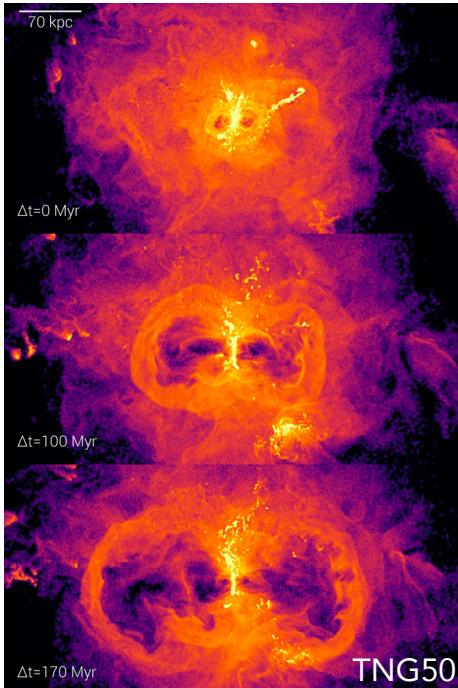


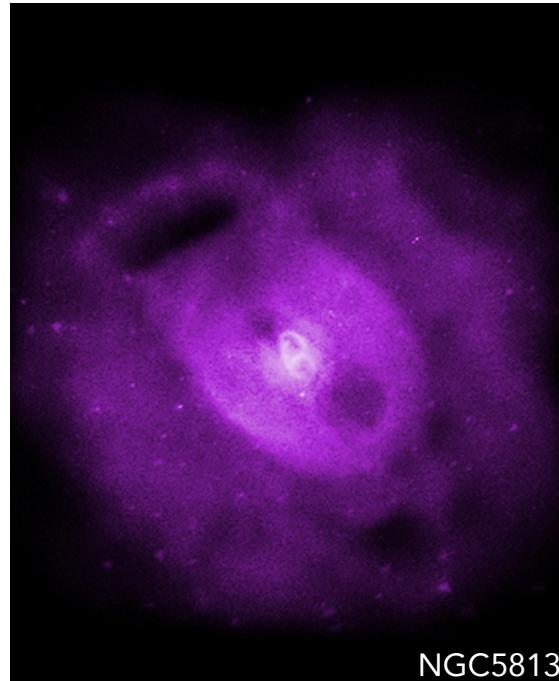
Exploring the link between star formation activity and black hole mass in central galaxies

SIMULATIONS



TNG50

OBSERVATIONS



NGC5813

CENTER FOR

ASTROPHYSICS

HARVARD & SMITHSONIAN

Bryan A. Terrazas
Future Faculty Leaders Postdoctoral Fellow



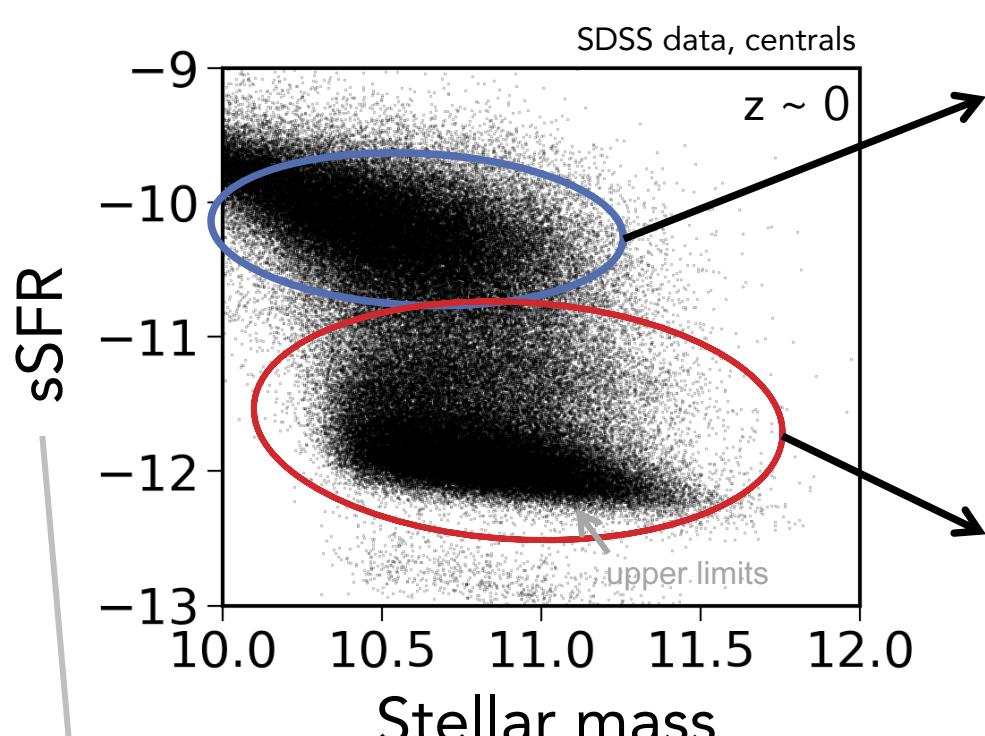
Eric Bell
Simon White
Andrea Cattaneo

Bruno Henriques
Joanna Woo
Dylan Nelson

Rachel Somerville
Annalisa Pillepich
Shy Genel

Rainer Weinberger
Melanie Habouzit
Yuan Li

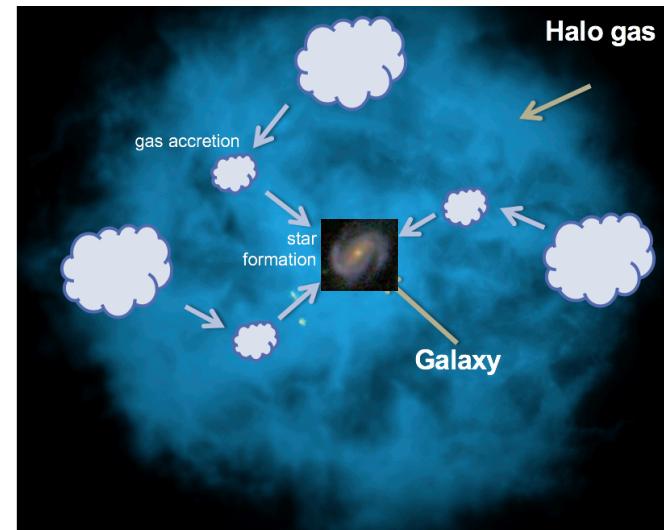
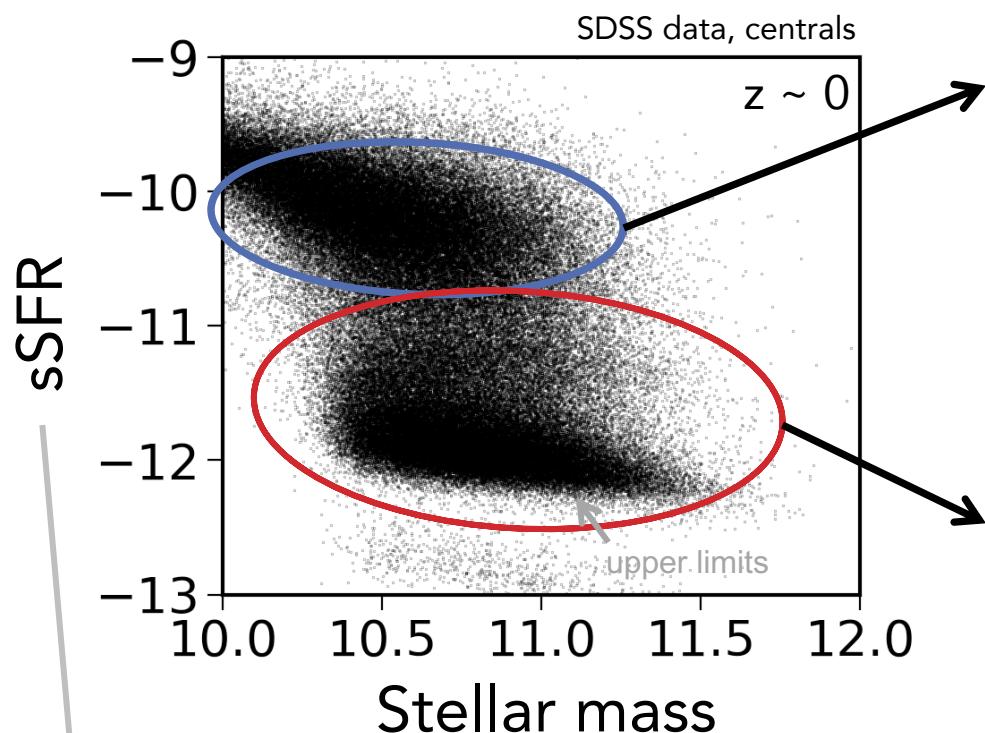
Lars Hernquist
Mark Vogelsberger



