Unraveling the properties of active galaxies in hierarchical cosmologies

Outline

- **Gal**axy **form**ation (**GalForm**): the semi-analytic approach
- Galaxy evolution and black hole growth
- Modelling active nuclei
- Predictions-results

Galaxy Formation, July 21

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Galaxy **form**ation (**GalForm**): the semi-analytic approach

- Dark matter with gas simulations:
  - High resolution is important
  - Need for correct subgrid physics
  - Usually limited dynamical range

  Talks from Schaye, Mayer, McCarthy
- Semi-analytical approach:
  - Fast and flexible
  - Ideal for studying statistical properties, creating mock catalogues and lightcones

  Talks from White, Lagos, Lacey

GalForm

1. Dark matter haloes

Merger trees from Millennium simulation (Springel et al. 2005)

2. Galaxy formation

Analytical/numerical models for:

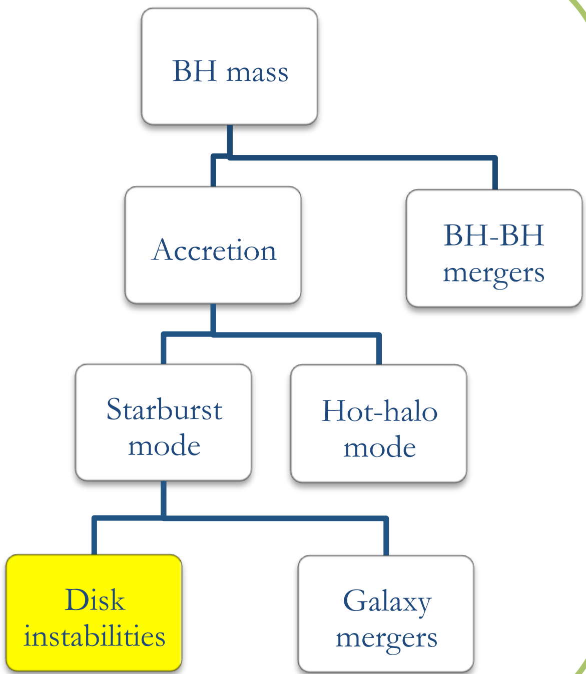
✓ Gas cooling
✓ Star formation (Lagos et al. 2011)
✓ SN feedback
✓ Chemical evolution
✓ Galaxy mergers
✓ Galaxy sizes
✓ SMBHs, AGN feedback

Bower et al. (2006)

Cole et al. 2000; see also Baugh et al. (2005)

The growth of BHs in GALFORM

Bower et al. (2006)
Malbon et al (2007)
models

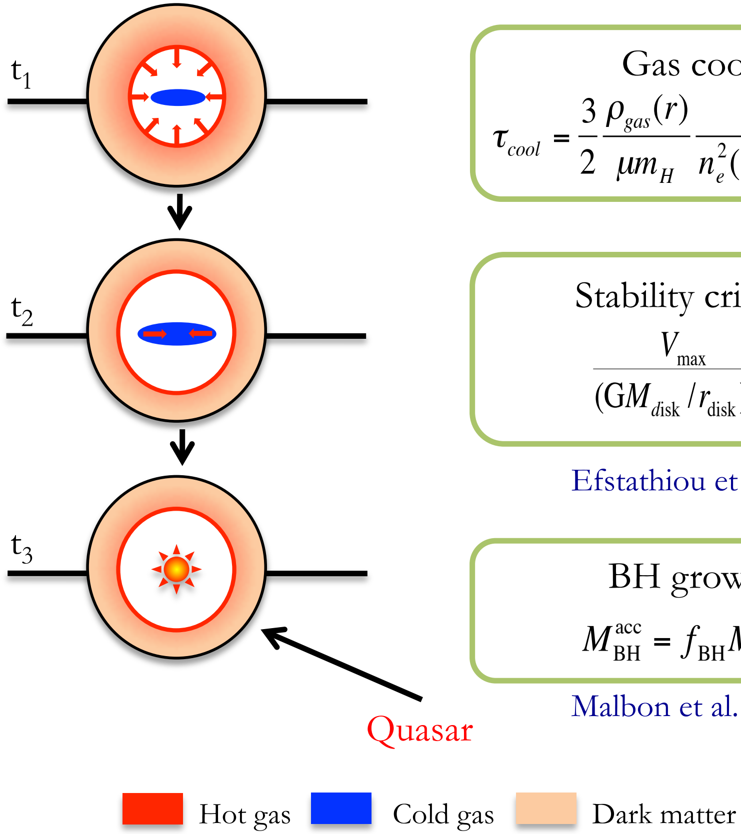


Accretion only during burst star formation (SF)

SF as in Blitz & Rosolowsky (2006) (Lagos et al. 2010)

BH-BH mergers only redistribute the BH mass

Disk instabilities



Gas cooling

$$\tau_{cool} = \frac{3}{2}\frac{\rho_{gas}(r)}{\mu m_H}\frac{k_B T_{gas}}{n_e^2(r)\Lambda(T_{gas},Z_{gas})}$$

Stability criterion

$$\frac{V_{\rm max}}{(GM_{disk}/r_{\rm disk})^{1/2}} < 1$$

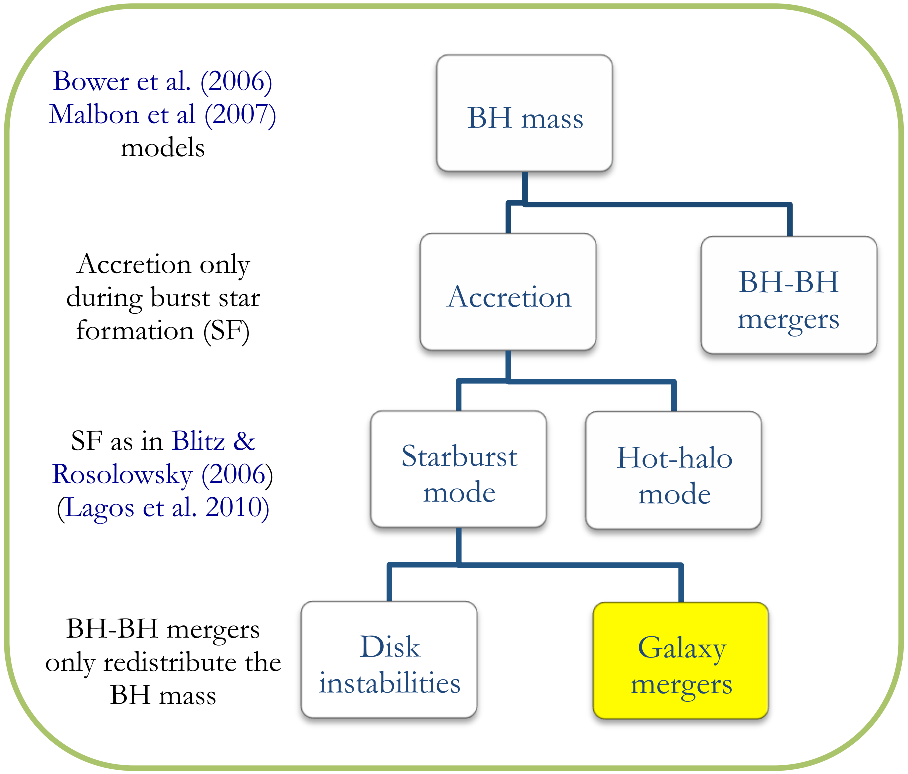
Efstathiou et al. (1982)

