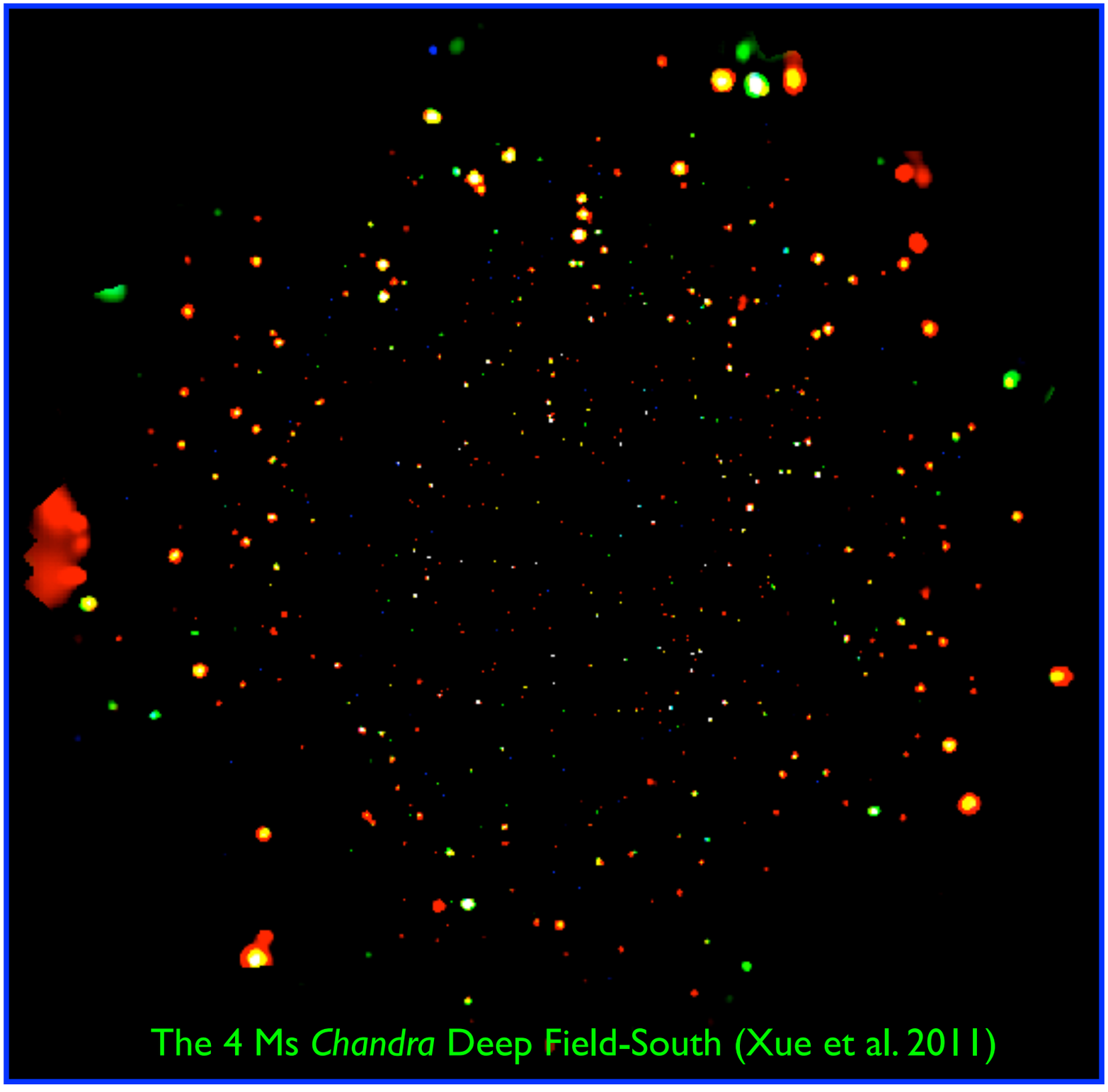
X-ray Number Counts in the 4 Ms Chandra Deep Field South (CDF-S): Characterizing New X-ray Source Populations



The 4 Ms *Chandra* Deep Field-South (Xue et al. 2011)

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Einstein Fellow

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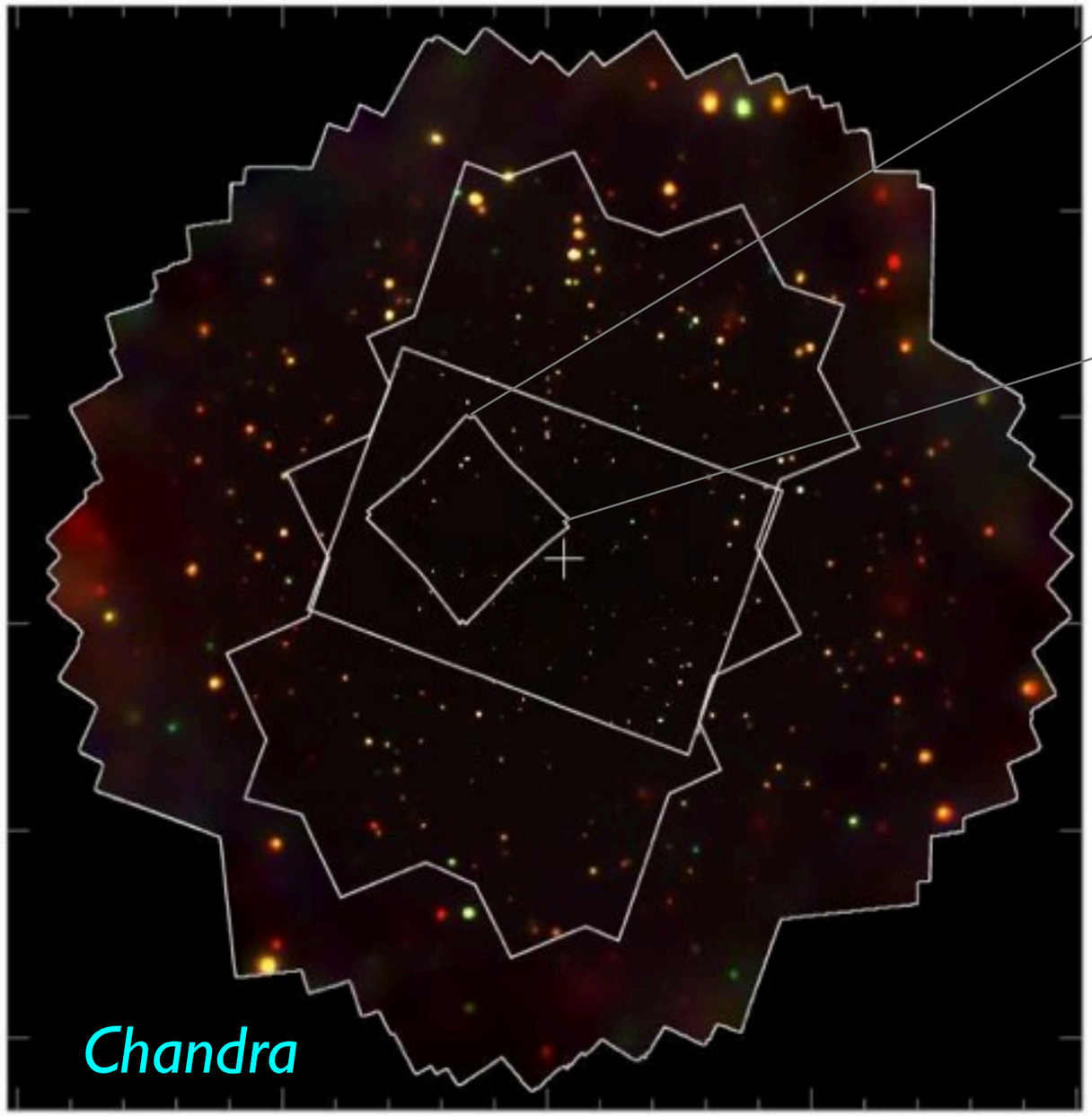
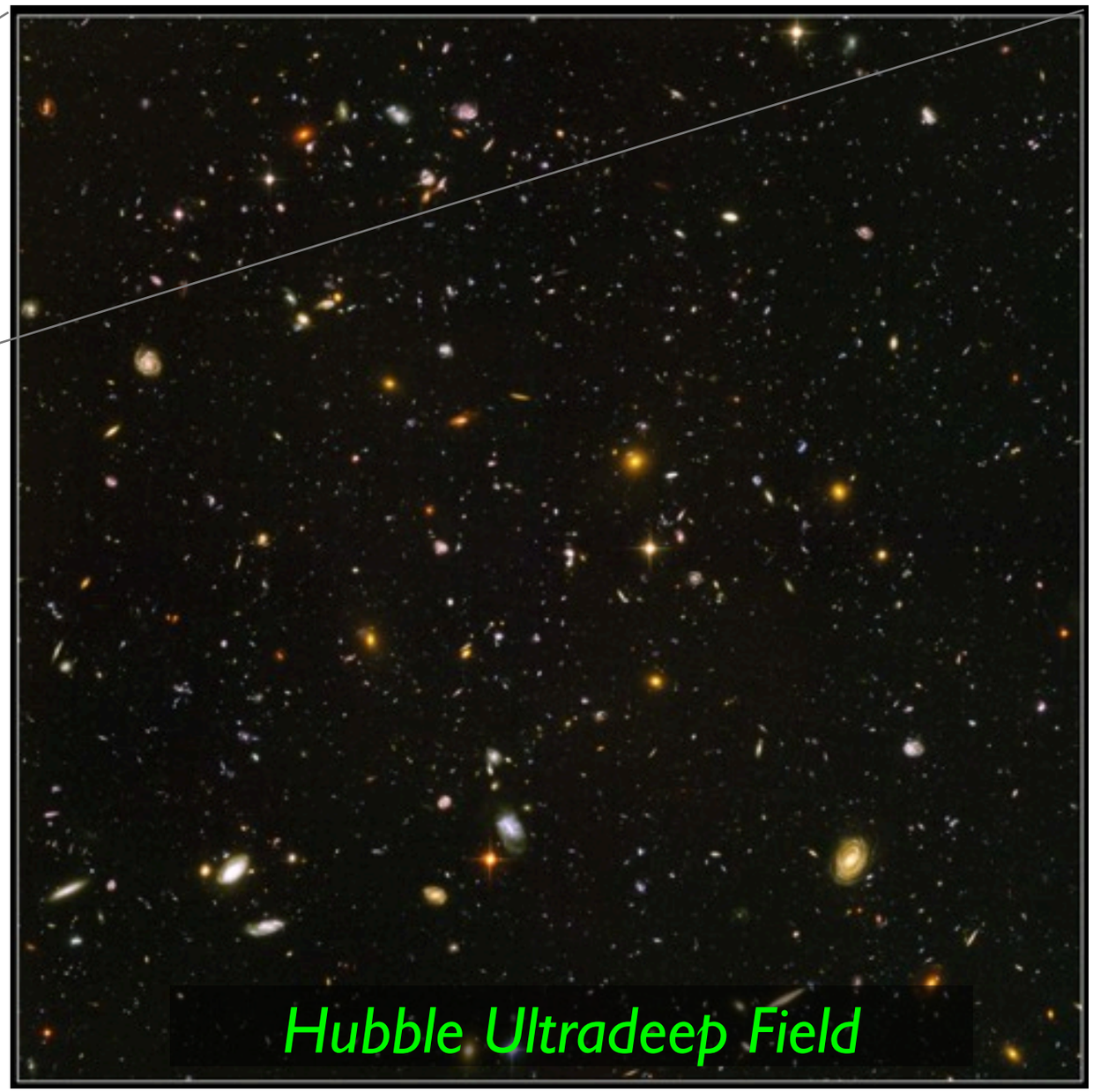
CDF-S Multiwavelength Data

- Extensive multiwavelength coverage from space and ground-based observatories covering radio, submm, IR, optical, and UV, allows for redshift measurements and classification of sources.

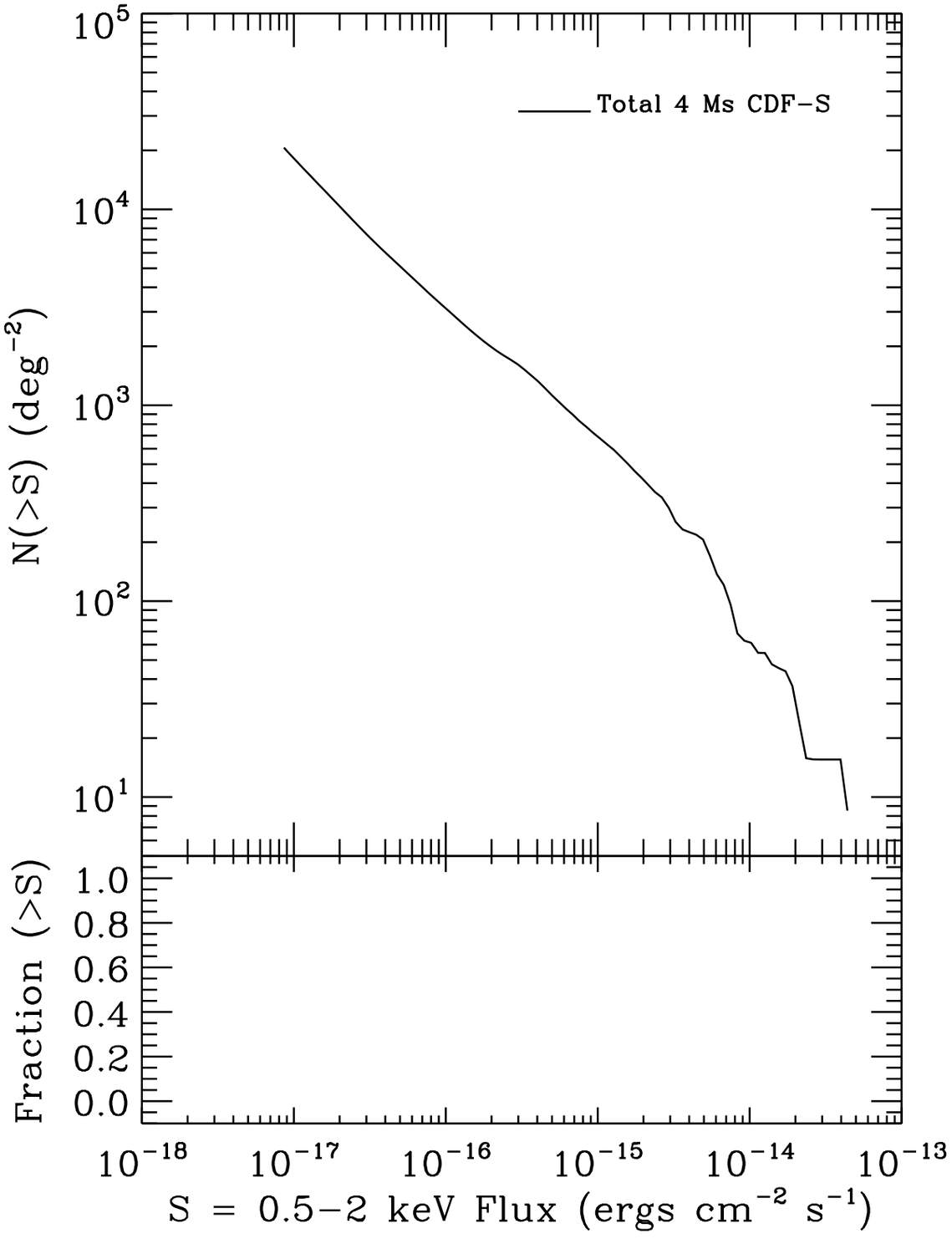




Source Counterpart Identification

- 740 X-ray sources are detected (~400 arcmin^2 region):
  - 716 (97%) have multiwavelength counterparts.
  - 673 (91%) have either spectroscopic or highly-accurate photo-zs.
  - Sources detected include
    - Active Galactic Nuclei (AGNs; 568)—Accretion from SMBHs.
    - Normal galaxies (162)—X-ray binaries, supernovae, stars, and hot gas.
    - Galactic stars (10)—Magnetic X-ray flares.

