

TOWARDS POPULATION SYNTHESIS MODELS FOR LISA

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THE POPULATION OF SUPERMASSIVE BHs

- LOCAL POPULATION: DYNAMICAL STUDIES (E.G. MAGORRIAN ET AL. 1998):

- SMBHs ARE ALMOST UBIQUITOUS IN NEARBY LUMINOUS GALAXIES

- GALAXIES PROBED “EXTENSIVELY”: $M_{tot} \geq 10^{11} M_{sun}$

- DISTANT POPULATION: QUASAR LUMINOSITY FUNCTION:

- OPTICAL : COMOVING DENSITY OF LUMINOUS QUASARS AT $z=3$ IS 10^{-3} OF THAT OF CORRESPONDING BRIGHT HOST GALAXIES (E.G. RICHSTONE ET AL. 1998)

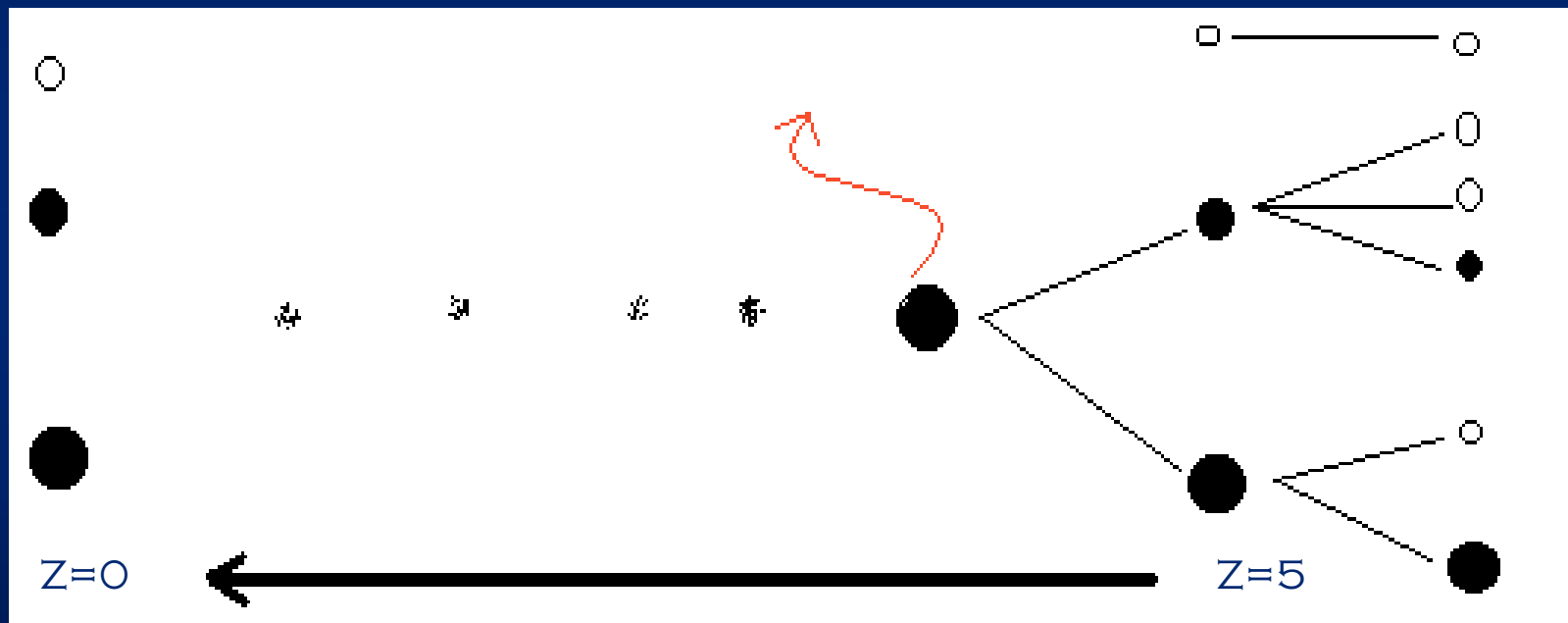
- X-RAY: ~ 10% OF ALL BULGE-DOMINATED OPTICALLY-LUMINOUS GALAXIES SHOW HARD X-RAY ACTIVITY FOR $z < 2-3$ (MUSHOTZKY ET AL. 2000; BARGER ET AL. 2001)



MERGER TREE

(MENO, HAIMAN & NARAYANAN 2001)

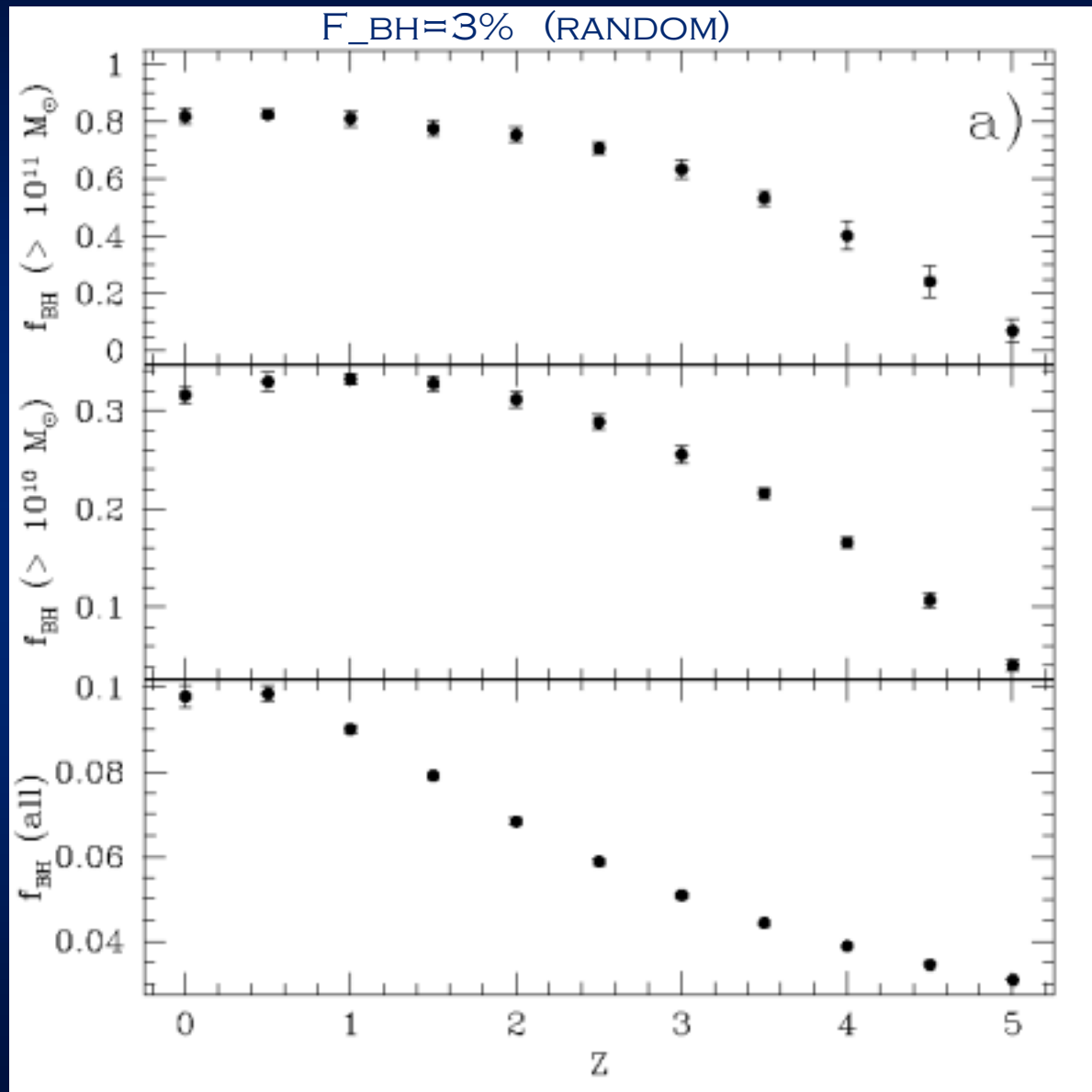
- DESCRIBES MERGER HISTORY OF DM HALOS IN LAMBDA-CDM COSMOLOGY:
 - ASSUME ONE-TO-ONE CORRESPONDENCE BETWEEN HALOS AND GALAXIES
 - ASSUME SMBHS CAN EXIST ONLY IN HALOS WITH $T_{\text{VIR}} > 10^4 \text{ K}$ (BARYON COOLING)
 - $\sim 10^5$ HALOS AT $z=5$ MERGE INTO $\sim 10^4$ HALOS AT $z=0$ (COMOVING 10^4 Mpc^3)