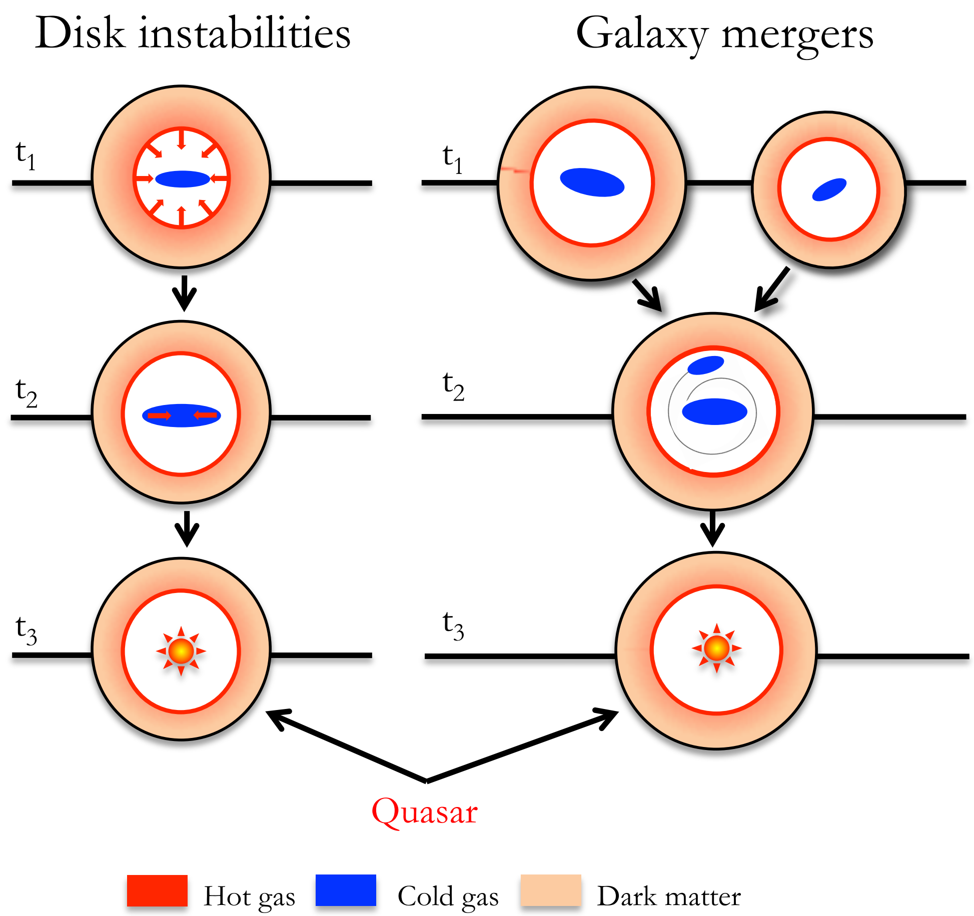
BH growth

$$M_{\rm BH}^{\rm acc} = f_{\rm BH} M_{\rm burst}^{*}$$

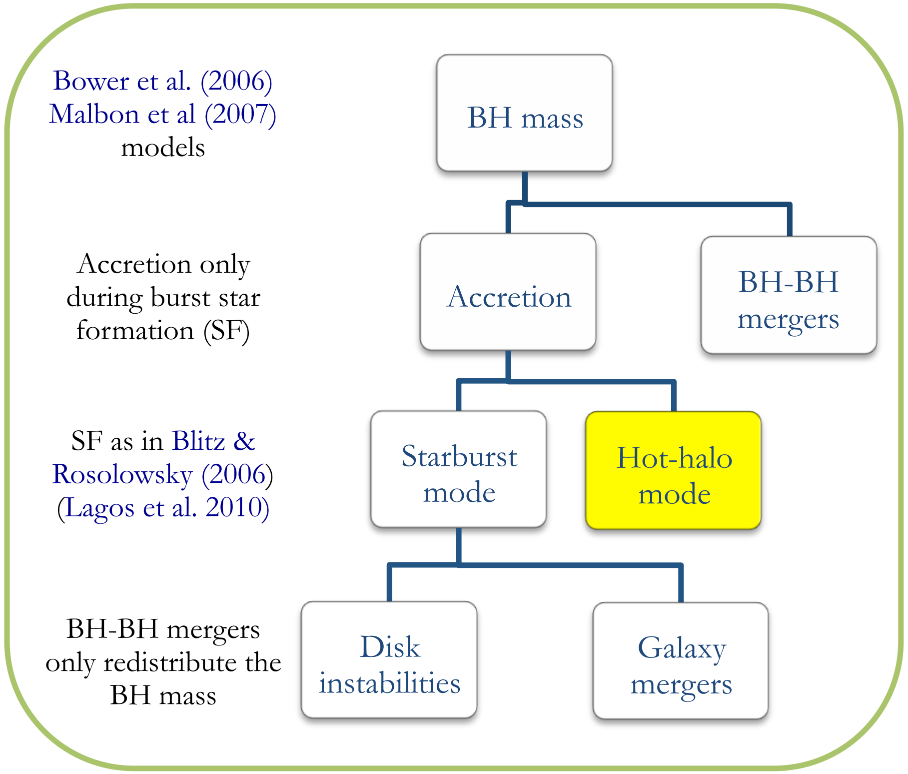
Malbon et al. (2007)

