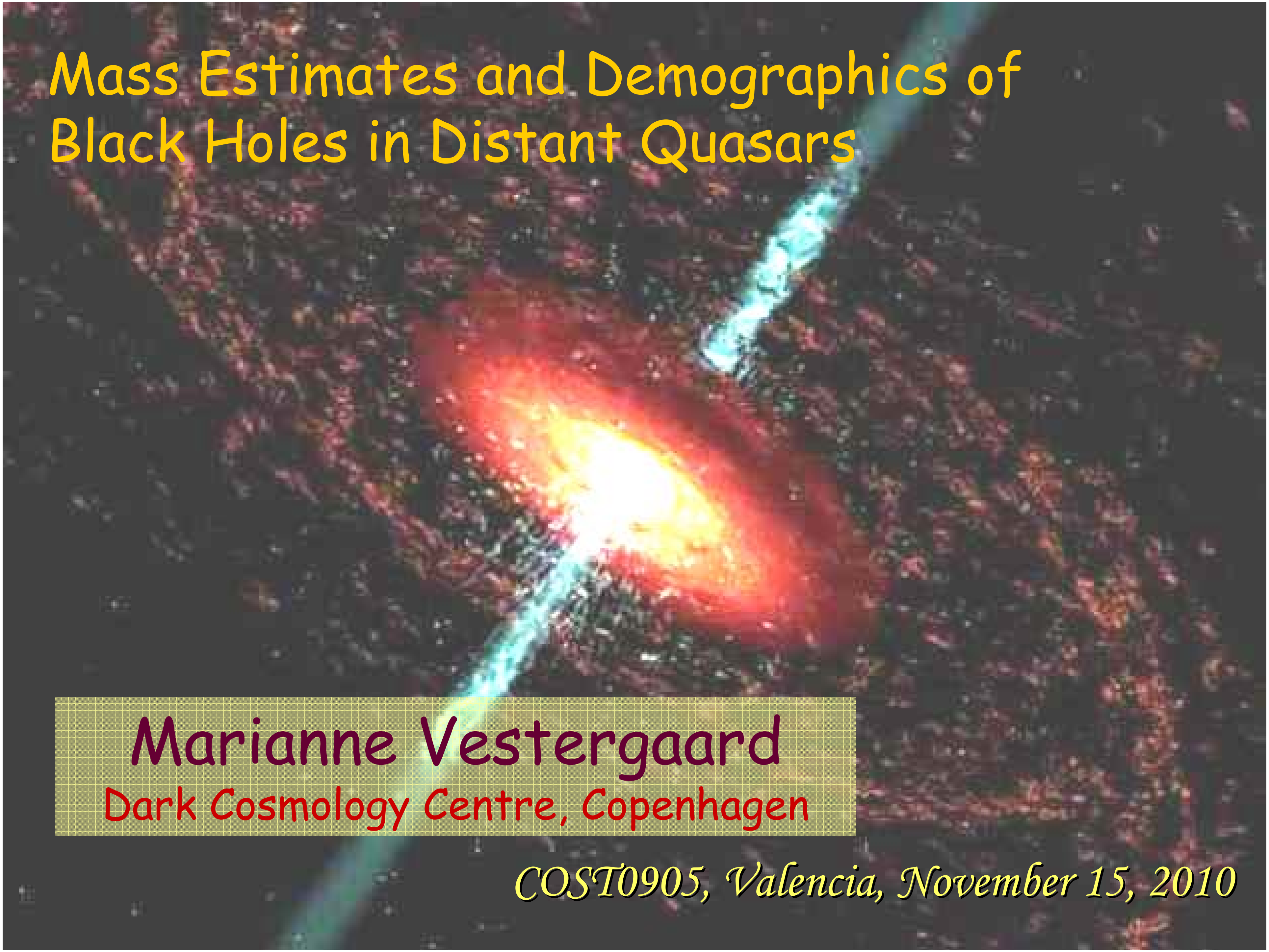
Mass Estimates and Demographics of Black Holes in Distant Quasars



Marianne Vestergaard
Dark Cosmology Centre, Copenhagen

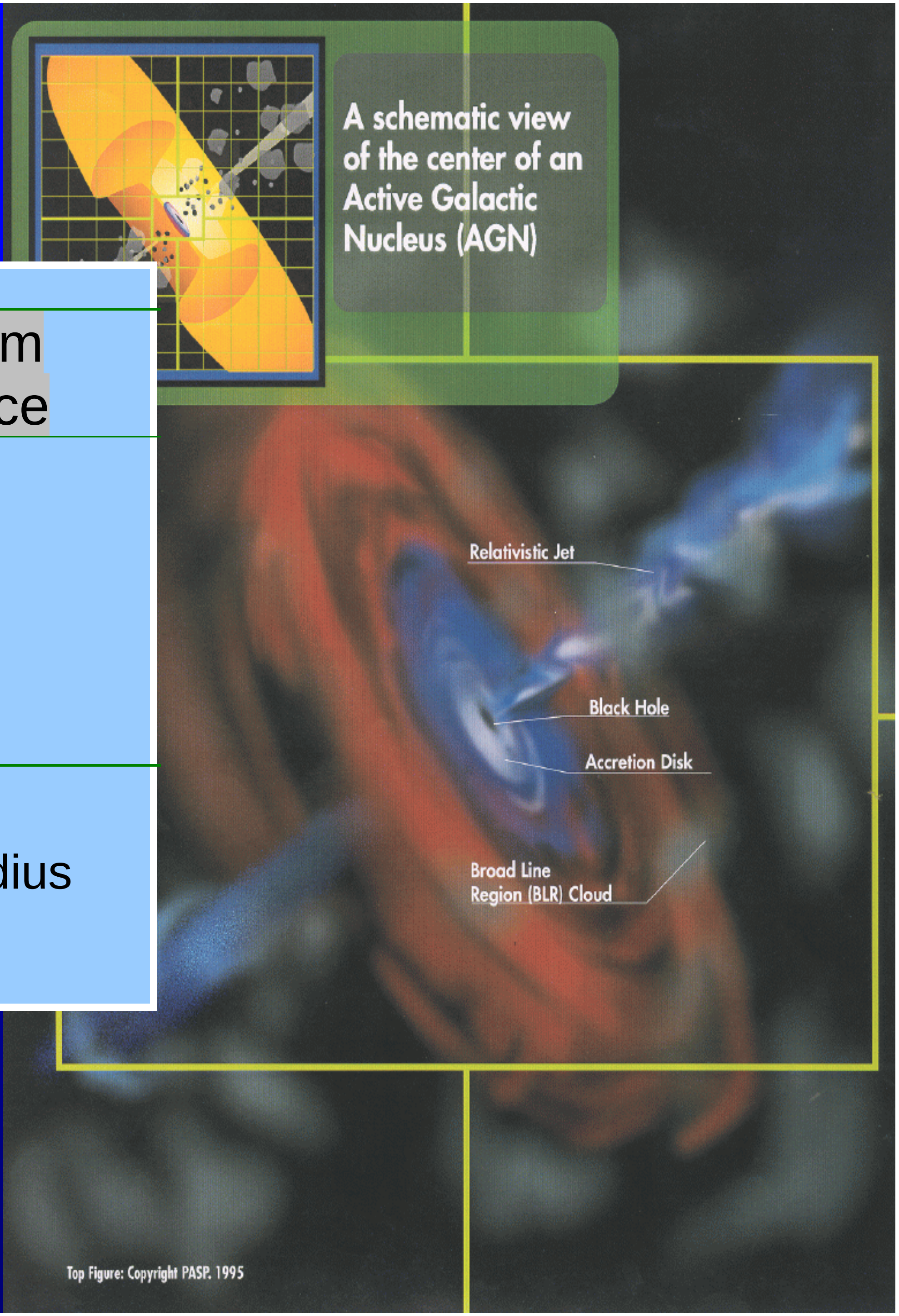
COST0905, Valencia, November 15, 2010

Possible Virial Estimators

Source	Distance from central source
X-Ray Fe Kα	3-10 R_S
Broad-Line Region	600 R_S
Megamasers	4×10^4 R_S
Gas Dynamics	8×10^5 R_S
Stellar Dynamics	10^6 R_S

In units of the Schwarzschild radius
$R_S = 2GM/c^2 = 3 \times 10^{13}\ M_8$ cm .

