Deep Surveys with the VLA, MERLIN, and the SKA

Ken Kellermann
NRAO

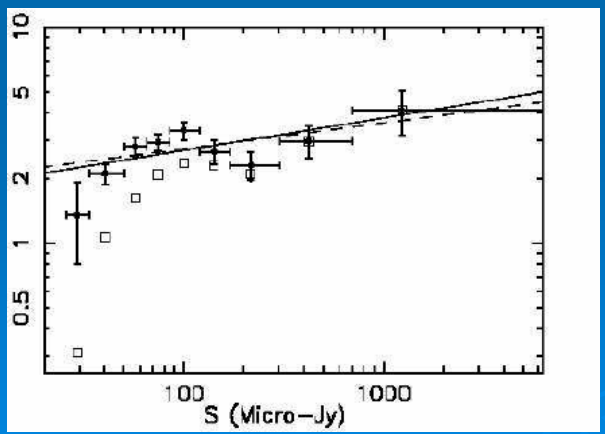
Why do Deep Radio Surveys?

- Accurate astrometry
  - Identify optical, IR, sub-mm, X-ray counterparts
- High angular resolution
  - Distinguish galaxies from AGN
  - Relate black hole formation to host galaxy properties
- To see through the gas and dust
- Early radio telescopes could detect strong radio galaxies at z~1
- VLA
  - Radio galaxies, quasars, AGN (massive BH's) to z >>1
  - Moderate star forming galaxies (M82) & LLAGN, and radio quiet quasars to z ~ 1
  - Beyond limits of most sensitive optical telescopes
- Expanded VLA (EVLA)
  - Star forming galaxies, RQQ, and LLAGN to z > 1

Deep Surveys with the SKA

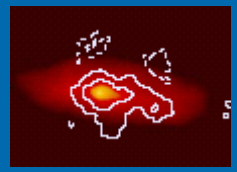
- SKA will have two orders of magnitude better sensitivity sufficient to observe
  - even normal galaxies at early cosmological epochs ($z \sim 1$) to trace early history of the formation of stars and galaxies
  - Radio quiet quasars and LLAGN to $z >> 1$ to trace formation and evolution of MBHs
  - To try to understand the relation between BHs and star formation

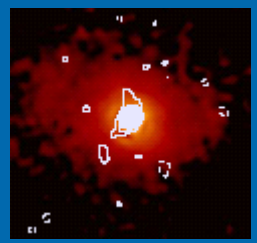
- Discover new things (e.g., quasars, pulsars, cosmic masers, CBR, gravitational lensing, jets, cosmic evolution, etc)

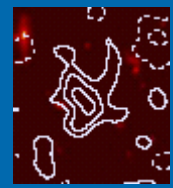

0.5
1
2
5
10
100
1000
S (Micro−Jy)

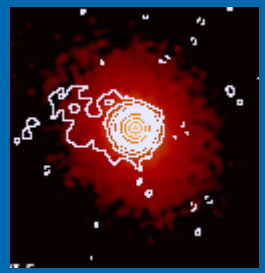
Limits of Radio Telescopes

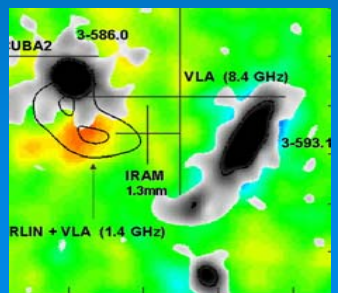
- Strong radio galaxies and quasars
- Weak radio galaxies
- Star forming galaxies
- Normal galaxies