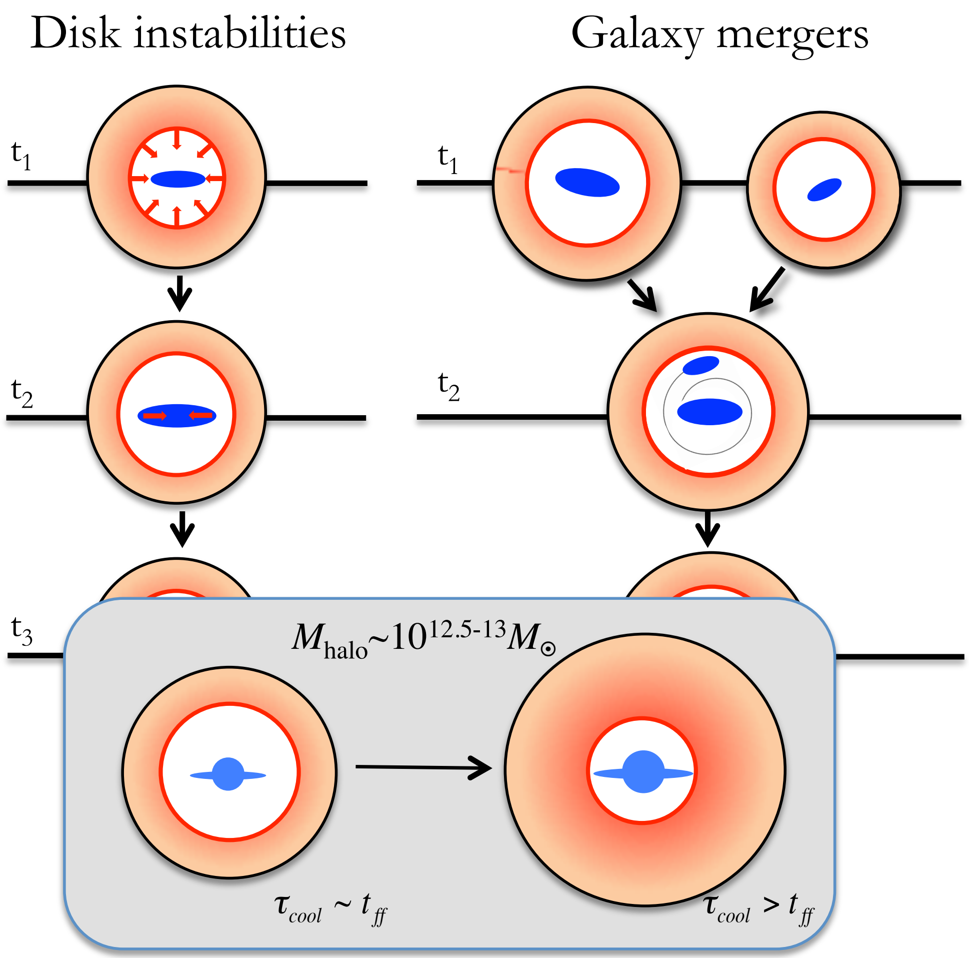
The growth of BHs in GALFORM





The growth of BHs in GALFORM





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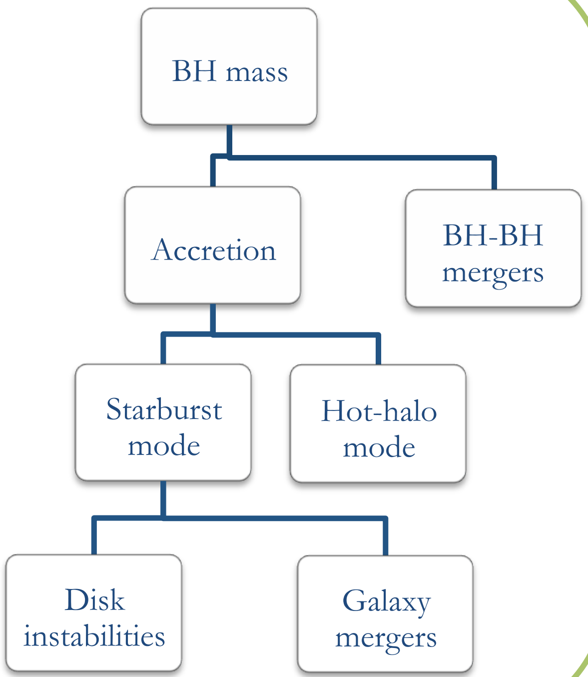
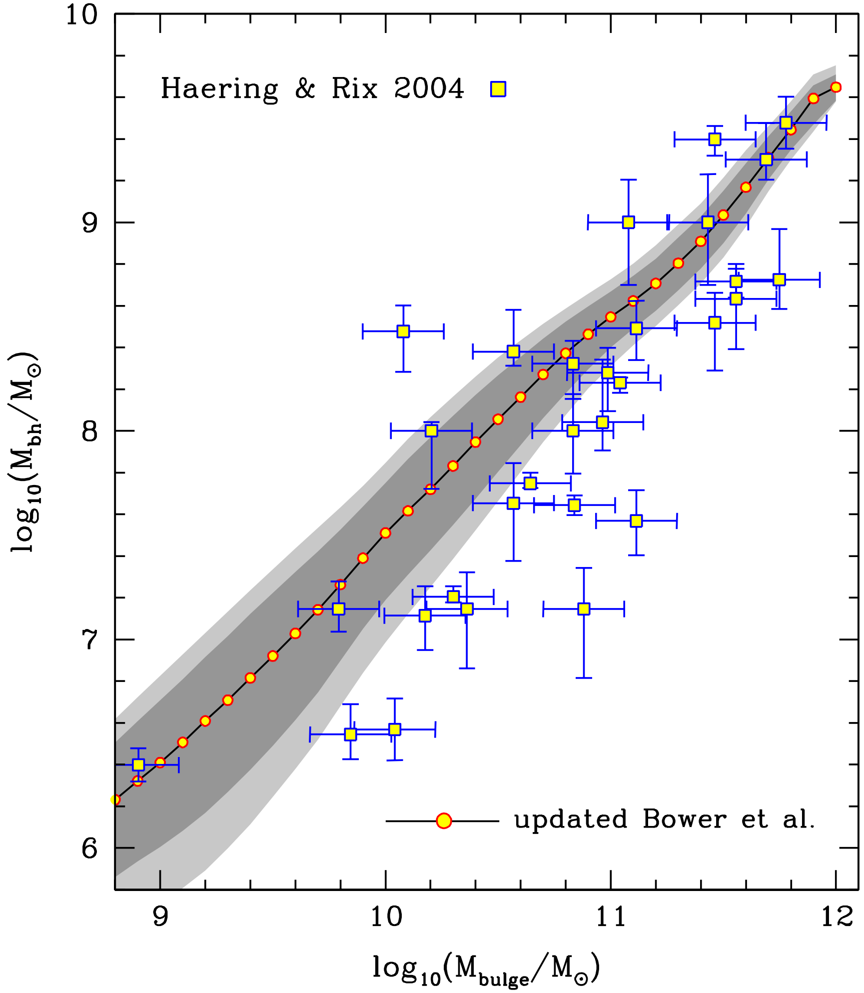


NF et al. 2011, MNRAS 410, 53



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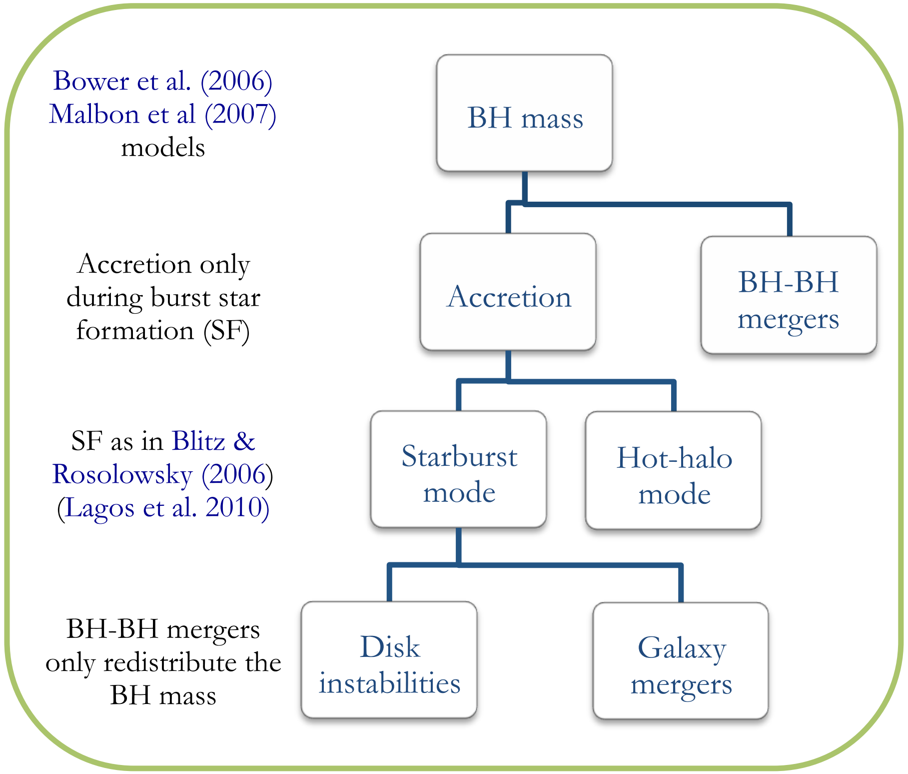
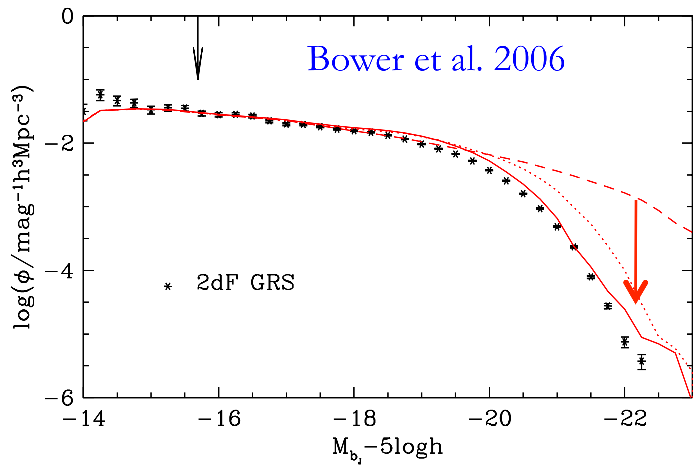
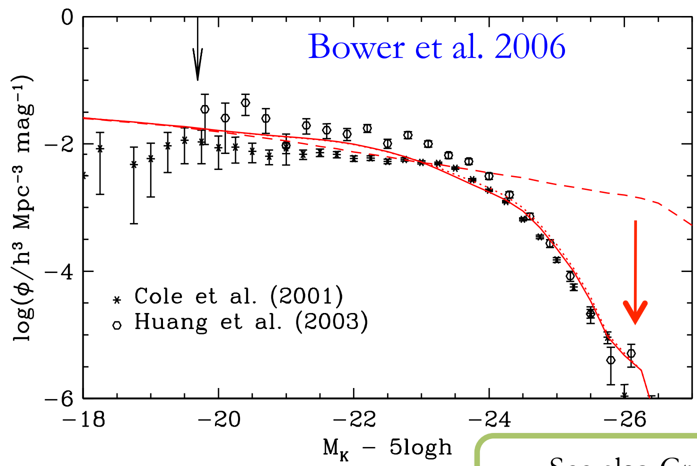
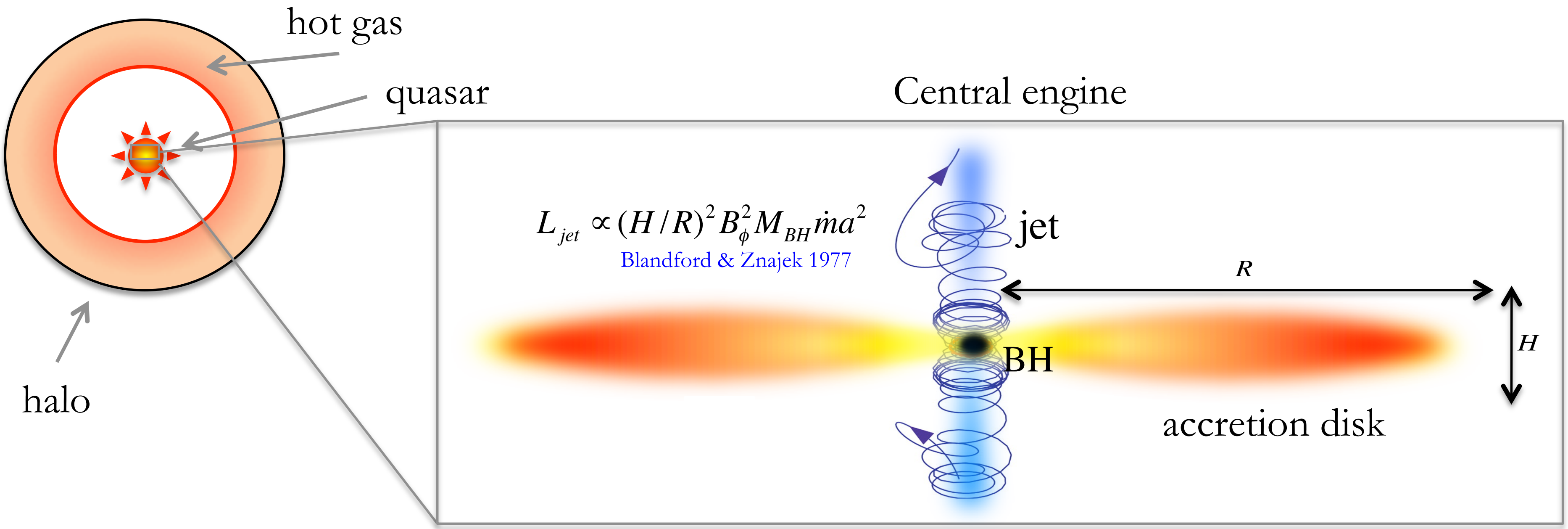






