
Modeling the QSO luminosity and spatial clustering at low redshifts

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**Modeling the quasi-stellar object luminosity and spatial clustering at low redshifts:
F.Marulli, D.Crociani, M.Volonteri, E.Branchini and L.Moscardini (accepted by MNRAS)**

Contents

- **Aim of this work**

- Compare the predictions of standard theoretical models to the most recent observational data at low redshifts ($z < 2$)

- **Observational data**

- $M_{\text{bh}}-\sigma$ and $M_{\text{bh}}-M_{\text{halo}}$ relations
- Luminosity function (LF)
- Clustering

- **Theoretical models**

- Semi-analytic methods
- Standard assumption: QSO emission triggered by galaxy mergers

Observational data 1

■ $M_{\text{bh}} - \sigma$ relation

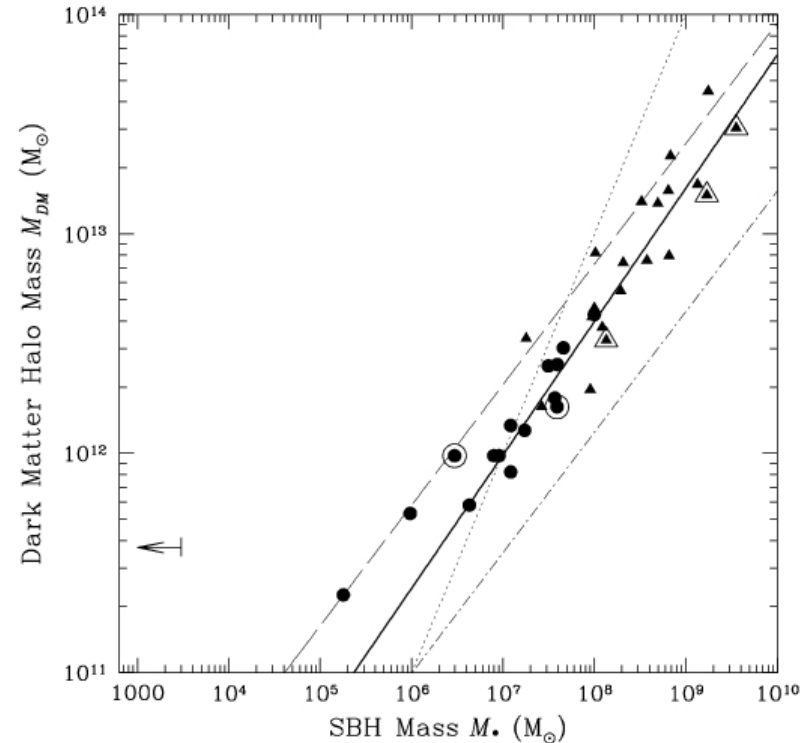
- Ferrarese&Merritt 2000
- Tremaine et al. 2002
- Ferrarese&Ford 2004

$$\frac{M_{\bullet}}{10^8 M_{\odot}} = (1.66 \pm 0.24) \left(\frac{\sigma}{200 \text{Km} \cdot \text{s}^{-1}} \right)^{4.86 \pm 0.43}$$

■ $M_{\text{bh}} - M_{\text{halo}}$ relation

- Ferrarese 2002
- Ferrarese&Ford 2004

$$\frac{M_{\bullet}}{10^8 M_{\odot}} \approx 0.1 \left(\frac{M_{\text{DM}}}{10^{12} M_{\odot}} \right)^{1.65}$$



→ **Fundamental link between the assembly of BHs and the evolution of cosmic structures**

Observational data 2

■ Luminosity function

□ Optical data

- Richards et al. 2005/2006: SDSS QSO Survey
- Croom et al. 2004: 2dF-6dF QSO Survey
- Grazian et al. 2000: ROSAT All-Sky Survey