Star-forming
main sequence

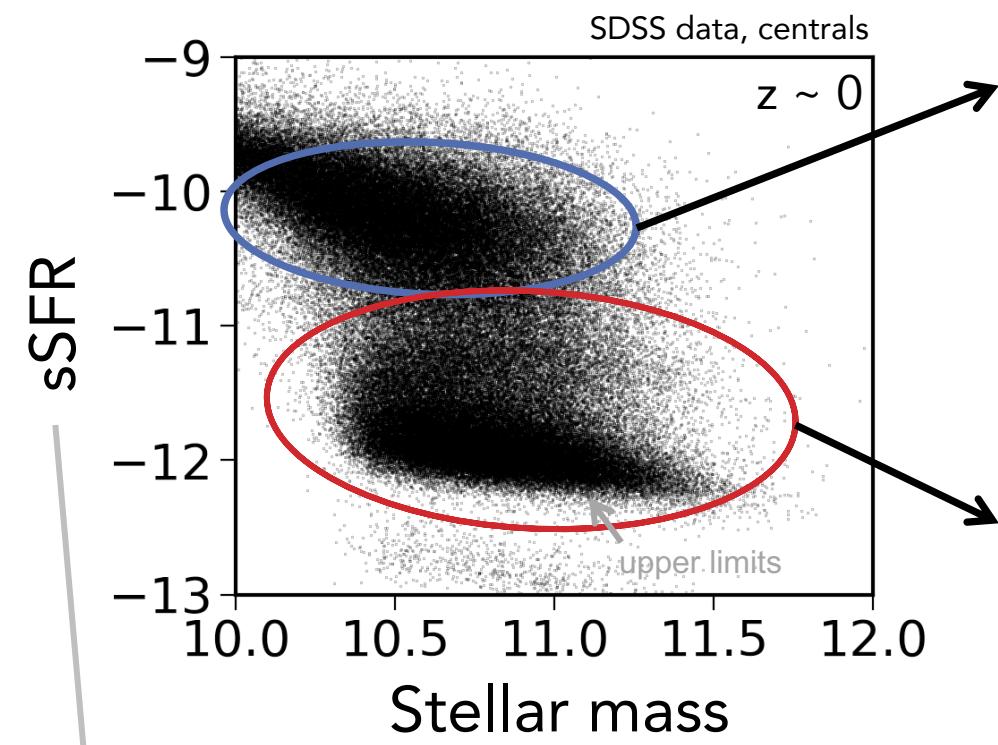
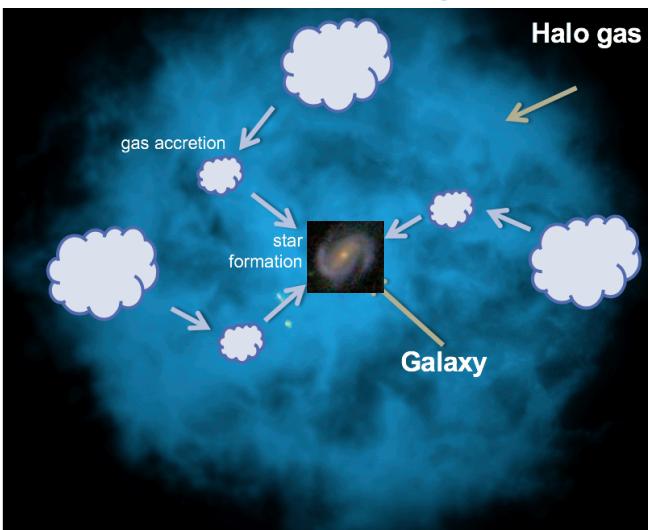
Quiescent
population

Star-forming

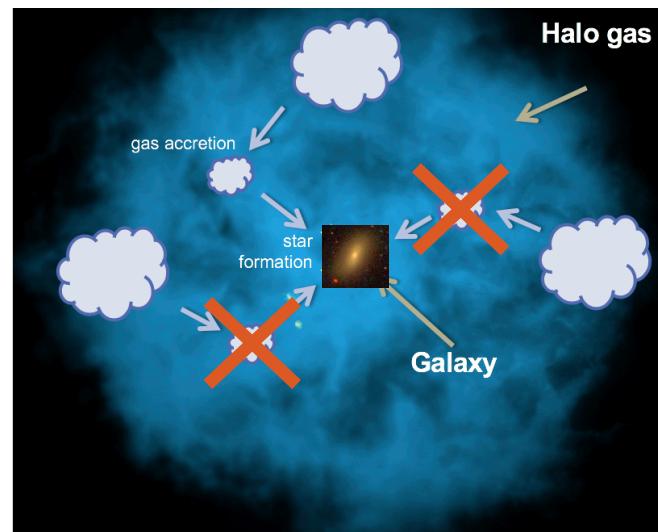


Quiescent
population

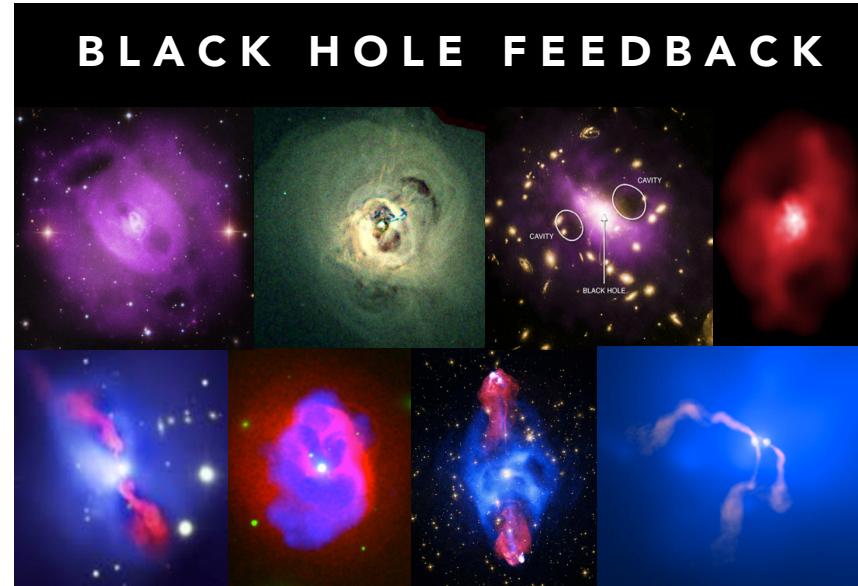
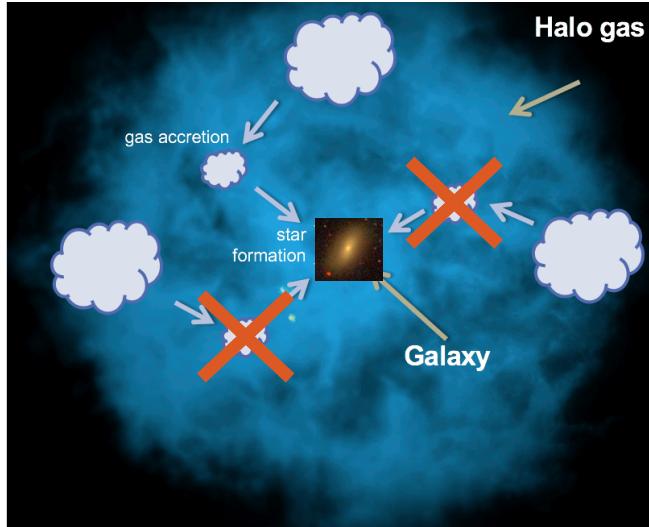
Star-forming



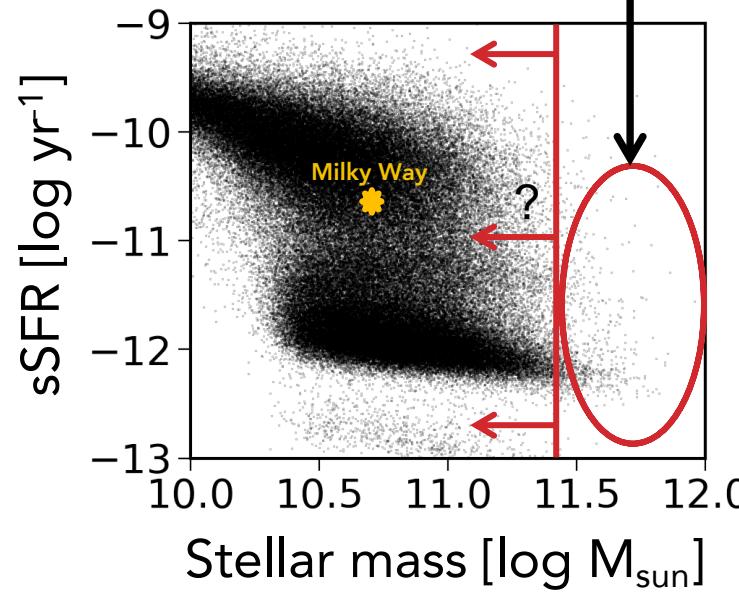
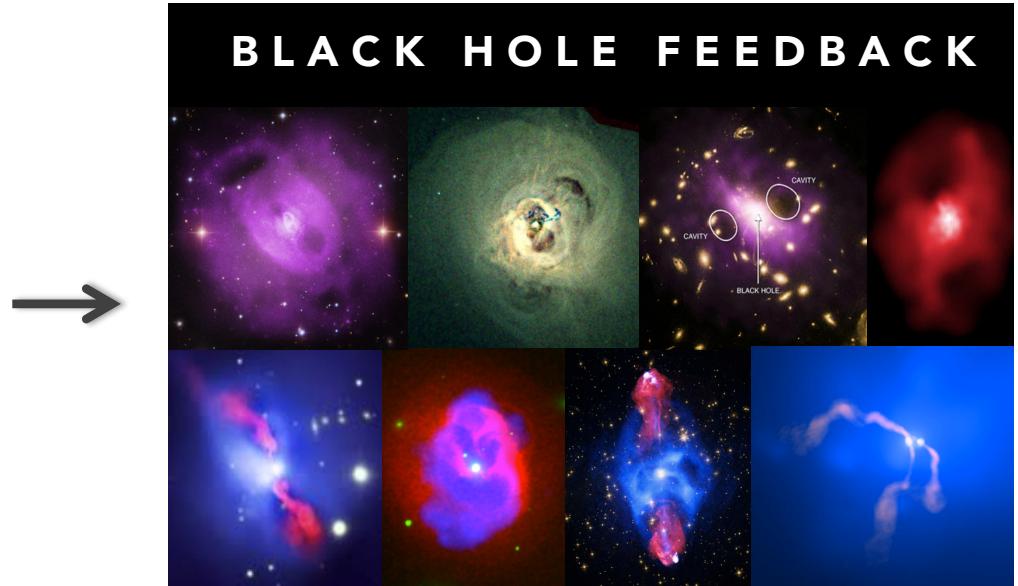
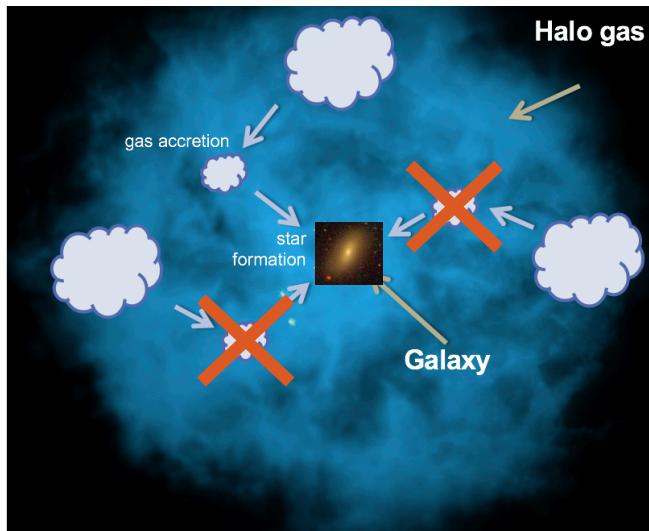
Quiescent**



Observational evidence of this disruption?

