

***The LOPES-Tools package***

-

***A first-generation LOFAR end  
user software***

Lars Bühren (ASTRON, Dwingeloo, NL)

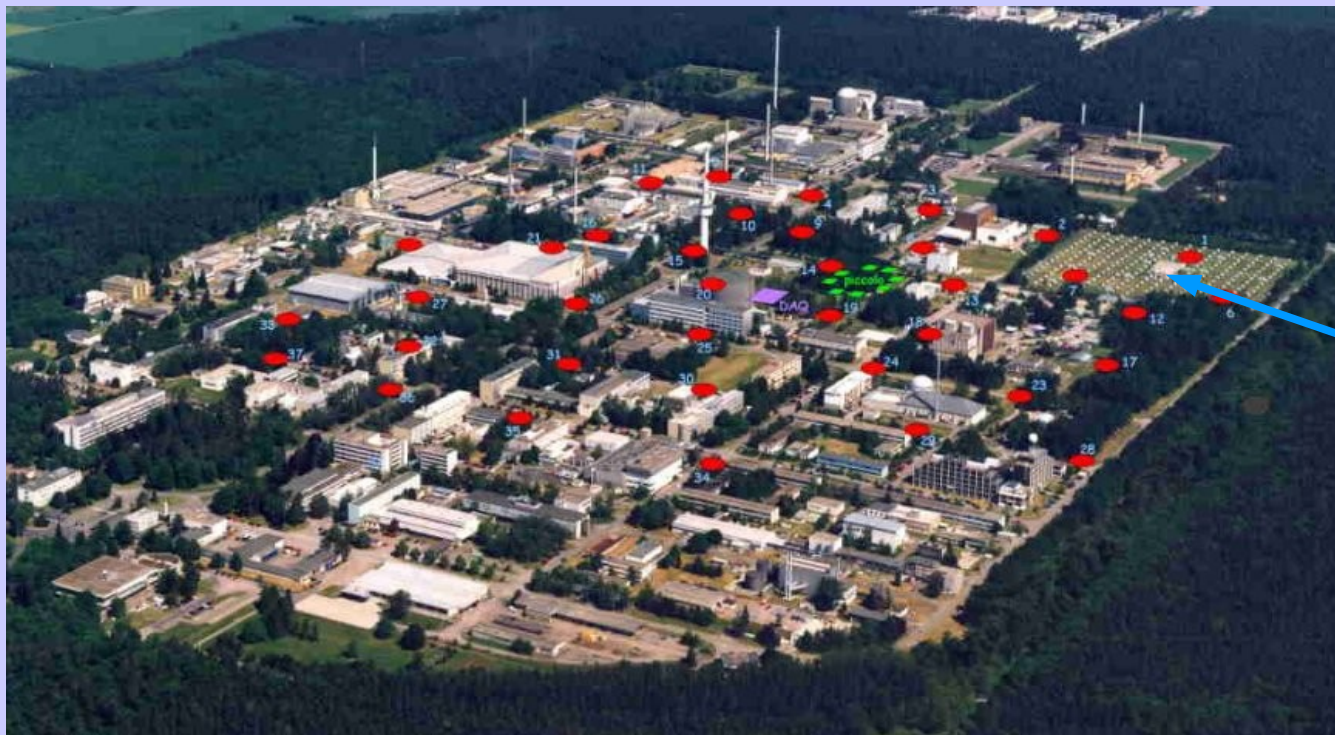
# *Contents*

- ◆ LOPES
- ◆ Coding & Architecture  
(Team, work-packages, framework, documentation)
- ◆ Usage  
(GUI, Tools)
- ◆ Cosmic ray data analysis  
(Processing steps & visualization)
- ◆ Outlook
- ◆ Summary

# ***LOPES (i)***

## *The LOPES experiment*

- ◆ LOPES = LOFAR Prototype Station
- ◆ Located in Karlsruhe
- ◆ Operated in coincidence with KASCADE



LOPES

# ***LOPES (ii)***

## ***The LOPES Collaboration***

- ◆ On September 20, 2004, the members of the LOPES Steering Committee signed an agreement to forge the **LOPES Collaboration**
- ◆ Participating institutes from Germany, Netherlands, Romania, Poland & Italy
- ◆ Project web page:  
<http://www.astro.ru.nl/lopes>

# ***LOPES-Tools: Coding (i)***

## *Environment & Languages*

### ◆ AIPS++/CASA

- ◆ free software (GPL) for development of applications
- ◆ modules for processing astronomical data
- ◆ Build environment



### ◆ Glish

(program kernel, GUI, data processing)

### ◆ C/C++

(data I/O, data processing)

### ◆ Shell scripts

(code maintenance, documentation generation, file transfer)

# ***LOPES-Tools: Coding (ii)***

## ***Documentation***

- ◆ **Doxygen:**
  - ◆ documentation of source code (C/C++)
  - ◆ parallel maintenance of source code and its description
- ◆ Wiki
  - ◆ description of the individual tools in the package
- ◆ LATEX documentation
  - ◆ mathematical background to implemented algorithms
  - ◆ User manual, Tutorial, ...

=> all documentation available online

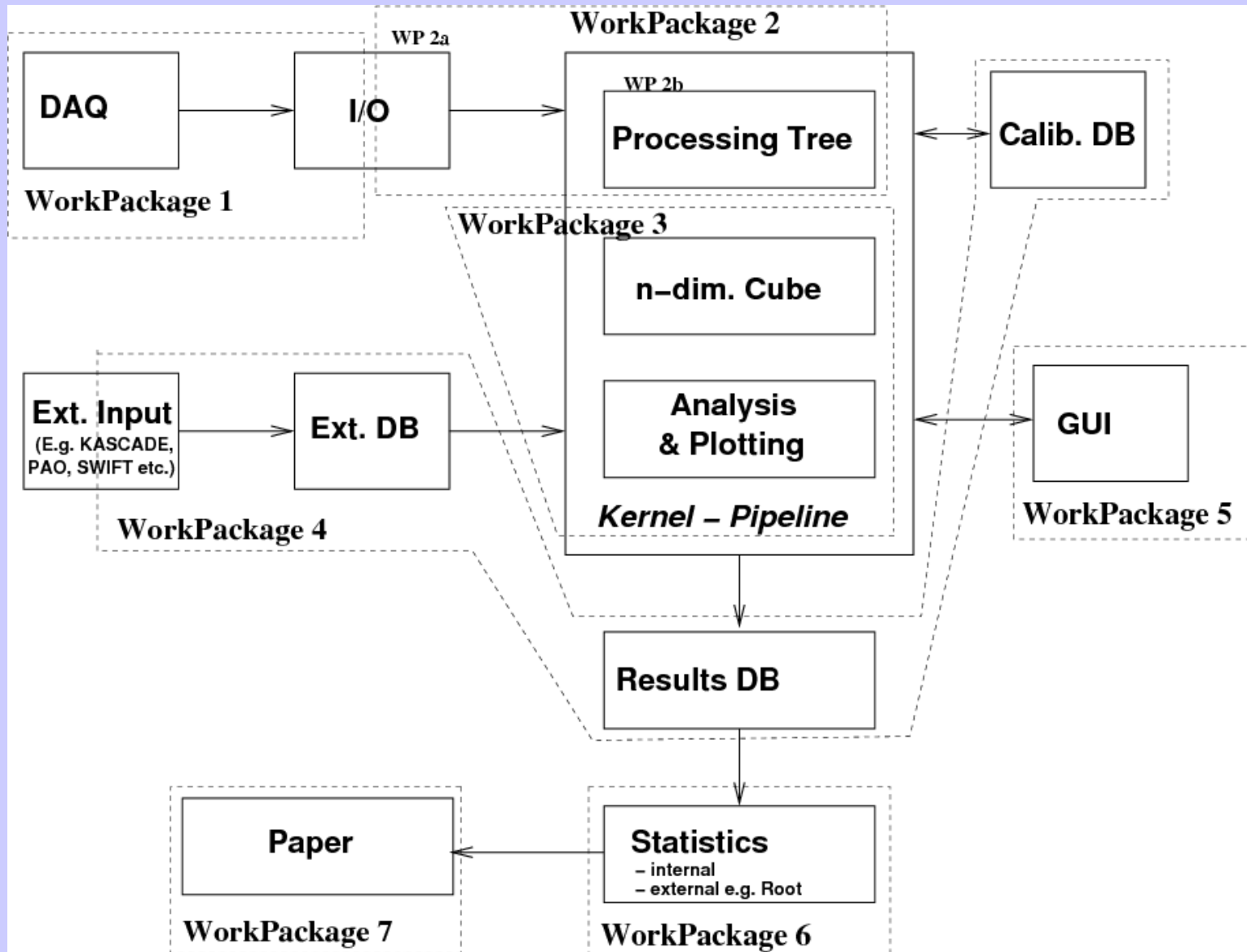
# ***LOPES-Tools: Coding (iii)***

## *The LOPES-Tools software group*

- ◆ Heino Falcke  
(supervision, CR pipeline)
- ◆ Andreas Horneffer  
(Program kernel, DAQ, CR pipeline)
- ◆ Andreas Nigl  
(Dynamic spectra, Archiving)
- ◆ Sven Lafebre  
(CR trigger)
- ◆ Lars Bähren  
(Skymapper, build environment, documentation)

