What can we learn from the scatter in galaxy scaling relations?

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Census, Evolution, Physics

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Outline

• Star-forming galaxies lie on *narrow* scaling relations

• The loci of the relations is set by a handful of parameters, according to simple considerations from equilibrium models

• The narrowness of the scaling relations sets strong limits on the galaxy-to-galaxy variability of galactic winds
Star-forming galaxies lie on scaling relations

Whitaker+ 2012

Kewley & Ellison 2008

Papastergis+ 2012

SFR  Z  gas/stellar mass
Equilibrium models

\[ \dot{M}_g = \dot{M}_{\text{ext}} - f_R \dot{M}_* - \dot{M}_{\text{out}} \]

Net change \hspace{2cm} SFR \hspace{2cm} Outflows

Accretion

Bouche+ (2010), Dave+ (2012), Lilly+ (2013), Forbes+ (2014b)
Equilibrium models

\[ \dot{M}_g = \dot{M}_{\text{ext}} - f_R \dot{M}_* - \dot{M}_{\text{out}} \]

Net change \hspace{1cm} SFR \hspace{1cm} Outflows

Accretion

\[ \dot{M}_g = \dot{M}_{\text{ext}} - (f_R + \eta) \frac{M_g}{t_{\text{dep}}} \]

\[ \eta \equiv \frac{\dot{M}_{\text{out}}}{\dot{M}_*} \]

\[ t_{\text{dep}} \equiv \frac{M_g}{\dot{M}_*} \]


Lilly+ (2013)
Equilibrium models

\[ \dot{M}_g = \dot{M}_{\text{ext}} - f_R \dot{M}_* - \dot{M}_{\text{out}} \]

- Net change
- SFR
- Outflows
- Accretion

\[ \eta \equiv \frac{\dot{M}_{\text{out}}}{\dot{M}_*} \]

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\[ \dot{M}_g = \dot{M}_{\text{ext}} - \frac{M_g}{t_{\text{loss}}} \]

Bouche+ (2010), Dave+ (2012), Lilly+ (2013), Forbes+ (2014b),

Lilly+ (2013)
Equilibrium models

When \( t_{\text{loss}} \ll t_{\text{Hubble}} \),

\[
SFR = \frac{\dot{M}_{\text{ext}}}{f_R + \eta}
\]

\[
M_g = \dot{M}_{\text{ext}} \frac{t_{\text{dep}}}{f_R + \eta}
\]

\[
Z_{eq} = Z_{\text{IGM}} + \frac{y f_R}{f_R + \eta}
\]

Lilly+ (2013)
Equilibrium models

When $t_{\text{loss}} \ll t_{\text{Hubble}}$,

$$\text{SFR} = \frac{\dot{M}_{\text{ext}}}{f_R + \eta}$$

$$M_g = \dot{M}_{\text{ext}} \frac{t_{\text{dep}}}{f_R + \eta}$$

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Lilly+ (2013)
Equilibrium models

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Lilly+ (2013)
Equilibrium models

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Lilly+ (2013)
Takeaway points: equilibrium models

- Basic properties of galaxies are determined independently of merger trees and the past history of the galaxy by:
  - The accretion rate
  - The depletion time
  - The mass loading factor
What happens when you kick an equilibrium model?

\[
\frac{dM_g}{dt} = \dot{M}_{\text{ext}} - (f_R + \eta)\dot{M}_{\text{SF}}
\]

\[
\sigma = 1
\]

\[
\tau_c = \frac{t_{\text{coherence}}}{t_{\text{loss}}} = 1
\]

Forbes et al. (2014b)
Quick variations

\[
\frac{dM_g}{dt} = \dot{M}_{\text{ext}} - (f_R + \eta)\dot{M}_{\text{SF}}
\]

\[\sigma = 1\]

\[\tau_c = \frac{t_{\text{coherence}}}{t_{\text{loss}}} = 1\]

Forbes et al. (2014b)
An ensemble

\[ \tau_c = \frac{t_{\text{coherence}}}{t_{\text{loss}}} \]

Forbes et al. (2014b)
Scatter in the SFR at fixed mass

Slow variation

Fast variation

Forbes+ (2014b)

scatter in the SFR (dex)

small scatter in accretion

large scatter in accretion
Scatter in the SFR at fixed mass

Slow variation

Fast variation

small scatter in accretion

large scatter in accretion

Forbes+ (2014b)
Including metallicity gives you two other constraints

SFR

Z

Anti-correlation between SFR and Z

Forbes+ (2014b)
The whole procedure

Vary
- The coherence time
- Scatter in the **accretion rate**
- Scatter in the **SMHM**
- Scatter in the **mass loading factor** at fixed mass
- Scatter in the **depletion time** at fixed mass
- Scatter in the **median accretion rate** at fixed mass

Generate

Check
- Does the synthetic SFR-M* relation have a **smaller scatter** than the real one?
- Does the synthetic Z-M* relation have a **smaller scatter** than the real one?
- Are SFR and Z **anti-correlated** at fixed mass?
Some constraints

\[ \sigma_\eta \]

\[ \sigma_{\text{accr}} \]

First guess

- Blue: Allowed
- Purple: 1 constraint violated
- Red: 2 constraints violated
- Dark red: 3 constraints violated

Forbes et al. (2014b)
We don’t know what the mass loading factor is!

Schroetter+ (2015)
Final thoughts

• The **mass loading factor** and **depletion time** set the location of galaxy scaling relations, but are poorly-understood.

• The mass loading factor has to have a surprisingly **small variance** from galaxy to galaxy at fixed mass.
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- The equilibrium model should be checked against more sophisticated models.
Final thoughts

• The **mass loading factor** and **depletion time** set the location of galaxy scaling relations, but are poorly-understood.

• The mass loading factor has to have a surprisingly **small variance** from galaxy to galaxy at fixed mass.

• The equilibrium model should be checked against more sophisticated models

• A good avenue for pinning down the mass loading factor is high-resolution dwarf galaxy simulations