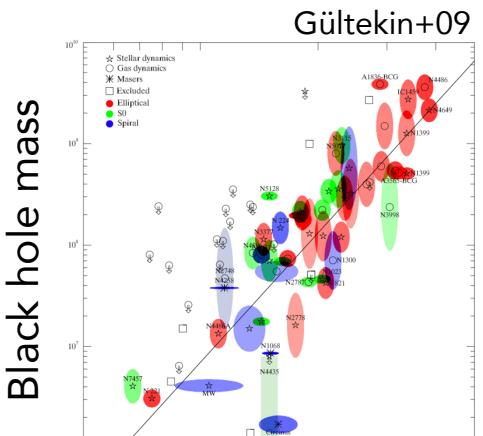


Observational evidence of this disruption?



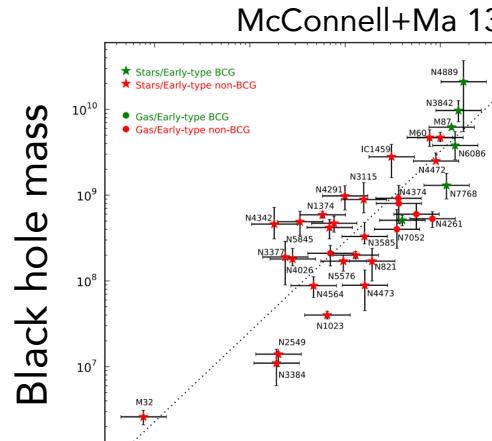
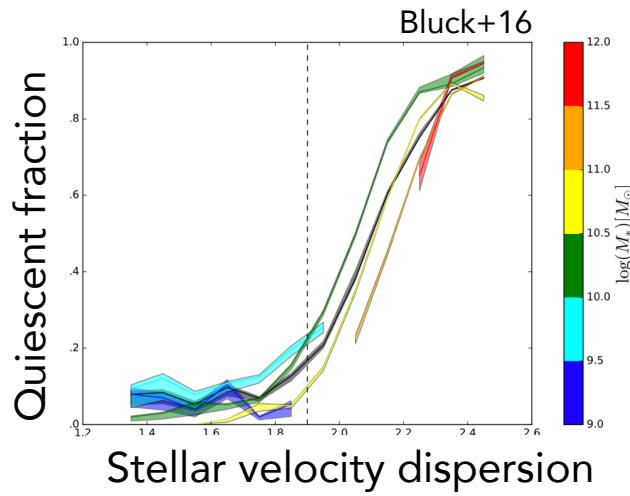
Black hole mass and quiescence

Black hole-galaxy correlations

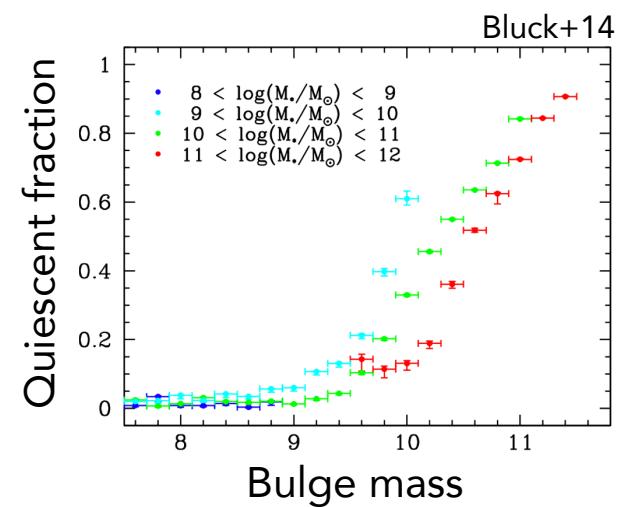


Stellar velocity dispersion

Galaxy-quiescence correlations



Bulge mass



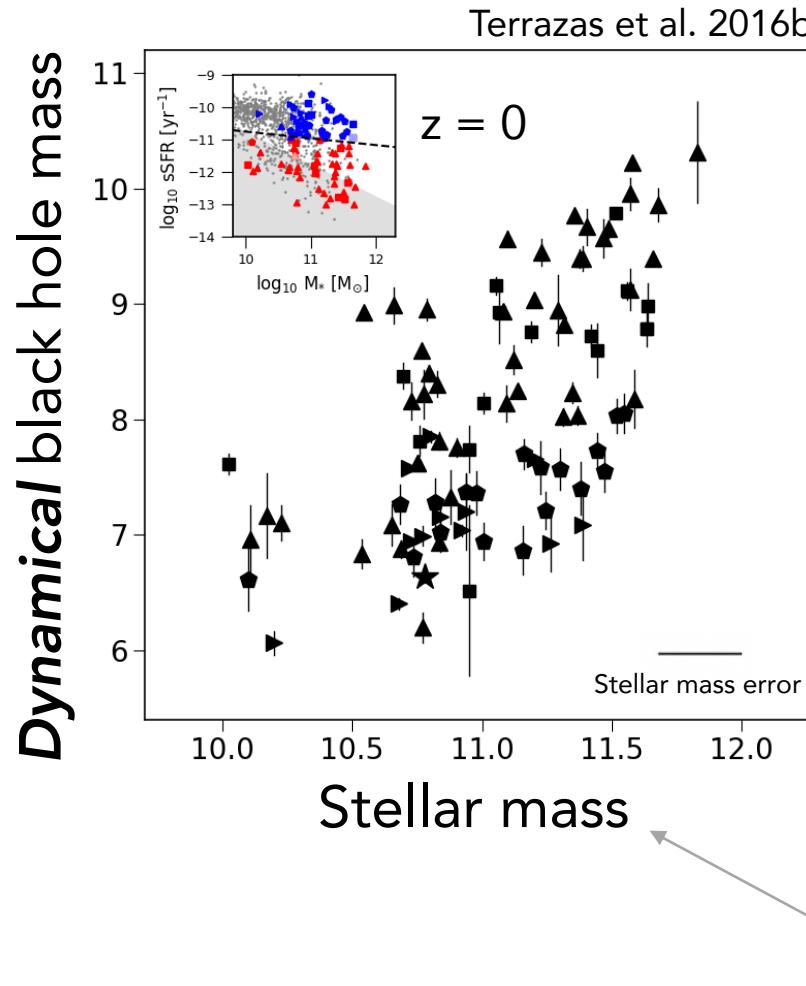
→ Indirect link between black holes and quiescence

- $M_{\text{star}} \rightarrow L_K$ (2MASS)
- $M_{\text{BH}} \rightarrow$ Dynamically detected
(van den Bosch 16, Saglia+16)
- $\text{SFR} \rightarrow L_{\text{FIR}}$ (IRAS)