X-ray Counts: The Rise of Normal Galaxies



Lehmer et al. (2011)

- Reach 0.5–2 keV flux limit of 8.6×10^{-18} ergs cm^{-2} s^{-1} and source densities of 20,646 deg^{-2}.

- AGNs make up majority of number counts but normal galaxies quickly rise to make up ~40% of the counts above the flux limit.

$$N(>S_X) = \frac{1}{\Omega_{sky}} \int_{\infty}^{S_X} \left(\int_0^{\infty} \boxed{\frac{dN}{dL_X dV}} \frac{dL_X}{dS_X} \frac{dV}{dz} dz \right) dS_X$$

Redshift-Dependent
X-ray Luminosity Function

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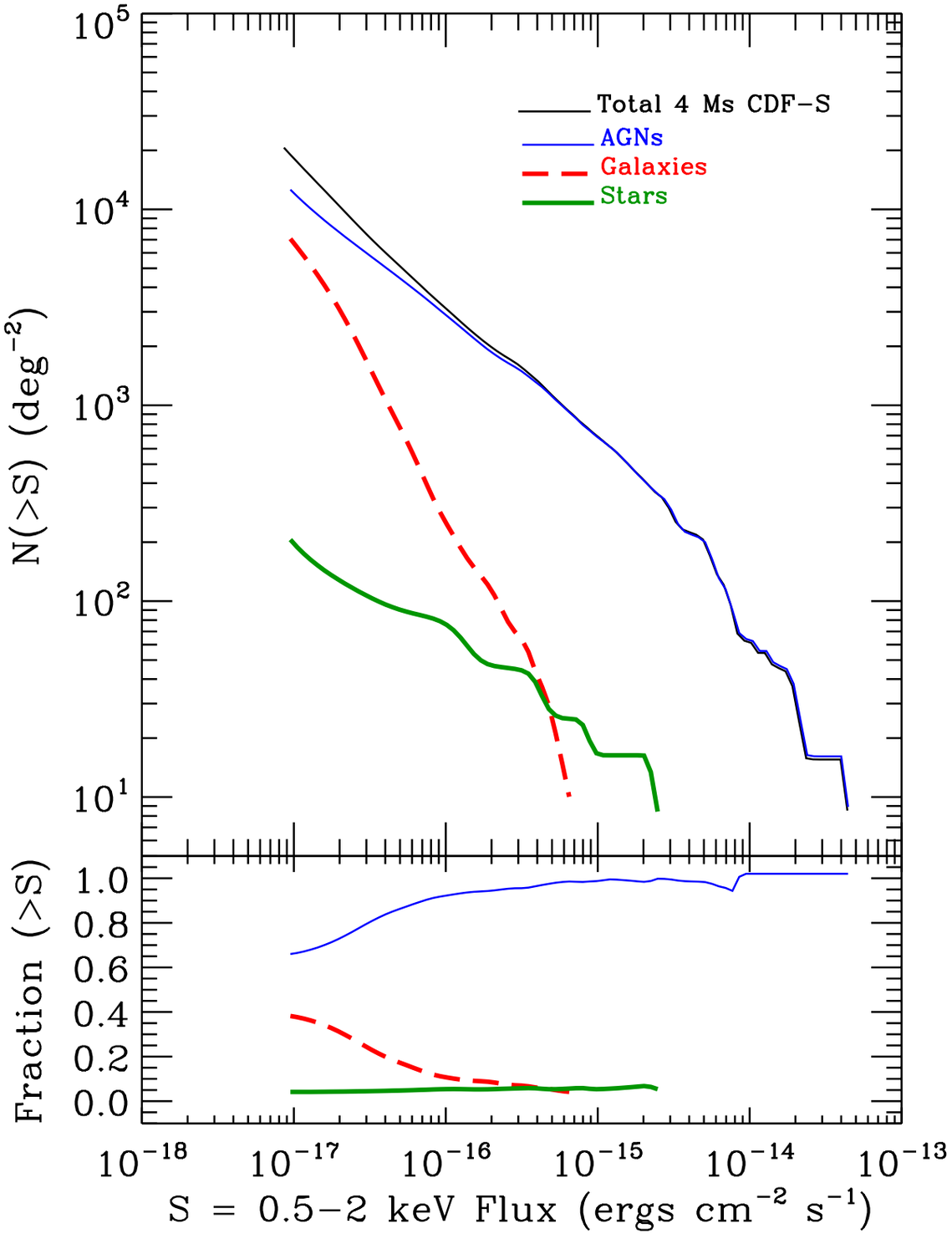

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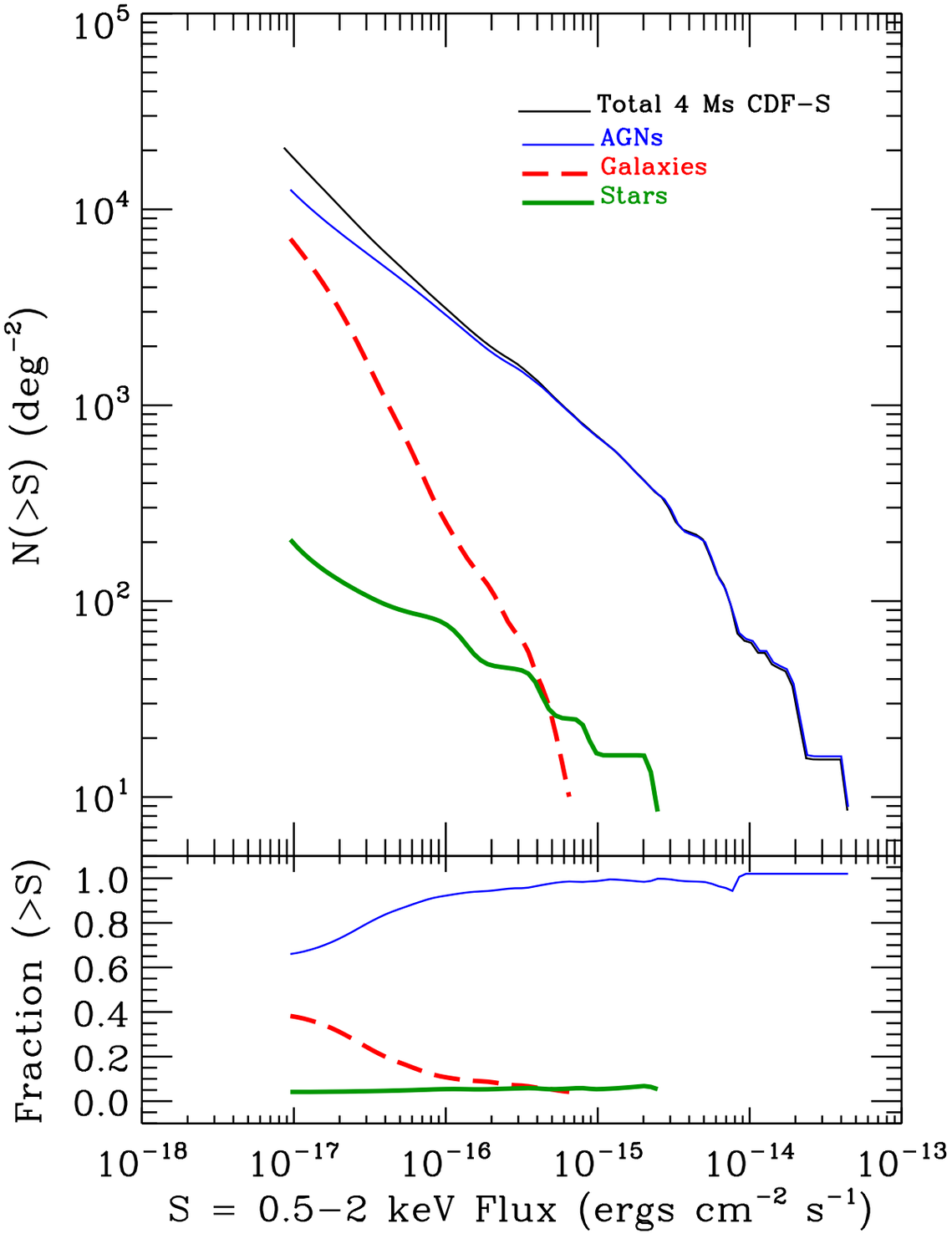

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Goal for this Talk:

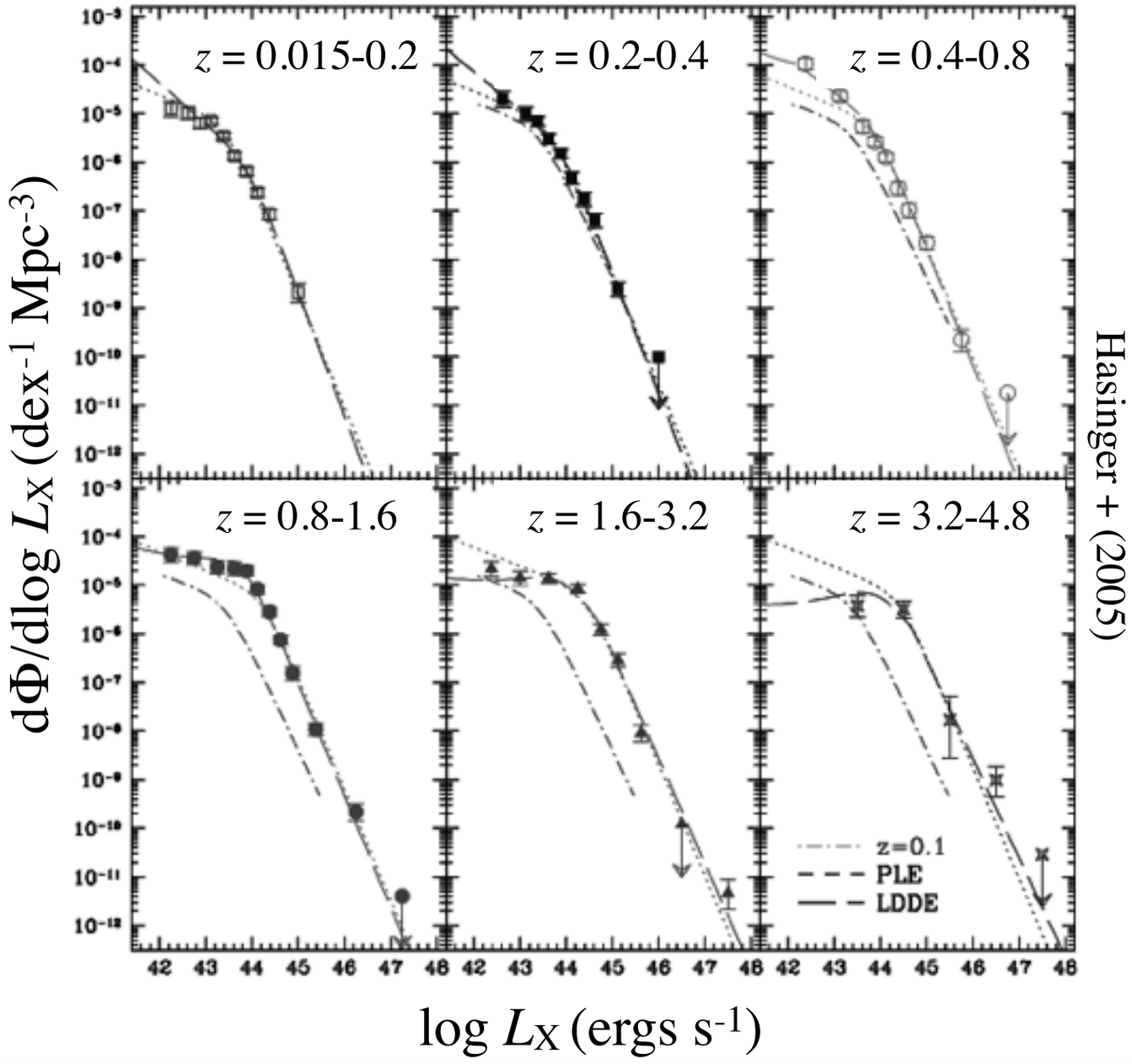
1. What key factors drive rapid rise in number counts?

