THE GLOBAL STAR-FORMATION LAW IN GALAXIES

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Outline

- Introduction
- Methods & Results
- Application
- Summary

Introduction

- Gas converts to star
- SFR-gas relationship
- **The Schmidt Law** by M.Schmidt in 1959

$$\Sigma_{SFR} = A\,\Sigma_{gas}^{N}$$

N → index

A → SFR efficiency

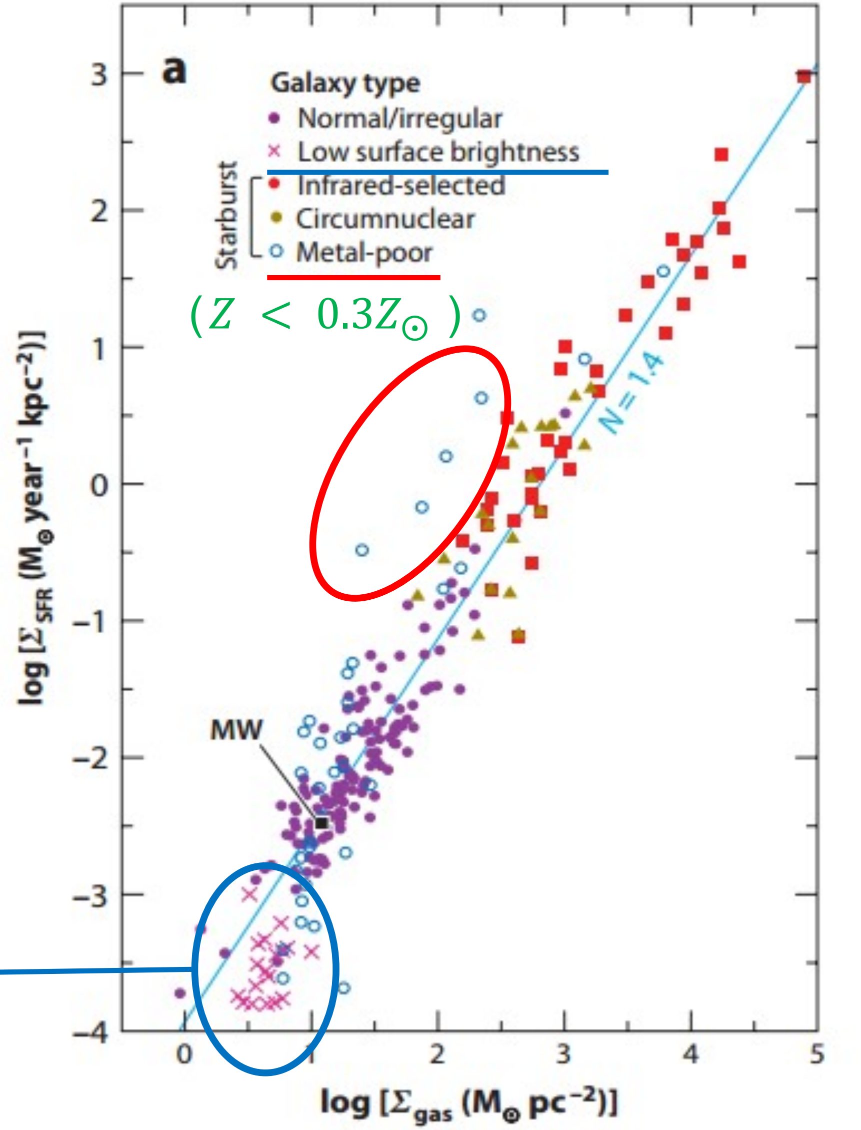
Kennicutt-Schmidt (KS) Law

- Kennicutt et al. in 1989 and 1998

- $N = 1.4 \pm 0.15$

$$\frac{\mathbf{M(H_2)}}{\mathbf{L_{CO}}} = \boldsymbol{\alpha}$$

steep, nearly vertical



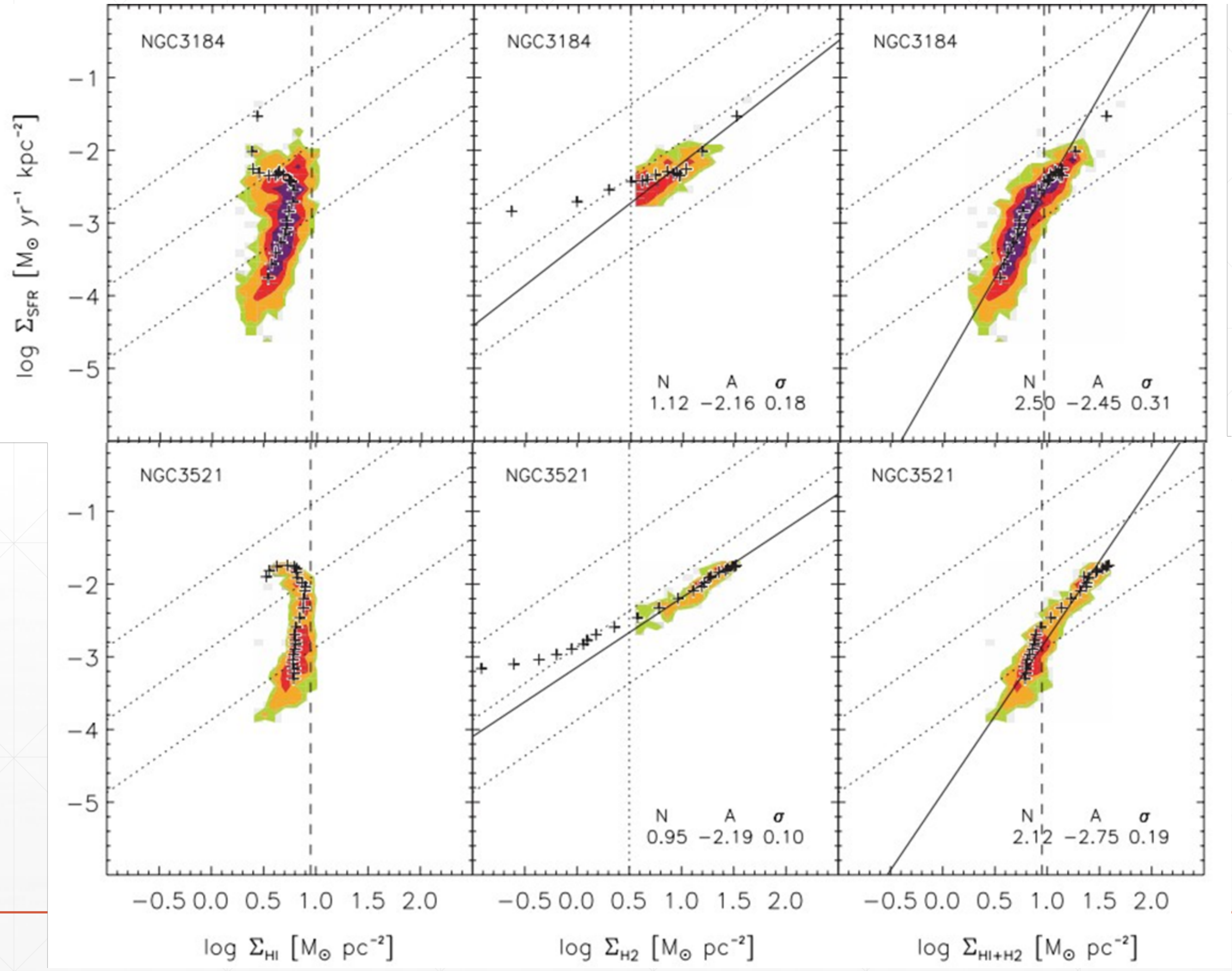
(Rober C. Kennicutt, Jr., and Neal J. Evans II 2012)

