The SKADS Simulated Skies

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2° x 1° field from S3-SEX

ENS PARIS, 3 MARS 2008

Outline

The Square Kilometer Array

- **Specifications and timeline**
- **Key science projects**

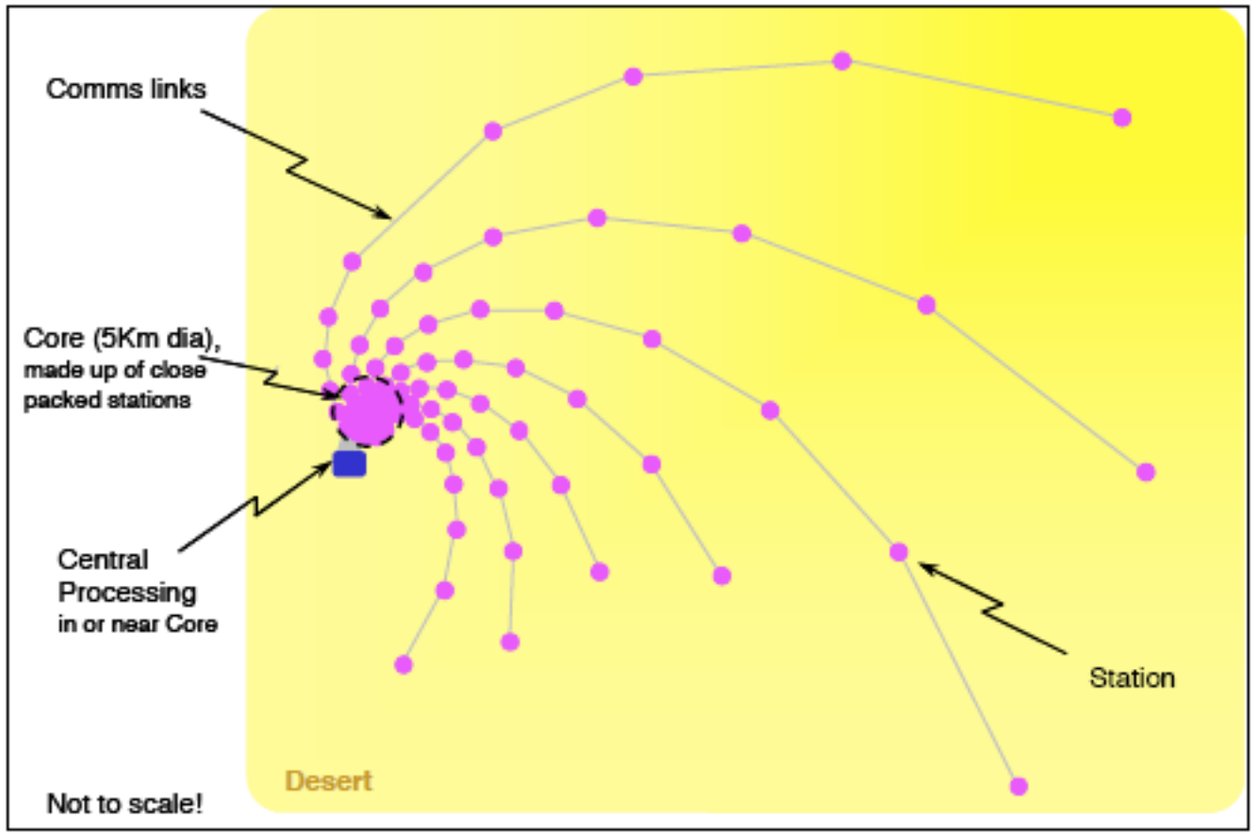
The SKADS Simulated Skies (S-cubed)

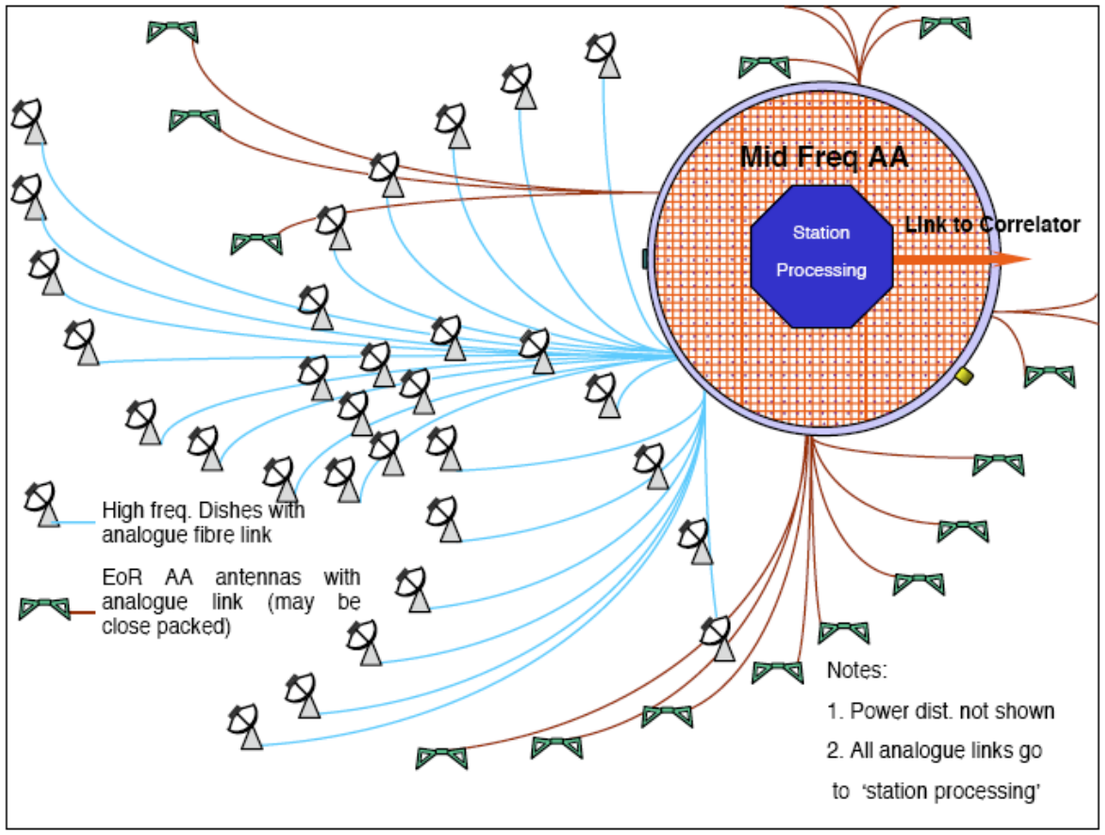
- **SEX and SAX simulations of the radio sky**
- **Database structure and access**
- **Making the SKADS sky**
- **A few applications....**

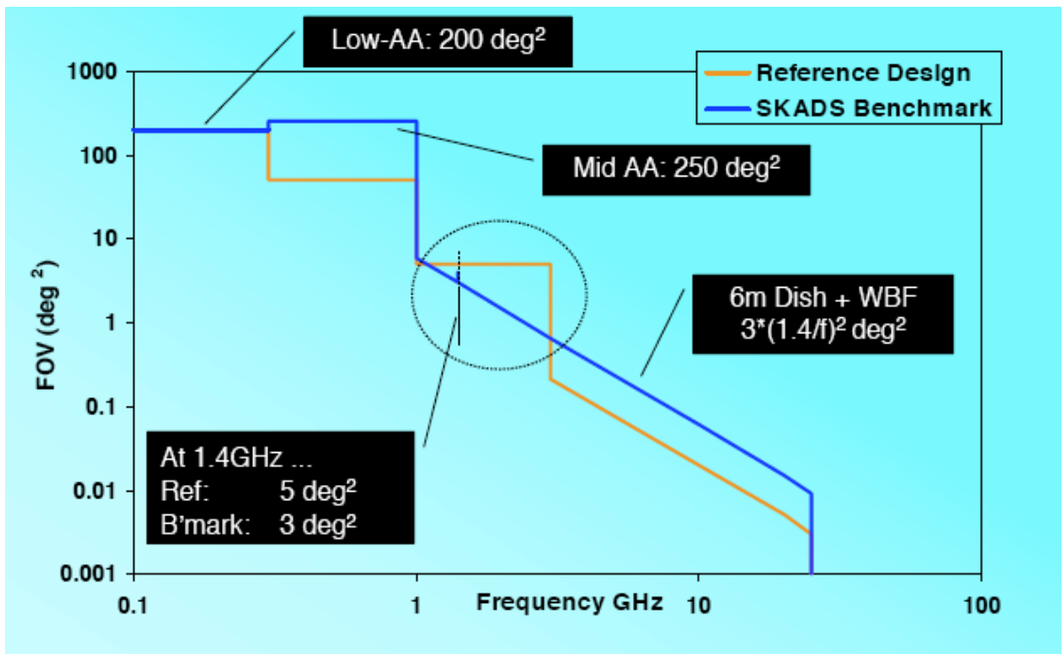
Simulating the observations with SKA

- **The Measurement Equation**
- **MeqTrees**
- **Generating skeleton Measurement Sets**