2. What predictions can we make about deeper X-ray observations?

Active Galactic Nucleus (AGN) Number Counts

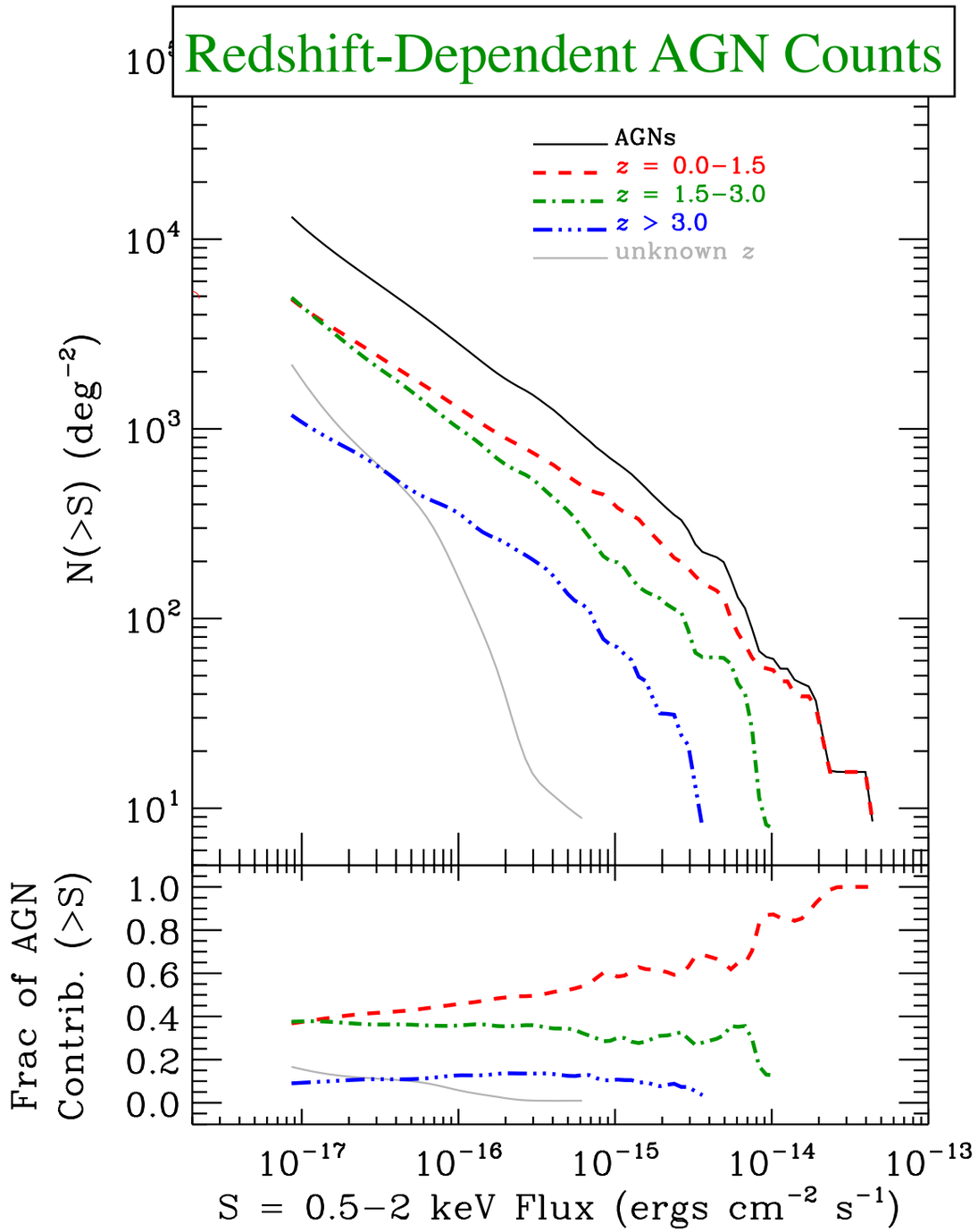
- AGN in the CDF-S make up 77% of the X-ray detected sources and provide a direct view of SMBH accretion history out to z = 7.6 (over the last 95% of cosmic history).

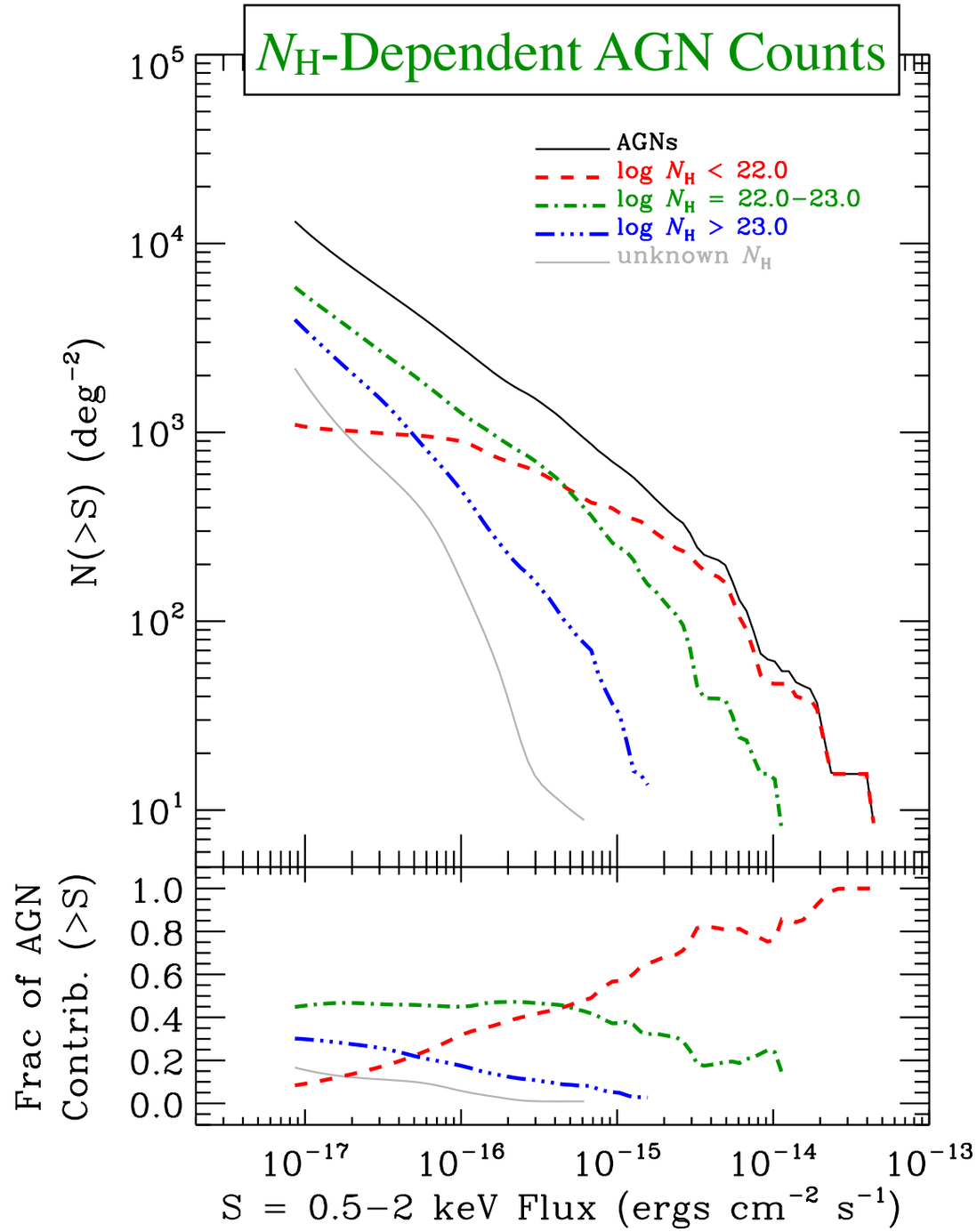
- AGNs have been studied extensively and the rise in AGN number counts is attributed to a rapidly evolving AGN population with redshift.



Break-Down of AGN Number Counts

- AGNs at z = 1.5−3 and moderately obscured AGNs ($N_H > 10^{23}$ cm^{-2}) provide increasingly important contributions to overall number counts going to faintest fluxes.





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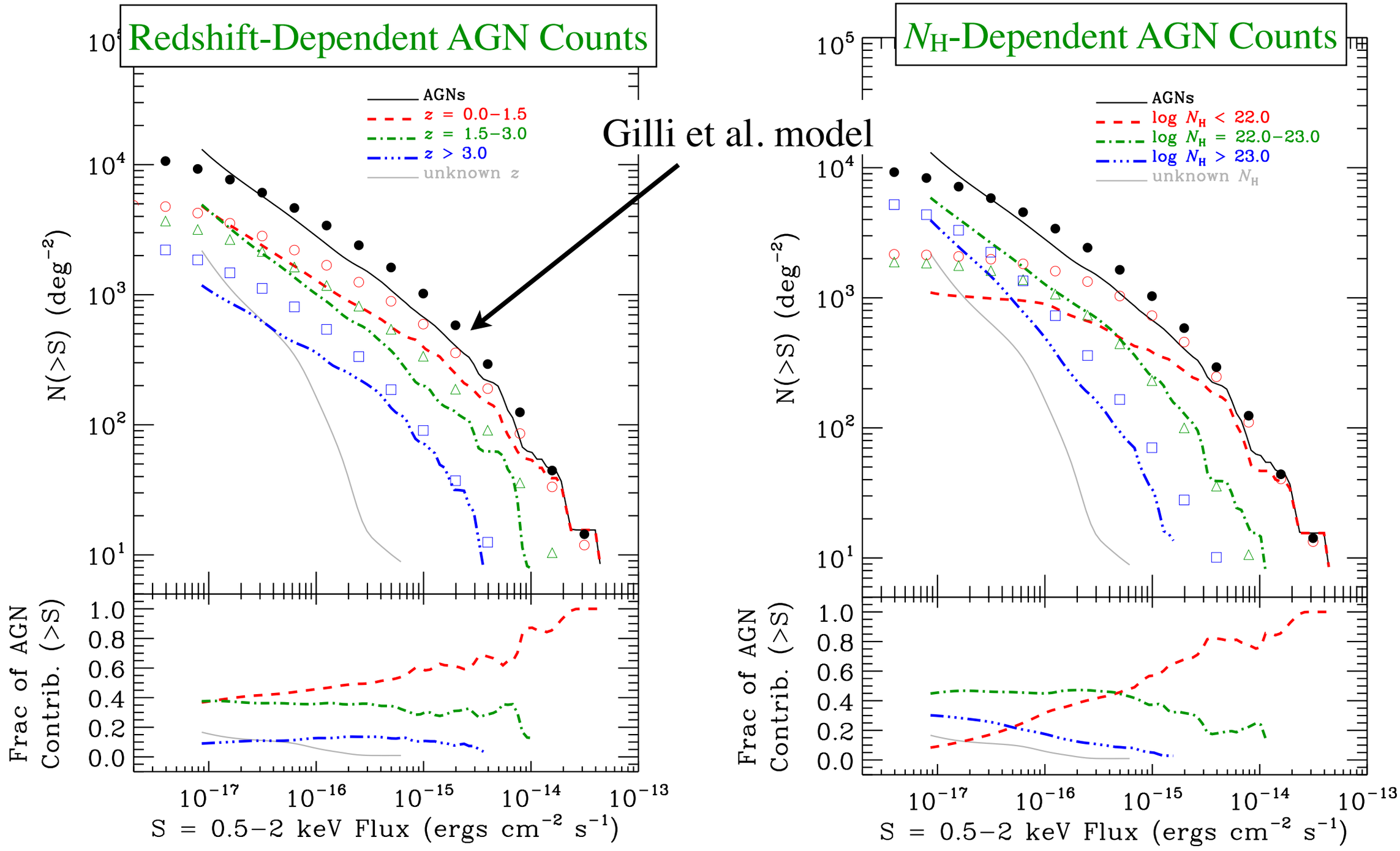
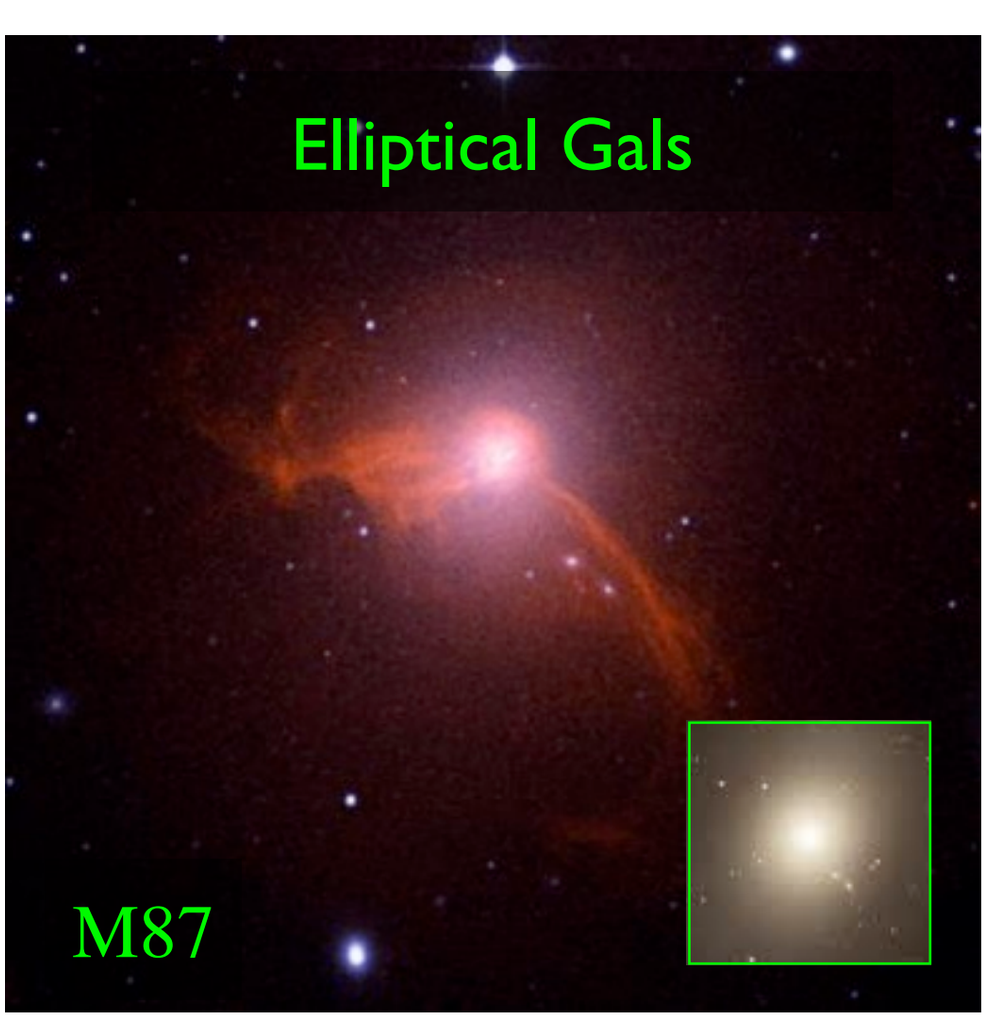


Galaxy Number Counts

- 161 normal galaxies are detected in the CDF-S; these galaxies can be divided broadly into two categories.