SFR - molecular gas/atomic gas

- Molecular Schmidt Law

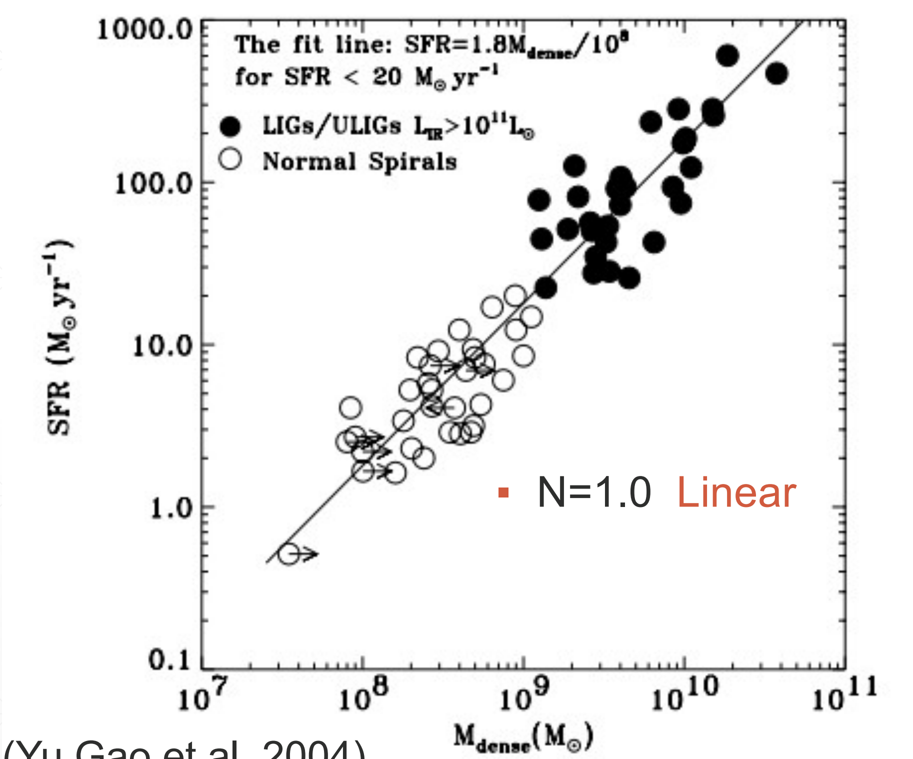
$$\Sigma_{SFR} = 10^{-2.1\pm0.2}\Sigma_{H2}^{1.0\pm0.2}$$

- Star formation is a direct product of the molecular gas in a galaxy

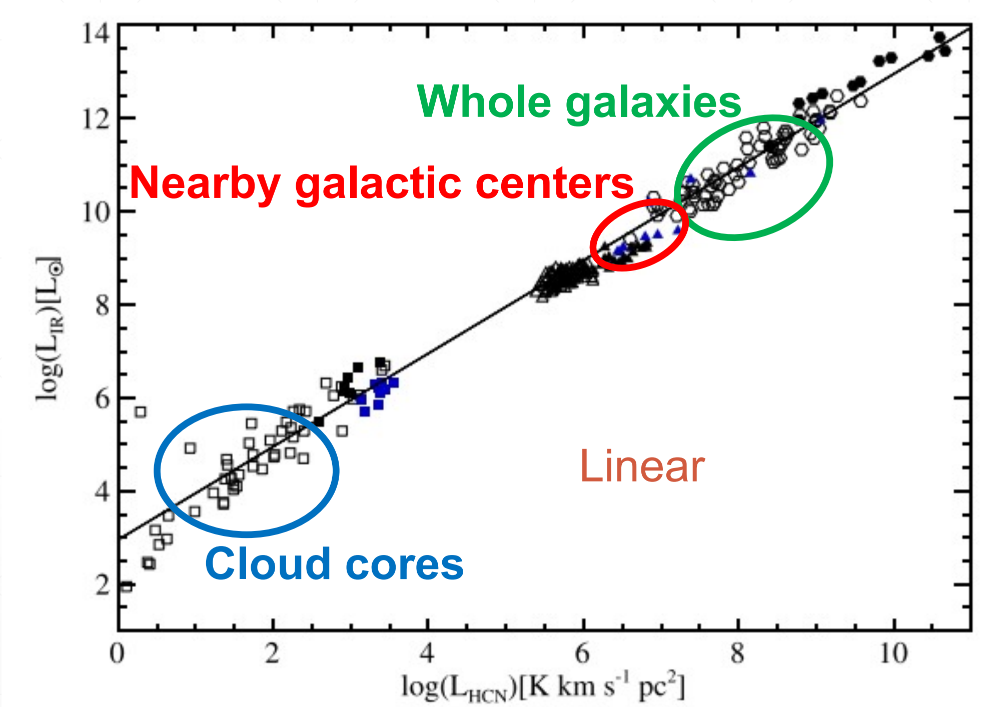


(Bigiel et al. 2008)