- ▶ maser
- gas
- ▲ stars
- ◆ reverb. mapped
- ★ MW

Central galaxies only

91 galaxies

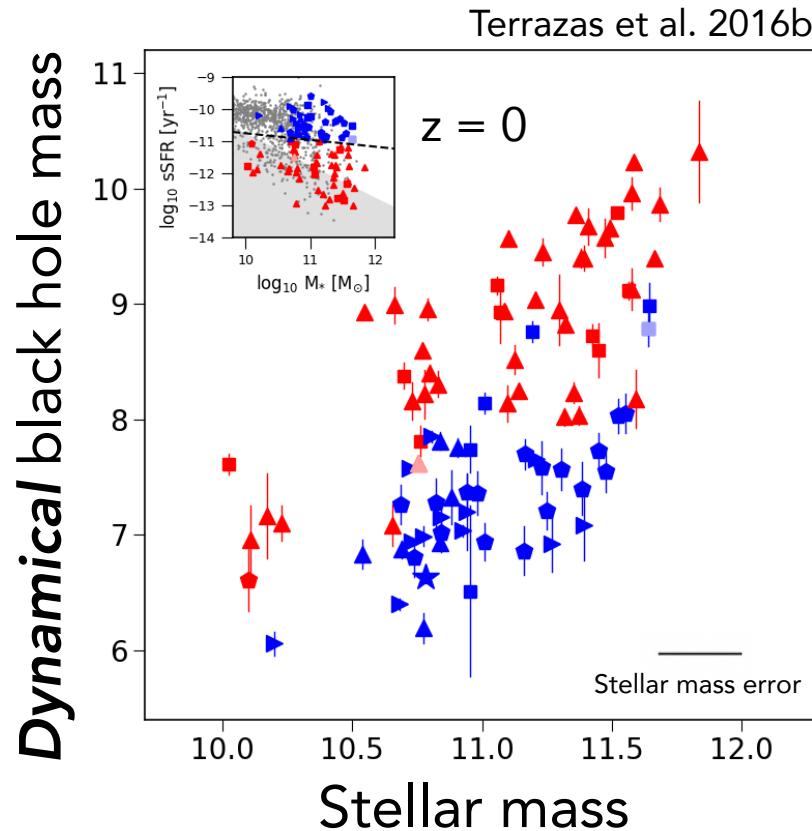


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Central galaxies only

91 galaxies

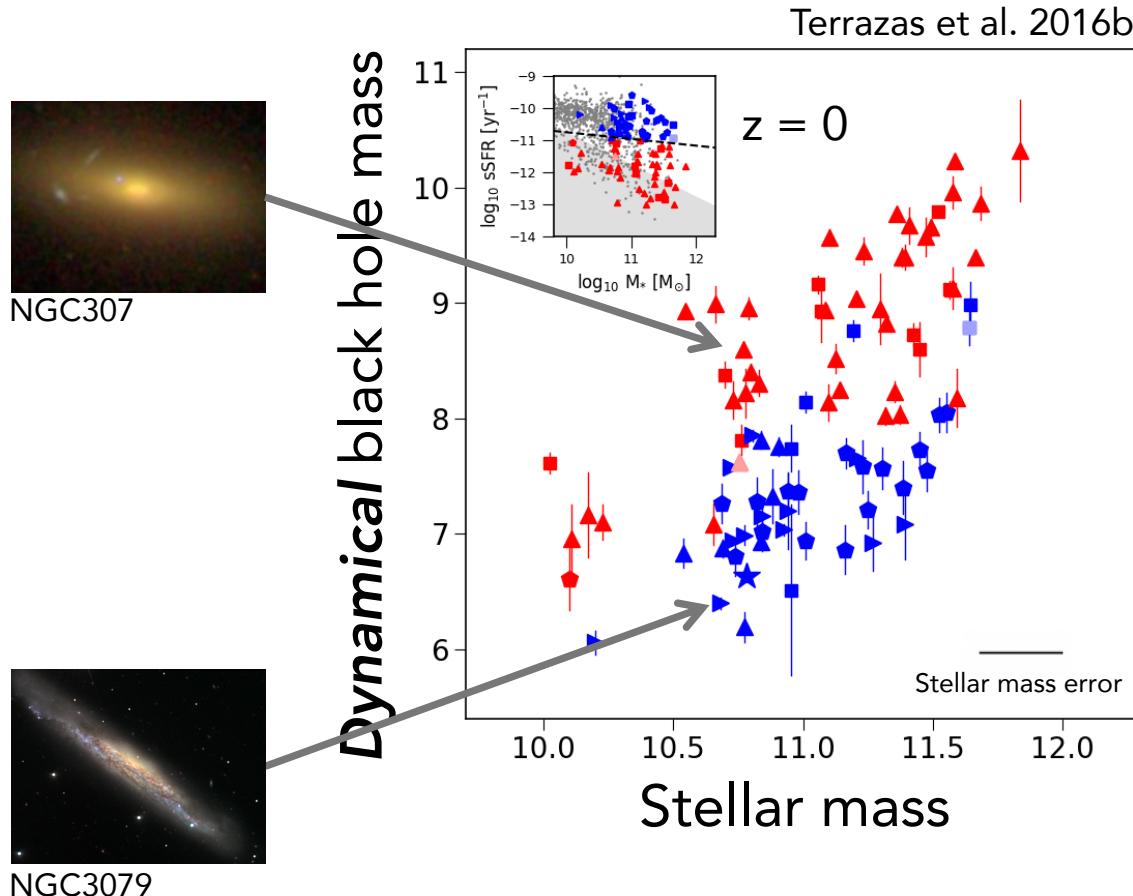


- $M_{\text{star}} \rightarrow L_K$ (2MASS)
- $M_{\text{BH}} \rightarrow$ Dynamically detected
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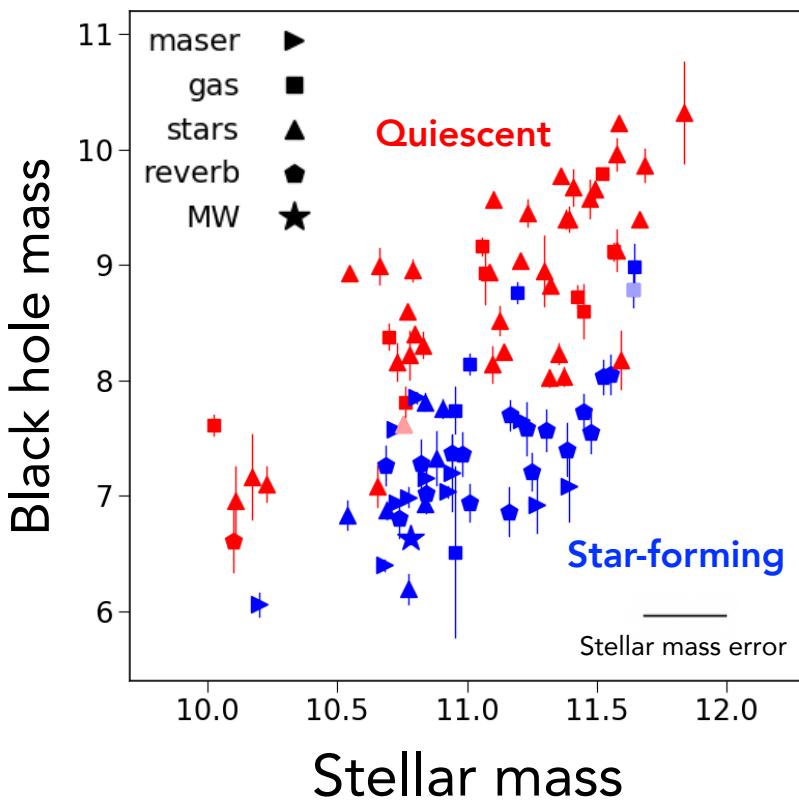
Central galaxies only

91 galaxies



Observations

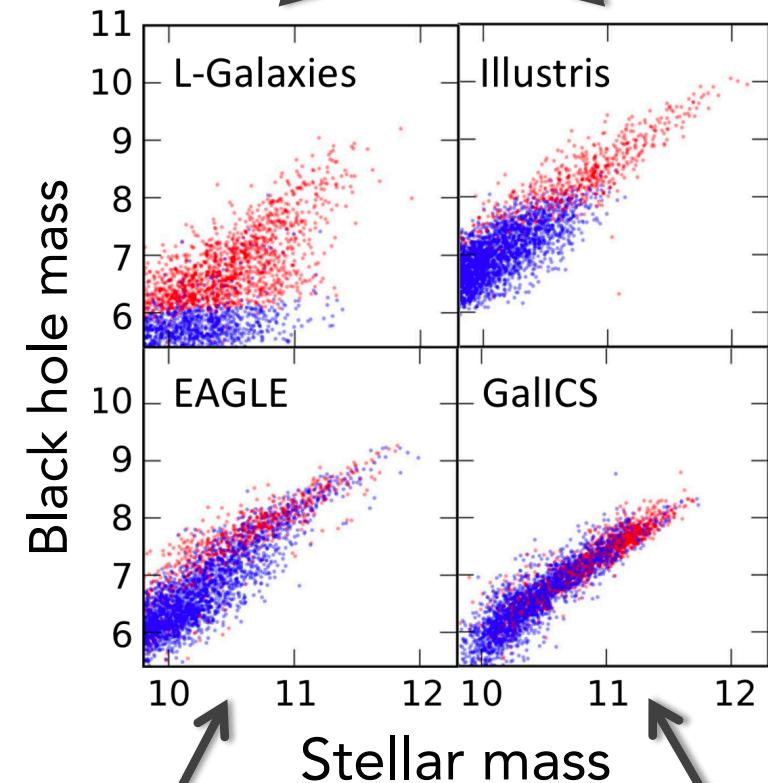
Clear separation between quiescent & star forming galaxies



