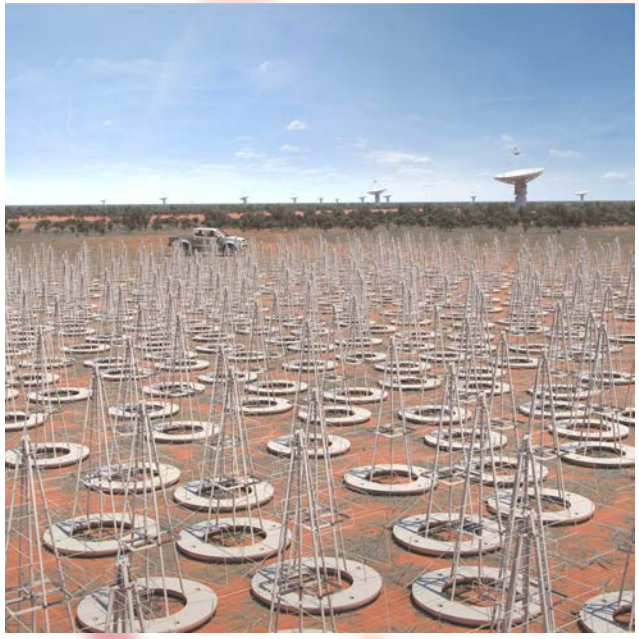
ICRAR

International Centre for Radio Astronomy Research



Continuum Surveys with SKA1

Nick Seymour – OzSKA – 9th April 2015

(for the SKA Continuum WG)

Curtin University

The Government of Western Australia

The University of Western Australia

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SKA Key Science Goals

Science Goal	SWG	Objective	SWG Rank
1	*CD/EoR*	Physics of the early universe IGM - I. Imaging	1/3
2	*CD/EoR*	Physics of the early universe IGM - II. Power spectrum	2/3
4	*Pulsars*	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection	1/3
5	*Pulsars*	High precision timing for testing gravity and GW detection	1/3
13	*HI*	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8	1/5
14	*HI*	High spatial resolution studies of the ISM in the nearby Universe.	2/5
15	*HI*	Multi-resolution mapping studies of the ISM in our Galaxy	3/5
18	*Transients*	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4
22	*Cradle of Life*	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5
27	*Magnetism*	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
32	*Cosmology*	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5
33	*Cosmology*	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
37 + 38	*Continuum*	Star formation history of the Universe (SFHU) – I+II. Non-thermal & Thermal processes	1+2/8

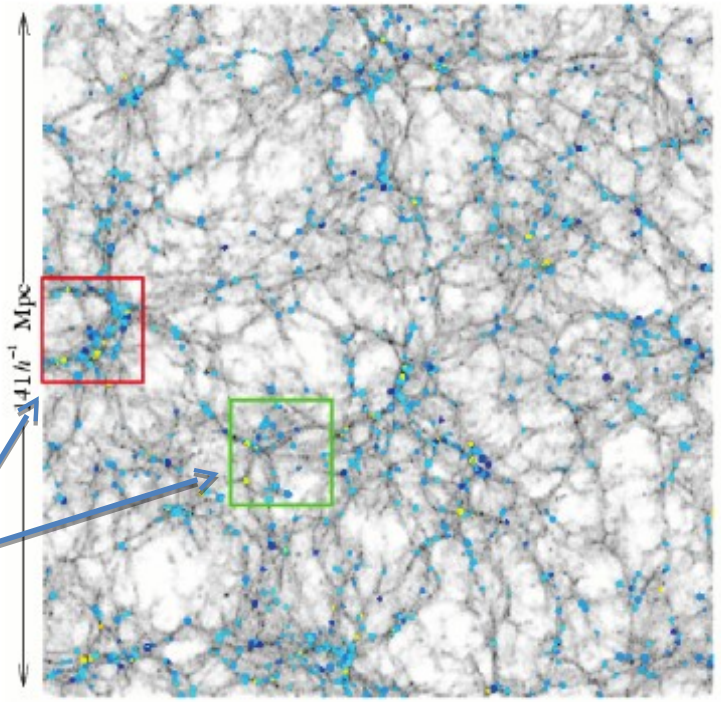
Table 2. List of highest priority SKA1 science objectives, grouped by SWG, but otherwise in arbitrary order.

Radio Continuum Survey Science Drivers

- **Evolution of galaxies**
  (in combination with HI + multi-λ informatio
  - Star formation & BH accretion history
  - Role of AGN feedback over cosmic time
  - Origin of FIR-Radio correlation
  - AGN and SF physical processes
  - diffuse non-thermal emission in clusters
  - radio continuum emission from the cosmic we
  - first galaxies, BHs & protoclusters
  - Detailed study of ISM physics in nearby galax
  - Strong lensing

Deep fields 10-100deg^2

z=2



GALFORM, Benson et al. 2000

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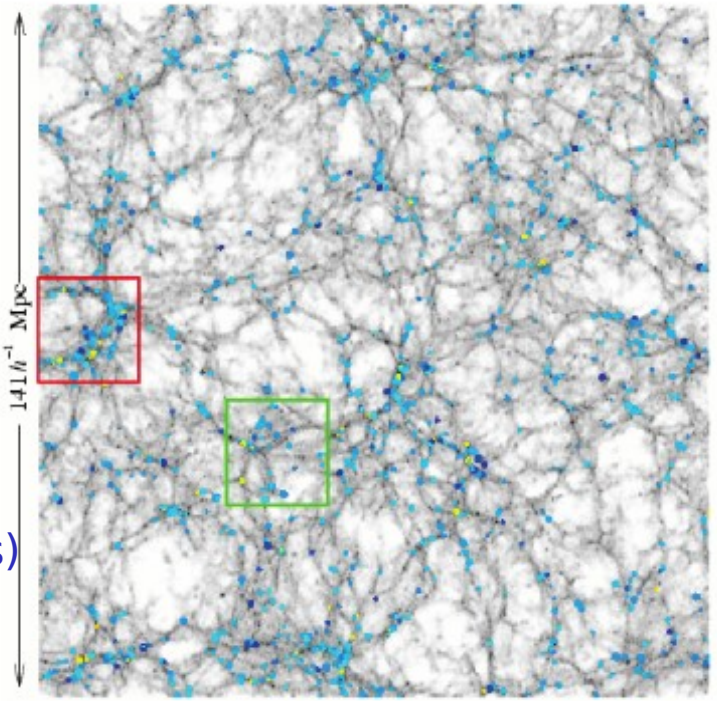
- Cosmology (in combination with HI/redshift surveys)
  (Constrain dark energy and non-Gaussianity)
  - -Baryonic Acoustic Oscillations
  - -Integrated Sachs-Wolfe Effect
  - -Magnification Bias
  - -Weak lensing
  - -HI Intensity Mapping

Deep fields 10-100deg^2

Shallower wide-area surveys >1/4 sky

z=2



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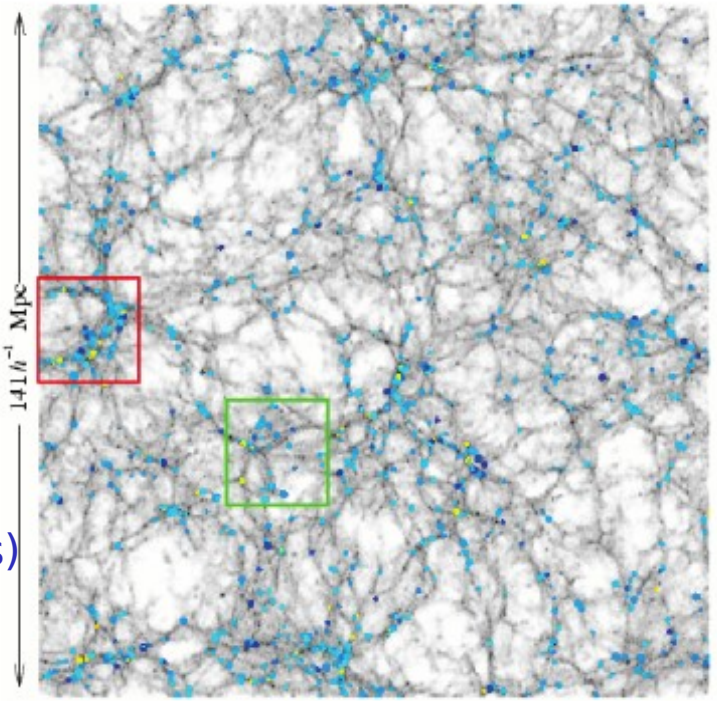


GALFORM, Benson et al. 2000

- Synergy with surveys in other wave-bands (LSST, Euclid, JWST, eROSITA)

SKA$_1$ Reference Surveys @ Band 2 (Full BW)

