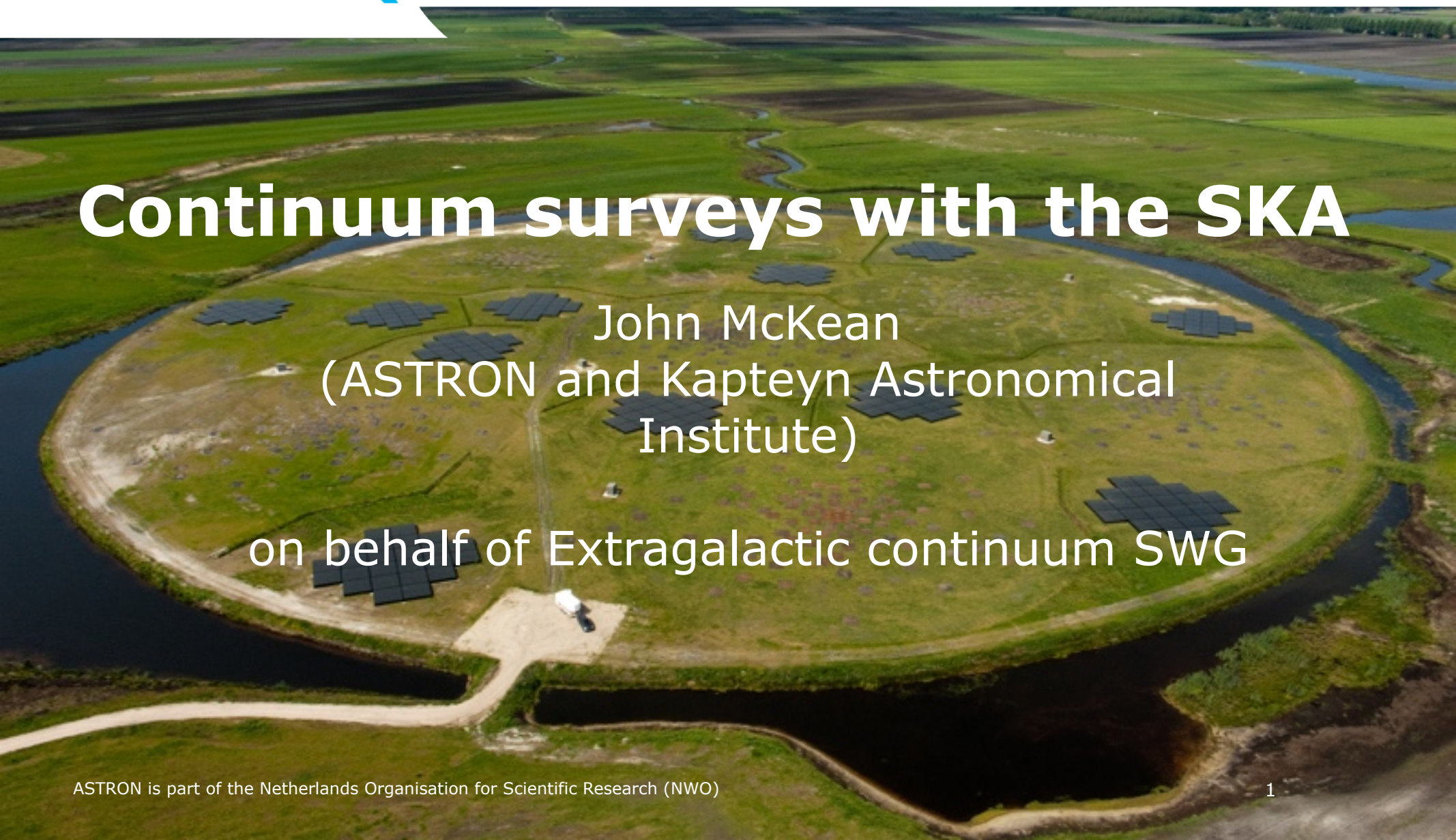
ASTRON

Netherlands Institute for Radio Astronomy



Continuum surveys with the SKA

John McKean
(ASTRON and Kapteyn Astronomical Institute)

on behalf of Extragalactic continuum SWG

Extragalactic continuum SWG

- **AIM:** SWG established to investigate survey strategies and science capabilities of using continuum science (mainly star-forming galaxies and active galaxies).

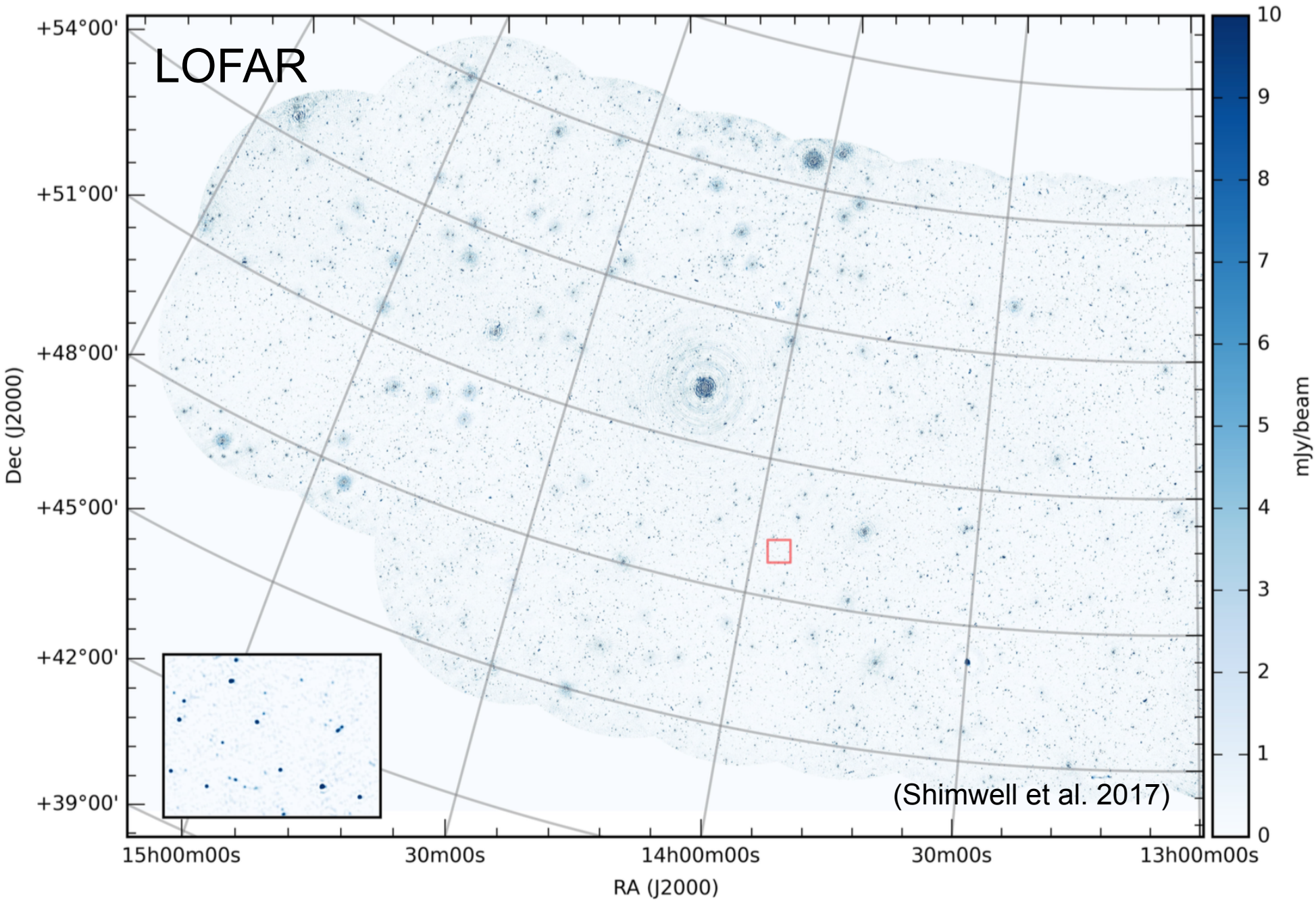
- **OUTLINE:**

    1. Continuum science
    2. Minimum data products (images of sky surface brightness distribution)
    3. Desirable data products (re-processed images)

