Radio Continuum Extra-galactic Surveys & Deep fields The pathway to the SKA

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Science-driven Requirements for the SKA

Based on SKA Science Book

(Carilli & Rawlings Eds. 2004)

•Sensitivity ≈ 1-2 10^4 m^2 K^{-1}

(low T_{sys} receivers)

•Survey speed

≈ 0.2-60 10^8 deg^4 m^4 K^{-2}

(large FOV, up to 1 deg^2)

•Resolution ≈ 1-100 mas

(long baselines, up to 4500 km)

	Description of Key Science Project	Frequency Range (GHz)	FoV	Sens-itivity	Survey Speed	Resn.	Base-line	Dyn. Range Driver	Poln. Driver
		.1 0.3 1.0 3.0 10 30	deg^2	m^2/K	$deg^2 m^4 K^{-2}$	mas*	Km		
1	**The Dark Ages**								
1a	EoR				>~3x10^7		10	√	√
1b	First Metals		0.003	15,000		50	125		
1c	First Galaxies & BHs			20,000		10	4500	√	√
2	**Galaxy Evolution, Cosmology & Dark Energy**								
2a	Dark Energy				6x10^9		5		
2b	Galaxy Evolution			20,000	1x10^9		10		
2c	Local Cosmic Web				2x10^7		0.5		
3	**Cosmic Magnetism**								
3a	Rotation Measure Sky				2x10^8		10-30		√
3b	Cosmic Web				1x10^8		5		√
4	**GR using Pulsars & Black Holes**								
	Search				1x10^8		< 1		
4a	Gravitational Waves		-	>15,000		1	200		√
4b	BH Spin		1	10,000			-		√
4c	Theories of Gravity			>15,000		1	200		√
5	**Cradle of Life**								
5a	Proto-planetary Disks		0.003	10,000		2	1000		
5b	Prebiotic Molecules		0.5-1	10,000		100	60		
5c	SETI		1						
6	**Exploration of the Unknown**		Large	Large	Large				

*milli-arcseconds of angular resolution

From Dewdney et al. 2009

Radio Continuum Extragalactic Survey Science

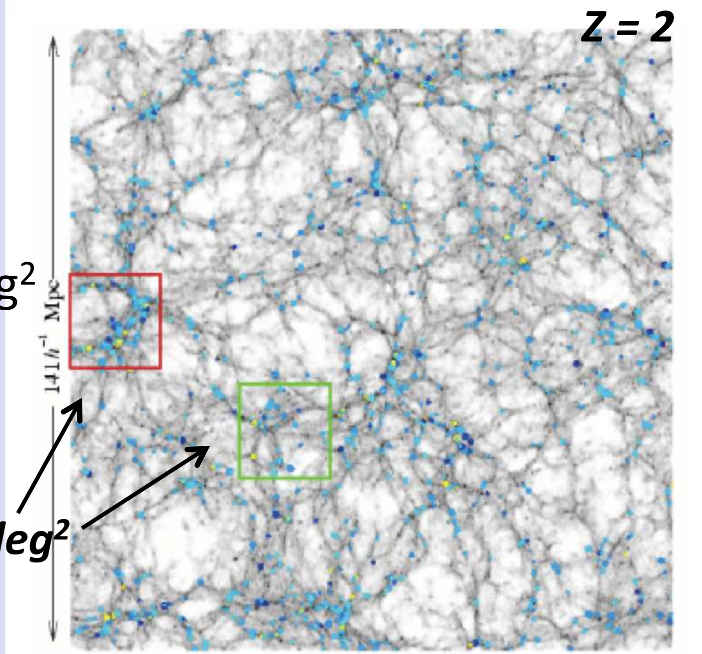
- Evolution of galaxies and clusters
  (in combination with HI + multi-λ information)
  - Star formation & BH accretion history
  - Role of AGN feedback over cosmic time
  - Interplay between SF and AGN activity
  - Origin of FIR-Radio correlation
  - diffuse non-thermal emission in clusters
  - first galaxies, BHs & protoclusters

Deep fields
~10-100 deg^2

- Cosmology (in combination with HI/redshift surveys)
  - Baryonic Acoustic Oscillations
  - Integrated Sachs-Wolfe Effect
  - Magnification Bias
  - Weak lensing

- Magnetism (in combination with polarization)
  - Formation & evolution of magnetic fields

Shallower wide-area surveys
>1/4 sky



GALFORM, Benson et al. 2000

- Commensality between line/continuum/polarization surveys
- Synergy with surveys in other wave-bands

Large Area vs Deep Fields

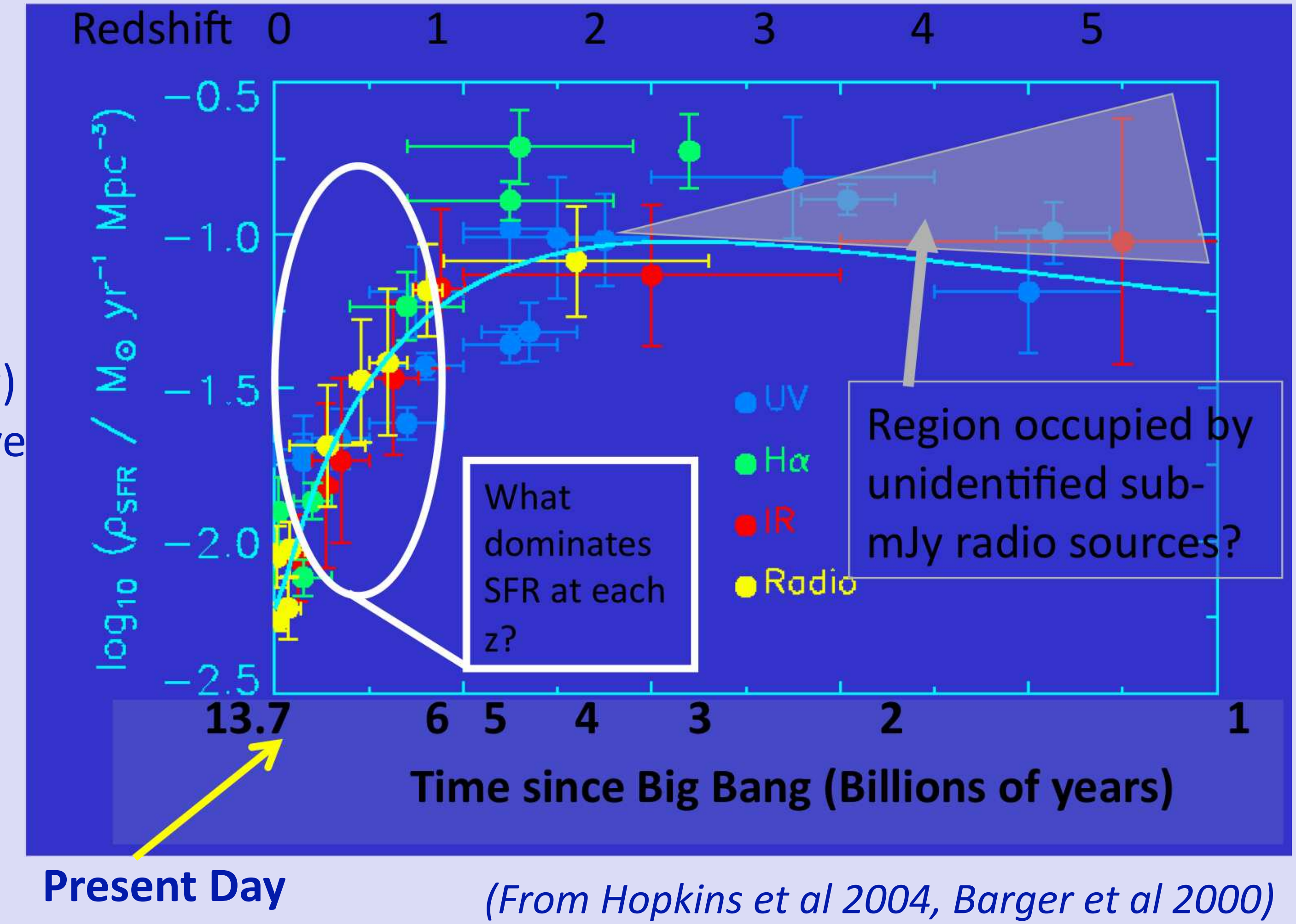
- Deep fields crucial for galaxy evolution (10-100 sq.degr):
  - Detect the highest redshift sources
  - Push down luminosity function – detect faintest galaxies
  - Limited area allows multi-band coverage
- Large area (>1/4 sky) is necessary for cosmology:
  - Number of sources
  - Cosmic variance
  - Power spectrum scales probed (e.g. ISW needs $l < 10$)
- Complementary and both required to meet science goals