□ Hard-X data

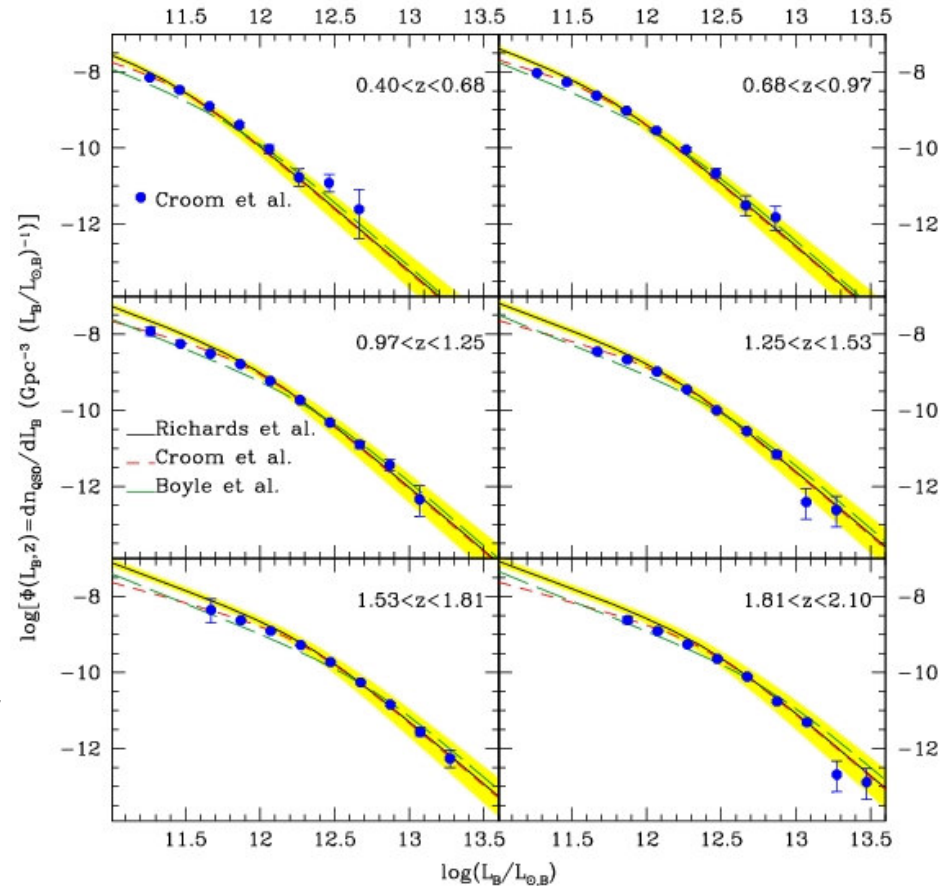
- Shinozaki et al. 2006: HEAO-1 All-Sky Catalog
- La Franca et al. 2005
- Ueda et al. 2002