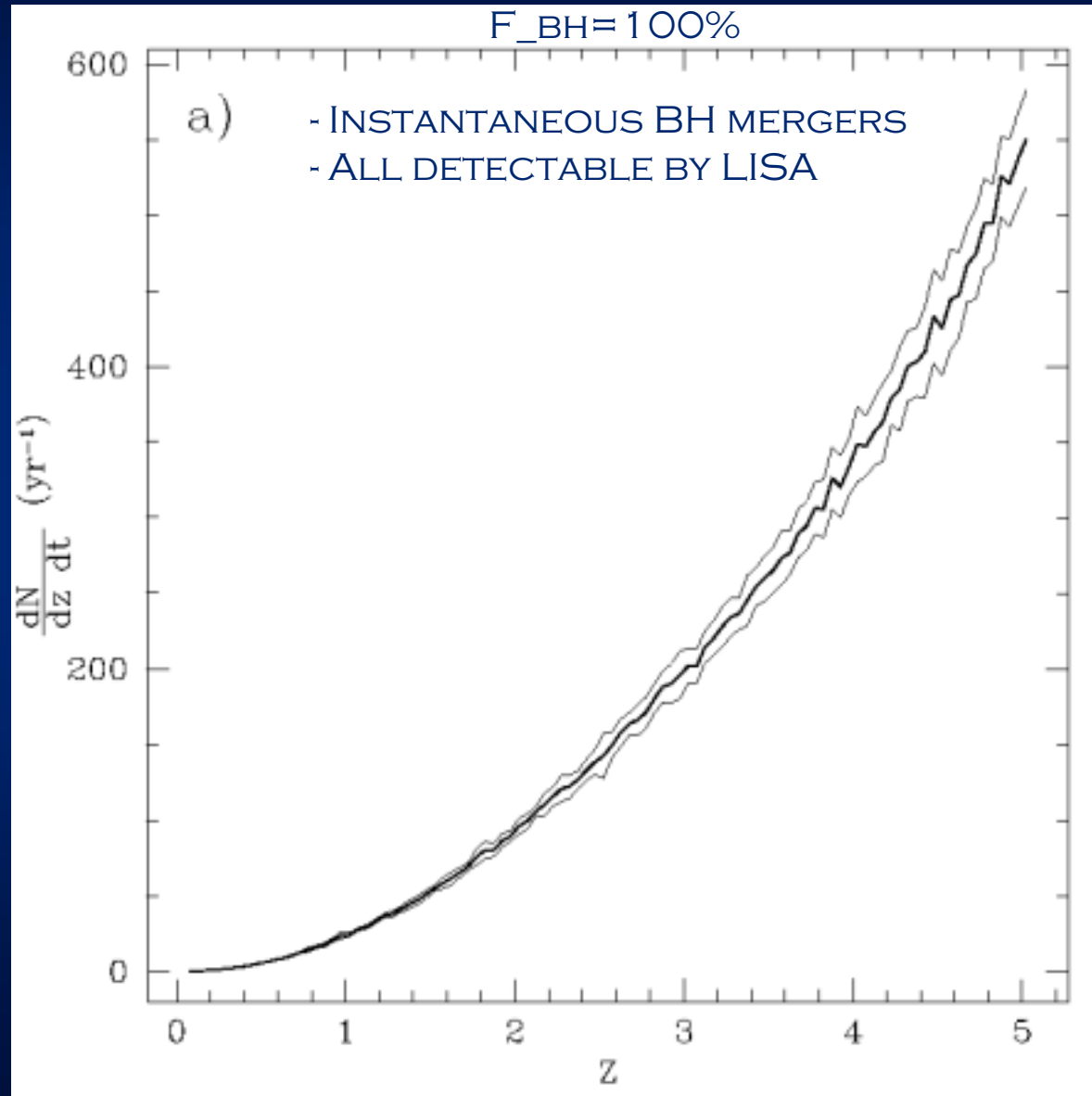
- POPULATING GALAXIES WITH SMBHS (NO BH MASS REQUIRED SO FAR)
 - $F_{\text{BH}} = 1$ AT $z=5$ (ALL GALAXIES)
 - $F_{\text{BH}} < 1$ AT $z=5$: RANDOMLY OR MOST MASSIVE ONLY