- In star-forming galaxies, the X-ray emission provides an unobscured tracer of star-formation activity and the black hole and neutron star population in the galaxy.

- In passive elliptical galaxies, the X-ray emission is generally dominated by hot (>1 keV) gas embedded in the deep gravitational potential well and provides a measure of the gas cooling rate.

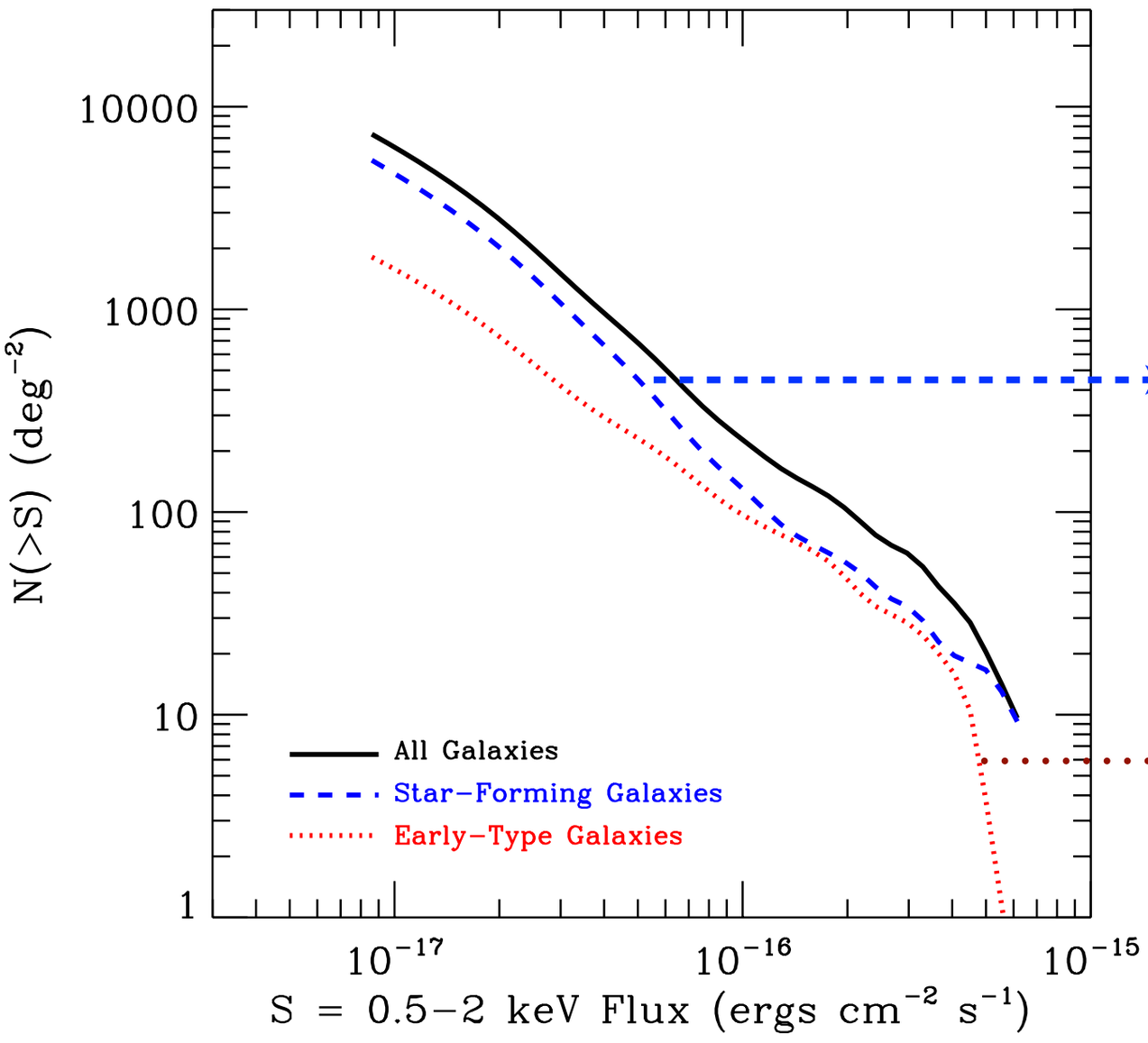


Breakdown of Normal Galaxy Number Counts

- Galaxy number counts are dominated by SF late-type galaxies with a smaller contribution from passive early-type galaxies.

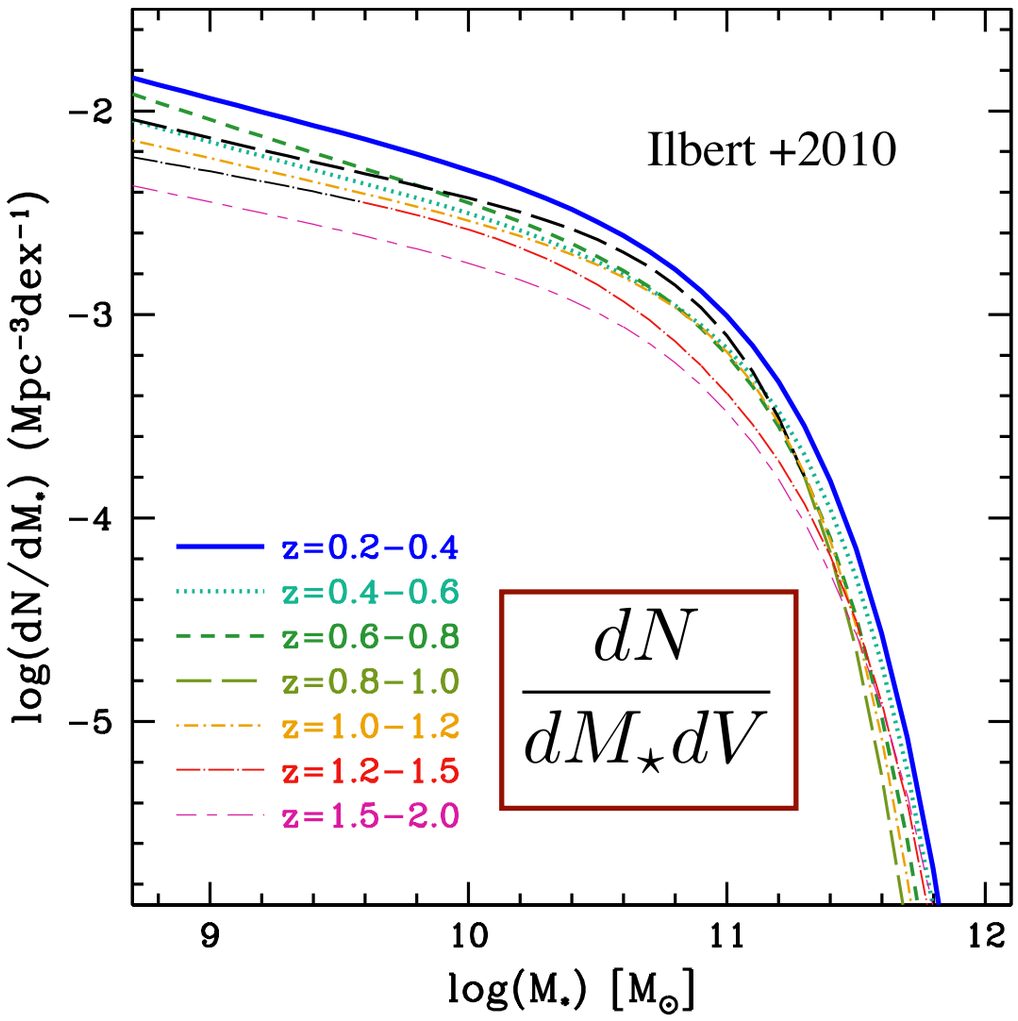
$$N(>S_{\rm X}) = \frac{1}{\Omega_{\rm sky}} \int_{\infty}^{S_{\rm X}} \left(\int_0^{\infty} \boxed{\frac{dN}{dL_{\rm X} dV}} \frac{dL_{\rm X}}{dS_{\rm X}} \frac{dV}{dz} dz \right) dS_{\rm X}$$

Redshift-Dependent
X-ray Luminosity Function

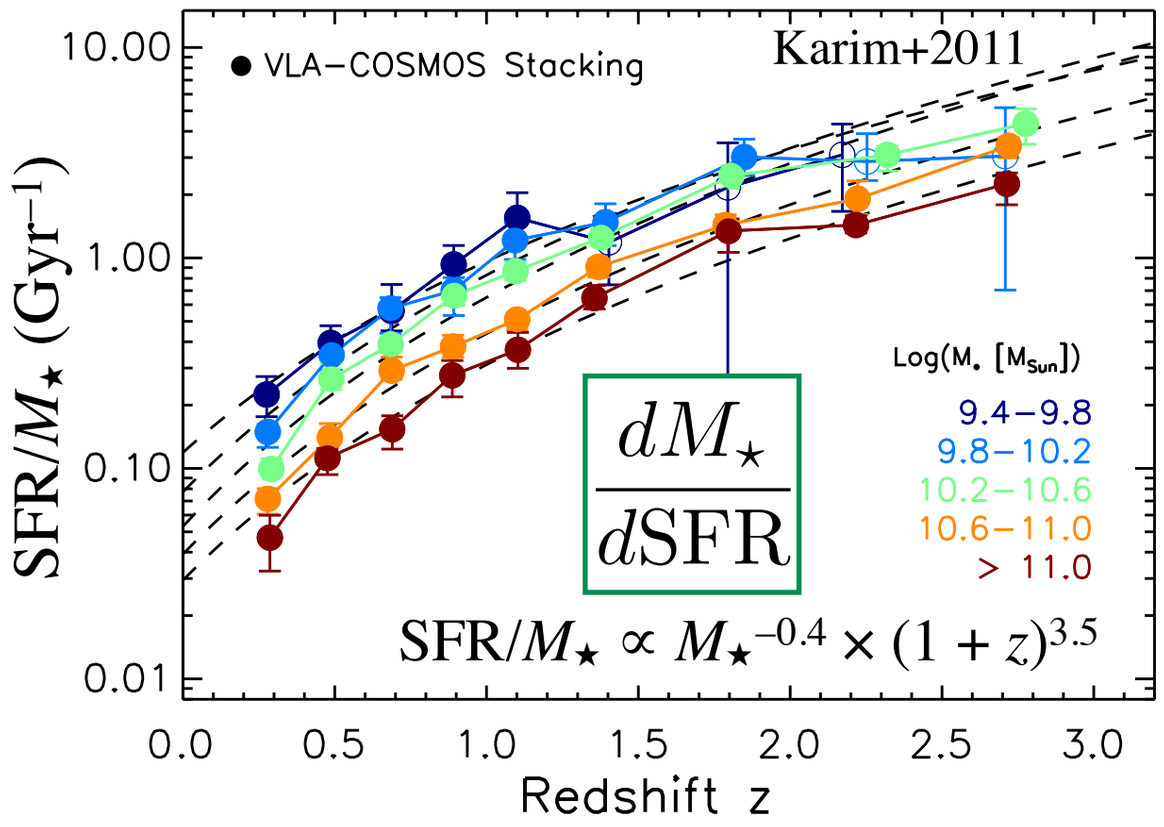


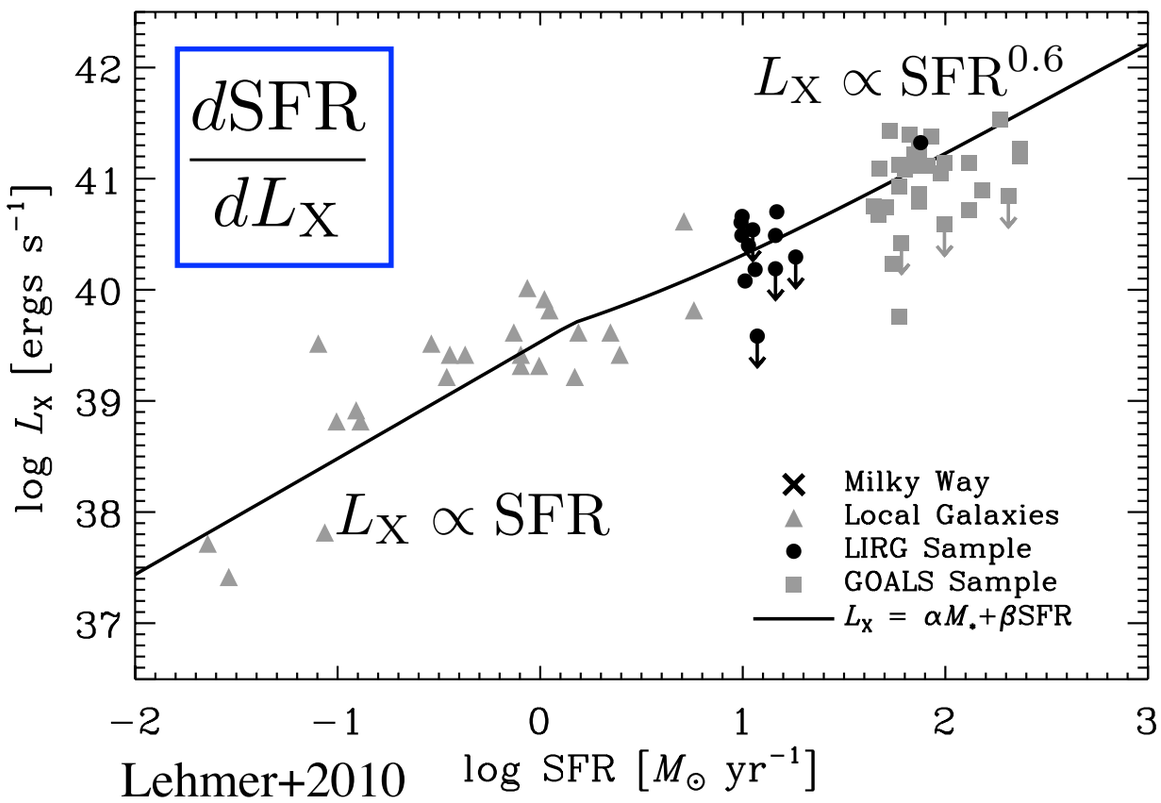
Cosmic Evolution of Star-Forming Galaxy Population

$$\frac{dN}{dL_{\rm X}dV} = \boxed{\frac{dN}{dM_\star dV}}\boxed{\frac{dM_\star}{d{\rm SFR}}}\boxed{\frac{d{\rm SFR}}{dL_{\rm X}}}$$



Roughly constant values Schechter-function values M^* and faint-end slope α. Strong decrease in ϕ^* with z.





