SKA's impact on Galaxy Assembly

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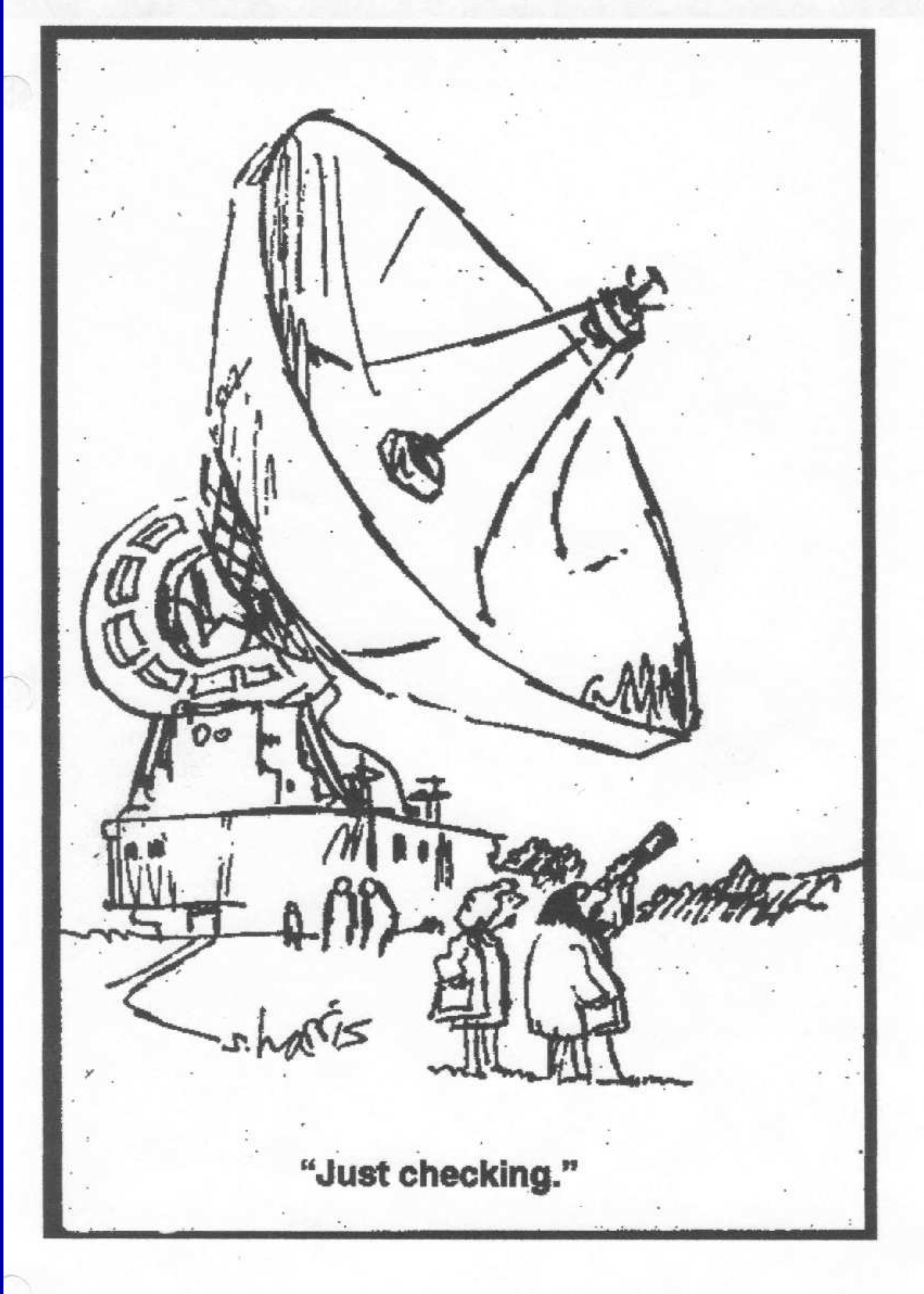
NRAO Community Workshop, Tucson, Aug. 4, 2006



Radio community must convince other astrophysics sub-disciplines about SKA !

PARTICIPANTS IN THE SKA GALAXY ASSEMBLY DISCUSSION

Cotton, Dey, Dewdney, Dickman, Ghosh, Henning,

Lewis, Lockman, Kellermann, Narayanan, Pisano,

Schreier, Stockdale, Strauss, Taylor, Ulvestad,

van Gorkom (by Email), Windhorst (Chair), M. Yun.

OTHERS: Forgive me if I missed your name here.

WHAT ARE CRITICAL SCIENCE DRIVERS FOR RADIO TELESCOPES OF THE NEXT DECADE?

A) HIERARCHICAL GALAXY FORMATION & GALAXY ASSEMBLY:

- How do small HI clouds at z=7–15 transform into the giant spirals and ellipticals seen today?

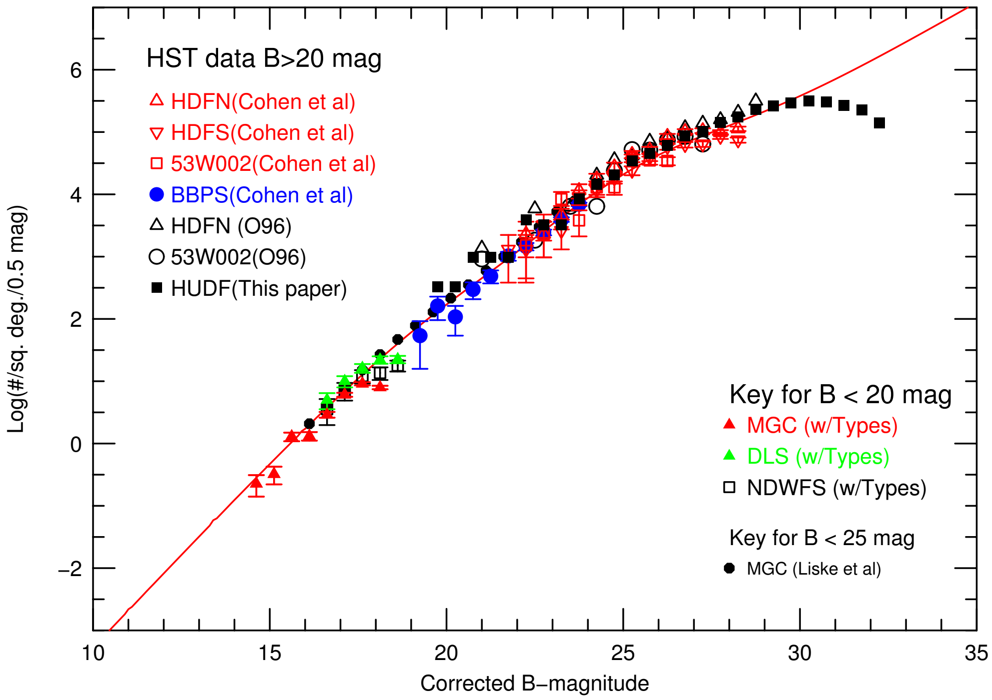
B) THE GALAXY FORMATION–AGN PARADIGM:

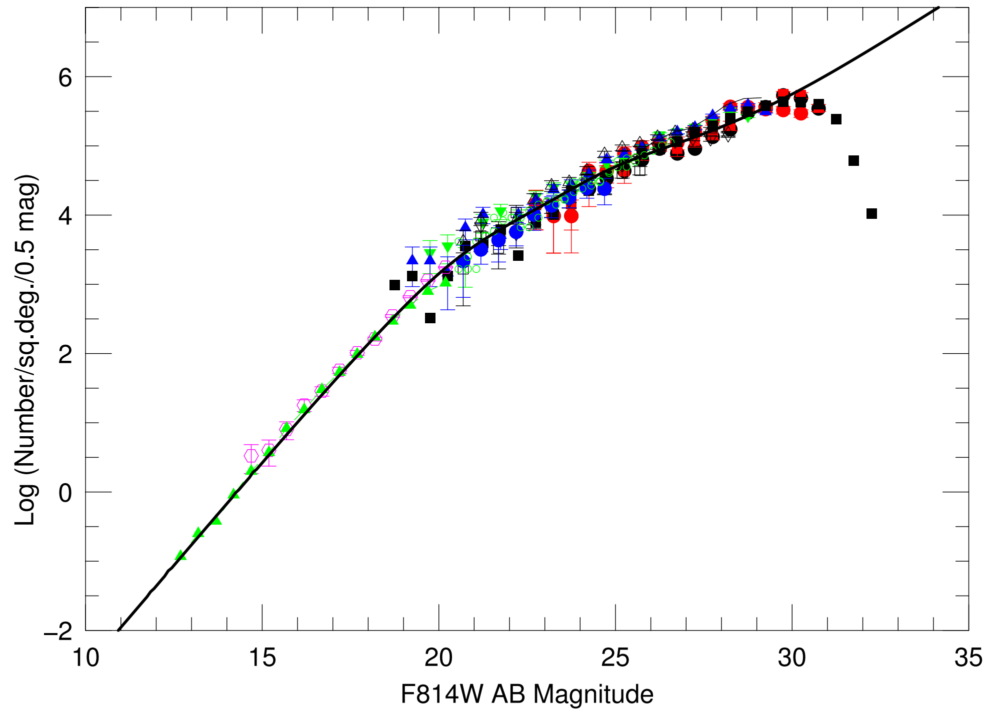
- How did supermassive black hole growth keep up with galaxy assembly?

C) RADIO GALAXIES, JETS, and QUASARS:

- How does the accretion disk feed the SMBH, and how are radio jets and lobes produced as a result?

D) TECHNICAL REQUIREMENTS FOR NEXT GENERATION RADIO TELESCOPE.

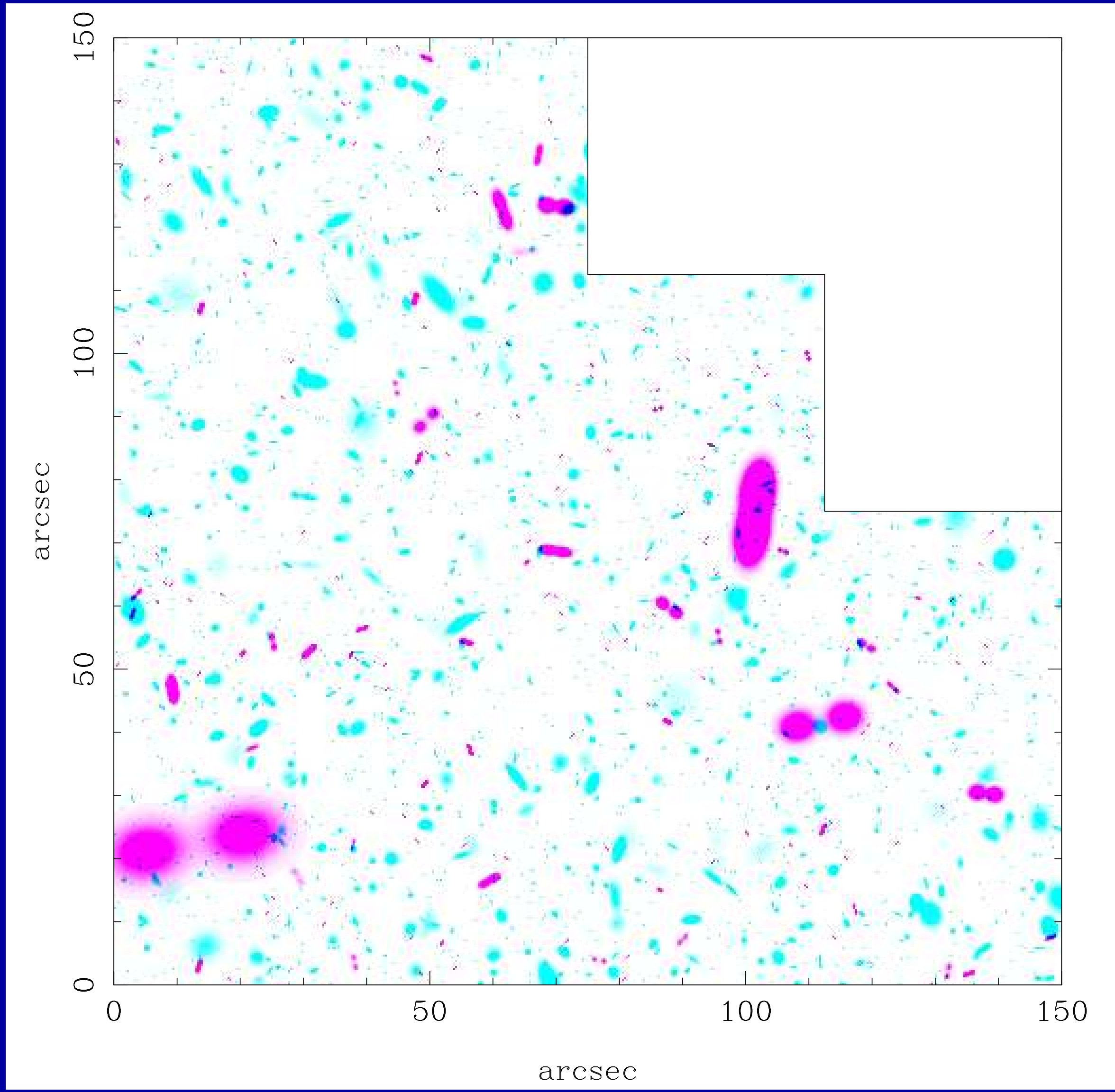




- HUDF galaxy counts (Cohen et al. 2006): expect an integral of $\gtrsim 2\times10^6$ galaxies/deg^2 to AB=31.5 mag ($\simeq$ 1 nJy at optical wavelengths). SKA will see similar surface densities down to $S_{1.4} \simeq$10 nJy.