Note: the reverberation technique is independent of angular resolution

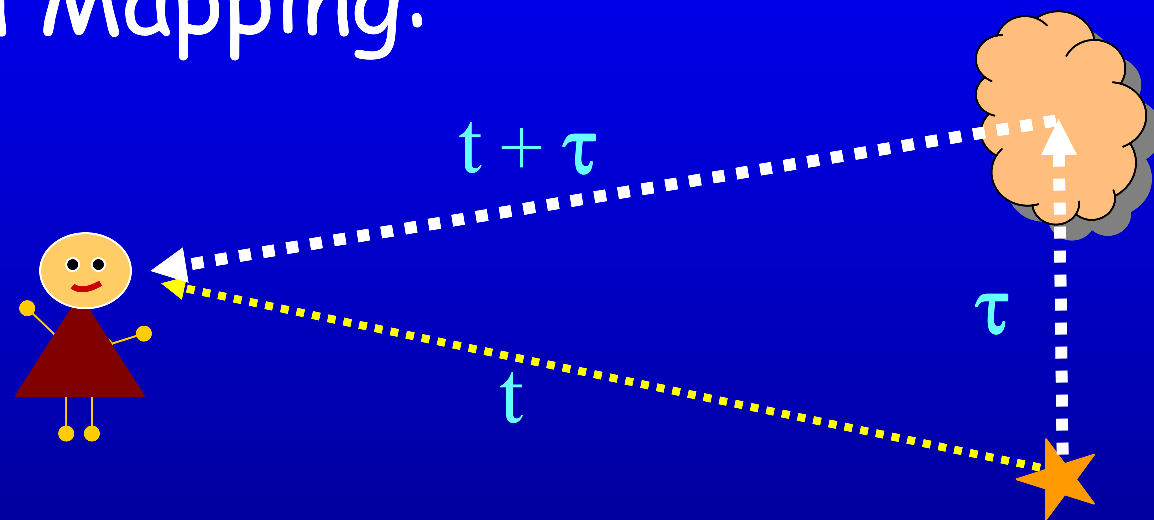


Virial Mass Estimates

$$M_{BH} = f \; v^2 R_{BLR}/G$$

Reverberation Mapping:

