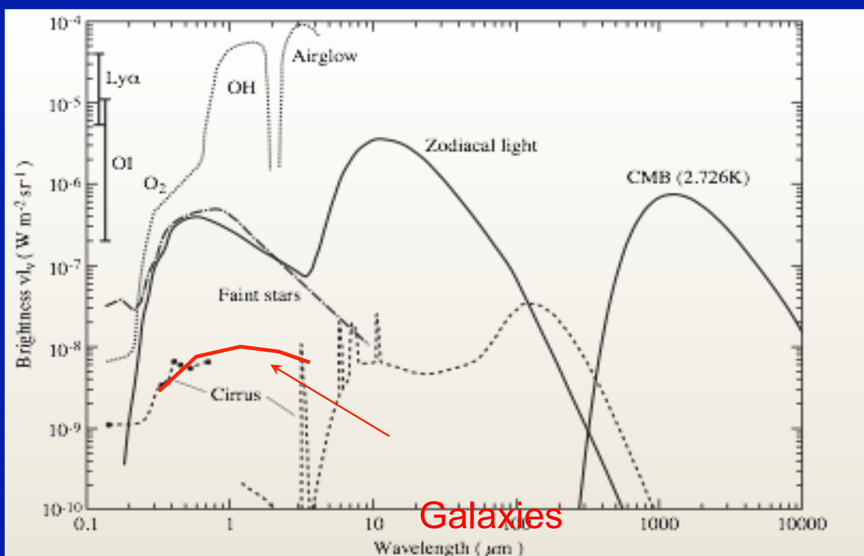
Galaxy formation and evolution as probed with Extragalactic Background Light

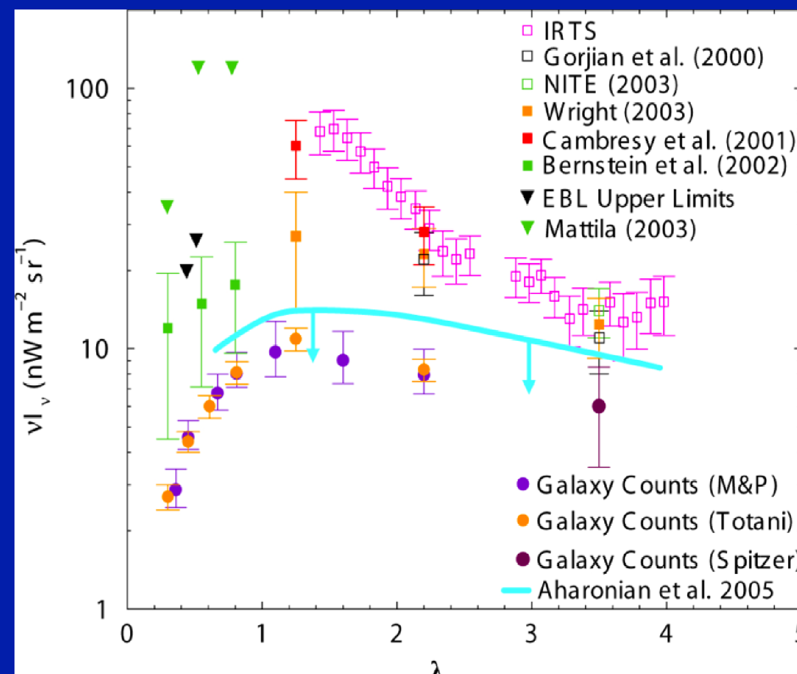
- Galaxy Counts and the EBL
- Diffuse light from galaxies
- Is there something interesting in the near-IR?
  - The “fossil record” at z>3
  - The extrapolation of the high-z luminosity functions
- Searching for fluctuations with WFC3/IR

Background

- We have resolved 30-100% of the EBL
- We do not know how much is due to:
  - The wings of galaxies
  - The faint end of the LF post reionization
  - Sources at the epoch of reionization

- The night sky is bright compared to galaxies!

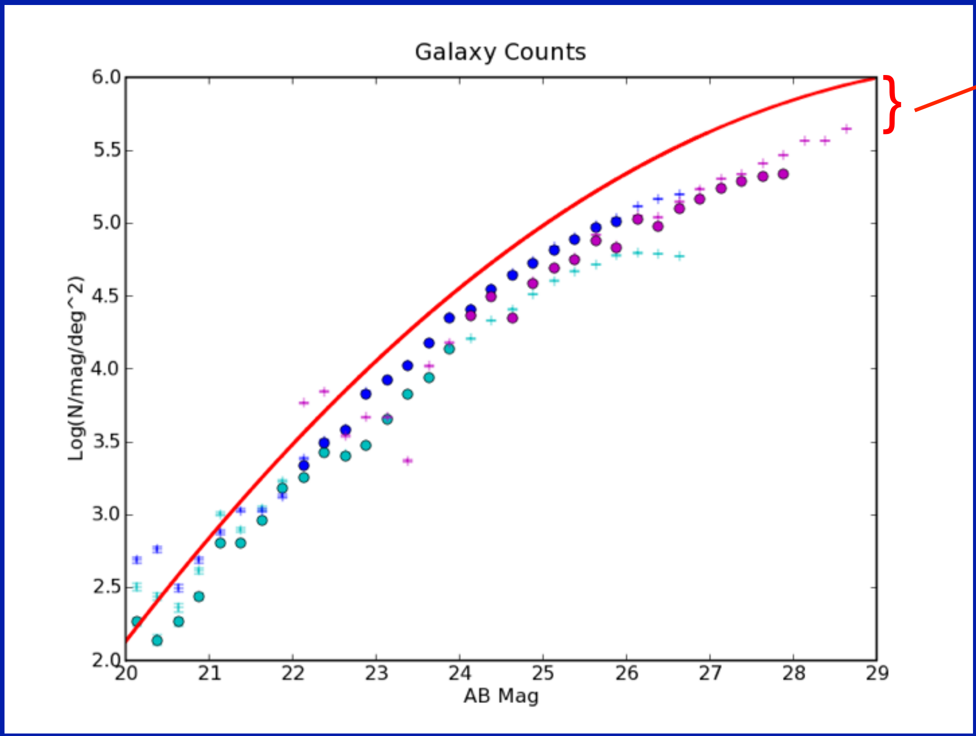




Adapted from Leinert 1998

Bock+ 06

Modeling the light from detected galaxies

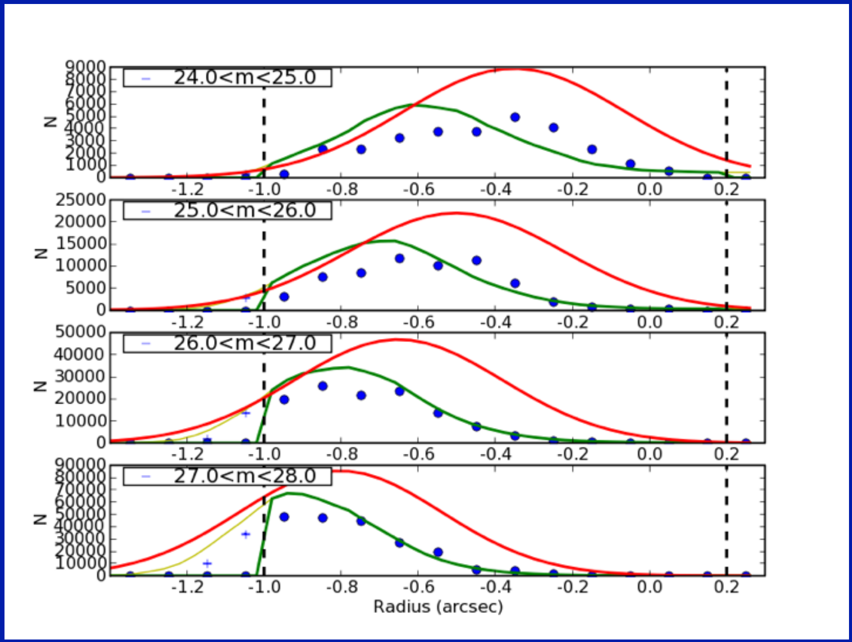


Missing light due to

– incompleteness

– wings of galaxies

– photometric biases



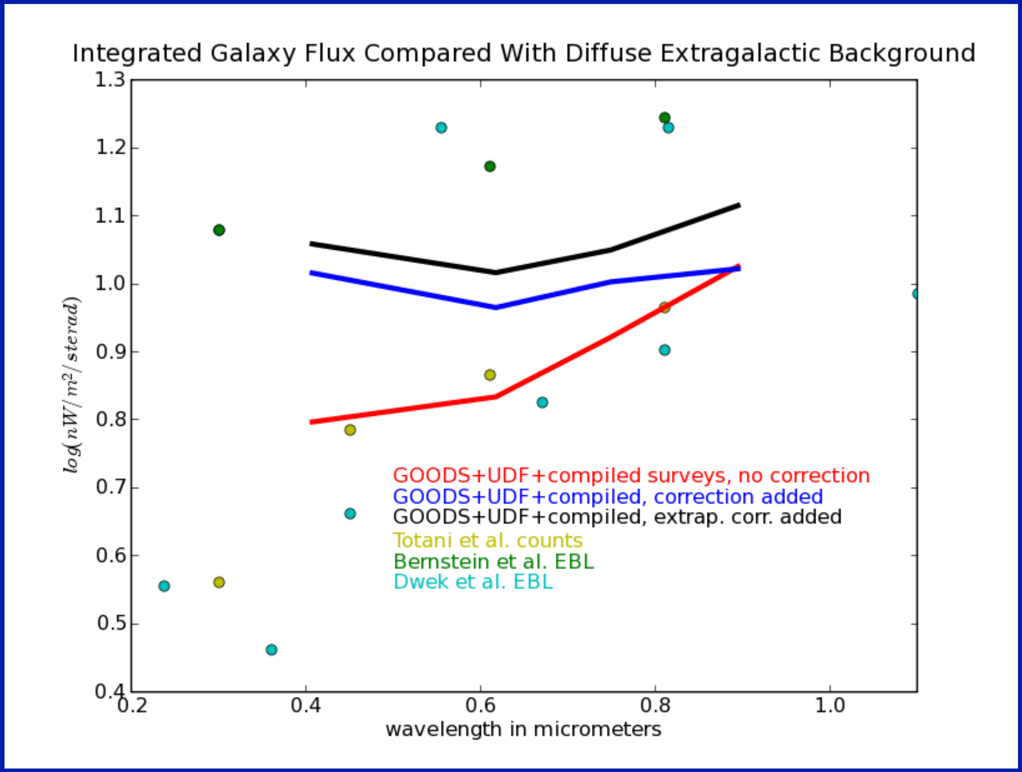
- Galaxy counts

–UDF, GOODS, NDWS, SDSS

–Fit HST size-magnitude relation, and extrapolate

Dolch et al. in preparation

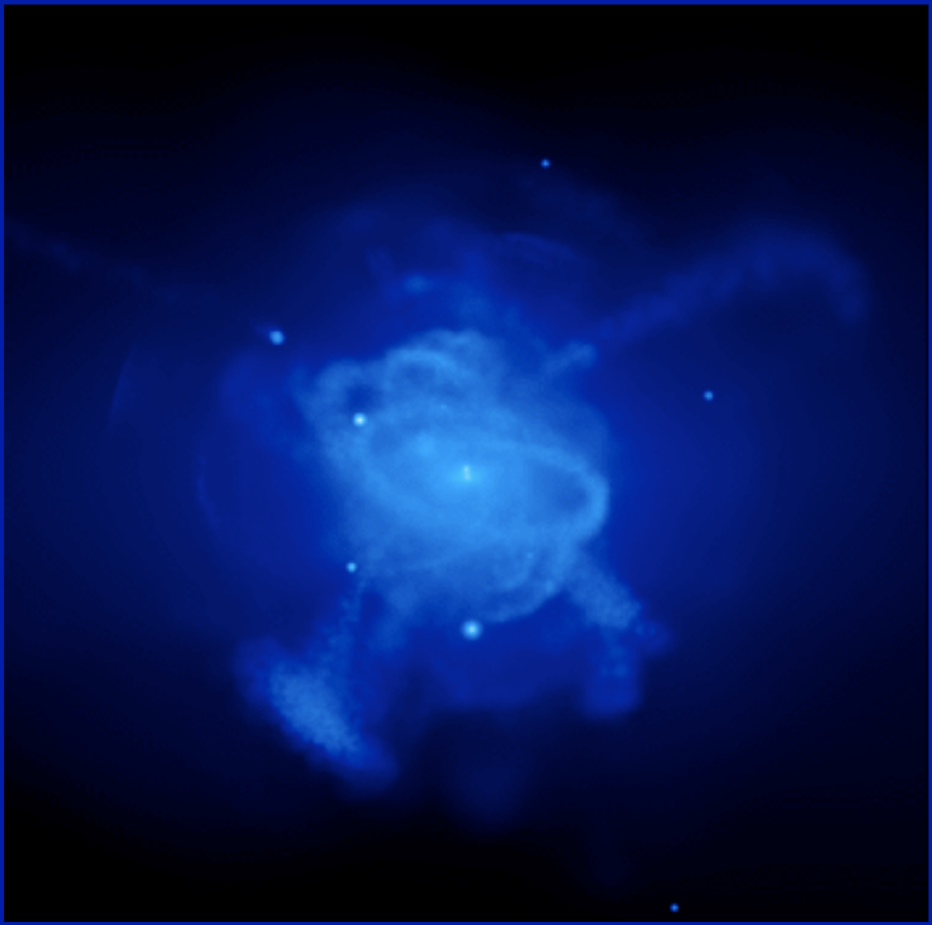
Integrating the light from detected galaxies



