Exploring the link between star formation activity and black hole mass in central galaxies

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OBSERVATIONS

SIMULATIONS

TNG50

NGC5813
Star formation rate
stellar mass

SDSS data, centrals
$z \sim 0$

upper limits

Star-forming main sequence

Quiescent population

star formation rate
stellar mass

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Black holes and galactic quiescence
Star-forming population

Quiescent population

SDSS data, centrals

Star-forming

Halo gas

gas accretion

star formation

Galaxy

upper limits

SSFR

star formation rate
stellar mass

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Star-forming

Quiescent**

Star-forming rate
stellar mass

SDSS data, centrals

\[ z \sim 0 \]

Upper limits

black holes and galactic quiescence

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Observational evidence of this disruption?

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Black holes and galactic quiescence
Observational evidence of this disruption?

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Black holes and galactic quiescence

sSFR \[ \log \text{ yr}^{-1} \] vs. Stellar mass \[ \log M_{\text{sun}} \]

Galaxy

Halo gas

gas accretion

star formation

\( \text{Milky Way} \)

\( ? \)
Black hole mass and quiescence

Black hole-galaxy correlations

Galaxy-quiescence correlations

⇒ Indirect link between black holes and quiescence
- $M_{\text{star}} \rightarrow L_K$ (2MASS)
- $M_{\text{BH}} \rightarrow$ Dynamically detected (van den Bosch 16, Saglia+16)
- SFR $\rightarrow L_{\text{FIR}}$ (IRAS)

Central galaxies only

91 galaxies

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Black holes and galactic quiescence
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Central galaxies only

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Dynamical black hole mass vs. Stellar mass

Terrazas et al. 2016b

$z = 0$

Stellar mass error

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Black holes and galactic quiescence
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Central galaxies only

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**Dynamical black hole mass**

**Stellar mass**

**Terrazas et al. 2016b**

$z = 0$

**Stellar mass error**

**Black holes and galactic quiescence**
Observations

Clear separation between quiescent & star forming galaxies

Models

Long-lived, preventative, low $\dot{M}_{BH}$ BH feedback

Short-lived, high $\dot{M}_{BH}$ BH feedback

Halo mass threshold for quiescence

Terrazas et al. 2016a, b
**Observations**

Clear separation between quiescent & star forming galaxies

**Models**

Long-lived, preventative, low $\dot{M}_{BH}$

BH feedback

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BH feedback

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Black holes and galactic quiescence
Observations

A galaxy’s degree of quiescence is a smoothly decreasing function of $M_{\text{BH}} / M_{\text{star}}$. 

$\log_{10} \text{sSFR} = 0.80 \log_{10} \frac{M_\star}{M_\star, \text{avg}} - 0.82 \log_{10} \frac{M_{\text{BH}}}{M_{\text{BH}, \text{avg}}} - 11.84$

(BH feedback energy / gas cooling)
$M_{\text{star}} - M_{\text{BH}} - \text{sSFR}$ parameter space is sensitive to the feedback physics of quiescence in models and the observations can be used to assess models and simulations.
The black hole model in IllustrisTNG

Two modes of feedback

- **Thermal mode**
  - Continuously injected heat
  - Regulates $M_{BH}$ growth

- **Kinetic mode**
  - Pulsed, randomly-directed momentum kicks
  - Produces quiescence

Black hole mass vs. $\dot{M}_{BH}/\dot{M}_{Edd}$
Physics behind quiescence: Cooling vs heating

**TEST:** Semi-analytic models use heating + cooling rates to determine quiescence

E.g. De Lucia & Blaizot 07, Somerville+08, Guo+11, Henriques+15
Physics behind quiescence: Cooling vs heating

TEST: Semi-analytic models use heating + cooling rates to determine quiescence.

\[
\dot{E}_{\text{BH winds}} = 0
\]

A comparison of instantaneous rates is not a good predictor for quiescence in TNG.

\[
\frac{\dot{E}_{\text{BH winds}}}{\dot{E}_{\text{cooling}}} \rightarrow \text{BH wind energy rate / Halo gas cooling rate (instantaneous)}
\]
Physics behind quiescence: gravitational (un)binding energy

Gas is bound to galaxy $\leftrightarrow$ BH feedback unbinds gas

Accumulated BH wind energy

Gravitational binding energy of gas in the galaxy

$$\frac{1}{2} \sum_{g(<r_{gal})} m_g \varphi_g = \int \dot{E}_{BH \text{ winds}} \, dt / E_{bind, gas(<r_{gal})}$$
TNG galaxies retain a *memory* of kinetic wind feedback energy effects
IllustrisTNG: Comparison to observations

Quiescence correlates with BH mass – in qualitative agreement with observations

- SF
- Q

TNG100 + obs scatter

(Note: Stellar mass dependence is gone)
**IllustrisTNG: Comparison to observations**

But $M_{\text{BH}} - M_{\text{star}}$ relation is too tight and quiescence is very abrupt.

(Note: Stellar mass dependence is gone)

- SF • Q TNG100 + obs scatter
- SF o Q Observations

$M_{\text{BH}}$ threshold for quiescence
**IllustrisTNG: Comparison to observations**

$M_{\text{star}} - M_{\text{BH}} - \text{sSFR}$

- Black holes occupy galaxies.

- Black hole mass correlates with quiescence.

- Black holes determine the stellar mass distribution of SF + Q galaxies.

*Observations*:

- SF
- Q

*TNG100 + obs scatter*
IllustrisTNG: Comparison to observations

Black hole mass is an essential third parameter in this fundamental plot.

 Terrazas et al. 2019

Black holes and galactic quiescence
How $M_{BH}$ correlates \textit{quantitatively} with sSFR and $M_{\text{star}}$ determines the distribution of star formation within the central galaxy population.
\( M_{\text{star}} \), \( M_{\text{BH}} \), \( \text{sSFR} \)

Correlated
(models say causally linked)

Colored by \( M_{\text{star}} \)

Colored by \( M_{\text{BH}} \)

Colored by \( \text{sSFR} \)
SDSS centrals

$M_{BH}$ estimated from sigma

Terrazas+16, 17
Dynamical $M_{BH}$

Courtesy of Asa Bluck
Quiescence correlates with strongly with $M_{\text{BH}}$

Successful models have preventative feedback

- On what timescales does BH feedback operate?

$$M_{\text{star}} - M_{\text{BH}} - \text{sSFR}$$ parameter space is sensitive to feedback physics in models

- Powerful diagnostic tool to test models

The *quantitative* link between $M_{\text{star}} - M_{\text{BH}} - \text{sSFR}$ determines the distribution of star formation within the central galaxy population

- Current models do not agree with each other