Deep Surveys with the VLA:
The CDFS and UDF

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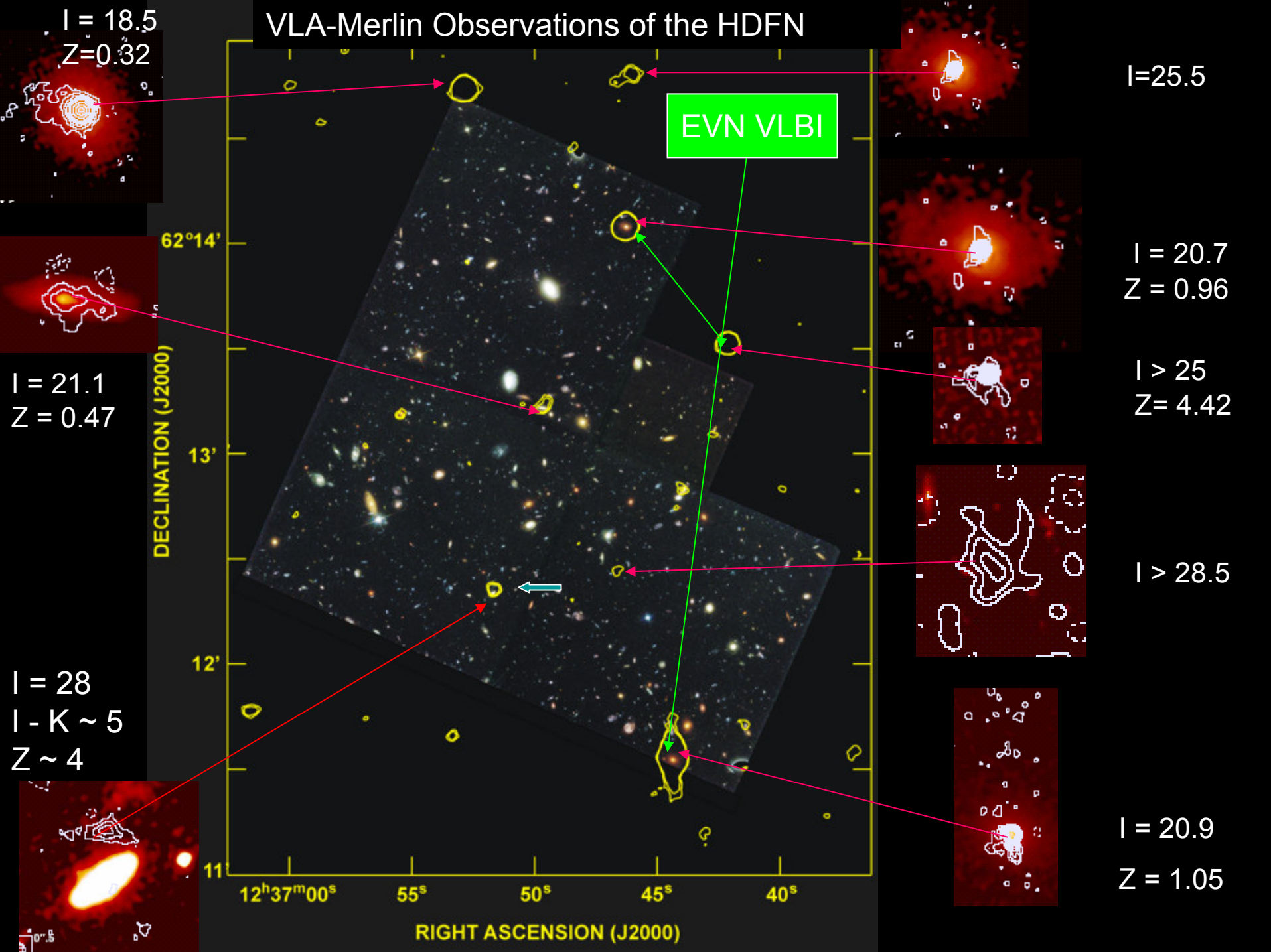
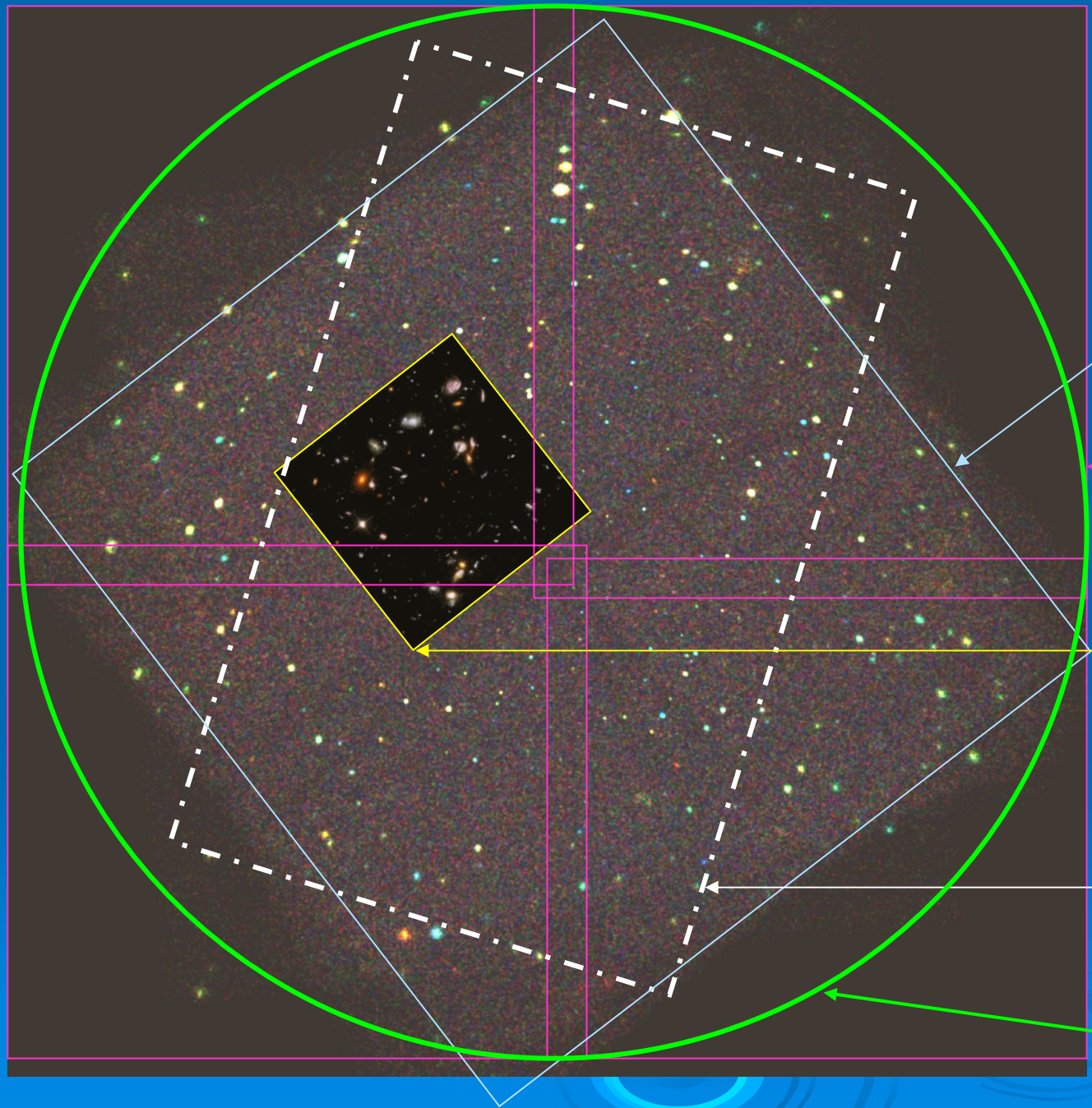
Deep VLA Surveys