See also Croton et al. (2006); Lagos et al. (2008)

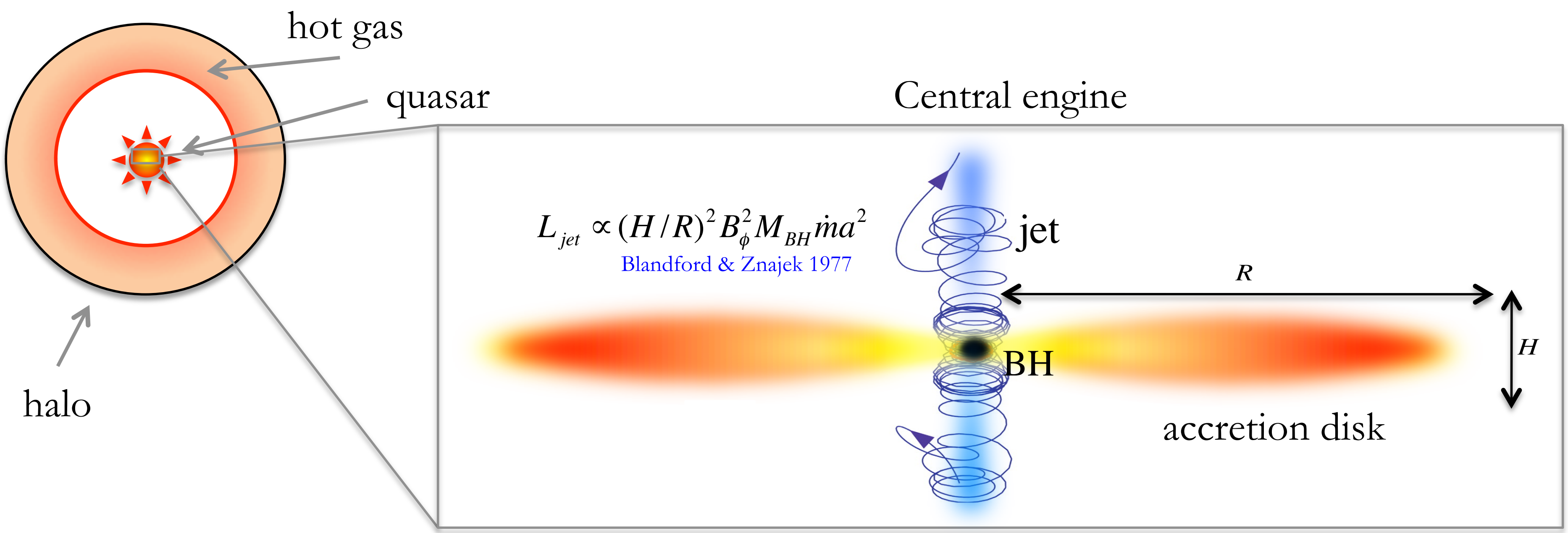
Modelling the active nucleus

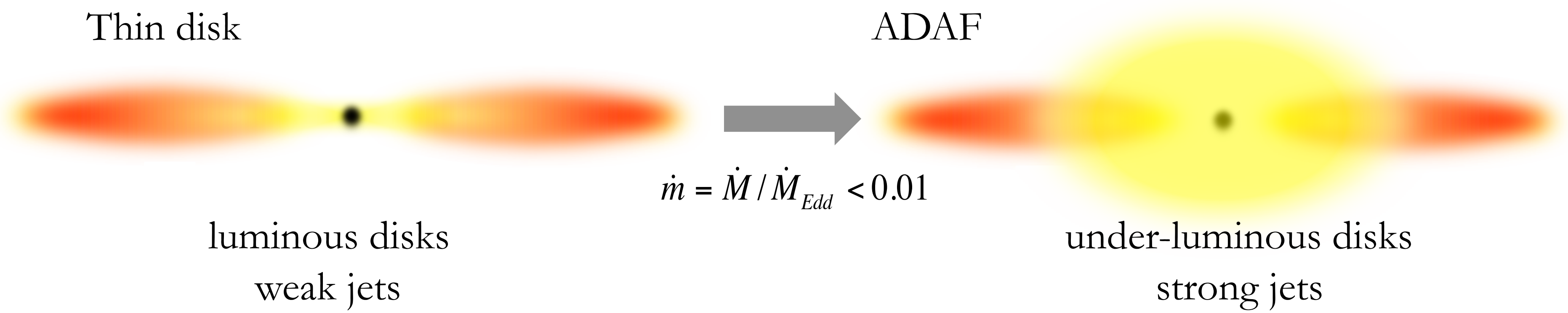


Basic ingredients

1) Accretion rate calculation
2) Disk structure (thin-disk/ADAF) Shakura & Sunyaev (1973); Mahadevan (1997)
3) BH spin evolution (accretion and BH-BH mergers) King et al. (2005)
4) Bolometric corrections for optical, x-ray, UV emission Marconi et al. 2005)
5) Empirical obscuration Hasinger (2008)
6) Jet total and radio luminosity Blandford & Znajek (1977)

Modelling the active nucleus



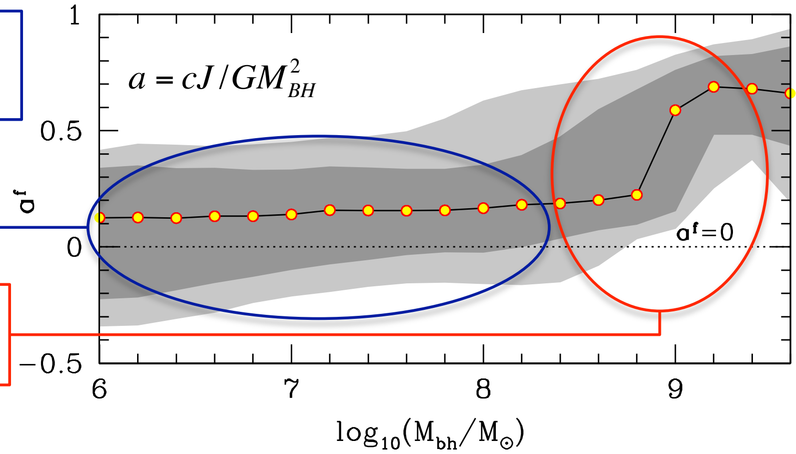


Predictions

episodic and random gas accretion: net spin is kept low!