BH OCCUPATION FRACTION



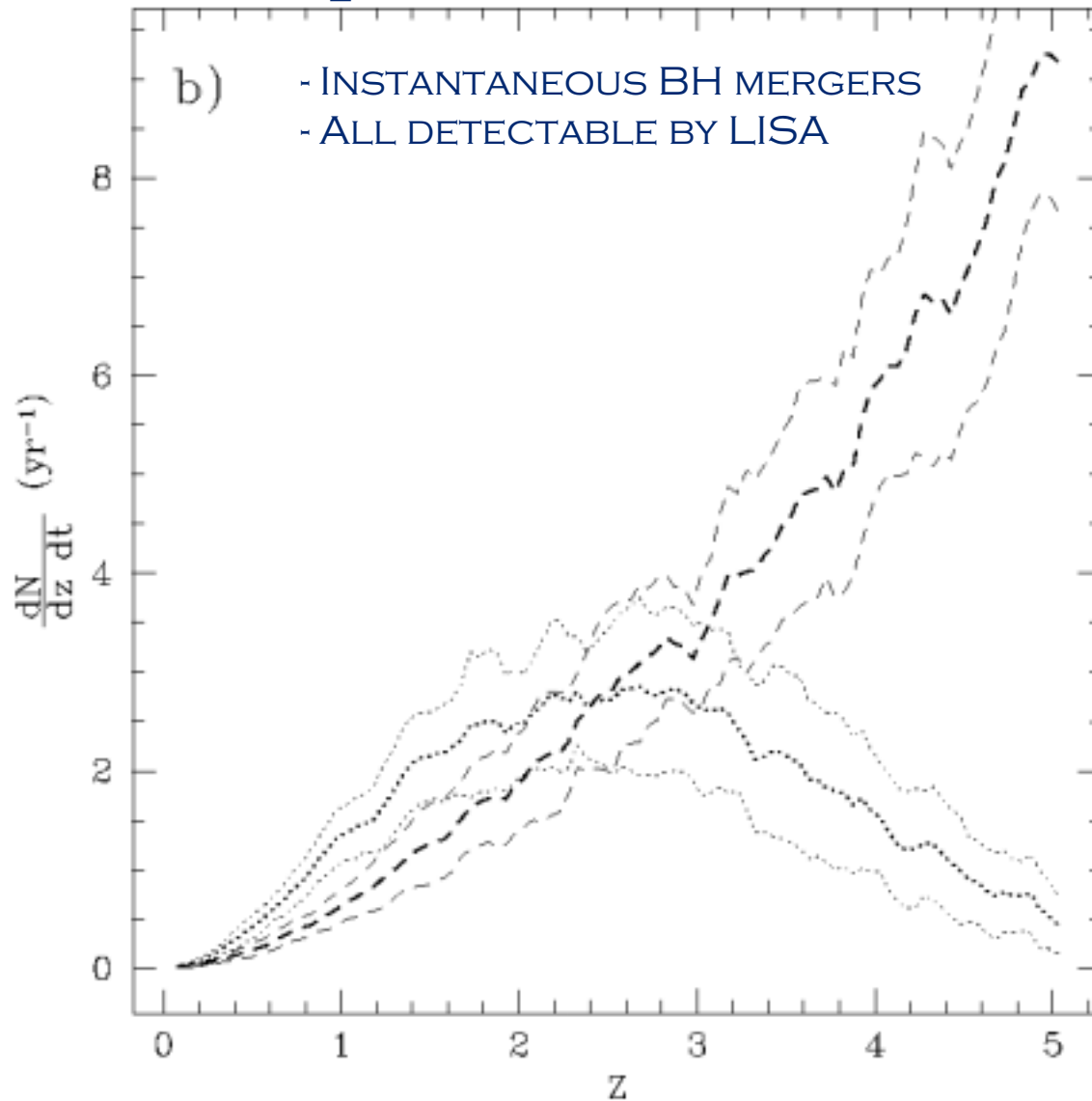
BH MERGER RATES





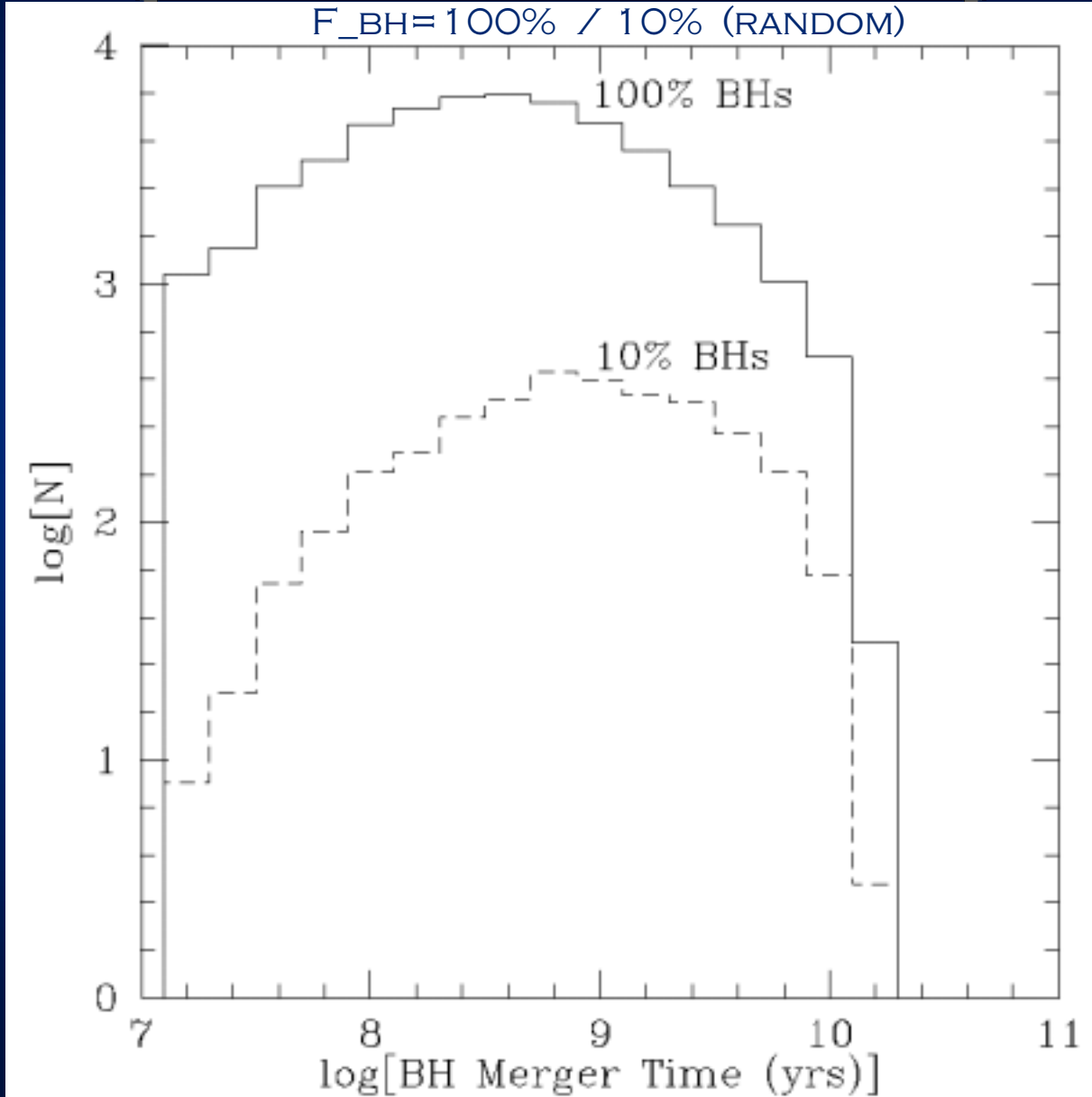
BH MERGER RATES

$F_{BH}=3\%$ (MASSIVE/RANDOM)



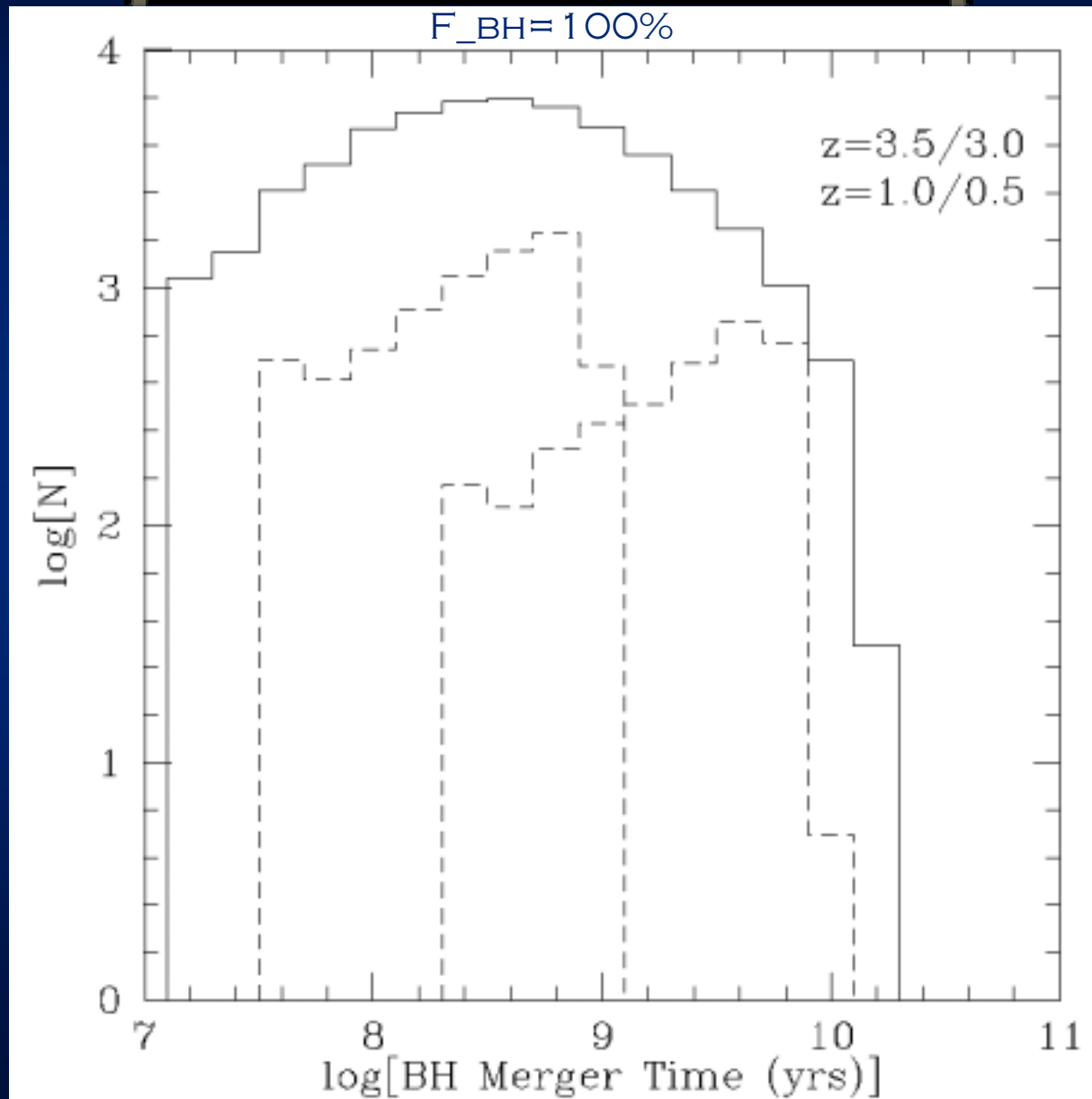


TIME BETWEEN SUCCESSIVE “BH MERGERS”





TIME BETWEEN SUCCESSIVE “BH MERGERS”





MASS ASSEMBLY OF SMBHS

ACCRETION vs. MERGERS

- SEVERAL MODELS REPRODUCING THE QUASAR LUMINOSITY FUNCTION EXIST:

VOLONTERI, HAARDT & MADAU (2002):

- PRESCRIPTIONS FOR SEED BHs, DYNAMICAL PROCESSES, ACCRETION PHASES
- CLOSEST TO POPULATION SYNTHESIS
- SMBHS ARE RARE AT HIGH REDSHIFT

KAUFFMANN & HAEHNELT (2000):

- PRESCRIPTIONS FOR ACCRETION PHASES, GALAXY FORMATION & EVOLUTION
- SMBHS ARE COMMON AT ALL REDSHIFTS

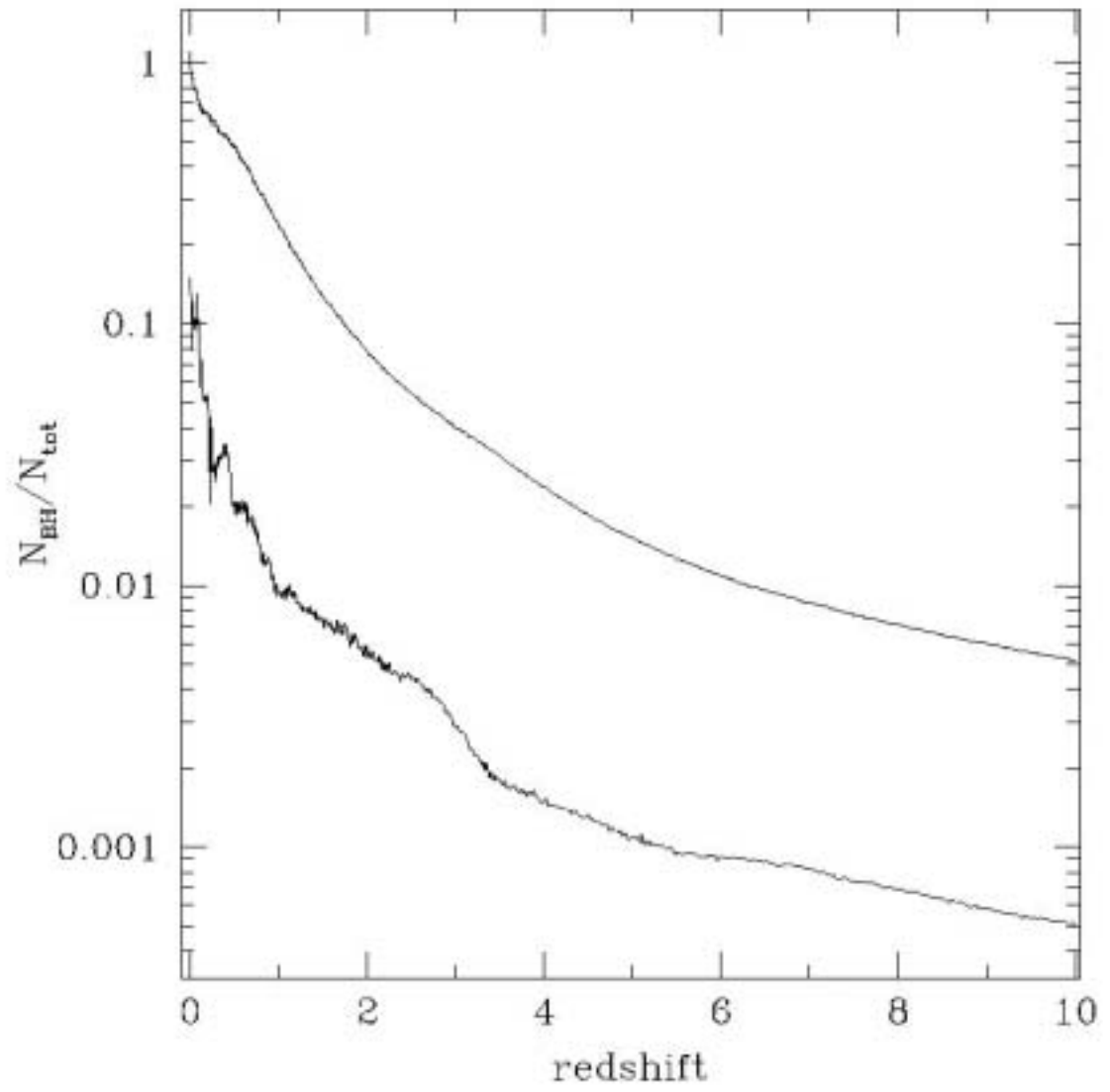
- NEXT STEP:

- WHAT IS THE RANGE OF ACCEPTABLE MODELS FOR THE QUASAR LUMINOSITY FUNCTION?
- CAN LISA CONSTRAIN THE DETAILS OF THE MASS ASSEMBLY?



BH OCCUPATION FRACTION

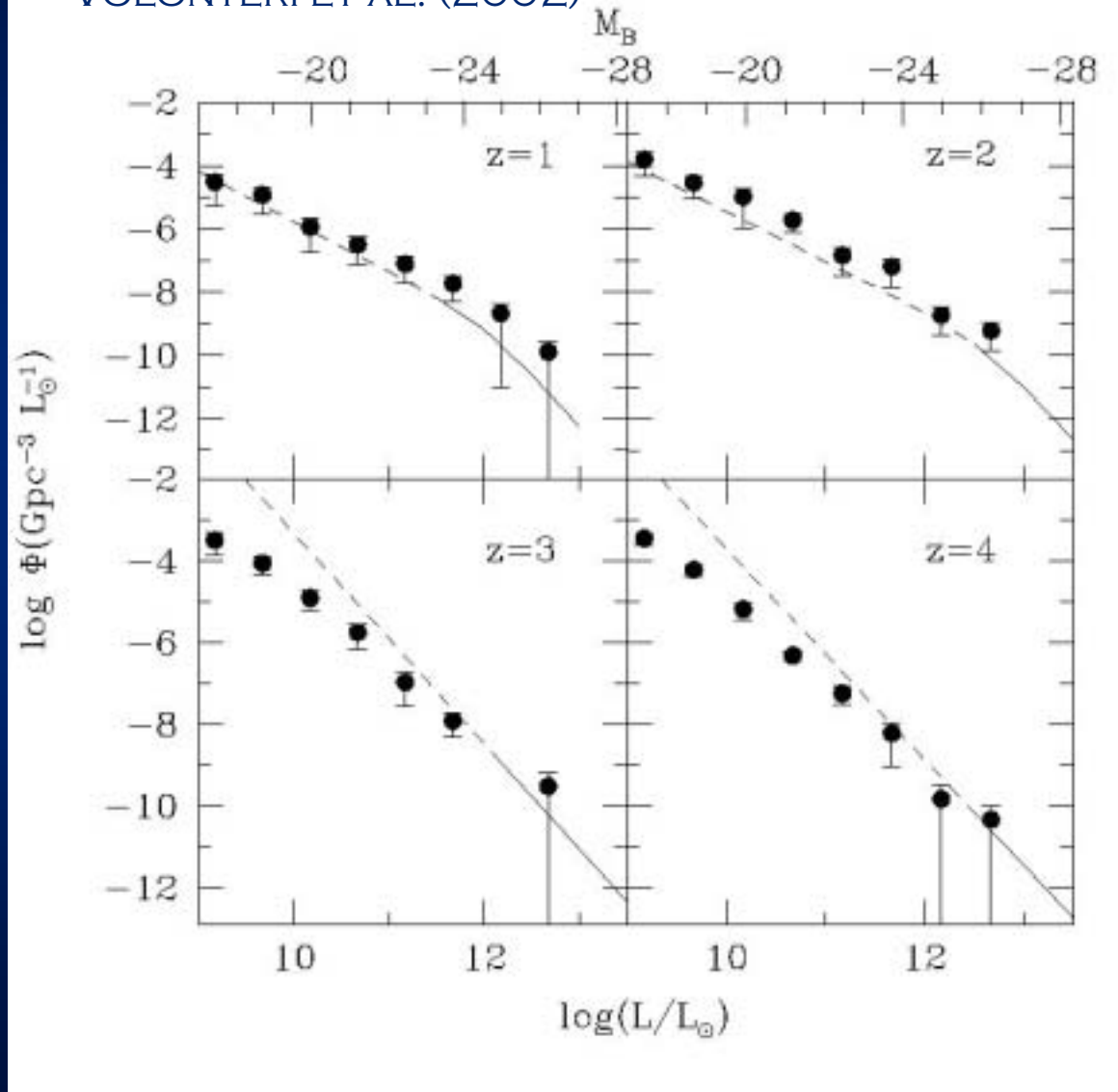
VOLONTERI ET AL. (2002)





B-BAND QUASAR LUMINOSITY FUNCTION

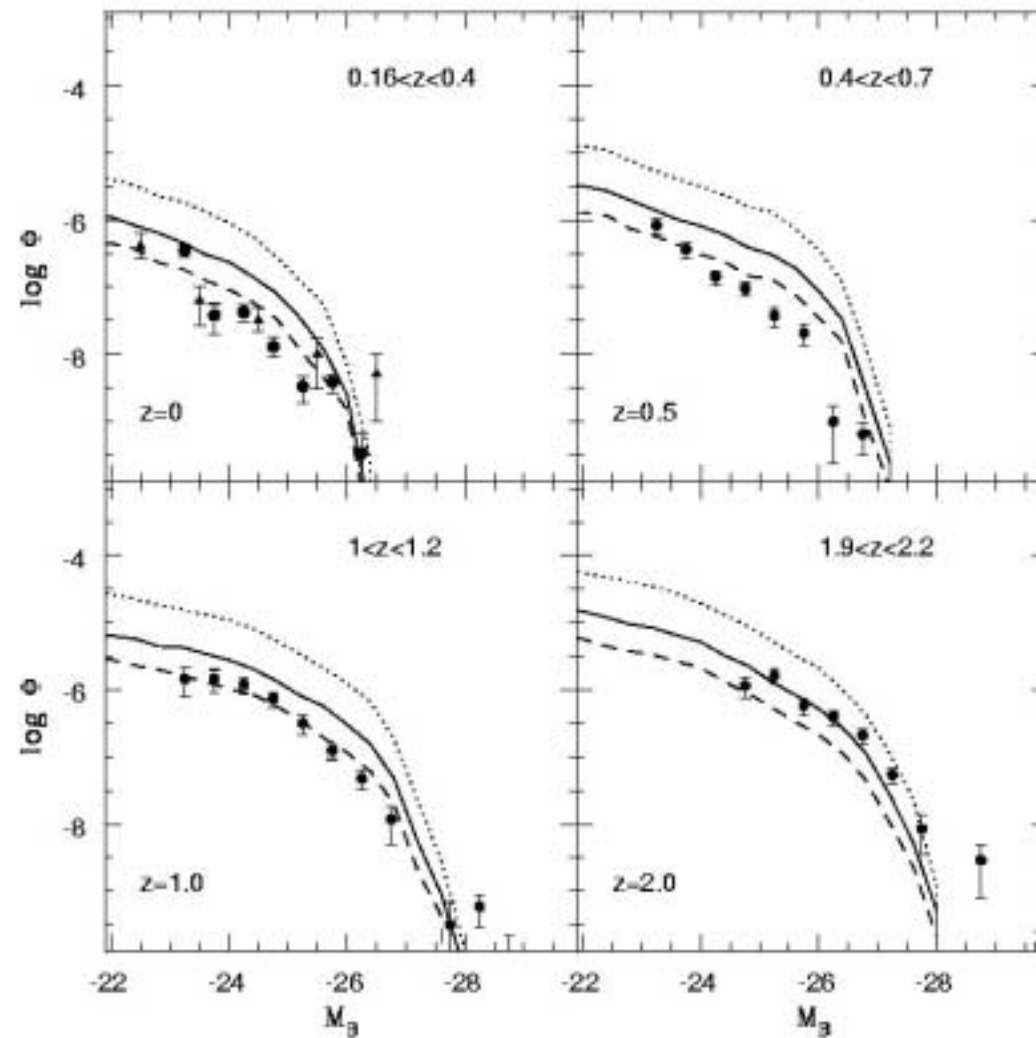
VOLONTERI ET AL. (2002)