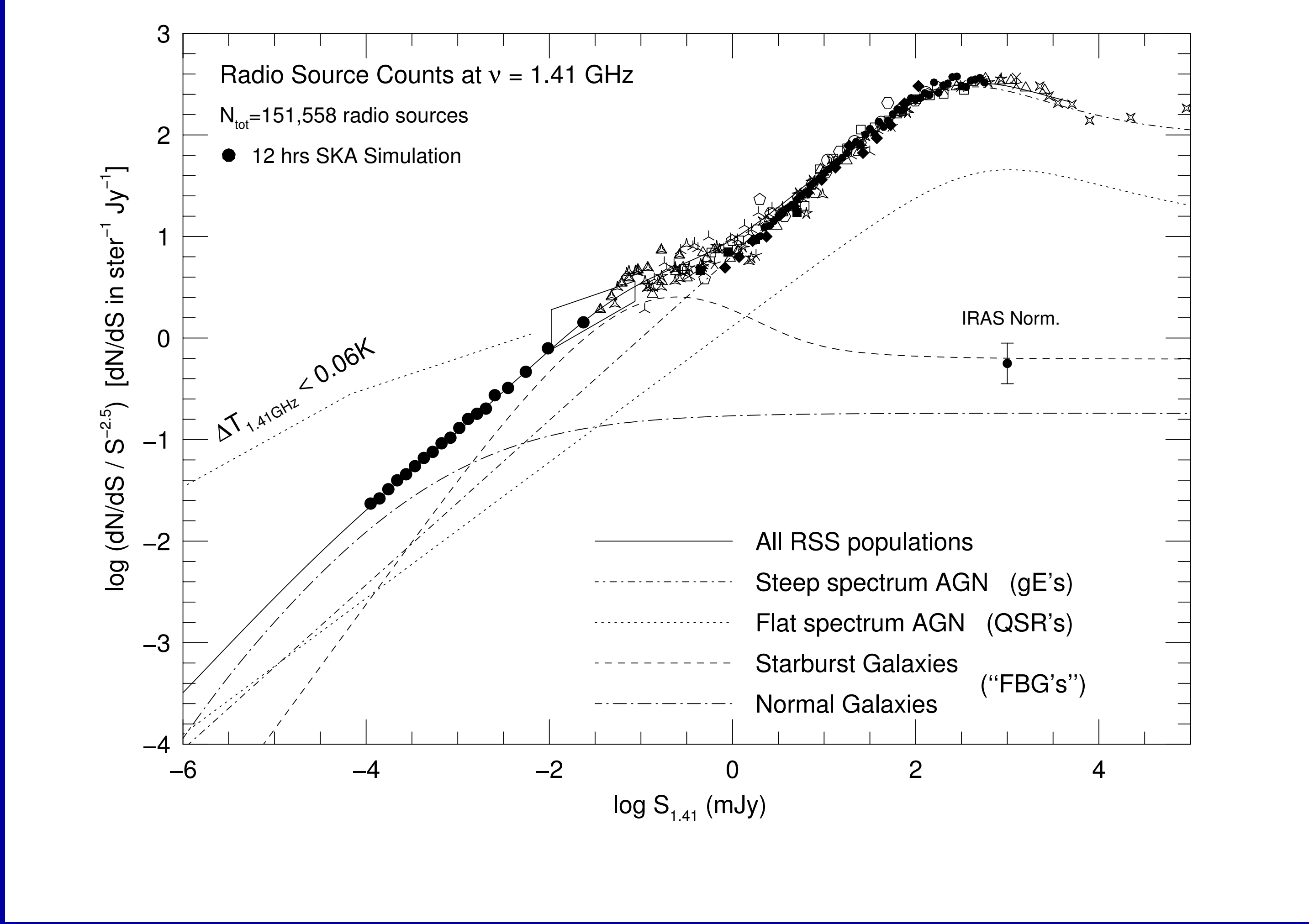
- $\Rightarrow$ Must carry out SKA nJy-surveys with sufficient spatial resolution to avoid object confusion (for HST this means FWHM$\lesssim$0.″08).

- $\Rightarrow$ Always obtain SKA HI line channels, so can disentangle overlapping continuum sources in redshifts space, and find all the enclosed HI.



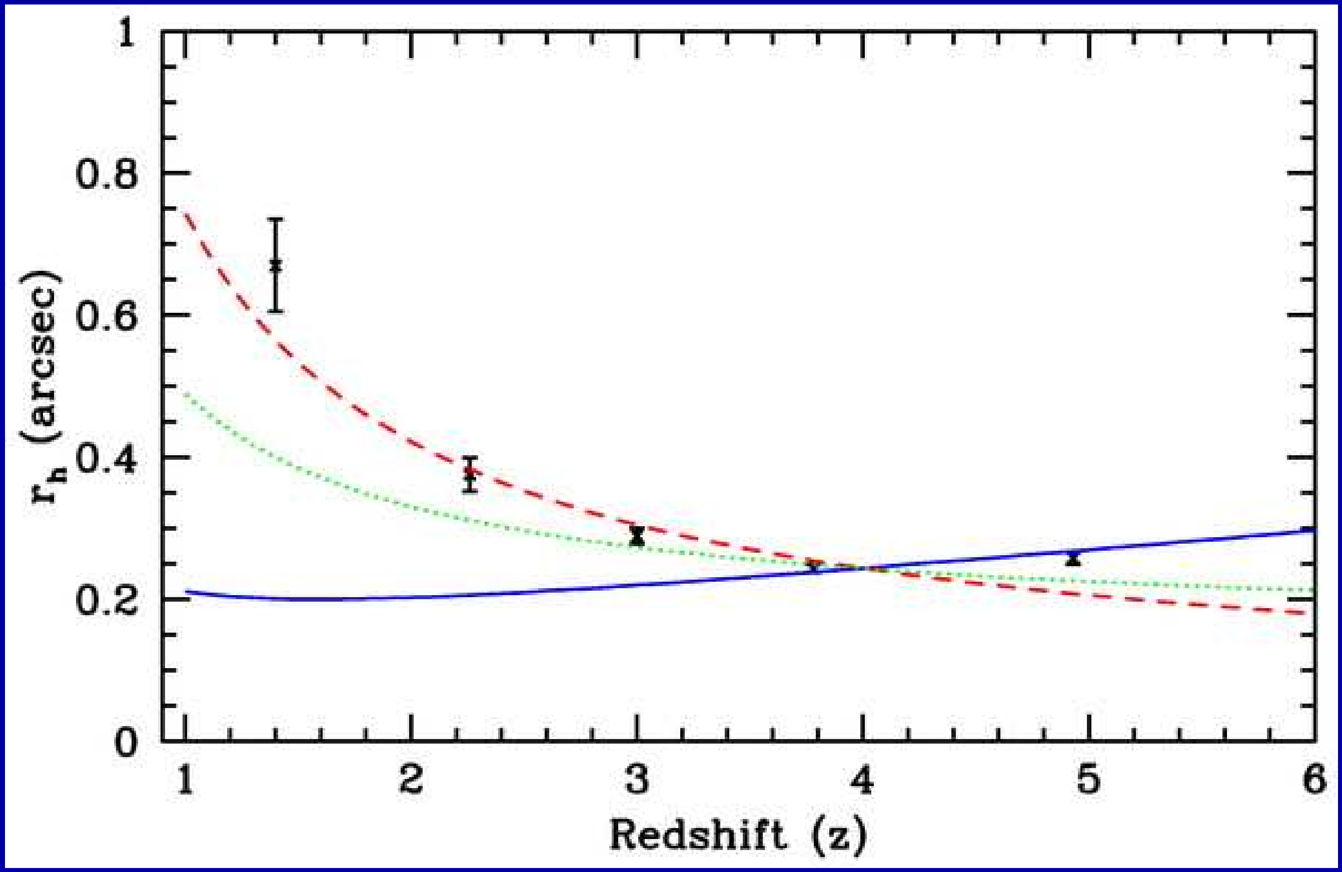
Simulated 12-hr SKA 1.4 GHz image: FWHM$\simeq$0$''\!.$1 and flux limit $\mathbf{0.1}$ μJy (5-σ). Of the 1 deg^2 FOV, only an HST/HDF area is shown (2$'\!.$5$\times$2$'\!.$5).