SFR-Dense Molecular Gas → $N(H_2) > 3 \times 10^4\ cm^{-3}$



(Yu Gao et al. 2004)



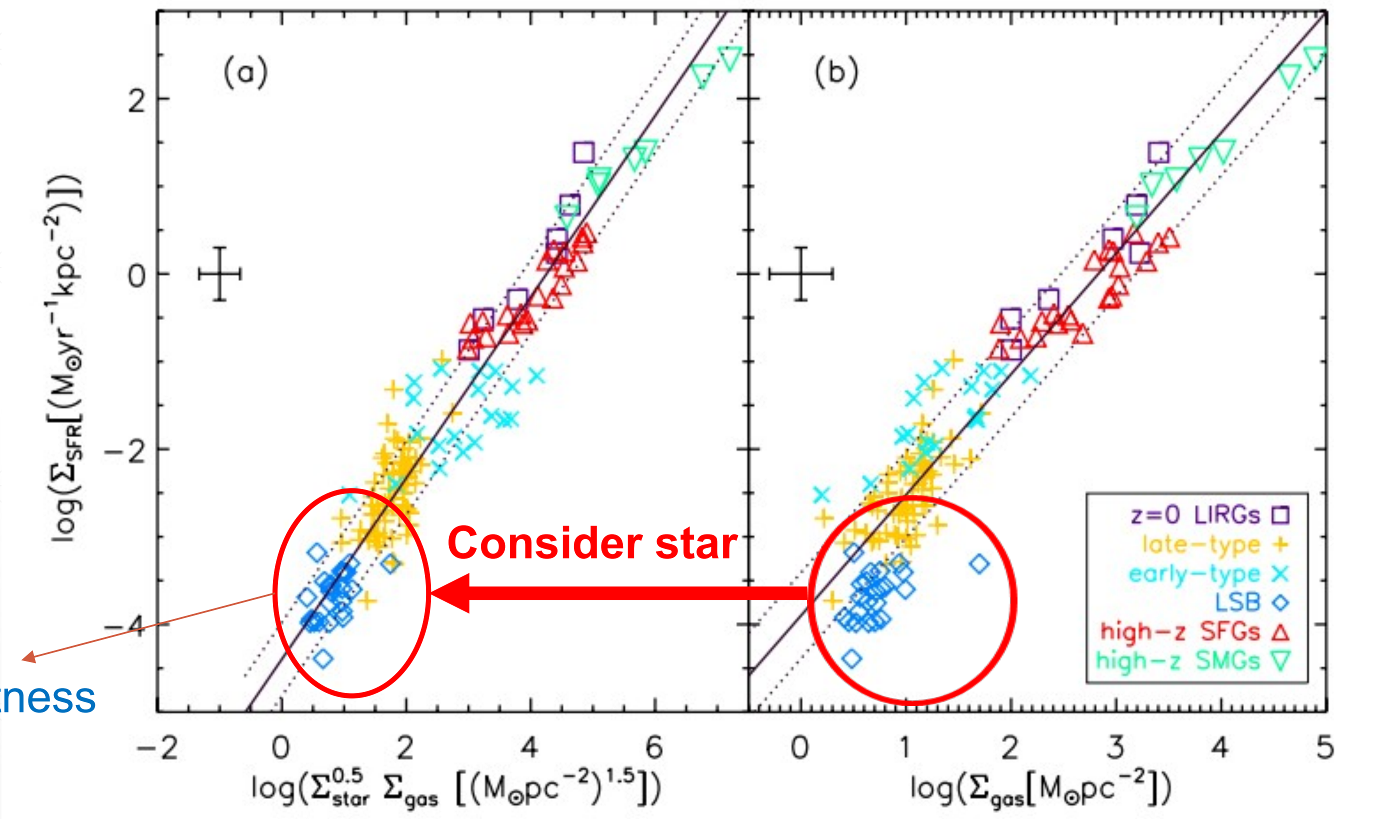
(Hao Chen,Yu Gao et al. 2015)