The Square Kilometer Array



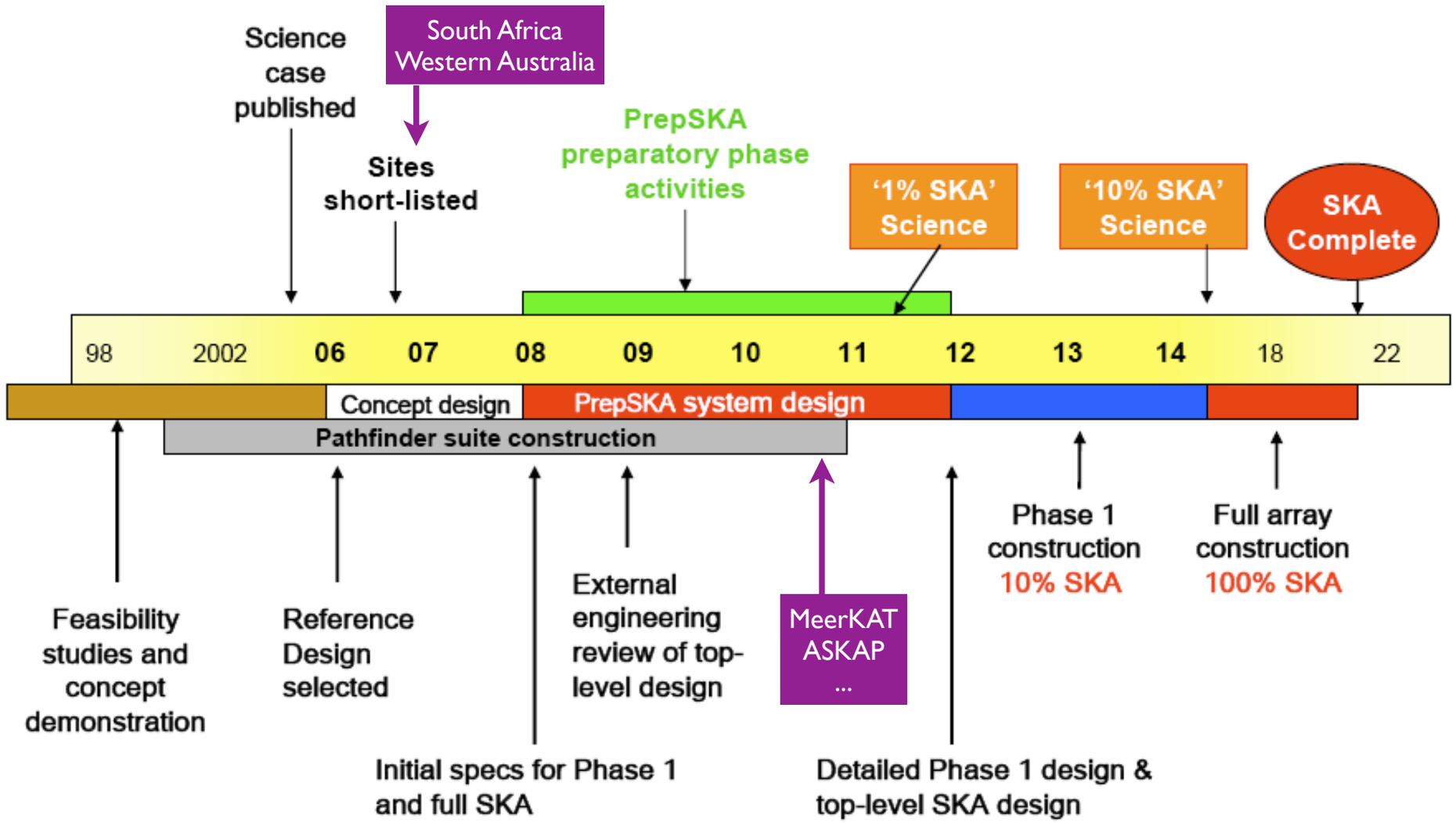




- Low-Frequency Dipole Array (0.1-0.3 GHz)
- Mid-Frequency Aperture Array (0.3-1 GHz)
- Dish Array (0.7-20 GHz)

- Baselines up to 3000 km
- Sensitivity ~10,000 m^2/K at 1.4 GHz

The SKA Timeline



... pushed back one year (every year)

The SKA Key Science Projects

Cradle Of Life

- Thermal imaging of protoplanetary disks (0.15 AU at 150 pc @ 20 GHz)
- Leakage radiation from ETI

Tests of General Relativity in Strong Fields

- ~20,000 detectable pulsars : probable pulsar+BH binary
- Timing of millisecond pulsars : GW background

Cosmic Magnetism

- 100,000,000 Rotation Measures from extragalactic sources (spacing 60")
- Spectropolarimetric observations of galaxies up to z>3

Galaxy Evolution And Cosmology

- Detection of HI emission at high redshift (z~2)
- Star-formation through continuum emission

Epoch Of Reionization

- Intergalactic medium HI at high redshift
- Star-formation through studies of molecular gas and dust

The SKADS Simulated Skies (S-Cubed)

Semi-Empirical eXtragalactic

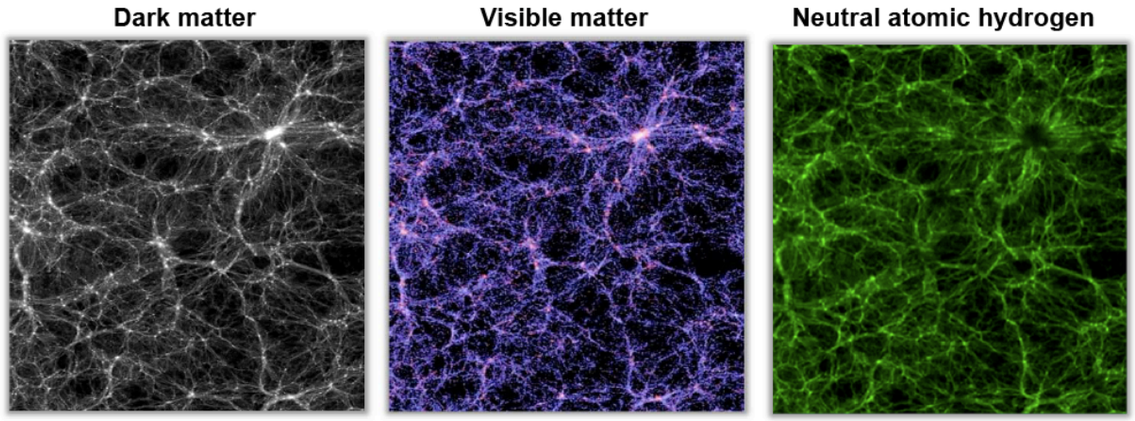
Wilman et al. (submitted)

- **Underlying dark-matter distribution evolved from linear theory**
- **Populations of AGN and galaxies drawn randomly from observed/extrapolated luminosity functions down to 10 nJy**
- **HI mass ascribed via $L_{1.4\mathrm{GHz}}$**
- **400 square degrees**
- **Maximum redshift z=20**
- **RQ-AGN, FRI, FRII, SFG, SB**

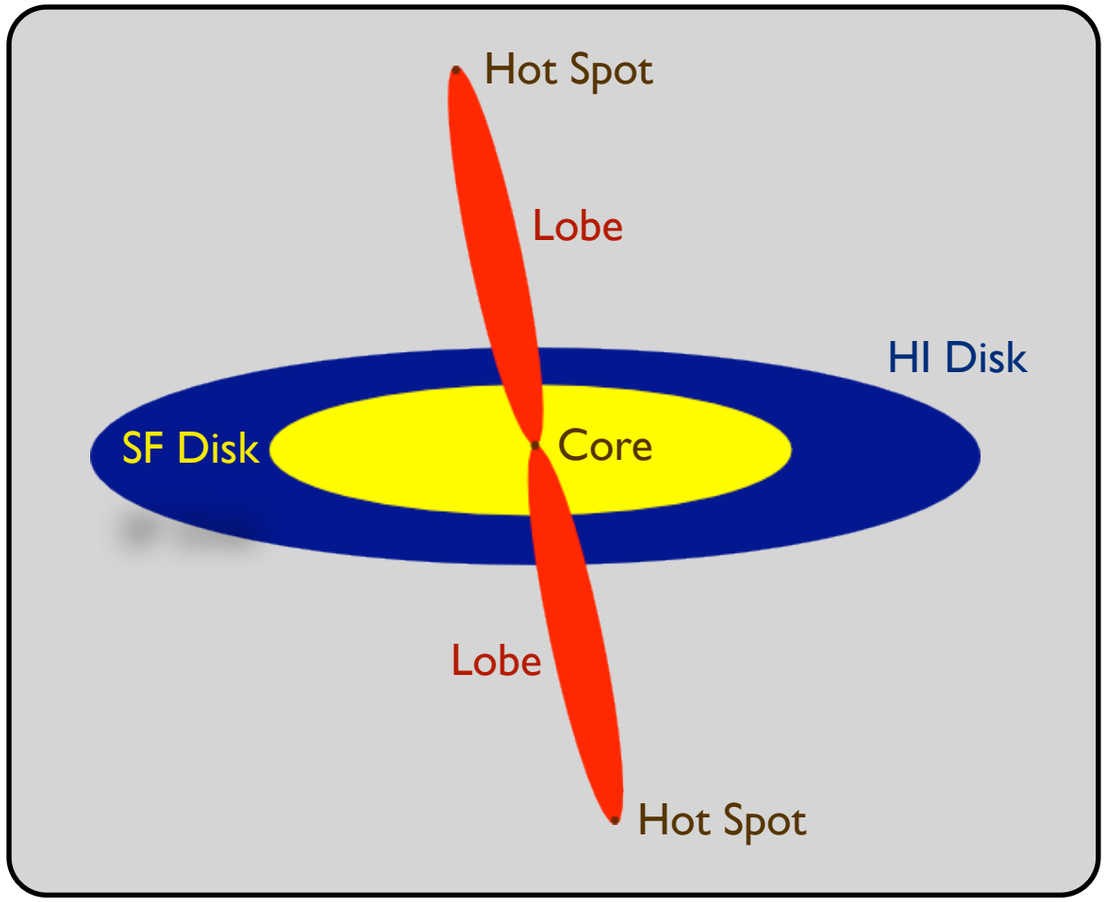
Semi-Analytical eXtragalactic

Obreschkow et al. (in prep.)