- **THE TEAM:**

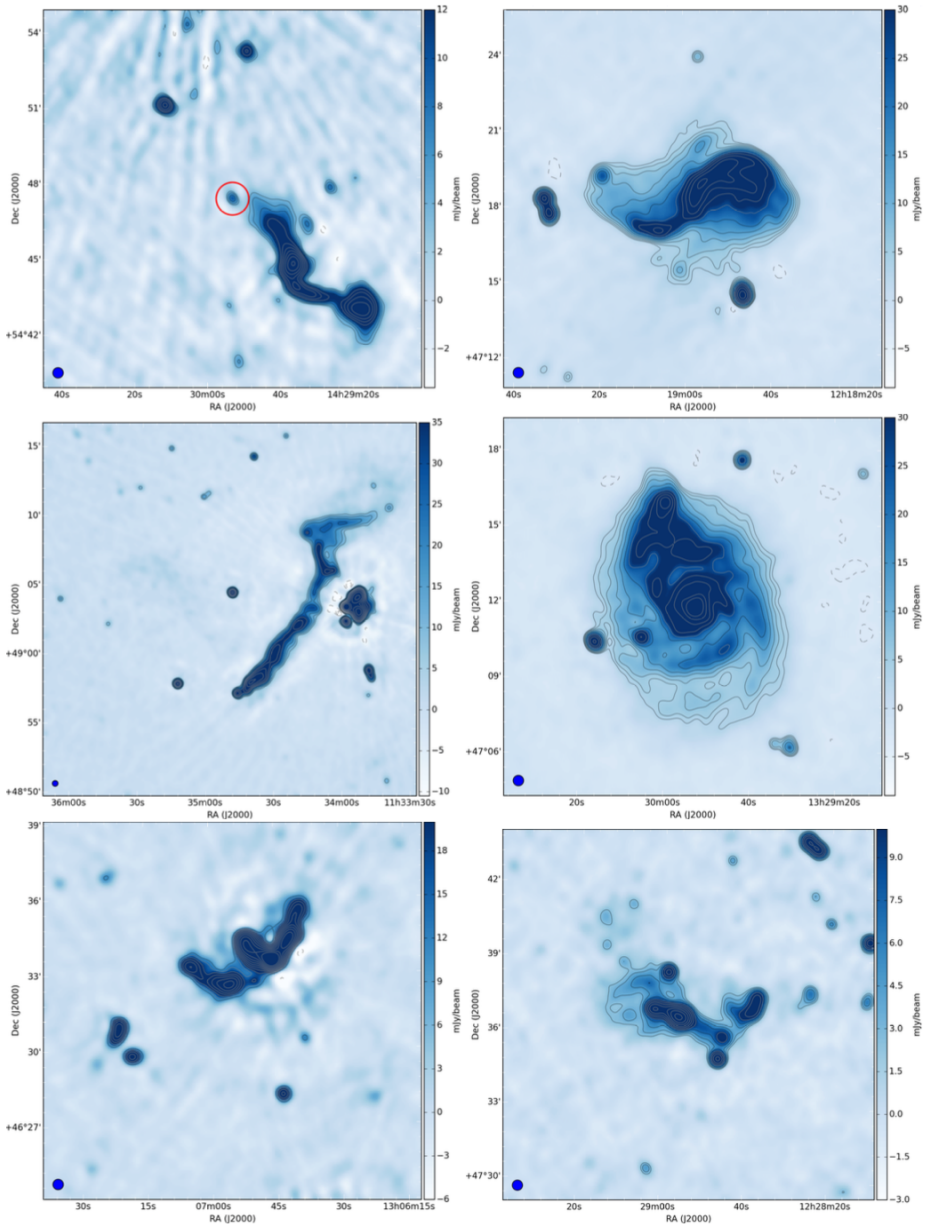
    - **Chairs**: Mark Sargent (Sussex) and Natasha Hurley-Walker (Curtin)
    - **Associate Members**: 100 from 21 countries

Continuum science

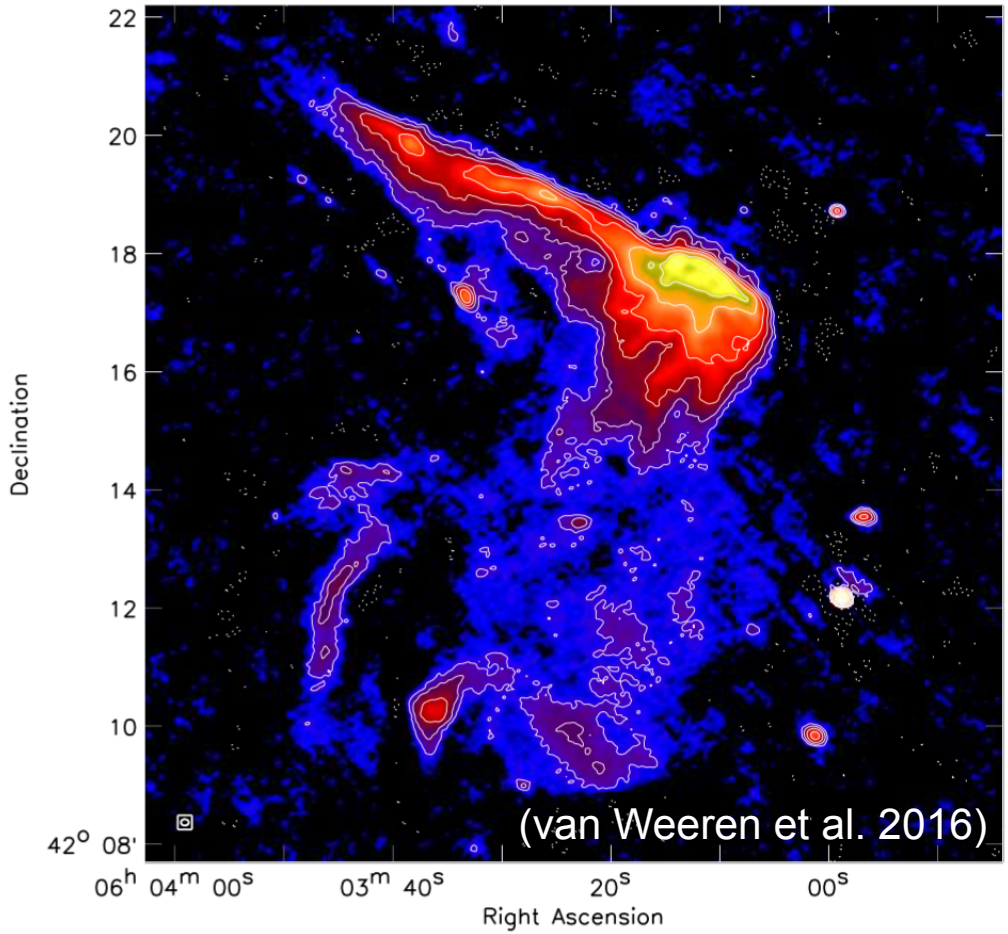


Continuum science

LOFAR



(Shimwell et al. 2017)



Key requirement: Images that describe the surface brightness distribution of the sky as a function of position.

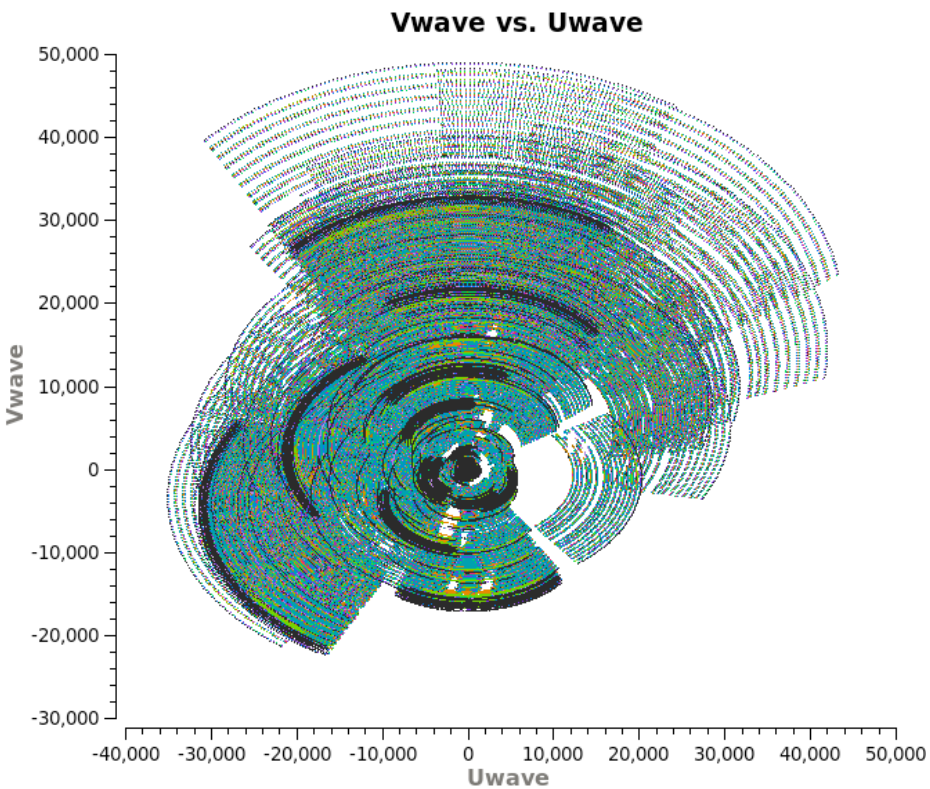
1. Accurate positions
2. Accurate flux-densities