Star Formation History

• Radio is sensitive tracer of star formation rates unaffected by dust or gas (at ν>> 1 GHz it traces thermal emission)

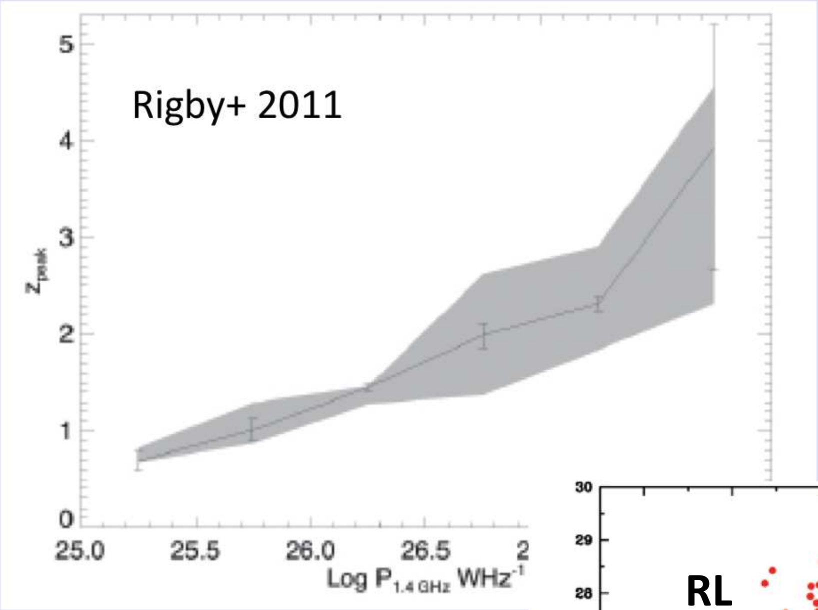
- SFRD vs redshift
  [Dust enshrouded
  SFH up to high z]

- SFRD as a function
  of mass (downsizing)
  (need of very sensitive
  radio observations



(From Hopkins et al 2004, Barger et al 2000)

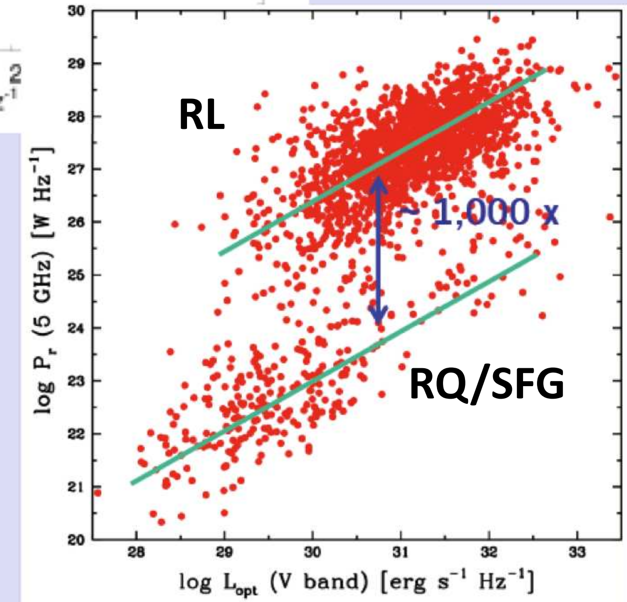
BH Accretion hystory

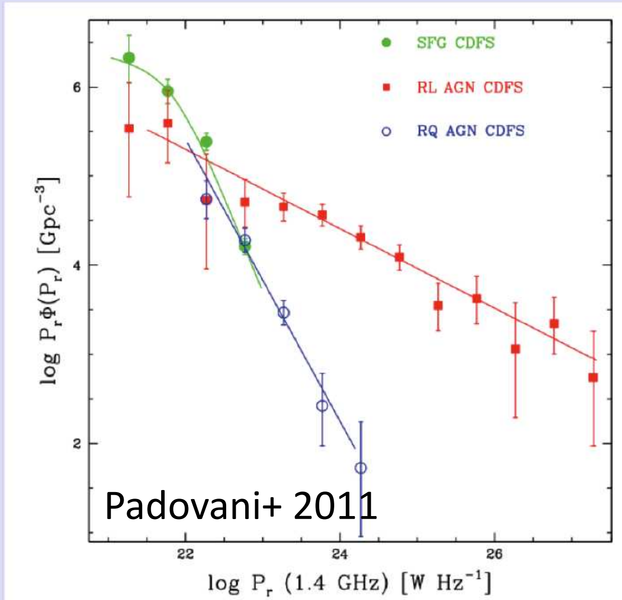


- Probe downsizing for low-P radio AGN: most powerful RS peak at the highest z
  Evolution at $P \ll 10^{25}$ W/Hz?

- Evolution of radio-selected RQ-AGN: they start to appear at microJy levels & share many properties with SFGs → radio em. dominated by SF?

- Interplay between AGN and SF activity in galaxies?





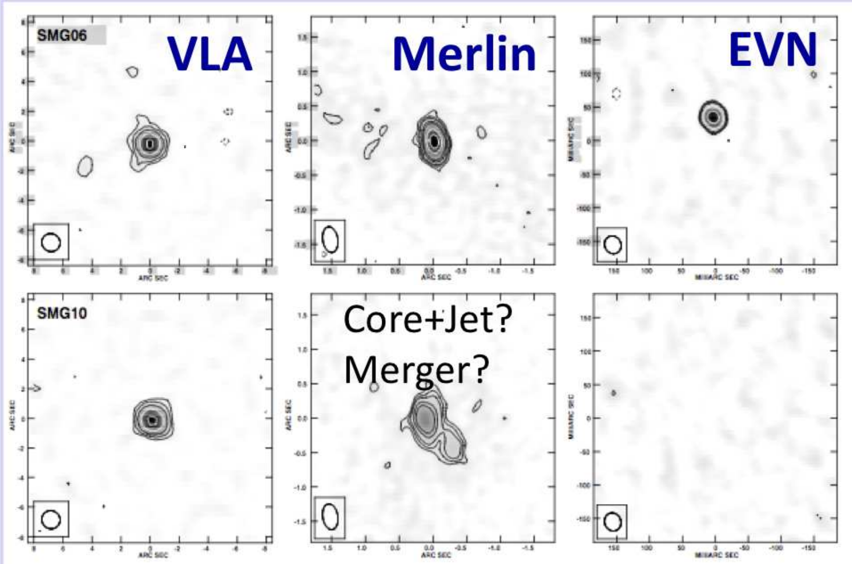
Composite sources: Separating AGN/SF activity

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

z=2.7
S=246 μJy

z=1.2
S=295 μJy

HDFN
Biggs+ 2010



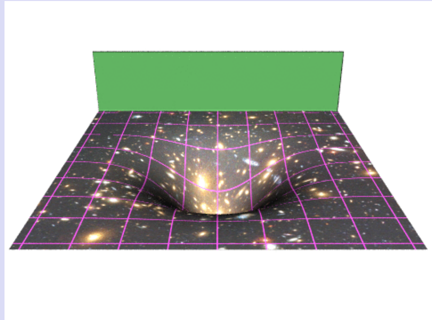
High spatial resolution allows to separate AGN/SF contributions in *hybrid* sources