B-BAND QUASAR LUMINOSITY FUNCTION

KAUFFMANN & HAEHNELT (2000)



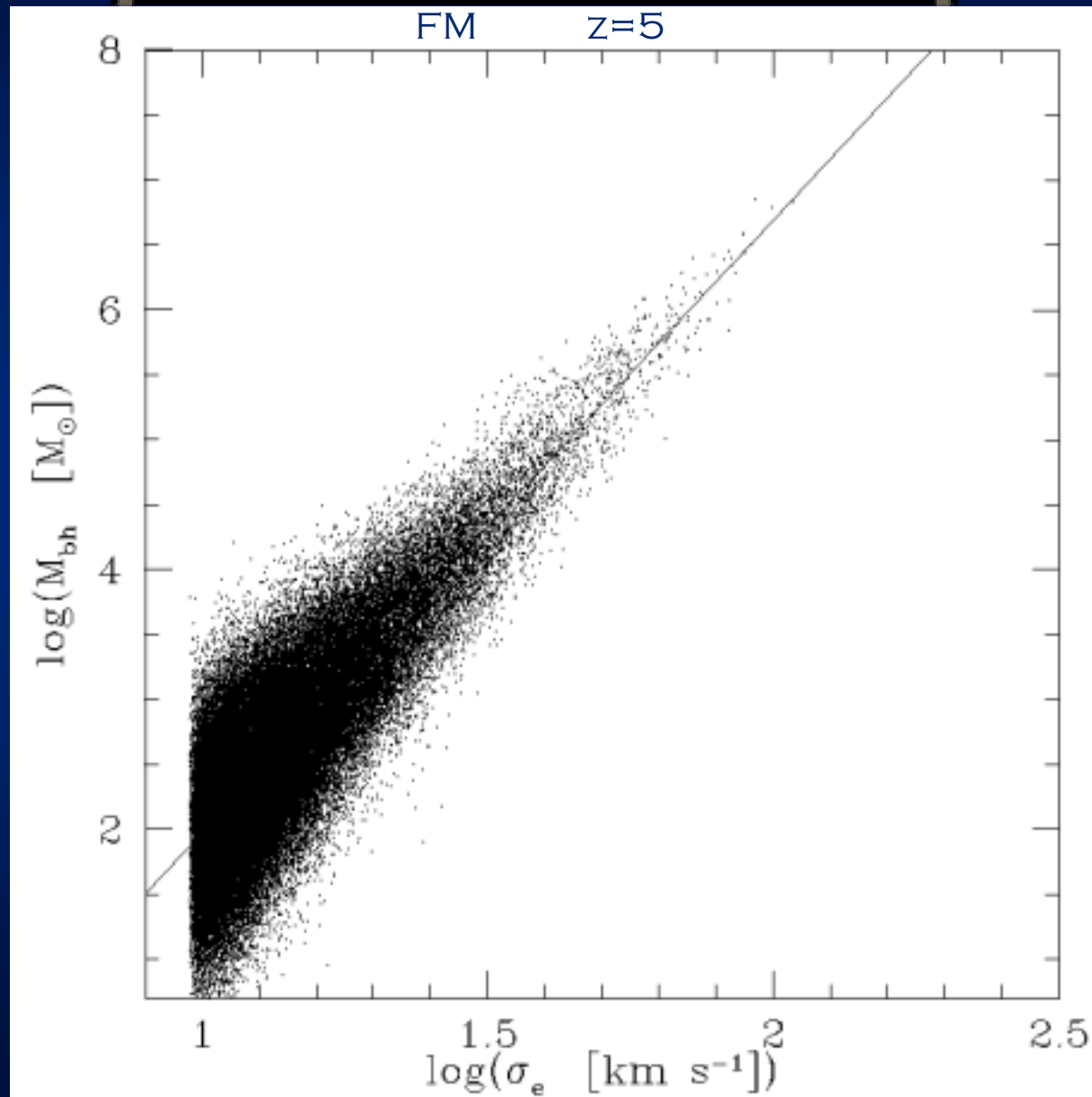


CONCLUSIONS

- LISA RATES (ALONE) WILL TELL US ABOUT THE EXTENT OF THE POPULATION OF SMBHS AT HIGH REDSHIFT, WHICH IS CURRENTLY UNKNOWN
- LISA RATES WILL LIKELY BREAK EXISTING DEGENERACIES AMONG MODELS FOR THE QUASAR LUMINOSITY FUNCTION
- [TO BE DEMONSTRATED WITH POPULATION SYNTHESIS MODELS:] LISA MASS MEASUREMENTS SHOULD PROVIDE A DETAILED ACCOUNT OF THE MASS ASSEMBLY OF SMBHS (ACCRETION VS. MERGERS)