- **Dark-matter haloes of galaxies identified in the Millenium simulation**
- **Gas properties, star-formation and BH accretion rates ascribed**
- **27 square degrees**
- **maximum redshift z=4**



Simulation Output



- ASCII files for clusters and sources
- Sources = point sources and ellipses
- One row per subcomponent
- SEX : 47 GB and 235,301,766 sources
- SAX : 71 GB and 77,443,475 sources
- Continuum @ 151, 610, 1400, 4860, 18000 MHz

Source morphologies

	Core	Lobes	Hot Spots	SF Disk	HI Disk
Radio-quiet AGN	x				
FR I	x	x			
FR II	x	x	x		
"Normal" galaxies				x	x
Starburst galaxies				x	x

Source counts (SEX)

Number of Sources
36 132 566
23 853 134
2 354
168 046 330
7 267 382

Data Distribution

Source Table Structure

- Source index *Unique key*
- Cluster index
- Galaxy index
- Hubble type
- HI type index
- Star-Formation type index
- AGN type index
- Structure type index
- Right Ascension [degree] *Index*
- Declination [degree] *Index*
- Comoving distance [Mpc]
- Observed redshift
- Position angle [rad]
- Inclination [rad]
- Major axis [arcsec] *Index*
- Minor axis [arcsec]
- $\log(I)$, $\log(Q)$, $\log(U)$, $\log(V)$ @ 151 MHz [Jy]
- $\log(I)$, $\log(Q)$, $\log(U)$, $\log(V)$ @ 610 MHz [Jy]
- $\log(I)$, $\log(Q)$, $\log(U)$, $\log(V)$ @ 1400 MHz [Jy]
- $\log(I)$, $\log(Q)$, $\log(U)$, $\log(V)$ @ 4860 MHz [Jy]
- $\log(I)$, $\log(Q)$, $\log(U)$, $\log(V)$ @ 18000 MHz [Jy]
- $\log(I_{\rm HI})$, $\log(Q_{\rm HI})$, $\log(U_{\rm HI})$, $\log(V_{\rm HI})$ [Jy km/s]
- HI line width [km/s]
- HI circular velocity [km/s]
- $\log(M_{\rm HI}/M_{\odot})$
- cos(viewing angle)

Q, U, V : NULL

- SAX only
- SEX only

Step 1

- **Conversion of ASCII files to MySQL / PostgreSQL**
- **Cluster table + Source table**
- **Indexing on major axis, right ascension and declination**

Step 2

- **Hosting by Oxford e-Research Center**
- **Web interface for query** http://s-cubed.physics.ox.ac.uk/

Step 3

- **Collaboration with N. Walton @ Cambridge for implementation into AstroGrid (VO)**

Making the SKADS continuum sky

Input map parameters

region - source types - *resolution* - *frequency* - *flux limit*

Query databases

Read structure information

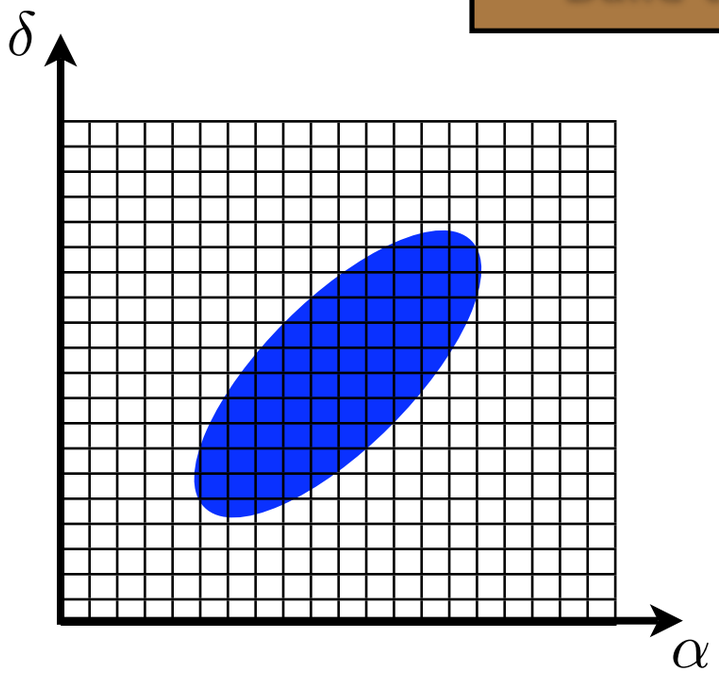
position - size - orientation - *reference fluxes*

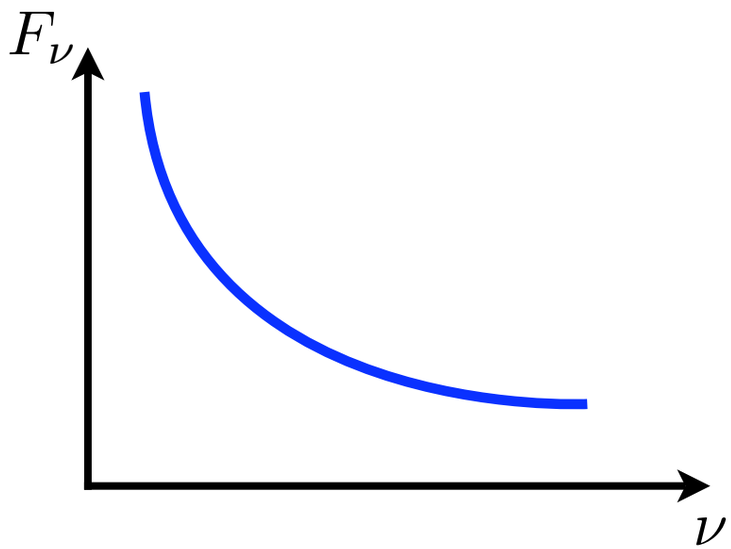
Build template image

Compute flux

Scale template image

Paste into full map



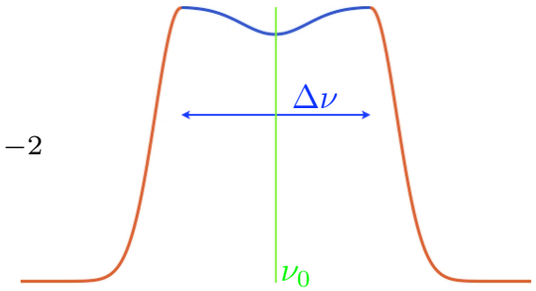


Making the SKADS HI sky

First approach @ low resolution : synthetic spectra

- HI flux from HI mass and distance
- "Random" line width (SEX)
- Synthetic double-peaked shape

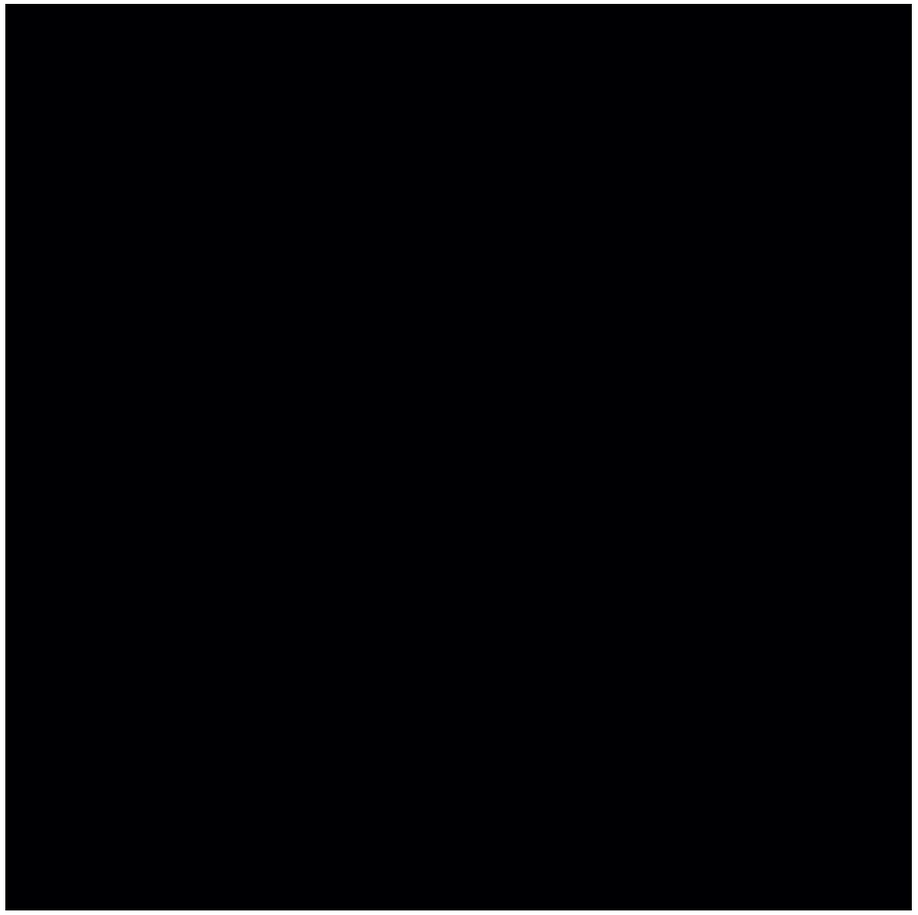
$$\int (S/\mathrm{Jy})(\mathrm{d}v/\mathrm{km.s}^{-1}) \approx 4.24 \times 10^{-6}(M_{HI}/M_{\odot})(D/\mathrm{Mpc})^{-2}$$



Second approach @ high resolution : template cubes from R. Boomsma (Kapteyn)