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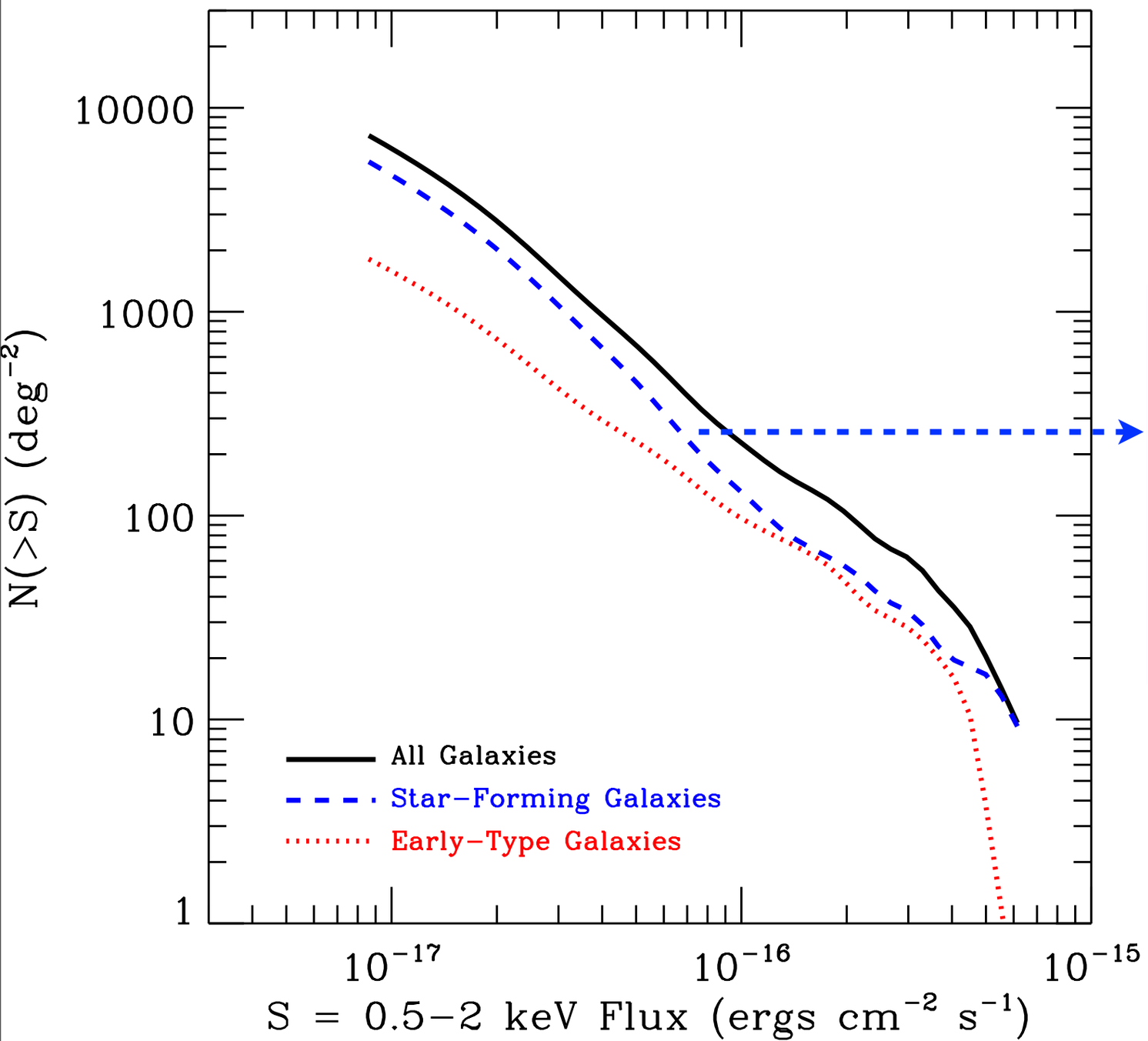

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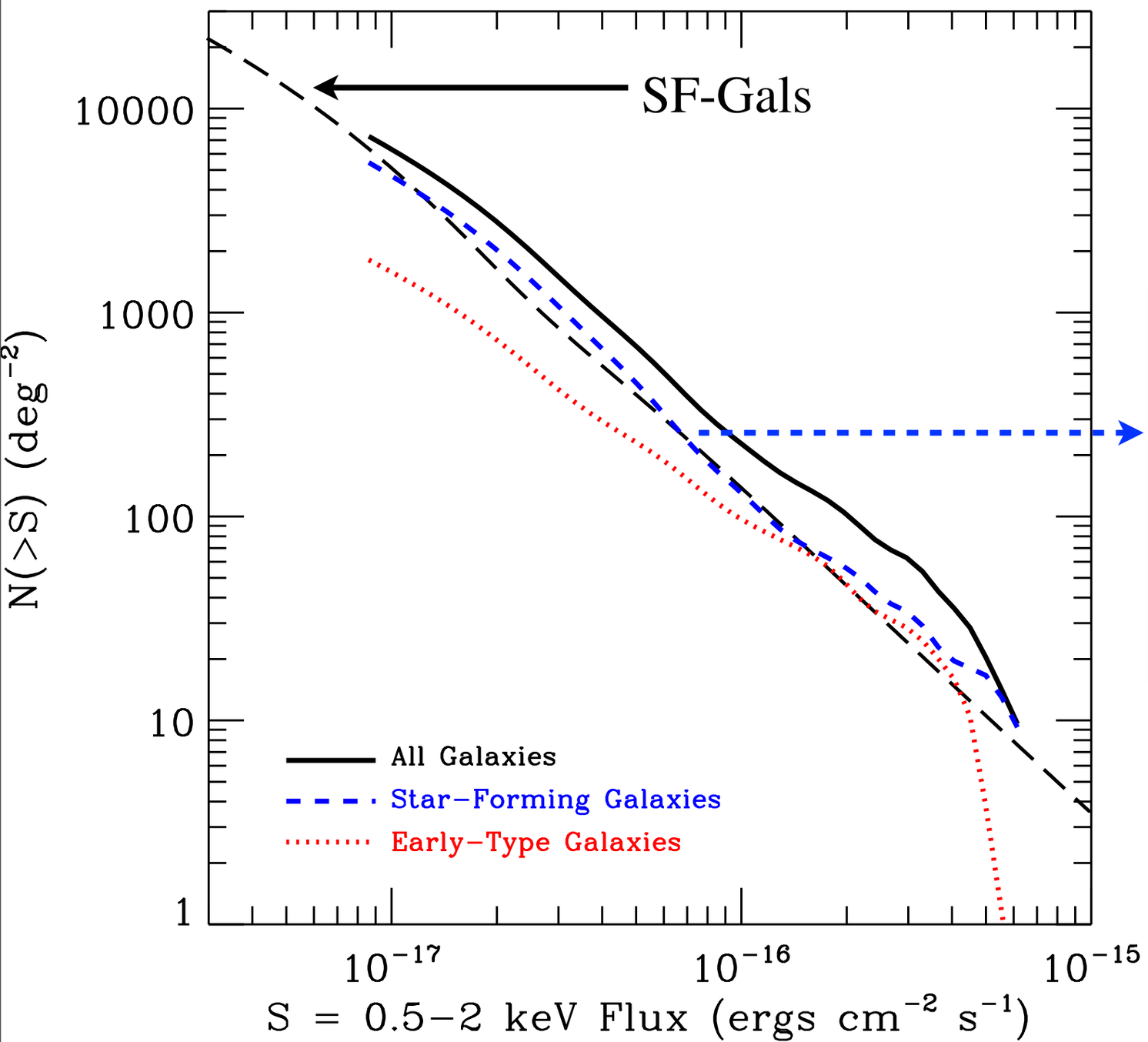
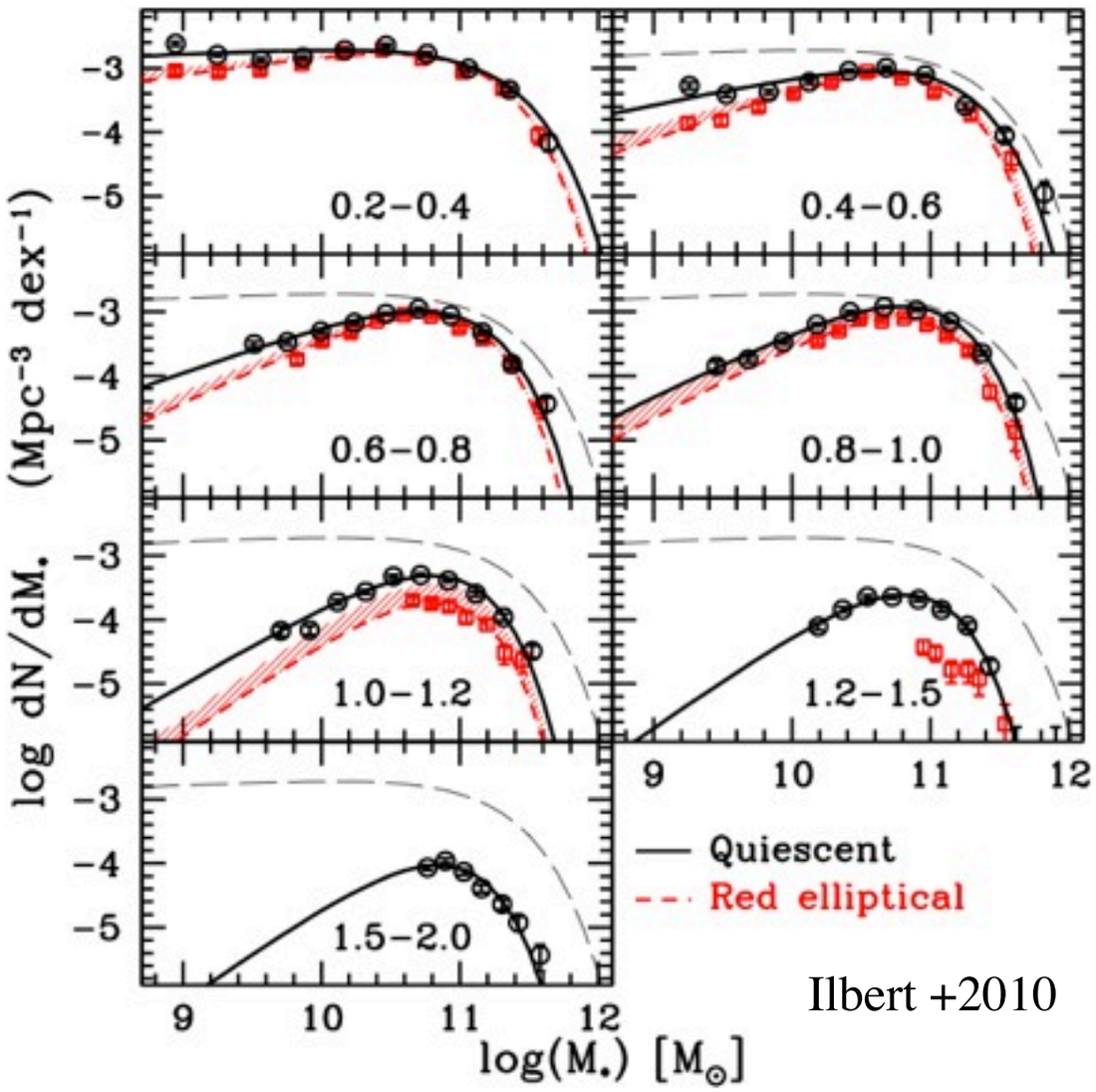


Evolution of Passive Early-Types

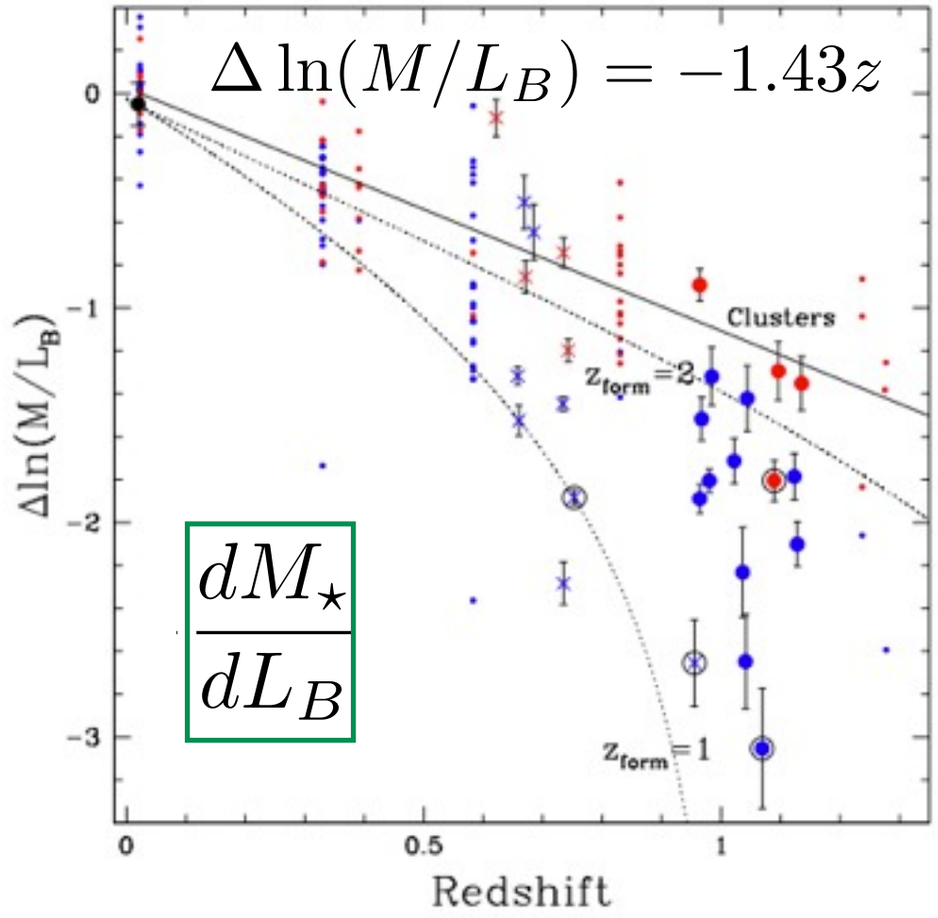
$$\frac{dN}{dL_{\rm X}dV} = \boxed{\frac{dN}{dM_\star dV}}\boxed{\frac{dM_\star}{dL_B}}\boxed{\frac{dL_B}{dL_{\rm X}}}$$