SKA1: factor 30x over JVLA
factor 5x over pathfinders

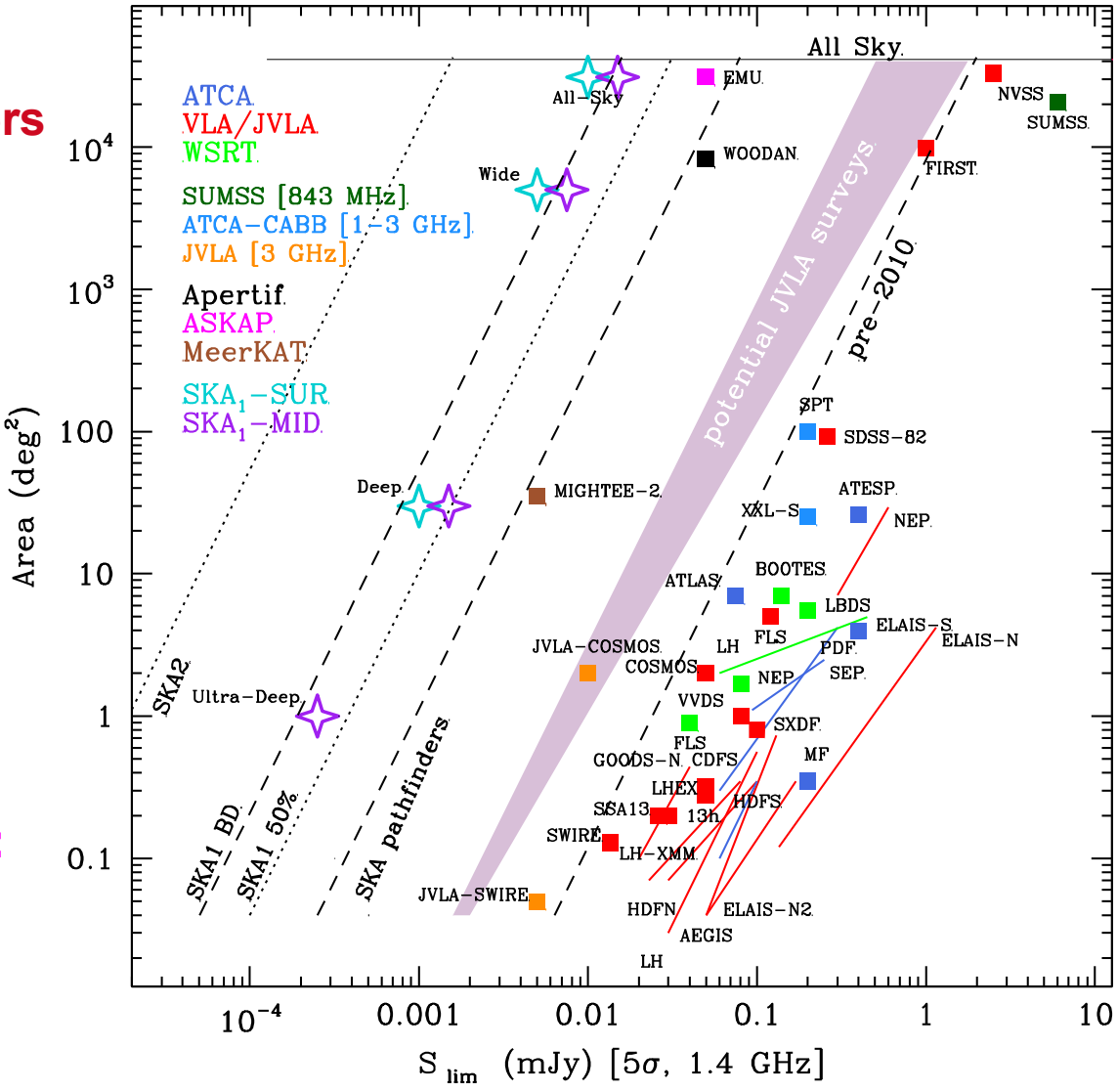
All-Sky (2 yr) ⊟ 3π
Wide (1 yr) ⊟ 5000 deg²
Deep (2000^h) ⊟ 30 deg²
Ultra Deep (“) ⊟ 1 deg²
(pre-rebaselining!)

SKA1-SUR Surveys:

Resolution: ~2-3 arcsec
Rms noise: 2, 1, 0.2 uJy/b

SKA1-MID *High-res* Surveys:

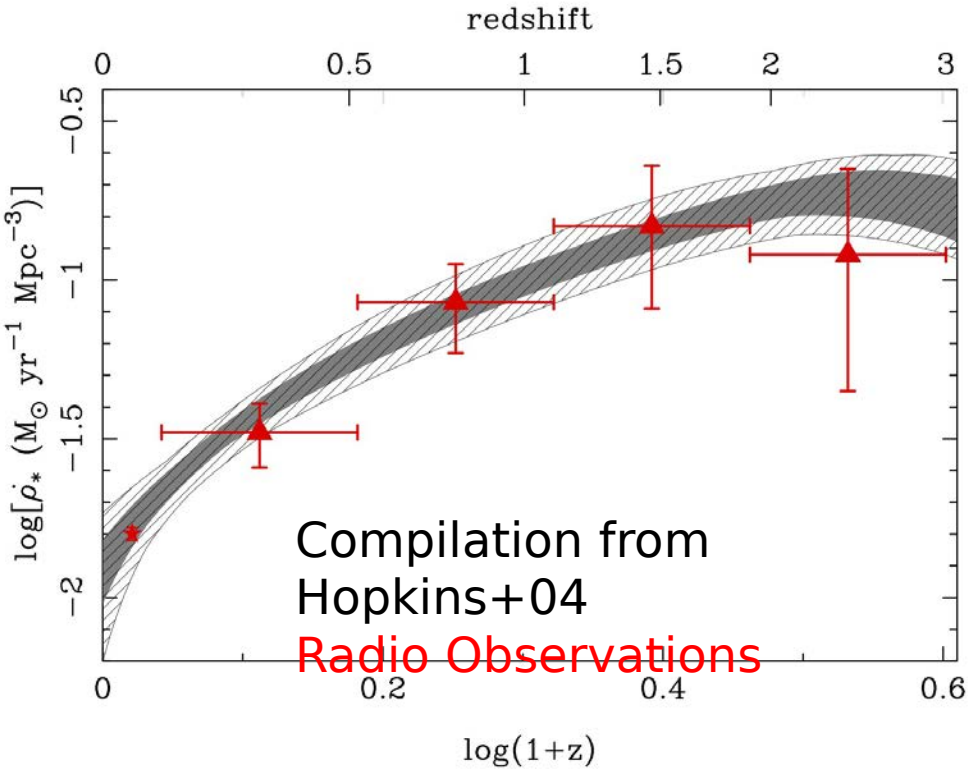
Resolution: ~0.6-3 arcsec
Rms noise: 3, 1.5, 0.3 uJy/b
+ 0.05 uJy/b



Prandoni & Seymour (2015)