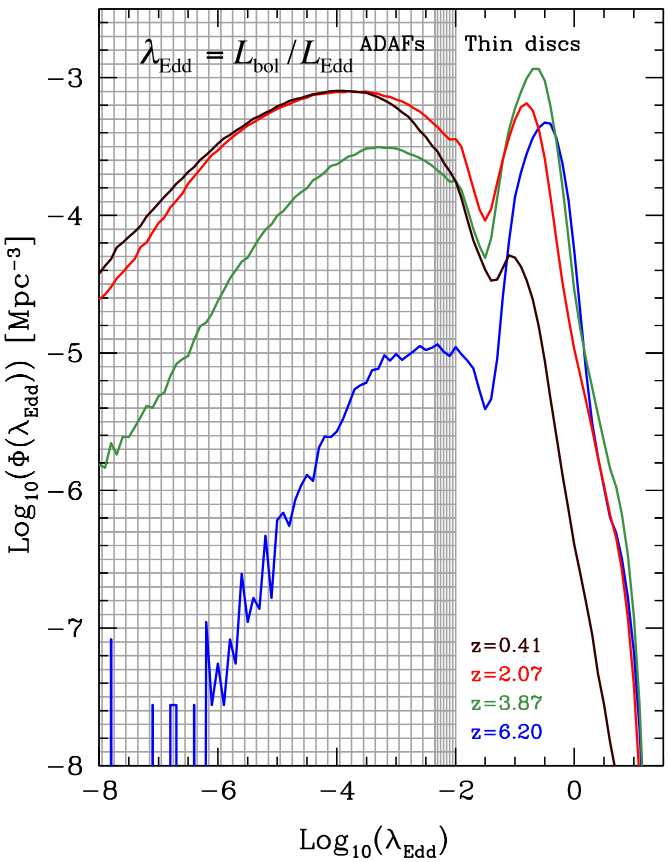
BH-BH mergers have the opposite effect!

1) BH spin

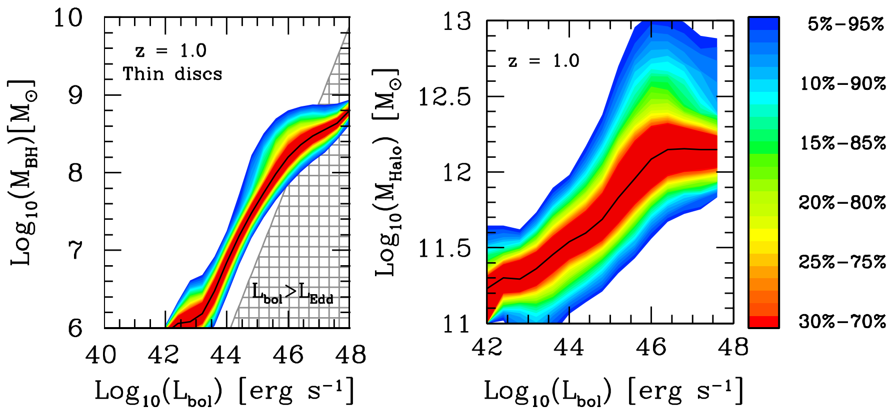


NF et al. 2011, MNRAS 410, 53

2) Disk luminosities



3) Scaling relations



z	$\langle M_{Halo} \rangle$
0.5	$\sim 3\times10^{12}$ $M_\odot$
1	$\sim 1.5\times10^{12}$ $M_\odot$
2	$\sim 1.9\times10^{11}$ $M_\odot$

NF et al. 2011 (arXiv:1011.5222)

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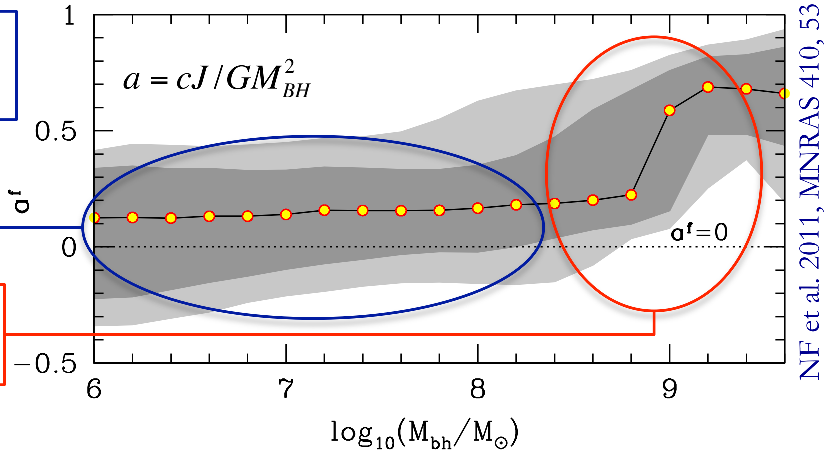

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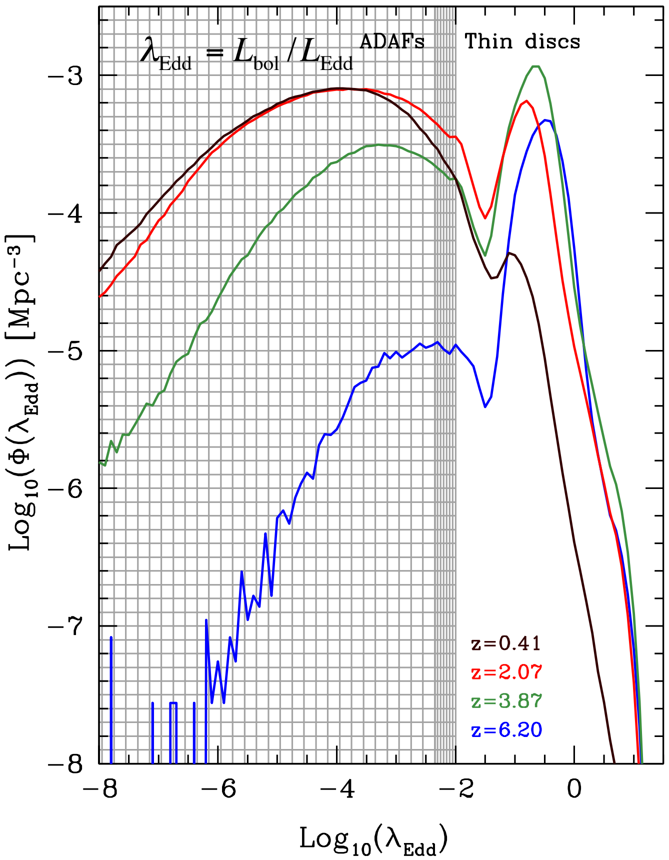
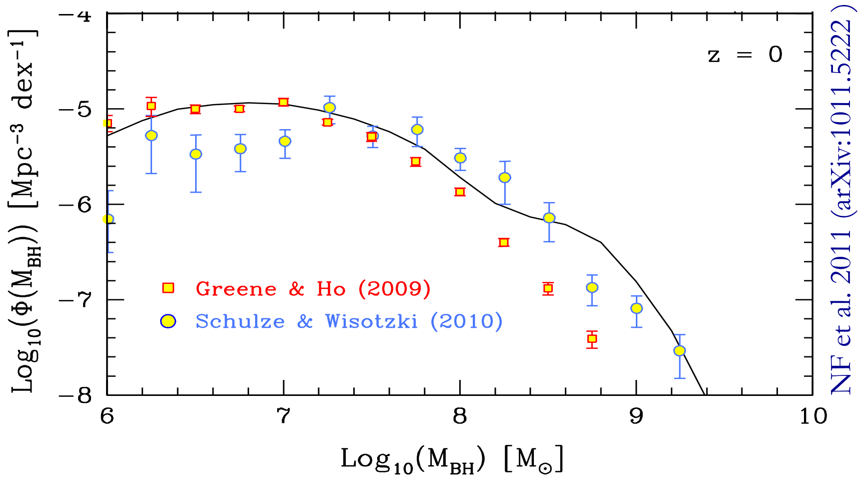
2) Disk luminosities