- **Dense molecular gas(GMC cores): Active star forming region**

Extended-Schmidt Law

- SFE: related to Stellar mass surface density

$$\Sigma_{SFR} \propto \Sigma_{gas} \Sigma_{star}^{0.5}$$

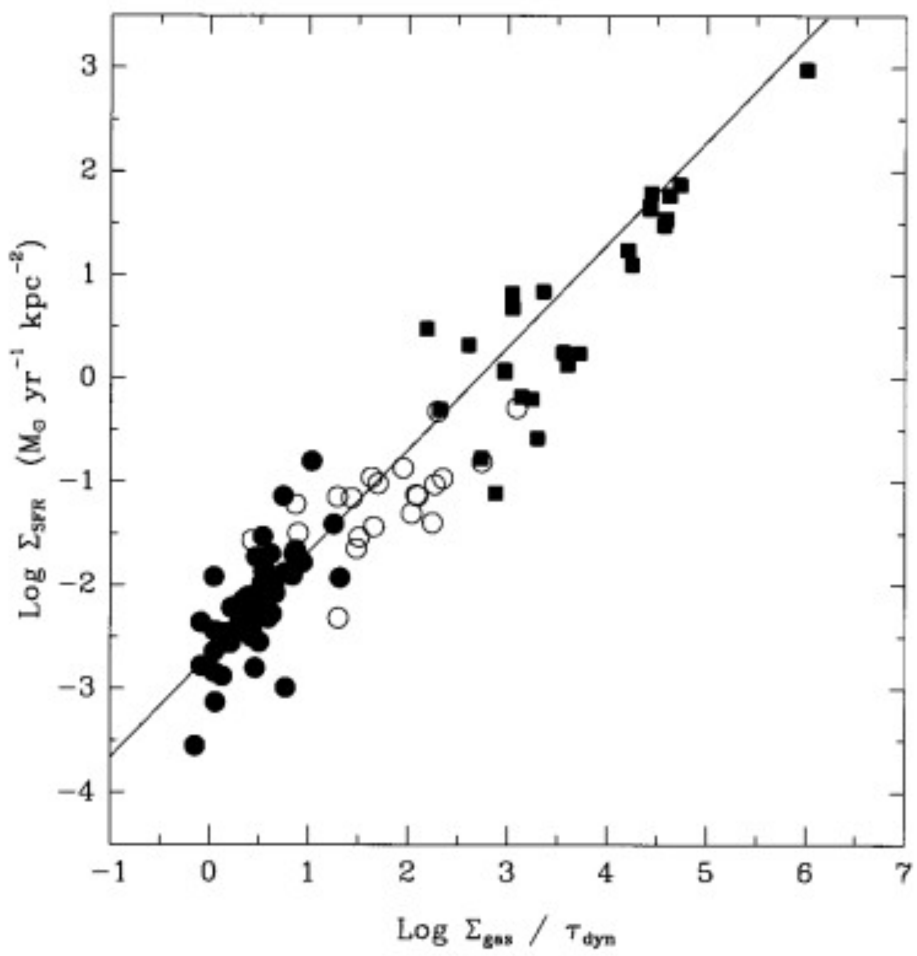


(Shi et al. 2011)

Silk-Elmegreen Relation

- Silk (1997) Elmegreen(1997)
- dynamical timescale

$$\Sigma_{\mathrm{SFR}} \propto \frac{\Sigma_{\mathrm{gas}}}{\tau_{\mathrm{dyn}}}$$



(Kennicutt.1998)

Application

- Estimate the gas mass
- E.g. The origin of the mass-metallicity relation

(Christy A.Tremonti et al. 2004)

$$\Sigma_{\rm SFR} = 1.6 \times 10^{-4} \left(\frac{\Sigma_{\rm gas}}{1\ M_\odot\ {\rm pc}^{-2}} \right)^{1.4} M_\odot\ {\rm yr}^{-1}\ {\rm kpc}^{-2}$$

(Kennicutt 1998)

Summery

- The global Star formation Law can be described by Kennicutt-Schmidt law: $\sum_{SFR} = A \sum_{gas}^{N}$
- SFR is mainly related to molecular gas, especially dense molecular gas: Stars form in dense molecular core
- Extended-Schmidt Law: $\sum_{SFR} \propto \sum_{gas} \sum_{star}^{0.5}$
- Silk-Elmegreen Relation: $\sum_{SFR} \propto \frac{\sum_{gas}}{\tau_{dyn}}$
- A good way to estimate gas mass