Star Formation vs Cosmic Time

Deep Fields
Dominated by SFGs

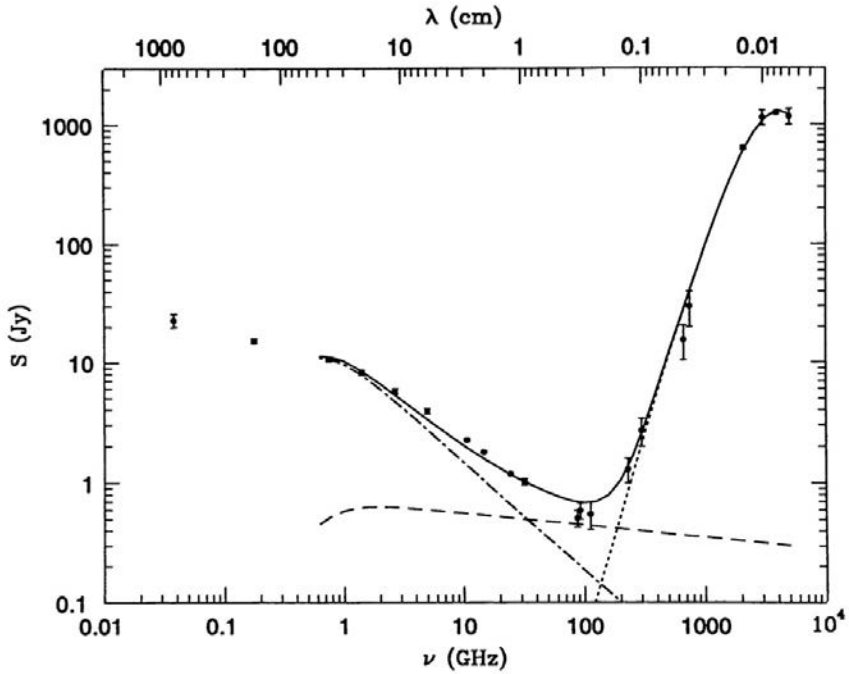


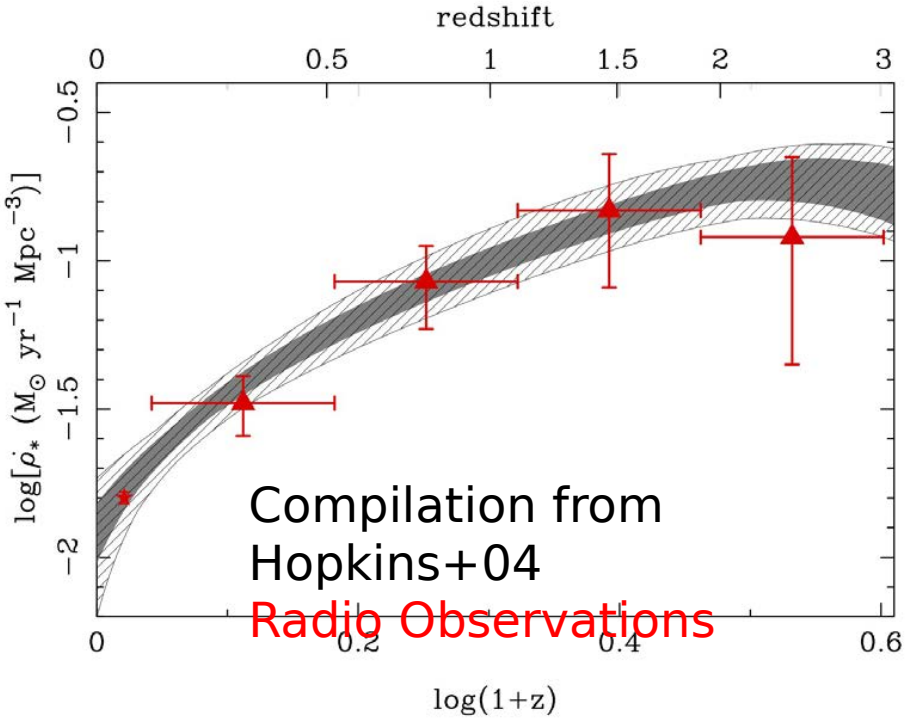
(Seymour et al 2008)

Star Formation vs Cosmic Time

Deep Fields
Dominated by SFGs

Thermal emission traced at high-nu





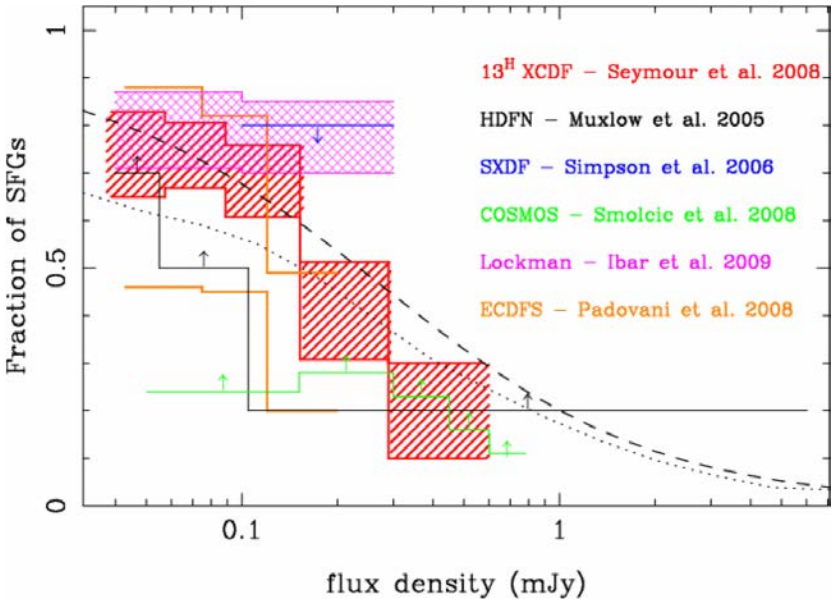
(Seymour et al 2008)

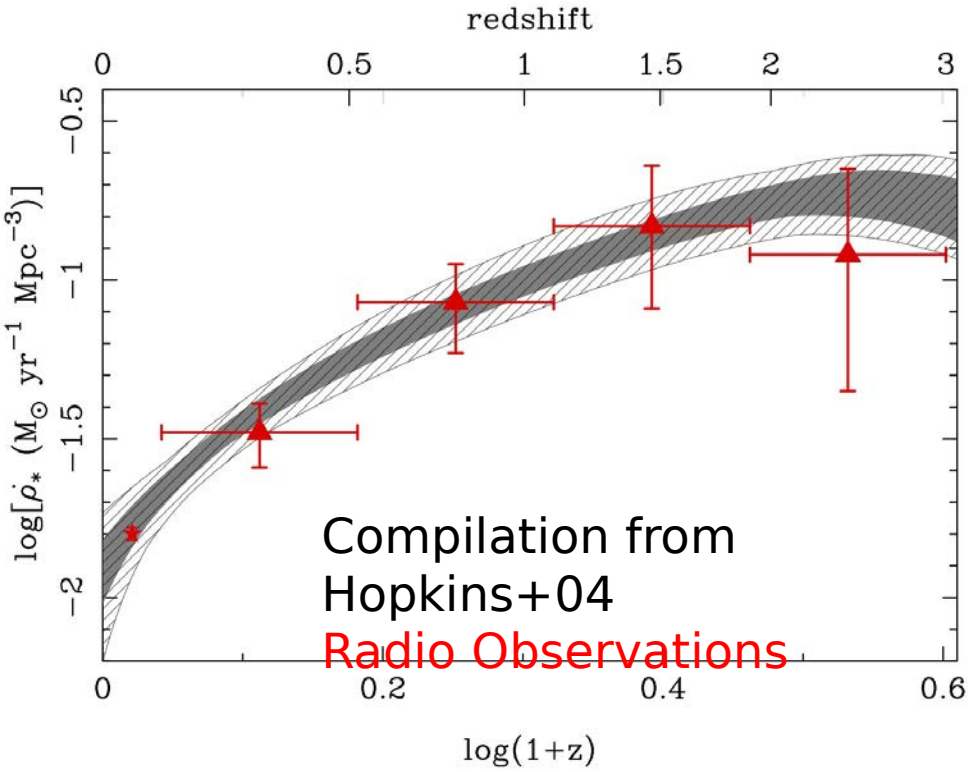
Condon et al. 1992

Star Formation vs Cosmic Time

Deep Fields
Dominated by SFGs

Fraction of SFGs





Compilation from Hopkins+04
Radio Observations

(Seymour et al 2008)

Star Formation vs Stellar Mass

Effect of Galaxy Mass

Requirement: sensitive to low SFR systems at high z ▭ **nJy sensitivities**

Ultra Deep:

