ASTRON

Netherlands Institute for Radio Astronomy

Extragalactic Continuum (and spectral line) surveys with the SKA

John McKean
(ASTRON and Kapteyn Astronomical Institute)

on behalf of Extragalactic continuum/line 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).

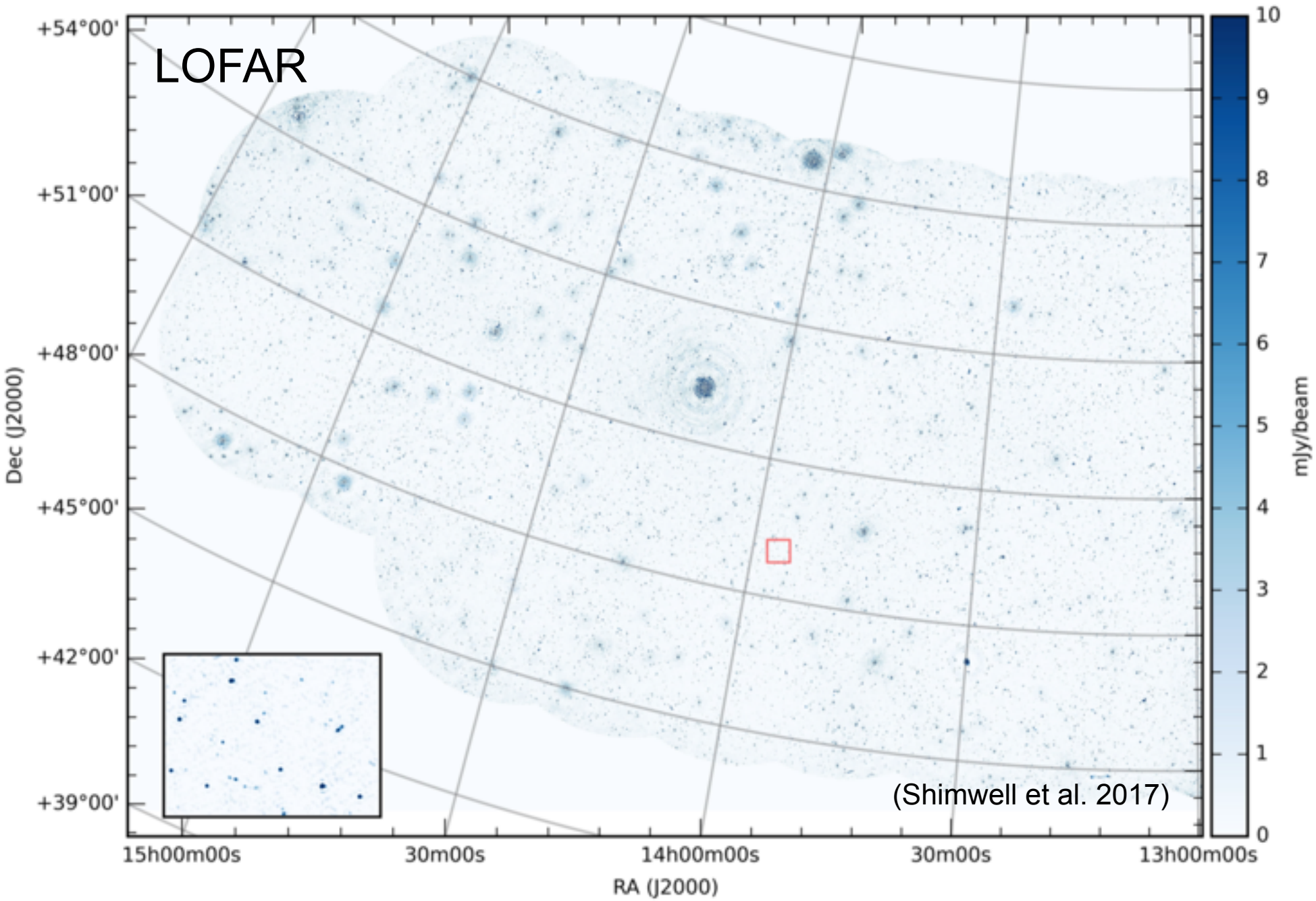
- **OUTLINE:**

1. Continuum science (overview)
2. NL focus / interests (KSP)
3. Issues and concerns

- **THE TEAM:**

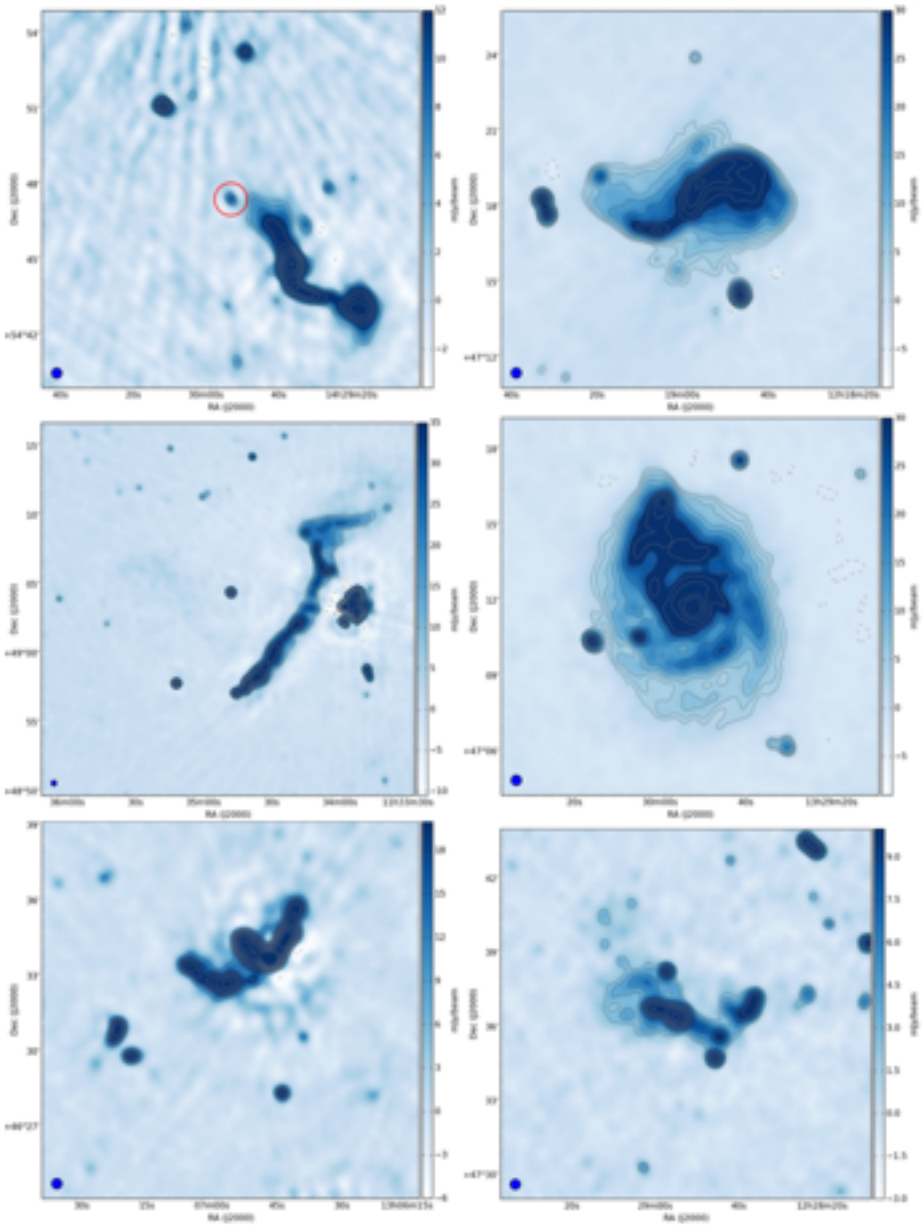
- **Chairs**: Mark Sargent (Sussex) and Natasha Hurley-Walker (Curtin)
- **Associate Members**: 103 from 21 countries
- **NL Team Members:** John McKean (core), Ilse van Bemmel, Jamie Farnes, Huib Intema, Carole Jackson, Tom Oosterloo, Jack Radcliffe, Huub Rottgering, Tim Shimwell, Reinout van Weeren,

Continuum science (low-frequencies)

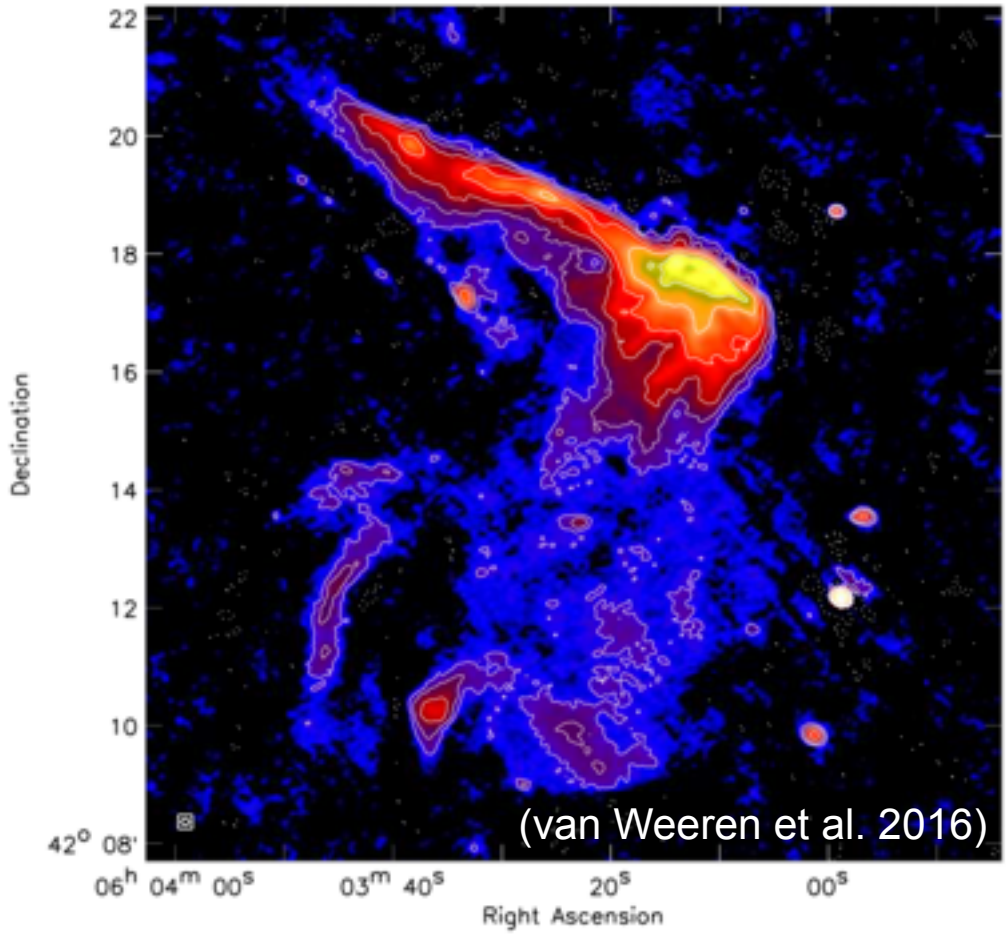


Continuum science (low-frequencies)