- $R_{BLR} = c\,\tau$



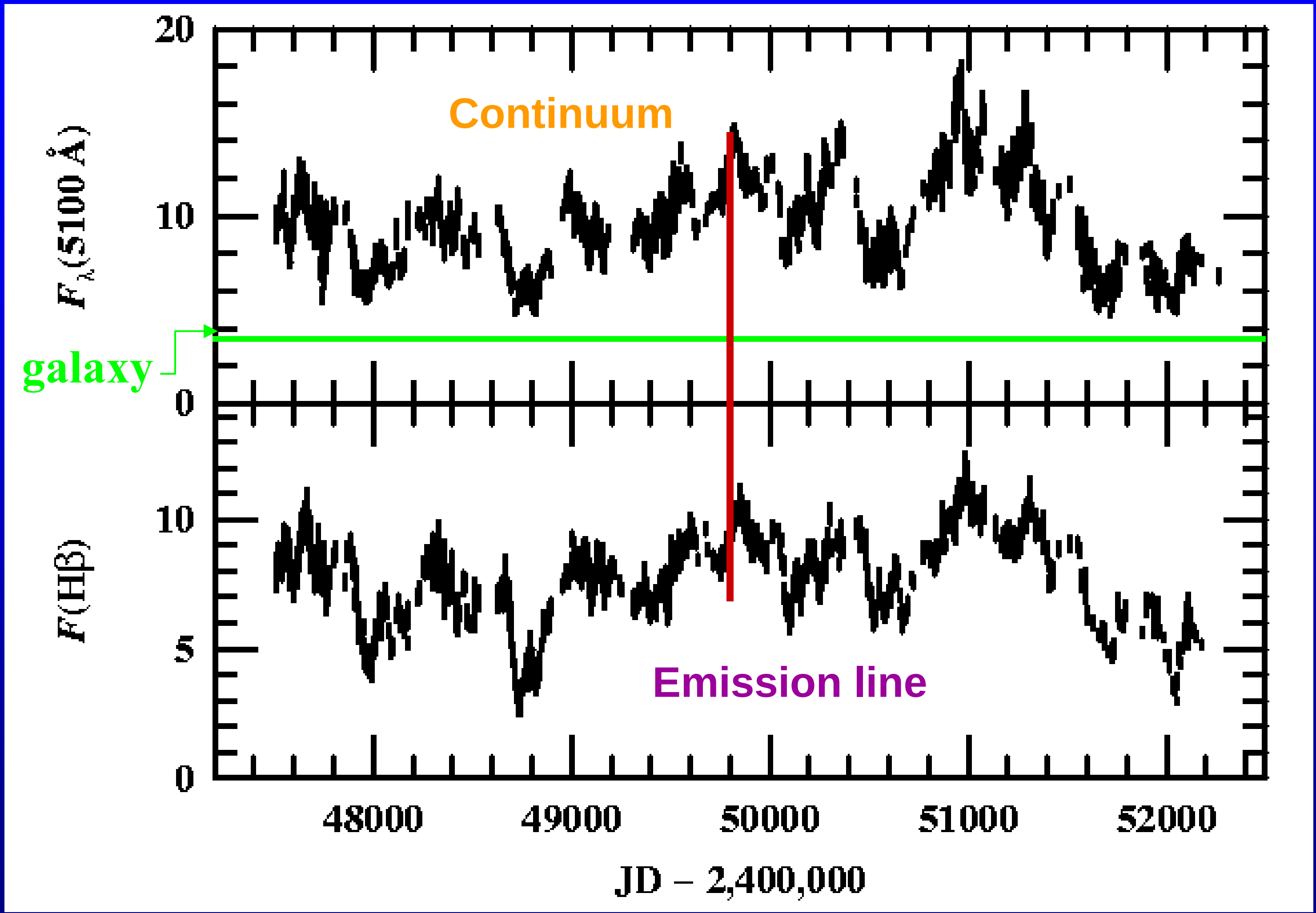
- v_{BLR}

  Line width in variable spectrum

Reverberation Mapping Results

Light Curves

13 years of data

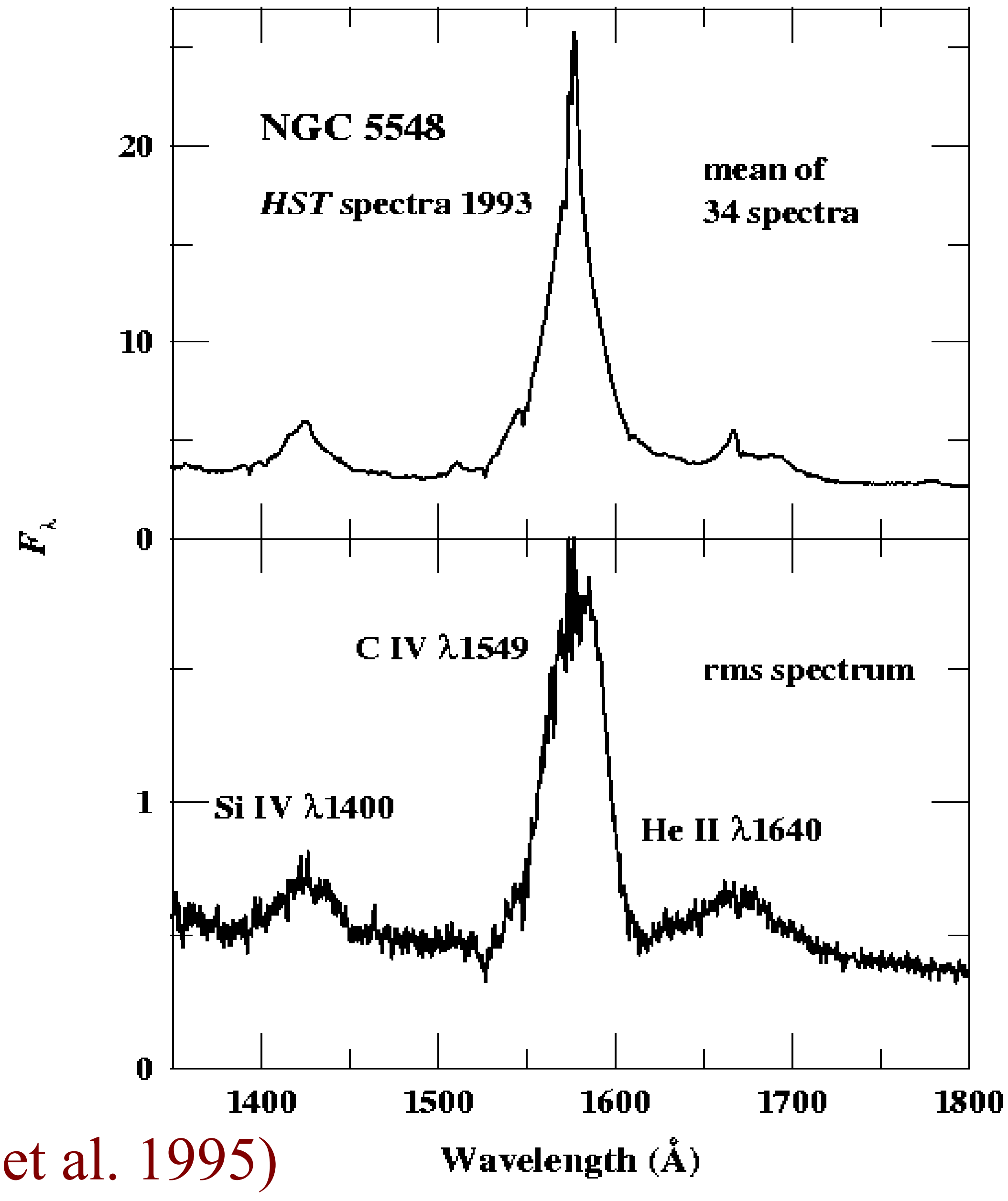


NGC 5548, the most closely monitored active galaxy

(Peterson et al. 2002)

Velocity Dispersion of the Broad Line Region and the Virial Mass

- Velocity dispersion is measured from the line in the rms spectrum.
  - The rms spectrum isolates the variable part of the lines.
  - Constant components (like narrow lines) vanish in rms spectrum



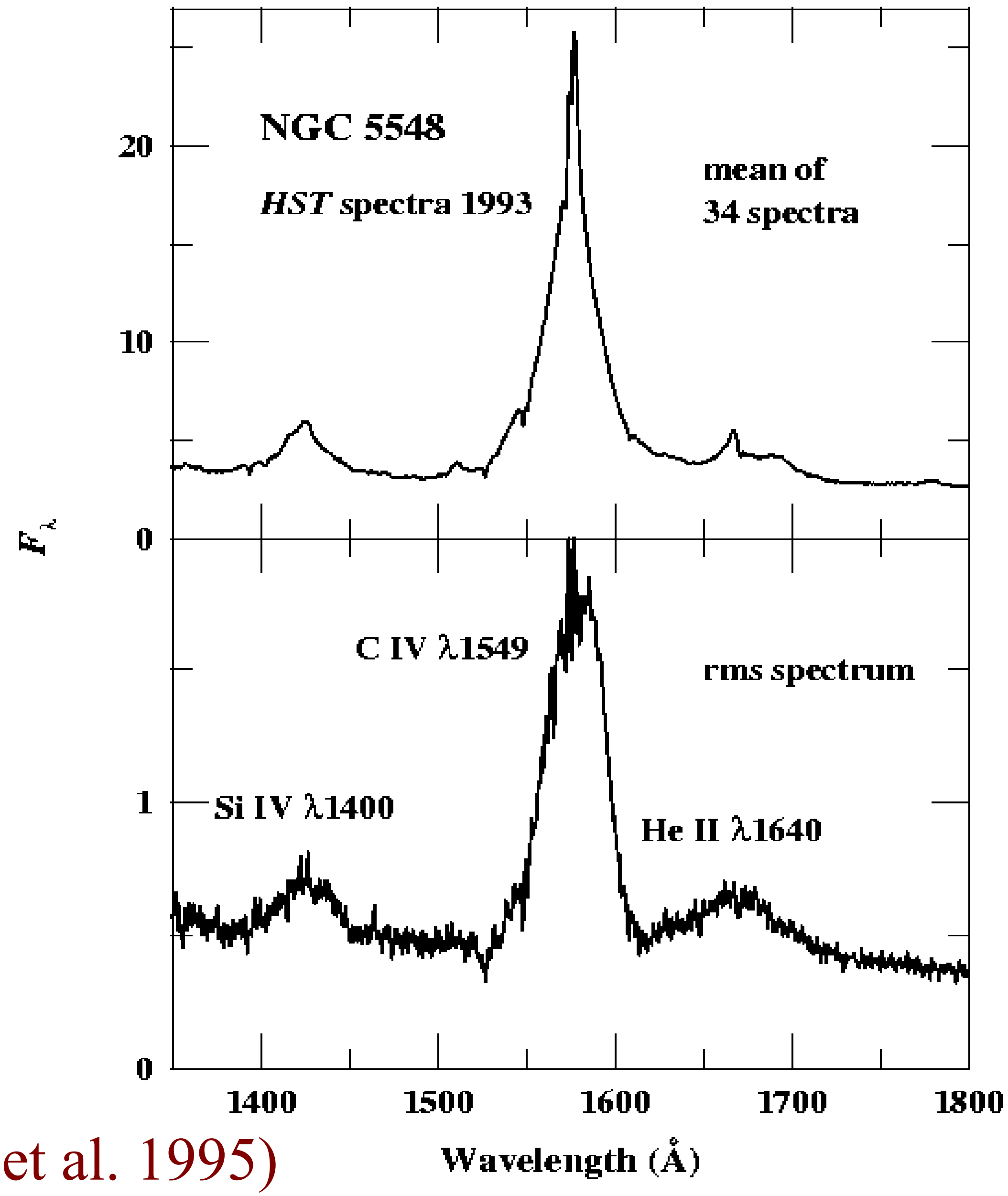
(based on Korista et al. 1995)

Velocity Dispersion of the Broad Line Region and the Virial Mass

$$M_{BH} = f\ v^2 R_{BLR}/G$$

f depends on structure and geometry of broad line region

$f \approx 1$ for v = FWHM



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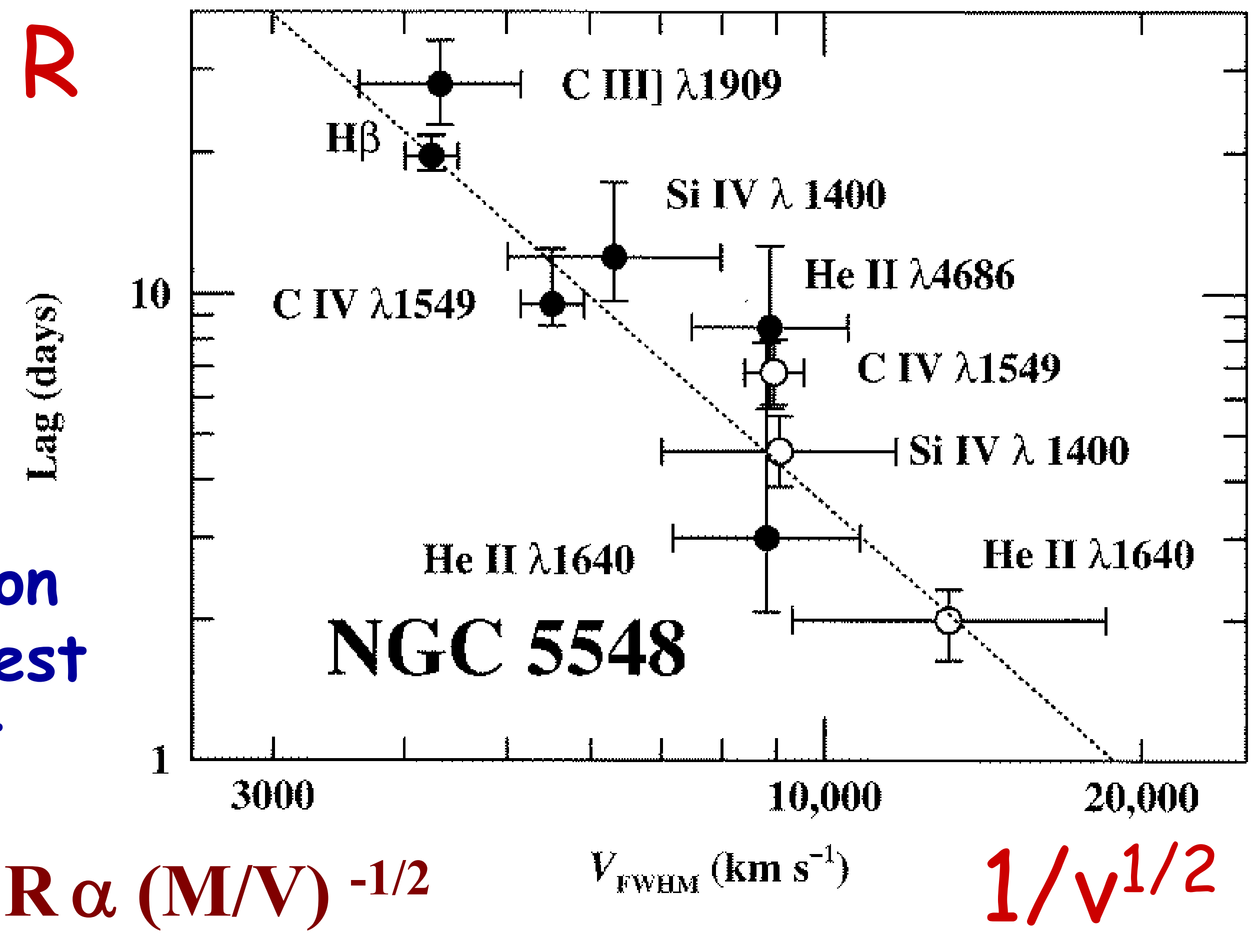
Virialized BLR