Red extended radio sources are AGN in early-type galaxies. Blue mostly point-like or disk-shaped sources reside in star-forming galaxies, which dominate the counts below 1 mJy. Normal spiral will dominate below 100 nJy.



Normalized differential 1.41 GHz source counts (Windhorst et al. 1993, 2003; Hopkins et al. 2000) from 100 Jy down to 100 nJy. Filled circles below 10μJy show the 12-hr SKA simulation of Hopkins et al. (2006).

Models: giant ellipticals (dot-dash) and quasars dominate the counts to 1 mJy, starbursts (dashed) below 1 mJy. Normal spirals at cosmological distances (dot-long dash) will dominate the SKA counts below 100 nJy.



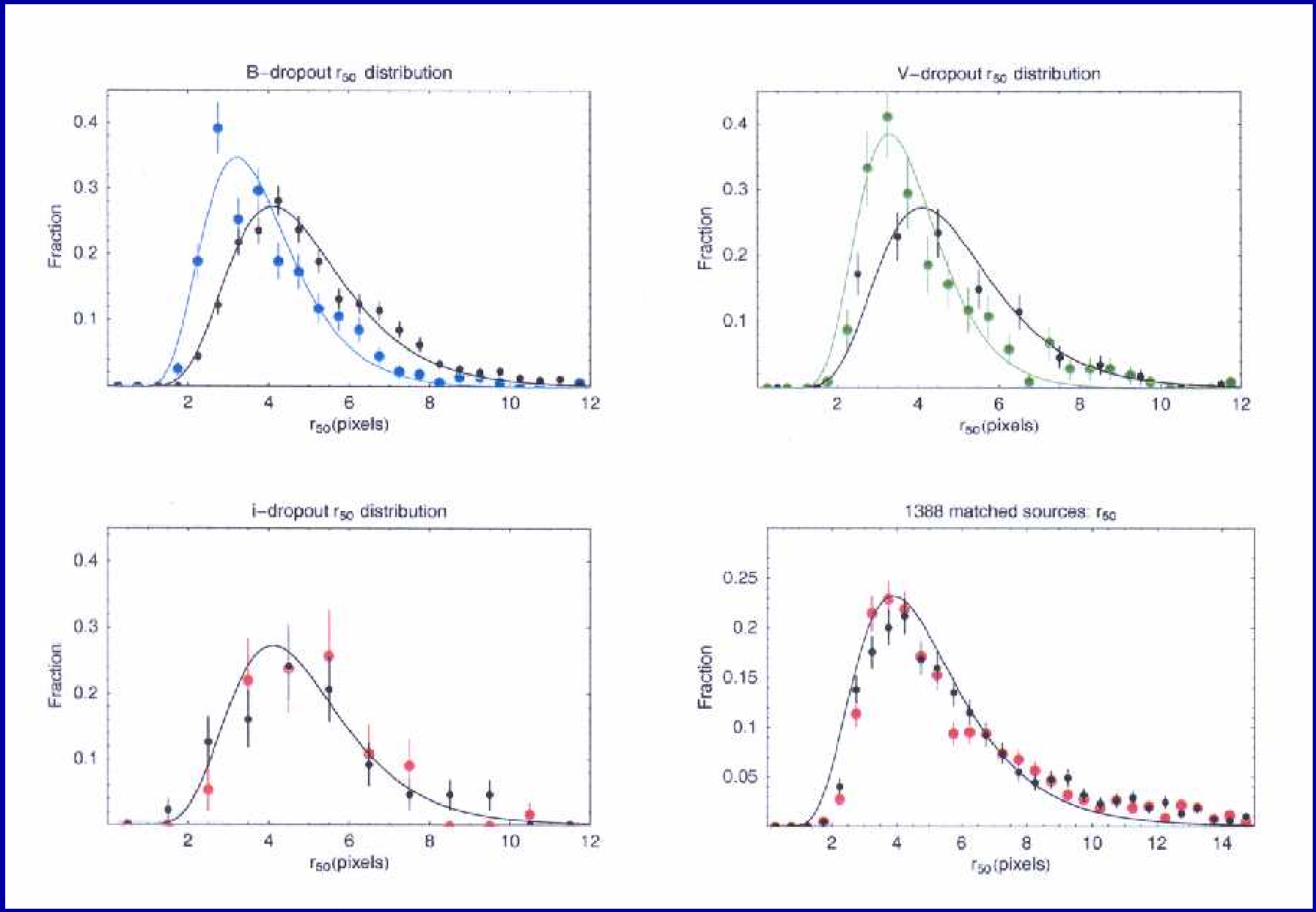
HST GOODS measured galaxy size evolution (Ferguson et al. 2004 ApJL):

• Median galaxy sizes decline steadily at higher redshifts, despite the cosmological Θ–z relation that minimizes at $z \simeq 1.6$ for Λ-cosmology.

• Evidence of intrinsic size evolution: $r_{hl}(z) \propto r_{hl}(0) \, . \, (1+z)^{-s}$, $s \simeq 1$.

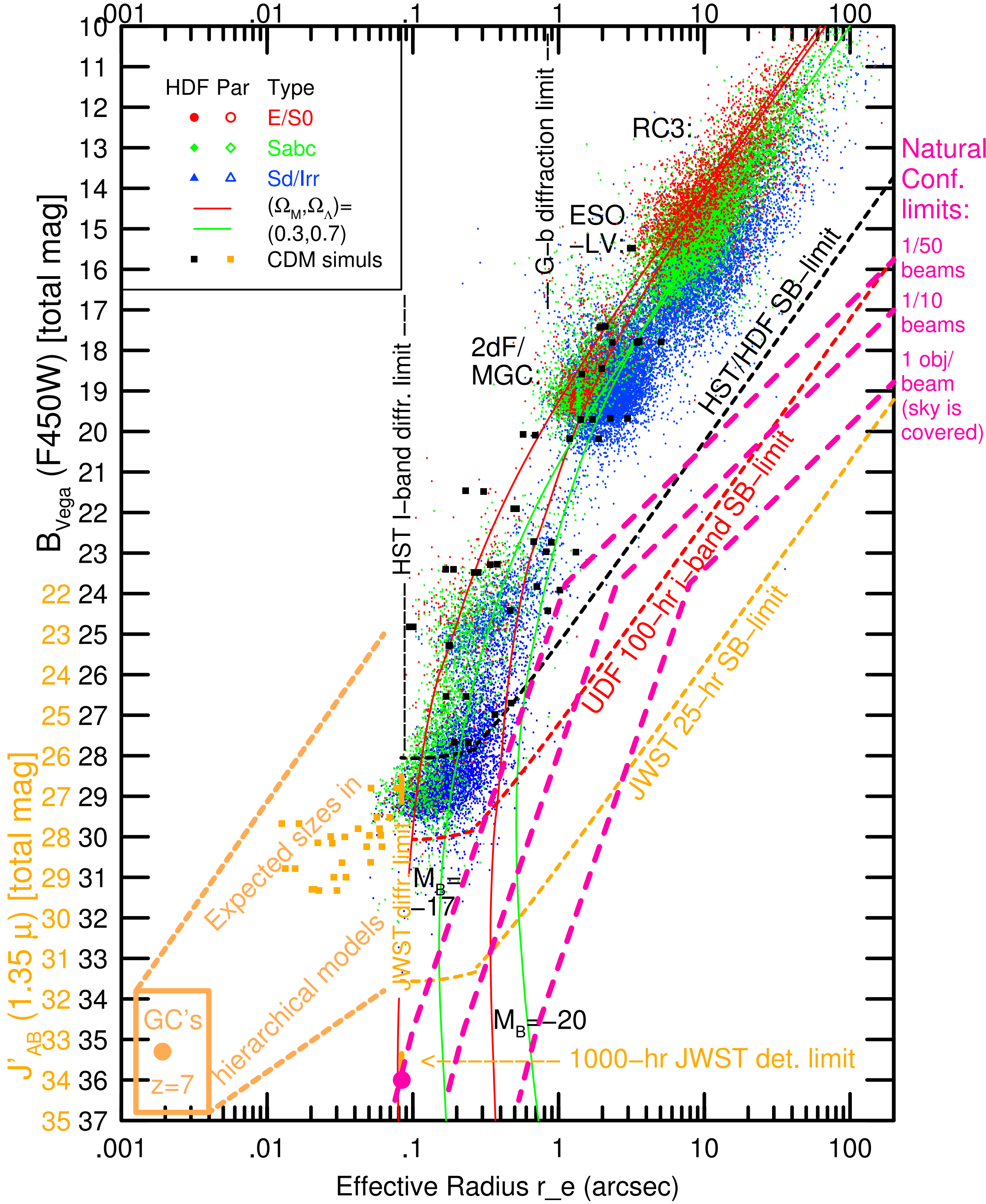
• Caused by hierarchical formation of galaxies, leading to intrinsically smaller galaxies at higher redshifts, where fewer mergers have occurred.