Terrazas et al. 2016a, b

Models

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

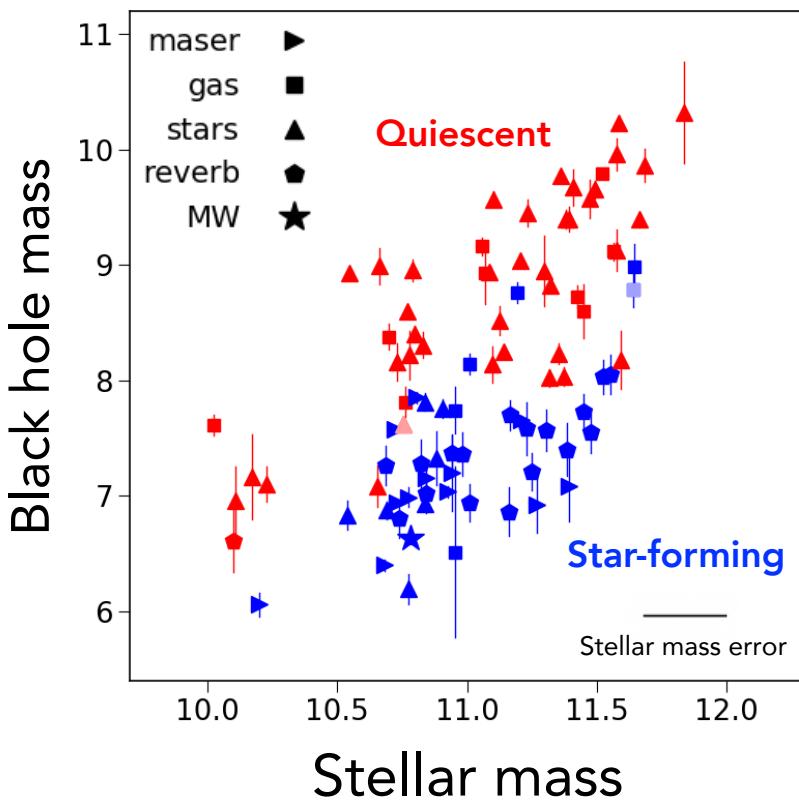


Short-lived,
high \dot{M}_{BH}
BH feedback

Halo mass threshold
for quiescence

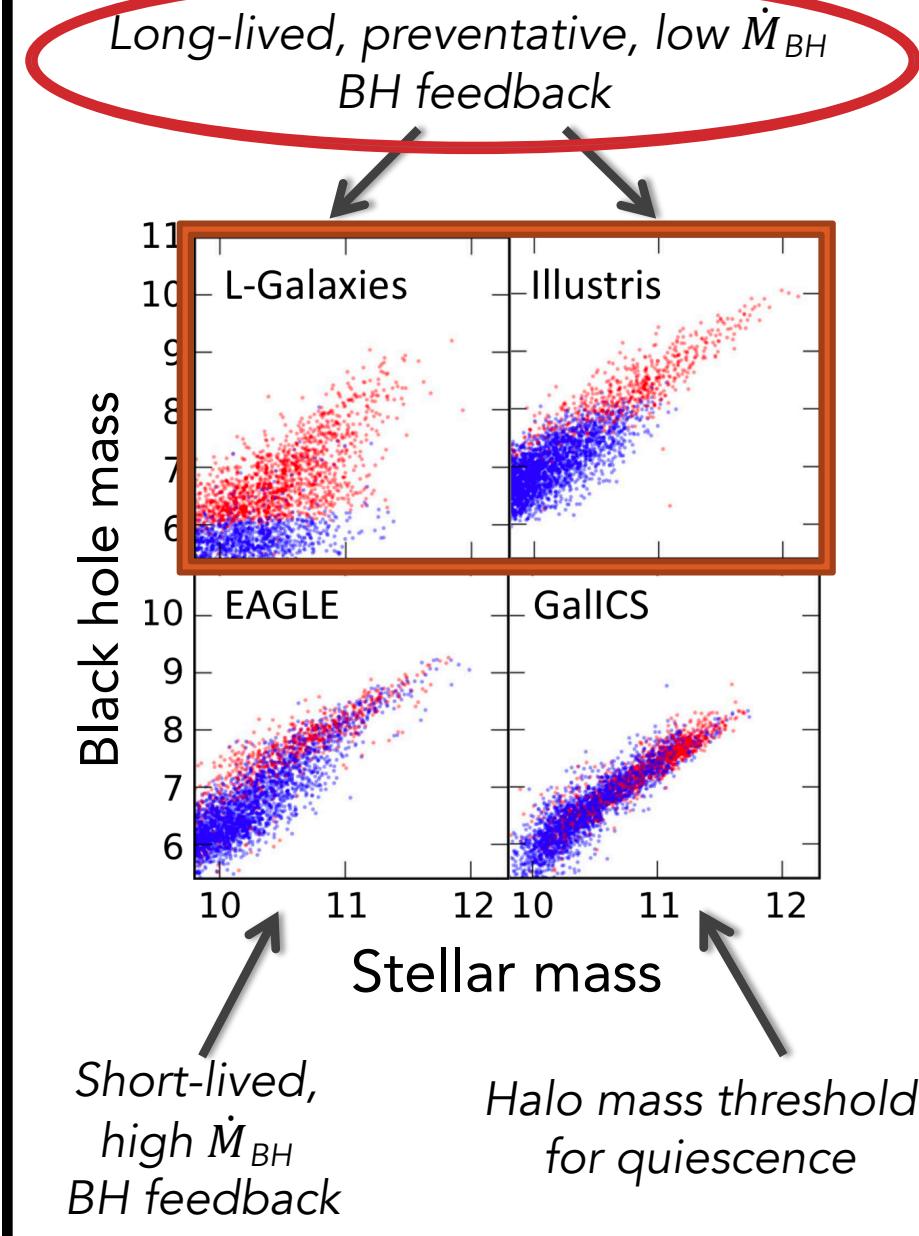
Observations

Clear separation between quiescent & star forming galaxies



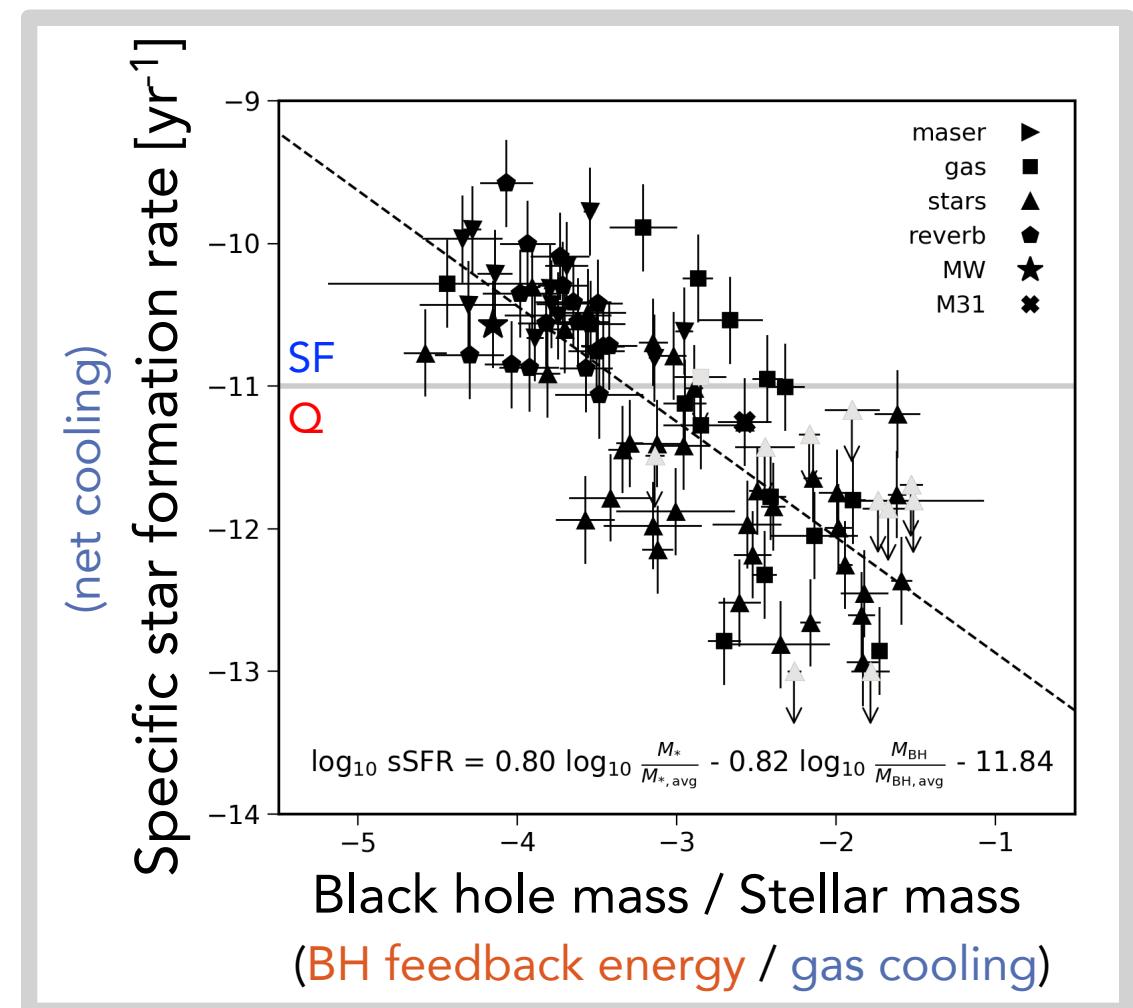
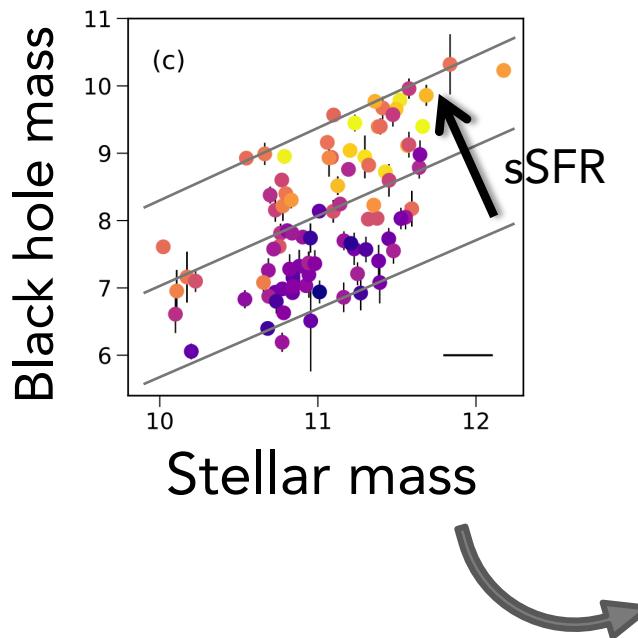
Terrazas et al. 2016a, b

Models



Observations

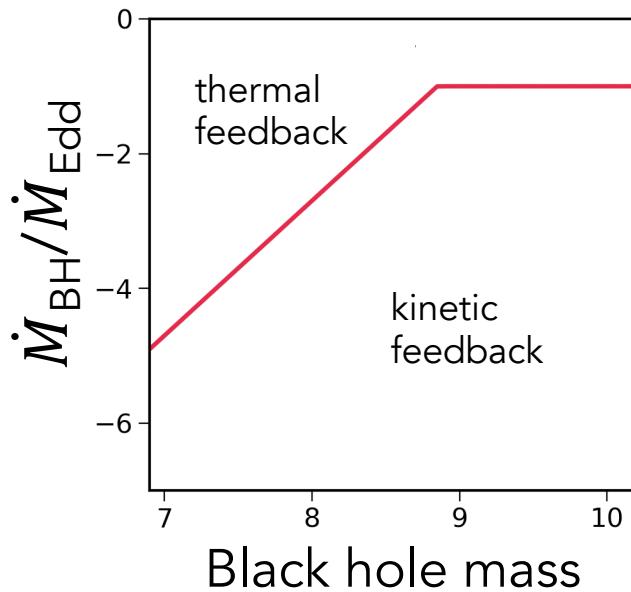
A galaxy's degree of quiescence is a smoothly decreasing function of $M_{\text{BH}} / M_{\text{star}}$