- Unbiased estimation of SF/BH History especially at high-z

- Overall Energy budget of gals (balance of fusion vs. accretion)

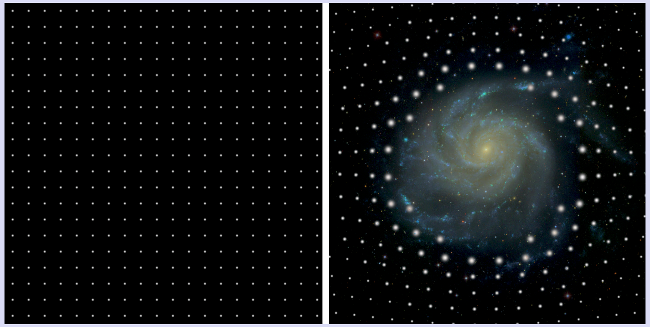
- Interplay between AGN and SF

Cosmology Tests



- ISW Effect

  Test: Cross-correlate radio sources with CMB

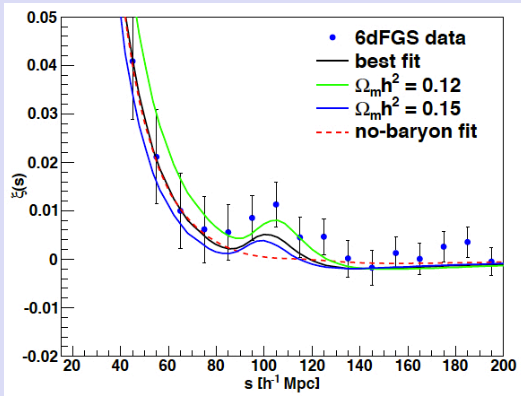


- Magnification Bias

  Test: Cross-correlate low-redshift opt/NIR galaxies with higher redshift radio sources

- Weak lensing

  Test: measurement of *cosmic shear* vs. redshift (in combination with HI line survey)

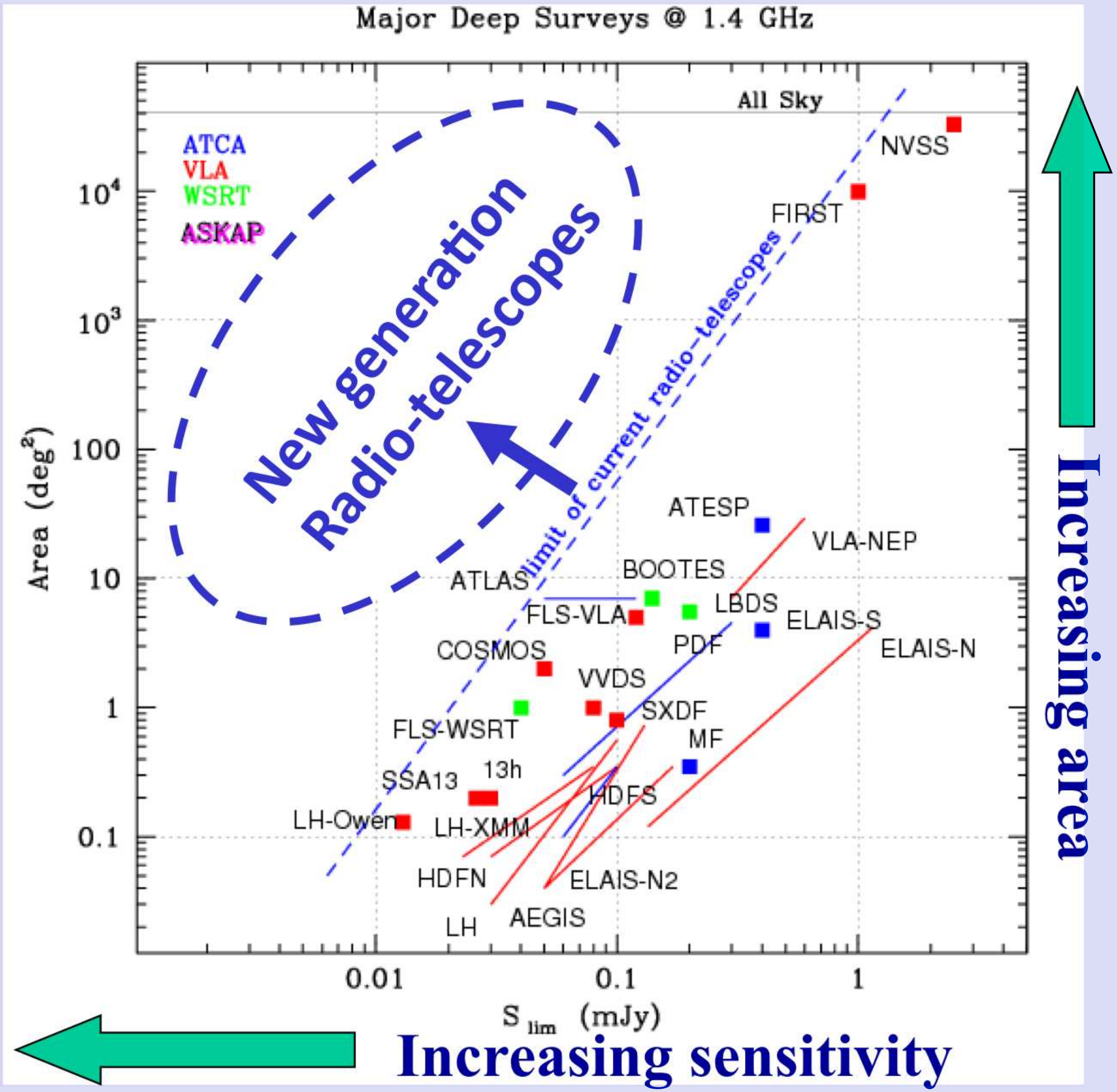


- BAO

  Tests: (angular?) autocorrelation or power spectrum (for spatial info → HI line survey)

Radio Continuum extra-galactic surveys

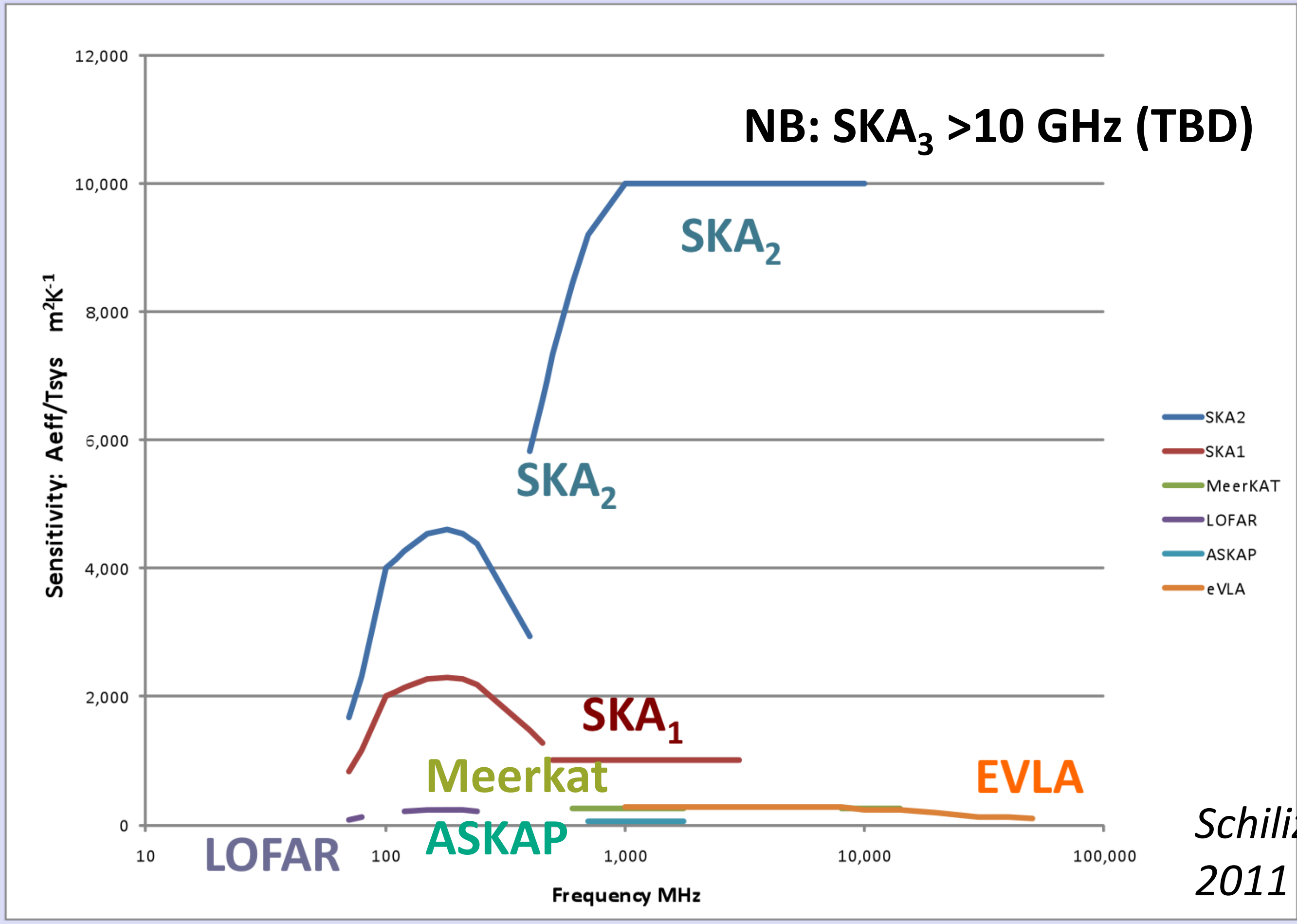
- Available extragalactic surveys & deep fields with current facilities
- Next generation radio telescopes will push the boundary by a factor of 10-1000
- Need of high sensitivity, together with high survey speed and high spatial resolution to beat confusion
- New region of parameter space will be explored, new discoveries expected