- Red curve:
  - Typical galaxy catalog results
- Blue curve
  - Integrating over the size distribution
  - Accounting for the wings if the galaxies are a 50/50 mix of disks and spheroids
  - Accounting for photometric biases
- Black curve
  - Extrapolating to fainter magnitudes
- Green & cyan points
  - Estimates of the optical diffuse EBL

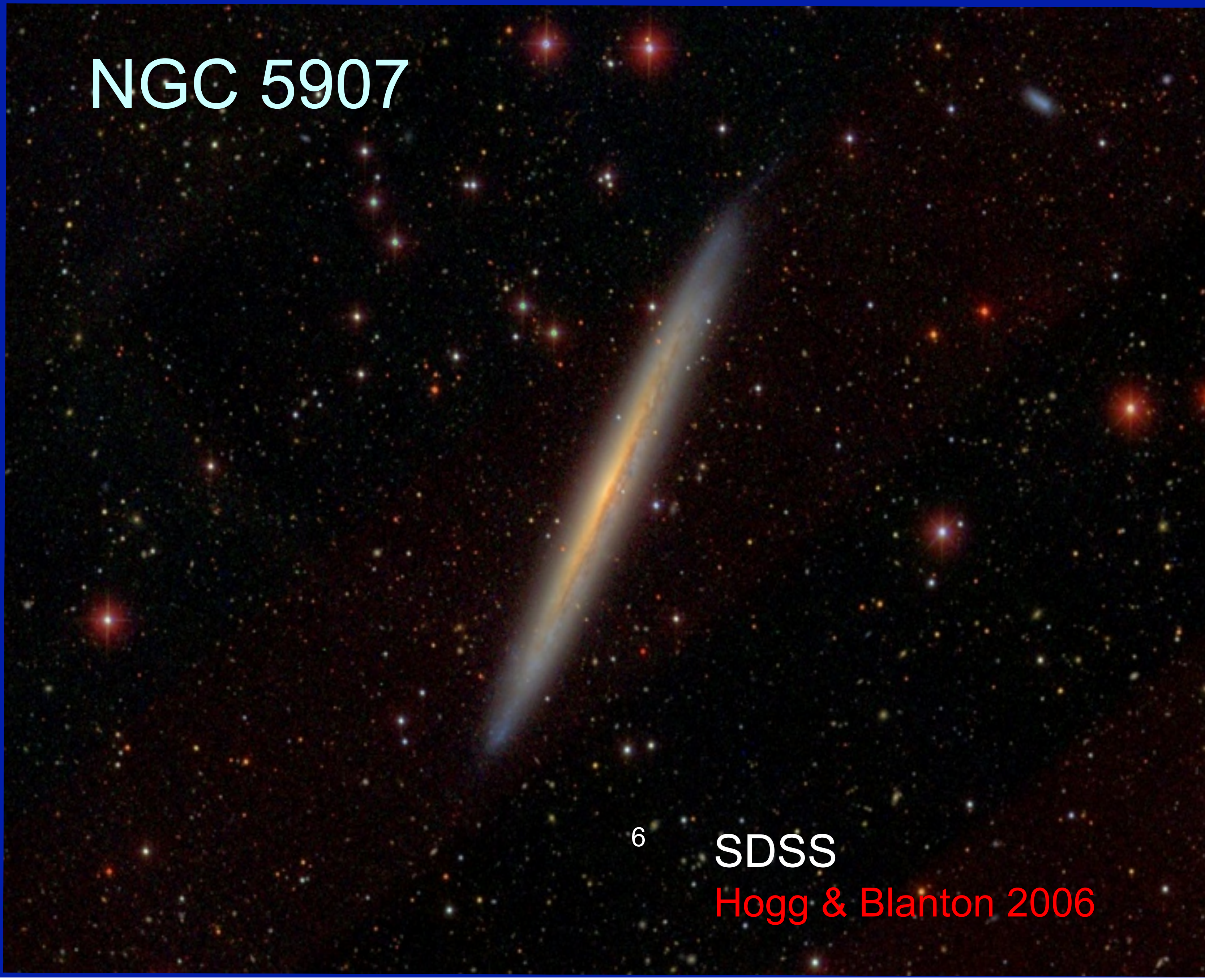
Well-behaved wings of galaxies can account for about half of the estimated diffuse optical EBL.

The outskirts of galaxies



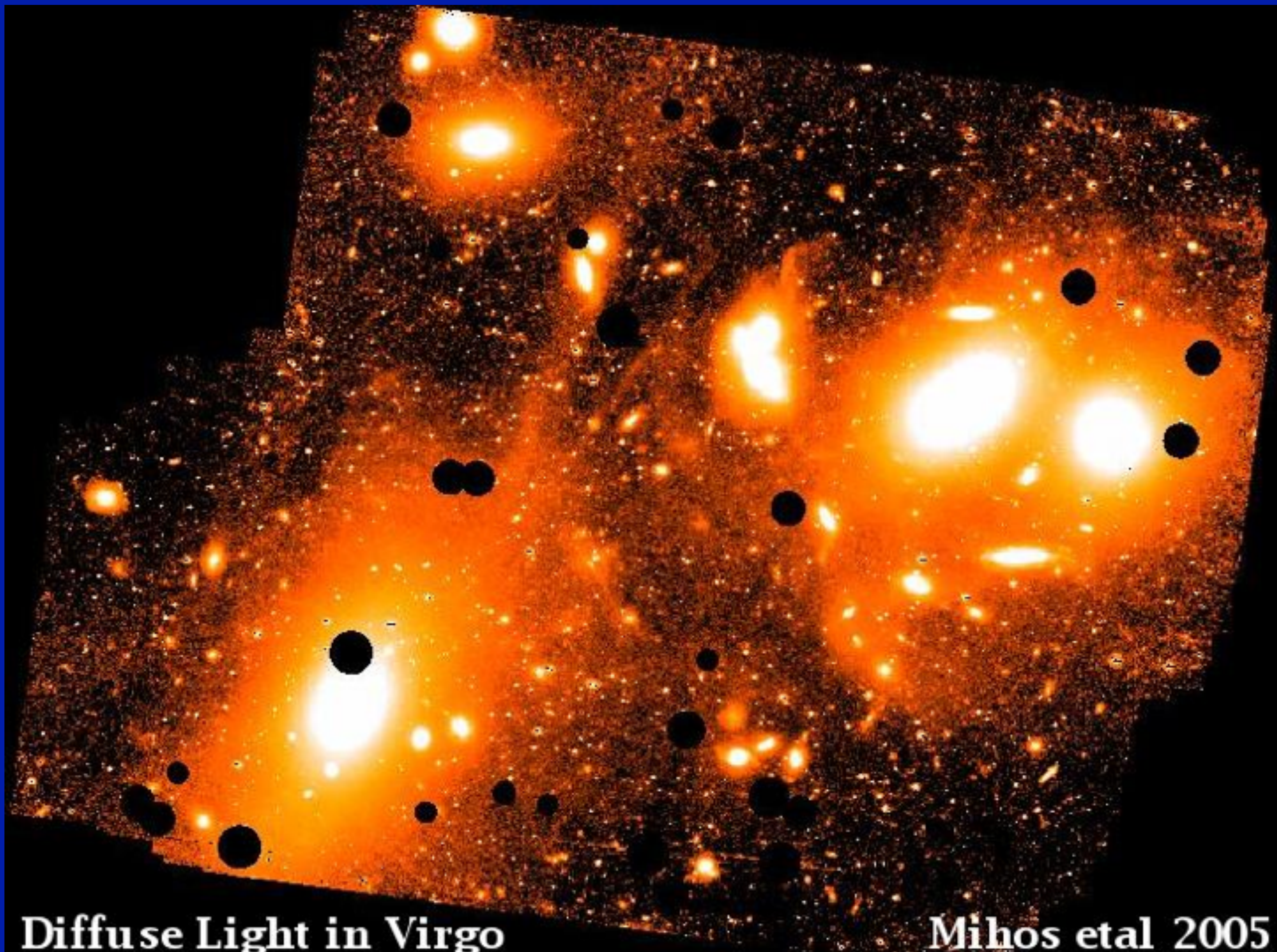
Bullock & Johnston 2005

- The wings of galaxies may not be well behaved
- Hierarchical models build lumpy halos
- Streams and filaments can extend for 100s of kpc