Highest ionization lines have smallest lags and largest Doppler widths.



$R \; \alpha \; (M/V)^{-1/2}$

- ● Filled circles: 1989 data from *IUE* and ground-based telescopes.
- ○ Open circles: 1993 data from *HST* and *IUE*.
- … Dotted line corresponds to virial relationship with $M = 6 \times 10^7 M_\odot$.

Peterson and Wandel 1999

Virial Mass Estimates:

$$M_{BH} = v^2 R_{BLR}/G$$

- Variability Studies: $R_{BLR}=c\tau$, v_{BLR}

$$R_{BLR} \propto L_\lambda(\text{nuclear})^{0.50}$$

(Kaspi et al. 2005; Bentz et al. 2006, 2009)

- For individual spectra:

$$M_{BH} = k(\text{line})\ FWHM^2\ L^\beta\ ;\ \beta \approx 0.5$$

Lines: Hβ, MgII 2800, CIV 1549

(see e.g. MV 2002, McLure & Jarvis 2002, MV & Peterson 2006; MV & Osmer 2009)

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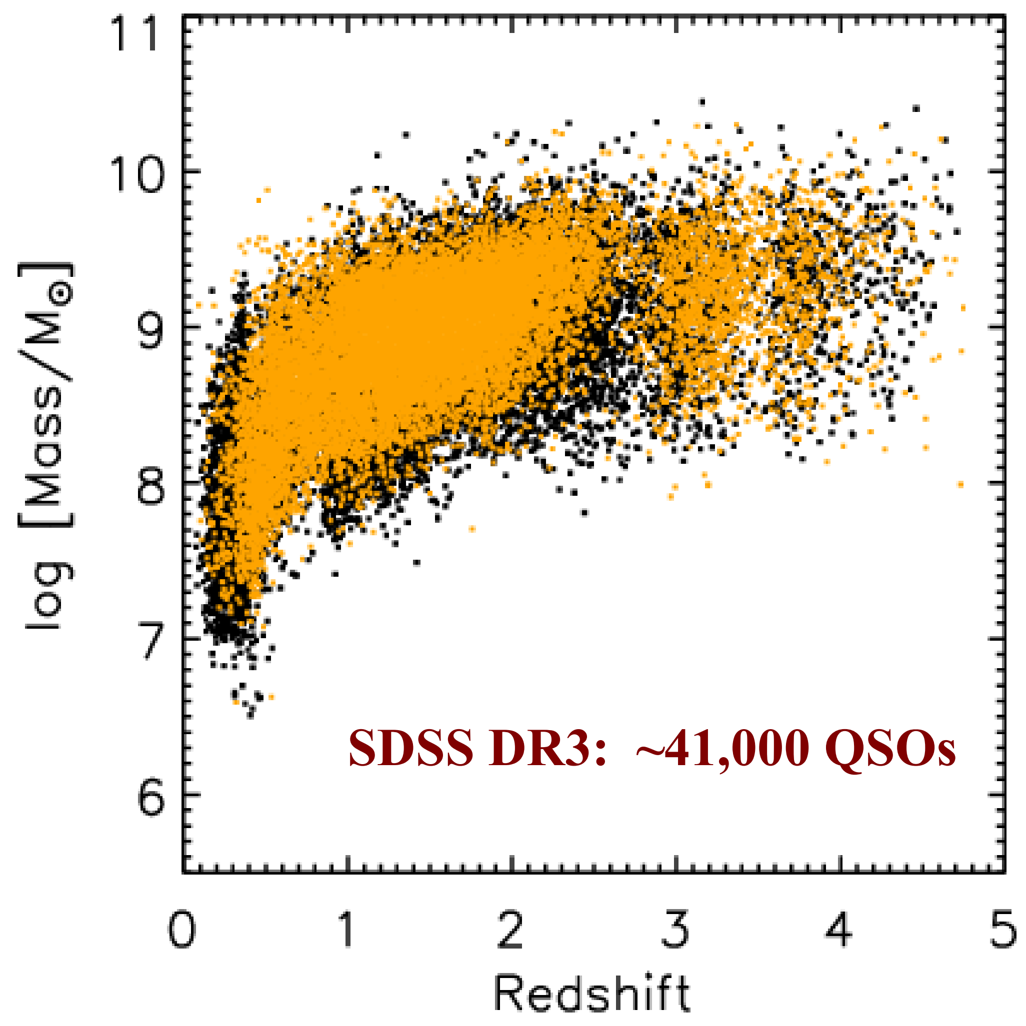
1σ absolute uncertainty: factor ~3.5 - 4

(see r 2009)

Masses of Distant Quasars

- Ceilings at $M_{BH} \approx 10^{10}\ M_\odot$ $L_{BOL} < 10^{48}$ ergs/s
- $M_{BH} \approx 10^9\ M_\odot$ even beyond space density drop at $z \approx 3$



(DR3 Qcat: Schneider et al. 2005)

(MV + 2008, MV+ in prep)