LOFAR



(Shimwell et al. 2017)

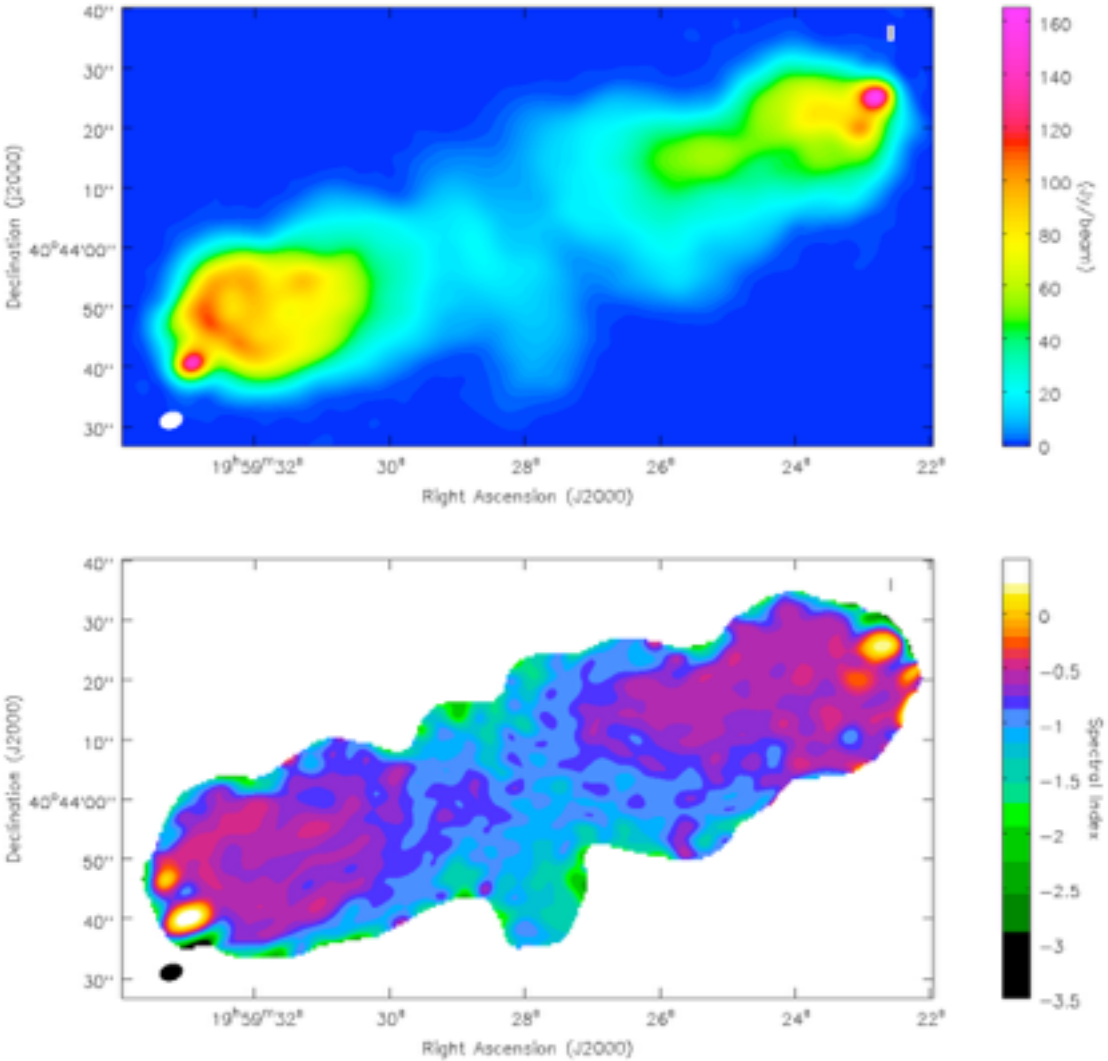


Key science: Testing particle acceleration in the largest colliders.

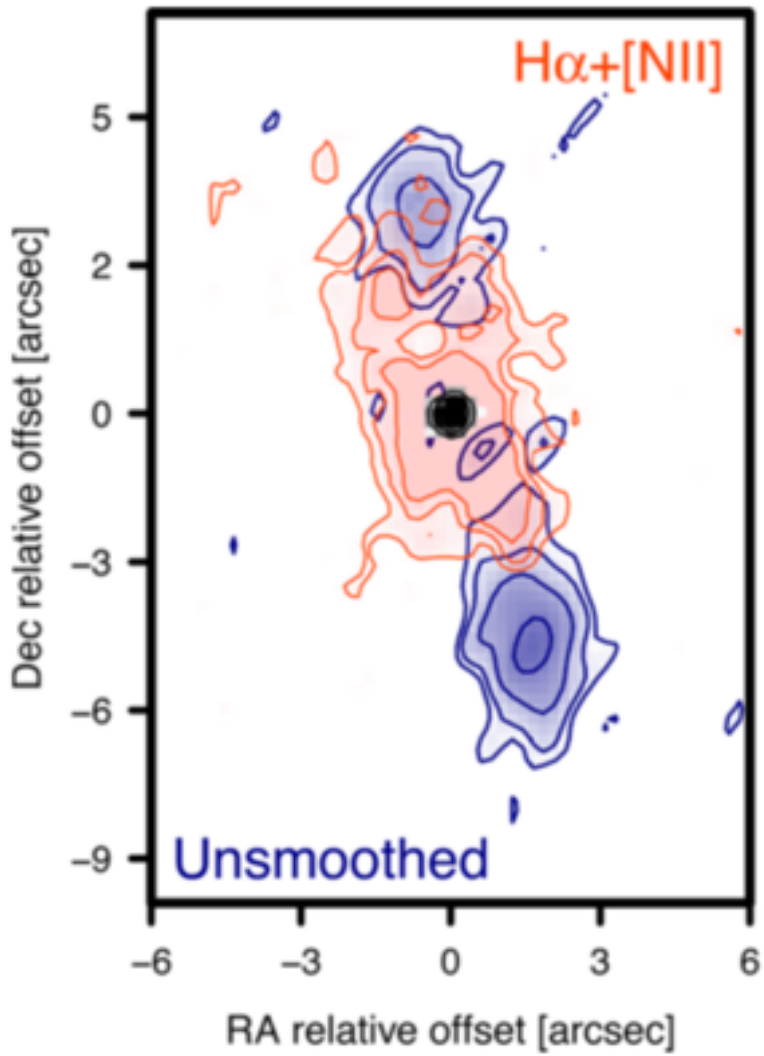
Key lesson: Calibration needs the raw visibilities.

Continuum science (low-frequencies)

(McKean et al. 2017)



(Morabito et al. 2016)

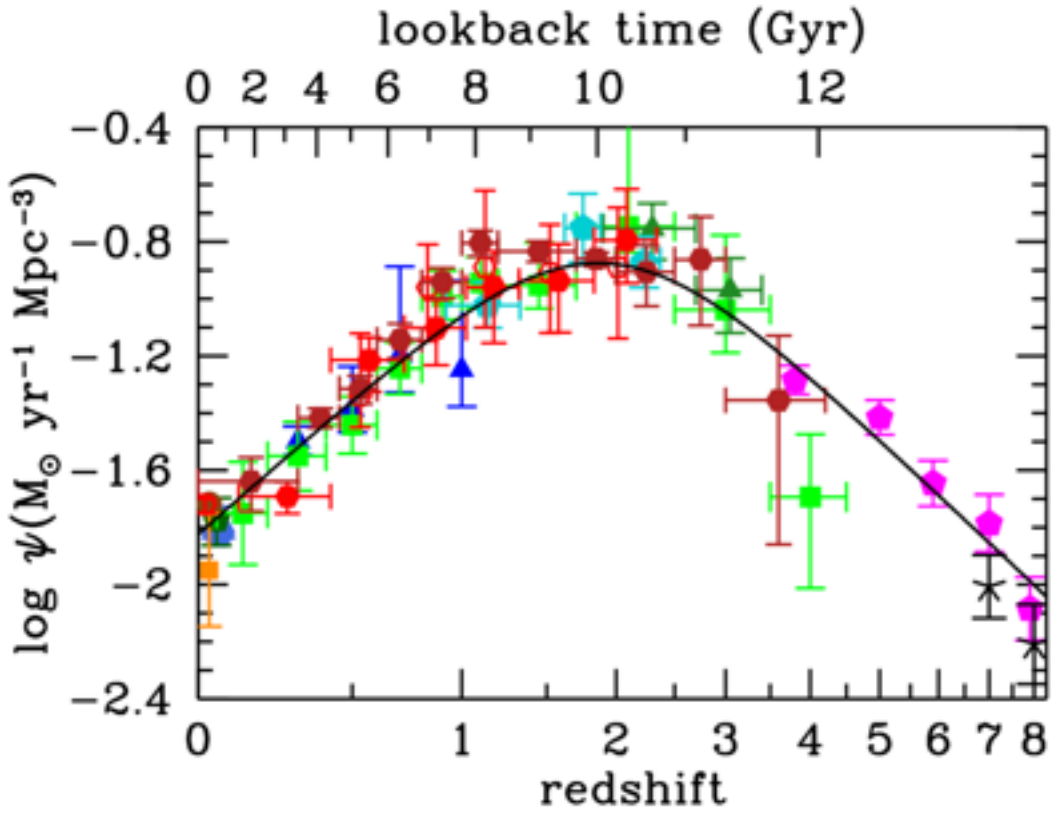


Key science: Test AGN feedback at the jet/interstellar medium interface.

SKA Continuum survey plans

Main science goal: Study the evolution of star-formation and active galactic nuclei activity across cosmic time (in competition with JWST and ALMA).

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 — user friendly?