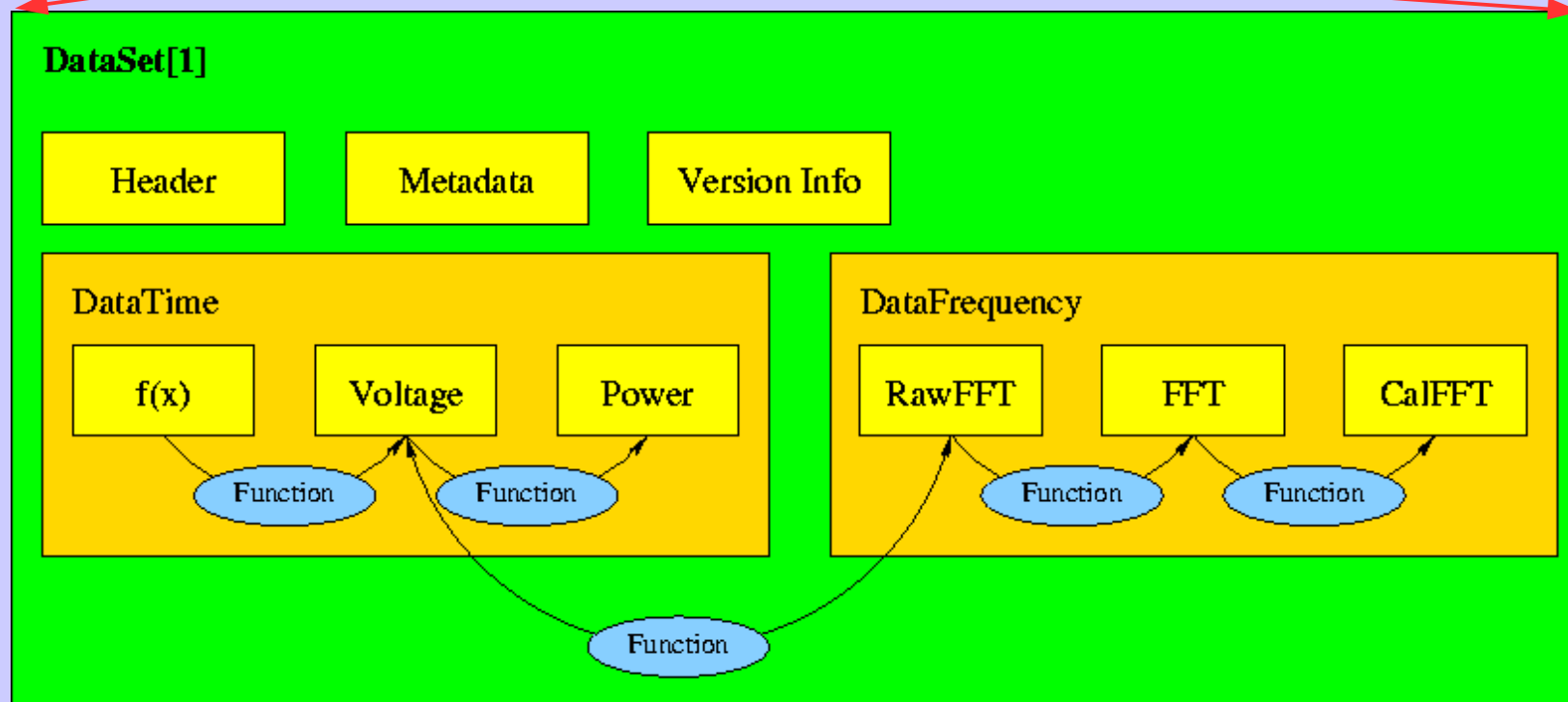
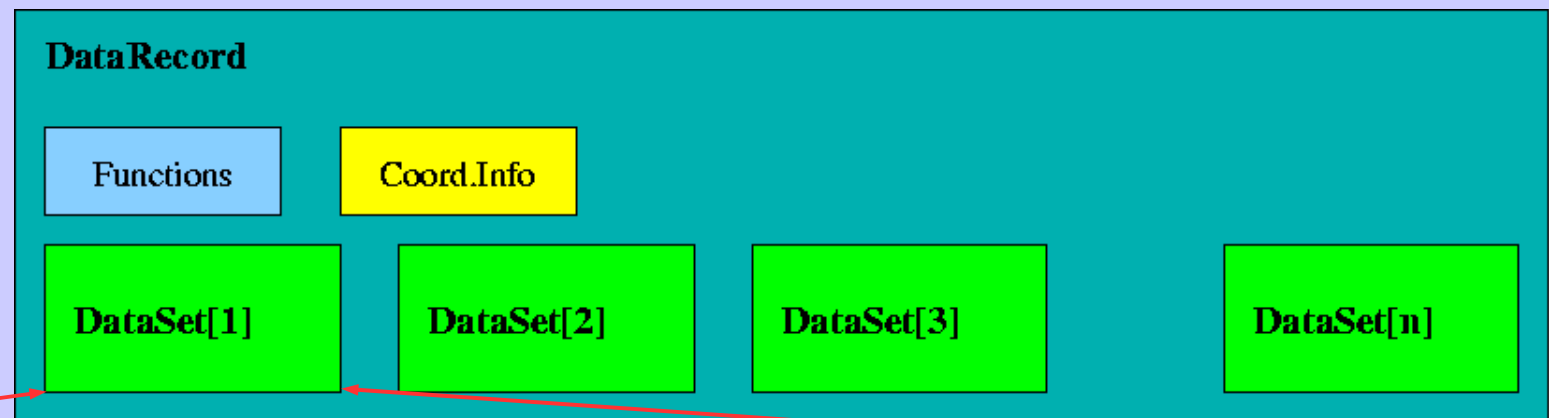
# *LOPES-Tools: Architecture (i)*