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

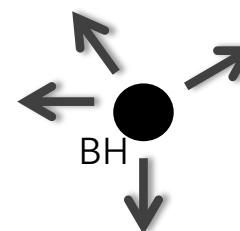


BH

Regulates M_{BH} growth

Kinetic mode

Pulsed, randomly-directed momentum kicks



BH

Produces quiescence

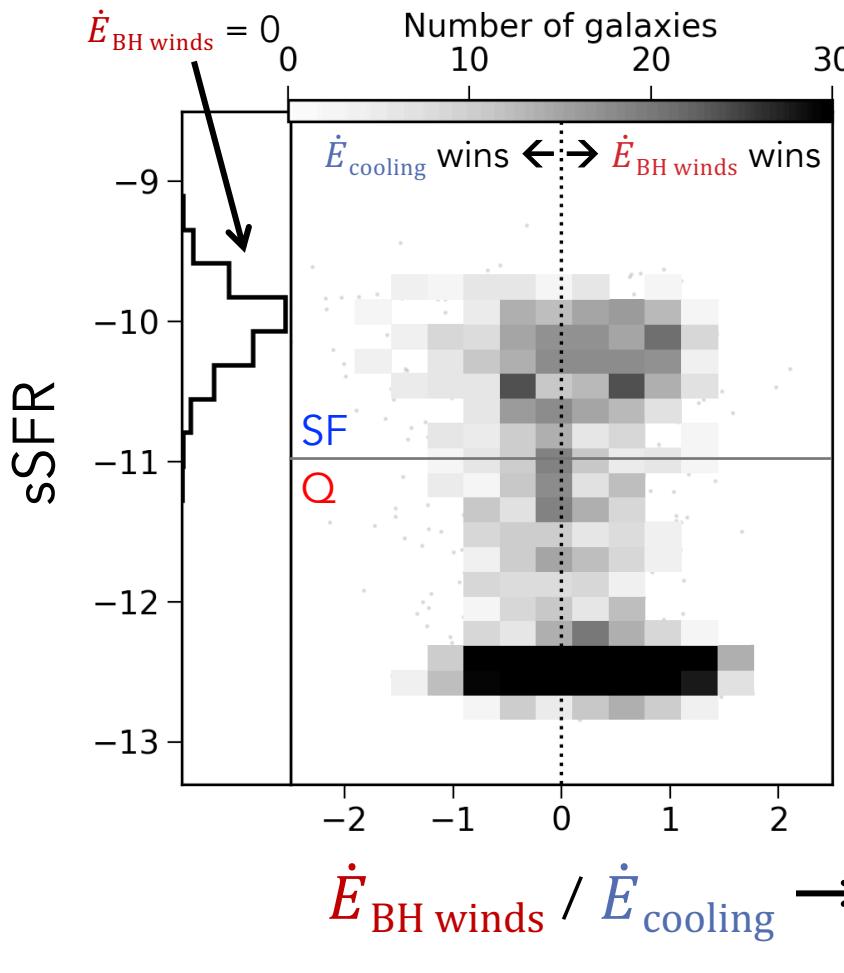
Physics behind quiescence: Cooling vs heating

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

E.g. De Lucia & Blaizot 07, Somerville+08, Guo+11, Henriques+15

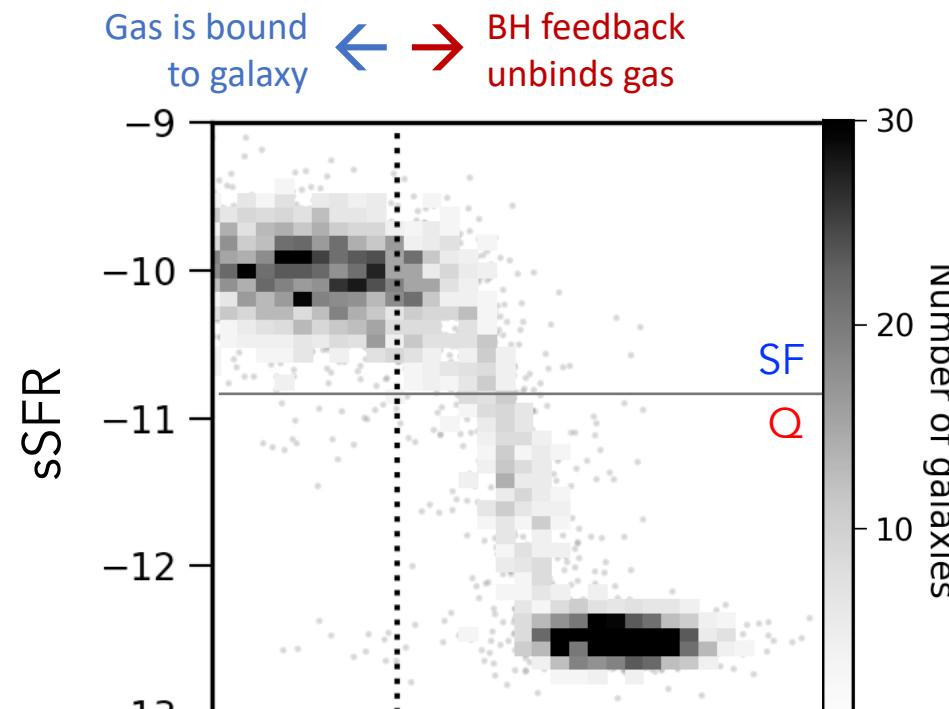
Physics behind quiescence: Cooling vs heating

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



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

Physics behind quiescence: gravitational (un)binding energy



$$\int \dot{E}_{\text{BH winds}} dt / E_{\text{bind,gas}}(<r_{\text{gal}})$$

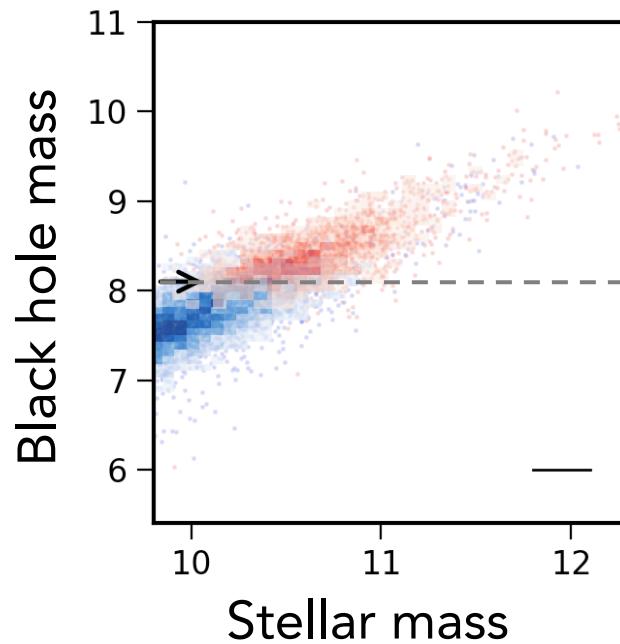
Accumulated BH
wind energy

Gravitational binding energy of gas in the galaxy = $\frac{1}{2} \sum_{g(<r_{\text{gal}})} m_g \varphi_g$

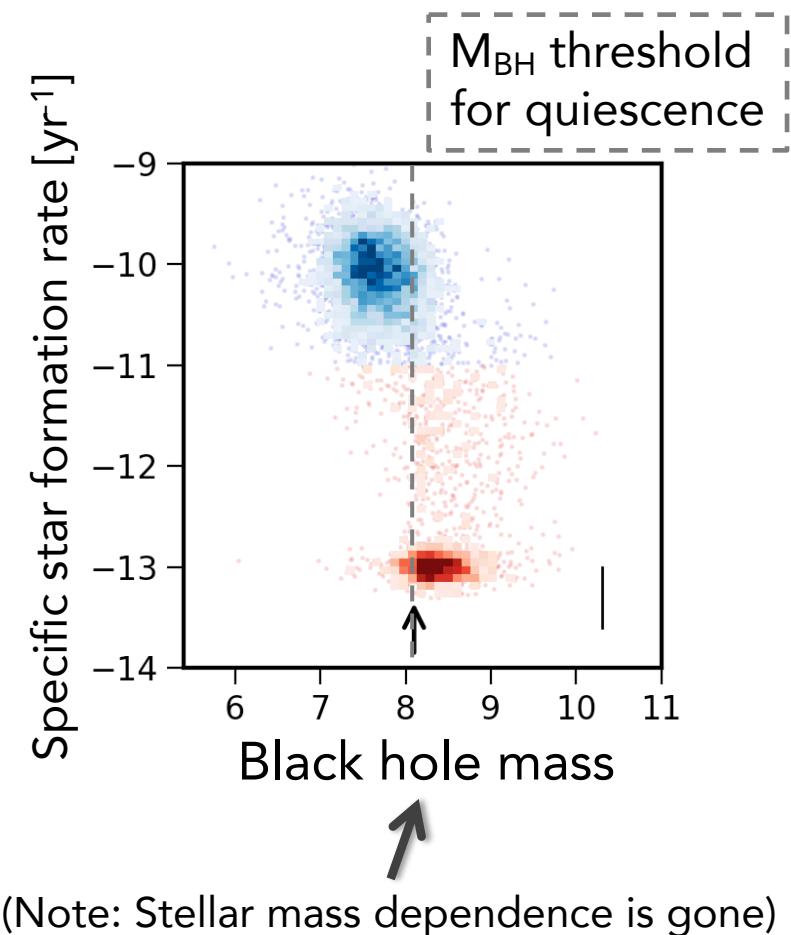
TNG galaxies retain a *memory* of
kinetic wind feedback energy effects