SKA Continuum survey plans (Dark Matter and Energy)

Key questions:

1) What is dark energy?
2) What is dark matter?

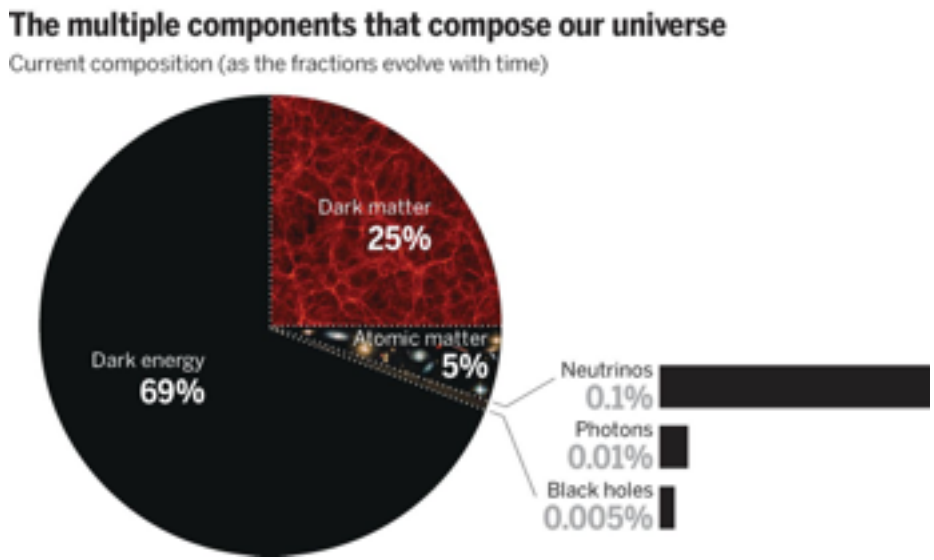
Large surveys aimed to answer these question (LSST, DES, *Euclid*).

Can the SKA answer these questions?

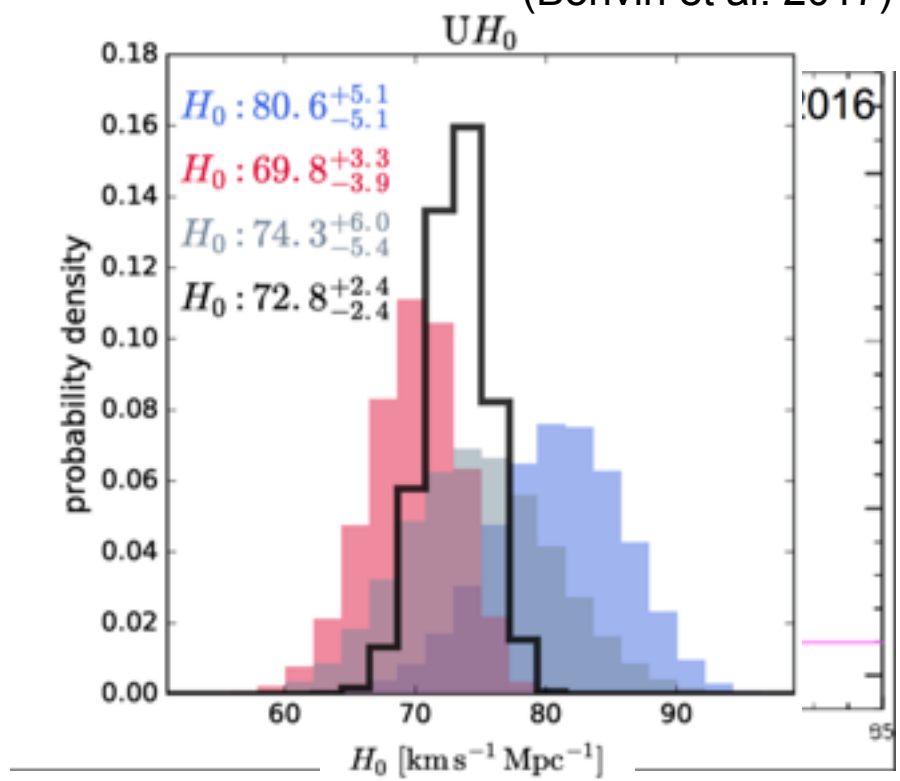
The key issue is being **competitive** (small error bars) and **independent** (different systematics).

Key observables:

1) Angular diameter distance (standard rulers, e.g. masers, lenses)
2) Luminosity distances (standard candels, SN1a, FRBs?, GW?)



(Bonvin et al. 2017)



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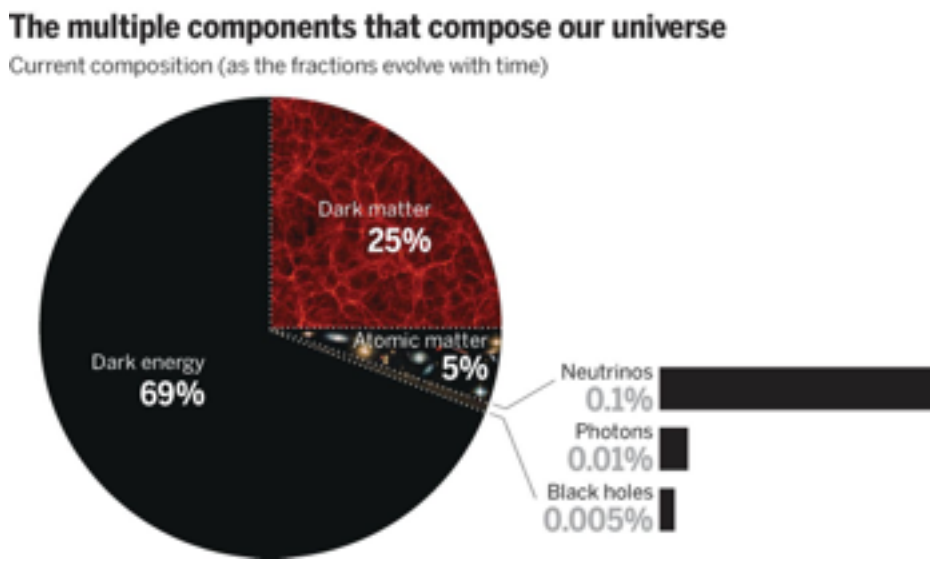
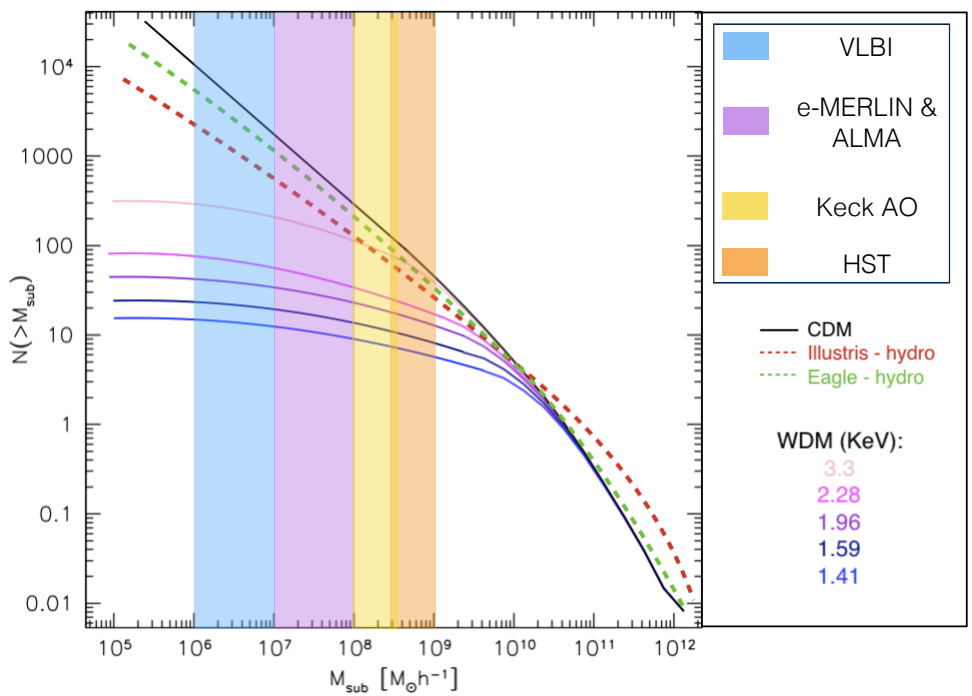


Key observables:

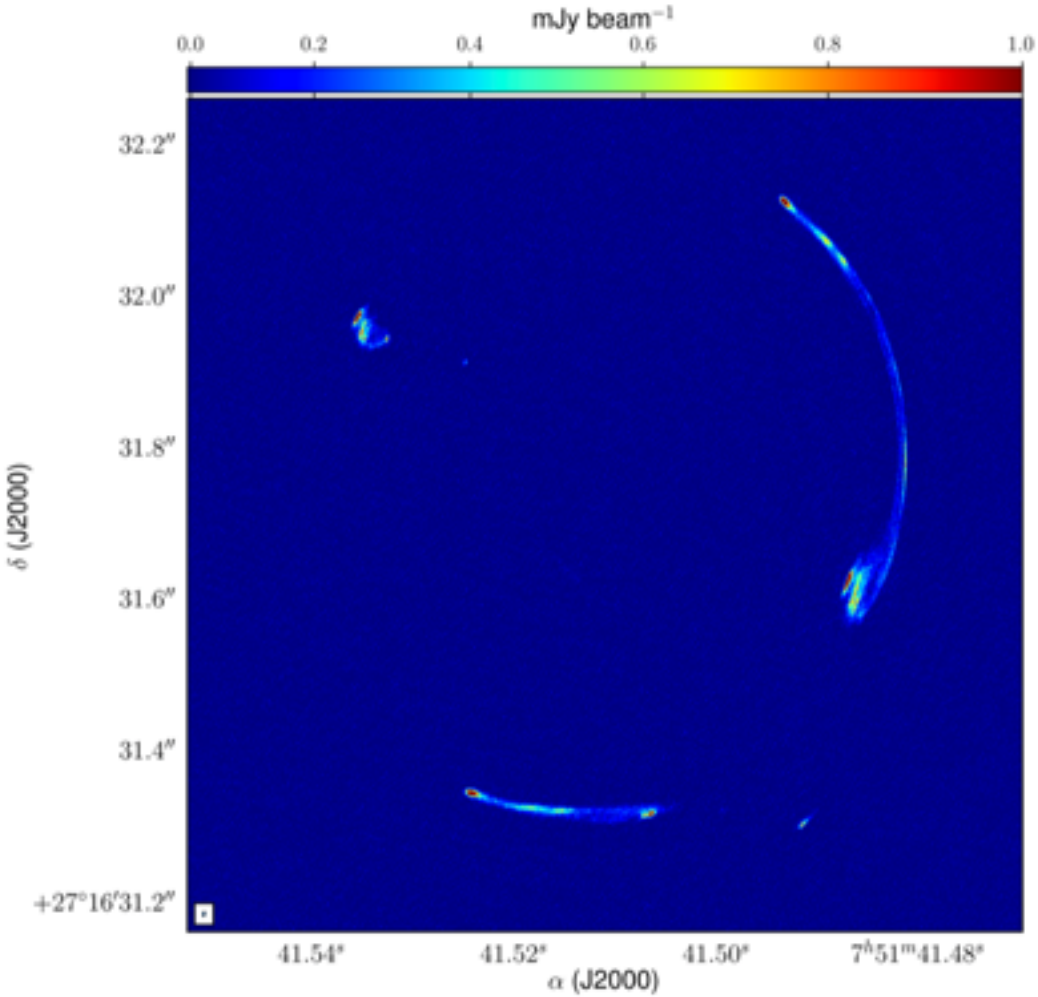
1) Mass function of sub-haloes to low mass levels 10^6 M_{sun}.