Field	Θ_{asec}	λ_{cm}	$\sigma_{\mu Jy}$	N arcmin^{-2}	Reference
HDF_{VLA}	**1.5**	**4**	**1.8**	**0.5**	Richards et al. 1998, ApJ 116, 1039
HDF_{VLA}	**1.5**	**20**	**8**	**0.6**	Richards, 2000, ApJ, 533, 611
$HDF_{VLA+MERLIN}$	**0.2**	**20**	**3**	**0.6**	Muxlow et al. 2005, MN, 358, 1159
$SSA13_{VLA}$	**4**	**4**	**1.5**	**0.6**	Fomalont et al. 2002, AJ, 123, 2402
$SSA13_{VLA}$	**1.5**	**20**	**5**	**1.5**	Fomalont et al. 2006, ApJS, in press
$CDFS/UDF_{VLA}$	**3.5**	**20**	**8**	**0.8**	Unpublished
$CDFS/UDF_{VLA}$	**3.5**	**6**	**8**		Unpublished


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)



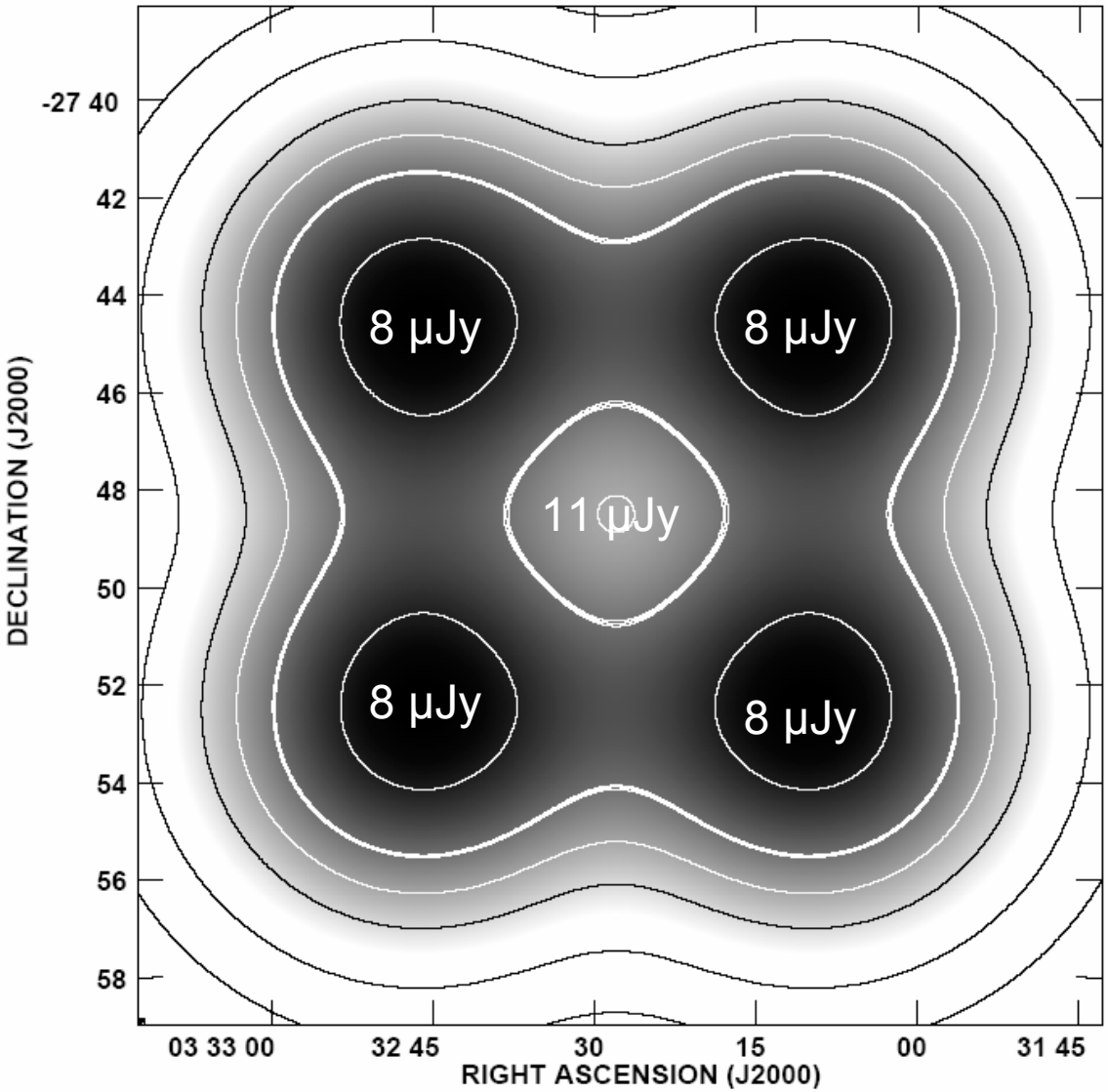
Chandra Deep Field South
942 ks exposure
361 X-ray sources
5×10^{-17} ergs/sec