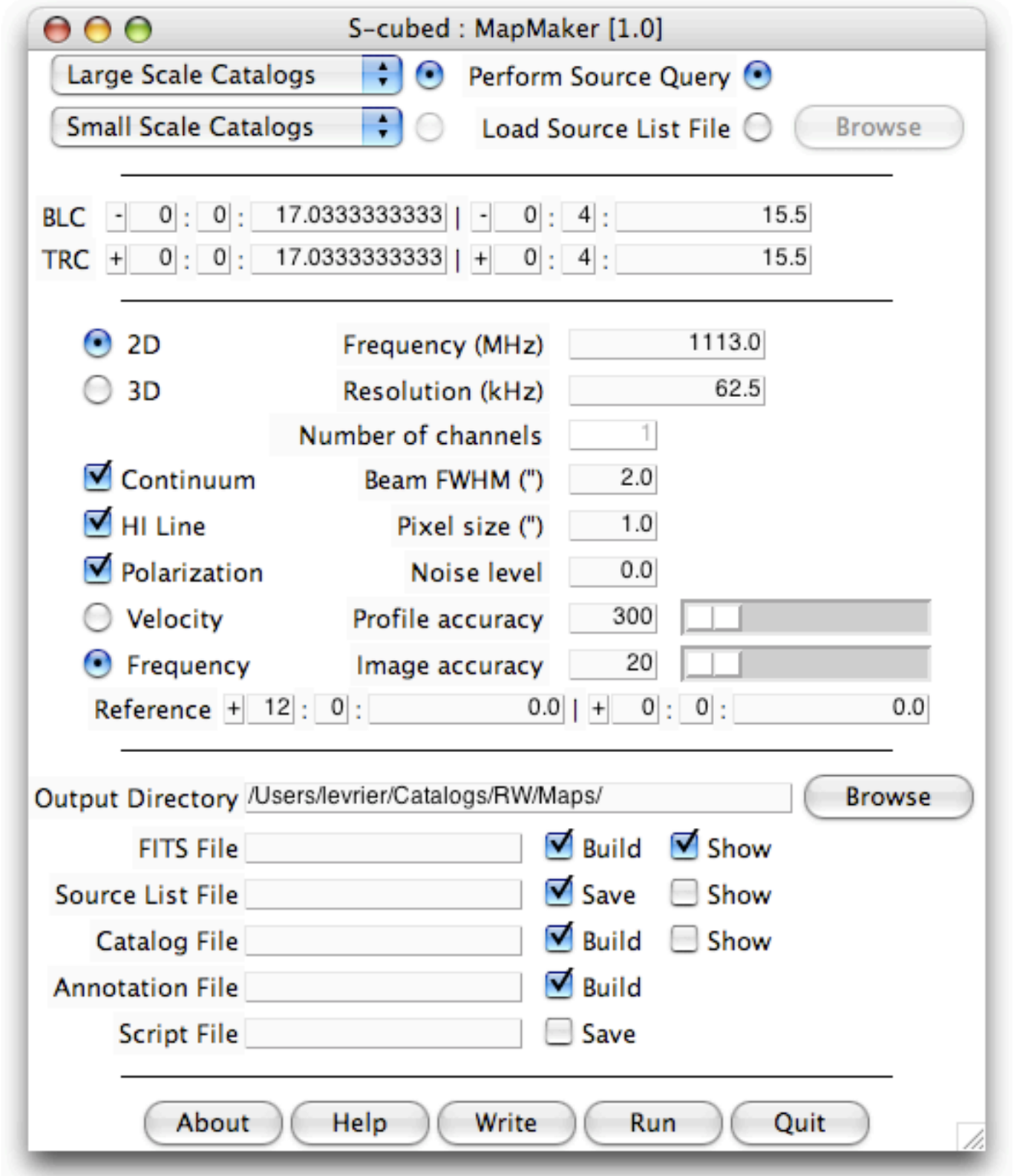
- Galaxy models made of "clouds"
- Placed according to density profile
- Orbiting according to velocity curve
- 5 galaxy types (spirals and irregulars)
- 46 inclination values (0-90 degrees)
- 5 asymptotic velocities

scale / rotate / paste



S0-Sab galaxy type 200 km/s asymptotical velocity 42 degrees inclination

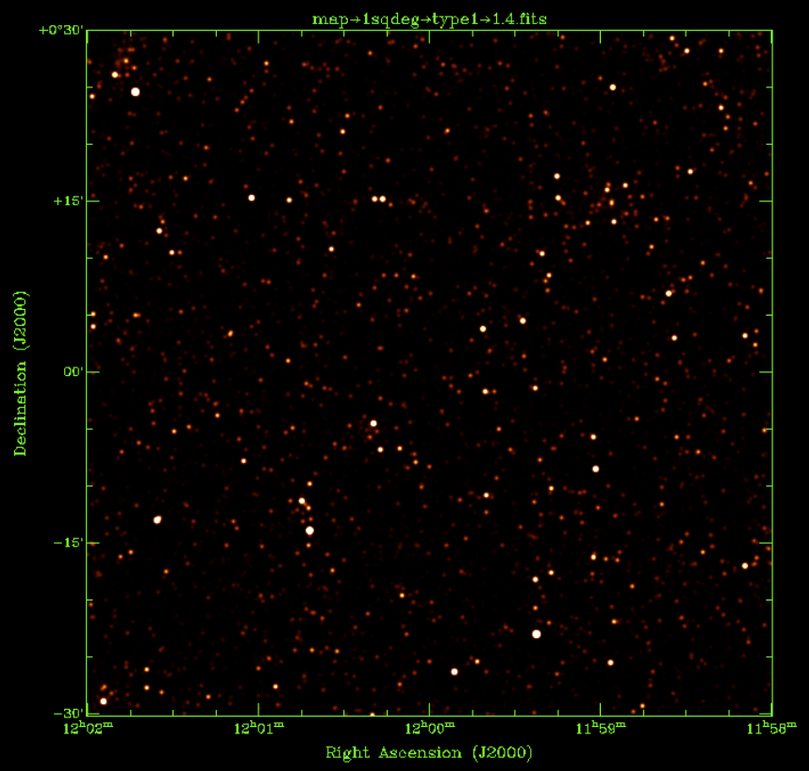
The MapMaker



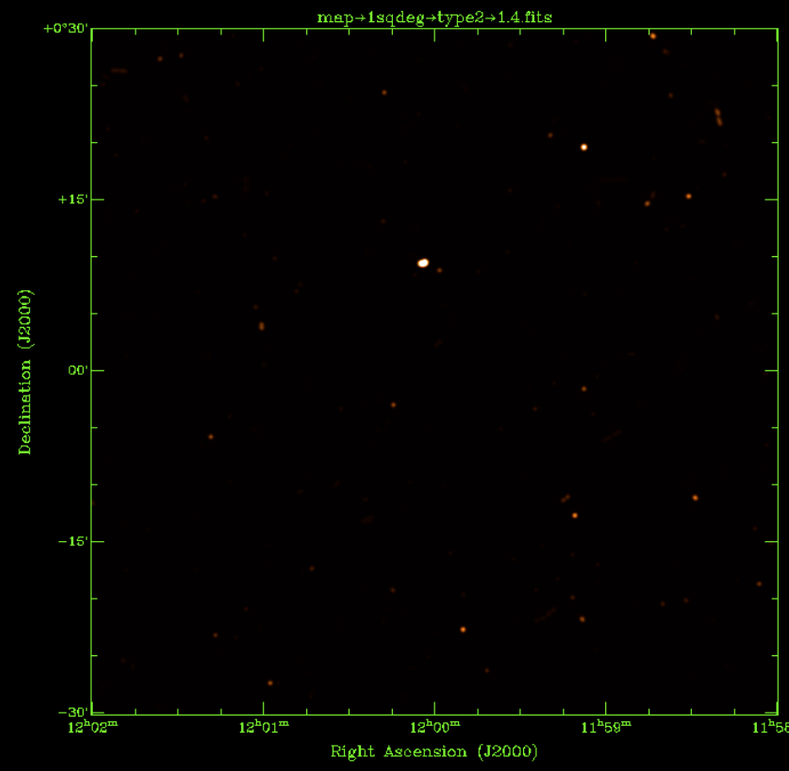
- Standalone application in Python
- SQL/Python interface
- Source list = query + post-processing
- FITS output with annotation file
- 2D images or 3D cubes
- Backend routines to be parallelized and plugged into VO