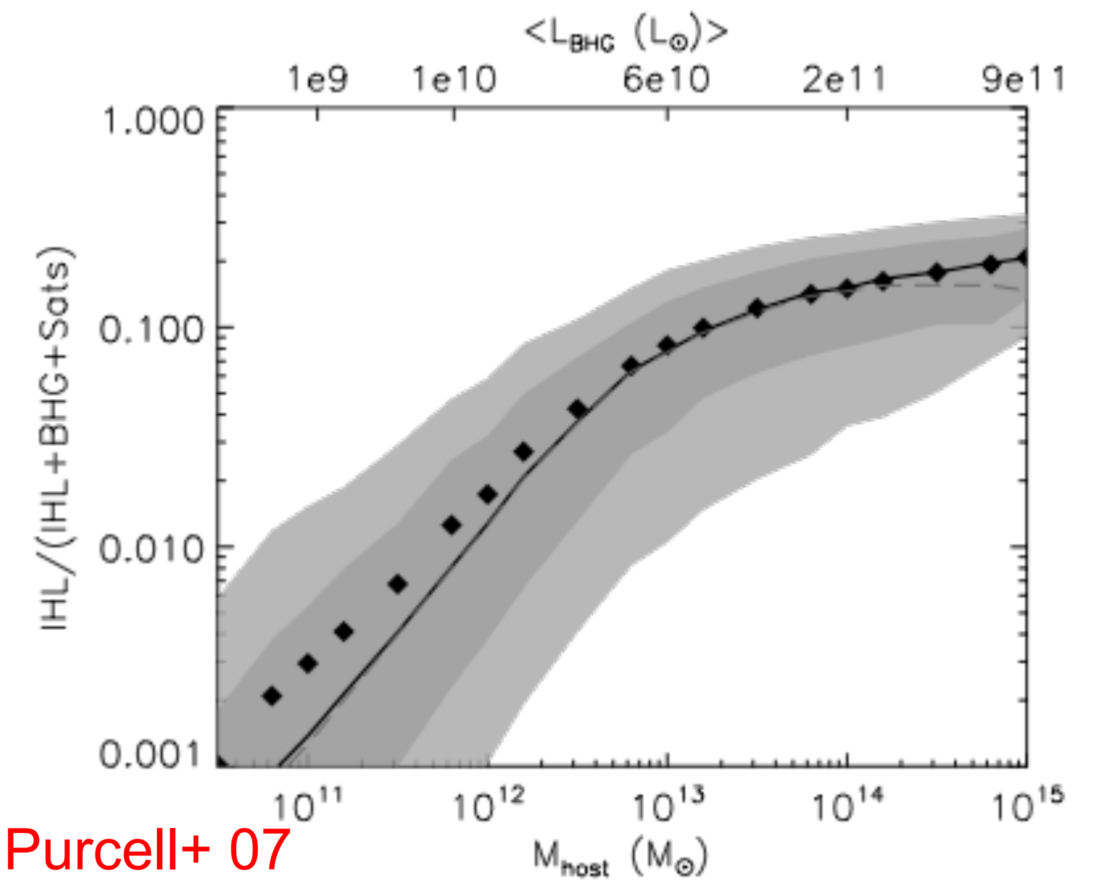

NGC 5907
SDSS
Hogg & Blanton 2006

Martinez-Delgado+ 08

Cluster Diffuse Light


Diffuse Light in Virgo
Mihos etal 2005

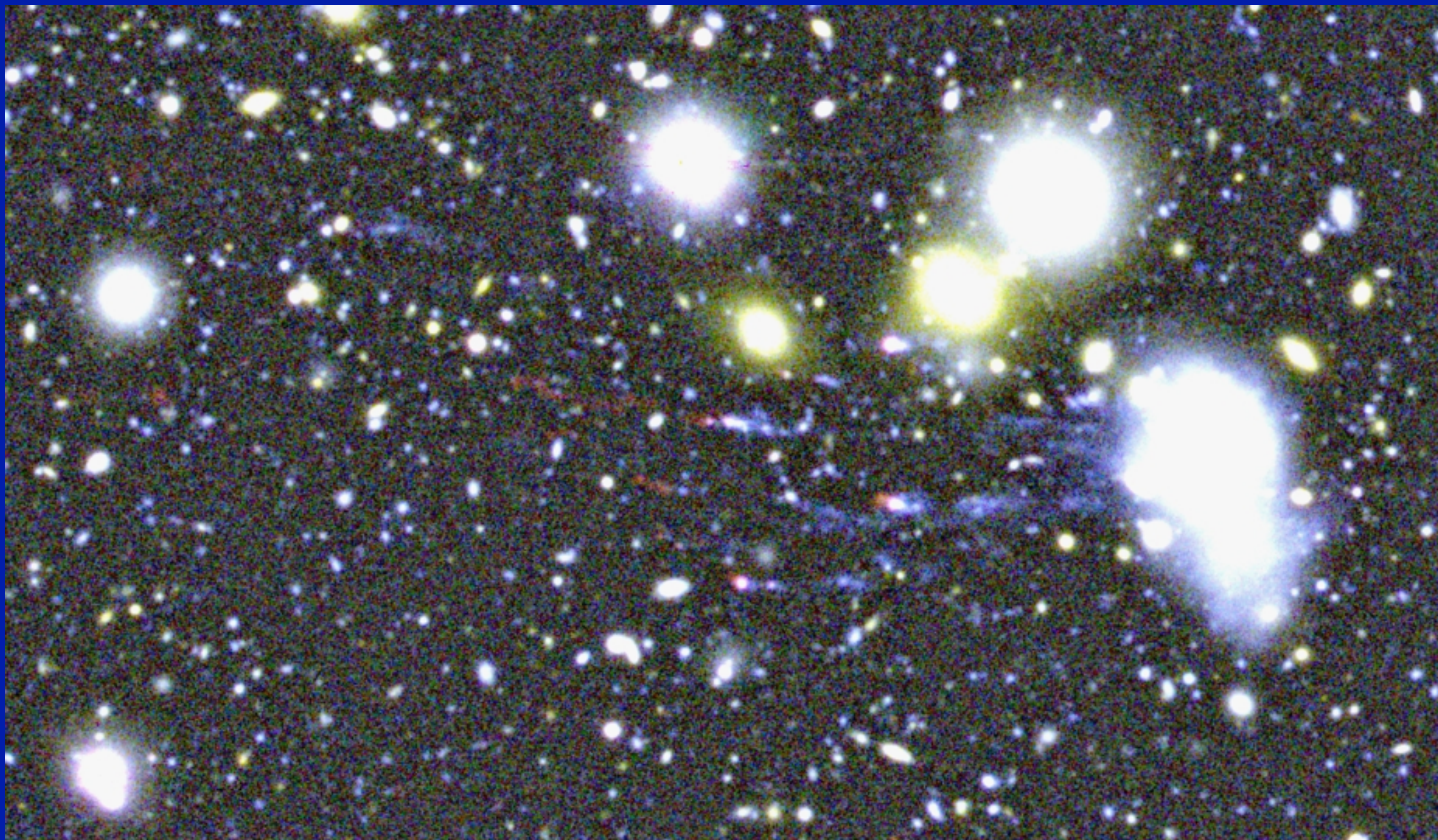
Intra-halo light from hierarchical models



Purcell+ 07

- Expected to contribute 10-20% for halos with $>10^{13}\ M_{\odot}$

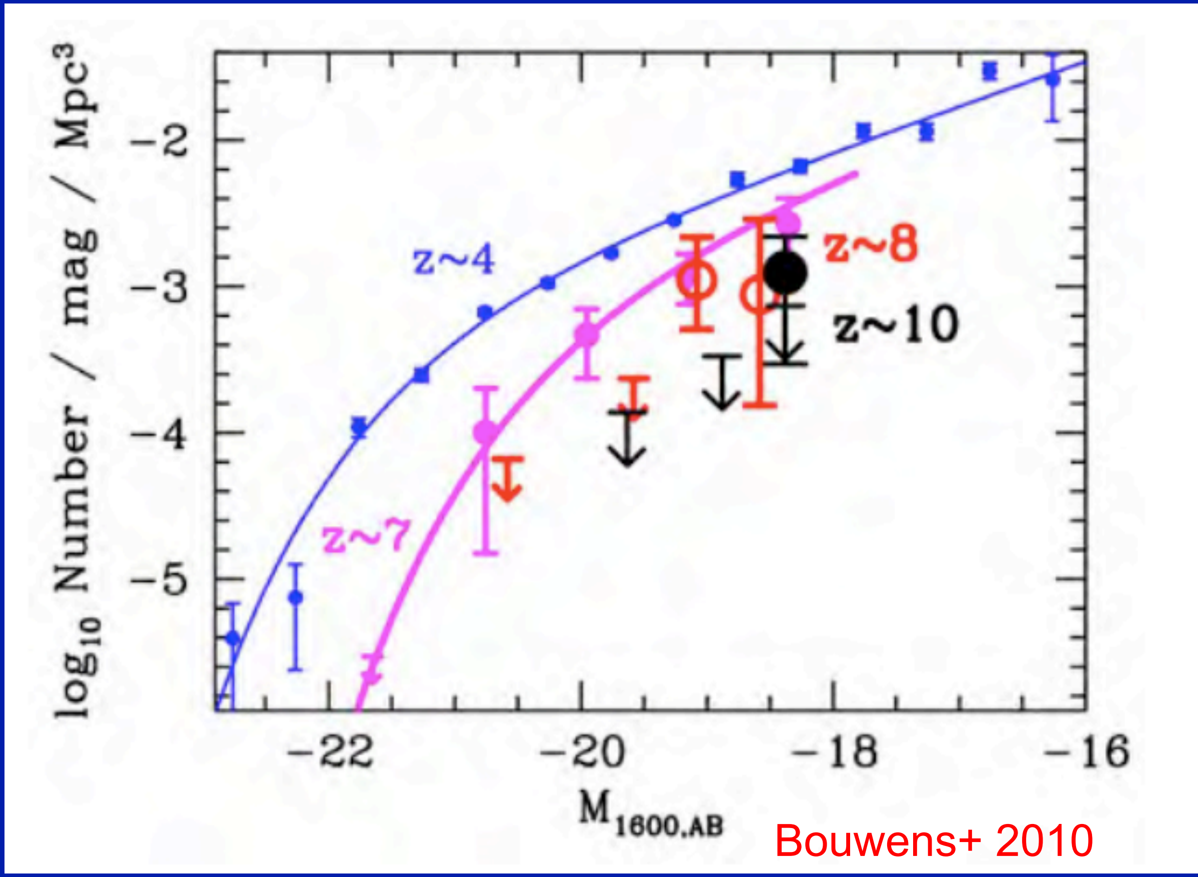
Ram pressure "fireballs"



- Subaru galaxy RB199
- 80 kpc ; Yoshida+ 08

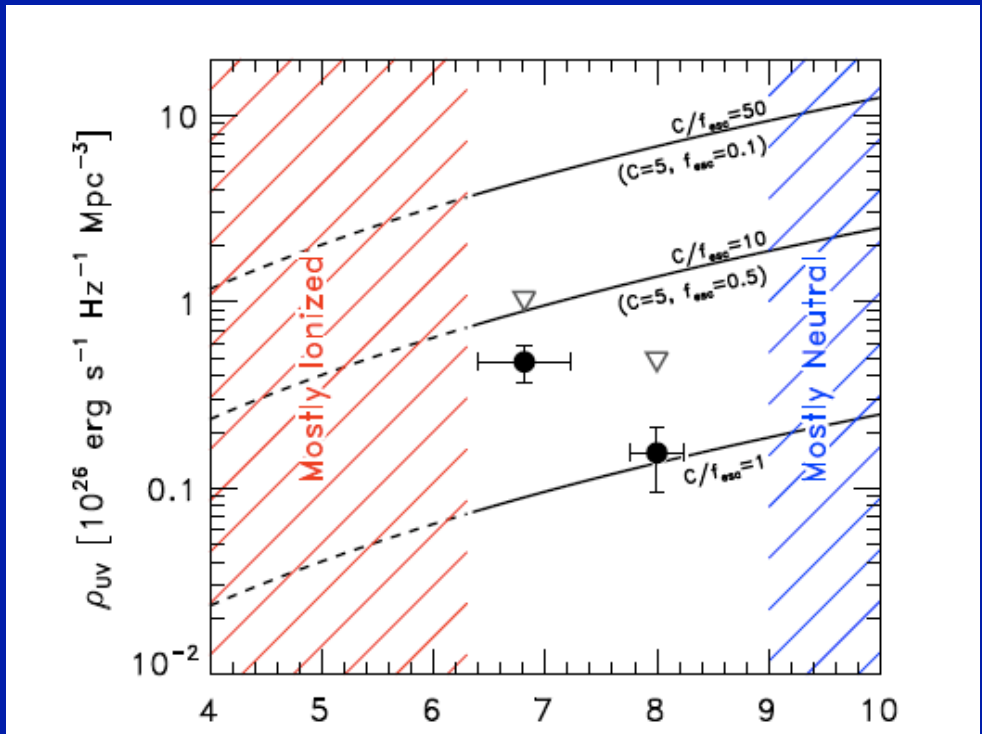

60x2 kpc Optical filament in the Coma Cluster
Subaru image; Yagi+ 07

The "fossil record" at z>3



- The Luminosity function is evolving
  - Consistent with L* decreasing toward higher redshift

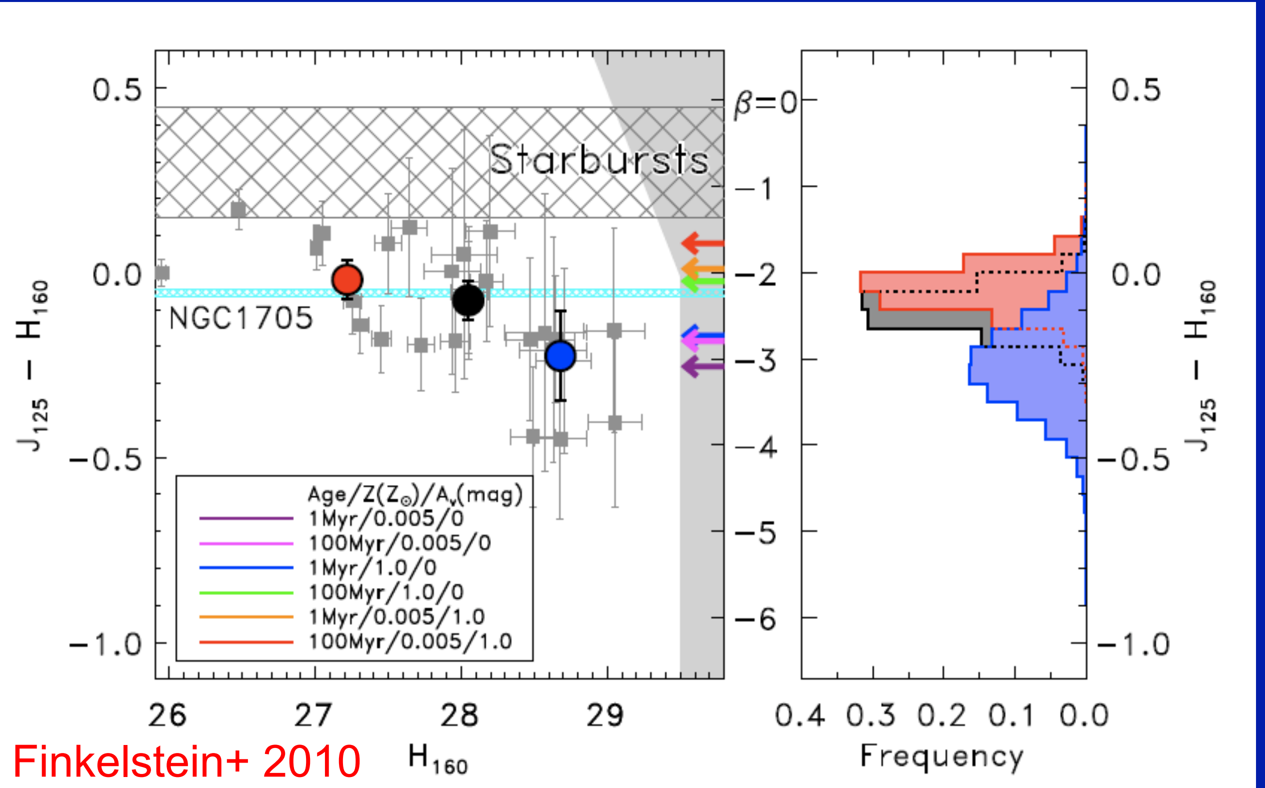
The “fossil record” at z>3



Finkelstein+ 2010

- Closing the energy budget for reionization requires one or more of the following:
  - Low IGM clumping
  - A steep faint-end LF
  - A large escape fraction,
  - Bluer galaxies