Extended CDFS
250 ks per field

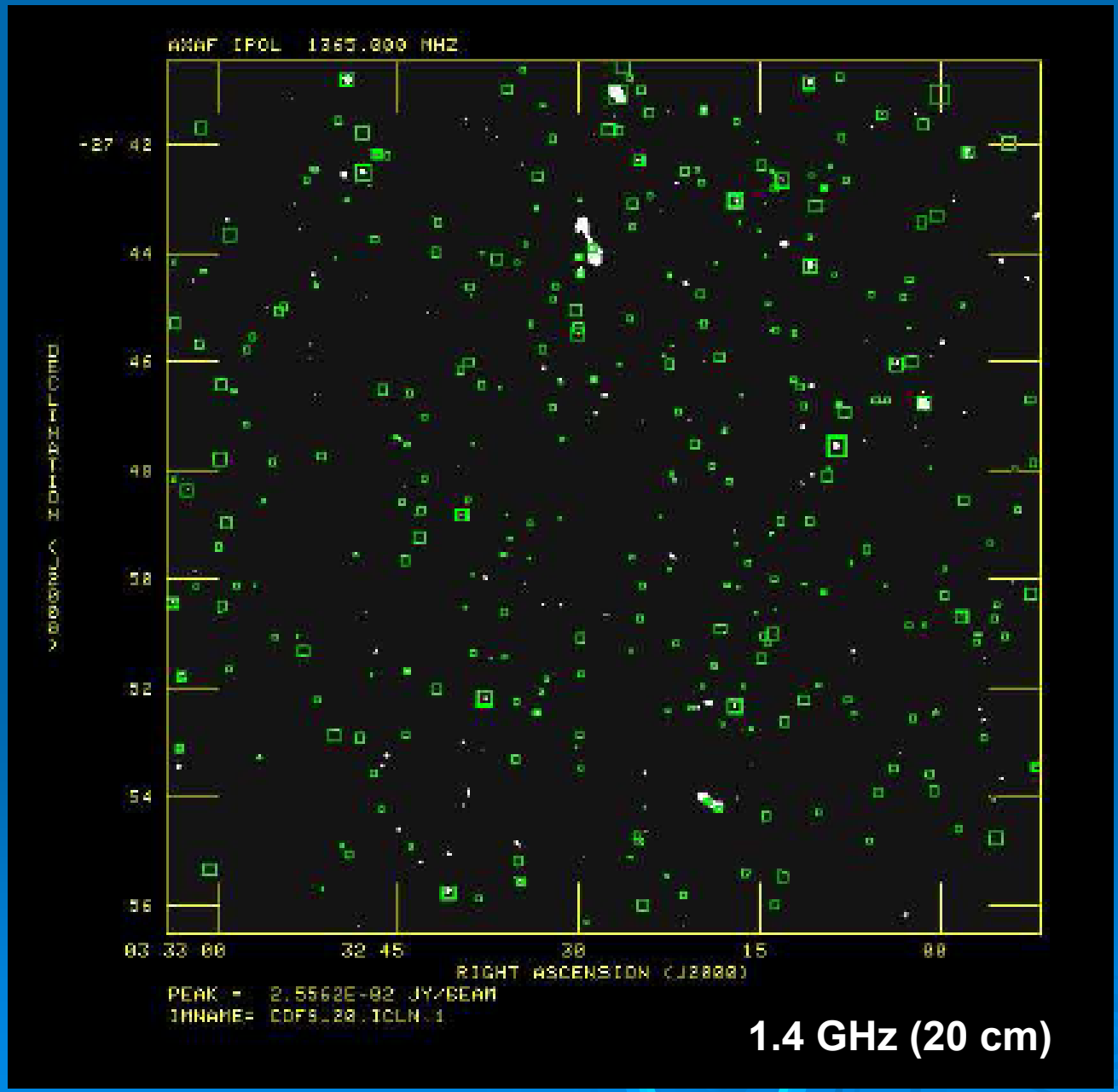
Hubble UDF
976 ks exposure
B, V, I, z
10,000 galaxies
I < 29

GOODS ACS
B, V, i, z
I < 28

VLA 20 cm


8 µJy
8 µJy
11 µJy
8 µJy
8 µJy
-27 40
42
44
46
48
50
52
54
56
58
DECLINATION (J2000)
03 33 00
32 45
30
15
00
31 45
RIGHT ASCENSION (J2000)