The SKA in steps: Sensitivity Comparison

Phased construction allows maximum use of advances in technology and incremental **fine-tuning of** science drivers/technical requirements

- Building on precursors & pathfinders (mainly EVLA & Meerkat) for SKA_1
- Building on SKA_1 (mainly SPF) for SKA_2

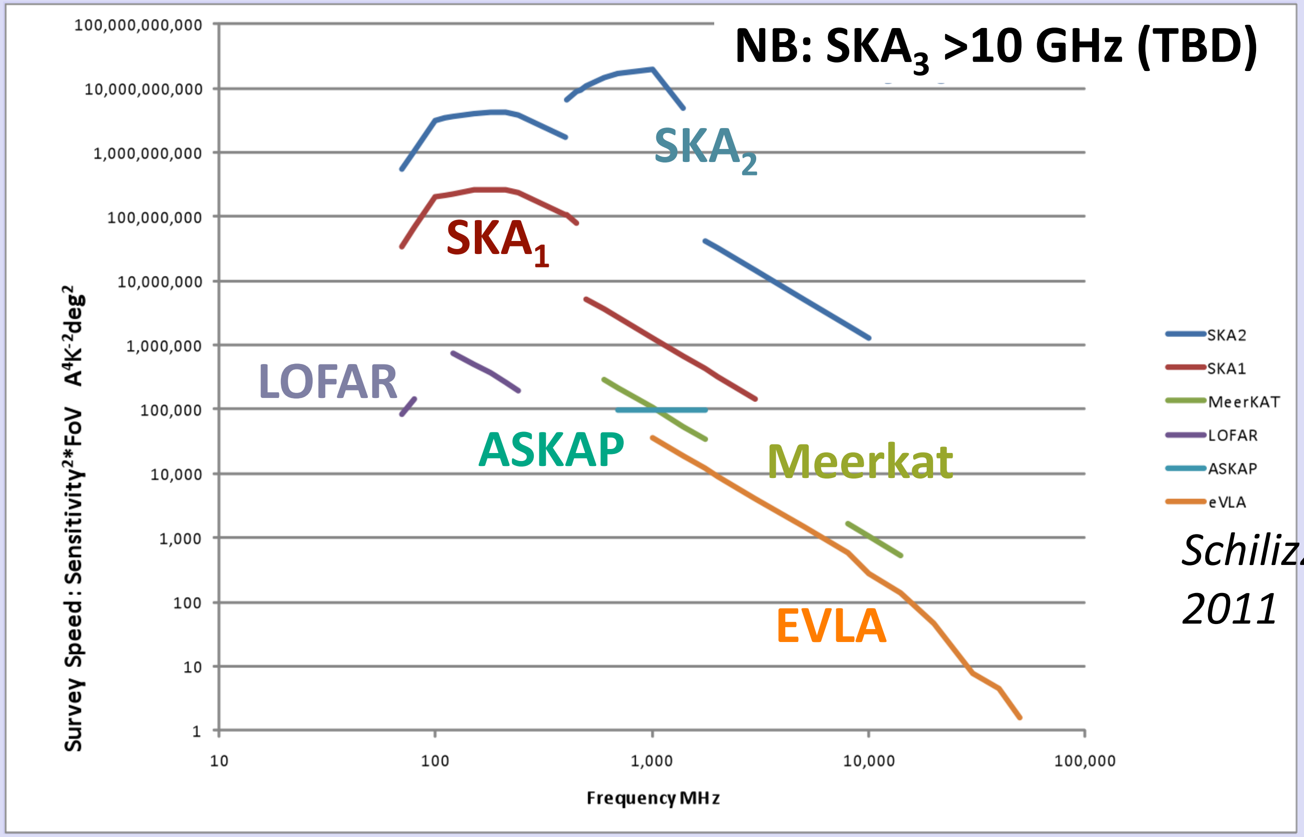


Schilizzi, 2011

The SKA in steps: Survey Speed Comparison

Phased construction allows maximum use of advances in technology and incremental **fine-tuning of** science drivers/technical requirements

- Building on precursors & pathfinders (mainly LOFAR & ASKAP) for SKA_1
- Building on SKA_1 (mainly AA & PAF) for SKA_2



Schilizzi, 2011

SKA_1 – Dual Site Implementation

Incremental approach confirmed by dual site implementation

- SKA1_Low: Western Australia (ANZ) → Sparse AA (50 stations)
- SKA1_Mid: South Africa (RSA) + '*survey instrument*' in WA

  - RSA: ~250 dishes w. low-Tsys SPF (incl. MeerKAT, 64 *13.5-m* antennas)

    high A/T (1000 m^2/K) lower SS ($1\ 10^6\ deg^4\ m^4\ K^{-2}$)

    [FOV(1 GHz)=1 deg^2]

  - ANZ: ~100 dishes w. PAF (incl. ASKAP, 36 *12-m* antennas)

    lower A/T (275 m^2/K), higher SS ($3\ 10^6\ deg^4\ m^4\ K^{-2}$)

    [FOV(1 GHz)=30 deg^2]

Implications for surveys: all-sky → ANZ; deep → RSA

Spatial Resolution Comparison

- High spatial resolution needed to beat confusion and to probe thermal processes