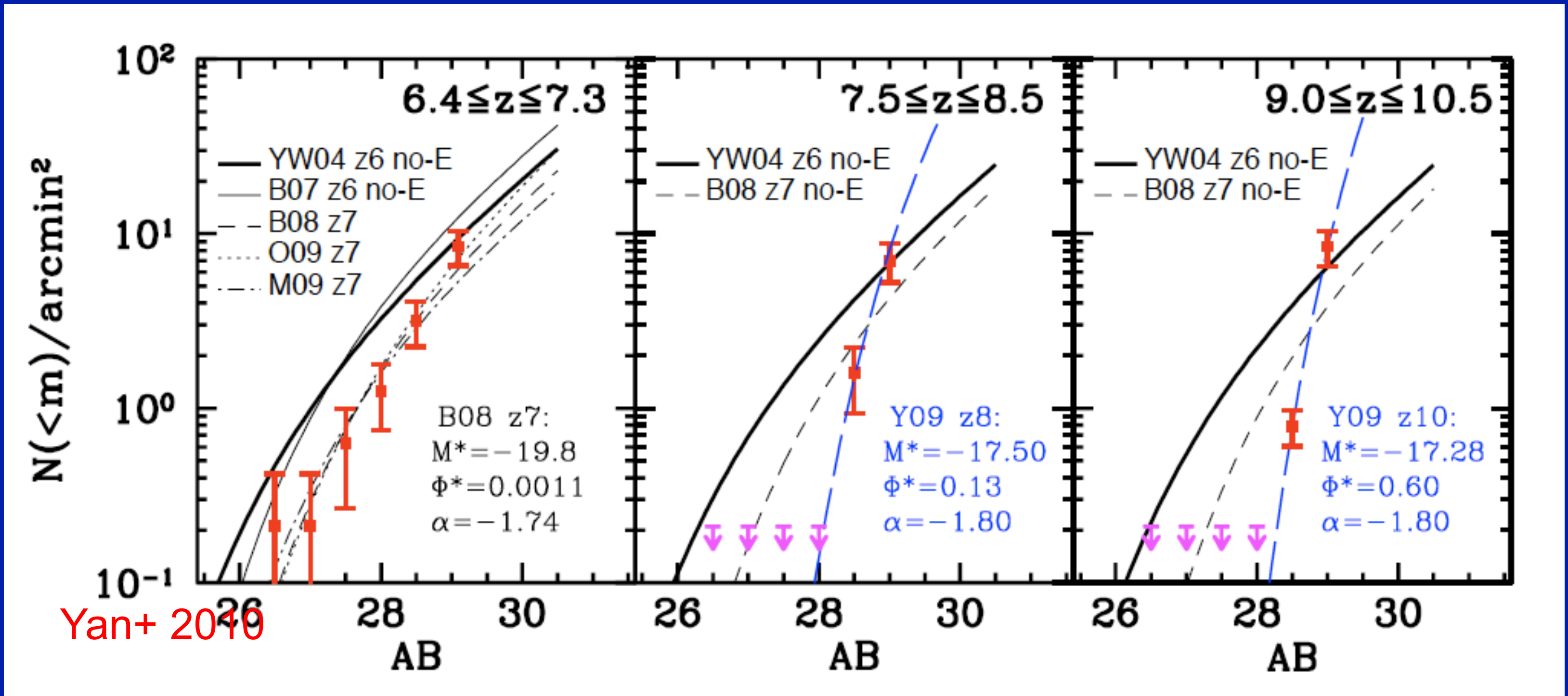
The “fossil record” at z>3



Finkelstein+ 2010

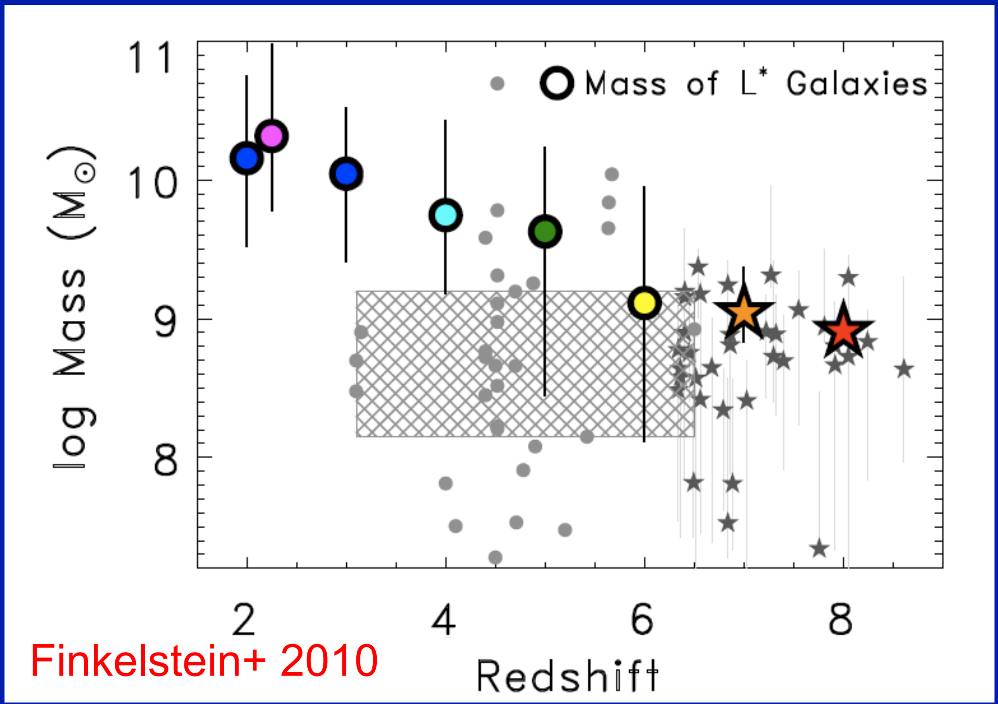
- UV slopes appear to be getting bluer
  - Toward high redshift
  - Toward lower luminosity

