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ASTROPHYSICS

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The connection between local and global star formation in galaxies

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The value of gas depletion time is a long-standing puzzle

$$\tau_{\rm dep} = M_{\rm gas}/\dot{M_{\star}} \sim 2-10 \,\rm Gyr$$

 τ_{dep} is **much longer** than any dynamical timescale relevant for SF:

$$t_{\rm turb} = \frac{h}{\sigma} \sim 10 - 30 \text{ Myr} \qquad t_{\rm ff} = \sqrt{\frac{3\pi}{32G\rho}} \sim 2 - 20 \text{ Myr}$$
$$t_{\rm orb} = \frac{2\pi R}{V_{\rm rot}} \approx 200 \text{ Myr at } R_{\odot}$$

i.e. star formation in galaxies is surprisingly inefficient.



Inefficiency of actively star-forming regions is an important factor:

$$\tau_{\rm dep,sf} = \frac{M_{\rm sf}}{\dot{M_{\star}}} = \frac{t_{\rm ff}}{\epsilon_{\rm ff}} \sim 0.1 - 0.5 \; {\rm Gyrs}$$

but their depletion times are too short to explain global τ_{dep}

Isolated ~L_{*} galaxy simulation



Gas evolution between star-forming and non-star-forming states



Semenov, Kravtsov & Gnedin 2017, ApJ 845, 133 (arXiv:1704.04239)

Gas evolution between star-forming and non-star-forming states

- Gas cycles between SF and non-SF states on <100 Myr timescale
- Feedback disperses SF regions making SF stages short
- Most of the time gas spends in the non-SF state



Semenov, Kravtsov & Gnedin 2017, ApJ 845, 133 (arXiv:1704.04239)

Physical origin of long gas depletion times



(depletion time) = (depletion time in SF state) + (total time in non-SF state over N_{dep} cycles)

Although each cycle is short, depletion is long because the number of cycles is large

Semenov, Kravtsov, Gnedin 2017 ApJ 845, 133 2018 ApJ 861, 4

Direct analogy: "inefficiency" of football

Field-crossing time ~ 20 seconds

UEFA Champions League 2018–19 Average # of goals scored per match: 2.93



Final (Liverpool vs Tottenham) Image from https://www.whoscored.com

Dependence of depletion time on local SF efficiency



Semenov, Kravtsov, Gnedin 2018 ApJ 861, 4

Dependence of depletion time on local SF efficiency



By definition:

$$\tau_{\rm dep,sf} = \frac{\rho}{\dot{\rho_{\star}}} \propto \epsilon_{\rm ff}^{-1}$$

Feedback limits SF stages:

 $t_{
m sf}\propto\epsilon_{
m ff}^{-1}$

Model explains self-regulation!

(i.e., insensitivity of global depletion time to local ε_{ff}) *Dobbs+'11; Agertz+'13,'15; Hopkins+'13,'18*

Star-forming gas mass fraction has opposite behavior:

$$f_{\rm sf} \sim \left(1 + \frac{t_{\rm nsf}}{t_{\rm sf}}\right)^{-1}$$

 $f_{\rm sf}$ can be used to constrain $\epsilon_{\rm ff}$ Hopkins+'13

Semenov, Kravtsov, Gnedin 2018 ApJ 861, 4

Summary

A simple framework based on the physical picture of ISM gas cycling explains the origin of gas depletion times in galaxies



Other insights from the model:

- The origin of constant depletion time of molecular gas on kiloparsec and larger scales (linear molecular Kennicutt-Schmidt relation)
- Insights into the scatter of depletion times (scatter of the Kennicutt-Schmidt relation)
- Evolution of depletion times in galaxies

Semenov, Kravtsov, Gnedin 2017 ApJ 845, 133; 2018 ApJ 861, 4; 2019 ApJ 870, 79