## *Structure & Workpackages*



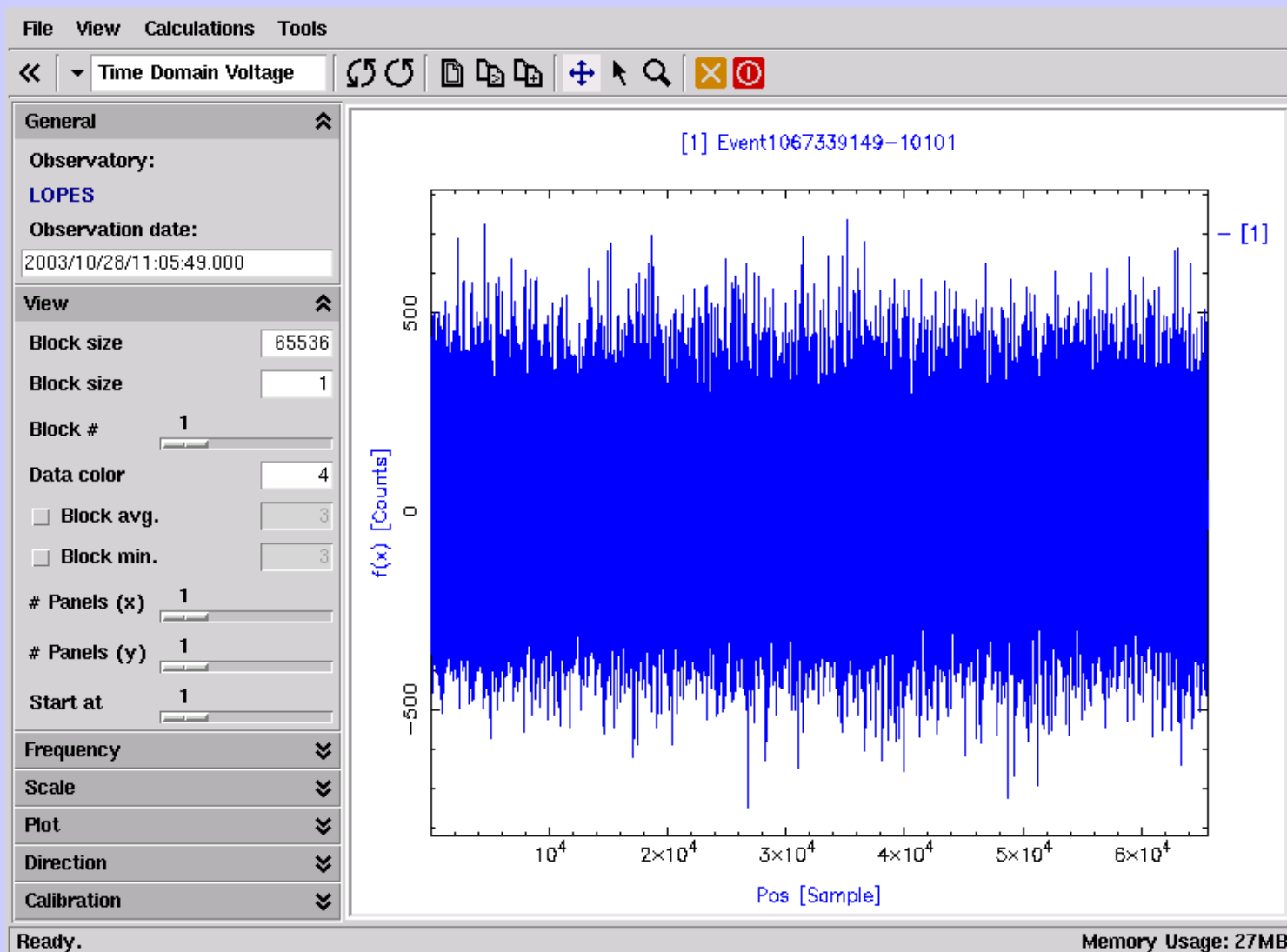
# *LOPES-Tools: Architecture (ii)*

## *Data object & Processing tree*



# Usage & Tools (i)

## The graphical user interface

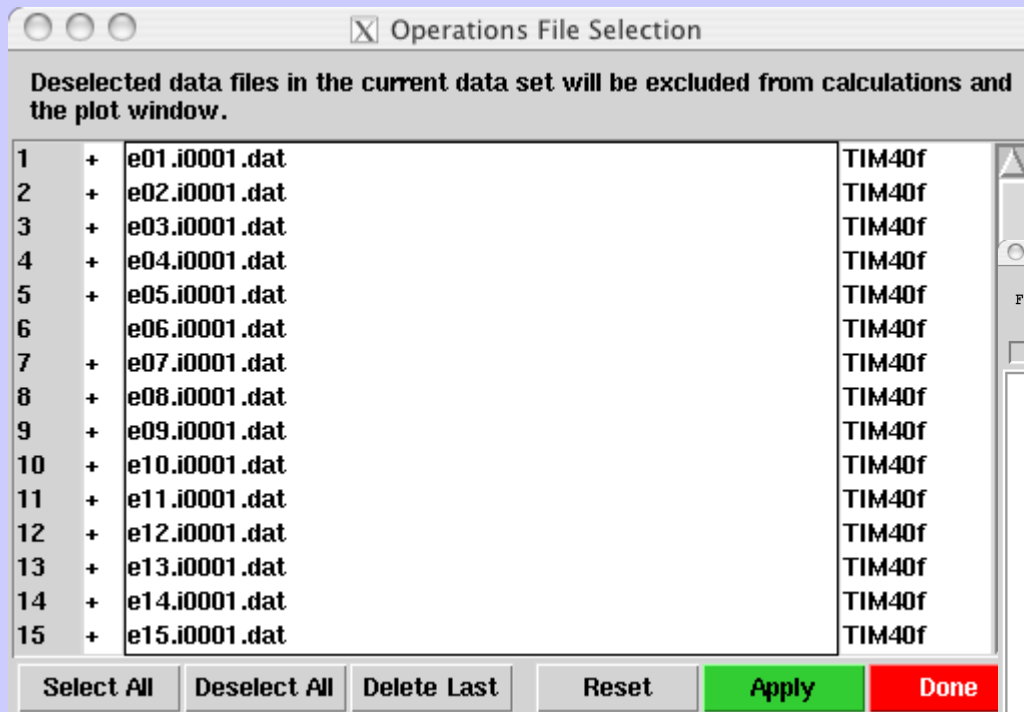


- Open
- CR-Event GUIs...
- Submit ITS Experiment...
- Submit ITS Trigger...
- Get ITS files from Aviary...
- Print...
- Dismiss window
- Exit glish

- Create skymap...
- Create dynamic spectrum...
- Create dynamic spectrum (2)...
- Detect peaks
- Analyze/Manipulate image tool...
- Annotate Skymap (J2000)...
- Map 408 MHz Survey
- Decode TV/Radio...
- Browse CR Events...
- Auto-process CR event
- Find CR distance
- GUI-pipeline for current event

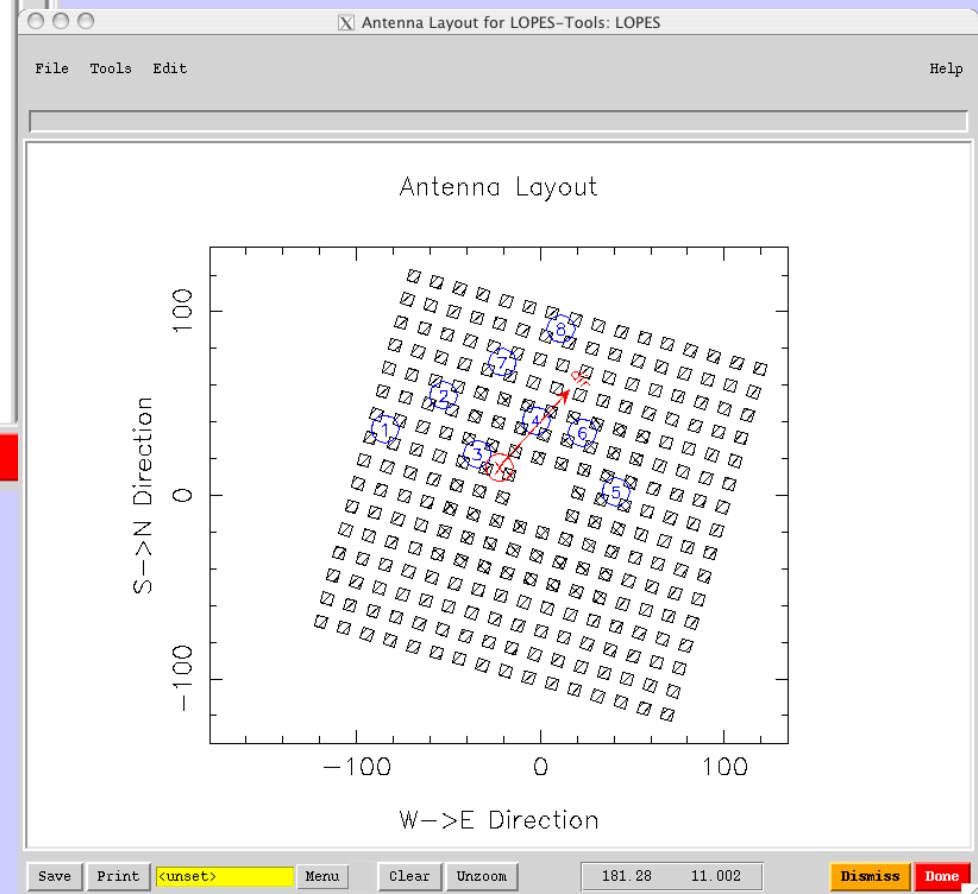
# Usage & Tools (ii)

## Antenna selection & layout



Manual (de)selection of antennas included into analysis / computation

- Layout of antennas
- Direction toward Sun
- Direction of incoming CR



# Usage & Tools (iii)

## Processing tools: dynamic spectra

**Dynamic spectrum Generator**

**Dynamic spectrum: Data I/O**

Input dataset : Event1067339149-10101

Observation date : 2003/10/28/11:05:49.000

**Dynamic spectrum: Generation**

Antenna selection : [1,2,3,4,5,6,7,8]

Start block : 1

Number of blocks : 1

Samples per block : 65536

Frequency band [MHz] : [42,78]

Computation method: beamforming

Beam direction : [0,90]