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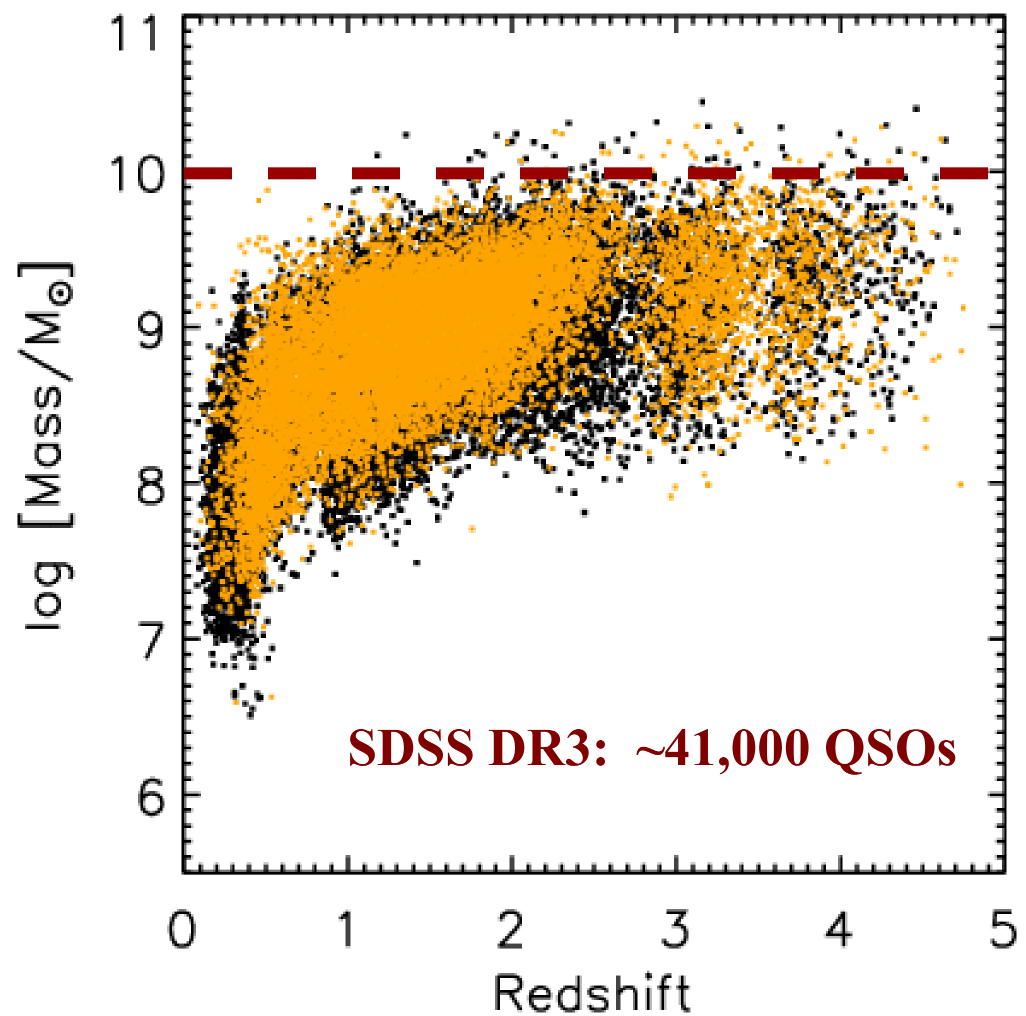

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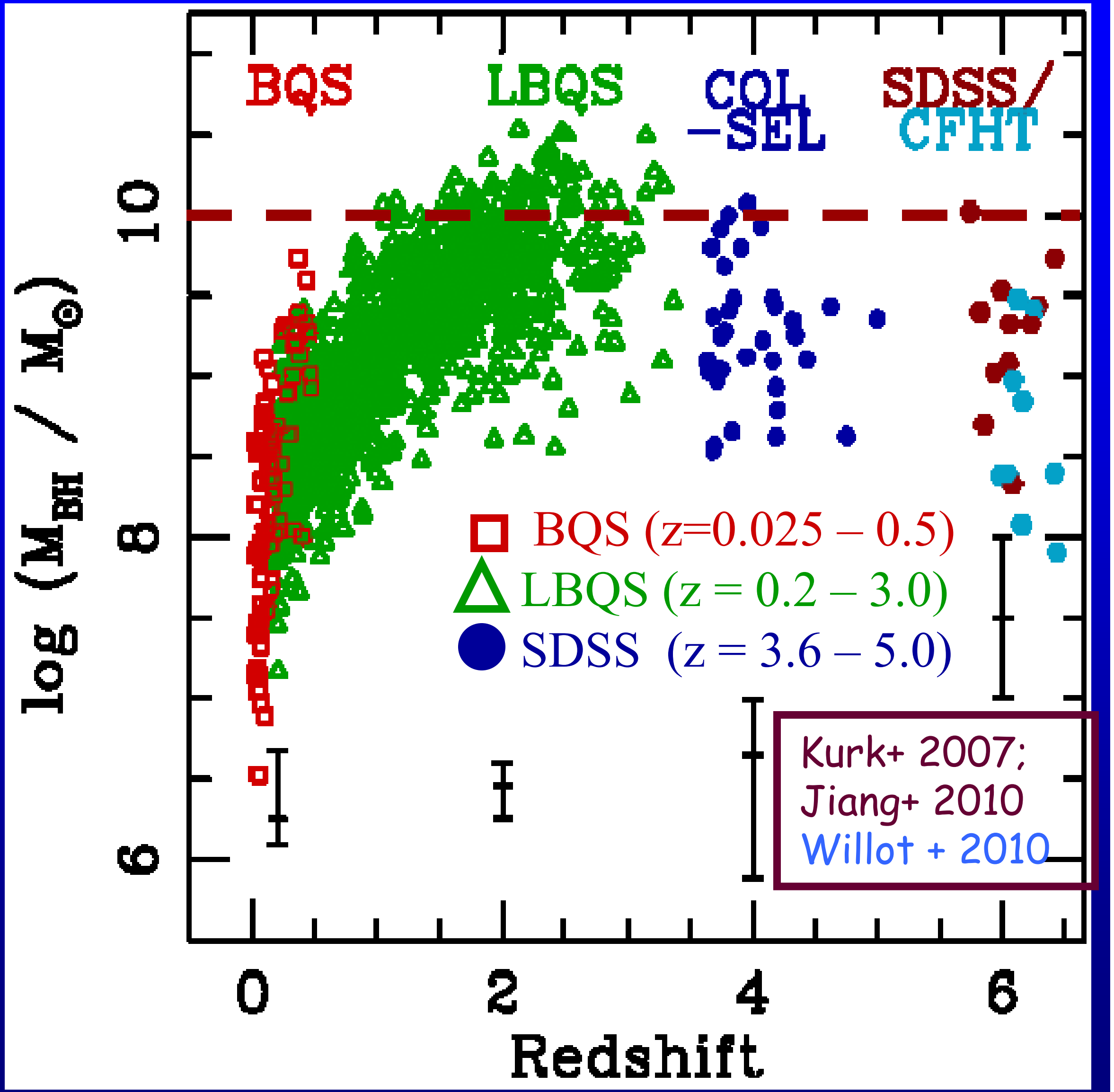
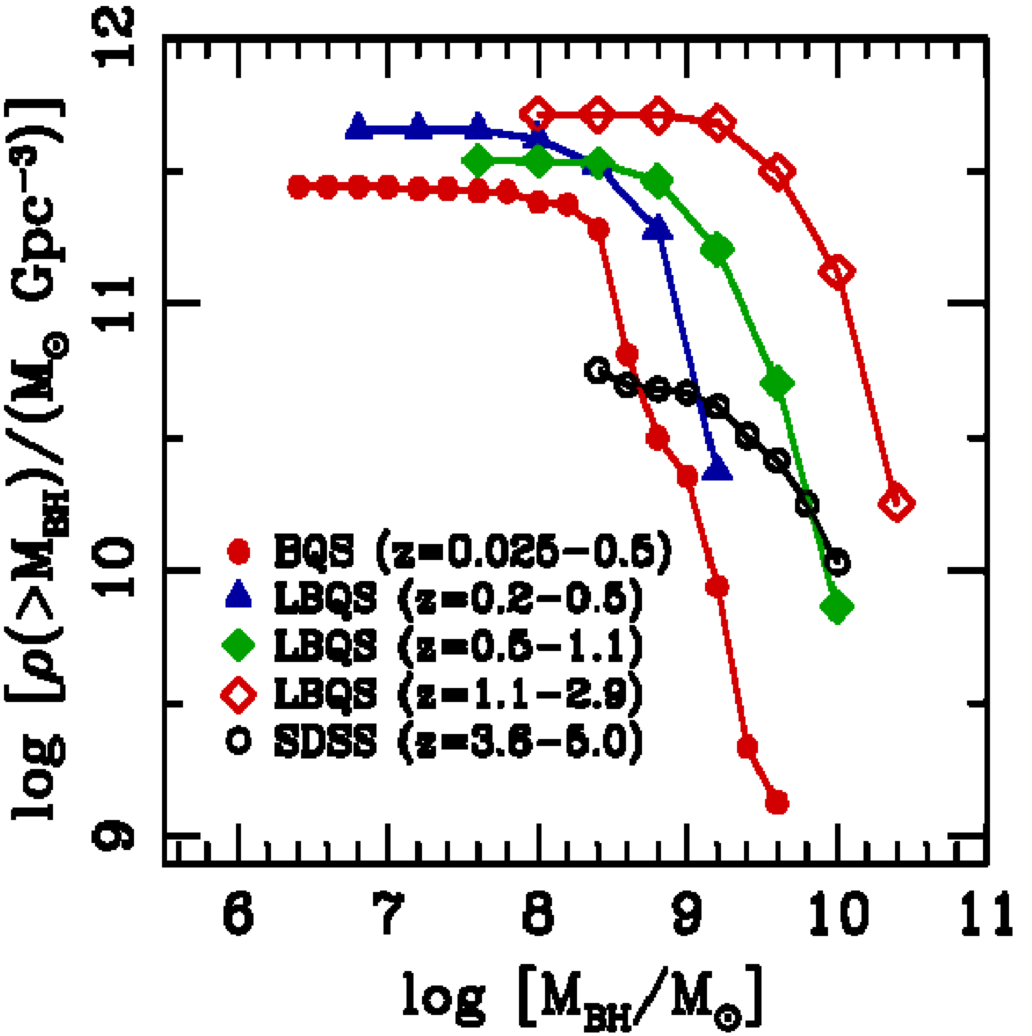
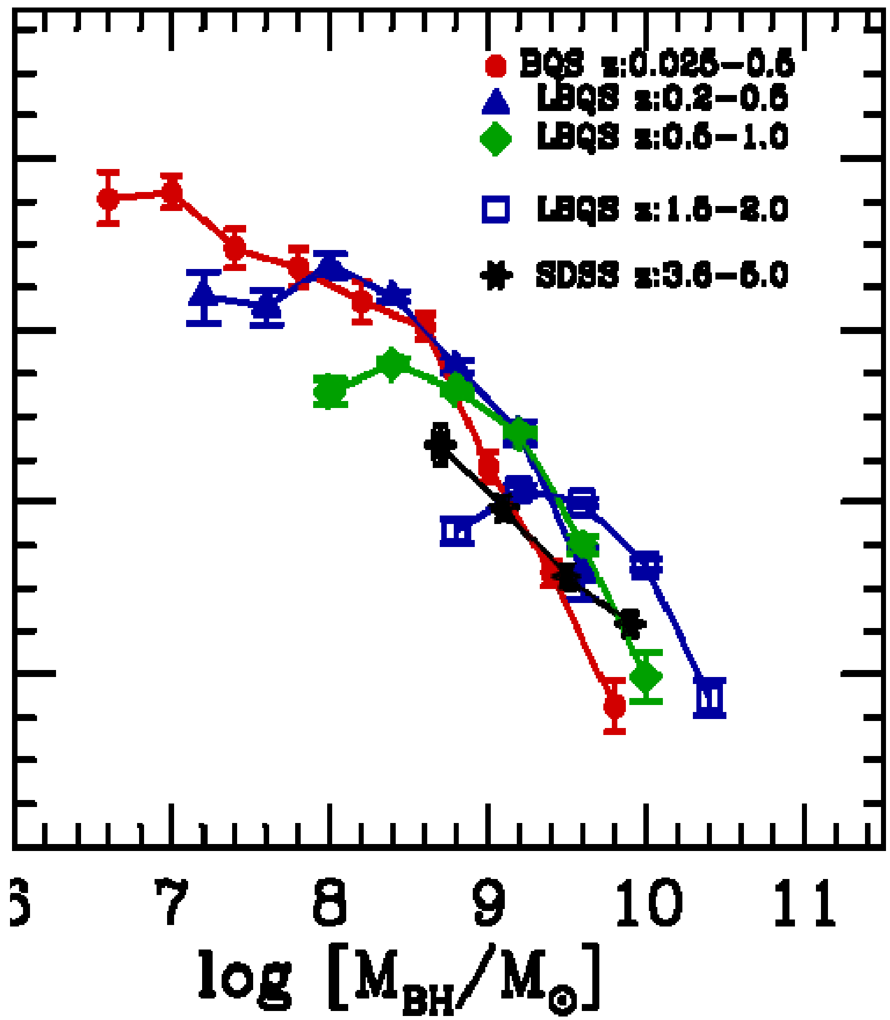


