Unraveling the properties of active galaxies in hierarchical cosmologies

Outline

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

Galaxy Formation, July 21
Nikos Fanidakis,
and Carlos Frenk, Carlton Baugh, Shaun Cole, Richard Bower,
Chris Done, Ryan Hickox, Andrew Benson, Claudia Lagos
Galaxy formation (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

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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)
The growth of BHs in GALFORM

BH mass

Accretion

BH-BH mergers

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

\[ \tau_{cool} = \frac{3 p_{gas}(r)}{2 \mu m_H n_e^2(r) \Lambda(T_{gas}, Z_{gas})} \frac{k_B T_{gas}}{\epsilon_{\text{cool}}} \]

Stability criterion

\[ \frac{V_{\text{max}}}{(GM_{\text{disk}} / r_{\text{disk}})^{1/2}} < 1 \]

Efstathiou et al. (1982)

BH growth

\[ M_{\text{acc}}^\text{BH} = f_{\text{BH}} M_{\text{burst}}^\text{BH} \]

Malbon et al. (2007)

Introduction ★ GALFORM ★ The AGN model ★ Results ★ Summary-Conclusions
The growth of BHs in **GALFORM**

- **Introduction**
  - **GALFORM**
  - The AGN model
  - Results
  - Summary-Conclusions

**Disk instabilities**
- BH mass
  - Accretion
    - Starburst mode
    - Hot-halo mode
  - BH-BH mergers
    - Disk instabilities
    - Galaxy mergers

**Galaxy mergers**
- BH-BH mergers only redistribute the BH mass
- SF as in Blitz & Rosolowsky (2006) (Lagos et al. 2010)
- Accretion only during burst star formation (SF)

**Quasar**
- Hot gas
- Cold gas
- Dark matter
The growth of BHs in GALFORM

- BH mass
  - Accretion
    - Starburst mode
      - Disk instabilities
      - Galaxy mergers
    - Hot-halo mode
    - BH-BH mergers
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Accretion only during burst star formation (SF)

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The growth of BHs in GALFORM

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

- Accretion only during burst star formation (SF)

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- Disk instabilities
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Accretion

- Starburst mode
- Hot-halo mode

BH-BH mergers

- Updated Bower et al.
The growth of BHs in GALFORM

- Accretion only during burst star formation (SF)
- SF as in Blitz & Rosolowsky (2006) (Lagos et al. 2010)
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- Accretion
- BH-BH mergers
- Starburst mode
- Hot-halo mode
- Disk instabilities
- Galaxy mergers

See also Croton et al. (2006); Lagos et al. (2008)
Modelling the active nucleus

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)
6) Jet total and radio luminosity Blandford & Znajek (1977)
Modelling the active nucleus

- Hot gas
- Quasar
- Halo
- Thin disk
- Luminous disks
- Weak jets
- ADAF
- Under-luminous disks
- Strong jets

Central engine

Thin disk

Luminous disks

Weak jets

ADAF

Under-luminous disks

Strong jets

Introduction ★ GALFORM ★ The AGN model ★ Results ★ Summary-Conclusions
Predictions

1) BH spin

\[ a = cJ / GM_{BH}^2 \]

2) Disk luminosities

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

BH-BH mergers have the opposite effect!

3) Scaling relations

<table>
<thead>
<tr>
<th>z</th>
<th>(&lt;M_{\text{Halo}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>(\sim3\times10^{12} M_{\odot})</td>
</tr>
<tr>
<td>1</td>
<td>(\sim1.5\times10^{12} M_{\odot})</td>
</tr>
<tr>
<td>2</td>
<td>(\sim1.9\times10^{11} M_{\odot})</td>
</tr>
</tbody>
</table>
Predictions

1) BH spin

\[ a = \frac{cJ}{GM_{BH}^2} \]

2) Disk luminosities

BH-BH mergers have the opposite effect!

3) Active BH mass function

Introduction ★ GALFORM ★ The AGN model ★ Results ★ Summary-Conclusions
Quasar luminosity functions

Optical

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

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

NF et al. 2011 (arXiv:1011.5222)
The model suggests strong differential evolution for the different luminosity populations.
Quasar evolution

**Soft X-ray luminosity function**

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

NF et al. 2011 (arXiv:1011.5222)
Radio galaxies at $z=0$

Radio luminosity function

$$L_{\text{jet}} \propto (H/R)^2 B_\phi^2 M_{BH} ma^2$$

The AGN model

Powerful radio sources are found in the most massive haloes. This is where the high spin, high BH mass and ADAF accretion criteria are met.

Introduction ★ GALFORM ★ The AGN model ★ Results ★ Summary-Conclusions
The clustering of AGN

-- Quasars are more clustered than radio galaxies.
-- Radio galaxies are found in the extremes of the dark matter distribution.

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

NF et al., in prep.
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☉) should have higher spins than lower mass BHs.
- Quasars in the low redshift universe are found in ~10^{12.5} M☉. In contrast, radio galaxies inhabit 10^{14-15} M☉ haloes.