Beam direction WCS : AZEL

**Dynamic spectrum: Analysis**

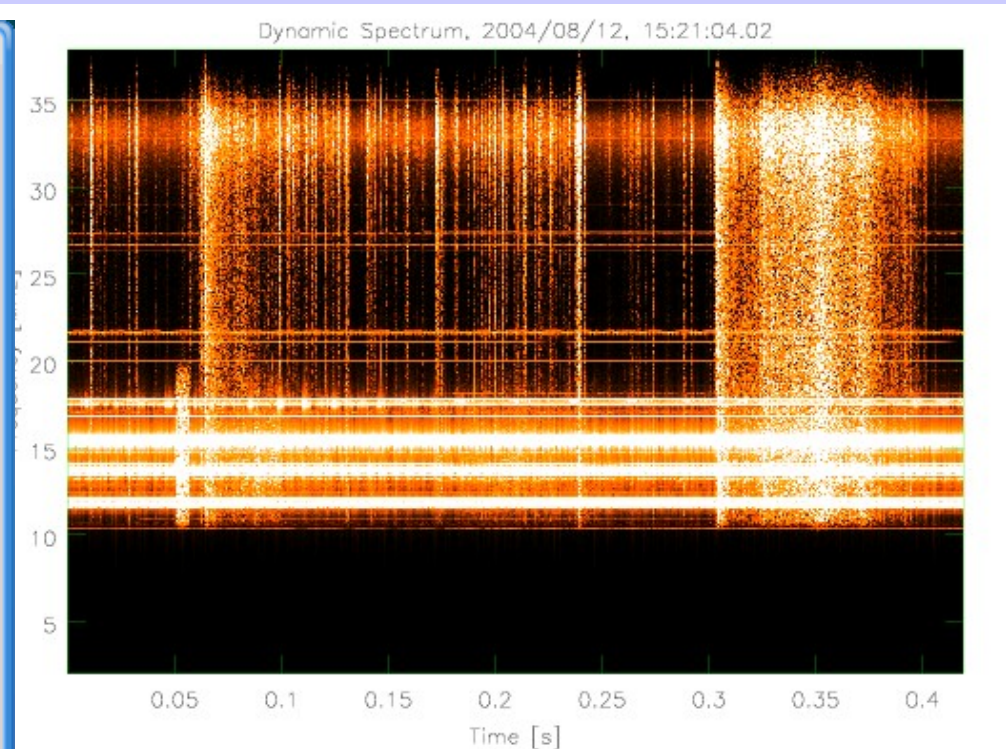
Compute averaged spectra

Compute differential spectra

Cross-correlation of antenna signals

**Dynamic spectrum: Plot annotation**

Start computation Save settings Load settings Dismiss



# Usage & Tools (iii)

## Processing tools: dynamic spectra

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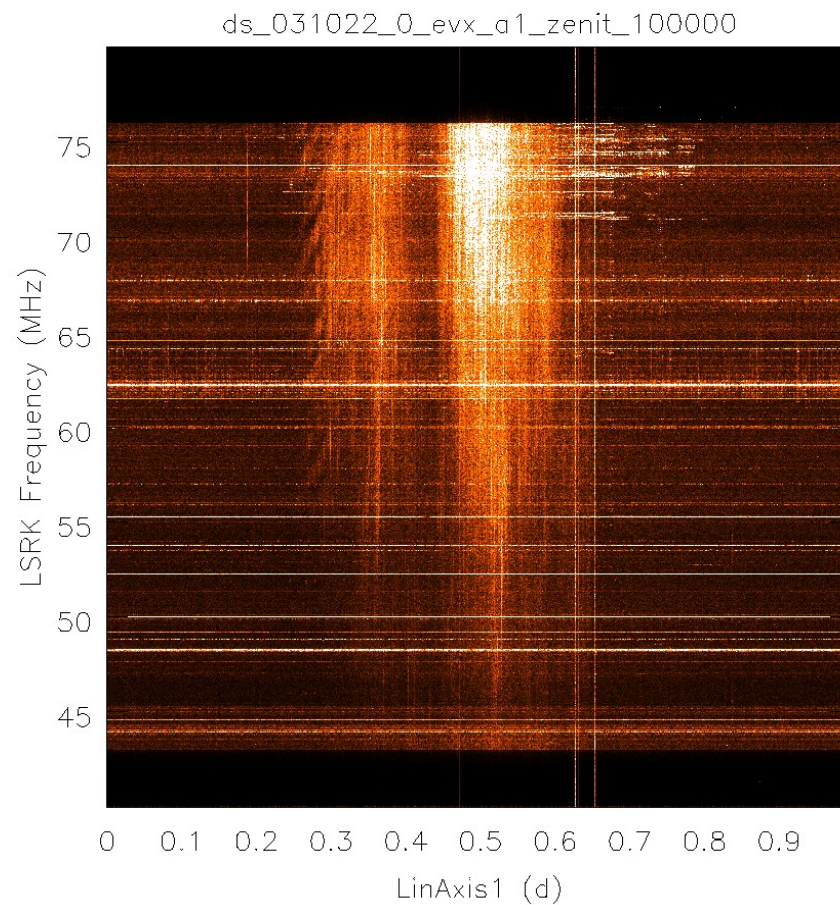
Compute averaged spectra

Compute differential spectra

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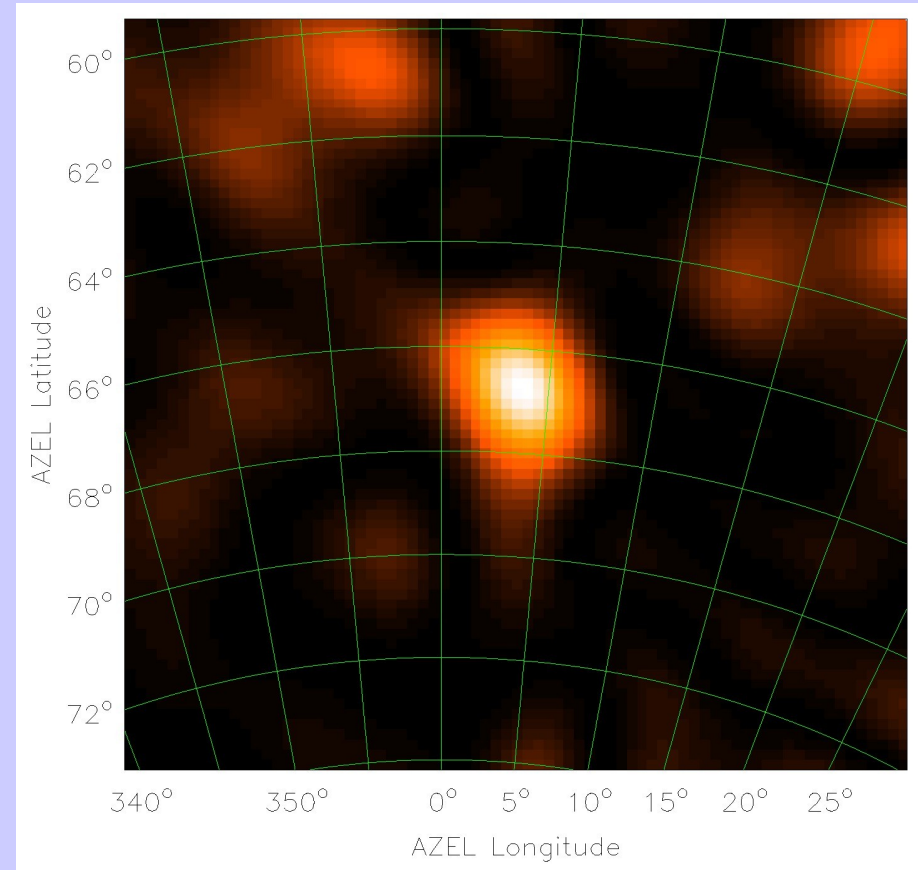
Start computation Save settings Load settings Dismiss



# Usage & Tools (iv)

## Processing tools: Skymapper

Source of data		⌵		
Antenna selection		⌵		
Processing of the data		⌶		
Number of Integrations :	<input type="text" value="1"/>			
Datablocks / Integration :	<input type="text" value="1"/>			
Samples / Datablock :	<input type="text" value="65536"/>			
First datablock processed :	<input type="text" value="1"/>			
Process complete dataset :	-- unused --			
Beamforming method :	addSignals			
Processed data type :	CalFFT			
Characteristics of the map				
Center of the map :	<input type="text" value="0"/> <input type="text" value="90"/>	(deg)		
Reference code :	AZEL			
Pixels of the map :	<input type="text" value="120"/> <input type="text" value="120"/>			
Range in Elevation :	<input type="text" value="0"/> <input type="text" value="90"/>	(deg)		
Angular Resolution :	<input type="text" value="2"/>	(deg)		
World Coordinate Systems (WCS)			⌵	
Processing in the Frequency domain			⌶	
Selected frequency band :	<input type="text" value="42.8"/> <input type="text" value="77.2"/>	(MHz)	Selection	
# frequency channels :	<input type="text" value="-1"/>			
RFI Mitigation :	<input type="checkbox"/> Autoflagging RFI contamination			
Electrical quantity displayed	Electric ...	<input type="radio"/> ... power	<input type="radio"/> ... field	
	Signal domain	<input type="radio"/> Frequency	<input type="radio"/> Time	
Calibration			⌵	
Display and export of generated data			⌵	
Generate Map		Analyze skymap	Clean-up disk	Dismiss



Data product: 5-dim image volume  
(ra,dec,**dist**,time,freq)

# Usage & Tools (v)

## Radio/TV Decoder

**TV Decoder** [ - ] [ □ ] [ X ]

Decode a TV picture ←

Decode AM Radio ←

Transmitter Frequency (in MHz) :

Bandwidth (in kHz) :

Exclude Antennas :

Filename :