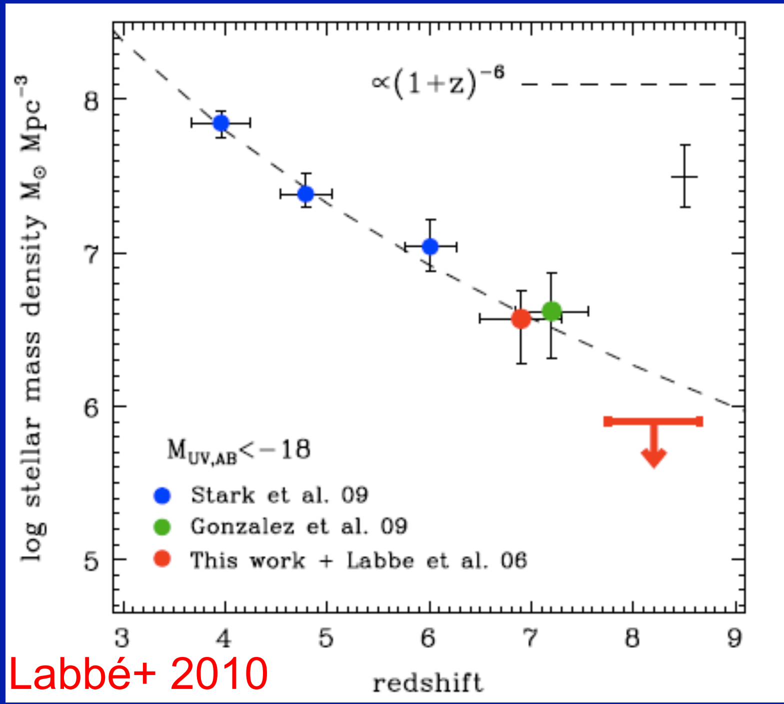
The "fossil record" at z>3



- Controversial hints of a steeper LF at z>8

The "fossil record" at z>3

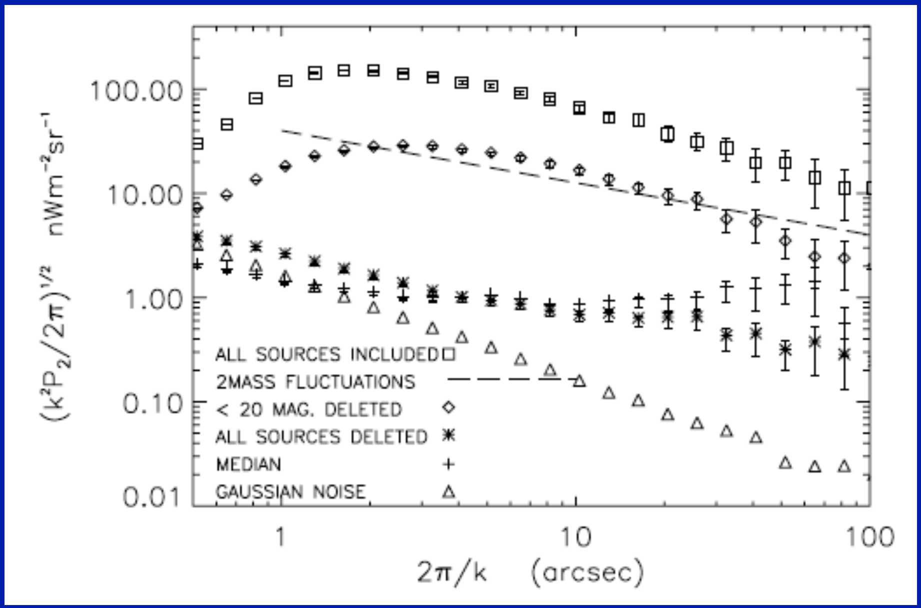


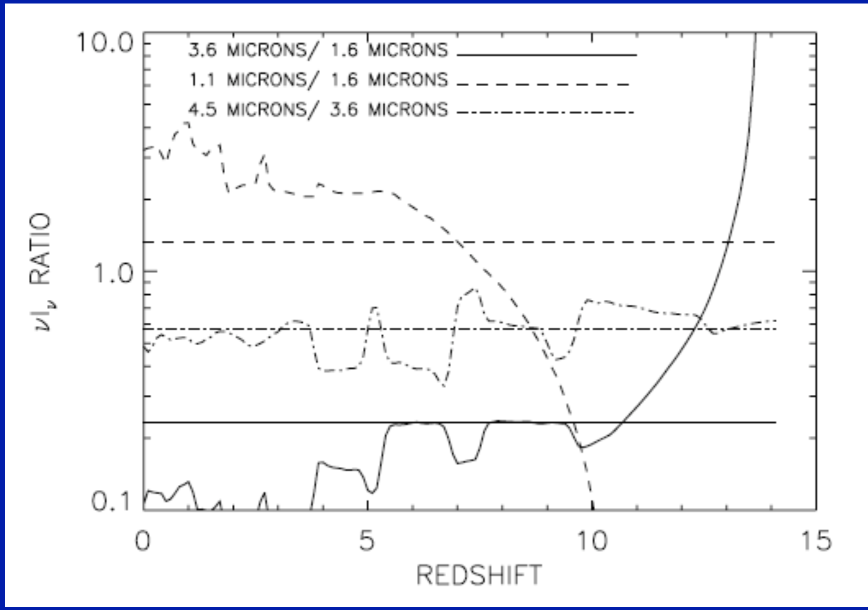


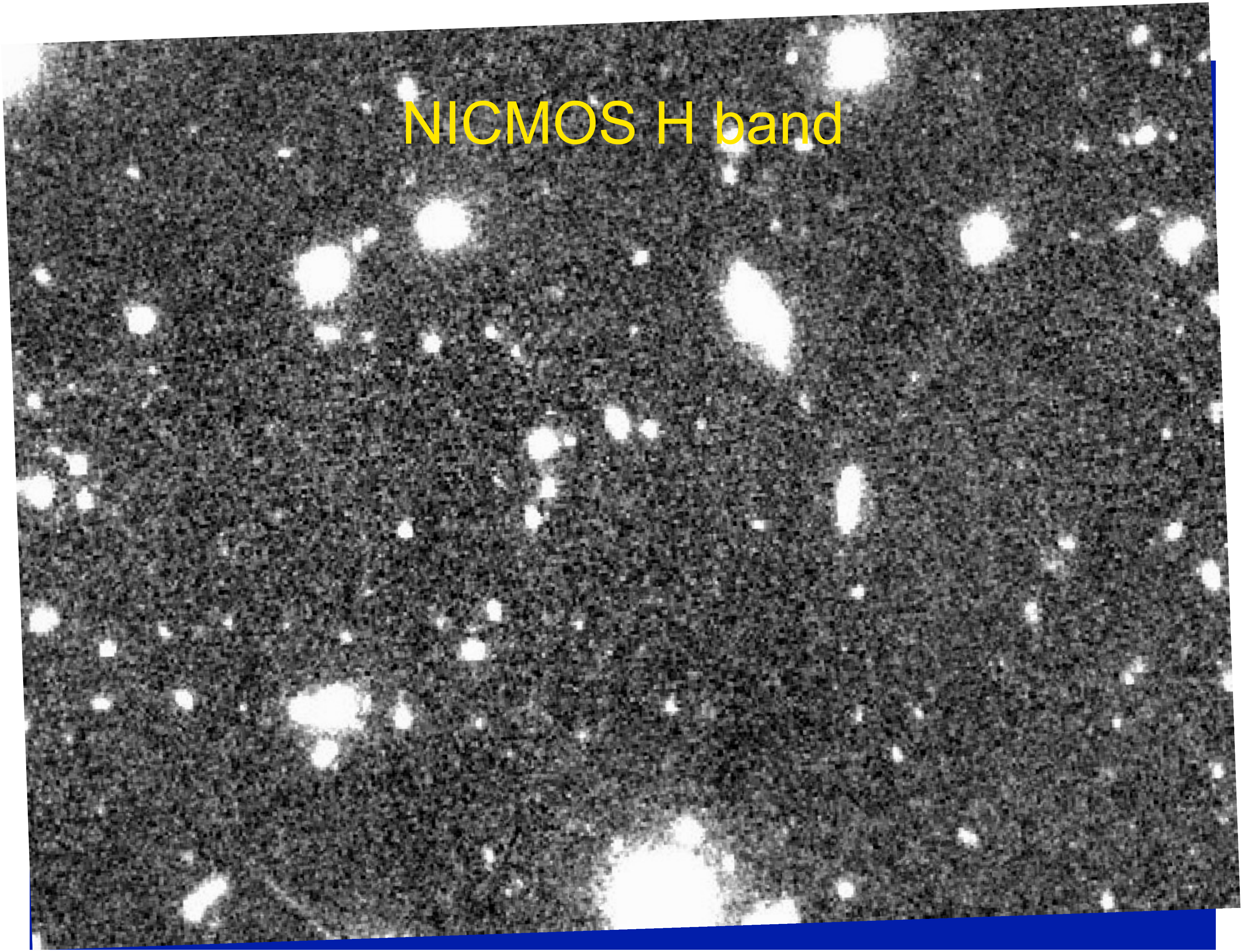
- Stellar mass evolution
  - Stellar masses at L* are not large at z~7
  - At most a few percent of present stellar mass density
  - Hard to hide the remnants of higher-z star formation if the IMF was not very top heavy

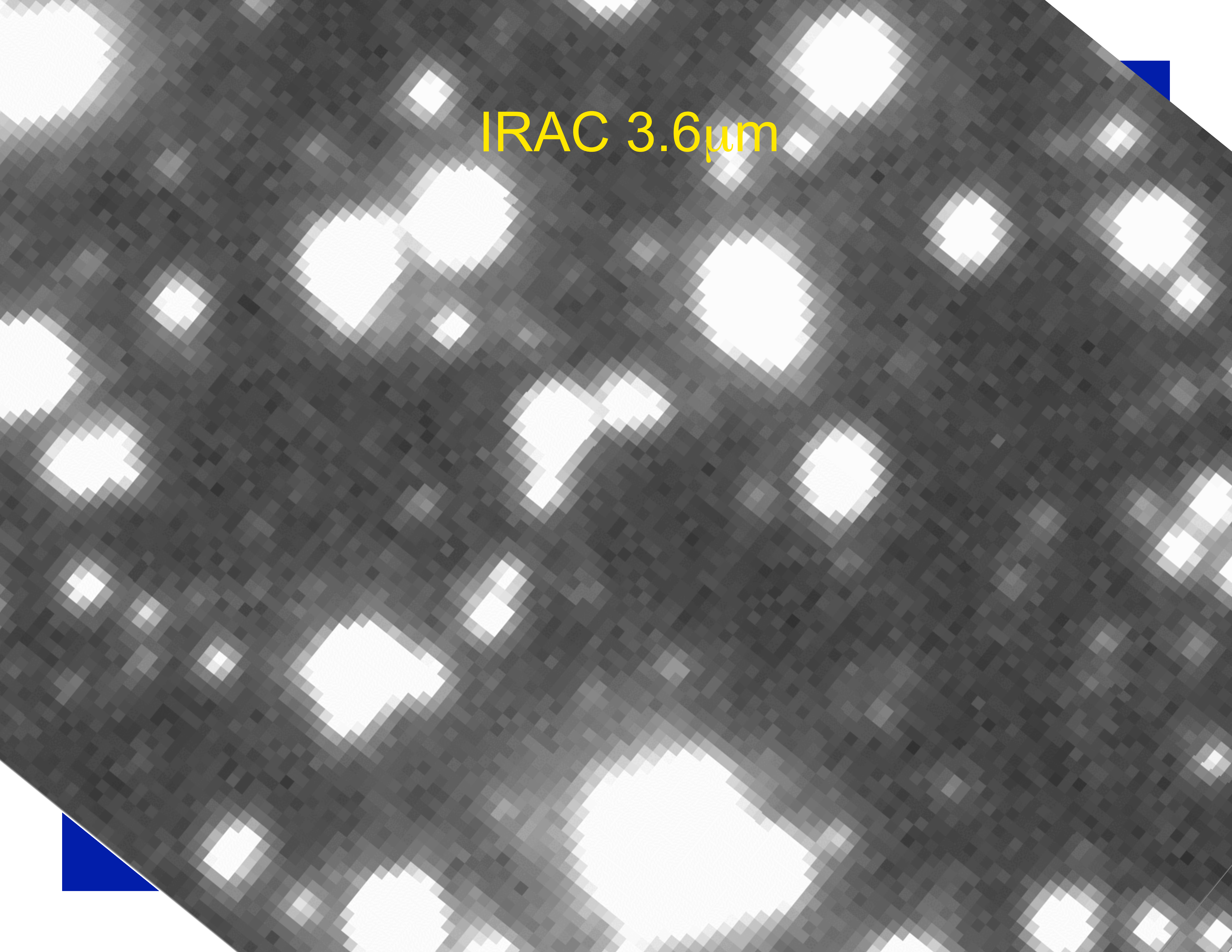
Fluctuations in the Near-IR from HST

- Thompson et al HST NICMOS:
  - Detected sources emit 7 nW m^2 sr^{-1} compared to DC-level estimate of 70 nW m^2 sr^{-1} from Matsumoto+ 2005
  - Sources of the remaining fluctuations are probably at z<8 (even for the longer-wavelength IRAC data).