(Slope and normalization)

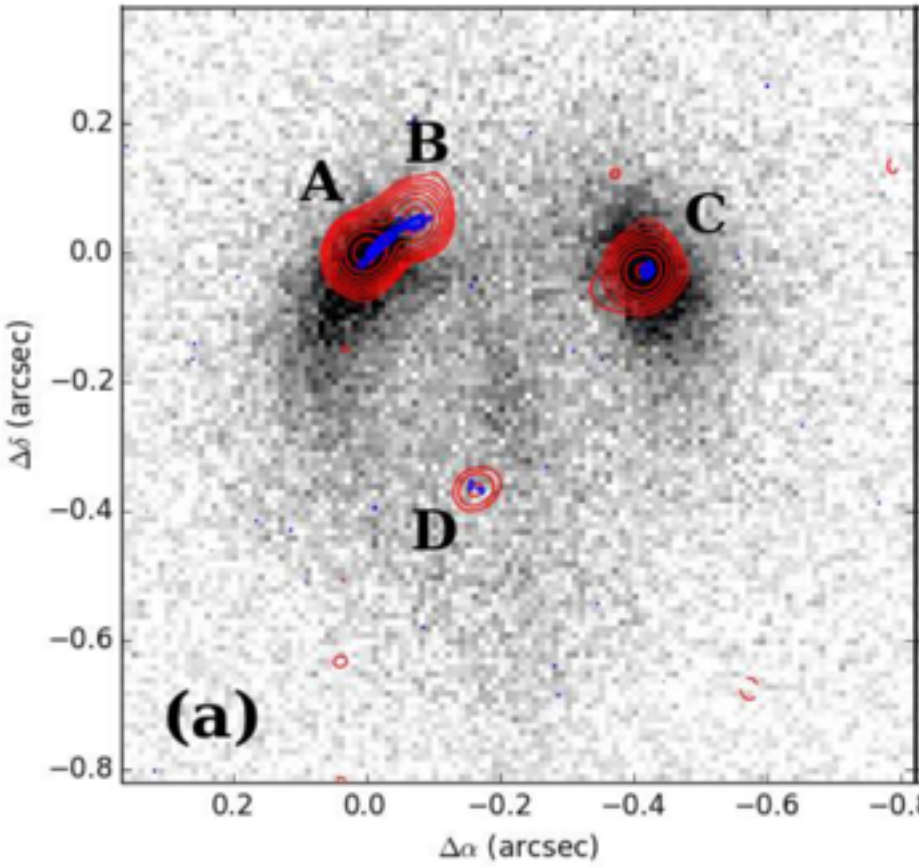


SKA Continuum survey plans (Dark Matter and Energy)

(Spingola et al. 2018)



(Hsueh et al. 2017)



KSP requirement/issue: Requires high angular resolution to find new lenses (~0.3 arcsec) and mas-resolution to test models for dark matter / BH populations.

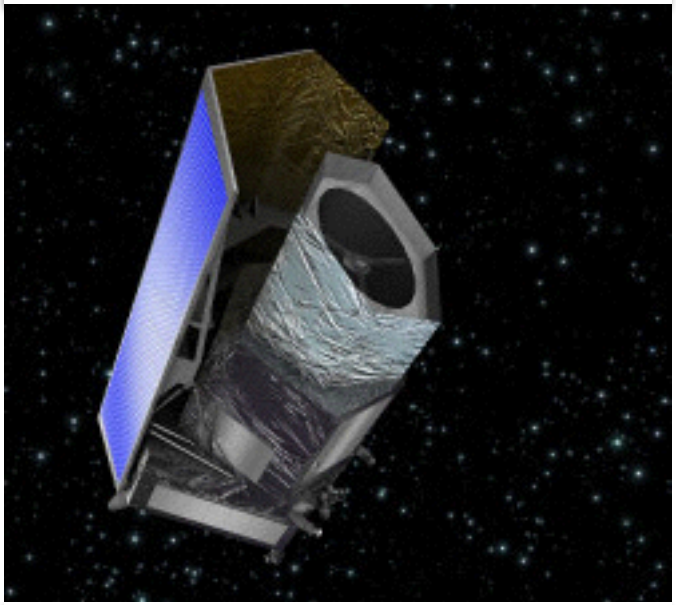
SKA Continuum survey plans (Towards a KSP)

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
Polarisations	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
Polarisations	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)

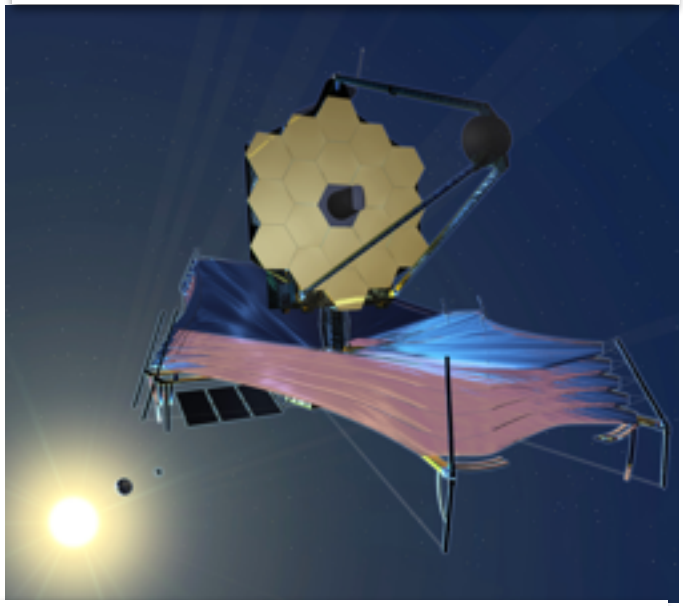
Multi-wavelength synergies (going beyond a blob)

Euclid



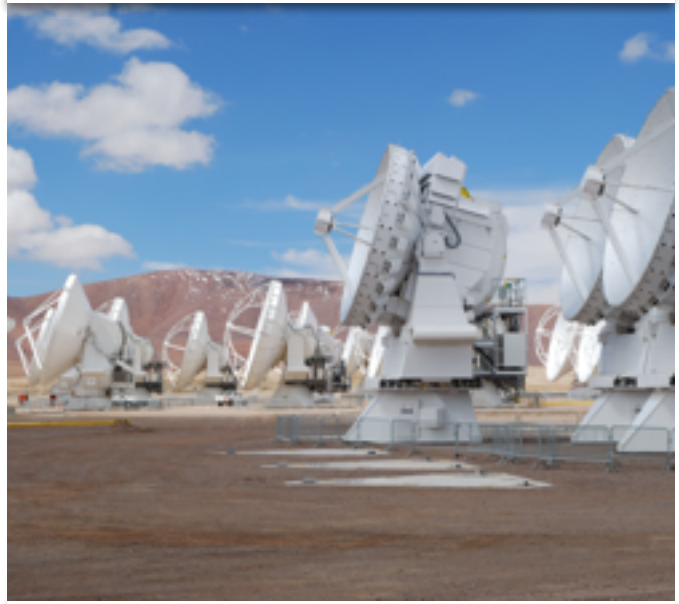
- VIS-NIR (0.55–2 μm)
- Stellar emission
- Photometry (1.5 x 10^9 galaxies)
- Spectroscopy (2 x 10^7 galaxies)
- Resolution 0.2–0.6 arcsec.
- Wide-field (15000 deg^2)
- Narrow-field (2 x >10 deg^2)
- Launch 2020