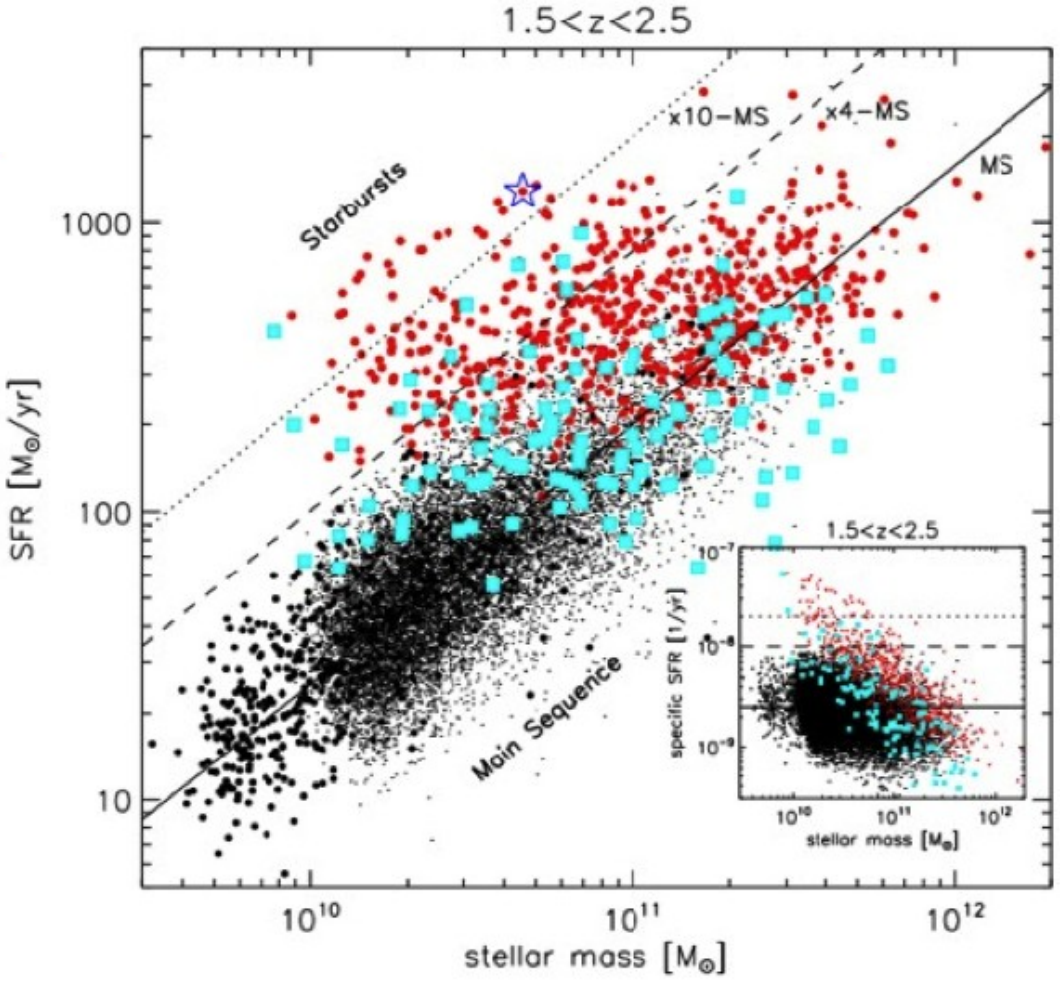
SKA_1~10 M_{sun}/yr @ z<2-3

1 M_{sun}/yr @ z~1

SKA_2~10 M_{sun}/yr @ z~6-7

1 M_{sun}/yr @ z~3

Rodighiero+2011



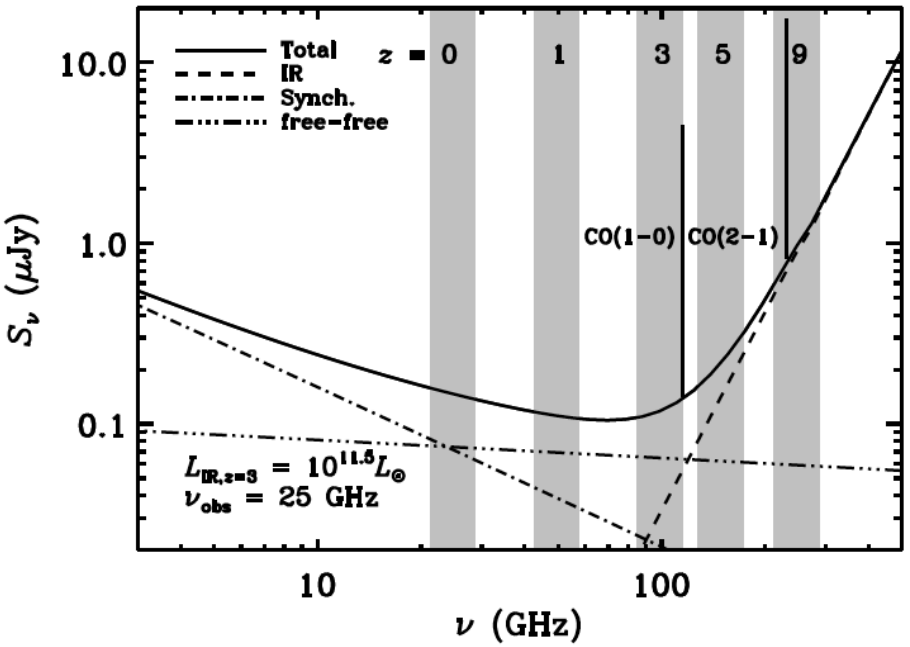
Detailed Astrophysics of SF

@ z>2

v_{obs}~10 GHz ▭ v_{rest}>30 GHz

Thermal emission
more accurate SFR

High resolution for resolved
SFG studies



Requirement: sub-uJy sensitivity

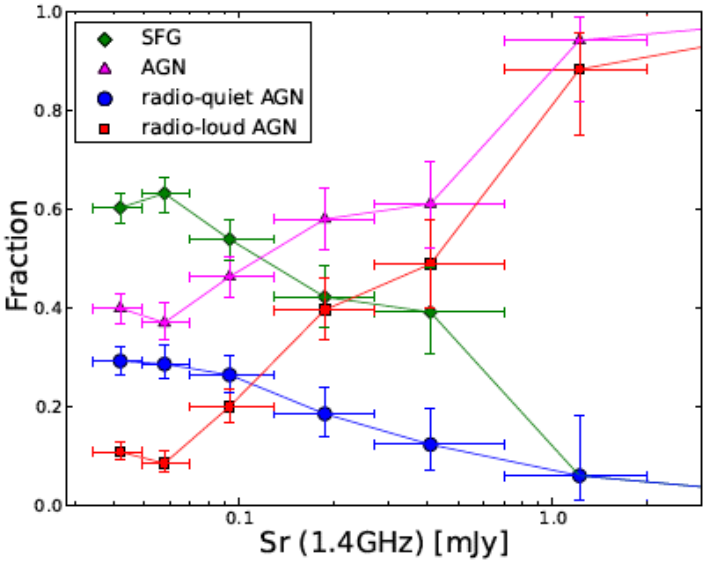
@ sub-arcsec spatial resolution

SKA1 ▭ 0.1 arcsec resolution at ~10 GHz

100 M_{sun}/yr SFGs up to z~2 & 10 M_{sun}/yr SFGs up to z~0.5

SKA2 ▭ extend frequency coverage to 30 GHz (synergy with ALMA for High-z molecular lines)

Black Hole Accretion History



Bonzini+ 2013

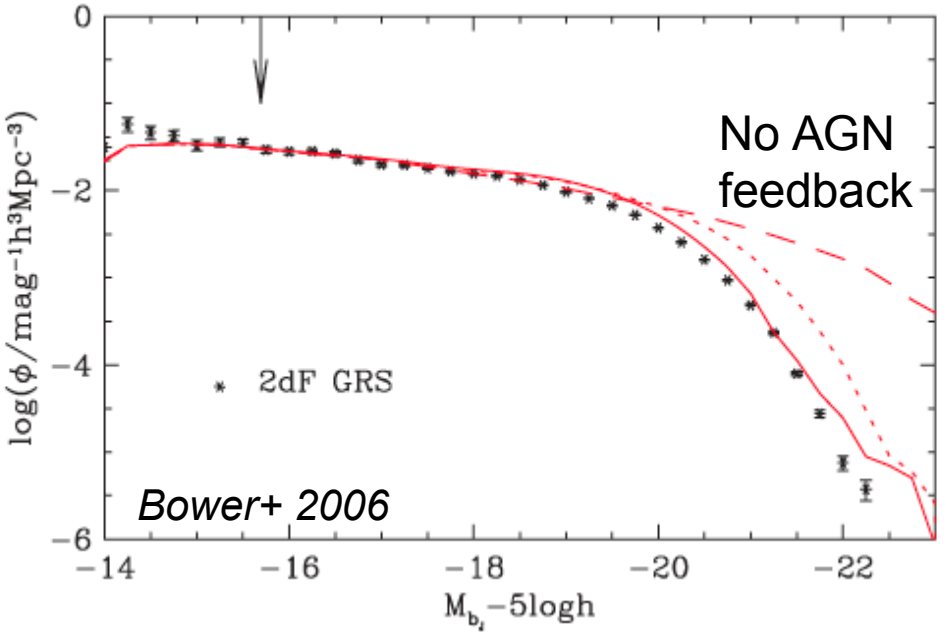
Complete census of RL and RQ AGNs
- complete view of AGN feedback

RL AGN - Radio Mode
→jet-driven mechanical feedback

RQ-AGN - QSO Mode
→radiation-driven feedback (winds)

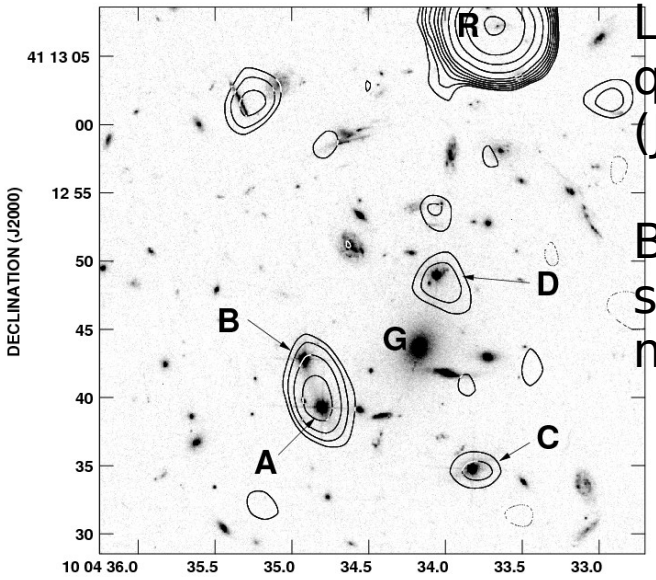
•RQ-AGN start to appear at uJy levels in deep radio fields