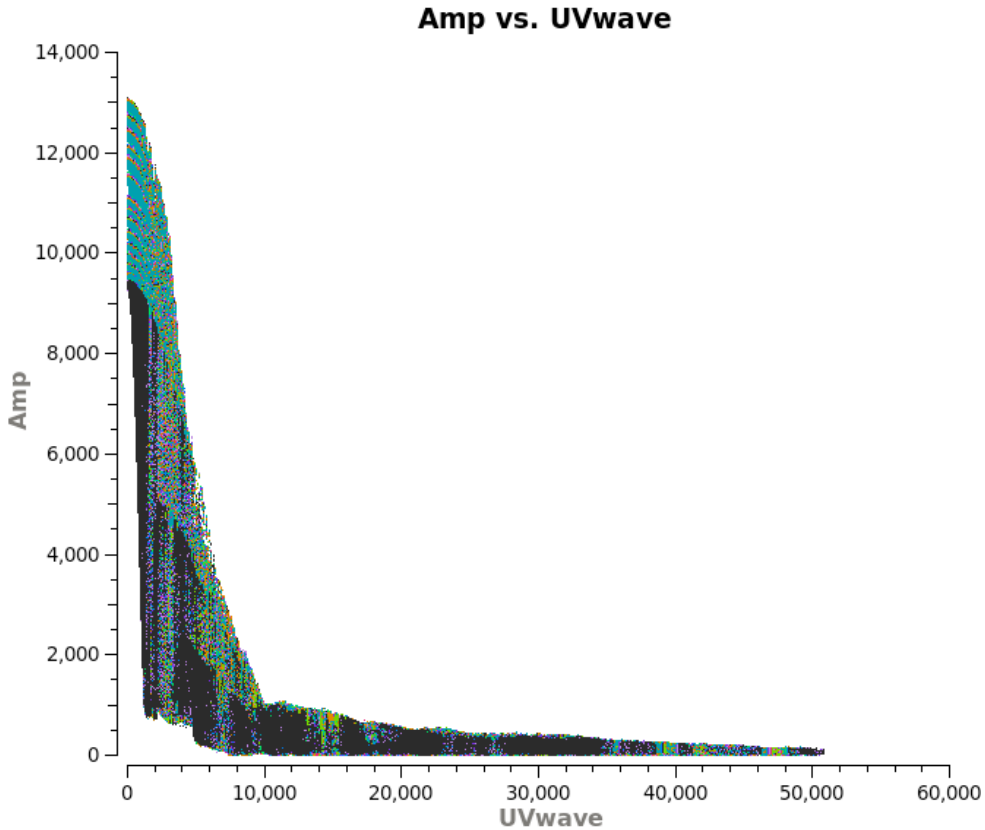
Large spectral bandwidths

The SKA will have a large fraction bandwidth:

1. Good for sensitivity: $\sigma_T \sim (\Delta v)^{-0.5}$
2. Better for image fidelity: good uv-coverage.

Must know the surface brightness distribution as a function of frequency.





Multi-frequency synthesis

We can represent the sky in emission interms of a Taylor expansion about some reference frequency (see Rau & Cornwell 2011).

Build *I(v)* model:

MS model image

Taylor co-efficient images

$$I_\nu^{\mathrm{m}} = \sum_{t=0}^{N_t-1} w_\nu^t I_t^{\mathrm{sky}} \quad \text{where} \quad w_\nu^t = \left(\frac{\nu-\nu_0}{\nu_0}\right)^t$$

A power-law model is used to describe the spectral dependence of the sky emission.

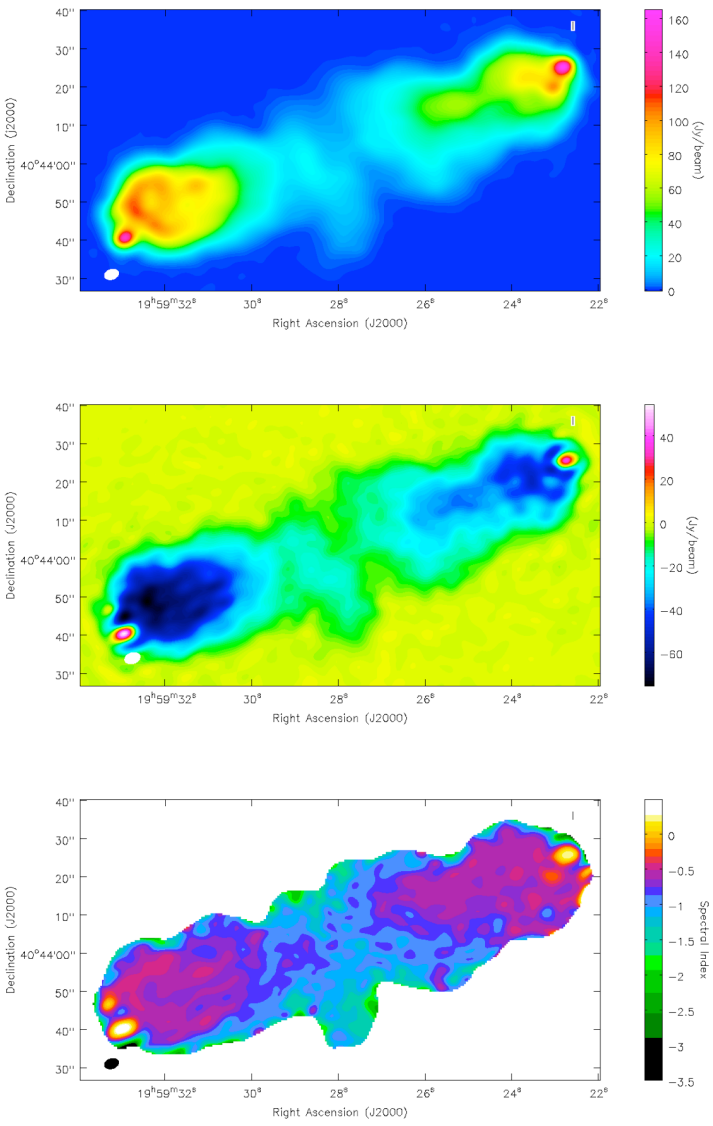
Parameterise:

$$I_\nu^{\mathrm{sky}} = I_{\nu_0}^{\mathrm{sky}} \left(\frac{\nu}{\nu_0}\right)^{I_\alpha^{\mathrm{sky}} + I_\beta^{\mathrm{sky}} \log\left(\frac{\nu}{\nu_0}\right)}$$