□ Soft-X data

- Hasinger et al. 2005: Chandra, XMM-Newton Survey
- Miyaji et al. 2001: ROSAT

□ Mid-Infrared data

- Matute et al. 2006



Observational data 3

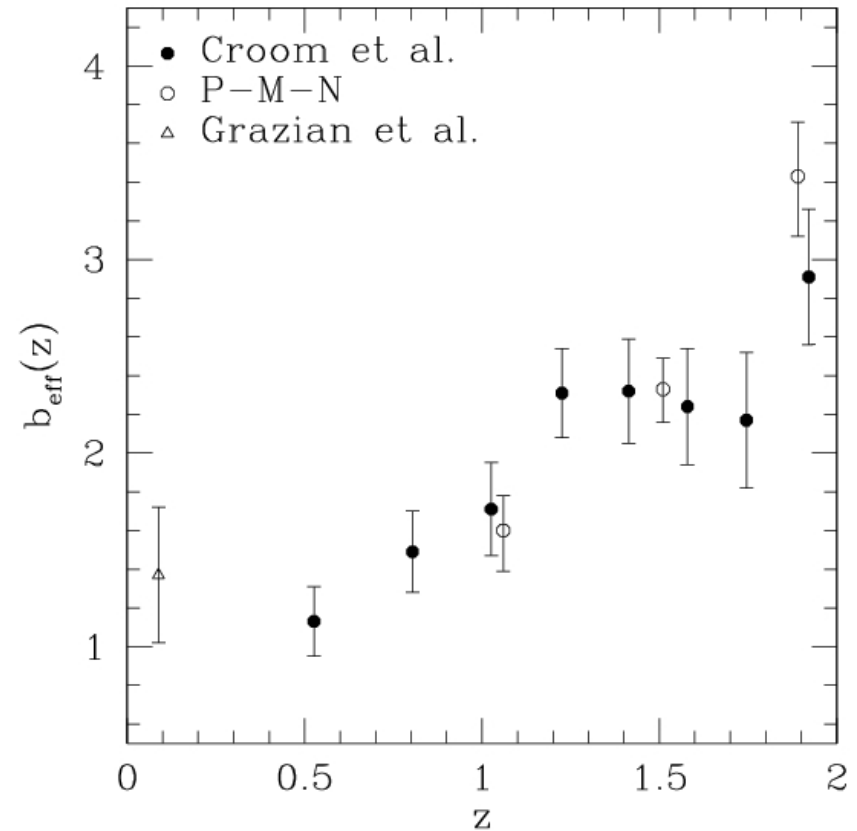
- **Bias function**

- **Optical data**

- Grazian et al. 2004
- Croom et al. 2004
- Porciani-Magliocchetti-Norberg 2004

$$\delta P_{12} = n^2 \delta V_1 \delta V_2 [1 + \xi_{12}]$$

$$b_{QSO}^2 = \frac{\xi_{QSO}}{\xi_m}$$



Semi-analytic model: VHM

Method

■ Assumptions

- Hierarchical structure formation: EPS model (Monte Carlo procedure)
- QSO phenomenon is triggered by halo-halo major mergers
- BHs seeds: $M=150 M_{\text{sun}}$, $z=20$, $M_{\text{halo}}=1.6e7 M_{\text{sun}}$ (3.5σ)

■ Kind of accretion

- Coalescence of BH binary (neglected)
- Gas accretion