Example : Central square degree of S-cubed SEX

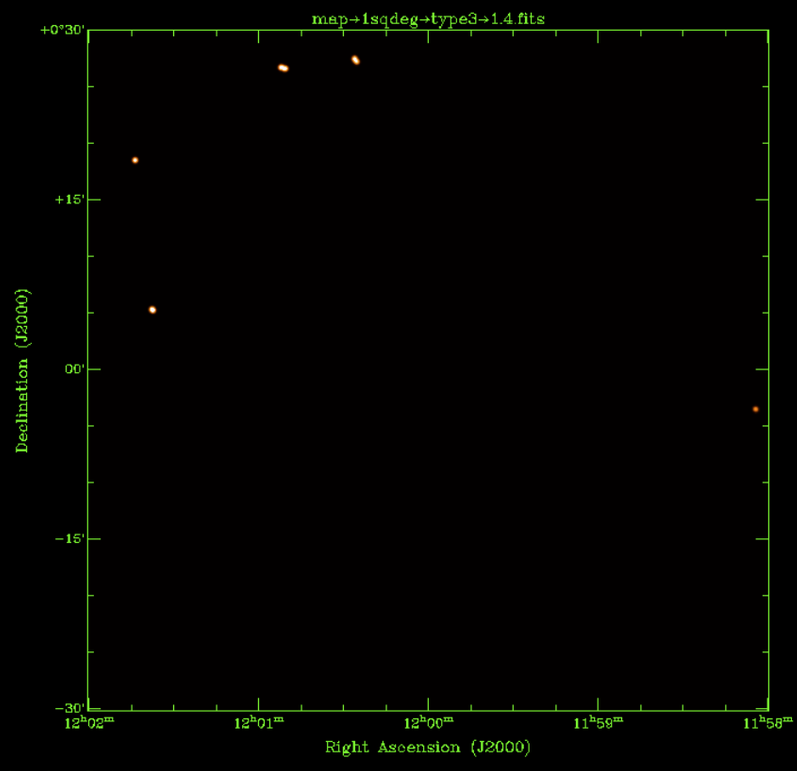
Radio-quiet AGN



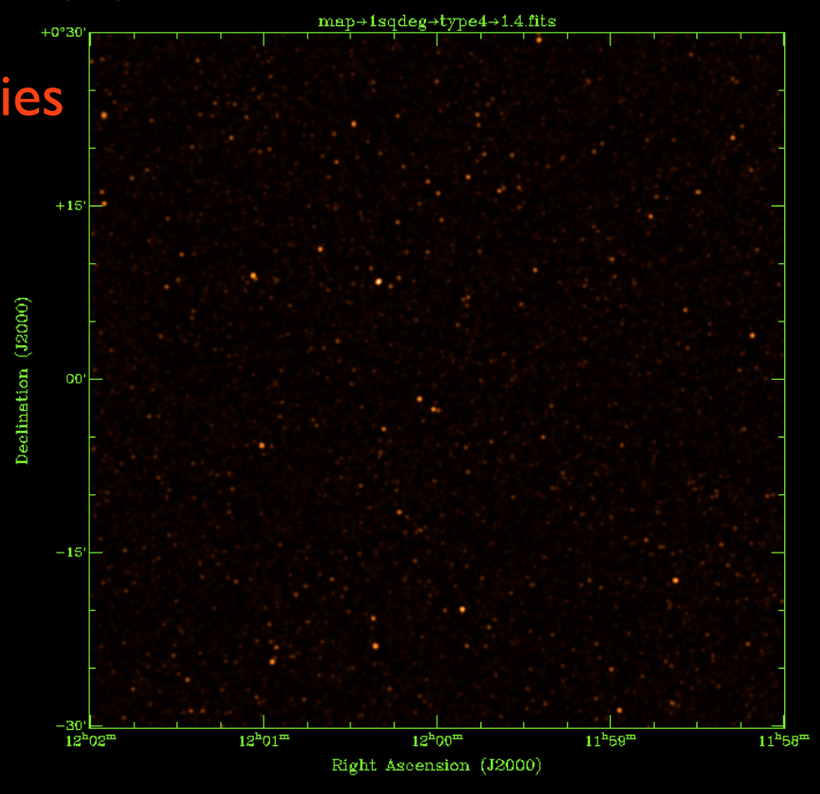
FR I



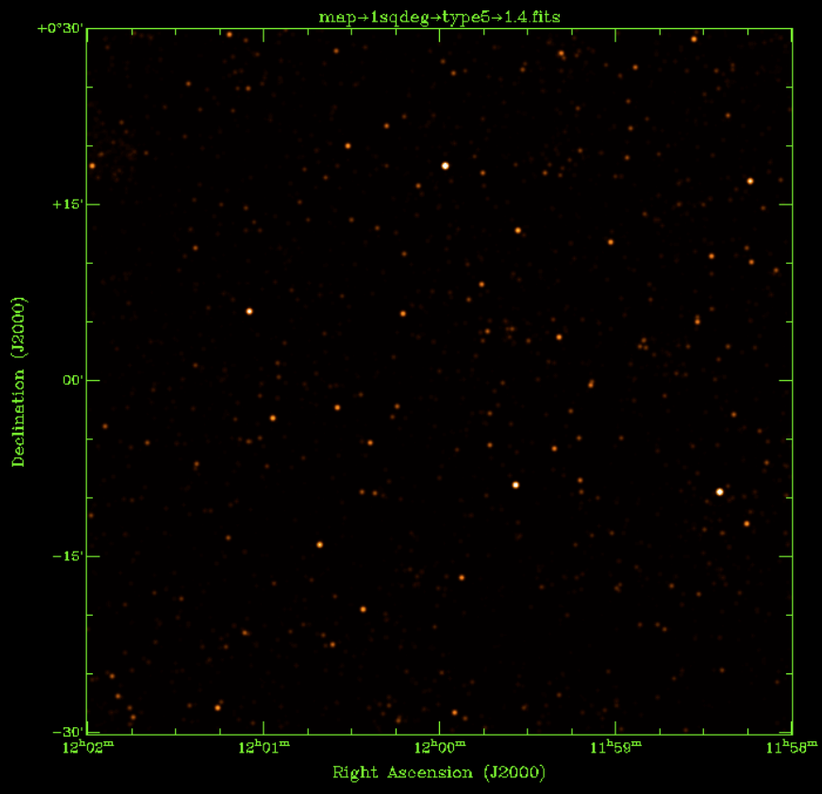
FR II



"Normal" galaxies

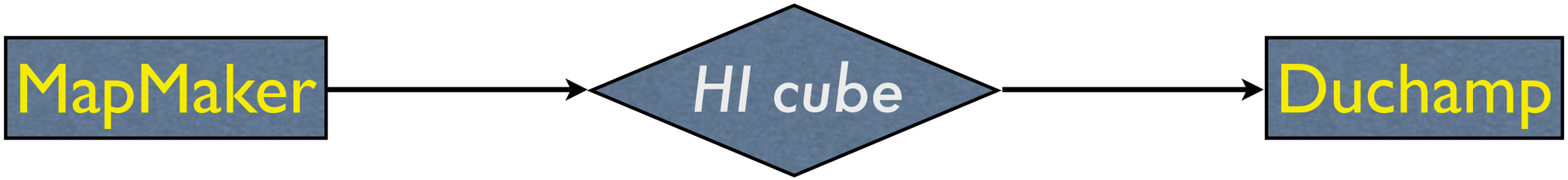


Starburst



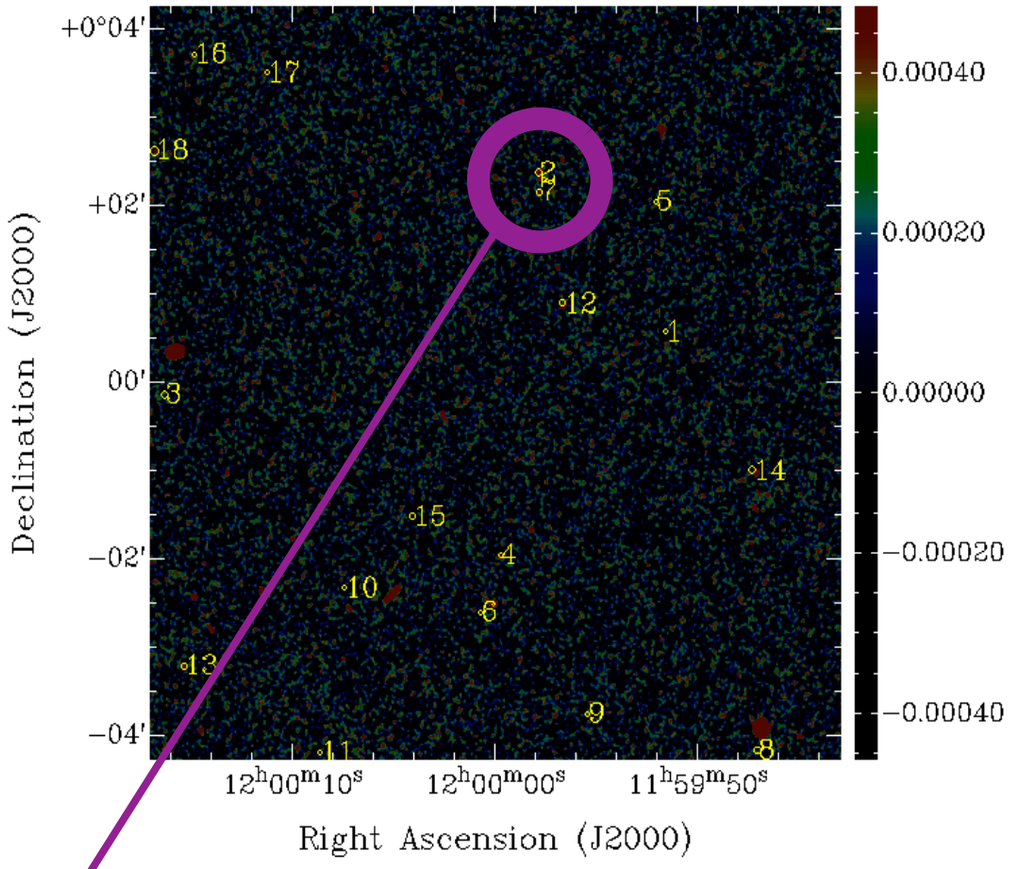
Source Extraction

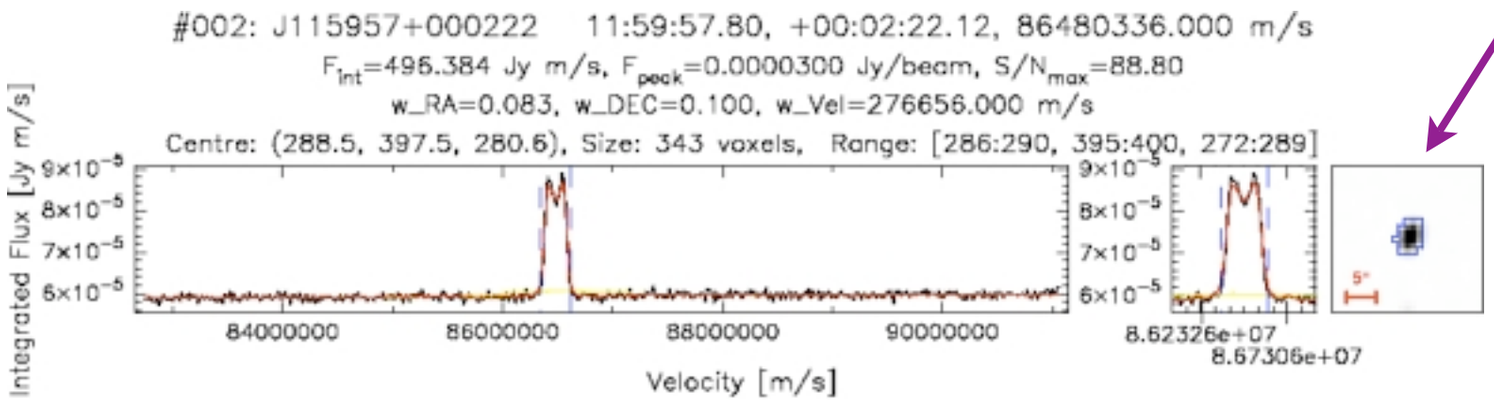
In collaboration with R. Auld (Cardiff)



Duchamp

- **ATNF (M. Whiting)**
- **Locates sets of contiguous voxels above some threshold**
- **Uses spectral, spatial or wavelet smoothing for enhancement**
- **Very quick (30 minutes for 512 x 512 x 1024 cube on a laptop)**
- **VO-compliant**
- **Memory and process intensive**
- **Completeness issues (misses high S/N sources)**