VLA Observations



1.4 GHz (20 cm)

6 and 20 cm

θ = 3.5 arcsec

σ = 8-11 μJy

266 Radio sources

198 Sources in Complete sample
S_{20} > 40 microJy
Within CDFS

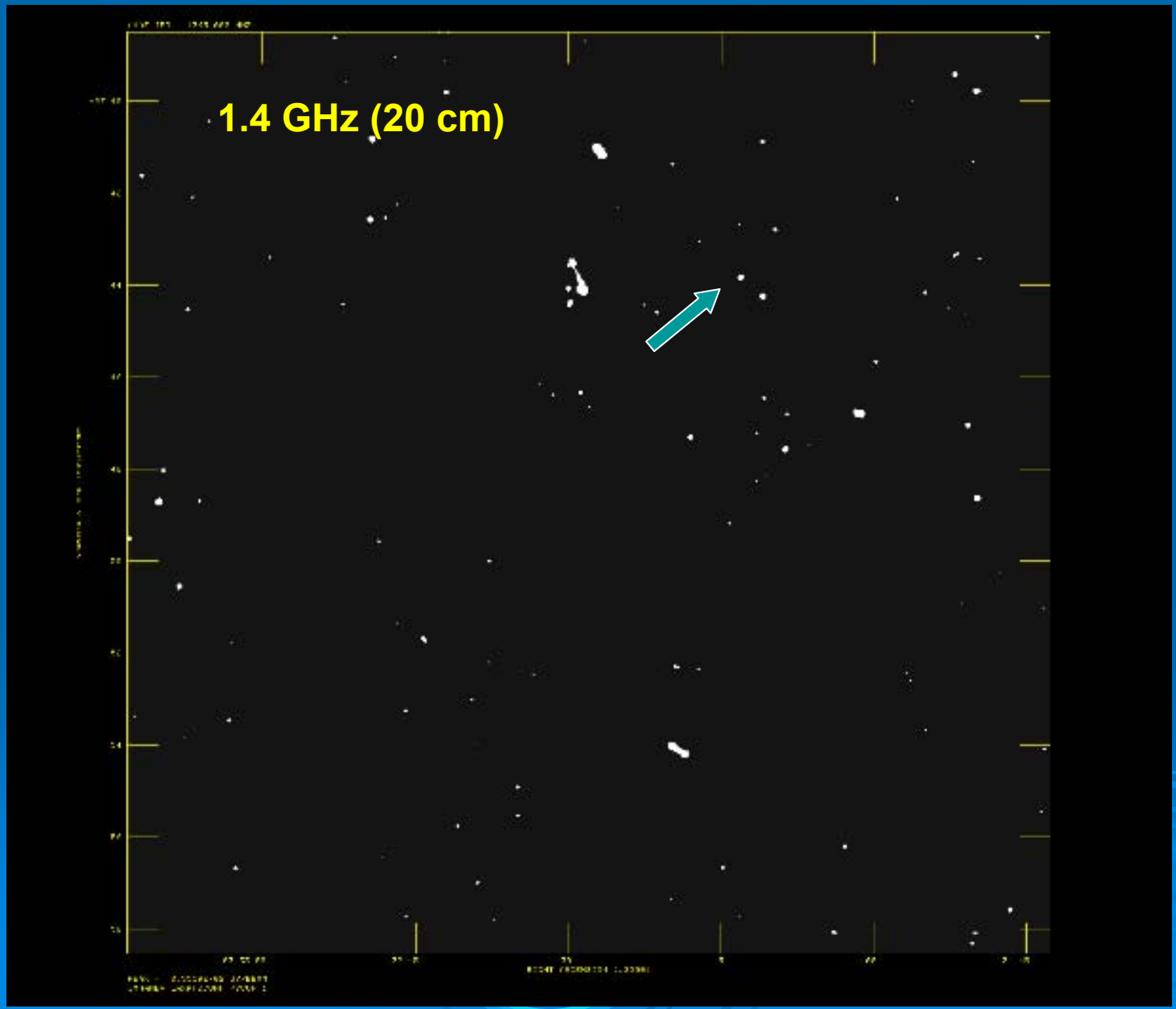
57 in CDFS X-ray list
74 additional in ECDFS

New Observations
@ 6 cm
σ = 6 (4) μJy

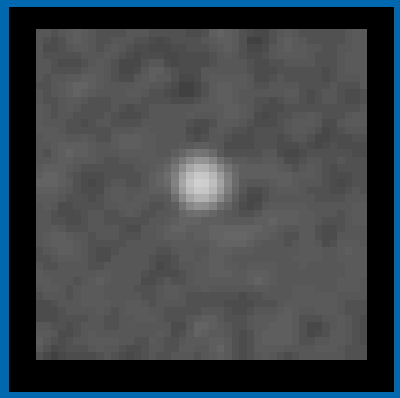
Optical Counterparts

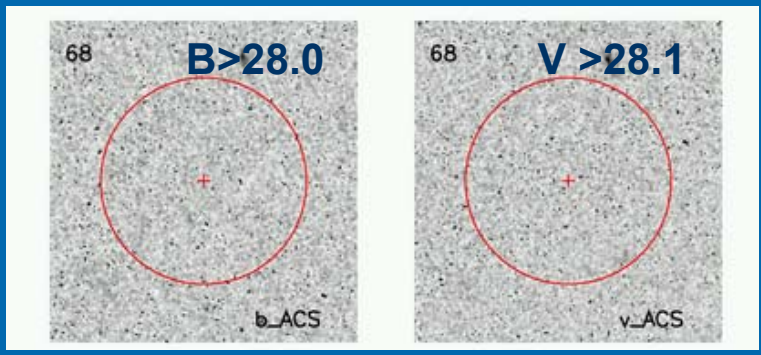
- More than 90% optical counterparts
- A few classical radio galaxies I < 20
- Most radio sources have optical counterparts in the range 20 < I < 25
  - Typically red: (R - z) ~ 2
  - Some are very red (R-z) ~ 5
  - Galaxies with luminous starforming regions in interacting systems (groups or pairs)
  - AGN s
- Optically quiet radio sources

