Astronomy in Focus, XXIXB, Focus Meeting 18
XXIXth IAU General Assembly, August 2015
Piero Benvenuti, ed.

doi:10.1017/S1743921316006633

A universal, turbulence-regulated, multi-freefall star formation law

Christoph Federrath, Diane M. Salim and Lisa J. Kewley

Research School of Astronomy and Astrophysics,
The Australian National University, Canberra, ACT 2611, Australia
email: christoph.federrath@anu.edu.au

Abstract. We develop a new star formation (SF) law based on the density PDF of turbulence and on the multi-freefall concept of gas collapse. We derive a relation where the star formation rate (SFR) correlates with the molecular gas mass per multi-freefall time, whereas previous models had used the average, single-freefall time. We define a new quantity called *maximum (multi-freefall) gas consumption rate* (MGCR) and show that the actual SFR is only about 0.4% of this maximum possible SFR, confirming the observed low efficiency of star formation.

Keywords. galaxies: high-redshift — galaxies: ISM — galaxies: starburst — stars: formation

---

The rate of star formation controls a galaxy's fundamental properties and evolution (Padoan *et al.* 2014). Nonetheless, the functional dependence of the column density of star formation ($\Sigma_{\rm SFR}$) is still one of the most debated topics in astrophysics, with historical parameterizations including the mean column density of gas ($\Sigma_{\rm gas}$) (Kennicutt & Evans 2012), as well as the ratio between $\Sigma_{\rm gas}$ and the average freefall time $t_{\rm ff}$ (Krumholz *et al.* 2012; Federrath 2013; Krumholz 2014).

Significant scatter remains in both these approaches, such that $\Sigma_{\rm SFR}$ can vary by more than an order of magnitude for any given $\Sigma_{\rm gas}$ or $\Sigma_{\rm gas}/t_{\rm ff}$. Here (published in Salim *et al.* 2015), we improve the single-freefall law by the multi-freefall concept of gas collapse, taking into account the density PDF (Hennebelle & Chabrier 2011; Federrath & Klessen 2012). We find

$$\Sigma_{\rm SFR} = 0.4\% \times {\rm MGCR} = 0.4\% \times \Sigma_{\rm gas}/t_{\rm ff} \times \left(1 + b^2\mathcal{M}^2 \tfrac{\beta}{\beta+1}\right)^{3/8},$$

where $\mathcal{M}$ is the Mach number, $1/3 \leqslant b \leqslant 1$ is the turbulence driving parameter (Federrath *et al.* 2008; 2010) and β is the ratio of thermal to magnetic pressure. Our new SF law implies that SF is inefficient with the SFR reaching only 0.4% of the MGCR. In Salim *et al.* (2015) we show that this new SF law provides superior fits to Milky Way and extragalactic data compared to any previous SF law.

References

Federrath, C. 2013, *MNRAS*, 436, 3167
Federrath, C. & Klessen, R. S. 2012, *ApJ*, 761, 156
Federrath, C., Klessen, R. S., & Schmidt, W. 2008, *ApJ*, 688, L79
Federrath, C., Roman-Duval, J., Klessen, R. S., Schmidt, W., & Mac Low, M. 2010, *A&A*, 512, A81
Hennebelle, P. & Chabrier, G. 2011, *ApJ*, 743, L29
Kennicutt, R. C. & Evans, N. J. 2012, *ARAA*, 50, 531
Krumholz, M. R. 2014, *Physics Reports*, 539, 49
Krumholz, M. R., Dekel, A., & McKee, C. F. 2012, *ApJ*, 745, 69
Padoan, P., Federrath, C., Chabrier, G., *et al.* 2014, in: H. Beuther, R. S. Klessen, C. P. Dullemond, & T. Henning (eds.), *Protostars and Planets VI*, p. 77
Salim, D. M., Federrath, C., & Kewley, L. J. 2015, *ApJ*, 806, L36