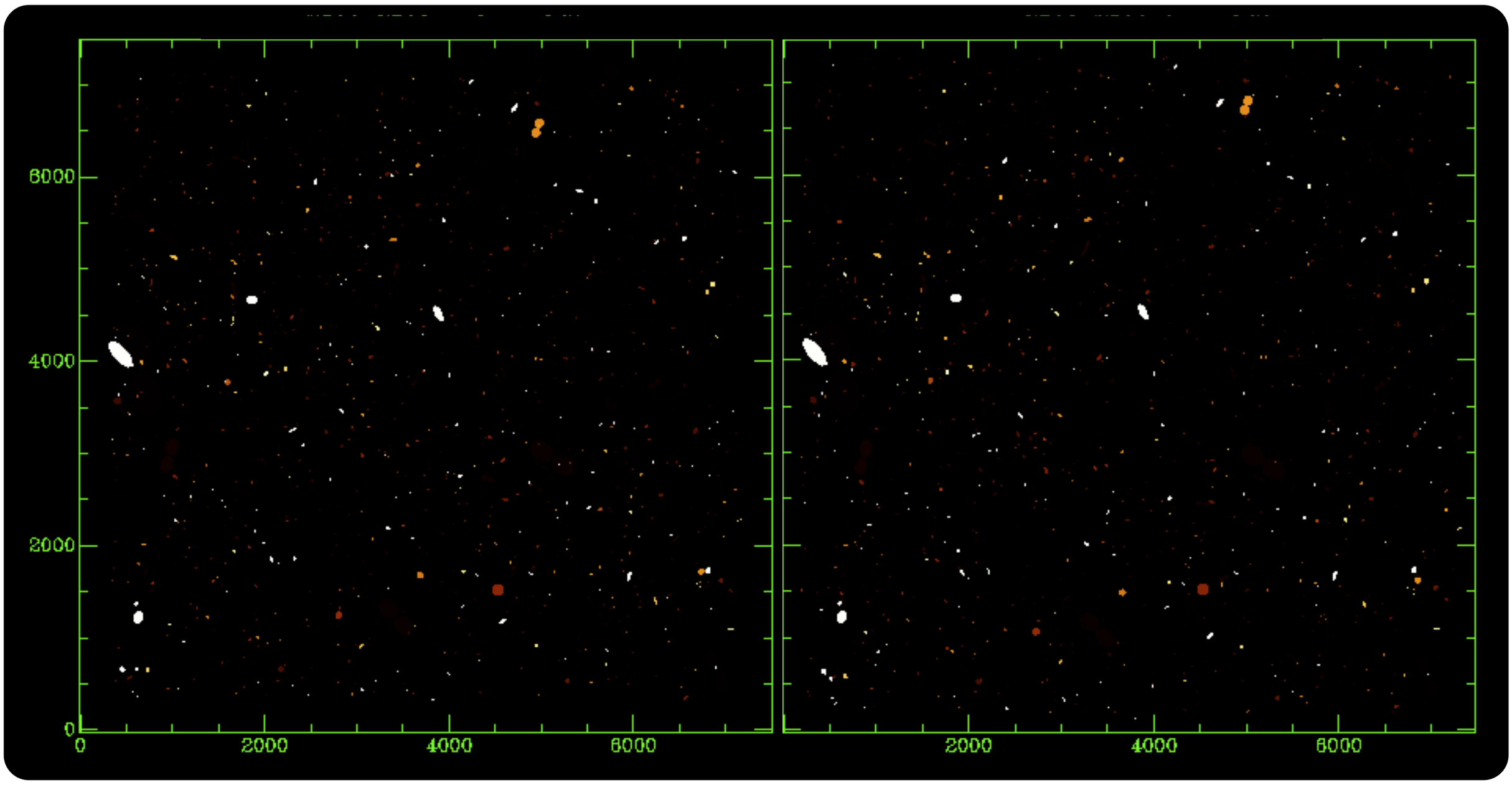




Lensing

In collaboration with B. Metcalf (Garching)

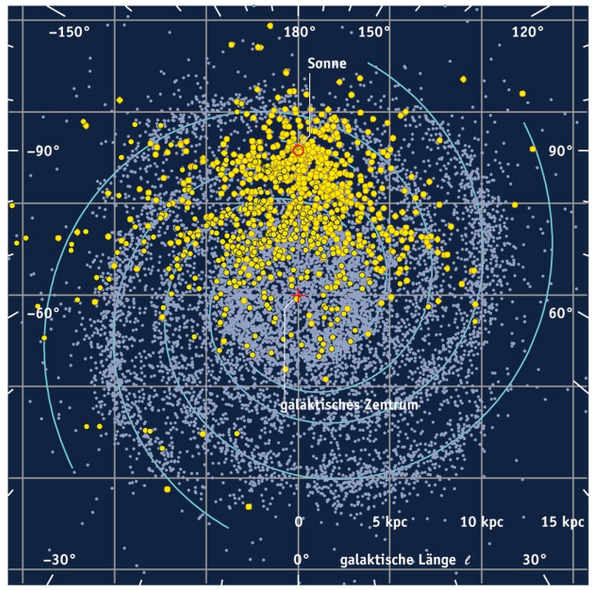
- **Potentially 10,000 - 100,000 lensed systems in SKA all-sky surveys**
- **Internal mass structure and evolution of clusters up to z~1**



S3-PUL : A pulsar database

In collaboration with R. Smits (Jodrell Bank)
& A. Karastergiou (Oxford)

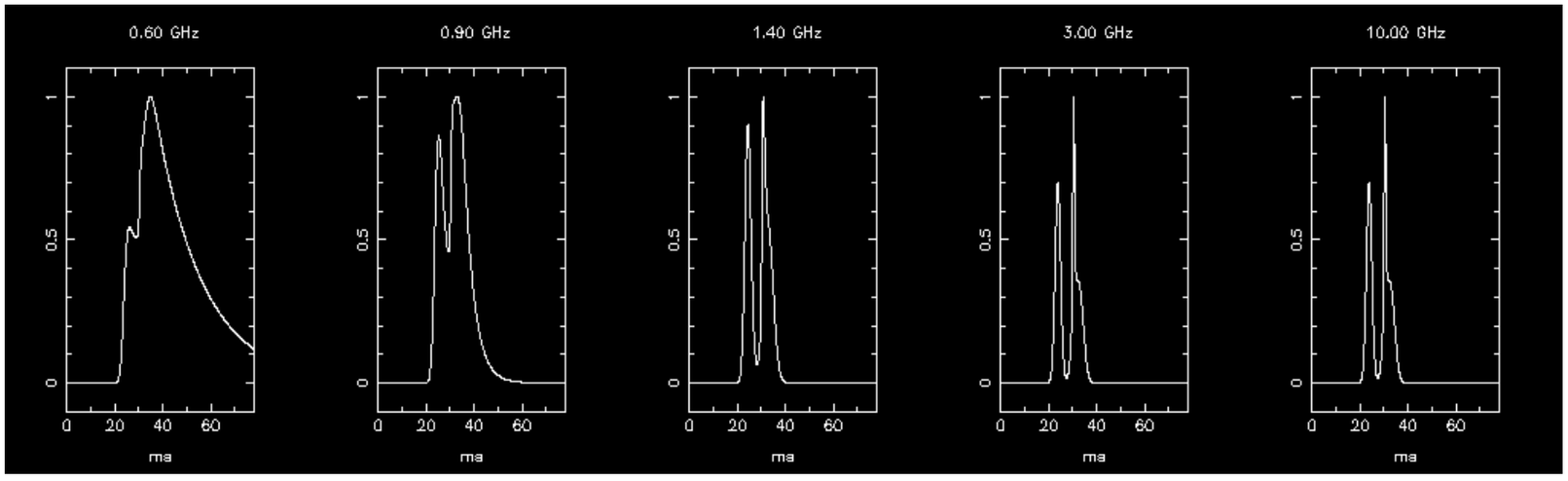
- **With SKA sensitivity : ~20,000 detectable pulsars**
- **Generation of pulsar population**
- **Generation of synthetic profiles**



[M. Kramer]

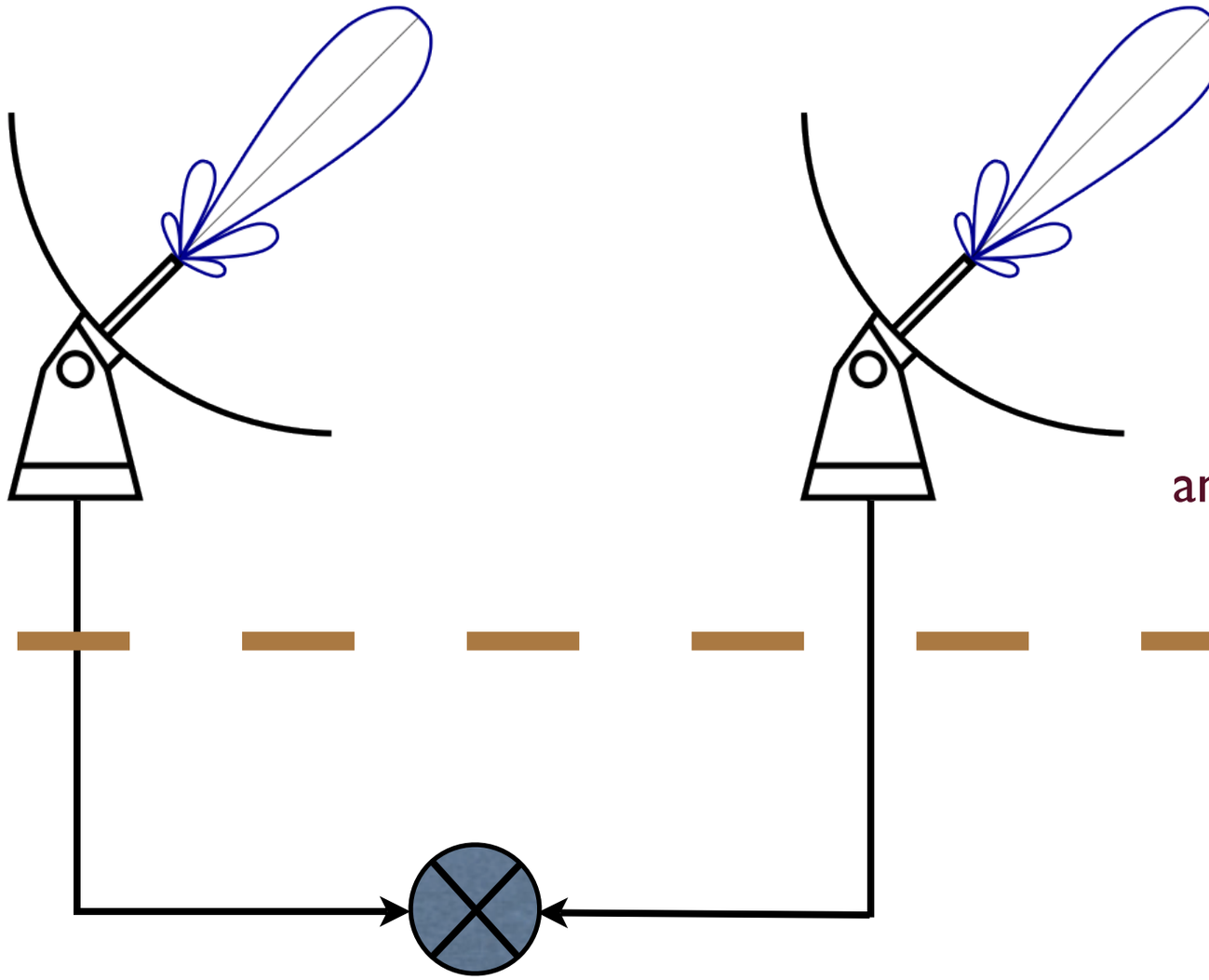
☑ **Period**	20	20000	ms
☑ **Dispersion Measure**	0	1700	cm^{-3} pc
☐ **Pulse Width**	0	3000	ms
☐ **Galactic Longitude**	−180	180	degrees
☐ **Galactic Latitude**	−90	90	degrees
☐ **Flux**	0	250000	mJy
☐ **Spectral Index**	−3	0	
☐ **X Galactic**	−20	20	kpc
☐ **Y Galactic**	−20	20	kpc
☐ **Z Galactic**	−4	4	kpc
☐ **D Earth**	0	30	kpc
☐ **R Galactic**	0	20	kpc
☐ **Luminosity**	0	250000	mJy kpc^2