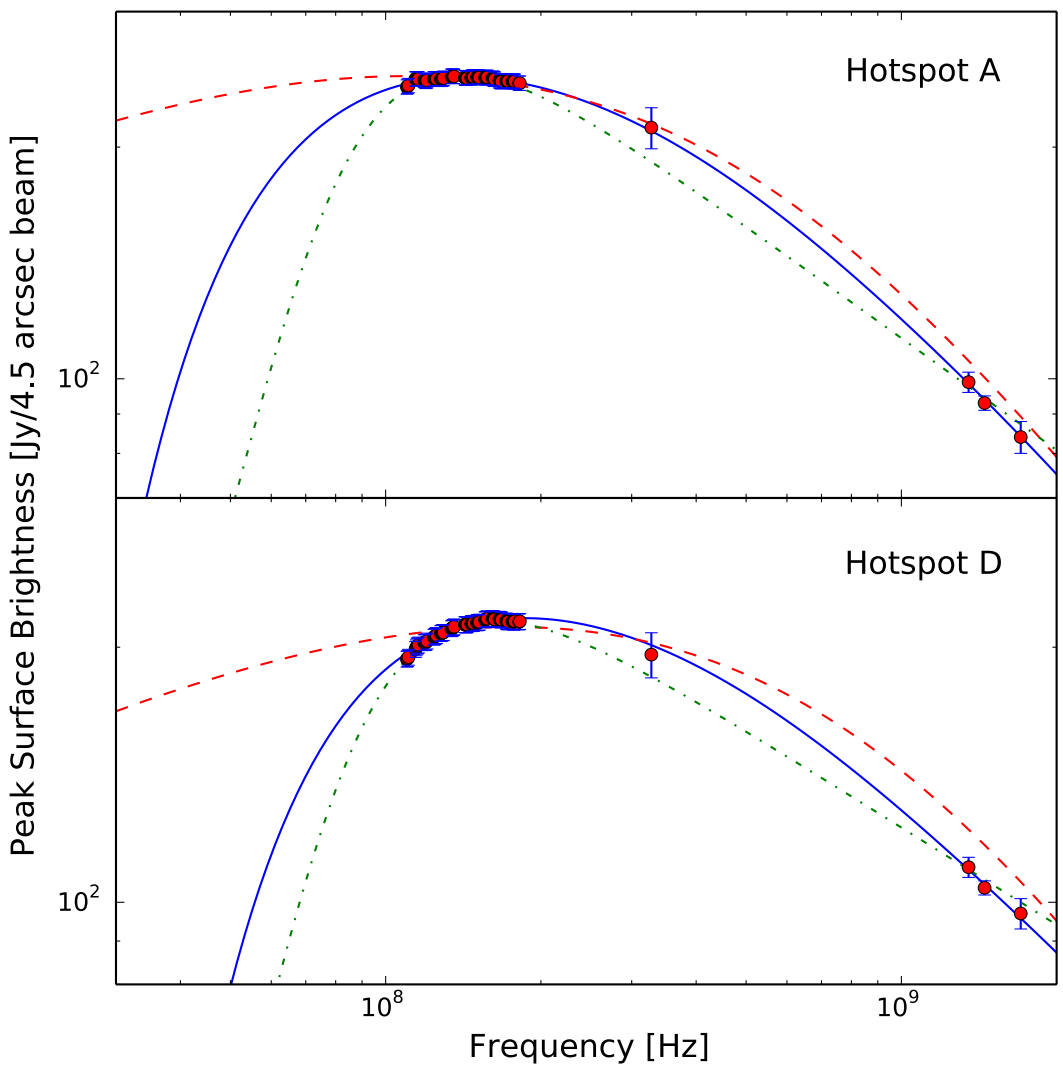
Sky images:

$$I_0^m = I_{\nu_0}^{\mathrm{sky}} \;;\; I_1^m = I_\alpha^{\mathrm{sky}} I_{\nu_0}^{\mathrm{sky}} \;;\; I_2^m = \left(\frac{I_\alpha^{\mathrm{sky}}(I_\alpha^{\mathrm{sky}}-1)}{2} + I_\beta^{\mathrm{sky}}\right) I_{\nu_0}^{\mathrm{sky}}$$

Spectral imaging



(McKean et al. 2017)

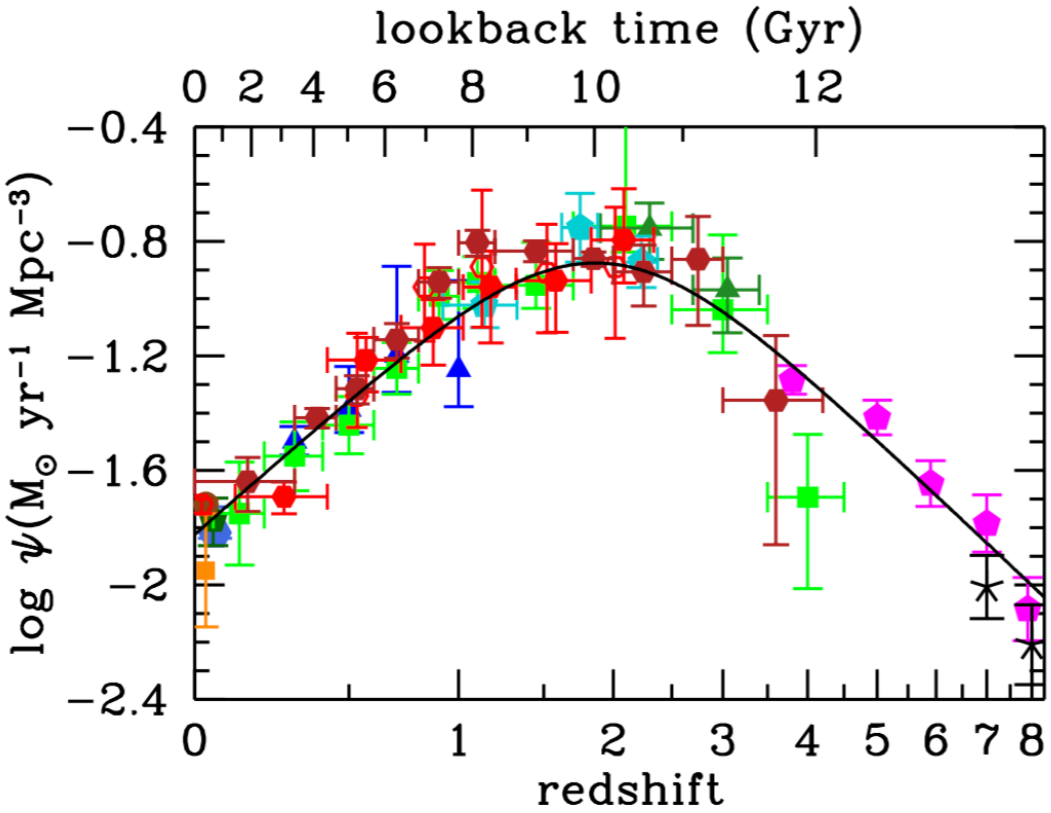


Key requirement: Images that describe the surface brightness distribution of the sky as a function of frequency (coarse).

SKA Continuum survey plans

Main science goal: Study the evolution of star-formation and active galactic nuclei activity across cosmic time.

Methodology: Will be carried out in a tiered survey approach from wide-shallow to narrow-deep.



General user: Continuum science will be the basic observing mode for the SKA and will have extensive general user appeal, requiring additional observations with different field of view and frequency requirements.

SKA Continuum survey plans

Survey Parameter	Tier 1	Tier 2	Tier 3
Area	1000	3-10	1
Sensitivity (μJy / beam)	1	0.2	0.05
Total time (h)	17200	12900	6560
Time per pointing (h)	8.2	205	3278
Pointing	2097	63	2
Frequency (GHz)	0.95-1.67	0.95-1.67	0.95-1.67
Time resolution (s)	0.13	0.13	0.13
Frequency resolution (kHz)	12.4	12.4	12.4
Taylor Terms	2	2	2
Polaisations	1	1	1
Field of view (deg)	0.70	0.70	0.70
Max baselines (km)	150	150	150
Pixel size (arcsec)	0.1 (25k x 25 k)	0.1 (25k x 25 k)	0.1 (25k x 25 k)

Survey Parameter	Tier 1	Tier 2
Area	1	0.04
Sensitivity (μJy / beam)	0.3	0.04
Total time (h)	1520	3300
Time per pointing (h)	11.8	662
Pointing	130	5
Frequency (GHz)	8.3-13.2	8.3-13.3
Time resolution (s)	0.2	0.2
Frequency resolution (kHz)	157.4	157.4
Taylor Terms	2	2
Polaisations	1	1
Field of view (deg)	0.088	0.088
Max baselines (km)	150	150
Pixel size (arcsec)	0.013 (25k x 25 k)	0.013 (25k x 25 k)

Images and catalogues

Example of possible continuum imaging data products from the FIRST survey.

sundog.stsci.edu

apple astro banks blogs e-prints movies music news travel observatories universities JBF2 JBF-SDSS lofar

Home | What's New | Description | Status | Publications | Cutouts | Search | Images | Catalogs

FIRST Catalog Search

RA and Dec: 22 14 33.131 -00 16 17.34 Equinox: J2000 or RA/Dec File: Choose File no file selected
Search Radius: 30 arcsec
Additional Constraints:
Output Format: HTML Text
Search the Catalog Reset Form Help

Search Results

```
Searching for first_cat sources within 30.0000 arcsec of
22 14 33.131 -00 16 17.34 (J2000)

Map RMS at search position is 0.104 mJy/beam
Catalog detection limit (including CLEAN bias) at source position is 0.77 mJy/beam

1 sources found within 30.0000 arcsec
```