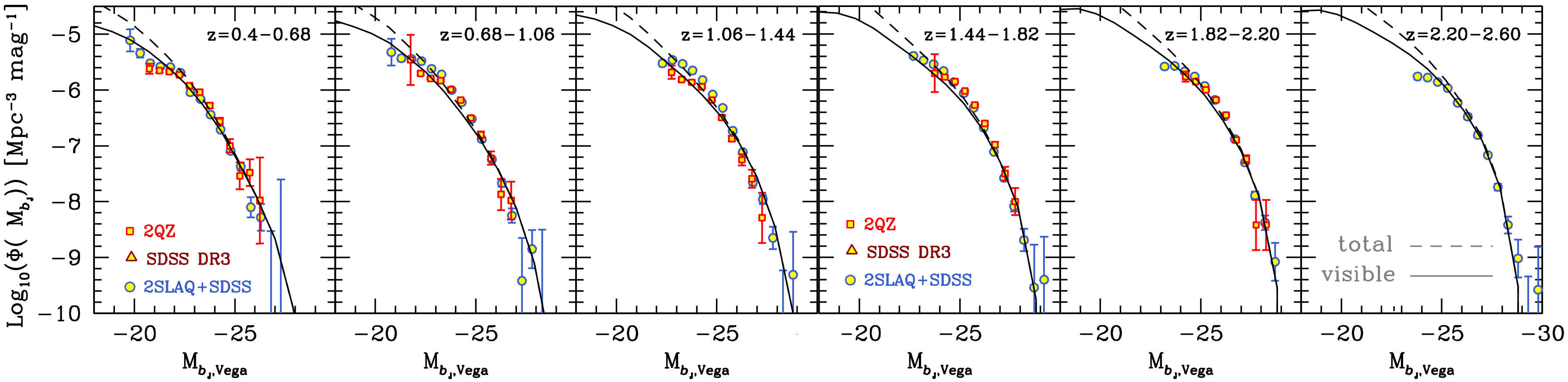
4) Active BH mass function



Quasar luminosity functions

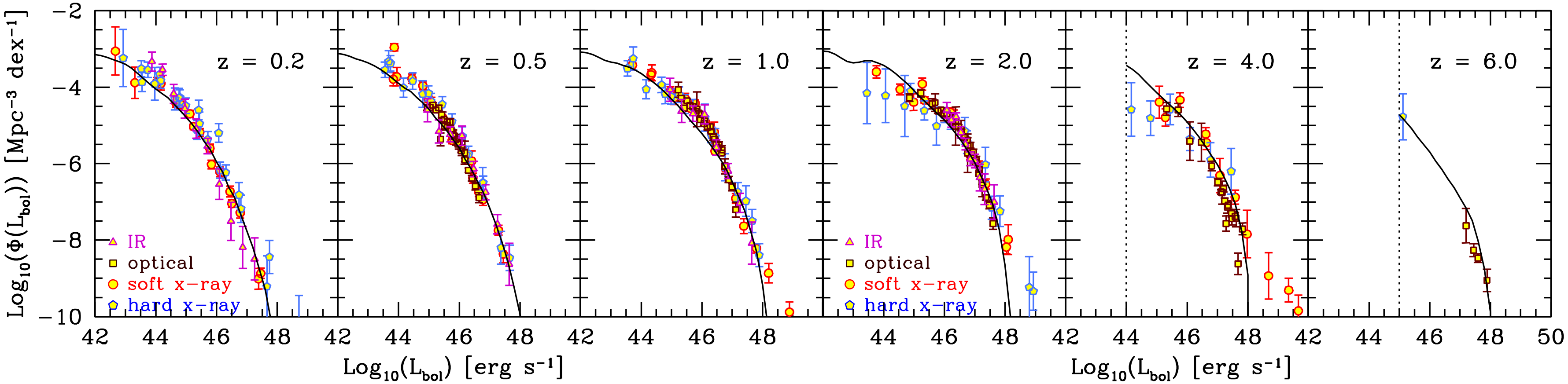
Optical

AGN are strongly obscured in the optical (and soft X-rays): $f_{obsc}=f_{obsc}(z,L)$



Bolometric

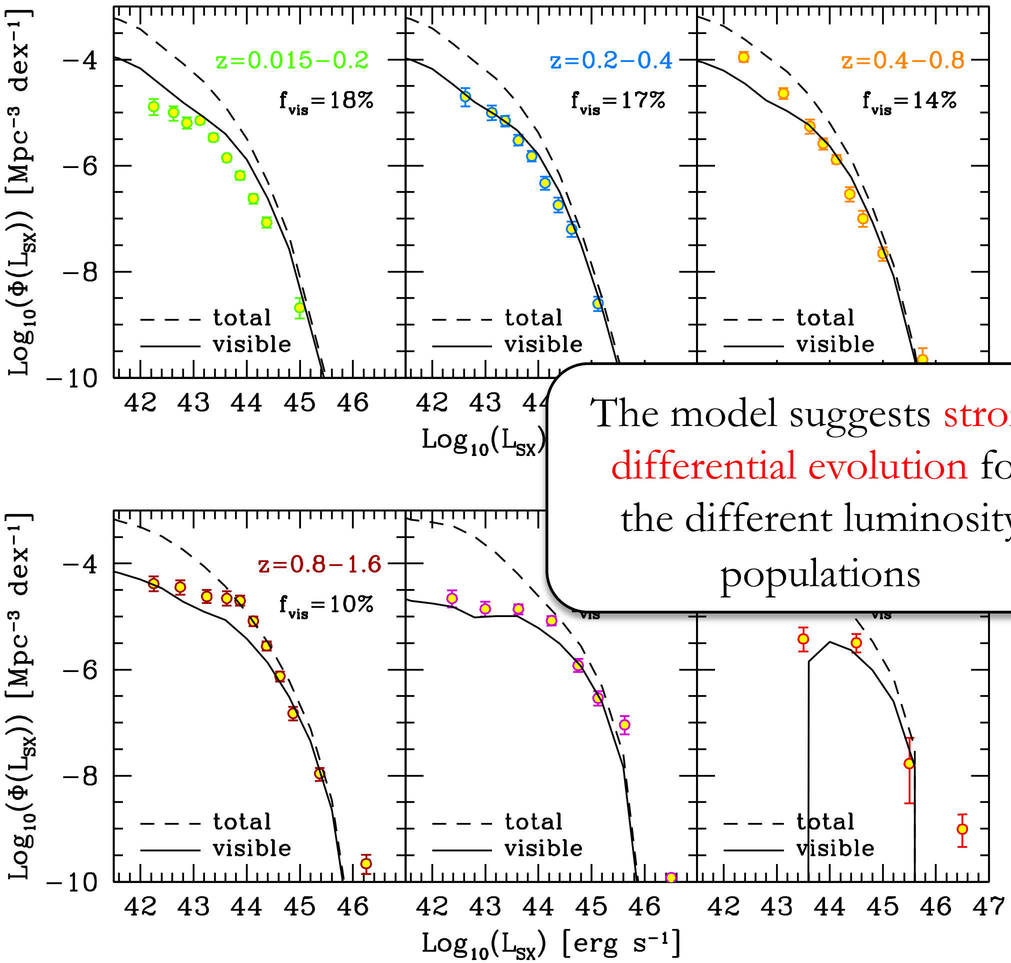
(compilation of LF's from Hopkins et al. 2007)



NF et al. 2011 (arXiv:1011.5222)