(H_0=70 km/s/Mpc; Ω_Λ = 0.7)

(Vestergaard & Osmer 2009)

Mass Functions of Active Supermassive Black Holes





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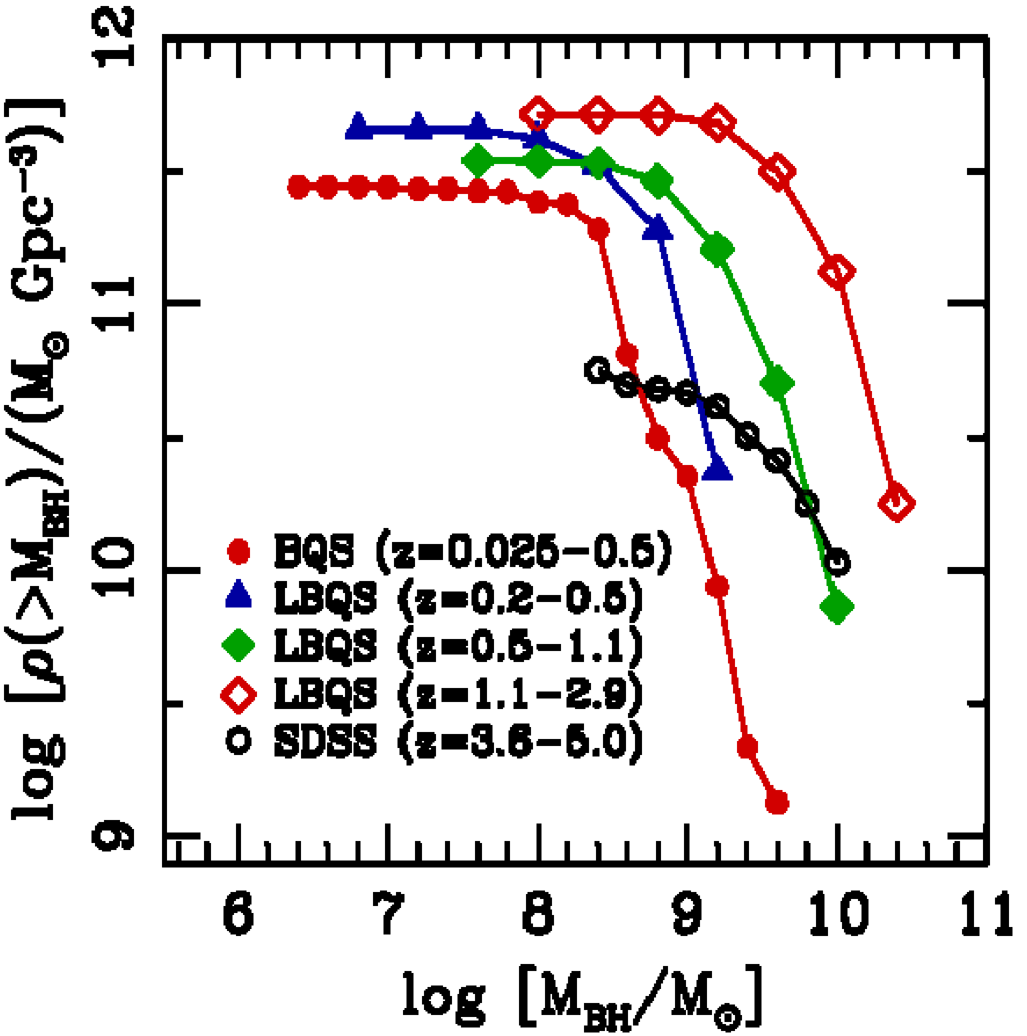