#	Name	Period	DM	Width	l	b	S	\alpha	X	Y	Z	D	R	L
1	J2000+0134	184.48	254.39	20.1	13.1	6.6	5.6	-1.67	1.58	1.71	0.81	7.02	2.33	0.28



The Measurement Equation

Hamaker, Bregman & Sault, 1996



incoming electrical field

$$\vec{v}_p = \left(\prod_i^n \boldsymbol{\mathcal{J}}_{ip} \right) \vec{e} = \boldsymbol{J}_p \vec{e}$$

antenna voltage pattern — Jones matrices

Brightness

$$\boldsymbol{V}_{pq} = \boldsymbol{J}_p \boldsymbol{B} \boldsymbol{J}_q^\dagger$$

Visibility function

- field and voltage pattern are 2-element vectors (2 polarizations)
- Visibility function, Jones matrices and brightness are 2 by 2 matrices

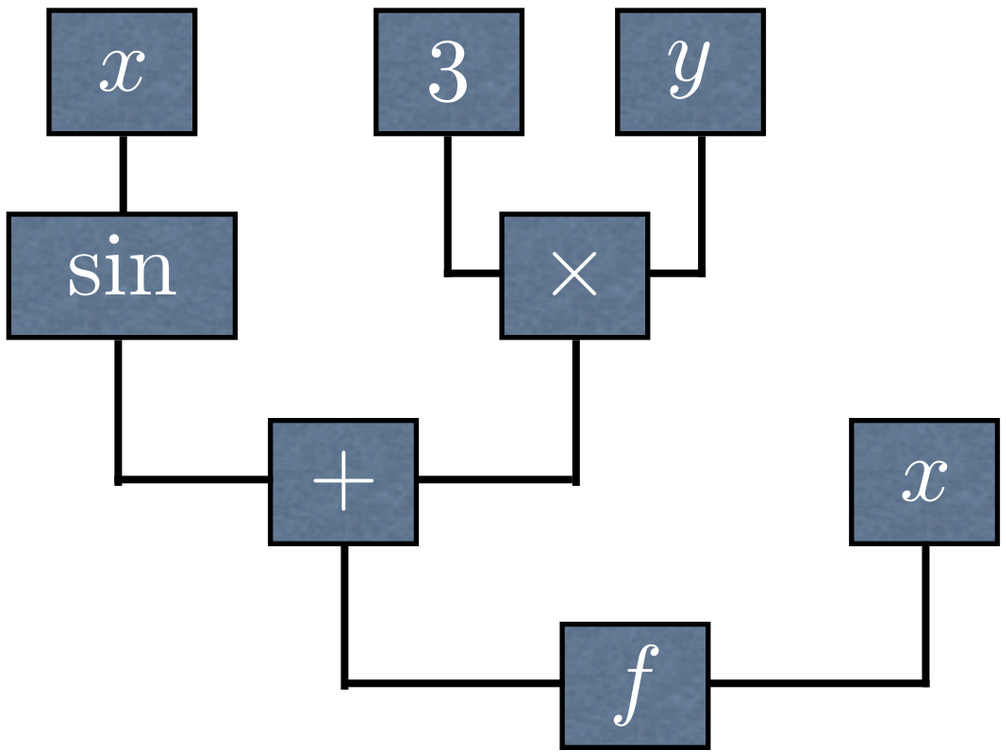
Effortlessly describes interferometric polarimetry