 - E1: $\Delta M_{\text{accr}} = \alpha M_{\text{halo}} \quad \alpha = 7 \cdot 10^{-6}$
 - E2: $\Delta M_{\text{accr}} \propto k \cdot v_c^5 \quad k = k(z) = 0.15(1+z) + 0.05$
 - B: early stage of super critical accretion (Bondi-Hoyle; $z > 12$)

Semi-analytic model: VHM

Method

- **Data and equations**

- 220 binary merger trees of parent halos with masses in the range (1.43e11, 1e15 Msun)

$$M_{BH}(t + \delta t) = M_{BH}(t) \exp\left(\int_{t_{Edd}}^{\delta t} f_{Edd}(t) \frac{1 - \varepsilon}{\varepsilon} dt\right)$$

$$\varepsilon = \frac{L}{f_{Edd}(t) \dot{M}_{Edd} c^2}$$

$$\log(L / L(2 - 10 \text{keV})) = 1.54 + 0.24\Lambda + 0.012\Lambda^2 - 0.0015\Lambda^3$$

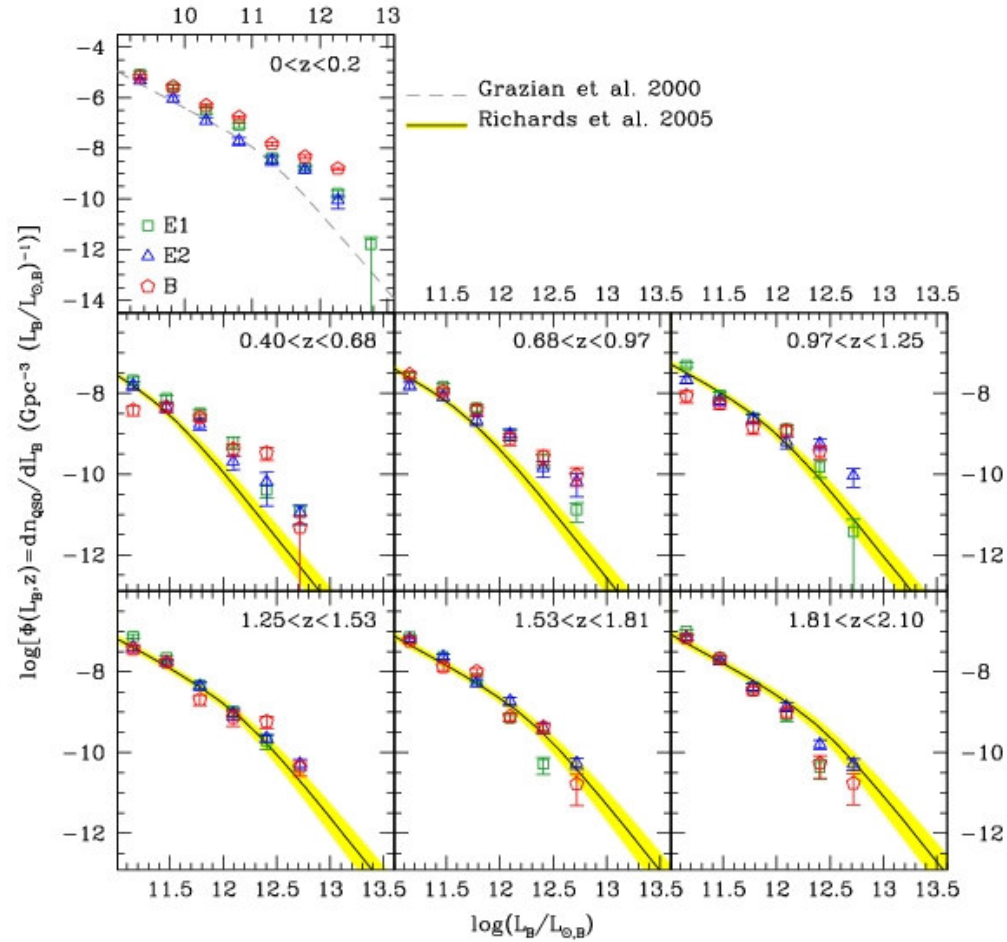
$$\log(L / \nu_B L_{\nu B}) = 0.8 - 0.67\Lambda + 0.017\Lambda^2 - 0.0023\Lambda^3$$