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

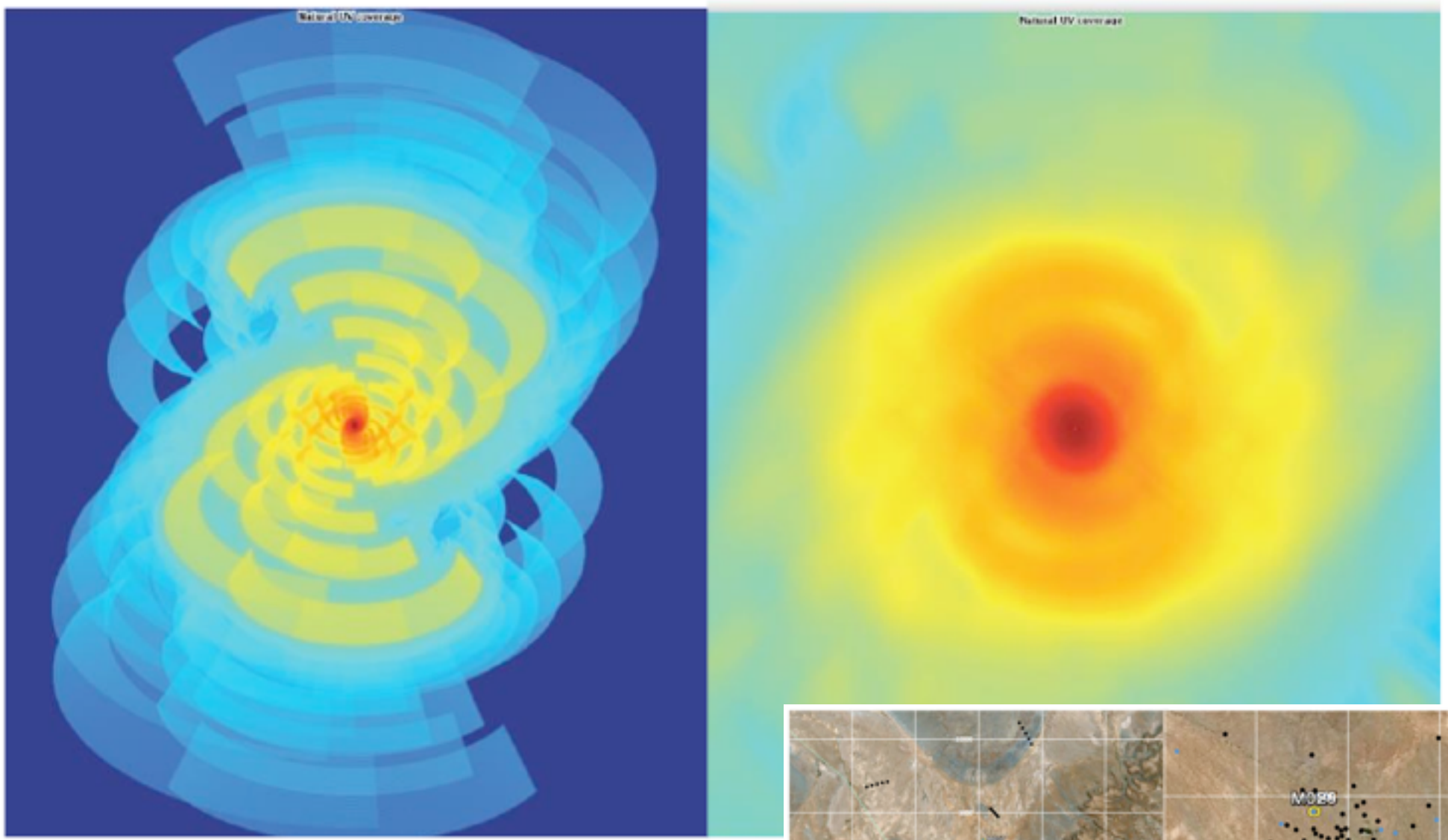
ALMA



- 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

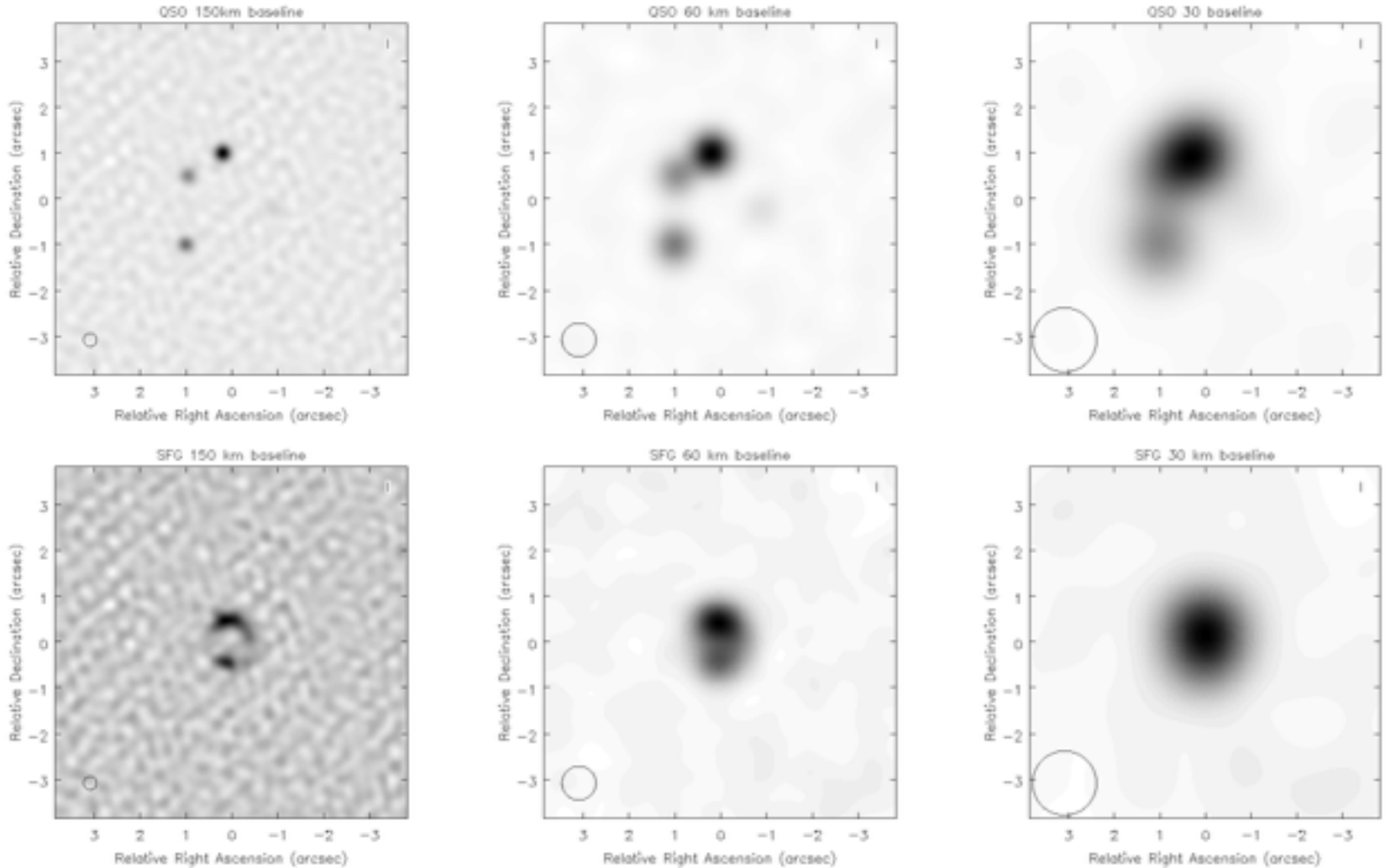
Re-processing to higher angular resolution (SRC)



KSP requirement/issue: HPC resources to re-process data to required angular resolution.

Re-processing to higher angular resolution (SRC)

Example of a gravitational lens observed with different visibility weightings.

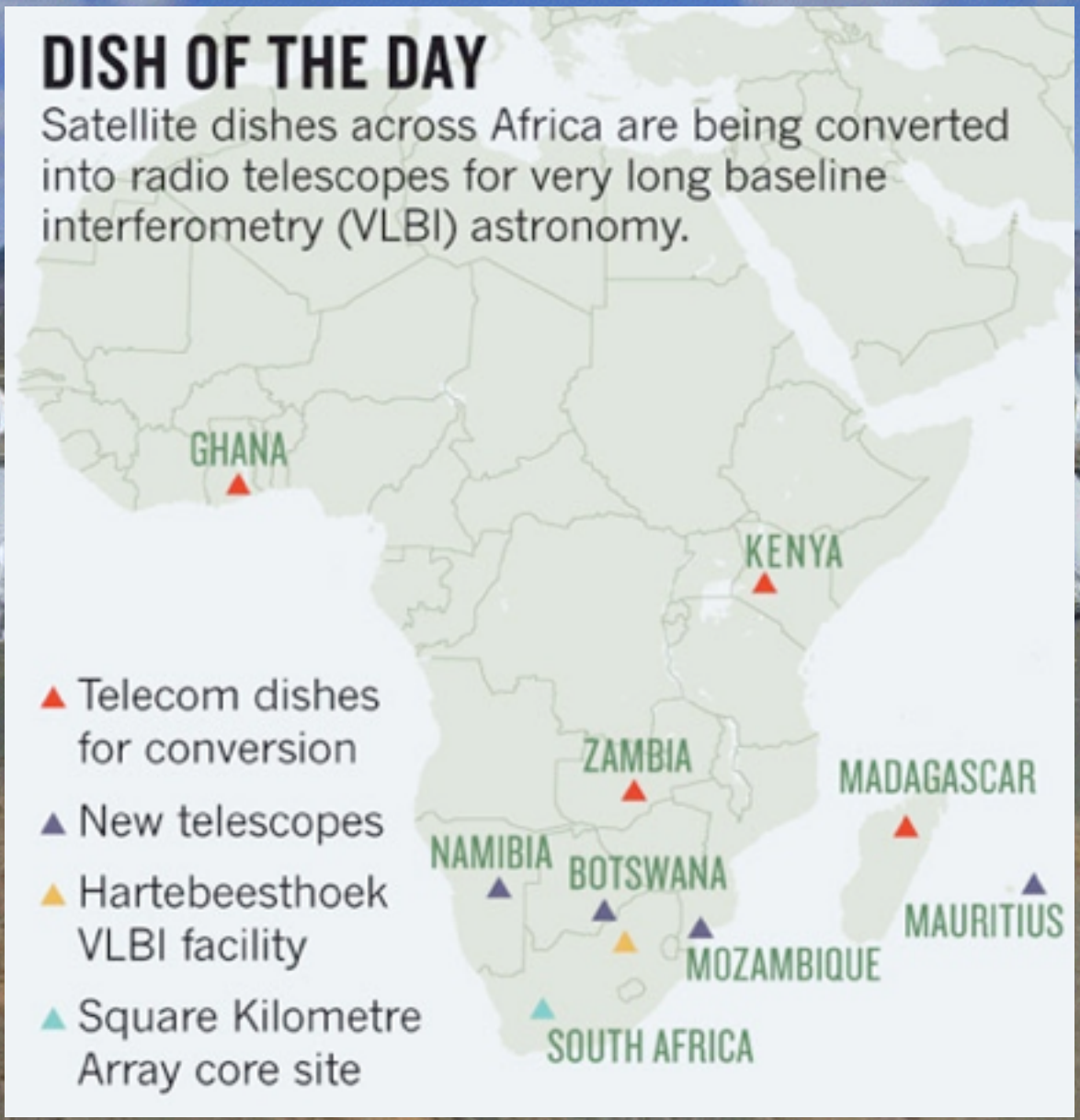


(McKean et al. 2015)

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

SKA-MID — MeerKAT (and MIGHTEE)

Area: 20 deg^2
rms: ~1 μJy / beam
Resolution: 6 arcsec (L-band)



Extragalactic (non-HI) Spectral line SWG

- **AIM:** SWG established to investigate survey strategies and science capabilities of using (non-HI) spectral lines at both low and high redshift (Born in Stockholm).