LINEARITY

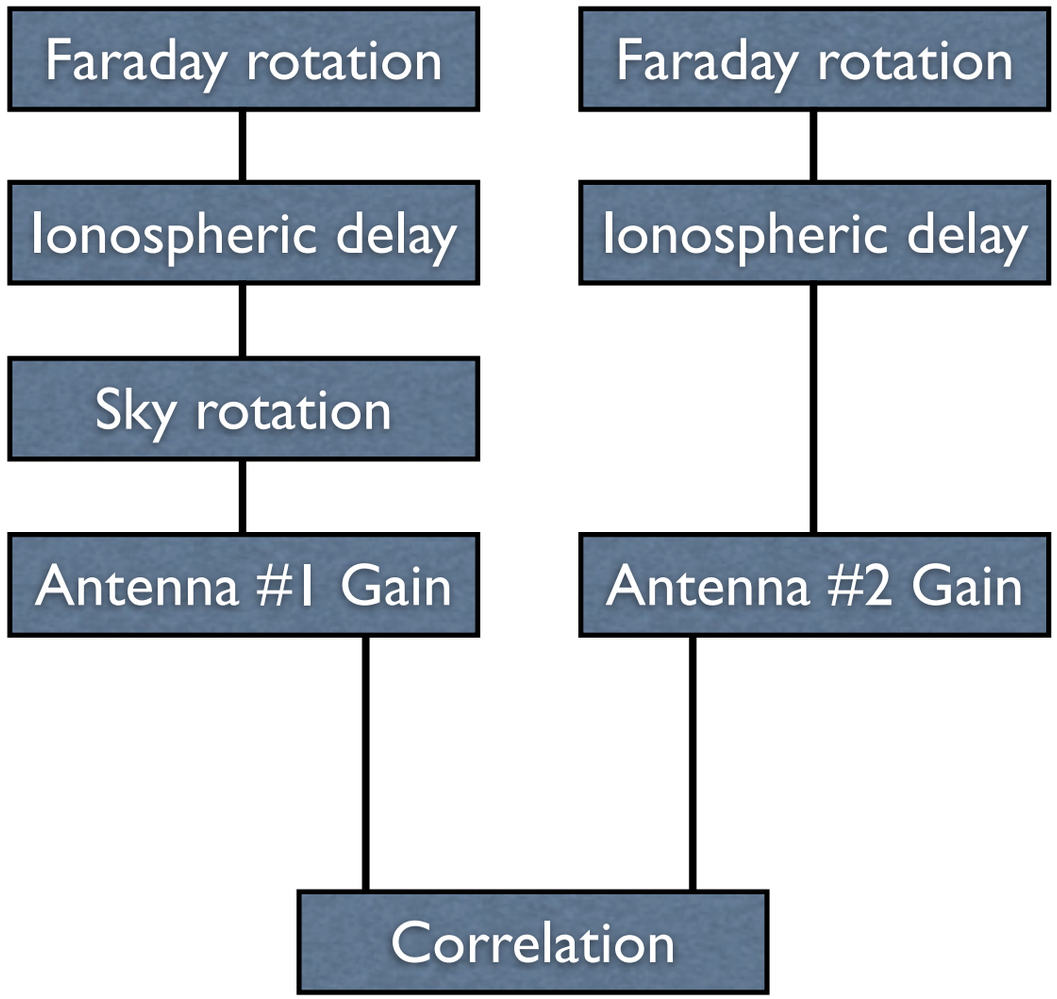
MeqTrees=Meq+Trees

Every mathematical expression is a tree …

$$z = f(x, 3y + \sin x)$$

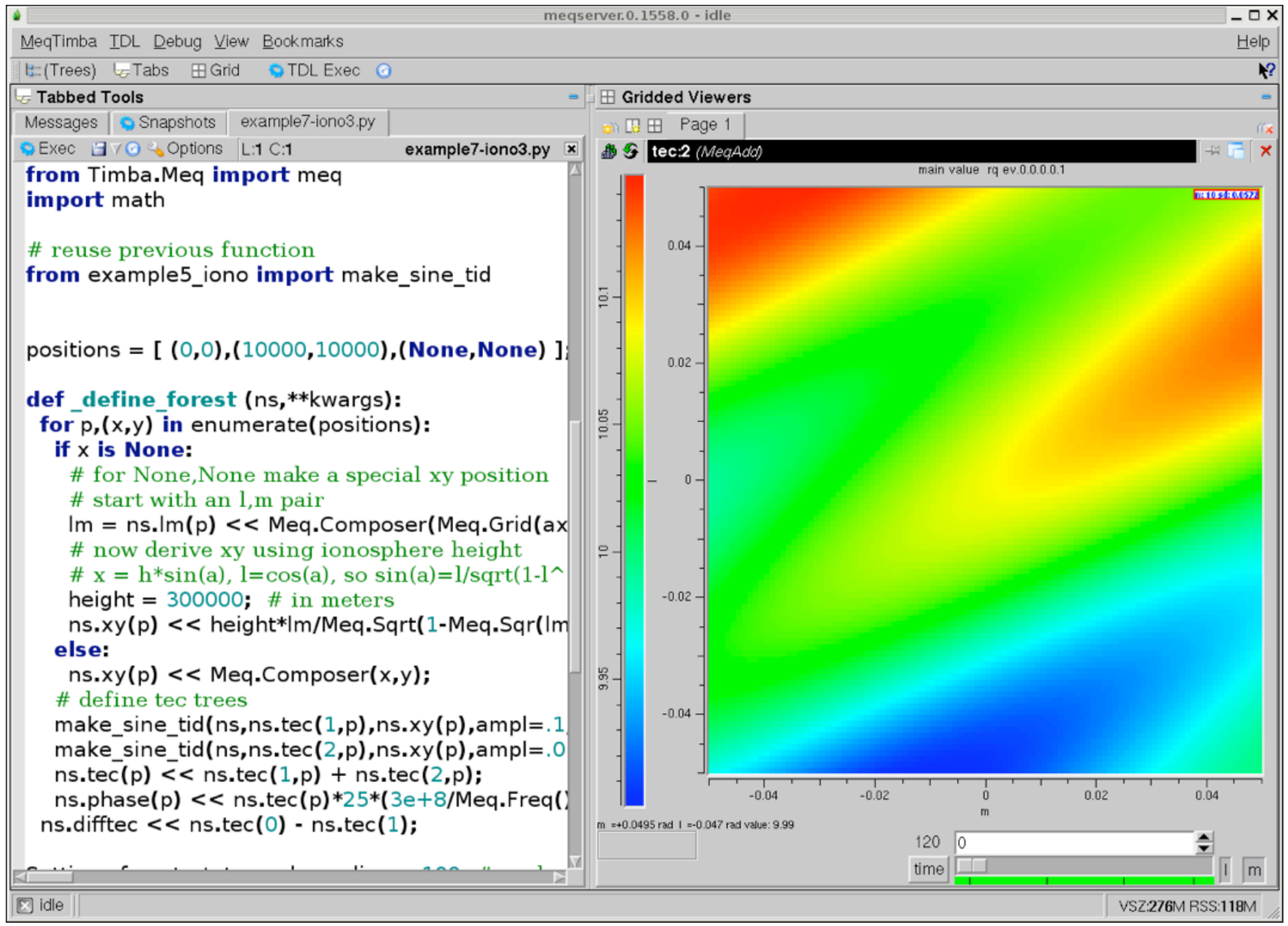


… So is the Measurement Equation



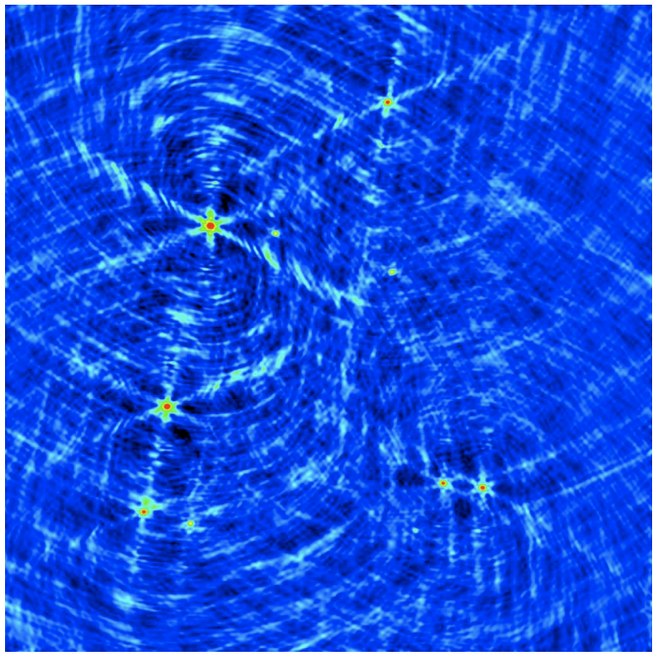
The MeqTrees Software

- Developed @ ASTRON [Smirnov, Noordam] with outside contributions [Willis]
- Primarily designed as calibration suite for LOFAR
- Open source code Linux / UNIX (virtual machine available)
- Code repository for beam shapes, ionospheric models, ...
- Trees are declared by python scripts and executed by a C++ kernel

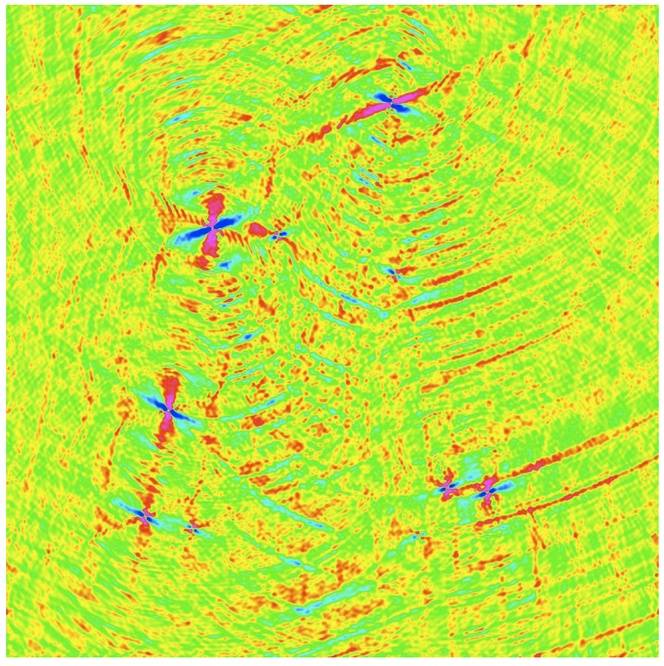


MeqTrees Features

- Powerful calibration : almost any parameter can be solved for
- Fast and smart evaluation on time/frequency grids
- Per-station effects and polarization effortlessly included
- Visual assessment of different models via difference trees



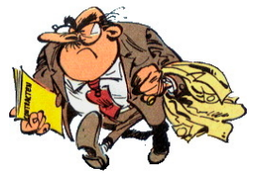
symmetrical vs asymmetrical beam
error level: 2%

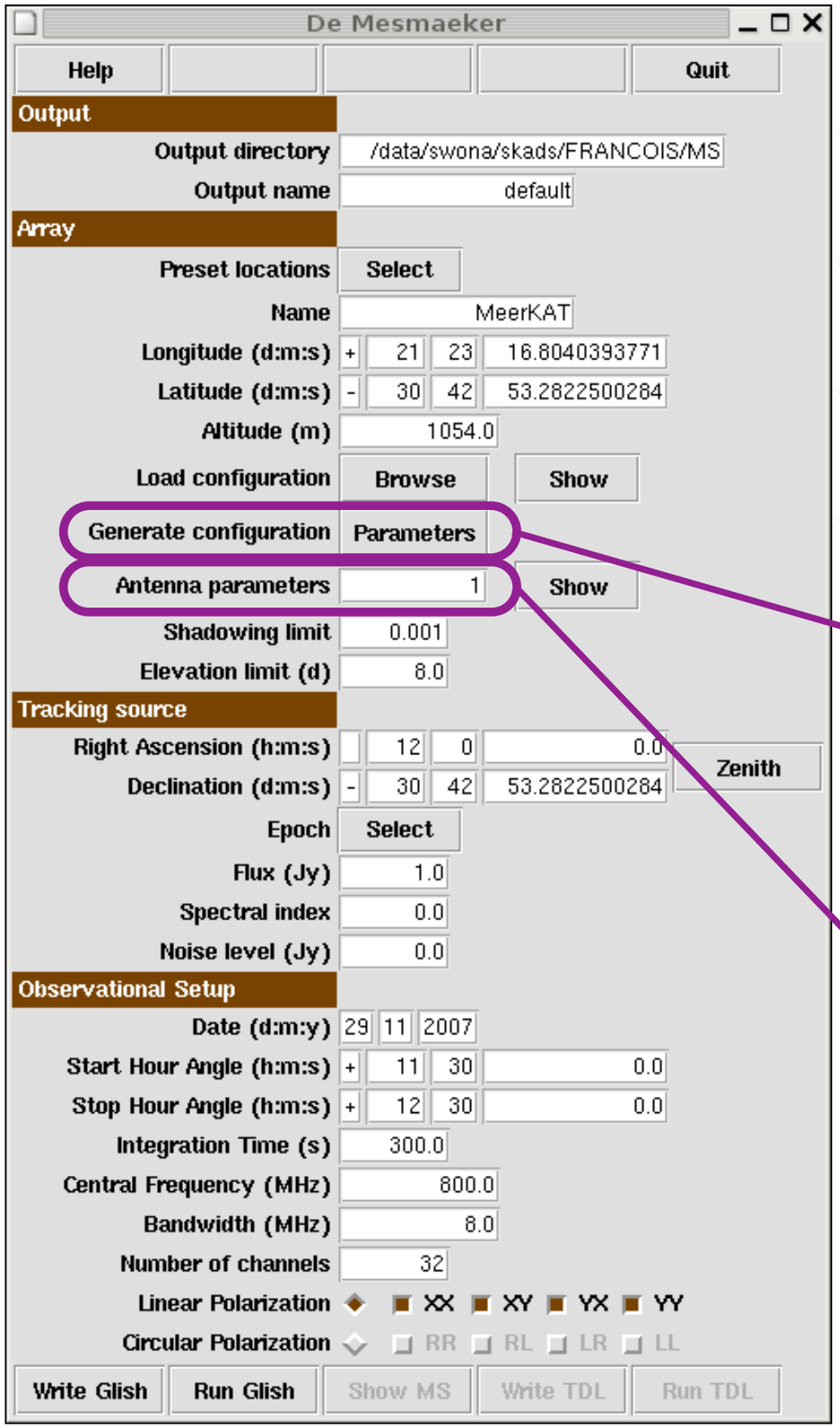


average vs per-station beam
error level: 0.02%

- No decent parallelization yet : limited number of sources and antennae
- Uses Measurement Sets but does not generate them
- Input skies are source lists, not images

Measurement Set Generator (De Mesmaeker)



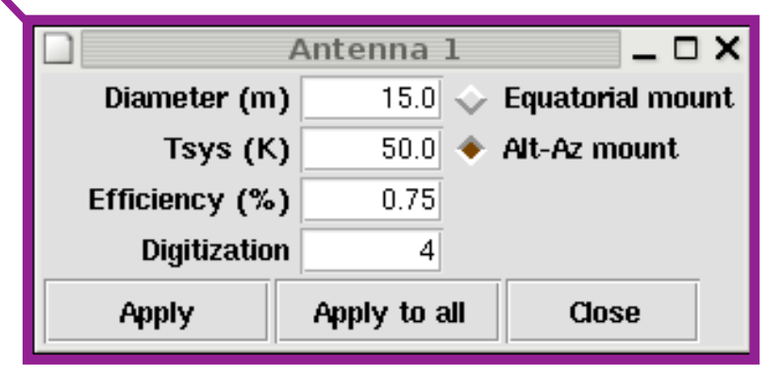


Python interface to a glish script from T. Willis

Uses AIPS++ “newsimulator” task

Uses existing configurations or generates random ones

Builds a skeleton MS to be used by MeqTrees



Conclusions