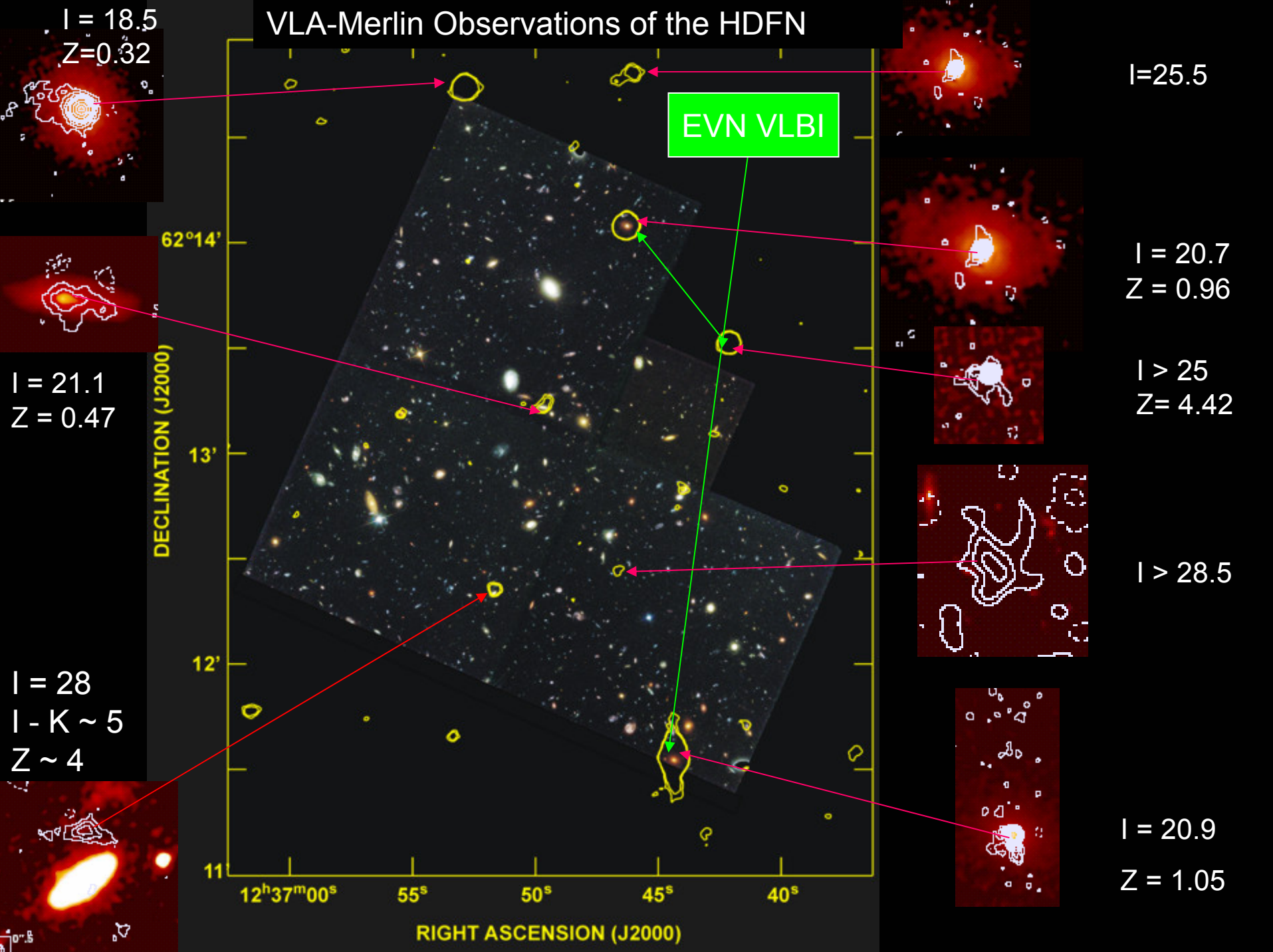

UBA2
3-586.0
VLA (8.4 GHz)
3-593.1
IRAM
1.3mm
RLIN + VLA (1.4 GHz)