FIRST Catalog Database (2014dec17)

Do NED	Get Opt SrchImg	Get FRST Img	Search Distance (arcsec)	RA (2000)	Dec (2000)	Side lobe Prob	Peak Flux (mJy/bm)	Int. Flux (mJy)	RMS (mJy/ beam)	Deconv. MajAx (arcsec)	Deconv. MinAx (arcsec)	Deconv PosAng (deg)	Meas. MajAx (arcsec)	Meas. MinAx (arcsec)	Meas. PosAng (degrees)	Field Name	SDSS Mtch <8"	Closest SDSS Sep(")	i (mag)	SD Cl	2MAS Mtch <8"	Closest 2MASS Sep(")	K (mag)	Mean Epoch (year)	Mean Epoch (MJD)	RMS Epoch (MJD)
NED	OPT	FIMG	0.7	22 14 33.089	-00 16 17.74	0.014	11.97	12.81	0.104	1.95	0.99	49.2	6.58	5.62	6.9	22135-00130Z	1	1.00	20.88	g	0	99.00	99.00	1998.840	2451121.0	1221.447

Description of the table

See the catalog description and the catalog paper for detailed information on the creation of the catalog and its interpretation. Use the IAU source naming convention to refer to FIRST sources in publications. Here is a brief summary of the search result table:

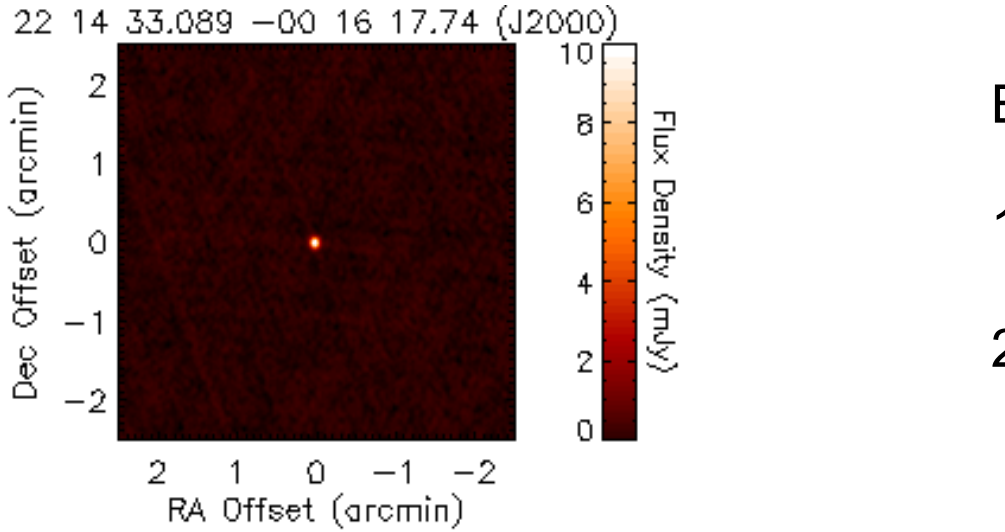
Column	Description
NED	Search NASA/IPAC Extragalactic Database at this position.
OPT	Extract 3x3 arcmin optical images from the STScI Digitized Sky Survey and the Sloan Digital Sky Survey. The images are shown in the browser, with a form that can be used to change the region size if desired.
FIMG	Extract 5x5 arcmin cutout from the original FIRST image at this position. See the cutout help for more information.
Search Distance	Distance from search position to source (arcsec).
RA, Dec	J2000 coordinates.
Sidelobe Probability	Probability that this catalog entry is a sidelobe of a nearby bright source. Low values mean the source is unlikely to be spurious.
Peak Flux, Int. Flux	Peak flux density (mJy/beam) and integrated flux density (mJy) for source.
RMS	RMS noise in map (mJy/beam).
Deconv. MajAx, MinAx, PosAng	Source major axis (FWHM arcsec), minor axis, and position angle of major axis (degrees) after deconvolving synthesized beam.
Meas. MajAx, MinAx, PosAng	Source major axis (FWHM arcsec), minor axis, and position angle of major axis (degrees) measured directly from map (before deconvolving synthesized beam.)
Field Name	Name of coadded image containing this source.
SDSS match info	The next 4 columns give information on matches from the Sloan Digital Sky Survey DR10 catalog. *SDSS Mtch* is the number of SDSS sources within 8" of the FIRST position (-1 means the position is outside the DR10 area so no SDSS data are available.) Information on the closest match are given in the columns *Closest SDSS Sep* (distance in arcsec), *SDSS i* (*i* magnitude), and *SD Cl* (morphological classification, 's' is star = SDSS type 6, 'g' is galaxy). If *Closest SDSS Sep* is 99.00, that means that there is no SDSS source within 8 arcsec of the FIRST position and the distance to the nearest SDSS object is unknown.
2MASS match info	The next 3 columns give information on matches from the 2MASS infrared catalog. *2MAS Mtch* is the number of 2MASS sources within 8" of the FIRST position. Information on the closest match are given in the columns *Closest 2MASS Sep* (distance in arcsec) and *2MASS K* (*K* magnitude). If *Closest 2MASS Sep* is 99.00, that means that there is no 2MASS source within 8 arcsec of the FIRST position and the distance to the nearest 2MASS object is unknown.
Observation epoch info	The final 3 columns give information on the mean epoch of observation for the FIRST catalog entry. FIRST catalog entries are derived from coadded images that including multiple pointings. See the catalog description for more information. *Mean Epoch (year)* is the weighted mean epoch of all the contributing pointings at the position of the source. *Mean Epoch (MJD)* is the same weighted mean epoch expressed as Modified Julian Date rather than years. *RMS Epoch (MJD)* is the weighted rms of the pointing epochs at the source position. It is a measure of the spread in epochs that contribute to the measurement and ranges from minutes to years depending on the source position.

When multiple sources (specified in a file) are matched against the catalog, positions that do not match any FIRST source are listed at the end of the source list, giving the search position and the FIRST rms noise level at that position. Rms values less than zero indicate positions outside the FIRST survey area. Rms values flagged with an asterisk (*) indicate that the position is near the edge of the FIRST survey area.

We welcome suggestions for improvements or additions to the FIRST search facility.

FIRST Home | What's New | Description | Status | Publications | Image Cutouts | Catalog Search | Images | Catalogs

Images and catalogues



Example from FIRST survey.

1. Quick look (jpg, png) to see the structure.
2. Downloadable FITS images for analysis.

Image server required so that the imaging data can be inspected:

1. Reliability: Has a real object been found (calibration or deconvolution error)?
2. Significance: Has the object of interest been detected at low significance and not identified in automated detection algorithms (<6.5σ)?
3. Multi-wavelength: How does the object compare with other wavebands?

Key requirement: VO catalogues specifying the source properties (position, flux-density, size, etc.) and downloadable science analysis (FITS?) images.

