Schmidt’s Conjecture and Star Formation in Giant Molecular Clouds and Galaxies

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What are the physical processes that set the SFR and control galaxy evolution?

Bouwens et al. 2010
Schmidt’s Conjecture:

\[ \Sigma_{\text{SFR}} = \kappa (\Sigma_g)^\beta \quad (M_\odot \text{ pc}^{-2}) \]

“\text{It would seem most probable that the rate of star formation depends on the gas density and we shall assume that the number formed per unit interval of time varies with a power of the gas density ...}”   Schmidt (1959)
$z = 0$

**Schmidt-Kennicutt Law**

$$\Sigma_{\text{SFR}} = A \left( \Sigma_{\text{gas}} \right)^{1.6}$$
Giant Molecular Clouds
Milky Way GMCs

SFRs: Direct Counting of YSOs and measured ages.

Masses: Resolved measurements of dust column densities and an assumed gas-to-dust ratio
Does a Schmidt Law exist for MW GMCs?
Giant Molecular Clouds

A Schmidt Law does NOT exist between GMCs
Giant Molecular Clouds

Well known scaling relation of Larson (1981)

A Schmidt Law does NOT exist between GMCs
Does a Schmidt Law exist within GMCs?
Schmidt Law in Orion

\[ \Sigma_\star(A_K) = \kappa A_K^\beta \]

\[ \beta = 2 \]

Orion A

Lada et al. 2013
Schmidt Law in Giant Molecular Clouds

Results:

$$\Sigma_* = \kappa (A_K)^\beta$$

A Schmidt Law Exists within GMCs

Gutermuth et al. 2011
Giant Molecular Clouds

A Schmidt Law within clouds does NOT explain variations in SFRs between clouds.
$N_*(>A_K) = \Sigma_*(>A_K) \times S(>A_K)$
Cloud structure plays critical role in determining the SFR in clouds!

Surface Area Distribution Function, $S(>A_K)$
Scaling Relations for Local GMCs

Need to consider *integrated* quantities

\[ \text{SFR} = (t_c)^{-1} M_{\text{gas}} \]
Extending SFR Scaling Relations to Nearby Galaxies

NGC 300

Faesi et al. 2014
A Relation between Dense Gas and Star Formation
Dense Gas and Star Formation

Orion A

Lombardi et al. 2014

Herschel: 250 µm
Dense Gas and Star Formation

Orion A

90% of Protostars at $A_K > 1.0$ mag

Lombardi et al. 2014

Herschel: 250 $\mu$m
Dense Gas and Star Formation

90% of Protostars at $A_K > 1.0$ mag

Evans et al. 2014
Star Formation Scaling Law for Local Clouds

A linear scaling relation\(^1\)

\[
\text{SFR} = (t_{gc})^{-1} M_{\text{dense}}
\]

Lada et al. 2010

The SFR is controlled by the mass or total amount of dense gas contained within molecular clouds

\(^1\)SFR = 2.5 \times 10^{-5} N(\text{YSOs}) \, M_\odot/\text{yr}
The Star Formation Rate (SFR) is controlled by the mass of dense gas contained within molecular clouds and entire galaxies.

\[ \text{SFR} = \left( \frac{1}{t_{\text{gc}}} \right)^{-1} \mathcal{M}_{>0.8} \]

From GMCs to Galaxies

Gao & Solomon 2004
The SFR is controlled by the mass of dense molecular gas within GMCs and galaxies. 

\[ \text{SFR} = (t_{gc})^{-1} M_{>0.8} \]

*From GMCs to Galaxies*
The physical process of star formation in galaxies must be very similar to that in MW GMCs.
The physical process of star formation in distant galaxies and through much of cosmic history must be reasonably the same as it is presently in the nearest molecular clouds.
Deconstructing the Kennicutt-Schmidt Scaling Relation
Deconstructing the Kennicutt-Schmidt Law:

Bigiel et al. 2008 AJ 136:2846

Schruba et al. 2011 AJ 142:37
Deconstructing the Kennicutt-Schmidt Law:

Galaxies:

Starburst Galaxies:

Bigiel et al. 2008
Summary

1. There is no Schmidt Law *between* GMCs

2. A Schmidt Law *does* exist within GMCs but it does not provide a complete description of a cloud’s star formation activity.

3. The structure of a cloud plays a pivotal role in setting its global SFR and the overall level of its star formation activity.

4. The integrated SFR scales *linearly* with, and is most reliably traced by, the dense gas mass in a star forming region.

5. The amount of dense gas sets the SFR in systems ranging from individual GMCs to entire galaxies.

6. The Kennicutt-Schmidt law for galaxies is largely the result of unresolved measurements of GMCs and not a result of any underlying physical law of star formation.
Conclusion

The physical process of star formation in distant galaxies and through much of cosmic history may be reasonably the same as it is presently in the nearest molecular clouds.
The End