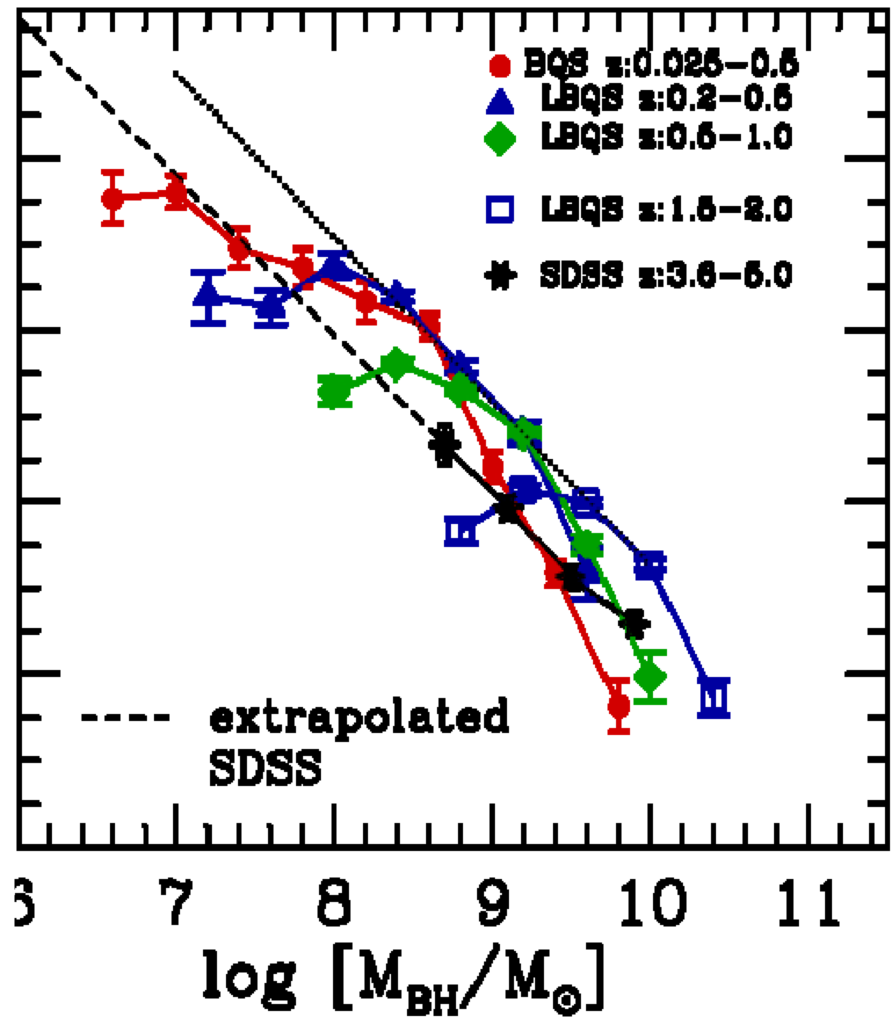

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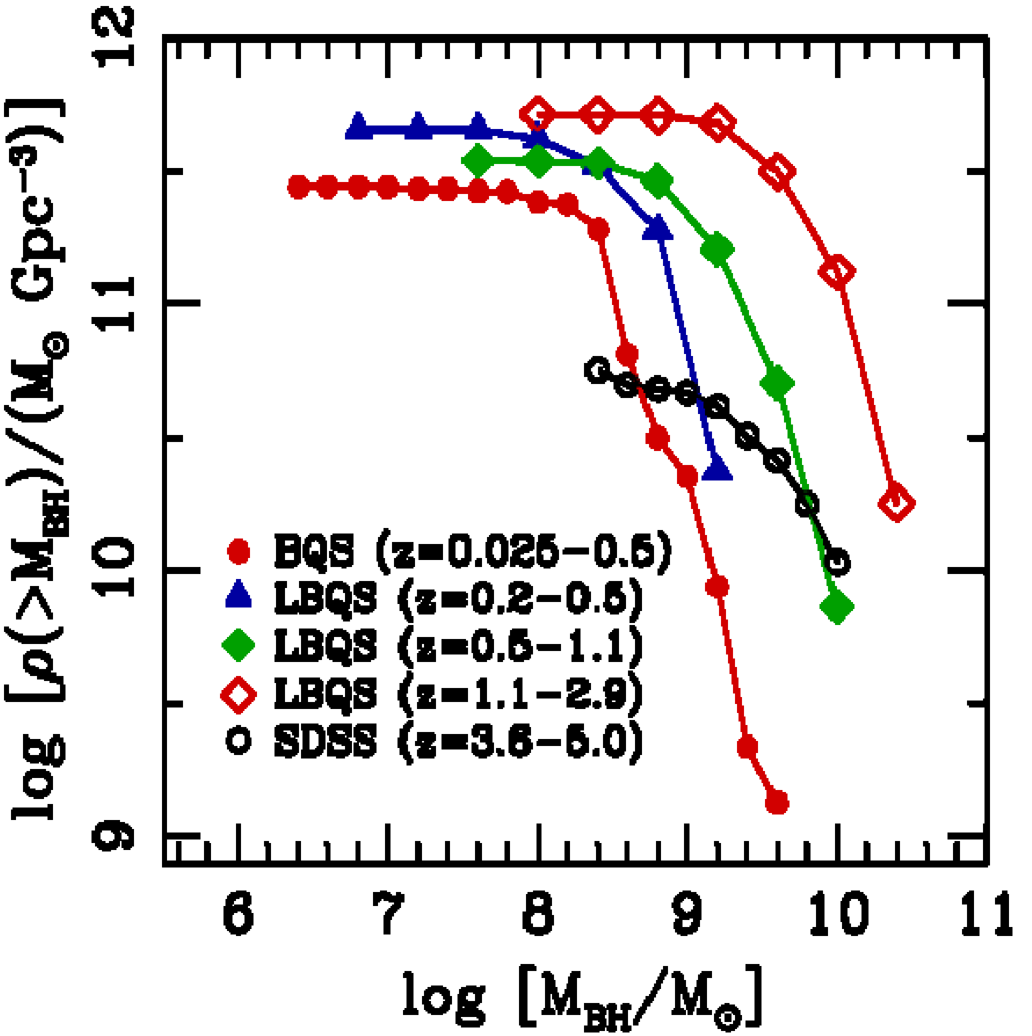