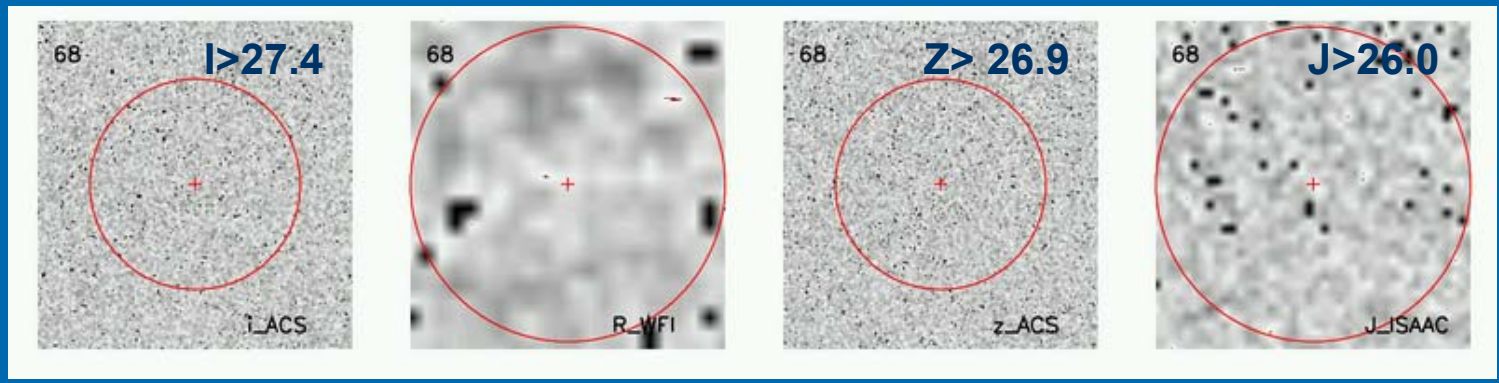
VLA Observations

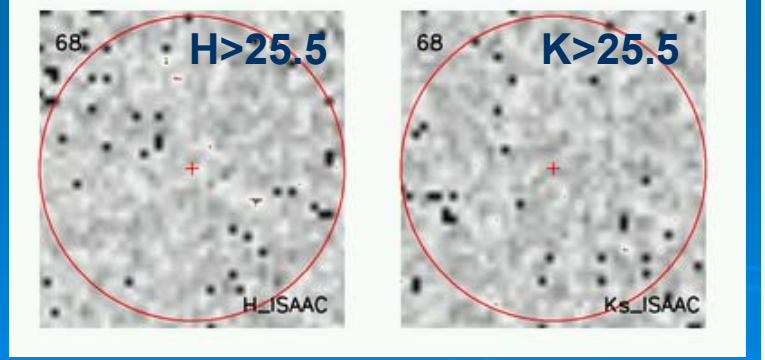


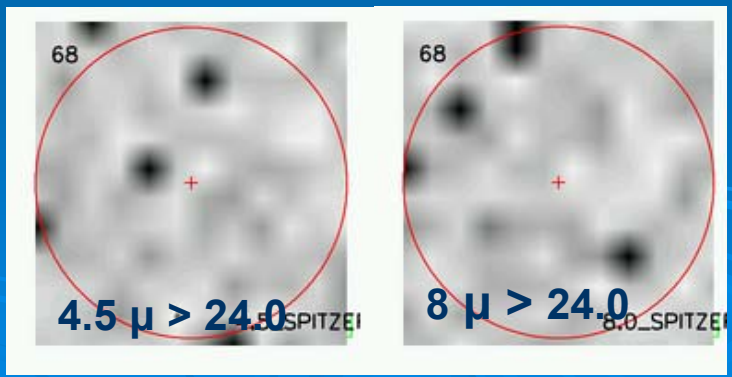
S_{20} = 1.4 mJy
S_6 = 0.5mJy
α = - 0.7







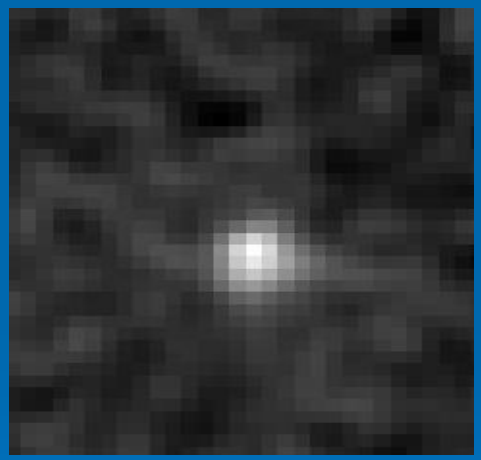




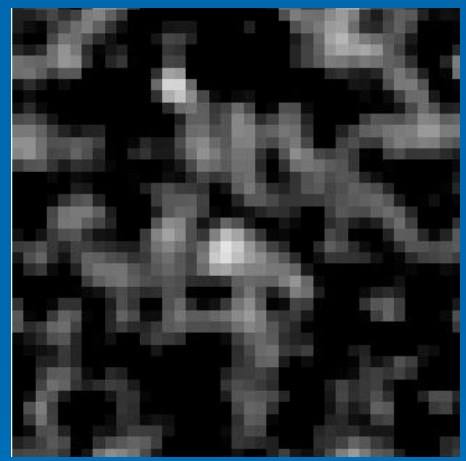
Radio/x-ray source properties

198 radio sources with S_{20} > 40 μJy

57 sources have X-ray counterparts

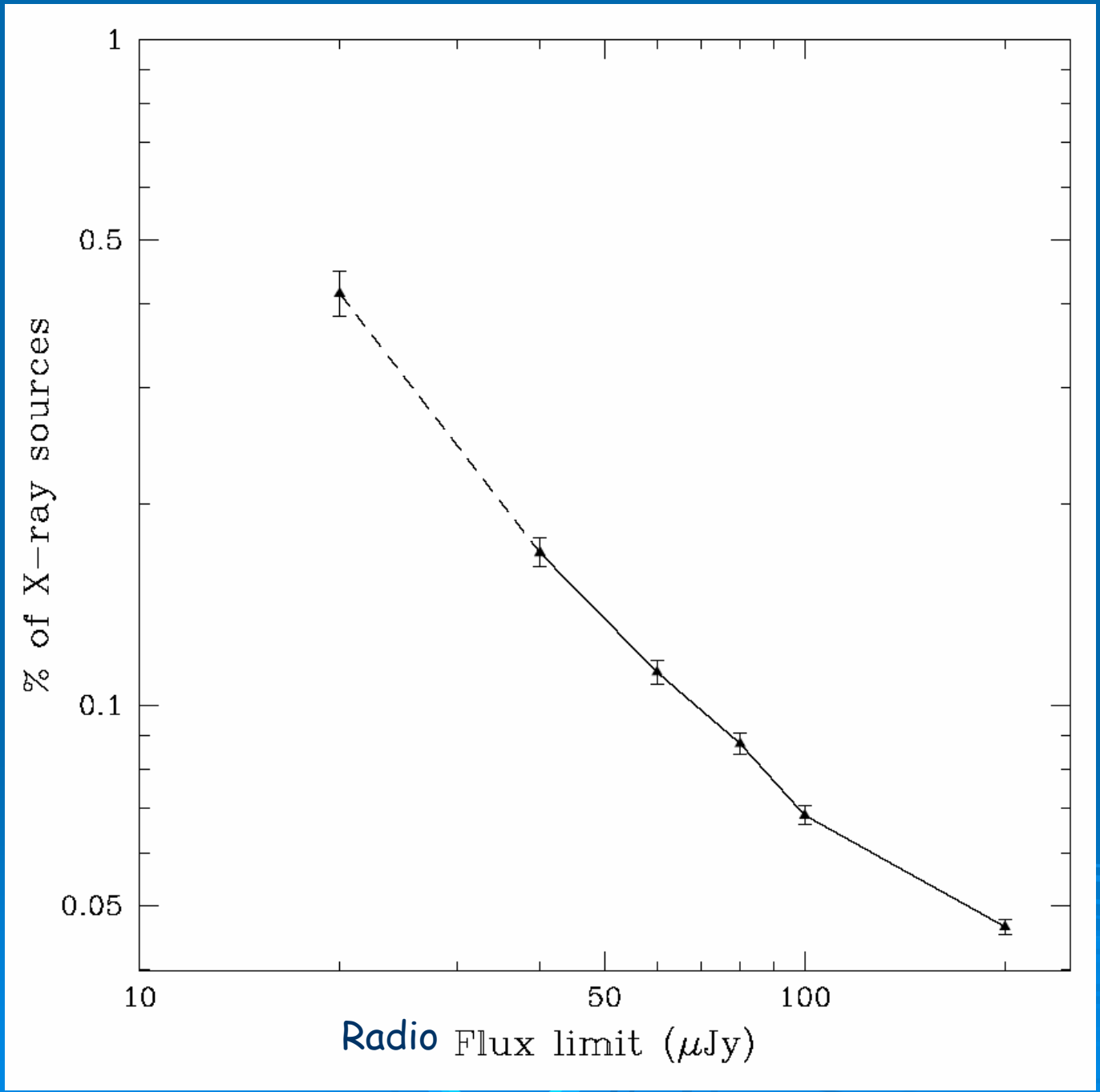


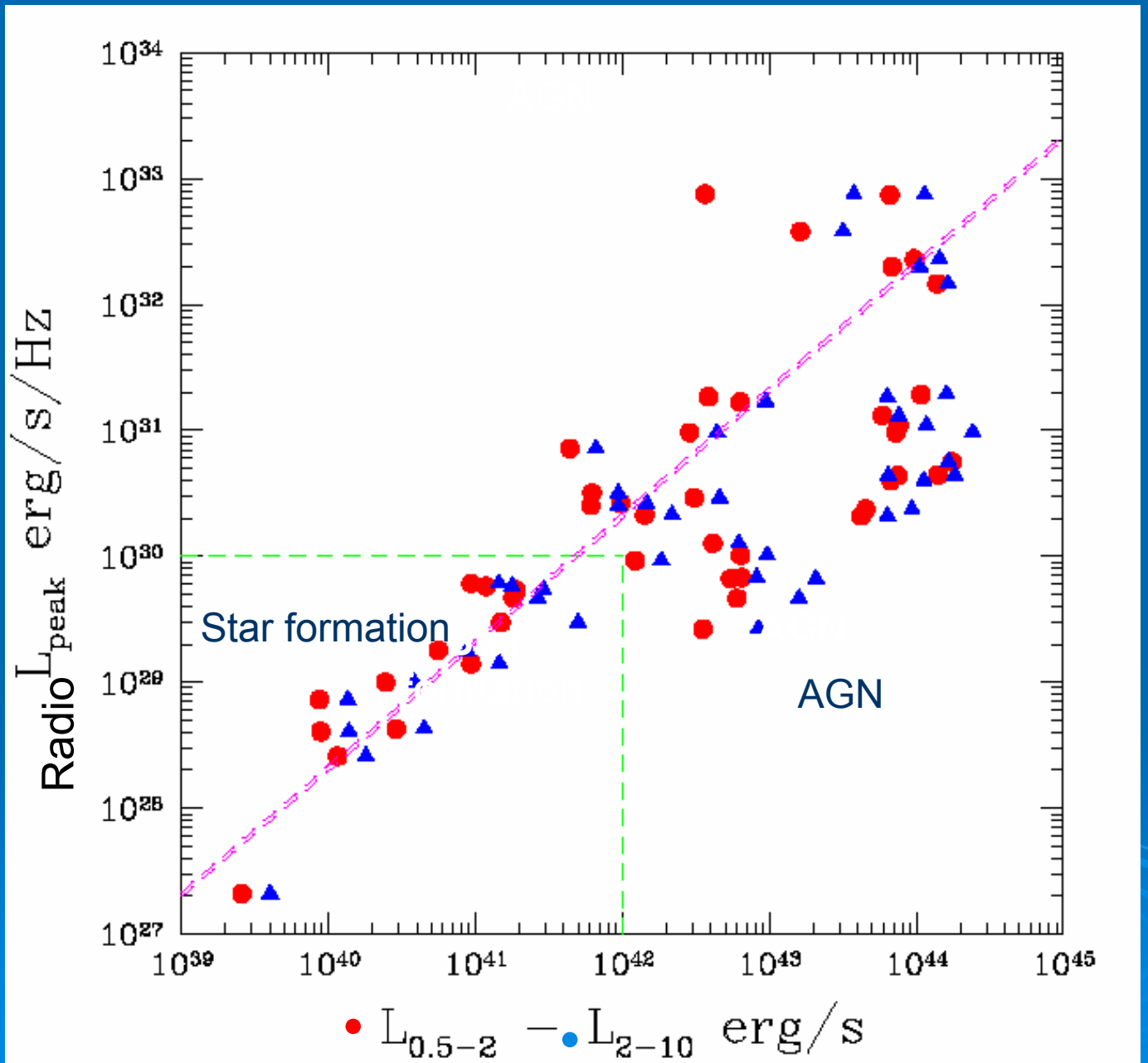
Soft (0.5-2 kev) band flux
3.8×10^{-17} ergs/s/cm^2



Hard (2-10 kev) band flux
4.6×10^{-17} ergs/s/cm^2

Remaining 141 sources


1
0.5
0.1
0.05
% of X−ray sources
10
50
100
Radio Flux limit (μJy)