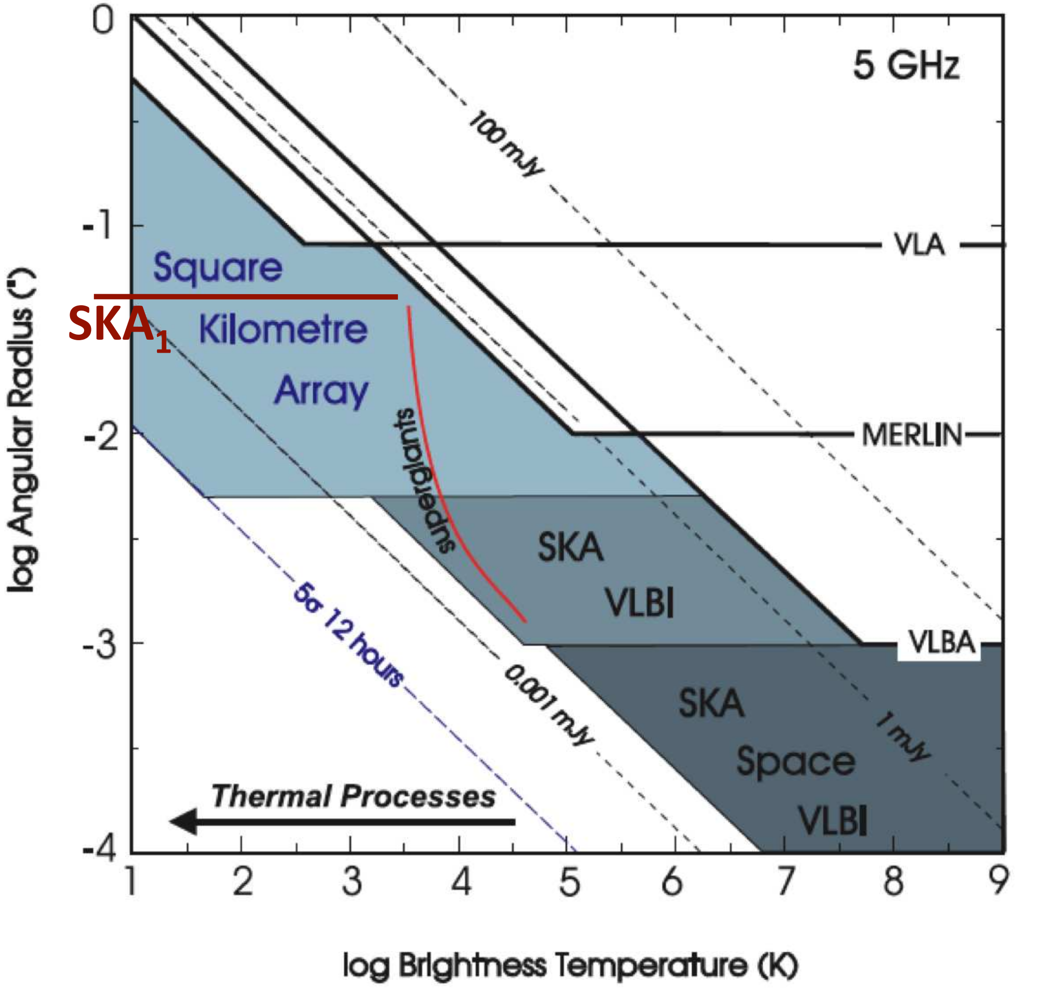
- The SKA will provide angular resolution of 10 milli-arcsec at λ=6cm down to continuum brightness temperatures T<100 K, and, as an element of a global VLBI array, a few milli-arcsec resolution at T ≈10^3 – 10^4 K.

- Possible issue related to natural confusion, due to finite source sizes

- Building on precursors and pathfinders (mainly eMerlin and eEVN) for SKA_1

- Building on SKA_1 for SKA_2

From Taylor & Braun Eds., 1999



Next Radio Continuum extra-galactic surveys

All-sky (rms 14 μJy)

- ASKAP: EMU

[+ APERTIF: WOODAN]