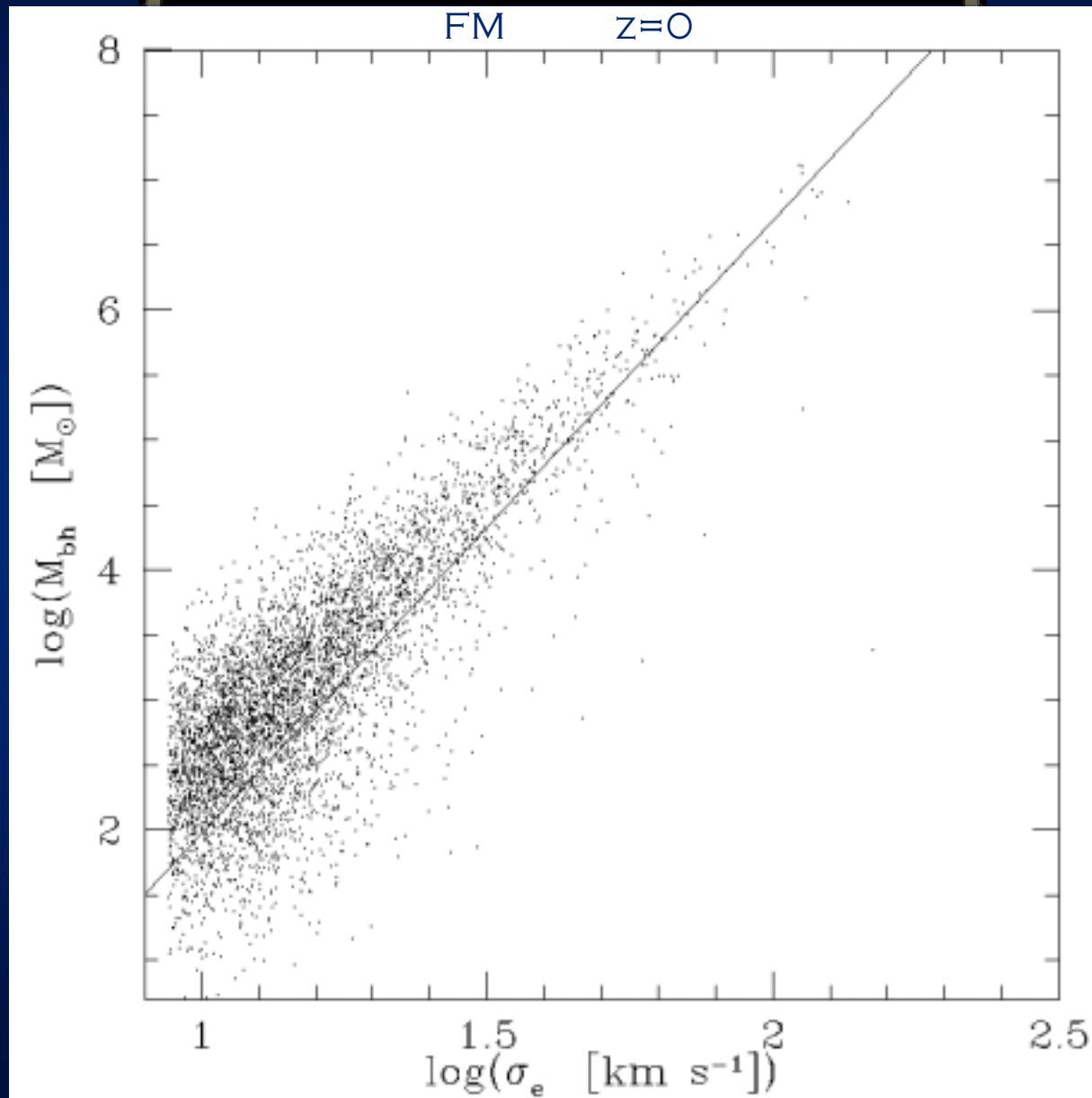


EVOLUTION THROUGH MERGER PROCESS



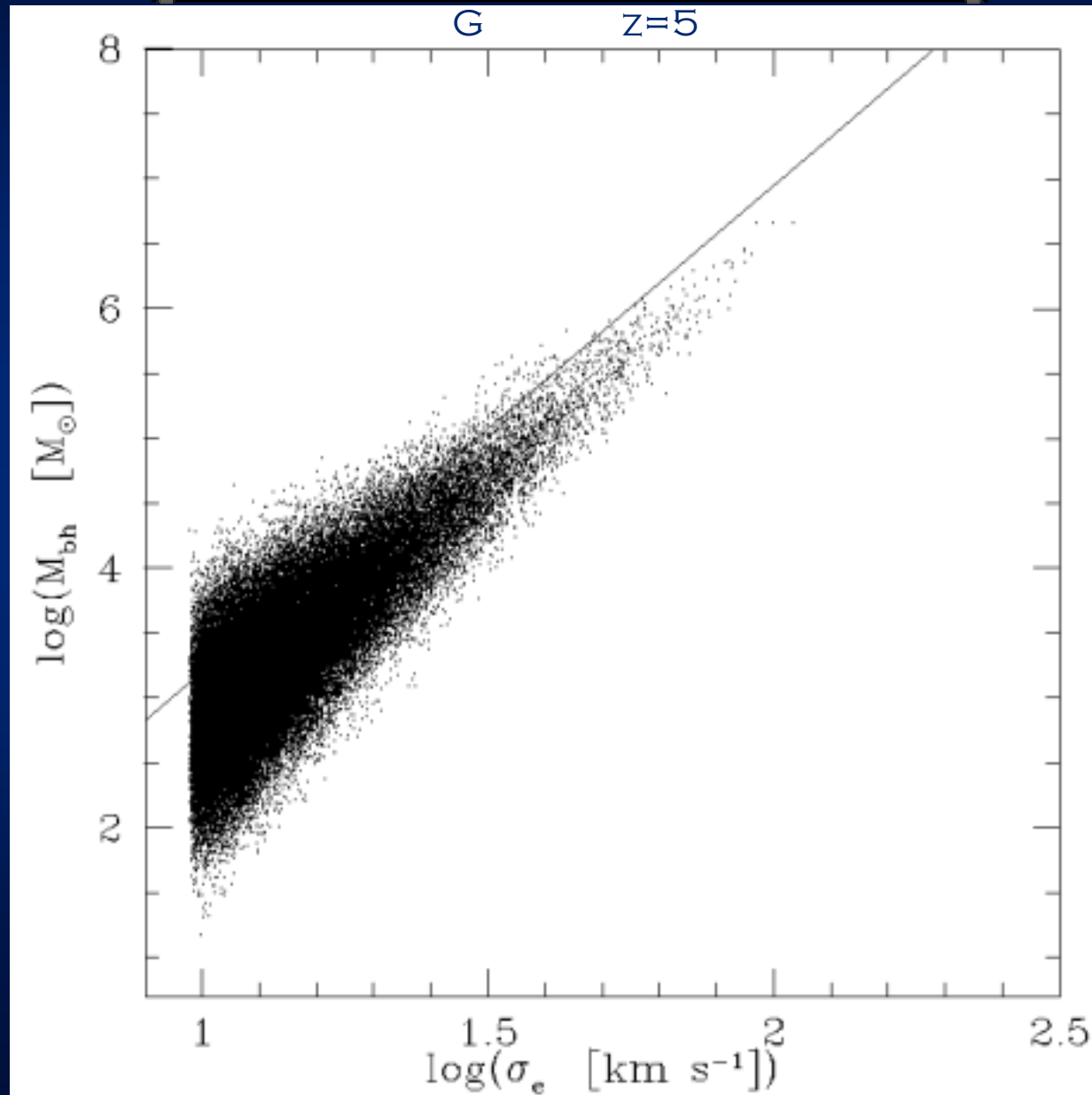


EVOLUTION THROUGH MERGER PROCESS



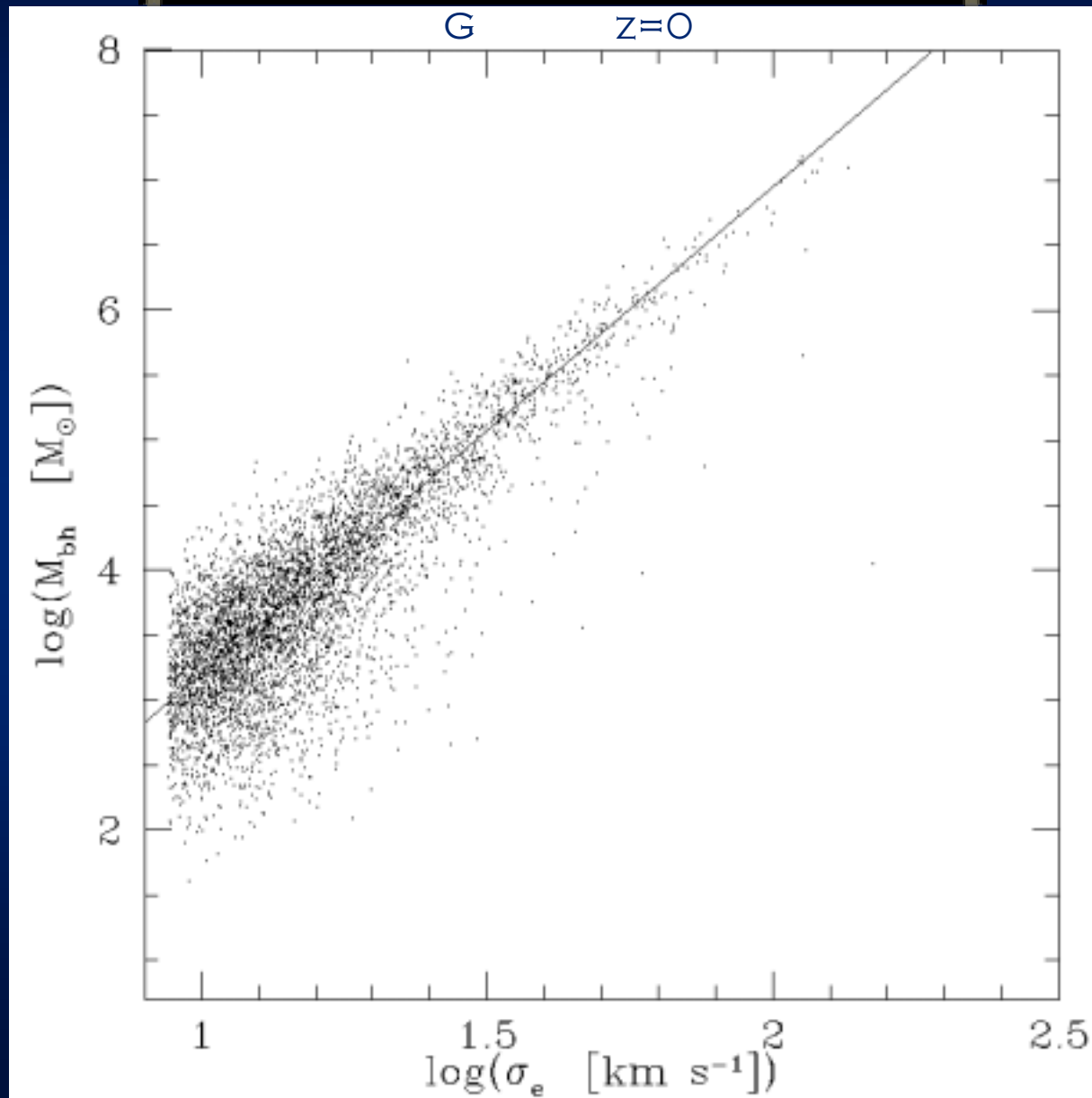


EVOLUTION THROUGH MERGER PROCESS

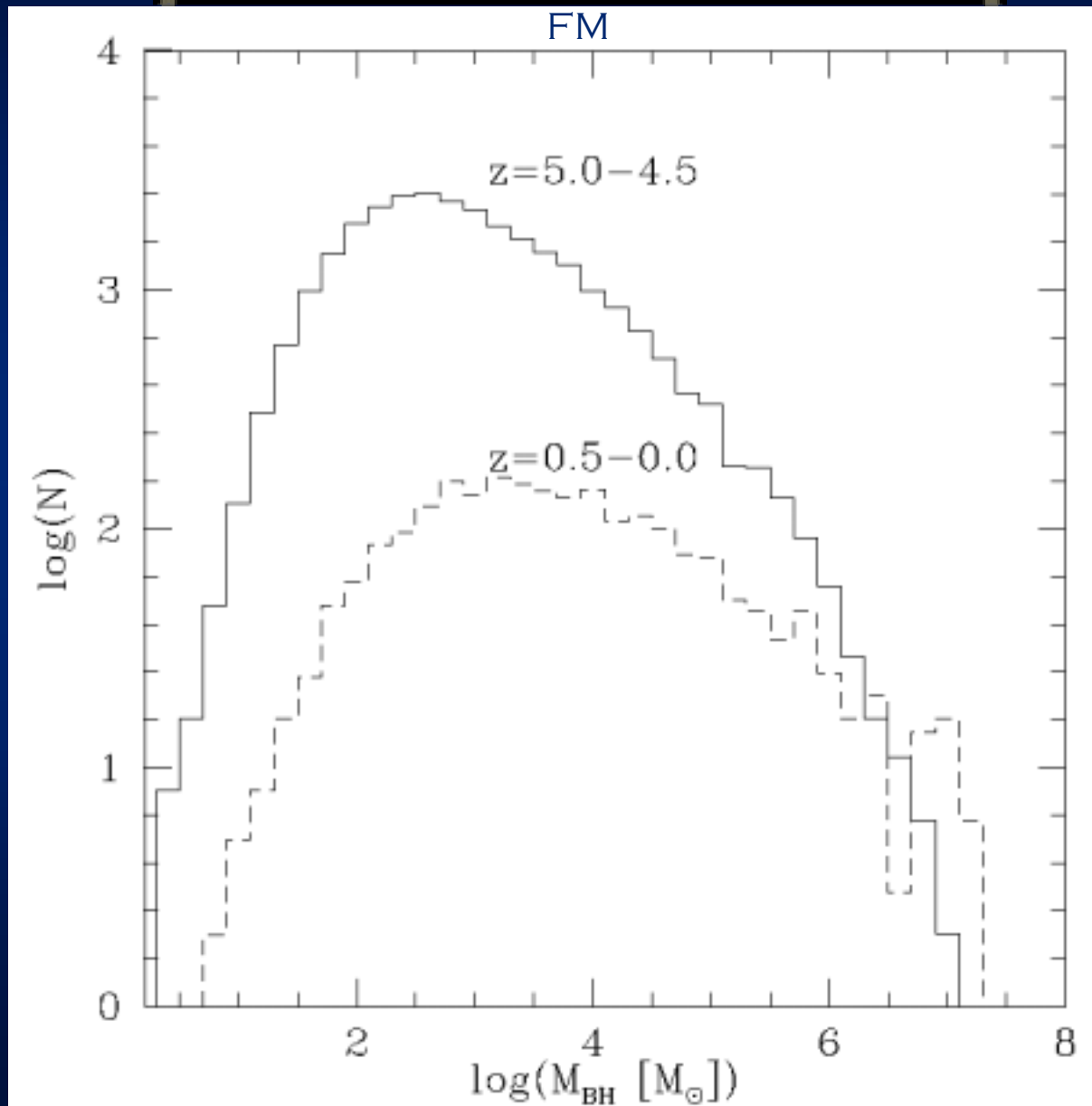




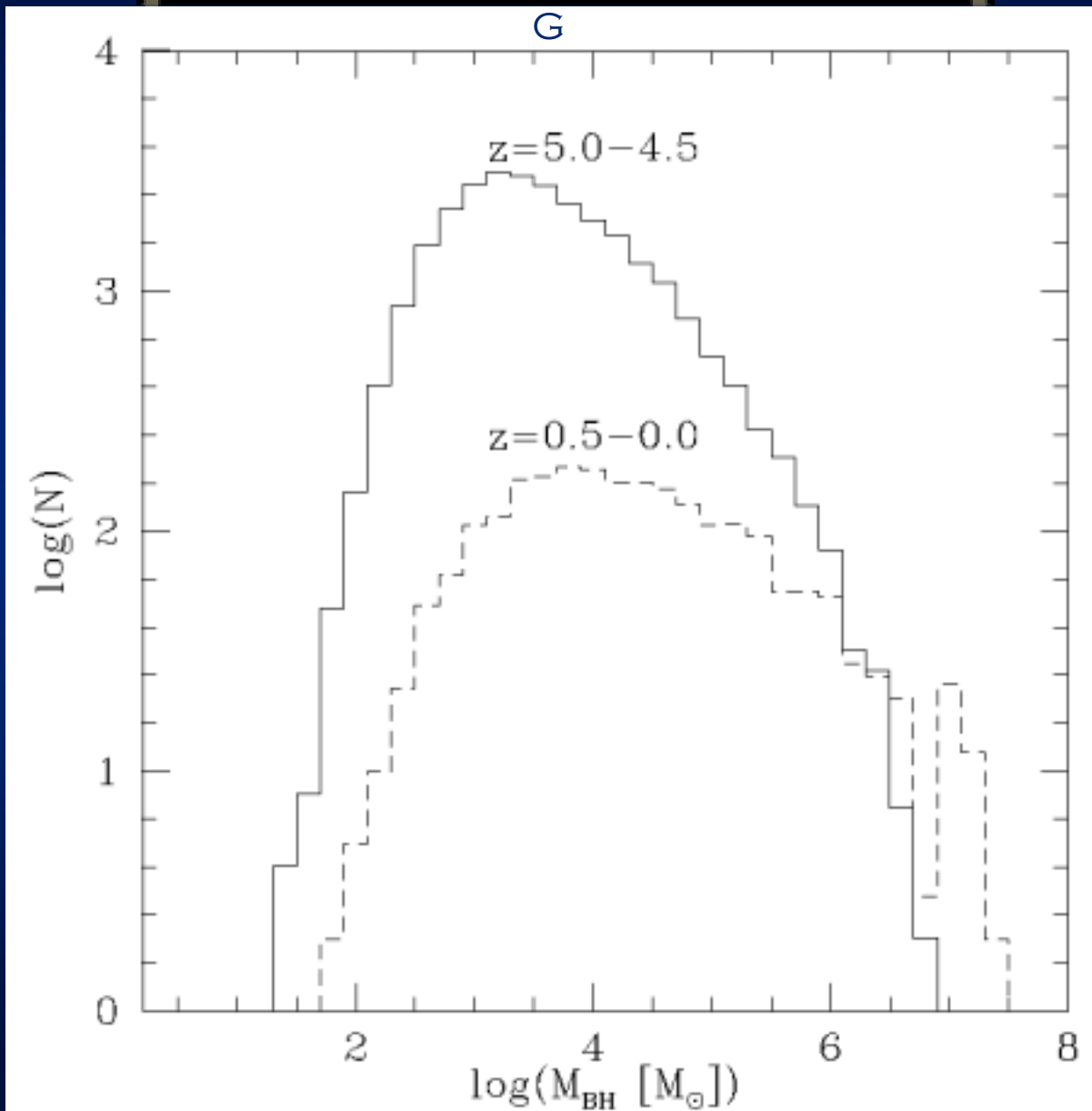
EVOLUTION THROUGH MERGER PROCESS



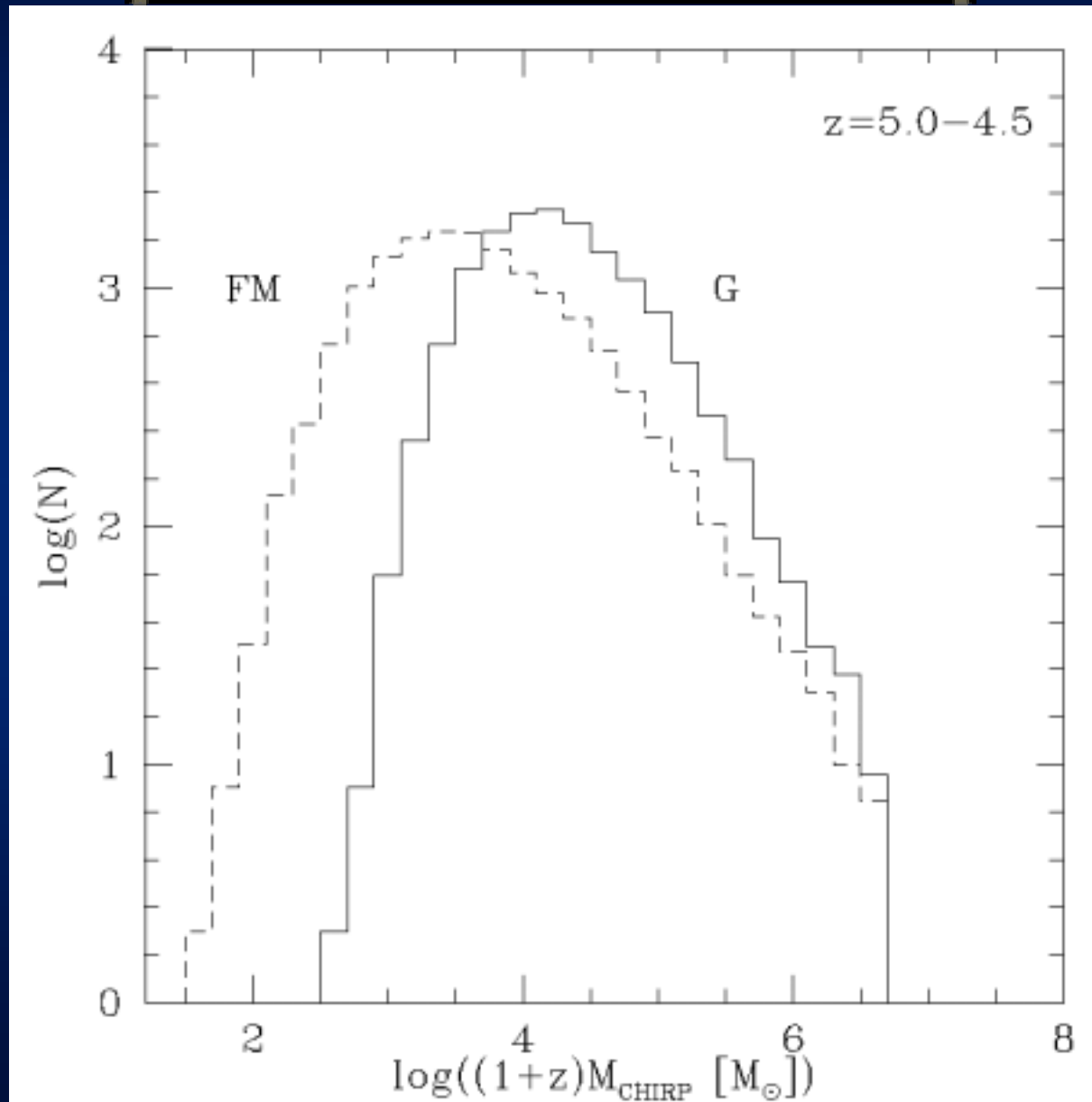
MASS DISTRIBUTION OF BH MERGERS