References

- [1] Maarten Schmidt. 1959, ApJ, 129, 243
- [2] Robert C. Kennicutt, JR. 1998, ApJ, 498: 541-552
- [3] Robert C. Kennicutt, Jr., Neal J. Evans II. 2012, Annu. Rev. Astron. Astrophys: 50:531–608
- [4] F. Bigiel, A. Leroy, F. Walter, E. Brinks, W. J. G. de Blok, B. Madore, and M. D. Thornley. 2008, ApJ, 136:2846–2871
- [5] Hao Chen, Yu Gao, Jonathan Braine, and Qiusheng Gu. 2015, ApJ, 810:140 (9pp)
- [6] Yu Gao and Philip M. Solomon. 2004, ApJ, 606:271–290
- [7] Yong Shi, George Helou, Lin Yan, Lee Armus, Yanling Wu, Casey Papovich, and Sabrina Stierwalt. 2011, ApJ, 733:87 (15pp)
- [8] Joseph Silk. 1997, ApJ, 481:703È709
- [9] Christy A. Tremonti, Timothy M. Heckman, Guinevere Kauffmann et al. 2004, ApJ, 613:898–913

Thank you!

Gas tracers

- The cold atomic phase: The cold, neutral atomic phase is traced by the hyperfine transition of hydrogen(HI), occurring at 21 cm in the rest frame
- Molecular gas: CO is the most commonly used tracer of molecular gas because its lines are the strongest and therefore easiest to observe.
- Dense-gas : Lines other than CO $J = 1 \rightarrow 0$ generally trace warmer (e.g., higher J CO lines) and/or denser (e.g., HCN, CS, etc.) gas. For example: CS: $J = 2 \rightarrow 1$, $J = 5 \rightarrow 4$, and $J = 7 \rightarrow 6$; HCN: $J = 1 \rightarrow 0$, $J = 3 \rightarrow 2$)

The Atomic HI Mass

- Observed HI line emission fluxes at 21 cm:

  integrate the HI emission profile in the velocity space:

  $SHI_0 = \int S(V)dV$

  can be used to derive the total atomic hydrogen mass, M(HI), of

a galaxy: $M(HI)[M_{\odot}] = 2.356 \times 10^5 SHI\ [Jy\ km\ s^{-1}] D^2\ [Mpc]$

where D is the distance of the galaxy, in Mpc;

SHI is its total corrected HI flux, in $Jy\ km\ s^{-1}$

The Molecular H2 Mass

H2 from CO Emission Lines Observations

- Cold ISM: The molecular hydrogen interstellar medium

  of normal, late-type galaxies is generally cold (T_R ~ 10 K)

- Assumption: CO is a good tracer of the mass of giant molecular clouds

- $\frac{M(H_2)}{L_{CO}}\left[\frac{M_\odot}{K\ km\ s^{-1} pc^2}\right] = \alpha = c_2\sqrt{n(H_2)[cm^{-3}]}T_R^{-1}[K]$ or

  $\frac{N(H_2)}{I_{CO}}\left[\frac{cm^{-2}}{K\ km\ s^{-1}}\right] = X = c_1\sqrt{n(H_2)[cm^{-3}]}T_R^{-1}[K]$

N(H2) is the mean molecular gas volume density; I(CO) is the intensity of the CO line;

n(H2), whose value is ~ 200 cm^-3 in normal galaxies

M(H2) is the molecular gas mass (including helium); L_{CO} the luminosity of the CO line

T_R is the equivalent Rayleigh–Jeans brightness temperature of the (optically thick) CO line

SFR

- $SFR = K(\lambda)L(\lambda)$

K is calculated from the model of stellar population synthesis

Hα-based SFR

- $K(H\alpha) = 7.9 \times 10^{-42} \left[\frac{M_{\odot} yr^{-1}}{erg s^{-1}}\right]$

FIR-based SFR

- $K(FIR) = 4.5 \times 10^{-44} \left[\frac{M_{\odot} yr^{-1}}{erg s^{-1}}\right]$
- $L_{FIR}(\nu) = 4\pi D^2 S(\nu)$