IllustrisTNG: Comparison to observations

Quiescence correlates with BH mass – in qualitative agreement with observations

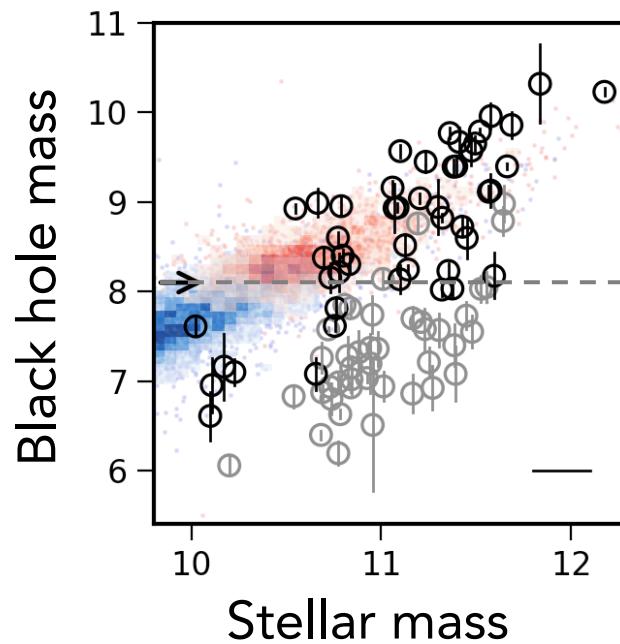


- SF
- Q
- TNG100 + obs scatter

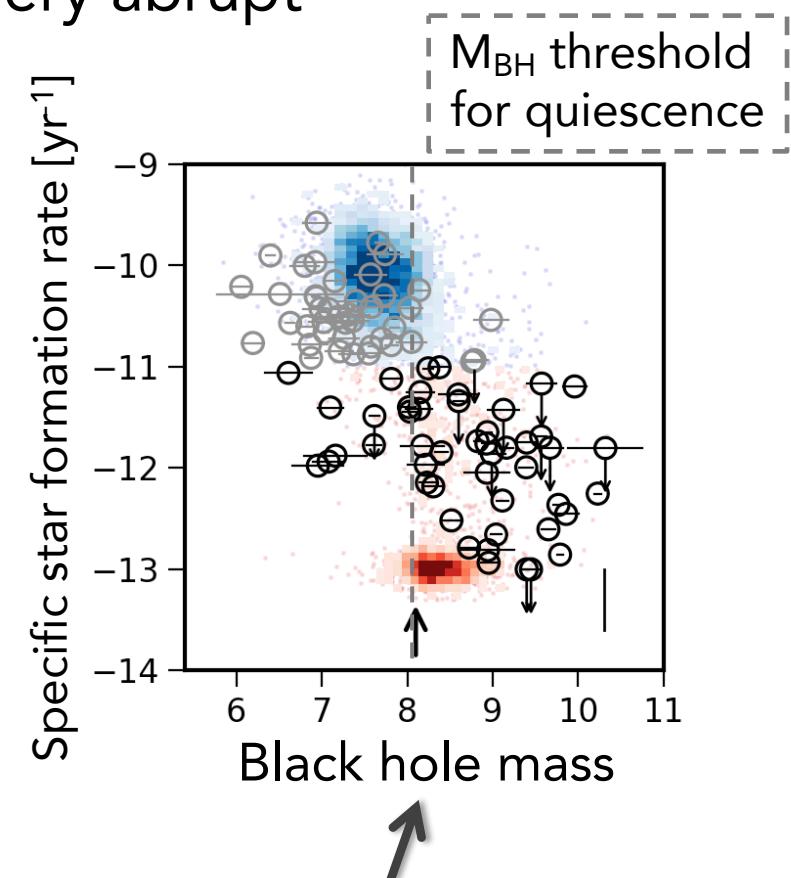


IllustrisTNG: Comparison to observations

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



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

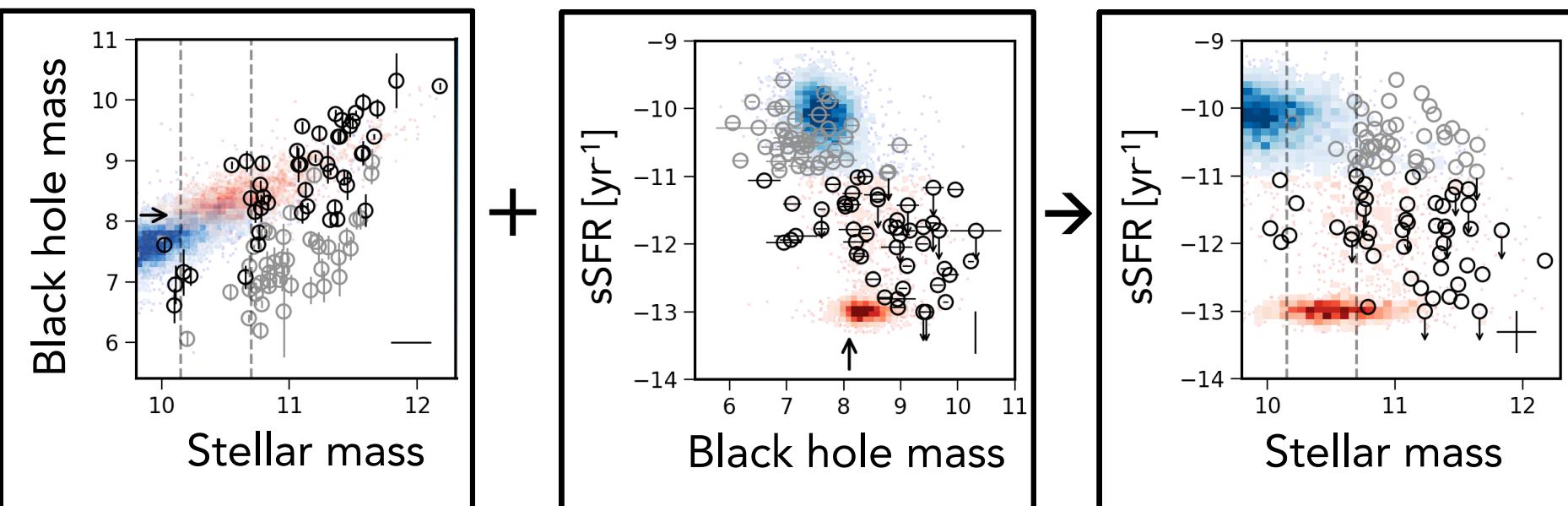


(Note: Stellar mass dependence is gone)

IllustrisTNG: Comparison to observations

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

• SF • Q TNG100 + obs scatter
○ SF ○ Q Observations



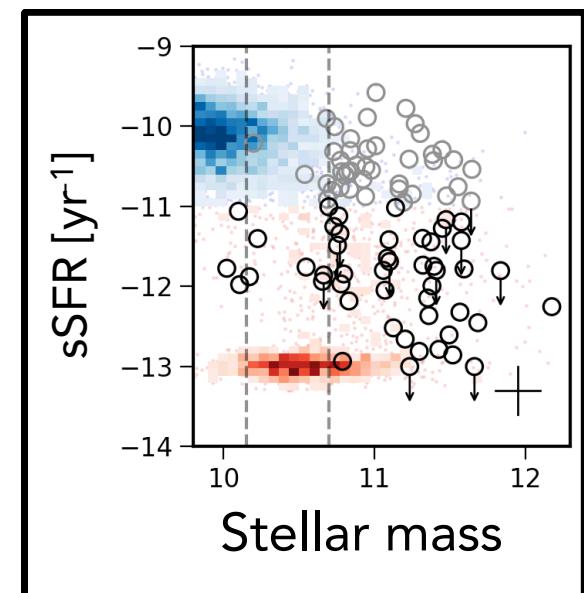
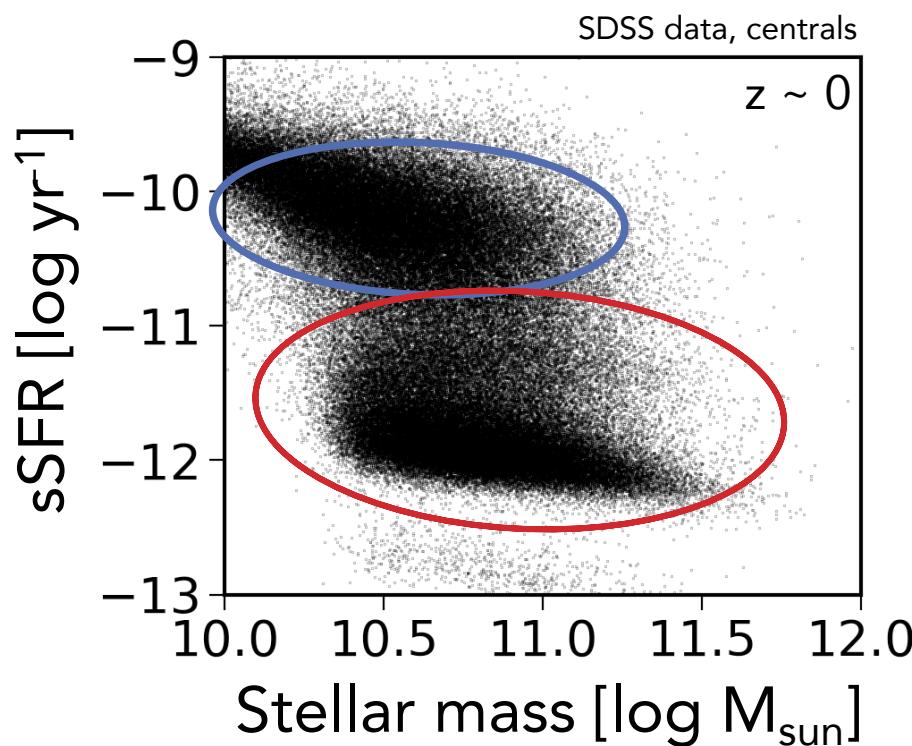
Black holes
occupy galaxies.

Black hole mass
correlates with
quiescence.