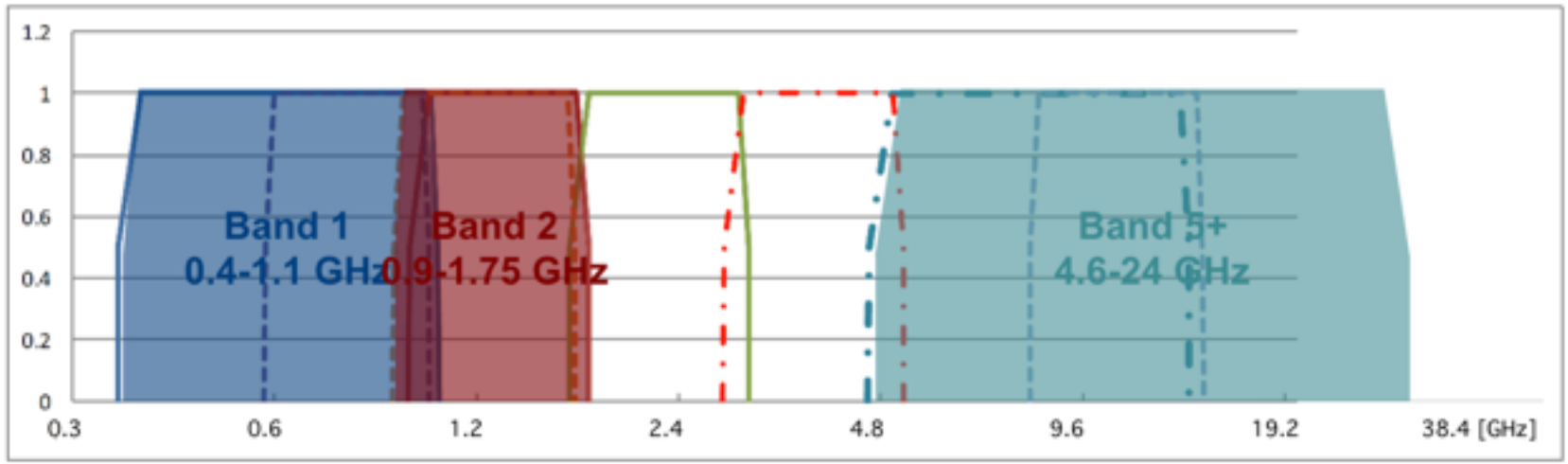
- **OUTLINE:**

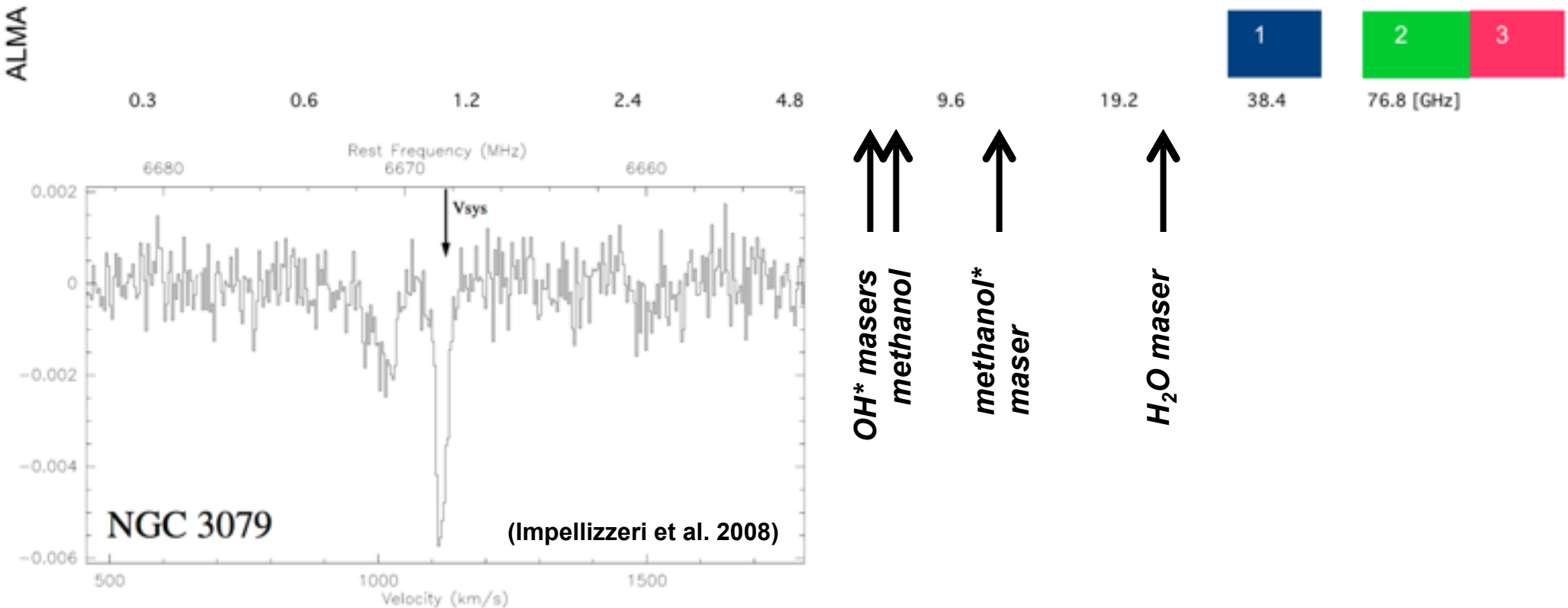
1. Processes probed by non-HI spectral lines with the SKA
2. Science projects targeting Local Group/low-redshift galaxies
3. Science projects targeting high-redshift galaxies/EoR

- **THE TEAM:**

- **Chairs**: Robert Beswick (JBO) and Francoise Combes (Obs. Paris)
- **Associate Members**: 40 from 12 countries
- **NL Team Members**: William Baan, Jacqueline Hodge, John McKean, Raymond Oonk, Paco Colomer

Frequency coverage of the main lines





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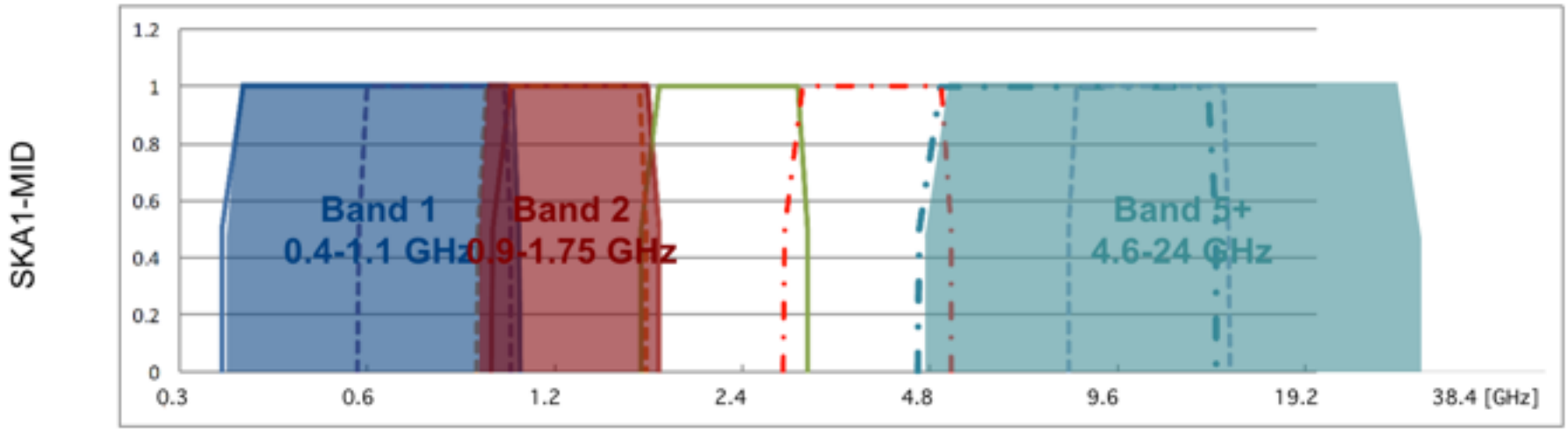
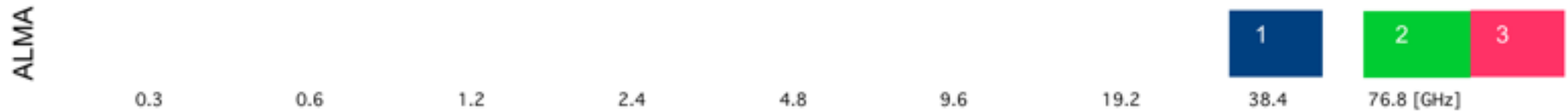
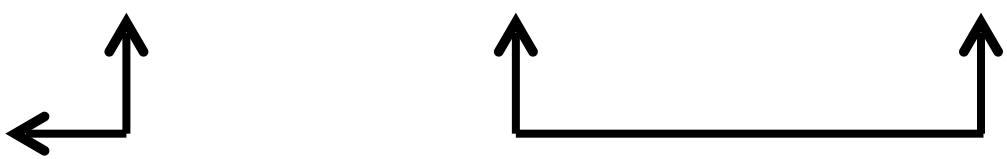