Deep fields

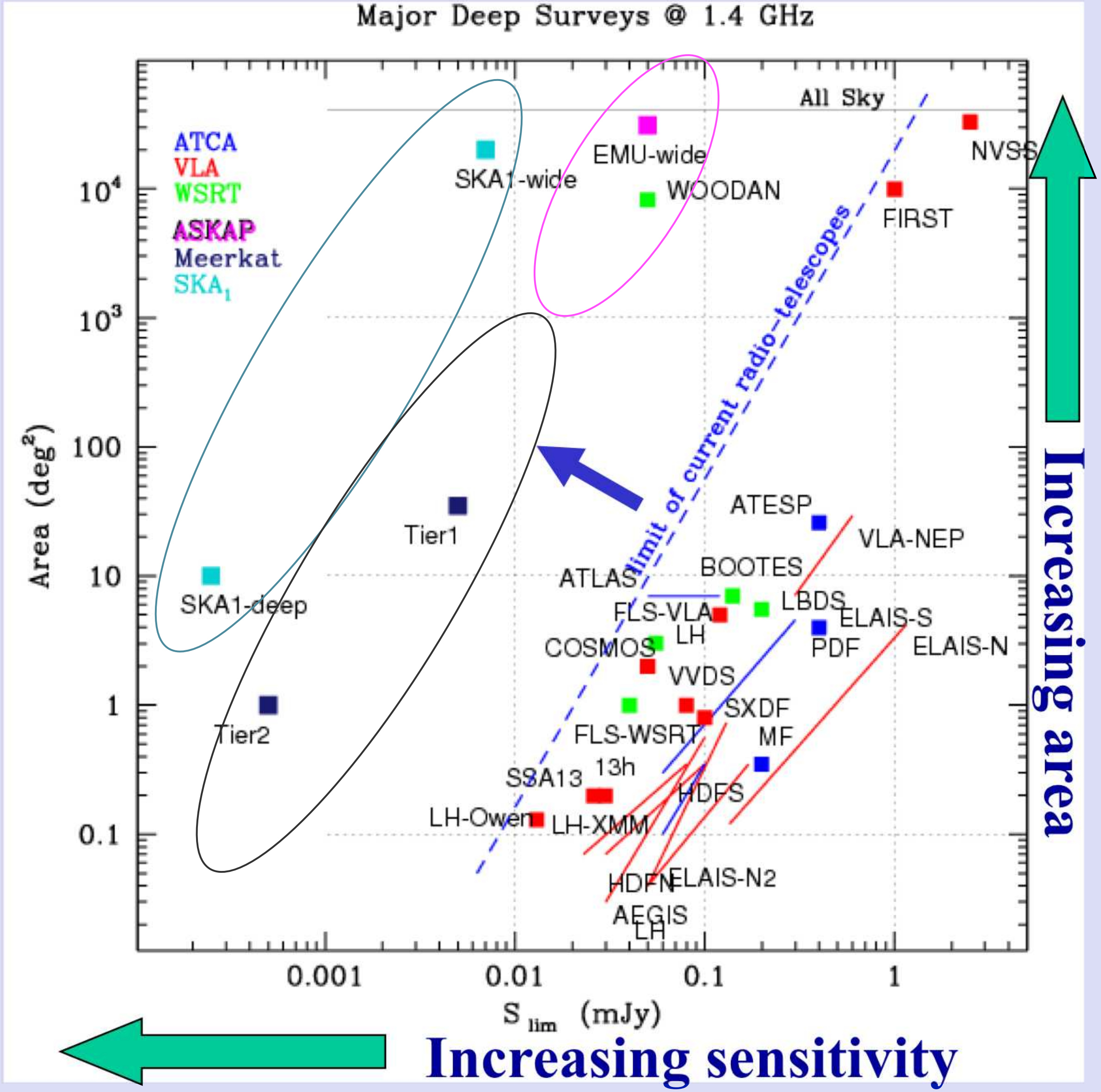
- Meerkat: MIGHTEE

Tier 1: 35 deg^2 rms 1 μJy

Tier 2: 1 deg^2 rms 0.1 μJy

SKA$_1$ Killer survey

work in progress

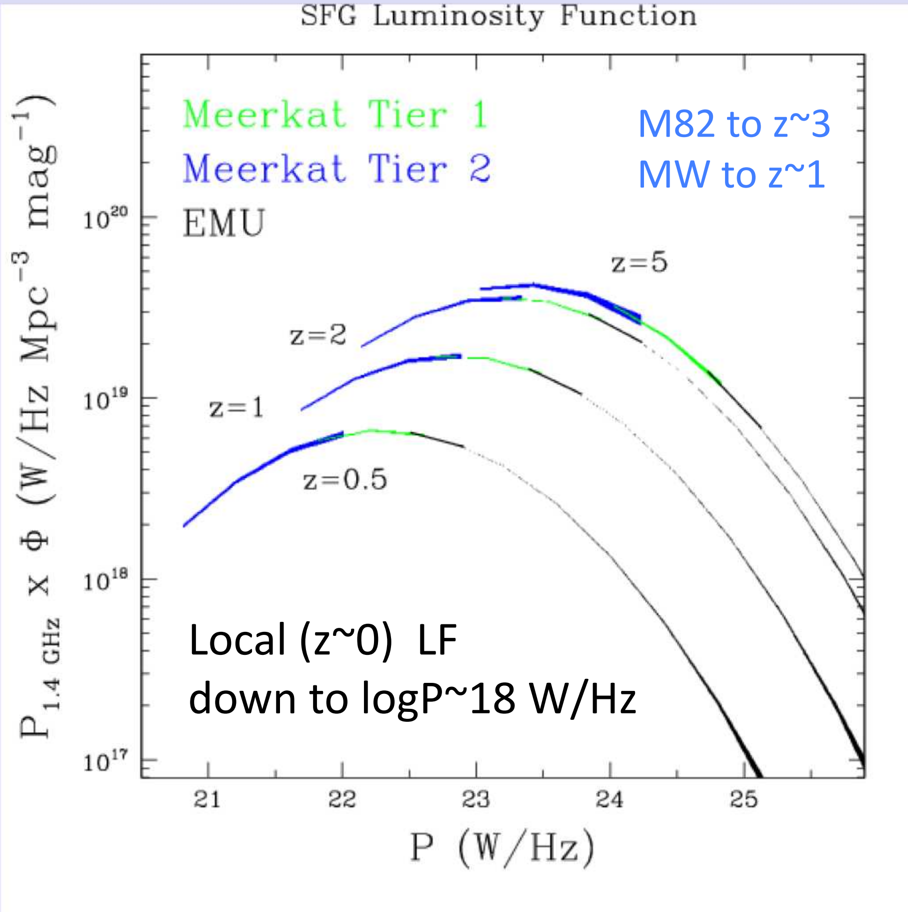


A Killer SKA_1 Survey
Courtesy M. Huynh (Deputy International SKA PS)

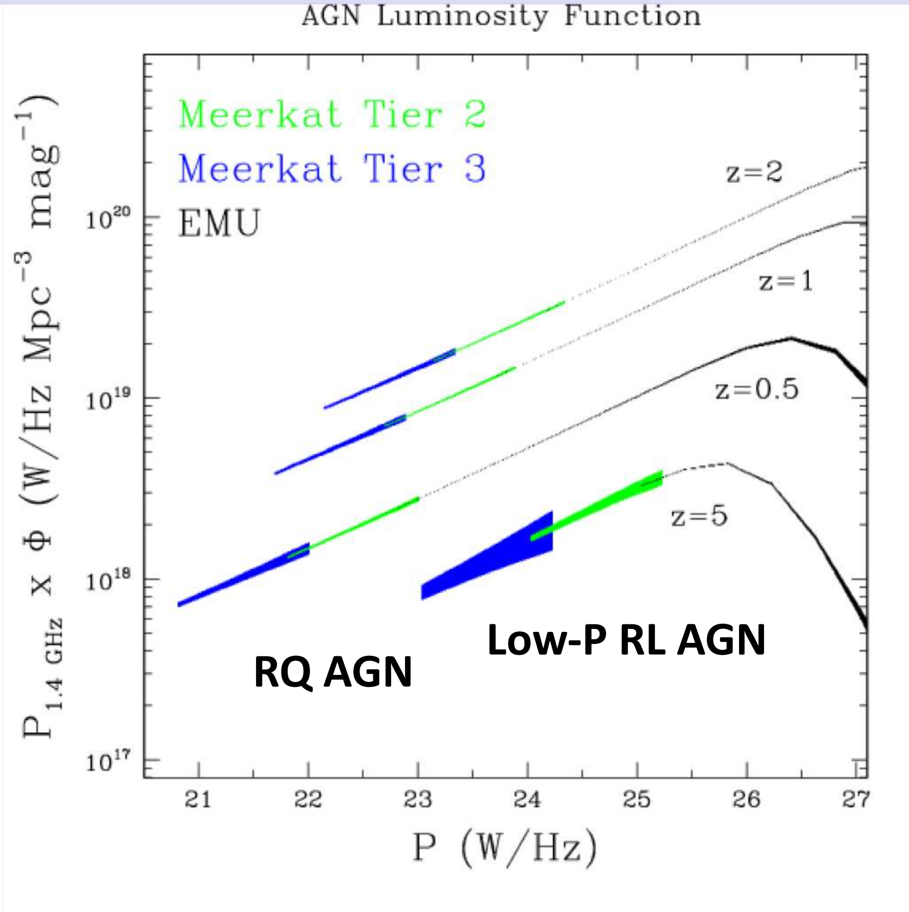
- Large-area SKA1_Survey at 1.4 GHz for cosmology (factor 10 deeper than EMU):
  - 20,000 deg^2 to ~1.4 μJy rms at 0.2 (2) arcsec resolution
  - Detect ~10 billion galaxies (5σ) c.f. 70 million in EMU
  - Approx 10,000 hours
  - Consider 750 MHz
- Deep SKA1_Mid survey at 1.4 GHz for galaxy evolution (factor 2 deeper than Meerkat Tier 2):
  - 10 deg^2 area to ~0.05 μJy rms at 0.2 arcsec resolution
  - Approx 10,000 hours (1000 hours per deg^2 pointing)
  - Basically at confusion limit
- SKA1_Low Surveys at 130 and 400 MHz for cosmology and spectral indices:
  - 20,000 deg^2 130 MHz survey to confusion limit (~10 μJy rms) at 2.3 arcsec resolution
    - Less than a day (Lofar Tier 3)
    - Opportunity for all-sky transient search with multiple epochs
  - 20,000 deg^2 400 MHz survey to ~5 μJy rms at 0.8 arcsec resolution (factor 2 deeper LOFAR Tier 3)
    - Well matched to 1.4 GHz large area survey depth
    - Approx 2000 hours