**Start** **Dismiss**

**TV Decoder** [ - ] [ □ ] [ X ]

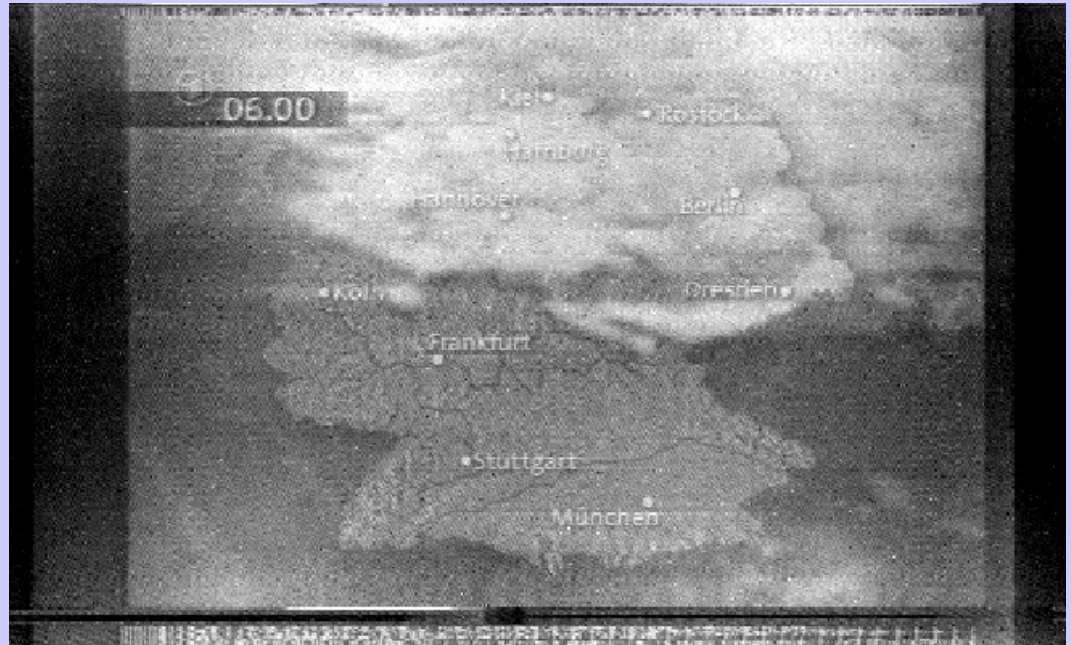
Decode a TV picture ←

Position of reference H-Sync :

Exclude Antennas :

Decode AM Radio ←

**Start** **Dismiss**



# Usage & Tools (vi)

## Image to MPEG converter

Skymap MovieMaker

**Characteristics of the input image** ⌵

Image shape : [2047 4096]  
Coordinate types : Linear Spectral

**Name settings** ⌵

**Pre-Processing of the image** ⌵

Smoothing :  Apply Hanning filter

**Image axis ranges** ⌵

Range of the x-axis : 1 ... 2047  
Range of the y-axis : 1 ... 4096  
Range of frames used : 1 ... 168751048  
Exclude frames: []  
Frame order:  Reverse

**Processing of the image** ⌵

Additional frames : 0  
◆ No additional frames  
◆ ... by linear interpolation  
◆ ... by cosine slope

Create still images

GIF  
 JPG  
 EPS  
 PPM  
 TGA  
 XPM

Post conversion actions

Keep parameter file  
 Keep movie image tool

**Generate Movie** **Dismiss**

# *Usage & Tools (vii)*

## *Data products & formats*

- ◆ Input:
  - ◆ Raw & CC data from LOFAR ITS
  - ◆ LOPES event files for CR data (C++ wrapper class provided)
  - ◆ FITS (as intermediate product for DS)
- ◆ Output:
  - ◆ AIPS++ images
  - ◆ Glish records
  - ◆ PgPlot files
  - ◆ FITS
  - ◆ MPEG

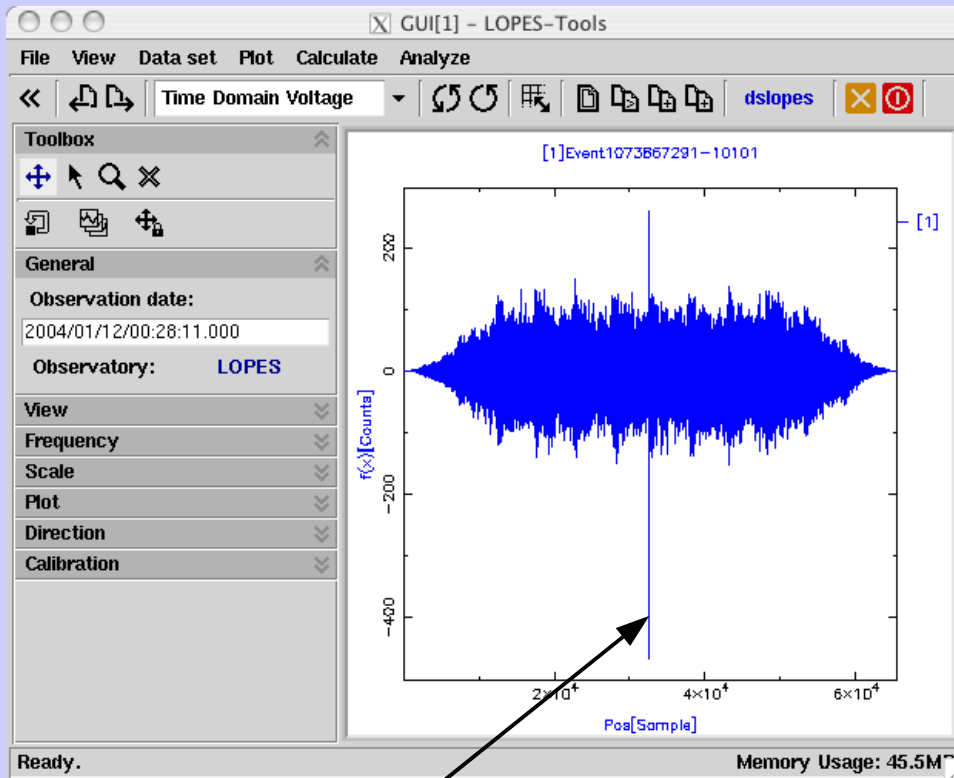
# *Cosmic ray analysis (i)*

## *Air shower events*

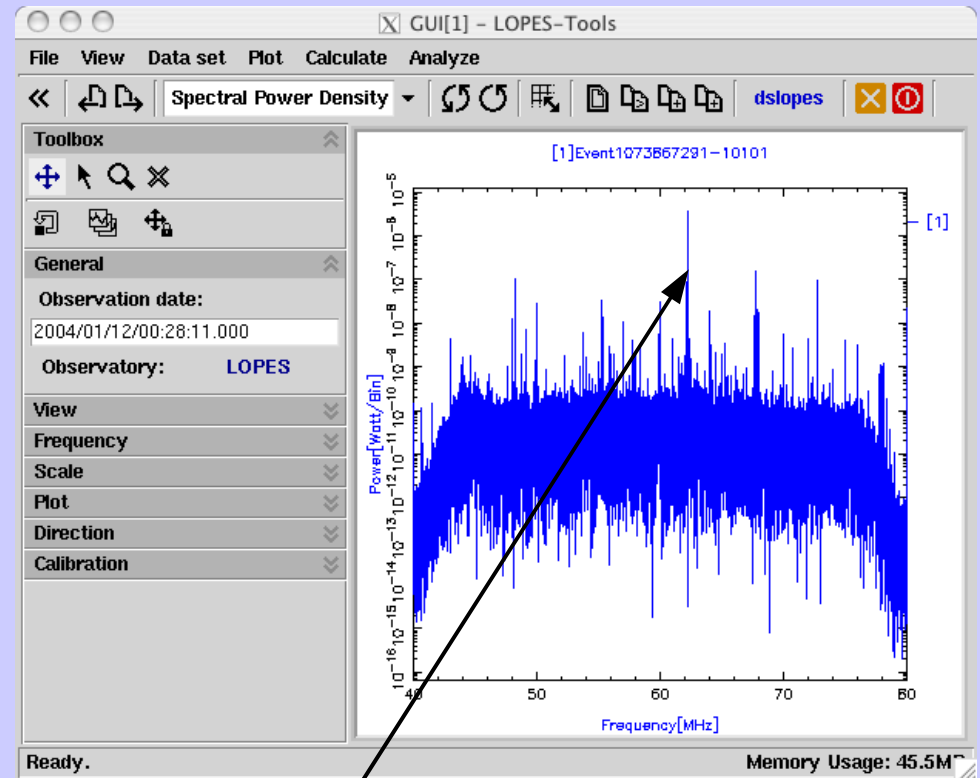
- ◆ Correlation between LOPES and KASCADE-Grande events
- ◆ Event selection
- ◆ FFT to frequency domain
  - ◆ Correction of instrumental delays
  - ◆ Frequency dependent gain correction
  - ◆ Suppression of narrow-band RFI
- ◆ Flagging based on signal level
- ◆ Correction of trigger delays
- ◆ Beamforming towards direction of air shower
- ◆ Quantification of peak parameters
- ◆ Optimization of radius of curvature