Radio L_{peak} erg/s/Hz
10^{34}
10^{33}
10^{32}
10^{31}
10^{30}
10^{29}
10^{28}
10^{27}
10^{39}
10^{40}
10^{41}
10^{42}
10^{43}
10^{44}
10^{45}
Star formation
AGN
$L_{0.5-2}$ L_{2-10} erg/s

Next Steps

- Examine 20 cm image over a range of surface brightness
- Analyze new 6 cm image including UDF
- Obtain spectra (redshifts) for all radio sources ECDFS X-ray sources
- Get deeper radio images at 6 and 20 cm

http://www.mpe.mpg.de/~mainieri/cdfs_pub/

Comments

- Both weak X-ray and weak radio emission are increasingly due to star formation rather than AGN, but AGN are important at all levels.
- Weak X-ray sources are mostly ordinary late type galaxies, while radio sources are a mixture of bright (AGN) and fainter (star-forming) galaxies showing signs of mergers or interactions.
- Many microJy radio sources are identified with very red galaxies, possibly with submm excess.
- About 10% of microJy radio sources unidentified, some to very low levels in other wavebands
- There is no missing population of low surface brightness microJy radio sources
- There are significant field to field variations (cosmic variance). HDF is low, CDFS is high. Sub milliJy differential count slope is -2.4.
- About 10% of radio sources displaced from nucleus
- Natural confusion may limit the ultimate sensitivity of deep surveys