EMU+MIGHTEE: SFG/AGN LF

SFG Luminosity Function



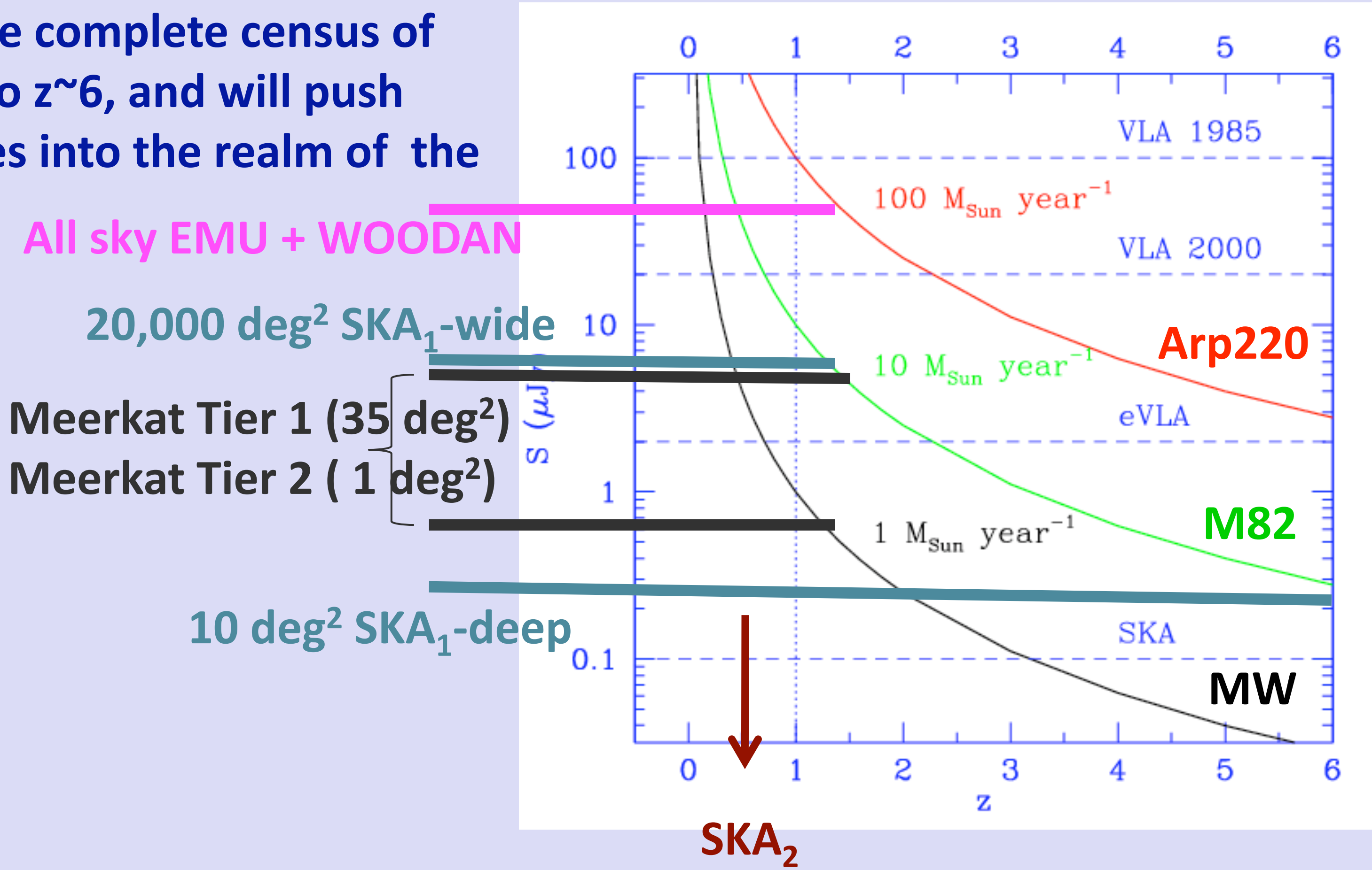
AGN Luminosity Function



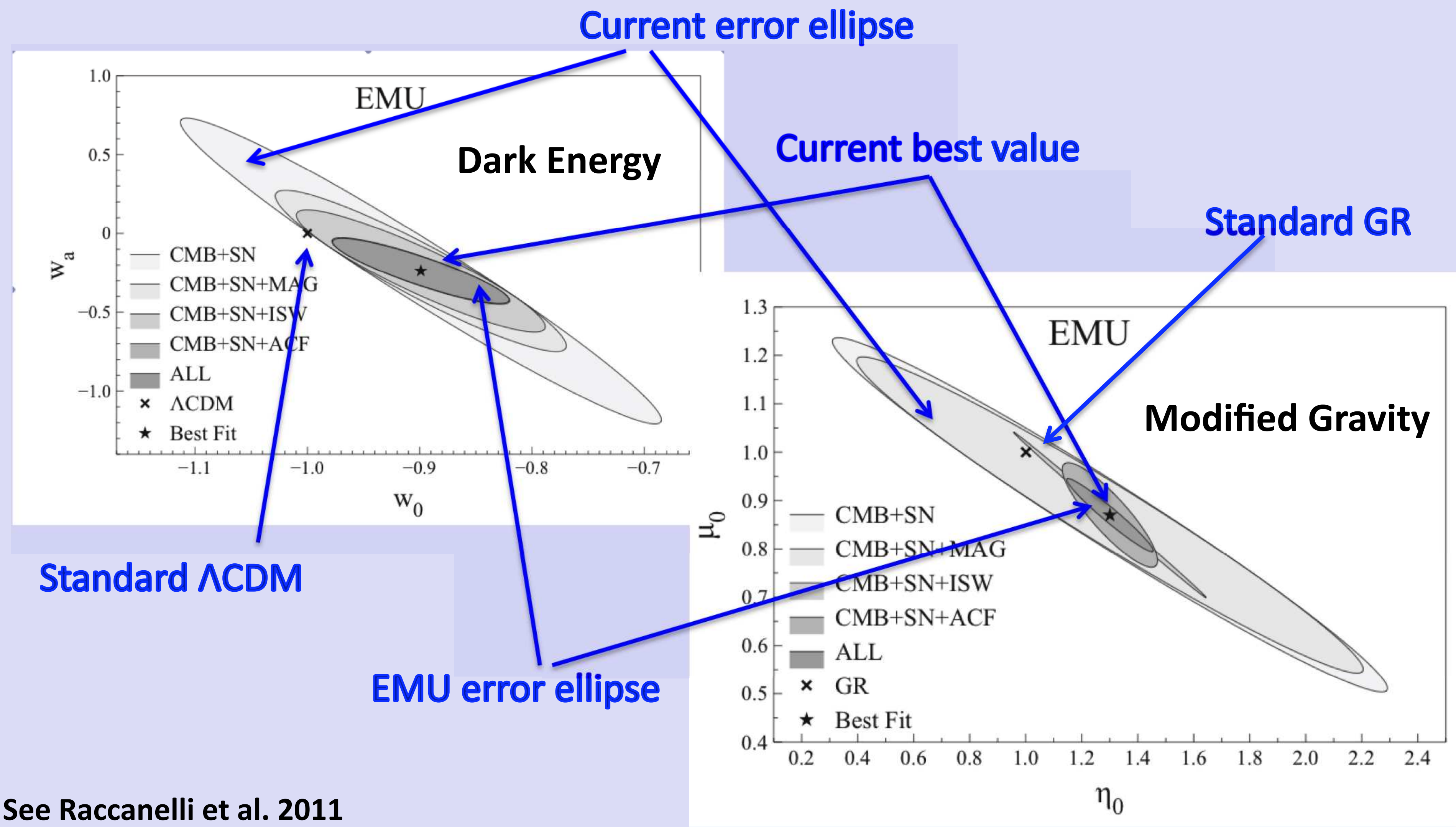
SKA_1 1.4GHz Surveys

•SKA_1 Surveys designed to give a complete census of galaxies (including MW-like) up to z~2 and to probe more intense star-forming gals to z~6

•SKA_2 will give complete census of galaxies up to z~6, and will push galaxy studies into the realm of the EOR (z>>6)