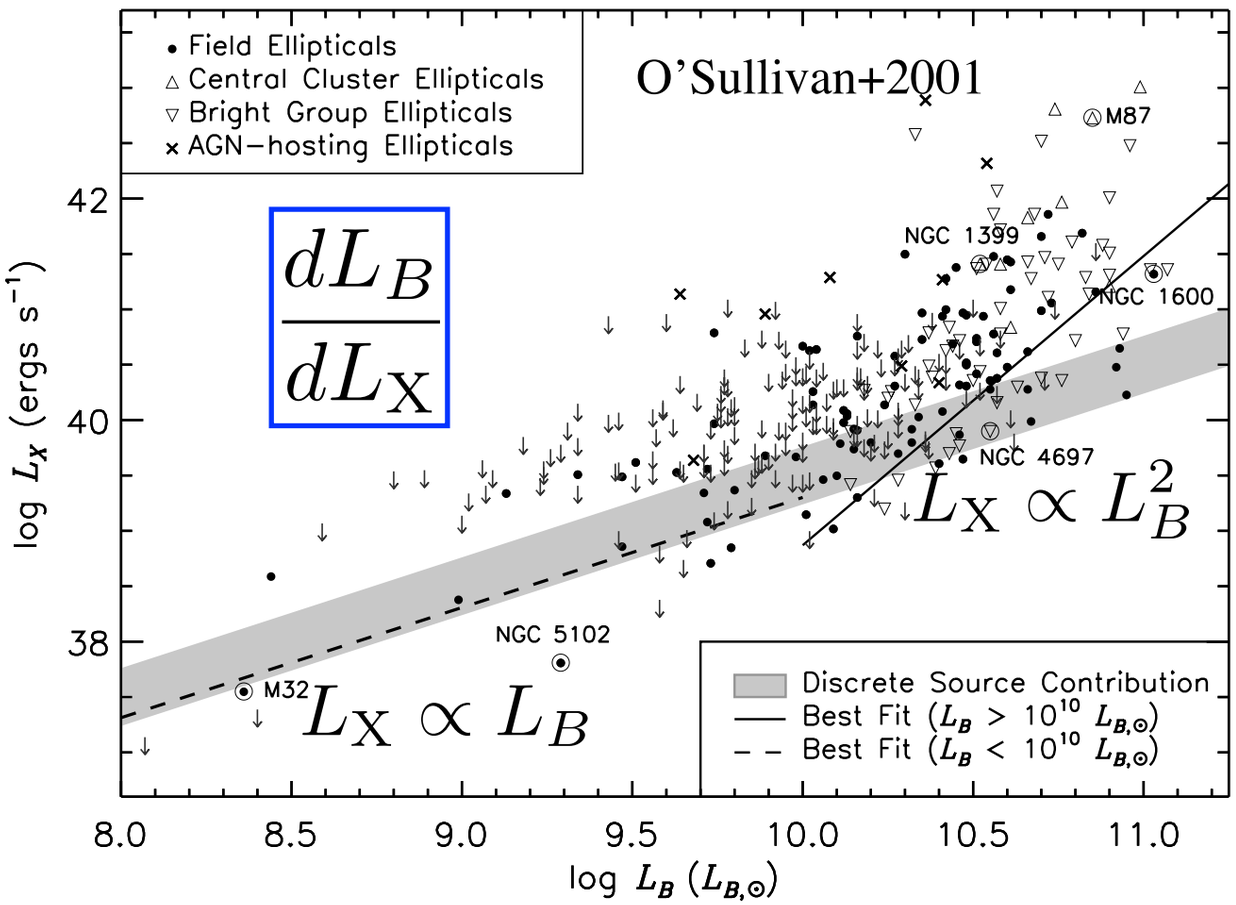
Ilbert +2010

$$\boxed{\frac{dN}{dM_\star dV}}$$

Strong evolution in all Schechter-function parameters (M^*, α, and ϕ^*) with z.



van der Wel +2005



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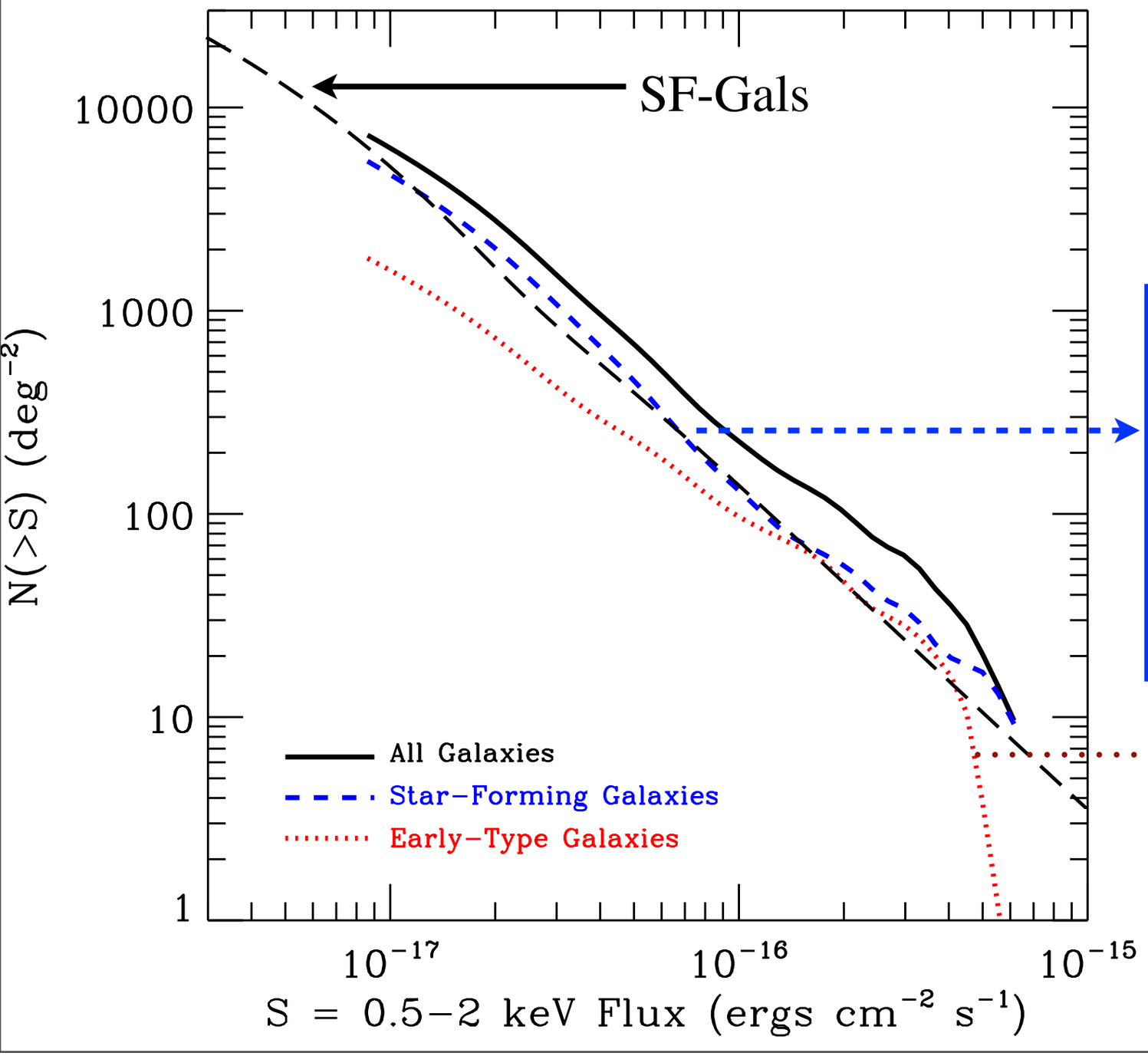

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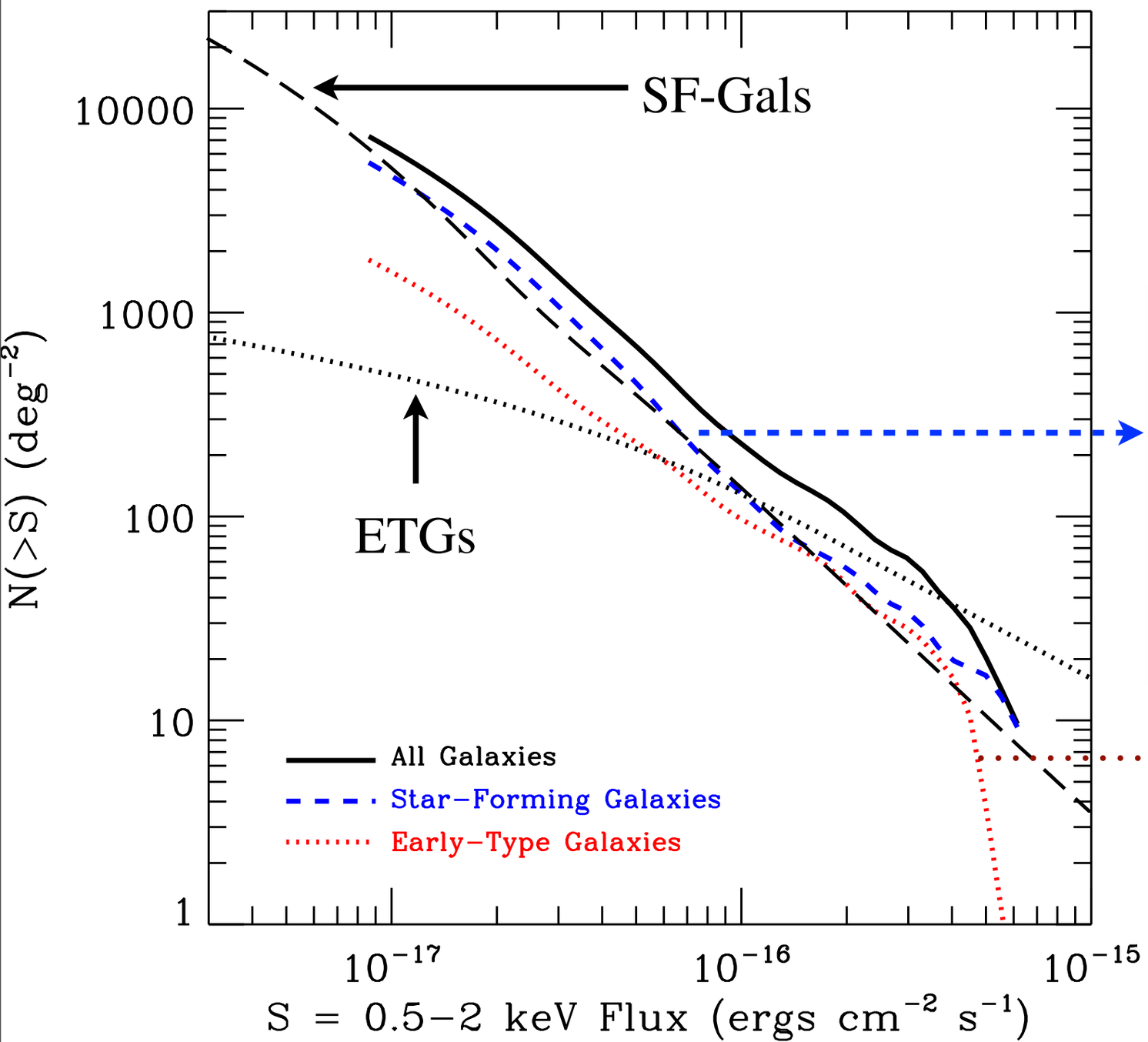
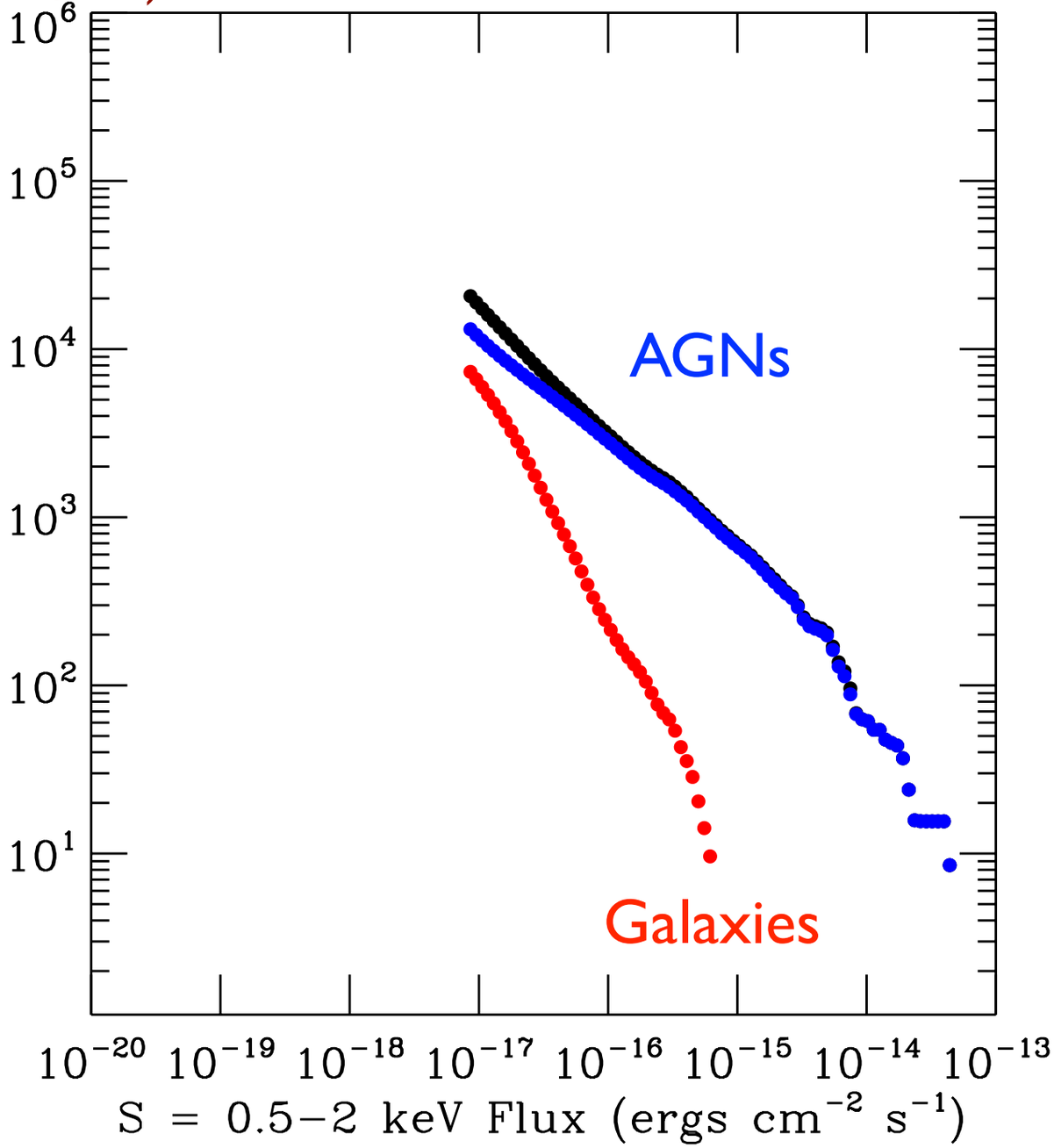


Predicting the Future: Model Extrapolation

- Extrapolation of number counts to fainter fluxes reveals that normal galaxies will quickly overtake AGNs at ~(3−6) × 10^{-18} ergs cm^{-2} s^{-1} becoming the most numerous X-ray population.

