the LOFAR Superterp share a clock.

**FLAG\_ROW** True if the row does not contain valid data. Does not imply flagging in MAIN.

### 3.9 LOFAR\_HISTORY table

LOFAR_HISTORY Table: History information					
Name	Format	Units	Measure	Default	Comments
<i>Key</i>					
Time	Double	s	EPOCH		Time-stamp for message
OBSERVATION_ID	Int				Points to OBSERVATION table
<i>Data</i>					
MESSAGE	String				Log message
PRIORITY	String				Message priority
ORIGIN	String				Code origin
OBJECT_ID	String				Originating ObjectID
APPLICATION	String				Application name
CLI_COMMAND	String(*)				CLI command sequence
APP_PARAMS	String(*)				Application parameters

Notes: This sub-table contains associated history information about how the data was processed. **Currently the assumption is that the history of the MeasurementSets that were used to generate the image are not included, this might need further discussion.**

**TIME** Time-stamp for the history record. Required to have the same TIME Measure reference as used in MAIN.

**OBSERVATION\_ID** Observation identifier. This is an index into the OBSERVATION table.

**MESSAGE** Log message.



**PRIORITY** Message priority with allowed types: DEBUGGING, WARN, NORMAL, SEVERE  
**ORIGIN** Source code origin from which the message originated. Contains version/revision number.  
**OBJECT\_ID** Origination ObjectID if available, else blank.  
**APPLICATION** Application name.  
**CLI\_COMMAND** CLI (Command Line Interface) command sequence invoking the application.  
**APP\_PARAMS** Application parameter values. For LOFAR this is an array of strings with the parset key-value pair values.

### 3.10 LOFAR\_ORIGIN table (Optional)

LOFAR_ORIGIN Table: ORIGIN information					
Name	Format	Units	Measure	Default	Comments
<i>Data</i>					
OBSERVATION_ID	String				Observation ID
SUB_ARRAY_POINTING	Int				Sub-Array Index
SUBBAND	Int				Subband index
NUM_CHAN	Int				Number of Channels
CHANNEL_WIDTH	Double	Hz			Channel Width
EXPOSURE	Double	s			Effective integration time
FREQUENCY_MAX	Double	MHz			Maximum frequency
FREQUENCY_MIN	Double	MHz			Minimum frequency
FREQUENCY_CENTER	Double	MHz			Centre Frequency
START	Double	s	EPOCH		Start time
END	Double	s	EPOCH		End time
<i>Flag information</i>					
FLAG_ROW	Bool			False	Row flag

Notes: This is a custom table for use by LOFAR only. It contains a list of all the MeasurementSets that were used in creating the image. The index into this table can be used in the other tables to clarify the relations to these origin MeasurementSets if multiple MeasurementSets have been used in creating the image. **This table is a new addition in 0.02, and might need further changes.**

**OBSERVATION\_ID** Observation ID as used by SAS, MAC and MOM based on the SAS VIC tree number.  
**SUB\_ARRAY\_POINTING** Number of the SubArrayPointing used for this MeasurementSet within the SAS observation.  
**SUBBAND** Number of the Subband used for this MeasurementSet within the SAS observation.  
**NUM\_CHAN** Number of channels.  
**CHANNEL\_WIDTH** Width of the individual channels in the MeasurementSet.  
**EXPOSURE** This is the effective data interval, including bad data and partial averaging.  
**FREQUENCY\_MAX** Maximum frequency of the SPECTRAL\_WINDOW in the MeasurementSet.  
**FREQUENCY\_MIN** Observation minimum frequency.  
**FREQUENCY\_CENTER** Observation center frequency.  
**START** MeasurementSet start time/date.  
**END** MeasurementSet end time/date.  
**FLAG\_ROW** True if the row does not contain valid data. Does not imply flagging in MAIN.

### 3.11 Schema of the LOFAR CASA Image

The figure below shows a graphical representation of the LOFAR CASA Image. All subtables and columns in the file format are presented.

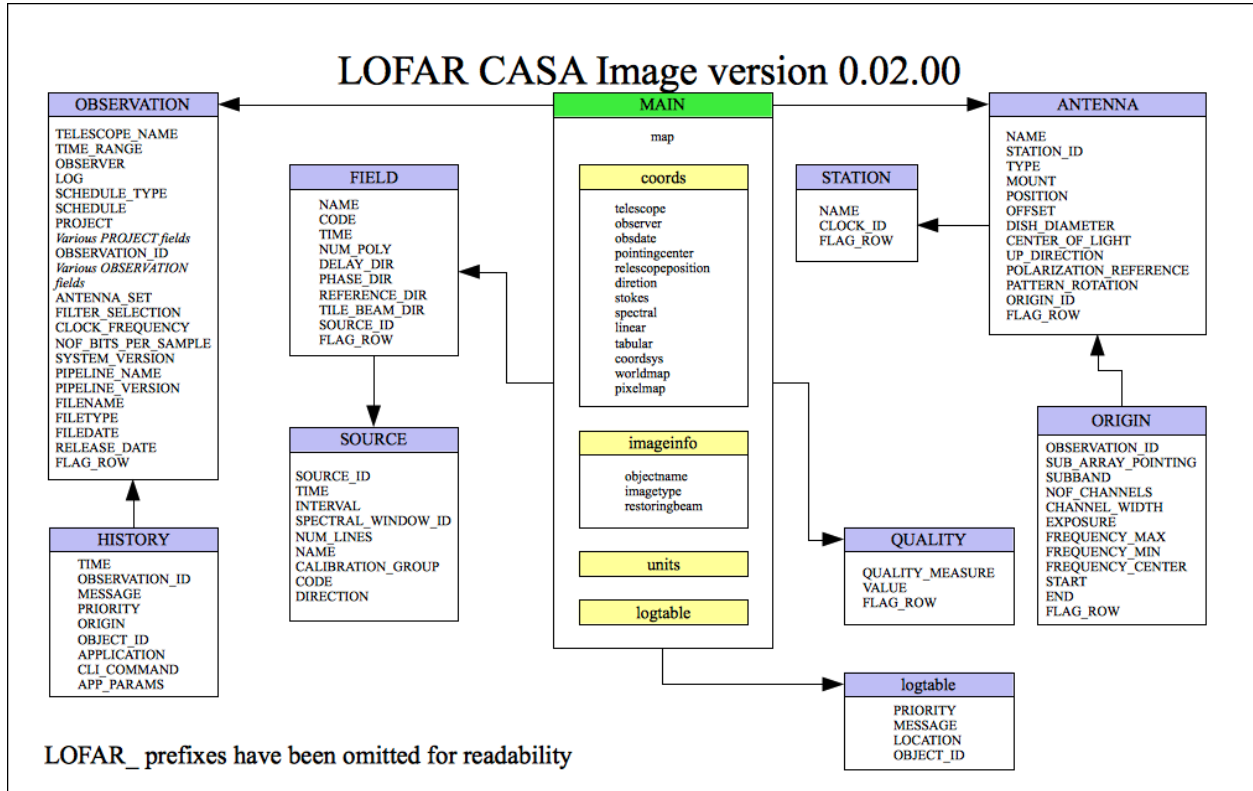


Figure 1: Schema of the LOFAR CASA Image