- Evolution of radio-selected AGN down to RQ regime [P~10^{21} W/Hz]
→RQ/RL Dichotomy
- Role of AGN feedback



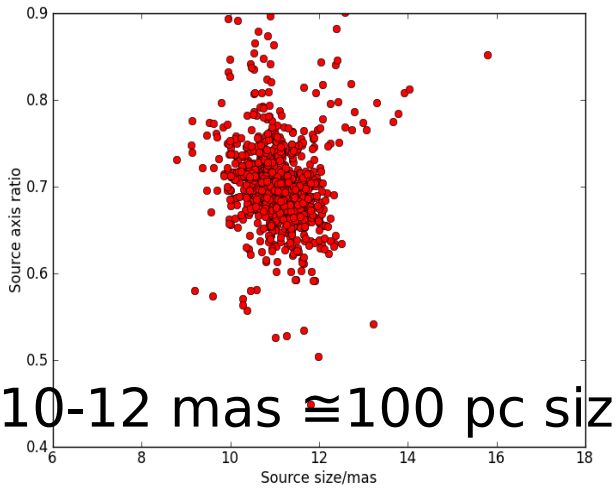
Gravitational Lensing

Courtesy N. Jackson

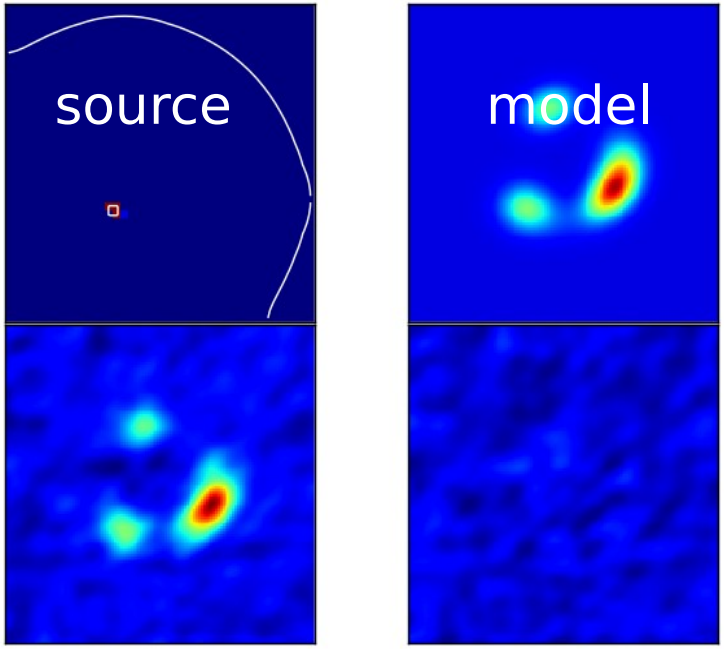


Left: SDSS J1004+4112 (z=1.7; 6hr JVLA 5GHz , C co
quad-imaged radio-quiet quasar of ~1 uJy intrinsic fl
(Jackson 2011)

Below: HS0810+2445 (z=1.5, 3hr JVLA 5GHz, C conf
similarly faint RQ quasar (Jackson, et al. in prep):
modelling shows intrinsic extent of RQQ



10-12 mas ≅100 pc size



SKA as a VLBI Machine

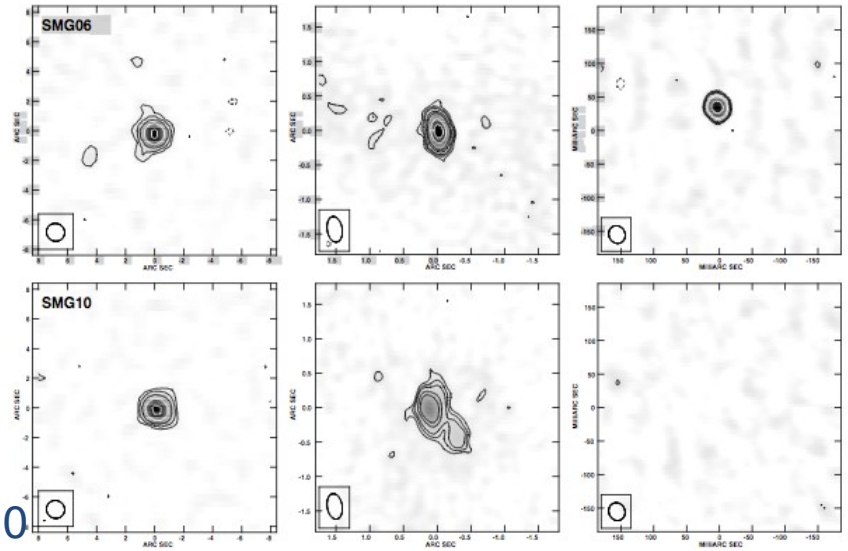
High resolution sensitive radio observations most direct and neat way to securely pinpoint AGN radio emission in deep radio fields

Requirement:

sub-uJy sensitivity @ mas resoluton

Baselines >1000 km ⊏ SKA_2

SKA_1: First analysis with resolution of 50 mas in Band 5 (<0.5 kpc at z~1) +VLBI



z=2.7
S=246 mJy

z=1.2
S=295 mJy

HDFN
Biggs+ 2010

High spatial resolution allows to separate AGN/SF contributions in *hybrid* sources

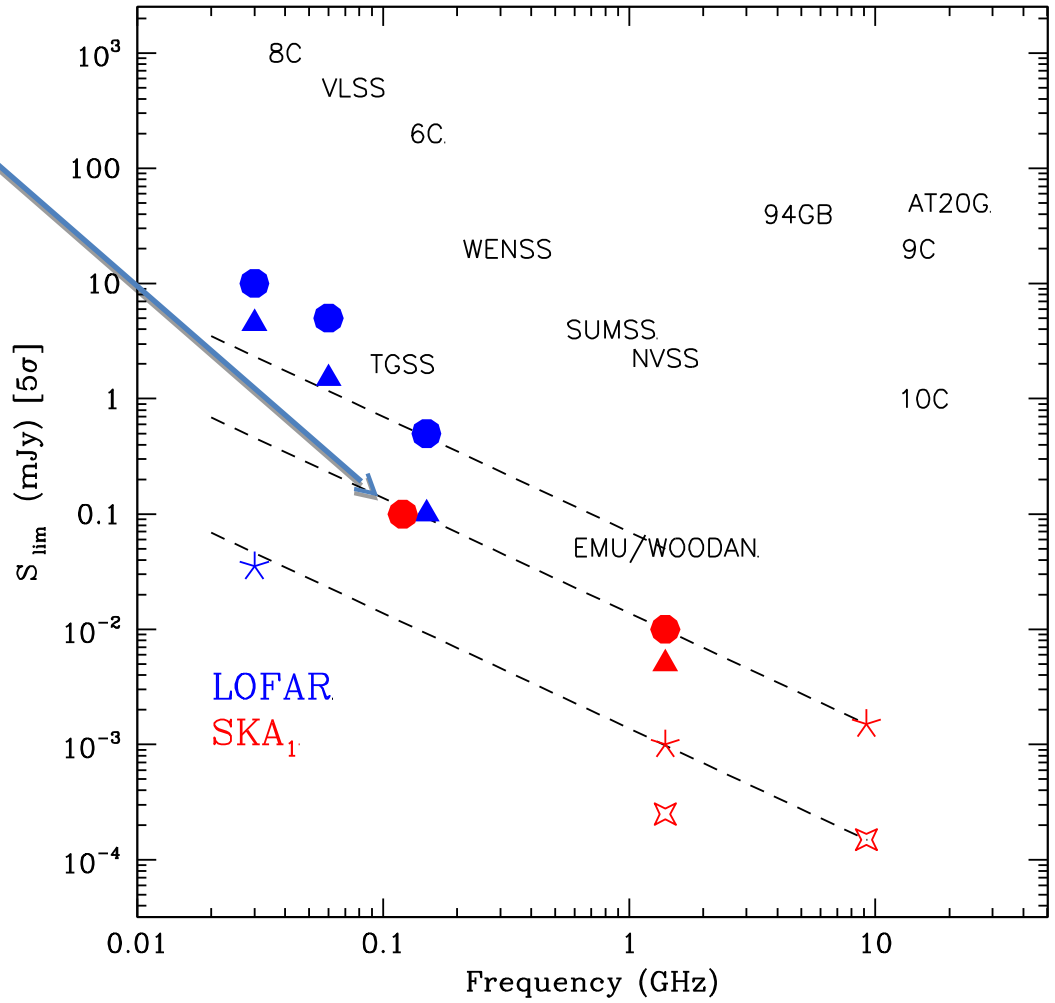
SKA_1 Reference Surveys vs frequency

SKA1-LOW: All sky at LOFAR *Deep Survey* level

Confusion limited @ ~20 uJy/b rms (120 MHz, 10" res.)