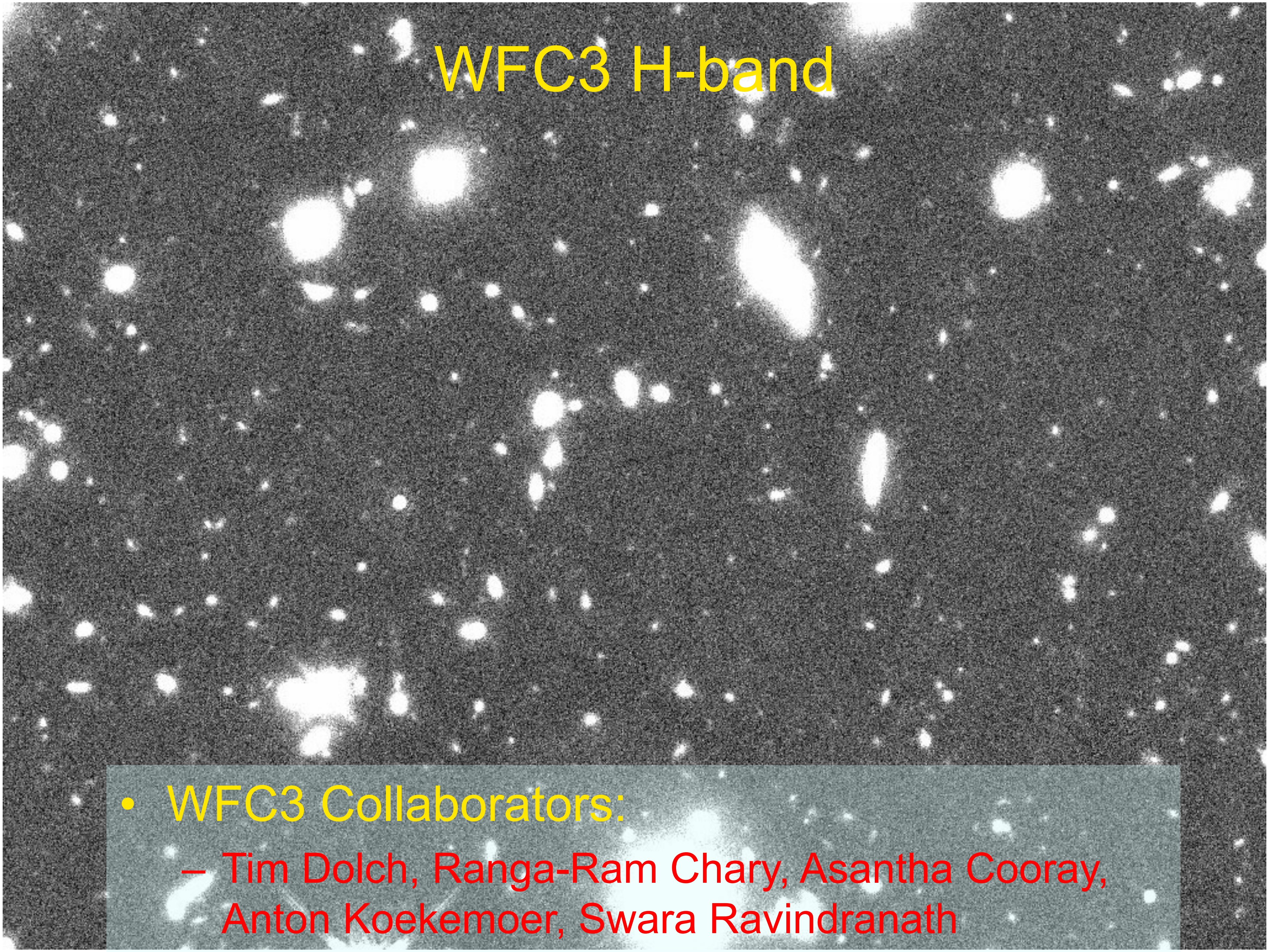




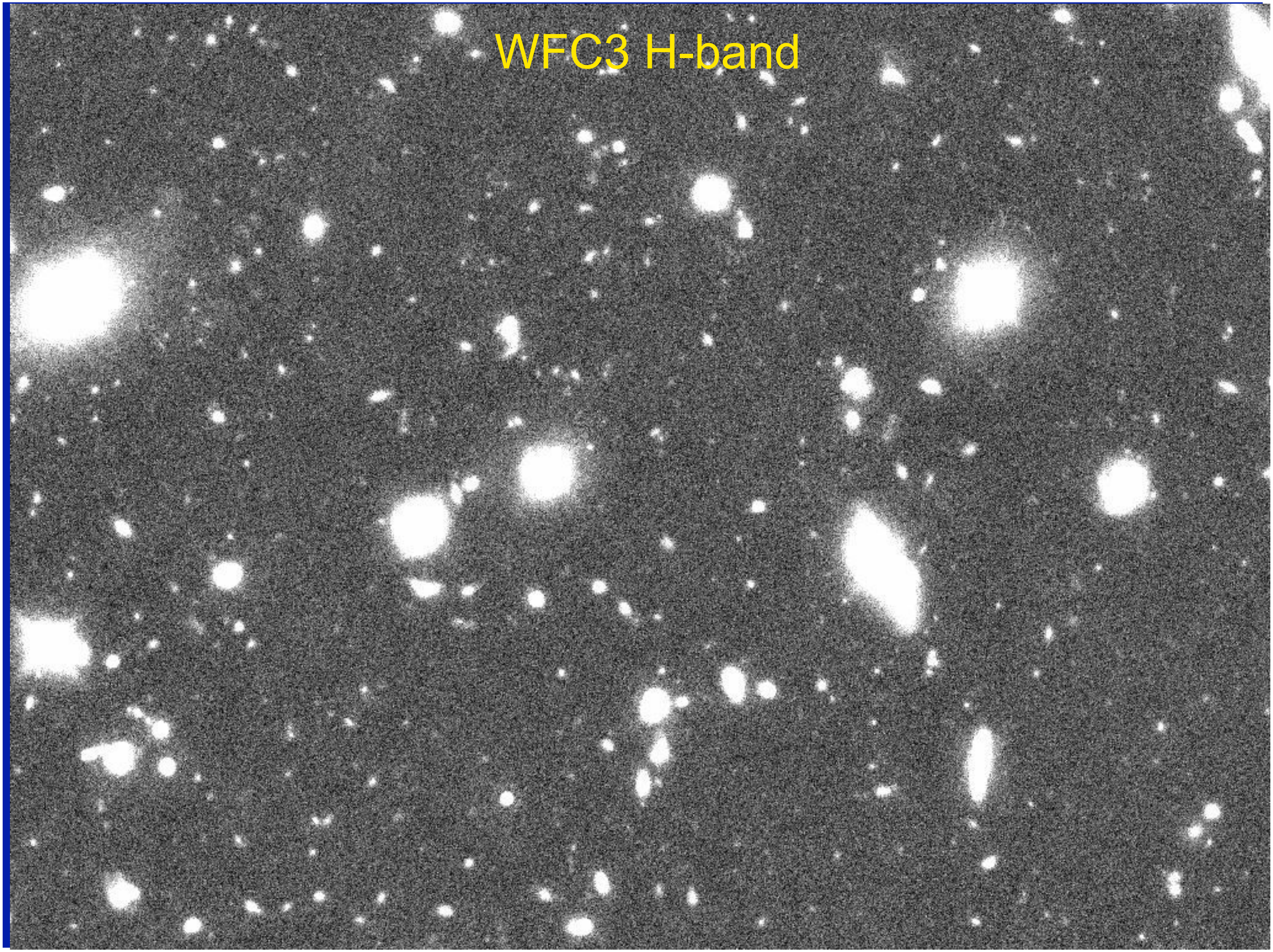

NICMOS H band

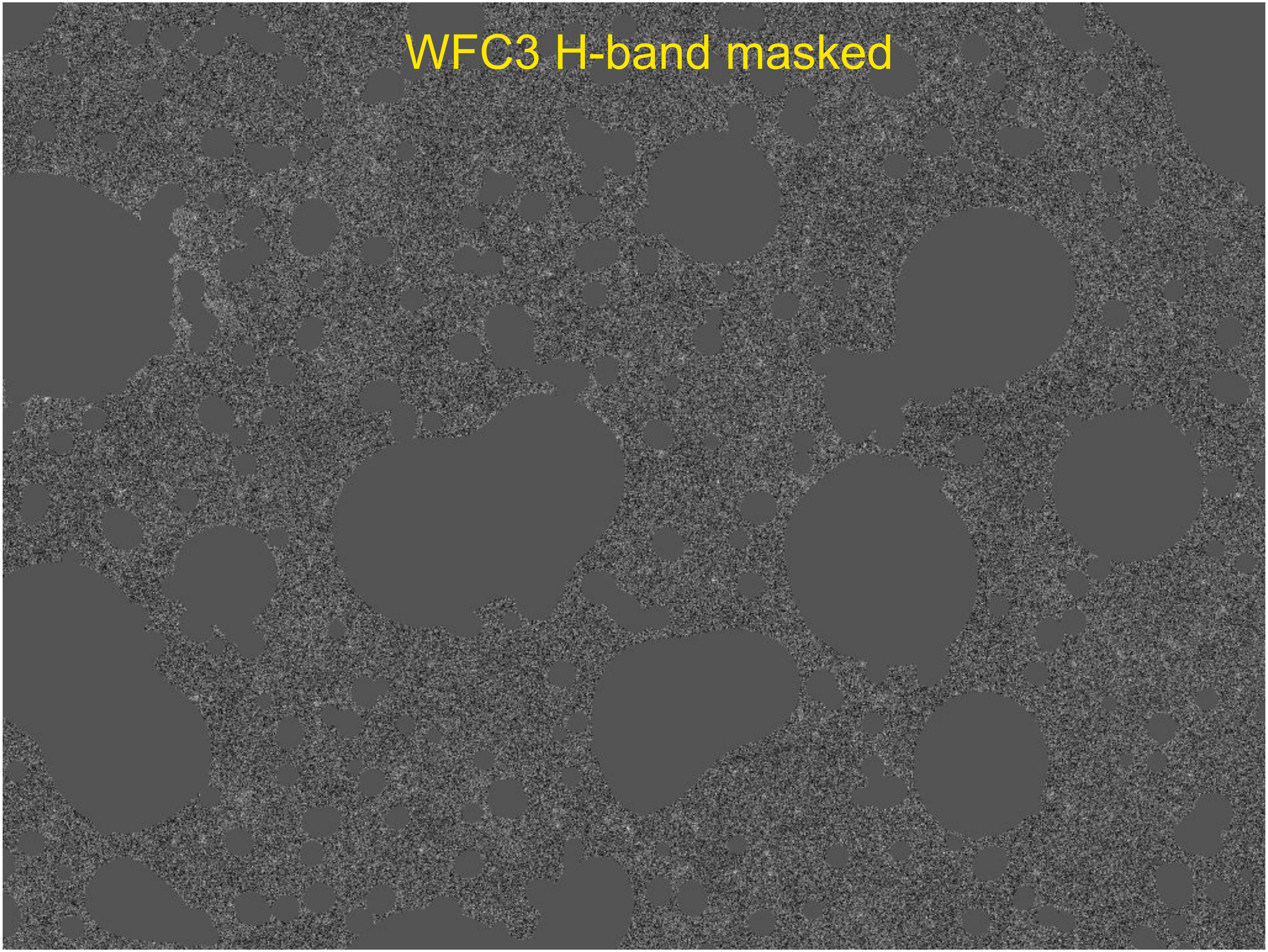

IRAC 3.6μm

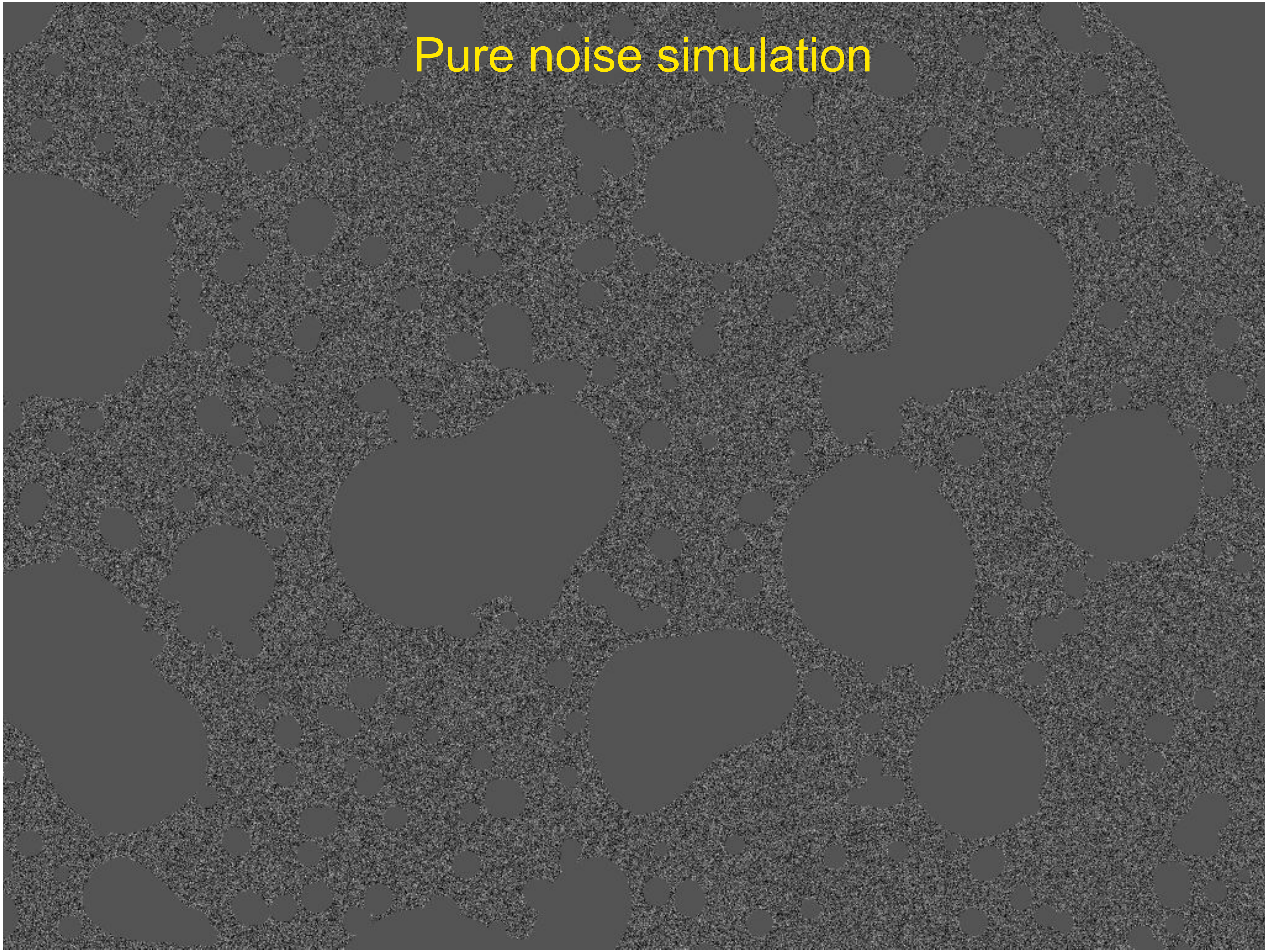
WFC3 H-band



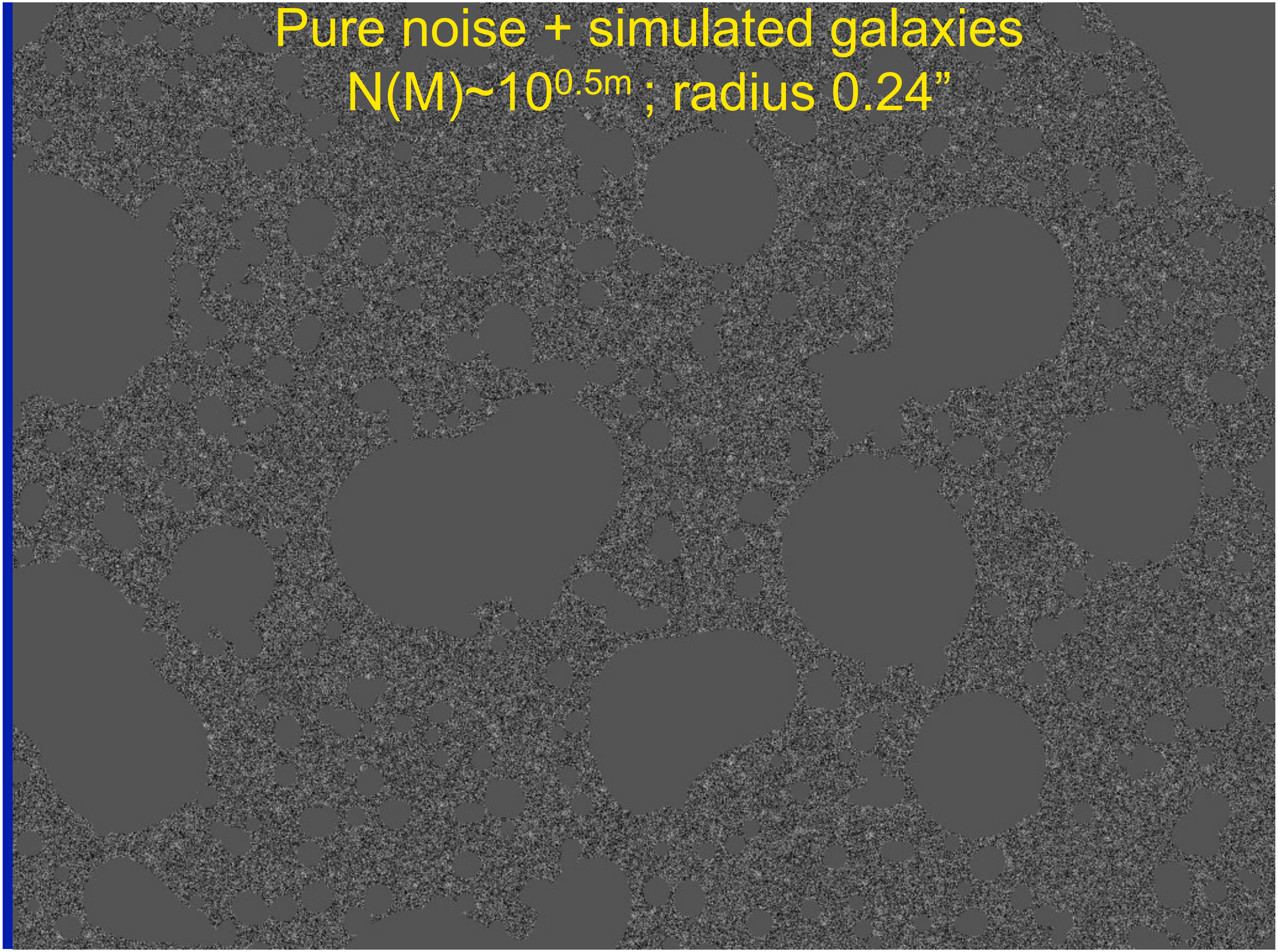
- WFC3 Collaborators:
  – Tim Dolch, Ranga-Ram Chary, Asantha Cooray, Anton Koekemoer, Swara Ravindranath

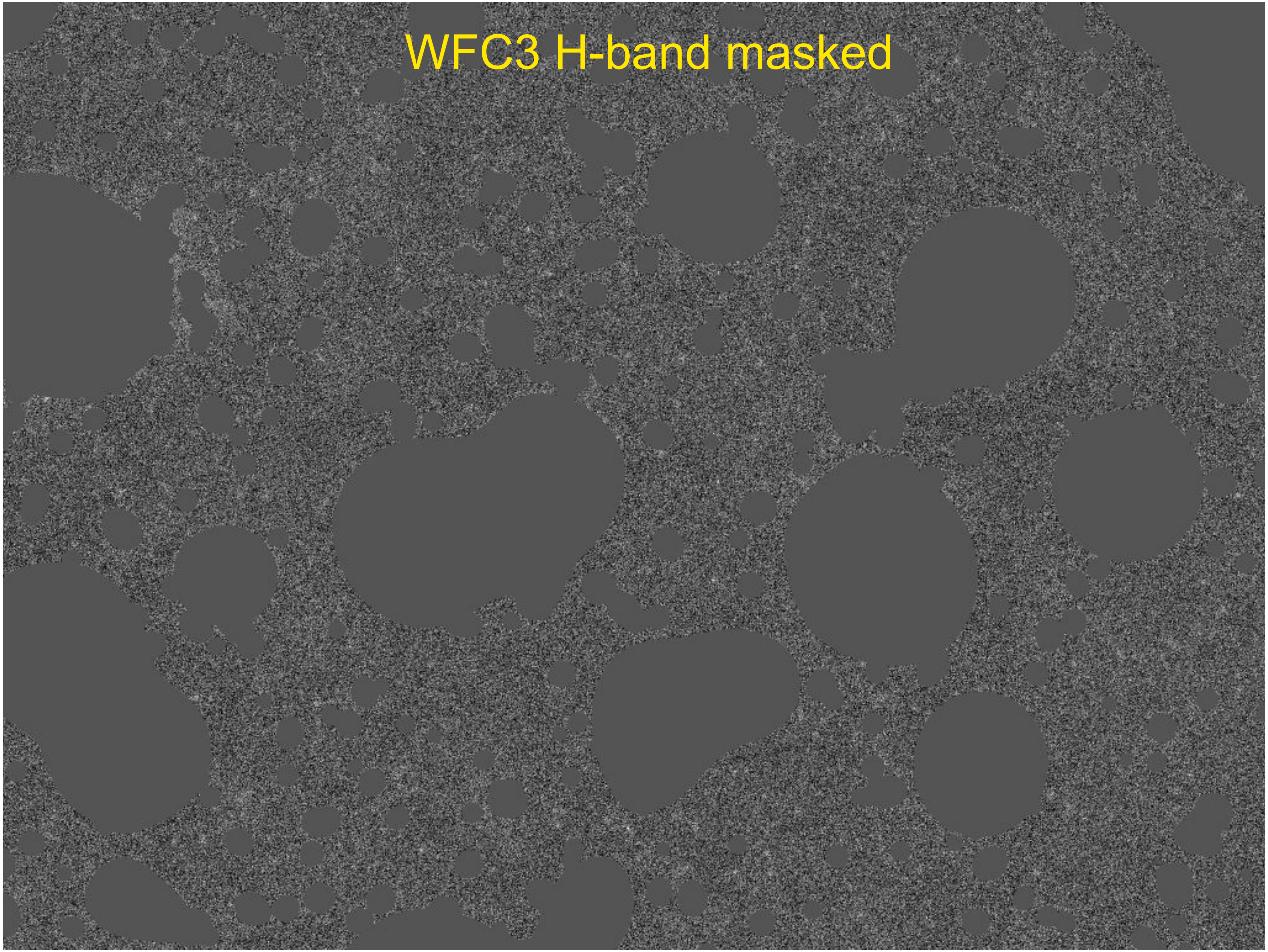

WFC3 H-band


WFC3 H-band masked


Pure noise simulation

Pure noise + simulated galaxies
N(M)~$10^{0.5m}$; radius 0.24”



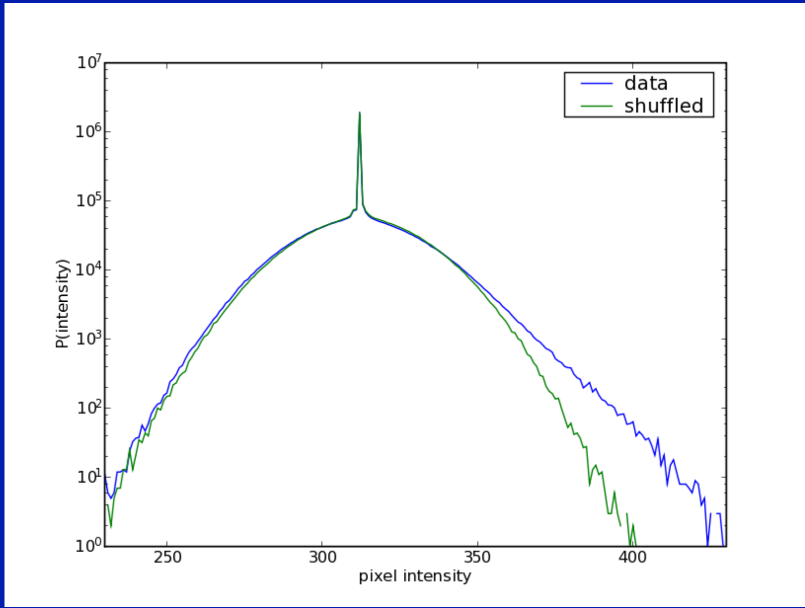

WFC3 H-band masked

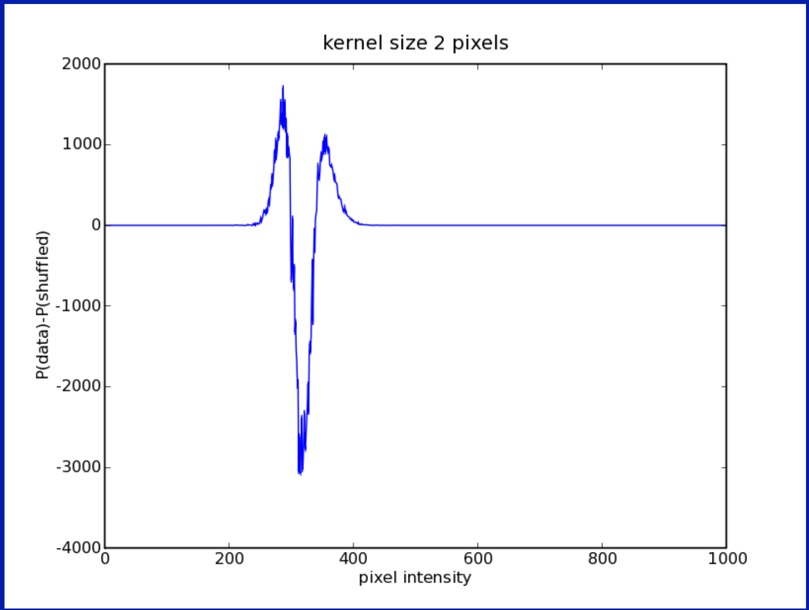
Data Preparation

- Iteratively remove detector blemishes
  - Combined dithered images with some masking
  - Transfer combined image back to original image geometries and subtract
  - Smooth and detect blemishes or persistence