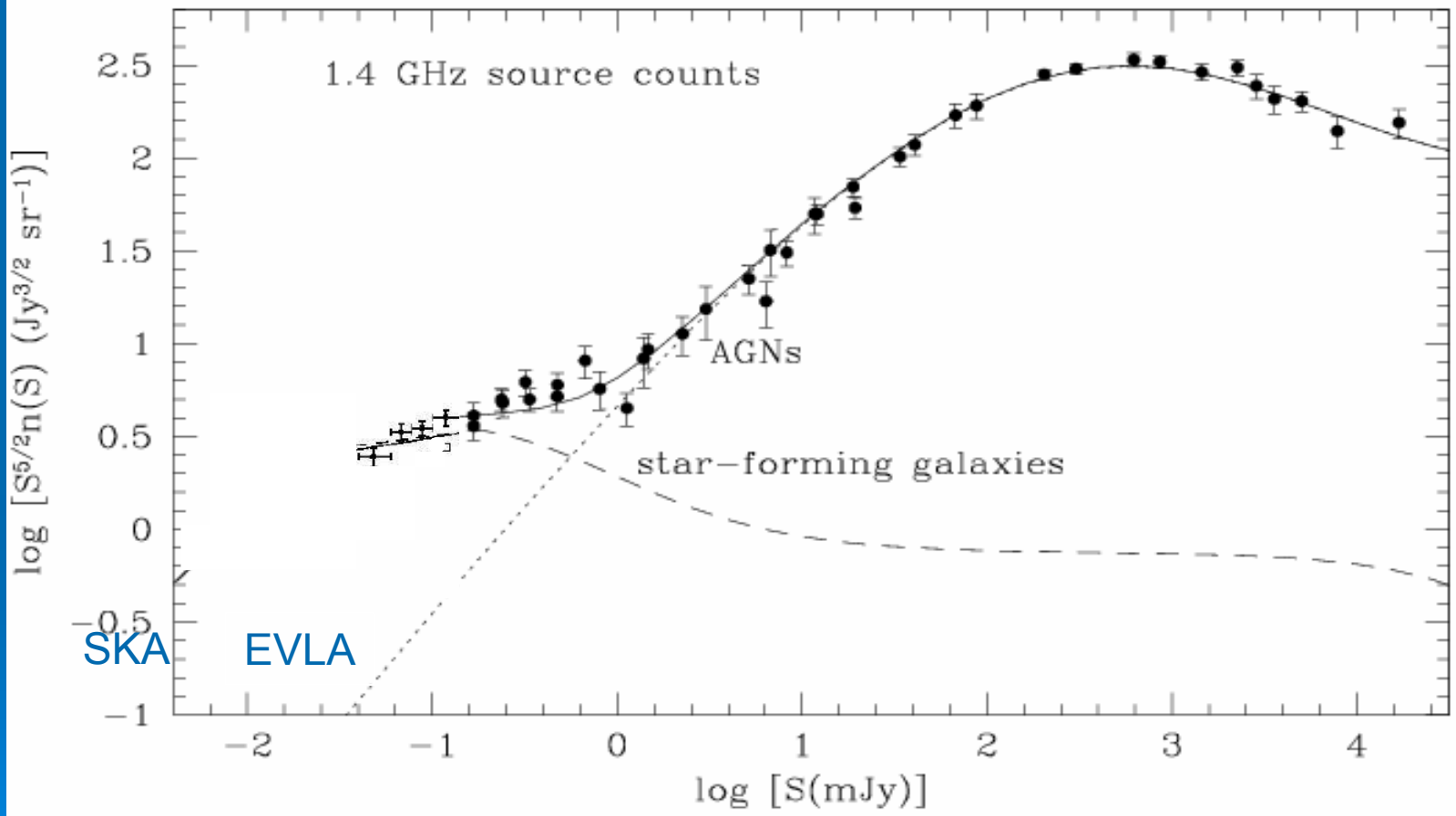
Some Existing Deep Surveys

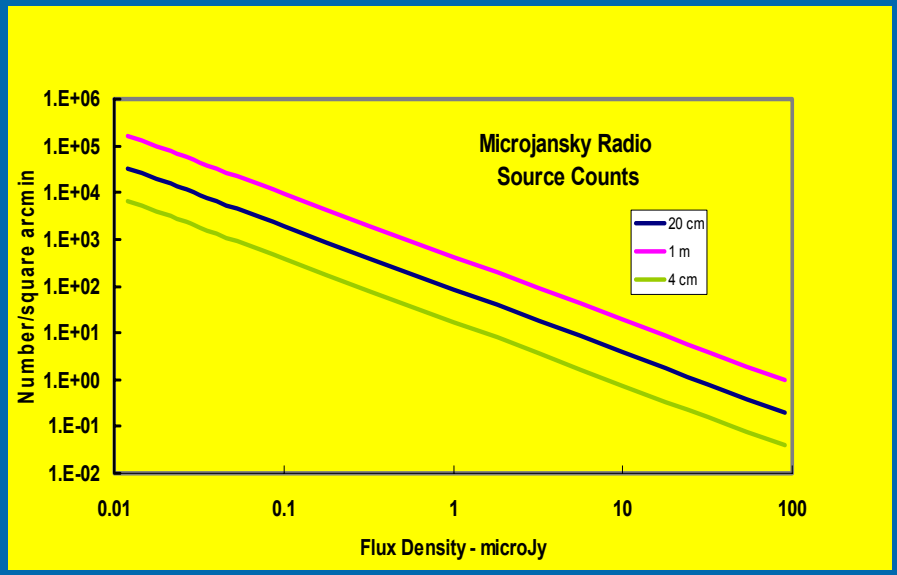
Field	λ_{cm}	$\sigma_{\mu Jy}$	N arcmin^{-2}	Reference
HDF_{VLA}	**4**	**1.8**	**0.5**	Richards et al. 1998, ApJ 116, 1039
HDF_{VLA}	**20**	**8**	**0.6**	Richards, 2000, ApJ, 533, 611
$HDF_{VLA+MERLIN}$	**20**	**3**	**0.6**	Muxlow et al. 2004, MNRAS, in press
HDF_{WSRT}	**20**	**8**	**0.8**	Garrett et al. 2000, A&A, 361, L44
HDF_{VLBI}0.025sec	**20**	**35**	**0.2**	Garrett et al. 2001, A&A 366, L5