• SKA must anticipate the small $\lesssim 0\farcs15$ radio sizes of faint galaxies.



The HST/ACS Hubble UltraDeep Field (HUDF; Beckwith et al. 2006 AJ; astro-ph/0608xxx) has similarly shown that:

- High redshift galaxies (B-drops at $z \simeq 4$; V-drops at $z \simeq 5$; and i-drops at $z \simeq 6$) are intrinsically very small:
- Galaxies at $z \simeq 4$–6 have: $r_{\mathbf{hl}} \simeq 0''.12 \simeq 0.7$–$0.9$ kpc intrinsically.
- SKA must anticipate the small $\lesssim 0''.15$ radio sizes of faint galaxies.



HDF Par Type
E/S0
Sabc
Sd/Irr
$(\Omega_M,\Omega_\Lambda)$=
(0.3,0.7)
CDM simuls
RC3:
ESO
–LV:
2dF/
MGC:
— G–b diffraction limit —
HST I–band diffr. limit
HST/HDF SB–limit
UDF 100–hr I–band SB–limit
JWST 25–hr SB–limit
JWST diffr. limit
Expected sizes in
hierarchical models
GC's
z=7
M_B=
–17
M_B=–20
<– – – – – – – 1000–hr JWST det. limit
Natural
Conf.
limits:
1/50
beams
1/10
beams
1 obj/
beam
(sky is
covered)
B_{Vega} (F450W) [total mag]
J'_{AB} (1.35 μ) [total mag]
Effective Radius r_e (arcsec)

Combination of ground-based and space-based HST surveys show:

- (1) Apparent galaxy sizes decline from the RC3 to the HUDF limits:

- (2) At the HDF/HUDF limits, this is *not* due SB-selection effects (cosmological $(1+z)^4$-dimming), but instead due to:

- (2a) hierarchical formation of galaxies, which causes size evolution $r_{hl}(z) \propto r_{hl}(0) \,.\, (1+z)^{-s}$, $s \simeq 1$.

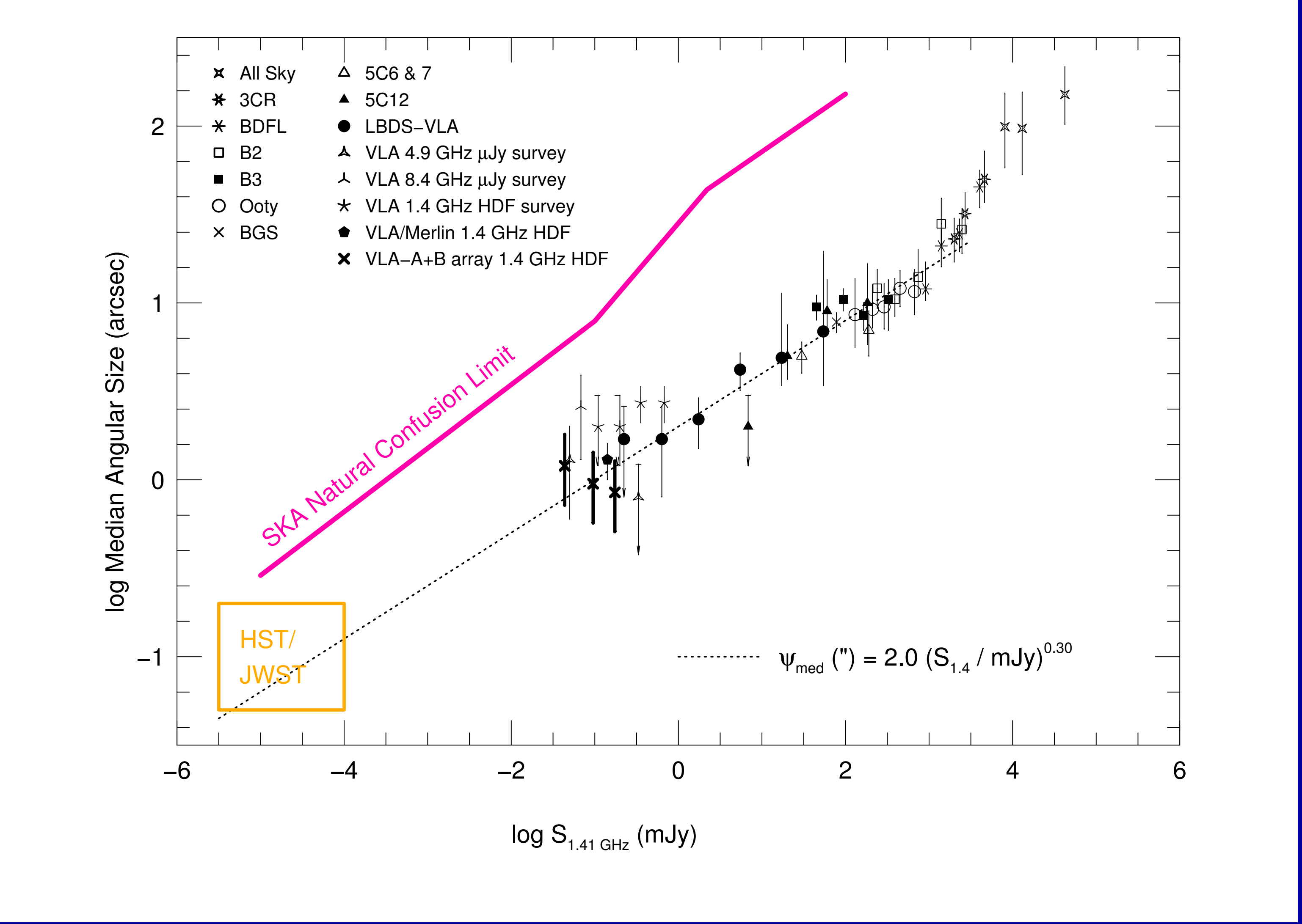
- (2b) increasing inability of object detection algorithms to deblend galaxies at faint mags ("natural" confusion $\neq$ "instrumental" confusion).