  - Mask and recombine for the final image
- Create pure noise images in original detector coordinates
  - Gaussian statistics okay for these images; match sky background
  - Predicted RMS matches measured RMS to within a few percent
  - Combine these just as for the real images
- Mask the detected sources
  - Ideally -- subtract the galaxy wings (work in progress)

Analysis Procedure

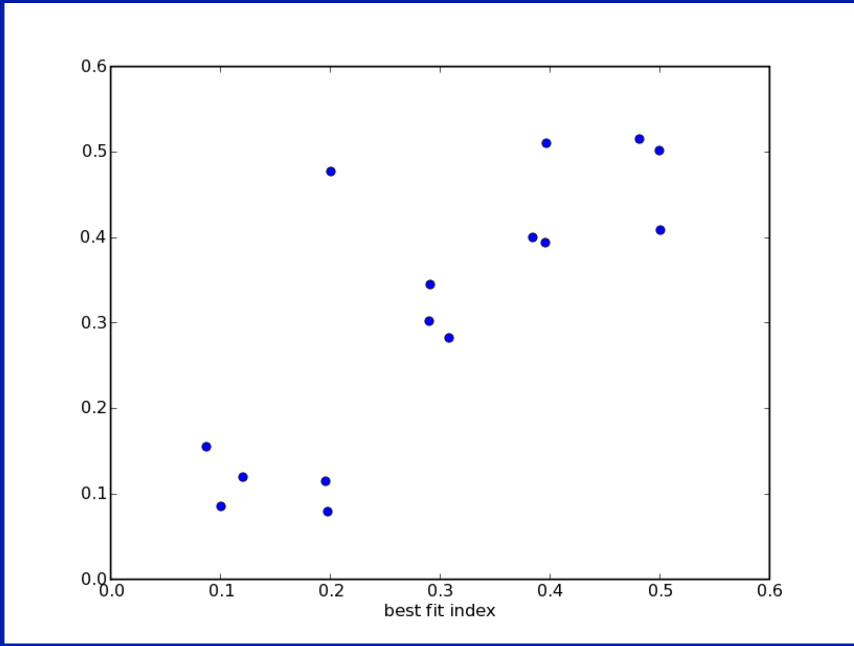
- Create a shuffled version of the image
  - Unmasked pixels are randomly shuffled, removing correlations
- For both the shuffled and unshuffled version:
  - Convolve the masked images with kernels of various sizes
  - Compute the histogram of pixel intensities P(D)
- Subtract the shuffled P(D) from the unshuffled P(D).
  - Excess is amplified when kernel matches the characteristic size of the sources