Quasar evolution

Soft X-ray luminosity function



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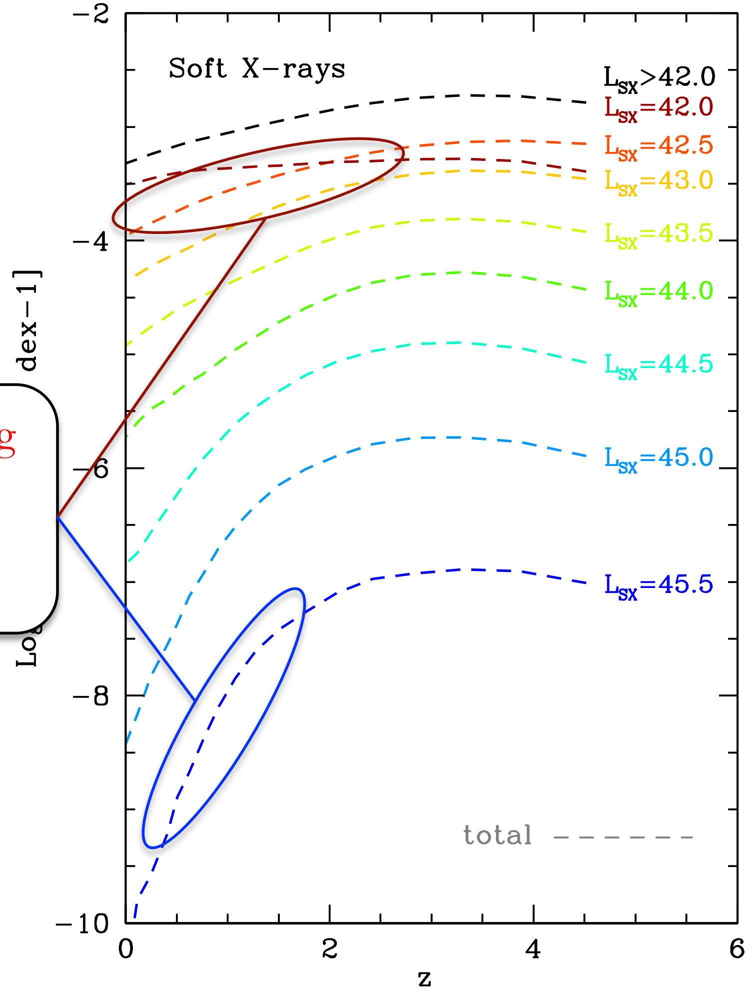
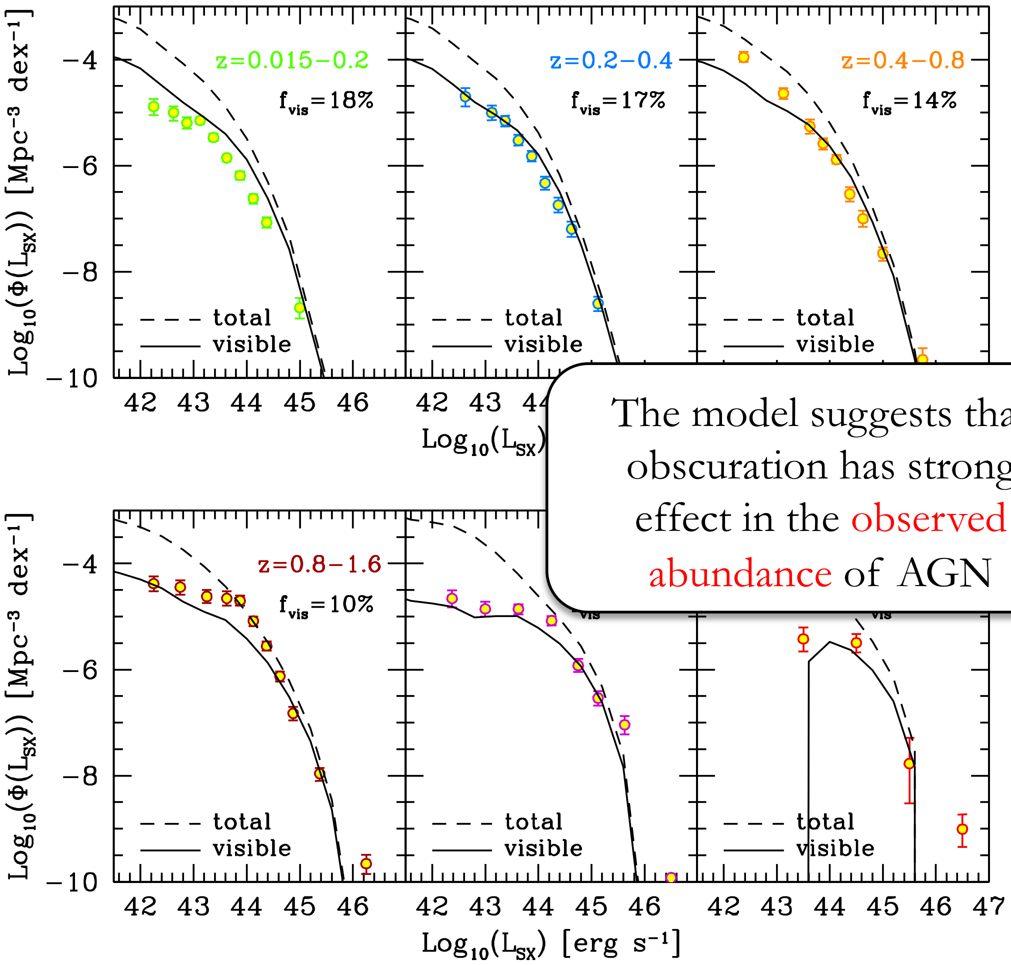


The model suggests strong differential evolution for the different luminosity populations

Quasar evolution

Soft X-ray luminosity function



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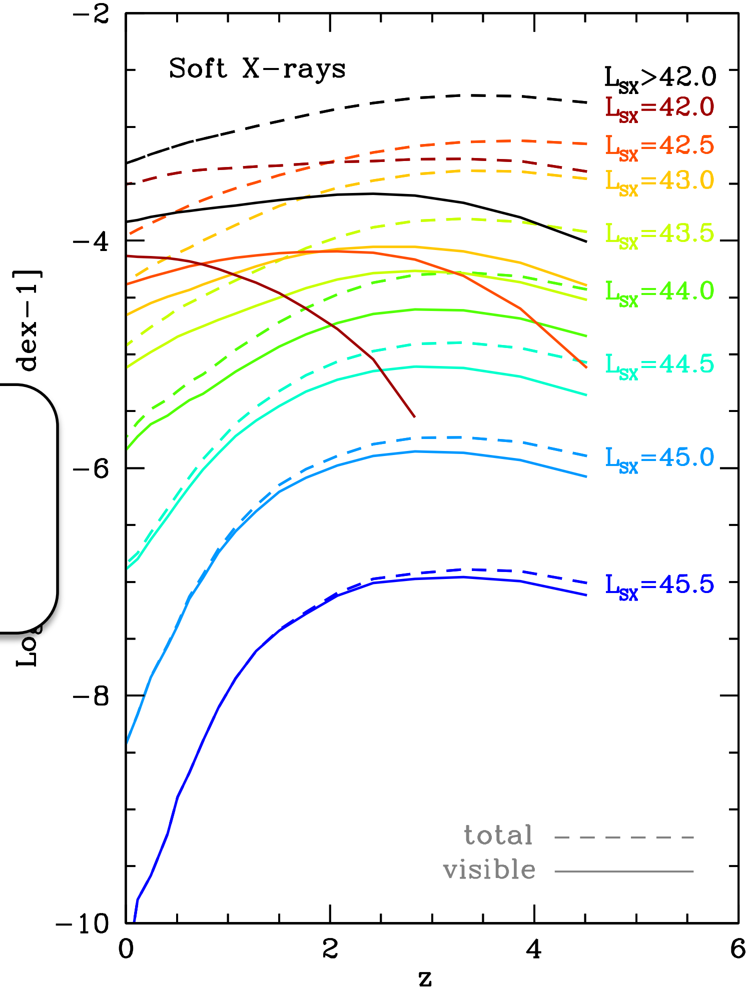
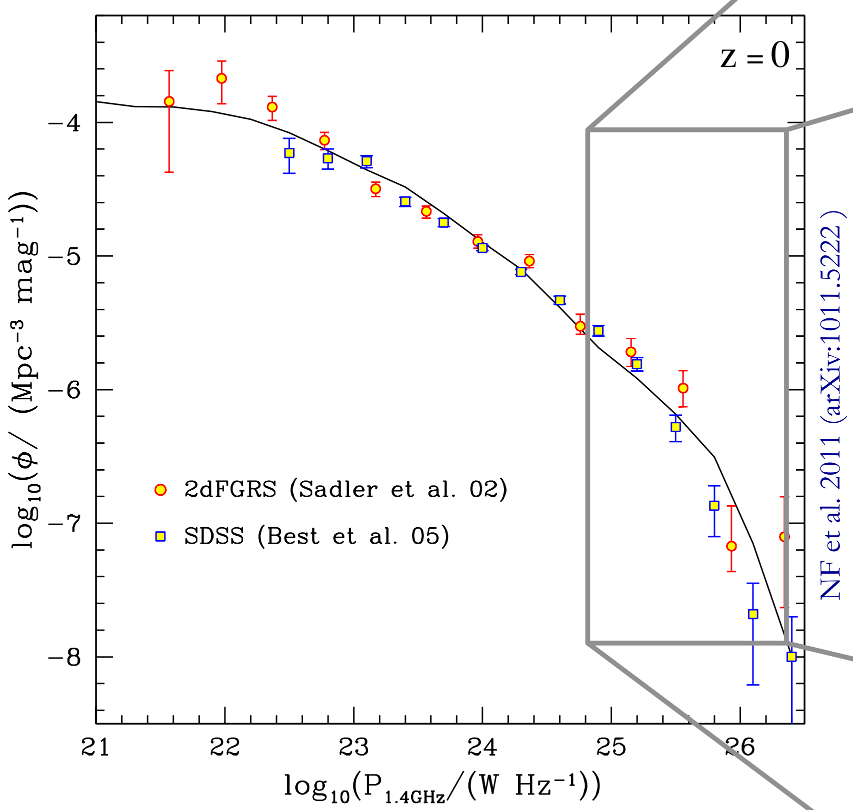