# Cosmic ray analysis (ii)

## First look at the data



Spike from CR  
(time domain)

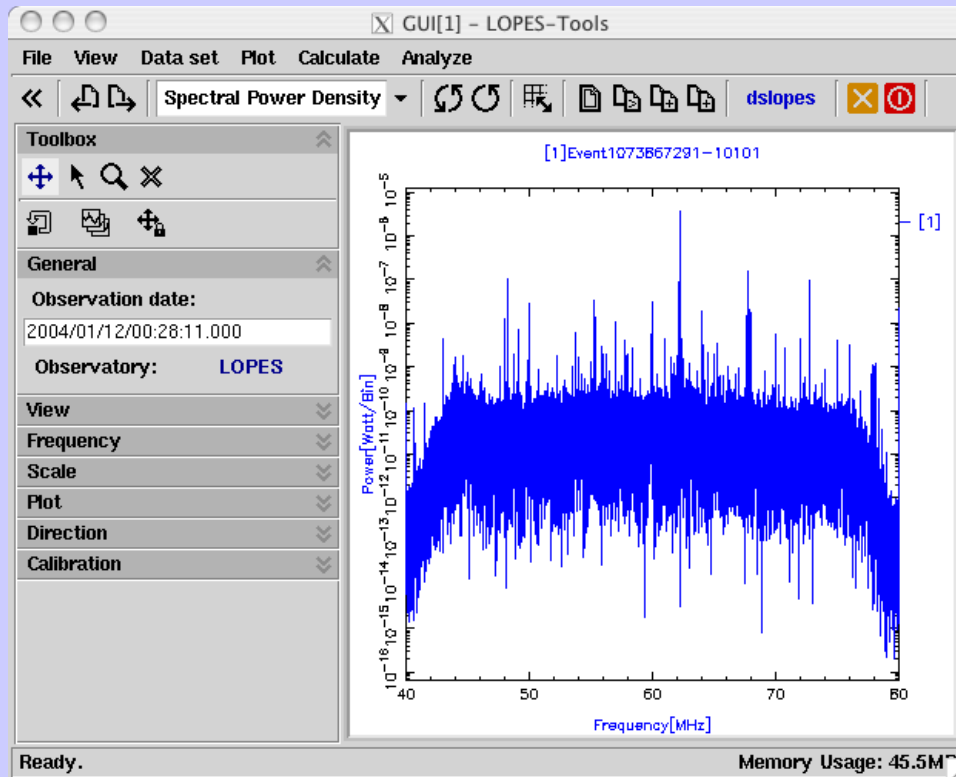


Spike from TV transmitter  
(frequency domain)

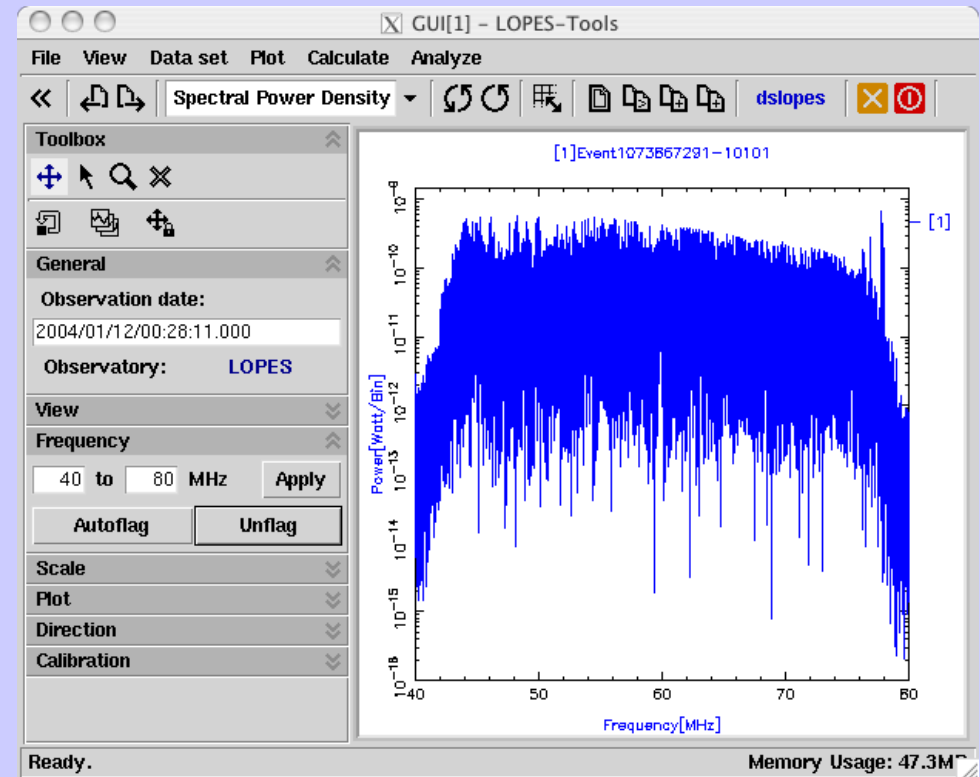
# Cosmic ray analysis (iii)