Calibration issues

Imaging wide-fields is useful for,

1) Efficient all-sky survey
2) Looking for rare objects

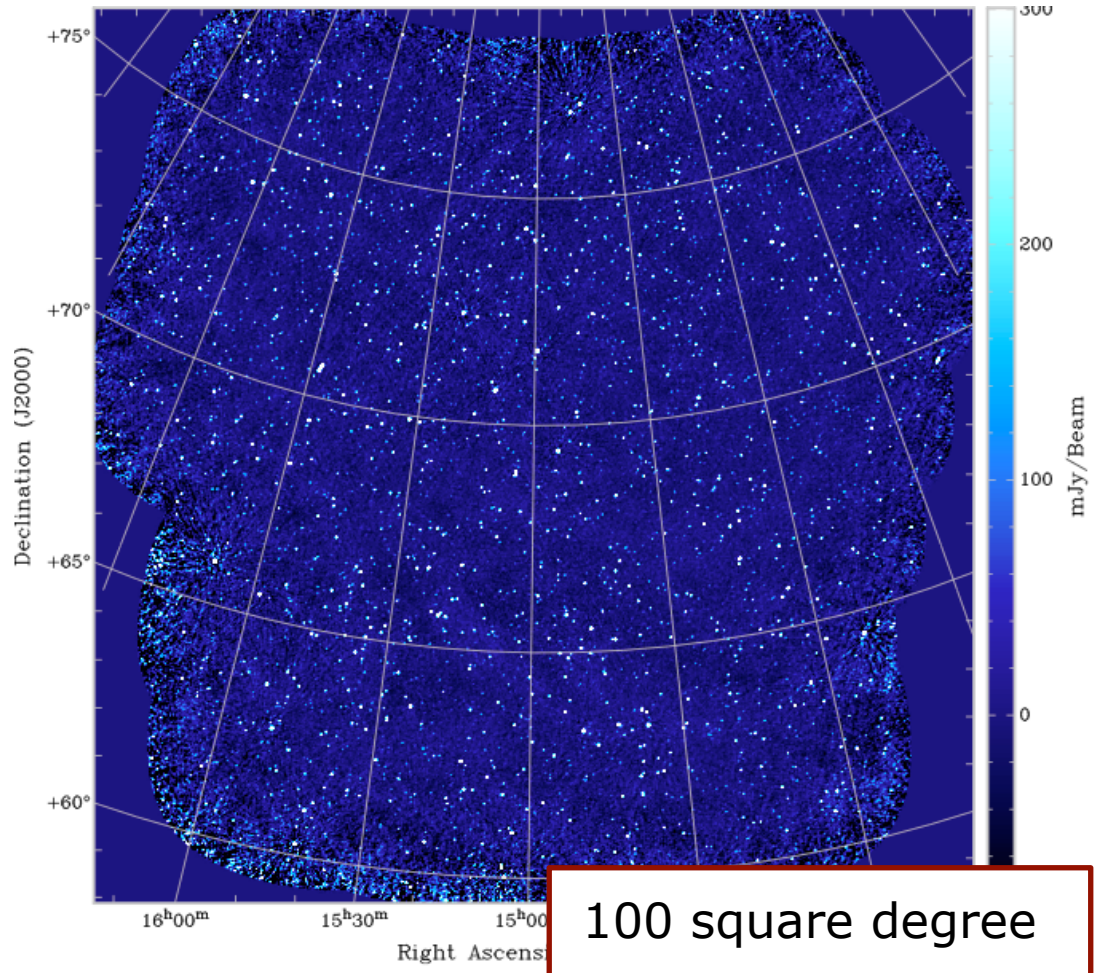
Wide-fields introduce many issues for a good calibration,

1) Variable beam power as a function of position results in a more complicated amplitude calibration.
2) The phase solutions in one direction cannot be applied to another.
3) Sky model is complicated (many sources).

An error in your model can be absorbed in the calibration

$$\vec{V}_{ij} = J_{ij}\vec{V}_{ij}^{\mathrm{IDEAL}}$$

LOFAR MSSS SVF (Heald et al. 2015)

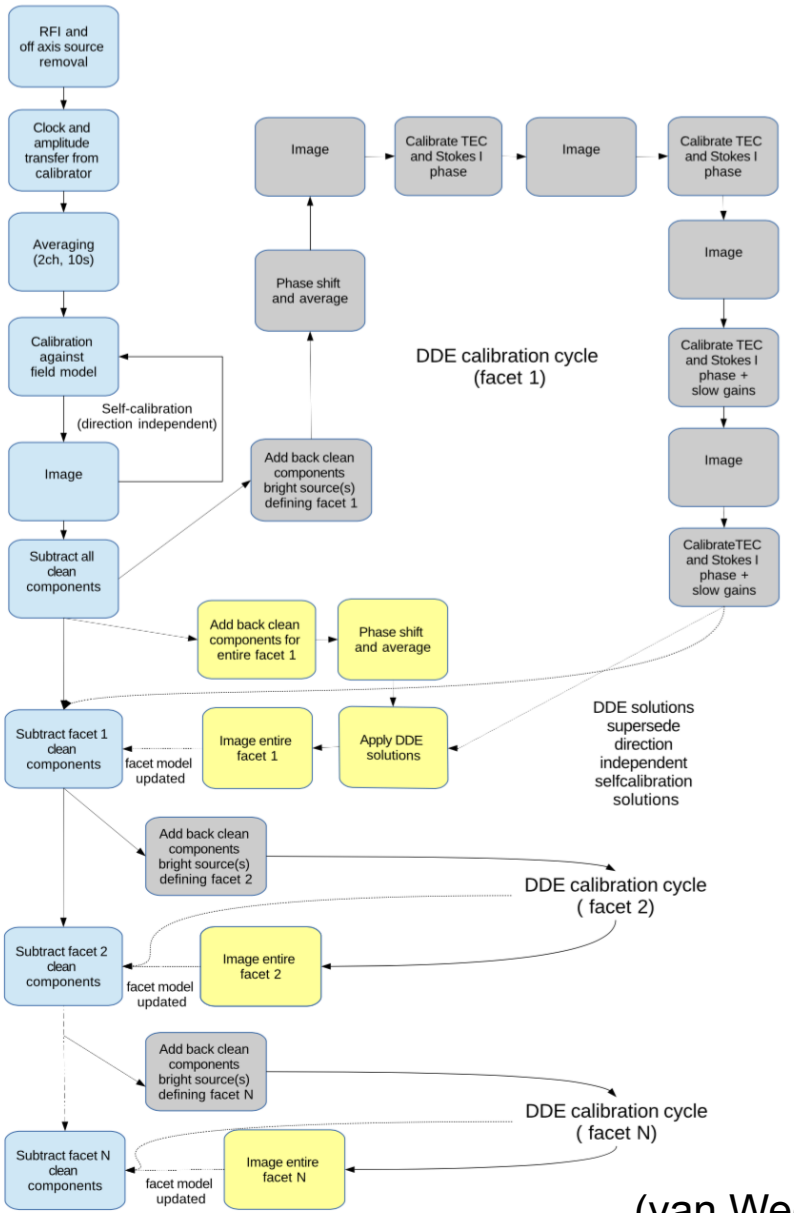


100 square degree

~10 mJy /beam [2 arcmin resolution]

Calibration issues

Sophisticated calibration schemes being developed for LOFAR, MeerKAT, ASKAP.



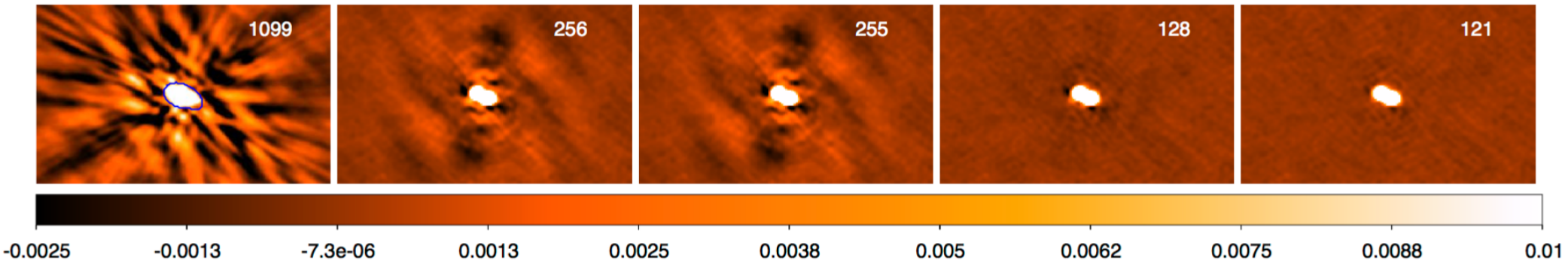
Basic calibration processes within the SDP.

1. RFI mitigation and flagging (AOflagger)
2. Direction independent calibration (GSM?)
3. Direction dependent effects calibration (facet based or all-in-one?)
4. Deconvolution (MS, MFS, compressed sensing?) — dependent on science goal (HI, magnetism, continuum-diffuse, continuum-compact).