- (3) At AB$\gtrsim$30 mag, JWST and at $\gtrsim$10 nJy, SKA will see more than 2×10^6 galaxies/deg^2. Most of these will be unresolved ($r_{hl} \lesssim 0''\!.1$ FWHM. Since $z_{med} \gtrsim 1.5$, this will significantly mitigate the $(1+z)^4$-dimming.

SKA needs to strike the right balance between having a resolution that is:

- High enough to disentangle the expected faint small HI and continuum sources from their neighbors, and

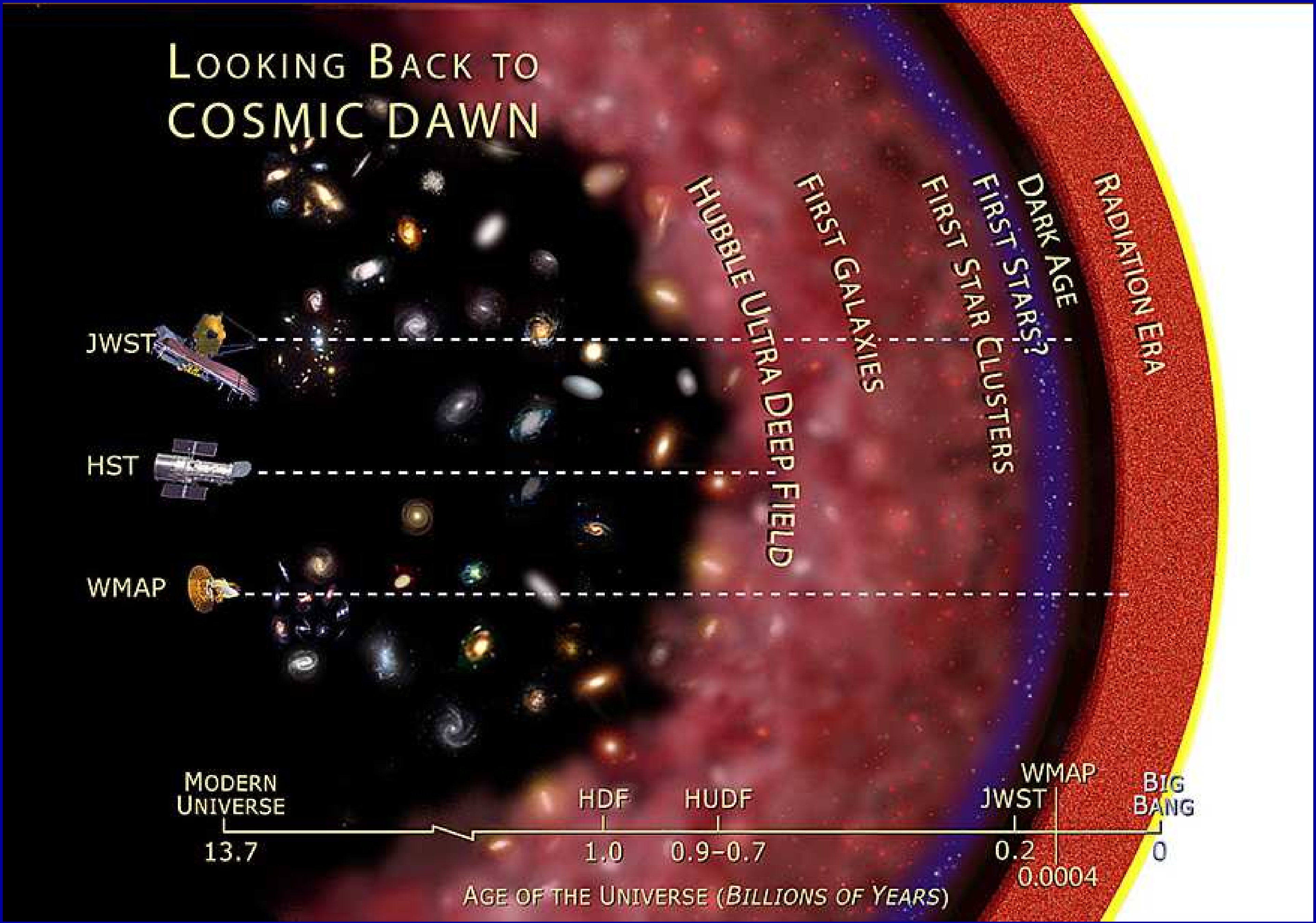
- Not so high that small HI and continuum sources at very redshifts are highly resolved, so as to mitigate the SB-dimming as much as possible.



Median angular size vs. 1.41 GHz flux from 100 Jy down to 30 μJy (Windhorst et al. 2003). SKA sizes at 10–100 nJy are estimated from the HST N(r_{hl}) to AB=30 mag (3 nJy), where both detect $\gtrsim 10^6$ objects/deg^2.

Purple line is the natural confusion limit due to the intrinsic source sizes, above which sources unavoidably overlap. SKA needs $\sim$0.″10 FWHM resolution to best match the expected HI and radio continuum sizes.

SKA will trace HI from Dark Ages to the giant galaxies seen today.



Telescopes penetrating Cosmic Dawn, First Light, & Recombination

(A) HIERARCHICAL GALAXY FORMATION AND GALAXY ASSEMBLY:

• Galaxies of Hubble types formed over a wide range of cosmic time, but with a notable phase transition around redshifts z$\simeq$0.5–1.0:

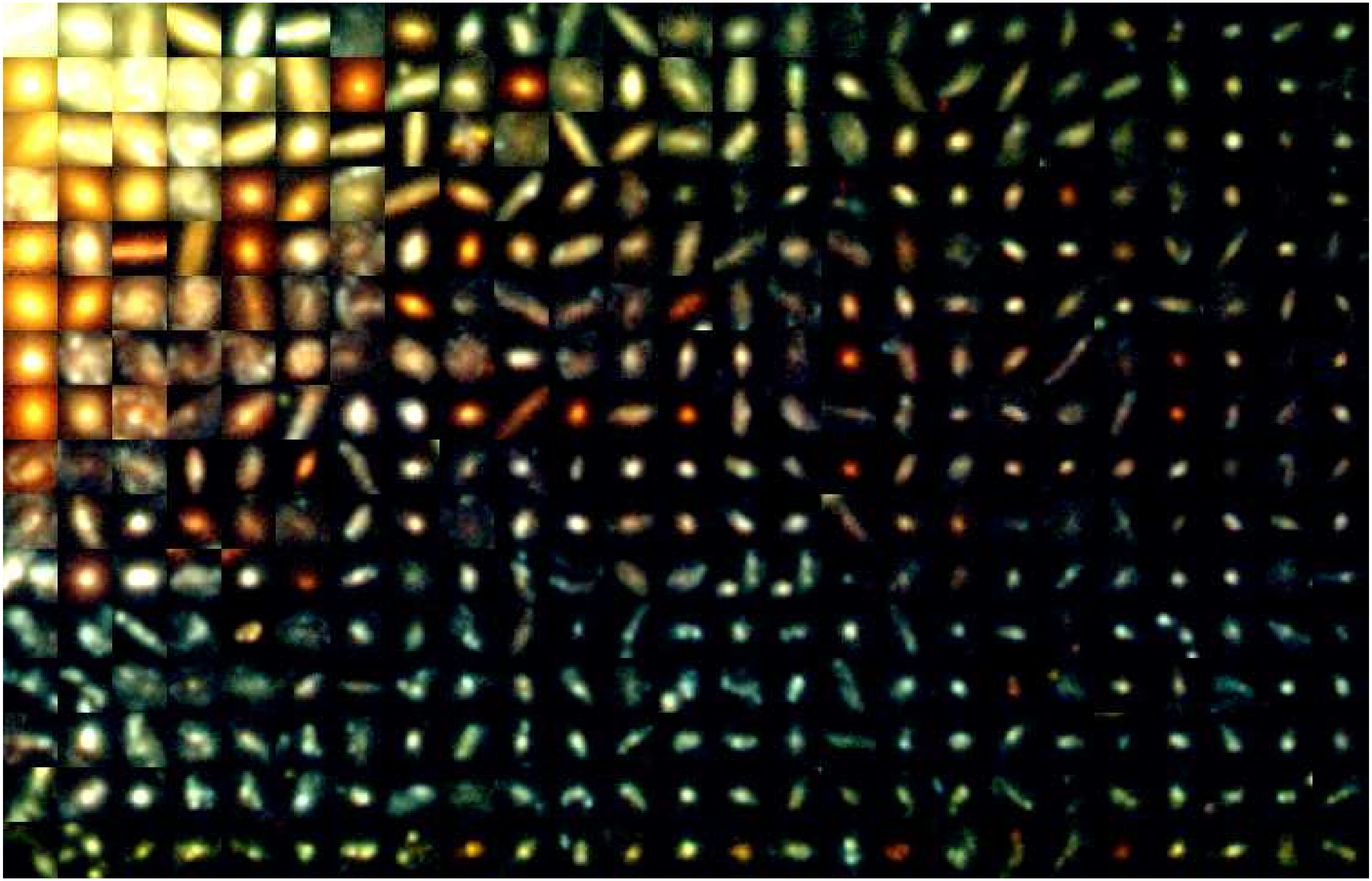
(1) Subgalactic units rapidly merge from z$\simeq$7$\longrightarrow$1 to grow bigger units.

(2) Merger products start to settle as galaxies with giant bulges or large disks around redshifts z$\simeq$1. These evolved mostly passively since then (their mergers tempered by the Cosmological Constant?), resulting in the giant galaxies that we see today.

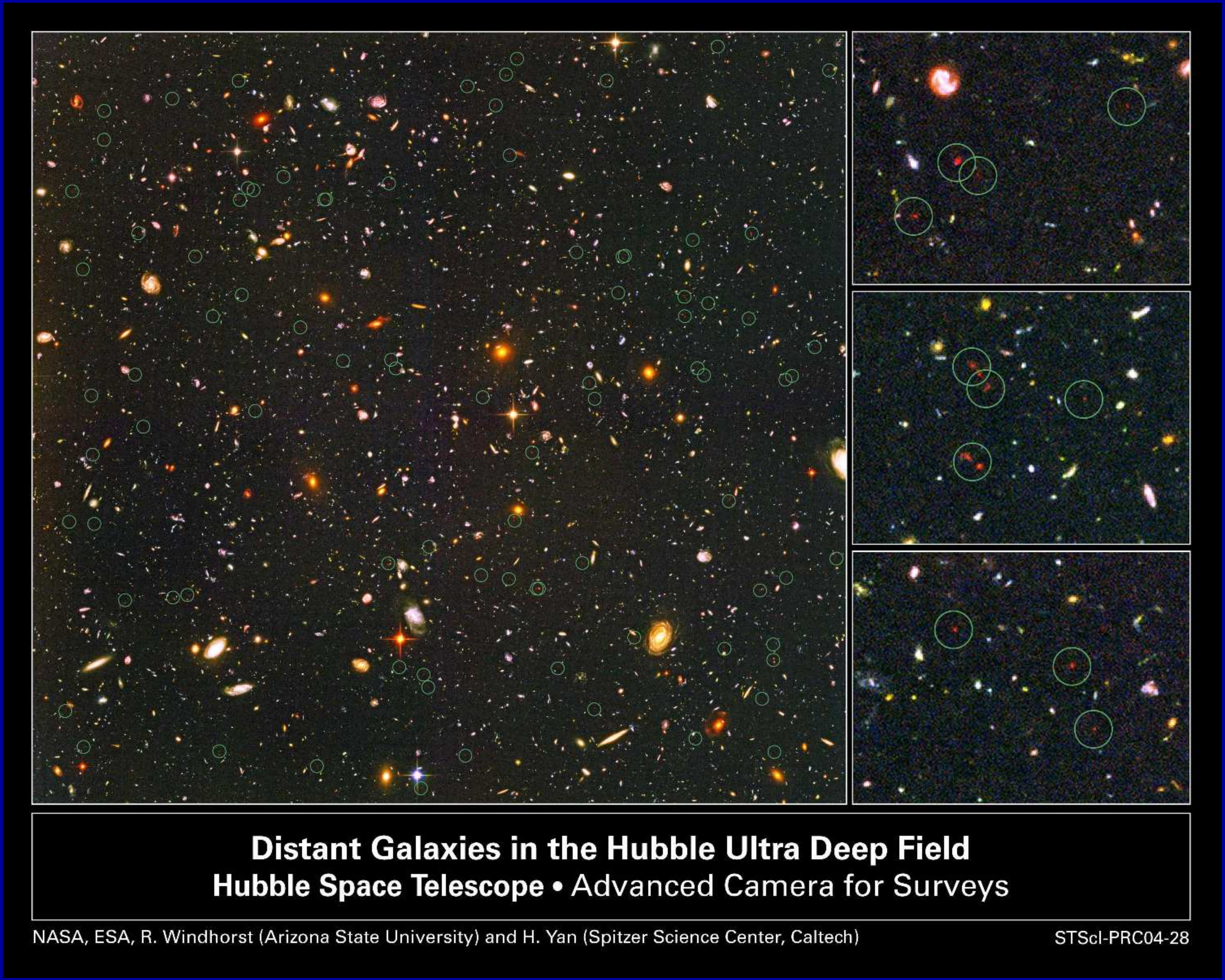
• SKA will measure how galaxies of all types assembled their HI and turned it into stars over a wide range of cosmic time: from z=6–10 to z=0.

• HI and radio continuum sizes of 10^7–10^9 $M_\odot$ starforming objects are so small ($\lesssim$0$''\!.$2) that with proper resolution ($\gtrsim$0$''\!.$2–0$''\!.$5 FWHM), SKA will not resolve them, and so mitigate the high redshift surface brightness-dimming.