- We could study these galaxies with a deeper (10 Ms) Chandra observation and with future observatories with improved specs: e.g., Gen-X (100 m^2; 0.1").



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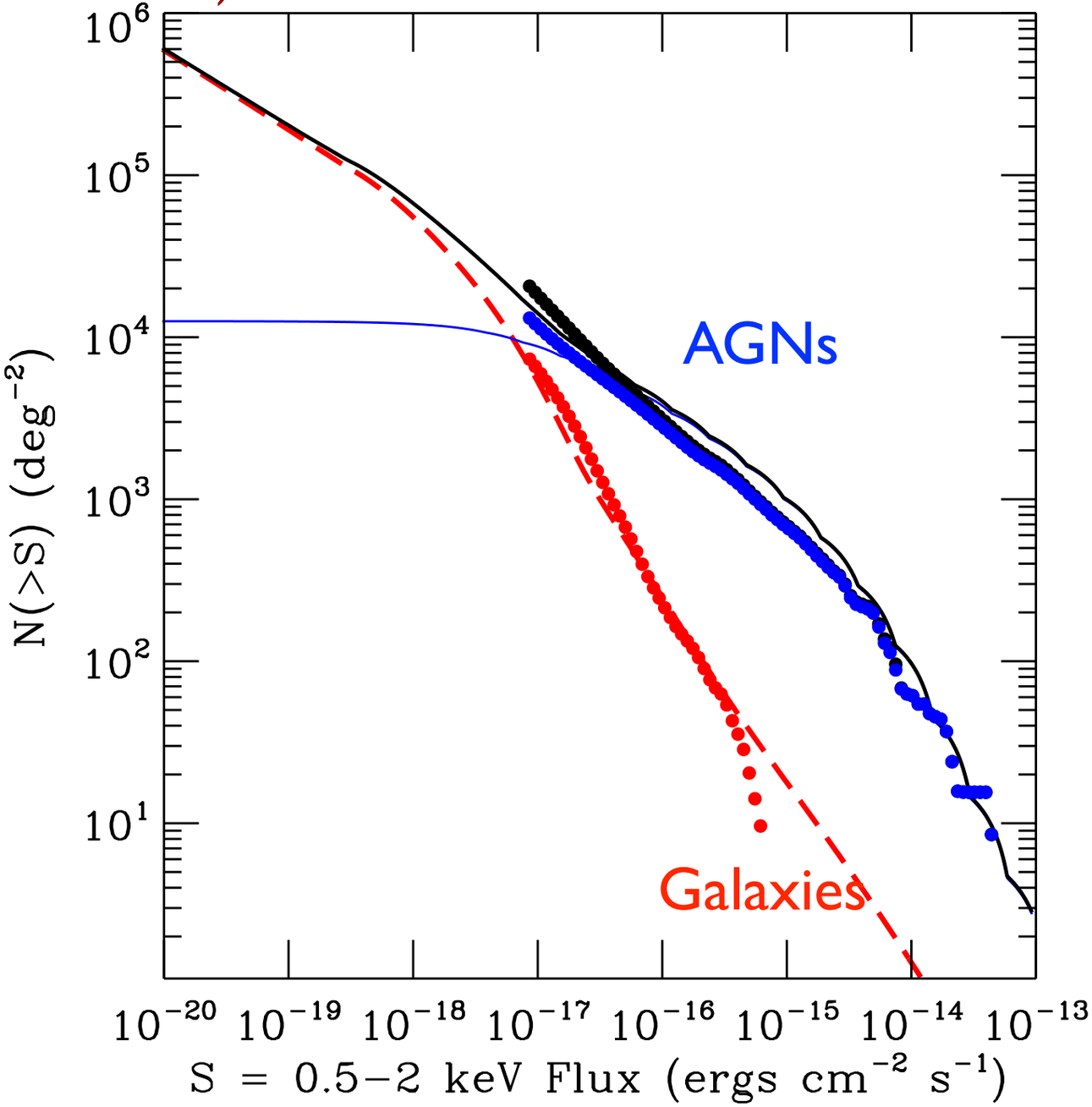

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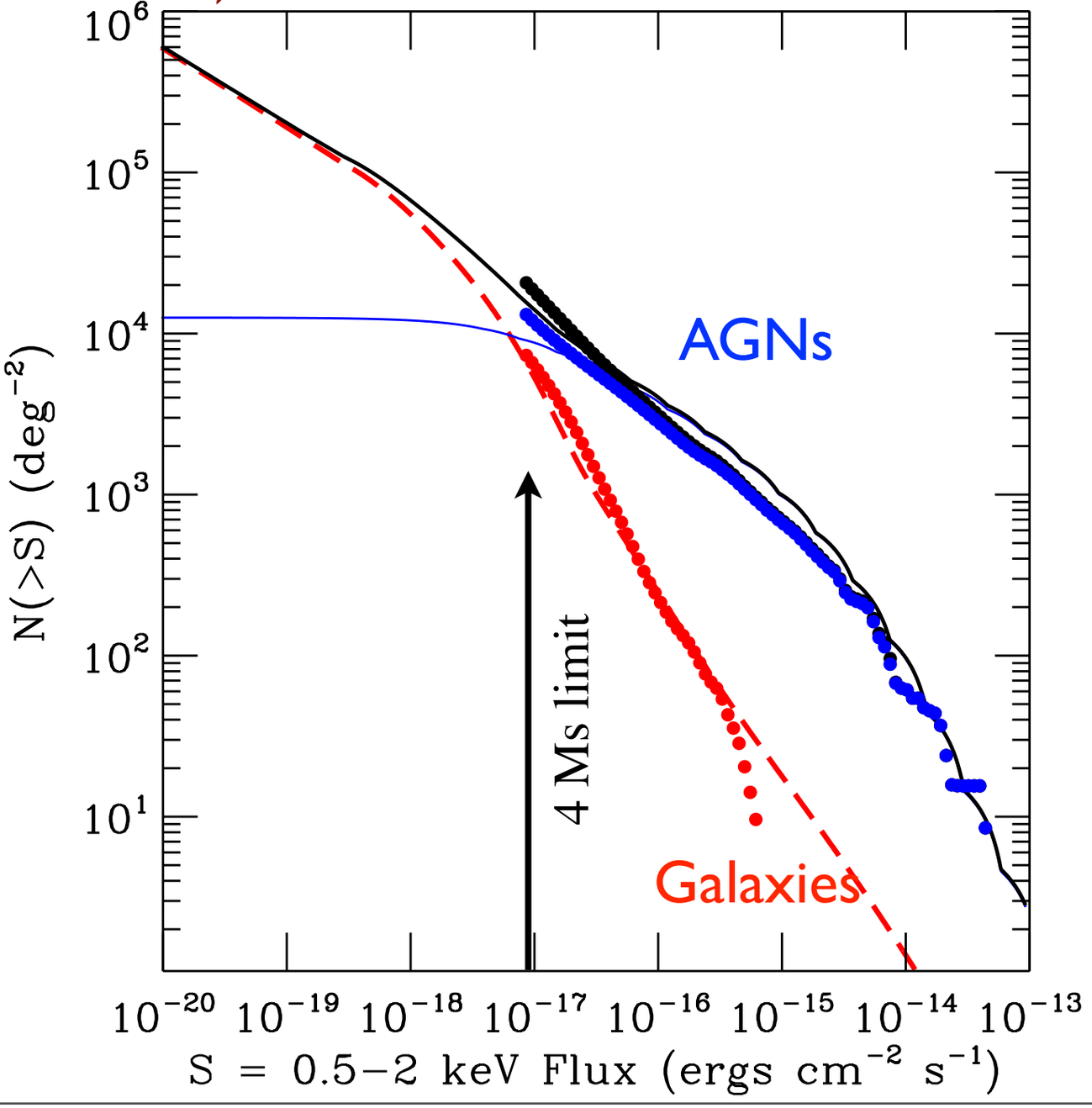

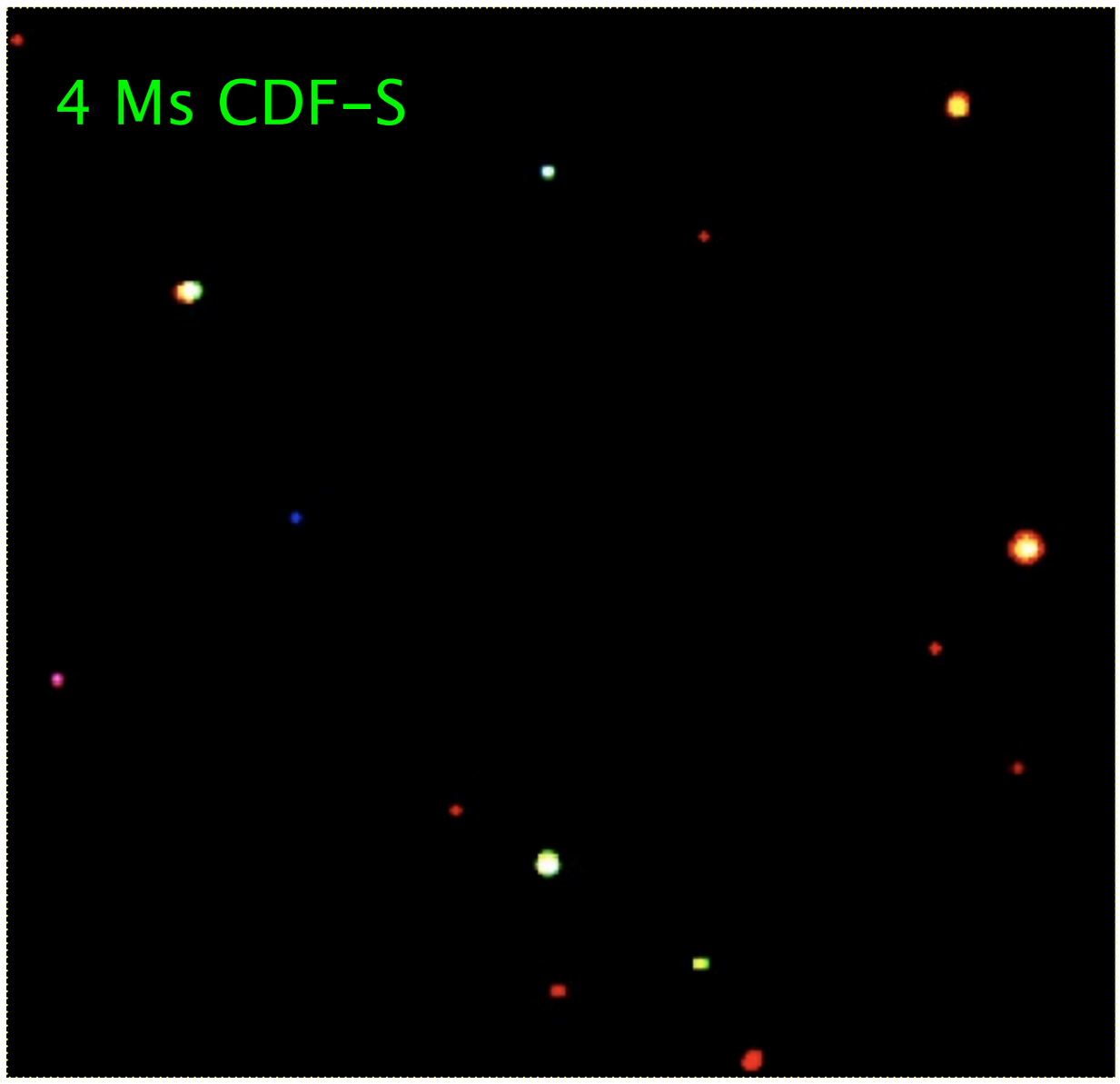

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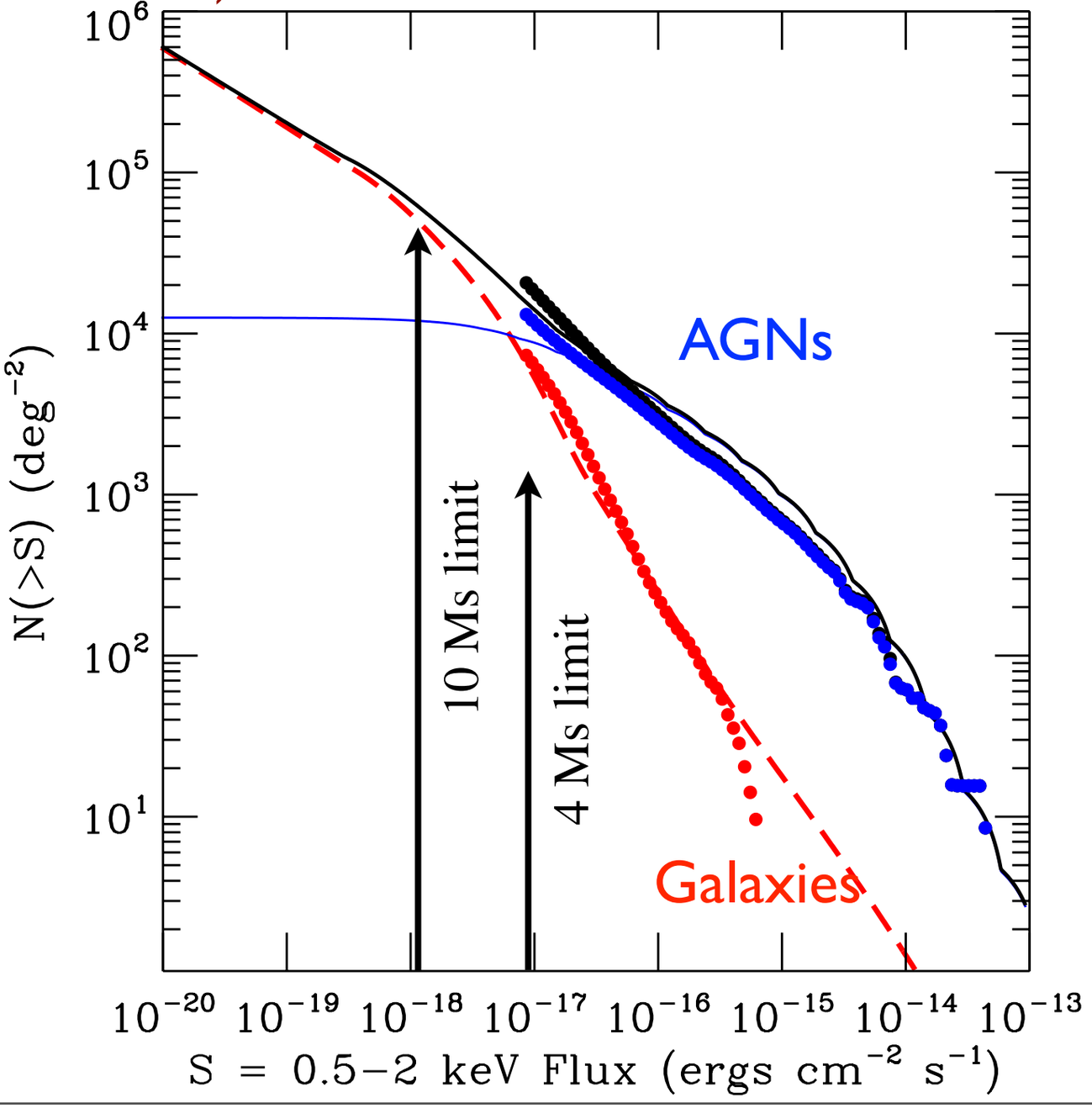