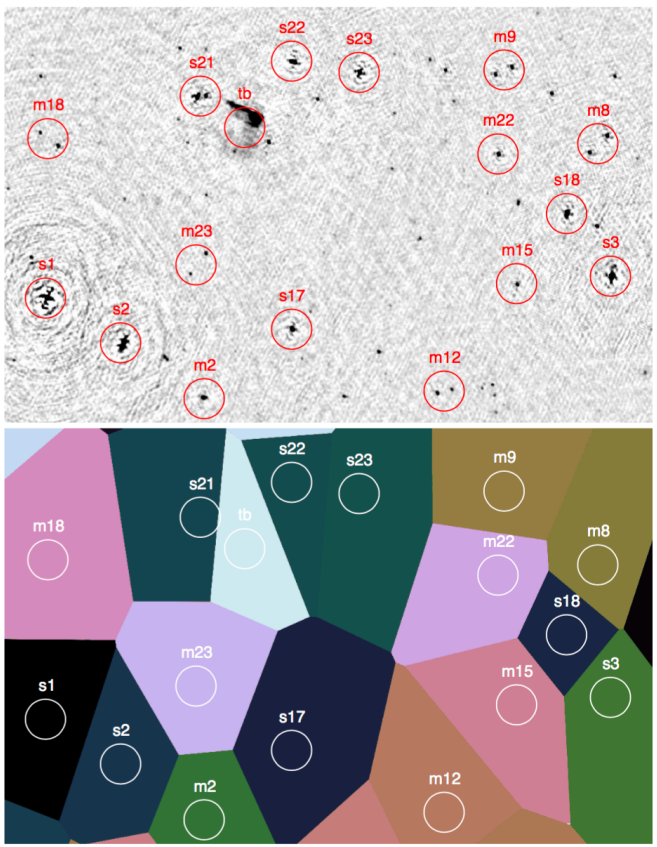
(van Weeren et al. 2016)

Calibration issues

Sophisticated calibration schemes being developed for LOFAR, MeerKAT, ASKAP.



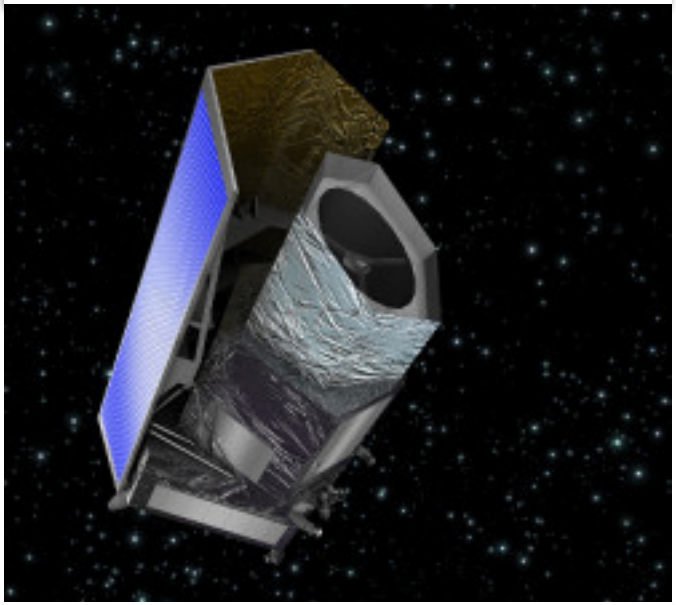
(van Weeren et al. 2016)



Key requirement: The visibility data (gridded) must be kept for calibration (especially at low frequencies).

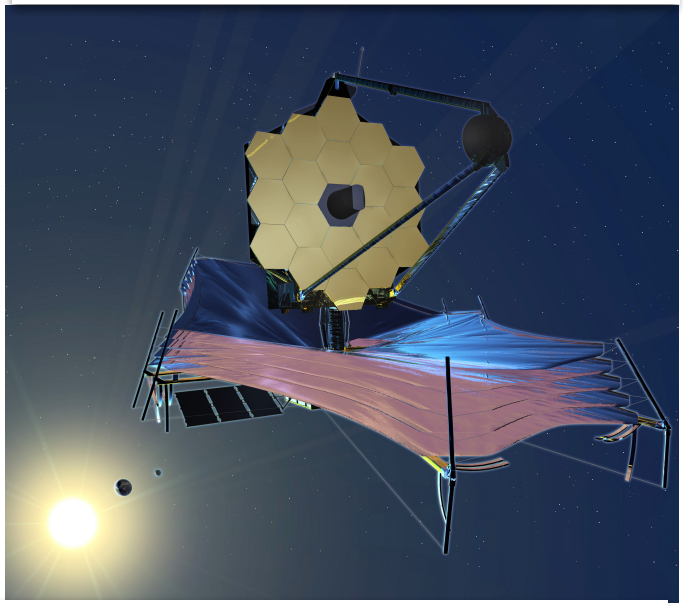
Multi-wavelength synergies

Euclid



- VIS-NIR (0.55–2 μm)
- Stellar emission
- Photometry (1.5 x 10^9 galaxies)
- Spectroscopy (2 x 10^7 galaxies)
- Resolution 0.2–0.6 arcsec.
- Wide-field (15000 deg^2)
- Narrow-field (2 x >10 deg^2)
- Launch 2020

JWST



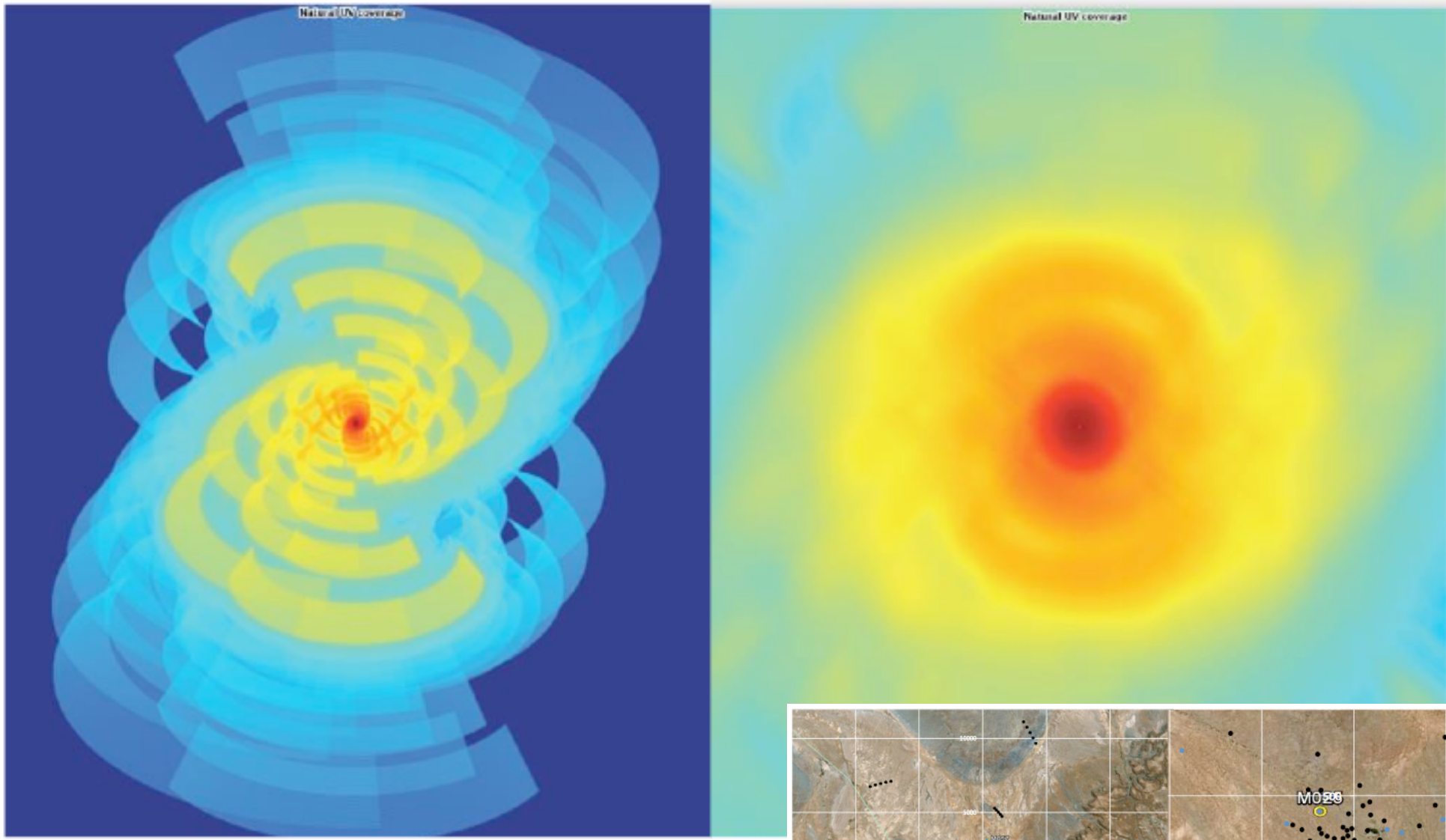
- VIS-MIR (0.6–28.5 μm)
- 6.5 m mirror
- Stellar and hot dust emission
- Targeted photometry
- Targeted spectroscopy
- Resolution 0.1–5 arcsec
- Narrow-field (5-9 $arcmin^2$)
- Launch 2018