THE HUBBLE DEEP FIELD CORE SAMPLE ($I < 26.0$)



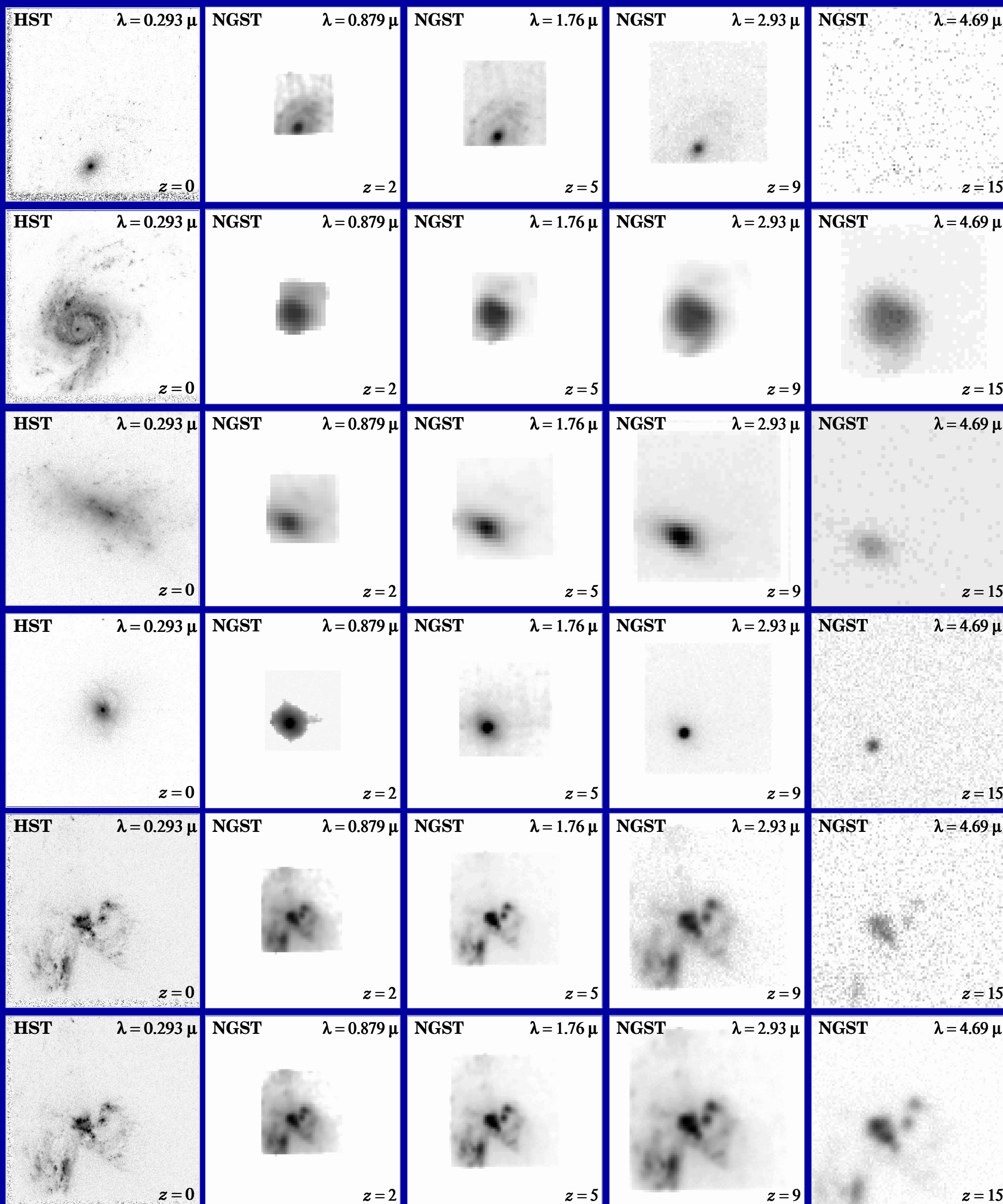
z	Age ($q_o = 0.5$)
0.19	77%
0.44	58%
0.54	52%
0.64	48%
0.74	44%
0.87	39%
0.97	36%
1.03	35%
1.14	32%
1.24	30%
1.41	27%
1.61	24%
1.76	22%
2.05	19%
2.57	15%
3.59	10%



i-band drops in the HUDF: Most confirmed at $z \simeq 6$ (Malhotra et al. 2005)

Predicted Galaxy Appearance for JWST and SKA at z≃1–15

HST z=0 JWST z=2 z=5 z=9 z=15



SKA will observe HI and continuum structures over a wide range of cosmic time. If these trace UV-starlight, then SKA will observe that:

- (1) Most disks will SB-dim away at high z, but most formed at $z_{form} \lesssim 1$–2.
- (2) High SB structures are visible to very high z.
- (3) Point sources (AGN) are visible to very high z.
- (4) Unresolved high SB-parts of mergers/train-wrecks are visible to very high redshifts.

B) THE GALAXY FORMATION–AGN PARADIGM:

- How did supermassive black hole growth keep up with galaxy assembly?

C) RADIO GALAXIES, JETS, and QUASARS:

- How does the accretion disk feed the SMBH, and how are radio jets and lobes produced as a result?

For B) and C), please see the notes that I Emailed you.

SUMMARY: SKA's IMPACT ON GALAXY ASSEMBLY

1) FIND ALL BARYONIC (HYDROGEN) MASS IN THE UNIVERSE FROM FIRST LIGHT UNTIL TODAY.

2) MAP THE MASS-ASSEMBLY AND GAS-ASSEMBLY OF GALAXIES OVER ALL OF COSMIC TIME.

3) TRACE THE FORMATION OF GALAXIES AND MASSIVE BLACK HOLES OVER ALL OF COSMIC TIME

4) FIND THE FIRST BLACK HOLES AND THE FIRST GALAXIES.

Brief one-liners that summarize most of SKA science:

"SKA: FROM HYDROGEN GAS TO PLANETS" (Windhorst)

or:

"SKA: FROM PROTONS TO PLANETS" (Hogan).

D) TECHNICAL REQUIREMENTS FOR SKA

1) WAVELENGTH RANGE: 200 MHz – 2.0 GHz.

- Consider hybrid array: 10% of dishes up to 22 GHz (costs 25% more?).

2) SPECTRAL RESOLUTION: 1.0*(1+z) km/sec FWHM

- Needed for spectral line work at z$\simeq$0–10.

3) SPATIAL RESOLUTION: 0.1–1.0" FWHM, but:

- $\lesssim$10 mas ($\lesssim$10 pc) FWHM to separate AGN from starbursts at z=1–10.
- 10–60" FWHM to detect low-mass HI clouds at z$\lesssim$0.05.
- Need a logarithmic or geometric baseline-distribution, ranging from 10's of meters to 1000's of km, heavily weighted towards the central 50 km.

4a) CONTINUUM SENSITIVITY: 10–100 nJy at 1.4 GHz (5 sigma)

- Need nJy sensitiviy to see the relevant objects to z$\lesssim$10.

4b) LINE SENSITIVITY: 1.0 μJy sensitivity (5 sigma 12 hrs) in 1 km/sec line channels. Needed to detect a M$\simeq$3$\times$10^9 $M_\odot$ galaxy in HI at z$\sim$1.

5) POLARIZATION: Need Stokes I, Q, U, V to measure RM for $\lesssim$2 GHz.