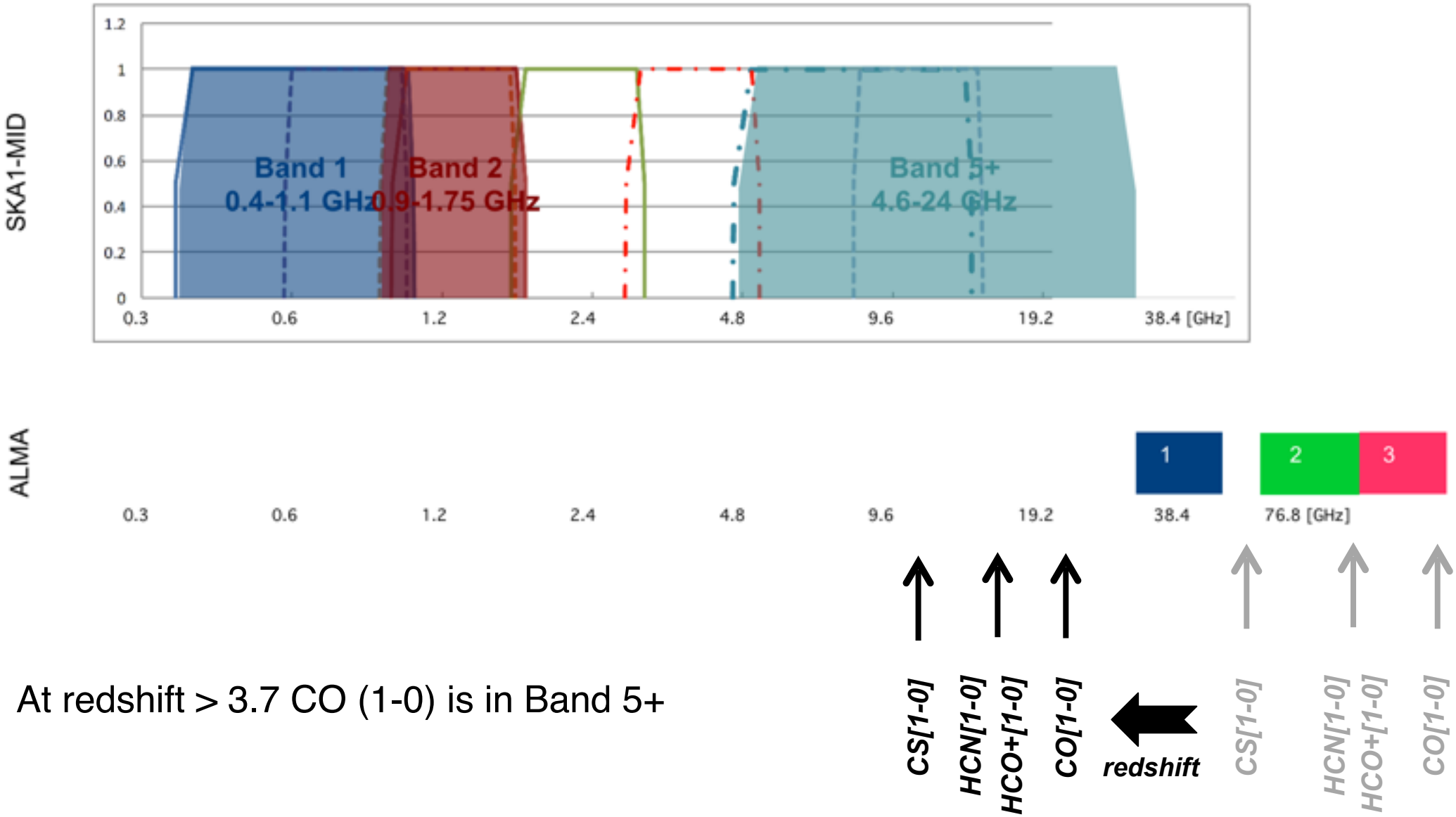


Radio recombination lines

Radio recombination lines

Local dense gas tracers — HCN, HCO+, HNC, etc.

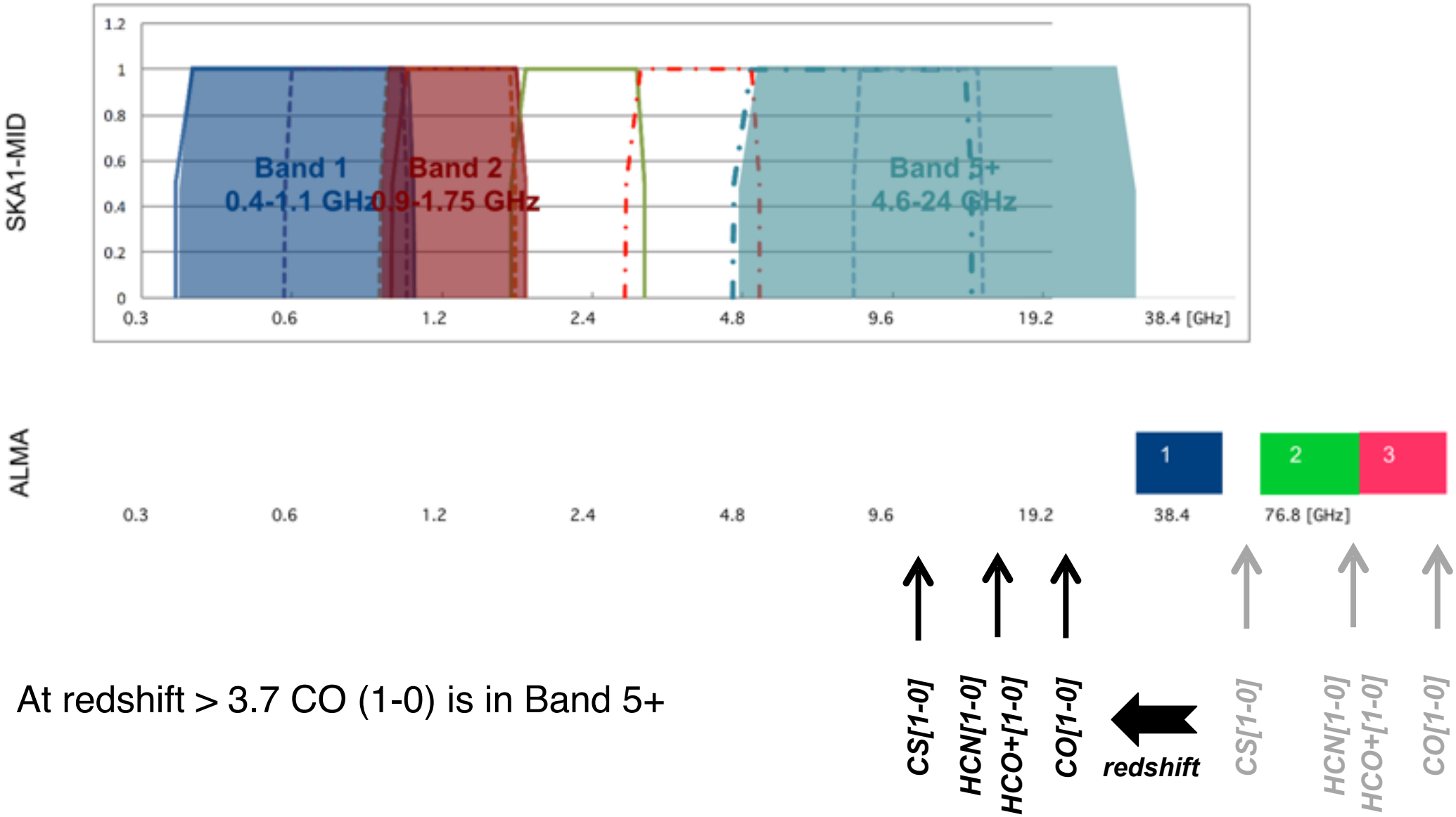
Frequency coverage of the main lines



At redshift > 3.7 CO (1-0) is in Band 5+

Issues/concerns: Much of the science capability (beyond HI on the local Universe) is dependent Band 5+ being on the SKA-MID dishes.

Frequency coverage of the main lines



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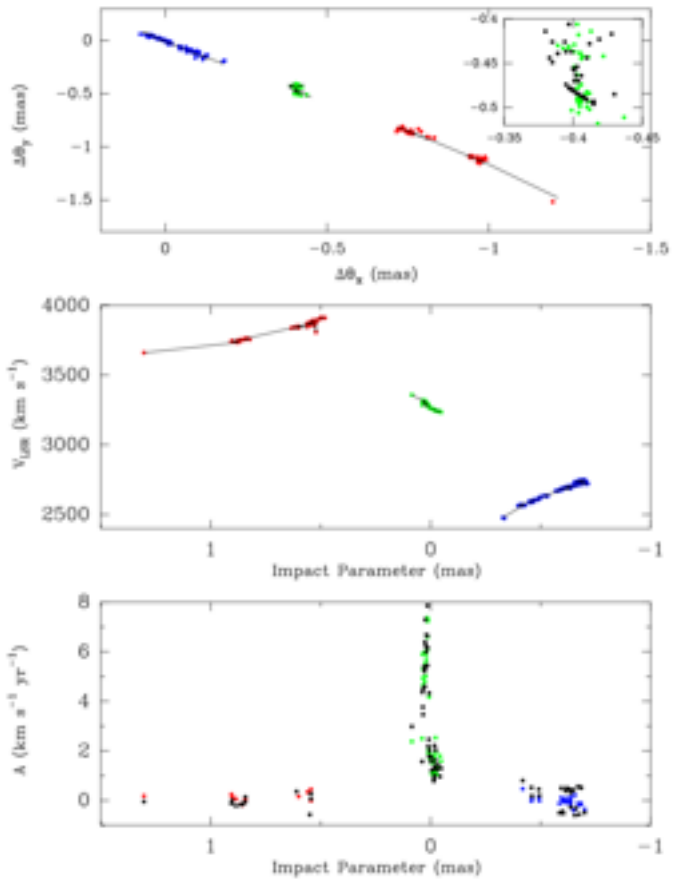
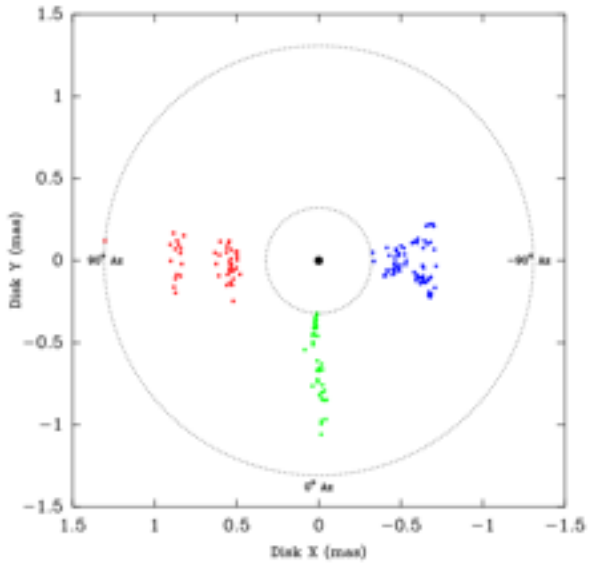
Issues/concerns: Much of the science capability (beyond HI on the local Universe) is dependent Band 5+ being on the SKA-MID dishes.