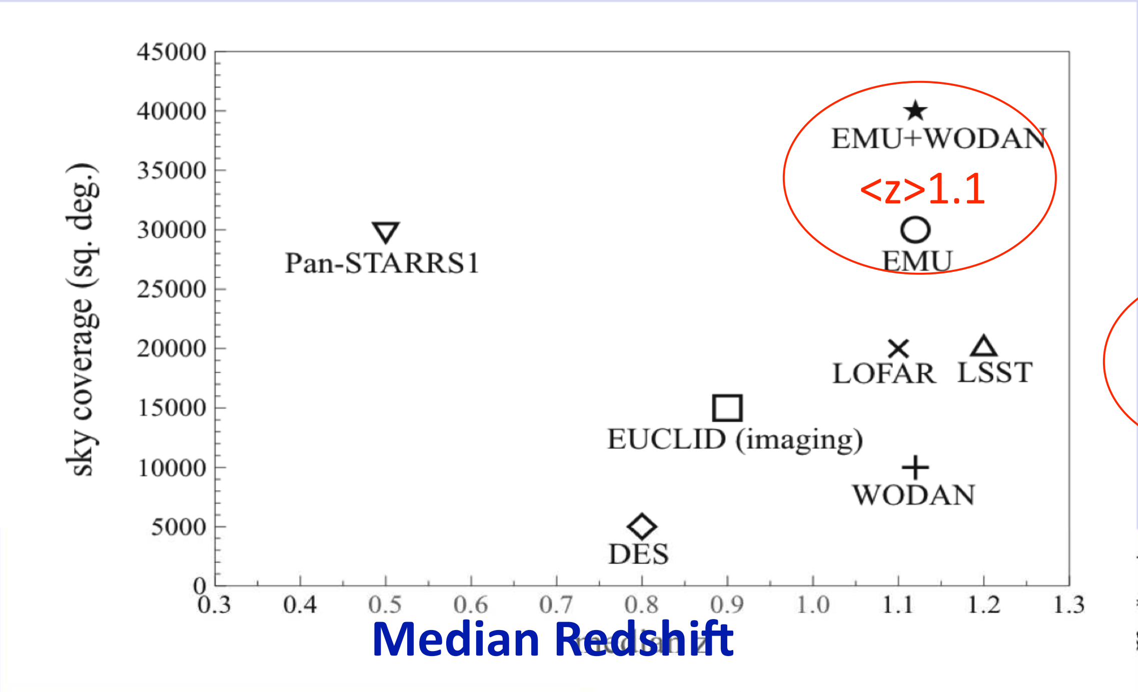
EMU: Precision Cosmology



See Raccanelli et al. 2011

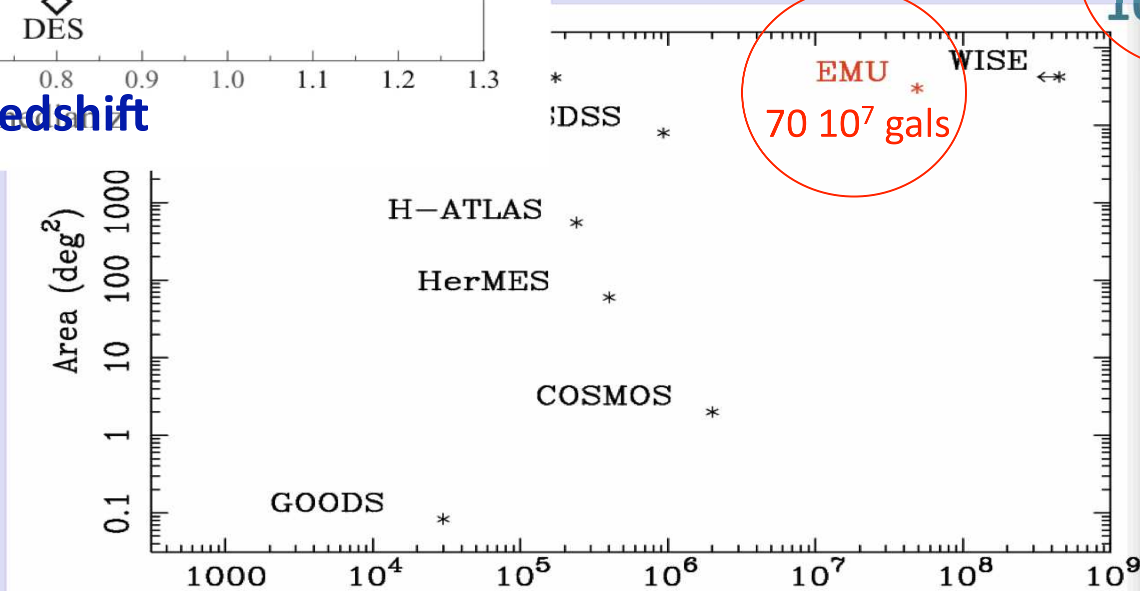
“Current error ellipse” based on Amanullah et al., 2010, plus Planck data

Precision Cosmology



SKA$_1$
<z>~2.5

SKA$_1$
10^{10} gals



SKA$_1$-wide will allows more precise measurements up to z~1-1.5, and will push cosmology studies to z>>1, probing the evolution of cosmological parameters

Open Issues for next-generation survey design

All expected results stronly based on simulations and/or extrapolations of current observations

Strong role of precursors & pathfinders (also in synergy with studies at other λ)

Fine-tuning necessary to better design SKA_1/SKA_2 surveys. For instance:

- **Better SFG/AGN Modeling** (including composite AGN/SF sources)
  - number counts at microJy levels
  - size evolution (implications on natural confusion)
  - radio SED (spectral index of faint radio sources)

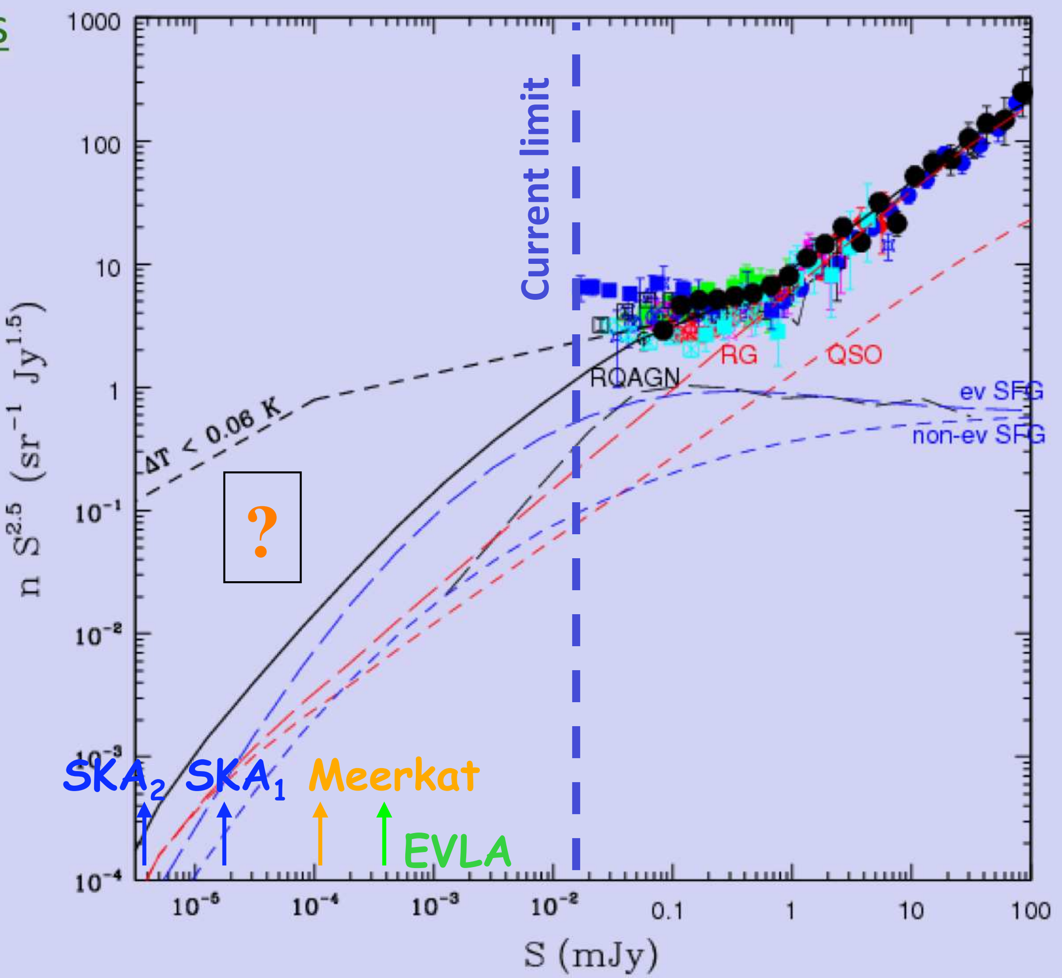
Galaxy/AGN Evolution – Modeling

Need of Fine-tuning source models

- Classical RL-AGNs
- SF gals.
- RQ-AGN
- Other classes?

Some Critical Issues for pathfinders/precursors:

- ev. of Low-P AGNs (Meerkat)
- extrapolation of local LF of SF & AGN to lower powers (ASKAP)



1.4 GHz Source Counts

Conclusions

- Valuable science expected in all phases to the full SKA:
  - from Pathfinders to Precursors to SKA1 & SKA2

- Previous phases will provide valuable constraints (both scientific & technological) to better fine-tune following phases
  - Better sky modeling + technology advances

- We don't need to wait for the full SKA. A lot of work can be done already now!

- Need for coordination among various groups (see e.g SPARCS), in coordination with ESKAC