## Flagging of narrow band RFI

- ◆ Median filter @ Frequency domain
- ◆ Multiple passes for effective removal



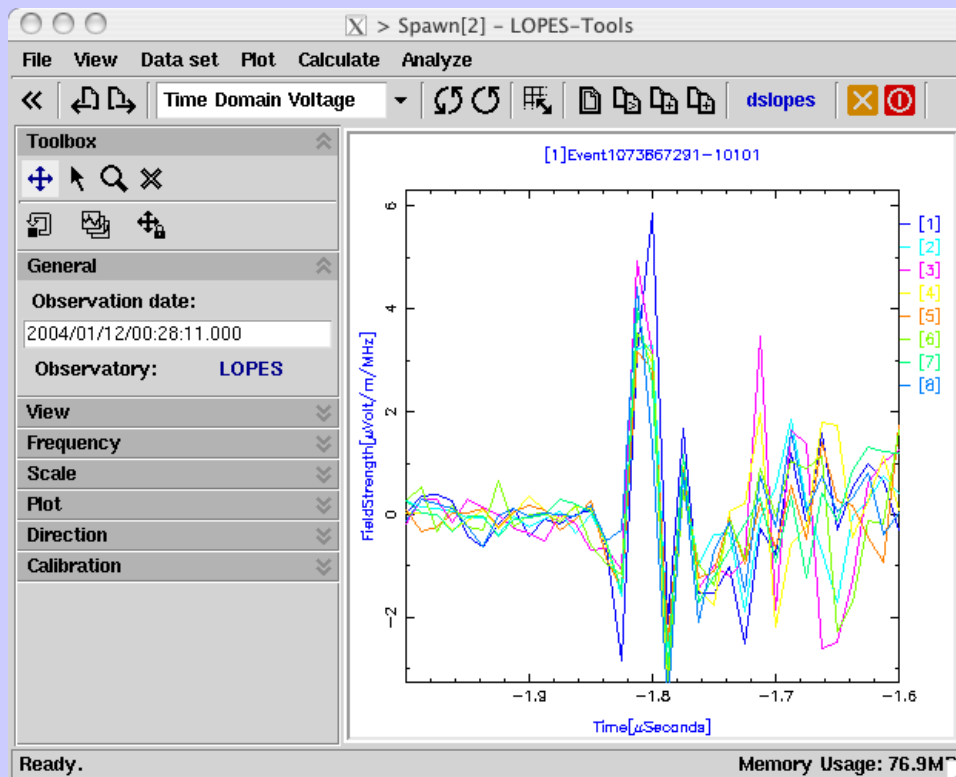
Initial power spectrum



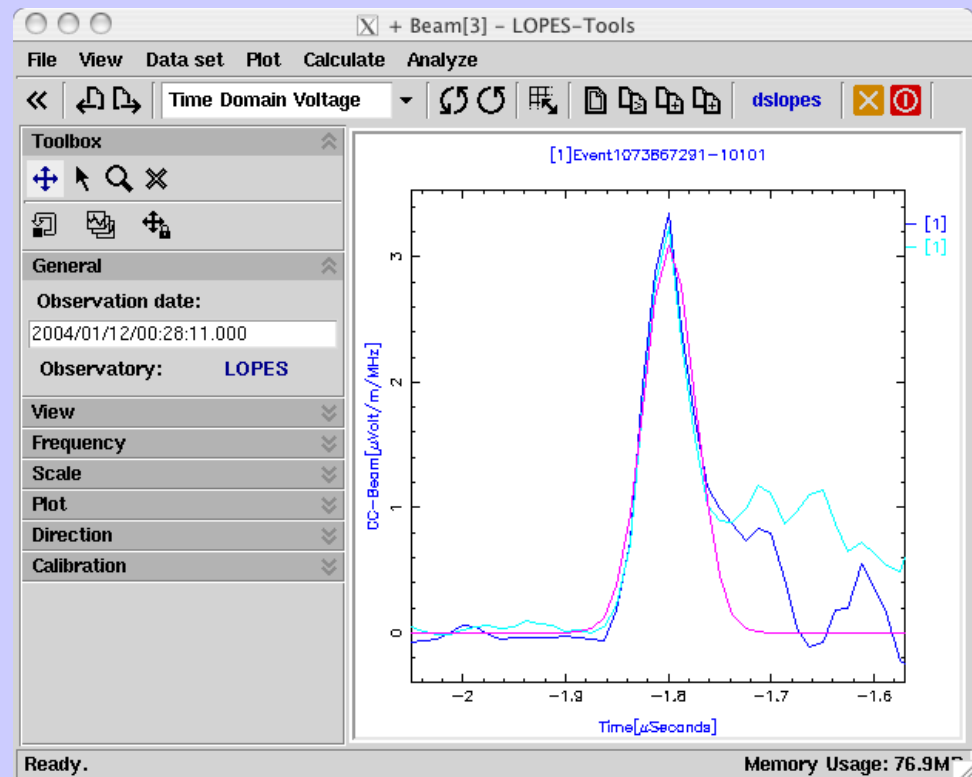
After 2 flagger passes

# Cosmic ray analysis (iv)

## Radio peak reconstruction



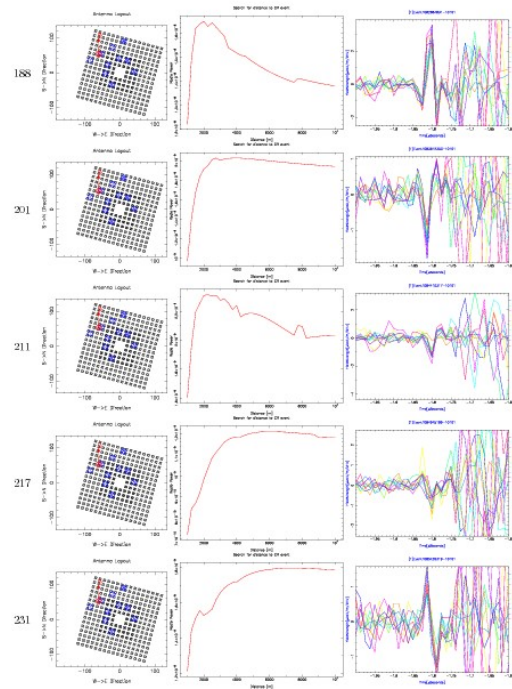
Individual antenna signal after correction for instrumental & geometrical delays (beamforming)



Time-series for cross-correlated antenna signals (towards CR)

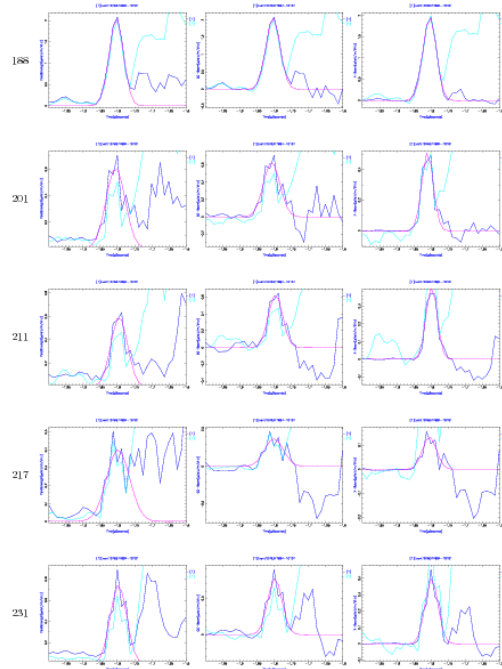
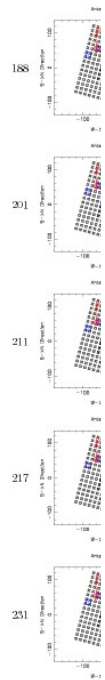
# Cosmic ray analysis (v)

## Automated processing



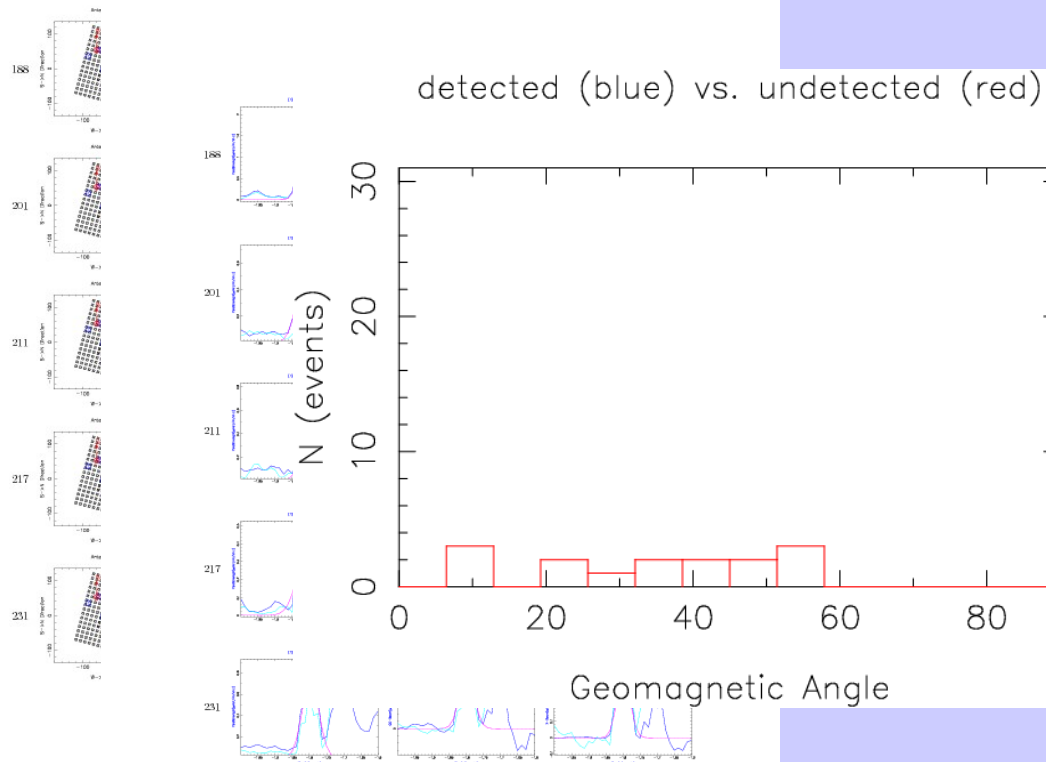
# Cosmic ray analysis (v)

## Automated processing



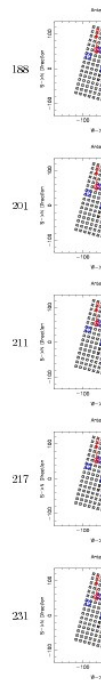
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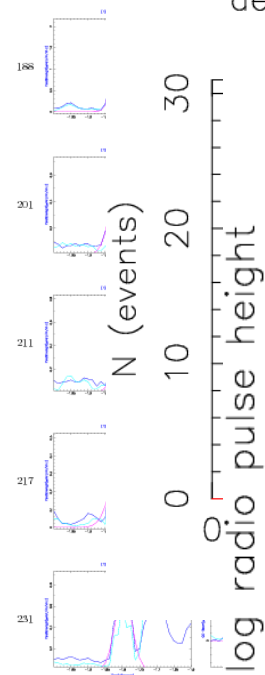


# Cosmic ray analysis (v)

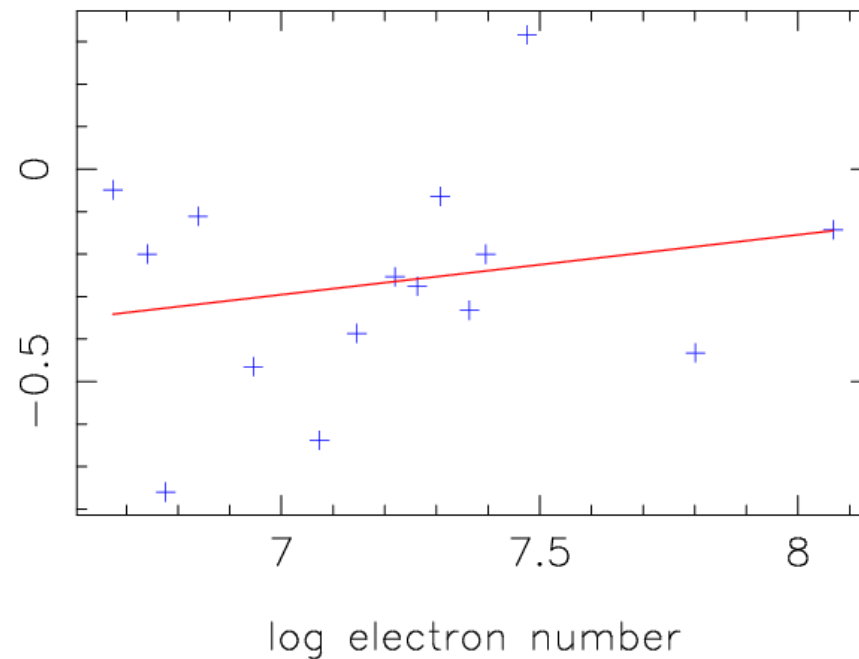
## Automated processing



detected (blue) vs. undetected (red)