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

IllustrisTNG: Comparison to observations

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



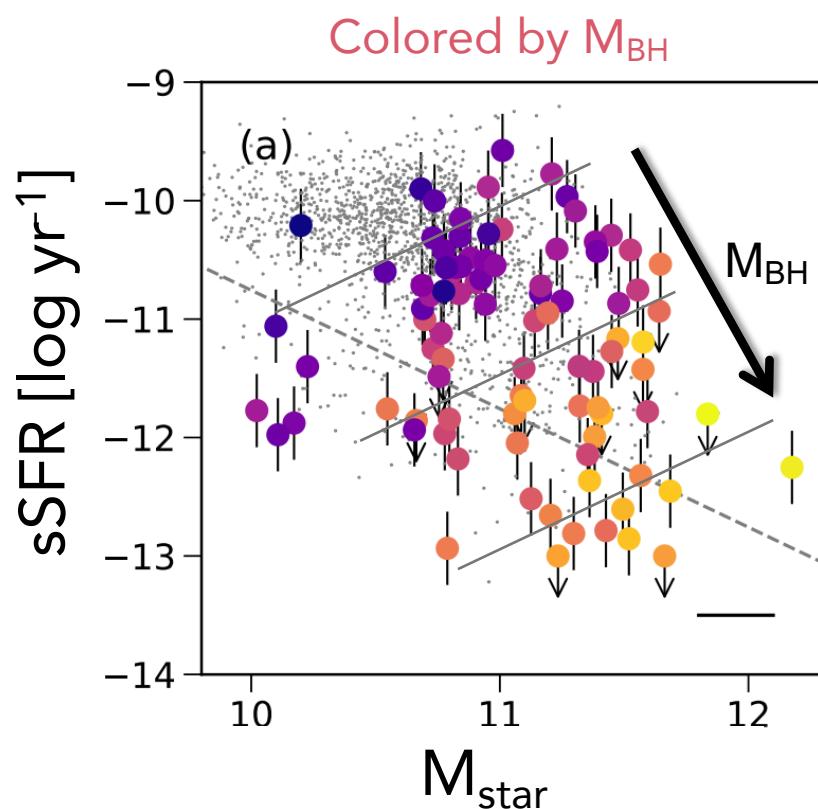
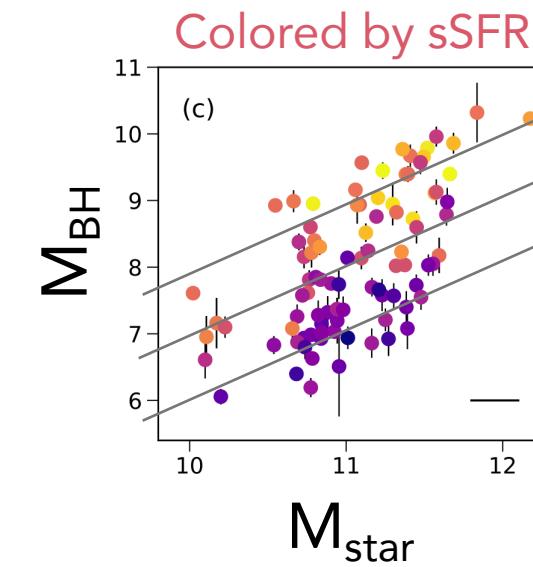
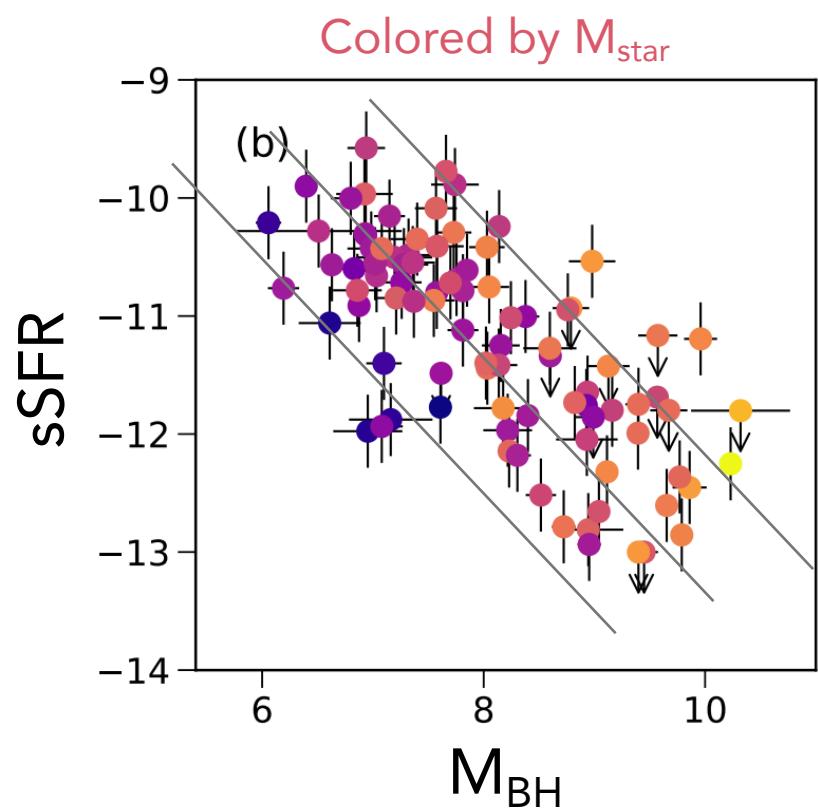
How M_{BH} correlates *quantitatively* with sSFR and M_{star}
determines the distribution of star formation
within the central galaxy population

M_{star}

M_{BH}

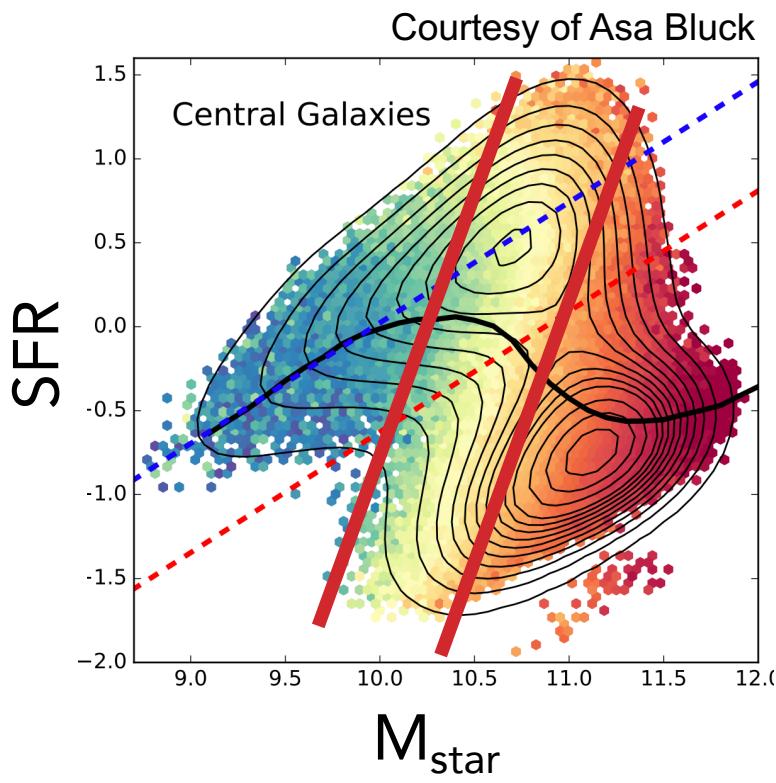
sSFR

Correlated
(models say causally linked)



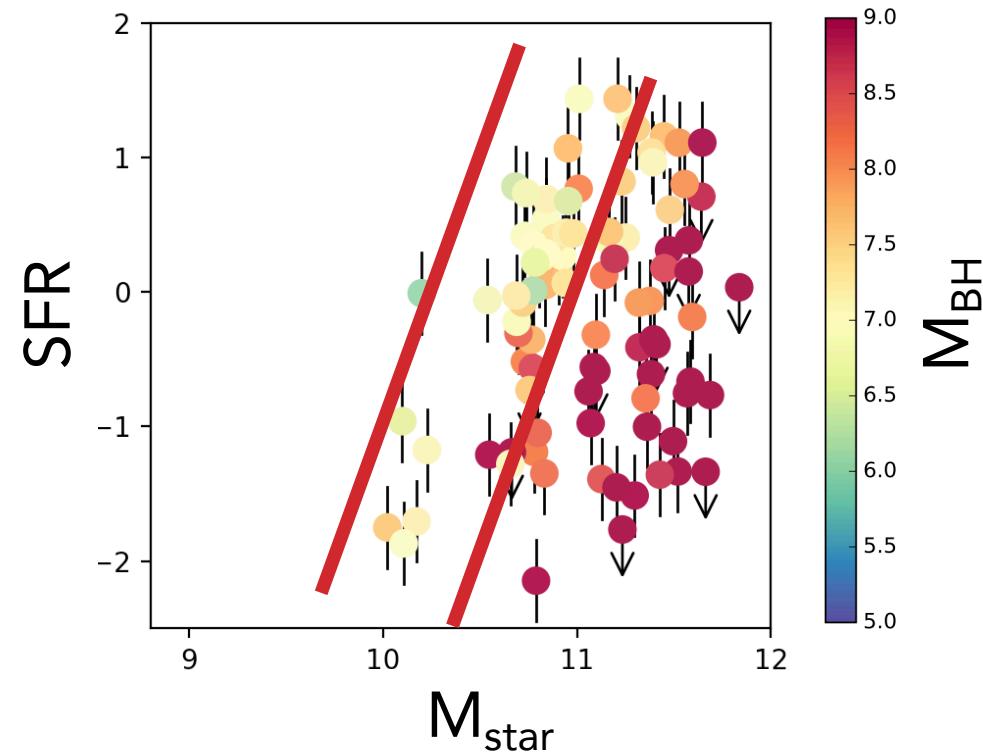
SDSS centrals

M_{BH} estimated from sigma

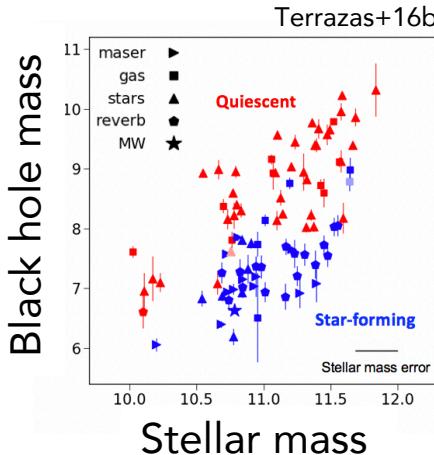


Terrazas+16, 17

Dynamical M_{BH}



Quiescence correlates with strongly with M_{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