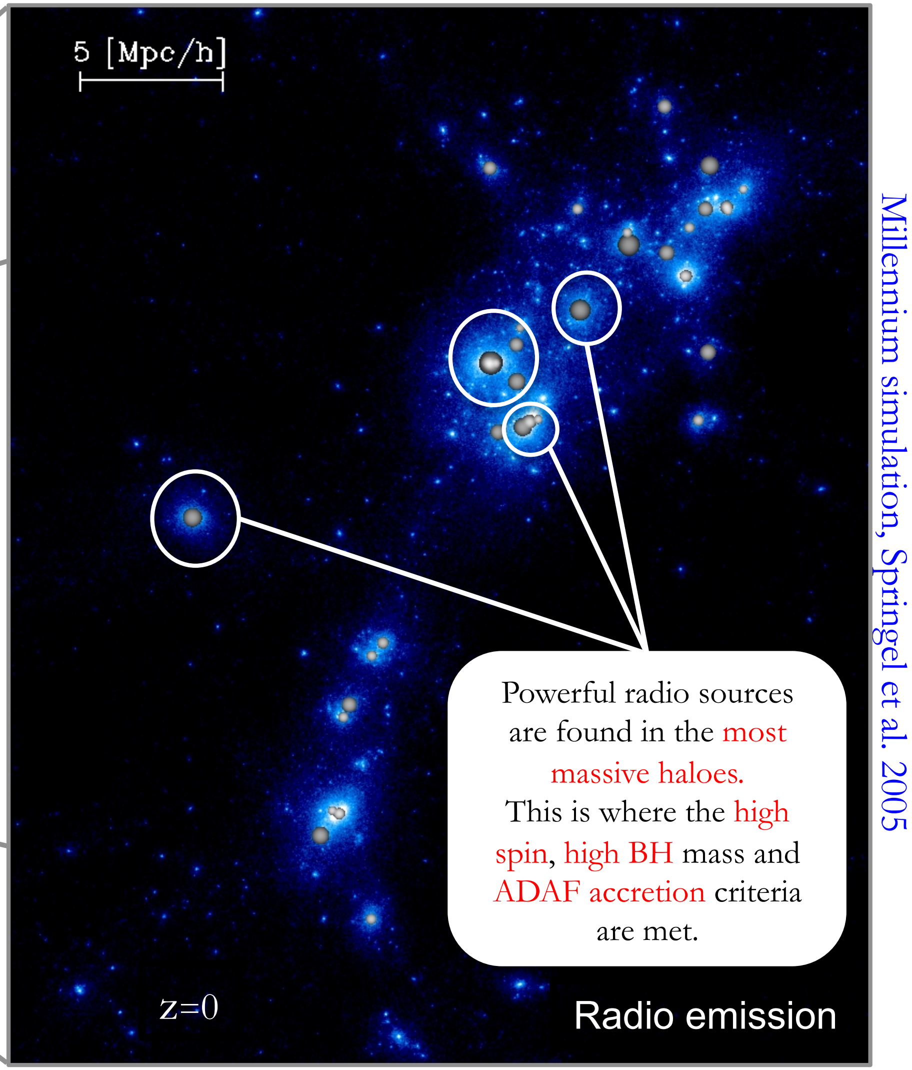
The model suggests that obscuration has strong effect in the observed abundance of AGN

Radio galaxies at z=0

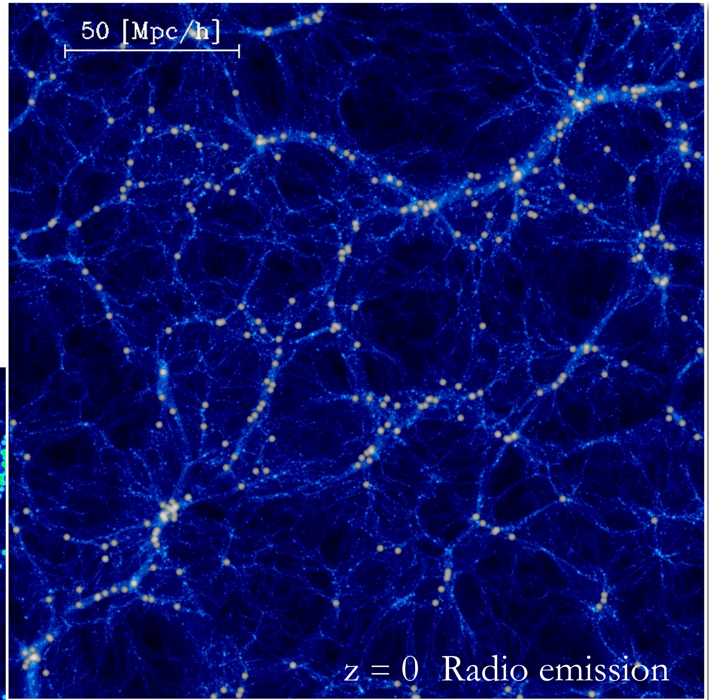
Radio luminosity function

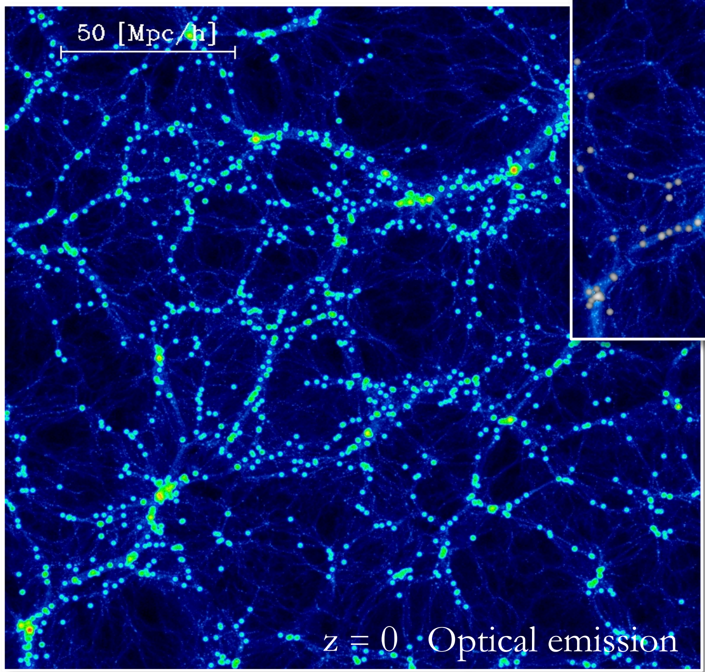


$$L_{jet} \propto (H/R)^2 B_\phi^2 M_{BH} \dot{m} a^2$$

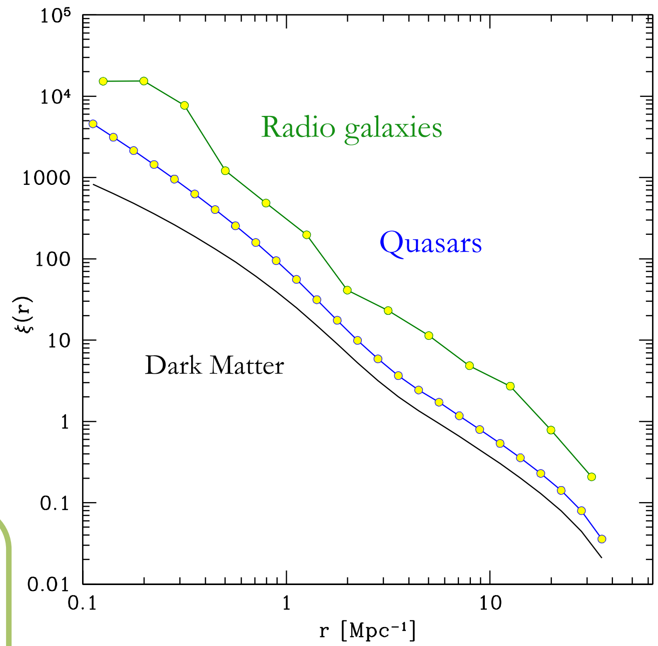


The clustering of AGN





Good agreement with Wake et al. (2008) & Donoso et al. (2010) results



NF et al., in prep.

-- Quasars are more clustered than radio galaxies.

-- Radio galaxies are found in the extremes of the dark matter distribution.

Summary-Conclusions

- The **GALFORM** galaxy formation model is coupled with a BH model to reproduce:
  - The phenomenology of AGN in the local universe.
  - The radio luminosity function in the local universe.
  - The evolution of AGN (optical, X-rays, bolometrically).
  - The clustering of AGN.
- Our model suggests that:
  - The complex evolution of AGN (downsizing) arises naturally from the interplay between the different accretion modes.
  - The radio properties of an AGN seem to be determined by the spin and the accretion regime characterising the central BH.
  - To reproduce the LF of radio galaxies the model requires that massive BHs ($>10^8\ M_\odot$) should have higher spins than lower mass BHs.
  - Quasars in the low redshift universe are found in $\sim 10^{12.5}\ M_\odot$. In contrast, radio galaxies inhabit $10^{14-15}\ M_\odot$ haloes.