$$(\Lambda = \log(L - 12))$$

$$b_{eff}(z) = \frac{\int_0^\infty b(M_{halo}, z) \Psi(M_{halo}(L_B > L_{min,B}), z) dM_{halo}}{\int_0^\infty \Psi(M_{halo}(L_B > L_{min,B}), z) dM_{halo}}$$

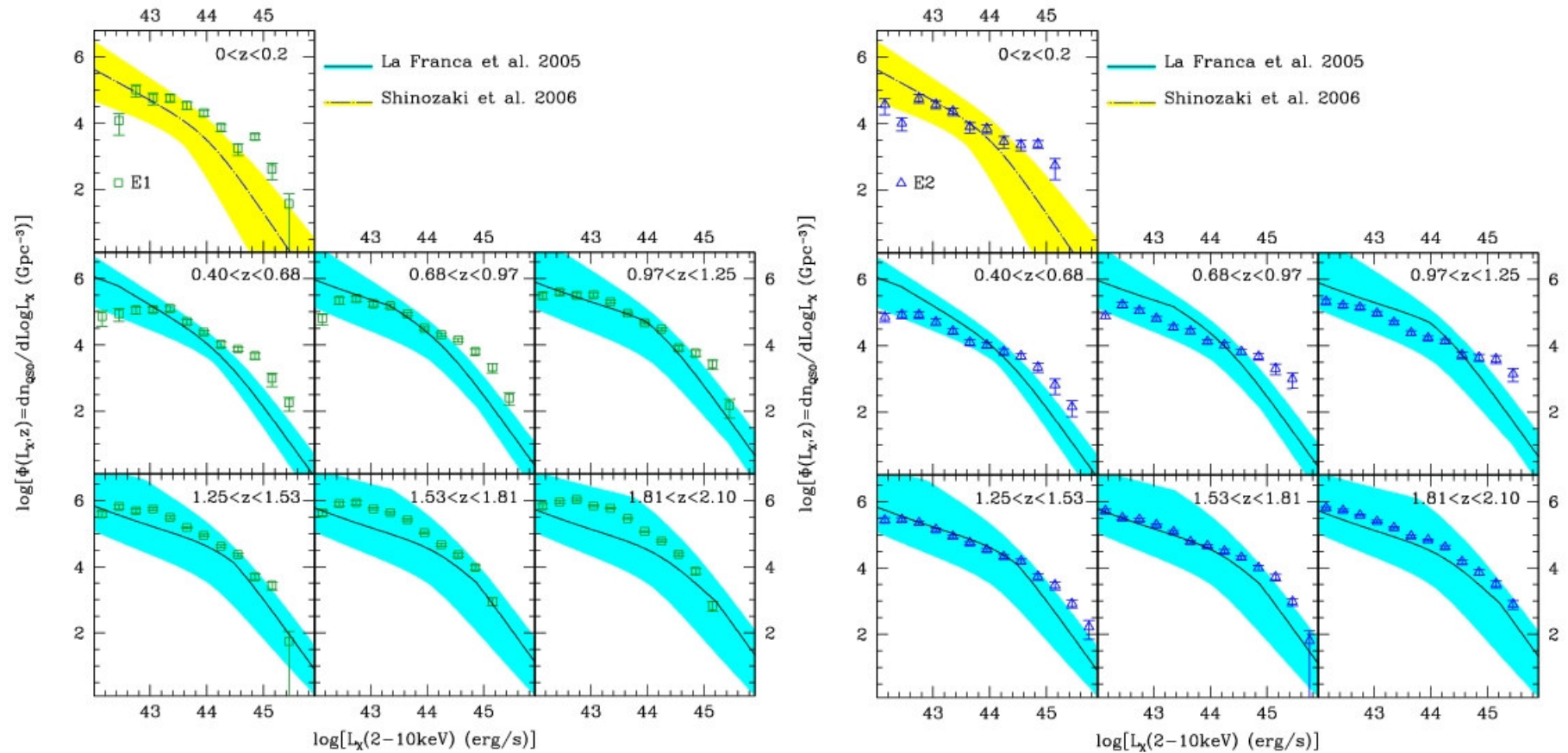
Semi-analytic model: VHM

Results



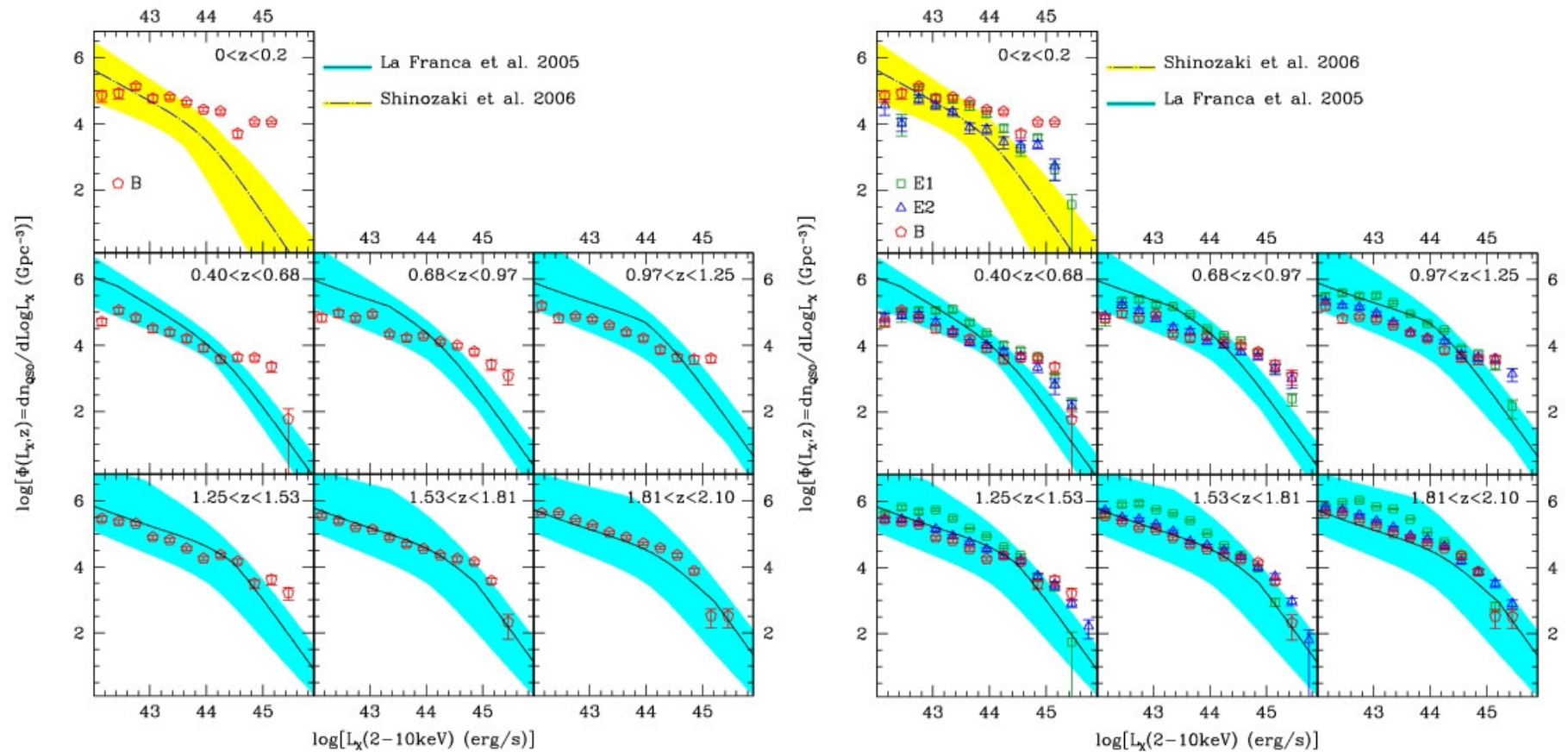
Semi-analytic model: VHM

Results



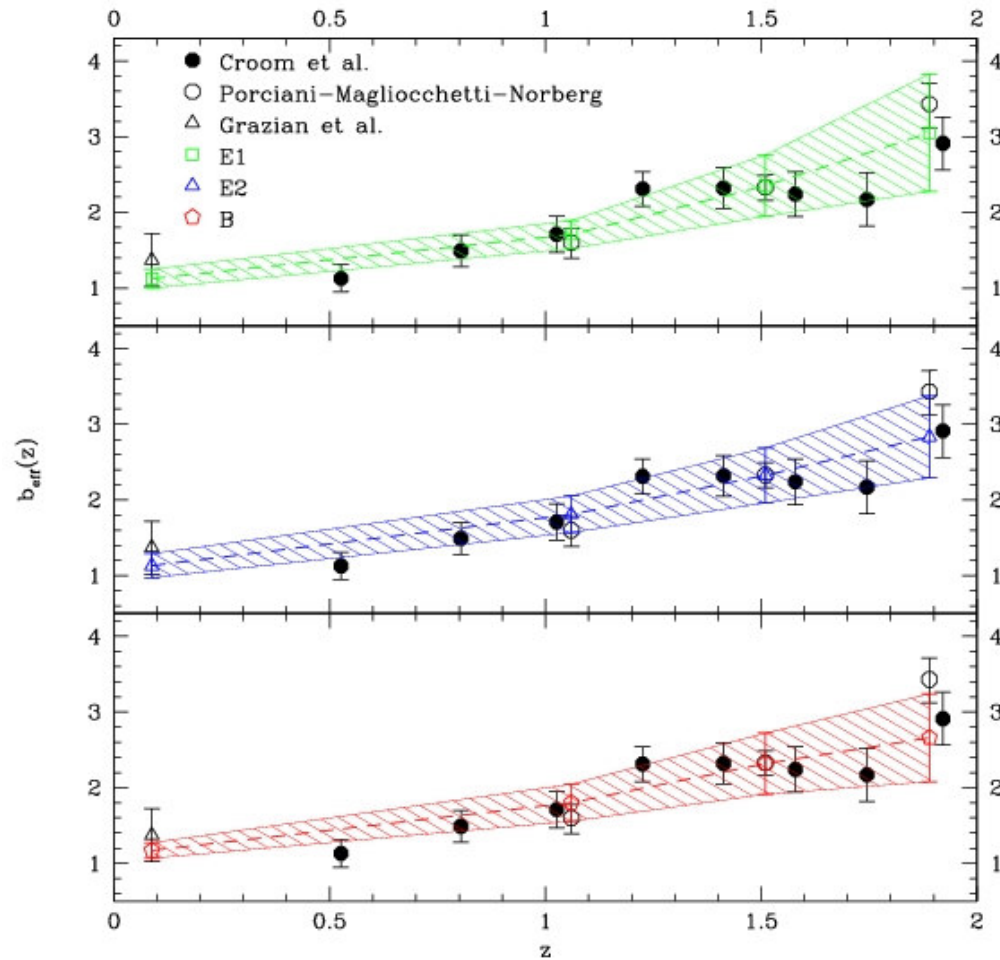
Semi-analytic model: VHM

Results



Semi-analytic model: VHM

Results



Conclusions

- **Results**

- LF and bias can be reproduced at the same time

- **Future works**

- Use the output of N-body simulations to construct binary merger trees of dark matter halos
- Calculate the luminosity dependence of QSO clustering
- Include more Physics in the model