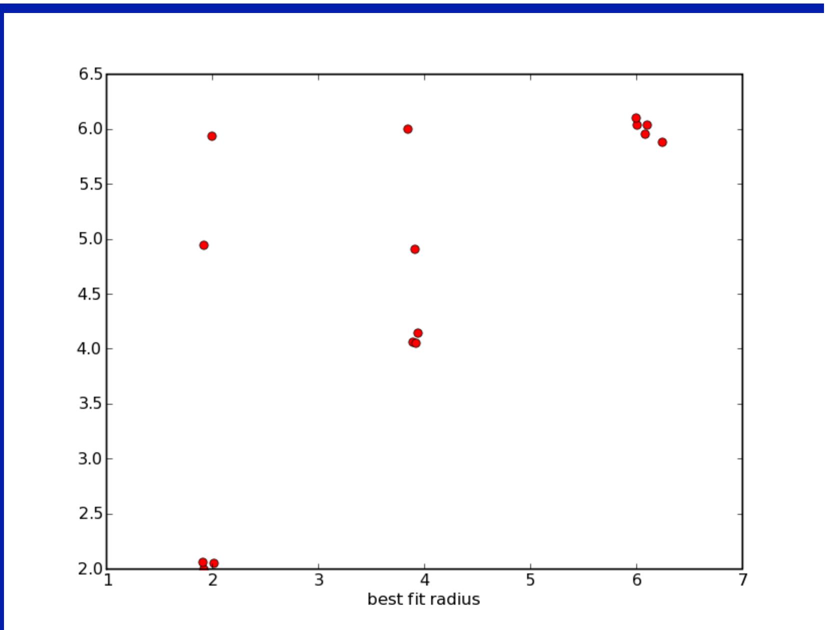




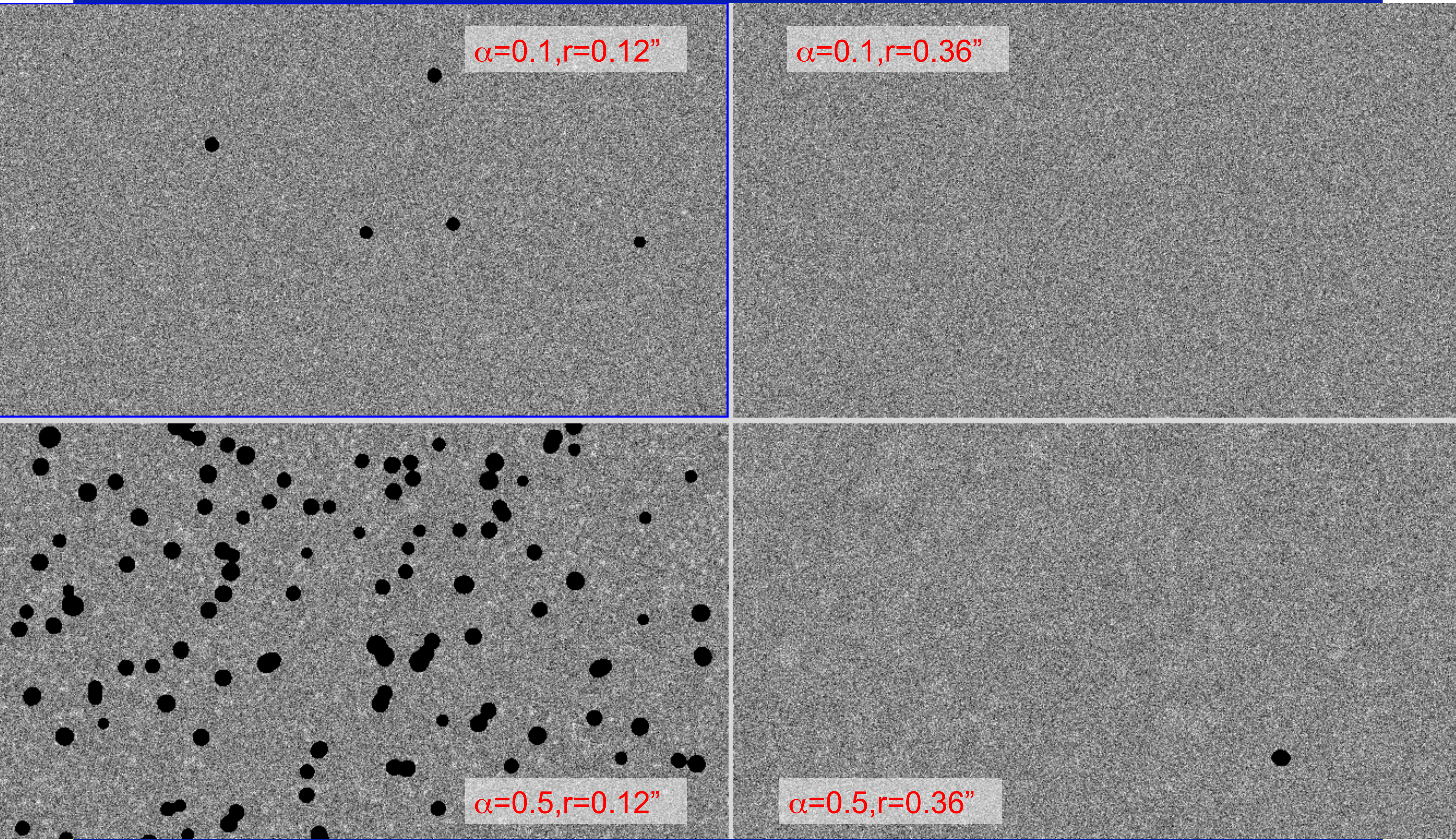
Validation

- Tests on simulated UDF data
  - Recover power-law slope to about ±0.1
  - Generally recover the input size, with some outliers
- This should get better with more data





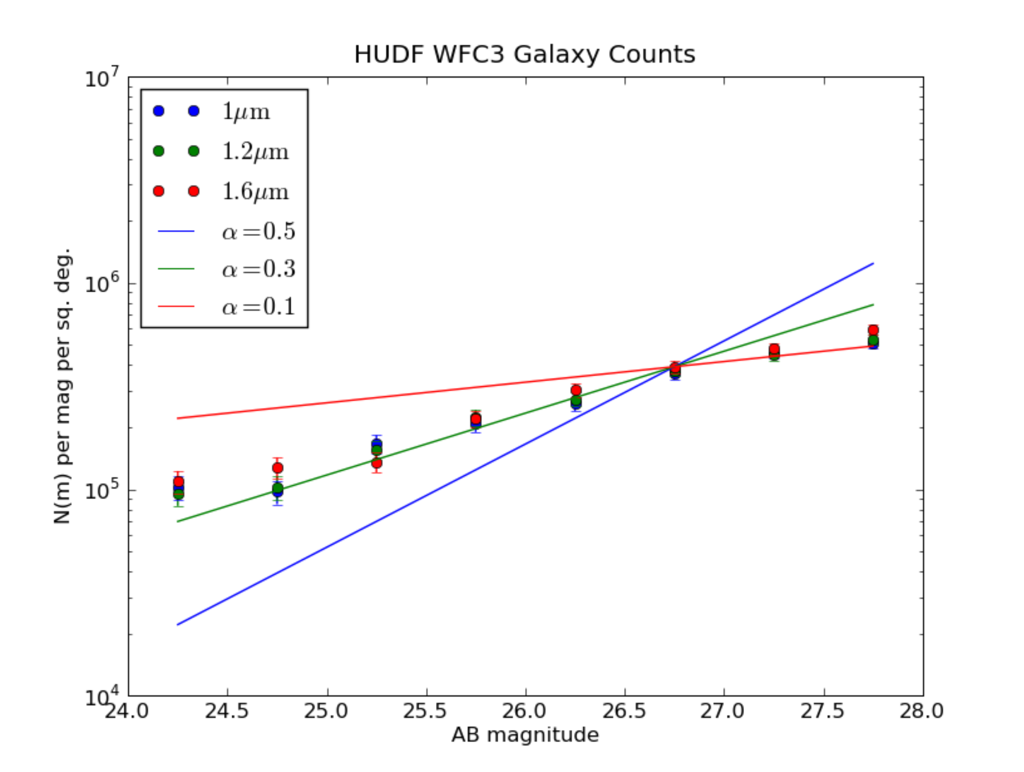
Simulated data



Preliminary results

- Simple power-law model:
  - $N(M) \sim 10^{\alpha m}$
  - Normalization fixed to match total counts $27<m<28$
  - Constant size modeled with Gaussians
- Best fits
  - F160W: $\alpha = 0.5$, $r = 0.24''$
  - F125W: $\alpha = 0.1$, $r = 0.12''$
  - F105W: $\alpha = 0.3$, $r = 0.21''$
- Steep slope in F160W is intriguing
- Change in slope is puzzling
  - More sanity tests needed

Near-IR Galaxy counts



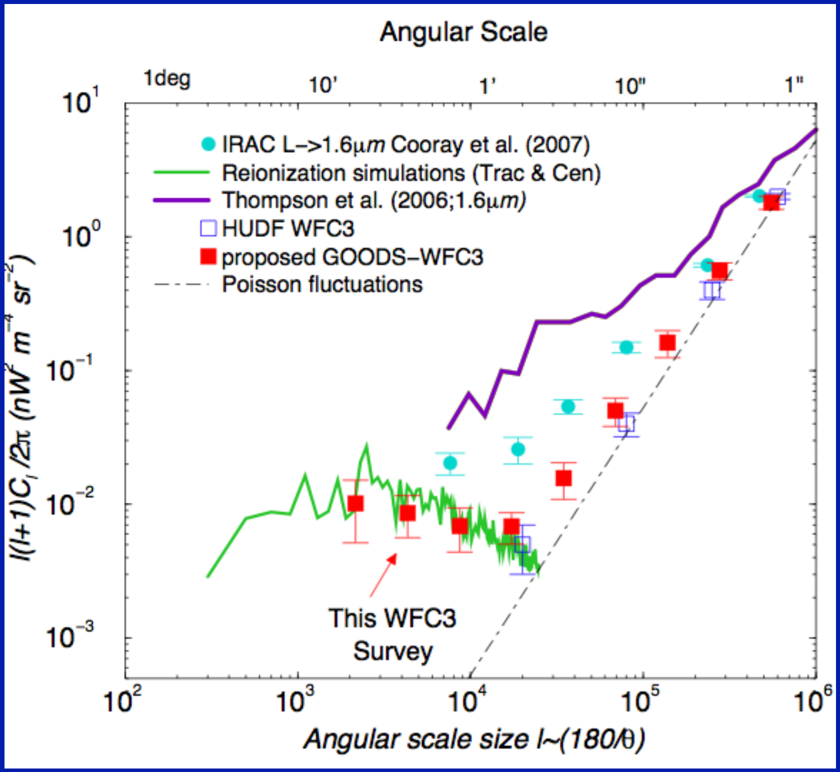
- Faint-end slope is:
  - Flatter than α=0.5
  - Similar in all three bands
- Less than 5% of the galaxies at H>26.5 are identified as Lyman-break galaxies at z>6.5

Future Efforts

- Galaxy subtraction
- More sophisticated models
  - Galaxy size magnitude relation with scatter
- Better calibration of hot pixels and persistence
- More data

Potential for EBL measurements

- HST Multicycle treasury program will cover 830 square arcminutes at 1.2 and 1.6 microns to 27-28 magnitude
- Fluctuation measurements on larger scales will be possible



Reionization Simulation from Trac and Cen 2007

Large θ ←←←←← →→→→→ Small θ

- The large angle (θ ~ 1/30 °) peak (green curve) is a linear-theory prediction of clustering of reionization sources.
- Small scale power is sensitive to the slope and normalization of the luminosity function and the sizes of the sources.
- large area surveys with WFC3 can (barely) reach large angle peak

Summary

- A conservative estimate suggests that known galaxies can account for about 50% of the observed (optical) EBL.
- Lumpy halos and intracluster light could contribute another 10-20%
- The fossil record at $z>6$ does not provide much support for a huge burst of star formation at $z>10$.
- WFC3 IR fluctuation analysis suggests fluctuations are consistent with a modest extrapolation of the number counts.

Theories crumble, but good observations never fade.— Harlow Shapley