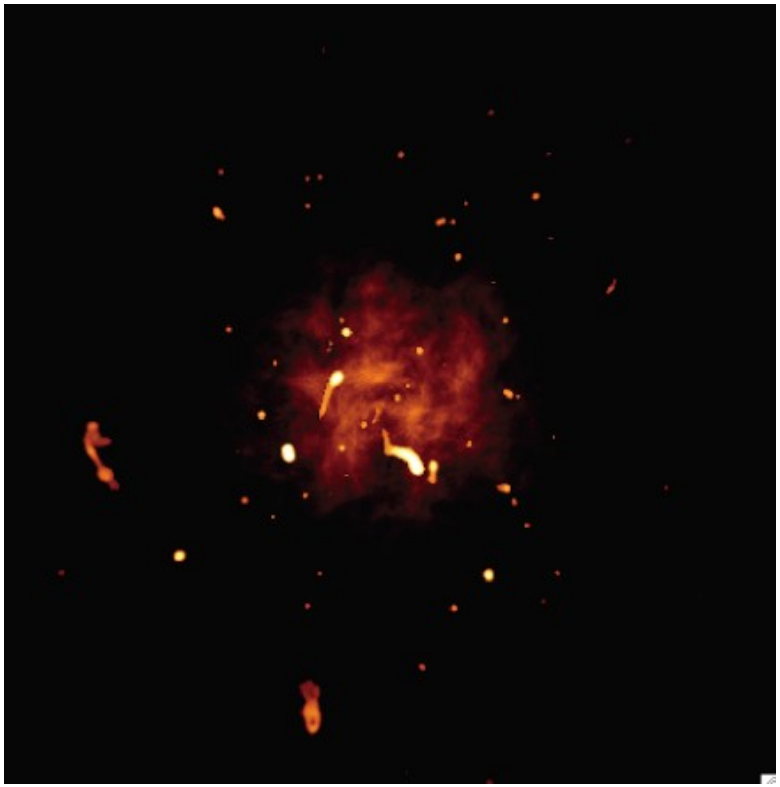
+ SKA_1-LOW + Band 2/5 surveys

→ Good match in sensitivity for steep spectrum sources



Prandoni & Seymour (2015)

Galaxy Clusters – SKA_LOW



Ferrari et al. (2015)

SKA1-LOW:
Confusion limited @ ~20 uJy/b rms (120 MHz, 10” res.)

Exploit excellent surface brightness Sensitivity of SKA-LOW in synergy with eROSITA, up to z~0.5

SKA will be sensitive to
USSRHs (low-mass mergers) and “off-state” RHs (relaxed clusters)

SKA2:
For higher-z needs <10” resolution to remove foreground galaxies

Physics & Life Cycle of RL AGNs

Surface brightness sensitivity + steep spectrum:
- Resolved studies of extended RGs

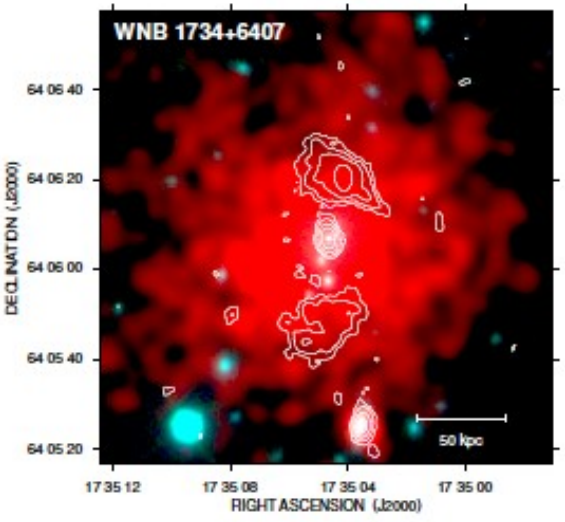
SKA1 – most extended RGs (>10 arcsec)

SKA2 – full RG population

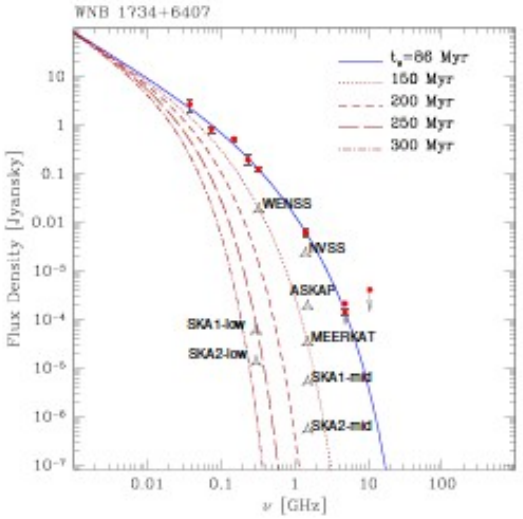
- USS dying radio sources

→1st generation RL AGNs (z>6)

SKA2 – <50 MHz



Italian SKA White Paper
Courtesy M. Murgia



Key Challenges to Continuum Surveys

- **How do we get redshifts?**
- **How do we separate AGN and SFGs?**
- **How do we convert radio luminosity to SFR and AGN jet power?**
- **How do we match to simulations?**

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POSSIBLE POSTDOC POSITION!!

Development of KSP from SWG

Issues:

- **Large overlap in key personal**
- **SWG has different mandate**
- **Need to engage young people who will actually lead the SKA1 analysis**
- **How to manage? Will it happen organically, how will leadership be shared?**

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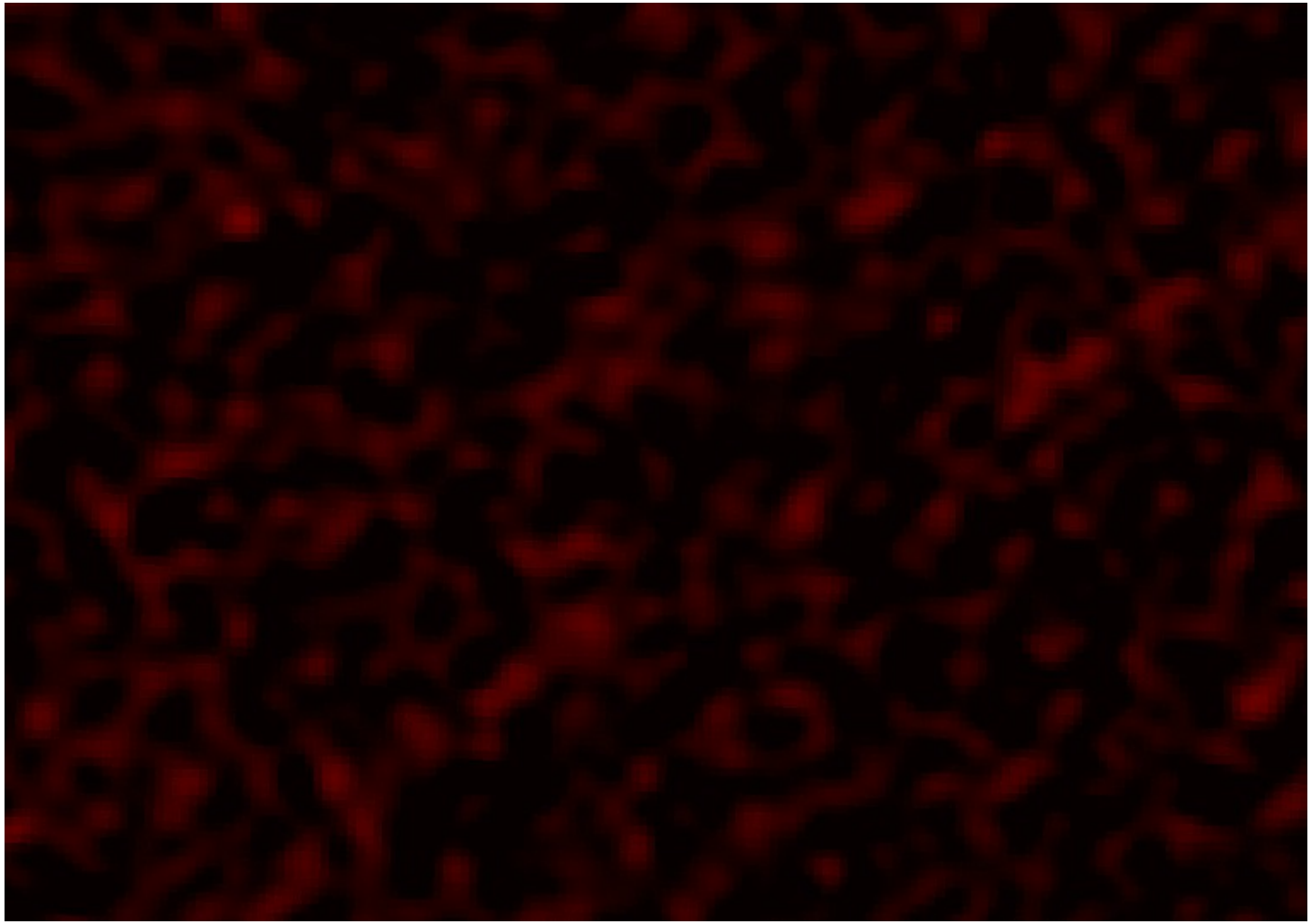
http://www.ast.uct.ac.za/sparcs2015/