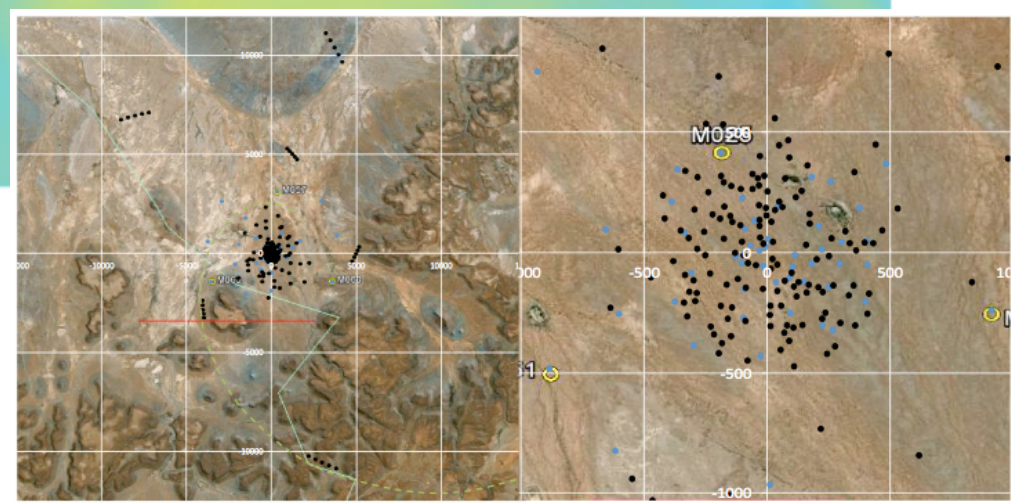
ALMA

- mm-sub-mm (85—1000 GHz
- 54 x 12 m and 12 x 7 m dishes
- Heat dust and molecular gas emission.
- Follow-up photometry and spectroscopy
- Resolution 0.01–19 arcsec
- Narrow-field (0.1 $arcmin^2$)
- Operational!

All a big step forward in resolution (and sensitivity) from e.g. SDSS, HST+Spitzer, SMA+PdB

Re-processing to higher angular resolution (SRC)

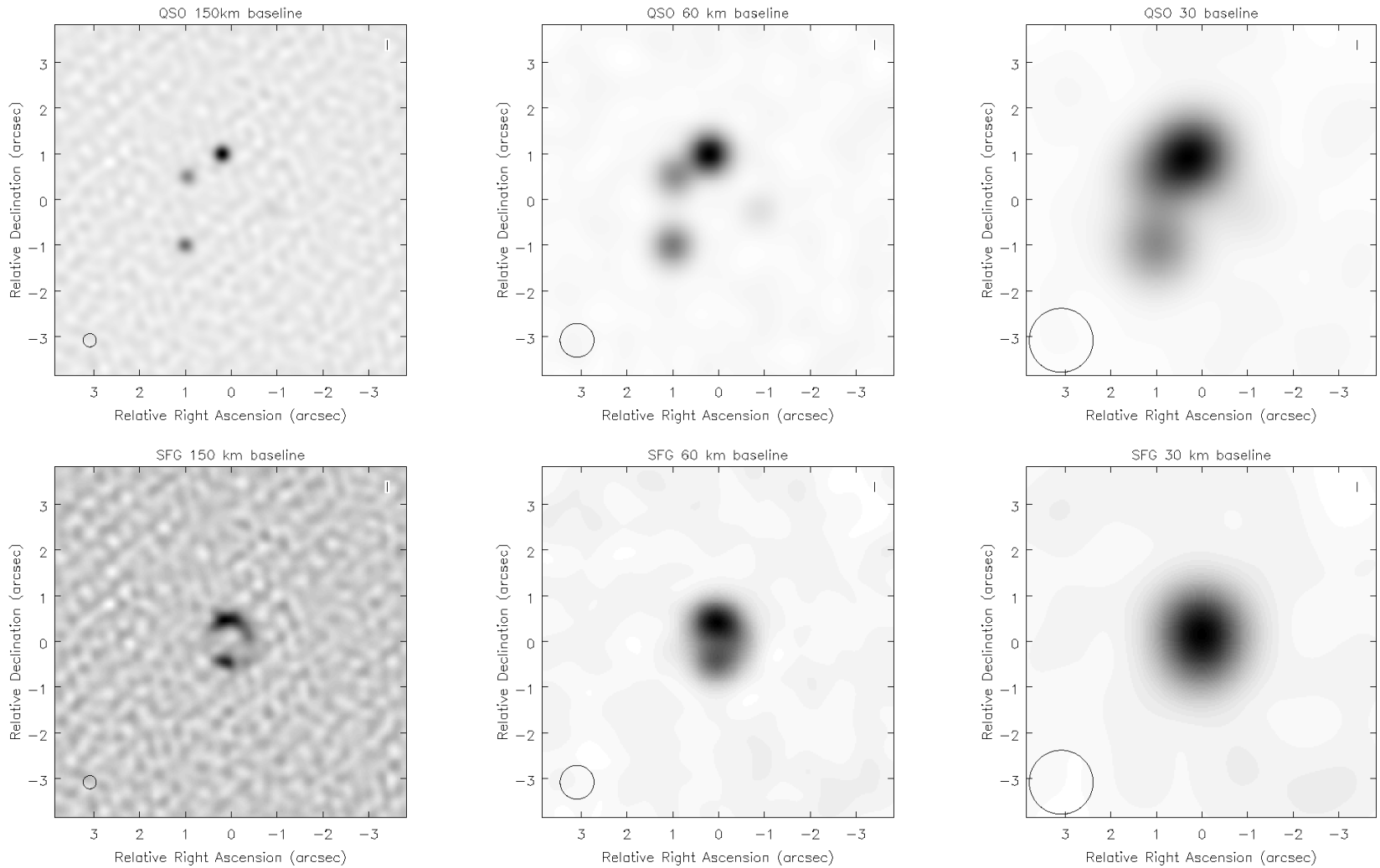




Imaging performance / requirements can be flexible, depending on how the uv-data are used.

Re-processing to higher angular resolution (SRC)

Example of a gravitational lens observed with different visibility weightings.



(McKean et al. 2015)

Desirable requirement: The visibility data (gridded) must be kept and be re-processed for different uv-coverage requirements.

Data products accessed at SRC

Data Product	Description (For each product a QA and Processing Log will also be maintained)
Image Products 1: Image Cubes	1. Imaging data for Continuum, as cleaned restored Taylor term images (n.b. no image products for Slow Transients detection have been specified maps are made, searched and discarded) 2. Residual image (i.e. residuals after applying clean) in continuum 3. Clean component image (or a table, which could be smaller). 4. Spectral line cube after continuum subtracted 5. Residual spectral line image (i.e. residuals after clean applied) 6. Representative Point Spread Function for observations (cutout, small in size compared to the field of view (FoV))
Image Products 2: UV-grids	1. Calibrated visibilities, gridded onto grids at the spatial and frequency resolution required by the experiment. One grid per facet (so this grid is the FFT of the dirty map of each facet). c.f. ECP150007 2. Accumulated Weights for at each uv cell in each grid (without additional weighting applied).
Calibrated Visibilities	Calibrated visibility data (for example for EoR experiments) and direction-dependent calibration information, with time and frequency averaging performed as requested to reduce the data volume.
LSM Catalogue	Catalogue of a subset of the Global Sky Model (GSM) containing the sources relevant for the scheduling block being processed. These are the sources in the FoV, as well as, potentially, strong sources outside of the current FoV. Initially, the LSM is filled from the GSM; during the data processing the sources found in the images are added to the LSM.
Transient Source Catalogue	Time-ordered catalogue of candidate transient objects pertaining to each detection alert from the real-time, so-called, Fast Imaging.

From SKA SDP pipeline design

Summary

1. Continuum observing modes and associated data products will be the work horse of the SKA, with the largest range of science goals and users.
2. The Extragalactic Continuum SWG is designing a 3 / 2 tier survey approach at 2 observing frequencies with the SKA.
3. General User experiments will have different science and therefore technical requirements (but will broadly be consistent with the SWG plans).

Key/desirable requirements:

1. Catalogues specifying the source properties (position, flux-density, size, etc.) and downloadable FITS images.
2. Images that describe the surface brightness distribution of the sky as a function of position.
3. Images that describe the surface brightness distribution of the sky as a function of frequency (coarse).
4. The visibility data (gridded) must be kept for calibration (especially at low frequencies).
5. The visibility data (gridded) must be kept and be re-processed for different uv-coverage requirements.