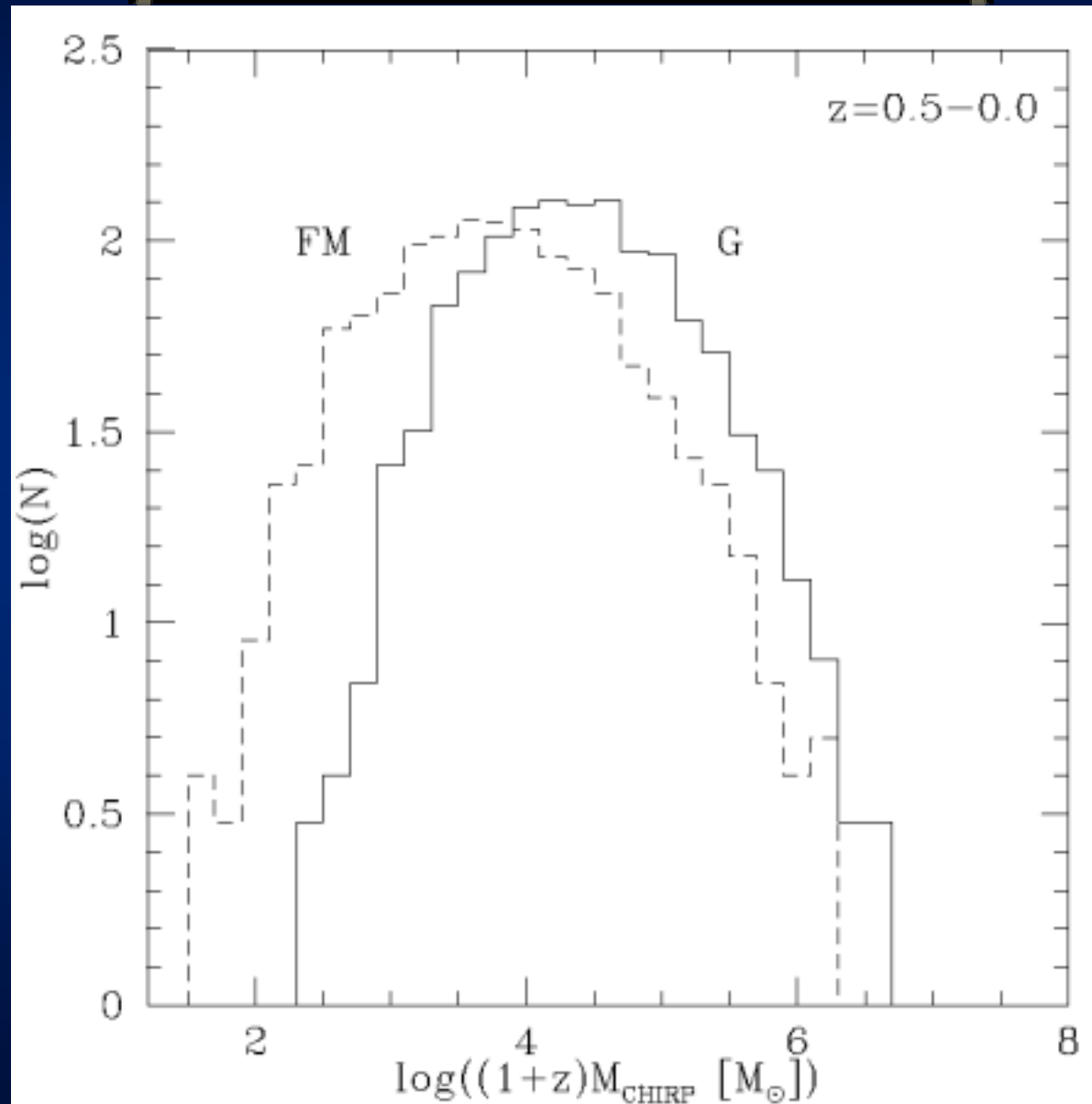
MASS DISTRIBUTION OF BH MERGERS



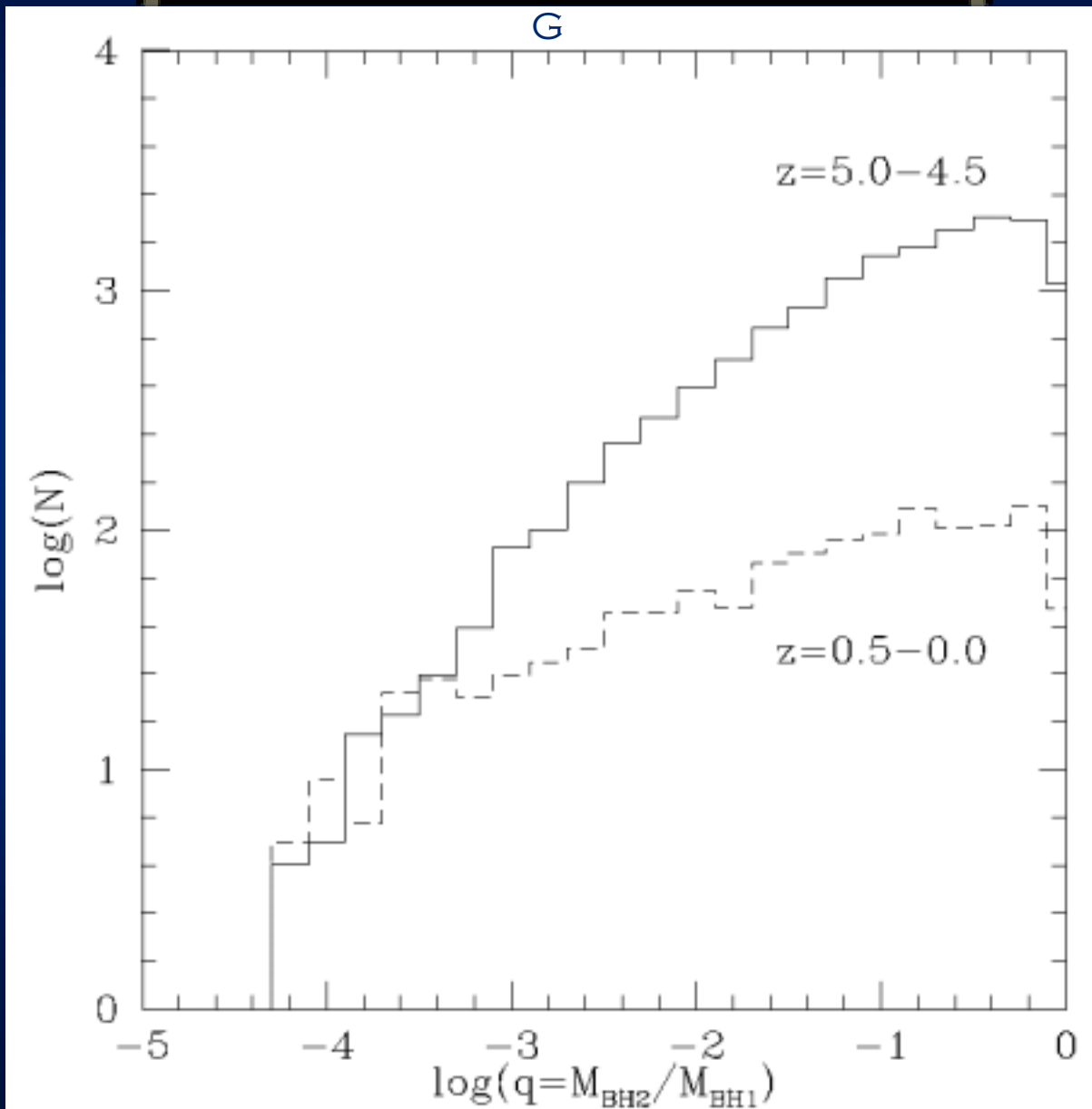
RED. CHIRP MASS DISTRIBUTION OF BH MERGERS



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BH MERGER MASS RATIO



TOWARDS POPULATION SYNTHESIS MODELS FOR LISA

● COSMOLOGY:

- TREES FROM N-BODY SIMULATIONS ARE BETTER THAN FROM EXTENDED PRESS-SCHECHTER (OVERMERGING PROBLEM)

● GALAXY FORMATION:

- $T_{\text{VIR}} = 10^4 \text{ K}$ DEPENDS ON METALLICITY, H₂ CHEMISTRY

- BULGE-LESS AND SPIRAL GALAXIES ARE A POSSIBLE ISSUE

● GALACTIC STRUCTURE & DYNAMICS:

- EFFICIENCY OF BINARY BH MERGERS? (AS A FUNCTION OF GALAXY TYPE, REDSHIFT)

● GENERAL RELATIVITY:

- UNCERTAIN MASS LOSS TO GW RADIATION DURING BH MERGERS

● EXAMPLE:

LISA RATES ARE LOW → RARE BHs, MASS SPECTRUM, INEFFICIENT MERGING?