http://askap.pbworks.com/w/page/94530611/Meeting_2015Aug12

Conclusions

- **Continuum science covers diverse topics: galaxy evolution, galaxy clusters, strong lensing, AGN & SF physics**
- **Sensitivity plus survey speed = novel view of galaxy evolution**
- **Added value from uJy and sub-uJy sensitivities @ sub-arcsec resolution + Band 5 in phase 1**
- **Continuum Chapters all available: http://arxiv.org/html/1412.6942v1**
- **Next step: commence KSP planning, refine reference surveys, examine commensality**

Bonus: more foregrounds



Credit: MWA, Hurley-Walker & Seymour

Questions for Continuum Discussion

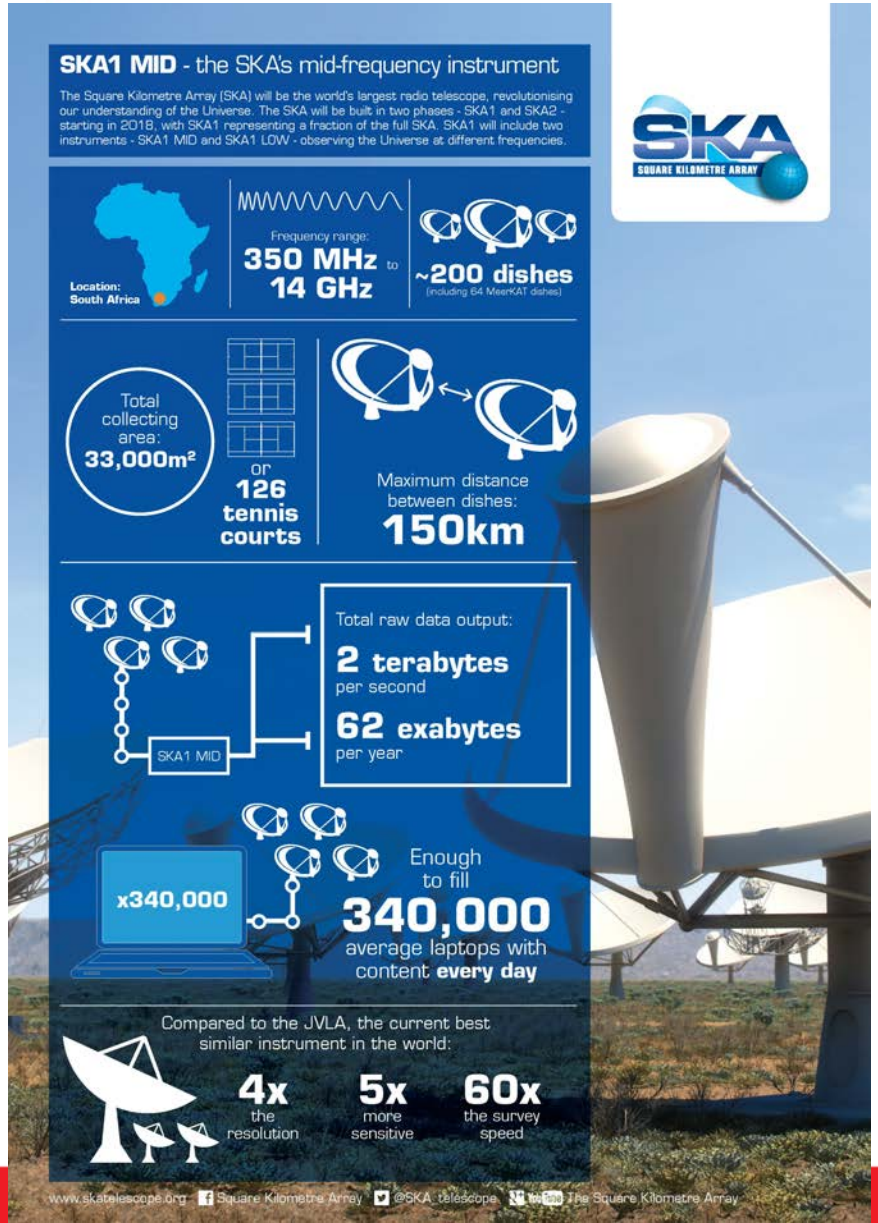
Chapters all available: http://arxiv.org/html/1412.6942v1

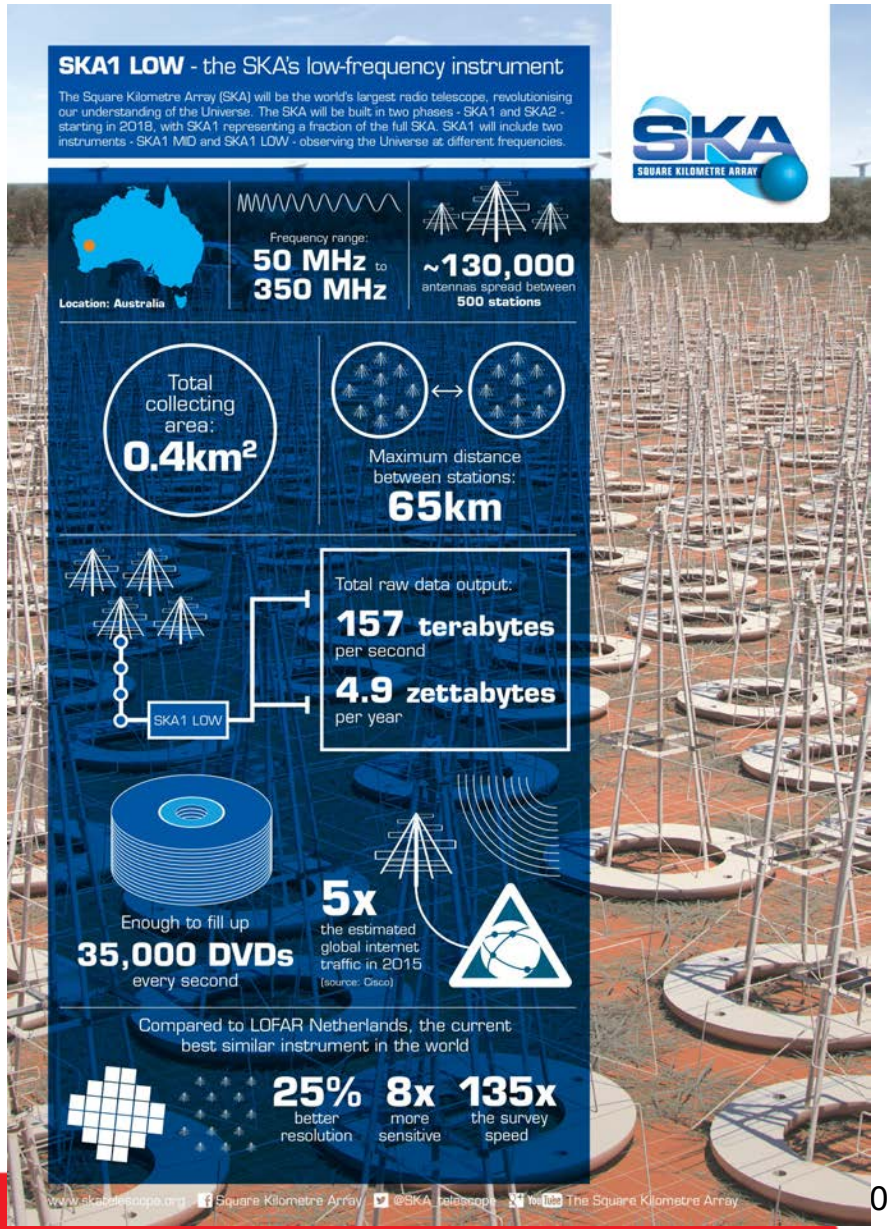
- **What is the key science planned for SKA1? Refine from EMU**
- **Where does Australia have critical mass (research-wise)? Leadership potential? Yes, Build on ASKAP/MWA**
- **What are the synergies with other wavelengths? Are these links in place? Keep track of multi-lambda**
- **Is there potential science that has been missed by the written science cases – how well developed is it – is there work to be done?**
- **(Have you considered developing new science interests over the next 5 years?)**
- **What is the most exciting science that you think should be pursued by SKA1? The new class of objects from EMU**