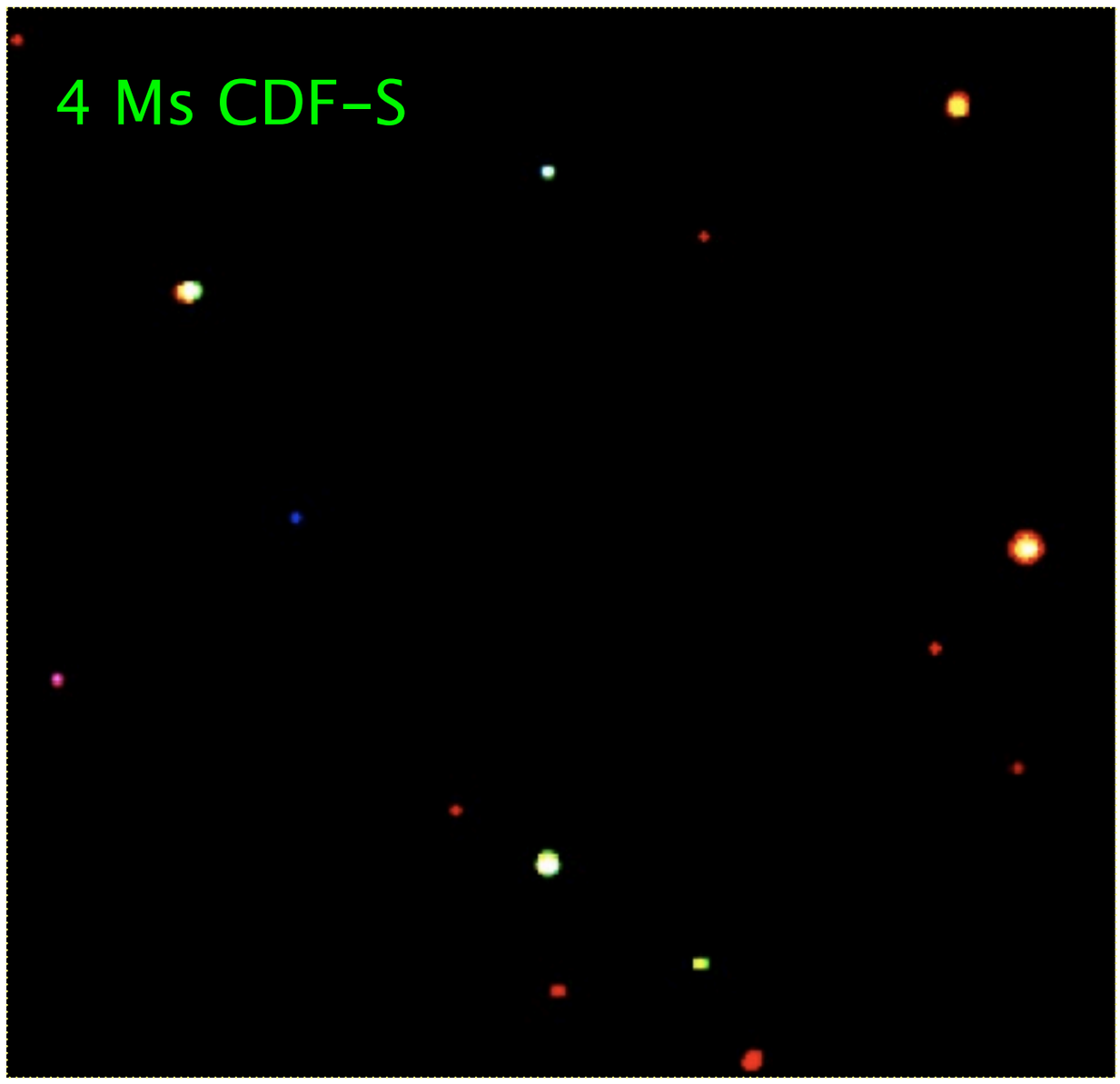

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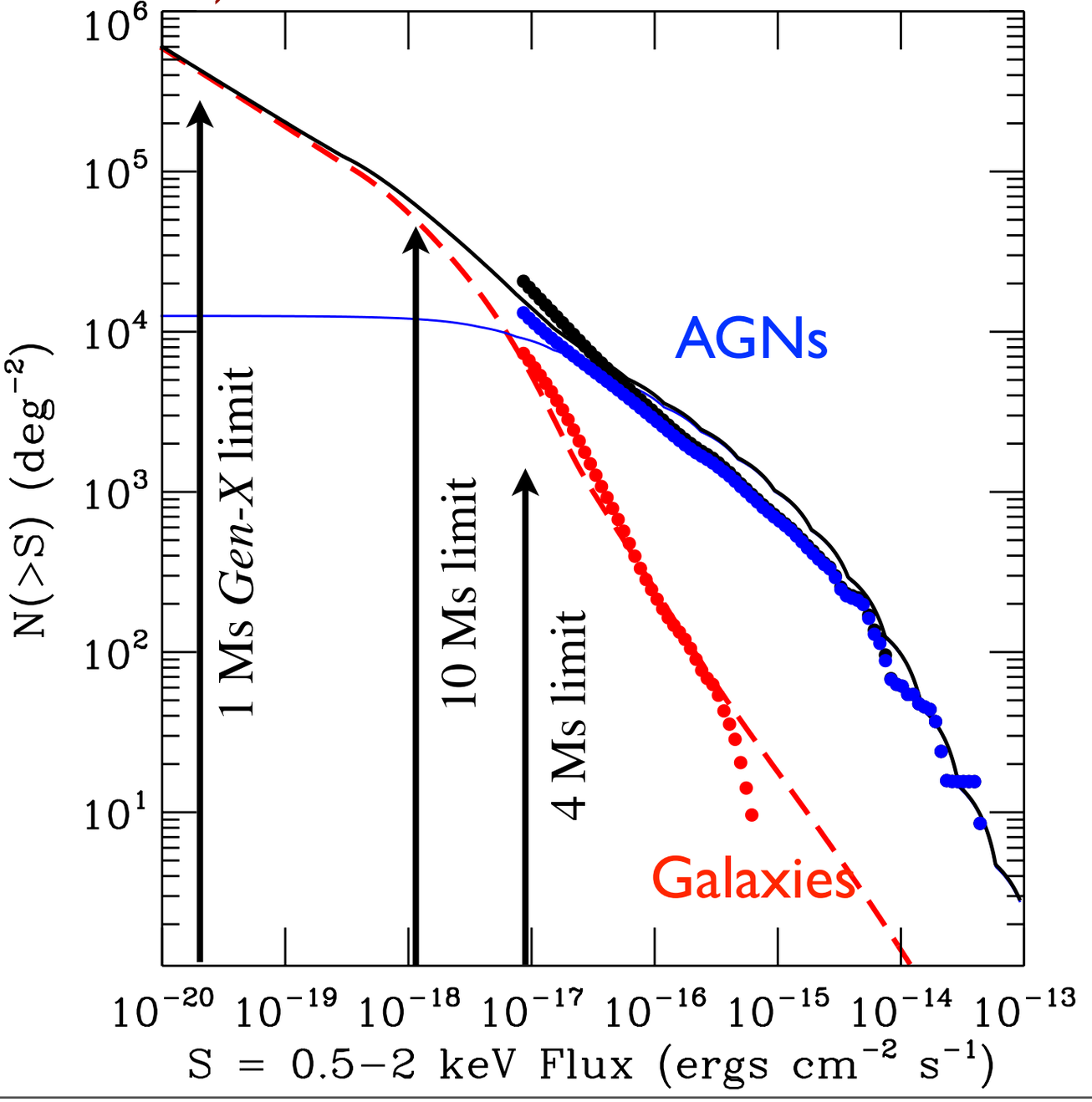

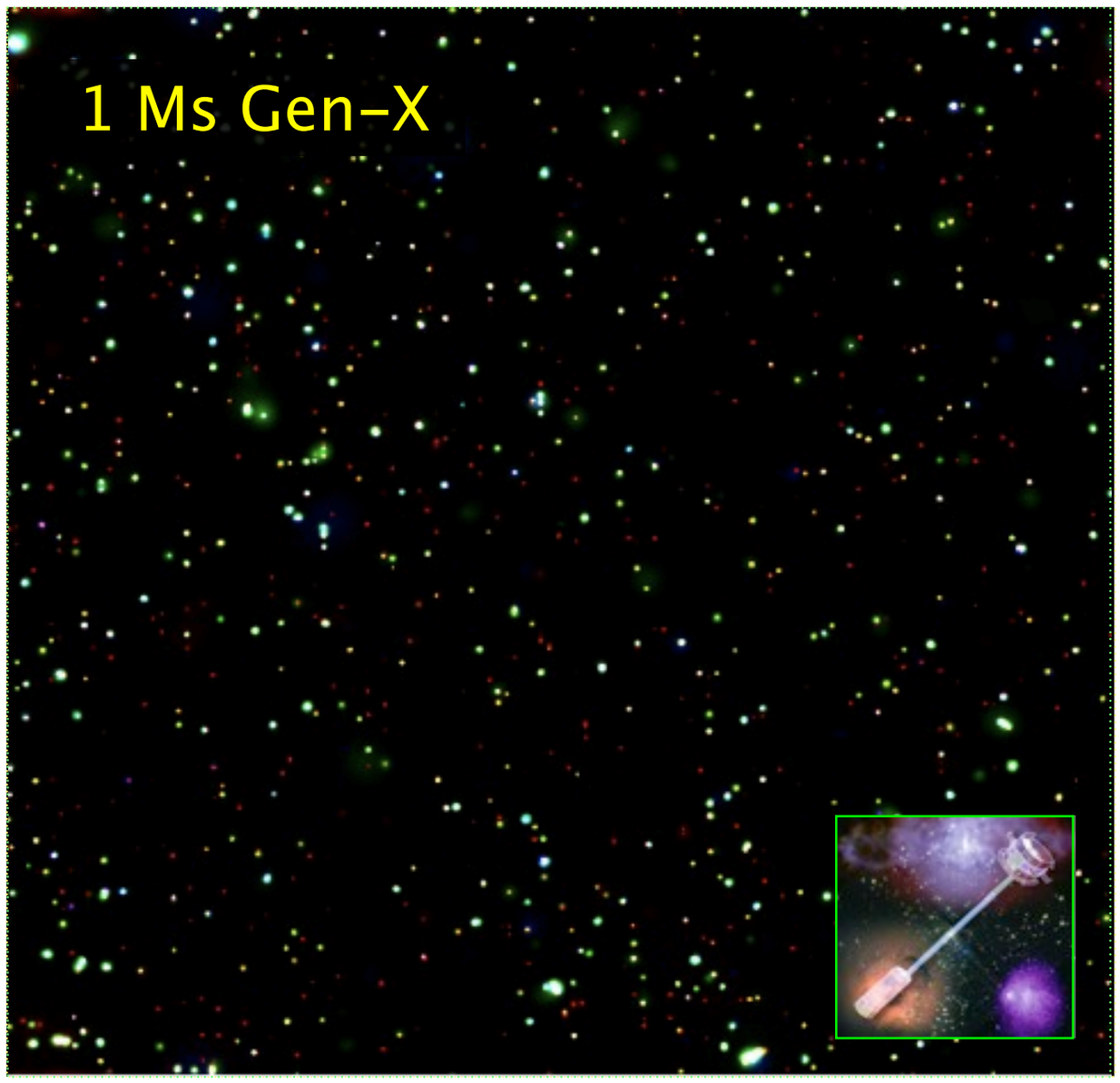

Conclusions

1. 740 X-ray sources are detected in the 4 Ms CDF-S down to 0.5−2 keV flux limit of 8.6×10^{-18} ergs cm^{-2} s^{-1}

2. Source densities of 20,646 deg^{-2} are reached with ~40% of the sources being normal galaxies.

3. Obscured AGNs ($N_H > 10^{23}$ cm^{-2}) and AGNs at $z = 1.5-3$ are providing largest increase in AGN activity at the faintest CDF-S fluxes. Semi-analytic modeling is broadly consistent with the break-down of AGN number counts.

4. The increase in galaxy number counts is largely driven by star-forming galaxies with passive early-type galaxies playing a small role. The increase in number counts is consistent with the observed evolution of galaxy properties (e.g., SFR, stellar mass, etc.) without significant change in X-ray scaling relations.

5. Future ultra-deep X-ray surveys (e.g., with Chandra and Gen-X) will "see" an X-ray sky dominated by normal galaxies.

4 Ms data and results publicly available:
http://www2.astro.psu.edu/users/niel/cdfs/cdfs-chandra.html