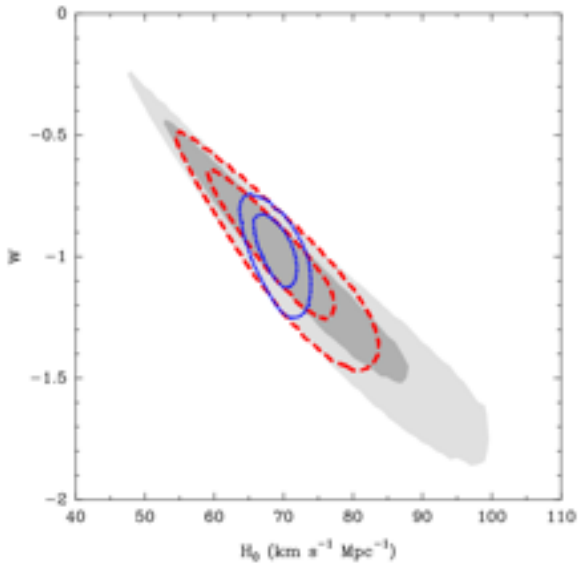
Probing the Dark Energy H_2O masers

Proof of concept demonstrated by the NRAO key science programme: Megamaser Cosmology Project (MCP; PI Jim Braatz).



Targets 22.2 GHz water masers in disk galaxies with GBT and VLBA.



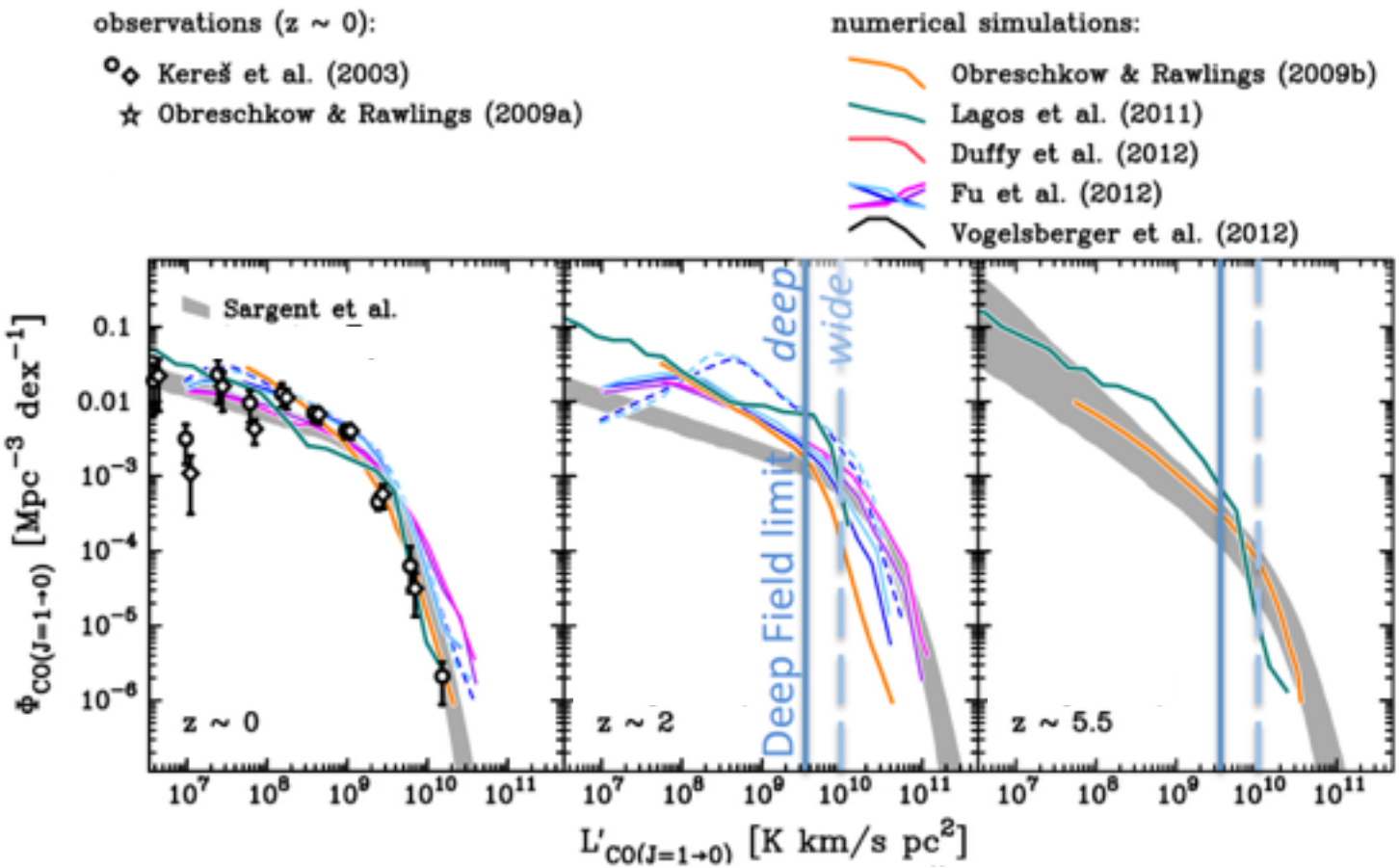


Only weakly constrains *w* (low redshifts) and may be limited systematics (e.g. BH proper motions, relative to the galaxy systemic velocity) at the few % level.

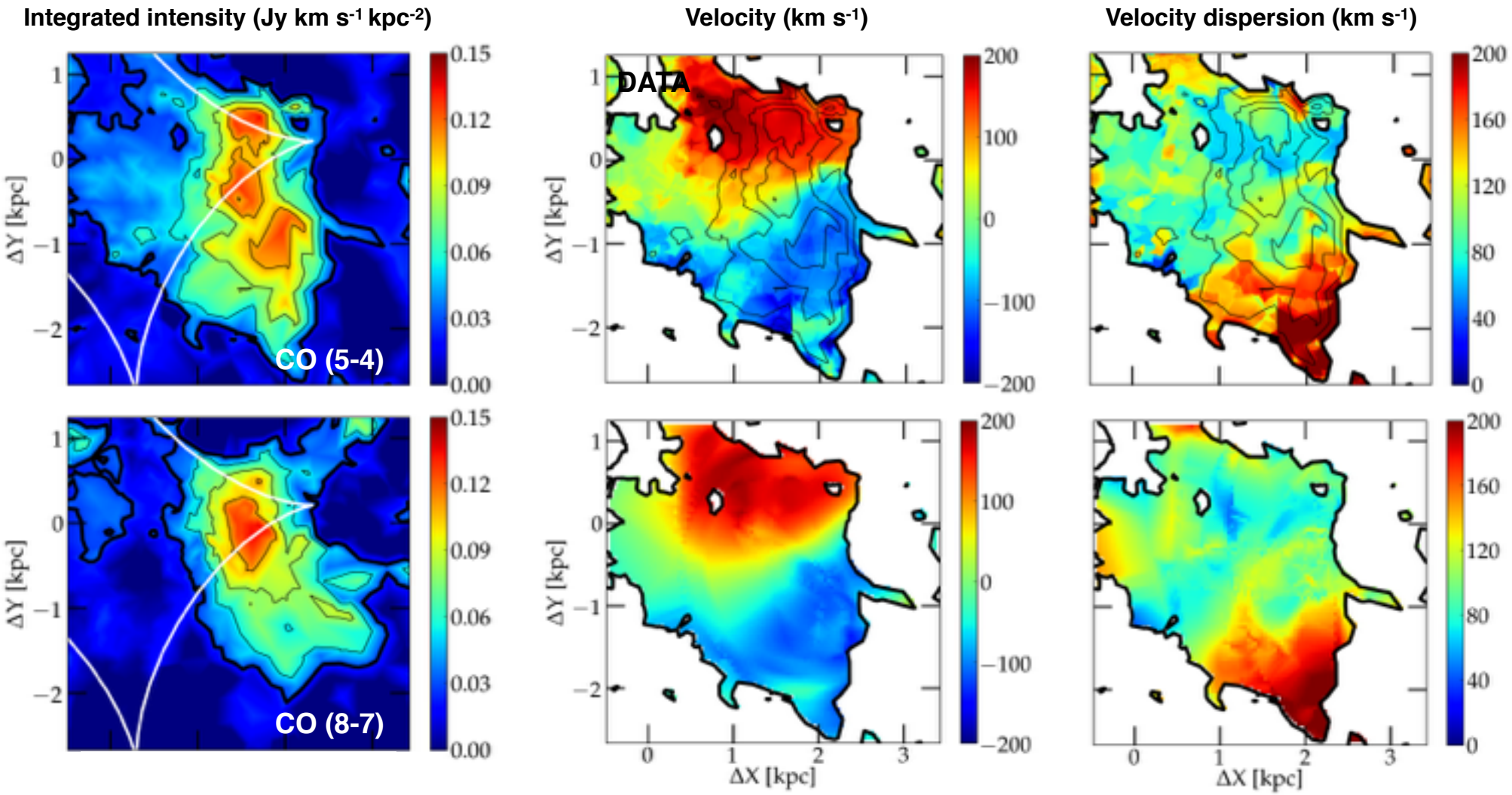
Tracing galaxy formation with CO (samples)

Can test (calibrate) galaxy formation simulations through studies of the **CO luminosity function**.

Ideally want to use the ground-state (115.2 GHz) as this traces the total molecular gas content [z ~ 3.8 — 7.2 with CO (1-0), 8.6 — 15.5 CO (2-1)].



Tracing galaxy formation with CO (individual)



(Rybak et al. 2015a,b)

ALMA study of a lensed starburst at z = 3.046 (state-of-the-art kinematics and modelling).

Evolving to a KSP

1. Continuum science is already well organised (LOFAR, ASKAP, MeerKAT, ngVLA) — SPARCS.

2. The continuum science working group has defined a standard tiered survey approach to achieve their science goals, which will naturally evolve into a (several) KSP(s).

3. Simulations being planned/carried out to test calibration and imaging.

4. MeerKAT to SKA-MID (smooth?)

5. To be competitive with LOFAR and MeerKAT, the SKA will need to provide significant improvement in sensitivity and angular resolution, which will require the full array and baselines (as planned) — no further re-baselining please (calibration, source identifications, beyond number counts).

6. To be competitive with the current and next generation of facilities (ALMA, JWST, Euclid and the ELTs) an angular resolution of <0.3 arcsec will be required (mas in reality).

Concerns (Continuum SWG related / general)

1. Budget: Not clear what the plans are for further re-baselining.

2. Band5+: Not clear what the rollout of this receiver is, vital for most of the line work (except HI).

3. Multi-wavelength interest: Not clear what the interest is beyond the radio astronomy community. Need to improve synergies (push unique and complementary science goals).

4. Computing: Not clear what the national and global strategy is for offline processing. The visibility data (gridded) must be kept and be re-processed for different uv-coverage and calibration requirements.

5. Momentum: We have pathfinders to keep us busy…

6. SKA Phase 2…