OzSKA Continuum Discussion

- **Key Science is SFH officially, but can't disentangle from the general theme of galaxy evolution**
- **Good expertise already here in Australia, but little overlap with SKA Continuum SWG, get engaged**
- **Key to science is to align with other multi-lambda deep surveys**
- **Accept science case will evolve, e.g. with EMU we keep generating new KSPs after we thought we'd exhausted ideas**
- **How do percusors feed into SKA: MWA/GLEAM and ASKAP/EMU will provide SKA with an all-sky model**
- **Match to simulations, possible new KSP for EMU**
- **The new class of objects from EMU/GLEAM**
- **Broad band radio science**
  - LOW quickly confused -> cover wide-lambda
  - Need to get continuum from FLASH between MWA+EMU
  - High-nu survey (300MHz) from eMWA
  - Deep/Wide CX-band observation of the ATLAS survey fields

SKA Rebaselining





SKA Science WGs

- **Provide advice on science requirements**
- **Provide operational advice**
- **Make recommendations on potential improvements**
- **Promote SKA and science**
- **Structure:**
  - SWG chairs
    - Core members
    - Full teams

Table 1: Outline of Reference Surveys

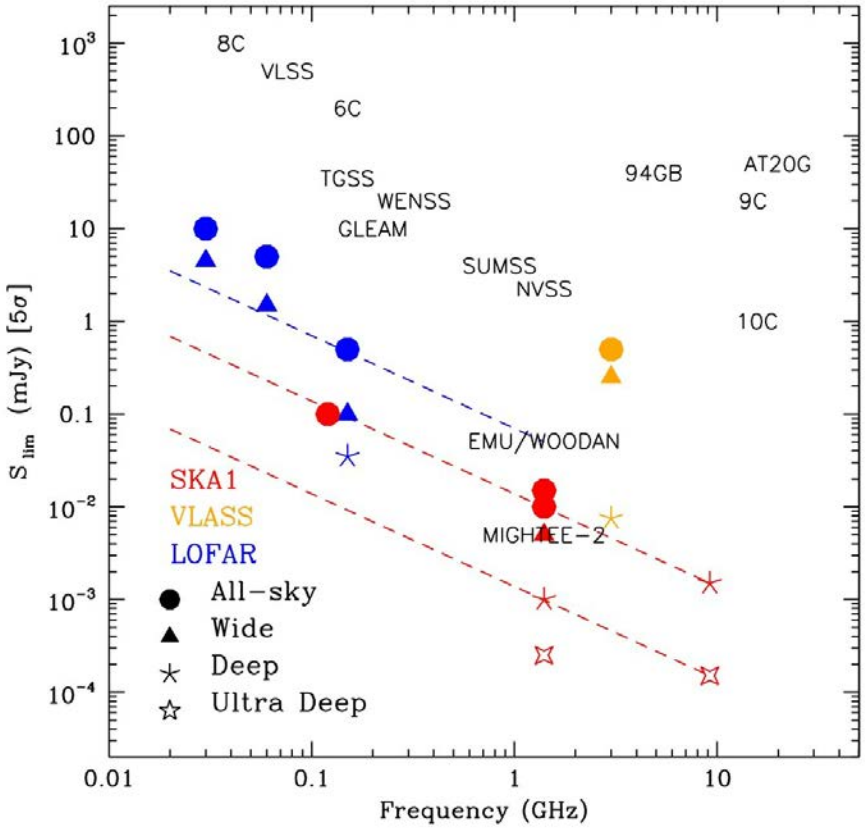
Main Science Drivers	Frequency (GHz)	Tier	Sensitivity rms μJy/b	Area deg^2	Resolution arcsec	Relevant Science
SFHU	$\sim 1^a$	Ultra Deep	0.05	1	0.5^b	SFHU non-thermal; $z \sim 3-6$
						SMBH evolution/AGN feedback
		Deep	0.2	10-30	0.5	SFHU non-thermal; $z \sim 1-2$
						SMBH evolution/AGN feedback
		Wide	1	$1\text{-}5\times10^3$	0.5	SFHU non-thermal; $0 < z < 1$
						Resolved SF in nearby Universe
						SMBH evolution/AGN feedback
						RL/RQ AGN dichotomy
						SF/AGN astrophysics in nearby galaxies
	~ 10	Ultra Deep	0.03	0.008	0.1	SFHU thermal; $z \sim 3-6$
						Resolved SF at $z \sim 1-2$
						SF/AGN Interplay
		Deep	0.3	0.5	0.05	SFHU thermal $z <\sim 1-3$
						Resolved SF at $z < 1$
						SF/AGN Interplay
Clusters	0.12	All-sky	$\sim 20^c$	31×10^3	10	RH and USSRH
						hadronic 'off-state' RH
						cosmic filaments
						RL AGN physics
						RL AGN in the EoR
Strong GL	1.4	All-sky	3	31 10^3	≤ 0.5	Strong GL
						SF/AGN astrophysics in nearby galaxies
						rare populations
Legacy	1.4	All-sky	2	31 10^3	~ 2	Legacy
			2			Galaxy Plane
			2			Serendipity
						rare populations

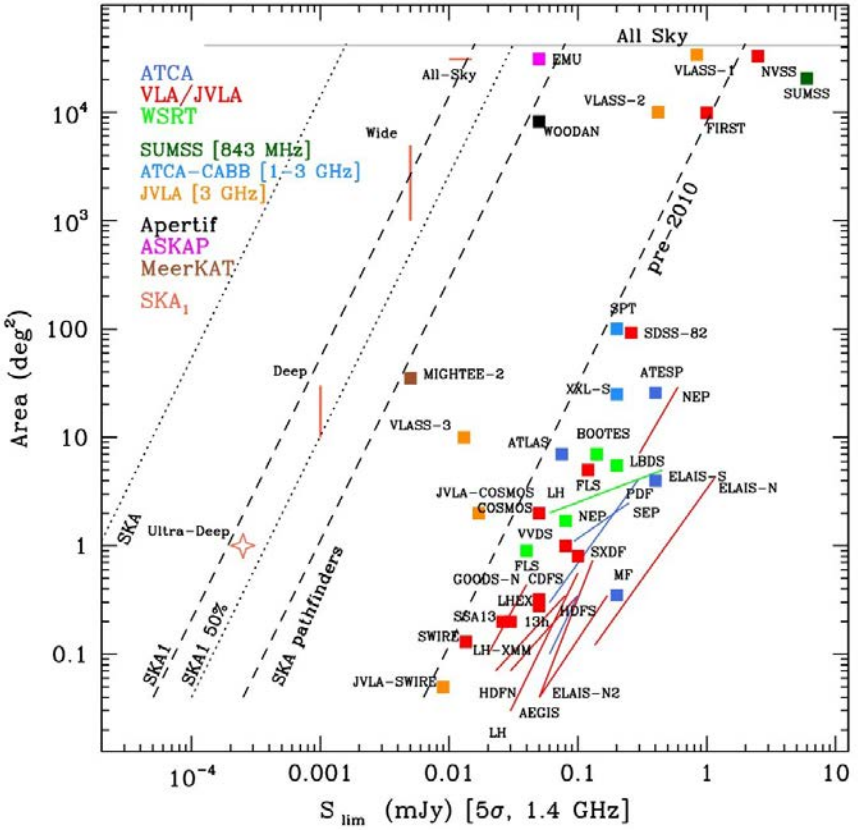
[a] Reference value. The observing frequency can be fine-tuned within Band 1 and/or 2

[b] Reference value at 1 GHz. <1 arcsec required to avoid confusion (see text)

[c] Confusion limited

SKA Continuum Reference Surveys





SKA KSPs

- Ensure KS objectives addressed
- Facilitate deliverary of data products
- Share expertise between members
- 50-70% of time dedicated to KSPs
- KSPs expected to dedicate resources
- Membership open to SKA members, but some restrictions for non-members
- Great opportunity to get involved now
- 2-3 workshops per year: 1st in Stockholm this August