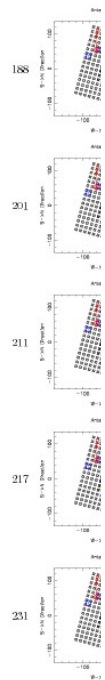


(all events with  $r < 70$  m)

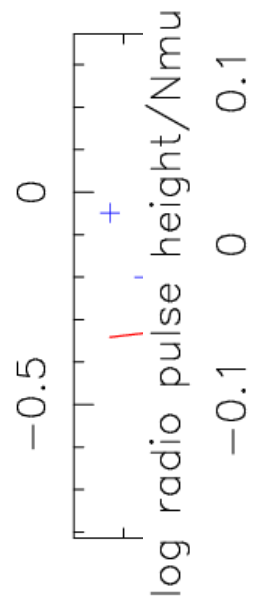
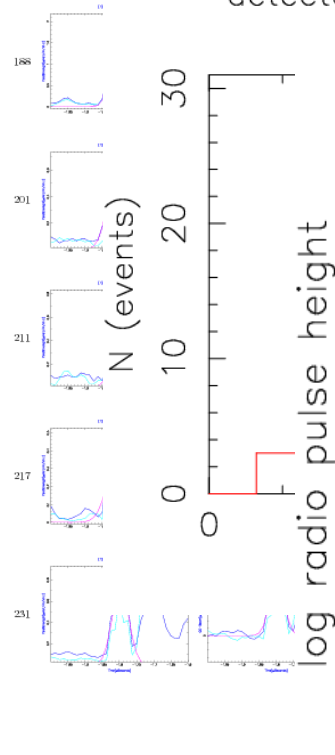


# Cosmic ray analysis (v)

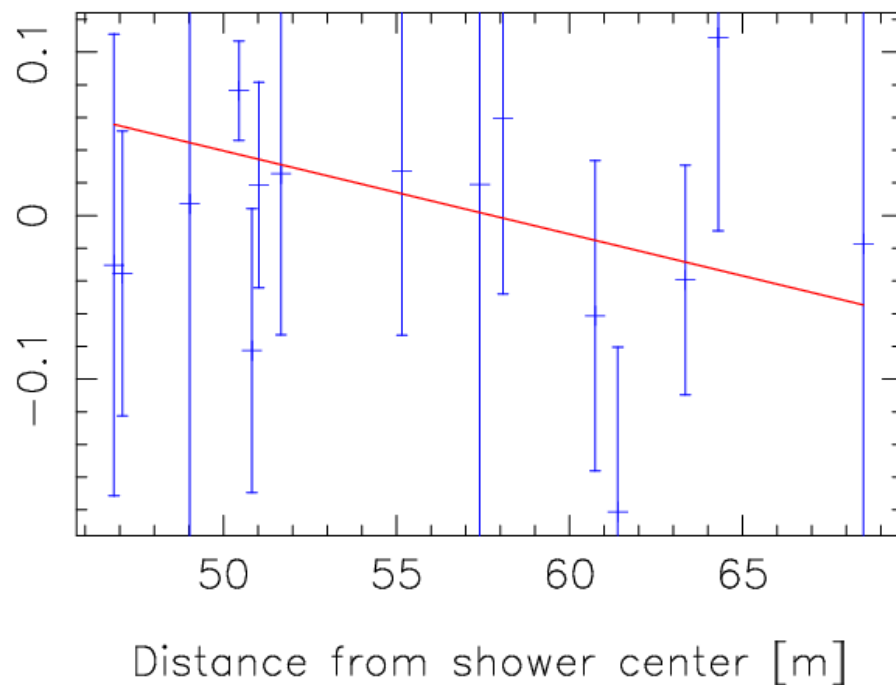
## Automated processing



detected (blue) vs. undetected (red)

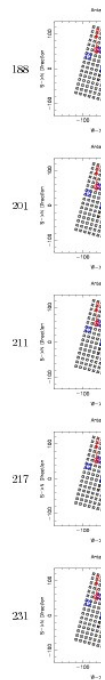


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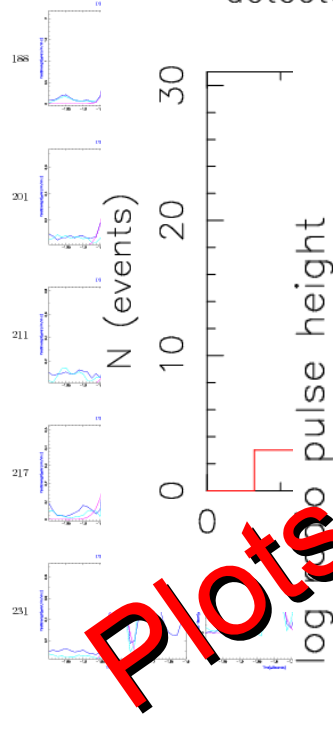


# Cosmic ray analysis (v)

## Automated processing



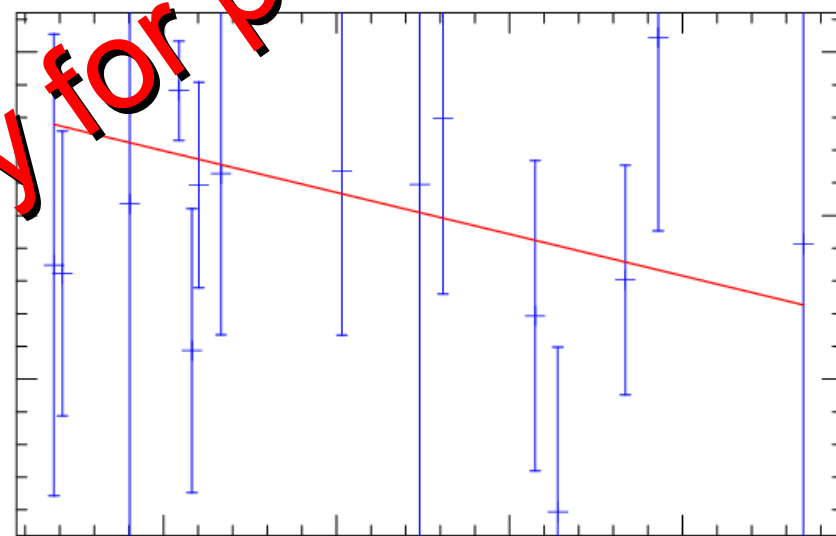
detected (blue) vs. undetected (red)



(all events with  $r < 70$  m)

log radio pulse height/Nmu

-0.1 0.1



Distance from shower center [m]

**Plots ready for publication!**

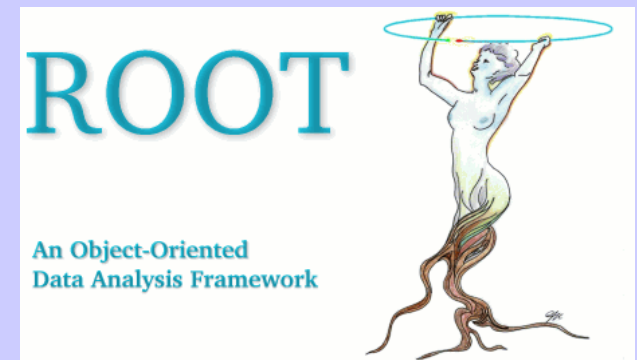
# Outlook

- ◆ Rewrite of the program kernel:
  - ◆ Finish transition from AIPS++ to CASA libraries
  - ◆ Transition from Glish to C++
  - ◆ Transition from Glish to Python
- ◆ Display:
  - ◆ Transition from GlishTk to PythonTk, Gtk, Qt...?
  - ◆ ROOT display libraries?



... get more users

... produce further exiting results



# *Summary*

LOPES-Tools is a production software!

- ◆ Used on real data
- ◆ Contains data processing pipeline
- ◆ Utilized by scientific end users
- ◆ Has delivered published scientific results (Nature)

# *Summary*

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... Questions ??