$SSA13_{VLA}$	**4**	**1.5**	**0.6**	Fomalont et al. 2002, AJ, 123, 2402
$SSA13_{VLA}$	**20**	**5**	**1.5**	Fomalont et al. 2004, ApJS, in press
$CDFS/UDF_{VLA}$	**20**	**6**	**0.7**	unpublished

Array Sensitivity

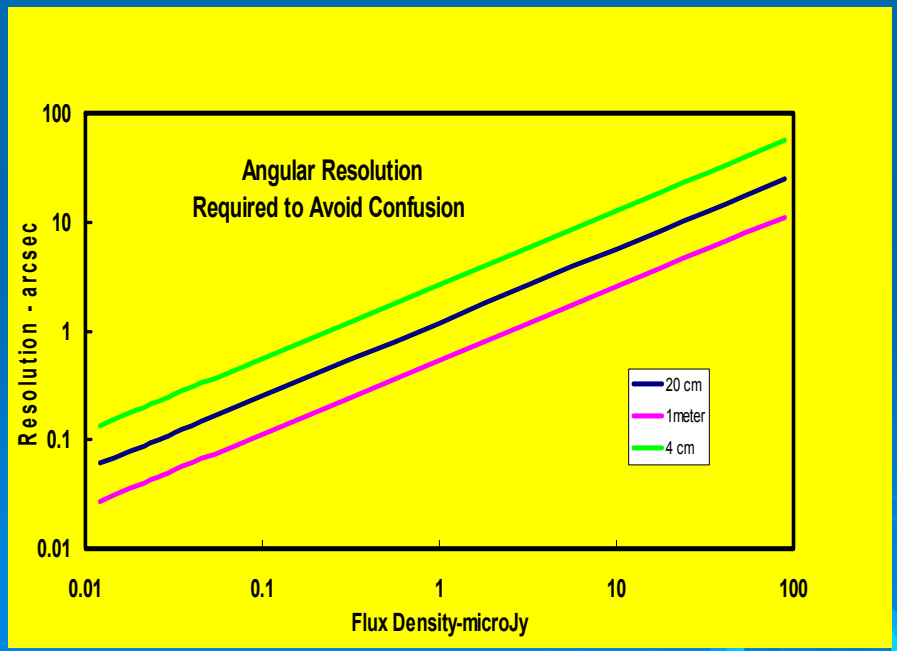
Array	Aeff	T_S	A_{eff}/T (m^2/K)	T_s(Jy)	σ_{nJy} – 400 hrs
ATNF	1600	35	45	60	4,000
WSRT	4100	30	140	20	2,500
VLA	7300	40	180	16	2,000
e-MERLIN	4000	25	160	18	250
EVLA I	8,000	30	270	10	140
EVLA II	10,000	30	370	8	100
SKA	400,000	20	20,000	0.2	2