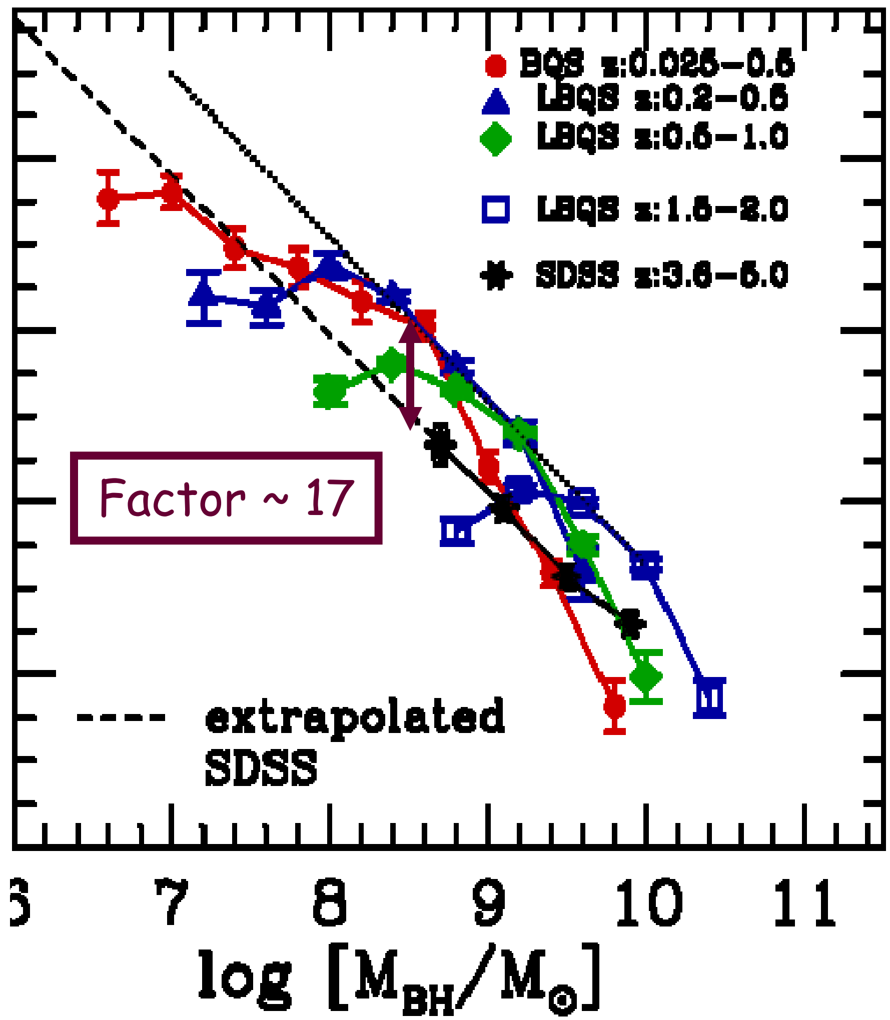

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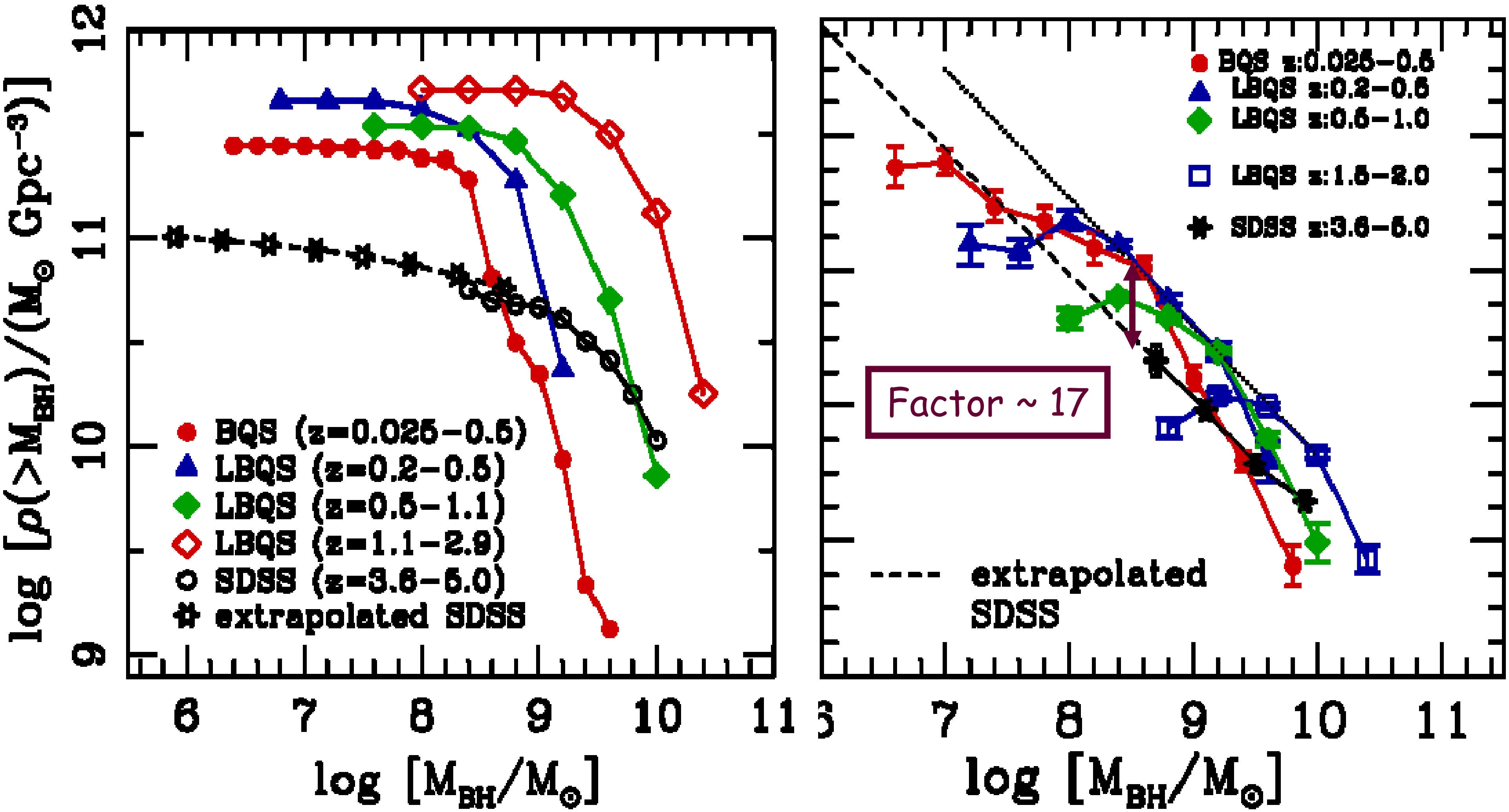

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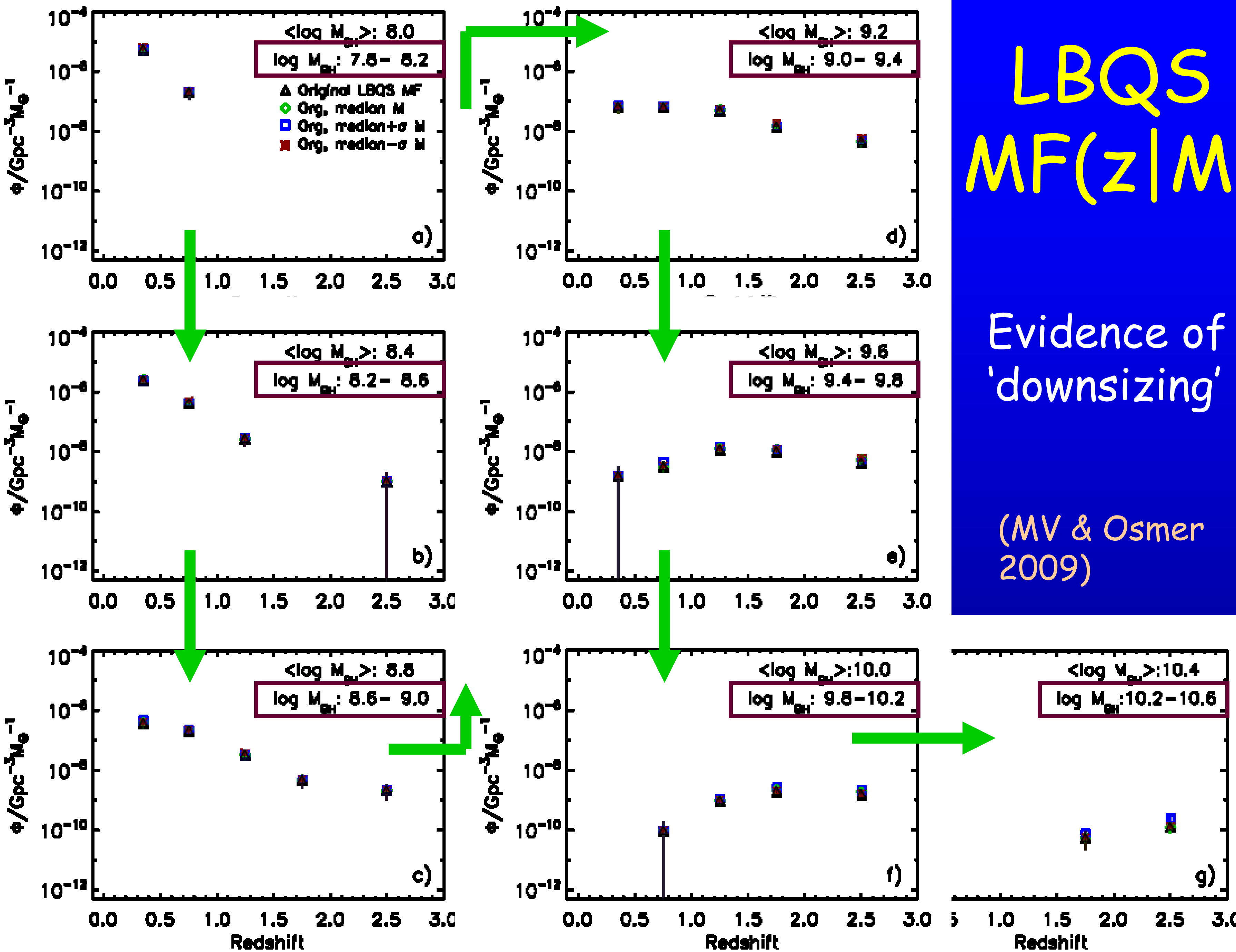
LBQS MF(z|M)



Evidence of 'downsizing'

(MV & Osmer 2009)

Main Points to Take Away

- Reliable masses of active black holes can be obtained; uncertainties similar to quiescent black holes (~0.3dex)
- Single-epoch mass estimates: accurate to within a factor of 3.5 – 4
- Distant quasar black holes are massive: $10^9 - 10^{10}\ M_{\odot}$ and build up quickly after birth of universe.
- Demographics:
  - BHs at z~4 are much rarer
  - we see strong build-up of massive active black holes at redshifts 4 to 2.
  - Evidence of Cosmic Downsizing in black hole growth