The (chemo)-dynamics of gas accretion onto star-forming galaxies

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The role of gas in galaxy dynamics
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Accretion on star-forming galaxies

Main sequence of star-forming galaxies:

\[ sSFR \sim 0.1 \text{ Gyr}^{-1} \sim (\text{age of the Universe})^{-1} \]
\[ SFR \sim \langle SFR \rangle \]
(cfr. Scalo 1986 birthrate parameter)

Cold gas content approx constant since at least z~1
(DLA density distribution, e.g. Zafar et al. 2013)

Continued accretion needed, also at recent times!
(e.g. Fraternali & Tomassetti 2012)
Modes of gas accretion

What dominant mode for *star-forming* galaxies at low z?

**HOT MODE**

Condensation above the disc
Directly available to star formation

**COLD MODE**

Fueling *outer* discs
Radial flows *within* the disc to fuel SF
Indications from observations

Ionized inflow

\[ \Delta v = 110 \text{ km s}^{-1} \]
\[ \dot{M}_{\text{acc}} = 2.9 \text{ M}_\odot \text{ yr}^{-1} \]
Chemo-dynamical approach

Data: disc structure, metallicity gradients, kinematics... “easy” (easier)

Modeling: Chemo-dynamics: much more difficult?

\[
\frac{d\tilde{X}}{dt} = \frac{\dot{M}_*}{M_{\text{gas}}} - \tilde{X} \frac{\dot{M}_{\text{acc}}}{M_{\text{gas}}}
\]

\(\alpha\)-elements
ISM

(Fe → Time-delay effects)

(Stars → Multiple populations, migration...)

Star formation (source)

Normalized abundance

Accretion (dilution)

Linear equation → Closed-form solution

GP & Fraternali (2016)

Schönrich & Binney (2009)
Purely vertical accretion

“Independent annuli”

Spatially resolved $\rightarrow$ surface densities

$$\frac{\partial \tilde{X}_i}{\partial t} = \frac{\dot{\Sigma}_*}{\Sigma_g} - \tilde{X}_i \frac{\dot{\Sigma}_{\text{acc}}}{\Sigma_g}$$
Purely vertical accretion

“Independent annuli”

Spatially resolved → surface densities

$$\frac{\partial \tilde{X}_i}{\partial t} = \frac{\dot{\Sigma}_*}{\Sigma_g} - \tilde{X}_i \frac{\dot{\Sigma}_{\text{acc}}}{\Sigma_g}$$

Ways out, tuning:
- accretion time-scales
- star formation efficiencies
- ...

Abundance gradient
MW obs gradient
Genovali et al. (2015)
Purely radial accretion

**RADIAL MASS FLUX**
- Incoming flow
- Gradual consumption (star formation)

**RADIAL VELOCITY**
- $u_R$ (km/s)

Diagram showing the flow of material into and out of a star-forming region, with radial velocity and mass flux as functions of radius.
Purely radial accretion

Along gas trajectories
(Method of characteristics)

Edmunds & Greenhow (1995)
GP & Fraternali (2016)
Is the truth in the middle?
Dynamics of gas accretion

- Purely radial accretion -

Filament

DISC

Filament

Who to transfer the angular momentum to?

To the stars? (spiral structure; bar interactions)
To the gas itself? (viscosity? violent disc instability?)
To the dark matter?
Dynamics of gas accretion

- Purely vertical accretion -

\[ g + \frac{1}{\rho} \nabla P + \frac{l^2}{R^3} e_R = 0 \]

Cold disc \rightarrow Pressure negligible

\[ l_{\text{disc}} = \sqrt{R^3 |g|} \]

Hot corona \rightarrow rotation + pressure

\[ l_{\text{acc}} < l_{\text{disc}} \]

ONLY IF \( l_{\text{acc}} = l_{\text{disc}} \)
Dynamics of gas accretion

Vertical accretion + radial flows!

Cold disc \[ \text{Pressure negligible} \]

Hot corona \[ \text{rotation + pressure} \]

\[ l_{\text{disc}} = \sqrt{R^3 |g|} \]

\[ l_{\text{acc}} < l_{\text{disc}} \]

Radial flows

Dynamically coupled flows!

One parameter: AM mismatch (due to $\nabla P$) \[ \text{GP \& Fraternali (2016)} \]

Solved with “method of characteristics”

E.g. Pitts & Tayler (1989)

Bilitewski & Schönrich (2012)
Hot-mode accretion with radial flows

Model requirement $V_{\text{cor}} = (0.7 - 0.8) V_{\text{disc}} \approx 180 \text{ km s}^{-1}$

First direct observation (Hodges-Kluck, Miller & Bregman 2016)
A hydrodynamical cosmological model

\[ g + \frac{1}{\rho} \nabla P + \frac{l^2}{R^3} e_R = 0 \]

Rotating equilibrium

\[ \frac{dM}{dl} = \psi(l) \]

Angular momentum distribution (AMD)

Required velocity matched with minimal assumptions

\[ T \lesssim T_{\text{vir}} \]

and cosmological AMD

GP, Fraternali & Binney (2017)
Summary

Chemo-dynamics is...
- “not so difficult”
- sensitive to the mode of accretion

Star formation (at low $z$) can be fueled like this:

Natural consequence of hot-mode accretion with a cosmological AMD