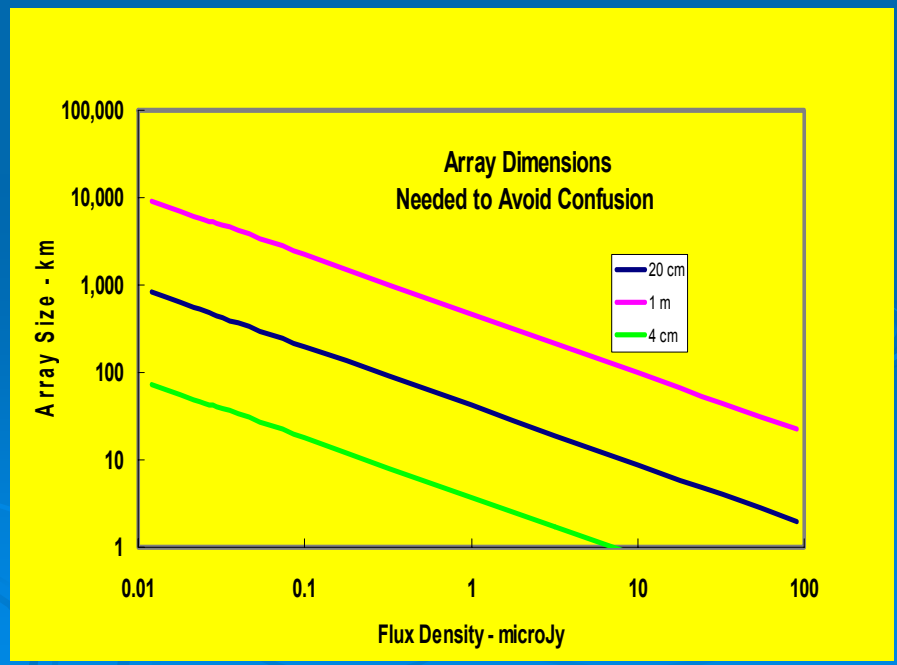

VLA-Merlin Observations of the HDFN
I = 18.5
Z=0.32
EVN VLBI
I=25.5
I = 20.7
Z = 0.96
I > 25
Z= 4.42
I = 21.1
Z = 0.47
I > 28.5
I = 28
I - K ~ 5
Z ~ 4
I = 20.9
Z = 1.05
62°14'
13'
12'
11'
DECLINATION (J2000)
12h37m00s
55s
50s
45s
40s
RIGHT ASCENSION (J2000)


1.4 GHz source counts
AGNs
star−forming galaxies
log [S(mJy)]
log [S^{5/2}n(S) (Jy^{3/2} sr^{-1})]
SKA
EVLA



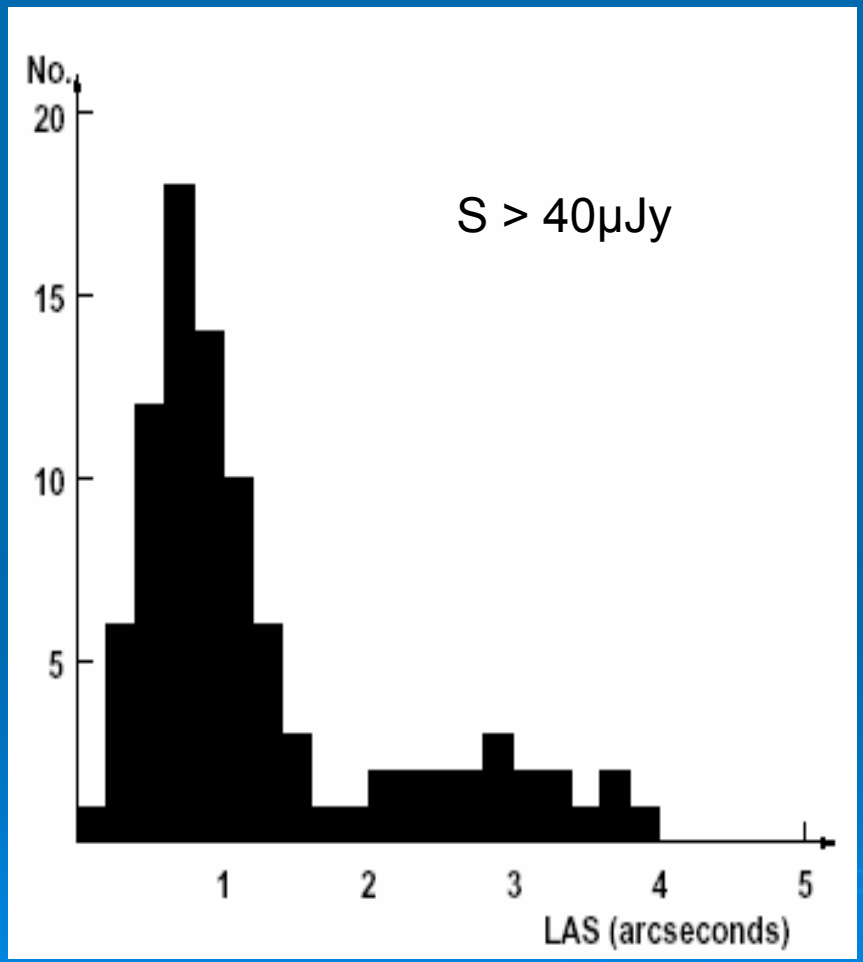
Resolution requirements to avoid confusion for point sources





Angular size Distribution of microJy Radio Sources from VLA-Merlin imaging of the HDFN

Muxlow et al. MNRAS (In press)



- $N(S_{40\mu Jy}) = 0.5$ armin^{-2}
- $N(S_{400nJy}) = 400$ sources armin^{-2}
- If $\theta \sim 1$ arcsec, 15% area covered by radio sources and will overlap
- Spectrum (color) and surface brightness differences may help disentangle overlapping sources

EVLA & e-MERLIN – SKA Pathfinders

- EVLA has an order of magnitude improvement in sensitivity over VLA
- EVLA and e-MERLIN have an order of magnitude improvement in resolution over VLA .
- Fill-in missing spacings between VLA and VLBA. EVLA gives continuous coverage from 30m to 8000 km.

Summary

- Sub μJy sources mostly due to star formation + weak AGN + ???
- EVLA will have improved sensitivity, angular resolution, and image quality needed to characterize the sub-μJy sky.
- Deep surveys made with the SKA will have sufficient sensitivity to
  - Observe radio galaxies, quasars active star forming galaxies anywhere in the Universe
  - Observe normal galaxies at z ~ 1
- With more than an order of magnitude improvement in sensitivity over other radio telescopes the SKA will have the potential for discovering new phenomena and to raise new questions.
- To reach theoretical noise the SKA will require sufficient angular resolution to avoid confusion. This implies array dimensions of ~ 1,000 km at 20 cm
- Natural confusion may limit the ultimate sensitivity of deep surveys